A compelling resolution to H0 tension

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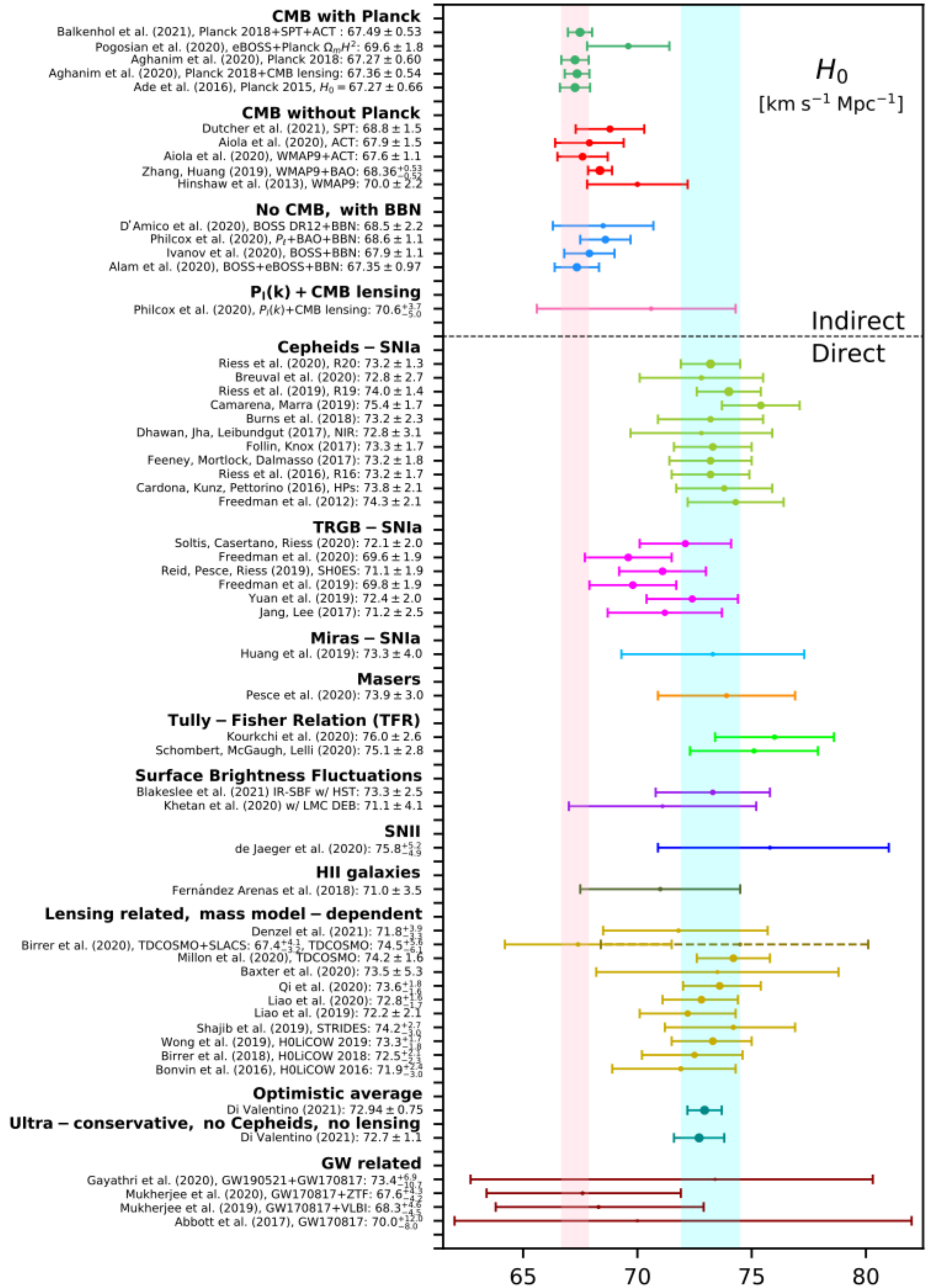
Cosmology proceeds by assumption.

Contradictions are inevitable.

Systematics or contradiction?

Di Valentino et al. (2103.01183)



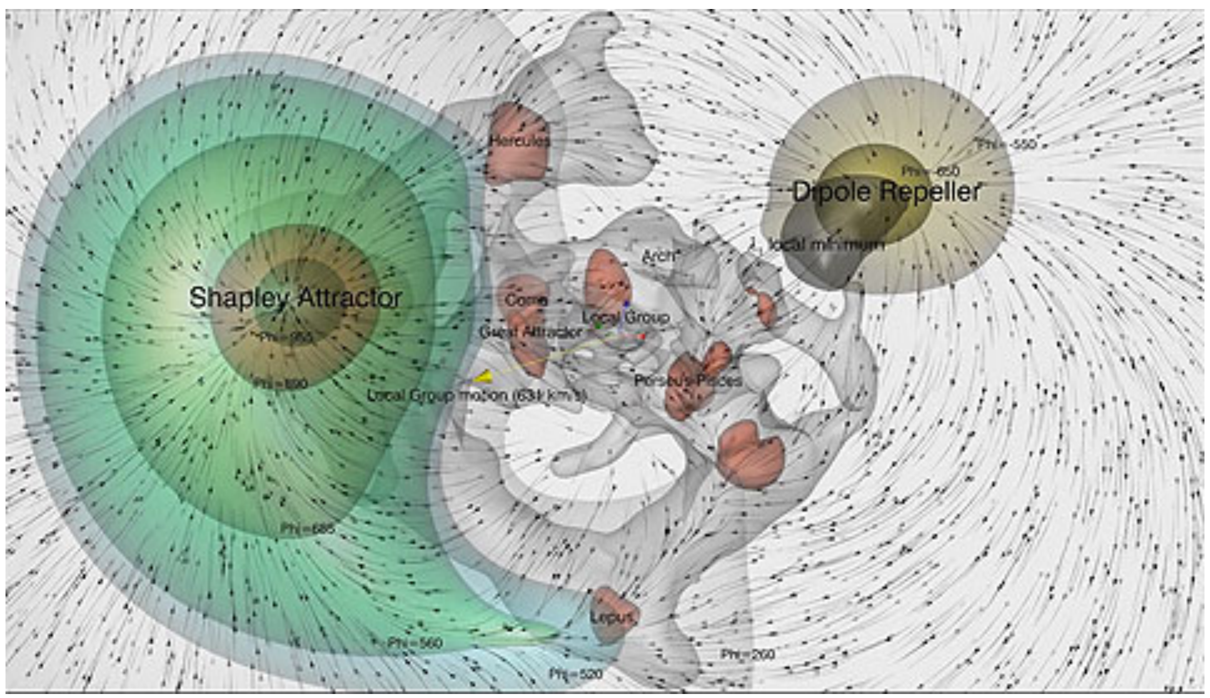
H0 tension only makes sense within the context of FLRW (cosmological principle).

