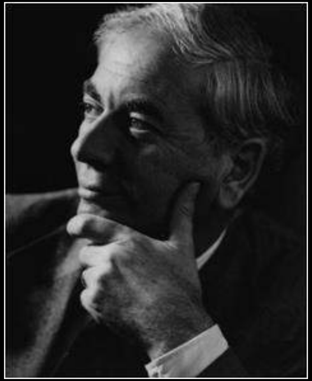
A challenge to the standard cosmological model

Subir Sarkar

None of us can understand why there is a Universe at all,
why anything should exist; that's the ultimate question.
But while we cannot answer this question, we can at
least make progress with the next simpler one of
what the Universe as a whole is like.

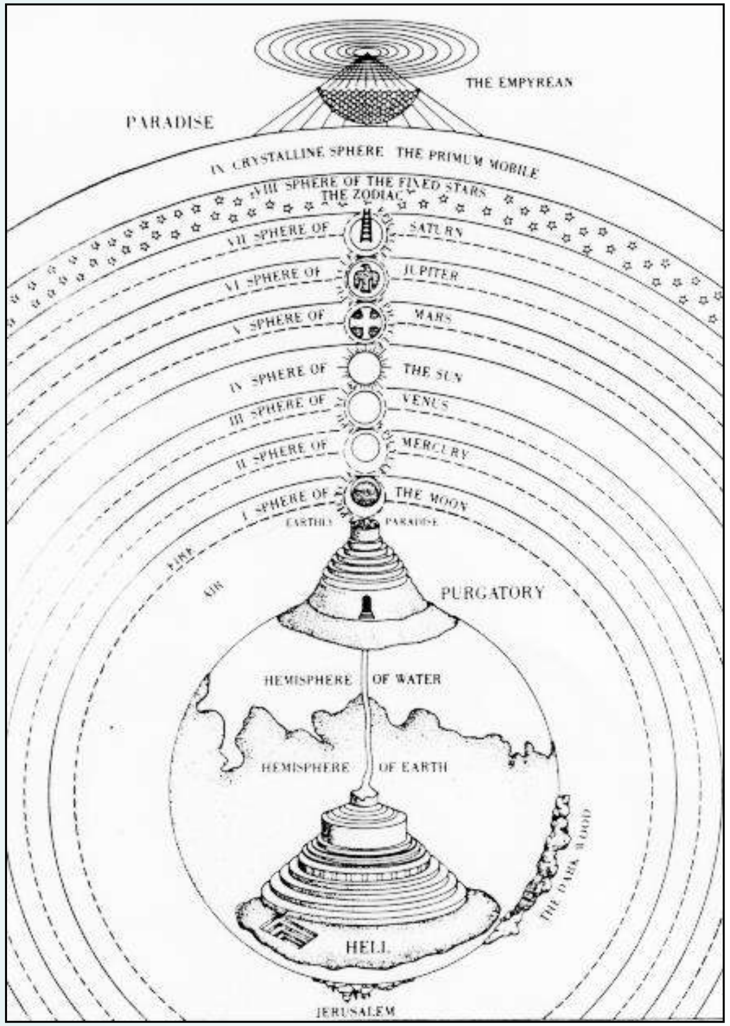
Dennis Sciama (1978)



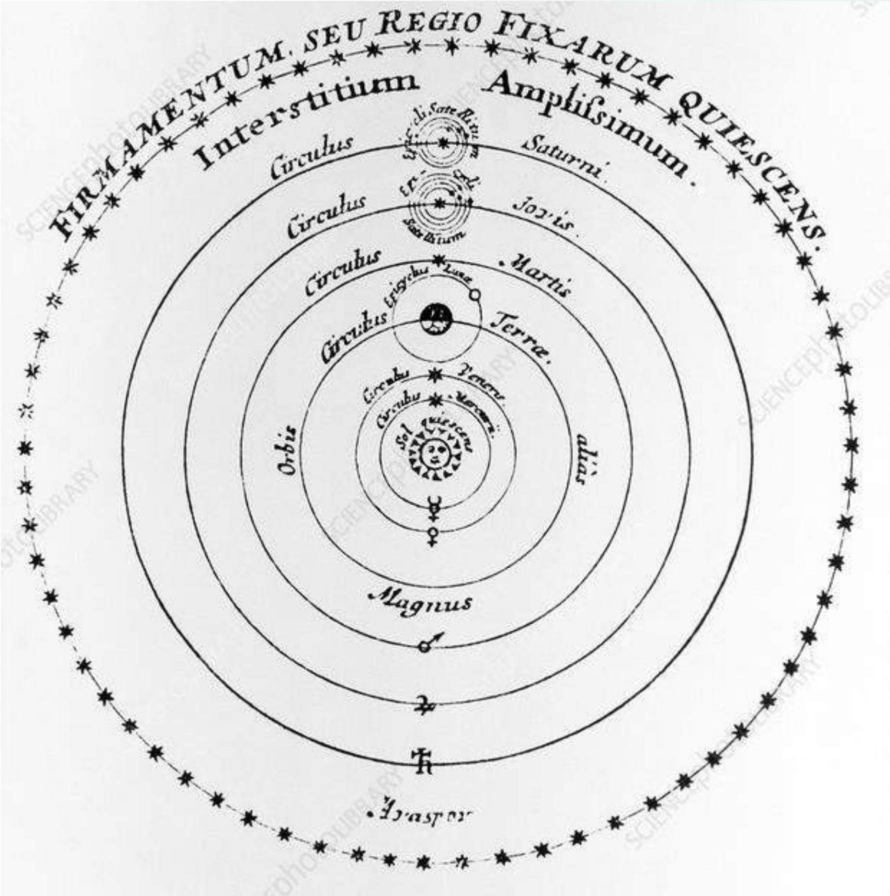
Rutherford Appleton Laboratory, 18th February 2026

Aristotle … Ptolemy → The Divine Comedy, Dante Allighieri (1321)

The ‘standard cosmology’ (in Europe) ~350 BC ⇝ 1540 AD was ‘simple’ and provided a *good* fit to all the data



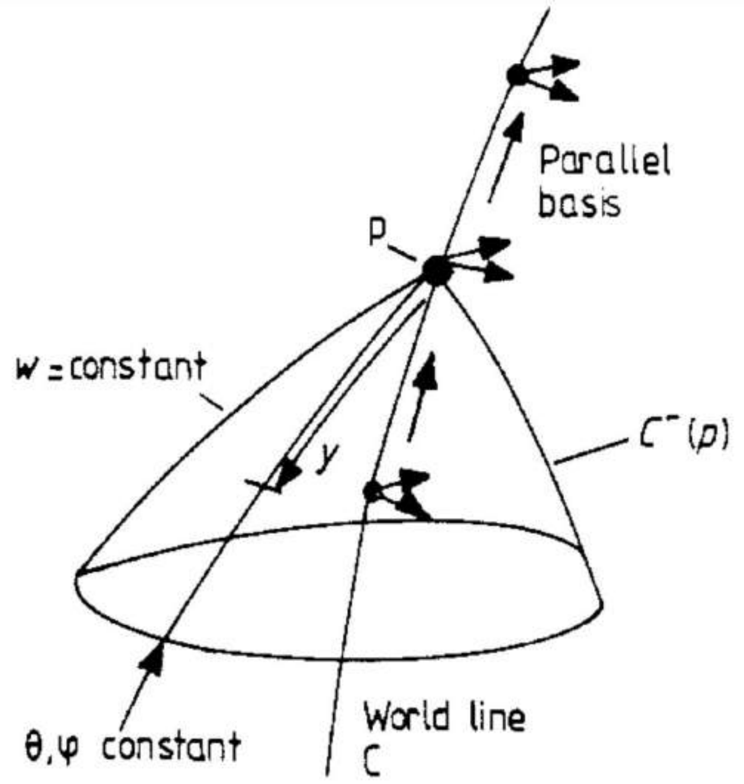
it gave way to the heliocentric Universe, where the Earth was demoted from being at its centre … the Sun took its place



Nicholas Copernicus, *De revolutionibus orbium coelestium* (1543)

Four centuries later when the first relativistic cosmological models were constructed (Einstein 1917, Friedmann 1921, Lemaître 1927), this ‘Copernican Principle’ was extended to demote the Sun too from being at the centre of the Universe

All we can learn about the universe is contained in our past light cone



Ellis & Stoeger, CQG 4:1697,1987

We cannot move over cosmological distances and check if the universe looks the same from 'over there'
… so just *assume* that our position is not special

The Universe must appear to be the same to all observers wherever they are. This 'cosmological principle'…

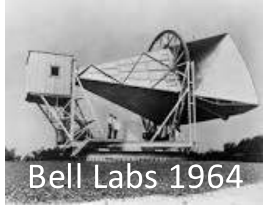
Edward Arthur Milne `*Kinematics, Dynamics & the Scale of Time*' (1936)

Mathematical Proceedings of the Cambridge Philosophical Society
Volume 51, Issue 4, October 1955 , pp. 678-683

THE COSMOLOGICAL PRINCIPLE
BY D. E. LITTLEWOOD

Many models of the universe have been proposed, by de Sitter, Milne, Bondi and Gold, Hoyle and others. The observed data being insufficient, the models are usually based on some simple hypothesis. The simplest is the cosmological principle, namely, that apart from local irregularities the universe presents the same general aspect at every point. Milne (5) has used a restricted form of the principle, namely, that the aspect is independent of spatial position but is dependent on the observed time from some fixed epoch in the past. Bondi and Gold (1) have proposed the 'perfect cosmological principle' that the aspect is completely independent of space and time.

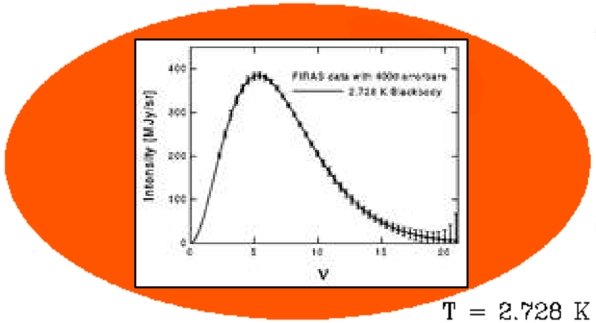
This was the basis of the `steady state cosmology' which was falsified by the discovery of the CMB



A MEASUREMENT OF EXCESS ANTENNA TEMPERATURE
AT 4080 Mc/s

Measurements of the effective zenith noise temperature of the 20-foot horn-reflector antenna (Crawford, Hogg, and Hunt 1961) at the Crawford Hill Laboratory, Holmdel, New Jersey, at 4080 Mc/s have yielded a value about 3.5° K higher than expected. This excess temperature is, within the limits of our observations, isotropic, unpolarized, and

A. A. PENZIAS R. W. WILSON



$T = 2.728$ K

… but the not-so-perfect cosmological principle lived on

The real reason, though, for our adherence here to the Cosmological Principle is not that it is surely correct, but rather, that it allows us to make use of the extremely limited data provided to cosmology by observational astronomy. …

… If the data will not fit into this framework, we shall be able to conclude that either the Cosmological Principle or the Principle of Equivalence is wrong. Nothing could be more interesting.

S. Weinberg, *Gravitation and Cosmology* (1972)

This remains the *key* assumption of the standard cosmological model:
maximally symmetric space-time + general relativity + ideal fluids

$$ds^2 = a^2(\eta)\left[d\eta^2 - d\bar{x}^2\right]$$

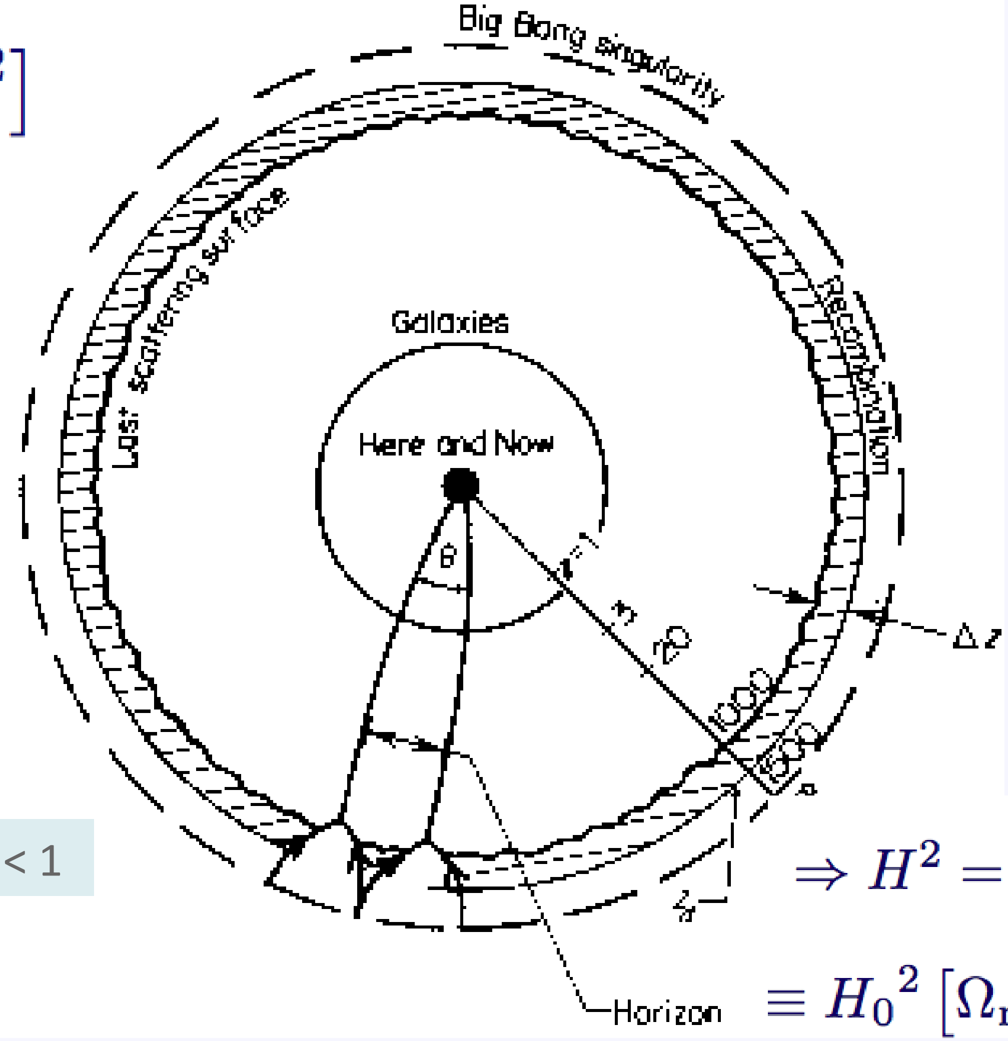
$$a^2(\eta)d\eta^2 \equiv dt^2$$

Space-time metric
Robertson-Walker

It is the *assumed* homogeneity and isotropy that enables the Einstein eqn. to be simplified to the Friedmann-Lemaître eqns.

Eqn. of state of Λ: $p = -\rho \Rightarrow$ accn. at $z < 1$

$$\ddot{a} = -\frac{4\pi G}{3}(\rho + 3P)\,a$$



$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \lambda g_{\mu\nu} = 8\pi G_N T_{\mu\nu}$$

Geometrodynamics
Einstein

'Dust' → quantum fields

$$T_{\mu\nu} = -\langle\rho\rangle_{\text{fields}}\, g_{\mu\nu}$$

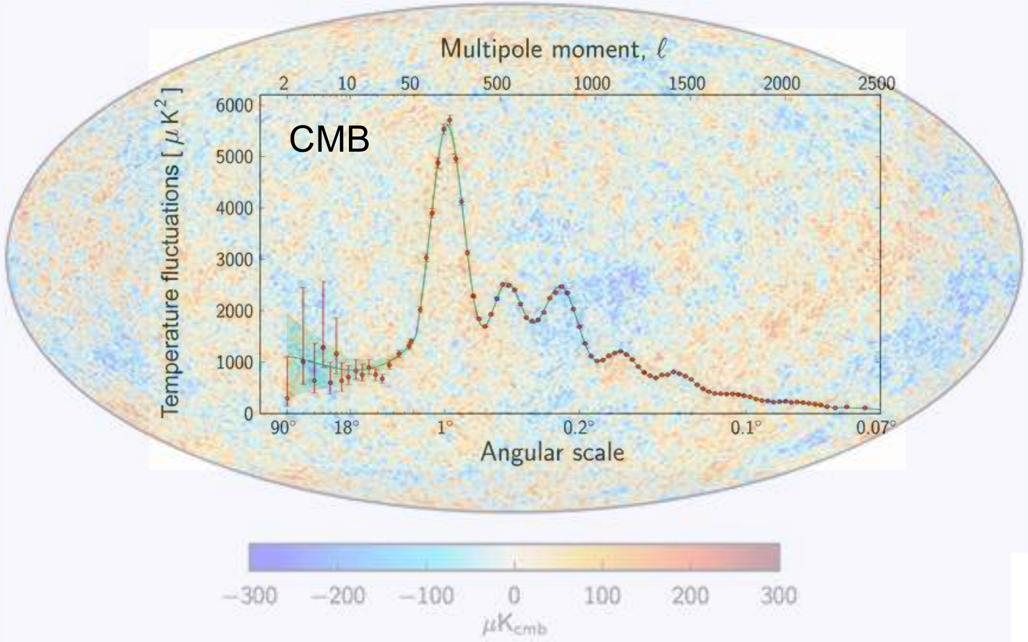
$$\Lambda = \lambda + 8\pi G_N \langle\rho\rangle_{\text{fields}}$$

$$\Rightarrow H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G_N \rho_m}{3} - \frac{k}{a^2} + \frac{\Lambda}{3}$$

$$\equiv H_0^2\left[\Omega_m(1+z)^3 + \Omega_k(1+z)^2 + \Omega_\Lambda\right]$$

$$z \equiv \frac{a_0}{a} - 1,\ \Omega_m \equiv \frac{\rho_m}{3H_0^2/8\pi G_N},\ \Omega_k \equiv \frac{k}{a_0^2 H_0^2},\ \Omega_\Lambda \equiv \frac{\Lambda}{3H_0^2}$$

