Is the Hubble constant a constant?

Eoin Ó Colgáin



based on work with A. Banerjee, H. Cai, L. Heisenberg, C. Krishnan, O. Luongo, R. Mohayaee, M. Muccino, M. M Sheikh-Jabbari, Lu. Yin

Hubble tension is fascinating & confusing.

It can be sharply defined as a mismatch between:

- early Universe model dependent (ACDM) inference of HO
- 2. late Universe model independent HO determinaton

KEY OBSERVATION:

The only local determination below HO = 70 km/s/Mpc is TRGB-SN (Freedman et al.).

CMB with Planck

Balkenhol et al. (2021), Planck 2018+SPT+ACT : 67.49 ± 0.53 Pogosian et al. (2020), eBOSS+Planck $\Omega_m H^2$: 69.6 ± 1.8 Aghanim et al. (2020), Planck 2018: 67.27 ± 0.60 Aghanim et al. (2020), Planck 2018+CMB lensing: 67.36 ± 0.54 Ade et al. (2016), Planck 2015, $H_0 = 67.27 \pm 0.66$

CMB without Planck

Dutcher et al. (2021), SPT: 68.8 ± 1.5 Aiola et al. (2020), ACT: 67.9 ± 1.5 Aiola et al. (2020), WMAP9+ACT: 67.6 ± 1.1 Zhang, Huang (2019), WMAP9+BAO: 68.36^{+0.33} Hinshaw et al. (2013), WMAP9: 70.0 ± 2.2

No CMB, with BBN

D'Amico et al. (2020), BOSS DR12+BBN: 68.5 ± 2.2 Philcox et al. (2020), P₁+BAO+BBN: 68.6 ± 1.1 Ivanov et al. (2020), BOSS+BBN: 67.9 ± 1.1 Alam et al. (2020), BOSS+eBOSS+BBN: 67.35 ± 0.97

P₁(k) + CMB lensing Philcox et al. (2020), P₁(k)+CMB lensing: 70.6^{+3.7}_{-5.0}

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 – Camarena, Marra (2019): 75.4 ± 1.7 – Burns et al. (2018): 73.2 ± 2.3 – Dhawan, Jha, Leibundgut (2017), NIR: 72.8 ± 3.1 – Follin, Knox (2017): 73.3 ± 1.7 – Feeney, Mortlock, Dalmasso (2017): 73.2 ± 1.8 – Riess et al. (2016), H16: 73.2 ± 1.7 – Cardona, Kunz, Pettorino (2016), H16: 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): 69.6 ± 1.9 Reid, Pesce, Riess (2019), SH0ES: 71.1 ± 1.9 Freedman et al. (2019): 69.8 ± 1.9 Yuan et al. (2019): 72.4 ± 2.0 Jang, Lee (2017): 71.2 ± 2.5

> Miras – SNIa Huang et al. (2019): 73.3 ± 4.0

Masers

Pesce et al. (2020): 73.9 ± 3.0

Tully – Fisher Relation (TFR)

Kourkchi et al. (2020): 76.0 ± 2.6 Schombert, McGaugh, Lelli (2020): 75.1 ± 2.8

Surface Brightness Fluctuations

Blakeslee et al. (2021) IR-SBF w/ HST: 73.3 ± 2.5 Khetan et al. (2020) w/ LMC DEB: 71.1 ± 4.1

