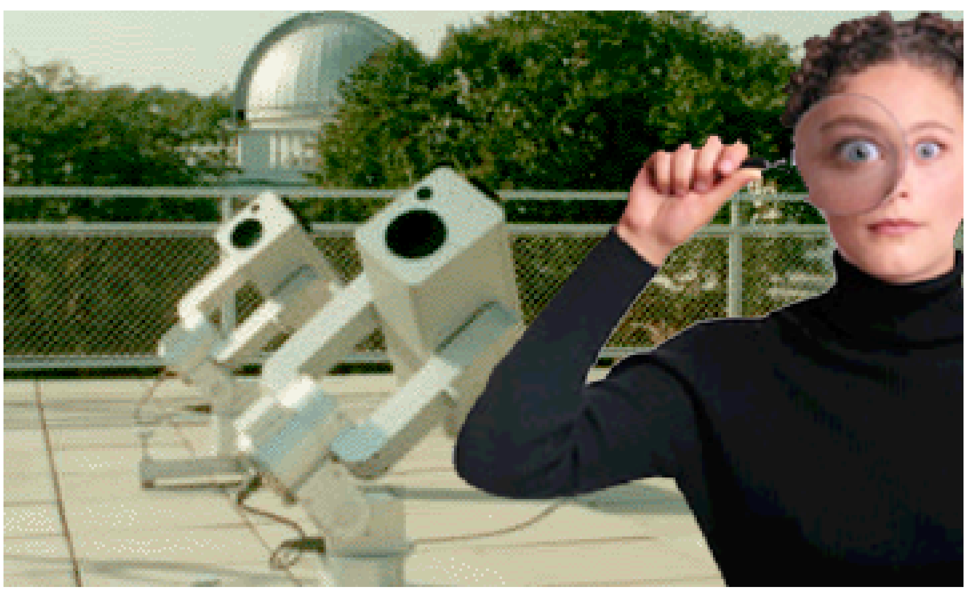
How does my eye compare to the telescope?

The challenge

The telescope you are about to control is a powerful instrument. So is your own eye.

In this challenge, you'll compare your own eyes' performance to that of a MicroObservatory online telescope. There are some things your eye can do much better—and some things that the telescope does better.

When you're done, you'll be able to get an idea of what to expect from the telescope's performance. Be sure to record your results on the DATA PAGE.



The MicroObservatory telescopes are less than 4 feet tall and weigh about 150 pounds. They are completely weatherproof and can be stationed anywhere in the world with an Internet connection. The telescopes shown here are at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts.

Your ideas about telescopes and the eye

In what ways is a telescope like your own eye? Things to consider: How does the light get in? How is an image produced? What senses the light? How is the image recorded or interpreted?

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What are some of your own questions about the telescope? About your own eye?

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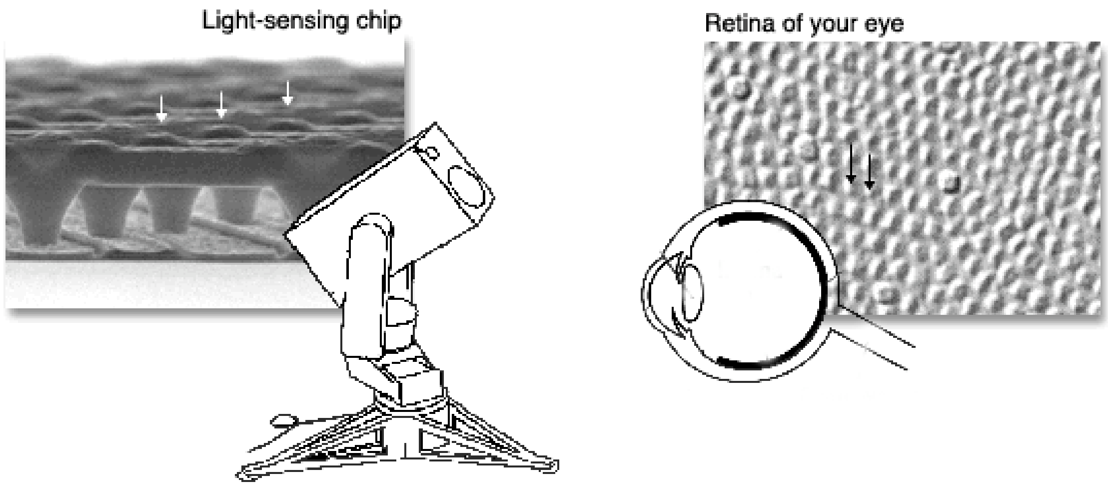
Your eye and the telescope are more alike than you might think.

