Title:	**Arecibo's Giant Mirror**
Initial Version Revision:	3 December 2008 28 April 2010
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Appropriate Level:	High School Physics, Astronomy
Abstract:	Students perform a series of guided activities that illustrate the basic workings of a radio telescope. The activities focus on two aspects of a radio telescope: 1) the relationship between the size and curvature of the dish and the signal intensity 2) the analysis of individual signals.
Time Required:	Two 40 minute lab periods
NY Standards Met:	Performance Indicators • 4.3b Waves carry energy and information without transferring mass. This energy may be carried by pulses or periodic waves • 4.3g Electromagnetic radiation exhibits wave characteristics. Electromagnetic waves can propagate through a vacuum. • 4.3h When a wave strikes a boundary between two media, reflection (can) occur.
Special Notes:	This activity assumes knowledge of: • light frequency ($c = f\lambda$) • the law of reflection • the difference between real and virtual images in curved mirrors Photodiode set-up design and construction: Martin Alderman Created by the CNS Institute for Physics Teachers via the Nanoscale Science and Engineering Initiative under NSF Award # EEC-0117770, 0646547 and the NYS Office of Science, Technology & Academic Research under NYSTAR Contract # C020071

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Cognitive Objectives:
Upon completion of this lab activity, students should be able to:

- Describe the relationship between the focal point and the radius of a spherical mirror
- Explain how a spherical mirror may be used to monitor very weak radio signals from space
- Describe how colored filters may be used to select specific frequencies of light signals received by a detector and explain how this is a model for signal processing at a radio telescope facility.

Class Time Required: 80 minutes for main lab activities

Teacher Preparation Time: Minimal. Setting out materials and background reading.

Materials:

- 6" plastic ruler
- semicircular refraction dish
- mirror tape (taped on the inside curve of refraction dish)
- powdered milk
- coffee stirrer
- aluminum roofing nail, 1 ½"
- red laser pen
- wooden holder for laser
- drawing compass
- mini remote control
- PVC pipe, 7" for remote control holder
- 30cm spherical mirror
- set of hardware – one bolt, nut, wing nut, small and large washer
- radio telescope photodiode set-up on aluminum rod
- wooden telescope stands
- test photodiode set-up – photodiode with monoplug
- mini-amplifier
- signals pages in report covers
- transistor radio
- 12 alligator clip earphone jack
- blue LED light box
- red cellophane filter paper
- multi-meter
- masking tape
- meter sticks
- paper towels

Tips for the teacher:

- Check all meters and batteries prior to lab
- Secure meter sticks and masking tape from local supplies.

Assumed Prior Knowledge of Students:

- Transmission of electromagnetic energy through the vacuum of space.
- $c = \lambda f$
- The law of reflection
- The difference between real and virtual images in curved mirrors

Background:

The Arecibo Observatory is part of the National Astronomy and Ionosphere Center (NAIC), a national research center operated by Cornell University under a cooperative agreement with the National Science Foundation (NSF). As the site of the world's largest single-dish radio telescope, Arecibo is recognized as one of the most important national centers for research in radio astronomy, planetary radar, and terrestrial aeronomy (the study of chemical and physical phenomena in the upper atmosphere).

Those who see the Arecibo radio telescope for the first time are astounded by the enormous reflecting surface, or radio mirror. This huge "dish" is 305 m (1000 feet) in diameter, 167 feet deep, and covers an area of about twenty acres. The surface is made of almost 40,000 perforated aluminum panels, each measuring about 3 feet by 6 feet, supported by a network of steel cables strung across the underlying karst sinkhole. It is a spherical (not parabolic) reflector.

Purpose:

To perform a series of activities that will help the learner understand how the shape of the radio telescope influences its ability to receive and listen to very weak signals from space. The activities will end with a discussion on signal analysis.

