Title: The dipole tension

Speakers: Roya Mohayaee

Series: Cosmology & Gravitation

Date: October 16, 2023 - 1:30 PM

URL: https://pirsa.org/23100099

Abstract: Standard model of cosmology is based on the cosmological principle. The cosmological principle states that the Universe is statistically homogeneous and isotropic on large scales. Is this hypothesis supported by the observations ? After a historical survey of the field, I shall use the high redshift data from radio galaxies and quasars to show that the early Universe does not seem to be isotropic and the rest frame of cosmic microwave background radiation does not coincide with the rest frame of distant sources. I shall also demonstrate that the cosmological principle is violated at a statistical significance of over 5-sigma.

Zoom link: https://pitp.zoom.us/j/94290315794?pwd=STFpalNNb1NNUHNPNWcvZlkreWNpZz09

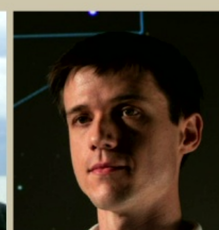
The anomalous dipôle:
Testing the cosmological principle

Roya Mohayaee
IAP , Sorbonne Université


Subir Sarkar (Oxford, UK)


M. Rameez (TIFR, India)


Jacques Colin (IAP, Paris)


Nathan Secrest (NO, USA)


S. Von Hausegger (Oxford, UK)

PI, Waterloo , Monday Octobre 16, 2023

Cosmological principle

The Universe is **homogeneous** and **isotropic**

Translation and Rotation invariance

Cosmological principle

The Universe is **homogeneous** and **isotropic**

$$ds^2 = -c^2dt^2 + a^2(t)(dx^2 + dy^2 + dz^2)$$

FLRW

Homogeneous but anisotropic → Axis

$$ds^2 = -dt^2 + a_x(t)^2 dx^2 + a_y(t)^2 dy^2 + a_z(t)^2 dz^2.$$

Bianchi

Inhomogeneous & isotropic → Centre

$$ds^2 = -dt^2 + X^2(r,t)dr^2 + A^2(r,t)\left(d\theta^2 + \sin^2\theta d\varphi^2\right)$$

LTB

Inhomogeneous & anisotropic

$$ds^2 = dt^2 - A^2dx^2 - B^2(dy^2 + dz^2)$$

$$\begin{aligned} ds^2 = dt^2 &- (A'^2_{\parallel}\sin^2\theta + A'^2_{\perp}\cos^2\theta)dr^2 \\ &- (A^2_{\parallel}\cos^2\theta + A^2_{\perp}\sin^2)d\theta^2 \\ &- (A^{2\prime}_{\parallel} - A^{2}_{\perp}{}') \sin\theta\cos\theta dr d\theta + -A^2_{\parallel}\sin^2\theta d\phi^2. \end{aligned}$$

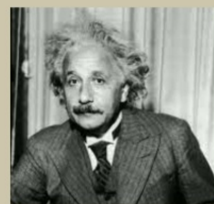
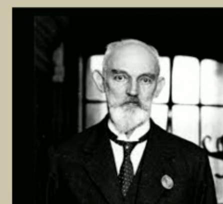
(eg Szekeres models)

The Cosmological principle

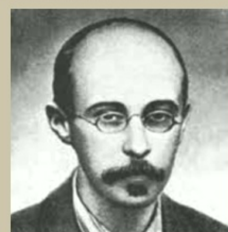
1915

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = 8\pi G T_{\mu\nu}$$

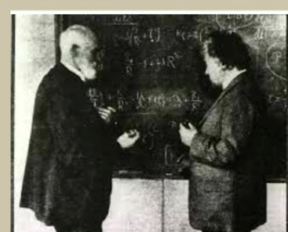
1917

1922-1935




1932



1935
The Cosmological principle
Milne

A new basis for cosmology

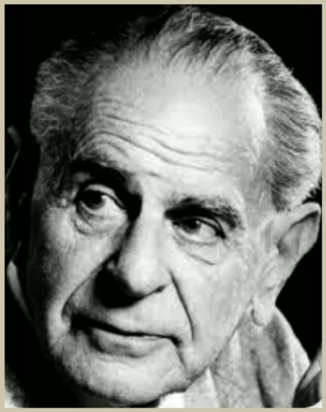
BY P. A. M. DIRAC, F.R.S.
St John's College, Cambridge

(*Received* 29 *December* 1937)

We now feel the need for some new assumptions on which to build up a theory of cosmology. This need is partially satisfied by the assumptions, which Milne calls the Cosmological Principle, that, apart from local irregularities, the universe is everywhere uniform and has spherical symmetry (in three dimensions)

these assumptions are fairly plausible and have a great simplifying effect on the subject, and until there is more definite evidence of their inadequacy it does not seem worth while to try more complicated schemes.

The cosmological principle were, I fear, dogmas that should not have been proposed



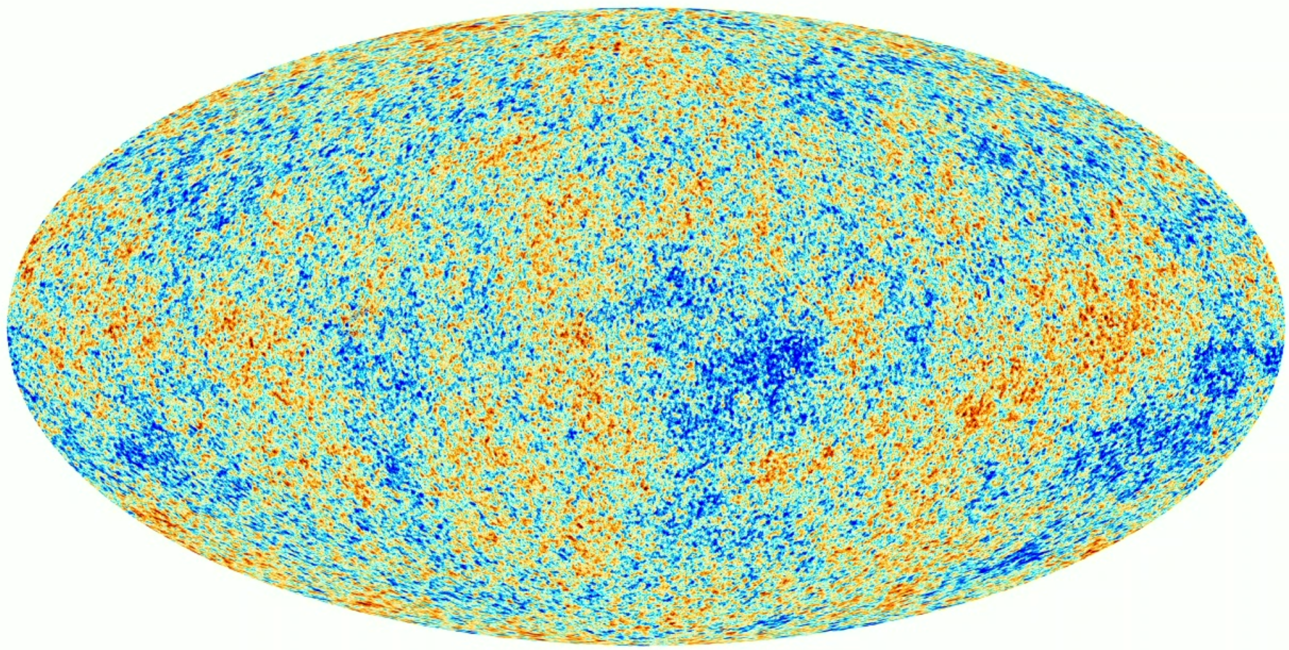
Sir Karl Popper

The scientific status of a theory is its falsifiability, refutability, testability

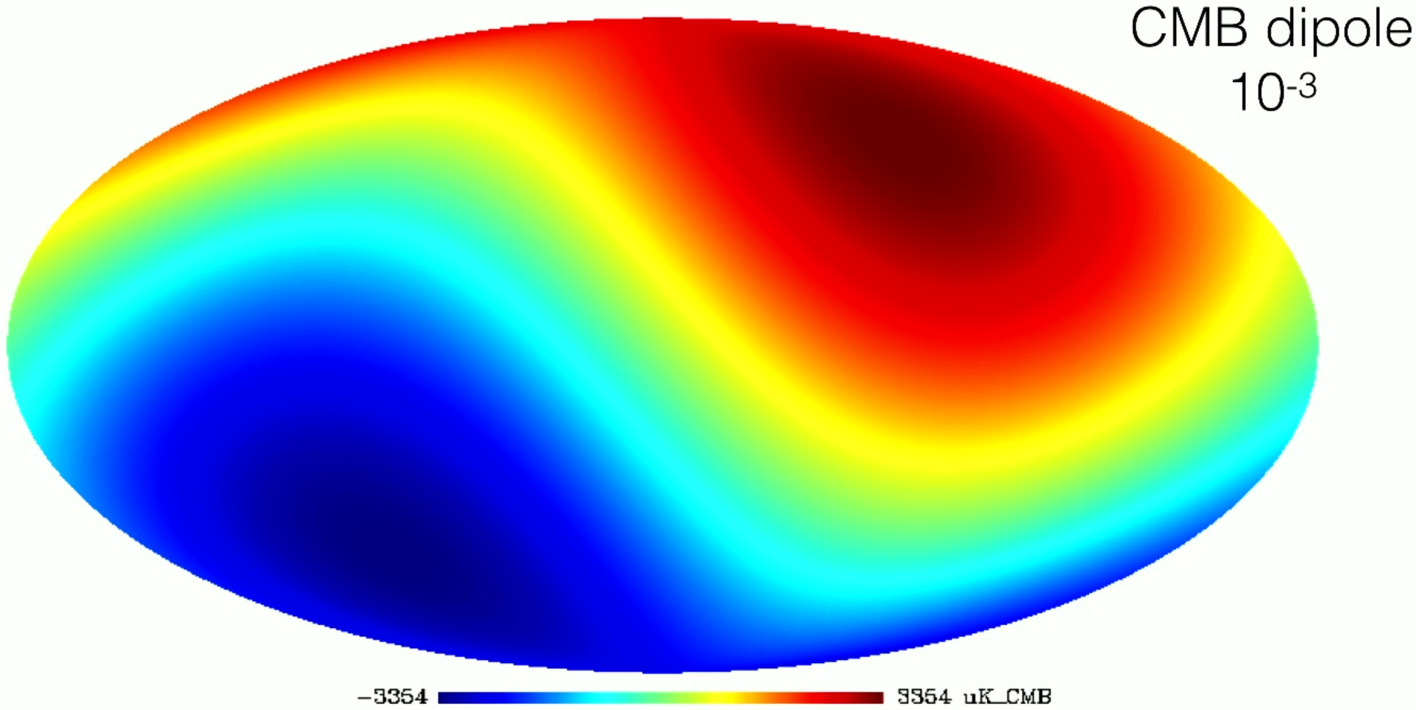
Logik der Forschung , 1934

Observational evidence for the cosmological principle

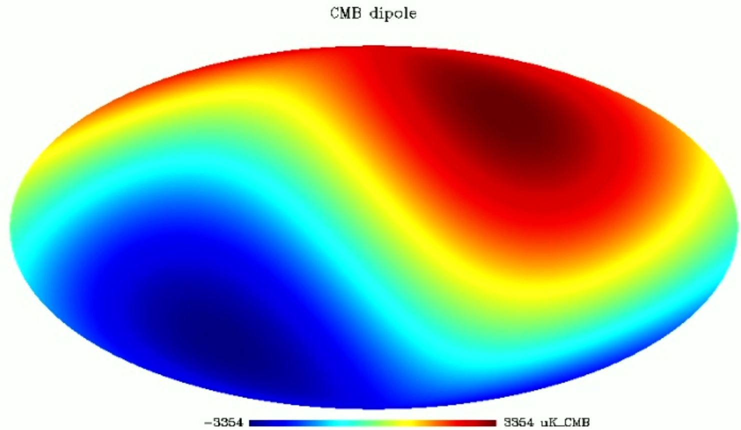
Cosmic microwave background



Cosmic microwave background
Dipole —-Anisotropy



The origin of the CMB dipole ?



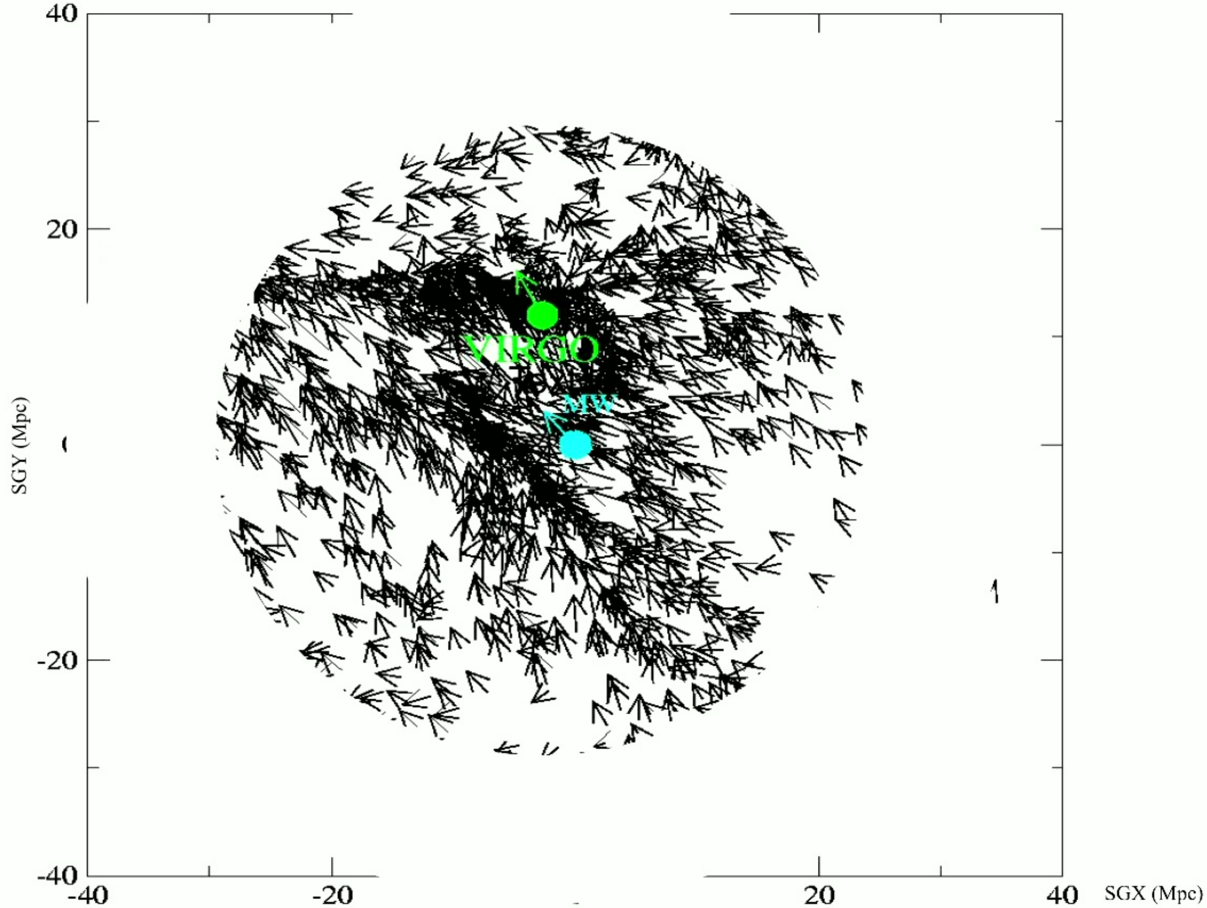
Dipole is purely Kinematic
Universe is anisotropic

Comment on the Anisotropy of the Primeval Fireball*

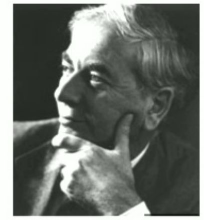
P. J. E. PEEBLES† AND DAVID T. WILKINSON†
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey 08540
(Received 17 June 1968)

$$\mathcal{T}'(\theta') = \mathcal{T}(1 - v^2/c^2)^{1/2}[1 - (v/c)\cos\theta']^{-1}$$

