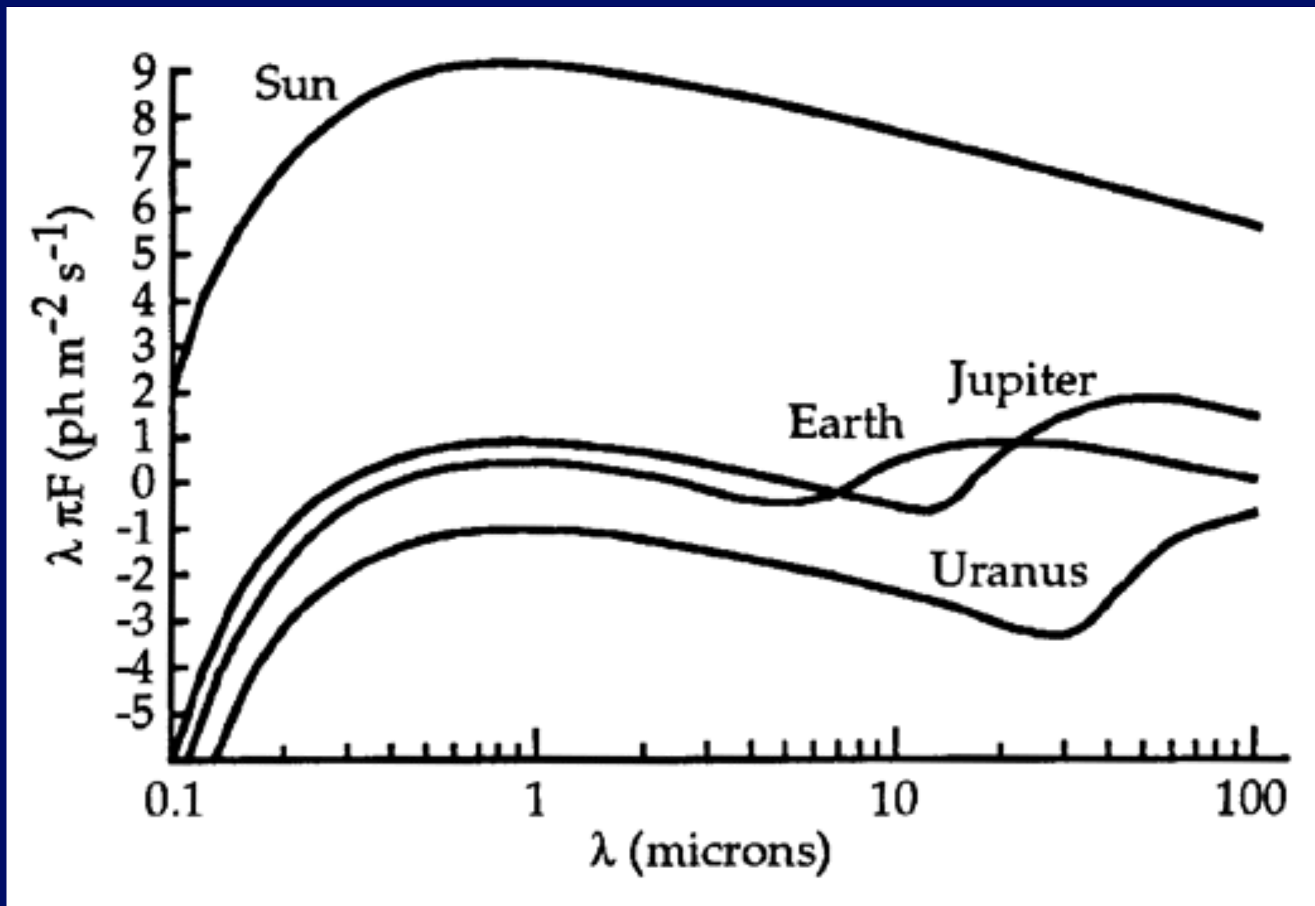
Planet Detection

Estimating f_p

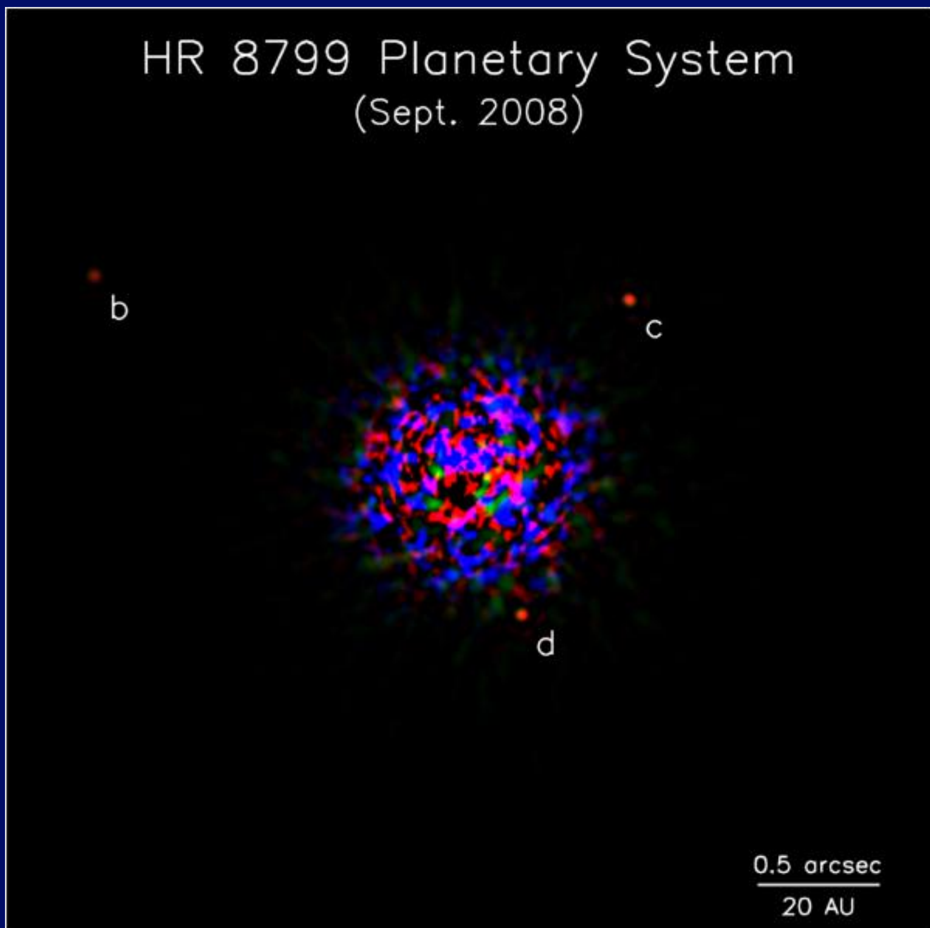
Can We See Them?

