Review for Final Exam
(These study notes are provided thanks to the generosity of Dr. Jonathan Williams)

Chapter 1: Our place in the Universe

What do we mean by the Universe? How big is it, how old is it? Where is Earth located? Where did Earth come from?

Important concepts:

- Earth is one of nine planets orbiting an ordinary star
- Earth rotates on its axis and orbits the Sun (a day is a full rotation of the Earth about its axis and a year is a full orbit of the Earth around the Sun: the tilt of the Earth's axis is the reason for the seasons)
- the Sun is one of about a hundred billion stars in a system we call the Milky Way (a spiral galaxy which is continually forming new stars today)
- stars like the sun shine because of hydrogen fusion in their centers
- the Milky Way is just one of about a hundred billion other galaxies in the Universe (and the Universe is expanding uniformly in all directions from which we estimate that it is between 12-16 billion years old)

Chapter 2: Discovering the Universe for yourself

We see the Universe from the Earth and its view changes as the Earth rotates on its axis and around the Sun. As the moon orbits the Earth, its appearance changes too and this explains its phases.

Important concepts:

- night and day (due to Earth's rotation, we move in and out of direct sunlight)
- the circling sky (due to Earth's rotation, the Sun in the day and stars at night appear to rotate through the sky)
- seasonal changes (due to Earth's orbit around the Sun, we are on different sides of the Sun in winter and summer and therefore see a different group of stars at night)
- phases of the moon (the moon is bright because it *reflects* sunlight: we see only various parts of this reflected half as the moon orbits the Earth)
- eclipses (occur when the Sun, Earth, and moon line up)
- retrograde motion of the planets (the Earth revolves faster around the Sun than the more distant planets so as it catches up and overtakes them they appear to move backwards against the background of distant stars)

Chapter 3: The science of astronomy

Astronomy is a science and makes progress by observing, creating a physical model that makes a prediction, and then testing the prediction.

Important concepts:

- ancient observatories (observing and trying to figure things out are a natural human characteristic)
- the scientific method (any scientific theory must make predictions that are testable: if the predictions are not verified the theory must be modified or discarded)

Chapter 4: A Universe of matter and energy

This chapter discusses basic physical concepts about energy and matter that come up throughout the rest of the course. Its important to understand these ideas to understand later material in the course.

Important concepts:

- types of energy (kinetic, thermal, potential: gravitational and mass-energy)
- conservation of energy (energy converts from one form to another such as kinetic into heat but the sum total remains the same)
- atomic structure (matter is made of atoms which consist of a nucleus of protons and neutrons surrounded by a cloud of electrons: the number of electrons equals the number of protons in a neutral atom)
- phases of matter (as temperature increases, solid } liquid } gas } plasma)
- energy levels (energy can only be added or taken away from an atom or molecule in certain discrete amounts as electrons move up and down a ladder of energy levels *[this is explained in the theory of quantum mechanics]*. The spacing of the energy levels is a unique fingerprint of an element and allows us to measure the composition of matter in distant stars)

Chapter 5: Universal motion

We describe the motion of objects through measuring their velocity and acceleration. Motions are changed through the application of forces as first described by Newton who went on to explain why planets move around the Sun in ellipses as first described by Kepler.

Important concepts:

- Newton's laws of motion (describes how a force moves an object)
- conservation of angular momentum (a spinning object will rotate faster if it is made smaller - spin in an office chair and move your arms in and out)
- Kepler's laws of planetary motion (planets move in ellipses, they go faster when nearer the Sun, and take longer to orbit the further they are from the Sun)
- universal law of gravity (all masses attract other masses: this explains why an apple falls to Earth from a tree and why the Earth orbits the Sun. We will talk about gravity throughout the course - how stars form, evolve, and die; how galaxies form and collide with each other; and how the Universe began and how it will end)

Chapter 6: Light, telescopes, and spacecraft

Astronomy is all about collecting light with telescopes. We cannot travel to the stars to find out what they are made of but by collecting their light as it streams by the Earth, we can learn all about them.

