EE262

Handout # 36

Finding extrasolar planets

One great question is whether the Earth has any "twins" in the universe that can sustain life such as our own. You may have seen a form of Drake's equation for calculation the probability of existence of other advanced civilizations in the galaxy:

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_e \cdot f_i \cdot f_c \cdot L$$

N = number of advanced civilizations

R = rate of star formation in the galaxy

f_s = fraction of stars suitable for planets

f_p = fraction of suitable stars with planets

n_e = number of "earth's" per planetary system

f_e = fraction of those with life

f_i = fraction with intelligent life

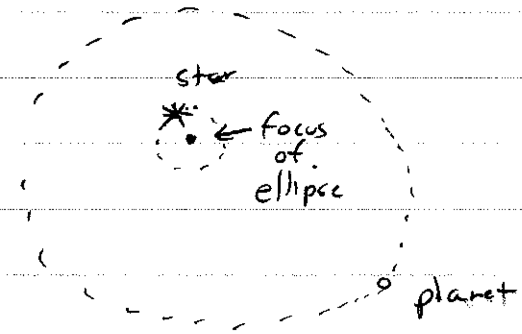
f_c = fraction with high technology

L = lifetime of civilizations

Usually people estimate from $10^4 - 10^6$ civilizations in our galaxy alone.

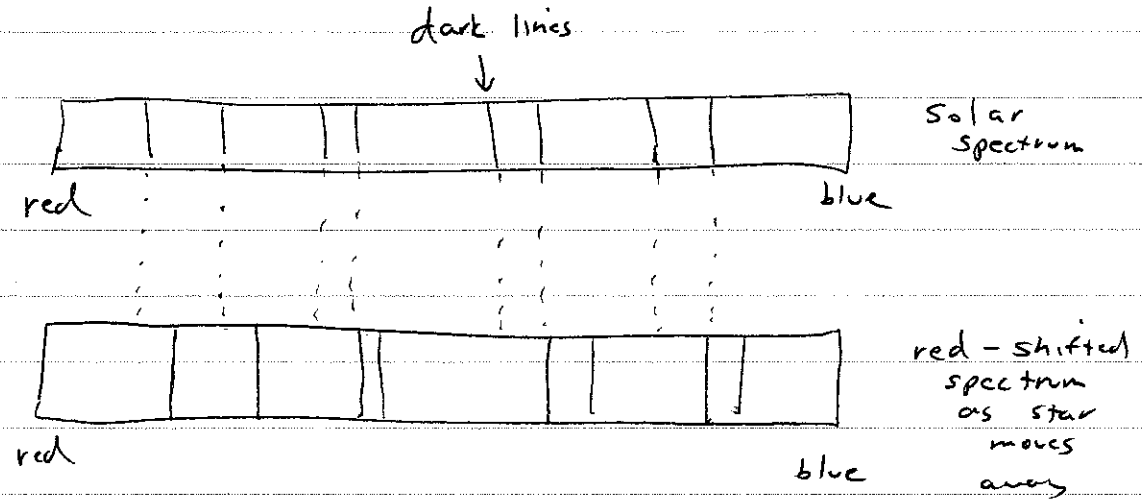
But, how common are planets, and how can we detect them?

The traditional way to detect potential planets is to look for "wobbles" in the position of a star due to a planet in orbit around it. According to Kepler both planet and star revolve about a common point:



So the star would have a position that looks like a small ellipse in the sky with a period of about a year for an Earth-like planet. But this method requires extremely precise location of the star, and is beyond current telescope capabilities for all but the closest stars with <u>very</u> large planets.

