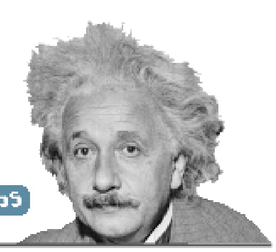
1905 - 2005

INSIDE EINSTEIN'S UNIVERSE

Journey through the Expanding Universe – Demonstration Manual

The activities presented in this manual are modular and can be used in a number of different ways. The outline below represented a suggested sequence of events for helping your audience to build a mental model of the expanding universe using basic concepts and simple tools.

- I. Introduction and cosmology of 1905: A single galaxy
  - A. Stars as building blocks, random motion, but static (unchanging) overall
  - B. Einstein's prediction of expanding universe and his incredulity thereof
- II. A Universe of Galaxies – discovered in the last century: our universe is made of galaxies
- III. Measuring Distances
  - A. Smaller = farther (Exploration 1 – distance duck activity with volunteer)
  - B. Dimmer = farther (Exploration 2 – light bulb activity with volunteers)
- IV. Messages from Space – properties of light
  - A. Einstein's discovery of the photoelectric effect
  - B. Light as energy: Vibrations emitted by glowing stuff (Exploration 3 – rope activity)
  - C. Wavelength and color: red = longer, blue = shorter
- V. Fingerprints from Space – emission line spectra
  - A. White light is actually many colors (Exploration 4 – white light activity)
  - B. Signature spectra from elements (Exploration 5 – spectra activity)
- VI. Galaxies in Space – motion and redshift
  - A. Signature hydrogen spectra (Exploration 6 – human galaxies activity)
  - B. Stretching of space = stretching of light (Exploration 7 – elastic band activity)
  - C. Einstein's new idea: Space as a thing!
- VII. Galaxies in the Universe
  - A. Motion of galaxies (Exploration 8 – expanding universe activity)
  - B. The large-scale universe (Exploration 9 – transparencies activity)
- VIII. Einstein's unsettling predictions – general discomfort with the idea of stretching space
  - A. Stretching space implies a beginning to time and a changing universe
  - B. Observations made in Einstein's lifetime helped realize the truth behind this idea
  - C. A key piece of evidence in the model of Big Bang cosmology
- IX. Conclusion – imagining back in time (Exploration 10 – CO_2 tank activity)
- X. Epilogue – Dark Energy (not part of demonstration)



Overview

The idea of an unchanging universe was well established at the turn of the 20th century. When Einstein introduced his revolutionary ideas, the thought of an expanding universe was preposterous. Now, nearly one hundred years later, we have actual evidence to support the story of an accelerating, expanding universe. This hands-on demonstration offers a series of interactive explorations modeling the ways in which we explore distance and motion in the universe.

Each exploration contains an educational goal, a list of materials needed, and the procedure for the activity. In some cases, additional notes are given to provide the presenter with guidelines for discussion, supplemental background information, alternate presentation ideas, or related images for your audience to look at during or after the activity. Transition text between explorations provides content information and suggested narration, images and/or activities for bridging the gap between activities and connecting activities to the larger picture. At the end of the manual, you will find a list of materials and suggested sources from which to obtain them. Many materials may be found through sources not listed in this manual. Pricing, of course, may vary. Photographs of various materials and their set-up follow this list.

It will be important to note throughout this demonstration that the explorations presented are models – nothing more, nothing less. Every model presented below represents something about the real thing well, but because it is not actually the real thing, there are some things it does not represent very well. As a presenter, it is your job to focus on the key correct idea presented by each exploration, while explaining to your audience that that no one model can explain every aspect of the thing it models. In some cases, you will have the opportunity to address misconceptions directly, but audiences should be reminded that all models have limitations.

Welcome to Einstein's Universe

Welcome to the year 1905. Astronomy is about to enter a revolution. A young man named Albert Einstein is about to publish a series of revolutionary papers. This work will be a cornerstone of modern astrophysics in the 20th century. What do we know about the universe?

The Universe of 1905 is a pretty simple place. Our Sun sits at the center our Milky Way galaxy. The Milky Way is filled with stars, the planets in our solar system, comets, and a few hundred cloudy nebulae. These nebulae come in all different shapes and sizes – from amorphous blobs to distinct, yet fuzzy, spirals. The cutting edge of astronomy research is the properties of planets. Only a handful of scientists are interested in those strange spiral nebulae. However, these fuzzy nebulae will soon become the hot topic of the early 20th century. Some astronomers are daring to suggest that these objects might not be a part of our Milky Way galaxy. If this is true, our universe must be much larger than we think. And is our Sun really at the center of everything? How can we figure out how far away the stars and nebulae are? How can we figure out our place in the Universe?

The determination of distance in the universe is one of the most important investigations an astronomer can undertake. We cannot journey to distant objects and measure how far we travel; the universe, even a universe made of a single galaxy, is much to large and distances are much too vast. Instead, we look for clues from our view here on Earth. The first two activities in this demonstration will explore two crucial understandings that help us develop a picture of how far away things are.

Suggested Images: *Sketch of Milky Way Star System, circa 1905. Lord Parsons/Cornelius Easton (included in accompanying Power Point slide show), Sketch of "Spiral Nebula M51" compared to Hubble Space Telescope image of same (M51, The Whirlpool Galaxy) taken in January 2005 (also included in accompanying Power Point slide show)*

We now know that these fuzzy spirals are, in fact, other galaxies like our own Milky Way. The entire universe contains billions of galaxies outward as far as our eyes (and telescopes) can see, and each one of those galaxies contains billions of stars, many of which may or may not have solar systems like our own around them. Our solar system, we also know, is not at the center of the Milky Way, but located two thirds of the way out in the dusty disc.

Suggested Images: *The Andromeda Galaxy, and the Hubble Ultra Deep Field. (These images are included in the accompanying Power Point slide show.)*

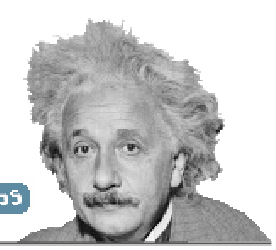
Exploration 1 – Size and Distance

Purpose:
The purpose of this activity is for the audience to learn that the apparent size of an object can help give clues as to the distance of an object.

Materials:
- 1 volunteer
- 2 galaxy placards (galaxies must be the same size) – on a CD or printed out on 8.5” x 11” paper

Preparation
1. To download templates for CD labels, visit the “Inside Einstein’s Universe” Resources Page and click on Educational Resources → Presentations for Informal Educators → Journey through the Expanding Universe, or see the Suggested Shopping List at the end of this manual for 8.5” x 11” images.
2. Create the galaxy placards by printing out four CD template labels and gluing/taping them to both sides of two CDs. If you are not using a CD, print out two galaxy images on 8.5” x 11 ” paper. (Remember, galaxies must appear the same size across the paper.)
3. (If desired) You can use a binder clip and a piece of string to turn them into a necklace or punch holes in your paper galaxies and run a string from one hole to the other.

Procedure:
1. Put a galaxy placard around your neck. (You may wish to do this before the demonstration begins)
2. Invite a volunteer up to the stage and hand him/her the second galaxy placard to put around his/her neck. (You will want to name this galaxy with the volunteer’s name – Galaxy Chris, for example)
3. Position your volunteer at the front of the stage.
4. Explain to your audience that they are going use a very sophisticated tool to measure the distance of these two galaxies – something called a “Distance Duck” (or, if you prefer, a “Measuring Duck”). Demonstrate what the Distance Duck looks like by holding up your hand with your fingers flat and your thumb below them, parallel. (Your hand will look like a duck’s head.)



5. Instruct your audience to pull out their Distance Ducks, close one eye and measure the size of Galaxy Chris by putting the galaxy (not the volunteer) in the duck's mouth. The top of the galaxy should be just underneath their fingers, and the bottom just above their thumbs.
6. Move yourself to the back of the stage and instruct the audience to keep their duck's mouth in the exact same position as they shift their duck to measure Galaxy You (The Presenter's galaxy placard)
7. Ask the audience to tell you what they notice about the difference between Galaxy You and Galaxy Chris. Which one is bigger?
8. Discuss the ideas that "bigger means closer" and "smaller means further" with your audience.
9. Don't forget to thank your volunteer at the end of this activity!

<u>Discussion</u>
From our view looking out, nearby objects look larger. They appear to take up more space in the sky. In some cases larger-looking objects are actually larger, but if two objects are the same size (as with our two volunteer galaxies) the one that appears smaller is further away. In general, astronomers can assume that if most spiral galaxies are roughly the same size, then galaxies that appear to cover less sky are probably further away than the galaxies that appear to cover more sky.

<u>Extension</u>
If you stand twice as far away from the audience as your volunteer galaxy, does your audience notice a quantitative difference in your sizes? The most astute Distance Duck users will be able to see that a galaxy twice as far away appears half as small. This relationship holds true in the universe as well. The suggested image for this exercise offers a real-life application of this principle.

<u>Alternate Presentation Ideas:</u>
If you are using 8 1/2 x 11 galaxy placards, you can use fingers rather than Distance Ducks to measure the size of the galaxies. Ask your audience how many fingers they need to cover up each galaxy. (It should require more fingers to cover the closer galaxy.)

Suggested Image: *HST's "Celestial Composition." These two galaxies are both spiral galaxies. Astronomers assume them to be the same size. If this is true, which galaxy is closer? By how much? (See the extension above.) (This image is included in the accompanying Power Point slide show.)*
http://hubblesite.org/newscenter/newsdesk/archive/releases/2003/24/
Image credit: NASA, the Hubble Heritage Team and A.Riess (STScI)

Exploration 2 – Brightness and Distance

Purpose:
The purpose of this activity is for the audience to learn that the apparent brightness of an object can help give clues as to the distance of an object.

