## Extrasolar Planets

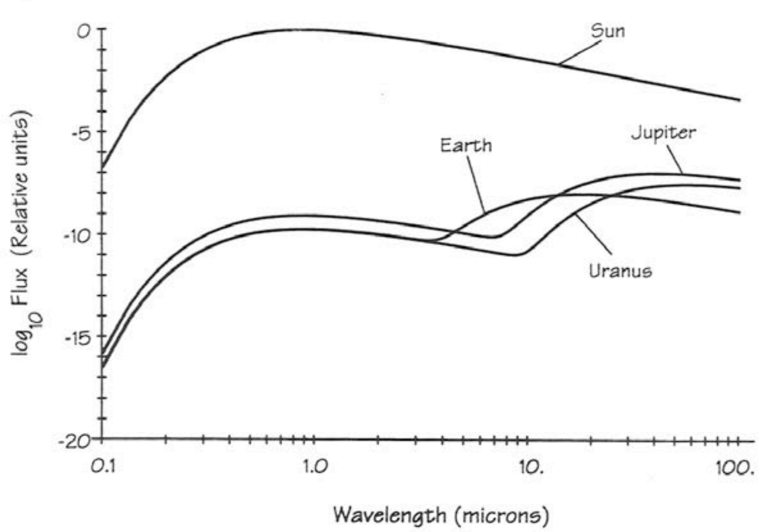
**(This is sec. 15.6, 15.7 in textbook online—page and figure numbers here may not match text because the online version of chapter 15 wasn't ready when I wrote them, so I had to use the previous edition. This should cause no problem at all—it should be clear from context which figure I'm referring to.**

**Also, your textbook does not emphasize this topic as heavily as I would like, so these notes are a little more detailed than the book. They are also out of date by about nine months.**

**Please notice that there is a "homework problem" buried among these notes, one that I may ask you about on the exam.)**

Formerly the "holy grail" of astronomers, since 1995 about 100 planets orbiting stars other than the sun have been discovered. There are several techniques available, but we'll just discuss a few.

**1.** **Direct detection**—not possible at present. Reflected light from planet is about a billion times less than that of the star (less in the infrared, but still about a million or more—see illustration below), and the distance from the planet to the star (in angular separation) is so small that we can't resolve any planets if they are there. It may be possible to directly detect giant planets around very faint stars, but certainly not terrestrial-like planets.




*The spectral energy distributions of the Sun, Jupiter, Earth, and Uranus as they would appear at 5 pc, averaged over a 10% spectral bandpass. Note the decreased ratio of solar to planetary flux in the thermal infrared, compared to visible wavelengths.*

