Astronomy 10

Section 1 (M through F, 7:30 – 8:20 am)

*Are you studying for something **other** than Test 1? Click the tab (above) for your upcoming test.*
*Note that the page numbers given in these tabs are for the **8th edition** of the Seeds/ Backman text. (9th-edition pages are in parentheses.)*

Here are the chapters for Test 1, in the order that we covered them:

Chapter 1 (Overview of our place in the universe)
Chapter 2 (What we see in the sky, and basic motions of the Earth)
Chapter 3 (Moon's motions, phases, and eclipses)
Chapter 4 (The Origin of Modern Astronomy)
Chapter 5 (Gravity)
Chapter 6 (Telescopes)

Chapter 1: Here and Now

Section 1-2 does a `cosmic zoom-out' starting with a person sitting on a bench. What do Seeds and Backman mean by the *field of view* in Figures 1-2 through 1-13? Notice that the field of view in Figs. 1-2 through 1-13 are given as distances. (Jumping ahead to Chap. 2 for a moment, astronomers also talk about a related concept called **angular distance**, which is covered on p. 19 (same page in both editions), in Chapter 2. Make sure you're clear on what we mean by the **angular size** of an object in the sky, or the angular distance between two objects in the sky. What are the units of angular distance?)

As we zoom out through Figure 1-6, we encounter a term called an **astronomical unit**. This is a very important term that we'll use over and over in this course. It's a basic `distance-measuring unit' in the solar system. Make sure that you understand what an astronomical unit is. Seeds gives some measurements using numbers, but it's most important for you to be able to understand it in words, in terms of the distance between the Earth and the Sun.

What is the **Solar System**? Is our solar system (the one that contains the Sun and the Earth) the *only* solar system?

What's a **light-year**? This is another very important distance unit. Here are some things to be clear about when it comes to light-years:

- Which is bigger - an astronomical unit or a light-year?
- Is a light-year a unit of *time* or *distance*?
- What is the definition of a light-year, in words?
- Here's a tougher question - how are an astronomical unit and a light-year related to each other? (Hint: How are they both related to the Earth?)

What's a **galaxy**? What do we call the one we live in? Make sure you understand the difference between a galaxy, the solar system, and the **universe**. (Seeds and Backman point out on p. 6 (same in both editions) that people often have a Common Misconception about this.)

There are some things to know about the scientific method from Chapter 1---these are covered in `How Do We Know' 1-1. For example, after a scientists makes a **hypothesis**, what do they have to *do* to that hypothesis? (Hint: They use evidence to do it.)

Chapter 2: The Sky

In this chapter, we learned about what the sky looks like from here on the Earth, how it appears to move, and what's really behind these motions. We'll also learn something about how bright things look, which turns out to be a major concept in astronomy.

What's a **constellation**? Have all cultures throughout history thought up the *same* constellations? What's the official definition of a constellation, according to the IAU? How many of them are there? What's the difference between a *constellation* and an **asterism**?

How are Greek letters used to `name' stars? Are those `name a star' things that you hear about on the radio legitimate?

Now we get to an important, but tricky, subject---the magnitude system. Here are some things to make sure you remember, understand, and can explain:

- What does the **apparent visual magnitude** of a star or planet mean?
- Does a star with an apparent visual magnitude of 1 look *brighter* or *dimmer* to the eye than a star with an apparent visual magnitude of 2? (Hint: Think about the analogy between `1st magnitude' and `1st class'.)
- What's the apparent visual magnitude of the *dimmest* stars visible to the unaided eye?
- Make sure you understand the definition of **flux** on p. 16 (same page in both editions).
- What's the ratio of flux between two stars that are 1 magnitude apart?
- What's the ratio of flux between two stars that are 5 magnitudes apart?
- EXTRA CREDIT: Be able to solve problems using the two equations on p. 16. To do this, you can use a regular calculator on the test, but not a cell-phone or tablet-device calculator.

What's a **scientific model**? Can a physical model be used as part of a scientific model? (How Do We Know 2-1)

Now for another big, fundamental topic---the **Celestial Sphere** (see p. . I'll also talk about `The Two-Sphere Universe', although you won't find that exact term in the textbook. We'll spend a lot of time talking about the celestial sphere, and we'll probably use the planetarium to do this.

Make sure you understand the 3 concepts and 16 italicized terms on the left half of p. 17 (right half of p. 17 in the 9th ed.). (If you have some extra time, you might want to play around with the free programs Stellarium and Celestia.)The `Sky Around You' spread on p. 18-19 is a big, important illustration for this topic, along with your notes and visual memories from the planetarium. (Same pages in both editions)

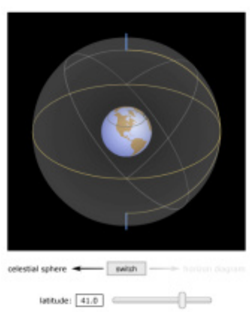
Here are some details that we (hopefully) went over in the planetarium:

- Make sure you understand the idea of the **cardinal points** (also called the `*four directions*' by Seeds and Backman on p. 17): **north point**, **south point**, **east point**, **west point**.
- Make sure you understand the idea of the **celestial sphere**. This is a very visual idea, so it can be tricky. Is it a real sphere? Or just a model? Make sure to carefully study the diagram in the upper-right corner of p. 18.
- What *direction* does the celestial sphere appear to rotate around the Earth? Does it really rotate in this direction? What's *actually* rotating?
- What are the **horizon**, **zenith**, and the **nadir**? (In addition to describing them in words, imagine standing outside under a clear night sky and pointing them out to a fellow observer.)
- What are the **celestial poles** and the **celestial equator**?
- What's the importance of your **latitude** on how the sky looks and how it appears to move? (If we had enough time, we might have used the planetarium to travel to the southern hemisphere. How did the sky look different from there?)
- I mentioned this earlier, but how are **angular distances** measured on the sky?

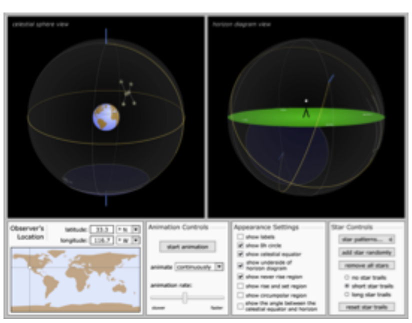
Are units like *miles* used? What sorts of units are *really* used? Know the difference between a degree, an (arc)minute, and an (arc)second.

To help you understand all of these concepts, it's useful to "play" with them when you're not in the Planetarium. One way to do that is to download and play with programs like Stellarium and Celestia. Those programs take a little time to learn, however, so you may find it easier to "play" with the following simulations, which were made by the amazing folks in Astronomy Education at the University of Nebraska-Lincoln. They've made some really great simulations, and you'll see links to many of them as you scroll down on this page. When you see an `image link' to one of the simulations, I recommend right-clicking it and selecting `Open In New Tab'. That way, you can click back and forth between this list, which your'e reading right now, and the animation.

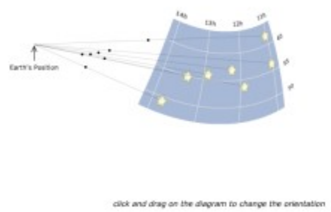
To get you started, try playing with this simulation, which will help you understand the difference between what we called the `Snow-Globe Universe' and the `Two-Sphere Universe'. First, drag to rotate the model around, and look at it from different directions. Then hit `Switch'. Then Switch back. Then move the slider, hit `switch', and so on.



Next, here's their simulation of the diurnal motion. There are a ton of great features in this one, and you can really learn a lot about how the rotating Earth makes it look like the sky is rotating! If I can ever find the time, I'd love to write a `how-to guide' for this simulator, and post it in the class's blog section. For now, I just recommend playing around with this one:



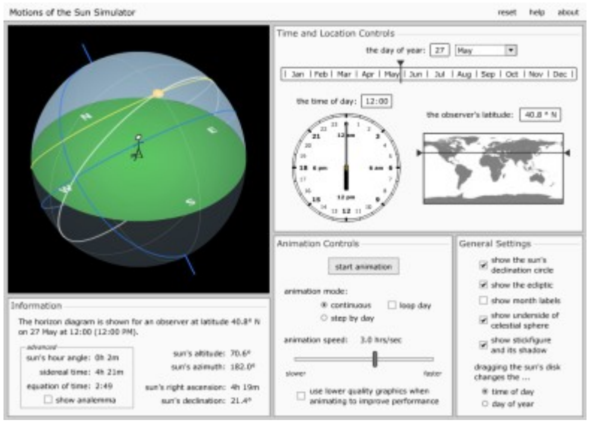
Here's a simple one, but a good one - a simulation of the Big Dipper, showing how the stars are **actually** scattered through space, even though they **seem** to be `attached' to a sphere (drag-rotate the model):



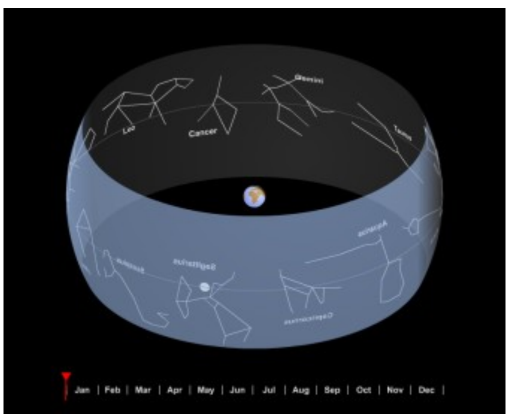
Next, we get to the `Cycles of the Sun' (p. 21). (It's called "Sun and Planets" in the 9th ed., and also stars on p. 21.) Here are some things to know about the Sun's apparent motion in the sky:

- What's the difference between **rotation** and **revolution**?
- What causes day and night? (Hint: Study Fig. 2.8.)
- How does the Sun *appear* to move through the sky during the year? What's really moving? (Carefully study Figure 2.9. If you can re-draw Figure 2.9 and explain it to someone, that would be a great skill to have.)
- What is the **ecliptic**? What do we mean when we talk about the *plane* of the ecliptic? (Hint: How is the word `ecliptic' related to eclipses? Also, we might have used an analogy between part of the Infinum projector and this concept.)

Again, the good folks at UNL have made some nice simulations for this. To start, here's one that shows the Sun's apparent motion through the sky. Like the celestial sphere simulator, this has a lot of controls, and can get a bit confusing. But, if you play around with it enough, it can really help you get a handle on the motions of the Sun. (Don't forget that, like most of their simulations, you can drag-rotate the model to look at it from different directions.) If you find it too detailed or confusing, though, it's okay to focus on studying the book's section on `Cycles of the Sun' on p. 21. (It's called "Sun and Planets" in the 9th ed., and also stars on p. 21.)



Here's a simulation of the ecliptic. Drag-rotate this one, to look at it from different directions. Also play with the slider, to see where the Sun `appears' at different times of year. (As always, opening it in a new tab is handy.)

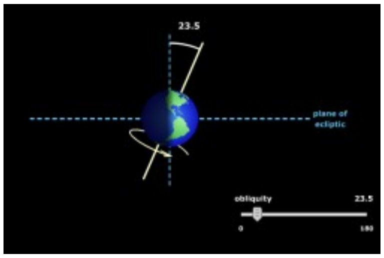


Now, we get to yet another big chunk of visualization. We probably spent a lot of time in the planetarium on this one, too. This is the topic of the **seasons**. Here are some things to know about seasons:

- What do we mean when we say that the Earth's axis is tilted 23 degrees from the plane of the ecliptic?
- What is the Common Misconception that most people have as to the cause of the seasons?
- What's the *real* cause of the seasons? (See the spread on p. 24-25.) Being able to make one or more diagrams like the ones on p. 24-25 would be another good example of a
- Make sure you understand the terms **solstice** and **equinox**. At what time of year does the noon Sun appear to pass *highest* in the sky? How about *lowest*?

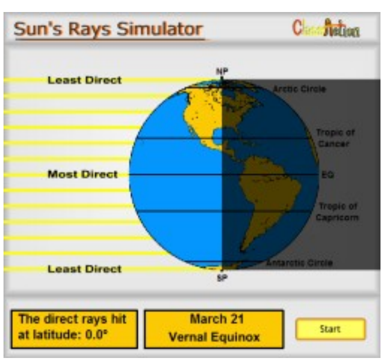
(Pages 24 and 25 are the same in both editions - a two-page spread on "The Cycle of the Seasons".)

You guessed it, there are some good UNL simulations to help you understand the seasons. The first simulation, shown below, is a good starting point. Open it in a new tab, and drag the slider to see what `obliquity' means:

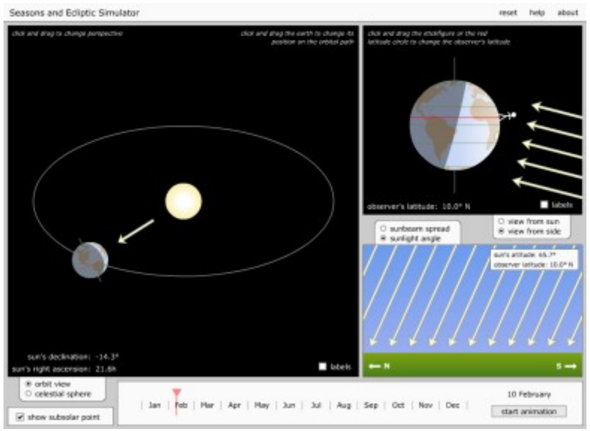


Another important concept, which we've used when talking about the celestial sphere, and when talking about the seasons, is **latitude**. Use this simulation to see what latitude is. Open it in a new tab, and drag the observer's location around on the globe (and shift-click to rotate the globe). The observer's latitude is the blue coordinate.