The origin of CMB dipole



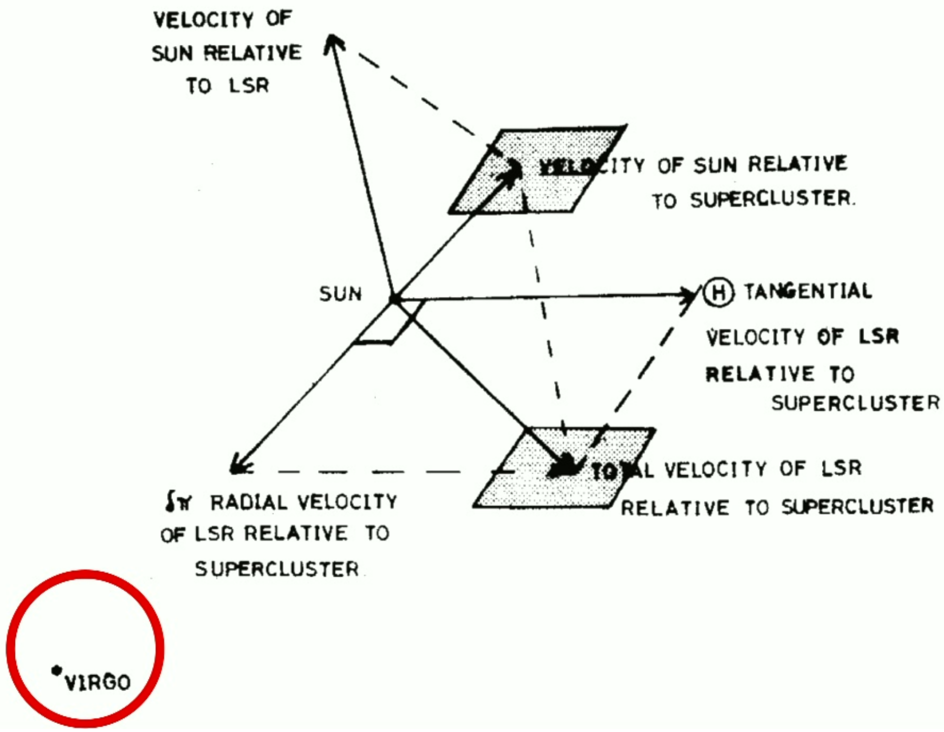
The origin of the CMB dipole



NATURE, VOL. 216, NOVEMBER 25, 1967

Peculiar Velocity of the Sun and its Relation to the Cosmic Microwave Background

by
J. M. STEWART
D. W. SCIAMA



The origin of the CMB dipole

THE ASTROPHYSICAL JOURNAL, **294**:81–95, 1985 July 1

THE INFALL VELOCITY TOWARD VIRGO, THE HUBBLE CONSTANT, AND A SEARCH FOR MOTION TOWARD THE MICROWAVE BACKGROUND

G. A. TAMMANN[1]
Astronomisches Institut der Universität Basel; and
European Southern Observatory

AND

ALLAN SANDAGE
Mount Wilson and Las Campanas Observatories of the Carnegie Institution of Washington

The best estimate of the infall of the Local Group toward Virgo of $v_{vc} = 220$ km s^{-1} is too small and is in the wrong direction to explain the observed motion toward the MWB of 630 km s^{-1} toward $l = 275°$, $b = 30°$ as seen from the centroid of the Local Group. A search for the motion of the Virgo Cluster frame itself of 500 km s^{-1} toward $l = 274°$, $b = 12°$ (a direction found by subtracting our Virgocentric infall from the observed MWB dipole), which is required to explain the data, neither confirms nor denies the existence of such a motion of the Virgo complex *carrying the Local Group with it*. The presently known distance ratios to galaxies in the shell between $V = 2500$ and $V = 5000$ km s^{-1} are just sufficiently inaccurate for a definitive test.

Tammann & Sandage (1985) also suggested the gravity of the Hydra-Centaurus supercluster as the cause of the Local Group's motion relative to the CMB.

The origin of the CMB dipole

Presidential Address of 1987 February 13: Light, Gravity and Galaxy Streaming

D.Lynden-Bell
Institute of Astronomy, The Observatories, Madingley Road, Cambridge, CB3 0HA

(Received 1987 February 25)

Tammann & Sandage (1985) also suggested the gravity of the Hydra-Centaurus super-cluster as the cause of the Local Group's motion relative to the CMB.

However, there is something not quite right

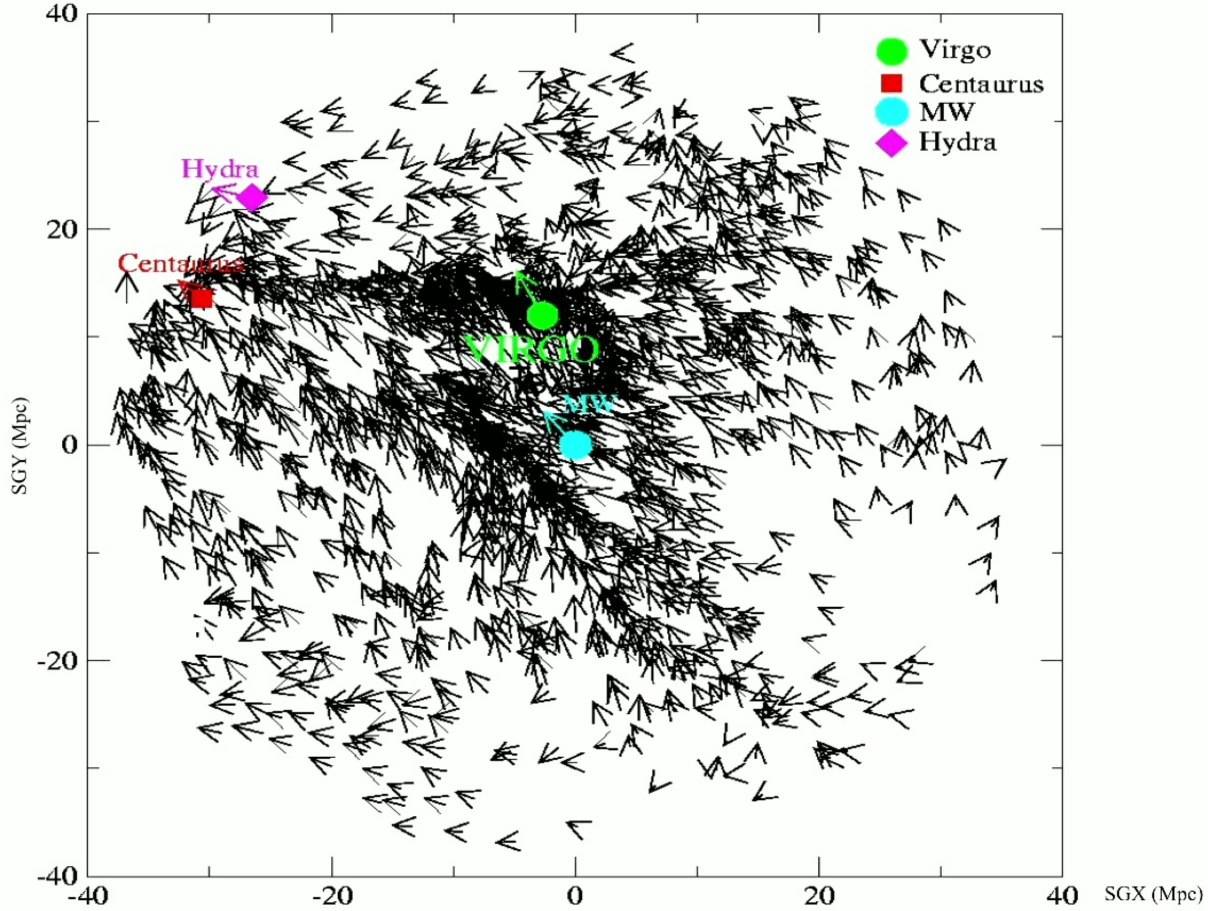
Comment on the Anisotropy of the Primeval Fireball*

P. J. E. PEEBLES† AND DAVID T. WILKINSON†
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey 08540
(Received 17 June 1968)

$$\mathcal{T}'(\theta') = \mathcal{T}(1 - v^2/c^2)^{1/2}[1 - (v/c)\cos\theta']^{-1}$$

Convergence to CMB dipole at great-attractor

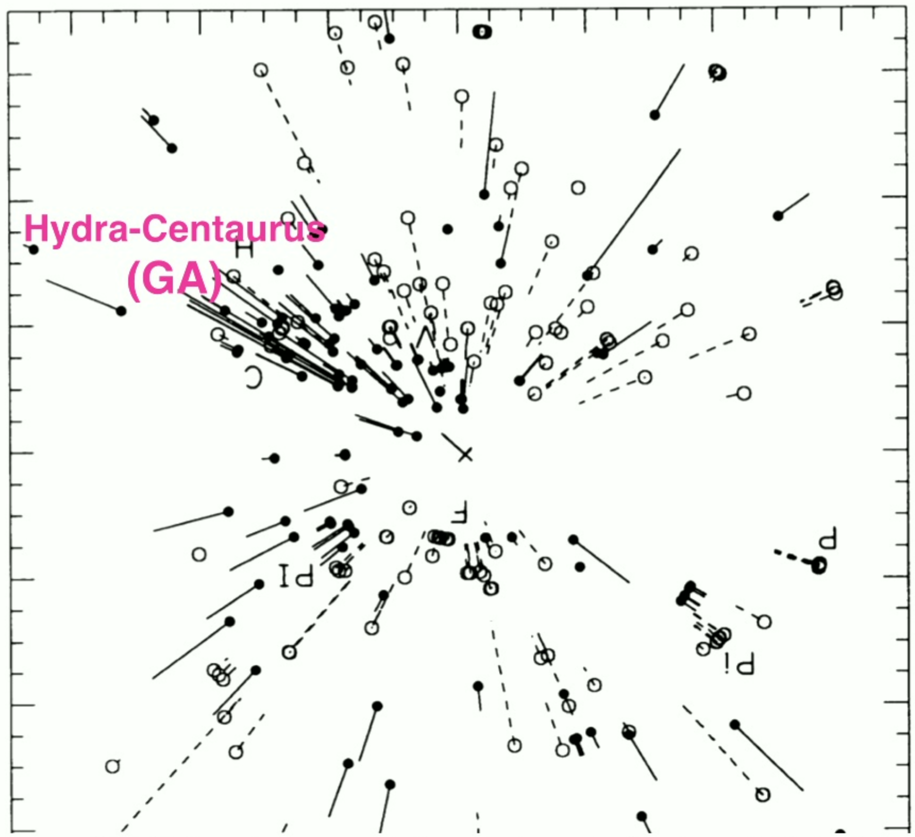
Confirmed by Aaronson et al 1987, etc….



The origin of the CMB dipole

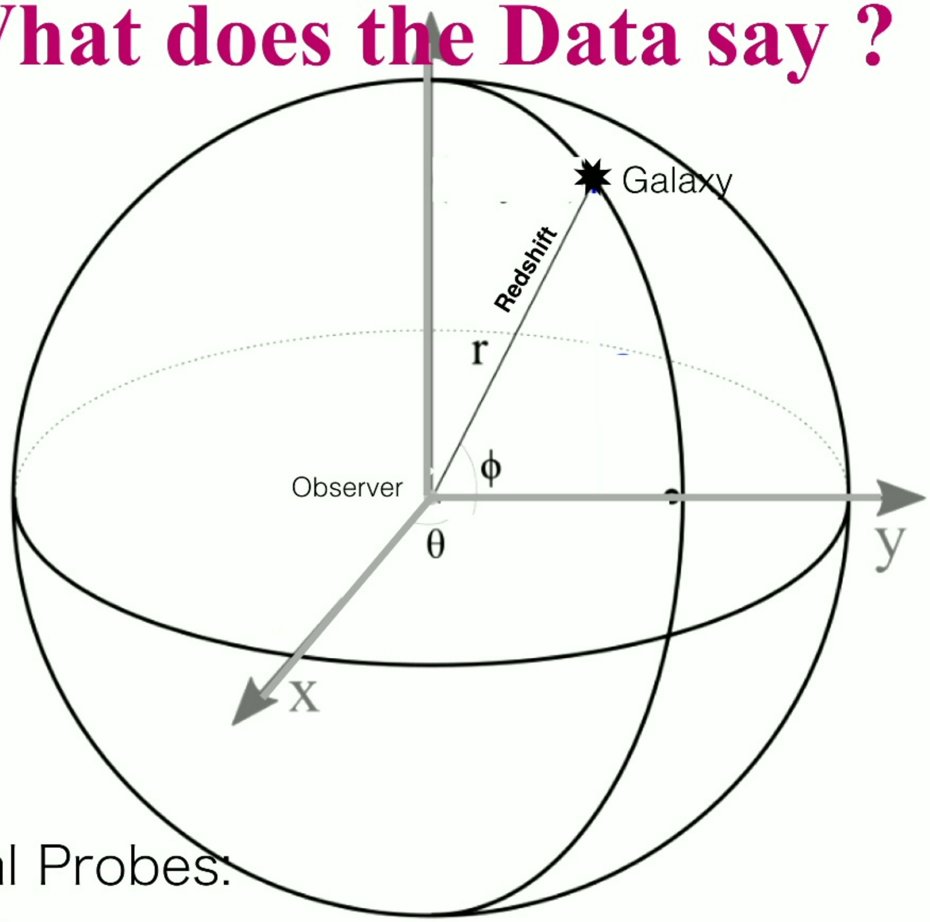
Alan Dressler, Sandy Faber, David Burstein, Roger David, Donal Lynden-Bell, Terlevich, Gary Wagner

Seven Samurai , 1987



Our data show that if the microwave dipole anisotropy is due to a motion of the Local Group of ~ 600 km s^{-1}, as conventionally interpreted, this motion is *not* primarily the result of gravitational acceleration by local ($V < 5000$ km s^{-1}) mass concentrations.

What does the Data say ?



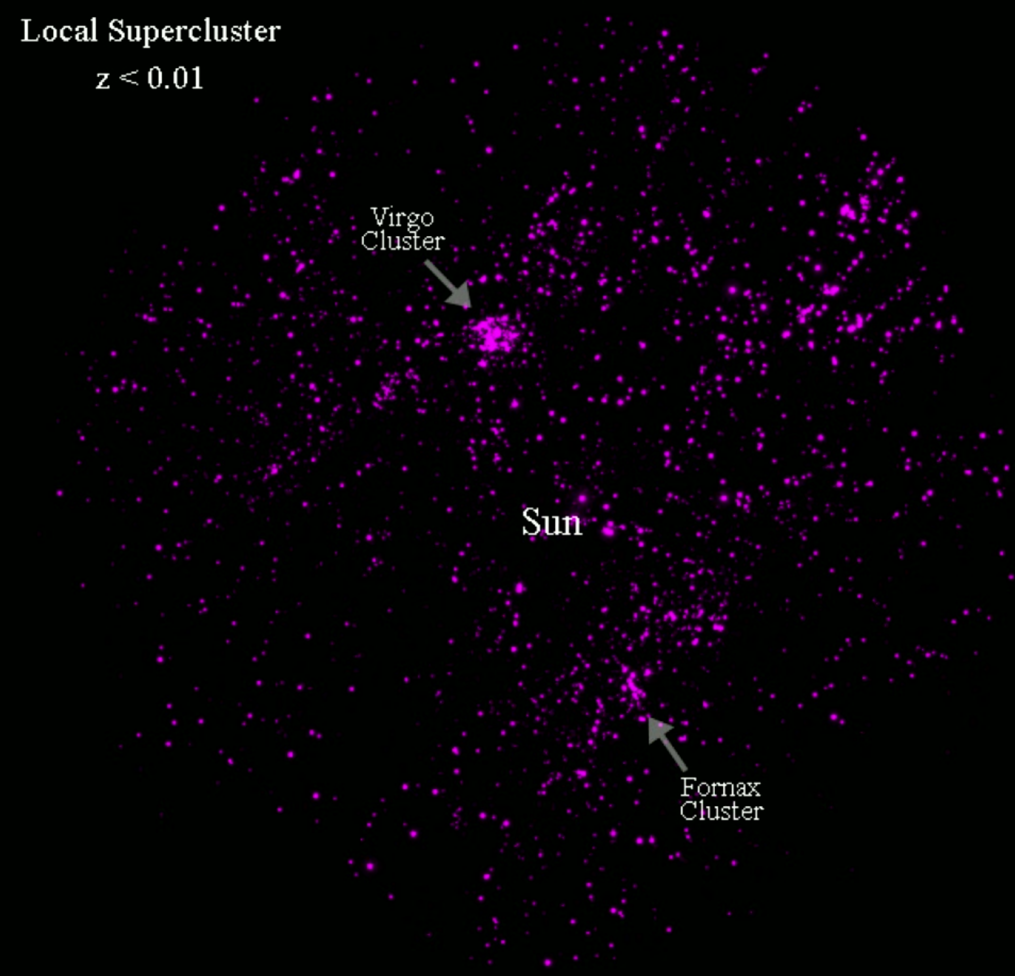
Observational Probes:

(I) Θ, φ, z, d (distance catalogues)

