DESIGNING A TELESCOPE

Astronomy is driven forward by always asking new questions. When we get to a question that we can't answer, it usually means that we don't have the technology, or the knowledge, to get to the bottom of the problem. This drives technology forward, and there are constantly new telescopes in development.

When deciding upon what new telescope to build, the primary driver is the science – what questions are we trying to answer and what technology do we need to answer them.

For example, to be able to answer the question 'can any exoplanets support life?', we needed to build a telescope that could analyse the atmospheres of these planets and look for biological tracers of life. This is one of the big science questions that the James Webb Space Telescope aims to answer.

In this activity the students are given a big science question and must work together to build a telescope to answer it. They will have a budget to work with and must discuss several options for ultimately selecting:

- An observing site
- A telescope mirror design
- A material to build the telescope structure from

Learning Objectives, students will learn:

1. what requirements go in to selecting an observing site
2. about the engineering challenges involved with telescope design
3. to successfully budget
4. to develop their discussion and persuasion skills
5. to work as a team to reach a consensus

*These sheets can be found at the end of this document.

+If choosing to run the workshop in Option 2 below.

**For the extra (optional) activity only.

Each group will require the following:

REQUIRED RESOURCES
Pens/Pencils
Map and fact files of observatory sites*
Information page on telescope mirrors*
Table on material selection for telescope structure*
Poster paper+
Marker pens+
Access to the internet**

Before the Session:
There is very little preparation needed for this session because most of the activities will involve discussion. Students will need access to the map, fact files, mirror information and materials table. You can choose to print out a copy to give to each team – or share the PDF on screen.

Students will need to complete sections in their sheets as you go through the tasks.

There are two options on how to run this activity. Decide on which option you will use before the session starts. You can choose which option best suits your classes size and dynamics:

Option 1: Split your class into small groups. Each small group will need to complete activity 1 (observing site selection), 2 (mirror selection) and 3 (telescope structure material selection) together in their team. They can then compare their completed telescope selection with the other groups at the end of the session.

Option 2: Split your class into three groups. One group will lead the selection of the observing site, one will take the mirror selection, and the final group will take the material for the telescope structure. The groups will need to talk to each other during the planning phase as the decisions made by one group will affect the choices of another. Each group should pick their first choice, and then a backup. Once each group has discussed and made their selections, they must all come together and see if their choices are within budget. If not, they must each try to persuade the other teams to take their primary choice, or willingly take the backup option. The three groups must reach a consensus on the telescope site and design which is within budget.

At the beginning of the session:
Introduce the science goal to your students:

In 2015 the first detection of a gravitational wave was recorded. A gravitational wave is a ripple which travels through the fabric of space (often called space-time) much the same as a ripple travels through water when you drop a stone. They were first predicted by Einstein in 1916 with his theory of relativity. They are made when very massive objects move quickly in space. For the ripples to be strong enough to be detected on Earth, the movement of these objects has to be very fast. The following events are likely to lead to gravitational waves:

- Black holes colliding together
- Huge supernova explosions
- Neutron stars colliding together
- Neutron star merging with a black hole

Gravitational wave detectors on Earth 'listen' out for these events. They can measure the size of the waves and then try to figure out what event caused them. To learn more about this new area of astronomy it is useful to also 'see' the events with telescopes. If the source of the waves includes a neutron star or a supernova explosion, then we should be able to see an optical source alongside the gravitational wave detection. This will help scientists to answer questions like:

- Where did the event take place?
- Do gravitational waves travel at the speed of light?
- What is going on inside a neutron star?
- How do stars actually explode?

Set the scene:

- Split your class into groups using either option 1 or 2 outlined above.
- Allocate your students a budget of £150 million to produce a new telescope which will look for the optical counterparts of gravitational waves. Make it clear that the budget does **not** need to be split equally across the three components they need to select.
- If you're using **Option 1** then go through each activity below in turn.
- If you're using **Option 2** then allocate one of Activities 1 to 3 (below) to each group.

ACTIVITY 1: OBSERVING SITE SELECTION

Allow 10-15 minutes for this activity.