SNII

de Jaeger et al. (2020): 75.8^{+5.2}

HII galaxies Fernández Arenas et al. (2018): 71.0 ± 3.5

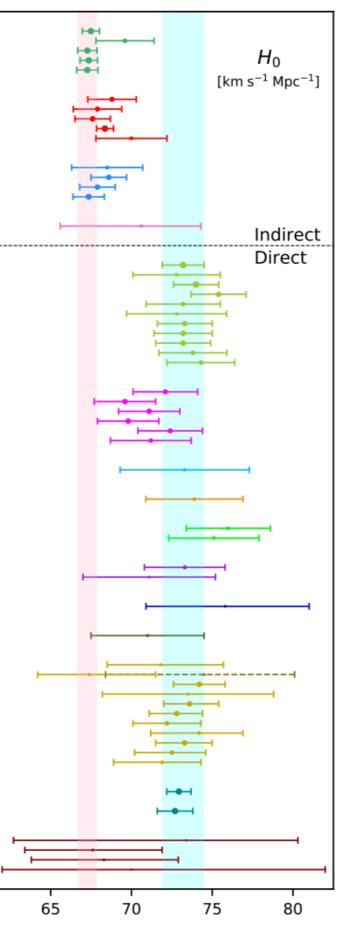
Lensing related, mass model – dependent

 $\begin{array}{c} \text{Denzel et al. (2021): } 71.8^{+3.9}_{-3.7} \\ \text{Birrer et al. (2020), TDCOSMO+SLACS: } 67.4^{+3.2}_{-3.7}, TDCOSMO: 74.5^{+3.6}_{-5.7} \\ \text{Millon et al. (2020), TDCOSMO: } 74.2 \pm 1.6 \\ \text{Baxter et al. (2020): } 73.5 \pm 5.3 \\ \text{Qi et al. (2020): } 73.5 \pm 5.3 \\ \text{Qi et al. (2020): } 73.6^{+1.6}_{-1.6} \\ \text{Liao et al. (2020): } 72.8^{+1.7}_{-1.7} \\ \text{Liao et al. (2019): } 72.2 \pm 2.1 \\ \text{Shajib et al. (2019), STRIDES: } 74.2^{+2.7}_{-3.0} \\ \text{Wong et al. (2019), HOLICOW 2019: } 73.3^{+1.6}_{-3.6} \\ \text{Birrer et al. (2016), HOLICOW 2018: } 72.5^{+2.5}_{-2.3} \\ \text{Bonvin et al. (2016), HOLICOW 2016: } 71.9^{+2.6}_{-2.5} \\ \end{array}$

Optimistic average

Di Valentino (2021): 72.94 ± 0.75 Ultra – conservative, no Cepheids, no lensing Di Valentino (2021): 72.7 ± 1.1

GW related



Almost all local HO > 70 km/s/Mpc.

This biasing has profound consequences.

Di Valentino et al. (2103.01183)

Dark Energy May Be Incompatible With String Theory

A controversial new paper argues that universes with dark energy profiles like ours do not exist in the "landscape" of universes allowed by string theory.

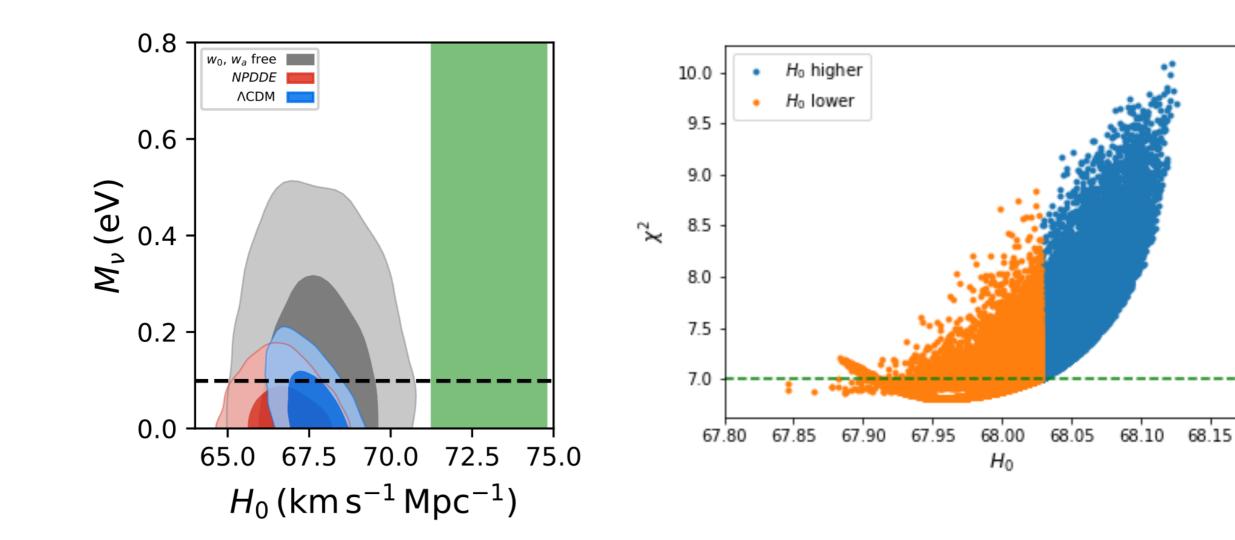
Obied, Ooguri, Spodyneiko, Vafa (1806.08362)

Turns out that embedding de Sitter vacua in string theory is beyond your average HEP theorist, cf. Eva's talk.

