Was Venus the first Habitable World of our Solar System?

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&
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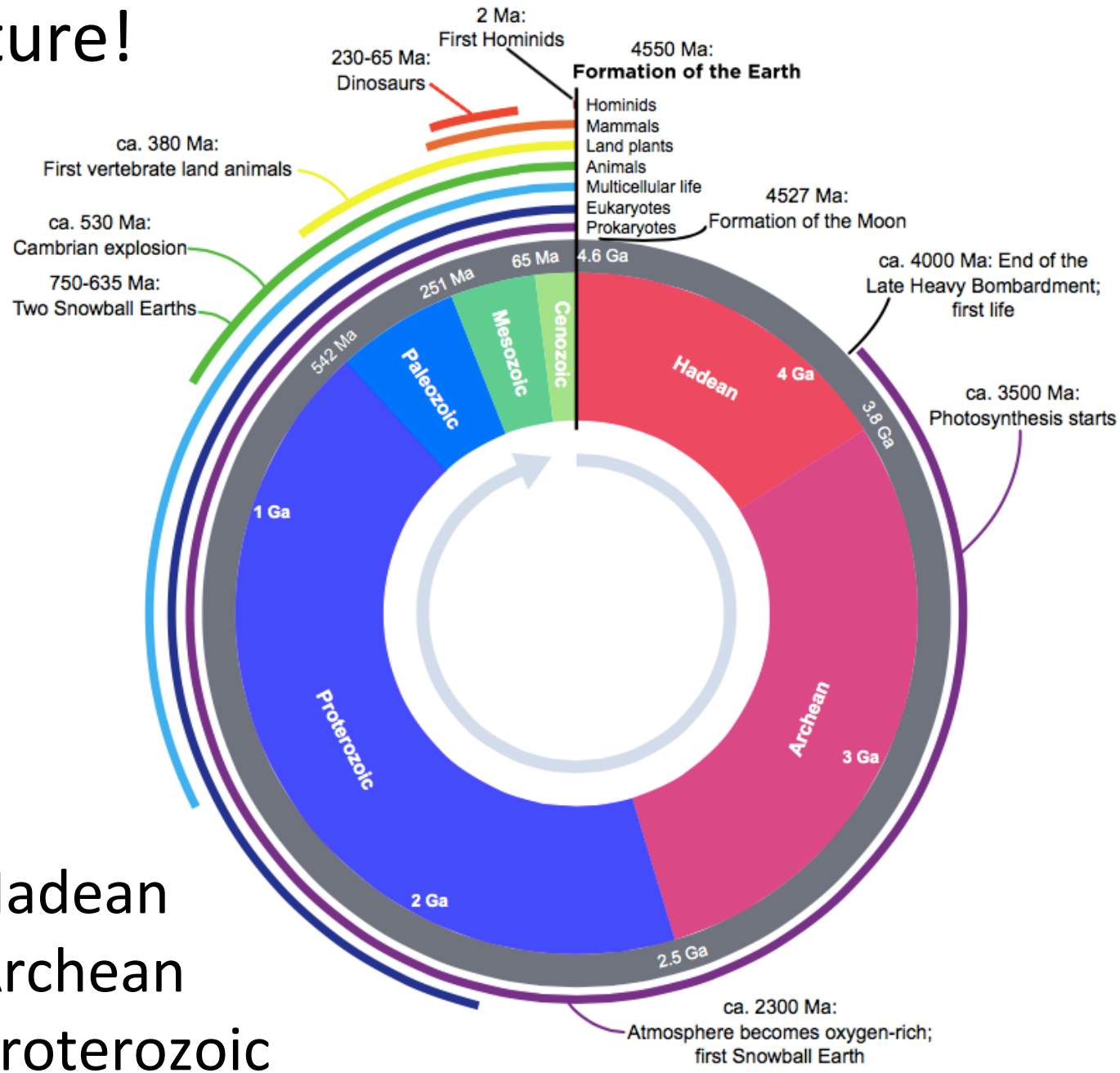
[NeXSS-ROCKE3D]

Nomenclature!



4.6-3.8 Gya Hadean

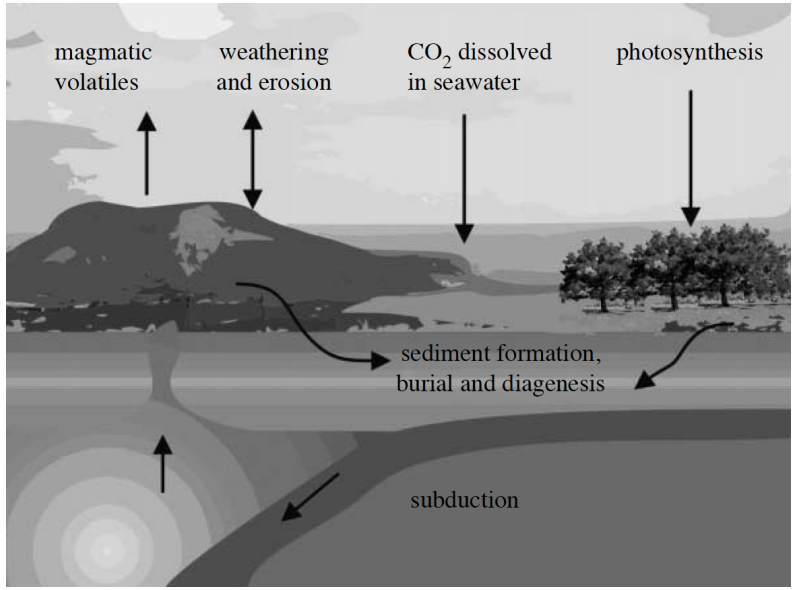
3.8-2.5 Gya Archean

2.5-0.5 Gya Proterozoic

Habitability Needs

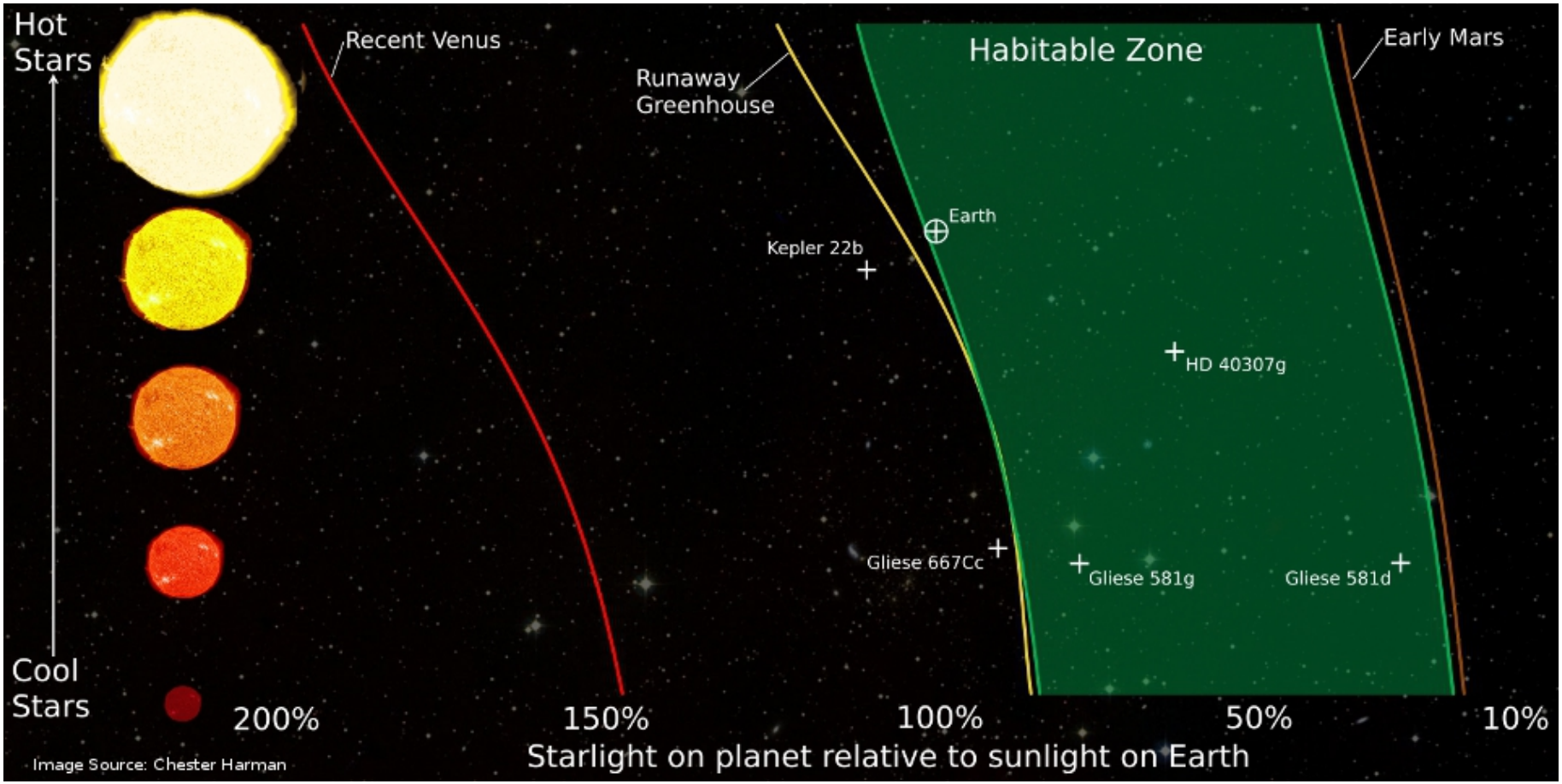
(basic requirements for complex multicellular life as we know it?)

