**The radial velocity method - selection effects**

Instrumentation: Astronomical spectroscopes were originally designed to detect doppler shifts due to stellar and galactic velocities - $\mathrm{km\ s^{-1}}$.

Typical Doppler shifts due to an orbiting exoplanet ~ $\mathrm{m\ s^{-1}}$

Mass ratio

Semi-major axis of planetary orbit

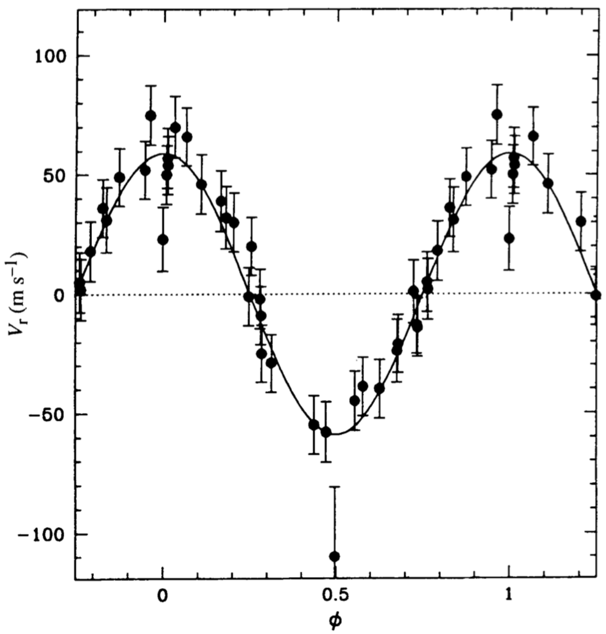



FIG. 4 Orbital motion of 51 Peg corrected from the long-term variation of the $\gamma$-velocity. The solid line represents the orbital motion computed from the parameters of Table 1.

From Mayor & Queloz 1995, Nature, **378**, 355

Peg 51 Orbital period = 4.2 days
Exercise: what is the semi-major axis of orbit?

Orbital velocity of the star around the common CoM of the system is ~ $150\,\mathrm{m\ s^{-1}}$

# The other methods of detecting exoplanets

## Micro-lensing

From Physics World 10th June 2004 (https://physicsworld.com/a/gravitational-lensing-brings-extrasolar-planets-into-focus/) accessed 10th April 2023