In order to detect the maximum number of gravitational wave sources it is important for the observing site to be close to the equator, from which both the northern and southern hemispheres can be observed. The students must choose between the 6 options for an observing site.

Students should consider:

- How stable the site is in terms of ground movements and air turbulence (seeing).
- The weather on site (cloud cover, wind, rain, dust etc.).
- How easy the site is to access for both building and maintenance of the telescope.
- The cost of land rental for the telescope - this scales with the size of the telescope mirror needed.
- Any special cultural impacts of developing on the site.
- The levels of light pollution.

1. Provide the group(s) with the map of available observing sites for their telescope, and the associated fact files.
2. Instruct the group(s) to consider all the factors for each observing site and come to a decision on which site they would like to select for their primary choice and backup choice.
3. Ensure that the students fill in their sheets with their primary choice and back up choice, whilst also filling in the table of pros and cons for each site selected.
4. Note down the budget which needs to be allocated to each choice.

ACTIVITY 2: MIRROR SELECTION

Allow 10-15 minutes for this activity.

Gravitational wave sources can come from very distant objects. In order to be able to see these distant sources, astronomers must use telescopes with as large a mirror as possible. The bigger the diameter of the mirror, the more light that can be collected, enabling you to see fainter objects.

Students should consider:

- ☆ How the different shaped mirrors fit together and how much light is lost through any gaps.
- ☆ The overall weight of their mirror – the lighter the better – this will affect which materials they can use for the structure.
- ☆ The total diameter of the mirror – the larger the mirror the fainter the objects they will be able to see – this means that they will be able to look for objects at greater distances.
- ☆ The price of the mirror.
- ☆ How easily the mirror can be transported to site.
- ☆ How easily the mirror can be assembled on site.

1. Provide the group(s) with the mirror information page.
2. Instruct the group(s) to consider the size and shape of the mirrors and come to a decision on which mirrors they would like to select for their primary choice and backup choice.
3. Ensure that the students fill in their sheets with their primary choice and back up choice, whilst also filling in the mirror diagram, weight and mirror diameter information.
4. Note down the budget which needs to be allocated to each choice.

ACTIVITY 3: TELESCOPE STRUCTURE MATERIAL SELECTION

Allow the students 10-15 minutes for this activity.

Gravitational wave sources are also likely to emit flashes of optical light, which appear and then fade very quickly. This means that the telescope needs to move very quickly to see the light before it disappears. The materials need to be strong enough to support the mirror, but light enough to move at speed.

Students should consider:

- ☆ The material properties (e.g., strength, malleability, weight and stress tolerance).
- ☆ The availability of the material (e.g., new vs proven technology, mass manufacturing).
- ☆ The cost of their material.

1. Provide the group(s) with the Material Selection table.
2. Instruct the group(s) to consider the benefits of each material, balanced against its cost. They should come to a decision on which material they would like to use for their telescope structure, and what their backup choice is.
3. Ensure that the students fill in their sheets with their primary choice and back up choice, whilst also filling in the pros and cons table.
4. Note down the budget which needs to be allocated to each choice.

ACTIVITY 4: REACHING A DECISION

If you are using **Option 1**:

1. Allow the students 5 minutes in their groups to total up the budget for their primary telescope design. If this exceeds the given budget, then they should decide in their group which backup choices to use to ensure they come in under/on budget whilst maintaining the best telescope they can for the science.

2. Once the group has reached a decision, get them to note this final design down in their workbooks.

If you are using **Option 2**:

1. Allow each group 15 minutes to choose a member (or several) of the group to pitch their primary and back up choices to the rest of the club. The group should transfer their ideas to poster paper to present to the rest of the club. They should justify their decisions and relay the cost implications.

2. Allow each team 5 minutes to pitch their ideas to the class and bid for the budget they need.

3. Get the students to vote as a class for the primary or backup option for each aspect of the telescope design. They need to reach a consensus for the telescope which comes in under/on budget.

4. Once a decision has been made, get the students to fill in the rest of their sheets, under the activity headings their teams did not focus on in stage 1. They only need to complete the details of the consensus for each activity, not any back-up options.

