# News and Reminders

**JC 1:** Monday, 9/16 (in one week) - *Evidence for Hidden Nearby Companions to Hot Jupiters* - Sarah Stamer

# Chiron's chaotic orbit

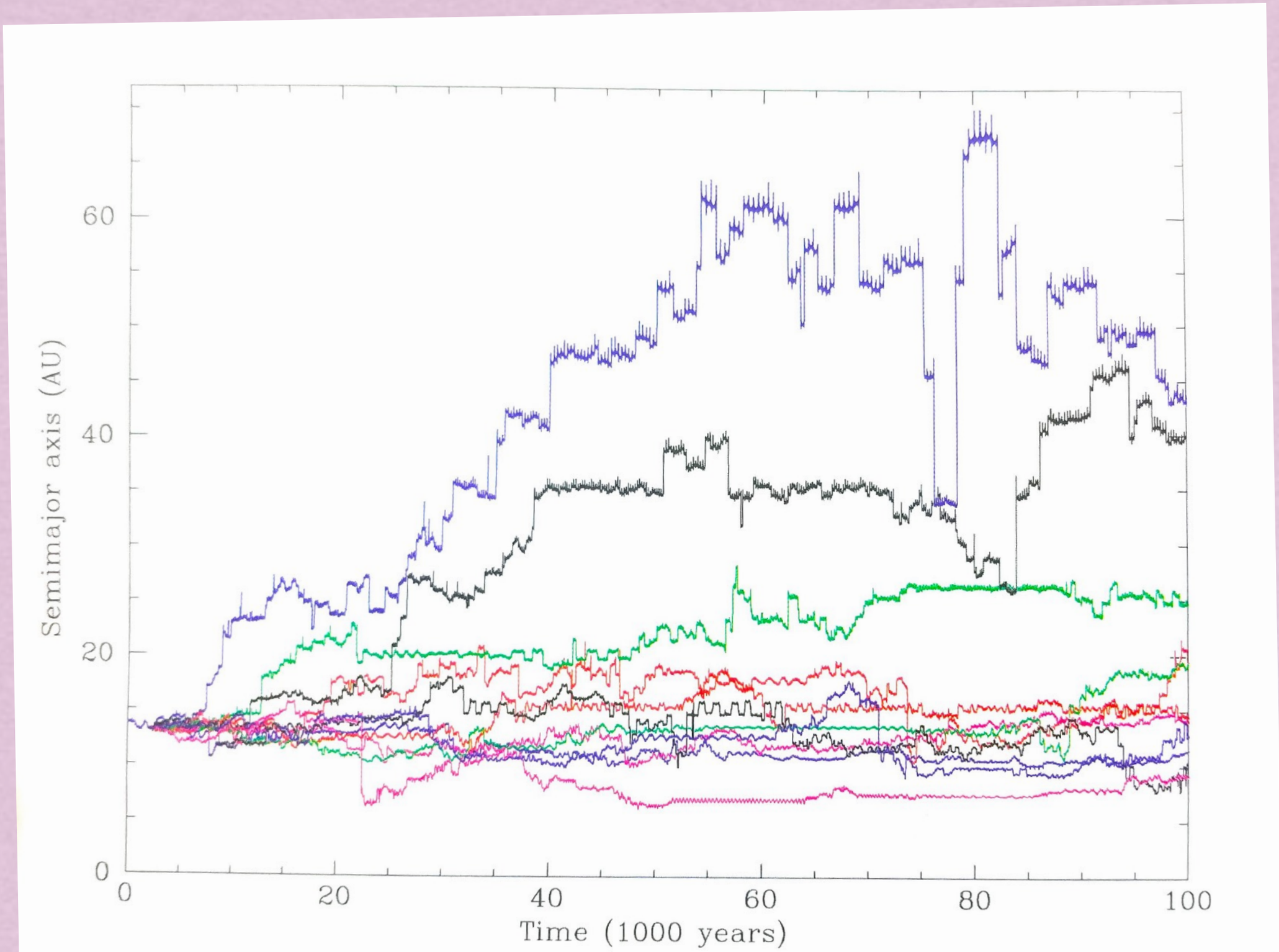
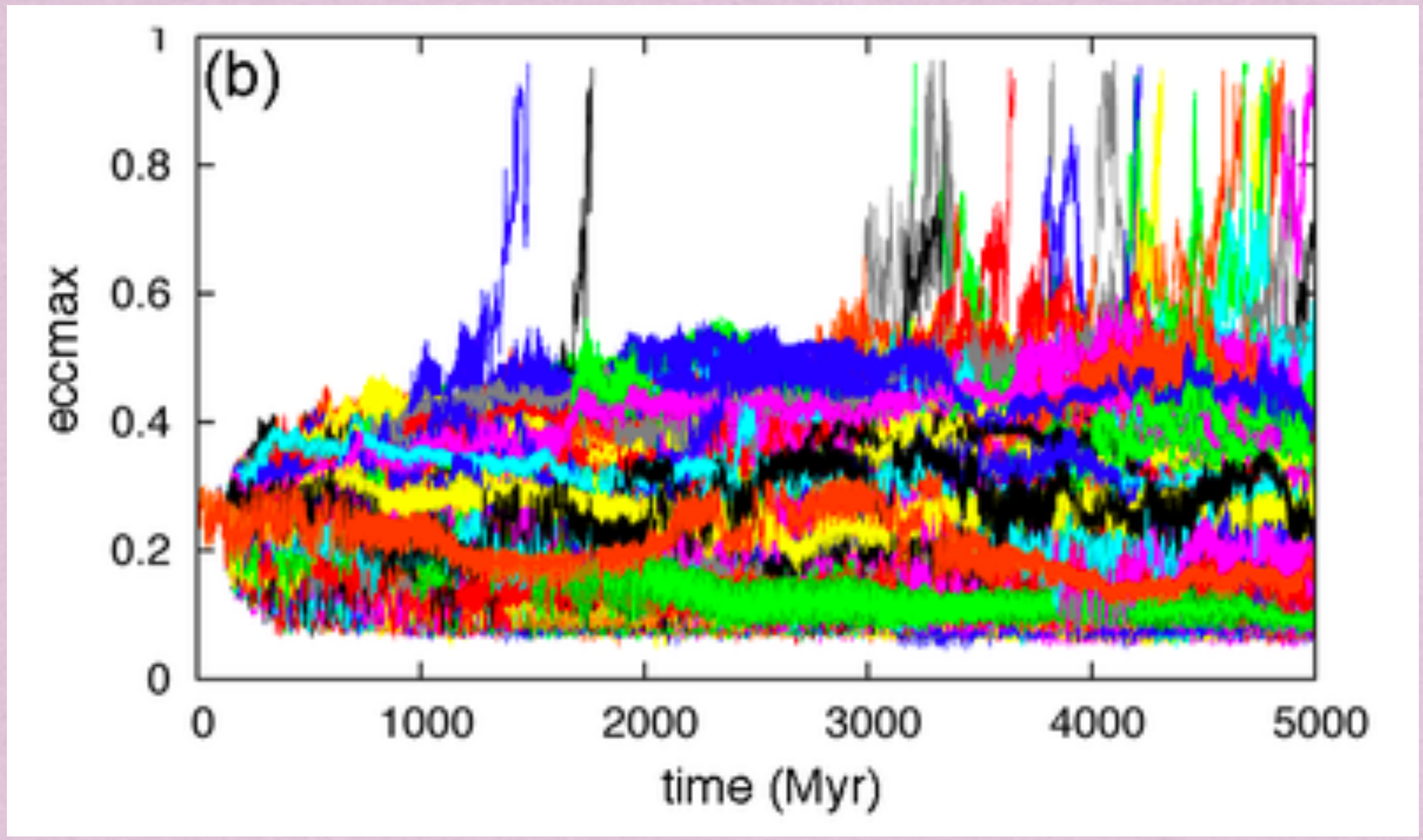



