DEMONSTRATIONS MANUAL

Museum of Science, Boston

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Introduction

The public presentations focus on *how* we know what we know about the universe. Astronomers have made astounding discoveries about the universe without ever having traveled further than the moon. How, then, have we been able to discover what stars are made of, or estimate the age of the universe? The following demonstrations have been designed to provide the audience with the methods astronomers use to find answers to such questions.

Scientists often use models to conceptualize very small things such as molecules and atoms, or very large things such as the universe. Most of the demonstrations provided in this guide are models. All models have limitations. While they do a good job demonstrating one point, they often fail to demonstrate others and may possibly lead to misconceptions. When using these models, it is often useful to point out the strengths as well as the weaknesses of the models to the audience.

Two outlines have been provided as suggested ways of organizing the demonstrations. "How Do We Study the Universe?" has a broad focus on methods astronomers use to learn about many different aspects of the universe and what's in it. "The (Real) Time Machine" focuses more specifically on determining distances to objects and therefore the age of those objects, ending with the estimated age of the beginning of the universe. Two mini-outlines suggest demonstrations that may work well for young audiences.

The public presentation is recommended to last 20-30 minutes. Each of the bigger outlines contains more demos than will fit in a presentation of this length. It is recommended you select five or more demonstrations of your choice. There are enough demonstrations to develop a 45 minute formal presentation. Alternatively, each demonstration can also be used by itself as an interpretation.

No scripts have been provided. The philosophy of the Museum of Science is that each educator develop his/her own presentation to suit to each individual's teaching style. Please develop your presentation to suit your institution's programming missions and needs.

The (Real) Time Machine
Suggested outline

I. Introduction

Welcome audience to presentation
Invite audience to visit Cosmic Questions exhibit
Highlight some topics you will be covering

Telescope
Introduce the concept that when we see light from stars, we are seeing them as they were, rather than as they are.

II. Using light to measure distances

Lightning Video
Just as we use sound to determine how far a lightning bolt happened, we can use light to determine how far stars and galaxies are.

Slides of moon, sun, constellations, galaxies
Give distances in light years of several objects in space.

Brightness
Comparing the actual brightness of a star to its apparent brightness, allows astronomers to determine the distance to that star.

III. Fingerprints of atoms

Emission Tubes and Diffraction Glasses
This can be used to demonstrate how scientists know what stars are made of. It also gives them the baseline fingerprints of different atoms.

IV. Expanding Universe and Redshift

Slide of Edwin Hubble
This man observed that the fingerprints of light from galaxies are shifted towards the red area of the visible spectrum. The further the galaxy, the greater the shift.

Elastic Band & Cosmic Redshift
Describe and demonstrate redshift

Rope/Chain & Wavelength
Demonstrate why we see different colors

PVC tubes/Slide whistle
Demonstrate that as things expand, sound is shifted to lower frequencies. We perceive this as a lower pitch. Light also shifts to lower frequencies. We perceive this as redder colors.

Expanding Universe (volunteers)
Demonstrate that as the universe expands, all of the galaxies are moving away from each other.

V. Invisible Light

Infrared Thermometer
Some light in the universe has been redshifted past visible light and into invisible microwave light. Invisible light may be a confusing for some audience members. The infrared thermometer demonstrates the presence of invisible IR light that people are more familiar with.

Black Light
This is another way to demonstrate to presence of invisible light.
*Note: UV light is invisible light located beyond the violet end of the visible spectrum rather than the red. Therefore, visible light would be blueshifted to ultraviolet, not redshifted.

VI. Photograph of Big Bang

Cosmic Microwave Background Radiation slide
There are several CMBR slides to select from. If you select the slide in the oval format, you may want to use the oval map of the earth to explain the shape.

VII. Model of the Big Bang

CO2 Fire Extinguisher
Make a model of the big bang. Highlight both strengths and weaknesses of this model.

How Do We Study the Universe?
Suggested outline

I. Measuring Distances to Stars

Parallax
This demonstration can be as involved as using the parallax model to measure an actual distance, or as simple as the thumb activity, depending on your audience's age and interest.

Brightness
This demonstration can be used to show a second way of measuring distances to stars.

II. Spinning Stars

Astronomers can determine which direction a star is rotating by looking a light from stars. The light from the side that is spinning towards us is "bluer "and the light from the side that is spinning away from us is "redder". (This redshift is the result of the Doppler effect, which is different from the Comic Redshift.)

Tuning Fork or Wiffle Ball
Demonstrate that this shift in light that results from an object moving towards or away from the viewer also happens with sound. Sound can be shifted higher or lower if something is moving towards or away from the viewer.

Radar Gun
The radar gun compares the shift in reflected light from a moving object to the original light that first left the radar gun. The difference is recorded in miles per hour. This is similar to what astronomers do when looking at light from stars.

III. Finding Invisible Objects

Astronomers can learn about the universe using special tools that allow them to see invisible light produced by different objects.

IR thermometer
Astronomers can use infrared light to look at objects that are too cool to radiate visible light, such as cool stars, brown dwarf stars, planets and clouds of particles around stars.

Black Light
UV light can be used to study young, hot stars

IV. What stars are made of

Emission tubes and Diffraction Glasses

Astronomers can determine the chemical makeup of stars by observing fingerprints of light emanated by stars. The audience can observe several different fingerprints of light using diffraction glasses to look at several different gasses.

Young Audiences

2 Suggested outlines

Outline 1
Measuring Distances to Stars

Parallax
This demonstration can be as involved as using the parallax model to measure an actual distance, or as simple as the thumb activity, depending on your audience's age and interest.