This will have to wait for space-borne optical interferometers (Terrestrial Planet Finder/Darwin), which *might* occur around 2010.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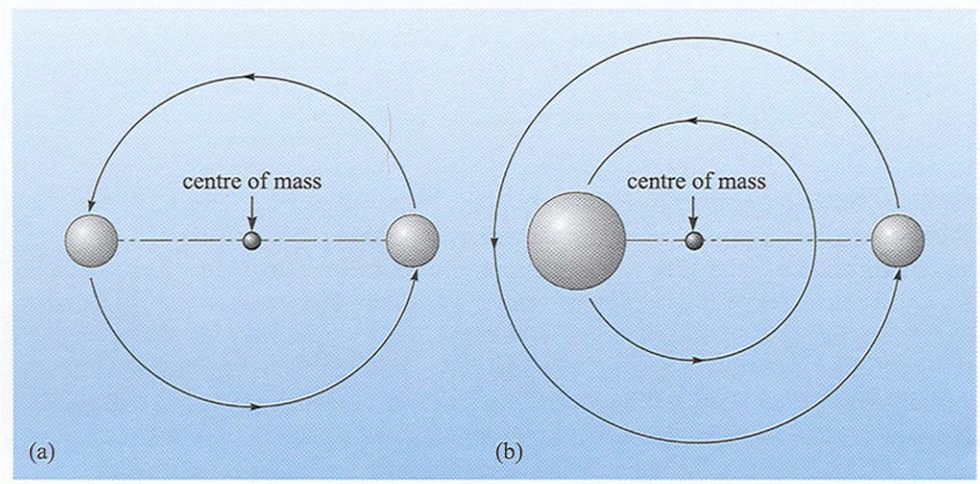
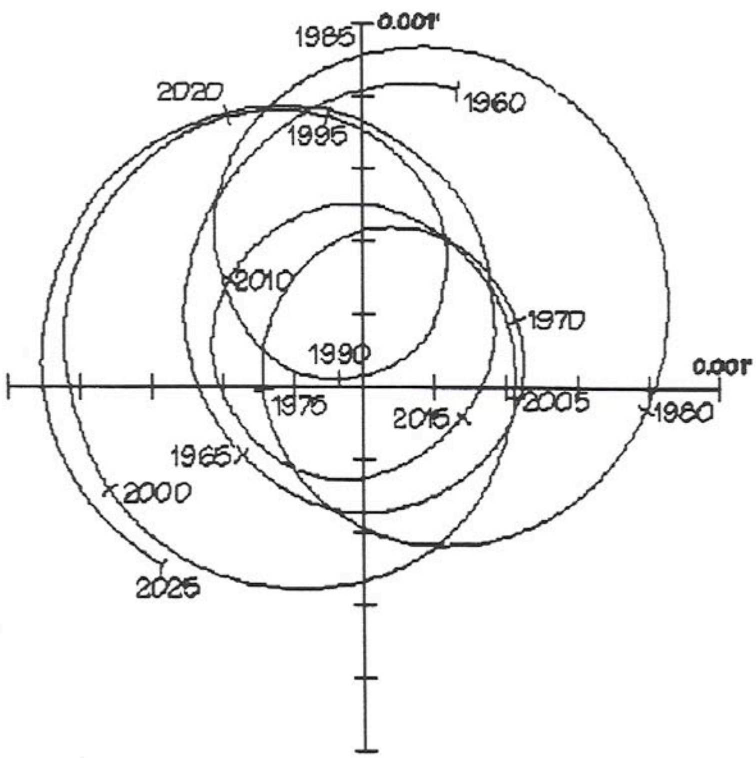
**Method 2 (includes two techniques: radial velocity, and astrometric)**

Detect **wobbles** in the *star's* motion due to the planet's gravitational perturbations.



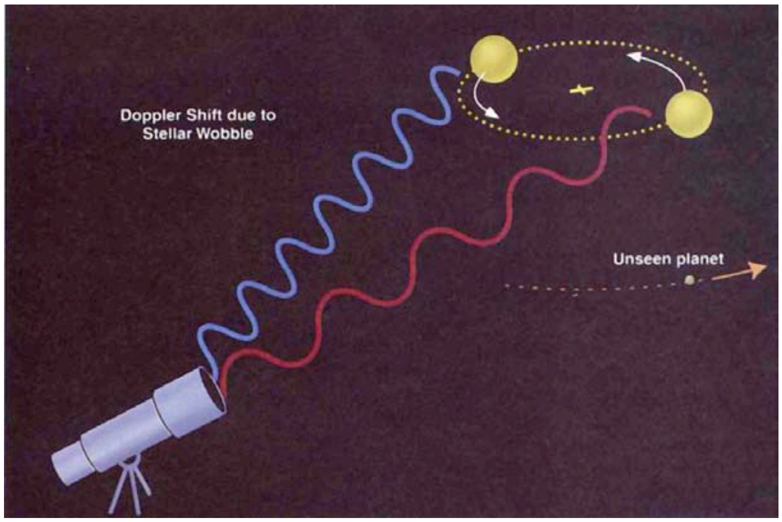

The orbits of a two-body system, showing the centre of mass in each case, for (a) two equal masses; (b) one mass greater than the other.

