A study of lunar and solar eclipses

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Goals

- Understand why the Moon has phases
- Understand the cause of Lunar eclipses
- Understand why there are Solar eclipses
- Determine distances and diameters of the Earth-Moon-Sun system

Vision of lights and shadows

- The Earth-Moon-Sun System:
  Phases and eclipses

- Relative positions and shadows

Activity 1: Model of the far side of the Moon

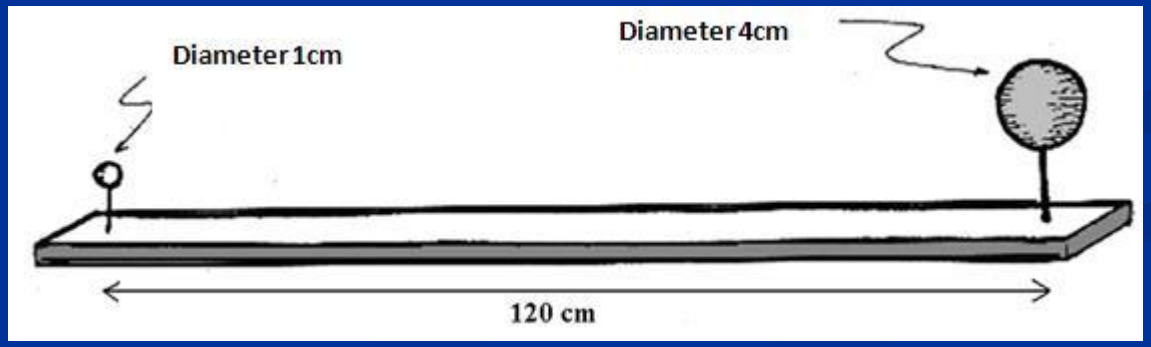
- 2 volunteers: one in the centre (the Earth) and the other revolving around it (the Moon)
- Place the Moon facing the Earth and have it revolve around the Earth by 90° and rotate itself also by 90º. Repeat the process until the starting position is reached

Activity 2: Model with flashlight (Sun) to explain the phases of the Moon

- 5 volunteers: one in the centre (the Earth) and 4 others to simulate the 4 phases of the Moon with masks (1 completely illuminated, 2 partially illuminated and 1 completely dark)

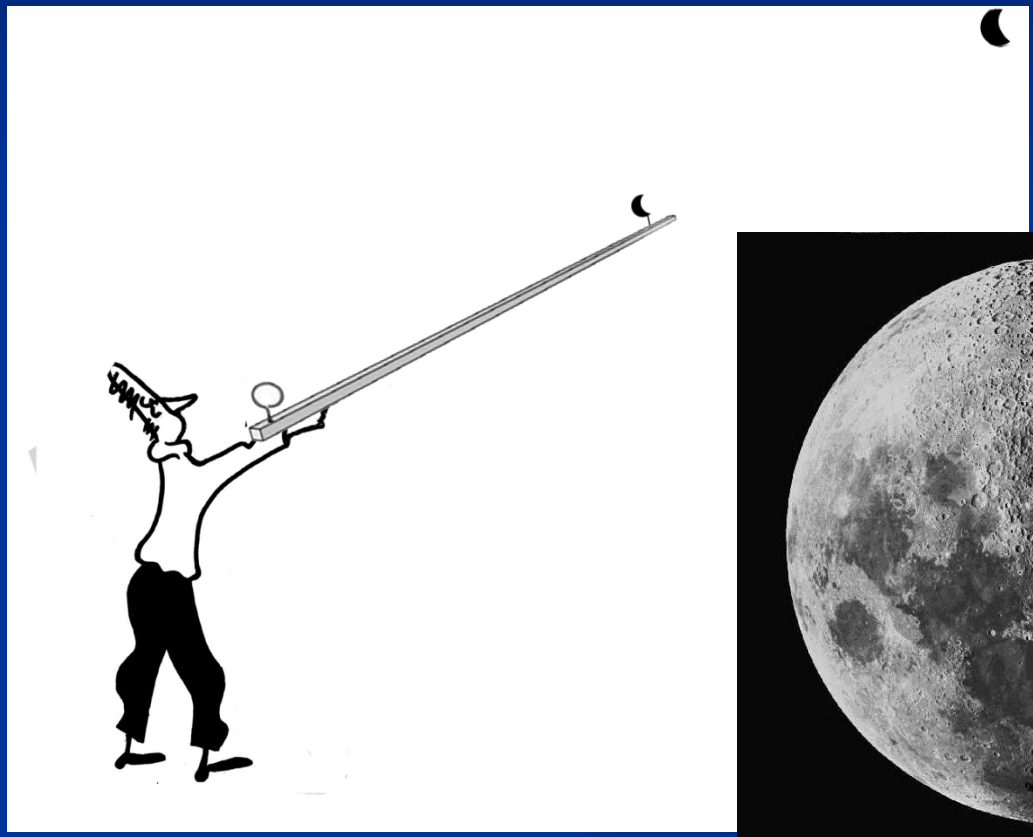
Distances and diameters of the Earth-Moon-Sun system

Earth Diameter	**12 800 km**	⇒	**4 cm**
Moon Diameter	**3 500 km**	⇒	**1 cm**
EM Distance	**384 000 km**	⇒	**120 cm**
Sun Diameter	**1 400 000 km**	⇒	**440 cm = 4.4 m**
ES Distance	**150 000 000 km**	⇒	**47 000 cm = 0.47 km**

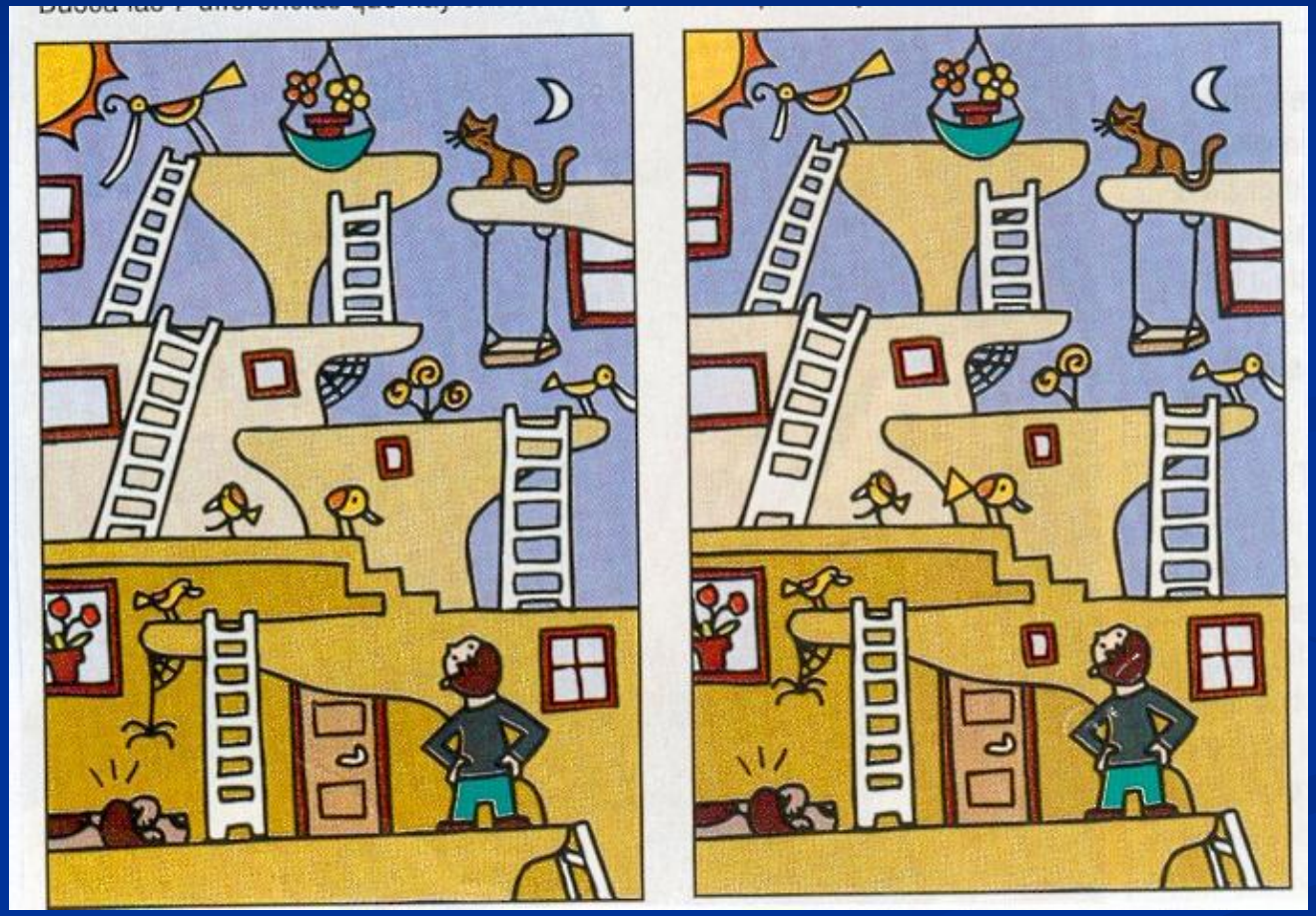


Activity 3: Simulation of Phases of the Moon

- Direct the small moon of the model to the Moon and we can see both with the same phase

