Cosmic Anomalies?

Ned Wright

Two and a half Facts

Peter Scheuer (1963)*: “There are only two & a half facts in cosmology:

1) The sky is dark at night.
2) The galaxies are receding from each other as expected in a uniform expansion.
3) The contents of the Universe have probably changed as the Universe grows older.”

* In Longair, 1993, QJRAS, 34, 157

COSMOLOGY:
A SEARCH FOR TWO NUMBERS

Precision measurements of the rate of expansion and the deceleration of the universe may soon provide a major test of cosmological models

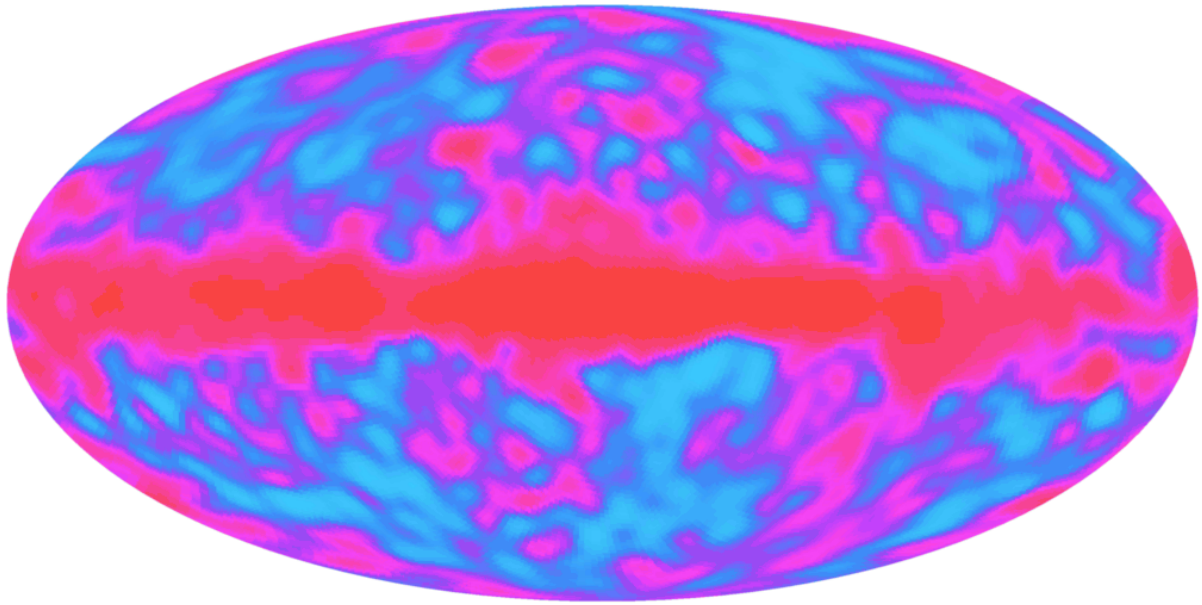
- Sandage, Feb 1970, Physics Today
- H_o = 49 to 130 km/sec/Mpc
  - Sandage not yet hard over on 50
- $q_o = 1.2 \pm 0.4$
  - Notes not close to -1 for SS
  - Also not close to true -0.5 to -0.6

A Big Media Splash in 1992:

THE TIMES

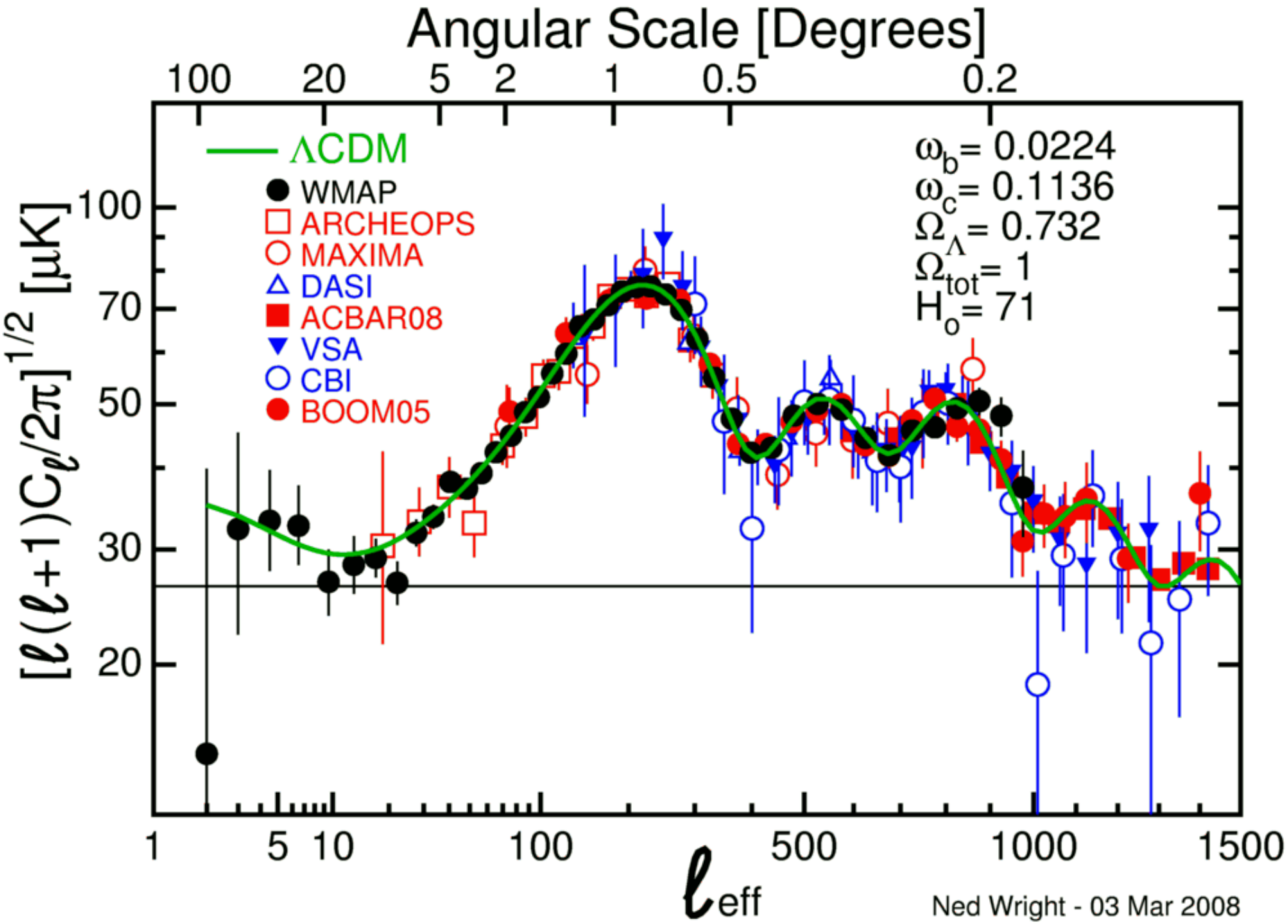
25 April 1992

Prof. Stephen Hawking of Cambridge University, not usually noted for overstatement, said: “It is the discovery of the century, if not of all time.”