- Not easily
  - Best cases were reported in late 2008
  - Will see these later…
- Problem is separating planet light from star light
  - Star is 10^9 times brighter in visible light
  - "Only" 10^6 times brighter in infrared

Planet is Much Fainter than Star



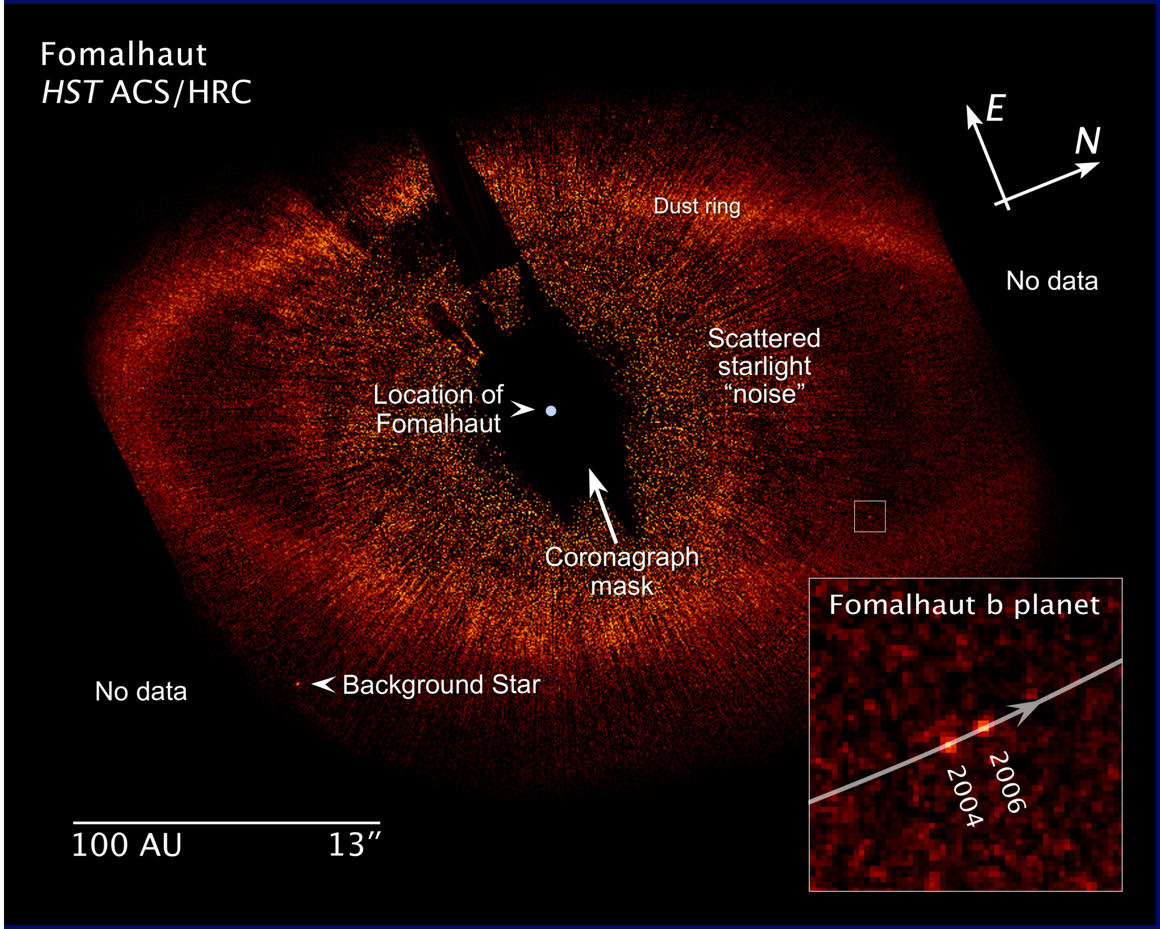
Direct Detection



Three planets detected with ground-based telescopes working in the near-infrared. They used adaptive optics and other techniques to block the direct starlight and obtain very good spatial resolution.

Three planets at 24, 38, and 68 AU. Evidence for orbiting the star. Best guess masses 5-14 $M_{jupiter}$. Reported in Science, 2008, 322, 1348 by Marois et al.

And, in the same issue…



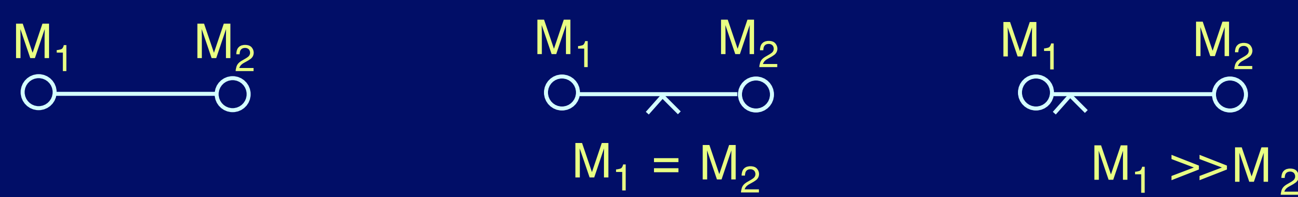
A planet just inside the dust ring around the star Fomalhaut. A coronagraph was used to block the star light and the Hubble Space Telescope avoids seeing. The faint spot in the box moves across the sky with Fomalhaut (proper motion), but with a slight shift due to its orbital motion (see inset). Announced by Kalas et al. Science, 2008, 322, 1345.

Planet about 3 $M_{jupiter}$ and 119 AU from star. Keeps inner edge of dust ring sharp. Light may actually be reflected off a circumplanetary disk.

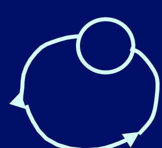
Indirect Detection

Wobbling star

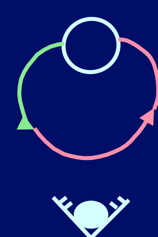
Detect effect of planet on star (both orbit around center of mass)



Large planet will make a star "wobble"



