Evolution and formation of the solar system – what we know today

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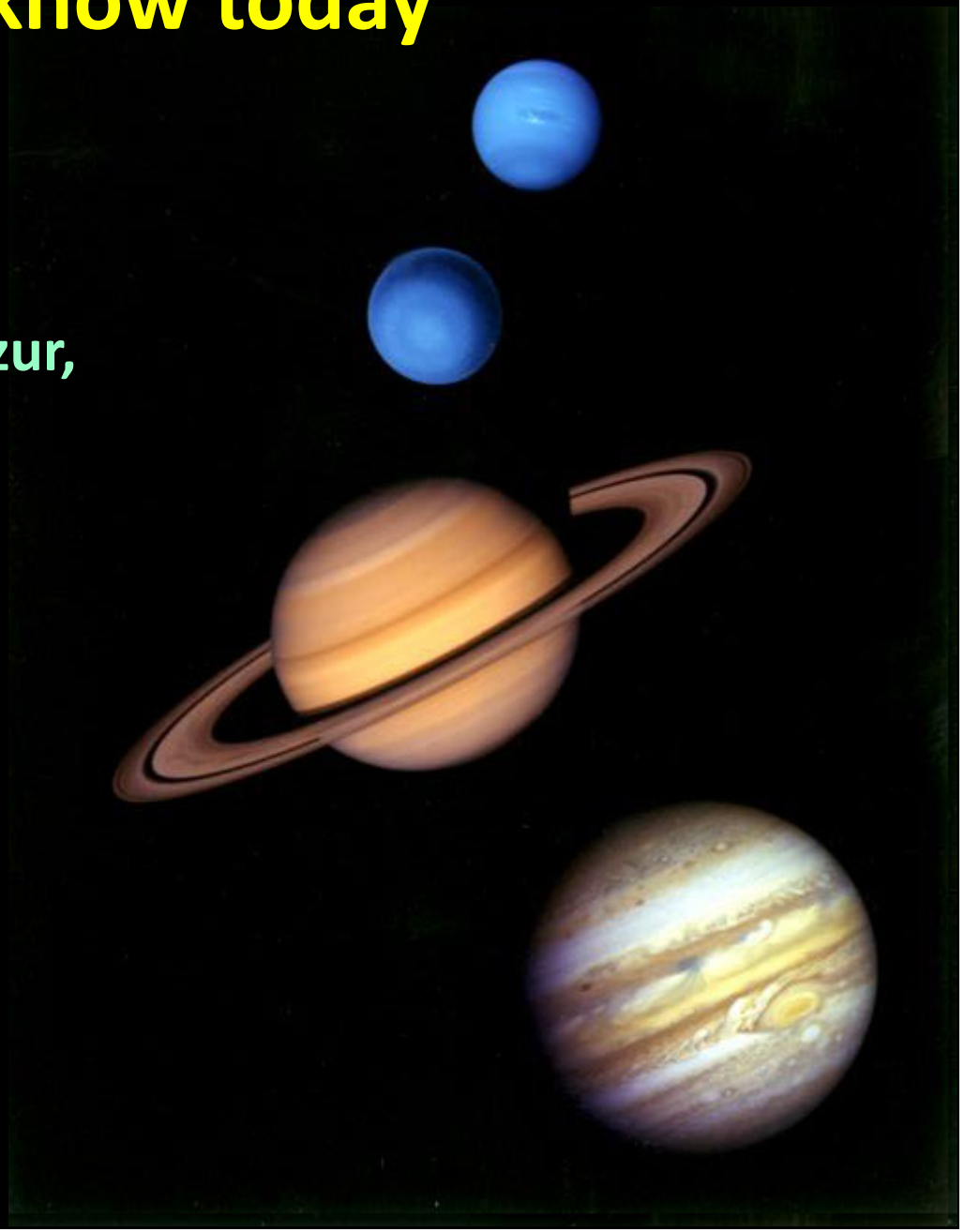
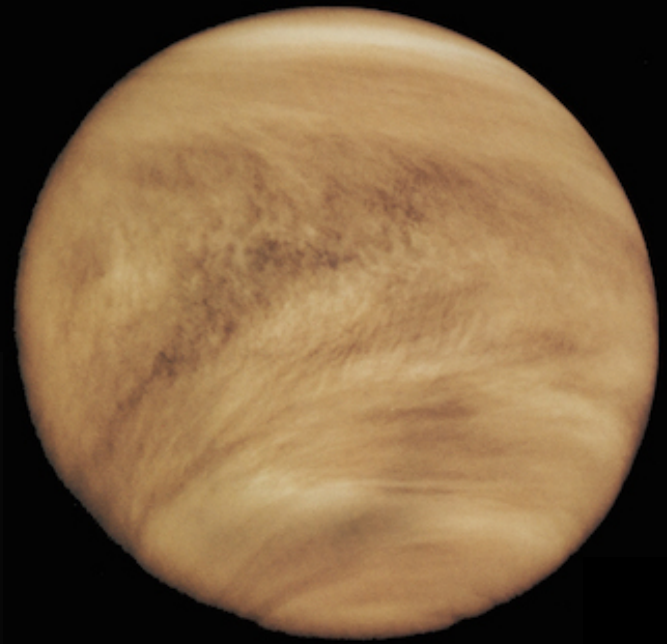


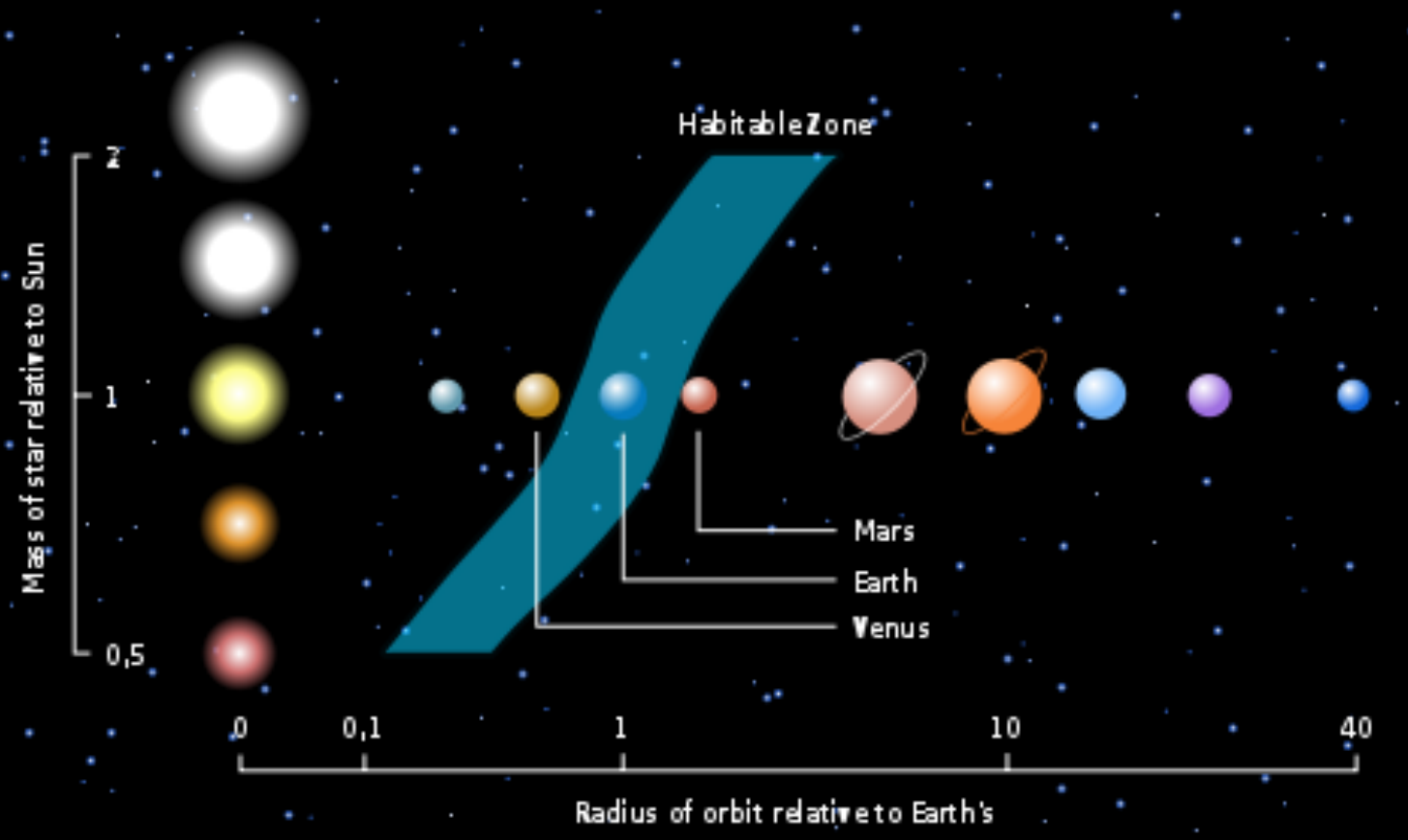
The lesson of Copernicus is that the Earth has no privileged position in the Universe

