

# Astronomy 162

## Lecture 1

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- INTRODUCE SELF, T.As
  - ASK STUDENTS ABOUT THEMSELVES, INTERESTS
  - HOW MANY TOOK Ay161 LAST QUARTER?
  - HOW MANY WORK?
- 
- ASK ABOUT IF THEY HEARD ABOUT RECENT HST, CHANDRA, AND SPITZER SPACE TELESCOPE RESULTS

## A SURVEY

- WHY ARE YOU TAKING THIS COURSE?
- WHAT DO YOU HOPE TO LEARN?
- DO YOU FIND SCIENCE INTERESTING?
- WHAT DO YOU THINK OF THE TEXTBOOK?

## E-MAIL AND THE WORLD WIDE WEB

- NOTE THAT LECTURE NOTES AND COURSE INFORMATION WILL BE POSTED ON THE WEB SITE FOR THE COURSE:  
[www.astronomy.ohio-state.edu/~posmer/Ay162/index.html](http://www.astronomy.ohio-state.edu/~posmer/Ay162/index.html)
- INFORMATION IS SUBJECT TO CHANGE, SO KEEP CHECKING THE WEB SITE
- **COME TO CLASS!!** I cannot guarantee that everything I say will be on the web notes.

## PURPOSE OF A LECTURE

- BACKGROUND
- HISTORY
- PERSONAL COMMENTS
- CURRENT EVENTS

- TIE MATERIAL TOGETHER, BRING IT ALIVE
- DESCRIBE HOW DISCOVERIES AND UNDERSTANDING OCCUR IN ASTRONOMY
- PROVIDE MOTIVATION
- MAYBE EVEN SOME HUMOR

## STUDY OF SCIENCE

- SCIENCE IS:
  - THE COLLECTION OF FACTS AND OBSERVATION OF PHENOMENA
  - THE EFFORT TO FIND AN UNDERLYING ORDER AND UNDERSTANDING

## ASTRONOMY

- THE STUDY OF THE UNIVERSE
- FROM OUTSIDE THE EARTH'S ATMOSPHERE TO THE LIMIT OF OBSERVATION

## OBSERVATIONAL ASTRONOMY:

- DISCOVERY OF COMPONENTS OF UNIVERSE (PLANETS, STARS, NEBULAE, BLACK HOLES, GALAXIES)
- OBSERVING THEIR PROPERTIES
- SURVEYING AND MAPPING THEIR DISTRIBUTION IN SPACE

## ASTROPHYSICS AND THEORY

- UNDERSTANDING THE PHYSICAL PROCESSES OF THE OBJECTS IN THE UNIVERSE
- DETERMINING THEIR COMPOSITIONS, ORIGINS, EVOLUTION, FINAL STATES

# COSMOLOGY

- THE STUDY OF THE UNIVERSE AS A WHOLE AND HOW IT HAS EVOLVED

## THEMES

- DISTANCE SCALE OF UNIVERSE -
  - IT DETERMINES FUNDAMENTAL PROPERTIES OF OBJECTS
- GRAVITY
  - AN OVER-RIDING FORCE IN ASTRONOMY
  - CONTEST OF GRAVITY AND PRESSURE IN STELLAR EVOLUTION

## Origins

- ORIGIN OF ELEMENTS
- FORMATION AND EVOLUTION OF STARS AND GALAXIES
  - e.g., The Birth, Life, and Death of Stars

## WHAT IS A STAR?

- WE SEE PLANETS BY REFLECTED LIGHT, STARS BY THEIR OWN LIGHT
- STARS: SELF-LUMINOUS, GASEOUS BODIES HELD TOGETHER BY THEIR OWN GRAVITY

## MEASURING THE STARS

- We begin with two main topics
  - How do we measure distances to stars?
  - How do we measure motions of stars?
- Refer to Ch. 19 of text

