A study of lunar and solar eclipses
日月食的研究

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Goals 目标

- Understand why the Moon has phases
  了解为什么月球有月相
- Understand the cause of Lunar eclipses
  了解月食成因
- Understand why there are Solar eclipses
  了解为什么有日食
- Determine distances and diameters of the Earth-Moon-Sun system
  测定地球-月球-太阳系统（简称EMS系统）的距离和直径

Vision of lights and shadows
光与影

- The Earth-Moon-Sun System:
  Phases and eclipses
  EMS系统，相与食

- Relative positions and shadows
  相对位置和阴影

Activity 1: Model of the far side of the Moon
活动1：关于月球背面的模型

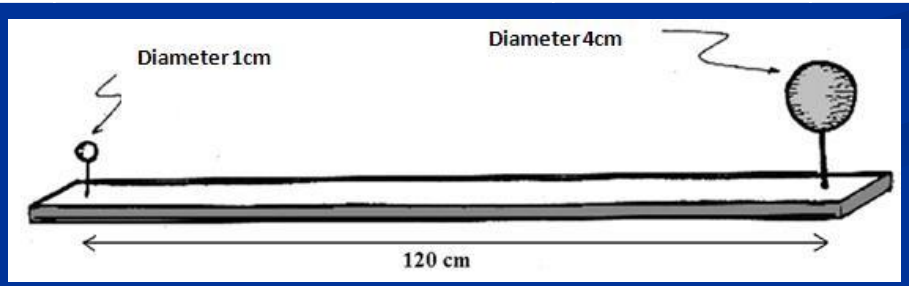
- 2 volunteers: one in the centre (the Earth) and the other revolving around it (the Moon)
- 2个志愿者：一个站中间（地球），另一个绕其旋转（月球）。
- Place the Moon facing the Earth and have it revolve around the Earth by 90° and rotate itself also by 90º. Repeat the process until the starting position is reached
- 令月球面向地球，绕地球公转90º，同时自转90º。重复这个过程，直到到达起始位置。

Activity 2: Model with flashlight (Sun) to explain the phases of the Moon
活动2：手电筒（太阳）模型解释月相

- 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)
- 5志愿者：一个站中间（地球），其余4个模拟4种月相（1个完全被照亮，2个一半被照亮，1个完全黑暗）。

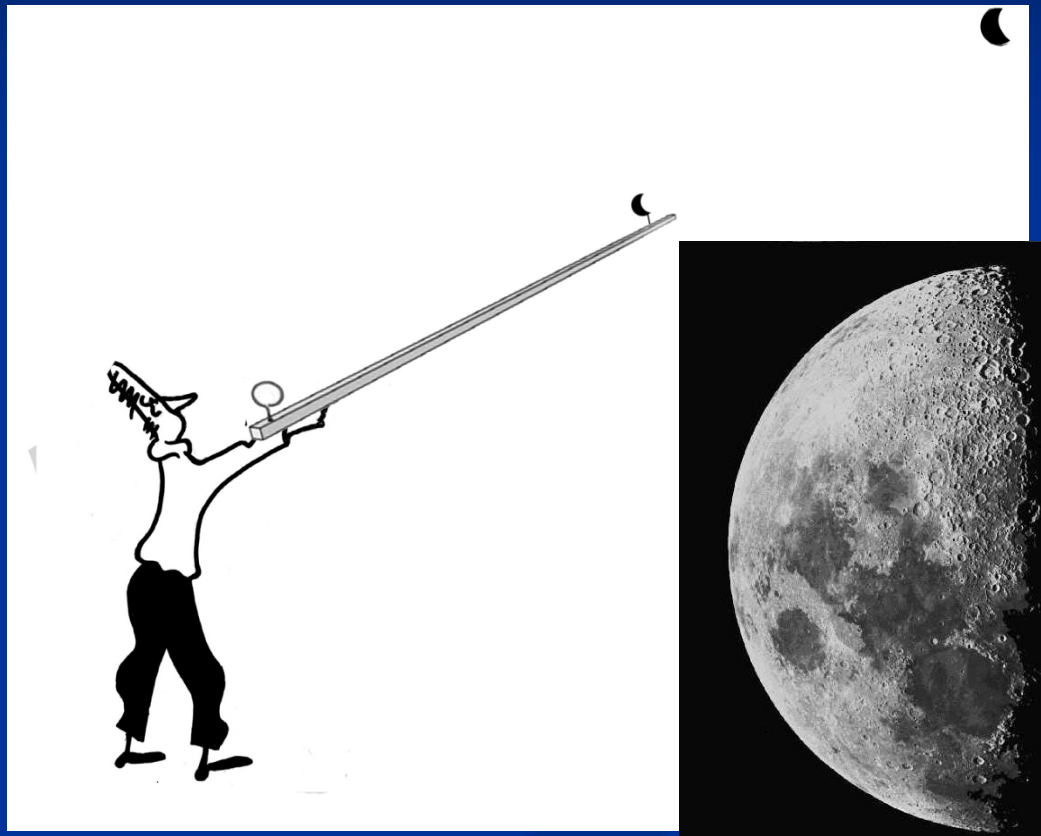
Distances and diameters of the Earth-Moon-Sun system
EMS系统的距离和直径

Earth Diameter 地球直径	12 800 km	→	4 cm
Moon Diameter 月球直径	3 500 km	→	1 cm
EM Distance 地月距离	384 000 km	→	120 cm
Sun Diameter 太阳直径	1 400 000 km	→	440 cm = 4.4 m
ES Distance 日地距离	150 000 000 km	→	47 000 cm = 0.47 km

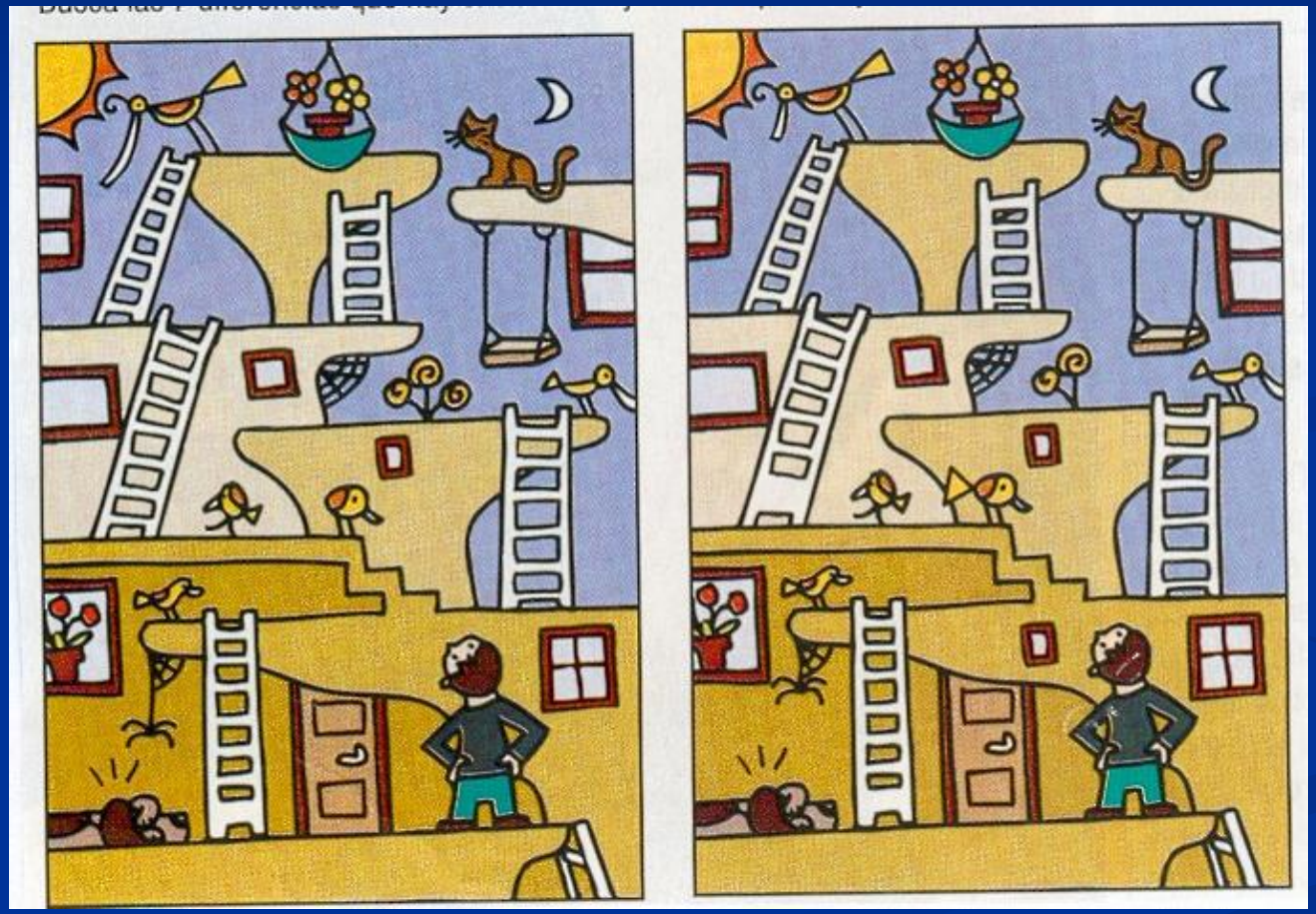


Activity 3: Simulation of Phases of the Moon
活动3：月相模拟

- Direct the small moon of the model to the Moon and we can see both with the same phase
- 将模型中的小月亮指向月亮，我们能看到两个月亮有同样的月相。