Another method is to use spectral techniques to detect the Doppler shift of radiation from the star. The solar spectrum contains many dark "lines" in the spectrum due to absorption of energy by the sun's outer layers. If the star is wobbling toward or away from us these lines will be displaced due to the Doppler effect as the planet revolves around the star:

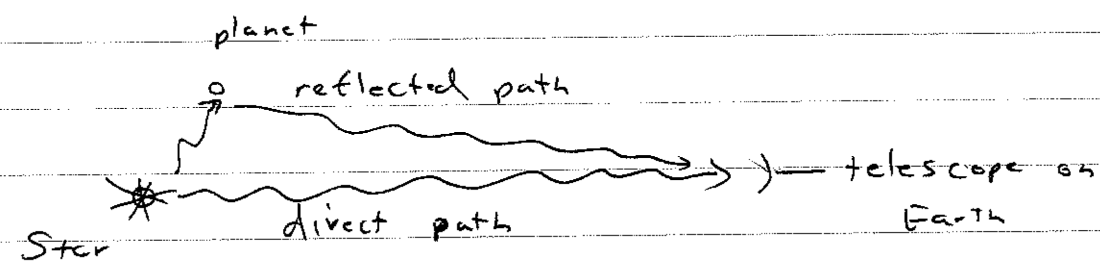


This method has been used to locate a few stars that may have planetary companions. If the Doppler shifts have the correct period over time they likely are due to wobbling "in the plane" from an orbital mass, perhaps a planet.

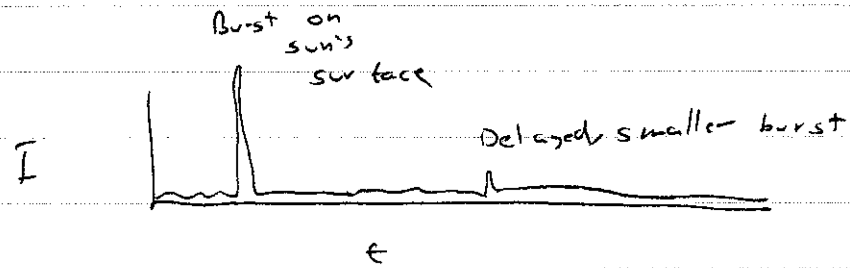
What can we do using techniques we have discussed here?

Correlation approach

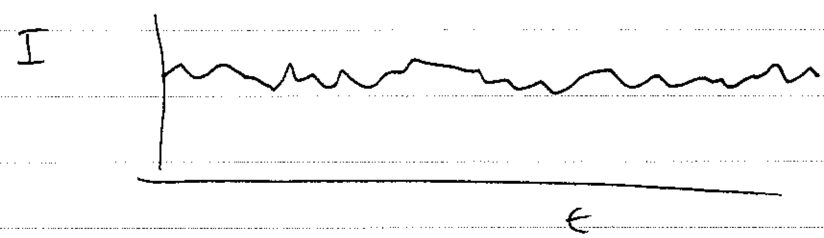
One of the main reasons we can't easily see stellar companions is that they are much dimmer than the star itself, perhaps by a factor of 10^{12}. Such a small object near a bright object is exceedingly hard to detect. But say we do the following experiment:



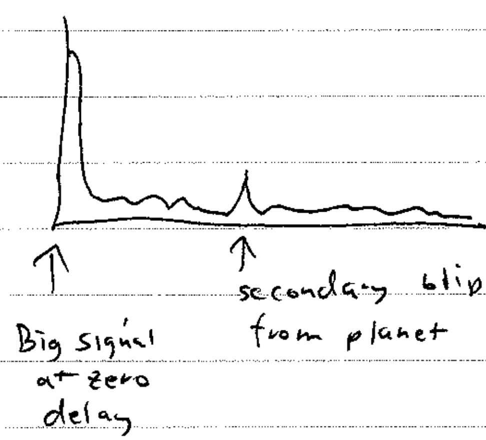
Light reflected from the planet is delayed by several minutes but otherwise is identical to the light emitted by the sun. In a noiseless case, suppose a large fluctuation in light from the star occurs, say due to a disturbance on the star's surface. A plot of intensity vs. time might look like



But usually the star's light fluctuates constantly, so the trace actually looks like



If there is a delayed version of the sun's output added in we can't easily see it. But what if we calculate the autocorrelation of the light?