## DISTANCE

- ONE OF THE MOST FUNDAMENTAL MEASURES OF ASTRONOMY.
- SETS SCALE FOR SOLAR SYSTEM, FOR THE GALAXY, FOR THE UNIVERSE.
- ALSO RELATED TO TIME SCALE OF UNIVERSE

## TWO IMPORTANT CONCEPTS

- PARALLAX
- ARCSECOND

### Parallax

- Parallax
  - “The apparent displacement of an object because of a change in the observer’s point of view” (text, p. 410)
  - It is an *angle*
- Stellar parallax
  - The angular shift of a star’s position for the Earth moving 1 AU (AU = Astronomical Unit = Earth-Sun distance)

### Angles

- Circle has 360 degrees or  $2\pi$  radians
- There are 60 arcminutes in 1 degree and 60 arcseconds in 1 arcminute
- Thus, 1 degree has 3600 arcseconds
- And, 1 radian has 206,265 arcseconds
- (Review Ch. 1, sec. 5 and 7 and accompanying boxes)

## PARALLAX DISTANCES

- STARS ARE DISTANT, THUS
- PARALLAX ANGLES ARE SMALL
  - LESS THAN 1 SECOND OF ARC
- PARSEC (FROM PARALLAX SECOND)
  - UNIT OF DISTANCE
  - DISTANCE FOR PARALLAX OF 1 ARC SEC
  - 206,265 AU (Astronomical Unit)

## DISTANCE FORMULA

- DISTANCE IN PARSECS =  $1/P$ 
  - P IS PARALLAX IN ARCSEC
  - IF  $P = 1$  ARCSEC, DISTANCE IS 1 PARSEC
  - IF  $P = 0.1$  ARCSEC, DIST = 10 PARSECS
  - 1 PARSEC = 3.26 LIGHT YEARS
    - 1 LIGHT YEAR = DISTANCE LIGHT TRAVELS IN ONE YEAR

## PRACTICAL MATTERS

- PARALLAXES HARD TO MEASURE
  - ANGLES ARE SMALL (1 ARCSEC IS THE SIZE OF A DIME 1.3 MILES AWAY)
  - LIMIT FROM GROUND HAS BEEN LESS THAN 100 PC
  - NOW, HIPPARCOS SATELLITE REACHED TO BEYOND 100 PC
- NEAREST STAR HAS  $P = 0.77$  ARCSEC
  - $D = 1.3$  PARSECS OR  $4 \frac{1}{4}$  LIGHT YRS
- NEXT NEAREST STARS ARE A FEW PARSECS AWAY
- SPACE NEAR SUN IS VERY EMPTY!

## SUMMARY

- PARALLAX METHOD:
  - ONLY DIRECT WAY TO MEASURE DISTANCES TO STARS
  - BASIS FOR ENTIRE DISTANCE SCALE OF UNIVERSE
  - OTHER METHODS FOR DISTANCES ARE INDIRECT

# MOTIONS OF STARS

- PROPER MOTION
  - HOW A STAR'S APPARENT POSITION CHANGES ON THE SKY. OFTEN MEASURED FROM PHOTOGRAPHS TAKEN AT DIFFERENT TIMES
  - AN ANGULAR MOTION
  
- RADIAL VELOCITY
  - SPEED ALONG LINE OF SIGHT. MEASURED FROM DOPPLER SHIFTS
  - Review Ch. 5-9 & Box 5-6
- PROPER MOTIONS AND RADIAL VELOCITIES ARE THE MOTIONS WE CAN OBSERVE!

