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Reconstruction of Ancient Greek Astronomy

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Abstract:*Here in this paper we will review and revise the ancient Greek methods of calculating distance to the sun and distance to the moon from earth.*

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I. Introduction

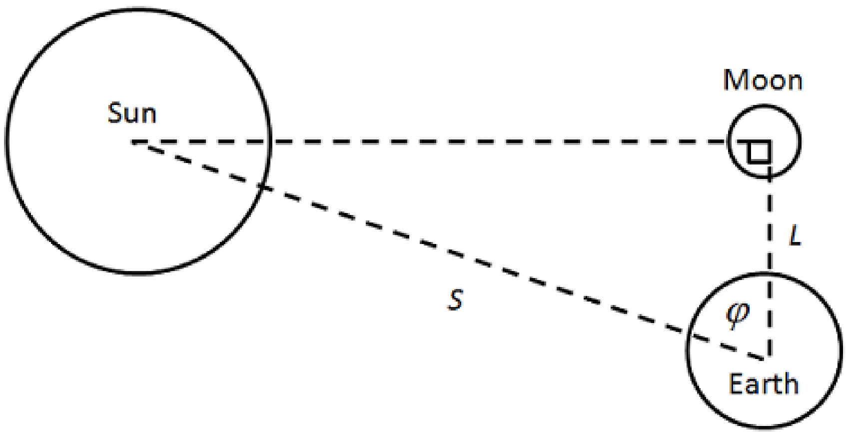
On the Sizes and Distances (of the Sun and Moon), Peri megethon kai apostematon) is widely accepted as the only extant work written by Aristarchus of Samos, an ancient Greek astronomer who lived circa 310–230 BCE. This work calculates the sizes of the Sun and Moon, as well as their distances from the Earth in terms of Earth's radius.The book was presumably preserved by students of Pappus of Alexandria's course in mathematics, although there is no evidence of this. The edition princeps was published by John Wallis in 1688, using several medieval manuscripts compiled by Sir Henry Savile. The earliest Latin translation was made by Giorgio Valla in 1488. There is also a 1572 Latin translation and commentary by FredericoCommandino[1-4].

II. Methodology

The work's method relied on several observations:
The apparent size of the Sun and the Moon in the sky.
The size of the Earth's shadow in relation to the Moon during a lunar eclipse
The angle between the Sun and Moon during a half moon is very close to 90°.
The rest of the article details a reconstruction of Aristarchus' method and results.[4]
The reconstruction uses the following variables.

φ	Angle between the Moon and the Sun during a half moon (directly measurable)
L	Distance from the Earth to the Moon
S	Distance from the Earth to the Sun
ℓ	Radius of the Moon
s	Radius of the Sun
t	Radius of the Earth
D	Distance from the center of Earth to the vertex of Earth's shadow cone
d	Radius of the Earth's shadow at the location of the Moon
n	Ratio, d/ℓ (a directly observable quantity during a lunar eclipse)
x	Ratio, $S/L = s/\ell$ (which is calculated from φ)

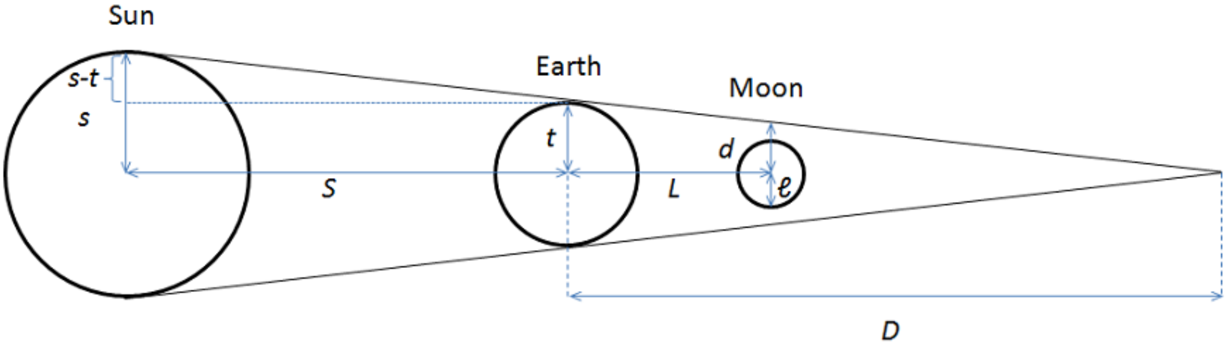
III. Mathematical Calculations



Aristarchus began with the premise that, during a half moon, the moon forms a right triangle with the Sun and Earth. By observing the angle between the Sun and Moon, φ, the ratio of the distances to the Sun and Moon could be deduced using a form of trigonometry.The diagram is greatly exaggerated, because in reality, $S = 390$ L, and φ is very close to 90°. Aristarchus found φ to be a thirtieth of a quadrant (3°) less than a right angle: in current terminology, 87°. In reality it is exactly 89.853°.

$$\frac{S}{L} = \frac{1}{\cos\varphi} = \sec\varphi = 389.76763518$$

Aristarchus then used another construction based on a lunar eclipse:



By similarity of the triangles, $\frac{D}{L} = \frac{t}{t-d}$ and $\frac{D}{S} = \frac{t}{s-t}$.

