Giant planet sculpting of outer planetesimal disks

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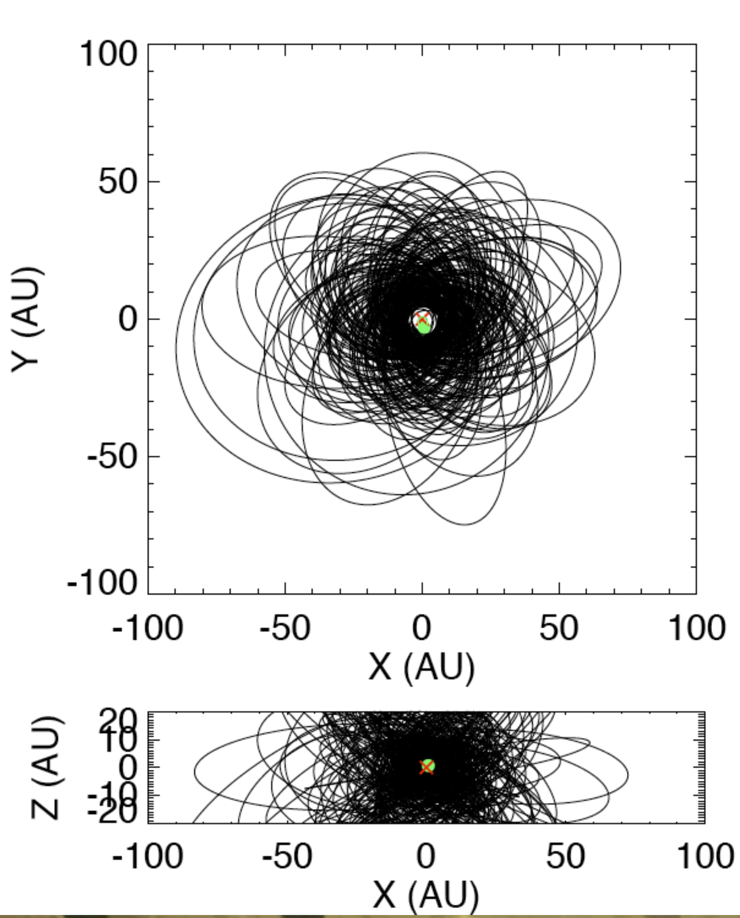
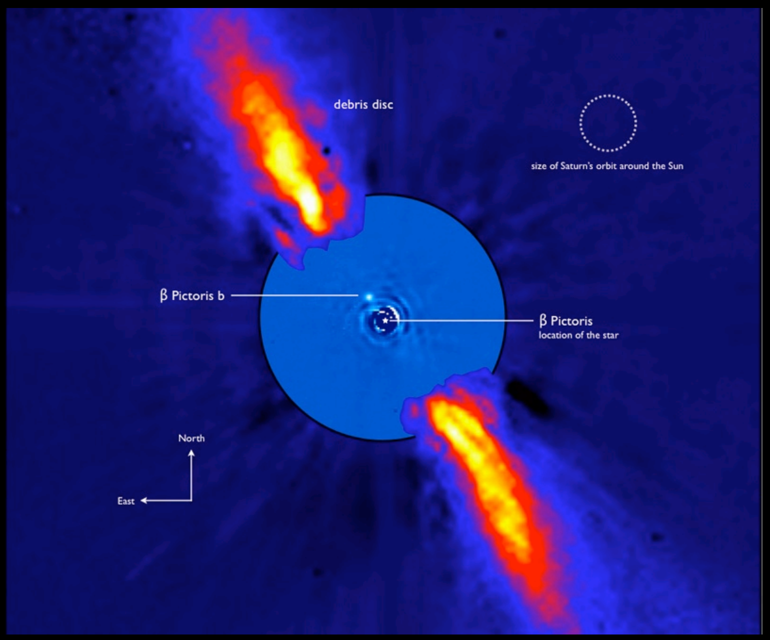
Featuring Mini Oort clouds!



Motivation

- Gas giants exist around at least ~20% of stars (Cumming et al 2008, Mayor et al 2011).
  - Dynamical instabilities are common (e.g. Marzari & Weidenschilling 2002, Chatterjee et al 2008, Raymond et al 2010).

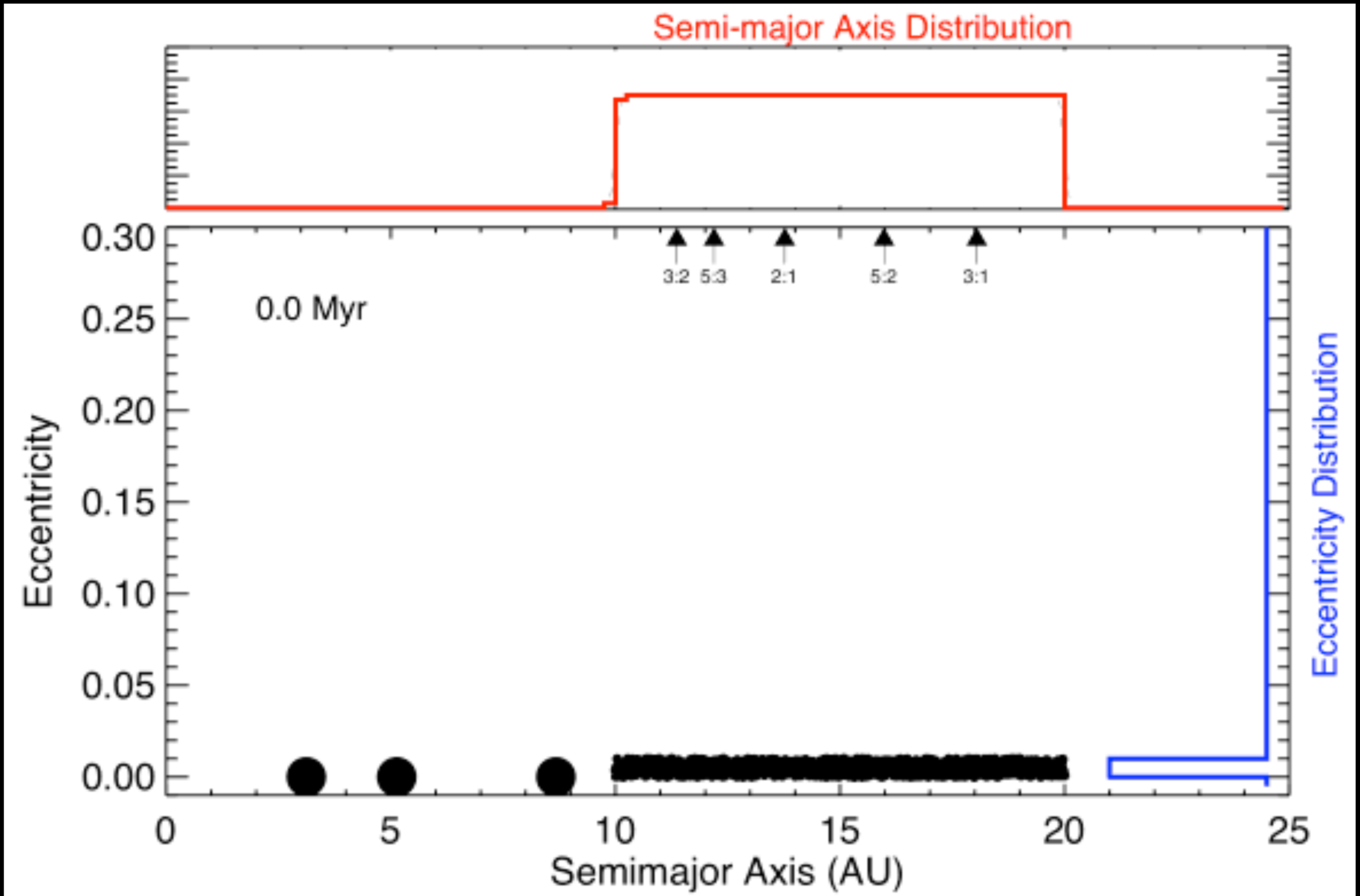
- Outer planetesimal disks are common
  - Cold dust around ~15% of old stars,~25-30% of young stars (Trilling et al 2008, Carpenter et al 2009).