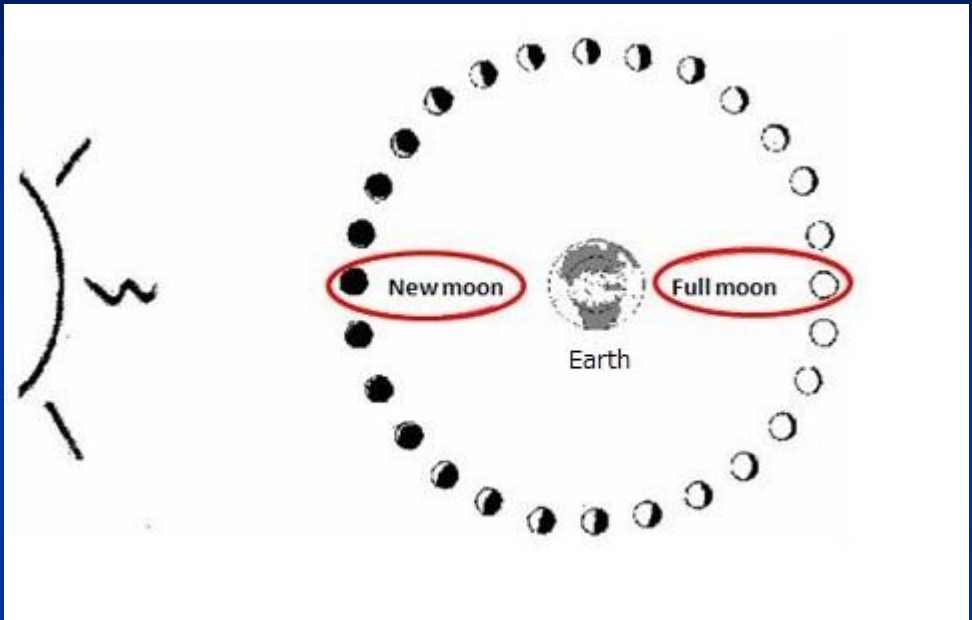


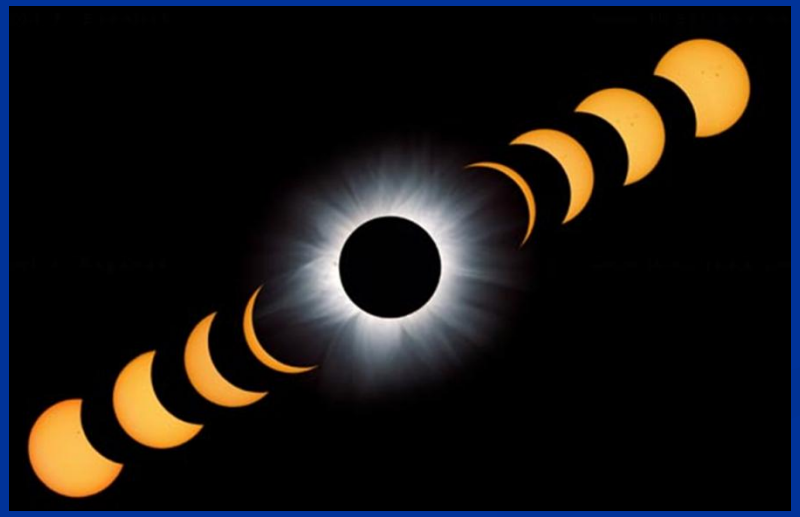
Activity 4: Illustration Errors



- Phases of the Moon depend on the position of the Sun

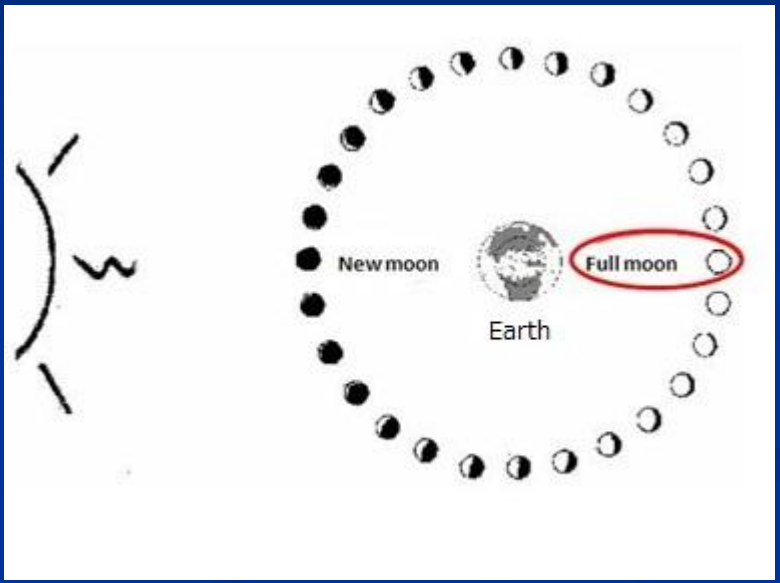
Moon Phases and Eclipses

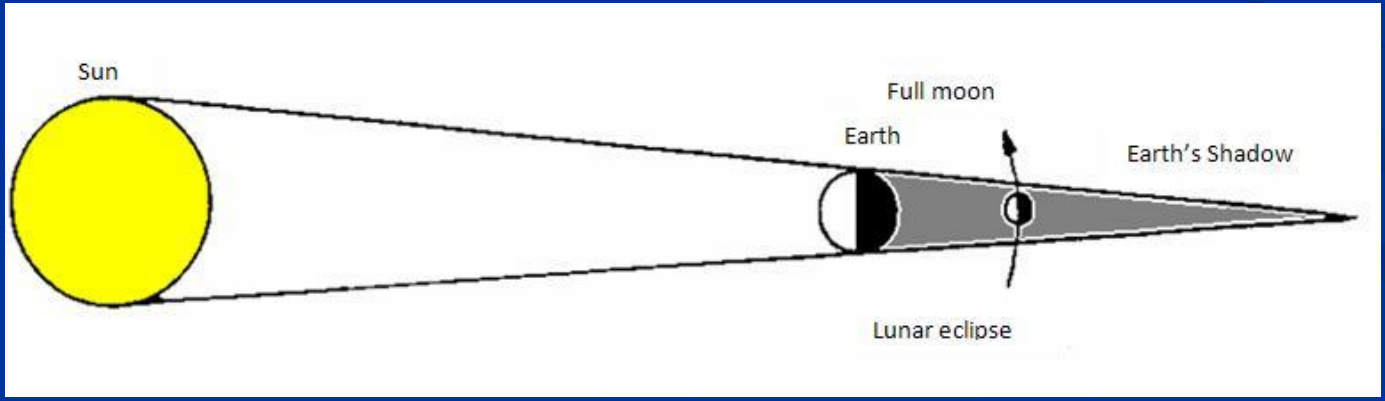




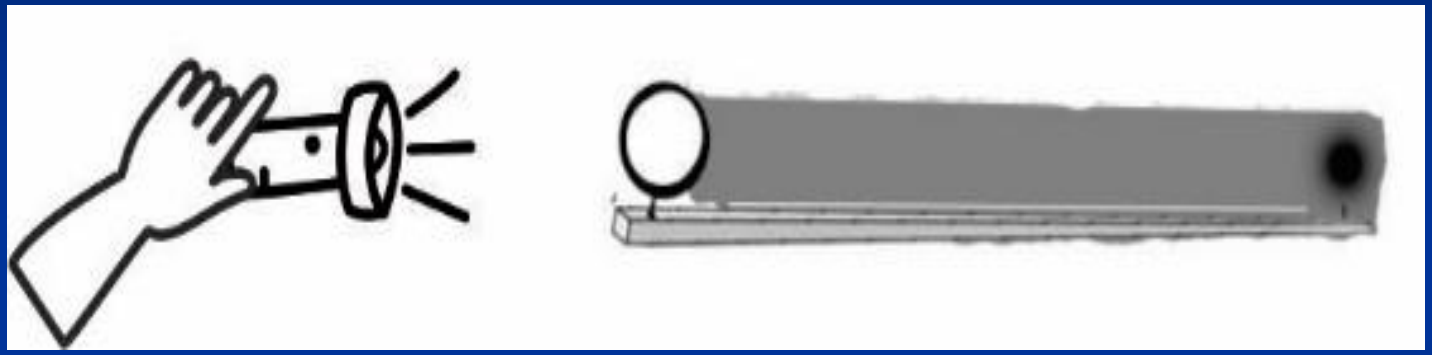
Activity 5: Lunar Eclipses

- Lunar eclipses only occur when the Moon is full