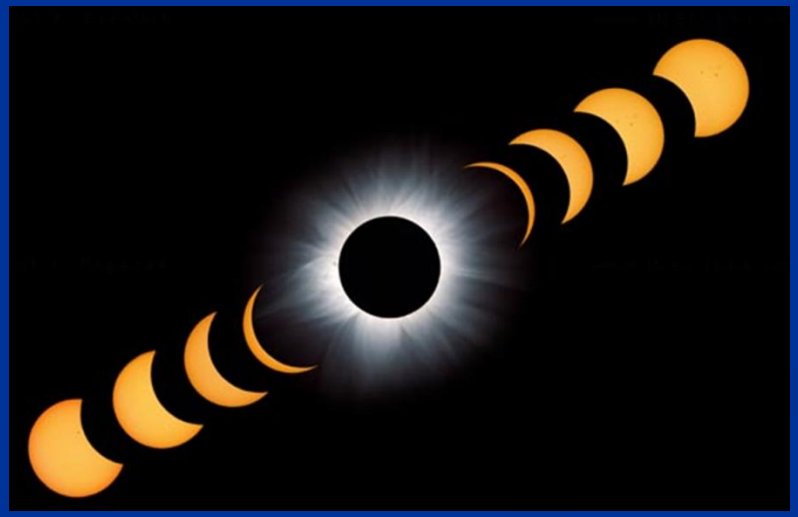


Activity 4: Illustration Errors
活动4：插图的错误



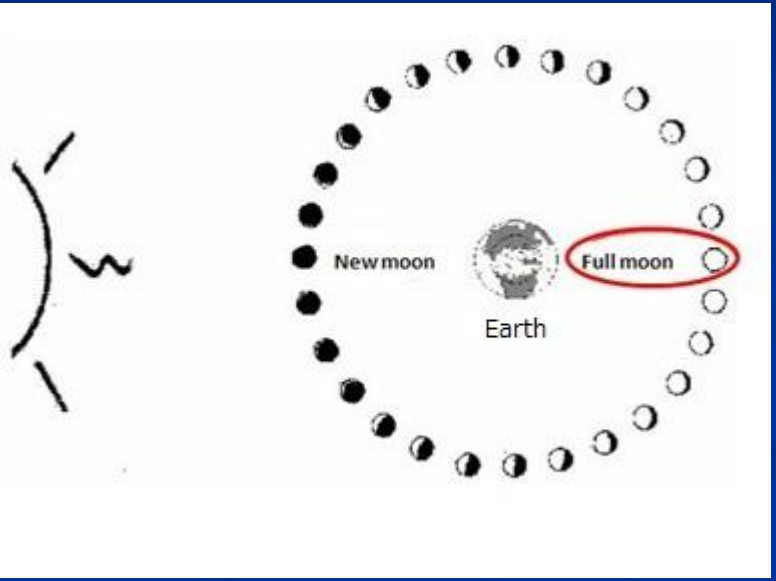
- Phases of the Moon depend on the position of the Sun
- 月相取决于太阳的位置

