

Astronomy 162

Week 2, Part 1

Patrick S. Osmer

Spring, 2006

Announcement

- 1st quiz on Friday, April 7
- Review Session – Wednesday, April 5
5:00PM, Planetarium (5033 Smith Lab)
 - So far, we have learned about, for stars,
 - Distances
 - Motions
 - Brightnesses and colors
 - Luminosities
 - Spectra
 - This tells us about the scale and nature of nearby universe
 - Also about the physical nature of stars
 - This week, we'll pursue both themes
by studying groupings of stars
 - first, Binary stars
 - then, Clusters of stars
 - They tell us about the mass and evolutionary states of stars and,
 - about the distribution and structure of matter in the universe

Binary stars

Ch. 19, Section 9, 10, 11

- Two stars in orbit about each other
- Three types
 - Visual
 - Spectroscopic
 - Eclipsing

- The types come from the different ways we can observe binaries
- Visual - observe two stars orbit each other
- Spectroscopic - observe changes in radial velocity
- Eclipsing - observe changes in brightness

Visual Binaries

- History - Herschel showed Castor was a true double star by 1803
- What did he observe?
 - Changes in the position angle
 - and in separation, denoted by letter a
- What can we learn from this?

- Recall Kepler's 3rd law of planetary motion

$$M_A + M_B = a^3/P^2$$

- Sum of the masses goes as the cube of the separation divided by the square of the period
- If we can determine a , the separation, in AU, and P , the period, in years, we can get the sum of the masses of the two stars in unit's of the sun's mass

Gravity theme

- Remember - the basis for Kepler's 3rd law is (Newton's) law of gravity
- Main point - the law of gravity plus observations of double stars allows us to determine the *masses* of binary stars directly!

Visual binaries, continued

- The harder parts:
 - to get masses, we must know the distance to the binary (from parallax if close enough)
 - the plane of the orbit is usually inclined to the line of sight
 - but we can correct for this
 - and get the ratio of the masses of the two stars

–

What conditions favor observations of a visual binary?

- Stars must be fairly close
 - so orbital period is not too long
 - but still see them as separate stars
- Also, orbit is easier to observe if it is more face on than edge on

Spectroscopic Binaries

- What if we can't see both stars separately?
 - because more distant or too close
- Or, What if orbit is more edge on?
- We can observe the changes in radial velocity (if we have good spectroscopic data)

Data

- We can determine the orbital period and observe how much the velocities change
- Can also rewrite Kepler's 3rd law to make use of velocities instead of separation
- So, can also determine mass of system (if we know the inclination)

Summary so far

- Binary stars orbit each other (because of mutual gravity)
- From Kepler's 3rd law, can get their masses in favorable cases
- The observed type of binary depends on distance from Sun, separation of the two stars, and the inclination of the orbit

- Visual binaries - both stars can be seen and orbit measured
- Spectroscopic - lines of one or both stars can be seen and the radial velocity changes measured

Eclipsing binaries

- Special case - orbit nearly edge on
 - One star can pass in front and eclipse the other.
- What do we see?
 - During the eclipse, the stars get fainter
 - We can observe the brightness of the system and determine the period of the orbit. Can also determine the duration of the eclipses.

What does this tell us?

- From the light curve, we can determine the inclination of the orbit and the sizes of the stars relative to their separation
- If system is also a double-line spectroscopic binary, we can get
 - the masses of both stars
 - diameters of both stars
 - relative surface brightnesses of both stars, which gives their temperatures

Sirius - a fascinating binary

- History - Bessel - 1844 - noticed Sirius (the brightest star in the sky) had a wavy motion on the sky.
- He concluded it had an unseen companion
- Measures were made, orbit calculated, before companion was discovered
- Clark - 1862 - testing a new 18 in. telescope, was first to see the companion

- Thus, Sirius is a visual binary.
 - Sirius A has magnitude -1.5, Sirius B, 8.6 mag. (note the large difference)
 - Period of system is 50 years
 - a is 7.5 arcsec, distance is 2.7 parsecs
 - sum of masses is 3.2 solar masses
 - bright star is about 2 solar masses
 - faint star is about 1 solar mass

- Faint companion was first discovery of a white dwarf star
- Radius is about 1/100 of sun (earth size), but mass is about 1 sun
- Density is approx. 1 million times density of water
- White dwarfs are made of a new state of matter

Astronomy 162

Week 2, Part 2

Patrick S. Osmer

Spring, 2006

Outline

Today we will finish our discussion of the main properties of stars as individual objects and begin to study how the properties of stars that live in large groups, called clusters.