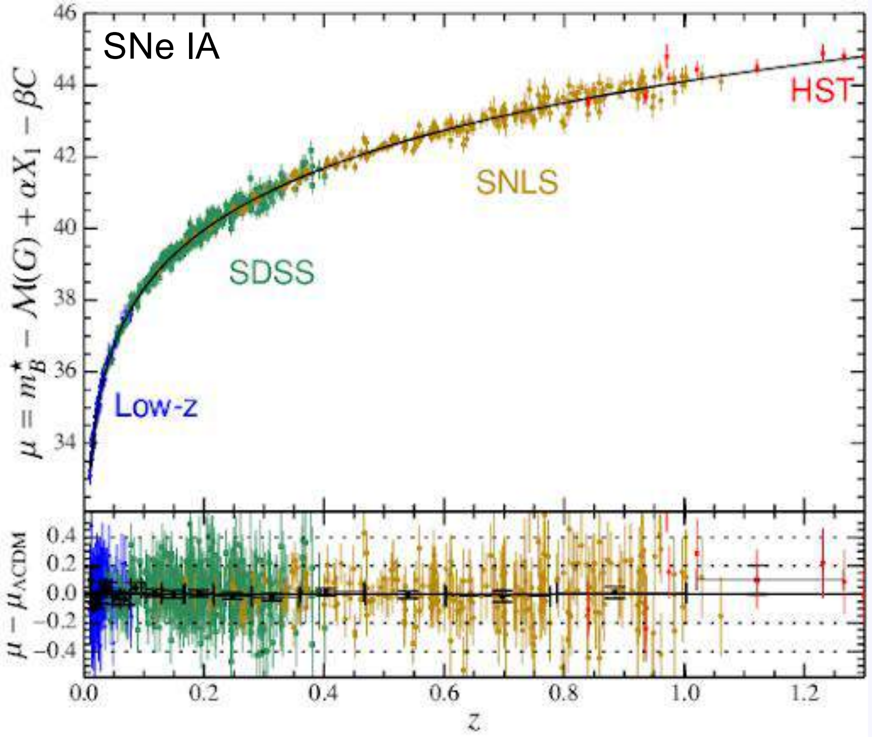
This yields the 'cosmic sum rule': $1 \equiv \Omega_m + \Omega_k + \Omega_\Lambda$



How did ΛCDM come to be today's standard 'concordance' model?

$$\Omega_m + \Omega_k + \Omega_\Lambda = 1$$

NB: *All* these deductions rely on the **assumption** of (statistical) isotropy



$0.8\Omega_m$ - $0.6\Omega_\Lambda$ H -0.2 (SNe Ia)

Ω_k H 0.0 (CMB)

$\Omega_m \sim 0.3$ (BAO, Clusters)

$\Omega_\Lambda = 1 - \Omega_m - \Omega_k \sim 0.7 \Rightarrow \boldsymbol{\Lambda \sim 2H_0^2}$

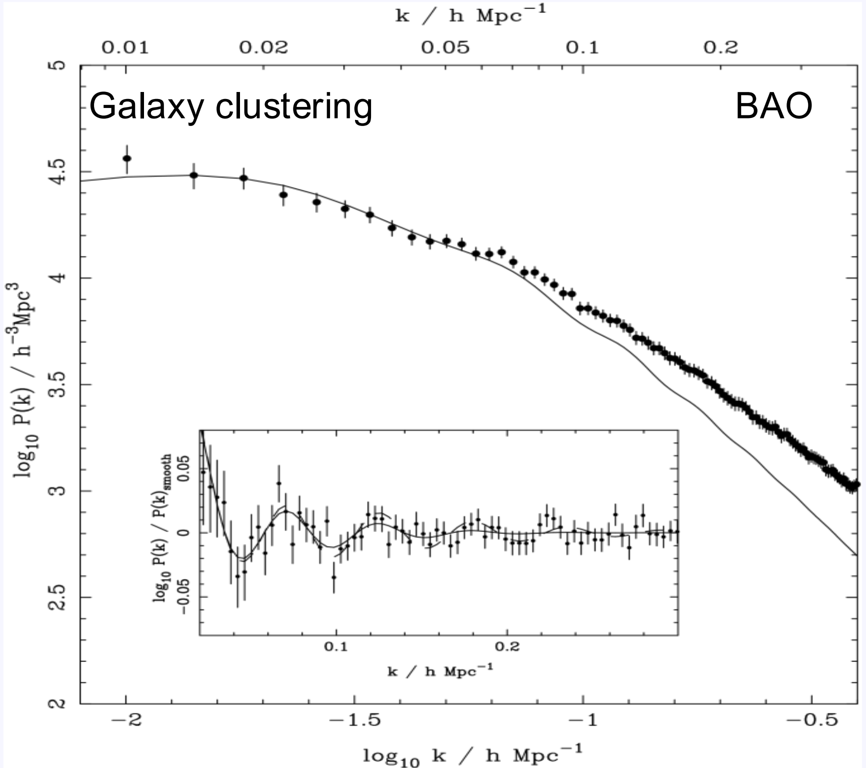
$\Rightarrow (\rho_\Lambda)^{1/4} = (2H_0^2/8\pi G_N)^{1/4} \sim 10^{-12}$ GeV

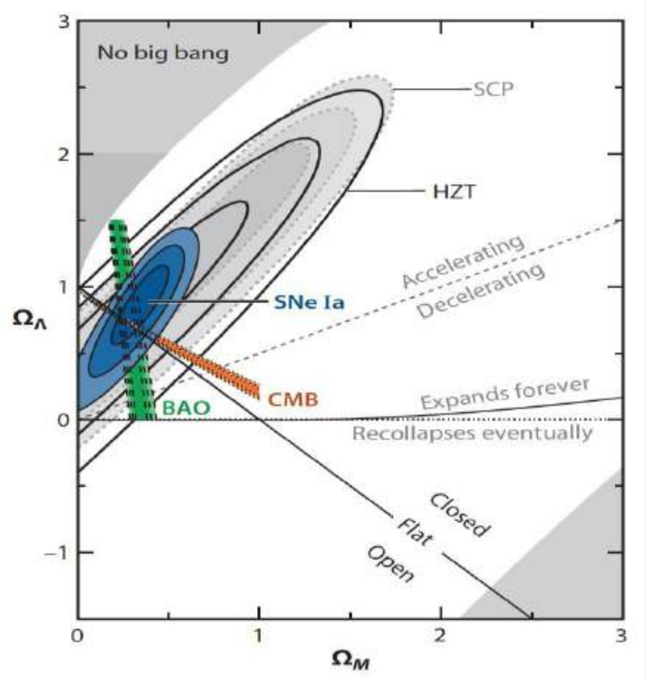
The *only* physical scales here are

$H_0 \sim (10^{28}\ \mathrm{cm})^{-1} \sim 10^{-42}$ GeV

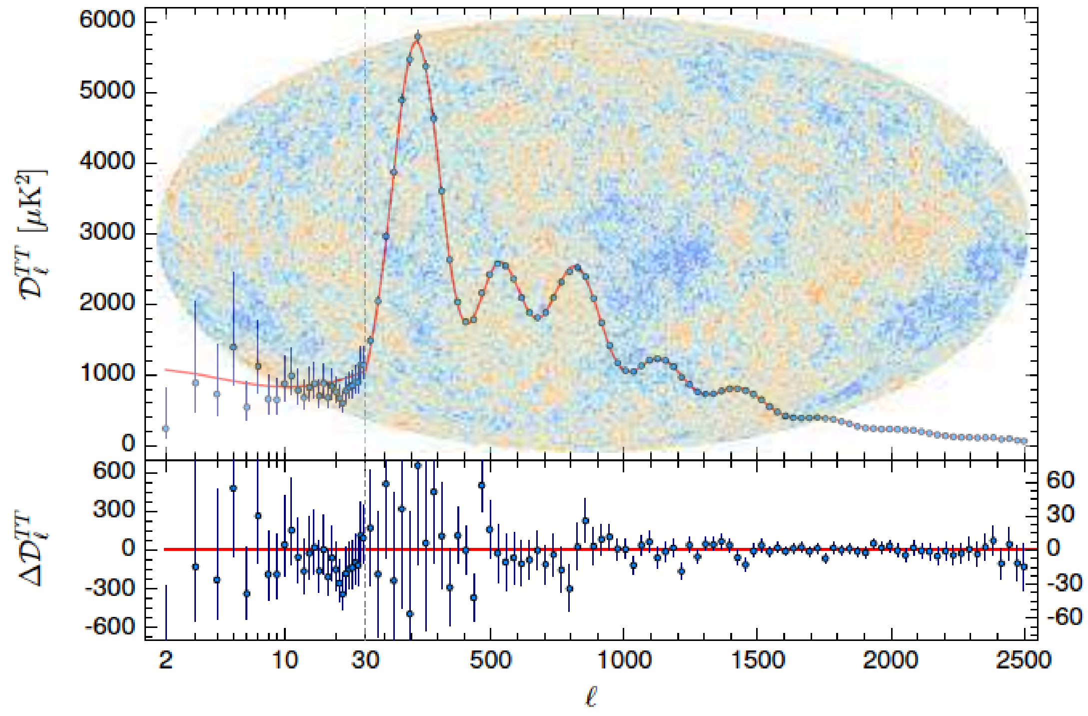
$M_{Pl} \equiv 1/\sqrt{8pG_N} \sim 10^{19}$ GeV

Do we infer $\Lambda \sim H_0^2$ simply because $\boldsymbol{H_0}$ is the *only* scale in the F-R-L-W model and is impr*inted* on *every* observation?





CMB data is well-fitted by the 6-parameter ΛCDM model + power-law $P(k)$



Planck collab., *A&A* **594**:A13(2016)

Parameter	[1] *Planck* TT+lowP	[2] *Planck* TE+lowP	[3] *Planck* EE+lowP	[4] *Planck* TT,TE,EE+lowP
$\Omega_b h^2$	0.02222 ± 0.00023	0.02228 ± 0.00025	0.0240 ± 0.0013	0.02225 ± 0.00016
$\Omega_c h^2$	0.1197 ± 0.0022	0.1187 ± 0.0021	$0.1150^{+0.0048}_{-0.0055}$	0.1198 ± 0.0015
$100\theta_{MC}$	1.04085 ± 0.00047	1.04094 ± 0.00051	1.03988 ± 0.00094	1.04077 ± 0.00032
τ	0.078 ± 0.019	0.053 ± 0.019	$0.059^{+0.022}_{-0.019}$	0.079 ± 0.017
$\ln(10^{10} A_s)$	3.089 ± 0.036	3.031 ± 0.041	$3.066^{+0.046}_{-0.041}$	3.094 ± 0.034
n_s	0.9655 ± 0.0062	0.965 ± 0.012	0.973 ± 0.016	0.9645 ± 0.0049
H_0	67.31 ± 0.96	67.73 ± 0.92	70.2 ± 3.0	67.27 ± 0.66
Ω_m	0.315 ± 0.013	0.300 ± 0.012	$0.286^{+0.027}_{-0.038}$	0.3156 ± 0.0091
σ_8	0.829 ± 0.014	0.802 ± 0.018	0.796 ± 0.024	0.831 ± 0.013
$10^9 A_s e^{-2\tau}$	1.880 ± 0.014	1.865 ± 0.019	1.907 ± 0.027	1.882 ± 0.012

There is no entry for Λ!

But there is no *direct* sensitivity of CMB anisotropy to dark energy … it is *inferred* (using $\boldsymbol{\Omega_m + \Omega_k + \Omega_\Lambda \equiv 1}$)

(To *directly* detect Λ at 5σ using late-ISW correlations between CMB & structure requires all-sky redshift survey of 10 million galaxies at $z \sim$ 0-1)

Afshordi, *Phys.Rev.D***70**:083536(2004)

What do we know about Λ from the Standard $SU(3)_c \times SU(2)_L \times U(1)_Y$ Model (viewed as an **effective field theory** up to some high energy cut-off scale ***M***)?

$$m_H^2 \simeq \frac{h_t^2}{16\pi^2}\int_0^{M^2} \mathrm{d}k^2 = \frac{h_t^2}{16\pi^2} M^2$$

$$+M^4 + M^2\Phi^2$$

Vacuum energy — Higgs mass correction

super-renormalisable

$$-\mu^2\phi^\dagger\phi + \frac{\lambda}{4}(\phi^\dagger\phi)^2, m_H^2 = \lambda v^2/2$$

$$\mathcal{L}_{\text{eff}} = F^2 + \bar{\Psi}\, \not{D}\Psi + \bar{\Psi}\Psi\Phi + (D\Phi)^2 + V(\Phi)$$

renormalisable

$$+\frac{\bar{\Psi}\Psi\Phi\Phi}{M} + \frac{\bar{\Psi}\Psi\bar{\Psi}\Psi}{M^2} + \ldots$$

neutrino mass — proton decay

non-renormalisable

However the 'super-renormalisable' operators become more important as *M* is raised

2nd SR term ⇒ quadratic divergence of the Higgs mass (attempted solutions: supersymmetry, compositeness, …)

1st SR term couples to gravity, so the expectation (*not* formally calculable) is: $\rho_\Lambda \sim (1\ \text{TeV})^4 \Rightarrow \sim 10^{60} \times (10^{-12}\ \text{GeV})^4$

i.e. the universe should have been inflating since, or recollapsed at, $t \sim 10^{-12}$ s after BB

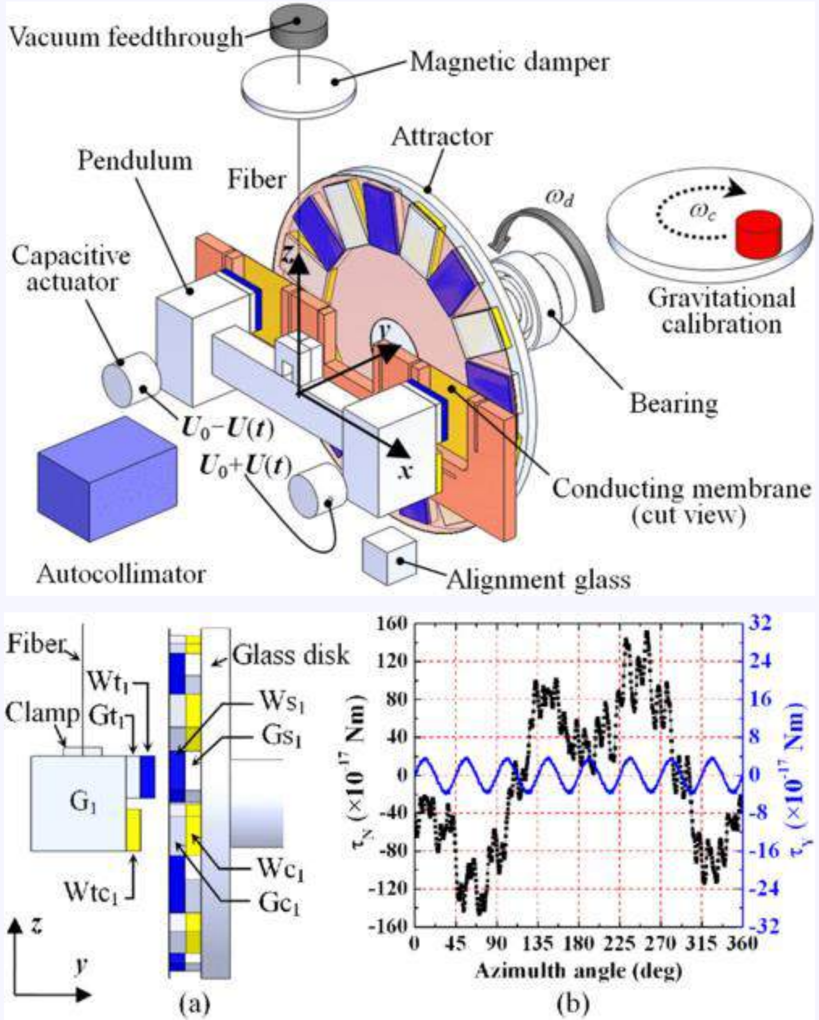
There must be a very good reason why this did *not* happen!

