Origin and Detection of Planets

Estimating $f_p$
Recall this Picture

Features:
Dusty envelope
Rotation
Disk
Bipolar outflow

R. Hurt, SSC
The Disk

The Star (AU Mic) is blocked in a coronograph. Allows you to see disk. Dust in disk is heated by star and emits in infrared.

All young stars appear to form with disks.
Angular Momentum

- Measure of tendency to rotate
  - $J = mvr$
- Angular momentum is conserved
  - $J =$ constant
  - As gas contracts ($r$ smaller), $v$ increases
  - Faster rotation resists collapse
  - Gas settles into rotating disk
  - Protostar adds mass through the disk
Angular Momentum Example

Spinning Skater
The Wind

• Accretion from disk will spin up the star
  – Star would break apart if spins too fast
• Angular momentum must be carried off
• The star-disk interaction creates a wind
• The wind carries mass to large distances
  – $J = mvr$, small amount of $m$ at very large $r$
  – Allows star to avoid rotating too fast
• Wind turns into bipolar jet
  – Sweeps out cavity
The Bipolar Jet
Summary: Disks around forming stars

- Rotating disks form naturally when stars form
- Conservation of angular momentum
- They are observed around almost all young stars
- They are a natural place for planets to form
  - More on this later…
- Now let’s look at what we know about planets around other stars: exoplanets
Can We See Exoplanets?

- Not easily
- Problem is separating planet light from star light
  - Star is $10^9$ times brighter in visible light
  - “Only” $10^6$ times brighter in infrared
- New techniques to block starlight are allowing direct detection
Planet is Much Fainter than Star

Contrast is better in infrared
Image of Planet around Nearby Star β Pic

January 2014 from Gemini Planet Imager (GPI)
Works in infrared light
Indirect Detection

• Motion of the star is detected
  – Astrometric
  – Spectroscopic (Doppler)
• Change in light is detected
  – Microlensing
  – Transits
Star and Planet Orbit Center of Mass
The Sun as viewed from 10 pc (~30 ly)
1 mas = $10^{-3}$ arcseconds = $1.7 \times 10^{-5}$ arcminutes = $2.8 \times 10^{-7}$ degrees: A VERY small angle!

Sun’s apparent size would be 0.48 mas at 30 ly
The Spectroscopic Method

• Relies on Doppler Effect
• Motion of star towards and away from us
• Motion across our line of sight does not produce the effect
• We get a lower limit to mass by assuming that the orbit is viewed edge-on
Doppler Demo

- http://www.youtube.com/watch?v=a3RfULw7aAY
Motion of the Sun caused by Jupiter, ...
10 m s\(^{-1}\) is at level humans can run; stars have much faster motions in atmosphere. Very hard.
Detection by Change in Light

• Microlensing
  – Example of General Relativity
    • Light follows space
    • Space is curved by mass
Planet Detected by Microlensing

Planet detected by microlensing: OGLE 2005-BLG-235Lb, announced 1/25/06

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

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
Transits

- Requires alignment of planet orbit
- Allows determination of size of planet
- Has provided most planet detections recently
- Kepler spacecraft
  - Stared at a patch of sky for several years
  - Found 4706 candidates
  - 1039 confirmed (as of Dec. 2015)
Artist’s conception of Transit of HD209458
Fig. 1 Schematic illustration of a planetary orbit and the variations in stellar brightness and RV that it causes.

(A) A planet orbits its host star and eclipses ("transits") the star as seen by a distant observer.

(B) The star’s light is dimmed by the planet and the observer sees a slight shift in the "velocity" of the star as the different sides of the star are eclipsed, one after the other.

(C) A longer view, where one sees multiple transits and distortions of the star’s velocity.
## Advantages of Methods

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Direct</th>
<th>Astrometric</th>
<th>Spectroscopic</th>
<th>Transits</th>
<th>Microlensing</th>
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<td>Yes</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Edge-on Orbit</td>
<td>No</td>
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Current Statistics (Jan. 2015)

• Based on Extrasolar Planets Encyclopedia
  – http://exoplanet.eu/
• 2052 Planets
• 507 stars with multiple planets
• 3667 Kepler candidates
• Most planets in one system is 5
• Least massive
  – $M = 0.3 \, M_{\text{earth}}$ (Kepler Object of Interest 1843 b)
GAIA: The Revenge of Astrometry

• Launched 19 Dec. 2013
• Five year mission
• Measure star positions with great accuracy (24 micro-arcseconds!)
• Discover ~7000 planets out to 600 ly
An Ongoing Story…

• For Updates:
  • http://planetquest.jpl.nasa.gov/
Binary Stars

• About 2/3 of all stars are in binaries
  – Most common separation is 10-100 AU
• Can binary stars have disks?
  – Yes, but binary tends to clear a gap
  – Disks well inside binary orbit
  – Or well outside binary orbit
• Planets also found around some binaries
Brown Dwarfs

- Stars range from 0.07 to ~100 $M_{\text{sun}}$
- Jupiter is about 0.001 $M_{\text{sun}}$
- Brown dwarfs between stars and planets
  - Dividing line is somewhat arbitrary
  - Usual choice is 13 $M_{\text{jupiter}}$
  - Brown dwarfs rarely seen as companions to stars
  - But “free-floaters” as common as stars
  - Many young BDs have disks
    - Planets around BDs?
How Big can Planets Be?

• Brown dwarfs now found to very low masses
  – Some clearly less than $13 \, M_{\text{jupiter}}$
    • Can’t even fuse deuterium
    • Some people call these rogue planets
    • Some are less massive than known planets
    • Sites for life??
  – Usual definition: planets orbit stars
    • Some brown dwarfs may have “planets”

• Nature does not respect our human desire for neat categories!
Summary

• Detecting planets is hard
• Correcting for that suggests planetary systems are very common
• Binary stars may be less likely sites for planets, but some do have planets
• Many stars have multiple planets
• $f_p$ is fraction of stars with planetary systems
• Probably at least 0.5 and could be 1