Brightness
This demonstration can be used to show a second way of measuring distances to stars.

Outline 2
Learning from Light

Rainbow Projector
Demonstrate that white light is made up of all the colors of the rainbow using a prism. Can also be used to show that the rainbow extends past the red end of the spectrum to infrared light and the blue extends to the ultraviolet light.

Emission Tubes and Diffraction Glasses
Audience can use diffraction glasses to see that different elements produce different patterns or fingerprints of light. This helps astronomers learn what stars are made of.

Infrared Thermometer
We can learn about objects in space by investigating invisible light they emit.

Ultraviolet Light
Some objects in space emit invisible ultraviolet light. We can learn about them by investigating this light.

Black Light

Purpose:
To demonstrate the presence of invisible ultraviolet light
To discuss ways astronomers use invisible light to learn about the universe

Materials:
Black light bulb
Lamp
Tide
Quinine water

Suggested use:
Show a slide of the electromagnetic spectrum. Point out that visible light comprises a very small percentage of the spectrum. Beyond the color we see as red is infrared and beyond the color we see as violet is ultraviolet. Most people are familiar with ultraviolet rays from the Sun. Black lights produce violet light (visible light) and ultraviolet light (invisible light).

Turn off the white lights and turn on the black light. The quinine water and the tide will glow. There are non-harmful chemicals in the water and in the detergent called phosphors. A phosphor is a substance that converts UV light to visible light.

Astronomers use special cameras and telescopes that are able to detect wavelengths of light such as UV, infrared and microwave, to see things in the universe that the unaided human eye is unable to see. For example, the Cosmic Microwave Background Radiation in this photograph was taken using another form of invisible light, called microwave radiation. (Please see the "Cosmic Microwave Background Radiation" section for more information.)

Background:
Black lights emit invisible ultraviolet-A light and visible violet light, which is why we see purplish colored light when they are on. Ultraviolet, or UV, light is emitted by the Sun and other stars. Ultraviolet light is divided into three categories according to wavelength. UVA are the longest wavelengths (320-400 nanometers) and is the least harmful to the skin. UVB (280-320 nanometers) and UVC (280-4 nanometers) are the shortest and more harmful to the skin. Much UVB and most UVC are absorbed by the Earth's atmosphere. Glass, clothing and impurities in the air absorb UVA.

When a black light is turned on, many objects in the room will glow. Many objects such as quinine water, laundry detergent, teeth, and fingernails contain phosphors. Phosphors are materials that convert UV light to visible light by fluorescing. When a photon of UV light hits a fluorescing molecule, that energy is absorbed. The result is that one of the electrons in the fluorescing molecule jumps to a higher energy level.

When the electron falls back to its normal level, that extra energy is released in the form of a visible light photon. Thus, the material will glow.

Using special cameras and telescopes, astronomers can now create false color images to see invisible light in the universe. Since the Earth's atmosphere absorbs most UVB and UVC light, telescopes detecting UV light must be sent above the Earth's atmosphere.

Young, hot, massive stars emit great amounts of UV light, while most older stars generate little UV light. Therefore, using UV images, young, hot stars can be easily detected without light interference from older stars. (For more information, please see the article, "Pinwheel Galaxy in M101 in UV".)

Brightness

Purpose:
The purpose of this demonstration is for the audience to learn that the brightness of an object can help give clues as to the distance of an object, its rotation, and the object's shape.

Materials:
2 flashlights of equal power
1 presenter
1 volunteer

Suggested use:
Distance:
Hold a flashlight in each of your hands and show the audience that both lights have the same luminosity. They both emit the same amount of light. Give your volunteer one of the flashlights and you walk up to the audience and shine the flashlight over the audience's heads. Have your volunteer positioned as far away from the audience as possible. The volunteer shines his/her light directly over your shoulder as you slowly walk past the audience. Tell the audience to compare the apparent brightness of each of these lights. They will notice that the light that is far away appears dimmer than the light that is closer.

Rotation:
Take one flashlight and shine it at the audience. Begin to spin the flashlight and have them look at the apparent brightness and how it changes as you spin the flashlight. You can also spin an object and have the light hit a spinning object. Spin the object or flashlight quickly and then slowly. Scientists can see how fast objects are spinning by looking at how the light changes as the objects move.

Shape:
Spin an object that has a unique shape. Shine a light on it and watch it spin. The audience can tell what the object's shape is by looking at the object's dark and bright spots. The audience can also figure out the orientation of the object as it gets dark and light.

Background:
History:
The Greek astronomer Hipparchus divided stars into six brightness groups in the second centuray BC. At that time the brightest stars were classified as the 1st magnitude and the faintest being in group 6. Norman Podgson of Radcliffe Observatory, by 1856, had quantified the relationship of stars' magnitude, or brightness. A 1st magnitude star was 100 times brighter than the faintest star visible without a

telescope. Hertzprung and Russel, made observations about star brightness early in the 20th century and created diagrams describing star brightness, color and temperature.

Explanation:
The true brightness of a star tells us how much power is emitted from the surface in the form of light. This can be determined once the distance to the star is known. Scientists often compare the luminosity, the true brightness, of stars with Earth's sun. Our sun shines with a power output of 4 x 1026 Watts. Scientists set this amount of power equal to one Sun. Stars that have half the power output of the Sun are said to have a luminosity of 1/2.

The apparent brightness of stars depends on their distance. The apparent brightness of a star decreases by $1/\text{distance}^2$. The observer must also know the true brightness to determine the distance to the star.

Temperature and Color:
Since the actual distribution of energy emitted by a star closely approximates a black body curve, astronomers can determine the surface temperature of a star by accurately measuring the colors of the light it radiates. The relative amounts of light emitted in various colors are directly related to the temperature of the stars.