## WHAT DO MOTIONS TELL US?

- IF WE KNOW DISTANCE,
  - CAN CONVERT PROPER MOTION INTO TANGENTIAL VELOCITY, VELOCITY ACROSS LINE OF SIGHT
  - THEN CAN COMBINE TANGENTIAL VELOCITY WITH RADIAL VELOCITY TO GET SPACE VELOCITY

## WHAT DO WE OBSERVE?

- SUN IS MOVING WITH RESPECT TO NEARBY STARS
- WE ARE MOVING TOWARD A POINT BETWEEN THE CONSTELLATIONS HERCULES AND LYRA AT ABOUT 20 KM/SEC
- NEARBY STARS DEFINE LOCAL STANDARD OF REST

- WE'LL SEE LATER THAT THE SUN AND NEARBY STARS ARE ALL ORBITING ABOUT THE CENTER OF OUR GALAXY

## Summary

- Measuring distances to stars
  - Definition of parallax, which is an angle
  - Caused by orbit of Earth around Sun
  - Definition of parsec (=3.26 light years)
  - All stars are more than 1 parsec distant
- Motions of stars
  - Proper motion
  - Radial Velocity
  - Motion of Sun with respect to nearby stars
  - Local Standard of Rest

# Astronomy 162

## Week 1, Part 2

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Spring, 2006

### Main Topics for Today

- Brightness of stars, luminosities
- Colors of stars, temperatures
- Spectra of stars, physical properties
- Hertzsprung-Russell diagram
- Ch. 19 continues to be the reference in the text

### Brightness of Stars

- We have discussed measuring distances and motions of stars
- Their brightnesses are also fundamental
- Combination of brightness and distance will tell us much about the nature of stars
- How? Why do we care?
  - Brightness is a measure of energy output of a star (if we know the distance)

### Apparent Magnitudes

- The eye works on a logarithmic scale
- Good thing - range in brightness from daylight to a dark night is tremendous
- Hipparchus (129 B.C.) introduced magnitude scale with categories:
  - Brightest stars - 1st magnitude
  - Faintest stars - 6th magnitude

- Pogson (19th century) noted that brightness ratio of 1st (bright) and 6th mag. (fainter) stars was about a factor of 100
- Today - a difference of 5 magnitudes is **defined** to be a factor of 100
  - diff. of 1 mag is factor of 2.512 in brightness
  - diff. of 10 mag is factor of 10,000
  - fainter stars have larger numerical magnitudes

## Luminosity

- Luminosity –
  - the total rate of energy radiated by a star
  - measured in watts, for example
  - also referred to as bolometric luminosity
- Solar luminosity
  - the luminosity of the sun –  $4 \times 10^{26}$  watts
  - convenient unit of reference for other stars and for galaxies

## Absolute Magnitude

- Another measure of total luminosity of a star
- Use a reference distance of 10 parsecs
  - (convenient for nearby stars)
- Absolute magnitude defined to be magnitude a star would appear to have if it were placed at a distance of 10 parsecs

## Inverse square law

- Stars get fainter as the square of their distance
  - twice as far away means four times fainter
  - 10 times more distant means 100 times fainter (5 mag. fainter)
- However, for stars at, say, 10 parsecs distance, differences in brightness reflect differences in true luminosity

## Apparent, Absolute Magnitudes, and Distance

- Two stars of same apparent brightness can have much different luminosities, distances
  - For example, the stars Capella and Rigel appear to have the same brightness
  - But, Capella is 13 parsecs away  
Rigel is at 280 parsecs
  - Thus, Rigel has a higher total luminosity

## Relation of distance and magnitude

- $M = m + 5 - 5 \log d$ 
  - M: absolute magnitude
  - m: apparent magnitude
  - d: distance in parsecs
- Note that for  $d = 10$ ,  $m = M$ , as it should
  - for  $d = 100$ , m is 5 mag. fainter than M
- If we know m, M, can determine distance

## Key concept - Colors of stars

- Stars do have different colors
- In Orion, Rigel is blue, Betelgeuse is red
- What does this mean?
  - Colors indicate the temperature of the surface of a star
  - A red star is cooler than a blue star
- Colors are determined numerically by measuring ratio of brightness of star in different filters
  - for example, using a blue and yellow/green (visual) filter
  - a blue star will be brighter in blue filter compared to the visual filter
  - red star will be brighter in the visual filter

