The Broken Cosmic Distance Ladder

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ma per seguir virtute e canoscenza
SISSA

Credit: NASA/Bill Dunford

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Visiting Professor of Cosmology

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Messier 107 as seen by the Hubble Space Telescope

Credit: ESA/NASA

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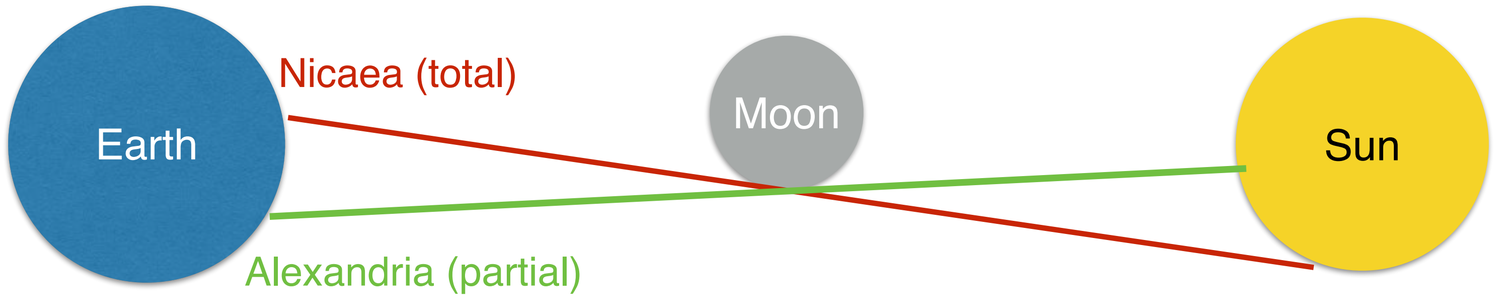

Not to scale!

Hipparchus (190 BC)

Distance to the Moon:

63 Earth radii

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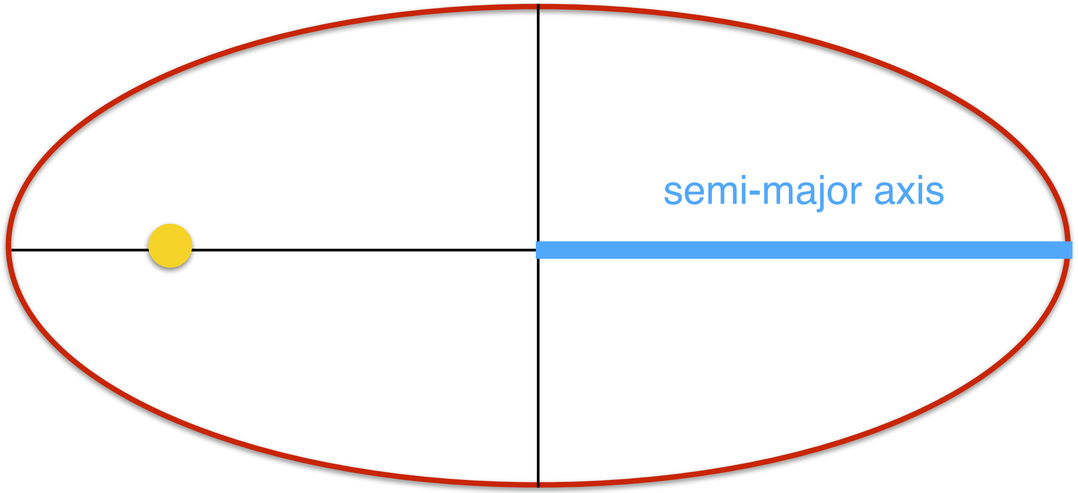
Kepler's Third Law:



$$\frac{(\textit{orbital period})^2}{(\textit{semi-major axis})^3} = \textit{constant}$$

Mercury: 0.39 AU

Venus: 0.72 AU

Earth: 1.00 AU

Mars: 1.52 AU

Jupiter: 5.20

Saturn: 9.5 AU

AU = Astronomical Unit

= ??? Km

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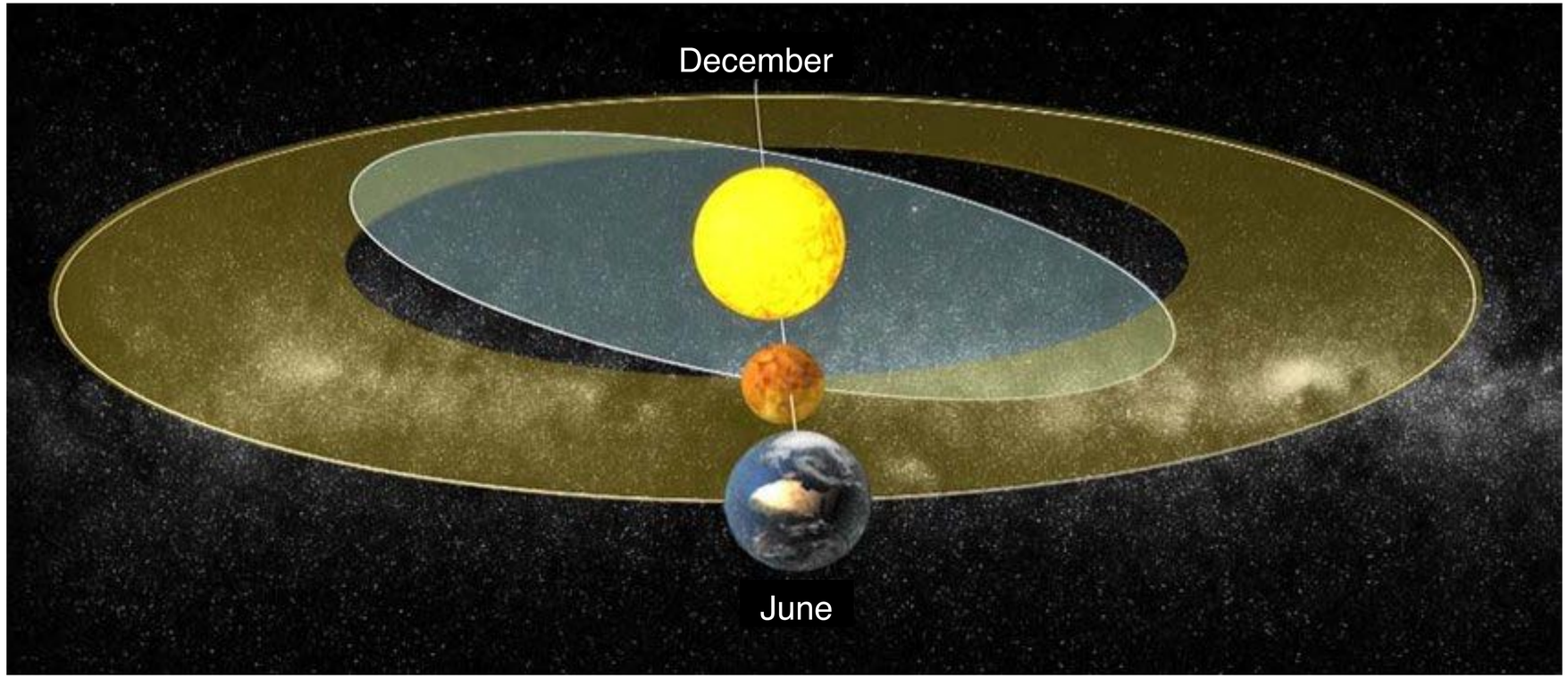

Edmund Halley

Sources: Left, B.S. Shylaja. (2004). Practical observations of the transit of Venus. Resonance. 9. 79-83. 10.1007/BF02834018; Above: Halley, E., Tabulae Astronomicae (1749)

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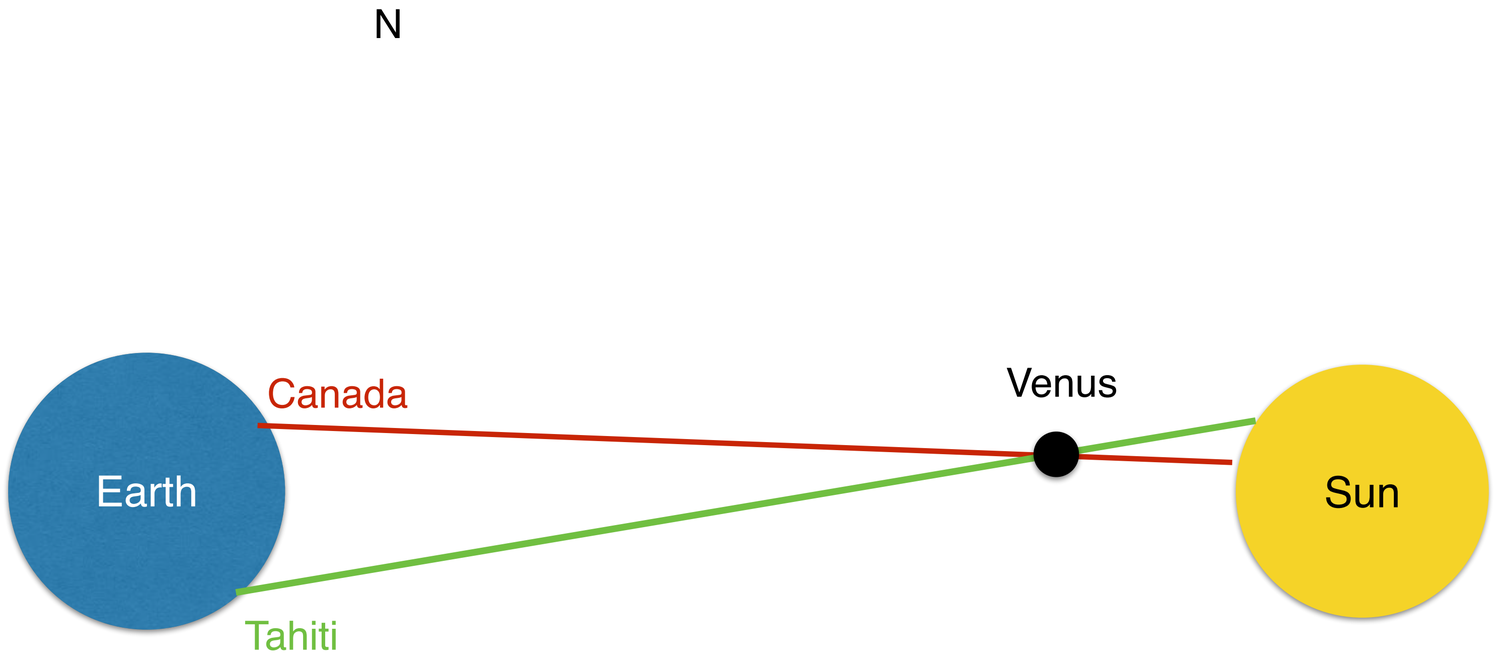
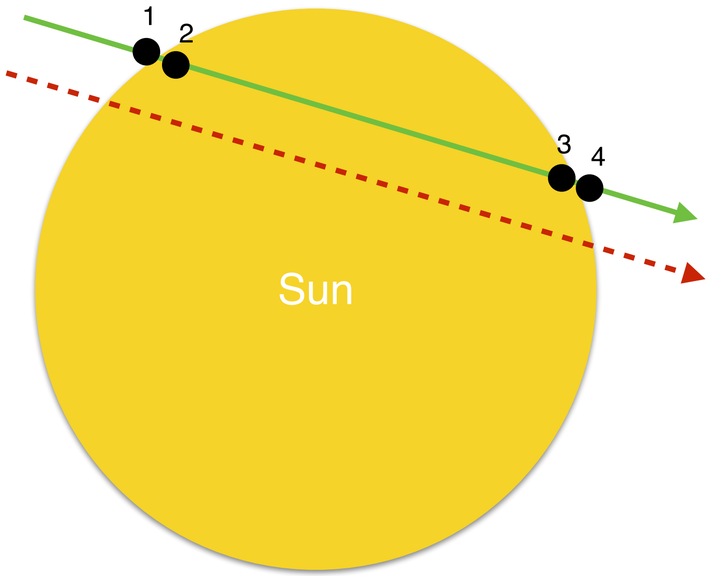


