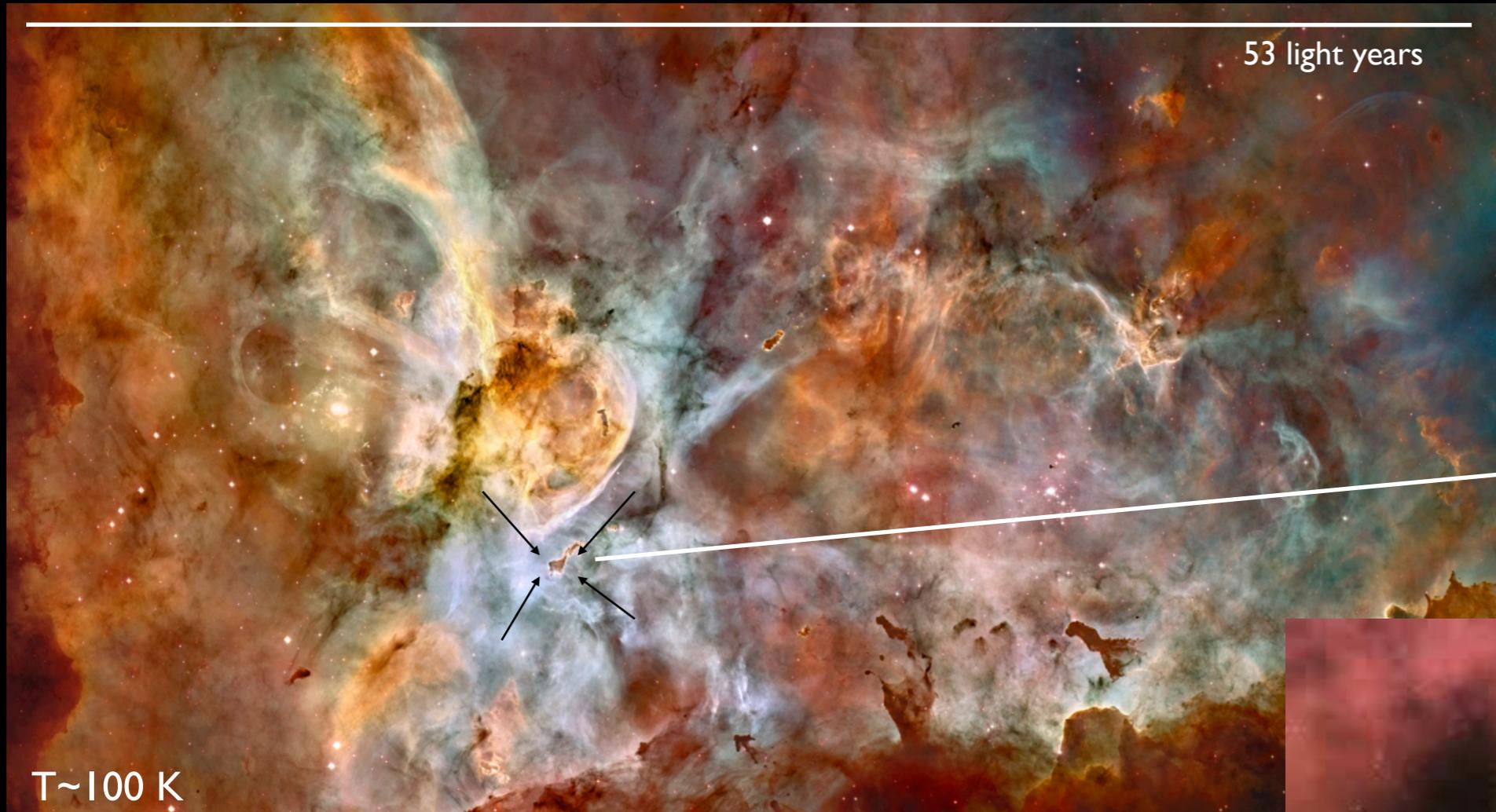
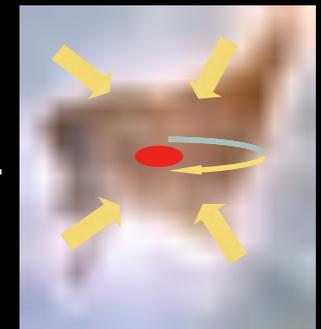