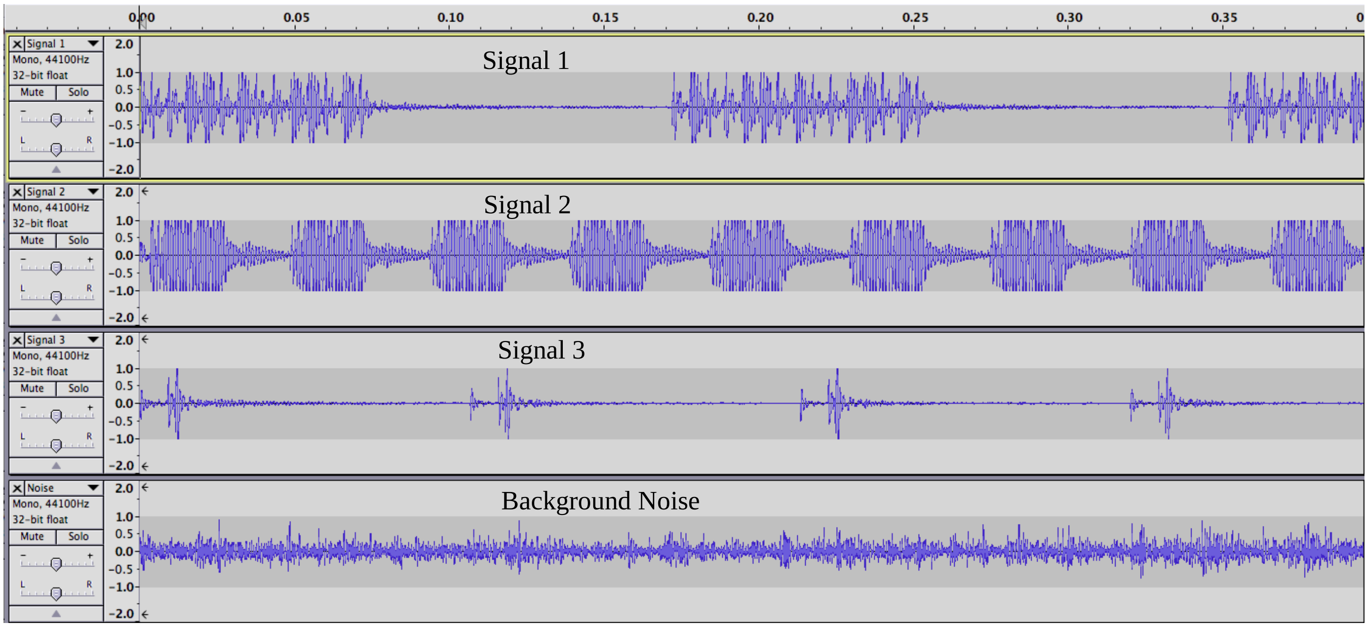
Answers to Questions: *send email to cipt_contact@cornell.edu to request answers*

Arecibo’s Giant Mirror

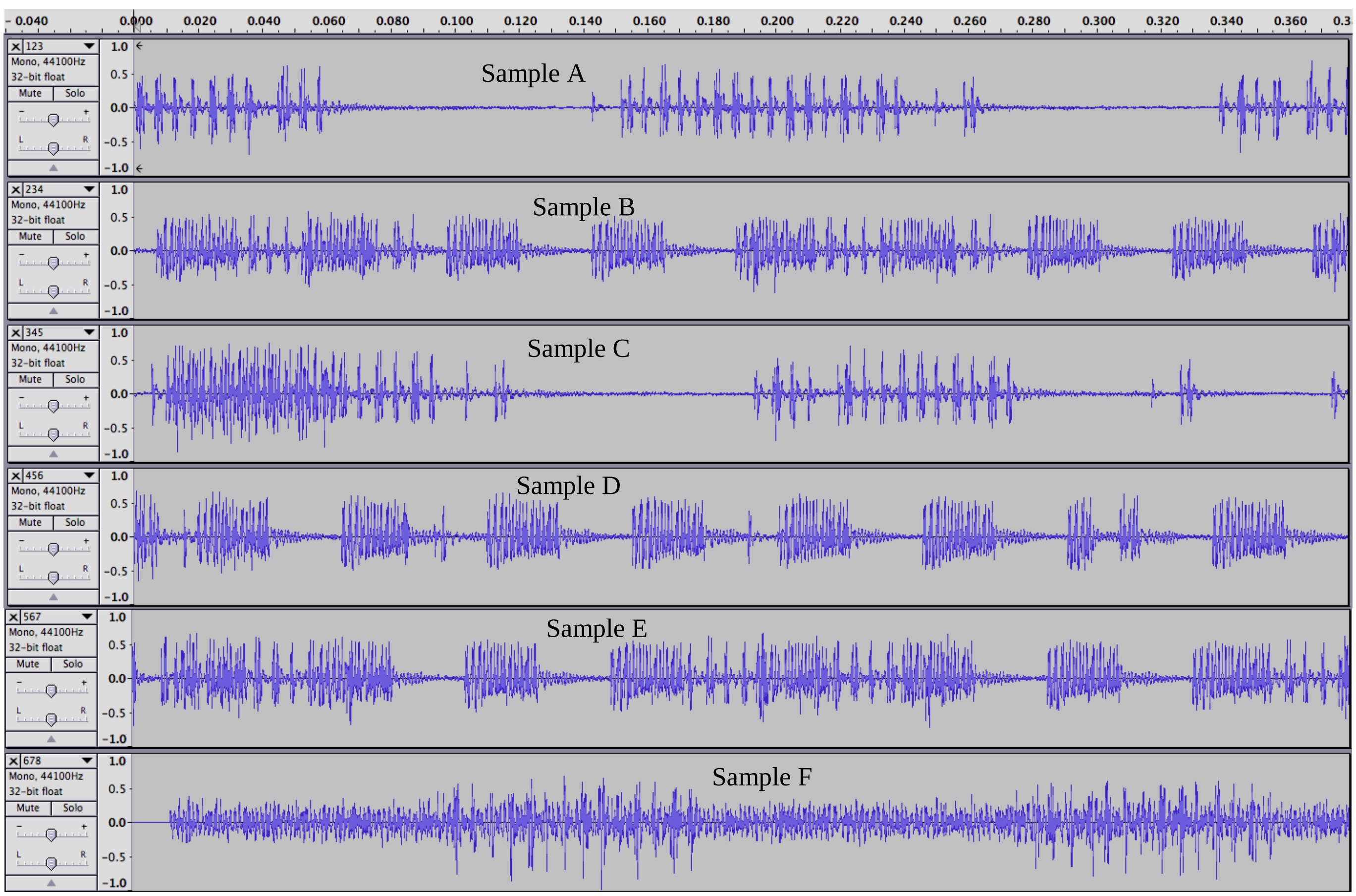
1	6” plastic ruler
2	semicircular refraction dish with mirror tape on inside curve, aluminum roofing nail
3	powdered milk
4	coffee stirrer
5	red laser pen
6	wooden holder for laser
7	drawing compass
8	mini remote control
9	PVC pipe, 7” for remote control holder
10	30cm spherical mirror
11	set of hardware –bolt, nut, wing nut washers
12	radio telescope photodiode set-up on aluminum rod
13	wooden telescope stand
14	test photodiode set-up – photodiode with monoplug
15	mini-amplifier
16	signals pages in report covers
17	transistor radio
18	blue LED light box
19	red cellophane filter paper
20	multi-meter with alligator clips
21	masking tape
22	meter stick

