Unit 11
Dark Energy

Introduction

Because dark energy makes up about 70% of the universe, it dominates over the matter content. That means dark energy will govern expansion and, ultimately, the fate of the universe.
- Eric Linder, astrophysicist

In the last unit, we learned about dark matter, an unseen form of matter that would account for the gravitational attraction that has pulled material in the universe together into the kinds of large-scale structures that astronomers have observed. In this unit, we learn about evidence for an unseen *repulsive* component of the universe—*dark energy*, which would account for the surprising fact that not only is the universe expanding (as first observed by Edwin Hubble, leading to the Big Bang theory), but that the expansion is *accelerating.* However, the exact nature of this dark energy—which accounts for a whopping 73% of the universe—is still a mystery.

What Will Participants Learn?

Participants will be able to:

1. Describe and explain how astronomers use *luminosity* and *redshift* to measure the distance and speed of celestial objects.
2. Describe, using pictures, graphs and/or words, what astronomers mean by an *expanding* universe. Describe several different ways that the expansion could change over time (e.g., decelerate, accelerate, remain constant) and what this means for the fate of the universe.
3. Explain how observations logically suggest the presence of *dark energy*. Describe dark energy in terms of its observed effect on the universe, and contrast with dark matter.

What's in this Unit?

Text: In Unit 11: *Dark Energy* we learn how astronomers came to their current understanding of the structure of the universe, particularly by measuring aspects of celestial bodies such as *luminosity* and *velocity* (through observation of *redshift*). Edwin Hubble observed that distant galaxies were moving away from us faster than nearby galaxies, constructing the *Hubble diagram* of distance versus velocity, showing that the universe was expanding. But how is this expansion changing over time? Because most *standard candles* for judging distance from the earth were relatively close, previous measurements of the universe's expansion were over a somewhat small range of distances. New measurements from *Type 1a supernovae* have allowed astronomers to judge the distance and velocity of objects much further from the earth, and thus much further back in time. These observations provide evidence that indeed the expansion of the universe is not constant or slowing, but instead accelerating. *Dark energy* is the proposed agent of this acceleration—a repulsive type of energy that could be thought of as an "anti-gravity force" unlike anything yet known to us. Dark energy accounts for 73% of the mass-energy in the universe. Additionally, from the *cosmic microwave background (CMB)*, we can infer the *geometry* of the universe (measurements indicate that it is flat)—this, in turn, provides information about the *density* of the universe.

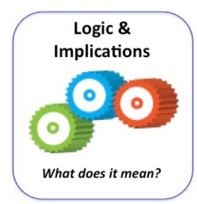
Video: In this program we hear from two researchers who are investigating the effects and origin of dark energy. Robert Kirshner, at the Harvard-Smithsonian Center for Astrophysics is investigating what this dark energy may be. He studies distant supernovae to gain a better understanding of how this force has shaped our universe over time, leading to the conclusion that the universe is accelerating. At Princeton University, David Spergel is looking back even further in time, into remnants of light emitted only 300,000 years after the Big Bang, searching for clues about dark energy. His work with the cosmic microwave background radiation has provided information about the geometry of the universe (suggesting it is flat), providing information about its density. These two research threads allow scientists to conclude that the universe is composed of about 73% dark energy.

Interactive Lab: *Evolution of Large Scale Structure in the Universe.* Experiment with different initial conditions to see what structures form, and try to build a universe similar to the one we live in today.

Activities:

- The Hook: The Night Sky Is Dark (10 minutes)
- Activity 1: Touch the Sky (15 minutes)
- Activity 2: How Far Away Is It? (15 minutes)
- Activity 3: How Fast Is It Moving? (15 minutes)
- Activity 4: The Universe is Expanding (15 minutes)
- Activity 5: Looking Back in Time (optional)
- Activity 6: Watch and Discuss the Video (20 minutes)
- Activity 7: The Fate of the Universe (15 minutes)
- Back to the Classroom (15 minutes)

Nature of Science Theme: *Logic & Implications*. You may wish to display the *Logic & Implications* icon during the session and remind participants of the central ideas of this theme. Science is founded on principles of logical reasoning and arguments. Can we accept the implication of a new scientific idea or model of the natural world? Sometimes the logical implications of an observation or model will cause scientists to reject previously accepted principles.