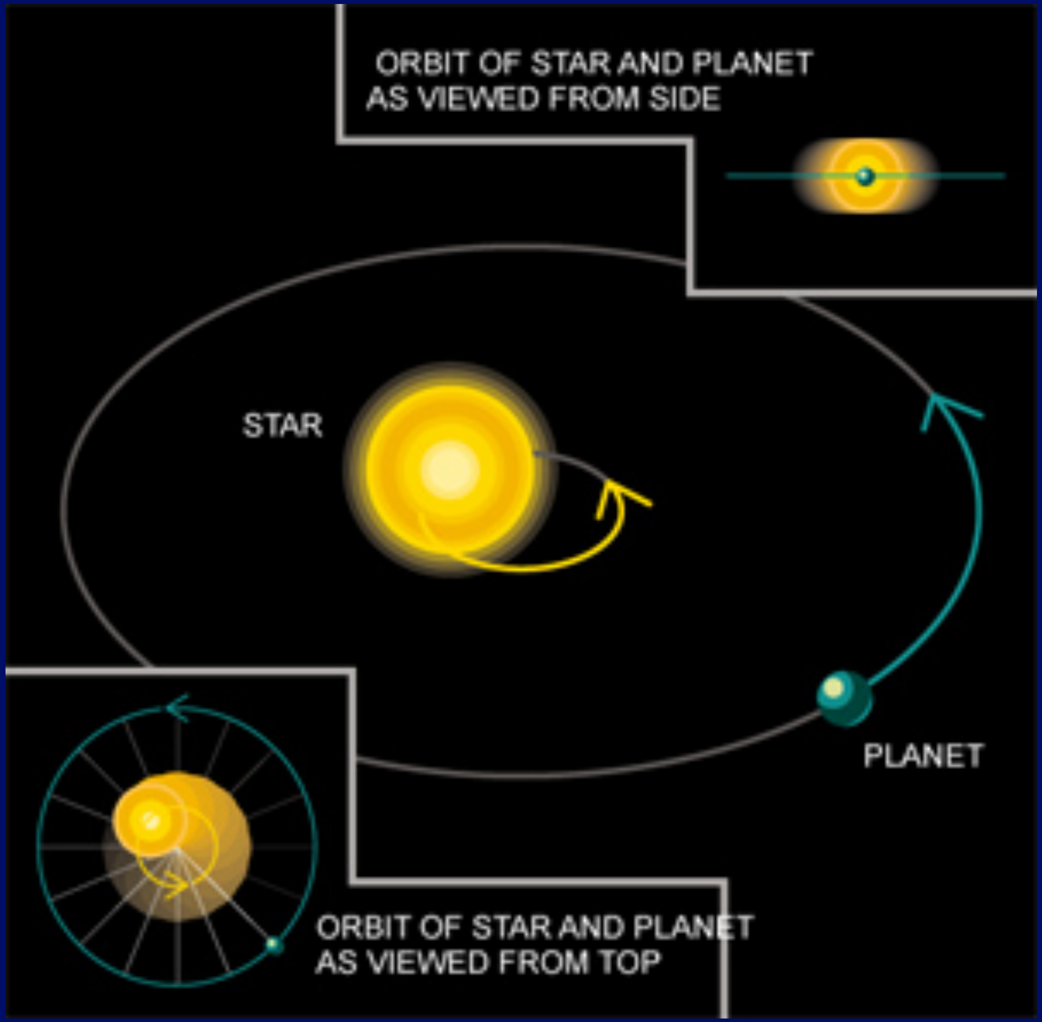
In plane of sky observe position shift



Along our line of sight

Observe Doppler Shift

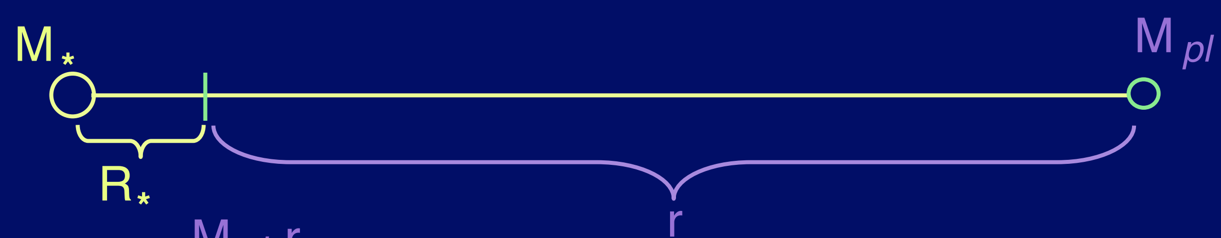
Star and Planet Orbit Center of Mass



The Astrometric Technique

Measure stellar position (angle) accurately - see wobble compared to more distant stars

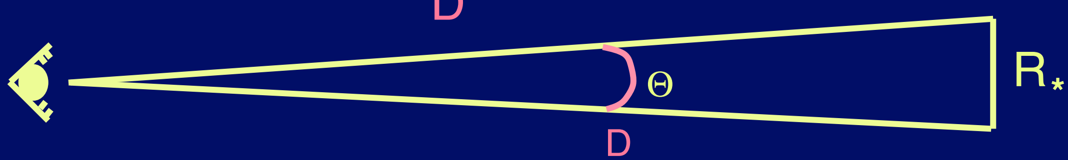
How far does the star wobble?