At the end of the session:

If you are using **Option 1**:

1. Bring the class back together.

2. Quickly run through the groups to see if there has been any consensus in the final design decisions of the groups – have they picked the same observing site, mirror setup or material?

3. Ask the group if they have found anything challenging or surprising about this session.

4. Talk to the group about the cost of building various telescopes as listed in the student workbooks. The massive budgets involved mean that countries must work together to develop new technologies. No single state can afford to do this alone.

If you are using **Option 2**:

1. Bring the class back together.

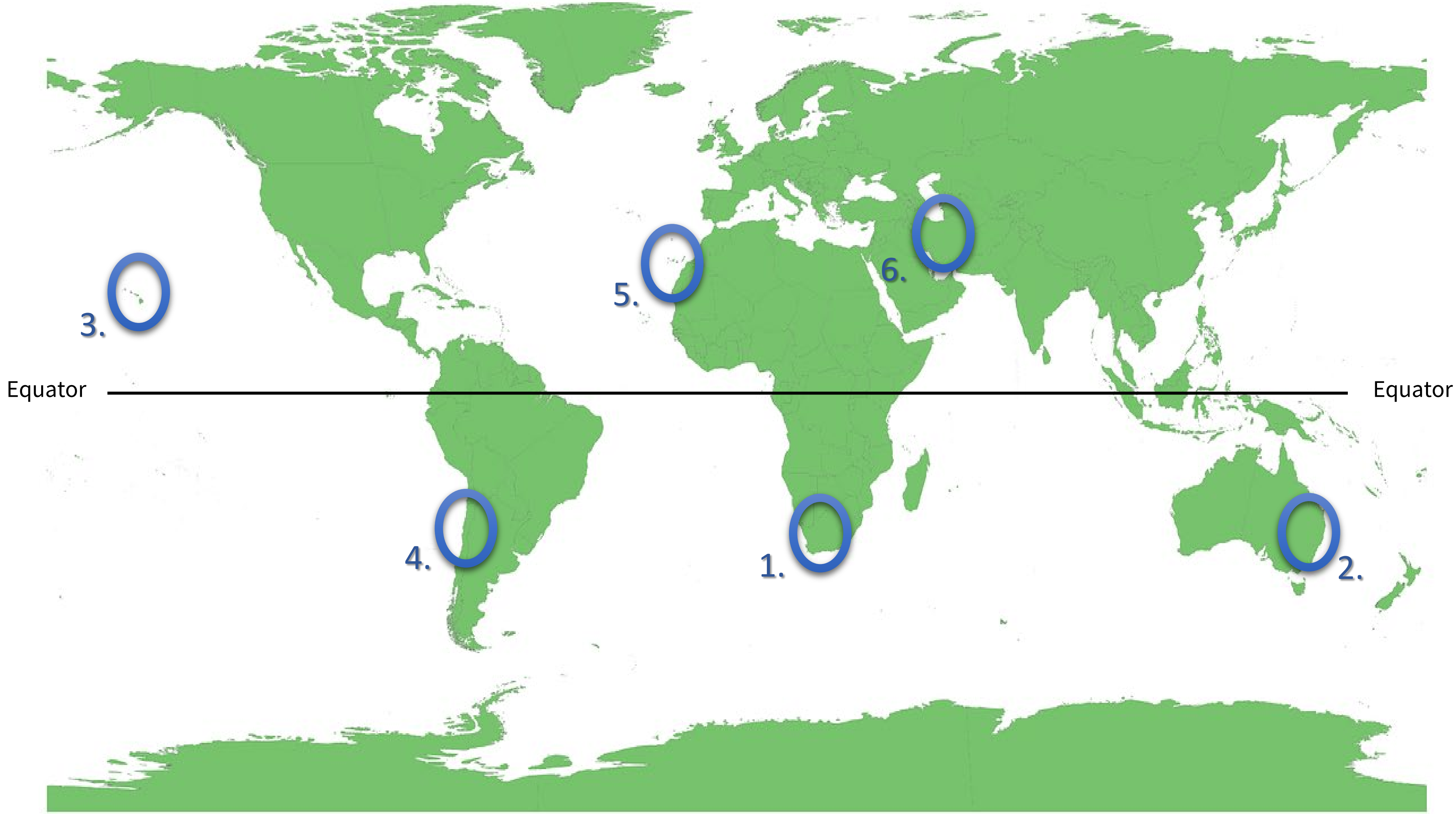
2. Ask the group if they have found anything challenging or surprising about this session.

