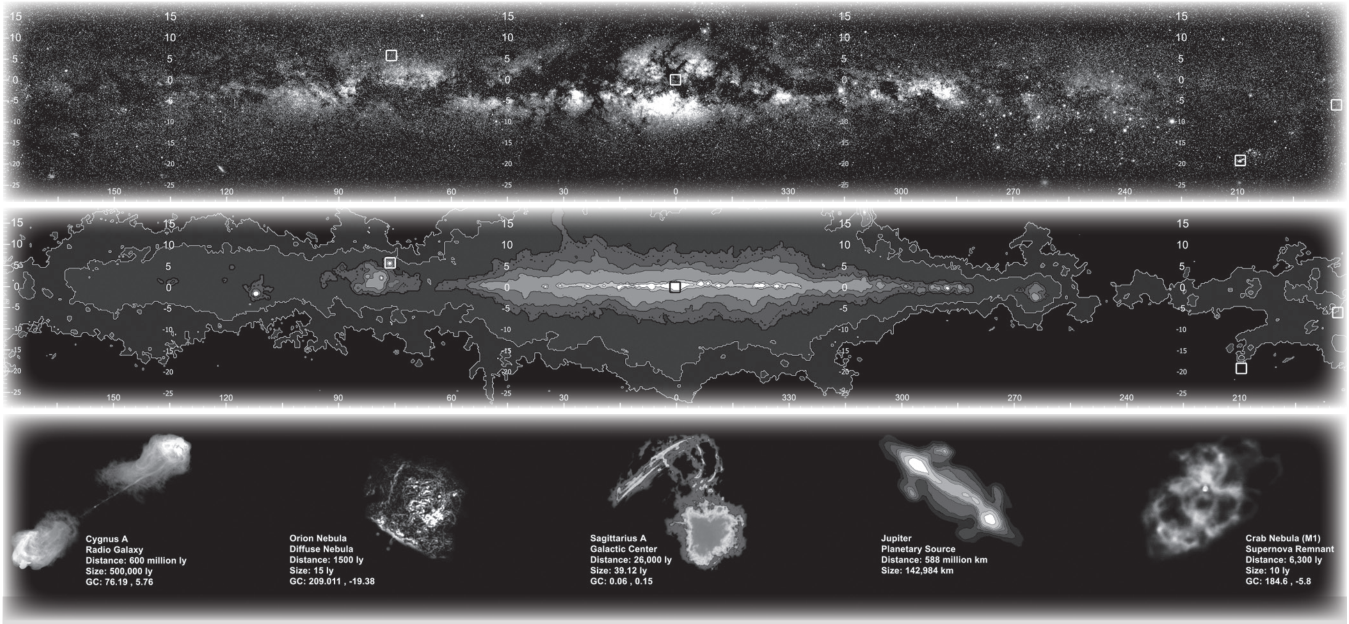

A Collection of Curricula for the STARLAB® Radio Sky Cylinder

Including:

Sensing the Radio Sky by Pisgah Astronomical Research Institute

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Curriculum Guide Contents

Sensing the Radio Sky Manual

This manual provides information fundamental to understanding the STARLAB Radio Sky presentation. Enclosed in this manual, teachers will find:

- Background information about radio astronomy (page 4)
- Script to be read inside the STARLAB (page 7)
- Teacher Lesson Plan (page 12)
- Student activity to be completed during and after the STARLAB presentation (page 13)

The enclosed background information in this manual must be presented to students before they enter the STARLAB planetarium (in order for students to understand exactly what they are seeing inside the planetarium).

Additionally, the Radio Sky Cylinder package is supplemented by the Radio Sky Web page, http://campus.pari.edu/radiosky/, with instructional material and illustrative, interactive diagrams designed to teach students about numerous aspects of radio astronomy. It is strongly recommended that teachers take advantage of the material on the Website. The material that is included in this manual necessarily needs to be presented to students before the STARLAB presentation, and the Website is supplemental and strongly recommended.

