

# The Nature of Light

## Instructional Objectives

After viewing the program and participating in the follow-up activities, the student will be able to:

1. explain the property of light that supports the particle nature of light (photoelectric light),
2. demonstrate a property of light that supports the wave nature of light (interference),
3. evaluate why the dual nature of light is believed by today's scientists, and
4. demonstrate that colored lights and colored paints do not mix in the same manner (postviewing activity).

## Synopsis

The program guides us through several major experiments conducted since the 1600s on the nature of light. Galileo Galilei's attempt to measure the speed of light is depicted along with the successful measurement of the speed of light by Michelson.

Newton's views of light as a stream of particles is depicted and developed. Huygens' opposing view of light as a wave is also developed. The debate of Huygens and Newton as a motivation for Young's experiment is described.

To clarify Young's experiment, waves are described, including crests and low points and their interaction, constructive, and destructive interference. The prediction based on Newton's Theories of Light for Young's slit experiment is stated; then the results of the experiments are shown. The program then explicates the dual nature of light by showing Einstein's support for both the particle and wave behavior of light.

The underlying theme in this piece, though, is that the basic nature of science has changed over time. The question has changed from "what is the nature of light" to "how does light behave." Science has moved from the philosophical approach to a more objective approach.

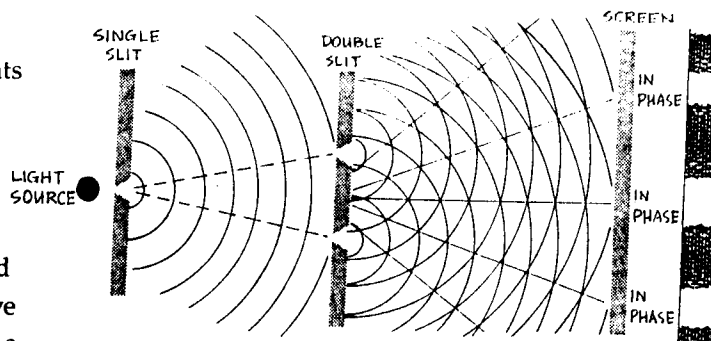
Also in this program, Eric Chaisson updates us on the latest information from the Hubble Space Telescope. Bob Bless describes the remarkable high-speed photometer and his role in the mission of the Hubble Space Telescope.

## Vocabulary

**Interference** - An effect that occurs when two waves of equal frequency are superimposed. If, at the point of meeting, the two waves are in phase, that is, they are vibrating in unison with the crest of one coinciding with the crest of the other, the waves will combine to form a new wave of the same frequency. The amplitude of the new wave is the sum of the amplitudes of the original waves. If two waves meet



out of phase, the result is a wave whose amplitude is the difference of the original amplitudes. (See graphic of interference.)



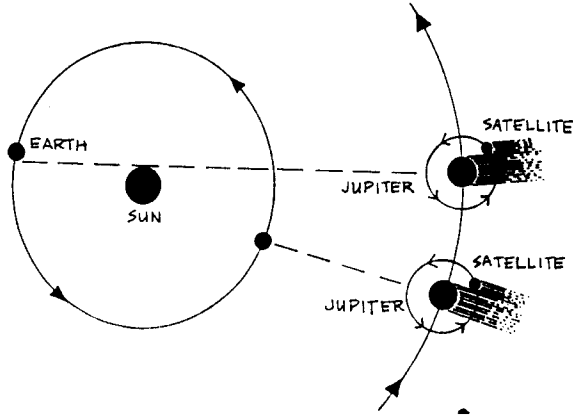
**Photon** - A unit of light energy that acts as a particle. The energy of each photon depends on its frequency. The frequency of an emitted photon is proportional to the energy lost by the electron in falling to a lower energy state.

**Speed of Light** - Approximately 186,000 miles per second. More accurately, it is 186,282 miles per second or 299,793 kilometers per second. The speed of light in free space is always the same. The speed of light is independent of both source and measurer.

## Previewing

Danish astronomer Olaf Roemer gave the first finite value of the speed of light in 1675. His means of measuring is not presented in the video and would provide a superb foundation for Galileo's and Michelson's approach. Below is a summary of Roemer's approach. Discuss with the students why this might work.