Natural to look beyond Λ and Quintessence is as good a first guess as any.

Agrawal, Obied, Steinhardt, Vafa (1806.09718)

But with local HO being biased high, this idea cannot work.



Vagnozzi et al. (1801.08553)

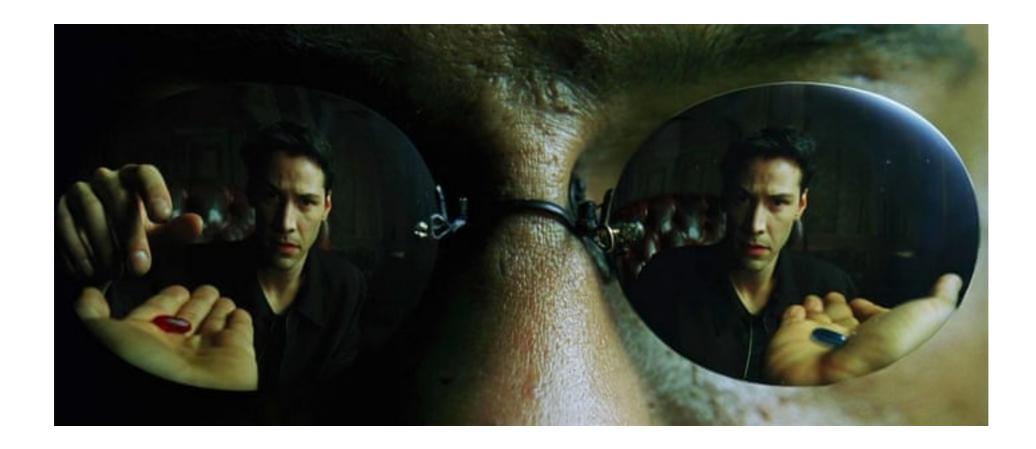
$$w(z) = w_0 + w_a \frac{z}{1+z}$$

Banerjee et al. (2006.00244)

68.20

generic $V(\mathbf{\phi})$ at low z

This apparent conflict between HEP and Λ CDM may have a more drastic resolution.

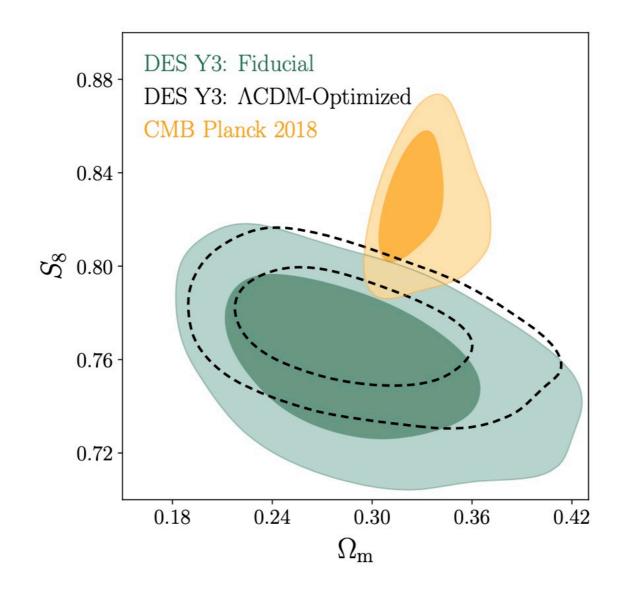


Red pill and the Universe profoundly changes.

Blue pill and one returns to your weekly HO tension arXiv feed.

Recall that HO tension is not the only game in town.

There is a model dependent early-late Universe discrepancy in S_{8} .



MORE TROUBLING, there appears to be completely cosmological model independent early-late Universe discrepancy in the cosmic dipole.

