A compelling resolution to HO tension

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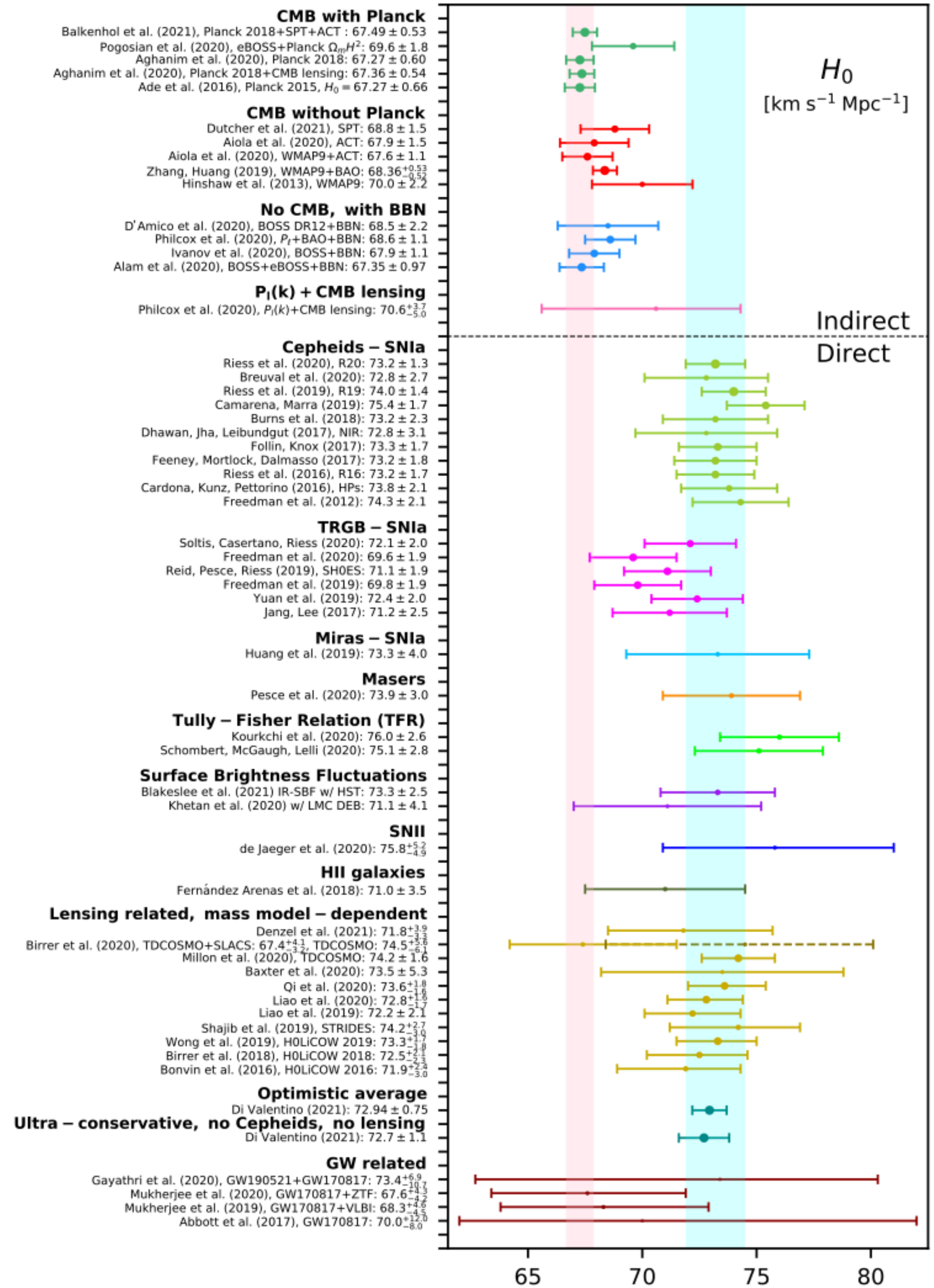
based on work with Chethan Krishan, Roya Mohayaee,
M. M. Sheikh-Jabbari & Lu Yin

Cosmology proceeds by assumption.

Contradictions are inevitable.

Systematics or contradiction?

Di Valentino et al. (2103.01183)



Few if any of the “solutions” are compelling.

Some modify GR: no observational evidence (even if some theorists invoke Black Hole singularities, better to wait on LIGO etc.).

Some play with the sound horizon (motivation for EDE rests on one input, namely SNe-BAO scale mismatch, it appears not to work!).

However, multi-faceted motivation is now appearing.

cf. nice talk by Lingfeng Li (H0, Li-7, s8, cosmic birefrigence!)

We should not introduce new physics lightly.

