# Voids may solve cosmology's biggest questions!

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Cosmology and Astrophysics

- In part because they have some major puzzles to solve, researchers have been searching for new instruments.
- The first, and most confusing, is the Hubble constant, which measures how quickly the universe is expanding.
- Scientists have been unable to reconcile divergent estimations of this rate for over ten years; some have even dubbed the problem the biggest cosmological catastrophe.
- Furthermore, disparate measurements of the average density of massive structures, dark matter, galaxies, gas, and voids spread throughout the universe as a function of time, as well as the clumsiness of cosmic stuff, exist.

Hubble constant calculated using different survey methods



Hubble tension



## CMB with Planck

Balkenhol et al. (2021), Planck 2018+SPT+ACT : 67.49 ± 0.53 Balacennoi et al. (2021), Planck 2018+SP1+AL 1: 67,49 ± 0.53 Pogosian et al. (2020), e80055+Planck (0.14<sup>2</sup>: 69.6 ± 1.8 Aghanim et al. (2020), Planck 2018: 67.27 ± 0.60 Aghanim et al. (2020), Planck 2018: 4.64 Ade et al. (2020), Planck 2018: 4.64 Ade et al. (2016), Planck 2018: 4.64 Ade et al. (2016), Planck 2018: 4.65 Ade et al. (2016), Planck 2018: 4.55 Ade et al. (2016), Planck 2018: 4.65 Ade et al. (2016), Planck 2018: 4.65 Ade et al. (2016), Planck 2018: 4.65 Ade et al. (2016), Planck 2018: 4.55 Ade et

### CMB without Planck

Dutcher et al. (2021), SPT: 68.8 ± 1.5 Aida et al. (2020), ACT: 67.9 ± 1.5 Aida et al. (2020), WMAP9+ACT: 67.6 ± 1.1 Zhang, Huang (2019), WHAP9+BAO: 68.36\*212 Hinshaw et al. (2013), WHAP9: 70.0 ± 2.2

### No CMB, with BBN

D'Amico et al. (2020), BOSS DR12+88N 68.5 ± 2.2 Colas et al. (2020), BOSS DR12+88N; 68.5 ± 2.2 Philcox et al. (2020), Py+8AO+88N; 68.7 ± 1.5 Philcox et al. (2020), Py+8AO+88N; 68.6 ± 1.1 lyanov et al. (2020), P/TB/05TBBN: 68.9 ± 1.1 Alam et al. (2020), BOSS+cBOSS+88N: 67.35 ± 0.97

### P<sub>i</sub>(k) + CMB lensing

Philosx et al. (2020), P(R)+CMB lensing: 70.6123

Cepheids – SNIa Riess et al. (2020), R20: 73.2 ± 1.3 Breuval et al. (2020), 72.8 ± 2.7 Riess et al. (2019), R19: 74.0 ± 1.4 Riess et al. (2019), R19; 74.0 ± 1.4 Camarena, Marra (2019); 75.4 ± 1.7 Burro et al. (2018); 73.2 ± 2.3 Dhawan, jha, Leikundgut (2017), NIR; 72.8 ± 3.1 Folio, Kong (2017); 23.3 ± 1.7 Former Montion's Database (2017): 73.3 ± 1.7 Riess et al. (2016), H9: 73.2 ± 1.8 Riess et al. (2016), R16: 73.2 ± 1.7 Cardona, Kunz, Pettorina (2016), H9: 73.8 ± 2.1 Freedman et al. (2012): 74.3 ± 2.1

TRGB – SNIa Soltis, Casertano, Riess (2020): 72.1 ± 2.0 Freedman et al. (2020): 60.6 ± 1.9 Reid, Perce, Riess (2020), SH0ES; 7.11.1 ± 1.9 Freedman et al. (2019): 59.8 ± 1.9 Yean et al. (2019): 69.8 ± 1.9 Jang, Lee (2017): 71.2 # 2.5