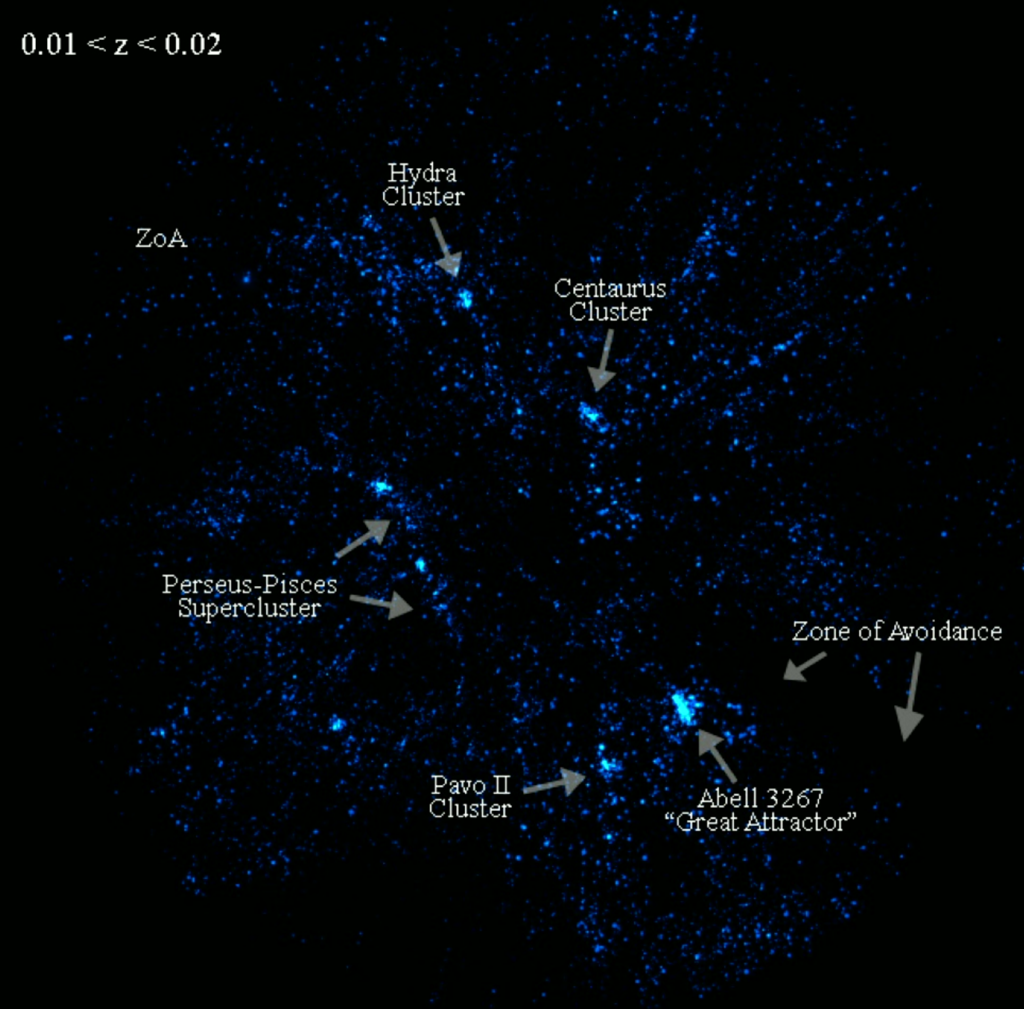
(II) Θ, φ, z (redshift surveys)

(III) Θ, φ (Imaging surveys)

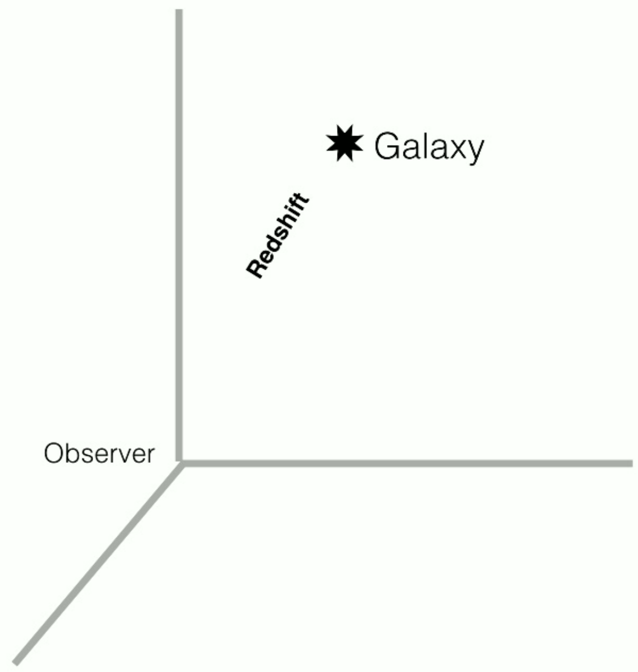
Bulk flow of increasingly volume: CMB rest frame ?



Bulk flow of increasingly larger volume: CMB rest frame ?



Real Data



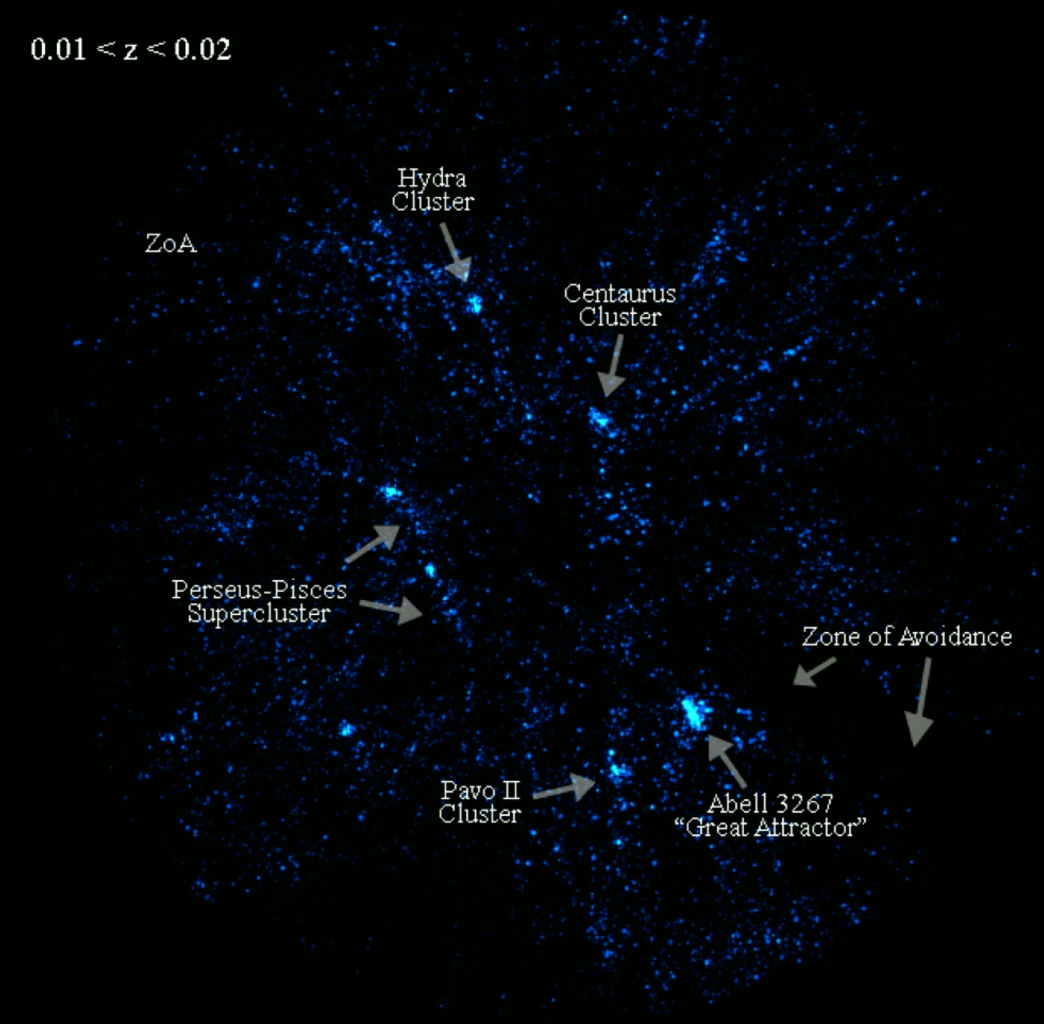
Observational Probes:

(I) Θ, φ, z, d (distance catalogues)

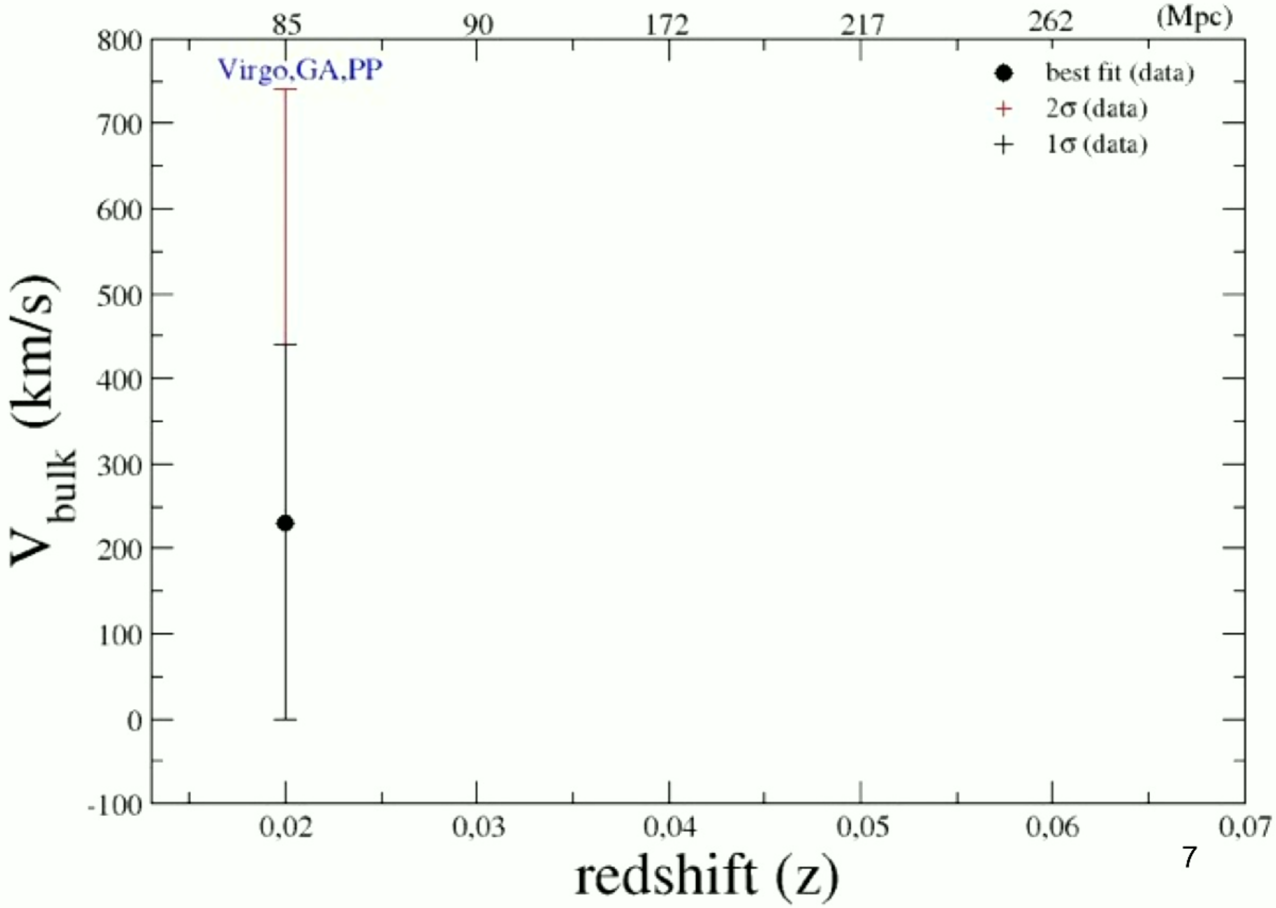
(II) Θ, φ, z (spectro surveys)

(III) Θ, φ (imaging surveys)

Bulk flow of increasingly larger volume: CMB rest frame ?



|Bulk flow| from SNe Ia data



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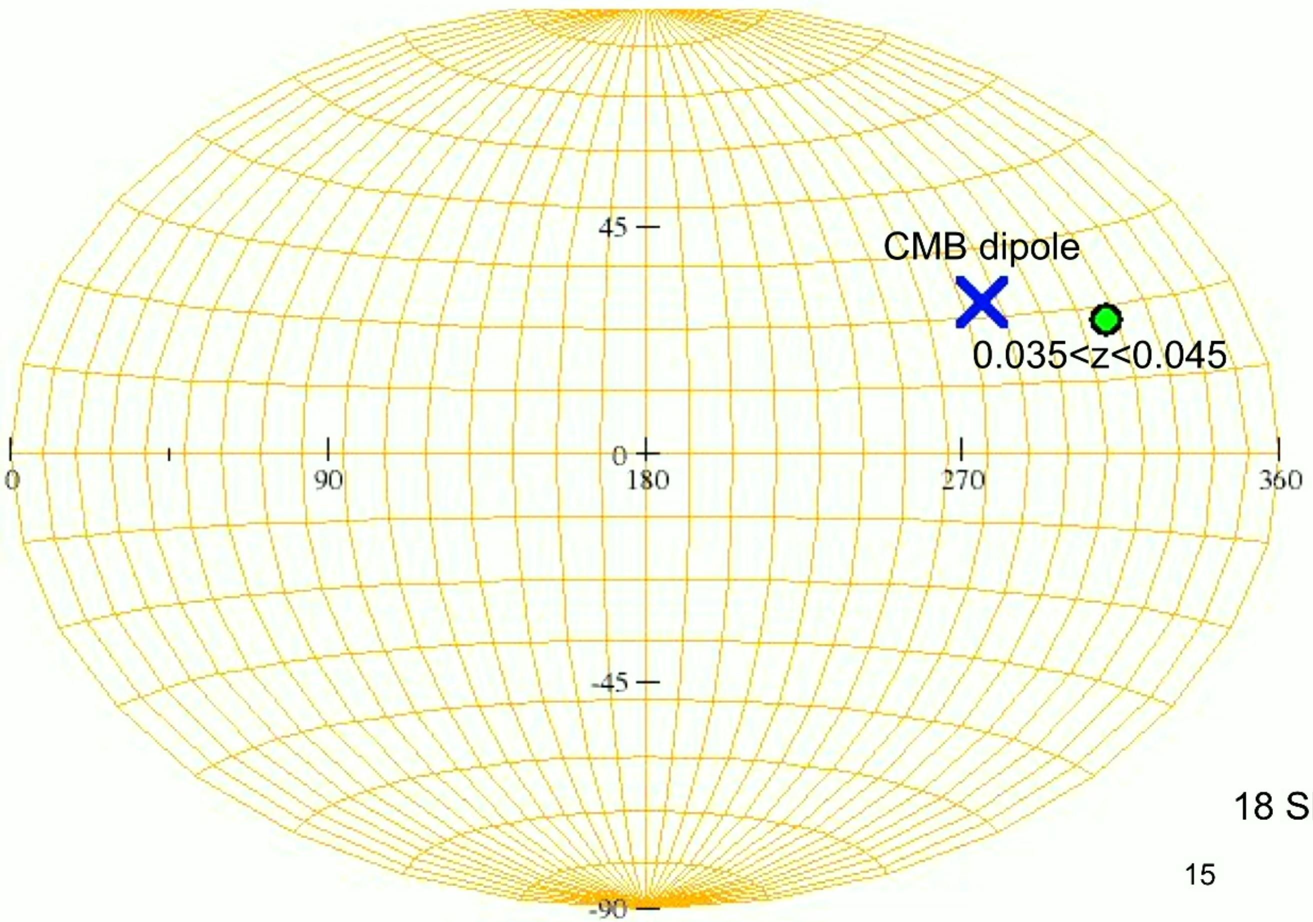
Bulk flow direction from data