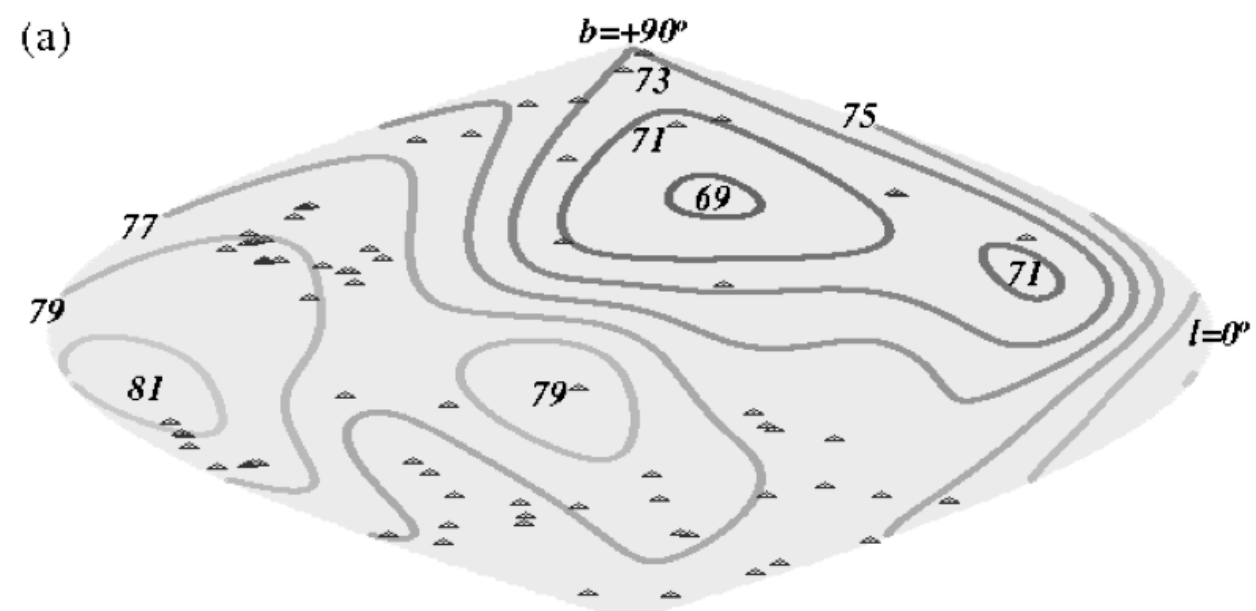
If there are discrepancies from FLRW expectations, then logically they take precedence and H0 tension is ill-defined.

It is prudent to make sure that we are not discussing a problem that is ill-defined.

Local Universe is very messy.

Determining H0 is not easy (GW170817 is ~ 40 Mpc distant).





Hoffman, Pomarède, Tully, Courtois, Nat. Ast. (2017)

McClure & Dyer New Aston. (2007)

Is there a maximum H0 within FLRW?

Analysis 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)

