The Hubble Tension

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Hubble's Law

- Edwin Hubble, 1929
- Cosmic Expansion
- Hubble Constant H_0

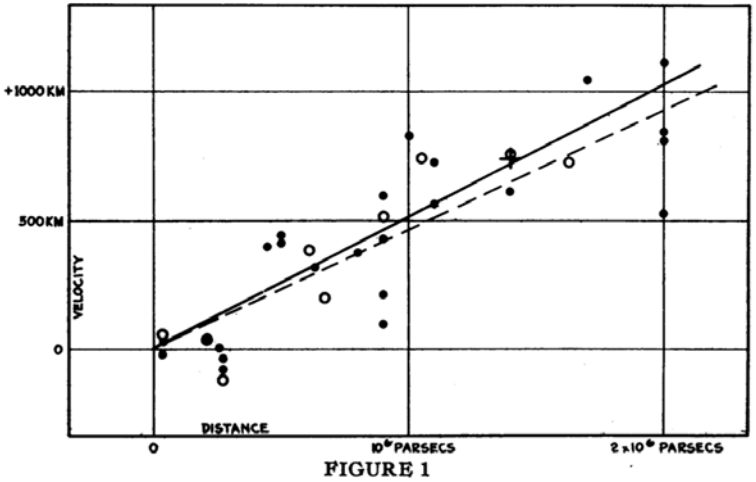


FIGURE 1

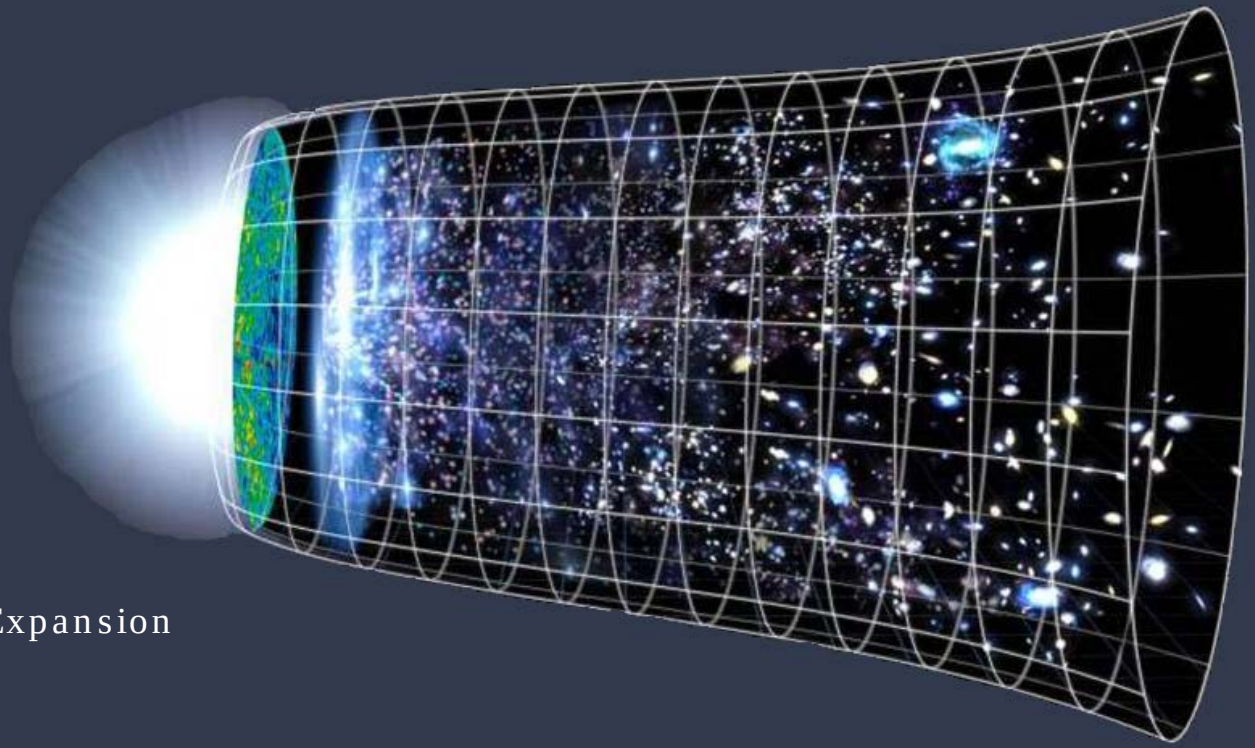
Velocity-Distance Relation among Extra-Galactic Nebulae.