Materials:
- 3 volunteers
- 2 “stars” created using the following materials:
    - 2 small round low-wattage light bulbs (6.3V, 0.15A Bulb with Threaded Base)
    - 4 AA batteries
    - 2 battery holders
    - 2 bulb sockets to fit bulbs (E10 Bulb Socket with Threaded Base)
    - Wires with which to connect bulb & socket to battery (18 or 20 AWG)

  NOTE: Battery voltage should be lower than the voltage required by the bulbs. Bulbs should be dim for best effect.

Preparation:
Before the demonstration begins, create your stars as follows:
1. Mount a bulb socket on top of each battery holder, connecting the metal leads with wires.
2. Put batteries into each holder and test the circuit by screwing the bulbs into the sockets.
3. When the circuits are completed, both bulbs should glow with the same brightness. A dim glow works best for this exploration. (Note: leaving the circuit connected between demonstrations will drain the battery and wear out the bulb, requiring you to replenish your supplies more often.)

Procedure
1. For this activity you will need three volunteers: one Shining Star and two Observers.
2. Invite your Shining Star up to the stage and screw in both bulbs to the sockets, creating a glow.
3. Ask your Shining Star to confirm for the audience that these two stars are the same brightness.
4. Dim the lights and position your Shining Star on one side of the stage, facing the audience, holding their star in front of them. (Be careful not to keep their arm out in front of them too long; this can get tiring!)
5. Position yourself on the other side of the stage, in the same position as your volunteer.

6. Invite an Observer to join you, and position him on the other side of you opposite from the Shining Star volunteer. (Your observer should be much closer to you than the Shining Star, however.)
7. Ask your observer which star he thinks is brighter. (He should say that your star is brighter.) Confirm that he is very sure about this.
8. Invite your second observer up to the stage and ask her to stand near your Shining Star volunteer.
9. Ask her which star she things is brighter. (She should say that Shining Star is brighter)
10. Alternate between both observers asking them again and again which star he or she thinks is brighter.
11. Finally, ask the audience what is going on. After all, you agreed at the beginning of the activity that both stars were the same brightness!
12. Don't forget to thank your volunteers at the end of the activity!

Discussion

Your audience will likely be able to identify that the light bulb that is far away appears dimmer than the light that is closer. The key point is that both light bulbs have the same brightness, but whichever bulb is closer to us APPEARS brighter. In astronomy, if we know two stars (or galaxies) are the same type of object and have the same inherent brightness, we can follow the principle that "closer means brighter; farther means dimmer" to figure out their distance. Tell your audience that we will talk about how astronomers know whether or not two things are the same thing in a few minutes.

Note: Although it would technically be more correct to ask your volunteers which bulb "appears" brighter, it is more fun for them to argue about which bulb "is" brighter. Be sure to emphasize in your follow-up discussion that we are talking about apparent brightness, not actual brightness.

Alternate Presentation Idea:

If you have a large audience, you can have multiple observers at each star.

Suggested Image: *The three bright stars in the constellation Leo's hindquarters happen to be the same type of star. If you have a good picture of the constellation Leo, audience members can actually look at the picture and tell you which star is closest and which star is furthest by looking at their respective brightness. (This image is included in the accompanying Power Point slide show.)*

Let there be light!

Both these methods of determining distance (brighter = closer, larger = closer) rely on being able to assume that stars or galaxies are similar in inherent size or brightness, but how can we be sure? Is there some sort of device or tool we can use to find out more about the conditions at these far off points of light?

Einstein's Revolutionary Work

Both the previous activities rely on an assumption: that the objects we're looking at are the same type of object or that they're made of the same thing or that they shine with the same light. How do we know whether or not those assumptions are correct if we cannot go visit those objects?

When we cannot travel to other locations, we must rely on the messages sent to us from those locations. On Earth, we receive post cards or letters or email from friends far away. In the universe, we receive messages in the form of light. Albert Einstein wanted to understand the properties of light from far-away objects. In 1905 his curiosity and hard work paid off; his 1905 paper about the characteristic energy of light won him the Nobel Prize in 1921. The next three activities explore the properties of light, particularly energy and wavelength.

Suggested Image: *Post Cards from Space. Any image taken with a telescope can be described as a "post card from the universe." (An example of such an image – the Trifid Nebula – is included in the accompanying Power Point slide show.) Before showing this image, you can ask members of the audience about the farthest place they've ever gotten a post card. Have they ever been there? Have they ever gotten a post card from outer space? They probably don't think so, but in fact they have! Every time a telescope collects light from a far-away object, it is receiving a message from that object.*

After showing the image, ask them what we can learn about the object from looking at this post card. Size, shape, whether the object is bright or dark, and perhaps most obviously, color! (If you plan to use Explorations 5 or 6 to talk about the element hydrogen, you should be sure to choose an astronomical "post card" that has a good example of pinkish gas, such as the Trifid Nebula, and point this pink hydrogen gas out to the audience.)

Exploration 3 – Wavelength of Light

Purpose:
The purposes of this activity are to introduce the notion of light as an electromagnetic field vibrating at a given energy, to introduce the idea of wavelength as the distance between two successive peaks or troughs in a wave, and to explore the relationship between energy of light and its wavelength, as well as its color.

Materials:
- Rope or long metal coil

Preparation
Before the presentation begins, attach the rope to stationary object such as the leg of a chair. The rope will need to be on the ground. (If you do not have a stationary object you can ask a volunteer to hold one end of the rope, but this is a boring job for a volunteer and will probably take more time to set up than the demonstration itself.)

Procedure:
1. Explain to the audience that light can be thought of as a little "packet" of energy (a photon) vibrating with a specific amount of energy. (Albert Einstein helped us to create this model and in fact, won a Nobel Prize for this work!)
2. We are going to explore this idea using a model of a wiggling rope. Remind your audience that this is just a model – light is not actually a rope!
3. Fasten one end of the rope to a stationary object and pull the rope across the stage – loose enough that you can shake the rope without unsettling your stationary object.
4. Wiggle the free end of the rope back and forth horizontally (side-to-side) so that sinusoidal waves can be seen propagating down the rope along the stage floor.
5. Explain to your audience that wiggling this rope represents a vibrating packet of energy. Their job is to observe what happens to the distance between the peaks of the waves (this is called wavelength) as you wiggle the rope with different energies.
6. As you wiggle the rope with more energy (a higher frequency) ask your audience to tell you what happens to the distance between the peaks of each wave. (The distance decreases.)
7. Slow your wiggling back down and ask your audience what happens. (The distance increases.)

8. Alternate between low and high energy for a bit, saying “High energy, short wavelength; low energy, long wavelength”

Discussion

Tell your audience that the room they are sitting in contains a number of highly specialized detectors for figuring out what energy of light an object emits. Can they guess what those detectors are? (Eyes and brains.)

Explain that our eyes see light of different energies as different colors. Our eyes interpret higher energy light as blue and lower energy light as red. If you wish, you can also explain that there are other energies of light we don’t see, such as infrared light, which does not have enough energy for our eyes to detect, and ultraviolet and x-ray light, which has too much energy to stimulate our light.

Background

Albert Einstein told us that light comes in discreet packets of energy and when light hits an atom or a part of an atom, it will interact with it or not, depending on how much energy the light and the atom have. Einstein won the Nobel Prize for this discovery, known as “The Photoelectric Effect.”

Our eyes are an example of the photoelectric effect. We don’t see the packets of light that don’t have the right amount of energy to stimulate our eyes. We perceive the energy packets we do see as having different colors. The light with the lowest energy we see is red, the highest is blue.

In our model, the rope shaken with more energy represents blue light and the rope shaken with less energy represents red light. Remember, however, that light is not actually a rope!

Historical Note:

Many people are surprised that it was Einstein’s paper on the photoelectric effect that won him the Nobel Prize, NOT his paper on special relativity. The photoelectric effect describes the interaction between light (photo) and charged particles (electric). It should also be noted, however, that Einstein’s work built on the previous work of scientists such as Isaac Newton, James Maxwell, Max Planck, and J.J. Thompson.

Suggested Image: *The electromagnetic spectrum (This image is included in the accompanying Power Point slide show.)*

Exploration 4 – White Light

Purpose:
The purpose of this activity is to demonstrate that white light is made up of all the colors of the rainbow.

Materials:
- 200 W clear light bulb with vertical filament
- Socket, cord, and electrical outlet
- Diffraction glasses
- (Optional) White strip of paper with a rainbow on one side

NOTE: Filament should be long and narrow to produce best effect. A bulb with wattage under 200 W will not display as much blue in its spectrum, and is therefore not recommended.

Preparation
1. Have the diffraction glasses easily accessible.
2. Make sure the light bulb can be plugged in easily.
3. (Optional) Roll up the strip of paper so that the rainbow is on the inside

Procedure:
1. Set up the light bulb in the front of the room and turn it on.
2. Tell your audience that the light bulb they are looking at is sending out billions and billions of packets of light (photons) every second. Those packets come in all different energies and are being emitted in every direction.
3. Ask the audience what color light they see. (White.) “Is white a color?”
4. Explain that you are going to hand them each very useful (and fashionable!) tool that will sort the light for them and allow them to see what energy the light coming from the bulb really is.
5. Hand out diffraction glasses to your audience and have them put the glasses on. When your audience members look at the light bulb through the glasses, they will see a continuous rainbow of light to either side of the source (or in a star shape surrounding the source, depending on the type of glasses you have).
6. Draw their attention to the spectrum on the left side of the bulb. (Red is on the left, and blue on the right.) This will be useful as you continue your explorations of light.
7. Audience members should hold onto their diffraction glasses for the next exploration.

8. If you like, you can demonstrate what their glasses are doing with the rolled up piece of paper:
    a. Explain that the paper is a beam of light traveling to you from the light bulb. All our eyes see is white light.
    b. Touch the rolled up paper to the glasses, and begin unrolling it as you explain that the glasses take that white light and spread it out, so you can see all the different energies and colors of light.

