ASTR 405
Planetary Systems
Astrometry

Fall 2025

Prof. Jiayin Dong

Module I: Exoplanet Detection Methods

- Radial Velocity: detecting exoplanets by measuring Doppler shifts from a star's **radial** reflex motion along our line of sight

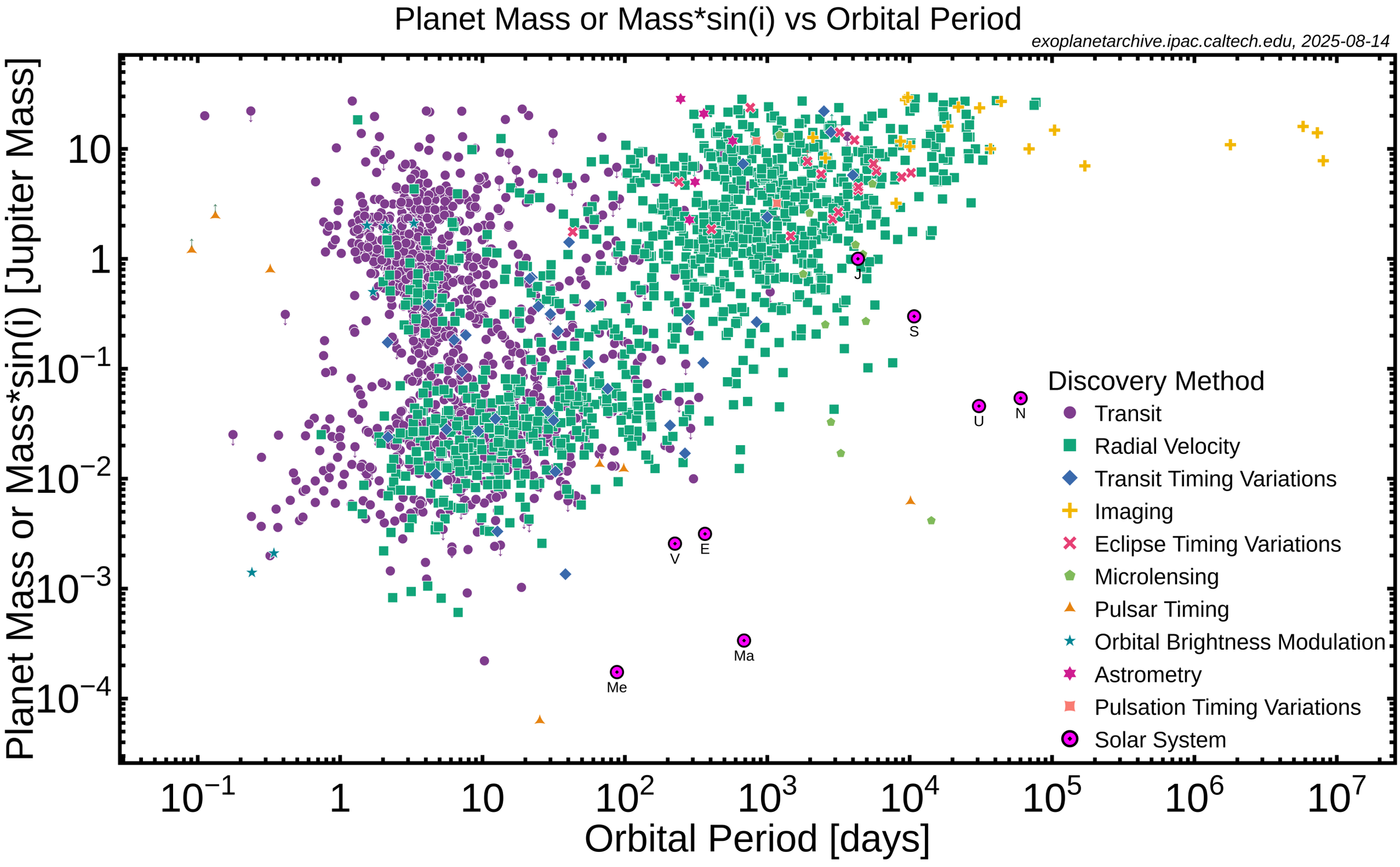
- Astrometry: detecting exoplanets by measuring tiny changes in a star's sky position from its **tangential** reflex motion.