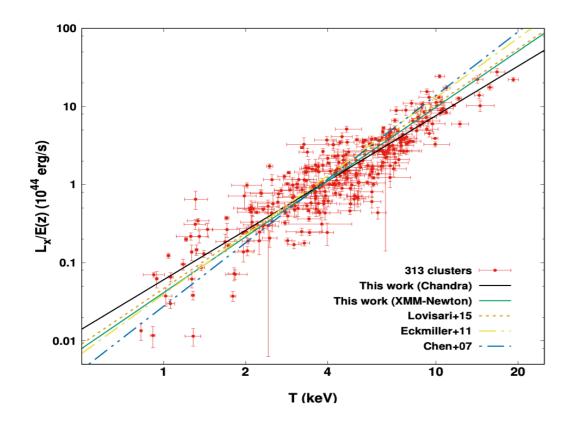
TGSS 150 mJy Blake & Wall (2002); Singal (2011); WENSS 55 mJy SUMSS 35 mJy Rubart & Schwarz (2013); Tiwari & NVSS 25 mJy Nusser (2016); Bengaly et al. (2018) 5 $d imes 10^2$ Siewert, Schmidt-Rubart, 3 Schwarz (2010.08366) 2 102 10³ ν [MHz] Secrest, Sebastian von Hausegger et al. (2009.14826) CMB CatWISE Galactic 0.3 60° 40.2 30° 9 0.1 ° 0.0 12 10 14 6 8 16 $\ell = 330^{\circ}$ 300° 240° 270° 210°

 \triangle CatWISE \bigstar CMB dipole

D [10⁻³]

Here I will argue that cosmological HO is larger in the CMB dipole direction despite being in "CMB frame".

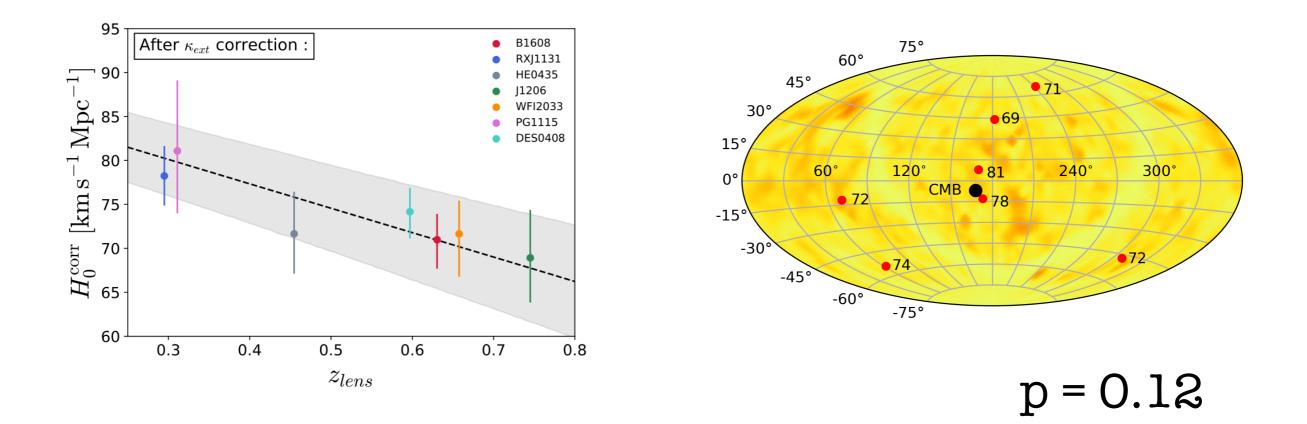
Related work at low redshifts.



$$\frac{L_X}{10^{44} \text{ erg/s}} E(z)^{-1} = A \times \left(\frac{T}{4 \text{keV}}\right)^B$$

Migkas et al. (2004.03305, 2103.13904)

Anisotropy in the slope A, but can be translated into HO variations across the sky once one assumes $\Omega_{\rm m}$.



Millon et al. (1912.08027)