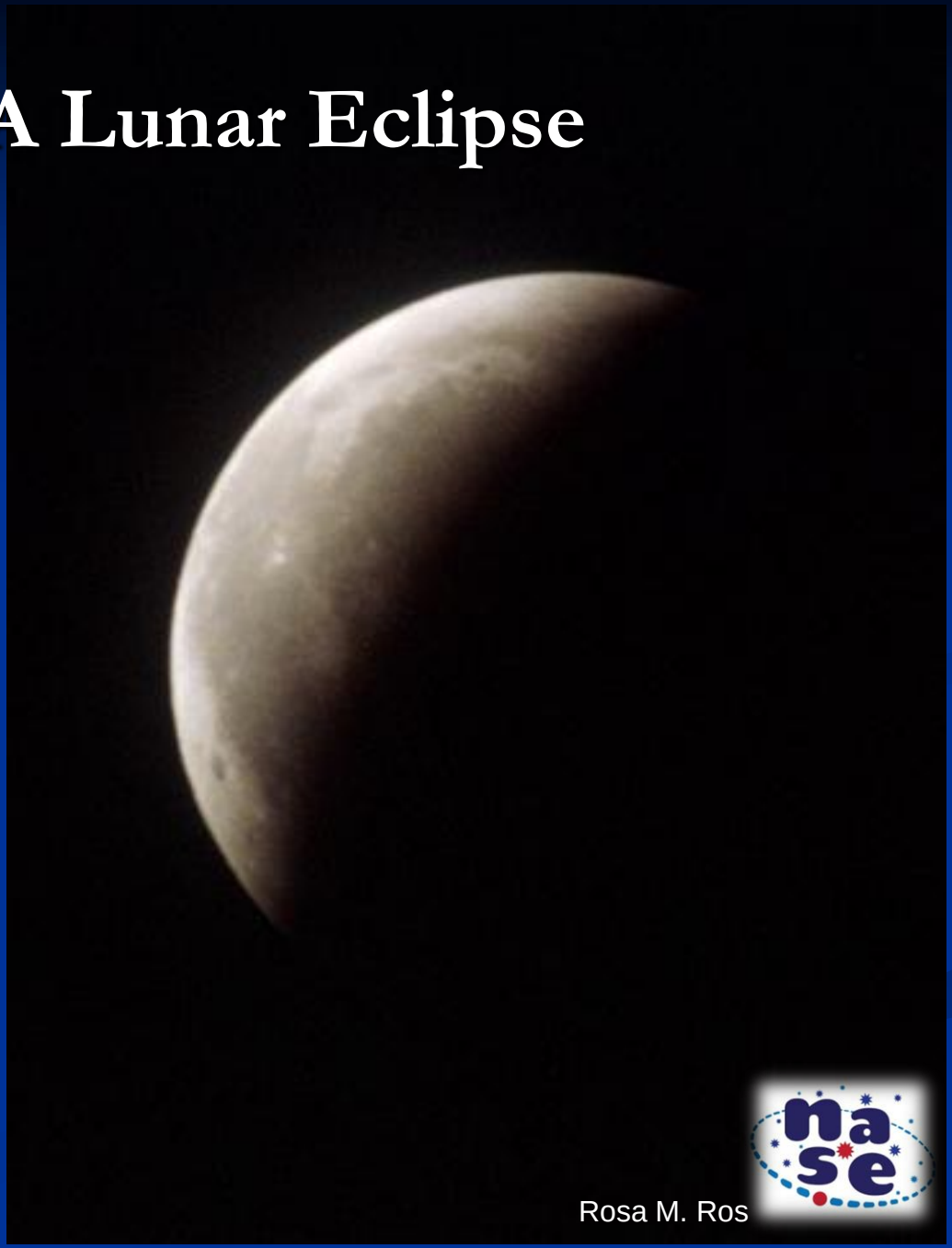
Activity 5: Simulation of a Lunar Eclipse



Activity 5: A Lunar Eclipse

Activity 5: A Lunar Eclipse

- Lunar eclipses can be visible to half of the Earth (night side)



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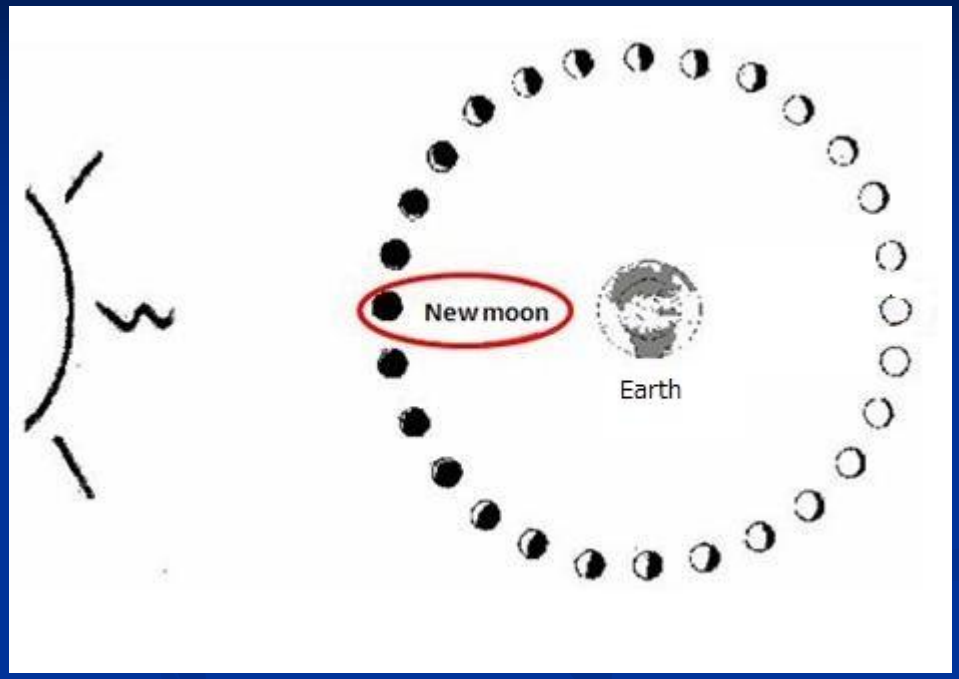
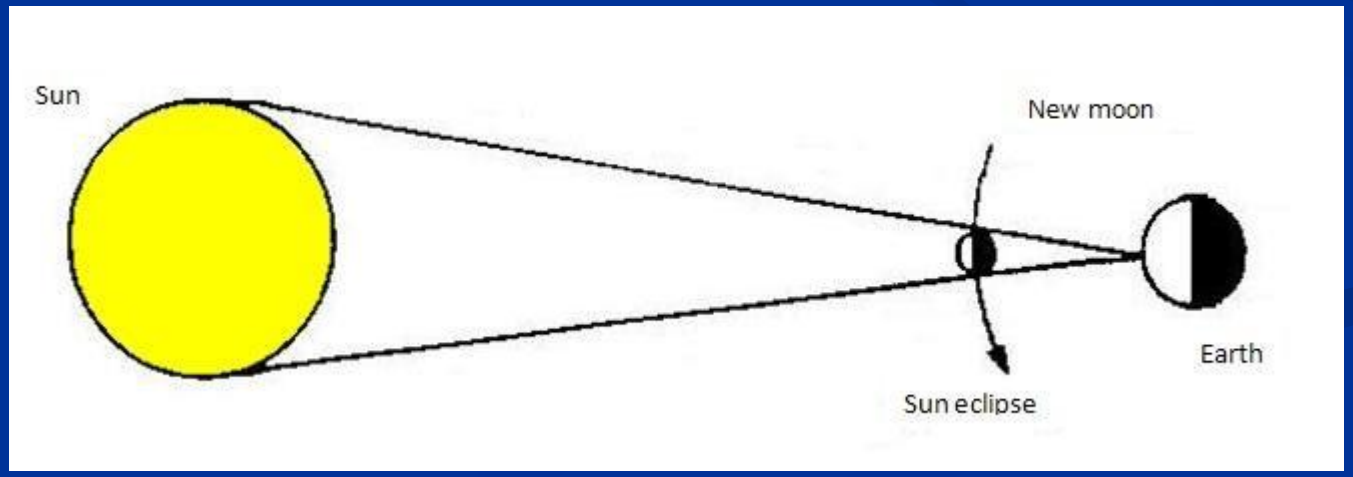
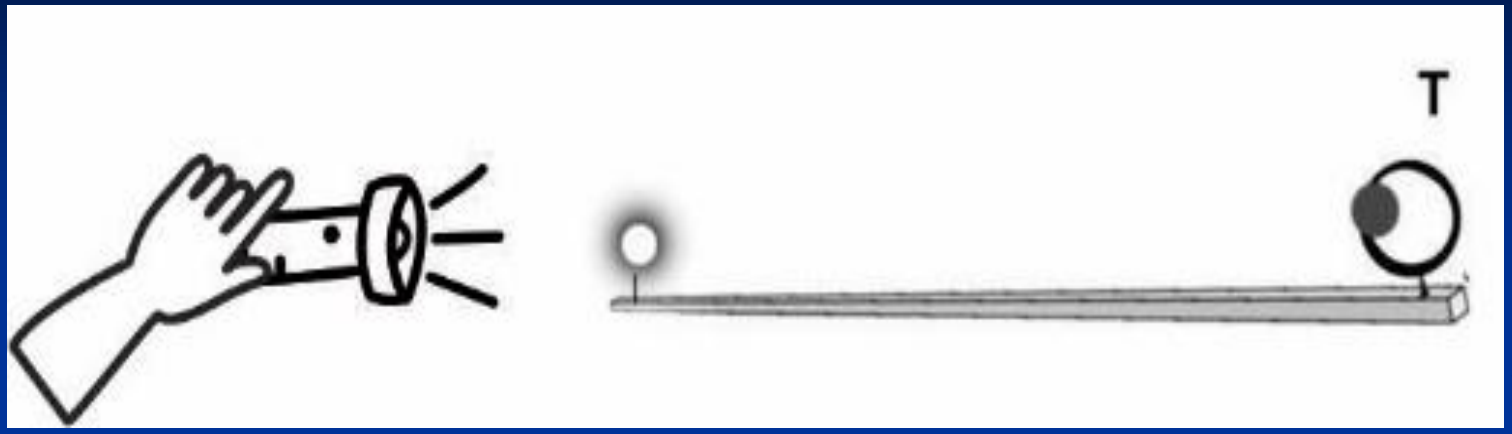
Activity 6: Solar Eclipses