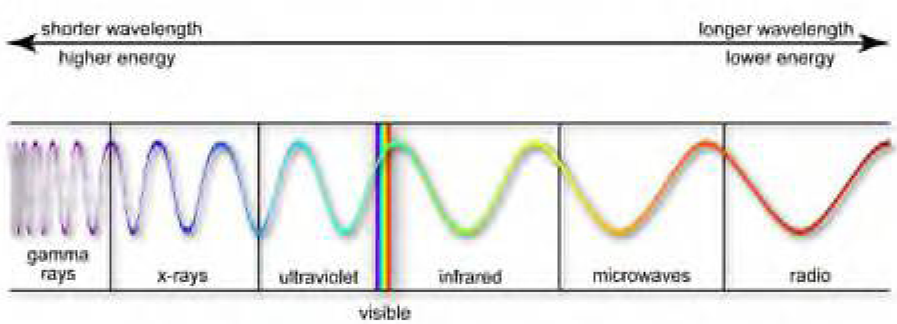
Introduction and Background Information

Waves

Waves are a fundamental area of study in science since they are constantly occurring in the natural world. There are two basic forms of waves in nature: **mechanical waves** and **electromagnetic waves**. Mechanical waves are more familiar to us in everyday experiences. Some examples of mechanical waves are waves on water, sound waves in air, and fields of wheat waving in the wind. Each of these waves requires a **medium** through which to travel. Without the ocean, there would be no ocean waves. Without wheat, the wind could not blow waves through it. Mechanical waves are also subject to one more limitation. Their wave velocity cannot equal or exceed **the speed of light in a vacuum (c = 300,000 km/s)**. Electromagnetic waves are special because they do not require a medium (they can travel through both vacuum and matter), and these waves all travel at exactly the speed of light in a vacuum.

Visible light is the most familiar type of electromagnetic wave, but many other types of electromagnetic waves exist. Gamma rays, X-rays, ultraviolet light, visible light, infrared light, microwaves, and radio waves are all types of electromagnetic waves (also called radiation). Collectively, these types of electromagnetic waves make up the **electromagnetic spectrum**. The only differences between these types of waves are their wavelengths (the distance from one crest of a wave to the next crest, or one trough to the next trough).

The wavelength of radiation influences its energy. Shorter wavelength (higher energy) forms of electromagnetic waves, like gamma rays, X-rays, and ultraviolet rays, are harmful to living creatures, while longer wavelength (lower energy) forms, like radio waves, are not. It should be emphasized, however, that the distinctions between types of radiation are not exact. There is much overlap between categories. The diagram above is a continuous spectrum of electromagnetic radiation.



Optical Astronomy and Radio Astronomy

Many celestial objects emit radiation from all parts of the electromagnetic spectrum, and modern astronomers study all of these types of radiation. However, only two types of astronomy can be performed accurately from Earth: **optical astronomy** and **radio astronomy**. Optical astronomy is the study of visible light emitted by celestial objects (light with a wavelength between 400 and 700 nanometers). Radio astronomy is the study of radio waves emitted by celestial objects (radio waves have a wavelength of 1/10 meter or longer).

Radio Telescopes

Note that common usage of the word "radio" brings to mind the device in your car that allows you to hear music, voices, and other sounds, but the car stereo does not allow you to hear radio waves. Instead, the antenna on your car receives electromagnetic radio waves, the information about the sound is extracted from the radio signals, and your speakers change the data that was sent over electromagnetic waves into mechanical sound waves which vibrate your ear drum. Astronomers use a similar process to observe the universe at radio wavelengths. Their telescopes receive radio waves from celestial objects. These waves are then converted into data that computers display, allowing the astronomers to create either a visible or audible representation of the data they've collected. If you were to convert radio data to audible forms, the sound produced is white-noise static, similar to the sound you hear when you tune your radio to a spot between stations. The static gets louder if the telescope is pointed directly at a strong source of radio emission.

Radio telescopes most often look similar to the satellite dishes you may have seen by peoples' homes. They usually consist of a large, rounded **dish** which collects radio waves and focuses them to the **antenna**. The radio waves are then transmitted to a **receiver**, which amplifies the signal before sending it on to be processed and displayed on a computer.

Radio Images

A radio telescope is like a one-pixel camera capable of recording only the intensity in the direction the telescope is pointed. Rather than having an optical picture of the source, we receive a voltage corresponding to the **intensity** of the radio source. If you point a radio telescope at different locations while measuring voltages, you can map out the intensity of the sky, one "radio pixel" at a time.