Harlow Shapley

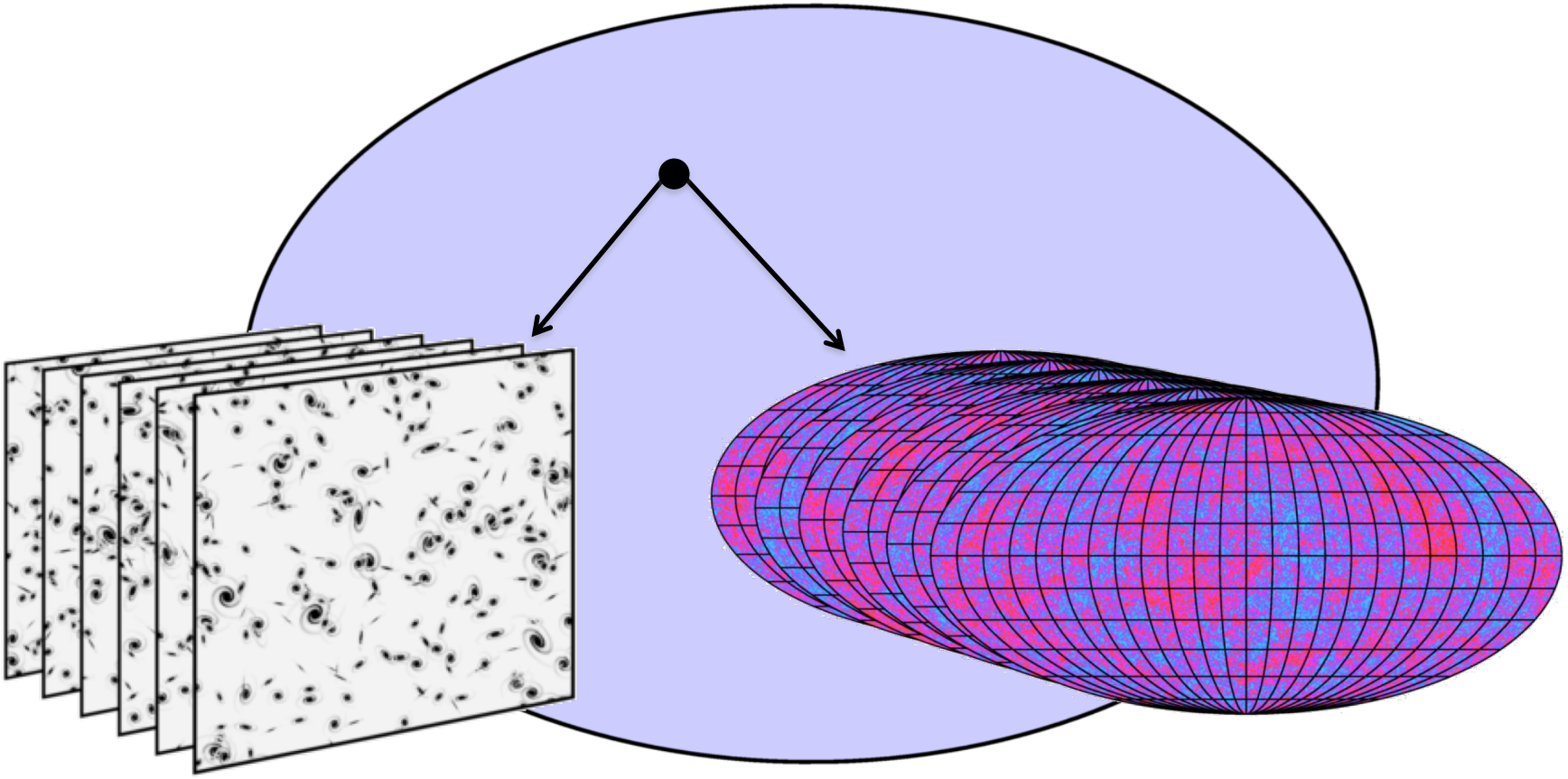
- “A hypothesis or theory is clear, decisive, and positive, but it is believed by no one but the man who created it.
- Experimental findings, on the other hand, are messy, inexact things, which are believed by everyone except the man who did the work.”


Angular Scale [Degrees]
100
20
5
2
1
0.5
0.2
ΛCDM
WMAP
ARCHEOPS
MAXIMA
DASI
ACBAR08
VSA
CBI
BOOM05
ω_b = 0.0224
ω_c = 0.1136
Ω_Λ = 0.732
Ω_tot = 1
H_o = 71
[ℓ(ℓ+1)C_ℓ/2π]^1/2 [μK]
100
70
50
30
20
1
5
10
100
500
1000
1500
ℓ eff
Ned Wright - 03 Mar 2008

