Chapter 13
Other Planetary Systems
The New Science of Distant Worlds

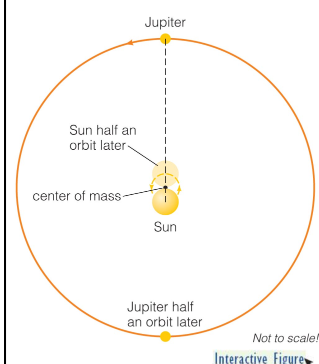
Detecting Extrasolar Planets Brightness Difference

- A Sun-like star is about a billion times brighter than the sunlight reflected from its planets
- Like being in San Francisco and trying to see a pinhead 15 meters from a grapefruit in Washington, D. C.

How do we detect planets around other stars?

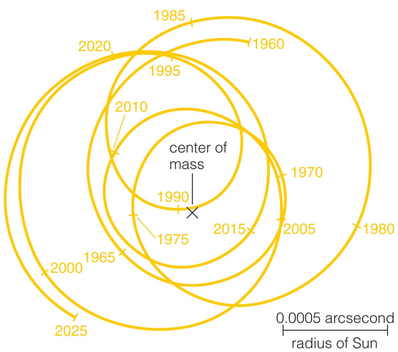
- **Direct:** Pictures or spectra of the planets themselves
- **Indirect:** Measurements of stellar properties revealing the effects of orbiting planets

Gravitational Tugs



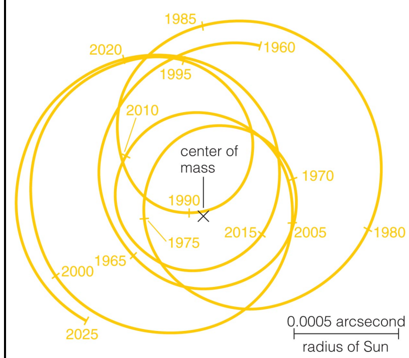
- Sun and Jupiter orbit around their common center of mass
- Sun therefore wobbles around that center of mass with same period as Jupiter

Gravitational Tugs



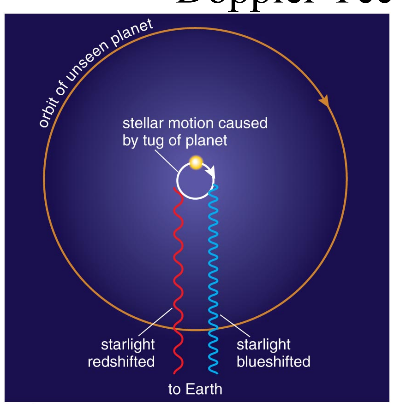
- Sun's motion around solar system's center of mass depends on tugs from all the planets
- Astronomers around other stars could determine masses and orbits of all the planets

Astrometric Technique



- We can detect planets by measuring the change in a star's position on sky
- However, these tiny motions are very difficult to measure (~0.001 arcsecond)

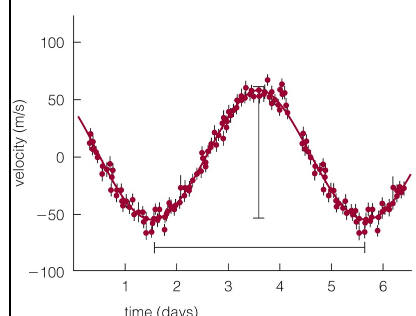
Doppler Technique



Interactive Figure

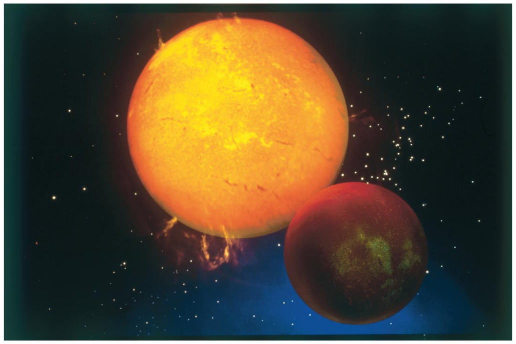
- Measuring a star's Doppler shift can tell us its motion toward and away from us
- Current techniques can measure motions as small as 1 m/s (walking speed!)
- Nearly all exoplanets have been detected this way.