Not to scale!



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Jeremiah Horrocks observing the transit of Venus in 1639, painting by Eyre Crowe (1891), detail.

Credit: Public domain

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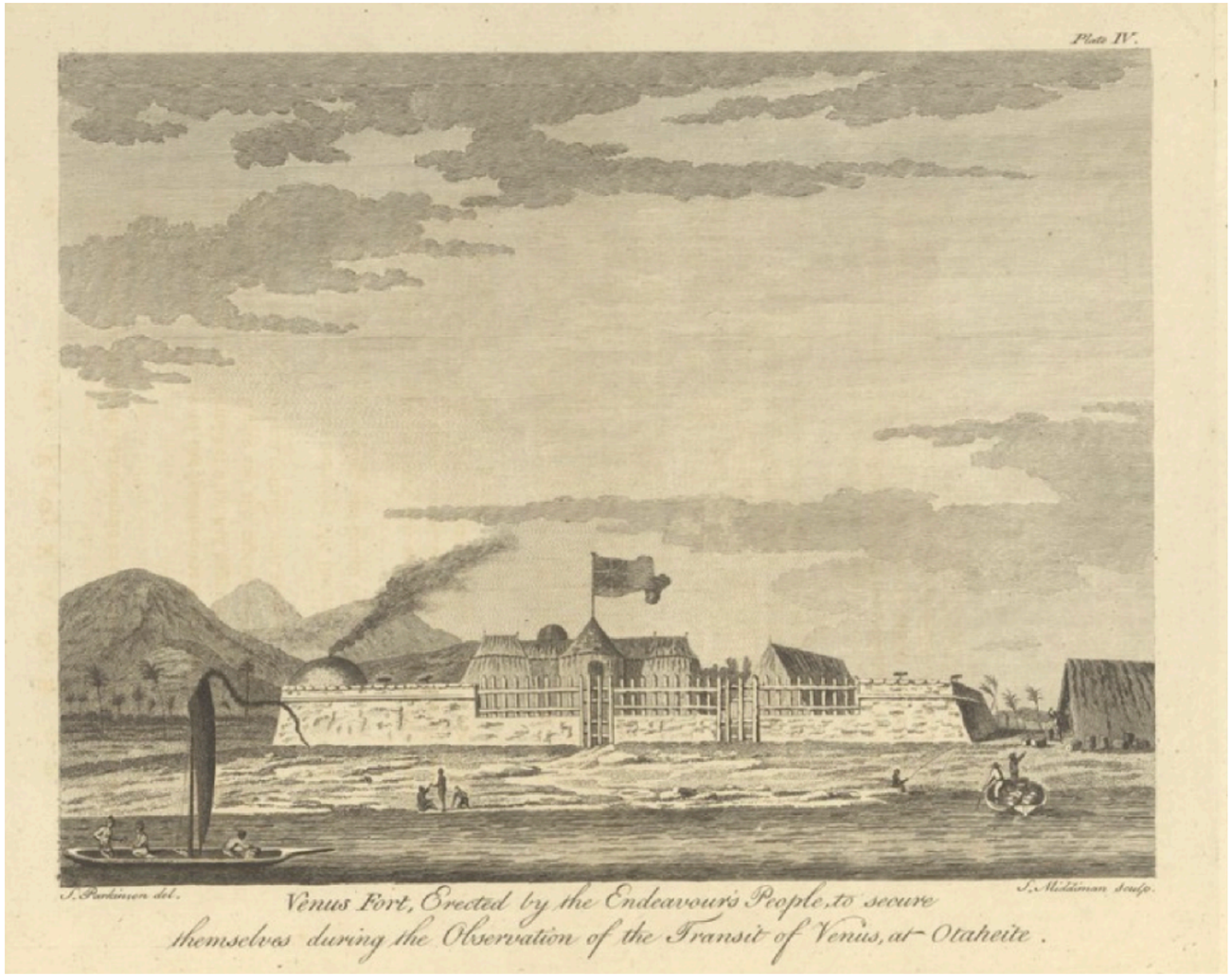

Fort Venus in Tahiti, 1769

Source: A journal of a voyage to the South Seas, in His Majesty's ship, the Endeavour / Faithfully transcribed from the papers of the late Sydney Parkinson. Draughtsman to Joseph Banks, Esq. on his late expedition, with Dr. Solander, round the world.
Credit: The Wellcome Collection

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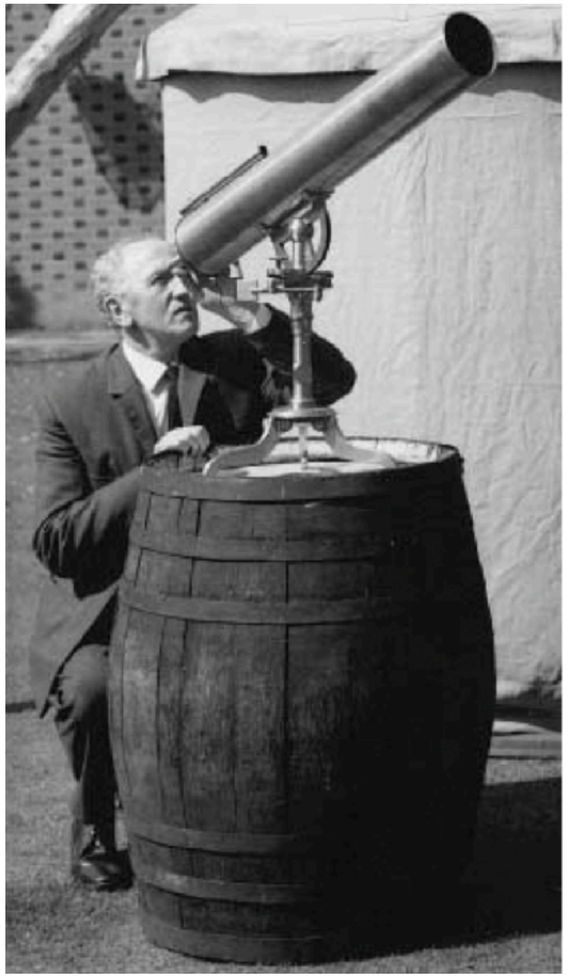

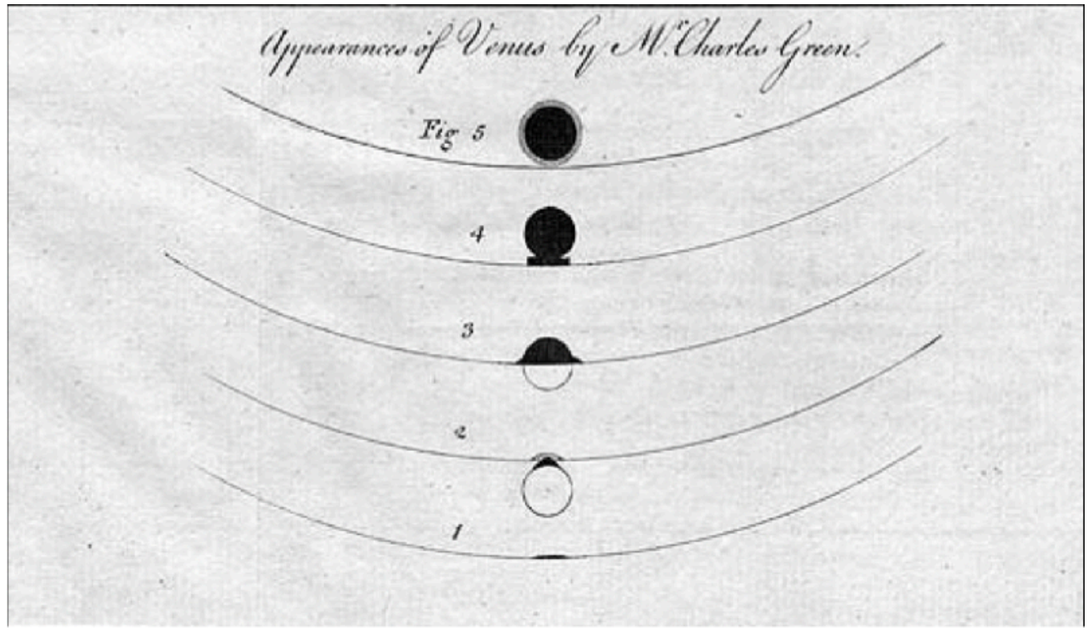

Transit of Venus, June 3rd 1769

Source: Left, reconstruction by the Royal Observatory Greenwich (from: Orchiston, W. (2017). Cook, Green, Maskelyne and the 1769 transit of Venus: the legacy of the Tahitian observations. *Journal of Astronomical History and Heritage, 20*, 35-68.)

