Astronomy 102: Stars and Galaxies
Spring 2003

Review topics for Examination 3

This test will cover material from Chapters 14, 15, 16, and 18. Some of the material in the text will not be covered on the test; the test will of course focus on what we have covered in classes. See below for a list of topics that you should have some understanding of, broken down into details.

The primary topics for this exam are the interstellar medium, the life cycle of stars (low and high mass), and the Milky Way Galaxy. Although this exam isn't specifically cumulative, a lot of what you have learned for previous exams is necessary to understand the current material. As such, even though it won't be directly tested, in order to succeed on this exam you will need to understand basic gravity as well as light (e.g. how temperature and size affects the luminosity of a star, how colors of stars change with temperature, etc.), as well as the H-R diagram (from Chapter 12) and some basic ideas about fusion (from Chapter 14 as well as 15 and 16).

If you see any equations below, don't memorize them. You should have some idea what the variables and equations mean, though.

Extrasolar Planets

(This was discussed extensively in class on March 12, but is only briefly discussed in the text; you can find a little information on p. 142-143. What was discussed in class *will* be covered on the exam.)

- The Doppler Effect
  - $\frac{\lambda_{\rm obs}-\lambda_{\rm em}}{\lambda_{\rm em}} = \frac{v}{c}$
  - Receding = redshift (shift to longer wavelength)
  - Approaching = blueshift (shift to shorter wavelength)
  - Extrasolar planets are mostly known from the reflex "wobble" of their primary star, detected via the Doppler effect.
- None have been directly imaged; $\sim$100 are known.
- It is easier to find *big* planets *close* to the star: greater gravitational effect, shorter period (i.e. observations don't have to be made for as long to see the effect).
- Many extrasolar planets don't look like the solar system; they have "hot Jupiters", gas giants very close to the star.

The Interstellar Medium (ISM)

- Overview: very low density everywhere (compared e.g. to Earth atmosphere), very dusty.
  - Infrared (IR) light better penetrates dust.
- Phases
  - low density warm & hot gas
  - embedded clouds (atomic and molecular)
- Ionization
  - What it is: electrons stripped from atoms
  - Possible collisionally in very hot gas (10^6K)
  - Usually indicates that there is Ultraviolet (UV) radiation with photons of enough energy to ionize Hydrogen.
- Star Formation
  - Gravitational collapse of cool, dense clouds
  - Stars form in clusters (many stars from one cloud)
  - Planets form around stars.
  - Hottest (OB) stars have enough UV to ionize the nearby gas, forming "HII regions" (star forming regions). The ionized gas glows with a characteristic spectrum.

The Life and Times of Stars

- The pressure generated by fusion and the gravity of the star's mass are in balance.
  - As fusion fuel is used up, gravity starts to win out; this can compress the core trigger new stages of fusion in the star (e.g. H shell burning, core He burning).
- Main sequence stars burn H to He at their core.
- Stars *leave the main sequence* once they use up the H at their core.
  - Massive stars do this sooner, getting cooler and becoming supergiants.
  - Cluster shows age-dependent *main sequence turn-off* on the H-R diagram.
  - Low mass stars get *more luminous* and *cooler*, becoming *red giants*.
- Low Mass Stars ($M < 8M_\odot$):
  - Eject a *planetary nebula*
  - Leave behind a *White Dwarf*

The Life and Times of Stars (continued)

- High Mass Stars ($M > 8M_\odot$):
  - Fuse elements all the way up to iron at their core. You can't get iron out by fusing iron to heavier elements.
  - The core collapses, releasing gravitational energy as a *Type II Supernova* or a *Core Collapse Supernova.*
  - Leave behind a *Neutron Star* or (for the most massive stars) a *Black Hole.*
- Compact Stars
  - White Dwarf
    - Electron degenerate; not fusing, cooling off.
    - Carbon (or carbon and oxygen)
    - About the mass of the Sun, about the size of the Earth
  - Neutron Star
    - Degenerate nuclear matter.
    - Up to 3 times the mass of the Sun, about $\sim$ 10 km in radius.
    - Rotating neutron stars with magnetic fields can be observed as *pulsars.*
  - Black Hole
    - An object so dense even light can't escape it.
    - Event horizon at $R = 2GM/c^2$ (R=$\sim$ 3 km for $M = M_\odot$)
- Tidal Forces
  - Differences in gravity from one side to the other
  - Cause Tides on Earth
  - Would rip you apart near the event horizon of a stellar mass black hole.
- Novae and Type Ia Supernovae
  - White dwarf pulls mass from a companion star.
  - *Nova*: Hydrogen builds upon the surface, eventually fuses in a thermonuclear explosion, blowing away most of the acquired layer, leaving behind the white dwarf.
  - *Type Ia Supernova (thermonuclear supernova)*: white dwarf gets up to $M = 1.4\ M_\odot$ (the "Chandrasekhar Limit") and compresses so that the carbon in it can fuse, and runaway fusion blows the White Dwarf apart.
- Supernovae
  - Type Ia (thermonuclear) and Type II (core collapse) (above).
  - Supernova blast waves heat the ISM and enrich the ISM with heavy elements.
  - Supernovae are *rare* ($\sim$1 per century in our galaxy), and *very luminous* (for a few weeks, they can be as bright as an entire galaxy).

The Milky Way Galaxy

- Components of the Milky Way
  - Bulge: spheroid in the middle
    - $2.6 \times 10^6\ M_\odot$ black hole right at the center.
  - Disk
    - Stars and gas in the disk circle the center of the galaxy.
    - Shows *differential rotation* with a *flat rotation curve*
    - Is actively forming stars: stars at a wide range of ages and heavy element abundances are seen.
    - *Open Clusters* are clusters of relatively young stars.
  - Stellar Halo
    - Stars orbit the galaxy every which way.
    - Stars are all *old* (>10 billion years) and have low heavy element abundances.
    - No cool gas.
    - *Globular Clusters*.
- Dark Matter
  - Comprises 90-95% the mass of the galaxy.
  - Evidence comes from the flat rotation curve.
  - MACHOs
    - "Massive Compact Halo Objects"
    - Discovered through gravitational lensing
    - Can be dark stars: brown dwarfs, cool white dwarfs, black holes.
    - Probably makes up no more than $\sim 20\%$ of the dark matter in our galaxy.
  - WIMPs: "Weakly Interacting Massive Particles" are exotic, unknown particles that probably make up most of our Galaxy!
- Chemical Evolution
  - All heavy elements are synthesized in stars and supernovae.
  - Supernovae return heavy elements fused in stars to the ISM.
  - The cycle: stars from from the ISM, synthesize heavy elements, return some of this mass enriched with heavy elements to the ISM, a new generation of stars form with higher heavy element abundances.
  - Stars with *low* heavy element abundances were formed from gas which had only been processed through a small number of generations. These are seen in the halo of the Milky Way (including in Globular Clusters).
  - Stars with *high* heavy element abundances were formed from gas which has been processed through several generations. These are seen in the disk of the Milky Way.
  - We have not directly seen the first generation of stars (which would have *no* heavy elements)!