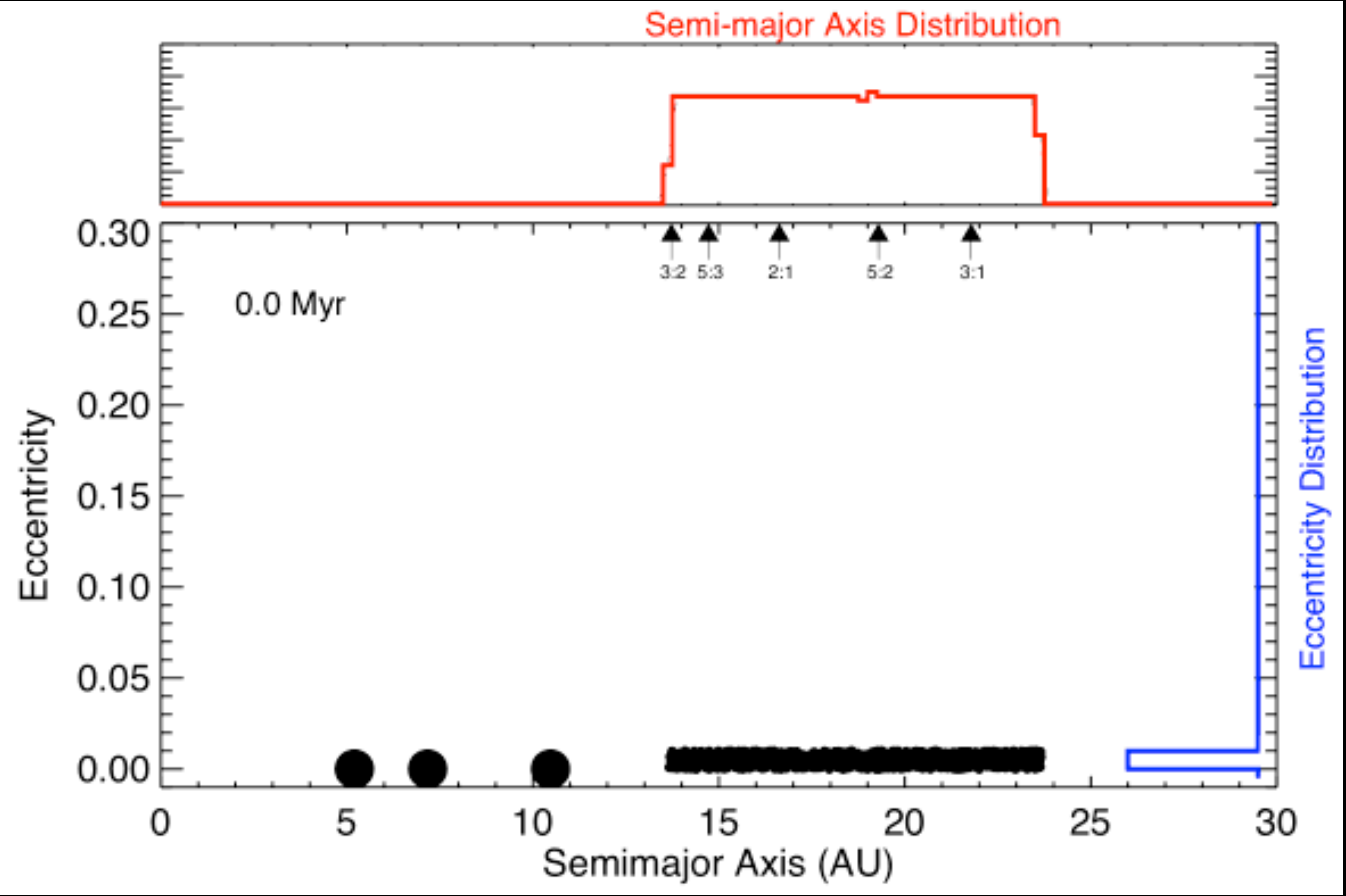
Beta Pic; Lagrange et al 2011

Simulations

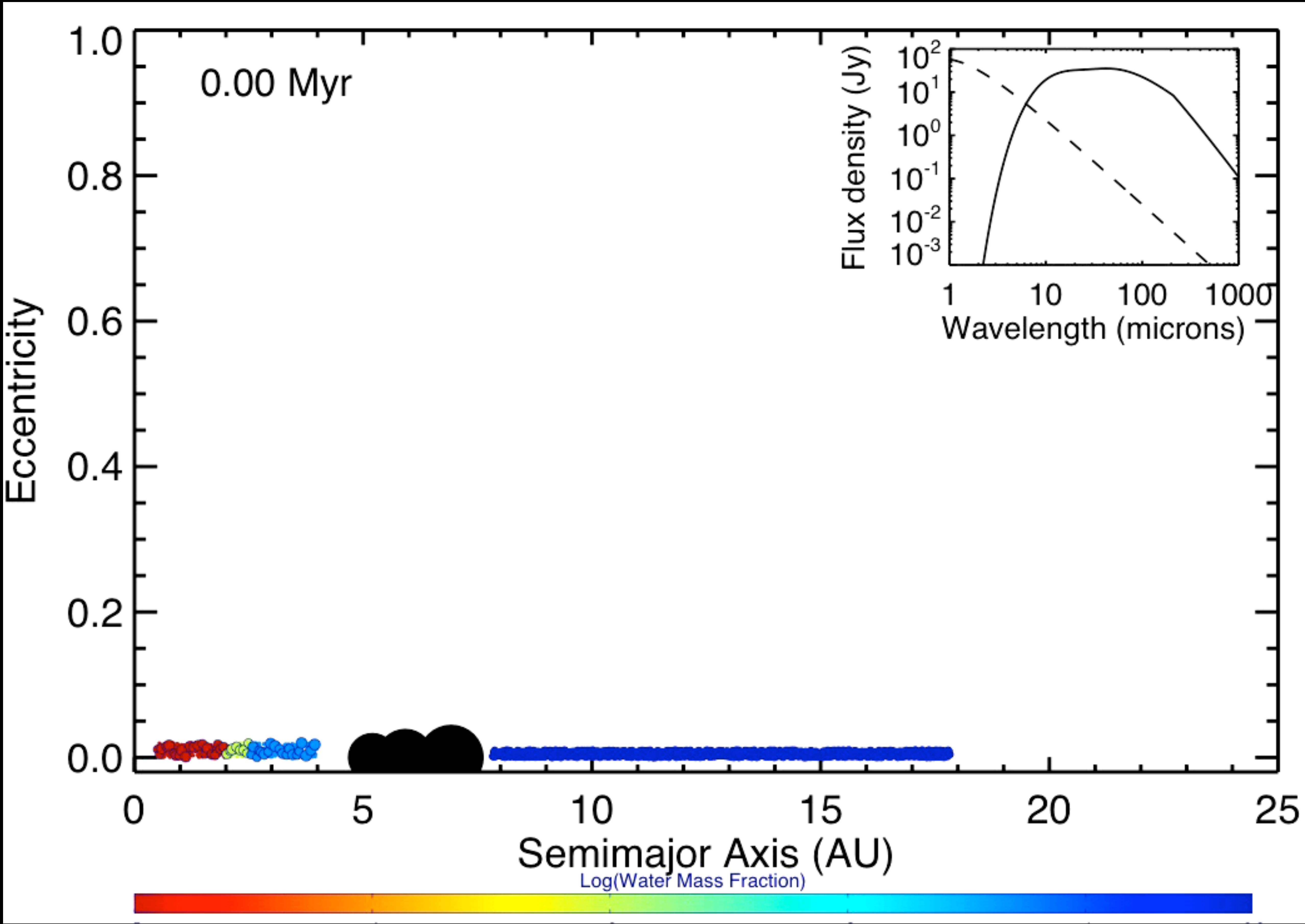
- Sun-like star
- 3 giant planets at Jup-Sat distances (~3-10 AU)
  - Vary masses and mass distribution
- Planetesimal disk from 10-20 AU: 1000 particles, 50 Earth masses
- Integrate for 100 Myr with N-body code (Chambers 1999).



