AST 301--Scalo
Review for Exam 5

What is covered: All of stellar evolution, described in Chapters 19, 20, 21, and 22. Four thick chapters make for a very large amount of material, but in one way it may be easier to understand because it is unified by one theme—the story of a star's birth ("star formation"), life (main sequence evolution), old age (red giant…asymptotic branch) and eventual death (white dwarf, supernova, perhaps gamma-ray burst, neutron star, black hole). Nearly all the material was covered in class, *except* for the material on black holes (22.5, 7, 8). It is up to you to read that material in the textbook (it also appears in the slides and notes). There will be relatively fewer questions on this topic, but it WILL be covered on the exam.

What is NOT covered: The sections you can skip (for the exam) describe the phenomena that can occur when stars evolve in binary systems (20.6, 21.1, and binary neutron stars, 22.3). Another section that will not be on the exam is 22.6, Einstein's Theory of Relativity. Of course you are urged to read or look through these sections for your own interest.

I strongly recommend that you try the questions at the end of each chapter; I sent you a list of the questions that are most relevant by email. I'll include them again below for completeness. I have also included selected questions from the interactive ebook selection (MC1, MC2 at the ebook web site).
I do *not* recommend that you spend most of your study time trying to find the answers to these questions: they should be attempted after you have studied, as a self-test, although a quick look at them might be good to give you an idea of how much you understand. Fifteen minutes spent talking to someone in a study group about why you or they think a certain answer is correct could be a total waste of time. Instead, spend that fifteen minutes just trying to state what that particular question is about, and saying what you know about that topic (to yourself)—the degree of hesitation you experience in doing this will give you a good idea of why you don't know the answer. If you are having trouble, you should go back and study the chapter again, but this time try to summarize what each paragraph or subsection was trying to get across to you in your own words.

A good way to review this material is to try to "tell the story" of the evolution of stars of different masses, starting with the main sequence phase, making sure you can explain all the stages of evolution and the differences between the evolution of low-mass and high-mass stars. Each time you use some new terminology, e.g. "degenerate core," try to explain what you mean, as if you were explaining this to someone with no background. Try some really simple-sounding questions whose answers are not simple at all. For example, "What is the difference between a brown dwarf and a white dwarf?" As you explain how their similar-sounding names have little to do with anything they have in common, ask yourself if you understand the one basic property that they do have in common, and which controls their futures; and why are they called "white" and "brown"?

Another approach is contained in the notes that accompany the lecture slides. There the material is presented in a condensed way, skipping all details and irrelevant side stories, but in many cases including illustrations, not from your textbook, that I think may give you a more visual way of remembering the various phases of stellar evolution, or a visual guide for trying to tell the story yourself.

Here is a condensed summary of what I consider to be the most important features of each chapter. Suggested end of chapter questions, and excluded sections, are listed for each chapter.

Chapter 19.

Most of this material was covered in class, and will appear on the exam. Notice that sec.19.6 (the last section, on Star Clusters) is closely related to the next chapter, especially the technique for obtaining the ages of star clusters. This is extremely important in astronomy because it is one of the only ways that we can determine the ages of stars.. Probably the most important part to feel comfortable with is sec. 19.2, because it is similar to what you'll be reading in the next chapter, using the H-R diagram to describe the evolution of stars. However you DON'T have to memorize the "stages" that the authors describe, not by number—i.e. I won't ask you "In what stage does X occur?" I don't care about the numbers, just that you understand something about the evolution, how a cloud becomes a protostar which becomes a main sequence star. Try to draw an evolutionary track for a protostar approaching the main sequence. The same statements apply to the more advanced stages of evolution described in Ch. 20 and 21.

Not on exam: Sec. 19.5 Shock Waves and Star Formation

End of chapter questions: Review and … (R&D): Try these as a group—they all have to do with evolutionary tracks: 1, 5, 11, 12, 15, 19. Also I suggest 6, 9, 16-18.

True and False/Multiple Choice (TF/MC; I'm skipping the true and false): 11, 13, 14, 18, 19.

Online eboook interactive multiple choice questions:

19: MC1: 1 (leave out "meaning" or substitute "definition"), (2*, 3, 5 on clusters), 8*, 9, 10, 12, 14 (take "fragment to mean the stage before it is opaque to its own radiation).

MC2: 1 b or c are tricky: protostar is when nuclear fusion first begins, not after it is stabilized (that is the zero-age main sequence). 2 (try to answer the question, but don't assume one of the choices given there is correct); 3 (brown dwarfs: b is misleading because "small" has nothing to do with it but "dim" is the entire answer). 6. You don't need to know the numerical answer (it varies with mass), but that it is a small fraction of the mains sequence lifetime. 7 (think in terms of evolutionary tracks in the H-R diagram); 8 (only to see if you would know how to do this calculation; remember that the brightness per unit area varies as temp. to the fourth power, and the luminosity is this brightness times the surface area); 9* (notice the book doesn't say how we know this—it is a theoretical result, which matches overvations well); 10 (add "where are white dwarfs?" and "where are red giants?" just to make sure you know); 11, 12, 14, 15*.

