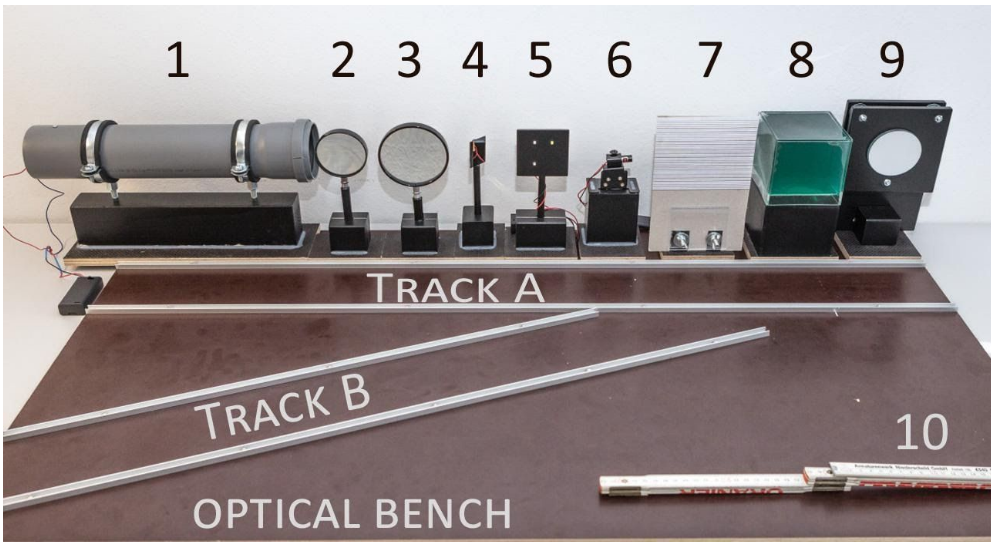
Catching Starlight: Student Worksheet

Attention: In this workshop you will use a Class 2 laser. Laser light can be focused by the eye into an extremely small spot on the retina, resulting in localised burning and permanent damage in seconds. The lasers used in this activity are safe because the blink reflex will limit the exposure to no more than 0.25 seconds. BUT staring in the beam or intentional suppression of the blink reflex could lead to eye injury.

You are going to investigate telescopes by making different designs yourself using lenses and mirrors.

Check that you have the following equipment (see Picture 1):

1 Laser cannon
2 Small lens
3 Large lens
4 Flat (plane) mirror
5 LED panel
6 Red laser
7 Small screen
8 Light-ray block and stand
9 Circular mirror
10 Ruler/tape measure
Optical Bench (Tracks A and B)
Calculator



Picture 1

If you have all of the equipment, now follow the instructions below.

Starter Activity

Telescopes need to collect light and give you a clear focussed (non blurry) and magnified image of a very distant object.

Safety: Never look directly at the Sun.

Q. Pick up the biggest lens. What do you see when you look at a distant object through the big lens? How clear is the image, what size? (Choose a distant object outside if possible)

Q. Now pick up the small lens. What do you see when you look at a distant object through the small lens? How clear is the image, what size? How does it differ from the view through the big lens?

Q. Would either of these lenses on their own be an effective telescope?

Work in pairs/groups

1. Someone takes one lens (this is the "Observer"), shuts one of their eyes and holds the lens up close to the open eye.
2. Find an object in the distance to look at through the lens, e.g. distant vehicle.
3. Now someone else takes the other lens and lines it up between the other lens and the object they are looking at.
4. The Observer should now be looking through BOTH lenses at the distant object.
5. Both people can now move one or both lenses backwards or forwards to try and get a clear picture of the object the Observer is looking at.
6. Also try switching the lenses around.
7. Let everyone in the pair/group have a turn as the Observer.

Q. Which lens is closer to the observer's eye when the image appears CLEAR and CLOSER?

When the image appears closer you have made a telescope. The lens nearest to the Observer's eye is called the eyepiece lens.

Part A: Refracting Telescopes

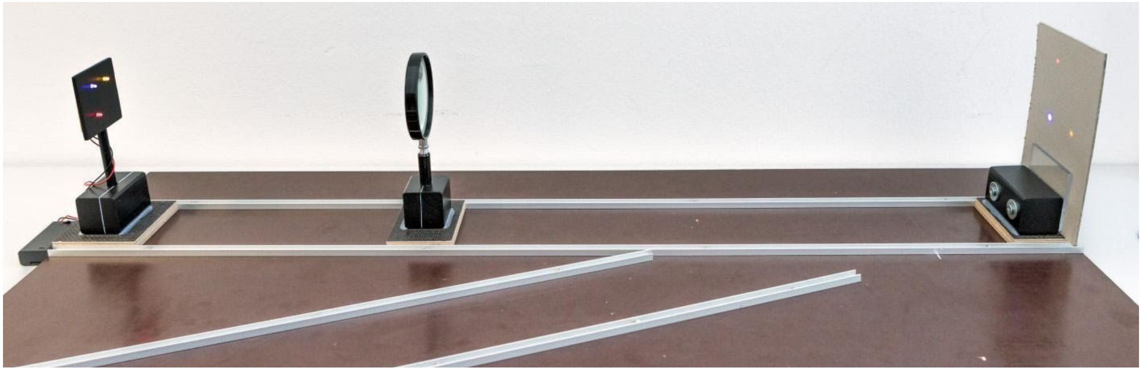
A1. Set up the equipment as follows (see Picture A1):

i. Place the LED panel on the optical bench at one end of Track A.

ii. Place the screen at the other end of Track A.

iii. Put the large lens (called the “Objective Lens’’) in between them.

iv. Turn the LEDs on with the switch on the battery pack and look at the image now visible on the screen. The image is in focus when the dots are not blurry and the pattern looks like the lights do on the LED panel.



