Hubble Tension

- One of the prominent Problems to address in cosmology

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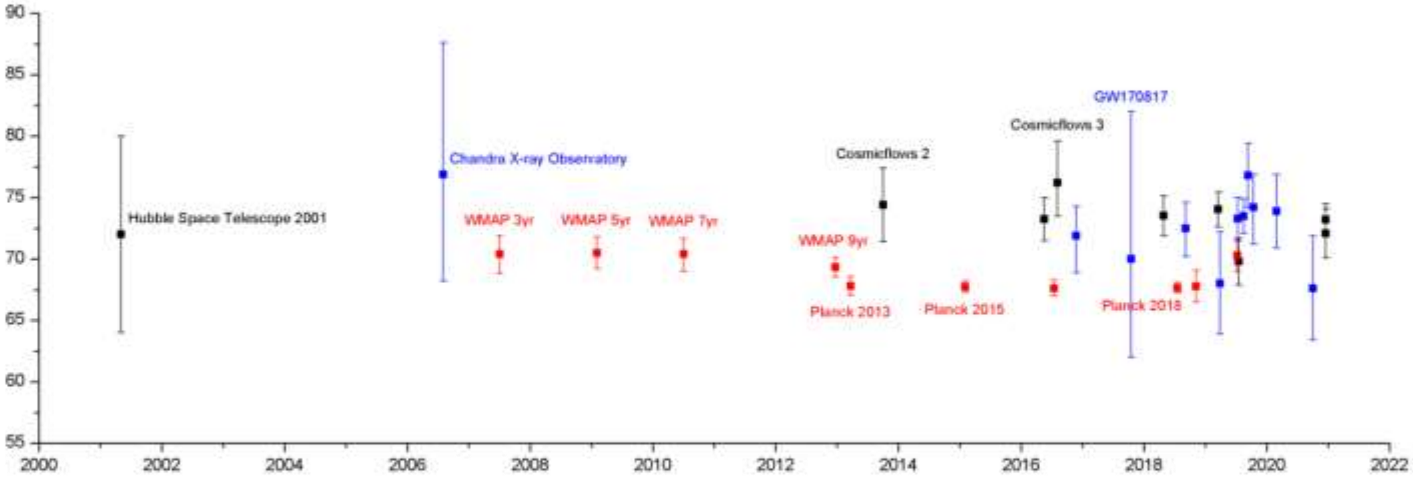
What is Hubble Tension ?

The variation we get during the calculation of Hubble constant by using different techniques and technology is called H_0 Tension.



Estimated values of the Hubble constant, 2001–2020. Estimates in black represent calibrated distance ladder measurements which tend to cluster around 73 km/s/Mpc; red represents early universe CMB/BAO measurements with ΛCDM parameters which show good agreement on a figure near 67 km/s/Mpc, while blue are other techniques, whose uncertainties are not yet small enough to decide between the two.

The range for the values of H_o lies between 67 Km s^{-1} Mpc^{-1} - 74 Km s^{-1} Mpc^{-1} .

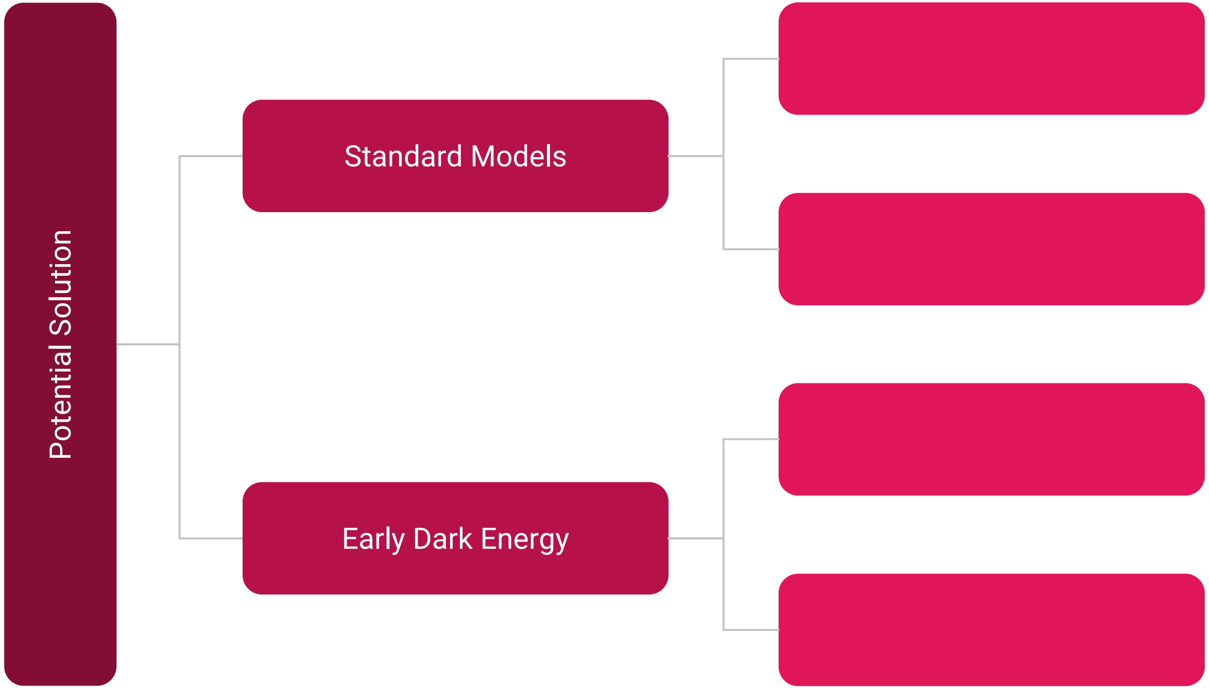
Hubble tension is a matter of Concern as Hubble constant helps us to define the expansion rate of the Universe and hence, the receding velocities of astronomical bodies, age of Universe, etc.

