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

- 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”

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.

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).

Direct Detection

- 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.