Source: E Hubble, A relation between distance and radial velocity among extra-galactic nebulae. *Proc Natl Acad Sci USA* **15**, 168–173 (1929).

$$v = H_0 D$$

ΛCDM Cosmology

- Big Bang
- Inflation
- Structure Formation
- Recombination
- Galaxy Evolution
- Accelerated Late Time Expansion



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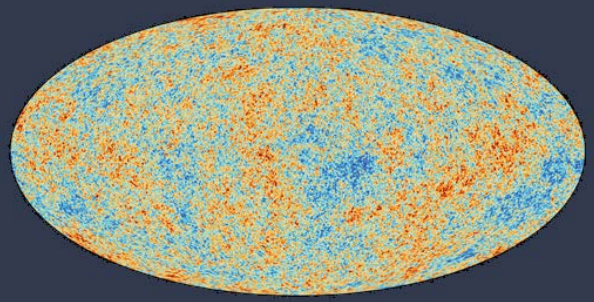
ΛCDM Cosmology

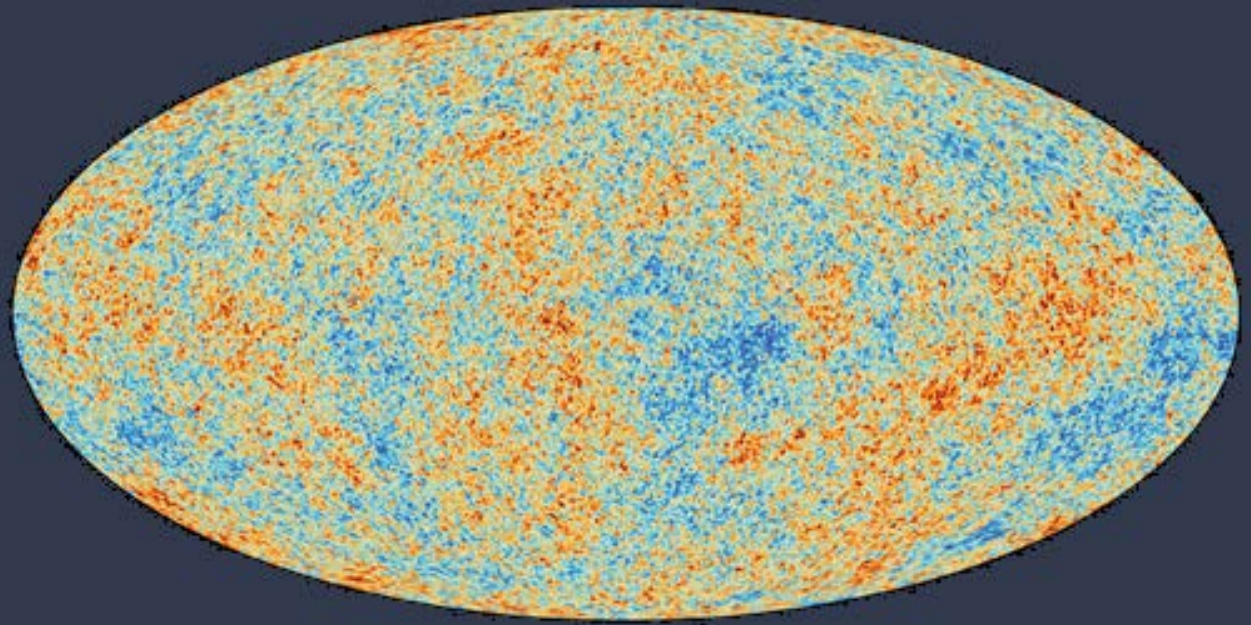
Physics Ingredients

- Cosmic expansion driven by dark energy Λ
- Structure formation dominated by non-relativistic "cold" dark matter (CDM)
- Friedmann–Lemaître–Robertson–Walker metric
- Six Parameters: age, dark matter density, baryon density, etc.