First Extrasolar Planet



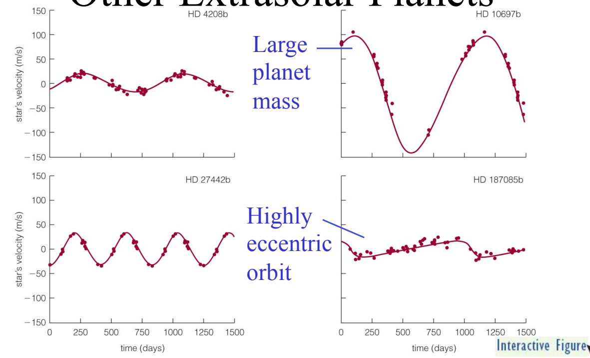
- Doppler shifts of star 51 Pegasi indirectly reveal a planet with 4-day orbital period
- Short period means small orbital distance
- First extrasolar planet to be discovered (1995)

First Extrasolar Planet



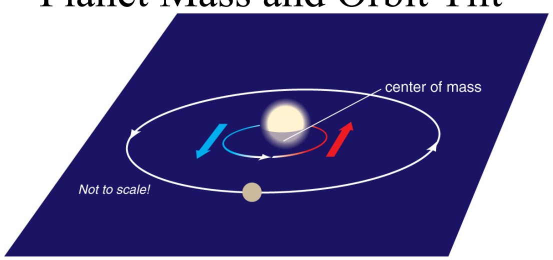
- Planet around 51 Pegasi has a mass similar to Jupiter's, despite its small orbital distance

Other Extrasolar Planets



- Doppler data curve tells us about a planet's mass and the shape of its orbit

Planet Mass and Orbit Tilt



- We cannot measure an exact mass for a planet without knowing the tilt of its orbit, because Doppler shift tells us only the velocity toward or away from us
- Doppler data gives us lower limits on masses

Thought Question

Suppose you found a star with the same mass as the Sun moving back and forth with a period of 16 months—what could you conclude?

A. It has a planet orbiting at less than 1 AU.
B. It has a planet orbiting at greater than 1 AU.
C. It has a planet orbiting at exactly 1 AU.
D. It has a planet, but we do not have enough information to know its orbital distance.

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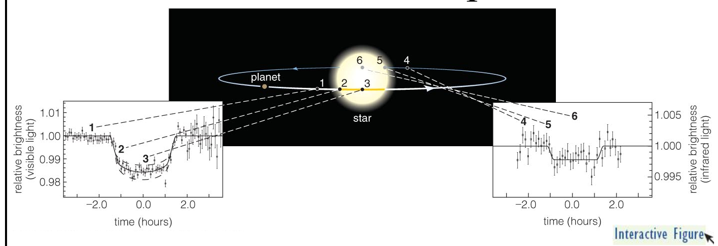
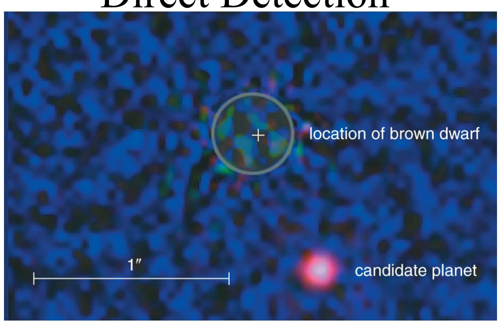
Transits and Eclipses