Images from radio observations are often depicted as contour maps, resembling topographical maps. Since radio waves are not visible, it is difficult to create comprehensible images of radio sources. Astronomers overcome this problem by assigning different colors to the different levels of measured intensity. More intense radio sources release more energy and have higher voltages. These high intensity sources correspond to the brighter colors on a radio map (with yellow and white representing the most intense sources). Less intense sources have a lower voltage and correspond to cooler colors (usually blue) on the radio map. By creating maps of radio sources we can observe their sizes and structures.

Radiation in the Milky Way

The Milky Way, our galaxy, is one celestial object that we can map with the radio waves that it emits. The map of the Milky Way that you will see in the STARLAB shows a type of electromagnetic radiation known as **synchrotron radiation**. Synchrotron radiation is produced when a free charged particle accelerates around a very strong magnetic field. This particle must be traveling at close to the speed of light for synchrotron radiation to be emitted. The view shown in the STARLAB is a low-resolution radio image of our galaxy. Therefore, distinct sources are not readily apparent, but instead a halo of emission appears in regions rich in cosmic ray electrons and protons in strong magnetic fields. Cosmic rays are actually particles with incredible amounts of energy. Most scientists believe their origins lie in the aftermath of supernovae, or explosions that occur when massive stars die. These particles encounter strong magnetic fields around cosmic objects and begin circling them and accelerating in ever–widening spirals. When this occurs, the particles emit synchrotron radiation. It is this synchrotron radiation, generated from the charged particles of cosmic rays, that produces the radio waves we will see imaged in the STARLAB.

An electron, moving at relativistic speeds (near the speed of light) begins to spiral in the presence of a magnetic field (represented in this diagram by a series of field lines). As it spirals, the electron emits cones of synchrotron radiation.

What you will see in the STARLAB is a map of the intensity of synchrotron of radiation in our galaxy. The galactic center, having much more matter with magnetic fields, will emit more radiation than the periphery, or edges, where there are fewer magnetic fields for particles to spiral around. The brighter areas shown in the STARLAB generally have more intense magnetic fields and therefore trap more particles, giving off more intense radiation. Likewise, at the dim edges of the galaxy, there are very few sources to trap cosmic rays and produce radiation. So, we detect fewer radio waves from the edges of the Milky Way.

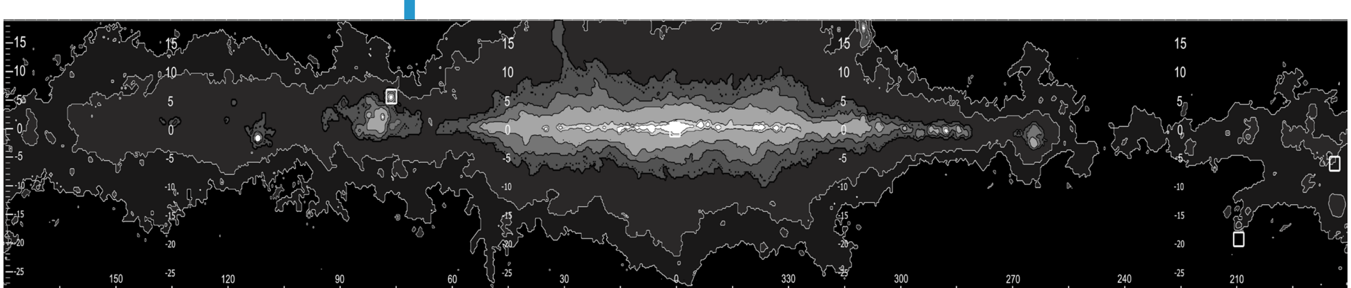
Galactic Coordinates

Astronomers have developed a way of measuring location within our galaxy. They use a system of **galactic coordinates** to identify the locations of different objects. Galactic coordinates are a special set of latitude and longitude lines. The Milky Way has a flat, spiraled disc shape. Zero degrees **galactic latitude** goes right through the center of the disc, parallel to it. This plane bisecting the galaxy is called the **galactic plane**. Objects located above the galactic plane have positive galactic latitude coordinates, and objects located below the galactic plane have negative galactic latitude coordinates. Galactic latitude measures from -90° to +90°.

