Planetary systems in stellar clusters – a lesson from Planet Nine?

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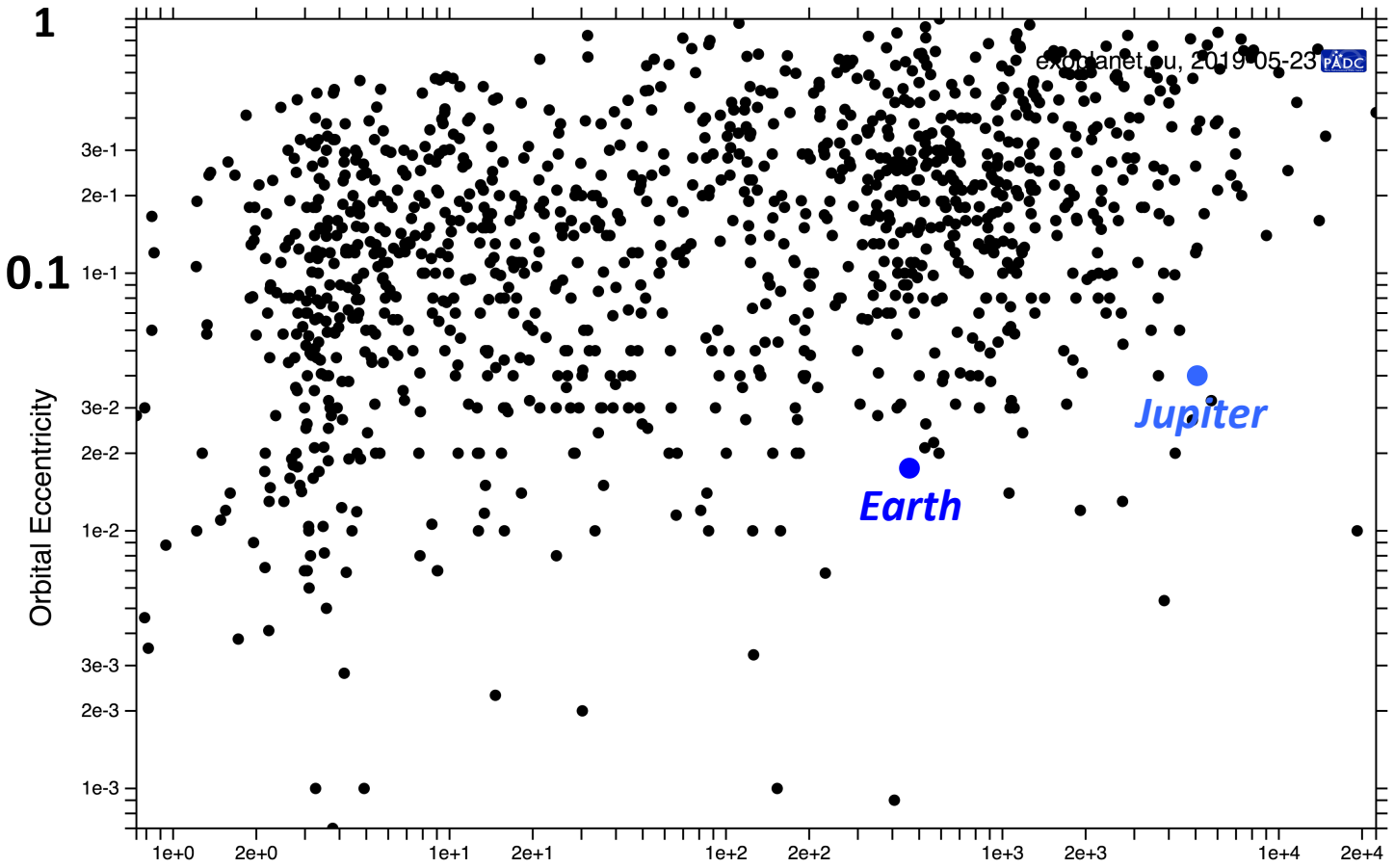
The solar system is uncommon



Rad. vel. + Transits

Exoplanet eccentricities are rarely at the level of solar system planets

Limits to regularity…

- ***Intrinsic:***

– Successful migration sets constraints on disk properties and planet masses

– Tight, multi-resonant systems may break down due to planet-planet interactions

- ***External:***

– Photo-evaporation effects

– Perturbations due to the cluster tide

– Close encounters by cluster member stars

...

- ***Question:*** What is the relative importance of external vs intrinsic effects in the shaping of planetary systems?