Useful Website: Jose Wudka 9/24/1998
http://phyun5.ucr.edu/~wudka/Physics7/Notes_www/node109.html

Application:
In September of 2002, an unidentified object was observed in Earth's orbit. Carl Hergenrother and Robert Whiteley, astronomers at the Lunar and Planetary Laboratory at the University of Arizona, measured reflected light from the object to help identify the object. The photometric measurements showed that the object spins once every 63.5 seconds or once every 127 seconds. The scientists were making more observations to determine exactly its rotation rate. Hergenrother said, "Such a rapid rate of rotation is not unheard of either for an asteroid or a piece of man-made space junk, bit is very consistent with each." This information about the spin rate, in addition to spectral information from the light that was reflected off the object, helped astronomers solve the mystery. They determined that the paint was titanium oxide and that the object was a booster from the Apollo 12 mission.

Cosmic Microwave Background Radiation (CMBR) Image

Purpose:
For the audience to see an image and have a better understanding of the CMBR

Materials:
Select a slide of CMBR

Suggested use:
Select at least one slide of the CMBR. Tell the audience that this is an image of the light left from the Big Bang and is 12 to 15 billion years old. Discuss in as much detail as you feel is appropriate for your audience.

Background:
The Big Bang model of the origin of the universe states that the universe originated in a very hot, very dense state 12-15 billion years ago and has been expanding and cooling ever since. In 1948, physicists George Gamow, Ralph Alpher, and Robert Herman predicted that there must be light throughout the universe left over from the early universe. Today, this light is called the Cosmic Microwave Background. It wasn't until 1965 that the CMB was accidentally discovered by Robert Wilson and Arno Penzias at Bell Telephone Laboratories in New Jersey. They were using a radio receiver that kept picking up microwave static noise no matter where or when they aimed it. When Robert Dicke of Princeton University heard of these results, he realized that they had discovered the CMB. In 1978 Penzias and Wilson shared the Nobel Prize for their discovery.

The light from the CMB is no longer visible to the unaided human eye. Astronomers estimate this light to be 12 to 15 billion years old. Over these billions of years, the expansion of the universe has caused light that was once visible to be redshifted to the microwave region of the electromagnetic spectrum. (Please see "Elastic Band & Cosmic Redshift" for more information about redshift.) Using telescopes that are able to convert microwave light to visible light images, scientists are now able to photograph the CMBR. If we could see microwave light, the CMBR would fill the entire sky. The blotchy pattern of the CMBR is the result of very slight differences in temperature and density.

The slide of the CMBR with a skyline, shows us what the sky might look like if we could see microwaves.

The slide of the CMBR shaped as an oval is one way of mapping a 3 dimensional sphere onto 2 dimensional paper. Imagine that you are standing at the center of Earth. If you were to look all around, you would see the continents surrounding you. If you were to flatten this view of the continents, you would have a two-dimensional world map, called an Aitoff projection. Now imagine that you could peel back the Earth. You would see the sky surround you in all directions. If you photographed the sky surrounding you with a microwave sensitive camera, and then took those images and flattened them onto a piece of paper, it would give you the oval shaped image of the CMBR.

For an example of this, use the slide temperaturemaps.jpg. The top map shows the continents of the Earth (the outside of a sphere) mapped onto two-dimensional oval. The bottom map shows the sky (the inside of a sphere) mapped onto a two-dimensional oval.   Both images use different colors to represent the different temperatures over the respective spheres.

CO_2 Fire Extinguisher

<u>Purpose:</u>
To model the big bang

<u>Materials:</u>
*1 10 lb. carbon dioxide fire extinguisher
1 3ft. hose with cone shaped nozzle
1 pair cryogenic gloves
1 wrench

*Obtaining CO_2 fire extinguisher:
The Museum of Science maintains a supply of CO_2 extinguishers through a local fire extinguisher/fire safety company. Check your local phone book under "fire extinguishers."

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!

<u>Suggested use:</u>
Before presentation begins:
Attach nozzle to canister. Use a wrench to tighten nozzle **securely**! If nozzle is not tight, CO_2 may leak out and increase risk of frostbite.

For Presentation:
Remove safety pin from handle.
Put on cryogenic gloves
Warn audience that when CO_2 is released, it will be very loud! They may want to cover their ears.
Aim nozzle above the heads of audience. Do not aim nozzle directly at audience. This allows CO_2 snowflakes to fall gently around.

<u>Background:</u>
We observe the universe to be expanding. That is, everything in it is moving apart. Scientists theorize that if we reverse this process, everything must have once been compacted together in a hotter, denser state. A major explosion, bigger than any supernova or atomic bomb, must have caused everything to expand in all directions. As the universe expanded, it cooled. Rapid expansion of this hot dense early universe is called the Big Bang.

Make a model of the Big Bang using a carbon dioxide fire extinguisher. Stress that this is a model. Like all models, it models some things well and other things not as well.

Limitations:

One of the limitations of this model is that obviously the universe did not come from a can. Another limitation is that when CO_2 is released, it is released into a room with air, people, furniture, etc already in it. Before the Big Bang occurred, it is unlikely that space and time existed. To make this model more accurate, we would have to put the room, ourselves, the furniture, the air, and time inside of the extinguisher along with the CO_2. When we squeezed the handle of the extinguisher, the room and everything in it, along with the CO_2 would come out.

Strengthsl:
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.

Elastic Band & Cosmic Redshift

Purpose:
To explain the red-shifting 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.

