NMSU ASTRONOMY CUME 443, 25 April 2020 **Jon Holtzman**

This cume is partly motivated by and will ask about material discussed in the letter: "Betelgeuse Just Is Not That Cool; Effective Temperature Alone Cannot Explain the Recent Dimming of Betelgeuse" by Levesque and Massey (2020).

A 75 percent grade will guarantee a pass.

Gravitational constant $G = 6.67 \times 10^{-8} cm^3 g^{-1} s^{-2}$, mass of sun $M_{sun} = 2 \times 10^{33} g$, radiua of sun $R_{sun} = 6.96 \times 10^{10} cm$, speed of light $c = 3 \times 10^{10} cm/s$, $1pc = 3.086 \times 10^{18} cm$, $1au = 1.496 \times 10^{13} cm$

1. (12 points) High Resolution observations

   (a) Given the information in the paper, what is the angular diameter of Betelgeuse?

   $$\theta = \frac{2 \times 887 R_{sun}}{2223.086e18} = 0.037 arcsec$$

   (b) The paper mentions imaging of Betelgeuse with the VLT SPHERE instrument, which is an adaptive optics instrument on one of the VLT 8m telescopes.

      i. Describe the purpose of an adaptive optics system. (Note the next question is about how one works, so don't answer that here!).
      To remove the blurring effects of the Earth's atmosphere

      ii. Describe how an adaptive optics system works. What are the main components? What are the timescales on which an AO system has to work?
      Need to measure the wavefront distortions caused by atmosphere and correct for them. An AO system needs to include a wavefront sensor and then a wavefront corrector, generally, a deformable mirror. These need to operation on ∼ 10-100 msec timescales.

      iii. Would you expect the VLT to be able to image Betelgeuse? Why or why not? Be quantitative.
      VLT is an 8m telescope. Diffraction limit:

      $$\theta_{min} = \frac{1.22\lambda}{D} = .031 \frac{\lambda}{1\mu} \text{arcsec}$$

      So, marginally resolved at 1 micron.

      iv. The VLT SPHERE web page reports achieiving a Strehl ratio of >75% in the H band and >20% in the R band. What is the definition of the Strehl ratio?
      Strehl ratio gives the ratio between peak flux of a point source and the peak flux in a diffraction limited image.

      v. Why is the Strehl ratio better in the H band than in the R band (two reasons)?
      It is better in the H band because 1) the diffraction peak is lower, and 2) AO is more effective in the near-IR because r_0 is larger.

2. (6 points) Spectroscopy

   (a) What is the distinction between spectrophotometry and spectroscopy?
   Measuring flux as a function of wavelength.

   (b) What is the definition of the parallactic angle? What is the value of the position angle (angle from the N-S line) for the parallactic angle of an object observed on the meridian?
   Parallactic angle is the angle between N and the zenith. Position angle of parallactic angle for object on meridian is zero.

   (c) Why did they make their observations with the slit aligned at the parallactic angle?
   So that differential refraction does not lead to light loss that is a function of wavelength.

3. (6 points) Fluxes and effective temperatures

(a) By what multiplicative factor did the **flux** from Betelgeuse decline from its typical maximum to the level reported on December 7?

$$10^{-0.4(1.12-0.25)} = 0.45$$

(b) How much would the effective temperature need to change to explain the change in flux if the flux change represented a change in bolometric flux and was caused exclusively by a change in T_{eff}? If you didn't get how much the flux changed in part (a), express your answer in terms of F_{Dec}/F_{prev}.

$$\frac{T_{new}}{T_{old}} = 0.45^{0.25} = 0.82$$

So for an original $T_{eff} = 3650$, would expect $T_{eff} \sim 3000$ K.

(c) Given that the observations were in the V bandpass, would the effective temperature need to change by more or less than the amount calculated in part (b) to explain the observed flux change? Why?

At these T_{eff}, peak is in the near-IR, so flux will be dropping faster in the optical, so T_{eff} wouldn't need to drop as much.

4. (2 points) Extinction

(a) If an observed dimming of 1 magnitude in the V band were caused by extinction by normal interstellar dust, what amount of dimming would be expected in the B band, **quantitatively**?

$$E(B-V) = \frac{A_V}{R_V} \sim 0.32$$
$$A_B = 1.32$$

5. (6 points) Surface structure on stars

(a) The authors mention that they measure a flux-weighted T_{eff} across the surface of Betelgeuse. Adopting a reasonable T_{eff} for the solar photosphere and a reasonable T_{eff} for a sunspot, calculate the change in solar bolometric flux and flux-weighted T_{eff} between a spotless Sun and an active Sun with a spot coverage of 1% of the solar surface.

$$.99F + .01(3000/5777) * *4F = .991F$$
$$.99 * 5777 + .001 * 3000 = 5722$$

(b) If sun/star spots are dark, how can they be distinguished from exoplanet transits? Note as many ways as you can.

Periodic across multiple solar rotation periods. Duration of transit generally shorter, as rotation periods are of order days. Confirmation by Doppler motions.