Chapter 20

The evolution of low-mass stars is the primary subject here, with a short discussion of the very different evolution of higher-mass stars once they evolve "off" the main sequence. You should be able to describe (e.g. how is its size, mass, luminosity, ... changing?) and explain the different phases of evolution that these stars go through, and what fuel they are burning and where.

What is the main sequence, and why do stars spend so much time there? Explain how stars try to rejuvenate themselves as red giants. Why do they eventually fail? How do they die? What is a planetary nebula--what do you expect to see at the center of it? Why can't stars below a certain critical mass become a star?

Although I urge you to read the sections describing the phenomena that can occur when stars evolve in binary systems (20.6, 21.1), you will not be tested on this material; the same goes for material on nova explosions in Ch. 21 and on binary neutron stars in Ch. 22 (22.3). Also remember that the section on star clusters at the end of chapter 20 (20.5) is closely related to the material from section 19.6 on the same subject.

Not on exam: 20.6 (evolution of stars in binary star systems)

End of chapter questions: R&D 1-4, 7, 8, 11, 13, 14, 16, 18. TF/MC 11-15, 17-20.

Online eboook interactive multiple choice questions:

MC1: 1, 5, 6, 7, 8, 10*, 12* (tricky because it is out of place, as if it is asking you about white dwarfs); 14, 15.

MC2: 2-9, 12-15.

Chapter 21

This chapter is about the very different late evolution and death of stars above a certain mass. There is a crucial phase at which the massive stars and low-mass stars (of Ch. 20) rapidly begin to evolve very differently. What happens? Why are the subsequent events of crucial importance in the formation of many of the chemical elements heavier than carbon? How do the other elements get produced? These massive stars end their lives as supernovae, amazingly powerful explosions in which most of the star is expelled into space; what will this expelled gas look like? What happens to material that doesn't get expelled? Try to explain the difference between a core-collapse supernova and a carbon detonation supernova, explaining the sequence of events that occur in each case. Attempt an explanation of how all the elements up to iron are cooked up inside of massive stars, with the abundances of the different elements partially set by what the explosion does to the "onion skin" structure of the envelope when the star explodes. Why does element production by nuclear fusion stop at iron? How is this related to the physical reason why cores collapse in supernovae of the same name? Can you explain several lines of evidence that massive stars really do explode as supernovae? Some have to do with the abundances of elements, others have to do with historically observed supernovae, supernova 1987A, and detection of pulsars, covered in the next chapter, at the centers of some supernova remnants.

Not on exam: Section 21.1

End of chapter questions: R&D: 3-6, 8, 13-20 (12 is good but probably too difficult).
TF/MC: 13, 14, 15, 18.

Online eboook interactive multiple choice questions:

MC1: 3, 4, 5, 6, 8, 10*, 11

MC2: 3, 5, 6, 7, 8 (I would not ask you to remember “Type I” and “Type II” for supernovae, and will refer to them as “carbon detonation” and “core collapse” supernovae.), 11, 13.

Chapter 22

The subject here is primarily about what becomes of the central portions, the cores, of stars of different masses. Except for carbon detonation supernovae, which are believed to completely destroy the star without leaving any remnant at all, the other end states of stellar evolution are associated with different kinds of remnants—white dwarfs were already covered in Ch. 20. Here the remnants are **neutron stars and black holes**. Inbetween is a section on **gamma-ray bursts**, some of which may involve remnants (the inspiraling collision of a binary neutron star), but which may also represent “hypernovae,” presently the more favored theory.

All these sections are represented in the slides and notes available at the course website, but we will NOT cover the material on black holes in lecture because of time limitations. Instead, you are to read those sections of the chapters (22.5, 22.7, 22.8) yourself.

Don’t worry about “More Precisely” 22-2. **The material on binary neutron stars (22.3), and Einstein’s Theory of Relativity (22.6) will not appear on the exam**, although I urge you to read them anyway. Besides that, study it all, but remember to try to get the main ideas and how they are related. We don’t care much about names and other details.

A few exceptions are the “famous” objects: You probably already know about Supernova 1987A, but here you should learn more detail about the Crab Nebula, and the object known as Cygnus X-1. Why are they important?

