This study guide covers the material on galaxies and cosmology. It does not cover material that was on Test1, Test 2, and Test 3.

White dwarfs, neutron stars, and supernovae

- White dwarfs are earth-sized, dead stars. Degenerate electrons produce the pressure.
- Neutron stars are Lansing-sized stars made of degenerate neutrons
- Black holes are so compact that light cannot escape from them.
- Exploding stars, supernovae, spew elements into space.
- Pressure caused by degenerate electrons or degenerate neutrons does not depend upon temperature. For an ordinary gas, pressure is proportional to temperature.

Galaxies

- What is our Milky Way Galaxy made of? Stars and gas orbit the galaxy. Dark, unseen, matter makes up most of the mass.
- The parts of the Milky Way Galaxy are the disk, bulge, halo, and globular cluster system. The disk is made of young and old stars, gas, and dust. The motion of the stars is approximately circular. The budge is made of old star, whose orbits are elongated. The halo has no young stars; the orbits of the stars are elongated. Besides these, the majority of the mass is made of dark matter.
- Astronomers measure the mass of galaxies by measuring the orbital speed of gas in the galaxy.
- Most of the mass in galaxies is dark matter.
- Hydrogen gas illuminated by O stars produce light by electrons falling from the 3^{rd} to 2^{nd} levels of hydrogen.

Big Bang. How old is the universe?

- Hubble's Law is the consequence of the Big Bang. The universe expands according to Hubble's Law.
- Hubble's Law is a self-similar expansion. All distances expand by the same factor.
- Hubble's Law implies a Big Bang, an instant when all matter was very close together. The age of the universe is approximately 1/H, where H is Hubble's constant.
- Hubble Law implies there is no unique center to the Big Bang.
- What obeys and what does not obey Hubble's Law?

Quasars

- All galaxies have black holes in their centers.
- For a galaxy to be a quasar, matter has to fall toward the black hole and be heated.
- Astronomers measured the mass of the black hole in the center of the Milky Way Galaxy by observing the orbits of stars and using Kepler's 3^{rd} Law.

What is the story of the universe? Radiation from the Big Bang

- The radiation from the Big Bang is the same as a 2.7-K black body that appears in all directions.
- The radiation was hotter in the past.
- When the universe was 1/1000 of its present size, the temperature of the radiation was 2700K. Before that, the matter in the universe was ionized, and the universe was opaque. After that, the matter in the universe was un-ionized, and the universe was transparent.
- When the universe was 3 minutes old, the universe became cool enough for deuterium to be stable, and the free neutrons became incorporated primarily in ^{4}He with trace amounts in ^{7}Li, ^{2}H, and ^{3}He. Before then, neutrons were gradually changing into protons, because it takes energy for a proton to change into a neutron. The abundance of ^{4}He is a "fossil" from the Big Bang.

What is the universe made of?

- The universe is made of 4% ordinary matter, 27% dark matter, and 73% dark energy.
- What is dark energy? The force between matter and dark energy is repulsive.
- How does dark matter differ from ordinary matter?
- To weigh the universe, astronomers figure out how long it takes the universe to expand by a certain amount. If the universe took a longer time to expand, there is less mass in the universe. If the universe more time to expand than it takes a universe with no mass, there must be dark energy.