Picture A1

Now answer the questions below in the spaces provided.

A1a) Describe what happens to the image when you move the large lens backward and forwards along the track.

Hint: You could draw and describe how the size of the dots change.

A1b) How many times do the dots come into focus as you move the lens along the track?

A1c) Describe what do you notice about the positions of the three colours on the image on the screen compared to those on the LED panel?

2. Now leave the large lens in one of the positions when the image is in focus. Use the ruler or tape measure to measure the following distances.

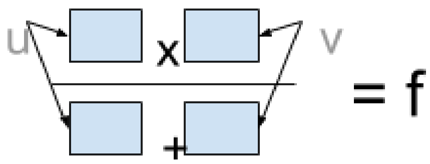
Hint: Some of the equipment items have white lines marked on them to help you know where to measure the distances from.

A2a) What is the distance between the large lens and the screen (v)?
v =

A2b) What is the distance between the large lens and LED panel (u)?
u =

A*2c) What is the focal length (f) of the large lens?*
Hint: You need to use the equation 1/f = 1/v + 1/u.
[advanced - rearrange the formula and calculate the focal length]

[regular - fill in the boxes and calculate the focal length]



3. Now replace the large lens on Track A with the small lens and move it along the track until you get a focussed image (similar to Picture 2 above).

A3a) Determine the focal length of the small lens the way you did with the large lens:

v =

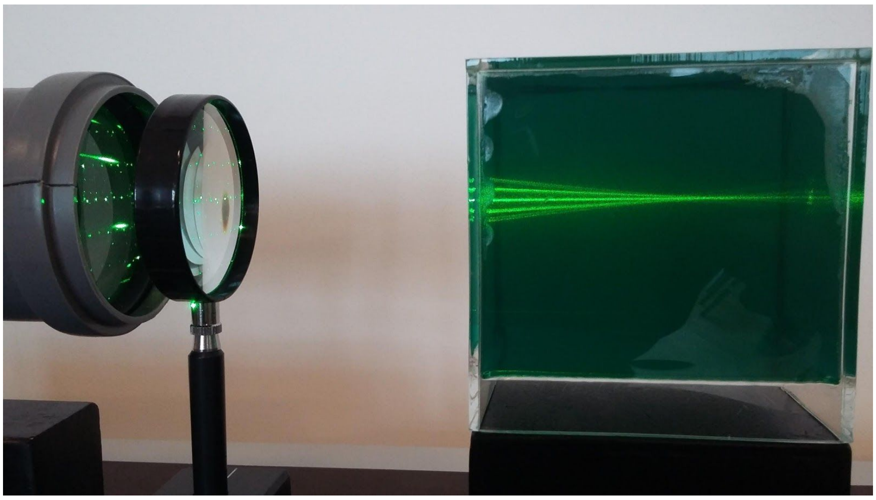
u =

f =

A*3b) Based on what you observed and measured, describe the differences between the two lenses.*

A4. You will now build a refracting telescope. Lasers will represent the light coming from very distant objects in space so that you can investigate their light paths. Light coming from distant objects are parallel when they reach Earth. First investigate the lenses individually.

i. Replace the LED panel with the laser cannon. (object 1 on Picture 1 first page)
ii. Replace the screen with the light-ray block and turn the laser cannon on.
iii. Now put the large lens on the board in between the laser cannon and the light-ray block close to the laser cannon.
iv. Move the light-ray block until you see the point where all laser rays intersect inside the light-ray block. See Picture A2.



Picture A2

A4a) Use the ruler/ tape measure to measure the distance between the large lens and the point where the laser rays intersect (focal length):

f_{large} =

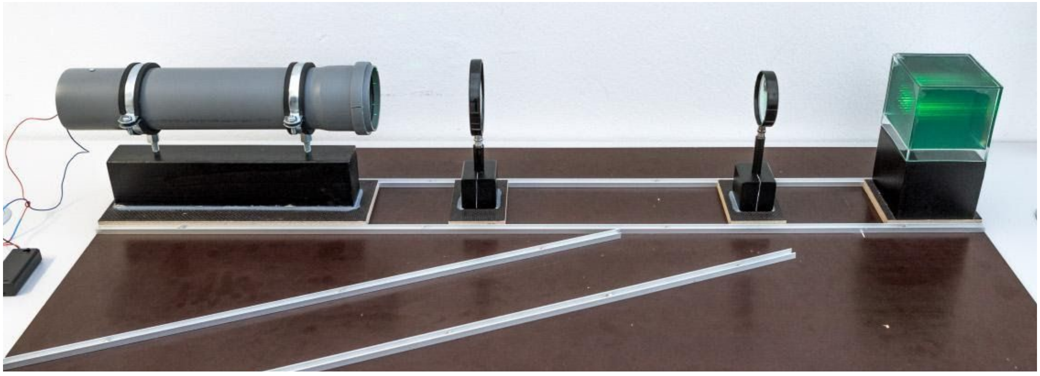
A4b) Replace the large lens with the small lens and determine its focal length the same way you did with the large lens.