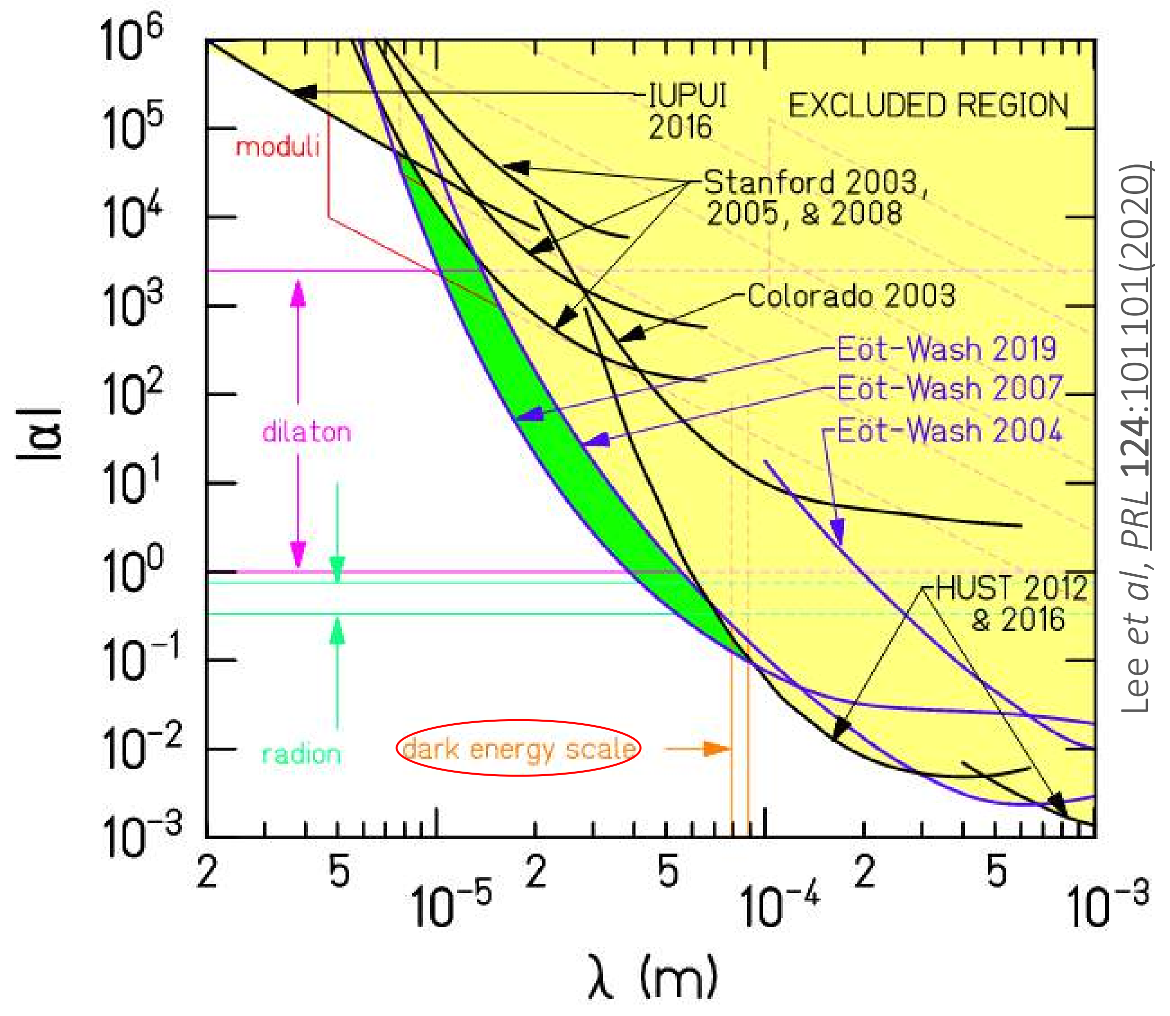
*"Also, as is obvious from experience, the [zero-point energy] does **not** produce any gravitational field"*

- Wolfgang Pauli (Die allgemeinen Prinzipien der Wellenmechanik, *Handbuch der Physik*, Vol. XXIV, 1933)

There is no evidence for any change in the inverse-square law of gravitation at the inferred 'dark energy' scale of ~ 10^{-3} eV ⇒ $\rho_\Lambda^{-1/4} \sim (H_0/\sqrt{G_N})^{-1/2}$ ~ 0.1 mm

$$V(r) = -G\frac{m_1 m_2}{r}[1 + \alpha \exp(-r/\lambda)]$$

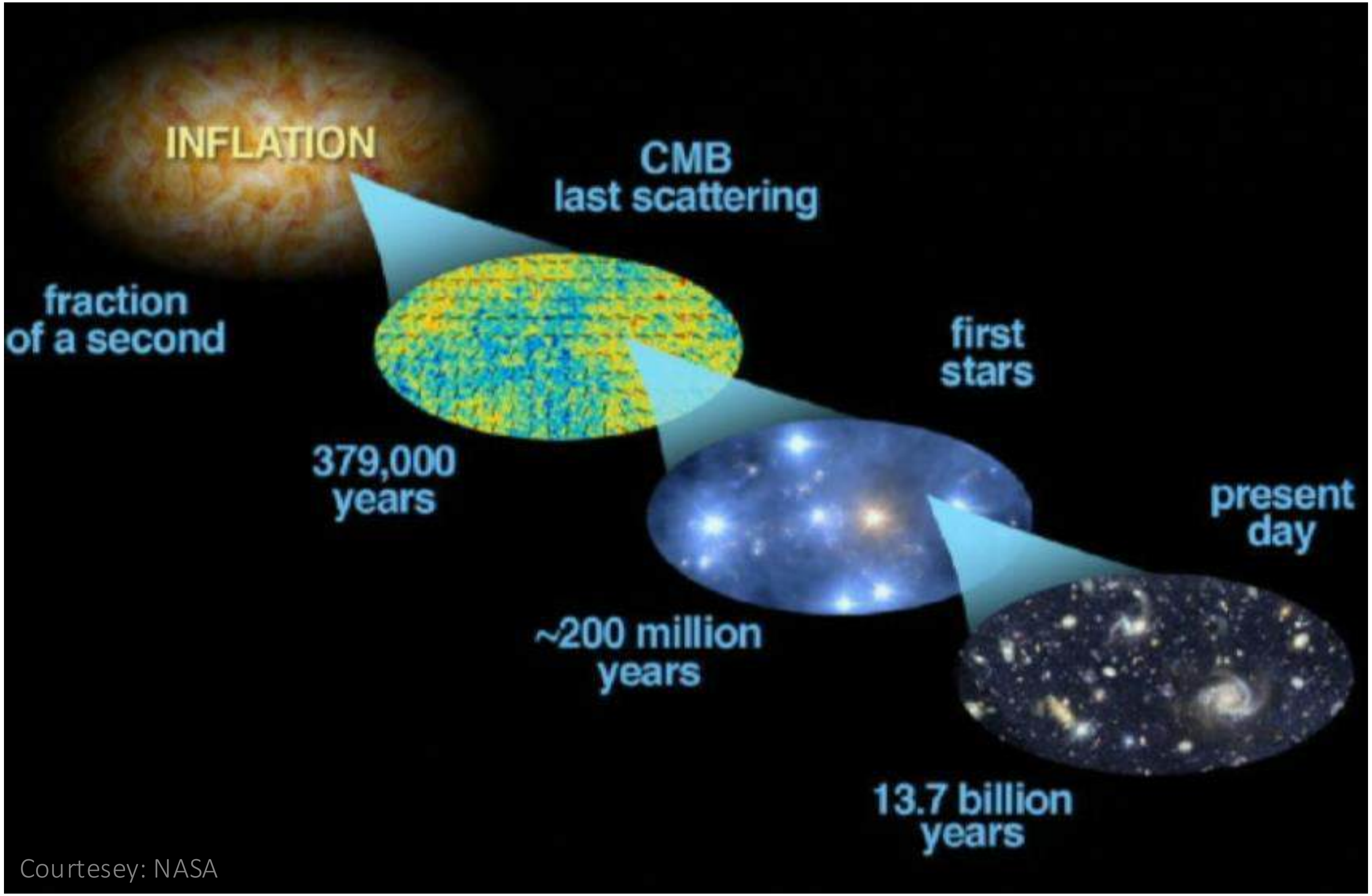




Lee *et al*, *PRL* **124**:101101(2020)

… or for any proposed 'screening' mechanisms, e.g. chameleon and symmetron theories of modified gravity

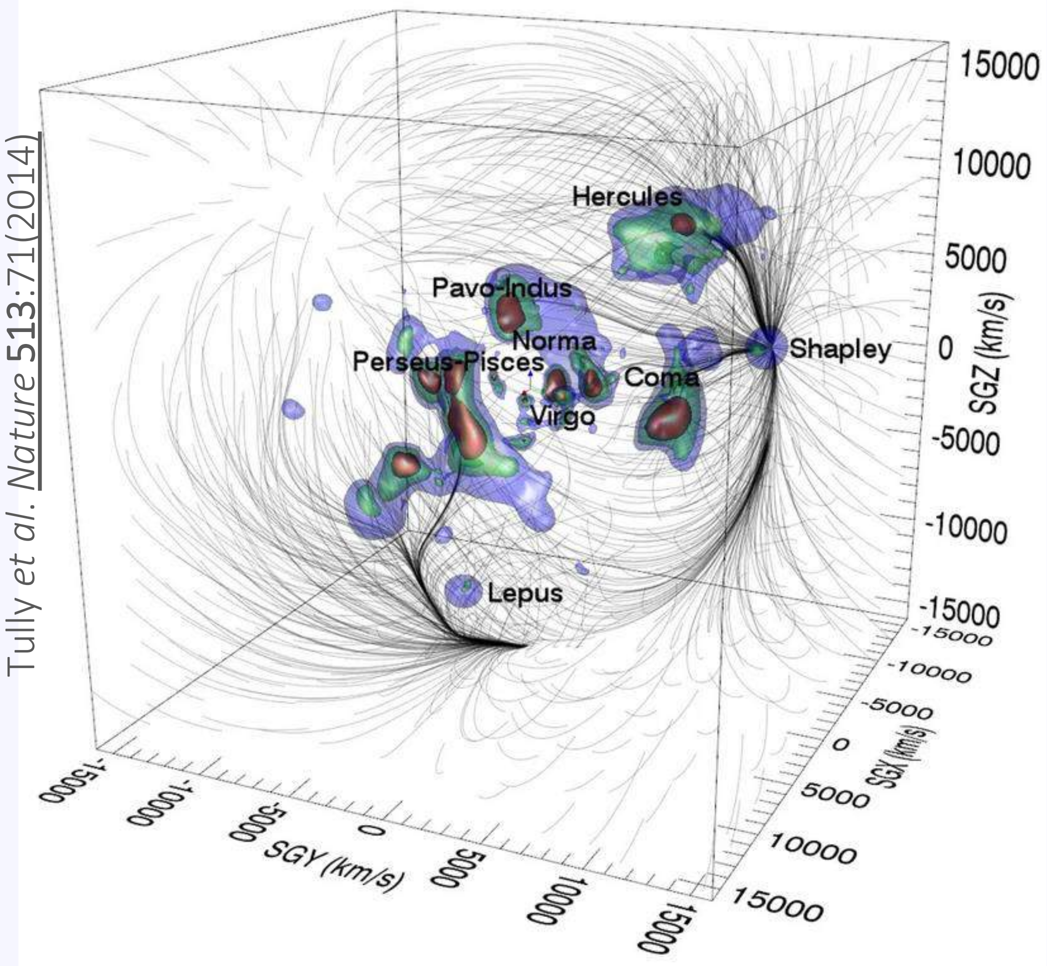
ΛCDM + standard model of structure formation



The ~10^{-5} CMB temperature fluctuations are due to ~**Gaussian scalar density perturbations with ~scale-invariant spectrum**, generated during an early ~**de Sitter phase of inflationary expansion** … these perturbations have grown into the **large-scale structure** of galaxies we see today through gravitational instability in a sea of (cold) **dark matter**

The real universe is *inhomogeneous* … how well does it conform to the F-L-R-W model description?

Tully *et al.* *Nature* 513:71(2014)



Peculiar velocity: $u = cz - H_0 d$

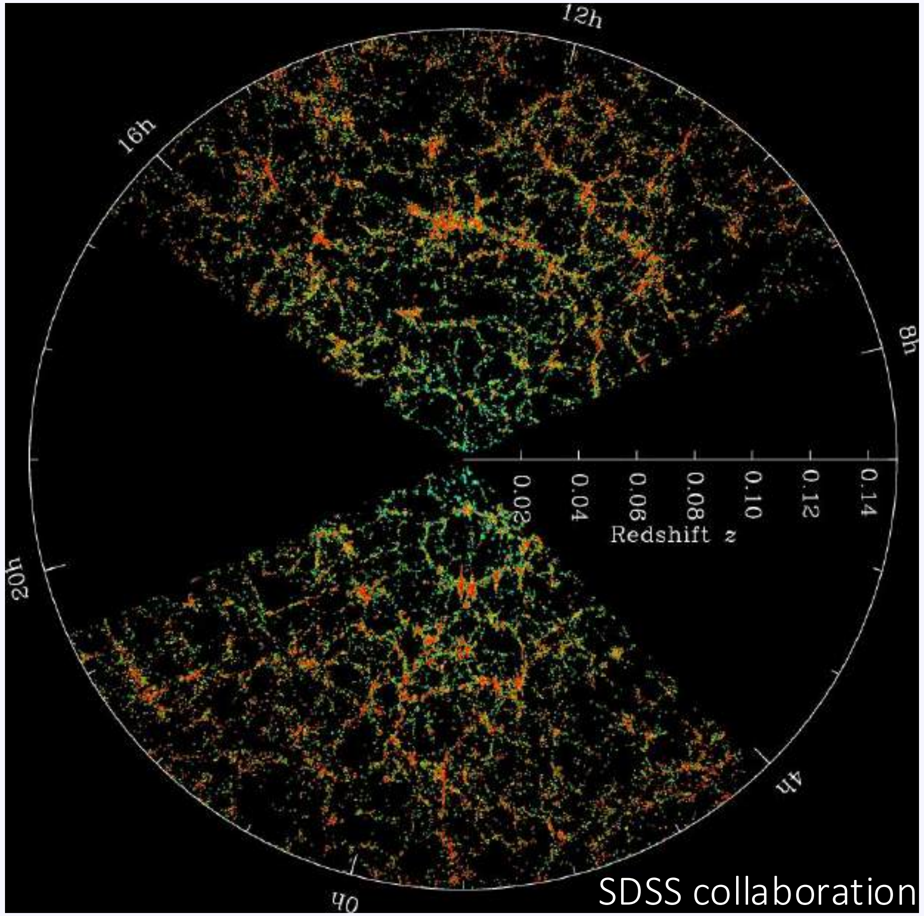
Is it justified to approximate it as *exactly* homogeneous?

… to assume that we are '*typical*' observers?

… to assume that all observed directions are *equivalent*?

← This is what our Universe *actually* looks like locally (out to ~200 Mpc)

… and on the largest scales (~ 600 Mpc) mapped so far →

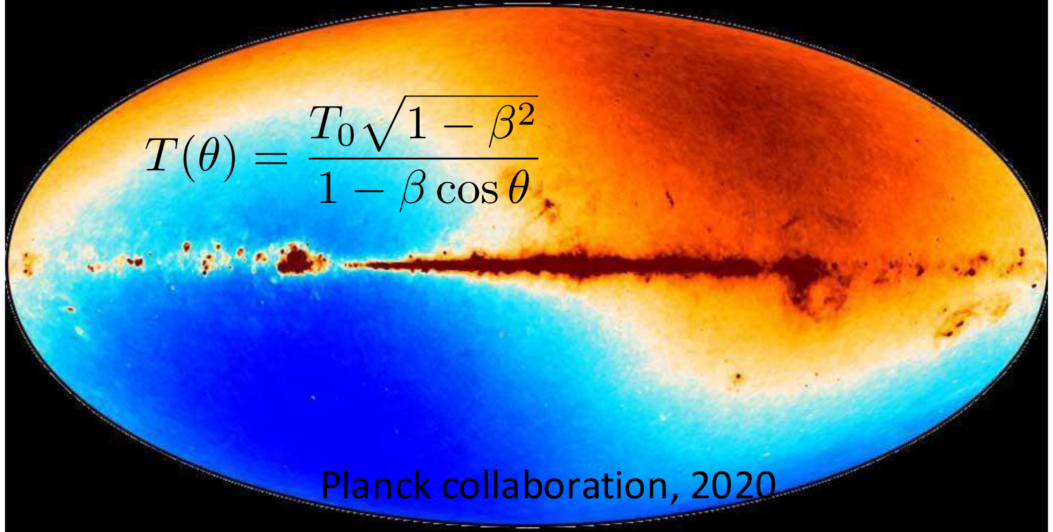


SDSS collaboration

We are flowing towards the Shapley supercluster – supposedly pulled by the 'Great Attractor' – our 'peculiar velocity' should then fall off as ~$1/r$ as we converge to the CMB frame in which the universe is supposed to be isotropic & homogeneous .. so can be described by the FLRW metric