Next, play the animation in the following simulation, Notice how the angle of the Sun's rays changes from season to season. Compare this to p. 24-25:



Finally, for the brave-hearted, try UNL's Seasons Simulator. This is another big one, with lots of controls, but if you invest the time, you can really visualize and `internalize' what's going on as the seasons change:



What's the **zodiac**, and what's its relationship to the ecliptic? What do astronomers mean when they call astrology a **pseudoscience**? (See `How Do We Know 2-2)

What is **precession**? We might or might not have had time to cover this in the planetarium, but it's covered on p. 17 of the textbook, and also Figure 2-7 on p. 20. (p. 17 and 18, and p. 21, in the 9th ed.) If we could live for many thousands of years, what would we see in the sky? What's really happening (hint: it has to do with the Earth's rotational axis.) How long does is a cycle of precession? What effect does this have on the locations of the celestial poles?

Chapter 3: Cycles of the Moon

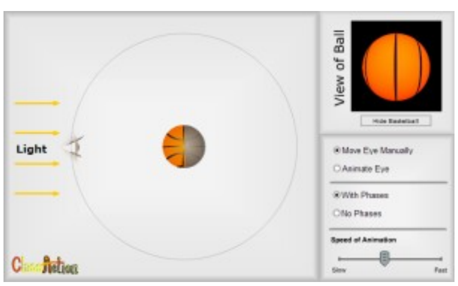
What is the difference between the **nearside** and the **farside** of the Moon? Why is there this difference? (This isn't really discussed until chapter 21, but I will probably talk about it in class before Test 1, at least briefly. It is briefly shown in diagram 1 in the upper-right corner of p. 34, or p. 36 in the 9th edition.))

Does the Earth's shadow cause the **phases** of the Moon, or is this merely a common misunderstanding?

How does the Moon's phase change from day to day, and why? It will be worth studying Section 3-1 (starting on p. 33 (p. 34 in the 9th edition)) and the two-page spread `The Phases of the Moon' (on p. 34-35 (9th ed.: p. 36-37)) in detail. We probably made at least one detailed drawing of the phases of the Moon, similar to diagram 2 on p. 34 (p. 36 in the 9th ed.). Being able to redraw diagrams like this, with good explanations, would be a great skill to have. We probably also made some drawings that I called `phase drawings'. They showed the direction of the Sun's rays, as well as the direction of our line of sight, and the **terminator** and the *nearside/farside boundary*. These drawings also included an `as seen from Earth' view. If we made drawings like this in class (and we probably did), make sure you can draw them on your own! This might seem strange for a multiple-choice test, on which you won't have to actually **draw** this stuff. But if you have the ability to **make** such a drawing, I think it will help you figure out the deeper multiple-choice questions.

Now for the UNL simulations of the Moon's phases… I recommend starting with this one, to test your knowledge of the phases and their names:

Next, it's good to reinforce your understanding of how a spherical object can show phases if it's lit up from different directions. We did this in the Planetarium when I turned on a bright light at the back of the room and shone it on the Infinium projector ball. This `basketball' simulation will allow you to practice the same idea. (Tips: As always, right-click and open it in a new tab if you can. I like to `Move Eye Manually'. And remember all that stuff about "Is this the <u>left</u> side of the nearside or the <u>right</u> side of the nearside? Think about that while you play with this simulation.)

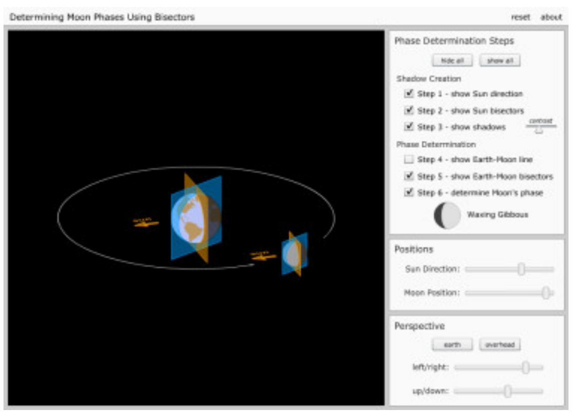


A little ways above, in this list, I reminded you about the "phase drawings" we made in class. Like I said, these are great things to practice. The next UNL simulation is very similar to our phase drawings! I recommend working carefully through this one, step-by-step, to help yourself understand how the phase drawings work. Right-click on it and open it in a new tab, and try this sequence of steps (the link is below the sequence):

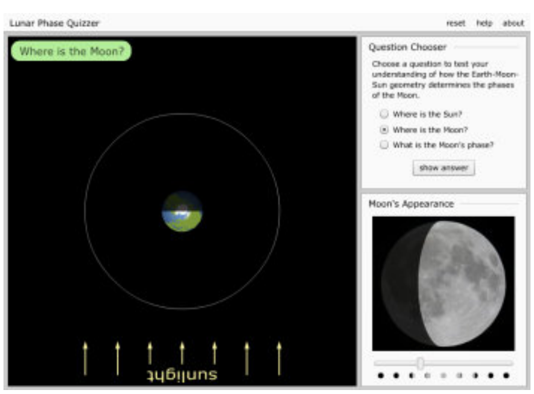
1. First, familiarize yourself with how to rotate the model. You can drag-rotate it in the usual way if you want. (Hold down the left mouse button and drag the

mouse around in the model, to rotate it.) You can also use the "left/right" andy "up/down" sliders.

2. Next, click your way through Steps 1 through 3, but, make sure you **drag-rotate the model around for a while in between each step**. That's important!
3. After you've clicked Step 5, rotate the model so you're looking "down" on the north poles of the Earth and Moon. Ask yourself what phase the Moon will show, as seen from the Earth. Then, **before you click step 6**, rotate the model so you can <u>see the moon through the Earth</u>. (They've made the Earth `go transparent' for this, which is handy.) Did you get the phase right?
4. Now click Step 6, to double-check your guess.
5. Having quizzed yourself once, move the "Sun Direction" and/or "Moon Position" slider, rotate the model around for a while, and try to figure out the phase.
6. Keep doing this over and over again. You could spend hours playing with this model, and if you did, it might help the idea of the lunar phases `seep into your bones' the way it does for an astronomer!



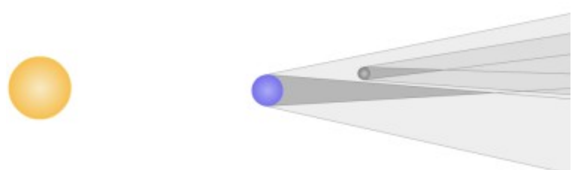
Finally, if you want to make sure you're a total bad mo-getter when it comes to Moon phases, use this simulation to quiz yourself on all aspects of the subject! You can develop Jedi-level Moon-phase skills with this!



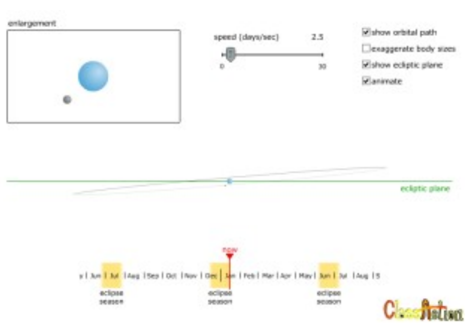
Make sure you understand the difference between a **solar eclipse** and a lunar eclipse. What's the difference between a **partial** eclipse and a **total** eclipse, in both the solar and lunar cases? What's an **annular** solar eclipse? If you want to see a total or annular solar eclipse, why is it important to be in the path of totality?

Why don't we get a solar eclipse every month? (Carefully studying Figures 3-13 and 3-14 will be worthwhile here. (They are Figs. 3-14 and 3-15 in the 9th edition.) This involves the concept of the *plane of an orbit*, which is kind of a tricky thing to visualize.

Happily, there are… you guessed it! Some nice UNL simulations to help you understand why there isn't a solar or lunar eclipse every month. Start with this next simulation, just to familiarize yourself with the idea of the umbra and penumbra some more. Move the Earth and Moon around, and compare what you see with Figures 3-2, 3-3, 3-8, and 3-9. (In the 9th edition, these are Figs. 3-3, 3-4, 3-9, and 3-10. Fig. 3-2 in the 9th edition is like one of the animations, below.)



Okay, now move on to the next simulation, which shows the Earth **as seen from the Sun**. You can watch the Moon's orbit, as the months go by, and see why the Moon doesn't always line up perfectly with the Earth and Sun. This one is a little advanced, but it's worth running the animation and comparing it to Fig. 3-13 and Fig. 3-14 (Figs. 3-14 and 3-15 in the 9th edition).



Chapter 4: The Origin of Modern Astronomy

What is **archaeoastronomy**?

What do **Stonehenge**, **Newgrange**, and the **Sun Dagger** all have in common?

Why did Plato argue that all of the motions we see in the sky can be explained by **uniform circular motion**? How was this related to the concept of the *perfection of the heavens*? (This is discussed on p. 55 (p. 56 in the 9th ed.).)

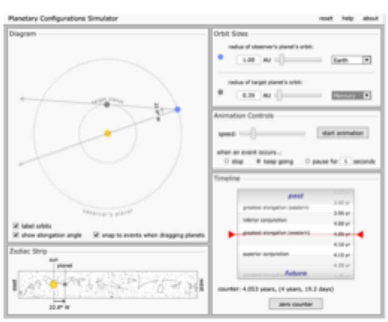
What did Aristotle say was the main difference between the Earth and the heavens? (This is related to the previous question.) What was at the center of the universe, as he saw it?

What did Eratosthenes measure, and how accurate was his measurement? Being able to draw a diagram showing how he made this measurement would be a great idea. (Studying Figure 4-7 will be helpful here. It's the same figure number in both the 8th and 9th editions.)

As seen by the unaided eye, what's special about the planets? Which ones are visible with the unaided eye? Where do we find them in the sky? (Hint: What do we call the `pathway in the sky' that the Sun, Moon, and planets all seem to travel along?)

Which two planets are only ever seen near the Sun? To understand this a little better, try the UNL "Configuration Simulator", below. Here are some tips for understanding the two `inferior planets':

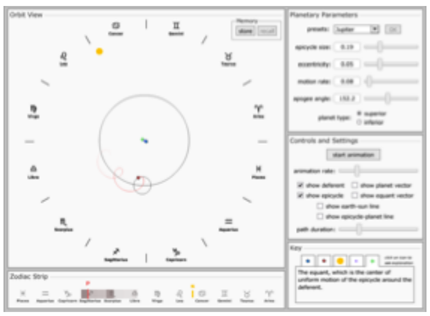
1. Open the animation in a new tab or window, as usual.
2. Set the "observer's planet" to Earth.
3. Set the "target planet" to Mercury.
4. Run the animation.
5. Experiment with checking and un-checking "show elongation angle".
6. After you've played with this for a while, try it all over again with Venus as the "target planet".



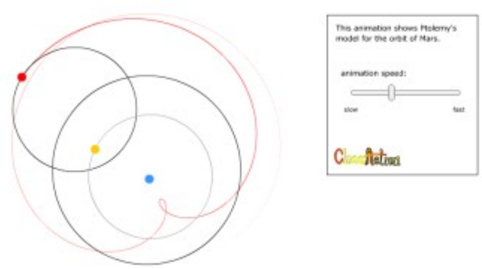
What is **retrograde motion**? (Hint: It's a good idea to be really clear on retrograde motion---both what it appears to be, and what it really is. The rest of this chapter will make a real big deal about it.)

How did Ptolemy explain things like the retrograde motion of Mars? What's an **epicycle** and a **deferent**? Carefully studying the two-page spread about `The Ancient Universe' on p. 58-59 will be very useful. (p. 60-61 in the 9th edition)

If you're feeling adventurous, you can play with the next UNL simulation, although it's kind of advanced. It simulates the Ptolemaic universe, and is worth comparing to "The Ancient Universe" on p. 58-59 (p. 60-61 in the 9th edition). It's rather complicated, though, so if you try it, plan on spending some time figuring out what all the controls do. If you've got the time, though, you can become like Ptolemy himself!



Even if you didn't have time to investigate that last simulation very deeply, try playing around with this next model, which shows Mars in the Ptolemaic system. (Big thanks to the folks at UNL!) Earth is the yellow dot, Mars is the red dot. When, in this model, does Mars show a retrograde motion, as seen from the Earth?

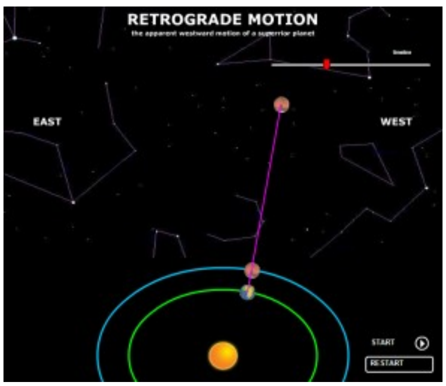


What was fundamentally different between Copernicus' model of the universe and the models of Ptolemy and Aristotle? (Hint: Carefully compare `The Ancient Universe' with Copernicus's model in Fig. 4-10. The figure number is the same in both editions.)

Why didn't the pre-Copernican astronomers believe in the sort of model that Copernicus argued for? In other words, what was their argument against it? (Hint: How is it related to the thumb on p. 58? (p. 60 in the 9th ed.)) Is there a way for the Copernican model to be correct, even if the `thumb effect' is not seen? What would this imply about the *outermost* part of the model?

Here's a huge point... a really important one to understand... How did Copernicus' model of the solar system explain *retrograde motion* in a simpler way than the earlier models?

In fact, you may find it helpful to play with the model show below (As always, it's from UNL.) I recommend dragging the red slider along the timeline, so you can control the planets for yourself.



Copernicus's model wasn't perfect - what were some of its flaws? Did it predict the positions of the planets any better than its competitor at the time? (Hint: The textbook's section on `*De Revolutionibus*' is worth reviewing in detail here, especially the part about the *Prutenic Tables* versus the *Alphonsine Tables*, which we may not have talked about in detail in class.) Which was more accurate in the long run: The Copernican **model**, or the Copernican **hypothesis**? What was a basic part of Copernicus's model that was later modified by Kepler?

