Imaging a black hole

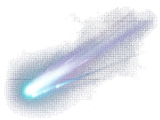
Our Solar System

Our Sun is a star, in the Milky Way galaxy. Surrounding our Sun is our Solar System. Due to the immense gravity of the Sun many things are kept in orbit surrounding it:

- **Planets** - A planet must have enough gravity of its own to form a spherical (round) shape. It must also have enough gravity to 'clear the neighbourhood' of its orbit. This means pulling smaller objects which are in the same orbit path into orbit around the planet, such as the Moon around our Earth. There are 8 planets in our Solar System.
- **Moons** (Satellites) - A Satellite is something that orbits a planet. Moons are naturally occurring satellites. Larger planets, such as Saturn, have many moons (Jupiter has nearly 80).

- **Dwarf planets** - Although dwarf planets have enough gravity of its own to form a spherical (round) shape, they are unable to 'clear the neighbourhood'. This means that there may be other things in the same orbit around the Sun. There are hundreds of dwarf planets in our Solar System, including Pluto.

- **Asteroids** - Asteroids are smaller objects, made of metal and rocky material, which orbit the Sun in elliptical (oval) shapes. They may take millions of years to complete an orbit. Between Mars and Jupiter there are many asteroids in an area called the asteroid belt.



- **Comets** - Comets are similar to asteroids, however, they are made of rocky material, dust and ice. Comets begin to vaporise (turn into a gas) as they approach the sun. This leaves a trail behind them.

Measuring the Solar System

The distance across our Solar System is vast; it is hard to imagine the huge distances involved. To travel from the Sun to the orbit of the furthest planet (which is still not the edge of the Solar System) at 70 mph it would take more than 4500 years!

Therefore, when measuring distances in space a unit called the light year is used. One **light year** is the distance that light can travel in one year. Calculate this figure below, using the speed of light (which is given for you) and following the steps outlined.

Speed of light

300,000,000 m/s = 300,000 km/s *(kilometres per second)*

= 300 Mm/s *(megametres per second – 1 Mm = 1000 km)*

= 18,000 Mm/m *(megametres per minute)*

= 1,080,000 Mm/h *(megametres per hour)*

= 25,920,000 Mm/d *(megametres per day)*

= 9,460,800,000 Mm/y *(megametres per year – use 365 days/year)*

Convert your answer into standard form (a x 10^n), where a is a number between 1 and 10 and n is the power of 10 to multiply a by. An example is done for you:

300,000,000 m/s = 3 x 10^8 m/s

9,460,800,000 Mm/y = 9.46 x 10^{9} Mm in a **light year**

Our Solar System is not even one light year wide. Therefore we measure the distances between our planets in **light minutes**. In the same way a light year is the distance light can travel in one year, a **light minute** is the distance light can travel in one minute.

Planets: A Scale Solar System

You are going to build a model of our Solar System, as a group. You will be given one planet to examine.

1. Measure the **diameter** of your planet in cm.
2. The planetary scale is given on the *Instructions* sheet. Measure the actual distance of the planetary scale bar. Then, use the following equation to calculate the diameter of your planet in km:

$$diameter\ (km) = diameter\ (cm) \times \frac{represented\ distance\ of\ planetary\ scale\ (km)}{actual\ distance\ of\ planetary\ scale\ (cm)}$$

   Note that the scale is given in Mm, but you need to use it in km.

3. You are given the distance of your planet from the Sun in km. Use the following equation to calculate the distance of your planet from the Sun in light minutes:

$$distance\ (light\ minutes) = \frac{distance\ (km)}{distance\ in\ one\ light\ minute\ (km)}$$

   You already calculated the distance in a light minute above, in Mm.