- ❑ Both have *an opening* to let light in.

- ❑ Both have *an optical system* to bring the light to a focus. (In your eye, the optical system is a lens. In the MicroObservatory telescope, the optical system is a series of curved mirrors.)

- ❑ Both have a *light-sensor*. (Your eye's light-sensor is the retina, which contains thousands of light-sensing cells. The telescope's light-sensor is a silicon chip, which contain thousands of light-sensing "wells".) The sensors are about equally sensitive to light. (See images, next page.)

If the eye and telescope are so similar, then why is the telescope so useful? Try the comparison tests to find out.



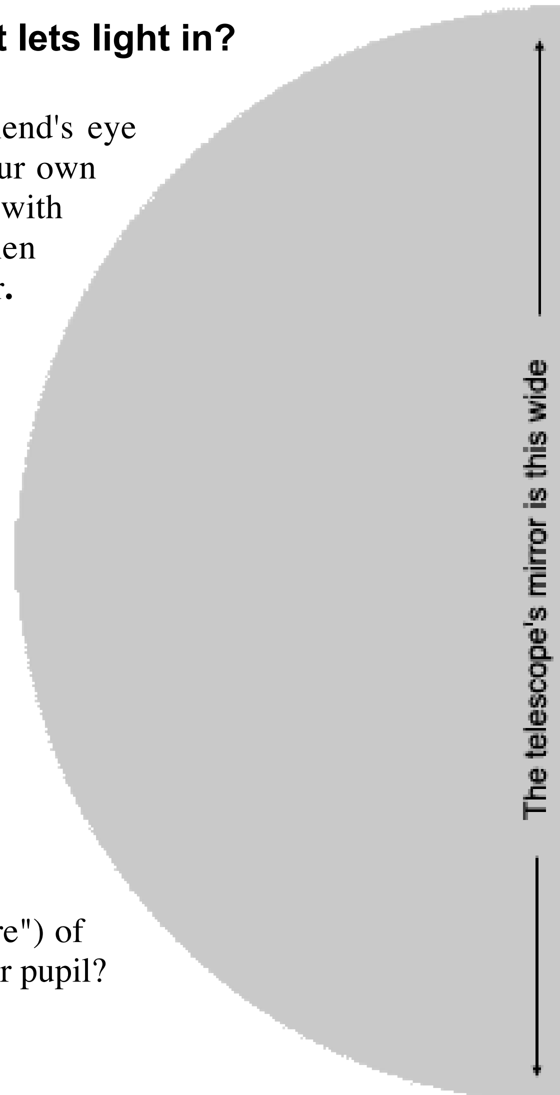
Left: Magnified view of the light-sensing silicon chip in the telescope. Each "well" (arrows) senses light and sends out an electrical signal proportional to the amount of light falling on it during the exposure time. The wells are about one-thousandth of a millimeter apart. Each well produces one dot (one “pixel”) in the final image.

Right: Magnified view of the light-sensing part of your eye (the retina). Each of the circles is a cell that detects light and sends out an electrical signal to your brain.

Comparison 1: Size of Opening

How big is the opening of your eye that lets light in?

This one's easy. Look at the pupil of your friend's eye (that's the black part of the eye). Or look at your own eye in a mirror. Compare the size of the pupil with the grey circles below to find a match. Then measure the width of the circle with a ruler. (**CAUTION: Never put a measuring device or other object near anyone's eye!**) Note that the size of the pupil changes depending on whether you are in bright or dim light.



Match pupil size, then measure:

When you think you can estimate the *largest* opening of the pupil, record the result on the DATA PAGE.

