Book of Abstracts

Sixteenth Conference on Electromagnetic & Light Scattering

University of Maryland/College Park, MD, USA
19–25 March 2017

Edited by

Nadia Zakharova

Trinnovim, LLC
New York, NY, USA

OBJECTIVE

The 16th Electromagnetic and Light Scattering Conference (ELS-XVI) will be held at the University of Maryland/College Park, MD, USA from 19–25 March 2017. It will build on the remarkable success of the previous ELS conferences held in Amsterdam, Helsinki (twice), New York, Vigo, Halifax, Gainesville, Bremen, Salobreña, St. Petersburg, Bodrum, Hatfield, Taormina, Lille, and Leipzig. The main objective of the conference is to bring together scientists and engineers studying various aspects of light scattering and to provide a relaxed atmosphere for in-depth discussions of theoretical advances, measurements, and applications.

SCOPE

The specific topics covered by ELS-XVI include (but are not limited to) the following:

- new theoretical developments, numerical simulations, and laboratory measurements of light scattering by nonspherical and morphologically complex particles and particle groups
- detection and characterization of atmospheric particulates using laboratory, in situ, and remote sensing techniques
- scattering of light by terrestrial aerosols and clouds
- scattering of light by oceanic particulates
- scattering of light by solar system objects, exoplanets, and exoplanetary environments
- scattering of light by various astrophysical objects
- applications of light scattering methods in biology and biomedicine
- light scattering in densely packed particulate media
- near-field and coherent effects in light scattering, optical trapping, and manipulation
- light scattering methods to control material properties and technological applications

SPECIAL SESSIONS

- Study of aerosol and environmental chemistry through analyses of light scattering
- Tropospheric aerosols: the NASA perspective

INVITED REVIEWS

- S. P. Burton, J. Hair, R. Ferrare, C. Hostetler, M. Vaughan, and A. Omar, *Characterization of tropospheric aerosols with polarization lidar*
- N. G. Khlebtsov and B. N. Khlebtsov, *Optimal design of Au core-shell nanoparticles with embedded Raman reporters*
- D. Mackowski, *Application of DDA to plane parallel, discrete random media*
- P. L. Marston, *Insight into scattering and caustics from the evolution of glare points and wavefronts*
- P. A. Martin, *Aspects of scattering in the time domain*

- J. P. Reid, R. E. Willoughby, A. Valenzuela, B. R. Bzdek, H. Lin, and A. J. Orr-Ewing, *Light scattering and absorption studies with single trapped particles*
- C. M. Sorensen, *Light scattering by particles: the view from Q-space*
- N. Thomas, A. Pommerol, Y. Brouet, O. Poch, B. Jost, and Z. Yoldi, *Laboratory studies of light scattering by well-controlled and characterized ice samples*
- M. A. Yurkin, *Estimation of solution uncertainties for parametric inverse light-scattering problems*

CONVENERS

Ludmilla Kolokolova, *University of Maryland, College Park, MD, USA*
Matthew J. Berg, *Kansas State University, Manhattan, KS, USA*
Jay D. Eversole, *Naval Research Laboratory, Washington, DC, USA*
Michael Mishchenko, *NASA GISS, New York, USA*
Gorden Videen, *Army Research Laboratory, Adelphi, MD, USA*

ORGANIZING COMMITTEE

Anthony Davis, *NASA/JPL, Pasadena, CA, USA*
Oleg Dubovik, *CNRS/University of Lille, France*
Gerard Gouesbet, *National Institute of Applied Sciences, Rouen, France*
Joop Hovenier, *University of Amsterdam, Amsterdam, The Netherlands*
Olga Kalashnikova, *NASA/JPL, Pasadena, CA, USA*
Nikolai Khlebtsov, *Russian Academy of Sciences, Saratov, Russia*
Alexei Lyapustin, *NASA/GSFC, Greenbelt, MD, USA*
Hal Maring, *NASA HQ, Washington, DC, USA*
Alexander Marshak, *NASA/GSFC, Greenbelt, MD, USA*
M. Pinar Mengüç, *Ozyegin University, Istanbul, Turkey*
Karri Muinonen, *University of Helsinki & National Land Survey, Finland*
Vijay Natraj, *NASA/JPL, Pasadena, CA, USA*
Thomas Wriedt, *University of Bremen, Germany*
Ping Yang, *Texas A&M University, College Station, TX, USA*

Monday, March 20

8:45-9:00 **Opening of the conference**

9:00–10:30 **Tropospheric aerosols: the NASA perspective /** H. Maring

- **(Invited review)** S. P. Burton, J. Hair, R. Ferrare, C. Hostetler, M. Vaughan, and A. Omar, *Characterization of tropospheric aerosols with polarization lidar*
- G. L. Schuster, R. Espinosa, L. D. Ziemba, A. J. Beyersdorf, A. Rocha-Lima, B. E. Anderson, J. V. Martins, O. Dubovik, F. Ducos, D. Fuertes, T. Lapyonok, M. A. Shook, Y. Derimian, and R. H. Moore, *A Laboratory Experiment for the Statistical Evaluation of Aerosol Retrievals (STEAR)*
- J. V. Martins, R. Fernandez-Borda, B. McBride, W. R. Espinosa, and L. A. Remer, *Combination between in situ and remote-sensing measurements of tropospheric aerosols*
- F. Xu, D. J. Diner, M. Luo, D. Fu, and O. Dubovik, *Coupled retrieval of aerosol properties, column trace gas abundance, and surface reflectance using multiangle and multispectral polarimetric measurements*
- J. Wang, S. Ding, and X. Xu, *Polarimetric remote sensing in oxygen A and B bands: sensitivity study and information content analysis for vertical profile of aerosols*

10:30–11:00 **Coffee break**

11:00–12:00 **Tropospheric aerosols: the NASA perspective /** H. Maring

- R. C. Levy, R. A. Kahn, A. Sayer, O. Torres, N. C. Hsu, P. R. Colarco, and L. A. Remer, *Passive remote-sensed observations of tropospheric aerosols: a GSFC perspective*
- E. Kassianov, M. Pekour, C. Flynn, L. K. Berg, J. Beranek, A. Zelenyuk, C. Zhao, L. R. Leung, P. L. Ma, L. Riihimaki, J. D. Fast, J. Barnard, A. G. Hallar, I. B. McCubbin, E. W. Eloranta, A. McComiskey, and P. J. Rasch, *What can satellite observations, surface data and model simulations tell us about trans-Pacific dust transport?*
- G. Wind, A. Da Silva, K. Meyer, S. Platnick, R. Levy, P. Norris, and S. Mattoo, *Multi-sensor Cloud and Aerosol Retrieval Simulator and its applications*
- W. Hou, J. Wang, and X. Xu, *Feasibility analysis of hyperspectral remote sensing of aerosols from future geostationary satellites*

12:00–13:30 **Lunch**

13:30–14:30 **Memorial Borghese Session /** M. Mishchenko

- *Ferdinando Borghese: his life and scientific legacy*
- T. Väisänen, J. Markkanen, A. Penttilä, and K. Muinonen, *Radiative Transfer with Reciprocal Transactions R^2T^2*
- J. M. Dlugach, M. I. Mishchenko, and D. W. Mackowski, *Electromagnetic scattering by discrete media*
- L. Bi, W. Lin, and D. Mackowski, *Modeling the optical properties of complex mixed aerosol particles based on a new combinational T-matrix approach*

14:30–15:30 **Electromagnetic scattering /** J. A. Lock

- **(Invited review)** J. P. Reid, R. E. Willoughby, A. Valenzuela, B. R. Bzdek, H. Lin, and A. J. Orr-Ewing, *Light scattering and absorption studies with single trapped particles*
- S. Edalatpour and M. Francoeur, *Near-field radiation heat transfer between arbitrarily-shaped objects and a surface*
- A. Didari and M. P. Mengüç, *Spectrally selective thermal emission by structured mesoporous metamaterials*

15:30–16:00 **Coffee break**

16:00–17:30 **Electromagnetic scattering /** P. Yang

- G. Gouesbet and J. A. Lock, *A comment on the description of axisymmetric Bessel beams*

- J. Charon, J.-F. Cornet, J. Dauchet, and M. E. Hafi, *A first investigation on solving integral equations of electromagnetic scattering with the Monte Carlo method: application to arbitrarily shaped particles*
- Y. Grynko and J. Förstner, *Second harmonic emission from plasmonic gap nanoantennas with rough surfaces*
- A. V. Konoshonkin, N. V. Kustova, V. A. Shishko, D. N. Timofeev, and A. G. Borovoi, *Light scattering by irregular ice crystals of cirrus clouds*
- J. B. Maughan, A. Chakrabarti, and C. M. Sorensen, *Rayleigh scattering and the internal coupling parameter for arbitrary particle shapes*
- J. Seneviratne and M. J. Berg, *Electromagnetic scattering by spheroidal particles*

17:30–18:30 Meeting of the *JQSRT* Editorial Board

Tuesday, March 21

8:30–9:30 Multiple scattering / E. Kassianov

- **(Invited review)** D. Mackowski, *Application of DDA to plane parallel, discrete random media*
- M. I. Mishchenko, J. M. Dlugach, L. Liu, and D. W. Mackowski, *What makes a multi-particle group look like a turbid medium?*
- T. A. Reichardt and T. J. Kulp, *Radiative transfer model for the reflectance of packed particulate media*

9:30–10:30 Laboratory and field experiments / J. Eversole

- **(Invited review)** N. Thomas, A. Pommerol, Y. Brouet, O. Poch, B. Jost, and Z. Yoldi, *Laboratory studies of light scattering by well-controlled and characterized ice samples*
- Z. Gong, Y.-L. Pan, and C. Wang, *Optical trapping and manipulation configurations for measuring light extinctions of single particles*
- D. Landgraf, J. Zallie, R. Pinnick, Y.-L. Pan, and K. B. Aptowicz, Insights into particle morphology from single-particle light scattering

10:30–11:00 Coffee break

11:00–12:00 Laboratory and field experiments / J. Eversole

- P. Lane, M. Hart, and J. D. Eversole, A system for measuring forward light scattering by spherical and nonspherical silica particles
- H. Li, C. D. Rosebrock, T. Wriedt, and L. Mädler, *Experimental investigations on single burning droplets with micro-explosions using shadowgraphy, interferometric particle imaging, and standard rainbow refractometry*
- Y.-L. Pan, R. Fu, G. Videen, C. Wang, and J. L. Santarpia, *Simultaneous measurement of elastic back-scattering pattern and image from laser-trapped single airborne particles*
- A. Ronen and S. Elisha, *Performance of electro optical sensor in dusty environment: theory and experiment*

12:00–13:30 Lunch

13:30–15:30 Study of aerosol and environmental chemistry through analyses of light scattering / G. Videen & M. Berg

- S. C. Hill, D. C. Doughty, A. E. Wetmore, and D. James, *Raman spectra of individual atmospheric aerosol with spatial resolution of one to a few micrometers*
- M. J. Berg, Y. Heinson, O. Kemppinen, and S. Holler, *Light scattering and imaging of aerosol particles with digital holography*
- M. B. Hart, V. Sivaprakasam, J. Czege, and J. D. Eversole, *Using a linear electrodynamic trap and elastic scattering for single particle environmental fate studies*
- W. D. Herzog, J. M. Richardson, D. S. Wolinski, J. M. Jong, B. G. Saar, S. M. Redmond, and J. D. Eversole, *Micron-sized particle detection and discrimination using scattered infrared light*

- M. D. Alexandrov and M. I. Mishchenko, *Accuracy and information content of bistatic lidar observations of aerosols from space*
- R. Ceolato, N. Rivière, and M. J. Berg, *Spectral polarimetric light-scattering by soot aerosols: from single particles to complex fractal aggregates*
- J. M. Conny and D. L. Ortiz-Montalvo, *Effect of shape on optical properties of urban dust based on 3-dimensional reconstruction of individual particles*
- R. Furstenberg, C. A. Kendziora, V. Nguyen, and R. A. McGill, *Infrared microscopy of small particles on solid surfaces*

15:30–16:00 Coffee break

16:00–16:30 Study of aerosol and environmental chemistry through analyses of light scattering / G. Videen & M. Berg

- A. B. Milstein, J. M. Richardson, R. E. Martinez, J. J. Lacirignola, and R. G. Vanderbeek, *Polarization-dependent optical scatter from multi-particle aerosol samples*
- V. Sivaprakasam, M. B. Hart, and J. D. Eversole, *Enhanced Raman spectroscopy of aerosol particles*

16:30–17:30 Optical characterization / J. Dlugach

- **(Invited review)** C. M. Sorensen, *Light scattering by particles: the view from Q-space*
- D. Dannhauser, D. Rossi, M. Ripaldi, P. A. Netti, and F. Causa, *Differentiation of leukemia stages by scattering signatures of individual cells*
- C. A. Jeffery and B. Henderson, *Phenomenological theory of the reflectance of particulate media: scattering regimes and Lorentz features*

17:30–18:30 ELS Business Meeting

Wednesday, March 22

8:30–10:30 Electromagnetic scattering / K. Muinonen

- **(Invited review)** P. L. Marston, *Insight into scattering and caustics from the evolution of glare points and wavefronts*
- **(Invited review)** P. A. Martin, *Aspects of scattering in the time domain*
- J. A. Lock, *Electromagnetic scattering of a plane wave by a radially inhomogeneous sphere in the short wavelength limit*
- R. L. Panetta, S. Zhai, and P. Yang, *On the stopping time for time-domain exact simulations of single particle interactions with Gaussian optical pulse*
- M. P. L. Sentis, F. R. A. Onofri, and F. Lamadie, *In-line digital holographic near-field reconstruction applied to particles characterization in astigmatic optical systems and refractive index measurements*
- A. A. Shcherbakov, *Calculation of electromagnetic scattering by non-spherical particles by means of the generalized metric sources*

10:30–11:00 Coffee break

11:00–12:00 Astrophysical applications / V. Rosenbush

- O. Muñoz, F. Moreno, D. Guirado, J. Escobar-Cerezo, and J. W. Hovenier, *Scattering by mm-sized cosmic dust grains*
- N. N. Kiselev and D. V. Petrov, *Position and maximum of linear polarization of different asteroids types: Observations and computer simulation*
- L. Kolokolova, L. Nagdimunov, and C. Master, *Light scattering by hierarchical aggregates*
- E. Zubko, G. Videen, D. C. Hines, and Y. Shkuratov, *Positive polarization in comets: clues to the coma composition*

12:00–15:15 Poster session

- P. Barton and J. Pavlu, *Measurement of single object light scattering: experiment development and first results*
- T. Cheng, Y. Wu, X. Gu, and H. Chen, *Effects of mixing states on the multiple-scattering properties of soot aerosols*
- K. Du, K. Xue, and Z. Lee, *GPU accelerated 3D Monte Carlo ocean radiative transfer simulation*
- A. Egel, Yu. Eremin, Th. Wriedt, D. Theobald, and U. Lemmer, *The T-matrix method for light scattering by oblate particles near interfaces: improved accuracy through Sommerfeld integral truncation*
- Y. A. Eremin and T. Wriedt, *Unified formula for extinction cross-section for multipole of an arbitrary order*
- W. R. Espinosa, L. Remer, O. Dubovik, L. Ziemba, A. Beyersdorf, D. Orozco, A. Puthukkudy, G. Schuster, T. Lapyonok, D. Fuertes, and J. V. Martins, *Retrievals of aerosol optical and microphysical properties from imaging polar nephelometer scattering measurements*
- Z. R. Fathi, M. P. Mengüç, and H. Ertürk, *Optimization of iterative solvers for DDA-SI*
- T. Fauchez, S. Platnick, K. Meyer, C. Cornet, and F. Szczap, *Estimation of cirrus 1-km subpixel radiance variance in MODIS TIR channels using VIS reflectances at 250-m resolution*
- M. Gritsevich, S. Sonnett, J. Torppa, K. Muinonen, A. Penttilä, Amy Mainzer, T. Grav, J. Masiero, J. Bauer, and E. Kramer, *Shapes and rotational properties of selected Hilda and Trojan asteroids*
- O. Jobe, D. B. Thiessen, and P. L. Marston, *Hyperbolic umbilic caustics from oblate water drops with tilted illumination: observations*
- J. M. Jong, W. D. Herzog, J. M. Richardson, D. S. Wolinski, B. G. Saar, S. M. Redmond, and J. D. Eversole, *The Single Particle InfraRed Elastic Scatter (SPIRES) brassboard sensor*
- A. Kar, A. K. Sen, and R. Gupta, *Laboratory simulation of light scattering from regolith analogue: effect of porosity and particle size*
- F. K. Khosroshahi, H. Ertürk, and M. P. Mengüç, *Enhancement of spectral absorption of graphene based nano-structures in narrow bands*
- R. R. Li, G. Tang, J. Ding, and P. Yang, *Laboratory measurements of scattering phase function of dust samples at 532 and 1064 nm*
- W. Lin, L. Bi, D. Liu, and K. Zhang, *An efficient and accurate extinction simulator for atmospheric aerosols*
- C. Liu, J. Li, and Y. Yin, *How significantly can mixing enhance absorption of black-carbon aerosols*
- L. R. Llanza, P. G. Piedra, and H. Moosmüller, *Optical losses due to particles on solar cells: experimental scattering and absorption spectra for absorbing and non-absorbing mineral dust*
- B. A. McBride, J. V. Martins, R. Fernandez-Borda, *Hyper-angular polarimetric measurements of aerosols and clouds with the Hyper-Angular Rainbow Polarimeter (HARP)*
- G. Okyay, S. Bellayer, M. Jimenez, F. Samyn, and S. Bourbigot, *Radiative properties of in-flame sooty aggregates from fire scenarios of polymer burning*
- C. V. Pandya, U. Prajapati, and D. B. Vaidya, *Optical properties of core–mantle grains with ices as mantle*
- A. N. Pavlov, K. A. Shmirko, and E. Zubko, *Characterizing atmospheric aerosol: comparative analysis of active and passive techniques*
- A. Penttilä, G. Maconi, I. Kassamakov, M. Gritsevich, E. Hæggström, and K. Muinonen, *Experimental light scattering by small particles: first results with a novel Mueller matrix scatterometer*
- A. V. Romanov, A. I. Konokhova, K. V. Gilev, V. P. Maltsev, and M. A. Yurkin, *A spectral method to characterize single spheres from light-scattering patterns*
- S. Roy, N. Barua, G. A. Ahmed, and A. K. Buragohain, *Scattering properties of Mycobacterium smegmatis*
- S. Roy, N. Barua, G. A. Ahmed, and A. K. Buragohain, *Simulation of light scattering properties of Pseudomonas aeruginosa*
- T. V. Russkova, *GPU-based Monte Carlo simulation of radiative transfer in a cloudy atmosphere*

- S. Savenkov, S. Yoo, E. G. Caurel, Y. Oberemok, I. Kolomiets, T. Novikova, R. Ossikovski, and A. Klimov, *Linear polarization memory of inhomogeneous birefringent medium in visible wavelength range*
- A. A. Shcherbakov, *Rigorous simulation of electromagnetic scattering by rough surfaces*
- O. V. Shefer and T. V. Russkova, *Numerical study of the influence of different dispersed components of a crystal cloud on transmission of radiant energy*
- H. Shen, L. Wu, G. Liu, and W. Wang, *Capability and limitation on size and shape determination of a non-spherical particle by Interferometric Laser Imaging for Droplet Sizing technique using Fourier Transform*
- D. B. Vaidya and R. Gupta, *Interstellar polarization by spheroidal composite grains*
- J. Wang, J. Ge, M. Wei, Z. Yang, and Q. Zhang, *Theoretical and experimental study on echo fluctuation suppression of cirrus cloud by millimeter wave MIMO radar*
- Y. Wu, T. Cheng, L. Zheng, and H. Chen, *Black carbon radiative forcing at TOA decreased during aging*
- M. A. Yurkin and M. I. Mishchenko, *Group-theoretical foundation of the random orientation in far-field electromagnetic scattering*
- E. Zubko, N. Zubko, O. Muñoz, A. M. Zakharenko, K. S. Golokhvast, A. N. Pavlov, and G. Videen, *Modeling sea-salt aerosol: light-scattering experiment and numerical simulations*
- N. Zubko, O. Muñoz, E. Zubko, M. Gritsevich, J. Peltoniemi, J. Escobar-Cerezo, M. Berg, and J. Wen, *Light scattering by volcanic sand: single-scattering particles versus particulate surface*

15:30–22:00 Bus tour and Conference Banquet

Thursday, March 23

8:30–10:30 Atmospheric radiation and remote sensing / A. Marshak

- R. K. Chakrabarty and W. R. Heinson, *Electromagnetic light interaction with coated soot aggregates*
- P. Yang, K.-N. Liou, G. W. Kattawar, B. Baum, S. Platnick, and M. D. King, *Searching for an optimal optical property model for ice clouds*
- H. Moosmüller and C. M. Sorensen, *Large and small particle limits of single scattering albedo for homogeneous, spherical particles*
- Z. Zhang, F. Werner, H.-M. Cho, G. Wind, S. Platnick, A. S. Ackerman, L. Di Girolamo, A. Marshak, and K. Meyer, *A framework based on 2-D Taylor expansion for quantifying the impacts of sub-pixel reflectance variance and covariance on cloud optical thickness and effective radius retrievals based on the bi-spectral method*
- K. D Knobelspiesse, M. Segal-Rosenhaimer, J. Redemann, B. Cairns, and M. D. Alexandrov, *Multi-angle, polarimetric cloud observations using a radiative transfer model trained Neural Network*
- B. van Diedenhoven, A. S. Ackerman, A. M. Fridlind, and B. Cairns, *An evaluation of average ice crystal shapes to represent scattering properties of ice crystal population ensembles*
- A. Levis, *Three-dimensional microphysical tomography of clouds*
- T. V. Russkova and T. B. Zhuravleva, *3D Monte Carlo polarized radiative transfer model for simulation of light propagation into scattering media*

10:30–11:00 Coffee break

11:00–12:00 Van de Hulst Session / G. Videen

12:00–13:30 Lunch

13:30–15:30 Atmospheric radiation and remote sensing / K. Knobelspiesse

- P. G. Stegmann and P. Yang, *Electromagnetic scattering and radiation transport involving heterogeneous ice particles in the community radiative transfer model*

- A. Marshak, T. Várnai, and A. Kostinski, *Specular reflection from oriented ice crystals observed from deep space*
- I. Veselovskii, P. Goloub, T. Podvin, D. Tanre, M. Korenskiy, A. Borovoi, Q. Hu, and D. N. Whiteman, *Ice-crystal corner reflection observed with two-wavelength polarization lidar*
- B. Sun, P. Yang, and G. W. Kattawar, *A physical–geometric optics method for obtaining the scattering properties of inhomogeneous faceted particles*
- F. Xu and A. B. Davis, *Markov chain approach for computing polarized radiative transfer: formalism and application*
- Z. Wang, S. Cui, J. Yang, H. Gao, C. Liu, and Z. Zhang, *Rapid and accurate Monte Carlo simulations of radiative transfer in cloudy atmosphere*
- G. P. Milinevskyi, Y. S. Yatskiv, I. I. Syniavskyi, A. P. Bovchaliuk, O. V. Degtyaryov, M. G. Sosonkin, M. I. Mishchenko, V. K. Rosenbush, V. O. Danylevsky, Y. S. Ivanov, Y. A. Oberemok, V. M. Masley, and S. I. Moskalev, *Satellite mission Aerosol-UA for atmosphere aerosol study*
- P. Srivastava, S. Dey, S. N. Singh, and A. K. Srivastava, *Modulation of aerosol forcing by mixing state and particle morphology: case study from Delhi NCR, India*

15:30–16:00 Coffee break

16:00–17:30 Optical characterization / L. Kolokolova

- **(Invited review)** N. G. Khlebtsov and B. N. Khlebtsov, *Optimal design of Au core-shell nanoparticles with embedded Raman reporters*
- L. Al-Gebory and M. P. Mengüç, *The effect of pH value on particle agglomeration and the radiative properties of nanoparticle suspensions*
- S. A. Nouri, K. Fuller, D. A. Gregory, and A. Smith, *Angle scanning spectropolarimetry of particle deposits*
- G. Okyay and F. Enguehard, *Towards more realistic generation of numerical soot aggregates with particle overlapping*
- J. Archer, M. Kolwas, M. Wozniak, D. Jakubczyk, G. Derkochov, T. Wojciechowski, and K. Kolwas, *Observation of transient elastic light scattering properties of Sodium Dodecyl Sulphate (SDS) on colloidal silica nano-sphere aggregates from evaporating single microdroplet of suspension*

Friday, March 24

8:30–10:00 Multiple scattering / R. L. Panetta

- K. Muinonen, J. Markkanen, T. Väisänen, and A. Penttilä, *Light scattering in planetary regoliths: numerical solution*
- B. Ramezan pour and D. W. Mackowski, *Prediction of polarized reflection and transmission in plane parallel dense media*
- S. Korkin, A. Lyapustin, A. Sinyuk, and B. Holben, *Recent updates on the RT code SORD*
- L. A. Dombrovsky, D. L. Reviznikov, A. P. Kryukov, and V. Y. Levashov, *Solar probe shielding from intense thermal radiation: estimates of the effect of a generated cloud of SiC particles*
- P. G. Piedra, L. R. Llanza, and H. Moosmüller, *Optical losses due to particles on solar cells: DDA-substrate calculations and experimental validation*
- A. J. Brown, *Rayleigh coherent backscattering and circular polarization*

10:00–10:30 Astrophysical applications / O. Muñoz

- V. Rosenbush, O. Ivanova, L. Kolokolova, N. Kiselev, and V. Afanasiev, *Possible explanation of spatial variations of polarization and color of dust in comet 67P/Churyumov–Gerasimenko*
- G. Ito and T. D. Glotch, *Improving planetary remote sensing mineralogical analysis using T-matrix and radiative transfer hybrid models*

10:30–11:00 Coffee break

11:00–12:00 Astrophysical applications / O. Muñoz

- J. Herranen, J. Markkanen, and K. Muinonen, *Dynamics of interstellar dust particles in electromagnetic radiation fields*
- O. Ivanova, J.M. Dlugach, and V. Afanasiev, *The scattering properties of dust in distant comets*
- J. Markkanen, A. Penttilä, T. Väisänen, and K. Muinonen, *Numerical solution for light scattering by space-weathered planetary bodies*
- J. Martikainen, A. Penttilä, T. Kohout, H. Suhonen, S. Huotari, M. Gritsevich, and K. Muinonen, *Spectral modeling for the Chelyabinsk meteorite at UV–Vis–NIR wavelengths*

12:00–13:30 Lunch

13:30–15:30 Optical characterization / M. P. Mengüç

- **(Invited review)** M. A. Yurkin, *Estimation of solution uncertainties for parametric inverse light-scattering problems*
- W. Blohm, *Modelling light scattering in the shadow region behind thin cylinders for diameter analysis*
- C. Gerlein-Safdi, B. T. Draine, S. Frolking, and K. K. Caylor, *Microwave scattering by a dew-wetted leaf*
- O. Kemppinen, Y. Heinson, and M. Berg, *Three-dimensionality of digital holography reconstructions*
- H. S. Das and A. M. Mazarbhuiya, *Investigating the correlation between different parameters in an aggregate dust model*
- S. Hioki and P. Yang, *Estimating phase matrix from multi-viewing satellite measurements*
- R. Medina, *Light scattering studies at the El Paso del Norte Region in Texas*

15:30–16:00 Coffee break

16:00–17:30 Astrophysical applications / N. Kiselev

- P. A. Yanamandra-Fisher, W. McLean, P. Miles, A. Wesley, P. Madingsly, and L. Rossi, *Polarization of hazes and aurorae on Jupiter*
- J. Escobar-Cerezo, C. Palmer, O. Muñoz, F. Moreno, A. I. Penttilä, and K. Muinonen, *Scattering properties of large irregular cosmic dust particles at visible wavelengths*
- D. Guirado, F. Moreno, O. Muñoz, and J. Escobar-Cerezo, *Monte Carlo model of light scattered by mm-sized particles covered with micrometric irregular grains*
- R. Nežič, L. Kolokolova, S. Bagnulo, G. Borisov, A. Stinson, C. Snodgrass, H. Böhnhardt, G. H. Jones, J. Licandro, and J. de León, *Polarimetric observations of comet 67P/Churyumov–-Gerasimenko and preliminary modelling results*
- C. Legett IV, T. D. Glotch, and P. G. Lucey, *Comparison of Multiple Sphere T-matrix and Mie models for space weathering relevant materials*
- G. A. Ahmed and M. J. Boruah, *Light scattering experiments and simulated studies using DDA of interstellar dust analogue modelled with fayalite and graphite*

17:45 Farewell party

Invited Reviews

Ordered alphabetically according to the first author's last name

Characterization of tropospheric aerosols with polarization lidar

Sharon P. Burton*, Johnathan Hair, Richard Ferrare, Chris Hostetler, Mark Vaughan, and Ali Omar

NASA Langley Research Center, Hampton, VA 23669, USA

**Presenting author (sharon.p.burton@nasa.gov)*

The impacts of tropospheric aerosols on climate and air quality depend on the amount, vertical distribution, source, type, size and optical properties of the aerosols. Therefore, knowledge of vertically resolved aerosol properties is important for assessing aerosol radiative forcing, source attribution, air quality applications, and model verification. Lidar is unique among remote sensing measurement techniques for providing full vertically-resolved profiles of tropospheric aerosols and aerosol properties. Both qualitative and quantitative retrievals of aerosol abundance and microphysical properties are routinely made using ground-based, airborne, and satellite-borne lidar data, with the amount of information content varying among different types of lidar instruments. Lidar measurements characterize both extensive properties – those that vary with the amount of aerosol, including aerosol extinction and backscatter – and also intensive properties, which do not depend on aerosol abundance, but instead indicate microphysical properties like aerosol shape, size or absorption. In this talk we survey the ways that lidar measurements of extensive and intensive properties are used to characterize tropospheric aerosols, with a specific focus on the measurement of particle depolarization. Particle depolarization at one or more wavelengths, along with other intensive lidar measurements, has been used for such applications as distinguishing different aerosol types such as dust and smoke; identifying atmospheric dust and tracking the transport of dust aerosols across the globe; calculation of mixing between different aerosol types; and assessment of particle size.

Optimal design of Au core-shell nanoparticles with embedded Raman reporters

Nikolai G. Khlebtsov[a,b,*] **and Boris N. Khlebtsov**[a,b]

[a]*Institute of Biochemistry and Physiology of Plants and Microorganisms Russian Academy of Sciences, 13 Prospekt Entuziastov, 410049, Russia*
[b]*Saratov National Research University, 83, Astrakhanskaya Str., 410012 Saratov, Russia*

[*]*Presenting author (khlebtsov@ibppm.ru)*

Recently, several research groups have reported on highly efficient multilayer SERS tags (also called nanomatryoshkas, NMs), in which Raman molecules are embedded in a nanometer-sized interior gap between the metallic core and the shell [1–5]. Such multilayered structures have great potential for biomedical applications due to several advantages: (1) Raman molecules are protected from desorption, subjected to a strongly enhanced electromagnetic (EM) field in the gap, and their SERS response does not depend on the environmental conditions and NM aggregation; (2) owing to bright and uniform spectral pattern, NMs provide a linear correlation between probe concentration and SERS intensity and allow for a real-time *in vivo* imaging and high throughput sensing with short integration times; (3) NM size and spectral properties can be designed for effective cellular uptake and tissue imaging with negligible background from sample autofluorescence; (4) NM probes can be multiplexed by incorporating different Raman molecules into two-layered or multilayered NMs. However, the synthesis and design of optimal gold NMs remain still challenging. Here, we report a detail analysis of EM enhancement in a (core/gap/shell) Au NMs as a function of NM structure, including the core size, the gap and shell thicknesses, and the gap refractive index. The optimization strategy is based on an efficient rigorous solution for internal EM fields in a layered sphere and explicit analytical solutions for the surface and volume averaged EM intensities within a particular layer and around the NM. The SERS enhancement is shown to be strongly dependent, in a resonance manner, on the core and gap size, whereas the shell thickness plays a minor role. The simulation data are exemplified by experimental measurements of SERS spectra for Au NMs with 1,4 benzenedithiol molecules embedded in a sub-nanometer gap.

References

1. Lim D. K. et al. *Nat. Nanotechnol*. **6**, 452 (2011).
2. Lin L. et al. *Nano Lett*. **15**, 6419 (2015); *Chem. Commun*. **51**, 17740 (2015).
3. Khlebtsov B.N. and Khlebtsov N.G. *J. Phys. Chem. C* **120**, 1538 (2016).
4. Gandra N. et al. *Nanoscale* **8**, 8486 (2016).
5. Lee J.-H. et al. *Small* **12**, 4726 (2016).

Application of DDA to plane parallel, discrete random media

Daniel Mackowski

Department of Mechanical Engineering, Auburn University, Auburn, AL 36849, USA (mackodw@auburn.edu)

The talk will discuss the application of discrete dipole approximation (DDA) methods to the prediction of polarimetric reflectance from plane parallel layers of random particulate media. Such methods are intended for situations in which the characteristic size of the particles is comparable to the probing radiation wavelength, yet no restriction is made regarding the concentration of the particles. In particular, the application is specifically intended for high particle concentrations characteristic of planetary regolith, powder layers, pigment films, and so on. A periodic unit cell approach is used to model plane parallel geometries, in which the unit cell contains a representative sample of the medium and is repeated, periodically to infinity, in the lateral dimensions of the layer. The periodic model enables a reciprocal-space reformulation of the DDA model that is distinct from that traditionally used when applied to single particle scattering. It is shown that this model can become equivalent to the radiative transport equation (RTE) in the limit of dilute particle concentration. For random particulate media, the system of DDA equations in reciprocal space can be significantly truncated without significant loss in model accuracy. This, along with a preconditioning scheme involving the analytical estimation of the coherent field, results in a rapidly-converging numerical method that can make tractable the prediction of reflectance from high-concentration particle layers having optical thicknesses well in excess of unity. Test calculations show that the plane parallel DDA method can reproduce direct simulation predictions of hemispherical reflectance from layers of spherical particles as calculated by multiple sphere superposition solutions. The method, when applied to low particle concentration conditions, can also reproduce the overall features of polarized, bidirectional reflection as predicted by the RTE. It will also reveal reflection phenomena not predictable by the traditional RTE, such as coherent backscattering and polarization opposition.

Insight into scattering and caustics from the evolution of glare points and wavefronts

Philip L. Marston

Physics and Astronomy Department, Washington State University, Pullman, WA 99164-2814, USA (marston@wsu.edu)

In the 1970s M. V. Berry and J. F. Nye developed catastrophe optics as a framework for classifying caustics and associated wavefields. Bright regions in short-wavelengths far-field scattering are often associated with a caustic corresponding to an absence of curvature of an outgoing wavefront. The discovery of far-field cusp and hyperbolic-umbilic scattering patterns in the rainbow region of oblate acoustically levitated drops in the 1980s helped to motivate the application of generalized ray tracing to the analysis of the curvature of scattered wavefronts. Associated glare points are visible when viewing levitated drops through an aperture within the angular region spanned by such caustics. In certain symmetric situations not only is it possible to approximate caustic and wavefield properties, the dependence of glare points on drop shape can also be predicted. The merging of glare points is related to the caustics in a predictable fashion. One analytical approach utilizes methods for evaluating the principal curvatures of wavefronts in optical systems developed by J. A. Kneisly and O. N. Stavroudis in the 1960s and 1970s. Lip-shaped caustics are visible in the backscattering region for sufficiently oblate drops. When viewing higher-order rainbow regions, complicated patterns can be produced with only small deformations of a drop. Related investigations include the nature of glory scattering by gas bubbles in liquids and the relation of caustics and polarization of the scattering to bubble shape.