The Earth is NOT a special planet

The subsequent space exploration has shown that the Earth is quite special, as it is the only habitable planet in the Solar System



This has not shaken the Copernican paradigm, but has simply lead to the recognition of two categories of planets (terrestrial and giants) and of a habitable zone



The Copernican paradigm translated to the expectation that the Solar System is not special

The discovery of extrasolar planets, suggesting that most stars have planets, seems to support this expectation

However, there appears to be a great diversity among planetary systems, and our Solar System does not seem to be the "standard" case

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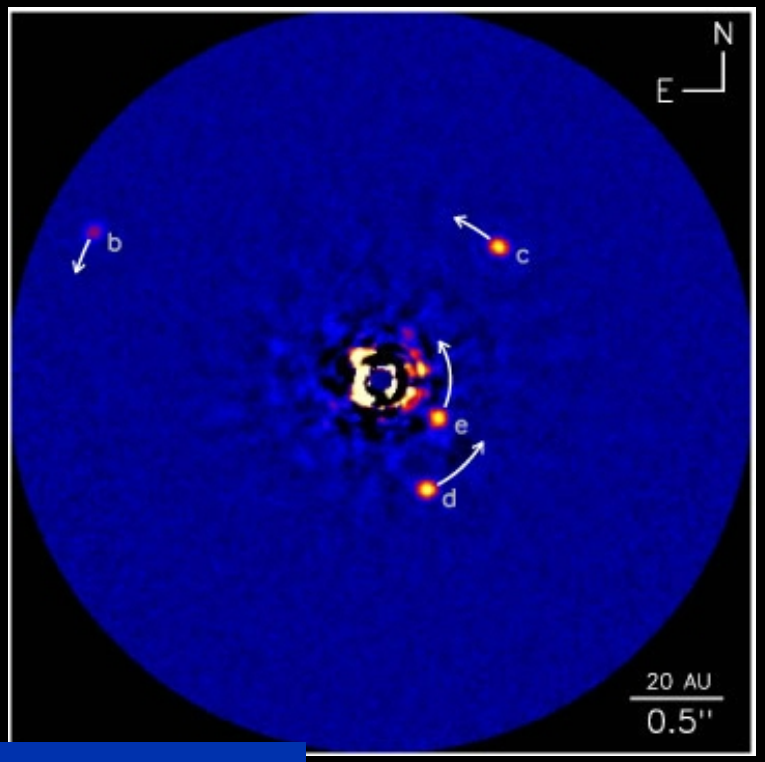

