how do we know how far things are

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August 15, 2025

how do we know how far things are?

this will be our leading question

enjoy :)

parallax, mostly

parallax

this may be what you're picturing :)

Figure: Parallax as seen looking out a moving car's window[0].

[0] Image: https://stock.adobe.com/images/view-out-the-car-window-as-the-scenery-blurs-by/193746850

parallax

two types of parallax

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moving parallax

stationary parallax

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moving parallax

- involves movement

stationary parallax

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- things close to observer appear to move more, things farther appear to move less

stationary parallax

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- the change in an objects appearance from two different locations (at once or at different times)

parallax

two types of parallax

moving parallax

- involves movement
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stationary parallax

- does not
- the change in an objects appearance from two different locations (at once or at different times)

(these are actually the same, kinda. motion is just being in two places at different times :))

moving parallax

moving parallax car picture again here look

Figure: Parallax as seen looking out a moving car's window again[0].

[0] Image: https://stock.adobe.com/images/view-out-the-car-window-as-the-scenery-blurs-by/193746850

stationary parallax

like human eyes, for example
this is how depth perception works

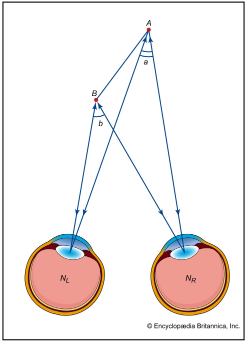


Figure: Eyes doing parallax[0].

[0] Image: https://cdn.britannica.com/85/4085-050-5575ACA3/parallax-points-NL-eyes-NR-left.jpg

summary

we know how far things are away from us
because we have EYES dipshit

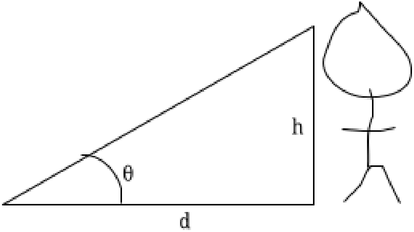
ok but what about numbers

like what if we want to MEASURE a distance

Apparent Size

What if you *know the size of a distant object?*

Easiest solution for measuring a distance.



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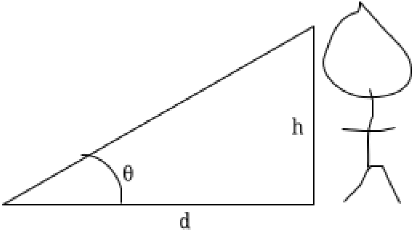

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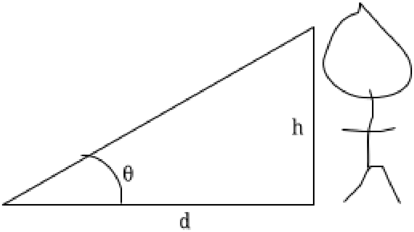

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(you just need to know the size of the distant object and be able to measure the *angular extent* θ)

dawg wt f

what if I don't have a protractor or konw the size of the thing?

Figure: Man scratching his head, confused about how to measure a distance without prior knowledge of a distant object's size or the ability to measure angular extent[0].

[0] Image: https://stock.adobe.com/images/portrait-of-a-mixed-race-man-scratching-his-head-in-confusion/68695988


ITC
25'/7.5M
MOD. NO. ITM-425R
PROD. NO. 022020

Units :)

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- Historically we've used things like a foot but truly make up anything
- If you want other people to use this unit just make sure their unit is the same as yours

Measuring Devices

Figure: A tape measure and a rolly measurey thing[1].

[1] Image: https://cdn.shopify.com/s/files/1/0404/0048/6557/products/7_CDM1001_1024x10242x.png?v=1615341175

how far is this fucker?

Figure: Moon[2].

[2] Image: Me :)

The Distance Ladder

Earth $\implies$ Moon $\implies$ Sun $\implies$ Planets $\implies$ Stars $\implies$ Galaxies

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We need to know each distance/size in order to find out the next object's size/distance.
The goal of measuring the Earth, Moon, Sun, and stars is as old as humanity.

(so let's go back)

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- The Moon is closer than the Sun

Solar eclipses, the moon passing between the Earth and Sun

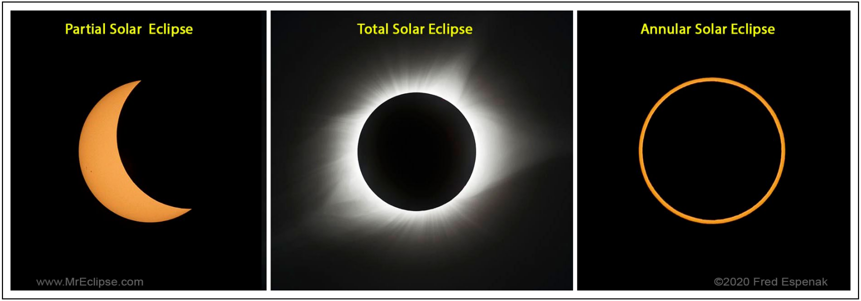

Figure: Partial, total, and annular eclipse images[3].