$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu} \qquad H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G\rho}{3} - \frac{kc^2}{a^2}$$

The Cosmic Microwave Background (CMB)



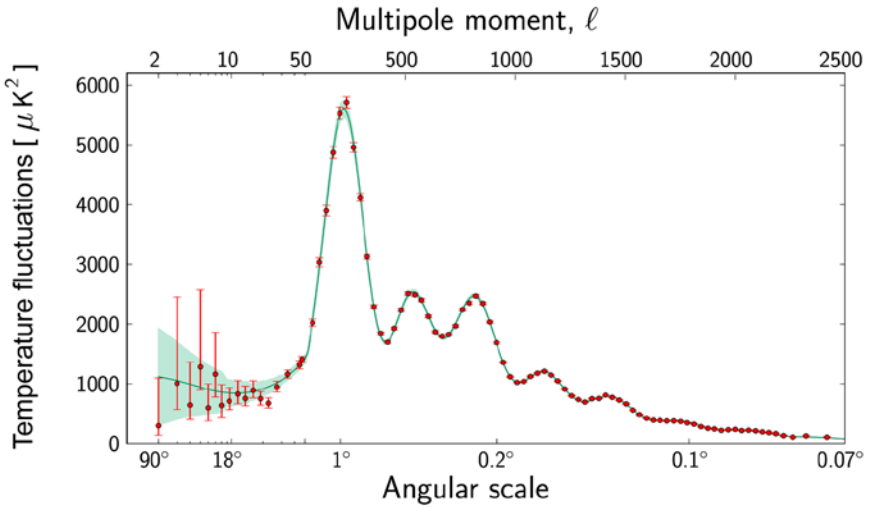
Determining H_0

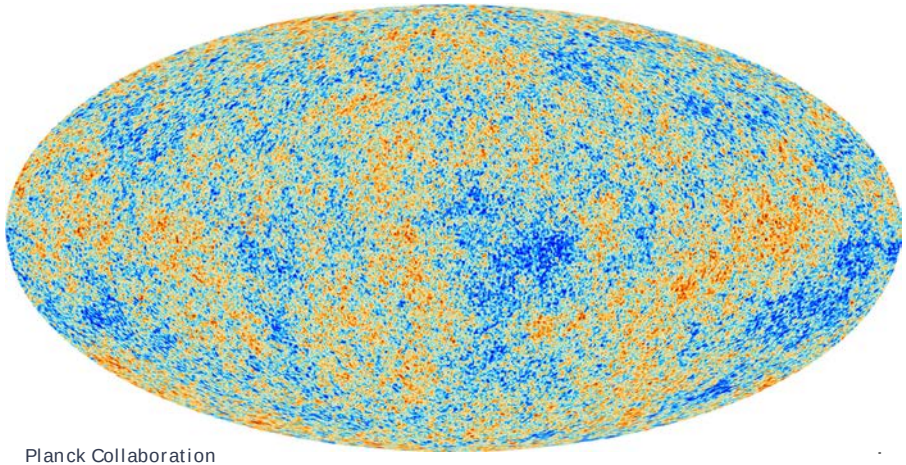
- Roughly two types of method
- Early vs. Late

Let’s look at early methods first.

The "Early" Method

- Based on ΛCDM Model
- CMB Temperature Fluctuations vs Angular Scale
- Curve fitting gives H_0
- Planck data
- $H_0 = 67.4 \pm 0.5$ km/s/Mpc