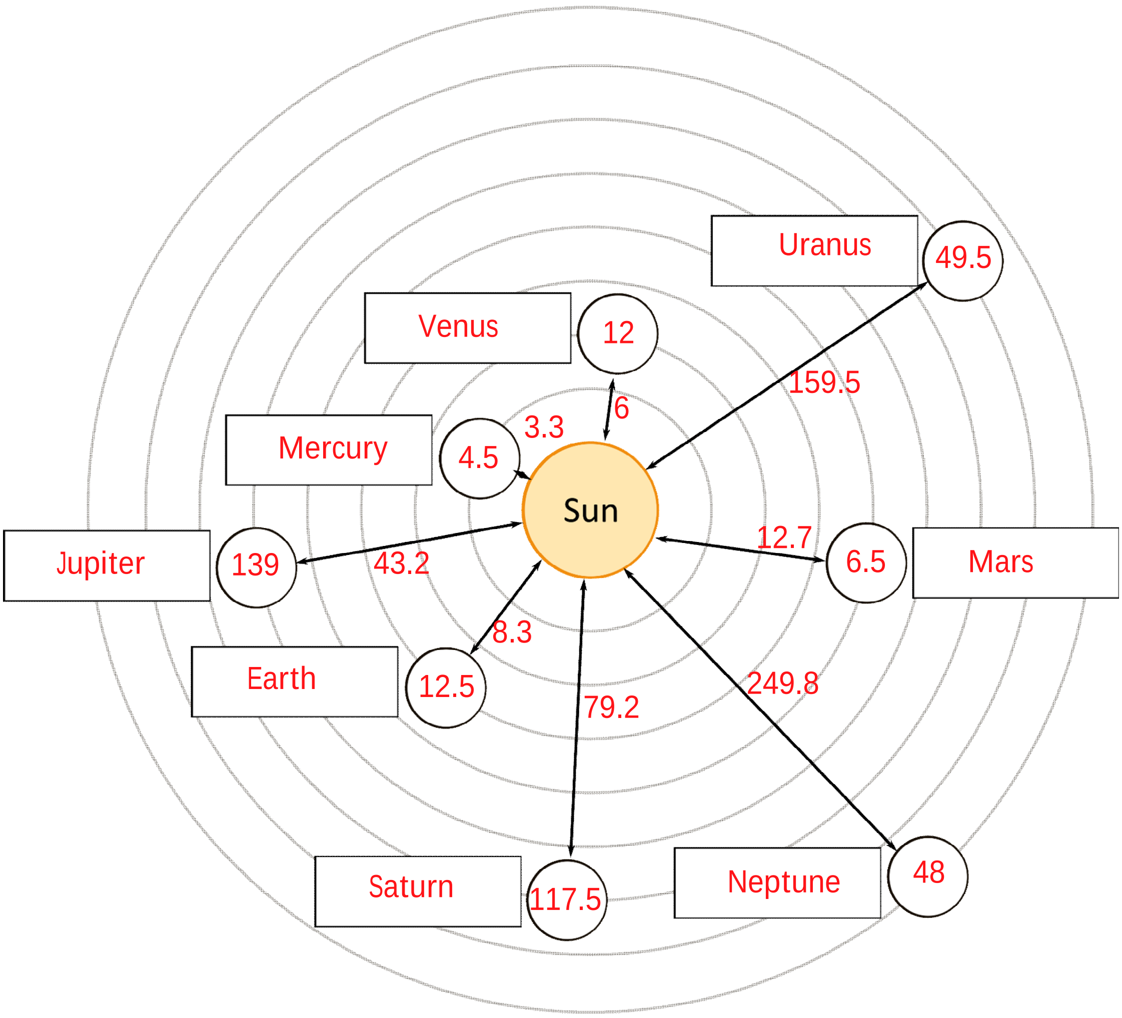
This space is provided for any workings you want to do:

4. The light scale is given on the *Instructions* sheet. This is a different scale to the planetary scale because the distances between planets (if calculated using the same scale as the planets themselves) would be too big to fit into the room. Measure the actual distance of the light scale bar. Then, use the following equation to calculate the distance of your planet from the model Sun in cm:

$$distance\ (cm) = distance\ (light\ min) \times \frac{actual\ distance\ of\ light\ scale\ (cm)}{represented\ distance\ of\ light\ scale\ (light\ min)}$$