- Magnitude system well suited for colors
  - B-V means ratio of brightness in blue and visual, because magnitudes are logarithmic
- But, a single filter captures only part of energy emitted by star
- We would like to know the total energy or luminosity of a star
  - Need many filters or a different technique

## Spectra

- Passing light through a prism or grating produces a spectrum
- For stars, spectra enable us to determine:
  - Radial velocity
  - Temperature
  - Chemical composition
  - Pressure
  - Speed of rotation
- Review spectra
  - (Review Ch. 5 as needed )
  - Continuous
  - Emission line
  - Absorption line
  - Every chemical element has spectral signature

## Composition of Stars

- Work of Cecilia Payne
  - used spectroscopic observations and atomic physics
  - found that stars are mostly hydrogen and helium, very unlike the earth

## Rotation of Stars

- Another fundamental property of stars is how fast they rotate -
- Different stars rotate at different rates
- Rotation broadens their spectral lines via the Doppler effect (in a different way from pressure or luminosity effects)

# Spectra and Astrophysics

- Pickering, Fleming, Maury, Cannon pioneered study of stellar spectra
- They developed:
  - Classification system
  - Spectral sequence
  - Spectral types
- They defined type A to be stars with the strongest lines of hydrogen

## Spectral Sequence

- Application of atomic physics showed:
  - **Spectral sequence is a temperature sequence**
  - Correct order of types from hottest to coolest is
  - O B A F G K M
  - O stars are hottest (40,000 deg), have weak hydrogen lines (because hydrogen is ionized), show lines of ionized helium
  
  - A stars, 10,000 deg, strong hydrogen lines
  - G star (Sun), 5,500 deg, weak hydrogen, medium ionized calcium
  - M stars, 3,000 deg, very weak hydrogen lines, strong TiO (molecule) lines
  - Review Fig. 19-11, 19-12, Table 19-2
    - They contain very valuable information

## Hertzsprung-Russell Diagram

- Key to understanding nature of stars
- 1911- Hertzsprung graphed apparent magnitudes and colors for stars in clusters
  - Such stars are at same distance from us
  - Thus, apparent magnitude is indicator of relative luminosities

- 1913 - Russell graphed absolute magnitude vs. spectral type for nearby stars
- Both astronomers found a sequence of stars in their graphs, not a random distribution
- Their work led to the major observational tool for understanding the structure and evolution of stars
- Now called the H-R diagram

## Main points of H-R Diagram

- Vertical axis corresponds to luminosity
- Horizontal axis corresponds to temperature
- Luminosity and temperature turn out to be fundamental, physical parameters for stars
- Main sequence runs from cool stars of low luminosity to hot stars of high luminosity
- Stars above main sequence are the giants and supergiants
- Stars below and to left of main sequence are the white dwarfs
- Russell noted in his famous 1914 article the existence of:
  - Main sequence
  - Giant sequence
  - The selection effect that the apparently brightest stars in the sky are intrinsically more luminous than average stars

## Bright Stars in the Winter/Early Spring Sky

- Learn where Orion is in sky. Identify
  - the stars Rigel and Betelgeuse in Orion
  - the belt stars
  - the sword and its nebulosity
- Look for Pleiades star cluster (Fig. 19-6b)
- Also the stars Sirius, Procyon, Castor and Pollux
- (refer to Star Charts, p. S-2 to S-4, of text)

# Summary

Today we have discussed brightness, colors, and spectra of stars and how the luminosity is found from the apparent brightness and distance. Colors or spectra indicate the temperatures of stars. Spectra also yield astrophysical information about stars, such as their chemical composition, atmospheric pressure, and rotational speed. Luminosity and temperature are two of the fundamental properties of stars; the H-R diagram provides important clues about the nature of stars.