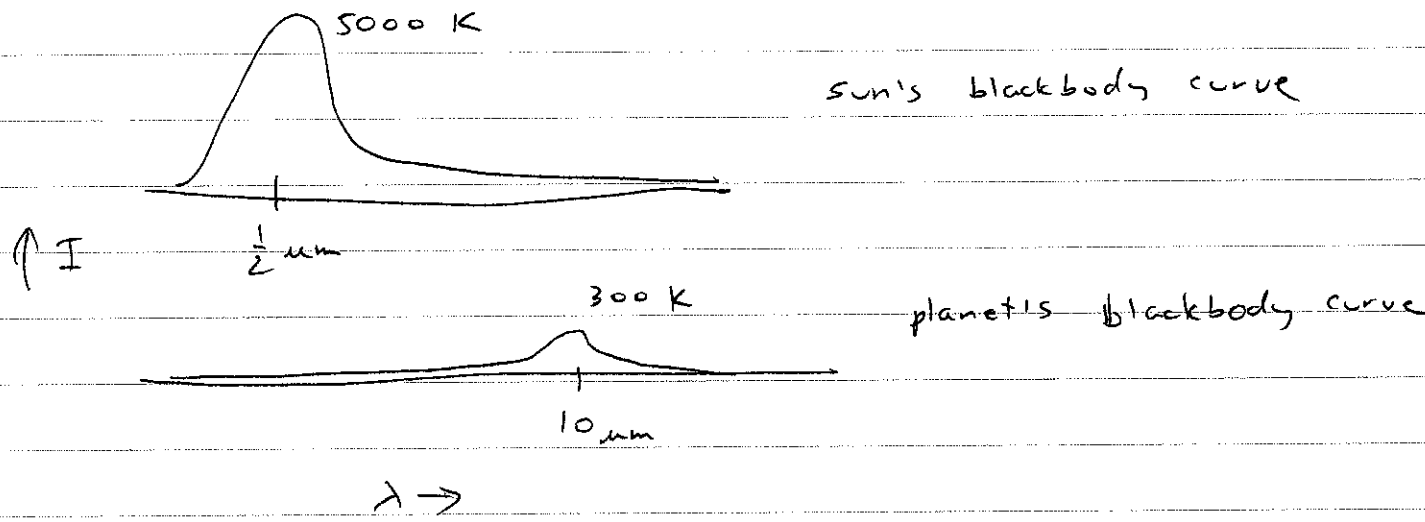


In forming the autocorrelation we can integrate over a long time, giving us confidence in the result. The proper motion of the blip would indicate a planet.

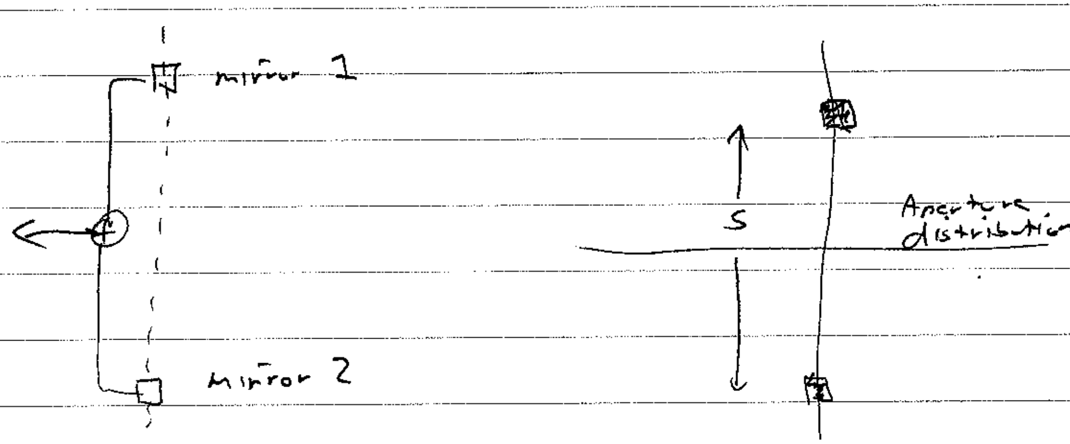
Unfortunately detectors with enough linear dynamic range are not yet available and this method has not been used (at least to my knowledge).