Stable system: gaps carved by resonances

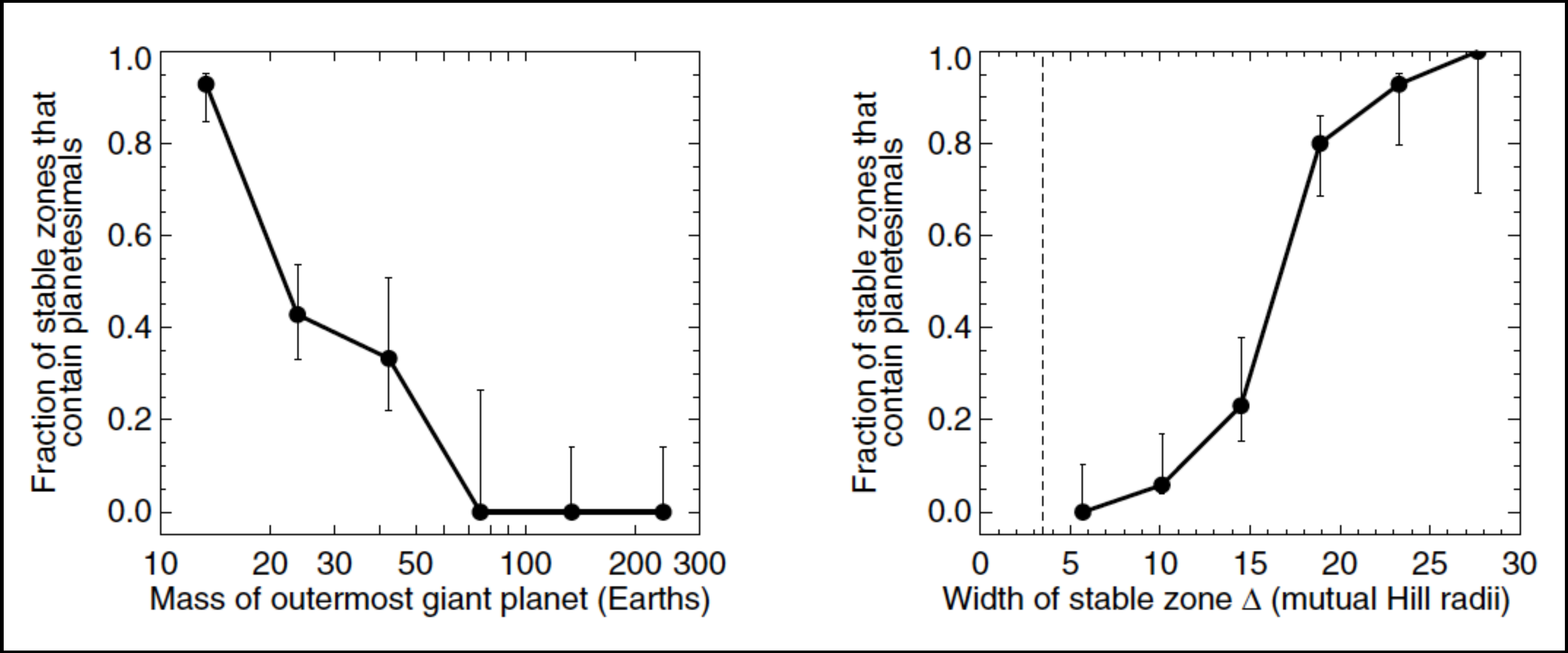


Weak instability: only resonant planetesimals are stable

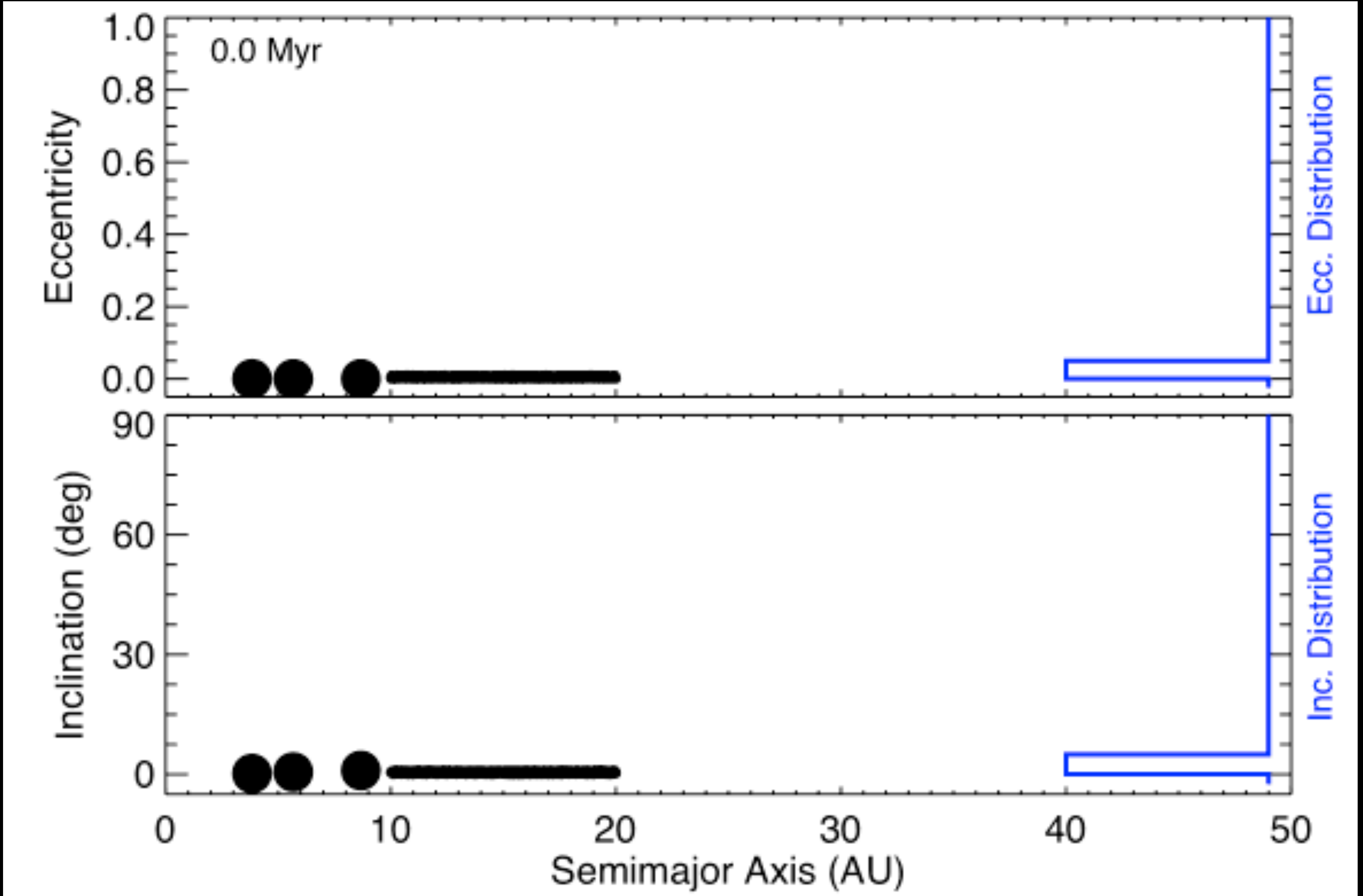


Ice giant system: Trapped planetesimal belt and outer scattered disk

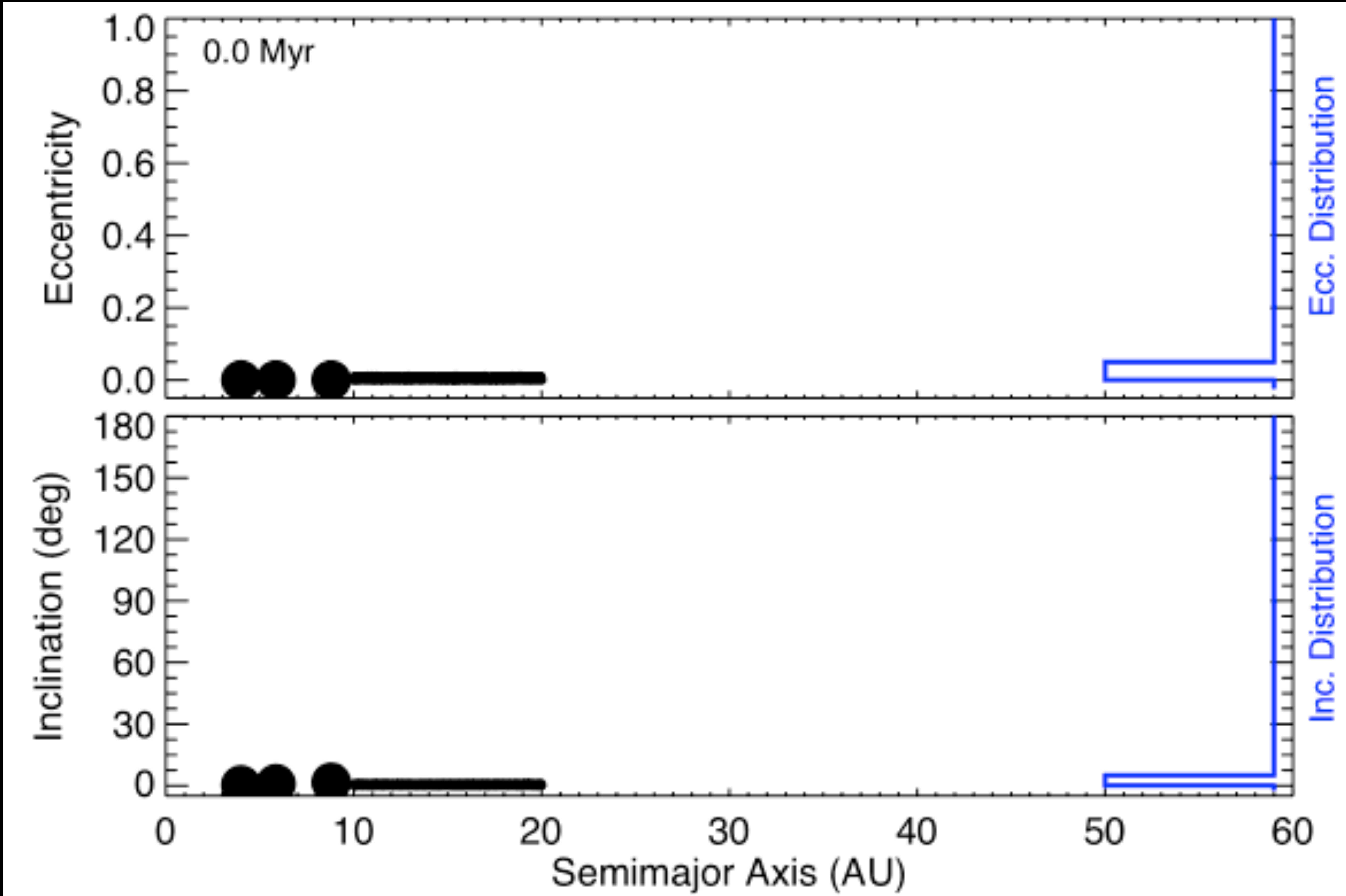
Belts of planetesimals trapped between two giant planets



Raymond et al 2012, A&A



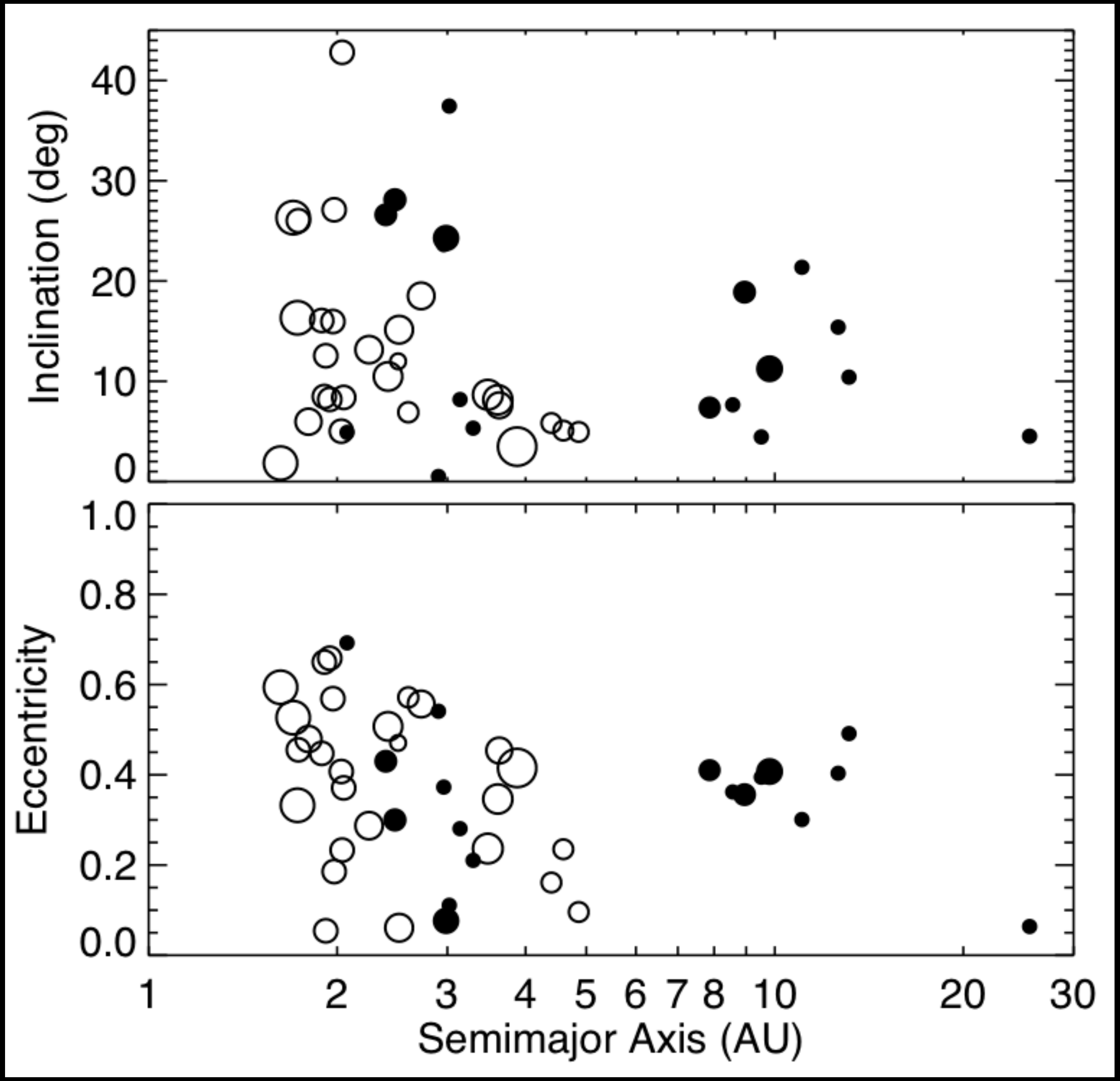
Late instability makes scattered disk



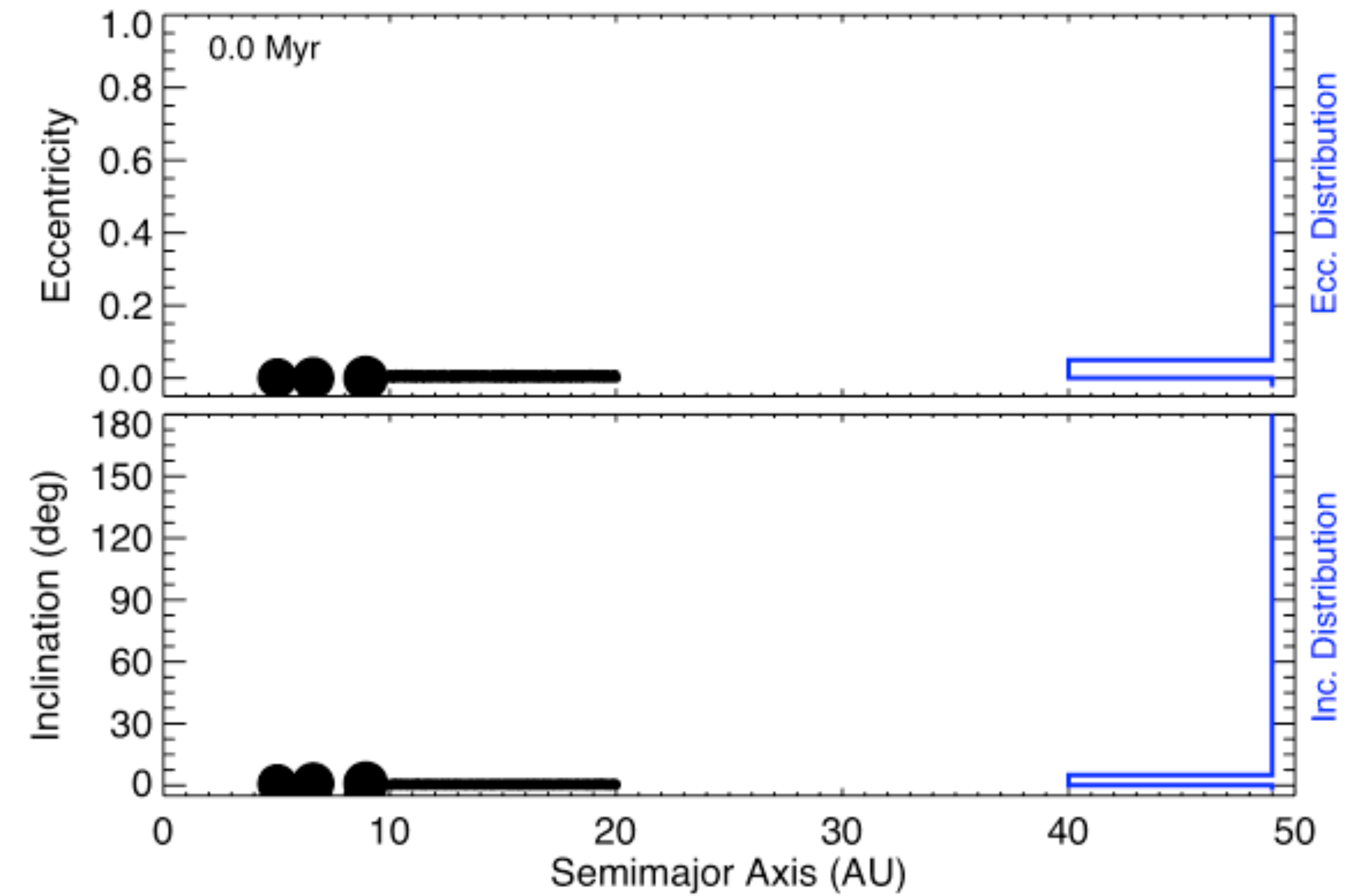
A mini-Oort cloud!