Imagine that we are floating in space in the Milky Way, somewhere in the vicinity of Earth. We have made the Earth, the Moon, the Sun, and all of the planets transparent so that we can look out into our galaxy and get a clear view of all the stars in it. If we could do that, we could see the galaxy at every **galactic longitude**. Galactic longitude lines run perpendicular to the plane of the galaxy. Zero degrees galactic longitude runs straight through the galactic center, perpendicular to the galactic plane. If we are facing the galactic center from our point in space, zero degrees galactic longitude is directly in front of us, and 180° galactic longitude is directly behind us. Galactic longitude measures from 0° to 360°.

Galactic coordinates help astronomers to locate objects within the galaxy from our perspective here on Earth. Unfortunately, they do not provide a way to know how far away an object is. An object could lie perfectly at 0,0, but its coordinates do not tell us if it is located at the galactic center, on the far edge of the galaxy, or six inches from the end of our telescope. Astronomers have other techniques to precisely locate an object in three-dimensional space.

Imagine that there are galactic longitude lines printed on the inside of a cylinder, and the point in space where you have been observing from is at the center of the cylinder. There are lines marking galactic latitudes that run perpendicular to the galactic longitude lines. Now, if someone were to take an enormous pair of scissors and cut down the zero longitude line, we could uncurl the cylinder and lay it flat, making a kind of map of the galaxy. You will be using a map like this in the following activity.



Cylinder Script

This script is a guideline for the Sensing the Radio Sky presentation in the STARLAB planetarium. Presenters may read it directly to students as a script, but may also feel free to use it as a guideline for material that should be covered during the in-dome presentation.

The class should enter STARLAB planetarium and be seated around the outer edge of the optical Milky Way sleeve on the cylinder. The cylinder should be in an upright dome. The red lights should be on as the class enters. The presenter should begin with position. Please note that it will take some time for the students' eyes to adjust to the dark (up to 10 or 15 minutes if they enter the STARLAB after being in bright sunlight). Once the class is settled in, the presenter should dim the red lights, turn on the projector light, and begin the presentation.

Hello, and welcome to the STARLAB. Today you will learn about the night sky, and specifically our galaxy, the Milky Way, but in a way you've probably never seen it before. You may have seen the Milky Way if you've ever gone to a place far away from any city lights, cars, homes, shopping centers, and other sources of light pollution and looked up at the night sky. It looks like a fuzzy band of stars stretching overhead.

The Visible Milky Way and the STARLAB Perspective

In actuality, the Milky Way is a spiral-shaped galaxy, and our Solar System is in one of the arms of the spiral. If you were to get in a spaceship and fly from your position here on Earth to a point many light years above the Milky Way, you could look down at our galaxy and see this spiral shape, with several arms swirling around a dense center. If you then pointed your spaceship back down towards the plane of the galaxy (the galactic plane, as astronomers call it) and flew to a spot within the disc, this is what you would see. If you look in this direction, you are looking towards the center of the spiral. [Gesture with pointer towards the galactic center, where Sagittarius A is located]. *If you turn around and look in the opposite direction, you are looking out towards the edge of the spiral.* [Gesture with pointer towards the edge of the galaxy, across the dome from Sagittarius A].

As you can see, our galaxy contains hundreds of billions of stars. These stars are more densely clustered towards the center of the spiral than they are at the edge. Each one of these stars before you is emitting electromagnetic radiation in the form of visible light waves. Visible light waves, if you recall, have wavelengths between 400 and 700 billionths of a meter, and it is these wavelengths that human eyes are sensitive to. There are more things than just stars that emit visible light, though. Astronomers can also study objects like nebulae and even other galaxies with their optical tools.

Take a minute to look around at the Milky Way, and remember any bright spots or dark spots that you notice. On your activity sheet, keep track of where they are in the galaxy. You may want to write down approximate coordinates to help you remember any spots that stand out to you. Pay special attention to the locations marked by boxes. Which ones have a bright object in them? Which ones are dark? Which ones just look like more stars? Make some notes to yourself about which ones are which. Astronomers spend hours and hours making observations about certain spots in the sky, just like you are doing quickly right now.