$$R_* = \frac{M_{pl}\, r}{M_*}$$

We measure angle; for small angles,

$$\Theta = \frac{R_*}{D} \qquad \text{in radians}$$

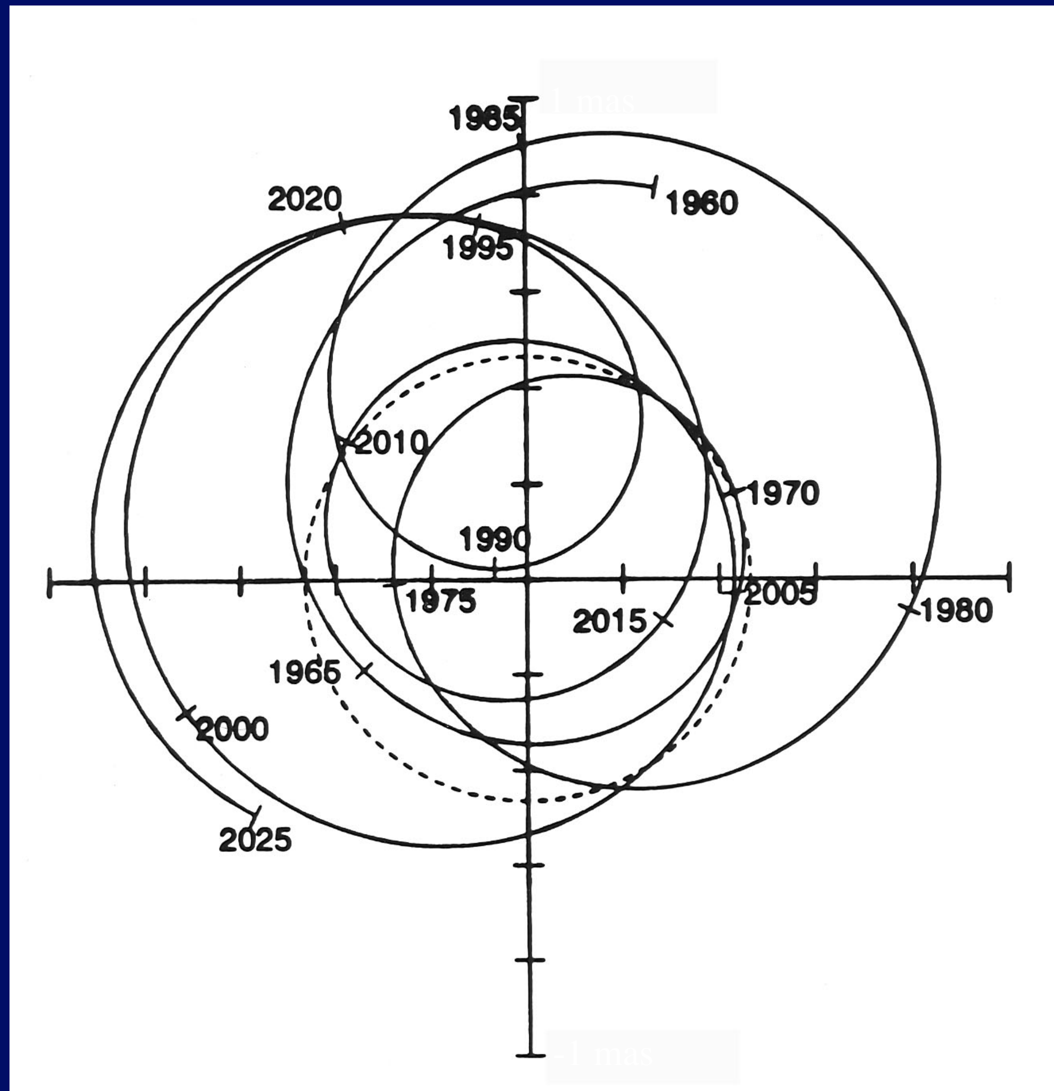


so $$\Theta = \frac{M_{pl}\, r}{M_*} \frac{1}{D}$$

Big planet, big orbit
small star, close to sun

Current limit: 1 mas = 10^{-3} arcsec = 2.8×10^{-6} degrees
= 4.9×10^{-8} radians

e.g. $M_{pl} = M_{Jupiter}$, $M_* = M_\odot$, $D = 15\ ly \Rightarrow \Theta = 1$ mas



The Sun as viewed from 10 pc (~30 *ly*)

30 *ly*

Planet	M_P (M_J)	R (AU)	P (years)	$V_\star$ ($m\,s^{-1}$)	Θ at 10 pc (mas)
Mercury	1.74E-4	0.387	0.241	0.008	6.4E-6
Venus	2.56E-3	0.723	0.615	0.086	1.8E-4
Earth	3.15E-3	1.000	1.000	0.089	3.0E-4
Mars	3.38E-4	1.524	1.881	0.008	4.9E-5
Jupiter	1.0	5.203	11.86	12.4	0.497
Saturn	0.299	9.54	29.46	2.75	0.273
Uranus	0.046	19.18	84.01	0.297	0.084
Neptune	0.054	30.06	164.8	0.281	0.156
Pluto	6.3E-6	39.44	247.7	3E-5	2.4E-5

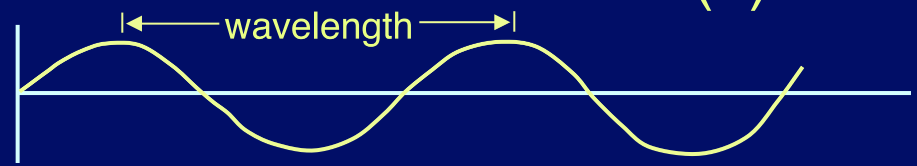
The Spectroscopic Method

- Relies on Doppler Effect
- Motion of star towards and away from us
- Most planets found around other stars so far were by this method

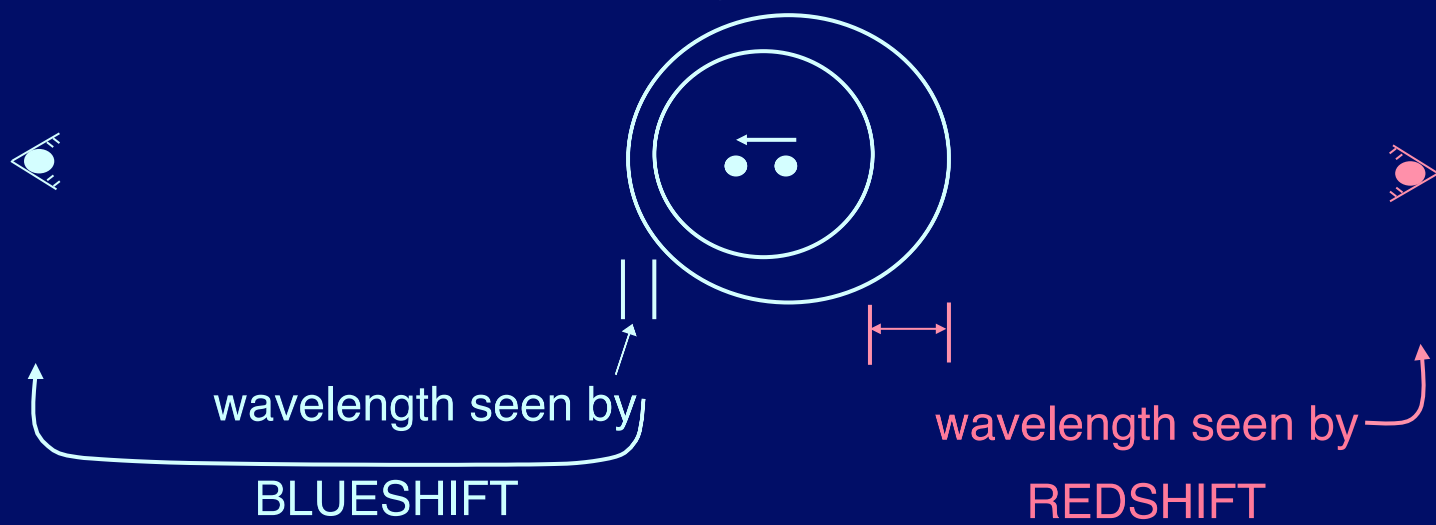
The Doppler Shift

Light is a wave

(λ)



moving star



$$\frac{\lambda_{observed}}{\lambda_{emitted}} = 1 + \frac{v}{c}$$

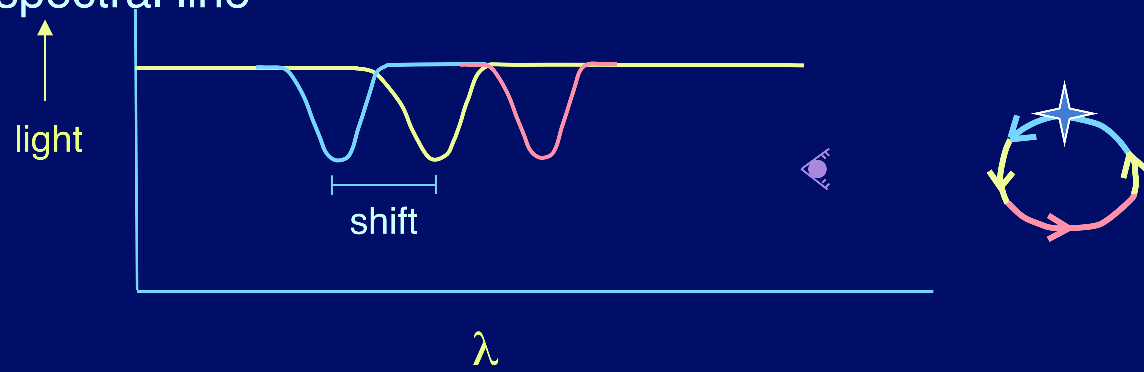
Doppler Shift ⟶ Magnitude and direction of velocity