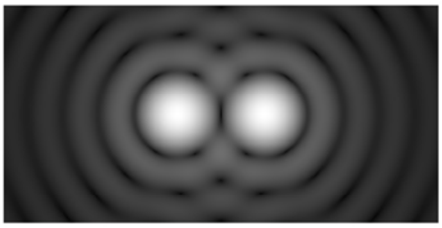
5. As a group, choose a point in your room to be the model Sun. Arrange the planets their correct distances (in cm) away from the model Sun, using the tape measure.
6. Once all the planets are laid out, write the information each group has collected about the planets onto the diagram below:

Write the **names** of the planets (black circles) on the diagram in the spaces, based on the distances of planets from the Sun that you have just worked out. Add labels on the black arrows to indicate the **distance** of the planet from the sun, in **light minutes**. Write the planet **diameter** in Mm inside each planet.

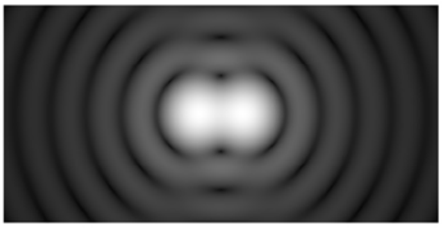


Resolution

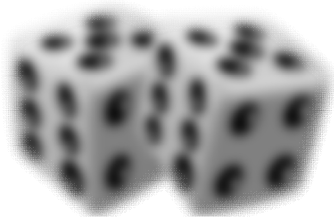
In imaging, the **resolution** refers to the smallest distance between objects that can be distinguished from one another. As the resolution distance increases the image becomes more blurred. This is because points cannot be distinguished from one another.

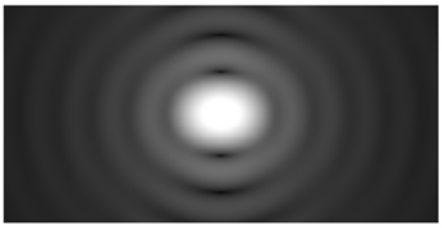


Small resolution distance
Two points can be distinguished here, as they are further apart than the resolution distance.

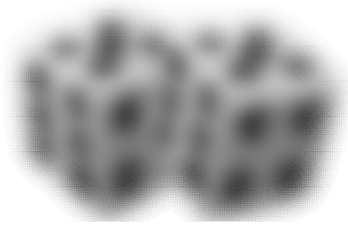


Medium resolution distance
Here the distance between the points approaches the resolution distance. Points can just be distinguished but begin to overlap.





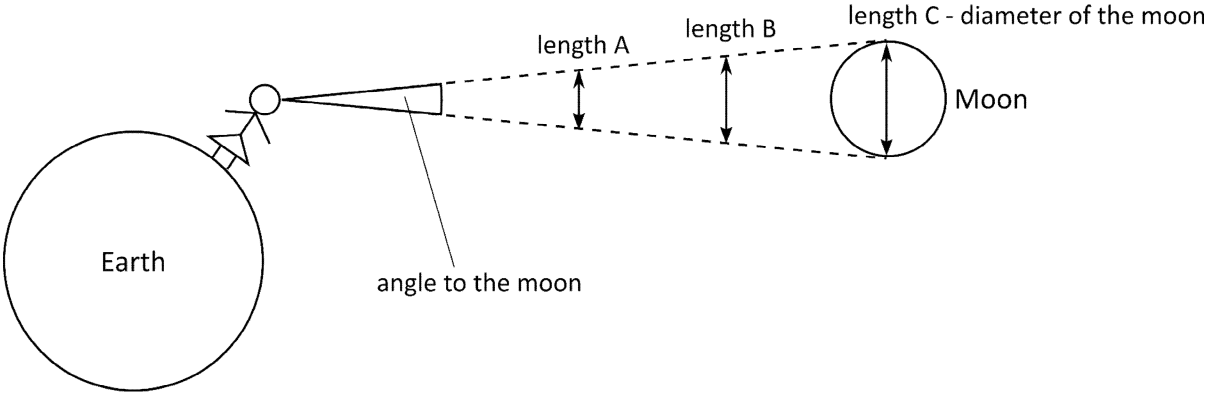
Large resolution distance
The two points are now closer than the resolution distance, and cannot be distinguished from one another.