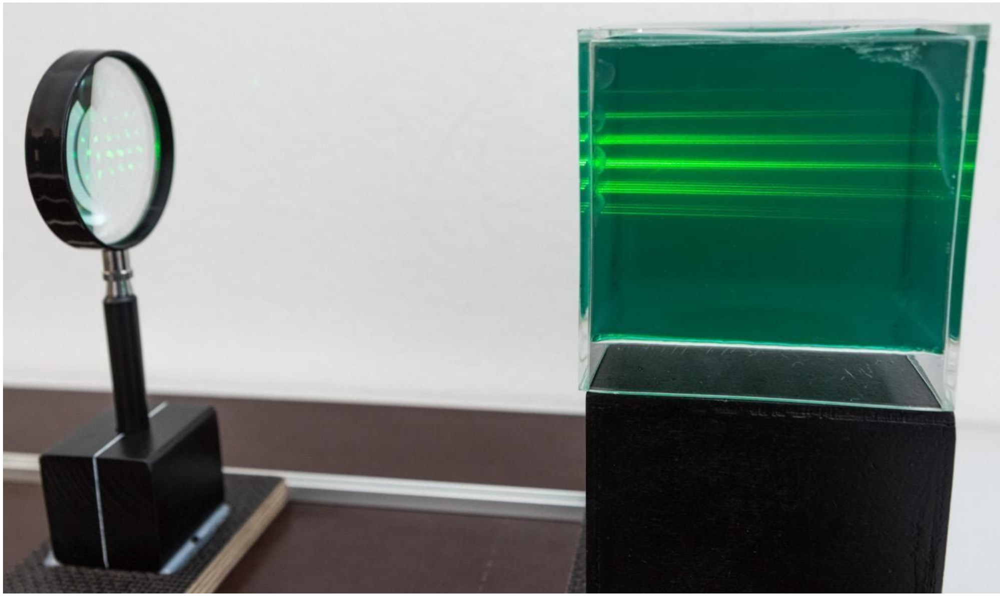
f_{small} =

A4c) Describe how these new measurements of the focal lengths for the two lenses compare to your calculations in section 2c) and 3a)? How do they compare to the numbers from other groups? Comment on possible reasons for any differences.

A5 You will now investigate the combination of both lenses:

i. Put both lenses on the board with the large lens next to the laser cannon and the small lens ("eyepiece") close to the light-ray block. See Picture A3.
ii. Move the small lens until the light rays leaving the small lens (eyepiece) are parallel when you look sideways into the light-ray block. See Picture A4.


Picture A3

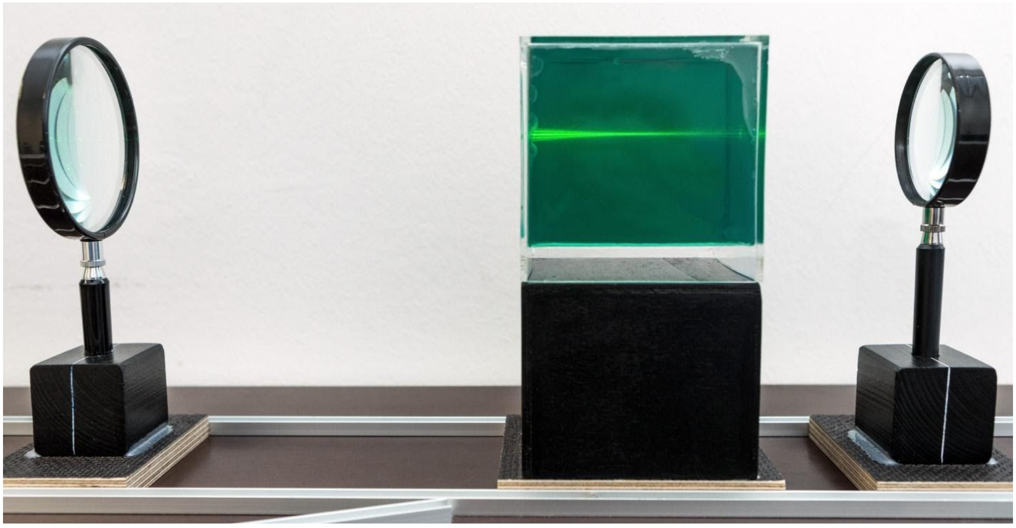

Picture A4

A5a) Fill in this `light ray diagram' to show the path of three example light rays (1, 2 and 3) through the optical system.
Hint: Move the light block to different positions e.g. between the two lenses, to see where the rays are going (see Picture A5):

A5b) Label on your diagram where all three light rays cross as the "focal point".

A5c) Try to explain why the image of the LEDs in section 1c) was upside down?

iii. Now place the light-ray block between the lenses (see Picture A5) and line up so that the focal point (where all of the light rays cross) is in line with the white line on the block. DO NOT MOVE ANY OTHER EQUIPMENT.
vi. Use the ruler/ tape measure to measure the distances and answer the questions written below.



Picture A5

A5d*) Determine the distance from large lens to focal point (the focal length).*
F_o =

A5e) Determine the distance from small lens to focal point (the focal length).
F_e =

A5f) With the findings of F_o and F_e comment on the separation distance of the two lenses when the light rays leaving the small lens (eyepiece) are parallel.