- Transit

- Microlensing

- Direct Imaging

Exoplanet Mass–Period Distribution



Exoplanet Detection via Astrometry

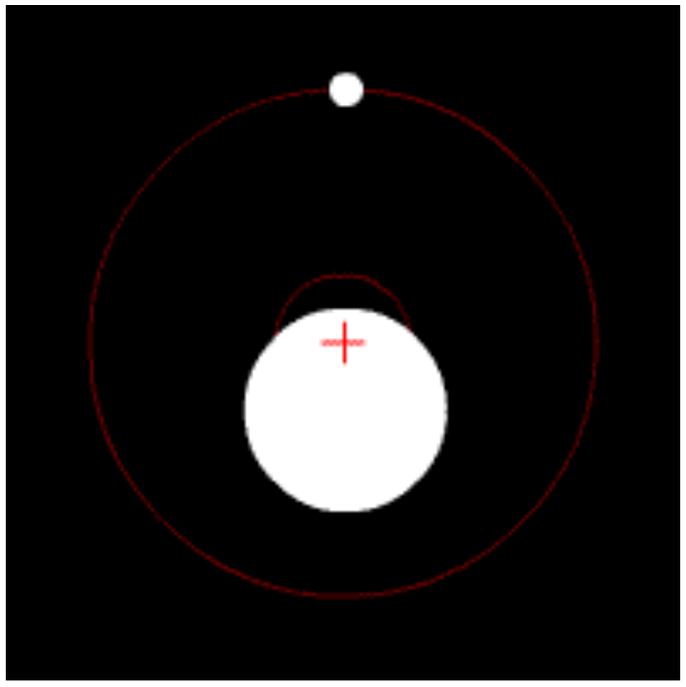
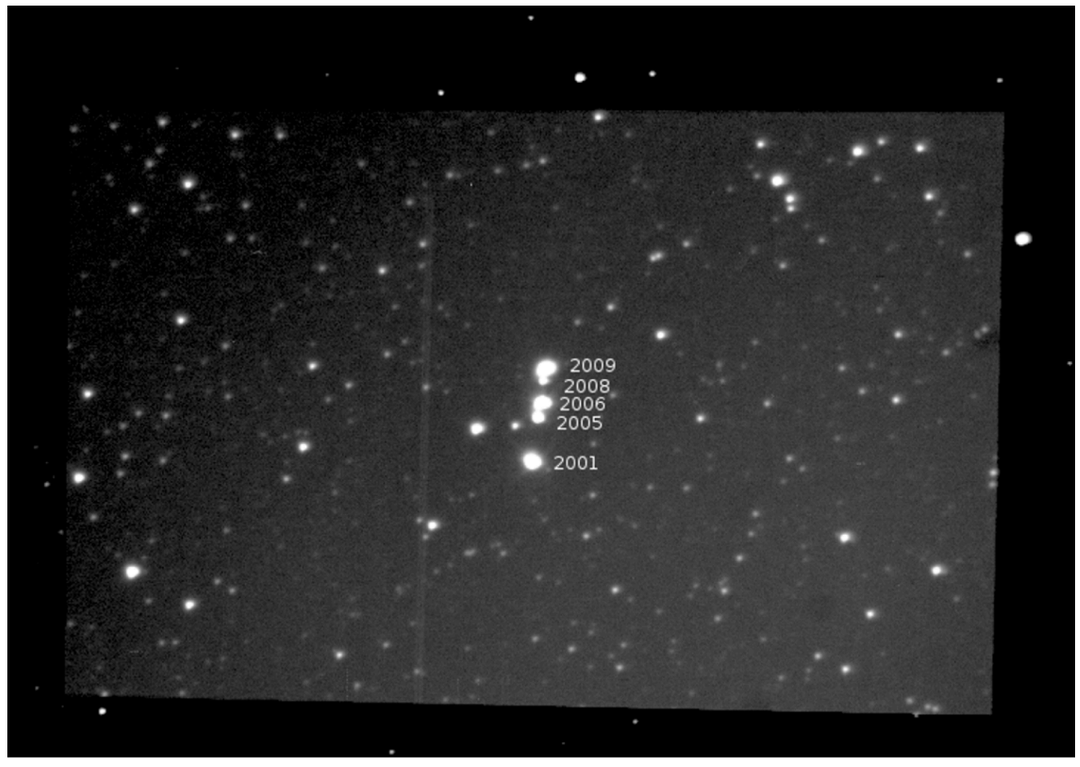


Diagram showing how an exoplanet orbiting a star could produce changes in position and velocity of the star as they orbit their common center of mass (red cross). *Wikipedia*