We will see begin to see how such observations have given us key insights into the physical nature of stars and why mass is one of the most fundamental properties of a star.

Later in the course we will see how the study of stars in clusters helped solve the mysteries of how stars evolve with time during the life of the universe.

Mass-Luminosity Relation

- We now have ways of measuring the mass and luminosity of stars
 - Some are only 0.1 solar mass
 - Others are nearly 100 solar masses
 - Luminosities can go from 10^{-4} to 10^6 solar
- A surprising result is that mass and luminosity are very well correlated for main-sequence stars
 - see Fig. 19-20, 19-21 in text - Mass-luminosity relation
 - Luminosity is proportional to $M^{3.5}$ (M is mass)
 - Giants, supergiants, white dwarfs do not follow the relation

Stellar densities

- Note that there is also a huge range in densities
 - Main sequence stars have average density like that of water
 - Giants, supergiants much lower density (because of their large size and volume)
 - White dwarfs much more dense than water (because have one solar mass in volume of earth)
- This is a clue that internal structure (and history) of main sequence stars, giants and supergiants, and white dwarfs are much different

Recap Main Properties of Stars

- Sun
 - 109 times larger in radius than Earth
 - 333,000 Earth masses
 - a typical star
- Stars
 - Masses of about 0.1 to nearly 100 times Sun
 - Sizes from about 0.01 to 1000 times Sun
or, from about Earth size (white dwarfs) to filling the solar system nearly to Jupiter's orbit
 - Composed mostly of hydrogen and helium

Clusters of stars

- With binoculars, one can see that some stars exist in large groups or clusters
- Clusters provided key information to solving the mystery of the structure and evolution of the stars
- Recall Hertzsprung's work on H-R diagram

Clusters of stars

- Three main types
 - Open clusters
 - Globular clusters
 - Associations

Open Clusters

- Examples: Pleiades, Hyades
- Properties
- Loose, irregular shapes
- Diameters: 1 to 20 parsecs
- Located near disk of Milky Way Galaxy

Open Clusters

- H-R diagrams (color-magnitude)
 - usually show normal main sequence
 - don't usually have giant stars
 - we'll see later that H-R diagrams indicate ages of clusters

Globular Clusters

- Large, round-looking clusters of stars
- Held together by their own gravity
- Can have up to a million stars
- Are distributed throughout halo of Milky Way

Reference Web Sites

- Good image galleries can be found on the following web sites
 - Hubble Heritage Images (heritage.stsci.edu)
 - Hubble Space Telescope (www.stsci.edu)
 - National Optical Astronomy Observatories (www.noao.edu)

Globular Clusters

- H-R diagrams
 - short main sequence
 - many giants
 - also stars on a horizontal branch between giants and main sequence
 - We'll see that globular clusters are very old

Associations

- Very loose groupings of O and B-type stars
- Unlike clusters, the groupings are not held together by their own gravity
- The stars formed together, but now are separating
- The stars and the associations are very young!

Summary of clusters

- Clusters are keystones for understanding the evolution of stars
- They are also important to understanding the formation of the galaxy

Astronomy 162

Week 2, Part 3

Patrick S. Osmer

Spring, 2006

The Interstellar Medium (ISM) and the Birth of Stars (Ch. 20)

- The ISM is the material between the stars
- Note interstellar space is very empty
- a very high vacuum
- But not completely empty
- It has the material from which stars form
- Terms - nebula (singular), nebulae (plural)
- Latin for clouds

How empty?

- 1 cubic cm of air on earth contains 10^{19} atoms
- The ISM might have only 1 atom
in 1 cubic cm

Interstellar Medium (ISM)

- The material between the stars
- It is mostly gas and dust
- Dust is only 1% of the total mass of ISM
- Almost all mass is in the gas
- Gas temperatures range from 10 deg absolute to millions of degrees

ISM, continued

- The ISM contains the regions where stars are being born today
- Star formation is the beginning of the story for stars
- First let us learn more about the ISM

Diffuse Emission Nebulae

- Orion nebula is most famous example
 - see with unaided eye or with binoculars
- Diffuse nebulae glow or **fluoresce**
- Process is like black (ultraviolet) light and glowing paints
- Fluorescence - conversion of ultraviolet radiation to visible light

Fluorescence

- The glowing gas near hot stars shines by conversion of ultraviolet light of stars to visible light