The **resolution** of telescopes is given in **angles** instead of distance. This represents the smallest angle between objects that can be distinguished from one another. Being able to resolve smaller angles gives a clearer image. Read on to find out how this works…

Angular measurements

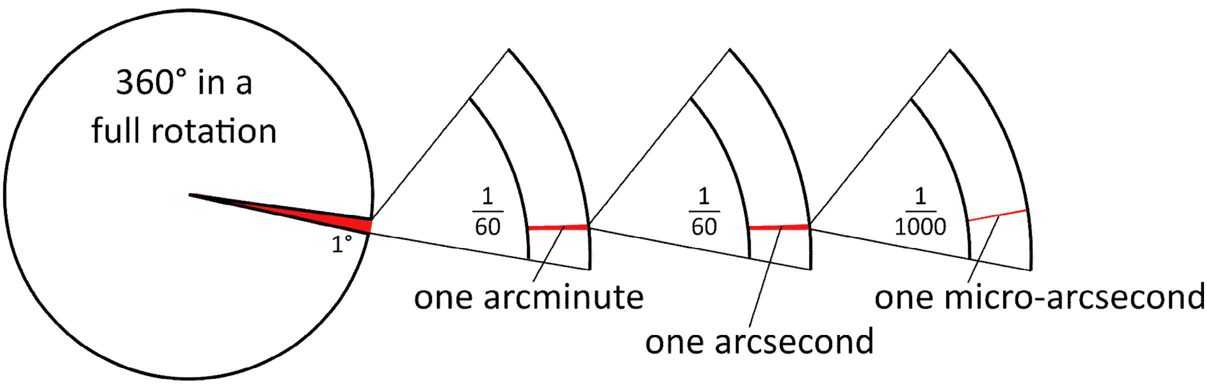
It is not (yet) possible to go to space and measure the size of galaxies or even our Moon. Therefore, when thinking about distances in space (such as the width of a planet or the distance between two stars) angles are used instead. We do not need to know any distances to say what angle is represented by an object, such as the moon.



The angle just considers the size from our perspective. This is useful as we can talk about how big something in space appears to us, on Earth, without knowing how big it is or how far away. When something new is discovered in space, its size is therefore recorded as an angle.
360 degrees (written as 360°) make a full rotation.

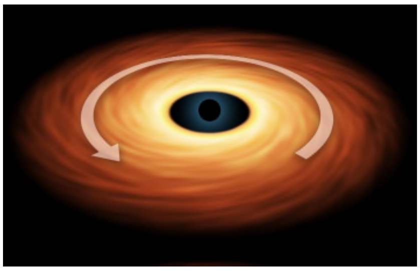
However, the further away from Earth you travel, the larger the distance between one degree becomes (e.g. in the figure above length C is longer than length A).

Therefore astronomers use smaller units, called **arcminutes** and **arcseconds**. One **arcminute** is 1/60th of one degree, and one **arcsecond** is 1/60th of an arcminute, or 1/3600th of one degree! The moon is approximately 30 arcminutes in diameter.



