Build It Yourself: Telescope

The main game screen is dark blue with lighter blue and green swirls. At left is an illustrator drawing of the James Webb Space Telescope with its golden mirrors and silver 5-layer sunshield. At right are the credits.

Author/Creator: Maggie Masetti
Programmer: Mike Wojnarowski
Artist: Susan LIn
Special Thanks To: Dr. Kevin Boyce, Dr. Barb Mattson, Dr. Koji Muka, Dr. Scott Rohrbach, , Dr. Douglas Schwer, and Dr. Amber Straughn

Below this is a button that says Start.

The next Screen has black outlines of various unidentified spacecraft against a backdrop of blue with lighter blue and green filaments. There are 3 buttons at the left that say Level 1, Level 3, Level 3. At bottom right is a button that says “Need a hint.”

Level 1

The Science Screen. On this screen you will pick your science goals.

There is an instruction box at the bottom center where you can click to bring up instructions. At bottom right there are “previous” and “next” buttons. At bottom left is a button that says “Back to Main Menu”

The instructions box says, “Move the cursor over the science icons on the right to learn more about each one. Tap or click one if you'd like to select it. If you change your mind, click on another icon to select it instead.”

The main part of the screen is divided into two halves. On the right are science buttons: Black Holes, Star Formation, Early Universe, Galaxies, and Exoplanets. Each button has an image representative of that topic. When you mouse over the buttons text is displayed on the left part of the screen. After reading through, you select one and then choose next. The science text is as follows:

Science

Black Holes:

Black holes vary in size. Most local, massive galaxies are thought to have a supermassive black hole (hundreds of thousands to billions of times the mass of our Sun) at their centers. Other, much smaller, black holes are collapsed stars.

Black holes are so dense that light cannot escape. This means we cannot "see" them directly, but there are indirect ways to detect and learn about them.

*Choose to study **black holes** and you might learn how the nuclei of galaxies are powered or about the life cycles of stars!*

Star Formation

There are details of how stars are born and evolve that are still mysterious to scientists. To "see" individual star birth, we have to be able to peer into the clouds of dust and gas that act as stellar nurseries. Scientists are also interested in how the many stars in galaxies act collectively to affect the evolution of those galaxies over cosmic time.

*Choose to study **star formation** and maybe you will learn something new about star birth – or even about the formation of planetary systems!*

Early Universe

Because light from objects that are very far away from us must travel a long time to reach us, when we observe these objects, we are really seeing them as they were a long time ago. Studying the most distant objects can help us to learn about the first ever galaxies, and maybe even the first stars.

Additionally, the Big Bang (which occurred ~13.7 billion years ago) left residual radiation. Observing this radiation can help us to understand the conditions of the early universe.

*Choose to study the **early universe** and investigate our cosmic beginnings!*

Exoplanets

Planets around other stars are more common than we once thought. Currently, large gaseous planets, orbiting very close to their parent star, are most frequently discovered. Who knows how far away we are from finding another Earth, or even signs of life elsewhere in the universe?

*Choose to study **exoplanets** and learn about the building blocks of planet formation and the evolution of planetary systems.*

Galaxies

Scientists still have many unanswered questions about galaxies, like how the first galaxies formed, or how we ended up with the large variety of galaxies we see today.

Scientists would also like to know what the relationship is between the extremely large black holes that live at the centers of most galaxies and the galaxy that hosts them, and about how dark matter plays into the formation of galaxies.

*Choose to study **galaxies** and learn about how galaxies are powered and see how stars form within them.*

At this point, the game will vary based on what science goal you have picked. The instruction box says, “Move the cursor over the wavelength icons on the far right to learn how that wavelength might be used to study your science topic. Tap or click one if you'd like to select it. If you change your mind, click on a different icon to select it instead. “

Here are all the choices with respect to the science goal previously chosen.

Wavelength

(with respect to the science previously chosen)

Black Holes -> X-ray

Though no light can escape from a black hole itself, we can detect when matter is pulled into a black hole. As the matter falls toward the black hole, it gains energy and heats up, emitting ultraviolet light, X-rays, and gamma rays. For stellar black holes, this can happen if a black hole passes through a cloud of interstellar matter or ”steals” matter from a close binary companion.

When a supermassive black hole is at the center of a galaxy, it can spew a massive amount of energy outward, often in the form of powerful jets or streams of particles. Part of the energy emitted is in the form of X-rays and gamma rays.