### Miras - SNIa Huang et al. (2019): 73.3 ± 4.0

Masare

Petro et al (2020) 23.9 ± 3.0

Tully - Fisher Relation (TFR) Kourischi et al. (2020): 76.0 = 2. Schombert McGaugh Leli (2020) 251+2.8

## Surface Brightness Fluctuations Bakestee et al. (2021) IR-SBF wr HST: 73.3 ± 2.5 Shetan et al. (2020) wr LMC DEB: 71.1 ± 4.1

de jaeger et al. (2020): 75.8:23 HII colorios

## Fernindez Arenas et al. (2018): 71.0 ± 3.5

### Lensing related, mass model - dependent

Denzel et al. (2021); 71.8133 Birrer et al. (2020), TDCOSMO+SLACS: 67.4151, TDCOSMO: 74.5127 Yang, Birrer, Hu (2020); H<sub>0</sub> = 73.65129 Million et al. (2020); DCOSMO: 74.2123 I. (2020), TDCOSMO: 74.2 ± 1.6 Baster et al. (2020): 73.5 ± 5.3 Qi et al. (2020): 73.5 ± 5.2 Qi et al. (2020): 73.6 ± 1 Liao et al. (2020): 72.8 ± 1 Liao et al. (2019): 72.2 ± 2.1 Shajib et al. (2019), 57HDE5: 74.251 Wong et al. (2019), 57HDE5: 74.251 Birner et al. (2019), HOLICOW 2019: 73.351 Berwin et al. (2016), HOLICOW 2018: 72.551 Berwin et al. (2016), HOLICOW 2016: 71.952

### **Optimistic average**

Ultra – conservative, no Centra (2021): 72.94 ± 0.75 Ultra – conservative, no Centra (2021): 72.7 ± 1.3

### GW related

Gayathri et al. (2020), GW190521+GW170817: 73.4-54 Mukherjee et al. (2020), GW170817+ZTF: 67.6-24 Mukherjee et al. (2019), GW170817+VI.B: 67.6-24 Mukherjee et al. (2019), GW170817+VI.B: 68.3-55 Abbett et al. (2017). GW170817+9Uill: 88.8-2-2

Hubble tension

- Astronomers typically gauge those values using two complimentary methods.
- Strangely, these two approaches provide different values for the so-called matter clustering strength and the Hubble constant.
- Pisani and her colleagues have developed a unique method to determine both values: they employ cosmic voids.
- Additionally, their preliminary findings, which appear to align more closely with one of the conventional approaches than the other, are currently adding more complexity to an already contentious dispute.
- Inside a void "very little happens". As structures never originated and evolved inside voids, voids are considered to be "time capsules of the early universe." Put another way, the gaps might have maintained the physics of the early cosmos if it differed from the physics of the present.
- Voronoi diagram, a mathematical tool has been used for 6,000 voids from Baryon Oscillation Spectroscopic Survey (BOSS), which identifies the shapes that make up a 3D mosaic.

- A higher density of more compacted, smaller voids was created by a slower rate of expansion.
- On the other hand, they anticipated finding more big, smooth voids if growth had been rapid and matter had not clumped as easily.
- The Hubble constant found in the vacuum data differed from the CMB estimate by less than 1%.
- Clumsiness produced a more jumbled output, but it also matched the CMB more closely than Type Ia supernovas.
- Upcoming projects like SPHEREx Observatory and NASA's Nancy Grace Roman Space Telescope to gather sufficient void data to match the contradictory Type Ia supernova and CMB readings.
- We could be witnessing something different due to new physics, since the CMB and supernova groups are making quite different measurements.

# Something is created out of nothing

- Every cosmic emptiness serves as a window into a major cosmic struggle.
- The enigmatic factor responsible for the rapid expansion of our universe, known as dark energy, is present on one side.
- Dark energy rules the physics of the emptiness since it exists even there.
- Gravity, on the opposing side of the fight, aims to bring the emptiness together.
- The clumpiness of matter then gives the voids wrinkles.















# Future