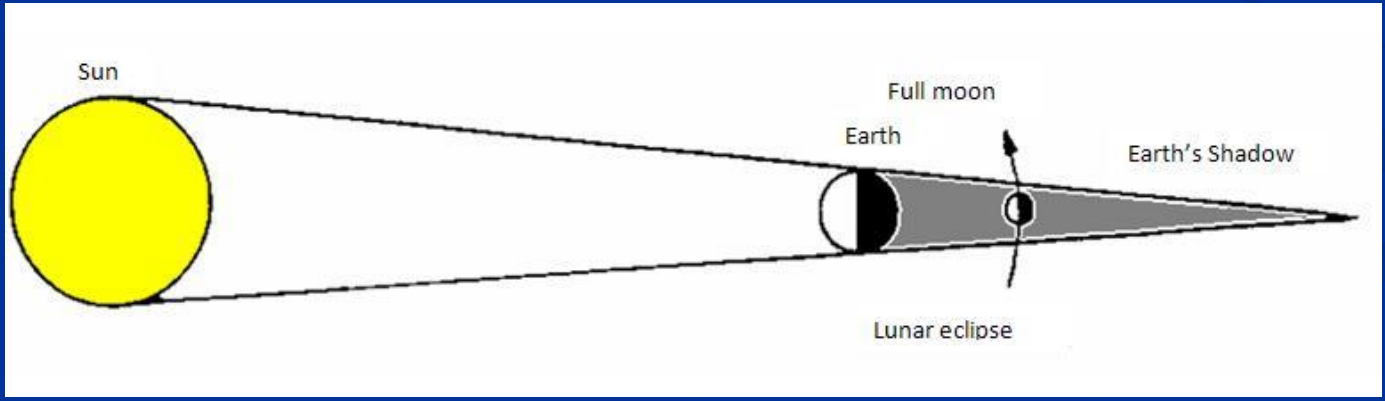
Moon Phases and Eclipses月相和食



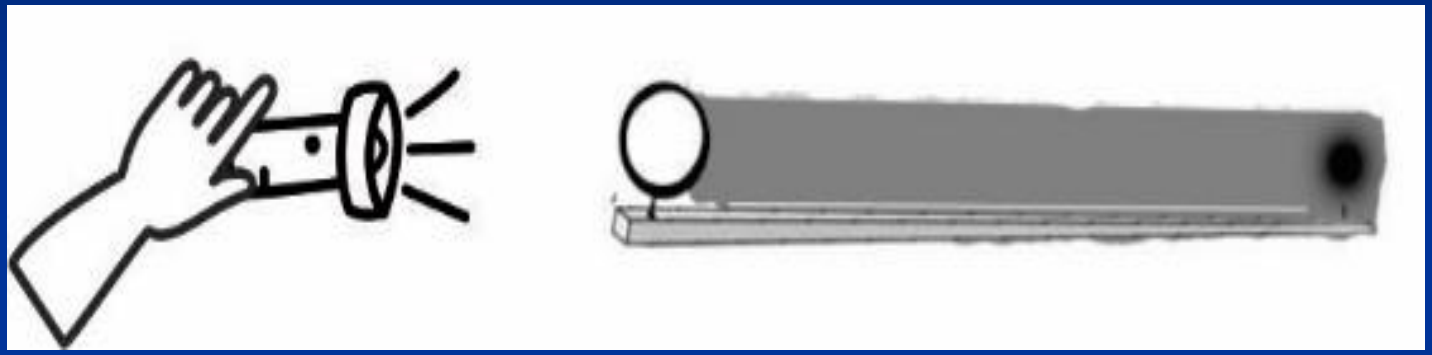
Activity 5: Lunar Eclipses
活动5：月食

- Lunar eclipses only occur when the Moon is full
- 月食只发生在满月





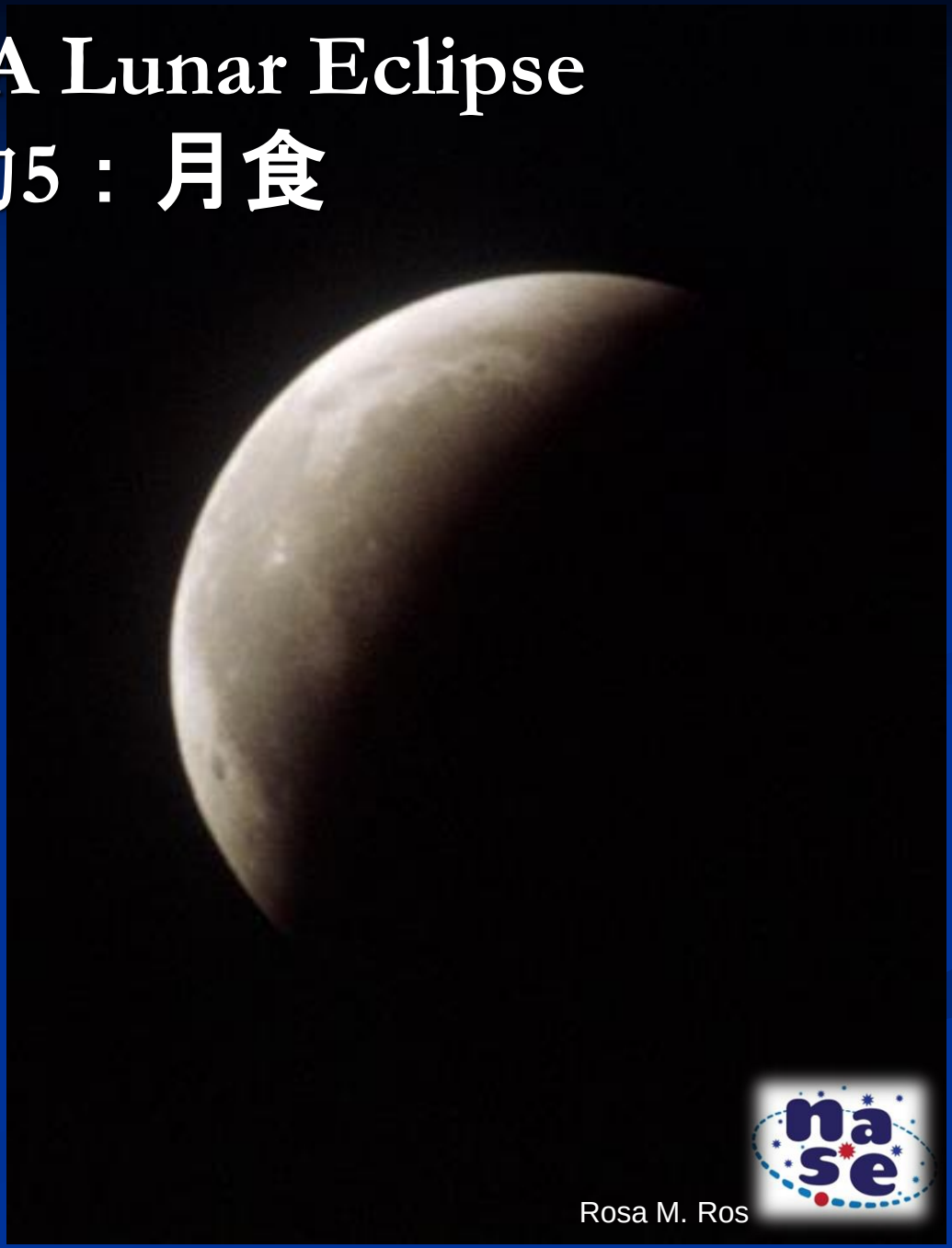
Activity 5: Simulation of a Lunar Eclipse
活动5：月食模拟



Activity 5: A Lunar Eclipse
活动5：月食

Activity 5: A Lunar Eclipse
活动5：月食

- Lunar eclipses can be visible to half of the Earth (night side)
- 月食能被半个地球（黑夜部分）的人观测到。



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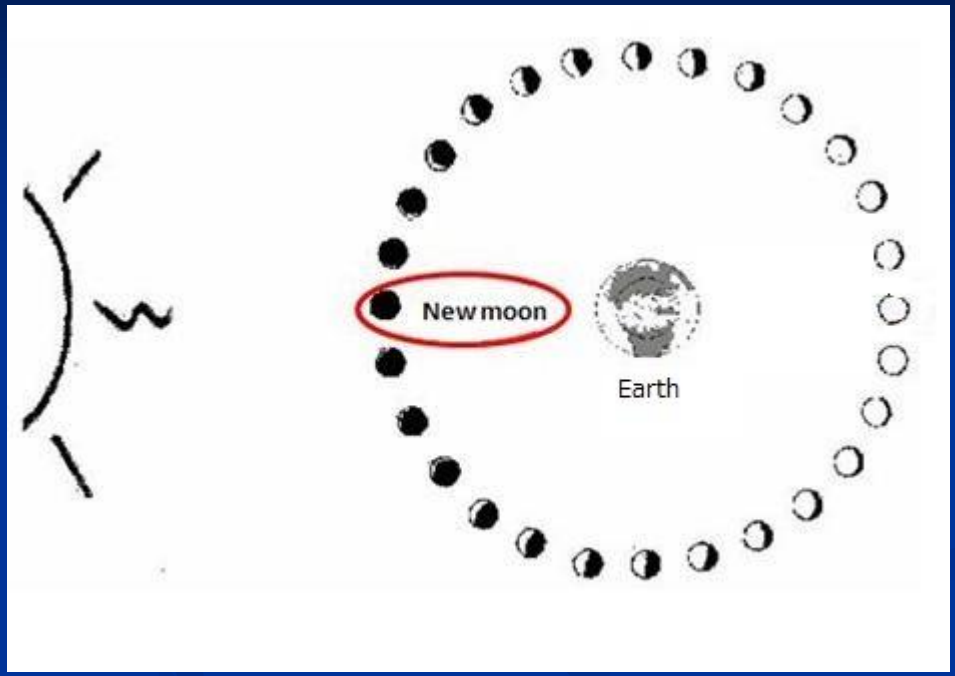
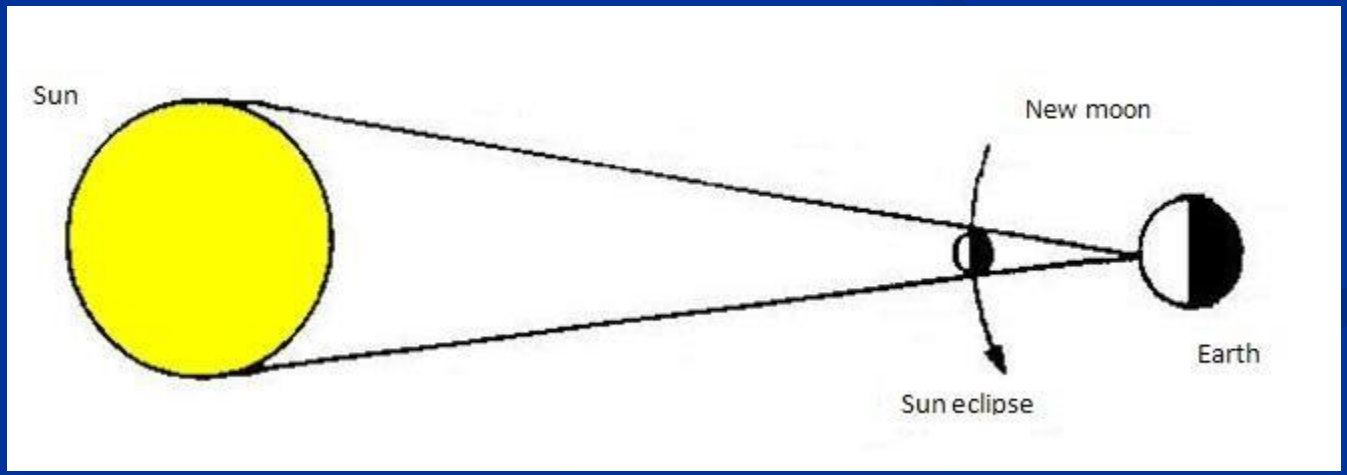
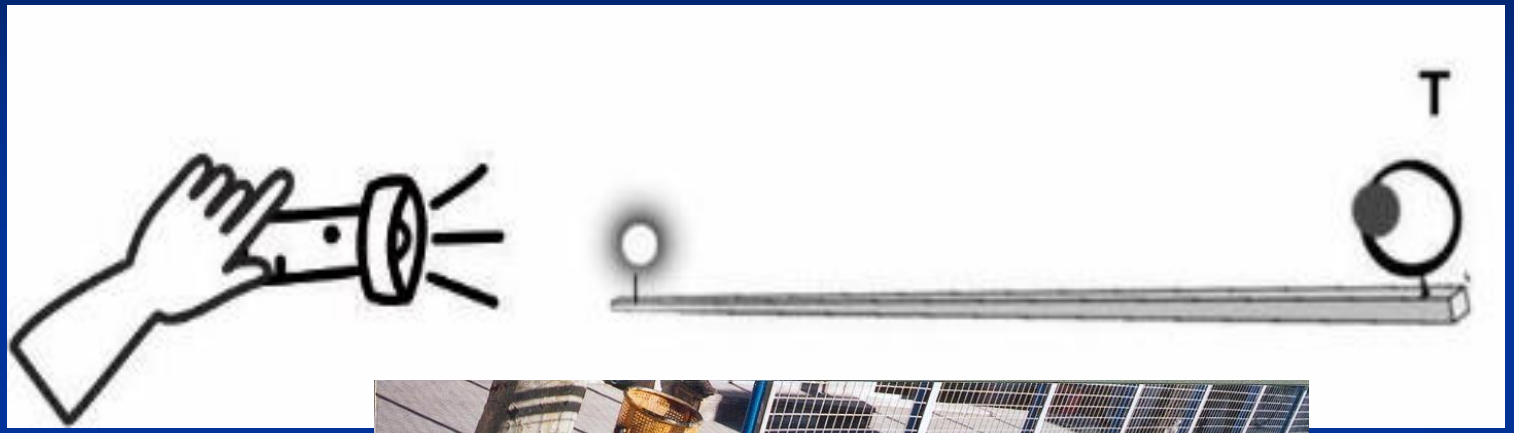
Activity 6: Solar Eclipses 活动6：日食