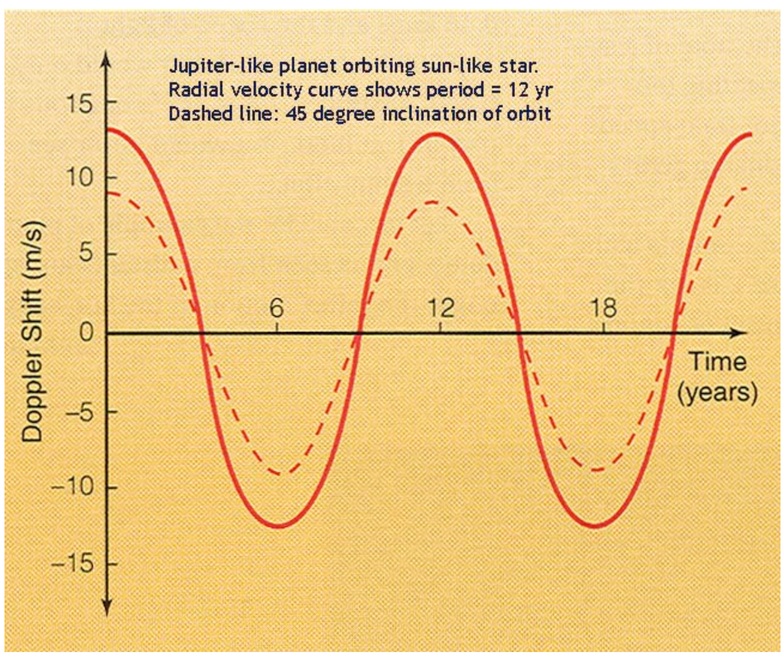


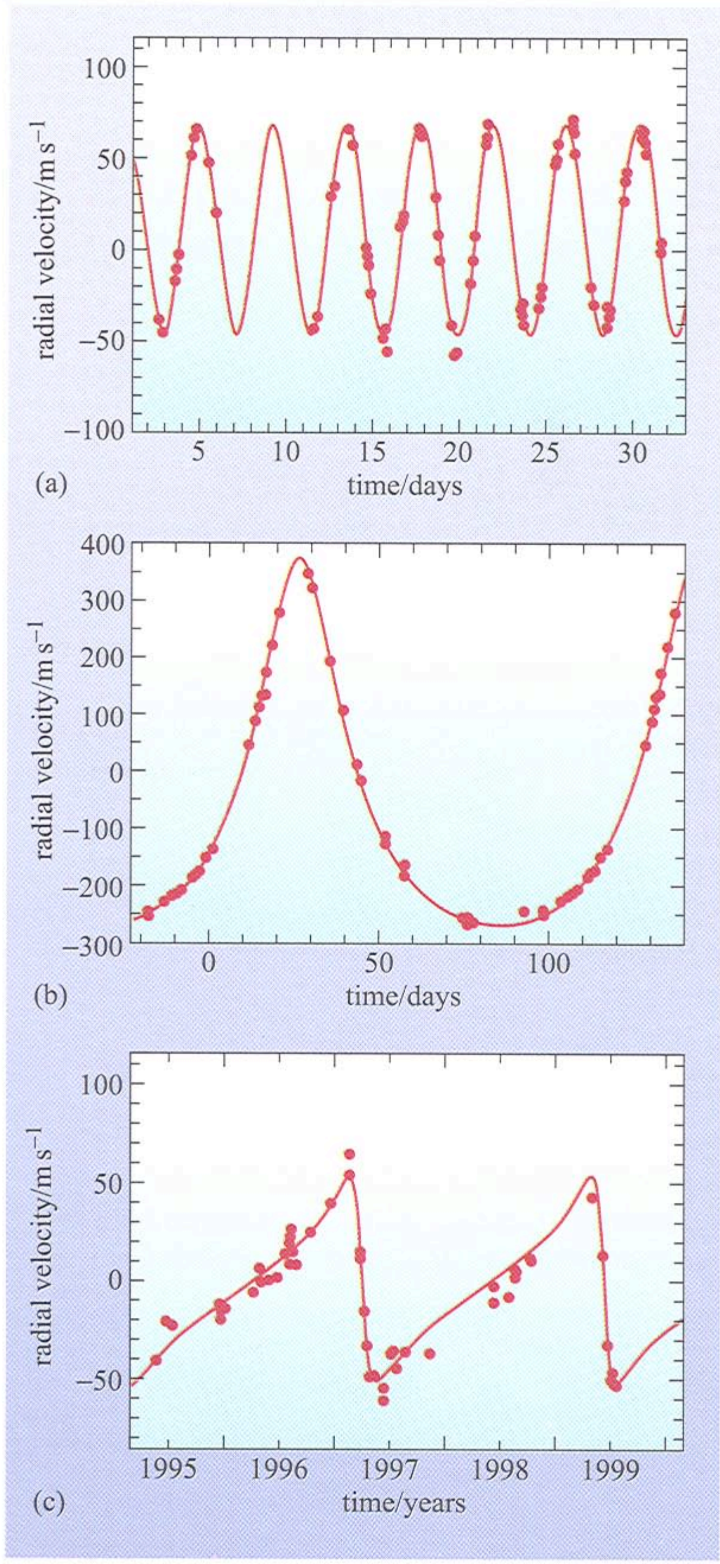

Sun's wobble if observed from a nearby star, over 50 years.