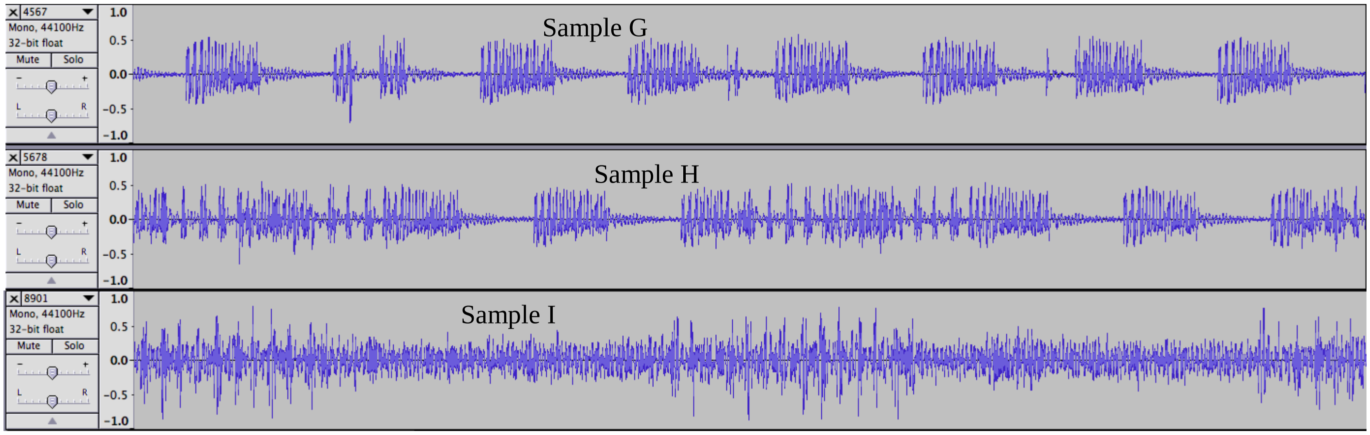
Arecibo’s Giant Mirror

Base signals:



Sample combined signals:




4567
Mono, 44100Hz
32-bit float
Mute
Solo
1.0
0.5
0.0
-0.5
-1.0
Sample G
5678
Mono, 44100Hz
32-bit float
Mute
Solo
1.0
0.5
0.0
-0.5
-1.0
Sample H
8901
Mono, 44100Hz
32-bit float
Mute
Solo
1.0
0.5
0.0
-0.5
-1.0
Sample I