the universe is *not* isotropic around us

The CMB has a dipole anisotropy with $\Delta T/T \sim 10^{-3}$



$$T(\theta) = \frac{T_0\sqrt{1-\beta^2}}{1-\beta\cos\theta}$$

Planck collaboration, 2020

This was *predicted* based on our 'peculiar' velocity

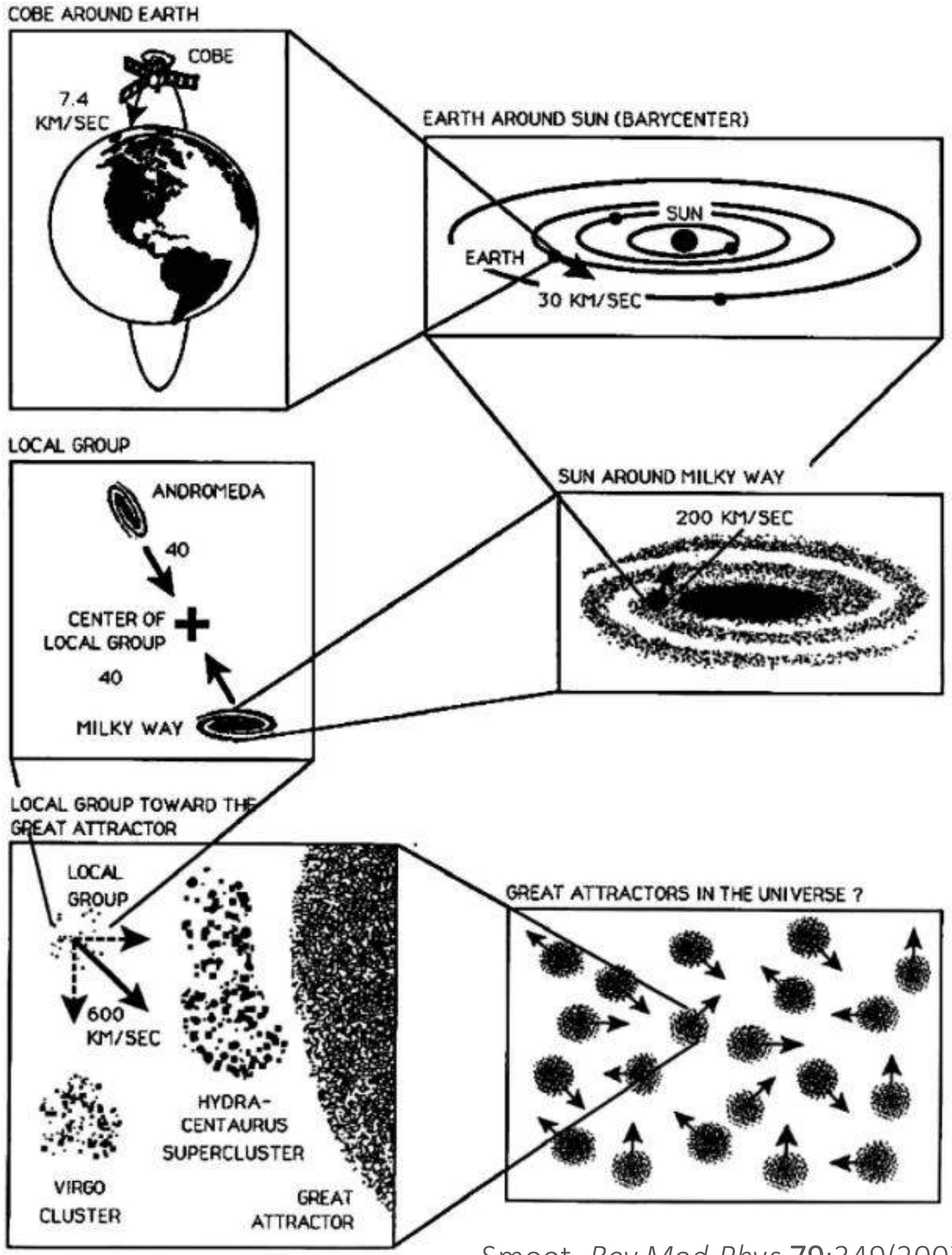
Stewart & Sciama *Nature* **216**:748(1967)

Peebles & Wilkinson, *PRL* **174**:2168(1968)

We interpret this as due to our motion at 370 km/s wrt the frame in which the CMB is truly isotropic ⇒ motion of the Local Group at 620 km/s towards l = 271.9°, b = 29.6°

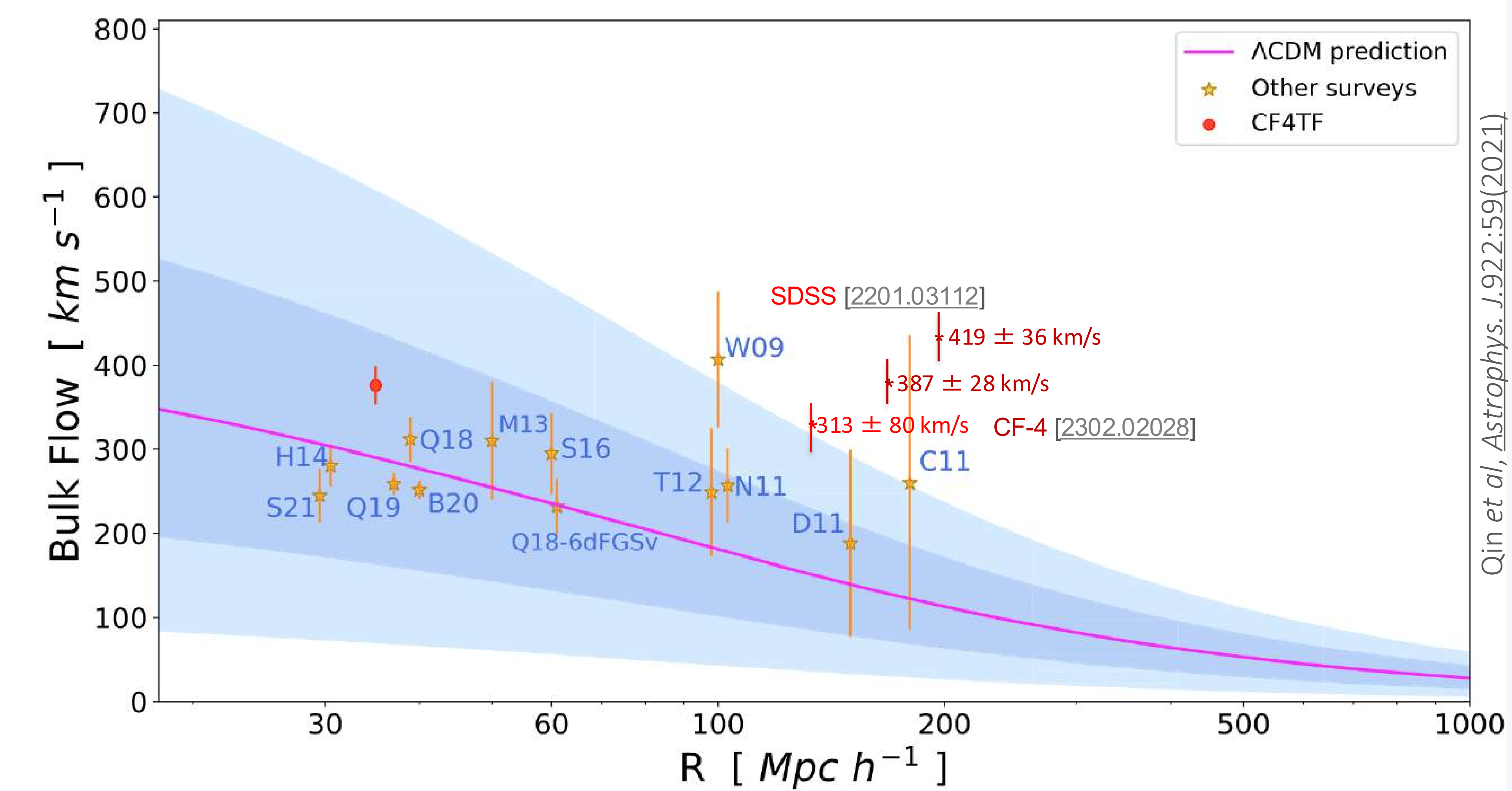
This motion is presumed to be due to *local* inhomogeneity in the matter distribution … according to the theory of structure formation in ΛCDM we should converge to the 'CMB frame' by averaging on scales larger than ~100/h Mpc

So all observational data is routinely 'corrected' by first transforming to the CMB frame in which FLRW *should* hold



Smoot, *Rev.Mod.Phys.* **79**:349(2007)

But convergence to the 'CMB frame' is *not* seen even out to $\gtrsim 200h^{-1}$ Mpc



Bulk flow measurements from different surveys. The pink curve is the ΛCDM prediction for a spherical top-hat window function. The shaded areas indicate the 1σ and 2σ cosmic variance.

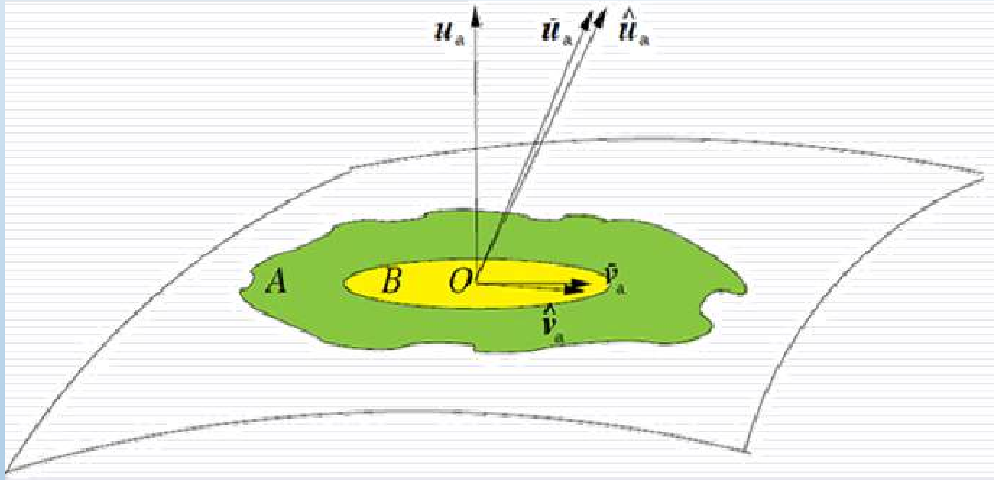
"This bulk flow is in even greater tension with the standard model, having $\sim 1.5\times10^{-4}$ % probability of occurring"

Analysing the large-scale bulk flow using cosmicflows4, Watkins *et al*, *MNRAS* **524:**1885(2023)

we are *'tilted* observers' in a bulk flow so may infer acceleration … even though the expansion rate is actually decelerating

(Tsagas, *Phys.Rev*.D **84**:063503(2011), Tsagas & Kadiltzoglou, *ibid* **92**:043515(2015)

If so there should be a *dipole asymmetry* in the inferred deceleration parameter in the direction of the bulk flow



The patch A has mean peculiar velocity $\tilde{v}_a$ with $\vartheta = \tilde{\mathrm{D}}^a v_a \gtrless 0$ and $\dot{\vartheta} \gtrless 0$

(the sign depending on whether the bulk flow is converging or diverging)

Inside region B, the r.h.s. of the expression

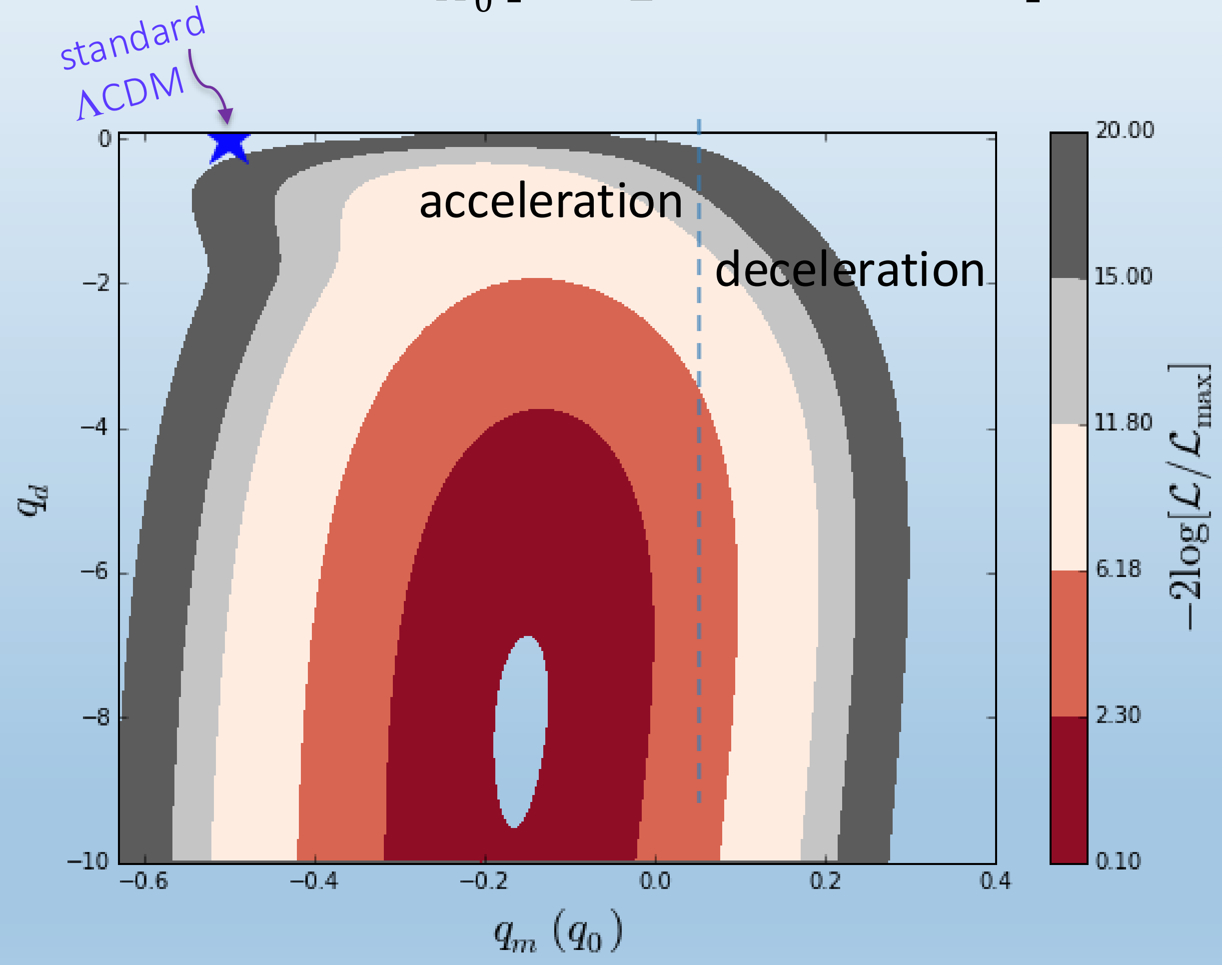
$$1 + \tilde{q} = (1+q)\left(1 + \frac{\vartheta}{\Theta}\right)^{-2} - \frac{3\dot{\vartheta}}{\Theta^2}\left(1 + \frac{\vartheta}{\Theta}\right)^{-2}, \qquad \tilde{\Theta} = \Theta + \vartheta,$$

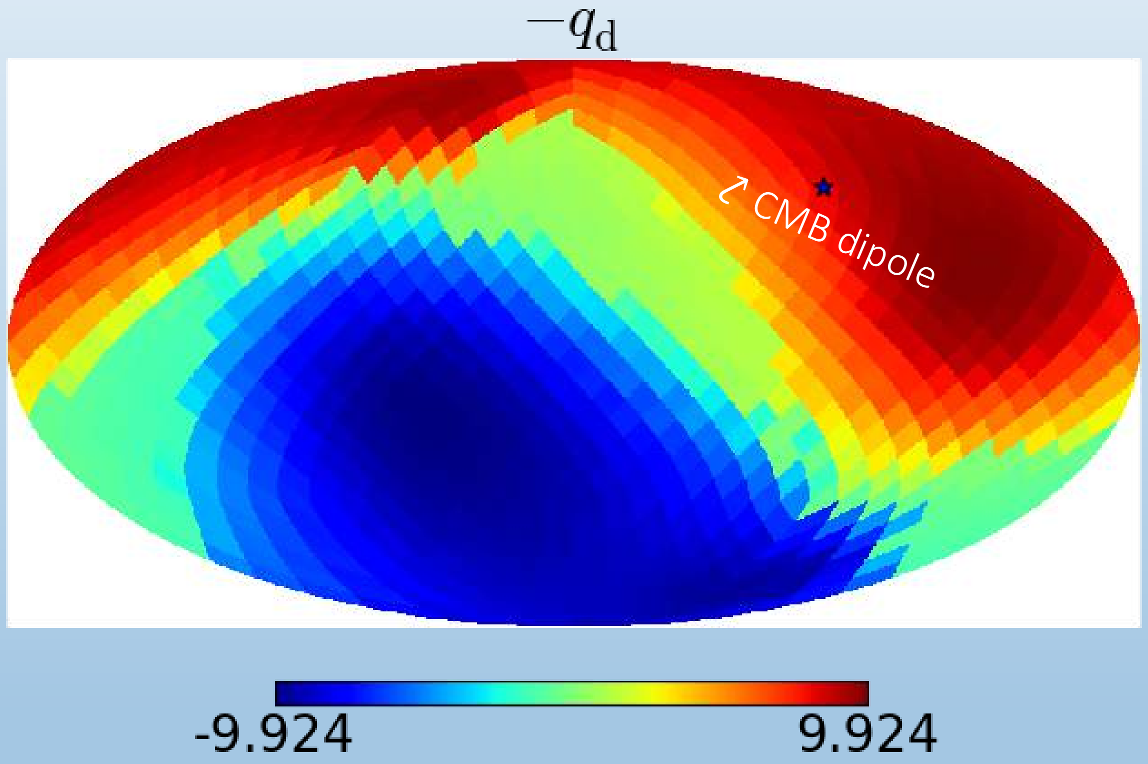
… drops below 1 and the comoving observer 'measures' negative deceleration parameter

Indeed a cosmographic analysis of 740 JLA supernovae (in the heliocentric frame) shows that the inferred acceleration is ~*aligned with the local bulk flow*

$$d_L(z) = \frac{cz}{H_0}\left[1 + \frac{1}{2}(1 - q_0)z + \ldots\right],$$

$$q_0 \equiv -(\ddot{a}a)/\dot{a}^2 \implies q_{\rm m} + \vec{q}_{\rm d}.\hat{n}\mathcal{F}(z, S)$$

