Astronomy 1144 Exam 3 Review

Prof. Pradhan

Stars and Stellar Classification

1. What is a star's energy source, or how do stars shine?
    - Stars shine by fusing light elements into heavier ones.
    - During fusion, some mass is converted into energy. For example, a Helium-4 nucleus (two protons, two neutrons) is lighter than the four protons that went into making it.
    - This energy is radiated as light/heat, causing a star to shine.
2. Nuclear fusion, as happens in stars, requires extremely high temperatures. Why?
    - Atomic nuclei are partially made of charged particles (protons).
    - In order to fuse, two nuclei must be able to overcome the electrical repulsion from their protons.
    - High temperatures = higher particle speeds = more likely to fuse.
3. How are stars classified?
    - Mainly by temperature/color and spectral line strengths.
    - The spectral classes (OBAFGKML) are defined by the ratios of spectral line strengths.
    - The spectral class sequence is also a temperature sequence, with O & B stars being the hottest/bluest, and M & L stars being the coolest/reddest.
    - For example, the Sun has a surface temperature of roughly 5800 K and has spectral type G.
4. What is the Hertzsprung-Russell (HR) diagram? What are some of its main features?
    - A plot of luminosity vs. temperature for stars.
    - Stars only fall into certain places on the diagram - they may not have arbitrary properties.
    - Most stars lie on the main sequence, where they burn hydrogen into helium.
5. What is the single most important attribute of a star for determining its properties and evolution?
    - Its mass.
    - More massive stars are more luminous, tend to be larger, tend to be hotter, and live much shorter lives than less massive stars do.
6. What is a star's apparent magnitude? What is its absolute magnitude?
    - A star's apparent magnitude is its apparent brightness, or how bright it looks from Earth. It is affected by both how far away the star is from Earth, as well as the star's actual luminosity.
    - A star's absolute magnitude is defined as what a star's apparent magnitude would be if it were 10 parsecs away from Earth. It is related to the star's luminosity, or how much energy the star actually puts out in a given time. It does not depend on the star's distance from Earth.
7. What is the distance modulus? How can we use the HR diagram to get distances to stars?

- The distance modulus is: $m - M = 5\log d - 5$, where m is the apparent magnitude and M is the absolute magnitude. So we can find the distance to a star if we know both the apparent and absolute magnitudes of the star.
- If we measure the apparent magnitude of a star, we can use the HR diagram to find the absolute magnitude by measuring its luminosity class and spectral type. Then we can use the apparent and absolute magnitudes in the distance modulus equation to get the distance.

Star Formation and the Interstellar Medium

1. How, generally, do stars form?
    - They collapse from clouds of gas, called giant molecular clouds (GMCs).
    - As the clouds collapse, they fragment and heat up, until the cores of the fragments are hot and dense enough for hydrogen to begin fusing.
    - They typically form as a cluster, so that many stars are born in roughly the same area at roughly the same time.
    - The remaining gas left over from star formation remains as nebula. The nebula may glow as a result of the newborn star's radiation ionizing the gas.
2. What is interstellar dust, and how may it be detected?
    - Interstellar dust consists of the heavy elements produced in stars.
    - Its larges components are silicates and graphite-like compounds.
    - It often is not hot enough to significantly glow on its own in visible light, so it is detected by looking at how it absorbs and scatters light coming from behind it.
    - Blue light is scattered more strongly than red by dust, so dust reddens light passing through it.
3. What is a forbidden transition/line? Why are they important?
    - A forbidden transition/line is a spectral line resulting from a transition with a low probability of occurring. They are typically much weaker than ordinary spectral lines such as Hα.
    - They are important in astronomy because such lines are often seen in emission nebulae.
4. What is a binary star system? What are the different types of binaries?
    - A binary star system is when two stars orbit their center of mass.
    - There are three types of binaries:
        - Visual binaries - systems where the two stars can be resolved with a telescope and their orbits can be tracked.
        - Spectroscopic binaries - systems where the spectral lines from the stars are Doppler redshifted and blueshifted because of their orbits.
        - Eclipsing binaries - systems where one star passes in front of the other (transits) and the brightness changes. These are detected with the transit method.

Evolution of Low-Mass Stars

1. Where does a low-mass star like the Sun spend most of its life? What is it doing during this time?
    - Low-mass stars spend most of their lives on the main sequence, where they fuse hydrogen into helium.

- They typically fuse hydrogen via the proton-proton (p-p) chain, as their cores are not hot enough for CNO fusion.