“Mini-Oort clouds”

- Form in 5-10% of systems with ~equal-mass giant planets
  - These systems must be common to explain mass-eccentricity correlation (Raymond et al 2010)
- Surviving giant planets need not have excited orbits



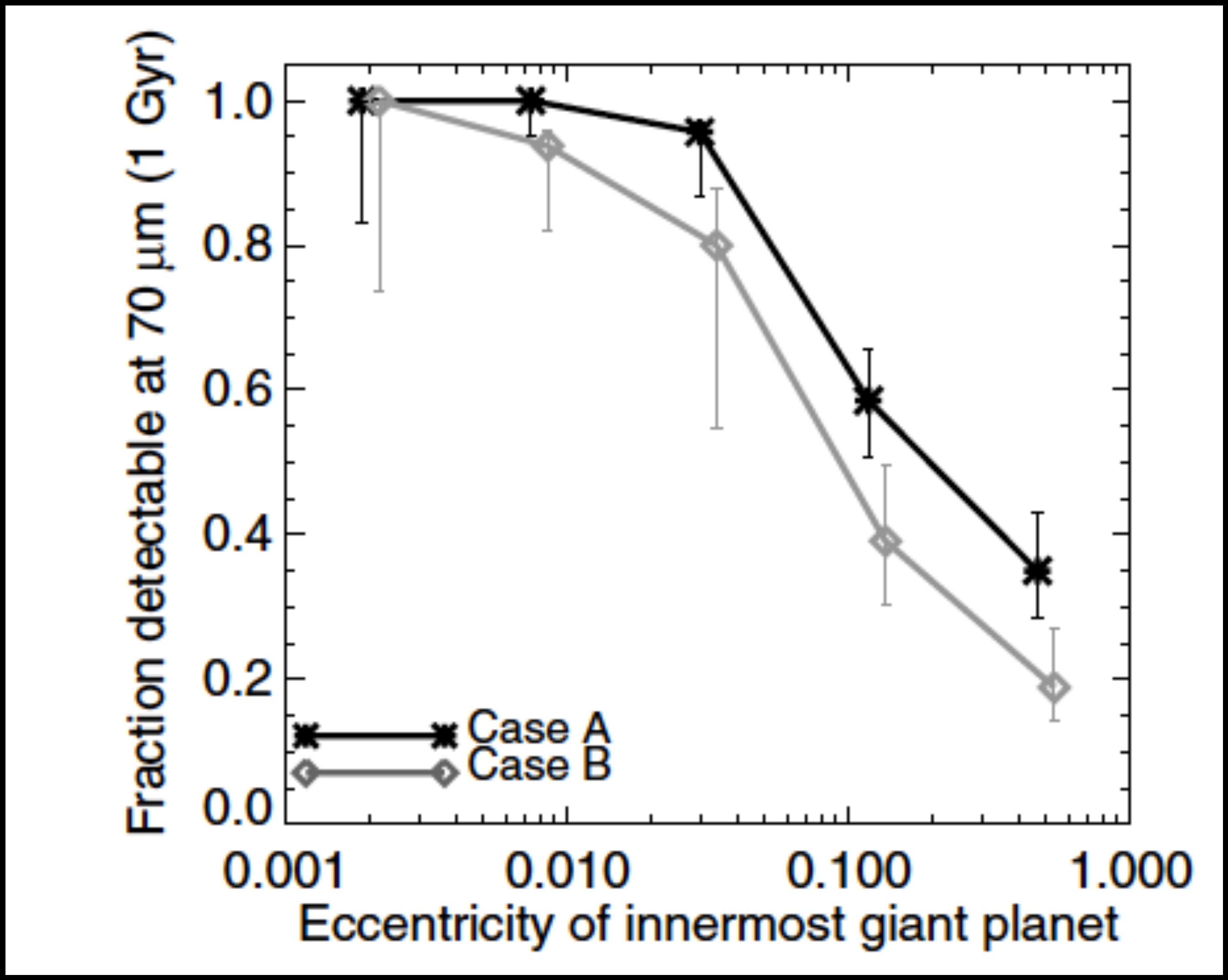
Orbits of surviving gas giants in mini-OC systems (open circle = single planet, filled = two surviving planets)



Complete ejection of planetesimal disk

The strongest instabilities systematically eject their planetesimals disks

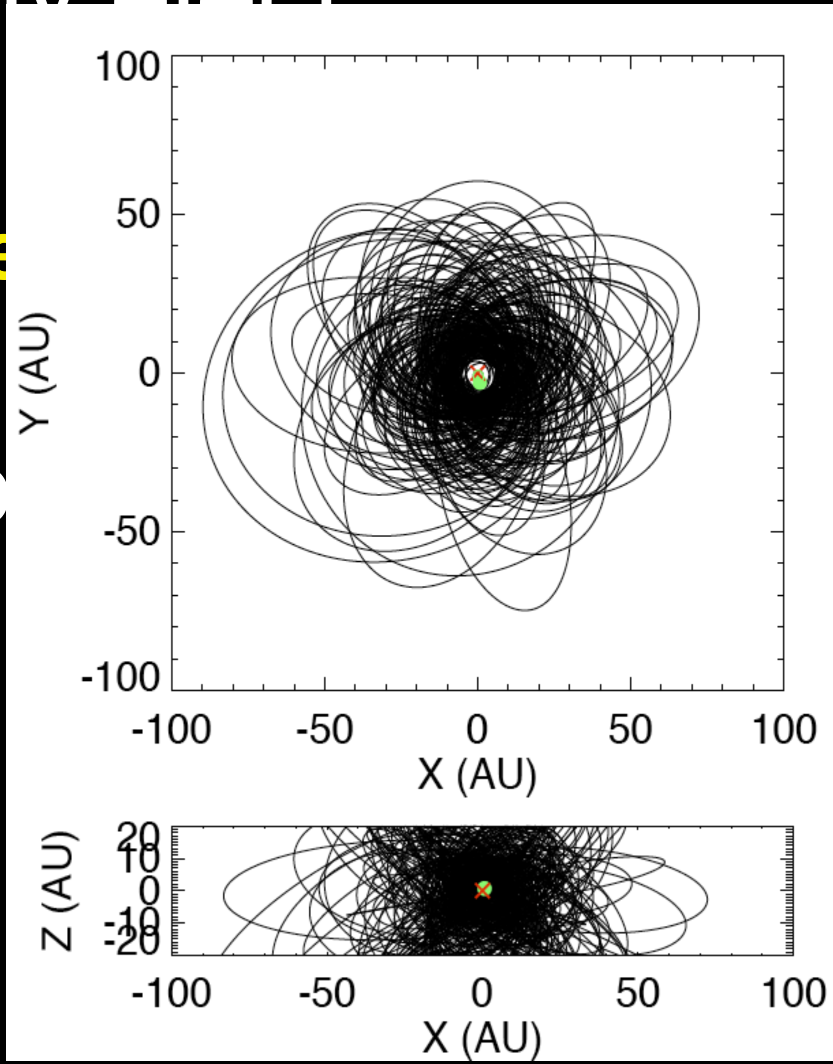
- We predict an anti-correlation between the presence of debris disks and eccentric giant planets
  - –A weak signal already observable (Bryden et al 2009; Raymond et al 2011)



Raymond et al 2012

Summary

- Planetesimal belts can be trapped:
  - between planets
  - in stable zones between resonances
  - in stable resonances
- Very strong instabilities completel
  planetesimal disks
  - **We predict an anti-correlation betwe
    giant planets and debris disks**
- Planet-planet instabilities can pro
  scattered disks of planetesimals

