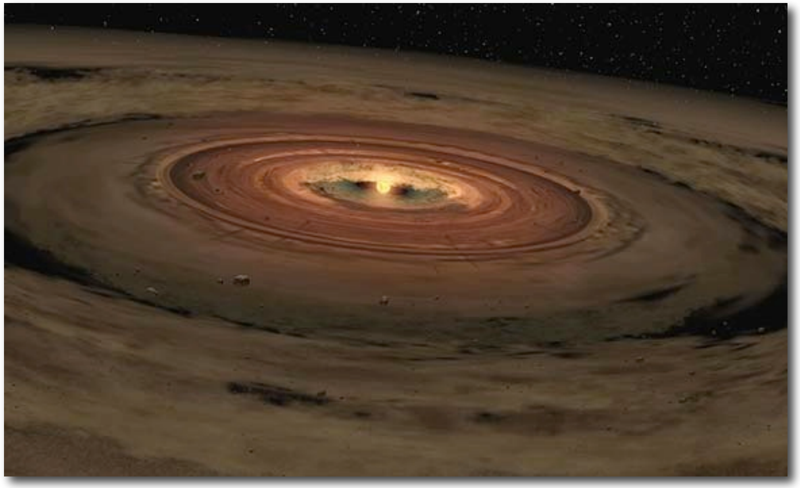
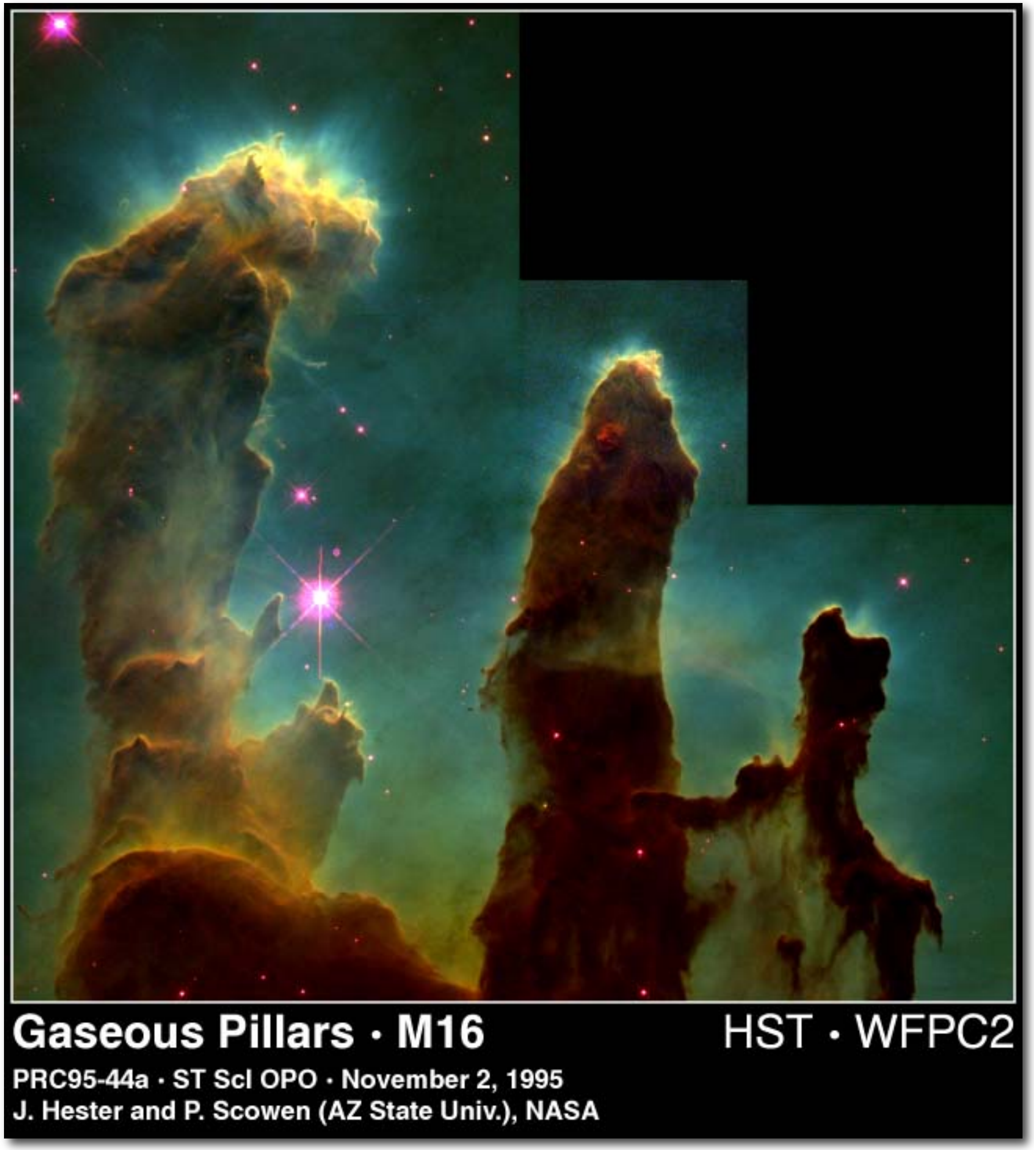
Solar System/Planet Formation