<u>The spinning interferometer</u>

One method under great study now is a spinning interferometer. These are being studied in the infrared region of the spectrum where the sun/planet ratio is least, for terrestrial planets.



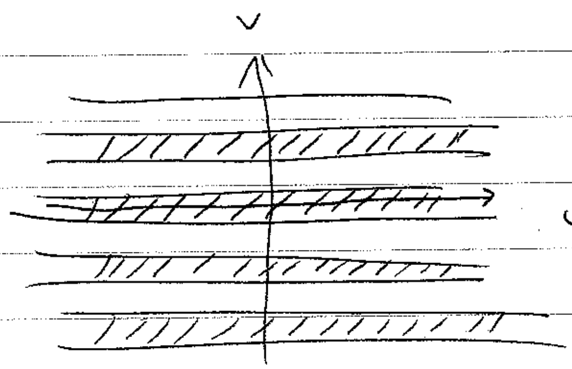
Suppose we form an optical interferometer with two telescope mirrors



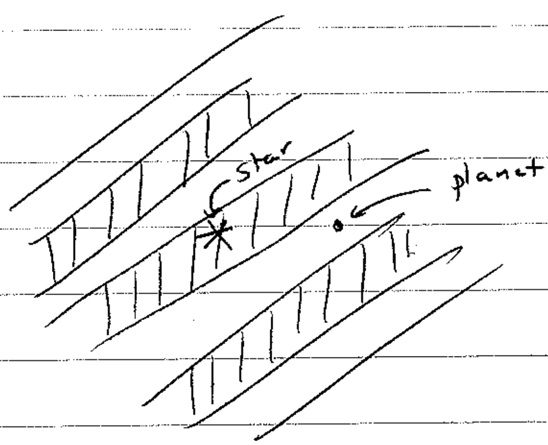
What is the intensity pattern of this distribution? Model it as a pair of δ- functions:

$$\delta\left(x, y-\frac{s}{2}\right)+\delta\left(x, y+\frac{s}{2}\right) \supset 2\cos \pi v s$$

The pattern in the sky looks like



Suppose we position the array so that a star under study is located at the origin, and then rotate the array. What will we see?



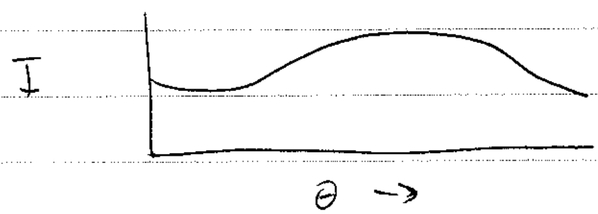
The signal from the star will be a constant intensity, while the signal from the planet will vary as the source is "swept" by the fringe pattern.

$$I_{planet}(\theta) = \cos \pi v s$$

$$= \cos(\pi\, r \sin\theta \cdot s)$$

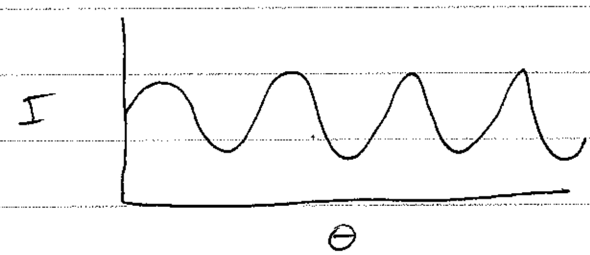
for a planet at distance v ($= r\sin\theta$) and a spacing s in the interferometer.

So, for a planet close in (r small) you might have



← cuts one lobe of interferometer

And for a farther out planet



← cuts several lobes

The equation above, a cosine of a sine, look like our Bessel function argument. You might want to investigate Hankel transforms as a way to analyze these data, as well as correlation analyses. This might be a good class project.