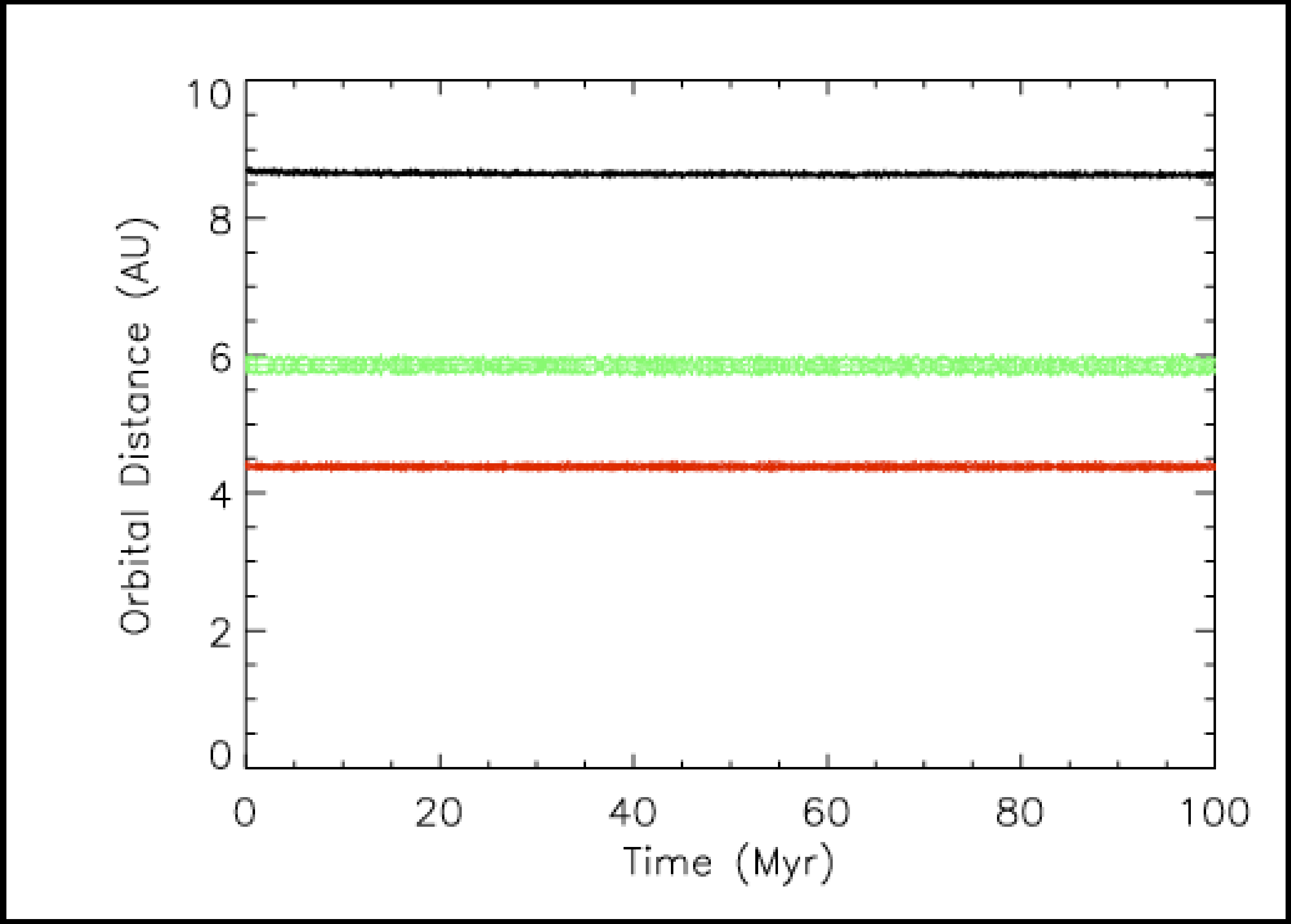


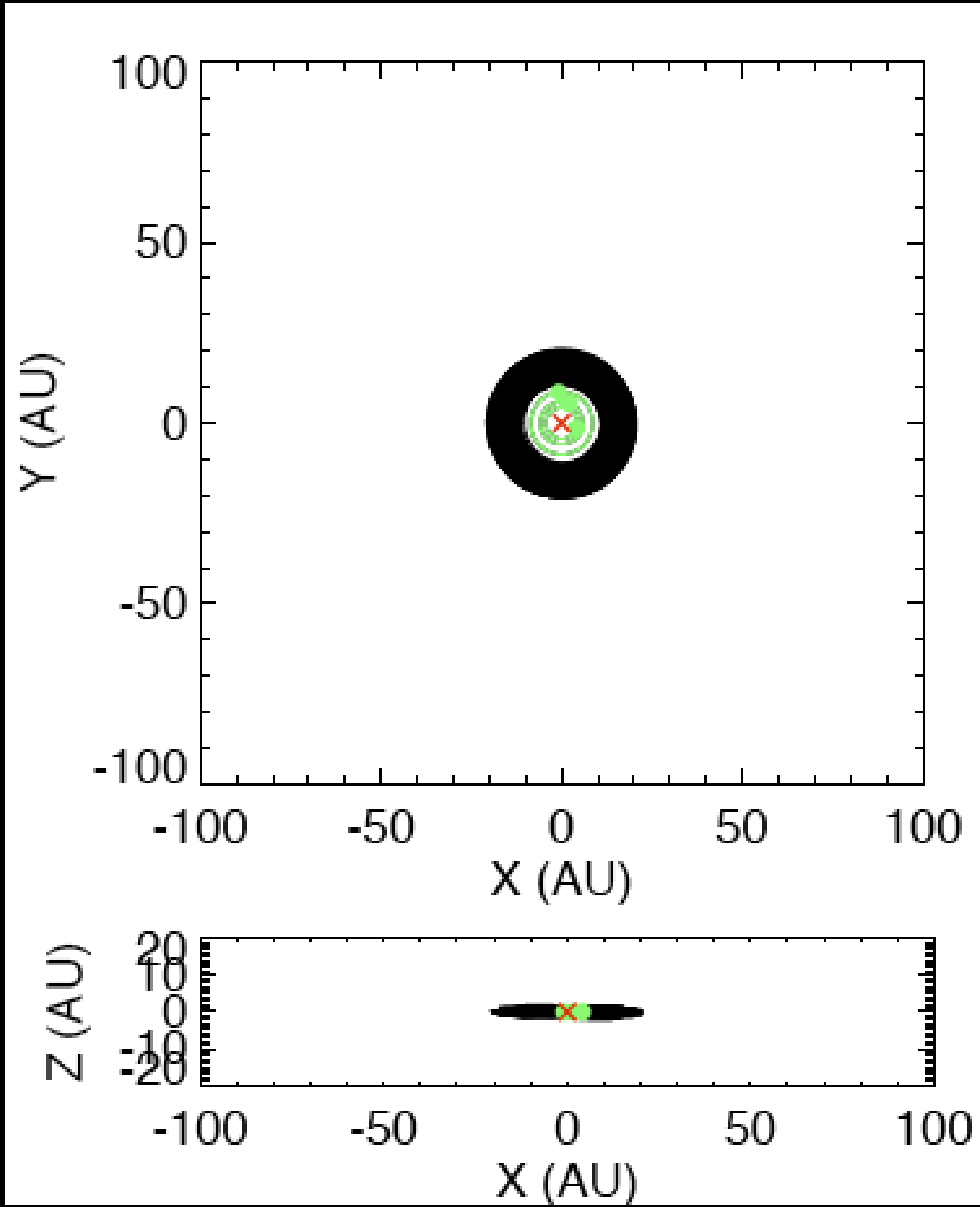
Mini-Oort clouds should be common: how to detect?

Extra Slides

Surviving planetesimal disks

Stable system

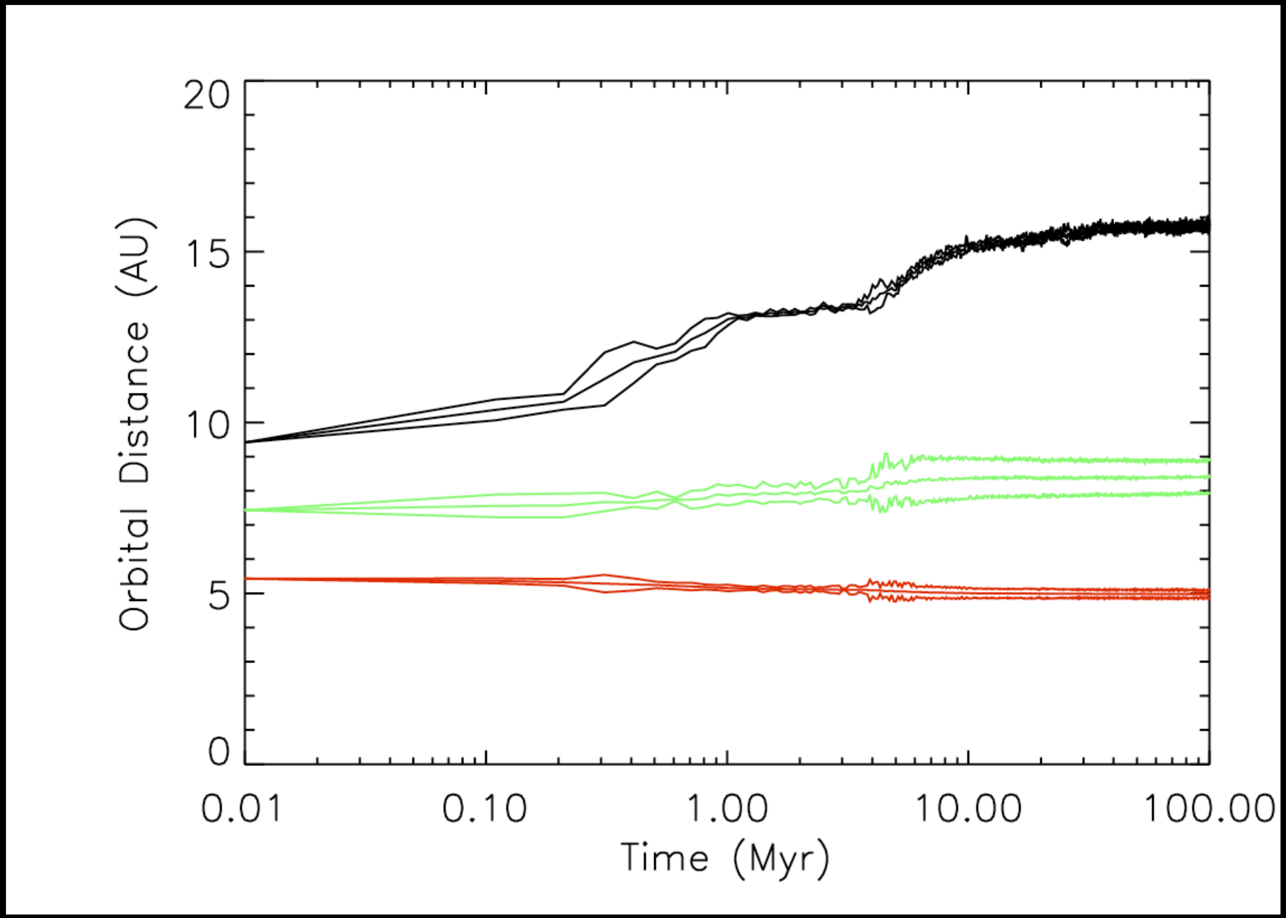


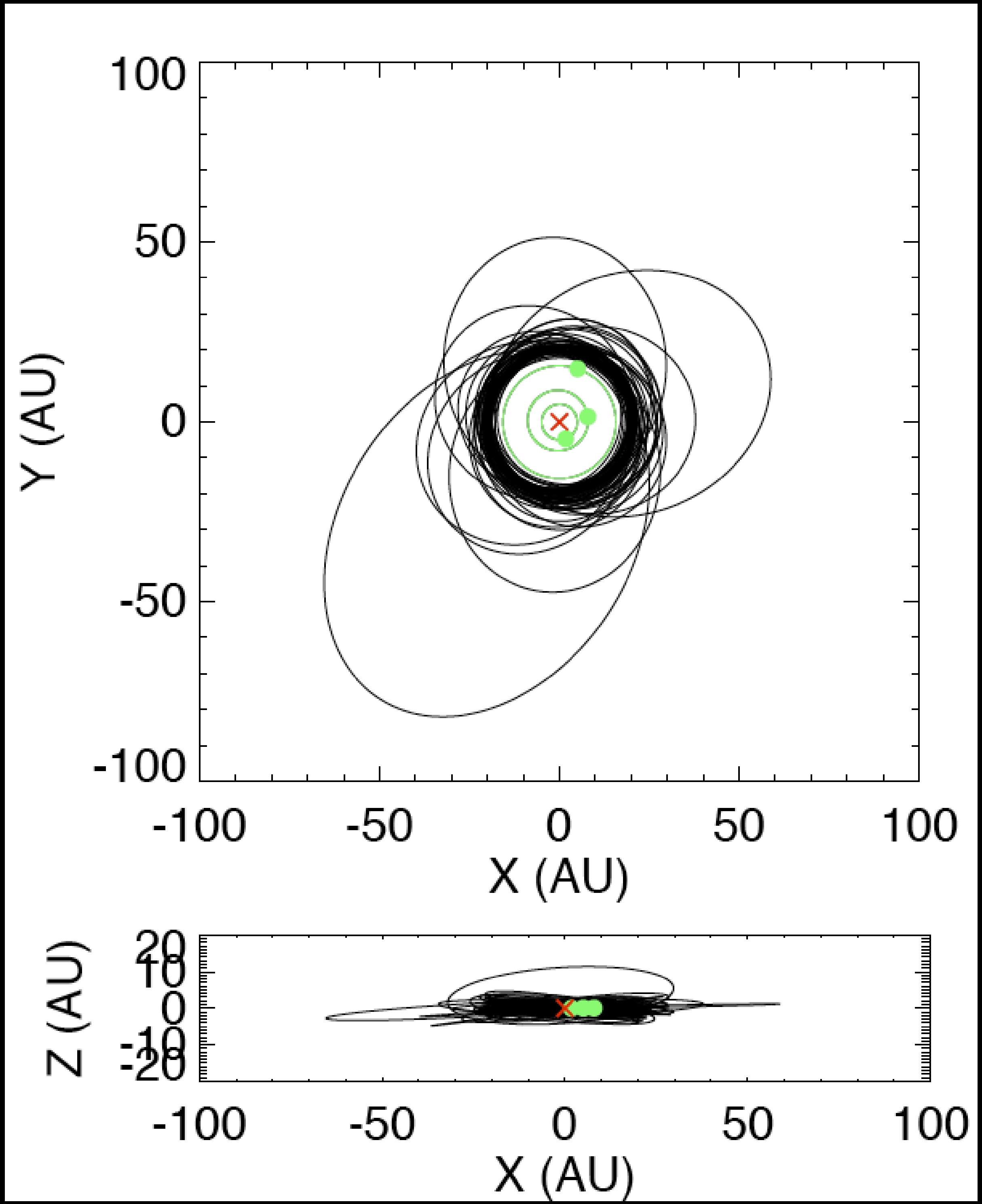


Raymond, Armitage & Gorelick in prep.