- Liquid Water
- Stable Climate/Carbon Balance?
  - Plate Tectonics (buries carbon)
    - Exposed Continents (Weathering/Erosion)
  - Volcanism (releases carbon)
  - Biology (mediates carbon)



Faint Young Sun Paradox (FYSP)
&
Habitability Through Time (HTT)
Earth/Mars vs. Venus

- Hard to get Earth warm enough to have liquid water during early Archean = 3.8-2.5 Gya
- Hard to get Mars warm enough for global scale oceans to persist in same period
- Martian magnetic field or plate tectonics? ~4 Gya
  - Yin 2012, Zahnle & Catling 2009, Solomon et al. 2005, Sleep 1994



Harman 2013 (http://phl.upr.edu/press-releases/anewhabitablezone)

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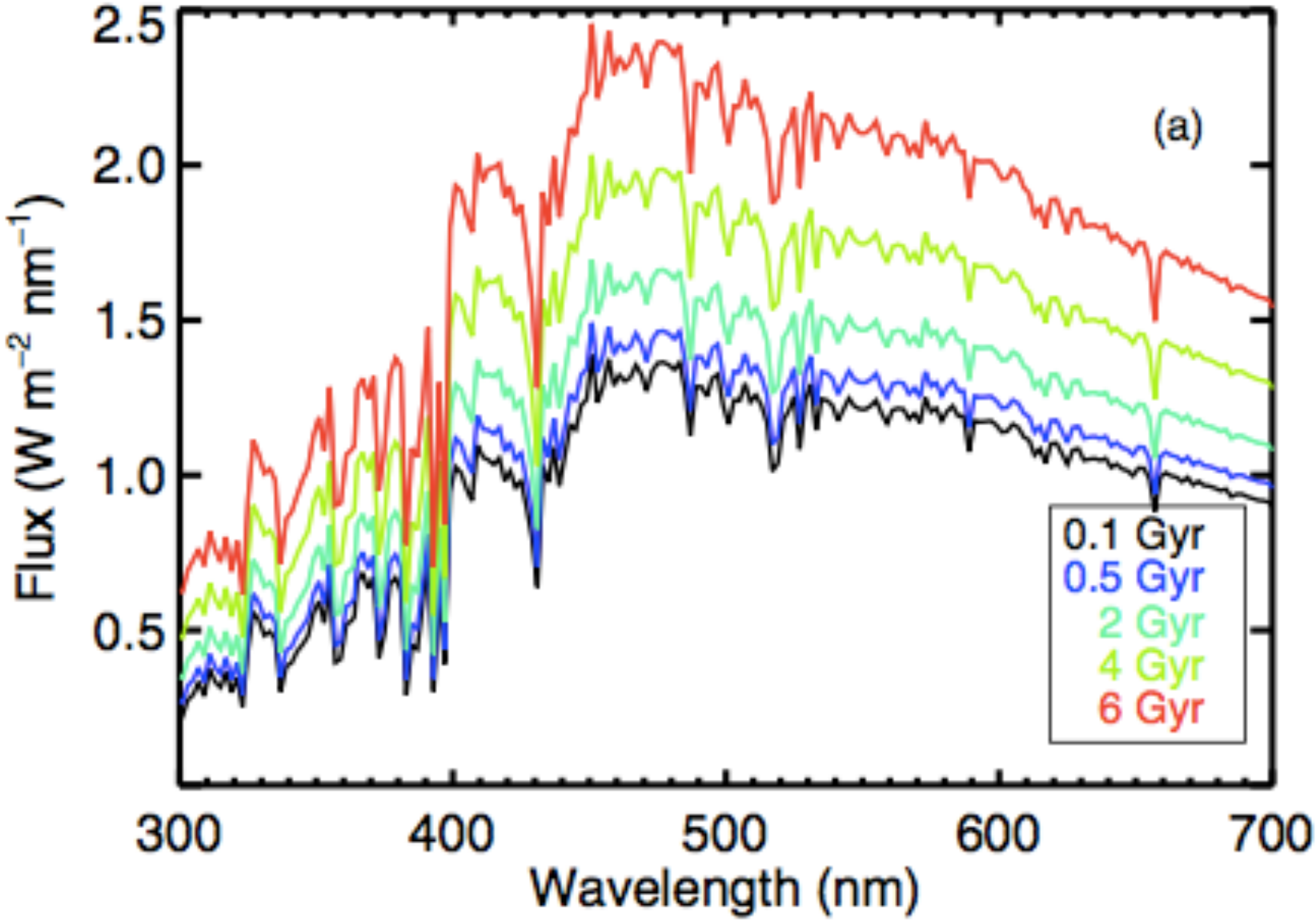
FYSP & HTT Ancient Venus?

- Lower solar flux 3-4 Gya
- Evidence for H_2O
- Slower rotation rate than Earth/Mars
- N_2 rich atmosphere?
- Plate Tectonics

Ancient Venus: Lower Solar flux at 3 Gya (2 Gyr)

Claire et al. 2012 (Solar Flux at 1 AU)



Ancient Venus: Water

- Water abundance
  - Earth & Venus received ~ same amount of H_2O?
  - High D/H ~150 × Earth
  - Estimates range **4-530m** of liquid water

- Early Dry/Wet impossible w/current knowledge
  - Arguments for & against both (Lewis & Prinn, 1984; Yung & DeMore 1999, Hamano et al. 2013).
  - Will future observations help us to constrain?

Venus slow Rotation a recent phenomenon?

1. Result of thick atmosphere (thermal tides):
   - Dobrovolskis & Ingersoll: Atmospheric tides and the rotation of Venus. *Icarus* 41, 1–17 (1980).
2. Perhaps thick atmosphere is not necessary:
   - J. Leconte et al. 2015

Sciencexpress

Asynchronous rotation of Earth-mass planets in the habitable zone of lower-mass stars

Jérémy Leconte,[1,2,3]* Hanbo Wu,[1,4] Kristen Menou,[3,5] Norman Murray[1,4]

Ancient Venus: N_2 rich Atmosphere?

C & N Budgets via Lecuyer et al. 2000

Inventory of carbon, nitrogen, oxygen and water abundances in Venus and Earth surface reservoirs

Mass of reservoirs	Earth	Venus
Bulk planet (kg)	5.97×10^{24}	4.87×10^{24}
Superficial C (kg)	5.4×10^{19} [a]	1.25×10^{20}
Superficial H_2O (kg)	1.41×10^{21} [b]	6×10^{15}
Atmospheric N (kg)	2×10^{18}	4.8×10^{18} ←←←
Superficial N (kg)	3×10^{18} [a]	$\geq4.8\times10^{18}$
C/N mass ratio	18	26
C/H mass ratio	0.69	$\approx10^{5}$

Nitrogen Sinks on Venus?

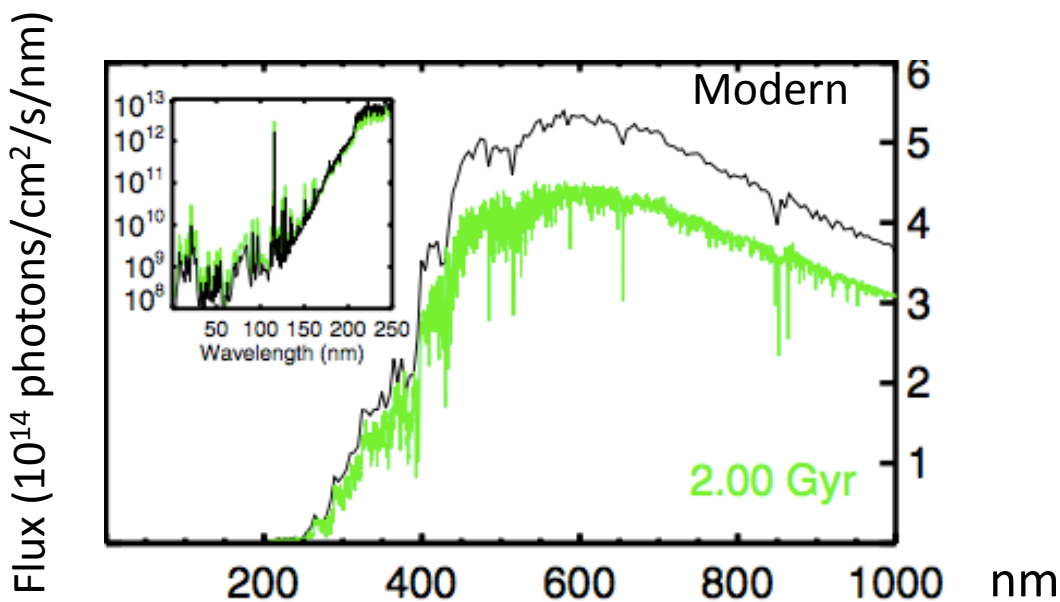
- Via solar wind: N2 + n ➔ C14 + p
- Lightning: N2 + e- ➔ N + N-