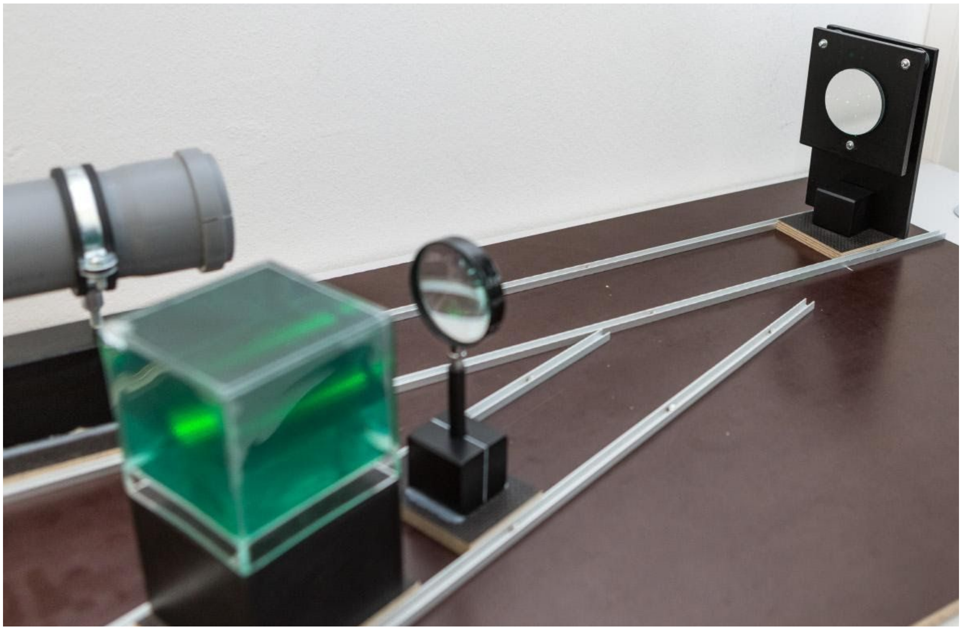
A5*g)* [advanced] *Calculate the magnification (M) of your optical system.*
Hint: Use the equation $M=f_{large}/f_{small}$ where f_{large} is the focal length of the large (objective) lens and f_{small} is the focal length of the small (eyepiece) lens.

Part B: Reflecting Telescopes

Another type of telescope is a reflecting telescope. They mainly use mirrors to collect light and move it around the telescope.

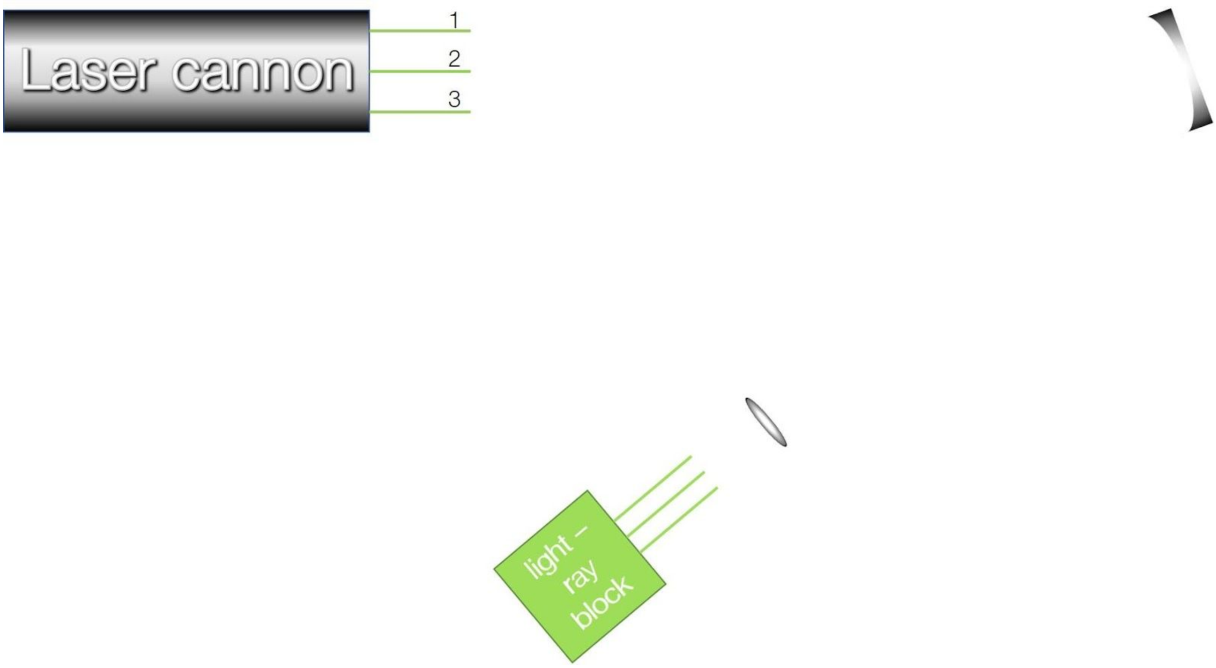
You will now convert your model refracting telescope into a model reflecting telescope. Switch off the laser cannon.
i. Remove the large lens.
ii. Move the small lens onto Track B - approximately in the middle
iii. Place the circular mirror near the end of Track A (opposite end to the laser cannon),
iv. Line up the front of the mirror stand with the white lines marked on the track.
v. Place the light-ray block somewhere behind the lens on Track B.
vi. With the laser cannon turned on (don't look directly at the lasers), rotate the position of the mirror until the light rays reflect off the mirror, go through the middle of the small lens and into the light-ray block. Be careful as you do this, making only small movements with the mirror.
vii. Adjust the position of the lens by moving it up and down the track until the light rays leaving the small lens look parallel as they go through the light block.

Your set up should now look like Picture B1.