<u>Discussion</u>
Each pair of glasses contains two diffraction gratings (one over each eye), which work like a prism to split the light into its component colors. Each color represents light of a different energy. (If your glasses produce a star shape, audience members should concentrate on the horizontal rainbows on either side of the source.)

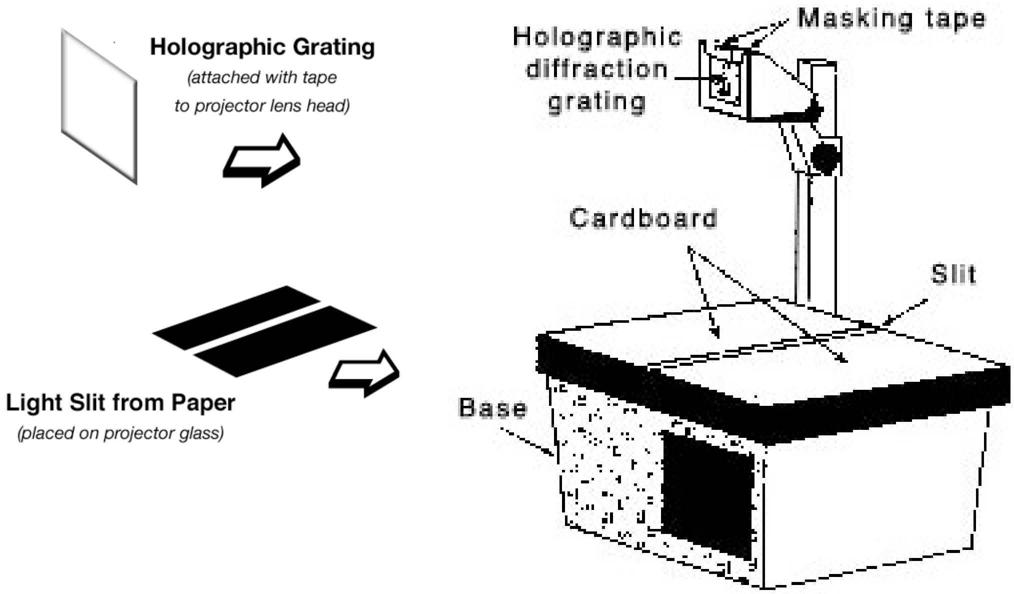
You can explain to your audience that these glasses are a type of tool that scientists use to split light into its different energies. A good analogy is putting pocket full of change into a coin sorter. While the coin sorter sorts the money into the different types of coins, this tool sorts the light into different colors, each with a particular energy.

<u>Background:</u>
In 1665 Isaac Newton first discovered the rainbow spectrum hidden in white light by splitting it with a glass prism. The rainbow had been seen since ancient times, but the colors were attributed to the material the light passed through, not to the structure of the light itself. His results (published in 1672) revolutionized the scientific understanding of light.

We think of light as little vibrating packets of energy. The amount of energy with which the packet is vibrating determines the type of light that is produced. The full range of all energies of light is called the electromagnetic spectrum. The types of light from lowest energy to highest are: radio waves, microwaves, infrared, visible light, ultraviolet, x-rays, and gamma rays. All of these types of light are unable to be seen by human eyes except for visible light. Visible light makes up a tiny portion of the entire electromagnetic spectrum. Of the visible light spectrum, we perceive differences in the amount of energy by seeing different colors. For example, the lowest energy of visible light we see as the color red and the highest energy of visible light we see as the color violet.

As Newton discovered, he could use a prism to break apart white light into its individual colors. Diffraction gratings (such as those in the diffraction glasses, or the larger holographic diffraction grating used in the Alternate Presentation Idea below) act just like prisms, splitting light into its individual energies. Astronomers use a tool called a spectroscope to break apart light. White light is made up of all the colors of the rainbow. So when we look at white light through the diffraction glasses, we see a continuous spectrum, or unbroken rainbow of light, every visible wavelength of light is radiated. Astronomers see this same pattern when they pass light through their spectroscopes.

Alternate Presentation Idea:
Rather than using diffraction glasses, you can project a spectrum using an overhead projector and a holographic diffraction grating. You will also need two pieces of heavy paper or cardboard and some masking tape. (See diagram below.) Attach the holographic diffraction grating in front of the projector's lens, using masking tape. Face the projector towards a white wall. To create a narrow slice of light, place two pieces of heavy paper or cardboard over glass surface of projector, leaving only a single slit of light to shine through. Turn on projector and focus it on the slit of light. Two rainbows will appear to either side of the projector. Adjust projector arm to produce rainbows in desired locations.



Transition – Continuous spectra to line spectra

Not all light is created equal, even if it appears the same at first glance. When atoms are very tightly packed together, such as in the filament of the light bulb in Exploration 4 or in a star, the atoms are vibrating every which way and light is being thrown out all over. When we pass this light through a prism or diffraction grating, we see a continuous rainbow of light.

When atoms are spread thinly enough, the spectrum appears much different. Simple elements, like gases that shine, those atoms are emitting very specific packets of energy. Passing this light through a prism or a diffraction grating will show a very distinct pattern of individual colors.

It may help to think about this in terms of people in a city. When the streets are very busy, and people are packed together, you only see the big picture – everyone crowded together. When the streets are less crowded, you can see the discrete activity of individual people.

A good way to present this to the audience would be to explain that the light bulb we're looking at has a solid filament shining, creating the light. The universe, however, is not filled with light bulbs! It is filled with gas. In order to figure out how objects in the universe shine and what they are made of, we will need to take a look at some glowing gases.

Exploration 5 – Fingerprinting Light

Purpose:
The purpose of this activity is for the audience to observe the “fingerprints” (emission spectra) of light produced by different elements. Because each element produces a different and distinct pattern of light, the audience is able to identify each gas by its light pattern. Astronomers are also able to determine what stars are made of, by looking at the spectra they produce.

Materials:
- 1 power supply
- 1 hydrogen gas tube
- 1 helium gas tube
- 1 neon gas tube (optional)
- 1 argon gas tube (optional)
- 1 mercury gas tube (optional)
- Electrical outlet
- Quantity of diffraction glasses (one pair per audience member)

NOTE: Alternative presentation materials for this exploration are listed in the suggested shopping list at the end of the script.

Preparation
Before the presentation begins, make sure your power supply is easily accessible. You may wish to pre-load the helium gas tube into the power supply:

> *To insert gas tube into power supply:*
> Insert one end of a gas tube into the holder closest to the on/off switch, which has a spring in the socket. Insert the other end of other socket. Turn on switch.
>
> *To remove gas tube from power supply:*
> Be sure power is off! Push gas tube against spring inside the holder near on/off switch. Remove end from far holder first. Caution: tube may be hot! Let it cool or handle with thermal insulating cloth.

Make sure the tube is at the right height for your audience to see the light through their diffraction glasses. You will likely want to mount the power supply on a table or demonstration cart.

Procedure:

1. If you have not presented Exploration 4 above, pass out one pair of glasses to each member of the audience.
2. If you have not presented Exploration 4 above, have the audience observe spectra from white light bulbs in the room. They will observe a continuous spectrum.
3. As explained in the transition "continuous spectra to line spectra" above, explain that the light bulb(s) they are looking has a solid filament emitting the light they see, but that the universe is not made of light bulbs. It is made of gas, so we are going to look at some shining gases.
4. Have the audience put down their glasses.
5. Turn off the white lights, so the room is dark and put the helium tube into the power supply. (NOTE: Please follow the proper safety procedure for connecting your gas tubes to your power supply.)
6. Have the audience look at the gas without their glasses. What color is it? What colors do they think they will see when they look through the glasses?
7. Have the audience observe the helium gas tube with their glasses. Remind them to observe the spectra to the left and right of the tube, rather than looking directly at the tube itself. They will observe bright bands of red, yellow, green, blue and violet.
8. Have the audience put down their glasses.
9. Remove the helium tube and insert the hydrogen tube.
10. Have the audience observe the hydrogen without their glasses. What color do they see? What colors would they expect to see in the spectrum?
11. (Optional) Point out the similarity between the pinkish gas in the tube and the pinkish gas the audience saw in "Post Cards from Space" (between Explorations 2 and 3 above).
12. Ask audience to observe the helium tube through their diffraction glasses. Ask them how the spectrum compares to the helium spectrum.
13. They will identify bright bands of red, blue and violet. (A good way to remember this pattern is "one line, two line, red line, blue line.")
14. Explain that different elements have different "fingerprints."
15. Collect glasses at the end of the presentation.

Discussion

This activity is often presented with the hydrogen gas first. We have chosen to start with helium because of its connection to the Sun, a "far-away object in space" with which audience is quite familiar. The pattern they see when they look at the helium gas with their "spectroscope" was first observed in the Sun, Helios, which gave helium its name. By way of transition, helium is the most common element in the universe, next to hydrogen. We have chosen to end this activity with hydrogen because the next exploration relates directly to the hydrogen spectra of galaxies. If you wish to do this activity with more elements, you may wish to start with hydrogen and move on to more and more complicated elements.

(Optional Fun Fact) Hydrogen and helium are the two most common elements in the universe. The relative amounts of hydrogen and helium in stars and galaxies all across the universe is one line of evidence that supports the Big Bang model for the origin and evolution of the universe

<u>Alternate Presentation Idea</u>
If your institution does not own or cannot acquire (through purchase or borrowing from a nearby museum or high school/college physics department) gas discharge tubes, there are a number of lower budget alternatives for demonstrating line spectra. Mercury vapor work lights and fluorescent lanterns give off distinct spectra, and many home supply or hardware stores carry neon nightlights. After carefully cutting a hole in the diffuse casing and safely pulling the light bulb through this hole, several of these bulbs can be lined up to create the desired spectrum. (Alternatively, the casing can be removed entirely, leaving the bare bulbs, but be careful! These bulbs have 120 volts of AC current! More information about these alternative methods for producing emission spectra is presented in the Suggested Shopping List at the end of this script. When using a bright light bulb or similar source, you may wish to create a simple slit opening in a piece of cardboard for the light to shine through. Because a spectrum is actually a reproduction of the object emitting the light, line spectra are much easier for audiences to view through diffraction gratings when the source is presented as a thin vertical stripe of light.