Figure 2.11

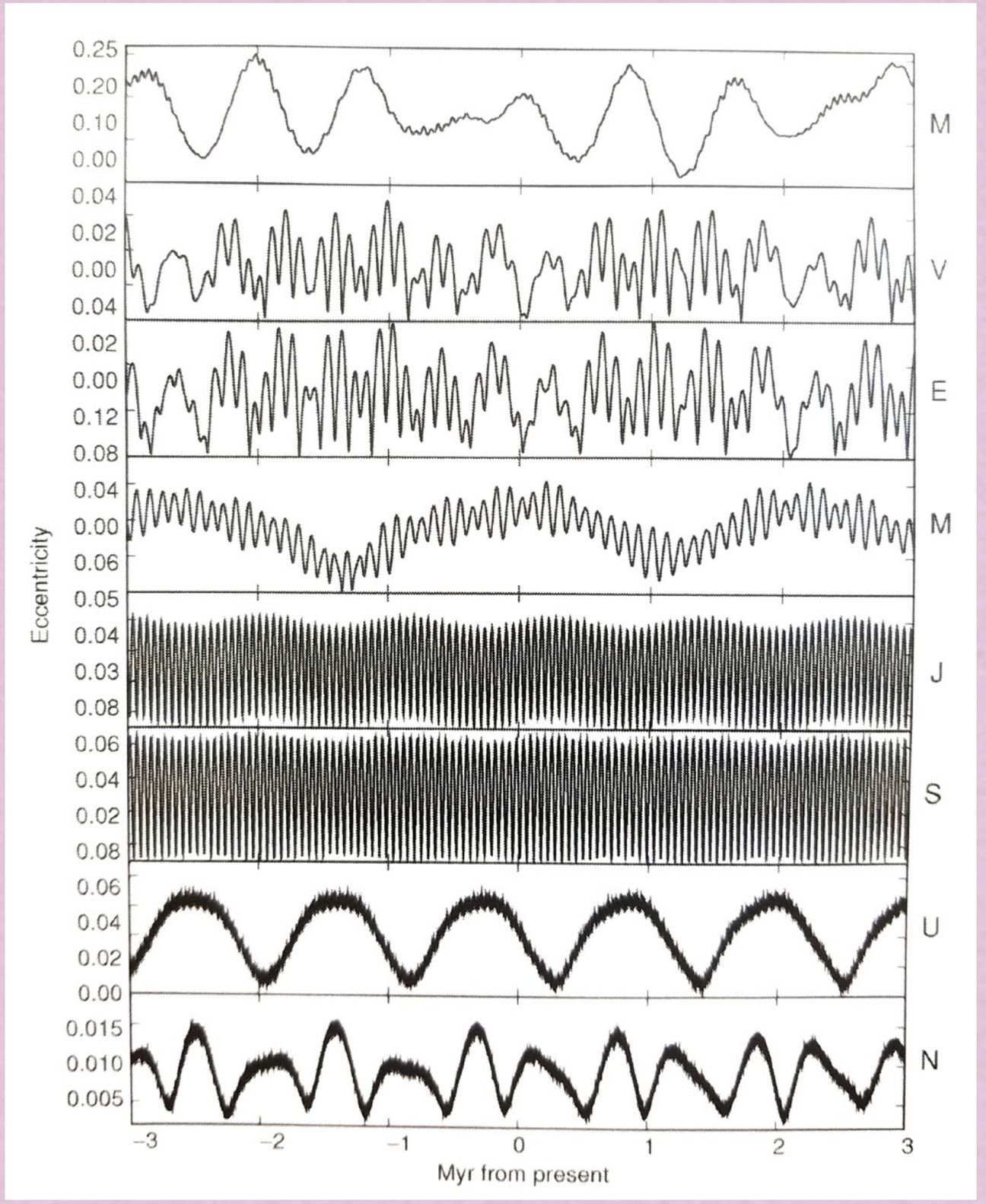
# Simulations of Mercury's Eccentricity



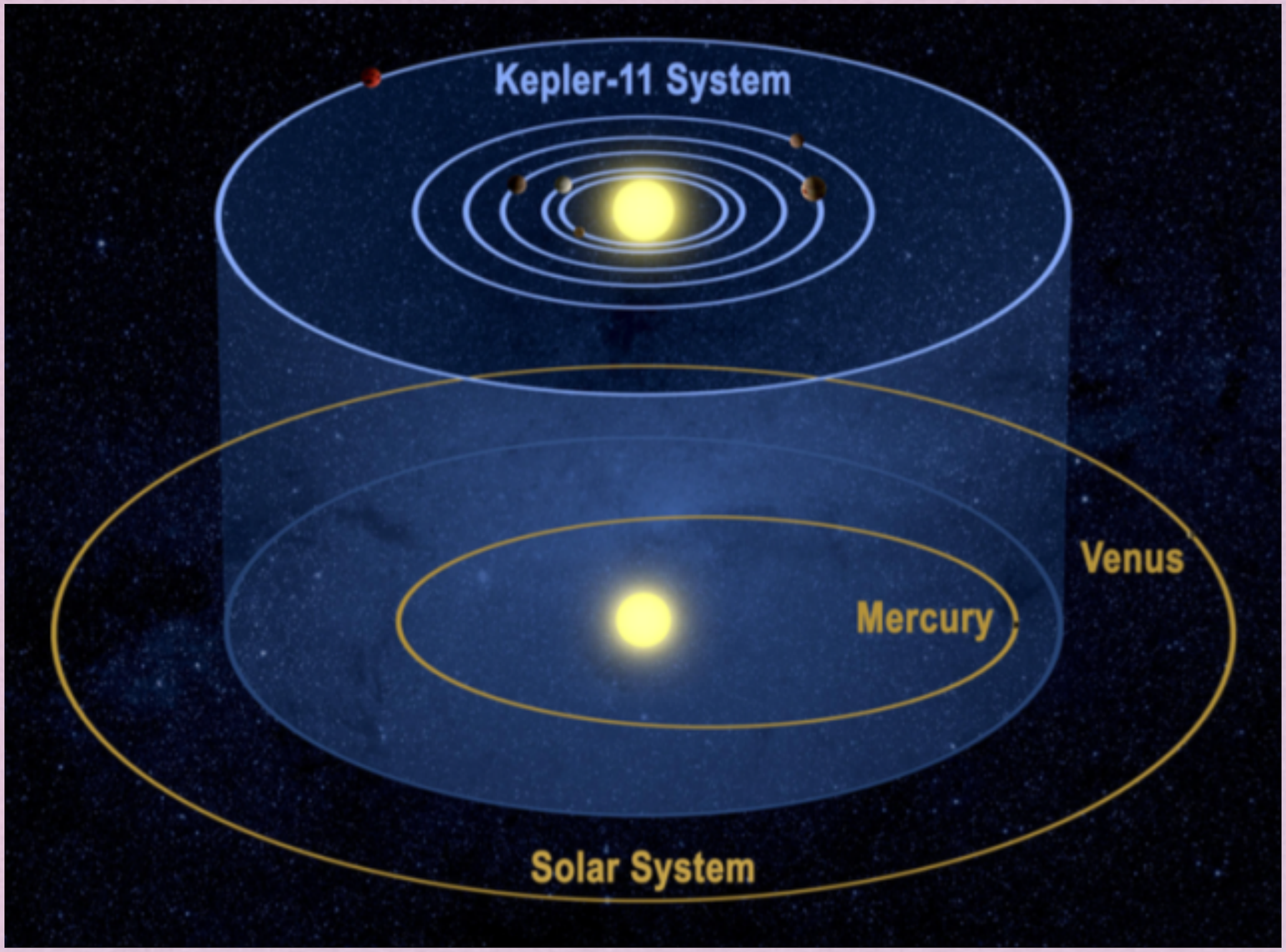

- Laskar & Gatineau (2009)
- also Batygin & Laughlin (2008)

Brown & Rein (2020): an error of 0.38 millimeters in measuring the position of the Mercury today makes it impossible to predict its eccentricity in just over 200 million years' time