Right: Green, C., and Cook, J., 1771. Observations made, by appointment of the Royal Society, at King George's Island in the South Seas. Philosophical Transactions of the Royal Society, 61, 397–421.

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The parallax on the 3d of June being 8″,65, the mean parallax will be found to be = 8″,78; and if the ſemidiameter of the Earth be ſuppoſed = 3985 Engliſh miles, the mean diſtance of the Earth from the Sun will be 93,726,900 Engliſh miles. And, as the relative diſtances of the planets are well known, their abſolute diſtances, and conſequently the dimenſions of the Solar Syſtem, will be as follows.

	Relative diſtance.	Abſolute diſtance.
Mercury,	387,10	36,281,700
Venus,	723,33	67,795,500
Earth,	1000,00	93,726,900
Mars,	1523,69	142,818,000
Jupiter,	5200,98	487,472,000
Saturn,	9540,07	894,162,000

Oxford, Dec. 17, 1771.

Hornsby, T. (1771). LIII. The quantity of the Sun's parallax as deduced from the observations of the transit of Venus, on June 3, 1769. Philosophical Transactions of the Royal Society of London, 61, 574-579. doi:10.1098/rstl.1771.0054

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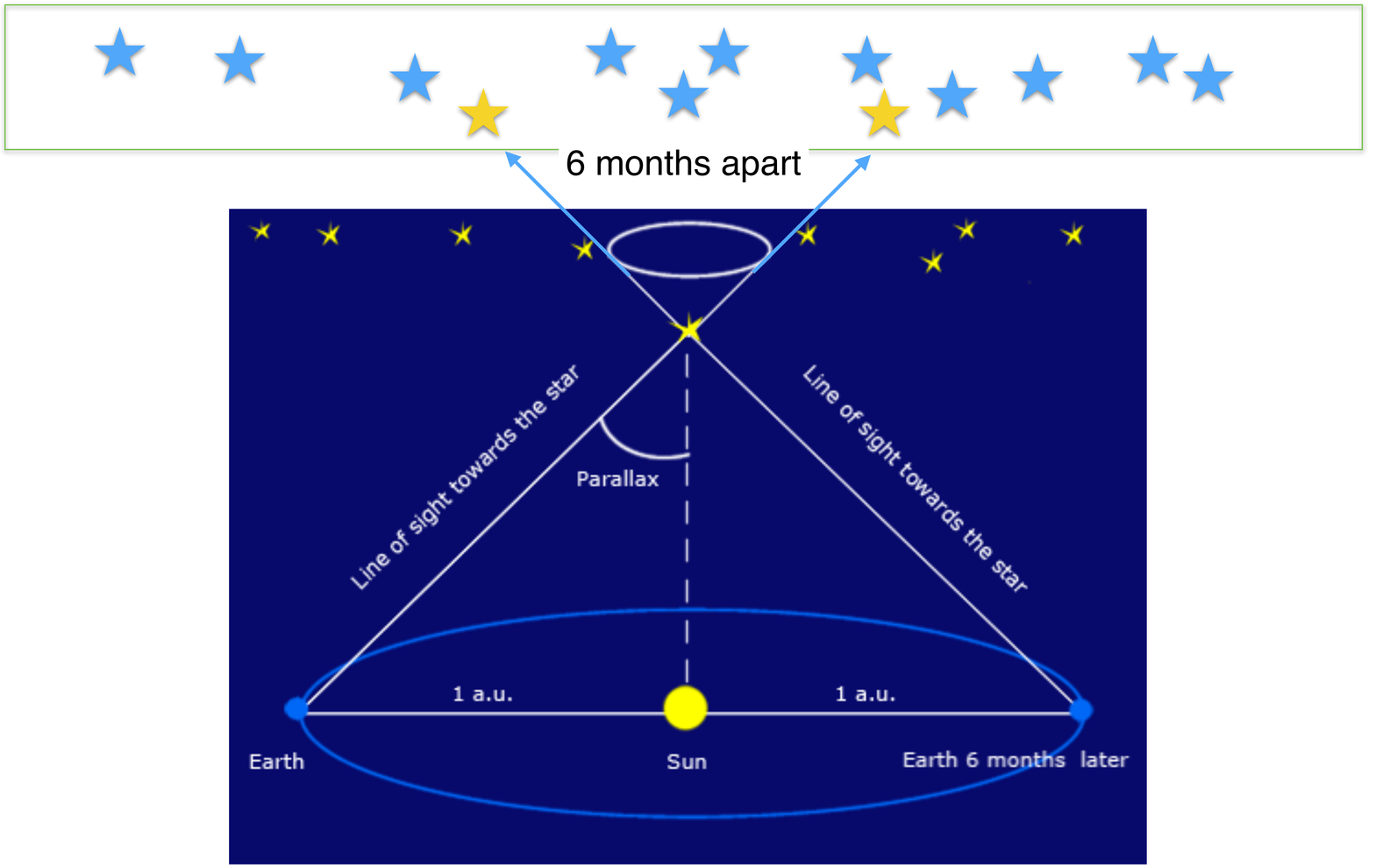

1 parsec (pc):

parallax of 1 arcsec

3.26 light years

30,000 billion km

Stellar parallax

Credi: GAIA/ESA

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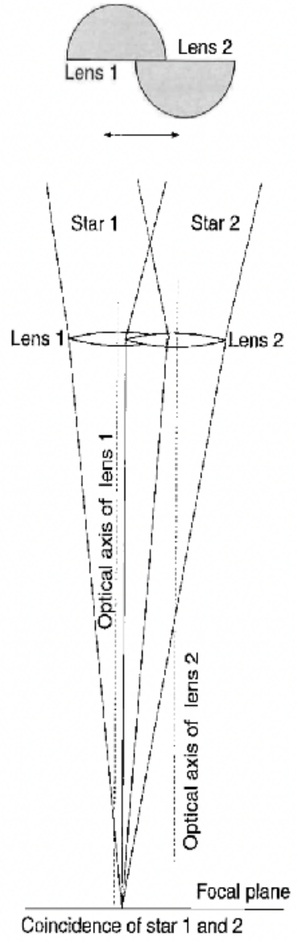

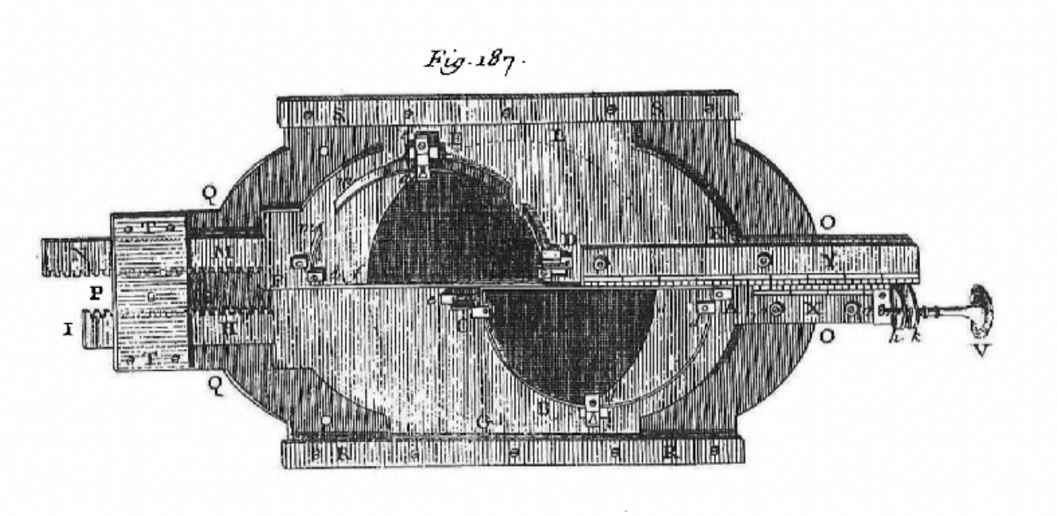

The heliometer

Source: Willach, R. (2004). The Heliometer: Instrument for Gauging Distances in Space. Journal of the Antique Telescope Society, 26, 5-16. Retrieved from https://ui.adsabs.harvard.edu/abs/2004JATSo..26....5W

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The Harvard Observatory computers

Source: https://www.lindahall.org/mary-anna-palmer-draper/, picture courtesy of Harvard College Observatory