Two methods using stellar wobble:

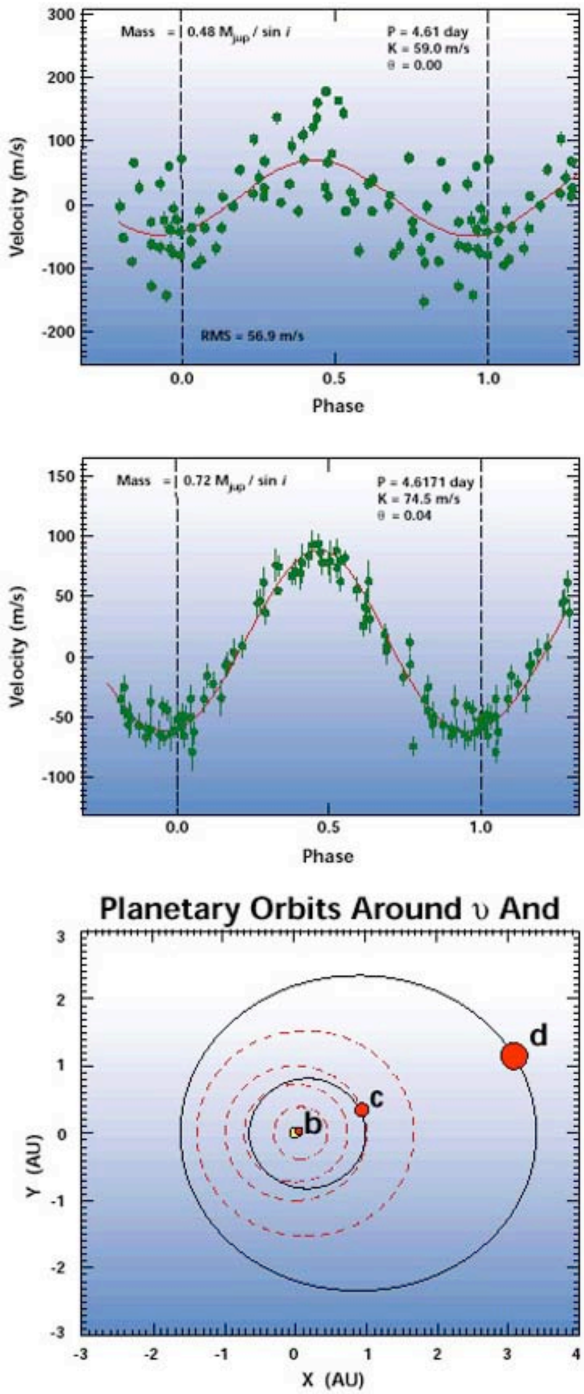
A. **Radial velocity method**—radial velocity of star varies by a small amount as it wobbles (depending on its orientation to the observer). So search for *periodic* small radial velocity changes in nearby (bright, so you can get good spectra) solar-like stars. Size of velocity change indicates mass of the invisible planet.





radial velocity/m s$^{-1}$
100
50
0
−50
−100
5
10
15
20
25
30
time/days
(a)
radial velocity/m s$^{-1}$
400
300
200
100
0
−100
−200
−300
0
50
100
time/days
(b)
radial velocity/m s$^{-1}$
100
50
0
−50
1995
1996
1997
1998
1999
time/years
(c)




*Radial velocity measurements have been used to infer the presence of multiple planets orbiting Upsilon Andromedae. The fit to the data for a single planet is relatively poor (top), while the fit for each planet is improved when the presence of three planets is taken into account (middle). Planets B, C, and D have orbital distances of 0.06, 0.85 and 2.5 AU, and Msin i of 0.73, 1.95 and 4.1 $M_J$, respectively (bottom). The orbits of the inner planets of our solar system are shown as dotted lines (Butler et al. 1999).*

Nearly all planets discovered so far have been discovered by this technique.

Best for close-in (so short period, high velocity) massive planets. (Understand why!)