Materials:
elastic band light wave

Suggested use:
Mention now that the concept of wavelength has been established,{see 'Rope and Wavelength'}, we can more firmly link cosmic red-shift and the expansion of the Universe using a 'cartoon' of a light wave drawn upon an elastic band. The presenter identifies a point on the stage as 'Earth', then steps a short distance away to the 'location' of a nearby galaxy. As light 'emitted' from this galaxy travels towards 'Earth',(the presenter moves back toward the original point, stretching the band so that when she/he arrives, it has a longer wavelength), the expansion of the space the light is travelling through 'stretches' the light to a longer wavelength, reddening its color. For a more distant galaxy, the light must travel through more space, so it is 'stretched' more than in the case of the closer galaxy.

Background:
Apparently, the red-shifting of light due to the expansion of the Universe is distinct from the Doppler effect, although both change the color/wavelength of the light we observe. If the Universe were imagined as a rising loaf of raisin bread, each raisin representing a galaxy, then the cosmic red-shift may be seen 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.

References:
'Cosmic Horizons', a publication of the American Museum of Natural History, p. 124-125 (Author? Michael A. Strauss?), p.128-129 (Robert Krishner)

'Expansion of the Universe', Lecutre by Paul Doherty from the Exploratorium,
Emission Tubes and Diffraction Glasses
http://www.exo.net/~pauld/activities/astronomy/expandinguniverselecture.html

Emission Tubes and Diffraction Glasses

Purpose:

The purpose of this demonstration is for the audience to observe the "fingerprints" (emission spectra) of light produced by helium and hydrogen. Because each element produces a different 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 produced by them.

Materials:

1 power supply
1 helium gas tube
1 hydrogen gas tube
1 argon gas tube (optional)
1 mercury gas tube (optional)
Box of diffraction glasses

Suggested use:

Pass out one pair of glasses to each member of the audience. Have audience observe spectra from white light bulbs in the room. They will observe a continuous spectrum. Now turn off the white lights, so the room is dark and have the audience observe the hydrogen gas tube. 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, blue and violet. Remove the hydrogen tube and insert the helium tube. Ask audience to observe the spectra of helium. They will observe bright bands of red, yellow, green, blue and violet. Collect glasses at the end of the presentation.

To attach power supply to tripod:
Power supply has attachment for quick release onto leg of tripod. Click into place and lock with lever.

To insert gas tube: Insert one end of a gas tube into the holder closest to the on/off switch. Insert the other end of the tube into the remanding holder. Turn on switch.

To remove gas tube: 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!

Background:

In 1665 Isaac Newton first discovered the rainbow spectrum hidden in white light by splitting it with a glass prism. This was the beginning of spectroscopy, the study of light emitted from an object. Light is energy that can be thought of as waves and/or particles. If we think of light as waves, the distance between 2 consecutive peaks or 2 consecutive troughs is called a wavelength. The size of the wavelength determines the type of light that is produced. The full range of all wavelengths of light is called the electromagnetic spectrum. The types of light from longest wavelengths to shortest 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 size of wavelengths by seeing different colors. For example, the longest wavelengths of visible light we see as the color red and the shortest wavelengths 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 wavelengths. The diffraction glasses act just like prisms, splitting light into individual wavelengths. 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.

In addition to continuous spectra there are also emission spectra, or bright line spectra and absorption spectra, or dark line spectra. Unlike the continuous spectra, not all colors of light are observed in line spectra. Rather, each element emits (for emission spectra) or absorbs (for absorption spectra) 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. Therefore, scientists are able to determine what stars are made of, by looking at their spectral lines. This so-called modern spectroscopy was pioneered in the 1860s by Robert Bunson and Gustav Kirchow.

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 comprised of, it will absorb specific wavelengths of light. When sunlight passes through a spectroscope, it produces an absorption spectrum because the Sun's atmosphere absorbs specific wavelengths 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 by hot transparent gases 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.)

Expanding Universe (modeled by volunteers)

Purpose:
To make of model of the expanding universe
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:
7 volunteers
6 galaxy signs with corresponding color squares
1 Milky Way sign with corresponding color square

Suggested use:
Set up:
Tape colored squares approximately 2 inches apart in a straight line, with the blue square in the middle. Place the galaxy signs of the same color on top of each square. Explain that the blue square represents Earth's place in the universe—the Milky Way galaxy.

Presentation:
Introduce the concept of the expanding universe. Make a model of the expanding universe. Ask for seven volunteers. Have each volunteer stand behind a colored square and wear the corresponding sign around their neck. Ask volunteers to hold hands with the people standing next to them. Tell them that on the count of three, they are going to move away from each other until their arms are out straight. At that point they can let go of hands, but remain where they are now standing. The audience can observe that the galaxy volunteers that were farthest from the Milky Way volunteer, had to move the fastest to "expand" uniformly with the rest of the "universe." The galaxy volunteers at the two ends are now proportionally further from their original starting places than the two galaxy volunteers closest to the Milky Way.
A limitation of this model is that the Milky Way is located at the center of the universe. In order to address this issue, you may want to repeat the experiment, but have the Milky Way stand in a different place in the universe. The volunteer will still experience the other galaxies moving away from him/her.

Background:
The Big Bang model for the origin of the universe says that the universe exploded 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 "Elastic Band & Cosmic Redshift" for more information). 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. Note that this needn't mean that we are at a central or special place in the Universe. A far more likely explanation is that the Universe is expanding uniformly, rather than away from a center that we have no evidence to believe exists. In a uniformly expanding Universe, other galaxies would observe all their neighbors moving away from them exactly as we do.

