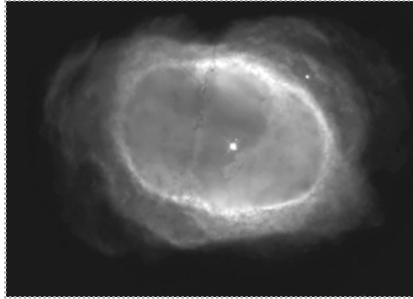


ASTR 1120: Stars & Galaxies



Planetary
Nebula
NGC 3132

Prof. Juri Toomre TA: Ben Brown
Lecture 15 Mon 14 Feb 05
zeus.colorado.edu/astr1120-toomre

Topics for Today

- How do we begin to classify the stars?
- Understand why *temperature and spectral lines* are *closely linked*
- Thus why *O A B A F G K M* makes some sense – even if naming convention is from historical accident !
- *Homework Set # 4* still available, due Fri
- Expect to return graded *Exam 1* on Wed

Reading for Next Lecture

- Complete detailed reading of Chap 16, 'Properties of Stars' by Wed 16 Feb
- Proceed to lay the stars out on the "Hertzsprung – Russell" (or H-R) diagram
- Will help to sort out the life history of stars

Reading Clicker Q **E.**

- The luminosity of a star is
- A. apparent brightness of the star in the sky
- B. surface temperature of the star
- C. lifetime of the star
- D. total amount of light that the star will radiate over its entire lifetime
- E. total amount of light that the star radiates every second

Puzzle Clicker: Stellar Parallax

- The biggest ground-based telescopes with adaptive optics can measure a stars' position to accuracies of about 0.05 arcsec. How far away could they map the positions of stars via parallax?

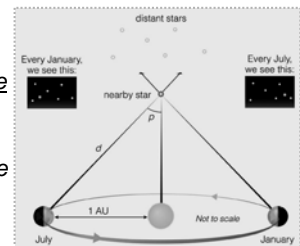
- A. 2 pc = 6.5 light years
- B. 20 pc = 65 light years
- C. 200 pc = 650 light years

B.



Parallax

- B. maximum distance is set by the accuracy with which you can measure positions in the sky (space does better than ground)

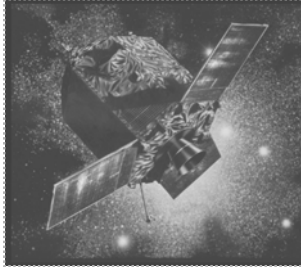


$$\begin{aligned} \text{Distance (pc)} &= \\ &= 1 / 0.05 \text{ arcsec} \\ &= 20 \text{ pc} = 65 \text{ ly} \end{aligned}$$

$$d \text{ (in parsecs)} = 1 / p \text{ (in arcsec)}$$

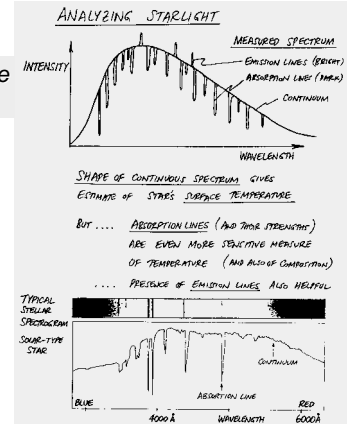
Best parallax measurer: *REMINDER*
Hipparcos satellite 1989-1993

- Space measurements not affected by atmosphere
- Measurement made many times until accurate to 0.001 arcsec (→ 1000 pc or 3300 ly)
- 100,000 stars mapped (2.5 million to slightly lesser accuracy)

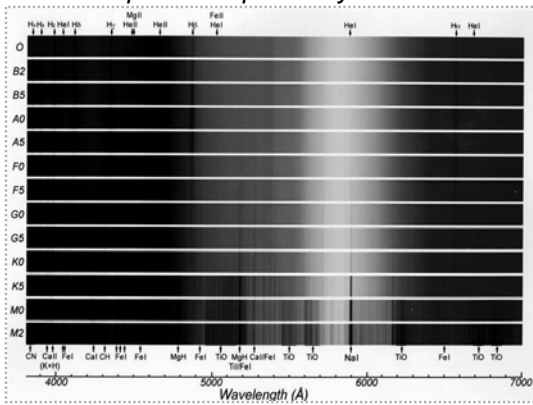


Measuring Surface TEMPERATURE

Shape of spectrum good ... but spectral lines much better



Spectra help classify stars



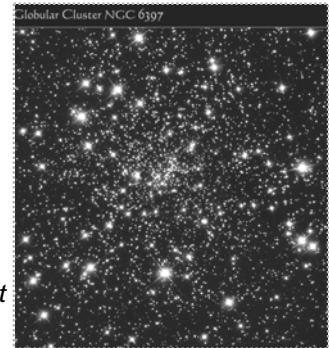
OBAFGKM ?!?