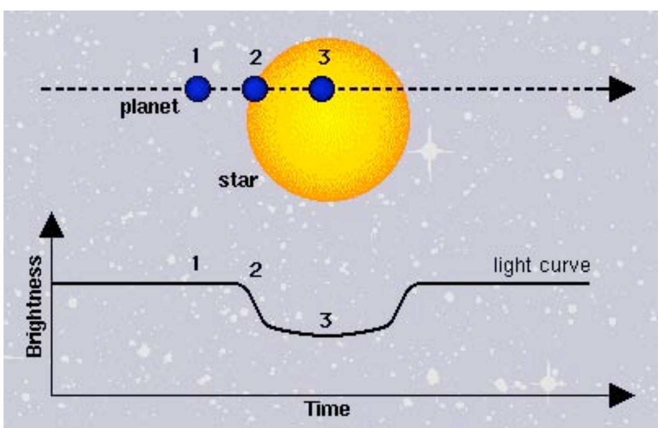
B. **Astrometric method**—search for periodic motions of the star in the plane of the sky, detecting the “wobble” directly. Size of the angular variation depends of the mass of the invisible planet.

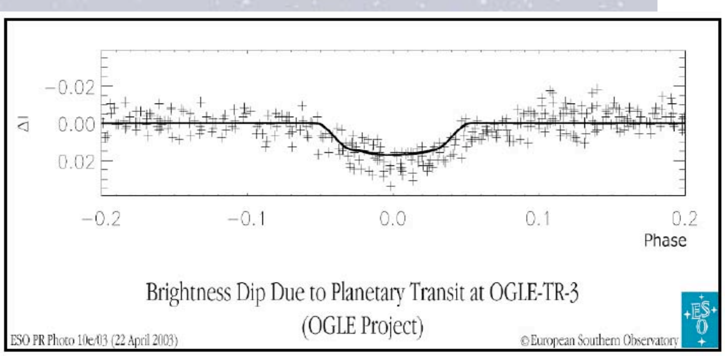
Works best for massive planets far from star (so center of mass is located further from center of star, so larger angular wobble—think about it; we’ll discuss in class). The problem is that such planets will have very long periods (many years), so it requires decades for a detection. So far a few planets have been found this way, but it had already been discovered by radial velocity technique.

**3. Transits** (eclipses)—this is the most active approach at present, with over 30 groups trying varying strategies, and a major space mission (“Kepler”) planned for the near future. Read about Kepler on p. 399.

The idea is to watch the light of the star very slightly decline if a planet in orbit passes in front of the star. (See “light curve” in Fig. 15.10.) You can get a *lot* more information about the planet using this technique than from radial velocity alone, but you have to monitor many 1000s of stars because the probability of detection is tiny (think about the orbit you need for a transit).

So far a few planets have been recently detected by transits (and then verified by radial velocity measurements).




*Folded photometry of the star, OGLE-TR-3 showing the small decrease due to the planet transit.*

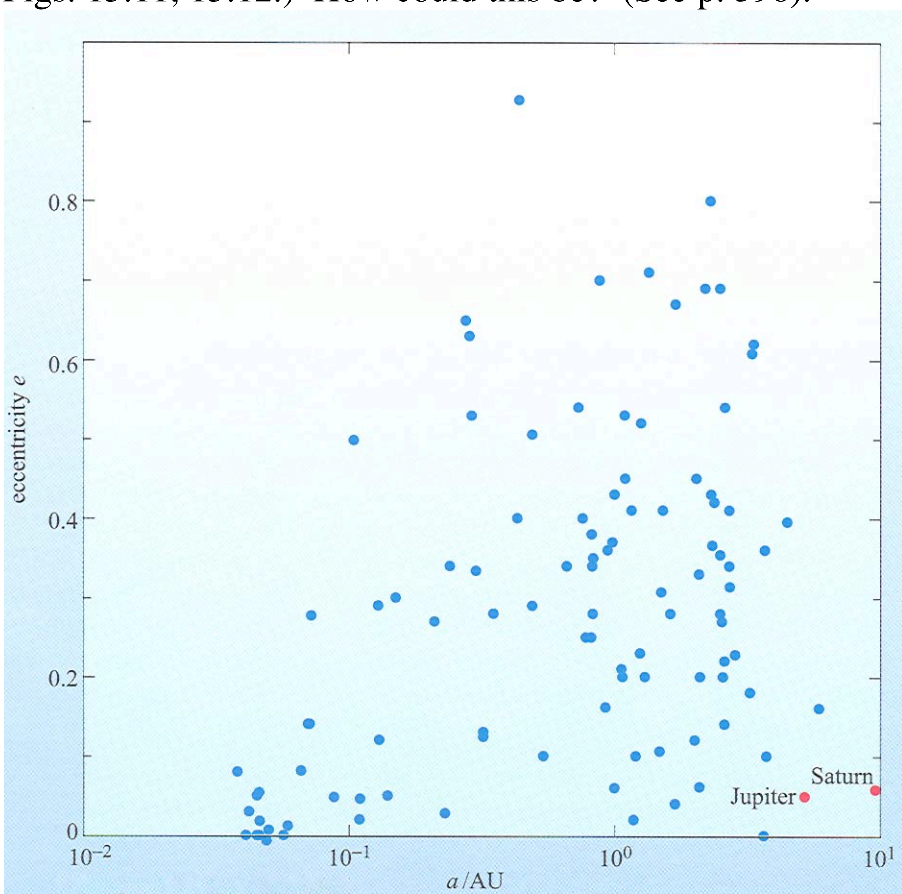
**Surprises from the 200 or so planets discovered so far:**