- ***Expectance:*** *Low density birth environments with small, short-lived clusters favor survival of regular systems*
- ***Consequence:*** Formation of sednoids in a small embedded cluster and the Oort Cloud in the Galactic field after cluster dispersal

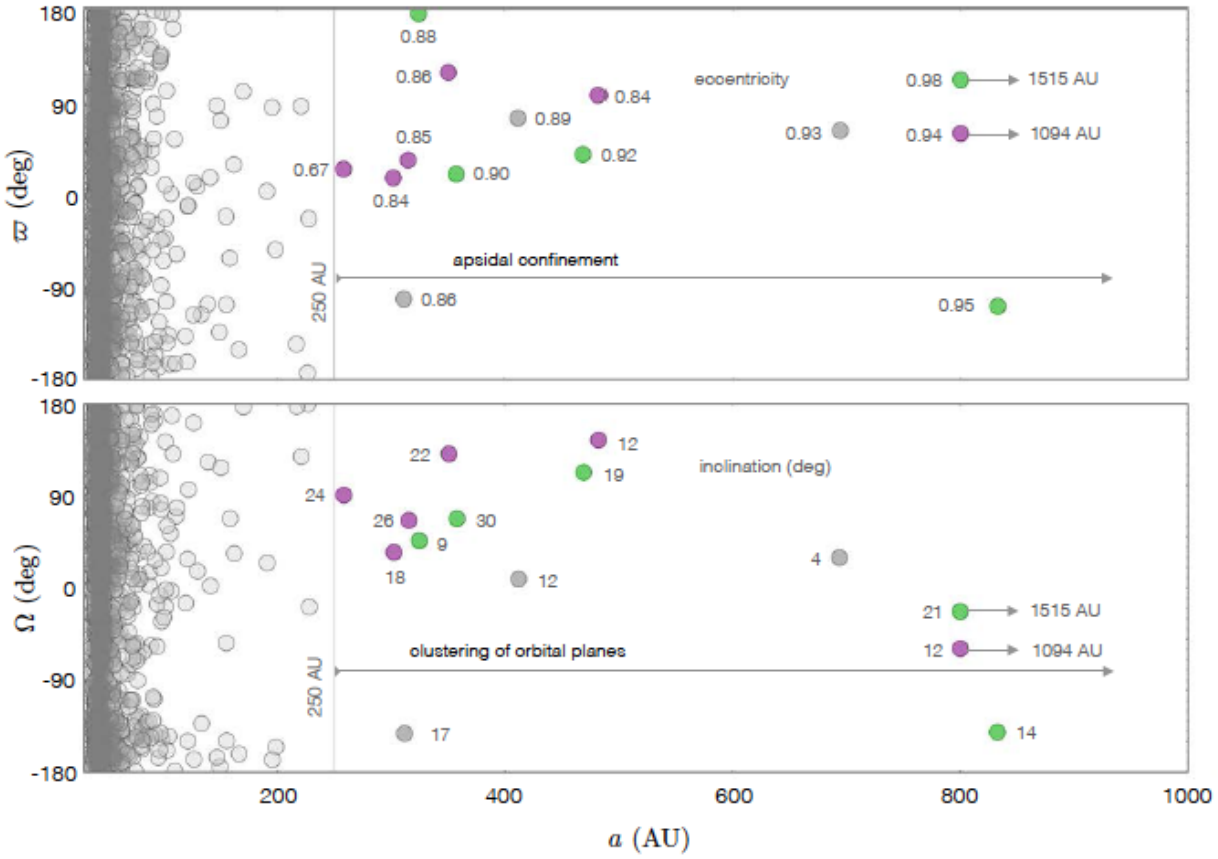
...

- ***Questions:***

- Does survival of regular systems **require** short-lived birth clusters?
- Do we expect an **absence** of regular systems in long-lived clusters?
- Is the favored picture for the solar system right or wrong?

Planet Nine may give an answer!

Planet Nine: Prediction



Perihelion longitude

Batygin et al. (2019)

Nodal longitude

Semi-major axis

- ***Gravitational shepherding by 5-10 M_E planet*** (Batygin & Brown)