Allow students a minute or two to complete question 1 under "Experimentation and Data Collection" on their activity sheets.

But not all astronomers are optical astronomers. Some astronomers are radio astronomers, which means that they study the radio wavelengths emitted by objects in our universe. Radio wavelengths are 1/10 of a meter or longer, which means that they are much longer than visible wavelengths. Since our eyes are not sensitive to these long wavelengths, radio astronomers use special radio telescopes to study the radio waves emitted by objects in space. In a minute, we are going to look at the Milky Way again, except we will see it as radio astronomers see it with their telescopes. What do you think it will look like overall? Will it have bright areas and dark areas, or will it all look the same? If it does vary in brightness, will the same bright and dark spots be present in the same places? Will the locations marked by boxes look the same way? Take a minute and write down some hypotheses about the Milky Way in radio.

Presenter should dim the white projector light, remove the optical Milky Way sleeve, and replace it with the radio Milky Way sleeve. The radio sleeve should be in the same orientation as the optical sleeve (the galactic center should fall in the same place on the dome). The cylinder should still be in an upright position.

The Radio Milky Way

What you see here is the same view of the Milky Way that you just saw, except this is how you would see it if your eyes were sensitive to radio wavelengths. Again, the center of the galaxy is over here [gesture with pointer towards Sagittarius A with the pointer], *and the edge of the spiral is over here* [gesture with pointer towards the opposite wall of the dome]. *Does the radio Milky Way look the way you thought it would? Take a minute to write down some notes about things you see that you expected, and write down some things that look different than you thought they would. Are the bright and dark spots that you picked out in the visible Milky Way the same spots that are bright and dark in the radio Milky Way?*

Allow students a minute or two to complete question 2 under "Experimentation and Data Collection" on their activity sheets.

As you can see, some areas of the galaxy are brighter in radio than in others. This means that the radio waves coming from the brighter parts are more intense, or stronger, than the radio waves coming from the darker parts. The strongest radio emission, shown here in white, comes from a band near the center of the galactic plane. As you look further up or down, away from the plane of the galaxy, the image becomes darker shades of gray. This means that the radio waves being emitted further from the plane are less intense. This is because most of the matter in the galaxy is clustered close to the galactic plane, so there are more objects there to emit radio waves than there are further from the plane.

You have probably noticed some things about the radio Milky Way that were not present in the optical Milky Way. Astronomers often find features of objects in one part of the electromagnetic spectrum that are not apparent in other parts of the spectrum. The most noticeable radio feature of the Milky Way is the North Galactic Jet [gesture with pointer towards the jet, near the top of the dome]. *Astronomers do not know for certain what caused this jet, but one theory is that the Milky Way used to be an active galaxy. This means that there was once an active black hole in the center of our galaxy that pulled in tons of surrounding matter. As this matter got pulled into the black hole, it emitted radiation. This emission resulted in two enormous jets of radiation coming from the black hole, with one jet going out the top of the galactic plane and one going out the bottom of the galactic plane. For some reason, this black hole became less active, so not as much matter was pulled in and not as much radiation was emitted. This jet that we see in radio, but not in visible light, might be a remnant of the huge jet that once came from the center of our galaxy.*

Now, take your coordinate sheet and use the galactic coordinates provided to locate the objects on your sheet. Make notes to yourself about where each object is located. [Give students a few minutes to realize that these locations are the ones marked with boxes.] *Do these objects look the same in radio wavelengths as they did in visible wavelengths? Write down notes about which objects were noticeable in which wavelengths. Were any objects noticeable in both sets of wavelengths?*

Allow students a minute or two to complete question 3 under "Experimentation and Data Collection" on their activity sheets.

Presenter should then tilt the cylinder so that the close-ups of radio sources are visible on the dome.

Radio Sources

These are close-up radio images of the sources you just located. Each one of these sources is an example of a type of object that radio astronomers often study. All of these sources emit synchrotron radiation, which is radiation from charged particles spiraling around magnetic fields at close to the speed of light.

Depending on the way the cylinder is tilted, sources may appear in a different order than they are listed here. Presenter should read the appropriate paragraph at the appropriate time.