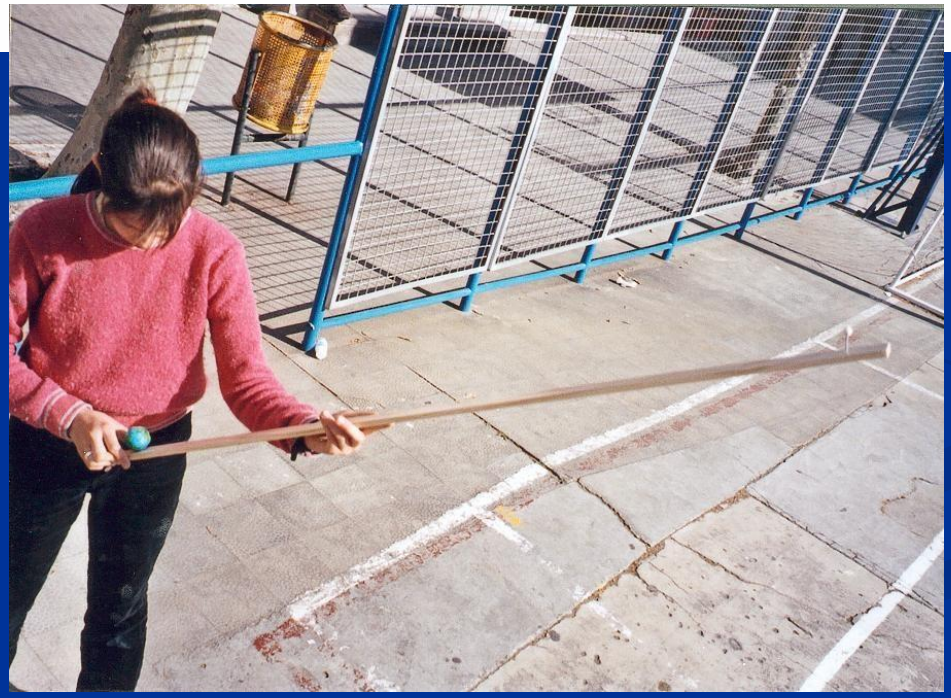
- Solar eclipses occur only when there is a New Moon
- 日食只发生在新月时





Activity 6: Simulation of a Solar Eclipse
活动6：日食模拟





Detail of a Solar eclipse 日食细节

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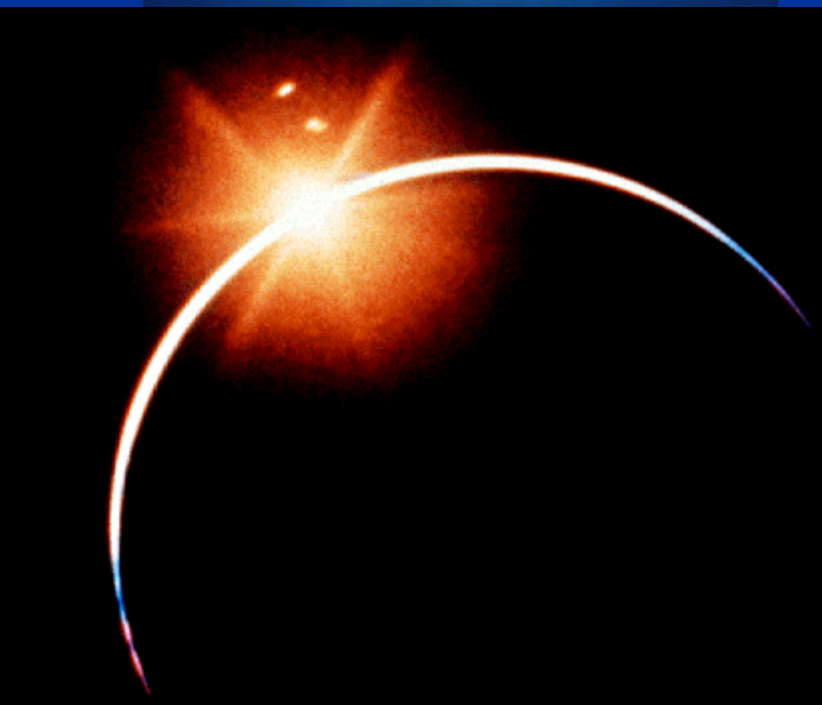
Activity 6: Solar Eclipse
活动6：日食

- Solar eclipses are visible only in a small region of the Earth
- 日食只能在地球的一个小区域看到



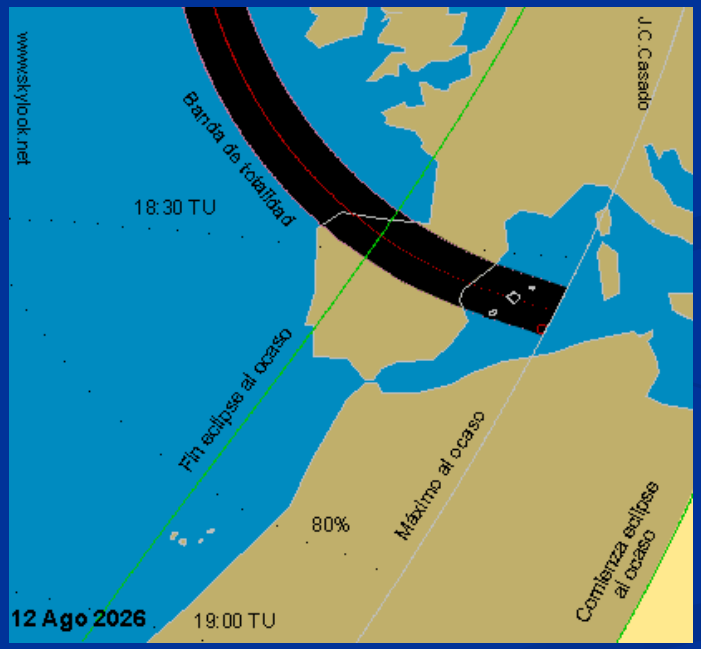
... we are feeling emotion!
…此刻，我们非常激动！

Observations 观测

- A lunar eclipse when there is Full Moon and a solar eclipse when there is a New Moon
月食发生在满月时，日食发生在新月时。
- A solar eclipse is seen only in a small area of the Earth
- 日食只能在地球的一个小区域看到
- 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
- 地球和月球很难“正好对齐”，因此并不是每次新月或满月都会发生日月食

Finally ... as an example ...
最后…举个例子

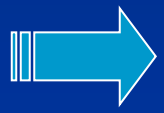
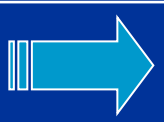
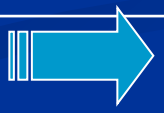
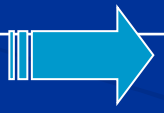
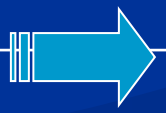
- Next total solar eclipse in Spain: August 12, 2026 (last one 2004 in a different area)
- 下次在西班牙能看的日全食：2026年8月12日（上一次是2004年）



- Each year there are between 0 to 3 lunar eclipses
- 每年有0到3次月食。

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

距离和直径，为了更形象地理解到太阳的距离

Earth Diameter **地球直径**	12 800 km		2.1 cm
Moon Diameter **月球直径**	3 500 km		0.6 cm
E-M Distance **地月距离**	384 000 km		60 cm
Sun Diameter **太阳直径**	1 400 000 km		220 cm
E-S Distance **日地距离**	150 000 000 km		235 m

Painting the Sun 画太阳

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

活动7：摆放“太阳”、“月亮”，让它们看起来差不多大

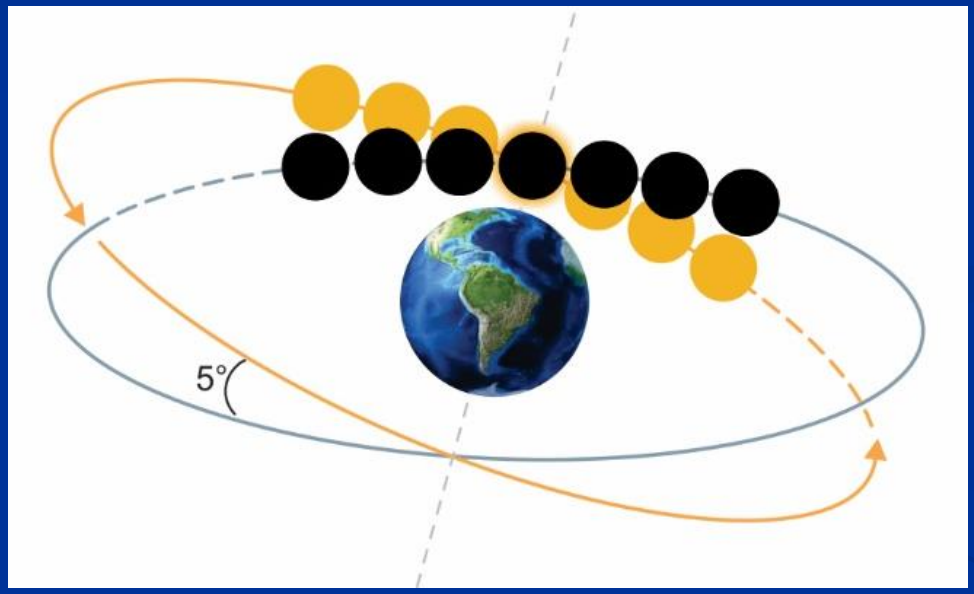
If every month there is
a New Moon and a Full Moon …
如果每个月有一次新月和一次满月…

