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

![Graph showing the brightness of different celestial objects as a function of wavelength (microns). The graph includes curves for the Sun, Earth, Jupiter, and Uranus, with the Sun being the brightest.](image)
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$_{\text{Jupiter}}$. 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 $3 \, M_{\text{jupiter}}$ 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)

\[ M_1 \approx M_2 \]

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?

Center of mass

\[ R_* = \frac{M_{pl} \cdot r}{M_*} \]

We measure angle; for small angles,

\[ \Theta = \frac{R_*}{D} \] in radians

so

\[ \Theta = \frac{M_{pl} \cdot r}{M_*} \cdot \frac{1}{D} \] Big planet, big orbit

small star, close to sun

Current limit: 1 mas = \(10^{-3}\) arcsec = \(2.8 \times 10^{-6}\) degrees = \(4.9 \times 10^{-8}\) 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)
<table>
<thead>
<tr>
<th>Planet</th>
<th>$M_P$ (M$_J$)</th>
<th>$R$ (AU)</th>
<th>$P$ (years)</th>
<th>$V_\star$ (m s$^{-1}$)</th>
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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

\( \lambda \) (wavelength)

moving star

wavelength seen by

BLUESHIFT

wavelength seen by

REDSHIFT

\[ \frac{\lambda_{\text{observed}}}{\lambda_{\text{emitted}}} = 1 + \frac{v}{c} \]

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

Big planet, small orbit
Low mass star
Distance doesn’t matter (except for brightness)
Edge - On

\[ \text{Shift} \propto V_* \propto \frac{M_{pl}}{M_*^{1/2}} r^{1/2} \]
Motion of the Sun caused by Jupiter, ...
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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 \( (M_{\text{planet}}) \)

Conservation of momentum

\[ M_{\text{pl}} \geq \frac{M_* V_0 P}{2\pi r} \]
= if we see orbit edge-on
> if tilted
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Other Methods

Transits: Planet passes in front of a star

Only about 0.5% of stars with planets will line up.


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

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

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
  - $M = 0.003 \, M_{\text{Jup}} = 1.0 \, M_{\text{earth}}$ (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 ($n_{\text{found}}/n_{\text{searched}}$)
  - 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