Venus Geology

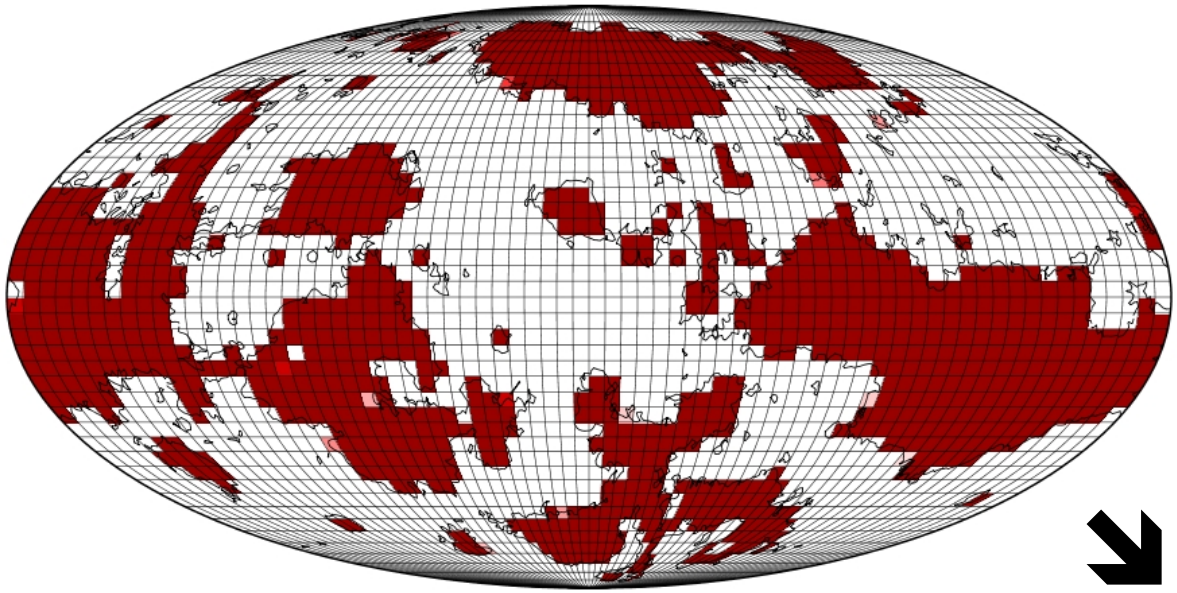
- Cosmochemical/geochemical **models** imply Venus' bulk composition ≈Earth (Lodders & Fegley 1998)
- Resurfacing of Venus in past 750My-1Gy
- Minimal magnetic field (today)
- No present day evidence of **global** plate tectonics
  - Evidence for past tectonics? See Platz et al. 2014.
  - Present day evidence of volcanism (Venus Express)?
  - VERITAS NASA (Stage 1) Venus proposal awarded
- Need in-situ measurements of Xe, Kr, Ar & isotopes
  - DAVINCI NASA (Stage 1) Venus proposal awarded

GISS: 3-D General Circulation Model

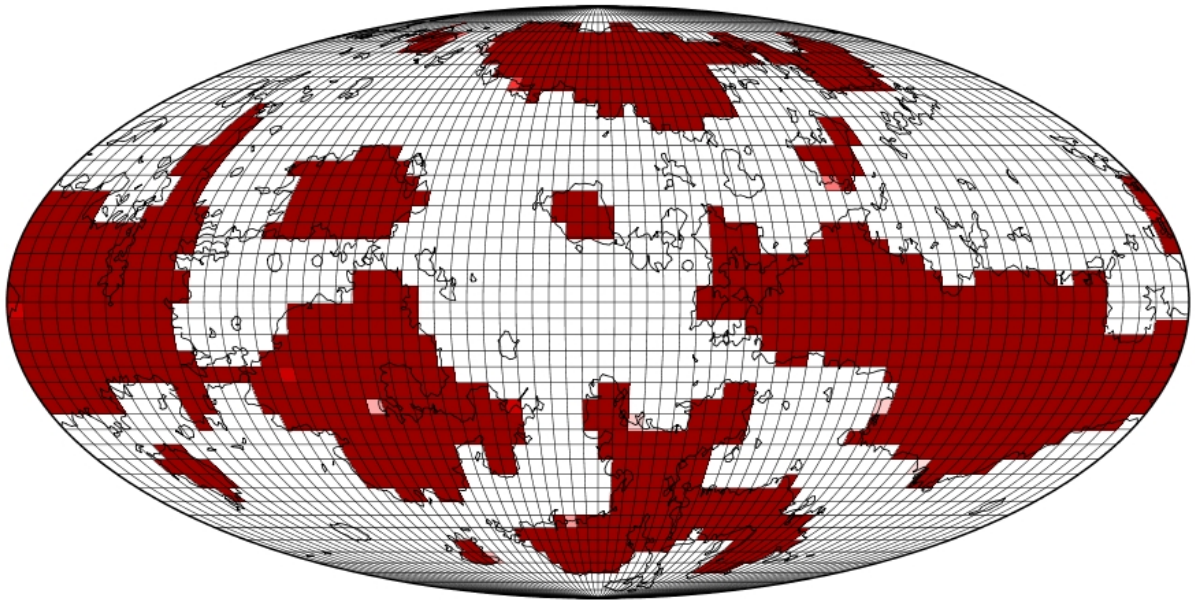
- 4 x 5 lat/lon, 20 layer, fully coupled ocean
- Modern Venus topography, radius, mass, spin
- N_2=1bar, CO_2=0.4mb, CH_4=0.001mb
- 2.9Gya solar spectrum via Claire et al. 2012
  - **82%** of present day solar luminosity



