Hubble Tension

***Prelims:** Current events of national importance | Science & Technology*

Why in News?

An international team of astronomers has achieved the most precise direct measurement of the Universe's expansion rate, determining the Hubble constant with just over 1% precision.

- **Definition** – It refers to the discrepancy between two independent methods of calculating the ***Hubble constant (H_0), the rate at which galaxies move apart due to cosmic expansion.***
- The difference is about 9%; both methods are now so precise that the gap cannot be explained by a simple measurement error.
- This statistical significance, often cited at the 5-sigma level or higher, means there is less than a 1 in 3.5 million chance the results are the same.

Feature	Local "Cosmic Distance Ladder" Method	Early Universe "CMB Method"
Expansion Value	73.5 km/s/Mpc	67.4 km/s/Mpc
Cosmic Era Measured	Late Universe (Recent history)	Early Universe (380,000 years old)
Key Instruments	Hubble (HST), James Webb (JWST)	Planck Satellite (ESA)
Methodology	Direct – Cepheids & Type Ia Supernovae	Model-Dependent – ΛCDM projection
Primary Conflict	Suggests faster expansion, challenging standard models.	Indicates slower expansion, supporting standard physics.

Key Concepts

- **Standard Candles –** Celestial objects with a known intrinsic brightness.
- By comparing how bright they look to how bright they are, astronomers calculate distance using the Inverse Square Law.
  - **Cepheid Variables –** Stars that pulsate periodically; their pulsation period is directly linked to their luminosity (Leavitt's Law).

    - **Type Ia Supernovae –** Exploding white dwarf stars that always reach nearly the same peak brightness, allowing for measurements across billions of light-years.
- **Redshift –** The phenomenon where light from receding objects is stretched into longer (redder) wavelengths.
- This is the primary observational evidence for an expanding universe.
- **Cosmic Microwave Background (CMB) –** Often called the "afterglow" of the Big Bang.
- It is the oldest light in the universe (380,000 years after the Big Bang) and provides a "snapshot" of the early universe.
- **The CDM Model (Standard Model) -** The tension is a direct challenge to the ΛCDM model, which is the current "standard model" of cosmology. The 3 pillars to support the model are –
    - **Λ (Lambda) –** Represents the Cosmological Constant or Dark Energy, which causes the universe's expansion to accelerate.
    - **CDM –** Stands for Cold Dark Matter, which provides the gravitational pull needed to form galaxies.
    - "Cold" means the particles move much slower than the speed of light.
    - **Ordinary Matter –** The baryonic matter (atoms) that makes up everything we can see, which is only about 5% of the universe.
- **Measuring Units**
    - **Light Year –** Distance light travels in a year (~9.46 trillion km).
    - **Parsec –** Approximately 3.26 light years; used for inter-stellar distances.
    - **Megaparsec (Mpc) –** One million parsecs; used for intergalactic distances and calculating the Hubble Constant.
- **Significant Missions to Remember**
    - **Planck Satellite (ESA) –** Known for the most precise mapping of the CMB.
    - **James Webb Space Telescope (NASA/ESA/CSA) –** Crucial for observing very distant Cepheids and validating that the "tension" is real physics, not a telescope error.
- **Significance -** The discrepancy is now at high statistical significance (not a fluke).
- Many researchers call it a Hubble Crisis, as it challenges the Standard Model of Cosmology (ΛCDM).
- Resolving it is crucial for refining our understanding of cosmic expansion and fundamental physics.

References

1. The Hindu | Hubble Tension
2. Scientific American | Hubble Tension