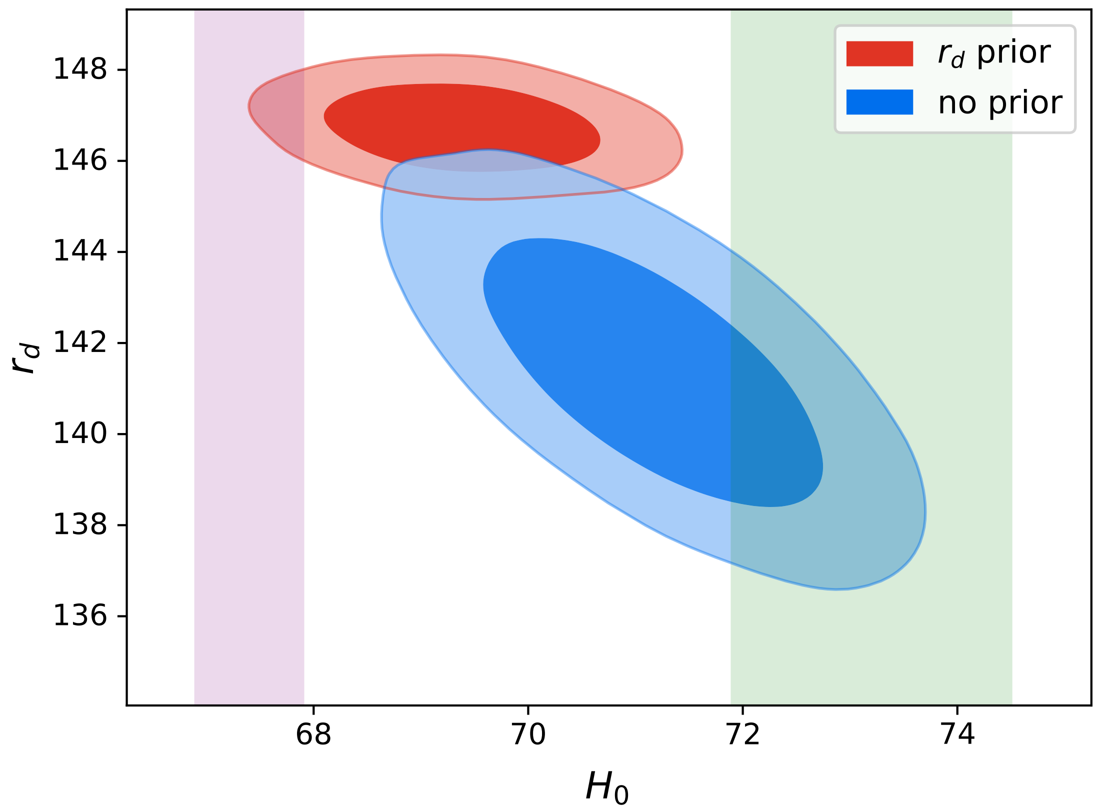
Vonlathen et al. (1003.0810)

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)

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

Karwal, Raveri, Jain, Khoury, Trodden (2106.13290)

$$H_0 = 71.19 \pm 0.99 \text{ km/s/Mpc}$$

Values of H0 ~73 km/s/Mpc are clearly within 2 sigma.

But FLRW needs to find an early Universe resolution that works (one should not make S8 tension worse).

“The coupling between dark matter and the scalar field, parametrised by β is the only difference between uncoupled EDE and CEDE and is hence responsible for the relative improvement of $\Delta\chi^2_{\rm total} = -8$, with our results showing a small preference for non-zero β. Unfortunately, along with these improvements comes a substantial increase in $\omega_{\rm dm}$ of $\sim 3\sigma$, which in turn increases σ_8 and hence S_8, exacerbating the LSS tension.”

Karwal, Raveri, Jain, Khoury, Trodden (2106.13290)

When should we give up on EDE and variants?

However, results stretching back decades make FLRW less clear cut. Prudent to confirm CMB dipole.

Siewert, Schmidt-Rubart, Schwarz (2010.08366)

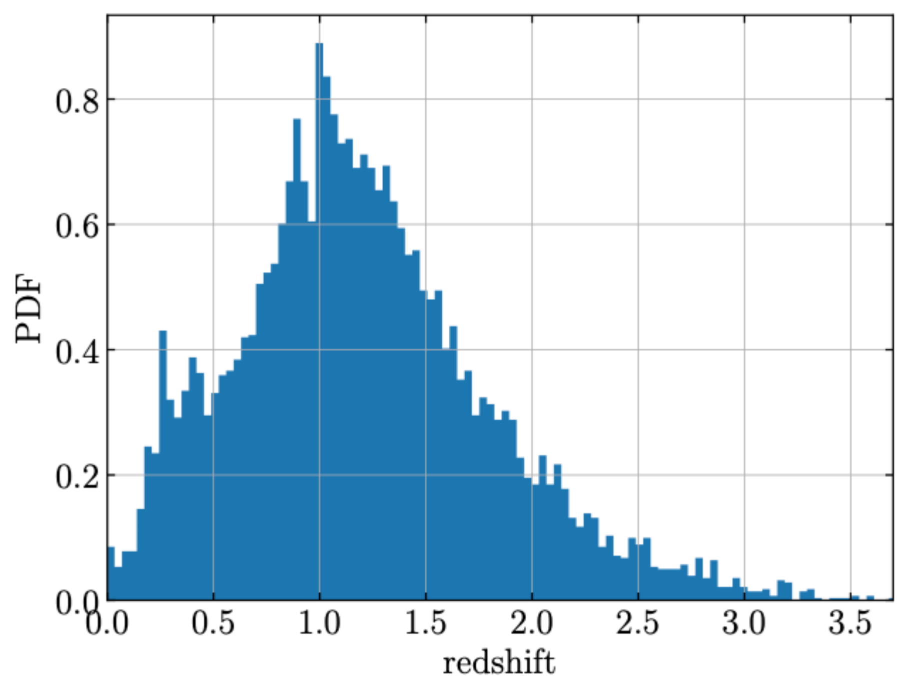
consistent with earlier results:

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

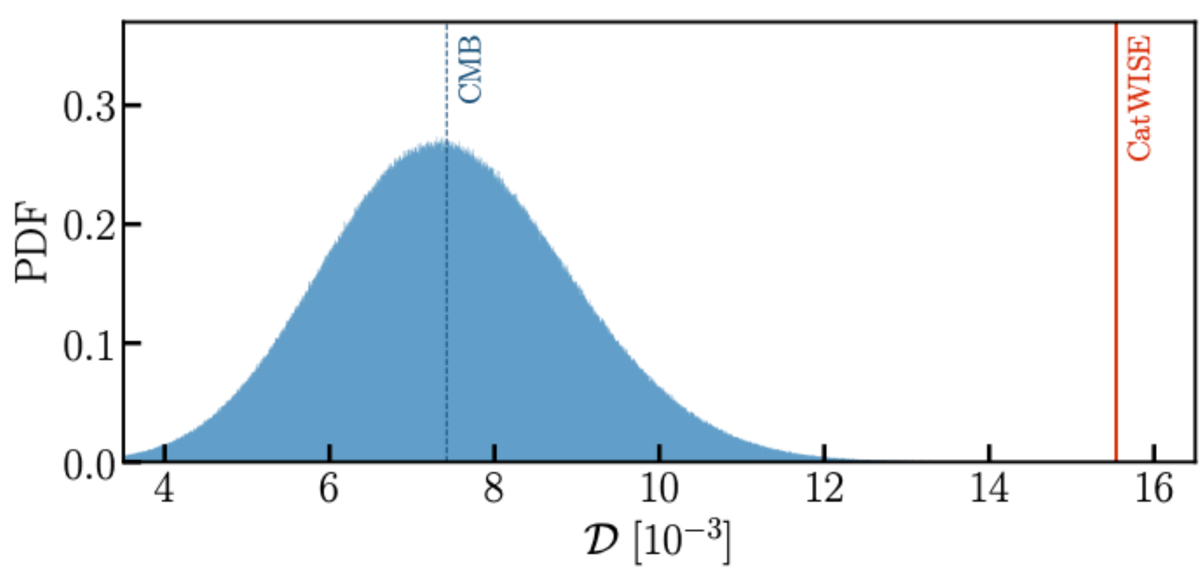
Survey	Mask	f_{sky}	S [mJy]	N	RA [deg]	DEC [deg]	$\Delta\theta$ [deg]	d ($\times 10^{-2}$)	χ^2/dof
TGSS	d	0.72	50	393 447	124.53 ± 4.13	25.66 ± 5.15	53.30 ± 4.02	6.6 ± 0.5	3.19
			100	244 881	135.61 ± 11.57	15.90 ± 11.24	39.33 ± 14.30	6.0 ± 0.8	2.91
			150	173 964	139.53 ± 11.33	12.88 ± 10.74	34.50 ± 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

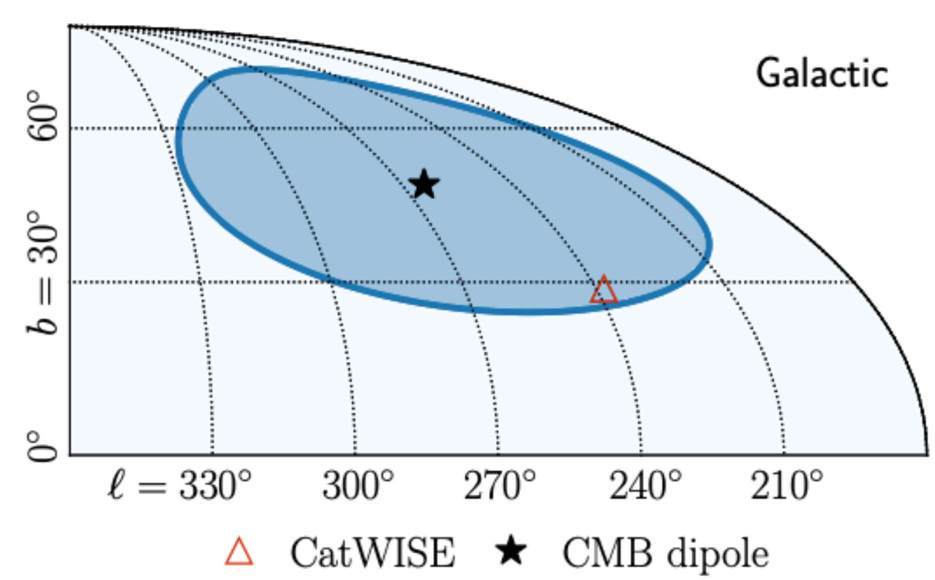
Dipoles agree with CMB direction but NOT magnitude.

Observation recently extended to QSOs (systematics are different). Authors are quoting 4.9 σ !!!