Exploring the Unit

The Hook: The Night Sky Is Dark

Time: 10 Minutes.

Materials:

- Optional video: "*Why Is it Dark at Night?*"

http://www.perimeterinstitute.ca/en/Outreach/Alice_and_Bob_in_Wonderland/Alice_and_Bob_in_Wonderland/

To Do and To Notice

Ask participants, what do you see when you look up at the night sky? Make a list of participants' observations, making sure that at least one of them is that the sky is dark between little points of light (the stars). Draw the night sky on the board. Ask them, "What are some ways that the stars might be scattered in the universe so that we would see something like this?" Prompt them to come up with as many models as they can. Discuss as many as you like—below are three common models.

Model 1: The universe is a black ceiling with a bunch of little lights stuck on it.
Are there problems with this model?

Model 2: The stars are spread out through space, which extends infinitely.
Are there problems with this model?

Model 3: The stars are spread out through space, with an "edge" to that space.
What does this model imply?

You may wish to show the 1-minute animated short from Alice and Bob in Wonderland called, "*Why Is it Dark at Night?*" http://www.perimeterinstitute.ca/en/Outreach/Alice_and_Bob_in_Wonderland/Alice_and_Bob_in_Wonderland/.

What's Going On?

Model 1: Using this model, we wouldn't expect the stars to move relative to each other, but we see that they do.

Model 2: If this were true, the entire night sky would be bright. Imagine you're standing in a thick glade of trees. If the glade has no end, you will see tree trunks everywhere. But if the glade has an end, you can see the space beyond the trees—which you see as daylight between the trunks. Similarly to a glade of trees, the universe looks very similar in all directions. If the universe were infinite, we would see stars (and thus light) everywhere we looked, with no space between them. This is true even though more distant stars are fainter (just like distant trees look smaller)—there are more stars at larger distances, balancing out their faintness. Another analogy: snowflakes block our view of a mountain, even though the furthest ones are very small. For more information, look up "Olbers' Paradox"—the Wikipedia entry is useful.

Model 3: This is the current model. Beyond this edge, there are either no stars, or their light has not yet reached us. The fact that the night sky is dark tells us that the universe has an edge in time, before which it did not exist.

Activity 1: Touch the Sky

Time: 15 Minutes.

Purpose: To digest the content of the reading, and consider how astronomers make use of the limited measurement tools available for them.

Lead into this activity from *The Hook* by noting that the simple observation that "the night sky is dark" provides deep information about our universe, even though we have no way of directly observing most portions of the universe.

To Do and To Notice

Ask participants to get out their lists from the reading, and create a master list of "measurement tools" and "measurements" as a group. Consider how the challenges of measurement in astronomy are similar/different to those of particle physics.

What's Going On?

Many of the problems of astronomy are problems of measurement. Astronomers can't physically touch the objects of their study, as they are too far away. Particle physicists can't physically touch the objects of their study, as they are too small. Note that some things that astronomers measure (such as spectra) could be viewed as a measurement in its own right, or as a tool for measuring other things (such as Doppler shift). Several of these measurement tools will be investigated in the next activities.

Possible measurement tools:

- Naked eye observations
- Telescopes
- Photographs
- Spectra of celestial objects (could also be considered a measurement)
- Standard candles

Possible measurements:

- Location and shape of objects
- Luminosity
- Distances, using luminosity and "standard candles"
- Velocities (towards/away from earth) using Doppler shift of spectra
- Changes in luminosity, location, and shape over time

Activity 2: How Far Away Is It?

Time: 15 Minutes.

Purpose: To explore one of the above measurements—luminosity—as a tool to measure distance. This is important in understanding the expansion of the universe.