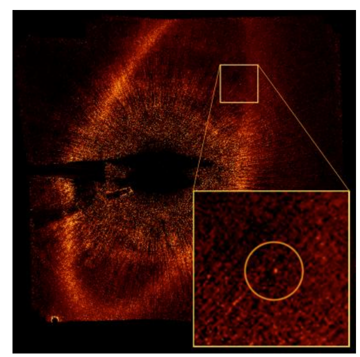
- A **transit** is when a planet crosses in front of a star
- The resulting eclipse reduces the star’s apparent brightness and tells us planet’s radius
- No orbital tilt: accurate measurement of planet mass

Direct Detection



- Special techniques can eliminate light from brighter objects
- These techniques are enabling direct planet detection

First Image of an Extrasolar Planet

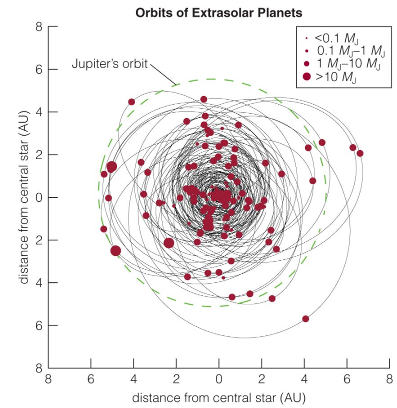


Hubble Space Telescope image of Fomalhaut b (Nov. 2008)

Measurable Properties

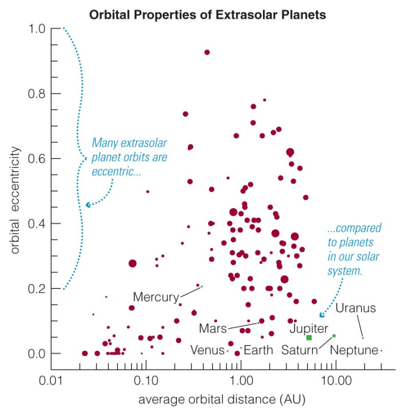
- Orbital Period, Distance, and Shape
- Planet Mass, Size, and Density
- Composition

Orbits of Extrasolar Planets



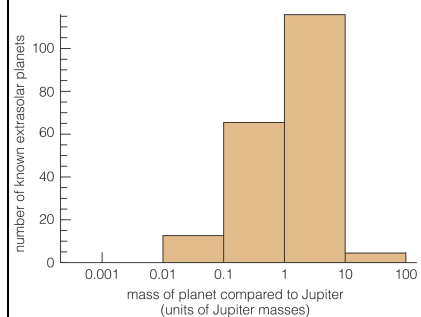
- Most of the detected planets have orbits smaller than Jupiter’s
- Planets at greater distances are harder to detect with Doppler technique

Orbits of Extrasolar Planets



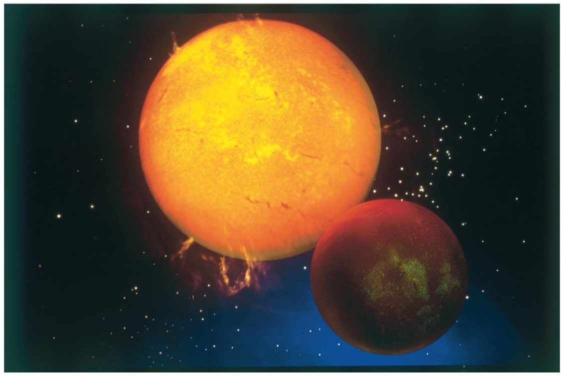
- Orbits of some extrasolar planets are much more elongated (greater eccentricity) than those in our solar system

Orbits of Extrasolar Planets



- Most of the detected planets have greater mass than Jupiter
- Planets with smaller masses are harder to detect with Doppler technique