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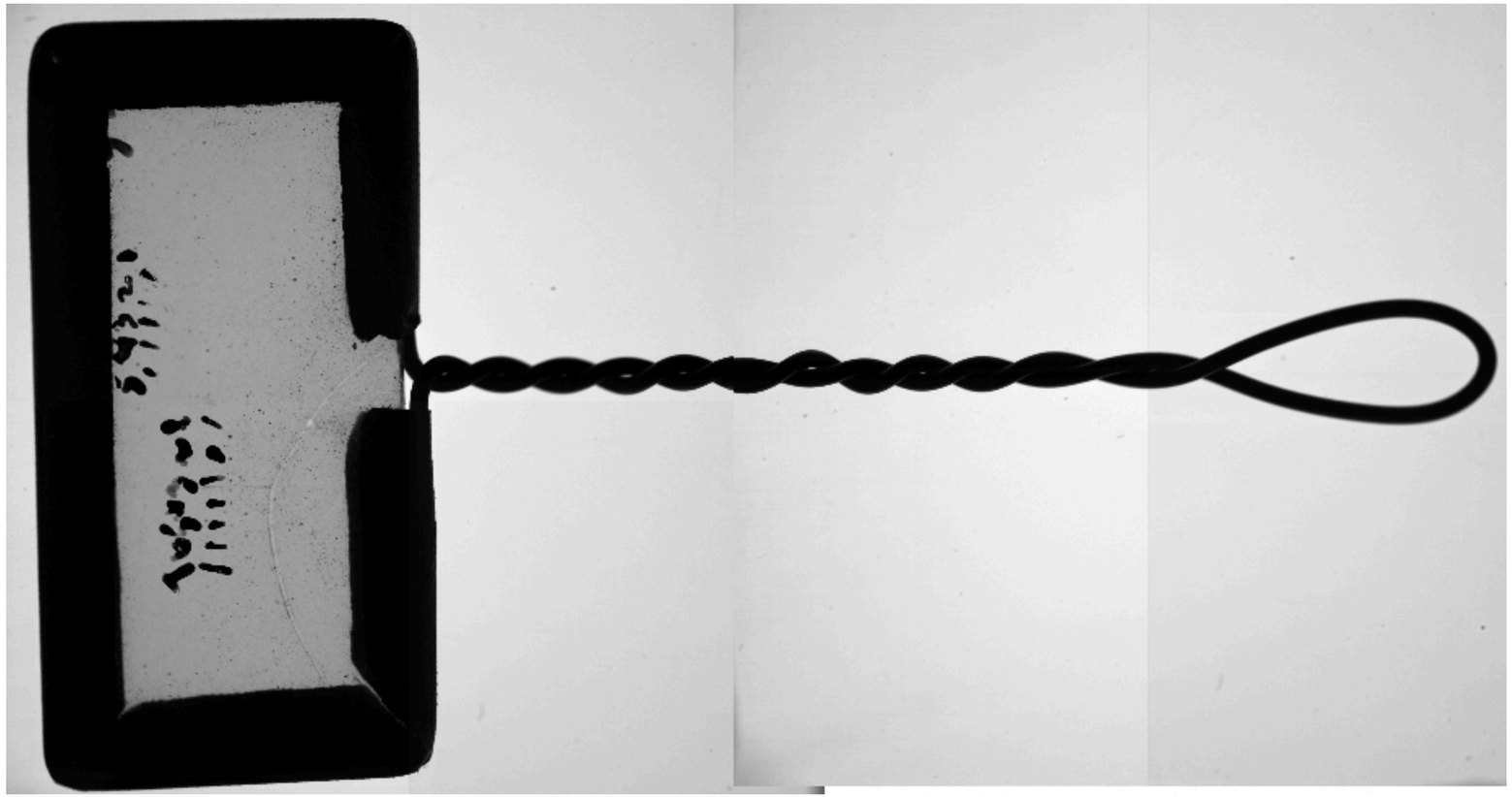

The fly spanker

Credit: Harvard College Observatory

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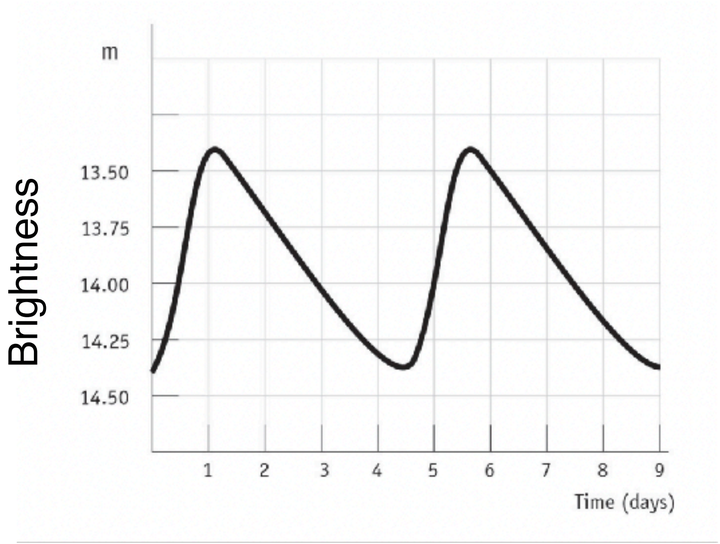
Cepheid variable



Time

log(period)

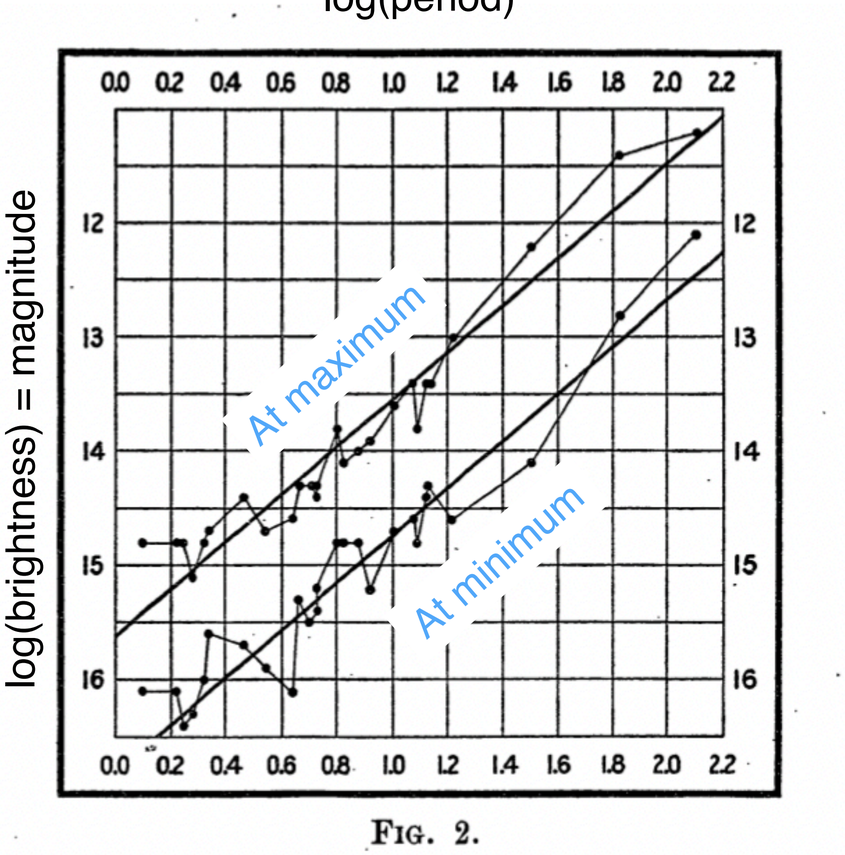


FIG. 2.

Henrietta Leavitt, 1921

Credit: public domain

Leavitt's Law

Sources: Left: The ESA/ESO astronomy exercice series 2
Right: Leavitt, H. S., & Pickering, E. C. (1912). Periods of 25 Variable Stars in the Small Magellanic Cloud. Harvard College Observatory Circular, 173, 1-3. Retrieved from https://ui.adsabs.harvard.edu/abs/1912HarCi.173....1L

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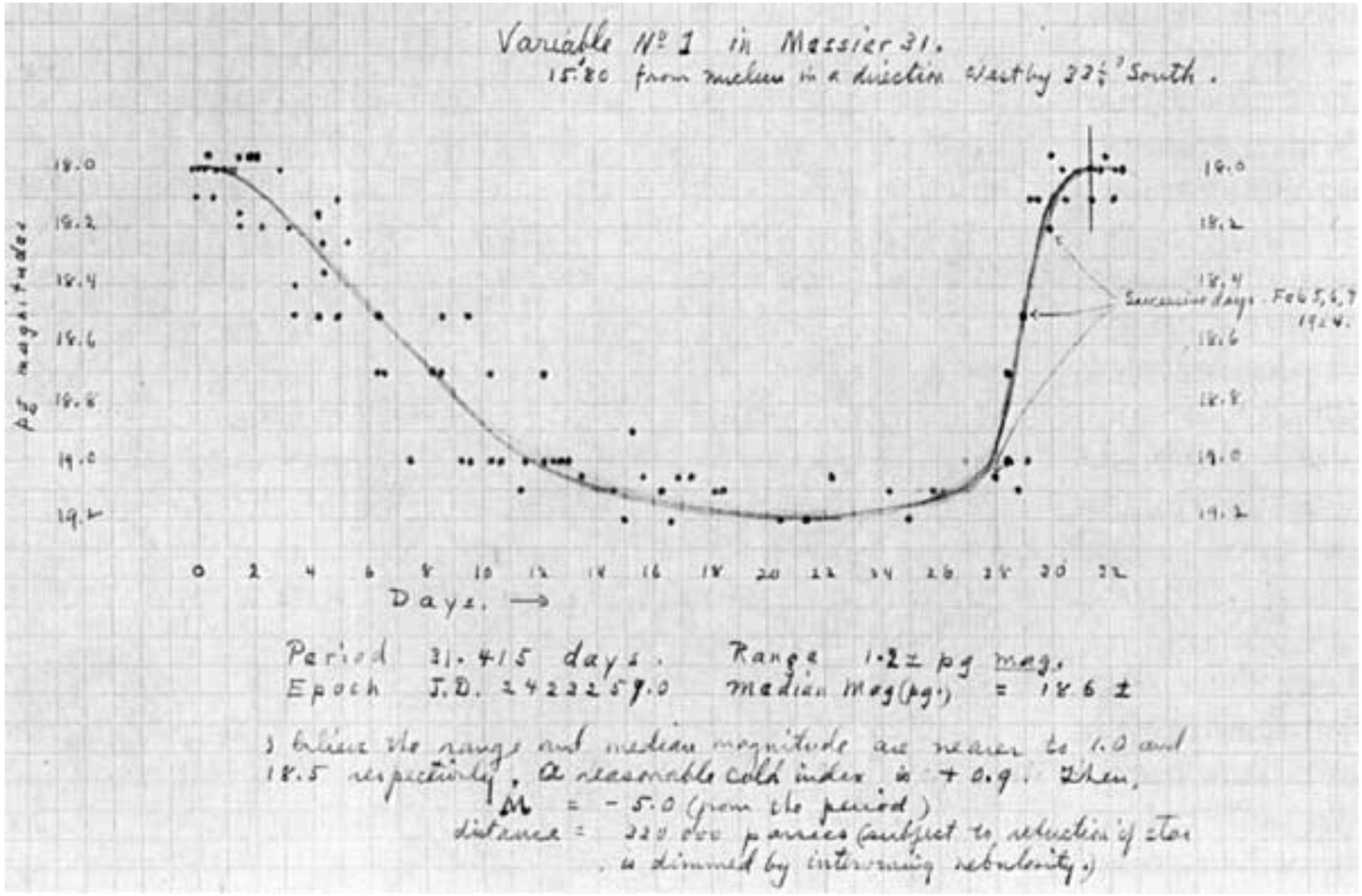

The end of Harlow’s universe

Source: Edwin Hubble to Harlow Shapely, Feb 19th 1924.

