ASTR 405
Planetary Systems
Solar System

Fall 2025

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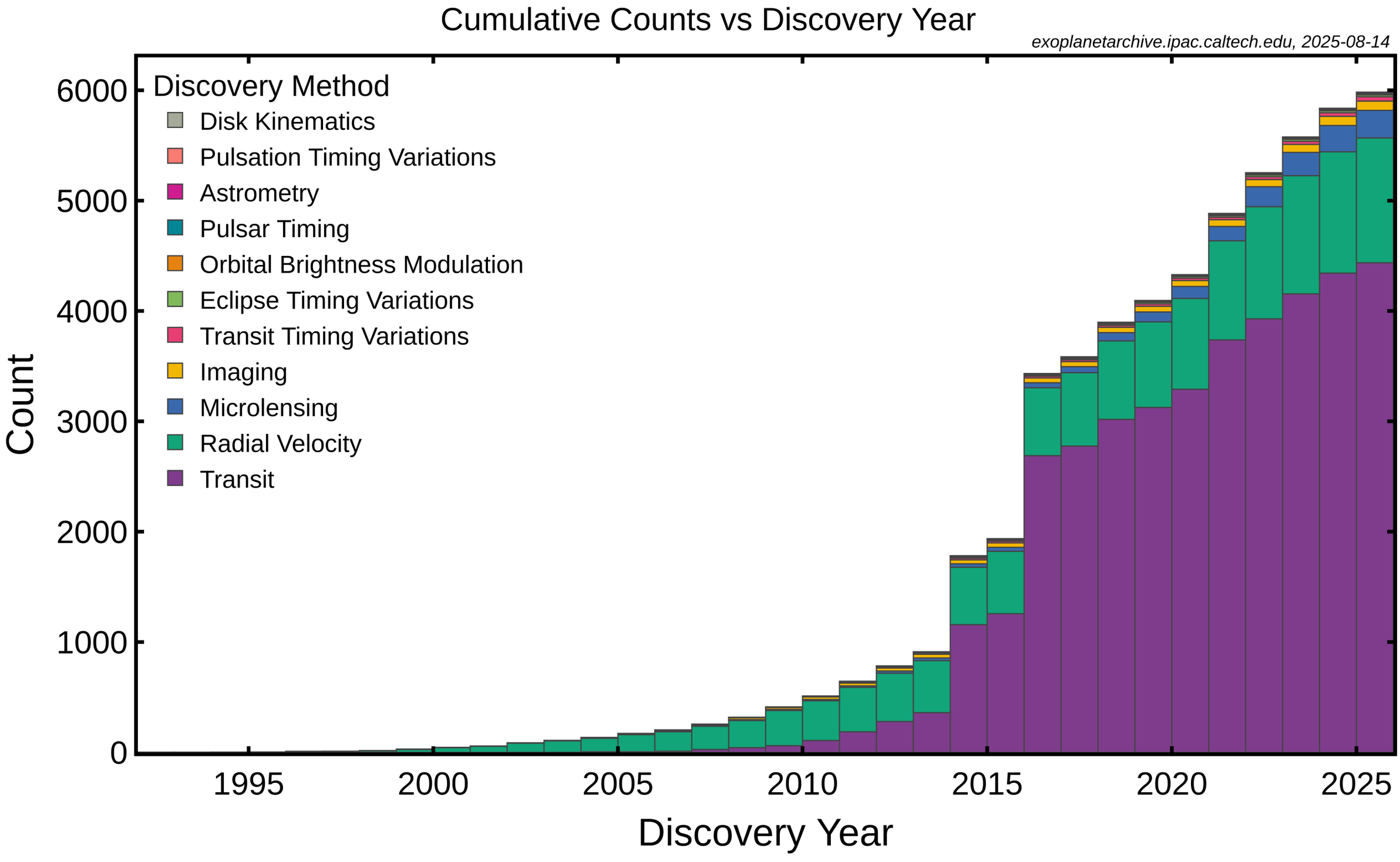
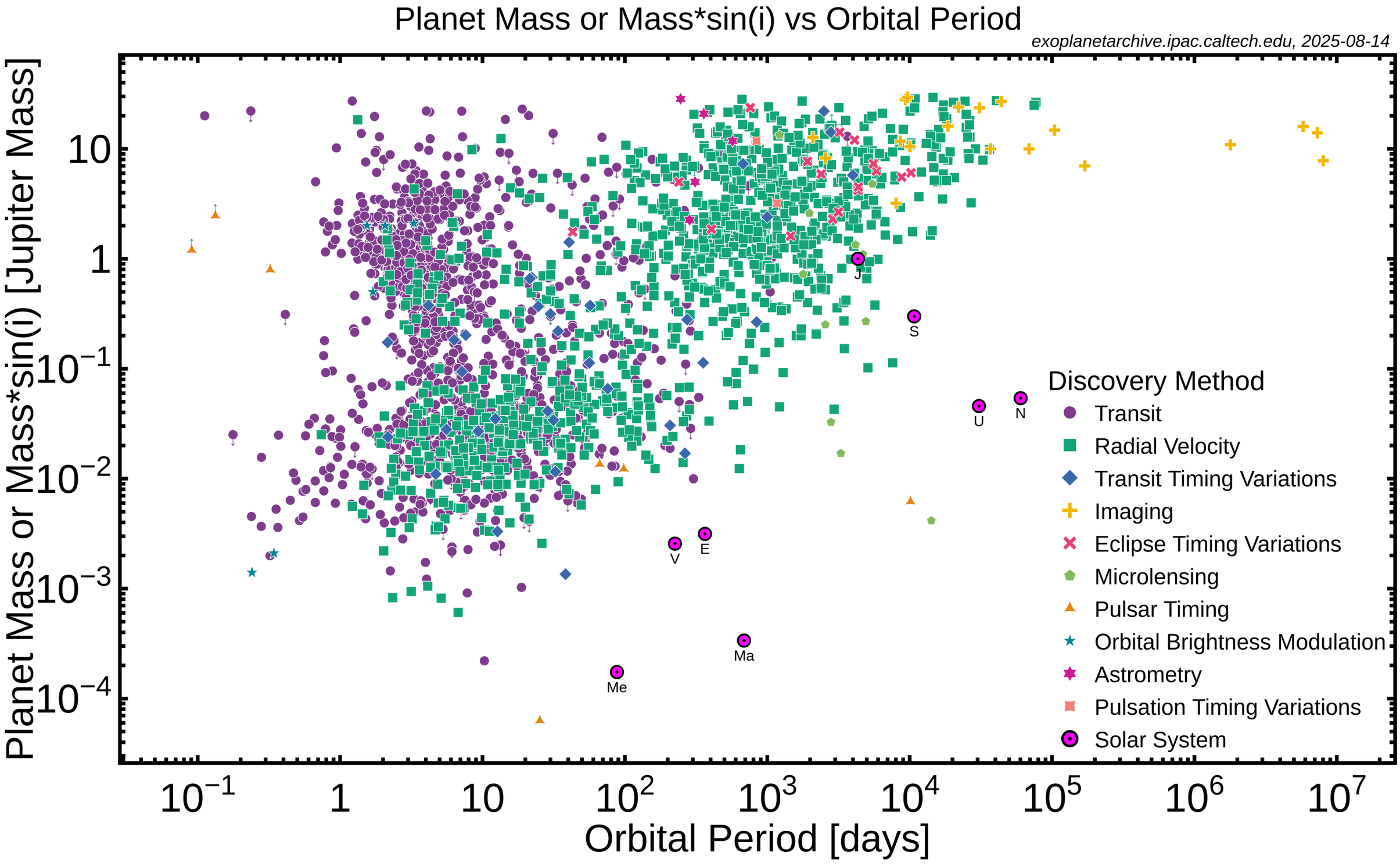
Cumulative Exoplanet Discoveries