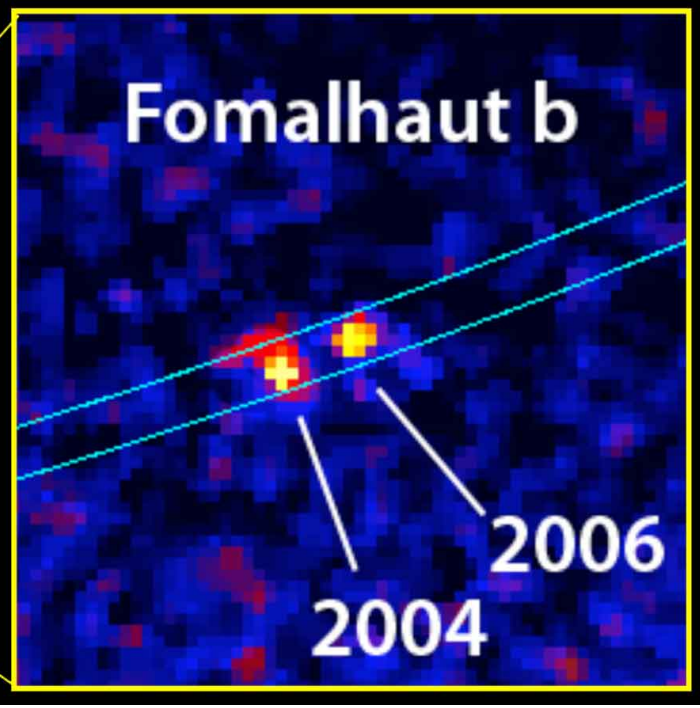

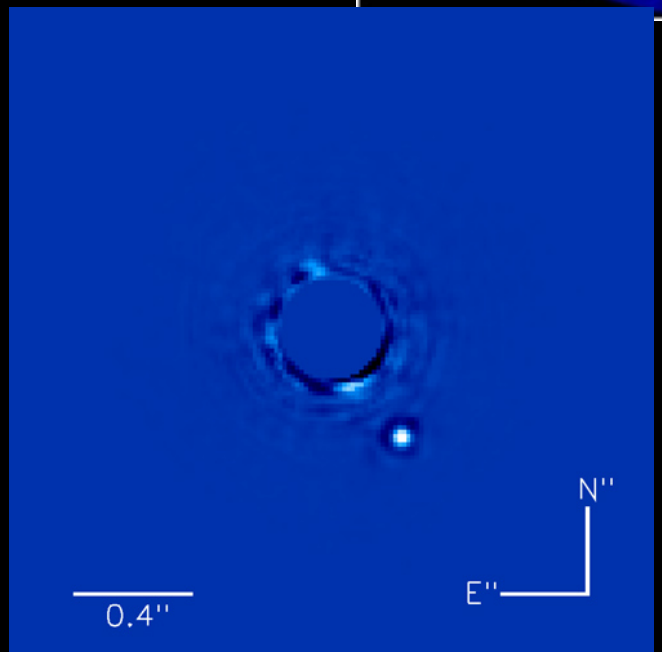

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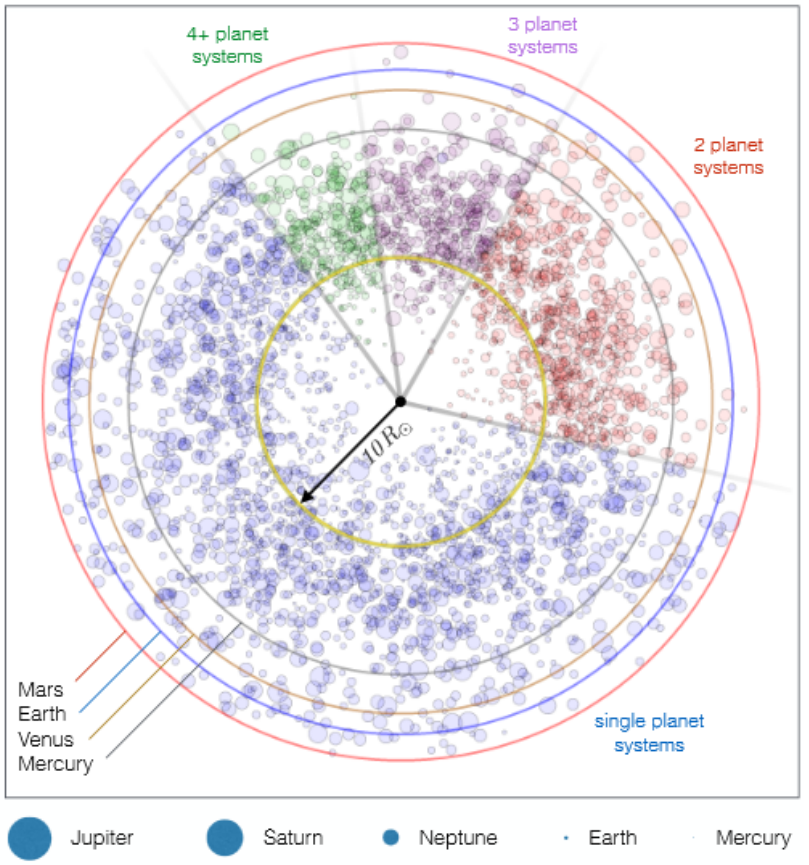
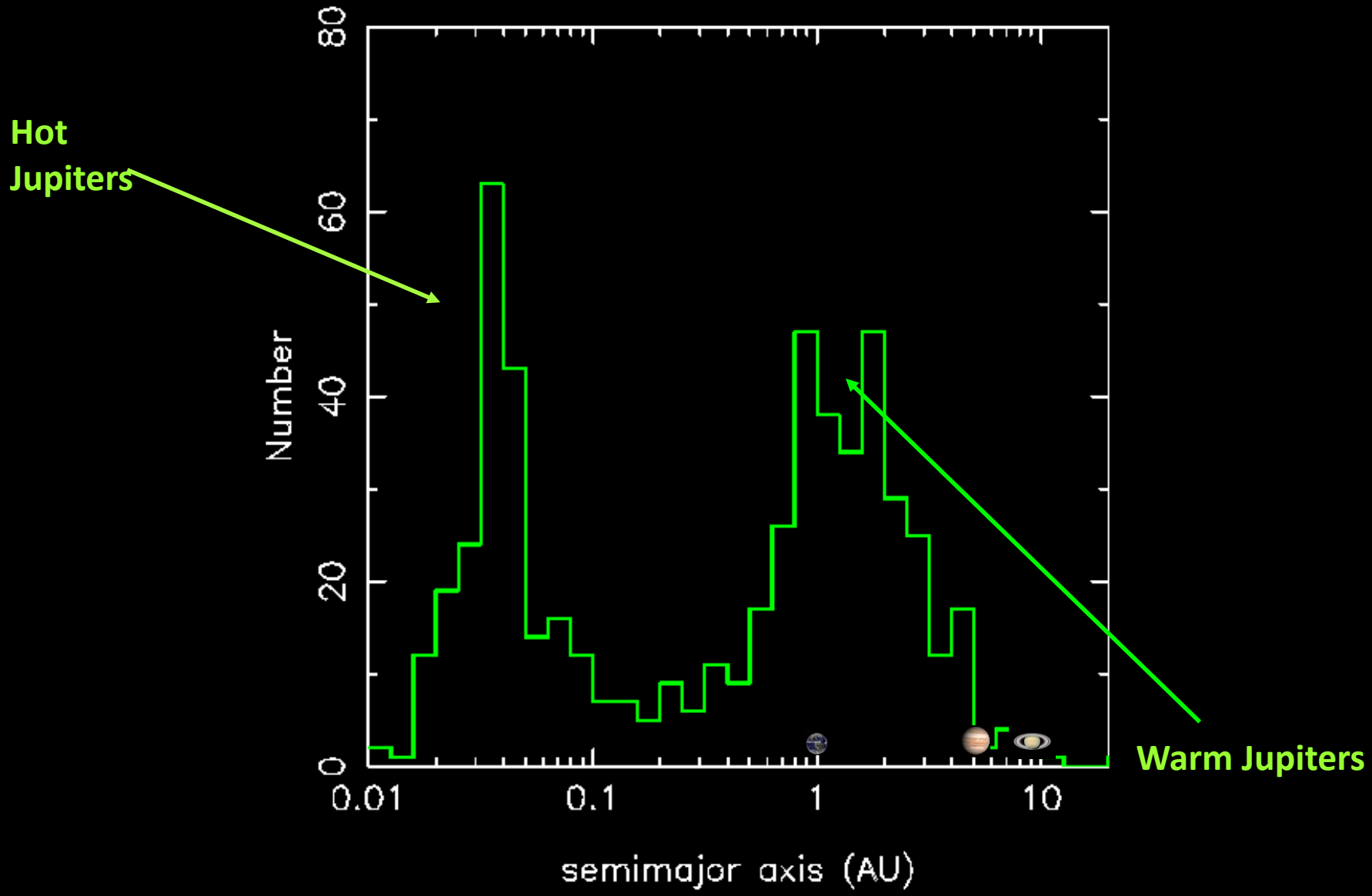
Radial velocity (Mayor et al., 2011) and transit surveys (Howard et al., 2012; Petigura et al., 2013; Fressin et al., 2013) suggest that many (most?) solar-type stars have close-in Super-Earths / Neptune-like (SEN) planets

The Solar System is atypical in that our Neptune-like planets are not close-in, but they are beyond Jupiter & Saturn

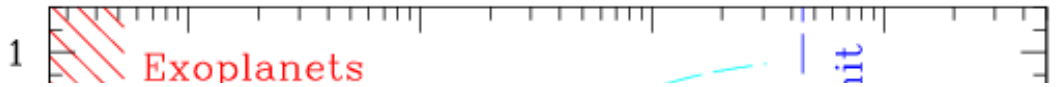
Batygin and Laughlin, 2015



Orbital distribution of extrasolar giant planets



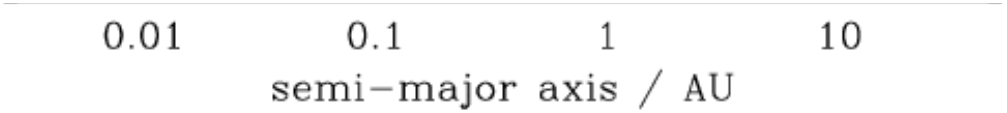
Giant planet orbital distribution



We now know that our Solar System is not typical: 65-80% of solar-type stars have planetary systems different from ours !

We don't know yet from observations if our Solar System represents 10%, 1%, 10^{-4}, 10^{-6} of the planetary systems

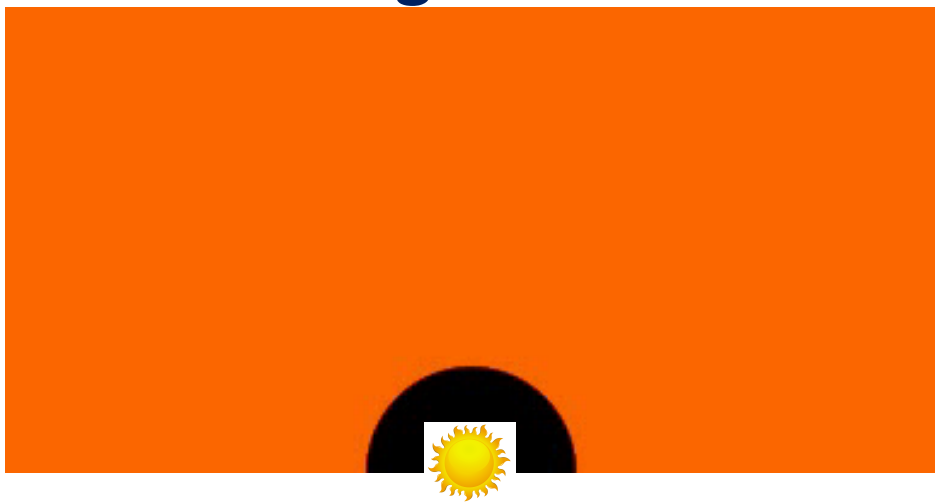
We need theory of planet formation/evolution to address this question



Formation of the solar system – what we know today.

A few facts

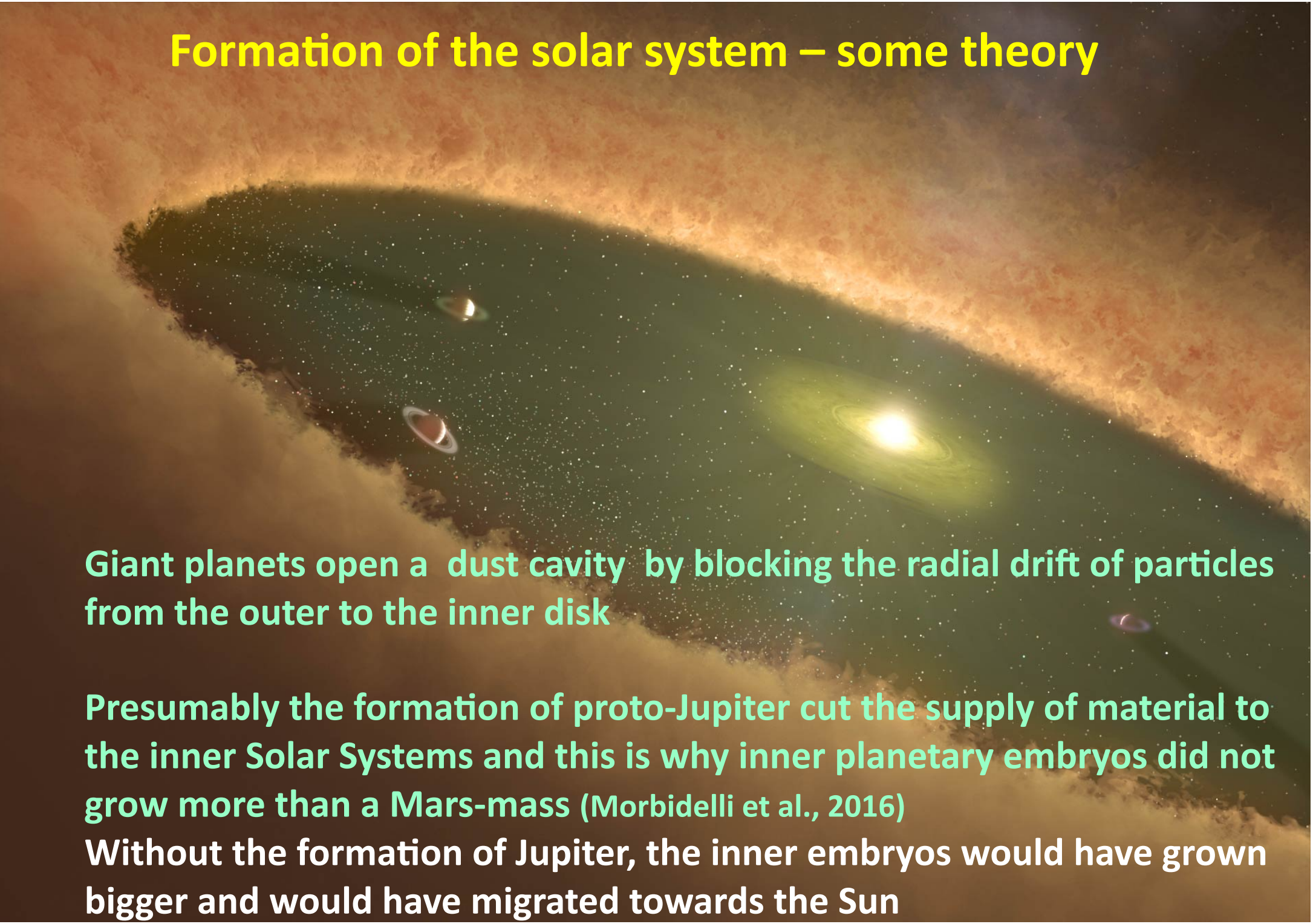
- The giant planets formed before the disappearance of the gas from the protoplanetary disk (3-5My)
- The Earth took ~ 100My to form
- At the end of the gas-disk phase in the inner Solar System protoplanets were ~Mars-mass
- No evidence that anything bigger formed inside the orbit of Jupiter
- Planets migrate towards the star