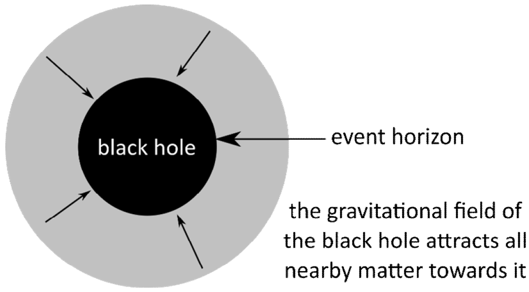
St John's inspire programme

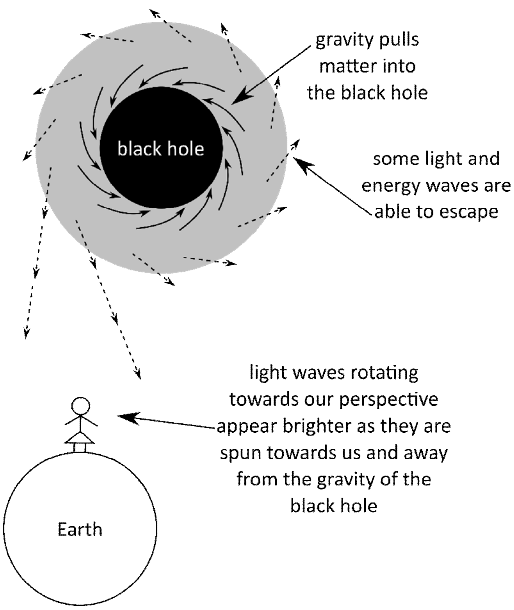
The M87 black hole



A **black hole** results from very large stars (at least 10 times the size of our Sun) when they collapse. It is the most concentrated form of matter, and has such a strong **gravitational field** that nothing can escape from – not even light! This means that seeing a black hole is quite a challenge!

In fact, it is impossible to image the black hole itself. Instead, scientists image the **event horizon** of a black hole. The gravity of a black hole pulls neighbouring matter in, which releases energy. Energy closest to the black hole cannot escape. The region around a black hole where not even light can escape is called the **event horizon**. Everything within this region appears black, and we cannot see it by definition.





However, energy from just outside the event horizon can escape, and this forms a ring of light around the event horizon. Some black holes rotate, and light which is moving towards our point of view appears **brighter** to us than light moving away from our point of view, because it is easier for this light to escape the gravity of the black hole in our direction. Therefore, when we look at a black hole, we expect to see a ring with a brighter side.

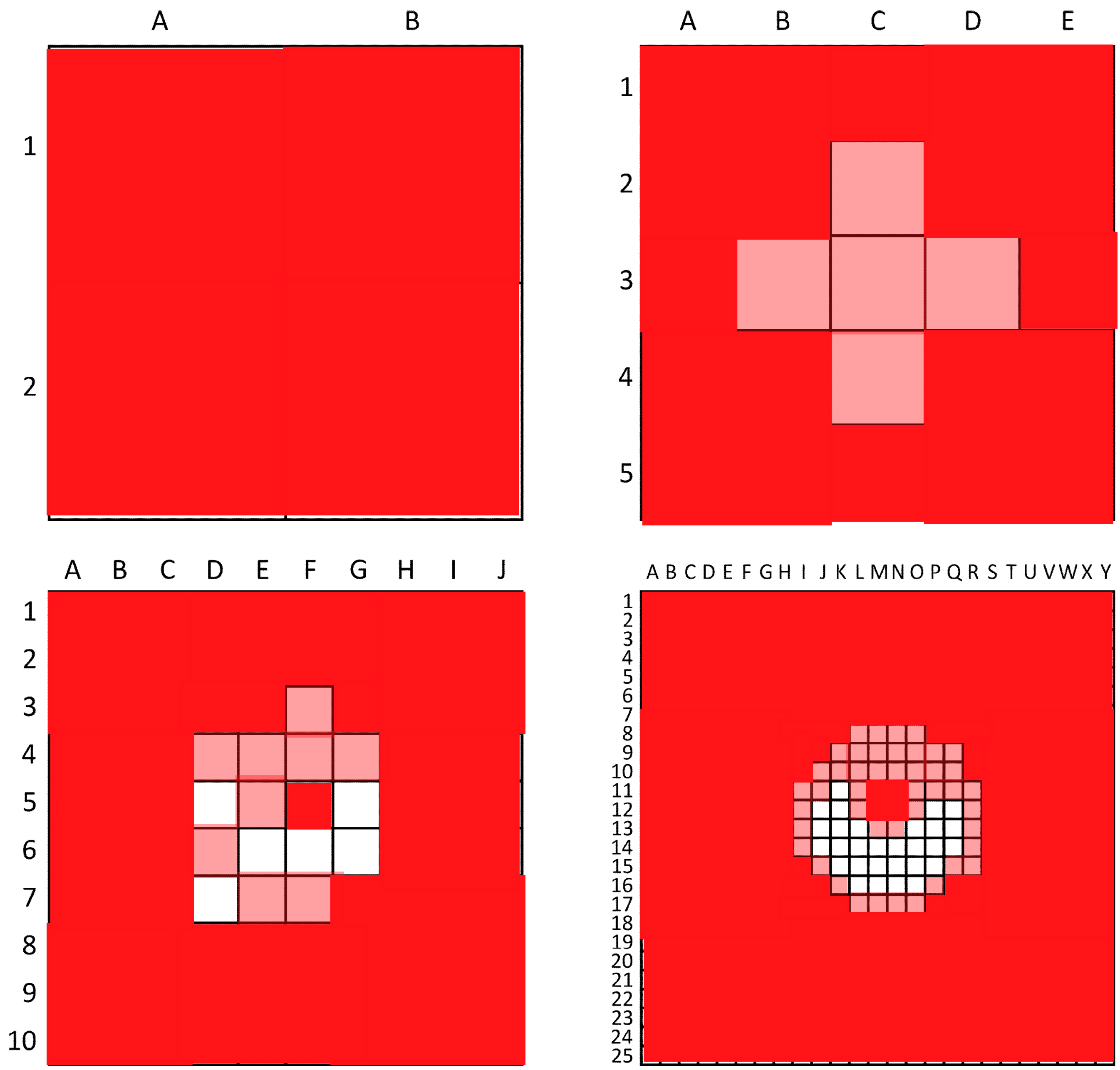
At the centre of another galaxy (M87), 55 million light years away from Earth, there is a huge black hole - 38 billion km in diameter! Because of how far away this is, it requires very good resolution to image the M87 black hole, even though it is so huge.