Aspects of scattering in the time domain

P. A. Martin

Department of Applied Mathematics and Statistics, Colorado School of Mines, Golden, CO 80401, USA
pamartin@mines.edu

Since I was a graduate student in the late 1970s, I have worked on scattering problems in the frequency domain: I was content with the mantra "time-domain problems can be treated using Fourier transforms". In the last couple of years, I have begun working in the time domain, "going back to basics", with a focus on the scattering of scalar waves by spheres and spheroids. It turns out that there are things to learn, with a few surprises (to me, at least), and these will be the subject of my talk.

Light scattering and absorption studies with single trapped particles

Jonathan P. Reid[a,*], Rose E. Willoughby[a], Antonio Valenzuela[a], Bryan R. Bzdek[a], Hongze Lin[b], and Andrew J. Orr-Ewing[a]

[a]*School of Chemistry, University of Bristol, BS8 1TS, UK*
[b]*Department of Optical Engineering, Zhejiang University, Hangzhou 310058, China*

[*]*Presenting author (j.p.reid@bristol.ac.uk)*

Aerosol particles scatter and absorb light, directly influencing the radiative balance of the atmosphere and climate. The optical cross-section depends on particle size, composition (refractive index) and morphology, and varies with the wavelength of incident light. In addition, the optical cross-section changes in response to environmental conditions (e.g. relative humidity), heterogeneous chemistry (e.g. the formation of light absorbing brown carbon components), and mixing state (e.g. internal and external mixtures). We will present a method for the accurate determination of the optical extinction cross-sections of an individual particle at multiple wavelengths and the dependence on environmental conditions, with continuous monitoring of the optical properties of the same particle over an indefinite timeframe. Such measurements provide accurate data for benchmarking and refining predictive models.

Cavity ringdown spectroscopy (CRDS) has become a widely used technique for interrogating the optical properties of ensembles of aerosol particles, both in field measurements and in laboratory studies. Uncertainties of ±2% are typical in the determination of the real part of the refractive index and larger for the imaginary part. We will discuss the advantages of coupling CRDS with a single particle trap formed from a Bessel beam for studying the optical properties of accumulation mode aerosol. The refractive index can be retrieved at three wavelengths simultaneously with an accuracy of better than ±0.1%. In addition, we will discuss the application of this approach to measurements of the complex refractive index of absorbing aerosol. By the introduction of a modulated heating laser beam in the near-IR, we will show that the temporal-dependence of the change in droplet size can be used to retrieve the imaginary part of the refractive index of solution aerosol with high accuracy at the wavelength of the heating beam.

Light scattering by particles: the view from Q-space

Christopher M. Sorensen

Department of Physics, Kansas State University, Manhattan, KS 66506, USA (sor@phys.ksu.edu)

We take an empirical approach to study the angular dependence of light scattering by particles. As the independent variable, the dimensionless quantity qR is used, where q is the magnitude of the scattering wave vector, $q = (4\pi/\lambda)\sin(\theta/2)$, λ is the wavelength of light, θ the scattering angle, and R is an effective radius of the particle. Moreover, and importantly, plots of intensity vs qR are double logarithmic. This "Q-space analysis" reveals functionalities of the scattering with q that are not apparent with conventional plotting, i.e. intensity vs linear θ. Often in Q-space analysis, the differential scattering cross section is normalized by the Rayleigh cross section of the particle, which we have generalized for any particle shape. For spheres we find the scattering evolves from the 3D Fraunhofer diffraction limit for weak refractivity to a combined 2D Fraunhofer diffraction with a remnant 3D diffraction regime for large, strongly refractive particles. These regimes are identified by, and connected with, power laws. This evolution is governed universally by an internal coupling parameter which also governs the forward scattering. The effects of the imaginary part of the refractive index are described by a second, universal parameter. Q-space analysis applied to particles with other shapes, including dust and fractal aggregate data from our lab and others, and computational data for Gaussian random and perturbed spheres, dense agglomerates and ice crystals, show similar evolution from the 3D diffraction limit and power law functionalities.

Laboratory studies of light scattering by well-controlled and characterized ice samples

Nicolas Thomas*, Antoine Pommerol, Yann Brouet, Olivier Poch, Bernhard Jost, and Zurine Yoldi

Space Research and Planetology Division, Physikalisches Institut, University of Bern, Switzerland

Presenting author (nicolas.thomas@space.unibe.ch)

Over the past 8 years, we have developed LOSSy – the Laboratory for Outflow Studies of Sublimating Materials – at the University of Bern. The aim of this laboratory is to produce ice and dirty ice samples that are reproducible and that can be characterized with an array of different instruments. This has primarily been for planetary science, although applications to Earth-orbiting remote sensing and studies of proto-planetary discs have also been looked at.

Ice particles of varying sizes can be produced using different setups. These setups use nebulizers with different characteristics. The surface structure of the resulting material can be investigated using scanning electron microscopy and optical coherence tomography. A spectro-goniometer (PHIRE-2) can then be used to determine the reflectance properties over the full hemisphere. Both the sample and the goniometer can be maintained at low temperature (typically –30°C) during these measurements. A thermal vacuum chamber (SCITEAS) is also available for space simulation and VIS–NIR hyperspectral measurements can be made while the sample evolves under different conditions. A system has also been developed to measure the polarization of icy samples at multiple wavelengths in the visible and 3°–30° phase angles (with direct applications to icy satellite observations). Approaches to determine the properties of the samples at sub-mm wavelengths have also been developed. The presentation will show some of our latest results.

Estimation of solution uncertainties for parametric inverse light-scattering problems

Maxim A. Yurkin[a,b]

[a]*Voevodsky Institute of Chemical Kinetics and Combustion, SB RAS, Institutskaya str. 3, 630090 Novosibirsk, Russia*
[b]*Novosibirsk State University, Pirogova 2, 630090 Novosibirsk, Russia (yurkin@gmail.com)*

Direct simulation of light scattering by single particles of arbitrary shape and composition in a wide range of sizes has become a routine endeavor due to both the development of numerically exact simulation methods and the increase of raw computer power. However, most practical applications of light scattering require one to solve the inverse problem, i.e., to characterize particles from the measured 1D or 2D light-scattering patterns (LSPs). This problem is much more challenging both conceptually and computationally; its solution currently seems feasible only if one assumes a specific particle model limiting the variation to several shape parameters. The parametric inverse problem boils down to a non-linear regression, which can be solved by standard local or global optimization techniques. However, the resulting best-fit parameters are rather meaningless without an estimate of their uncertainties. While standard statistical (e.g., Bayesian) methods exist for such estimation, they are based on strong assumptions about experimental noise, typically Gaussian errors with the same amplitude and mutually independent for all data points, i.e., for different scattering angles. There are two major limitations of these assumptions. First, many single-particle measurement techniques incur complicated distortions and do not allow repeated measurements to construct a rigorous model of the experimental noise. Second, the real particle shape can be significantly different from the simplified shape model used for the retrieval.

In my talk I will discuss an approximate method to handle both these issues, namely a concept of an effective number of degrees of freedom, calculated from the autocorrelation of the fit residuals. This concept is based on an approximate equivalence of correlated residuals (experimental errors) and a smaller number of uncorrelated ones, for which standard statistical methods are applicable. In particular, I will review the application of this concept to estimating uncertainties during the characterization of biological cells from the LSPs measured with scanning flow cytometry. I will also present a new theoretical analysis of this concept providing more rigorous justification of its usage and pinpointing remaining inherent limitations.

Regular Presentations

Ordered alphabetically according to the first author's last name

Light scattering experiments and simulated studies using DDA of interstellar dust analogue modelled with fayalite and graphite

Gazi Ameen Ahmed* **and Manash Jyoti Boruah**

Optoelectronics and Photonics Laboratory, Department of Physics, Tezpur University, Napaam, Tezpur-784028, Assam, India

**Presenting author (gaziaahmed@yahoo.com)*

Modelling, simulation and computation of the light scattering properties of size and shape distributed interstellar dust analogue of a mixture of fayalite and graphite using discrete dipole approximation (DDA) is presented. The light scattering properties of dust particles of arbitrary shapes having different size distributions were computed using DDSCAT 7.3.0. A comparison of the theoretical scattering parameters at particular incident wavelengths of laser light with experimentation in an indigenously developed setup for light scattering studies is reported. The astrophysical importances of the results are also highlighted.

Preferred mode of presentation: Oral

The effect of pH value on particle agglomeration and the radiative properties of nanoparticle suspensions

Layth Al-Gebory[a,b] and M. Pinar Mengüç[a,*]

[a]*Department of Mechanical Engineering and CEEE, Ozyegin University, Cekmeköy, 34794 İstanbul, Turkey*
[b]*Department of Materials Engineering, University of Technology, Baghdad, Iraq*

[*]*Presenting author (pinar.menguc@ozyegin.edu.tr)*

Nanofluids, or nanoparticle suspensions, have been used extensively to improve thermal efficiency of different thermal sytems. Because of their unique thermo-optical properties, which can be tailored by using different type and size particles, they can be adapted as effective working media in solar thermal collectors for photothermal energy conversion in addition to other thermal applications. However, particle agglomeration in nanosuspensions remains one of the most important challenges for their long term and reliable use. Also, particle agglomeration can have significant effect on the radiative properties of such fluids especially if their use requires selective absorption of radiative flux, such as in solar concentrating power systems.

The purpose of the present study is to investigate the effect of pH value on particle agglomeration. For this purpose, the optical and radiative properties of two types of nanoparticles (Al_2O_3 and TiO_2) are investigated to determine the effects of pH value on agglomeration. First, using a dynamic light scattering (DLS) technique, particle size distribution and average particle agglomerate size are measured. Also, the radiative properties (scattering and extinction coefficients) are experimentally determined using an UV/Visible spectroscopy technique. The comparisons of these results with different light-scattering model predictions are used to demark the dependent/independent scattering regime boundaries of different nanosuspensions. The ultimate objective of this research is to produce nanosuspensions with different average particle agglomerate sizes and size distributions to enhance and tailor their spectrally radiative properties.

Preferred mode of presentation: Oral

Accuracy and information content of bistatic lidar observations of aerosols from space

Mikhail D. Alexandrov[a,b,*] **and Michael I. Mishchenko**[b]

[a]*Columbia University, 2880 Broadway, New York, NY 10025, USA*
[b]*NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA*

[*]*Presenting author (mda14@columbia.edu)*

We present, for the first time, a quantitative error-propagation study for a bistatic high spectral resolution lidar (HSRL) system intended for detailed quasi-global retrievals of aerosol properties from space. Our results demonstrate that supplementing a conventional monostatic HSRL with an additional receiver flown in formation at a scattering angle close to 165° dramatically increases the information content of the measurements and allows for a sufficiently accurate characterization of tropospheric aerosols. We conclude that a bistatic HSRL system would far exceed the capabilities of currently flown or planned orbital instruments in monitoring global aerosol effects on the environment and on the Earth's climate. We also demonstrate how the commonly used *a priori* “regularization” methodology can artificially reduce the propagated uncertainties and can thereby be misleading as to the real retrieval capabilities of a measurement system.

Preferred mode of presentation: Oral

Observation of transient elastic light scattering properties of Sodium Dodecyl Sulphate (SDS) on colloidal silica nanosphere aggregates from evaporating single microdroplet of suspension

Justice Archer*, Maciej Kolwas, Mariusz Woźniak, Daniel Jakubczyk, Genadij Derkochov, Tomasz Wojciechowski, and Krystyna Kolwas

Institute of Physics of the Polish Academy of Sciences, Al Lotników 32/46, 02- 668 Warsaw, Poland

Presenting author (archer@ifpan.edu.pl)

It is well know that surface properties of materials are different from those of the corresponding bulk phase properties and that in any heterogeneous phenomenon, surface properties are at least as important as bulk properties of materials. One specific aspect of this phenomenon is the interaction of laser light radiation with the surface of an evaporating liquid droplet. In particular, evaporation of micrometer-sized liquid droplet containing sub-micron inclusions and droplet with surfactant evaporation represents an important morphological type of scattering objects with unique optical properties. The dependence of the scattered light radiation on particle size, shape and composition makes it suitable for numerous applications including particle sizing, characterization, sensing, and aggregation studies. Sodium dodecyl sulfate (SDS), an anionic surfactant which is often used to simulate the behavior of surfactants observed in the atmosphere is perhaps the most widely studied anionic surfactant in both fundamental scientific studies and in the formulation of industrial products. However, elastically scattered light diagnostics of droplet composed of SDS and other submicron inclusions are sparse in literature. In this presentation, we will examine the changes in the elastic scattered light and thermodynamic-like properties of an evaporating single microdroplet of diethylene glycol (DEG) with SiO_2 nanosphere inclusions and the influence of different percentages by mass of SDS added to the mixture. We will pursue this by analyzing the temporal evolution of the integrated elastically scattered light intensities over the angles of observation and the droplet radius obtained on the basis of the Lorenz-Mie theory. The optical radius will be supplemented by the droplet mass–to-charge ratio evolution. Additionally, we will further analyze Scanning Electron Microscope (SEM) images obtained from finally dried aggregates/micro-composites deposited on a substrate at the end of the evaporation process of the different percentages by mass of SDS added to the DEG/SiO_2 droplet mixture.

Preferred mode of presentation: Oral

Measurement of single object light scattering: experiment development and first results

Petr Barton* **and Jiri Pavlu**

Faculty of Mathematics and Physics, Charles University in Prague, Prague, Czech Republic

**Presenting author (bartonpe@aurora.troja.mff.cuni.cz)*

Light scattering is a complex phenomenon occurring in various environments (from atmospheric pollution to mesospheric dust and planetary rings to dust nebulae in distant galaxies). A broad range of dust sizes as well as of incident light wavelengths leads to many different cases. When the size of the dust is comparable to the incident light wavelength, theoretical determination is difficult. In such case, different computation codes are to be used, but we lack the information about compositions (and therefore optical constants) and shapes for most space-related dust grains.

For experimental measurement of light scattering, we designed an apparatus based on ultrasonic levitation. We are able to trap a dust grain in midair, irradiate it with laser, and observe scattering directly with a goniometer-mounted photodiode. This approach benefits from the ability to measure directly in the air (thus, no need for the carrier medium) and possibility to study non-spherical particles. The trap is in preliminary operation and initial experiments are being carried out; this paper presents the first tests on water droplets.

Preferred mode of presentation: Poster

Light scattering and imaging of aerosol particles with digital holography

Matthew J. Berg[a,*], Yuli Heinson[b], Osku Kemppinen[a], and Steve Holler[c]

[a]*Kansas State University, Department of Physics, 1228 N. 17th St., Manhattan, KS 66506-2601, USA*
[b]*Washington University in St. Louis, Center for Aerosol Science and Engineering, 1 Brookings Dr., Box 1180, St. Louis, MO 63130, USA*
[c]*Fordham University, Department of Physics and Engineering Physics, 208 Freeman Hall, Bronx, NY 10458-5198*

[*]*Presenting author (matt.berg@phys.ksu.edu)*

The recent availability of high resolution optoelectronic sensors has revived holography as a useful technique to study aerosol particles. By placing a two-dimensional detector in a collimated laser beam, the interference pattern produced by a particle in the beam can be easily measured. This pattern is the particle's in-line hologram and useful information can be extracted from it directly. For example, applying a Fourier-transform operation yields a silhouette-like image of the particle, thus revealing its size and shape without *a priori* information. Here, we will present our new laboratory work that employs two wavelengths of light and digital holography with a spatial-filtering technique to image freely flowing aerosol particles and measure their two-dimensional light scattering patterns. Both the imaging and pattern measurement are achieved simultaneously so that a particle's scattering pattern can be unambiguously associated with its physical image. Thus, in a sense this technique constitutes a laboratory-based solution to the classic inverse problem in electromagnetic scattering. Several examples will be presented including mineral and biological particles in the coarse-mode size range, and planned improvements to the experimental design will be discussed.

Preferred mode of presentation: Oral

Modeling the optical properties of complex mixed aerosol particles based on a new combinational T-matrix approach

Lei Bi[a,*], Wushao Lin[a], and Daniel Mackowski[b]

[a] *Department of Atmospheric Sciences, Zhejiang University, Hangzhou 310027,China*
[b] *Department of Mechanical Engineering, Auburn University, Auburn, AL 36849, USA*

[*] *Presenting author (bilei@zju.edu.cn)*

Atmospheric aerosol particles from multiple sources (soot, sulfate and dust) often mix together (externally or internally) and result in an extremely complex light scattering system. In this presentation, we focus on modeling the optical properties of mixed aerosol particles (the extinction efficiency, the single-scattering albedo and the phase matrix) to investigate the fundamental role of single light scattering by particulate matter in remote sensing studies involving aerosols.

The invariant imbedding T-matrix (IITM) approach [1] that was previously developed is applicable to arbitrarily shaped particles; however, it becomes inefficient for inhomogeneous particles that have a sparse distribution of internal inclusions. The relative inefficiency is primarily associated with the fact that the separation of variables method is no longer applicable for obtaining the T-matrix of the inscribed sphere as an initial matrix that can significantly speed the T-matrix computation. To economize the computational time for inhomogeneous particles, we examined the use of multiple-sphere T-matrix (MSTM) program [2] in order to enhance the computational speed for light scattering by a non-spherical particle with multiple spherical or non-spherical inclusions. Specifically, we discuss two numerical schemes:1) the MSTM+IITM, and 2) the IITM+MSTM+IITM. The first scheme is suitable for a non-spherical particle with spherical inclusions, and a cluster of individual particles. The second scheme is designed particularly for a non-spherical particle with multiple non-spherical inclusions.

The computational performances of the aforesaid combinational T-matrix approach will be discussed in details in comparison with a single IITM method. In addition, we will show representative results of the optical properties of mixed aerosols. In particular, we will illustrate the depolarization capabilities of mixed aerosols that would have important implications in aerosol typing and aerosol transport studies.

References

1. Bi L, Yang P, Accurate simulation of the optical properties of atmospheric ice crystals with invariant imbedding T-matrix method. *J Quant Spectrosc Radiat Transf* 2014; **138**:17–35.
2. Mackowski DW, Mishchenko MI, A multiple sphere T-matrix Fortran code for use on parallel computer clusters. *J Quant Spectrosc Radiat Transf* 2011; **112**: 2182–92.

Preferred mode of presentation: Oral

Modelling light scattering in the shadow region behind thin cylinders for diameter analysis

Werner Blohm

Jade University of Applied Sciences, Friedrich Paffrath-Str. 101, 26389 Wilhelmshaven, Germany (werner.blohm@jade-hs.de)

In this paper, light intensity distributions resulting in an observation plane behind monochromatically illuminated circular cylinders are modelled by sinusoidal functions showing a squared dependence on spatial position. Whereas two sinusoidal components appear to be sufficient for modelling the light distribution behind intransparent cylinders, at least three sinusoidal components are necessary for transparent cylinders.

Based on this model, a correlation approach for retrieving the diameter of thin cylindrical products like extra-fine metallic wires or optical fibers is presented. This analysis method was tested with numerical scattering data simulated by Lorenz–Mie theory as well as with real scattering data. Diameter accuracies below 0.1 µm could be achieved for intransparent products. However, scattering effects due to morphological-dependent resonances are problematic in the diameter analysis of transparent products. Modelling of these effects will be subject of future investigations.

Preferred mode of presentation: Oral

Rayleigh coherent backscattering and circular polarization

Adrian J. Brown*

SETI Institute, 189 N. Bernardo Ave, Mountain View, CA 94043, USA (abrown@seti.org)

We extend the work of Mishchenko et al. (2000) regarding the exact results of the polarized backscattering polarization effect, using the theory of Amic et al. (1997) to derive a model prediction for the polarization coherent backscattering opposition effect at small angles. Our extension is to assess the effect of circular polarized light, thus completing the exact derivation of the full Müller matrix for the semi-infinite non-reflecting slab of Rayleigh-sized particles. We find that the circular polarization peak is narrower than the coherent backscattering intensity peak, and weaker in intensity. We will discuss future opportunities to measure this effect and test this model.

We will also report on some corrections to the Amic et al. (1997) exposition which is based on the Chandrasekharian modification of the Weiner–Hopf approach (as elucidated in, e.g., Case 1957), and will discuss the efficacy and potential improvements on their particular solution and approach.

Finally, we will link our results to the general full Müller matrix equivalence relations for laboratory–lidar–planetary geometries recently derived by Brown (2014).

References

Amic, E., J.-M. Luck, and Th. M. Nieuwenhuizen. Multiple Rayleigh scattering of electromagnetic waves. *J. Phys. I* **7** (1997) 445–483.

Brown, A. J. Equivalence relations and symmetries for laboratory, LIDAR, and planetary Müller matrix scattering geometries. *J. Opt. Soc. Am. A* **31** (2014) 2789.

Case, K. M. On Wiener–Hopf Equations. *Ann. Phys.* **2** (1957) 384–405.

Mishchenko, M. I., J.-M. Luck, and Th. M. Nieuwenhuizen. Full angular profile of the coherent polarization opposition effect. *J. Opt. Soc. Am. A* **17** (2000) 888–891.

Preferred mode of presentation: Oral

Spectral polarimetric light-scattering by soot aerosols: from single particles to complex fractal aggregates

Romain Ceolato[a*], Nicolas Rivière[a], and Matthew J. Berg[b]

[a]*ONERA, The French Aerospace Lab, Toulouse, France*
[b]*Kansas State University, Manhattan, KS, USA*

[*]*Presenting author (Romain.Ceolato@onera.fr)*

The global warming and environmental issues imply the study of anthropogenic airborne particulate matter (PM), such as carbonaceous or soot aerosols, emitted by several sources. Carbonaceous particulate matter emitted by aircraft engines is due to incomplete fuel combustion. These particles can have long residence times in the upper troposphere and lower stratosphere and affects the global radiative budget. Soot particles are considered to influence ice and liquid water cloud droplet activation as they could be important centers of ice-particle nucleation and would promote ice formation involved in contrails formation for instance. The understanding of ice-forming activity of soot particles is closely related to the knowledge of their microphysical properties.

The primary soot particles, with size distribution in the nanoscale range, form large and robust complex-shaped cluster of particles such as fractal aggregates. Remote-sensing based on light-scattering, such as LIDAR, are proposed to characterize aircraft engine exhaust particulate matter. We have developed a model to generate soot aggregates with a range of morphology based on measurements reported in the literature. Our model aggregates may then be used in combination with the Spectral Discrete Dipole Approximation (SDDA) to accurately simulate the spectro-polarimetric light scattering properties over a broadband wavelength range relevant (from UV to SWIR). Our results from the SDDA method will be presented and compared with the well-established volume-equivalent carbon spheres commonly used to model soot particles.

Preferred mode of presentation: Oral

Electromagnetic light interaction with coated soot aggregates

Rajan K. Chakrabarty* **and William R. Heinson**

Washington University in St. Louis, Brauer Hall, Campus Box 1180, 1 Brookings Drive, St. Louis, MO 63130, USA

**Presenting author (chakrabarty@wustl.edu)*

Recent field observations have shown that soot aggregates (SAs) contain significant amounts of surface coatings of organic compounds which obfuscate their native fractal morphology and make them visually appear as "near-spherical". These studies have reported an absorption enhancement of up to a factor of three due to the presence of organic coating on SAs. To accurately quantify this phenomenon, we calculated the optical properties of simulated coated SAs using the discrete dipole approximation (DDA) technique. The DDA is optimal for coated SAs since it can easily model irregular geometries with no extra cost in computational time or accuracy. Concurrent with previous experimental findings, our results show an enhancement in light absorption cross-sections by coated SAs up to a factor of three. More surprisingly, however, is that the aerosol scattering cross-sections showed an increase of an order of magnitude compared to their absorption cross-sections. This enhancement leads to an increased single scattering albedo for coated SAs in comparison to nascent SAs of equivalent size. We infer that coated SAs could lead to a net negative forcing beyond a threshold coating mass. Our results could potentially lead to a revision of how coated SAs are currently modeled in climate models and upending our views on their role in enhanced warming amplification.

Preferred mode of presentation: Oral

A first investigation on solving integral equations of electromagnetic scattering with the Monte Carlo method: application to arbitrarily shaped particles

Julien Charon[a,b,c,d], Jean-François Cornet[d,e], Jérémi Dauchet[d,e,*], and Mouna El Hafi[a,b]

[a]*Université Fédérale de Toulouse Midi-Pyrénées, Mines Albi, CNRS UMR 5302, RAPSODEE, Campus Jarlard, F-81013 Albi CT Cedex 09, France*
[b]*CNRS, UMR 5302, RAPSODEE, F-81013 Albi, France*
[c]*Université Perpignan Via Domitia, ED 305, F-66860 Perpignan Cedex 9, France*
[d]*CNRS, UMR 6602, IP, F-63171 Aubière, France*
[e]*Sigma Clermont, Institut Pascal, BP 10448, F-63000 Clermont-Ferrand, France*

[*]*Presenting author (jeremi.dauchet@sigma-clermont.fr)*

The resolution of the problem of an electromagnetic wave scattered by arbitrarily shaped particles is a recurrent difficulty in the research and engineering fields. One way to solve this problem is to use the integral equation of the electromagnetic field deduced from Maxwell's equations. As a first investigation, we propose here the resolution of three integral equations: the rigorous Born series expansion, the zero-order Born approximation and the Schiff approximation (stationary phase approximation applied to Born series expansion). The two latter approaches are approximations for particles with a low refractive index and are respectively valid for small size parameter and large size parameter. In this work, to solve these integral formulations of electromagnetic scattering, we choose the Monte Carlo method (MCM) which allows multiple integrals to be computed, providing the exact solution with the associated numerical error. Another advantage of the MCM is that we can directly treat any geometry given in a CAD (Computer Aided Design) format without the need to create a volume mesh (no question about the fineness of the mesh to handle). This is due to the fact that we use computer graphics algorithms, and that all the algorithms are independent of the geometry. As a statistical method, the MCM permits treating any distributions of variables such as distributions over sizes, orientations and shapes, with almost the same CPU time as for a particle with fixed size and orientation. Another feature of this method is that it provides sensitivities of a given quantity computed by the MCM to any parameter, generally without additional CPU time (useful for optimization issues). The resolution of these integral equations using the MCM allows estimating radiative properties of any optically soft particles' suspensions over the entire size parameter range, taking into account their size, shape and orientation distributions. More precisely, our Monte Carlo algorithms estimate simultaneously the absorption and scattering cross sections, the differential scattering cross section for any geometry of particle as well as the sensitivities to the wavelength, and to the real and imaginary parts of the refractive index. This work should have a large impact in many fields such as biomedical engineering, oceanography, atmospheric science, and photobioreaction engineering when the aim is to calculate radiative properties of various particles such as red blood cells, ice crystals, micro-algae, etc.

Preferred mode of presentation: Oral

Effects of mixing states on the multiple-scattering properties of soot aerosols

Tianhai Cheng*, Yu Wu, Xingfa Gu, and Hao Chen

State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences. No.20 Datun Road, Chaoyang, Beijing, 100101, China.

*Presenting author (chength@radi.ac.cn)

The incident solar spectral radiative field can be modified due to scattering or absorption by soot aerosol particles. The radiative properties of soot aerosols are highly sensitive to the mixing states of black carbon particles and other aerosol components. To investigate and quantify the effects of mixing states on the multiple scattering of soot aerosols, the angular dependence of multiple-scattering effects with the top-of-the-atmosphere upward radiances/polarization and upwelling hemispheric flux are studied with variable soot aerosol loadings for clear and haze scenarios. Our study showed dramatic changes in upward radiance/polarization due to the effects of the mixing state on the multiple scattering of soot aerosols. The relative difference in upward radiance due to different mixing states can reach 16%, while the relative difference of upward polarization can reach 200%. The effects of the mixing state on the multiple-scattering properties of soot aerosols increase with increasing soot aerosol loading. The effects of the soot aerosol mixing state on upwelling hemispheric flux are much smaller than on TOA bidirectional radiance and polarization, which increase with increasing solar zenith angle. The findings should improve our understanding of the effects of mixing states on optical properties of soot aerosols and their effects on climate. Mixing mechanism of soot aerosols is of critical importance in evaluating the climate effects of soot aerosols, which should be explicitly included in radiative forcing and aerosol remote sensing.

Preferred mode of presentation: Poster

Effect of shape on optical properties of urban dust based on 3-dimensional reconstruction of individual particles

Joseph M. Conny* **and Diana L. Ortiz-Montalvo**

National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD 20899, USA

Presenting author (joseph.conny@nist.gov)

Ambient particles are ubiquitous in the atmosphere and exert a strong influence on the climate by altering the Earth's radiative balance. Their optical properties depend highly on the shape and how the chemical compounds are arranged in their internal structure. The objective of this study is to characterize the morphology and composition of ambient dust particles and study their optical properties using a method that combines advanced microscopy techniques and optical property modeling. Focused ion-beam scanning electron microscopy and energy-dispersive x-ray spectroscopy (FIB-SEM-EDS) was successfully used to reconstruct the three-dimensional (3-D) configuration of particles. 3-D reconstruction included the particle's inherent shape, voids and inclusions whether the inclusions were light-absorbing or light-scattering phases. The 3-D reconstructions were then used in a discrete dipole approximation method (DDA) to determine their optical properties such as extinction efficiency, asymmetry parameter, and single-scattering albedo (SSA). Optical properties where obtained using actual shapes of the particles, as well as, (theoretical) equivalently-sized shapes that would scatter light isotopically: spheres, cubes, and tetrahedral. This presented an interesting opportunity to test the commonly used assumption in climate models that particles are spherical. Results from a limited number of samples show that (1) particle shape is a more important factor for determining *extinction efficiency* than accounting for individual particle phases, and that tetrahedral geometric models and homogenous models with particle's actual shape provided better extinction accuracy compared to spherical or cubic models, (2) for heterogeneous particles, the *asymmetry parameter* as well as SSA varied with phase composition, even when the phase was less than 10% of the particle volume, and (3) for particles that exhibit very complex morphological and compositional heterogeneity (i.e., containing loosely held phases with widely varying refractive indexes) only models that account for phase heterogeneity may be sufficient for determining SSA. More work is still needed to better understand how geometric models could better approximate optical properties of heterogeneous particles, especially those that exhibit severe compositional and morphological heterogeneity. Lastly, the effect that size has on the optical properties of these unique 3-D reconstructions is currently being explored. Overall, the use of 3-D reconstructions of individual particles offers a unique way of studying light scattering by non-spherical and morphologically complex ambient particles.

Preferred mode of presentation: Oral

Differentiation of leukemia stages by scattering signatures of individual cells

David Dannhauser[a,*], Domenico Rossi[a], Mimmo Ripaldi[b], Paolo A. Netti[a,c], and Filippo Causa[c]

[a] *Center for Advanced Biomaterials for Healthcare@CRIB, Istituto Italiano di Tecnologia (IIT), Largo Barsanti e Matteucci 53, 80125 Naples, Italy.*
[b]*BMT Unit, Department of Pediatric Hemato-Oncology, Santobono-Pausilipon Hospital, Naples, Italy.*
[c]*Interdisciplinary Research Centre on Biomaterials (CRIB) and Dipartimento di Ingegneria Chimica, dei Materiali e della Produzione Industriale, Università degli Studi di Napoli "Federico II", Piazzale Tecchio 80, 80125 Naples, Italy.*

[*]*Presenting author (david.dannhauser@iit.it)*

Morphometric single cell analysis – by purely light-scattering investigations – nowadays permits us to cost-effectively identify different types of human blood stream cells, thereby being a serious alternative to the typically used monoclonal antibody labelling. Although morphometric cell analysis allows fast and straightforward identification, it can fail in the case of pathological blood stream cells. Beyond that, when analysing a bulk of cells – normally measured by the flow cytometry technique – it gets difficult to focus on a single cell of interest. Such a drawback implies a loss of diagnostic power, when the specific condition of a few or even one single cell in a bulk is researched. For instance, a relevant diagnostic case is the identification of leukemic minimal residual disease, which is important for patient follow-up and pharmacologic treatments. Therefore, a cost-effective, fast and precise single cell analysis is needed.

For this purpose, we intensively investigated a set of significant cell parameters in-flow, by exploiting accurate interaction of light with microfluidic aligned cells in sequence. We collected their optical signatures over a continuous scattering range and matched the obtained light scattering profiles with adequate simulation models. We show, that by adding non-morphometric cell parameters – which are confident obtained by pure light scattering analysis – it becomes possible to overcome the mentioned characterization issue of cells. Furthermore, showing its enormous potential in allowing direct label-free analysis of unknown cells in microfluidic flow, we extracted multiple biophysical parameters, including morphometric (dimension, shape, and cytosol-to-nucleus ratio) and other parameters (optical density of nucleus and relative frequency of cell type). While using morphometric parameters, we unequivocally identified physiological mononuclear blood stream cells, whereas by including additional parameters in the individual cell analysis, we could properly distinguish between pathological and physiological mononuclear blood stream cells. In particular, we show the possibility to directly identify different stages of lymphoid and myeloid leukemia cells.

We believe that our approach can open up a new route for the label-free detection of single cells in biological and biomedical applications, especially in the instant diagnosis of blood diseases.

Preferred mode of presentation: Oral

Investigating the correlation between different parameters in an aggregate dust model

Himadri S. Das* **and Ayesha M. Mazarbhuiya**

Department of Physics, Assam University, 788011, Silchar, India

**Presenting author (hsdas13@gmail.com)*

We study the light scattering properties of aggregate particles in a wide range of complex refractive indices ($1.4 \leq n \leq 2.0$, $0.001 \leq k \leq 1.0$) and wavelengths ($0.45 \leq \lambda \leq 1.25$ μm) to investigate the correlation between different parameters. We investigate the dependence of complex refractive index (n, k) on the positive polarization maximum (P_{max}) and geometric albedo (A) which are found to be related to each other via some empirical relations. At a fixed value of k, P_{max} and n are correlated via a *quadratic regression* equation and this nature is observed at all wavelengths. Further, P_{max} and k are found to be related via a polynomial regression equation when n is taken to be fixed. The degree of the equation depends on the wavelength, higher the wavelength lower is the degree. We also find that A and P_{max} are correlated via a *cubic regression* at $\lambda = 0.45$μm whereas this correlation is *quadratic* at higher wavelengths. We notice that the amplitude of the negative polarization (P_{min}) increases with the decrease of P_{max} and interestingly, a strong linear correlation between them is observed. This nature is noticed when k is changed in a range from 0.1 to 0.001, keeping n fixed. The depth of the negative polarization is highest at $k = 0.001$. At a fixed value of k, we find that P_{min} and P_{max} can be fitted well via a *quartic regression* equation when n is changed from 2.0 to 1.4. We also study the effect of wavelength (from optical to infrared) on different parameters (e.g., P_{max}, P_{min}, A, n, k) and obtain empirical relations to relate all. The set of empirical relations obtained from our model can be used to study the observed photopolarimetric properties of comets if one wants to use aggregate dust model.

