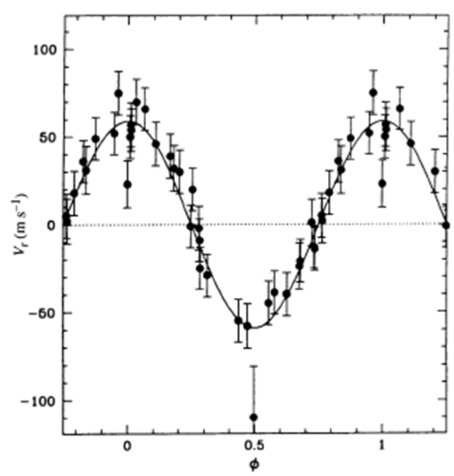
Discovery of planet around 51 Peg—11 Apr

- Discovery of 51Pegb
  - Measuring small Doppler velocities
  - Inclination angle
  - Determining mass
- Instrumental breakthrough

Discovery of first extra-solar planet

- Michel Mayor & Didier Queloz, 1995, Nature, 378, 355, “A Jupiter-mass companion to a solar-type star”
- Doppler motion of 51 Peg
  - Only motion along the line of sight produces Doppler shift (proportional to v).
- 3-min Q: The earth moves at 30km/s. Why is 51 Peg moving so slowly (60m/s)?

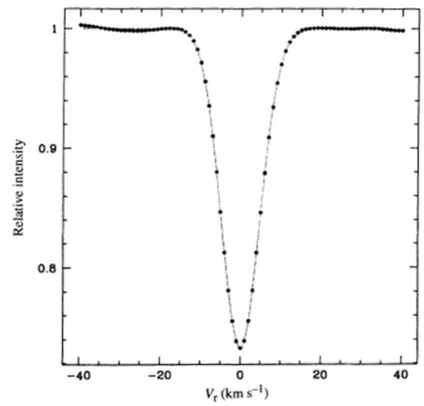


Finding velocity

- Measure velocity by cross correlating spectrum with a template

$$\frac{\sum_{\lambda} I(\lambda) I_{\text{template}}\left(\lambda\left(1+\frac{v}{c}\right)\right)}{(I^2 {I_{\text{template}}}^2)^{1/2}}$$

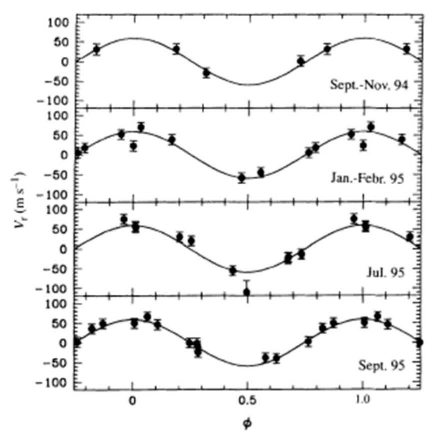
- At the correct velocity, cross correlation is big because *I*(λ) is big where $I_{template}(\lambda)$ is big.
- At an incorrect velocity, cross correlation is small.
- If spectral lines are sharp, width of cross correlation is sharp.



1 - cross correlation between spectrum *I*(λ) and $I_{template}(\lambda)$

- Radial velocity for 4 runs
  - Fit constant (γ velocity) and sinusoidal.

1. Why is the Doppler velocity zero at certain times?
   1. 51 Peg is stationary at certain times
   2. Motion is perpendicular to line of sight
   3. Planet blocks the light of 51 Peg at certain times.



Mass of planet: inclination of orbit

1. The star's Doppler velocity is 60m/s. Assume plane of planet's orbit is in the plane of the sky. What is the star's velocity?
   A. 60m/s
   B. Near zero
   C. Very large

- The actual velocity v and Doppler velocity v_r are related by $v_r = v\ \sin i$, where i is the inclination angle between the plane of the orbit and the plane of the sky.

Mass of planet

- Speed of a body of negligible mass orbiting the sun at 1AU
$$v = 29.8\text{km/s}$$
- For a circular orbit, Kepler's 3rd Law: $P = r^{3/2}$ and $v \propto r/P$ imply (Hwk 6)
$$v = 29.8(\text{r/1AU})^{-1/2}\text{km/s}$$
- Translate to 2-body problem to find the motion of the star (Hwk 6 &)
$$r_s = m_p/\left(m_s + m_p\right) r$$
$$v_s = dr_s/dt = m_p/\left(m_s + m_p\right) dr/dt$$
$$v_s = m_p/\left(m_s + m_p\right) 29.8(\text{r/1AU})^{-1/2}\text{km/s}$$
- In terms of Doppler velocity $v_r = v\ \sin i$,
$$v_r = (m_p \sin i)/\left(m_s + m_p\right)29.8(\text{r/1AU})^{-1/2}\text{km/s}$$
- What is measured is
$$m_p \sin i$$

which implies a lower limit for the mass.

Mayor & Queloz estimate inclination

- Line broadening due to rotation of star
- For sun (rotational period = 25day, radius=696Mm)

$$v_{\text{rotational}} = 2.0\text{km/s}$$

- Rotation broadens the spectrum by

$$v_{\text{rotational}} \sin i$$

- M&Q measure broadening to be

$$v_{\text{rotational}} \sin i = 2.2 \pm 1\text{km/s}.$$

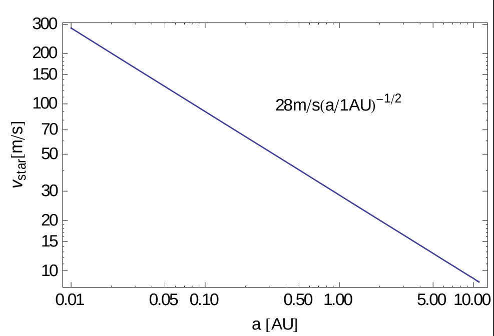
- Activity of chromospheric lines $\Rightarrow$ rotational period $\Rightarrow$ $v_{\text{rotational}} = 2.2 \pm 0.8\text{km/s}$
- Therefore

$$\sin i > 0.4$$
$$m_p < 1.2\ m_{\text{Jupiter}}$$

To find planets

- Need accurate velocities
- If the velocities are accurate to 300m/s, then you can find a planet with Jupiter's mass with an orbital radius of 0.01AU. (Not interesting.)

1. You are M & Q thinking about finding planets. What accuracy in velocity is needed to find a Jupiter orbiting at 1AU?
   A. 100m/s
   B. 30m/s
   C. 10m/s
   D. 3m/s
   E. 1m/s



Velocity of star vs semi-major axis for m_p=$m_{Jupiter}$