<u>Background:</u>
We now know that white light is made up of all the colors of the rainbow. When we look at white light through the diffraction glasses, we see a continuous spectrum, or unbroken rainbow of light; every visible wavelength of light is radiated. Not everything that shines emits light of all energies, however. When you have simple elements, like gases that shine, light emitted from those atoms will appear as a pattern of bright or dark lines.

Each element emits (for emission spectra) or absorbs (for absorption spectra) light with particular amounts of energy, creating a unique set of colors that appear as bright or dark lines. This unique set of lines acts as a “fingerprint” or “DNA” that can be used to identify the element that produced the light. Scientists are therefore able to determine what stars are made of, by looking at their spectral lines. The science of spectroscopy was pioneered in the 1860s by Robert Bunsen and Gustave Kirchhoff.

Absorption spectra (dark line spectra)
Absorption line spectra appear as darker lines within a continuous spectrum. These lines are produced when there is a cool gas in front of an object producing a continuous spectrum. Depending on what the gas is made of, it will absorb (or "steal") specific energies of light from the continuous spectrum behind it, creating "gaps" that match the element's own spectral pattern. When sunlight is observed with a spectroscope, we observe and absorption spectrum because the Sun's atmosphere absorbs specific energies of light. Most stars, planets with atmospheres, and galaxies produce absorption spectra. NOTE: The dark lines only *appear* to be missing. They are still there, however, just at a much lower intensity.

Emission spectra (bright line spectra)
Emission lines appear as bright lines or bands of light with a dark background. These lines are produced when hot transparent gases are in front of a cool background. When we heat the helium or hydrogen gases in the tubes, the gas becomes hotter than its background and produces emission lines. In astronomy, comets, nebulae, and galaxies produce emission lines. (Galaxies produce both absorption and emission spectra.)

So What?

Remember back to the beginning of this demonstration when used brightness and distance to figure out how far away things are and asked if there was any way to determine whether or not things are similar to each other? Well, an object's "fingerprint" is just what we need to figure out if two stars or two galaxies are made of the same thing or if they're doing the same things!

Surprising News

Light is a powerful tool for exploring the universe. Using measurements of distance and studying the composition of objects in the universe, the years following Einstein's 'miracle year' brought a series of startling revelations for astronomers everywhere. In 1918, Henrietta Leavitt and Harlow Shapley offered conclusive evidence that our Sun was not the center of the Milky Way, but rather that it was one of many stars much closer to the galaxy's edge. In 1923, the question of the so-called 'spiral nebulae' was resolved: each distant spiral was in fact another galaxy far outside our own Milky Way. Perhaps most shocking of all was Edwin Hubble's study of spectra from these distant galaxies. His observations, published in 1929, revealed a surprising view of the galaxy-filled universe. The next two activities explore the connection between spectra and motion in the universe.

Suggested Images: *An example spectrum of hydrogen observed in a laboratory, an example spectrum from a galaxy with a prominent hydrogen pattern, and a picture of a galaxy with prominent hydrogen regions for reference.*

Galaxy image: NGC 300: http://antwrp.gsfc.nasa.gov/apod/ap020821.html
Credit: European Southern Observatory

As the audience observed with the gas tubes, hydrogen glows with a seemingly pinkish light and it spectrum contains a prominent red line with less prominent blue and violet lines. In the universe, a glowing region of hydrogen glass also appears pinkish. In the galaxy image suggested above, prominent pink spots can be seen, representing hydrogen regions in the galaxy. It should also be noted that because stars are made primarily of hydrogen, and stars provide most of the light in galaxies, a strong hydrogen pattern is visible in most galactic spectra.

(Fun Fact: Bluish gas can be seen in reflection nebulae, which appear blue for the same reason that the sky appears blue – scattered light.)

Exploration 6 – Distant Galaxies

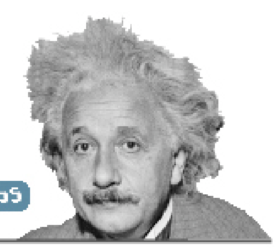
Purpose:
The purpose of this demonstration is for the audience to learn what the light from distant objects tells us about their motion.

Materials:
- 4 volunteers
- 4 galaxy images
- 4 spectrum images, numbered 1-4, printed out on overhead transparencies
- 4 envelopes large enough to hold a transparency, numbered 1-4
- An overhead projector and electrical outlet, etc.

NOTE: These files are available on the "Inside Einstein's Universe" web site. Visit http://www.universeforum.org/einstein/ and click on Resources → Educational Resources → Presentations for Informal Educators → Journey through the Expanding Universe

Preparation
1. Before the presentation begins, place each transparency in an envelope.
2. Hide or place envelope number 1 on a seat close to the stage.
3. Hide or place envelope number 2 on a seat further away from the stage.
4. Hide or place envelope number 3 on a seat even further away from the stage.
5. Hide or place envelope number 4 on a seat furthest from the stage.
6. Put a galaxy image on or near each of the four seats with the envelopes or on the envelopes themselves, if they are visible from the stage.
7. Have the overhead projector easily accessible for use during this activity.

Procedure:
1. As described in the transition above, take a moment to introduce the idea of galactic spectra to the audience by showing them an image of hydrogen and a sample galaxy spectrum. (You can use the rhyme "one line, two line, red line blue line" as an easy way to remember what the pattern/fingerprint of hydrogen looks like.)
2. Tell the audience that you spy several different galaxies out there in the audience. (If you wish, you can use a "Distance Duck" to confirm that they are at different distances.)
3. Reveal that each of those galaxies has a message to deliver to us here on Earth.



4. Ask for four volunteer “light messengers” to deliver those messages from the galaxies. (It will speed things along considerably if you choose people who are sitting on or near the chairs where the galaxies are located.)
5. Collect the message from the nearest galaxy, number 1.
6. Open the envelope and place the transparency on the overhead projector.
7. Point out that the colors on the blue end of the spectrum represent light with higher energy and shorter wavelength, while the colors and lines on the red end represent light of lower energy and longer wavelength
8. Point out the hydrogen lines, a stripe/peak in the red part of the spectrum and a smaller (dimmer) stripe/peak in the blue part of the spectrum. The audience should recognize this as a hydrogen pattern in this galaxy – one line, two line, red line blue line.
9. Now collect the envelope from light messenger number 2 – the next closest galaxy.
10. Remove Spectrum 1 from the screen and replace it with Spectrum 2
11. Point out the characteristic hydrogen lines – one line, two line, red line, blue line
12. Now put both Spectrum 1 and 2 on the projector, being sure to line up the ends of the continuous rainbow stripes on each spectrum. (You should be very explicit about how you are lining them up; otherwise your audience might suspect a trick. The overall range of energies in each spectrum is exactly the same.)
13. Act very certain that the hydrogen lines should be in the same place.
14. Collect the light message from the third galaxy.
15. Place Spectrum 3 on the overhead, being sure to line up the transparencies as before.
16. Once again assert that the hydrogen lines should be lined up because you were very careful to line up the continuous rainbows, deliberately glossing over audience members’ claims that the lines are NOT lined up.
17. Collect the message from the fourth galaxy and line it up with the other three.
18. Finally, allow the audience to voice their observation that the hydrogen fingerprints are in different places on each message.

Discussion

Thank your volunteers and allow them to return to their seats. Point out the trend observed in spectra from galaxies further and further away: the stripe (or spike) of each red hydrogen line appears to be moving further and further to the left with every more distant galaxy. This shift toward the redder end of the spectrum is called “redshift.” According to our data, the further away a galaxy, the more its light is redshifted. Something must be happening in space for the light from these galaxies to be redshifted. We will need another model (Exploration 8) to explain this!

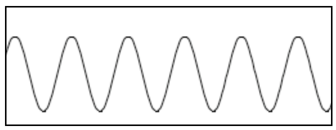
Background:
Redshift corresponds to an object moving away from the observer. The further the shift, the faster an object is moving! Edwin Hubble observed spectra in dozens of galaxies and discovered a very important pattern – the more distant the galaxy (determined in part by its smaller size compared with similar galaxies), the faster it is moving! These observations, published in 1929, are an important clue in determining how galaxies are moving in the universe. The next activity will explore the reason for this perceived redshift.

Alternate Presentation Ideas:
If you are not able to print out the spectra on transparencies, you can do this activity by printing out the spectra on a regular color printer and posting them on a wall. As you receive each spectrum, post it on the wall for your audience to see. Spectrum A should be on top, with Spectrum B directly below, lined up all the way down to Spectrum E. You can also post digital versions of each spectrum using a video projector, but it is helpful for your "light volunteers" to carry the actual "message" sent by the galaxy. Introducing a computer display adds an element of mystery to the process and the results can seem less genuine, and more like a trick on the presenter's part.

Exploration 7 – Elastic Band & Cosmic Redshift

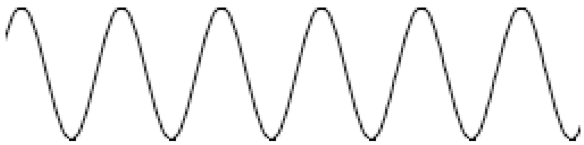
<u>Purpose:</u>
The purpose of this activity is to explain the redshifting of light from distant galaxies as the result of the expansion of the Universe. As light travels from a distant object, the space the light travels through itself expands, thereby lengthening the light's wavelength and altering it to a redder color.