- Solar eclipses occur only when there is a New Moon





Activity 6: Simulation of a Solar Eclipse



Detail of a Solar eclipse

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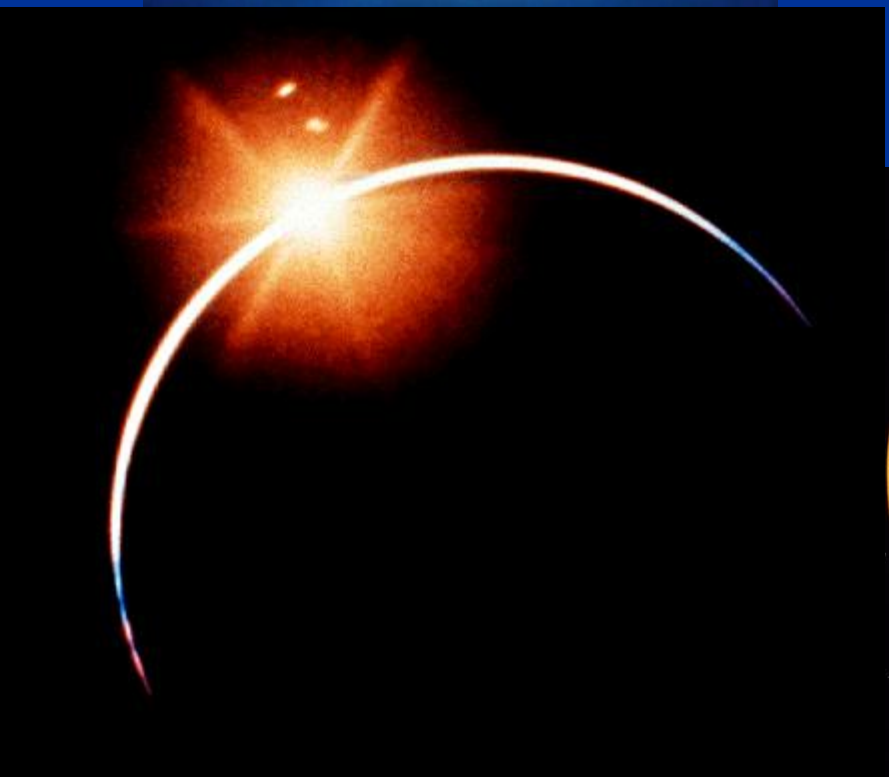
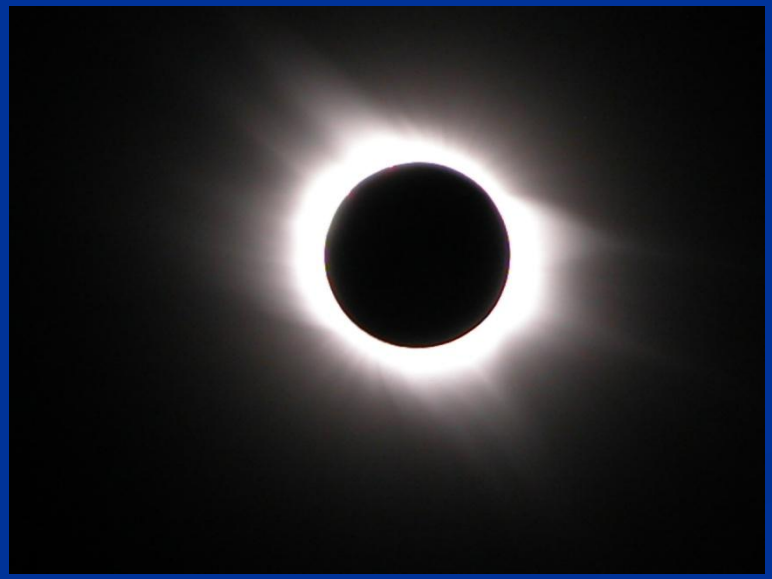
Activity 6: Solar Eclipse

- Solar eclipses are visible only in a small region of the Earth



... we are feeling emotion!

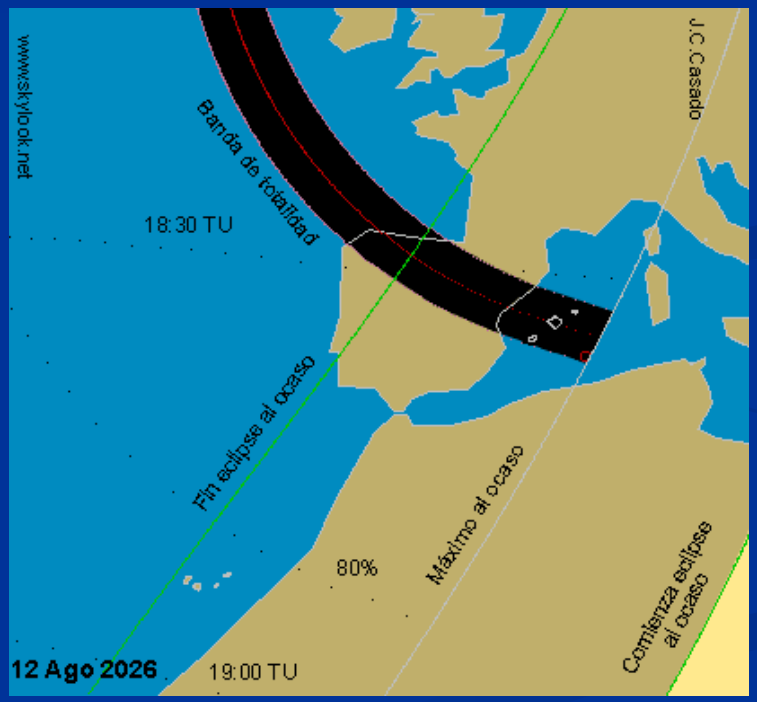


Observations

- A **lunar eclipse** when there is **Full Moon** and a **solar eclipse** when there is a **New Moon**
- A solar eclipse is seen only in a small area of the Earth
- It is very difficult for the Earth and Moon to be "well aligned", thus an eclipse does not occur every time that there is New or Full Moon

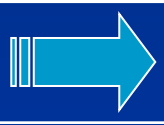
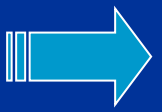
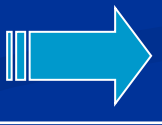
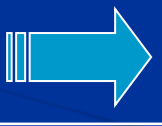
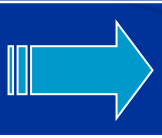
Finally ... as an example ...

- Next total solar eclipse in Spain: August 12, 2026 (last one 2004 in a different area)



- Each year there are between 0 to 3 lunar eclipses

Distances and diameters in order to visualize and better understand the distances to the Sun

Earth Diameter	12 800 km		2.1 cm
Moon Diameter	3 500 km		0.6 cm
E-M Distance	384 000 km		60 cm
Sun Diameter	1 400 000 km		220 cm
E-S Distance	150 000 000 km		235 m

Painting the Sun

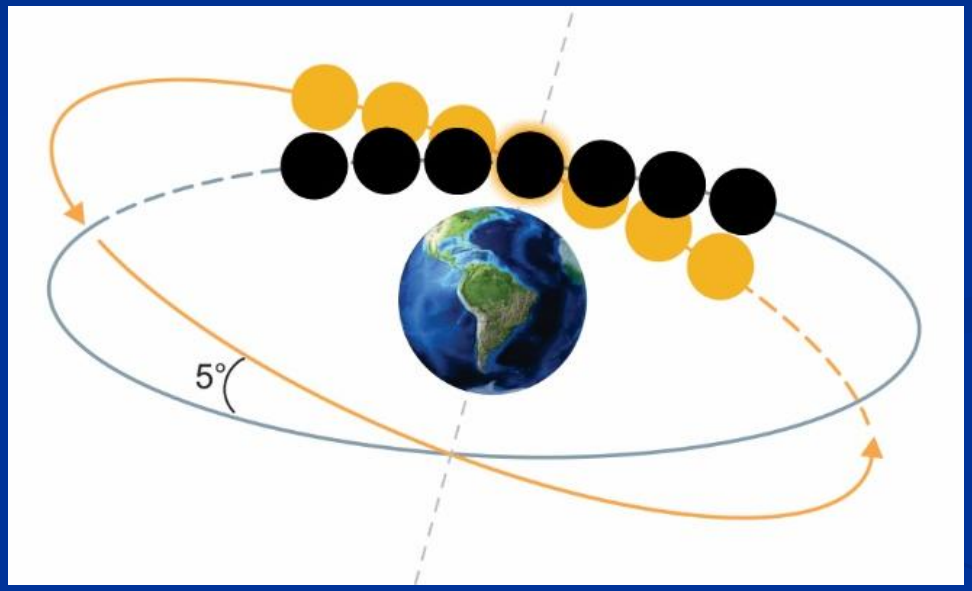
Activity 7: Making the large “Sun” look like the small “Moon”

If every month there is
a New Moon and a Full Moon …

Why there is not
a Solar eclipse and a Lunar eclipse
every month?