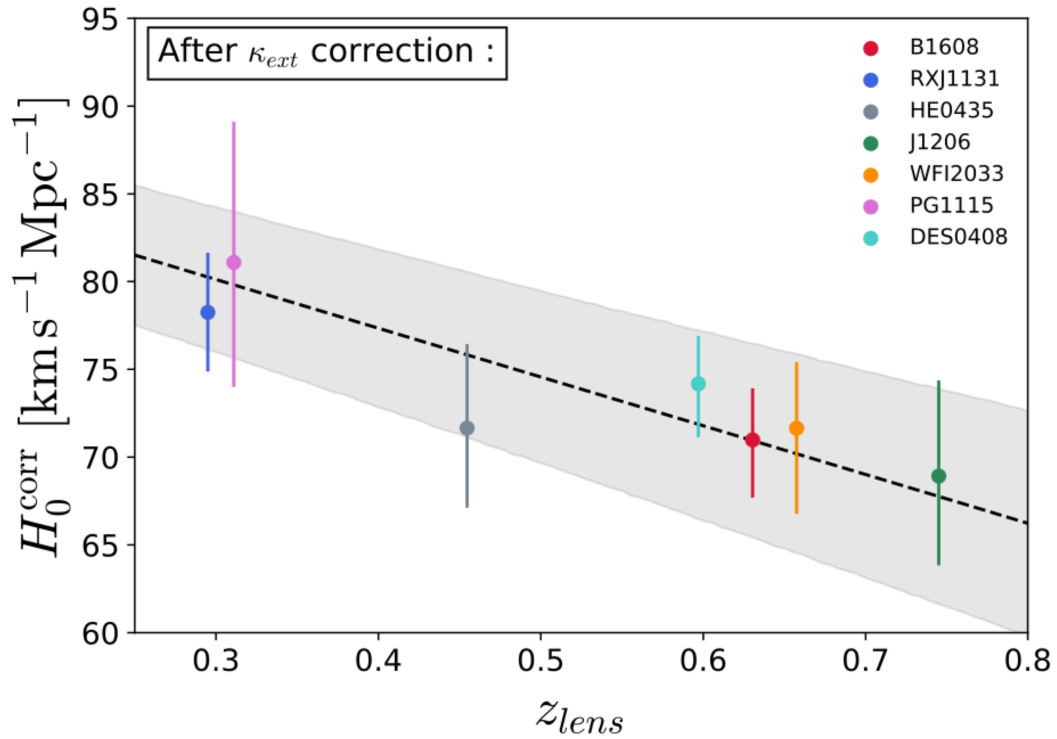


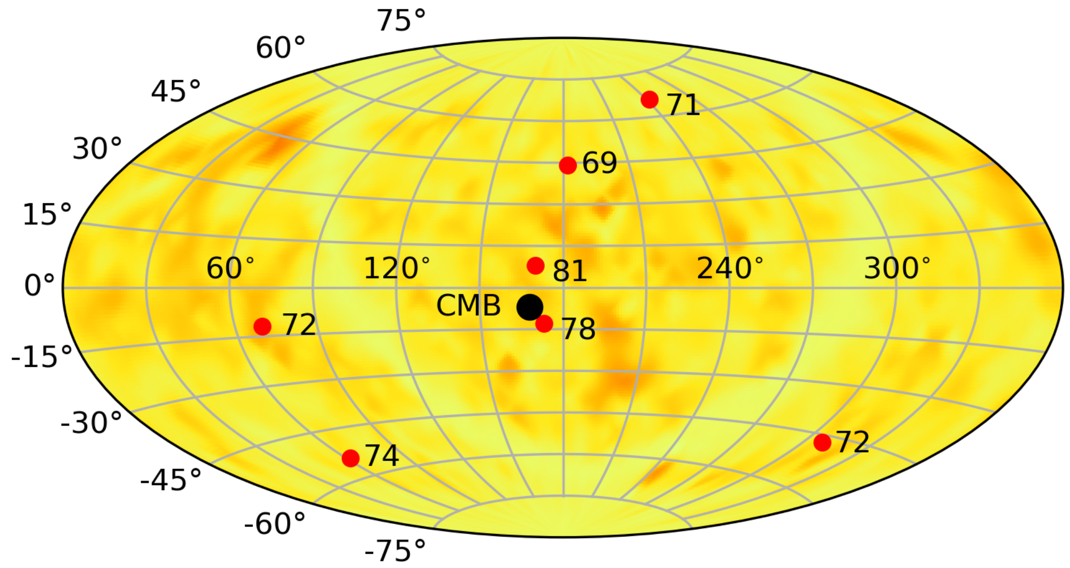
Secrest, Sarkar, Mohayaee et al. (2009.14826)





But dipoles are less accessible.





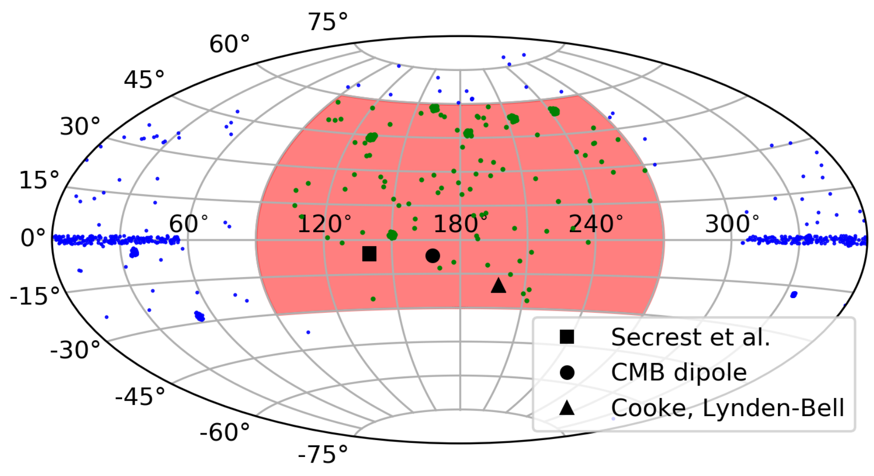
Millon et al. (1912.08027)

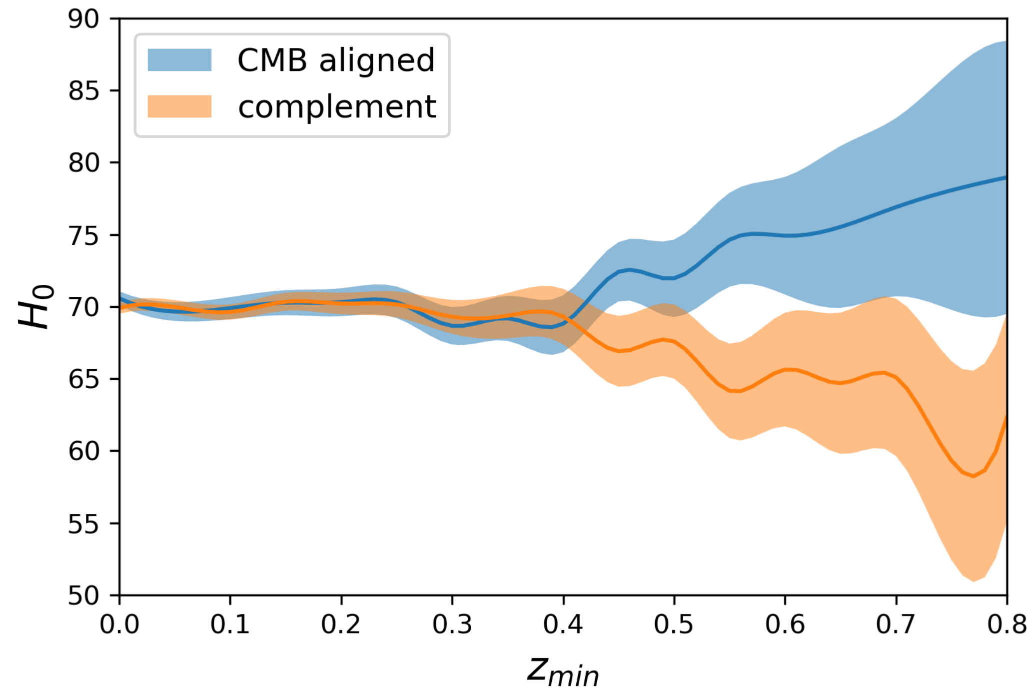
Krishnan et al. (2105.09790)