If you choose to study black holes using **X-rays**, you might be able to learn what happens near the black hole at the center of these galaxies - or you might learn about how black holes interact with nearby stars.

Black Holes -> Gamma ray

Though no light can escape from a black hole itself, we can detect when matter is pulled into a black hole. As the matter falls toward the black hole, it gains energy and heats up, emitting ultraviolet light, X-rays, and gamma rays. For stellar black holes, this can happen if a black hole passes through a cloud of interstellar matter or “steals” matter from a close binary companion.

When a black hole is at the center of a galaxy, it can spew a massive amount of energy outward, often in the form of powerful jets or streams of particles. Part of the energy emitted is in the form of X-rays and gamma rays. Scientists have also recently learned that the birth of a black hole is often signaled by a huge burst of gamma rays.

If you choose to study black holes using **gamma rays**, you might learn more about the physics of the particles present in a black hole’s jets, or about black hole formation.

Black Holes -> Optical

Measurements of the optical light emitted by stars can be used to determine their speed and motion. This can tell you if the star is orbiting a stellar black hole and what the mass of that black hole is. The faster the star moves, the more massive the object it’s orbiting is. (Because it is the spectra of the stars that contain the motion information you will need to detect the presence of a black hole, you’ll want your satellite to have a spectrometer.)

This technique of measuring orbital velocities of stars can also work for finding supermassive black holes at the center of galaxies. Additionally, measuring changes in the optical light in the center of a galaxy can tell you whether or not a central black hole is pulling material towards it. These types of “accreting” black holes at the centers of galaxies are called Active Galactic Nuclei (AGN).

If you choose **optical** light to study black holes, you might learn more about their strange properties.

Black Holes -> Ultraviolet

Though no light can escape from a black hole itself, we can detect when matter is pulled into a black hole. As the matter falls toward the black hole, it gains energy and heats up, emitting ultraviolet light, X-rays, and gamma rays. For stellar black holes, this can happen if a black hole passes through a cloud of interstellar matter or ”steals” matter from a close binary companion.

Sometimes the black hole will gravitationally rip apart and devour its companion star. When it does this, a bright ultraviolet flare is sometimes emitted.

If you choose to study black holes using **ultraviolet** light, you might be able to learn more about what happens when objects interact with black holes.

Star Formation -> Optical

While we know that stars are formed from collapsing clouds of dust and gas (or nebulae), we don’t fully understand the process. We do know that stellar wind and radiation from young stars can compress and shape nebulae, which can trigger more star formation. One way we can learn about stellar nurseries is to make optical observations of the clouds of gas that hide and help create new stars.

If you choose to study star formation at **optical** wavelengths, you might develop a better understanding of how stars, dust, and gas interact in regions where stars are being born.

Star Formation -> IR

Stars are born from collapsing clouds of dust and gas, though we don’t fully understand the process. Additionally, any optical light emitted by these young stars is absorbed by the dust clouds, essentially making them invisible. Fortunately, stars also emit infrared light, which isn’t absorbed by cosmic dust the same way visible light is.

If you choose to study star formation using **infrared** light, you’ll be able to see inside the dense clouds of dust and gas that keep young stars hidden from optical telescopes.

Star Formation -> UV

One characteristic of a star-forming region is the presence of young, hot, massive stars that radiate intense ultraviolet light, which can illuminate the surrounding dust and gas. This is true in our galaxy, as well as in others. A survey of the stars in other galaxies can tell us something about the ages of their stars, and ultimately, this could help us understand how galaxies evolve and change.

If you choose to study star formation using **ultraviolet** light, you might learn more about populations of young stars.

Early Universe -> Optical

Though infrared light is best for getting a view of the earliest galaxies, a powerful optical telescope will still allow us to look back to when the universe was a fraction of its current age.

If you choose to study the early universe at **optical** wavelengths, you might learn about types of galaxies that populated the early universe.

Early Universe -> Microwave

The Big Bang left behind a heat signature that permeates the entire Universe. Scientists call it the cosmic microwave background (CMB).

If you choose to study the early universe using **microwaves**, you might be able to get a picture of the universe only a few hundred thousand years after the Big Bang took place, long before stars or galaxies existed.

Early Universe -> IR

The Big Bang caused spacetime to expand, taking everything in the universe along with it. As a result, most galaxies are moving away from each other.