Because …

The plane of the Earth around the Sun and the plane of the Moon around the Earth are not in the same plane.

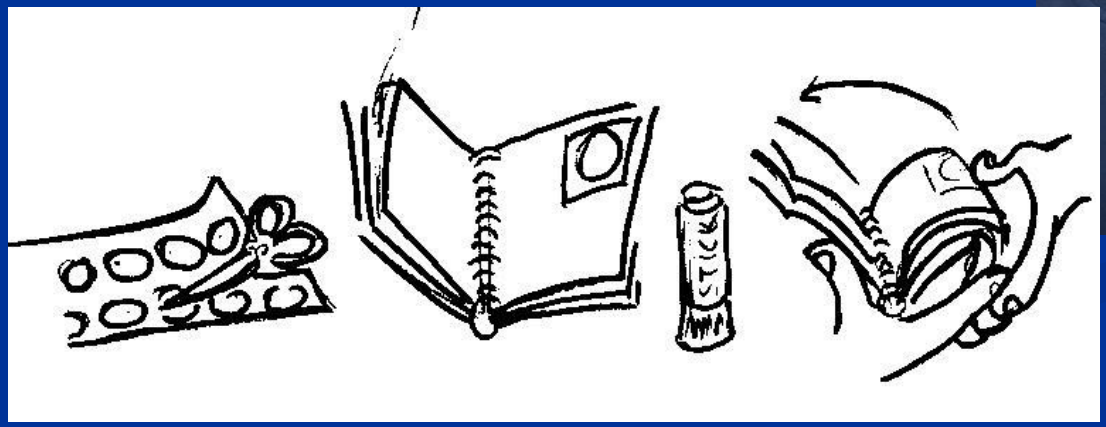


Both planes are inclined by 5º and the angular diameter of the Sun and the Moon is only 0.5º

The eclipses only can take place if the Sun and Moon are close to the line of intersection of the two planes.

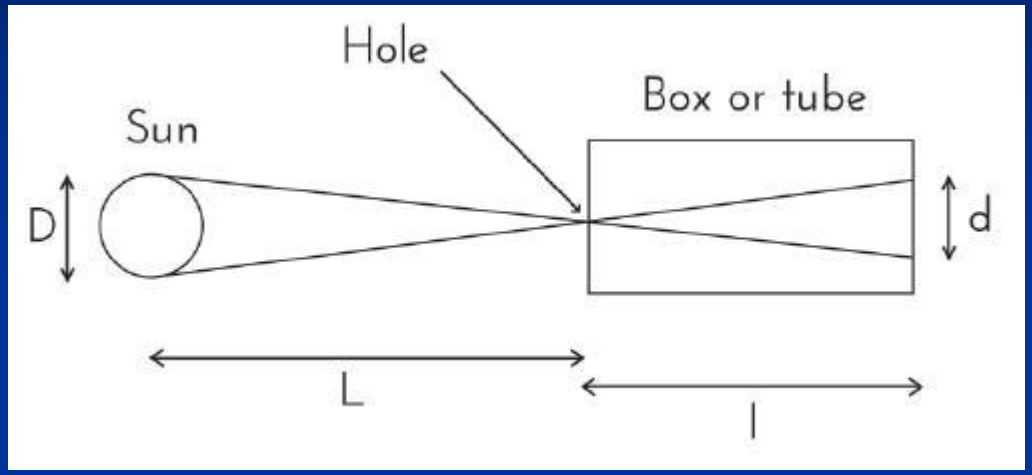
Activity 8: “Flip page” eclipse simulator

1. Trim and number the pictures in order
2. Paste each picture on a spiral notebook
3. Turn the pages quickly to see the demonstration.



Activity 9: Determination of the Sun's diameter - observations and measurements

Activity 9: Determination of the Sun's diameter



$$\frac{D}{L} = \frac{d}{l}$$

$$D = \frac{d\,L}{l}$$

We can establish the proportion and calculate the Sun's diameter

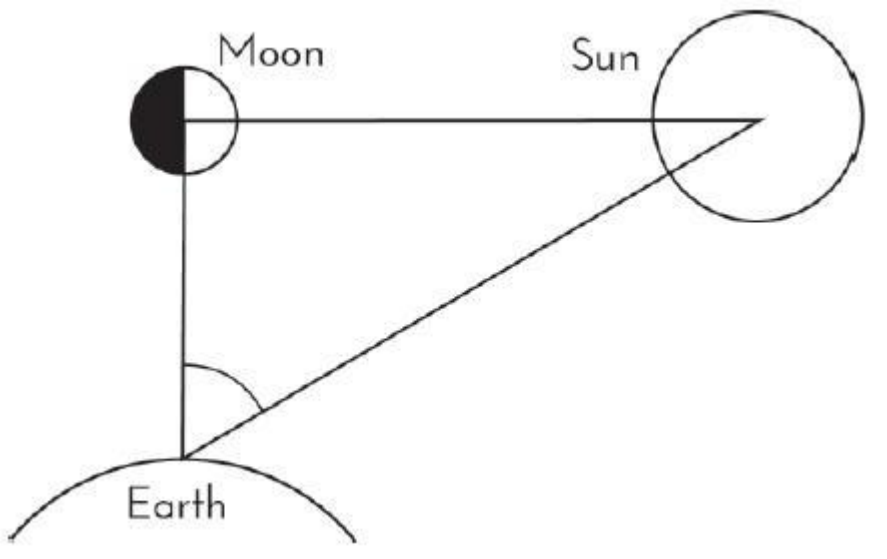
L = 150 000 000 km Earth-Sun distance, l = tube length,
d = diameter of the Sun on semi-transparent paper

Activity 10: Aristarchus's Experiment 310 to 230 BC

- Established relationships between the Earth-Moon-Sun distances and their diameters (but could not determine any absolute value). This had to wait until Eratosthenes.
  - 1) Distance of the Earth to Moon and the Earth to Sun
  - 2) Radius of the Moon and of the Sun
  - 3) Earth to Moon distance and the Moon's radius
  - 4) The Cone of the Terrestrial Shadow
  - 5) Relate them all

1) Distance Earth-Moon and Earth-Sun

- $\cos \alpha = EM / ES$ therefore $ES = EM / \cos \alpha$



1) Earth-Moon and Earth-Sun Distances

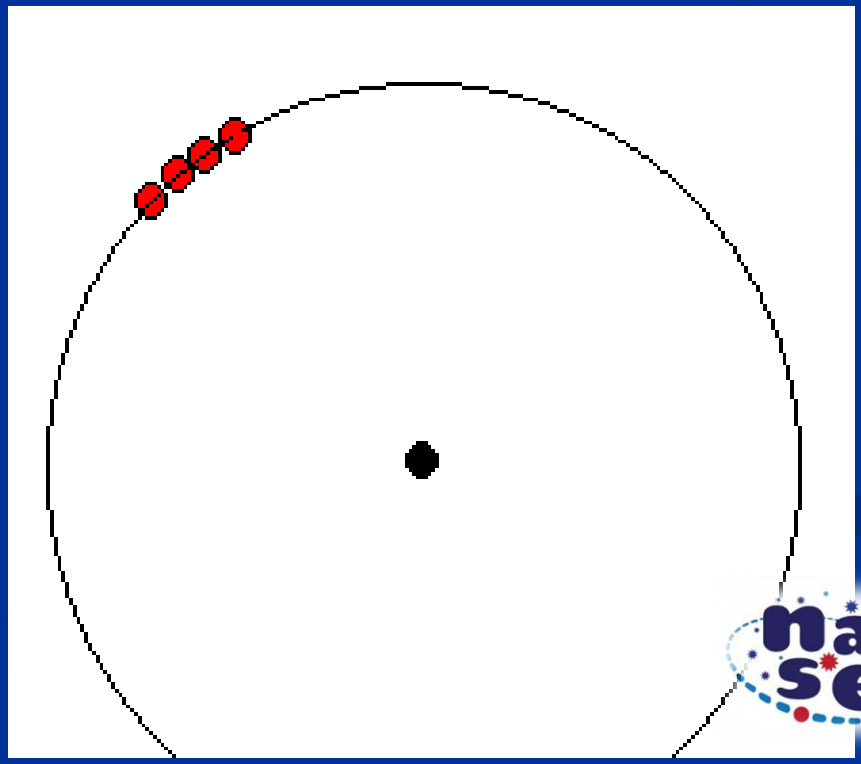
- Aristarchus $\alpha = 87^\circ$ then ES = 19 EM
- Now $\alpha = 89^\circ\ 51'$ therefore **ES = 400 EM**