Challenges in understanding the formation of planetary systems

Planet formation in a nutshell



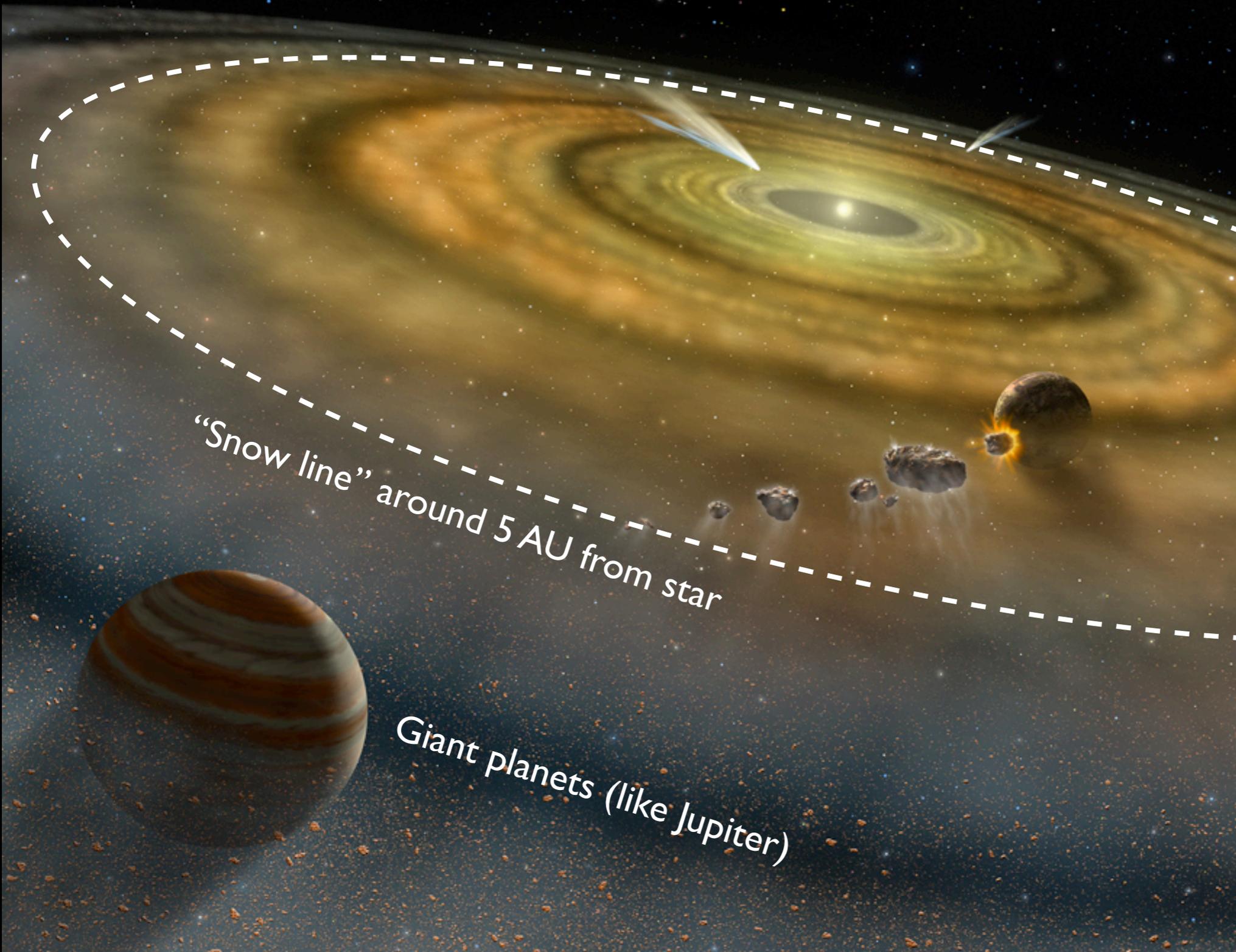
Gravitational collapse/
contraction of dense clumps
to accreting proto-stellar
disks



The proto-stellar/proto-planetary disk may range from a few thousandths to a few tenths of a solar mass. Initially - 99% is gas by mass, 1% is solids (dust $< 1\mu\text{m}$).



