From the Earth to the Universe

Demonstrations and activities for audiences who are blind or visually impaired

Chandra X-Ray Center
Smithsonian Astrophysical Observatory

Draft Document

Please note that these activities have not been field tested in their current form. Send questions, comments and revisions to Simon Steel at sjsteel@cfa.harvard.edu

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Introduction.

From Earth to the Universe is a collection of astronomical images that will showcase the most dramatic views of our Universe. The images represent the incredible variety of astronomical objects that are known to exist – planets, comets, stars, nebulae, galaxies and the clusters in which they congregate – and will be exhibited in numerous locations throughout the world in 2009. These exhibits, held in public parks, airports, art centers and at other unique sites, will bring the wonders of the Universe right to you. Over 30 countries are scheduled to host a FETTU exhibit.

This activity guide is to help visitors who are blind and visually impaired to share in the beauty and excitement of the images and ideas in the FETTU exhibit. Although astronomy is by its very nature a visual subject, many of the important astronomical phenomena can be interpreted in non-visual ways that are extremely helpful to the sighted, as well as non-sighted, person.

The last century has seen a revolution in the study of the universe through the study of light that is beyond the visual range of the electromagnetic spectrum. Huge discoveries and insights have been made by detecting high energy light such as X-rays and gamma rays, as well as low energy light in the form of microwaves and radio waves. Without the new technology of multi-wavelength astronomy, we would know practically nothing about the big bang and black holes, and be unable to unlock the secrets of how planets are made, and galaxies are born. Astronomers have to study the universe in non-visual ways.

From the Earth to the Universe Braille image displays.

There will be a set of 5 tactile image display panels that will form a satellite galley to the main FETTU display. Each tactile display will feature images taken and modified from the Chandra and NASA Braille book “Touch the Invisible Sky.” Special Braille and visual text will accompany each image. The five panels will feature:

1. An introductory panel that describes the electromagnetic spectrum and where in the universe different types of light comes from.

2. The Sun, with images taken in visible and ultraviolet light.

3. The Crab Nebula, with images taken in visible and X-ray light.

4. Eta Carinae, with images taken in visible and X-ray light.

5. The Whirlpool galaxy, with images taken in infrared and X-ray light.

Demonstrations and Activities to support the Tactile displays.

The set of activities described in this document form a learning guide to the images that the visitors will experience in the FETTU tactile exhibit. Each activity presents a fundamental concept in modern astronomy designed to put the FETTU images into a broader context of how the universe is structured and evolves. Although the activities are written with a class group in mind, they are equally suited to use by out of school groups, libraries, and for teacher professional development. All feature simple and cheap apparatus, with only a couple needing a trip to a hardware or electronics store. The five concepts covered are:

1. Telescopes.
The Earth's atmosphere distorts and absorbs starlight. Modern telescopes have special design features to allow us to see the full range of the electromagnetic spectrum.

2. Light and Energy.
The wavelength, or color, of light is directly related to the energy of light. Light from some astronomical objects have energies way beyond those detectible by human eyes.

3. Size and Scale.
The universe is vast, but the size of, and distance to, objects in the universe can be put into context by dividing the scale into three broad realms: solar systems, galaxies, and the universe of galaxies.

4. Life and Death of Stars.
Stars are born, live and die. This lifecycle is critical to the evolution of our universe, and to the existence of life itself.

5. Galaxies.
Galaxies are the building blocks of the universe. All stars are made in galaxies, and by observing how fast galaxies move apart, astronomers can measure the age of the universe.

1. Telescopes.

Astronomy from the surface of the Earth is sometimes described as bird watching from the bottom of a swimming pool. Putting telescopes on high mountains gets you above the densest and most turbulent parts of the atmosphere, but to get a clear picture of the universe, you need to go all the way into space. This is even more critical for telescopes observing the universe with non-visual wavelengths, such as infrared light and X-rays, as the atmosphere absorbs these wavelengths and the light never reaches the ground.

Getting above the atmosphere is just the first step. Some space telescopes need to have highly specialized and unique features to allow them to capture and image the types of light they are designed to study.

Activity 1A. What can you feel?

Telescopes are put into space to remove the distorting and absorbing effects of the Earth's atmosphere.

Equipment:
Sheets of bubble wrap
Selection of familiar (unbreakable) objects that are of handle-able size. Plastic cups and mugs, toy cars, baseball etc. We piloted this activity with plastic dinosaurs, which are much more exciting!
(optional) cardboard box, just big enough for the above objects to fit in.

Procedure:
1. Ask your students why astronomers want to put telescopes in space. By far the most common answer (from adults and children) is that the telescope will be closer to the objects it is studying. Amazingly, the Hubble Space Telescope is only 350 miles above the Earth's surface (that's New York to Boston); so you may ask whether 350 miles will make much difference if you are observing an object a hundred trillion miles away.

2. A B/VI audience may not have any experience with the twinkling of starlight, or seeing mirages and distortion of the air above a hot road in summertime, but they may have felt turbulence in water, either in a hot tub or swimming in a river, and using a water analogy for air is powerful. Imagine a ray of light as a fleet of toy boats trying to sail across a hot tub!

3. Tell the students that, in this tactile activity, bubble-wrap plays the role of the Earth's distorting atmosphere. Familiar objects are enclosed in bubble-wrap, and the students have to identify the objects within. A good idea would be to have an array of five or six objects. How many objects can you identify? If working in groups, students can confer, and compare experiences.

4. Now remove the bubble wrap, which is equivalent to you putting your telescope in space! Let the students confirm, or modify, their identification. How does your ability to identify an object improve once the blurring effect of the bubble wrap is removed? This is the reason why the Hubble Space Telescope, which isn't very big by modern standards, still gives us the clearest images of the universe of any telescope ever built.

5. As an extension, have one of the objects encased not in bubble wrap, but in a cardboard box. Students will be temped to shake the box to identify the contents, but they will unlikely manage more than a guess. This is equivalent to the Earth's atmosphere completely absorbing, instead of just blurring, the light from the object. The Earth's atmosphere is opaque to many wavelengths, including X-rays. This is good for our health, but means that all X-ray astronomy (and a lot of infrared) has to be done from space.