3-D Model Setup: Venus topography changes

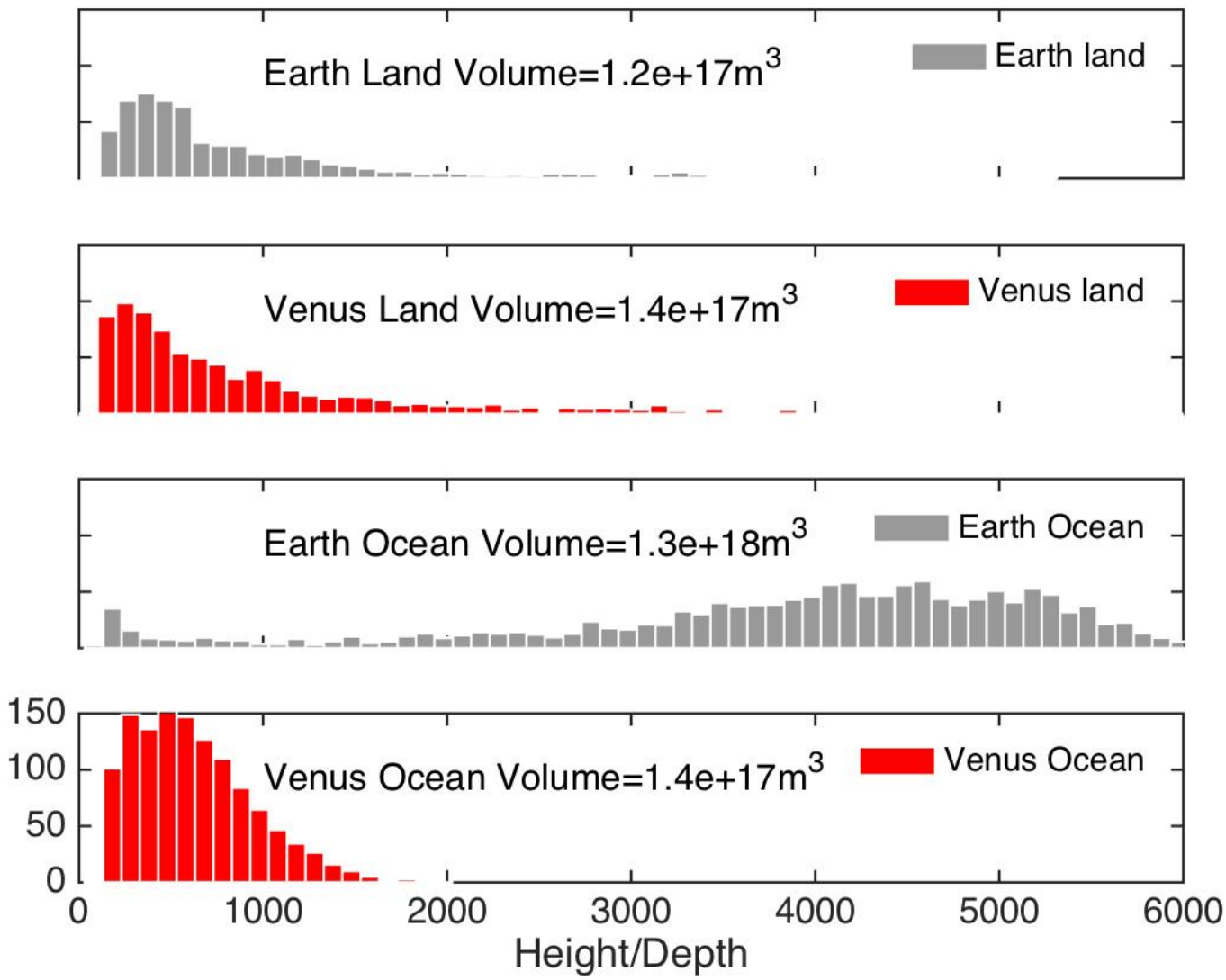


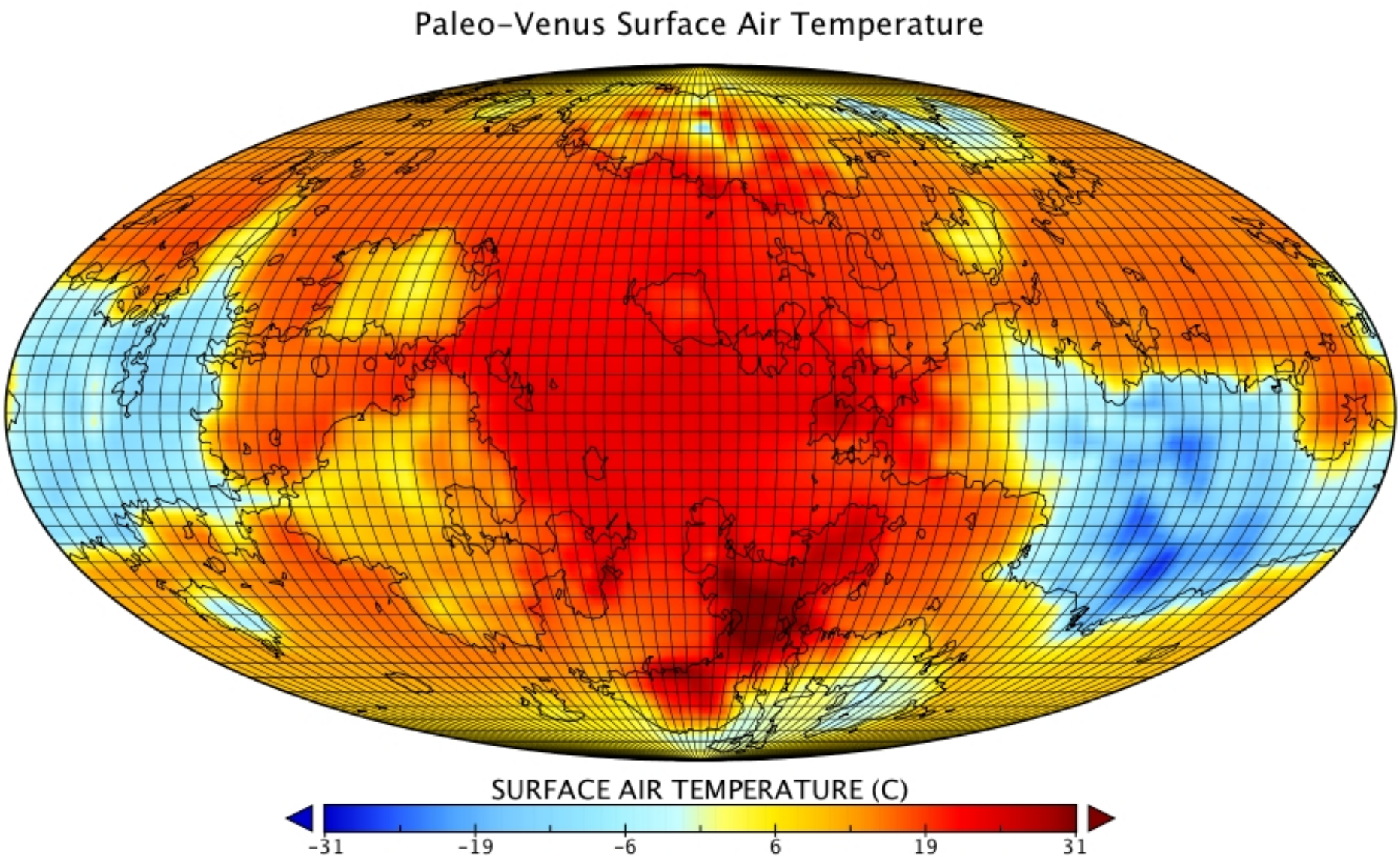
Removing a few islands



Venus land/ocean

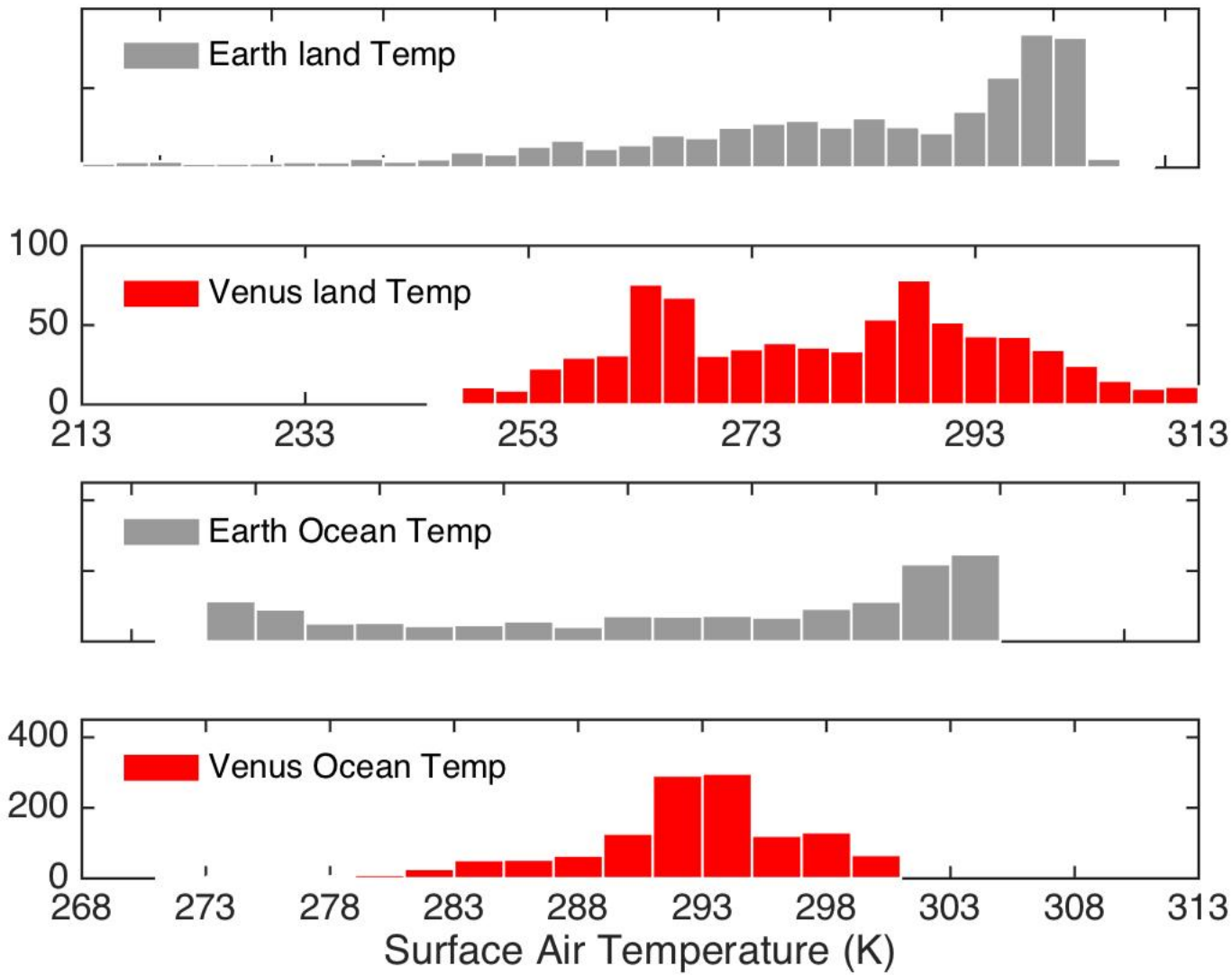
Venus Ocean volume equivalent to **310m** depth average