2) Radius of the Moon and of the Sun

- From the Earth, lunar and solar diameters are observed to be equal to 0.5°
- Therefore, the radius is
- $R_S = 400\ R_M$

3) Earth-Moon Distance and Moon's Radius

- Moon's diameter from the Earth is 0.5 º
- With 720 times this diameter, we can calculate the **circular** trajectory of the Moon
- $2\ R_M\ 720 = 2\ \pi\ EM$
- $EM = 720\ R_M / \pi$



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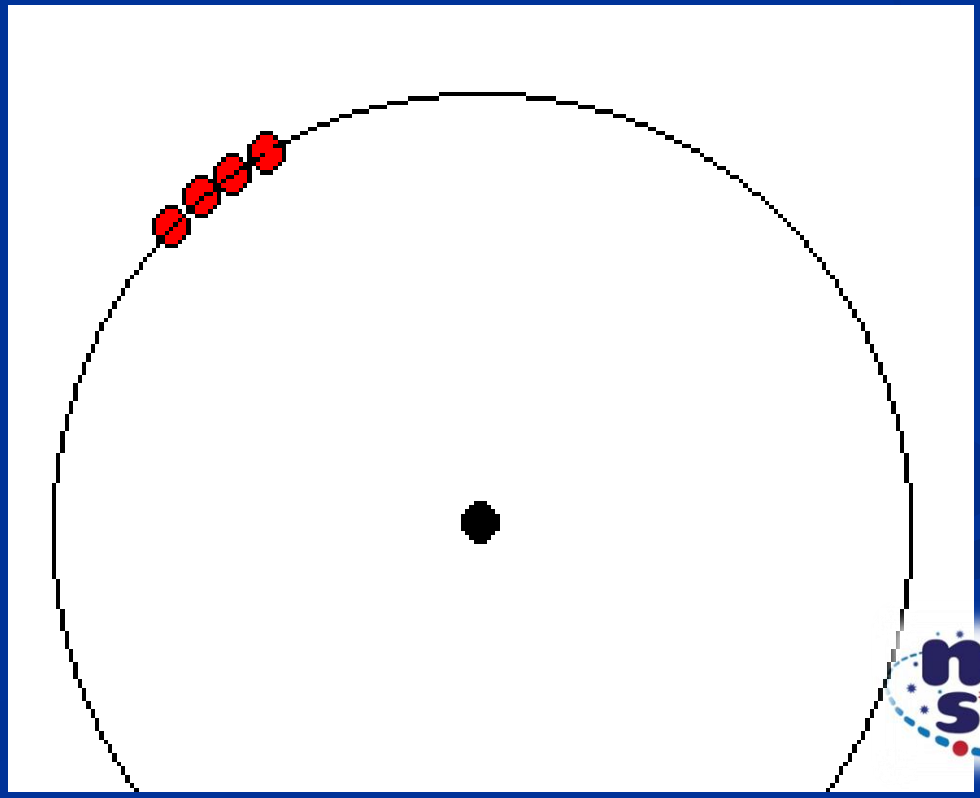
3) Earth-Sun distance and Sun radius

- By analogy
- ES = 720 Rs/ π

Aristarchus's 1st Heliocentric model

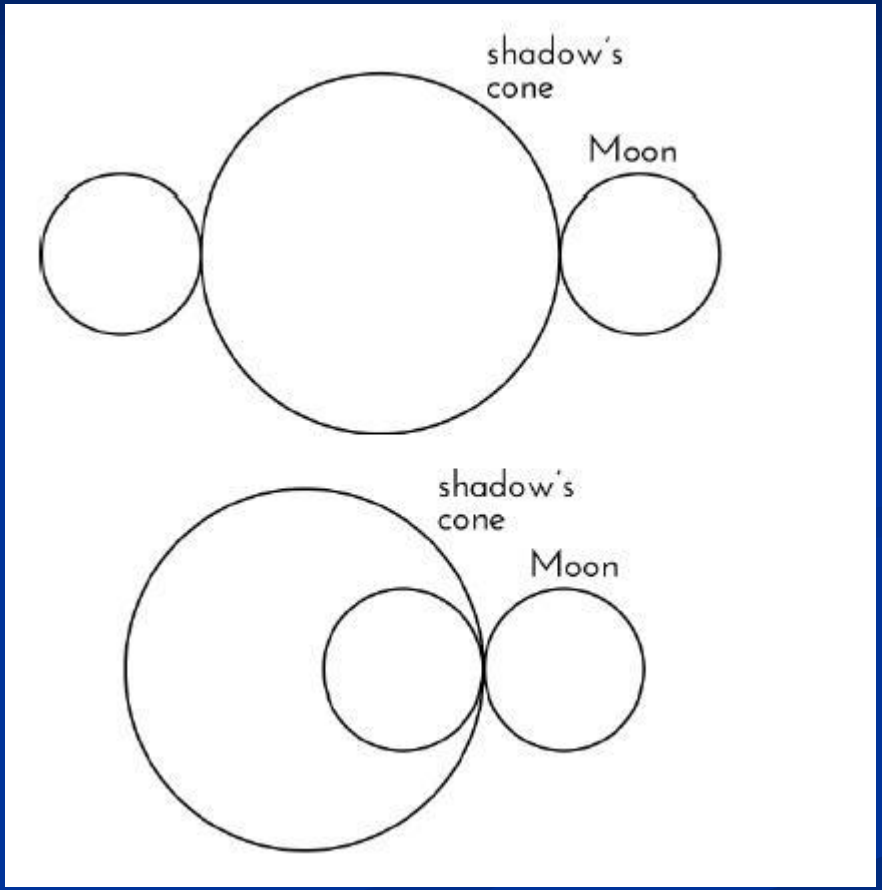


4) Cone of Terrestrial Shadow

- In a Lunar eclipse,

Aristarchus observed that the time required for the Moon to cross the shadow cone of the Earth was twice the time necessary for the surface of the Moon remain covered (i.e. 2:1)

- It is actually 2.6:1



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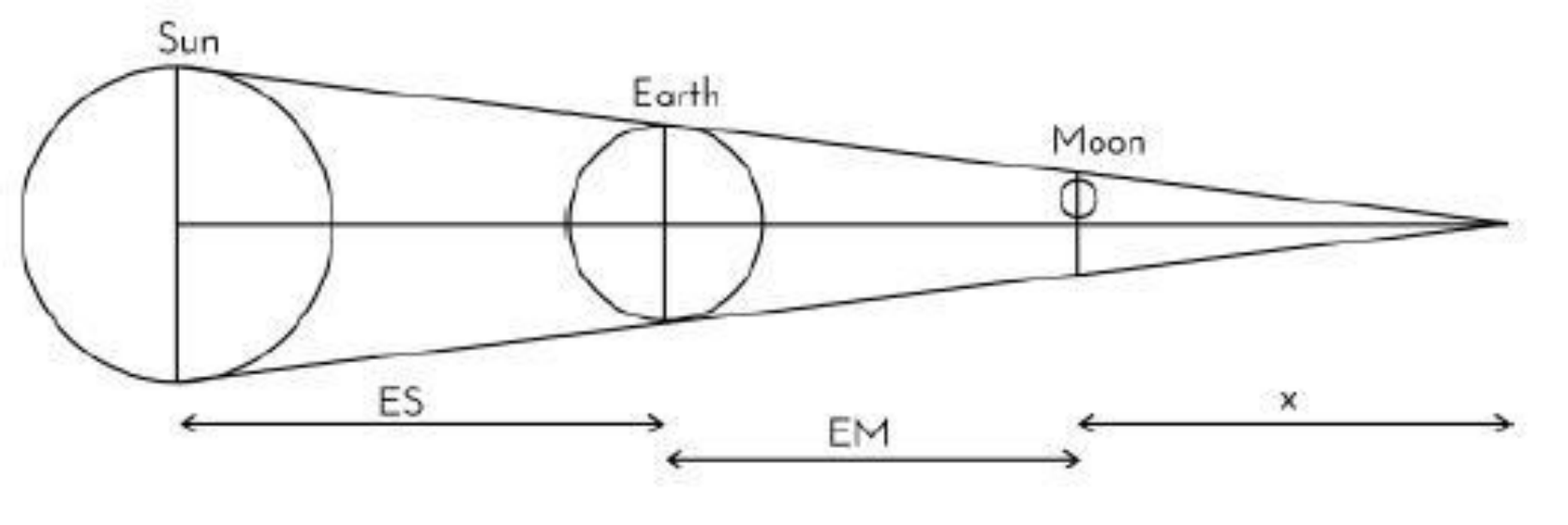
5) Relate them all

