

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

- System

Earth-Moon-Sun:
phases and eclipses

- Relative positions
and shadows



Model of the dark side of the Moon

- 2 volunteers: one in the center (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 90° , repeat the process until the initial position is reached



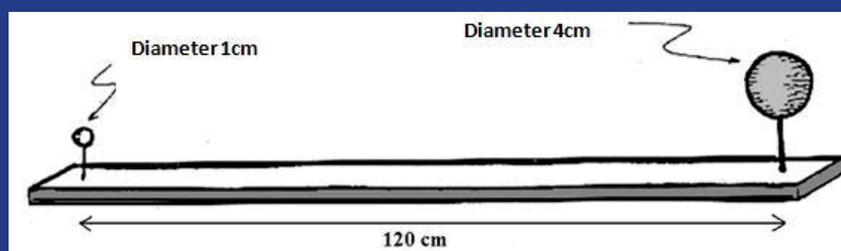
Model with flashlight (Sun) to explain the phases of the Moon

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



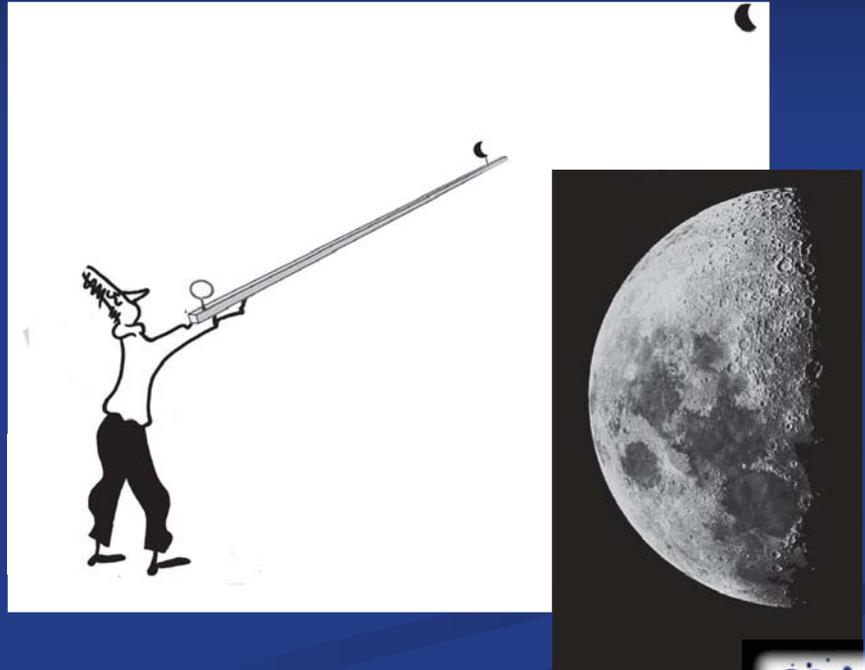
Distances and diameters of the system Earth-Moon-Sun

Earth Diameter	12 800 km		4 cm
Moon Diameter	3 500 km		1 cm
EM Distance	384 000 km		120 cm
Sun Diameter	1400 000 km		440 cm = 4.4 m
ES Distance	150 000 000 km		4700 cm = 0.47 km