Dividing these two equations and using the observation that the apparent sizes of the Sun and Moon are the same, $\frac{L}{S} = \frac{\ell}{s}$, yields

$$\frac{\ell}{s} = \frac{t-d}{s-t} \Rightarrow \frac{s-t}{s} = \frac{t-d}{\ell} \Rightarrow 1 - \frac{t}{s} = \frac{t}{\ell} - \frac{d}{\ell} \Rightarrow \frac{t}{\ell} + \frac{t}{s} = 1 + \frac{d}{\ell}.$$

The rightmost equation can either be solved for ℓ/t

$$\frac{t}{\ell}(1 + \frac{\ell}{s}) = 1 + \frac{d}{\ell} \Rightarrow \frac{\ell}{t} = \frac{1 + \frac{\ell}{s}}{1 + \frac{d}{\ell}}.$$

or s/t

$$\frac{t}{s}(1 + \frac{s}{\ell}) = 1 + \frac{d}{\ell} \Rightarrow \frac{s}{t} = \frac{1 + \frac{s}{\ell}}{1 + \frac{d}{\ell}}.$$

The appearance of these equations can be simplified using $n = d/\ell$ and $x = s/\ell$.

$$\frac{\ell}{t} = \frac{1+x}{x(1+n)}$$

$$\frac{s}{t} = \frac{1+x}{1+n}$$

The above equations give the radii of the Moon and Sun entirely in terms of observable quantities.

The following formulae give the distances to the Sun and Moon in terrestrial units:

$$\frac{L}{t} = \left(\frac{\ell}{t}\right)\left(\frac{180}{\pi\theta}\right)$$

$$\frac{S}{t} = \left(\frac{s}{t}\right)\left(\frac{180}{\pi\theta}\right)$$

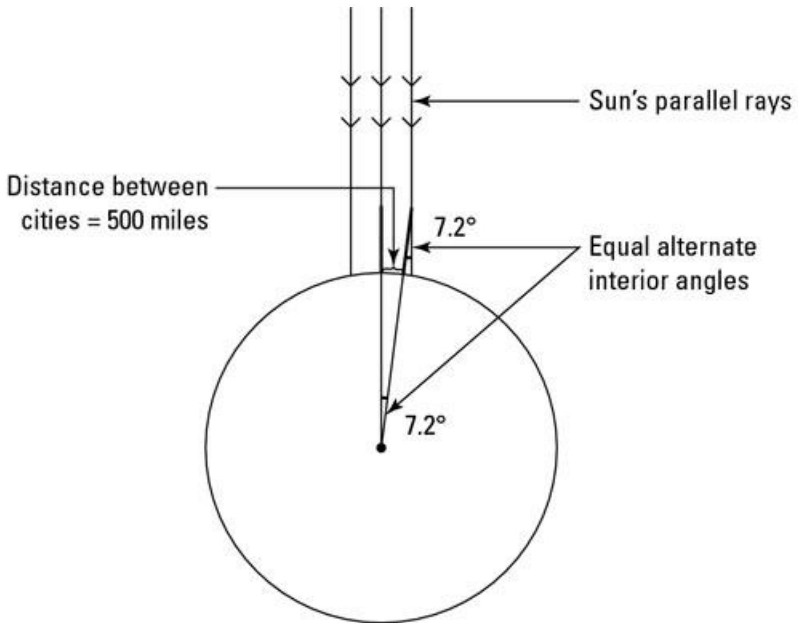
where θ is the apparent radius of the Moon and Sun measured in degrees.

Quantity	Relation	Reconstruction	Modern
s/t	Sun's radius in Earth radii	6.7	109
t/ℓ	Earth's radius in Moon radii	2.85	3.50
L/t	Earth-Moon distance in Earth radii	20	60.32
S/t	Earth-Sun distance in Earth radii	380	23,500

The table shows the results of a long-standing (but dubious) reconstruction using n = 2, x = 19.1 (φ = 87°) and θ = 1°, alongside the modern day accepted values. The error in this calculation comes primarily from the poor values for x and θ. The poor value for θ is especially surprising, since Archimedes writes that Aristarchus was the first to determine that the Sun and Moon had an apparent diameter of half a degree. This would give a value of θ = 0.25, and a corresponding distance to the Moon of 80 Earth radii, a much better estimate. The disagreement of the work with Archimedes seems to be due to its taking an Aristarchus statement that the lunisolar diameter is 1/15 of a "meros" of the zodiac to mean 1/15 of a zodiacal sign (30°), unaware that the Greek word "meros" meant either "portion" or 7°1/2; and 1/15 of the latter amount is 1°/2, in agreement with Archimedes' testimony.A similar procedure was later used by Hipparchus, who estimated the mean distance to the Moon as 67 Earth radii, and Ptolemy, who took 59 Earth radii for this value.

