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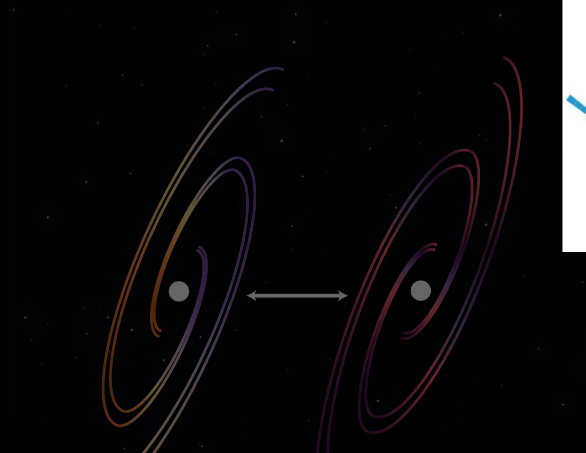

HUBBLE CONSTANT DISCREPANCY

Team VOYAGER (Astrophysics)

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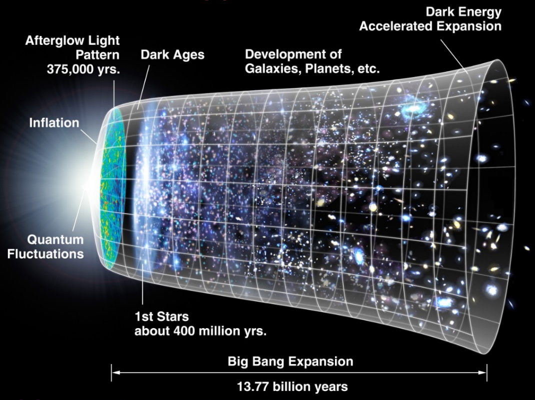
Problem Statement

To compare different methods used to calculate Hubble's constant and analyse the discrepancy among them, also stating the probable reasons for the same.

Introduction

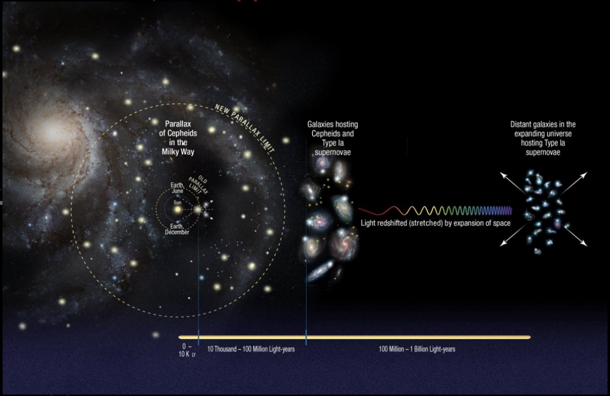
- 1929- observation of expansion of universe by Edwin Hubble
- Hubble's law - Recessional velocity directly proportional to distance $V = H_0 d$
- Hubble's constant - describes the rate of expansion of universe
- Different methods were used
- We have different values of Ho
- Let's look at them



credit:NASA/WMAP Science Team

Cosmic Distance Ladder

- Velocity can be calculated from redshifts:
  $v = cz$, where c is the speed of light and z is the redshift.
- Calculating distance can be tricky.
- Hence Cosmic Distance Ladder method.

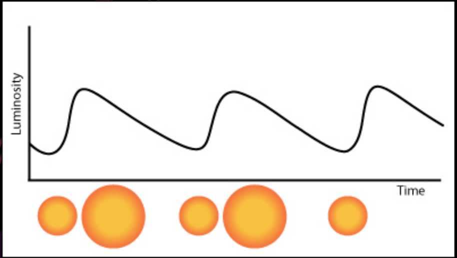


The Cosmic Distance Ladder Method

Type 1 Cepheids

- Standard Candles
- First Candidate—Type 1 Cepheids

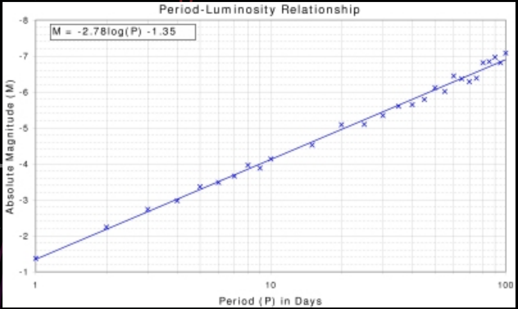
- Luminosity directly proportional to Time Period