- Spectral (color) classification

O = bluest, hottest

G = yellow (Sun)

M = reddest, coolest



A bit of history: Classifying Stars

World War I, Harvard College observatory

Women were hired by Pickering as "calculators" to help with a new survey of the Milky Way

Most had studied astronomy, but were not allowed to work as scientists



Devising the strange temperature code

- Original classification of spectra (1890) was:

A = strongest hydrogen feature

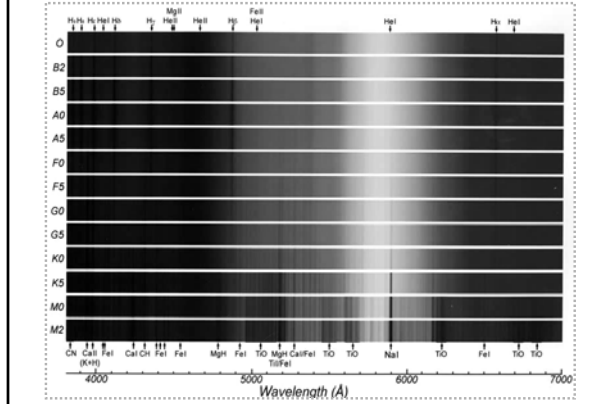
B = less strong hydrogen ... C, D, etc.

- Annie Jump Cannon realized that a different sequence made more sense (~1910)



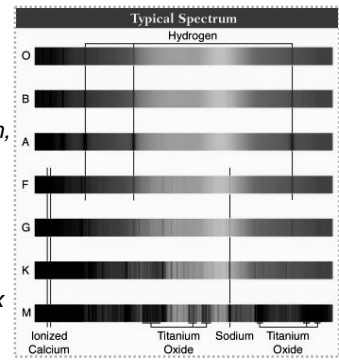
→ **O B A F G K M !!**

Which absorption (dark) lines are strongest?



Spectral Classification: O B A F G K M

- Hottest stars: O B
ionized helium only
- Hot stars: A F helium, hydrogen
- Cooler stars: G hydrogen, heavier atoms
- Coollest stars: M molecules, (complex absorption bands)



Stars and their spectral classification

Table 16.1 The Spectral Sequence

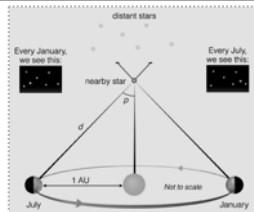
Spectral Type	Example	Temperature Range	Key Absorption Line Features	Diagnose Wavelength (nm)	Typical Spectrum
O	Star of Orion's Belt	>30,000 K	Lines of ionized helium, weak hydrogen lines	<97 nm (ultraviolet?)	
B	Rigel	30,000 K-10,000 K	Lines of neutral helium, moderate hydrogen lines	97-240 nm (ultraviolet?)	
A	Sirius	10,000 K-7,500 K	Very strong hydrogen lines	290-390 nm (visible*)	
F	Polaris	7,500 K-6,000 K	Moderate hydrogen lines, moderate lines of ionized calcium	390-480 nm (blue?)	
G	Sun, Alpha Centauri A	6,000 K-5,000 K	Weak hydrogen lines, strong lines of ionized calcium	480-580 nm (yellow)	
K	Arcturus	5,000 K-3,500 K	Lines of neutral and singly ionized metals, some molecules	580-830 nm (red)	
M	Betelgeuse, Proxima Centauri	<3,000 K	Molecular lines strong	>830 nm (infrared)	

*All stars above 6,000 K look more or less white to the human eye because they emit plenty of radiation at all visible wavelengths.