Gas Clouds
to Stars/Planets

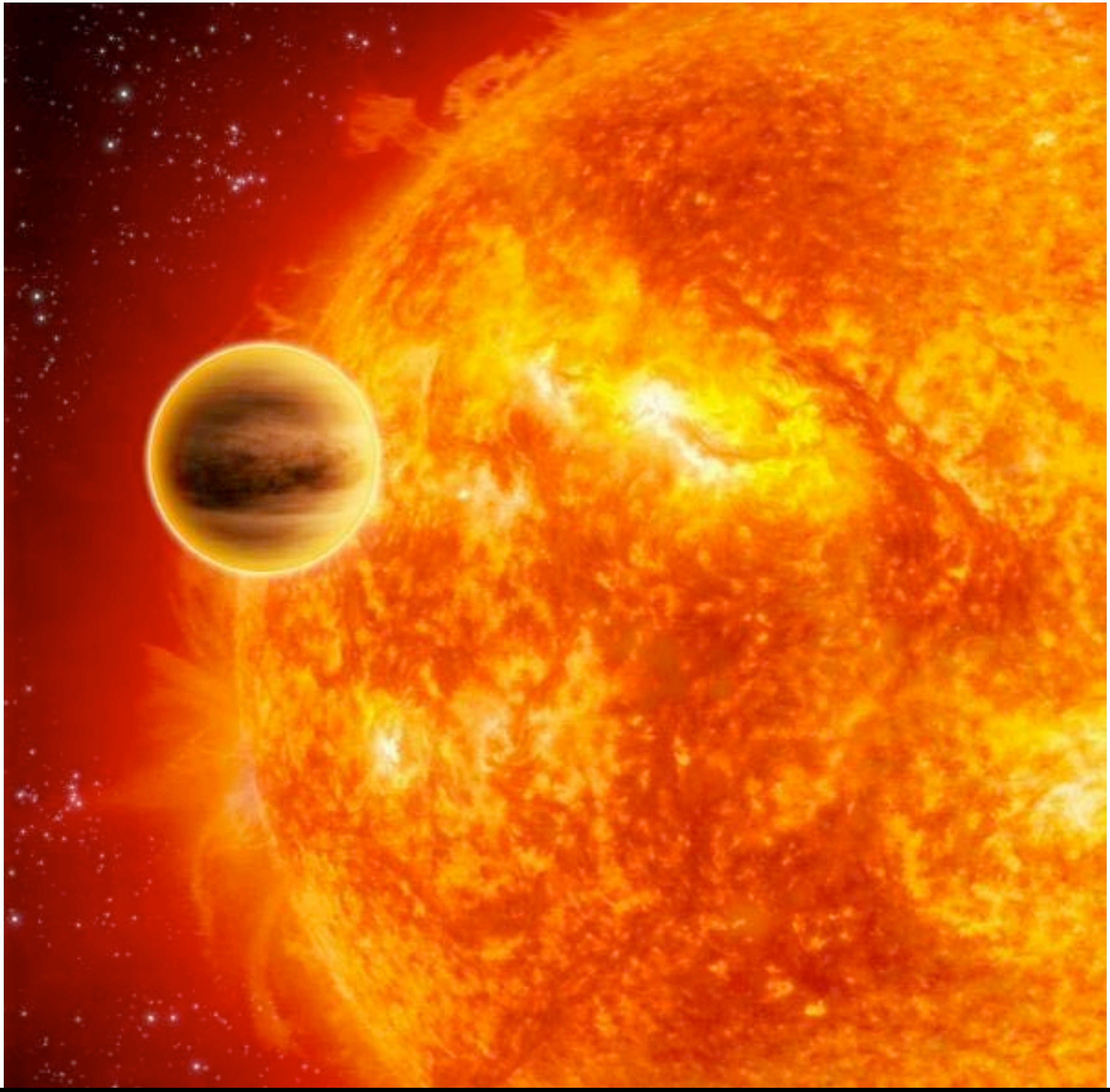
Planet Migration

Satellite Formation

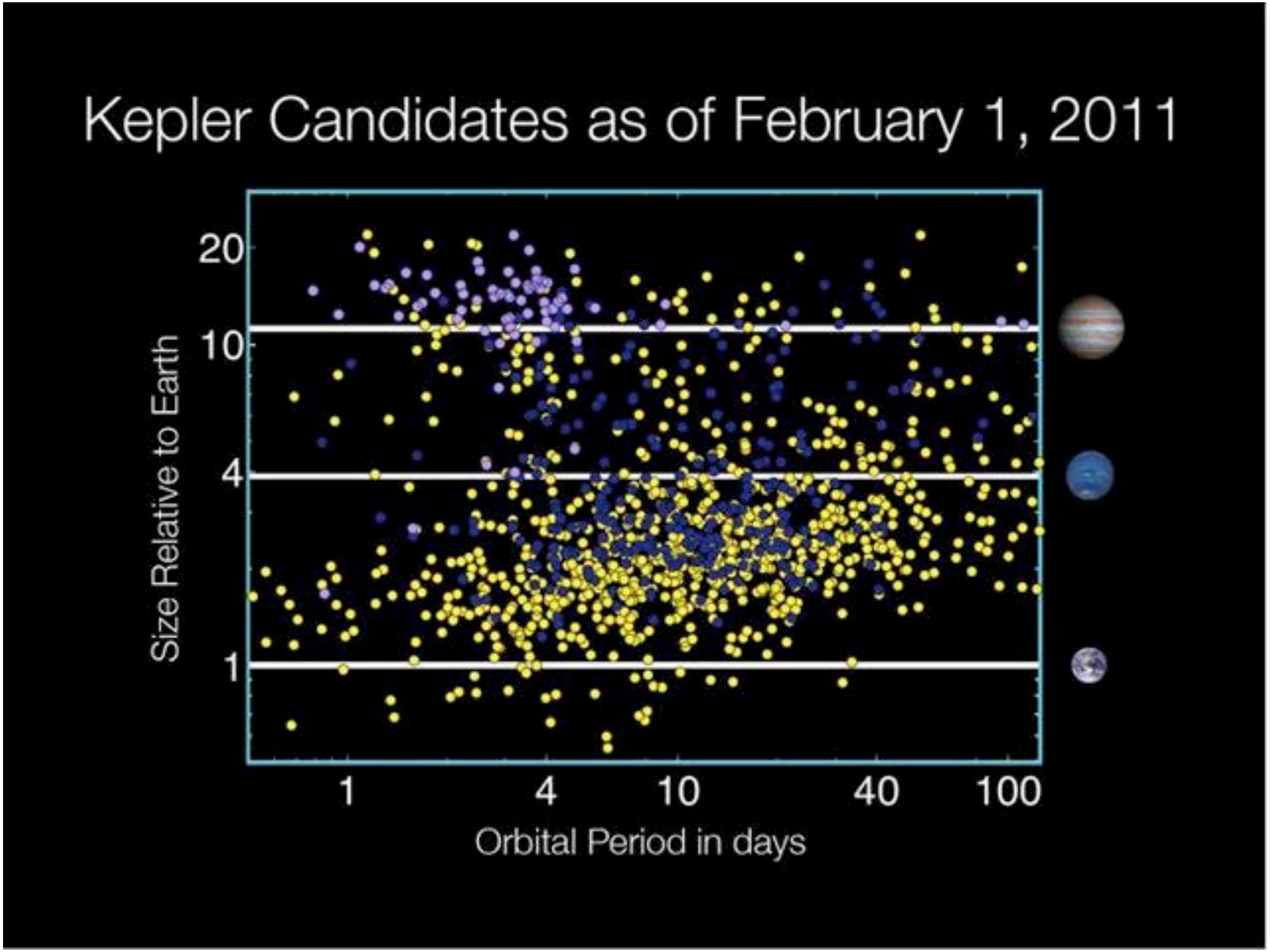




Close-in Giant Exoplanets → Migration



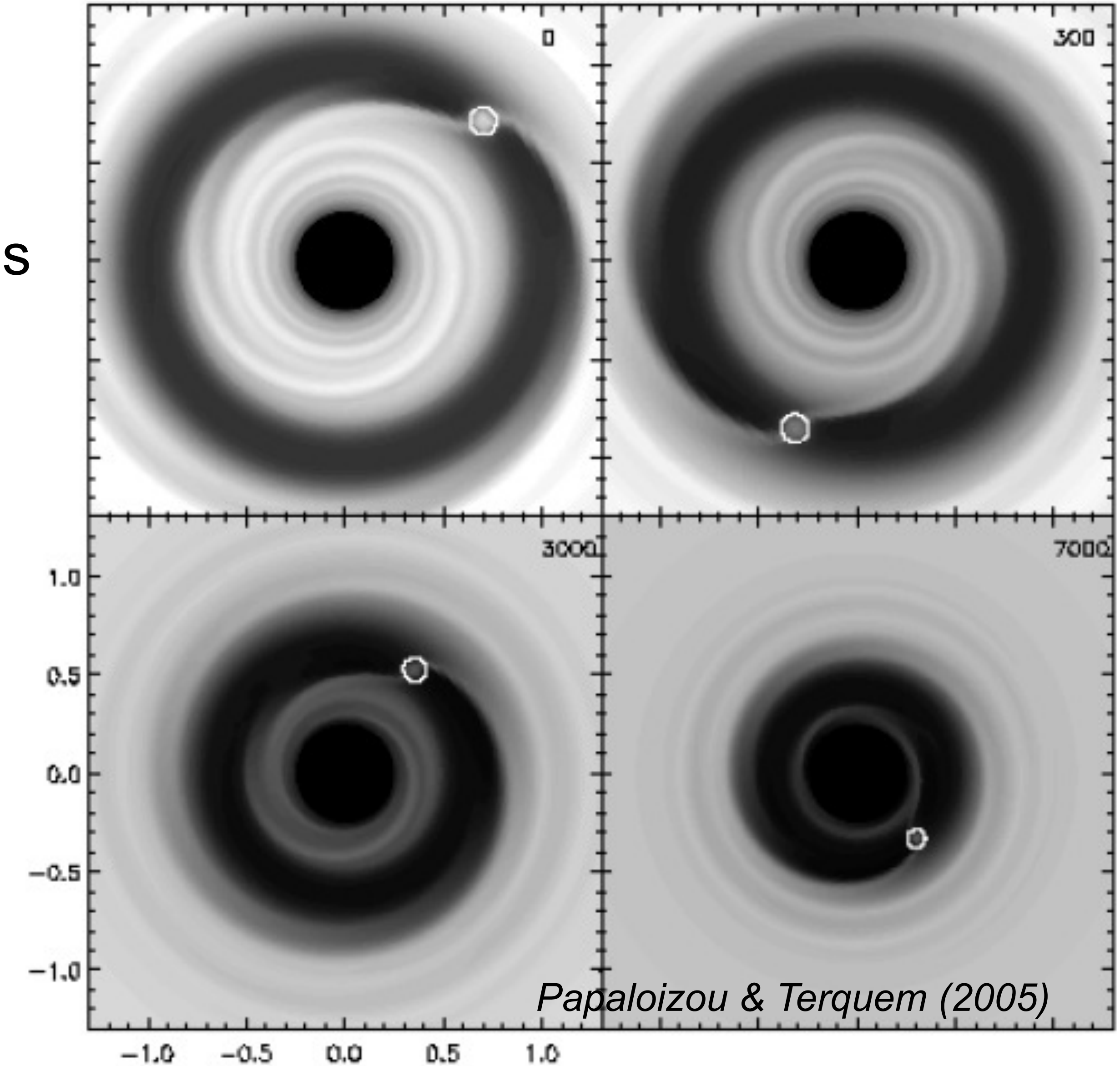
Close-in Giant Exoplanets → Migration



Inward Planet Migration

- Probably through angular momentum exchange with disk gas
  - Type II: planet orbits in disk gap