Preferred mode of presentation: Oral

Spectrally selective thermal emission by structured mesoporous metamaterials

Azadeh Didari and M. Pinar Mengüç*

Center for Energy, Environment and Economy (CEEE), Ozyegin University, Istanbul 34794, Turkey

**Presenting author (pinar.menguc@ozyegin.edu.tr)*

The possibility of manipulating structures at nanoscale levels in order to benefit from plasmonic and phononic interactions and geometric effects has attracted the attention of many researchers in recent years [1–4]. Control of radiative transfer has numerous applications in different areas of science and technology such as in advanced sensing applications, effective harvesting of radiative energy, and attaining radiative cooling. We report here that spectral emission from structured and layered porous metamaterials can be altered by adding a second nano-size film to the system and by changing the structure size and shapes in and on the films. The spectral changes are observed in the near-field emission as a function of geometric variations on the films, including nano-size corrugations, pores and thicknesses of the layers. We have used a newly developed FDTD based code, NF-RT-FDTD, to predict the behavior of such layered structures composed of SiC and BN. These findings and further simulations would allow the researchers to design and construct spectrally selective structures for different sensing and thermal management applications.

In this work, we focus on the results of near-field regime. The structure investigated is a double layer of SiC-BN separated from a non-emitting SiC layer by a vacuum nano-gap. The double layer is assumed to be at a temperature of 1000 K and the non-emitting layer is kept at 0 K. The double layer is a 50-nm thick SiC and a layer of BN, with varying thickness of 50, 20 or 10 nm placed on top of it. The non-emitting layer thickness is 20 nm and the vacuum gap is 50 nm.

We discuss the impact of combined surface and geometry effects, materials and their thicknesses on the near-field radiative transfer. We report on the spectral enhancements of near-field radiative transport in the mentioned double-layer thin film of SiC-BN. We note the appearance of additional peaks compared to the case of a single SiC layer, as reported in [5]. The results of this work show that by modifying the characteristics of a surface profile, it is possible to modify the spectral emissivity of a surface at a given spectrum above the surface. It is obvious that porous structures can enhance near-field thermal emission, which may allow researchers to design and construct novel nano-porous metamaterials for specific applications.

References

1. E. N. Economou. Surface plasmons in thin films. *Phys. Rev.* **182,** 539–554 (1969).
2. G. Chen. *Nanoscale Energy Transport and Conversion* (Oxford University Press, 2005).
3. Z. M. Zhang. *Nano/microscale Heat Transfer* (McGraw-Hill, 2007).
4. J. R. Howell, M. P. Mengüç, and R. Siegel. *Thermal Radiation Heat Transfer* (CRC Press, 2016).
5. A. Didari and M. P. Mengüç. Near-field thermal radiation transfer by mesoporous metamaterials. *Opt. Express* **23**, A1253–A1258 (2015).

Preferred mode of presentation: Oral

Electromagnetic scattering by discrete media

Janna M. Dlugach[a,*], Michael I. Mishchenko[b], and Daniel W. Mackowski[c]

[a]*Main Astronomical Observatory of the National Academy of Sciences of Ukraine, 27 Zabolotny Str., 03680, Kyiv, Ukraine*
[b]*NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA*
[c]*Department of Mechanical Engineering, Auburn University, AL 36849, USA*

[*]*Presenting author (dl@mao.kiev.ua)*

One of the main objectives of the discipline of electromagnetic scattering by particulate objects is the computation and analysis of optical characteristics that can be used to quantify the energy budget of a macroscopic volume or the results of measurements with actual optical instruments. In this study, we summarize the results of our extensive modeling of electromagnetic scattering obtained by using the superposition *T*-matrix method for different types of discrete media. In particular, we analyze the behavior of far-field electromagnetic scattering for two types of scattering objects, such as: (i) a fixed configuration of *N* identical spherical particles quasi-randomly populating a spherical volume *V*; (ii) a discrete random particulate medium composed of the same number *N* of particles randomly moving throughout the same volume *V*. We show that if Object (i) is illuminated by a parallel polychromatic beam then it generates a scattering pattern largely devoid of speckles, typical of the case of illumination of such an object by a quasi-monochromatic parallel beam, and closely reproduces the quasi-monochromatic pattern generated by Object (ii). Also, we compare scattering characteristics of fully ordered and quasi-random rigid particulate objects in fixed and random orientations. We observe some differences in the scattering patterns for these objects. In particular, some manifestations of coherent backscattering typical of discrete random media may not be accurately replicated in the case of fully ordered samples. We conclude that in order to replicate the scattering characteristics of a true discrete random medium it is necessary to combine averaging over orientations with a quasi-random arrangement of the particles in the fully ordered object.

Preferred mode of presentation: Oral.

Solar probe shielding from intense thermal radiation: estimates of the effect of a generated cloud of SiC particles

Leonid A. Dombrovsky[a,*], Dmitry L. Reviznikov[b], Aleksey P. Kryukov[c], and Vladimir Yu. Levashov[d]

[a]*Joint Institute for High Temperatures, Krasnokazarmennaya 17A, NCHMT, 111116 Moscow, Russia*
[b]*Moscow Aviation Institute (Aerospace University),Volokolamskoe Shosse 4, 125993 Moscow, Russia*
[c]*Moscow Power Engineering Institute (National Research University), Krasnokazarmennaya 14, 111250 Moscow, Russia*
[d]*Institute of Mechanics of Moscow State University, Michurinskiy Prospect 1, 119192 Moscow, Russia*

[*]*Presenting author (ldombr@yandex.ru)*

The effect of shielding of an intense solar radiation towards a solar probe with the use of micron-sized SiC particles generated during ablation of a composite thermal protection material is estimated on the basis of an approximate solution to a combined transient radiative and heat transfer problem. The spectral radiative properties of particles are calculated using the Mie theory taking into account the increase of the absorption index with temperature, and the two-flux model is used for the numerical radiative transfer calculations in the non-uniform particle cloud. A computational model taking into account the kinetics of sublimation of SiC particles enables one to estimate the rate of mass losses which appeared to be at the low level of 1 kg/m^2 per hour at the distance between the vehicle and the conventional Sun surface of about five radii of the Sun. This value can be even treated as an upper estimate because of the propagation of partially sublimated small particles to the internal region of the cloud due to the light pressure. The preliminary physical and computational analysis indicates that implementation of silicon carbide or similar particles into a thermal protection and the resulting generation of a self-protected cloud of sublimating and moving particles can be considered as a promising way to protect the solar probe from the Sun thermal irradiation. This shielding effect could be used to improve the possibilities of a space mission with the decrease in the working distance of the vehicle from the solar photosphere.

Preferred mode of presentation: Oral

GPU accelerated 3D Monte Carlo ocean radiative transfer simulation

Keping Du[a,*], Kun Xue[b], and Zhongping Lee[c]

[a] *School of Geography, Beijing Normal University, State key Laboratory of Remote Sensing Science, Beijing, China 100875*
[b] *State Key Laboratory of Lake Science and Environment Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing, China 210008*
[c] *School for the Environment, University of Massachusetts at Boston, Boston, MA, 2125*

[*]*Presenting author (kpdu@bnu.edu.cn)*

Radiative Transfer Equations (RTE) for a water body are complex integro-differential equations which can be solved by different numerical methods, e.g., the Monte Carlo ray tracing, the invariant imbedding, and the discrete ordinates. Monte Carlo methods are powerful techniques which can be used for any water body, even those whose boundary conditions and inherent optical properties (IOPs) vary in three dimensions. However, Monte Carlo methods are computationally costly, which limits their use for many problems in optical oceanography. In this paper, a new kind of acceleration technology to accelerate the ocean radiative transfer simulation using the CUDA-enabled graphics processing unit (GPU) is presented. GPU programs for ocean radiative transfer simulation are implemented, and the performances of two GPUs (NVIDIA GTX 670 GPU, NVIDIA Quadro 6000 GPU) with their CPU counterparts are compared. From our numerical results, a two-orders-of-magnitude speedup of some problems is achieved, compared with that obtained using CPU.

Preferred mode of presentation: Poster

Near-field radiation heat transfer between arbitrarily-shaped objects and a surface

Sheila Edalatpour[a,*] **and Mathieu Francoeur**[b]

[a]*Department of Mechanical Engineering, University of Maine, Orono, ME 04469*
[b]*Department of Mechanical Engineering, University of Utah, Salt Lake City, UT 84112*

[*]*Presenting author (sheila.edalatpour@maine.edu)*

Near-field radiation heat transfer between arbitrarily-shaped micro/nanosize objects and a large surface arises in many applications such as near-field thermal spectroscopy (De Wilde *et al*., *Nature* **444**, 740, 2006), tip-based manufacturing (Hawes *et al*., *Opt. Lett*. **33**, 1383, 2008) and localized radiative cooling (Guha *et al*., *Nano Lett*. **12**, 4546, 2012). An analytical solution for this type of problem exists only for the case of a single sphere above an infinite surface (Kruger *et al*., *Phys. Rev. Lett*. **106**, 210404, 2011; Otey and Fan, *Phys. Rev. B* **84**, 254431, 2011). When dealing with multiple complex-shaped objects above a surface, a numerical solution of the stochastic Maxwell equations describing near-field thermal radiation is required. Yet, numerical methods are difficult to apply to such a multi-scale problem due to the prohibitive calculation time associated with discretizing the macroscale surface that is many orders of magnitude larger than the micro/nanosize objects.

In this work, a general framework for modeling near-field radiation heat transfer between arbitrarily-shaped objects and a large surface, modeled as infinite, is provided. The interaction between the objects and the surface is treated analytically using Sommerfeld's theory of electric dipole radiation above an infinite surface (*Ann. Phys.* **81**, 1135, 1926). The volume integral equation for the total electric field derived from the stochastic Maxwell equations is solved using the thermal discrete dipole approximation (T-DDA). The T-DDA is a numerical method that has been previously used for predicting near-field radiative heat transfer between arbitrarily-shaped objects embedded in an infinite, homogeneous medium (Edalatpour and Francoeur, *J. Quant. Spectrosc. Radiat. Transfer* **133**, 364, 2014; Edalatpour *et al*., *Phys. Rev. E* **91**, 063307, 2015).

The T-DDA with surface interaction is first verified against exact results of heat rates between a sphere and a surface. A good agreement between the exact results and those obtained from the T-DDA with surface interaction is found. The framework is then applied to the case of a probing tip interacting with a surface. This problem is of particular interest in near-field thermal spectroscopy, where a probing tip is used to scatter the near-field thermal spectrum emitted by a surface. Recently, two independent experimental studies reported a spectral redshift of the measured scattered signal compared to the thermal emission spectrum of the surface (Jones and Raschke, *Nano Lett.* **12**, 1475, 2012; Babuty *et al*., *Phys. Rev. Lett*. **110**, 146103, 2013). Using the T-DDA with surface interaction, the physical mechanisms responsible for the redshift are elucidated by analyzing the spectral distributions of heat rate and power scattered by the probing tip. The framework proposed in this study is likely to assist in the development of thermal spectroscopy techniques for probing the near-field thermal spectrum of heat sources.

Preferred mode of presentation: Oral

The T-matrix method for light scattering by oblate particles near interfaces: improved accuracy through Sommerfeld integral truncation

Amos Egel[a], Yuri Eremin[b], Thomas Wriedt[c,*], Dominik Theobald[a], and Uli Lemmer[a]

[a]*Karlsruhe Institute for Technology, Kaiserstraße 12, 76131 Karlsruhe, Germany*
[b]*Lomonosov Moscow State University, ul. Leninskiye Gory 1, 119991 Moscow, Russia*
[c]*Institut für Werkstofftechnik, Badgasteiner Str. 3, 28359 Bremen, Germany*

[*]*Presenting author (thw@iwt.uni-bremen.de)*

The T-matrix method for the numerical description of light scattering by particles relies on the expansion of the scattered field in terms of outgoing spherical vector wave functions (SVWFs). However, it is a well-known fact that this expansion may diverge inside the circumscribing sphere of the scatterer. We address the implications of that divergence for the case of flat particles located near a planar interface – for example oblate spheroids on a substrate. Can the T-matrix method yield accurate results for such a configuration?

For the evaluation of the scattered field's reflection from the planar interface, the fields are temporarily expanded in plane vector wave functions (PVWFs). But the expansion in PVWFs, also known as the angular spectrum representation of the scattered field, is valid everywhere below (or above) the particle, even inside the circumscribing sphere. This apparent contradiction can be attributed to the interchange of two limit processes: the series connected to the expansion in SVWFs on the one hand, and the integral connected to the expansion in PVWFs on the other hand. In other words, by changing the order of summation and integration, a diverging expression can be turned into a valid representation of the scattered field. In praxis (i.e., for a finite SVWF expansion), this corresponds to a truncation of the PVWF expansion at some maximal in-plane wavenumber. We demonstrate the improved accuracy arising from truncated Sommerfeld integrals by comparing the differential cross section to accurate results obtained from the Discrete-Sources method (DSM).

Preferred mode of presentation: Poster

Unified formula for extinction cross-section for multipole of an arbitrary order

Yuri A. Eremin[a] and Thomas Wriedt[b,*]

[a]*Lomonosov Moscow State University, Lenin's Hills, 119991 Moscow, Russia*
[b]*Institut für Werkstofftechnik, Badgasteiner Str.3, 28359 Bremen, Germany*

[*]*Presenting author (thw@iwt.uni-bremen.de)*

Application of the conservation of energy law to electromagnetic waves scattering leads to a fundamental result of scattering theory, known as the Optical Theorem. The optical theorem has a long history, its occurrence in scattering theory starts about a hundred years ago and related results can also be found in acoustics, seismic wave propagation and quantum mechanics. The optical theorem relates the power extinguished from a plane wave impinging of a local obstacle to the scattering amplitude in the direction of the incident wave propagation. In this case, the Extinction Cross-Section is the total power lost to scattering and absorption of the exciting field caused by the obstacle. Generalization of the Optical Theorem to the case of a penetrable particle located in free space excited by a multipole of arbitrary order has already been done. It has been shown that the extinction cross-section can be evaluated via the calculation of some specific derivatives of the corresponding scattered field at the point of the multipole location and the order of the derivatives is specified by the order of the exciting multipole.

In the present paper we extend the range of validity the obtained formula for the extinction cross-section to the case of a particle located in the presence a complex structure in particular – a penetrable inhomogeneous substrate. A unified expression for the extinction cross-section can be written based on the Green tensor of the corresponding structure. Numerical results relating to the verification of the formula for the extinction cross-section will be presented. These results can be employed for estimation of the quantum yield of optical antennas excited by a quantum dot or investigation of the fine structure of a fluorescent process.

Preferred mode of presentation: Poster.

Scattering properties of large irregular cosmic dust particles at visible wavelengths

Jesús Escobar-Cerezo[a,*], Chris Palmer[a], Olga Muñoz[a], Fernando Moreno[a], Antti I. Penttilä[b], and Karri Muinonen[b,c]

[a]*Instituto de Astrofisica de Andalucia, CSIC, Glorieta de la Astronomia s/n, 18008 Granada, Spain*
[b]*Department of Physics, P.O. Box 64, 00014 University of Helsinki, Finland*
[c]*National Land Survey of Finland, Finnish Geospatial Reseach Institute, P.O. Box 84, 00521 Helsinki, Finland*

[*]*Presenting author (jescobar@iaa.es)*

The effect of internal inhomogeneities and surface roughness on the scattering behavior of large cosmic dust particles is studied by a comparison of model simulations with laboratory measurements. The present work shows the results of an attempt to model a Libyan sand sample measured in the laboratory with simulations performed with a ray-optics model code. The refractive index of the Libyan sand sample ($m = 1.5 + i4.10^{-5}$) is similar to that found in low-iron pyroxenes, so this sample can be used as a proxy for this material found in circumstellar disks, meteorites, and comets. Several sensitivity tests have been performed for both structural cases (internal inclusions and surface roughness). Three different samples have been selected to mimic inclusion/coating inhomogeneities: two measured scattering matrices of hematite and white clay, and a simulated matrix for water ice. These three matrices are selected to cover a wide range of imaginary refractive indices, *k.* The selection of these materials also seeks to study interesting environments such as Mars (hematite and clays have been detected there) and comets. Based on the results of the sensitivity tests shown in this work, we perform calculations for a size distribution of the silicate-type host-particle model with inclusions and surface roughness to reproduce the experimental measurements of a Libyan sand sample. The model fits the measurements quite well, thus proving that surface roughness and internal structure play a role in the scattering pattern of irregular cosmic dust particles.

Preferred mode of presentation: Oral

Retrievals of aerosol optical and microphysical properties from imaging polar nephelometer scattering measurements

W. Reed Espinosa[a,b,*], Lorraine Remer[a,b], Oleg Dubovik[c], Luke Ziemba[d], Andreas Beyersdorf[d,e], Daniel Orozco[a,b], Anin Puthukkudy[a,b], Gregory Schuster[d], Tatyana Lapyonok[c], David Fuertes[f], and J. Vanderlei Martins[a,b]

[a]*Department of Physics, University of Maryland Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, USA*
[b]*Joint Center for Earth Systems Technology, University of Maryland Baltimore County, 5523 Research Park DR, Baltimore, MD 21228, USA*
[c]*Laboratoire d'Optique Atmosphérique, UMR8518, CNRS – Université de Lille 1, 59655, Villeneuve d'Ascq, France*
[d]*Langley Research Center Science Directorate, National Aeronautics and Space Administration, Hampton, Virginia, USA*
[e] *Department of Chemistry and Biochemistry, California State University San Bernardino, 5500 University Parkway, San Bernardino, CA 92407, USA*
[f] *GRASP-SAS, Bat-P5, Université de Lille 1, 59655, Villeneuve d'Ascq, France*

[*]*Presenting author (reedespinosa@umbc.edu)*

A method for the retrieval of optical and microphysical properties from *in situ* light scattering measurements is presented and the results are compared with existing measurement techniques. The Generalized Retrieval of Aerosol and Surface Properties (GRASP) is applied to airborne and laboratory measurements made by a novel polar nephelometer. This instrument, the Polarized Imaging Nephelometer (PI-Neph), can make field measurements of the absolute phase function and the scattering matrix element S_{12}, at three visible wavelengths, over a wide angular range of 3° to 177°.

The retrieval technique is applied to over 1,500 aerosol measurements made aboard the NASA DC-8 aircraft during the Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC^{4}RS) and the Deep Convection Clouds & Chemistry (DC3) field experiments. The resulting samples represent a wide variety of aerosols, including measurements of desert dust, biomass burning, urban, biogenic and marine emissions. In almost all cases GRASP fits reproduced the angular scattering patterns measured by the PI-Neph to within experimental error. Additionally, the retrieved aerosol particle size distributions (PSDs) agreed well with measurements made by commercial optical particle counters (OPCs) sampling in parallel to the PI-Neph. The retrieval technique was also applied to laboratory measurements of three species of humidified, inorganic salts. In all three cases the retrieved real part of the refractive index is found to be within the predicted error of 0.02 from the expected values. These results provide confidence in the refractive index product, as well as in the retrieval's ability to accurately determine PSD, without the assumptions about refractive index that are required by most OPCs. Lastly, retrievals performed on measurements of 903 nm diameter polystyrene latex (PSL) spheres agreed with the manufacture's specifications to within ~1 nm in peak diameter and ~0.01 in refractive index, indicating that the technique has the potential to characterize some monodisperse aerosols with significantly greater accuracy than natural, polydisperse PSDs.

Preferred mode of presentation: Poster

Optimization of iterative solvers for DDA-SI

Zahra Rostampour Fathi[a], M. Pınar Mengüç [a,*], and Hakan Ertürk[b]
[a] *Ozyegin University, Center for Energy, Environment and Economy (CEEE), 34794 Cekmekoy, Istanbul, Turkey*
[b] *Bogaziçi University, 34342 Bebek, Istanbul, Turkey*

[*] *Presenting author (pinar.menguc@ozyegin.edu.tr)*

In this work, we address accurate and fast calculations of light scattering by particles on surfaces. The discrete dipole approximation with surface interaction (DDA-SI) [1,2] method is used to model the scattering profiles, and various solution methodologies are evaluated. The construction of a matrix for the discrete dipole approximation (DDA) on surface and its relationship to an iterative solver is analyzed. We demonstrate that the Least-Square (LSQR) iterative solver is the most efficient iterative method since it provides accurate results. This method accelerates the DDA calculations by decreasing the total number of iteration steps required for converging to the solution based on the preconditioning matrix. Since the interaction matrix of DDA-SI is complex, symmetric and well-conditioned, we prove that using LU-decomposition of interaction matrix as a preconditioning for the LSQR iterative solver provides significant increase in speed and decreases the relative residual to achieve more accurate results.

References

1. V. L. Loke, M. P. Mengüç, and T. A. Nieminen. Discrete-dipole approximation with surface interaction: computational toolbox for matlab. *J. Quant. Spectrosc. Radiat. Transfer* **112**, 1711–1725 (2011).
2. S. T. Moghaddam, H. Erturk, and M. P. Mengüç. Enhancing local absorption within a gold nanosphere on a dielectric surface under an afm probe. *J. Quant. Spectrosc. Radiat. Transfer* **178**, 124–133 (2016).

Preferred mode of presentation: Oral (or Poster)

Estimation of cirrus 1-km subpixel radiance variance in MODIS TIR channels using VIS reflectances at 250-m resolution

T. Fauchez[a,b,*], S. Platnick[a], K. Meyer[a,c], C. Cornet[d], and F. Szczap[e]

[a]*NASA Goddard Space Flight Center, Greenbelt, MD, USA*
[b]*Universities Space Research Association (USRA), Columbia, MD, USA*
[c]*Goddard Earth Sciences Technology and Research (GESTAR), Universities Space Research Association, Columbia, MD, USA*
[d]*Laboratoire d'Optique Atmosphérique, UMR 8518, Université Lille 1, Villeneuve d'Ascq, France*
[e]*Laboratoire de Météorologie Physique, UMR 6016, Université Blaise Pascal, Clermont Ferrand, France*

[*]*Presenting author (thomas.j.fauchez@nasa.gov)*

Cirrus clouds are an important part of the Earth's radiation budget, yet an accurate assessment of their role remains highly uncertain. Cirrus optical properties such as cloud optical thickness (COT) and ice crystal effective particle size are often retrieved with a combination of Visible/Near Infra-Red (VNIR) and ShortWave-InfraRed (SWIR) reflectance channels. Alternatively, Thermal Infra-Red (TIR) techniques, such as the Split Window Technique (SWT), have demonstrated a better accuracy for thin cirrus effective radius retrievals with small effective radii. The TIR range is thus particularly relevant in order to characterize, as accurately as possible, thin cirrus clouds. However, current global operational algorithms for both retrieval methods assume that cloudy pixels are horizontally homogeneous (Plane Parallel Approximation, or PPA) and independent of the adjacent pixels (Independent Pixel Approximation, or IPA). The impact of these approximations on ice cloud retrievals needs to be understood and, as far as possible, corrected. Horizontal heterogeneity effects inside MODIS 1-km observation pixels can be more easily estimated and corrected in the TIR than in the VNIR range because they are mainly dominated by the PPA bias depending on the sub-pixel inhomogeneity. The TIR radiances sub-pixel inhomogeneity can be roughly estimated using MODIS visible reflectance at higher spatial resolutions.

The aim of this study is to show how the TIR sub-pixel radiance inhomogeneity at 1 km can be approximately estimated using MODIS visible reflectance at higher spatial resolutions (0.86 µm at 250-m spatial resolution). Such estimation can then be helpful to mitigate the impact of cirrus horizontal inhomogeneity in cloud optical property retrieval. These investigations are performed using a cirrus 3D cloud generator (3DCloud), a 3D radiative transfer code (3DMCPOL), and a retrieval algorithm based on the optimal estimation method.

Preferred mode of presentation: Oral (or Poster)

Infrared microscopy of small particles on solid surfaces

Robert Furstenberg[*], Christopher A. Kendziora, Viet Nguyen, and R. Andrew McGill

U.S. Naval Research Laboratory, Code 6365, 4555 Overlook Ave SW, Washington, DC 20375, USA

[*]*Presenting author (robert.furstenberg@nrl.navy.mil)*

The detection of trace amounts of explosives, narcotics or other hazardous materials as micron sized particles on substrate surfaces is an area of significant interest for security applications. In the past decade, performance advances with IR light sources have allowed infrared (IR) spectroscopy to emerge as one of the leading candidates to probe surfaces in a non-contact fashion and from a distance. However, the size of surface-bound particles (for example, resulting from fingerprint transfers) is often on the order of the wavelength of IR light, and as a result, the spectral signatures may be complicated by particle size effects, which in turn can negatively affect the performance of detection algorithms. In order to study these changing signatures, we are developing a novel infrared microscope capable of resolving individual, micron-size particles. To achieve this, we employ a bright quantum cascade laser tunable in the 6 to 11 μm range. The microscope can record visible and IR reflectance signals as well as the photo-thermal signal (which scales with the absorption scattering coefficient.) The microscope is equipped with IR and visible cameras as well as single channel detectors for confocal acquisition. The visible camera images are used to identify particles and measure their size and various shape parameters using custom software which also controls all other aspects of the microscope. A motorized stage is carefully calibrated and allows for positioning any particle under the collection spot. This considerably speeds up and, more importantly, automates acquisition, thus allowing for statistical analysis of spectral signatures of a large number of particles. The particles are deposited on substrates using a modified commercial sieve stack. Sieving allows access to a large number of diverse particles with varying sizes and shapes. The areal mass loading and particle/substrate fill factor are kept low (~10 $\mu g/cm^2$ and <1%, respectively) to keep particles isolated and avoid agglomeration. We report on sample preparation, microscope design, and results from preliminary experiments.

Preferred mode of presentation: Oral

Microwave scattering by a dew-wetted leaf

Cynthia Gerlein-Safdi[a,*], Bruce T. Draine[b], Steve Frolking[c], and Kelly K. Caylor[a,d,e]

[a] *Department of Civil and Environmental Engineering, Princeton University, Princeton, NJ 08544, USA*
[b] *Department of Astrophysical Sciences, Princeton University, Princeton, NJ 08544, USA*
[c] *Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, NH 03824, USA*
[d] *Department of Geography, University of California, Santa Barbara, CA 93106, USA*
[e] *Bren School of Environmental Science and Management, University of California, Santa Barbara, CA 93106, USA*

[*] *Presenting author (cgerlein@princeton.edu)*

Dew deposition in a closed canopy is thought to be greatest on top of the canopy, since a clear view of the sky increases condensation. In tropical forests, these same leaves are also subject to direct sunlight and high transpiration rates. Dew deposition can offset some of the water stress through foliar uptake of the dew droplets, or transpiration suppression from the energy dissipation associated with dew evaporation. However, the long-term trends of dew formation and their global patterns have received little attention, despite the wide acknowledgement that non-meteoric water can be a key source of water for many species, especially in tropical ecosystems. Active microwave remote sensing has proven to be a unique tool to investigate canopy water, especially water deposited on the surface of the leaves.

In this presentation, we use the DDSCAT model to simulate the scattering from a dew-wetted leaf. The leaf is modeled as a thin cylinder covered with half-spheres of different radii sampled from a variety of distributions. We explore how the choice of drop number and drop size distribution affects the backscattered signal. The resulting backscattering matrix is then included in the Michigan Microwave Canopy Scattering Model to compare the expected microwave backscatter from a wet and a dry canopy with similar geometries. Applications to the quantification of dew deposition and rainfall interception will be explored.

Preferred mode of presentation: Oral

Optical trapping and manipulation configurations for measuring light extinctions of single particles

Zhiyong Gong[a,*], Yong-Le Pan[b], and Chuji Wang[a]

[a]*Mississippi State University, Starkville, MS, 39759, USA*
[b]*U.S. Army Research Laboratory, 2800 Powder Mill Road, Adelphi, MD 20783, USA*

[*]*Presenting author (zg143@msstate.edu)*

The light extinction of single particles, including scattering and absorption, plays an essential role in the study of particle's fundamental properties, surface structures, etc. The extinction measurement of single particles requires two basic techniques for: 1) trapping, manipulating, and transporting a single particle and 2) sensitively measuring extinction, scattering or absorption of the single trapped particle. Optical trapping is an efficient method for trapping single particles in air, and cavity ringdown spectroscopy (CRDS) is an ultra-sensitive method for measuring light extinction. To explore the full potential of diverse trapping methods for single particle studies, we demonstrate and compare six different types of optical schemes (single Gaussian/hollow beam trap, dual Gaussian hollow beams trap, and confocal Gaussian/hollow beam trap). We have built more than 21 optical configurations by varying optical parameters and evaluated them based on the four key aspects of an optical configuration: simplicity, robustness, flexibility, and efficiency. Those optical configurations include extremely simple ones (single laser beam trap) as well as highly robust ones (vertical confocal hollow beam trap). And they are able to trap various types of particles: strongly absorbing carbon nanotubes, weakly absorbing bioaerosols, non-absorbing silica microspheres, etc. By combining an optical trap (OT) with cavity ringdown spectroscopy (OT-CRDS), we determined extinctions of four different types of single aerosol particles. We also explored the extinction dependence on the number, positions, sizes, and materials of the trapped single particles inside the measuring laser beam. We found that different particles have different spectral structures in the UV spectral region. The detailed design, evaluation, and application examples of optical trapping configurations may help extend application of the optical trapping technique to the study of the single particle's scattering.

Preferred mode of presentation: Oral

A comment on the description of axisymmetric Bessel beams

Gérard Gouesbet[a] and James A. Lock[b,*]

[a]*CORIA-UMR 6614 – Normandie Université CNRS-Université et INSA de Rouen Campus Universitaire du Madrillet, 76800 Saint-Etienne-du-Rouvray, France*
[b]*Physics Department, Cleveland State University, Cleveland OH 44115, USA*

[*]*Presenting author (j.lock@csuohio.edu)*

The electric and magnetic fields of the description of a Maxwellian beam propagating in the +*z* direction are an exact solution of both Maxwell's equations and the vector wave equation. The beam is also said to be axisymmetric if the *z* component of its Poynting vector is independent of the azimuthal angle in a coordinate system containing the beam axis. The beam contains an optical vortex along its axis as well if the phase of the fields is indeterminant there while the amplitude vanishes. Assuming the electromagnetic beam in question is Maxwellian rather than a paraxial approximation, the Poynting vector may be determined in two different ways, depending on what is known about the beam. If the field components are known, the Poynting vector can be determined directly. But if the shape coefficients of the partial wave expansion of the beam fields are known instead, the Poynting vector is a double sum over partial waves of products of shape coefficients multiplied by Riccati–Bessel functions. Using both methods, we show that the $n = 2$ order axisymmetric Bessel beam description contains a phase indeterminacy on the beam axis without the beam amplitude vanishing there, and we comment on its physical implications.

Preferred mode of presentation: Oral

Shapes and rotational properties of selected Hilda and Trojan asteroids

Maria Gritsevich[a,b,*], Sarah Sonnett[c,d], Johanna Torppa[e], Karri Muinonen[a,f], Antti Penttilä[a], Amy Mainzer[c], Thomas Grav[d], Joseph Masiero[c], James Bauer[c], and Emily Kramer[c]

[a]*Department of Physics, University of Helsinki, Gustaf Hällströmin katu 2a, FI-00014 Helsinki, Finland*
[b]*Department of Computational Physics, Dorodnicyn Computing Centre, Russian Academy of Sciences, Moscow, Russia*
[c]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA*
[d]*Planetary Science Institute, USA*
[e]*Geological Survey of Finland, FI-70211 Kuopio, Finland*
[f]*Finnish Geospatial Research Institute, Geodeetinrinne 2, FI-02430 Masala, Finland*

[*]*Presenting author (maria.gritsevich@helsinki.fi)*

Binary asteroid systems contain key information about the dynamical and chemical environments in which they formed. For example, determining the formation environments of Trojan and Hilda asteroids (in 1:1 and 3:2 mean-motion resonances with Jupiter, respectively) will provide critical constraints on how small bodies and the planets that drive their migration must have moved throughout Solar System history, see, e.g., [1–3]. Therefore, identifying and characterizing binary asteroids within the Trojan and Hilda populations could offer a powerful means of discriminating between Solar System evolution models. Dozens of possibly close or contact binary Trojans and Hildas were identified within the data obtained by NEOWISE [4]. Densely sampled light curves of these candidate binaries have been obtained in order to resolve rotational light curve features that are indicative of binarity (e.g., [5–7]). We present analysis of the shapes, rotation, and pole solutions of some of the follow-up targets observed with optical ground-based telescopes. For modelling the asteroid photometric properties, we use parameters describing the shape, surface light scattering properties and spin state of the asteroid. Scattering properties of the asteroid surface are modeled using a two parameter H-G12 magnitude system. Determination of the initial best-fit parameters is carried out by first using a triaxial ellipsoid shape model, and scanning over the period values and spin axis orientations, while fitting the other parameters, after which all parameters were fitted, taking the initial values for spin properties from the spin scanning. In addition to the best-fit parameters, we also provide the distribution of the possible solutions, which should cover the inaccuracies caused by the observing errors and by the model. The distribution of solutions is generated by Markov-Chain Monte Carlo sampling the spin and shape model parameters, using both an ellipsoid shape model and a convex model, Gaussian curvature of which is defined as a spherical harmonics series [8].

References

1. Marzari F. and Scholl H. (1998), *A&Ap* **339**, 278.
2. Morbidelli A. et al. (2005), *Nature* **435**, 462.
3. Nesvorny D. et al. (2013), *ApJ* **768**, 45.
4. Sonnett S. et al. (2015), *ApJ* **799**, 191.
5. Behrend R. et al. (2006), *A&Ap* **446**, 1177.
6. Lacerda P. and Jewitt D. C. (2007), *AJ* **133**, 1393.
7. Oey J. (2016), *MPB* **43**, 45.
8. Muinonen K. et al. (2017).

Preferred mode of presentation: Poster

Second harmonic emission from plasmonic gap nanoantennas with rough surfaces

Yevgen Grynko* **and Jens Förstner**

Department of Electrical Engineering, University of Paderborn, Warburger Str., 100, 33102 Paderborn, Germany

**Presenting author (yevgen.grynko@upb.de)*

Second harmonic generation (SHG) is a nonlinear optical effect that is sensitive to the symmetry properties of the emitting structure. The condition of an efficient SHG is the broken symmetry of the nanostructure with respect to the polarization direction of the incident excitation pulse. Plasmonic gap antennas are inversion symmetric objects and theory forbids observation of the SHG in the far field. At the same time experimental nonlinear spectroscopy reveals measurable SHG signal from real fabricated samples. The possible source here is the imperfectness of the shape of the antenna arms and small-scale surface roughness. In this work we do numerical simulations to study SHG from golden gap nanoantennas with various morphologies of their surfaces. We use the Discontinuous Galerkin Time Domain Method and a Maxwell–Vlasov hydrodynamic model to describe dynamics of the free-electron gas in a metal. Our results show that even strongly deformed antenna arms make up a quality resonator, as good as the ideal structure. In the nonlinear regime random defects of the shape break axial symmetry enough to enhance the SHG signal in the far field by almost three orders of magnitude.

Preferred mode of presentation: Oral

Monte Carlo model of light scattered by mm-sized particles covered with micrometric irregular grains

D. Guirado*, F. Moreno, O. Muñoz, and J. Escobar-Cerezo

Instituto de Astrofísica de Andalucía (IAA-CSIC), Glorieta de la Astronomía s/n. 18008, Granada, Spain

Presenting author (dani@iaa.es)

Light scattering by ensembles of irregular micron-sized particles has been widely experimentally studied (www.iaa.es/scattering) and modeled: T-matrix, Discrete Dipole Approximation and other approaches. This phenomenon is interesting for understanding radiative transfer in planetary atmospheres, cometary comae and other astrophysical scenarios. Recent results on stellar dust rings and the analysis of Rosetta mission data have pointed out the importance of modeling and measuring light scattering by larger grains: mm- and cm-sized.