Make sure you understand the importance of Galileo's work. Here are some things to be clear about:

Galileo and the telescope:
Did he really invent the telescope?

Galileo and the Moon:
When he looked at the Moon through the telescope, what did he see that challenged the then-accepted Aristotelian ideas about the Moon?

Galileo and the Milky Way:
When he looked at the Milky Way through the telescope, what unexpected thing did he see?

Galileo and Jupiter:

- When he looked at Jupiter through the telescope, what did he see?
- What was really weird about what he saw around Jupiter? Why would people find it hard to accept?
- How did his observations of Jupiter provide some support for the Copernican model?

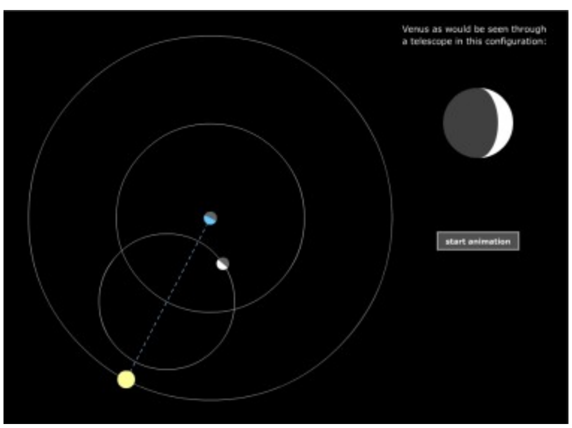
Galileo and Venus:

- When he looked at Venus through the telescope, what did he see?
- What did the Ptolemaic model of the solar system predict about the appearance of Venus? (Hint: See Fig. 4-18. (Fig. 4-17 in the 9th edition))
- Did Galileo's observations of Venus fit these expectations?
- Did they fit the Copernican model better or worse than the Ptolemaic one?

(Hint: As with Copernicus and retrograde motion, it wouldn't be a bad idea to be able to explain the `Galileo Jupiter story' and the `Galileo Venus story' to a fellow student, such as by making some well-labeled drawings like the ones in your notes.)

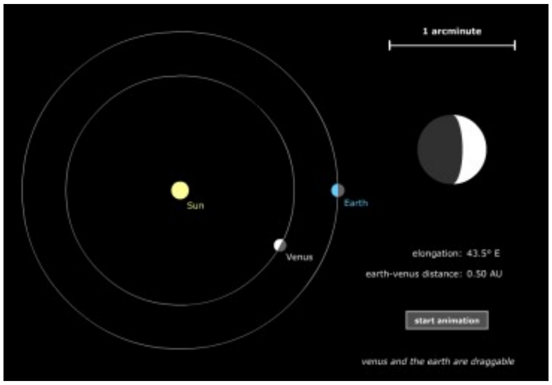
Try the simulations shown below, to better understand the `Galileo Venus story'. (As always, many thanks to the good folks at UNL!)

1) Play with this model, which shows VENUS'S PHASES IN THE PTOLEMAIC SYSTEM. (I recommend right-clicking it and opening it in a new tab.) Run the animation a few times, stop it, start it, and ask yourself this question: What is the only phase that Venus shows in this model? Compare the animation to Fig. 4-18. (Fig. 4-17 in the 9th edition)

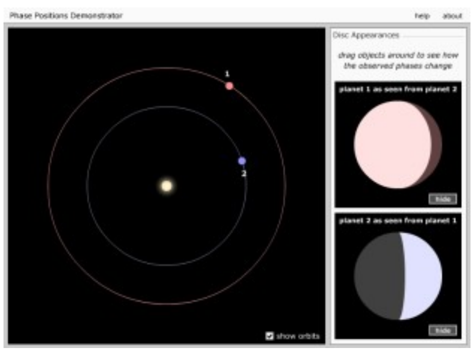


2) Now, play with this next model, which shows VENUS'S PHASES IN THE COPERNICAN SYSTEM. (Again, I recommend right-clicking it to open it in a new tab.) Drag Venus and the Earth to different positions, and see what Venus looks like from the Earth. Run it as an animation a few times. Always try to make sure you can understand why Venus shows the phase it does, as seen from the Earth. What phase does Venus show, in this model, that it didn't show in the Ptolemaic model?

(Looking at Fig. 4-18 would be a good idea here, too.) (Fig. 4-17 in the 9th edition)



And if you're just *dying* to do *one more* simulation, try this one… which planet is Earth, and which one is Venus?



Now we deal with Tycho Brahe, another really important figure in the history of astronomy:

How did Tycho's model of the solar system represent a compromise between the geocentric and heliocentric models? (See Fig. 4-11 on p. 64 (p. 65 in the 9th edition)).

When compared with Aristotle's ideas, what was really weird about the `new star' in 1572? How did he show that it wasn't below the `sphere of the Moon'? (This is explained in Figure 4-12, but the explanation itself is hard to figure out. It's worth spending some time looking at Fig. 4-12 and re-reading the paragraph that begins "In 1572, a "new star"…".)

What important information did Tycho collect, which became important for Kepler?

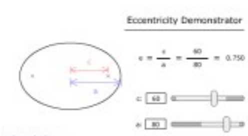
Next, we dealt with Kepler, who figured out some very important things about the planets' orbits:

Kepler's First Law - Make sure you understand the following points, which are covered on p. 67 (p. 68 in the 9th ed.):

- What is an *ellipse*?
- What are the *foci* of an ellipse?
- What's the *semimajor axis* of an ellipse?
- What does it mean if an ellipse has a high *eccentricity*?
- What do ellipses have to do with planetary motion?
- Make sure you don't confuse the terms *ellipse* and *eclipse*.

To better understand what an ellipse is, and what eccentricity is, play around with the next UNL simulation. Try this:

1. Move the sliders around to make the orbit look more eccentric or less eccentric.
2. If the number "e" has a large value, is the orbit more elliptical-looking, or less elliptical-looking?
3. Where are the foci in this simulation? (Make sure to compare the simulation to Fig. 4-14.)



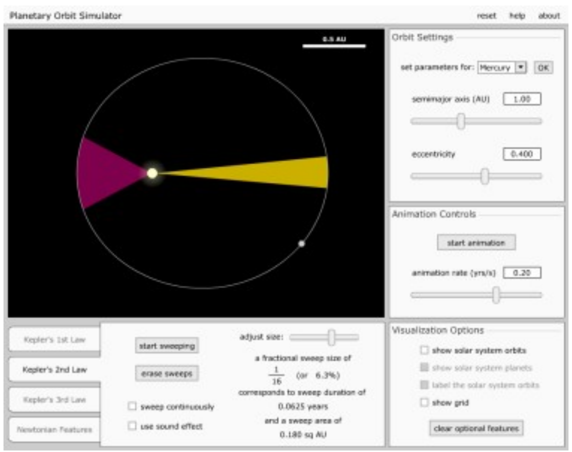
Kepler's Second Law - Make sure you understand the following points:

- What does the Second Law say?
- What is *angular momentum*? What's the analogy to an ice skater?
- Where, in its orbit, would an object be moving the *fastest*? Moving the *slowest*?

Kepler's Third Law - Make sure you understand the following points:

- As you go *farther* from the Sun, what happens to the *time* that it takes a planet to orbit the Sun?
- What does this imply about the *speed* at which, say, an outer planet is moving (relative to an inner one?)
- Would a `year' on an inner planet (like Mercury) be *longer* or *shorter* than the Earth's year? How about for an outer planet (like Neptune)?

As always, there's a detailed UNL simulation for Kepler's Laws. Like some of the other simulations, this one is very detailed. You might find yourself getting lost in all the details. But, if you have time to play around with it, exploring it step-by-step, you can learn a lot about Kepler's laws of planetary motion. This would be a great simulation for you to explore in a group study session, or for one or more students to explore with me during office hours!



Chapter 5: Gravity

Newton discovered three laws of motion that provided the foundation for understanding things like the orbits of planets around the Sun. There are a fair number of terms and details to keep straight when studying Newton. Here are some things to make sure you understand:

What is **Newton's First Law**? (Note: It's basically the same thing as Galileo's `law of inertia', which is described on p. 80.) (It's p. 82 in the 9th edition, and they put the term **inertia** in boldface in the 9th edition.) If an object is moving through space at a constant speed, in a straight line, what will happen to it, if no forces act on it? The textbook described Newton's laws of motion fairly briefly, but we may have made drawings in class showing a spacecraft that has its motion changed by forces. If you have these drawings in your notes, it's well worth reviewing them in detail. Make sure you're clear on how **forces** are what cause **changes in motion**.

What's a specific term we used for a `change in motion'? In class, we may have talked about how, in your car, you've got *three* controls for changing motion, rather than just the *one* that most people think of. In our drawings of the spacecraft, how did we show three different sorts of changes in motion?

What is **Newton's Second Law**? You can learn it using the equation on p. 81 (p. 83 in the 9th ed.) if you want, but it may be easier to think of it this way:

If we apply a *larger* force to an object, do we get a bigger change in motion, or a

smaller one?
If we make an object *more massive*, will the same force cause a bigger change in motion, or a smaller change?

(Hint: Think about hitting a baseball with a bat. This causes the ball's motion to change. Think about how a *harder* hit, or a *heavier* ball, would lead to different scenarios for the ball's change in motion.)

What is Newton's **Third Law**? This is the one that people have most commonly heard expressed as a spoken or written phrase. Here's an example of something important to understand about the Third Law: How does it allow a rocket to work? Is it really necessary for the rocket's exhaust to *hit* something, in order for the rocket to move? Or can a rocket, floating in empty space, ignite its engine and start moving? How is the Third Law relevant here?

Newton also came up with a very important idea called **mutual gravitation**. What does this mean? For example, if you travel across the universe, are you ever `beyond' the gravitational pull of the Earth?

What does it mean to say that the law of mutual gravitation is an *inverse square law*? Both light and gravity follow inverse square laws - it will be worth studying Fig. 5-6 on p. 83 here. (It's Fig. 5-5 on p. 85 in the 9th edition.)

(If you're feeling ambitious, you might want to play with UNL's Gravity Algebra simulation and their Newton's Law of Gravity Calculator . I've included these as text links, so people won't get too scared if they see something math-y-looking. However, even if you don't like math, these simulations might be worth exploring, because they do the math for you! They show what the results of Newton's `gravity math' are, when you stick different numbers into the formulas.)

Make sure you understand Newton's explanation of how orbits and orbital motion work. Figure 3 in the two-page spread on `Orbiting Earth' (`Orbits' in the 9th ed.) will be particularly important to understand here. You don't need to know the equation for orbital velocity, but make sure you understand why there is a certain orbital velocity for any given planet. In class, we probably talked about orbits by using the example of a cannon shooting cannonballs from the top of a tall tower. The textbook shows this in the `Orbiting Earth' spread, using the example of a tall mountain instead of a tall tower.

Another really useful way of understanding an orbit is the illustration in Fig. 1b of `Orbiting Earth'. In this example, the Moon's near-circular orbit it divided into many small segments. In each segment, notice how the Earth's gravity keeps *changing the direction* of the Moon's motion. Make sure you recall and understand that these changes of direction are examples of *acceleration*, and that this acceleration is caused by a *force*.

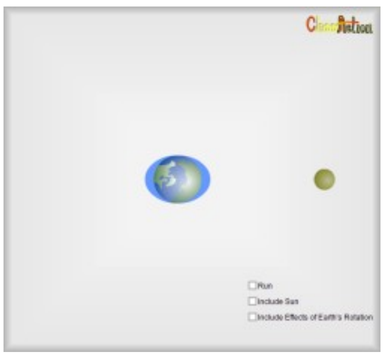
Here's an important point to be clear about: If you see an image of an astronaut floating `weightlessly' inside a spacecraft, what is *really* causing this? Have they really gone beyond the gravity of the Earth, as most people imagine?

EXTRA CREDIT: Memorize the equation for orbital velocity and be able to calculate the orbital velocity for a planet if you're given its mass, radius, and the value of G, the gravitational constant.

EXTRA CREDIT: Memorize `Newton's form of Kepler's Third Law', and use it to calculate the mass of a planet, if you're given the size of one of its moon's orbits, and the period of that moon's orbit.

How do the *tides* work? (Our textbook is one of the few that gives a correct presentation of how the tides work, as shown in Fig. 5-8). (It's Fig. 5-7 in the 9th edition.) How did tidal forces cause the Moon to `lock' its rotation so that it always has the same side facing the Earth? (The textbook may not fully explain this; we may have gone over it in class.)

You can get an idea of what the tidal bulges look like by running this UNL animation:



It's worth comparing that simulation in some detail to Fig. 5-8 on p. 90. (It's Fig. 5-7 in the 9th edition, on p. 92.) Here are some things to examine:

- Note that the simulation shows the bulging of the Earth's *oceans*. The solid body of the Earth and Moon bulge, too, but it's too small to notice at this scale.
- The most basic, starting configuration of the animation shows the basic tidal bulges, as shown in the first panel of the figure.
- To better understand the second panel of the figure, check the "Include Sun" box.
- To simulate the third panel of the figure, check the "Include Effects of Earth's Rotation" box.

Having studied Newton, we then went on to study Einstein. It sounds awfully scary, since we're studying Einstein's theories of relativity (!), but here are the things you should know and understand:

First, about **special relativity**:

- If you are moving in a straight line at a constant speed (i.e. you are in *uniform motion*), what's the only way you can judge your motion?
- Different observers are often moving in different directions and at different speeds. What happens when they measure the speed of light? How is this different from what people thought before Einstein?
- Can an object be accelerated to the speed of light? Can an object go faster than light?
- What happens to the observed mass of an object as its speed gets closer and closer to light speed?
- What happens to time (as measured by a moving observer) when that observer is moving at an appreciable fraction of the speed of light?
- What does the famous equation $E=mc^2$ tell us about the relationship between mass and energy?