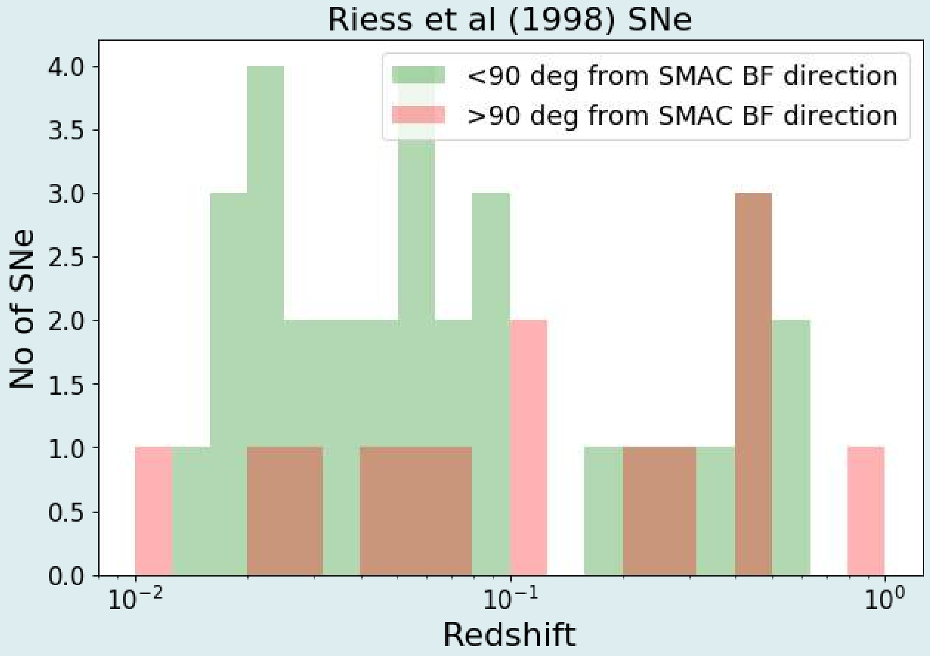


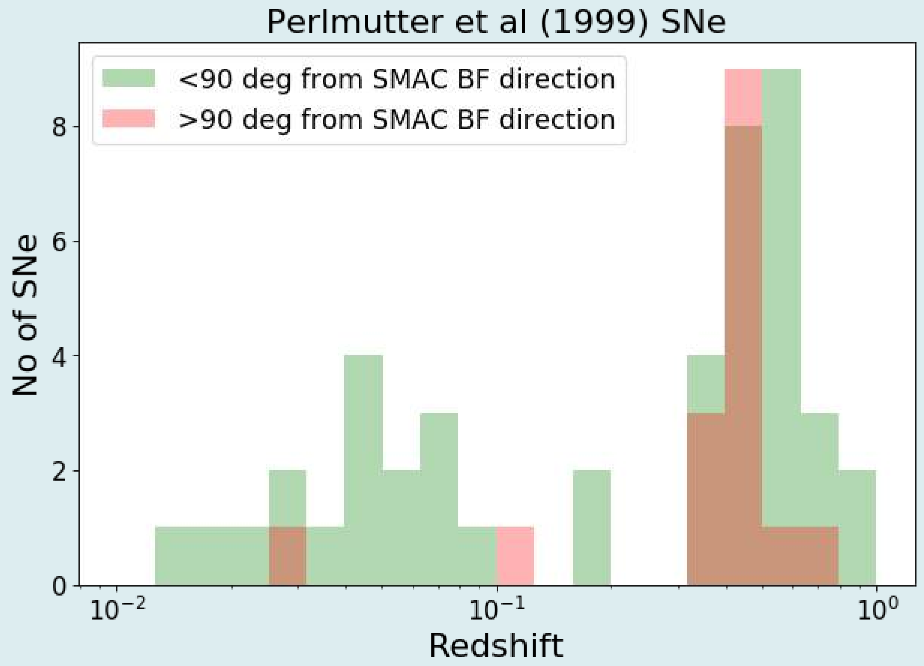


Colin, Mohayaee, Rameez & S.S., *A&A* **631**:L13(2019)

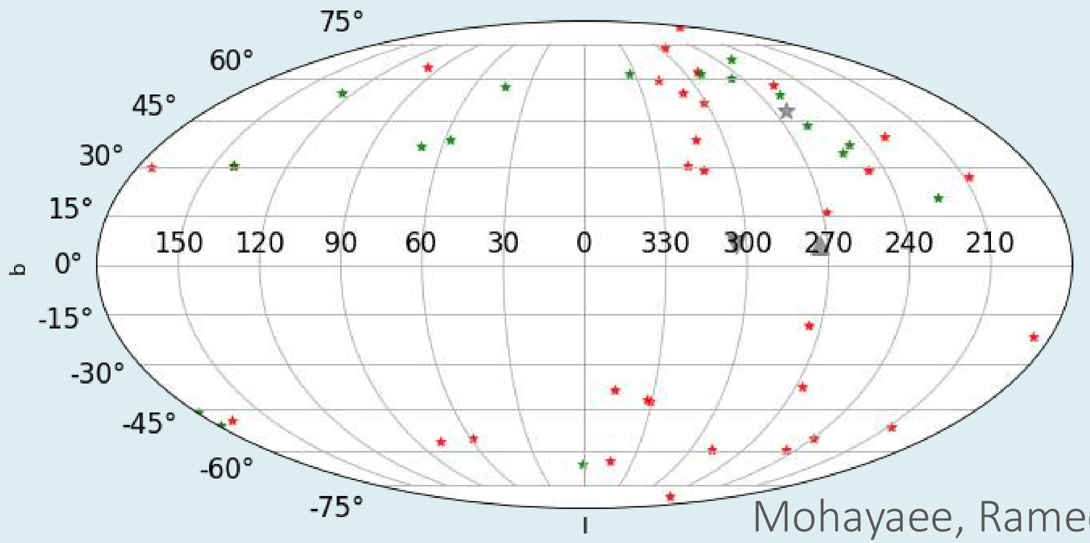
The significance of q_0 being negative has now *decreased* to only 1.4σ

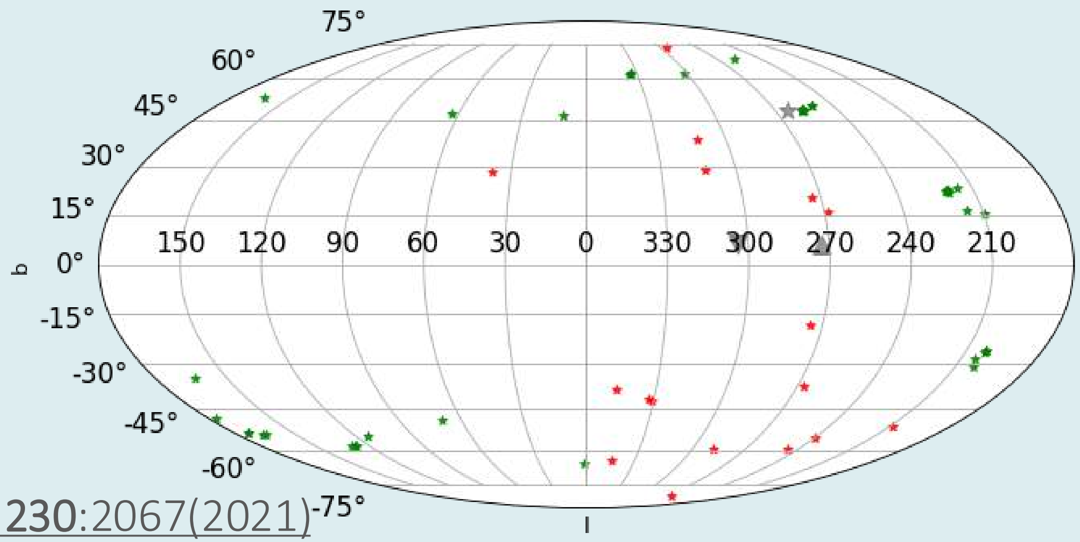
This suggests that cosmic acceleration is an artefact of our being located in a deep bulk flow … and *not* due to $\not\subset$



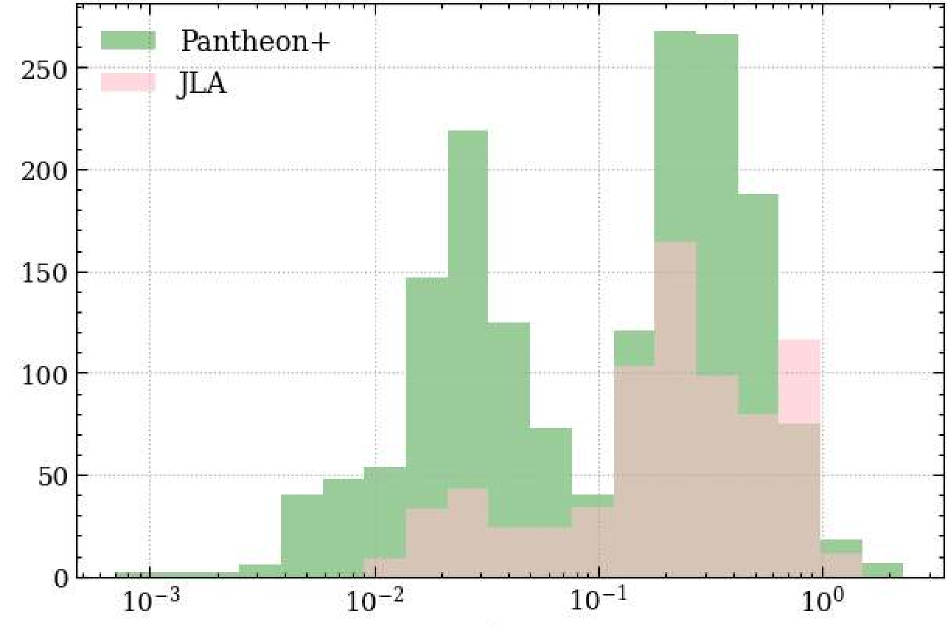


Interestingly, most of the 60 SNe Ia studied by the High-*z* Team and the 45 SNe Ia studied by the Supernova Cosmology Project were *in the direction* of the bulk flow



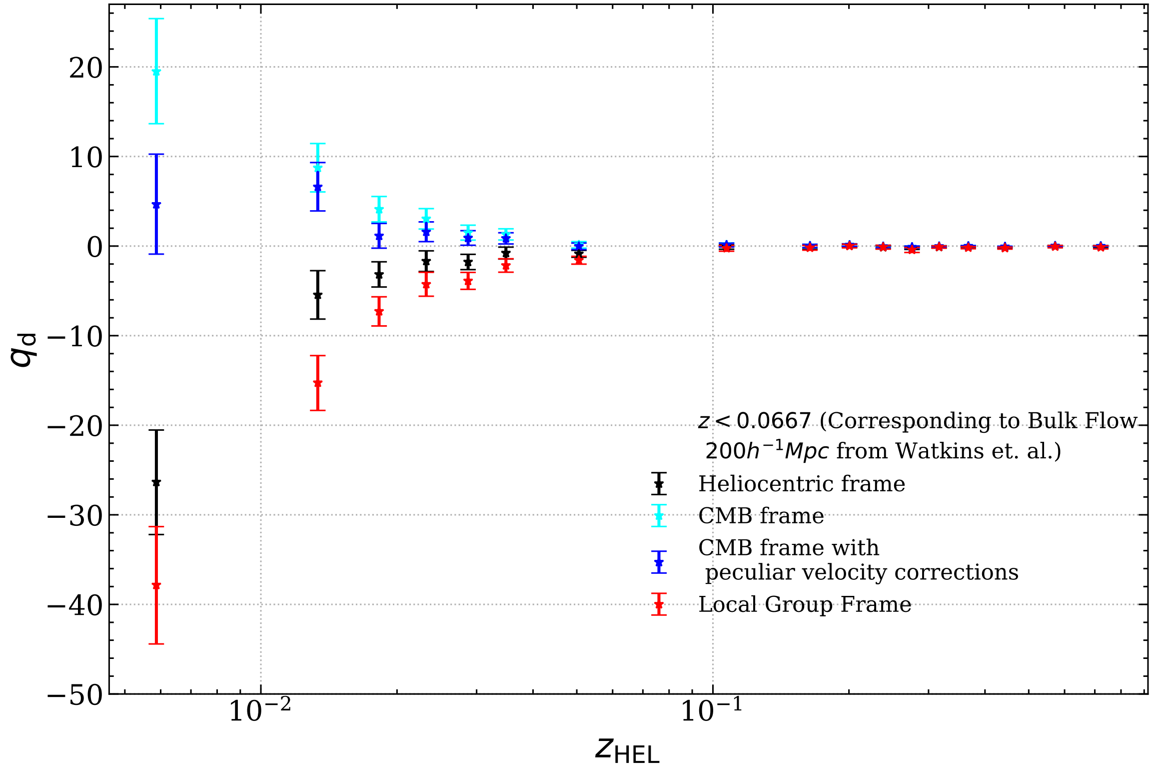


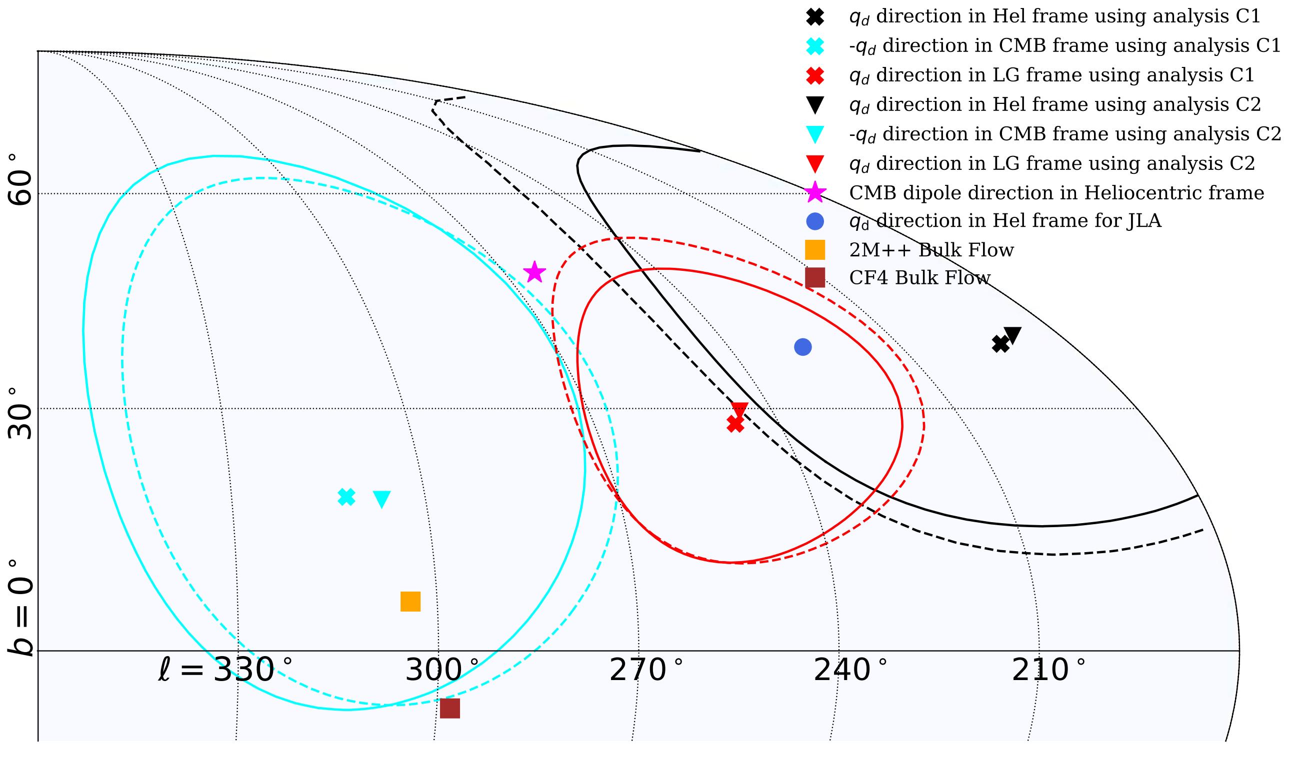
Mohayaee, Rameez & S.S, EPJST **230**:2067(2021)



Analysis of the new Pantheon+ catalogue of 1701 SNe Ia *confirms* our previous findings … the inferred acceleration of the Hubble expansion rate is anisotropic and in the ~direction of the CMB dipole