The most distant (and thus youngest) galaxies are moving away so quickly that the light they emit gets shifted towards the red end of the electromagnetic spectrum. (This is very similar to listening to a train whistle shifting from higher to lower frequency as it passes by.) Thus, visible light from far away, quickly-moving, “high redshift” galaxies is shifted to the infrared.

If you choose to study the early universe at **infrared** wavelengths, you might learn something new about the earliest galaxies.

Galaxies -> Optical

Optical wavelengths are useful for observations of galaxies because stars and some abundant gasses emit optical light. For example, clouds of ionized hydrogen gas emit light at visible wavelengths – these so-called H II regions are often associated with star birth. Optical observations of HII regions, their distribution and even presence/absence can be used to determine the distance, chemical composition, and structure of the galaxies they are in.

You can also use emission from hydrogen gas to figure out how fast a galaxy is spinning - a shift in the wavelength of the light, called Doppler shift, indicates that the gas is moving relative to you. These "rotation curves" provide one clue about the presence of dark matter.

If you choose to observe galaxies at **optical** wavelengths you could learn more about their structure.

Galaxies -> IR

Infrared light is useful for studying young (and very distant) galaxies because the optical light they emit is shifted towards the red end of the spectrum. (This is due to the Big Bang expanding spacetime, causing galaxies to move away from each other).

Additionally, infrared light can help us to learn about the cores of galaxies, which are obscured by dust and gas at other wavelengths.

Infrared spectroscopy can be used to identify the elements (particularly those heavier than hydrogen) that are formed in galaxies. If you choose to study galaxies in the **infrared**, you could learn something new about their evolution, structure, or composition.

Galaxies -> X-ray

X-rays are created when matter is heated to extremely hot temperatures. If a galaxy has a black hole at its center, it will pull in material from the region around it. As this material falls towards the black hole, it heats up and emits X-rays and gamma rays.

If you choose to study the **X-ray light** emitted from galaxies, you may learn more about the black holes that can live at their centers.

Galaxies –> gamma ray

Galaxies give off gamma rays, sometimes as a result of powerful jets of matter moving at relativistic speeds, and sometimes expelled in mysterious bursts. These gamma ray bursts, considered some of the most powerful explosions in the universe, are thought to be associated with the formation of black holes or the merging of neutron stars.

If you choose to study galaxies in **gamma rays**, you might learn more about the mechanisms behind gamma ray emission.

Galaxies -> UV

Young, hot, massive stars emit ultraviolet light, so ultraviolet surveys of the sky could reveal star forming regions both within our galaxy, as well as in other galaxies. We also know that the way galaxies form stars changes over time, so observing star formation in galaxies at different times in the universe’s history helps us to understand galaxy evolution on a large scale.

If you choose to study galaxies using **ultraviolet** light, you might survey and map galaxies to learn about the ages of their stars, leading to a better understanding about how galaxies evolve and change.

Exoplanets -> Optical

Optical telescopes on satellites have been used successfully to find extrasolar planets by measuring the relative brightness of a star over a long period of time and looking for small, periodic changes that could be caused by the transit of a planet across the star.

If you choose to study exoplanets in **optical** light, you might learn about how they are detected.

Exoplanets -> IR

Infrared light is useful for studying young planets for the same reason that it is useful for studying young stars. Infrared light isn’t blocked by the dust and gas in the regions where young solar systems are formed.

A very sensitive infrared telescope might be able to obtain images of giant planets and planetary systems, characterize their ages and masses by measuring their spectra, and maybe even discover the atmospheric composition of planets that pass in front of their stars.

If you choose to study exoplanets in **infrared** light, you might learn about planets and planet formation.

Now the game will vary based not only on what science goal you have picked, but on what wavelength. The instruction box says, “Move the cursor over the instrument icons on the far right to choose instruments for the wavelength you have chosen. Tap or click one if you'd like to select it. If you change your mind, click on a different icon to select it instead.”

Here are all the choices with respect to the science goal and wavelength previously chosen.

Instruments

(with respect to the wavelength)

Optical -> Camera IR -> Camera X-ray -> Camera UV -> Camera

Telescope cameras work very similarly to ordinary digital cameras. They generally have a kind of shutter to let light in or keep it out, and detectors that convert light into a digital signal. On a satellite, this electronic data is stored and then transmitted to Earth, where it is processed and converted to images.

There are many different kinds of cameras. If you choose a **camera** for your satellite, you can easily build one that is optimized for whatever wavelength you'd like to study.