Discussion:

The telescope has an opening (called an "aperture") of about 6 inches. How much wider is that than your pupil?

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Does the telescope let in more light than your eye? About how many times more light? (Think: Is it the *width* of the opening or the *area* of the opening that counts?)

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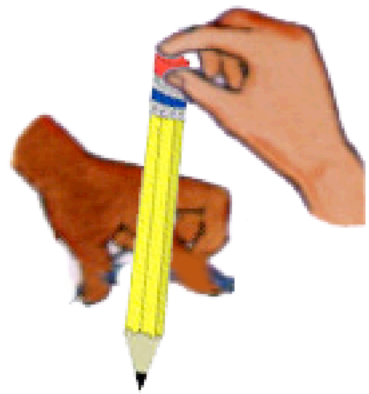
Comparison 2: Exposure time

Does your eye have a "shutter speed"?

Cameras can image faint objects because they can keep their shutter open for a long time — letting light in for a long time — as they record an image.   (You can control the telescope camera's shutter speed by selecting a shutter speed between 0.1 and 60 seconds.)

What about the eye? Your eye doesn't have a shutter that opens and closes to let light in. But your eye *does* have a kind of "shutter speed": It's the time it takes the nerve cells in your eye to record an image, before they send the image to your brain. This time depends on how fast a nerve cell works before it can "reset" itself and fire again.



You can estimate the "shutter speed" of your eye / brain system with this simple test of your reaction time:

Have a friend hold a pencil upright by the eraser. Hold your thumb and forefinger open near the middle of the pencil. When your friend drops the pencil, can you react fast enough to catch it?

This test gives you an *estimate* of how often your eye sends a message to your brain (and how fast your brain sends a message to your fingers).   Using a watch or clock with a second hand, see how long it takes you to react. Is it a fraction of a second? Can you estimate, roughly, what fraction of a second?

Record your estimate on the DATA SHEET. This estimate will tell you the *maximum* time that your eye can record an image before sending it off to your brain. To see if your estimate makes sense, find out how many frames a second your video machine plays. The time for one frame of video should roughly match the "shutter speed" of your eye -- because that's the speed at which your brain interprets separate images as one continuous scene.

Discussion

The telescope has a maximum useful exposure time of 60 seconds, during which it collects light. How does this compare with the "exposure time" of your own eye? How many times longer than your eye can the telescope let in light, for a single image?

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How does this allow the telescope to see fainter objects than your eye?

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Why not just make the telescope's exposure time as long as possible? What might be a drawback to very long exposures?

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Comparison 3: Sharpness of vision

How far away can you see a given object?

Make two small pinholes in a piece of aluminum foil, about 1/8 inch apart. Then place the foil over a flashlight. From how far can you see that there are two points of light, rather than one? (To estimate the distance, you can pace it off using your shoe as a ruler: Assume your shoe is about one foot long.)

Record your results here, and on your DATA PAGE.

I can just make out the two points of light from _________ feet.

The telescope can distinguish two points of light that are 1/8 inch apart from about 875 feet away. How many times further than your own eyesight is this?

The telescope has about __________ times better sharpness of vision than my eye.

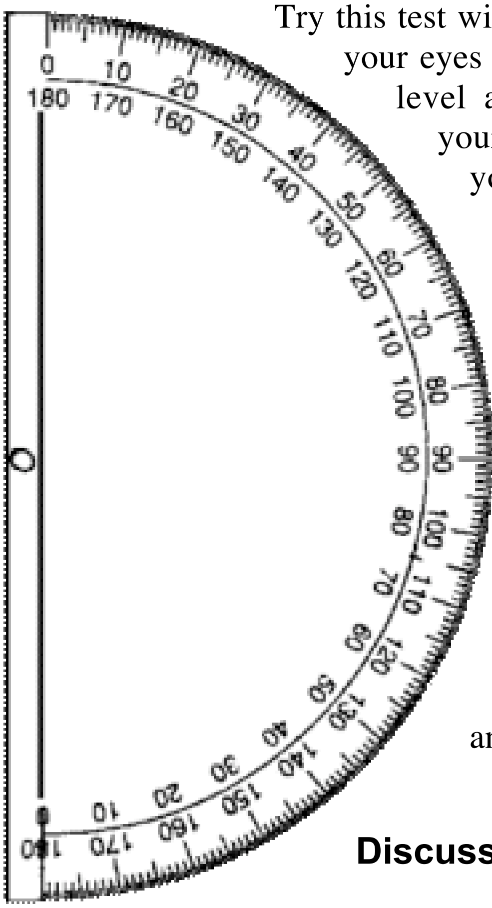
From how far away can you see a penny? The telescope can just detect a penny from a mile away.