Planets form in
some 30-50 million
years around stars
like the Sun

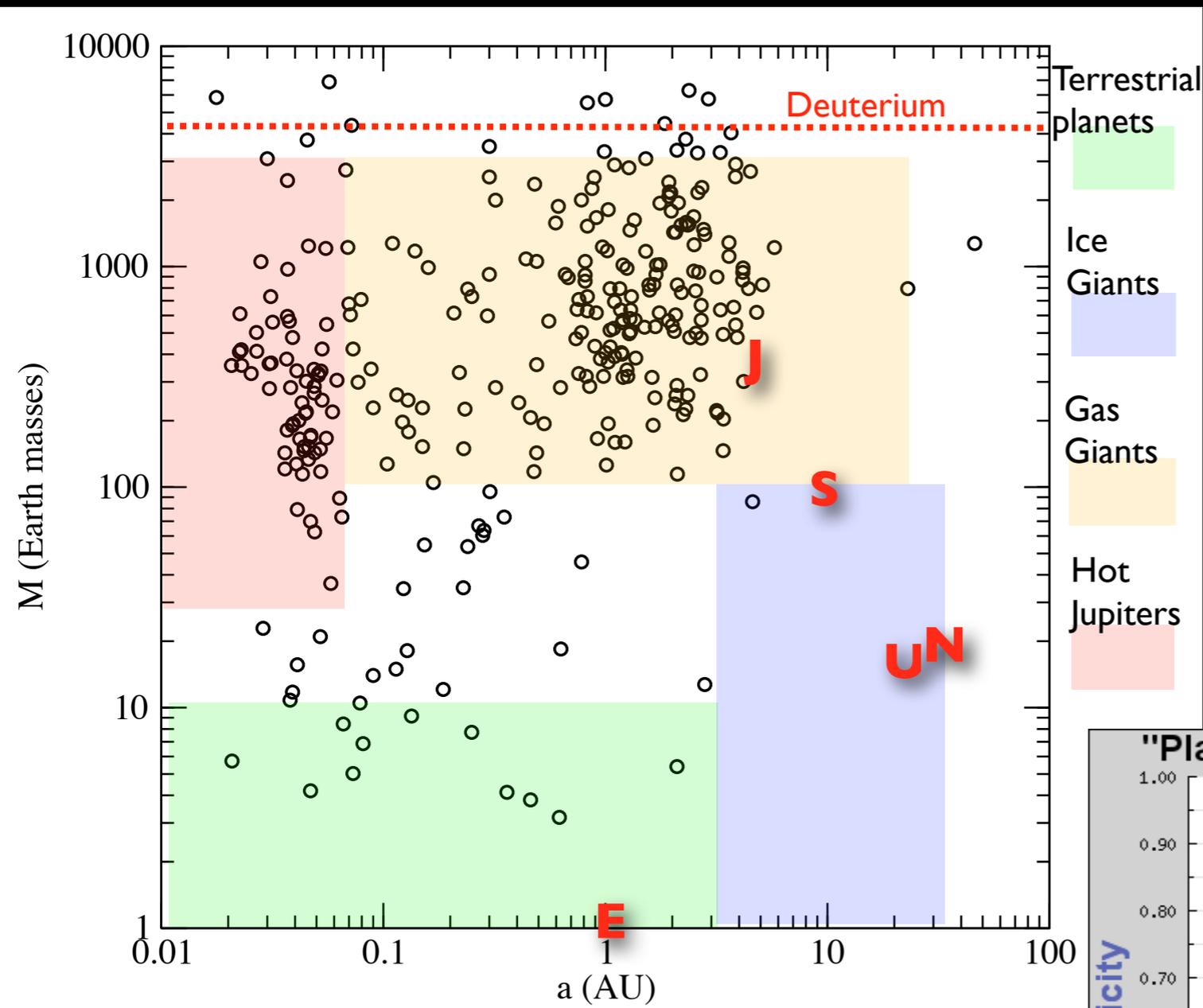


“Snow line” around 5 AU from star

Giant planets (like Jupiter)