3. Talk to the group about the cost of building various telescopes as listed in their sheets. The massive budgets involved mean that countries must work together to develop new technologies. No single state can afford to do this alone.

Extra Activity:
If any of your students have enjoyed this activity they may want to try a more advanced version – designing and launching a space telescope: Chris North's Design a Space Telescope activity:
chrisnorth.github.io/design-a-space-telescope

They might also like the computer game: Kerbal Space Program: www.kerbalspaceprogram.com

ACTIVITY 1: OBSERVING SITE SELECTION



Location	1. Sutherland (South Africa)	2. New South Wales (Australia)	3. Hawaii (USA)
Height above sea level:	1798 m	1164 m	4205 m
Risk of Natural Disaster:	Earthquake: Low Wildfire: Moderate	Earthquake: Low – Moderate Wildfire: Moderate	Earthquake: High Wildfire: Low
Clarity of sky: (the lower the better)	1.3	1.1	0.5
Risk of cloud:	20%	30%	25%
Average wind speeds:	4 m/s	3 m/s	5.5 m/s
Accessibility of site:	Good	Good	Medium
Light pollution levels:	Excellent	Excellent	Excellent
Anything you should know:	N/A	The site is within the Warrumbungle National Park which is home to many endangered bird species.	The mountain is considered sacred to the Native Hawaiian population and there are endangered native birds living in the area.
Cost of land rental: (per square metre)	£0.2 million per square metre	£0.2 million per square metre	£0.5 million per square metre

For every 1 meter wide your mirror is, you need 10 square meters of land.
E.g., if the widest part of your mirror is 9 metres, then you need 90 square metres of land.

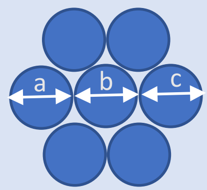
Location	4. Andean Mountains (Chile)	5. Canary Islands (Spain)	6. Isfahan Province (Iran)
Height above sea level:	2635 m	2396 m	3600 m
Risk of Natural Disaster:	Earthquake: High Wildfire: Low	Earthquake: Low Wildfire: Low	Earthquake: High Wildfire: Medium
Clarity of sky: (the lower the better)	0.7	0.8	0.7
Risk of cloud:	10%	35%	35%
Average wind speeds:	3.5 m/s	6 m/s	4.5 m/s
Accessibility of site:	Medium	Good	Medium
Light pollution levels:	Excellent	Good	Good
Anything you should know:	Some of the sites in this area have ancient archaeological finds such as stone circles and rock engravings.	The site is within the Caldera de Taburiente National Park, home to a species of endangered tree. The site is subjected to 'calima' frequently – dust and sand blown over from the Sahara desert.	This is a very new observatory site with access roads completed in 2016 and the first telescope on site opening in 2018.
Cost of land rental: (per square metre)	£0.4 million per square metre	£0.3 million per square metre	£0.1 million per square metre

For every 1 meter wide your mirror is, you need 10 square meters of land.
E.g., if the widest part of your mirror is 9 metres, then you need 90 square metres of land.

ACTIVITY 2: MIRROR SELECTION

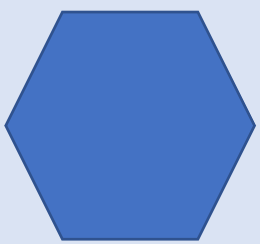
☆ The bigger the area of a mirror, the more light a telescope can capture. This allows us to see further, and in greater detail.
☆ Your telescope needs to have an **effective diameter of at least 8m** in order to detect the sources of gravitational waves.
☆ There are two main choices for you to make: Will you use circular or hexagonal mirrors? Will you use a single mirror or multiple mirrors?