As with Chapter 21, a good way to review Chapter 22 is to try to “tell the story” of the evolution of stars of different masses, this time starting with the red giant phase, when the helium has burned to carbon in the core, making sure you can explain all the events that occur after that. Each time you use some new terminology, e.g. “neutron degenerate core,” try to explain what you mean, as if you were explaining this to someone with no background.

Another general area that you can use to review concerns observational evidence for the various theoretical results that have been discussed. What is the evidence that supernova explosions actually occur according to the models? That the elements were produced in supernovae? That neutron stars exist? That black holes exist?

Not on exam: 22.3 (Neutron star binaries), 22.6 (Einstein’s theories of relativity)

End of chapter questions: R&D: 1, 3, 7-9, 12, 14, 15, 17, 18.
TF/MC: 11-13, 15-17, 19, 20.

Online eboook interaction multiple choice questions:

MC1: 2, 3, 4 (again, only in the ebook and textbook do you have to translate “Type II” into “core collapse” but I won’t use those on the exam), 6, 7, 8*, 11, 12, 15.

MC2: 1, 2 (think what happens to frequency of a wave if time slows down, then translate into wavelength “redshift”), 3, 5, 6, 11, 12, 13

Sample questions

Here are some sample questions to find if you are prepared to take the exam. As usual, most of these tend to be a little more difficult than the average exam question.

1. What distinguishes a protostar from its earlier stage as a collapsing interstellar cloud?
a) Hydrogen begins to fuse. b) It stops emitting infrared radiation and produces visible light.
c) Its central region becomes opaque and begins to heat up. d) It is at that point near the main sequence.

2. What characteristic of a star cluster is used to determine its age?
a. The number of red giants. b. The number of main sequence stars.
c. The faintest stars seen in the cluster. d. The extent of the main sequence in the H-R diagram.

What do you learn from comparing the ages of globular clusters with ages of open clusters? Something important!

3. What effect does a magnetic field have on the process of stellar birth?
a) It speeds it up. b) It causes fragmentation.
c) It heats the cloud. d) It opposes the collapse of the cloud.

4. How was the chemical composition of the sun different 3 billion years ago from what it is now?
a. more hydrogen now b. more helium now
c. more heavy elements now d. it won't change until the sun becomes a red giant
What part of this statement is different for stars of different masses?

5. When a star evolves from the main sequence to the red giant phase
a. the core gets hotter and the luminosity increases. b. the core gets cooler and the surface gets hotter.
c. the core gets hotter and the luminosity decreases. d. the core and the surface both get cooler.

6. Roughly how long does it take a stellar iron core to collapse?
a) One second. b) One year. c) A few million years. d) Forever.
Can you explain why it collapses? Why only the cores of massive stars collapse this way? What the end result will be?

7. What kind of evidence identifies the emission nebula known as the Crab Nebula with the supernova explosion recorded by the Chinese nearly a thousand years ago?
a) Enhanced abundances of metals in the gas
b) A faint binary companion with a period that agrees with the time since the recorded event.
c) Doppler shifts of spectral emission lines from the gas.
d) Discovery of the pulsar at the center of the nebula

This is actually a little tricky. d) shows that supernova explosions and neutron stars are related, as predicted, but doesn't answer the question. Most students do not pick c) for some reason, even though it is certainly the only way that we can get the date of the explosion.

8. Most properties of a neutron star are extreme in comparison to normal stars. Which of the following properties is **not** unusual when compared to a normal star?
a. mass b. rotation c. magnetic field d. density
The unusual properties are mainly due to a single other property, the small size of the neutron star. Explain.

9. The masses of neutron stars (not the original mass of their progenitor)
a. must be at least 8 solar masses. b. must be at least 1.4 solar masses.
c. are only known for those neutron stars in binary systems.
d. are only known for neutron stars that are also white dwarfs.
[Hint: Think about why the masses of white dwarfs must be less than the Chandrasekhar limit.]

10. For an object falling into a black hole, which of the following would be seen by a distant observer?
a. The object would get brighter the closer it got to the black hole.
b. Time would speed up as it got closer to the black hole.
c. Light emitted by the object would increasingly redshift as it got closer to the black hole.
d. The object would begin to flicker.

11. The key to identifying a black hole candidate, rather than some other type of stellar remnant, in a binary star system is (there is only one correct answer):
a) one of the two stars cannot be seen
b) the unseen companion in the system must have a sufficiently high mass
c) the system must be a strong source of x-ray emission.
d) the seen companion must be an evolving main sequence or giant star
e) there must be evidence for a very hot accretion disk.

Notice that some of these choices *are* important in identifying dense stellar remnants, but they don't distinguish black holes from neutron stars or white dwarfs. And a) only identifies a binary star system.

What is the evidence that the object called Cygnus X-1 contains a black hole? (Related to answer above)