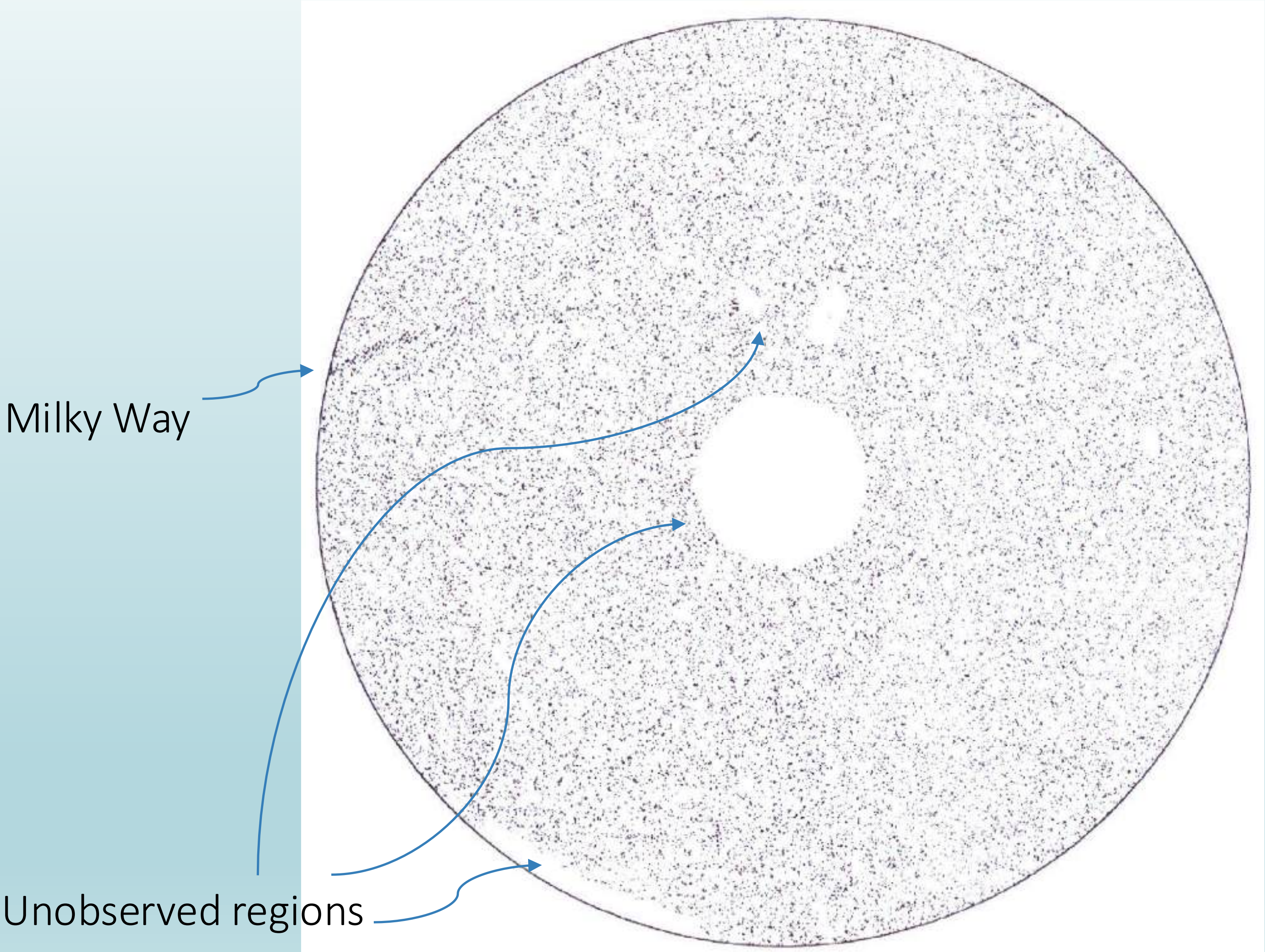
(The Hubble parameter too has an anisotropy of 2-3% in the redshift range $z \sim 0.023$–0.15 where the SNe Ia are calibrated against Cepheids in the SH0ES project)





Sah, Rameez, S.S., Tsagas, *EPJC* **85**:596(2025)

Textbooks say that the distribution of distant radio sources demonstrates the isotropy of the Universe



Peebles, *Principles of Physical Cosmology* (1993)

But if we are moving w.r.t. the cosmic rest frame, then distant sources *cannot* be isotropic!

If the CMB dipole is due to our motion wrt the frame in which the universe is isotropic then we should see a similar dipole in the sky map of cosmologically distant sources

$$\sigma(\theta)_{obs} = \sigma_{rest}[1 + [2 + x(1+\alpha)]\frac{v}{c}\cos(\theta)]$$

Aberration (Bradley 1728)

Rest frame

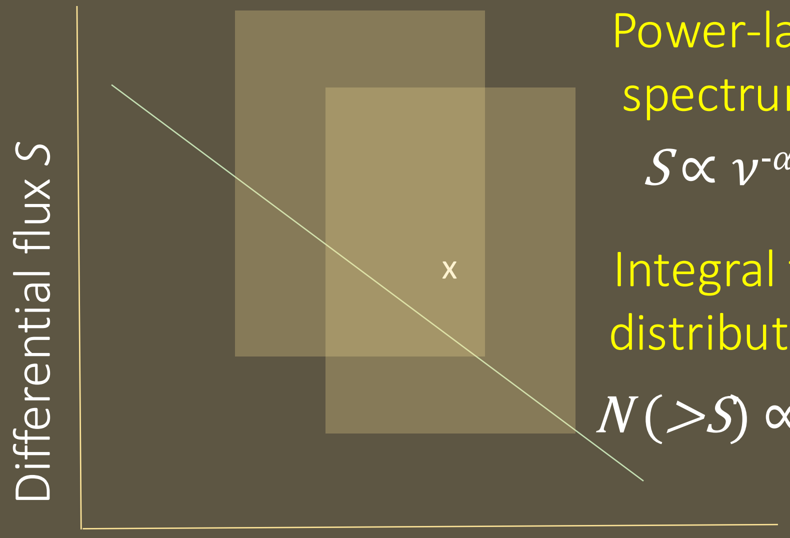
Moving frame

$$\tan\phi = \frac{\sin\theta}{\gamma(\cos\theta + \frac{v}{c})}$$

Observer, velocity $\boldsymbol{v}$

+

Doppler boosting (1842)



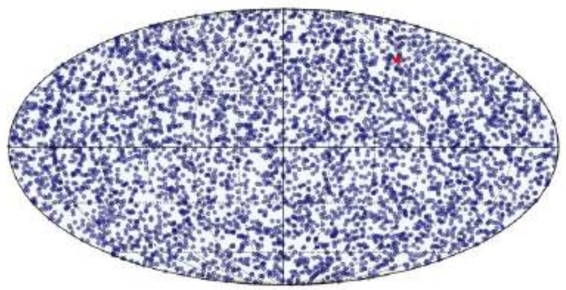
Power-law spectrum

$S \propto \nu^{-\alpha}$

Integral flux distribution:

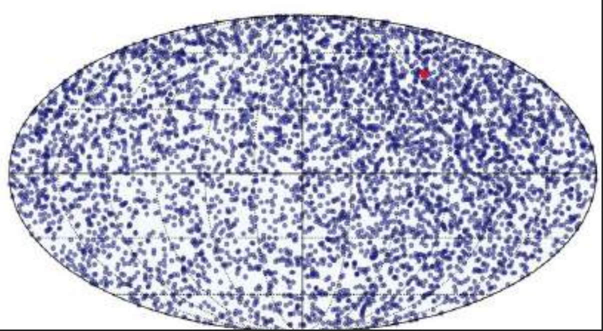
$N(>S) \propto S^{-x}$

Galaxies / quasars in CMB "rest frame"



Aberration ⇒ Source positions compressed in direction of motion

Doppler boosting ⇒ Otherwise too-faint objects boosted above the catalogue flux limit



Flux-limited catalogue ➞ *more* sources in direction of motion

Ellis & Baldwin, *MNRAS* **206**:377(1984), Secrest *et al*, *Forty years of the Ellis-Baldwin test, Nature Rev.Phys.***7**:68(2025)

This test was proposed after radio sources were observed at cosmological distances

On the expected anisotropy of radio source counts

G. F. R. Ellis* and J. E. Baldwin† *Orthodox Academy of Crete, Kolymbari, Crete*

Summary. If the standard interpretation of the dipole anisotropy in the microwave background radiation as being due to our peculiar velocity in a homogeneous isotropic universe is correct, then radio-source number counts must show a similar anisotropy. Conversely, determination of a dipole anisotropy in those counts determines our velocity relative to their rest frame; this velocity must agree with that determined from the microwave background radiation anisotropy. Present limits show reasonable agreement between these velocities. *Mon. Not. R. astr. Soc.* (1984) **206**, 377–381

4 Conclusion

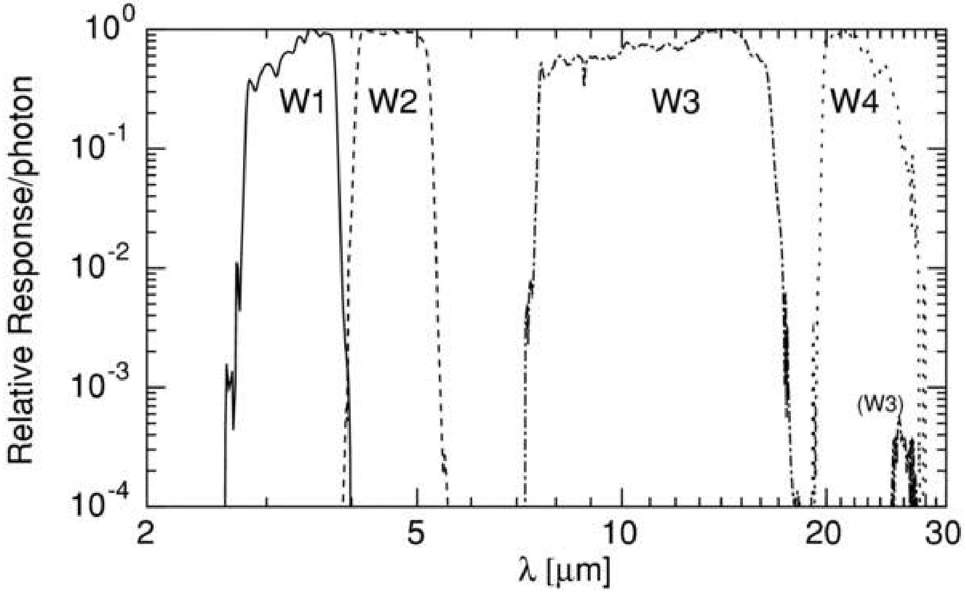
Anisotropies in radio-source number counts can be used to determine a cosmological standard of rest. Current observations determine it to about $\pm 500\ \mathrm{km\ s^{-1}}$, but accurate counts of fainter sources will reduce the error to a level comparable to that set by observations of the microwave background radiation. If the standards of rest determined by the MBR and the number counts were to be in serious disagreement, one would have to abandon either

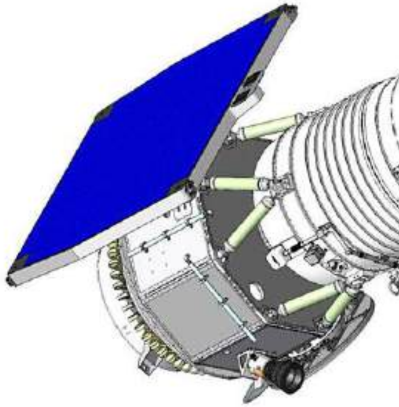
(a) the idea that the radio sources are at cosmological distances, or
(b) the interpretation of the cosmic microwave radiation as relic radiation from the big bang, or
(c) the standard FRW Universe models.

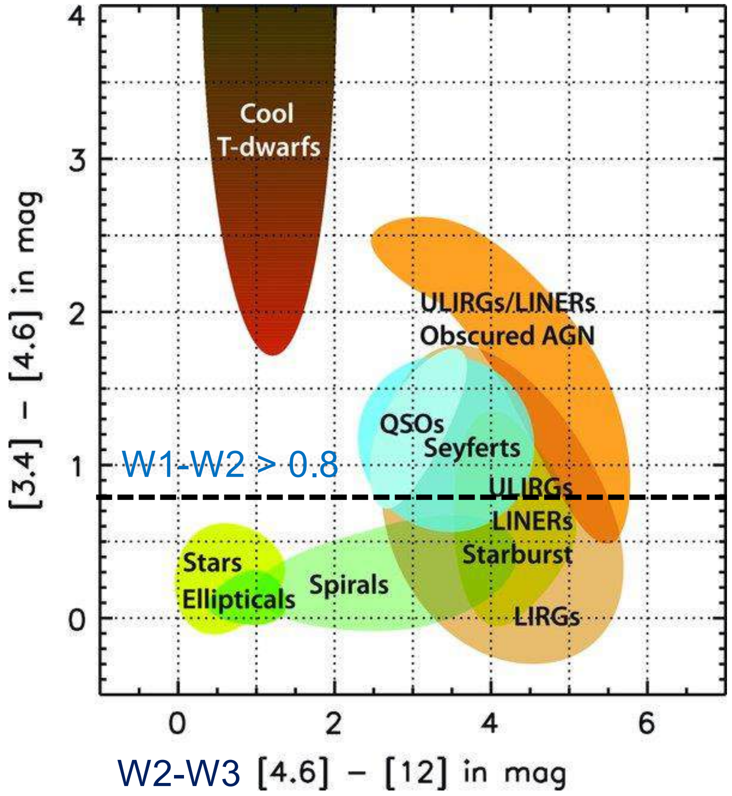
Thus comparison of these standards of rest provides a powerful consistency test of our understanding of the Universe.

The CatWISE quasar catalogue

Our colour cuts selectively select quasars … sample purity is 99% (confirmed by eBOSS spectra of sub-sample)



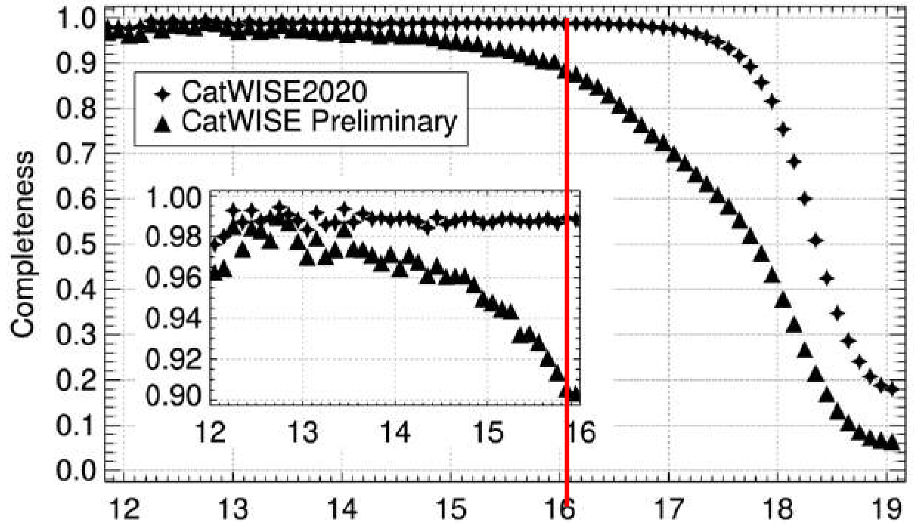




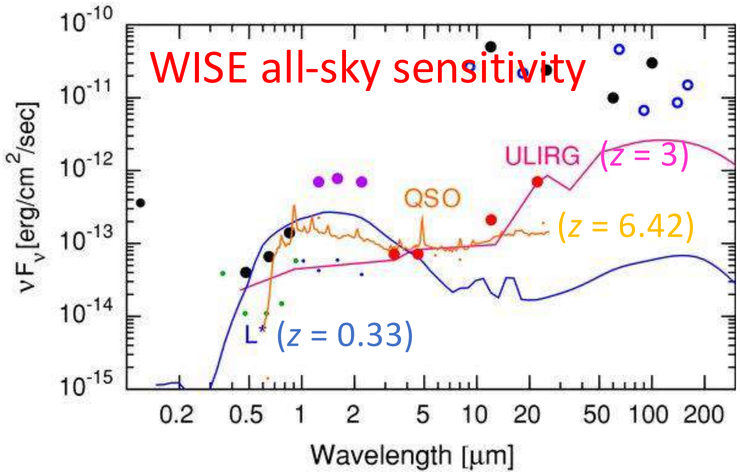
Wright *et al.*, *AJ* **140**:1868,2010

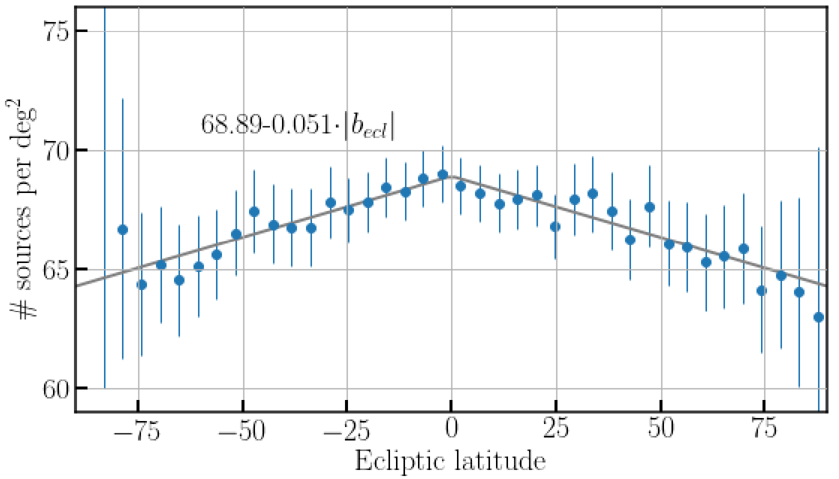
All-sky infrared survey in 4 bands: 3.4, 4.6, 12, 22 μm