<u>Materials:</u>
- Elastic band (approx. 5" in width/height x 18" in length) with a sinusoidal wave drawn on it. The peaks of the wave should be a few inches apart:

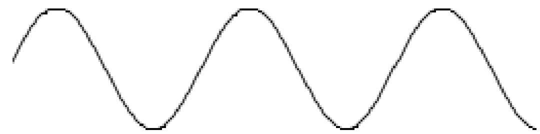


<u>Procedure:</u>
1. Remind your audience about the model you created in Exploration 3, using a wiggling rope to imagine light of different energies. Shaking the rope with higher energy created more frequent waves, with shorter wavelength, and shaking it with lower energy created less frequent waves, with longer wavelength.
2. Explain that we are going to see what happens to the wavelength of light as it travels through space by creating another model.
3. To represent light, we will use a "cartoon" of a light wave drawn on an elastic band. Remember that visible light with a shorter wavelength (more energy) appears blue, while visible light with longer wavelength (less energy) appears red. The line on the elastic band represents visible light with an average amount of energy.
4. Remind your audience that this is just a model. Light is not a line, and space is not an elastic band.
5. Identify a point on the stage as "the Milky Way Galaxy" (our home)
6. Step a short distance away to the "location" of a nearby galaxy, reminding your audience that this is just a model and that galaxies in the real universe are much further apart than in this model. (For more information about distances in the universe, please see the "Journey to the Beginning of Time" demonstration, also available from the "Inside Einstein's Universe" program.)

7. Holding one end of the elastic band in each hand, walk back towards "the Milky Way" stretching the band so that when you arrive, the peaks of the wave are further apart:



stretches into



8. Explain that as the light travels away from a distant galaxy to us, the expansion of the space through which the light is traveling "stretches" the light to a longer wavelength.
9. Ask your audience what color longer wavelength light appears as. (Red)
10. Show them an image of reddish distant galaxies.

Suggested Image: *http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/28/*
Credit: NASA, ESA, R. Windhorst (Arizona State Univ.) and H. Yan (Spitzer Science Center/Caltech); A. Bunker (Cambridge Univ./Univ. of Exeter); G. Illingworth (Univ. of California, Santa Cruz/Lick Observ.); M. Stiavelli (STScI), J. Rhoads (STScI), and the HUDF Team

11. If you wish, you can repeat this for an even more distant galaxy—step even farther away and stretch the band even more as you walk back to the "Milky Way," demonstrating that the wavelength stretches even more.

Discussion

If we think about our model using the shaken rope, another way to think about this is that light loses energy as it travels across the stretching space, which causes it to appear redder. The more space expands, the less energy the light has. From an even more distant galaxy, the light loses even more energy and becomes even more red. Of course, this "redshifting" corresponds to the images of galaxies we just saw.

(Optional Fun Fact) For very distant galaxies, the light loses so much energy and is stretched so much, it ceases to be visible, and shifts all the way into the infrared part of the electromagnetic spectrum. NASA's Spitzer Space Telescope can see infrared light and is being used to look at very distant galaxies. (The fourth galaxy spectrum in Exploration 7 shows a hydrogen line in the infrared.)

Alternate Presentation Idea

To shorten this activity, you can simply pose the idea of stretching space as a leading question using your elastic band. Having just told the audience that we need another model to describe the way light from distant galaxies is redshifted, you should pull out the elastic band and explain that the light wave drawn on it is a beam of light traveling through space. As you walk across the stage, stretching the band as described above, ask the audience obviously leading questions about “WHAT in the world could POSSIBLY cause the wavelength of the light from these galaxies to get longer?” and “How could the wavelength become LONGER?” as you emphasize your stretching motions.

Background

Stretching space was one of the most revolutionary ideas to come from Einstein’s work. Einstein himself was so amazed by this prediction that he refused to believe it was true. It was the observation of galaxy spectra made by Edwin Hubble that eventually caused him to change his mind and admit that the idea of stretching space was a real possibility.

For the Presenter:

We have made the pedagogical choice not to include mention of Doppler shift in this demonstration. The expansion of the universe is NOT a Doppler shift and the issue tends to confuse people when mentioned in the same presentation. The paragraph below is provided for your own reference and may be useful in addressing some of these questions with individual audience members after the presentation.

Many people confuse the idea of cosmic redshift with that of Doppler shift. Although both types of shift change the color/wavelength of the light we observe, the two effects are distinct. Doppler shift is caused by objects moving through space, such as the lights on a car driving toward or away from the observer. Using this analogy, cosmic redshift would be as if the cars remained stationary on an expanding road. The space between the cars is growing larger, giving the appearance of motion, but the cars themselves are not moving. In another popular analogy, the Universe can be imagined as a rising loaf of raisin bread in which each raisin represents a galaxy. The cosmic redshift can be interpreted as being due to the uniform expansion of the rising loaf (though each ‘raisin’ is ‘at rest’ within the dough). In contrast, the Doppler effect would result from motion through the dough separate from this expansion, such as a caterpillar crawling through it.

Einstein's Big Idea

Let us return briefly to the universe of 1905 – a single galaxy, The Milky Way, centered around our Sun, and with the exception of local movement through space, unchanging. It was against this backdrop in 1915 that Einstein published his general theory of relativity, which included a theory of gravitation. A key element to this theory was the idea that space itself was not just nothingness. According to Einstein's equations, "empty space" has its own energy and can create more of itself. This idea, that the space between objects in the universe could change, was a very unsettling prediction, especially in a universe that was thought to be unchanging. Einstein himself refused to believe it could be true and carefully tuned his equations to comply unchanging nature of the 1915 universe. In Einstein's own words, "in order to maintain this consistent view, we admittedly had to introduce an extension of the field equation of gravitation, which is not justified by our actual knowledge of gravitation." Paraphrased, Einstein invented a "cosmological constant" for which he had no observational evidence, and inserted it into his equations in order to make them explain a universe that does not change.

When Edwin Hubble published his results in 1929, scientists everywhere were forced to reconsider their view of an unchanging universe. Einstein denounced his cosmological constant in order to account for this newfound expansion. The recorded redshifts in Hubble's observations could now be explained by Einstein's theory of gravitation – galaxies pushed apart by the creation of new space between them!

The next two activities explore the expansion of the universe and test the implications of this revolutionary work.

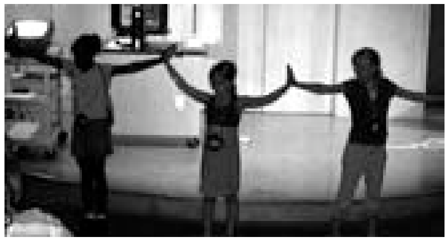
Exploration 8 – The Expanding Universe (modeled by volunteers)

Purpose:
The purposes of this activity are to make of model of the expanding universe and to demonstrate that as the universe expands, everything in it moves away from each other. The things that are the farthest from our galaxy are moving the fastest.

Materials:
- 5-8 volunteers
- 5-8 galaxy placards (one per volunteer) – attached to looped string around neck, stuck to shirt, mounted on hat, etc.

Procedure:
1. Call up your volunteers and give them each a galaxy image.
2. Explain that they, the volunteers, are empty space and the images they are wearing represent galaxies sitting in space.
3. Line them up in a straight line facing the audience, the palms of their hands touching their neighbors' hands (palm to palm). Each arm should be bent in a V shape on either side of its owner (the elbow is the bottom of the V). The line will look somewhat like this:

4. Explain to the audience that your volunteers are going to model what happens to galaxies when space stretches. In order to stretch, they should pretend they are just waking up in the morning and stretch their arms out to their full extent. (You will probably want to demonstrate what this will look like.)
5. Within the count of three ("ready, set, go…one, two three") our volunteers (space) should stretch (or "expand") by pushing their arms outward to their full extent. (When the expansion is complete, the line will look more like this:



(Note: you should be aware that holding one's arms up for extended periods of time can exacerbate arthritis and/or tire out the younger volunteers.)

6. The audience should watch the galaxies as space expands.
7. Have your volunteers perform this exercise several times to show the desired effects listed below.

Model Strengths:

1. Volunteers = space, NOT galaxies – the galaxies are being carried by space as it pushes itself apart. The galaxies themselves are not moving through space; they are moving with space.
2. Far away galaxies move faster – volunteers closer to the "end" of the chair move faster than the galaxies near the "middle." The further away a galaxy is from the observer, the faster it seems to be receding, or moving away. This is true for what Hubble observed, and what we observe today.
3. Each galaxy observes the same thing as the other galaxies – galaxies nearby seem to be moving more slowly and traveling less far. Galaxies further away appear to be moving faster and farther. (You can demonstrate this by having one person stand still and the space around that galaxy – including the arms of the volunteer on which that galaxy is sitting – expands, and watch how far and how fast different other galaxies move away from the person standing still. See Exploration 9 for more about this idea.)

Model Limitations:

1. Representing the whole universe – we are representing only a small portion of space in this model. Nobody knows exactly how big the entire universe is, but it would certainly take many more volunteers to truly model enough space to fill it.
2. Impossibility of the model – the galaxies are moving with respect to the room, but we have to imagine that the people and their arms are everything in the universe, and nothing exists

outside it. Ask the audience to imagine what it would be like to be a bug sitting on this galaxy, oblivious to the room.

3. Relative separation of galaxies – in this model, the galaxies are very close together relative to their sizes. Galaxies in the actual universe are not actually this close together. If each galaxy were really the size of a CD, it would take 20 CDs worth of space to reach the next galaxy.
4. The three-dimensional nature of space – this is a one-dimensional model. The expansion of galaxies in the universe happens in all directions.
5. The center of the universe – as mentioned in Strength #2, this model shows that galaxies closer to the center of the model do not move as fast or as far. In the true universe, there is no center. See Exploration 9 for ways to address this idea.
6. Perspective – the audience has a perspective that we can never have. Because we are a part of the universe, we must observe it from within.

Background:
The Big Bang model for the origin of the universe says that the universe expanded from a very hot, dense state, which then cooled and expanded to become the universe we observe today. For this model to be true, astronomers should observe objects in the universe moving apart from each other. In 1929 Edwin Hubble discovered that most galaxies in the universe appear to be moving away from us because the light he saw from the galaxies was redshifted. (Please see Exploration 8 for more information about the reason for this redshift). Additionally, he observed that the galaxies farthest from the Milky Way had the greatest amount of redshift and were moving the fastest. The galaxies closest to the Milky Way had a smaller amount of redshift and were moving more slowly.