But only along line-of-sight

The Spectroscopic Technique

Measure velocity, not position, of star

Use spectrometer to get Doppler Shift of spectral line



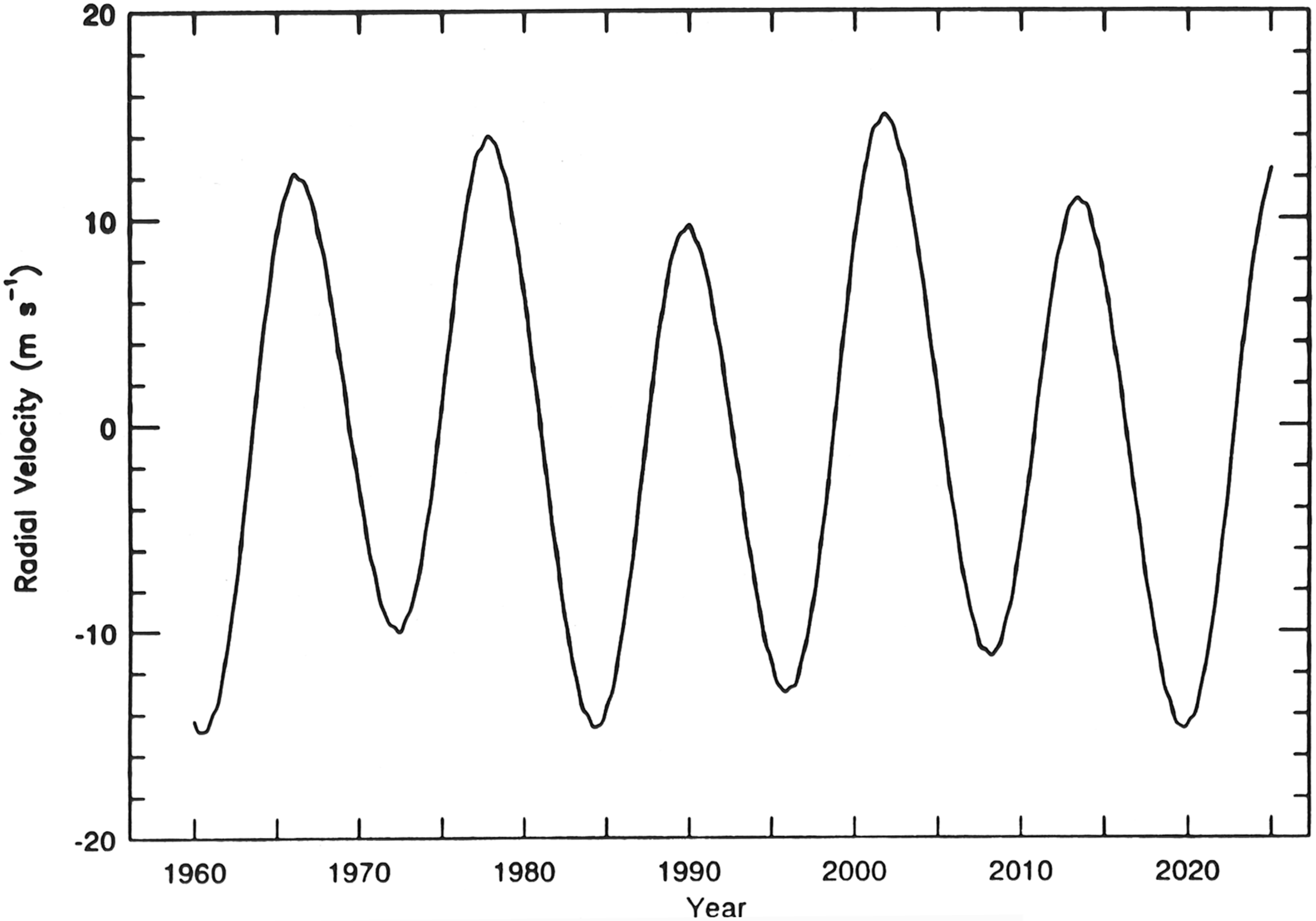
$$\text{Shift} \propto V_* \propto \frac{M_{pl}}{M_*^{1/2}\, r^{1/2}}$$

Big planet, small orbit

Low mass star

Distance doesn't matter (except for brightness)

Edge - On



Motion of the Sun caused by Jupiter, ...

30 *ly*

Planet	M_P (M_J)	R (AU)	P (years)	$V_\star$ ($m\,s^{-1}$)	Θ at 10 pc (mas)
Mercury	1.74E-4	0.387	0.241	0.008	6.4E-6
Venus	2.56E-3	0.723	0.615	0.086	1.8E-4
Earth	3.15E-3	1.000	1.000	0.089	3.0E-4
Mars	3.38E-4	1.524	1.881	0.008	4.9E-5
Jupiter	1.0	5.203	11.86	12.4	0.497
Saturn	0.299	9.54	29.46	2.75	0.273
Uranus	0.046	19.18	84.01	0.297	0.084
Neptune	0.054	30.06	164.8	0.281	0.156
Pluto	6.3E-6	39.44	247.7	3E-5	2.4E-5

What We Can Learn

1. There is a planet

   (If not a mistake)

2. The orbital period (P)

   (The time for pattern to repeat)

3. The orbital radius

   $$r^3 \propto M_* P^2$$

   (Kepler's Third Law)