Optical -> Spectrometer IR -> Spectrometer X-ray -> Spectrometer UV -> Spectrometer

A spectrometer (also sometimes called a spectrograph) is used to disperse light from an object into a spectrum. The atoms and molecules in the object actually imprint lines on its spectrum that uniquely fingerprint each chemical element present and can reveal a wealth of information about physical conditions in the object. Analyzing the spectrum of an object can tell us about its physical properties, including temperature, mass, chemical composition, and motion.

If you choose a **spectrometer** for your satellite, you can easily build one that is optimized for whatever wavelength you'd like to study, from optical to gamma ray. (Note that gamma ray astronomy of this type is done with a type of detector called a scintillator).

Microwave -> Radiometer

A radiometer is an instrument used to measure the radiant flux, or power, of electromagnetic radiation given off by an object. A microwave radiometer can be used to detect and study the low level of background microwave radiation that exists as a result of the Big Bang. One way to do this is to measure and compare the temperature differences between different points in the microwave sky. Fluctuations in the temperature of the cosmic microwave background can be related to the density of matter in the early universe.

If you choose a **radiometer**, you can learn about the initial conditions for the formation of things like galaxies and galaxy clusters.

X-ray -> Proportional Counter

Proportional counters are filled with gas (like Xenon) that produces an electrical pulse when an X-ray passes through it. You can determine things like the energy, time, and position in the sky of the X-ray photon from measuring the strength, shape, and timing of the electrical signal. Counters like this are used less frequently now than they used to be.

If you choose a **counter**, you won't need optics for it, and it can give you interesting X-ray data about objects like black holes.

Gamma ray -> Scintillator

One way to detect gamma rays is to use a scintillator. In this sort of detector, an incoming gamma ray produces charged particles when it hits the scintillator crystals in the instrument. The charged particles interact with the crystals and emit lower energy (usually visible) photons of light, which are then collected by photomultiplier tubes. (Photomultipliers are very sensitive light detectors, generally sensitive to the ultraviolet, visible and near-infrared parts of the spectrum.)

By adding up the energy of the light collected in the photomultiplier tubes, the energy of the initial gamma ray can be determined. In some cases, the flashes of visible light produced by the scintillator can even be used to locate the source of the gamma rays in the sky.

If you choose a **scintillator**, you can detect and analyze cosmic gamma rays.

Now the game will vary based not only on what science goal you have picked, but on what wavelength and what instrument. The instruction box says, "Move the cursor over the optics icons on the far right to choose optics for the instrument(s) you have chosen. Tap or click one if you'd like to select it. If you change your mind, click on a different icon to select it instead. If you have chosen more than one instrument, you will need to pick optics for each one."

Here are all the choices with respect to the science goal and wavelength and instrument previously chosen.

Optics

(with respect to instruments/wavelength)

Small or Med -> X-ray -> Segmented

Picture throwing a stone into a pond. Unless you throw it at a very shallow angle so that it skips on the surface, the stone will pass right through the surface of the water. In this way, X-rays will pass through a typical telescope mirror unless they approach the mirror at a very shallow angle. To maximize the number of X-rays captured, X-ray mirrors are made of multiple, nested layers of cylindrical shells. The X-rays enter the end of the cylinder and then hit the mirrors at a shallow enough angle that they can be directed to the instrument located at the mirror’s focal point.

Many X-ray mirrors are made with thin foils – they provide good collecting area, are relatively cheap, easy to make, and lightweight. They may not be as accurate as more expensive and heavy alternatives, such as glass, but they fit the budget that a smaller satellite would have.

If you have an X-ray instrument that requires optics, try a **segmented** mirror!

Large -> X-ray -> Segmented

Picture throwing a stone into a pond. Unless you throw it at a very shallow angle so that it skips on the surface, the stone will pass right through the surface of the water. In this way, X-rays will pass through a typical telescope mirror unless they approach the mirror at a very shallow angle. To maximize the number of X-rays captured, X-ray mirrors are made of multiple, nested layers of cylindrical shells. The X-rays enter the end of the cylinder and then hit the mirrors at a shallow enough angle that they can be directed to the instrument located at the mirror’s focal point.

Many X-ray mirrors are made with thin foils – they provide good collecting area, are relatively cheap, easy to make, and lightweight. However, if you are building a larger X- ray satellite, you might use glass mirrors. These are heavier (thus more expensive to launch) and thicker, so you won’t be able to fit in very many (just four or so). This means your collecting area will be small, but the mirrors will be very accurate.