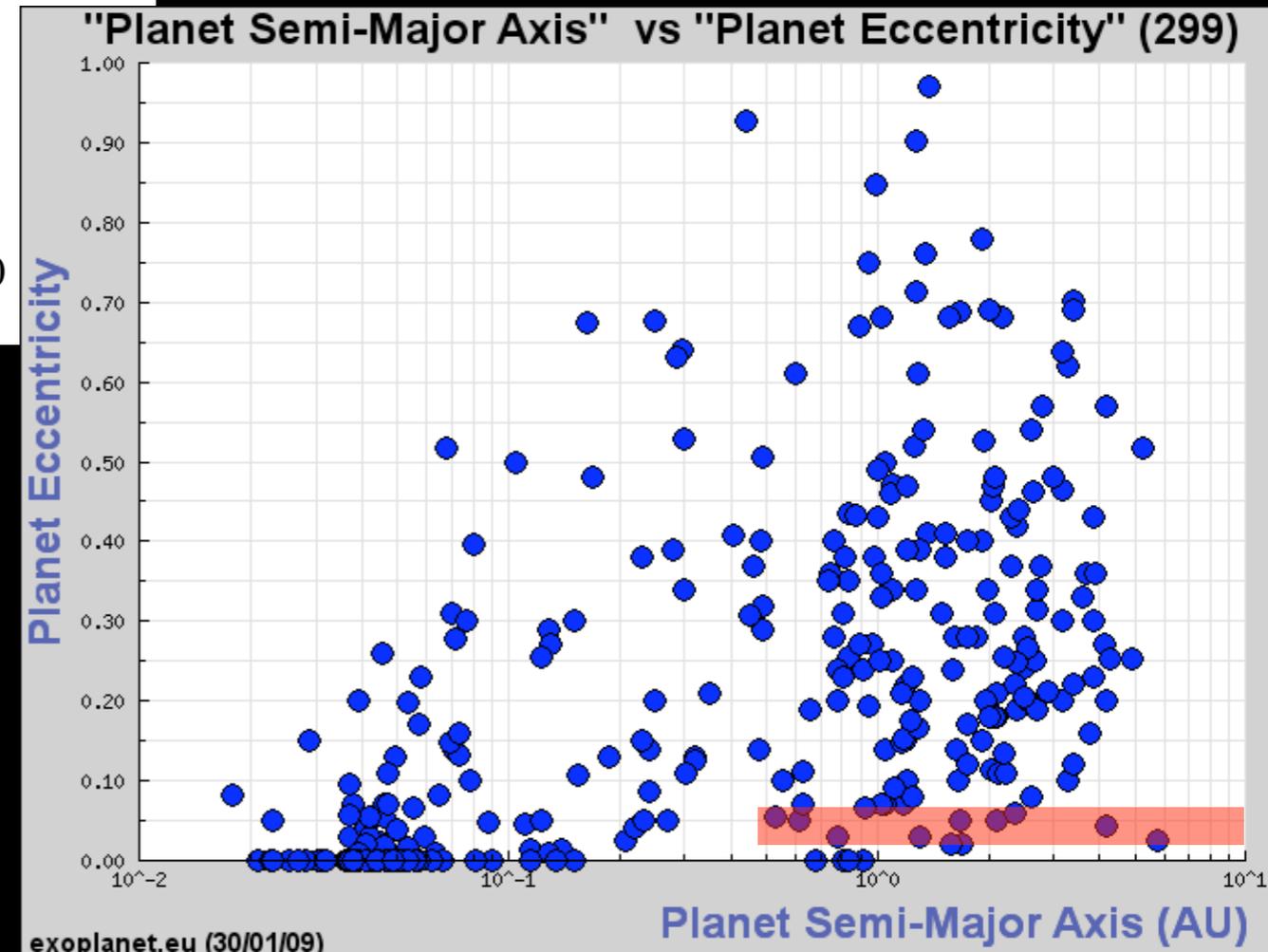
Most giant planets
expected to form
close to the “snow
line”...

The problem is that exoplanetary systems exhibit great diversity...