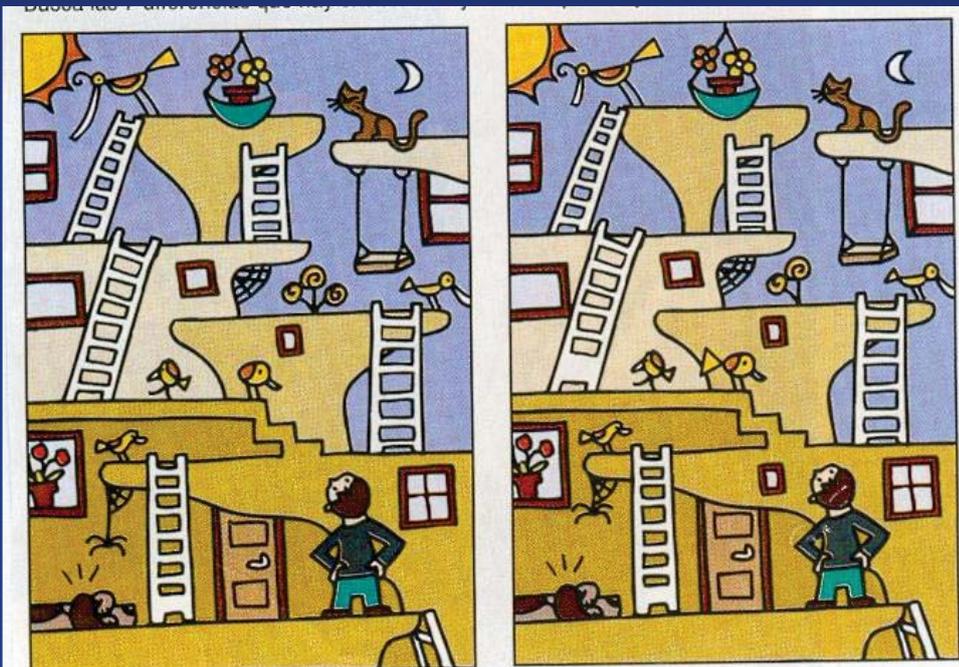


Simulation of Phases of the Moon

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



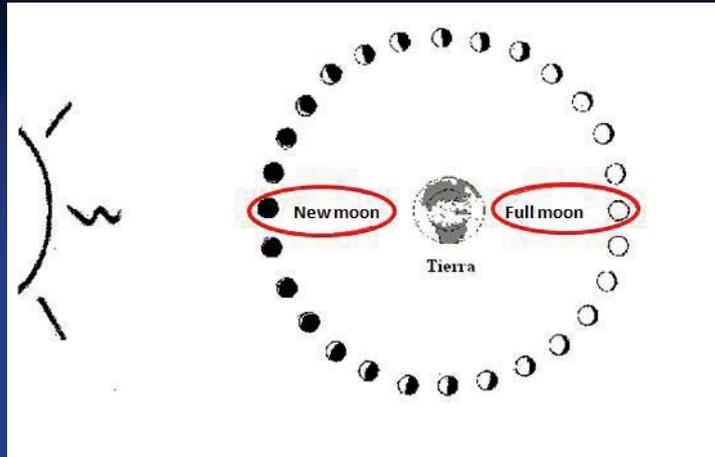
Errors



- Phases of the Moon depend on Sun's position

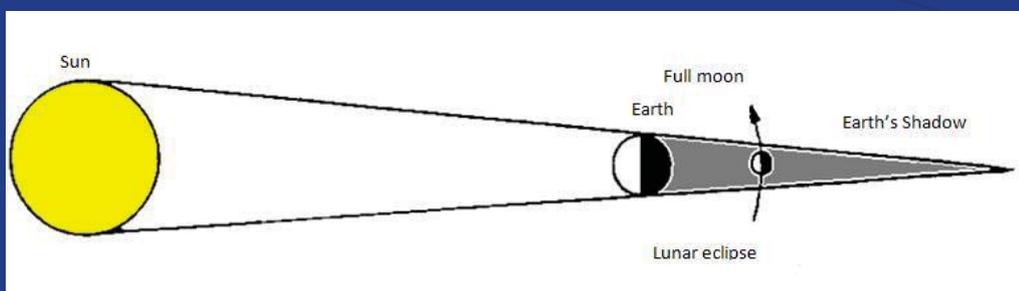
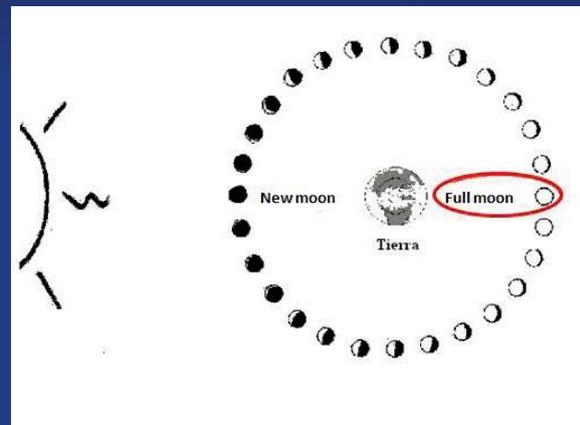