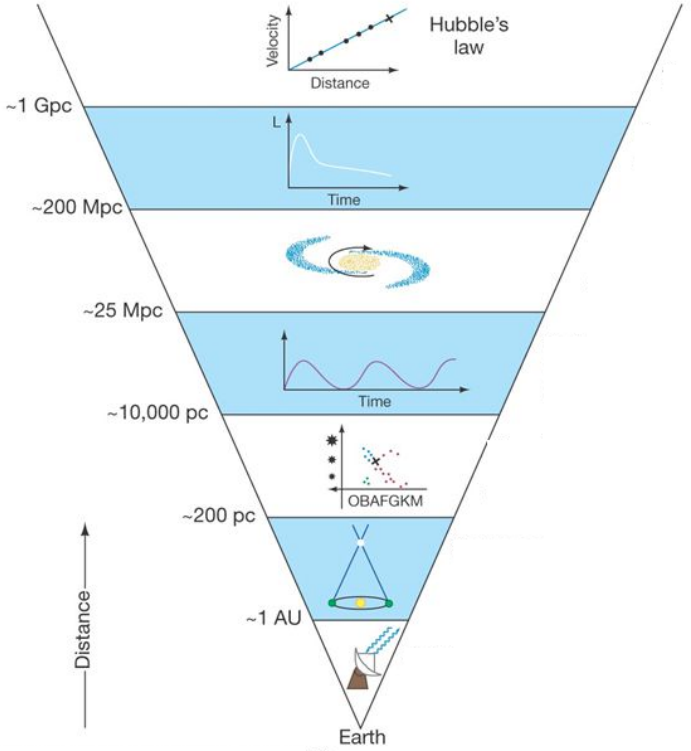


Planck Collaboration

The "Late" Method

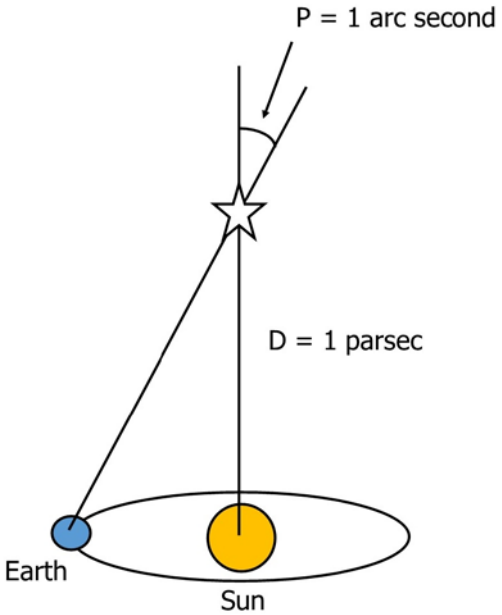
- Direct application of Hubble's Law
- Velocities determined by redshift
- Distance determined by Cosmic Distance Ladder
- $H_0 = 73.24 \pm 1.74$ km/s/Mpc

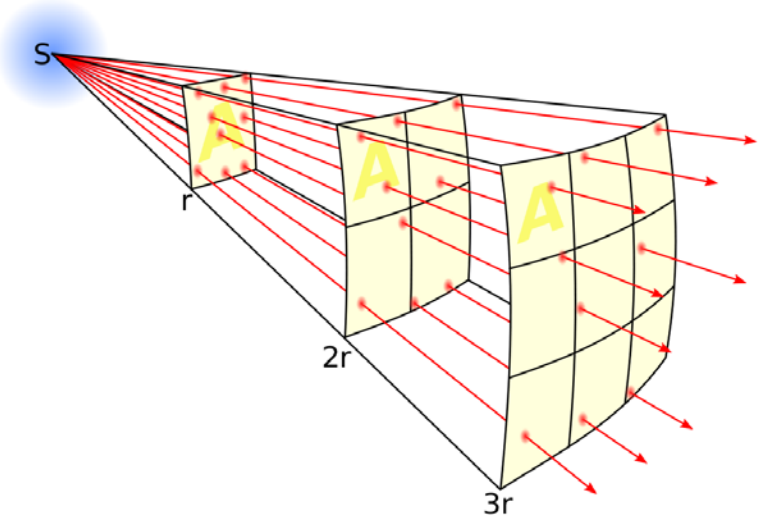
The "Cosmic Distance Ladder"



Credit: Pearson Education, Inc.