Why there is not
a Solar eclipse and a Lunar eclipse
every month?
为什么不会每个月都有日食和月食？

Because …因为…

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

地球绕太阳的平面和月球绕地球的平面不在同一个平面上。



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

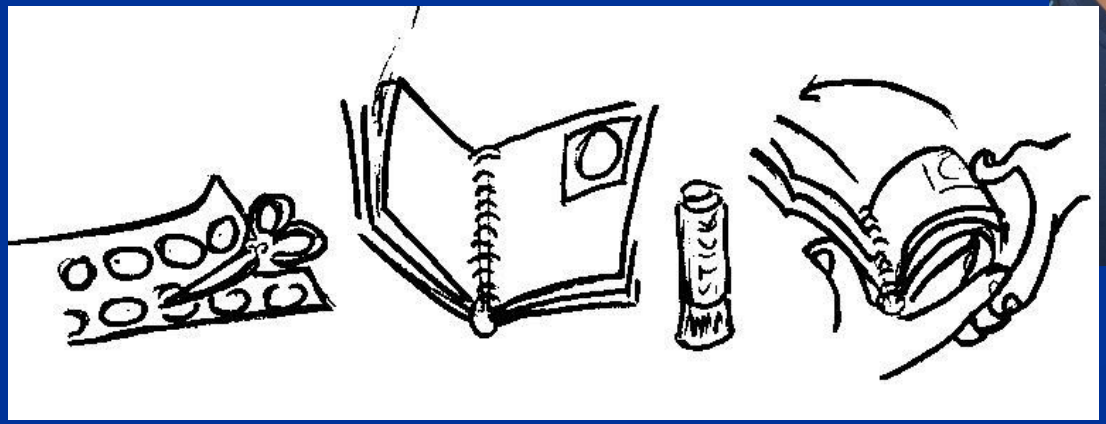
两个平面夹角5º，并且太阳和月亮的视直径只有0.5º

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

日月食，只能发生在两个平面的交线附近。

Activity 8: “Flip page” eclipse simulator
活动8：日月食模拟动画书

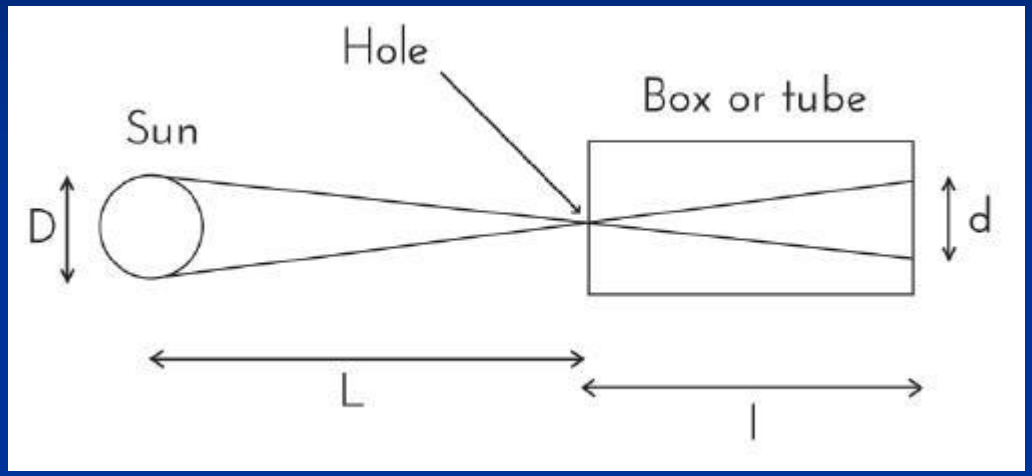
1. Trim and number the pictures in order
   剪下并按顺序将图片标上序号
2. Paste each picture on a spiral notebook
   将每张图片粘在螺旋笔记本上
3. Turn the pages quickly to see the demonstration.
   快速翻页进行演示



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

活动9：测定太阳直径——观测和计算

Activity 9: Determination of the Sun's diameter
活动9：测定太阳直径



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

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

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

我们能够建立比例式，并计算出太阳的直径

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

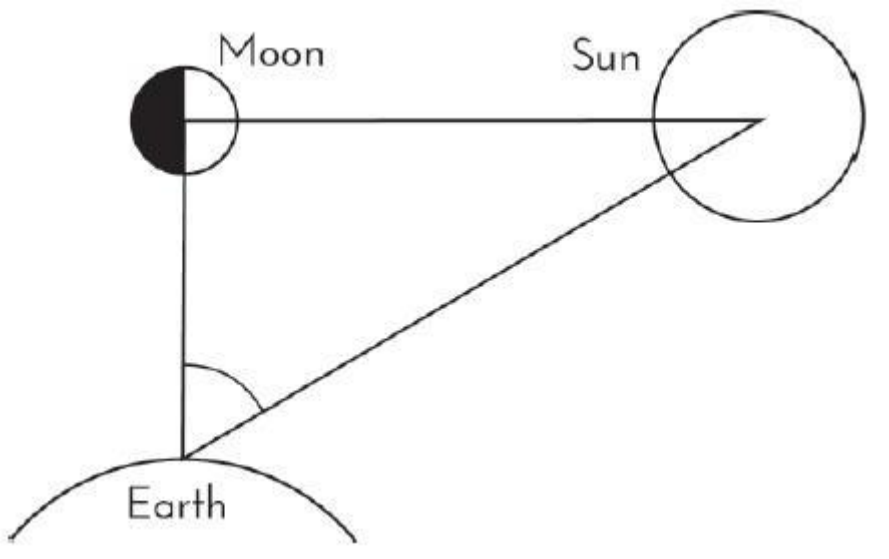
L = 150 000 000 km **日地距离**, l = **盒子**长度, d = **半透明**纸上的太阳直径

Activity 10: Aristarchus's Experiment 310 to 230 BC
活动10：阿里斯塔克实验 310到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.
- 确定地球-月球-太阳距离和直径的相互关系，但无法测定出具体数值，直到后来的埃拉托色尼。
  - 1) Distance of the Earth to Moon and the Earth to Sun
    地月距离和日地距离
  - 2) Radius of the Moon and of the Sun
    月球和太阳的半径
  - 3) Earth to Moon distance and the Moon's radius
    地月距离和月球半径
  - 4) The Cone of the Terrestrial Shadow 地球影锥
  - 5) Relate them all 将所有参数关联起来

1) Distance Earth-Moon and Earth-Sun
地月距离和日地距离

- $\cos \alpha = EM / ES$ therefore （因此） $ES = EM / \cos \alpha$



1) Earth-Moon and Earth-Sun Distances
地月距离和日地距离

（阿里斯塔克的值）

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

（现在的值）

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2) Radius of the Moon and of the Sun
月球和太阳的半径

- From the Earth, lunar and solar diameters are observed to be equal to 0.5°
  从地球上看，月亮和太阳的直径都是0.5°
- Therefore, the radius is
- 因此，半径为：
- $R_S = 400\ R_M$

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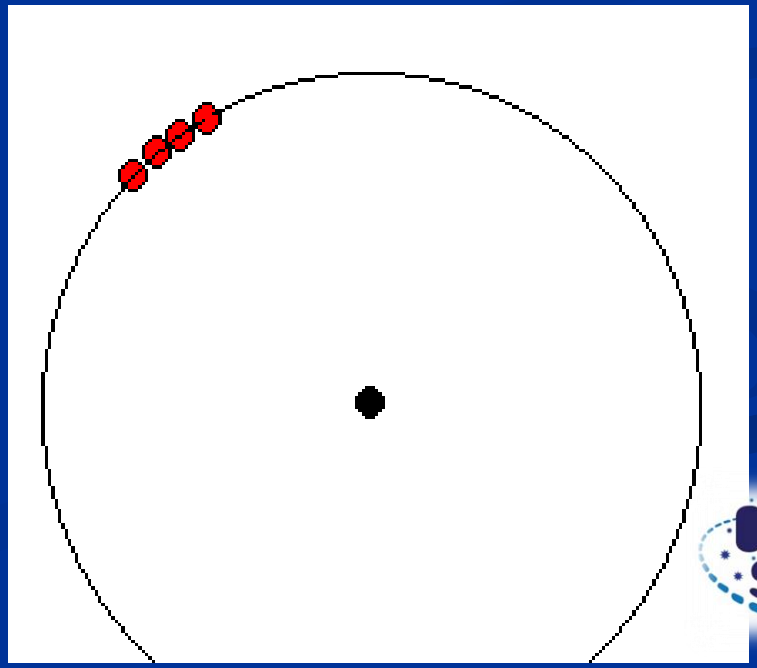
3) Earth-Moon Distance and Moon's Radius
地月距离和月球半径

- Moon's diameter from the Earth is 0.5 º
- 从地球上看月球的直径是0.5 º
- With 720 times this diameter, we can calculate the **circular** trajectory of the Moon
- 月球的整个**圆形**轨道是直径的720倍
- 2 RM 720 = 2 π EM
- $EM = 720\ R_M / \pi$