[3] Image: https://galamcdougal.blogspot.com/2022/10/solar-eclipse.html

What have we always known?

(This is essentially the same question as what can be observed with the eyes.)

- The Moon is closer than the Sun (solar eclipses) and *same angular size*
- The Earth is round

During a lunar eclipse, the Earth passes between a full Moon and the Sun

Figure: Two stages of a lunar eclipse[4].

[4] Images: me :)

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  - we also knew slower moving things were farther (parallax), so we knew Jupiter and Saturn are far and Venus and Mars are close

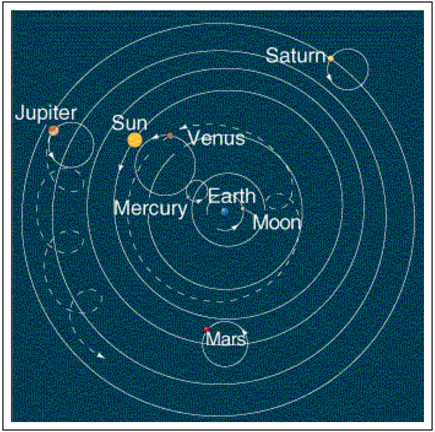
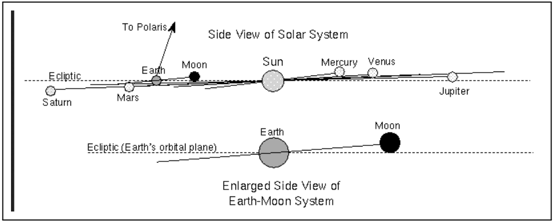


Figure: Geocentric model with subcircles that explain retrograde motion[5].

[5] Image: https://starrythoughts.weebly.com/uploads/1/6/3/0/16304784/2180964_orig.gif



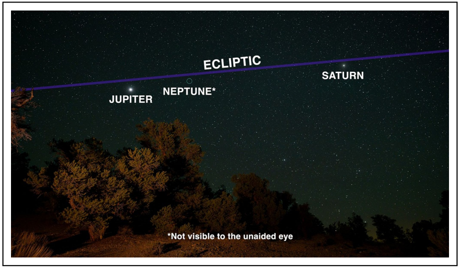


Figure: Ecliptic visuals[6].

[6] Images: https://www.astronomynotes.com/nakedeye/phases/solarsys.gif, NASA

In summary,

(this information is all we needed to figure out the distance to the stars. the rest is all measurements and math)

- The Earth is spherical
- The Moon is closer than the Sun and *same angular size*
- All solar system bodies orbit in a flat plane in perfect circles around the Earth

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- The Moon is closer than the Sun and *same angular size*
- All solar system bodies orbit in a flat plane in perfect circles around the Earth
    - (no physics behind this, but it was a pretty viable, elegant explanation)

The First Recorded Attempt of Measuring Things

Aristarchus of Samos, Greek, 270BC, Heliocentrist

Realized the distance of the sun would change when we observe a half-moon. Instead of starting humble with the size of the Earth bro went wacko and tried to get THIS distance first.

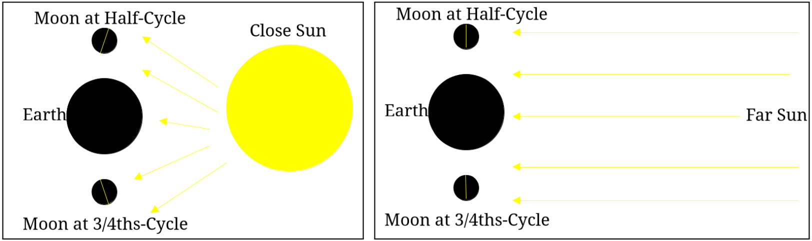
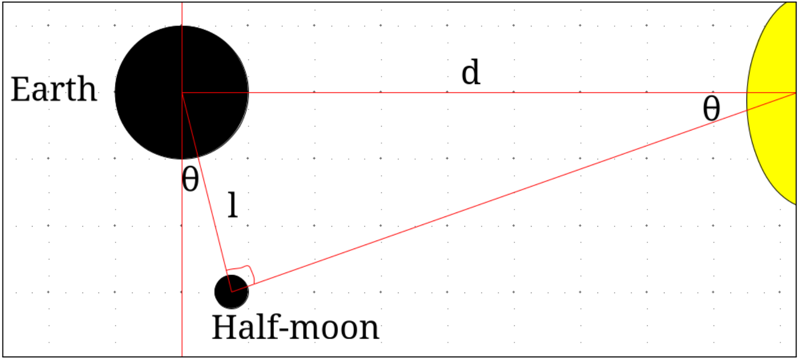


Figure: Near-Sun rays make a half-moon appear sooner in the lunar cycle, while far-Sun parallel rays mean half-moons happen at $\frac{1}{2}$ and $\frac{3}{4}$ in the lunar cycle.