## The other methods of detecting exoplanets

### Astrometry

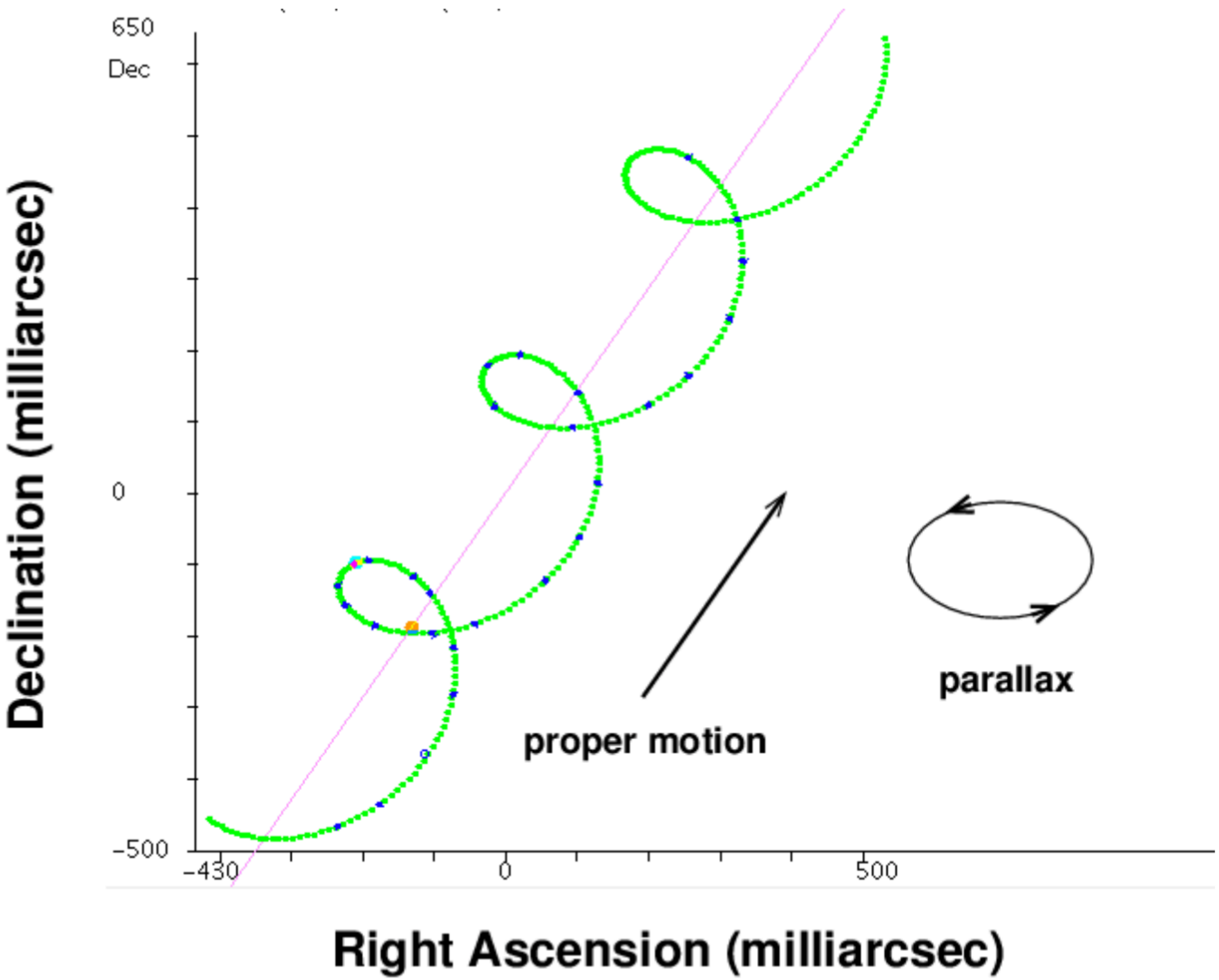



Image thanks to the terrific tools available at [the ESA Hipparcos Tools website]

Angular displacement of the star from it's CoM

$$\beta = \frac{M_p a_p}{M_* d}$$

Method requires repeated observations of the same region of the sky for an extended period of time.

Selection effect:
Angular resolution
$\beta < 1$ arcsec.

## The other methods of detecting exoplanets

### Polarimetry

Star light unpolarised.