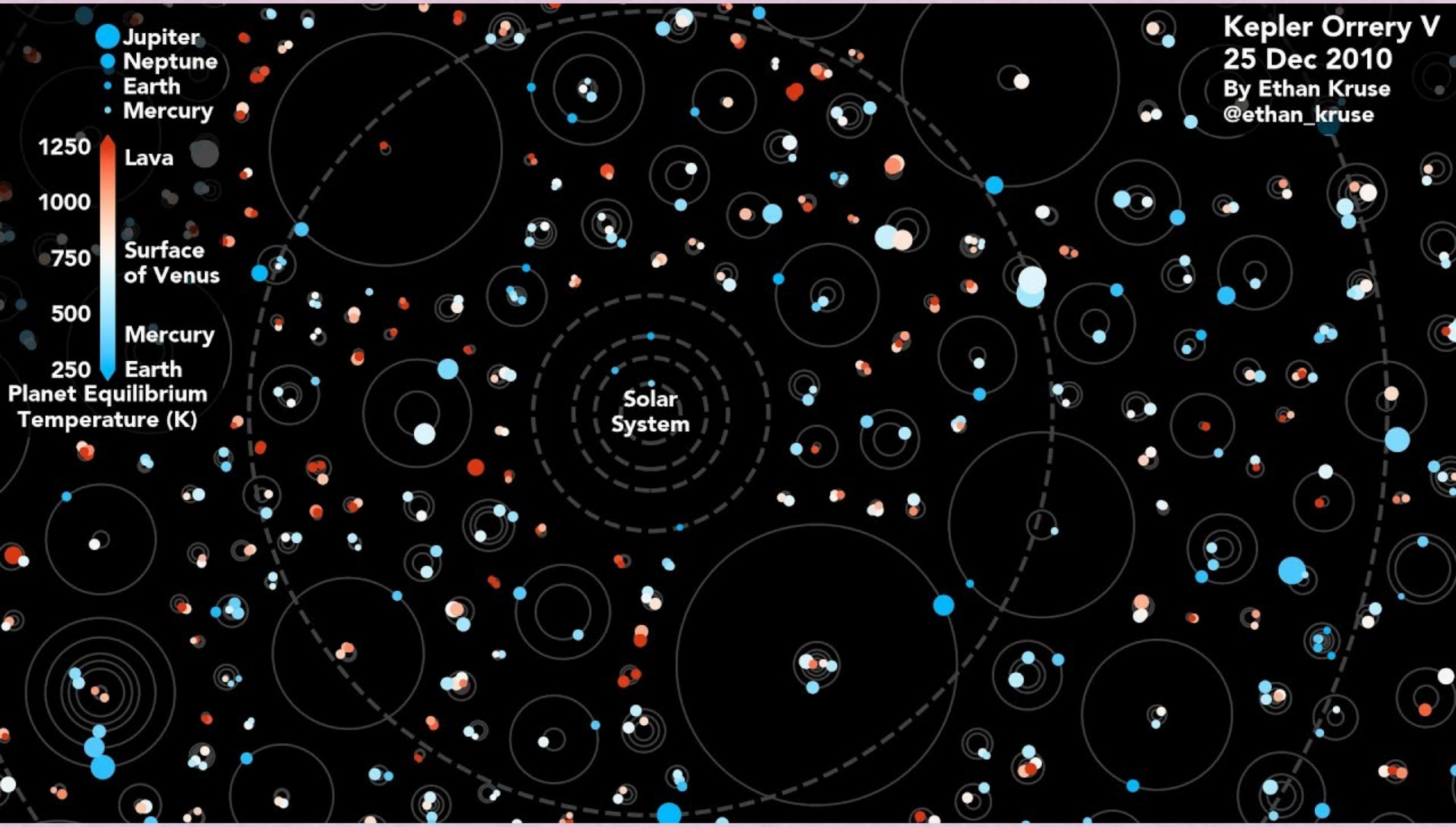
# What about the other planets?