Roemer was measuring the period of revolution of one of Jupiter's satellites by timing its eclipses behind the planet. The results were that the measurements made while the earth was traveling away from Jupiter showed longer periods than those made when the earth was approaching Jupiter. Roemer hypothesized that the difference was due to the fact that light had to travel a greater distance when traveling away from Jupiter than



when approaching Jupiter (see diagram). Roemer calculated that light took about 22 minutes to travel a distance equal to the diameter of the earth's orbit about the sun. Roemer's approach was correct, but his accuracy low. Today we know that the time for light to travel a distance equal to the diameter of the earth's orbit is 16.67 minutes.

Demonstrate various patterns of waves to the students prior to the demo. Ask them to describe the movement under these circumstances:

- small pebbles are dropped regularly from a fixed point into a wave tank or wide bucket of water,
- a board is placed in the path of the concentric waves (be sure to discuss the *bending* of the waves around the board), and
- an obstruction with a vertical slit is placed in the path of the concentric waves.

### Postviewing

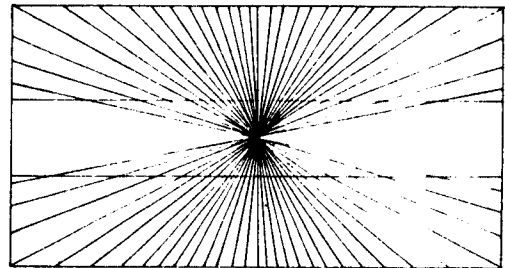
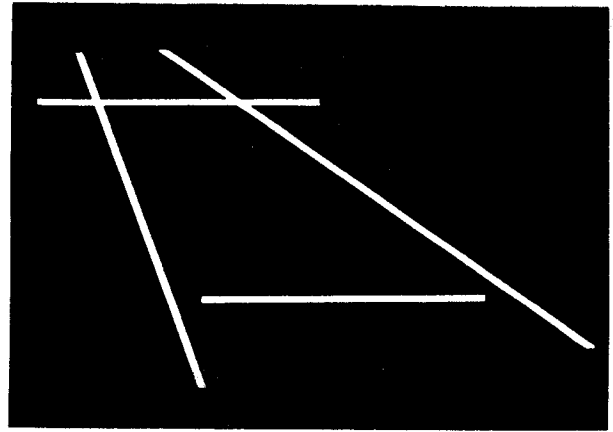
Reproduce Young's experiment with slits. Have students explain Young's findings using the water waves they have already experienced as a point of departure.

Have the students describe how to mix paints of red, blue and yellow in order to create the colors purple, green and orange. Then have students use flashlights and different colors of plastic (as filters) to mix colors of light. What differences do they detect? Using the colored lights, have the students combine hues to get white light. What combinations will result in white light?

Ask the students to describe Bob Bless' job. Why is he an essential link in the chain at the Space Telescope Science Institute?

### Active Involvement

Optical illusions can be a source of fun and heightened curiosity. Have the students bring in books on illusions and share them with classmates. Have students create some of their own illusions. Illusions are the result of a distorted perception sometimes caused by an unusual or deceptive presentation of an object or by some prejudice or emotion about it. What we see is strongly influenced by



HERING ILLUSION

what we think we see or by what we want to see. Here are two examples to motivate the students to do more with illusions. In Hering's illusion, the two long horizontal lines are actually parallel. What if the lines were turned vertically, would the illusion be as effective? In the perspective illusion, the upper line appears longer. Is it? Have the students try extensions of this illusion.

Have the students build a light box for the classroom. Using mirrors, the students can experiment with mixing light of different hues. Can students reach the conclusion that Thomas Young and others reached, that all the visible colors can be made by mixing red, green and blue light?

### Bibliography

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*For middle school readers:*

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Branley, Franklyn M. *Color: From Rainbows to Lasers*. New York: Thomas Y. Crowell Co., 1978.