Picture B1

a) Complete this ray diagram for your basic reflector design and label the focal point:
Hint: Move the light-ray block to different positions.



b). Determine the distance between the focal point and the small lens (f_{small}).
f_{small} =

c) Comment on how this compares to the value you measured for the small lens in the refractor model in Part A (question A4b)?

d) Determine the distance between the focal point and the mirror (f_{mirror}).
f_{mirror} =

e)* [advanced] *Calculate the magnification of your telescope
Hint: Use the equation $M=f_{mirror}/f_{small}$ where f_{mirror} is the focal length of the (primary) mirror and f_{small} is the focal length of the small (eyepiece) lens.

f)* [advanced] *Comment on how the magnification of this reflector compares with the refractor design in Part A?

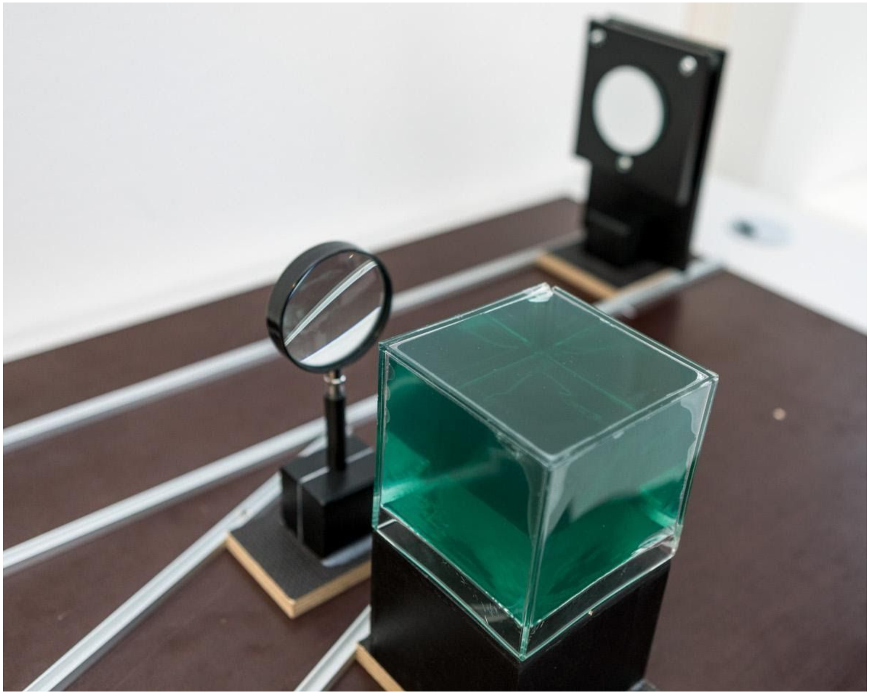
g) **[advanced]** ***If you had wanted to design a refractor (two lens system) that had the same magnification as this reflector design what would be the distance between the two lenses? Assume that you use the same eyepiece (small) lens in the design.***

h) Big telescopes like the VLT/ELT use mirror designs. Suggest some reasons why the biggest telescopes in the world all use mirror designs rather than lenses.

Part B - Extension Activity 1: Newtonian Design

In professional observatories, telescopes are used to direct light into instruments (e.g., cameras/spectrographs). These instruments can only be put in certain places. Therefore, in telescopes a series of mirrors are used to direct the light to the instruments.

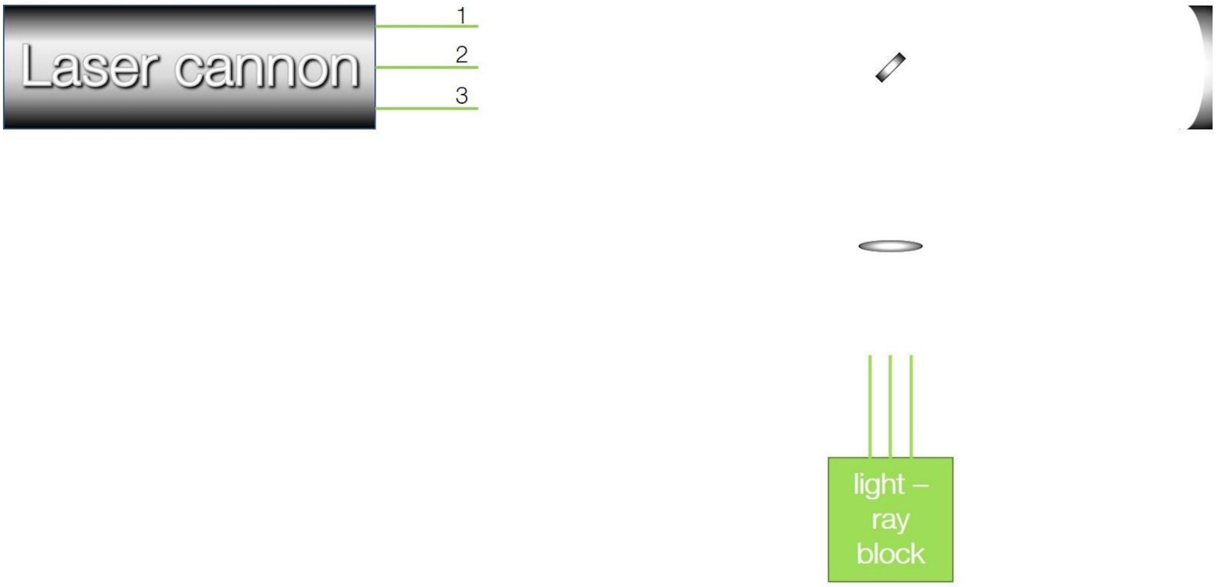
i. Keep the laser cannon in its place at the end of Track A.
ii. Keep the circular mirror near the other end of Track A (opposite end to the laser cannon)
iii. With the laser cannon turned on (don't look directly at the lasers), rotate the position of the mirror until the light rays reflect off the mirror, go back to the laser cannon.
iv. Place the light-ray block on the "instrument" location on the board. Place the small lens in front of it with the lens' surface parallel to Track A. See Picture 1.