  - Type I: no gap

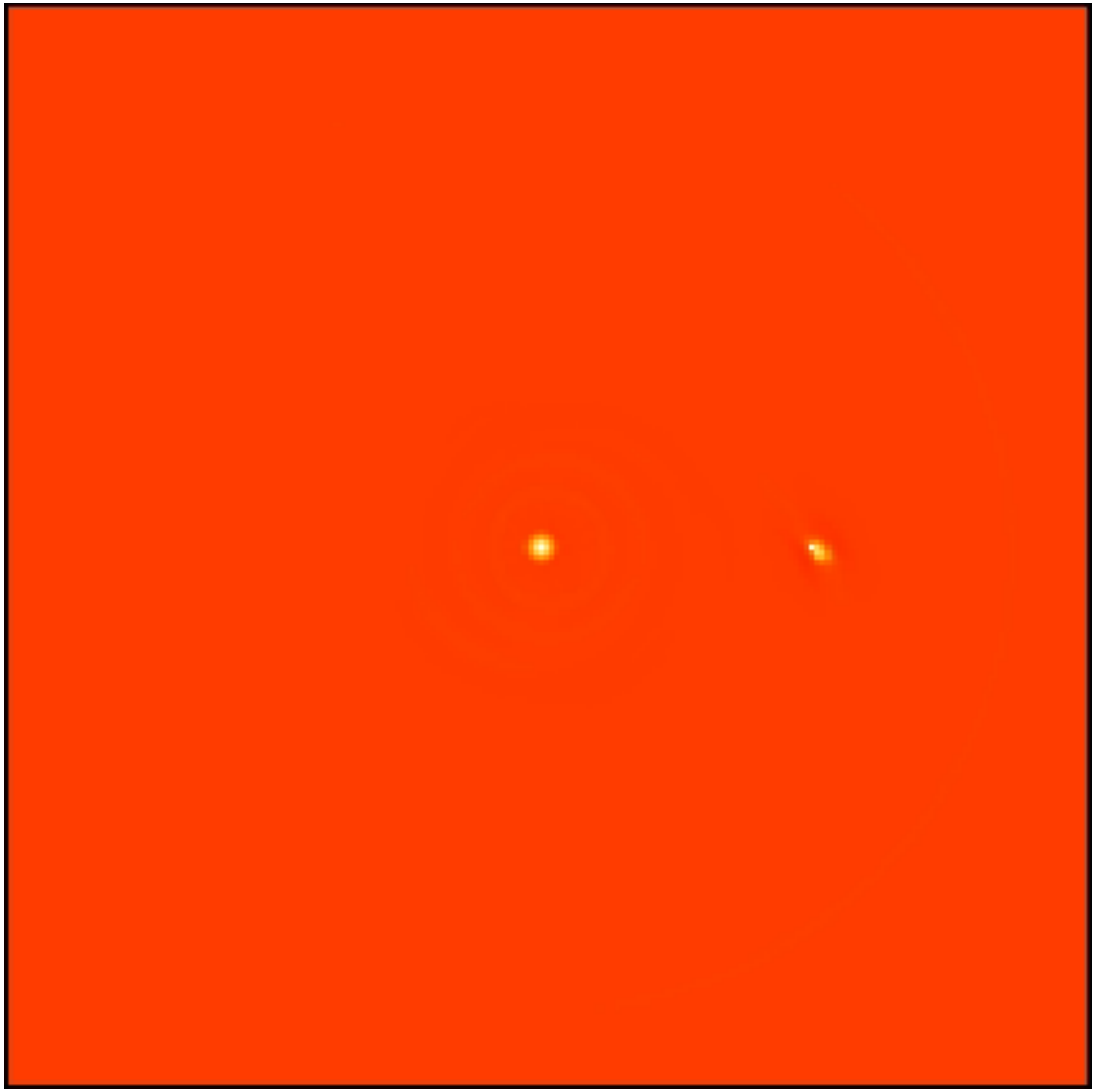
- Stopping migration before planets merge with the star may require concurrent nebula dissipation



Papaloizou & Terquem (2005)

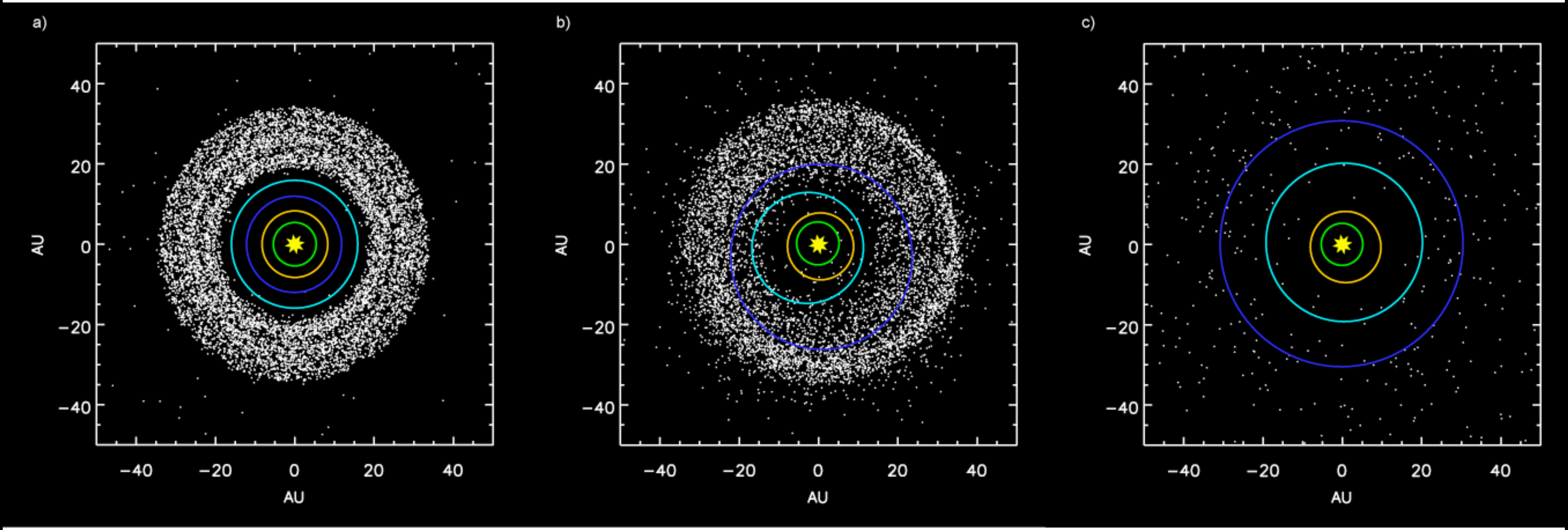
Inward Planet Migration

$1.5M_{\mathrm{Jup}}$ planet in $0.02M_{\odot}$ disk (MMSN): ~100 orbits ending with simulated gas dispersal



