# Agenda for Ast 309N, Oct. 11

- Quiz 4
- Search methods for exoplanets
- Video: results of Doppler searches
- Feedback on card, 10/9
- The transit method and its advantages
- Card: which planets are most easily found?
- Reading for next week, aging of Sun-like stars:
  - Kaler, ch. 3; Wheeler, pp. 27 – 37

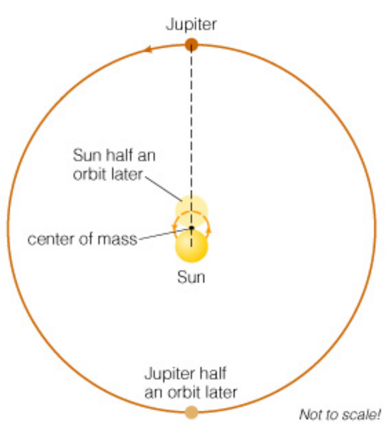


# Planet Detection: Types of Methods

- **Direct:** Images or spectra of the actual planets
  - Reflected Light (Visible): contrast about $10^9$
  - Emitted Light (Infrared): contrast "only" $10^6$
- **Indirect:** Measurements of the parent stars that reveal the effects of orbiting planets
  - Gravitational Tugs and "reflex motion" – seen as positional shifts and/or Doppler (velocity) shifts
  - Variations in the light due to transits, etc.



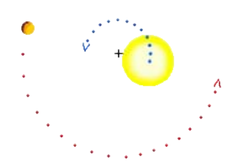
# Gravitational Tugs

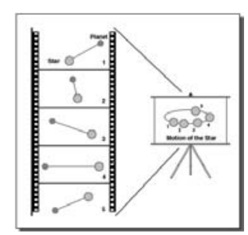


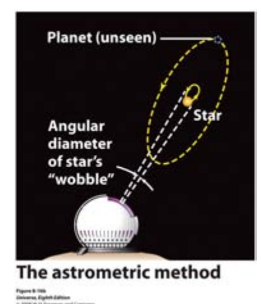

- The Sun exerts a gravitational force on Jupiter (Law of Gravity)
- Jupiter exerts an equal and oppositely directed force on the Sun (by Newton's Third Law)
- Therefore, the Sun moves through a small orbit around the center of mass; this "wobble" has the same period as Jupiter's larger orbit



# Astrometric or "Position Wobble" Method



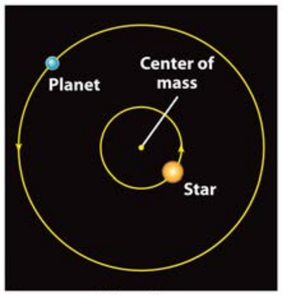




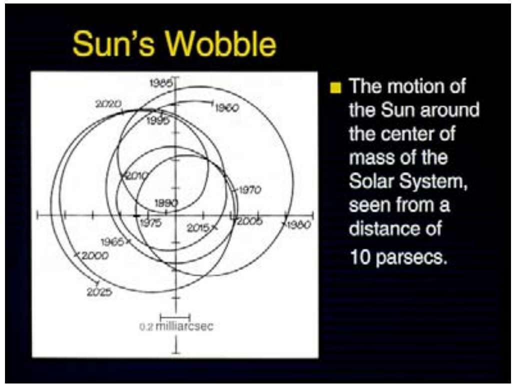

Newton's 3rd law tells us that *both* the planet and star orbit around the center of mass. Because the star has a larger mass it doesn't move as far as the planet does, but the star is bright, so it's what you can see. The measurement of accurate stellar positions is *astrometry.*

The reactive motion of the star is called *"reflex motion."*

## Astrometric Method

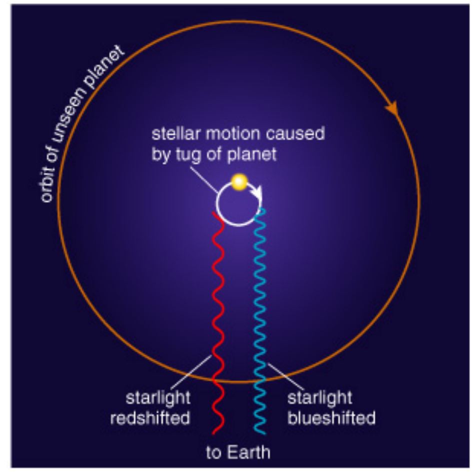



A star and its planet






## Spectroscopic or Doppler Wobble Method




- Measuring the Doppler shift of a star's spectral lines tells us its velocity toward and away from us
- As the star responds to the planet, it moves towards and away from us, with a fixed period (the period of the orbit)
- Current techniques can measure motions as small as 1 m/s (walking speed!)