Ockham's Razor

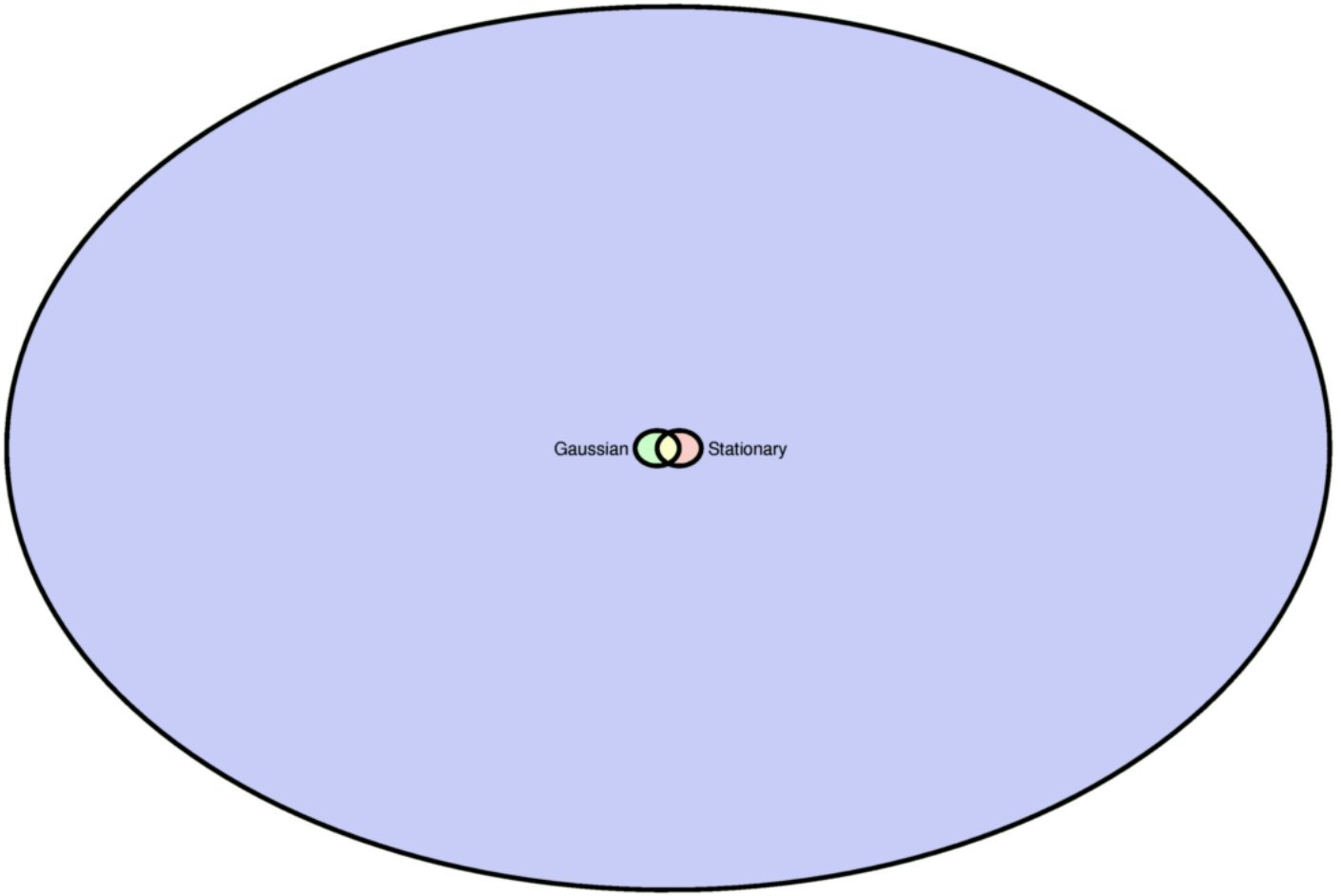
Ockham chooses a razor

Set of All Random Processes



- A cosmological model is a prescription for generating an ensemble of Universes. Each element of the ensemble describes a different realization of a random process.