Sagittarius A

Sagittarius A is a bright radio source at the center of our galaxy, located approximately 29,000 light years away from Earth. Astronomers can tell that it is an extremely dense, extremely compact object. It has the mass of three million suns in a sphere with a diameter smaller than the distance between the Sun and the Earth. Scientists think that Sagittarius A may be the black hole that was once responsible for our galaxy being active.

Cygnus A

Cygnus A is a radio source outside of our galaxy. It is, in fact, a galaxy itself, located about six hundred million light years away. Cygnus A is an example of a currently active galaxy. It has a compact object like a black hole in its center that is pulling in matter. As the matter is pulled into the compact object, it emits radiation that forms the two jets you see coming from the center of the galaxy. When that radiation runs into clouds of interstellar gas and dust, it slows down and spreads out to form the two lobes you see here.

The small dot you see in the center is radio emission from the only part of the galaxy that is noticeable in visible wavelengths. The two enormous jets are not present in visible wavelengths at all! As you can see, the radio jets are much larger than the optical component of the galaxy. The optical component of the galaxy is approximately one hundred thousand light years in diameter, but each lobe is three million light years wide and extends fifteen million light years from the center of the galaxy! Astronomers think that our own Milky Way may once have been an active galaxy just like this one. Without radio astronomy, we would never be able to know about these jets, and certainly would not be able to learn about our own history from them.

Crab Pulsar

This is the Crab Nebula. It is located in the Milky Way, about 6,300 light years from Earth. It is a supernova remnant from a star that exploded in the year 1054. Ancient Chinese astronomers kept very good records of this event, so we are able to learn a lot from this recently dead star.

The bright spot in the center of the Crab Nebula is the Crab Pulsar. Since the Crab Pulsar *is so young, it is still emitting radiation across the entire electromagnetic spectrum, and was the first pulsar to be observed in visible wavelengths.*

A pulsar is a type of neutron star. Neutron stars form when a star with eight to fifteen times the mass of the Sun explodes in a supernova, and the remaining core of the star condenses all of its protons and electrons into neutrons. Neutron stars are very small and very dense, and they rotate very quickly. These dead stars are thought to be between ten and fifteen kilometers in diameter, or only about the size of a small city. However, they contain approximately as much mass as the Sun! Neutron stars have extremely strong gravitational fields and very strong magnetic fields. Charged particles accelerate through these strong magnetic fields and emit radiation. This results in two beams of radiation coming from the neutron star, one from each magnetic pole. The poles of the magnetic field do not always line up with the neutron star's axis of rotation, though. This means that as the neutron star rotates, the beams from the magnetic poles sweep across the sky, like the beams of a lighthouse. When one of these beams passes by us here on Earth, we detect a brief increase in the radiation coming from that spot in the sky, or a radio pulse. When a neutron star behaves this way, it is called a pulsar.

The Crab pulsar has a frequency of approximately 30 Hertz (Hz), which means that it rotates approximately 30 times each second. Pulsars are some of the most accurate clocks in existence, slowing down only millionths of a second each year at most. They are more accurate than the best atomic clocks here on Earth.

Orion Nebula

The Orion Nebula is a diffuse nebula, or a widely-spread cloud of gas and dust. It is approximately 1,500 light years away, but still in the Milky Way. From our point of view here on Earth, it lies in the constellation Orion, and is the brightest diffuse nebula in the night sky when viewed in optical wavelengths. This is an image of the Orion Nebula in radio wavelengths. Studying the radio waves emitted from this nebula allows us to learn about the star formation regions that lie within it. The gas and dust that make up the nebula block visible wavelengths of light from deep within, so we need to use other kinds of astronomy to learn about the processes of star formation.

Jupiter

Although not marked on our image of the galaxy because it moves around in the sky from our point of view here on Earth, Jupiter is the brightest planetary radio source currently known. It is the only planet that emits synchrotron radiation, or radiation from accelerating charged particles traveling near the speed of light in a magnetic field. Jupiter's moon Io emits tons of charged particles into Jupiter's strong magnetic field. These particles accelerate in that field to emit radiation. As you can see, Jupiter's radio emission looks very different from its optical appearance. The two spots on either side of the planet are cross-sections of a ring of plasma along Io's orbit that surrounds the planet.

Presenter should tilt cylinder back upright and allow students to again view the radio image of the Milky Way.