# Astronomy 162

## Week 1, Part 3

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### Next topics

- Sizes of stars
- Luminosity classification
- Distribution of stars in space

### Relation of Luminosity, Temperature, Radius of Stars

- Recall radiation laws

$$L = 4 \pi R^2 \sigma T^4$$

- If star doubles in size, its luminosity increases by a factor of 4
- If temperature doubles, luminosity increases by a factor of 16

### Sizes of Stars

- Thus, we can find the radius (size) of star from the luminosity and temperature
- Traditional size classes are
  - Dwarfs (main sequence stars)
  - Giants (bigger)
  - Supergiants (really big)
  - Note also the white dwarfs, which are very small in comparison

### The Scale of Stars

- Sun
  - 109 times larger in radius than Earth
  - 333,000 Earth masses
  - Luminosity is  $4 \times 10^{26}$  Watts (equiv. to 4 billion atomic bombs per sec)  
also equiv. to 1.4 kW per sq meter at distance of Earth

- Sirius – about twice the diameter of the Sun
- Rigel – 80 times size of Sun
- Betelgeuse – 800 times size of Sun
  - (3.7 AU radius, almost to Jupiter)
- M dwarf – 1/8 size of Sun

## Luminosity Classes

- Maury noted hot stars had different spectral line widths
- Also found that stars with narrow lines had smaller proper motions (thus are farther away)
- They turned out to be more luminous intrinsically
- This effect provides a way to get stellar luminosities from their spectra

## Luminosity Classes

- Range from I (brightest) to V (faint)
  - Ia - Bright supergiant, Ib - Supergiant
  - II - Bright giant
  - III - Giant
  - IV - Subgiant
  - V - Main sequence (or dwarf)

## MKK Classification

- Morgan, Keenan (Ohio State), Kellman
- developed system used today
- established temperature and luminosity classes for stellar spectra
- Examples: Betelgeuse is class M2Ia - a cool supergiant
- Arcturus - K1 III - warm giant
- Sun - G2 V - dwarf (main sequence star) with temp = 5800 deg (absolute)

## Summary

- If we measure the apparent brightness of a star and classify its spectrum,
- we can determine its temperature, absolute luminosity, and distance
- A very powerful application of astronomy and physics

## Distribution of Stars in Space (19-2, p. 414)

- How many stars of the different spectral types are there in a volume of space?
- This is important for understanding:
  - How mass is distributed among stars
  - Later, we'll see it's related to the nature of the Milky Way galaxy and to where stars form and evolve

## Selection effects

- Counting stars is easy, but interpreting results isn't. Why?
  - Look at Appendices 4 and 5
    - The brightest stars in the sky are more luminous than the sun
    - The nearest stars are in general much less luminous
    - Why does this happen?
  
  - We can see luminous stars to much greater distances than we can less luminous ones
  - The sample volume is proportional to the cube of the distance
  - At 100 pc we sample a volume 1000 times greater than at 10 pc
  - Thus we need to determine the density of different types of stars
- 
- Recall that density is number per volume
  - The density of red dwarf stars is much higher than for hotter and more luminous stars (O and B types)
  - Thus, a sample of the apparently brightest stars is not representative of the true frequency in space.

## Summary of 1st week

- Have covered material from Ch. 19 in book - read for comparison and information
- We have covered:
  - Distances and motions of the stars
  - Apparent and absolute magnitudes
  - Colors and temperatures

- Spectra and spectral classification of stars  
O B A F G K M sequence
- Luminosity classes of stars (M2 I, G2 V, etc)
- The H-R diagram
  - Color - Magnitude diagram for clusters
  - Sp. type - Abs. Mag diagram for stars w. parallaxes
  - Luminosity - Temperature diagram (astrophysics)
  - Main sequence, giants, supergiants, white dwarfs
  
- Relation of luminosity, temperature, radius of stars
- Sizes of stars
- Distribution of stars in space
  - Selection effect makes O, B stars appear over-represented
  - Red dwarfs are more frequent than other types