Note: Some infrared astronomy can be done at high altitudes, where the observatory is above the densest part of the atmosphere. In fact, this is why all major observatories are built on top of mountains. X-ray astronomy can be done by attaching the X-ray telescopes to high altitude balloons. This isn't as good as getting into space, but it is much cheaper!

Activity 1B: Funneling photons

Normal mirrors don't work for X-rays. Instead of reflecting the photons from a curved mirror, you need to skip them through a cylindrical mirror.

Equipment:

Hand-full of small marbles
(optional) length of PVC piping, roughly 6 inches diameter and 8 inches long.
(optional): Small concave mirror (such as a bathroom vanity)

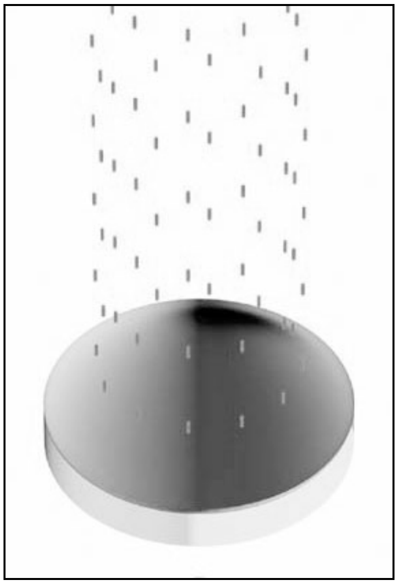
Figure 1.   Concave Mirror

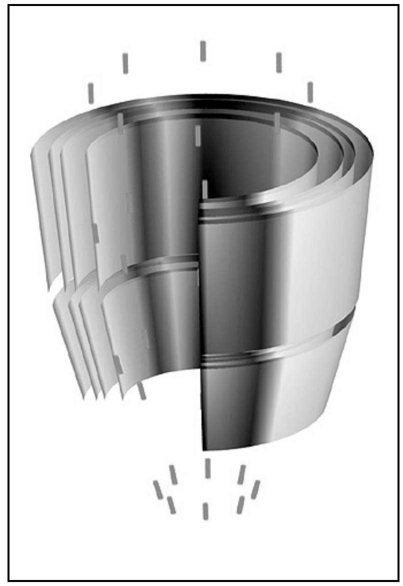
Figure 2. Cylindrical mirrors

Figure 1: In most telescopes, light strikes the mirror and is reflected onto a detector.
Figure 2: In Chandra's X-ray mirror, light grazes off the inside surface of cylindrical mirrors, and travels through to a detector.
(Illustrations: modified from NASA/CXC/D.Berry. Original images and animations at: http://chandra.harvard.edu/resources/illustrations/teleSchem.html

Procedure:
1. Talk about how telescopes work. Basically, all telescopes perform basically the same function. They gather as much light as possible from a faint astronomical object, and focus the light onto a detector. Historically, the gathering of light was done by a lens or concave mirror, and the detector was a photographic plate, or simply the astronomer's eye. However big or sophisticated, a telescope is basically a light bucket, collecting photons like drops of water from a leaking faucet! To study the invisible universe by detecting light beyond the visible range of the electromagnetic spectrum, the mirrors and the detectors in a particular telescope need to be highly specialized to detect the type of light they are designed to study (analogy: hawks, penguins and hummingbirds are all birds, but have evolved to suit their environment – hunting, swimming, hovering. Telescopes have evolved to detect X-rays, gamma rays, and radio waves).

X-rays are high energy, very short wavelength form of light. In fact, rather than thinking of X-rays as wave, they are more like a stream of bullets Thinking about light as particles rather than waves is much easier when talking about X-rays. These particles are called photons. These X-ray bullets are too small and powerful to get reflected when they hit a mirror, and simply smash through the surface! How then do you reflect and focus X-rays. The answer is akin to skimming stones on a pond (this wonderful analogy may be accessible to your audience depending on their experience). If you drop a stone onto water, it will simply splash and sink. If you throw a stone at a shallow angle across the surface of the pond, the stone will skip and bounce. X-ray mirrors are designed to skip photons over a mirror!

2. Get your students to hold their hands flat with fingers spread. Now drop a stream of marbles onto their fingers (not so much of a distance that it hurts!) The marbles strike the fingers then fall through the gaps, just like the X-ray photons slipping between the atoms in the glass mirror!

3. Now, keeping the fingers spread, rotate your hand so that it is almost vertical (30 degrees from vertical should work; 45 degrees is probably too shallow). Now drop the marbles. Instead of slipping through the fingers, they cascade down the hand, and you can, by altering the angle of your hand to the marbles, dictate where they land.

4. Now try this with two cupped hands, making a funnel with your open fingers. Again, if your palms were flat and you tried to capture the marbles, they would slip through your fingers. Now, even with fingers apart, you've created a funnel to direct the marbles to where you want them to go. This is how an X-ray telescope like Chandra works. Using the length of PVC (or equivalent) to represent the mirror, let students feel the shape and explain the orientation, with one open end to the sky, and the other to the detector, and the X-ray photons skipping across the inside surface of the cylinder and down to the detector. Note: the actual mirrors are not pure cylinders, but have a paraboloid shape to focus the X-ray photons. A cylinder however gets across nicely the radical design difference from a normal concave mirror, which could also be available to touch for comparison.

Activity 1C: Can you feel the Heat?

Infrared light is the same thing as heat. This means that an infrared telescope has to be very cold, or else it simply detects itself!

Equipment:
Ice cube trays (at least three cubes wide)
Plastic wrap ("Cling Wrap")
Modeling clay

Prepare the infrared detector by freezing ice in the ice cube holder. Remove several of the ice cubes and fill the vacancy with modeling clay. If you have an ice cube tray three cubes deep, you can use a 3x2 array as a Braille cell, and create a Braille character out of modeling clay (figure 1). The texture of the clay is a tactile giveaway when asking your audience to identify which cube is ice and which is clay, so put plastic wrap over the tray to keep the cubes and dripping water in place, and flip the tray over. The temperature difference between the cube base containing ice and containing clay is easily distinguishable.

