Mesuring distances in the Universe

Isabelle M. Santos

Astrozoom

April 22, 2021



Diameter of the Earth



- Eratosthenes measures an angle of 7°, for a distance of 5 000 stadions
- ▶ He deduces the circumference of the Earth: 250 000 stadions
- \blacktriangleright ~ a radius of 6 400 kilometers (in modern units)

Earth-Moon distance



- Aristarchus of Samos, in -350
- \blacktriangleright \rightarrow in 3 hours, the Moon travels the distance of 1 Earth radius
- How many Earth radii does the Moon travel in 1 month?

Earth-Moon distance



- Aristarchus of Samos, in -350
- \blacktriangleright \rightarrow in 3 hours, the Moon travels the distance of 1 Earth radius
- How many Earth radii does the Moon travel in 1 month?
- Circumference of the orbit = 216 Earth radii
- \blacktriangleright \Rightarrow diameter of the Moon's orbit = 70 Earth radii

Earth-Sun distance



- Aristarchus measures an angle of 87°
- He deduces that the Sun is 20 times further away from the Earth than the Moon is
- So the Sun is 20 times bigger than the Moon, or 7 times bigger than the Earth

Earth-Sun distance ... or not...



- Aristarchus measures an angle of 87°
- He deduces that the Sun is 20 times further away from the Earth than the Moon is
- So the Sun is 20 times bigger than the Moon, or 7 times bigger than the Earth
- \blacktriangleright Actually, the angle is $89,85^\circ \rightarrow$ He couldn't have measured the angle with so much precision
- \Rightarrow distance VERY underestimated!

The planets



The planets



Planetary distances

Planète	Distance Soleil - planète (en unités astronomiques)
Mercury	0,4
Venus	0,7
Earth	1
Mars	1,5
Jupiter	5,2
Saturn	9,5

But how many kilometers in an astronomical unit?

- Aristarchus was off by a lot
- By the 18th century, several scientists made different estimates of the Earth-Sun distance, but a lot of disagreement between them
- ▶ An opportunity in 1761 then in 1769 : the transit of Venus
- Several expeditions to observe the transit from different places

Transit of Venus



- Edmond Halley established the method in 1716
- Observe the transit from 2 different latitudes
- Given the radius of the Earth
- Johann Encke found 153 million kilometers (actually 140)
- Still a bit off, but the different measurements finally start to converge





Stellar parallax







- received light \neq emitted light
- Since Copernicus, we know that stars are much further away than the Sun
- Friedrich Bessel towards 1830
- ▶ 1 parsec $\simeq 3 \times 10^{13}$ kilometers

Stellar parallax







- received light \neq emitted light
- Since Copernicus, we know that stars are much further away than the Sun
- Friedrich Bessel towards 1830
- ▶ 1 parsec $\simeq 3 \times 10^{13}$ kilometers
- Hipparchos & Gaia space telescopes
- Stars that are a few thousand light-years aways

Variable stars

- Henrietta Swann Leavitt, 1912
- \rightarrow Cepheid variables
- Standard candles
- Period-luminosity link
- ▶ 10 million parsecs





Star colors

- Ejnar Hertzsprung, 1911
- Pleiades et Hyades
- Henry Norris Russell, 1914
- Color-magnitude link
- clusters up to 100 000 parsecs





Nearby galaxies

- Controversies on Andromeda's nature
- $\rightarrow\,$ Are there objects beyond the Milky Way?
- Edwin Hubble, 1927



Far-away galaxies



Thank you!

- Kwok, Sun. 2017. Our Place in the Universe. Springer International Publishing. Cambridge University Press.
- Maunder, Michael, and Patrick Moore. 2000. Transit: When Planets Cross the Sun. Springer London.
- Hughes, David W. 2001. Six Stages in the History of the Astronomical Unit. Journal of Astronomical History and Heritage 4 (June): 15–28.
- Marett-Crosby, Michael. 2013. Twenty-Five Astronomical Observations That Changed the World. The Patrick Moore Practical Astronomy Series. Springer New York.

Diameter of the Moon



$$R^{2} = (R - f)^{2} + \left(\frac{c}{2}\right)^{2}$$
$$2R = f + \frac{c^{2}}{4f}$$

- Aristarchus in -270
- Compare the curvature of the Moon to that of the shadow of the Earth
- radius of the Moon = 0.35 × radius of the Earth (actual ratio is 0.27)