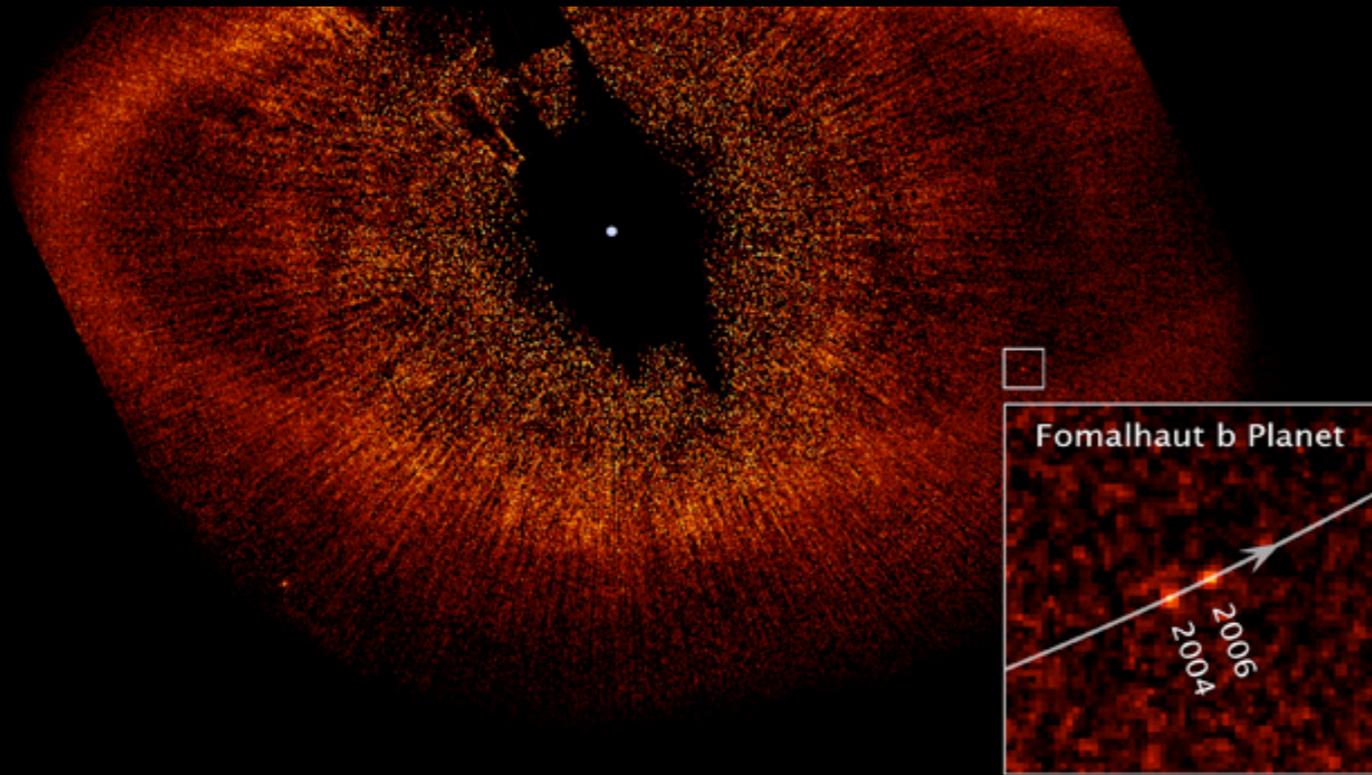


Many appear to be at "dynamic capacity" - i.e. planets are packed as closely as allowed without creating instability...

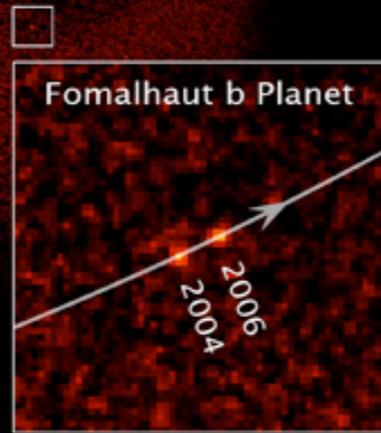
Many exhibit far more elliptical (eccentric) orbits than our own solar system