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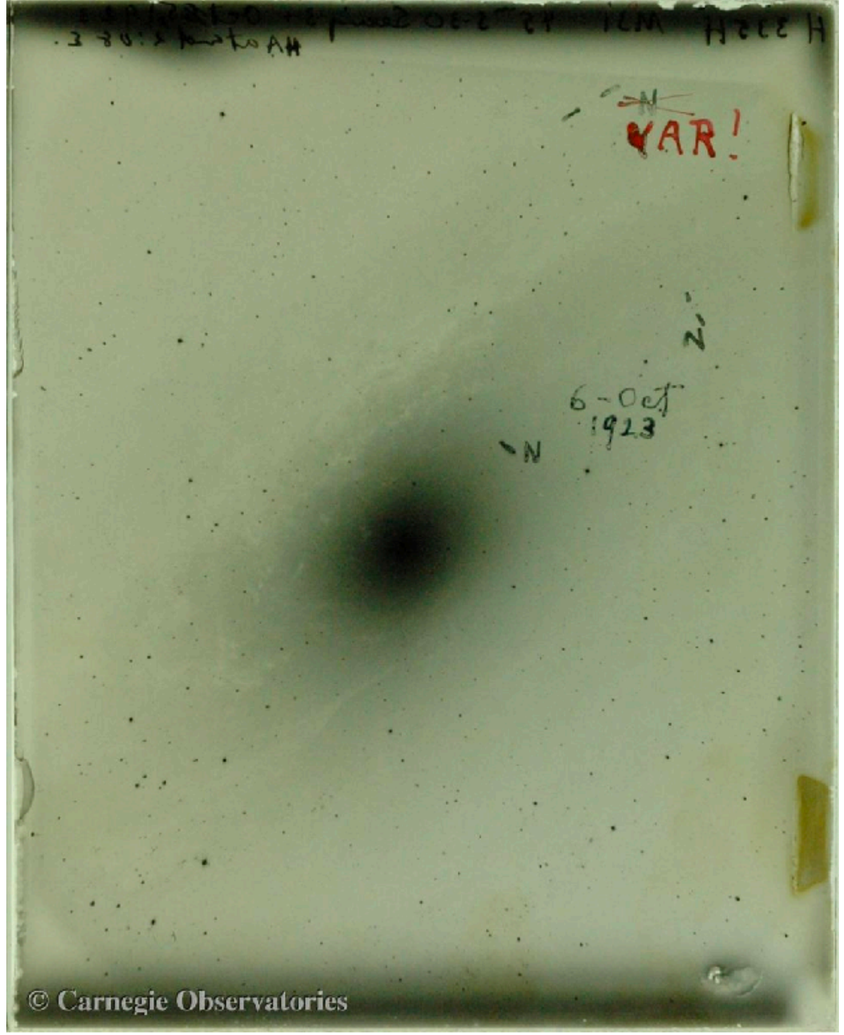

Hubble’s discovery

Credit: Carnegie Observatories

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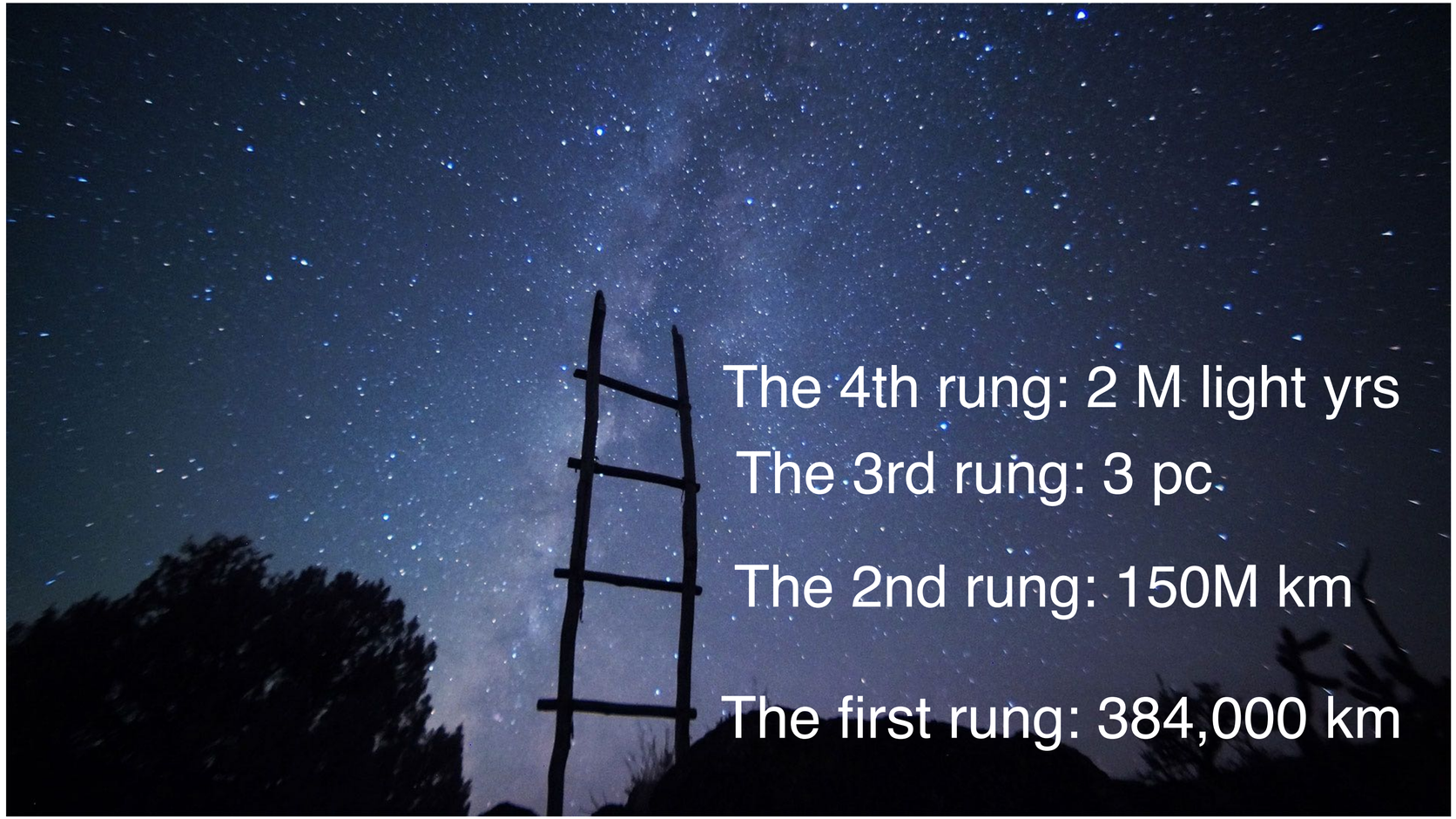

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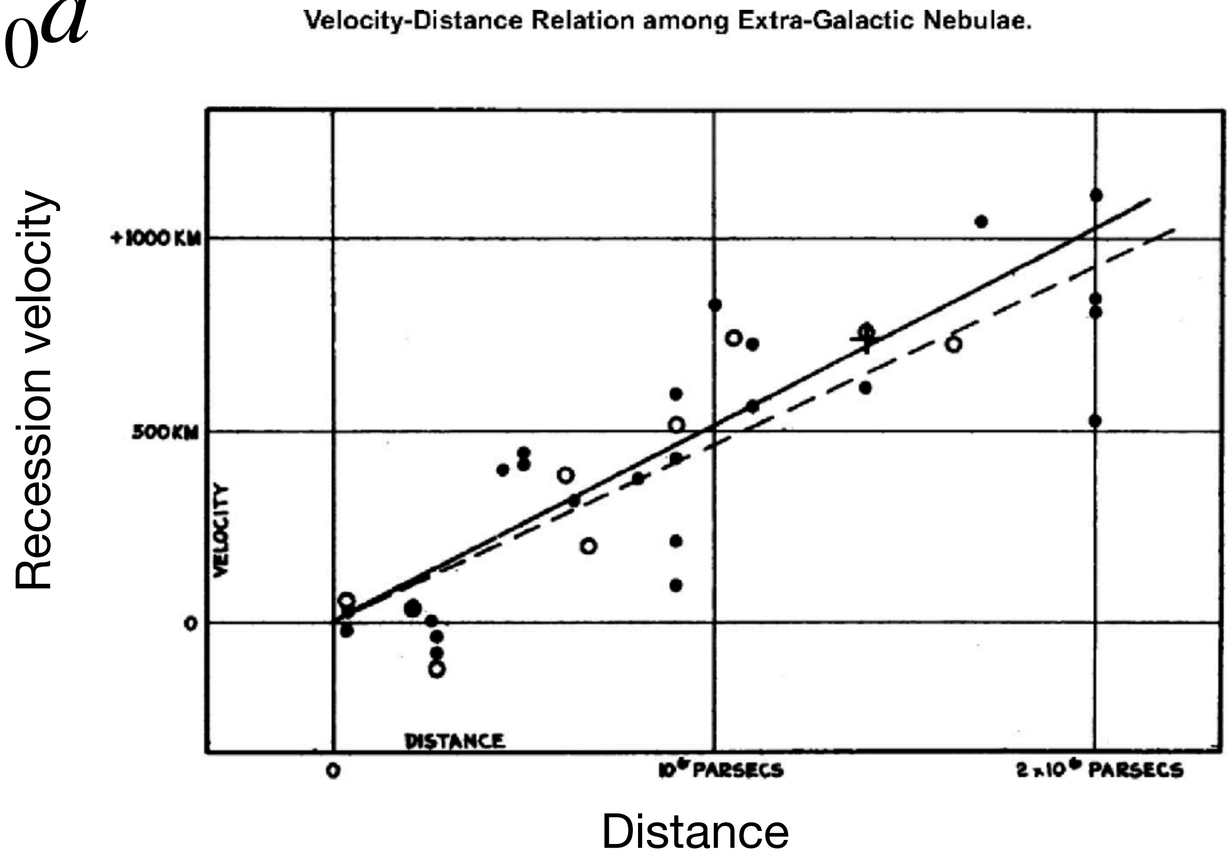
$$v = H_0 d$$



Edwin Hubble
ca 1922
Credit: Huntington Library

The Hubble-Lemaître constant

Source: E.P. Hubble (1929) Proc. Natl. Acad. Sci. USA 15, 168 –173.