Exoplanet Mass–Period Distribution



Scales

Jupiter in Solar Units

$$R_{\rm Jup} \approx 0.1\, R_\odot$$

$$M_{\rm Jup} \approx 10^{-3}\, M_\odot$$

$$a_{\rm Jup} \approx 5\,{\rm au}$$

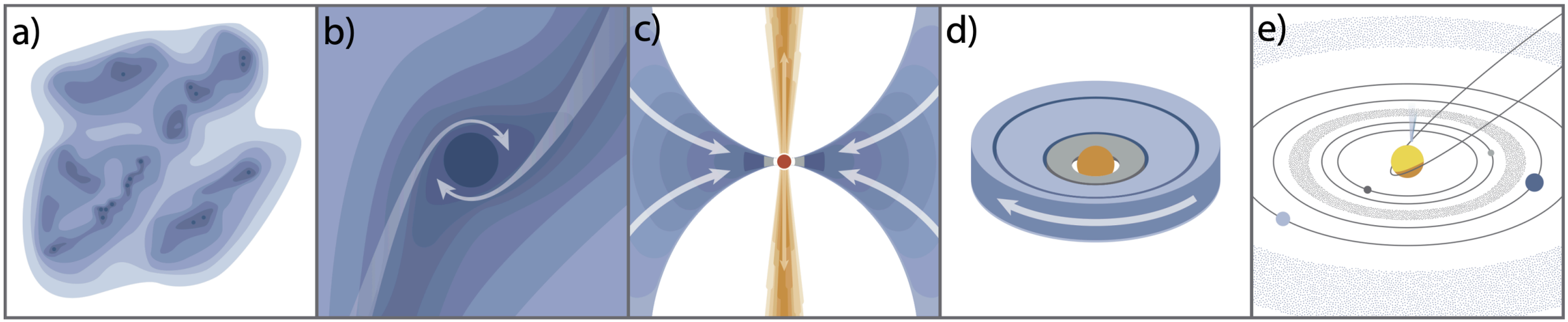
Earth in Jupiter Units

$$R_\oplus \approx 0.1\, R_J$$

$$M_\oplus \approx 3 \times 10^{-3}\, M_J$$

$$a_\oplus = 1\,{\rm au}$$

Formation of the Solar System



Oberg & Bergin 2021, https://arxiv.org/pdf/2010.03529

a) Stars form in dense cores in interstellar molecular clouds.

