Technical trials for easing the (cosmological) tension

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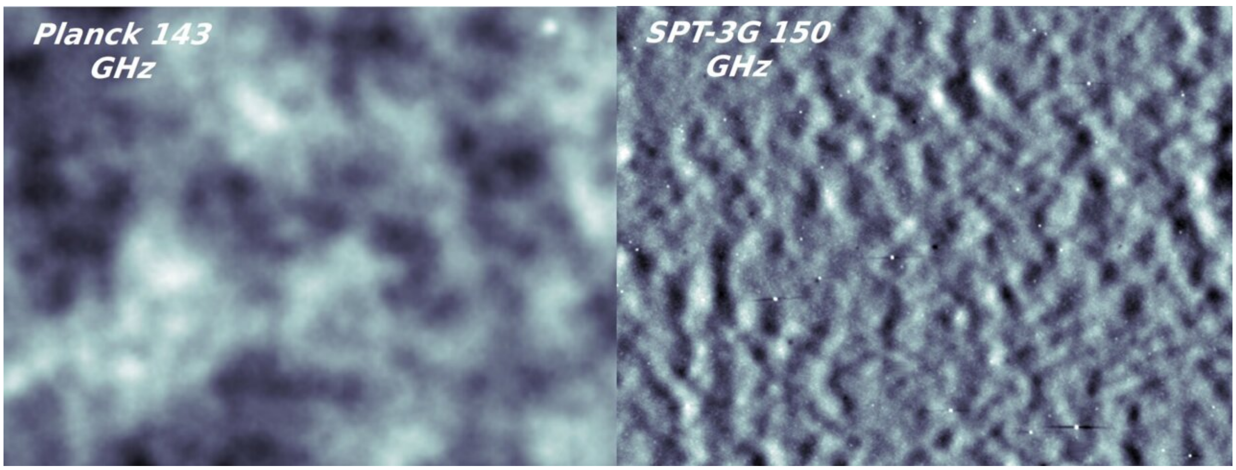

Comparison between CMB data resolution collected by Planck and SPT-3G. Credit: The South Pole telescope: https://pole.uchicago.edu/public/Home.html

Thanks to the dizzying growth of cosmic observations and measurement tools and some new advancements (primarily the "discovery" of what we call dark matter and dark energy) all against the backdrop of General Relativity, the early 2000s were a time when nothing seemed capable of challenging the advancement of our knowledge about the cosmos, its origins, and its future evolution.

Even though we were aware there was still much to uncover, the apparent agreement between our observations, calculations, and theoretical framework indicated that our knowledge of the universe was set to grow significantly and without interruption.

However, thanks to increasingly sophisticated observations and calculations, the emergence of an apparently small "glitch" in our understanding of the universe proved capable of jamming seemingly perfectly oiled gears. At first, it was thought it could be resolved with even more precise calculations and measurements, but this was not the case.

The "cosmological tension" (or Hubble Tension), is a discrepancy between the two ways in which we calculate the so-called Hubble parameter, H_0, which describes the universe's expansion.

The Hubble parameter can be calculated following two paths:

- The astrophysical observations of celestial bodies defined as local, i.e., not very far from us: it is possible to calculate the speed at which bodies at different distances are moving away. The expansion and H_0 in this case is calculated by comparing speeds and distances.
- The calculations based on data from the cosmic microwave background CMB, a faint and extremely distant radiation dating back to the very early universe. The information we gather at that distance allows us to calculate the universe's expansion rate and the Hubble parameter.

These two sources provided not exactly equal, but very close and consistent values of H_0, and at the time it seemed that the two methods were showing good agreement. Bingo.

It was around 2013 when we realized that the "numbers didn't add up." "The discrepancy that emerged might seem small, but given that the error bars on both sides are becoming much smaller, this separation between the two measurements is becoming large," Khalife explains.

The initial two values of H_0, in fact, were not too precise, and as the "error bars" were large enough to overlap, there was hope that future finer measurements would finally coincide. "Then the Planck experiment came along, giving very small error bars compared to the previous experiments" but still maintaining the discrepancy, dashing hopes for an easy resolution.

Planck was a satellite launched in space in 2007 to gather an image of the CMB as detailed as never before. Its results released a few years later confirmed the discrepancy was real and what was a moderate concern turned into a significant crisis. In short: the most recent and near sections of the universe we observe tell a different story, or rather seem to obey a different physics, than the oldest and most distant ones, a very unlikely possibility.

If it's not a problem of measurements then it could be a flaw in the theory, many thought. The current accepted theoretical model is called ΛCDM. ΛCDM is largely based on General Relativity—the most extraordinary, elegant, and repeatedly observationally confirmed theory about the universe formulated by Albert Einstein more than a century ago—and takes into account dark matter (interpreted as cold and slow-moving) and dark energy as a cosmological constant.

Over the last years, various alternative models or extensions to the ΛCDM model have been proposed, but so far, none have proven convincing (or sometimes even trivially testable) in significantly reducing the "tension."

"It is important to test these various models, see what works and what can be excluded, so that we can narrow the path or find new directions to turn to," explains Khalife. In their new paper, he and his colleagues on the basis of previous research lined up 11 of these models, bringing some order to the theoretical jungle that has been created.

The models were tested with analytical and statistical methods on different sets of data, both from the near and distant universe, including the most recent results from the SH_0ES (Supernova H_0 for the Equation of State) collaboration and SPT-3G (the new upgraded camera of the South Pole Telescope, collecting the CMB). The work was published in the *Journal of Cosmology and Astroparticle Physics*.

Three of the selected models that were shown in previous works to be viable solutions were ultimately excluded by the new data this research considers. On the other hand, the other three models still seem capable of reducing the tension, but this doesn't solve the problem.

"We found that those could reduce the tension in a statistically significant way, but only because they have very large error bars and the predictions they make are too uncertain for the standards of cosmology research," says Khalife.

"There is a difference between solving and reducing: these models are reducing the tension from a statistical point of view, but they're not solving it," meaning that none of them is predicting a large value of H_0 from CMB data alone. More in general none of the models tested proved superior to the others studied in this work in reducing the tension.

"From our test we now know which are the models that we should not look at to solve the tension," concludes Khalife, "and we also know the models that we might be looking at in the future."

This work could be a base for the models that will be developed in the future, and by constraining them with increasingly precise data, we could move closer to developing a new model for our universe.

More information: Ali Rida Khalife et al, Review of Hubble tension solutions with new SH0ES and SPT-3G data, *Journal of Cosmology and Astroparticle Physics* (2024). DOI: 10.1088/1475-7516/2024/04/059. On *arXiv*: DOI: 10.48550/arxiv.2312.09814

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