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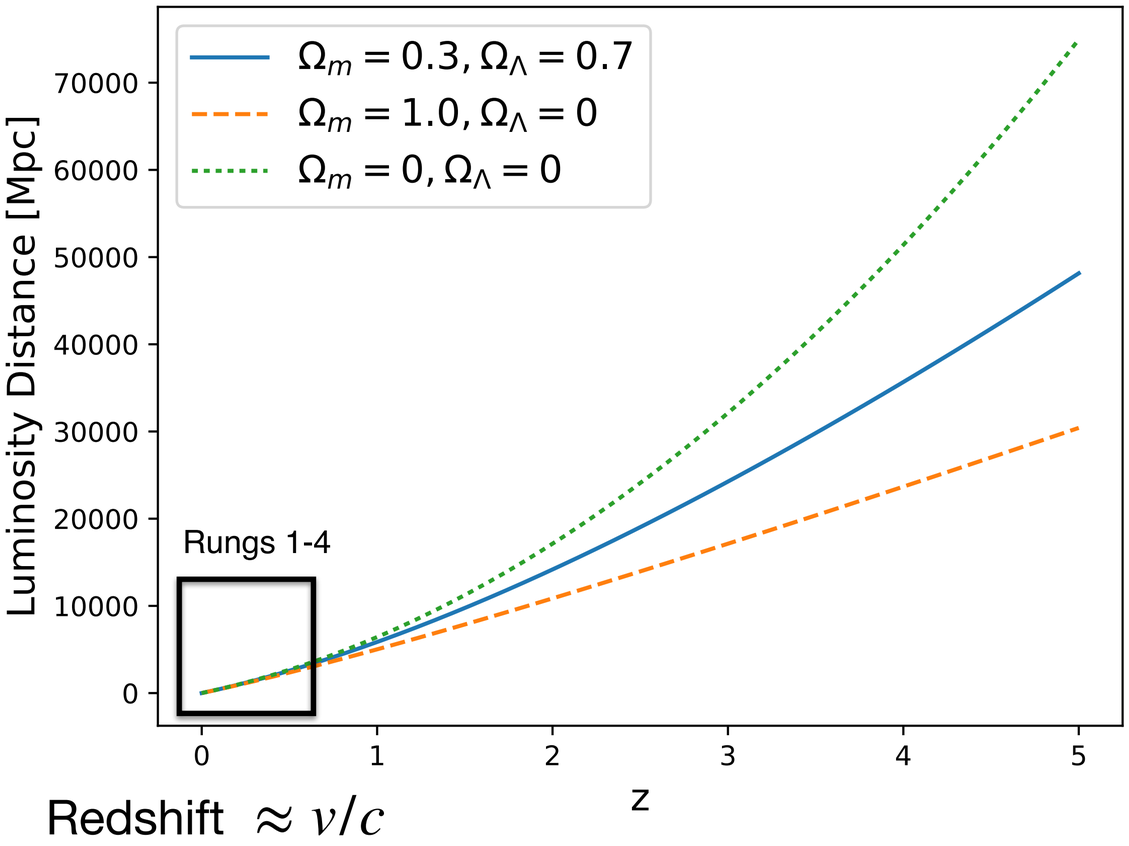

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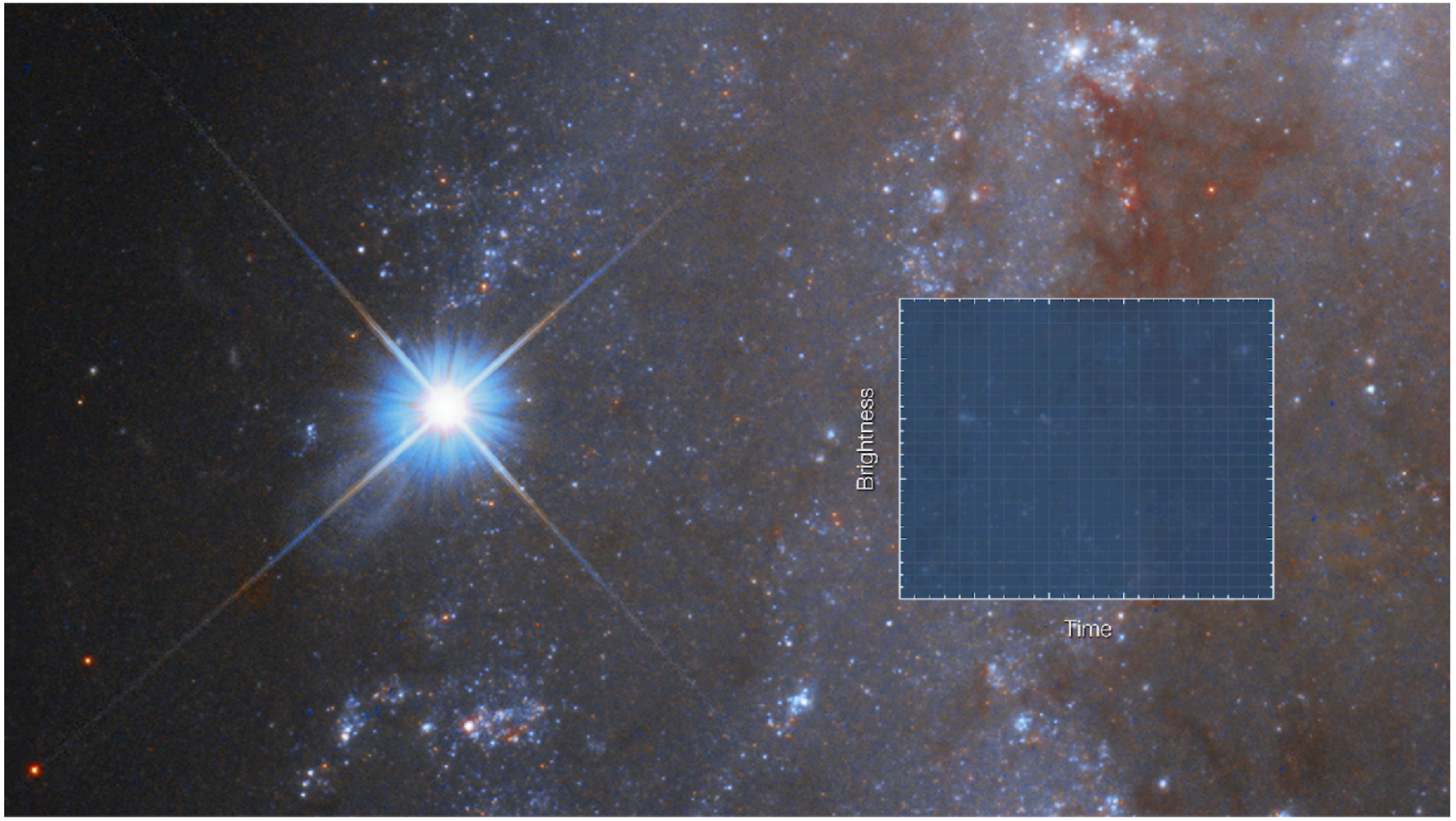

Credit: ESA/Hubble & NASA, M. Kornmesser, M. Zamani, A. Riess and the SH0ES team

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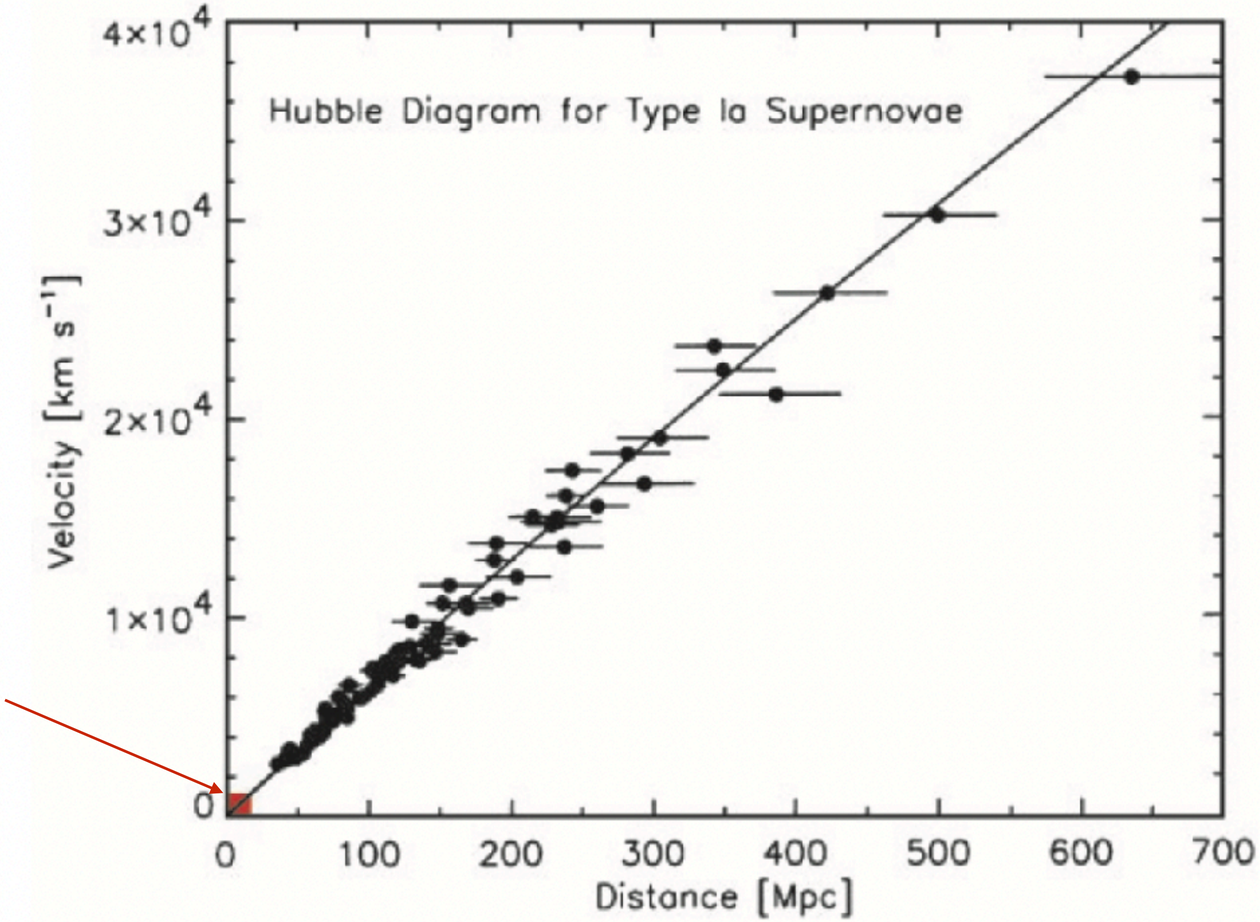