Mean surface temp = 284K vs 1D value of 300K

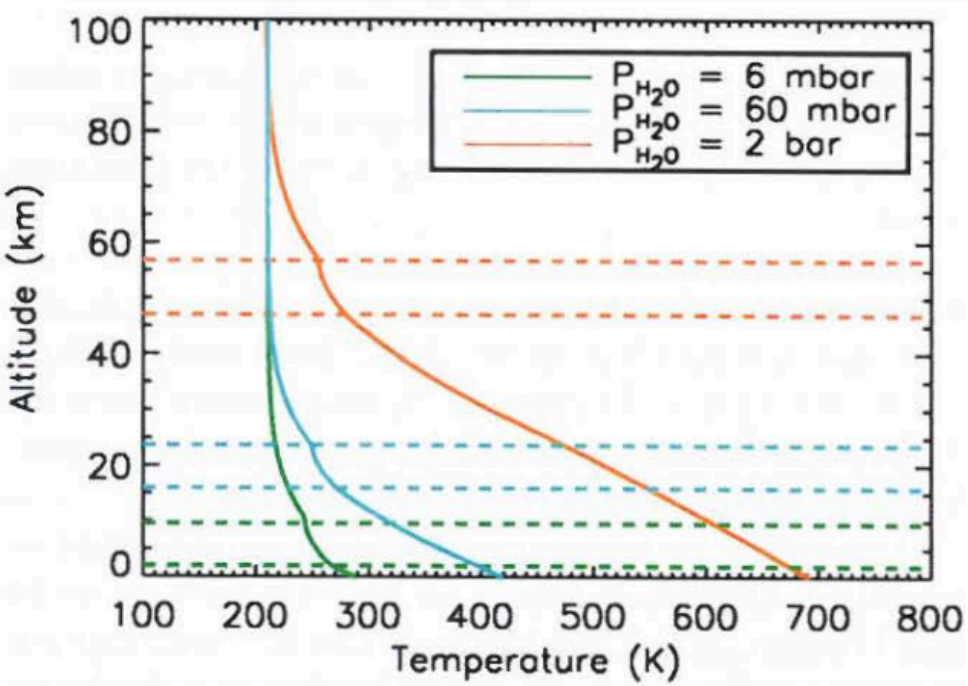
Venus vs Earth surface air temp

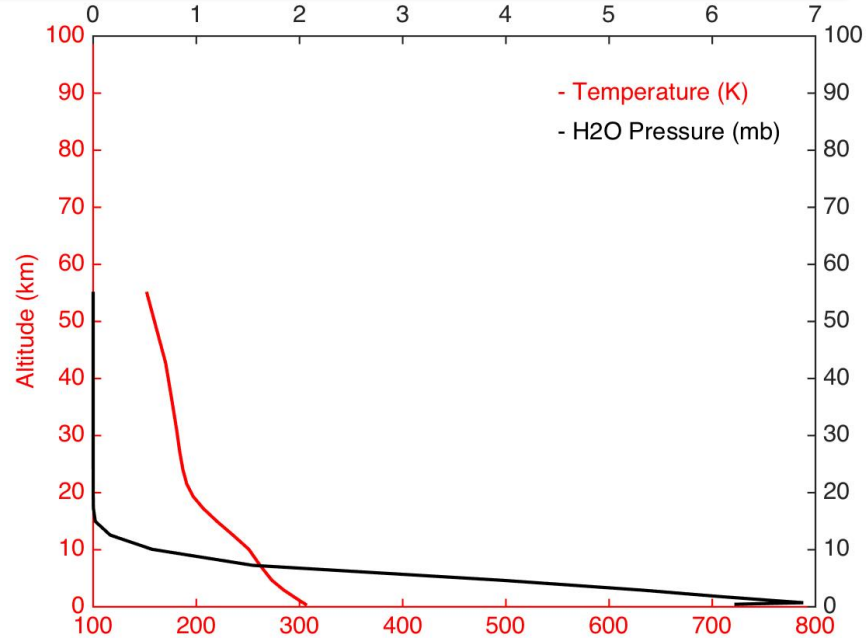


1-D Comparison: Grinspoon & Bullock 2003

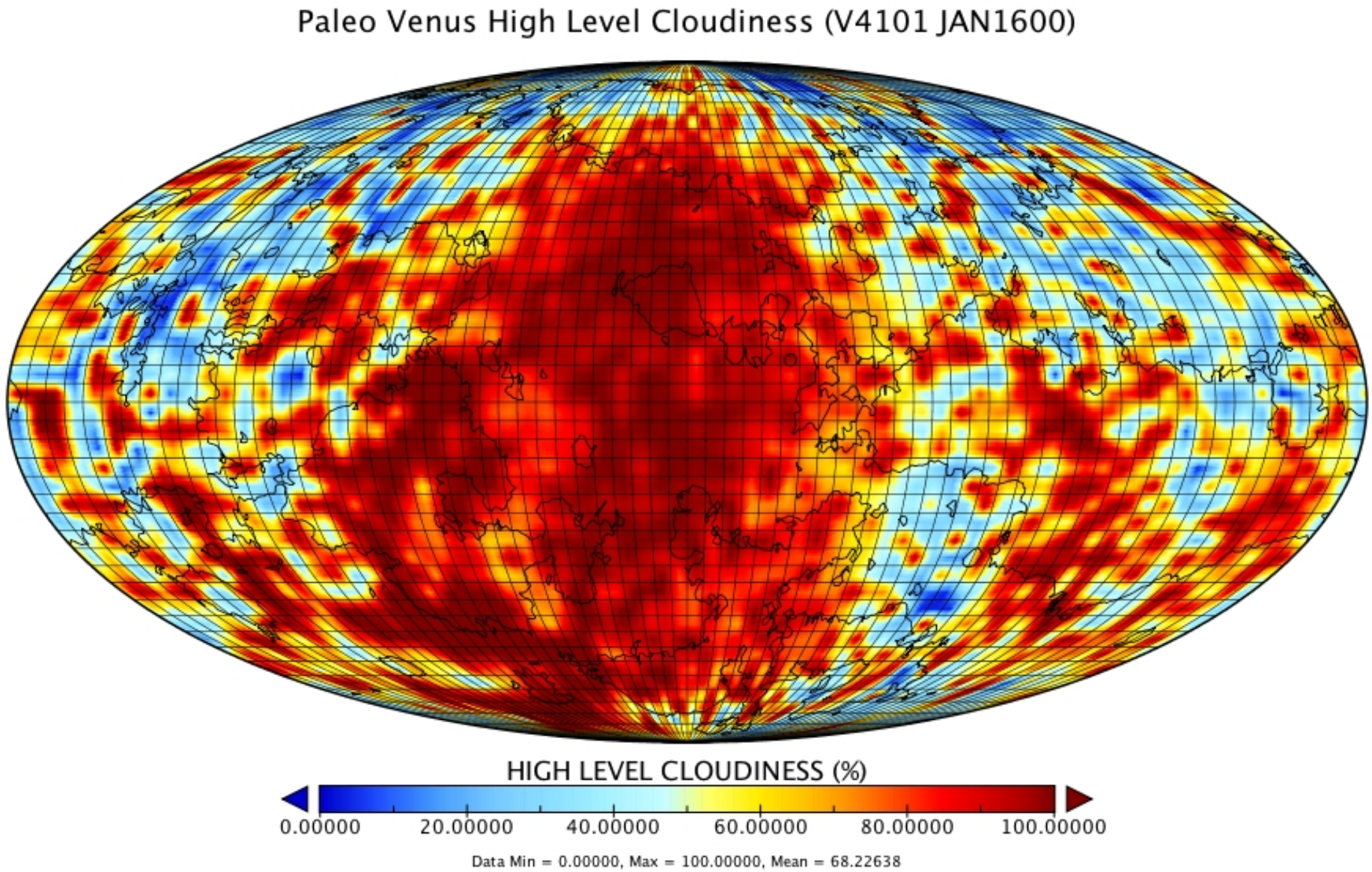
- 1 bar N_2, CO_2=.35mb, H_2O=6mb
- 100% cloud cover
- Yield mean global surface temp ~300K

1D vs 3D (hottest surface grid point)

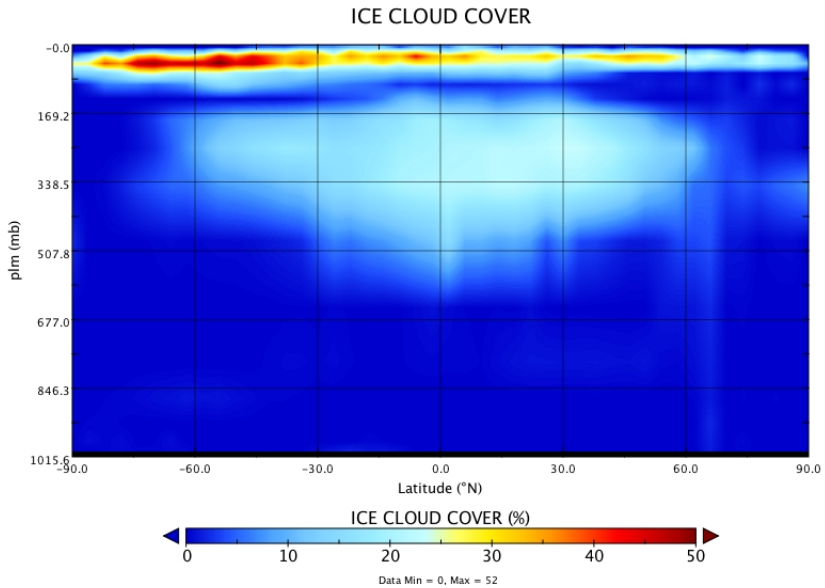




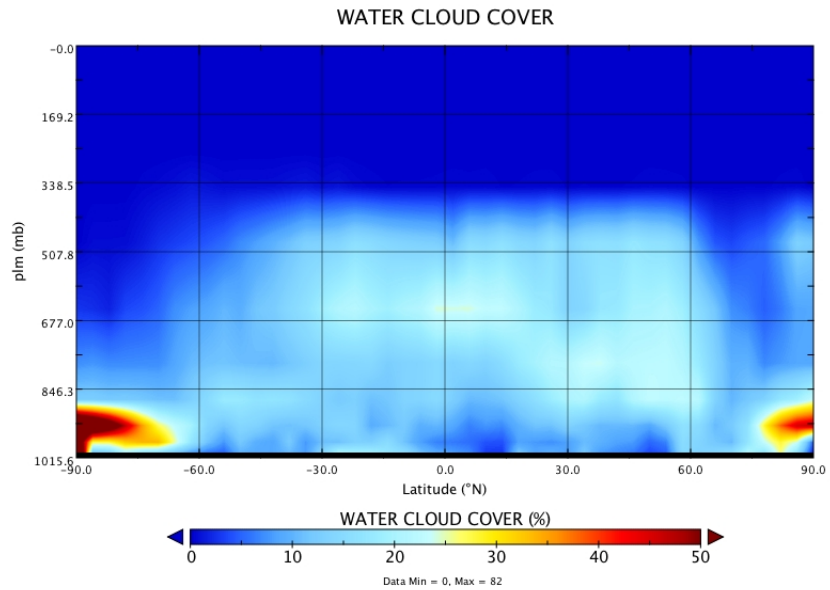
3-D explains why the 1-D 100% cloud cover works!

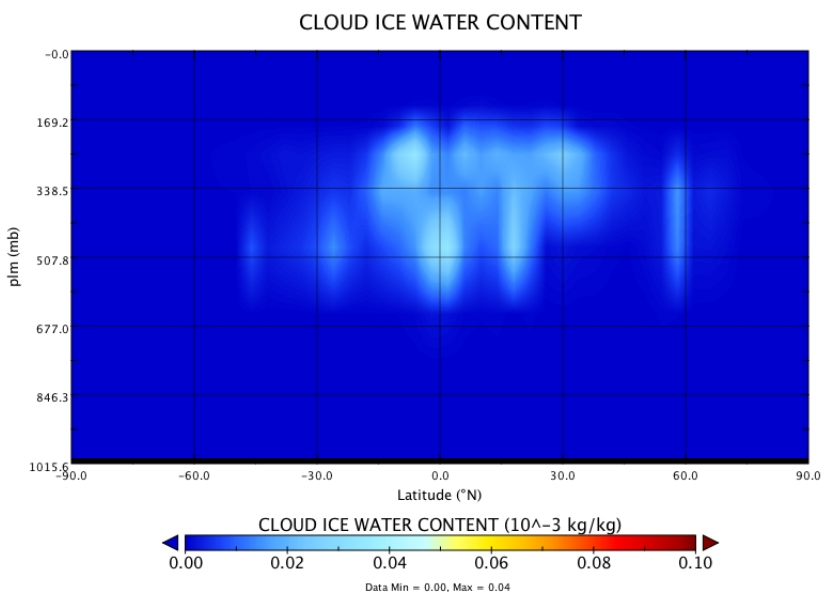


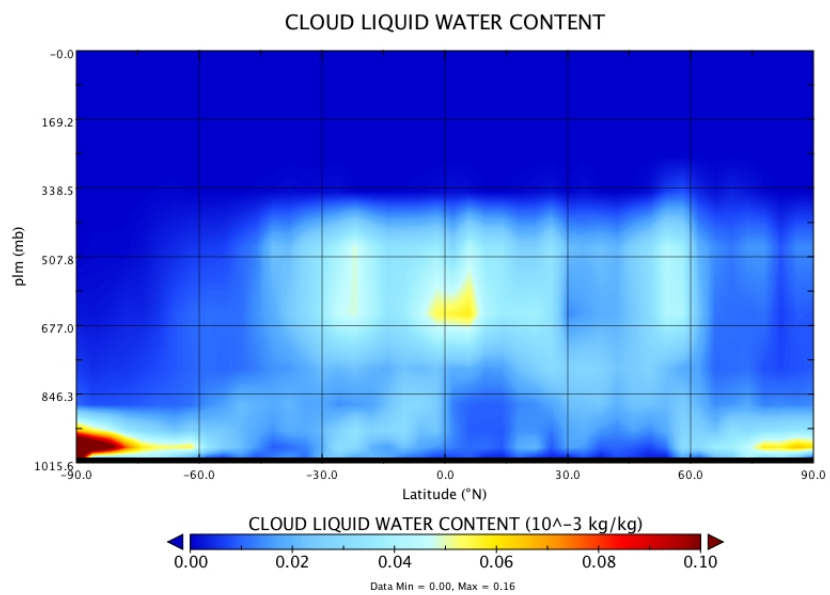
Cloud Type? (liquid->ice @ 500->300mb, -5<T<-35)