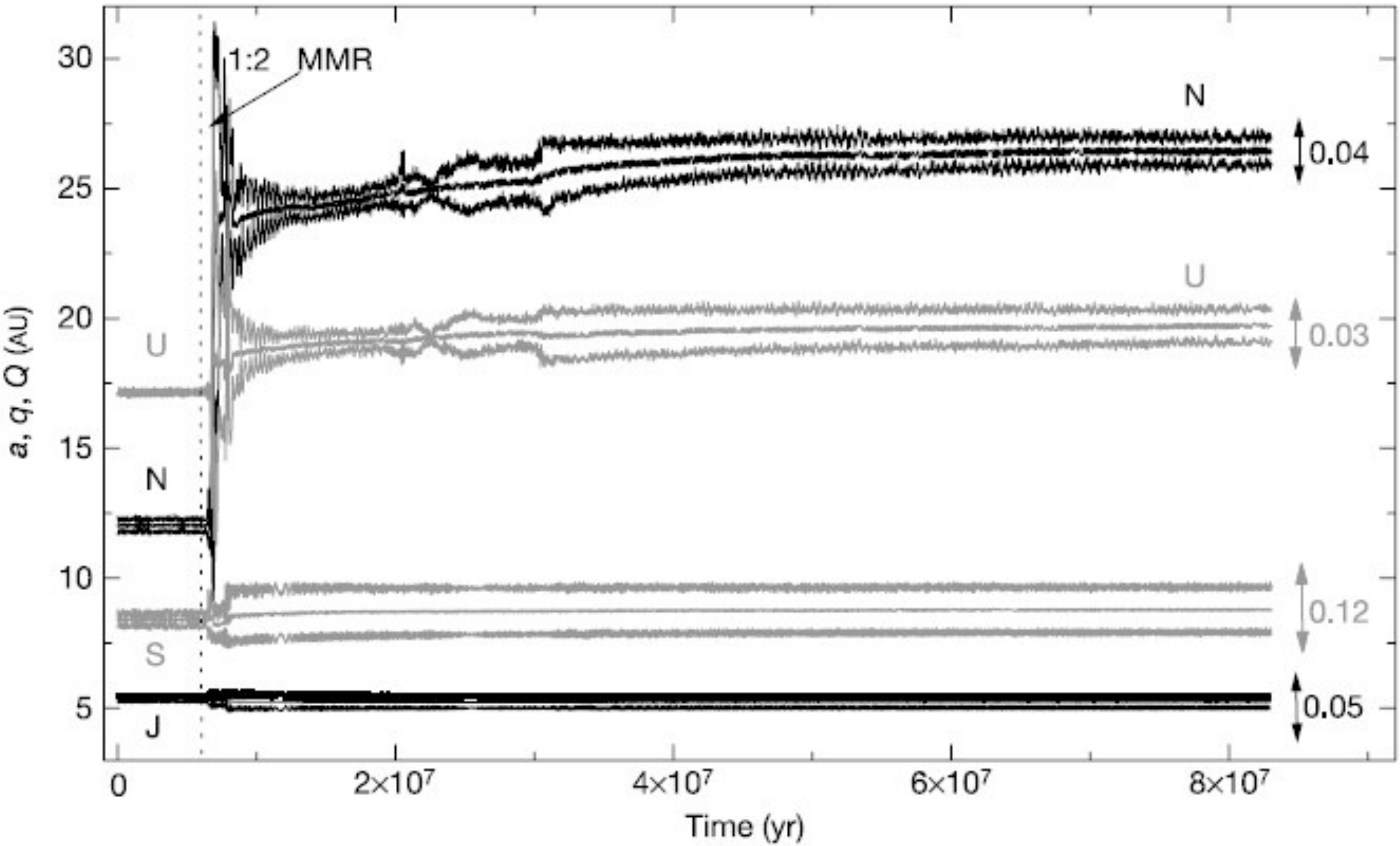
http://planets.utsc.utoronto.ca/~pawel/planets/movies.html

Outward Planet Migration: Nice Model



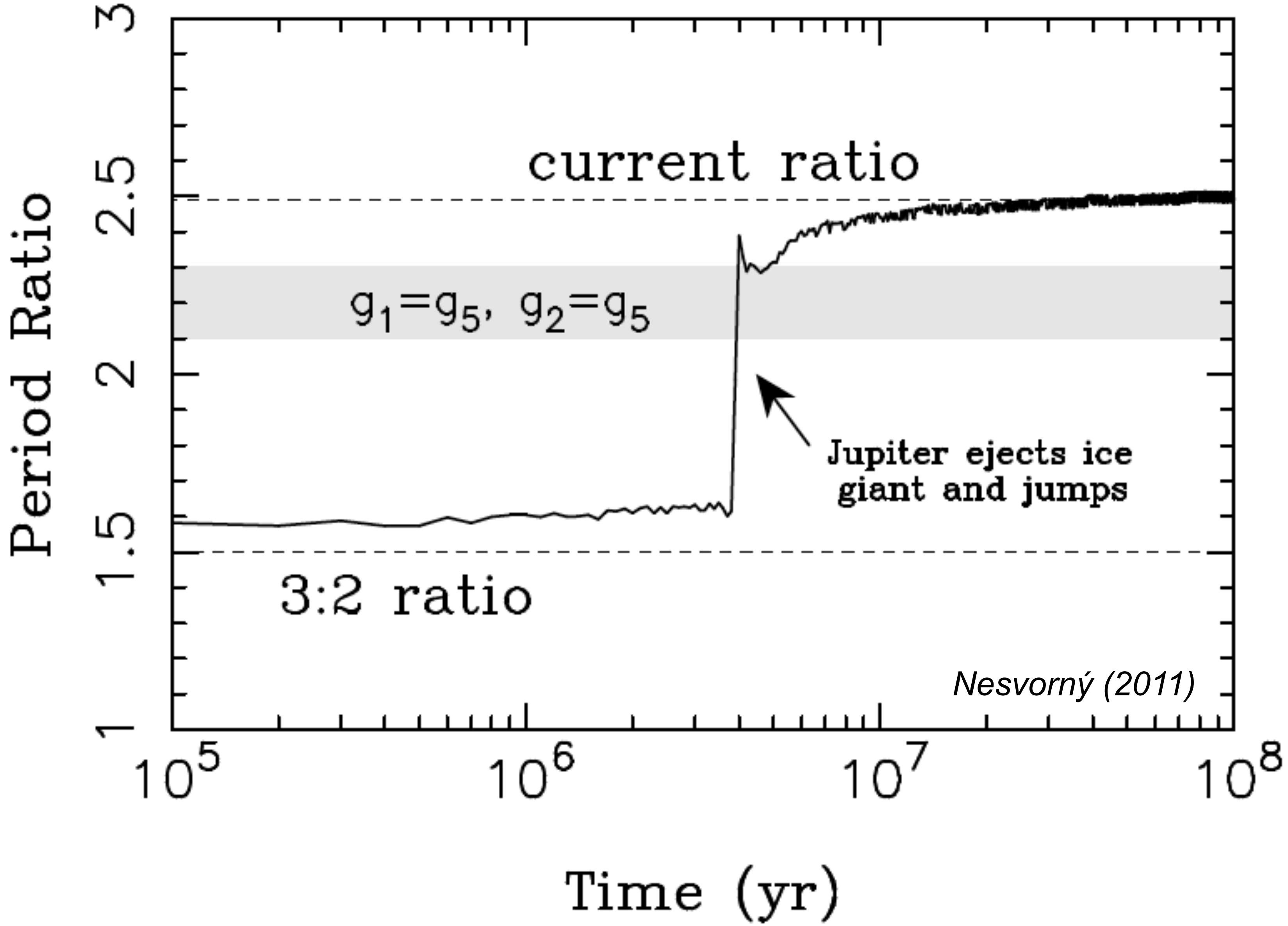
- All planets formed at <20 AU (high density, short orbital periods)
- Outermost planet (Uranus?!) interacted with KB planetesimals, typically "passing" them inwards to interact with other planets
- Interactions with Jupiter cause ejection to Oort cloud or beyond
- Reflex planet migrations cause Jupiter and Saturn to cross 2:1 resonance → mayhem!
  - *Uranus and Saturn move way out, switch places?!*
  - *Planetesimals scattered into inner solar system (LHB)*

