**Lecture 4: Stars**

* 1. Bright stars in the northern Spring sky
     1. Note the major constellations. You will become very familiar with Orion. Betelgeuse and Rigel are its brightest stars; as we'll see one is red one is blue.
     2. Taurus is this V-shaped one, with Aldebaran
     3. Pleiades is a very noticeable young cluster of stars
     4. Capella right now in the evening is directly overhead
     5. Castor and Pollux are this pair
     6. Regulus is rising in the East in the evening
     7. To the south the brightest star in the sky is Sirius
     8. To the North lies Polaris, flanked by Cassiopeia and the Big Dipper (part of Ursa Major)
     9. Merak and Dubhe point to Polaris
     10. You should get very familiar with this
     11. **As a test, if I tell you that Rigel is at RA = 5h 14m, what LST does this map correspond to?**
     12. **Can you figure out what day this would be actually at 8pm?**
     13. Today we are going to learn about what the stars ARE
  2. Colors and magnitudes
     1. Colors and magnitudes can be measured. Magnitude is a measure of brightness
     2. astronomers can measure color in a manner similar to your eye by inserting a filter in front of a camera.
     3. e.g. here are some common filters used in astronomy: U B V R I
     4. Notice they extend beyond the visible! In fact, astronomers observe over many wavelengths.
     5. Astronomers use these and calculate the magnitudes as a function of wavelength
     6. Often expressed as a color index: B-V, difference in magnitudes
     7. Because magnitudes are logarithmic, this would be the ratio of B light to V light
     8. It turns out that if you look at bright stars, they have an interesting color distribution
     9. Some very blue stars, some very red stars, not much in between
     10. This, it turns out, tells us a LOT about stars
  3. Luminosity
     1. But first we need to know something about not their APPARENT brightness
     2. but their INTRINSIC brightness, or what is known as their luminosity
     3. as you know, a faint object may be intrinsically faint, or just far away
     4. Apparent brightness, or magnitude, is smeared out due to distances: f = L/4pi d^2
     5. **Can you explain why this relationship?**
     6. This figure will become much clearer when y axis is ACTUAL luminosity
     7. also can be expressed as a logarithmic quantity, the “absolute magnitude”
     8. (what the magnitude would be if the star were at about 30 light-years -- but don’t worry about that)
     9. upshot is a 25 W bulb will look as bright as a 100 W bulb twice as far away
     10. it was this principle which first led the astronomer John Herschel to guess that stars were very far away, considering their brightness and assuming they were similar in luminosity to the Sun
  4. Parallax
     1. How do we know distances? direct distances to nearby stars are from PARALLAX
     2. Excellent story behind discovery of parallax in book “Parallax” by Alan Hirschfeld; sought for centuries but only measured in 1800s; lack of parallax was a strong evidence against the heliocentric theory.
     3. I’ll just give you the basics
     4. Recall that as you drive along the road, what is near streams by very fast, what is far does not
     5. This is simply due to parallax
     6. Allows you to estimate distance: the further away, the smaller the ANGULAR speed
     7. Same principle can be applied to stars
     8. E.g. imagine the following setup: we measure the position of star
     9. Then position six months later
     10. Must due this with reference to some very distant source, because actual angles are very small and hard to measure
     11. We can measure the angle theta; we know s (2 times distance from Earth to Sun)
     12. This makes a triangle, and in the small angle limit D = s/theta
     13. E.g. Proxima Centauri (closest star) has parallax of 1.4 arcsec
     14. This is a very small shift!
     15. This is the origin of the definition of a “parsec”: “parallax arcsecond”
     16. About 3 light years
     17. In reality, very difficult to measure, many competing effects and real-world complications
     18. But a satellite Hipparcos did it very well
     19. Here are some examples:
     20. note that one of the complications is that nearby stars are often moving noticeably!