Planet speed proportional to planet mass

Close-in planets and resonant planets are evidence for migration

Formation of the solar system – some theory

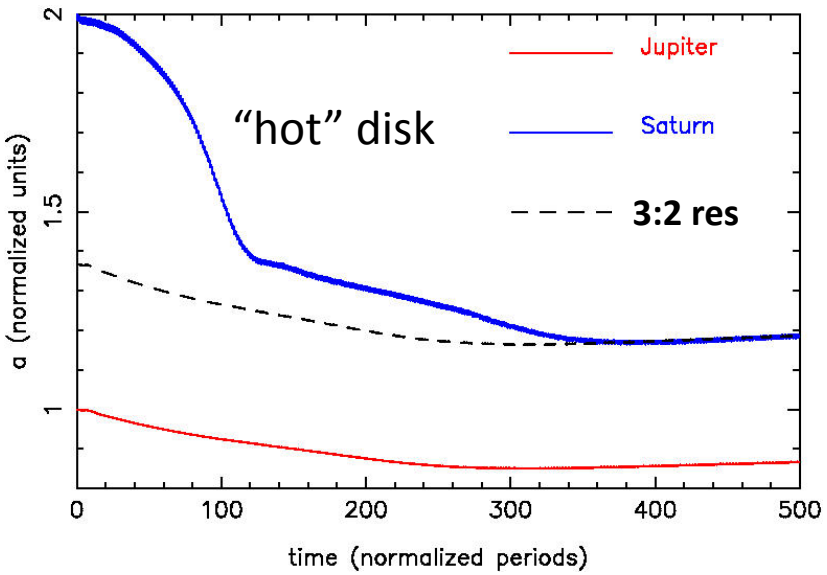


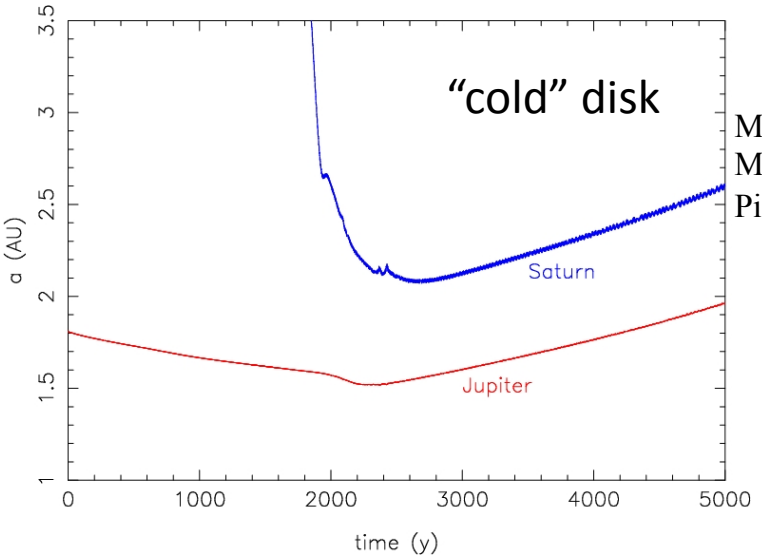
Giant planets open a dust cavity by blocking the radial drift of particles from the outer to the inner disk

Presumably the formation of proto-Jupiter cut the supply of material to the inner Solar Systems and this is why inner planetary embryos did not grow more than a Mars-mass (Morbidelli et al., 2016)

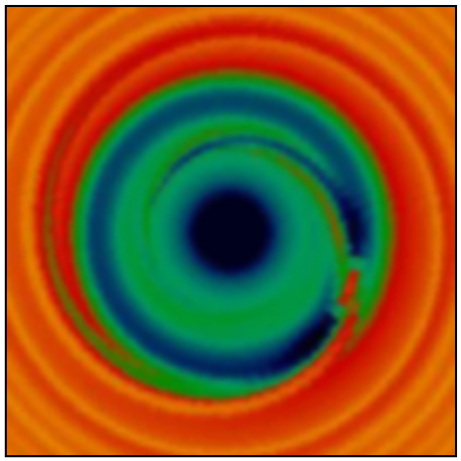
Without the formation of Jupiter, the inner embryos would have grown bigger and would have migrated towards the Sun

Jupiter and Saturn have the ideal mass-ratio to avoid inward migration

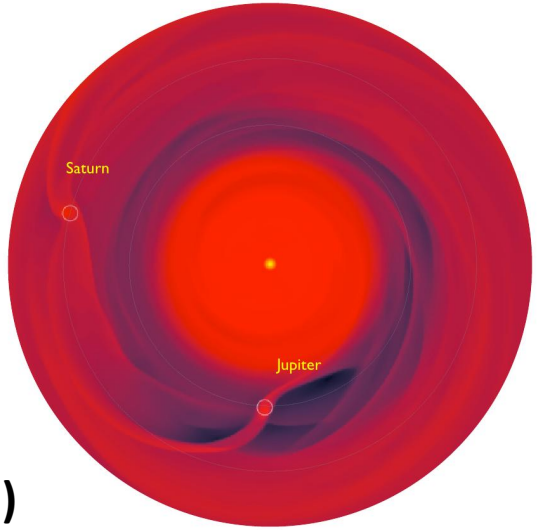




Masset et Snellgrove, 2001
Morbidelli et Crida, 2007
Pierens and Nelson, 2008



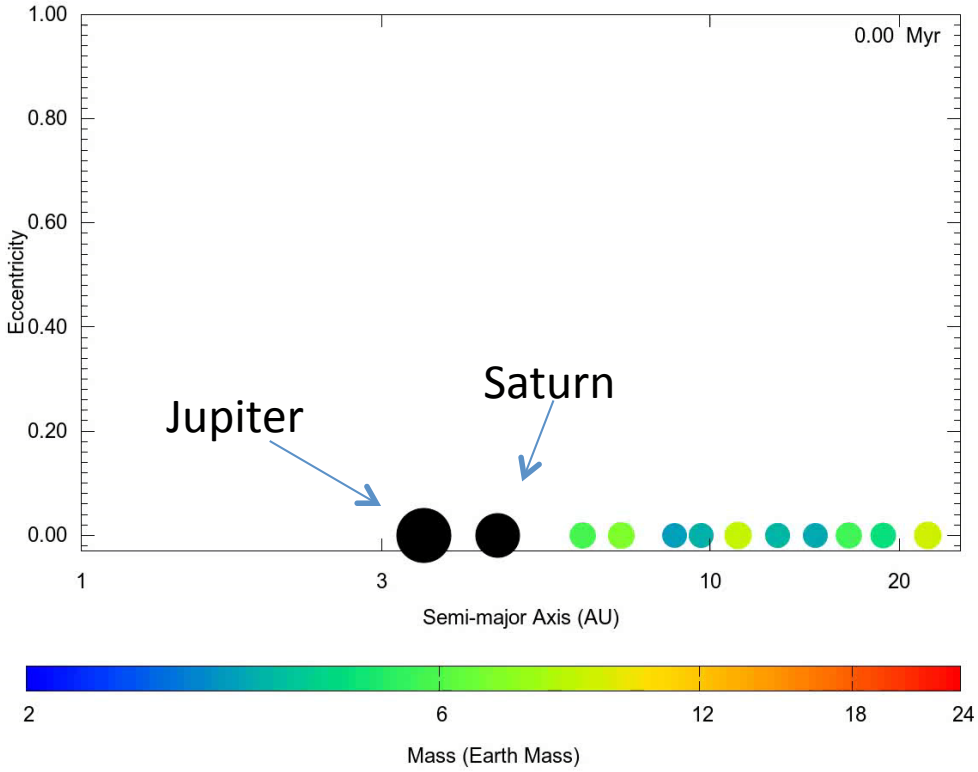
Jupiter only
(inward migration)