- $(x+EM+ES)/R_S = (x+EM) / R_E = x/(2.6\ R_M)$

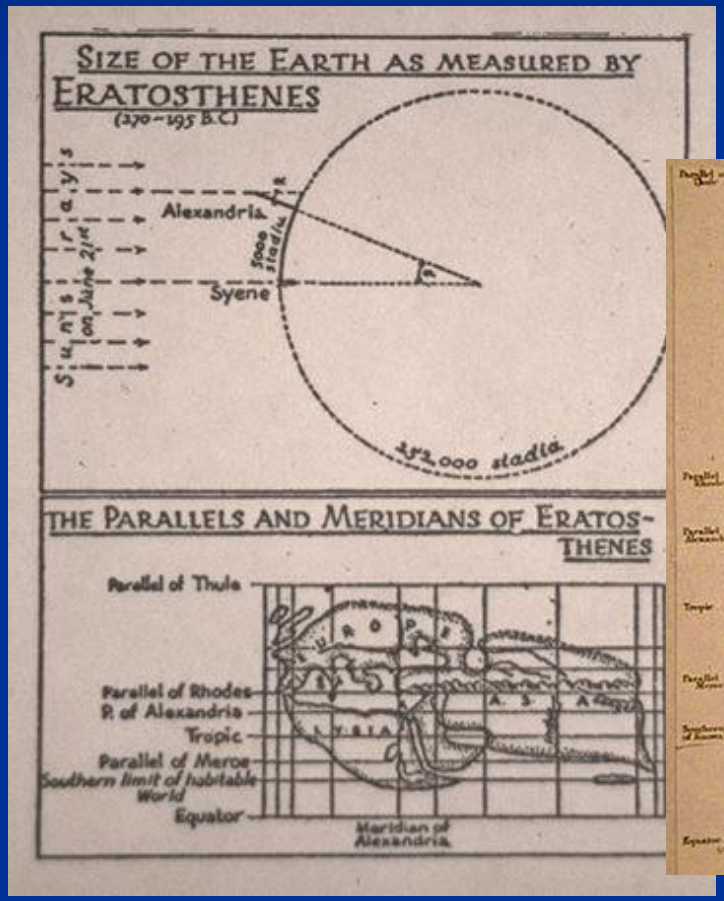


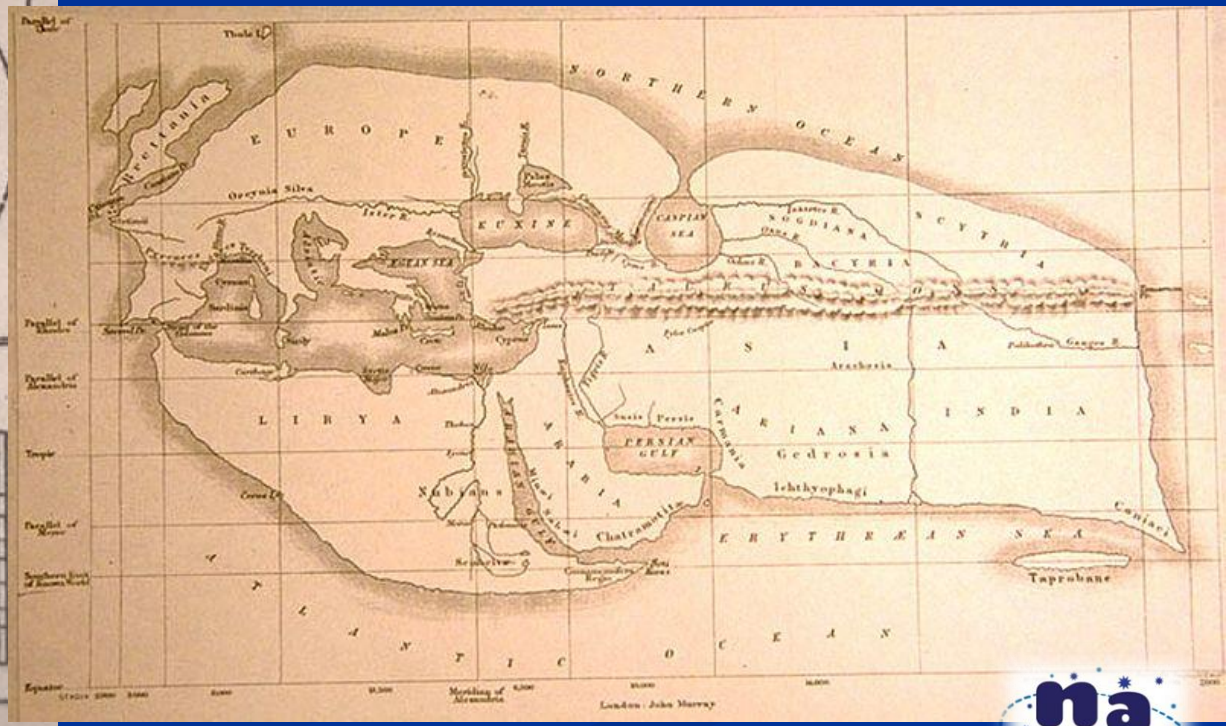
Solving the system shows (everything related to Earth's radius):

- $R_M = (401 / 1440)\ R_E$
- $EM = (401 / (2\pi))\ R_E$
- $R_S = (2005 / 18)\ R_E$
- $ES = (80200 / \pi)\ R_E$

- If we assume $R_E = 6\ 378$ km then
- $R_M = 1\ 776$ km (actual 1 738 km)
- EM = 408 000 km (actual 384 000 km)
- $R_S = 740\ 000$ km (actual 696 000 km)
- ES = 162 800 000 km (actual 149 680 000 km)

Activity 11: Eratosthenes' Experiment 280 to 192 BC





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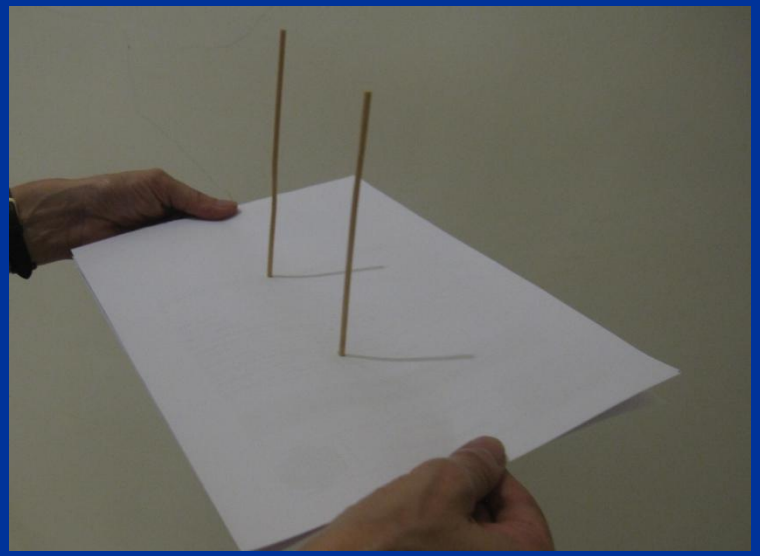
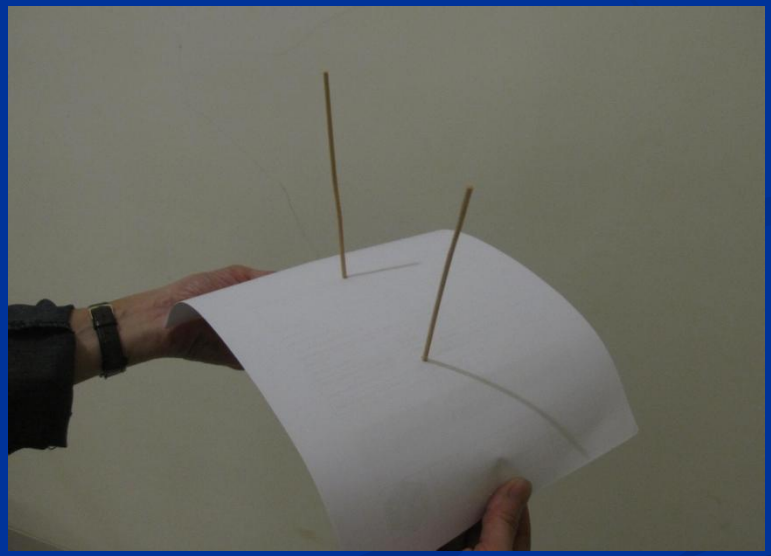
Activity 11: Eratosthenes again

- Two cities on the same meridian
- Simultaneous observations

Different shadows …

- Then the Earth is a sphere!