     21. So doing a (very small!) spiral on the sky
     22. We still have a long way to go: only a tiny part of our galaxy mapped
     23. The Gaia satellite is now telling us a LOT more
  5. HR diagram
     1. Once you know the distance, you plot the luminosity vs color, the classic HR diagram
     2. Very striking pattern!
     3. Stars are classified on this diagram according to their color
     4. OBAFGKM
     5. Stars are often either on the “main sequence”
     6. Or on the “red giant branch” (e.g. Betelgeuse)
     7. Some remnants of dead stars are down here: the “white dwarfs” (e.g Sirius’s companion)
  6. But what does this all mean? Stellar formation
     1. Stars form in gas clouds in disks of galaxies
     2. Those clouds are known as HII regions
     3. E.g. Orion’s Great Nebula (M42) is one of these
     4. tens to hundreds of thousands of stars forming together
     5. gas in cloud collapses under its own gravity
     6. forms star and accompanying disk of material within a few million years
     7. in Orion and Taurus, we have seen these disks directly
     8. If the star is big enough (> 80 Jupiters or 0.08 solar masses), can generate internal energy from fusion
  7. Basics of atoms
     1. To understand fusion energy, it is worth recalling some basics about atoms
     2. remember atoms are made of protons and neutrons
     3. the lightest two atoms are hydrogen and helium
     4. 75% of the ordinary mass in the Universe is hydrogen, so stars are mostly hydrogen
     5. recall position on periodic table is determined by number of protons
     6. but atomic nuclei also have neutrons
     7. different isotopes: different numbers of neutrons
     8. e.g. a lone proton is a hydrogen atom
  8. Fusion in the Sun
     1. The hydrogen gas at the center of the Sun is very hot (10 Million degrees Celsius!)
     2. In such an environment, two protons can hit each other and “stick”
     3. But like charges repel, so they can’t really stick together wel
     4. Unless one of them turns into a neutron
     5. This creates deuterium (deuteron); held together by the "strong" force
     6. During this process, they emit various other particles, in particular “neutrinos”, positrons and photons
     7. Don’t worry too much about this, but basically, the energy in these particles is ultimately the energy source of the light of the Sun
     8. The proton and neutron form an atom known as a “deuteron”
     9. Which can run into another proton, to form He3
     10. Then two He3 atoms can run into one another and form He4, releasing two protons
     11. all told, 6 protons go into this process, and one He4 nucleus and 2 protons come out
     12. So, net, 4 protons have produced one He4 nucleus
     13. Also, as I note, some energy has come out
     14. how much energy? well, it turns out that He4 is just a tiny bit less massive than 4 protons
     15. by about 1%
     16. that 1% is essentially all turned into energy
     17. a consequence of the famous E = mc^2 equation
  9. The Main Sequence
     1. Stars spend most of their lives (about 90%) burning H to He in their cores like this
     2. these are the stars on the “main sequence”
     3. our Sun is a G star, and can maintain this H burning for 10 Gyrs (we are about 4.5 billion years into this).
     4. O stars are more massive than the Sun -- e.g. Delta Orionis is a 20 solar mass O star
     5. Only 20X as massive, but look, 1000s of times more luminous!
     6. Thus, it is burning its H much more quickly, and will end its life on the Main Sequence sooner
     7. The most massive stars live only 10 Myrs, very low mass stars will live 10s or 100s Gyrs
     8. More massive stars are also HOTTER at their surface
     9. Our Sun is about 5500 K at its surface, the hottest stars are 10s of thousands of K
     10. When a whole bunch of stars form they do so in clusters; e.g., in an open cluster, where young stars form in the Milky Way today, they first are all on the main seq.
     11. Then the most luminous ones die, and the lower and lower mass ones die late and later
     12. What happens when they run out of hydrogen in their cores?
  10. Post Main Sequence: massive stars (> 8 solar masses)
      1. when hydrogen runs out in the core, core sinks deeper
      2. helium ignites, starts burning into higher mass elements
      3. that runs out quickly, and higher mass elements start burning
      4. many of the high mass elements are created in this process
      5. ultimately, iron forms, and it turns out that you can’t burn iron into anything else
      6. it has the least mass per nucleon
      7. at the point you have an iron core, it quickly collapses
      8. basically vaporizes, and a massive supernova goes off
      9. many of the elements returned to gas between the stars
      10. what is left over? perhaps sometimes a BH, sometimes a “neutron star”
      11. there is a good example, of a SN in a nearby galaxy that went off in 1987
      12. “SN 1987A” here is the before and after
      13. this was a quite distant star, but the SN was visible to the naked eye
  11. Post Main Sequence: low mass stars (< 8 solar masses)
      1. after hydrogen runs out in core, starts burning in a shell around core
      2. outside expands by factors of 100 or more, becomes a “red giant”
      3. here is an example: Betelgeuse, also Acturus and Aldebaran
      4. Betelgeuse is close enough we can \*measure\* its size (just barely!)
      5. for example, it is likely that when the Sun reaches this point ...