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# See for Yourself: Experiments/Projects (PART 1)

# STARFINDER

PROGRAM 15

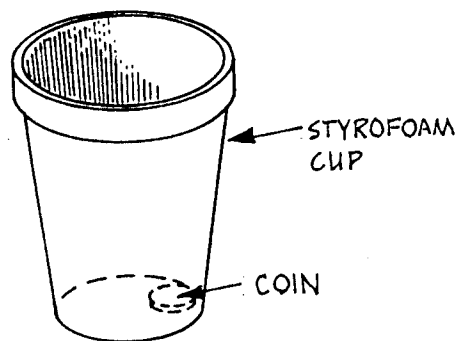
## Bending of Light

### ► MATERIALS:

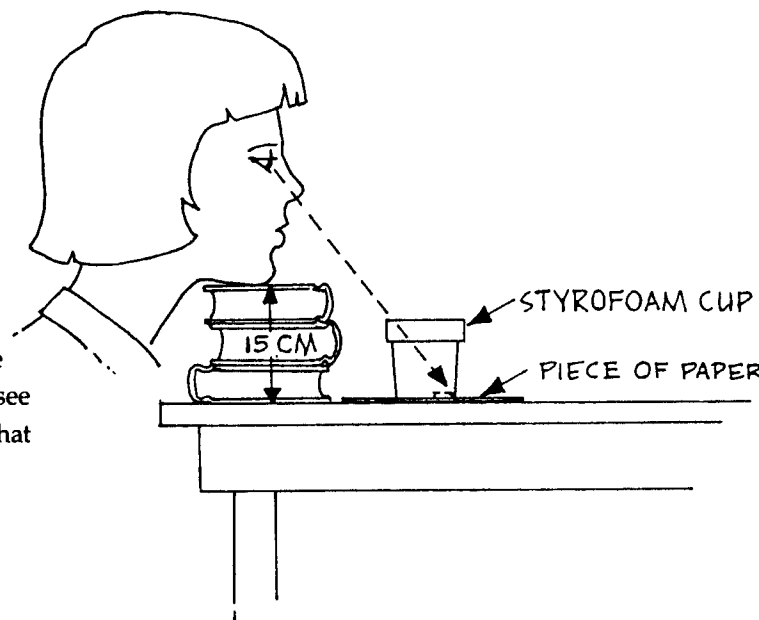
- ticky tac or other adhesive that will hold in water
- opaque cup such as styrofoam or ceramic
- stack of books
- coin
- piece of clean paper
- ruler
- water

### ► DIRECTIONS:

Attach a coin to the inside bottom of the cup so that the edge of the coin is close to the interior edge of the cup (see diagram). Set up a stack of books on a table or desk so that



the top of the stack is about 15 cm high. Rest your chin on the books. Place the cup on a clean sheet of paper in front of you. Hold your head very still. Have your partner adjust the position of the cup until the rim of the cup blocks your line of sight to the coin (see diagram). Tape the paper to the table. Have your partner mark the position of the base of the cup on the paper.



1. Hold your head very still while your partner fills the cup with water. What do you observe about the image of the coin?
2. Do not move as your partner slowly moves the cup away from you, sliding it across the paper. Tell your partner to stop moving the cup when the image of the coin is just out of sight. Have your partner mark the position of the base of the cup. Measure the distance the cup was moved. Record.
3. Repeat the experiment to check your accuracy. Record your results.
4. In which direction was light bent when the water was added? Sketch the experimental results.
5. Experiment with changing the amount of water in the cup and then with the height of the books. Do changing these variables change your results? Why or why not?  
ternal Reflection

## Internal Reflection

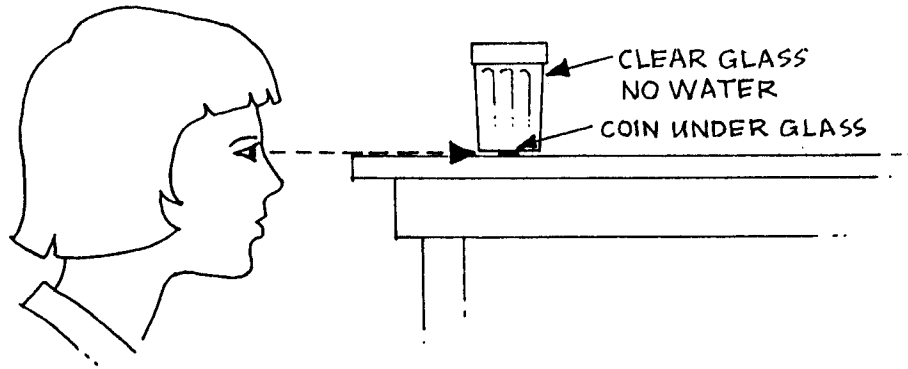
### ► MATERIALS:

- coin
- tall clear glass
- water

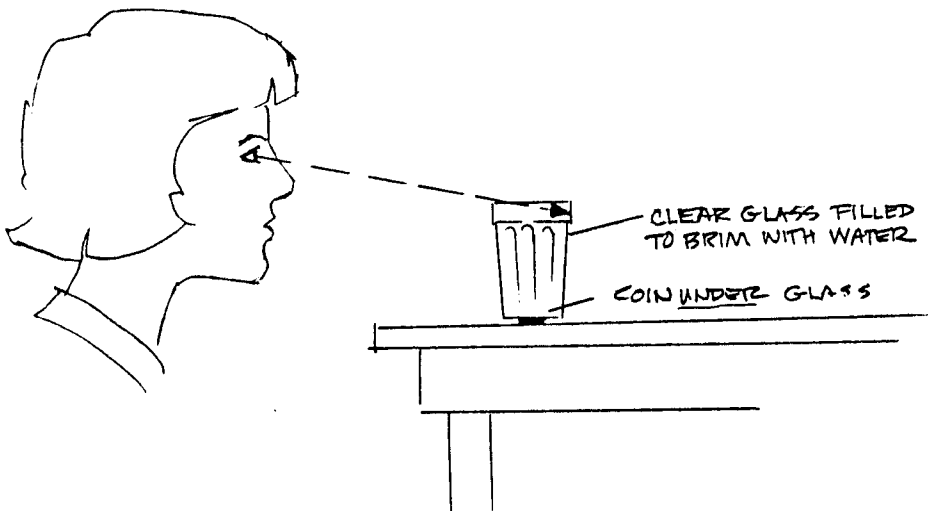
### ► DIRECTIONS:

Place the coin on the table, then place the tall glass on top of the coin.

1. Look through the side of the glass (see diagram). Record your observations.



2. While you are watching the coin through the side of the glass, have your partner fill the glass with water. What did you observe of the image of the coin? Record your observations.
3. Instead of looking through the side of the glass, look across the top at the opposite interior side of the glass (see diagram). Record your observations.



4. Sketch the path of the light. Can you explain what you observed?
5. Look up internal reflection. Using this concept, explain what happened.