FLRW cosmologies have limitations

One can produce an upper bound on H0 for any FLRW cosmology subject to certain assumptions:

i) Gravity described by General Relativity

ii) Age of Universe from globular clusters

Bernal et al. (2102.05066)

iii) Planck have accurately determined $\Omega_m h^2$ (with low multipoles subtracted)

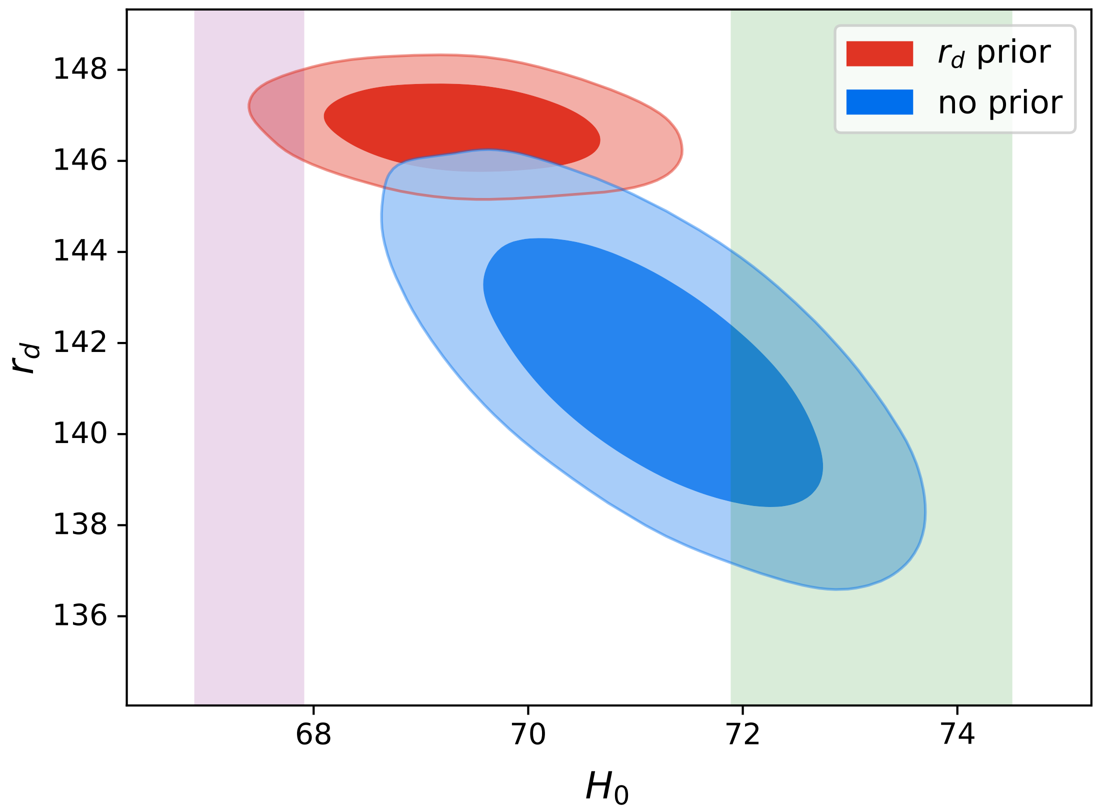
Vonlathen et al. (1003.0810)

iv) SHOES Prior on M_B

Efstathiou (2103.08723)

v) Matter + variable DE sector

vi) BAO, Type Ia supernovae, cosmic chronometers



Krishnan et al. (2105.09790)

$$H_0 \sim 71 \pm 1 \text{ km/s/Mpc}$$

Values of H0 ~73 km/s/Mpc are clearly within 2 sigma (no reason to panic).

But FLRW needs to find an early Universe resolution that works (again, I will wait on LIGO for modified GR).

However, results stretching back decades make FLRW less clear cut (this result has gone under the radar).

Siewert, Schmidt-Rubart, Schwarz (2010.08366)

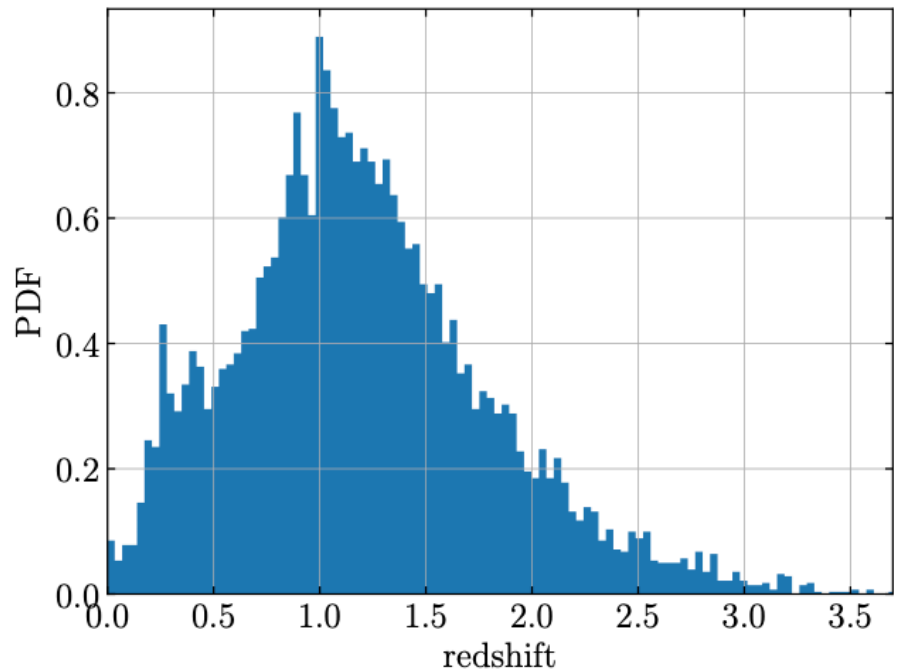
consistent with earlier results:

Blake & Wall (2002); Singal (2011); Rubart & Schwarz (2013); Tiwari & Nusser (2016); Bengaly et al. (2018)

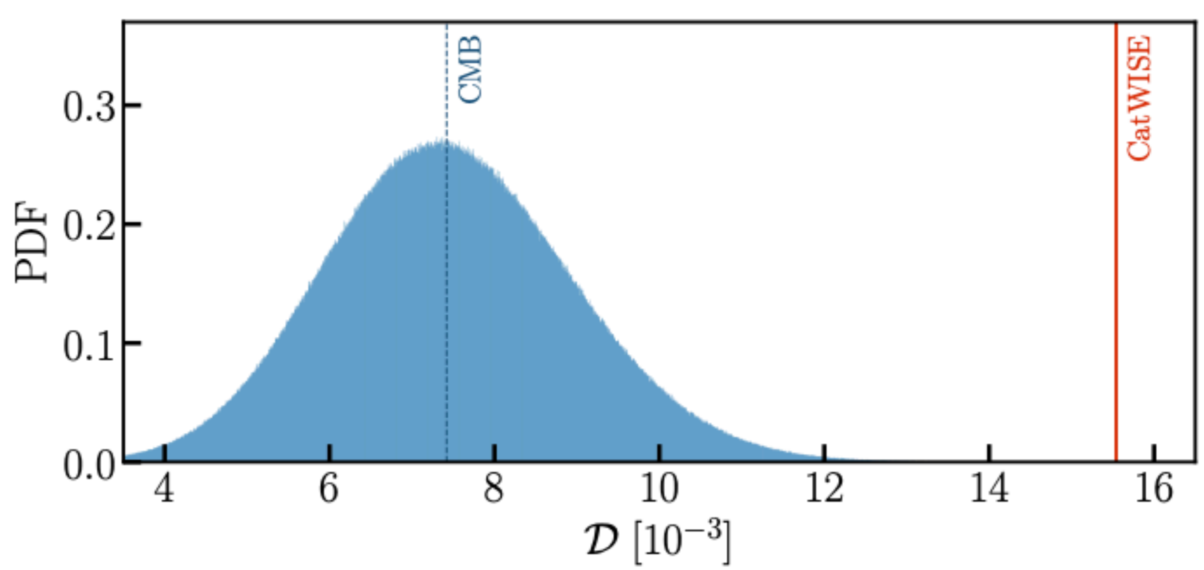
Survey	Mask	f_{sky}	S [mJy]	N	RA [deg]	DEC [deg]	$\Delta\theta$ [deg]	d ($\times 10^{-2}$)	χ^2/dof
TGSS	d	0.72	50	393 447	124.53 ± 4.13	25.66 ± 5.15	53.30 ± 4.02	6.6 ± 0.5	3.19
			100	244 881	135.61 ± 11.57	15.90 ± 11.24	39.33 ± 14.30	6.0 ± 0.8	2.91
			150	173 964	139.53 ± 11.33	12.88 ± 10.74	34.50 ± 13.86	5.9 ± 0.7	1.83
			200	133 547	141.99 ± 11.17	11.52 ± 10.21	31.74 ± 13.29	5.9 ± 0.7	1.65
	n	0.52	50	296 855	132.90 ± 4.57	15.68 ± 5.21	41.43 ± 4.17	6.2 ± 0.5	2.36
			100	179 951	137.25 ± 6.62	14.49 ± 5.39	37.23 ± 6.05	6.3 ± 0.6	1.94
			150	127 244	138.30 ± 6.25	14.96 ± 5.25	36.65 ± 5.63	6.5 ± 0.7	1.72
			200	97 355	138.86 ± 6.12	15.79 ± 5.51	36.69 ± 5.45	6.8 ± 0.8	1.54
WENSS	d	0.17	25	115 808	143.34 ± 19.48	−13.15 ± 4.58	24.99 ± 13.84	3.2 ± 1.0	1.91
			35	95 302	137.85 ± 24.47	−13.29 ± 4.98	30.27 ± 18.99	2.9 ± 0.9	1.77
			45	81 534	131.83 ± 27.76	−11.95 ± 6.28	35.94 ± 22.94	2.8 ± 0.9	1.68
			55	71 643	127.51 ± 29.27	−10.70 ± 6.59	40.10 ± 24.89	2.8 ± 0.9	1.57
	n	0.14	25	93 577	142.20 ± 23.25	−16.20 ± 5.77	26.83 ± 14.94	3.1 ± 0.9	1.88
			35	76 760	138.98 ± 27.58	−16.25 ± 6.16	29.81 ± 18.54	2.9 ± 0.9	1.75
			45	65 494	138.71 ± 34.24	−16.23 ± 7.66	30.06 ± 23.10	2.8 ± 1.0	1.67
			55	57 463	135.43 ± 35.16	−15.39 ± 7.60	32.95 ± 24.13	2.8 ± 1.0	1.56
SUMSS	d	0.16	18	99 835	106.67 ± 12.90	−9.50 ± 11.12	60.62 ± 12.49	3.8 ± 0.9	1.49
			25	75 642	106.18 ± 16.99	−5.11 ± 9.91	61.40 ± 16.79	3.5 ± 1.0	1.58
			35	55 973	108.05 ± 22.64	−4.12 ± 8.92	59.65 ± 20.85	3.4 ± 1.0	1.49
			45	44 403	105.33 ± 25.64	−4.08 ± 8.35	62.35 ± 23.73	3.3 ± 1.1	1.51
			55	36 646	106.72 ± 33.92	−4.92 ± 8.66	60.89 ± 27.50	3.2 ± 1.1	1.40
	n	0.16	18	96 816	106.67 ± 14.53	−9.50 ± 10.03	59.40 ± 14.36	3.8 ± 0.8	1.51
			25	73 356	106.18 ± 17.34	−5.11 ± 8.95	61.16 ± 17.28	3.5 ± 1.0	1.60
			35	54 336	108.05 ± 20.78	−4.12 ± 8.16	61.24 ± 20.09	3.4 ± 1.1	1.51
			45	43 121	105.33 ± 24.68	−4.08 ± 7.93	63.50 ± 23.62	3.3 ± 1.1	1.46
			55	35 574	106.72 ± 30.58	−4.92 ± 8.68	61.60 ± 25.75	3.2 ± 1.2	1.41
NVSS	d	0.66	15	328 207	138.90 ± 12.02	−2.74 ± 12.11	29.23 ± 11.07	1.6 ± 0.3	1.30
			25	209 034	140.02 ± 13.63	−5.14 ± 13.26	27.82 ± 12.17	1.8 ± 0.4	1.23
			35	151 702	140.51 ± 14.14	−8.32 ± 14.52	27.22 ± 12.61	1.8 ± 0.4	1.23
			45	117 617	140.67 ± 14.68	−13.01 ± 16.15	27.52 ± 12.65	2.0 ± 0.6	1.24
			55	95 129	143.86 ± 17.03	−16.45 ± 17.38	25.39 ± 12.76	2.1 ± 0.6	1.23
	n	0.53	15	266 839	156.33 ± 17.80	7.41 ± 17.63	18.44 ± 15.16	1.4 ± 0.4	1.18
			25	169 752	161.02 ± 17.37	2.69 ± 17.12	11.86 ± 13.94	1.6 ± 0.4	1.10
			35	123 037	165.14 ± 18.88	−1.84 ± 18.82	5.82 ± 13.65	1.6 ± 0.5	1.13
			45	95 291	169.15 ± 19.40	−5.99 ± 19.29	1.54 ± 13.05	1.8 ± 0.5	1.10
			55	77 081	173.60 ± 21.09	−9.18 ± 19.47	6.03 ± 13.47	2.0 ± 0.6	1.10