Proper Motion

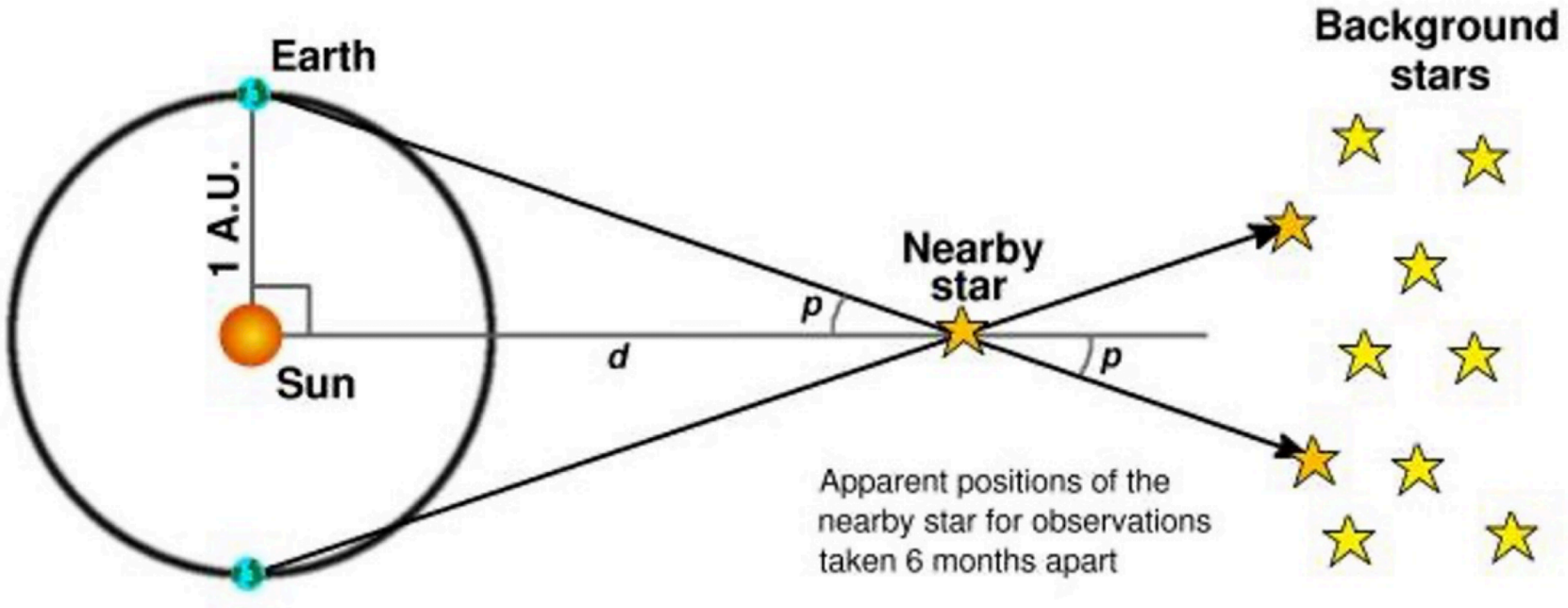
- Proper motion: $\mu \equiv \frac{d\theta}{dt} = \frac{v_\theta}{d}$
- The apparent shift in angular location (θ) of a star as it moves across the sky due to the star's tangential velocity (v_θ)
- Tangential velocity (v_θ) is orthogonal to radial velocity (v_r)