Note: We are not actually able to travel outside the Milky Way to observe the expanding universe from any other galaxy. However, the notion of a uniformly expanding Universe is a more likely explanation for what we observe than the supposition that we are at the center of our Universe.

IR Thermometer

Purpose:
To demonstrate the presence of invisible light (infrared)
To discuss ways astronomers use invisible light to learn about the universe

Materials:
Infrared thermometer
1 bottle cold water
1 bottle hot water

*The lids of the water bottles are covered with making tape to prevent the audience from seeing condensation from the hot water.

Suggested use:
Place the water bottles next to each other on a table. Tell the audience that each of these bottles represents a star. Both of these stars are shining brightly. One of them is brighter than the other. However, they are shining in a light that is not visible to the naked human eye. They are radiating a type of light called infrared or IR light. Anything that has a temperature greater than absolute zero radiates IR light. Hotter objects radiate greater amounts of IR. If we want to determine which of these stars is hotter, we can measure the amounts of IR each is emitting. We have a thermometer that is able to sense IR light. Ask for a volunteer. Give the volunteer the IR thermometer. Show them how it works, by pressing and releasing the button. Ask them to aim the thermometer at each of the bottles from about a foot away. The thermometer is able to give an accurate reading without touching the surface of the bottle. Give several examples of ways astronomers used IR light.

Background:
Infrared (IR) light was discovered around 1800 by the astronomer, William Herschel, when he placed a thermometer just beyond the red end of the visible light spectrum. There was a temperature increase, indicating that there was a presence of invisible energy. Infrared light is invisible light found between visible red light and invisible microwave light on the electromagnetic spectrum. Anything with a temperature above absolute zero gives off infrared light. Even objects we consider cold, such as ice cubes, radiate in the infrared. Objects that are not hot enough to radiate visible light, do radiate infrared light. However, the hotter the object, the stronger the infrared. Infrared light is commonly used in everyday items such as television remotes and motion sensors.

Since infrared light is emitted by anything with a temperature above absolute zero, almost everything in the universe emits this type of light. Therefore it is valuable for astronomers to learn more about the universe. Since infrared is invisible to the human eye, astronomers use special cameras and telescopes to “see” IR. Water vapor is the most absorbent material of infrared light. Therefore, infrared observatories are most successful in areas of low humidity. There are several infrared telescopes at the observatory at the 14,000 foot summit of Mauna Kea in Hawaii. Astronomers have also launched telescopes such as the Infrared Astronomical Satellite (IRAS), into Earth's orbit, above the water vapor within the Earth's atmosphere.

There many ways that infrared light is useful to astronomers. Infrared light is able to penetrate clouds of dust and gas that visible light is unable to pass through. Astronomers are therefore able to "see through" these dense areas to galaxy centers and nebulas. Infrared can also be used to look at objects that are too cool to radiate visible light, such as cool stars, brown dwarf stars, planets and clouds of particles around stars. Studying infrared is also an important key to learning about the past. Much of the light that has been redshifted due to the expansion of the universe, has been shifted into the infrared region of the electromagnetic spectrum.

Lightning Video Clip

Purpose:
To introduce the concept that there is a relationship between distance and time. Audience can estimate how far away a flash of lightning occurred by counting the seconds between when they see the flash of light and when they hear the thunder.

Materials:
Video clip from power point presentation

Suggested use:
Tell audience you have a video clip of a thunder and lightning storm you would like to share with them. Ask them to tell you when the lightning happens by saying “Now!” However, they must close their eyes. Have audience close their eyes. Play video clip. Most people will say “Now” when they hear the thunder. Play video a second time. This time ask audience to keep their eyes open. Most people will say “Now” when they see the flash of lightning.

Point out that there were two different responses depending on whether their eyes were opened or closed. Explain why the flash of light and sound of thunder do not happen simultaneously.
Invite audience to figure out how far away the lightning happened by counting the seconds between the flash of light and clap of thunder. It is approximately a 5 second delay, so the lightning happened about one mile away. Also, when we hear the thunder, we are listening to an event that happened 5 seconds earlier so we are listening to the past. Light travels about one million times faster than sound, but it still takes time for light to travel distances. It takes light about 5 millionths of a second to travel one mile, so when we saw the flash of light, we were looking 5 millionths of a second into the past.

Background:
In 1667 Galileo first experimented with measuring the speed of light by using lanterns placed at variable distances. He was unable to successfully measure the speed and concluded that light travels much faster than the human reaction time. In 1676 Olaus Roemer made more accurate estimates of the speed of light, using eclipses of the moon Io by Jupiter. Today we know the speed of light in a vacuum is 299,792,458 meter/second. It is more commonly rounded to 300,000 kilometers/second or 186,000 miles/second. Another way of expressing this number is that it takes light 5 millionths of a second to travel one mile.

Sound travels approximately 1 million times slower than light. Sound travels at about 340 meters/sec air or about 5 seconds to travel one mile.

In the case of a thunderstorm, we can determine the distance to where a lightning strike occurred by counting the seconds between when we see the flash of light and when we hear the thunder. For every 5 seconds, there is a distance of one mile. We can see then, that there is a relationship between speed, distance and time. If we know any two parts of the equation, we can solve for the third. In the case of the thunderstorm, we know the speed (of sound) and the time (the seconds between light and thunder) which allows us to determine the distance. When we look at light from stars, or other galaxies, we know the speed of light. If we are able to determine the distance to the stars or galaxies, we can then determine time, or how far into the past we are looking. There are several different methods astronomers use to determine distance to stars and galaxies. (See "Parallax,' 'Redshift,')

Parallax

<u>Purpose:</u>
For audience to have a better understanding of parallax and how it is used in astronomy.
To use parallax to determine the distance to an object on stage

<u>Materials:</u>
1 tripod
1 center piece with quick release attachment
2 long metal arms
2 swivels with lasers
1 paper star
scotch tape
tape measure

CAUTION:
Be careful not to shine laser in anyone's eyes.