Giant planets usually very close to parent star: migration and cannibalism! (Will explain in class.) But some more distant (see Fig. 15.11).

This is partly a *selection effect*, because the radial velocity method gets its strongest signals from close-in planets, but still, no one expected to see "Jupiters" closer to their parent star than Mercury is to the Sun!

Perhaps most planetary systems get devoured by their parent star before the system is cleared of the debris responsible for the migration. This might suggest that life is rare in our Galaxy!

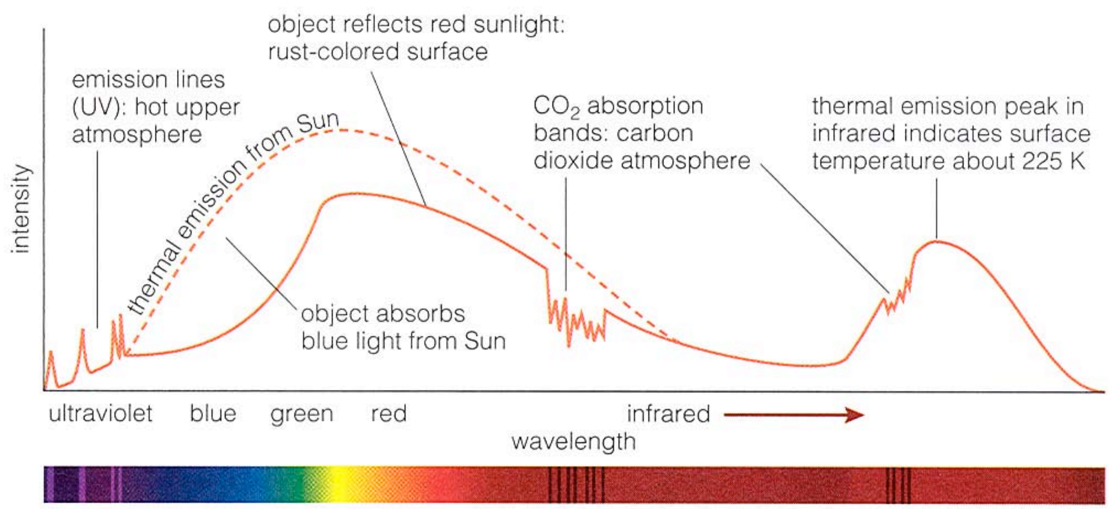
Some orbits fairly elliptical! (Compare: solar system orbits are nearly circular; see Figs. 15.11, 15.12.) How could this be? (See p. 398).



**<u>Homework question</u>: Almost all of the extrasolar planets have masses similar to Jupiter or a little smaller—so probably gas giants. Within the past couple of years, what discoveries have been made that have changed the situation? What method did these discoveries use? Why are they so interesting? I am asking about the smallest-mass planets yet discovered.**