Next, some things to know about **general relativity**:

- What is the *equivalence principle*? (Figure 5-13 illustrates this, and we may have used a similar analogy, involving an elevator in deep space.)
- What do we mean by *spacetime*?
- What are the four dimensions of spacetime?
- Gravity is said to be something like an illusion, and it's really a result of curved spacetime. What causes spacetime to curve?
- When Einstein was developing the general theory of relativity, what was it about the planet Mercury that told him he was on the right path?
- How can strong gravitational fields (i.e. strongly curved spacetime) affect light? How about time?
- How were observations of an eclipse in 1919 used to check general relativity?
- What are the ways we see and feel curved space-time in our universe?
- What is gravitational lensing? Make sure you can recognize images of gravitationally-lensed galaxies, like the ones behind galaxy cluster Abell 1689.)

Chapter 6: Light and Telescopes

What is *electromagnetic radiation*, and how is it different from the radiation that would come from a radioactive substance? (The textbook discusses a `Common Misconception' about the term `radiation' on p. 101 (p. 104 in the 9th ed.))

It's important to remember that light can be thought of as both *waves* and *particles*. (This is discussed on p. 101 and 102. (p. 104 and 105 in the 9th ed.)) When we think of light as a wave, what are the two *fields* that are vibrating as the waves move through space?

(Note: There's a slightly misleading sentence on p. 102 that might confuse you here. (This is on p. 105 in the 9th edition.) It says "In contrast, light is made up of electric and magnetic fields that can travel through empty space." It isn't actually the fields that are moving. The electric and magnetic fields permeate all of space. It's disturbances in those fields, which we call `waves' by analogy to disturbances of the ocean's surface, that are moving through space.)

What do we mean by the *wavelength*, *amplitude*, and *frequency* of an electromagnetic wave? What is the *speed* of all electromagnetic waves?

What is the electromagnetic spectrum? To what portion of it are our eyes sensitive? What portions of the electromagnetic spectrum come through our atmosphere?

Study Fig. 6-3, and make sure you know the major parts of the electromagnetic spectrum, and how they are arranged relative to each other (in terms of their wavelength):

- Gamma rays
- X-rays
- Ultraviolet
- Visible
- Infrared
- Radio

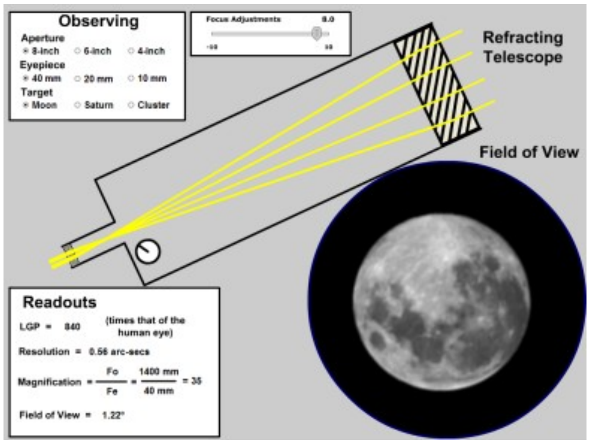
Now for some things to know about *telescopes*:

First, recall the three things a telescope does:

- Magnify
- Gather light
- Resolve small details

What are the two basic types of telescope? (Figures 6-5a and 6-6 will be particularly useful here.) How does each type of telescope gather light?

That list of three things a telescope does - which of those things is/are influenced by the telescope's *aperture*, and which is/are influenced by the telescope's *focal length*? (Figs. 6-5b and 6-9 will be worth studying here, as will the textbook's description of `The Powers and Limitations of Telescopes' on p. 106-108. (p. 109-112 in the 9th edition)) The UNL "Telescope Simulator" can be handy to play around with here, as well (see below). As with most of their simulations, it can be a bit complicated, but there are a few basic things to concentrate on. Mostly, I recommend clicking on different `Aperture' settings, and seeing what that does to the `Resolution' and `Magnification' readouts.



What do we call the problem that a refracting telescope has with color? Make sure you understand Fig. 6-7. Does a reflecting telescope have this same problem?

What is a telescope's *mounting*? Why would you want to use a very steady, high-precision mounting for your telescope? Why would the apparent diurnal motion of the sky be a problem for an astronomer, and how does the telescope's mounting counteract this effect? (Fig. 2 in `Modern Optical Telescopes' will be useful here.)

What is *seeing*? Why would it help an astronomer to build a telescope on top of a high mountain or to put a telescope in space? What are *adaptive optics*, and how do they help? What is light pollution, and how do astronomers cope with it?

Are all telescopes designed to operate at visible-light wavelengths? Which of the two main types of telescope would a *radio telescope* be an example of?

What are the advantages of placing a telescope in space?

Make sure you remember the three basic things that astronomers do with the electromagnetic radiation that their telescopes gather:

- Imaging
- Spectroscopy
- Photometry

What's a charge-coupled device (or `CCD')? What advantages do CCDs have over the old photographic plates? Is it possible you're carrying one or more CCDs with you on a daily basis, and if so, where?

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Astronomy 10

Section 1 (M through F, 7:30 - 8:20 am)

Here are the chapters to know for Test 2, in the order that we covered them (The chapter numbers are the same in both the 8th and 9th editions of the text):

Chapter 7 (Atoms and Spectra)
Chapter 8 (The Sun)
Chapter 9 (Stars)
Chapter 10 (The Interstellar Medium)
Chapter 11 (The formation of stars)

Chapter 7: Atoms and Starlight

What are the three kinds of *particles* in an atom? Which ones make up the *nucleus*? Which ones `orbit' the nucleus? (We probably mentioned in class that `orbit' isn't really quite the right description, and it's also mentioned in `A Model Atom' on p. 127 of the 8th ed., p. 131 of the 9th edition.)

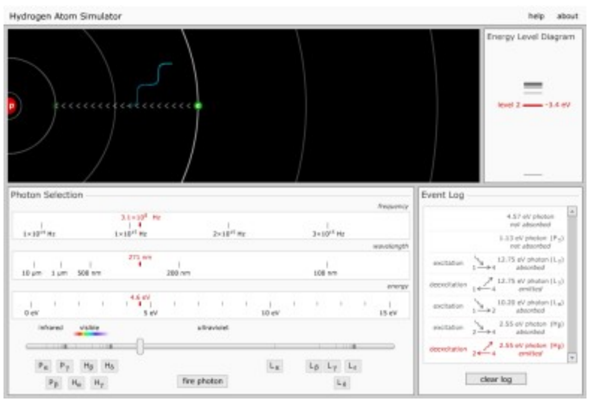
What are the *permitted orbits* of an electron?

How does the absorption of light relate to electrons and their permitted orbits? How is this related to the idea of *energy levels* and an *excited atom*? You should carefully study `The Excitation of Atoms' on p. 130 and 131 (p. 134 and 135 in the 9th edition). Here are some specific things to understand from these pages, and from our discussion of them in class:

- When an atom absorbs a *photon*, what happens to an orbiting electron? (Figs. 7-4 and 7-5 will be useful here.)
- Can an atom absorb a photon of any old wavelength?
- Can an atom emit energy that it's absorbed?

- If so, how does this affect an electron's energy level, and what gets emitted?

Here's a good UNL simulation to get you started learning this - the Hydrogen Atom Simulator. Here's a good way to learn from this one: Fire photons of various energies at the hydrogen atom, and watch what happens to the electron. Wait a little while after firing each photon, and see what happens to the electron if you just let it sit around for a while… does it stay in an upper energy level forever? Do you see why the lowest energy level is called the "ground state"?

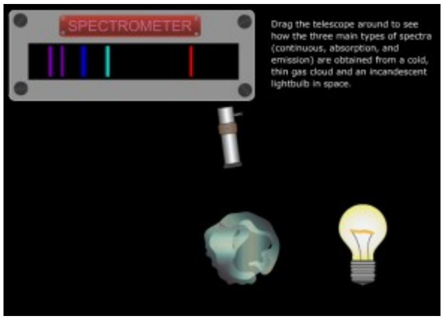


The next part of Chapter 7 to learn is the two-page spread on `Atomic Spectra', on pages 136 and 137 (140 and 141 in the 9th edition). Make sure you understand the differences between these three types of spectra, and how each one forms:

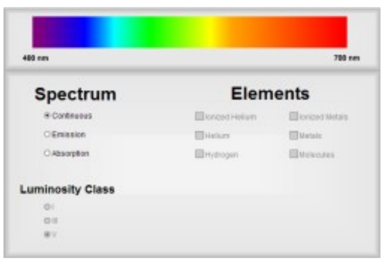
- Continuous
- Absorption
- Emission

Which type of spectrum would a hot, glowing object (like a light bulb or star) produce? (This is related to *thermal energy* and *blackbody radiation*, which are discussed on p. 131 in the 8th edition, p. 135 in the 9th edition.) If we observed a planet with a spectrograph, would we be likely to see the same type of spectrum? Why or why not?

Here's the UNL simulation for this concept - the "Three Views Simulator". This one is pretty simple. Click-drag the little telescope around so that you're looking at things from different directions, and see what kind of spectrum results. Here are some suggestions: 1) Look directly at the bulb - what kind of spectrum do you see? 2) Look at the bulb **through** the gas cloud - <u>now</u> what kind of spectrum do you see? 3) Look at the gas cloud from the side, so that you see the light it gives off when its atoms are *excited* by photons from the bulb. What sort of spectrum does *this* produce?



It will probably also be worth playing with this one, too. It's the "Spectrum Explorer", but don't worry about the `Spectral Type" and Luminosity Class" stuff, yet. We'll get to that in Chapter 9.

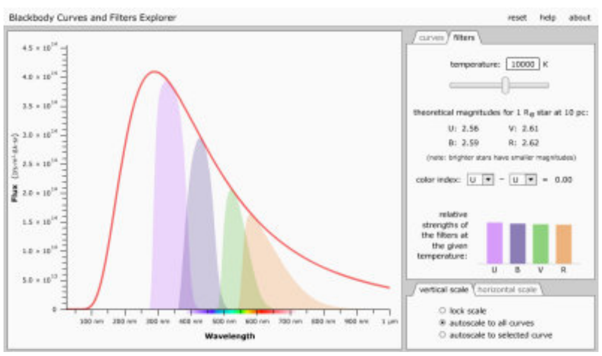


The section on `Radiation from a Heated Object' on p. 131 (p. 135 in the 9th edition) has a lot of important concepts, which you should understand now because we'll use these concepts over and over again later in the course. Here are some specific things to know:

- What does the textbook mean when they talk about the `acceleration of charged particles' in this section? (Don't forget what we talked about in Chapter 5 regarding acceleration, and how it doesn't just mean `speeding up'.)
- How does the `acceleration of charged particles' produce light?
- Why do hot objects (like hot horsehoes, or stars) have a lot of `accelerating' charged particles?
- Make sure you're clear on the meanings of *heat*, *temperature*, and *thermal energy*.
- How does the *Kelvin temperature scale* work? (and what is *absolute zero*?)
- Don't forget that *blackbody radiation* refers to the electromagnetic radiation (e.g. light) emitted by an object that's warmer than absolute zero.

It's very important to carefully study the textbook's description of blackbody radiation, which starts about 3/4 of the way through page 131 (135 in the 9th ed.), and finishes with the first few lines of p. 134 (last few paragraphs of p. 137 in the 9th ed.) It will be a very good idea to carefully study Figure 7-6 on p. 133 (it's on p. 137 in the 9th edition). Make sure you're clear on what is meant by the *wavelength of maximum intensity* (p. 132, or p. 137 in the 9th edition). How does this change as an object gets hotter, and what does this mean for the color of the light the object emits? (Note that this is the same thing as *Wien's Law*.) In class, we probably emphasized that you should understand Wien's Law in a conceptual way. If you can understand the equation for it on p. 133 (137 in the 9th ed.), great, but just make sure you understand the basic principle: <u>Hotter means bluer, and cooler means redder</u>.

And, as always, there is a great UNL simulation for this concept! For this one, the main thing you want to do is to slide the `temperature' slider back and forth. Watch what happens to the blackbody curve… it's pretty dramatic! I also recommend checking the `indicate peak wavelength box', and then moving the temperature slider some more. Also experiment with these two options: `lock scale' and `autoscale to all curves'. If you try the `lock scale' option, you'll get a *very* dramatic demonstration of how the intensity varies with wavelength!

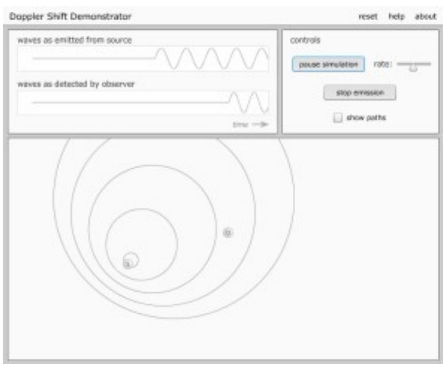


The Stefan-Boltzmann law is very important, too. As with Wien's law, you don't need to be able to use the equation for it (see p. 133, or p. 136 in the 9th ed.), but you should have a good conceptual understanding of the Stefan-Boltzmann law. As we probably emphasized in class, <u>a square meter of an object's surface puts out more energy per second as the object gets hotter</u>. And if you make the object hotter, <u>that square meter puts out **much, much more** energy than it did when it was cooler</u>! In fact, that's what you just studied when you were playing with the UNL "Blackbody Curves" simulation. Remember how dramatically the height of the curve changed when you checked the `lock scale' box? That's a demonstration of the Stefan-Boltzmann law.

How does the observation of the spectrum of a star, planet, nebula, or other object allow us to figure out what kinds of atoms and/or chemical compounds it's made of? (It's worth studying Fig. 7-7 here, as well as Fig. 2c and Fig 3, both on p. 137 [p. 141 in the 9th ed.].) To practice this concept, I recommend that you go back to the "Spectrum Explorer" simulation. Begin by checking the `Emission' radio button, and then play around with checking and unchecking the boxes for `Helium', `Hydrogen', etc… Try to imagine that you're an astrophysicist who specializes in identifying the things that stars are made of, from their spectral lines… think of how good someone like that would get at recognizing, say, the hydrogen lines!