We are presenting a MC model of radiative transfer by such large dust grains. In this model we consider dust grains as composed by a large bulk particle (mm- or cm-sized) covered by a layer of micrometric scatterers. The whole Stokes vector is computed as light interacts with the micron-sized grains covering the big particle in single or multiple scattering conditions. A Fraunhofer approach is used to model the interaction of light with the large bulk grain.

These calculations are complementary to the experimental work developed by Muñoz et al. and also presented at this conference.

Preferred mode of presentation: Oral

Using a linear electrodynamic trap and elastic scattering for single particle environmental fate studies

Matthew B. Hart*, Vasanthi Sivaprakasam, Jozsef Czege, and Jay D. Eversole

Naval Research Laboratory, 4555 Overlook Ave. SW, Washington, DC 20375, USA

**Presenting author (Matthew.Hart@nrl.navy.mil)*

Environmental influences on atmospheric aerosols is an important topic for understanding and affecting pollution and climate change. Using a linear electrodynamic quadrupole trap, we can hold either multiple or single particles in controlled environments for long term study [1]. We are able to trap liquid or solid particles ranging in size from 0.5 µm to 100 µm, and challenge them with specific atmospheric constituents at controlled temperature and relative humidity. Our initial studies have exploited laser beam elastic scatting intensities to measure the evaporation rates of liquid droplets with high precision. By matching observed elastic light scattering with computationally predicted values based on known initial composition, we can determine droplets radii to less than 10 nm, providing exceptional data for droplet size varying over time. Our system currently allows us to vary temperature between 10°C and 50°C and humidity between near zero to 80%. We describe the apparatus and droplet generation methods and present example data of elastic scattering and model matches from different droplet compositions such as dibutyl sebacate and glycerol. Results of these measurements are compared with a single-component evaporation computational model based on previously determined material parameters of vapor pressure and molecular diffusivity, and generally very good agreement has been observed. This initial work provides a demonstration of the use of this apparatus as a controlled environment for atmospheric study which we plan to extend to situations where droplet composition may also change in time due to physical adsorption or chemical reaction.

Reference

1. M. B. Hart, V. Sivaprakasam, J. D. Eversole, L. J. Johnson, and J. Czege, *Appl. Opt*. **54**, 174–181 (2015).

Preferred mode of presentation: Oral

Dynamics of interstellar dust particles in electromagnetic radiation fields

Joonas Herranen[a,*], Johannes Markkanen[a], and Karri Muinonen[b,a]

[a]*Department of Physics, University of Helsinki, Finland*
[b]*Finnish Geospatial Research Institute FGI, National Land Survey, Finland*

[*]*Presenting author (joonas.herranen@helsinki.fi)*

The observed polarization of the interstellar medium is due to scattering from asymmetrical, aligned dust particles. Alignment of interstellar dust particles has been under meticulous study for the last few decades, and it has been firmly established that the dominant alignment method in many situations is by radiative torques.

Due to the modern advancements of different scattering solutions, mainly of the integral equation methods, a complete dynamical scattering solution for arbitrary geometries without orientation averaging is possible with intolerable computational efforts. T-matrix methods have been used to study the forces and torques due to radiation pressure in the context of optical tweezers. The framework presented here can be used to solve essentially the same problem efficiently for arbitrary geometries.

We establish a theoretical framework for solving the equations of motion for an arbitrarily shaped, piecewise isotropic and homogeneous dust particle in the presence of radiation pressure, modelled via the T-matrix method. The T-matrix of an arbitrary scattering geometry is solved via a volume integral equation method. Using the T-matrix, the forces and torques due to scattering are then computed in a realistic model of an interstellar dust environment.

Preferred mode of presentation: Oral

Micron-sized particle detection and discrimination using scattered infrared light

William D. Herzog[a,*], Jonathan M. Richardson[a], David S. Wolinski[a], Jason M. Jong[a], Brian G. Saar[a], Shawn M. Redmond[a], and Jay D. Eversole[b]

[a]*MIT Lincoln Laboratory, 244 Wood St., Lexington, MA 02420, USA*
[b]*Naval Research Laboratory, 4555 Overlook Ave. S.W., Washington, DC 20375, USA*

[*]*Presenting author (wherzog@ll.mit.edu)*

We have recently demonstrated that micrometer-sized aerosol particles and droplets can be individually detected and discriminated using multi-wavelength infrared scatter in the 7.5–11.0 micrometer range. This novel approach allows for real-time quantification and sorting of aerosol mixtures. Potential applications of the technology include industrial process monitoring, industrial safety, environmental monitoring, and Chemical and Biological defense. The cross section for small particles depends on size, wavelength, and index of refraction. We have demonstrated that the features associated with variations in the real index of refraction can be successfully exploited, particularly when combined with particle sizing using a visible "trigger" laser system. As with the complex index (giving rise to absorption features), the real index of refraction includes features that arise from molecular resonances, thus the scatter spectrum is descriptive of the particle's chemical composition. This presentation will review the method and present the results of recent data collects demonstrating discrimination of various aerosol species using our current instrument.

This material is sponsored by the Defense Threat Reduction Agency-Joint Science and Technology Office for CB Defense under Air Force Contract No. FA8721-05-C-0002 and/or FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the U.S. Air Force.

Preferred mode of presentation: Oral

Raman spectra of individual atmospheric aerosol with spatial resolution of one to a few micrometers

Steven C. Hill*, David C. Doughty, Alan E. Wetmore, and Deryck James

US Army Research Laboratory, Adelphi, MD 20783, USA

Presenting author (steven.c.hill32.civ@mail.mil)

Improved methods are needed for determining the compositions of individual micrometer-sized particles, their homogeneous mixing state and/or spatial variation within particles, and in characterizing sufficient particles over adequate times and time resolutions to be relevant to atmospheric science. To begin to address these problems we are exploring the use of an automated aerosol Raman spectrometer (ARS, aka the REBS), developed by Battelle. This ARS automatically samples aerosol onto a metalized tape and measures Raman spectra from the collected particles [1]. We present results from several days of ambient sampling in Maryland, USA, examining over 15,000 spectra. Results of unstructured cluster analysis will be shown along with time-series of the numbers of spectra which fall into various clusters. We suggest that analysis of particle composition could benefit from development of light scattering models, and solutions of the inverse problem, for the Raman scattering from complex inhomogeneous particles resting on a metalized tape, when the particles are illuminated with a line source and when the focus of the illumination/collection optics is varied throughout the particle.

Reference

1. D. C. Doughty and S. C. Hill. Automated aerosol Raman spectrometer for semi-continuous sampling of atmospheric aerosol. *J. Quant. Spectrosc. Radiat. Transfer*, 2016

Preferred mode of presentation: Oral

Estimating phase matrix from multi-viewing satellite measurements

Souichiro Hioki* **and Ping Yang**

Department of Atmospheric Sciences, Texas A&M University, College Station, TX 77843, USA

**Presenting Author (s.hioki@tamu.edu)*

When a cloud particle has highly anisotropic scattering phase matrix, reflectivities from clouds depend primarily on the scattering angle defined by the solar direction and viewing direction. Even though the total intensity and the state of polarization cannot be explained by single scattering alone, small perturbation in phase matrix can be detected in the reflectivity as a function of scattering angle.

This study investigates the feasibility of estimating the difference of true and assumed phase function and a phase matrix element (P_{12}) from multi-viewing satellite data. Assuming plain parallel homogeneous (PPH) cloud, a small perturbation is imposed on the PPH radiative transfer equation to relate the retrieved optical thickness values and phase matrix corrections. A simple formula with a precomputed look-up table is derived as a result of approximations. We demonstrate the feasibility of the concept with the data from the Polarization and the Directionality of the Earth's Reflectance (POLDER) sensor.

Preferred mode of presentation: Oral (or Poster)

Feasibility analysis of hyperspectral remote sensing of aerosols from future geostationary satellites

Weizhen Hou[a], Jun Wang[a,b,*], and Xiaoguang Xu[a.b]

[a]*Earth and Atmospheric Sciences, University of Nebraska–Lincoln, 303, Lincoln, NE 68588, USA*
[b]*Now at Department of Chemical and Biochemical Engineering, Center of Global and Regional Environmental Studies, University of Iowa, 4133 Seamans Center, Iowa City, IA 52242, USA*

[*]*Presenting author (jun-wang-1@uiowa.edu)*

This paper describes a series of investigation to develop algorithms for simultaneous retrieval of aerosol parameters and surface reflectance from the future hyperspectral and geostationary satellite sensors such as Tropospheric Emissions: Monitoring of POllution (TEMPO). The information content in these hyperspectral measurements is analyzed for 6 principal components (PCs) of surface spectra and a total of 14 aerosol parameters that describe the columnar aerosol volume V_{total}, fine-mode aerosol volume fraction, and the size distribution and wavelength-dependent index of refraction in both coarse and fine mode aerosols. Forward simulations of atmospheric radiative transfer are conducted for 5 surface types (green vegetation, bare soil, rangeland, concrete and mixed surface case) and a wide range of aerosol mixtures. It is shown that the PCs of surface spectra in the atmospheric window channel could be derived from the top-of-the-atmosphere reflectance in the conditions of low aerosol optical depth (AOD $\leq$ 0.2 at 550 nm), with a relative error of 1%. With degree freedom for signal analysis and the sequential forward selection method, the common bands for different aerosol mixture types and surface types can been selected for aerosol retrieval. The first 20% of our selected bands accounts for more than 90% of information content for aerosols, and only 4 PCs are needed to reconstruct surface reflectance. However, the information content in these common bands from each TEMPO individual observation is insufficient for the simultaneous retrieval of surface's PC weight coefficients and multiple aerosol parameters (other than V_{total}). In contrast, with multiple observations for the same location from TEMPO in multiple consecutive days, 1–3 additional aerosol parameters could be retrieved. Consequently, a self-adjustable aerosol retrieval algorithm to account for surface types, AOD conditions, and multiple-day observations is recommended to derive aerosol parameters and surface reflectance simultaneously from TEMPO.

Preferred mode of presentation: Oral

Improving planetary remote sensing mineralogical analysis using T-matrix and radiative transfer hybrid models

Gen Ito* **and Timothy D. Glotch**

Department of Geosciences, State University of New York – Stony Brook, Stony Brook, NY, USA

**Presenting author (gen.ito@stonybrook.edu)*

Planetary remote sensing instruments, such as the Mars Global Surveyor Thermal Emission Spectrometer and the Diviner Lunar Radiometer Experiment, as well as ground- and space-based telescopes provide mid-infrared spectra (~5–50 μm) that can be used for quantitative analysis of bulk silicate mineralogy of planetary surfaces. However, spectra are not only dependent on mineralogical composition, but also on particle size, packing, and other factors. When the remotely sensed material's size is large compared to the wavelength, spectra add linearly, but when the size becomes on the order of a wavelength, spectra manifest strong non-linearity that hinders accurate mineralogical interpretations. Lunar and martian regolith commonly have particles with sizes on the order of mid-infrared wavelengths, resulting in non-linear spectral mixing. The non-linear effects have been difficult to model using current light scattering models and have been one limitation to quantitative remote mineralogical analysis of planetary surfaces.

As part of an effort to develop a more effective treatment of light scattering in planetary regolith, we explore the ability of T-matrix and radiative transfer (RT) hybrid models. We use the multiple sphere T-matrix (MSTM) code to compute scattering parameters of enstatite, a common mineral found on lunar and martian surfaces, in different particle sizes using inputs measured in a laboratory. The scattering outputs from the MSTM are used as inputs to different RT models to compute emissivity spectra. Computed spectra are compared with laboratory spectra of particulate enstatite with equivalent particle size and other properties. The T-matrix/RT hybrid models produced reasonably consistent emissivity spectra for the finest particle size (3.3 μm) and are more agreeable than the widely used Mie/RT models, but larger size fractions were more difficult to model. The models have the potential to be improved by using less simplified input parameters that were initially used. This work demonstrates the basic ability of T-matrix/RT hybrid models to compute mid-infrared spectra of particulates and the prospect for their applicability to remote sensing of particulate planetary surfaces with improvement.

Preferred mode of presentation: Oral (or Poster)

The scattering properties of dust in distant comets

Oleksandra V. Ivanova[a,b,*], Janna M. Dlugach[b], and Viktor L. Afanasiev[c]

[a]*Astronomical Institute of the Slovak Academy of Sciences, SK-05960 Tatranská Lomnica, Slovak Republic*
[b]*Main Astronomical Observatory of the National Academy of Sciences of Ukraine, 27 Zabolotnoho Str., 03143, Kyiv, Ukraine*
[c]*Special Astrophysical Observatory of the Russian Academy of Sciences, 369167 Nizhnij Arkhyz, Russia*

[*]*Presenting author (oivanova@ta3.sk)*

The Oort cloud and the Edgeworth–Kuiper belt are the two main reservoirs which supply new comets to the inner region of the Solar System. Some of cometary nuclei exhibit considerable activity at heliocentric distances much larger than 5 au. Since 2011, we are conducting a comprehensive program of polarimetric, photometric, and spectral investigations of active distant comets at the 6-m telescope BTA (SAO, Russia). The purpose of this program is to clarify the reasons for the activity of distant comets.

We present new results of continuum polarization measurements for six distant comets: C/2011 S1 (LINEAR), C/2011 R1 (LINEAR), C/2014 A4 (SONEAR), C/2013 V4 (Catalina), C/2012 J1 (Catalina), and C/2011 KP36 (Spacewatch) with perihelion distances more than 3 au. These comets show significant activity beyond the Jovian orbit. Polarization maps of these comets show spatial variations of polarization over the coma from about –2% up to –4% at phase angles α from 4.9° up to 14° what may be related to changes in physical properties of the dust particles. Average values of the polarization are significantly higher (in absolute values) than the typical value of polarization (~ 1.5%) observed for the dust comas of most comets close to the Sun. Probably the dust in distant comets differs from that in the short-period comets.

We compare all available observational data with the results of numerical modeling performed early for comet C/2011 S1 (LINEAR) by using the superposition T-matrix method. For this comet, the dust in the form of compact fractal aggregates with an overall radius $R \sim 1.3$ µm, composed of $N = 1000$ spherical monomers with a radius $a = 0.1$ µm and a refractive index $m = 1.65 + i\,0.05$, allows to obtain a satisfactory agreement between the results of polarimetric observations and computations. As a result of solving the radiative transfer equation for the cometary coma of different optical thickness composed of such aggregate particles, we present the values of the geometrical A_g and visual $A(\alpha)$ albedos. We conclude that the limited observational data do not permit to make reliable conclusions about the physical properties of particles in the atmospheres of distant comets. New photometric and polarimetric observations performed in a wide range of wavelengths and phase angles are required to provide a reliable physical model of the cometary dust.

Preferred mode of presentation: Oral

Phenomenological theory of the reflectance of particulate media: scattering regimes and Lorentz features

Christopher A. Jeffery* and Bradley Henderson

Space & Remote Sensing Sciences, Los Alamos National Laboratory, MS D436, Los Alamos, NM 87545, USA

Presenting author (cjeffery@lanl.gov)

The confounding effects of particle morphology on the spectra of particulate surfaces can impede the remote detection and identification of materials of interest. Hunt and Vincent (1968), and later Moersch and Christensen (1995), identified two regimes of media scattering behavior: volume scattering where increasing particle size decreases reflectivity, and surface scattering where reflectivity increases with increasing particle size. They further associated infrared (IR) spectral features that appear as reflectance "troughs" with volume scattering, and reflectance "peaks" with surface scattering. However, an analytic framework to predict scattering behavior and the evolution of spectral features with changing particle size is currently lacking. We present a phenomenological theory of the reflectance of particulate media that provides concrete analytical relationships separating volume and surface scattering regimes, and which further divides spectral features into three distinct classes: Volume, Transition and Reststrahlen. We present analytic boundaries for the problematic "Transition Class" of IR features where a reflectance peak can transition to a reflectance trough, and vice-versa, with changing particle size. Our new framework has important implications for the utilization of spectral features to identify powders of interest in remotely sensed thermal imagery.

Preferred mode of presentation: Oral or Poster

Hyperbolic umbilic caustics from oblate water drops with tilted illumination: observations

Oli Jobe[a], David B. Thiessen[b], and Philip L. Marston[c,*]

[a]*3670 Tupelo Trail, Auburn, GA 30011, USA*
[b]*Voiland Sch. Chem. Engr. & Bioeng., Washington State University, Pullman, WA 99164-6515, USA*
[c]*Physics and Astronomy Dept., Washington State University, Pullman, WA 99164-2814, USA*

[*]*Presenting author (marston@wsu.edu)*

Various groups have reported observations of hyperbolic umbilic diffraction catastrophes in the far-field scattering by oblate acoustically levitated drops with symmetric illumination [1–4]. In observations of that type the drop's symmetry axis is vertical and the illuminating light beam (typically an expanded laser beam) travels horizontally. In the research summarized here, documented in [5], scattering patterns in the primary rainbow region and drop measurements were recorded with horizontally tilted laser beam illumination having a grazing angle G as large as 4 degrees. The findings from these observations may be summarized as follows:

(a) It remains possible to adjust the drop aspect ratio (diameter/height) = D/H so as to produce a V-shaped hyperbolic umbilic focal section (HUFS) in the far-field scattering.

(b) The shift in the required D/H was typically an increase of less than 1% and was proportional to G^2.

(c) The apex of the V-shaped HUFS was shifted vertically by an amount proportional to G with a coefficient close to unity.

(d) With increasing G the apex shifted horizontally very slightly to smaller scattering angles with a shift proportional to G^2. These observations indicate the caustics previously reported can be utilized with tilted illumination.

This research was supported in part by ONR.

References

1. P. L. Marston and E. H. Trinh, *Nature* **312**, 529–531 (1984).
2. P. L. Marston, *J. Quant. Spectrosc. Radiat. Transfer* **63**, 341–351 (1999).
3. H. Yu, F. Xu, and C. Tropea, *Opt. Express* **21**, 25761–25771 (2013).
4. F. R. A. Onofri, K. F. Ren, M. Sentis, and Q. Gaubert, *Opt. Express* **23**, 15768–15773 (2015).
5. O. Jobe, M. S. Thesis (Washington State University, Pullman, August 2008).

Preferred mode of presentation: Poster (or Oral)

The Single Particle InfraRed Elastic Scatter (SPIRES) brassboard sensor

Jason M. Jong[a,*], William D. Herzog[a*], Jonathan M. Richardson[a], David S. Wolinski[a], Brian G. Saar[a], Shawn M. Redmond[a], and Jay D. Eversole[b]

[a]*MIT Lincoln Laboratory, 244 Wood St., Lexington, MA 02420, USA*
[b]*Naval Research Laboratory, 4555 Overlook Ave. S.W., Washington, DC 20375, USA*

[*]*Presenting author (jjong@ll.mit.edu)*

We have recently demonstrated that micron-sized aerosol particles and droplets can be individually detected and discriminated using multi-wavelength infrared scatter in the 7.5–11.0 micrometer range. To exploit this capability, we have developed a self-contained instrument we call the Single Particle InfraRed Elastic Scatter (SPIRES) brassboard. The SPIRES brassboard is completely self-contained within a 25 inch (63.5 cm) cube, including the optical, airflow, and electronics systems. The SPIRES includes 8 discrete wavelengths provided by quantum cascade lasers. To date, we have demonstrated detection/discrimination of particles as small as 2 micrometers. The sensor utilizes coherent amplification of the scatter signal, which enables simultaneous detection of all 8 wavelengths with high sensitivity. The system also includes a 405-nm scatter signal as a data acquisition trigger and optical particle sizer. This poster will present details of the SPIRES brassboard along with performance data.

This material is sponsored by the Defense Threat Reduction Agency-Joint Science and Technology Office for CB Defense under Air Force Contract No. FA8721-05-C-0002 and/or FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the U.S. Air Force.

Preferred mode of presentation: Poster

Laboratory simulation of light scattering from regolith analogue: effect of porosity and particle size

Amritaksha Kar[a,*], Asoke Kumar Sen[a], and Ranjan Gupta[b]

[a]*Dept. of Physics, Assam University, Silchar, India*
[b]*Inter-University Centre for Astronomy and Astrophysics, Ganeshkhind, Pune, India*

[*]*Presenting author (amritakshakar@gmail.com)*

The surfaces of most atmosphereless solar system objects are referred to as regolith or layers of usually loosely connected fragmentary debris produced by meteorite impacts. Measurements of light scattered from such a surface provide information about its composition and structure. A suitable way to characterize the scattering properties is to consider how the intensity and polarization of scattering depends on the particle size, composition, porosity, roughness, wavelength of incident light and the varying geometry of observation.

Here in Assam University, Silchar, India we have set up a laboratory to simulate the light scattering properties of such surfaces in intensity as well as in polarization. For the laboratory simulation a goniometer is used with a CCD as a detector and a He–Ne gas laser as a source having wavelengths 543.5 and 632.8 nm. For imaging, a thick lens (converging) is mounted in front of the CCD camera. For measuring the degree of polarization, an additional Polaroid has been mounted in front of the thick lens. The Polaroid can be rotated in many discrete steps. The light scattered from the regolith surface is detected by the CCD camera at three different positions of the Polaroid. The intensity and polarization are measured by varying the phase angle. In the present work, the effect of porosity and particle size on reflectance is studied for a diverse collection of regolith-like samples with a wide range of albedo. Results obtained by the above experiment will be discussed.

Preferred mode of presentation: Oral (or Poster)

What can satellite observations, surface data and model simulations tell us about trans-Pacific dust transport?

E. Kassianov[a,*], M. Pekour[a], C. Flynn[a], L. K. Berg[a], J. Beranek[a], A. Zelenyuk[a], C. Zhao[a], L. R. Leung[a], P. L. Ma[a], L. Riihimaki[a], J. D. Fast[a], J. Barnard[b], A. G. Hallar[c], I. B. McCubbin[c], E. W. Eloranta[d], A. McComiskey[e], and P. J. Rasch[a]

[a]*Pacific Northwest National Laboratory*
[b]*University of Nevada, Reno*
[c]*Storm Peak Laboratory, Desert Research Institute*
[d]*University of Wisconsin, Madison*
[e]*National Oceanic and Atmospheric Administration*

[*]*Presenting author (Evgueni.Kassianov@pnnl.gov)*

Perhaps the greatest challenge to studying the evolution of dust properties during long-range transport is the lack of observations, particularly integrated datasets that permit assessment of the complex and size-dependent processes associated with dust emission, transport, and removal. Maring et al. (2003) analyzed the Saharan dust size distributions along a trans-Atlantic transport pathway and provided some of the earliest observational evidence that the lifetime of super-micron particles is longer than expected from conventional deposition schemes. We examine contributions of super-micron particles from trans-Pacific transport of dust to North American aerosol properties using a dataset collected at the high-elevation Storm Peak Laboratory (SPL) and the nearby Atmospheric Radiation Measurement (ARM) Mobile Facility. Collected ground-based data are complemented by satellite observations (MODIS, MISR and CALIPSO data) and quasi-global model simulations. We identify a major dust event associated mostly with a trans-Pacific plume (about 65% of near surface aerosol mass) where the coarse mode with moderate (~3 μm) volume median diameter (VMD) is distinct and contributes substantially to total aerosol volume (up to 70%) and scattering (up to 40%). Our results demonstrate that the identified plume at the SPL site has a considerable fraction of super-micron particles (VMD ~ 3 μm), and thus suggest that these particles have a fairly invariant behavior despite trans-Pacific transport.

Mode of presentation: Invited

Three-dimensionality of digital holography reconstructions

Osku Kemppinen[a,*], Yuli Heinson[b], and Matthew Berg[a]

[a]*Kansas State University, 1228 N 17th St., Manhattan, KS 66506, USA*
[b]*Washington University in St. Louis, 1 Brookings Dr., St. Louis, MO 63130, USA*

[*]*Presenting author (okemppin@phys.ksu.edu)*

Digital holography is an imaging method for small particles. Scattered light interferes with the incident light, and the resulting pattern can be reconstructed computationally to produce an image of the particle. A feature of the method is that the particle distance from the detector, i.e. the traditional optical focus distance, does not need to be known *a priori*. This is because the focusing happens purely in the computational reconstruction phase.

Because light is scattered by the whole particle and not just the silhouette, the complete particle shape is, in some sense, encoded in the hologram pattern. In this presentation we describe what kind of three-dimensional information about the particle, in addition to the two-dimensional silhouette, can be acquired by varying the reconstruction distance and plane.

Preferred mode of presentation: Oral

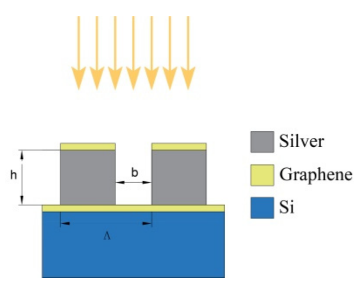
Enhancement of spectral absorption of graphene based nano-structures in narrow bands

Farhad Kazemi Khosroshahi[a], Hakan Ertürk[a], and M. Pınar Mengüç[b,*]

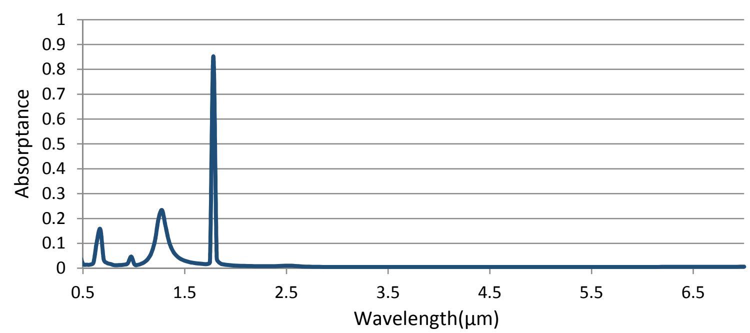
[a]*Boğaziçi University, Department of Mechanical Engineering, Bebek, 34342, Istanbul, Turkey*
[b]*Özyeğin University, CEEE & Department of Mechanical Engineering, Çekmeköy, 34794, Istanbul, Turkey*

[*]*Presenting author (*pinar.menguc@ozyegin.edu.tr)

Graphene has unique electrical and optical properties. It is considered a 2D material since its thickness is only about 0.3 nm, which is practically equivalent to atomic thickness. From the optical point of view, single graphene sheet acts as an absorptive dielectric, with a small absorptance of about 2.3%, and almost uniform along a broad wavelength range. Yet, for most applications, such as optical modulators, photodetectors, PV devices, and others, higher and selective absorption is required. Here a graphene-based nanostructures are theoretically studied to explore the possible enhancement of the absorption in a very narrow wavelength range. A code developed in MATLAB^{TM} based on the Rigorous Coupled Wave Analysis that is verified against the results of Zhao et al. [1] and Hu et al. [2] is used to predict the optical properties of different structures. A typical structure considered is composed of a graphene sheet coated by periodic silver strips on top of the graphene-coated silicon substrate (Fig. 1a). A parametric study is carried out to tune the absorption peak to longer or shorter wavelengths. The absorptance spectrum of the structure (with $h = 0.16$ µm, $b = 0.007$ µm, $\Lambda = 0.5$ µm) is shown in the Fig. 1b. As these predictions suggest, a very narrow-band absorptance is achieved at the wavelength of 1.78 µm, with no absorption at longer wavelengths. In this band, absorption is high and about 85%. These results show the promise of such modified structures for almost monochromatic absorptance, which can be used for sensor development and related applications.



(a)



(b)

Fig. 1. (a) Suggested graphene based structure; (b) absorptance spectrum.

References

[1] B. Zhao, J. M. Zhao, and Z. M. Zhang. Enhancement of near-infrared absorption in graphene with metal gratings. *Appl. Phys. Lett.* **105**, 31905 (2014).

[2] J.-H. Hu, Y.-Q. Huang, X.-F. Duan, Q. Wang, X. Zhang, J. Wang, and X.-M. Ren, “Enhanced absorption of graphene strips with a multilayer subwavelength grating structure,” *Appl. Phys. Lett.* **105**, 221113 (2014).

Position and maximum of linear polarization for different asteroids types: observations and computer simulation

Nikolai N. Kiselev[a,b,*] and Dmitry V. Petrov[b]

[a]*Main Astronomical Observatory, National Academy of Sciences of Ukraine, Akad. Zabolotnoho Str. 27, 03143, Ukraine*
[b]*Crimean Astrophysical Observatory, Nauchnij, Crimea*

[*]*Presenting author (kiselevnn@yandex.ru)*

Ground-based observations of near-Earth asteroids (NEAs) provide an opportunity to determine the parameters of the phase-angle dependence of polarization for the asteroids at large phase angles, specifically the maximum degree of polarization P_{max} and its angular position α_{max}. Hence there is a possibility to explore the parameters of an almost complete phase dependence of polarization for the small-planets population in the solar system. It is of great interest to determine the optical and physical characteristics of the particulate layer forming the asteroids' regolith.

From our previous observations, it was found that the maximum of the polarization phase curve for E-type asteroids reached $P_{max} \approx 1.6\%$ and occurred at a phase angle $\alpha_{max} \approx 75°$. Thus, high-albedo E-type asteroids have surfaces characterized by the lowest polarization values in the asteroid population, and the position of the polarization maximum is significantly shifted toward smaller phase angles with respect to that of S-type asteroids, for which $\alpha_{max} \approx 110°$, as well as for other known bodies in the Solar System, such as the Moon ($\alpha_{max} \approx 110°$) and Mars ($\alpha_{max} \approx 100°$). The parameter α_{max} has rarely been used for analyzing asteroids' polarization properties.

So it is seems to be very interesting to investigate the relationship between α_{max} and the optical properties of the particles forming the asteroid's surface layer. By performing calculations with the help of our modification of the *T*-matrix method for Gaussian random irregularly shaped particles, we estimate the influence of the complex refractive index on the scattering properties of the particles.

The calculations have shown that the position of polarization maximum depends on the imaginary part of the refractive index in a particular way. When the imaginary part of refractive index increases, the position of P_{max} initially shifts toward smaller phase angles, but then, upon reaching a certain critical value, α_{max} begins to grow again. The critical value of the imaginary part depends also on the real part of the complex refractive index. The higher the real part of the refractive index, the more the imaginary part should be increased to shift the polarization maximum toward the larger phase angles.

Regoliths covering the surfaces of various asteroids have different chemical compositions. In particular, the S-type asteroids are a mixture of silicates and metals, whereas high-albedo asteroids of the E-type are composed of neutral silicates. Accordingly, the regolith particles on thir surfaces should have different refractive indices. For particles on E-type asteroids, the imaginary part of the refractive index should be less than that for S-type asteroids. In that case, the phase angle α_{max} for the E-type asteroids should be shifted toward smaller phase angles with respect to that of the S-type asteroids, which is in agreement with the observations.

Mode of presentation: Invited

Multi-angle, polarimetric cloud observations using a radiative transfer model trained Neural Network

Kirk D Knobelspiesse[a,*], Michal Segal-Rosenhaimer[b,c], Jens Redemann[b], Brian Cairns[d], and Mikhail D. Alexandrov[d,e]

[a]*NASA Goddard Space Flight Center, Greenbelt, MD, USA*
[b]*NASA Ames Resarch Center, Moffett Field, CA, USA*
[c]*Bay Area Environmental Research Institute, Petaluma, CA, USA*
[d]*NASA Goddard Institute for Space Studies, New York, NY, USA*
[e]*Columbia University, New York, NY, USA*

[*]*Presenting author (kirk.d.knobelspiesse@nasa.gov)*

Multiangle polarimetric observations have the information content necessary to retrieve optical properties of complex scenes in the atmosphere, such as aerosols lofted above clouds (AAC). Operational retrieval algorithms for the AAC, however, have yet to be developed, and require many computationally expensive runs of a Radiative Transfer (RT) model to converge to a solution in a multi-parametric space. A potentially successful approach to this problem is to utilize machine learning (such as a Neural Network, NN) to rapidly select an appropriate starting point in an iterative retrieval algorithm. Doing so reduces the number of required iterations, and has the potential to significantly improve algorithm efficiency.

We are developing an algorithm based on these principles for NASA's Research Scanning Polarimeter (RSP), deployed on two aircraft to observe AAC as part of the ORACLES (ObseRvations of Aerosols above CLouds and their intEractionS) campaign. ORACLES takes place in the South-East Atlantic during the Austral Spring for each of 2016–2018. The study area encompasses one of the Earth's three semi-permanent subtropical Stratocumulus (Sc) cloud decks, and experiences very large aerosol optical depths, mainly biomass burning, originating from Africa. Over time, cloud optical depth, lifetime and cloud microphysics (number concentration, droplet size distribution and precipitation) are expected to be influenced by indirect aerosol effects. These changes play an uncertain but potentially important role in the energetic budget of the region.

Our algorithm is based on a NN trained with extensive RT simulations. Prior to a complete AAC retrieval, we have first established a cloud-only scene retrieval, so that we can validate our technique against results from existing algorithms. We will discuss parameter choices for the NN and present preliminary results of cloud retrievals from ORACLES, and discuss how our future plans are shaped by these results.

Preferred mode of presentation: Oral

Light scattering by hierarchical aggregates

Ludmilla Kolokolova[a,*], Lev Nagdimunov[a], and Catherine Master[a]

[a] *University of Maryland, College Park, MD, 20742, USA*

[*] *Presenting author (ludmilla@astro.umd.edu)*

Studies of cometary dust by the Rosetta dust instruments (COSIMA, MIDAS, GIADA) showed that cometary dust could, most appropriately, be represented by hierarchically structured aggregates, where large particles (>100 μm) are formed by ~10 μm-sized grains, which, in turn, are clusters of micrometer and submicrometer grains. To study how the hierarchical structure of aggregates affects their photopolarimetric properties, we build a model of cometary particles consistent with the Rosetta findings, and compare its light-scattering properties with those for Ballistic Particle–Cluster and Ballistic Cluster–Cluster Aggregates (BPCA and BCCA) which have often been used to model cometary dust particles. In our model, the clusters formed by the first level of aggregation are built via the BPCA mechanism, and at each higher level of aggregation the clusters of the previous level ballistically collide one at a time with a central cluster. The code can accommodate an unlimited number of the aggregation levels; however, here we consider a maximum of 3 levels of aggregation to be consistent with the Rosetta results. To model light scattering by hierarchical aggregates we used the Multi-Sphere T-Matrix (MSTM) code by Dan Mackowski (www.eng.auburn.edu/~dmckwski/scatcodes). We used the parallel computing version of this code and performed our computations using the NASA Pleiades supercomputer. We consider a variety of hierarchical structures, varying the number of monomers at each level of aggregation, but keeping the same total number of monomers in all computations. Our results show that each hierarchical structure has its own photopolarimetric properties, and these properties differ from those for the BPCA and the BCCA.

Preferred mode of presentation: Oral

Light scattering by irregular ice crystals of cirrus clouds

Alexander V. Konoshonkin[a,b,*], Natalia V. Kustova[b], Victor A. Shishko[a,b], Dmitriy N. Timofeev[b], and Anatoli G. Borovoi[a,b]

[a]*Tomsk State University, 36 Lenin Ave, 634050 Tomsk, Russia*
[b]*V. E. Zuev Institute of Atmospheric Optics SB RAS, Academician Zuev Sq. 1, 634055 Tomsk, Russia*

[*]*Presenting author (sasha_tvo@iao.ru)*

Light scattering by ice crystals of cirrus clouds poses an important issue for atmospheric optics due to two reasons: the improvement of radiance models and lidar data interpretation. In spite of numerous attempts to solve this problem with the help of geometrical and physical optics approximations or numerically exact methods, the solutions cannot clearly reproduce the observation results. It becomes obvious that it is not the methodology we use but the object we consider that causes the problem. Numerous independent studies using different approaches have demonstrated the inability of a perfect hexagonal ice prism to produce a lidar signal identical to that observed in cirrus clouds. It has also been shown that by taking roughness into account one can improve the agreement with lidar data but the solution is missing the 22° halo typical for cirrus clouds. In this talk we present the solution for irregular ice columns which is able to reproduce both the observed lidar data and the 22° halo. The solution was obtained within the framework of both the physical and the geometrical optics approximations.