b) Star formation begins when such a dense core begins to collapse due to self-gravity.

c) As the collapse proceeds the center heats up forming a protostar. Accretion of remnant cloud material continues, funneled through a disk, which is formed as a consequence of cloud angular momentum. This stage is also characterized by outflows of material.

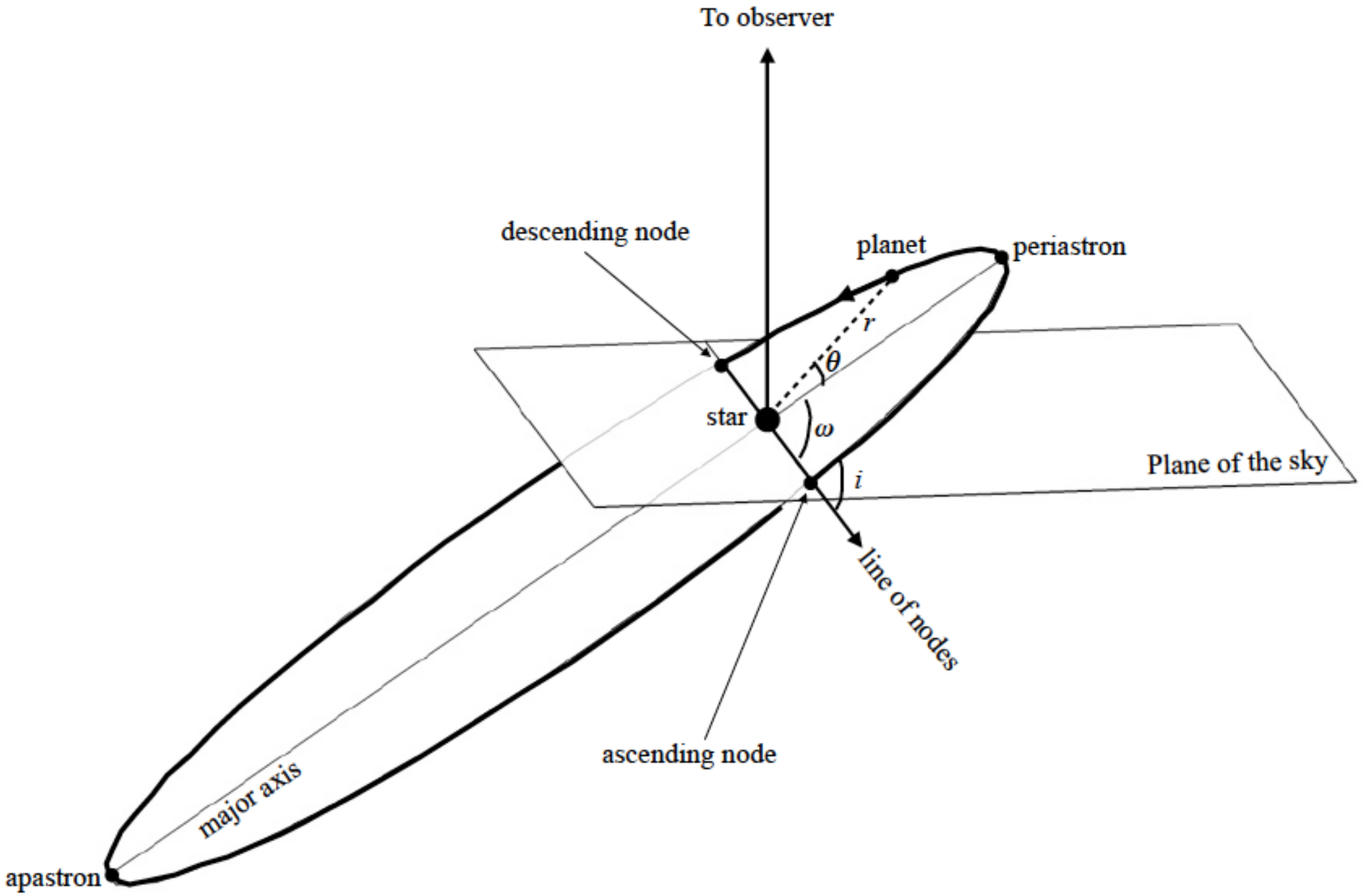
d) Following dispersal of the cloud remnant the now pre-main sequence star is left with a circumstellar disk, which is the formation sites of planets. The disk gas is dispersed through disk winds within ~2-5 Myrs, putting a halt to Gas Giant formation.

e) Rocky and icy planets can continue to grow for another 100 Myrs at which time a mature planetary system exists.