Jupiter and Saturn
(no inward migration)

Without Saturn, presumably Jupiter would have migrated into the terrestrial planet region

The lack of inward migration of Jupiter and Saturn facilitated the formation of Uranus and Neptune and prevented their migration into the inner Solar System



Izidoro et al., 2016
Jakubik et al., 2012

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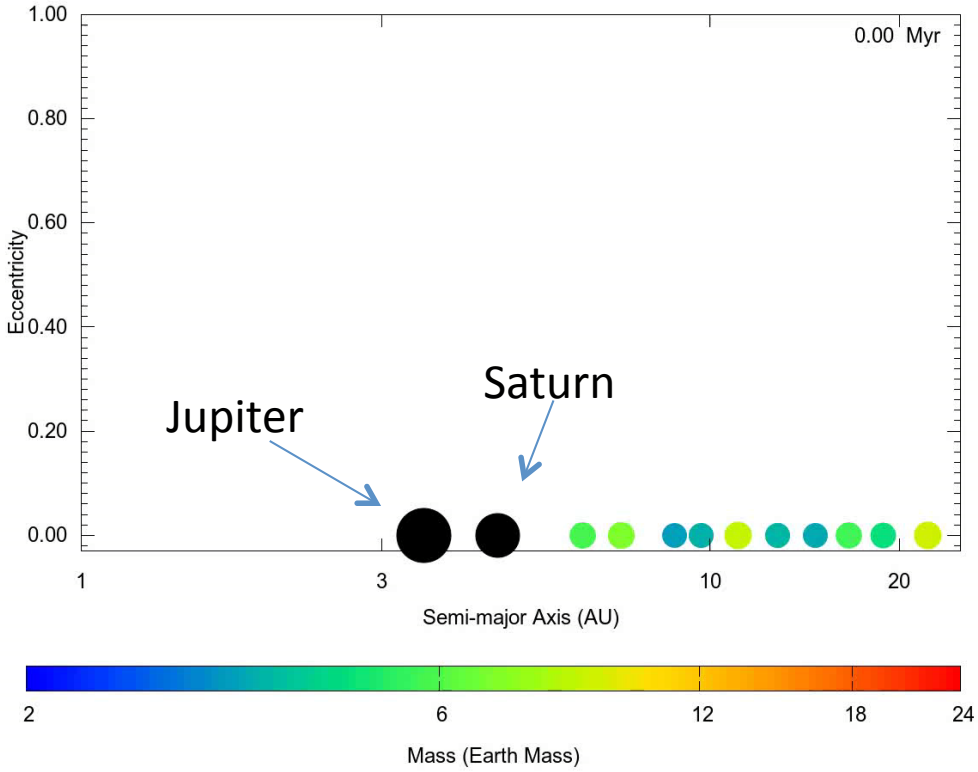

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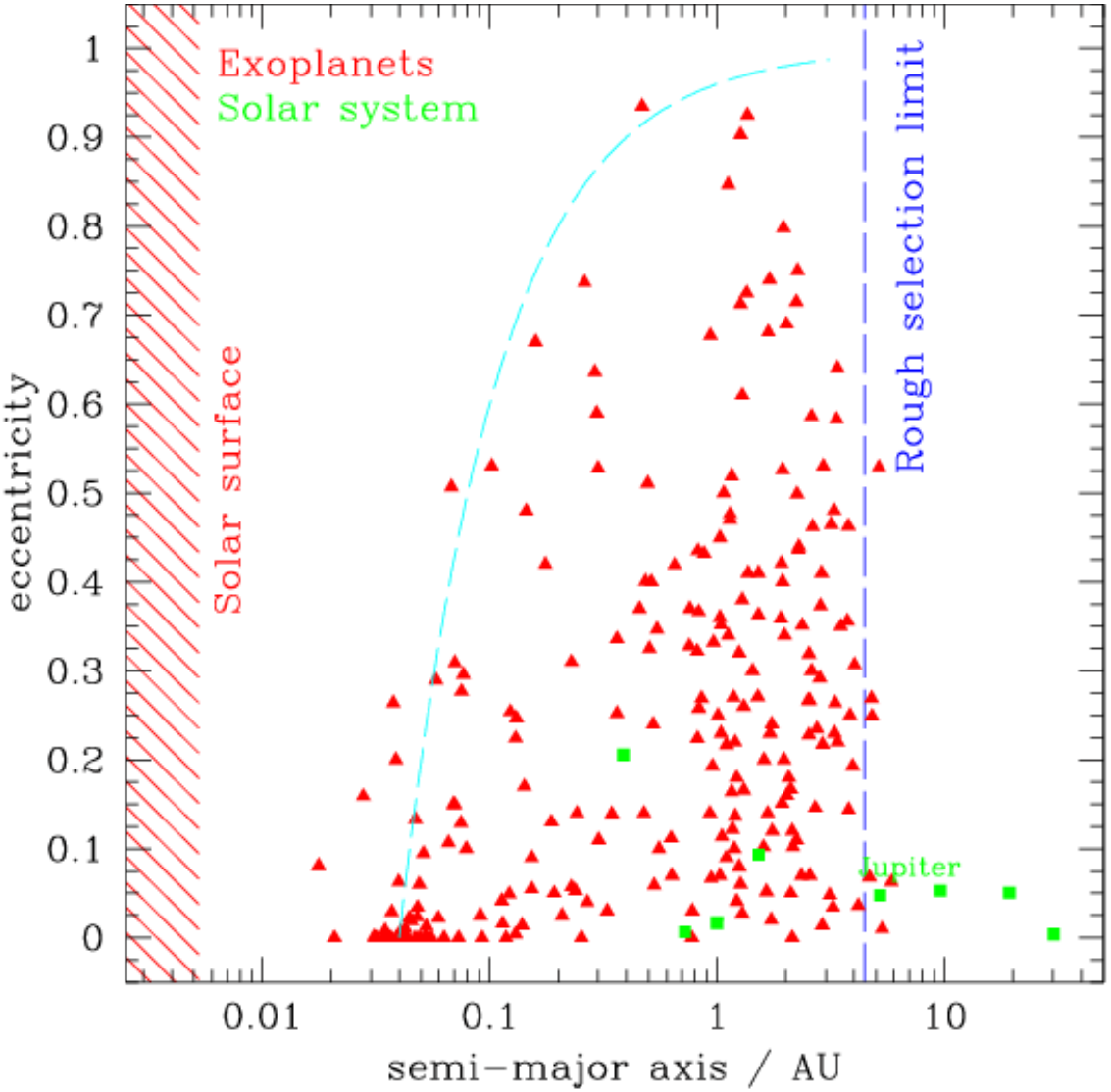
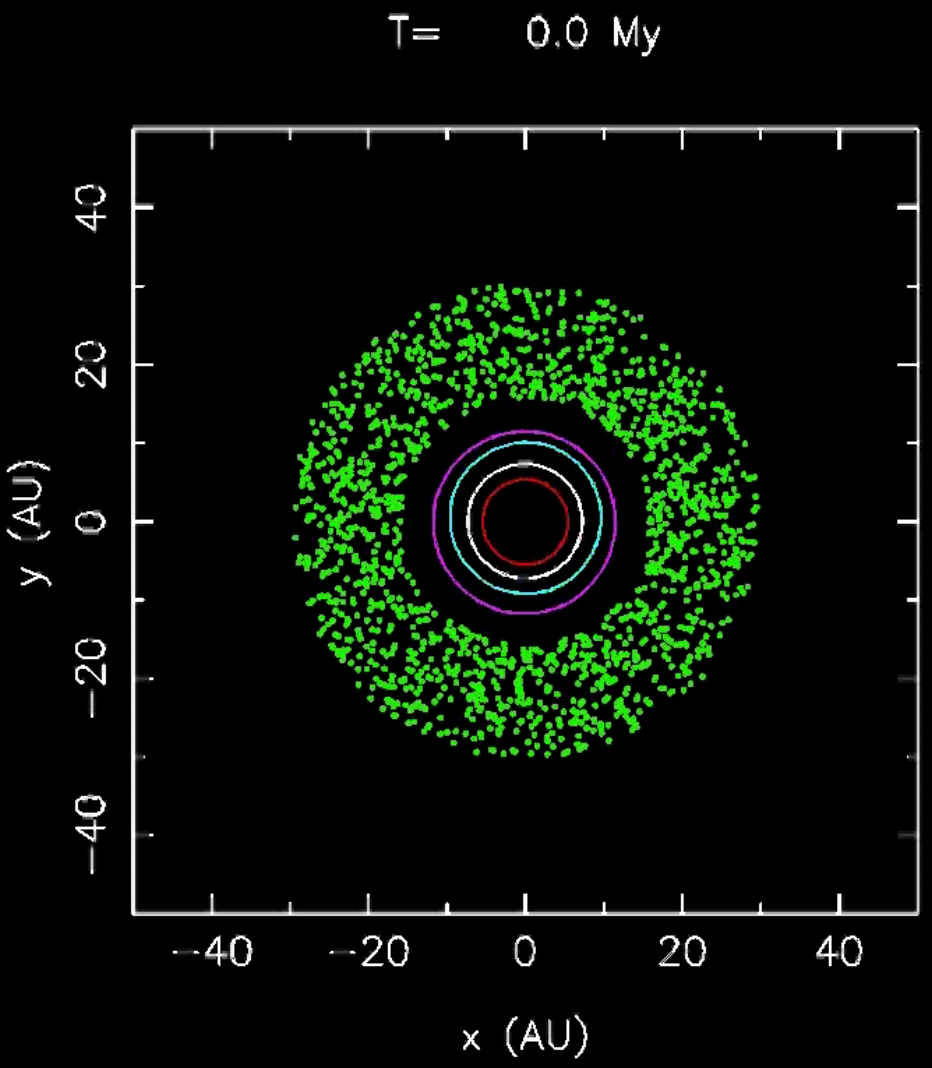
The large eccentricities of extrasolar giant planets are explained by dynamic instabilities that giant planet systems experience after the removal of the protoplanetary disk