Outside of school, where you have more room, have a friend hold up a penny from about a block away. Then have your friend move closer to you or further from you, until you can *just* make out the penny. How far away is that? The telescope can just detect a penny from a mile away. (A mile is 5280 feet.) How does that compare with your own eyesight?

Test 4: Field of view

How wide is your field of view?

So far, the telescope outperforms you... but here's where humans have it over the telescope.



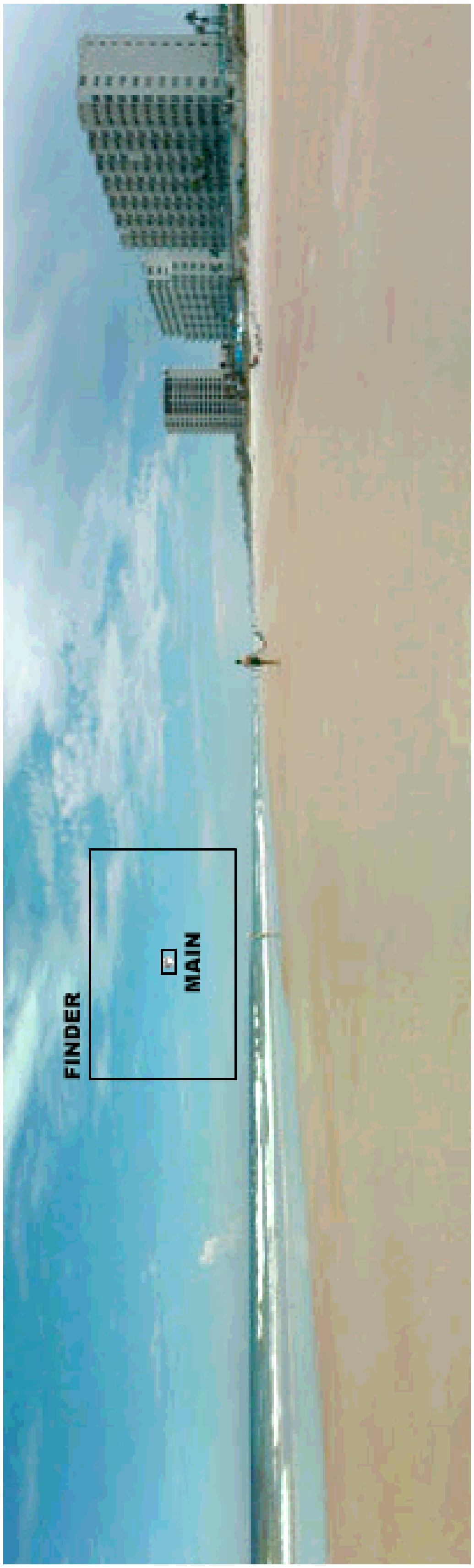
Try this test with a partner: Sit at a table, keeping your eyes straight ahead. With your left arm level and outstretched, SLOWLY bring your arm from behind your head into your field of view, while wiggling your thumb.   Make sure you keep your eyes straight ahead; don't look to the left or right. When you JUST see that your thumb is wiggling, stop the motion and have your partner measure the angle your arm makes with the straight-ahead direction.

Do the same with your right arm. The total angle, from left to right, where you can see an object, is your field of view. Record this angle on your DATA PAGE.

Discussion

The telescope's MAIN camera has a field of view of about 1 degree. How does this compare with your own field of view?