Planetary atmosphere can polarise star light, so by measuring changes in polarisation over an orbital period we can infer the presence of a planet.

Very difficult to do in practice.

From European Southern Observatory Press release 13 Oct 2022 (https://www.eso.org/public/news/eso2213/)

## The other methods of detecting exoplanets

### Transit Time Variations

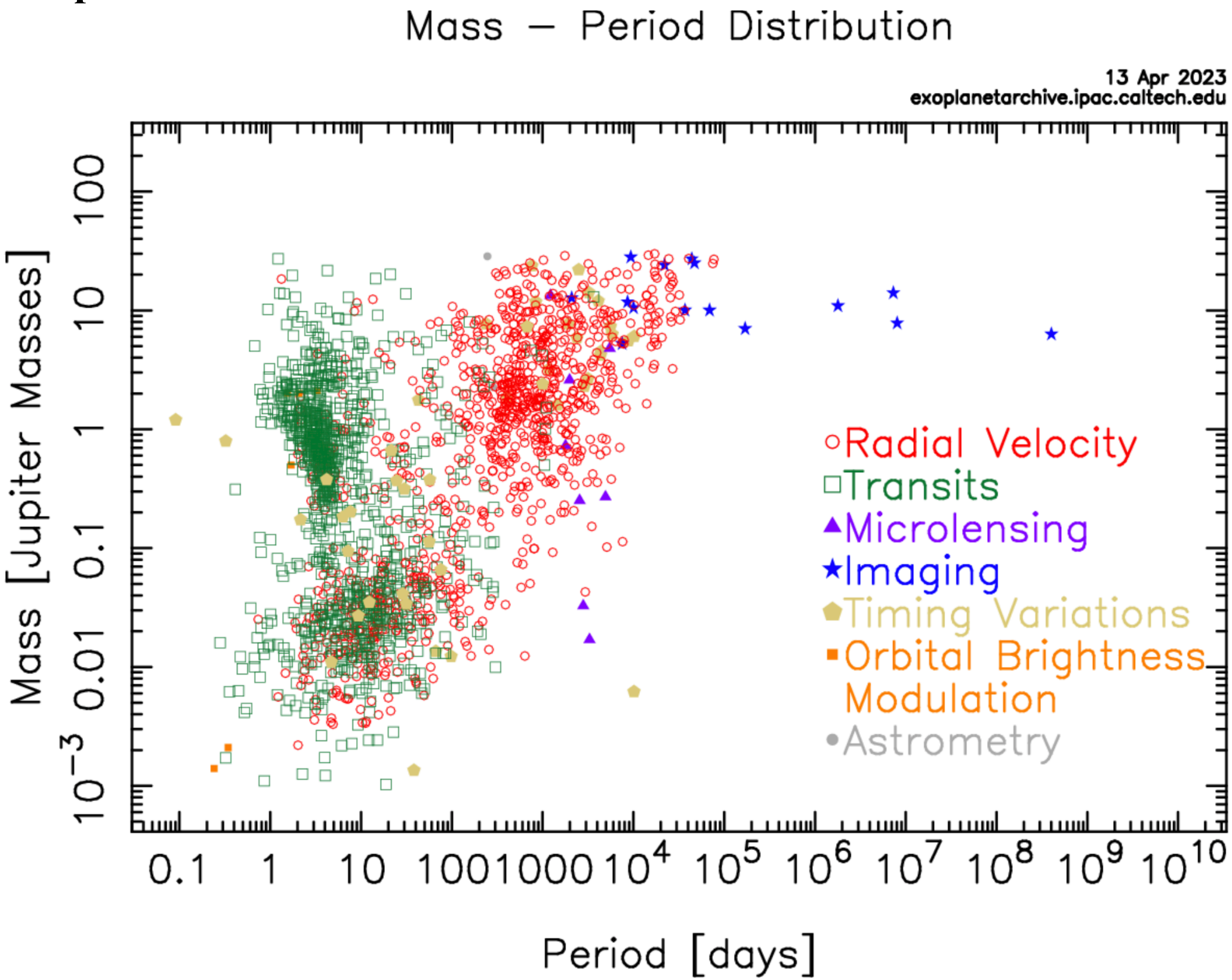
Previously undetected planets in a system may be found by looking for their gravitational effect on the known planets in a system.