ARECIBO'S GIANT MIRROR

Introduction

During this lab you will perform a series of activities to help you understand how the shape and size of a radio telescope influences its ability to receive and listen to very weak signals from space. The figure above is of the largest radio telescope in the world at the Arecibo Observatory in Puerto Rico. This huge "dish" is 305 m (1000 feet) in diameter, 167 feet deep, and covers an area of about twenty acres. The surface is made of almost 40,000 perforated aluminum panels, each measuring about 3 feet by 6 feet, supported by a network of steel cables. It is a spherical (not parabolic) reflector.

Activity 1: What do I look like in a curved mirror?

Figure 1

Materials:

- **curved metal mirror**

Procedure:

- Hold the large metal curved mirror with the mirror surface curved toward you as shown in Figure 1.
- Start with your nose almost touching the center of the mirror.
- Observe your image as you slowly move the mirror away from you until your arm is fully extended.
- Answer questions on the student activity sheets.

Activity 2: Finding the Focal Point

Materials:

- nail
- semi-circular dish with reflective curved surface
- water
- powdered milk
- laser pen with wooden base
- coffee stirrer
- ruler

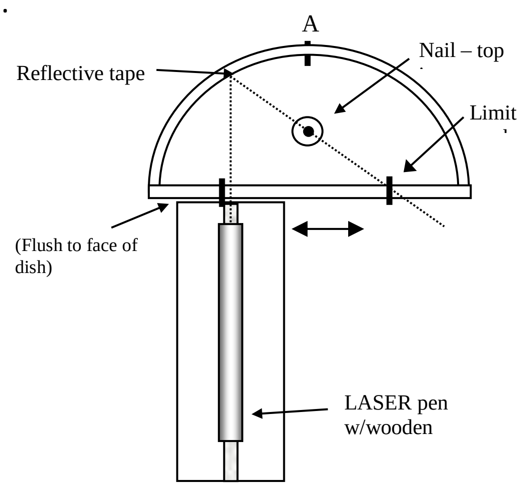


Figure 2: test set-up

Procedure:

- Fill the semi-circular dish with water, add a very small pinch of powdered milk, and stir until the milk powder dissolves. *(It is easier to see the laser in slightly milky water than clear water.)*
- Position the nail at the center of the dish.
- Position the laser as shown in Fig. 2. **Make sure the laser base is always flush with the base of the dish.**
- Move the laser to the right and to the left *keeping between the two limit marks* on the face of the dish.
- Adjust the nail position to identify the point where the reflected beam always travels through the nail.
- Measure the distance between the top edge of the dish (A) and tip of the nail.
- With the nail still in place, move the laser outside of the limit marks and observe what happens to the light beam.
- Answer questions on the student activity sheets.

Activity 3: Curvature of a spherical mirror

Materials:

- semi-circular dish
- drawing compass
- paper
- ruler

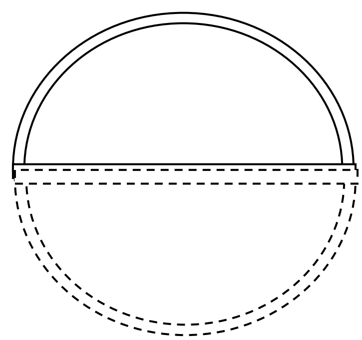


Figure 3

Procedure:

- On a separate sheet of clean paper, draw a complete circle as pictured in Figure 3 using your semi-circular dish as a template.
- Use the ruler to find the center of the circle.
- Using the drawing compass, set the length of the compass to *the calculated radius from Activity 2* and draw a circle with the point of the compass at the center point determined earlier.
- Answer questions on the student activity sheets.

Activity 4: The radio telescope: A giant hearing aid

Materials:

- mini-amplifier
- remote control
- assembled radio telescope with photodiode set-up (Figure 4)
- ruler
- remote control base (PVC pipe)
- blue LED box light source
- multimeter with alligator probes
- test photodiode set-up (Figure 6)