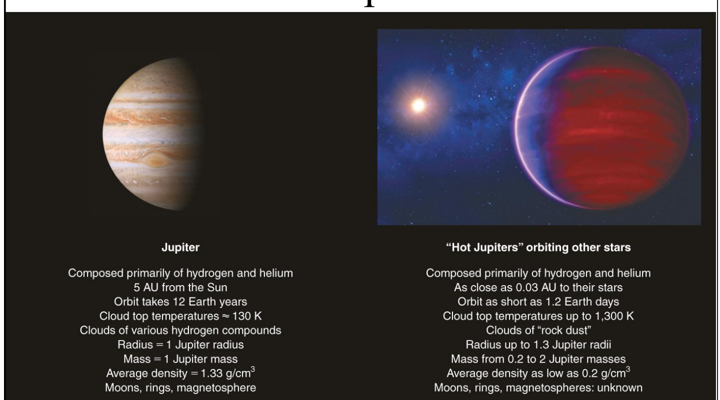
How do extrasolar planets compare with planets in our solar system?



Surprising Characteristics

- Some extrasolar planets have highly elliptical orbits
- Some massive planets orbit very close to their stars: “hot Jupiters”

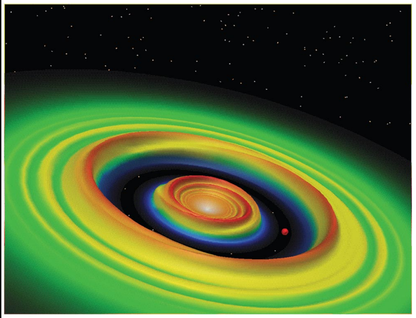
Hot Jupiters



Revisiting the Nebular Theory

- Nebular theory predicts that massive Jupiter-like planets should not form inside the frost line (at << 5 AU)
- Discovery of “hot Jupiters” has forced reexamination of nebular theory
- “Planetary migration” or gravitational encounters may explain “hot Jupiters”

Planetary Migration



- A young planet's motion can create waves in a planet-forming disk
- Models show that matter in these waves can tug on a planet, causing its orbit to migrate inward

Gravitational Encounters

- Close gravitational encounters between two massive planets can eject one planet while flinging the other into a highly elliptical orbit
- Multiple close encounters with smaller planetesimals can also cause inward migration

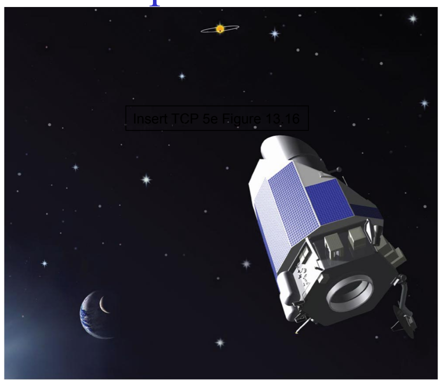
Modifying the Nebular Theory

- Observations of extrasolar planets have shown that nebular theory was incomplete
- Effects like planet migration and gravitational encounters might be more important than previously thought

Planets: Common or Rare?

- One in ten stars examined so far have turned out to have planets
- The others may still have smaller (Earth-sized) planets that current techniques cannot detect

How will we search for Earth-like planets?



Transit Missions

- NASA's *Kepler* mission is looking for transiting planets.
- It is designed to measure the 0.008% decline in brightness when an Earth-mass planet eclipses a Sun-like star

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Astrometric Missions

- *GAIA:* A European mission planned for 2013 that will use interferometry to measure precise motions of a billion stars
- *SIM:* A NASA mission that will use interferometry to measure star motions even more precisely (to 10^{-6} arcseconds)

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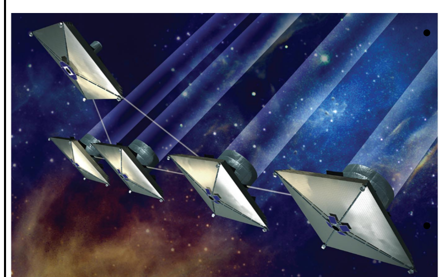
Direct Detection



Mission concept for NASA's Terrestrial Planet Finder (TPF)

- Determining whether Earth-mass planets are really Earth-like requires direct detection
- Missions capable of blocking enough starlight to measure the spectrum of an Earth-like planet are being planned

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