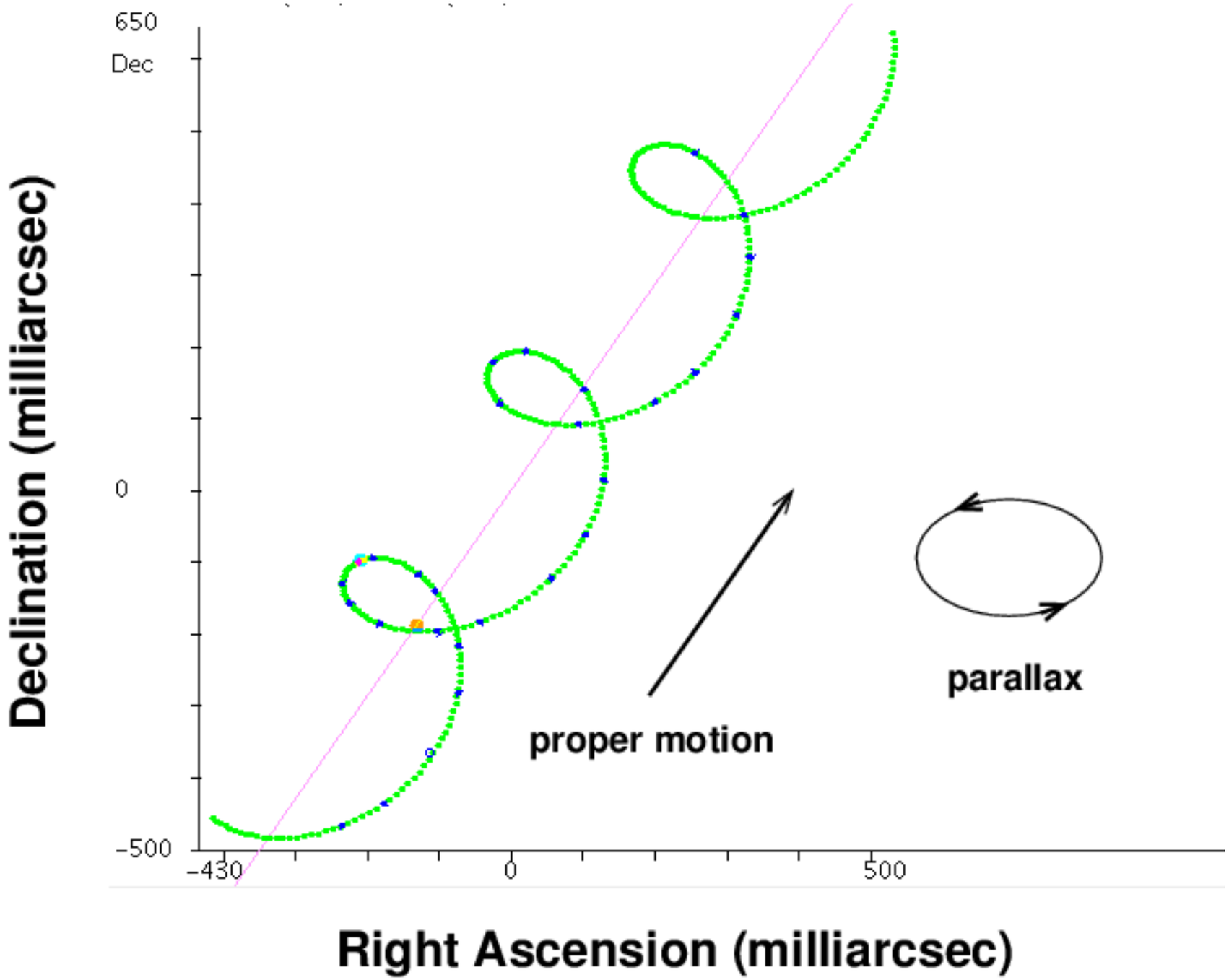
Barnard's star has a high proper motion of of 10.3 arcsec/yr.

Parallax

- Parallax: $p\,(\text{arcsec}) = \dfrac{1}{d\,(\text{pc})}$
- Apparent shift in position of a star on sky (relative to distant background stars) due to the motion of Earth around the Sun



Propor Motion + Parallax



https://www.youtube.com/watch?v=p4lCN8Ch2JA

Astrometric Wobble of a Star Induced by Its Companion Planet

- Center of Mass $M_\star r_\star = M_p r_p$

- Semi-major axis $a = r_p + r_\star$

- Thus, $r_\star = a\dfrac{M_p}{M_\star + M_p} \approx a\dfrac{M_p}{M_\star}$

- Angular astrometric shift $\alpha = r_\star / d$,

$$\alpha = \frac{a}{d}\frac{M_p}{M_\star + M_p} \approx \frac{a}{d}\frac{M_p}{M_\star} \approx \left(\frac{M_p}{M_\star}\right)\left(\frac{a}{1\ \text{au}}\right)\left(\frac{d}{1\ \text{pc}}\right)^{-1}\ \text{arcsec}$$

In-Class Activity

The wobbling of Barnard's star

Astrometric Missions

Ground-based

- Challenging due to atmospheric turbulence, limited seeing –> Solutions: Adaptive Optics, Interferometry

Space-based

- Hipparcos (1989-1993)
  - Achieved ~1 mas accuracy for V = 10
- Gaia (2013-2025)
  - Targeting at ~10 μas accuracy for G = 10