Preferred mode of presentation: Oral (or Poster)

Recent updates on the RT code SORD

Sergey Korkin[a,b,*], Alexei Lyapustin[b], Aliaksandr Sinyuk[c,b], and Brent Holben[b]

[a]*USRA GESTAR, 7178 Columbia Gateway Drive, Columbia, MD 21046, USA*
[b]*NASA Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt, MD 20771, USA*
[c]*Sigma Space Corp., 4600 Forbes Blvd., Lanham-Seabrook, MD 20706, USA*

[*]*Presenting author (sergey.v.korkin@nasa.gov)*

The radiative transfer (RT) code SORD numerically simulates the propagation of monochromatic solar radiation in a plane-parallel atmosphere over a reflecting surface using the method of successive orders of scattering (hence the name). For 52 benchmarks covering a wide range of scenarios, we discuss the accuracy and speed of computations (runtime). Unlike the accuracy, RT code developers rarely indicate runtime because of obvious reasons. Never before has the runtime been reported for such a wide range of scenarios. In particular, we show the accuracy of SORD for cases defined in the IPRT vector RT codes intercomparison (C. Emde et al. 2015, *JQSRT* **164**, 8). None of the existing successive orders RT codes participated in the IPRT tests.

We intend to use SORD to account for polarization of light in the AERONET data reprocessing. This important task dictates the main goal of this presentation: to get critical feedback from the community. To encourage the use of SORD, we recently developed two user-friendly input/output interfaces. The first one serves as a quick start guide and introduces the user to basic features of the code. The second one allows an independent reproduction of all the reported results on the user's machine (a Fortran 90/95 compiler required). It also shows how to define input for atmospheres with scattering and absorption height profiles.

Preferred mode of presentation: Oral

Insights into particle morphology from single-particle light scattering

Daniel Landgraf[a], Jason Zallie[a], Ronald Pinnick[b], Yong-Le Pan[b] and Kevin B. Aptowicz[a,*],

[a]*West Chester University, 700 S. High St. 700 S High St, West Chester, PA 19382, USA*
[b]*US Army Research Laboratory, 2800 Powder Mill Road, Adelphi, MD 20783, USA*

[*]*Presenting author (kaptowicz@wcupa.edu)*

The morphology of atmospheric aerosol particles varies greatly from homogenous spheres to complex aggregates. This diversity of particles morphologies challenges radiative models and remote sensing techniques since the light scattering behavior of aerosols is greatly influenced by particle morphology. In this work, we explore aerosol morphology at the single-particle level by capturing and analyzing angularly-resolved light scattering patterns. In particular, we calculate the two-dimensional autocorrelation of over 30,000 single-particle light-scattering patterns from atmospheric aerosol particles in Las Cruces, NM. The size and shape of the central peak of the autocorrelation function provides insight into particle morphology. By parameterizing the central peak of the autocorrelation function, the diverse range of particles morphologies in our dataset can be grouped into subpopulations. Preliminary results suggest one population consists of sphere and sphere-like particles such as liquid particles with or without inclusions. The second population appears to represent complex agglomerates, which are likely solid-like particles. We also explore how the optical properties, like the scattering phase function, vary between the different subpopulations.

Preferred mode of presentation: Oral

A system for measuring forward light scattering by spherical and nonspherical silica particles

Paul Lane*, Matt Hart, and Jay D. Eversole

Optical Sciences Division, U.S. Naval Research Laboratory, Washington, DC, USA

**Presenting author (paul.lane@nrl.navy.mil)*

We developed a method to measure elastic light scattering from aerosolized particles with high throughput and repeatability. An electrospray aerosol generator injected charged particles into a linear electrodynamic quadrupole (LEQ) trap in which particles flowed through the system confined along the centerline of the LEQ for optical interrogation. Forward light scattering was measured at three different wavelengths from three collinear laser beams multiplexed in time at 1 kHz. We validated the method by measuring scatter from silica microspheres with four selected diameters between 0.5 to 2.0 micrometers. The experimental data is de-multiplexed, fit to Gaussian waveforms to determine scattered light intensities, and then these data were fit to a Mie theory model for the measured forward solid angle. Variation in experimental data for each measured wavelength and sphere size is consistent with a size standard deviation of approximately 0.5% and scatter variance of 1.5% due to position**.** Ratios of the scattered intensities from each wavelength can be computed as a function of sphere size, and measured values for our discrete set can be aligned on this theoretical trajectory using a refractive index of approximately 1.40. Having established this agreement between experiment and model, we investigated forward scattering intensity data from two classes of non-spherical aerosols: aggregates of silica microspheres and highly irregular shards prepared by ball grinder hollow silica spheres. We further compared the effect of an absorbing coating on forward scattering on spherical and non-spherical particles. Comparisons of non-spherical to spherical particles show the non-spherical particles form a cloud of individual particle points that appear to follow the trajectories of the ratios of intensities of the spherical particles. More details will be presented summarizing the effects of absorption on these measurements.

Preferred mode of presentation: Oral (Poster is acceptable)

Comparison of Multiple Sphere T-matrix and Mie models for space weathering relevant materials

Carey Legett IV[a*], Timothy D. Glotch[a], and Paul G. Lucey[b]

[a]*Stony Brook University, 255 Earth and Space Sciences, Stony Brook, NY 11794-2100, USA*
[b]*Hawaii Institute of Geophysics & Planetology, 2525 Correa Road, University of Hawaii, Honolulu, HI 96822, USA*

[*]*Presenting author (carey.legett@stonybrook.edu)*

Space weathering can be defined as the gradual changes experienced by the surfaces of airless planetary bodies due to exposure to the vacuum of space, radiation, and micrometeorite bombardment. Characteristic VNIR spectral changes due to space weathering include a decrease in albedo and a general "reddening" of spectra (increasing reflectance with increasing wavelength). Apollo-returned lunar soils contain grains with amorphous rims with nanophase metallic-iron particles ($npFe^0$) dispersed throughout. Absorbing particles of this scale (tens of nm) have very strong optical effects. The size of the $npFe^0$ particles determines the amount of reddening observed with smaller particles being associated with redder spectra than larger particles. A transition occurs at a particle size of ~30–50 nm, above which the spectra darken without reddening. Previous modeling work has failed to robustly reproduce this transition at the observed iron particle size, instead requiring larger particles. We present work comparing the use of the Multiple Sphere T-matrix Model and a Mie model on several cases relevant to the space-weathered lunar soil grains. Scattering and extinction efficiencies and phase function data are taken from these models as inputs to a bidirectional reflectance model for comparison to remote sensing datasets of planetary surfaces.

Preferred mode of presentation: Poster

Three-dimensional microphysical tomography of clouds

Aviad Levis

Viterbi Faculty of Electrical Engineering, Technion Institute of Technology, Haifa, Israel (aviad.levis@gmail.com)

Current atmospheric remote sensing techniques rely on heavily plane-parallel models and the associated one dimensional (1D) radiative transfer (RT) to predict the signals measured from ground-based, airborne or satellite sensors. These models however do not express the true 3D nature of the atmosphere, thus introducing biases in retrievals.

Recent advances in multi-view high-resolution instruments enable, in principle, 3D volumetric recovery. Coupled with advances in computation power, a new type of previously intractable inverse problems may now be considered. Here, we pose and solve new inverse problems of passive atmospheric scatterer tomography, foremost convectivly-driven cumulus clouds. Our approach fits a 3D volumetric distribution of microphysical parameters to multi-angle/multi-spectral imaging radiometry. The forward model we use is a numerical 3D RT solver. We make the recovery computationally tractable on large scales. The approach is validated with synthetic LES (large-eddy simulation) clouds. It is then demonstrated experimentally using data from the Airborne Multi-angle Spectro-Polarimetric Imager (AirMSPI) collected during recent campaigns overflying broken cloud fields.

Mode of presentation: Invited

Passive remote-sensed observations of tropospheric aerosols: a GSFC perspective

Robert C. Levy[a,*], Ralph A. Kahn[a], Andrew Sayer[b,a], Omar Torres[c], N. Christina Hsu[a], Peter R. Colarco[c], and Lorraine A. Remer[d]

[a]*NASA Goddard Space Flight Center (GSFC), Code 613, Greenbelt, MD, USA*
[b]*Goddard Earth Sciences Technology And Research (GESTAR), Universities Space Research Association (USRA), Columbia, MD, USA*
[c]*NASA Goddard Space Flight Center (GSFC), Code 614, Greenbelt, MD, USA*
[d]*Joint Center for Earth Systems Technology (JCET), University of Maryland, Baltimore County (UMBC), Catonsville, Maryland, USA*

[*]*Presenting author (robert.c.levy@nasa.gov)*

NASA-Goddard Space Flight Center is a center of excellence for tropospheric aerosol research, especially in regards to inferring aerosol properties from passive remote sensing of solar radiation. There are many individuals and teams, using a variety of algorithms, applied to a variety of sensors, all aiming to characterize global tropospheric aerosol properties. All permutations have strengths and limitations, and each is providing a useful but incomplete picture of the global aerosol climatology. Although the original focus of our global products is characterizing aerosols for climate studies (estimating forcing, fluxes, aerosol/cloud interactions, etc.), our collective aerosol products are widely used for a huge diversity of applications, including real-time monitoring and forecasting of air quality and human health impacts.

From a climate perspective, we are using passive remote sensing to address some of the WMO-designated target requirements for creating multi-decadal aerosol-climate data records. We focus primarily on aerosol optical depth (AOD), which needs to be reported for the WMO at <10 km spatial resolution every four hours, with an accuracy of MAX(0.03 or 10%) and stability of within 0.01/decade. For single scattering albedo (SSA), with a WMO measurement accuracy requirement of ±0.03, we are developing space retrieval capabilities that combine radiometric and polarimetric observations in the entire UV to IR spectral range. As SSA is an intrinsic aerosol property that is difficult to interpret (e.g., dried aerosol or ambient? surface or column?), we are pursuing consistent and robust identification of aerosol "type" to categorize aerosol microphysical properties, sources and evolution.

In this presentation, we report on the diversity of tropospheric aerosol remote sensing at GSFC, and also highlight some applications and uses to which our aerosol data products have contributed. We show how our algorithms and products are informed and improved by *in situ* observations and aerosol transport modeling. This includes development and testing of Observation System Simulation Experiments (OSSEs) to reflect existing and future satellite capabilities.

Preferred mode of presentation: Oral

Experimental investigations on single burning droplets with micro-explosions using shadowgraphy, interferometric particle imaging, and standard rainbow refractometry

Haipeng Li*, Christopher D. Rosebrock, Thomas Wriedt, and Lutz Mädler

Department of Production Engineering, Foundation Institute of Material Science (IWT), University of Bremen, Badgasteiner Str. 3, Bremen 28359, Germany

Presenting author (haipeng.lie@iwt.uni-bremen.de)

As a promising and versatile technique for the production of highly pure nanoparticles, flame spray pyrolysis (FSP) has already notable applications in catalysis, optics and photonics, sensors, health care, magnetic materials and electroluminescent materials, electro-ceramics for fuel cells and composite materials. During FSP, small droplets vaporize and release metal containing precursors into the flame where they get oxidized and for nanoparticle. To obtain fundamental insights into the mechanisms of droplet combustion in FSP, especially the heat and mass transfer, single droplet combustion is applied with optical measurement techniques. The effect of the initial droplet diameter on the angle positions of the first and second rainbow maxima (rainbow positions) of burning single-component droplets has been studied with interferometric particle imaging and standard rainbow refractometry. It indicates that temperature gradients exist inside the burning single-component droplets (initial diameters from 85 to 142 μm), and temperature gradients cause rainbow positions increase first to a maximum, and then decrease. Different initial diameters lead to variations of both experimental rainbow position and simulated temperature profiles of burning droplets. Micro-explosions occur for single burning droplets containing metalorganic compounds during single droplet combustion, and these micro-explosions will largely increase the rate of precursor release and decrease the life-time of burning droplets. In order to gain a better understanding of droplet micro-explosions, combustion experiments on single droplet of Tin(II)2-ethylhexanoate (Tin-ETH) dissolved into xylene with the concentrations of 0, 0.05, 0.1, 0.25, 0.5, 0.75 and 1 mol/L were performed, using the optical measurement techniques of shadowgraphy, interferometric particle imaging and standard rainbow refractometry. The initial diameters of these droplets are similar (131–140 μm). The results demonstrate that droplet micro-explosions need less time with increasing precursor concentration. Moreover, the evolutions of rainbow positions of burning droplets are strongly affected by the precursor concentration, which could be caused by the preferential evaporation and shell formation before micro-explosions. Comparing to that of single-component droplets, new findings of the rainbow positions of burning droplets with micro-explosions have be obtained. The rainbow positions show one period of a long-time increase and subsequent a short-time decrease before the occurrence of micro-explosions for all burning Tin-ETH /xylene droplets. The rainbow positions of 0.05, 0.1, 0.25 and 0.5 mol/L Tin-ETH /xylene droplets increase first to a maximum, then decrease to one value, subsequently increase to another peak and then decrease until the micro-explosions happen. Oscillations are observed at the first increase and decrease period of 0.1 and 0.25 mol/L Tin/xylene droplets. Only one long-time increase and subsequent one short-time decrease are observed for the rainbow positions of 0.75 and 1 mol/L Tin-ETH /xylene droplets.

Preferred mode of presentation: Oral

Laboratory measurements of scattering phase function of dust samples at 532 and 1064 nm

Ron R. Li*, Guanglin Tang, Jiachen Ding, and Ping Yang

Department of Atmospheric Sciences, Texas A&M University, College Station, TX 77843-3150, USA

**Presenting author (ronli@tamu.edu)*

The scattering phase functions of dust samples are studied using a recently completed laboratory apparatus. The light source is a CW dual wavelength (532 and 1064 nm) diode-pumped solid state laser. Light scattered by dust particles is detected by a rotating CCD camera at different scattering angles. Samples are prepared through aerosolization of dust particles, using a six-hole collision nebulizer. Scattering angles are covered from 2.8° to 177.2°. Dust particle sizes are continuously monitored by a TSI 3321 APS (Aerodynamic Particle Sizer) during the measurements of the scattering phase functions. The measurement accuracy is assessed by comparing the measured phase function for an ensemble of water droplets with Mie theory calculations. Polarized phase functions at 532 and 1064 nm from the aerosolized dust particles with or without going through a diffusion drier are recorded and discussed. Three dust samples selected for this study are commercial products: kaolinite, zeolite, and iron (II, III) oxide. The measurements are compared with numerical simulations.

Preferred mode of presentation: Poster

An efficient and accurate extinction simulator for atmospheric aerosols

Wushao Lin[a,*], Lei Bi[a], Dong Liu[b], and Kejun Zhang[c]

[a] *Department of Atmospheric Sciences, Zhejiang University, Hangzhou 310027,China*
[b] *State Key Laboratory of Modern Optical Instrumentation, Department of Optical Engineering, Zhejiang University, Hangzhou 310027, China*
[c] *College of Computer Science and Technology, Zhejiang University, Hangzhou 310027, China*

[*]*Presenting author (linwushao@zju.edu.cn)*

The extinction efficiencies of aerosols in the atmosphere are essential to determining the radiation attenuation and thus are fundamentally related to air visibility. In addition, the values of the extinction efficiencies contain much information of particle physical characteristics and thus, for example, can be used to retrieve the particle sizes in the particle characterization techniques. In this presentation, we report on an efficient and accurate extinction simulator for atmospheric aerosols. The extinction simulator is based on the semi-empirical high-frequency formulas for spheroids in the context of the Complex Angular Momentum (CAM) theory. An essential step for applying the formulas is to determine an optimal number of edge-effect terms. We show that the optimal numbers can be accurately obtained based on the latest development of the invariant imbedding Debye series and *T*-matrix techniques. With a table of optimal numbers of the edge-effect terms, the simulator can be used for real-time computing with high accuracy. The aforementioned simulator has been fully tested for randomly oriented spheroids with various aspect ratios and representative refractive indices for atmospheric aerosols (e.g., mineral dusts and sea salts).

Preferred mode of presentation: Poster

How significantly can mixing enhance absorption of black-carbon aerosols

Chao Liu*, Ji Li, and Yan Yin

School of Atmospheric Physics, Nanjing University of Information Science and Technology, Nanjing, 201144, China

[*] *Presenting author (chao_liu@nuist.edu.cn)*

As one of the most important absorbing aerosols for solar radiation, black carbon (BC) plays a significant role in affecting the radiation budget of the Earth-atmosphere system. The BC absorption is further enhanced by mixing with other materials, whereas many general circulation climate models underestimate BC radiative forcing due to the ignorance of BC mixing structures. Meanwhile, the internal mixing of BC and non-absorptive aerosols also influences the retrievals of BC properties from in-situ measurement. Because natural aerosols show highly complex mixing structures, it is almost impossible to estimate their enhancement of the absorption. This study tries to answer the question of how significant internal mixing can enhance the absorption by BC aerosols. We treat BC particles as aggregates, spheres, or spherical monomers, and build over ten numerical mixing structures to consider internal mixtures of BC and non-absorbing aerosols. Our numerical results indicate that even with relatively small particle sizes, the internal structure plays an important role in absorption by BC-included mixtures. The internal mixing can enhance the absorption by BC aerosols by no more than four times that of homogeneous BC particles, and a combination of various mixture structures may be a better solution to consider the effects of BC aging on its optical properties.

Preferred mode of presentation: Oral (or Poster)

Optical losses due to particles on solar cells: experimental scattering and absorption spectra for absorbing and non-absorbing mineral dust

Laura R. Llanza*, **Patricio G. Piedra, and Hans Moosmüller**

Laboratory for Aerosol Science, Spectroscopy, and Optics, Desert Research Institute, Nevada System of Higher Education, 2215 Raggio Parkway, Reno, NV 89512, USA

**Presenting author (Laura.RodriguezLlanza@dri.edu)*

We present an experimental study of how absorption and scattering of atmospheric particles deposited on solar cells degrade their performance as function of particle mass deposited per unit area. We aerodynamically entrain absorbing (e.g., hematite) or largely non-absorbing (e.g., an off-white lakebed deposit, containing mostly diatoms, plagioclase, and quartz) mineral dust into a metal enclosure, from where it is released into a deposition chamber. Glass slides are placed at the bottom of this chamber and the entrained dust is allowed to deposit on the slides for about one hour. Once our glass slides acquire ~0.1$\frac{g}{cm^2}$ to ~ 8 $\frac{g}{cm^2}$ of deposited dust mass density, we remove them from the deposition chamber and measure their spectral transmission and reflection coefficients with a spectrophotometer with integrating sphere detector. From these measurements, we are deriving absorption and forward and backward scattering optical depth spectra as function of mass density. Further analysis includes comparisons with DDA-Substrate calculations of scattering and absorption processes for dust deposited on a glass surface.

Preferred mode of presentation: Poster

Electromagnetic scattering of a plane wave by a radially inhomogeneous sphere in the short wavelength limit

James A. Lock

Physics Department, Cleveland State University, Cleveland, OH 44115, USA

Presenting author (j.lock@csuohio.edu)

The interior and exterior electric and magnetic fields for scattering of a plane wave by a radially inhomogeneous sphere with refractive index $N(r)$ are expressed in terms of TE- and TM-polarized partial wave scalar radiation potentials. The wave equation for these potentials is approximately solved in the short wavelength limit using the WKB method. The WKB solution is expanded in terms of a Debye series, whose terms are interpreted as multiple internal reflections of the interior wave at the sphere surface. The sum over the partial wave contributions to the fields is approximately evaluated using the method of stationary phase. The final expressions for the far-zone scattered fields provide a generalization of both ray theory and Airy theory to scattering by a radially inhomogeneous sphere. This wave theory approach provides a rigorous foundation to various results that have previously appeared in the literature based on an analogy to scattering by a homogeneous sphere. The physical interpretation of the TE-polarized fields is straightforward. But the TM-polarized fields possess a number of additional terms beyond those expected by appealing to an analogy to TM ray scattering by a homogeneous sphere.

Preferred mode of presentation: Oral

Numerical solution for light scattering by space-weathered planetary bodies

Johannes Markkanen[a,*], **Antti Penttilä**[a], **Timo Väisänen**[a], **and Karri Muinonen**[a,b]

[a]*Department of Physics, University of Helsinki, Finland*
[b]*Finnish Geospatial Research Institute FGI, National Land Survey, Finland*

[*]*Presenting author (johannes.markkanen@helsinki.fi)*

Characteristics of scattered light can reveal physical and chemical surface properties of airless planetary bodies such as asteroids, moons, and comets. Airless bodies are exposed to space weathering, i.e., high-energy electromagnetic radiation, energetic particle radiation, and micrometeorite bombardment, which may alter physical and chemical composition of the surface. The space-weathering processes are known to produce nanophase iron ($npFe^0$) near the exposed surface having a significant effect on the light-scattering features [1].

We present a novel numerical solution for light scattering by airless planetary bodies based on the hierarchical geometric optics (GO) and radiative transfer (RT) with incoherent interactions approach. The object is assumed to consist of densely packed olivine grains with $npFe^0$ inclusions. The RT is applied to compute scattering by packed olivine grains, and the scattering matrices of the grains with $npFe^0$ inclusions, i.e., the input parameters for the RT solution, are computed in a finer scale with the hybrid GO/RT approach. Modeling scattering by $npFe^0$ inclusions, however, poses a major numerical challenge. The real part of the dielectric permittivity becomes negative in the visible wavelengths indicating a strong electromagnetic response in which case the independent scattering assumption may not be valid. Therefore, the standard RT-type modeling tools may fail to produce reliable results.

We utilize the so-called incoherent treatment of the wavelength-sized volume elements developed for the analyses of densely packed systems [2,3]. The volume elements may contain tens of thousands of $npFe^0$ inclusions leading to a massive computational task if executed naively. Thus, we compute the interactions inside the volume elements by the fast superposition T-matrix method (FaSTMM) [4]. The FaSTMM allows us to compute the incoherent input parameters, the incoherent mean free path and the averaged incoherent scattering matrix, to the GO/RT algorithm in reasonable computational time.

References

1. B. Hapke (2001) *J. Geophys. Res.* **106**.
2. L. Zurk (1996) *Radio Science* **31**.
3. K. Muinonen et at. (2016) URSI EMTS.
4. J. Markkanen and A. J. Yuffa (2017) *JQSRT* **189**.

Preferred mode of presentation: Oral

Specular reflection from oriented ice crystals observed from deep space

Alexander Marshak[a,*], Tamás Várnai[a,b], and Alexander Kostinski[c]

[a]*NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA*
[b]*University of Maryland Baltimore County, Baltimore, MD 21250, USA*
[c]*Michigan Technological University, Houghton, MI 49931, USA*

[*]*Presenting author (alexander.marshak@nasa.gov)*

Every hour or two, the Earth Polychromatic Imaging Camera (EPIC) onboard the DSCOVR satellite residing at the Lagrangian point (L1) about 1.5 million km from the Earth provides unique full-color images of the sunlit side of the planet. Casual glances at such images often reveal bright and colorful spots that stand out markedly from their surroundings. These spots are well seen not only over ocean but also over land. The presented study characterizes these flashes of light over land in terms of location, color, and brightness, and provides insights into the factors that lead to their appearance. Tracking the observed flashes using an automated image analysis algorithm reveals that most of them are caused by specular reflection of sunlight from clouds containing nearly horizontally oriented ice crystals. This means that oriented ice crystals can be detected from the distance four times farther than the moon.

Preferred mode of presentation: Oral

Spectral modeling for the Chelyabinsk meteorite at UV–Vis–NIR wavelengths

J. Martikainen[a,*], A. Penttilä[a], T. Kohout[a], H. Suhonen[a], S. Huotari[a], M. Gritsevich[a], and K. Muinonen[a,b]

[a]*Department of Physics, P.O. Box 64, FI-00014 University of Helsinki, Finland*
[b]*Finnish Geospatial Research Institute FGI, P.O. Box 84, FI-00521 Helsinki, Finland*

[*]*Presenting author (julia.martikainen@helsinki.fi)*

We are developing a new light-scattering code based on the one called SIRIS [1], which simulates light scattering by Gaussian-random-sphere particles that are large compared to the wavelength of the incident light. SIRIS traces rays according to geometric optics and radiative transfer, utilizing both Fresnel reflections and refractions at material interfaces and diffuse interactions within the material. Absorption is accounted for within the material both due to the complex refractive index and the diffuse interactions.

The reflectance spectra of the three lithologies (light-colored, dark-colored, and impact-melt) of the Chelyabinsk meteorite have been measured at UV–Vis–NIR wavelengths (0.25–3.2 μm) by utilizing the University of Helsinki integrating-sphere spectrometer. X-ray microtomography images of the three lithologies have been taken in the University of Helsinki X-ray Microtomography laboratory. The light-colored lithology has the highest reflectance and shows broad absorption bands of olivine and pyroxene near 1.0 and 2.0 μm. The dark-colored lithology has a flat spectrum with diminished intensity. The spectrum of the impact-melt lithology is somewhere between the spectra of the light-colored and dark-colored lithologies [2]. The differences in the spectra are caused by different patterns of iron and iron sulfides in the samples that can be seen in the X-ray microtomography and scanning electron microscope images. We utilize the new light-scattering code to model the effects of iron and iron sulfides in the spectra of the three lithologies of the Chelyabinsk meteorite by entering the physical properties, such as refractive indices, of the three lithologies as input parameters for the computations.

This research is funded by the ERC Advanced Grant No. 320773 (SAEMPL).

References

1. K. Muinonen K. et al. (2009) *JQSRT* **110**, 1628–1639.
2. T. Kohout et al. (2014) *Icarus* **228**, 78–85.

Preferred mode of presentation: Oral

Combination between in situ and remote-sensing measurements of tropospheric aerosols

J. Vanderlei Martins[a,b,*], R. Fernandez-Borda[b], Brent McBride[a,b], W. Reid Espinosa[a,b], and Lorraine A. Remer[b]

[a]*University of Maryland Baltimore County, Department of Physics, 1000 Hilltop Circle, Baltimore, MD 21250, USA*
[b]*Joint Center for Earth Systems and Technology – UMBC and NASA Goddard Space Flight Center, 5523 Research Park Dr., Baltimore, MD 21228, USA*

[*]*Presenting author (martins@umbc.edu)*

Satellite remote sensing is essential to give us a global picture of Earth's aerosol and cloud system but there are important limitations on what can be currently achieved with remote measurements. An important way to address this issue is the combination between in situ (laboratory, ground based, or airborne measurements) and satellite measurements which can be synergistic and complementary in many different ways. In this presentation we will summarize the combination of multiangle/multispectral polarized remote sensing measurements to be performed with the soon be launched (June/2017) HARP microsatellite (and the Air-HARP airborne sensor), the in situ characterization of aerosols performed by the UMBC polarized imaging nephelometers (PI-Neph and Open INeph), and other detailed in situ measurements including aerosol absorption, composition and size distributions. An important limitation of the remote sensing measurements resides in the determination of the aerosol composition, which can be performed in situ by multiple measurement techniques but so far, cannot be measured directly via remote sensing. As part of this presentation we will discuss different ways by which remote sensing can be used to approach the composition of the measured aerosol particles.

Preferred mode of presentation: Oral

Rayleigh scattering and the internal coupling parameter for arbitrary particle shapes

Justin B. Maughan*, Amitabha Chakrabarti, and Christopher M. Sorensen

Department of Physics, Kansas State University, Manhattan, KS 66506, USA

**Presenting author (maughan@phys.ksu.edu)*

Although analytical solutions for Rayleigh scattering exist for spheres and ellipsoids, analytical solutions for more complicated shapes do not exist. A general method for calculating the Rayleigh scattering by a particle of arbitrary shape using the discrete dipole approximation (DDA) is introduced. We find that in general the Rayleigh differential cross section goes as $k^4V^2|\alpha(m)|^2$ where $k = 2\pi/\lambda$ and λ is the wavelength, V is the volume of the particle and $\alpha(m)$ is the average volume polarizability which is dependent on the shape and the complex index of refraction, m. We use DDA to calculate the differential scattering cross section divided by k^4 and plot it vs V^2 to determine $|\alpha(m)|^2$. Furthermore, we show that this leads to a general description of the internal coupling parameter $\rho'_{\mathrm{arbitrary}} = 2\pi k \frac{V}{A}|\alpha(m)|$, where A is the average projected area of the particle in the direction of incident light. It is shown that this general method improves the analysis of scattering by particles of any size and shape.

Preferred mode of presentation: Oral

Hyper-angular polarimetric measurements of aerosols and clouds with the Hyper-Angular Rainbow Polarimeter (HARP)

Brent A. McBride[a,b,*], J. Vanderlei Martins[a,b], Roberto Fernandez-Borda[b]

[a]*University of Maryland, Baltimore County 1000 Hilltop Circle, Baltimore, MD 21250, USA*
[b]*Joint Center for Earth Systems Technology, 5523 Research Park Drive, Suite #320, Baltimore, MD 21228, USA*

[*]*Presenting author (mcbride1@umbc.edu)*

The Laboratory for Aerosols, Clouds, and Optics (LACO) at the University of Maryland, Baltimore County (UMBC) presents the Hyper-Angular Rainbow Polarimeter (HARP), a wide-FOV imaging polarimeter capable of performing highly accurate retrievals of cloud and aerosol microphysical properties from space. The HARP instrument will fly in a 3U CubeSat with 3-axis stabilization, maintaining a nadir pointing view along its inclined International Space Station (ISS) orbit (57° inclination, approximately 425 km). HARP has four polarized wavelengths (0.44, 0.55, 0.67, and 0.87 μm) with up to 20 unique, along-track viewing angles that span a ±47° cross-track and ±55° along-track FOV. The hyper-angular capability allows for 60 individual viewing angles at 0.67μm, providing the sampling of cloud parameters at higher angular and spatial resolution than POLDER (CNES). To achieve these wide-FOV measurements, the HARP design is a refractive system: a partially-polarizing prism redirects incident light into three unique, linearly polarized detector arrays. In this way, three polarization states can be imaged simultaneously with no moving parts. These advances aim to maximize the accuracy in retrieving cloud droplet effective radius and variance from polarized cloudbow measurements, and position the HARP instrument as a precursor to the multi-angle imaging polarimeter required for the upcoming NASA Aerosols, Clouds, and Ecosystems (ACE) mission.

The HARP CubeSat will launch in June 2017 for a mission lifetime of up to one year. The inclined orbit of HARP CubeSat will allow for co-incident measurements over AERONET ground stations and under NASA EOS satellites for both land and ocean targets. The HARP suite, including the AirHARP sub-orbital platform, will serve a vital role in validating and refining radiometer microphysical retrievals of clouds and aerosols. The AirHARP instrument is currently scheduled for flight campaigns aboard the NASA ER-2 in Spring and Fall 2017. This presentation will discuss current developments and testing in the HARP program, including polarimetric calibration and accuracy of the HARP instrument, microphysical data processing framework for clouds and aerosol through Level 2, and preliminary cloudbow retrievals from the Passive Aerosol and Cloud Suite (PACS) instrument, the HARP proof-of-concept imaging polarimeter that took part in the NASA PODEX campaign in 2013.

This project is funded by the NASA Earth Science Technology Office (ESTO) INVest program, with involvement from the Space Dynamics Laboratory (SDL) at Utah State University, Science and Technology Corporation (STC), and NASA Goddard Space Flight Center (GSFC).

Preferred mode of presentation: Poster

Light scattering studies at the El Paso del Norte Region in Texas

Richard Medina

Center for Atmospheric Sciences, Meteorology, Societal Impacts, and Environment (CAMSIE), Howard University Research Building One, Howard University, 1840 7th Street, NW, Suite 30, Washington, DC 20001, USA (richard.medinacalde@howard.edu)

The light scattering properties of atmospheric particles in the El Paso del Norte airshed were analyzed using both experimental data from an acoustic extinctiometer and a non-spherical mathematical model for polydispersed and random oriented particles in a medium with daily mean relative humidity less than 20% to avoid effects from hygroscopic growth. The model utilized is the T-matrix model which was extensively validated in many works made before to all types of aerosol geometries. In this particular study, the geometry of the particles were assumed to be spheroids which follows a lognormal distribution. The aerosol mass concentration for the airshed was considered as a mixture of particles with different refractive indexes where mineral dust and soot were the most predominant species in the region. A representative refractive index of this aerosol mixture was calculated by using the volume weighted method.

Finally, the comparison of both the extinction and scattering coefficients from the T-matrix and from the acoustic extinctiometer was made to the wavelength of 870 nm. Also, the single scattering albedo is analyzed from measurements and from the T-matrix to determine the concentration of scattering particles in the airshed. The results of this study will be used as a starting point of a new methodology of calculating scattering properties of aerosols by using a particle counter and a nonspherical light scattering model.

Preferred mode of presentation: Oral

Satellite mission Aerosol-UA for atmosphere aerosol study

Gennadii P. Milinevskyi[a,b,*], Yaroslav S. Yatskiv[b], Ivan I. Syniavskyi[b], Andrii P. Bovchaliuk[b], Oleksandr V. Degtyaryov[c], Mikhail G. Sosonkin[b], Michael I. Mishchenko[d], Vira K. Rosenbush[b], Vassyl O. Danylevsky[a], Yury S. Ivanov[b], Yevgeny A. Oberemok[a], Volodymyr M. Masley[c], and Sergii I. Moskalev[c]

[a]*Taras Shevchenko National University of Kyiv, 64/13 Volodymyrska Str., 01601 Kyiv, Ukraine*
[b]*Main Astronomical Observatory of the National Academy of Sciences of Ukraine, 27 Zabolotnoho Str., 03143 Kyiv, Ukraine*
[c]*Yangel Yuzhnoye State Design Office of the State Space Agency of Ukraine, 3 Krivorozhskaya Str., 49008 Dnipro, Ukraine*
[d]*NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA*

**Presenting author (genmilinevsky@gmail.com)*

The Ukrainian space experiment Aerosol-UA for the study of the terrestrial atmospheric aerosol spatial distribution and microphysics to quantify the aerosol contribution to the climate change is discussed. The aerosol remote sensing concept of the experiment is based on precise orbital measurements of the sunlight intensity and polarization scattered by the atmosphere, aerosol, and the surface by the Scanning Polarimeter (ScanPol) accompanied by the wide-angle MultiSpectral Imager-Polarimeter (MSIP). The ScanPol is designed to measure the Stokes parameters I, Q, and U within the spectral range from the UV to the SWIR in a wide range of phase angles (doi:10.1016/j.actaastro.2016.02.027). The expected ScanPol polarimetric accuracy is ~0.15%. The spectral channels of the ScanPol are used to estimate the tropospheric aerosol absorption, the aerosol over the ocean and the land surface, the signals from cirrus clouds, stratospheric aerosols caused by major volcanic eruptions, and the contribution of the Earth's surface. The imager-polarimeter MSIP will collect images on the state of the atmosphere and surface in the areas surrounding the ScanPol pixels to retrieve aerosol optical depth and polarization properties of aerosol by registration of three Stokes parameters simultaneously in three spectral channels. The main feature of the MSIP channels is the splitting of the image by a special prism-splitter into four images on the same image detector in each channel. In that way we can simultaneously measure four polarization components at 0°, 45°, 90°, and 135° as images in each of three polarization channels. One of the special features of ScanPol/MSIP concept is the calibration of the MSIP using ScanPol data in the same field-of-view with a ~1% expected polarization accuracy. The Aerosol-UA experiment is planned to be launched at the new satellite platform YuzhSat developed in DO Yuzhnoye.