What is the *Doppler effect*? How do we use *redshifts* and *blueshifts* to measure the velocity of an object? A good thing to examine in detail here is Fig. 7-8. Not only does this show how the Doppler effect works, but it shows what an absorption line looks like when it's redshifted or blueshifted. The Doppler effect will come up over and over again for the rest of the quarter, so it's a really good idea to make sure you understand how it works.

To understand the Doppler effect, I recommend playing around with the UNL "Doppler Shift Demonstrator", below. The controls take a little getting used to, but the most important button to know about is the `start emission' button. That starts making waves, which spread outward from the the Source, `S'. Then you can move the source OR the observer (`O'), and watch how the *received* wavelength changes. Compare what you see to Figure 7-8. (Tip: If you want to make the source or the observer *keep moving*, try holding down the left mouse button.)



Chapter 8: The Sun

The Sun's diameter is about how many times bigger than the Earth's?

What are the two most abundant chemical elements in the Sun? The remaining elements make up about what total percentage of the Sun's mass? (You will find it helpful to look at `Composition of the Sun', on p. 148-149 (p. 154 in the 9th ed.), particularly the part about Cecilia Payne's discoveries.)

Make sure you're clear on the basic parts of the Sun, particularly the *core*, *radiative zone*, *convective zone*, *photosphere*, *chromosphere*, and *corona*.

Which part of the Sun does the sunlight that we see come from? If you wanted to see the corona from the surface of the Earth, what sort of event will you have to wait for?

What causes the *granulation* that we see in the photosphere? (Figure 8-2 will be useful here, and this is related to the difference between the radiative and convective zones, see p. 163 for those, or p. 168-169 in the 9th ed.)

Here are some things to know about the Sun's magnetism.. the two-page spread on

p. 152-153 (`Sunspots and the Sunspot Cycle'; it's p. 158-159 in the 9th ed.) will prove useful here, as will the section on `The Sun's Magnetic Cycle' on p. 154-155 (p. 157 and 160 in the 9th ed.).

- What's a *sunspot*? How does its temperature compare the nearby, brighter portions of the solar surface?
- How many years does it take to go from one sunspot *maximum* (or *minimum*) to another?
- How do astronomers use the Zeeman Effect to measure the magnetic field on the Sun's surface, especially over sunspots? (see part 3 on p. 153 [p. 160 in the 9th ed.])
- What's an *active region*?
- What is meant by the Sun's *differential rotation*?

Make sure you understand the Babcock model, which is shown in Fig. 8-10. Try to visually remember the sequence of diagrams in Fig. 8-10, showing how the Sun's magnetic field gets `wound up'. Also make sure you compare the `loop of tangled magnetic field' (in the last drawing in Fig. 8-10) with Fig. 8-11. How do the drawings in Fig. 8-10 explain the magnetic polarities of the `leading spots' in Fig. 8-11?

What are *prominences*, *solar flares*, the *solar wind*, and a *coronal mass ejection*? (See the two-page spread on 159-160; it's p 162-163 in the 9th ed.)

What is *nuclear fusion*? What's the difference between fusion and *fission*? I may have told a goofy `analogy story' in class, describing two protons that get slammed into each other and fuse together. Why did they (initially) find each other `repulsive'? What force took over and made them say `ooh, I find you so powerfully attractive!' when they were slammed sufficiently **close** together? (Studying Section 8-3, `Nuclear Fusion in the Sun', will be helpful here.)

EXTRA CREDIT: Memorize the `proton-proton chain' shown in Figure 8-14, and be able to answer questions about it. Here are examples of good things to know:

- *How many protons go **in** to reactions in the proton-proton chain?*
- *Do any protons come **out** of reactions in the proton-proton chain?*
- *In what forms does energy emerge from the proton-proton chain?*
- *How does nuclear fusion heat the gas that makes up the Sun's core?*
- *What types of particles and/or electromagnetic radiation are produced in the proton-proton chain?*
- *What is the equation that describes the conversion of mass into energy?*

(You might want to play around with the UNL proton-proton chain simulation, too.)

Then we went on to Chapter 9: "The Family of Stars".

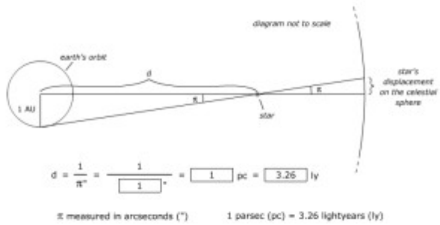
This chapter has a lot of fundamental information about the stars. We started out with how astronomers make basic measurements of stars, and then moved through a sequence of steps to figure out things like the sizes and masses of stars. Finally, we went over the all-important Hertzsprung-Russell diagram.

First, we dealt with how to find the distance to a star. The most basic way is to use triangulation. This is explained on p. 169-170 (176-177 in the 9th ed.). This can get a little intimidating, since there's some geometry and math involved, but the key here is to fall back on the *conceptual understanding* that we worked on in class. Here are some specifics:

- We may have mentioned (and drawn) a `Basic Idea of Triangulation'. It didn't have any numbers or equations, but it showed us what can be figured out if you have a long, skinny triangle, and you know the *baseline* and the angle in the skinny part. We probably drew this in class.
- Make sure you undersand (and, if necessary, could re-draw) Figure 9-2. Try to be clear, in your own mind, which part of the drawing is the distance to the star, which part is the Earth's orbit, and which part is the *parallax angle*. How do these things relate to our `Basic Idea of Triangulation'?
- What are the definitions of an *arcminute* and an *arcsecond*?
- If a star has a *parallax* of one arcsecond, how far away is it, in *parsecs*? How many light-years is this? What about for, say, 2 arcseconds, or 3 arcseconds?

You might find it useful to play around with the UNL Parallax simulator, but I recommend following these steps, so as to avoid getting confused:

1. As always, I recommend right-clicking on the simulation image, below, and doing an `Open in New Window'.
2. In this simulation, you can type a number in the box. Note that the box is on the BOTTOM of a fraction.
3. Start by typing a "1" in the box, if it isn't in there already. The simulation will calculate the distance to the star. This is the distance if the parallax is 1/1=1 arc second.
4. Then, explore what happens if we observe stars at **greater and greater** distances. Do this by typing numbers **smaller than 1** in the box, such as…
5. What's the distance if you type "0.5" in the box? (i.e. a parallax of 1/2 arc second = 0.5 arsecond)
6. Try smaller and smaller numbers, to see what happens to the distance as the parallax decreases.



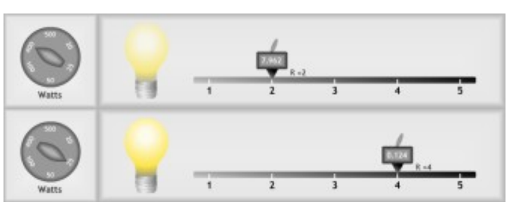
Then, there was a *proper motion method* for getting the distances to stars. We probably explained this in a simplified, conceptual way, probably using one or more analogies. The textbook uses an analogy to explain this method, at the end of Section 9-1.

What's the difference between a star's *apparent brightness* and its *intrinsic brightness*? We may have also called the intrinsic brightness the `Luminosity', and we probably made an analogy to a light bulb. What sort of units are printed on most light bulbs? What is a *watt*?

What do astronomers mean by flux? (See the end of p. 171, it's the last part of p. 178 in the 9th ed.)

How does the inverse-square law apply to light? Recall that we discussed the inverse-square law before, when we talked about gravity. You don't need to be all equation-y about it, but remember the basics: If a star could be moved to *twice* its current distance, the flux we get from it would drop to <u>what fraction</u> of its original value? How about for *three* times the distance, or *four* times?

You can try simulating this by playing around with the UNL Flux Simulator. This simulation shows two identical setups, one above the other. In each case, you can select the `luminosity' of the light bulb (50 watts, 100 watts, etc..) and the distance to the observer. Pick a brightness, and then slide the observer/detector (the little slide-able thingy) to different distances. Notice how the apparent brightness readout changes. That's the inverse-square law in action!



(This is a good place to review the magnitude scale, which was originally explained on p. 15-16 in both editions.)

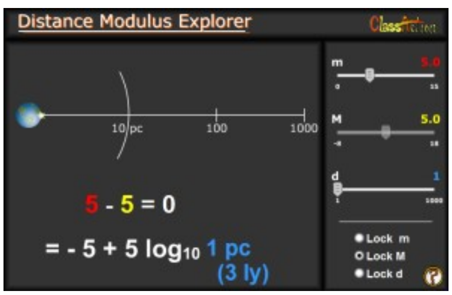
How do we define the *absolute magnitude* of a star? What's the `standard distance' for this calculation? What is the Sun's absolute magnitude?

Extra Credit: Memorize the magnitude-distance formula on p. 172 (p. 179 in the 9th ed.), and use it to solve problems. If you are given ***two*** *of these things, you should* *be able to figure out the third one: a) Apparent magnitude, b) Absolute magnitude, c) distance (in parsec).*

Here's a great way to absorb the concept of apparent magnitude versus absolute magnitude: Play around with the UNL Distance Modulus simulation. Here are some suggestions:

1. Start with "Lock M" selected.
2. Then change the distance, d. What happens to the apparent magnitude, m?
3. Next, try changing the apparent magnitude, m. If the star has a given absolute magnitude (as is the case if "Lock M" is selected, what does a changing `m' imply about the distance, d?

You may want to play around with other options, too, to try and internalize these concepts.



Okay, next step... time to deal with the *luminosities* of stars. First, make sure you understand the definition of luminosity (top of p. 173; it's the top of p. 180 in the 9th ed.). Recall, from class, that we didn't bother using numerical units very much, but instead we used the idea of `compared to the Sun'. This made our lives a lot easier! Notice, as shown on p.173 (p. 180 in the 9th ed.), that we used the little `disc with a dot in it' symbol to mean `...of the Sun'.

How does the *Balmer Thermometer* work? (see p. 173-174 [180-181 in the 9th ed.], and Fig. 9-5.)

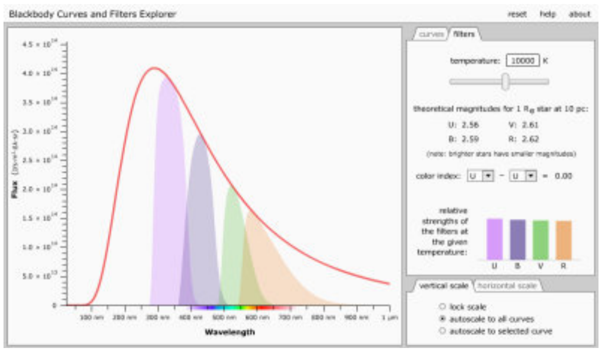
Ah, now it's time for the famous story of Annie Jump Cannon, and her famous mnemonic! (O B A F G K M) Here are the specific things to know:

- Memorize the sequence of spectral types: OBAFGKM
- How does the temperature change as we go from the "O" end of the sequence to the "M" end?
- What is the spectral type of the Sun?

(For more information about Annie Cannon's life and work, see, for example, this link from the International Astronomical Union and UNESCO, or this page about the

[AAS's Annie Jump Cannon award](#).)

If we return to the UNL Blackbody Explorer, we can see some of these concepts in action. Slide the temperature back and forth, and see what happens to the peak wavelength. You might also want to switch to the `filters' tab, to see what happens to the brightness of a star as seen through different filters, if we change its temperature:

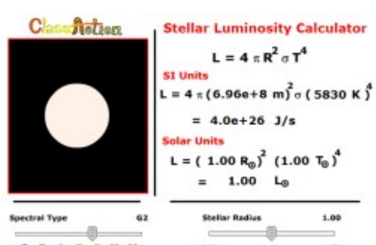


Okay, now we go for stellar sizes. It's cool, you can study this and master it, just like we went through it in class!

In class, we did this in our usual conceptual way, and that's a perfectly fine way to know this for the test. If it helps, you might want to carefully examine the **third** equation on p. 178 (p. 184 in the 9th ed.). Here are the concepts `contained' in that equation, that you should understand:

- What happens to the luminosity of a star if we increase the star's temperature?
- What happens to the luminosity of a star if we increase the stars's size?

At this point, you may find it easiest to answer those two questions by playing around with the UNL Luminosity Simulator:



Also make sure you remember that we can **solve for size** if we know luminosity and temperature. You don't have to do the algebra that's involved here, but make sure you're at least aware of the idea that we can take luminosity and temperature, and get size. Before we move on, though... how would we **get** the luminosity and the temperature in the first place? What would be the chain of observations and calculations that we'd make? (If you can answer that last question clearly and in detail, you are kicking some major rear end at this point!)

Okay, deep breath now... we're getting there! We can do this! We're getting through Chapter 9 just fine. Now it's on to the **big** topic... the Hertzsprung-Russell diagram:

First, I REALLY recommend carefully studying and understanding the "car analogy" shown in Figure 9-10. This is a really good analogy to the H-R diagram! If you can understand why most cars would fall along a `main sequence for cars', you'll be in a good place to understand the main sequence of stars.

(Here's something we probably mentioned in class, whch is really important to remember: Stars don't move **along** the main sequence, at least not very much. The main sequence is not a `journey taken by a star'. A star follows a pathway TO the main sequence (on the H-R diagram) as it forms, and then follows a pathway OFF OF the main sequence late in its life, but in general, it just SITS ON the main sequence during most of its life.)

We probably laid out a "Basic Outline of the H-R Diagram" in class. Carefully compare this outline to Figure 9-12, and make sure you could re-draw (and accurately label) the ouline on the test.