## Spectroscopic or "Doppler Wobble" Method

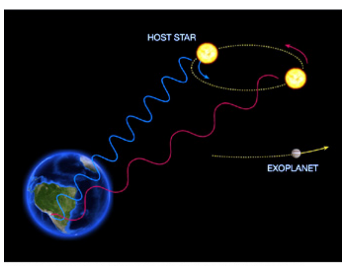



Diagram showing the Radial-Velocity method of detection
CREDIT
European Organisation for Astronomical Research in the Southern Hemisphere

Caution! The Doppler effect shows only the radial portion of the star's motion, so it gives a *minimum* mass (lower limit) for the planet. Finding the actual mass requires knowing the angle of inclination of the orbit.

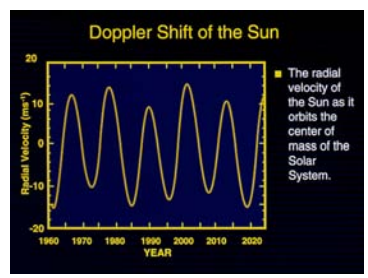
Recall that an object moving in an orbit has a net blueshift while moving towards the observer, and a redshift when moving away. Such a repeating, periodic Doppler shift tells us the star has a companion, which could be another star or a planet.

This was the first successful method for finding exoplanets.

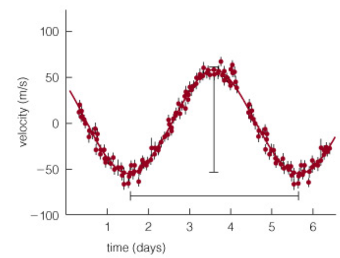


## 51 Peg b: The First Extrasolar Planet

What was expected:



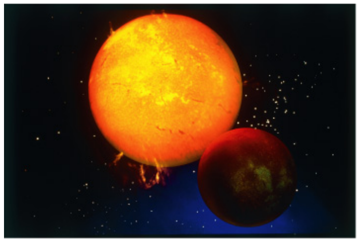

What was found:

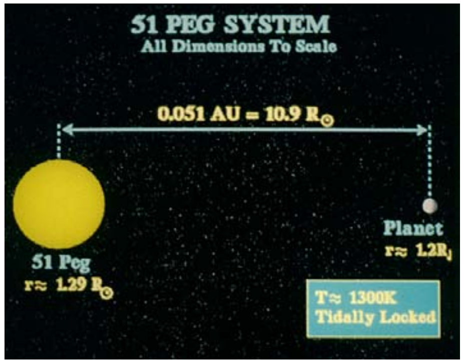



- Astronomers were astounded to find a Jupiter-mass planet in a 4-day orbital period; such a short period implies a small orbital radius (how do we know this?)

⇒ Semi-major axis only 0.05 AU, much smaller than Mercury!

# The Planet Orbiting 51 Peg



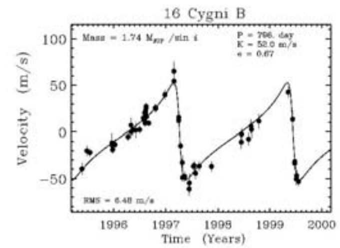


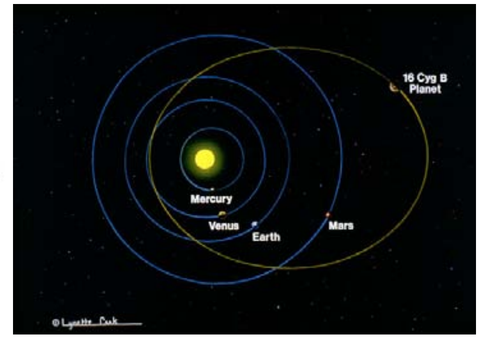

This planet has a mass similar to Jupiter's despite being so close to its star

New class of planets: "**Hot Jupiters**"