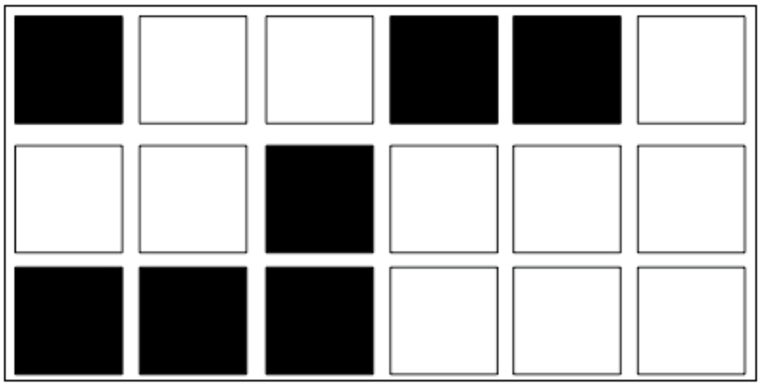

Figure 3. Ice cube tray spelling out “USA”

Procedure:

1. Discussion: Can our bodies detect light in other ways than with our eyes? What about feeling heat? When you are out in the bright Sun, you can tell where the Sun is in the sky by the direction of the warmth. Your skin is acting as a detector for infrared radiation. Detecting ultraviolet light is less pleasant (and not recommended as an experiment!) as sunburns are due to ultraviolet light from the Sun. What about radio waves? Our senses are not capable of detecting radio waves directly, so we use a “radio” to convert light (radio waves) into sound (pressures waves). A cell phone does the same thing with microwaves.

2. Infrared telescopes have a major problem. If they are designed to detect heat, they cannot themselves be warm. Otherwise, they will simply detect the infrared light that the telescope itself radiates. Almost everything in the universe emits infrared light to varying degrees, from stars, interstellar dust and gas, to planets and things on the surface of planets, like living creatures - trees, animals and humans. We as people are at a temperature of 38ºC (98ºF), which means we radiate a lot of infrared radiation. You can see this being put to good use on cop shows where criminals are being chased using thermal imaging cameras! Because people are hotter than trees or buildings, they emit more infrared and stand out against “cooler” buildings and trees which also emit infrared. [Note:

people do not emit visible light – they are not hot enough. We can see people, as well as buildings, trees, the Moon and planets, because of reflected visible sunlight]

3. Introduce the ice cube tray. You are going to decipher a message using heat! The ice cube array is serving a dual function. First, you will be using it as a Braille reader, with the raised bumps in the Braille text representing pixels heated by infrared light. But an infrared detector is actually a square array of individual electronic detectors (as are the electronic detectors of most telescopes, and digital cameras) called pixels. As light from an object is focused onto the detector, the photons strike individual pixels. The picture of the object is built up as you look at the array of pixels and see where the photons have struck. The ice cube tray is the cold detector. Where the photons have struck, the pixel has heated up. In a real image you will be sensing the shape of a galaxy or nebula and not characters of an alphabet, but the principle is the same.

Depending on the size of your group and the number of trays you have available, you could create a hidden message in the cubes, or put a set of trays together and make a simple object outline in clay, such as a stick figure or triangle. This activity would be a perfect introduction to the tactile images in Touch the Invisible Sky, especially those from Spitzer, which would require a 256 x 256 ice cube tray!

Touch the Invisible Sky

In Touch the Invisible Sky, the second chapter introduces you to multi-wavelength telescopes, and how each is specialized to observe a particular part of the electromagnetic spectrum. Three of the featured telescopes, the Hubble Space Telescope, Spitzer Infrared Space Telescope and the Chandra X-Ray Observatory, are in space, while one, the VLA radio telescope, is on the ground. Two of the space-based telescopes, Chandra and Spitzer, are in orbit because the atmosphere blocks the type of light they are trying to observe. Hubble Space Telescope detects visible light, but is in orbit to get above the distortion of the atmosphere.

2. Size & Scale

The universe is vast, but in order to understand the objects we study, we need to know how far away they are. To help navigate such distances, we can divide the cosmos into three realms: The solar system of a star and its orbiting planets; The galaxy, a city of hundreds of billions of stars; The universe, a web of galaxies and galaxy clusters perhaps without end.

Activity 2A: The Scale of the Solar System

Scaling activities in the Solar System realm for students who are B/VI have been developed and tested.

Equipment:

An object to represent the Sun. A Wiffle™ ball is good for its tactile feel, and its holes are good for attaching the distance string. A bell allows B/VI users to hear how far the Sun is as they work their way out through the Solar System. Using a low wattage light bulb allows users to feel the warmth of the sun when they are close to it. A low wattage prevents anyone burning themselves, but also limits the distance that its warmth can be felt. A combination of these objects may be good, such as mounting a small bell within the Wiffle ball.

Beads to represent planets. These should be spherical, although you may find something interesting for Saturn in a bead shop. The relative sizes of the planets are not important here, but bigger beads for the gas giants and tiny ones for Mercury and Pluto add to the activity.

String or thread. The amount depends on the scale you use, and how many sets of solar systems you intend to build. Stringing the bead planets can be done pre-activity or as part of the activity.

This activity demonstrates the relative separations of the Sun and planets. To do this, it is necessary to exaggerate and approximate the relative sizes of the planets themselves, which would be microscopically small on this distance scale. Distances between the planets are marked out by a string. The advantage with using beads to represent the planets is that they can be easily strung at the correct relative separations beforehand. The table below gives the interplanetary distances in Astronomical Units, where 1 AU is the average distance between the Earth and the Sun, or 150 million km. With 1 AU scaling to 10 cm, the Solar System out to Pluto is 4.0m. The scale of the model can be changed to suit your group and how much space is available.

Planet	AU	Distance (cm)	Object
Sun	0.0 AU	0	ball, bell or bulb
Mercury	0.4 AU	4 cm	v. small bead
Venus	0.7 AU	7 cm	small bead
Earth	1.0 AU	10 cm	small bead
Mars	1.5 AU	15 cm	v. small bead
Jupiter	5.0 AU	50 cm	large bead
Saturn	10.0 AU	1.0 m	large bead
Uranus	19.0 AU	2.0 m	large bead
Neptune	30.0 AU	3.0 m	large bead
Pluto	39.0 AU	4.0 m	v. small bead

Procedure:

1. Tell the students that we are going to build a model of solar system. You could start the activity with a discussion on models. What is a model, and why are they important in science? A scale model such as this gives you an idea of the relative size and separation of the planets, but in order to do so, we have to make compromises and approximations. Firstly, the sizes of the Sun and planets are exaggerated greatly. At this distance scale, the Sun would be 1mm across (the size of a peppercorn), Jupiter would be 0.1mm in diameter and the Earth 0.01mm in diameter! In other words, all the planets would be smaller than the thickness of the string.

