Extrasolar Planets

extrasolar = outside of (external to) our solar system
How can we discover planets?
How can we discover planets?

1. Try to image them

2. Observe the motion of the *star* as it gets pulled by the planet

3. Look at stars and wait for planets to go in front of them, making the stars temporarily dimmer
Techniques for finding extrasolar planets

1. Imaging
Here are some extrasolar planets
These are all fake. Why is it hard to image planets?
Can you think of a way around the problem?
Can you think of a way around the problem?

Telescope image of Saturn, rings and moons with a coronagraph

SOHO spacecraft image of the sun with a coronagraph

?
What kinds of planets would be easiest to image?
What could you learn about a planet if you had an image of it?
Fomalhaut

Comparison of Fomalhaut System and Solar System

Fomalhaut planet
Fomalhaut ring
Fomalhaut
Asteroid Belt
Kuiper Belt

Fomalhaut
Sun
Mars
Neptune
Jupiter
Asteroid Belt
Beta Pictoris

Combination of two near-infrared images obtained with the Very Large Telescope
It is difficult to directly image planets. Only a few planets have been detected with this method.
Techniques for finding extrasolar planets

2. Stellar “Wobble”
Is the sun influenced by the gravitational force of the planets?

Does Jupiter orbit around the center of the sun?
Stars and planets orbit around their center of mass.

The weight and the distance are the same on both sides. The Center of Balance is in the middle of the board.

\[ \text{weight} \times \text{distance} = \text{weight} \times \text{distance} \]
Stars and planets orbit around their center of mass.

When the weights are different, adjust the distances.

\[
\text{weight} \times \text{distance} = \text{weight} \times \text{distance}
\]

\[
40 \text{ pounds} \times 16 \text{ feet} = 160 \text{ pounds} \times 4 \text{ feet}
\]
Suppose Jupiter and the Sun could be placed on a see-saw. Which point is closest to the center of balance?

Size of sun, Jupiter roughly to scale.

Sizes and distances not to scale with each other.
Note that the star is much brighter than the planet, so we observe the motion of the star produced by the planet. This is called an “indirect detection technique”.
Now, how do we observe this wobble?
How do we observe stellar wobble?

First, let’s talk about the Doppler Shift. Think about what happens to the sound when an ambulance passes by.
How do we observe stellar wobble?
The same thing happens to light.
How do we observe stellar wobble?

(animation radialvelocitydemo.html)
How do we observe stellar wobble?

(Here’s what the data actually look like)
What kind of planets would be easiest to observe with the stellar wobble technique?
What could you learn about a planet if you found it with the stellar wobble technique?
We don’t know the inclination of the planet’s orbit
Which of these two orientations would produce the largest Doppler shift?

A

B
We don’t know the inclination of the planet’s orbit
Suppose we observe some Doppler shift, \( v \), but we do not know the orientation of the orbit. Which orbital orientation would imply a larger mass planet?

A

B
The Doppler technique only provides the *minimum mass* of the planet if the orientation is not known (which is most of the time).
The first planets were detected with this method, and to date, hundreds of planets have been detected with this method.

Before 2009, nearly all planets were detected with this method.
3. Planetary “Transit”
Planetary Transit
Transit of sun by Venus

http://apod.nasa.gov/apod/ap120611.html
Transit of sun by Venus

Telescopic H-alpha image from Chris Hetlage
Transit of sun by Venus

Image of Venus transit from Taj Mahal by Kevin Frayer
Transit of sun by Mercury

Images of Mercury transit from SOHO satellite

07:36 UT
08:45 UT
11:57 UT
13:12 UT
Transits are easier to detect if the planet is

(A) large
(B) small
What would you learn about a planet if you found it with the planetary transit technique?

(A) Its radius
(B) Its mass
(C) Its orbital period
(D) Both its radius and its orbital period
A special geometry is needed for a transit
Transits are rare
Transits get

(A) more
(B) less

likely as the planet’s orbit gets larger.
The Kepler mission has now discovered *thousands* of planets!
An astronomer calculates the likelihood of the Kepler mission detecting various extrasolar planets around a particular nearby star. Which of the following possibilities - all assumed to be in circular orbits viewed edge-on \( (i = 90^\circ) \) - is most likely to result in a Kepler detection in a few years' time?

(A) An Earth-like planet in a 1 AU radius orbit
(B) An Earth-like planet in a 10 AU radius orbit
(C) A Jupiter-like planet in a 1 AU radius orbit
(D) A Jupiter-like planet in a 10 AU radius orbit
(E) All are equally likely
The three extrasolar planet detection techniques are:
The three extrasolar planet detection techniques are:

1. Direct imaging
2. The “wobble” or “Doppler shift” technique
3. The transit method
What are extrasolar planets like?

Are they similar to the planets in the solar system?
The Kepler Orrery II

$\text{t[BJD]} = 2454965$

D. Fabrycky 2012
Sizes of Planet Candidates
As of February 27, 2012

- 1,118 - Neptune-size (2 - 6 $R_\oplus$)
- 676 - Super Earth-size (1.25 - 2 $R_\oplus$)
- 246 - Earth-size (< 1.25 $R_\oplus$)
- 210 - Jupiter-size, (6 - 15 $R_\oplus$)
- 71 - Larger, (> 15 $R_\oplus$)

Kepler
NASA