Mode of presentation: Invited

Polarization-dependent optical scatter from multi-particle aerosol samples

Adam B. Milstein[a,*], Jonathan M. Richardson[a], Robert E. Martinez[a], Joseph J. Lacirignola[a], and Richard G. Vanderbeek[b]

[a]*MIT Lincoln Laboratory, 244 Wood St., Lexington, MA, 02420*
[b]*Edgewood Chemical and Biological Center, Bldg. E5560, APG-EA, MD*

[*]*Presenting author (milstein@ll.mit.edu)*

We have developed an instrument for measuring angle-resolved polarization-dependent optical scatter from polydisperse aerosol samples from 2° of direct backscatter to 10° of forward at a range of wavelengths spanning UV to MWIR. The primary goal of these measurements was in support of remote bioaerosol detection efforts; however, the method is applicable to environmental sensing as well. Our instrument resolved the full Mueller scattering matrix at each scattering angle with high fidelity. Calibration using targets and measurement of the aerosol particle concentration provided absolute cross sections as well. The absolute cross section and Mueller matrices were compared with model predictions (Milstein and Richardson, *JQSRT* **151**, 110, 2015). This presentation will describe our approach and detail the results of several measurement campaigns that span the ultraviolet, near infrared, and mid-wave infrared.

This material is sponsored by Edgewood Chemical and Biological Center under Air Force Contract No. FA8721-05-C-0002 and/or FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the U.S. Air Force.

Preferred mode of presentation: Oral

Large and small particle limits of single scattering albedo for homogeneous, spherical particles

Hans Moosmüller[a,*] and Christopher M. Sorensen[b]

[a]*Laboratory for Aerosol Science, Spectroscopy, and Optics, Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512, USA*
[b]*Department* of *Physics, Kansas State University, 325A Cardwell Hall, Manhattan, KS 66506, USA*

[*]*Presenting author (hansm@dri.edu)*

The aerosol single scattering albedo (SSA) is the dominant intensive particle parameters determining the aerosols radiative forcing in the earth's atmosphere. Here, we use Mie theory to examine the behavior of SSA as a function of size parameter x and complex refractive index m for homogeneous spherical particles. We focus on the limiting cases of the small particle limit ($x \ll 1$) and the large particle limit ($x \gg 1$), where we compare Mie theory with Rayleigh and geometric optics plus diffraction approximations. We show how the SSA in the small particle limit depends on size parameter x and complex refractive m and in the large particle limit on m and how Mie theory results converge to Rayleigh and geometric optics plus diffraction approximations.

Preferred mode of presentation: Oral

Light scattering in planetary regoliths: numerical solution

Karri Muinonen[a,b,*], Johannes Markkanen[a], Timo Väisänen[a], and Antti Penttilä[a]

[a]*Department of Physics, Gustaf Hällströmin katu 2a, FI-00014 University of Helsinki, Finland*
[b]*Finnish Geospatial Research Institute FGI, Geodeetinrinne 2, FI-02430 Masala, Finland*

[*]*Presenting author (karri.muinonen@helsinki.fi)*

UV-Vis-NIR spectra of small Solar System objects show varying trends and absorption bands due to, for example, olivine and pyroxene minerals, as well as carbon and iron compounds. In photometry and polarimetry, two striking phenomena are observed at small solar phase angles (the Sun–Object–Observer angle). First, a nonlinear increase of brightness is observed towards zero phase in the magnitude scale (the opposition effect). Second, the scattered light is observed to be partially linearly polarized parallel to the Sun–Object–Observer plane (the negative polarization surge).

Light scattering in a macroscopic particulate medium composed of microscopic particles constitutes an open problem in electromagnetics, resulting in the absence of quantitative inverse methods to interprete astronomical observations of Solar System objects. We report an unprecedented advance in the theoretical understanding of scattering by macroscopic particulate media. We distribute open software for the computation of UV-Vis-NIR spectra as well as photometric and polarimetric characteristics.

We have generalized the numerical method of radiative transfer and coherent backscattering (RT–CB, [1,2]) for dense discrete random media of scattering and absorbing particles [3,4]. Generalizing the approach followed in [5], we incorporate, into the RT–CB, incoherent extinction, scattering, and absorption properties of a volume element. That allows us to remove shortcomings due to the assumption of independent scattering in a sparse random medium. In its most general order-of-scattering form entitled R^2T^2 (radiative transfer with reciprocal transactions [5]), interactions among the volume elements are computed exactly using FaSTMM, the fast superposition *T*-matrix method [6]. We have developed software for both RT–CB entailing incoherent interactions as well as R^2T^2. Finally, we have generalized the open-source SIRIS geometric-optics software for specular and diffuse interactions [7–9] to incorporate incoherent volume-element scattering and absorption input. The numerical methods have been validated through a comparison to large systems of scatterers treated with the exact FaSTMM method.

Our modeling framework allows for a quantitative end-to-end analysis spanning from modeling the single-particle scattering measurements to modeling multiple scattering in macroscopic media of particles (e.g., planetary regoliths). We point out that the modeling framework is already utilized for analyzing space-weathering effects [8] and meteorite spectrometry [9], as well as in modeling multiple scattering by high-albedo planetary-regolith analog samples of silica spheres measured in the laboratory [4].

This research is supported, in part, by the ERC Advanced Grant 320773.

References

1. K. Muinonen (2004) *Waves Random Media* **14**, 365–388.
2. K. Muinonen et al. (2012) *ApJ* **760**, 118.
3. K. Muinonen et al. (2016) In: *Electromagnetic Theory Symposium* (Espoo, Finland).
4. T. Väisänen et al., this meeting.
5. L. M. Zurk et al. (1995) *J. Opt. Soc. Am. A* **12**, 1772–1781.
6. J. Markkanen and A. J. Yuffa (2017) *JQSRT*, in press.
7. K. Muinonen et al. (2009) *JQSRT* **110**, 1628–1639.
8. J. Markkanen et al., this meeting.
9. J. Martikainen et al., this meeting.

Scattering by mm-sized cosmic dust grains

Olga Muñoz[a,*], Fernando Moreno[a], Daniel Guirado[a], Jesús Escobar-Cerezo[a], and Joop W. Hovenier[b]

[a]*Instituto de Astrofísica de Andalucía, CSIC, Glorieta de la Astronomía sn, Granada 18080, Spain*
[b]*Astronomical Institute "Anton Pannekoek", University of Amsterdam, Science Park 904, 1098 XH, Amsterdam, The Netherlands*

[*]*Presenting author (olga@iaa.es)*

Dust particles are ubiquitous in many different astrophysical bodies ranging from planetary and cometary atmospheres, zodiacal clouds, planetary rings to debris disks and protoplanetary systems. The ways those small particles scatter and absorb stellar light affect the thermal structure of the body under study and subsequently their chemistry and dynamical properties. Therefore, optical characterization of such dust particles are mandatory for any radiative transfer modelling. Dust grains in planetary atmospheres (Tomasko et al., *JGR* 1999; Wolff et al., *Icarus* 2010), debris and protoplanetary disks (e.g., Stolker et al., *A&Ap* 2016) usually produce strong forward scattering. This scattering behavior indicates the presence of dust particles with sizes ranging from sub-micron up to tens of microns. This is in agreement with experimental phase functions of cosmic dust analogues (Volten et al., *A&Ap* 2007; Muñoz et al., *Icarus* 2011; Dabrowska et al., *Icarus* 2015).

In contrast, dust orbiting Fomalhaut one of the closest main sequence stars, scatter most of the light in the backward direction (Kalas et al., *Nature* 2005; Le Bouquin et al., *A&Ap* 2009). Previous studies indicate that this anomalous scattering behavior could be caused by the presence of very large grains ($r > 100$ μm) at Fomalhaut dust ring (Min et al., *A&Ap* 2010). However, it is not clear how large those grains should be to reproduce the observational data.

In this work we present experimental phase functions of three types of mm-sized grains consisting of enstatite, quartz, and volcanic material from Mount Etna, respectively. The measurements have been obtained at 520 nm covering a scattering angle range from 3° to 170°.

Preferred mode of presentation: Oral

Polarimetric observations of comet 67P/Churyumov–Gerasimenko and preliminary modelling results

R. Nežič[a,b,*], L. Kolokolova[c], S. Bagnulo[a], G. Borisov[a], A. Stinson[a], C. Snodgrass[d], H. Böhnhardt[e], G. H. Jones[b,f], J. Licandro[g], and J. de León[g]

[a]*Armagh Observatory and Planetarium, College Hill, Armagh, BT61 9DT, UK*
[b]*Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking, Surrey RH5 6NT, UK*
[c]*Department of Astronomy, University of Maryland, College Park, MD 20742, USA*
[d]*Planetary and Space Sciences, School of Physical Sciences, The Open University, Milton Keynes, MK7 6AA, UK*
[e]*Max-Planck Institute for Solar System Research, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany*
[f]*The Centre for Planetary Sciences at UCL/Birkbeck, Gower Street, London WC1E 6BT, UK*
[g]*Instituto de Astrofísica de Canarias (IAC), C/vía Láctea s/n, 38205, La Laguna, Spain*

[*]*Presenting author (ron@arm.ac.uk)*

We present our results from the extensive ground-based observing campaign of comet 67P/Churyumov–Gerasimenko, performed in parallel with the main phase of ESA's Rosetta mission. The main source of our data was the FORS (FOcal Reducer/low dispersion Spectrograph) instrument installed at the 8 m Unit 1 Antu of the ESO's Very Large Telescope. We used FORS in imaging, imaging polarimetric and spectropolarimetric mode between January 10 and 12, 2016 (phase angle θ = 27°–26°), on February 4 (θ = 19°) and 16 (θ = 13°), and on March 4 (θ = 6°). We also obtained imaging polarimetric maps with the ISIS (Intermediate dispersion Spectrograph and Imaging System) instrument, and intensity and colour maps with the ACAM (auxiliary-port camera) instrument of the 4.2 m William Herschel Telescope, extending the observed phase-angle range to the interval between 31° and 4°. We show the polarimetric phase curve, as well as polarimetric and colour maps obtained along the comet's orbital track. We compare our data of 67P with those of other comets, and report on preliminary results of our modelling efforts. The dust particles in the coma and tail of the comet have been modelled as fluffy aggregates of sub-micron spherical monomers. This follows the ballistic cluster-cluster aggregate and ballistic particle-cluster aggregate models of dust particle formation. To model light scattering properties of multi-sphere aggregates, we use Multi-Sphere *T*-matrix Method (MSTM) developed by Mackowski and Mischenko (*JOSA A* **13**, 2266–2278, 1996).

Preferred mode of presentation: Oral

Angle scanning spectropolarimetry of particle deposits

Sahar A. Nouri[a,*], Kirk Fuller[b], Don A. Gregory[a], and Adam Smith[a,c]

[a]*Physics Dept., University of Alabama in Huntsville, Huntsville, AL 35899*
[b]*120 Vinewood Ln, Madison AL 35758*
[c]*Polaris Sensors, 200 West Side Square, #320 Huntsville, AL 35801*

[*]*Presenting author (sn0020@uah.edu)*

A fixed-angle spectropolarimeter capable of determining the Mueller matrix elements of light scattered from particle deposits (and standard optical elements) over the 300–1100 nm spectral range has been built, calibrated and extensively used. A second generation of this instrument is under development which will provide the capability to scan from 0° to 360°, enabling measurements of the bidirectional Mueller matrices of nanoparticle arrays, atmospheric aerosol deposits, and nano- and microstructured surfaces. This system also provides a metrology capability for fully characterizing the performance of optical devices and device components from the near-infrared through the medium wave ultraviolet. Novel findings from the fixed-angle system will be presented along with preliminary angle-scanning measurements for Au nanoparticle deposits.

Preferred mode of presentation: Oral (or Poster)

Towards more realistic generation of numerical soot aggregates with particle overlapping

Gizem Okyay* **and Franck Enguehard**

Laboratoire d'Energétique Moléculaire et Macroscopique, Combustion (EM2C), CNRS, CentraleSupélec, Université Paris-Saclay, France

**Presenting author (gizem.okyay@centralesupelec.fr)*

Light scattering properties of combustion soot and atmospheric particles were simulated by electromagnetic theory using different approaches such as T-matrix, DDA, GMM [1,2]. For those numerical simulations, morphologies were simulated using fractal theory, cluster aggregation algorithms and other virtual geometries which were often verified by microscopy images [1,3]. Nevertheless, electron tomography can provide even more realistic complex morphology [4]. Hence, DDA simulations were presented previously for 3D tomography of in-flame soot from propane combustion, compared with numerical aggregates of touching spheres [5] based on the methods given in literature [3]. In this study, our fractal aggregate numerical generation is improved by combining tomography information with DDA solutions: an overlapping coefficient is introduced for soot primary particles. This consists of an iterative correction between the overlapping coefficient, the aggregate equivalent volume, the total number of particles, and their radiative properties [6]. The absorption and scattering properties are computed using our in-house DDA tool. The improvement of numerical generation is evidenced by DDA solutions, because the final radiative spectra of improved numerical soot coincides exactly with the ones of the tomography soot in the near and mid-IR. This is an important outcome, first, because the validity conditions of the mass density autocorrelation for soot are somewhat proved by their radiative properties; and second, because the particle overlapping will lead to an overall increase of the extinction over the thermal radiation spectra for combustion systems of gaseous mixtures [6]. In the future, studies are to be complemented using different fuel and burning conditions. The findings shall also contribute to in-situ optical diagnostics of soot.

This study is supported by the Air Liquide, CentraleSupélec and CNRS Chair on oxycombustion and heat transfer for energy and environment and by the OXYTEC project, grant ANR-12-CHIN-0001 of the French Agence Nationale de la Recherche.

References

1. Mishchenko, M. I., Liu, L. and Mackowski, D. W. (2013). T-matrix modeling of linear depolarization by morphologically complex soot and soot-containing aerosols. *J. Quant. Spectrosc. Radiat. Transfer* **123**, 135–144.
2. Michelsen, H. A. Probing soot formation, chemical and physical evolution, and oxidation: A review of in situ diagnostic techniques and needs. *P. Combust. Inst*. (in press).
3. Mackowski, D. W. (2006). A simplified model to predict the effects of aggregation on the absorption properties of soot particles. *J. Quant. Spectrosc. Radiat. Transfer* **100**, 237–249.
4. Okyay, G., Héripré, E., Reiss, T., Haghi-Ashtiani, P., Auger, T., and Enguehard, F. (2016). Soot aggregate complex morphology: 3D geometry reconstruction by SEM tomography applied on soot issued from propane combustion. *J. Aerosol Sci*. **93**, 63–79.
5. Okyay, G., Enguehard, F., and Joumani, Y. (2015). Study of the effect of soot aggregation on thermal radiation: application of DDA on 3D combustion soot obtained by SEM tomography. In *ELS XV* (Leipzig).
6. Okyay, G. (2016). Impact of the morphology of soot aggregates on their radiative properties and the subsequent radiative heat transfer through sooty gaseous mixtures. PhD dissertation, CentraleSupélec, Université Paris Saclay.

Preferred mode of presentation: Oral (or poster)

Radiative properties of in-flame sooty aggregates from fire scenarios of polymer burning

Gizem Okyay*, Séverine Bellayer, Maude Jimenez, Fabienne Samyn, and Serge Bourbigot

Univ. Lille, ENSCL, UMR 8207, UMET, Unité Matériaux et Transformations, F59 000 Lille, France

**Presenting author (gizem.okyay@univ-lille1.fr)*

Light scattering properties of airborne particles are extensively simulated for atmospheric and combustion research in the literature [1,2]. Remembering that the thermal radiation can be considered as non-polarized electromagnetic waves, the electromagnetic theory is used to compute the thermal radiation interaction with groups of complex shaped objects. One of the numerical methods to solve this interaction is based on the discrete dipole approximation (DDA) theory. The radiative properties of nano- and micrometer-sized systems of multiparticles, such as soot aggregates, can be computed by the DDA. The application of the DDA to the radiative properties of 3D tomography of soot from controlled combustion were previously presented [3]. In this study a novel domain of application will be presented: the radiative properties are computed for sooty aggregates extracted from fire scenarios of burning of polymeric materials. Polymeric specimens, formulated as fire resistant/retardant, are ignited with external radiative heating. Aggregates are extracted on TEM grids from fire scenarios. The complex geometries of aggregates and the chemical compositions (such as internal mixing with elements other than black carbon and external coating [4]) are investigated using electron microscopy facilities. Then, the extinction properties are investigated accordingly by means of subsequent numerical simulations using the DDA theory. The resulting properties will be discussed to understand the impact of the complex agglomerates on the generated heat, flame radiation, and on the chemical decomposition pathway of our polymeric specimens during fire scenarios at laboratory scale. The findings are also expected to contribute to atmospheric soot data and aerosol optics from fire emissions.

This work has received funding from the European Research Council (ERC) under the European Union's H2020 – the Framework programme for Research and Innovation (2014-2020) / ERC Grant Advances Agreement n°670747 – ERC 2014 AdG/FireBar-Concept. It has benefited from the research facilities of University of Lille: Centre Commun de Microscopie and HPC cluster of CRI. Johan Sarazin and Benjamin Dewailly are acknowledged for their technical assistance on the specimen preparations for fire tests.

References

1. M. I. Mishchenko, L. Liu, and D. W. Mackowski (2013). T-matrix modeling of linear depolarization by morphologically complex soot and soot-containing aerosols. *JQSRT* **123**, 135–144.
2. H. A. Michelsen. Probing soot formation, chemical and physical evolution, and oxidation: a review of in situ diagnostic techniques and needs. *P. Combust. Inst*. (in press).
3. G. Okyay, F. Enguehard, and Y. Joumani (2015). Study of the effect of soot aggregation on thermal radiation: application of DDA on 3D combustion soot obtained by SEM tomography. In: *ELS-XV* (Leipzig).
4. G. Okyay et al. (2017). Physical characterization of carbonaceous products from fire and fire retardants: assessment of the impact on fire performance. In: *Fire and Materials* (San Francisco, accepted).

Preferred mode of presentation: Poster

Simultaneous measurement of elastic back-scattering pattern and image from laser-trapped single airborne particles

Yong-Le Pan,[a,*] Richard Fu,[a] Gorden Videen,[a] Chuji Wang,[b] and Joshua L. Santarpia[c]

[a]*Army Research Laboratory, 2800 Powder Mill Road, Adelphi, MD 20783, USA*
[b]*Department of Physics and Astronomy, Mississippi State University, Starkville, MS 39759, USA*
[c]*Sandia National Laboratories, Albuquerque, NM 87123, USA*

[*]*Presenting author (yongle.pan.civ@mail.mil)*

We demonstrate a method that can simultaneously measure the elastic back-scattering patterns and images of laser-trapped, single airborne particles. This arrangement allows us to observe how the back-scattering patterns change with particle size, shape, surface roughness, orientation, etc. The recorded scattering patterns cover the angular ranges of θ = 167°–180° (including at 180° exactly) and ϕ = 0°–360° in spherical coordinates. The patterns show that the width of the average speckle intensity islands or rings is inversely proportional to particle size and how the shape of these intensity rings or islands depends on the surface roughness. For an irregularly shaped particle with substantial roughness, the back-scattering patterns are formed with speckle intensity islands, the size and orientations of these islands depend more on the overall particle size and orientation, but have less relevance to the fine alteration of the surface structure and shapes. The back-scattering intensity at 180° is found to be very sensitive to the particle parameters. It can change from a maximum to a minimum with a change of 0.1% in particle size or refractive index. The method has potential use in characterizing airborne aerosol particles in arbitrary shapes, and could be used to provide back-scattering information for LIDAR applications.

Optical properties of core–mantle grains with ices as mantle

C. V. Pandya[a,*], Umangi Prajapati [b,*], and D. B. Vaidya[c,*]

[a]*M. G. Science Institute, Navarangpura, Ahmedabad 380009, India*
[b]*G/1 Mahabaleshwar flats, Opp. Rathi Hospital, Jodhpur Village, Satellite Road, Ahmedabad 380015, India*
[c]*Physics Department, Gujarat Arts and Science College, Ellisbridge, Ahmedabad 380006, India*

[*]*Presenting authors (cvpandya@gmail.com, prajapatiumangi91@gmail.com, dipak.vaidya@gmail.com)*

We calculate the absorption cross sections of core–mantle grains in the spectral range between 1.0 – 10 μm. The core–mantle grains consist of spherical silicate cores and ice mantles (i.e., H_2O/or carbon dioxide CO_2/or methane CH_4/or ammonia NH_3). We study the variation in the absorption profiles of the silicate grains with the mantle thickness of ices. In particular, we study the variation in the peak absorption wavelength(e.g., ~3.1 μm, for H_2O) with the mantle thickness, for various ices. We find that the absorption profiles of silicate grains are modified considerably with the ice mantles, and the absorption peaks also vary with the mantle thickness. We have also studied the absorption properties of the porous silicate grains. These results on the core–mantle grain models with ices as mantles would help to understand better the composition of the interstellar dust, circumstellar dust, cometary dust and the dust in the solar system objects. We have used optical constants for silicate given by Drain (2003) and for ices the optical constants are used from Huddings et al. (1993). We present the core–mantle grain model and discuss the results.

Preferred mode of presentation: Poster

On the stopping time for time-domain exact simulations of single particle interactions with Gaussian optical pulse

R. Lee Panetta*, Siyao Zhai, and Ping Yang

Department of Atmospheric Sciences, Texas A&M University, College Station, TX 77843, USA

**Presenting author (panetta@tamu.edu)*

Numerical simulation of the single-scattering optical properties of particles plays a fundamental role in development of algorithms used in the interpretation of satellite observations of light scattered by atmospheric aerosols and for radiative transfer calculations in atmospheric or climate models. When particle sizes are comparable to the wavelength(s) of interest in the radiation field, the most reliable single-scattering simulations involve what is called an "exact" method, one directly based on some form of Maxwell's equations. The simulations are cpu intensive if the size parameter of the particle much exceeds 100, and the issue of when a simulation may be stopped gains practical significance. A convergence test of some sort is applied, in which reliance is typically put on the convergence being monotonic. In many cases, however, the nature of convergence is in fact unknown. We consider convergence for one kind of commonly used time-domain numerical experiment: an optical pulse is directed towards and interacts with a particle. The simulation is stopped when the interaction is judged to be complete. Information gathered during this CPU-intensive simulation is then subjected to a less expensive near-to-far-field transformation to get the optical scattering properties. Here "completion" means field convergence outside the particle to a one of negligible amplitude. In this talk we show numerical evidence that the convergence in such an experiment can fail to be monotonic: the ultimate decay of amplitude in the near-particle electric field is punctuated by intermittent bursts of amplitude resurgence. We discuss the relation between these bursts and a form of trapping of the electric field that is excited as the pulse passes through the particle, as well as implications for determination of stopping time for such simulations.

Preferred mode of presentation: Oral

Characterizing atmospheric aerosol: comparative analysis of active and passive techniques

Andrey N. Pavlov[a,b], Konstantin A. Shmirko[a,b], and Evgenij Zubko[b,*]

[a]*Institute of Automation and Control Processes of the Russian Academy of Sciences, 5 Radio Str., 690041 Vladivostok, Russia*
[b]*School of Natural Sciences, Far Eastern Federal University, 8 Sukhanova Str., 690950 Vladivostok, Russia*

[*]*Presenting author (evgenij.s.zubko@gmail.com)*

Studying atmospheric aerosols is performed predominantly with active remote sensing techniques, wherein the retrieval of physical and chemical properties is based on analyses of light-scattering response from aerosol particles illuminated by a laser beam. This approach, however, suffers from two important shortcomings: (1) the geometry of light scattering is always limited to the regime of exact backscattering, and (2) the light-scattering response is measured at a few wavelengths only (two or three). In practice, this implies a limited amount of input data for the analysis and, as a consequence, loose constraints on physical and chemical properties of aerosols. These issues can be avoided in passive remote sensing that is based on analyses of sunlight scattering that makes it possible, for instance, to vary the scattering angle. Also, in passive remote sensing, one can exploit the degree of linear polarization, the light-scattering characteristic that has been demonstrated in numerous studies to be one of the most sensitive to properties of target particles. In this talk we discuss our measurements of atmospheric aerosols over Vladivostok (Russia) conducted simultaneously in the active mode (with a three-wavelength lidar) and the passive mode (a polarimeter with a wideband red filter). We compare characteristics of atmospheric aerosols obtained with these two techniques and demonstrate that both retrievals are consistent with one another. However, the aerosol characteristics retrieved with the polarimetry appear noticeably better constrained and, thus, the passive remote sensing suffers from much less uncertainty.

Preferred mode of presentation: Oral

Experimental light scattering by small particles: first results with a novel Mueller matrix scatterometer

A. Penttilä[a], G. Maconi[a], I. Kassamakov[a], M. Gritsevich[a], E. Hæggström[a], and K. Muinonen[a,b,*]

[a]*Department of Physics, P.O.Box 64, 00014 University of Helsinki, Finland*
[b]*Finnish Geospatial Research Institute FGI, Geodeetinrinne 2, 02430 Masala, Finland*

[*]*Presenting author (karri.muinonen@helsinki.fi)*

We describe a novel setup designed for measuring the full angular Mueller matrix profile of a single mm- to µm-sized sample, and verify the experimental results against a theoretical model. The scatterometer has a fixed or levitating sample, illuminated with a laser beam whose full polarization state is controlled. The scattered light is detected with a wave retarder-linear polarizer-photomultiplier tube combination that is attached to a rotation stage, to allow measuring the full angular profile, with the exception of the backscattering direction.

By controlling the angle of the linear polarizers and the angle of the axis of the wave retarders before and after the scatterer we record such a combination of intensities that reconstructing the full Mueller matrix of the scatterer is possible. We have obtained repeatable measurements of the calibration sample, a 5-mm sphere (N-BK7 glass, Edmund Optics).

We verify the first measurement results by comparing the angular scattering profile against the theoretical results computed using Mie theory. The profiles recorded using the linear polarizers only agree with the theoretical predictions in all scattering angles. With the linear polarizers, we are able to construct the upper left 2×2 submatrix of the full Mueller matrix. The constructed (1,1) and (2,2) elements of the matrix are almost identical, as they should for a sphere, as well as the (1,2) and (2,1) elements. There are some discrepancies, as expected, since calibration spheres are never perfectly spherical with completely homogeneous internal structure.

This research is funded by the ERC Advanced Grant No. 320773 (SAEMPL).

Preferred mode of presentation: Poster

Optical losses due to particles on solar cells: DDA-substrate calculations and experimental validation

Patricio G. Piedra*, Laura R. Llanza, and Hans Moosmüller

Laboratory for Aerosol Science, Spectroscopy, and Optics, Desert Research Institute, Nevada System of Higher Education, 2215 Raggio Parkway, Reno, NV 89512, USA

**Presenting author (patricio.piedra@dri.edu)*

The efficiency of solar panels is degraded by aerosol deposition. Experiments reveal that efficiency degradation can be significant (≳85%) depending on environmental factors. However, very little is known about the role that electromagnetic scattering and absorption play in reducing the total power received by the solar panel's semiconductor. Here, we assume solar panel orientation perpendicular to the incident solar radiation and use discrete dipole approximation with substrate interaction (DDA-substrate) to calculate the hemispheric backward scattering (HBS) cross-section of particles deposited on a substrate of refractive index 1.5 + i0 (similar to that of fused silica or glass). Calculating HBS cross-sections in addition to absorption cross-sections allow us to determine the electromagnetic power lost from propagating into the forward hemisphere direction and reaching the semiconductor. We modified the Beer–Lambert law with the condition that losses are due only to absorption and HBS. The resulting analysis shows that a parameter called the size-dependent backward extinction efficiency is appropriate to understand solar panel degradation as function of particle size and complex refractive index. In addition, we are currently performing spectrophotometric characterization of glass slides deposited with pure hematite dust to validate the use of our DDA-substrate calculations for predicting solar panel degradation. This study has the potential to help smart power grids to predict and adapt to variations in solar panel energy output due to aerosol deposition.

Preferred mode of presentation: Oral

Prediction of polarized reflection and transmission in plane parallel dense media

Bahareh Ramezan pour[*] and Daniel W. Mackowski

Department of Mechanical Engineering, Auburn University, Auburn, AL

[*]*Presenting author (bzr0011@auburn.edu)*

It is well known that the radiative transfer equation (RTE) is strictly valid only in the limit of vanishing particle volume fraction. Because of this issue, the validity of the RTE when applied to densely packed media is questionable. The objective of this work is to use a direct simulation method to assess and, if possible, modify the RTE when applied to high volume fraction conditions. The additional objective is to identify those features of polarized reflection and transmission that are most affected by particle volume fraction.

The plane parallel discrete dipole approximation method (PPDDA) is used as the exact simulation methodology for deposits of spherical, wavelength-size particles. This method is based on a DDA formulation in which a unit cell, representing the particulate medium, is repeated periodically in the lateral directions to infinity. The algorithm is implemented using FORTRAN-90 coupled with the parallel computational platform-MPI.

The adding and doubling technique is used as the solution to the RTE. In this model, the bulk coefficients of the absorbing and scattering media (the extinction coefficient, albedo, and scattering phase function) are obtained by Mie theory.

Computations are performed for the range of refractive index values including both non-absorbing and high absorbing materials. The thickness of the medium varies from one to several hundred particle diameters. The results indicate that the PPDDA and RTE predictions of the directional reflected and transmitted Stokes vectors converge when the particle volume fraction is below five percent. The effects of higher volume fraction will be discussed in more detail at the conference.

Preferred mode of presentation: Oral

Radiative transfer model for the reflectance of packed particulate media

Thomas A. Reichardt* and Thomas J. Kulp

Sandia National Laboratories, P.O. Box 969, MS 9033, Livermore, CA 94551, USA

**Presenting author (tareich@sandia.gov)*

We present a parameterized radiative transfer model to account for morphological effects on the reflectance signatures of packed particulate media. This model leverages computational tools developed within the planetary and atmospheric science communities, beginning with T-matrix and ray-tracing approaches for evaluating the scattering and extinction properties of individual particles based on their size and shape, and the complex refractive index of the material itself. These individual-particle properties then serve as input to the Ambartsumian invariant imbedding solution for the reflectance of a particulate surface composed of these particles. The inputs to the model include parameters associated with a functionalized form of the particle size distribution (PSD) as well as parameters associated with the particle packing density, surface roughness, and first-surface reflectance. The model is numerically inverted via Sandia's Dakota package, optimizing agreement between modeled and measured reflectance spectra, which we demonstrate on data acquired on ten size-selected silica powders over the 4–16 μm wavelength range. Agreements between modeled and measured reflectance spectra demonstrate a root-mean-square error of ~0.01 absolute reflectance, while the optimized PSDs resulting from the spectral fitting compare favorably to PSD data acquired from independent particle size measurements.

This research is supported by the U.S. Department of Energy (DOE) National Nuclear Security Administration (NNSA) Office on Nonproliferation and Verification Research and Development (DNN R&D). Sandia is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Company, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Preferred mode of presentation: Oral

A spectral method to characterize single spheres from light-scattering patterns

Andrey V. Romanov[a,b], Anastasiya I. Konokhova[a], Konstantin V. Gilev[a,b], Valeri P. Maltsev[a,b,c], and Maxim A. Yurkin[a,b,*]

[a]*Voevodsky Institute of Chemical Kinetics and Combustion SB RAS, Institutskaya Str. 3, 630090, Novosibirsk, Russia*
[b]*Novosibirsk State University, Pirogova Str. 2, 630090, Novosibirsk, Russia*
[c]*Novosibirsk State Medical University, Krasny Prospect 52, 630091, Novosibirsk, Russia*

[*]*Presenting author (yurkin@gmail.com)*

We report a fast method to determine the size and refractive index of homogeneous spheres from the power spectrum of their light-scattering patterns (LSPs), measured with the scanning flow cytometer. Specifically, we use two spectral parameters: the location of the non-zero peak and zero-frequency amplitude, and numerically invert the map from the space of the particle characteristics (size and refractive index) to the space of spectral parameters. The latter parameters can be reliably resolved only for particle size parameters greater than 11, and the inversion is unique only in the limited range of the relative refractive index with the upper limit between 1.1 and 1.25 depending on the size parameter and particular definition of uniqueness. The method developed was tested on two experimental samples, milk fat globules and spherized red blood cells, and resulted in accuracy not worse than the reference method based on the least-square fit of the LSP with the Mie theory. Moreover, for particles with a significant deviation from the spherical shape the spectral method was much closer to the Mie-fit result than the estimated uncertainty of the latter. The spectral method also showed adequate results for synthetic LSPs of spheroids with aspect ratios up to 1.4. We additionally tested two other spectral parameters, the absolute and relative amplitudes of the non-zero spectral peak. They performed fine on ideal data but led to large systematic shifts in the presence of even minor shape distortions. Hence, they were largely inferior to the method based on the zero-frequency amplitude in all test cases. Finally, the general framework developed can be used to construct an inversion algorithm for any other experimental signals.

Preferred mode of presentation: Oral (or Poster)

Performance of electro optical sensor in dusty environment: theory and experiment

Ayala Ronen[*] and Shmuel Elisha

IIBR, Environmental Physics Department, Ness Ziona, Reuven St. 24, 7924500, Israel

[*]*Presenting author (drronenayala@gmail.com)*

The performance of an electro-optical sensor in conditions of dusty atmosphere is altered due to extinction caused by the aerosol medium, which cause false positive and negative alarms. One way to avoid this difficulty is to test the sensor performance under controlled dusty environment in aerosol chamber.

The goal of the present study is to characterize the best practice of using aerosol chamber with varying dusty conditions, followed by theoretical analysis. The presentation will provide a detailed description of the experimental setup and a comparison of experimental results with theory.

Measurements were carried on in an in-house designed aerosol chamber discharged with various dust types, followed by real-time visibility and particle size distribution measurements.

The dusty atmosphere is emphasized by the mass extinction coefficient, which can be obtained experimentally out of the measured visibility inside the chamber and dust concentration. This value can be calculated using models of light scattering through aerosol medium, based on the measured size distribution.

Mie theory and T-Matrix method used to calculate mass extinction coefficient. A variation of ± 20% was found in the calculated values for ellipsoidal particles relative to that of spherical ones. A comparison of the calculated and measured mass extinction coefficient has shown similarity in the general behavior and tendency of measured and calculated mass extinction coefficients, although higher values were obtained for the measured coefficients. This can mainly be explained by the inherent difficulty in characterizing the dusty environment within the chamber.

In order to improve the fit of measurements and calculations, one has to enable spatial measurement of real-time size particles distribution, concentration and visibility inside the chamber. In addition, exact calculation based on the T-matrix method model will improve the agreement of calculated and measured values.