Also our giant planet system underwent an instability



The Nice model:

Tsiganis et al., 2005; Gomes et al., 2005; Morbidelli et al., 2007; Levison et al., 2011; Nesvorny and Morbidelli, 2012

The instability is needed to explain the current orbits of the planets and the structure of the populations of small bodies in the outer Solar System (Kuiper belt, irregular satellites, Trojans)

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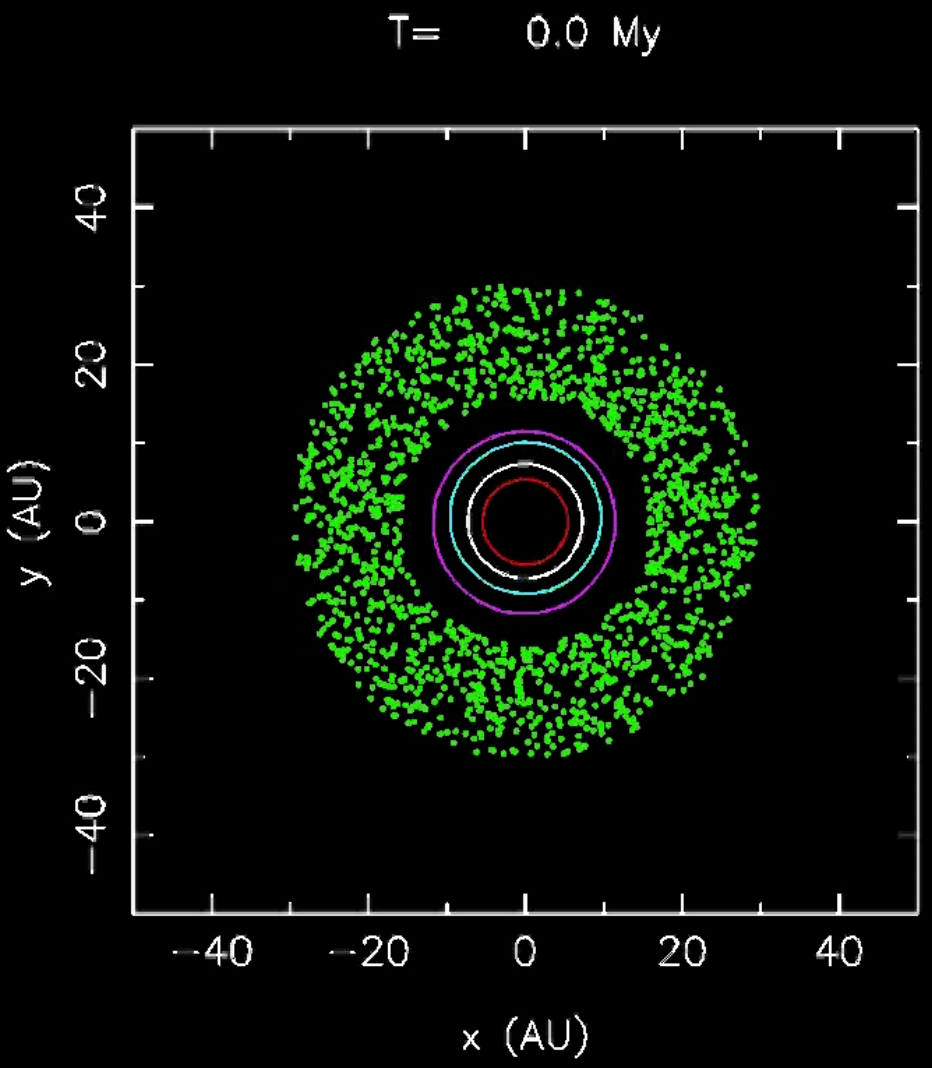

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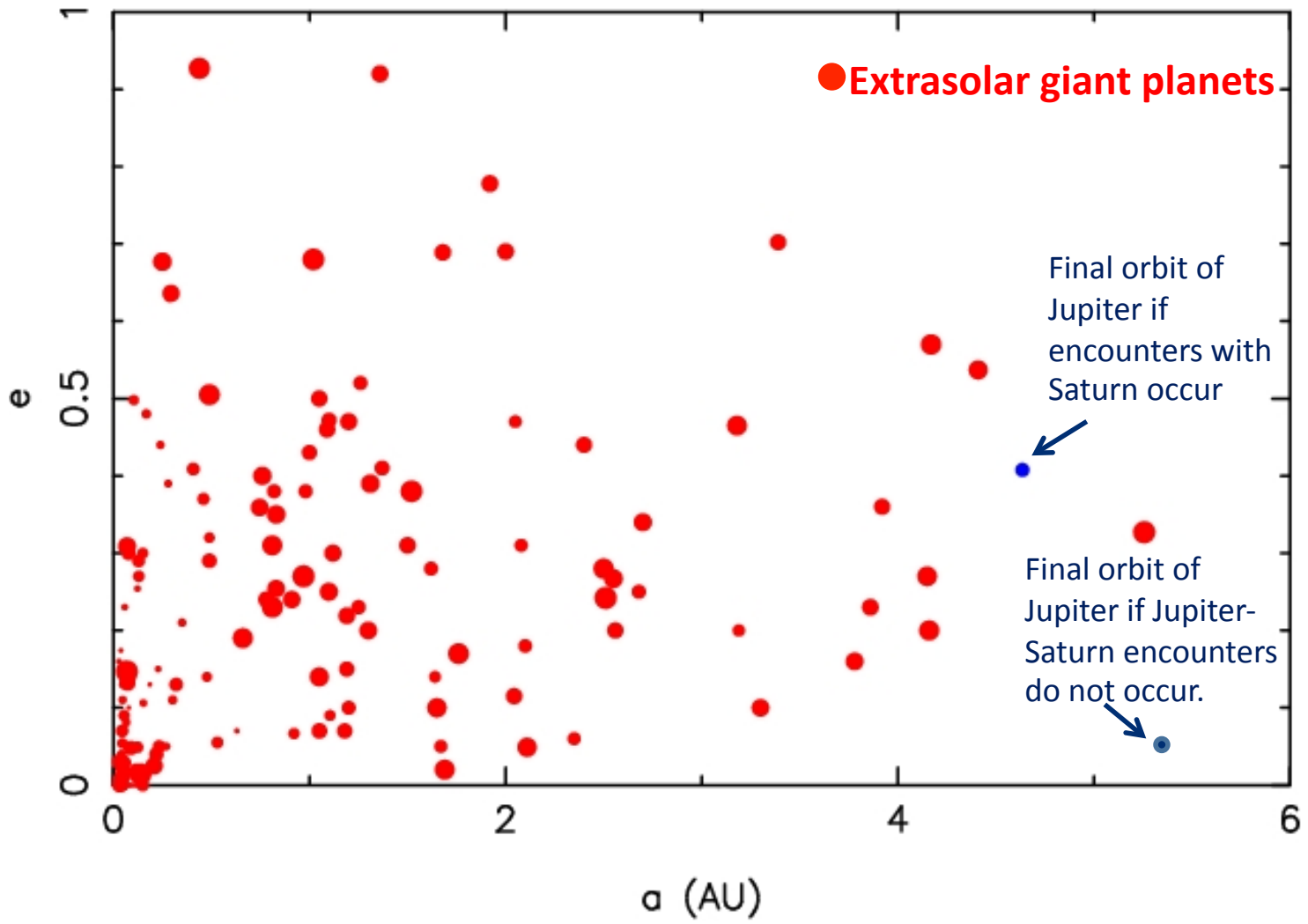
The key is that the instability in the Solar System was a weak one because our giant planets are relatively low-mass and in addition Jupiter and Saturn, by chance, did not encounter with each other.