Note that there is a trade-off between your *sharpness of vision* and your *field of view*. The telescope focuses a NARROW scene onto roughly the same number of sensors as you have in your eye — whereas your eye focuses a very WIDE field of view onto the same number of sensors. As a result, the telescope can make out much smaller objects than your eye, but with the trade-off of having a much narrower field of view. What you think is the advantage of having such a wide field of view?



YOUR EYE'S FIELD OF VIEW, COMPARED WITH TELESCOPE'S

If you were on this beach, your eye could take in the whole scene (more than 90 degrees wide).

The telescope's **main** camera has a field of view only about 1 degree wide (small box).

The telescope's **finder** camera has a field of view about 10 degrees wide (larger box).

Note how small the Moon appears in this image. (It's in the small box labeled **main**.) The Moon is about half a degree wide.

Comparison 5: Color vs. black-and-white

Do you see in color or in shades of grey?

If you're sure you see *only* in color, think again. Try the experiment under "Field of View", only this time, notice when you can just make out the COLOR of the object in your outstretched arm. How does your field of view for *color* compare to your field of view for just making out an object?

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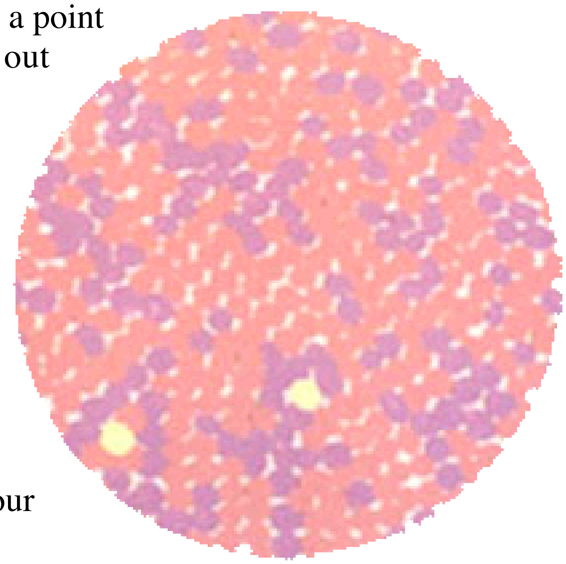
And try this in a room with very dim lighting: Is there a point where the light is so dim that you can still make out objects but NOT tell the color of the objects?

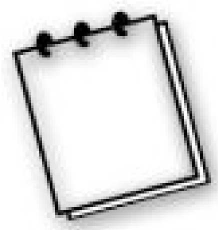
Discussion

The "rods" are a kind of cell in your eye that detect dim light, but give no information about color — just like the telescope. The "cones" are cells that can detect color, but they not sensitive enough to work in dim light. Also, they are concentrated in the central part of your retina that sees straight shead: Your color vision is best in the straight-ahead direction.

The telescope has only one kind of light sensor. It detects the brightness of light, but not its color. However, you can use the filters on the telescope to *reconstruct* a color image of a scene. (To see how, try Exploration 3: *Astro-photographer*).



Above: A microscope view of the color sensors in your eye. Can you make out the two very pale cells? These are the blue-sensitive cells. There are a hundred red- and green-sensitive cells for every blue-sensitive cell; no one knows why.



DATA PAGE:
Eye and telescope compared

YOUR EYE	THE TELESCOPE
Size of opening:	
Pupil is ____ inch wide or less.	Aperture is 6 inches wide, fixed.
Exposure time:	
About _____ second.	From 0.05 to 60 seconds..
Sensitivity to light:	
Retina very sensitive to light.	Silicon chip very sensitive to light.
Sharpness of vision:	
Two lights, 1/8” apart, at____feet. Resolution = ___ arc-seconds	Two lights 1/8” apart, at 275 feet. Resolution = 2.5 arc-seconds
Field of view:	
More than ______ degrees.	About 1 degree (main 'scope) About 20 degrees (finderscope)
Color vs. black and white:	
Color (in bright light) Black/white (in dim light)	Black and white. (But can make color image using filters.)
Seeing:	
Image from retina requires brain to interpret.	Records images, but does not "see."