4. Lower limit to planet mass (M_{planet})

   Conservation of momentum ⟶

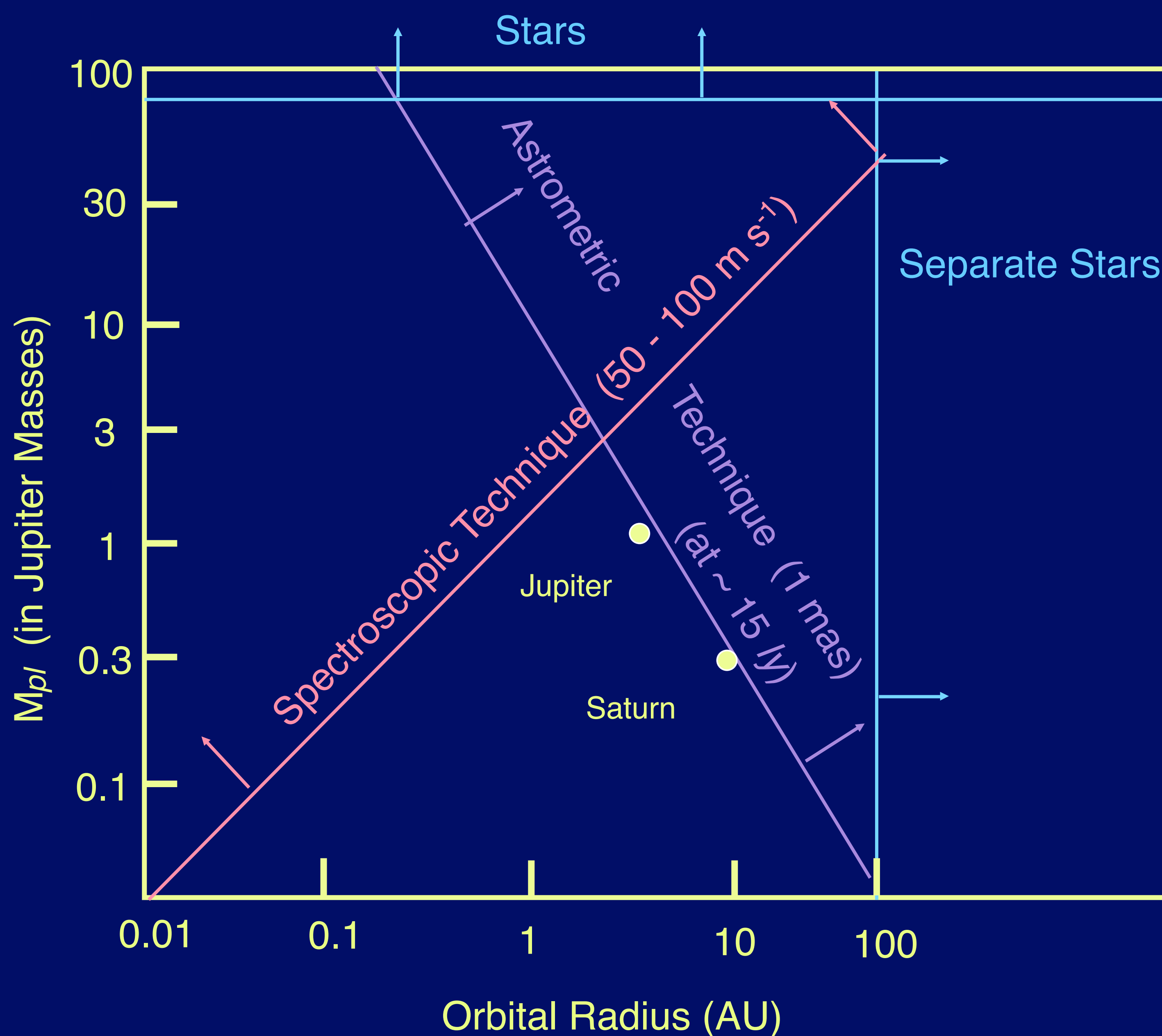
   $$M_{pl} \geq \frac{M_* V_* P}{2\pi r}$$

   = if we see orbit edge-on

   > if tilted

Comparison of Search Methods

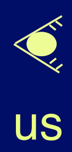
	Astrometric	Spectroscopic
Advantages	Big Planet	Big Planet
	Big Orbit	Small Orbit
	Small Star	Small Star
	Nearby Star	--
		Edge-on Orbit

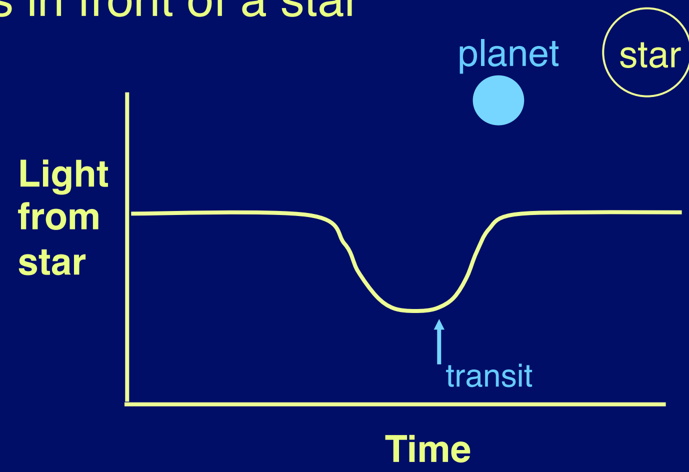


Stars
Separate Stars
Astrometric Technique (1 mas) (at ~ 15 ly)
Spectroscopic Technique (50 - 100 m s-1)
Jupiter
Saturn
100
30
10
3
1
0.3
0.1
Mpl (in Jupiter Masses)
0.01
0.1
1
10
100
Orbital Radius (AU)

Other Methods

Transits: Planet passes in front of a star



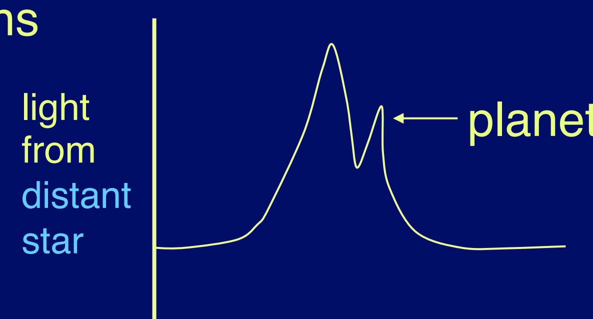


Only about 0.5% of stars with planets will line up

First planet found with this method in January 2003; 35 detected as of January 2008, 55 by January 2009, 291 by January 2013