Planet Nine: Consequences

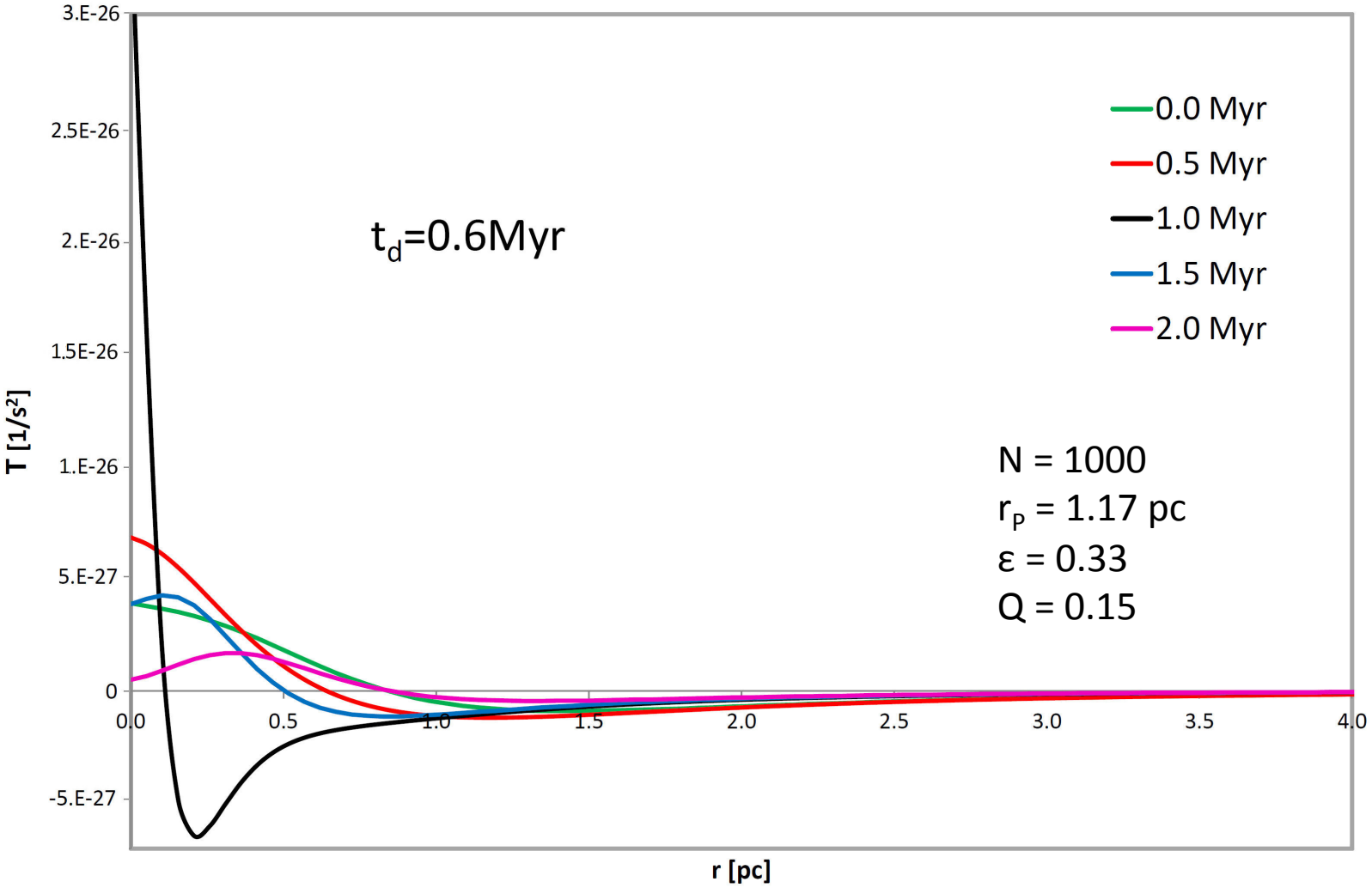
- ***We do not know if P9 exists!***
- *Its predicted orbit reminds of the sednoids* but with a more remote perihelion
- If P9 ***does not*** exist, we learn nothing
- If P9 ***does*** exist, we may learn an important lesson by modeling its origin

Origin of P9: ***Scenario 1***

- P9 grew and migrated along with the known giant planets but got scattered away at a close encounter before the settling of the giants into a quasi-stable system

- P9's perihelion got extracted just like those of usual sednoids by torques from the Sun's birth cluster during the embedded stage

The cluster tide



Rickman et al., in prep.

Extraction efficiency

- The chance per planetesimal to be extracted into a sednoid-like orbit is about 1/2000 (Brasser et al. 2012)
- With a total mass of about 20 M_E, this yields ~0.01 M_E for the sednoid population in perfect agreement with the observational estimate by Sheppard et al. (2019)

- ***But the extraction of P9 is extremely unlikely!***

We need a different scenario...

Origin of P9: ***Scenario 2***

- P9 was a failed giant planet core formed beyond the giant planet growth region

- After an early Nice Model instability (T ~ 50 Myr), P9 was scattered by Neptune and extracted by a close stellar encounter in a long-lived cluster

- ***The viability of this scenario remains to prove!***

Conclusions

- **If** Planet Nine is found, the only viable scenario for its formation **may be** “Scenario 2”

- **This would mean** the survival of a long-lived regular planetary system *(i.e., our own)* for a host star *(the Sun)* that was formed and stayed in a long-lived cluster

- Other similar systems may have similar histories