Where, on the H-R diagram, would we find the following types of stars?:

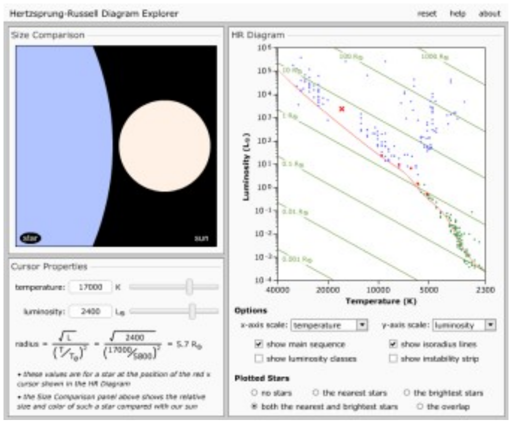
- Stars like the Sun
- Small, cool stars called *red dwarf* stars?
- Bright main-sequence stars like Spica?
- Giant stars like Aldebaran?
- Supergiants like Deneb and Antares?
- White dwarfs like the companion of Sirius?

(We probably pointed these stars out in class, using the planetarium.)

At this point, if you've studied the H-R diagram carefully, it may be worth playing with the UNL H-R simulator (below). Here are my suggestions for using it:

1. Set "x-axis scale" to `spectral type'.
2. Set "y-axis scale" to 'luminosity'.
3. Make sure the "show main sequence" and "show isoradius lines" boxes are checked.
4. Leave the boxes "show luminosity classes" and "show instability strip" unchecked.
5. For "Plotted Stars", start with `no stars'.
6. Next, look at the "Cursor Properties" sliders (there are two of them). Slide one, and see how the red 'x' moves off of the main sequence. What do you have to do to the other slider to get the red 'x' back ON the main sequence? What does this do to the size and color of the star?

7. After you've played around like that for a while, turn on "show luminosity classes", and try to make a red giant, and then a blue giant. How do the sizes of these stars compare to the size of the Sun?



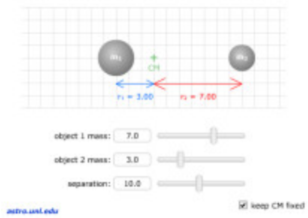
How do the *widths of spectral lines* allow us to figure out how big a star is? (This is explained at the bottom of p. 181, and on p. 182. [bottom of p. 188, and on p. 189, in the 9th ed.])

If you know a star's spectral type, how could you use *"spectroscopic parallax"* to figure out the distance to the star? Why do we need to use spectroscopic parallax to get the distances to most stars?

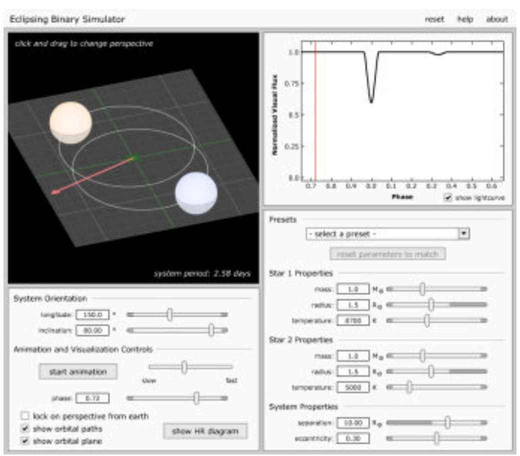
(You can play with the Spectroscopic Parallax Simulator at this point, but it's a bit complicated, so I'll let you explore this one on your own. It puts together most of the concepts we've been dealing with so far in Chapter 9.)

The last big thing we did in Chapter 9 was to go through the story of how astronomers figure out the masses of stars, using *eclipsing binary stars*. This is explained in section 9-5. You should be able to explain the basics of this line of reasoning, even though you don't have to do the math. The key point was where I conceptually explained a mathematical idea: If you have "two equations in two unknowns", you can solve for both unknowns. Remember, you don't have to do the solving, but you should be able to show how the problem is `set up'. What are the two basic relationships here, which involve a binary pair of stars? (Hint: Carefully read over p. 184 a few times [p. 190 and 191 in the 9th ed.]. One of the relationships is shown in Fig. 9-17 [9-15 in the 9th ed.], and is summarized in a sentence just above that figure, which begins "The ratio of the masses...". The other relationship is the equation shown on the upper-right part of the page. [right side of p. 190 in the 9th ed.])

As always, there are some UNL simulations for this. First, there's the Center-of-Mass simulation. Slide the two `mass' sliders around, and see where the center of mass winds up. (Can you make it be IN one of the two masses?)



Next, there's the Eclipsing Binary Simulator. This is one of those big, detailed, lots-of-stuff-to-tweak simulations. If you do nothing else with it, I recommend playing with the "inclination" slider after you've started the animation:



There's one more point that's important to learn here, even though it's not emphasized at this point in the textbook. That's the **lifetimes of the stars**. We might have made a general statement about this in class, at this point. What was that general principle? If you have a hot, high-mass star (and what spectral type would that be?), will it live for a *longer* time than the Sun, or a *shorter* time? What about a low-mass star? (And again, what spectral type would that be? Don't forget to look carefully at Fig. 9-12 to see where the high-mass and low-mass stars are located on the main sequence.)

Chapter 10: The Interstellar Medium

In class, we may have begun our discussion of this chapter by turning on the planetarium's projection systems and looking at *nebulae*. Make sure you're clear on the Three Kinds of Nebulae, as described and illustrated on p. 199-201 (205-207 in the 9th edition). (The two-page spread on p. 200-201 [206-207 in the 9th ed.] is particularly useful. Here are some specific things to know about the three types of nebulae:

- Which type glows with its own light?
- What kind of spectrum would a nebula like this show? (It may be worth going back to p. 136-137 [p. 140-141 in the 9th ed.] to review the three types of spectra.)
- Which type of nebula is also called an HII region? What do "HI" and "HII" mean?
- How does a *reflection nebula* shine?
- How is a *reflection nebula* similar to the Earth's atmosphere, as seen from the Earth's surface?
- What's a *dark nebula*? What is a dark nebula made of?

If you were looking at pictures of the Lagoon and Trifid Nebula, how could you tell which part(s) of these are <u>reflection</u> nebulae, and which parts are <u>emission</u> nebulae?

We'll probably look at images like Fig. 10-2, to explore the idea of interstellar reddening. Make sure to carefully study the section on `Extinction and Reddening', on p. 202-203 (p. 208-209 in the 9th ed.). What wavelengths could we use to see through a cloud of interstellar dust?

In general, what sort of spectrum to astronomers observe when they look at the light of stars, as seen *through* the interstellar medium? How does this allow them to figure out what the ISM is made of?

The story of *21-cm radiation* is a little tricky to understand, so it's worth carefully reading the section on `Interstellar Emission Lines', which starts on p. 205 (p. 211 in the 9th ed.). The so-called 21-cm radiation allows us to map out <u>which important aspect</u> of our galaxy's structure? How is *infrared radiation from dust* used for the same purpose, not only in our galaxy, but in galaxies like M51?

What is a *molecular cloud*? What's an example of a molecule found in molecular clouds?

How do X-rays reveal the existence of the hot *coronal gas* that exists between some stars? (Hint: It may be worth going back and reviewing Fig. 7-6 and Wien's Law, back on p. 133 [p. 137 in the 9th ed.].) What spectacular event heats this gas to such high temperatures?

What makes *interstellar dust*?

Chapter 11: The Formation and Structure of Stars

What do we call the `things' that collapse to form stars? What are these `things' mostly made of? (Hint: See p. 210, back in Chapter 10. This is p. 215 in the 9th edition.)

How does the mass of a `GMC' compare to the mass of a star like the Sun? Does a GMC just form **one** star?

A cloud of interstellar gas and dust has various ways of resisting compression. Make sure you are familiar with the four factors that cause this, as described in section 11-1:

- Thermal energy: What is the importance of the fact that the cloud, although cold, has some thermal energy? Specifically, what does this mean for the motion of its atoms and molecules? (Reviewing `Temperature, Heat, and Thermal Energy' on p. 132 wouldn't be a bad idea here. [It's on p. 136 in the 9th edition.])
- Magnetic fields: What kinds of atoms are affected by magnetic fields in interstellar clouds? Does this magnetic factor last forever?
- Rotation: What happens to an interstellar cloud's rate of spin as it contracts?
- Turbulence: What does it mean to say that there is *turbulence* in an interstellar cloud?

What's a *shock*? How can a shock trigger the collapse of an interstellar cloud? (Studying Fig. 11-2 would be a good idea here.)

Next, you'll want to understand the idea of heating by contraction, which is described on p. 220 (p. 227 in the 9th edition). We may have discussed this in some detail in class, talking about the difference between *gravitational potential energy* and *kinetic energy*. What does it mean to say that an object on a table (or a molecule or dust grain in an interstellar cloud) has gravitational potential energy? In class, I may have talked about an idea that I called `thermalizing' the gas. This is described at the bottom of the first column of text on p. 220 (p. 227 in the 9th ed.). How does this process of `thermalization' work?

If a cloud heats up when it contracts, why doesn't the resulting thermal energy just make it expand again? The infrared emission of the clouds is important here. It is discussed in the second column of text on p. 220 (p. 227 in the 9th ed.), particularly where the textbook talks about something called *cooling lines*.

You should study Fig. 11-4 and have a decent visual and conceptual memory of it. Here are some specific things to be clear about:

- On the H-R diagram, what is the pathway that a protostar follows toward the main sequence?
- Can a protostar be seen easily at visual wavelengths, as it approaches the main sequence? Why or why not?
- What does a newborn star have to do in order to make itself visible at visual wavelengths?

Section 11-2 (and the 2-page spread on p. 224-225 [p. 232-233 in the 9th ed.]) discuss star formation in the context of the *Orion nebula*. Here are some specific things to know and understand:

- Is the visible nebula the same thing as the interstellar cloud?
- What makes the Orion nebula visible? What sort of spectrum would the nebula show?
- What spectral class is the star that provides the necessary photons for making the nebula visible? Why can only this type of star do it? (See part 2 on p. 224. It's p. 232 in the 9th edition.)
- Behind the visible nebula, we can observe star formation. What wavelength of electromagnetic radiation is used to make these observations, and why?
- What's a *star-formation pillar*? How does one form? (See Fig. 11-6 [=Fig. 11-5 in the 9th ed.], and also see the picture of the `Pillars of Creation' in Figure 4c on p. 229 [p. 237 in the 9th edition].)

Section 11-3 talks about *Young Stellar Objects* and protostellar disks. There's also a 2-page spread for this, on p. 228-229 (p. 236-237 in the 9th edition). Here are some specific things to know:

On the H-R diagram, what's the birth line?
What's a protostellar disk?
What do we mean by a jet?
How are jets related to Herbig-Haro objects?
If a star is in the T Tauri phase of life, is it a young or old star?

What's an *OB association*? Why does the presence of O and B stars in a cluster or nebula imply that star formation is probably still occurring there? (It may be worth reviewing the paragraph that begins "You should not be surprised… on p. 223. It's on p. 230 in the 9th edition.)

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Astronomy 10

Section 1 (M through F, 7:30 - 8:20 am)

Here are the chapters to know for Test 3, in the order that we covered them:

Chapter 11: (The last part, about structure and balance in stars)
Chapter 12: Stellar evolution
Chapter 13: Star deaths and supernovae
Chapter 14: Neutron Stars and Black Holes
Chapter 15: The Milky Way Galaxy
Chapter 16: Galaxies

Chapter 11: Star Formation

The last part of Chapter 11 might as well be the first part of Chapter 12, since they cover similar subjects - the structure of stars and the concept of balance within a star:

The next big concept from Chapter 11 was hydrostatic equilibrium. This is described on p. 232 (p. 238 in the 9th ed.), and in Fig. 11-12 on p. 233 (= Fig. 11-11 on p. 239 in the 9th ed.). Spend some time studying these descriptions, because hydrostatic equilibrium is an extremely important concept in how stars work! We probably discussed this concept in some detail in class, and you may have a sketch (similar to the figure referred to above) in your notes.

Make sure you understand the three ways that energy can flow out of a star, as described on p. 233 (p. 240 in the 9th ed.).

You don't have to know the details of the CNO cycle, but here are some specifics you should know:

If a star uses the CNO cycle to fuse hydrogen into helium, is the star more or less massive than the Sun?

In a star that's using the CNO cycle, is the core temperature higher or lower than in the core of the Sun?
Does the C (carbon) atom get used up in the CNO cycle?

Inside a star, what's the difference between a radiative zone and a convective zone? (We studied this for the Sun, back in Chapter 8. (See Fig. 8-15, in particular. It's Fig. 8-16 in the 9th edition.)

What is the pressure-temperature thermostat? (It's described in detail on p. 236, [p. 243 in the 9th ed.].)

Chapter 12: Stellar Evolution

Chap. 12 begins with a discussion of stellar models on p. 240-241 (p. 248-249). Scary-looking stuff, isn't it? Especially those equations in Fig. 12-2… yikes! We probably talked about these models in class (without going through the math-y details!) There are a few basic points you should remember:

- A stellar model is `made of' equations, generally in a spreadsheet or computer program.
- In a stellar model, the star is divided into many imaginary layers.
- Each layer has a particular mass, density, temperature, etc…
- A system of mathematical equations gets solved, usually with the help of a computer, to figure out what the values of those properties should be in each layer.

Whew! Remembering those facts - and reviewing p. 240-241(p. 248-249 in the 9th ed.) - is a lot less scary than doing the math!

Make sure you study the concept of "Why Is There a Main Sequence" on p. 242 (p. 250 in the 9th ed.). The paragraph that starts "The keys to understanding…" is especially useful, and is worth reading several times, as well as committing its basic concept to memory.

How massive are the most massive stars that have been observed? Why are extremely massive stars thought to be unstable? (And what do *stellar winds* have to do with this?) If an extremely massive star were on the main sequence, what part of the main sequence would it be on?

What is it about stars near the lower end of the main sequence that makes them hard to observe? What makes a *brown dwarf* different from a normal star?