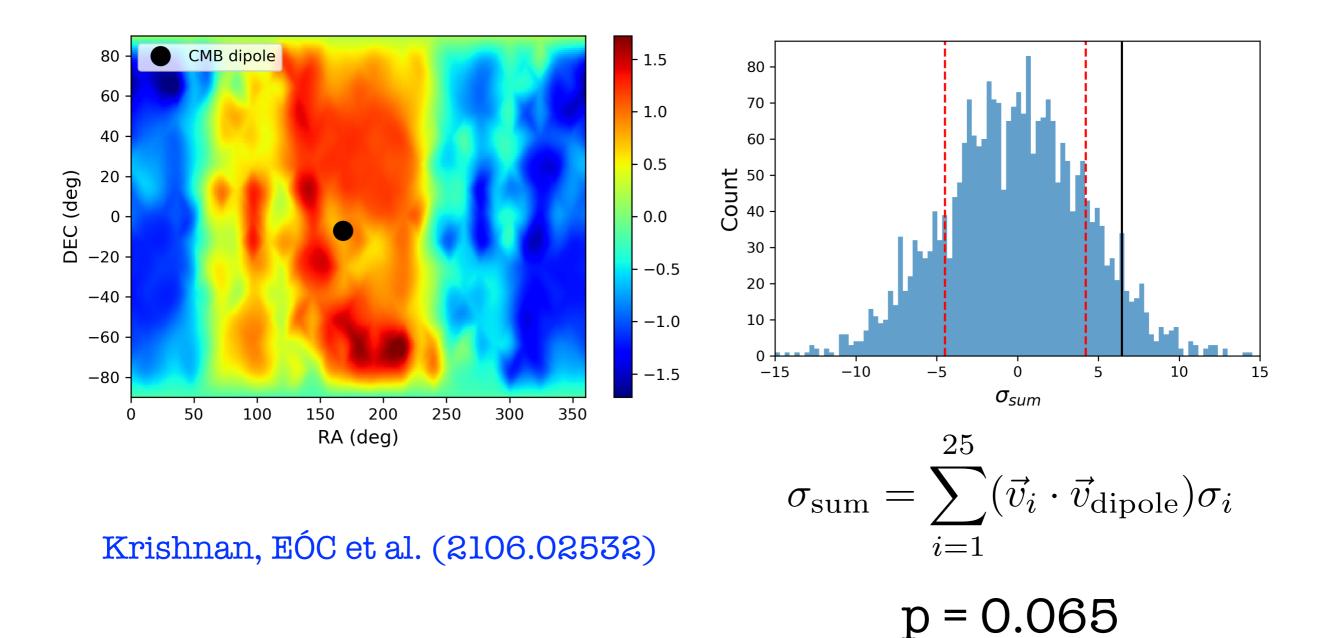
Krishnan, EÓC et al. (2105.09790)

Strongly lensed QSOs return higher HO values aligned with CMB dipole.

Same paper gives upper bound of HO ~ 71 km/s/Mpc for any FLRW cosmology.

Same trend in Pantheon Type Ia SN, which are in "CMB frame" by construction.

Caveat: intense discussion on redshift corrections. We take Scolnic's redshifts at face vale.



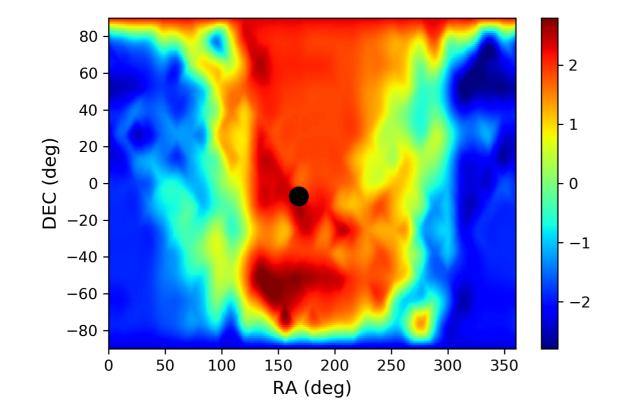
One can see the same thing in Risaliti & Lusso QSOs.

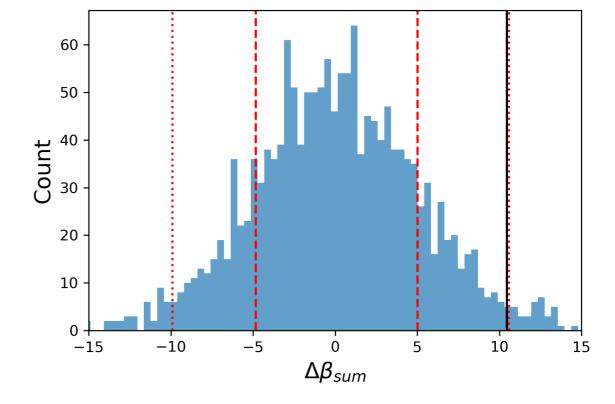
Risaliti, Lusso (1505.07118, 2008.08586)

$$\log_{10}(L_X) = \beta + \gamma \log_{10}(L_{UV}),$$

$$\log_{10}(F_X) = \beta + (\gamma - 1) \log_{10}(4\pi) + \gamma \log_{10}(F_{UV}) + 2(\gamma - 1) \log_{10}(D_L)$$