Important concepts:

- nature of light (radiative energy carried at a constant speed of 300,000 km/s)
- electromagnetic spectrum (radio waves are long wavelength, low frequency and low energy; gamma rays are short wavelength, high frequency and high energy but they - and all in between - are all forms of *light* moving at the same speed)
- absorption/emission lines (light shining through a gas will be *absorbed* at certain wavelengths corresponding to the energy levels of the atoms in the gas; similarly a gas will *emit* lines at certain fixed wavelengths due to these energy levels)
- thermal spectrum (solids, liquids, and dense gas emit radiation in a continuous range of wavelengths that gets brighter and bluer as the temperature of the material increases)

Chapter 6: Light, telescopes, and spacecraft (contd.)

Important concepts:

- doppler effect (the motion of an object toward or away from an observer changes its wavelength just as the pitch of sound changes: motion towards the observer make the wavelength shorter *[blueshift]* and away from the observer makes the wavelength longer *[redshift]*)
- telescopes (need large collecting area to gather lots of light and a large size to resolve fine details; place on remote sites to escape light pollution and on high mountaintops to get above some of the atmosphere that absorbs and distorts the light from space)
- spacecraft (expensive but best for astronomy because there is no distortion or absorption of the light rays from an atmosphere; note that spacecraft are not any closer to the stars)

Chapter 7: Formation of the solar system

When we look at some of the myriad stars in the Milky Way, we see some that are forming new solar systems. When we look at our own solar system, we see clues to its formation. By piecing together all the lines of evidence we are beginning to learn about how the Sun and planets formed 5 billion years ago.

Important concepts:

- patterns in the solar system (planets all orbit the Sun in the same direction and in a flattened plane; they are rocky close to the Sun and gaseous far away, icy comets have highly elliptical orbits and rocky asteroids orbit in a ring between Mars and Jupiter)
- nebular theory of solar system formation (stars form in chemically rich molecular clouds; as they condense they spin up and flatten *[conservation of angular momentum]* a star forms at the center and planets in a disk around it: rocky objects within the frost line and gaseous beyond)
- detection of extrasolar planets (indirectly measured through the slight periodic doppler shift of a star that is being tugged gravitationally by a planet)

Chapter 8: The terrestrial worlds

The terrestrial worlds are the inner planets of the Solar System; Mercury, Venus, Earth, and Mars. They formed inside of the frost line and therefore are small, rocky, and dense. All light elements including hydrogen and oxygen to make water came after their initial formation through the bombardment of comets and asteroids formed beyond the frost line.

Important concepts:

- planetary geology (impact cratering, volcanism, tectonics, & erosion shape planetary surfaces and make them different from each other; surfaces can be dated from looking at the number of craters - young surfaces have few or no craters, old surfaces have many; smaller planets lose their heat faster and become *geologically dead*, *e.g.*, Earth's moon, Mercury)
- planetary atmospheres (mainly created through volcanic outgassing; smaller planets have weaker gravitational fields and don't hold on to their atmospheres; greenhouse effect)

Chapter 9: Jovian planet systems

The Jovian planets are the giant gaseous planets in the outer Solar System; Jupiter, Saturn, Uranus, and Neptune. They formed beyond the frost line where there was plentiful hydrogen and other light elements to allow the growth of such enormous bodies.

Important concepts:

- nebular capture (there was so much material available to form planets beyond the frost line that their own gravity allowed them to hold onto the fast moving hydrogen and helium and therefore gain enormous atmospheres; they have no solid surface but are basically big balls of mostly hydrogen gas and helium and trace amounts of methane, ammonia, an other molecules)
- moons (because of the way they formed, Jovian planets are effectively miniature solar systems with large number of moons and rings around them; the moons are so close they feel tremendous tidal forces that continually stir and heat their interiors resulting in volcanism and possibly liquid water on some objects; rings are small pieces of rock and ice knocked off moons through collisions)

Chapter 10: Asteroids, comets, and Pluto

These are believed to be the remnants of the Solar System's formation: the last few pieces left of the original planetesimals and therefore hold important clues to our origins. They carried the water that allowed life to flourish on Earth but continue to impact today and may spell future disaster.