Materials:

- Optional light meter

To Do and To Notice

If there are two identical light bulbs in a dark room, how do we tell which is furthest away? Ask participants for their answers. Among the answers should be "the one that is less bright is furthest away." Tell participants that the power of a light source (like a star) is spread out equally over a sphere around the star. Thus, the intensity is given by the power divided by the area of a sphere surrounding the object ($Power/4\pi r^2$).

Clicker/Discussion Question:

If a star's total power is 100 W and you measure an intensity of 0.001 Watts/m^2, how far away is the star?

A. 0.001 m
B. 10 m
C. 90 m
D. 315 m
E. 1120 m

What did we need to know to figure out the star's distance? How could we get this information? Discuss as a group.

What's Going On?

Answer to the clicker question is (C): 90 m. You may want to discuss the unreasonableness of these numbers for the power and distance of a star! What kind of object would produce these numbers? (Answer: light bulb.) If a teacher has a light meter, they can demonstrate this type of power law to students in a classroom.

In order to figure out the distance of the star, we needed to know its intensity (which we can measure), and its total power. How can we know the power of a star? We use *standard candles*—an object that belongs to some class of objects that all have the same (and known) brightness. If the power of a star is known, then measured intensity (power/area) will allow the distance to the star's host galaxy to be calculated. This is similar to calculating the distance to a neighbor's house by measuring the brightness of the 100W bulb on the neighbor's porch.

Take-home message: Astronomers use intensity of celestial objects to determine their distance.

Activity 3: How Fast Is It Moving?

Time: 15 Minutes.

Purpose: To explore one of the above measurements—redshift—as a tool to measure velocity. This is important in understanding the expansion of the universe.

Materials:

- Football or other ball with embedded buzzer, or a buzzer on a string
- The PhET "Wave Interference" simulation at http://phet.colorado.edu/simulations/sims.php?sim=Wave_Interference. (*Note*: You do not need to be connected to the internet to use the simulation. You may download it locally to your computer.)
- *Optional*: PhET "Sound" simulation at http://phet.colorado.edu/simulations/sims.php?sim=Sound.
- *Optional*: Online "Doppler Shift" simulation. http://scatter.colorado.edu/STEM-TPSoft/.

To Do and To Notice

See the Doppler. Use the PhET "Wave Interference" simulation. Choose the "Water" tab. Demonstrate the basic features of the simulation, such as the ability to adjust the frequency and amplitude of the waves. Choose low frequency and high amplitude waves. You may now use the mouse to grab the faucet slowly, and observe the resulting pattern of the waves, such that they are higher frequency in front of the faucet. Discuss as a group and ensure that participants understand that objects coming towards us have a higher frequency, and objects moving away have a lower frequency. You may also use the "Sound" simulation (http://phet.colorado.edu/en/simulation/sound), with speakers connected to the computer, and move the person to hear the Doppler Effect. You may also use the online applet "Doppler Shift" (http://scatter.colorado.edu/STEM-TPSoft/).

Explain that the same process occurs for light—light is lower frequency (redder) if an object is moving away, and higher frequency (bluer) if an object is moving towards the observer. What other activities do participants use to show the Doppler Effect?[1]

If astronomers know the frequency of light originally emitted by a star, then we can measure how much the frequency is shifted when it reaches earth. But how do we know what frequency of light was originally emitted? What possible frequencies/colors of light could be produced by a star? Talk to the group and make some suggestions.

Clicker/Discussion Question: Frequencies emitted by a star

1. **What characteristic frequencies of light could a star produce that astronomers might be able to know in advance (in order to then measure how much it is Doppler shifted)?**

   A. The colors of light found in the sun, because all stars are the same color as the sun
   B. The color of light found in that particular type of star: Each type of star gives off all its light at a particular wavelength
   C. The particular colors of hydrogen atoms in the stars
   D. The particular colors of neon atoms in the stars

[1] Other standard demonstrations of the Doppler Effect include whirling a buzzer on a string overhead in a circle, or throwing a ball with a buzzer back and forth from the front to the back of the room. Can you tell if the object is moving towards or away from you? Think about cars at the Indy 500 – what do you hear when cars come towards you? When they go away?