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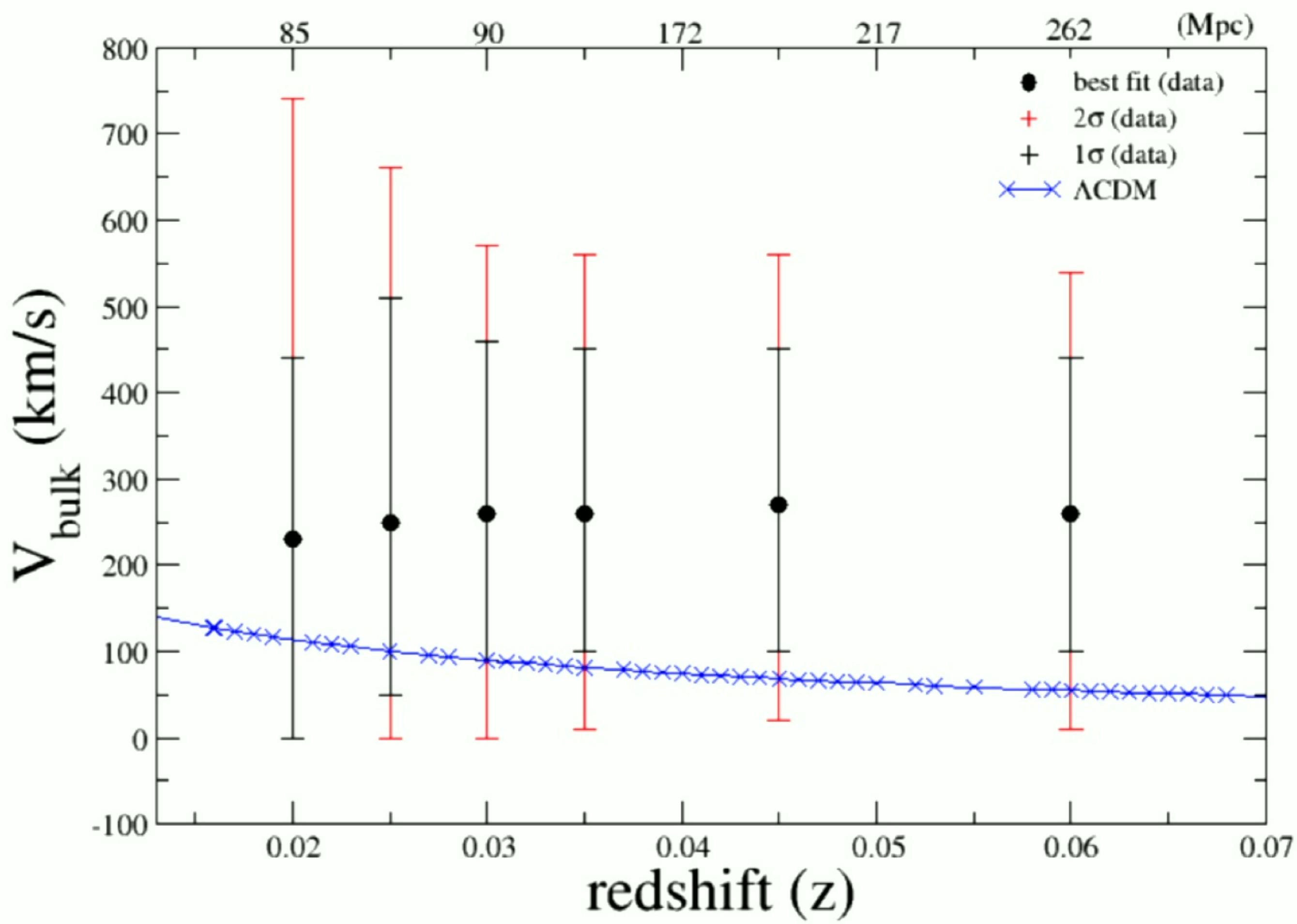
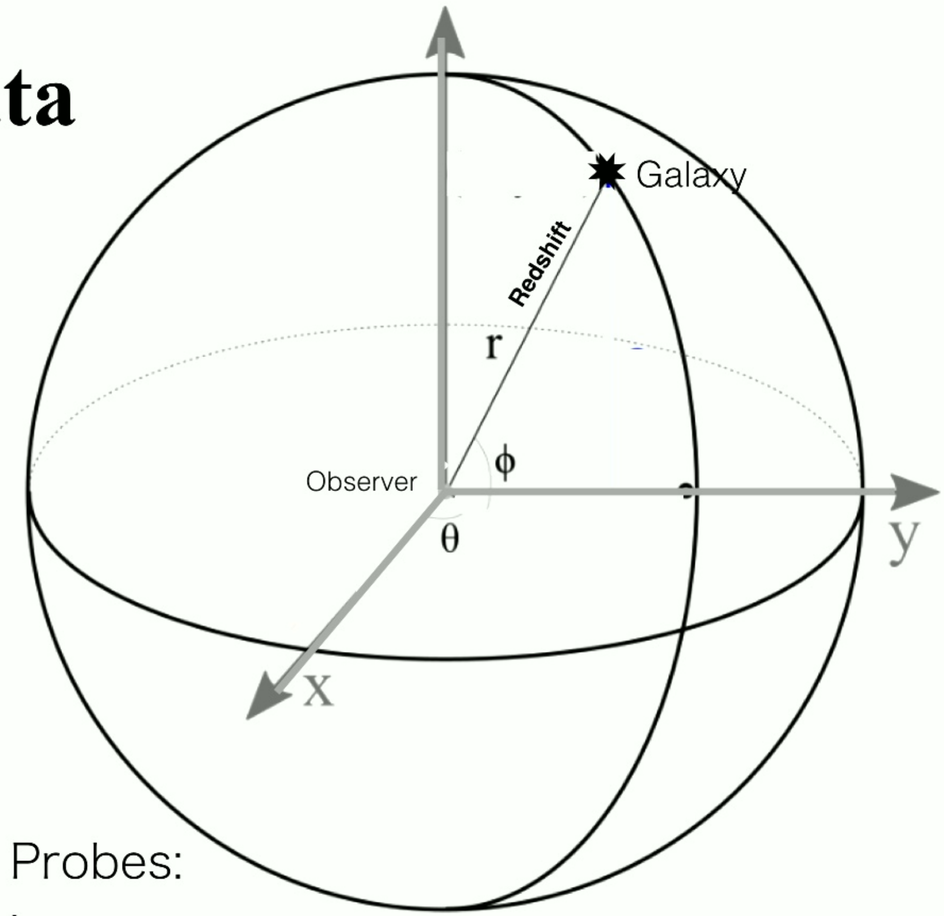

(Mpc)
85
90
172
217
262
800
700
600
500
400
300
200
100
0
-100
best fit (data)
2σ (data)
1σ (data)
ΛCDM
V bulk (km/s)
0.02
0.03
0.04
0.05
0.06
0.07
redshift (z)

Real Data



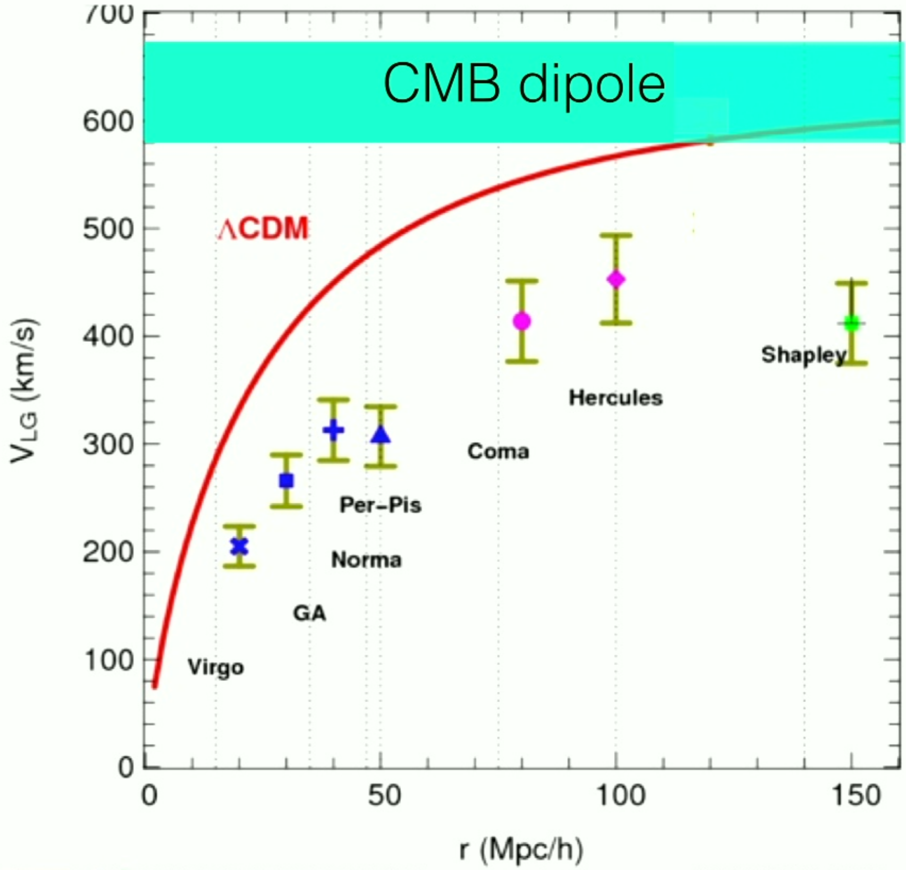
Observational Probes:

(I) Θ, φ, z, d (SNe Ia ⋯ catalogues)

(II) Θ, φ, z (redshift catalogues)

(III) Θ, φ (photometric catalogues)

Test of cosmological principle : CMB rest frame



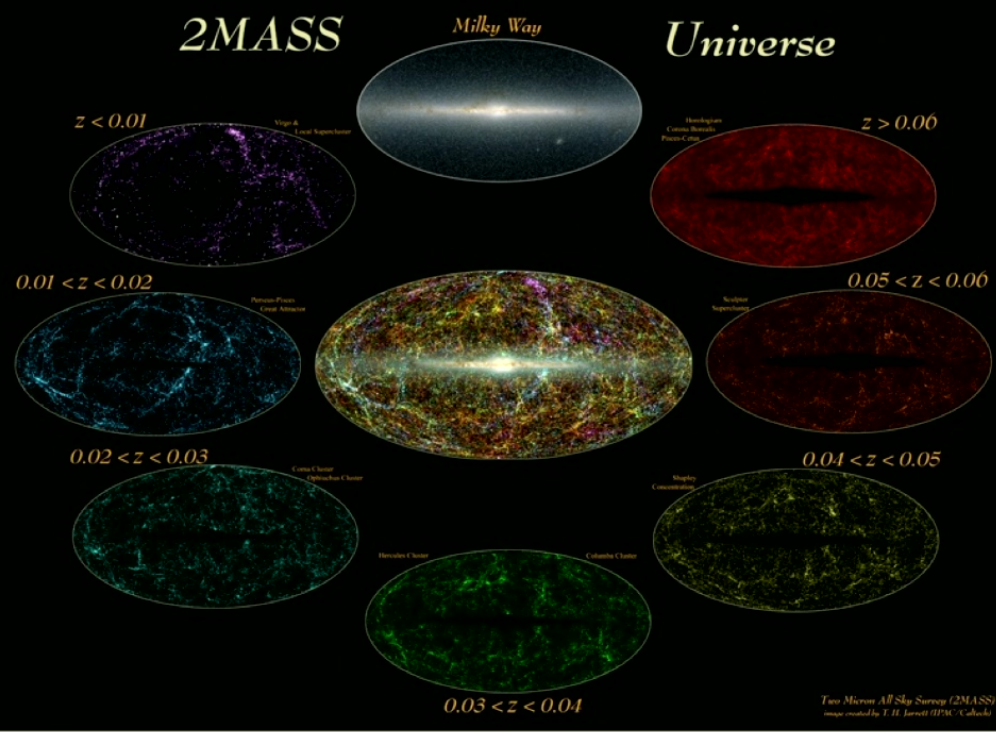
Cosmological principle:
rest-frame of high redshift "sources" = CMB rest frame

2MRS redshift survey

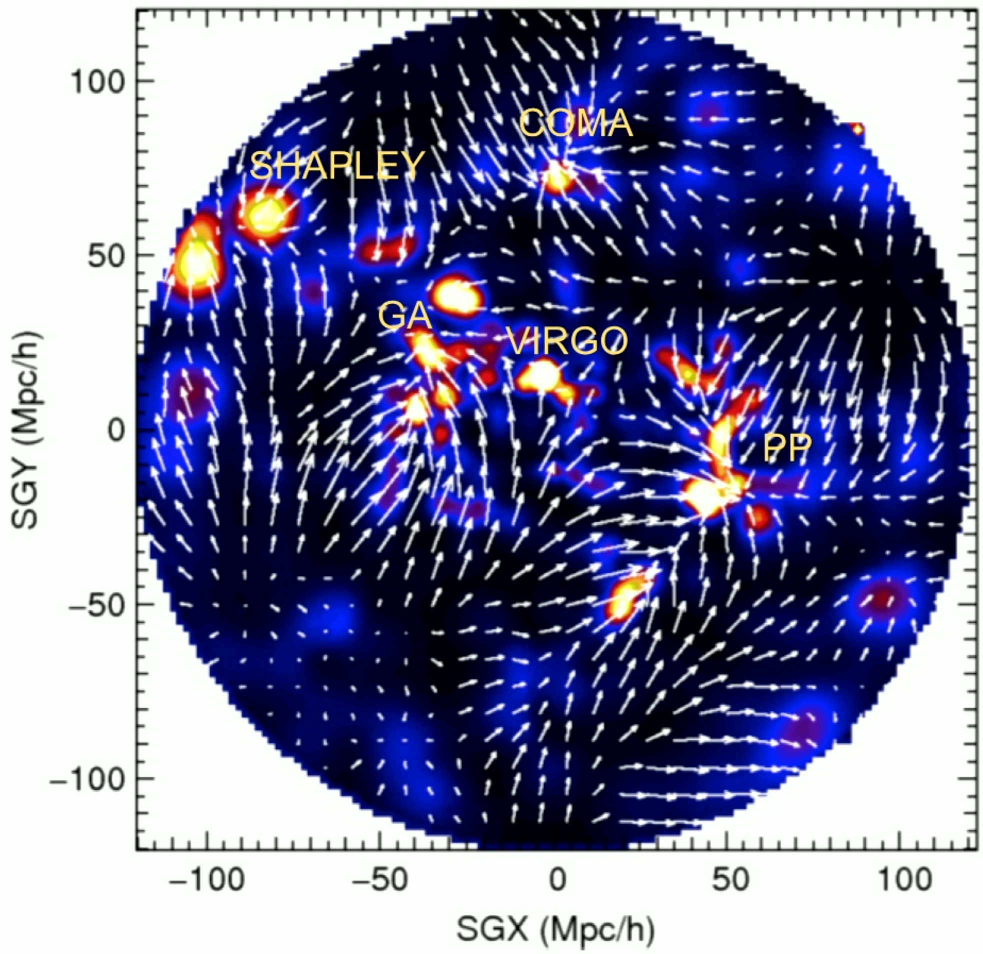
(Huchra etal 2005,...)

Based upon the 2MASS photometric galaxy catalog , Full sky
~25000 galaxies, selected with K_s<11.25

~250 Mpc/h (z~0.08) deep , Distribution peaks at ~90 Mpc/h (z~0.03)



Velocity field of 2MRS: from great attractor to Shapley infall



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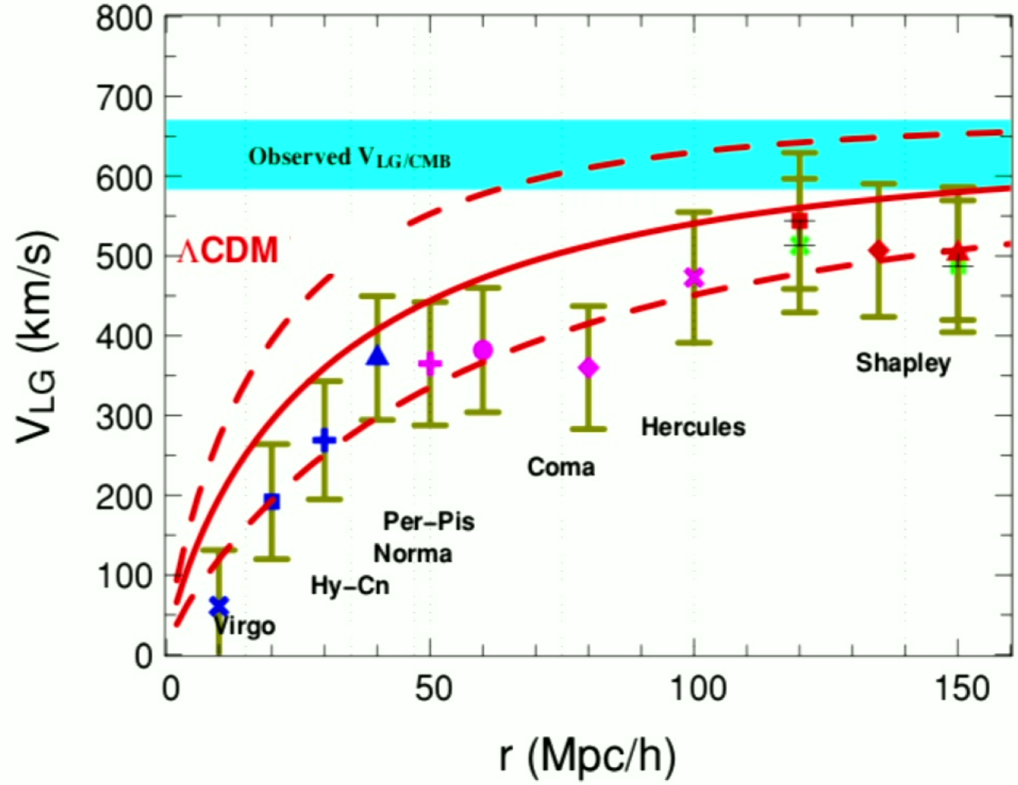
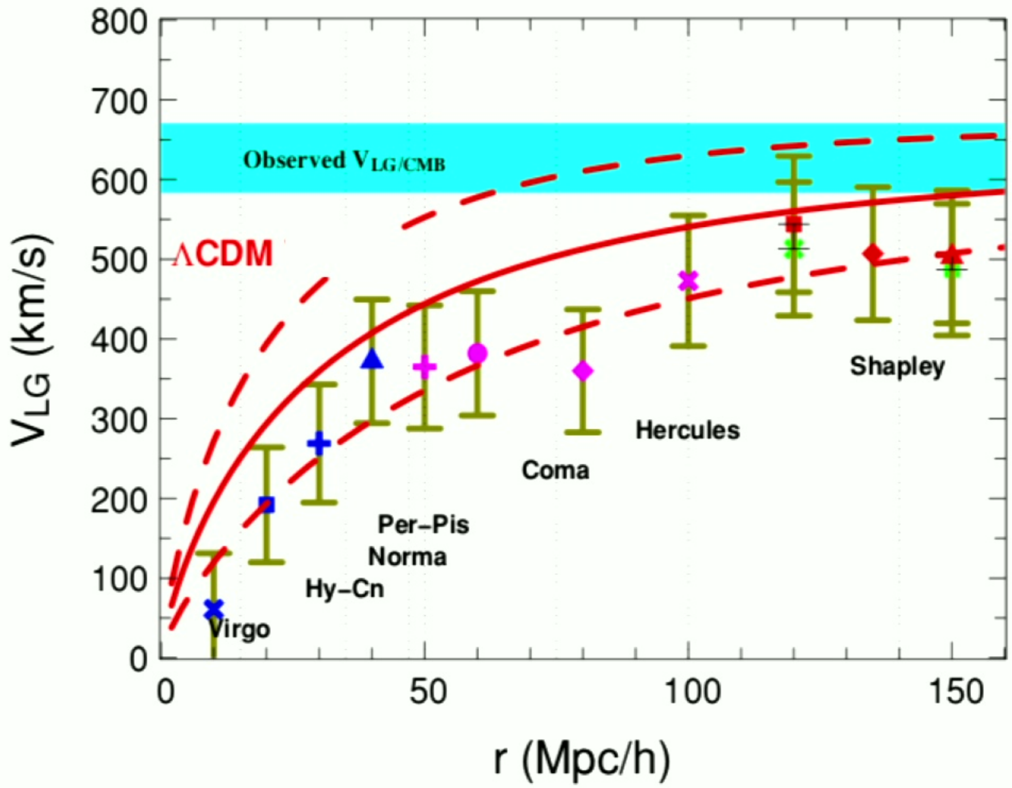
Test of cosmological principle : CMB rest frame



Cosmological principle:
rest-frame of high redshift “sources” = CMB rest frame

Test of cosmological principle : CMB rest frame

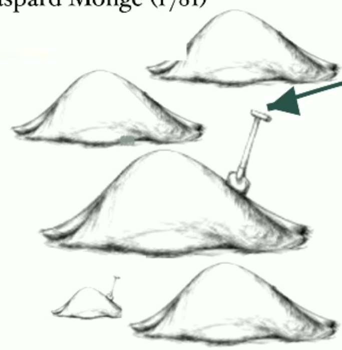


Cosmological principle:
rest-frame of high redshift "sources" = CMB rest frame

Can we measure velocities from positions ?