      6. it will swell such that the Earth is subsumed in its atmosphere
      7. expels gas from its atmosphere
      8. you can see this happening with Antares
      9. leaves behind a very hot “white dwarf” star
      10. for 50,000 yrs or so produces a “planetary nebula"
  12. Let’s see how that affects the HR diagram
      1. system starts as main sequence
      2. blue stars die quickly
      3. red stars become red giants at end of their life
      4. a young system like an open cluster just shows the Main Sequence
      5. the Pleiades is one of these, recall
      6. an old one like a globular cluster shows the RG branch
      7. nearby us in the galaxy, there is a mix of stellar ages
      8. Main Sequence has all young stars, and the low mass old ones
      9. RGB are old stars that just died
      10. Remnants of old stars that already died seen in white dwarfs
  13. NEED TO REMOVE A LOT OF WHAT IS BELOW!
  14. Definition of constellations
      1. let’s look at the brightest stars, and take a first look at them
      2. it is convenient to understand the sky in terms of the constellations
      3. original groups of stars, mostly defined by chance alignments on sky (not physical associations in three dimensions)
      4. but now defined in terms of regular lines in RA/Dec, as you saw in celestial sphere lab
      5. the brightest stars often have their own name, Greek, Latin, or often Arabic
      6. but stars also are named by their constellation: Greek letters from brightest to faintest: alpha, beta, gamma, delta, epsilon etc; often approximate as some have changed brightness or been reevaluated
      7. or “Flamsteed” number (in order of RA), which fainter stars in a constellation will have
      8. or some pretty obscure catalog name!
  15. Ursa Major:
      1. Let’s begin our tour near the North Celestial Pole
      2. Probably the easiest constellation to recognize is Ursa Major
      3. contains the Big Dipper; a great place to start when orienting yourself
      4. a massive star at most a few 100 Myr old, Mizar is actually a binary with Alcor
      5. with excellent eyesight in a good location you can see it: used as a test of eyesight by the ancient Arabs; also known as the horse & rider
      6. Mizar is itself a double star (the first binary to be identified with a telescope)
      7. it is actually six stars in a bound system
      8. Merak & Dubhe define the side of the ladle, point to Polaris
  16. Ursa Minor/Little Dipper
      1. Polaris is a star a bit more massive than our Sun, about 6 X more massive
  17. Casseiopia: Cass A
      1. On the other side of Polaris is Casseiopia, with the bright star Cass
      2. part of this characteristic W, opens up to Polaris
      3. has the massive blue star Caph
      4. inside this constellation is a famous extragalactic object Cass A
      5. a very detailed HST image (recall, this sees much deeper than you can!) shows this
      6. remnant of a SN about 300 yrs ago; not definitively recorded by anybody though
  18. Cepheus:
      1. In Cepheus, is one of the most important stars in history: Delta Cephei
      2. the prototypical Cepheid variable star
      3. they vary in magnitude
      4. the period of this variation is longer for brighter Cepheids
      5. discovered in 1912 by Henrietta Leavitt
      6. laid the groundwork for Edwin Hubble’s work, helped show universe's expansion
  19. Perseus:
      1. Algol
         1. one of the oldest known “eclipsing binary stars”
         2. two stars orbiting extremely closely
         3. with our view such that one blocks the other
         4. when hot blue star in back, a deep eclipse, for a few hours
         5. repeats every few days
         6. while this is an obvious case, it turns out that this same technique can be used to find much smaller orbiting objects, like planets
         7. the satellite Kepler has found over a 1000 candidates
         8. e.g. here is one of their confirmed planets around another star
         9. this one is a bit smaller than Jupiter
         10. 19 day period, a few hours transit
         11. < 1% decrement in flux!