If you have an X-ray instrument that requires optics, try a **segmented** mirror!

Large -> IR or Optical or UV-> Segmented

The bigger your mirror is, the heavier it will be, and the more expensive it will be to launch. One alternative is to make your mirror in multiple segments that will act like a single mirror when they are put together. This type of mirror can work for optical, infrared or even ultraviolet wavelengths.

If you choose a **segmented** mirror, it will be more expensive than just making a smaller mirror (and you’ll have to investigate new technologies to do it), but it will be less expensive than trying to launch a single giant mirror into space! If you use a lightweight, but strong substance (like beryllium) to make your mirror segments out of, you might just pull it off!

Sm, Med, Large ->Optical, IR, Microwave, UV -> Single Primary

A single primary mirror is traditional for telescopes and will work for a variety of wavelengths (from microwave to ultraviolet) and instruments. You can even make them fairly large in size – but the larger they are, the heavier and more expensive they are.

If you do want a mirror larger than Hubble's, you might want to look into a segmented mirror. However, if your satellite isn't big enough to support a mirror that big, a **single primary mirror** will suit your needs!

Sm, Med -> X-ray -> No optics

If you are building an X-ray imaging mission, you will likely want optics to increase the amount of light you collect and in turn decrease the amount of observation time you'll need to collect enough X-ray photos to create a good picture. However, there are types of measurements that don't require optics at all.

If you're doing X-ray spectroscopy, or doing timing measurements with a proportional counter, such as precisely measuring when each X-ray photon is detected, you won't necessarily need optics.

Sm, Med, Large -> gamma ray –> No optics

When a gamma ray hits a mirror or a lens, it won't be reflected or refracted like optical light, and it won't bounce off the way an X-ray would – it will interact with the mirror in such a way as to destroy the gamma ray or change its energy by a large amount. Thus, while we can focus X-rays using optics, we actually don't yet have the technology to focus gamma rays, so current gamma ray telescopes don't use optics at all! Some types of detectors can determine the direction of a strong source of light to a fine degree of accuracy, but they don't actually focus the light.

If you are building a gamma ray instrument, you won't need optics.

Now that you have made all your choices, you can launch your mission by clicking on the launch button.

An animation plays of a rocket blasting across the screen over the background of the Earth, and then your science result appears. The result will show a drawing of a real satellite similar to the one you built, and real data that might resemble that your instrument gathered, and text describing the science result.

Please see the other docs for the text for every possible permutation in the game.

Level 2/3

The user interface for these levels is the same as for Level 1.

For Level 2, you may pick up to two science goals, up to two wavelengths (think about whether they are compatible!). It may be possible to choose the same wavelength for each science topic, or if you have only chosen one, you may choose two wavelengths for it. Next you must pick instruments to match with the wavelengths you have chosen. Each wavelength must have at least one instrument so consider your options and pick carefully! Lastly you must pick optics to go with each instrument selected.

When you launch, a bigger rocket launches and a science result is displayed. Level 2 has a different range of comparable missions and comparable science data. You may get more than one science result, so look for the arrow on top to click through all your results!

If you play again, the shadows on the main screen fill in as comparable missions are unlocked.

For Level 3, you may select 4 science goals, a total of 3 wavelengths (one per science goal), a total of 3 instruments (one for each wavelength), and the optics options for optical/infrared include a segmented mirror like Webb.

When you launch, and even bigger rocket animation is shown, and a comparable mission and science result or results are displayed. Going back to the main menu each time you play and unlock one of the mystery missions causes that shadow to fill in with an illustration.

If you click the “need a hint” button, it tells you to move the cursor over an unknown satellite for a hint on how to build it.

The hints are:

Top left: Try something that would require the use of a scintillator. You'll have to figure out what wavelength it might be used for.

Bottom left: Try using a large segmented mirror - but a much higher energy wavelength than optical light.

Top middle: This large telescope looks pretty similar to JWST.

Bottom middle: Smaller than JWST, this telescope will also look at the infrared universe.

Top right: This X-ray telescope doesn't have optics, but can still "see" black holes.

Middle right: This type of satellite can observe radiation left over from the early universe at this wavelength. And it's not infrared.

Bottom Right: This large telescope looks pretty similar to Hubble.

To read through all the permutations, please view the other available docs.