Picture 1

v. Place the flat mirror on Track A in between the laser cannon and the circular mirror.
vi. With the laser cannon on, move the flat plane mirror on Track A to direct the light-rays into the small lens and light-ray block.
vii. Move the small lense to get the light-rays visible in the light-ray block parallel.

a) Complete this ray diagram for your newtonian design and label the focal point: *Hint: Move the light-ray block to different positions.*



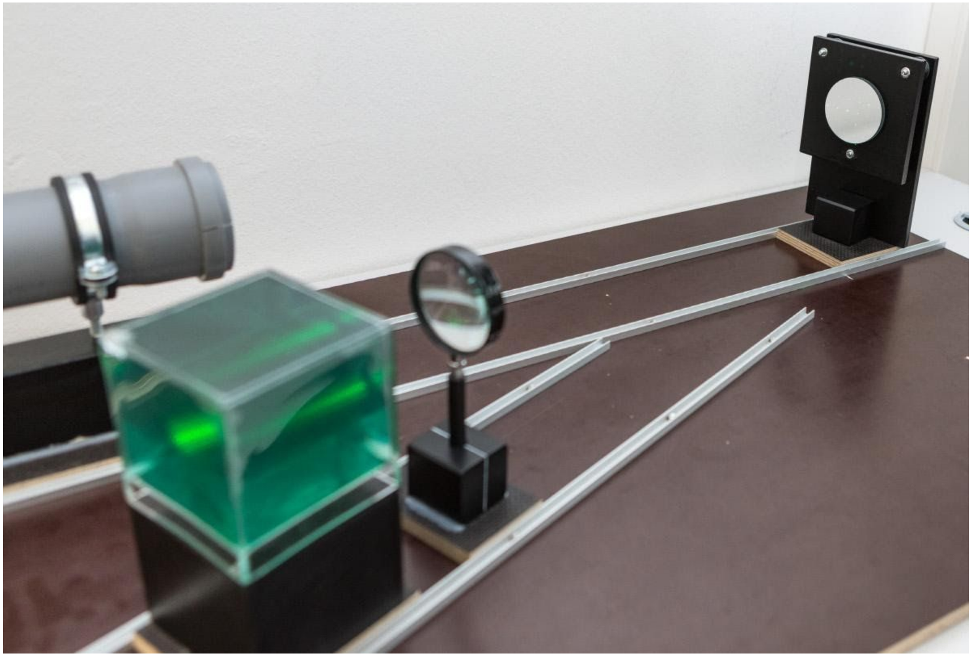
b) Measure the distance between the mirror and the small lens (via the flat mirror). How does it compare to the same measurement in Part B?

c) Discuss possible pros and cons of this design.

When you have finished this activity, go and collect Extension Activity 2 from the demonstrator if you have not already done it.

Part B - Extension Activity 2: angles and magnification

Adjusting the telescope:
i. Keep the laser cannon and the circular mirror in the positions they've been after Part B of this Workshop.
ii. Place the small lens on Track B with the light-ray box behind it (see Picture 2).
iii. Turn on the laser cannon and adjust the mirror angle and the position of the small lens until the laser beams visible in the light-ray block are parallel.



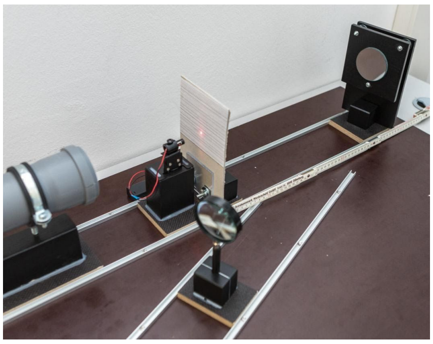
Picture 2

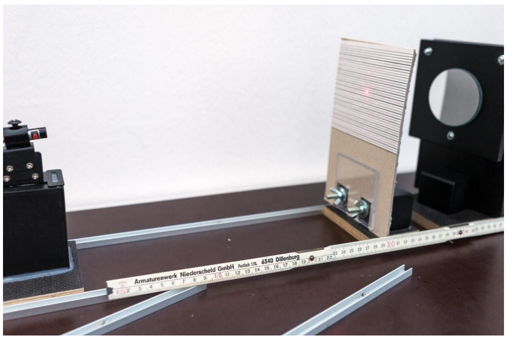
Adjusting a measuring laser:
iv. Turn off the laser cannon.
v. Remove the light-ray box and replace it with the screen
vi. Place the little red laser on Track A just in front of the laser cannon and about 50 cm from the circular mirror and turn it on. The red laser beam should be reflected by the mirror towards the small lens so that it hits the lens near its upper edge (Picture 3).

Picture 3

Now you will use the screen and the red laser to help you work out the magnification of this telescope.

i. Place the screen directly in front of the red laser so the beam shines on the scale paper.
ii. Read off the position of the red dot using the y axis and record the number.
iii. Move the screen 30 cm backwards along the track away from the red laser.
iv. Now record the new position of the red dot using the y axis.