Moon Phases and Eclipses



Eclipses: Moon

- Lunar eclipses only when the Moon is full



Simulation of a Moon Eclipse

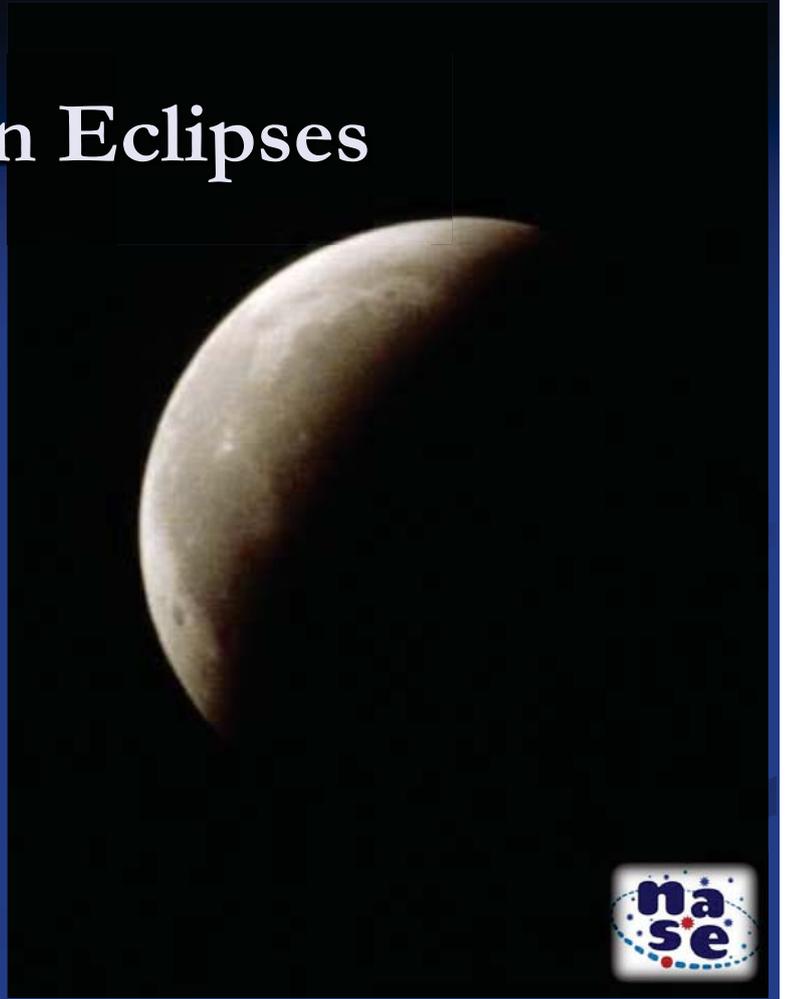


Moon Eclipse



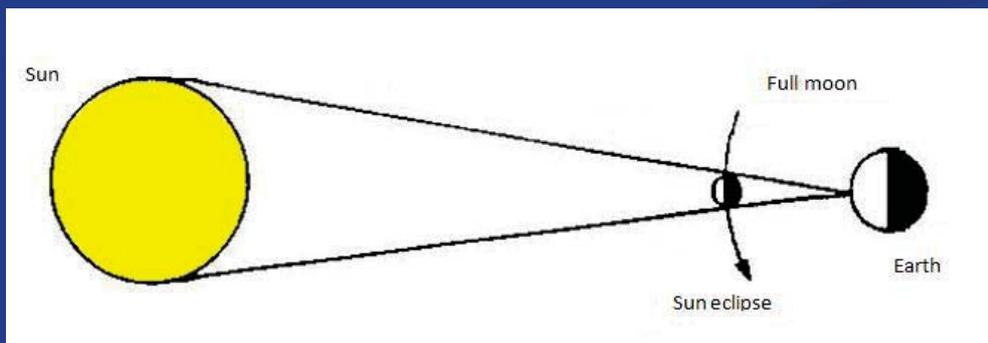
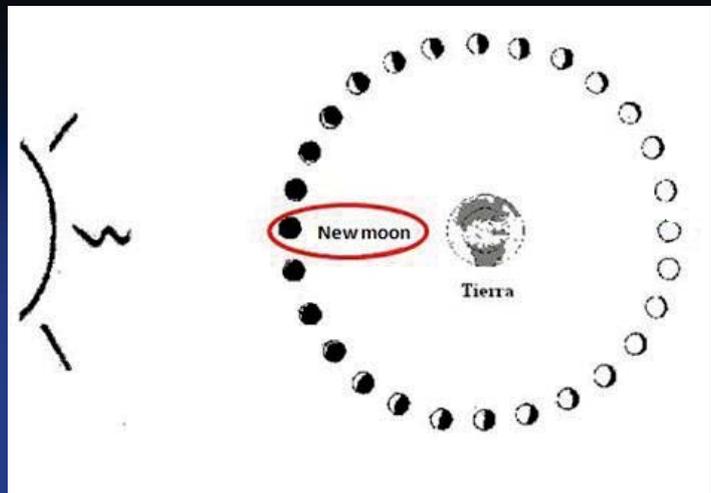
Moon Eclipses