Surviving planetesimal disks

Nice model analog

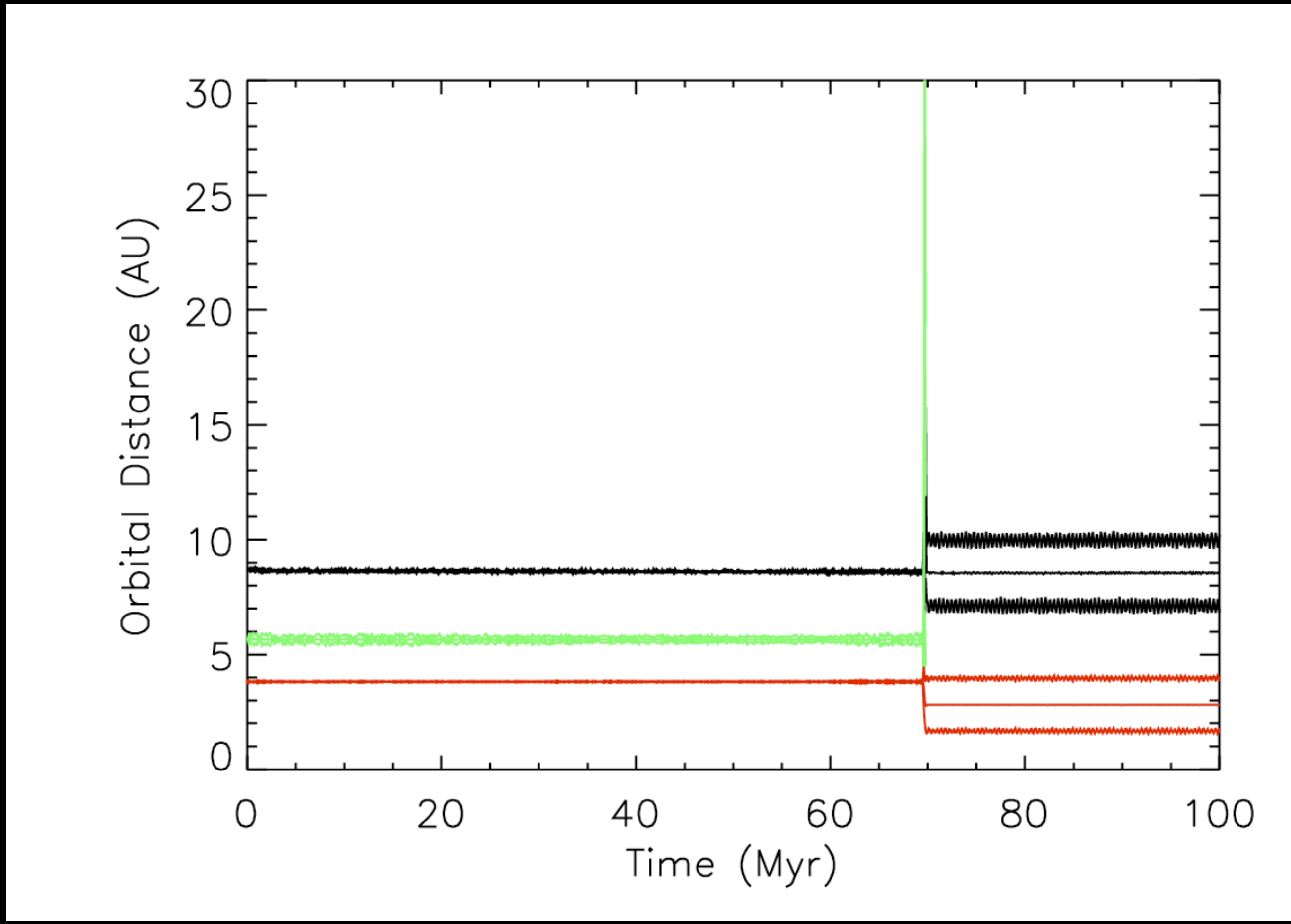


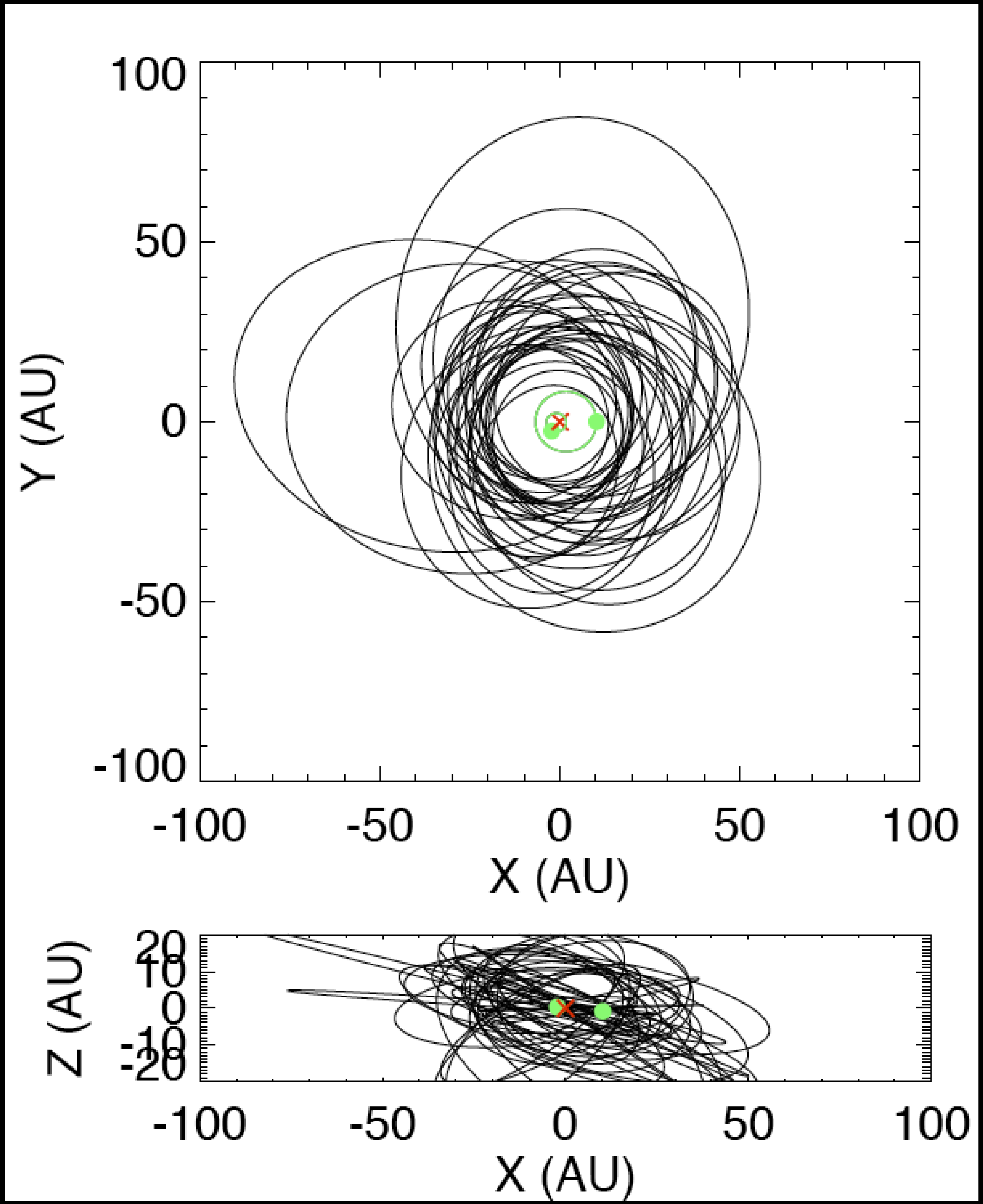


Raymond, Armitage & Gorelick in prep.

Surviving planetesimal disks

Unstable system
(Note: many unstable high-mass systems destroy their disks entirely)