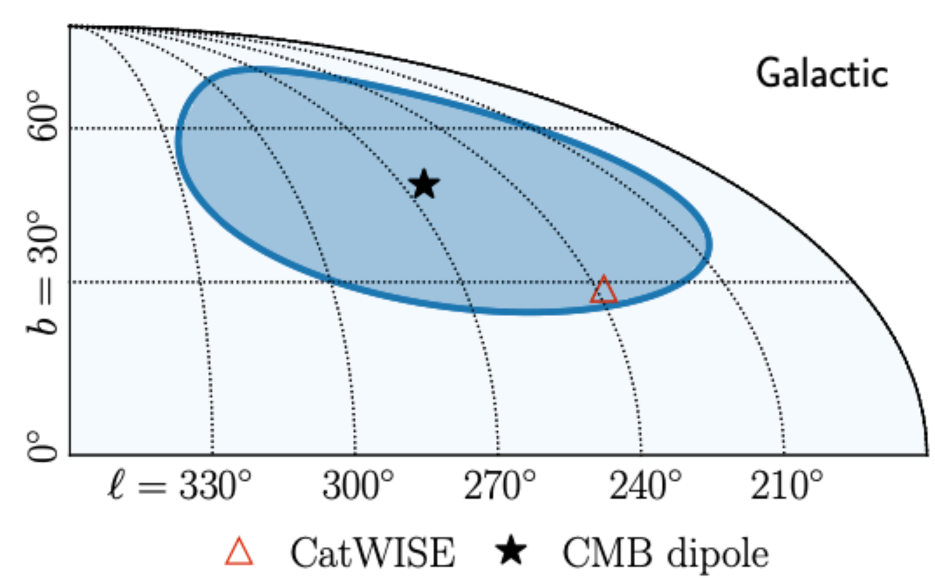
Dipoles agree with CMB direction but NOT magnitude.