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

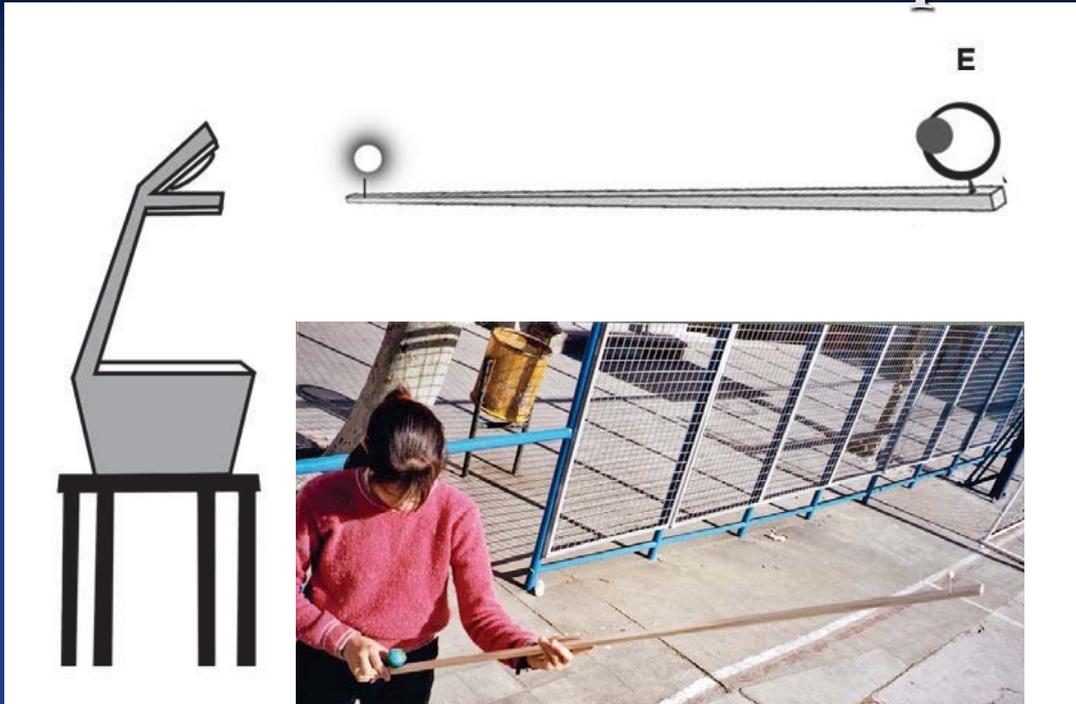


Eclipses: Sun

- Solar eclipses occur only when there is New Moon



Simulation of a Solar Eclipse



Detail of solar eclipse

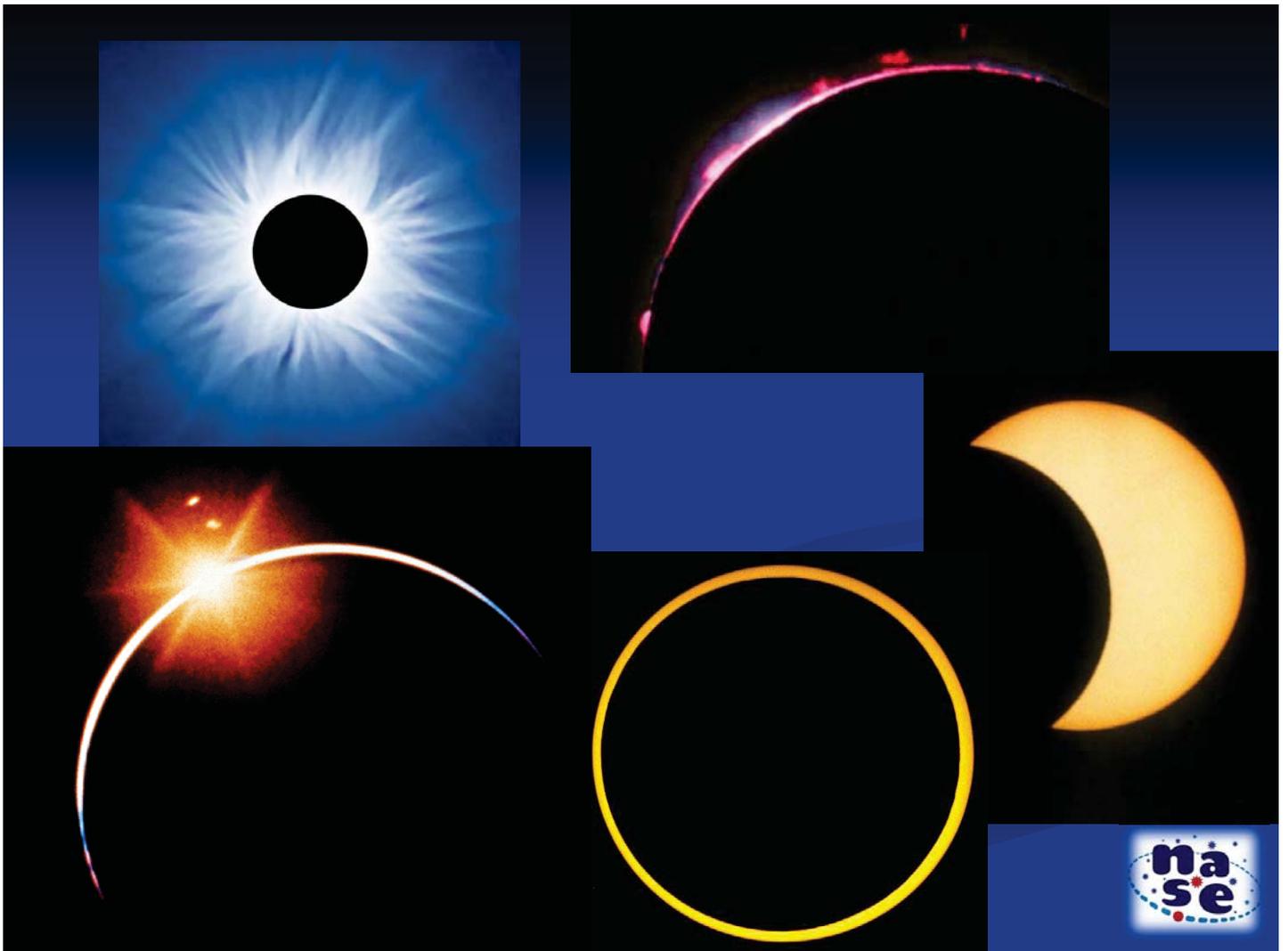




Solar Eclipse

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





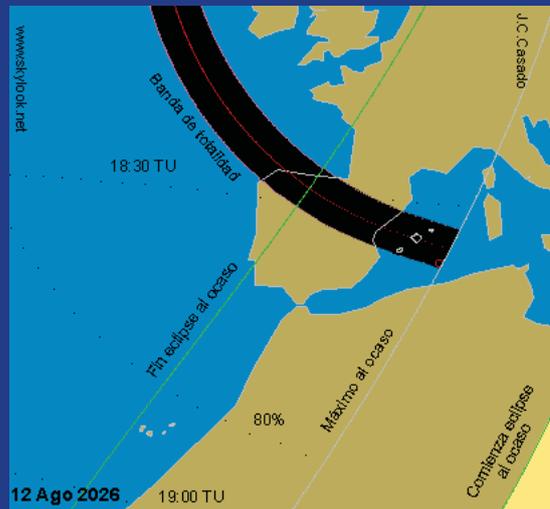
Observations

- It can only occur:
 - a **lunar eclipse** when is **full Moon**
 - and a **solar eclipse** when is **new Moon**
- A solar eclipse is seen only in a small area of the Earth
- It is very difficult for Earth and Moon to be "well aligned", thus an eclipse cannot 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 0 to 3 lunar eclipses

Distances and diameters in another small model

(to visualize and better understand the distances to the Sun)