  20. Andromeda
      1. M31 (nearest large galaxy)
      2. only galaxy MW-sized close enough to see naked eye (very dark sites only!)
      3. like our galaxy, 10s of billions of stars
      4. example of a Messier object
  21. Messier Catalog
      1. 110 objects
      2. Charles Messier, in 1700s, was looking for comets
      3. comets look like fuzzy little patches, that move from night to night
      4. but a lot of things look like fuzzy little patches, but don’t move
      5. Messier made a list of fuzzy things that were NOT comets: Messier Catalog of 1771
      6. quite a grab bag
      7. M31, but some other nearby galaxies too
      8. open clusters: systems filled with young stars that just formed
      9. globular clusters: ancient systems of stars
      10. planetary nebulae (stars like our Sun that just died)
      11. stellar nurseries like Orion nebula (M42)
  22. Taurus
      1. Pleiades (young star-forming region, ie. open cluster)
         1. 100 Myrs old
         2. 360 lyrs away
      2. Hyades (young star-forming region)
         1. a little older: 600 Myrs old
         2. 150 lyrs away
      3. Aldebaran
         1. not actually in Hyades, a red older star
  23. Orion
      1. after big dipper, most easily recognizable
      2. the belt, the sword, the bow (harder to see)
      3. Betelgeuse
         1. a truly massive star: 20 X the mass of our sun
         2. a red supergiant
         3. near the end of its life (though not necessarily going to explode in 2012)
      4. Rigel
         1. similar mass to Betelgeuse but blue
         2. we will learn later more about that
      5. Great Nebula (M42)
         1. a region of vigorous ongoing star-formation
         2. about 1300 light years away
         3. about 25 light years in size
         4. a cloud of neutral and molecular hydrogen, forming new stars
         5. lit up by the light from very massive young stars
         6. dust formed in outflowing gas from young stars
         7. a stellar “nursery”
         8. very young, still ongoing star formation
         9. will become a classic open cluster in next 100 Myr years or so
  24. Canis Major
      1. Sirius (and companion)
         1. brightest star on the sky
         2. not incredible massive (2 X mass of sun) but very close (8 lyr)
         3. has a much fainter companion: it is a binary star
         4. but in this case the companion is a white dwarf (8th mag)
         5. period of 50 years!
         6. first inferred due to motion of Sirius A in 1844 by the astronomer Bessel
      2. Procyon
         1. Interesting, Procyon nearby ALSO is about the same mass and distance
         2. 1.4 X mass sun, 11 lyrs (so fainter and further)
         3. also has a WD companion, in this case 13th mag , with a period in this case 40 years
  25. Leo
      1. Regulus: 3.5 X mass of the sun
      2. rotates very fast: so fast it is barely held together
      3. all stars rotate, but most not so extremely
      4. our Sun rotates every 25 days, Regulus every 16 hours
      5. probably related to its being very young
  26. Cancer
      1. One of my favorite objects is near here, in the constellation Cancer
      2. the Beehive (M44), an open cluster about 600 lyrs away, 600 Myrs old
      3. like a further away version of the Hyades
  27. Gemini
      1. Castor
         1. another binary star! found very early on, in 1678
         2. a period of 467 years!
         3. two comparably bright stars, about 2 arcsec apart right now
         4. (about 6 arcsce when found)
         5. each one similar to Sirius; system about 50 lightyears away
      2. Pollux
         1. a red giant
         2. interestingly, has a planet, about 1.6 AU, 2.3 times mass of Jupiter
         3. discovered originally in 1993, though not published until 2006
  28. Auriga
      1. Capella
         1. another binary, actually 4 bound stars, discovered in 1899
      2. Elnath
         1. a young massive star
  29. I haven’t really gone through all the constellations, which isn’t my intention anyway; I just want to introduce you to some of the easily visible stuff up right now; during the course of the year this changes; it is worth looking up at night in the Spring, Summer, Fall and seeing how the evening sky changes, and to see these patterns the constellations are incredibly useful, since you will find yourself seeing Castor and Pollux as just really looking like a pair of twin stars, and Auriga looking like a big hexagon, and starting to recognize these patterns.