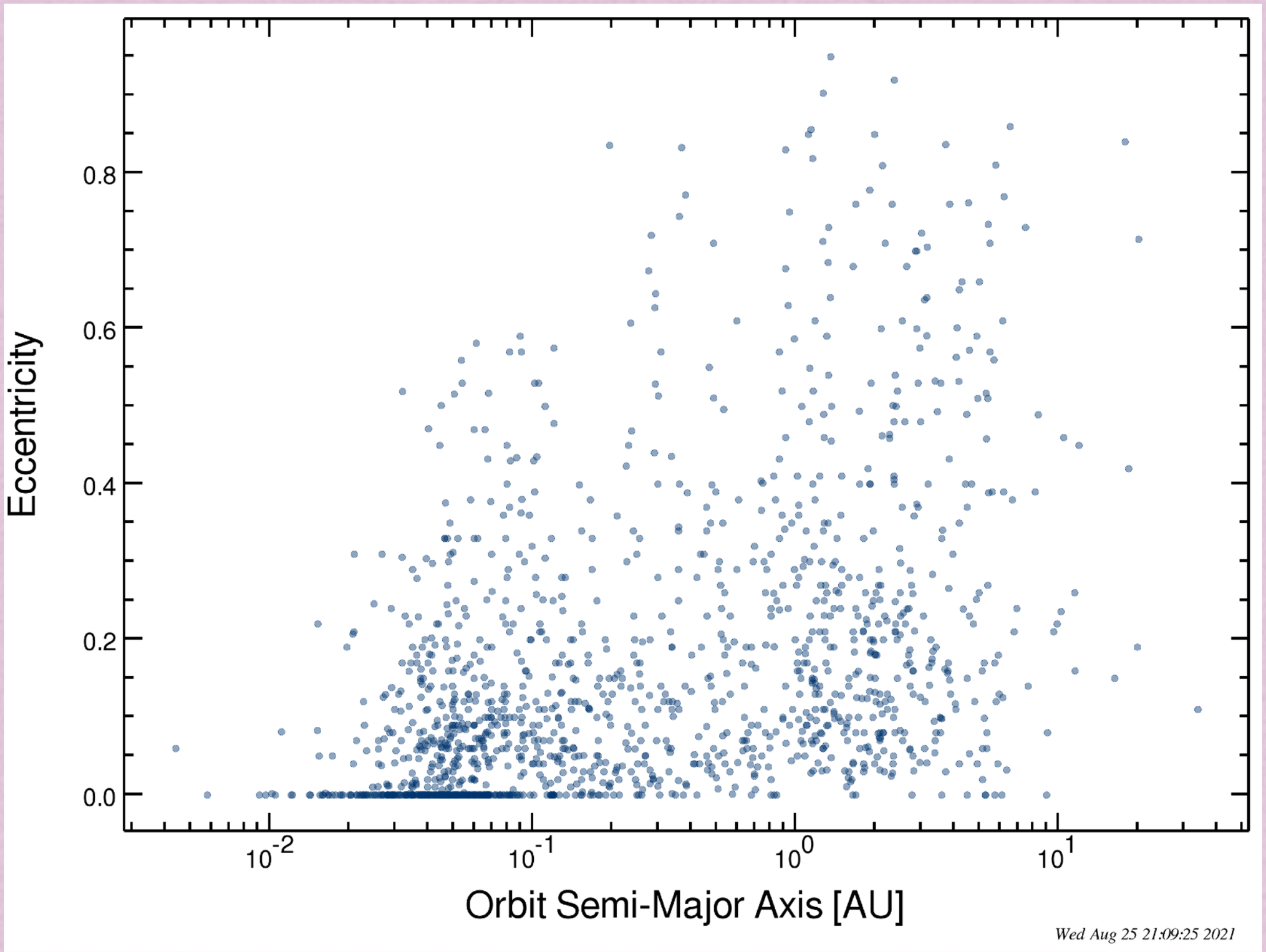
# Kepler-11



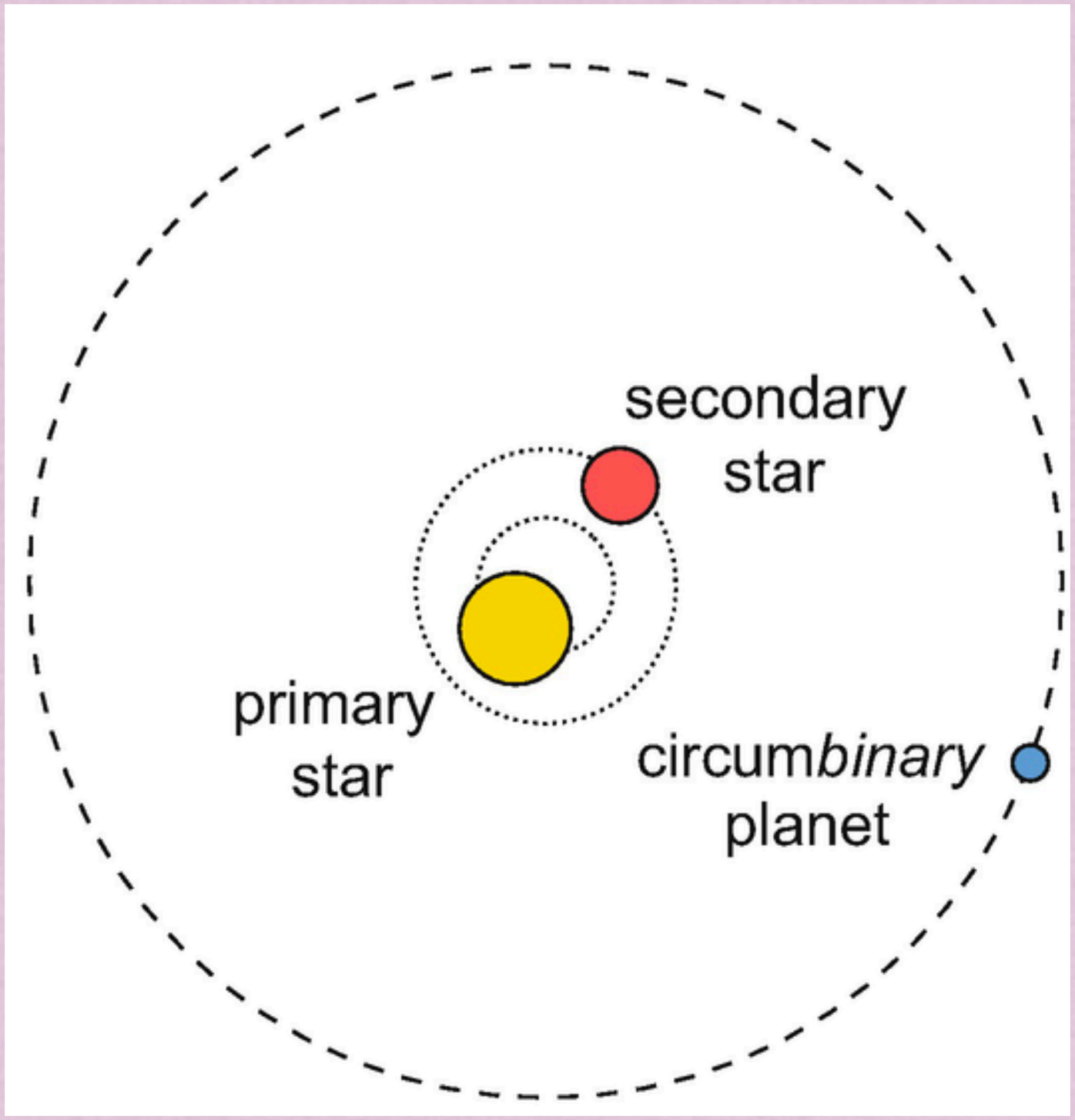
# Exoplanet Ensemble Properties



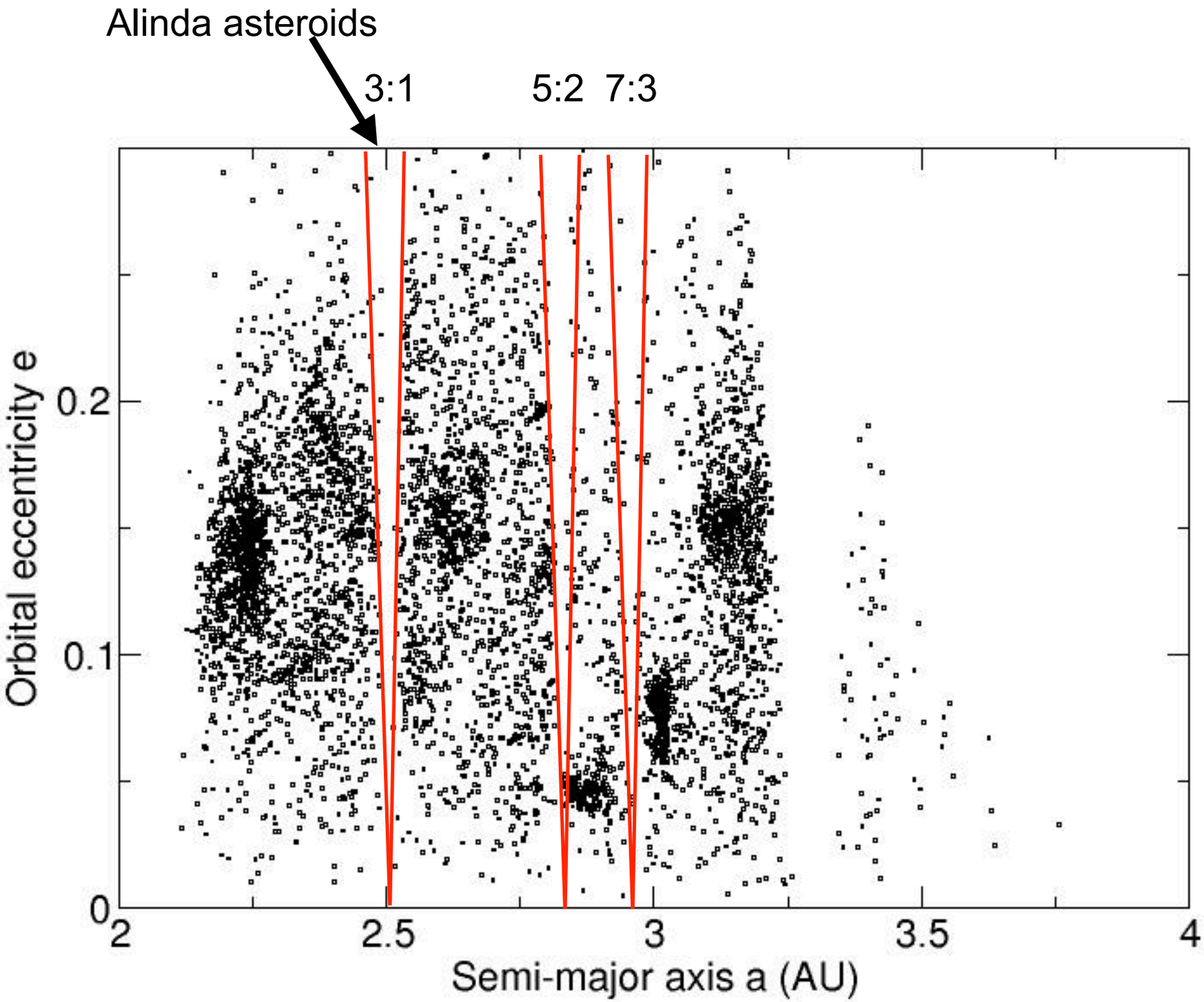
# Exoplanets have a wide range of orbital eccentricity