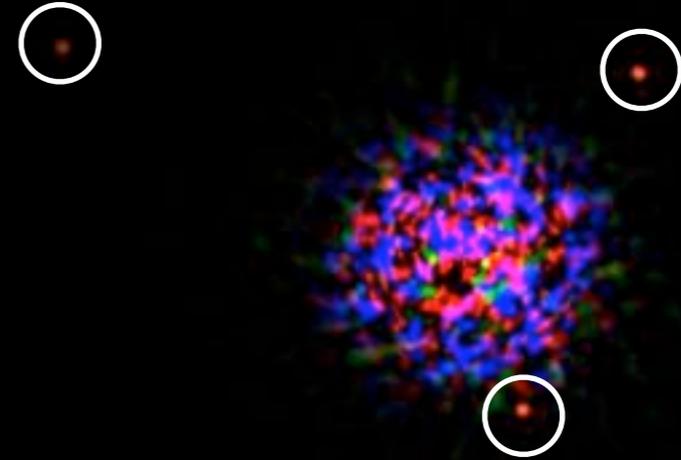
Direct imaging of gas giant planets (at least as massive as Jupiter)



119 AU from star



B



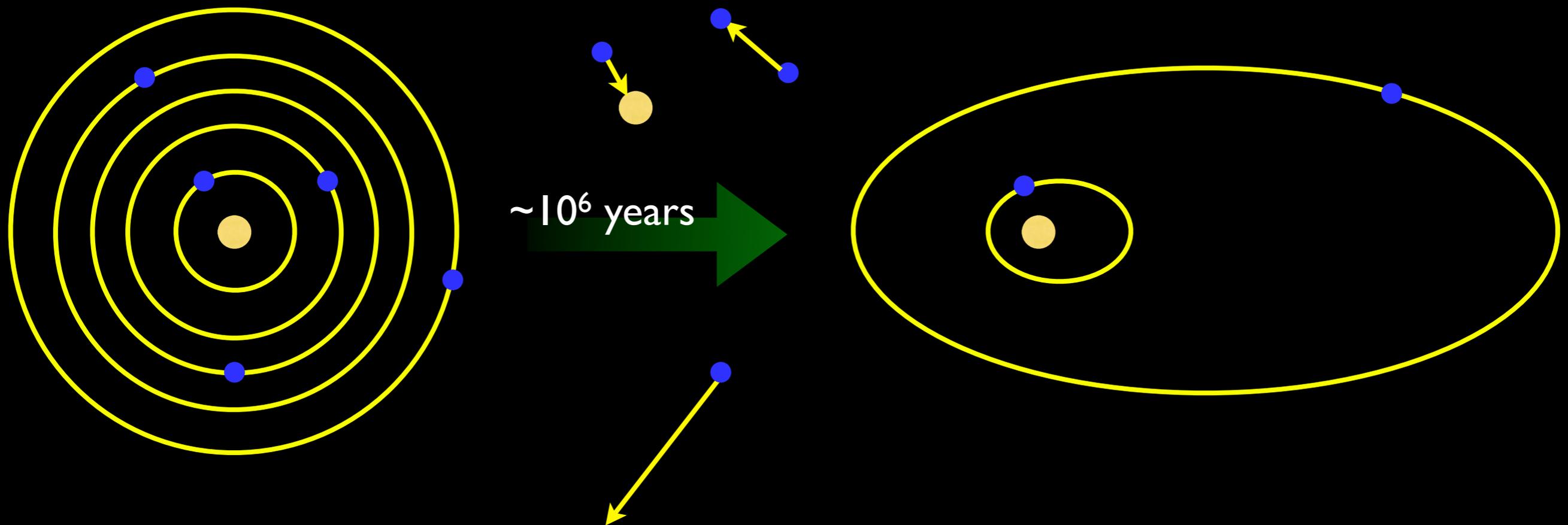
24, 38, 68 AU from star

$\frac{20\text{AU}}{0.5 \text{ arcsec}}$

What are these planets doing here ?!