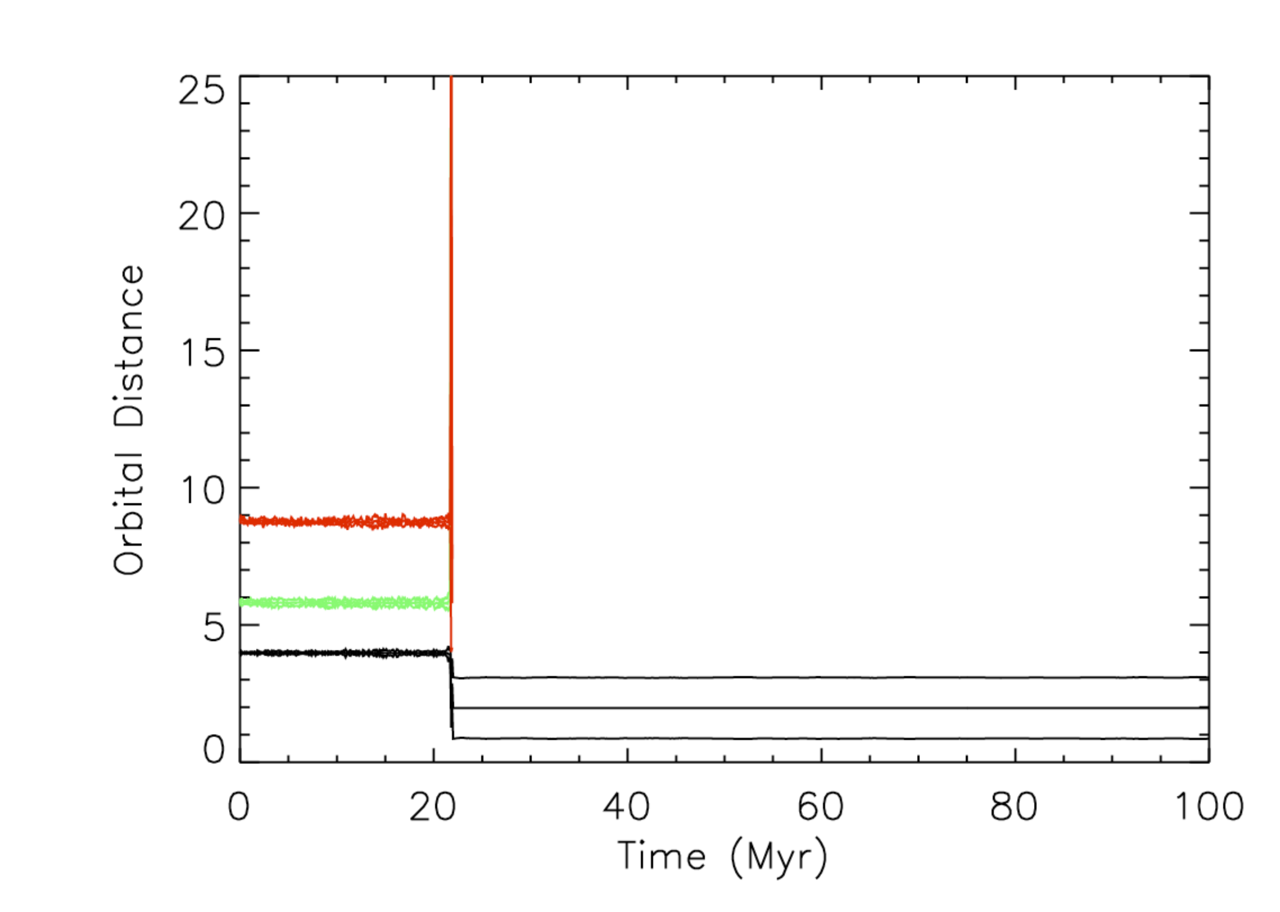


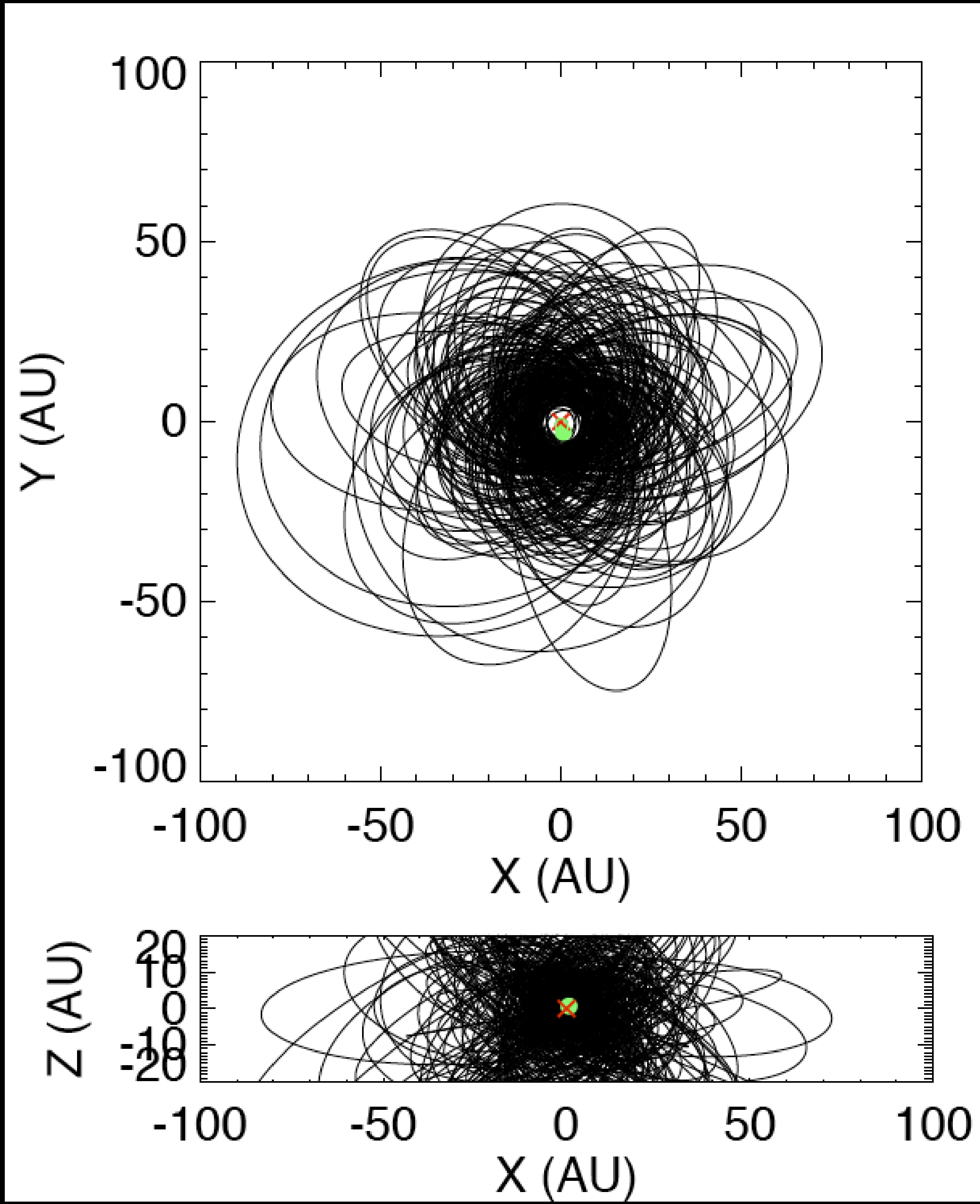


Raymond, Armitage & Gorelick in prep.

Surviving planetesimal disks

“mini Oort cloud”



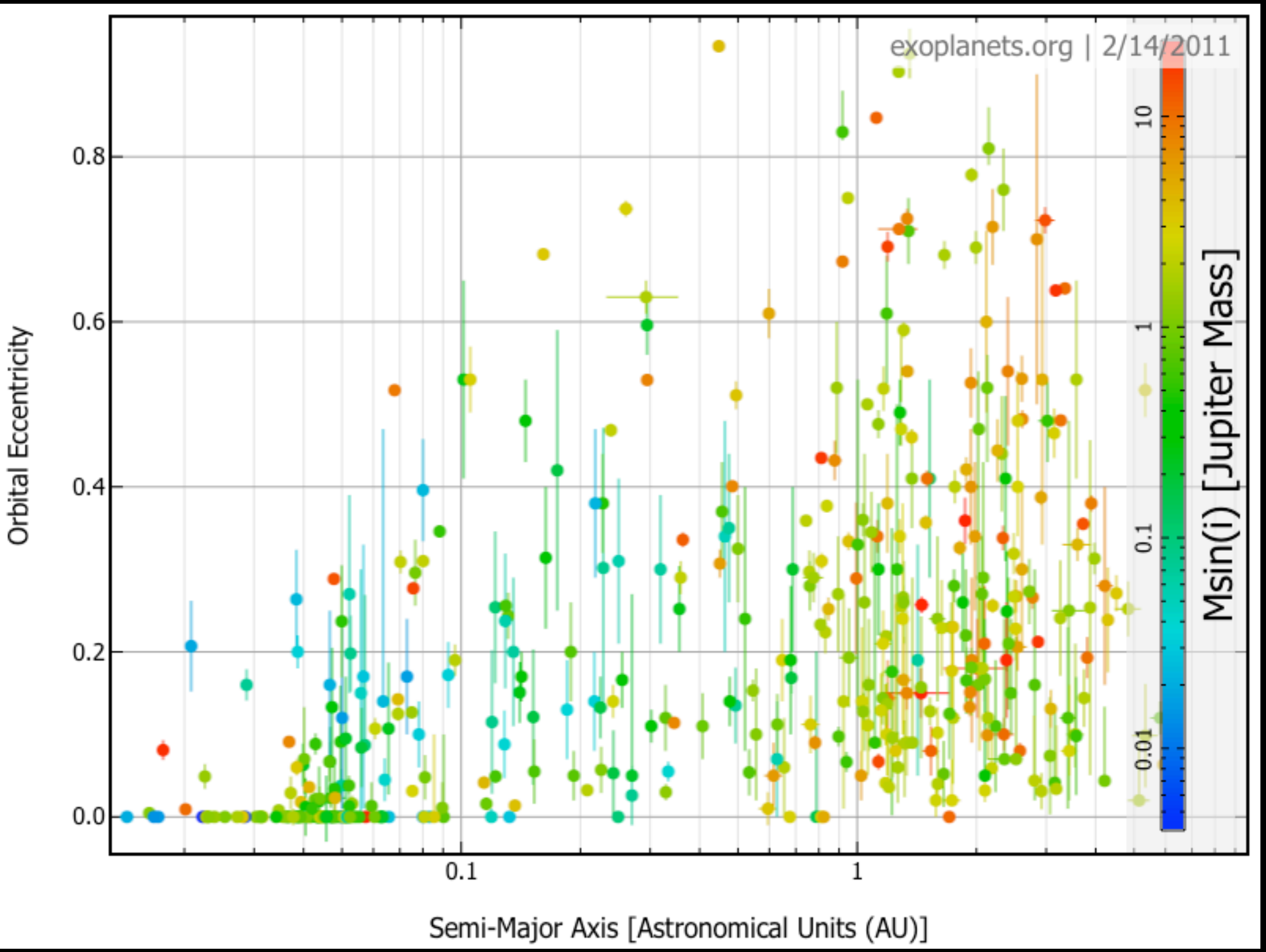


Raymond, Armitage & Gorelick in prep.

Exoplanet eccentricities

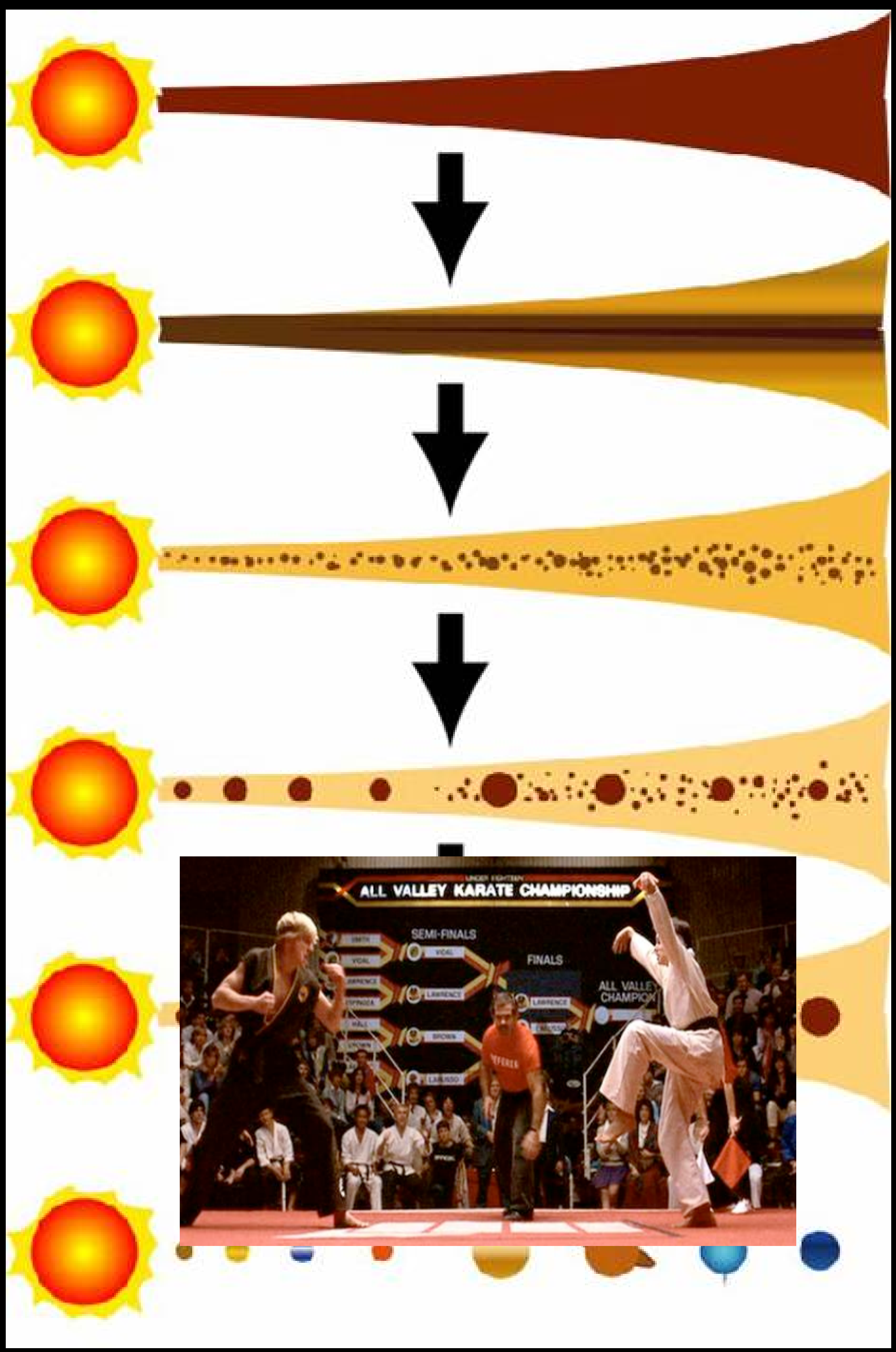
- Broad eccentricity distribution (up to 0.95)
  - Higher-mass planets have higher median e (Jones et al 2006; Ribas & Miralda-Escude 2007; Wright et al 2009)

- Best explanation: most observed planets are survivors of dynamical instabilities (Marzari & Weidehschilling 2002; Adams & Laughlin 2003; Chatterjee et al 2008; Juric & Tremaine 2008; Raymond et al 2010)



Wright et al 2011

Why do planetary systems become unstable?



