No Easy Fix for Cosmology’s “Other” Tension

The S_8 tension—a disagreement between cosmic-clumpiness measurements—is not going away, according to a new analysis of galaxy lensing data.

By **Michael Schirber**

If you move in the same circles as cosmologists, then you’ve likely heard of the Hubble tension—a troublesome discrepancy in the measurements of cosmic expansion. But you might not be familiar with another discrepancy, the so-called S_8 tension, which involves conflicting estimates for the clumpiness of matter in the Universe. A new analysis of galaxy data suggests that the S_8 tension might not be explained away by blaming messy galactic processes [**1**]. The implication is that cosmologists might need to rework their models for how galactic structures form in the expanding Universe.

Researchers have provided the latest estimates of the S_8 parameter using galaxy data from the Hyper Suprime-Cam on the Subaru Telescope, seen here in silhouette.

Credit: HSC

The S_8 parameter is a measure of how much cosmic matter has clumped together under the pull of gravity. It is calculated by looking at various regions in the Universe—where a region is defined by a length scale of 8 megaparsecs (26 million light-years)—and counting the number of galaxies and other structures in each region. Some regions have more stuff (more matter) than others, and the standard deviation of the matter distribution (called σ_8) is directly related to S_8. “A Universe with a higher value of S_8 corresponds to a Universe with more advanced structure formation, that is, one with more galaxies,” says Ryo Terasawa from the University of Tokyo, who worked on the new study.

In reality, estimating S_8 is more complicated than just counting galaxies. That’s because much of the matter in the Universe is composed of dark matter, which doesn’t form stars or other light-emitting objects. Astronomers get around this problem by measuring an effect called gravitational lensing. If you look at a distant galaxy, its light will be distorted by matter (both dark and light emitting) along the line of sight. Galaxy surveys can measure the overall matter distribution—and with it S_8—by detecting subtle distortions in galaxy shapes, an effect called cosmic shear. Several cosmic-shear surveys have measured S_8 over the years, returning values around 0.75. Terasawa and his colleagues have provided one of the latest estimates using galaxy data from the Hyper Suprime-Cam (HSC)—a camera installed on the Subaru Telescope in Hawaii. Their value of 0.747 is in line with previous values.

However, cosmologists have another way to estimate S_8 by using the cosmic microwave background (CMB), which provides an imprint of what the Universe looked like when it was 380,000 years old. Fluctuations in the CMB correspond to density variations in the distant past. These variations eventually grew into galaxies and other large-scale structures, but how that growth played out depends on what the Universe is made of. The standard cosmological model, the so-called ΛCDM, assumes that the cosmic constituents are 70% dark energy (in the form of a cosmological constant), 25% cold dark matter, and 5% normal (baryonic) matter. Using the ΛCDM model, cosmologists can convert CMB fluctuation data into an S_8 prediction.

Early estimates of S_8 using CMB data agreed with galaxy lensing estimates. But in 2013, researchers from the Planck mission—a high-precision CMB satellite—calculated an S_8 value of 0.83, which was above the gravitational-lensing estimates. “As the CMB is considered the gold standard, most people assumed that the galaxy estimates were wrong,” says Hendrik Hildebrandt, an astrophysicist at Ruhr University Bochum in Germany and a member of the Kilo-Degree Survey (KiDS) team, which has measured an S_8 value similar to that of the HSC [**2**]. But in subsequent years, more and more galaxy data came out, and the values remained consistently below the CMB estimate. “In the last eight years or so, people have started to take the discrepancy seriously, saying it might be something fundamental,” Hildebrandt says.

However, the S_8 tension has not been considered as serious as the Hubble tension. Current estimates have the Hubble tension at 5 sigma, which means that there is only a one-in-a-million chance that the discrepancy is a statistical fluke. The S_8 tension, by contrast, is typically around 2 to 3 sigma, so there is a one-in-a-hundred chance that it’s just a random variation. “This means that the S_8 tension is not as ‘tense,”’ says Tanveer Karim, an astrophysicist from the University of Toronto. In fact, some galaxy surveys have found little or no tension with the CMB estimate. The Dark Energy Spectroscopic Instrument (DESI), for example, mapped the positions of 4.7 million galaxies and quasars and, from the clustering of these objects, estimated an S_8 value of 0.84 [**3**].

But a closer examination of these surveys suggests that the S_8 parameter may be sensitive to the epoch and the galaxy scale that one looks at. In a separate study, Karim and his colleagues used the DESI data to map out the locations of so-called emission-line galaxies—relatively small galaxies that were abundant around 8 billion years ago (corresponding to a redshift of 1) [**4**]. By correlating the distribution of these galaxies with lensing data from the CMB, they found an S_8 value of around 0.71. The results are in line with other studies that suggest that S_8 decreases as one goes to later times and smaller length scales. “The tension keeps popping up in various galaxy surveys, so is it signaling something to us?” Karim asks.

What the S_8 tension might be signaling is still open for debate. Some cosmologists have tried to change the ΛCDM model by, for example, making dark energy time dependent or mixing in warm dark matter with the cold dark matter. But some of these solutions end up making the Hubble tension worse. “If you try to tweak it on one side, it falls apart on the other side,” Hildebrandt says.

Another solution to the S_8 problem is to consider galactic processes that can rearrange the distribution of matter. These “baryonic effects”—which include star formation, supernovae explosions, and black hole jets—would presumably smooth out clumpiness. Terasawa and his colleagues searched for signs of baryonic effects in their survey by measuring the lensing signal at small angles, where messy galactic processes are expected to have their greatest effect. “We find that the small-scale HSC data allow only modest baryonic effects, which are not strong enough to fully reconcile the S_8 tension,” Terasawa says. The researchers conclude that the S_8 tension remains a problem.

Hildebrandt says that previous surveys have looked for baryonic effects, but never at the level of detail with which Terasawa and colleagues looked. By analyzing the lensing signal at the smallest scales that are accessible, “they basically went all in,” Hildebrandt says. “The HSC data are fantastic, so they certainly have the best chance of doing this,” he adds.

But Hildebrandt cautions that this HSC result is only one data point. Other galaxy surveys, such as KiDS and the Dark Energy Survey, will soon be releasing their full data sets, so similar searches for baryonic effects will become possible. Hildebrandt also mentions upcoming surveys from the Euclid space telescope and the Vera Rubin Observatory in Chile. “I think the HSC result is super interesting because it’s really targeting one of the aspects that might tell us something about S_8. But I don’t think it’s the final word,” he says.

Michael Schirber is a Corresponding Editor for ***Physics Magazine*** based in Lyon, France.

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