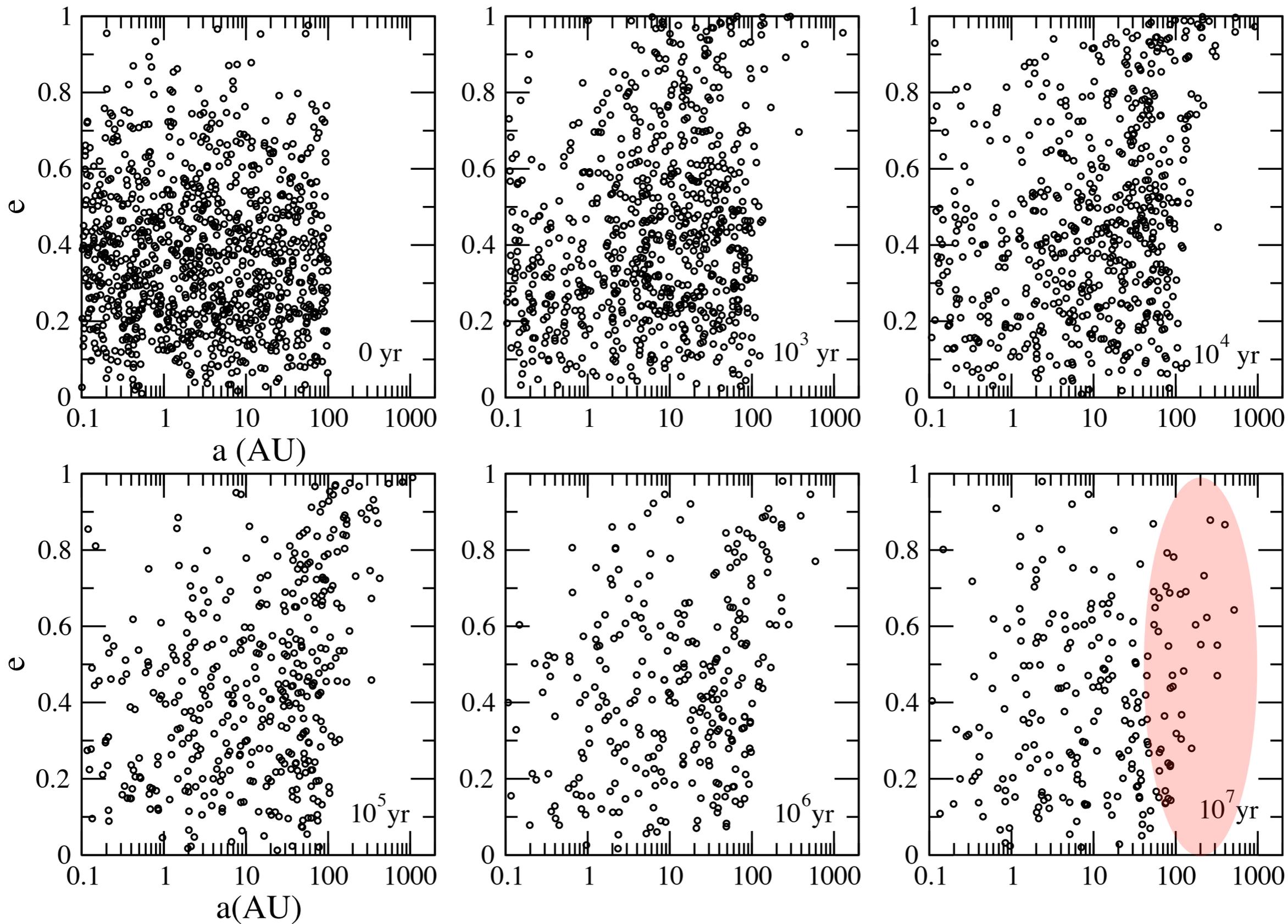
Scattering of planets (“relaxation”) in dynamically active systems can lead to many properties of the observed distribution of orbits (also predicts ejection of planets altogether..)

Highly non-linear problem



We model with high-precision “N-body” (gravitational) simulations of many statistically identical realizations of particular initial conditions

100 planetary systems, 10 initial planets each, evolved over 10 Myr (Scharf & Menou 2009)



(~10 hrs CPU per planetary system)

We use Monte Carlo techniques to generate fake data (i.e. for an imaginary observer studying this population of planets at arbitrary time and relative orientation)

Issues include:

Dealing with the small numbers in the (interesting) “tail” of the planetary distribution

Mining the outputs: 10^7 yr timelines, snapshots per year for 1000 objects, changes/events occurring on both on very short and very long timescales

Determining appropriate statistical questions to ask - e.g. what is conditional probability for outermost planets ?