Outward Planet Migration: Nice Model

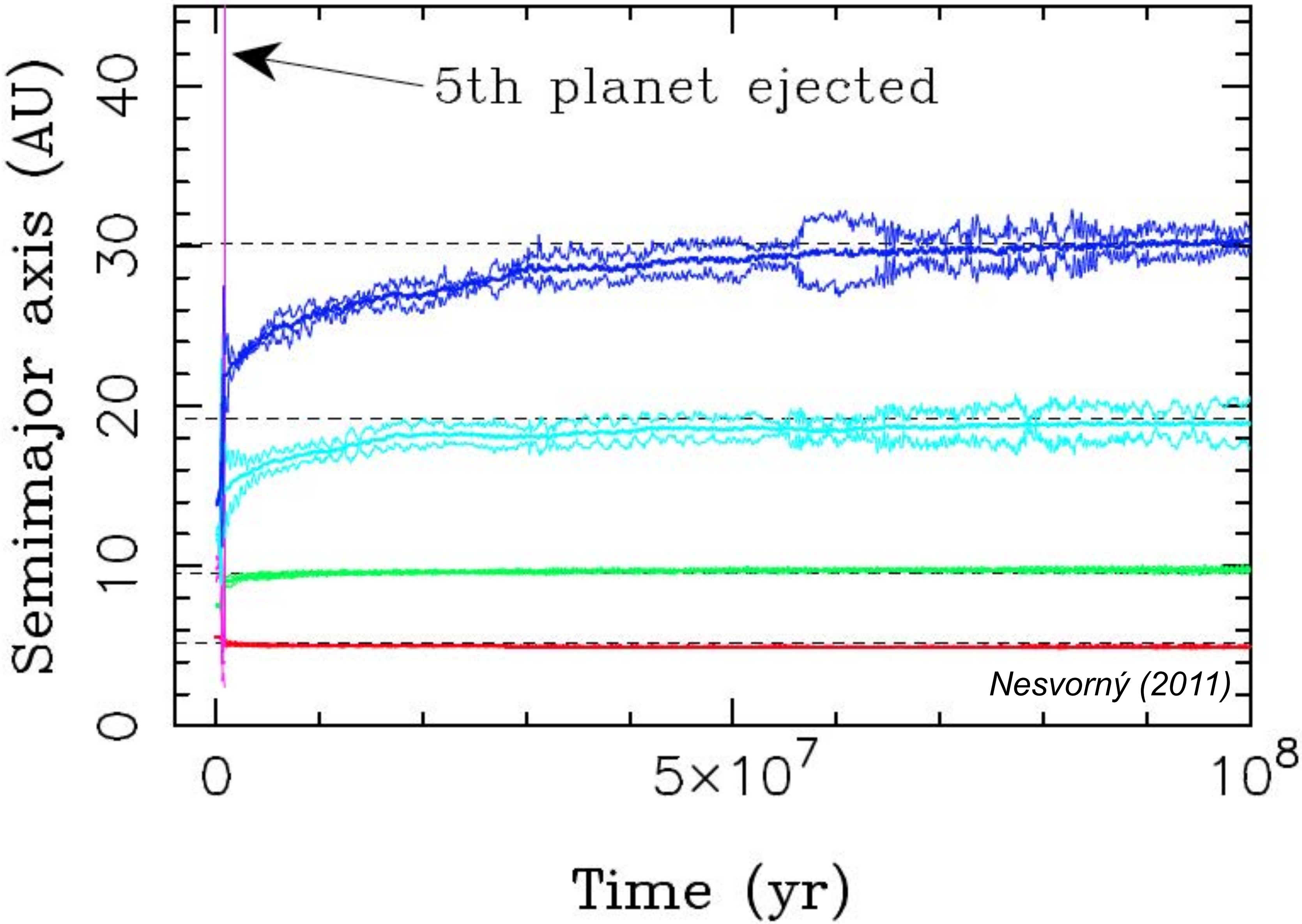


Problem: Terrestrial planet destabilization

Solution: 5th planet!?



Ejection of a 5th giant planet?



Pea shooter theory aims to build solar system - October 06, 2011

Bookmark in Connotea

Posted on behalf of Ron Cowen

The Nantes model?

Planetary scientists don't usually don catcher's masks at the end of a professional talk, but Hal Levison of the Southwest Research Institute in Boulder, Colorado, wasn't taking any chances. Acknowledging just how outrageous his new theory of planet formation is, Levison, who looks like an ex-hippie, joked that he wanted to be prepared in case his audience started throwing things. Levison presented the work on 6 October at a joint meeting of the European Planetary Science Conference and the American Astronomical Society's Division for Planetary Sciences in Nantes, France.

Levison is a formidable force in this field, well known for his contribution to the so-called 'Nice model' of outer solar system formation (see *Nature* 435, 459-461; 26 May 2005) Thus, the audience of planetary scientists was playful but remarkably respectful, given that Levison, David Minton of Purdue University in Indiana and their colleagues are now suggesting that all the planets in the solar system began forming at roughly Earth's distance from the Sun. As the researchers see it, each embryonic planet from Neptune to Mars would shoot outward in succession through the disk of gas and dust that surrounded the young Sun. During the journey, each would grab enough mass from the disk to reach its present planetary size in an incredibly fast one million years.

Neptune would be the oldest planet, since it shot through the disk first. That's in stark contrast to the traditional planet-forming model, in which fledgling planets stay put and continue forming at about the same orbital radii where they first coalesced, accumulating material only from their immediate surroundings. In that conventional scenario, Neptune would rank among the youngest planets since it would have taken much longer for material in the outer reaches of the disk to collide and stick together.

The standard model has had several successes, so why are Levison and his colleagues messing with a perfectly good theory? Because it isn't, they say. The theory can't explain how the giant planets, especially Uranus and Neptune, can finish forming before all the gas in the disk dissipates – a roughly five million year window.

It's widely accepted that all the planets started with rocky cores. In the case of the gaseous, outer planets, the rocky cores had to snare vast shrouds of gas. But in the outer part of the disk, where the standard theory says the outer planets formed, material orbits more slowly and it takes too long to form a core. By then the gas needed to build up the gas giants should already have departed. That apparent contradiction has left planetary scientists with an unsatisfying account of what happened.