Gaspard Monge (1781)

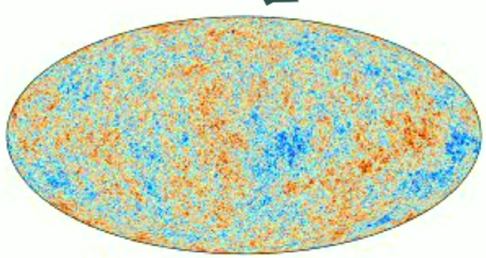
Remblais

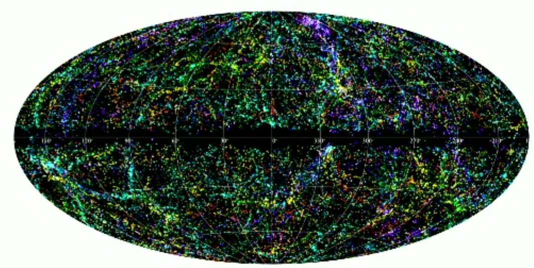


$$\inf_{T\#\mu=\eta} \int c(x, T(x))d\mu(x)$$

Déblais

$$\det(\nabla_{x_i} \nabla_{x_j} \Theta(\boldsymbol{x})) = \rho_0(\boldsymbol{x}).$$





Fluid dynamics in an expanding background

Mass Conservation :

$$\rho(\boldsymbol{x})\mathrm{d}\boldsymbol{x} = \rho_0(\boldsymbol{q})\mathrm{d}\boldsymbol{q},$$

$$\det\left[\frac{\partial q_i}{\partial x_j}\right] = \frac{\rho(\boldsymbol{x})}{\rho_0(\boldsymbol{q})}$$

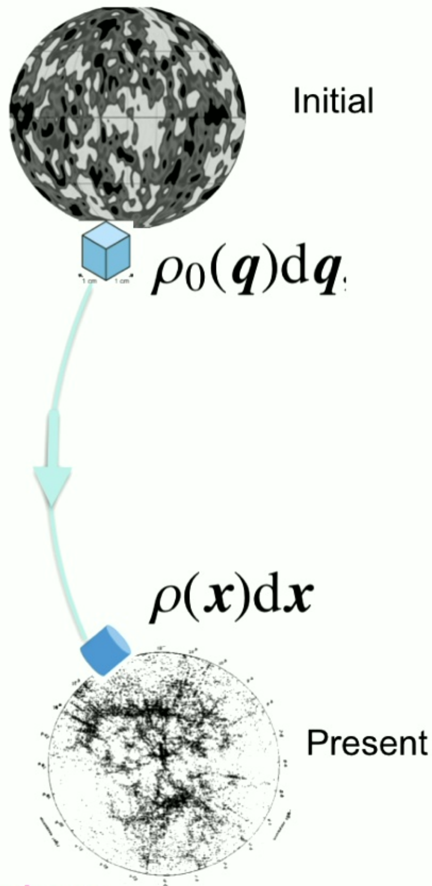
$$\boldsymbol{x}(\boldsymbol{q},t) = \nabla_q \Phi(\boldsymbol{q},t)$$

Legendre transform

$$\Theta(\boldsymbol{x}) = \max_{\boldsymbol{q}}\left[\boldsymbol{q}\cdot\boldsymbol{x} - \Phi(\boldsymbol{q})\right] \;\; ; \;\; \Phi(\boldsymbol{q}) = \max_{\boldsymbol{x}}\left[\boldsymbol{x}\cdot\boldsymbol{q} - \Theta(\boldsymbol{x})\right]$$

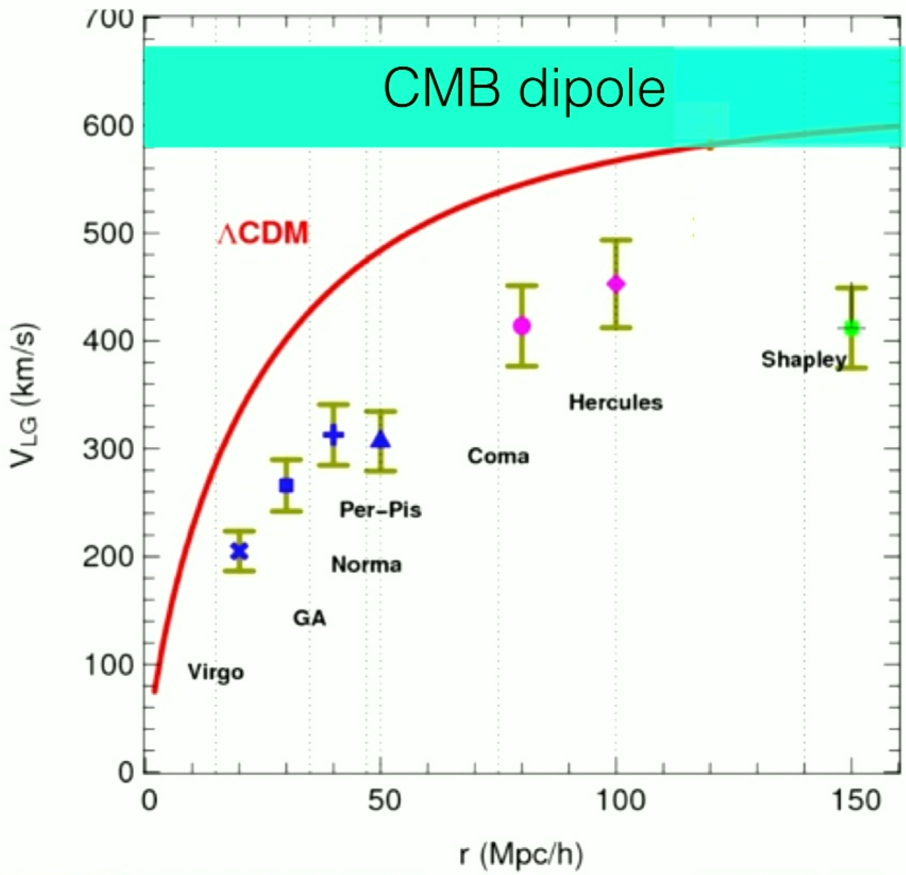
$$\boldsymbol{q}(\boldsymbol{x}) = \nabla_x \Theta(\boldsymbol{x})$$

$$\det\left[\frac{\partial^2\Theta(\boldsymbol{x},t)}{\partial x_i \partial x_j}\right] = \frac{\rho(\boldsymbol{x})}{\rho_0},$$



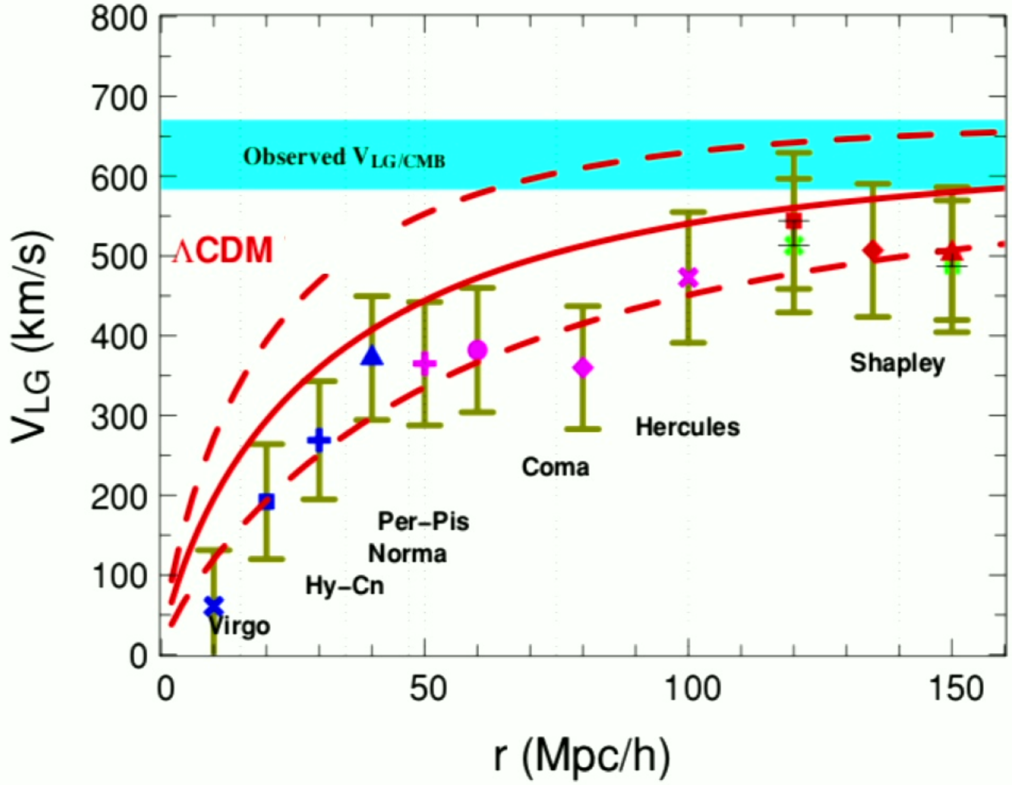
Solve using the Optimal Transport theory

Test of cosmological principle : CMB rest frame



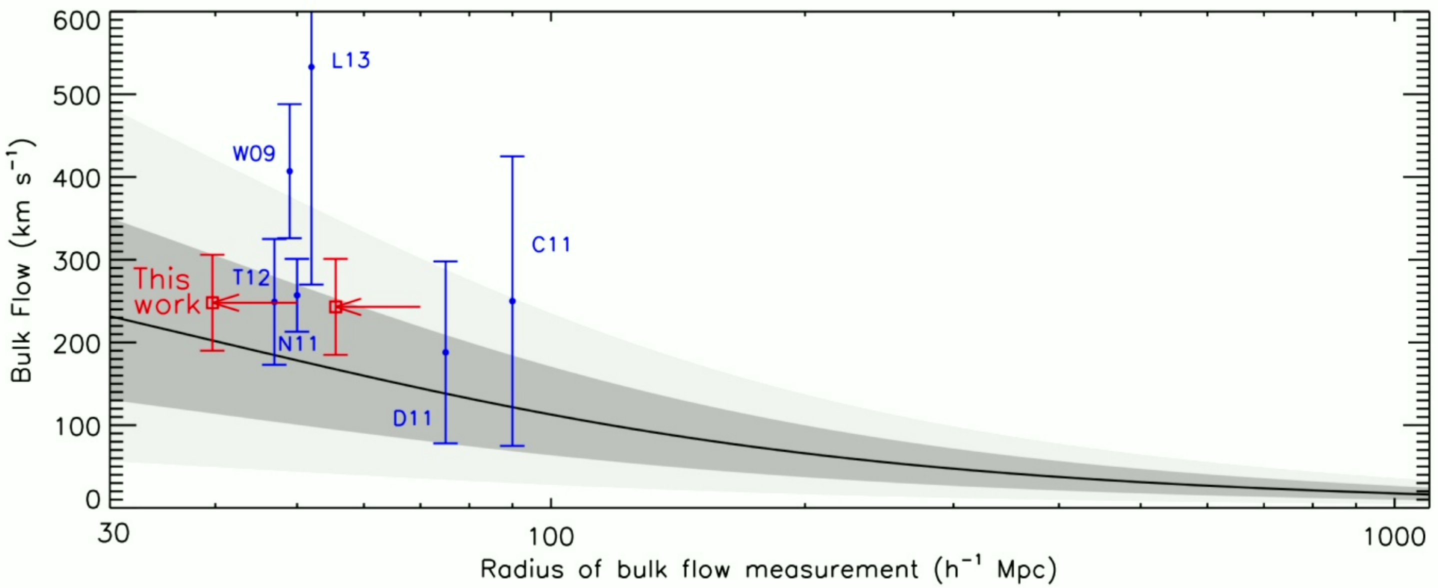
Cosmological principle:
rest-frame of high redshift “sources” = CMB rest frame

Test of cosmological principle : CMB rest frame



Cosmological principle:
rest-frame of high redshift "sources" = CMB rest frame

6dF galaxy survey: bulk flow 2016



Wide-field Infrared Survey Explorer

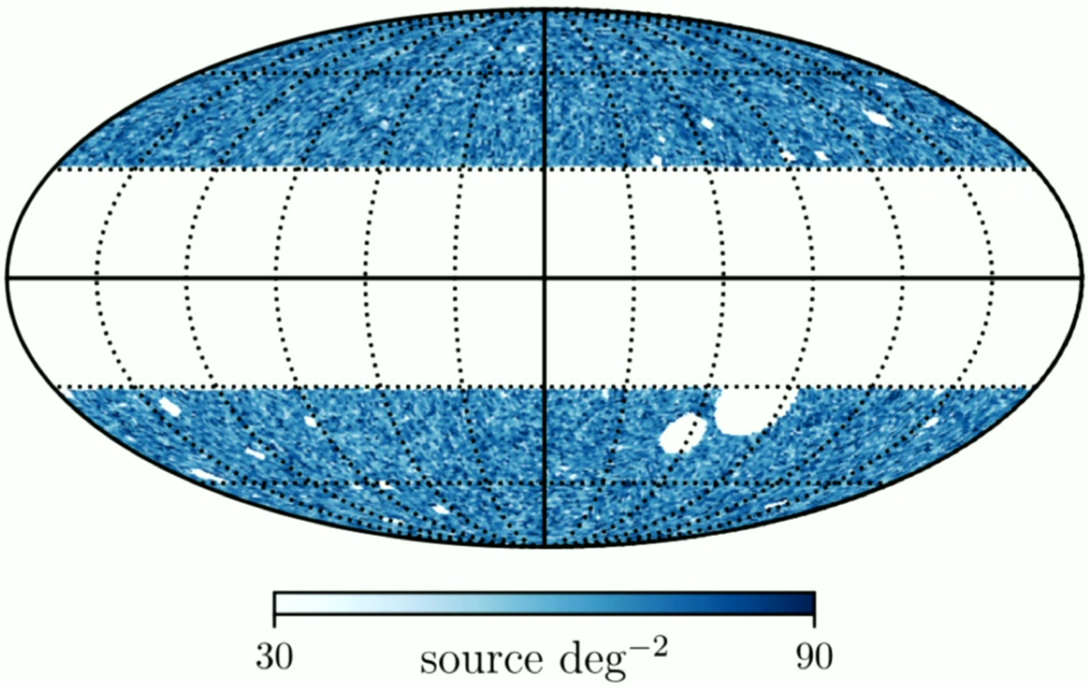
WISE :(Wright et al. 2010) & NEOWISE (Mainzer et al. 2011)

CatWISE : Eisenhardt et al 2020

positions and the four-band photometry for 747,634,026 objects

Full-sky **mid-infrared** survey in:

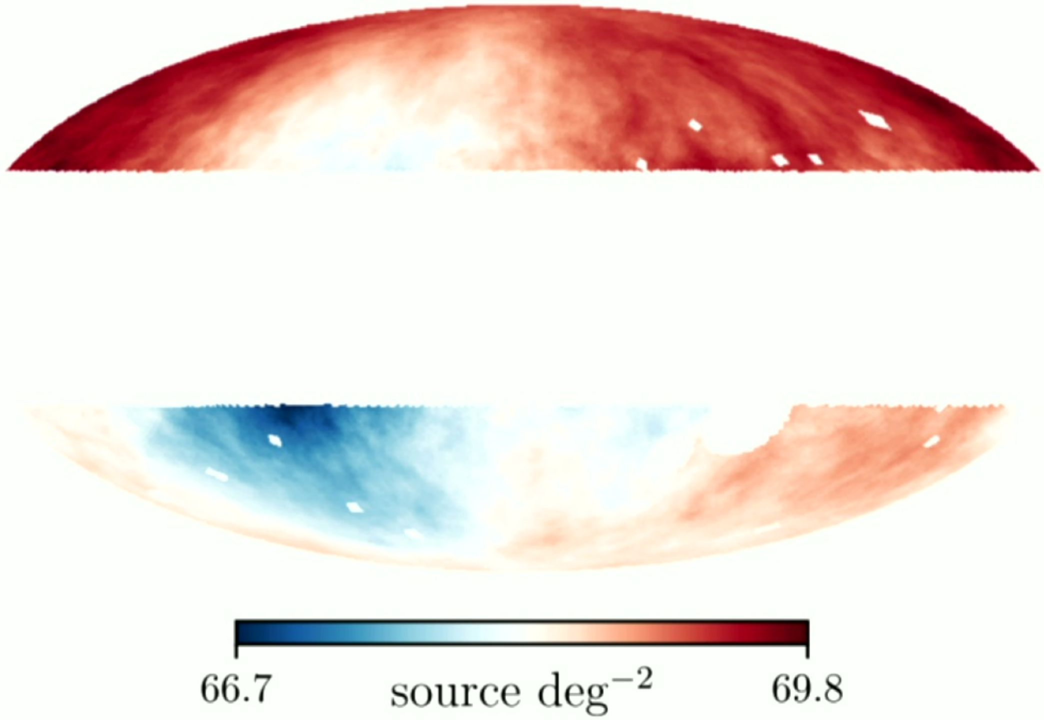
3.4um (W1) (2009 – present)
4.6um (W2) (2009 – present)
12um (W3) (2009 – 2010)
22um (W4) (2009 – 2010)



The Dipole

Quasar Dipole = 0.01554, (l, b) = (238°. 2, 28°.8).

CMB dipole. = 0.007 , (l, b) = (276°, 30°)



Aberration

Ellis and Baldwin 1984

Anisotropy in source distribution → observer's velocity

Aberration and Doppler boosting

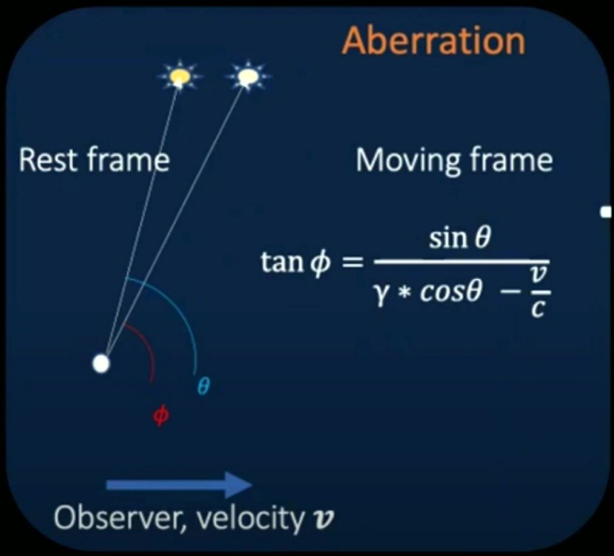
$$\textbf{Dipole} = [2 + x(1 + \alpha)]v/c.$$

$$dN/d\Omega(>S_\nu) \propto S_\nu^{-x}.$$

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

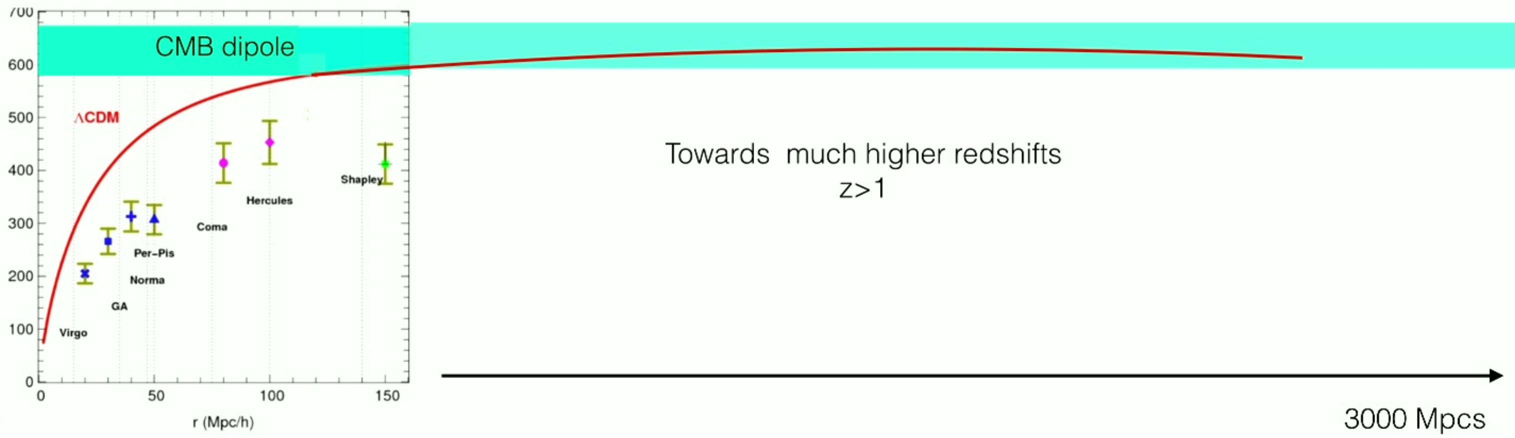
Independent of distance to the source

Probe 3 : Imaging surveys
Θ, ϕ
Aberration and Doppler boosting



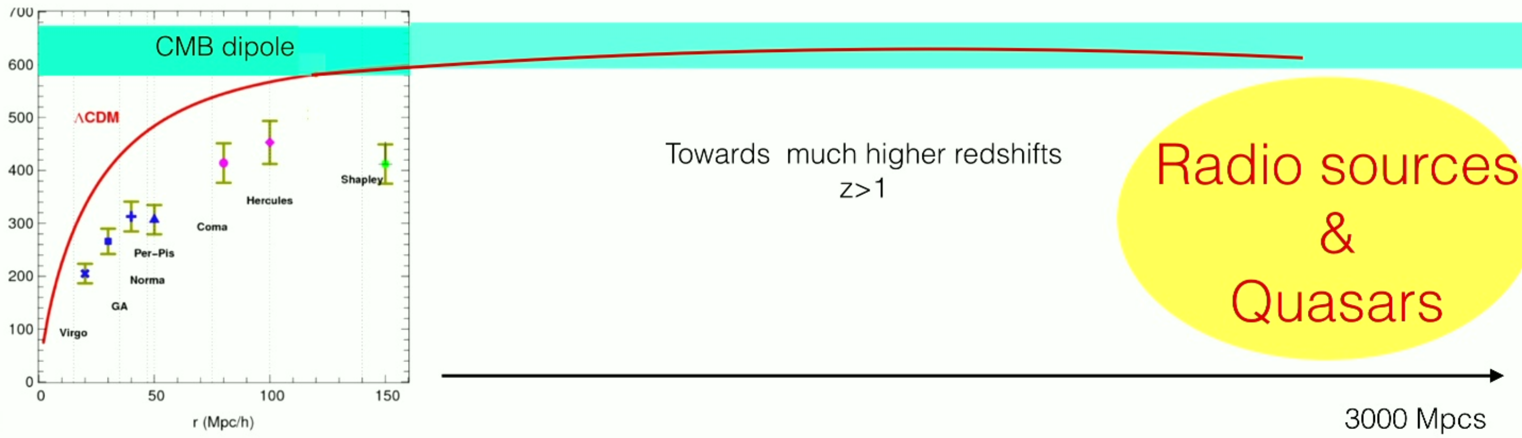
Ellis & Baldwin,
MNRAS 206:377,1984

Test of cosmological principle : CMB rest frame



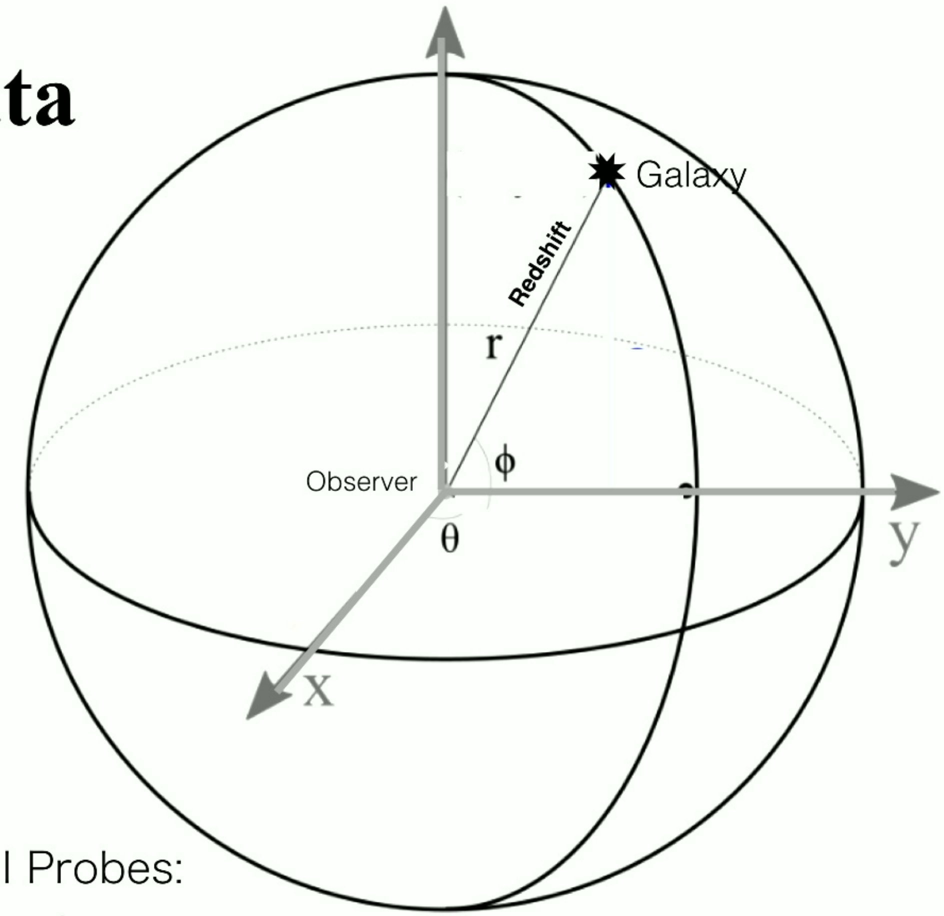
Cosmological principle:
rest-frame of high redshift “sources” = CMB rest frame

Test of cosmological principle : searching for CMB rest frame



Dipole in the rest-frame of high redshift sources = Dipole in the CMB rest frame

Real Data



Observational Probes:

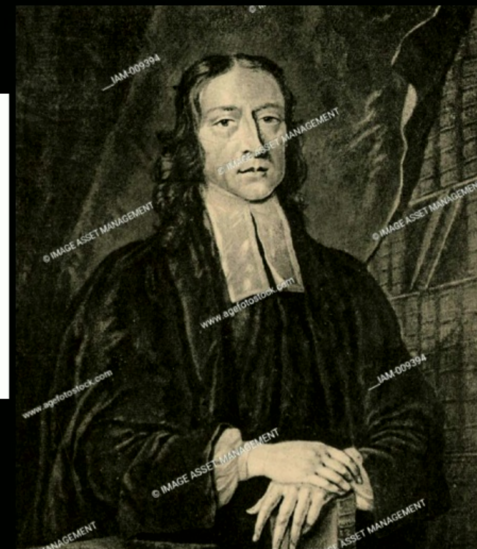
(I) Θ, φ, z, d (distance catalogues)

(II) Θ, φ, z (redshift surveys)

(III) Θ, φ (Imaging surveys)

Aberration

IV. *A Letter from the Reverend Mr.* James Bradley *Savilian Professor of Astronomy at* Oxford, *and F.R.S. to Dr.*Edmond Halley Astronom. Reg. *&c. giving an Account of a new discovered Motion of the* Fix'd Stars.

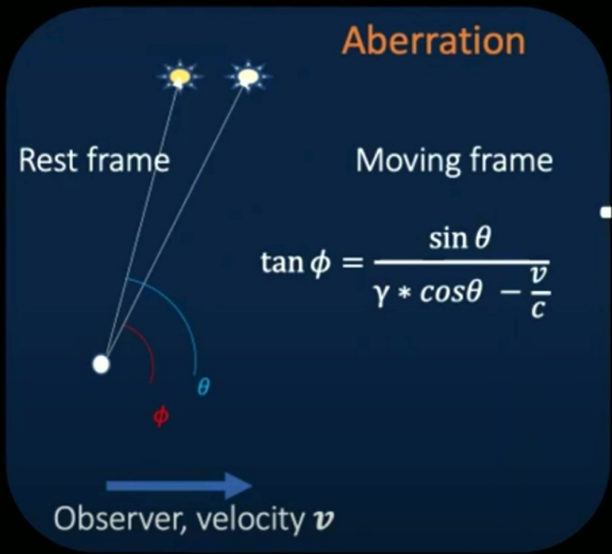


1727.	d.	The Difference of Declination by Observation. "	The Difference of Declination by the Hypothesis. "	1728.	d.	The Difference of Declination by Observation. "	The Difference of Declination by the Hypothesis. "
September -	14	29½	28½	*April* - -	16	18½	18
- - -	24	24½	25½	*May* - -	5	24½	23½
October - -	16	19½	19½	*June* - -	5	32	31½
November -	11	11½	10½	- - -	25	35	34½
December -	14	4	3	*July* - -	17	36	36
1728							
February -	17	2	3	*August* -	2	35	35½
March - -	21	11½	10½	*September* -	20	26½	26½

