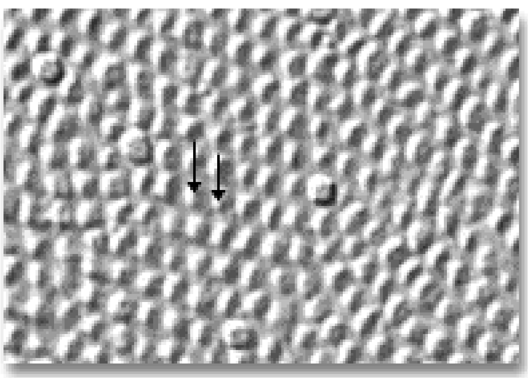
HOW DOES MY EYE COMPARE TO THE TELESCOPE?

GOAL: To get a better understanding of the some key performance characteristics of the telescope, as compared to your own eye.

THE CHALLENGE:

In this challenge, you'll compare your own eye's performance to the telescope's performance. There are some things your own eye can do much better... and some things that the telescope is better at. When you're done, you'll be able to get an idea of what to expect from the telescope's performance. Record your results on the DATA PAGE.

YOU...



THE TELESCOPE...

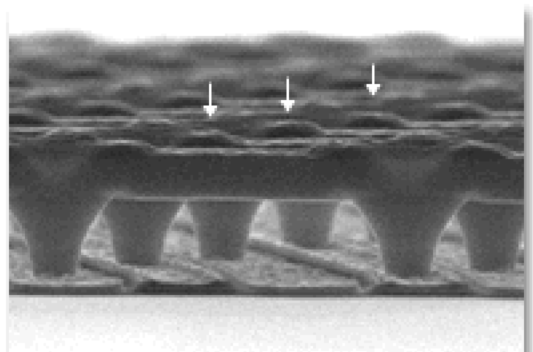


Figure. LEFT: Magnified view of the light-sensing part of your eye (the retina). Each of the circles is a cell that detects light and sends out an electrical signal. **RIGHT:** Magnified view of the light-sensing silicon chip in the telescope. Each "well" (arrows) senses light and sends out an electrical 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 pixel in the final image.

TEST 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). Compare the size of the pupil with the markings on a standard 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.

When you think you can estimate the LARGEST opening of the pupil (dim light), record the result on the DATA PAGE.

Discussion:

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

TEST 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.

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 figure out 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? Does this allow the telescope to see fainter objects than your eye? Why not just make exposure time as long as possible — are there any drawbacks to long exposures?

TEST 3: SHARPNESS OF VISION

How far away can you see a given object?

Outside of school, where you have more room, have a friend hold up a penny from a fair distance, about a block, say. 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? (Use your foot as a ruler: say your shoe is about a foot long.)

Discussion:

The telescope can detect a penny from a mile away. How does that compare with your own eyesight? (Recall that a mile is 5280 feet.) The limit of detection is called the "resolution" of your eye, or of the telescope.

As you work with the telescope you will learn about the "angular width" of an object. Your eye has a resolution of 1/60 of 1 degree — meaning that you can just make out an object as narrow as 1/60 of a degree wide. That's the angle a penny makes from about 225 feet away.

Alternate:

Make two small pinholes in a piece of aluminum foil, about 1/10 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? If everyone in the class stands at the spot where they can just distinguish the points, then the furthest person probably has the eye's limiting resolution. The close-in people need glasses!

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.

Sit at a table, keeping your eyes straight ahead. With your left arm level and outstretched, SLOWLY bring an object such as a pen or finger from behind your head into your field of view. Make sure you keep your eyes straight ahead; don't look to the left or right. When you JUST make out the object, stop the motion and have someone 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 number 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.

Figure. If you were on this beach, your eye could take in the whole scene (more than 90 degrees wide). The telescope's main field of view is only about 1 degree wide (small box). The finder camera's field of view is about 10 degrees. Note how small the moon appears in this image. It's about half a degree wide.