In the new model – which Levison stresses is so far only a 'fairy tale' whose details have yet be worked out – he and his collaborators considered the complex dance that emerges between vast numbers of 50-kilometer-size solid bodies, or planetesimals, that form at around Earth's distance from the Sun and a few bigger, moon-size bodies that also happen to coalesce every so often.They discovered that when certain conditions are met, interactions with

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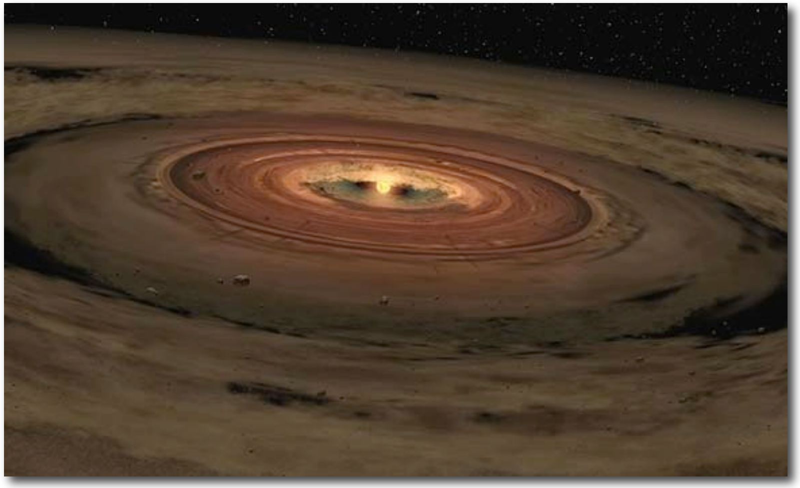
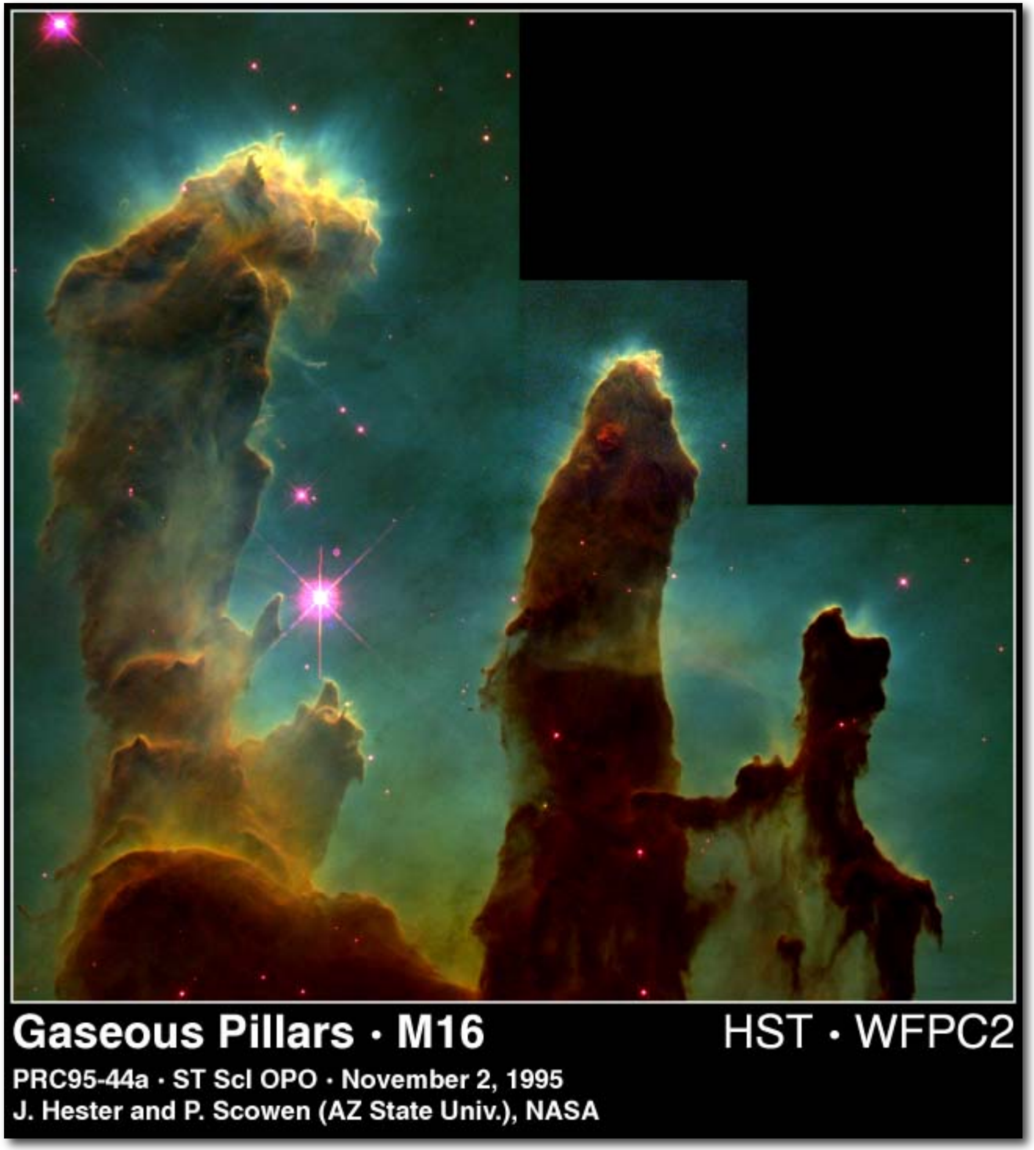
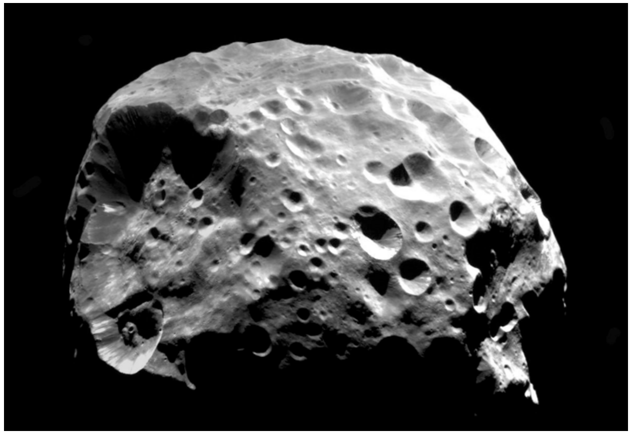




Satellite Formation Mechanisms

- Circumplanetary accretion disks (“regular satellites”)

- Capture (“irregular satellites”)