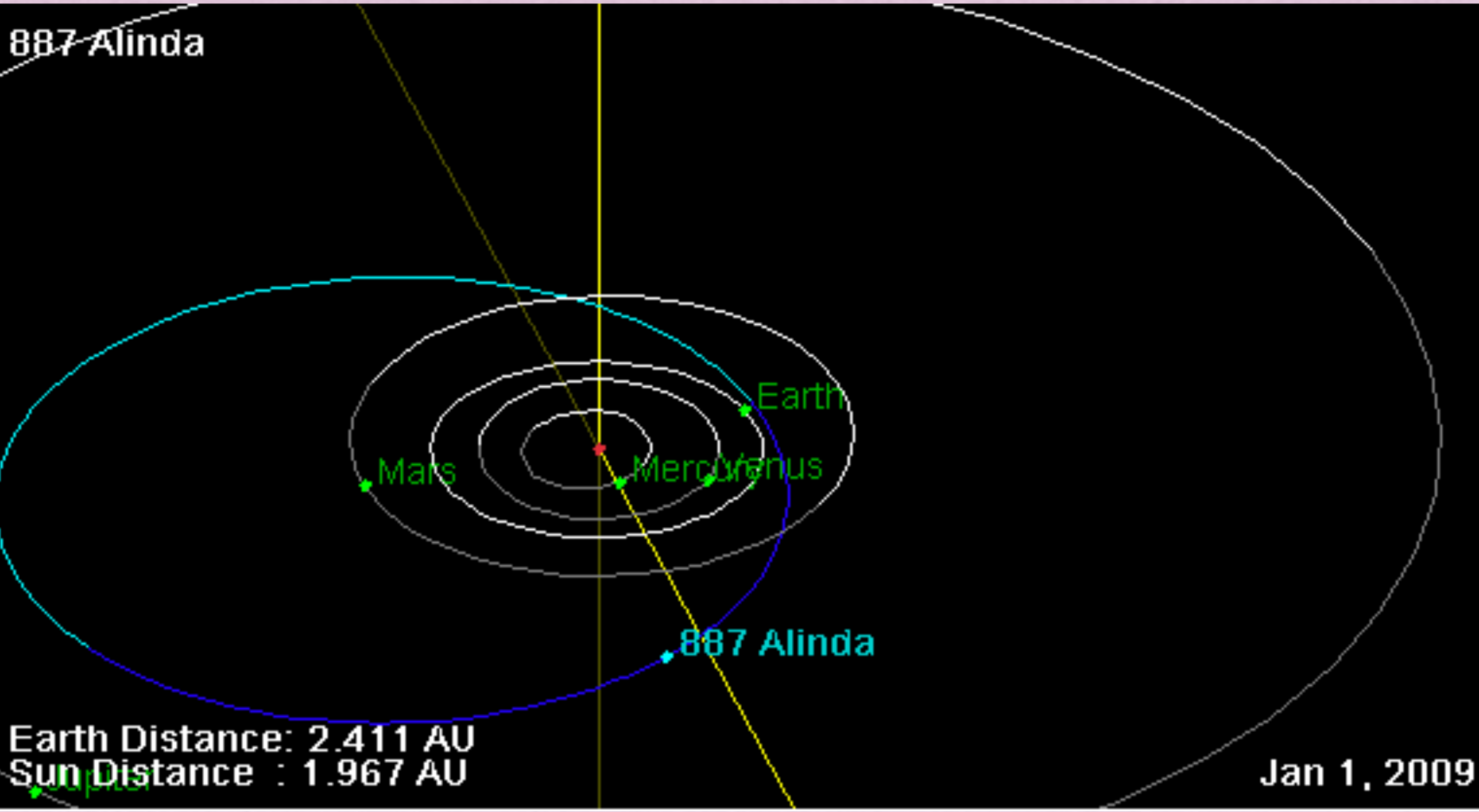
# Circumbinary Planets



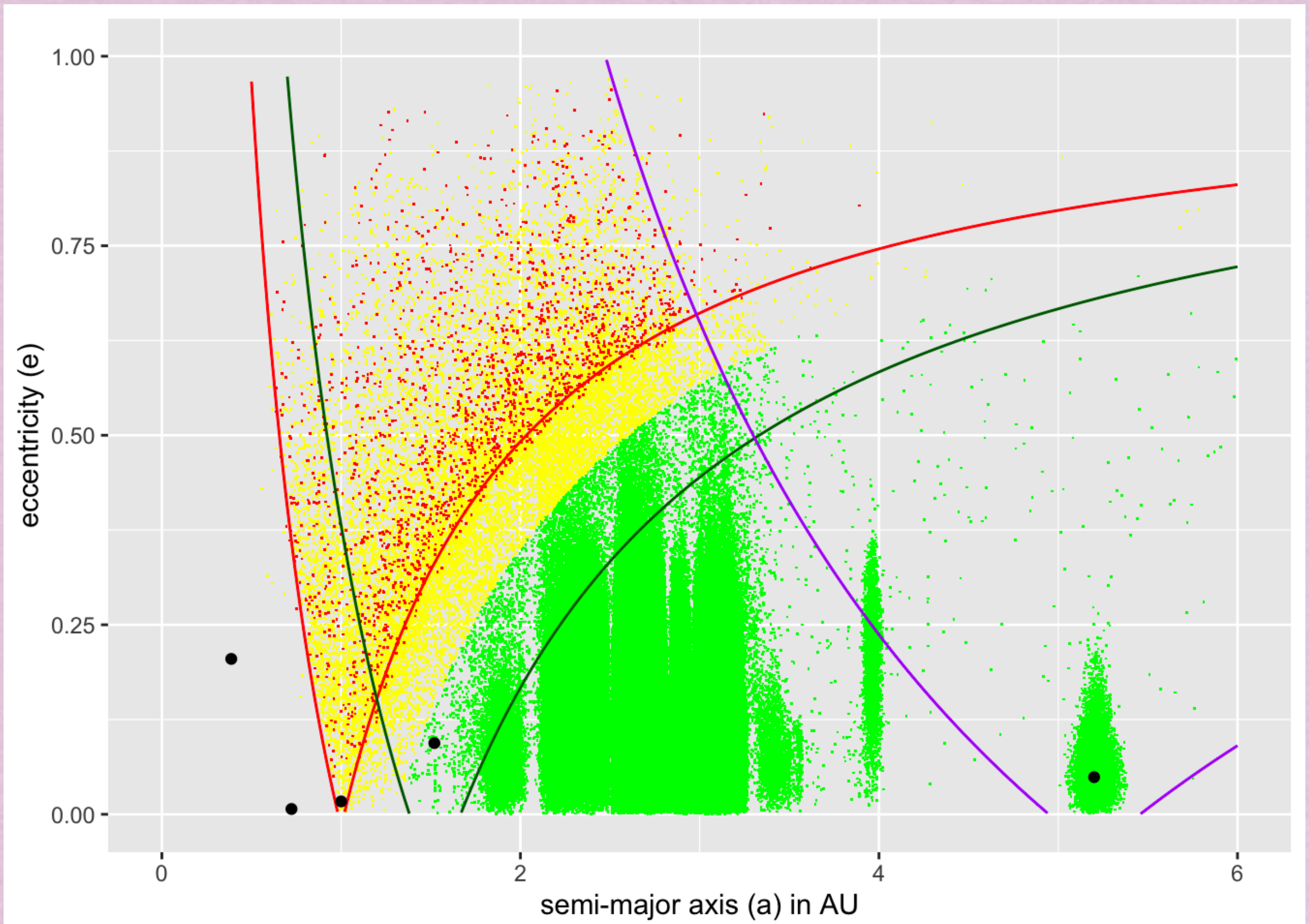
# Resonances


Alinda asteroids
3:1
5:2
7:3
Orbital eccentricity e
0
0.1
0.2
2
2.5
3
3.5
4
Semi-major axis a (AU)