Clicker/Discussion Question: Redshifted hydrogen

2. This image shows the hydrogen spectrum—it plots the lines of hydrogen spread out by wavelength.

The following four spectra represent the spectra measured from celestial objects. **Which one is moving away the *fastest?***

A. 

C. 

B. 

D. 

What's Going On?

1. Best answer is (C): Astronomers use the spectrum of hydrogen in order to calculate the redshift of the star. Answer (D) would work but there is very little neon in stars.

2. Best answer is (B): This spectrum is the most redshifted of all the spectra, indicating a star that is moving away the fastest.

So, now we know how to measure the velocity of objects (but only towards/away from the earth). In fact, we can use the amount the colors have shifted to calculate[2] an exact speed (towards/away) from us (v), using the change in wavelength ($\Delta\lambda$), the original wavelength (λ), and the speed of light (c): $\frac{\Delta\lambda}{\lambda}=\frac{v}{c}$.

<u>Take-home message</u>: Astronomers use the spectrum of hydrogen, and its redshift, to determine the speed of a star relative to the earth.

Activity 4: The Universe is Expanding

<u>Time</u>: 15 Minutes.

<u>Purpose</u>: To explore what it means to say that the universe is expanding.

<u>Materials</u>:
- Balloons
- Paper
- Tape
- Transparencies and overhead projector, and image from http://www.exo.net/~pauld/activities/astronomy/ExpandingUniverse.html (optional)

[2] This formula is only correct for velocities (v) much less than the speed of light.

- Digital image of expanding dots from online resources (optional)
- Hubble Plot and Closed/Open Universe plot (from the text)

To Do and To Notice

Ask participants, "How could Hubble calculate recessional velocity of a galaxy? How could he calculate the distance of the galaxy from the earth?" Show participants the Hubble Plot from the text, showing recessional velocity versus apparent distance. What do they notice? What could cause this behavior, such that distant galaxies are receding more quickly? Solicit responses.

Use one or more of the following visual models to help participants visualize why things move further apart from one another in an expanding universe.

- **Balloon Universe.** Stick paper dots on a balloon, randomly. Blow it up and watch the dots on the surface move further apart. [3] The space and time of the universe are modeled by the "skin" of the expanding balloon, and light can only travel on the surface of the balloon. Imagine you lived in a galaxy on the surface of the balloon; as the balloon expands, would all the other galaxies appear to move towards you or away from you?
- **Moving people.** Using the analogy from the text regarding desks in a classroom, ask participants to stand one meter from one another. Then ask them to move so that they are all two meters apart from one another. How far away is your neighbor from you now? (*Answer:* 2 meters). How far away is your neighbor's *neighbor*? (*Answer*: 4 meters). So what?
- **Expanding dots.** Show how all points in an expanding universe see all other points moving away from them, and thus no one point is at the center, using presentation software and a digital projector[4]. See online resource: *Facilitator's Guide High Resolution Graphics.*

What's Going On?

Edwin Hubble used redshift (Activity 3) to calculate the speed of galaxies, and luminosity (Activity 2) to calculate the distances of galaxies from the earth. Hubble noticed two things:

1. Nearly all galaxies were moving away from us.
2. The further away a galaxy, the faster it was moving.

This implied that the universe was expanding.

The visual activities serve to demonstrate that the universe appears to expand out from all points, even though no single point is the center of the expansion. Thus, all galaxies are moving away from us, on Earth, even though Earth is not the center of the expansion. The moving desks activity serves to illustrate that things that are further away are moving faster in an expanding Universe.

Take-home message: The universe is expanding, which means that all objects are moving further apart from one another. There is no center from which the universe is expanding.

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[3] See http://www.exo.net/~pauld/activities/astronomy/universalballoon.html for an example of this activity, and http://solar.physics.montana.edu/tslater/plunger/expand.htm for relevant discussion questions. Inspired by work by Colin Wallace at the University of Colorado at Boulder.
[4] If you have an overhead projector, see the following link for a variation using transparencies: http://www.exo.net/~pauld/activities/astronomy/ExpandingUniverse.html.