2. Start at the Sun, talk to the students about the location of the Sun at the center of the Solar System. 99.99% of the mass of the Solar System is the Sun. Ask the students which planet is closest to the Sun. Most will know that it's Mercury, but asking them to estimate its distance in this model won't work and the scale has not been defined for them. Unroll the string to the first bead. Here is tiny Mercury. If you are using the light bulb, the heat should be apparent at 4cm. The planets out to Mars will not yield any great surprise, but stop at Mars and ask if we're missing anything. Where is the Moon? Let the students run their fingers along the string, through the planets. How far from Earth will the Moon be? At this scale, the Moon is a tiny bead only 1.5mm from the Earth. This is how far humans have traveled in space! Feel how far Mars is in comparison.

This leads to the second approximation of the model. All the planets are in a straight line. In reality, they orbit the Sun and the radius of the orbit is represented by the string length out to that planet. Although the Moon never travels any further than 1.5mm from the Earth, Mars never gets any closer than 5cm from Earth and is usually much further (and as much as 25cm in this model). This is why human exploration of Mars is a much greater challenge than going to the Moon.

As you unwind the outer Solar System, let the students follow the string by touch. The distances now become huge in comparison, and that's why it takes so long to reach the outer planets. Talk about the Voyager spacecraft, and the New Horizons probe to Pluto, which has only just passed Jupiter. Remember that these spacecraft are chasing planets that are moving in orbits, so the bead solar system model, being one dimensional, does not capture the 2-dimensional expanse of the Solar system plane. How you address this depends on the level of your audience (see reference to Hurd & Runyon*, A tactile Guide to the solar system*).

Activity 2B. Distance to the nearest star

Equipment:
String or twine, the amount depending on the scale of your model and how many models you intend to build. In this example, you will need 200m. Put a marker or knot in the string at intervals of 5m, and one knot about 5cm along. At this scale, 5m represents 1 trillion (one thousand billion) km.

Two discs representing our Solar system and a second planetary system. Pieces of card 2 inches in diameter will work well, and raised dots on the disc (either using puffy paint or punching indents) can represent the planets in the disc. Two brass washers approx. 2 inches in diameter would also work. Two Oreo cookies are less practical but more interesting.

Procedure:
1. Recap with your students the vast scale of the Solar System, and how Pluto lies near the boundary of interstellar space (depending on available time, and the level of your audience, you can extend your discussion, and your Solar System, to include other Kuiper Belt objects or even the Oort cloud. Remember however that this is first and foremost a scaling activity designed to give students a feel and mental model of relative distances).

2. Ask your students to think about the distances to the stars. It is likely that some of your students have never seen stars, so an important pre-discussion will be needed to gauge each students internal models on what s/he perceive as the night sky and stars. Remind them that the Sun is a star, and therefore, all stars

are Suns, but obviously much further away. To get a feel for the distances to the stars, we need to shrink the scale of our model. We need to squeeze the entire solar system, out to Pluto, down into a disc 2 inches across.

Note that our experience shows that students of all ages and abilities have great difficulty making mental scale changes from one model to another. It is important to ensure that people are with you in one particular scale realm, and when scale change comes, do a Q&A to make sure you have everybody along. If you have more time, only do one scale realm in any session. If you can, give everyone a cardboard disc/washer/Oreo to hold to reinforce the scale change in their minds.

Even with our solar system shrunk to the size of an Oreo, we can only practically model the distance to the closest stars. Alpha Centauri is a star very similar to our Sun, and if it has planets (none have yet been found) then we can represent its solar system by a second disc/ cookie. How far apart should these cookies be?

3. Tell the students that we are taking a journey to Alpha Centauri. For this particular scale, the journey needs to take place out of doors, in a park or on some playing fields. Leaving our Solar System very quickly (Pluto is at the edge of the disc) we come across the first knot. At this scale, this is the distance that the Voyager spacecraft have traveled, after 25 years at 20,000 miles an hour! After 5m we come across the next knot, one trillion km. It takes sunlight light 3.5 days to travel out to this point. We keep walking, counting each know as 1 trillion km, until 40 knots, 200m or two football fields later, we arrive at the disc of Alpha Centauri's planetary system.

Note: This activity is a dramatic demonstration of interstellar distances, but may raise some logistical problems depending on audience and space available. Things can be scaled down even further, for example using a penny instead of a 2-inch disc to represent the solar system. However, there' s no getting away from the fact that it's a big distance!!

4. Despite the physical difficulties related to pacing out this considerable distance, it is only now that we begin to appreciate the vast difference between interplanetary and interstellar distances. How do these distances make you feel about the possibility of aliens visiting Earth from other stars? How easy is it to find planets around other stars?

5. Note that we have only journeyed to the closest star, about 4 light years away. We have only begun to explore the realm of our Milky Way galaxy, which is a city of 300 billion stars! Depending on the sophistication of your audience, you can make a rough estimate of the size of the Milky Way galaxy on this scale. By approximating the average separation of all the stars in the galaxy to 200m, our

galaxy will, on this scale, be a disc 25km thick and 2500km in diameter. A disc this size would cover a significant fraction of North America.

Activity 2C. Distance to the next Galaxy and the Edge of the Universe!

The third part of the scaling activity, the distance between the galaxies, is explored in Activity 5: Galaxies and the Size of the Universe.

3. Light and Energy

Practically everything we know about the universe is because of the light we receive. Light from the Sun and planets, from stars and galaxies even light from the Big Bang. The light is gathered by our telescopes and used to make sense of how our universe works. From light we can tell what an object is made of, how big and how far it is, its age, temperature, and how fast it's moving or spinning.

Light is also a form of energy, and there is a direct relationship between the energy of light, and its color (and wavelength). For the colors of the rainbow, blue light is high energy, and red light is low energy. However, visible light is only a small portion of the entire spectrum of light we receive from space, and being able to detect and study beyond the "visible range" has revolutionized astronomy.