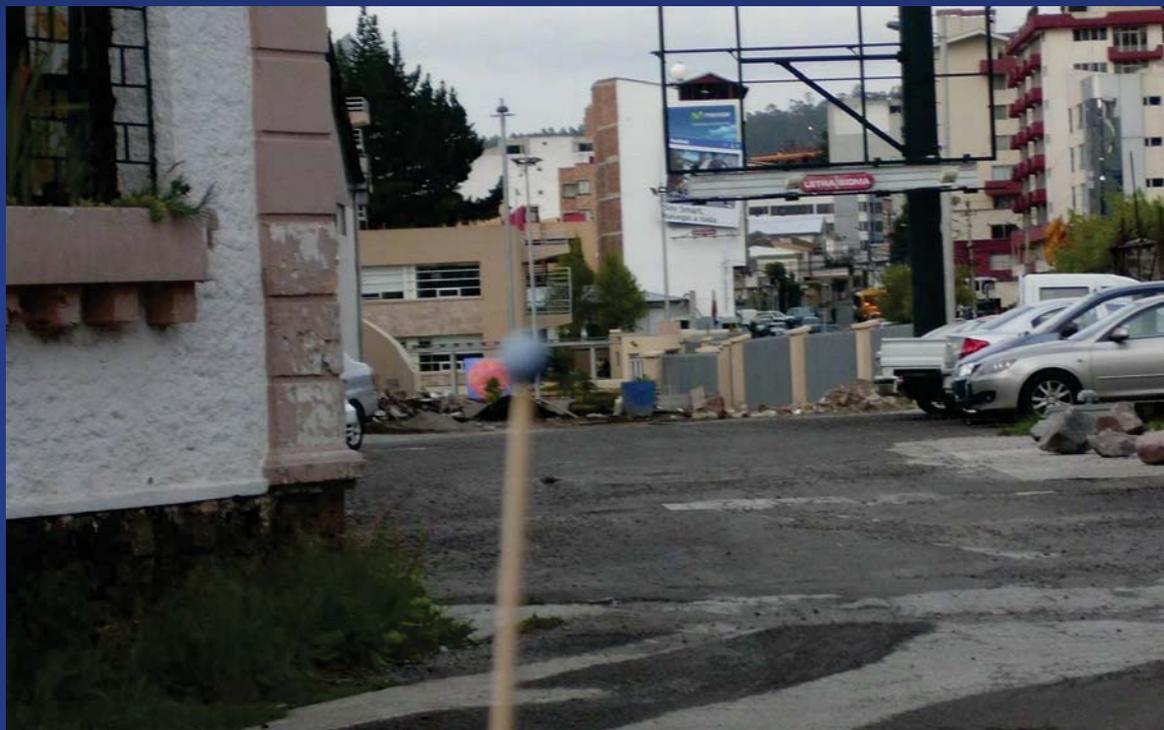
Earth Diameter	12 800 km		2.1 cm
Moon Diameter	3 500 km		0.6 cm
EM Distance	384 000 km		60 cm
Sun Diameter	1400 000 km		220 cm
ES Distance	150 000 000 km		235 m



Painting the Sun

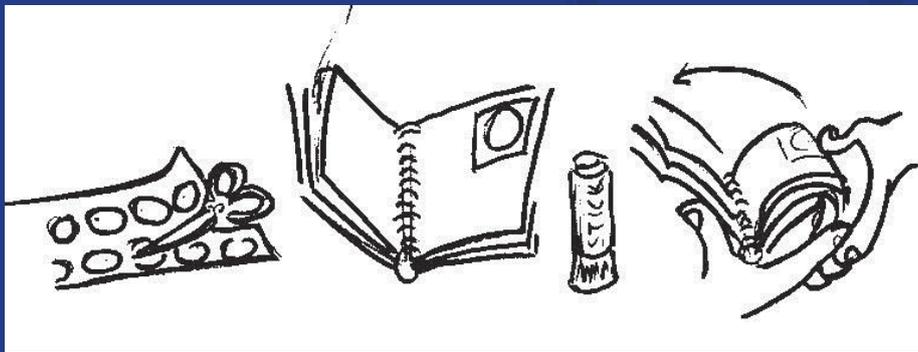


Looking at the small Sun from the Moon



“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 use the demonstrator.



Determination of Diameters

- Measure the diameter of the Moon (using some photos)
- Measure the diameter of the Sun (using pinhole camera)



Determination of the Moon diameter

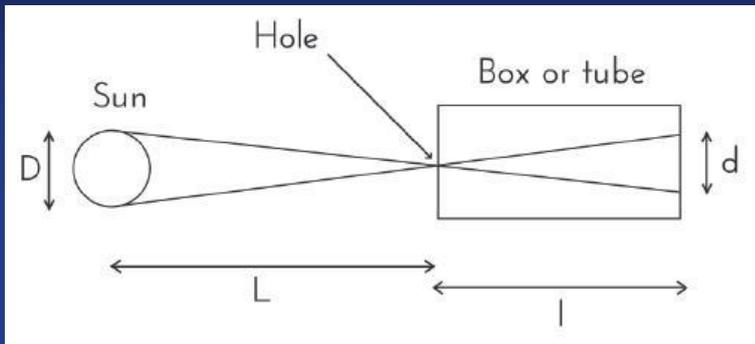
Photos that can show the Earth's shadow cone, represented by a cardboard



Determination of the Sun's diameter: with pinhole camera, observations and measurements