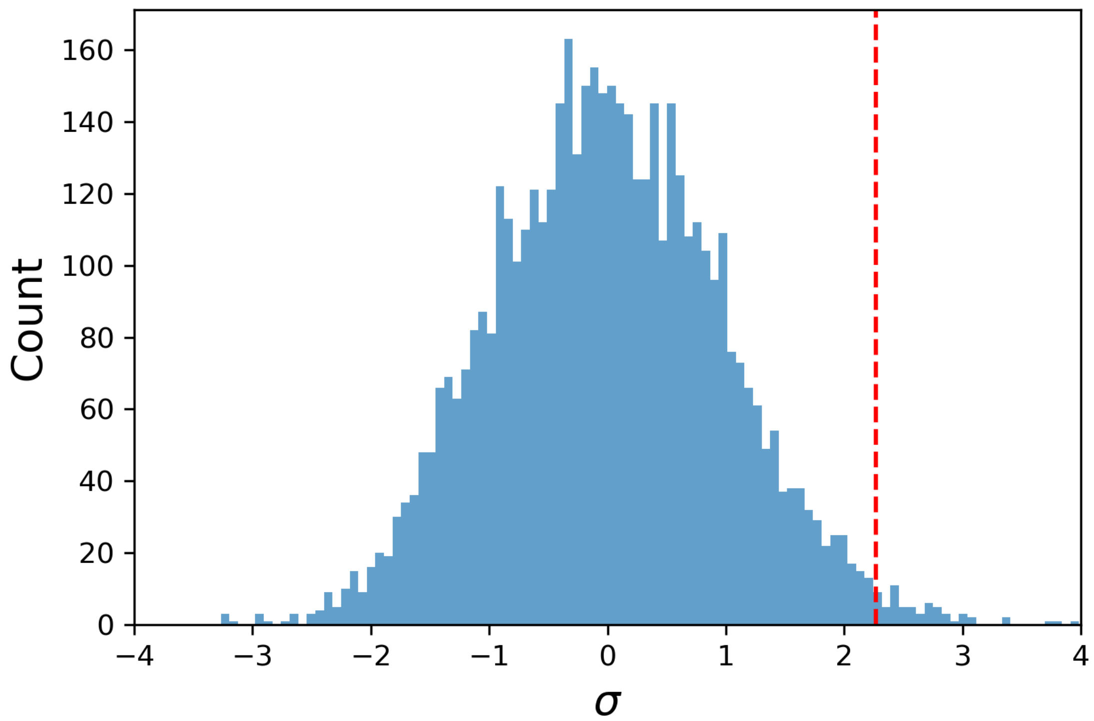
Strongly lensed QSOs have higher H0 values aligned with CMB dipole.

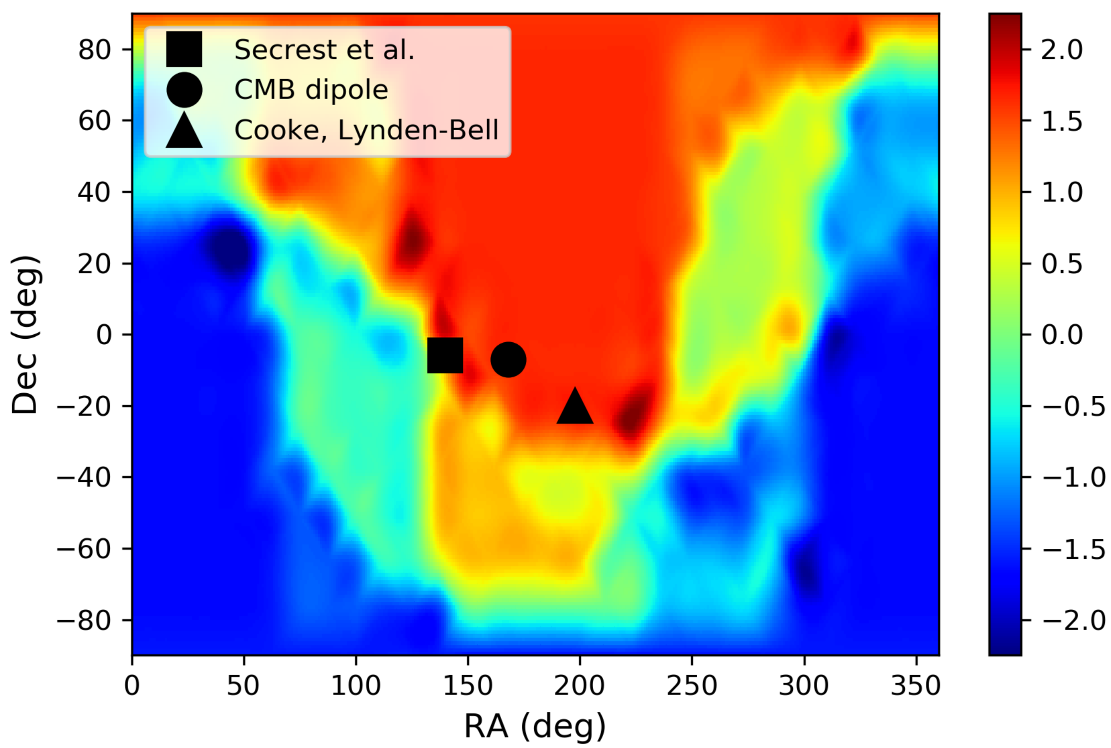
One can see a separation in H0 within SNE, i. e. a "standard candle", at higher z.