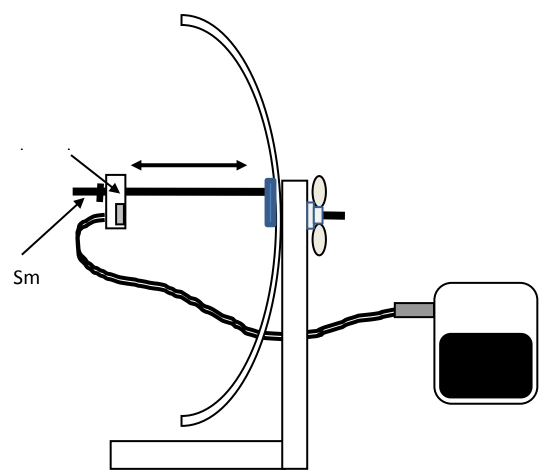


Figure 4: Assembled telescope

4a: Determining the focal point of the telescope

- Assemble the radio telescope set-up and attach it to the wooden base.
- Turn ON the mini amplifier, maximize the volume, and plug the radio telescope photodiode set-up into the INPUT port.
- Place the remote control on top of the PVC post and point it towards the center of the dish at close range. Press and hold the VOL button to listen to the IR signal produced.
- Move the photodiode set-up in and out along the aluminum rod to maximize the signal volume. **Make certain the photodiode is hanging straight down so that it is aligned with the center of the dish.**
- Measure the distance from the center of the dish to the face of the photodiode.
- Record this focal length in the data table on your student data sheet.
- Now you will determine the focal length using a second method. Instead of using the remote control and your ear, you will use the blue LED and a multimeter set to 20 VDC. See Figure 5 for assistance in hooking up the photodiode set-up output to the multimeter. **Remember again to ensure that the photodiode hangs vertically from the rod.**
- Record this focal length in the data table and answer questions on the student data sheets.

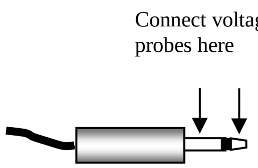


Figure 5 – Photodiode set-up, plug end

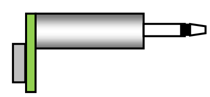


Figure 6 – Test photodiode set-up

4b: Observing the signal strength as a function of distance

- Attach the test photodiode set-up (Figure 6) to the INPUT port of the amplifier and set it on the floor.
- Turn ON the mini amplifier and maximum volume. Point the remote control at close range toward the test photodiode set-up and ***press and hold*** the VOL button to listen to the IR signal produced.
- While still pressing the VOL button and pointing toward the test photodiode, move away maintaining as strong a signal as possible until you are approximately 5 meters away. (See Figure 7)
- Observe the effect of increasing the distance on the signal strength.
- Answer questions on the student activity sheets.

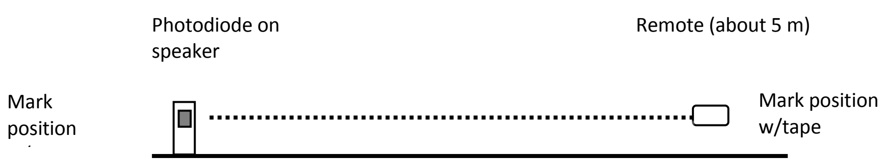


Figure 7

- Predict what will happen if you replace the test photodiode set-up with the telescope at the 5-m mark and record your predictions on the student data sheet.

- Now hold the remote on the PVC stand, point it in the direction of the dish, and push and hold the volume button. (See Figure 8) Observe any changes in signal strength and record them on the student data sheets.

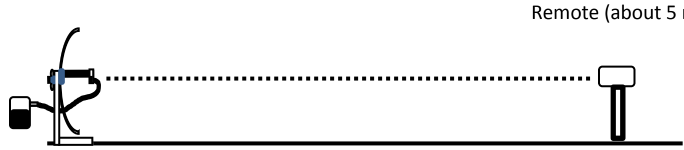


Figure 8

4c. Why is the dish at Arecibo so big?

- Measure the diameter of the telescope and calculate its area.
- Calculate the area of dish at Arecibo using information from the first page of the lab document.
- Record your data in the data table and answer questions on the student data sheet.

<u>Activity 5: Signal analysis</u>

<u>Materials:</u>

- Signals page

<u>Procedure:</u>

- Study the form of Signals 1, 2, 3, and the noise signal on the signals page.
- Identify which of these base signals is in each sample collected.
- Mark your conclusions in the table on the student data sheet by indicating the base signal with an 'X' in the appropriate box.