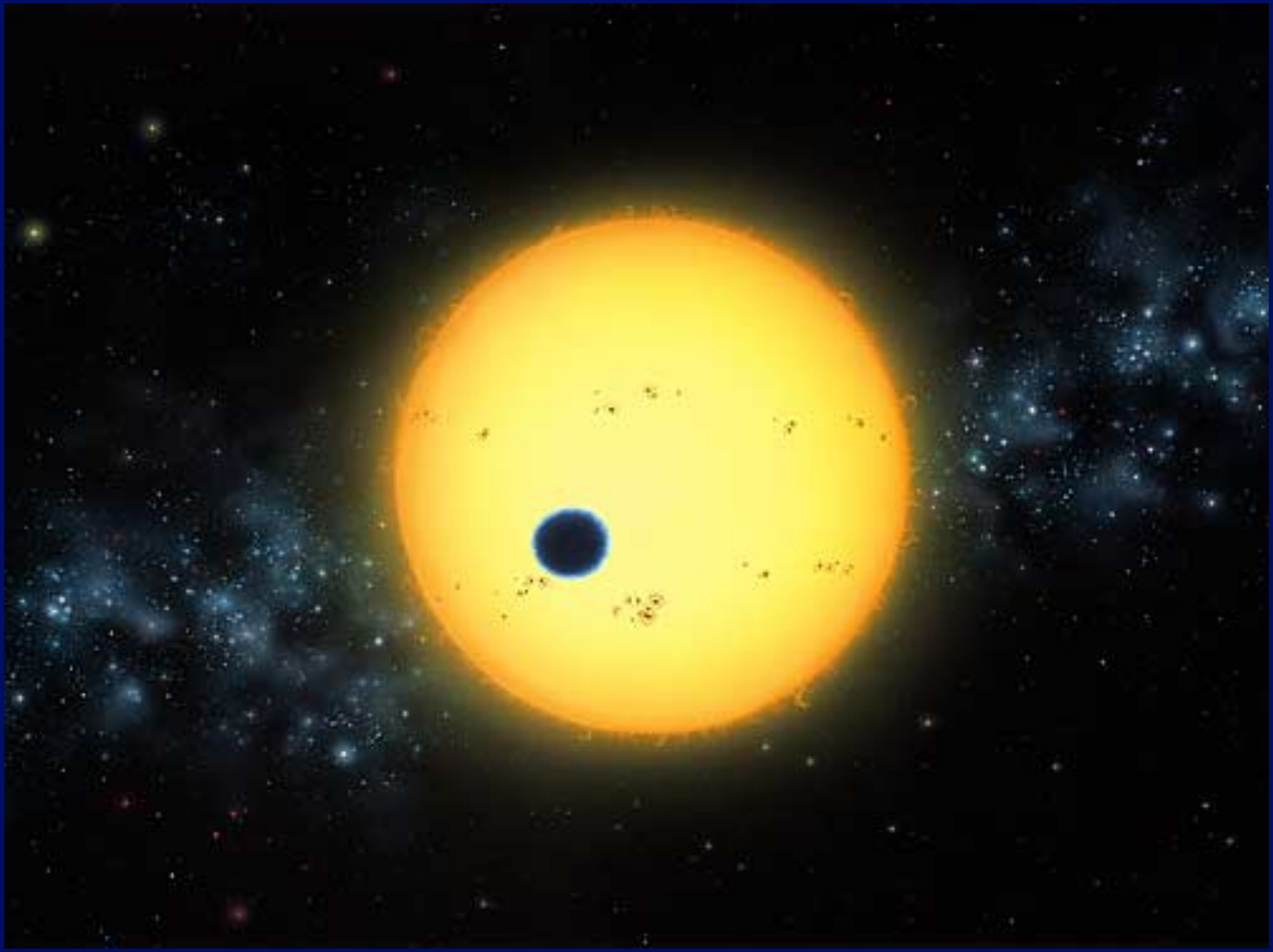
Microlensing: Light from more distant star is focused by gravity of nearer star passing in front

Fortuitous alignment ⇒ brightens



16 planets found this way as of January 2013

Artist's conception of Transit of HD209458



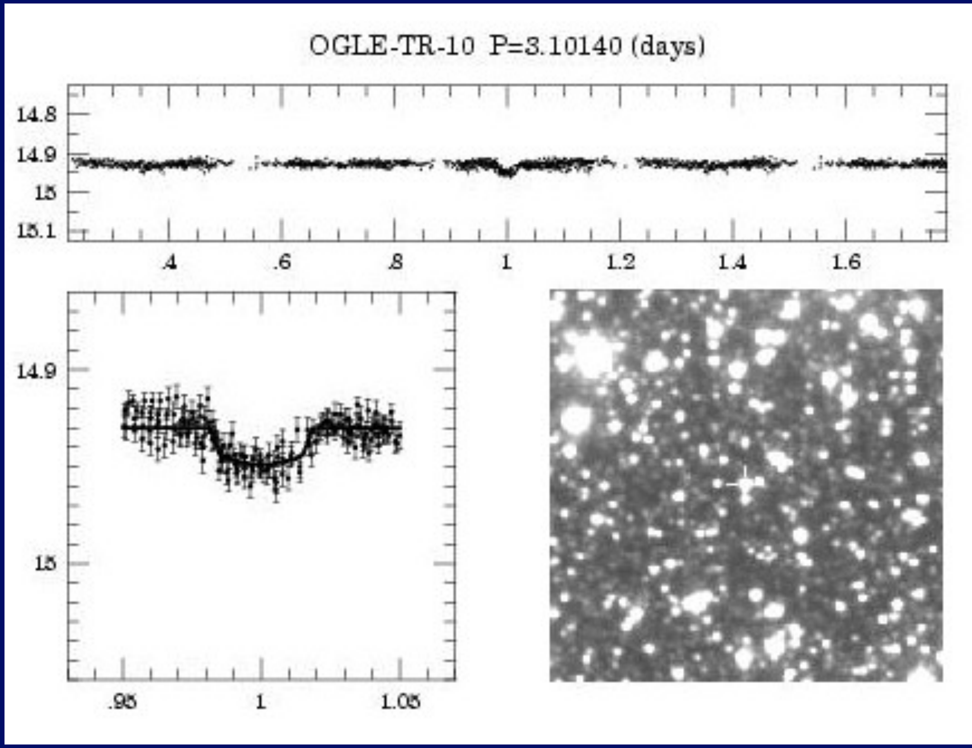
http://www.extrasolar.spaceart.org

To simulate, try http://planetquest.jpl.nasa.gov/gallery/gallery_index.cfm

Timing

- Delays or advances in periodic signals
  - Pulses from pulsar
    - First planets found that way in 1992
    - Not suitable for life!
  - Oscillations in white dwarfs
    - First found this way in 2007 by grad student at UT