Krishnan et al. (2106.02532)





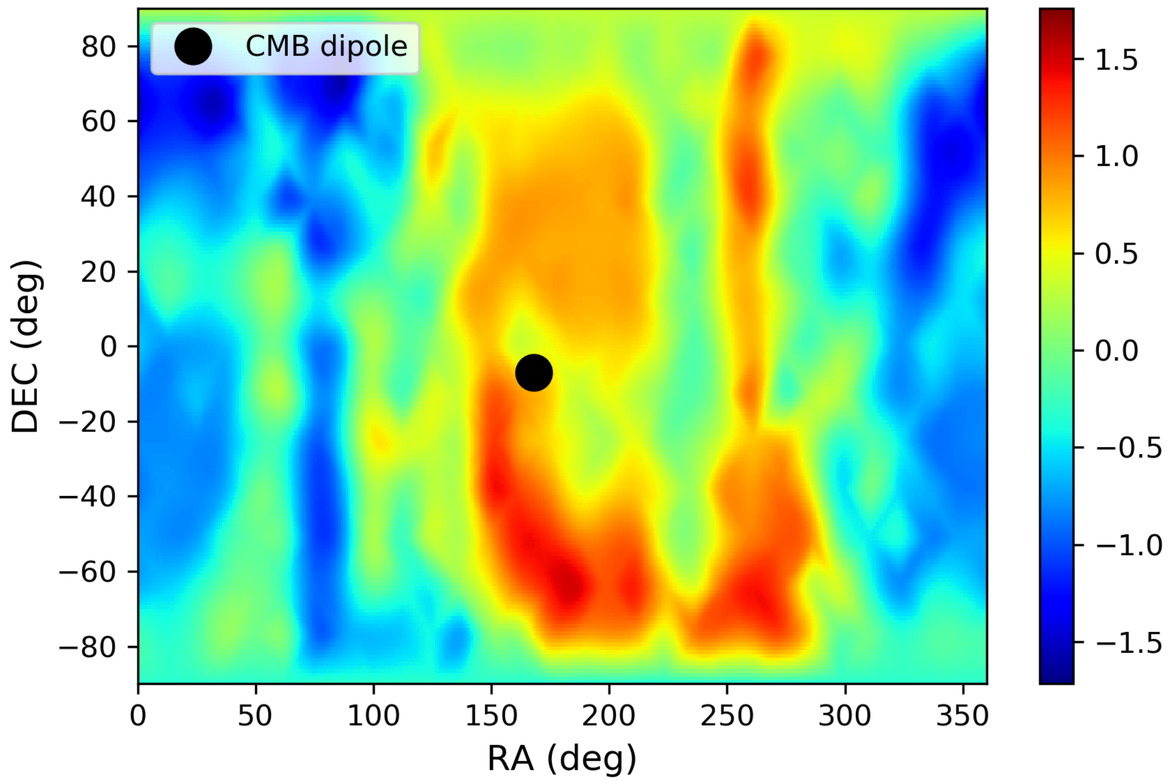


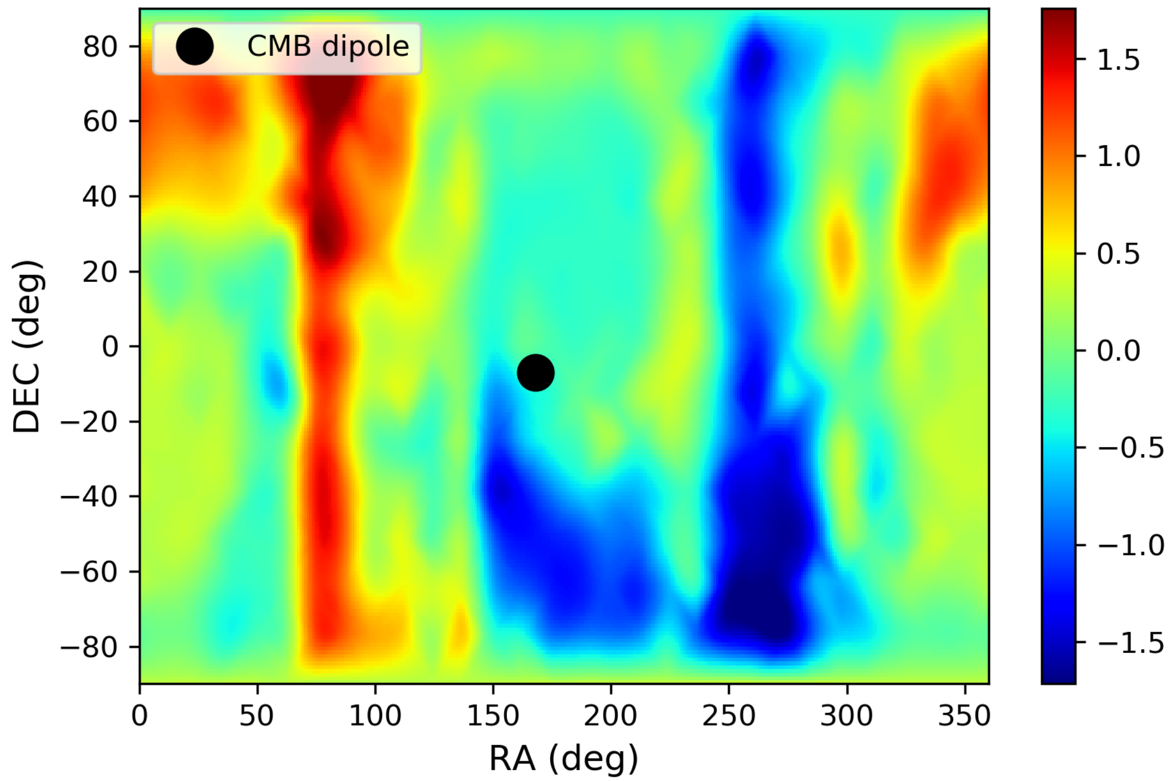


Cooke, Lynden-Bell (0909.3861)

One can find “evidence” at ALL redshifts in Pantheon.

Significance is low, but trend is obvious.





Consistent with a large “anisotropy”, one so blatant that one does not need to be in heliocentric frame.

Singal (2106.11968)

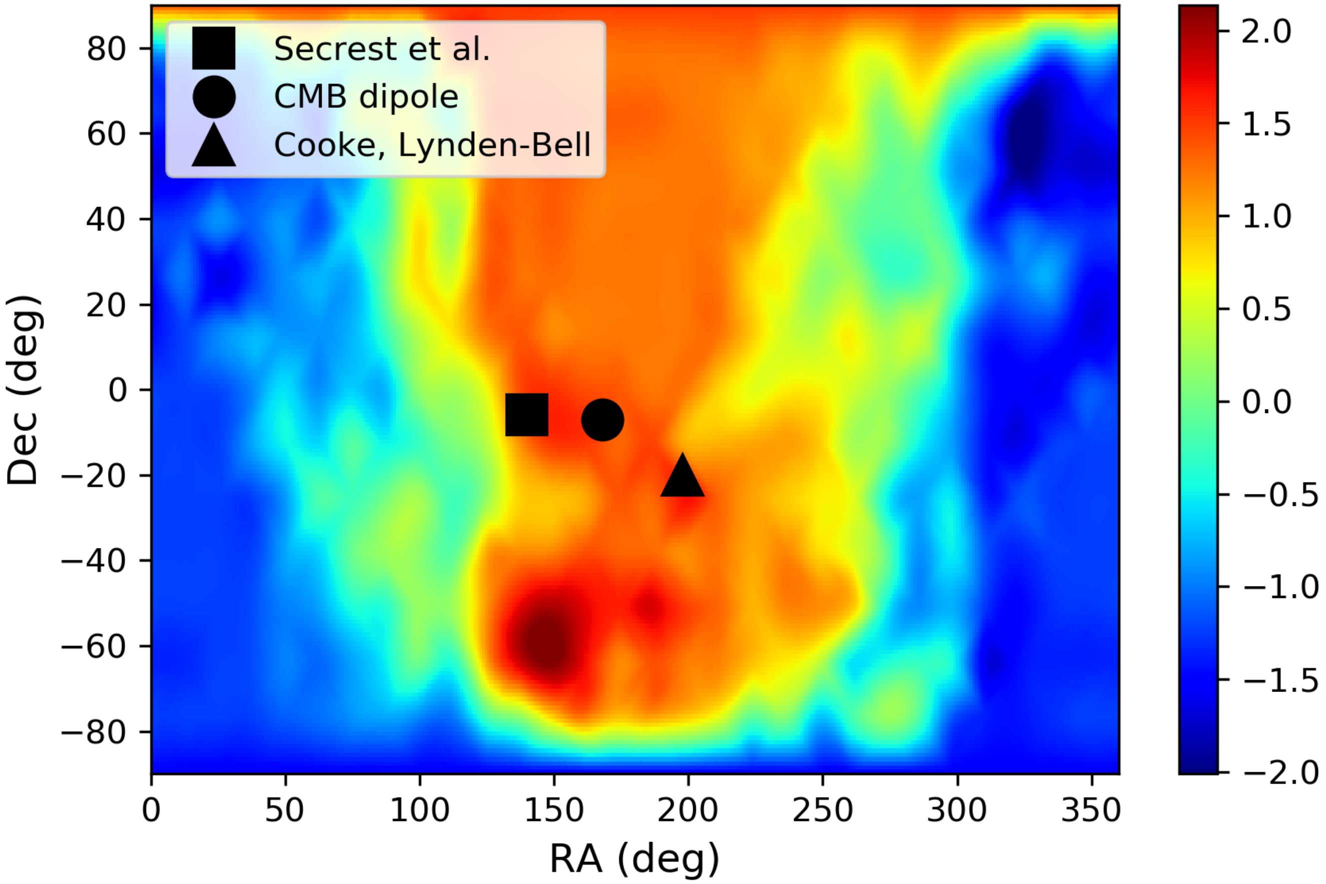
One can see the same thing in Risaliti & Lusso QSOs.

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.



Summary

We seem to have some unexpected separation in H0 in hemispheres even in "CMB frame".

In particular, Type Ia SN do not look very "FLRW".

One could imagine a comparison between Planck-ΛCDM in an FLRW frame (by construction), and SN in a frame that is starting to look unlike FLRW may spell trouble.

It needs to be checked if the late Universe is anisotropic.

Prudent to split datasets and take a look (significance may be low).