Luminosity vs Time Period

Type 1 Cepheids

- $M = -2.78 \log P - 1.35$, where M is the absolute magnitude and P is time period
- $d = 10^{(m-M+5)/5}$, where d is the distance and m is the apparent magnitude
- Multiple Cepheid in a galaxy, estimate the distance to the galaxy



Absolute magnitude vs Period

Type Ia Supernova

- Definition: Type of supernova that occurs in binary systems in which one of the stars orbiting the other one is a white dwarf. The other star can be anything from a giant star to an even smaller white dwarf
- Here, we analyse SNe Ia as standard candles in the near-infrared (NIR) in their peak J-band magnitudes
- Reason: Fairly consistent peak luminosity because of fixed critical mass, which is also comparable to entire galaxies of moderate luminosity, and hence can be observed to distances of hundreds of Mpc
- Advantages: Lower intrinsic scatter than in the optical, reduced effects of dust

Type Ia Supernova Data and Calculations

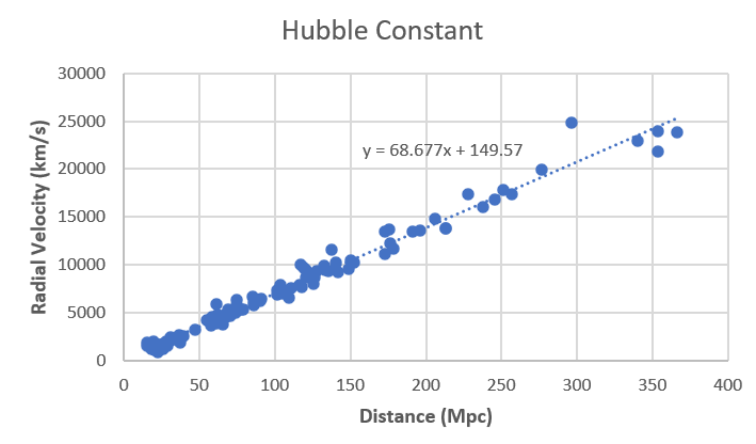
- Hubble-flow sample from SNe with NIR photometry was compiled from Vizier - Updated calibration of the CSP-I SNe Ia sample (Burns+, 2018)

- $z(hel) * 300000 =$ Radial Velocity (km/s)

- Distance mod. muCV gives Distance (Mpc) through:
  $d = 10^{0.2(muCV+5)} * 10^{-6}\ Mpc$

- On plotting the Radial Velocity vs Distance (Mpc) graph:
  Slope of the graph $= H_0 = 68.677\ km/s.Mpc$

Graph



Hubble constant calculated from the data collected

Errors in CDL

- Exact mechanism for the ignition of the explosion has not yet been theoretically or observationally established
- Theoretical astronomers long believed that the progenitor star for this type of supernova is a white dwarf, but there is no certainty
- Dependence of the period-luminosity relation on metallicity has not yet been accurately established

Errors in CDL

- Reddening : Selective absorption and scattering of light by interstellar grains

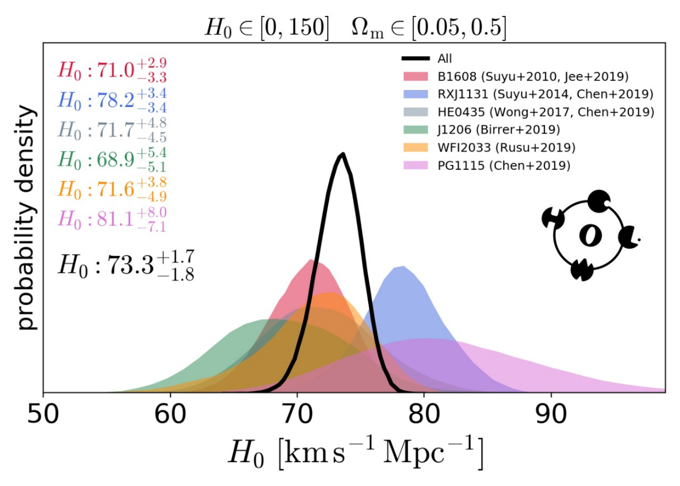
- Peculiar Motion : Velocity due to gravitational effects of the other galaxies or clusters. $V_{total} = H_o * D + V_{pec}$