The Distance Ladder

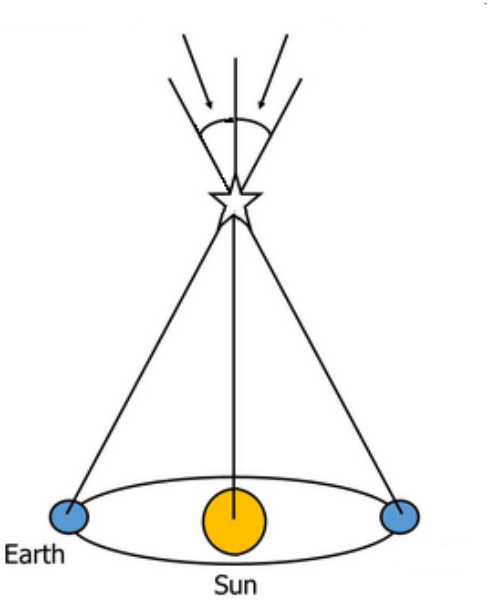


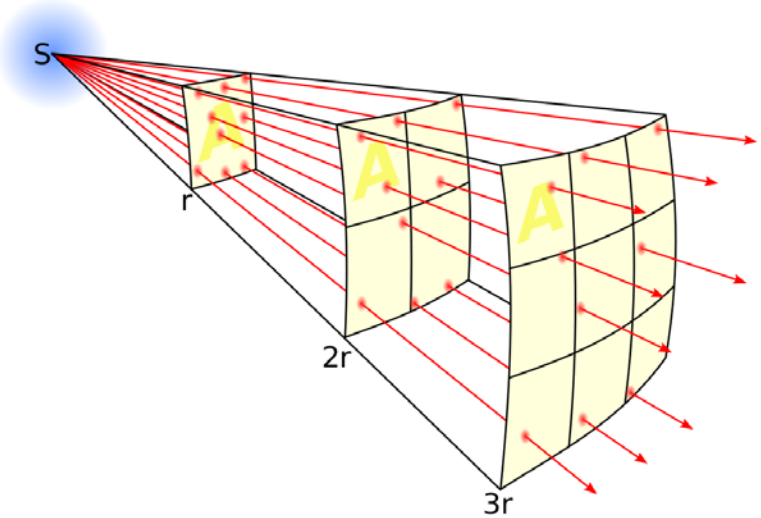


Mary McIntyre

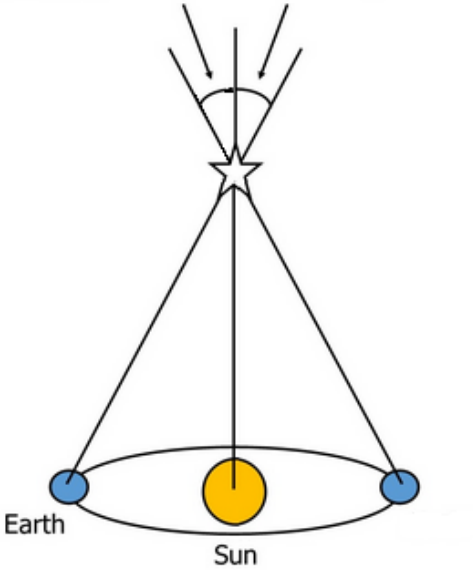
"Inverse square law" by Borb CC BY 2.0

The Distance Ladder

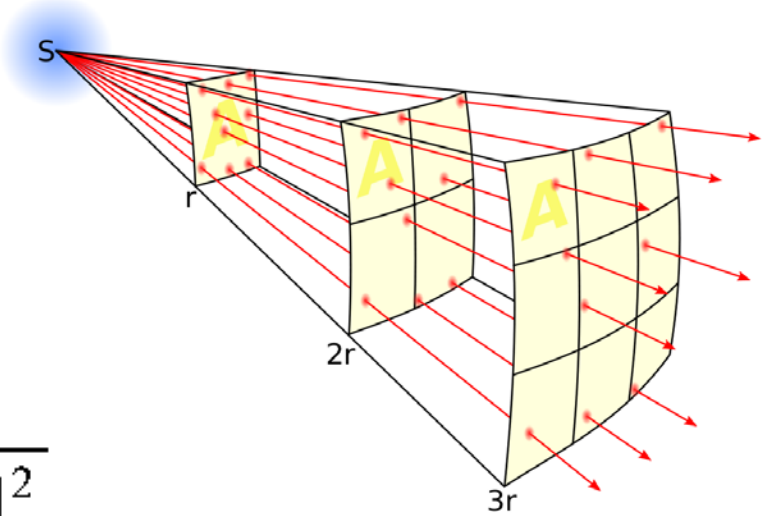




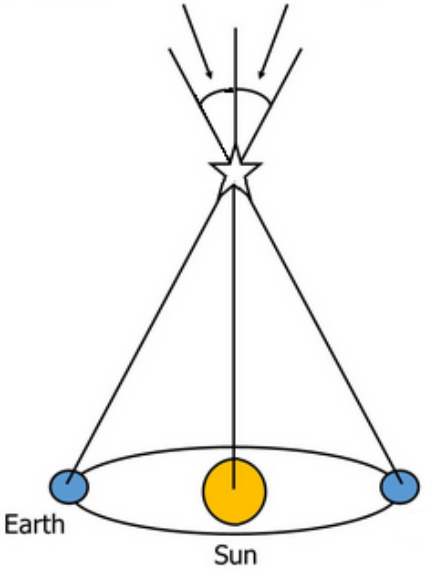
The Distance Ladder



$$B = \frac{L}{4\pi d^2}$$