Observation recently extended to QSOs (clearly a problem - systematics are different!). Subir et al. are quoting 4.9 σ !!!



Secrest, Sarkar, Mohayaee et al. (2009.14826)





Before we get into more data, some timely comments.

For the OXFORD group, the motivation may be either i) testing CP or ii) falsifying dark energy. They typically work outside FLRW and conventional frameworks, e. g. heliocentric frame, dipoles (arxiv:1808.04597). Finally, there is an evident rush to extrapolate results from high z down to $z \lesssim 0.1$ (but this may be premature).

AT SOGANG, we are motivated to study FLRW as a resolution to H0 tension, where we have already explained the limitations. Our statements are exclusively at high redshift, $z \sim O(1)$. Moreover, data is analysed (minimally) within FLRW models, e. g. LCDM (we hope our approach is more palatable).

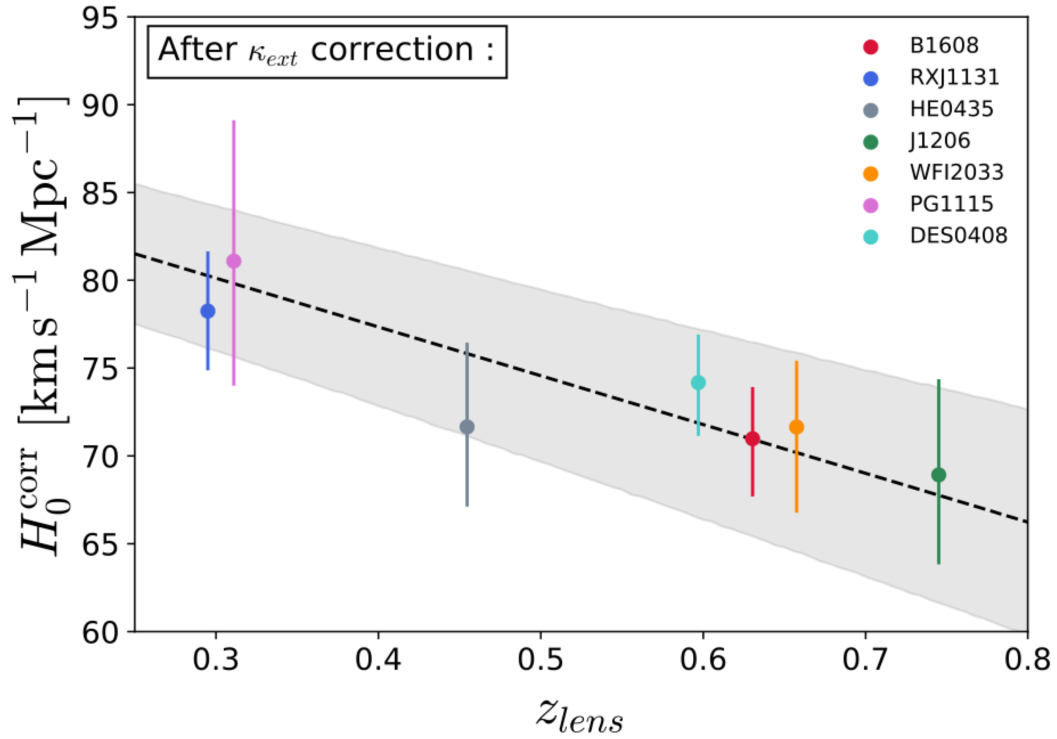
But taken a face value, the cosmic dipole results suggest a blatantly large anisotropy (one impossible to hide in our universe).

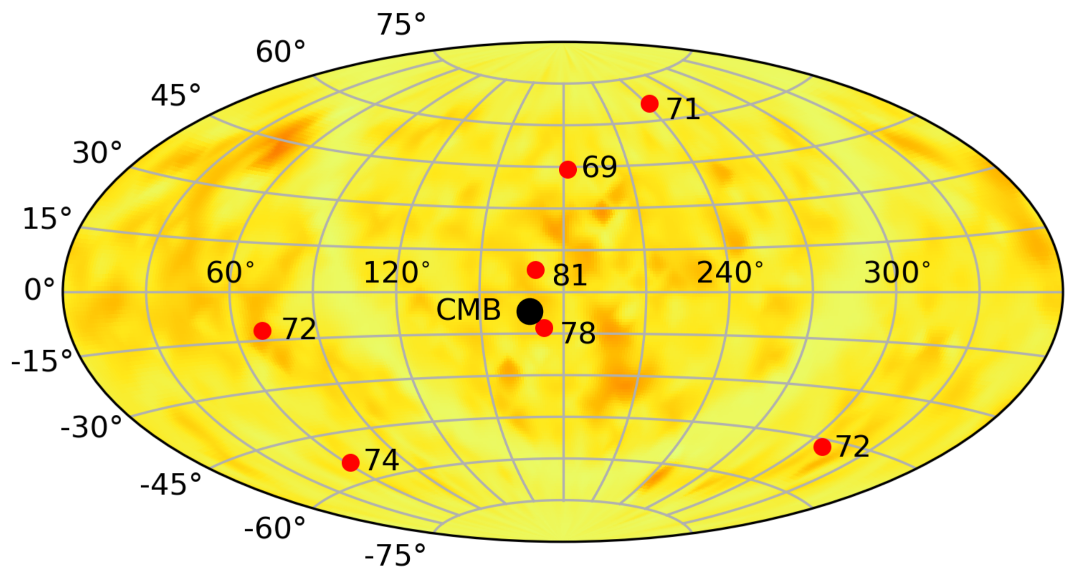
Logically, we have a binary choice:

1) Further data rejects this idea

2) Further data supports this idea

But dipoles may be less accessible...





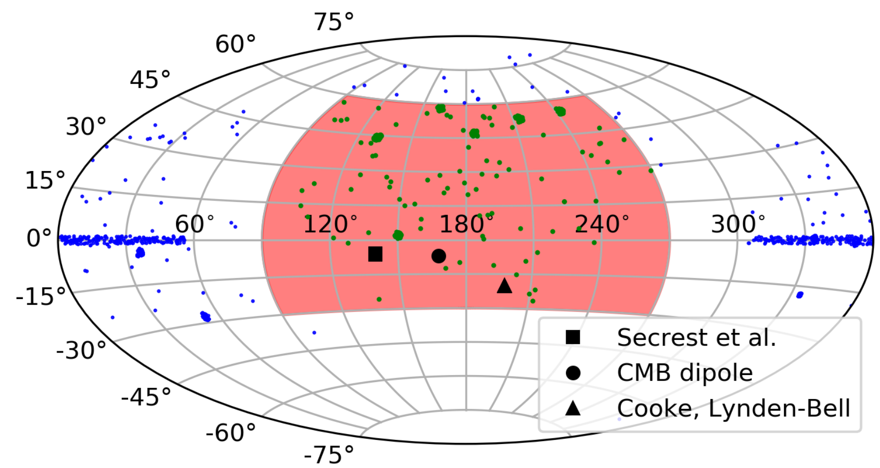
Millon et al. (1912.08027)

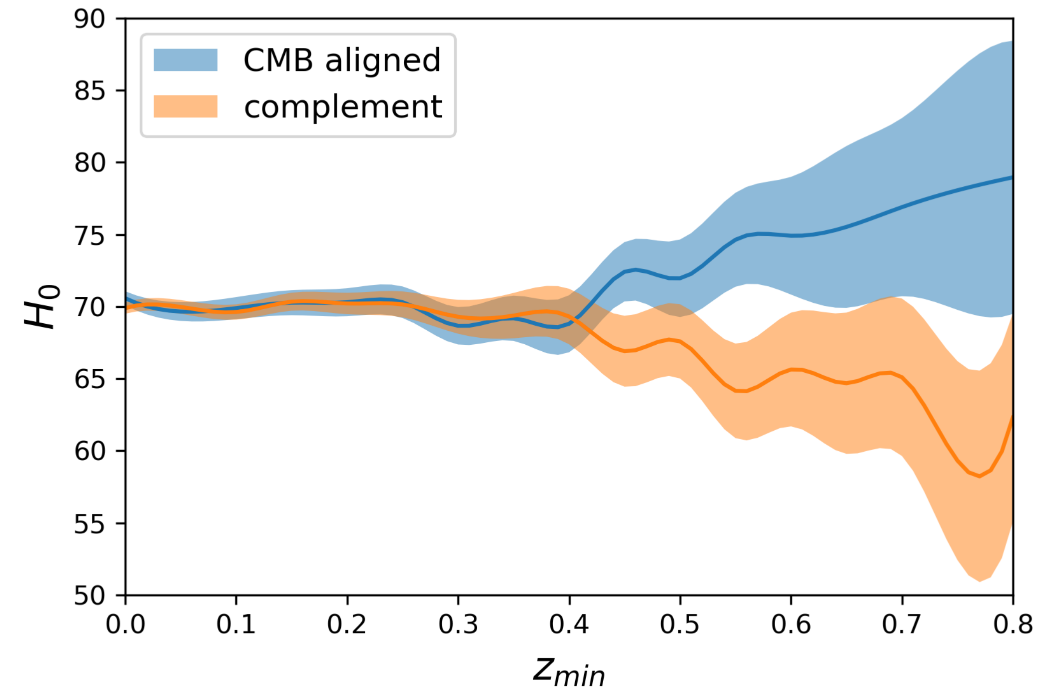
Krishnan et al. (2105.09790)