This activity uses sound to learn about light. Light and sound are both waves, and although very different in many ways, we can use wavelength spectrum of sound to explore the electromagnetic spectrum of light. With sound waves, the pitch of a note is equivalent to the energy of a color. We can use this equivalence to "hear" colors.

Activity 3A. Hearing Colors

Equipment:

A Keyboard of some sort, such as a piano, electronic keyboard, xylophone or software such as Garage Band. A real keyboard is preferable, especially if the vibrating strings are exposed to be touched. The activity can be modified depending upon equipment available and the student's familiarity with notes and music.

(optional) Dog whistle

Procedure:
1. Have a discussion about light and sound. What have light and sound in common? Both are waves, and the more energy in a wave the shorter the wavelength. Waves show up all through nature, so there is something fundamental about waves. Light and sound are very different in other ways: sound is a pressure wave through a medium, such as air and through rock during earthquakes. Light consists of packets of energy, called photons, made up of electric and magnetic fields, hence their name electromagnetic radiation. Light

waves are “self-contained” which means they don’t need to travel through anything (so can pass through empty space).

2. This activity will allow the student to hear the colors of the rainbow, and beyond. The frequency of light is equivalent to the pitch of sound, and although the frequency ranges of audible sound and visible light are vastly different, we can construct a relationship between color and sound.

Human eyes break down the visible rainbow into six colors – red, orange, yellow, green, blue and violet. Each color represents a wavelength range, with the wavelength (pitch) of red being roughly twice the wavelength of violet. Using six keys on the keyboard, you can “play” the pitches of each color. Use the center of the keyboard, and either use six adjacent keys, or spread the six colors out to a full octave, say Middle C (which has the scientific designation C4) to Tenor C (designated C5).

3. Ask the students if they think they can hear higher or lower sounds than these played. The answer will certainly be yes. Play the notes again, starting with red, up to violet, then play the next note. Can you hear it? Keep moving up the scale. Our hearing range for sound waves is much broader than the human eye’s range for light waves. In our sound model of light, we are hearing ultraviolet light. Moving the other way down the scale past red, we are listening to infrared light.

Note: Playing the center octave of keys on a piano, C4=261.6Hz to C5=523.3Hz represents the visible spectrum, and the six colors are spread to include eight keys. The visible spectrum covers just under 1 octave: violet at 7.5×10^{14}Hz to red at 4.0×10^{14}Hz, whereas human hearing ranges about eleven octaves (20Hz to 20kHz). The electromagnetic spectrum however covers at least fifty octaves from the radio to gamma radiation; but with the visible region covering this amount of keyboard, the piano can only play near infrared to near ultraviolet.

Is there sound we cannot hear? It’s called ultrasonic. You can demonstrate this using a dog whistle (make sure there are no dogs around!)

4. [Note: This part of the activity requires someone who is able to play a keyboard, or be able to program a song into music software].
Because our color range is so limited, so was our ability to study the universe before the development of multi-wavelength astronomy. In this activity, we are going to model our understanding of a galaxy with our understanding of a song. The keyboard now represents the entire electromagnetic spectrum, such that the center three keys now represent visible light.

Name That Tune!
A well known song will be played on the keyboard, but only the keys in the visible part of the spectrum will be hit. If the song can't be named, the keys in the visible and infrared will be hit. If not, the ultraviolet keys will also be added.

Song examples:
Happy birthday
Chopsticks
Beethoven's *Für Elise*

To identify a song, and understand it, you need a broad range of wavelengths available to you. This is the same for light and astronomy!

Activity 3B. Line spectra

We now know that visible light is made up of white light, which is a combination 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.

What element is being played?

Procedure:
1. The line spectrum reveals the chemical composition of a gas. This is equivalent to specific individual notes being struck at the same time. White light is all the colors being played at the same time (demonstrate this, either by hitting all the notes at once, or running your finger up the scale). Now play the sound of an element. [You can either use the eight key range from Activity 1, or use a wider scale to highlight the pitch differences]. Just as with the white light sound, you can strike all keys at the same time (conceptually more accurate, but may be tricky to pull off) or play up the scale of notes (which sounds clearer and is easier to do).

The sound of Hydrogen

Hydrogen	wavelength	key
Purple	410	C4 (Middle C)
Blue	436	C4#
Green	486	E
Red	656	C5

The sound of Helium

Blue	448	D
Green	502	F
Yellow	588	A
Red	668	C5#

The sound of Oxygen

Blue	459	C4#
Green	493	E
Green	495	E
Orange	615	B

Play helium, then oxygen. Now choose one element to play. Can people identify the element? The combination of keys is the unique fingerprint of that element. Wherever hydrogen atoms are in the universe, they radiate with the same combination of lines/pitches. In this way, we can tell what the universe is made of.

Activity 3C. Doppler effect and redshift.

Equipment:
Plastic Wiffle-Ball™

Mini-speaker that emits a sound (these can be bought cheaply from an electronics store such as Radio Shack)

Battery for mini-speaker (usually 9V)

Foam padding to protect an enclosed mini-speaker

To create a Wiffle-ball shrieker the ball needs to be cut in half and held together with duct tape. It can therefore be easily opened and the speaker engaged just before throwing. Make sure the speaker itself isn't muffled by the foam padding, and that the battery is good. You can also wire in a switch to the battery/speaker circuit)

A very important effect for both sound and light waves is the Doppler effect. Most people have heard the effect as a police car goes past – the siren's pitch is higher as it approaches you, and then drops as the car recedes. This works for light too, and is how a police radar gun (radio waves) clocks your speed. In astronomy, Doppler shift is used to detect the motions of planets orbiting stars, and how fast galaxies rotate.

Astronomer Edwin Hubble in 1929 discovered that our universe is expanding. He determined that galaxies are racing away, and apart from each other by measuring the shift in the wavelength of light from the galaxies. Note that this particular shift to longer, redder wavelengths is not strictly a Doppler shift. The Doppler effect measures the speed of objects *through space*; the red shift Hubble discovered measures the speed of the expansion *of space.* As space expands, galaxies are carried along with it, mimicking (to close approximation) a Doppler shift.