Probe 3 : Imaging surveys

Θ, ϕ

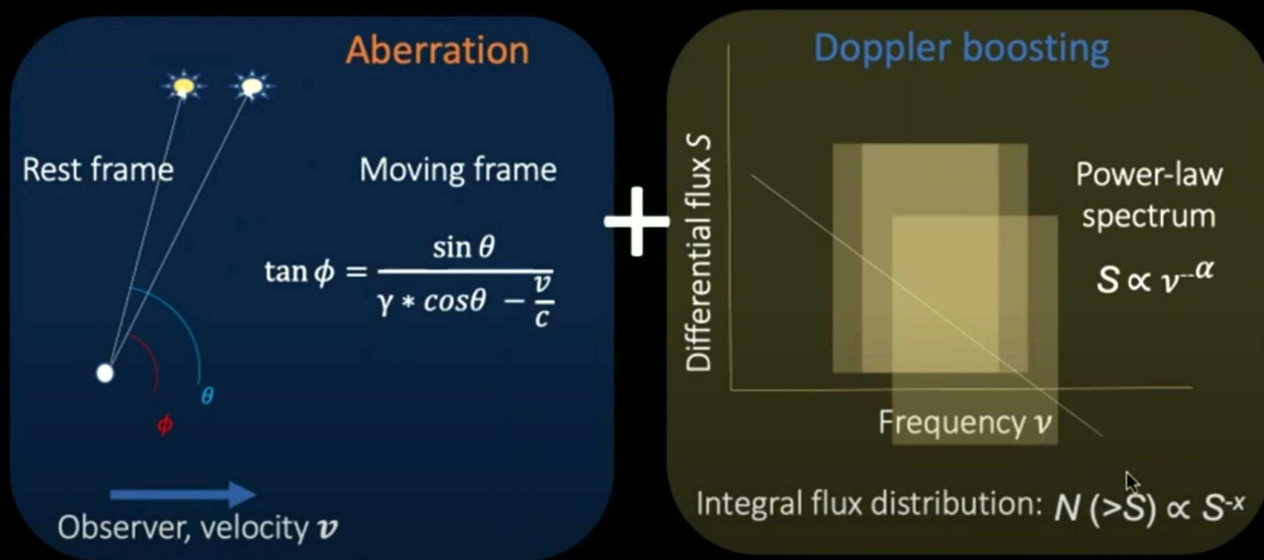
Aberration and Doppler boosting



Ellis & Baldwin,
MNRAS 206:377,1984

Imaging surveys (Θ, ϕ)
Aberration and Doppler boosting

Bradly 1727 Doppler 1842



Ellis & Baldwin, MNRAS 206:377,1984

Aberration

Ellis and Baldwin 1984

Anisotropy in source distribution → observer's velocity

Aberration and Doppler boosting

Dipole $= [2 + x(1 + \alpha)]v/c.$

$$dN/d\Omega(>S_\nu) \propto S_\nu^{-x}$$

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

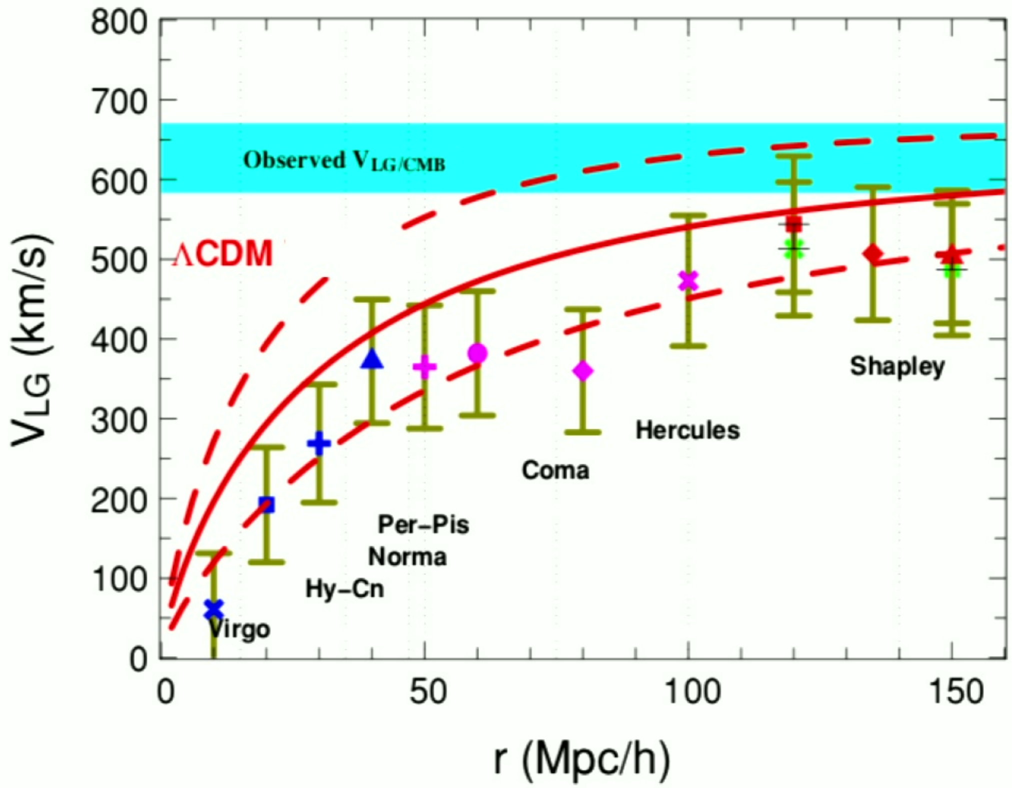
Independent of distance to the source

Aberration

Ellis and Baldwin 1984

Thus existence of such an observed anisotropy is a test of the isotropy of the source counts in their rest frame. The great power of this test is that the measurements can be made (and the result must hold) for any source counts, whether in a wide or a narrow solid angle, for flat or steep source spectra, etc, irrespective of selection effects or source evolution, as long as the forward and backward measurements are done in the identical manner.

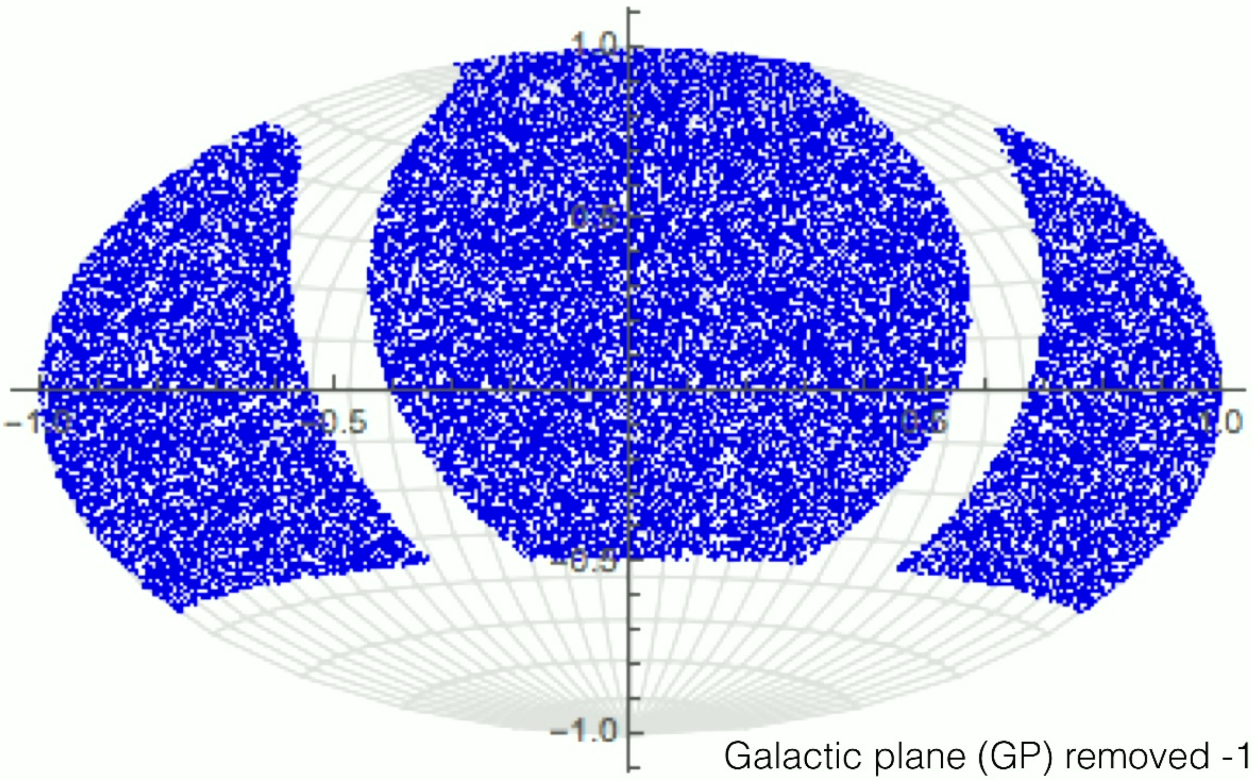
Test of cosmological principle : CMB rest frame



Cosmological principle:
rest-frame of high redshift "sources" = CMB rest frame

DATA: NRAO VLA Sky Survey Catalogue (NVSS)

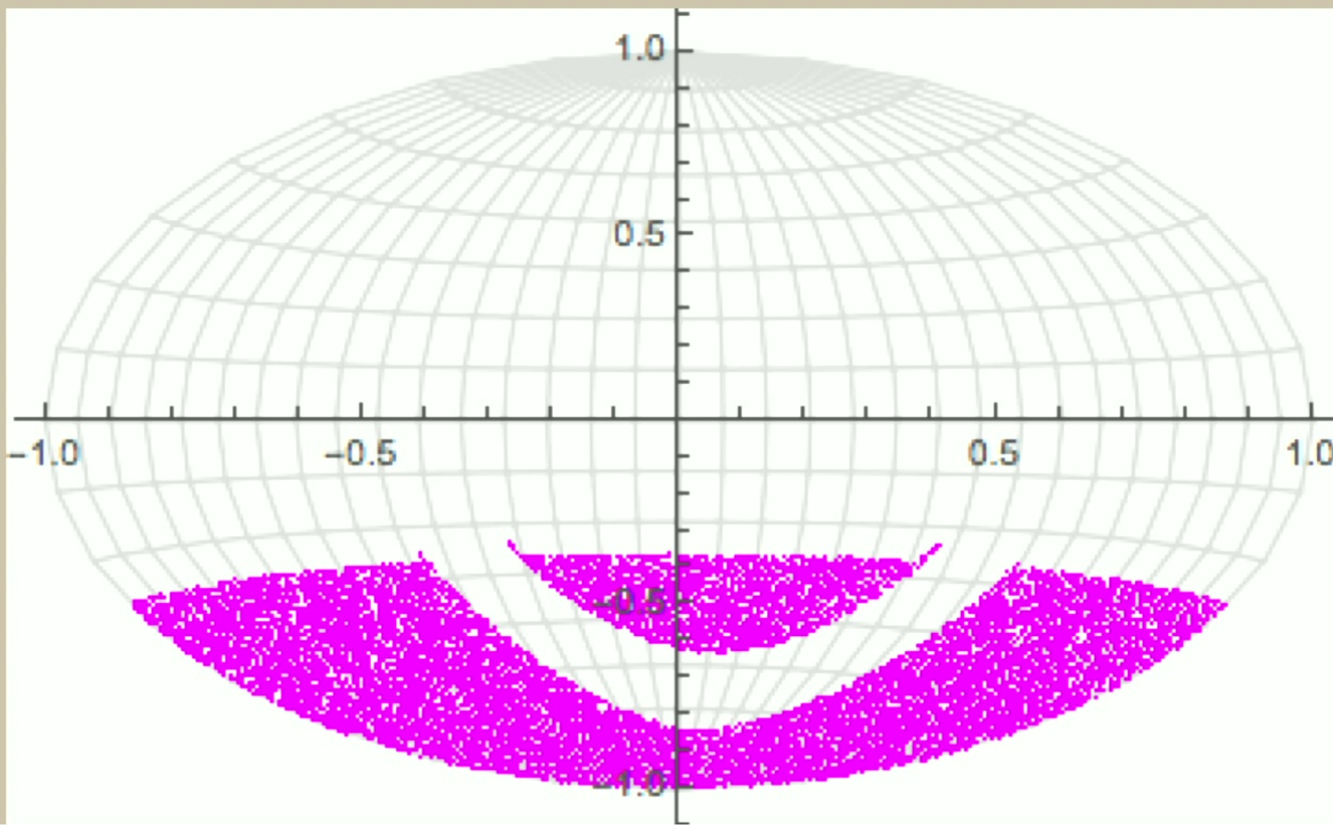
1773488 Radio galaxies
583587 Radio galaxies in 10 mjy <Flux< 1000 mjy



Galactic plane (GP) removed $-10^{o}<b<10^{o}$

DATA: The Sydney University Molonglo Sky Survey SUMSS

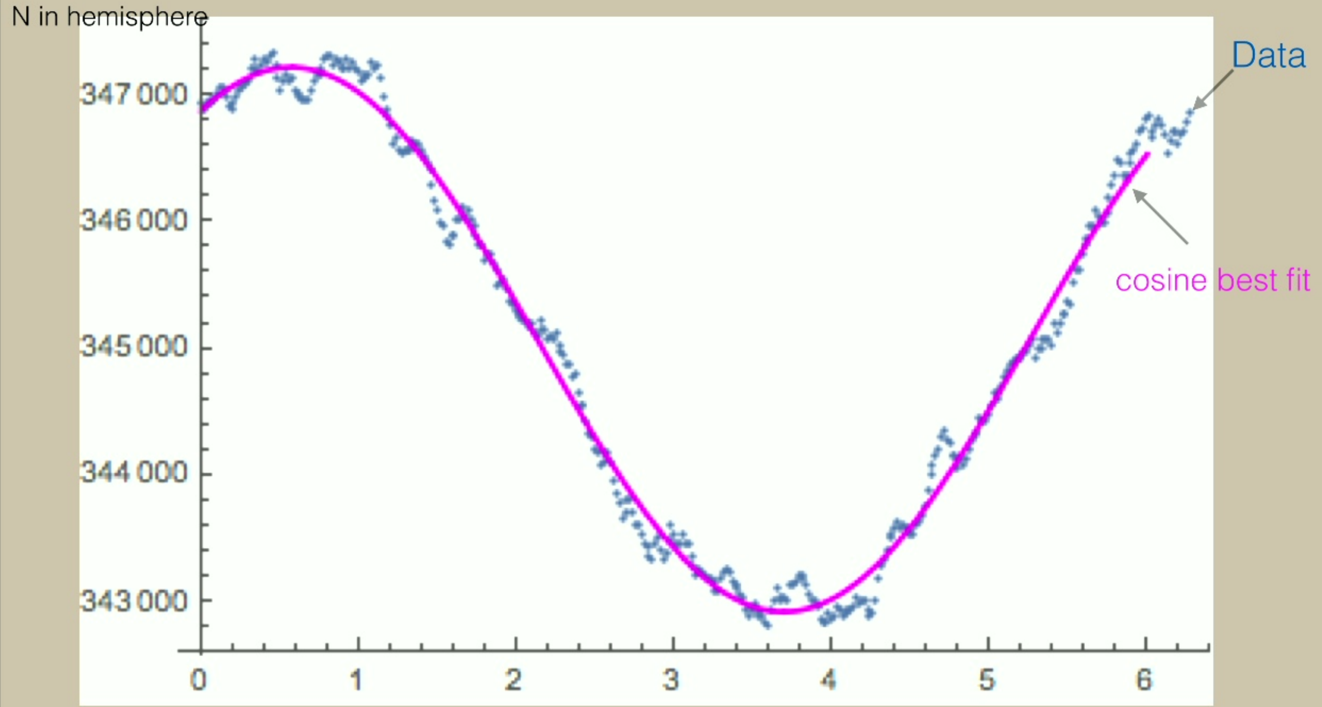
211050 Radio galaxies
183720 Radio galaxies in 10 mjy <Flux< 1000 mjy



Searching for dipole

Example of hemispherical counting:

Here we fix the axis $\theta=\{0,90\}$ and turn φ every one degree

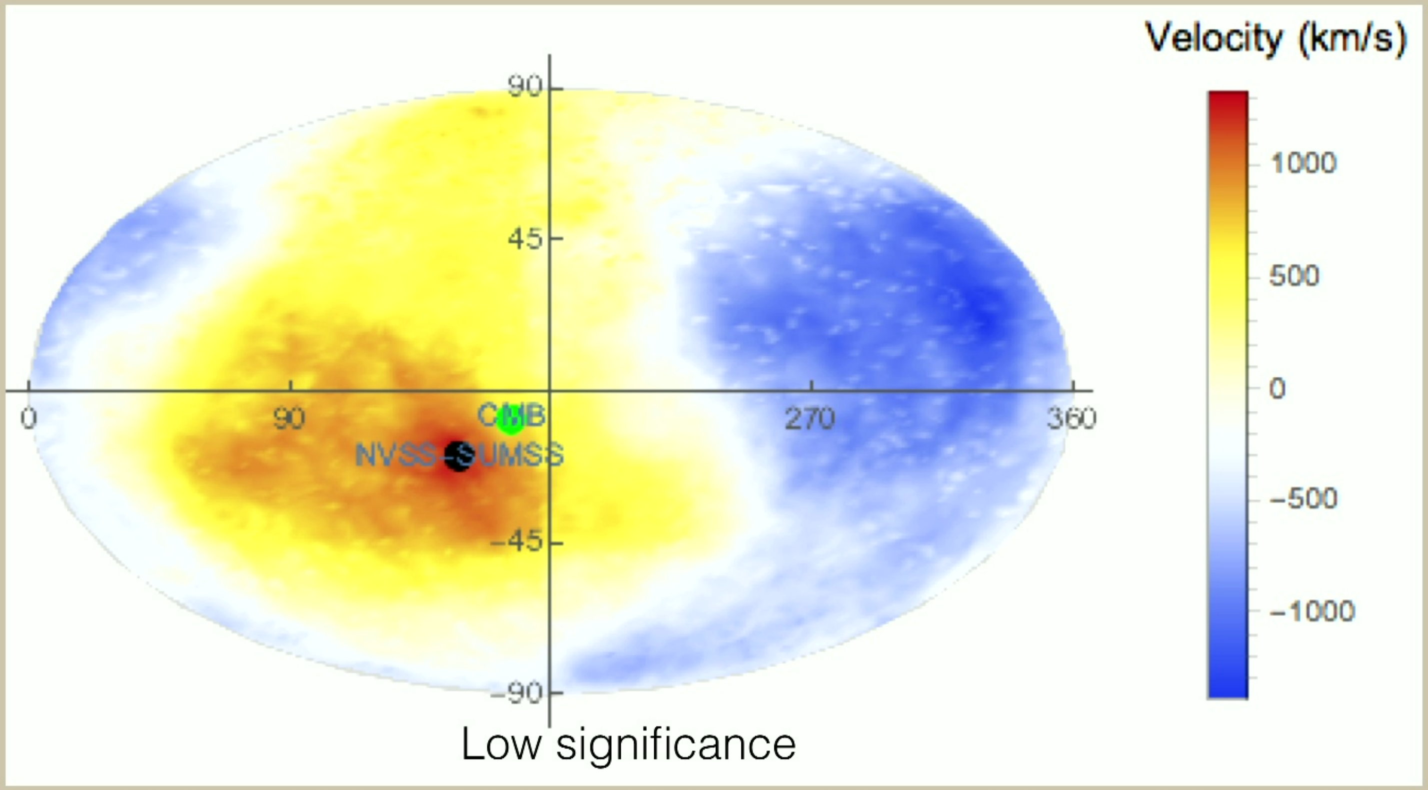


φ (Radians)