<u>Activity 6: Signal interference</u>

<u>Materials:</u>

- transistor radio
- blue LED light box
- remote control
- meter stick
- photodiode set-up
- red cellophane filter paper

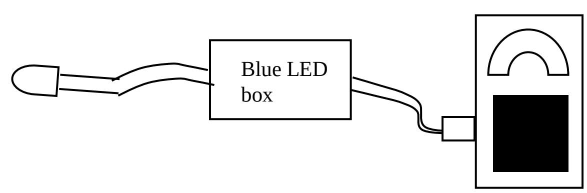


Figure 9: Radio w/ blue LED light box

<u>Procedure:</u>

- Using the transistor radio, find a station-less band that is only static.
- Increase the volume to maximum.
- Connect the blue LED box to the headphone jack of the radio (Figure 9)
- Attach the test photodiode set-up to the amplifier.
- Hold the blue LED close to the photodiode on the test photodiode set-up.
- While holding the position of the blue LED, press the VOL button on the remote control and position it so both the static and the remote's signal can be heard in the amplifier.

- Still holding down the remote button, slowly move it away from the test photodiode set-up until its signal is barely audible over the static.
- While both signals are being sent to the detector, place the red filter between the photodiode and the two signaling devices.
- Answer questions on the student activity sheets.

ARECIBO'S GIANT MIRROR

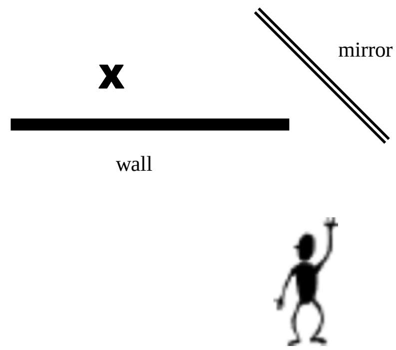
Student Data Sheets

Name: ___________________________________

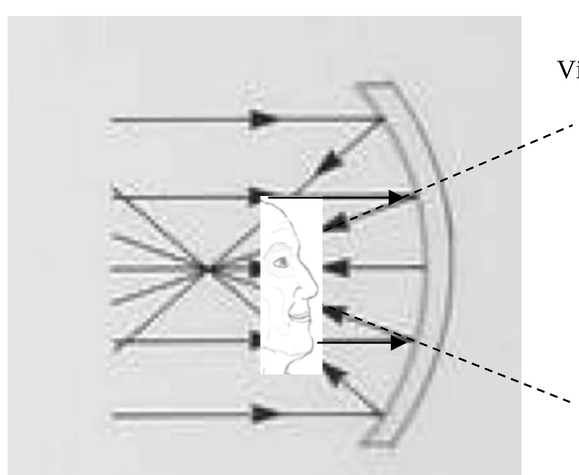
Activity 1: What do I look like in a curved mirror?

1. Describe the image you see when the mirror is close to your nose, as you move it slowly away from you, and when your arm is fully extended.

2. If you are positioned at the "X" in the illustration below, draw a solid line to show the path of the light that allows you to see the person waving at you in the mirror. Now draw a dashed line to show where your brain perceives the person in the person to be.

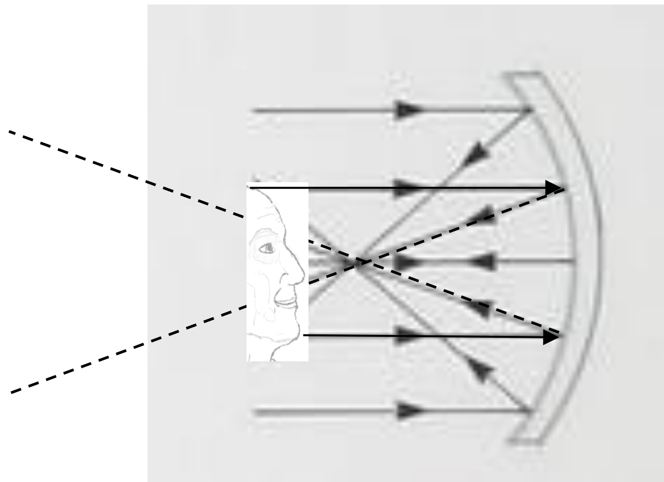


3. When your nose is close to the mirror, the image you see in the mirror is actually assembled by your brain. This is a virtual image. So, why is the image of your nose in the mirror larger than normal? In the illustration below, what do the dashed lines represent? Show on the diagram where the person's brain 'sees' his face.



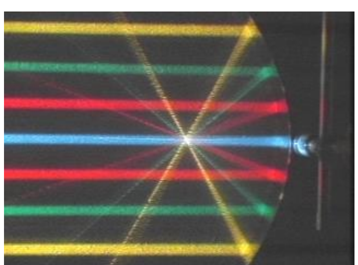
4. When the mirror is held at arm’s length, the image is upside down. This is a real image and one that is actually produced by the mirror and in front of the mirror. In the illustration below of the face positioned away from the mirror, show where the real image of his forehead and chin are produced.