Activity 5: Looking Back in Time (optional)

Purpose: To understand how looking at distant objects—such as supernovae or the cosmic microwave background—is equivalent to looking back in time. This helps prepare participants for understanding of the video.

Materials:

- Drawing paper
- Optional, "*Is That Star Really There?*" from Alice and Bob's Adventures in Wonderland http://www.perimeterinstitute.ca/en/Outreach/Alice_and_Bob_in_Wonderland/Alice_and_Bob_in_Wonderland/

To Do and To Notice

Participants imagine what a city would look like if it took light ten years to travel each city block—three blocks away, you can see people in the bell-bottoms of the 1970's; fourteen blocks away, the city did not yet exist. Use the "City Universe" activity at http://www.exo.net/~pauld/activities/astronomy/cityUniverse.html.

You may want to introduce this topic with the 1-minute animated short, "*Is That Star Really There?*" from Alice and Bob's Adventures in Wonderland.

What's Going On?

Because light takes time to reach the Earth, we are observing the universe as it was, not as it currently is. Thus, observational astronomy offers a glimpse back in time.

Activity 6: Watch and Discuss the Video

Time: 20 Minutes.

If participants are watching the video in class, have them view it now. Remind them of the guiding questions listed in *Between Sessions* from the previous unit.

After the video, discuss each experiment and the logical chains described by each scientist as to how their results suggest that some repulsive force exists in the universe. Field and discuss any questions. For example:

KIRSCHNER

Premise 1: Fainter supernovae are further away.
Premise 2: The more red-shifted supernovae are moving faster.

Observation 1: Distant supernovae are more red-shifted than closer supernovae.

Conclusion 1: Distant supernovae are moving faster → universe is expanding (Hubble's Law).

Observation 2: Highly red-shifted supernovae are further away than expected by Hubble's Law.

Conclusion 2: The expansion of the universe is speeding up. (And this could be related to the cosmological constant).[5]

SPERGEL

Premise 1: The cosmic microwave background (CMB) radiation represents a snapshot of the density fluctuations in the early universe, when it was 400,000 years old.
Premise 2: The angular size of the hot and cold spots in the CMB should be 1 degree because that's how far light could travel from the Big Bang up to 400,000 years.

Observation 1: The observed size of the hot and cold spots in the CMB is 1 degree.

Conclusion 1a: The universe is flat, because light traveling in a straight line in Euclidean space will yield spots of the same apparent size as their actual size.

Conclusion 1b: The Universe has a density of 1 (characteristic of a flat universe).

Observation 2: The pattern and temperature of the temperature variations in the CMB.

Conclusion 2: The pattern produced indicates that the universe has a flat geometry, and thus a particular density (the critical density).

Conclusion 3. Because there is not enough dark and normal matter to account for this calculated density, there is a deficit of 73%, consistent with the presence of dark energy causing the universe to accelerate.

Possible concluding discussion questions:

- What if the rules of physics (e.g., the propagation of light) are different very far away/very long ago? What would that mean? How do we know that the same rules apply here as there?
- Why can't we just say that there's dark matter we don't see and dark energy that we don't see, and that their effects cancel each other out (and thus we can ignore them)?

Activity 7: The Fate of the Universe

Time: 15 Minutes.

Purpose: To explore what the expansion of the universe implies about the ultimate fate of the universe—the "big chill" versus the "big crunch."

[5] This logic is not made explicit in the video—you may want to return to the balloon activity to help participants understand this conclusion. For those who are interested, the additional redshift of distant supernova is due to the *expansion of space* rather than additional motion of those supernovae: http://www.exo.net/~pauld/activities/astronomy/expansionoflight.html.

To Do and To Notice

Clicker/Discussion Question:

How do we know that the universe's expansion is speeding up?