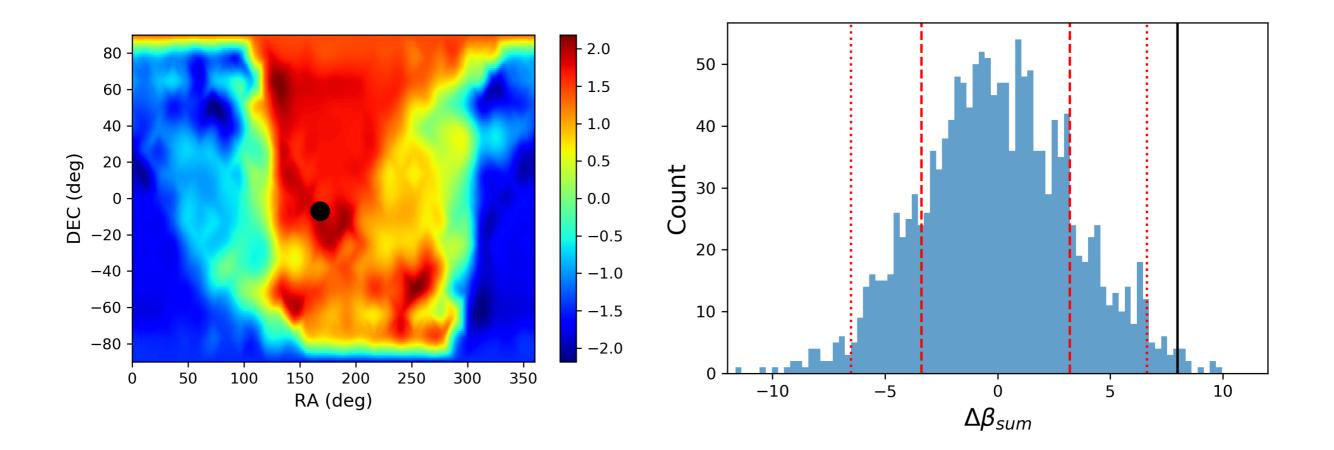
Luongo, EÓC et al. (2108.13228)