There's a section on `The Life of a Main-Sequence Star', that starts on p. 244 (p. 253 in the 9th ed.). Here are some things to take away from this section:

First, I'd recommend reading the paragraph that starts with "Hydrogen fusion combines four nuclei…" several times. (In the 9th edition, it starts with "As you know, hydrogen fusion combines four nuclei into one…") Commit the facts in this paragraph to memory, because they'll be important for understanding stellar evolution, but don't freak out if the paragraph doesn't make complete sense. It's weird, the way stars change as they burn hydrogen through time, but it really does work the way the textbook says in this paragraph. To review:

1. In the proton-proton chain, four hydrogens make one helium.
2. This reduces the total number of nuclei in star's core.
3. The smaller number of particles bouncing around means **lower pressure** in the core.
4. The lower pressure makes the core **contract**.
5. The contraction of the core makes the core burn **hotter**.
6. Here's where it really gets weird: The increased energy flowing outward through the core makes the outer layers of the star expand (okay, that's not so weird), and **cool off**.
7. So, as time goes by the star gets large and cooler.

Now, that might seem like the star will get dimmer, overall. But it doesn't! Here's the logic:

- The star emits fewer watts of power from each square meter of surface area, because it's cooler. (See the Stefan-Boltzmann law, back on p. 133 [p. 136 in the 9th ed.].)
- The stars has expanded, so it has so many more square meters of surface area, than it did before.
- As a result, the star ends up emitting *more light overall*! The star actually gets **more luminous** as its main-sequence lifetime goes by.

It's good to review Figure 12-5 on p. 245 [p. 253 in the 9th ed.], to see how the star moves a little ways up and right on the H-R diagram during its main-sequence lifetime. What's the *ZAMS*?

In the case of the Sun, what does this changing luminosity mean for the future of life on Earth?

\`The Life Expectancies of Stars' : You don't have to memorize the equations show here, but make sure you know the basic principle: Do the more massive stars live longer or shorter lifetimes than the less-massive ones? What will be the total main-sequence lifetime of the Sun?

Section 12-2: Lots of details here, but for our test, make sure you know the basic highlights:

- Make sure you read and understand the `campfire' analogies on the first part of p. 247 (p. 255 in the 9th ed). (What kind of `ash' does a hydrogen-burning star create in its core? Does this material get mixed around in the star's interior?)
- What is *hydrogen shell burning*, and how does it get started?
- How does a star become a giant star during this phase of its life?
- How does it move on the H-R diagram as a result? (See Fig. 12-7.)

Degenerate Matter: Whoo-ee, this gets complicated! (See the discussion on p. 248 [= p. 257 in the 9th ed.]). As always, though, we can concentrate on a few basic highlights as we're reading and re-reading this section:

- What kind of particle is occupying energy levels in this discussion?
- Can you compress degenerate matter?
- If you heat degenerate matter, does the pressure change? Would normal matter, like a gas, behave this way?

Make sure you take note of the paragraph that **ends** with "…the toughest hardened steel."

How hot does a star's core have to be (in Kelvin) in order to start *helium fusion*? What kinds of atoms go into the *triple-alpha process*, and what kind of atom comes out?

How much energy is released by the *helium flash*? Do we see the helium flash, if we're observing the star from a distance?

Carefully examine Figure 12-11, which shows how a 3-solar-mass star evolves through time. Make sure you understand how a star's interior becomes like an onion, with many layers. As a matter of fact, I'd recommend being able to reproduce Fig. 12-11 if you study with someone else! That sounds like a real good idea to me, along with being able to explain why a star gets bigger and brighter as its core gets hotter.

Don't worry about Figure 12-12. Just make sure to remember that as giant stars continue to age, their cores get hotter and hotter, and produce heavier and heavier elements. This is the story of **nucleosynthesis**, which is an amazing story! Here a few basic facts to know about nucleosynthesis:

- What elements were produced in the early universe? (That's the era we call the `Big Bang'.)
- Where were the heavier elements made?

(Stay tuned for the story of the heaviest elements, which stars on p. 274 [p. 283 in the 9th ed].)

Next, we dealt with star clusters and the `turn-off point'. This is described on p. 253 (p. 264 in the 9th ed.), and in the two-page spread on p. 254-255 (p. 262-263 in the 9th ed). Here are some things to know about this story:

- What are *open clusters*?
- What are *globular clusters*?
- Why might the H-R diagram of a star cluster NOT have any stars on the uppermost part of the main sequence? (Hint: Study part 2 on p. 254. [p. 262 in the 9th ed.])
- How does a cluster's H-R diagram change through time? (Hint: Study part 3 on p. 255. [p. 263 in the 9th ed.])
- What do we mean by the `turn-off point' on a cluster's H-R diagram? How can this be used to estimate the cluster's age?

Finally, the long odyssey of Chapter 12 wrapped up with a discussion of *variable stars*:

- What are Cepheid variable stars and RR Lyrae variable stars?
- What is the *period-luminosity relation* for Cepheids? (We'll come back to this in a later chapter, because it will be **hugely important** for cosmology!)

There's a lot to know from Chapter 12 already, so I won't make you learn all the details of the `instability strip' and the `helium partial ionization zone'. I'd recommend simply reading `Pulsating Stars' a few times (it starts on p. 257 [p. 265 in the 9th ed.]), and understanding the general idea that in some stars, energy can alternately build up and be released, causing them to pulsate in size and luminosity.

Don't sweat the Type 1 and Type 2 Cepheids… it's a cool story, and I'd be happy to explain it to you during office hours, but we won't deal with it here.

Chapter 13: The Deaths of Stars

The textbook starts by sorting stars into categories by mass. (And as a reminder, where do we find stars of different masses on the H-R diagram?)

What's the lowest mass a star can have and still ignite hydrogen fusion?

What are two reasons why a red dwarf star can live much longer than the Sun?

What fuels **can** a sunlike star fuse, and what fuel **can't** it fuse? (In other words, what sort of nuclei make up the final `ash' in its core?)

What is meant by *mass loss*? What do we call the Sun's current method of mass loss?

Next, we got to *planetary nebulae*. The two-page spread on p. 266 and 267 is worth studying in detail. (It's on p. 276-277 in the 9th edition.) Here are some specific things to know:

- Is a planetary nebula the same thing as a planet? How were they originally named?
- How does the *slow wind - fast wind* mechanism work? (See part 2 on p. 266. [=p. 276 in the 9th ed.])
- What must be the minimum temperature of the stellar remnant (at the center of a planetary nebula), in order to make the nebula ionize and glow? (Hint: This is similar to the story of the hot star in the Orion nebula, described on p. 224. [=p. 232 in the 9th ed.])

This leads us to white dwarfs. These are some bizarre stellar remnants! Here are some specific things to know, from pages 265 and 268 (p. 275 and p. 278-279 in the 9th ed.):

- What was the first white dwarf discovered?
- What is its surface temperature?
- How does its mass compare to the Sun's?
- How does its size compare to the Sun's?
- What does this imply about its density?
- What strange kind of matter is a white dwarf made of?
- What will a white dwarf eventually turn into?
- Why don't we see any of the things that a white dwarf will turn into?

And a few things to know about the strange ways in which its degenerate matter would behave if you added mass to it:

- If you **added mass** to a white dwarf, what strange thing would happen to its size?
- What would happen to its radius if it you added enough mass to bring it up to the *Chandrasekhar limit*?
- How many solar masses is this?

What is *mass transfer* between binary stars? (This is described on p. 270-271 [p. 280-281 in the 9th edition].)

How does a *nova explosion* work? What role do binary stars and white dwarfs play?

Next we dealt with some really big blasts… supernovae! (This is Section 13-3, "The Deaths of Massive Stars".) Here are some tips for studying this section:

Which element, produced in massive star's core, *can't* be fused into a heavier element? Why is this? (Hint: It has to do with how strongly the atomic nucleus is **bound**.)
When these nuclei star to be produced, what happens to the core?
Make sure to study the `traffic jam' analogy for a shock wave, on p. 275. (It's on p. 285 in the 9th edition.)
How do *neutrinos* and *turbulence* help to explain the explosion of a supernova?

There are two main types of supernovae: *Type II* and *Type 1a*. What's the observable difference between each one? What's different about the cause of each one? (Hint: Which one could also be called a `core-collapse supernova'?)

In what year did Chinese astronomers observe a supernova that they called a "guest star"? What constellation was it in? What's at that position on the sky **now**?

Where (in space) did Supernova 1987a occur? What type of supernova was it? What special type of subatomic particle from the supernova was detected on Earth before the supernova's light reached us?

Chapter 14: Neutron Stars and Black Holes

What two types of cosmic event (or object) did Walter Baade and Fritz Zwicky propose in 1932? Were they right in proposing that such things exist?

What does the *Pauli Exclusion Principle* have to do with the neutrons in a *neutron star*? (In addition to the description of this phenomenon on p. 287 [p. 297 in the 9th ed.], you may want to review `Degenerate Matter' on p. 247 and 248. (That's p. 256-257 in the 9th edition.) Don't forget, however, that in neutron stars we're dealing with *neutron degeneracy*, as opposed to the *electron degeneracy* in white dwarfs.

What type of stellar death event produces a neutron star?

How are the neutrons in a neutron star produced? What role do *neutrinos* play?

What is the range of masses for stars that will end up leaving behind neutron stars after they die?

What is the upper limit for the **mass** of a neutron star itself? How **big** is a typical neutron star?

What's special about the **density** of neutron-star material?

Why do we expect that neutron stars should spin rapidly?

Make sure you understand -and can explain - how we know that (at least some) neutron stars do indeed spin rapidly. Keep in mind that spinning neutron stars are also called *pulsars*. This story is described in "The Discovery of Pulsars" and "A Model Pulsar" on p. 288 and 289 (p. 298 and 299 in the 9th ed), as well as in the 2-page spread on "The Lighthouse Model of a Pulsar" on p. 290-291 (p. 300-301 in the 9th ed.). Here are some specific things to know about the `lighthouse model':

- How are the *beams* of electromagnetic radiation related to the pulsar's magnetic field?
- Are the **rotational** poles of the pulsar necessarily the same as the **magnetic** poles?
- How does the pulsar's rotation cause it to <u>appear</u> to `pulse', as seen from the Earth?
- If we can't see a neutron star from the Earth, does that mean it doesn't have beams like other pulsars? What's a simple explanation for why we might not be able to observe the `pulses'?

(Being able to explain the lighthouse model to another student would probably be a useful skill to have!)

In what form does about 99.9% of a pulsar's radiated energy get emitted? What lights up small nebulae near pulsars? (Studying Fig. 14-4 will be useful here.)

How did Taylor and Hulse discover the first *binary pulsar*? We may have gone over the special type of redshift and blueshift that they observed - note that it wasn't exactly a shift in the wavelength of the light emitted by a pulsar. (It may be worth re-reading the paragraph that talks about the `pulse period', at the bottom of p. 293 [= p. 303 in the 9th ed].) What else did they observe, that suggested the binary pulsar system is losing energy via *gravitational waves*?

How can a pulsar in a binary system create powerful X-ray beams? It is worth studying the story of *Hercules X-1*, on p. 295.

What is the current explanation for why *millisecond pulsars* rotate so rapidly?

How were the first *pulsar planets* discovered? (Figure 14-11 will be useful here.)

Next, it was on to *black holes*...

How is the concept of *escape velocity* related to black holes? What role does the speed of light play, as well, in the definition of a black hole?

What's the minimum mass for the collapsing core of a star, if you want that core to become a black hole?

What are the radius, density, and gravity of a *singularity*?

What's special about the <u>curvature</u> of *space-time* in a black hole?

What's the Schwarzschild radius of a black hole? (You don't need to memorize the equation on p. 299 [= p. 310 in the 9th edition], but you should know what happens to the Schwarzschild radius as the mass of the black hole increases.)

Make sure you understand the **Common Misconceptions** described on p. 300 (p. 310 in the 9th edition). If the Sun became a black hole, what would happen to the orbits of the planets in our solar system?

What would happen if you jumped into a black hole? Make sure you understand *time dilation*, *gravitational redshift*, and the tidal stretching effect.

Detecting black holes: How can astronomers detect a black hole, if the hole itself can't be directly seen? It is worth carefully studying "The Search for Black Holes" on p. 301-303 (p. 311-313 in the 9th edition). Two key concepts to understand:

- What is the importance of the <u>mass</u> of the compact object?
- How do <u>bursts of energy</u> (or their absence) indicate a black hole? (See Fig. 14-17.)

Make sure you understand the relationship between *accretion disks* and *jets*. (Figure 14-18 depicts this nicely.)

The textbook doesn't have a description of the direct detection of black holes by means of gravitational waves, but I may have described it in class. (As of Winter 2016, it's too recent to be in the textbook!) What sort of event causes the type of gravitational-wave signature that was detected by the LIGO observatory in September 2015? You may find <u>this link from LIGO</u> useful, as well as <u>this article from the New York Times</u>.

Extra Credit: What are *gamma-ray bursts*, *hypernovas*, and *magnetars*? How are each of these things related to each other? If ask an extra-credit question about one of these things, it would be a good idea to be know the section on `Gamma-Ray Bursts' (in Ch. 14) in detail. For example, you'll want to know how short and long gamma-ray bursts form, in detail. If a gamma-ray burst happened in our part of the Milky Way, could it be dangerous for us, and why?

Chapter 15: The Milky Way Galaxy

What overall shape did William and Caroline Herschel deduce for the Milky Way? What was accurate about their ideas, and how were they mistaken?

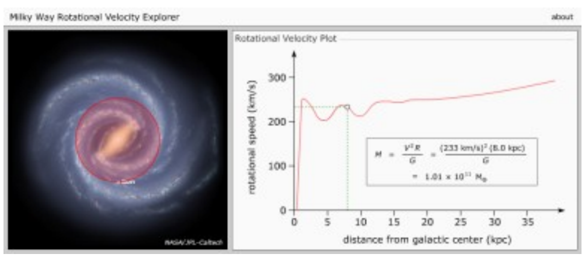
How did Harlow Shapley use the *Cepheid variable stars* to measure the distance to *globular clusters*, and how did he then use the globulars to estimate the size of the Milky Way? (It will be worth carefully studying "Variable Stars and the Size of the Galaxy" on p. 311-314. [= p. 323 - 326 in the 9th edition])

You should know the structure of the Milky Way galaxy, as described in Section 15-2. Here are some specific things to know:

- What is the approximate diameter of the Milky Way, in light years and kpc? How far is the Sun from the Galaxy's center?
- What are the spheroidal and disk components of the Milky Way?
- What kinds of things are in each of those components?
- Where (within the Milky Way) does star formation occur?

