Instrument for finding planets—15 Apr

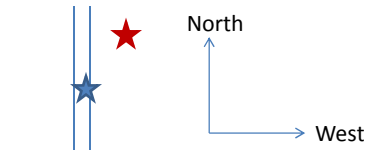
- Instrumental breakthrough
- Spectrograph ELODIE
  - Use of optical fibers
  - Accuracy
- Transit method for finding extra-solar planets
- Entire set of extra-solar planets (exoplanets.org)

ELODIE

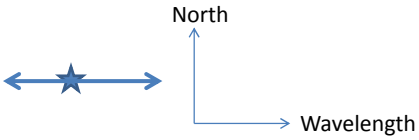
- A. Baranne et al., 1996, Astron & Astrophys Suppl, 119, 373. "ELODIE: A spectrograph for accurate radial velocity measurements"
- You are M & Q thinking about finding planets. What accuracy in velocity is needed to find a Jupiter orbiting at 1AU? 10m/s.
- Goal: Measure velocities with an accuracy of 15m/s.
- Trick: Use a fiber to transfer light from telescope to spectrometer. This eliminates a large systematic error in velocities.

Spectrometer

- The telescope focuses a star on a slit.
- Slit passes light in the slit & blocks light that is off of the slit.
- Spectrometer disperses light by color & focuses the dispersed light on detector.



At telescope focus
Light from blue star goes into spectrometer
Red star is blocked by slit

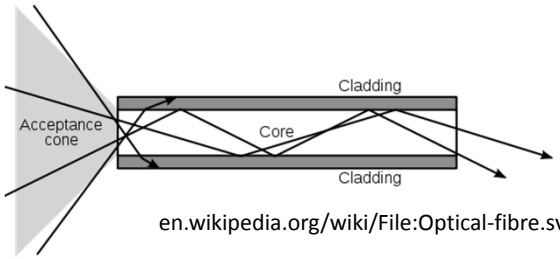


At focus of spectrometer
Light from blue star is dispersed by color

Problem with spectrometers

- Positioning star in slit introduces wavelength & velocity errors.
- Example of OSIRIS on the SOAR Telescope
  - Slit width 0.42 arcsec.
  - One pixel on detector is also a wavelength shift of 0.368nm.
    - 0.368nm/2200nm c = 50 km/s.
    - In principle, with 10^6 photoelectrons, one can measure 50m/s.
  - Left & right side of slit focus on detector separated by 3 pixels.
  - 3 pixels is also 1.1nm in wavelength or 150km/s
  - Placing the star on the left rather than the right side of the slit is equivalent to shifting the Doppler speed by 150km/s.
    - This is 3000 times worse than the ideal.
    - That light from calibration lamps do not pass through the same path as light from star introduces similar errors.
    - With OSIRIS, we use absorption lines in the atmosphere to calibrate wavelength.

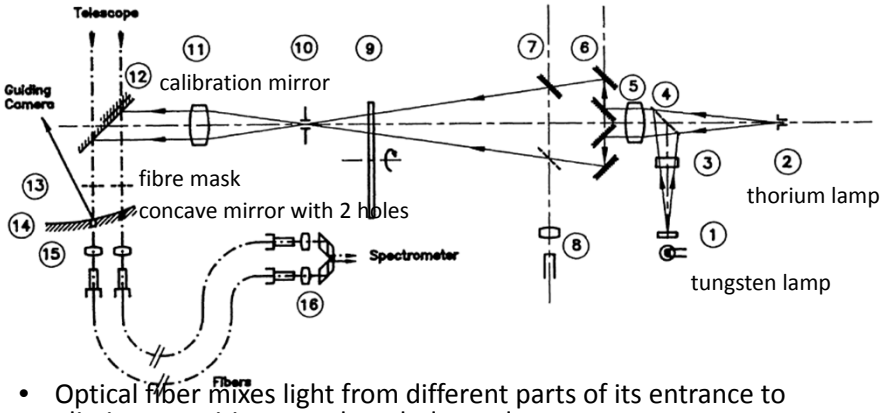
Mixing with optical fiber



en.wikipedia.org/wiki/File:Optical-fibre.svg

- Optical fiber mixes light from different parts of its entrance to eliminate position-wavelength dependence.
  - A small shift in position (or angle) at entrance changes the path inside the fiber by a large amount. That means a large shift in the position (and angle) at the exit. (Heacox W., 1986, AJ 92, 219)

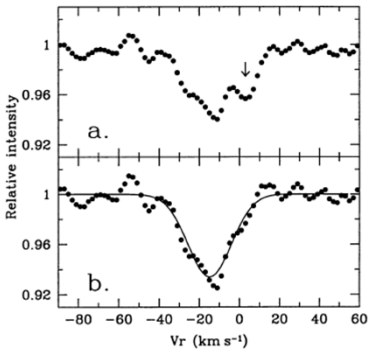
ELODIE design



- Optical fiber mixes light from different parts of its entrance to eliminate position-wavelength dependence.
- Light from calibrating lamps and from star feeds spectrometer in the same way.
- Star & calibrating source are measured simultaneously.
- Spectrometer is stationary in a room kept at constant temperature.

Cross correlation measurement of velocity

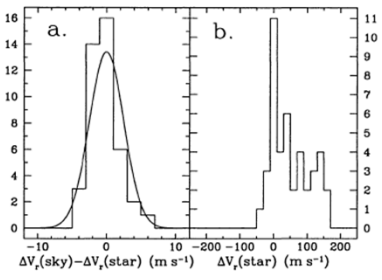
- Why does the sky have a velocity of 5 km/s?



(a) cross correlation of the spectrum of a faint star and the template.
(b) same with cross correlation of the sky removed.

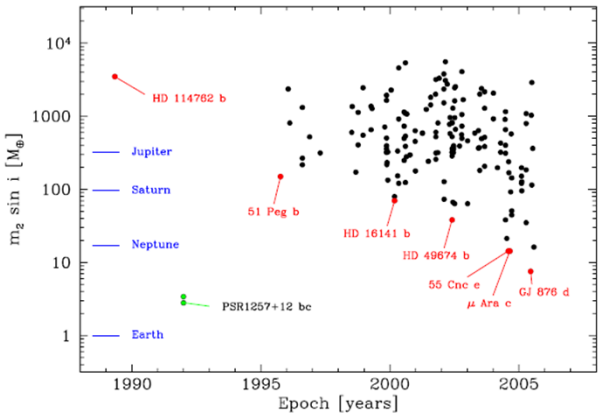
Accuracy

- Measure the velocity of the calibrating lamp in the two paths.
  - Instrument was shocked by changing its temperature by 1C.
  - Short-term accuracy is 4m/s.
- Measure a star over 3hr
  - Short-term accuracy is 6m/s.
- Long-term accuracy
  - 106 stars over years
  - 13m/s
    - 1/270 pixel.



(a) Velocity difference between two channels
(b) Velocity of one channel

10-year progress



- Mayor & Queloz, 2005, in "Tenth Anniversary of Peg51b," Arnold, L, & Bouchy, F, ed.

Transit method

- Monitor the light of the star.
- When planet passes in from of the star, it blocks some of the light.
- How much?

1. You are an alien observing the sun, and Jupiter passes in front of the sun. How much does the sun dim? (Rsun=700Mm. Rjupiter=71Mm)
   A. 10%
   B. 1%
   C. 0.1%
   D. 0.01%