Determination of the Sun's diameter



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

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

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



Aristarchus Experiment 310 to 230 BC

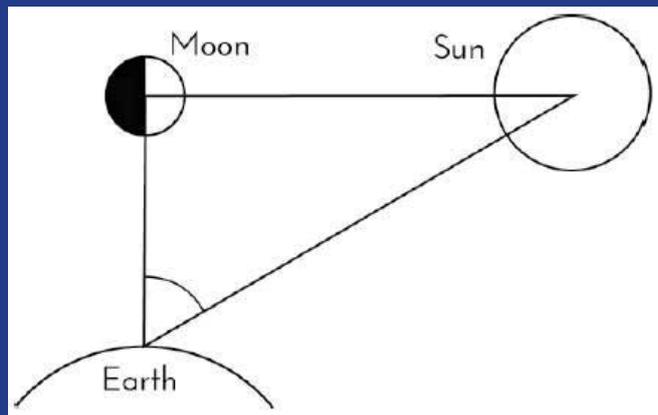
- Established relationships between distances Earth-Moon-Sun and their diameters (but could not determine any absolute value), had to wait until Eratosthenes
 - 1) Distance Earth-Moon and Earth-Sun
 - 2) Radius Moon and Radius Sun
 - 3) Distance Earth-Moon and Moon Radius or distance Earth-Sun and Sun Radius
 - 4) Cone of Terrestrial Shadow and Moon Radius
 - 5) Relate all



1) Distance Earth-Moon and Earth-Sun

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

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



1) Distance Earth-Moon and Earth-Sun

- 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

- $R_s = 400 R_M$



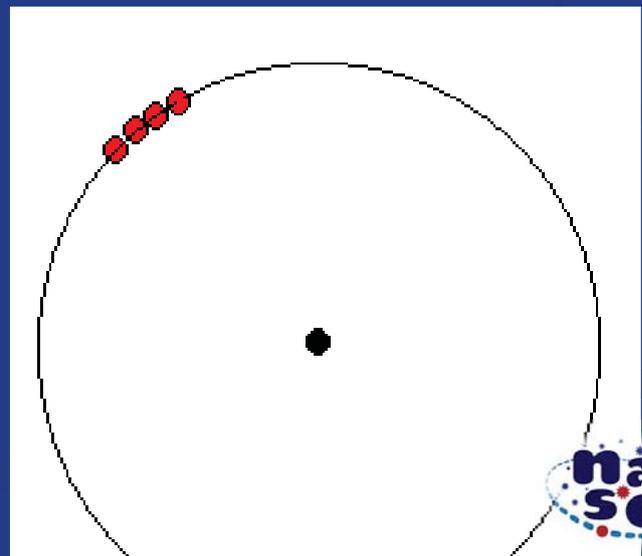
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3) Distance Earth-Moon and Moon Radius

- Moon diameter from the Earth is 0.5°
- With 720 times this diameter, we can discover the **circular** trajectory of the Moon