- Objects misidentified as cepheids while taking the observations

Gravitational Lensing

- Gravitational lensing :As the light emitted by distant galaxies passes by massive objects in the universe, the gravitational pull from these objects can distort or bend the light.
- The light travel time from source to the observer depends on both their path length and gravitational potential.
- Time delay: $t(\theta, \beta) = D_{\triangle}t/c[((\theta - \beta)^2/2) - \psi(\theta)]$
- Time delay distance : $D_{\triangle}t = (1 + z_d)D_dD_s/D_{ds}$
- The value of Ho from flat $\wedge$ CDM cosmology where constraints are used from strong lenses is found to be$73.3_{-1.8}^{+1.7}kms^{-1}Mpc^{-1}$,a 2.4% precision measurement.

Graph

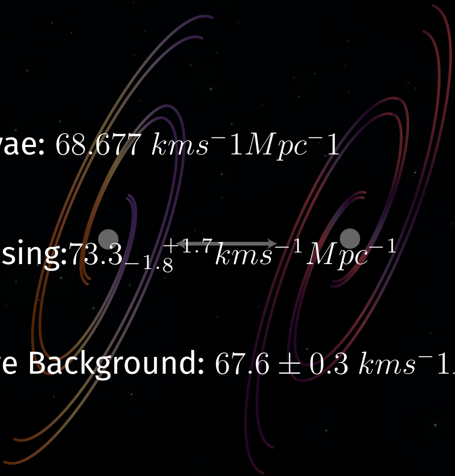


Resource : HoL*i*COW XIII: A 2.4% measurement of H_0

CMB Model and Ho

- The cosmic microwave background, in Big Bang cosmology, is electromagnetic radiation which is a remnant from an early stage of the universe.
- To get the Hubble's constant we use the planck satellite analysis of CMB from which we first figure out what starting cosmological parameters could give the power spectrum observed by plank. Parameters like the starting combination of both dark and light matter, radiation and the initial expansion rate. Then we calculate how a universe with these parameters should evolve to the present day.
- The value of H_0 from this method has higher precision than all the other methods being $67.6 \pm 0.3\, kms^{-}1 Mpc^{-}1$ which is only about $1/2\%$

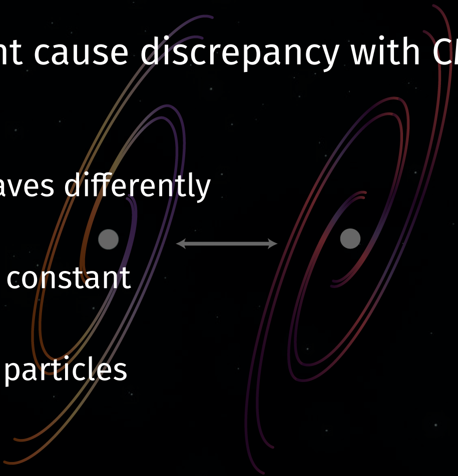
Discrepancy in the value of Ho



- Type Ia Supernovae: $68.677\ kms^{-}1Mpc^{-}1$
- Gravitational Lensing:$73.3_{-1.8}^{+1.7} kms^{-1}Mpc^{-1}$
- Cosmic Microwave Background: $67.6 \pm 0.3\ kms^{-}1Mpc^{-}1$

Possible reasons for discrepancy

Reasons that might cause discrepancy with CMB model include:



- Dark matter behaves differently
- Dark energy isn't constant
- New fast moving particles

Possible reasons for discrepancy

Reasons that might cause discrepancy with Gravitational lensing model include:

- Ripples and warps in space-time. Kilonova formed by black hole - neutron-star merger might emit dark radiation.
- Redshift calculation for time delay.

Reasons that might cause discrepancy with CDL model include:

- Compounding errors in distance ladder.

Conclusion

In this project, we have compared and analyzed the methods of finding the Hubble constant by cosmic distance ladder, cosmic microwave background and gravitational lensing. We then explored the possible reasons for the discrepancies.

THANK YOU