Important concepts:

- asteroids (small, dense, rocky & metal objects that orbit mostly between Mars and Jupiter: total mass is much less than Earth's moon)
- comets (small, icy objects that formed beyond the frost line; one group (Kuiper Belt) orbits in the plane of the Solar System beyond Neptune - these are original undisturbed planetesimals; the other group (Oort Cloud) lies well beyond all the planets in a spherical cloud - these were flung out by Jupiter during the formation of the planets and have highly elliptical orbits that on occasion bring them close to the Sun and Earth)
- Pluto (the ninth planet but is small, dense, and icy like a big comet)

Chapter 11: Earth and lessons on life

A short chapter tying up many of the concepts learnt in previous chapters. Earth is a miraculous place, formed with the right mass to hold on to its atmosphere and at the right distance to not be too hot (water would be all steam) or too cold (water would be all ice).

Important concepts:

- Earth's young surface (due to active volcanism and plate tectonics)
- photosynthesis (conversion of carbon dioxide to oxygen from plants)
- importance of liquid water (due to Earth being at the right distance from the Sun; dissolves carbon dioxide, ideal medium for chemical reactions to occur - believed to be essential for life)
- greenhouse gases (trap solar radiation and allows surface temperature to be higher; water vapor and carbon dioxide act like this but too much may lead to a runaway greenhouse effect as on Venus)
- ozone (absorbs high energy ultraviolet solar radiation thus preventing it from reaching the surface where it can damage or destroy organisms)

Chapter 12: Our star

Our Sun is a star, just like all the other stars in the night sky, only this one is closer (a LOT closer!). Consequently, we can study it in more detail than any other star.

Important concepts:

- nuclear fusion (conversion of mass to energy as hydrogen > helium)
- gravitational equilibrium (sun supported against gravity by thermal pressure)
- the solar thermostat (maintains a steady core temperature)
- neutrinos (generated in nuclear reactions and detected on Earth)
- transport of energy from core to photosphere (radiative/convection zones)
- sunspots (link to magnetic fields, 11 year number cycle; 22 year magnetic cycle)

Chapter 13: Stars

All the stars in the night sky are Suns. They shine through nuclear reactions occurring in their cores. But some are bright, some are dim, some are hot, some are cool. It depends on their mass and age.

Important concepts:

- Stellar luminosity (depends on apparent brightness and distance)
- Inverse square law
- Surface temperature (thermal spectrum) and spectral classification
- Stellar masses (measure through binary star systems)
- Hertzsprung-Russell diagram (plots luminosity of a star against its surface temperature; different stars appear in different parts of the diagram and this allows us to determine how stars evolve)
- main sequence (H > He), giants, dwarfs, lifetimes
- stellar clusters (measure ages from H-R diagram)

Chapter 14: Star Stuff

The nuclear reactions in stellar interiors convert hydrogen to helium and then on to heavier elements. All elements on Earth such as iron were created in high mass stars that died and cast off their outer atmospheres long before the Sun was formed.

Important concepts:

- stars try to resist gravity through thermal pressure from nuclear reactions but as the fuel is used up, the the core compresses and heats up. This changes the luminosity and surface temperature of the star: *it evolves off the main sequence*
- low mass stars (giant, planetary nebula, white dwarf)
- *high mass stars (supergiant, iron core, supernova, neutron star/black hole)*

Chapter 15: The bizarre stellar graveyard

When no more nuclear fusion reactions can occur (carbon core for low mass stars, iron core for high mass stars), gravity compresses the stars to incredibly high densities. The end product may be a white dwarf, a neutron star, or a black hole.

Important concepts:

- low mass stars end up as white dwarfs (electron degeneracy pressure)
- high mass stars end up as neutron stars (neutron degeneracy pressure) or black holes (not even light moves fast enough to escape)
- neutron stars spin very rapidly – may be seen as pulsars (conservation of angular momentum)
- general relativity (because black holes are so small, the gravitational field around them is very intense and Newton's theory of gravitation breaks down)
- gravity warps the shape of space (positive curvature: sum of angles > 180 degrees)

Chapter 16: Our Galaxy

Galaxies are systems of stars. 100 billion of them in a big spiral galaxy like our Milky Way. There is also a lot of gas in spiral galaxies that continually form new stars. As stars age, evolve, and die, they release gas back out into the interstellar medium where it gradually gathers and forms new generations of stars.