One of the most important assumptions to the Big Bang model is that the universe behaves the same no matter where you are in it. If we observe galaxies moving away from us, then it follows that observers in a distant galaxy should observe galaxies, including our own Milky Way, moving away from them. The next exploration addresses this idea.

Exploration 9 – The Center of the Universe

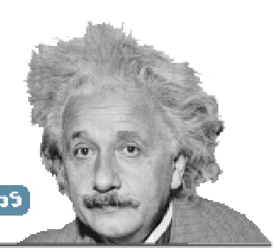
<u>Purpose:</u>
The purpose of this activity is to model what the expansion of the universe looks like on a large scale, from several different perspectives.

<u>Materials:</u>
- Overhead projector
- Transparency with many dots ("Universe")
- Same transparency enlarged to 115% ("Universe After Expansion")

NOTE: You can download the files for creating these transparencies on the "Inside Einstein's Universe" web site: Click on Resources → Educational Resources → Presentations for Informal Educators → Journey through the Expanding Universe

<u>Procedure:</u>

1. Place the first transparency ("Universe") on the overhead projector and explain that each dot represents a single galaxy in the universe.
2. Show the audience the second transparency and explain that it shows this same universe some time (say, a billion years) later, after it has expanded. We have just modeled (using volunteers) that distant galaxies appear to be moving away from our own Milky Way galaxy. Therefore, in this 'later' universe, the galaxies are spaced further apart.
3. Choose one dot to represent the Milky Way galaxy, the observer's home. (A fairly large dot near the center of the transparency tends to be a good choice for this.) Explain that because we are in the Milky Way galaxy, we cannot feel our own galaxy move. Therefore, our location in the 'later' universe appears to be the same as our location as in the 'earlier' universe. To represent this, we must keep the two Milky Way dots in the same place.
4. Place the 'later' transparency ("Universe After Expansion") on top of the first transparency, making sure to line up the Milky Way dots. Make sure the edges of the transparencies are parallel, vertically and horizontally, or the effect will be distorted.
5. Your audience will observe several things:
    a. Each galaxy in the later universe appears farther away than it did in the earlier universe.
    b. All the galaxies appear to be moving away from the Milky Way.
    c. The galaxies furthest from the Milky Way appear to have moved the most.



6. Now, let's try the same experiment from a different perspective. Let's say we live in a different galaxy. Choose another dot on the page and repeat the process, making sure to match your second dot on both transparencies.
7. Now the universe looks like it is expanding away from THAT galaxy!
8. You can try this with any dot you like, but the effect remains the same. Other galaxies appear to be moving away from whatever galaxy you choose.

Discussion

From the first part of this exploration, is easy to conclude that the Milky Way is the center of the universe. People in Einstein's day believed this to be true. However, an important assumption in astronomy is that different parts of the universe behave in similar ways, following the same laws of physics. In this activity, we are doing the impossible, stepping "outside" the universe to see multiple perspectives. Every new perspective yields a different center of the universe. Either every galaxy is the center of the universe or there is no center!

Alternate Presentation Idea

You can model this same phenomenon using the exercise in Exploration 8. Designate one volunteer in or near the center of the line to be the part of space containing the Earth's place in the universe – the Milky Way galaxy. Because we do not observe the Milky Way moving through space, the Milky Way will remain stationary in this model. (The person – space – holding the Milky Way will still extend his/her arms as space expands.) This model represents the Milky Way's perspective of the universe, NOT the actual motion of the Milky Way. The audience can observe that the galaxies being carried by the space (people) that were farthest from the Milky Way volunteer, had to move the fastest to "expand" uniformly with the rest of the "universe."

Repeat the exercise above from another galaxy's perspective, one closer to an end of the chain. The person representing that portion of space will remain stationary (while still extending his/her arms) and the galaxies furthest from the stationary galaxy (including the Milky Way) will move faster than the galaxies closer to the stationary galaxy. Remind your audience that this is an effect of more space expanding, not actual motion of galaxies in the universe.

Einstein Unsettled

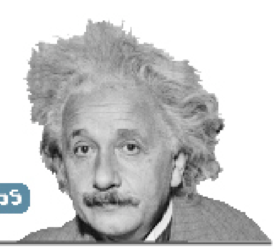
As discussed previously, the idea of an expanding universe was incredibly uncomfortable to most of the scientists in Einstein's day. Not only did it refute the idea of a static (unchanging) universe, but it also suggested a beginning to time itself. The paradox of a time when time did not exist is confounding, but observations made in Einstein's lifetime offer scientific evidence that galaxies were once much closer together.

We observe the universe to be expanding. That is, everything in it (i.e. galaxies) is moving apart. If we reverse this process and run our observations backwards, everything must have once been compacted together in a hotter, denser state. During this time, something caused the material to expand in all directions. As the universe expanded, it cooled. The Big Bang model describes this rapid expansion of this hot dense early universe.

Today, by calculating how fast galaxies are moving apart, we can figure out the rate of expansion and make a rough estimate of how long ago they (or the material in them) were all in the same place. According to these calculations, the universe we observe today began expanding almost 14 billion years ago. This number is consistent with the calculated ages of stars and planets, and comprises one of the key pieces of evidence supporting the Big Bang model for the origin and evolution of the universe. The final activity in this demonstration models how the universe behaved just moments after the so-called Big Bang.

<u>For the Presenter</u>
The Big Bang model describes how material in an expanding universe clustered together to form stars, galaxies, and eventually, the objects that exist today. It is suspected that this matter originally existed as a yet unknown form of energy, but nothing is known about where this energy came from in the first place. The term "Big Bang" is used to describe the moment when the transformation from energy to matter occurred. It is not, as commonly believed, an explosion where material flew away from a central point.

(Optional Fun Fact) The term "Big Bang" was a disparaging name coined by astronomer Fred Hoyle, who was championing his own rival theory of the expanding universe.



Exploration 10 – Big Bang in a Can

Purpose:
The purposes of this activity are to introduce the idea of an expanding cooling universe, and model the clustering of matter in the expanding universe just after the Big Bang.

Materials:
- 1 10 lb. carbon dioxide fire extinguisher (available from a local fire extinguisher/safety company)
- 1 3ft. hose with cone shaped nozzle
- 1 pair cryogenic gloves
- 1 wrench

CAUTION: CO_2 is –78.5 degrees C (-109 degrees F) when released from extinguisher! Be sure to wear cryogenic gloves when releasing CO_2 from extinguisher to prevent frostbite!

Preparation:
Attach nozzle to canister. Use a wrench to tighten nozzle **securely**! If nozzle is not tight, CO2 may leak out, increasing the risk of frostbite.

Procedure:
1. Remove safety pin from handle.
2. Put on cryogenic gloves.
3. Warn audience that when CO_2 is released, it will be very loud! They may want to cover their ears.
4. Aim nozzle above the heads of the audience members. Do not aim the nozzle directly at the audience.
5. Squeeze extinguisher, allowing CO_2 snowflakes to fall gently around, as you walk around the stage, making sure to keep the nozzle aimed above your audience.

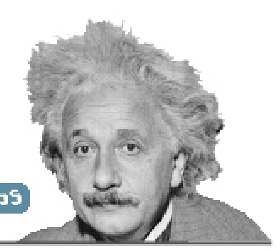
Background:
The Big Bang model describes the origin of our universe, 14 billion years ago. At this time the universe was extremely hot, dense and very uniform. Over the intervening fourteen billion years the universe has expanded and cooled. Regions of space that began with slightly higher density condensed over time to form the stars and galaxies that make up the universe we inhabit today. We can *model* this behavior using a carbon dioxide fire extinguisher. Like all models, it models some things well and other things not as well.

Limitations:
There are several limitations of this model. Obviously, the universe did not come from a can. In this model, we are creating a universe into existing space. When CO_2 is released, it is released into a room with air, people, furniture, everything, including time already in it. To make this model more accurate, we would have to put the entirety of our OBSERVABLE universe inside of the extinguisher, mixed in with the CO_2!

The model only accounts for the part of the universe we can see – the observable universe. The universe at the time of the Big Bang was dense, but not confined to a small volume. If the universe is infinite now, then it was infinite at the time of the Big Bang. It is true that the observable universe could have been contained in a volume of space roughly the size of a grapefruit at the time of the Big Bang, but the whole universe at the time of the big bang would consist of an infinite (or at least an unimaginably huge) number of grapefruits!

Strengths:
The fire extinguisher in this demonstration models certain aspects of the evolving universe. As a liquid inside the extinguisher, the carbon dioxide is very dense and uniform. As it is released through the nozzle, the CO_2 cools very rapidly, and condenses into solid dry ice around nucleation points of higher density, illustrating the gravitational clumping of regions of high density in the early universe.

More Information:
The liquid carbon dioxide inside the extinguisher is room temperature (about 70 degrees F) and under high pressure. When the CO_2 is released into the air, the pressure drops and therefore the temperature, to –78.5 degrees C (-109 degrees F). The CO_2 that was compressed inside a small extinguisher spreads over a much larger area. This is also the case in the Big Bang. Fourteen billion years ago, everything was more tightly compacted and very hot! The average temperature of the universe was about 3000 degrees C (6000 degrees F)! The universe is continuing to expand and cool so that the average temperature is now about 276 degrees C (–450 degrees F), or three degrees above absolute zero. Astronomers measure this temperature in degrees Kelvin—the universe that was 3000 degrees 14 billion years ago has cooled by a factor of 1000 and is now 3 degrees Kelvin. This model also does a good job demonstrating the "clumping" that occurred with the big bang. When the CO_2 is released, electrical forces cause the gas to form crystals or snowflakes. When the Big Bang occurred, gravity caused gases to form stars and galaxies. So in this model, the crystals represent stars and galaxies.