Step i. Step ii. Step iii.

a) Calculate the difference between the two values you measured.

v. Now move the screen to directly behind the small lens (as in Picture 3). The red laser beam should still be shining on the scale paper.
vi. Record the position of the red dot using the y axis.
vii. Again move the screen 30 cm backwards along the track away from the small lens.
viii. Now record the new position of the red dot using the y axis.

b) Calculate the difference between these two values.

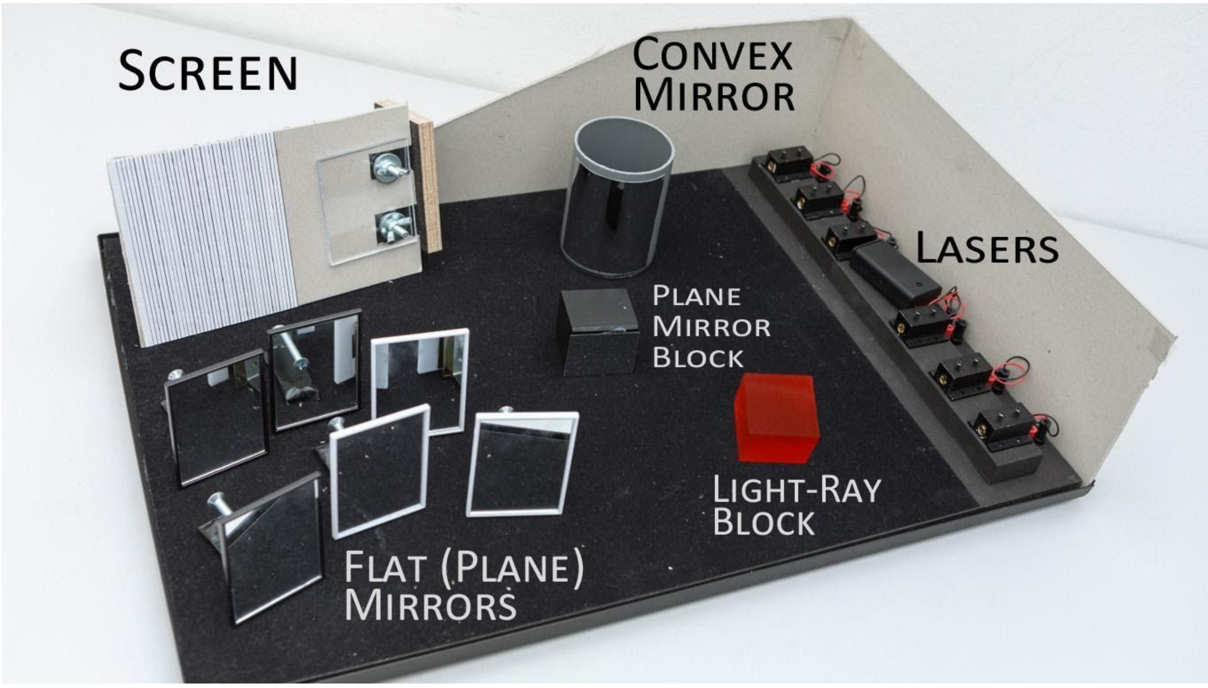
c) As the differences (results of a) and b)) are taken at same horizontal legs, the ratio of the differences is the magnification. Having this information calculate the magnification of this telescope.

When you have finished this activity, go and collect the other Extension Activity 1 if you have not already done it.

Part C: Segmented Mirrors

Check that you have the following equipment (see Picture C):

1 Laser table with six laser points in their holders
2 Six plane (flat) mirrors
3 Light-ray red plastic block
4 Convex Mirror
5 Screen
6 Plane Mirror Block
7 Laser guard placed around the perimeter of the table



Picture C

C1. You will create a basic model of a segmented mirror design.
i. Place the light-ray block in the middle of the laser table.
ii. Turn on the 6 red lasers in the holders.
iii. Line up the six plane (flat) mirrors on the other side of the laser table to the lasers to create an arc or "C" shape which effectively acts as one large curved mirror. Note that there should be a gap in the shape of the segmented mirror. (see picture C1)
iv. Adjust the positions of the mirrors by using the screws or *actuators* on their stands and changing their angles until all six reflected light rays focus into the centre of the light ray block.
The set-up should now look like Picture C1.

Picture C1

C1a) ESO's Extremely Large Telescope will use a segmented mirror design. When it is finished, its segmented mirror will be 39m in diameter and consist of 798 segments. Why do you think the astronomical images will be difficult to get in focus?