- $2 R_M 720 = 2 \pi EM$

- $EM = 720 R_M / \pi$

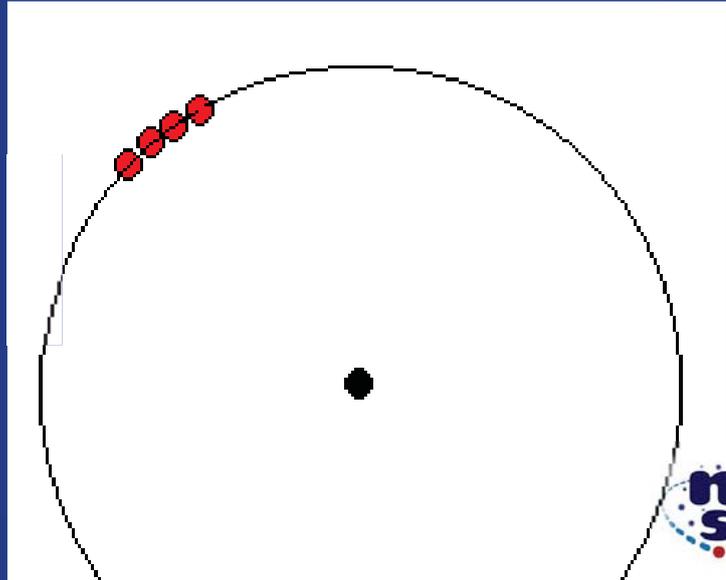


3) Earth-Sun distance and Sun radius

- By analogy

- $ES = 720 R_s / \pi$

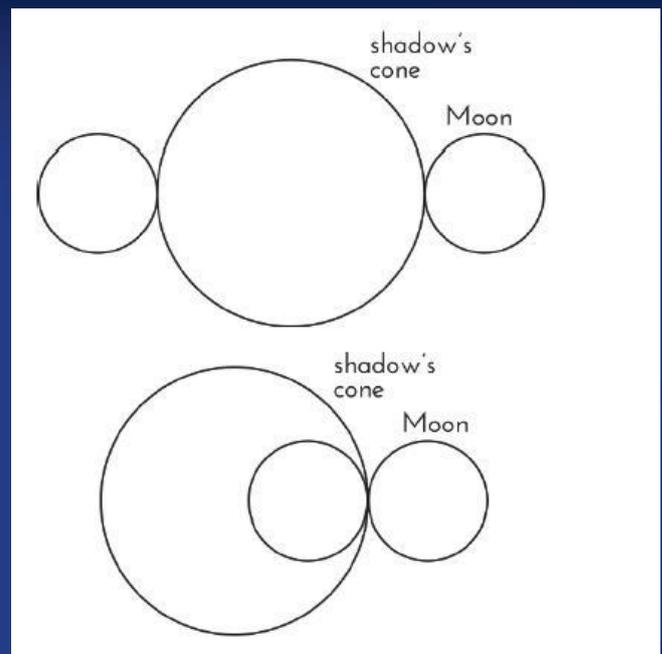
Aristarchus 1st heliocentric model



Cone of Terrestrial Shadow

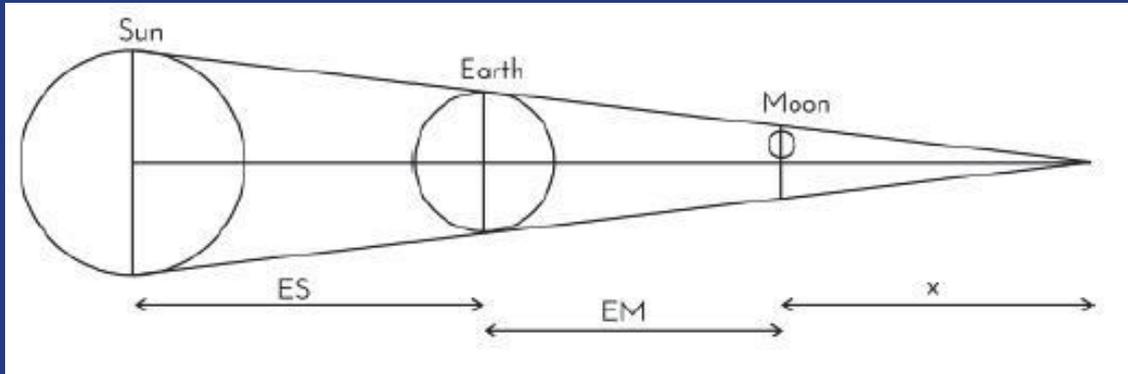
- In a lunar eclipse, Aristarchus observed that the time required for the Moon to cross the shadow cone of the Earth was twice the time necessary for the surface of the Moon remain covered (i.e. 2:1)

- It really is $2.6:1$



5) Relate all

- $(x+TL+TS)/R_s = (x+TL) / R_T = x/(2.6 R_L)$

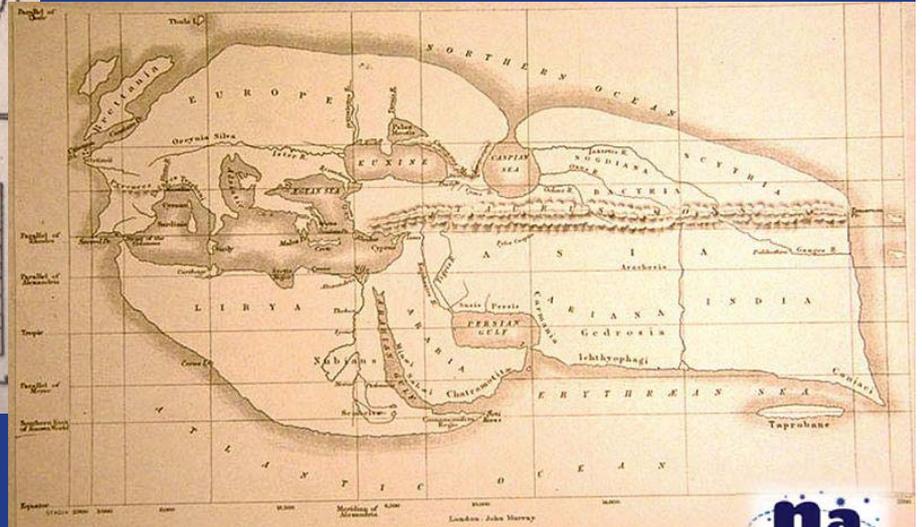
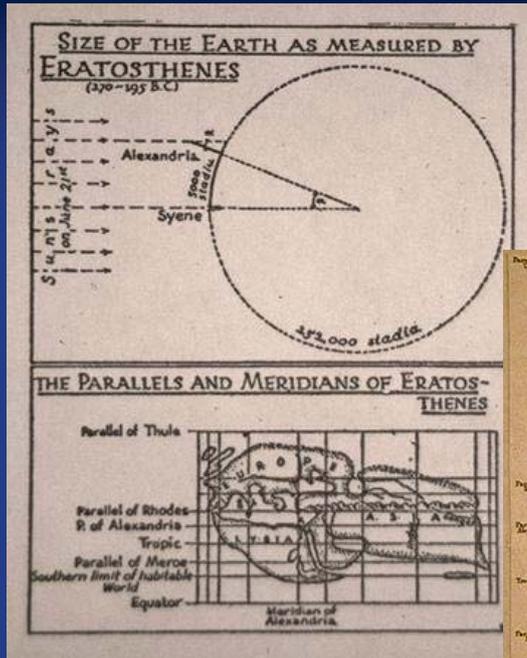


Solving the system follows
(everything related to Earth's radius):

- $R_M = (401 / 1440) R_E$
- $EM = (401 / (2 \pi)) R_E$
- $R_s = (2005 / 18) R_E$
- $ES = (80200 / \pi) R_E$
- We assume $R_E = 6645$ km
- $R_M = 1850$ km (real 1738 km)
- $EM = 424\,000$ km (real 384\,000 km)
- $R_s = 740\,000$ km (real 696\,000 km)
- $ES = 169\,600\,000$ km (real 149\,680\,000 km)