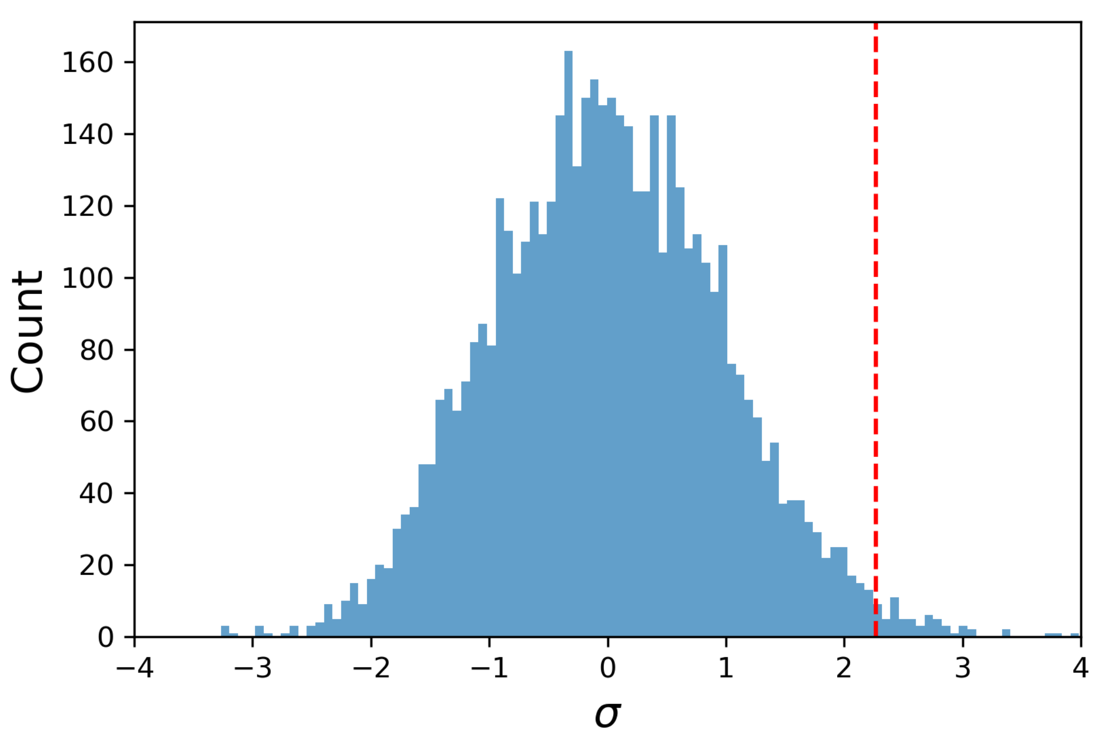
Strongly lensed QSOs currently have higher H0 values aligned with CMB dipole. Is it worth a punt?

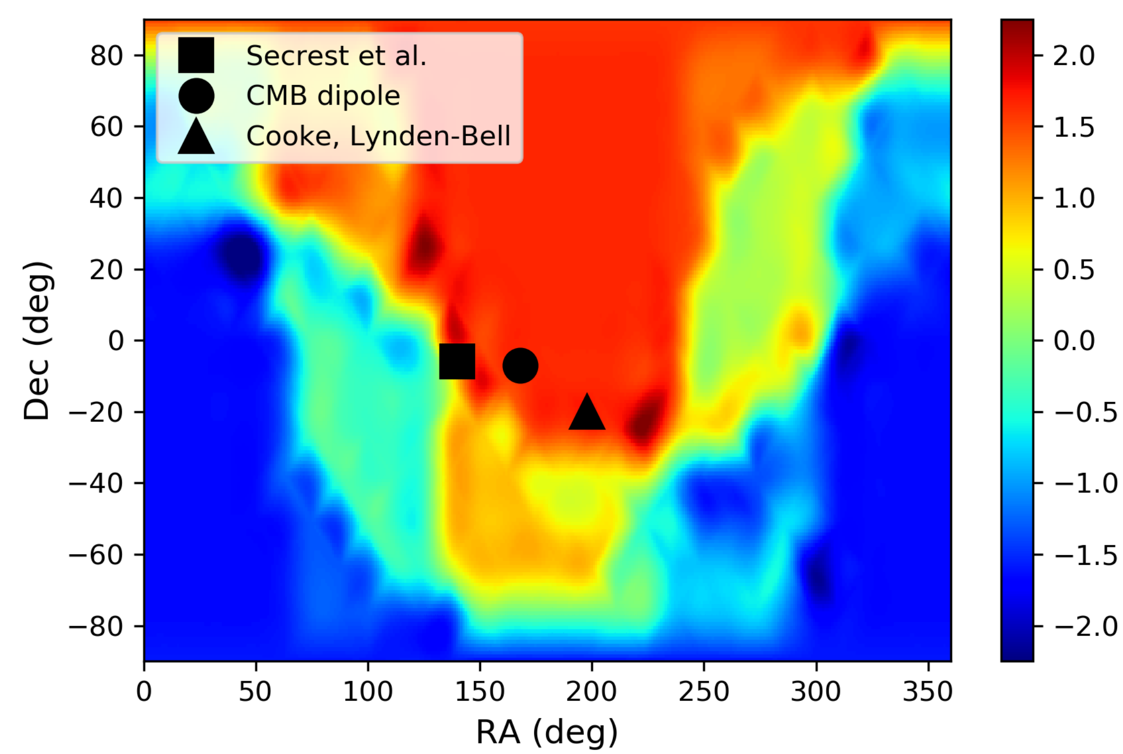
One can see a separation in HO within SNE, i. e. a "standard candle", at higher z.