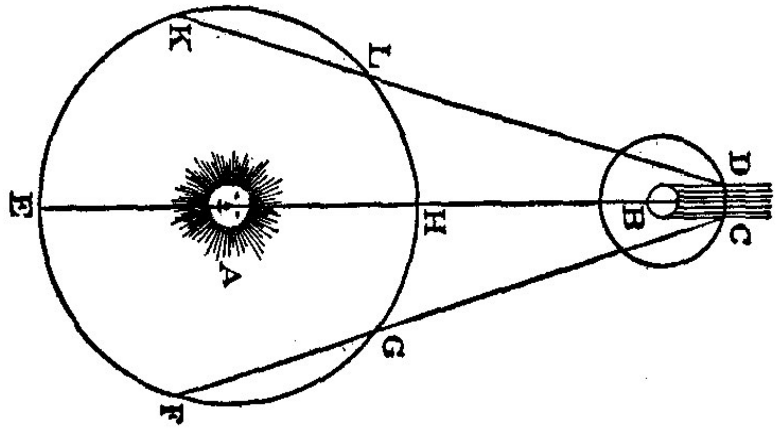
One can figure out the earth’s circumference using a geometric formula that’s over 2,000 years old. Contrary to popular belief, Christopher Columbus did not discover that the Earth is round. Eratosthenes (276–194 B.C.) made that discovery about 1,700 years before Columbus.Eratosthenes was the head librarian in Alexandria, Egypt, the center of learning in the ancient world. He estimated the circumference of the Earth with the following method: He knew that on the summer solstice, the longest day of the year, the angle of the sun above Syene, Egypt, would be 0°, in other words, the sun would be directly overhead. So, on the summer solstice, he measured the angle of the sun above Alexandria by measuring the shadow cast by a pole and got a 7.2° angle.

The following figure shows how the Eratosthenes’s earth measurement worked.



Eratosthenes divided 360° by 7.2° and got 50, which gave him the distance between Alexandria and Syene (about 500 miles) was 1/50 of the total distance around the Earth. So, he multiplied 500 by 50 to arrive at his estimate of the Earth’s circumference: 25,000 miles.This estimate was only 100 miles off the original circumference of 24,900 miles. Also, from this circumference value radius of the earth can also be calculated to be less than 4,000 miles.

Hence, by putting this value we can figure out that the radius of sun is 4×10^5 miles. Radius of moon is 1,000 miles. The distance between earth and moon is 2.4×10^5 miles and distance between sun an earth is less than 10^8 miles.



Rømer's determination of the speed of light was the demonstration in 1676 that light has a finite speedand does not travel instantaneously. The discovery is attributed to Danish astronomer Ole Rømer (1644–1710), who was working at the Royal Observatory in Paris at the time.By timing the eclipses of the Jupiter moon Io, Rømer estimated that light would take near about 22 minutes to travel a distance equal to diameter of Earth's orbit around the Sun. This would give light a velocity of about 220,000 km/s, about 26% lower than the true value of 299,792 km/s.

IV. Conclusion

Using Newtonian mechanics, mass of the sun and mass of the earth can also be calculated using these data. Say, the mass of the sun is Ms, the mass of the earth is Me and the mass of the moon is Mm.

$$F = G.\frac{Ms.Me}{R^2} = \frac{Me.v^2}{R} \Rightarrow \mathrm{G}\frac{Ms}{R} = v^2 \Rightarrow \mathrm{G}\frac{Ms}{R} = \left(\frac{2\pi\mathrm{R}}{T}\right)^2 \Rightarrow 1.6 \times 10^{-20}\frac{Ms}{10^8} = \left(\frac{2\pi \times 10^8}{365 \times 24 \times 60 \times 60}\right)^2$$

Here, R is taken 10^8 milesinstead of 9×10^7 miles.So, the actual mass of sun is $2.5\times(0.9)^2\times10^{30} = 2\times10^{30}$ kg.

$$G.\frac{Me.Mm}{R^2} = \frac{Mm.v^2}{R} \Rightarrow \mathrm{G}\frac{Me}{R} = v^2 \Rightarrow \mathrm{G}\frac{Me}{R} = \left(\frac{2\pi\mathrm{R}}{T}\right)^2 \Rightarrow 1.6 \times 10^{-20}\frac{Me}{2.4 \times 10^5} = \left(\frac{2\pi \times 2.4 \times 10^5}{30 \times 24 \times 60 \times 60}\right)^2$$

And the calculated mass of earth becomes more than5×10^{24} kg while the original value is less than 6×10^{24} kg.

Acknowledgement

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