Procedure:

1. Ask your audience if they have ever heard a police car or ambulance rush by. How can you tell the exact moment when it passes you? (You may get the answer that it's loudest when it's closest, which is also true). This audio demonstration is a very useful analog to the optical red shift and blue shift exhibited by astronomical sources moving relative to the Earth.

Remind students of the "sound" of hydrogen. Then play the same sequence redshifted.

Hydrogen	wavelength	key	redshift
Purple	410	C4	D4
Blue	436	C4#	D4#
Green	486	E	F
Red	656	C5	[D5]

Note that the red line note has moved out of the optical range of the spectrum. So if you only play the visible spectral lines, there will be no fourth note. When you play hydrogen at rest and hydrogen redshifted, ask what has changed. Depending on your audience, you may not even tell them it's hydrogen! This result is historically interesting, as when the first *quasars* (very bright, very distant galaxies) were discovered, their redshift was so great astronomers failed to recognize any of the lines!

4. Life & Death of Stars

Stars, like people, are born, live and die. Through their life and in their death, stars manufacture the raw materials for the next generation of stars, as well as planets and in at least one instance, life. The story of us begins with the story of stars.

Activity 4: How do stars work?

Equipment:

Balloons (as near spherical as possible)
30-35 cm sheets of aluminum foil (~3 per balloon)
Balloon popping device (pin, scissors, etc.)
(optional) ear protection

This activity models two basic aspects of stellar structure and stellar evolution
1. The balance between gravity and thermal energy that keeps a star like the Sun in equilibrium for 10 billion years.

2. The change that comes when a star no longer generates energy, and gravity's subsequent victory as the star collapses and dies. Both processes are complex in reality, but the basic principle is easy to understand with this simple demonstration.

Procedure:
1. Blow up several balloons (one for each volunteer) or invite your volunteers to blow the balloons up themselves. Tie off the ends when you/they are done.

2. Cover the inflated balloons with several sheets of aluminum foil. These layers of foil represent the outer layers of your "Model Star". Be generous with the foil and cover the balloon thoroughly. It works best if you use several 30-35 cm long sheets and wrap around at least twice.

3. Ask the students to squeeze their balloon with both hands. The balloon resists being squeezed, and doesn't want to get any smaller. Your hands are the "Crushing Hands of Gravity" trying to compress the star, which is also made of gas (hydrogen and helium instead of air). The star's gas doesn't compress because it is very hot and as such is trying to expand. The source of the heat is thermonuclear reactions at the core of the star, turning hydrogen into helium and releasing vast amounts of energy. The balance between the inward force of

gravity and outward thermal pressure keeps a star stable – constant size and brightness – for a very long period of time (in the case of the Sun, this balance has been maintained for five billion years, and without this long term stability, life on Earth would never have happened).

4. What happens when the nuclear fuel that is resisting gravity runs out? Prepare to end your balloon star's resistance to squeezing, using a pin! (Warn your audience that you are going to pop balloons – and earplugs are available!). Working in pairs, one partner holds the balloon between his/her hands, while the other pops the balloon through the aluminum foil. With no nuclear fuel to generate heat, gravity wins, and now, with only a little pressure, the foil can be squeezed down into a tight ball.

5. What is left? When a real star such as the sun runs out of nuclear fuel, the outer layers of hydrogen and helium are blown into space, while the core of the star, now made of elements such as carbon and nitrogen, are crushed down by gravity to a dense ball no bigger than the Earth (note that the Sun currently has a volume of a million Earths!) This dense, hot ball is called a white dwarf star, and is our Sun's destiny. So just as your balloon release its supply of gas as you popped it, so the crushed aluminum foil represents the dense, small white dwarf star that remains.

For stars much bigger than the Sun, the end is much more dramatic, but can be modeled in the same way. When the nuclear fuel is exhausted, the star dies in an immense explosion called a supernova. The outer part of the star is ripped away, while the core is compressed even further by the intense gravity. All that remains is a dense ball of neutrons no more than a few miles across (the size of a small city). This is called a neutron star.

Discussion:
All stars are in a constant battle between pressure and gravity during most of their life. In all cases, gravity will eventually win, but the final end state of a star's collapse is dictated by the original mass of the star. Notice that in both these cases – a white dwarf or neutron star, that gravity won, but not totally. Just like squeezing the ball of foil as tight as you can, gravity is resisted by the atomic and nuclear forces of the remnant. If the core mass is great enough even these forces cannot resist gravity, and the star's core (the foil ball) will be squeezed out of existence – a black hole!

Notes on the model:

1. A limitation of this model is that the aluminum foil initially represents the outer layers of the star, which in a supernova explosion are blown out into space. What collapses to form a white dwarf or neutron star is the core of the star, which is what the foil represents at the end.

2. On the scale of the balloon, both the white dwarf and neutron cores would be microscopic in size (or you can say the size of a tiny grain of salt). Interestingly, a red giant star in the last stages of its life has an average density less than your balloon full of air!

3. A star approaching the end of its life changes in size dramatically. In the case of the Sun, its volume will increase by a factor of a million (roughly 100 diameters). This red giant (or super giant in the case of high mass stars) cannot be included in this simple demo unless you have access to very large balloons!

Stellar evolution and the FETTU Exhibit

Visit the Crab Nebula panel. The Crab Nebula is the remnant of a supernova explosion which was visible from Earth in the year 1054. Originally called a nova because it was a new star in the sky, a supernova is the death of an old star. As you touch the visible image, you can feel the jagged outer edge of the nebula revealing the chaotic and violent nature of the explosion that ripped off the outer layers of a once majestic star. The nebula is still expanding outwards at 1500 kilometers per second, almost a thousand years after the explosion occurred!

Now touch the combined visible and X-ray image. You can feel the outline of the visible Crab. Move your finger towards the center of the image to feel the X-ray emission, a tilted ring of high-energy particles surrounding a tiny point source. Two jets of high energy particles are shooting outwards at two and eight o'clock. The source is called a pulsar, a rapidly spinning neutron star no larger than an average city, but spinning on its axis 30 times a second. As the neutron star spins it flashes its jets towards the Earth. This pulsar is the leftover core of the original supergiant star that exploded.