Directionally unbiased survey
arcsecond angular resolution
multi-band photometry



Magnitude cut W1 < 16.4 ensures completeness

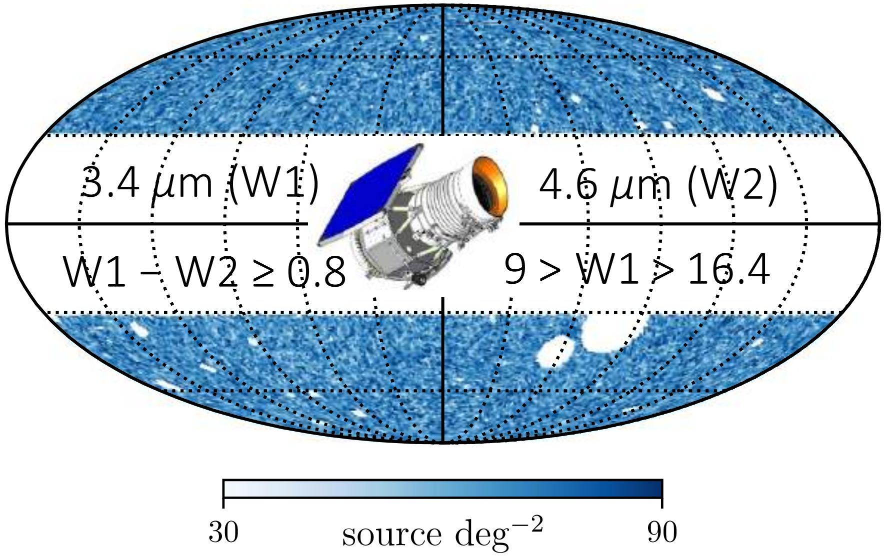


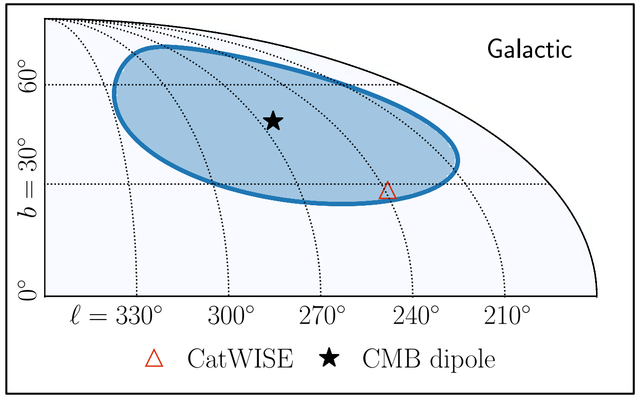


Correction for mild linear trend in source density with ecliptic latitude

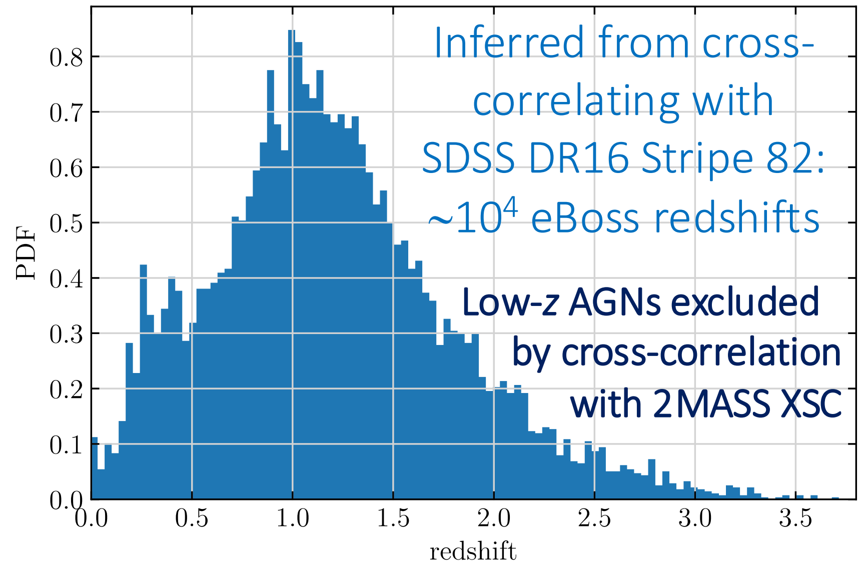
The CatWISE quasar catalogue

Secrest, Rameez, Von Hausegger, Mohayaee, S.S. & Colin, *ApJL* **908**:L51(2021)



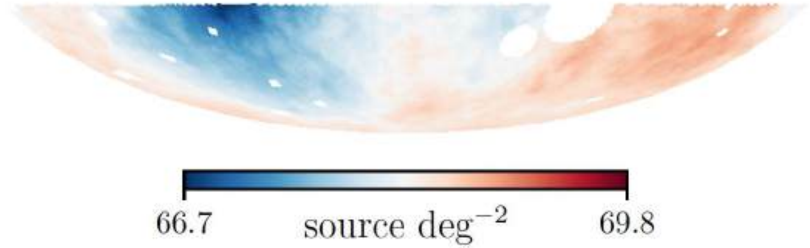


1.36 million high redshift quasars (99% with $z > 0.1$)

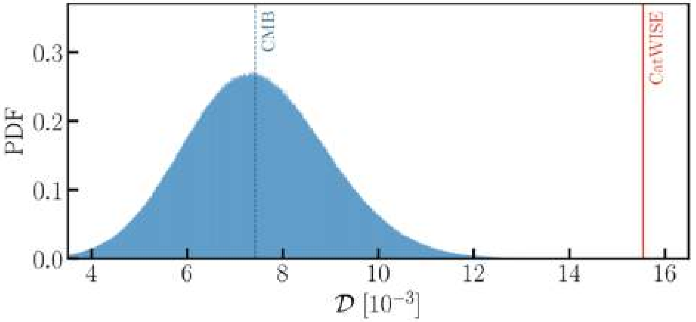


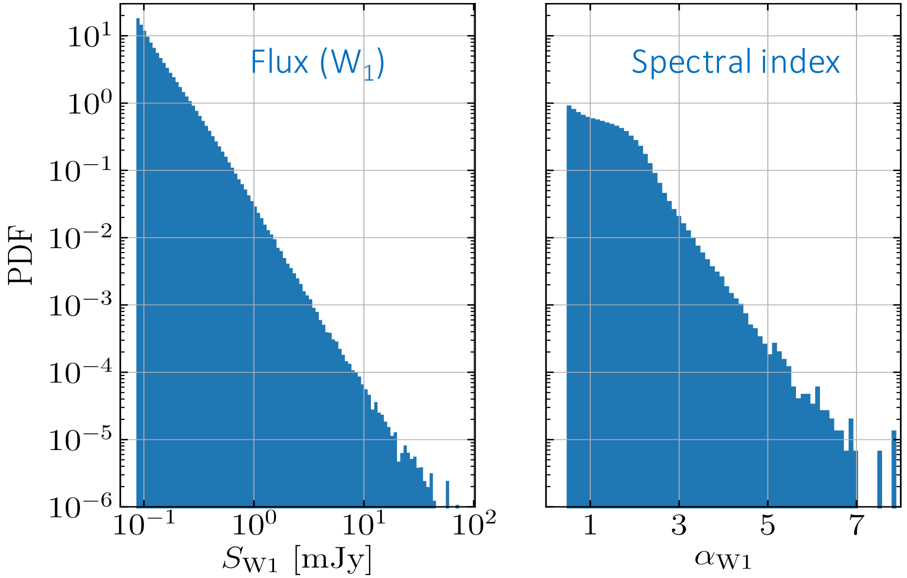
Generate mock-skies from these distributions

Now compare dipole to that predicted by E&B, given their ☛ spectrum and flux distribution



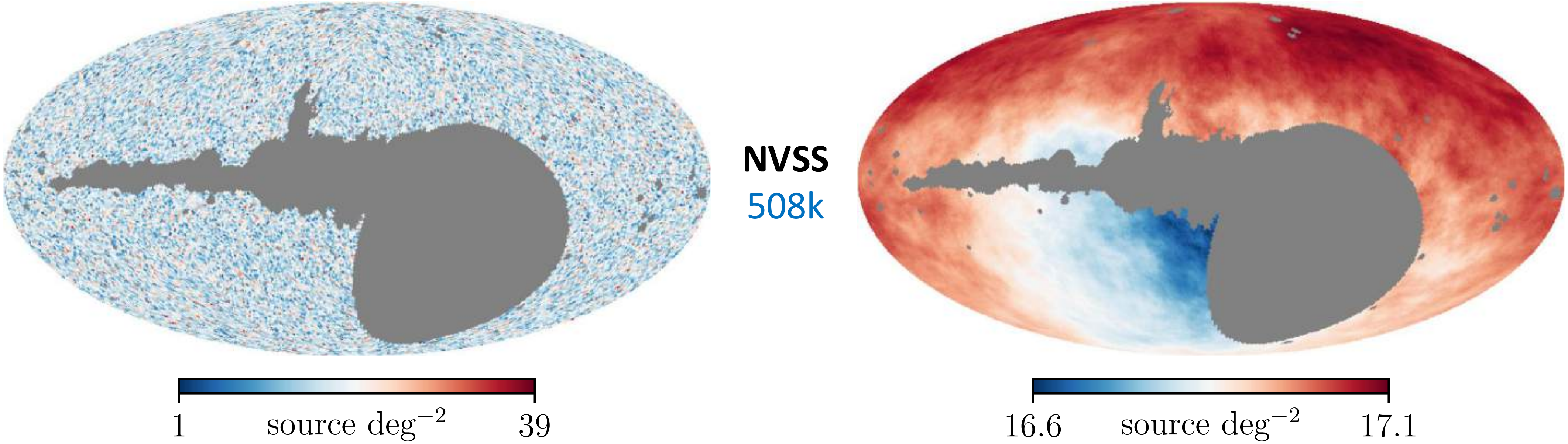
The direction is consistent with the CMB dipole – but the amplitude is x2 higher ↷



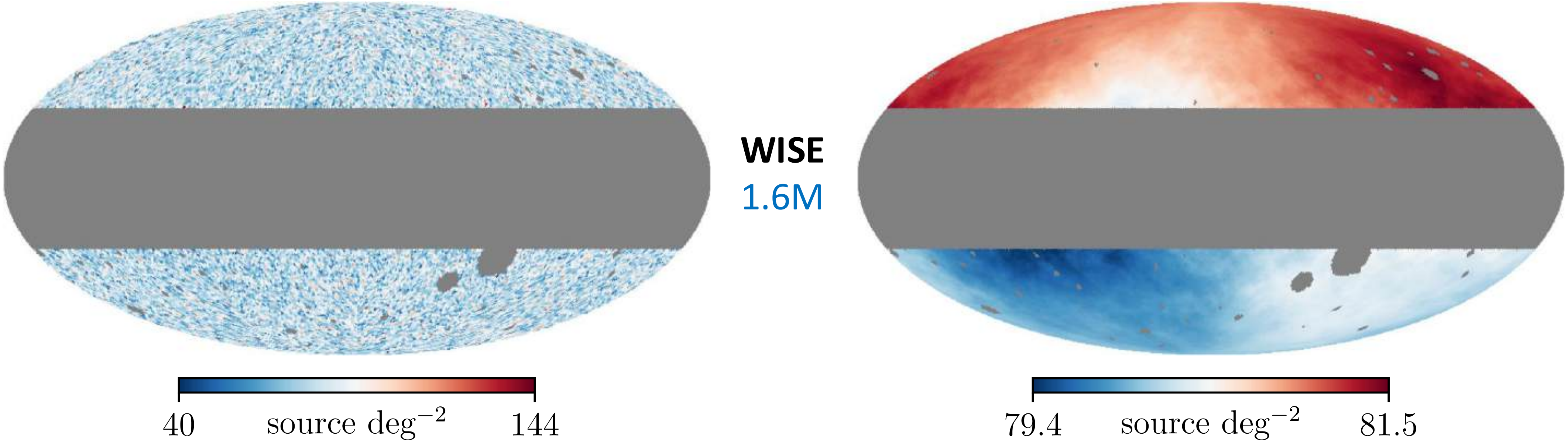


The kinematic interpretation of the CMB dipole is *rejected* with p = 5 x 10^{-7} ⇒

The anomaly is seen both in radio sources (mapped from ground) & quasars (mapped from space)



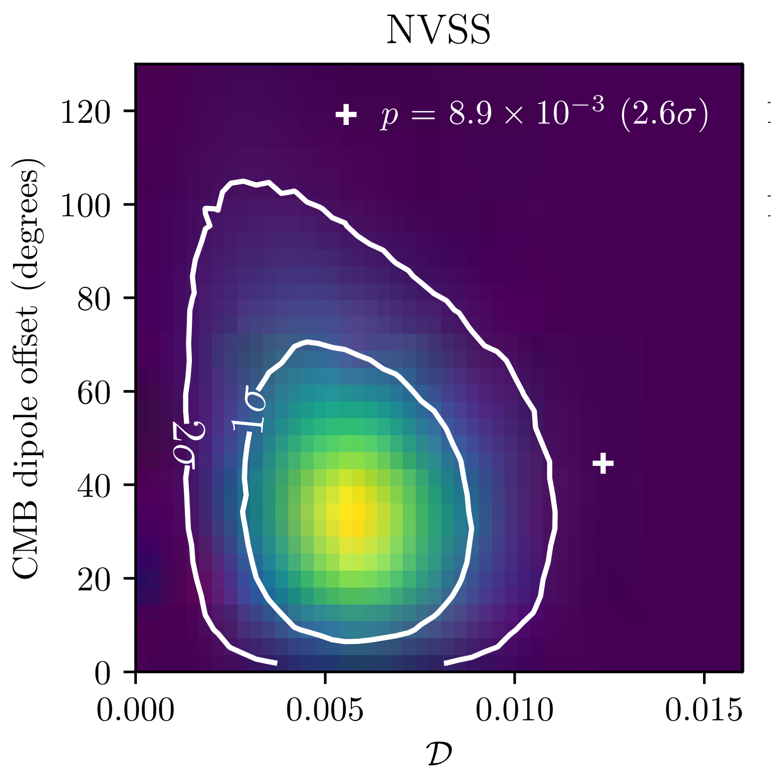
The two dipoles are *consistent*; vector mean: $D = (1.40 \pm 0.13) \times 10^{-2}$ towards (l, b) = (233.0,+34.4)



The agreement *improves* if we first subtract out the CMB dipole (assumed kinematic) from both

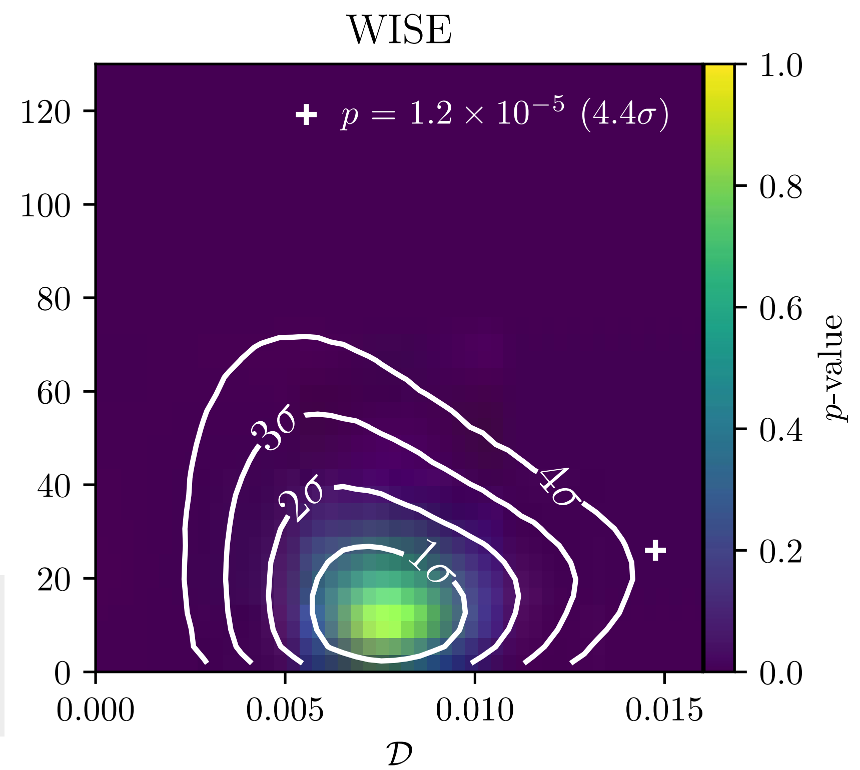
Secrest, Rameez, Von Hausegger, Mohayaee, S.S., *ApJL* 937:L31(2022)

Since the NVSS & WISE AGN catalogues are *independent*,
we can combine the p-values by which each rejects the null hypothesis



Distribution of CMB dipole offsets and kinematic dipole amplitudes of simulated null skies for NVSS (left) and WISE (right). Contours of equal *p*-value and equivalent σ are given (where the peak of the distribution corresponds to 0σ), with the found dipoles marked with + and *p*-values

Combined significance ⇒ standard expectation is rejected at 5.1**σ**



Secrest, Rameez, Von Hausegger, Mohayaee, S.S., *ApJL* 937;L31(2022)

- This is *not* a `clustering dipole' … fitting the CatWISE angular power spectrum to the ΛCDM expectation enables this to be estimated – it is *much* smaller than the observed dipole (Tiwari, Zhang & Nusser *ApJ* **943**:116,2023)
- This result is *independent* of statistical method used … Dam, Lewis & Brewer (*MNRAS* **525**:231,2023) analyse the CatWISE catalogue by Bayesian means and report rejection of the standard cosmology with a significance of 5.7*σ*
- New RACS-low survey gives 5.4*σ* evidence for anomaly from radio data *alone* (Böhme *et al*, *PRL* 135:201001,2025)

The same formula for the dipole is obtained in a General Relativistic framework

(Maartens, Clarkson & Chen, *JCAP* 01:013(2018); Nadolny, Durrer, Kunz & Padmanabhan, *JCAP* 11:009(2021))

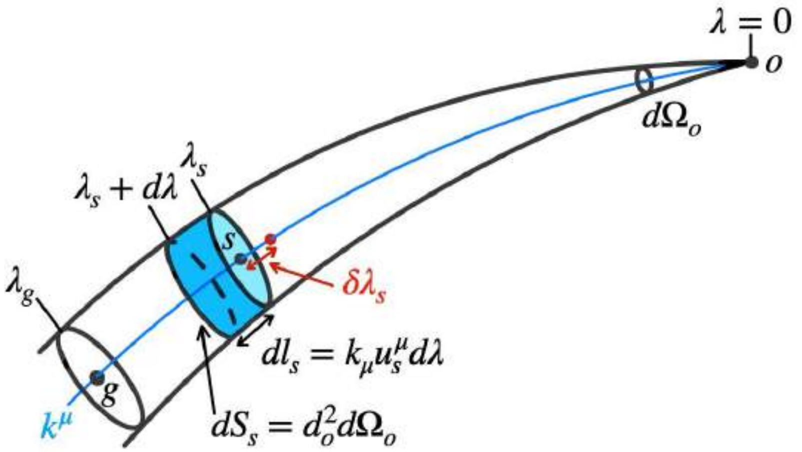


FIG. 1. A source at s emits photons which reach us at o along null geodesics k^μ parameterised by the affine parameter λ. Due to the source velocity u_s^μ, the photon has a spatial displacement dl_s following an infinitesimal change in the affine parameter $d\lambda$. The observed infinitesimal volume is $dV_s = dl_s dS_s$ and the cross-section dS_s of the photon bundle defines the Observer's area distance d_o. A fixed affine parameter λ_s hypersurface is related to a fixed redshift z hypersurface by shifting the affine parameter of the source by $\delta\lambda_s$. There may also be another source g beyond s. The total number count N per solid angle at o is the integral along the whole photon bundle. (After Figure 8 in Ellis [74].)