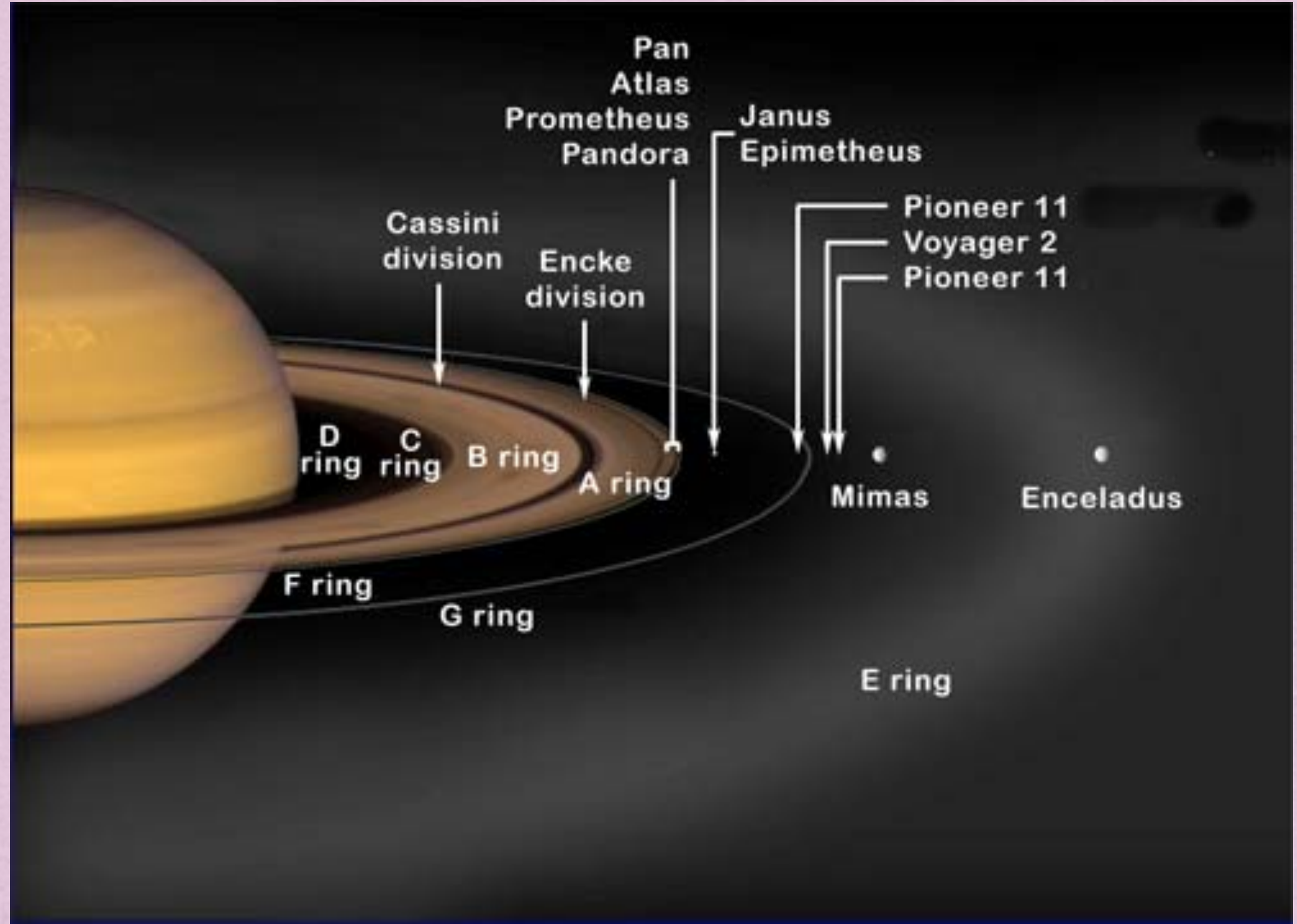
# Alinda Asteroid orbit



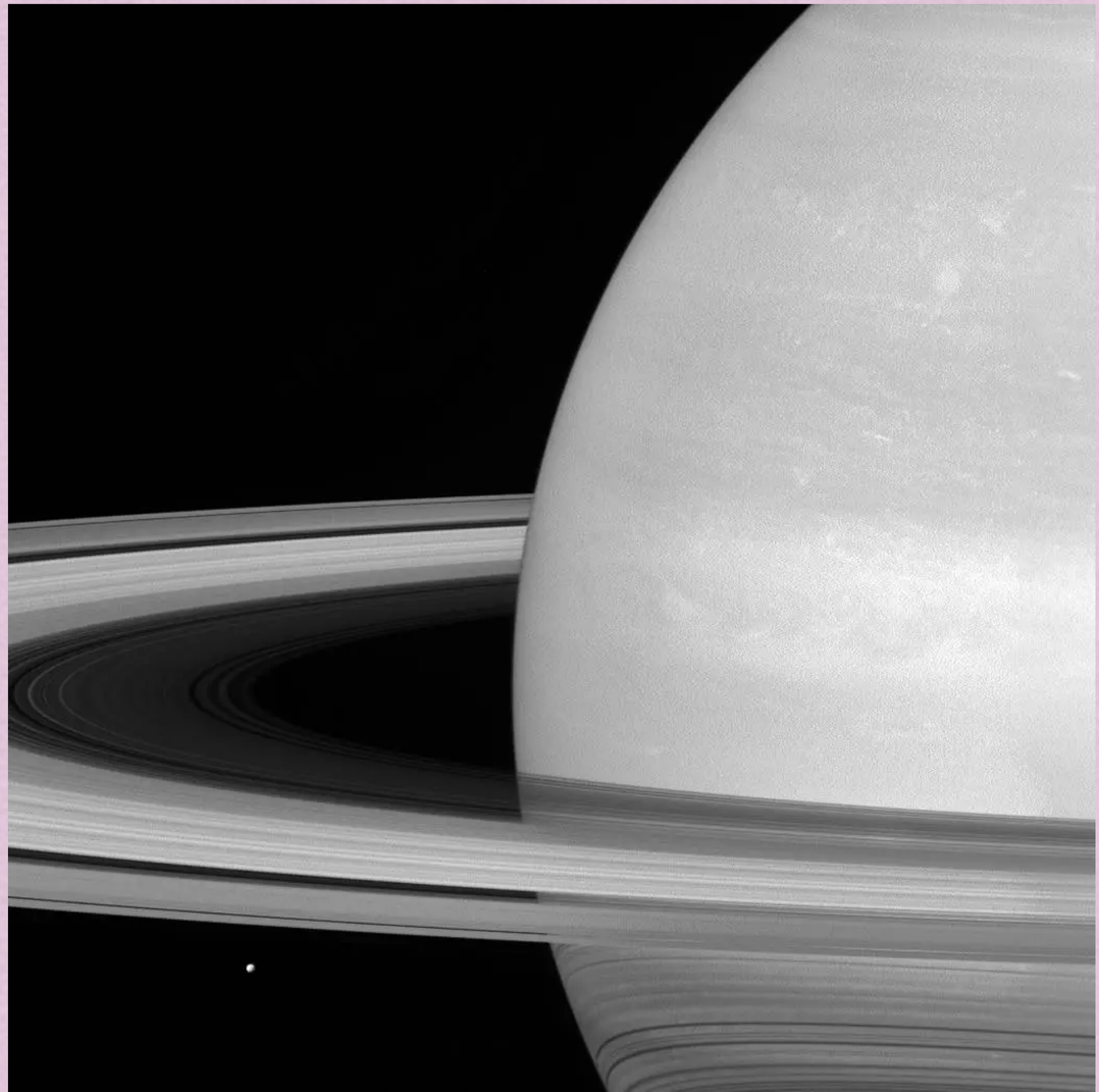
# Near-Earth Asteroids



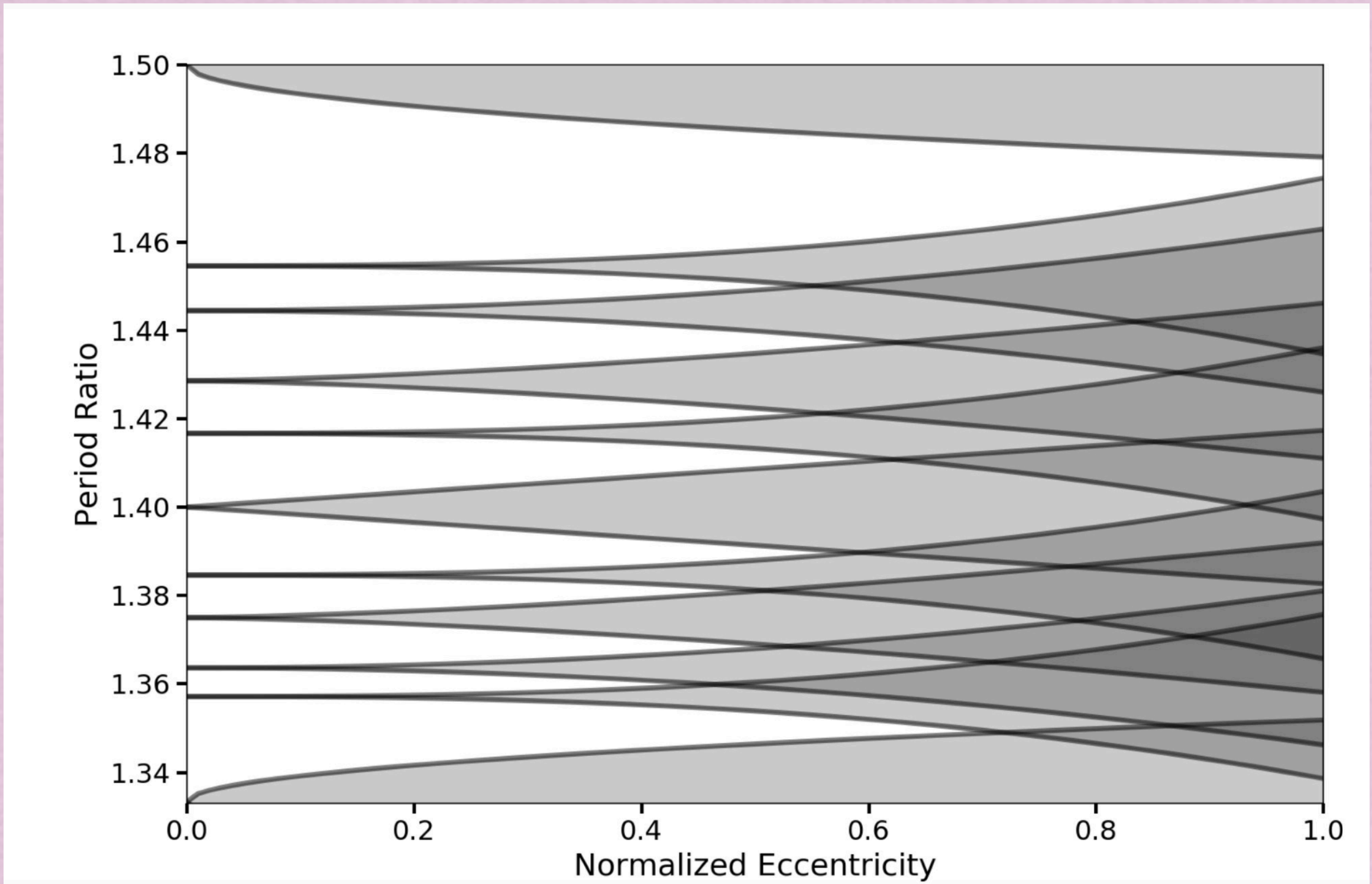