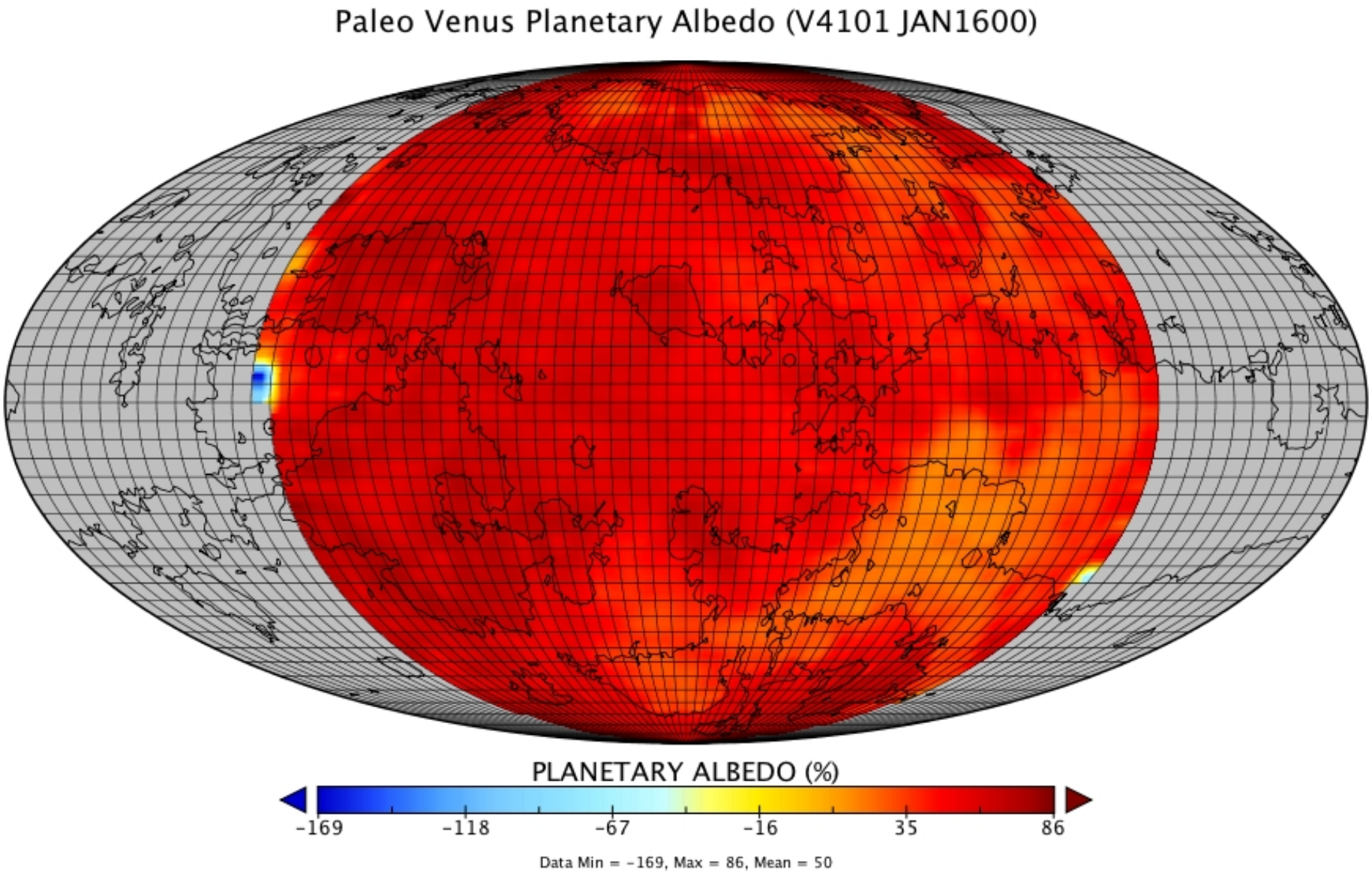
4x5 low top artifact?



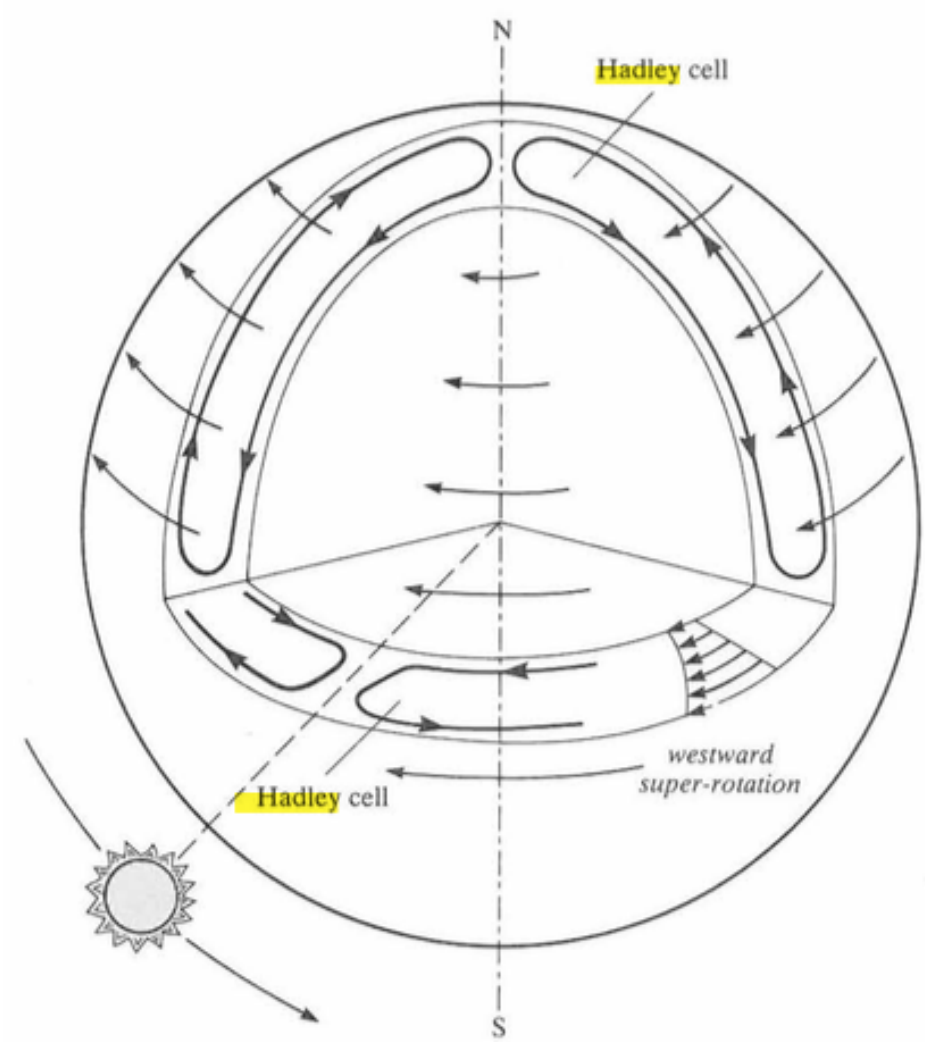




Planetary Albedo is what you would expect



Venus' Hadley Cell is different from Earth's



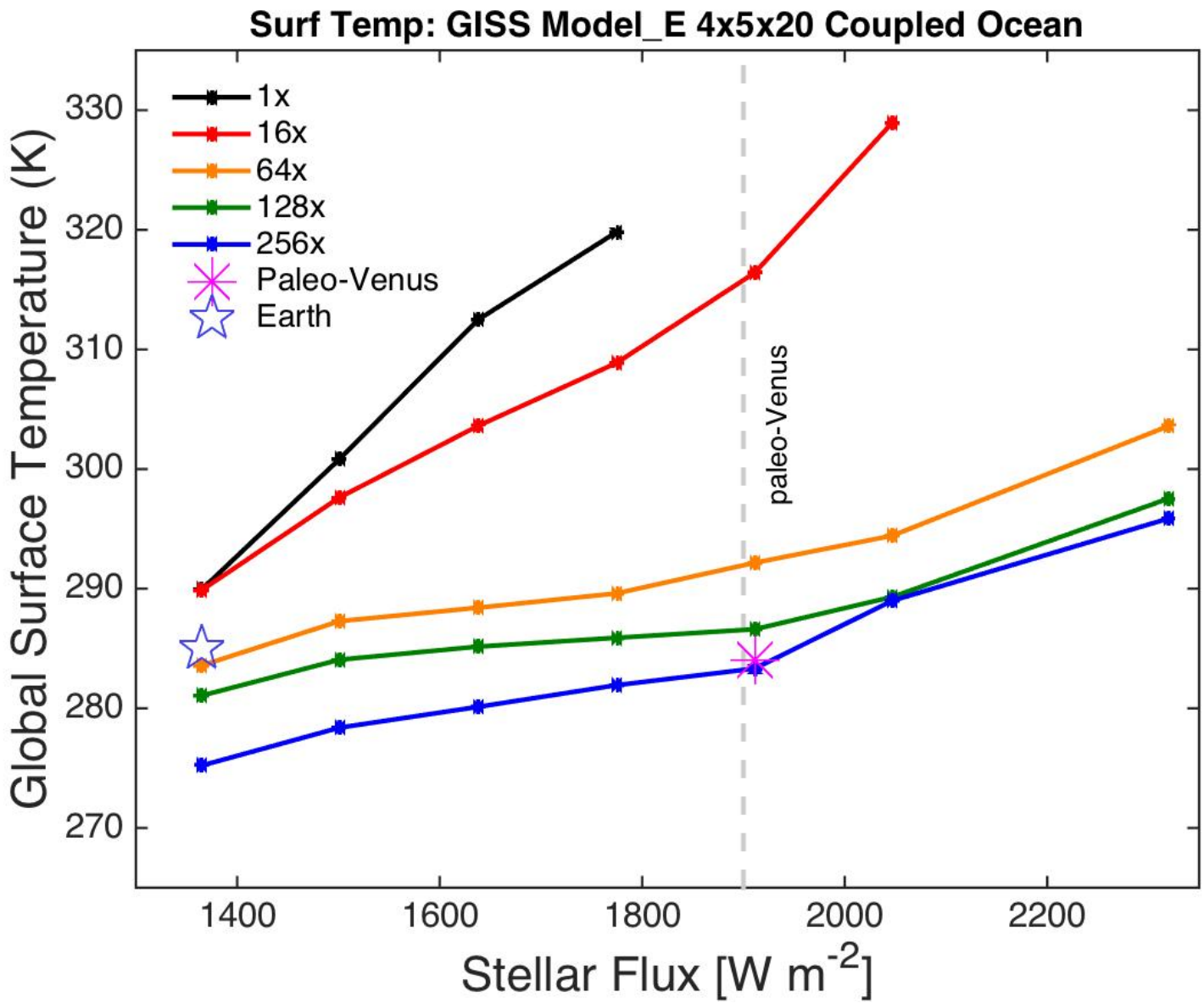
Ancient Venus seeded Earth?