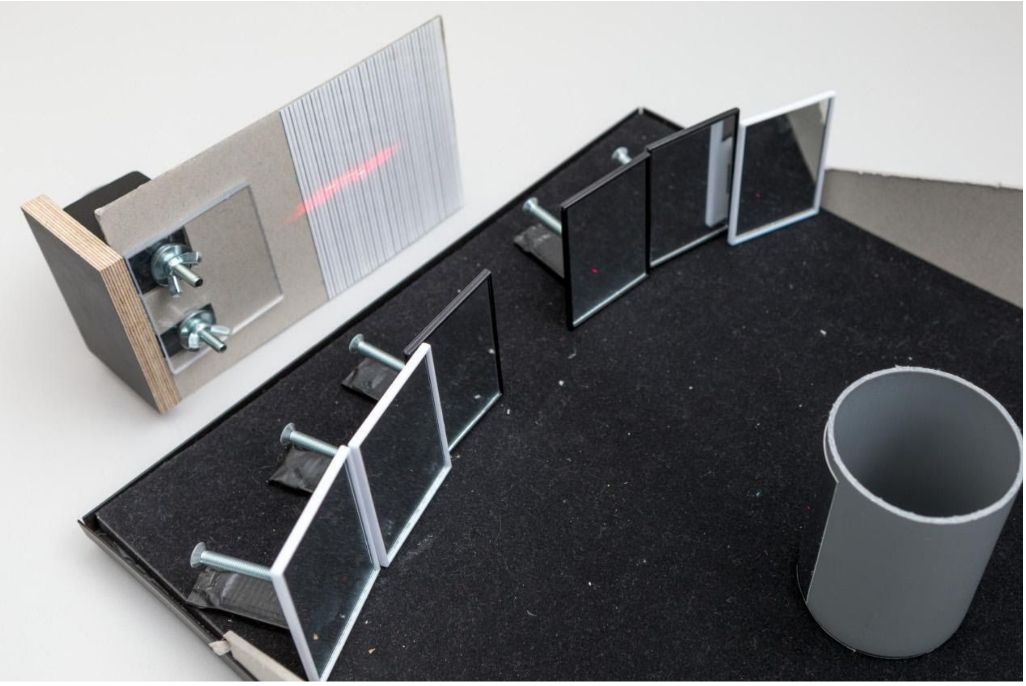
C1b) Each segment in the ELT will be able to be automatically adjusted using actuators on the back. How do you think the actuators will "know" how to move?

C2. It’s nearly impossible to have the instruments of a telescope where the light rays focus in your segmented mirror design. So, you will now use your segmented mirror and get the light to the “Cassegrain” focus. This is where the light rays are reflected to the back of a telescope. This means the light can travel the same distance but the telescope does not need to be as long.

i. Replace the light-ray block with the convex mirror.

ii. Put the screen behind the gap in the segmented mirror (you might want to lie it down sideways).

iii. Re-adjust the mirror segments so that you get an image on the screen, noting that the lasers do not need to meet at one focus point on the convex mirror, but instead on the screen (see Picture C2). Note that due to imperfections in the optical design, it is unlikely that you will achieve a sharp image on the screen.



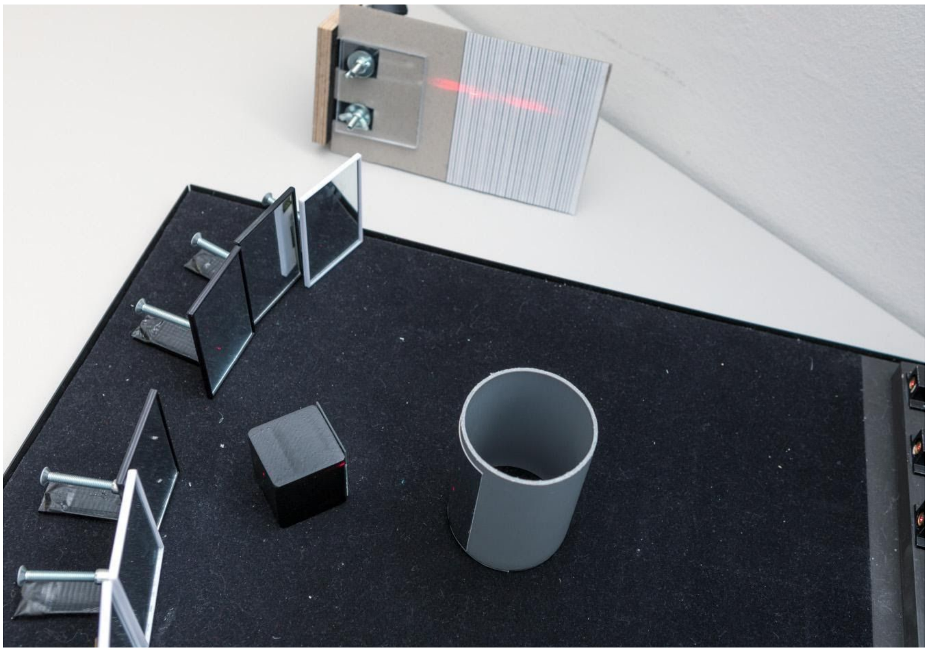
Picture C2

C2a) Comment on the advantages of the Cassegrain focus in a real telescope. Think about what you actually might want to do with the light in modern telescopes e.g., where would you put a big camera if you wanted to take a photo of your image?

C2b) Instruments mounted at the Cassegrain focus will need to move with the mirror. Discuss possible disadvantages of this design?

C3. You will now use your segmented mirror and direct the light to another different focus,

the “Nasmyth” focus.
i. Move the screen off to the side of the laser table
ii. Use a flat (plane) mirror to try and direct the light reflecting off the convex mirror onto the screen (see Picture C3).



Picture C3

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C3a) Comment on some advantages of the Nasmyth focus in a real telescope

C3b) Draw a light-ray diagram for this experiment below.

Extension Activity 3: Building a Telescope

a) If you were going to build a telescope, what factors would you need to consider?

b) What particular design features might your telescope need if…

...you want to use your telescope to study the details of the surface of the Moon in your home.

...you want to build a telescope in a very isolated place and it will not be easy to service it regularly.

...you are a scientist and you want to use your telescope to study the most distant galaxies.

...you want to build a telescope to take on holiday for looking at distant objects during the day and looking at the planets at night.