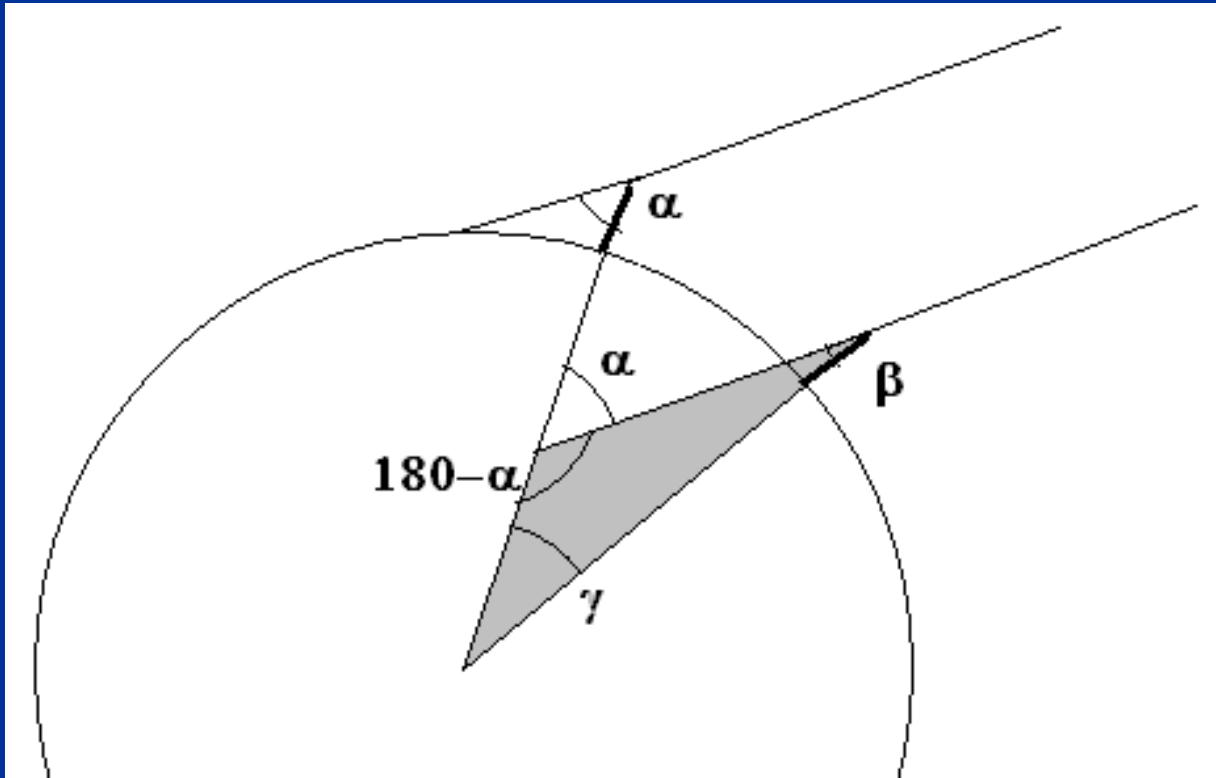


Activity 11: Eratosthenes again

- $\pi = \pi - \alpha + \beta + \gamma$
- therefore $\gamma = \alpha - \beta$

where α and β are measured in radians

(180 degrees = π radians)



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Activity 11: Eratosthenes again

- We measure the length of the plumb line (or stick) and its shadow

$$\alpha = \arctan(\text{shadow})/(\text{stick})$$

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Activity 11: Eratosthenes again

- by proportionality

  $2\pi R_E / 2\pi = d / \gamma$

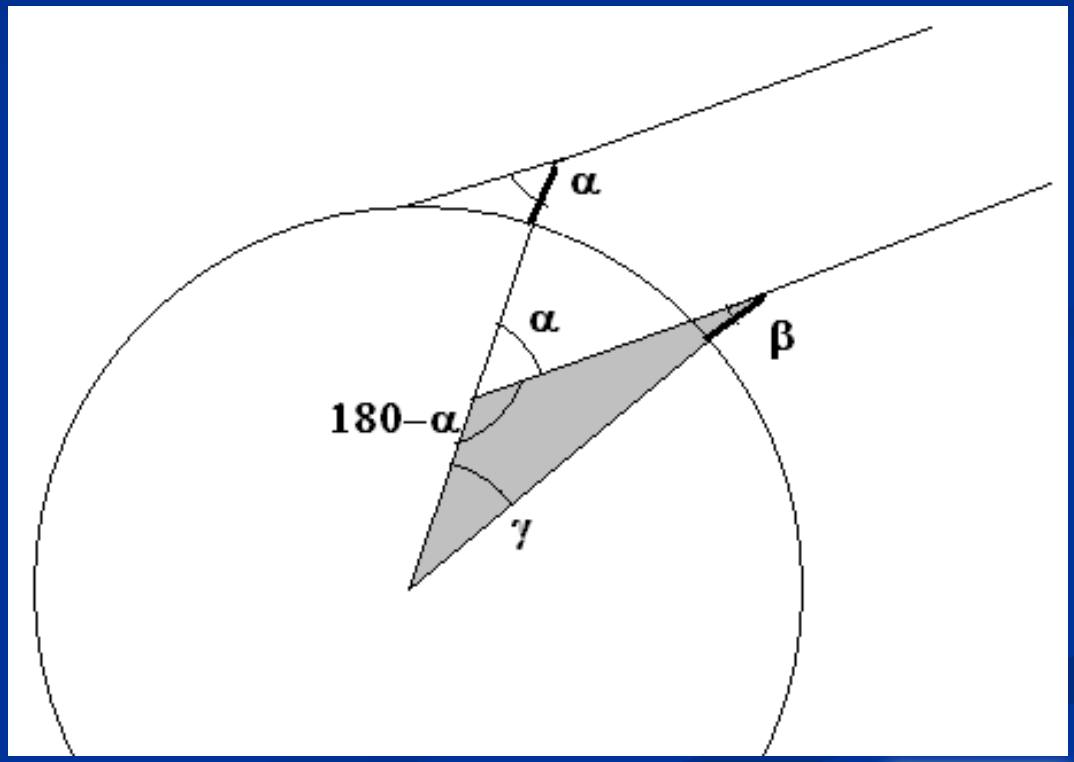
- is deduced

  $R_E = d/\gamma$

- γ we know (in radians)

  $\gamma = \alpha - \beta$

- d is the distance between cities - using a map



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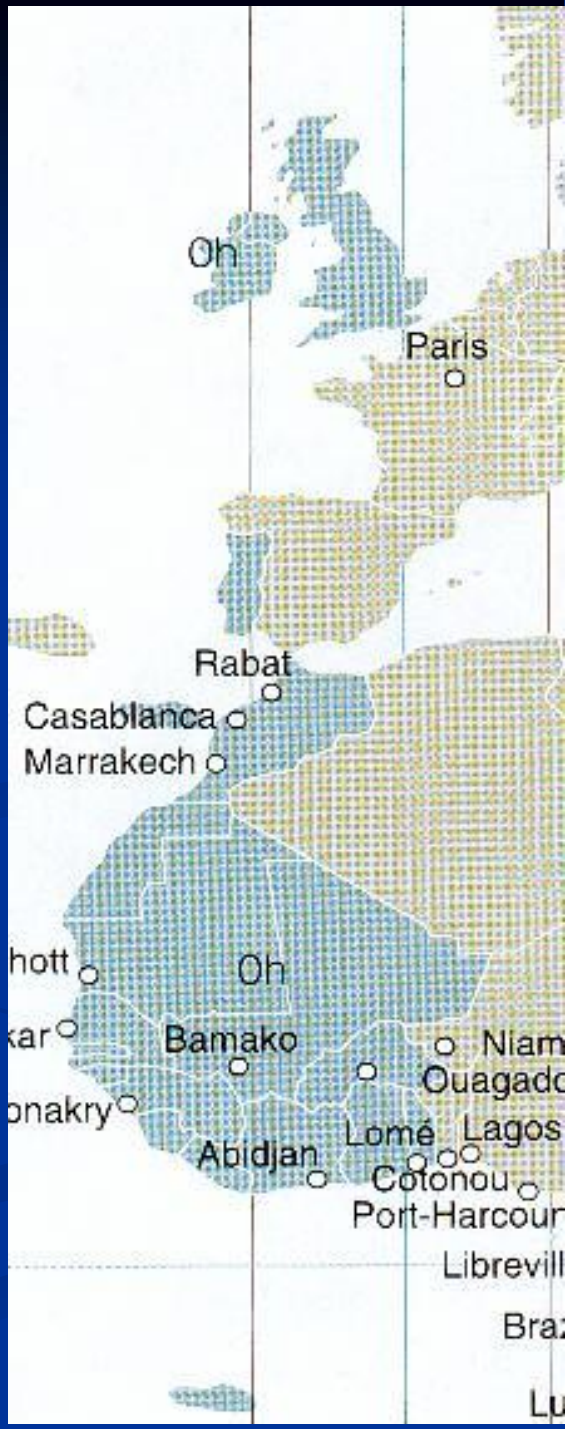
Our results with the method of Eratosthenes

- Ripoll- Barcelona
- $\alpha = 0.5194$ radians
- $\beta = 0.5059$ radians
- $\gamma = 0.0135$ radians
- d = 89.4 km

- R_E = 6 600 km (actual 6 378 km)



Conclusions

- We now understand the eclipses
- Have established size relationships for the Earth-Moon-Sun system
- It is verified that by observing and analysing the data obtained, we can learn much more about the universe

Many Thanks
for your attention!