# See for Yourself: Experiments/Projects (PART 2)



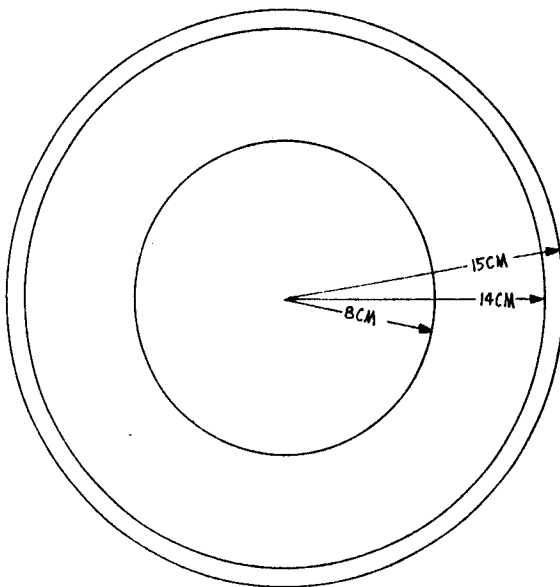
## Stroboscope

### ► MATERIALS:

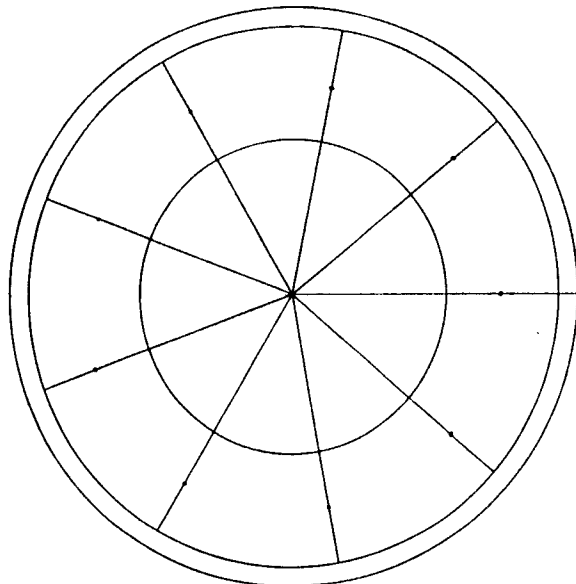
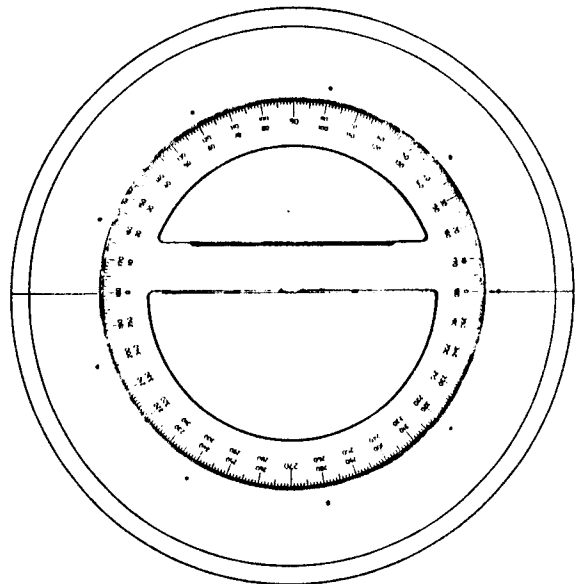
- scissors and utility knife
- empty spool of thread (with hole large enough for a pencil to slide into)
- glue
- liquid detergent
- cardboard
- tack
- pencils (one unsharpened or with an eraser head)
- cardstock white on one side, black on the other (17cm x 17cm)
- ruler
- compass
- protractor
- bicycle or fan (one for the entire class)

### ► DIRECTIONS:

Find the center of your cardstock. On the white side, draw a circle with radius of 15cm. Cut around the edge of the circle. Draw a second, concentric (with the same center) circle with radius of 14cm. Draw a third concentric circle with radius 8cm (see diagram).

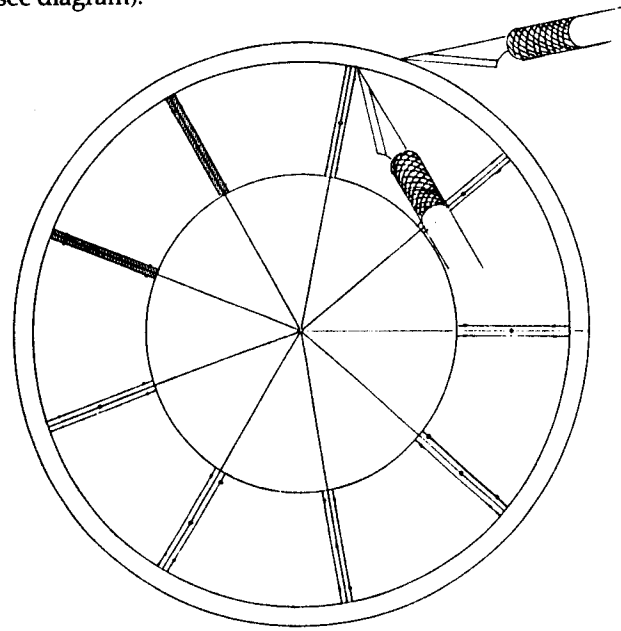
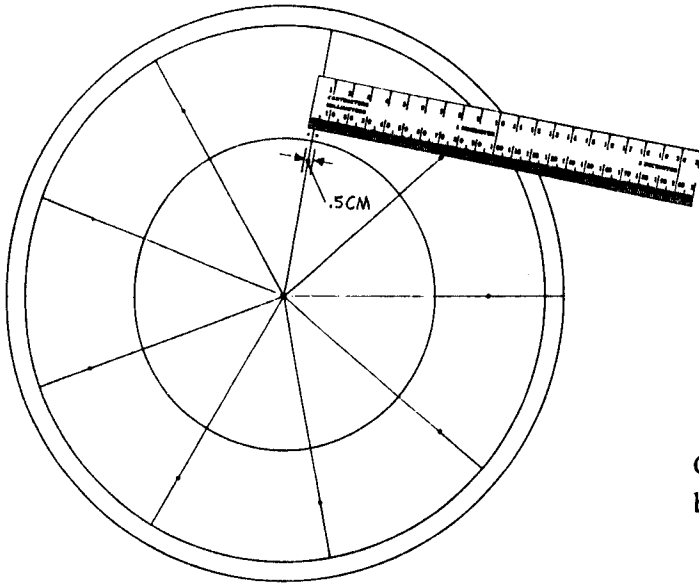