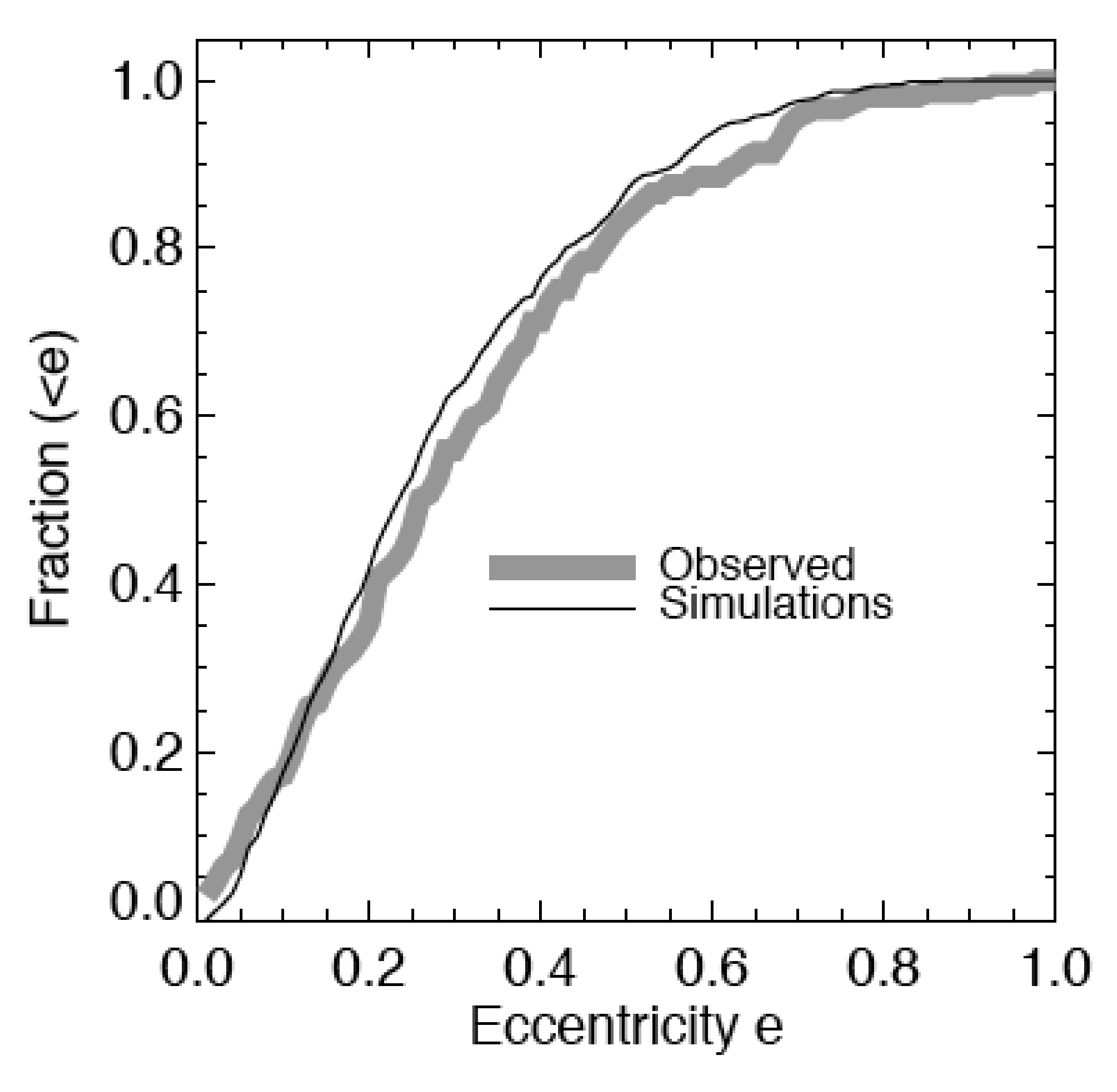
- Giant planets tend to form with characteristic spacing, close to edge of stability (Laskar 1996; Barnes & Quinn 2004)
  - Consistent with hydrodynamic planet-gas disk models (Lee & Peale 2002; Adams et al 2008)
- Stability criterion changes as gas disk dissipates (Iwasaki et al 2001)

Transition from marginally stable to unstable configuration toward end of gas disk lifetime (e.g., Lin & Ida 1997)

Although chaotic dynamics can destabilize systems at any age (Marzari & Weidenschilling 2002)

Planet-planet scattering can explain:

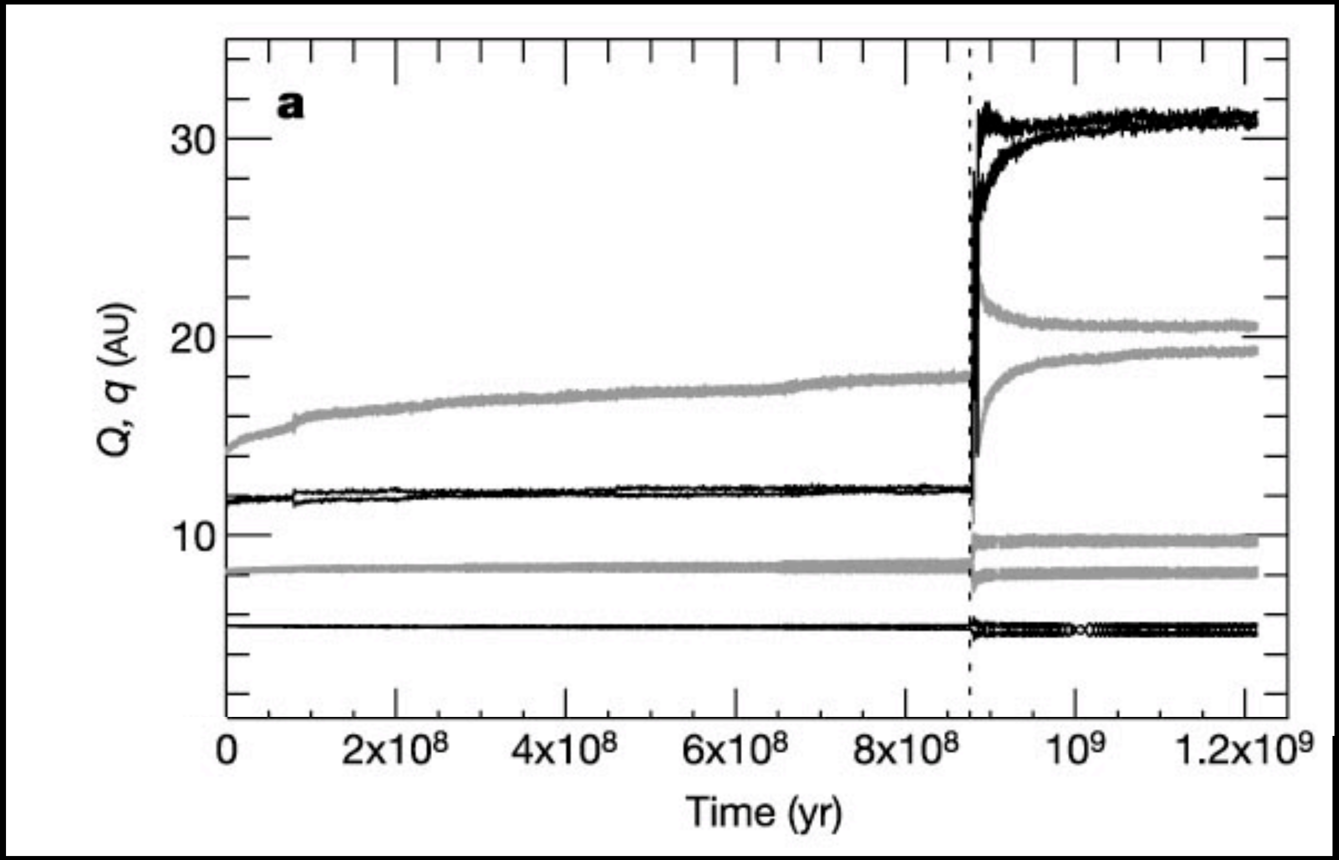
- Exoplanet eccentricity distribution (e.g., Chatterjee et al 2008; Juric & Treimaine 2008)
- Mass-eccentricity correlation if $M>M_J$ planets form in multiple planet systems (Raymond et al 2010)
- Distribution of dynamical configurations of 2-planet systems (Raymond et al 2009)
- The origin (with tidal friction) and high inclinations of hot Jupiters (Nagasawa et al 2008; Winn et al 2010; Triaud et al 2010)



Raymond et al (2009)

The Solar System's outer planetesimal disk

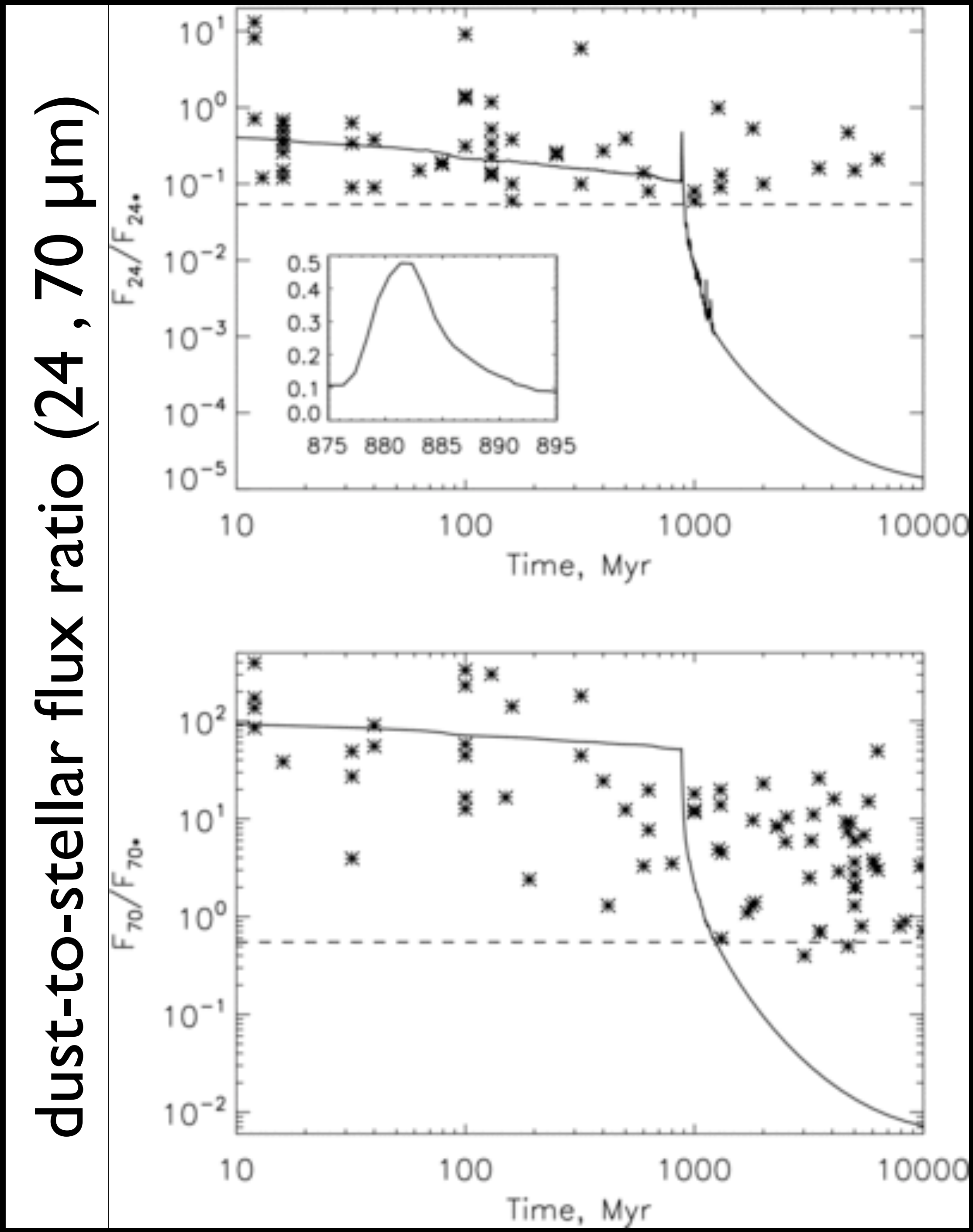
- Interaction with outer giant planets causes planetesimal-driven migration (Fernandez & Ip 1984)
- Primitive Kuiper belt thought to have contained 30-50 M_E from about 15-30 AU.
- In the Solar System, interactions between the giant planets and the disk may have triggered late heavy bombardment (LHB; Gomes et al 2005; Levison et al 2011)



Tsiganis et al 2005; Gomes et al 2005

The Solar System's debris disk

- Before the LHB, collisions in the primitive Kuiper Belt produced lots of dust -- comparable to observed debris disks (Booth et al 2009)
- During LHB, influx of comets generated spike in flux at λ < 50 μm, monotonic decrease at longer λ
- Current dust brightness is very small (Backman et al 1995)



Booth et al (2009)