Preferred mode of presentation: Oral

Possible explanation of spatial variations of polarization and color of dust in comet 67P/Churyumov–Gerasimenko

V. Rosenbush[a,*], O. Ivanova[a,b], L. Kolokolova[c], N. Kiselev[a,d], and V. Afanasiev[e]

[a]*Main Astronomical Observatory of the National Academy of Sciences of Ukraine, 27 Zabolotnoho Str., 03143, Kyiv, Ukraine*
[b]*Astronomical Institute of the Slovak Academy of Sciences, SK-05960 Tatranská Lomnica, Slovak Republic*
[c]*University of Maryland, College Park, MD 20742, USA*
[d]*Crimean Astrophysical Observatory, Nauchnij, Crimea*
[e]*Special Astrophysical Observatory of the Russian Academy of Sciences, 369167 Nizhnij Arkhyz, Russia*

[*]*Presenting author (rosevera@mao.kiev.ua)*

The comet 67P/Churyumov–Gerasimenko was the target of the European Space Agency's Rosetta mission. As part of the ground-based support of the Rosetta mission, we carried out three sets of photometric and polarimetric observations of the comet at the 6-m telescope of the Special Astrophysical Observatory in 2015–2016. The heliocentric distance of the comet was within the range from 1.61 AU to 2.72 AU and the phase angle ranged from 33.2° to 10.4°.

The spatial distribution of the intensity, color, and linear polarization over the coma showed the following features. Two bright long-lasting jets and tail, observed from November 2015 to April 2016, have a color redder than the surrounding coma. The near-nucleus area is also redder and more polarized than the adjacent coma. These findings may be a sign of the presence of large (or more abundant in organics) particles discovered by the Rosetta mission in the near-nucleus coma. With increasing distance from the nucleus, the coma becomes bluer. The near-nucleus polarization drops sharply from ~8% near the nucleus to ~2% at 5000 km, and then gradually increases with distance, reaching ~8% at 40,000 km. In April 2016, at a phase angle about 10°, the negative polarization varied between –0.6% in the near-nucleus area and –4% in the outer coma.

The radial variations of polarization and color suggest an evolution of the particle properties, most likely, fragmentation and/or sublimation of the dust particles from sizes >100 micrometers near the nucleus to sizes ~5–10 micrometers at about 5000 km from the nucleus and even smaller at larger distances. It is likely that the "turning point", where the polarization trend changes from decreasing to increasing, can be diagnostic of the dust fragmentation rate. The values of color and polarization near the nucleus may be used to estimate the initial size of particles. A comparison of the observations with laboratory and computer modeling shows that the size of particles at which the polarization changes its trend also depends on the particle composition. In order to understand how different physical properties of the dust particles affect the behavior of color and polarization, further numerical simulations of light scattering by cometary dust particles are needed.

Preferred mode of presentation: Oral

Scattering properties of *Mycobacterium smegmatis*

Sanchita Roy[a,*], Nilakshi Barua[b], Gazi A. Ahmed[a], and Alak K. Buragohain[b]

[a]*Optoelectronics and Photonics Laboratory, Department of Physics, Tezpur University, Napaam, Tezpur-784028, Assam, India*
[b]*Department of Molecular Biology and Biotechnology, Tezpur University, Napaam, Tezpur-784028, Assam, India*

[*]*Presenting author (rsanchita1@gmail.com)*

Light scattering investigation from *Mycobacterium smegmatis* mc2 155 was carried out at wavelength of 632.8 and 543.5 nm by using an original polar and azimuth-dependent light scattering setup. *M. smegmatis* is a gram positive bacterium and holds its importance because it is considered as a model system of *Mycobacterium tuberculosis* as it possesses all the characteristics of *M. tuberculosis* except its pathogenic behaviour. The most favorable cell density to which single scattering regime could be considered was found out before carrying out experimental investigation. Simulation of light scattering of the same particles was also carried out using a novel Monte Carlo simulation technique. The closeness of agreement or disagreement between experimental, theoretical and simulated result will be presented in this talk. One point where we focused more is the divergence found between the experimental and theoretical result, which actually gives a clue that the azimuthal dependency in light scattering experiment cannot be ruled out for bio-particles like *M. smegmatis.* Experimental and simulation analyses allowed us to understand the morphology of such bio-particles in a better way, which in turn can play an important role in characterising pathogenic *M. tuberculosis*.

Preferred mode of presentation: Oral

Simulation of light scattering properties of *Pseudomonas aeruginosa*

Sanchita Roy[a,*], Nilakshi Barua[b], Gazi A. Ahmed[a], and Alak K. Buragohain[b]

[a]*Optoelectronics and Photonics Laboratory, Department of Physics, Tezpur University, Napaam, Tezpur-784028, Assam, India*
[b]*Department of Molecular Biology and Biotechnology, Tezpur University, Napaam, Tezpur-784028, Assam, India*

[*]*Presenting author (rsanchita1@gmail.com)*

Pathogenic aerosol-spread in the environment require very advanced detection system that may be able to detect and distinguish these pathogenic aerosols from non-pathogenic ones. Only experimental scattering technique may not be sufficient to provide complete information about such particles. This calls for a need to make use of theoretical approach and computer simulation for a better insight into the properties of such particles. *Pseudomonas aeruginosa* is a gram-negative rod-shaped bacterium whose length ranges from 1.5 to 3.0 micrometeres and diameter ranges from 0.5 to 0.8 micrometers. These bacteria are highly drug resistant and hold great importance in biomedical sciences. Light scattering studies by novel Monte-Carlo technique was carried out for *P. aeruginosa* bio-particles. In this paper, we present the simulated results of such bio-particles. Our results may be used for comparative analysis with experimental results of such bio-particles. This step enhances the possibility of revealing actual scattering phenomenon by *P. aeruginosa* bio-particles. The data obtained by light scattering studies and analyses points out possibility of development of bio-sensors that can be used to detect and arrest problems of pathogenic contamination of environment.

Preferred mode of presentation: Poster

GPU-based Monte Carlo simulation of radiative transfer in a cloudy atmosphere

Tatiana V. Russkova

V.E. Zuev Institute of Atmospheric Optics, SB RAS, 1, Academician Zuev sq., 634055, Tomsk, Russian Federation (btv@iao.ru)

The large amount of information provided by Earth-observing satellites and ground-based measurement stations calls for effective tools for data processing as well as for accurate and fast methods for simulating light propagation in the terrestrial atmosphere for real-time data interpretation. In atmospheric optics, the Monte Carlo method is one of the most powerful computing approaches, both due to its accuracy and flexibility in simulating light transport in complex environments (twilight, optically thick cumulus clouds, inhomogeneous and broken cloudiness, cirrus, etc.). However, the widespread use of Monte Carlo simulations is limited by their computational demand.

The development of software for supercomputers with parallel architecture applications opens new promising possibilities for mathematical modeling of radiative transfer. The vast majority of the existing radiative transfer codes are already adapted for clustered multi-processor systems. However, these are stationary, have to be constantly upgraded to support and improve the calculating efficiency; building capacities of these systems require considerable financial injections and complicated hardware settings.

Recent years have seen an increasing trend towards the transfer of scientific calculations to alternative platforms, specifically non-graphics computing on graphics processors. GPU-accelerated computing offloads compute-intensive portions of the application to the GPU (Graphics Processing Unit), while the remainder of the code still runs on the CPU (Central Processing Unit). The main advantage of GPU cards is a large number of processing cores. The current generation of GPU has enough flexible architecture; GPU cards are economical and easily replaced.

In this work, the GPU-based code for simulation of radiative transfer was developed. The solar irradiances in clear and cloudy (cumulus, stratocumulus, cirrus) atmospheres can be calculated for different altitudes of the Sun. We used CUDA-enabled (Compute Unified Device Architecture) NVIDIA processors (GeForce GTX 1080). The accelerated code was compared to the original single-threaded code. Our results show that GPU provides a substantial speedup over conventional CPUs by supporting the parallel computation of large numbers of independent radiative calculations and allows for a much higher computational performance at lower prices.

The work was supported by the Russian Foundation for Basic Research (Project No. 16-31-60057 mol_a_dk).

Preferred mode of presentation: Poster

3D Monte Carlo polarized radiative transfer model for simulation of light propagation into scattering media

Tatiana V. Russkova* **and Tatiana B. Zhuravleva**

V.E. Zuev Institute of Atmospheric Optics, SB RAS, 1, Academician Zuev sq., 634055, Tomsk, Russian Federation

**Presenting author (btv@iao.ru)*

Polarization of light arises as a result of interaction of unpolarized solar radiation with atmospheric particles. Aerosols and clouds are the primary polarizing factors in the atmosphere. Polarimetric measurements are increasingly performed from space, from the ground, and from aircraft and can be used to improve the retrieval of their optical and microphysical properties. The neglect of the state of polarization of scattered light can in turn lead to non-negligible errors. An accurate and fast polarized radiative transfer model is thus required.

The Monte Carlo codes included in the software package MATHART (Monte CArlo Codes for THree-DimensionAl Radiative Transfer) were improved through the polarization effects. Two ways of simulating the new photon direction were implemented. In the first one, the scattering angle is chosen from a scattering phase function, and an azimuthal angle is chosen uniformly between 0 and 2π to sample the scattered direction (Marchuk et al. 1980). The advantages of this approach are simplicity (the scattering phase function does not depend on the photon polarization) and the possibility to calculate polarized and unpolarized radiances simultaneously. However, this approach may lead to increasing variations of estimates of statistical simulation in non-absorbing environment. In the second approach, the scattering and azimuth angles are chosen by a 'rejection method' (Oppel et al. 1998; Ramella-Roman et al. 2005) which does not have this shortcoming.

On the basis of numerical experiments, the performance of both algorithms was analyzed. The simulations have also been tested by comparison with the International Radiation Commission (IRC) polarized radiative transfer model intercomparison benchmarks results for the Stokes parameters, both for reflected and transmitted light, in the cases of molecular, aerosol, and cloudy multiply scattering media.

This work was supported by the Russian Foundation for Basic Research (Project No. 16-31-60057 mol_a_dk).

Preferred mode of presentation: Oral

Linear polarization memory of inhomogeneous birefringent medium in visible wavelength range

Sergey Savenkov,[a*] Sanghyuk Yoo,[b] Enric Garcia Caurel,[b] Yevgen Oberemok,[a] Ivan Kolomiets,[a] Tatiana Novikova,[b] Razvigor Ossikovski,[b] and Alexander Klimov[a]

[a] *Taras Shevchenko National University of Kyiv, Radiopysics Department, Vladimirskaya str. 64, 01 033 Kiev, Ukraine*
[b] *LPICM, CNRS, Ecole Polytechnique, Universite Paris—Saclay, 91128 Palaiseau, France*

[*] *Presenting author (sns@univ.kiev.ua)*

The purpose of the paper is to provide a rigorous experimental and theoretical analysis of light scattering by an inhomogeneous linear birefringent medium considering only single scattering. The medium under consideration is an anisotropic crystalline slab with surface roughness. We measure the complete Mueller matrix of the samples as a function of the observation angle in the range of wavelength from 440 to 1000 nm. To study depolarization properties of the samples we calculated parameters characterizing depolarization of samples, i.e., the single valued depolarization metrics (depolarization index, Q(M)-metric, first and second Lorenz indices, Cloude and Lorenz entropy, purity indices) for all measured Mueller matrices.

The results show that some of the depolarization metrics (purity indices (P2, P3), Q-metrics, Lorenz entropy (HL), and Lorenz depolarization indices (L1, L2)) are almost completely insensitive to roughness. While the depolarization index and the purity index (P1) exhibit pronounced sensitivity to discontinuities, Cloud's entropy occupies an intermediate position.

It is shown that the samples under consideration show a very interesting feature, i.e., polarizing memory. For some of the input polarizations output radiation remains completely polarized. There are only two such input polarizations. And there are input polarizations for which the output radiation is completely depolarized. As it turns out, there are an infinite number of such polarizations.

Mode of presentation: Invited

A Laboratory Experiment for the Statistical Evaluation of Aerosol Retrievals (STEAR)

Gregory L. Schuster[a,*], Reed Espinosa[b], Luke D. Ziemba[a], Andreas J. Beyersdorf[c], Adriana Rocha-Lima[b,d], Bruce E. Anderson[a], Jose V. Martins[b], Oleg Dubovik[e], Fabrice Ducos[e], David Fuertes[f], Tatyana Lapyonok[e], Michael A. Shook[a,g], Yevgeny Derimian[e], and Richard H. Moore[a]

[a]*NASA Langley Research Center, Hampton, Virginia 23681, USA*
[b]*University of Maryland, Baltimore County, Baltimore, MD 21250, USA*
[c]*California State University, San Bernardino, CA 92407, USA*
[d]*NASA Goddard Space Flight Center, Greenbelt, MD, USA*
[e]*U. de Lille 1/CNRS; Villeneuve d'Ascq, France*
[f]*GRASP-SAS, LOA/Universite Lille-1, Villeneuve d'Ascq, France*
[g]*Science Systems & Applications, Inc., Hampton, VA 23666, USA*

[*]*Presenting author (gregory.l.schuster@nasa.gov)*

We have developed a method for validating Aerosol Robotic Network (AERONET) retrieval algorithms by mimicking atmospheric extinction and radiance measurements in a laboratory experiment. This enables radiometric retrievals that utilize the same sampling volumes, relative humidities, and particle size ranges as observed by other in situ instrumentation in the experiment. We utilize three Cavity Attenuated Phase Shift (CAPS) monitors for extinction and UMBC's three-wavelength Polarized Imaging Nephelometer (PI-Neph) for angular scattering measurements. We subsample the PI-Neph radiance measurements to angles that correspond to AERONET almucantar scans, with solar zenith angles ranging from 50° to 77°. These measurements are then used as input to the Generalized Retrieval of Aerosol and Surface Properties (GRASP) algorithm, which retrieves size distributions, complex refractive indices, single-scatter albedos (SSA), and lidar ratios for the in situ samples. We obtained retrievals with residuals less than 10% for ~100 samples. Samples were alternately dried or humidified, and size distributions were limited to diameters of 1.0 or 2.5 μm by using a cyclone. The SSA at 532 nm for these samples ranged from 0.59 to 1.00 when computed with CAPS extinction and PSAP absorption measurements. The GRASP retrieval provided SSAs that are highly correlated with the in situ SSAs, and the correlation coefficients ranged from 0.955 to 0.976, depending upon the simulated solar zenith angle. The GRASP SSAs exhibited an average absolute bias of +0.023 ± 0.01 with respect to the extinction and absorption measurements for the entire dataset. We also compared the GRASP size distributions to aerodynamic particle size measurements, utilizing densities and aerodynamic shape factors that produce extinctions consistent with our CAPS measurements. The GRASP effective radii are highly correlated ($R = 0.88$) and biased high of the corrected aerodynamic effective radii by 1% (for a simulated SZA of 50°). The effective variance indicated a correlation of $R = 0.72$ and a relative bias of 116%. Finally, our apparatus was not capable of measuring backscatter lidar ratios, so we measured bistatic lidar ratios at a scattering angle of 173°. The GRASP bistatic lidar ratios had correlations of 0.488 to 0.735 (depending upon simulated SZA) with respect to in situ measurements, positive relative biases of 6%–10%, and average absolute biases of 4.0–6.6 sr.

Preferred mode of presentation: Oral

Electromagnetic scattering by spheroidal particles

Jehan Seneviratne[a] and Matthew J. Berg[b,*]

[a]*Department of Physics and Astronomy, Mississippi State University, Mississippi State, MS 39762, USA*
[b]*Department of Physics, Kansas State University, Manhattan, KS 66506, USA*

[*]*Presenting author (jas919@msstate.edu)*

Electromagnetic scattering by small particles has been studied over the years and many patterns have been recognized. Yet some of the patterns still need a proper explanation regarding the physics at play. In this talk, we present our work on electromagnetic scattering patterns of wavelength-scale spheroidal particles. The scattering patterns were numerically simulated using T-matrix and discrete dipole approximation (DDA) methods. Both far-field scattering patterns and internal fields were studied. Furthermore, how the scattering pattern changes with particle shape, size, and orientation will be discussed. The conditions for enhanced backscattering will be proposed based on our observations.

Preferred mode of presentation: Oral

In-line digital holographic near-field reconstruction applied to particles characterization in astigmatic optical systems and refractive index measurements

Matthias P. L. Sentis[a,*], Fabrice R. A. Onofri[b], and Fabrice Lamadie[a]

[a]*CEA, DEN, DMRC, SA2I, F-30207 Bagnols-sur-Cèze, France*
[b]*Aix-Marseille Université, CNRS, IUSTI, UMR 7343, 13453 Marseille Cedex 13, France*

[*]*Presenting author (matthias.sentis@cea.fr)*

Digital in-line holography (DH) is widely used to characterize two-phase flows as it allows determining, simultaneously and in one shot, the shape, 3D center position, and size of particles. In this communication, two extensions of the DH are presented. The first one concerns particle characterization in astigmatic optical systems (e.g., optical lenses, cylindrical cells, etc.). Problems induced by astigmatism are solved, in the paraxial approximation, with propagators derived from the generalized diffraction integral that is expressed in the framework of a classical ray transfer matrix formalism. These generalized propagators associated with suitable sampling conditions allow to simulate or back propagate holograms in an accurate, flexible, and numerically effective way.

The second extension relies on the measurement of the refractive index of spherical and transparent particles, for material recognition purposes and extensive multiphase flows characterization. The method is based on the analysis of a photonic jet generated by this kind of particles. Direct calculations with the Lorenz–Mie theory show that the structure of this optical near-field caustic is strongly dependent upon the particle refractive index and diameter. Even if the particle near-field appears to be roughly reconstructed with the DH, we demonstrate in this communication that the particle refractive index can be straightforwardly retrieved using the localization of the photonic jet maxima and geometrical considerations. In this presentation, the mathematical background of these solutions is detailed and illustrated by numerical and experimental results.

Preferred mode of presentation: Oral

Calculation of electromagnetic scattering by non-spherical particles by means of the generalized metric sources

Alexey A. Shcherbakov

Moscow Institute of Physics and Technology, Institutsky 9, 141700 Dolgoprudnyi, Russia (shcherbakov.aa@mipt.ru)

Accurate simulation of electromagnetic scattering by non-spherical particles is important for different applications, such as biomedical optical tweezing or lazer induced melting. To widen the capabilities of modern numerical methods used for such simulations, this work aims at developing an idea of introducing volume metric sources. This idea was previously proposed in our group for corrugated grating diffraction simulation and consists of the introduction of a curvilinear coordinate system in a grating region so as to make a curved grating corrugation to become a plane in new coordinates. Owing to such coordinates, the problem of diffraction by the curved corrugation is replaced by a problem of diffraction by an inhomogeneous volume grating near a plane interface. This approach allowed one to dramatically improve the efficiency of metallic structure simulations. The current work focuses on the investigation of ways of application of the mentioned approach in the 3D spherical basis. In this case a complex particle shape is transformed into a sphere inside some bounded spherical shell. The scattering problem for the resulting inhomogeneous volume scatterer can be solved with an integral, differential, or modal formulation related to the well-known invariant imbedding method.

Preferred mode of presentation: Oral

Rigorous simulation of electromagnetic scattering by rough surfaces

Alexey A. Shcherbakov

Moscow Institute of Physics and Technology, Institutsky 9, 141700 Dolgoprudnyi, Russia (shcherbakov.aa@mipt.ru)

Rigorous methods in electromagnetic diffraction and scattering face increasingly high requirements due to advances in optical manufacturing and measurements. On the other hand, the development of computing capabilities opens ways for reformulation of well-known numerical methods and for development of others. During the last several years our group has been engaged in research of highly efficient numerical methods of the grating diffraction simulation based on the generalized sources concept. Apart from applying the methods to grating diffraction, we have developed an approach allowing one to simulate scattering by particulate layers through a rigorous diffraction simulation on periodic structures of extremely large and complex periods. This work focuses, first, on the investigation of capabilities of the generalized source method for rigorous simulation of electromagnetic scattering by rough surfaces, and, second, on the demonstration of the dramatic improvement of computing capabilities through the use of modern graphical processing units.

Preferred mode of presentation: Poster

Numerical study of the influence of different dispersed components of a crystal cloud on transmission of radiant energy

Olga V. Shefer[a] and Tatiana V. Russkova[b,*]

[a]*National Research Tomsk Polytechnic University, Institute of Cybernetics, 30, Lenin Ave., 634050, Tomsk Russia*
[b]*V. E. Zuev Institute of Atmospheric Optics, SB RAS, 1, Academician Zuev Sq., 634055, Tomsk, Russia*

[*]*Presenting author (btv@ioa.ru)*

We will report on calculations of the transmission of visible and infrared radiation by an atmosphere layer involving ensembles of large preferentially oriented crystals and spherical particles. To calculate the extinction characteristics, the physical-optics method and the Mie theory are applied to these two scatterer types, respectively. Among all atmospheric particles, both particles small relative to the wavelength of the incident radiation and large plates and columns are distinguished by a pronounced dependence of the transmission on the spectra of radiant energy. For large crystals having the same projected area, it is shown that plates provide a dominant role in the emergence of polarization effects and strong spectral variations of the extinction characteristics. This work illustrates various traits of the influence of the parameters of the particle size distribution, particle aspect ratios, orientation, and particle refractive index on the transmission. For preferentially oriented plates having a different chemical composition, taking into account the polarization effect of extinction may change the value of the transmission function by more than 10%, compared to a few percent for pure ice particles. Separate and cumulative contributions from large plates and small-volume spherical particles to the common transmission by a medium are considered. We discuss the conditions wherein one should take into account the combined effect of the large plates and small crystals to the total transmission of visible and infrared radiation, and wherein it is sufficient to account for only one of these components of the medium.

The work was partially supported by The Russian Foundation for Basic Research (Project No. 16-31-60057 mol_a_dk).

Preferred mode of presentation: Poster

Capability and limitation on size and shape determination of a non-spherical particle by Interferometric Laser Imaging for Droplet Sizing technique using Fourier Transform

Huanhuan Shen*, Lingyuan Wu, Guodong Liu, and Weiping Wang

Institute of Fluid Physics, 64 Mianshan Road, Mianyang, 6219000, China

Presenting author (huanhuan.shen@caep.cn)

For a long period of time, holography had been considered the only method for the characterization of non-spherical particles in a three dimensional flow. Nowadays, a number of techniques for particle flow characterization have been developed. However, retrieving the fine characteristics of non-spherical particles (including their shape, size, etc.) from scattered light is still a challenging task. The Interferometric Laser Imaging for Droplet Sizing (ILIDS) technique has been demonstrated as being capable of yielding the size of each non-spherical particle and is very promising for behavior study of 3D particle flows. In this technique, the size and shape retrieval is based on the Fourier spectrum analysis of the speckle-like pattern. In fact, besides the size determination capability, the ILIDS technique sometimes can provide shape information as well. Care should be exercised nevertheless since ambiguity can arise. In this talk, we summarize the capability and limitation on size and shape determination of this technique through an investigation on a variety of particle shapes covering the most basic geometries. Furthermore, the capability of the ILIDS simulator of producing X-ray scattering patterns is demonstrated.

Preferred mode of presentation: Oral

Enhanced Raman spectroscopy of aerosol particles

V. Sivaprakasam*, M. B. Hart, and J. D. Eversole

Naval Reaseach Laboratory, 4555 Overlook Ave. SW, Washington DC 20375, USA

Presenting author (vasanthi.sivaprakasam@nrl.navy.mil)

Raman spectroscopy is a widely used technique to measure vibrational and rotational molecular modes that can provide very specific spectral signatures for chemical identification. However, typically low Raman scattering cross-sections have been a barrier to using this technique for *in situ* characterization of environmental aerosols or monitoring hazardous materials present in the air. By combining metallic nano-particles (MNPs) with aerosol particles, we have been able to observe enhanced fluorescence (Sivaprakasam et al. 2014) and Surface Enhanced Raman Spectra. We have explored the comparison measurements of spontaneous Raman spectra with MNP-enhanced Raman spectra using identical materials under controlled conditions as aerosols and bulk liquid samples. The repeatability of spectral response and enhancement factors as well as their dependence on factors such as the MNP composition, MNP concentration, and material composition will be investigated.

A Raman spectroscopy test-bed has been constructed that is capable of interrogating single aerosol particles or bulk samples in a cuvette for comparison/validation studies. Aerosol particles are suspended in a linear electrodynamic quadrupole (LEQ) trap (Hart et al. 2015) that gives us ample time to study the weak spontaneous Raman for extended periods of time. Aerosol particles are created and charged using a customized nozzle-reservoir droplet generator, and particles ranging from 1 to 60 micrometers in diameter have been successfully generated and maintained. For validation and calibration, droplets of materials such as glycerol and dibutyl sebacate were studied, using a 532-nm laser for excitation. Initial SERS has been observed and studied for Pyridine and Rhodamine laser dye, plans to extend the study to other chemicals and proteins are under way. The latest results in terms of spectral signatures resulting from the addition of the MNPs to these materials will be presented.

References

V. Sivaprakasam, M. B. Hart, V. Jain and J. D. Eversole, "Metallic-nanoparticles-enhanced fluorescence from individual micron-sized aerosol particles on-the-fly," *Opt. Express* **22**, 18966–18978 (2014).

M. B. Hart, V. Sivaprakasam, J. D. Eversole, L, J, Johnson and J. Czege, "Optical measurements from single levitated particles using a linear electrodynamic quadrupole trap," *Appl. Opt.* **54**, F174–181 (2015).

Preferred mode of presentation: Oral

Modulation of aerosol forcing by mixing state and particle morphology: case study from Delhi NCR, India

Parul Srivastava[a,*], Sagnik Dey[a], S. N. Singh[b], and A. K. Srivastava[c]

[a]*Indian Institute of Technology Delhi, New Delhi, India, 110016*
[b]*National Physical Laboratory, New Delhi, India,110012*
[c]*Indian Institute of Tropical Meteorology, Delhi Branch, New Delhi, India, 110060*

[*]*Presenting author (parulsri.iit@gmail.com)*

Major sources of uncertainty in aerosol direct radiative forcing (DRF) stems from unknown aerosol composition, mixing state and particle morphology. The problem is critical in the Indo-Gangetic Basin, Northern India, where various aerosol species mix and show strong seasonal variation. A detailed chemical analysis is carried out to understand aerosol composition in Delhi National capital region (NCR) during 2007–2008. These data are used to examine the sensitivity of optical properties to the mixing state and particle shape. The species are grouped into five major components – accumulation dust, coarse dust, water-soluble (WS), water insoluble (WINS), and black carbon (BC). To infer the probable mixing state of aerosols in the Delhi NCR, six different mixing cases – external, internal, and four combinations of core-shell mixing (BC over dust, WS over dust, BC over WINS and WS over WINS) have been considered. These core shell mixed components are then externally mixed with rest of the aerosol species. The spectral aerosol optical properties - extinction coefficient, single scattering albedo (SSA) and asymmetry parameter (g) for each of the mixing state cases are computed and further used to estimate the aerosol DRF using a radiative transfer model. The surface-reaching flux for each of the cases is compared with ground-based measurement. "WS coating over dust externally mixed with BC and WINS" seems to be the case for the winter season (Dec–Feb), while choice of 'external mixing' seems reasonable in the other seasons. Mean seasonal TOA (surface) aerosol DRF for the most probable mixing states in 'clear-sky' conditions is 4.4 ± 3.9 (–25.9 ± 3.9), 6.7 ± 0.5 (–13.8 ± 4.4), 9.1 ± 13.1 (–58.1 ± 23.6) and –5.4 ± 7.7 (–80.0 ± 7.2) Wm^{-2}, respectively, in the pre-monsoon (Mar–May), monsoon (Jun–Sep), post-monsoon (Oct–Nov) and winter seasons. We next examine the modulation of aerosol DRF due to particle morphology, for which three non-spherical shapes – spheroid, cylinder, and Chebyshev – are considered based on the SEM images. We have calculated optical properties of non-spherical dust using the T-Matrix code. Dust DRFs are not significantly different for individual shapes, but non-spherical dust causes more cooling at TOA due to enhanced backscattering (as g decreases and SSA increases). The surface dimming increases due to overall increase in attenuation of solar radiation. When non-spherical dusts mix externally with other spherical particles, the TOA cooling is enhanced from 0.45 to 1.8 Wm^{-2}. These results will help in reducing the uncertainty in the aerosol DRF estimates for the Indian region.

Preferred mode of presentation: Oral

Electromagnetic scattering and radiation transport involving heterogeneous ice particles in the community radiative transfer model

Patrick G. Stegmann* **and Ping Yang**

Department of Atmospheric Sciences, Texas A&M University, 3150 TAMU, College Station, TX 77843-3150, USA

**Presenting author (pstegmann@tamu.edu)*

The NOAA Community Radiative Transfer Model, abbreviated as CRTM, is a fast radiative transfer code for comparative calculations of radiances for satellite infrared or microwave sensors and written in Fortran 95/2003. In its current state, the CRTM has several shortcomings in relation to the treatment of strongly heterogeneous ice particles such as snow and graupel. The first issue is the strong temperature dependence of the absorption spectrum of ice in the microwave regime. Only recently a new lookup table could be computed for ice crystals based on MODIS collection 6, in order to enable the consideration of the temperature dependence at least in the case of homogeneous ice particles. The second issue is the morphology of the heterogeneous ice particles itself. Up to now, the corresponding Mie solution has been used as the source of the single scattering properties for ice particles in the Microwave range in the CRTM, irrespectively of the exterior shape or internal constitution of the scatterer. Strongly heterogeneous particles on the other hand have a highly increased and complicated surface area, as well as a mass density very different from a particle consisting of sheer bulk material. Thus it is to be expected that a more faithful representation of snow and graupel particles in comparison to simple homogeneous spheres will yield significantly different results both in the single and multiple scattering case. In the framework of this presentation, both the computation of the temperature dependent refractive index of ice, as well as the model for the heterogeneous internal structure will be explained. Specifically, the model for the particle morphology involves three different escalation steps, each one having a higher complexity and simultaneously a higher physical accuracy as the preceding one. Starting from the Bruggeman effective medium approximation, the second step consists of the representation of the inhomogeneous structure as a bicontinuous random medium, while the third and last step is the exact computation of the snow crystal growth process by means of a Level-Set solution to the so-called Stefan problem. The resulting shapes are used as an input for FDTD, IITM and IGOM calculations to compute single scattering properties and coefficient lookup tables for the CRTM. Especially in light of the practical application to the CRTM, the necessary trade-off between complexity and accuracy of the presented methods will be explained.

Preferred mode of presentation: Oral

A physical–geometric optics method for obtaining the scattering properties of inhomogeneous faceted particles

Bingqiang Sun[a,*], Ping Yang[a], and George W. Kattawar[b]

[a]*Department of Atmospheric Sciences, Texas A&M University, College Station, TX, 77843, USA*
[b]*Department of Physics and Astronomy, Texas A&M University, College Station, TX 77843, USA*

[*]*Presenting author (bqsun@tamu.edu)*

For a particle with a large size parameter, the electromagnetic near field can be approximately obtained using the geometric optics method, while the far field can be accurately obtained using a rigorous electromagnetic relation. Furthermore, for faceted particles, the ray-tracing process in the near-field simulation can be performed analytically. Accordingly, rays incident on the same facet can be treated as one beam whose cross section is a polygon. When a beam is incident on multiple facets, it must be a split into various sub-beams with respect to the original beam to insure each sub-beam is incident on one facet. An effective beam-splitting technique is a critical step in simulating light scattering of a large complex faceted particle.

For a homogeneous convex particle, a geometric splitting technique is sufficient to generate the sub-beams; however, a new splitting technique is necessary for complex particles, such as an inhomogeneous convex particle. The technique used in this study first uses a 3-dimensional transformation to project a possible incident facet onto the original beam facet. Secondly, a polygon-clipping technique is used to generate a sub-beam incident only on a possible facet. The beam-splitting technique used in this study can be applied to any ray-tracing process of a complex faceted particle.

Preferred mode of presentation: Oral

Interstellar polarization by spheroidal composite grains

Deepak B. Vaidya[a,*] and Ranjan Gupta[b]

[a]*Gujarat College, Ahmedabad 380006, India*
[b]*Inter University Centre for Astronomy & Astrophysics, IUCAA Pune, 411007, India*

[*]*Presenting author (dipak.vaidya@gmail.com)*

Using the discrete dipole approximation (DDA), we calculate the polarization efficiencies (Q_{pol}) for the composite spheroidal dust grains. The polarization is attributed to dichroic extinction caused by the aligned composite spheroidal grains. The composite spheroidal grains are assumed to be made up of host silicate grains and inclusions of graphite/or silicon carbide (SiC)/or voids. We study the variation in the polarization profile as a function of volume fraction of inclusions and porosity, in the infrared spectral region, between 5 and 25 μm. In particular, we study the variation in the polarization efficiencies at the absorption features; i.e. at 10 and 18 μm. We also study the variation in the polarization ratio $R = Q_{pol}(18)Q_{pol}(10)$, with the volume fraction of inclusions. We compare the polarization efficiencies for the composite grains with the observed interstellar polarization. The composite grain models with the axial ratio 1.33 and volume fraction of graphite inclusions between $f = 1.3$ and 0.2 fit the observed data satisfactorily; whereas, the composite grain models with the inclusions of SiC do not fit the observed polarization. The porous silicate grains also do not fit the observed polarization. The polarization ratio $R = Q_{pol}(18)Q_{pol}(10)$ for these composite grains is higher than the polarization ratio obtained for the observed data. These results on the polarization for the spheroidal composite grains show that the polarization is sensitive not only to the shape, but it is also sensitive to the composition and structure of the grains. These results also indicate that composite grain models with other carbonaceous inclusions (e.g., amorphous carbon, PAHs) are required to fit the observed polarization better.

Preferred mode of presentation: Oral

Radiative Transfer with Reciprocal Transactions R^2T^2

Timo Väisänen[a,*], Johannes Markkanen[a], Antti Penttilä[a], and Karri Muinonen[a,b]

[a]*Department of Physics,University of Helsinki, Finland*
[b]*Finnish Geospatial Research Institute FGI, National Land Survey, Finland*

[*]*Presenting author (timo.h.vaisanen@helsinki.fi)*

Radiative transfer is an approximate method which is applicable to sparse media. We are developing methods to extend the applicability of the radiative transfer to dense media. Our approach is a method called Radiative Transfer with Reciprocal Transactions (R^2T^2) which combines exact Superposition T-matrix method and Monte Carlo radiative transfer. The method is based on locally exact treatment of multiple scattering, in which electric fields are presented using spherical wave functions and the single-scattering properties are computed for a volume element containing a cluster of particles instead of a single particle. The R^2T^2 uses scattered incoherent fields instead of scattered fields, and this has been shown to work for dense media with the Monte Carlo radiative transfer code RT-CB-ic (Radiative Transfer Coherent Backscattering with Incoherent interactions) by comparing the validity to the radiative transfer without incoherent fields (RT-CB) and to the exact solution (Muinonen K. et al. *EMTS* 2016). The scattered incoherent fields are acquired by removing the coherent field from the scattered field (Zurk L. et al. (1996), *Radio Science* **31**). Comparison between the exact solution (Superposition T-matrix method), the RT-CB and the R^2T^2 for various dense and sparse spherical media composed of equisized spherical scatterers will be presented as a preliminary result.

The research is funded by the ERC Advanced Grant No. 320773 (SAEMPL).