The literature on mass exchange between terrestrial planets is clear:

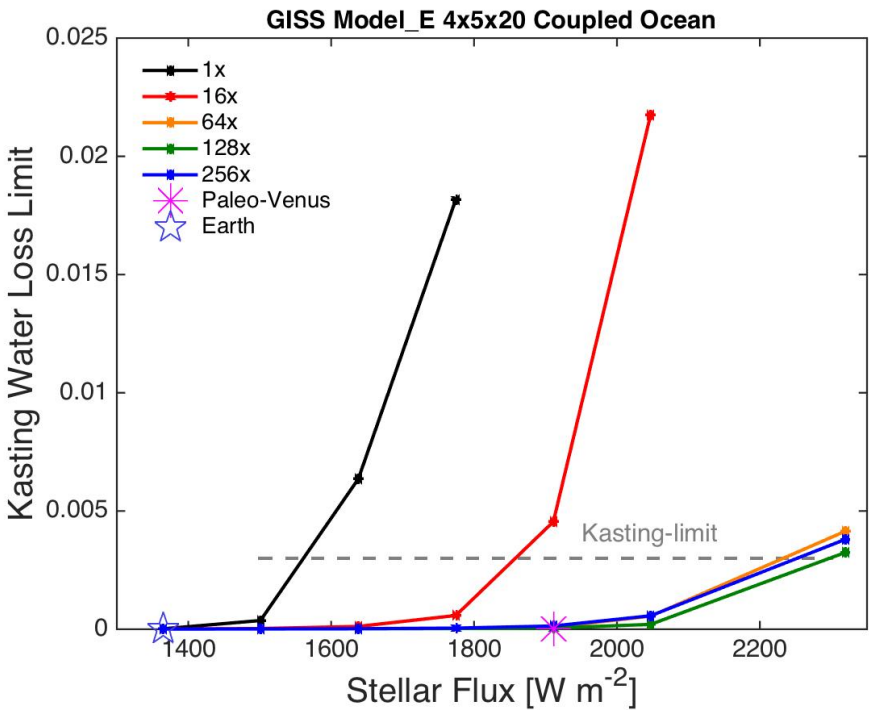
Gladman 2005 (Astrobiology 5, 483)
Melosh 1993 (Meteoritics 28, 398)
Melosh 1984 (Icarus 59, 234)

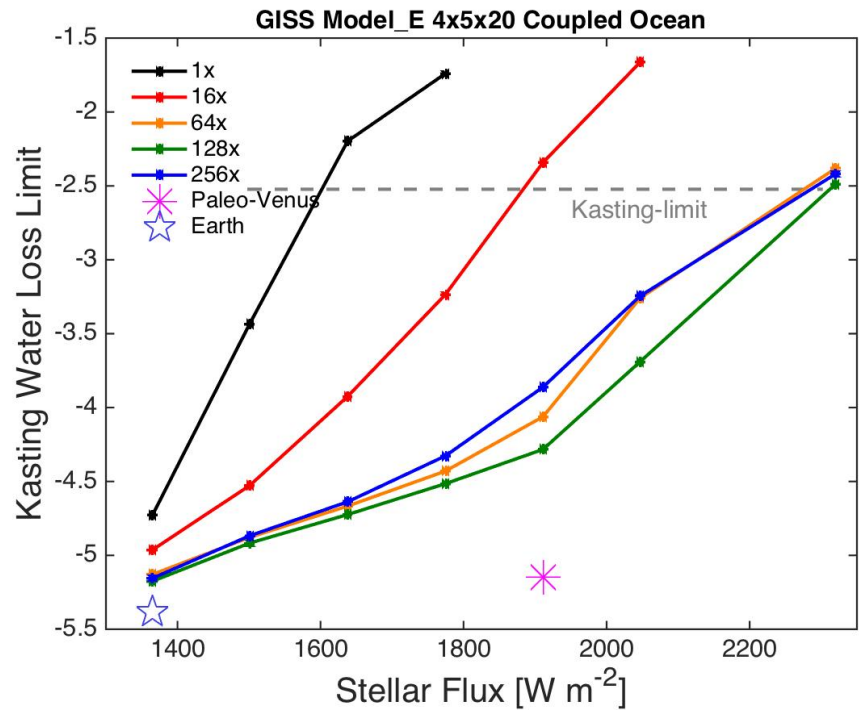
Do we have Venus meteorites on Earth today?
Who seeded who?

Other Worlds



Will they lose their water anytime soon?





Conclusions

- Venus not Earth or Mars was the first habitable world of our solar system?
- Can fewer assumptions be made for Venus vs Earth or Mars?
- Need for new in-situ observations to confirm Venus' geologic history – and water inventory

But lets keep looking for Ziggy Stardust on Mars.