Stellar evolution and Touch the Invisible Sky

Touch the Invisible Sky features two supernova remnants. The Crab, described above, and Kepler's supernova remnant. Unlike the Crab, Kepler's remnant was formed from a star like the Sun, but under very special circumstances. As described in this activity, a white dwarf is the remains of a small star, like the

Sun, when that star runs out of nuclear fuel. The Sun will become a white dwarf roughly 5 billion years from now. If the white dwarf is alone in space, that's where its story ends. But if the white dwarf has a companion star, then its gravity can strip away the outer layers of the companion, cloaking itself in a thick layer of hydrogen gas. The layer of hydrogen around the white dwarf gets thicker and hotter, creating a ticking hydrogen bomb. When a critical temperature is reached, the white dwarf blows itself to pieces in a supernova explosion. Evidence suggests that Kepler's Supernova of 1604 was the white dwarf type.

5. Galaxies

Galaxies are cities of stars and the building blocks of the universe. They are also giant star factories in constant motion. Some galaxies, such as our own Milky Way, are magnificent spirals, others, called elliptical galaxies, are immense balls of stars like a swarm of bees around a honey pot. Some galaxies show no apparent shape of form, and are called Irregular galaxies.

Astronomers are still trying to figure out why some galaxies are spiral shaped, some are ellipticals and some are irregular. It may have something to do with the way they were formed, and how they evolve through interactions and collisions with other galaxies.

Activity 5A. What does a galaxy look like?

This activity helps define a galaxy, its structure and morphology, and the different classes of galaxy in the universe.

Equipment:
To make a spiral galaxy, you will need a CD or DVD (an old one or freebie you don't need to play anymore!).
puffy paint (Tulip® 3D Fashion Paints),
cotton balls
modeling clay, such as Play Doh®
galaxy image template, available for download at:
http://www.cfa.harvard.edu/seuforum/einstein/resources/JourneyExpand/JourneyExpandGalaxyTemplate.pdf

Making a spiral galaxy.
Conveniently, the dimensions of a typical spiral galaxy such as our own Milky Way, are very similar to a CD; both are 100 times as wide as they are thick. Start by printing out the CD labels containing an image of the spiral galaxy M74. You are going to stick one on each side of the CD. This is useful for the sighted user, but you can also use the spiral arms of M74 to apply the tactile arms to your CD. Apply the puffy paint along the spiral arm lines (leave one side to dry first before doing the other). Spiral galaxies have a spherical bulge of stars at their center. Take a cotton ball and stick it through the hole at the center of the CD. You now have a scale model of a spiral galaxy!

Making an elliptical galaxy
Elliptical galaxies are giant balls of stars, and are less interesting than spirals in look and touch. You can use a softball, orange or Styrofoam ball to represent spherical elliptical galaxies, and a mini football or grape for the more prolate shaped. Use modeling clay to make a flattened (oblate) sphere. Preferably, use a setting clay that can be handled without being deformed any further. Cotton balls work well for smaller elliptical galaxies.

Making an irregular galaxy
To make an irregular galaxy, distort or pull a cotton ball, or use modeling clay or setting clay to create an irregular shape, such as a warped disc or bent cigar shape. Another method could be to make a wireframe with pipecleaners and glue on cotton wool to make amorphous shapes.

Procedure:

1. What is a galaxy? People often confuse the differences and relationship between galaxies, solar systems and the universe itself. Some of this may be historical, and this could, with some audiences, be brought into the discussion. Indeed, only a century ago it was assumed that our Milky Way galaxy was the Universe, and during the era of Copernicus and Galileo, the Solar System also represented the majority, and certainly the center, of the universe.

If this activity follows on from Size and Scale, students will already have an idea of a solar system, the relative separation of stars, and that the Milky Way is a vast city of stars, almost inconceivably larger than a solar/planetary system. Let the students have a few moments to imagine a journey out of our solar system, traveling through the vast stretches of interstellar space before the arrival at even the closest star. Jump again to the next star and the next. All these stars, hundreds, thousands, billions, are part of one great city of stars called the Milky Way, and our Sun is just one of three hundred billion. Depending upon the location of your presentation, compare the Milky Way to your or a nearby city. Our solar system is located in the suburbs, a leafy neighborhood far from the hustle and bustle of downtown.

What does our Milky Way look like from the outside. We can't leave the galaxy, and, in fact, our Milky Way/City analogy, we humans have not even gotten out of the bedroom, let alone out of the neighborhood! But observations of the stars in the galaxy using many different types of telescope have let us map our galaxy and its shape.

2. Hand out the CDs and let the students explore the shape. Tell them we have had to squeeze down the entire Milky Way of 300 billion stars into the size of a CD. For the Milky Way, the dimensions are 100,000 light years across by 1000

light years deep; a CD is 12cm across and 1.2mm deep. At this scale, our entire Solar System is smaller than an atom!

As you touch the CD galaxy, you can understand why they are also known as disc galaxies. Most of the stars, including our Sun, reside in the disc plane. You can feel the lines of the spiral arms, which represent the locations of young hot stars that have only recently been born. The spiral arms mark the locations of pressure waves that move through the gas and stars of the galaxy, almost like sound waves move through air. The pressure waves squeeze the gas that sits between the stars, allowing gravity to collapse the gas clouds into new stars.

The Sun is about half way out to the edge of the disc, and sitting just off the crest of one of the spiral arms. Although CDs spin fast in their player (about 1.4m/s, galaxies spin faster – at 100 km/s! But because the Milky Way is so big, it take 200 million years to make one revolution (the Sun, being roughly 5 billion years old, has made about 25 orbits)

Apart from the disc, there is a spherical ball of older stars at the center of the Milky Way called the central bulge. Because the bulge is not affected by the spiral arms, no new stars are being made.

3. Galaxies come in different shapes and sizes, and only about half are the beautiful spirals like the Milky Way. We are going to examine models of other galaxy types, and then test a set of galaxies to determine their classification.

Elliptical galaxies. Hand around the elliptical galaxy models. Elliptical galaxies are giant balls of stars, some spherical, some squashed down almost as flat as spiral discs. The biggest elliptical galaxies are roughly the same size as spiral galaxies, but many (called dwarf ellipticals) are much smaller. If you use cotton balls to represent the smaller ellipticals, then the students may comment on the similarity between the dwarf ellipticals and the central bulge of a spiral galaxy. This is a good inference, as the stars and dynamics of the central bulge and some dwarf ellipticals are very similar.