Hubble's original range

Source: Kirshner, R. P. (2004). Hubble's diagram and cosmic expansion. Proceedings of the National Academy of Sciences, 101(1), 8-13. doi:10.1073/pnas.2536799100

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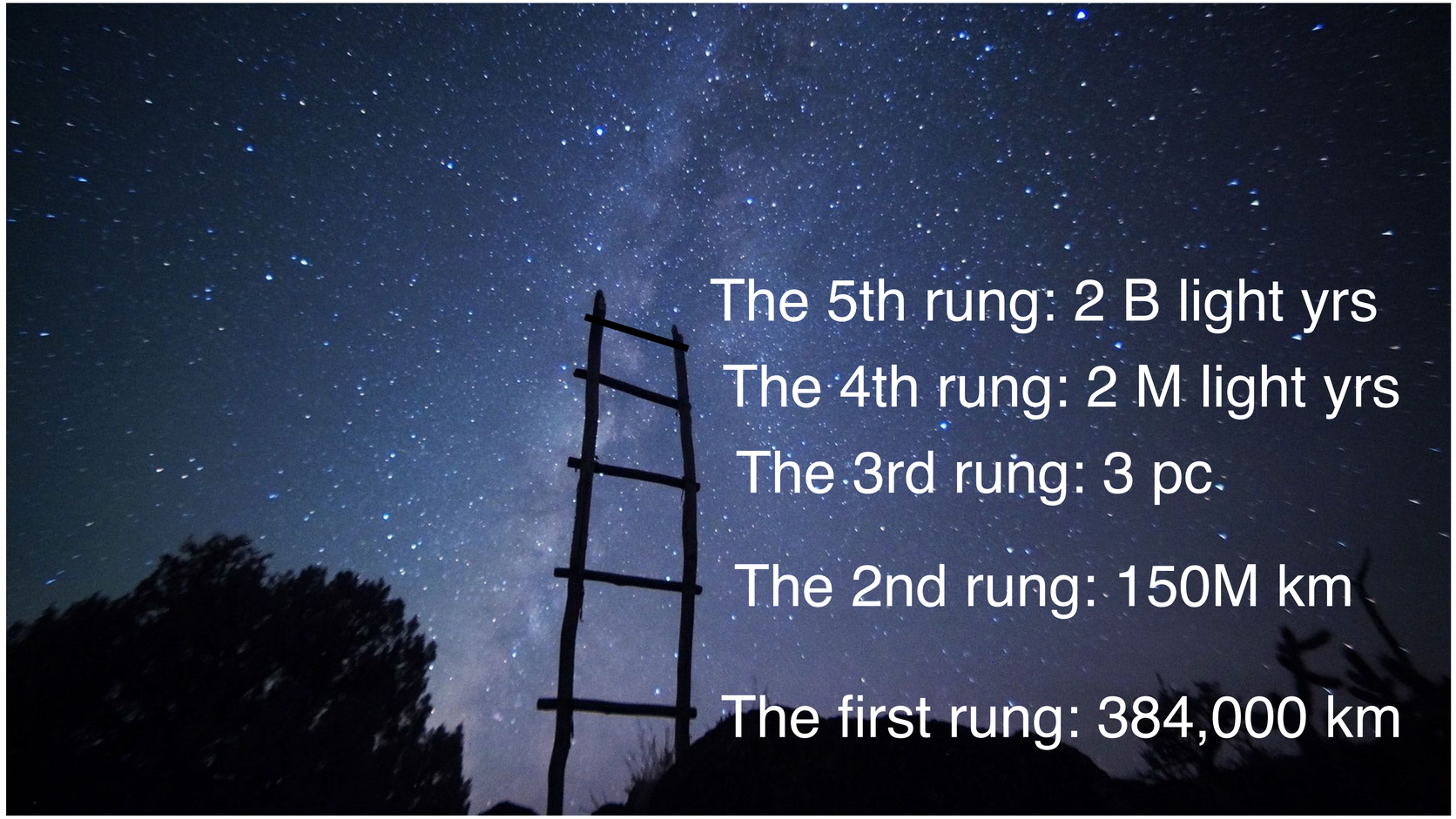

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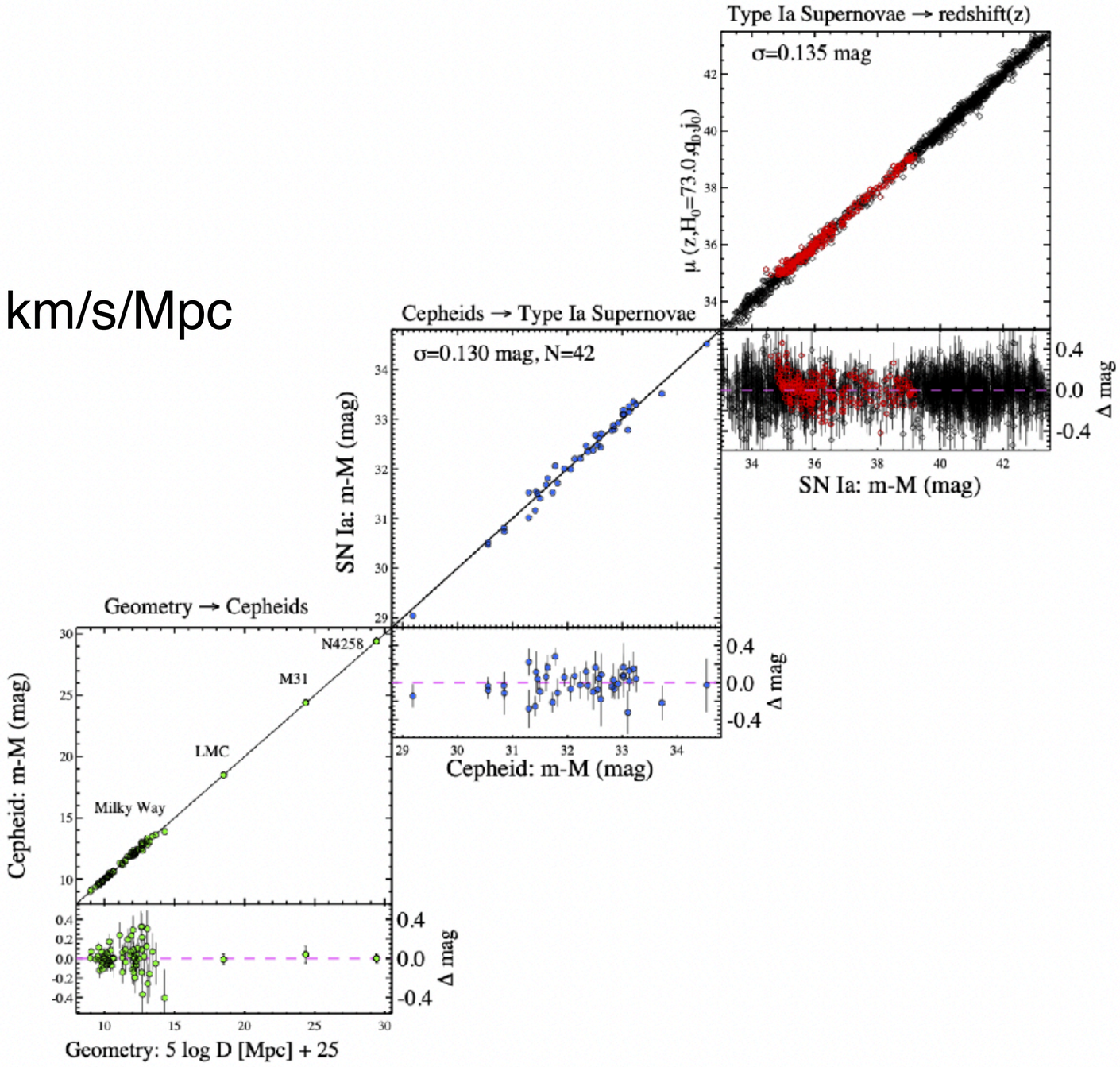
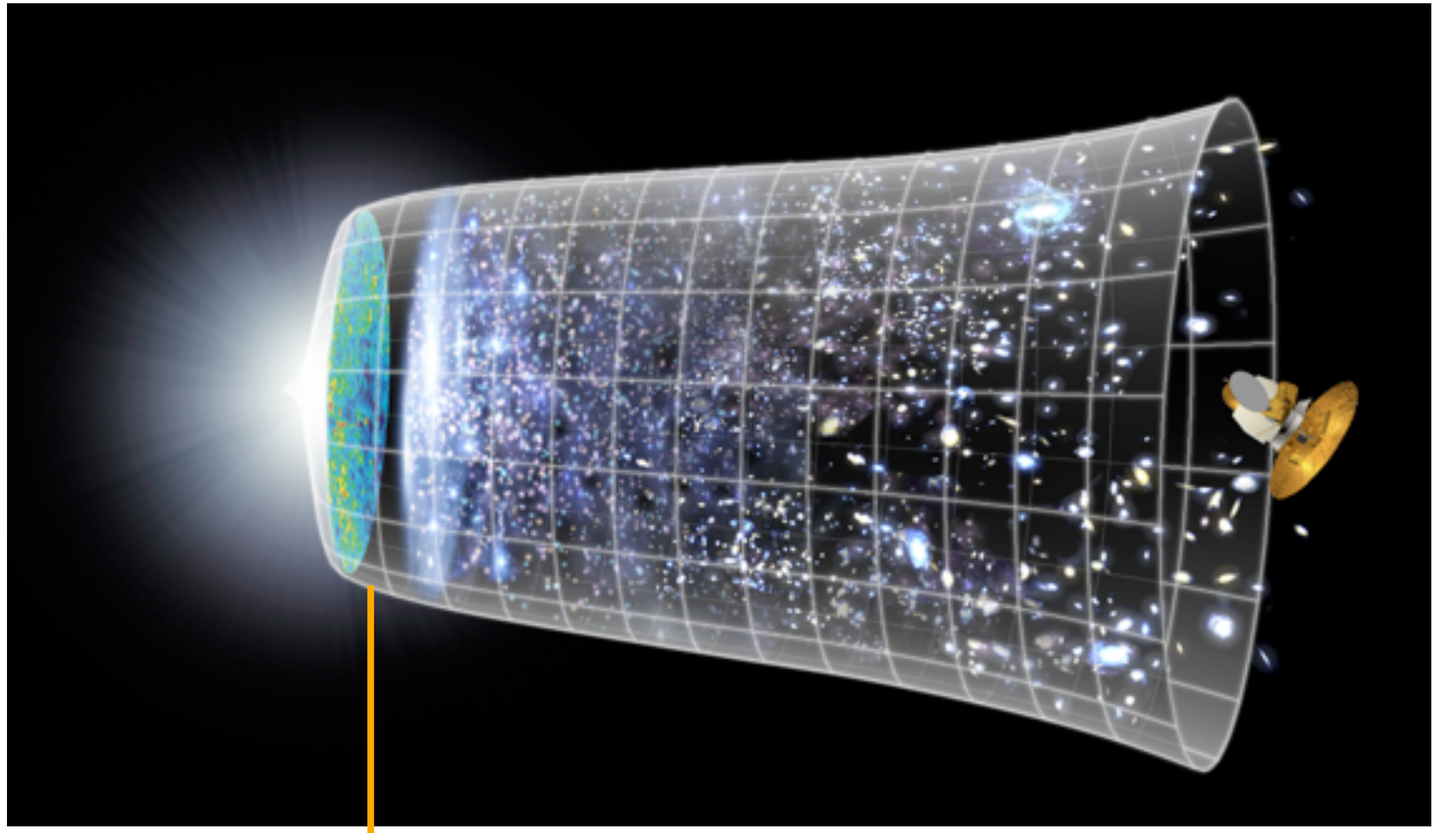
Source: Riess, A. G., Yuan, W., Macri, L. M., Scolnic, D., Brout, D., Casertano, S., . . . Zheng, W. (2021). A Comprehensive Measurement of the Local Value of the Hubble Constant with 1 km/s/Mpc Uncertainty from the Hubble Space Telescope and the SH0ES Team. arXiv:2112.04510. Retrieved from https://ui.adsabs.harvard.edu/abs/2021arXiv211204510R