Dipole

Dipole direction: {RA=156º, DEC=-17º} compare to CMB DIpole {RA=168º , DEC=-7º}

Dipole Amplitude : velocity of barycentre of solar system w.r.t. Radio galaxies restframe = 1097 km/s
velocity of barycentre of solar system w.r.t. CMB restframe = 369 km/s



Wide-field Infrared Survey Explorer

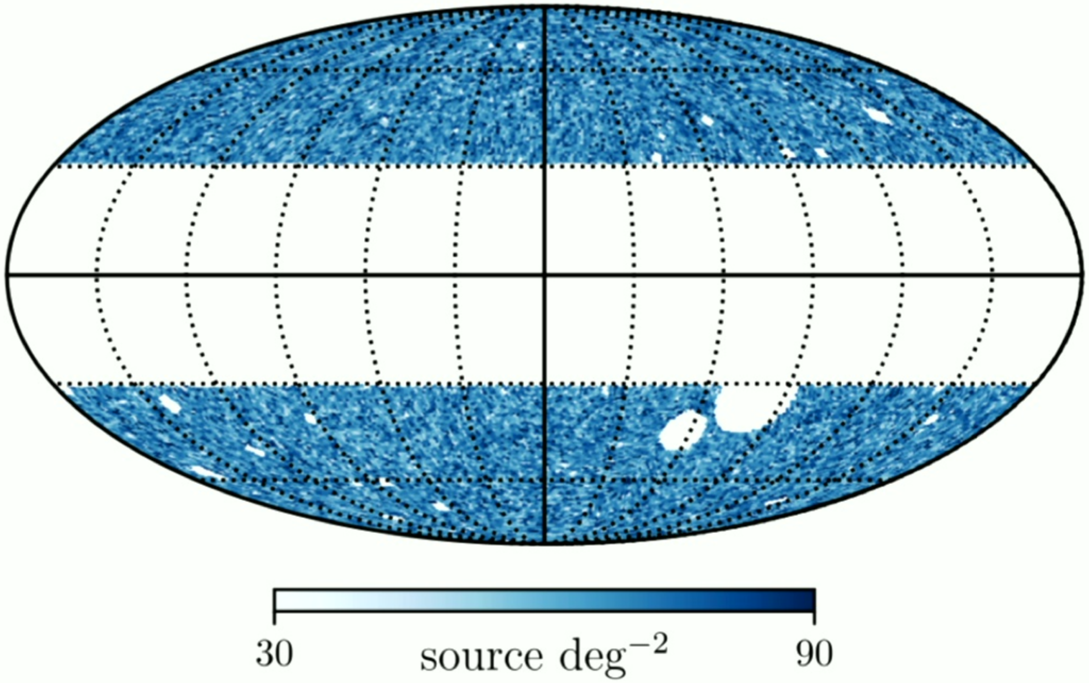
WISE :(Wright et al. 2010) & NEOWISE (Mainzer et al. 2011)

CatWISE : Eisenhardt et al 2020

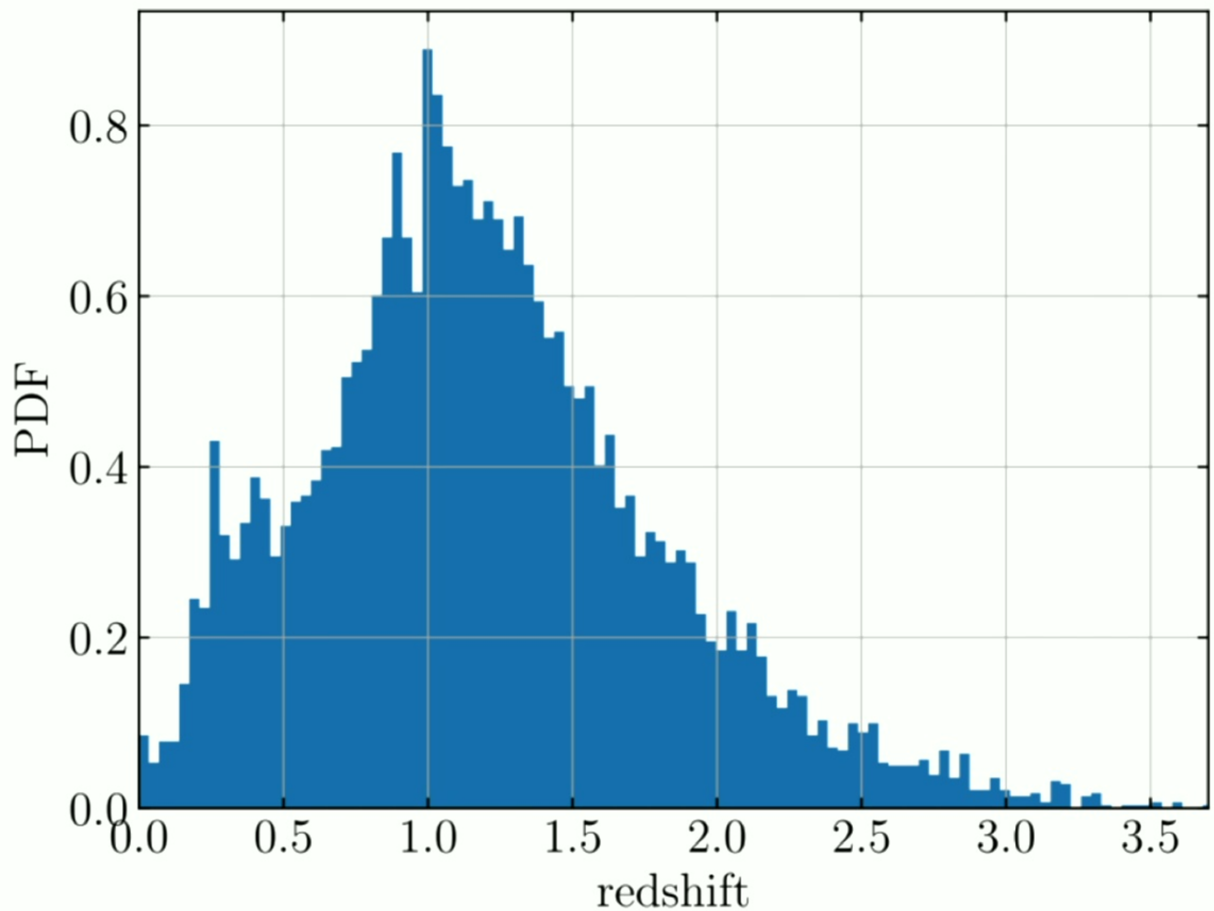
positions and the four-band photometry for 747,634,026 objects

Full-sky **mid-infrared** survey in:

3.4um (W1)	(2009 – present)
4.6um (W2)	(2009 – present)
12um (W3)	(2009 – 2010)
22um (W4)	(2009 – 2010)



Redshift distribution

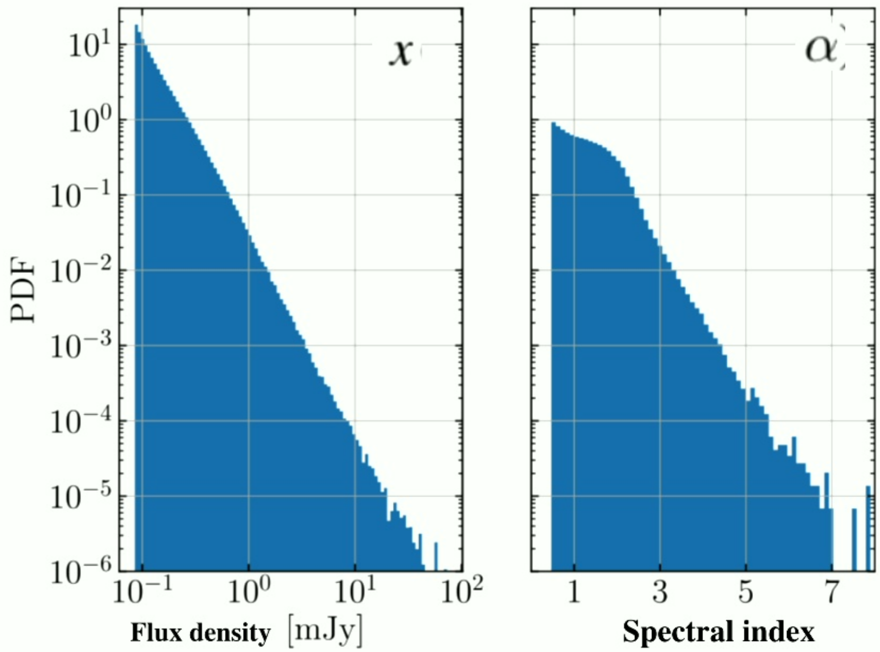


Statistical significance

10^7 random sky

mimicking CatWISE
same masks,
estimator, flux….

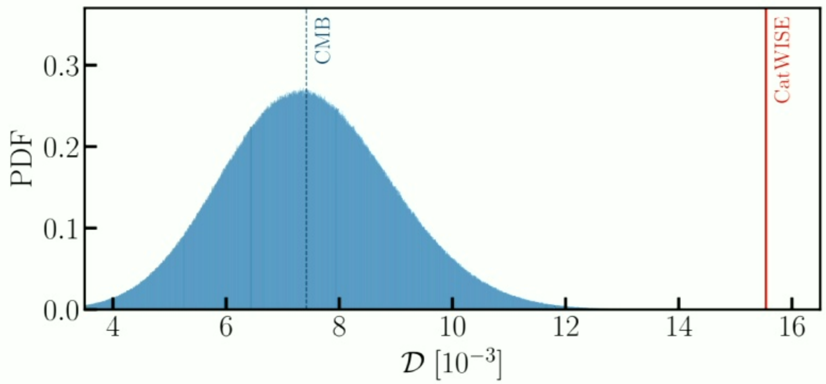
Dipole $= [2 + x(1 + \alpha)]v/c.$

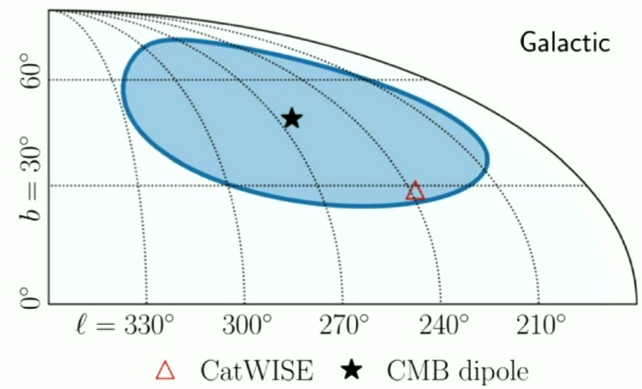


The null Hypothesis:
An observer moving with a velocity of 369.82 km/s (CMB expectation) can see a dipole twice that of CMB" !
Rejected : p value of $5x10^{-7}$

Statistical significance

4.9 sigma





Is quasar data consistent with radio data ?

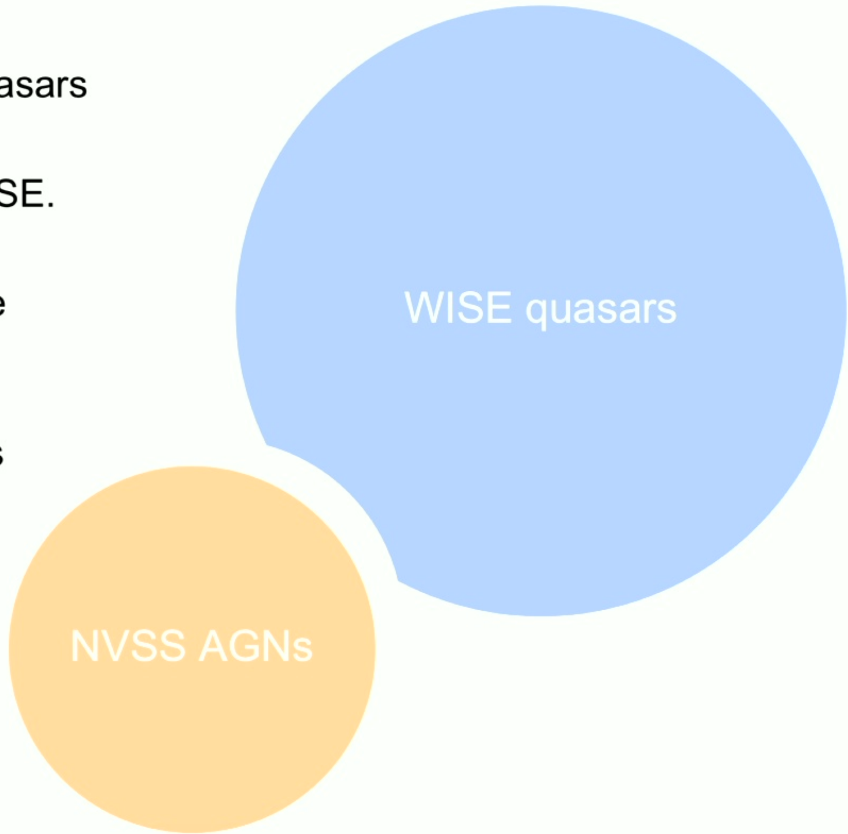
Shared sources: 1.4% of WISE quasars

Removed shared sources from WISE.

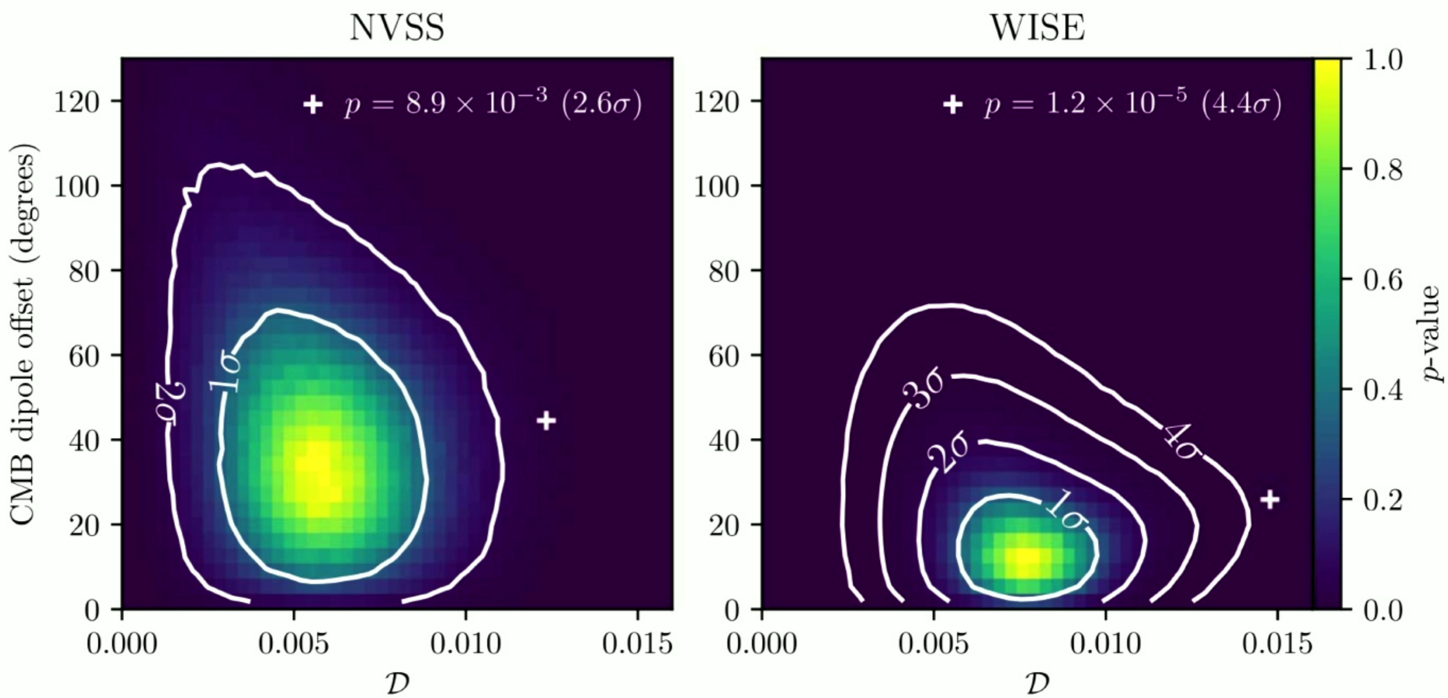
Kept sources in NVSS to maximize sources in smaller catalog.

WISE quasars in unshared regions removed randomly to preserve uniformity.

→ **Totally orthogonal catalogs.**



Joint Analysis: Infrared (Wise) and radio sources (NVSS)
Statistical significance: 5.1 sigma



George Ellis and Baldwin

MNRAS, 1984

vations 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.

Anomalies in Physical Cosmology

P. J. E. Peebles

Nobel laureate 2019

Annals of Physics **2022**

The ΛCDM cosmology passes demanding tests that establish it as a good approximation to reality. The theory is incomplete, of course, and open issues are being examined in active research programs.

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.)

END