cf. Neptune and Pluto in the Solar system

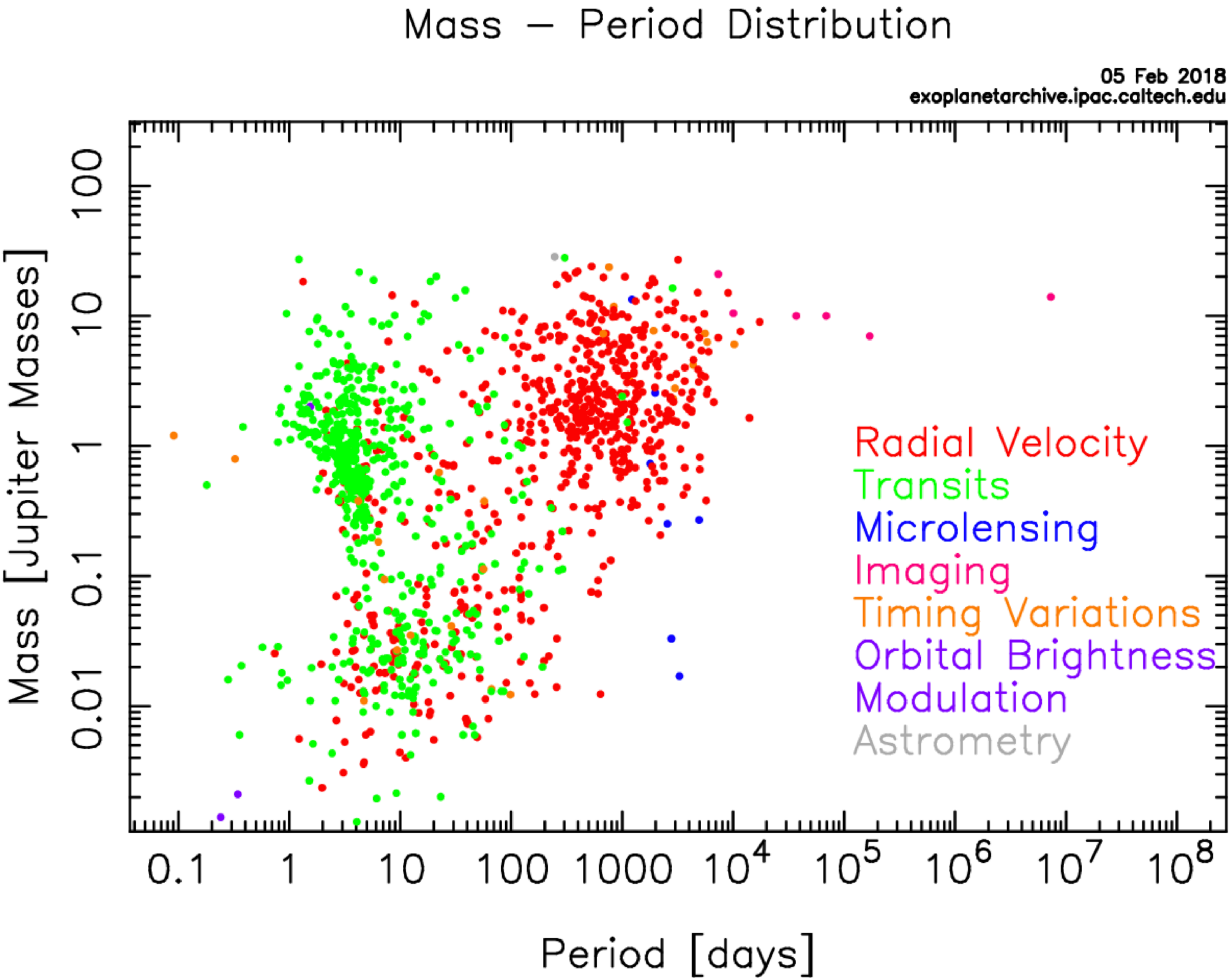
Only works in systems where we have previously found a planet by another method.