SH0ES:

$H_0 = 73.04 \pm 1.04$ km/s/Mpc





End of the visible cosmos
t = 380,000 yrs

Today: 13.8 B yrs

Credit: NASA/WMAP

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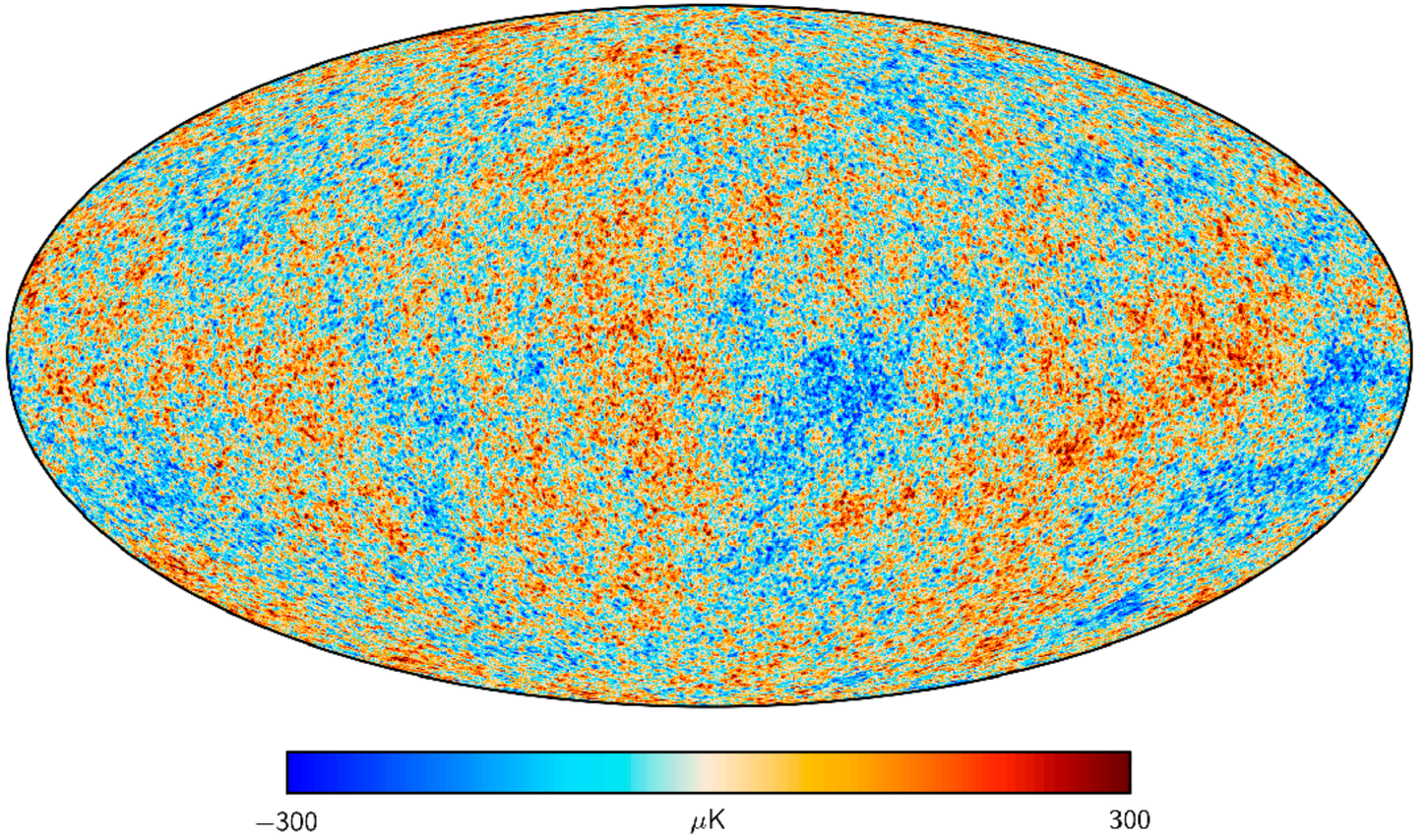

Credit: ESA/Planck

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Relic light:

$H_0 = 67.4 \pm 0.5$ km/s/Mpc

THE LADDER IS BROKEN!

SH0ES:

$H_0 = 73.04 \pm 1.04$ km/s/Mpc

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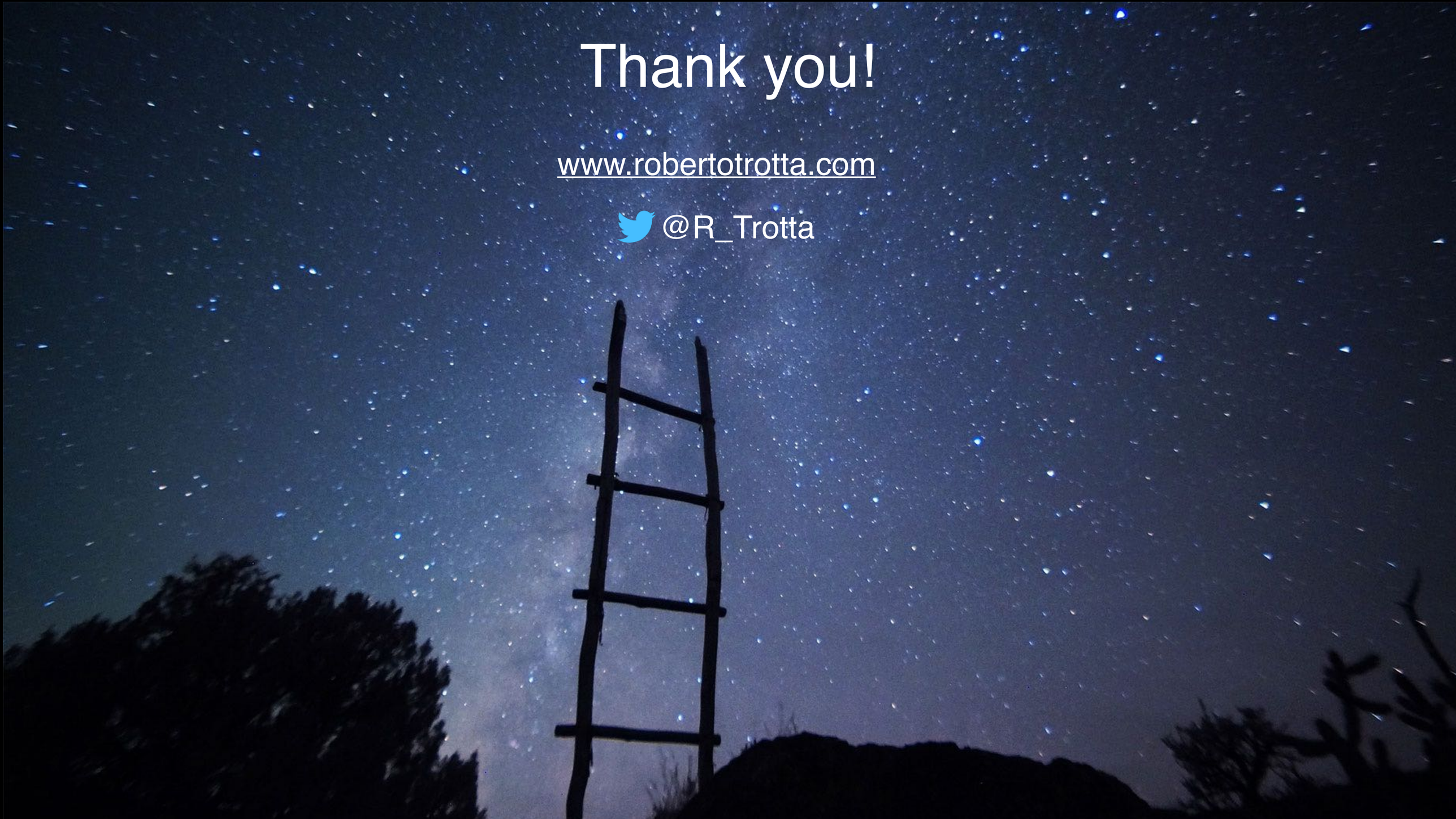
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