Aristarchus' Method

Measure the angle θ at exactly half-moon.



$$\sin\theta = \frac{l}{d} \implies \frac{l}{d} = \sin\theta$$

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Nowadays, we know that half-moons occur 30 mins after it reaches those 90° marks
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Aristarchus measured 87°, meaning $\frac{l}{d} = \sin(90^\circ - 87^\circ) = 19.1$ the Sun is 19x farther away than the Moon.
In reality, this half-moon angle is 89.88°, which gives a much larger number: the Sun is 409x farther away than the Moon.

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good effort dipshit

Eratosthenes and the Size of the Earth

Greece, 230BC

The first good measurement of the size of the Earth

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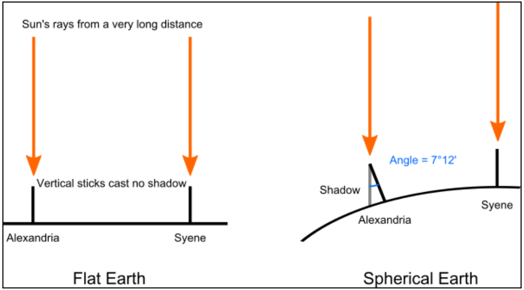


Figure: Eratosthenes' experimental setup[7].

[7] Image: https://www.mezzacotta.net/100proofs/images/002-SyeneAlexandria.png

Eratosthenes and the Size of the Earth

Greece, 230BC

Eratosthenes knew the city of Syene was on the Tropic of Cancer (no shadows on summer solstice, sun right overhead)

He also knew the distance between Alexandria and Syene

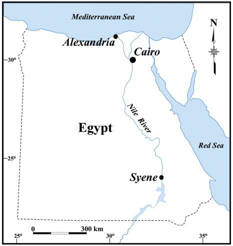
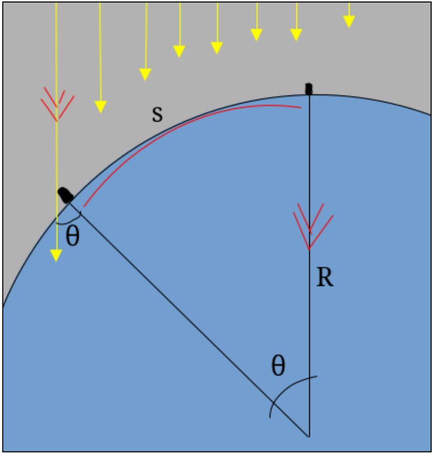


Figure: Alexandria and Syene along the Nile River in Egypt[8].

[8] Image: https://www.researchgate.net/profile/Alok-Kumar-111/publication/253596660/figure/fig2/

Eratosthenes' Method



Arc length:

$$s = \frac{\pi R\theta}{180^\circ}$$

Rearrange for R, Earth's radius:

$$R = \frac{180s}{\pi\theta}$$

s was already known from geographical data, and θ was measureable from shadows cast in Alexandria.

Eratosthenes and the Size of the Earth

Greece, 230BC

To avoid doing difficult division with π, he opted to calculate the circumference, not the radius:

$$C = 2\pi R = \frac{360s}{\theta}$$

To which he found a value of 252,000 stadia.
In ancient Greece, they used a unit called a 'stade'. We don't really know how big a stade was, but we estimate 1 stade is about 525ft, making his calculation *less than 1% off.*

Eratosthenes: 25,050mi.
Modern value: 24,901mi.

Hipparchus and the Distance to the Moon

Greece, 189BC

Looking at a solar eclipse from two different places allowed for the calculation of the distance to the moon.

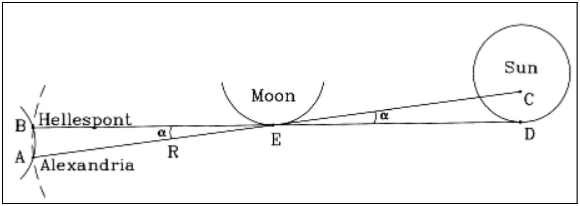


Figure: Parallax configuration that allowed our boy to measure the size of the moon[9].

[9] Image: https://pwg.gsfc.nasa.gov/stargaze/Shipparc.htm

Hipparchus

Enjoy this drawing, I'm getting lazier and I'm just going to use MSPaint