Small Subsets of All Models



- Gaussian and/or stationary random processes

Gaussian models

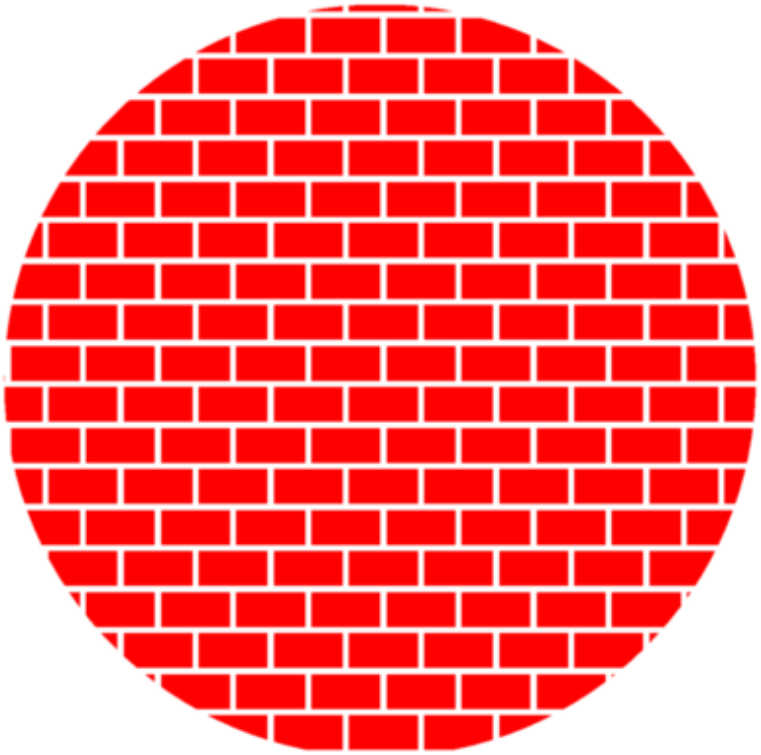
- The one point distribution function is Gaussian for all locations.
- The two point distribution function is Gaussian.
- The three point distribution function is Gaussian [and derivable from the two point function].
- […]

Stationary Models

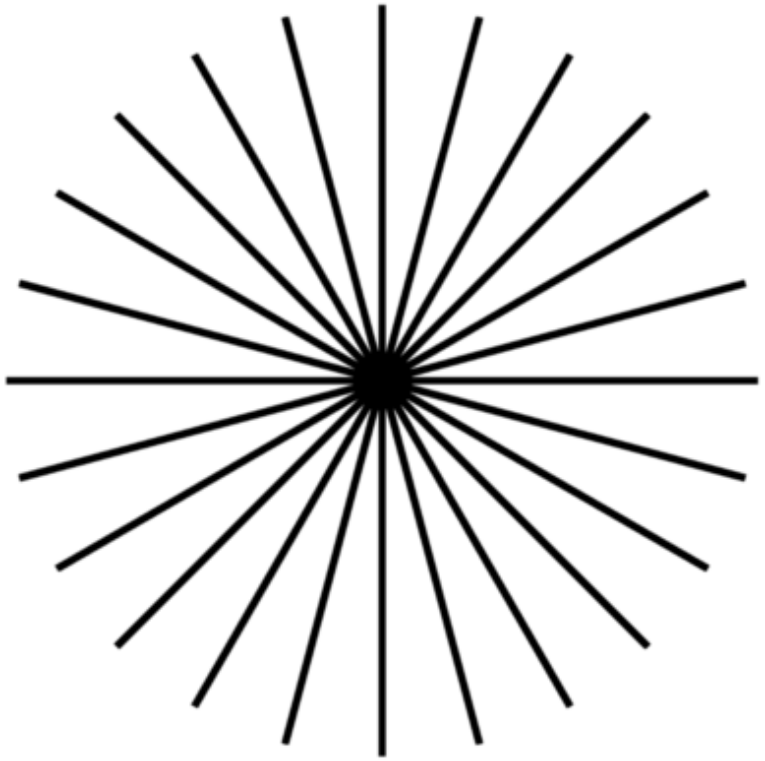
- The one point distribution function is independent of the location.
- The two point distribution function depends only on the (vector) separation.
- ISOTROPIC models: the distribution functions are invariant when the set of points is rotated.
- Stationary & isotropic models satisfy the Cosmological Principle.