Make sure you understand the basics of the mass of the Milky Way. What does the *rotation curve* for our galaxy look like? How does the outer part of the rotation curve differ from *Keplerian motion*? What does this imply about *dark matter*?

(You might find it interesting to play with the UNL simulator for the Milky Way's rotation curve. Right-click and open it in a new browser window:)



The next thing we discussed was the *spiral-arm* structure of the Milky Way. Here are some specific things to know:

- What are the various tracers of the spiral arms?
- How do astronomers use *CO emission* and *21-cm radiation* to map the spiral arms?
- How does the *spiral density wave theory* work? (It will be worth studying Fig. 15-15 in detail here.)

(In addition to looking at Fig. 15-15, you might want to run the UNL traffic-jam-analogy simulation:)

What's the difference between a *grand-design* spiral galaxy and a *flocculent* spiral galaxy? How might *self-sustaining star formation* help to explain flocculent spirals?

What makes astronomers think there's a *supermassive black hole* at the center of the Milky Way? (And what do we call this object?) Section 15-4 and the two-page spread on p. 326-327 will be helpful here. (It's on p. 338-339 in the 9th edition.)

What are the differences between *Population I* and *Population II* stars? (And, just to make your life really fun, which of these populations would include the Type II supernovae?)

What do astronomers mean by *metals*? How do these elements form, and how do *galactic fountains* help disperse them through the Galaxy?

Formation of the Milky Way: What are the difference between the *top-down* and *bottom-up* models?

The Milky Way would make good fodder for one or more short-answer / concept-sketch questions. You could, for example, imagine drawing and labeling the galaxy's structure, perhaps as seen from `edge-on' and `face-on' views, and the various elements of that structure. Making drawings to illustrate the process of spiral-arm formation by way of density waves might be a useful skill, too.

Chapter 16: Galaxies

What were the two main hypotheses about the nature of the *spiral nebulae*, at the time of the *Shapley-Curtis debate* in 1920?

How did Edwin Hubble show that the Andromeda `nebula' (M31) is in fact a galaxy, similar to the Milky Way?

Galaxy classification: Make sure you know how to recognize the differences between the major types of galaxies:

- Spiral galaxies (both barred and non-barred)
- Elliptical galaxies
- Irregular galaxies

(It will be worth studying the two-page spread on p. 340-341. [= p. 354-355 in the 9th edition])

Which types have active star formation, and which don't? How is this related to the differences in color between various galaxy types?

How are Cepheids and Type 1a supernovae used to measure distances to galaxies?

If you've managed to measure the distance to a galaxy, how could you figure out its diameter, and its luminosity?

How do astronomers measure galaxy masses? You should understand the basic idea behind each of the following:

- The rotation-curve method (See Fig. 16-7)
- The velocity dispersion method
- The `cluster' method

(The sentences that begin `If you assume the galaxy…' and `You could ask how massive…' will be particularly useful to understand. They are on p. 345 in the 8th edition, and on p. 359 in the 9th edition.)

Do other galaxies have supermassive black holes, like the Milky Way? Do other galaxies seem to have significant amounts of dark matter?

How do astronomers detect hot, low-density gas in clusters of galaxies? Is this the dark matter? Why or why not?

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Astronomy 10

Section 1 (M through F, 7:30 - 8:20 am)

Chapters 17 and 18 won't be on Test 3, but they will show up on the Final Exam. There was also some material from Chapters 15 and 16 that we covered after Test 3.
Here are the things you should know:

Chapter 16: Galaxies

Interacting Galaxies: It's worth studying the two-page spread on p. 354-355. (It's on p. 364-365 in the 9th edition.) When two galaxies collide, do their stars actually collide? What are *tidal tails*?

What's going to happen to the Milky Way and the Andromeda galaxy (M31) in a few billion years? How did we refer to the thing that will result?

Chapter 17: Active Galaxies and Supermassive Black Holes

This class was about AGN: Active Galactic Nuclei. We may have started the class with images like Part 1 of p. 364-365 (`Cosmic Jets and Radio Lobes'). (This is p. 378-379 in the 9th edition.) What's remarkable about the size of the `lobes' in these images? What kind of telescope (or array of telescopes) is needed in order to make images like these?

What characteristics do we notice when we look at a Seyfert galaxy? In particular, what's special about the spectral lines that we observe from that galaxy, and what looks different about its core (compared to normal galaxies)? What do the spectral lines (and their widths) imply is going on in the galaxy's core?

In the 1950s and 1960s, the early radio astronomers noticed some very strange objects, such as the *double-lobed radio sources* and things they called *quasars*. What was "quasar" short for?

When astronomers like Maarten Schmidt examined quasars like 3C 273, what was strange about the spectral lines? What remarkable conclusion did they eventually come to?

(Note: Some of what's special about the quasar redshifts is related to Hubble's Law, which we covered just a bit later, in the first part of Chapter 18. This was actually first mentioned back in Chapter 16, starting on p. 343, so you may want to re-read that section while you're studying the quasar redshifts.)

What sort of compact object powers a quasar / AGN?

Make sure you're clear on the relationship between the central b.h., the accrection disk, and the jets. The drawing for part 4 (on p. 365) illustrates this. (It's on p. 379 in the 9th edition.)

What is the *unified model* for AGN? What's special about our <u>angle of view</u> toward an AGN?

Chapter 18: Modern Cosmology

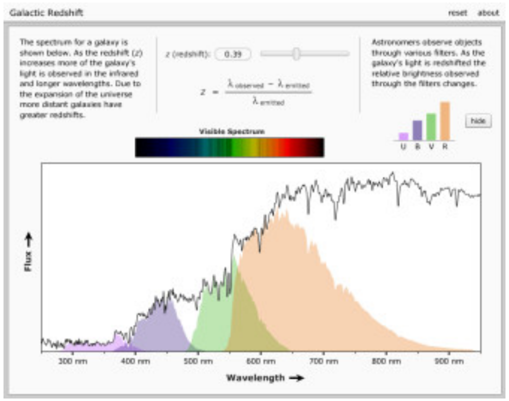
We may have started our discussion of cosmology with the *edge-center problem*, described in Section 18-1 of the textbook. Does the universe have an edge, or a center?

Make sure you understand what we meant by the *observable universe*, and how that's different from the <u>whole</u> universe. Is is possible that the universe could be <u>infinite</u> in size? How does *look-back time* limit our ability to determine this?

Why is it dark at night? We probably spent some time discussing *Olbers' Paradox*. What is the basic idea of this paradox? What do we observe when we look out into the universe, and how does this relate to the old model of a infinite, static universe? How does the idea of a changing universe help resolve the problem?

What is the *redshift-distance relation* (a.k.a. the `Hubble Law', first described back on p. 343-344 in Ch. 16 [= 356-357 in the 9th ed.]), and how can this be used to measure galaxy distances?

(You might find it useful to play with the UNL galaxy redshift simulator. As always, it's a good idea to right-click on it, and open it in a new browser tab.)



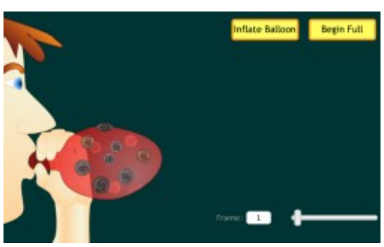
What's *look-back time*?

Here are some specific things to know about the redshift-distance relation and the expansion of the universe:

- How did the work of people like Vesto Slipher and Edwin Hubble reveal the redshift-distance relation?
- When we measure the redshifts of galaxies, are we measuring their speeds *through* space?
- Is it possible for the expansion of the universe to go faster than light? (We may have discussed this in class.)
- What is the *Hubble constant*?
- What is the *Hubble time*?

You should understand the basic ideas of the *Big Bang* model for the universe. Be very sure that you understand (and avoid) the **Common Misconception** on p. 379! (It's on p. 395 in the 9th ed.) The raisin-bread analogy in Figure 18-5 is useful, but as noted in the text, is also imperfect. We probably spent some considerable time in class, trying to explain how there's no center to the universe, and how the Big Bang wasn't an explosion. We might have used the term *scale factor*, which isn't in the text.

The UNL `balloon simulation' might be useful here:



What are the basic consequences of the expansion of the universe? In addition to the distances between the galaxies growing larger, what were two things that we kept repeating? (In other words, in class, remember those two things that we said happened to the *temperature* of the universe and the *density* of matter and radiation?)

A big topic that we encountered after Test 3 was the *CMB* (= *Cosmic Microwave Background*). Cosmologists make a big deal out of the CMB, and it's worth knowing the basic reasons why. (This is referred to as the `Cosmic Background Radiation' in the textbook, and it starts on p. 379 [= p. 395 in the 9th ed].) Here are some specific things to know about the CMB:

- What was the prediction that George Gamow made in 1948?
- What additional prediction was made by Alpher and Herman, later that year?
- How did Penzias and Wilson discover the CMB?
- What is the apparent temperature of the blackbody spectrum that we measure for the CMB?
- What is the redshift of the CMB?

It's worth studying Fig. 18-7 in some detail, particularly 18-7c. Notice how we see different sorts of things at different distances from Earth. How does this relate to the concept of look-back time? Is the universe **really** a series of spherical shells centered on us? (Come to think of it, it might not be a bad idea to be able to draw Fig. 18-7c yourself, with written explanations of what's really going on. Also, imagine adding an explanation of what the universe would look like to an observer located somewhere along the part of the diagram that shows the "shell-like" representation of the CMB. If they drew what the universe looks like, 13.8 billion years after expansion, what would <u>their</u> drawing look like?)

Is the apparent temperature of the CMB <u>really</u> perfectly uniform everywhere? How big are the variations, if there are any?

What is the evidence for the existence of dark matter, from galaxy rotation curves and gravitational lensing? (Hint: Go back to Ch. 15, p. 317-318, and Ch. 16, Fig. 16-7 and p. 347-349.) (In the 9th edition, these are Ch. 15, p. 328-330, Ch. 16, Fig. 16-7, and p. 360, respectively.)

You should be able to briefly summarize the odd story of *matter* and *antimatter* in the universe. Here are some specific things to know:

First, recall that there's normal matter (a.k.a. `baryonic' matter), and it comes in `regular' and `anti' varieties. (*Dark matter* is something entirely different from `regular' versus `anti' varieties of baryonic matter. Dark matter probably has its own `anti' version, though, too.)

- What would be different about an *antiproton*, compared to a regular proton? How about an *antielectron* versus a regular electron?
- How did photons produce particles of matter and antimatter, in the very early universe? (We may have used the term "pair production" for this process when

we discussed it in class.)

- What happened to most of the particles of matter and antimatter?
- Which type of baryonic (i.e. non-dark) matter do we see in the universe today?
- What was the ratio between the numbers of "victim" particles and "survivor" particles?

Next, we dealt with *Big Bang Nucleosynthesis*. (This is discussed in `A Few Minutes of Nucleosynthesis', which starts on p. 382 [= p. 398 in the 9th ed].)

During its first few minutes, the universe acted like a nuclear fusion reactor, and was able to make some of the chemical elements. What were the two main elements produced? What percentage of the total mass of the universe is made of each?

*Extra Credit: Remember the elaborate song-and-dance we went over in class, showing **how** these proportions came about? If you know how that process worked, it might help you with an extra-credit question. What was the deal with "1 for every 7...", and "2 for every 14", and all that?*

What was the event called *recombination*? How is it related to the CMB? (Carefully studying Fig. 18-10 and the text on p. 383 will be useful here. That's Fig. 18-10 and p. 399-400 in the 9th ed.) If you have a hard time understanding how recombination and the CMB are related, look at the temperature the textbook mentions just before they mention "**recombination**" on p. 383 [=p 400 in the 9th ed]. Does that look familiar? Did it perhaps crop up a few pages back...?

What was the *dark age*? How did *reionization* bring it to an end?

Why did the universe go through different eras of `dominance'? What were the three main eras, and which one are we in now? (Fig. 18-12 shows two of them.) How are these related to the expansion of the universe?

What is the *cosmological principle*? What do we mean when we say that we feel fairly confident that the universe is *homogeneous* and *isotropic*?

Remeber how we came up with an `accounting system' for what the universe is made of? What was the `universal currency' in that system? What are the four types of things/stuff we said the universe is made of? What percentage does each one contribute?

Extra credit: I may have tried to explain the story behind Fig. 18-15. If you can understand the story behind how the abundances of the light elements provide evidence for dark matter, you'd find yourself well-armed for a possible extra-credit question.

What do we mean by *open*, *closed*, and *flat* universes? Which one do we live in? What could have caused the universe to be closed, if that had been the case?

What's the *critical density*?

How does the CMB tell us that the universe's spatial geometry is flat? (This is shown in Fig. 18-24 [= Fig. 18-23 in the 9th ed.], and I may have talked about a giant version of the distance triangle, in class.)

What are the *horizon problem* and the *flatness problem*? How does the theory of *inflation* solve them?

What is *dark energy*? How was it discovered? (See p. 393 and Figure 18-17. In the 9th edition, this is "Acceleration and Dark Energy", and Fig. 18-19.)

What's strange about the energy density of the dark energy, as time goes by? What does dark energy imply about the fate of the universe, and about the appearance of the universe from the Milky Way, in the distant future?

What was the origin of the universe's *large-scale structure*? (This is covered in "The Origin of Large-Scale Structure", on p. 396-397. This is on p. 407-409 of the 9th ed.)

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