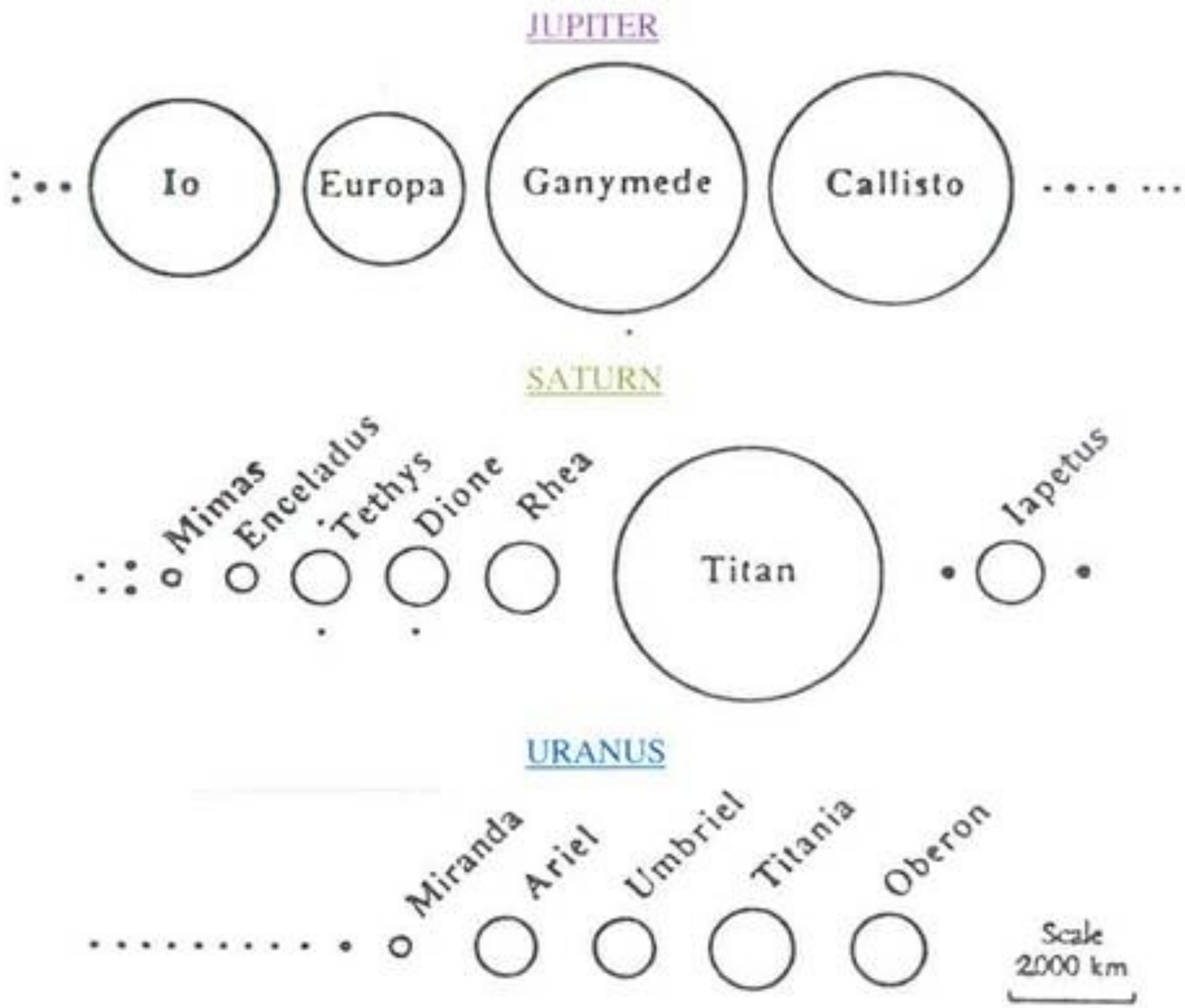
- Giant impacts

Formation of Regular Satellites

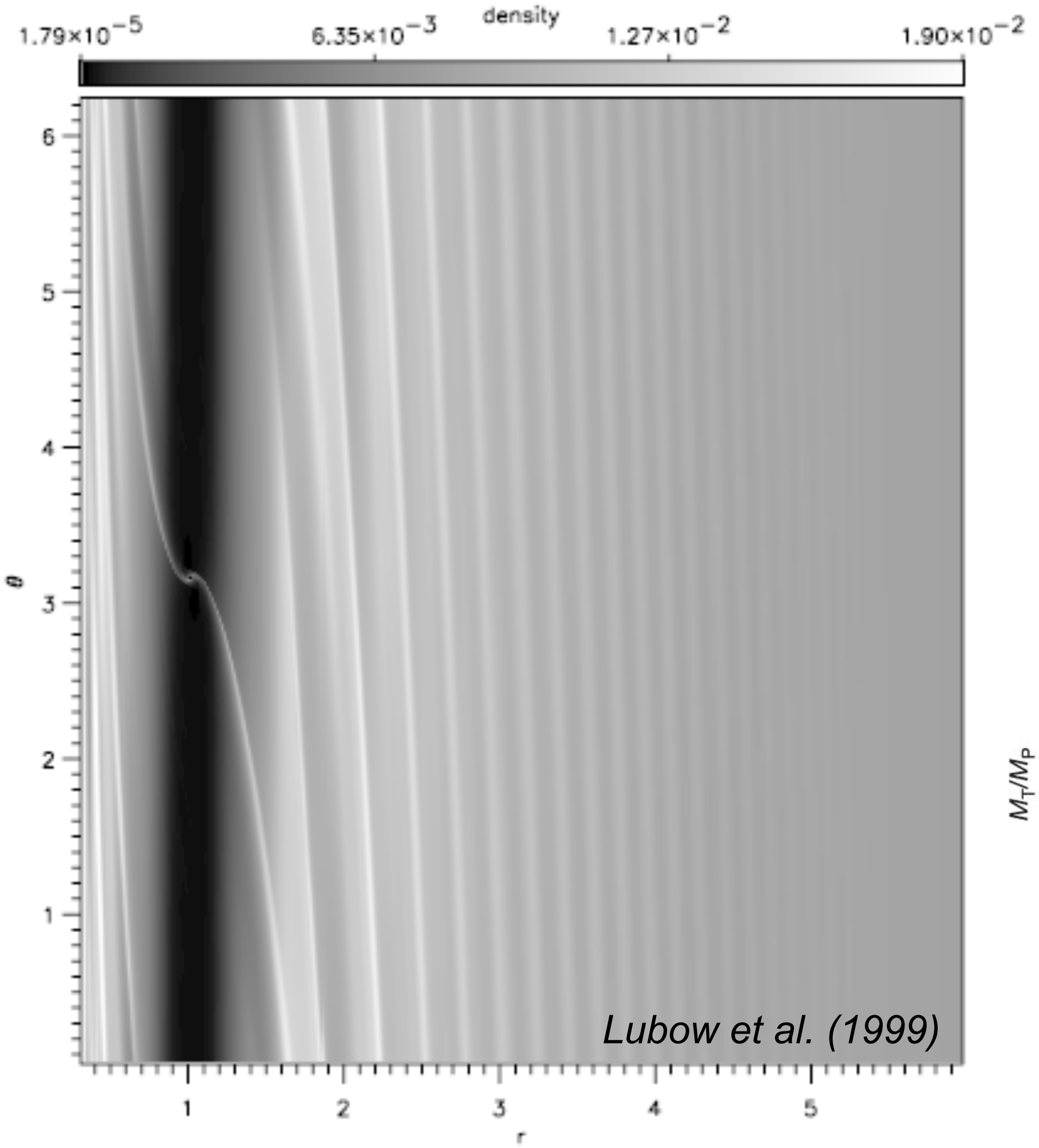
- Regular Satellites:
  - $M_s \sim 10^{-4} M_p$
  - $a_s <$ ~20-30R_p
  - $e, I \approx 0$

- Form in "subnebula" of ~solar composition?

Problems:
- *Moons are consumed*
- *Callisto accretes too quickly*

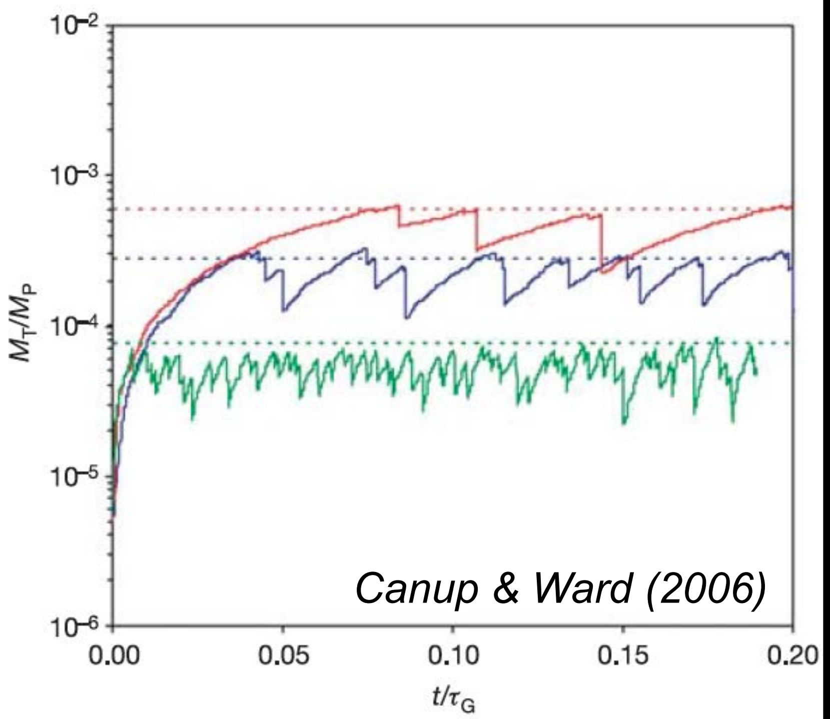


Formation of Regular Satellites



• Newer idea: moons form from late-accreted solids after planet has cleared gap in gas disk (Canup & Ward, 2002, 2006)