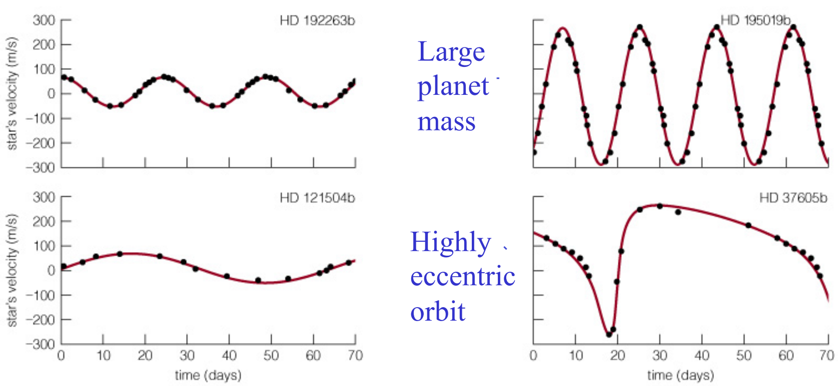
# Planet in an Eccentric Orbit, in a Binary Star System!





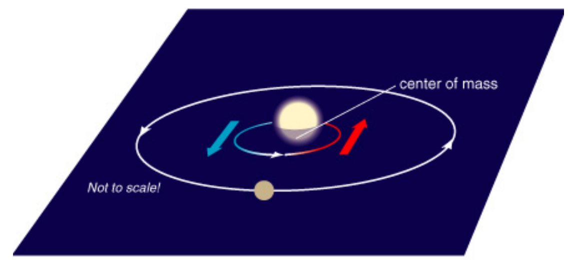

# Other Radial Velocity Planets




The shape of the "radial velocity" curve tells us the planet's mass and how elliptical its orbit is



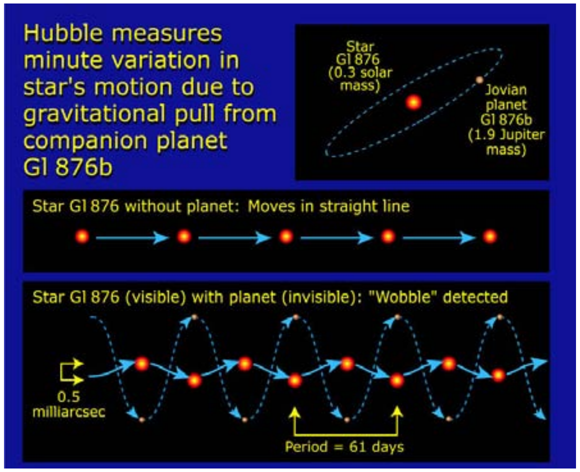
# Planet Mass and Orbit Tilt




- We cannot measure the true mass for a planet without knowing the orbital tilt, because the Doppler shift tells us only the *radial* velocity (for an orbit in the plane of the sky, the shift is zero!)
- The Doppler method gives us only the ***lowest possible*** mass; it could be (and most likely is) larger.
- It may be possible to decipher the tilt by combining astrometric and spectroscopic observations

# Multiple Methods

Combine the astrometric and Doppler methods methods to get both the orbit tilt and planet mass.






# The "Habitable Zone" (HZ) of a Star

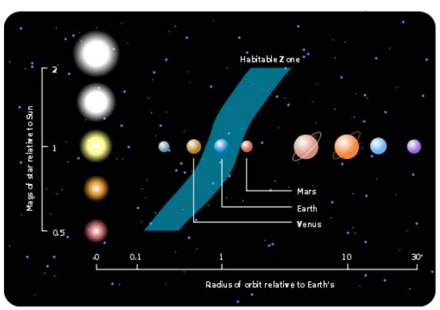
- The Habitable Zone is the region where orbiting planets have conditions favorable to life, usually defined in terms of water being in liquid form. If the planet is too close to its parent star, the water will evaporate; if too distant, the water will freeze out.
- The location & width depend on the star's luminosity: for cool, low-luminosity stars, the HB will be located close-in, while for hotter, higher-luminosity stars, it will be farther from the star (in standard units, e.g. A.U.s).

See http://planetquest.jpl.nasa.gov/video/29 - "Comparative Life Zones of Stars" (with text)



# "Goldilocks" Planets?

- Region where water can exist in a liquid state (oceans)
- Location depends on properties of the parent star
- Possible Goldilocks planet: Gliese 581c

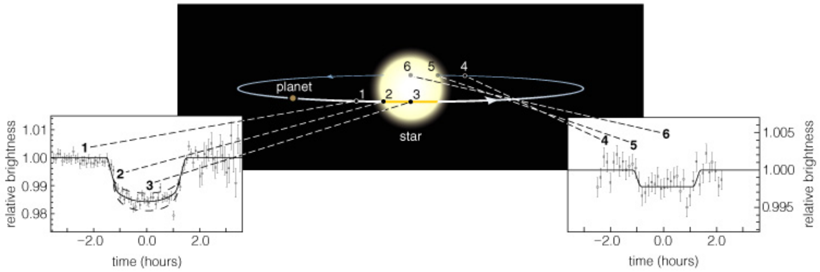



# Photometric or "Transit" Method

When a planet moves between the observer and the star the planet orbits, we get a mini-partial eclipse, because the planet covers up part of the stellar disk. (In our Solar System, we see occasional transits of Mercury and Venus on our Sun.)

