

## Measuring Motion, Doppler Effect—28 Oct

- Outline
  - Doppler effect
  - Pickering's spectra of Mizar
    - Capstone example
- Announcements
  - Monday is the start of Hubble's Law and Big Bang. Essential class

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## Measuring speed without seeing motion

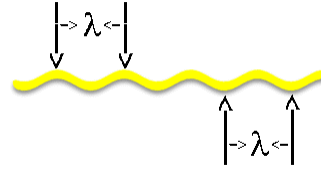
- You are driving 80mph. Just over the crest of a hill, you see a cop car in the distance. In an instant, the cop's computer writes you a ticket.
- Astronomers can measure the speed of a star in orbit around the Milky Way without seeing it move very far.
  - $\text{Velocity} = (\text{change in position})/\text{time}$
  - The orbit takes 200Myr. Measuring speed by  $(\text{change in position})/\text{time}$  is impossible.
- Q: How can cops & astronomers figure out speed without seeing the object move?
  - A. Measure the wavelength of light from object
  - B. Measure the intensity of light from the object

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## Wavelength, Frequency

- Wavelength  $\lambda$  = distance between successive crests.
  - m meter
  - nm nanometer ( $10^{-9}\text{m}$ )
  - Å angstrom ( $10^{-10}\text{m}$ )
- Wave moves at speed of light  $c$ .
- Frequency is rate at which crests pass.
  - $f = c/\lambda$
  - Cycles/second; Hertz



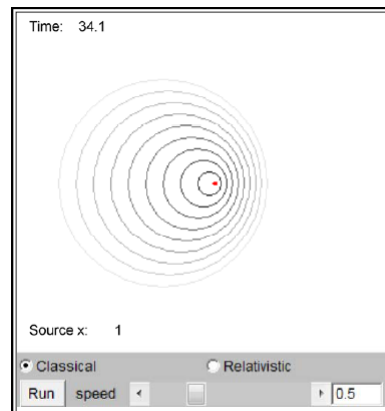
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## Measuring Motion: Doppler effect

### Doppler

- Velocity is encoded in the light that the stars emits.
- Waves emitted from a star moving towards us are bunched together.
  - Star moves between emitting one wave crest and another. Therefore wavelength is shorter.
- Key idea: If motion is perpendicular to the line of sight, there is no change in wavelength.



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## Doppler effect

- Velocity is encoded in the light that the stars emits.
  - Waves emitted from a star moving towards us are bunched together.
    - Star moves between emitting one wave crest and another. Therefore wavelength is shorter.
- $$\lambda_{\text{observed}} / \lambda_{\text{rest}} = 1 + v/c$$
- v is the component of velocity towards or away
  - v is positive if star is moving away from us.
  - c is speed of light.
- $\Delta\lambda = \lambda_{\text{observed}} - \lambda_{\text{rest}}$  is called the shift in wavelength.
    - Shift is called a redshift if positive (star is moving away)
    - Shift is called a blueshift if negative (star is moving toward)

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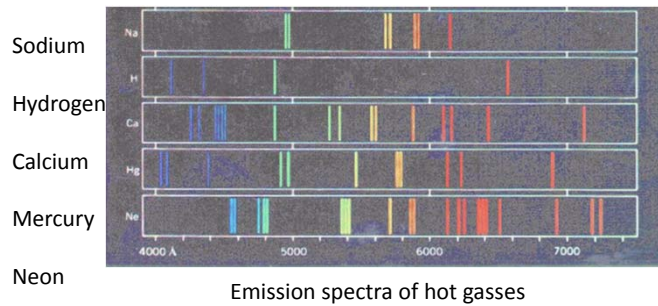
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## Doppler effect

- Idea
  - Velocity is encoded in the light that the stars emits.
  - Waves emitted from a star moving towards us are bunched together.
- Formula
 
$$\lambda_{\text{observed}} / \lambda_{\text{rest}} = 1 + v/c$$
- Now try to understand the key ideas.

## How do you know the “rest wavelength”? An element’s fingerprint

- Spectral lines are an element’s finger print. (5.4 in textbook)
- Eg, in the visible part of the spectrum, hydrogen emits and absorbs light at 656.2, 486.1, 434.0, 410.1nm.