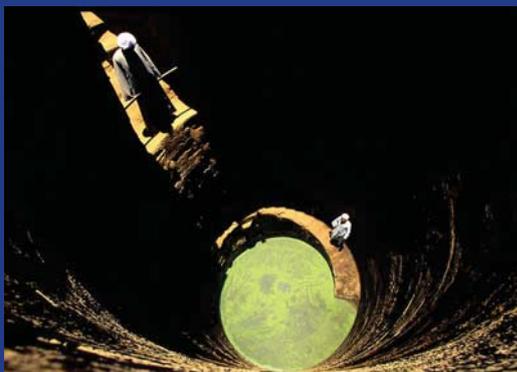
Eratosthenes Experiment 280 to 192 BC



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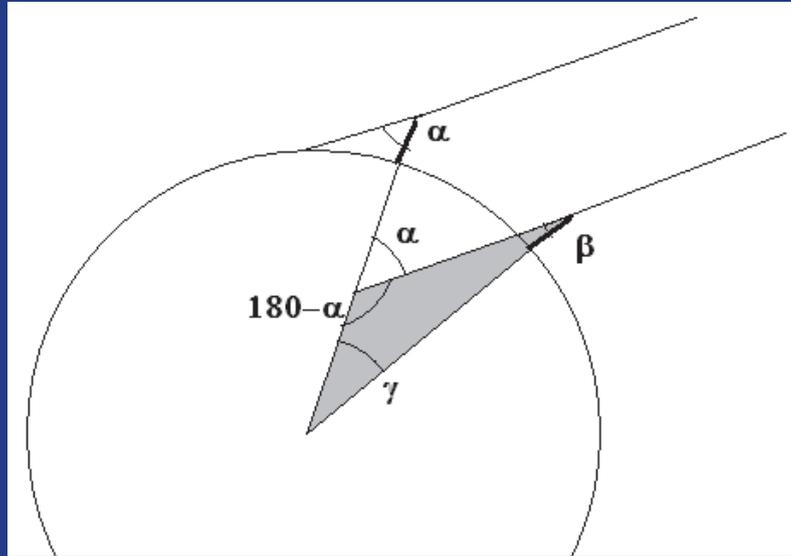
Eratosthenes again

- Two cities on the same meridian
- Simultaneous observations



Eratosthenes

- $\pi = \pi - \alpha + \beta + \gamma$
- therefore $\gamma = \alpha - \beta$
- where α and β are measured in radians



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Eratosthenes



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

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



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- by proportionality

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

- is deduced

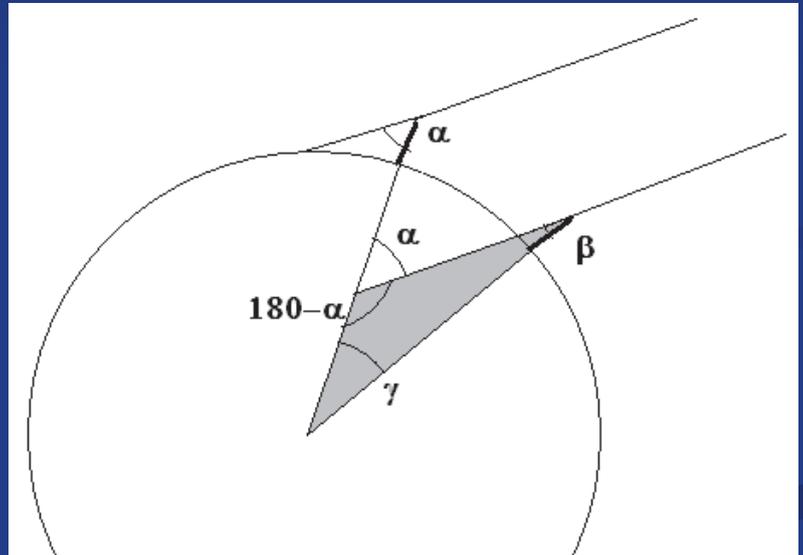
$$R_E = d / \gamma$$

- γ we know

$$\gamma = \alpha - \beta$$

- d is the distance between cities (map)

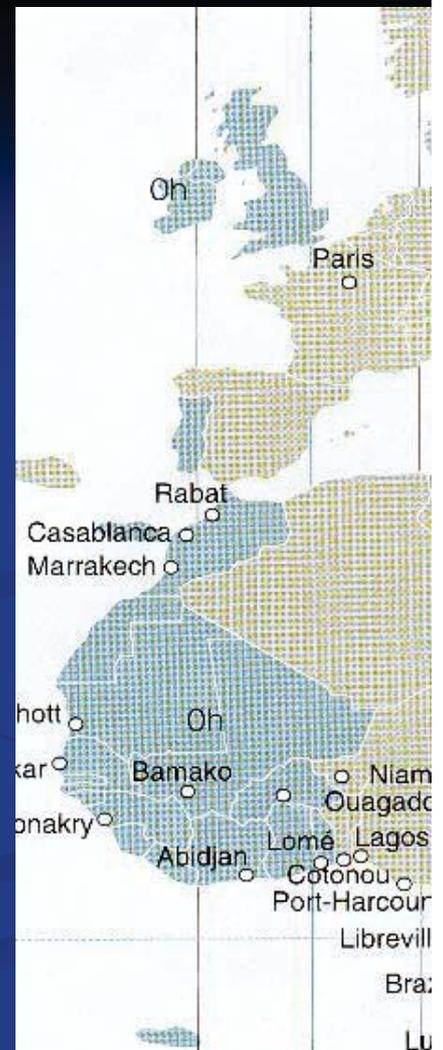
Eratosthenes



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Our results with the method of Eratosthenes

- Ripoll- Barcelona
- $\alpha = 0.5194$ radian
 $\beta = 0.5059$ radian
- $\gamma = 0.0135$ radian
- $d = 89.4$ km
- $R_E = 6600$ km (real 6645 km)



Conclusions

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



**Many Thanks
for your attention!**