Although the Milky Way is the brightest radio source in our night sky, it is not the most interesting object to study in radio. It is only so bright because it is so close to us. Radio astronomers spend a lot of their time studying objects outside of our galaxy. Although these objects are so far away that they only appear as specks on our radio map of the sky, they offer far more information, and present opportunities teach us about our own Solar system, our galaxy, and our universe.

Through radio astronomy and other types of astronomy, we can learn things that optical astronomy cannot show us. Telescopes that are sensitive to wavelengths across electromagnetic *spectrum have led to developments across all of science, and present rich opportunities for science in the future. Radio astronomy is just one tool that allows us to see the universe in a whole different light.*

Lesson Plan for Teachers – Sensing the Radio Sky

Suggested Grade Levels: Grades 9-12.

Goal

Engage in the process of scientific inquiry in order to develop an understanding of radio astronomy.

Objectives

- Describe the basic differences in radio and optical astronomy.
- Identify optical and radio images of the Milky Way from the galactic plane perspective.
- List several different sources of radio emission.
- Understand the process of scientific inquiry and the scientific method.

Educational Standards

This lesson highlights some components of the National Science Education Content Standards:

- Standard A: Science As Inquiry
- Standard B: Physical Science

Background Information

Unlike optical astronomy, radio astronomy is difficult to understand intuitively. Consequently, background information about radio astronomy is provided in following pages of this manual, as well as on the Radio Sky Web page, http://campus.pari.edu/radiosky/.

Procedure for Teaching

1. Provide students with background information about radio astronomy. Background information necessary to understanding the STARLAB presentation is provided in this manual. This background material can be taught in an approximately one-hour lecture. Additionally, supplementing the Radio Sky Cylinder is the Web page with interactive animations, activities, and images to instruct students about radio astronomy. Lesson plans on this Website can be used in classroom, or individually viewed by students with computers.
2. Explain the concept of galactic coordinates (explanation is available in Background Information in the manual, on page 6). Instruct students to complete the galactic coordinates activity, in order to develop their understanding of the galactic plane perspective prior to entering the STARLAB. Understanding the galactic plane perspective is imperative to understanding the image of the radio Milky Way that is projected in the STARLAB.
3. Enter the STARLAB and read the Radio Sky script, located on page 7 of the manual (or teachers can use this script as a guide for your own presentation in the dome, being sure to cover the same material). Prompts in the STARLAB script will aid teachers in instructing students about how to complete the lab write-

Materials

- STARLAB Portable Planetarium
- LED pointer
- Radio Sky Cylinder with Optical and Radio Milky Way sleeves
- Student activities worksheets (galactic coordinates worksheet and student lab write-up worksheet)
- Supplemental materials from the Radio Sky Web page, http://campus.pari.edu/radiosky/

up activity (informing students of when they should take notes and what they should write down).

4. Exit the STARLAB and instruct students to complete the remaining questions in their lab write-up exercise.

Name____ Date_____________________

Student Activity — Sensing the Radio Sky with the Scientific Method

The process of scientific inquiry is most commonly performed using the scientific method, a series of steps that scientists use to create and to test a hypothesis. Through the STARLAB experience, we will go through all of these steps in order to learn about the radio sky.

The scientific method includes 7 steps:

1. Research background information.
2. Identify the problem.
3. State your hypothesis.
4. Decide on procedure.
5. Perform the experiment and collect data.
6. Analyze the results.
7. Form a conclusion.

Research Background Information

When performing a scientific experiment, you first must research and gain knowledge about the subject.

Through the STARLAB Sensing the Radio Sky experience, you will learn about radio emission from the Milky Way galaxy. However, before collecting any data, you must understand several basic topics about radio astronomy.

Before entering the STARLAB, you learned about the following topics:

- The electromagnetic spectrum
- The differences between radio and optical astronomy
- How objects in space emit radiation
- The coordinate systems that astronomers use to study the sky (specifically galactic coordinates)

After learning this material, you have a sufficient background in radio astronomy to allow you to identify a problem.

Identify the Problem

Why do scientists study radio astronomy? Optical images are easier to understand intuitively and more aesthetically pleasing. What can radio waves tell us that optical waves cannot? What are the differences between a radio image and an optical image of the sky? What appears in radio images that we cannot see in optical images?