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## Doppler effect: Summary

$$\lambda_{\text{observed}} / \lambda_{\text{rest}} = 1 + v/c$$

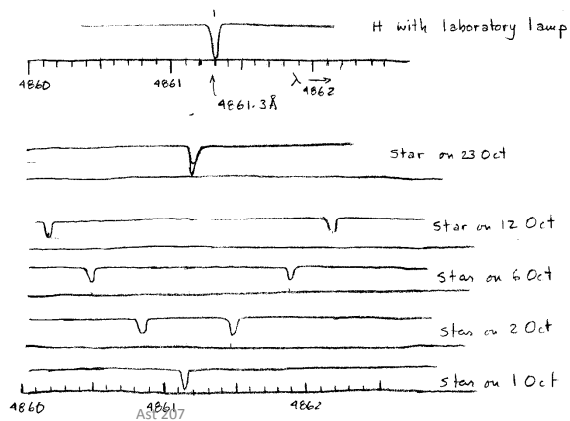
1. Is it possible for a star to be moving and not show a Doppler shift? \_\_\_\_, and this is an example.
  - A. Yes
  - B. No

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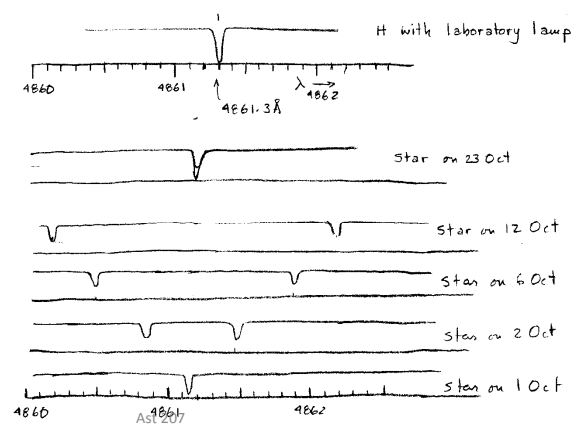
## Pickering's discovery

- We are interpreting E. C. Pickering's spectra of Mizar (a star in the Big Dipper) in 1889.
  - Spectra showing the H $\beta$  line of hydrogen.
  - These are *absorption* spectra: The amount of light is high except at wavelengths where hydrogen absorbs.
- Describe the changes in the spectra. (Spectra repeat every 22 days.)



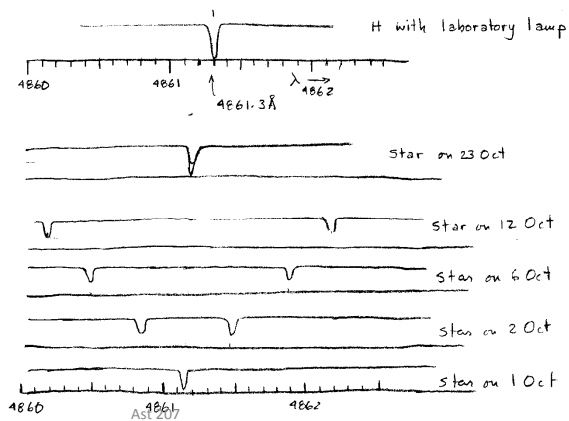
## Pickering's discovery

- Describe the changes in the spectra. (Spectra repeat every 22 days.)
  - A single wavelength is seen on 1 Oct.
  - Two wavelengths are seen on 2 Oct
  - Separation of two wavelengths grows larger, then smaller.



## Pickering's discovery

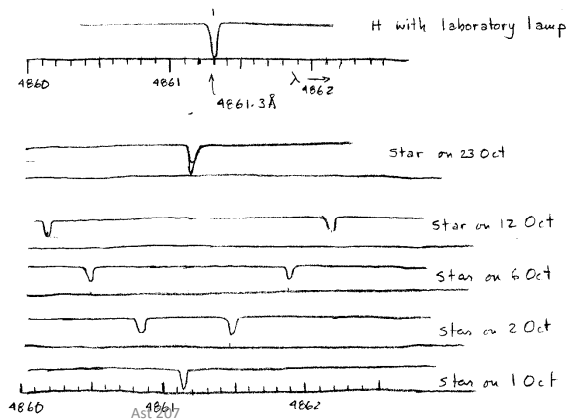
- How can the spectral line of hydrogen appear at different wavelengths?
  - The star is moving.
  - Hydrogen emits at different wavelengths at different times.
  - There was something wrong with Pickering's spectrometer.
  - Some other reason.