Real image

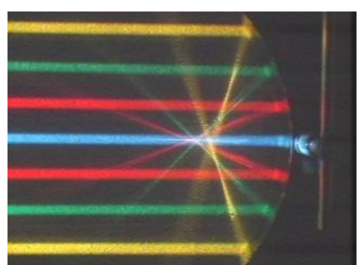


5. Consider the point where all the light rays cross. What would you see if your eye were positioned at this point and why?

6. Study the illustrations below of a parabolic and spherical mirror. In the space below the images, describe the differences between the reflections from the two types of curve mirrors.



Reflection: parabolic mirror



Reflection: spherical mirror

Ref.http://www.physics.montana.edu/demonstrations/video/6_optics/demos/sphericalaberrationinamirror.html

7. How do you think these differences affect the images you see in each mirror?

Activity 2: Finding the Focal Point

8. The nail position you determined represents the 'focal point' of the mirror. Define the term 'focal point' in the space below.

9. What is the purpose of the limit marks on the flat side of the dish? Why is it important to stay inside these marks when determining the focal point?

10. What is the measured distance between the mark (A) on the semi-circular dish (mirror) and the focal length, f?

f = _________________ cm

11. Based on your data in above determine the radius of the spherical mirror. [Equation: $f = r/2$]

r = _________________ cm

Activity 3: Curvature of a spherical mirror

12. How well did the actual traced circle match the calculated circle? Suggest possible sources of error in your measurement.

13. The radio telescope at Arecibo, Puerto Rico has its receiving equipment positioned 137 m (450 ft) above the spherical reflecting dish. Using this information, determine the following:

    Radius of the Arecibo radio telescope dish:

    Diameter of the Arecibo radio telescope dish:

14. On Figure 3B below, draw the ray diagrams for the light incident on the semicircular dish outside of the hash marks.

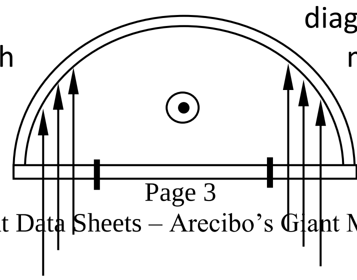


Figure 3B: Top view

15. The image to the right shows a receiving antenna that is part of the Arecibo detection platform. Knowing that the dish at Arecibo is spherical, suggest a reason why the antenna is long and pointed toward the center of the dish.

<u>Activity 4: The radio telescope: A giant hearing aid</u>

4a. Determining the focal point of the telescope

Laboratory Radio Telescope Focal Length Data		
	Sound Determined	Light Determined
Focal length (in cm)		
Estimated error (in cm)		

16. Compare the focal length data gathered using the infrared remote and the blue LED. Which method do you think is more accurate for determining the focal point of the dish?

4b: Observing the signal strength as a function of distance

17. If the lab telescope and the Arecibo telescope are the same in every aspect except the diameter, why is the Arecibo telescope considered a better device in studying space?

18. Explain why the signal from 5 meters was louder when the photodiode was replaced with the telescope. (Illustrate if necessary.)

4c. Why is the dish at Arecibo so big?

	Focal length (m)	Measured dish D (m)	Calculated 2-D Dish area (m^2)
Laboratory radio telescope (sound source)			
Laboratory radio telescope (light source)			
Arecibo radio telescope	265 m		

Activity 5: Signal analysis

19. Each of the sample signals on the Signals Page is composed of two or more of the base signals. Study each sample and determine which of the base signals compose the sample and place a check in the corresponding box for the base signal included in that sample.

Base signals → / Sampled signals	Signal 1	Signal 2	Signal 3	Noise (background)
Sample A				
Sample B				
Sample C				
Sample D				
Sample E				
Sample F				
Sample G				
Sample H				
Sample I				

20. A noise signal is defined as signals that are not being studied but picked up by the radio telescope from nearby sources. What are some possible sources of 'noise' at a radio telescope facility?