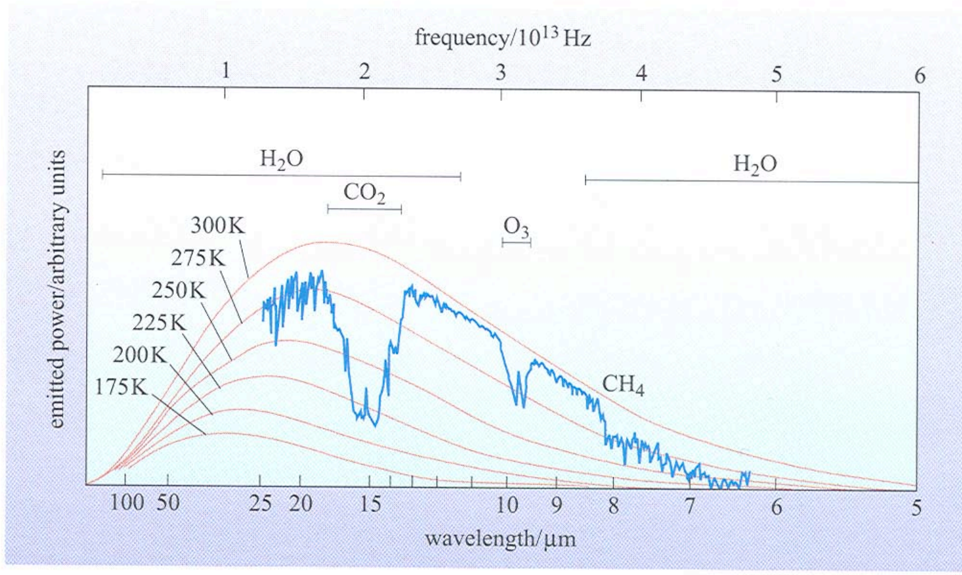
Detecting other Earth-like planets? Will have to wait for transit sensitivity of Kepler space mission (launch~2007, read p. 399), or, for imaging and spectroscopic "biomarkers," the "Terrestrial Planet Finder" TPF mission around 2012.

Illustration below shows how spectrum can give information about characteristics of a planet (what planet do you think this is? [it was used in the last set of notes, so if you remember the answer, think about how the spectrum could be used to diagnose some other planet.)

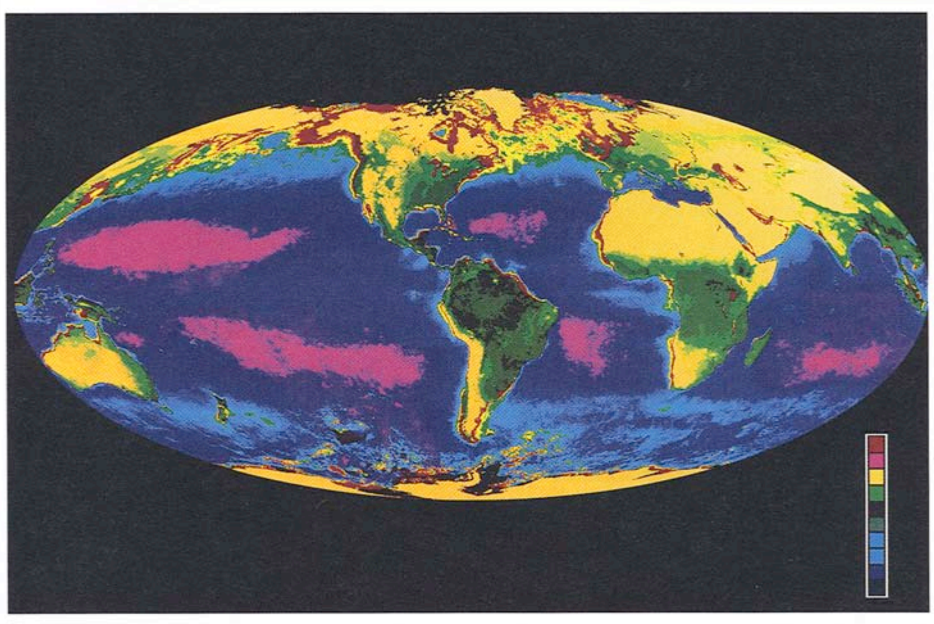


Detecting "biosignatures" from a planet's spectrum.

Notice ozone (photosynthesis) and methane (bacteria).




If we could travel to an Earth-like planet orbiting another star (no plan in foreseeable future), this is what we might see. This would be *high* resolution!



**The Earth's Biosphere** This computer-generated picture shows the distribution of plants over the Earth's surface. Ocean colors in the order of the rainbow correspond to phytoplankton concentrations, with red and orange for high productivity to blue and purple for low. Land colors designate vegetation: dark green for the rain forests, light green and gold for savannas and farmland, and yellow for the deserts. (NASA)