• Early generations are consumed after reaching critical (~Moon-to-Mars-like) mass



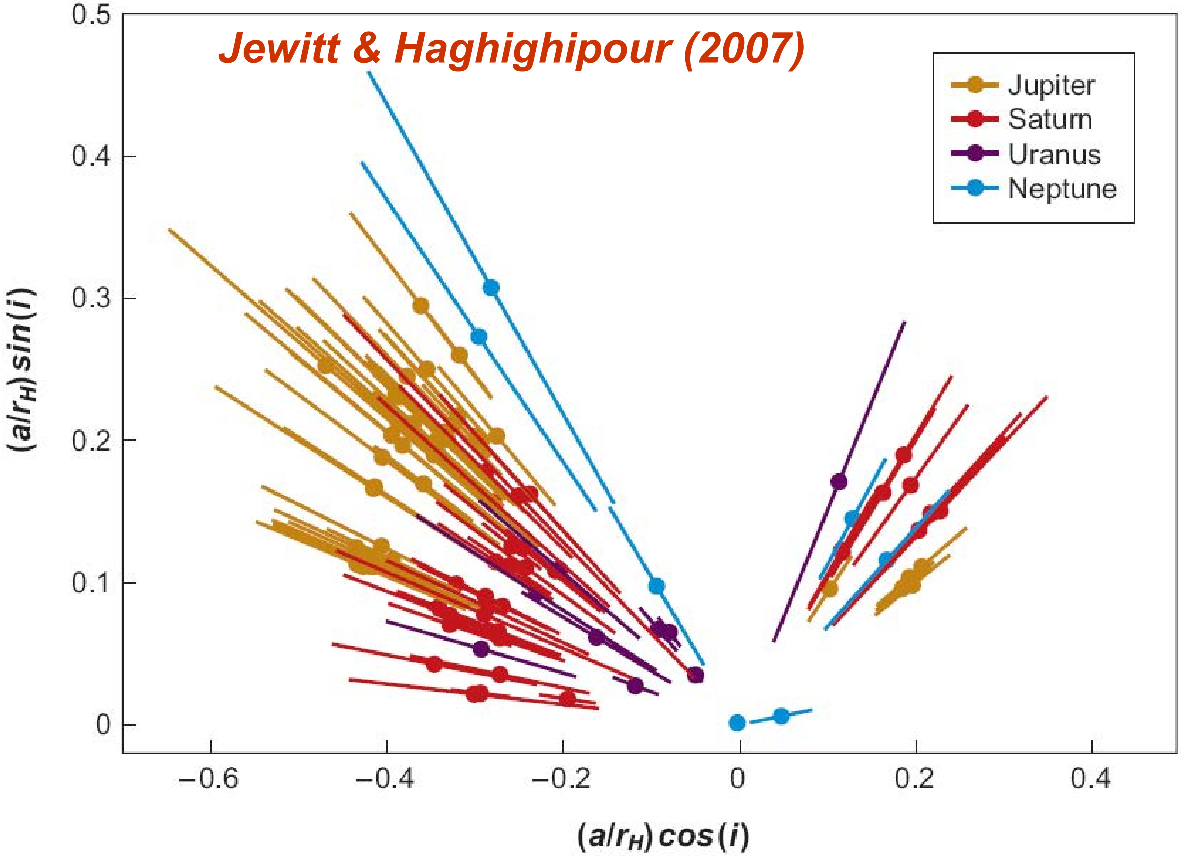
Is Pandora possible?

For the most massive planets, $10^{-4}M_p \approx$ only $0.4M_{Earth}$
… but Mars-mass worlds can retain atmospheres

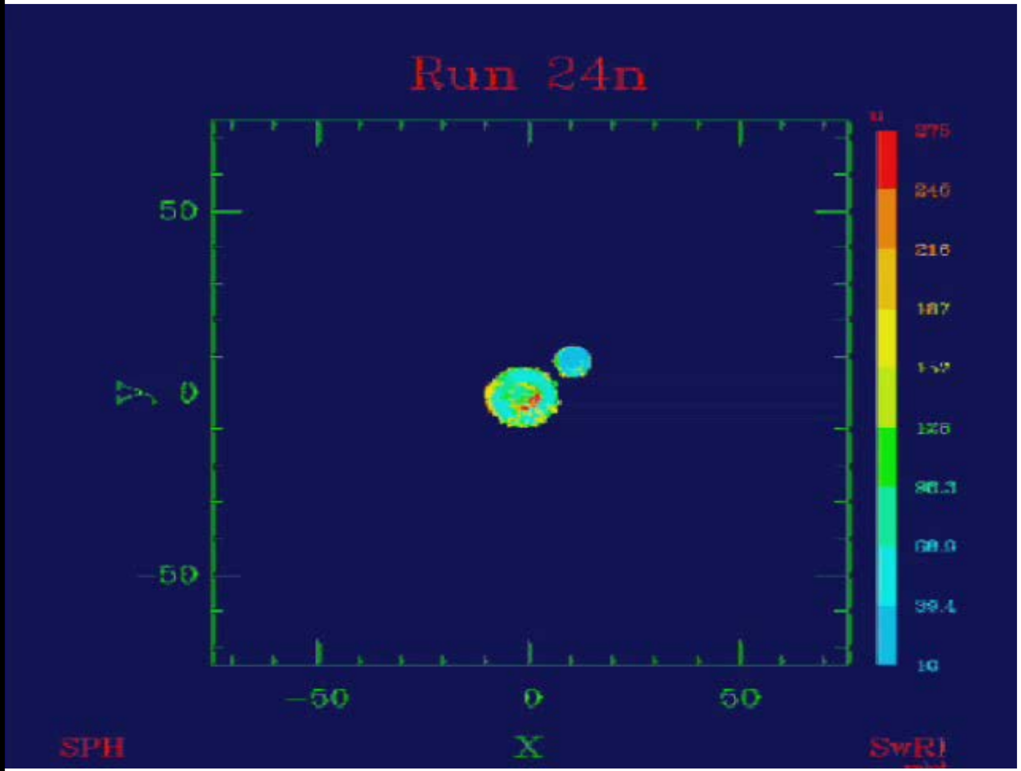
Capture of Irregular Satellites

- Irregular Satellites: small, distant, eccentric and/or inclined (often retrograde)

- Capture due to 3-body interactions (collisions or scattering) most likely, probably early



The Oddballs: Formed by Impact?



- Earth's Moon ($\sim 10^{-2} M_{Earth}$) (Canup, 2004)
- Charon ($\sim 10^{-1} M_{Pluto}$) (Canup, 2005)

For our Moon, this explains:

- Age (~4.4 – 4.53 Ga)
- Low volatile content
- Low bulk density (minimal iron core)
- Similar oxygen isotope ratios to Earth
- Early proximity and fast rotation of Earth