From Songhu, Dong-Hong, Barclay, & Laughlin 2017 (2017arXiv170404290W)

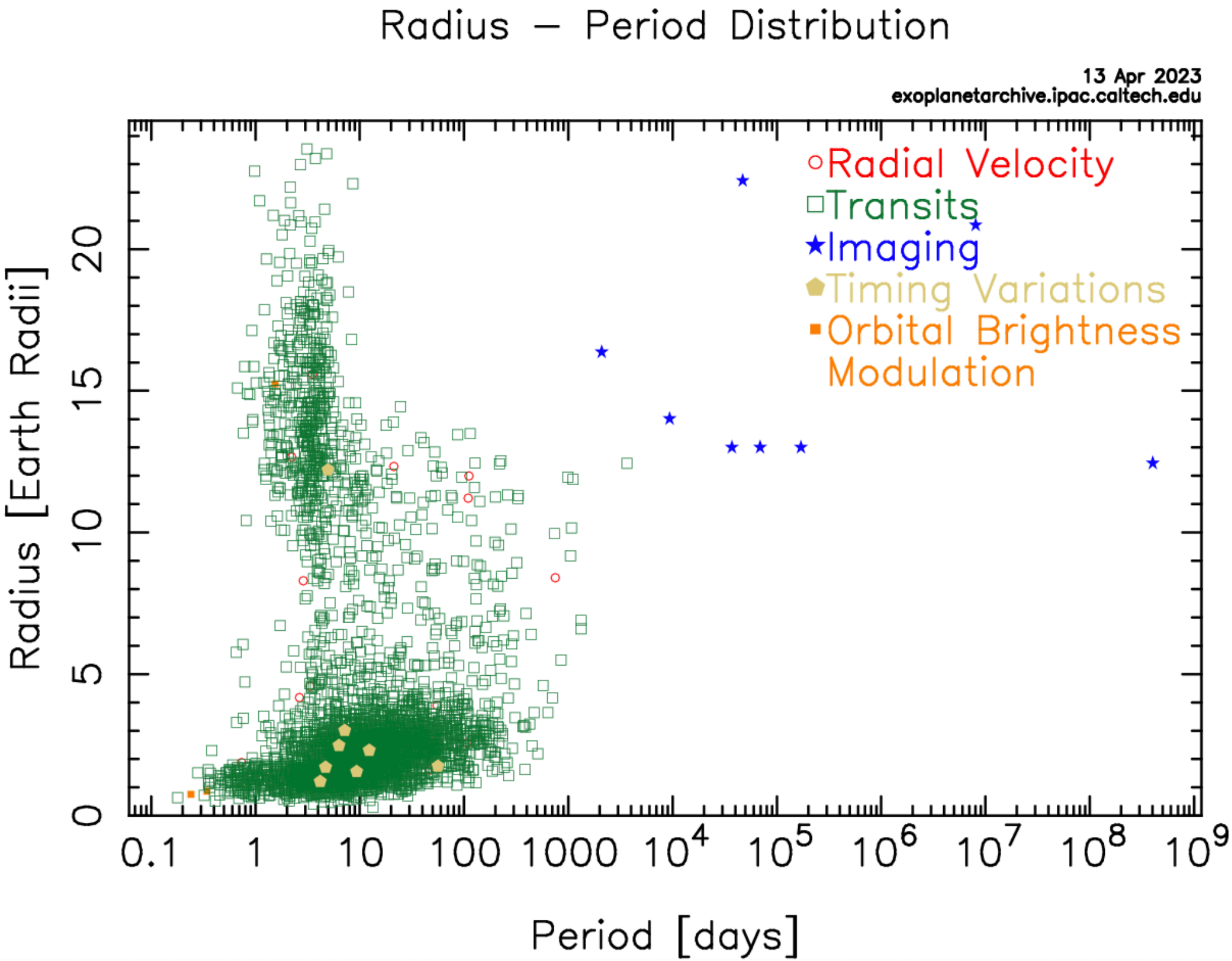
## The exoplanet 'zoo'