Irregular galaxies. Hand around a model representing an irregular galaxy. As their name suggests irregular have no obvious shape, although by feeling the shape you may be able to discern an underlying form, perhaps a distorted disc or ball, that suggests this galaxy may have had a more regular shape in the past. This may indeed have been the case - irregular galaxies could have been spirals or ellipticals, and have been involved in collisions that have messed up their shape.

4. Galaxy classification. What type of galaxy is it? Lay out a set of galaxy models (try 5 or six). By feeling the shape of the galaxy, classify it as a spiral, elliptical or irregular. At the end of the activity, ask what features allowed you to make the classification. Depending upon your audience, you could add some jokers into the mix. Glue two CDs together with their discs inclined, or embed a CD in a Styrofoam ball. These represent colliding galaxies, but how would you classify them? Put out a CD with no spiral arms or bulge. Is this a spiral galaxy, or a very flat elliptical?

Galaxy classification is in fact an important task, and because so many new galaxies are being discovered by modern automated telescopes, astronomers have enlisted the public to help with the workload in the Galaxy Zoo project: https://www.galaxyzoo.org/

An extension of this activity could be to go to the Galaxy Zoo website, and using your modeling skills, build tactile 3D models of some of the galaxies in the images you see. Alternatively, print out the galaxy field image, and highlight the shape of galaxies using puffy paint or other raised media.

Activity 5B. How far are the galaxies?

This activity models the distance scale between galaxies, and by extension, the scale of the local and observable universe. It forms a natural extension to the size and scale models in Activity 2.

Equipment
2 galaxy CDs
String or thread

The Milky Way is 100,000 light years in diameter. The Andromeda spiral galaxy, which is a similar size, is 2 million light years, or 20 galaxy diameters, from the Milky Way. On the scale of our CD galaxies, 1 cm = 8300 lyr, so the separation of the Milky Way and Andromeda galaxy CD will be 240cm or roughly 8 feet.

Add a marker to the thread (either a knot or a bead) every 12cm representing 100,000 lyr or one galaxy diameter. Tie one end of the thread through the center of the Milky Way CD and the other through the center of the Andromeda CD.

Procedure:

1. How far apart are galaxies? What about the next closest spiral galaxy, called the Andromeda galaxy. Students may remember how far the nearest star was to the Sun within the galaxy, and make predictions of similar separations for galaxies.

2. Have two volunteers hold each of the galaxies. At 8 feet apart, they may be just beyond each other's reach. Can they estimate their separation by the loudness of the other's voice? Now let other students walk the separation between the Milky Way CD and Andromeda, counting off the light year markers (if students are working in pairs, then the galaxies will need to be clamped in place so the students can make the journey).

3. What are the student's impressions of the separation between, or distance to, the next galaxy. This separation between Andromeda and the Milky Way is quite typical. In fact, the distances between stars within a galaxy are proportionally much larger than the typical distances between galaxies [notice the phrase *proportionally larger* – interstellar distances are a few light years; galaxy separations are a few million light years). The relatively small separation means that galaxy collisions are very common, and is an important feature of galaxy evolution. Indeed, in about four billion years time, the Milky Way and Andromeda may well collide!

4. This activity could be extended to include other galaxies. Most notably, the Milky Way has two small satellite galaxies, called the large and small Magellanic Clouds. In your model, you can represent these by two small cotton balls located just 18cm above the disc of the Milky Way CD. Other galaxies that could be built into your scale model could be the spiral galaxies M33 and the Whirlpool Galaxy, which is featured in *Touch the Invisible Sky*.

5. How big is the universe?
This question is a natural extension of this activity, and is bound to be asked by someone! Amazingly, at this scale, the furthest galaxies we can detect are only several kilometers away, and the edge of the *observable universe* a mere 16 km [see note below for more advanced audiences] from our Milky Way CD. With this scale model of galaxies, the observable universe suddenly seems very finite! We do not know how much further the universe of galaxies extends, simply because light from more distant galaxies has not had time to reach us. It is without doubt much bigger than the observable portion, and may even be infinitely large.

Note: This value is calculated using the age of the universe, 13.7 billion years, so that the furthest we can see (the furthest light has been able to travel) is 13.7 billion light years. Strictly speaking, the region of space that emitted this light *was* 13.7 billion light years away when the light started its journey, but is *now* roughly 45 billion light years away due to the expansion of the universe. Taking this into account, the edge of the observable universe is 54km away in our scale model.

Galaxies and the FETTU Exhibit

Visit the Whirlpool panel. This features images of the Whirlpool galaxy in infrared and X-ray light. The Whirlpool is a spiral galaxy with a small companion elliptical galaxy. As you touch the infrared image, you can trace out the spiral arms that contain the brightest stars. The source of the infrared light is huge dust clouds between the stars, and marks the location of stellar nurseries where the next generation of stars are being born. As you touch the outline of the Whirlpool you come across a small companion galaxy at eleven o'clock. The companion contains little dust, and its infrared light comes from old, red stars.

As you touch the X-ray image of the Whirlpool, you will not detect the beautiful spiral arms that give the galaxy its name. Most of the X-ray emission coincides with the core of the Whirlpool and its companion galaxy. The X-rays are coming from heated gas that is falling into giant black holes at the centers of each galaxy. As you move around the image, you feel pinpoints of X-ray emission. These are called X-ray binaries, where a neutron star or black hole is closely orbiting a normal star and feeding off the star's atmosphere.

Galaxies and Touch the Invisible Sky

Two galaxies are featured in Touch the Invisible Sky. The Whirlpool described above, and the Antennae galaxy pair, so named because their distorted streamer-like spiral arms look like insect antennae. Initially two separate spiral galaxies, gravity drew NGC 4038 and 4039 together in a titanic collision. As described in this activity, galaxies are relatively close together, and interactions and collisions are a common part of a galaxy's history. The Antennae system gives us a glimpse of how the Milky Way and Andromeda may appear in five billion years time.

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http://imagine.gsfc.nasa.gov/docs/teachers/blackholes/imagine/page12.html

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