Brightness / Distance Clicker Q **B.**

- Leonardo and Guinevere are two stars that have the same apparent brightness. Leonardo has a larger parallax angle than Guinevere. Which star is more luminous?
- A. Leonardo
- B. Guinevere
- C. Cannot determine from data given

Brightness / Distance



- Leonardo has a larger parallax angle -- thus he is closer
- They both have the same APPARENT brightness, but Leo is closer
- B. Guinevere must be more luminous

Cecelia figured out WHY stellar spectra are so different: TEMPERATURE

- She showed that SURFACE TEMPERATURE is the big factor (not composition)
- She used the newly-devised SAHA EQUATION, estimating how many electrons remain attached to atoms as temperature is changed (or the level of ionization)



Cecelia Payne-Gaposchkin (Harvard PhD thesis 1925)

O B A F G K M → decreasing temperature

Why temperature and spectral lines are linked?

SAHA gives the answer:

can estimate "population of different energy levels" in H, He ... and ionization

STUDY OF STELLAR ATMOSPHERES:
WHY ARE SPECTRAL LINES AND TEMPERATURE RELATED?

REAL TEMPERATURE OF GAS IS MEASURE OF AVERAGE KINETIC ENERGY (OR VELOCITY²) OF ATOMS
AND... THE FASTER ATOMS COLLIDE, THE MORE THEY DISTURB OR DISLODGE ELECTRONS

SAHA EQUATION: (MICHAS SAHA, 1909, INDIAN ASTRONOMER)
PREDICTS RELATIVE NUMBERS OF ATOMS IN EACH EXCITED STATE OF ELECTRON (ENERGY LEVEL), GIVEN TEMPERATURE & PRESSURE OF GAS.

→ SPECTRAL LINE STRENGTHS (AND VICE VERSA)

JUST WHICH PHOTONS CAN BE ABSORBED DEPENDS ON WHICH ELECTRONIC ORBITS ARE POPULATED!

FOR HYDROGEN, VISIBLE (BALMER) SERIES OF STRONG ABSORPTION LINES IF MANY ATOMS IN EXCITED $n=2$ STATE
→ TEMP $\sim 10,000$ K

SAHA predicts spectral line strengths with temperature

WHAT SAHA PREDICTS:

SAHA EQUATION FOR HYDROGEN:

- FOR HOTTEST STARS (O, B), PAULI PAWLOD QUANTUM NUMBER PREDOMINANT
- FOR COOLEST STARS (M), MOSTLY AT GROUND LEVEL ($n=1$), SO ABSORPTION OF LY PHOTONS (LYMAN)
- FOR A-TYPE STARS ($\sim 10,000$ K), MANY ATOMS AT EXCITED $n=2$ LEVEL, STRONG BRANER (VISIBLE) ABSORPTION LINES

Spectral Classification: O B A F G K M

Hottest stars: ionized helium only

Hot stars: helium, hydrogen

Cooler stars: hydrogen, heavier atoms

Cooler stars: molecules, (complex absorption bands)

Further refinements:

DECIMAL SUBDIVISION

LUMINOSITY CLASSES

Sun is: G2 V

COLOR CLASS

STARS: REFINEMENTS IN CLASSIFYING THEM

SUBDIVISION OF SPECTRAL COLOR CLASSES:

A: G0, G1, G2, G3, G4, G5, G6, G7, G8, G9

LUMINOSITY CLASSES:
FOR THE SAME COLOR OF STAR (SPECTRAL CLASS), LARGER STARS HAVE NARROWER ABSORPTION LINES
WHY? PRESSURES AT SURFACE ARE LESS, ATOMS ARE LESS DISTURBED BY COLLISIONS

EXAMPLE:

THIS LUMINOSITY (OR "BRIGHTNESS") CLASS:

I SUPERGIANTS (BRIGHTLY)
II GIANTS
III GIANTS
IV SUBGIANTS
V MAIN SEQUENCE (OR DWARF) FAINTLY

H-R DIAGRAM

Hertzsprung-Russell (H-R) Diagram

EJNAR HERTZSPRUNG (DANISH) 1911-1913
HENRY NORRIS RUSSELL (AMERICAN) 1913

Luminosity (magnitude) vs Spectral class (temperature)

H - R Namesakes

Ejnar Hertzsprung

Henry Norris Russell