# Resonances

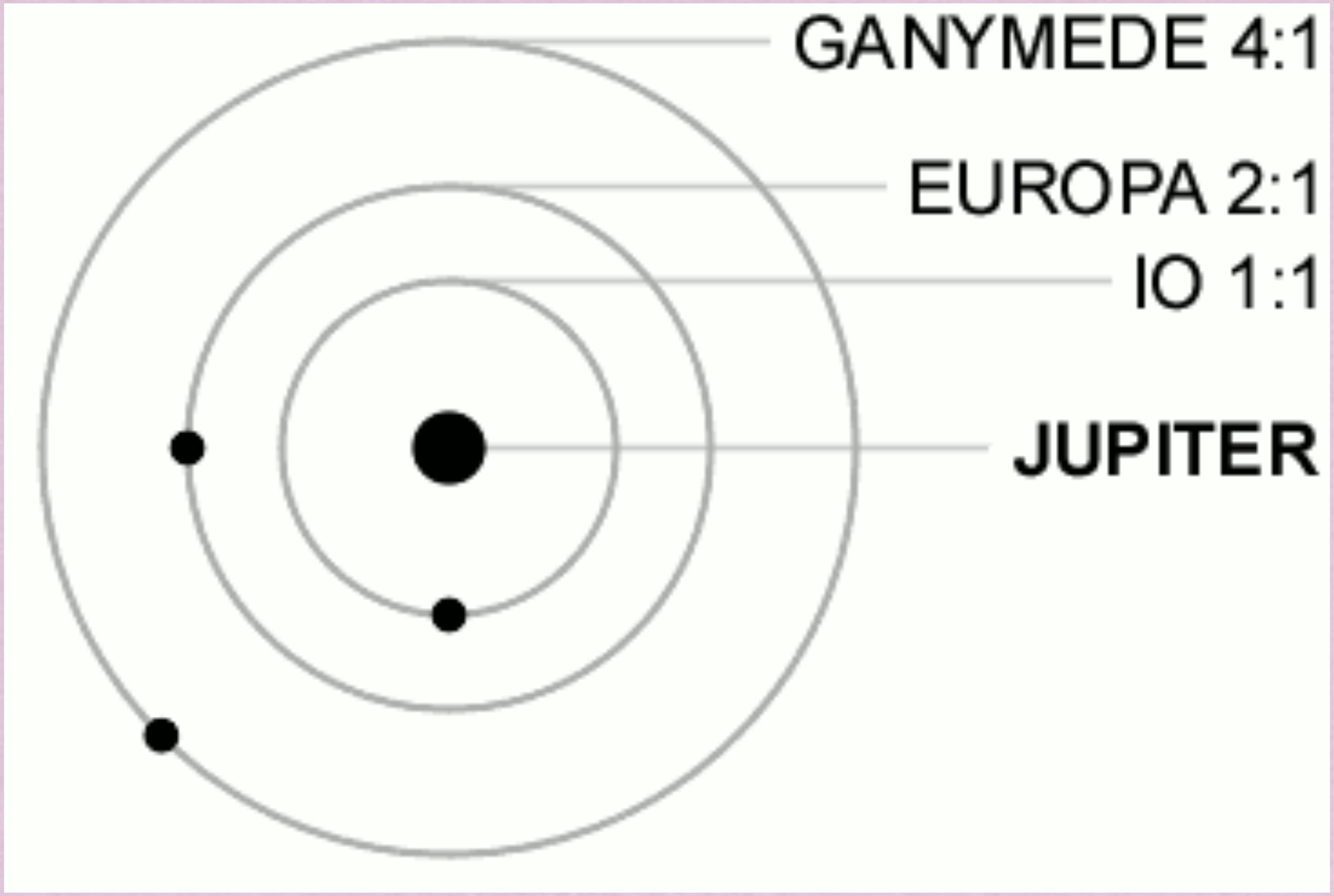

Pan
Atlas
Prometheus
Pandora
Janus
Epimetheus
Cassini division
Encke division
Pioneer 11
Voyager 2
Pioneer 11
D ring
C ring
B ring
A ring
Mimas
Enceladus
F ring
G ring
E ring