Activity 6: Signal interference

21. What affect did the red filter have on the pair of signals?

22. Explain how the red filter acted to select a specific signal based on the information below.

Blue light frequency: 6.4×10^{14} Hz
Red light frequency: 4.0×10^{14} Hz
Infrared frequency: 3.5×10^{14} Hz

<u>Post Lab: What the heck are these specs?</u>

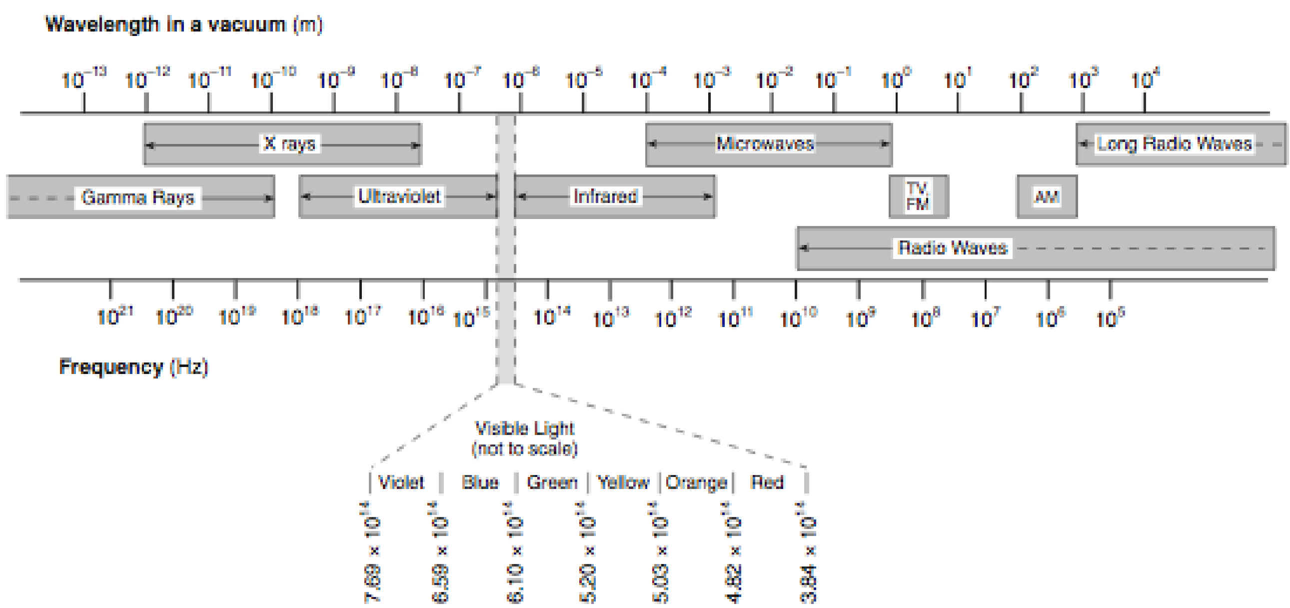
23. The radio telescope at Arecibo can detect electromagnetic signals from 50 MHz – 10,000 MHz (10GHz). On the table below of the electromagnetic spectrum, circle the region on the chart that represents the frequencies detected at Arecibo.

24. A cell phone transmits in a frequency of about 824-849 MHz. Place an arrow (↑CP) on the frequency line of the chart below that shows the location for cell phone signals.

25. Wi-Fi and Bluetooth use frequencies in the 2400 MHz (2.4 GHz) range. Mark this location with another arrow (↑W/BT) on the chart.

26. Most household cordless phones operate at a frequency of 5.8 GHz. Mark this location with another arrow (↑W/BT) on the chart.

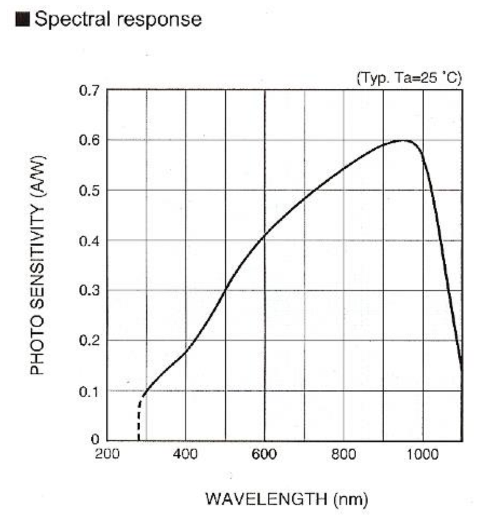
Ref. 2006 NYS Physical Setting: Physics Reference Table



27. You are not allowed to use cell phones and cordless phones at the Arecibo Observatory. In fact, you will anger the research scientists there if you do! If you had to explain the technical reason for these phone restrictions to a friend, what would you tell them?

28. A flashlight also emits electromagnetic radiation. Why doesn't using a flashlight at Arecibo upset the scientists collecting data there? Explain your answer.

29. Study the chart of Spectral response for the photodiode used in this lab. Based on what you have learned in this lab, explain why the small radio telescope used in class did not pick up someone's cell phone call.



30. Study the illustration of faint starlight striking the surface of the earth form a distant light source. Explain why having a large telescope is important to collecting these faint signals from distant stars.