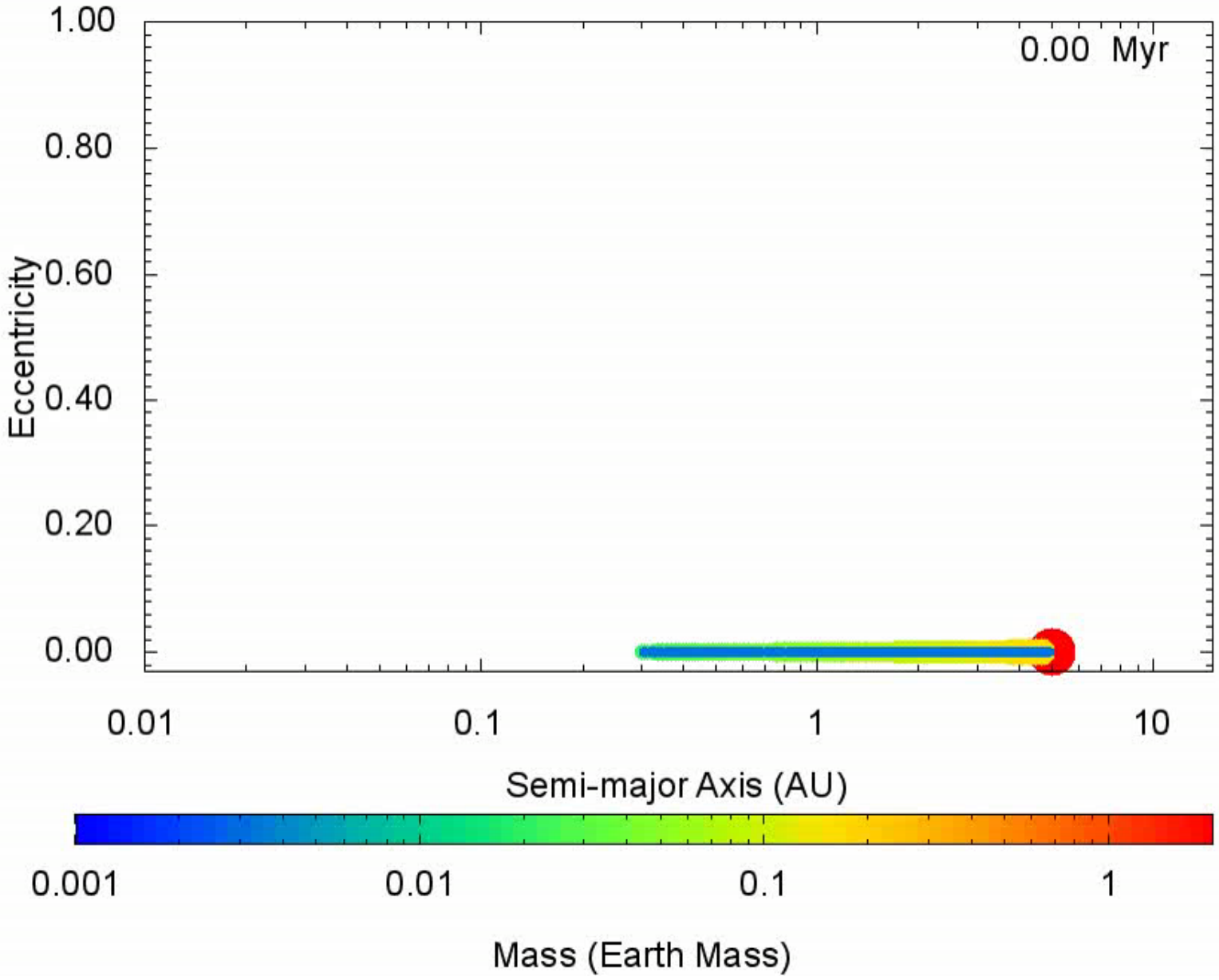


To summarize:

1. Without Jupiter, the inner planetary embryos would have grown bigger and would have migrated towards the Sun -> close-in rocky super-Earths
2. Without Saturn, Jupiter would have migrated into the terrestrial region
3. Without Jupiter & Saturn, Uranus and Neptune would have migrated close to the Sun -> hot Neptunes
4. If Jupiter & Saturn had had close encounters with each other, their orbits would be very eccentric today

Is the Solar System atypical?

There are a few reasons to leave in an atypical planetary system



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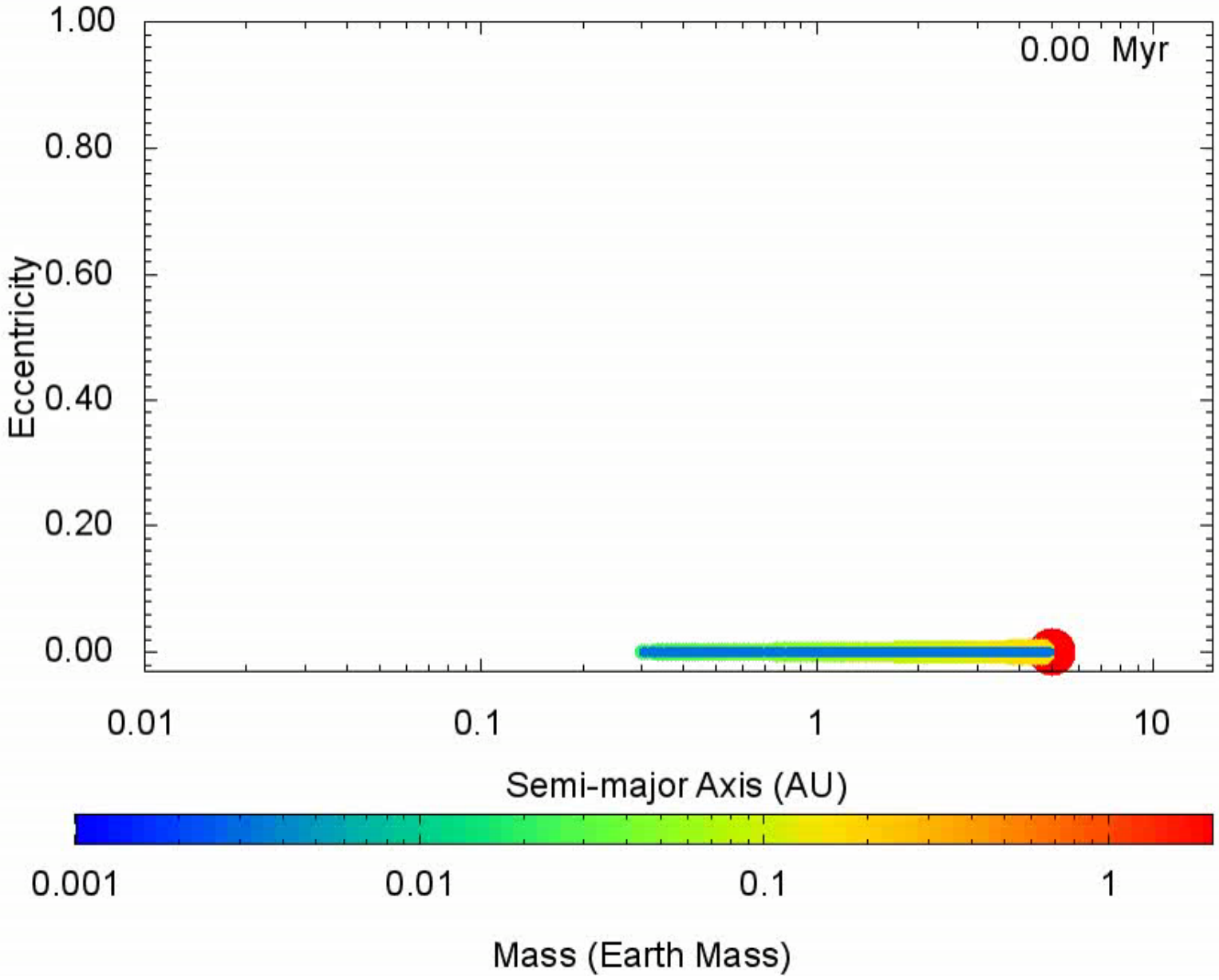