TEST 5: COLOR VS. BLACK AND WHITE

Do you see in color or black and white?

If you're sure you see only in color, think again. Try the experiment above, for field of view, only this time, notice when you can just make out the COLOR of the object in your outstretched arm. Is your field of view for COLOR much narrower than for merely seeing an object?

And try this: Turn the lights down in a room gradually. Is there a point where you can still make out objects, but can NOT tell the color of anything?

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 the Investigation, "Astro-photographer").

DATA PAGE: HOW DOES MY EYE COMPARE WITH THE TELESCOPE?

Size of opening:

Pupil is ____ inch wide or less.

Aperture is 6 inches wide, fixed.

Exposure time:

About _____ second.

From 0.01 to 60 seconds..

Sensitivity to light:

Retina very sensitive to light.

Silicon chip very sensitive to light.

Sharpness of vision:

See a penny ______ feet away.
(1 arc-min.)

See a penny a mile away.
(2.5 arc-sec.)

Field of view:

More than ______ degrees.

About 1 degree (main 'scope)
About 20 degrees (finderscope)

Color vs. black and white:

Black/white (dim light)
or color (bright light)

Black and white. (Can make color image using filters.)

Seeing:

Image from retina requires brain to interpret.

Records images, but does not "see."

TEACHER'S GUIDE

Exploring students' ideas about telescopes. Is the main purpose of a telescope to magnify... or to collect light? Students may be surprised to learn that telescopes are designed primarily to collect light, rather than to magnify very much. That's because astronomical objects tend to be large but dim. (For example, the Andromeda galaxy, a neighbor to our Milky Way, takes up more of the sky than the full moon! It's just too dim to see.) This idea will become clearer as students use the telescopes.

Carrying out the activities. You can divide the class into smaller groups, each of which reports on one of the tests above.

Using the results of this activity:

How much further can the telescope see than your own eye?

Surprisingly, the answer depends NOT on the magnification of the telescope, as you might expect, but on HOW MUCH LIGHT the telescope can collect. It's easy to get a rough idea of how much more efficient the telescope is.

Which factors on your data page will affect how dim an object the telescope can see?

The larger the opening, the more light a telescope can collect. The longer the exposure time, the more light a telescope can collect.

How much more light can the telescope collect than your eye?

Comparing eye and telescope:
Telescope **aperture** is 6 inches, versus pupil of your eye which is about 1/4 inch. Telescope aperture is therefore about 24 times wider. Its collecting area — the size of the circle through which light passes — is 24 x 24 times greater. (Area of a shape goes as the square of its dimension.)

So the telescope intercepts **576** times more light than your eye.

The telescope also can collect light for a longer **time** than your eye: Telescope **exposure time** is up to 60 seconds, compared to your eye's 1/15 th of a second "exposure". (That is, your eye can collect light for no more than about 1/15th of a second before sending an image to your brain.) Telescope exposure timee is therefore 60 x 15 times longer than your eye's exposure time.

So the telescopes can collect light for **900** times longer than your eye.

Together, these two factors mean that the telescope can collect about 576 x 900 times as much light as your eye. This is more than **half a million** times as much light as your eye!

How much further can the telescope see than my eye can?

Since the telescope collects about 500,000 times as much light as your eye, it can see objects much further than your eye — objects that would be too dim for you to see.

How *much* further can the telescope see? Recall that the brightness of a light falls off as the square of its distance from you. Therefore, if you can just make out a star or galaxy with your naked eye, the telescope could see the same star or galaxy up to about **700 times further** (because the object would be 700 x 700 times dimmer, or about 500,000 times dimmer).

Is this number reasonable? As you work with the telescope, you'll find that it is: For example, your eye can just make out the center of the Andromeda galaxy, which is roughly 2 million light-years away. The telescope can just make out a galaxy up to about 1 billion light-years away!

It also means that **you can see a volume of space 700 x 700 x 700 greater than with your eye!** That's more than **300 million** times more space than your eye can make out!