The Distance Ladder



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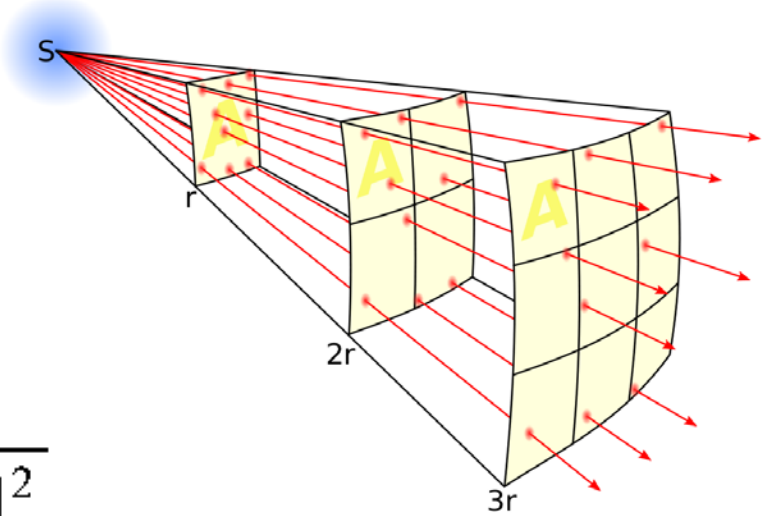
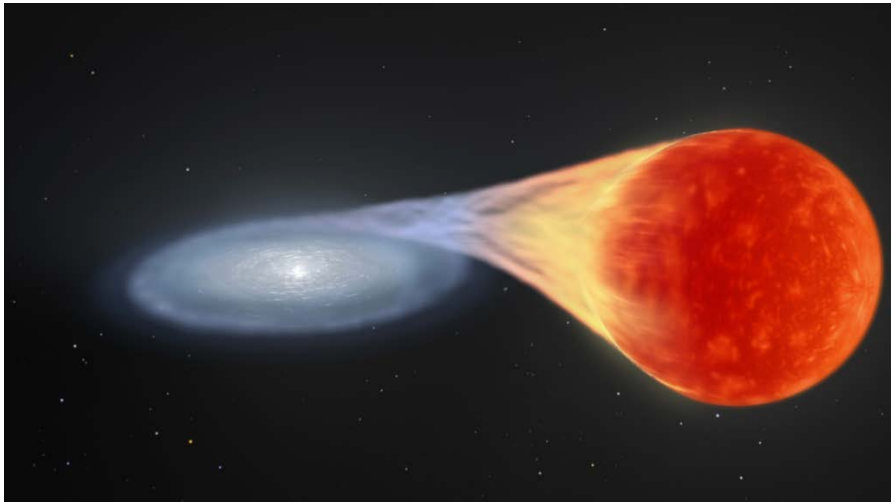


Standard Candles!

Type IA Supernovae

- Accretion of mass onto white dwarf stars
- Occurs at reliable mass threshold
- Provides a reliable luminosity
- Great Standard Candles