Optional materials:
Sunglasses
Scarf
Yellow balloon

<u>Suggested use:</u>
Set up:
Set up tripod no further than 20 feet from a wall.
Fasten center piece to top of tripod. Lock into place by closing arm of quick release plate.
Attach a metal arm to each side of center piece.
Attach a swivel with laser to each metal arm.
*For the most accurate measurements, adjust pan and tilt handle so that the lasers are parallel to the floor.
Inflate the yellow balloon, but keep it small enough to fit between the 2 laser swivels when they are fastened to the center piece. Tape it to the center piece. (optional step)

Tape star to the wall so that when the lasers are on, they are close to the center of the star.

Presentation:
Introduce the activity by giving the audience some background information about parallax. You may want to have them try the thumb activity described in the "Background" section.

Tell the audience that you are going to use parallax to measure the distance from the tripod to the paper star. Ask for 2 volunteers to help. (Recommended age for volunteers: 12 and older.)
When astronomers calculate distances to nearby stars, they observe the star at two different points in the Earth's orbit around the Sun. One volunteer will represent the Earth during the summer. (You can have them wear the sunglasses.) Have that volunteer stand next to one of the lasers. The second volunteer will represent the Earth six months later during the winter. (You can have them wear the scarf.)

Imagine that the paper star is too far to measure with a ruler. Therefore, we'll use parallax to determine the distance. Have volunteers adjust swivels so that the lasers are aligned on top of each other on the paper star. You have now created a triangle, with the three points being the paper star, the summer Earth, and the winter Earth. To determine the distance to the paper star, we will make this triangle 10 times smaller. To do this, carefully remove the swivels with lasers.

IMPORTANT: Do not change the angles of the lasers! If the angles change, the experiment will not work!

Reattach swivels to the center piece. Again, be careful not to change the angles. Have volunteers hold down buttons on lasers. Holding a blank piece of paper, start from the wall with the star on it and walk towards the tripod until the laser dots are again lined up on the paper. Once they are lined up, remain holding the paper in that spot. Ask one of the volunteers to use the measuring tape to measure the distance from the center piece to the blank paper. Take that number and multiply it by 10. This will give you the distance to the paper star. You can confirm whether the number is accurate using the tape measure to measure from the center piece to the paper star.

Limitations of this model: This model works best for measuring distances to objects 10-20 feet away. It is good to point out that astronomers are also limited to measuring distances to the closest stars to Earth using this method.

<u>Background:</u>
Parallax is a method used by astronomers to measure distances to nearby stars. Parallax is the apparent shift an object seems to make against its background as a result of a change in the viewer's perspective. For example, human eyes are about 2 inches apart. When we look at an object, our right eye sees it against a particular background while our left eye sees it against a slightly different background. This allows us to see in 3 dimensions and we are able to estimate how far away the object is. To test this, hold up your thumb a few inches in front of your nose. Close your left eye and observe your thumb against the background with your right eye. Now open your left and close your right eye. Observe your thumb against the background with your left eye. You will see that your thumb appears to shift against the background. If you were to measure the apparent shift of your thumb and compared it to the distance between your eyes, you would be able to calculate the distance of your thumb from your face. This method works well for objects that are relatively near, but does not work for objects

that are relatively far. To test this, hold up your thumb again in front of your nose. This time, extend your arm as far as you can. Observe your thumb with your right eye and then with your left eye. You will observe that the apparent shift of your thumb against its background is less than when your thumb was close to your face. If you could extend your thumb to the other side of the room, you would not observe any apparent shift, and therefore would be unable to calculate the distance. To demonstrate this, have a friend stand across the room with their thumb in the air while you observe the apparent shift (or lack thereof). The demonstrator can have the audience observe his or her own thumb at the front of the room.

Astronomers use a similar method to determine distances to nearby stars. As the Earth orbits the Sun, nearby stars appear to shift against the background of distant stars. To determine distances to nearby stars, astronomers measure the position of a star against the background, at one point of the Earth's orbit around the Sun. Six months later, when the Earth has moved in its orbit, they measure the position of the same star against the apparently shifted background. That number is compared to the distance between the two points of Earth in its revolution around the Sun. Thus, the distance to the star from Earth can be calculated.

To give a sense of scale, the definitions and values of three of the most common astronomical units are given below:

Astronomical Unit (AU) – The distance from the Earth to the Sun.

Light Year (ly) – The distance light travels in a year.

Parsec (pc) – The distance of an object that exhibits an shift (parallax) with half-angle of 1 arcsecond (1/3600 of a degree), between observations from the Earth taken 6 months apart. In this time, the Earth has traveled to opposite ends of its orbit, so the observations are separated by a distance of 2 AU. Comparing the observations, the total angular shift of an object 1 parsec away is 2 arcseconds, and its half angle is one arcsecond.

1AU = 92.96 million miles.
1ly = 5.9 trillion miles
1 pc = 3.26 light years

PVC Tubes/ Slide Whistle

Purpose:
To model the expanding universe.
To demonstrate that as something expands, the sound it produces gets lower in pitch. Likewise, as something expands, the light it produces gets redder.