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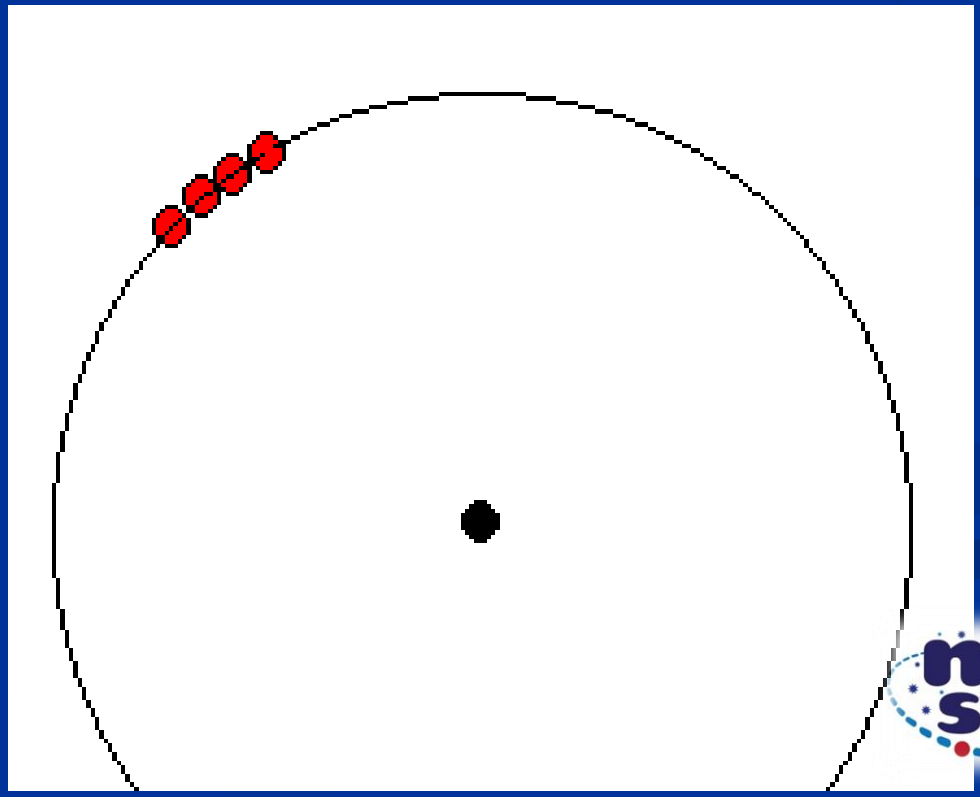
3) Earth-Sun distance and Sun radius
日地距离和太阳半径

- By analogy　类推
- ES = 720 Rs/ π

Aristarchus's 1st Heliocentric model
阿利斯塔克的第一个日心模型

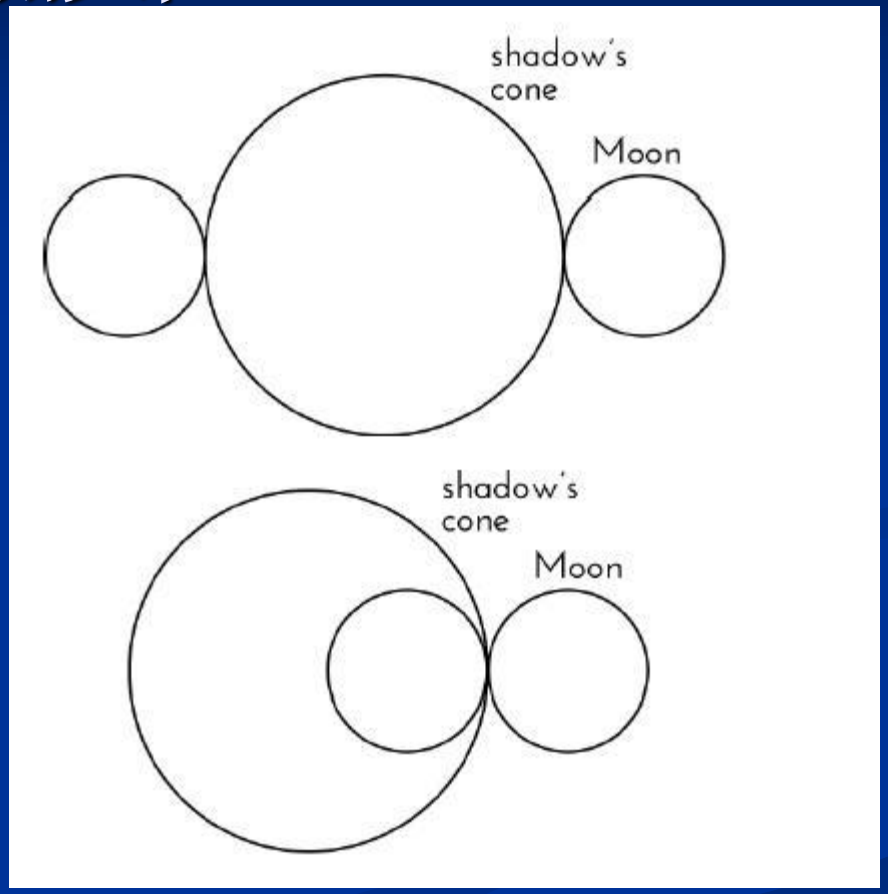


4) Cone of Terrestrial Shadow
地球的影锥

- In a Lunar eclipse,

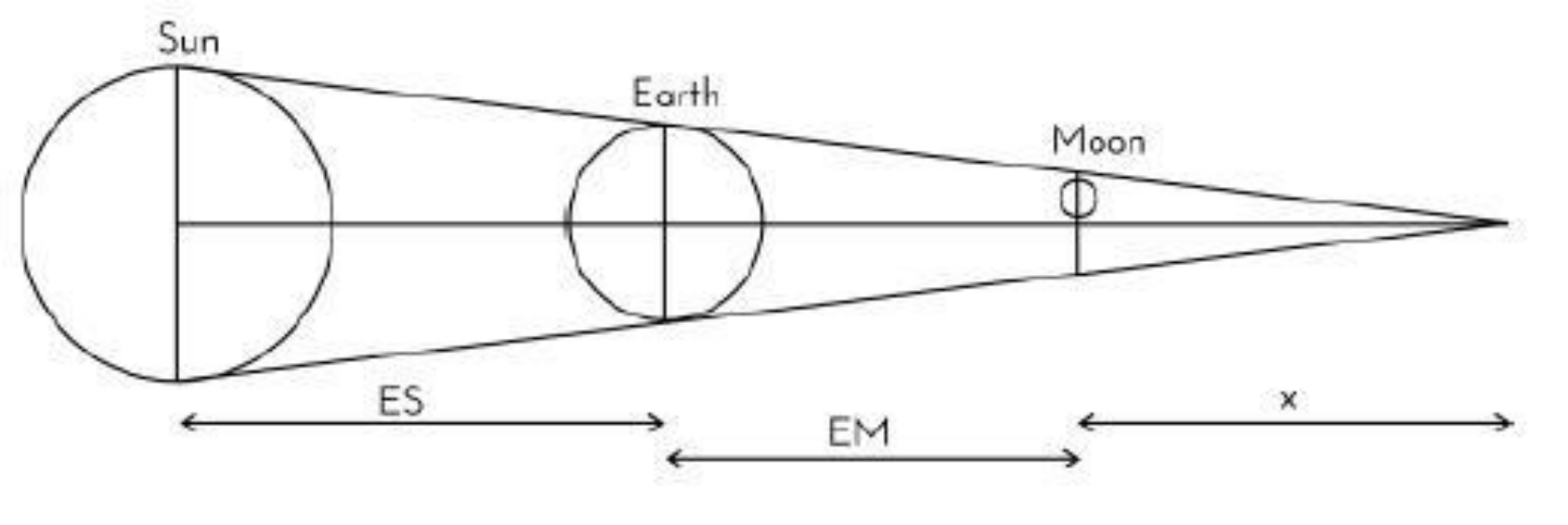
Aristarchus observed that the time required for the Moon to cross the shadow cone of the Earth was twice the time necessary for the surface of the Moon remain covered (i.e. 2:1)

- It is actually 2.6:1
- 在一次月食中，阿利斯塔克观测到月亮完全穿过地球影锥的时间（初亏到复圆）是月亮完全在地球阴影里时间（食既到生光）的两倍（即2:1）。
- 真实应该是 2.6:1