NASA's Goddard Space Flight Center Conceptual Image Lab

The Hubble Tension

Early Method: 67.4 ± 0.5 km/s/Mpc

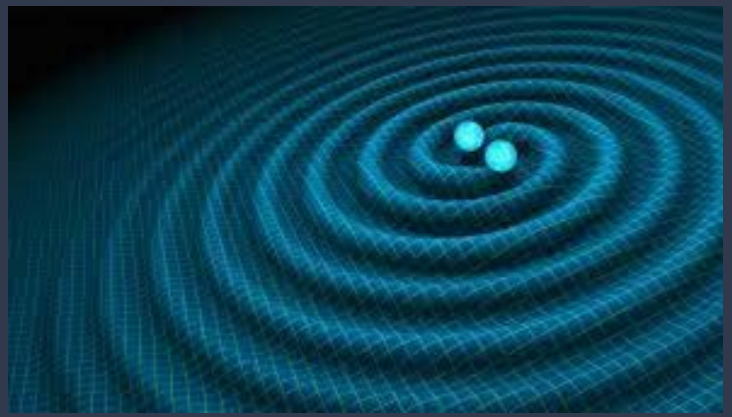
Late Method: 73.24 ± 1.74 km/s/Mpc

The Hubble Tension

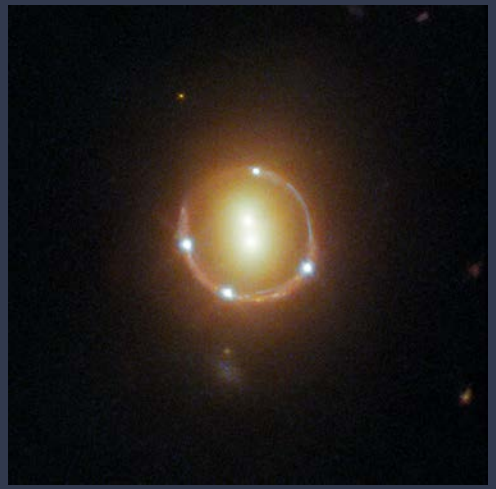
- These results can not be reconciled with current uncertainties
- New methods are needed for measuring H_0
- The ΛCDM model may fail!

Experimental Resolutions

- Systematic error appears unlikely
- Multimessenger astronomy may provide alternative measurements
- Gravitational Lensing can constrain H_0 as well



R. Hurt/Caltech-JPL



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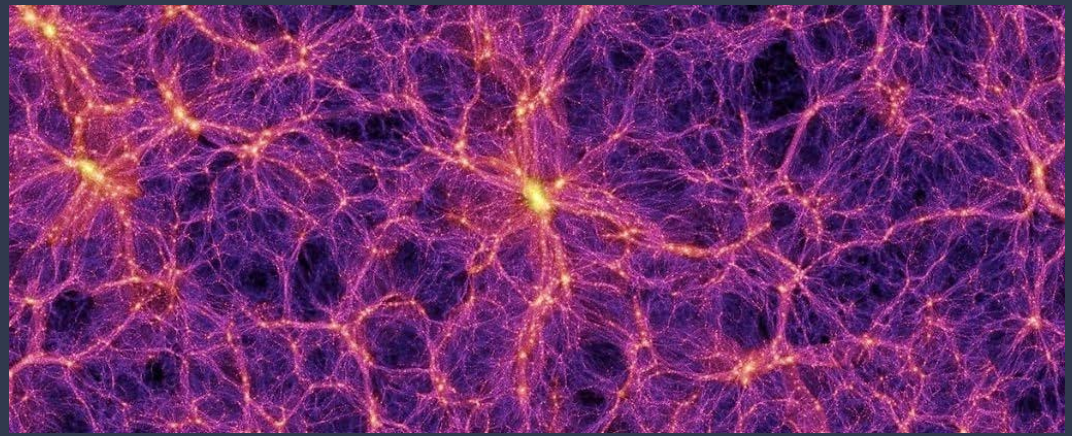
Theoretical Resolutions

- Early Dark Energy
- Modified Gravity
- New Physics in early baryon-photon interactions



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Summary

- The Hubble Tension is a discrepancy between values of H_0 for different experimental methods
- The resolution will require either new physics or expose deficiencies in observational methodologies
- New areas of astronomy may provide alternative measurements that guide us toward a solution

The End

Sources

1. https://iopscience.iop.org/article/10.1088/1361-6382/ac086d
2. https://vickyscowcroft.github.io/PH40112_rmd/ch-obs-techs-cmb.html
3. https://arxiv.org/pdf/1911.11786.pdf
4. https://www.nasa.gov/feature/goddard/2016/nsf-s-ligo-has-detected-gravitational-waves
5. M. Kamionkowski and A. G. Riess, The Hubble Tension and Early Dark Energy. 2211.04492