A. We measure for a long time and see that galaxies are speeding up
B. We look back into the past different amounts of time, to see how the expansion changes with time
C. Neither/Something else

If we shoot a rocket straight up from earth, what different things can happen to it? What basic features determine which it will be?

Facilitate a discussion, helping participants make the connection between this analogy and the two possible outcomes for the universe (the "big chill" or the "big crunch"). Show the plot of open versus closed universes from the text. What are the parallels with the rocketship trajectories, above?

Now, what if we shot a rocket up from the earth and it zoomed away from earth at an ever-increasing rate? What could cause that?

What's Going On?

The answer to the clicker question is (B), as can be discerned from the video. It's not possible to measure for a long enough period of time to see the change in rate of expansion.

The rocket would have two possible trajectories:

A. It could fly off into space. This happens if its velocity (the escape velocity) overwhelms the force of gravity.
B. It could go up a distance, then turn around and crash back to earth. This happens if the force of gravity overwhelms its velocity.

Option A is analogous to the "big chill" in which the acceleration of the universe continues forever, with dark matter too weak to reverse the expansion.

Option B is analogous to an eventual contraction of the universe—the "big crunch"—in which dark matter is strong enough to reverse the expansion.

If the rocket, instead, zoomed away from Earth at an accelerating rate, this would be surprising. This would require some sort of anti-gravity force acting on the rocket—like dark energy.

Take-home message: The expansion of the universe is accelerating, which doesn't make sense if the only thing causing the expansion was the energy from the Big Bang. Dark energy acts as an anti-gravity force, increasing the expansion of the universe.

Back to the Classroom

Time: 15 Minutes.

Following is a list of high school topics and standards that are relevant to this material. See http://strandmaps.nsdl.org/ for a visual representation of science standards and benchmarks. Facilitate a discussion with participants:

- **Where might this unit fit into your curriculum?** Brainstorm a list of topics with participants. You may share additional items from the list below, as you see fit.
- **What do your students know about this topic?** Brainstorm with participants.
- Optionally, you may ask participants to **find one or more of the relevant topics on the Science Literacy Maps**, and explore related ideas and misconceptions.

Topics and Standards

Forces and Motion. Gravitational force is an attraction between two masses; the strength of the force is proportional to the masses and weakens rapidly with distance between them. All motion is relative to whatever frame of reference is chosen, for there is no motionless frame of reference from which to judge all motion.

Size and Scale. When describing and comparing very small and very large quantities, express them using powers-of-ten notation. Natural phenomena often involve sizes, durations, and speeds that are extremely small or extremely large. These phenomena may be difficult to appreciate because they involve magnitudes far outside human experience.

Waves and Light. The observed wavelength of a wave depends on the relative motion of the source and the observer. Visible light is a small band in the electromagnetic spectrum.

The Universe. Because the light seen from almost all distant galaxies has longer wavelengths than comparable light on earth, astronomers believe the whole universe is expanding. The Big Bang theory suggests that the universe began 10-20 billion years ago in a hot dense state.

Nature of Science. Mathematical models and computer simulations are used in studying evidence from many sources in order to form a scientific account of the universe. Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models. Although all scientific ideas are tentative and subject to change and improvement, for most major ideas in science there is much experimental and observational confirmation. Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations. Observation, evidence, and logic are important in the interpretation of experimental results.

Classroom Resources

The **Sloan Digital Sky Survey teachers' page** at http://cas.sdss.org/dr5/en/proj/teachers/basic/ includes a lesson plan regarding the expansion of the Universe, including creation of students' own Hubble plot.

The **Universe Adventure** online interactive textbook about cosmology from University of California at Berkeley: http://www.universeadventure.org/. Teachers' page with lesson plans at http://www.universeadventure.org/index/teachers.htm.

A full **Supernova Educator Unit** from NASA and Sonoma State University at http://xmm.sonoma.edu/edu/supernova/index.html.

Wilkinson Microwave Anisotropy Probe (WMAP) teachers' page on the cosmic microwave background, with classroom activities and an inflatable WMAP globe: http://map.gsfc.nasa.gov/resources/edresources1.html.