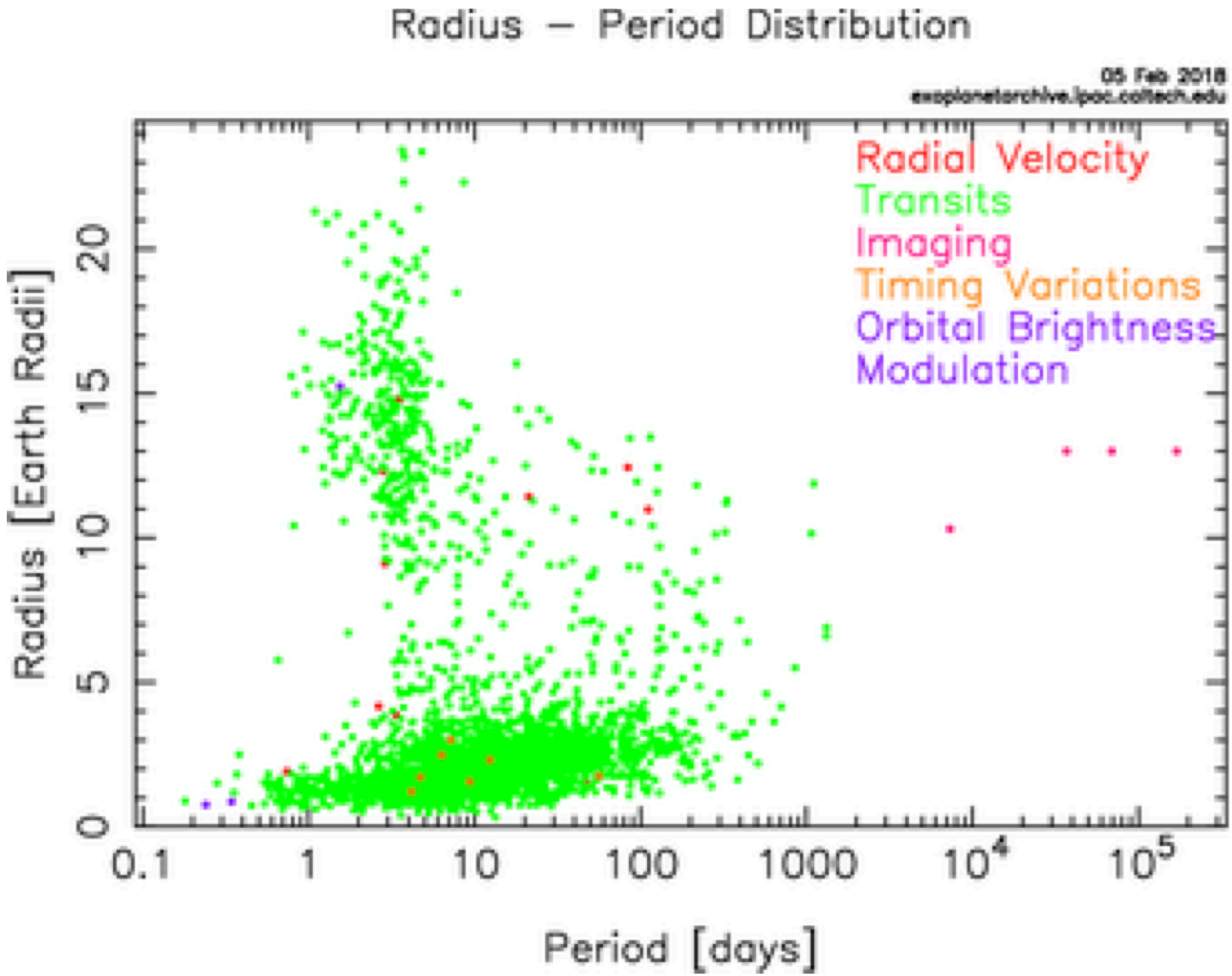
**The exoplanet 'zoo'**



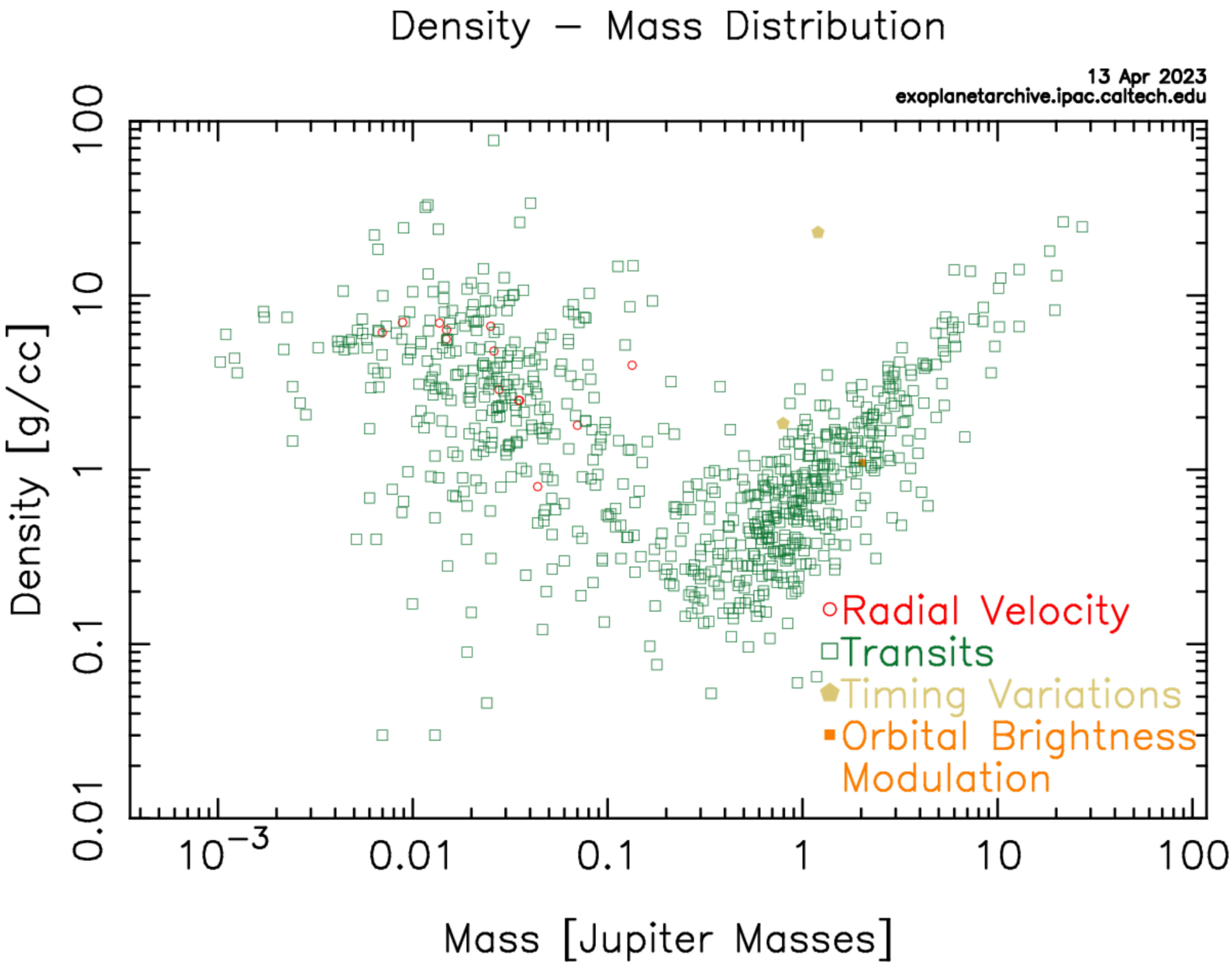
**The exoplanet 'zoo'**



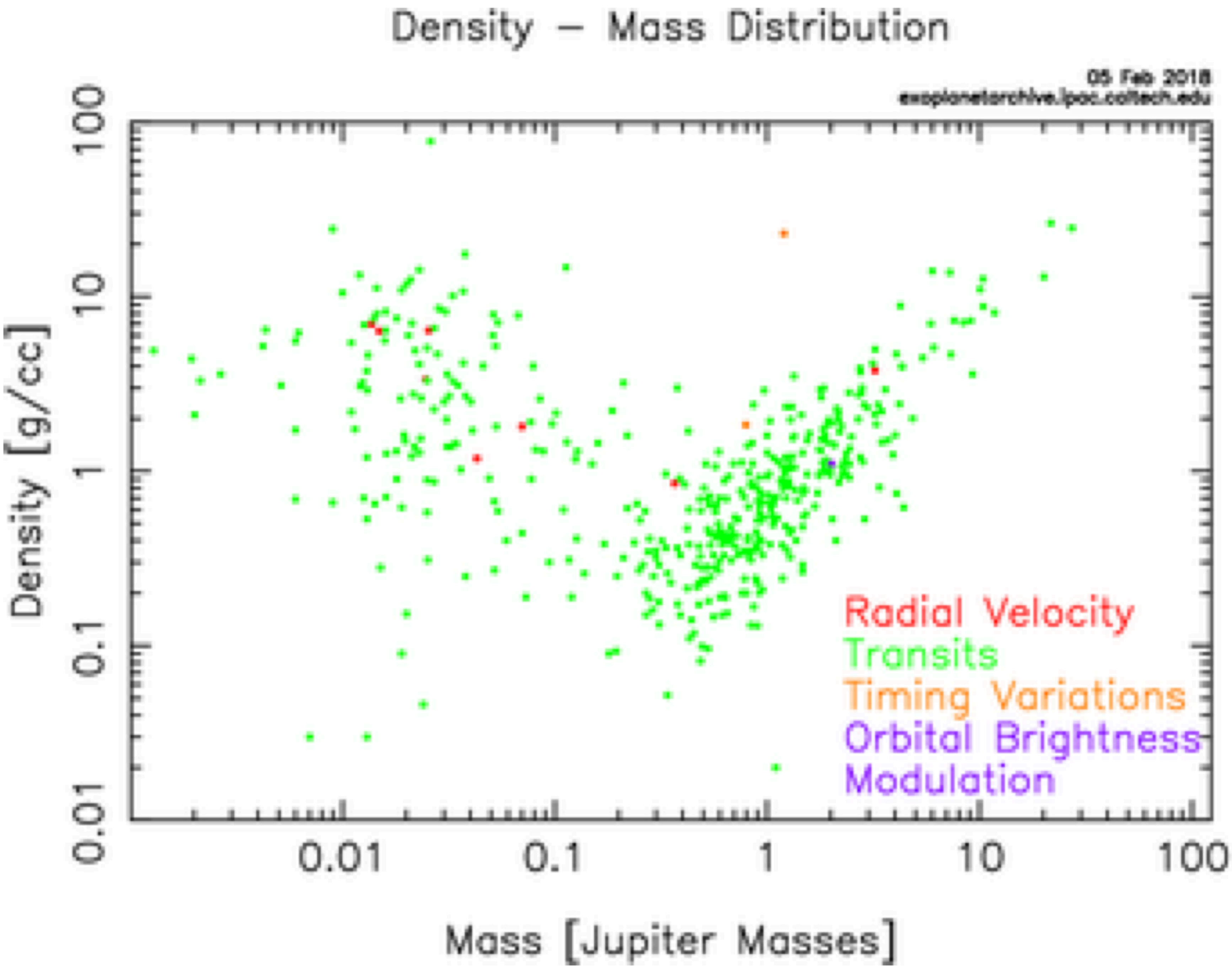
## The exoplanet 'zoo'



# The exoplanet ‘zoo’



**The exoplanet ‘zoo’**



# The exoplanet 'zoo'

Is our solar system an outlier?

Wider orbits, light weight planets

Selection effects again:

Transit: Low radius planets are harder to detect
High distance (from Sun) less likely to transit

Radial velocity: Low mass, long orbital period harder to detect.

So not possible to claim that Solar System is an outlier. As we continue the search for longer times, more planets will be found in RV.

As instrumentation improves, smaller planets will be findable in transit.

# Orbital alignment of exoplanets

In the solar system, planets co-rotate with the Sun

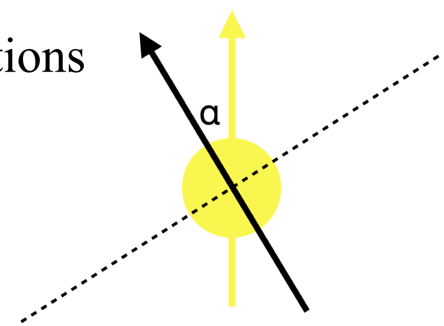
co-rotating counter-rotating

Planets assumed to form from a rotating ‘proto-planetary disc’ surrounding newly formed star (See later section for planet formation).

In the solar system, the angular momentum vectors of the sun is ~ perpendicular to the planes of orbit all eight planets. $\alpha$ is the ‘spin parameter’.