Minerva

Isaiah

Darren Archibald

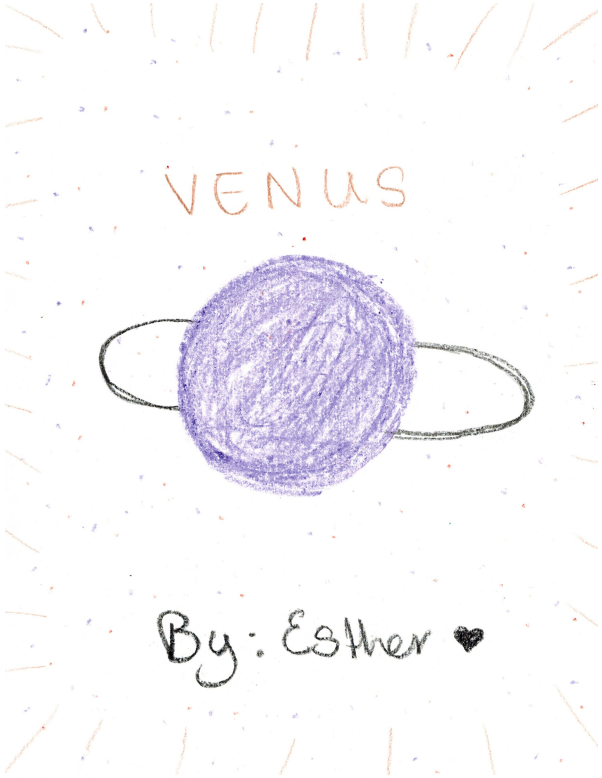
Alex. C

Ava

Mariam Abalo-Toga

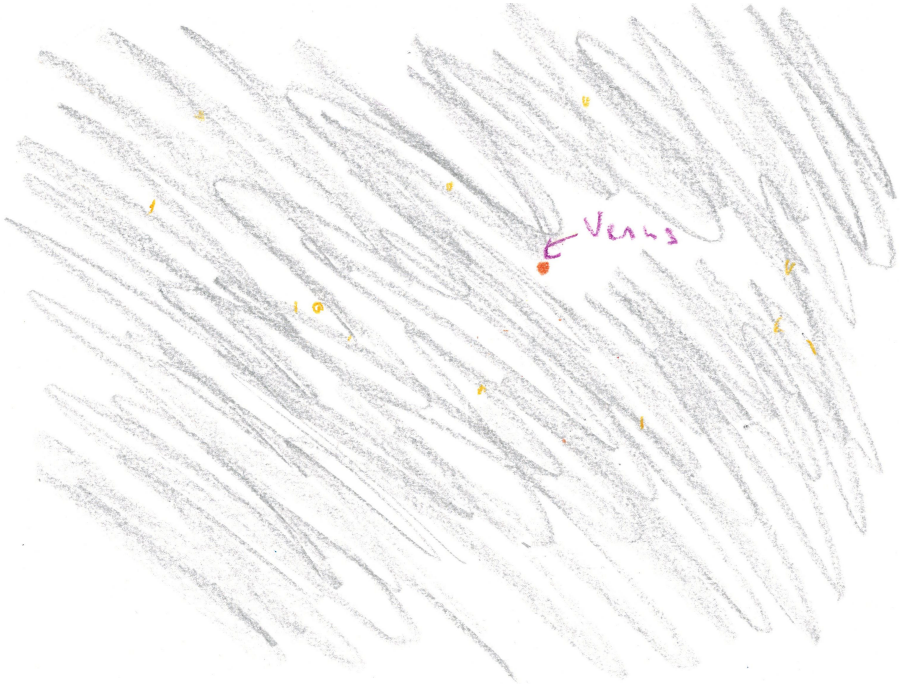
Venus

Helena



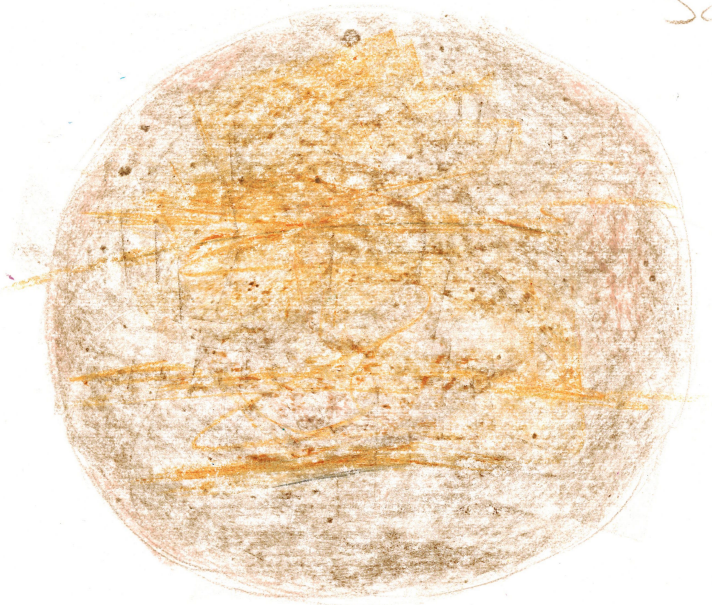
Hana Kaneko

Giannina



Iris

Jonathan Soto

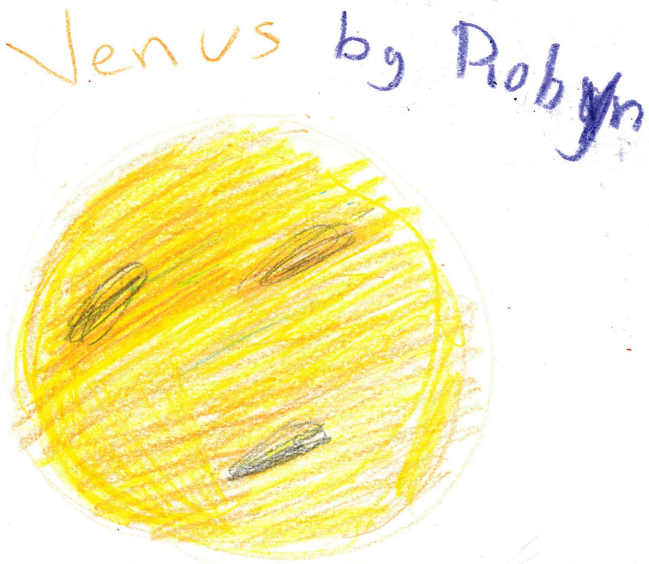


Harper Clees-

Baron

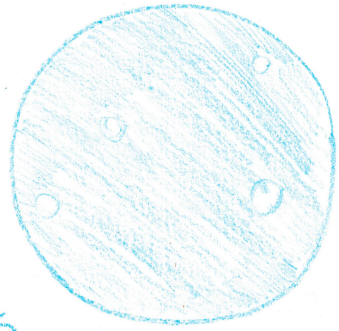
Alex

Khakima Khalizova


Venus by Robyn

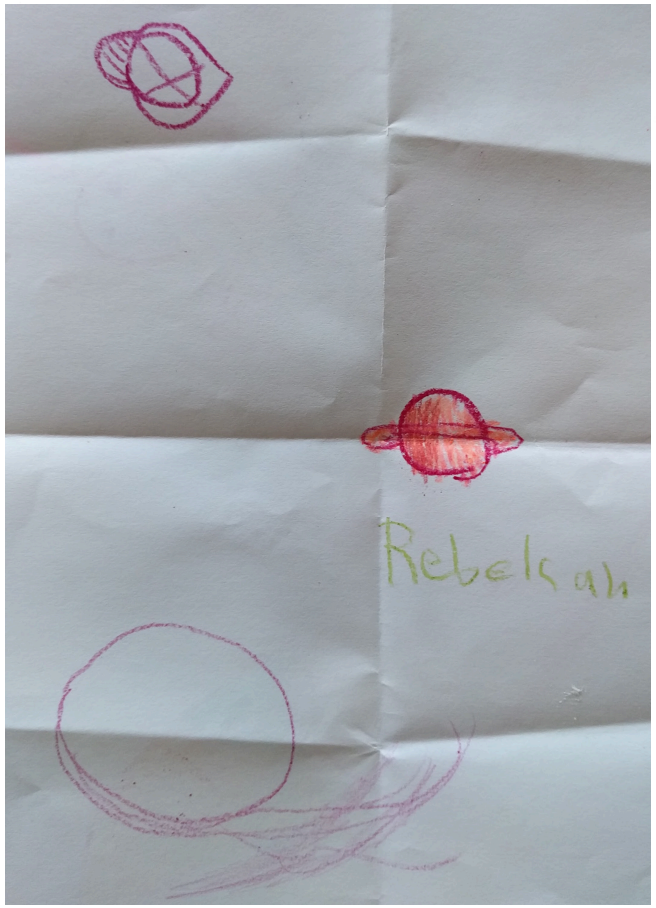
Samantha
Ratner

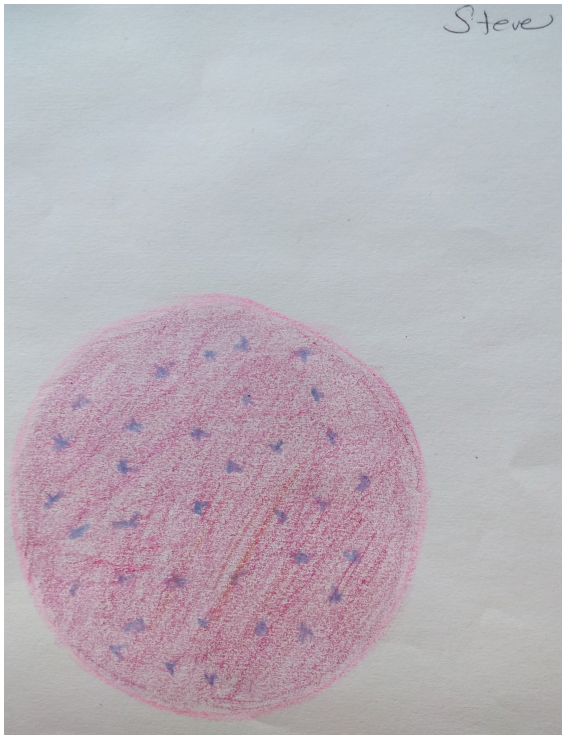
Miranda


Venus
By Mandi

MATT

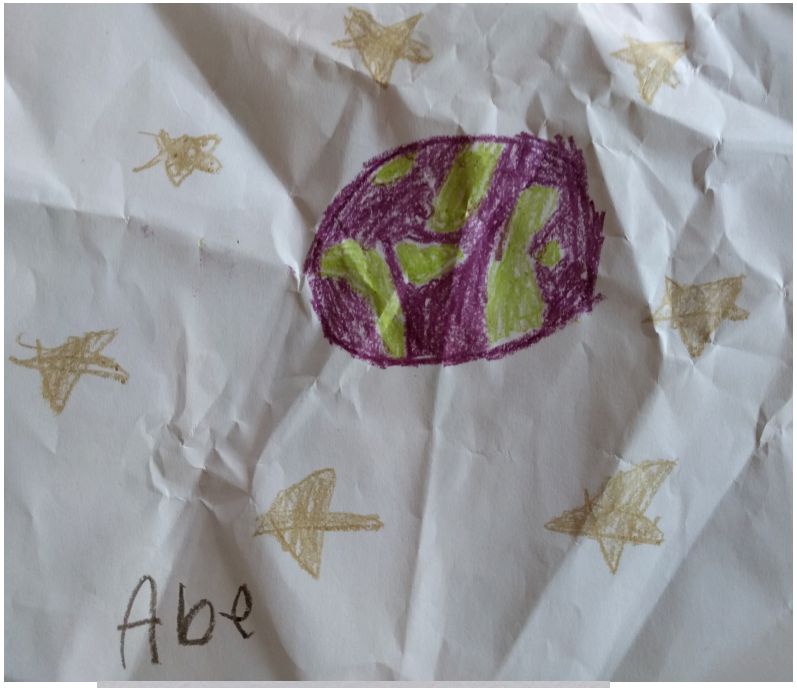
SUSUSah


Rebeka

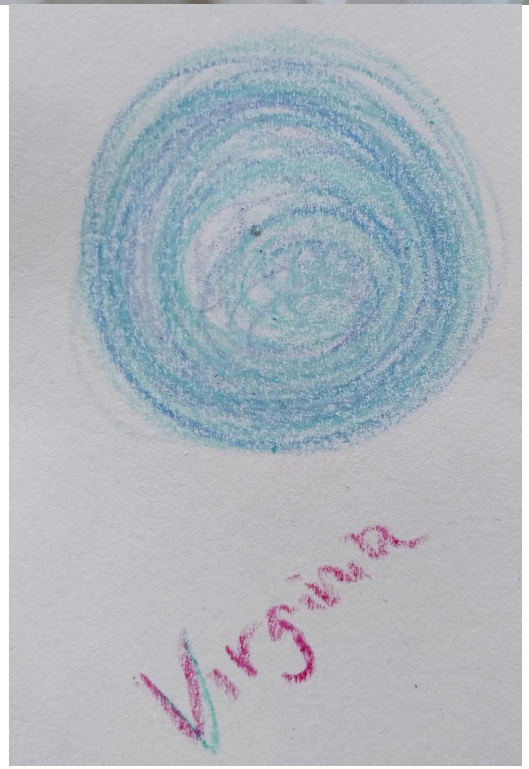

Steve

MOM

Evan


Abe

KAY


Virginia