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## Pickering's discovery

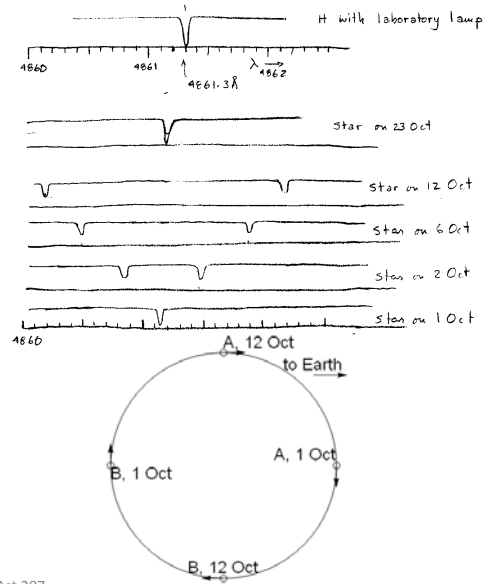
- Devise a model for Mizar that explains the data. How can a star move at two speeds?



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### Pickering's discovery

- Provisional model: Two stars are in orbit. Test against evidence.
- How can the two stars move so as to show the same wavelength, for example, as on Oct 1? (If possible, you want explanations that do not depend on special accidents.)
    - The stars move in the same direction at the same speed on Oct 1.
    - The Doppler effect is insensitive to the orbital motion on Oct 1.
    - One star hides the other on Oct 1.

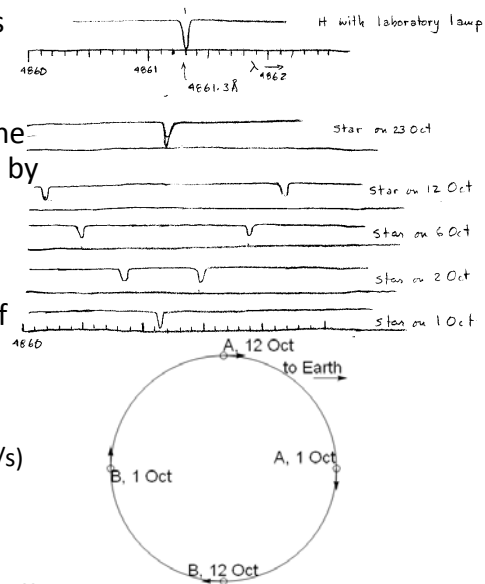


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### Pickering's discovery

- Provisional model: Two stars are in orbit. Test against evidence.
- What is the wavelength of the  $H\beta$  line of hydrogen emitted by star A on 12 Oct?
    - $4860.18\text{\AA}$ .
    - $4862.17\text{\AA}$ .
  - What is the relative speed of stars A & B on 12 Oct? Hint: only one has the right units.
    - $(1.99\text{\AA})/(4861\text{\AA})$
    - $(1.99\text{\AA})/(4861\text{\AA}) \times (300,000\text{km/s})$
    - $(1.99\text{\AA}) \times (300,000\text{km/s})$
- Relative speed is  $120\text{km/s}$ .

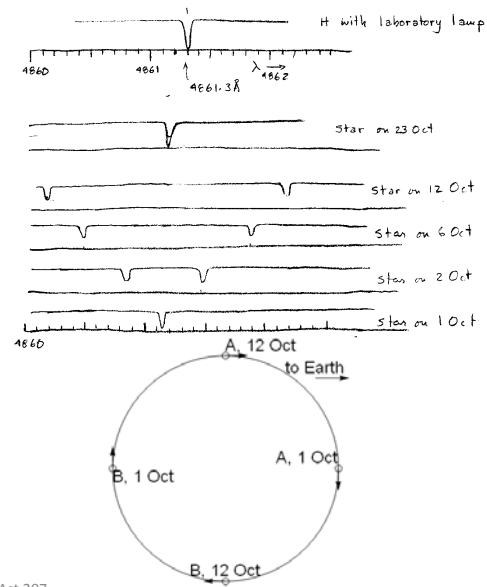


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## Pickering's discovery

1. What evidence tells you whether the binary star system is moving toward or away from us?
  2. What is  $v/c$ , where  $v$  is the velocity of the binary star system?
    - A.  $-0.17 / 4861.13 = -3.5 \times 10^{-5}$
    - B.  $-0.17 / 4861.3 = -3.5 \times 10^{-5}$
    - C.  $4861.13 - 4861.3 = -0.17$
    - D.  $4861.3 - 4861.13 = 0.17$
    - E.  $0.17 / 4861.3 = 3.5 \times 10^{-5}$
- Pickering discovered the first binary star where the evidence was in the spectra, called a "spectroscopic binary star."



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