5) Relate them all 将所有参数关联起来

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



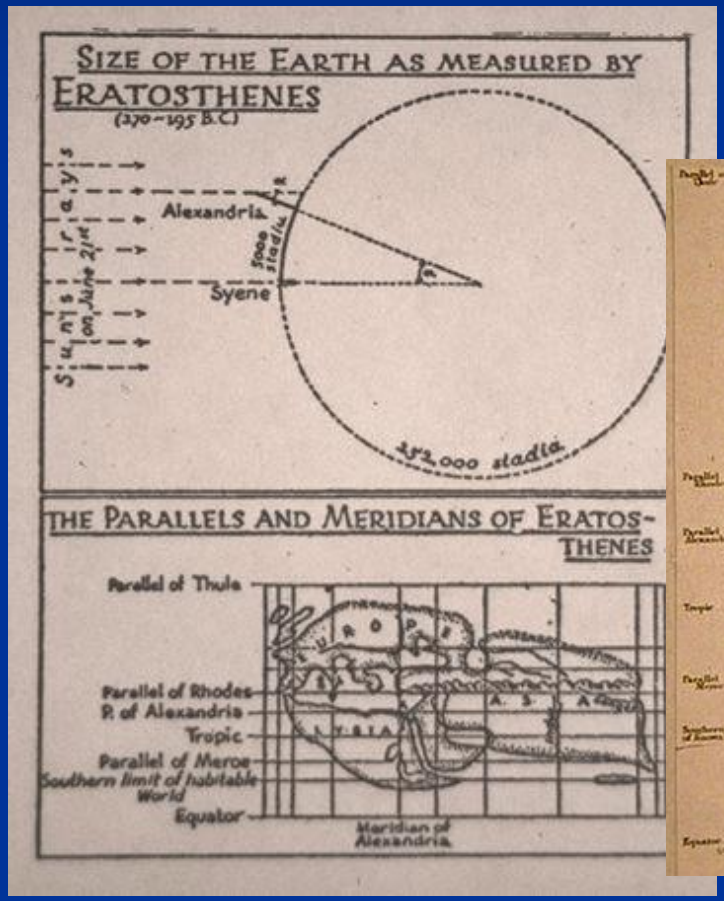
Solving the system shows 做如下解 (everything related to Earth's radius): （均相对于地球的半径）

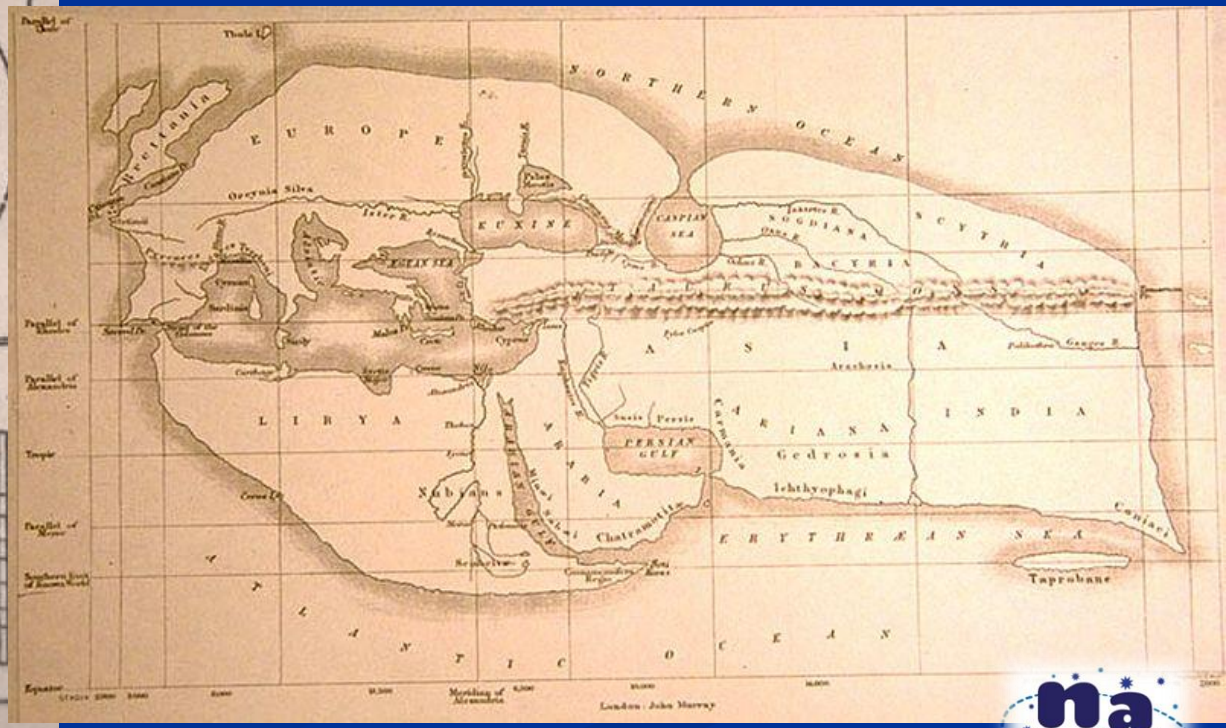
- $R_M = (401 / 1440)\ R_E$
- $EM = (401 / (2\pi))\ R_E$
- $R_S = (2005 / 18)\ R_E$
- $ES = (80200 / \pi)\ R_E$

- If we assume（如果我们假定） $R_E = 6\ 378$ km then（那么）
- $R_M = 1\ 776$ 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

活动11：埃拉托色尼试验 280到192 BC





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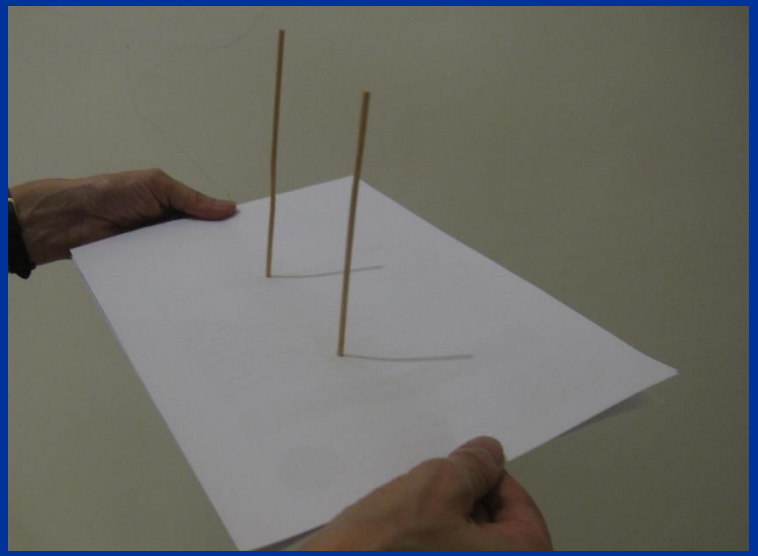
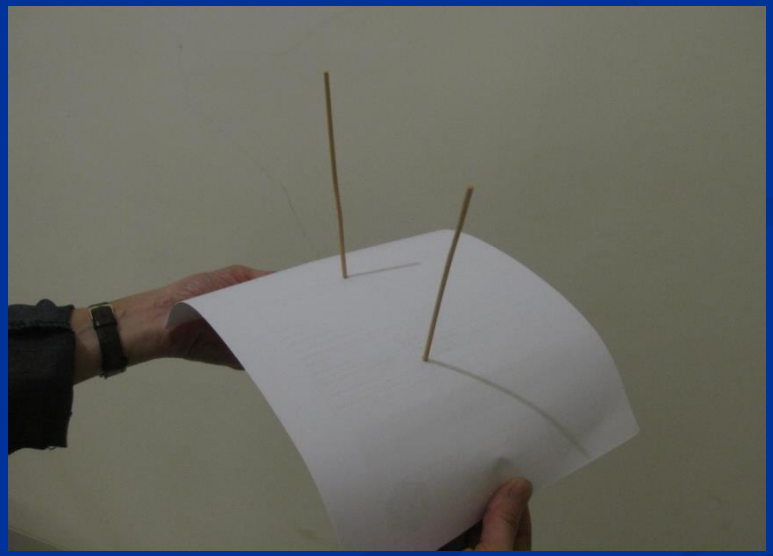
Activity 11: Eratosthenes again
活动11：重复埃拉托色尼