But with successive measurments we are getting better and better precision for the value of H_o .

Various research groups are working around the globe on it.

“Potential solutions to Hubble Tension”

Early dark energy (EDE) that behaves like a cosmological constant at early times (redshifts $z \gtrsim 3000$) and then dilutes away like radiation or faster at later times can solve the Hubble tension. In these models, the sound horizon at decoupling is reduced resulting in a larger value of the Hubble parameter H_o inferred from the cosmic microwave background (CMB). We consider two physical models for this EDE, one involving an **oscillating scalar field** and another **a slowly rolling field**. We perform a detailed calculation of the evolution of perturbations in these models. A **Markov Chain Monte Carlo** (MCMC) search of the parameter space for the EDE parameters, in conjunction with the standard cosmological parameters, identifies regions in which H_o inferred from Planck CMB data agrees with the SH0ES local measurement. In these cosmologies, current baryon acoustic oscillation and supernova data are described as successfully as in the **cold dark matter model** with a cosmological constant, while the fit to Planck data is slightly improved. Future CMB and large-scale-structure surveys will further probe this scenario.


Potential Solution
Standard Models
Early Dark Energy

Standard Models ~

1} ΛCDM (Lambda Cold Dark Matter) - H_o^p **= 67 Km s^{-1} Mpc^{-1}**

2} ΛCDM-Nx (Lambda Cold Matter - Nx) - H_o^R **= 74 Km s^{-1} Mpc^{-1}**

Here, we have assumed in our models (ΛCDM) and (ΛCDM-Nx) the same amount of matter and radiation at the present time but with different value H_o.

The primary difference between the two model is the extra dark energy component in (ΛCDM-Nx) model to compensate for the larger value of H_o.

ΛCDM (Lambda Cold Dark Matter) ~

“Sm” corresponds to a Universe with CDM , a cosmological constant **Λ (lambda) as Dark Energy.**

ΛCDM-Nx (Lambda Cold Matter - Nx) ~

The **ΛCDM-Nx** has an extra parameter for the dark energy component as described -

“sm”

$$\rho_{sm} = \rho_r^{sm} + \rho_m^{sm} + \rho_\Lambda^{sm}$$

“smx”

$$\rho_{smx} = \rho_r^{smx} + \rho_m^{smx} + \rho_\Lambda^{smx} + \rho_{ex}^{smx}$$

EDE (Early Dark Energy) ~

EDE behaves like cosmological constant at early times and then dilutes away like radiation or faster than radiation. In these models, the sound horizon at decoupling is reduced resulting in larger vale of H_o .

Two fields are described as ~

1} **An Oscillating scalar field.**

2} **A Slowly rolling field.**

<u>An Oscillating scalar field ~</u>

A scalar field (ϕ) with a potential **$V(\phi)\ \alpha\ (1 - \mathrm{Cos}[\phi/f])^n$**

At early times field is frozen and acts as a cosmological constant, but when the hubble parameter drops below a certain value, at a critical redshift of **($z_c = a_c^{-1}$ -1),** the field becomes to oscillate and then behave as a fluid with an equation of state.

(w_n = n-1/ n+1).

In practice, numerical evaluation of the scalar-field equation of motion become rapid compared with expansion rate and so our numerical work is accomplished with an ***effective fluid approach****,* that has been tailored specifically for this potential. Still, as that work (and discussion below) indicates, our conclusions do not depend on the details of the potential and would work just as well with, e.g., a simpler **φ^{2n}** potential.

Slowly Rolling Field ~

It is a fluid that slowly rolls down a potential that is linear in (ϕ) at early times and asymptotes to zero at late times. Numerical evolution of the scalar-field equations of motion confirms that the resolutions we find here with the effective-fluid approach are valid for that model as well.

In the effective-fluid approximation, the EDE energy density evolves as ~

$$\Omega_\varphi(a) = \frac{2\Omega_\varphi(a_c)}{(a/a_c)^{3(w_n+1)} + 1}, \tag{1}$$

which has an associated equation-of-state parameter

$$w_\varphi(z) = \frac{1 + w_n}{1 + (a_c/a)^{3(1+w_n)}} - 1. \tag{2}$$

It asymptotically approaches −1 as $a \to 0$ and w_n for $a \gg a_c$, showing that the energy density is constant at early times and dilutes as $a^{-3(1+w)}$ once the field is dynamical . The homogeneous EDE energy density dilutes like matter for $n = 1$, like radiation for $n = 2$, and faster than radiation whenever $n \geq 3$. For $n \to \infty$, on reaching the minimum of the potential, $w_\infty = 1$ (i.e., the scalar field is fully dominated by its kinetic energy) and the energy density dilutes as a^{-6} .