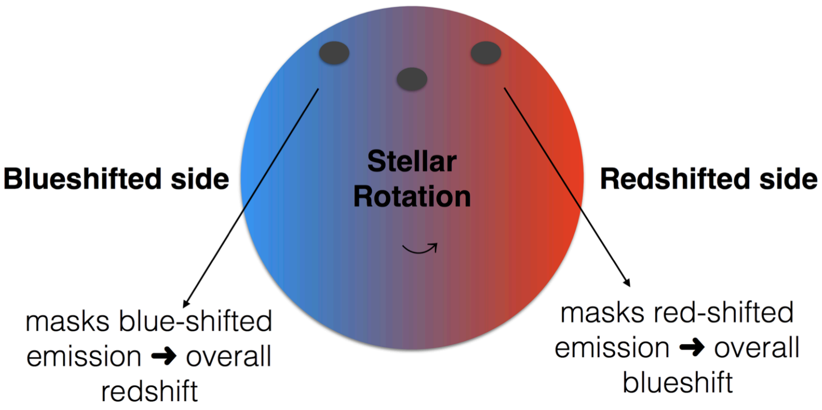
$\alpha \neq 0$ implies past kinematic interactions

Orbital alignment can be measured via the Rossiter-McLaughlin effect



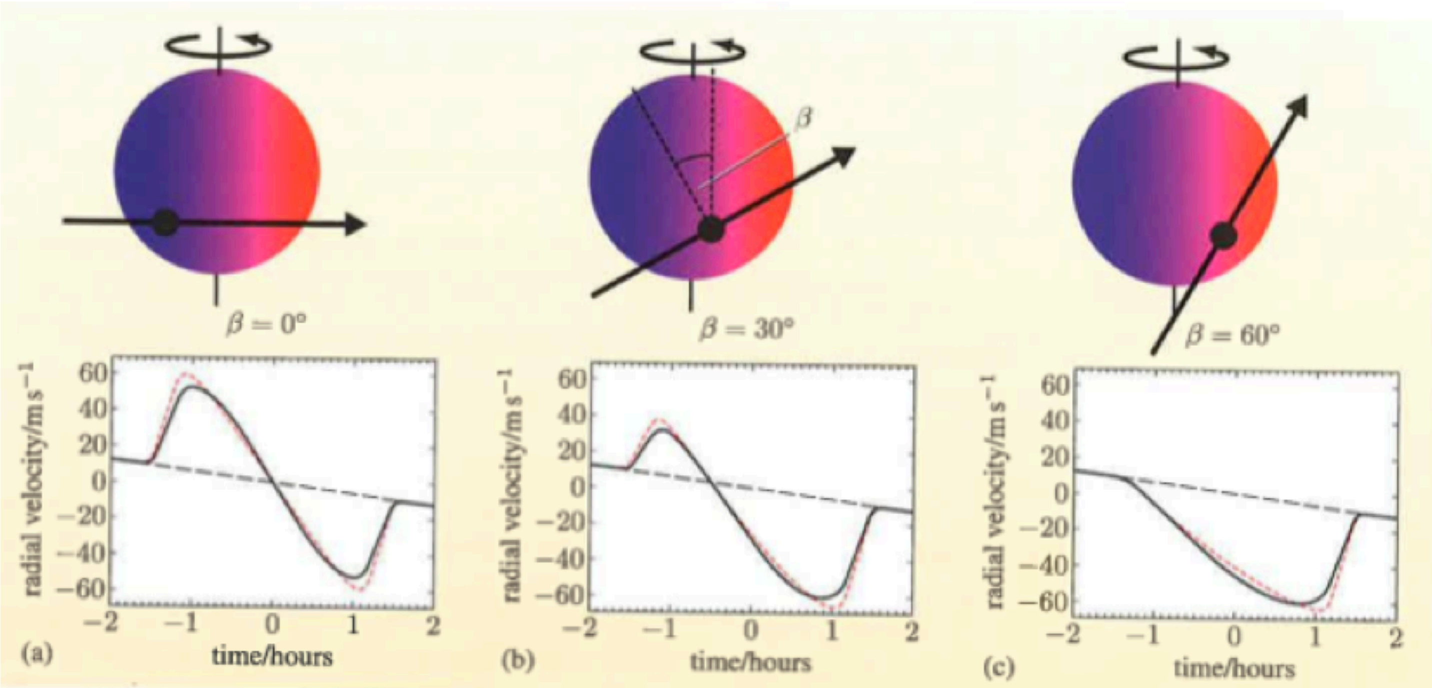

Orbital alignment provides clues to planet formation processes

# Orbital alignment of exoplanets: The Rossiter-McLaughlin effect




Co-rotating planets begin transit on blueshifted side, and end on redshifted side.

Counter-rotating planets begin on redshifted side, and end on blueshifted side.




From Transiting Exoplanets, Haswell 2010, Cambridge University Press
Note, Haswell uses $\beta$ for the spin parameter.

We can combine the radial velocity signal due to star orbiting the common CoM of the system with the apparent signal caused by the planet blocking some of the star's light to estimate the spin parameter $\alpha$.

The RM effect has been measured for several planets. As expected, $\alpha \sim 0$ in most, But not all cases

## Secondary transits

We can detect exoplanets by the fact that they can block some of the light of the star.

But the star can also block radiation coming from the planet