Draw a diameter through the center of the circle. Measure off 40° angles at 0°, 40°, 80°, 120°, 160°, 200°, 240°, 280°, and 320°. Draw radii from the points to the center, dividing the circles in nine equal parts (see diagram). Erase left radius, leaving nine equal segments.

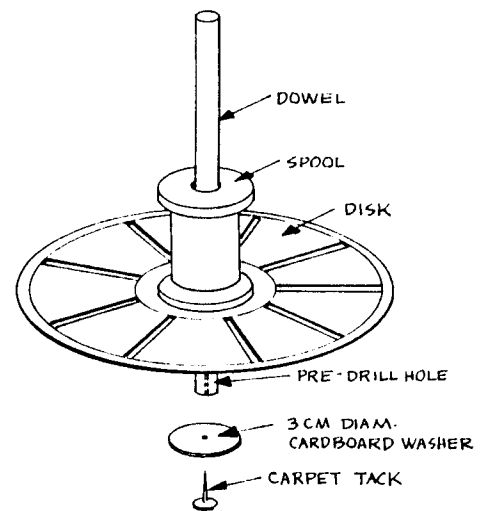
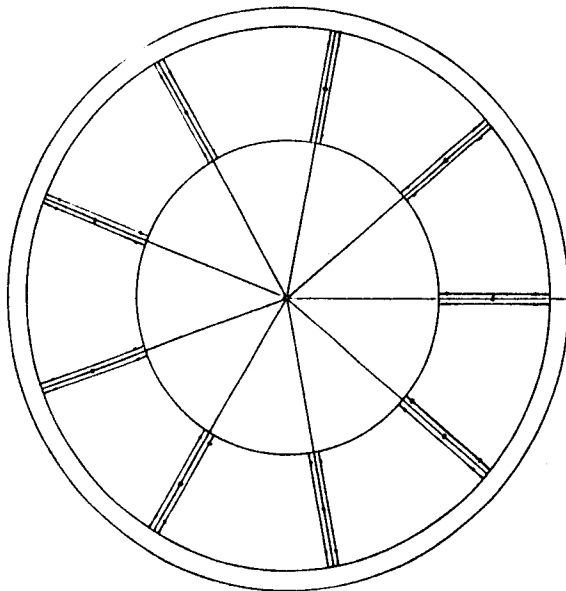


On the innermost circle, place the ruler across a radius. Measure and mark with a pencil 0.5cm on either side of the radius (see diagram). Slide the ruler to the next larger circle and mark off 0.5cm on either side of the radius again. Draw a line parallel to the radius to connect the points you have just drawn. Repeat this for every radius (see diagram).

Carefully cut these rectangles out using a sharp edge (see diagram).



Glue the empty spool of thread onto the center on the black side (see diagram). Allow the glue to dry.



Rub some liquid detergent onto the pencil that will act as an axle. Cut a circle out of cardboard the size of one end of the spool. Push the pencil through the spool and push the tack through the washer and the cardstock and into the pencil (see diagram).