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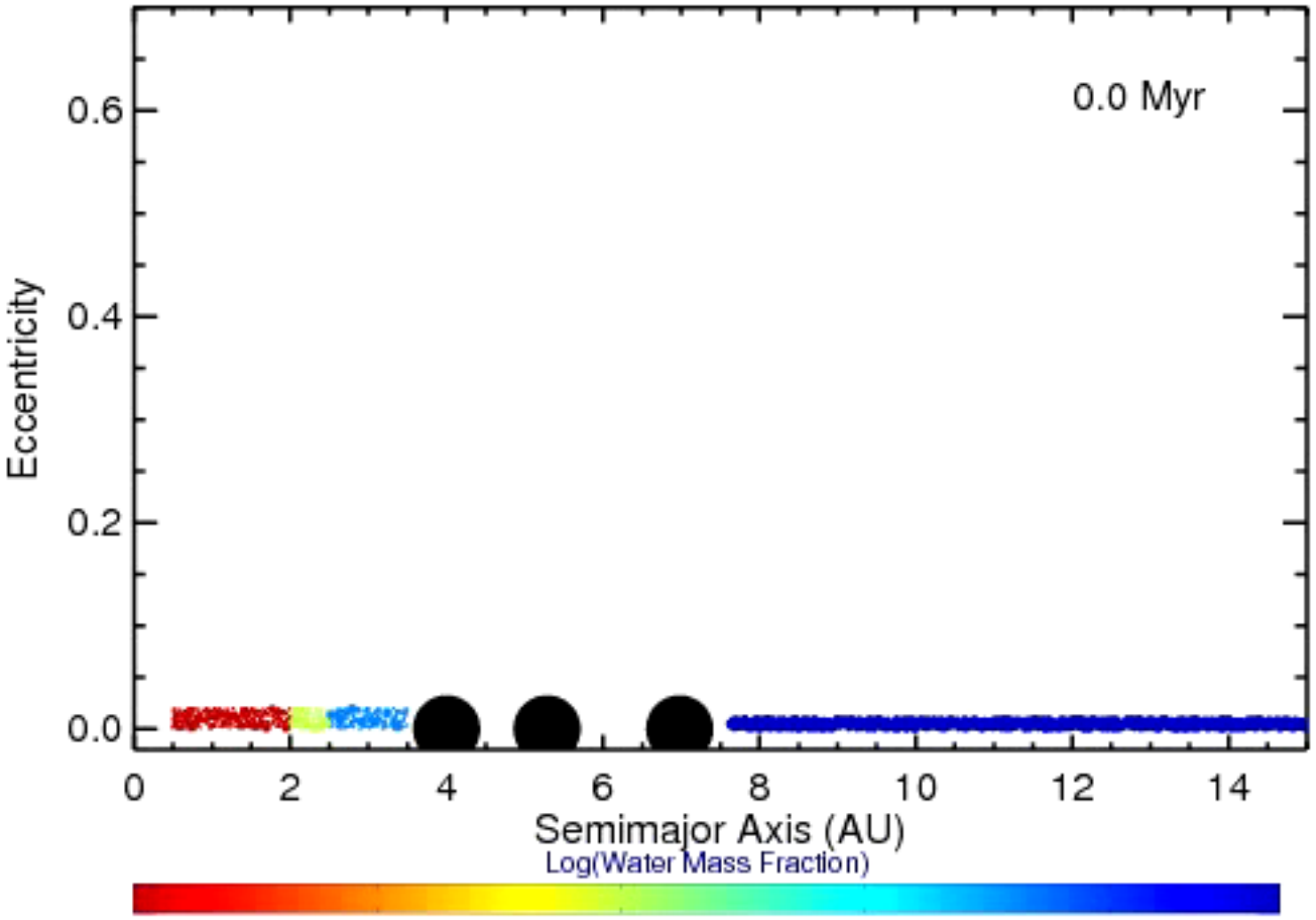

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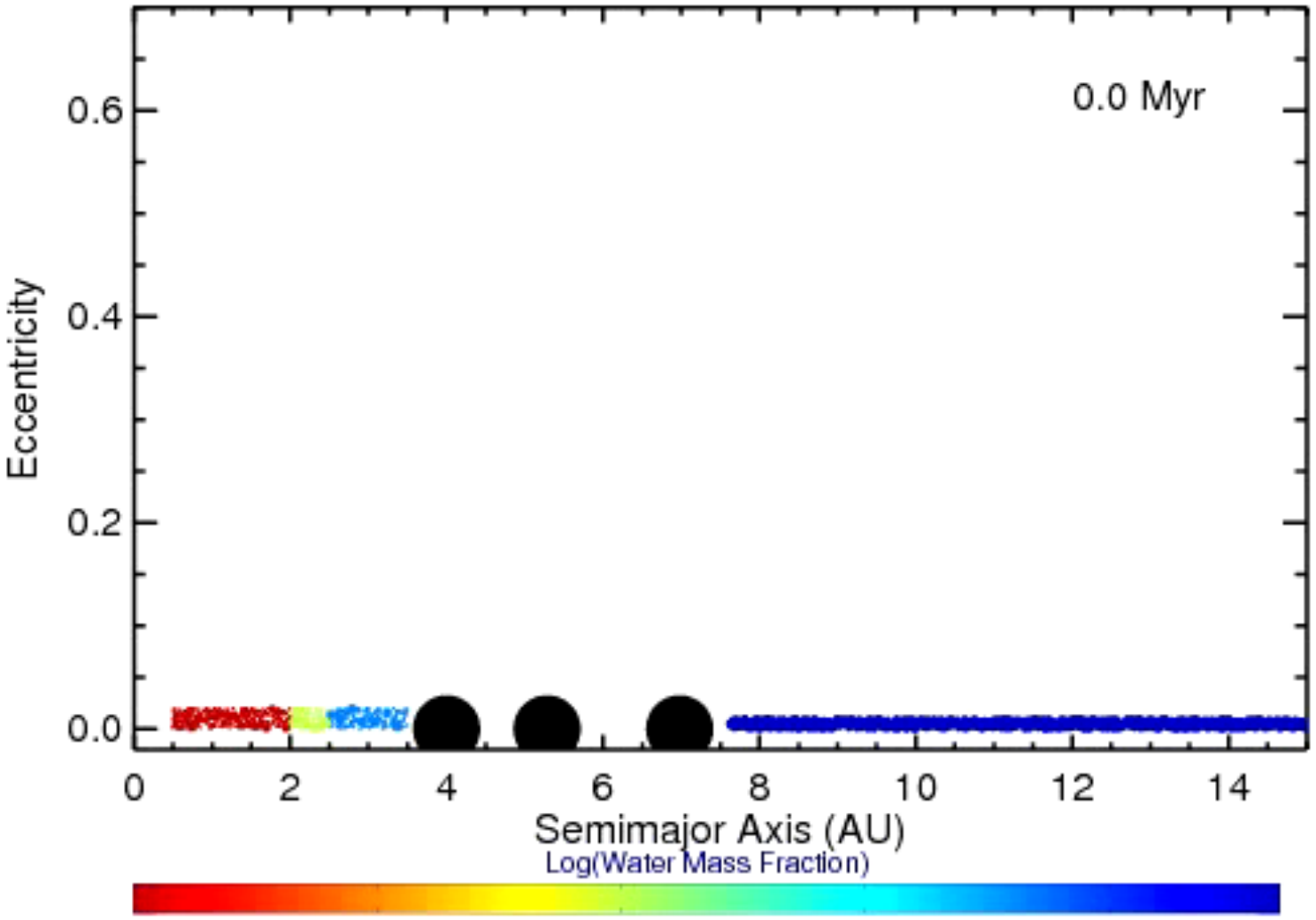

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Coming back to Copernicus….

The Earth is certainly not the center of the Universe, but it is also not a trivial planet in a trivial planetary system

With the discovery of extrasolar planetary systems and advances in models of planet formation, the Solar System appears "special" (means atypical, not unique)

Is this "specialty" needed for life?

Recognizing the special character of our system is a sort of Copernican counter-revolution