QSOs in range 0.7 \lessapprox z \lessapprox 1.7

p = 0.027

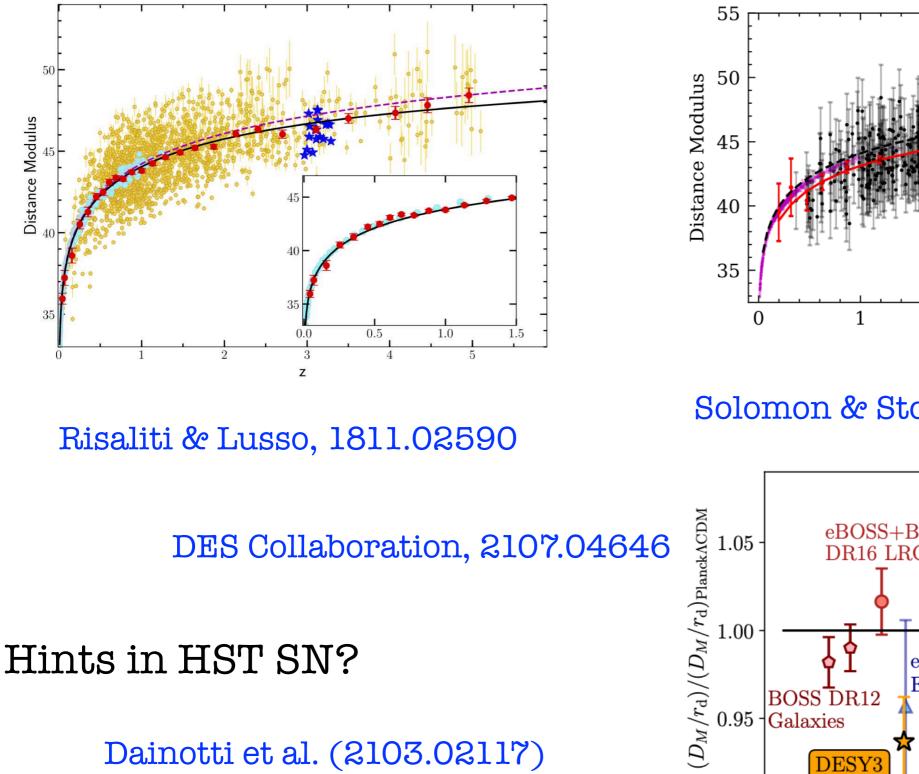


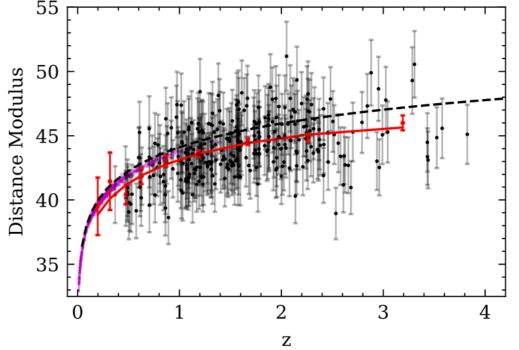
p = 0.004

QSOs in range 0.7 \lessapprox z \lessapprox 7.5413

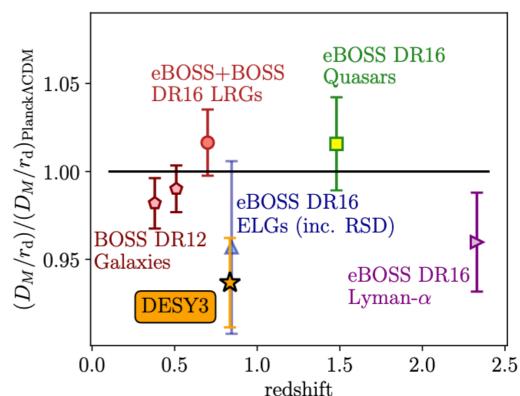
Luongo, EÓC et al. (2108.13228)

Are QSOs standardisable? Obviously discrepant with Λ CDM.



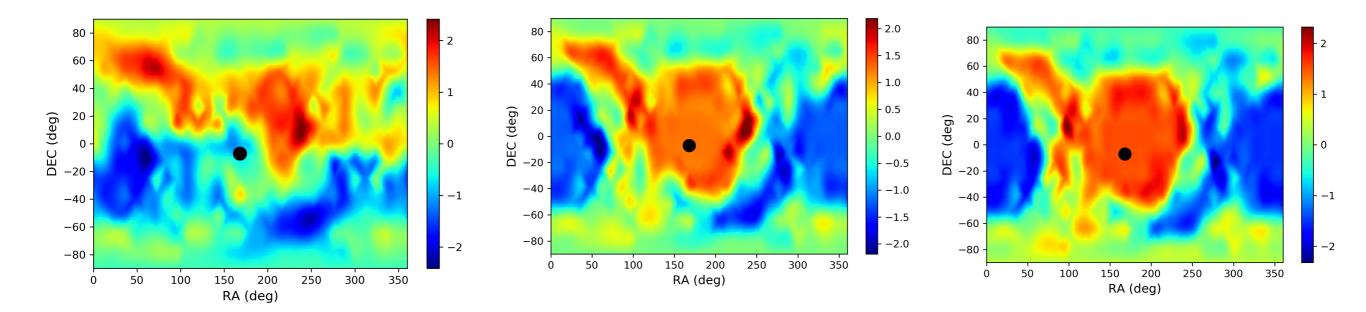


Solomon & Stojkovic, 2110.03671



GRBs are currently the most mysterious. Different samples give different results.

Demianski et al. (1610.00854)



inconclusive

p = 0.091

p = 0.047

Luongo, EÓC et al. (2108.13228)

Can now do some simply exercises.

SN + strong lensing - 2.4 σ

SN+strong lensing+QSOs (z < 1.7) (conservative) - 3.5 σ

SN+strong lensing+QSOs - 4 σ

SN+strong lensing+QSOs+GRBs (optimistic) - 4.6 σ

Punchlines

The most serious cosmological tension concerns the cosmic dipole as this is cosmological model independent.

HO within *A*CDM may be higher in the CMB dipole direction.

Easy to check our claim with any "standardisable candle".

Obvious implications for Hubble hunters.

As this is an interdisciplinary meeting: Cumrun Vafa and collaborators bet against Λ may work out ok in the end.