Important concepts:

- shape/size of the Milky Way (very flat, 100,000 light years across; sun is 25,000 LY from center, takes 240 million years to orbits)
- components of the Milky Way (globular clusters, bulge, halo, and disk stars: globular clusters and halo stars are very old; new stars form within the arms)
- gas > star > gas cycle (each time, gas is enriched, but some is locked up forever in `dead' stellar remnants such as white dwarfs, neutron stars, etc)
- stellar motions (halo stars orbit in a randomized, spherical halo, disk stars orbit in an ordered, flattened disk } clues to galaxy formation)
- rotation curve (measure the orbital speed at different distances from the galaxy center } gravitational force } mass } there must be lots of dark matter)

Chapter 17: Other galaxies

The Milky Way, containing about 100 billion stars, is just one of about 100 billion galaxies in the observable Universe! Galaxies come in all sorts of sizes, shapes, and colors, are generally found in clusters, and may collide with each other, changing their appearance over hundreds of millions of years.

Important concepts:

- galaxy types (spirals, ellipticals, and irregulars)
- measuring distances and standard candles (comparing apparent brightness to known luminosity implies distance)
- Hubble's Law (the further away a galaxy, the faster it moves away from us; space is uniformly expanding)
- galaxy evolution (we see distant galaxies as they were when the light left them and therefore when the Universe was younger: by looking at galaxies at different distances, we can directly see how galaxies evolve)

Chapter 17: Other galaxies (contd.)

Important concepts:

- galaxy formation (a protogalactic cloud collapses: halo stars form first, disk stars later when the cloud is smaller and flattened)
- mergers (compared to their size, galaxies are much closer together than stars } collisions are common, especially when the Universe was younger and therefore smaller)
- active galactic nuclei (some galaxies are exceptionally bright; their luminosity comes from material falling into a central black hole. Evidence for these black holes come from the fast rotation of stars and gas around them. Such active galaxies - the brightest and most active are called quasars - are mostly seen at large distances, and therefore must have been more common in the past)

Chapter 18: Dark matter

Most of the mass in the Universe is too dark to see. We know its there because of its gravitational influence on things we can see: stars and gas. There is much more dark matter than luminous matter and in its hands rests the fate of the Universe.

Important concepts:

- dark matter in individual galaxies (rotation curves)
- dark matter in galaxy clusters (galaxy orbits, hot intracluster gas, gravitational lensing)
- what is it? (MACHOS: brown dwarfs, white dwarfs, neutron stars, black holes and/or WIMPS: extraordinary matter)
- fate of the Universe (if the density of matter is greater than a critical value the Universe will ultimately collapse but if it less than this critical value the Universe will expand forever)

Chapter 19: The early Universe

The Universe is expanding and therefore must have been smaller in the past. By extrapolating backwards in time, we can learn about the conditions of the early Universe right up to the Big Bang.

Important concepts:

- the early Universe was hotter and denser than today (matter was in different phases: first elementary particles, then matter/anti-matter, then protons/neutrons, then nuclei, then atoms)
- cosmic background radiation (from when light escaped from hot plasma: thermal spectrum T=3 K, same in every direction with very slight fluctuations)
- origin of Helium (most came not from stars, but was made during first the 3 minutes of the Universe)
- Olber's paradox (the night sky is dark because the Observable Universe is finite in size, and therefore in age: it had a beginning)
- Inflation (the Universe underwent a period of enormous expansion at very early times - this explains why the background radiation is incredibly similar, but not quite the same, from place to place in the sky)

Chapter 20: Interstellar travel (not on final exam)

All that we have learnt about stars and galaxies comes from the light that we receive in our telescopes. Can we more directly explore our Universe through interstellar travel?

Important concepts:

- stars other than our Sun are a long way away! (our best rockets would take tens of thousands of years to reach the nearest one. Even if we went at close to the speed of light we would return to a much older Earth)
- we can send and listen for messages through radio waves (unlike visible light, radio waves are not absorbed by interstellar dust and can be seen across the galaxy - this is the essence of the SETI project)
- the Drake equation (used to estimate how many civilizations are in the Milky Way but many factors in the equation are completely unknown)
- Extraordinary claims require extraordinary evidence (do any stories of UFOs and aliens really stand up to intense scrutiny?)