Alice and Bob in Wonderland. A charming set of 1-minute animated shorts, suitable for classroom viewing, on some of the mysteries of nature from the Perimeter Institute of Theoretical Physics. Relevant videos include "*Is that star really there?"* and *"Why is it dark at night?"*"
http://www.perimeterinstitute.ca/en/Outreach/Alice_and_Bob_in_Wonderland/Alice_and_Bob_in_Wonderland/.

NASA's *Imagine the Universe* teachers' site at
http://imagine.gsfc.nasa.gov/docs/teachers/teachers_corner.html.

- The Fall-Off of Light, and Hubble's Law and the Doppler Shift
  http://imagine.gsfc.nasa.gov/docs/teachers/lessons/swift_grb/how_far.html
- Roy G. Biv: the relationship between color and wavelength
  http://imagine.gsfc.nasa.gov/docs/teachers/lessons/roygbiv/roygbiv.html

Cosmic Times. A collection of curriculum materials for grades 7-12 that traces the history of our understanding of the universe from general relativity to the discovery of dark energy in newspaper-style posters including inquiry lessons. http://cosmictimes.gsfc.nasa.gov/.

From the **Exploratorium's Paul Doherty**, a variety of activities on the expansion of the Universe: Balloon Universe, Circle Universe, City Universe, City Universe Size, Doppler Model, Expanding Universe, Expansion of Light, and Sound Circles at http://www.exo.net/~pauld/site_map.html.

Determining Red-Shift in a Receding Star from PBS.
http://www.pbs.org/deepspace/classroom/activity2.html.

PhET simulations on waves, Blackbody spectra, and Doppler Effect, and accompanying teaching activities. http://phet.colorado.edu.

What the WMAP! Article on the Cosmic Microwave Background and cosmology on Physics Central. http://www.physicscentral.com/explore/action/wmap-1.cfm.

Singing' the Black and Blues. A discussion activity from NASA on "why the night sky is black" with explanations suitable for high school students.
http://spaceplace.nasa.gov/en/educators/bluesky_blacksky.pdf.

Teacher Conferences Talks from the Kavli Institute for Theoretical Physics. Online archives of talks geared towards teachers, by leading scientists and educators. Particularly relevant are *The State of the Universe* and *Forging the Elements and Probing the Universe with Stars.* See also the public lectures by notable scientists on a variety of topics. http://www.kitp.ucsb.edu/talks.

Your Cosmic Context: An Introduction to Modern Cosmology, Todd Duncan and Craig Tyler, Pearson: Addison-Wesley, 2009. A very readable and lively text including many topics found in this course, such as general relativity, the expansion of the universe, redshift, the cosmic microwave background, dark matter, and dark energy. Highly recommended.

Between Sessions

FACILITATOR

You may wish to share the learning goals from *What Will Participants Learn?* with participants in preparation for the next session.

PARTICIPANTS

Review your notes and other course materials to remind yourself of earlier topics. Be prepared to answer the following questions in the next session:

1. **Prepare a presentation slide: Which topic or idea was your absolute personal favorite?** Consider the topics you found the most intellectually stimulating or that sparked your curiosity, regardless of whether you might use it in the classroom. Why was it your favorite? Prepare a slide to present to the group for the next session.
2. **How do some of the topics, research studies, or nature of science themes relate to one another?** Brainstorm: How might you start to organize these into a coherent framework?
3. **Pick at least two topics that you might use in your classroom.** These “topics” don’t need to be the subject of an entire unit (such as “dark energy”) but can be a subtopic within that unit (such as “the expansion of the universe.”) Think about how you might approach using these topics with your students. Where might they fit within your curriculum, and what teaching approaches might you use?
4. **Identify at least two challenges to using materials in the classroom**. You may identify (a) the challenge(s) you anticipate in using one of the two topics you chose, above, or (b) one or two topics that you *didn’t* choose to include and what barriers you anticipate would prevent you from using that topic in your classroom.