2. When they exhaust their hydrogen supply, what happens to the low-mass stars?
   - When they exhaust the hydrogen in their cores, they start burning hydrogen in a shell around the core.
   - The outer envelope of the star massively expands and cools as the star grows much more luminous.
   - The star becomes a red giant, and moves up and to the right of the main sequence on the HR diagram.
3. How is core helium burning ignited? What happens to the star after that? By what process is helium fused?
   - Core helium burning begins explosively once the core is hot and dense enough; this is the "helium flash." Once the flash is over, the star stably burns helium.
   - After the helium flash, the star contracts and its surface gets hotter as it settles onto the horizontal branch. The star is still much brighter than it was on the main sequence.
   - Helium is fused via the triple-alpha process. Because Beryllium-8 is so unstable, three helium nuclei must come together very quickly to form Carbon-12.
   - Helium burning is *highly* temperature sensitive; while p-p fusion goes as T^4, the triple-alpha process goes roughly as T^{40}!
4. What happens after the end of helium burning?
   - These stars fuse hydrogen and helium in shells around the core, and rise up the asymptotic giant branch. The asymptotic giant branch (AGB) is named because it asymptotes to the red giant branch on the HR diagram; i.e., it gets closer and closer, but never touches or crosses it.
   - The star then puffs off its outer layers, as the AGB shell-burning configuration is unstable.
5. What is left of the star at this point?
   - When the star puffs off its outer layers, it generates a planetary nebula.
   - This nebula glows, because it is ionized by the high levels of radiation emitted by the now-exposed hot carbon-oxygen core of the star.
   - The core of the star, no longer able to fuse, cools and collapses to become a white dwarf.
   - Eventually, the white dwarf may crystallize, once it is cold enough to no longer be able to be a gas, and may effectively become a huge diamond/carbon crystal.
6. If white dwarfs cannot fuse, how are they supported against gravity?
   - White dwarfs support themselves against their own gravity through electron degeneracy pressure.
   - Due to the Pauli exclusion principle, electrons cannot be in the same quantum state as their neighbors, and thus cannot be in the same place as their neighbors.
   - This fact creates a pressure which can resist the star's gravity.
   - However, it also means that a white dwarf is very small, only about the size of the Earth.
   - The pressure from electron degeneracy is also not limitless; if, at the end of the star's life, the mass of its core is more than 1.4 solar masses, gravity will overcome the electron degeneracy pressure and the core will collapse further. This is called the Chandrasekhar Limit.

Evolution of Massive Stars

1. How is a massive star's early life different from a lower-mass star's?
    - Massive stars burn through their fuel much more quickly than low-mass stars, and are thus much, much brighter.
    - Because they burn their fuel much faster, they also live much shorter lives, and die relatively quickly. The most massive stars live only a few million years, while the Sun will end up living over 10 billion years in total.
    - Massive stars do not use the p-p chain to fuse hydrogen on the main sequence; instead, the high temperatures in their cores allow them to use the CNO cycle.
2. What happens to a massive star after it moves off the main sequence?
    - Massive stars are able to fuse helium into carbon and oxygen, just like low-mass stars.
    - They are, however, able to go further still, and burn carbon into oxygen, neon, and magnesium. In contrast to burning hydrogen or helium, this process takes about 1000 years maximum.
    - If the star is between about 4-8 solar masses, the burning stops there, and the star blows off its outer layers and becomes an oxygen-neon-magnesium white dwarf.
    - Above 8 solar masses, the star can burn oxygen, neon, and magnesium into silicon; this stage lasts no more than a few years.
    - Once a silicon core has formed, the star begins fusing silicon into even heavier elements, reaching iron and nickel.
    - The star's core at this point resembles an onion, with lighter elements burning in shells surrounding the core.
3. What happens to a massive star when it tries to fuse iron?
    - Iron fusion does not generate energy; instead, it consumes it. A star cannot continue to shine via iron fusion.
    - This means that the end of the line has been reached, and a stellar collapse is unavoidable.
    - The same as a white dwarf, however, the core is able to support itself against gravity via electron degeneracy pressure until it hits the Chandrasekhar Limit.
    - Once the core hits the limit, it collapses extremely quickly, becoming only a few kilometers across. The outer shells rush in to fill the void left by the collapsing core.
    - The inrushing material essentially bounces off the collapsed core and rebounds, destroying the star in a huge explosion known as a supernova.
    - The core is left behind and becomes either a neutron star or a black hole, depending on how massive it is.

Observatories & Telescopes

1. What is a telescope's main function?
    - To gather light, NOT magnify an image.
    - Astronomical objects are typically very faint, so a lot of light/radiation needs to be gathered together in order to get a good image.
2. What are the main parts of a telescope?

  - The objective, or main mirror/lens, which collects the light.
  - The eyepiece, a small lens/mirror which magnifies the image after it is formed from the light collected by the objective.

3. What are the two main types of telescopes?
   - Reflecting and refracting.
   - Reflecting telescopes (or reflectors) use mirrors to gather light.
   - Refracting telescopes (or refractors) use lenses instead.

4. What are some advantages of reflectors over refractors?
   - Reflectors can be built much larger than refractors, as mirrors may be supported much more effectively against gravity.
   - Reflectors do not suffer from chromatic aberration.

5. How does refraction work?
   - Light travels different speeds in different media.
   - Because of this, light waves bend when entering or leaving different media.
   - The amount by which light slows down and bends in a material compared to a vacuum is called the index of refraction. It is defined as the ratio between the speed of light in a material and the speed of light in vacuum.
   - The refractive index/index of refraction varies with the wavelength/frequency of light. Typically, red light is bent less by a material than blue light.

6. What about reflection?
   - At any interface between two materials of differing refractive indices, at least some light is reflected.
   - What fraction of the incoming light is reflected depends on many factors which can be ignored here.
   - The Law of Reflection states that the angle of incidence is equal to the angle of reflection; i.e., light will reflect off a surface at the angle it came in at.

7. Where are most observatories placed?
   - High, dry places far away from city lights.
   - These places offer good weather/clear skies, and a steady atmosphere.
   - They are also above much of the atmosphere's low level turbulence.

8. What wavelength ranges are available to ground-based telescopes?
   - The visible and near-infrared.
   - Radio waves with wavelengths above ~ 1 mm.
   - All others are blocked by the Earth's atmosphere, and must be observed from space.

9. What is the largest optical telescope in the world? How about the largest radio telescope?
   - The largest optical telescope is the Keck 10 m.
   - The largest radio telescope is the 1000 ft. Arecibo telescope.
   - Radio telescopes are almost universally much larger than their optical counterparts.