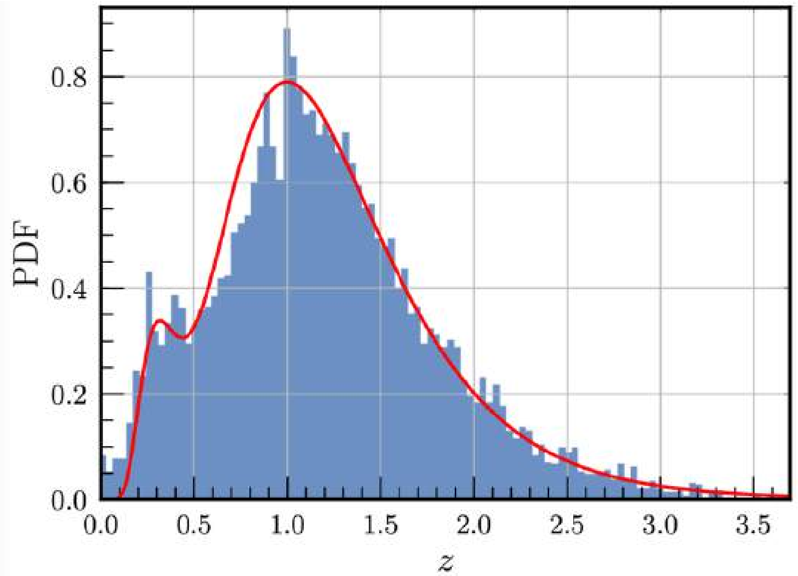
$$d_{\mathcal{N}}^{\text{kin}} = \frac{1}{\int_0^{\lambda_s} \mathcal{N}_s(\lambda, L) r^2 d\lambda} \int_0^{\lambda_s} \left(2 + x(1+\alpha) + \frac{1}{\mathcal{H}} \frac{d}{d\lambda} \ln\left(\frac{r^2 \mathcal{N}_s}{\mathcal{H}}\right)\right) \beta \mathcal{N}_s(\lambda, L) r^2 d\lambda$$

$$= \left(2 + x(1+\alpha)\right)\beta + \boxed{\frac{1}{\int_0^{\lambda_s} \mathcal{N}_s(\lambda, L) r^2 d\lambda} \frac{r_s^2 \mathcal{N}_s}{\mathcal{H}_s} \beta}.$$

Ellis & Baldwin (1984)

where, $\hat{\mathcal{N}}_s(z, F > F_*) = \int_{L_s(z,F)}^{\infty} dL \, \hat{n}_s(z, \ln L)$

Now plugging in $N_s(z)$ for the CatWISE catalogue

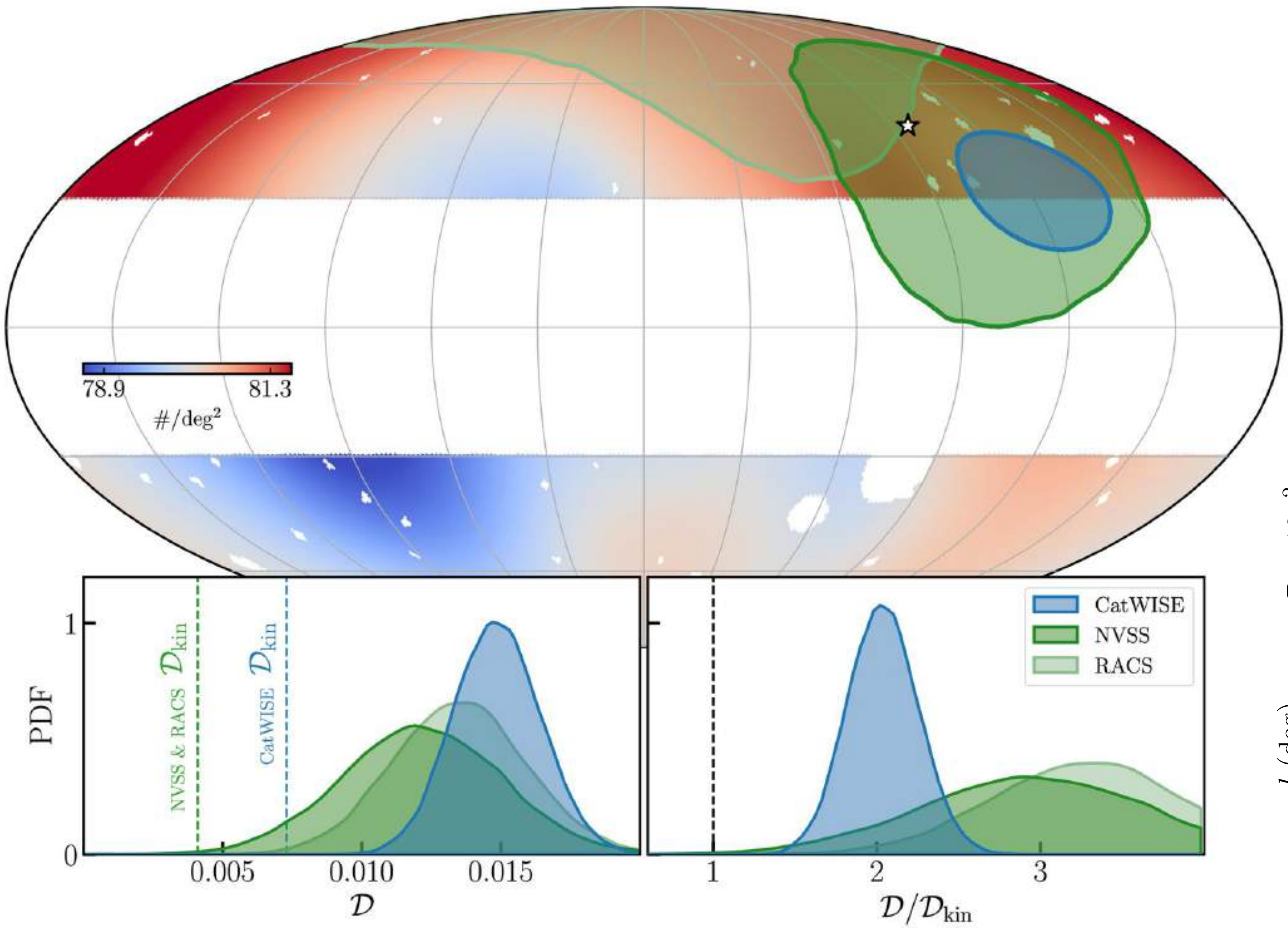


We find that the correction term is <0.001β, so the Ellis & Baldwin (1984) formula is very accurate!

Dalang & Bonvin (*MNRAS* **512**:3895,2022) suggest there may be correlated redshift evolution of x and α which enhances the expected dipole – however von Hausegger shows that the E&B test is quite *robust* when the dipole is evaluated *at the flux threshold* (*MNRAS* **535**:L49,2024)

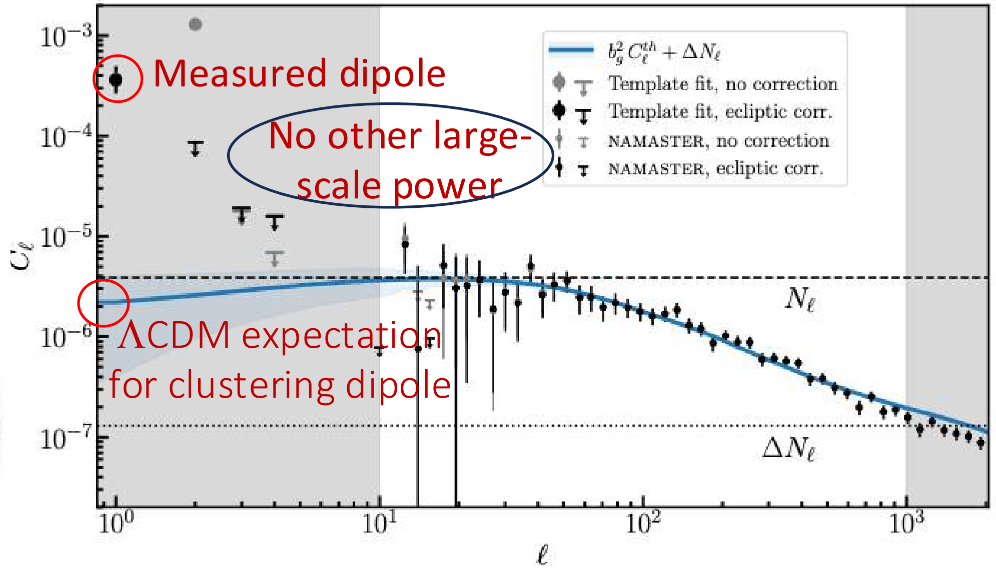
Domenech, Mohayaee, Patil & S.S., *JCAP* **10**:019(2022)

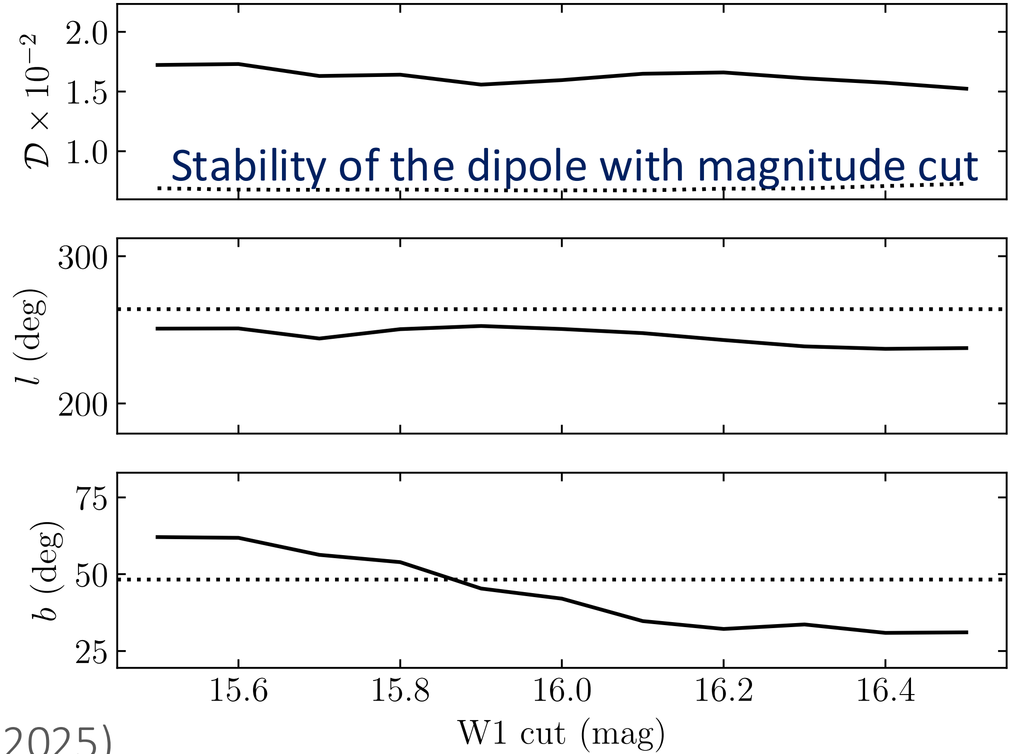
Most significant matter dipole measurements to-date using the CatWISE AGN, NVSS, and RACS-low samples



Posterior probability densities of the inferred dipole amplitudes D compared against their standard kinematic expectations, D_{kin}

CatWISE angular power spectrum





Von Hausegger *et al*, arXiv:2510.23769

Secrest, Rameez, Von Hausegger, Mohayaee, S.S., *Rev.Mod.Phys.* **97**:041001(2025)

Anomalies in physical cosmology

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Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544, USA

Received 9 August 2022, Accepted 21 October 2022

The evidence to be reviewed here is that the dipole anisotropy in the distribution of objects at distances comparable to the Hubble length is about in the direction expected from the kinematic effect if the dipole anisotropy in the CMB is due to our motion relative to the rest frame defined by the mean mass distribution, but the dipole amplitude is at least twice the prediction. **This anomaly is about as well established as the Hubble Tension, yet the literature on the kinematic effect is much smaller than the 344 papers with the phrase "Hubble Tension" in the abstract in the SAO/NASA Astrophysics Data System.** (I expect the difference is an inevitable consequence of the way we behave.)

Annals Phys. **447**:169159(2022)

The mismatch of the CMB & matter frames is motivating interesting attempts at explanation

Dipole Cosmology: The Copernican Paradigm Beyond FLRW
Chethan Krishnan, Ranjini Mondol, M. M. Sheikh-Jabbari [2209.14918]

QCD axion dark matter and the cosmic dipole problem
Chengcheng Han [2211.06912]

Large-scale geometry of the Universe
Yassir Awwad & Tomislav Prokopec [2211.16893]

Spatially Homogeneous Universes with Late-Time Anisotropy [2212.03224]
Andrei Constantin, Thomas R. Harvey, Sebastian von Hausegger & Andre Lukas

Modelling the emergence of cosmic anisotropy from non-linear structures
Theodore Anton & Timothy Clifton [2302.05715]

Superhorizon isocurvature fluctuations relax tensions
Alessandra Fumagalli, Yodovina Piškur, Anže Slosar [2305.15238]

Anisotropic cosmology in the local limit of nonlocal gravity [2308.08281]
Javad Tabatabaei, Abdolali Banihashemi, Shant Baghram & Bahram Mashhoon

Precision cosmology with exact inhomogeneous solutions of General Relativity: the Szekeres models
Marie-Noëlle Célérier [2407.04452]

The Cosmological Dipole in Tilted Anisotropic Universes
Alicia Martin et al [2512.03867]

Superhorizon fluctuations and the cosmic dipole problem
Ge Chen, Chengcheng Han & Linwei Qiu [2507.20462]

Modified Gravity and the Origin of the Excess Radio Galaxy Number-Count Dipole
John Moffat [2601.07487]

Summary

➢ The 'standard model' of cosmology was established before there was any data ...
its empirical foundations (homogeneity, isotropy) have not been rigorously tested.
Now that we have data, it should be a priority to *test the cosmological model assumptions* – not just measure the model parameters with `precision'

➢ We are in a 'bulk flow' which stretches out *beyond* the scale at which the universe is supposed to become statistically homogeneous

The inference from Type Ia supernovae that the Hubble expansion rate is *accelerating* is likely an artefact of this bulk flow and *not* due to Λ

Indeed the inferred acceleration is mainly towards the direction of our local motion

➢ The rest frame of distant matter ≠ the rest frame of the CMB
This is a serious challenge to the assumption of a FLRW metric

With the forthcoming avalanche of data from SPHEREx, Euclid, Rubin/LSST, SKA *etc.*
we must begin again – to construct a new standard model of cosmology
... following the manifesto of Ellis & Stoeger: The 'fitting problem' *CQG* 4:1697(1987)

INFERENCE

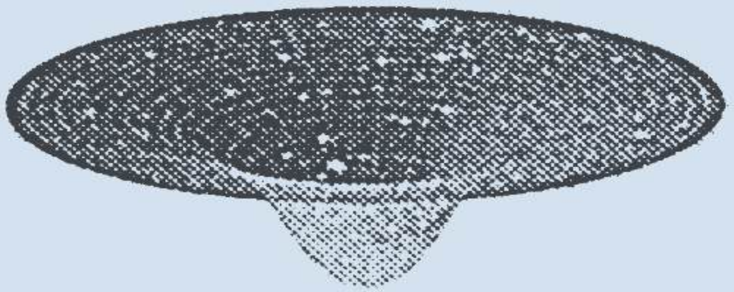
SEARCH

PHYSICS / CRITICAL ESSAY

VOL. 6, NO. 4 / **MARCH 2022**

Heart of Darkness

Subir Sarkar



Cosmologists are often in error, but never in doubt.
—**Lev Landau**[1]

IN THE STANDARD MODEL of cosmology, about seventy percent of the energy density of the universe—the dark energy driving its accelerating rate of expansion—is described by Albert Einstein's cosmological constant.[2] In this essay, I argue that the standard model of cosmology is wrong. This should come as no surprise. "The history of science," Georges Lemaître remarked, "provides many instances of discoveries which have been made for reasons which are no longer considered satisfactory." It may be, he added suggestively, "that the discovery of the cosmological constant is such a case."[3]

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https://doi.org/10.37282/991819.22.21