All of these questions are important to consider. For our experiment, we will address the following specific question:

Will our galaxy, the Milky Way, and other specific sources of radiation within our galaxy and other galaxies appear similar in optical and radio wavelengths?

State Your Hypothesis

Now it's your turn to decide. While viewing the optical image of the Milky Way in the STARLAB, form a hypothesis by answering the following question:

Will the radio sky look similar to the optical sky? Will the Milky Way look similar in radio and optical wavelengths? Will the same objects and features be noticeable in visible and radio wavelengths?

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Name____ **Date**________________________

Decide on Procedure

We will go through each of the following steps in our procedure:

1. Enter the STARLAB.
2. View the optical image of the Milky Way, record your hypothesis, and note some features of the optical Milky Way.
3. View the Milky Way at radio wavelengths.
4. Note some differences in the radio and optical Milky Way images (you will be asked to record some information about these images while inside the STARLAB).
5. Locate the 5 radio sources in the Milky Way.
6. View the 5 enlarged radio sources in the STARLAB.
7. Record data describing these sources and their locations in the Milky Way.

Experiment and Collect Data

These questions should be completed inside the STARLAB.

1. Write some brief notes describing the optical Milky Way. Are any spots particularly noticeable to you? What do you notice about the locations marked by boxes?

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2. Write some brief notes describing the radio Milky Way. Does it look similar or different to the optical Milky Way? Do the spots you noticed in the visible Milky Way look similar or different in radio? Do the locations marked by boxes look similar or different?

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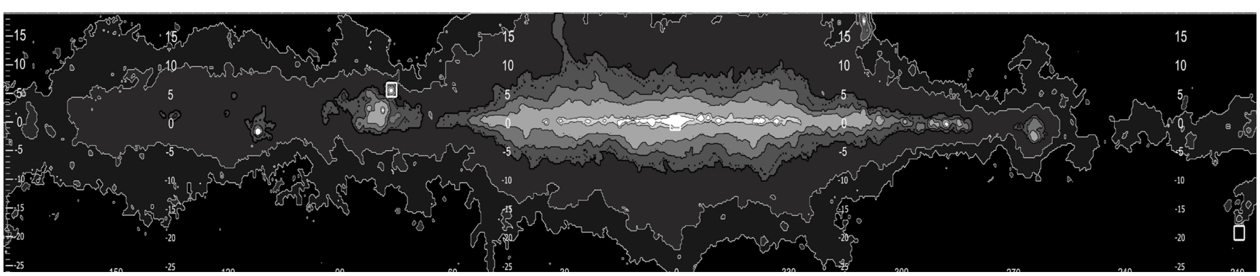
3. On your coordinate sheet, use the galactic coordinates provided to locate each of the 5 radio sources.
   a. On the radio map of the galaxy, note where each object is located.



Name____ **Date**________________________

b. Do these objects look the same in radio wavelengths as they did in visible wavelengths? Which radio sources were noticeable in the Milky Way image in optical wavelengths? In radio wavelengths? Were any objects or features noticeable in both radio and optical wavelengths?

Analyze Results

Answer the following questions once you have left the STARLAB and returned to your classroom, referring back to the data you collected while in the STARLAB.

1. What were some similarities between the optical and radio Milky Way images?

2. What were some differences between the optical and radio Milky Way images?

3. Which of the 5 radio sources did you find most interesting? Why did you find it interesting?

4. Compare the radio image of Jupiter with the optical image that you are familiar with. What did you learn from viewing the radio image that you could not learn by viewing an optical image of Jupiter?

Form a Conclusion

Was your hypothesis correct? What did you learn through the STARLAB experience about the radio and optical radiation from the Milky Way galaxy?

Further Activities (Optional)

Now that you are familiar with radio astronomy and understand similarities and differences between the radio and optical sky, you can continue to use the scientific method to learn more about these subjects.

Research one of the 5 radio sources, Cygnus A, the Orion Nebula, the Crab Nebula, Sagittarius A, or Jupiter. Find gamma ray, x-ray, optical, infrared, and radio of this object. Does this source appear different in each set of wavelengths? Explain.