1. Hold the disc level with your eyes. Looking at a stationary object, spin the disc. Write down your observations.
2. Now look at the rotating bicycle wheel or fan while you spin the disc. Vary the speed of the disc. Vary the speed of the fan or bicycle wheel. Record your observations.
3. Explain your observations using what you know about the nature of light.

# Science Career Profile

## ROBERT BLESS

Professor of Astronomy, University of Wisconsin

Principal Investigator, High Speed Photometer

Education: B.S. Physics

Ph.D. Astronomy



### General Responsibilities

Bob Bless is a scientist who wears two hats. He is a professor of Astronomy at the University of Wisconsin, but he is also the Principal Investigator of the High Speed Photometer (HSP) aboard the Hubble Space Telescope. How can he do both? While teaching astronomy over the past few years, he has had to split his time with his work for NASA. But the demands of the Hubble Space Telescope have become so intense during its first year of testing and calibration, he has had to take a year's leave from his university position in order to work full time on HST.

Bob's connection with the Hubble Space Telescope actually began in 1971, when he was involved with its early development. Before such a venture could be undertaken, NASA needed many questions answered. Was such a telescope possible? How much would it cost? How would it be built and launched? He was one of many astronomers and engineers who helped answer such questions. Then, in 1976, NASA sent out a call for proposals for the space telescope mission. Bob wrote a proposal for the High Speed Photometer, an instrument which can measure up to 100,000 samples of the brightness of an object every second. He was surprised to learn in November, 1977, that the HSP would be one of the main instruments aboard the Hubble Space Telescope.

Every one of the instruments aboard the HST has a principal investigator, someone who is totally responsible for its development, testing and use. Bob Bless is the principal investigator for the High Speed Photometer. Since the photometer was chosen as one of the Hubble instruments, Bob has had overall responsibility for the design, construction, testing and, finally, the operation of the HSP.

Because some of the HSP test plans have had to be changed, his group is currently rewriting tests and software so that the High Speed Photometer can be utilized to its fullest potential.

After the HSP is fully operational, Bob will be responsible for carrying out specific observations and research with the High Speed Photometer. He must keep in touch with the group of astronomers who will be looking for such phenomena as pulsars, quasars, and black holes in almost every part of the universe, from within our solar system to the distant quasars.

At the end of one year, the Space Telescope Science Institute will take over the day to day operations of the High Speed Photometer. Although Bob will still be highly involved in the research and operation of the HSP, he will return to his teaching position at the University of Wisconsin.

### A Typical Day

Even though Bob spends most of his time in Wisconsin, he is still connected to the Space Telescope Science Institute, Goddard Space Flight Center, and the world's scientific community through his electronic mail.

If Bob is in Maryland visiting the Space Telescope Science Institute or Goddard Space Flight Center, he will meet with any one of a number of committees with which he is involved. The Users Committee is primarily comprised of astronomers who will use the HST. The committee advises the Science Institute and Goddard as to how they can best meet the needs of the HST's users. He must meet often with HSP the engineers to discuss the day to day operations of the photometer. They might discuss what is going on, any problems with data, or who is going to cover a particular test. Any major changes must be discussed in meetings at the Science Institute.

Bob must spend time doing both long term and short term planning. The HSP group is continually looking at data and deciding how to revise their tests and interpret their observations.

Surprisingly, Bob frequently spends part of his day working with graduate students who are using a ground-based high speed photometer. Their research is carried out using telescopes in Wisconsin and in the Southwest. They are able to try out techniques on the ground that they hope astronomers can use as guidance for use with a space telescope.

It is not uncommon for Bob to meet with one or two reporters in a week. Since the deployment of the Hubble Space Telescope, Bob has needed to be available to provide information to the public. He has done this through interviews and press conferences, and even testifying before Congress.

### **Career Viewpoint**

Bob urges students to take the time to look around at the multiple possibilities available to them. Then, even if a goal appears to be difficult to attain, go for it. It may not be easy, but if determined and willing to work hard, most students should be able to do anything they set their minds to.

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