Krishnan et al. (2106.02532)









Cooke, Lynden-Bell (0909.3861)

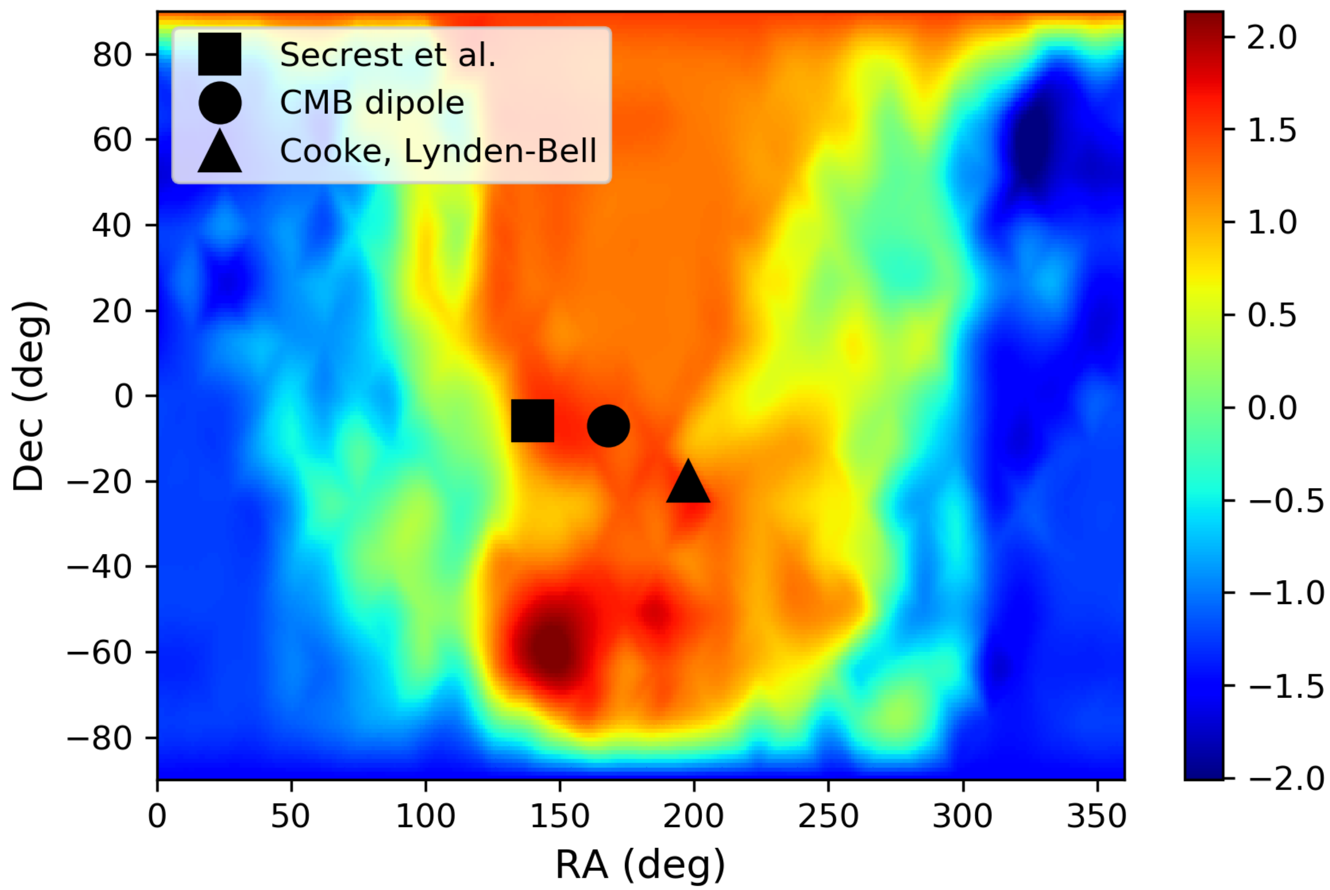
One can see the same thing in Risaliti & Lusso QSOs.

Risaliti, Lusso (1505.07118, 2008.08586)

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

There appears to be a value of **β** so that $D_L(z)$ from QSOs agrees with SNE in range $0.7 \lessapprox z \lessapprox 1.7$ (~ 1000 QSOs)

$\Delta\beta$ is over 2 σ & can be checked by MCMC.



Take home

I have presented a number of interesting "coincidences" across unremarkable data sets & within LCDM.

Exercise for the cosmology community is simple: go away from this talk, take off the FLRW glasses, split your data in hemispheres and reanalyse.

This large anisotropy idea is interesting, but far from subtle (if real, it's glaring. If real, it rewrites cosmology).

If idea is wrong, it can be quickly challenged by independent data (thus bringing us back to H0 tension within FLRW).