Planets from the Transit Method

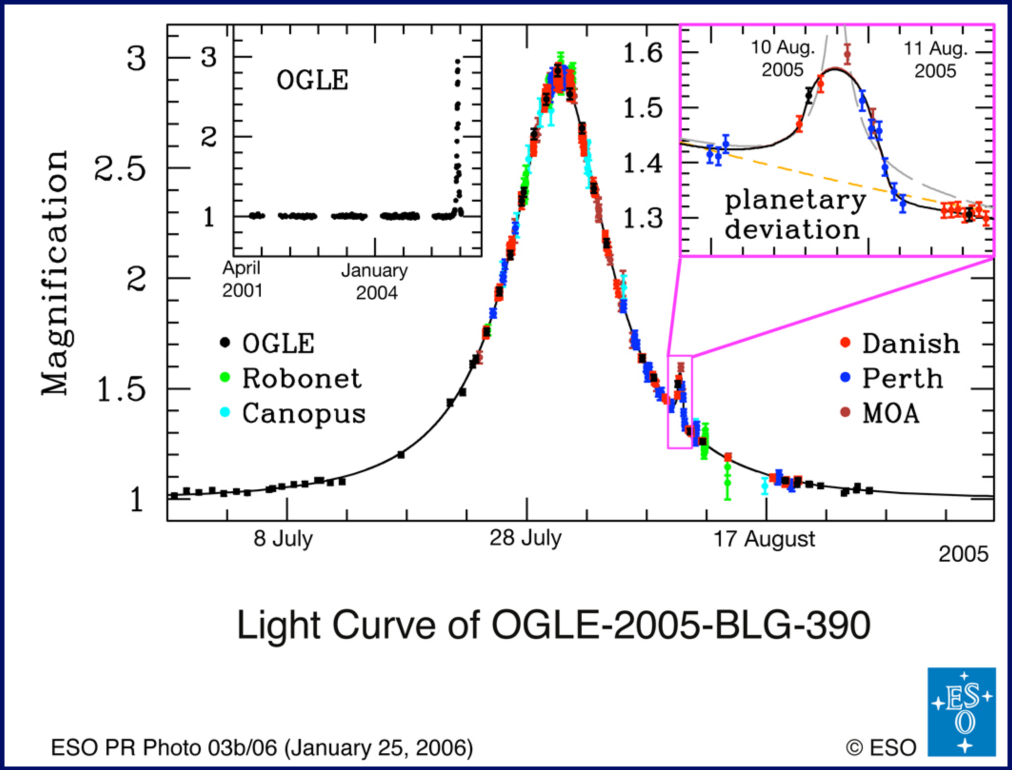


OGLE-TR-10

Light curve

Star field, shows star

Planet Detected by Microlensing



Sharp spike indicates second lens. Mass of second lens only 8 x 10^{-5} as massive as star. Most likely mass of planet is 5.5 M_{earth} and separation from star is 2.6 AU. Most likely star is low mass (0.22 M_{sun}).

This method can detect very low mass planets, but they are one-time events. Cannot follow up.

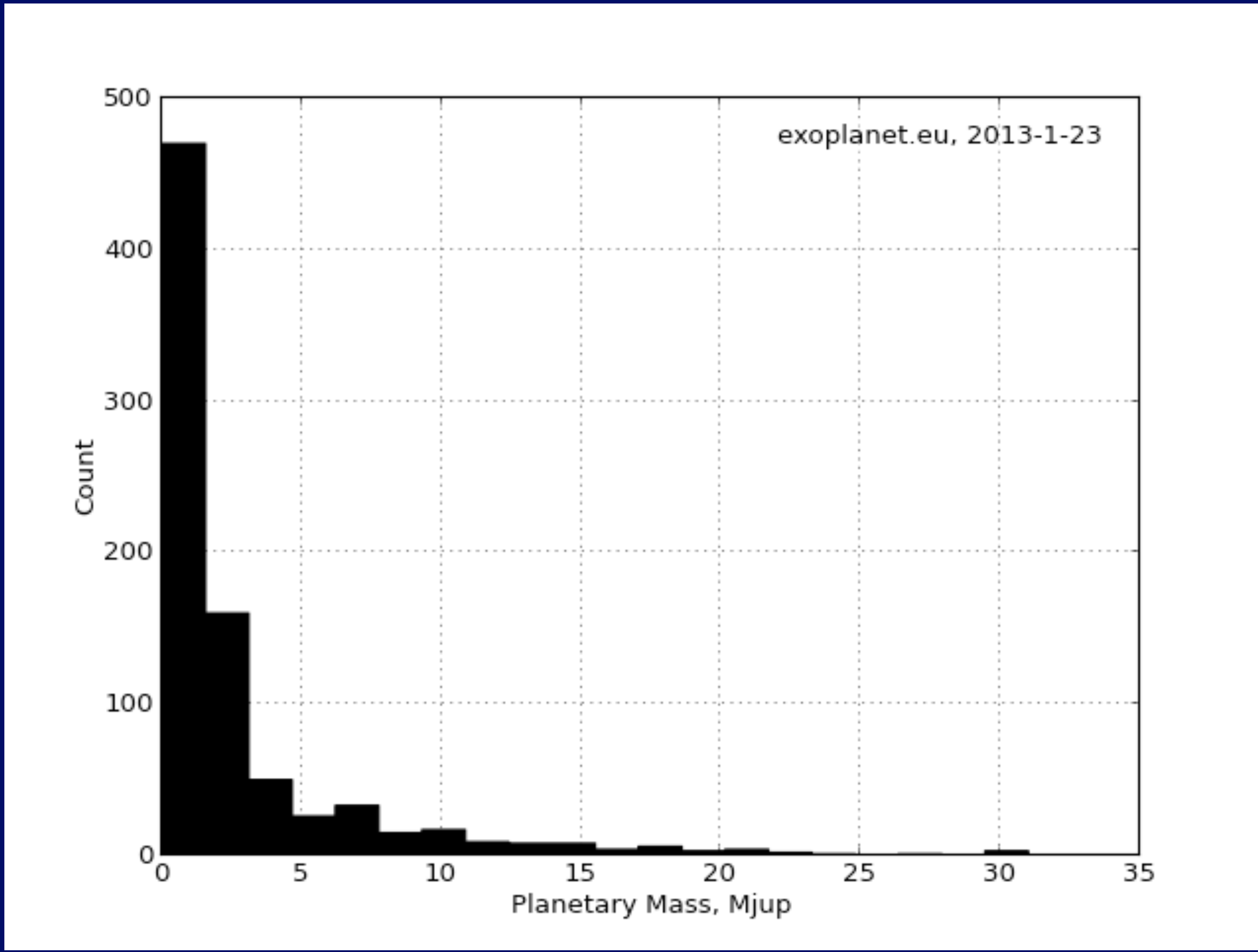
OGLE 2005-BLG-235Lb, announced 1/25/06

http://www.eso.org/outreach/press-rel/pr-2006/pr-03-06.html

Current Statistics (Jan. 2013)

- Based on Extrasolar Planets Encyclopedia
  - http://exoplanet.eu/
- 859 Planets
- 128 stars with multiple planets
- Most planets in one system is 5 (55 Cancri)
- Least massive
  - $M = 0.003\ M_{Jup} = 1.0\ M_{earth}$ (Kepler 42d)

Number of planets for different masses



Estimating f_p

- Maximum? $f_p \sim 1$
  - All young stars may have disks
- Binaries?
  - Can have disks, but planet formation?
  - Even if form planets, orbits may not be stable
  - If reject binaries, $f_p < 0.3$

Estimating f_p

- Minimum?
  - Based on success rate of searches ($n_{found}/n_{searched}$)
  - Extrapolate trends to finding
    - Smaller planets, larger orbits, …
  - Estimates range upward from 0.5
- Allowed range: f_p = 0.5 to 1.0 if include binaries
  - Explain your choice!
  - Include/exclude binaries?

Ongoing Missions and Future Prospects

Transits

CoRoT Dec. 2006-present

Has reported numerous new planets

Kepler (Launched March 2009)

Monitor 100,000 stars for 4 years

"Hundreds of Terrestrial Planets"

So far, 70 announced, > 2000 candidates

Most notable: Kepler 10b, first rocky planet, 1.4 times size of Earth

Astrometric Method

GAIA Launch planned for 2013

M_J Planets out to 600 ly; predicted to detect 15,000 planets