When we look at a distant star, we cannot see the actual image of the planet silhouetted against its star, but the star's light is dimmed (slightly). By measuring the depth of the mini-eclipse, we can estimate the radius of the planet. To see this effect, we have to measure how the star's brightness varies with time – such a plot is called a ***light curve***.

# Transit Method




- A **transit** is when a planet crosses in front of a star
- The resulting (partial) eclipse reduces the star's apparent brightness and tells us planet's radius
- The orbital tilt is known (it must be nearly edge-on), so you can determine the actual planet mass



# Transit Method

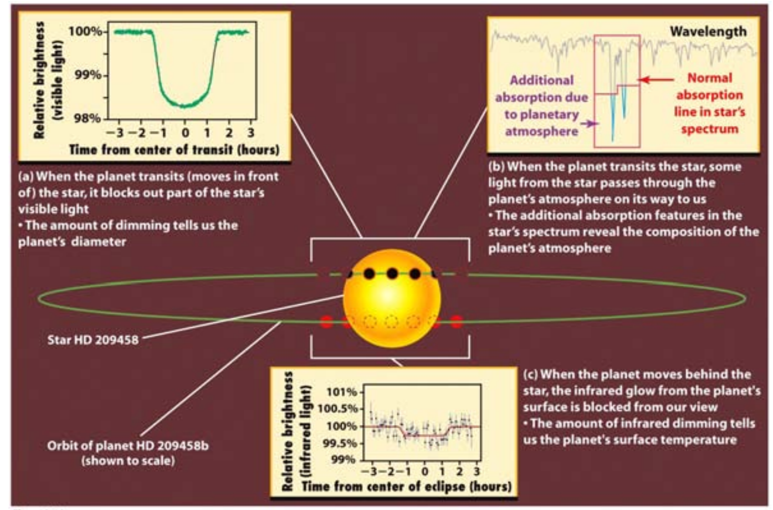
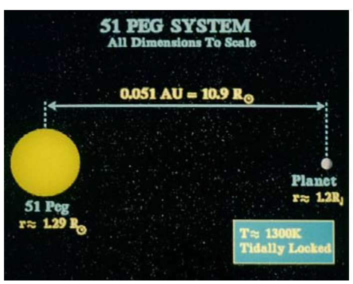



Figure 8-18
*Universe, Eighth Edition*




# Spectroscopy of Hot Jupiters

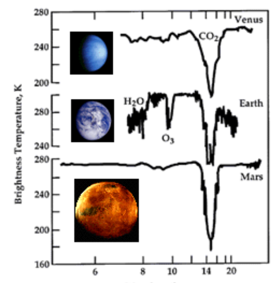




It's been suggested that planet HD 209458b be designated a "cometary planet" because it's evaporating like a comet

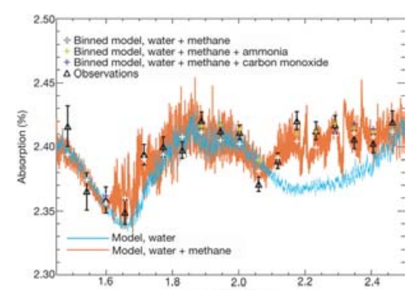


# Molecules in Transiting Exoplanets




- Molecules in the atmospheres of the terrestrial planets may provide information on biological activity; but obtaining such spectra will be challenging…

- Water ($H_2O$) and methane ($CH_4$) have been detected in the transiting planet HD 187933b; CO might be present as well.



# Group Card Activity, Oct. 11

It is beginning to look like there exist exoplanets with a wide range of physical and orbital properties. Yet for each search method we tend to find the planets with properties that are favorable for that method.

For the three most common methods of planet hunting – (a) positional shifts (astrometric), (b) Doppler shifts (spectroscopic), and (c) transits (light curves) – what values of the planet's mass, radius, and orbital size or period are easiest to detect? Assume they are all orbiting stars of about a solar mass.