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

- 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.

![Diagram of spectrometer and telescope focusing a star on a slit.]

**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 10⁶ 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

- 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%