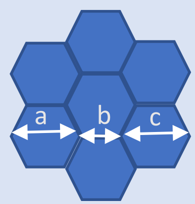
Using circular mirrors



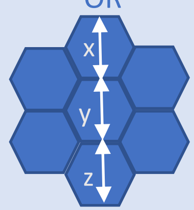
☆ Multiple mirrors don't fit together tightly
☆ 10% of the light is lost through the gaps between the mirrors
☆ So the effective diameter (ED) when using multiple circular mirrors is the total diameter of the mirrors combined multiplied by 0.9
☆ **ED = 0.9 x (a + b + c)**

Using hexagonal mirrors

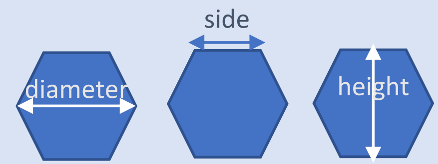




OR

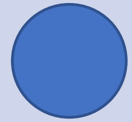


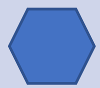
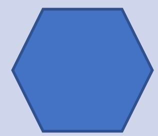
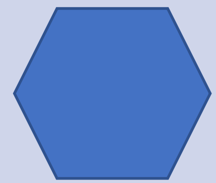
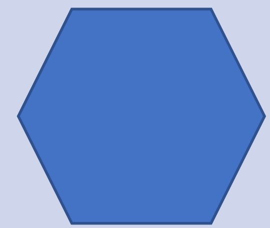
☆ Multiple mirrors do fit together tightly
☆ So the effective diameter (ED) when using multiple hexagonal mirrors is the total diameter of the mirrors
☆ **ED = a + b + c or x + y + z**
☆ For a hexagon:
  ☆ Side = 0.5 x diameter
  ☆ Height = 0.87 x diameter



DESIGNING A TELESCOPE

ACTIVITY 2: MIRROR SELECTION

Circular Mirrors	Diameter	1 m	2 m	3 m	8 m
	Mirror				
	Cost	£0.5 million	£2.5 million	£7 million	£60 million
	Weight	500 kg	2,000 kg	4,500 kg	32,000 kg

Hexagonal Mirrors:	Diameter	1 m	2 m	4 m	10 m
	Mirror				
	Cost	£1 million	£5 million	£15 million	£100 million
	Weight	400 kg	1,600 kg	6,400 kg	40,000 kg

You must consider…

- ☆ How the different shaped mirrors fit together and how much light is lost through any gaps.
- ☆ The overall weight of their mirror – the lighter the better – this will affect which materials they can use for the structure.
- ☆ The price of the mirror.
- ☆ The total diameter of the mirror – the larger the mirror the fainter the objects they will be able to see – this means that they will be able to look for objects at greater distances.
- ☆ The overall shape of the mirror - a roughly circular shape will focus the most light onto the detectors.

ACTIVITY 3: TELESCOPE STRUCTURE MATERIAL SELECTION

Select the Structure Material for your Telescope

Material	**Strength** – Weight Limit (units – kg)	**Weight** – Density of material (Lower the better – units g/cm^3)	**Stress tolerance** (Higher the better – units ksi)	**Malleability** – How easy is it to shape?	**Proven Technology?**	**Mass Produced?**	**Total Cost (£)**
Iron alloy	50,000	10.5	24	Easy	Yes	Yes	10 million
Steel	39,000	8.1	100	Easy	Yes	Yes	39 million
Aluminium alloy	28,000	2.7	19	Moderate	Yes	Yes	13 million
Graphene	12,000,000	2.3	70000	Extremely Easy	No	No	90 million
Carbon fibre	326,000	2.0	250	Easy	Yes	Yes	50 million
Polycarbonate plastic	7,000	1.2	46	Moderate	Yes	Yes	2 million

You must consider…

- ☆ The material properties (e.g., strength, malleability, weight and stress tolerance).
- ☆ The availability of the material (e.g., new vs proven technology , mass manufacturing).
- ☆ The cost of the material.