Preferred mode of presentation: Oral

An evaluation of average ice crystal shapes to represent scattering properties of ice crystal population ensembles

Bastiaan van Diedenhoven[a,b,*], Andrew S. Ackerman[b], Ann M. Fridlind[b], and Brian Cairns[b]

[a]*Center for Climate System Research, Columbia University, 2880 Broadway, New York, NY 10025, USA*
[b]*NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA*

[*]*Presenting author (bastiaan.vandiedenhoven@nasa.gov)*

There is a virtually limitless variation of shapes of ice crystals in natural clouds. Even within a small cloud volume, broad distributions of crystal geometries can be expected. However, scattering properties of ice clouds are usually represented by a single or limited number of crystal geometries. Since the scattering properties of ice crystals strongly depend on the crystal shape, the question is raised how to determine an effective average shape that most accurately represents the scattering properties of the ensemble. The two most important shape characteristics determining the scattering properties of ice crystals are the aspect ratio of their components and surface distortions. Using ensembles of simple hexagonal ice prisms with varying aspect ratios and distortion parameters, we evaluate the use of ensemble-average values of aspect ratio and distortion parameter for the estimation of ensemble-average scattering asymmetry parameters. Several definitions of crystal aspect ratio and various averaging strategies are evaluated. Using crystal aspect ratios greater than unity generally leads to ensemble-average values of aspect ratio that are inconsistent with the ensemble-average asymmetry parameters. When a definition of aspect ratio is used that limits the aspect ratio to below unity ($\alpha_{\leq 1}$) for both hexagonal plates and columns, the effective asymmetry parameters calculated using ensemble-average aspect ratios are generally consistent with ensemble-average asymmetry parameters, especially if aspect ratios are geometrically averaged. Ensemble-average distortion parameters generally also yield effective asymmetry parameters that are largely consistent with ensemble-average asymmetry parameters. In the case of mixtures of plates and columns, it is recommended to geometrically average the $\alpha_{\leq 1}$ aspect ratios and to subsequently calculate the effective asymmetry parameter using a column or plate geometry when the contribution by columns to a given mixture's total projected area is greater or less than 50%, respectively. These conclusions are relevant for estimating scattering properties of ice crystals based on modeled properties or those measured in situ, as well as for the interpretation of ice crystal shape characteristics retrieved by remote sensing. We argue that these conclusions should also largely apply to internal mixtures of plate- and column-like crystal components, such as in the case of asymmetric bullet rosettes, aggregates of varying plates and/or columns, and plate-capped columns.

Preferred mode of presentation: Oral

Ice-crystal corner reflection observed with two-wavelength polarization lidar

Igor Veselovskii[a,b,*], Philippe Goloub[c], Thierry Podvin[c], Didier Tanre[c], Michail Korenskiy[b], Anatoli Borovoi[d], Qiaoyun Hu[c], and David N. Whiteman[e]

[a]*Physics Instrumentation Center, Troitsk, Moscow, 142190, Russia*
[b]*Joint Center for Earth Systems Technology, UMBC, Baltimore, MD, USA*
[c]*Laboratoire d'Optique Atmosphérie, Université de Lille-CNRS, 59650, Villeneuve d'Ascq, France*
[d]*Institute of Atmospheric Optics, 1 Academician Zuev Sq., Tomsk, Russia*
[e]*NASA GSFC, Greenbelt, MD, USA*

[*]*Presenting author (iveselov@hotmail.com)*

One of the intriguing questions in the study of the scattering phase function of ice crystals is the possible contribution of the so-called corner reflection (CR) effect to total backscattering. The CR may occur in crystals of a simple shape, such as hexagonal plates and columns. In contrast to the extinction coefficient, which is spectrally independent, the account of Fraunhofer diffraction associated with backscattered plane-parallel beams in the case of the CR results in a spectral dependence of the backscattering coefficient and this is how it can be identified. In 2015–2016 the field campaign SHADOW was organized in Senegal. The Raman lidar used in the campaign allowed measurements of the particle extinction and backscattering coefficients and the depolarization ratio (δ) at 355 and 532 nm at a 43° off-zenith angle. In some cases the backscattering Ångström exponent in the mixed-phase clouds increased up to 0.6 simultaneously with a decrease of the $\delta_{355}/\delta_{532}$ ratio from 1.0 to 0.8. At the same time, the extinction coefficient showed no spectral dependence. Such a behavior can be the result of the CB by horizontally oriented ice plates.

Preferred mode of presentation: Oral

Polarimetric remote sensing in oxygen A and B bands: sensitivity study and information content analysis for vertical profile of aerosols

Jun Wang[a,b,*], Shouguo Ding[a,c], and Xiaoguang Xu[a,b]

[a]*Earth and Atmospheric Sciences, University of Nebraska–Lincoln, 303, Lincoln, NE 68588, USA*
[b]*Now at Department of Chemical and Biochemical Engineering, Center of Global and Regional Environmental Studies, University of Iowa, 4133 Seamans Center, Iowa City, IA 52242, USA*
[c]*Now at Earth Resources Technological Inc., Laurel, MD 20707 USA*

[*]*Presenting author (jun-wang-1@uiowa.edu)*

Theoretical analysis is conducted to reveal the information content of aerosol vertical profile in space-borne measurements of the backscattered radiance and degree of linear polarization (DOLP) in Oxygen (O_2) A and B bands. Assuming a quasi-Gaussian shape for aerosol vertical profile characterized by peak height H and half width γ (at half maximum), the Unified Linearized Vector Radiative Transfer Model (UNL-VRTM) is used to simulate the Stokes 4-vector elements of upwelling radiation at the top of atmosphere (TOA) and their Jacobians with respect to H and γ. Calculations for different aerosol types and different combinations of H and γ values show that the wide range of gas absorption optical depth in O_2 A and B band enables the sensitivity of backscattered DOLP and radiance at TOA to the aerosol layer at different altitudes. Quantitatively, DOLP in O_2 A and B bands is found to be more sensitive to H and γ than radiance, especially over the bright surfaces (with large visible reflectance). In many O_2 absorption wavelengths, Degree of Freedom for Signal (DFS) for retrieving H (or γ) generally increases with H (and γ) and can be close to unity in many cases, assuming that the composite uncertainty from surface and aerosol scattering properties as well as measurements is less than 5%. Further analysis demonstrates that DFS needed for simultaneous retrieval of H and γ for high-lofted aerosol profiles (H > 2 km) can be obtained from a combined use of DOLP measurements at ~10 O_2 A and B absorption wavelengths. However, challenges still remain for resolving aerosol profiles with H less than 2 km. Future hyperspectral measurements of DOLP in O_2 A and B bands are needed to continue studying their potential and their combination with radiance and DOLP in atmospheric window channels for retrieving the vertical profiles of aerosols, especially highly scattering aerosols, over land.

Preferred mode of presentation: Oral

Theoretical and experimental study on echo fluctuation suppression of cirrus cloud by millimeter wave MIMO radar

Jinhu Wang[a,b,c,*], Junxiang Ge[a,b,d], Ming Wei[a,b,c], Zexin Yang[d], and Qilin Zhang[a,b,c]

[a]*Collaborative Innovation Center on Forecast and Evaluation of Meteorological Disasters, Nanjing University of Information Science and Technology, Nanjing 210044, China*
[b]*Key Laboratory of Meteorological Disaster, Ministry of Education, Nanjing University of Information Science and Technology, Nanjing 210044, China*
[c]*Key Laboratory for Aerosol-Cloud-Precipitation of China Meteorological Administration, Nanjing University of Information Science and Technology, Nanjing 210044, China*
[d]*Jiangsu Key Laboratory of Meteorological Observation and Information Processing, Nanjing University of Information Science and Technology, Nanjing 210044, China*

[*]*Presenting author (goldtigerwang@nuist.edu.cn)*

The scattering properties of non-spherical particles can be approximately computed with the equivalent spherical theory, which was firstly demonstrated by the method of moment. Secondly, the scattering properties of ice particles were approximately computed with the Rayleigh approximation because the size of ice particle is smaller than the wavelength of the millimeter-wave radar. Based on the above assumption, we could analyze the echo fluctuation by computing the total backscattering field of a cirrus cloud using the concept of the classical vector potential technique. Simulation results have shown that the echo fluctuation influences the accuracy of retrieving cloud macro-physical and micro-physical parameters. In order to suppress the echo fluctuation of a cloud, the average technique should be employed when using the video integrator of a millimeter wave cloud radar; however the video integrator has defects of losing the rapid change information of a meteorological target and reducing the radar range resolution. Therefore, we propose the space-diversity technique of the MIMO radar to suppress the echo fluctuation, which could be validated by theoretical computations and measurements.

Preferred mode of presentation: Oral

Rapid and accurate Monte Carlo simulations of radiative transfer in cloudy atmosphere

Zhen Wang[a,*], Shengcheng Cui[b], Jun Yang[a], Haiyang Gao[a], Chao Liu[a], and Zhibo Zhang[c]

[a]*Key Laboratory for Aerosol-Cloud-Precipitation of China Meteorological Administration, School of Atmospheric Physics, Nanjing University of Information Science and Technology, Nanjing 210044, China*
[b]*Key Laboratory of Atmospheric Composition and Optical Radiation, Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Hefei 230031, China*
[c]*Physics Department, University of Maryland, Baltimore County, Baltimore, MD 21250, USA*

[*]*Presenting author (intersharp@126.com)*

A well-known long-standing challenge in Monte Carlo radiative transfer simulations is how to reduce the radiance variances in a cloudy atmosphere with highly forward-peaked scattering phase functions. In previous studies, the variance reduction is achieved either by using the scattering phase function forward truncation technique or the target directional importance sampling technique. We now present a novel scattering order-dependent variance reduction method to combine them and implement into our Multiple-Scaling-based Cloudy Atmospheric Radiative Transfer (MSCART) model. It can greatly improve the trade-off between numerical efficiency and accuracy order by order because all the tuning parameters used for the phase-function truncation and importance sampling techniques at each order of scattering are optimized by the scattering order-dependent numerical evaluation experiments. It is a novel feature of our method. To make such experiments feasible, we present a new scattering order sampling algorithm by remodeling integral radiative transfer kernel for the phase function truncation method. More importantly, this method is built upon a newly developed theoretical framework that not only unifies both forward and backward radiative transfer in a scattering-order-dependent integral equation, but also generalizes the variance reduction formalism in a wide range of simulation scenarios (such as 3D clouds, polarization and passive/active measurements).

This work was supported by the National Natural Science Foundation of China (Grants No. 41305032, 41571348, and 41304124).

Preferred mode of presentation: Oral

Multi-sensor Cloud and Aerosol Retrieval Simulator and its applications

Galina (Gala) Wind[1, 2*], Arlindo Da Silva[1], Kerry Meyer[1,3], Steven Platnick[1], Robert Levy[1], Peter Norris[1,3], and Shana Mattoo[1,2]

[1]*NASA Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt, MD 20771, USA*
[2]*SSAI, Inc., 10210 Greenbelt Rd #600, Lanham, MD 20706, USA*
[3]*USRA, 7178 Columbia Gateway Dr., Columbia, MD 21046, USA*

[*]*Presenting author (gala.wind@nasa.gov)*

Algorithm verification is a continuing issue for atmospheric remote sensing algorithms. Field campaigns and in-situ ground sites provide means of validation, but can be very limited in location and data amount. Existing and proposed remote sensing algorithms can benefit greatly from having a controlled sandbox environment that provides synthetic data that appears equivalent to real instrument-acquired measurements. The Multi-sensor Cloud and Aerosol Retrieval Simulator (MCARS) is such a sandbox that is able to generate MODIS-like radiances in a standard operational MODIS radiance file format using atmospheric column data provided by the GEOS-5 model coupled with the discrete-ordinates radiative transfer model using plane-parallel, homogeneous assumptions. When we examined the performance of the MODIS dark target aerosol product (MOD04DT) using synthetic granules of biomass burning in Brazil, we found the reason for the low bias in MOD04DT aerosol optical depth retrievals when compared to AERONET. We also used synthetic scenes of clouds and aerosols off the coast of Namibia to test the performance of the research-level MODIS above-cloud aerosol properties retrieval algorithm (MODACAERO). The results of executing the MODACAERO algorithm on synthetic data show that the algorithm performs well and achieves closure where the retrieval result matches well against given "truth". We make some suggestions for quality filtering of data before using it in modeling applications and propose some additional studies of the cloud bow scattering angle range in the aerosol model used to create the lookup tables for the MODACAERO retrieval algorithm.

Preferred mode of presentation: Oral (or poster)

Simulation of Total Internal Reflection Microscopy (TIRM) based on the T-Matrix method

Thomas Wriedt[a,*] and Adrian Doicu[b]

[a]*Institut für Werkstofftechnik, Badgasteiner Str. 3, 28359 Bremen, Germany*
[b]*Remote Sensing Technology Institute, DLR, 82234 Weßling, Germany*

[*]*Presenting author (thw@iwt.uni-bremen.de)*

Since its invention in the eighties, Total Internal Reflection Microscopy (TIRM) has become an extremely sensitive technique for measuring weak interaction forces between colloidal particles suspended in water and a planar interface with a resolution down to a few fN. In a TIRM-based experimental setup, a laser beam propagates in the glass prism and hits the prism–water interface with an angle slightly larger than the angle of total internal reflection. As a result, an evanescent field is generated at the other side of the interface. This evanescent field decays exponentially into the water. If a colloidal particle is near the interface, it will scatter light from the evanescent field. This light will detected by an integrating detector system. To evaluate an actual TIRM measurement a calibration curve giving intensity versus particle height above the interface is needed. As there is interest in particles that are more complex the simulation theory has to be extended from spherical colloidal particles to nonspherical particles.

In the talk, I will show how we applied a variant of the T-matrix method, the null-field method with discrete sources (NFM-DS) to model light scattering by a nonspherical particle near a plane surface in an evanescent wave field. The incident field strikes the particle either directly or after interacting with the interface, while the fields emanating from the particle may also reflect from the interface and interact with the particle again. The transition matrix relating the incident and scattered field coefficients is computed in the framework of the null-field method and the reflection matrix characterizing the reflection of the scattered field by the surface is computed by using the integral representation for the vector spherical wave functions. To handle the arbitrary particle orientation we will use the rotation addition theorem for vector spherical wave functions.

Preferred mode of presentation: Oral

Black carbon radiative forcing at TOA decreased during aging

Yu Wu*, **Tianhai Cheng, Lijuan Zheng, and Hao Chen**

State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences. No.20 Datun Road, Chaoyang, Beijing, 100101, China.

**Presenting author (wuyu@radi.ac.cn)*

During aging processing, black carbon (BC) particles may tend to be mixed with other aerosols, and highly influence their radiative forcing. In this study, freshly emitted soot particles were simulated as fractal aggregates composed of small spherical primary monomers. After aging in the atmosphere, soot monomers were coated by a thinly layer of sulfate as thinly coated soot particles. These soot particles were entirely embedded into large sulfate particle by further aging, and becoming heavily coated soot particles. In clear-sky conditions, BC radiative forcing with different aging states was investigated for the bottom and top of atmosphere (BOA and TOA). The simulations showed that black carbon radiative forcing increased at BOA and decreased at TOA after their aging processes. Thinly and heavily coated states increased up to ~12% and ~35% black carbon radiative forcing at BOA, and BC radiative forcing at TOA can reach to ~20% and ~100% smaller for thinly and heavily coated states than those of freshly emitted states, respectively. The results also indicated that the effect of BC aging on the radiative forcing highly depends on BC aerosol loadings (aerosol optical depth), surface albedo and solar zenith angles. These findings should improve our understanding of the effects of aging states on the radiative properties of soot aerosols and their effects on climate.

Preferred mode of presentation: Poster

Markov chain approach for computing polarized radiative transfer: formalism and application

Feng Xu* **and Anthony B. Davis**

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA

**Presenting author (fengxu@jpl.nasa.gov)*

The Markov chain (MarCh) radiative transfer (RT) approach was first proposed by Esposito and House for efficiently modeling unpolarized radiative transfer in a plane-parallel (p-p) atmosphere [1]. In this talk, we briefly review its principle and introduce recent developments for enhancing its modeling accuracy and applicability. We will introduce our efforts on 1) developing a polarized MarCh (pMarCh) algorithm to model RT in a p-p atmosphere that overlies a surface with complex surface reflectance – with the application to analyze Earth's atmospheric radiation; 2) developing a pMarCh algorithm to model RT in a spherical-shell atmosphere – with the application to analyze Titan's atmospheric radiation; 3) linearizing and integrating the pMarCh algorithm with an optimization approach – with the application to retrieve aerosol/cloud microphysical properties and surface reflectance; and 4) combining the pMarCh algorithm with a line-by-line model and the double-*k* method [2] to account for the influence of gaseous absorption lines – with the application to instrument vicarious calibration and trace-gas abundance retrieval. Moreover, we introduce the extension of the MarCh algorithm to compute the transport of polarized radiation according to Generalized Radiative Transfer theory [3], which was developed to account for unresolved random fluctuations of scattering particle density. It was found that angular reciprocity is violated to a degree that increases with the spatial variability, as observed for finite portions of real-world cloudy scenes. While the degree of linear polarization in liquid water cloudbows, supernumerary bows, and glories is affected by spatial heterogeneity, the positions in scattering angle of these features are relatively unchanged.

References

[1] L. W. Esposito and L. L. House. Radiative transfer calculated by a Markov chain formalism. *Astrophys. J.* **219**, 1058–1067 (1978).

[2] M. Duan, Q. Min, and J. Li. A fast radiative transfer model for simulating high-resolution absorption bands. *J. Geophys. Res*. **110**, D15201 (2005).

[3] A. B. Davis and F. Xu. A generalized linear transport model for spatially-correlated stochastic media. *J. Comput. Theor. Transp.* **43**, 474–514 (2014).

Preferred mode of presentation: Oral

Coupled retrieval of aerosol properties, column trace gas abundance, and surface reflectance using multiangle and multispectral polarimetric measurements

Feng Xu[a,*], David J. Diner[a], Ming Luo[a], Dejian Fu[a], and Oleg Dubovik[b]

[a]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA*
[b]*Laboratoire d'Optique Atmosphérique, University of Lille, Lille, France*

[*]*Presenting author (fengxu@jpl.nasa.gov)*

Passive aerosol remote sensing with spectral channels of finite bandwidth is subject to trace gas contamination by water vapor, ozone, and other trace gases. At the same time, optical throughput, one of the key factors affecting signal-to-noise ratio and aerosol uncertainty, is enhanced by using broad spectral bandwidths. To fully account for the influence of gaseous absorption lines, we developed an efficient and flexible optimization scheme that simultaneously retrieves aerosol properties, column trace gas abundance, and surface reflection properties. Gaseous absorption is fully modeled by integrating the Markov chain radiative transfer model [1] with the double-*k* method [2]. This forward model is coupled into a multi-pixel retrieval algorithm that involves the use of both observational and physical constraints to stabilize the algorithm and improve retrieval accuracy [3,4]. Observations include multiangle and multispectral polarimetric measurements, while the algorithmic constraints include limitations on (i) the spectral variation of the Bidirectional Polarization Distribution Function and angular shape of the Bidirectional Reflectance Distribution Function; (ii) the spectral variation of aerosol optical properties; and (iii) the spatial variation of aerosol parameters across neighboring image pixels. In addition, we impose an extra constraint on horizontal variation of trace gas abundance. Our retrieval approach has been tested using a number of datasets acquired by JPL's Airborne Multiangle SpectroPolarimetric Imager (AirMSPI) [5] during various NASA field campaigns. In step-and-stare operation mode, AirMSPI acquires multiangle radiance data within a water-vapor band centered at 935 nm (with 48-nm bandpass) and seven aerosol bands centered at 355, 380, 445, 470*, 555, 660*, and 865* nm (* denotes polarimetric bands). The imaged area covers about 10×10 km and is observed from 9 view angles between ±67° relative to nadir. The retrieval is compared with AERONET results which include precipitable water vapor, aerosol optical depth, and single scattering albedo, as well as aerosol size distribution and refractive index.

References

1. F. Xu et al. *Opt. Lett.* **36**, 2083 (2011).
2. M. Duan, Q. Min and J. Li. *J. Geophys. Res.* **110**, D15201 (2005).
3. O. Dubovik et al. *Atmos. Meas. Tech.* **4**, 975 (2011).
4. F. Xu et al. *Atmos. Meas. Tech.* **9**, 2877 (2016).
5. D. J. Diner et al. *Atmos. Meas. Tech.* **6**, 1717 (2013).

Preferred mode of presentation: Oral

Polarization of hazes and aurorae on Jupiter

Padma A. Yanamandra-Fisher[a,*], W. McLean[b], P. Miles[c], A. Wesley[d], P. Madingsly[e], and L. Rossi[f]

[a] *Space Science Institute, Rancho Cucamonga, CA 91739, USA*
[b]*Armagh Observatory*
[c]*Gemeye Observatory, Rubyvale, Queensland, 4702, AU*
[d]*Astronomical Society of Australia, Rubyvale, Queensland, 4702, AU*
[e]*British Astronomical Association, Manchester, UK*
[f]*Delft University of Technology, Delft, NL*

[*]*Presenting author (padma@spacescience.org)*

The versatility of polarimetric exploration is exploited to address: (1) understanding the formation of planetary systems and their diversity; and (2) search for habitability. Polarized light occurs in three states: unpolarized, linear and circularized. Each mode of polarized light provides information about the scattering medium, from atmospheres to search for signatures of habitability. Spectral dependence of polarization is important to separate the macroscopic (bulk) properties of the scattering medium from the microscopic (particulate) properties of the scattering medium. Linear polarization of reflected light by solar system objects provides insight into the scattering characteristics of aerosols and hazes in atmospheres and surficial properties of atmosphereless objects. Atmospheric phenomena such as rainbows, clouds and haloes exhibit polarimetric signatures that can be used as diagnostics to probe the atmosphere and may be possible to extend this approach to other planets and exoplanets. Renewed efforts for ground-based polarimetry are emerging, from probing planetary atmospheres to the study of magnetic field lines and taxonomy of asteroids. While imaging and spectroscopy are routinely performed by amateurs, there is growing interest and progress in developing polarimetric exploration amongst the amateur community, with encouraging results. I will present a review of these efforts, especially for polarimetric exploration of Jupiter to understand the neutral atmosphere (clouds and aerosols) and its aurorae. With NASA/Juno mission in a 53-day orbit around Jupiter, and recent outbreaks in the atmosphere, changes in the polarimetric signature will provide insight to the changes occurring in the atmosphere. The polarimetric observations of Jupiter are being acquired by a team of amateur planetary imagers (based in Australia) using small apertures and modeled by amateur astronomers based in the U.K.; pilot observations of Jupiter, Saturn and Mars were also acquired at the 1-m Celearn Observatory, France. Details/results of these studies will be presented to optimize the observing strategy of planetary atmospheres and their role in the atmospheric retrievals.

Preferred mode of presentation: Oral (or Poster)

Searching for an optimal optical property model for ice clouds

Ping Yang[a,c,*], Kuo-Nan Liou[b], George W. Kattawar[c], Bryan Baum[d], Steven Platnick[e], and Michael D. King[f,a]

[a]*Department of Atmospheric Sciences, Texas A&M University, College Station, TX 77843, USA*
[b]*Department of Atmospheric and Oceanic Science, University of California, Los Angeles, CA 9005, USA*
[c]*Department of Physics & Astronomy, Texas A&M University, College Station, TX 77843, USA*
[d]*Space Science and Engineering, University of Wisconsin, Madison, WI 53706, USA*
[e]*Earth Science Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA*
[f]*Laboratory for Atmospheric & Space Physics, University of Colorado, CO 80303*

[*]*Presenting author (pyang@tamu.edu)*

Ice clouds are ubiquitous in the atmosphere and strongly regulate the radiation budget of the earth-atmosphere system. A significant amount of work by the atmospheric research community has been dedicated to a better understanding of the single-scattering and bulk radiative properties of these clouds. The appropriate optical properties of ice crystals within ice clouds are required *a prior* for implementing it into a remote sensing technique for retrieving the microphysical and radiative properties of these clouds and radiative transfer simulations under ice cloudy conditions. In this presentation, we will review the evolution of the search for an optimal optical property model for ice clouds. The review will focus on two parallel efforts: 1) improving the accuracy of light-scattering computational methods for ice crystals, and 2) developing appropriate particle morphological models. Specifically, a variety of models ranging from "equivalent-sphere" to the newly developed MODIS (Moderate Resolution Imaging Spectroradiometer) Collection 6 ice cloud will be reviewed from the perspectives of remote sensing and radiative transfer. In addition, we will also discuss a statistical approach based on using an ensemble of irregular shapes to model the single-scattering properties of ice clouds. Finally, uncertainty in simulating the backscattering and relevant polarization properties of ice crystals will be further presented.

Preferred mode of presentation: Oral

Group-theoretical foundation of the random orientation in far-field electromagnetic scattering

Maxim A. Yurkin[a,b,*] **and Michael I. Mishchenko**[c]

[a]*Voevodsky Institute of Chemical Kinetics and Combustion, SB RAS, Institutskaya str. 3, 630090 Novosibirsk, Russia*
[b]*Novosibirsk State University, Pirogova 2, 630090 Novosibirsk, Russia*
[c]*NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA*

[*]*Presenting author (yurkin@gmail.com)*

Although the model of randomly oriented nonspherical particles has been used in a great variety of applications of far-field electromagnetic scattering, it has never been defined in strict mathematical terms. We used the formalism of Euler rigid-body rotations to clarify the concept of statistically random particle orientations and derived its immediate corollaries in the form of most general mathematical properties of the orientation-averaged extinction and scattering matrices. In particular, we related the notion of random orientation to the invariance of the orientation-averaged quantities with respect to any fixed rotation of the reference frame. Then the widely used probability density function $\sin\beta/(8\pi^2)$ for averaging over three Euler angles (α, β, γ) follows from the known invariant Haar measure of the 3D rotation group, parametrized with the Euler angles. Our results serve to provide a rigorous mathematical foundation for numerous publications in which the notion of randomly oriented particles and its light-scattering implications have been considered intuitively obvious. More details can be found in [1].

Reference

1. M. I. Mishchenko and M. A. Yurkin. On the concept of random orientation in far-field electromagnetic scattering by nonspherical particles. *Opt. Lett.* **42**, 494–497 (2017).

Preferred mode of presentation: Poster

A framework based on 2-D Taylor expansion for quantifying the impacts of sub-pixel reflectance variance and covariance on cloud optical thickness and effective radius retrievals based on the bi-spectral method

Z. Zhang[a,b,*], F. Werner[b], H.-M. Cho[c], G. Wind[d,e], S. Platnick[d], A. S. Ackerman[f], L. Di Girolamo[g], A. Marshak[d], and K. Meyer[d]

[a]*Physics Department, UMBC, Baltimore, MD, USA*
[b]*Joint Center for Earth Systems Technology, UMBC, Baltimore, MD, USA*
[c]*Electronics and Telecommunications Research Institute, Korea*
[d]*NASA Goddard Space Flight Center, Greenbelt, MD, USA*
[e]*Science Systems and Applications, Inc., Maryland 20706, USA*
[f]*NASA Goddard Institute for Space Studies, New York City, NY, USA*
[g]*Department of Atmospheric Sciences, University of Illinois, Urbana-Champaign, IL, USA*

[*]*Presenting author (zhibo.zhang@umbc.edu)*

The bi-spectral method retrieves cloud optical thickness τ and cloud droplet effective radius r_e simultaneously from a pair of cloud reflectance observations, one in a visible or near infrared (VIS/NIR) band and the other in a shortwave-infrared (SWIR) band. A cloudy pixel is usually assumed to be horizontally homogeneous in the retrieval. Ignoring sub-pixel variations of cloud reflectances can lead to a significant bias in the retrieved τ and r_e. In the literature, the retrievals of τ and r_e are often assumed to be independent and considered separately when investigating the impact of sub-pixel cloud reflectance variations on the bi-spectral method. As a result, the impact on τ is contributed only by the sub-pixel variation of VIS/NIR band reflectance and the impact on r_e only by the sub-pixel variation of SWIR band reflectance.

In our new framework, we use the Taylor expansion of a two-variable function to understand and quantify the impacts of sub-pixel variances of VIS/NIR and SWIR cloud reflectances and their covariance on the τ and r_e retrievals. This framework takes into account the fact that the retrievals are determined by both VIS/NIR and SWIR band observations in a mutually dependent way. In comparison with previous studies, it provides a more comprehensive understanding of how sub-pixel cloud reflectance variations impact the τ and r_e retrievals based on the bi-spectral method. In particular, our framework provides a mathematical explanation of how the sub-pixel variation in VIS/NIR band influences the r_e retrieval and why it can sometimes outweigh the influence of variations in the SWIR band and dominate the error in r_e retrievals, leading to a potential contribution of positive bias to the r_e retrieval. We test our framework using synthetic cloud fields from a large-eddy simulation and real observations from MODIS. The predicted results based on our framework agree very well with the numerical simulations. Our framework can be used to estimate the retrieval uncertainty from sub-pixel reflectance variations in operational satellite cloud products and to help understand the differences in τ and r_e retrievals between two instruments.

Preferred mode of presentation: Oral (or Poster)

Positive polarization in comets: clues to the coma composition

Evgenij Zubko[a,*], Gorden Videen[b,c], Dean C. Hines[d,b], and Yuriy Shkuratov[e]

[a]*School of Natural Sciences, Far Eastern Federal University, 8 Sukhanova Str., 690950 Vladivostok, Russia*
[b]*Space Science Institute, 4750 Walnut Street, Boulder Suite 205, CO 80301, USA*
[c]*U.S. Army Research Laboratory, 2800 Powder Mill Road, Adelphi, MD 20783, USA*
[d]*Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218 USA*
[e]*Institute of Astronomy, V.N. Karazin Kharkov National University, 35 Sumskaya St., Kharkov, 61022, Ukraine*

[*]*Presenting author (evgenij.s.zubko@gmail.com)*

While sunlight is initially unpolarized, the sunlight scattered by comets acquires partial linear polarization, which is quantified in terms of the degree of linear polarization. All comets reveal qualitatively the same dependence of the degree of linear polarization on phase angle. At small phase angles (<25°) the electric field vector is oriented preferentially within the scattering plane (generally designated negative polarization); whereas, at larger phase angles, it appears perpendicular to the scattering plane (designated positive polarization). Different comets reveal significant dispersion of their positive polarization with maximum polarization ranging from ~7% up to 30% and beyond. In this talk we demonstrate that this cannot be explained through depolarization by gaseous emissions. Instead, we suggest that the observed dispersion results from different properties of cometary dust. Using agglomerated debris particles we model the spectral polarimetric observations of comets. The vast majority of observations can be reproduced with a mixture of weakly absorbing (e.g., Mg-rich silicates) and highly absorbing (e.g., organics or amorphous carbon) agglomerated debris particles, which obey the same power-law size distribution. Within this extremely simple approach, polarization at side-scattering angles in a given comet is governed by the relative abundance of weakly and strongly absorbing particles. We find that in comets with the highest polarization, the weakly absorbing particles appear in proportions of only 14%–23% by volume; whereas, in comets with the lowest polarization, their abundance is much greater, 82%–95%.

Preferred mode of presentation: Oral

Modeling sea-salt aerosol: light-scattering experiment and numerical simulations

Evgenij Zubko[a,*], Nataliya Zubko[b], Olga Muñoz[c], Alexander M. Zakharenko[d], Kirill S. Golokhvast[d], Andrey N. Pavlov[a,e], and Gorden Videen[f,g]

[a]*School of Natural Sciences, Far Eastern Federal University, 8 Sukhanova Str., 690950 Vladivostok, Russia*
[b]*Finnish Geospatial Research Institute, Geodeetinrinne 2, FIN-02430 Masala, Finland*
[c]*Instituto de Astrofísica de Andalucía, CSIC Glorieta de la Astronomía s/n, Granada, 18008, Spain*
[d]*Scientific Educational Centre of Nanotechnology, Engineering School, Far Eastern Federal University, 8 Sukhanova Str., 690950 Vladivostok, Russia*
[e]*Institute of Automation and Control Processes of the Russian Academy of Sciences, 5 Radio Str., 690041 Vladivostok, Russia*
[f]*Space Science Institute, 4750 Walnut Street, Boulder Suite 205, CO 80301, USA*
[g]*U.S. Army Research Laboratory, 2800 Powder Mill Road, Adelphi, MD 20783, USA*

[*]*Presenting author (evgenij.s.zubko@gmail.com)*

Sea-salt aerosol is an important component of the marine atmosphere. It originates from the sea water and consists of predominantly sodium chloride (NaCl, up to ~98%) with some impurities. Due to low abundance, the contaminants only slightly affect the effective refractive index of sea-salt aerosols compared to that of pure NaCl. Their effect can be seen clearly on a macroscopic scale. However, they do not affect light-scattering response from single-scattering submicron- and micron-sized sea-salt particles, which are the focus of the current research; therefore, we model the chemical composition of sea-salt aerosol with pure NaCl. Note also that depending on humidity, sea-salt aerosol could appear in dry or wet form; whereas, here, we investigate only the dry case. We simulate submicrometer- and micrometer-sized sea-salt particles by milling commercially available mm-sized grains of NaCl. Using Raman spectroscopy, we verify that the milling does not alter the chemical composition of the sample. We characterize the size distribution and shapes of the resulting particles with the facility Malvern Morphologi G3-ID that is available at FEFU. We measure the single-scattering from sample particles with the experimental setup available at IAA. What results from these measurements are nearly full angular profiles of the Mueller matrix elements M_{11}, M_{12}, and M_{22} at the wavelength $\lambda = 0.648$ μm. Furthermore, we model the measured light-scattering response with the discrete dipole approximation (DDA) and agglomerated debris particles. In this talk we demonstrate these experimental results along with the resulting numerical simulations.

Preferred mode of presentation: Oral

Light scattering by volcanic sand: single-scattering particles versus particulate surface

Nataliya Zubko[a], Olga Muñoz[b], Evgenij Zubko[c,*], Maria Gritsevich[d], Jouni Peltoniemi[a], Jesús Escobar-Cerezo[b], Matthew Berg[e], and Jing Wen[e]

[a]*Finnish Geospatial Research Institute, Geodeetinrinne 2, FIN-02430 Masala, Finland*
[b]*Instituto de Astrofísica de Andalucía, CSIC Glorieta de la Astronomía s/n, Granada, 18008, Spain*
[c]*School of Natural Sciences, Far Eastern Federal University, 8 Sukhanova Str., 690950 Vladivostok, Russia*
[d]*Department ofPhysics, University of Helsinki, Gustaf Hällströmin katu 2a, P.O. Box 64, FI-00014 Helsinki, Finland*
[e]*Department of Physics and Astronomy, Mississippi State University, Starkville, MS 39759, USA*

[*]*Presenting author (evgenij.s.zubko@gmail.com)*

Weathering of solid volcanic lava produces an extremely dark volcanic sand with a geometric albedo of ~5%. The small volcanic-sand particles can get lifted off the surface by wind and, thus, contaminate the atmosphere. We experimentally study light scattering by volcanic sand particles in two regimes: (1) when these particles are suspended in the air, forming an optically thin cloud, and (2) when the same particles are deposited on a substrate, forming a dense particulate surface. We measure phase functions of the intensity and the degree of linear polarization of the scattered light. In the single-scattering regime this is achieved with the IAA experimental setup (CoDuLab); whereas, in the case of a particulate surface with the FGI experimental setup (FIGIFIGO). In this presentation we compare the light-scattering responses in an optically thin cloud and a particulate surface made of the same volcanic-sand particles. In addition, we model the measurements of single-scattering particles with the agglomerated debris particles (computed with the discrete dipole approximation). The obtained fits make it possible to constrain the complex refractive index of volcanic sand in visible.

Preferred mode of presentation: Poster