Dark Energy

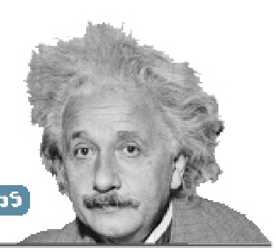
The model of the Big Bang using the CO_2 fire extinguisher provides a very satisfying conclusion to this demonstration. The following information is provided as additional content knowledge, but can shared with interested audience members at the presenter's own discretion.

One of the most important discoveries of the 1990s was that the expansion of the universe was accelerating. Not only are galaxies moving apart from each other as the space between them grows larger, but they are doing it at a rate that gets faster over time. Astronomers suspect that an unknown form of energy existent in space is causing space itself to grow at a continually faster rate. While not much is known about this "Dark Energy," it can be described using Einstein's original cosmological constant. One must wonder how Einstein would react if he were alive to see its return!

Note: Dark Energy is NOT the same thing as Dark Matter. Dark Matter accounts for extra gravitational force in the universe – for example, the extra mass that causes galaxies to rotate faster than expected – while Dark Energy drives the acceleration of the expansion of the universe. The quest to understand Dark Energy is one of the key astronomy investigations of the 21st century and a dramatic continuation of Einstein's legacy.

<u>For the Presenter</u>
There are a number of ways to connect Dark Energy to the activities presented in this demonstration. Exploration 7 introduces the idea of stretching space and Einstein's discomfort with the idea, as well as his "cosmological constant." The discovery of Dark Energy is due to the study of supernovae (exploding stars) in high-redshift (very distant) galaxies. Like the "stars" in Exploration 2, supernovae* have a known brightness and can be used to determine relative distance. (I.e. supernovae a given distance away will be dimmer by a certain amount.) Astronomers observed supernovae in distant galaxies (see Exploration 6 for the idea of redshift) and found them to be even dimmer than expected. The fact that they were even further away than expected meant that the space between us and them had expanded at an even faster rate than the universe was previously thought to be expanding. This speeded up expansion (acceleration) is an effect of the mysterious Dark Energy. The supplemental presentation contains two slides for describing the history of Einstein's cosmological constant and Dark Energy. (Be sure to read the "Notes" field below the images!) A good way to help your audience see the connection between these two ideas is to present them both as "anti-gravity" factors.

* There are multiple types of supernovae, but one particular type (Type 1a) has this known intrinsic brightness.



Credits

"Journey through the Expanding Universe" was created for NASA by the Universe Education Forum, located at the Harvard-Smithsonian Center for Astrophysics, as part of the "Inside Einstein's Universe" education program. Select activities for this demonstration were created jointly between the Museum of Science, Boston and the Universe Education Forum as part of the "Cosmic Questions" traveling exhibition. Learn more at http://www.universeforum.org/

Explore the Big Bang: http://www.universeforum.org/bigbanglanding.htm
"What was the Big Bang? What powered the Big Bang? Where did the universe come from?"

Explore Dark Energy: http://www.universeforum.org/darkenergylanding.htm
"Where did the idea come from? What might dark energy be? Why do we care?"

The Museum of Science, Boston offers the following references for informal educators:
'Cosmic Horizons', a publication of the American Museum of Natural History, p. 124-125 (Michael A. Strauss), p.128-129 (Robert Krishner)
'Expansion of the Universe', Lecture by Paul Doherty from the Exploratorium, Emission Tubes and Diffraction Glasses
http://www.exo.net/~pauld/activities/astronomy/expandinguniverselecture.html

The Universe Forum would like to thank to NASA, the Smithsonian Institution, and the numerous scientists and educators who contributed their time and expertise to develop these activities.

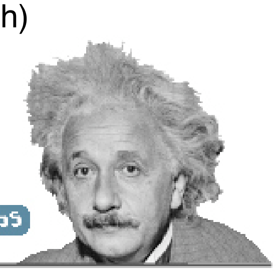
Suggested Shopping List
If you do not have the full set of materials for this demonstration, the following list provides information about where you can obtain some of the featured equipment. This list does not represent any endorsement on the part of NASA or the Smithsonian regarding these suppliers; materials may be available for different prices elsewhere.

Note: The following materials are available from the "Inside Einstein's Universe" web site:
- Galaxy CD template images (Explorations 1, 6, 8)
- Rainbow (Exploration 4)
- Galaxy spectrum images (Exploration 8)
    - Choose transparency option for aligned overlay images
    - Choose printer option if you do not plan to overlay images
- Expansion transparencies (Exploration 9)

To access these files, visit http://www.universeforum.org/einstein/resources_ed.htm and click on "Journey through the Expanding Universe" under "Presentations for Informal Educators."

<u>Galaxy images (Explorations 1, 6, and 8)</u>
- Templates for CD placards available "Inside Einstein's Universe" as described above.
- NGC 4414 from the Hubble Space Telescope:
  http://hubblesite.org/newscenter/newsdesk/archive/releases/1999/25/
  Credit: Hubble Heritage Team (AURA/STScI/NASA)
- Sombrero Galaxy from the Hubble Space Telescope:
  http://hubblesite.org/newscenter/newsdesk/archive/releases/2003/28/
  Credit: NASA and the Hubble Heritage Team (AURA/STScI)
- M74 from Gemini North: http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/43/
  Credit: NASA, ESA, and the GMOS Commissioning Team (Gemini Observatory)
- Other: http://hubblesite.org/newscenter/newsdesk/archive/releases/category/galaxy/

<u>Light Bulbs, etc. (Exploration 2)</u>
- Available from your local hardware store or Kelvin (http://www.kelvin.com)
    - 6.3 V, 0.15 A Bulb with Threaded Base (Kelvin Item #260019, $0.35 each)
    - E10 Bulb Socket with Threaded Base (Kelvin Item #250036, $4.95 for a package of 10)
    - Battery holder – plastic – for 2 AA batteries (Kelvin Item #220090, $0.60)
- Basic Science Supplies also stocks these items: http://www.BasicScienceSupplies.com
- AA batteries, available locally
- 20 or 18 AWG wire (can order 100 foot rolls for approximately $5-$10 each)



Rope (Exploration 3)

- Clothes line rope available from your local hardware store. It MUST be flexible, not stiff. At least 10 feet of cord required. (Approximately $1)
- Metal coil available from scientific supply companies:
    - Basic Science Supplies for $7.50 (Item 310605) (http://www.BasicScienceSupplies.com)
    - Arbor Scientific ($14) (Item 33-0140) (http://www.arborsci.com)

Light Bulb (Exploration 4)

- A clear glass incandescent light bulb with a single vertical filament. Recommend 40 Watt tubular display case bulb. Make sure bulb is NOT frosted glass type. Available from local hardware store for approximately $2-$4.
- Will need a lamp socket to screw bulb into.

Diffraction Grating Glasses (Explorations 4 and 5)

- Rainbow Symphony, Inc – 13,500 lines per inch, star-shaped dispersion, $0.40 each
    - Available in bulk: $35 for 100, $150 for 500, $250 for 1000
    - Order Information: http://store.yahoo.com/rainbowsymphony/difgratglas.html
- Edmund Scientific – normal dispersion, $4.95 for package of 6, also available in bulk:
    - 150 - $111.50 for 25 packages at $4.46 each
    - 500 - $347.00 for 100 packages at $3.47each
    - 1500 - $437.50 for 250 packages at $1.75 each

Holographic Diffraction Grating (Exploration 4 – Alternative)

- Rainbow Symphony, Inc.
    - 4.75 x 4.75 inch sheet mounted in plastic with filters (PS-08D, $30.00)
    - 2 sheets, each 5 x 5 inch (PS-08A, $9.50)
    - 6 foot x 5 inch roll (PS-08B, $40.00)
    - Order Information: http://www.starlab.com/psprod.html#Anchor-Holographic-35882

Gas Discharge Tubes (Exploration 5)

- Local college or high school physics department
- Basic Science Supplies (http://www.BasicScienceSupplies.com)
    - Spectrum tube power supply – $180
    - Spectrum tubes -- $15-$20 each

- Edmund Scientific
  - 115 Volt power supply – $180
  - Gas tubes – $30-$40 each
- Rainbow Symphony, Inc.
  - Spectrum Tube Power Supply – $199
  - Gas tubes – $35-$40 each
- Western Neon (http://www.westernneon.com) has created a gas tube assembly in the style of a light saber, in association with the education outreach program from the NOVA Origins series
  - Cost for one light saber with back up tube is $984 + tax
  - Address: 2700 1st Ave South, Seattle, WA 98134
  - Phone: 206-682-7738 or toll free at 1-888-682-7850
  - Email: info@westernneon.com

Lower-cost Emission Sources (Exploration 5 – Alternative)

- Mercury vapor lantern (fluorescent bulb fixture) (Cost: $5-$15+)
  - Can also use single light bulb available at local grocery, hardware or drug store (need a lamp socket to screw bulb into)
  - A fluorescent work lamp (a workshop 'light stick'), which is rugged and durable.
- Neon nightlights ($3.00/package of two at home supply store: Lowe's, Ace, Home Depot, etc.)
  - These low light bulbs are packaged in a diffusing plastic cover. Several (two to four) are required to produce an effective emission spectrum. With an UNPLUGGED nightlight, cut a 1 cm square hole in the front cover of the plastic cover with a sharp craft knife. Gently pull the small bulb within out so that it sticks out of the cover. Make sure the thin wires to the bulb are NOT outside of the plastic cover. Repeat for several nightlights. Plug each of these into a small power strip so all lights are lined up to create a bright strip of neon light. (Assembly included in Photographs at the end of this manual.)

Galaxy Spectra (Exploration 6)

- Spectra are available on the "Inside Einstein's Universe" as described at the beginning of this shopping list. There are two different image sets—one designed for overlaying images using transparencies, and one designed for side-by-side presentation.
- Use galaxy images from Exploration 1. Label each with numbers 1-4.
- Envelopes available wherever school or office supplies are sold.