- Two cities on the same meridian
- 两座城市，同一经度
- Simultaneous observations
- 同时观测

Different shadows …
不同的影子…

- Then the Earth is a sphere!
- 因此，地球是球形！





Activity 11: Eratosthenes again

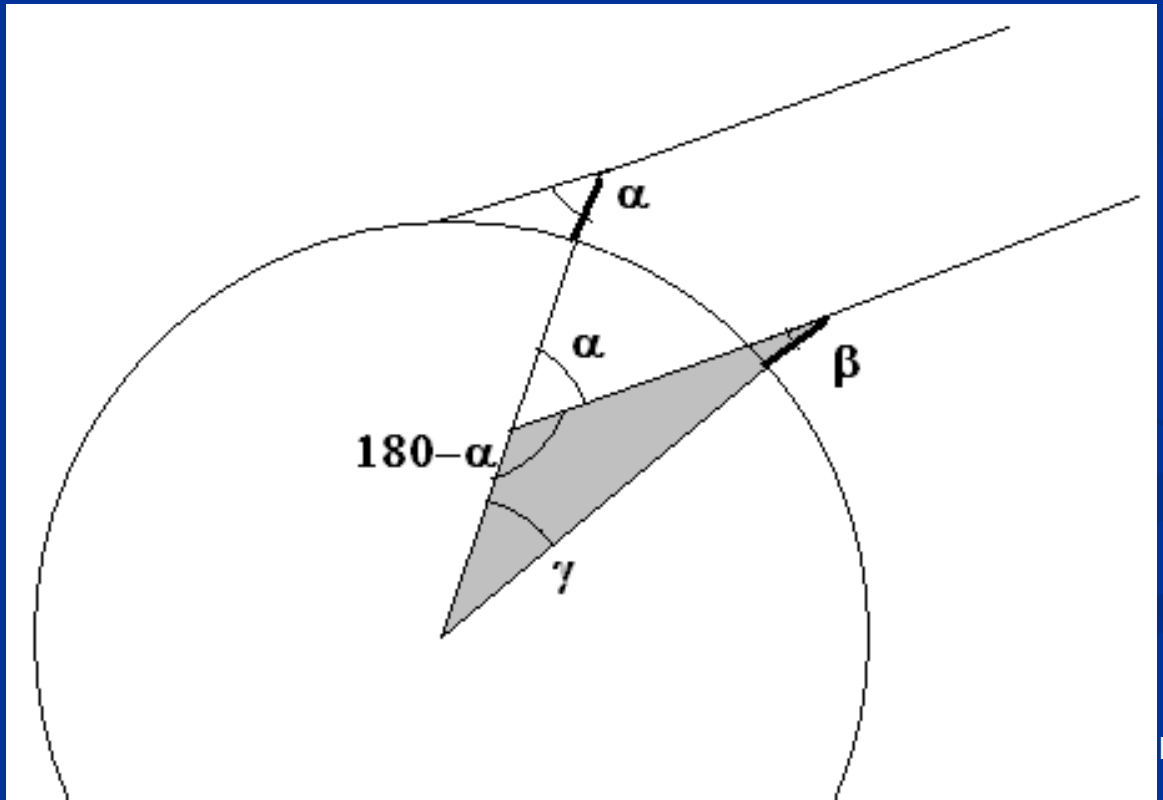
活动11：重复埃拉托色尼

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

where α and β are measured in radians

(180 degrees = π radians)

在这里α和β以弧度测量



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Activity 11: Eratosthenes again
活动11：重复埃拉托色尼

- We measure the length of the plumb line (or stick) and its shadow
- 我们测量铅垂线（或棍）和它的影子

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

（影子）　（棍）

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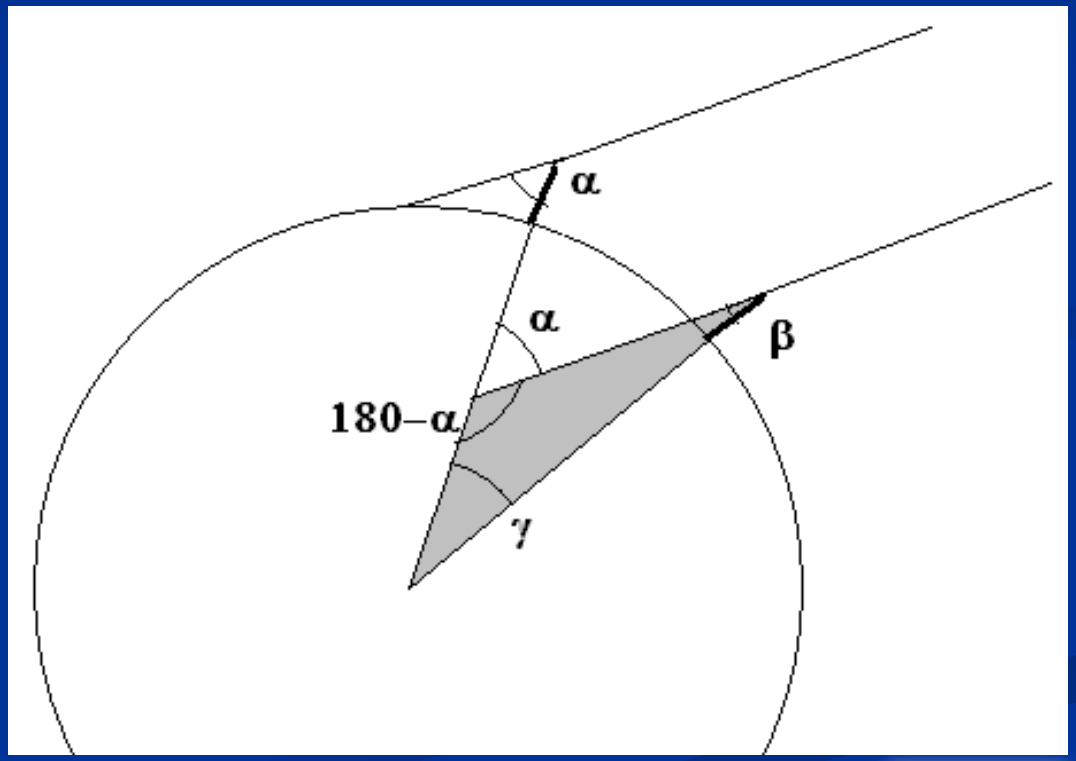
Activity 11: Eratosthenes again
活动11：重复埃拉托色尼

- by proportionality
  根据比例
  $2\pi R_E / 2\pi = d / \gamma$
- is deduced 推出

$$R_E = d/\gamma$$

- γ we know (in radians)
  我们知道（用弧度计量）
  $\gamma = \alpha - \beta$
- d is the distance between cities - using a map
  d是城市之间的距离，使用地图测量。



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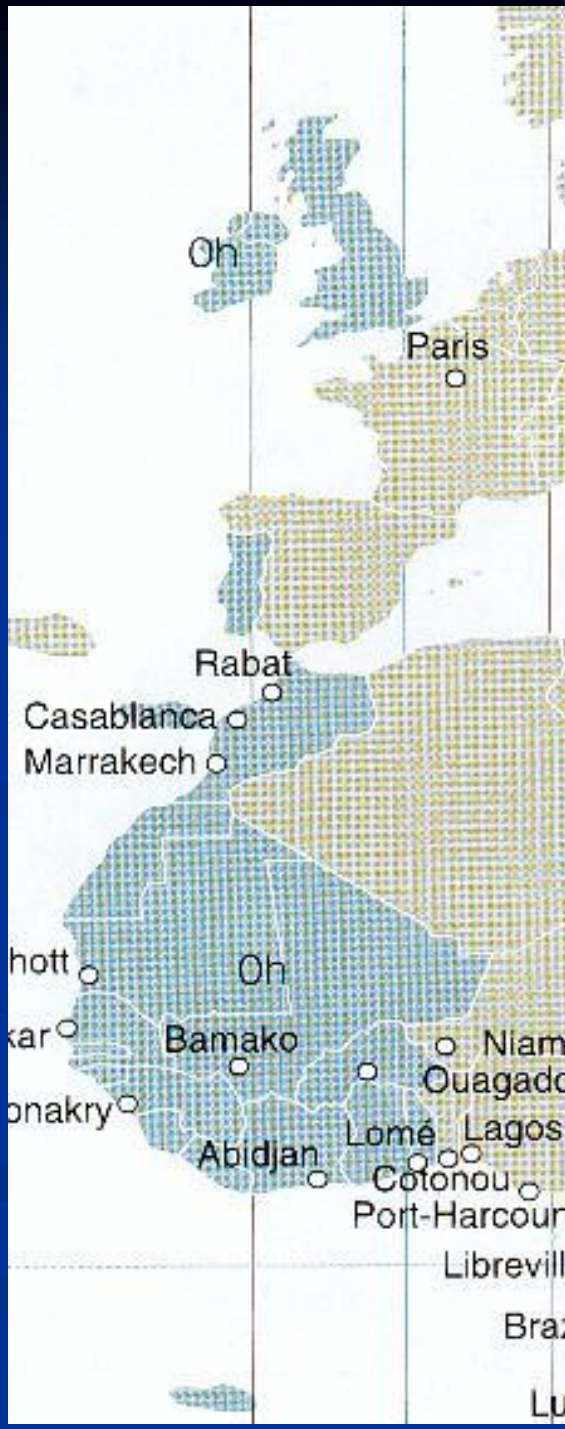
Our results with the method of Eratosthenes
我们利用埃拉托色尼方法的结果

- Ripoll- Barcelona 里波尔-巴塞罗那
- $\alpha = 0.5194$ radians （弧度）
- $\beta = 0.5059$ radians
- $\gamma = 0.0135$ radians
- $d = 89.4$ km

- $R_E = 6\,600$ km (actual 6 378 km)
（真实值）



Conclusions
结论

- We now understand the eclipses
- 我们了解了日月食
- Have established size relationships for the Earth-Moon-Sun system
- 建立了地球-月球-太阳系统的大小关系
- It is verified that by observing and analysing the data obtained, we can learn much more about the universe
- 证实了：通过观测获取数据，并对数据进行分析研究，我们能够了解更多关于宇宙的知识。

Many Thanks

for your attention!

谢谢