# Mimas and Cassini division in 2:1 MMR

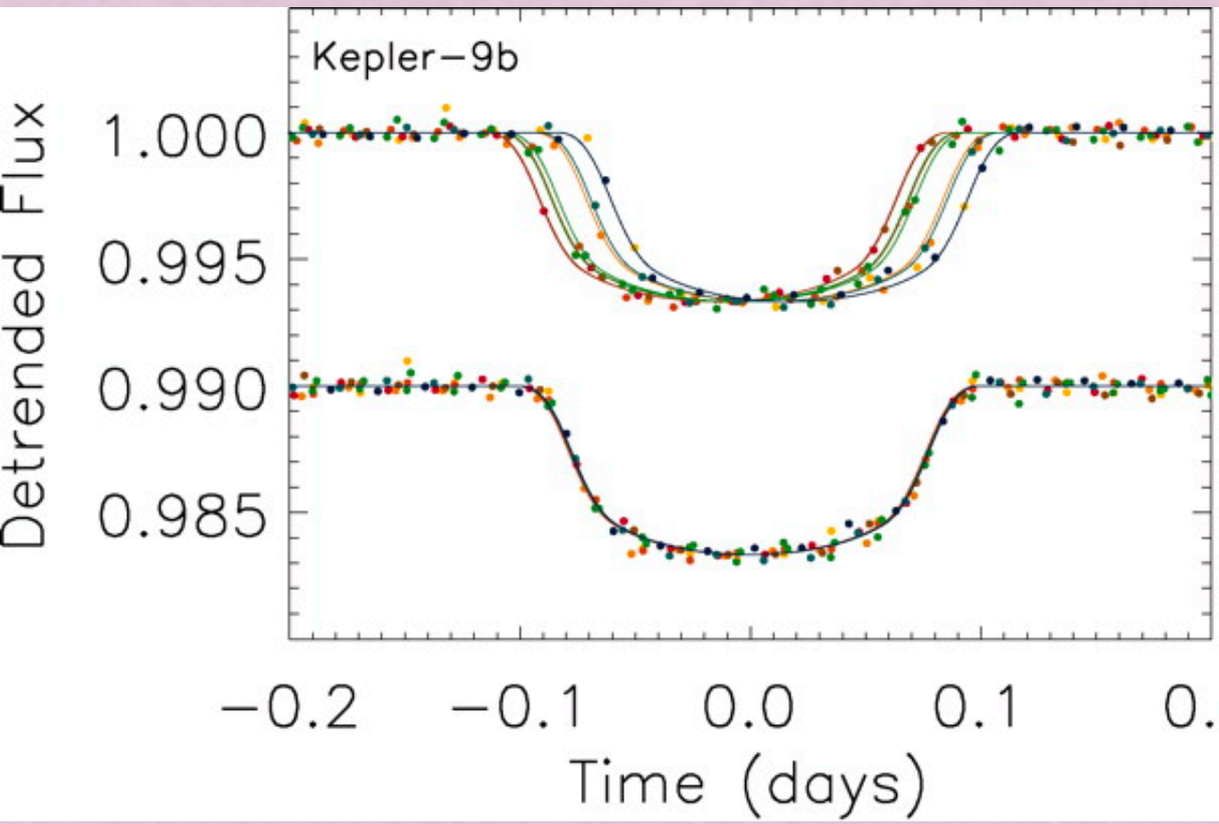


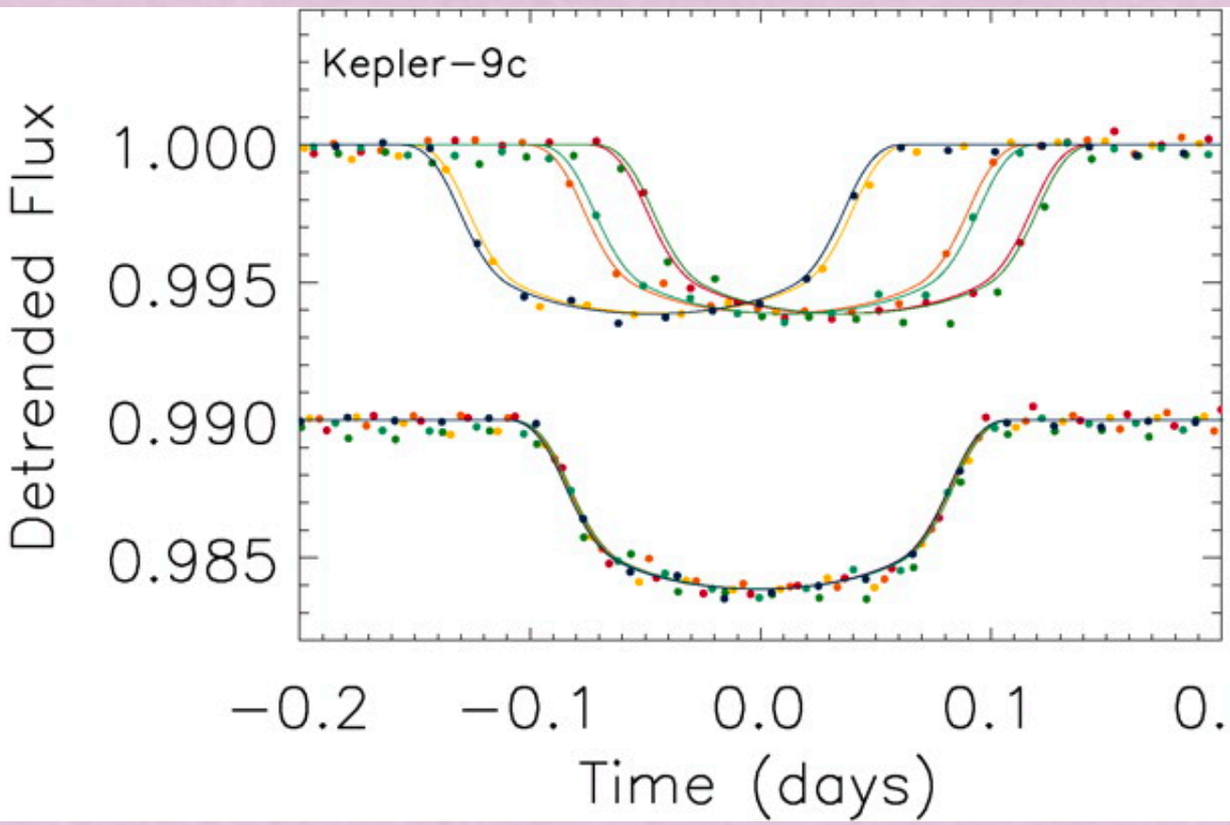
# Mean Motion Resonance vs. Eccentricity




GANYMEDE 4:1
EUROPA 2:1
IO 1:1
JUPITER

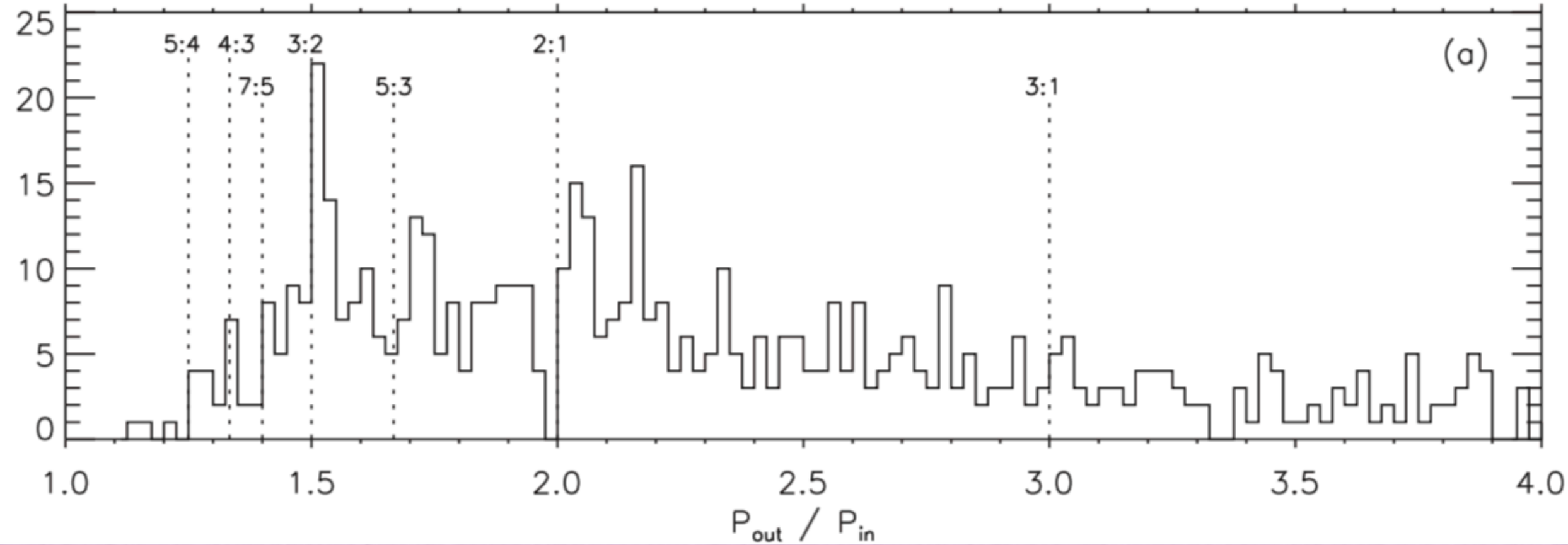
# Transit Timing Variations




Holman et al. (2010)

# Resonant Systems




Fabrycky et al. (2014)

Kepler systems - we still don't understand why so many exoplanet pairs are just *outside* of mean motion resonances

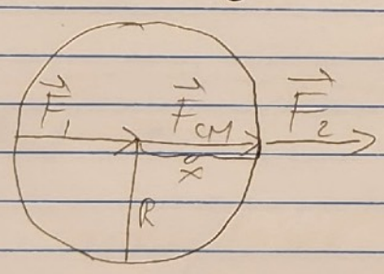
## Tides:

Gravitational force varies for different parts of a body ⇒ tidal force
⇒ produced by differential tugs

Tidal forces can deform a body and change its rotation via torques. For eccentric orbits, tidal forces are time-variable ⇒ deformation is time-variable, generating internal friction and thus heat!

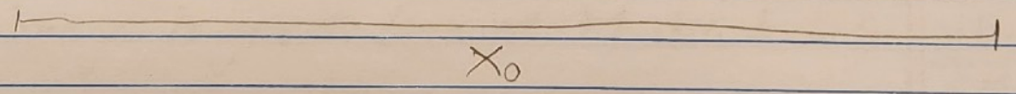
For planets, the solid parts can behave like fluids on long (geologic) timescales, E.g. Earth causes Moonquakes through tidal forces.

## Tidal bulges:




$\vec{F}_1 \neq \vec{F}_2 \neq \vec{F}_{CM}$

$x_0 \gg R$




along x-axis: $F_t = F_2 - F_{CM} = \frac{Gm}{(x_0 - x)^2} - \frac{Gm}{x_0^2}$

$F_t$ is tidal force per unit mass

Class activity: in teams of 2,

-show that $\frac{Gm}{(x_0 - x)^2} - \frac{Gm}{x_0^2} \approx \frac{2 \times Gm}{x_0^3}$