Elastic Band (Exploration 7)

- HNW Company, phone: (401) 728-2018. Black or white polyester & latex elastic band material.
  - Recommend white elastic 5-inch width, product #Knit500WK003 $1.35 per yard or black elastic 5-inch width, product #Knit500B-K003 $1.41 per yard. Order information.
  - Permanent black marker will work fine for drawing the wave on the white elastic.
  - The black elastic requires white-pigmented paint or 'White Out' correction fluid, to create a high enough contrast wave to see the wave. The paint (either acrylic or oil-based fabric paint or 'White Out') will absorb into the black elastic and bleed through the other side of the fabric.
- Another option is to purchase a standard elastic exercise band from your local drug store or sporting goods shop.
  - Vendor example: ShapeUpShop.com, $3-4 per 4-foot length, available in bulk pricing. http://www.shapeupshop.com/bands_balls_tubes_bars/flat_bands.htm
  - Latex-free bands are also available from some vendors, e.g. http://www.bindependent.com/hompg/bi/bindep/store/aisles/exercise/bands/bands.htm
  - Note: Depending on thickness of the band, you may need to wrap the ends around a pencil or dowel rod to maintain a consistent vertical height across the length of the band.

Exploration 8 – The Expanding Universe (modeled by volunteers)

- Use galaxy images from Exploration 1 or 6, or use CDs (one per volunteer) available new from office supply store or used from personal supplies/mailings/etc.

Transparencies (Exploration 9)

- Available "Inside Einstein's Universe" as described at the beginning of this shopping list.

CO_2 Fire Extinguisher (Exploration 10)

- Recommend at least a 10lb. Carbon dioxide (CO_2) fire extinguisher with cone shaped nozzle. Container is refillable from local vendors.
- Extinguishers available from a local fire extinguisher/safety company.
  Check your phone book under the listings "Fire Protection Equipment, Systems, & Services," "Fire Extinguishers Commercial & Industrial," or "Fire Extinguisher Recharging."
- Online fire equipment vendors: SmokeSign.com or SafetyEmporium.com
- Cryogenic safety gloves available from lab supply company. Lab Safety Supply Co., $100-120.

Photographs of Equipment and Set-Up

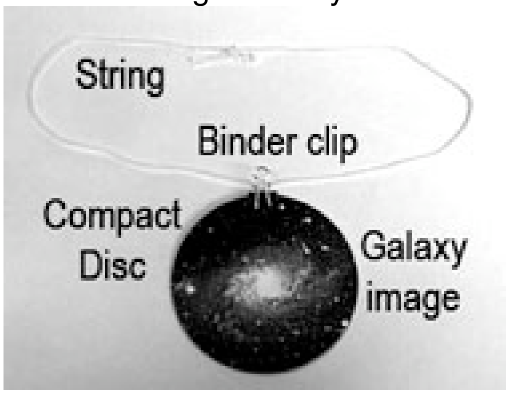
Photographs are provided in black and white for clarity in printing. Color images are used when the black and white version does not convey the full sense of the equipment.

See the end of this manual for a sample galaxy CD template for or download it from the "Inside Einstein's Universe" web site as described in the Suggested Shopping list above.

<u>Exploration 1</u>

The Distance Duck:

The Low Budget Galaxy:



Measuring a Nearby Galaxy:

Measuring a Far Away Galaxy:

Exploration 2

A Shining Star:

Top View:

Supplies:

(Top left, clockwise) Batteries, case, socket, bulb, wires

Soldering supplies:

(Optional) to attach wires to sockets

Fully assembled:

A miniature toggle switch can be attached to the unit (not pictured)

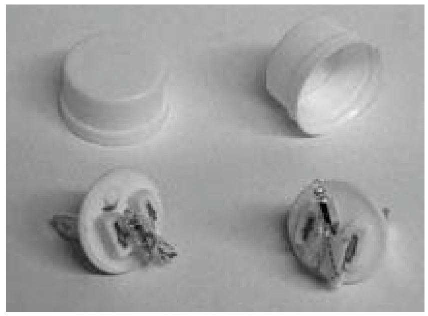
Exploration 4

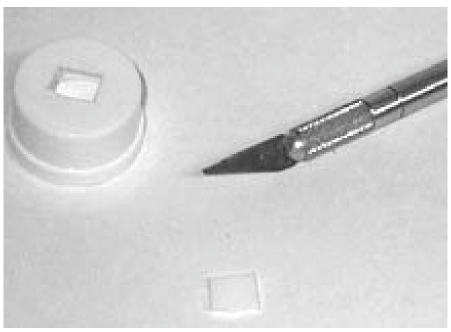
Rainbow is provided at the end of this manual or separately on the “Inside Einstein’s Universe” web site, as described in the Suggested Shopping list above.

Exploration 5 (Low budget emission sources)

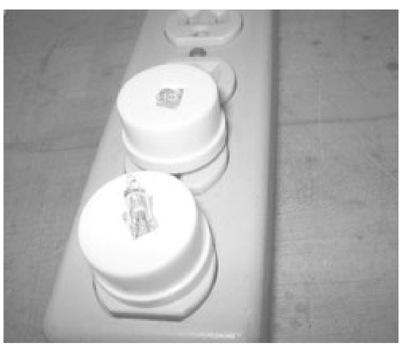
Neon Bulb Assembly:


1. Unwrap nightlights from package


2. Remove covers of nightlights


3. Cut hole in middle of cover


4. Reattach cover and pull bulb through hole

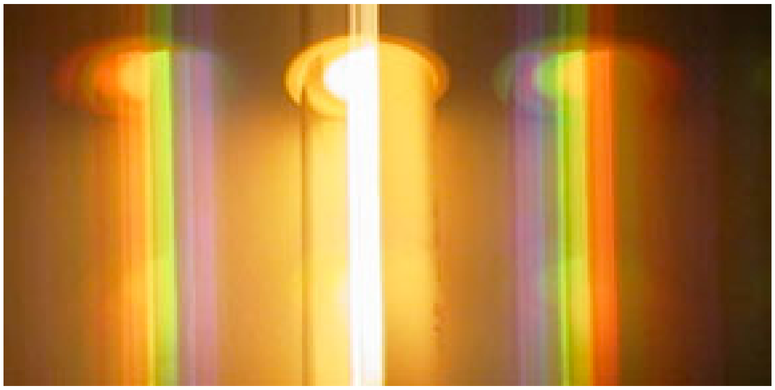

5. Plug into power strip

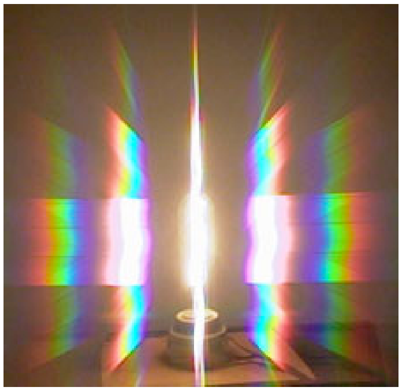
See next page for color image

Neon lights (assembly above):

Fluorescent work light:

Note that the spectra from the neon bulb (above) and the worklight (below left) differ significantly from the continuous spectrum created by the white light bulb (below right)

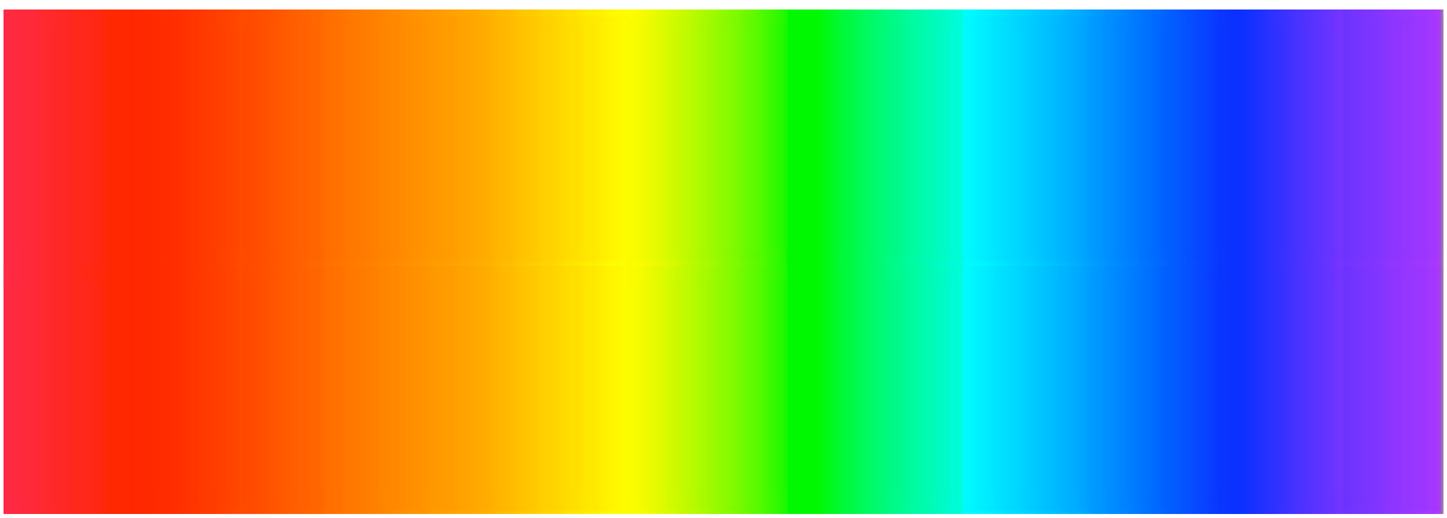




Exploration 10

Fire extinguisher and cone-shaped nozzle (Do not forget cryogenic gloves!)

Example rainbow for Exploration 4



Print out on white paper and roll up so rainbow is on the inside

Example template for creating galaxy CDs

Trace out CD and cut along circle. (This template is also available in higher resolution from the "Inside Einstein's Universe" web site.)