Materials:
1 PVC pipe, 1 1/2 inch diameter
1 PVC pipe, 2 inch diameter
1 ping pong ball paddle
OR
1 slide whistle

Suggested use:
Put smaller diameter tube inside larger diameter tube. Ask 2 volunteers to support (the model of) the universe. Have each volunteer supporting each end of the PVC tube, with the smaller tube inside, so that the tube is parallel with the floor. This is a model of the universe. Imagine that the universe produced a specific pitch of sound. Tap the mouth of the tube with the ping pong paddle. It will produce a sound. To model the universe expanding, slowly slide the inner PVC tube out, lengthening the tube, while continuing to hit the mouth of the tube with the paddle. The sound will decrease in pitch as the tube lengthens. Slide the tube back in, continuing to hit the mouth with the paddle, and the pitch will increase. Just as sound is shifted to a lower pitch by the lengthening, or expansion, of the tube, visible light is shifted towards the red colors of the visible spectrum by the expansion of the universe.

This demonstration can also be done using a slide whistle instead of the PVC tubes. Blow into the whistle and extend the slide. The pitch will decrease.

Background:
Pipe organs produce different pitches of sound by forcing air through different lengths of tube. Short tubes make high frequencies of sound when air passes through them. Long tubes make low frequencies of sound. Therefore, as the PVC tube lengthens, the pitch lowers. However, it is important to note that all these frequencies are always present. The organ pipe only selectively amplifies one frequency over another. As the tube lengthens, different frequencies are amplified.

In the case of the universe, as the universe expands, light is shifted to lower frequencies. These new frequencies of light were not present before. In the visible light spectrum, we perceive low frequencies of light as the color red and high frequencies of light as the color violet. Because of this, when light shifts to lower frequencies, this is called red shift. When light shifts to higher frequencies it is called blue shift. It is important to note that light can shift to lower frequencies than those in the visible light spectrum. Light can be redshifted lower past red visible light and into the infrared, microwaves and radio waves. Likewise, light can be blueshifted past violet visible light and into the ultraviolet. For more information on redshift, please see “Elastic Band & Cosmic Redshift.” Page: 29

Radar Gun

Purpose:
To show that the wavelength and frequency of light are shifted when an object producing or reflecting the light is moving. To discuss how the shift is useful to astronomers.

Materials:
Radar gun
Baseball bat

Suggested use:
Select volunteer to swing baseball bat. Aim radar gun at baseball bat. Ask volunteer to swing bat away from you quickly. Tell them what their speed was. Ask them to swing again. Tell them what their speed was the second time. The larger of the two speeds was caused by a greater Doppler shift. Talk about what Doppler shift is, and how it can be used in astronomy.

Manual – At this setting, the radar gun will register a speed when the trigger is pulled and held. Speed will be displayed for 5 seconds.

Automatic – At this setting, the radar gun will continually register speeds. Speed will be registered for 5 seconds. A new speed cannot be taken until the previous speed disappears. To clear the speed before the 5 seconds has elapsed, pull the trigger.

Background:
In 1842, Christian Doppler, a mathematics professor, observed that motion changes the wavelength and frequency of a wave – an effect that since bears his name. Motion can affect both waves of sound (please see "Tuning Fork"), as well as light. If an object emitting light is moving towards you, the waves are compressed. Each consecutive wave is emitted from a progressively shorter distance. Light is therefore shifted towards shorter wavelength and higher frequency, which we perceive in visible light as the color blue. This phenomenon is called blueshift. It is important to note that light can be shifted past the visible light spectrum and into shorter, invisible waves such as UV. More dramatic blueshifts into x-rays, and gamma rays have never been observed.
On the other hand, if an object emitting light is moving away from you, the waves of light are stretched towards longer wavelength and lower frequency, which we perceive as the color red. This phenomenon is called redshift. Light can be shifted past the visible light spectrum and into longer, invisible waves such as infrared, microwaves and radiowaves.

The faster an object is moving, the greater the light is shifted. Therefore, if you measure the amount of redshift (or blueshift) of an object, you can determine the speed of the object. This is the basis for the way a radar gun works.

The radar gun emits a specific frequency of invisible microwave light. The light leaves the gun, bounces off the baseball bat and is reflected back to the gun. If the bat is not moving, the wavelength of the reflected light is the same as when it originally left the gun. Since there is no shift in wavelength, no number is registered on the radar gun. However, when the volunteer swings the bat away from the gun, the reflected light has a longer wavelength of light than the light that was originally emitted from the gun. The radar gun calculates the difference and records it on the screen in terms of miles per hour. If you prefer, you can change the setting to kilometers per hour. The radar gun will also work if the volunteer swings the bat towards you. As a safety precaution, you may prefer to have them swing the bat away from you.

The Doppler effect is useful to astronomers because it can be used to gather information about the motion of planets, stars, and galaxies. As a galaxy rotates, astronomers observe a redshift from the part of the galaxy is moving away from them, and a blueshift from the part moving towards them. By measuring the magnitude of these Doppler shifts, they determine how fast the galaxy is rotating. This *rotation velocity* provides a stepping stone for measuring masses of galaxies—how much material is in the galaxy.

***The redshift that results from the Doppler effect is different than the cosmic redshift that results from the expansion of the universe.** The difference between each is perhaps best explained by imagining our Universe as a rising loaf of raisin bread, the raisins representing galaxies. Cosmic redshift arises due the expansion of space between the galaxies, and occurs even though the galaxies are at ‘rest’ within the expanding ‘dough’. Doppler shifts arise due to any motion through the ‘dough’, such as a caterpillar burrowing through the bread—a motion that is separate from the expansion of the dough itself. (See the elastic band demonstration for information about cosmological redshift.)

