Extrasolar Planets
Learning Objectives

- How is the radial velocity ("wobble") method used to discover exoplanets and to characterize their orbits? How is (Newton’s version of) Kepler’s 3rd Law useful for this?
- Why did the discovery of the first exoplanet challenge our view of what a typical star system might look like?
- How is the transit method used to discover exoplanets?
- Is it possible to directly image planets around other stars?
- What are the general sizes and orbital distances of the exoplanets discovered to date? What are hot jupiters?
- Have we discovered many (or any) planets of Earth’s radius or mass orbiting their host star at 1AU yet? Why is this the case?
Exoplanets (Extrasolar Planets) are Difficult to Find

- Planets are small compared to interstellar distances
- 10 billion to 1 scale
- Say, the Sun is the size of a melon
  - Then, Jupiter would be the size of a fingernail, and the Earth the size of a pencil tip
  - The nearest star would be in San Francisco
- Plus, stars are very bright and planets, which shine by reflected light, are hidden in their glare
Imaging - Jupiter-Sized Planets!

- Around the star Fomalhault
- 25 light years from our Sun
- Planet orbits at ~120 AU (~3x Pluto’s orbit)

- 4 planets around HR 8799
- 129 light years from our Sun
- Closest planet to star orbits at ~15 AU (similar to Uranus)
Wobbling Stars

- A star and its planets are actually orbiting each other
- The period of the wobble of the star is the same as the period of the planet’s orbit
- We can measure the wobble as a Doppler Shift of the star’s spectrum
Doppler shift tells us about a planet’s mass and orbit

- **Smaller planet mass**
  - Elliptical orbit
  - Larger orbital distance
  - Smaller planet mass
- **Larger planet mass**
  - Circular orbit
  - Elliptical orbit

[Graphs showing the relationship between Doppler shift and orbit characteristics.]
“First” Exoplanet

- In 1995, Doppler shifts of the star 51 Pegasi revealed a Jupiter-like planet!
- But, it has a 4-day orbital period!
  - it orbits at ~0.05AU
  - 8x closer than Mercury!
- About 4000 exoplanets have been definitively confirmed in about 3000 different star systems
Transits

- We can also detect planets if they pass in front of their host or "parent" star.
- The fraction of the star’s light that is blocked tells us the planet’s size.
- This is one of the best current methods for searching for Earth-like planets.

The effect on the observed brightness when a planet passes in front of its host star.
Kepler Mission

- Looked for transits by simultaneously observing about 100,000 stars
- Our best chance to detect Earth-like planets prior to 2018
- First images taken April 7, 2009
- Partially disabled as of August, 2013
Kepler-37b...the smallest Kepler Planet Discovered (by radius)

- **Kepler-37b**: 0.35 x Earth
- **Kepler-37c**: 0.74 x Earth
- **Kepler-37d**: 1.99 x Earth
Some of the “most Earth-like” Kepler finds

Kepler-452b, radius ~ 1.5 x Earth, orbits at 1.0AU (existence still needs to be confirmed)

Kepler-442b, 1.3 x Earth, orbits at 0.41AU

Kepler-438b, 1.1 x Earth, orbits at 0.17AU

Kepler-186f, 1.2 x Earth, 0.43AU
An “Unusual” System

Artist’s impressions of Kepler 16

A planet orbiting a *binary* star...the planet is about the mass of Saturn
Some Extrasolar Systems
Most detected extrasolar planets orbit at less than 1 AU.

Planets that are farther from their star are harder to detect with the wobble/Doppler techniques.
Most detected exoplanets have orbits far smaller than Jupiter’s orbit.

Planets that are farther from their star take more total time to detect with wobble or transit techniques.

Extrasolar Planet Orbits

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Results (to Date)

No surprise

- Many planets are big
- Why? Big planets make a big wobble and block more of their star in transit
- If they weren’t big or massive, we couldn’t have found them

Big surprises

- Many big planets are very near their parent stars
  - these are called *hot jupiters*
- CoRoT-3b is 21.7 times more massive than Jupiter, but its orbit is ~7 times smaller than Mercury’s!
Detecting our Solar System

Upsilon Andromedae: A Multiple Companions System shown for 16-APR-1999

Our Solar System, Inner Planets & Jupiter shown for 16-APR-1999
Next Time

Extraterrestrial Life