Thanks to work from a world-wide team of scientists, in **April 2019** the M87 black hole was imaged - the first ever image of a black hole!

You have been given four copies of the M87 image. Each copy of the image has a grid drawn on top. These grids illustrate different possible resolutions (50, 20, 10 and 4 micro-arcseconds). Use the grids provided on the laminated copies of M87 images to help you shade the boxes on your grids. You must choose whether to shade each box white (light), black (no light) or grey (some light) based on the most common colour in each box on the grid.

The M87 black hole image

Use the grids provided on the laminated copies of M87 images to help you shade the boxes on your grids. You must choose whether to shade each box white (light), black (no light) or grey (some light) based on the most common colour in each box on the grid.



Look at the images you've created to see how the resolution of the telescope used affects the resulting image.

What is the minimum resolution required to see the M87 black hole? 20 micro-arcseconds

At what resolution does the M87 black hole show a ring shape? 10 or 4 micro-arcseconds

The precise shape produced will depend on the discretion of the student in shading the boxes - this should be used as a guide. The resolution at which the M87 is a ring shape should reflect what their picture shows.

Recap

Complete the summary using the words below:

There are 8 planets in our Solar System. In order from the Sun, these planets are __Mercury__, __Venus__, __Earth__, __Mars__, __Jupiter__, __Saturn__, __Uranus__ and __Neptune__. Because the distances in space are so vast, they are measured in __light years__, which is the distance that light can travel in one year.

The __resolution__ is the smallest difference that can be measured by a piece of equipment. The resolution of telescopes is measured in __degrees__. An __arcsecond__ is one 60th of an __arcminute__. The moon is approximately 30 __arcminutes__ in diameter. The M87 black hole is approximately __13__ micro-arcseconds in diameter.

Mars	**Jupiter**	**resolution**	**Earth**	**degrees**
Saturn	**arcsecond**	**arcminutes**	**Uranus**	**arcminute**
light years	**13**	**Venus**	**Mercury**	**Neptune**

If you would like to know more about space, the M87 black hole and how it was imaged, you can look at the following resources:

TOPIC	MEDIA FORMAT	HOW TO FIND IT
How to image an orange on the Moon	TED talk	https://www.ted.com/talks/katie_bouman_how_to_take_a_picture_of_a_black_hole#t-202483
Real images from space	NASA website photo gallery	https://www.nasa.gov/mission_pages/hubble/multimedia/index.html
How to build a telescope at home	Instructions sheet	https://science.howstuffworks.com/question568.htm