Rainbow Projector

Purpose:
To demonstrate that white light is made up of all the colors of the rainbow using a prism. To show where ultraviolet light and infrared light is found beyond the visible light spectrum.

Materials:
Slide projector
Prism

Suggested use:
Swing arm on projector out in front of projector light. Attach prism. Face projector towards a white wall. Turn on projector. Two rainbows will appear. Adjust prism to produce rainbows in desired locations.

Background:
In 1665 Isaac Newton first discovered the rainbow spectrum hidden in white light by splitting it with a glass prism. This was the beginning of spectroscopy, the study of light emitted from an object. Light is energy that can be thought of as waves and/or particles. If we think of light as waves, the distance between 2 consecutive peaks or 2 consecutive troughs is called a wavelength. The size of the wavelength determines the type of light that is produced. The full range of all wavelengths of light is called the electromagnetic spectrum. The types of light from longest wavelengths to shortest 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 size of wavelengths by seeing different colors. For example, the longest wavelengths of visible light we see as the color red and the shortest wavelengths 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 wavelengths. The diffraction glasses act just like prisms, splitting light into individual wavelengths. 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.

Rope & Wavelength

Purpose:
To introduce the notion of wavelength as the distance between two successive peaks or troughs in a wave.

Materials:
Rope

Suggested use:
Explain to the audience that in order to understand why light from distant galaxies is red-shifted, the notion of wavelength must first be explored. Toward this end, light will be modeled using a shaken rope. With one end of the rope fastened, the presenter spans the rope across the stage, thereafter shaking its free end horizontally back and forth so that sinusoidal wiggles are observed propagating down the rope in the plane of the stage. By shaking the rope with a uniform (initially slow) period, the demonstrator explains that all waves, including light, have a property known as their wavelength, defined as the distance between two successive peaks or troughs, and that they are currently observing a relatively long wavelength. The rope is then shaken more rapidly to shorten the wavelength, and this is pointed out to the audience.

Background:
Although light is oscillating electric and magnetic fields rather than an oscillating rope or chain, it too has a wavelength. Although the wavelength of visible light is too small to measure with a normal ruler (less than a thousandth of a millimeter), our eyes perceive wavelength as color – red, orange, yellow, green, blue, indigo and violet being in placed in order from longest to shortest wavelength. Light from distant galaxies is shifted toward the red (ie toward longer wavelengths) because the Universe, and the space within it, is expanding - thereby ‘stretching’ the light toward longer wavelengths and thus redder colors.

Telescope

Purpose:
To introduce the concept that when we look at stars and galaxies, we are seeing them as they were in the past. If we can calculate the distances to them, we can determine how far into the past we are looking.

Materials:
Tripod
Telescope
Black cloth

Suggested use:
Set up:
Set up tripod. Fasten telescope to top of tripod. Drape black cloth over telescope.

Presentation:
Welcome audience to presentation. Tell them you have a real time machine. Our time machine does not allow us to travel to the past, but it does allow us to look at the past. Unveil the telescope. A telescope is an actual time machine. We use telescopes to look at stars and galaxies. The light from those distant stars and galaxies have traveled through great distances of space and time to reach our eyes. So when we see light from stars, we are looking into the past. If we are able to calculate how far the stars are, we can determine how far into the past we are looking.

Background:
Scientists have calculated that the speed of light in a vacuum is 299,792,458 meters/second. (It is more commonly rounded to 300,000 kilometers/second or 186,000 miles/second). Since the speed of light is constant, and we know that speed = distance/time, if we are able to determine distance to a star, we can then solve for time. This will tell us how far into the past we are looking.

Tuning Fork/Wiffle Ball

Purpose:
To demonstrate that the pitch of a tone is shifted when the object producing it is moving.To introduce the concept of redshift. (The redshift produced by Doppler effect is the result of different phenomena than the cosmic redshift produced by the expansion of the universe.)

Materials:
Tuning fork on string
Solid surface to strike fork on
Or
Wiffle Ball
1 volunteer

Suggested use:
Tuning Fork
Tell audience that the tuning fork vibrates at a particular pitch. Strike the fork. You will hear the pitch. This fork will always produce this particular pitch. However, if it is moving, we will hear a shift in pitch. Strike tuning fork. Hold string about three feet from tuning fork. Swing fork in circles above your head. Audience will hear an “wobble” in the sound. As the fork moves towards the audience, the pitch is shifted higher, so you could call this a “high shift.” As the fork moves away from the audience, the pitch is shifted lower, so you could call this a “low shift.” A similar shift happens with light when an object is moving. If it is moving towards you, the light is shifted “bluer.” Therefore, this is called a blueshift. If it is moving away from you, it is shifted “redder.” Therefore, this is called a redshift.

Wiffle Ball
Ask for a volunteer. Turn on switch on wiffle ball. Gently toss the ball back and forth with your volunteer. As the ball is thrown, the pitch appears to change - increasing if coming towards you, decreasing if heading away. A clear demonstration of the Doppler effect in sound; it can be used as an analogy for the redshift/blueshift of light observed in astronomical objects.

Background:
As an object producing a sound moves towards you, the sound waves are compressed, resulting in a higher pitch. As an object moves away from you, the sound waves are stretched, producing a lower pitch. This phenomenon is called the Doppler effect. We have experienced this when we hear a fire truck with sirens moving towards us, we hear the sirens increase in pitch. When it passes us and continues moving away, we hear a decrease in pitch. (Please see “Radar Gun” for more information.)

The difference between Doppler shift and cosmic redshift might be explained as follows: Doppler shifting of the pitch in a fire engine’s siren is due to the motion of the engine, but cosmic redshift would be due to the expansion/stretching of the road between us and the engine.