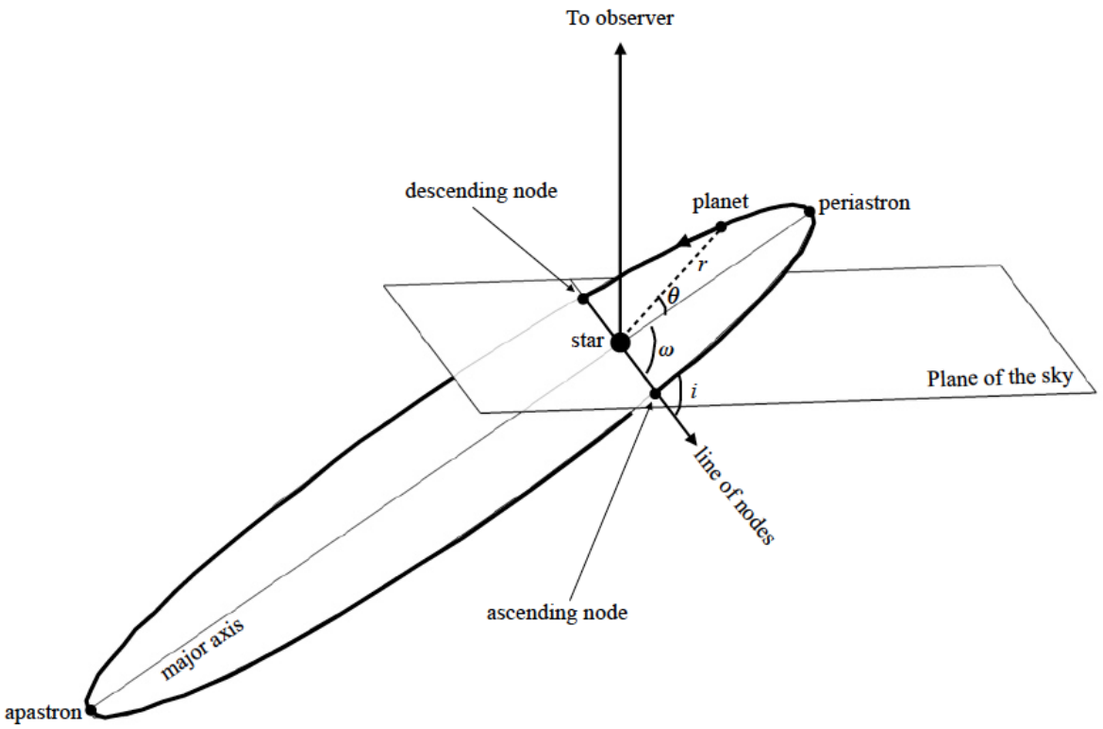
In-Class Activity

Angular momentum in the Solar System

Geometry of a 3D Orbit



Geometry of a 3D Orbit



- Plane of the sky: The plane oriented perpendicular to the observer's line of sight, which passes directly through the star being orbited.
- Plane of the orbit: The two-dimensional plane in which the planet and star orbit.
- Inclination angle i: The angle between the plane of the sky and the plane of the orbit. It is 90 degrees for edge-on orbits and 0 degrees for face-on orbits.
- Periastron: The location of closest approach between the star and planet, similar to perihelion in Sun-centered orbits.
- Apastron: The location of greatest separation between the star and planet, similar to aphelion in Sun-centered orbits.
- Ascending and descending nodes: The two locations where the planet's orbit crosses the plane of the sky. The ascending node is where the planet moves from below to above the plane of the sky; the descending node is where it moves from above to below.
- Line of nodes: The line connecting the ascending and descending nodes.
- Argument of periastron ω: The angle between the line of nodes and periastron. This defines how the orbit's ellipse is oriented relative to the observer.
- True anomaly (θ as a function of time): The angle between periastron and the planet's current location in its orbit. This angle changes over time.

Kepler's Three Laws

- **First Law:** All planets move in elliptical orbits with the Sun at one focus. $r = \dfrac{a(1-e^2)}{1+e\cos\theta(t)}$

- **Second Law:** Equal areas swept in equal time (planets move faster when closer). $\dfrac{dA}{dt} = \dfrac{r^2}{2}\dfrac{d\theta}{dt} = \text{constant}$

- **Third Law:** Square of period ∝ Cube of semi-major axis $T^2 \propto a^3$