The Cosmological Principle

- The Universe is homogeneous and isotropic



Not isotropic



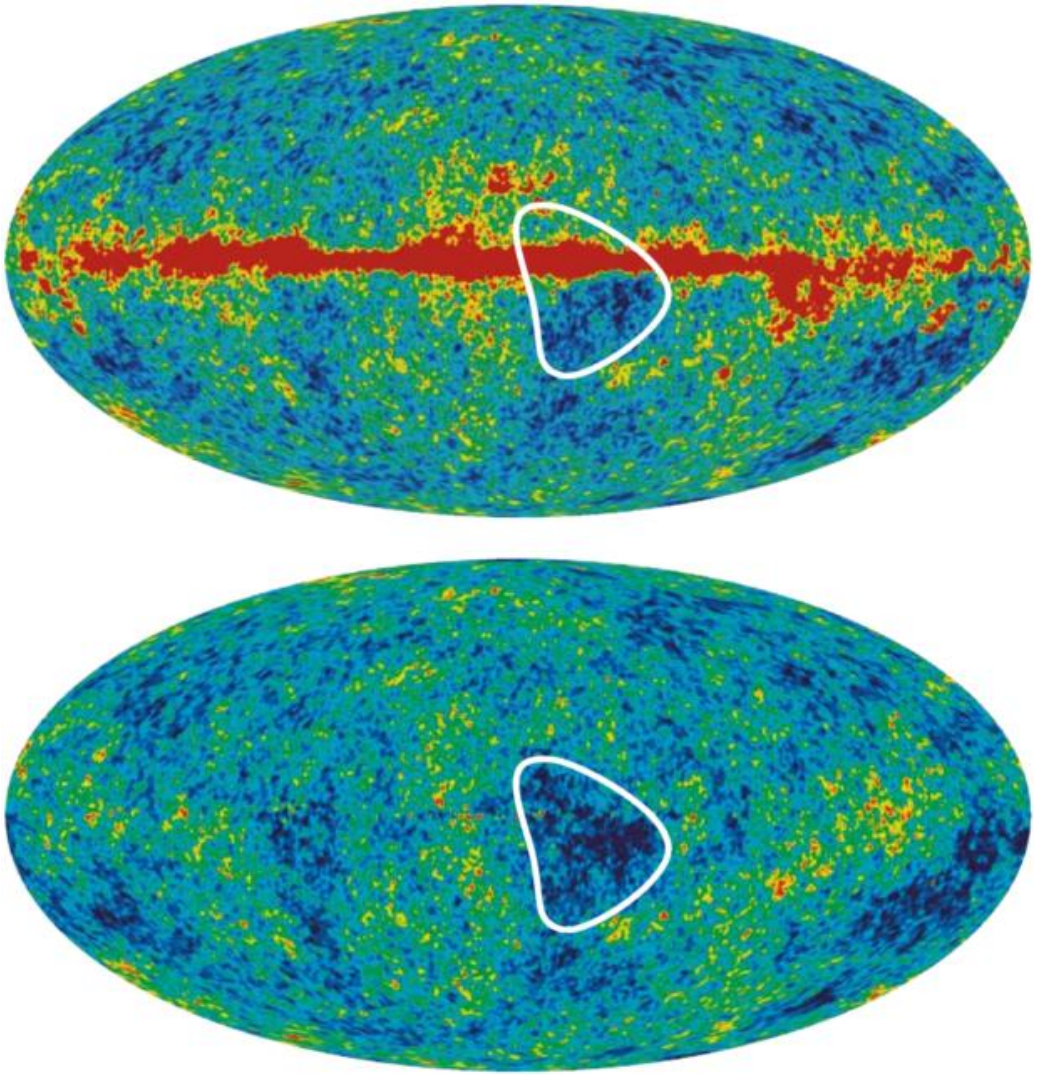
Not homogeneous

Large Scale Effects

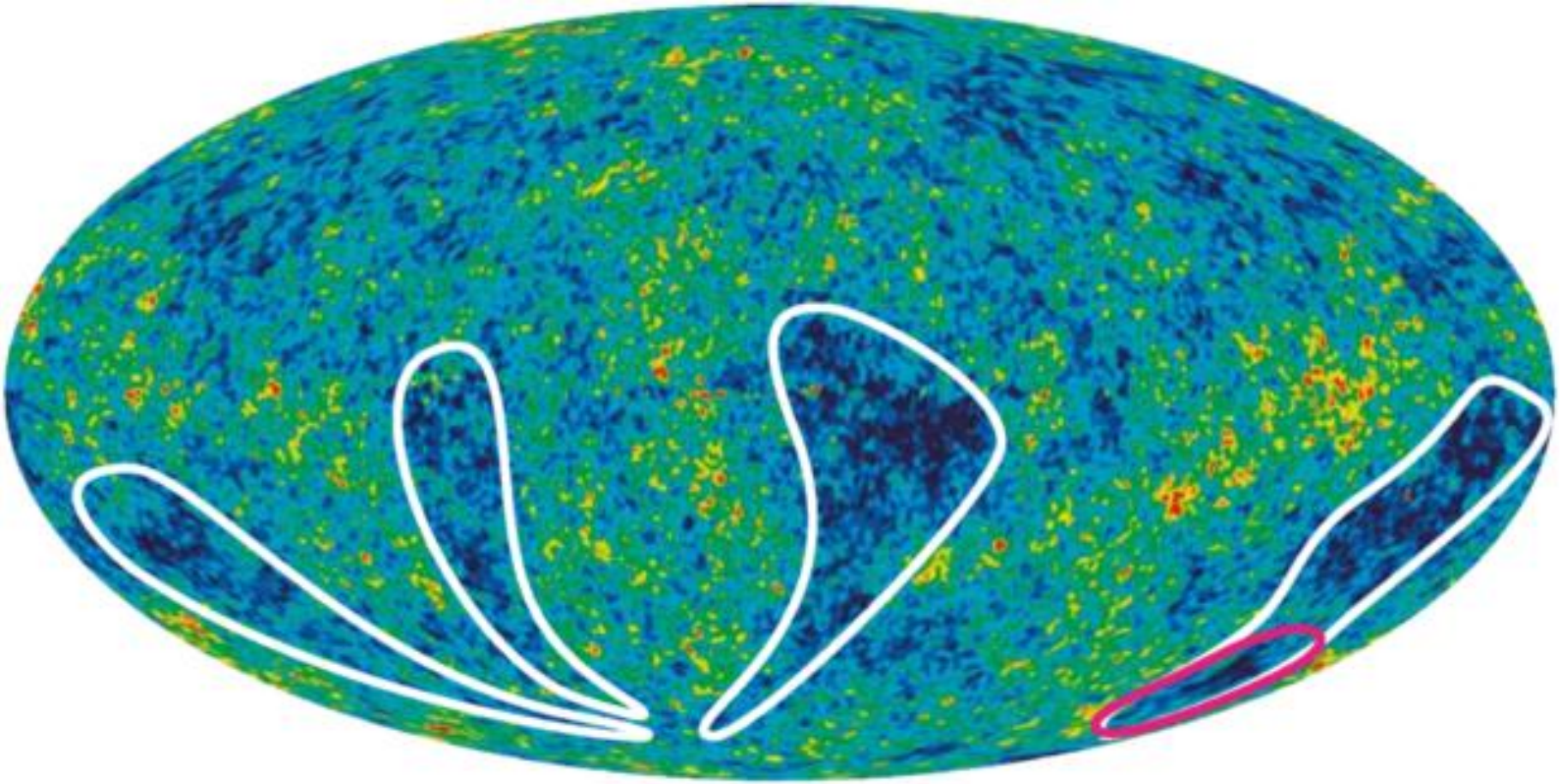
- The CMB quadrupole is low compared to ΛCDM.
- The octupole and quadrupole appear to be roughly aligned.
- There is the infamous “dark spot”.

Look at the (W)MAP

- Fig of Bennett etal, arXiv:1001:4758
- This huge dark spot at the GC is not “the” dark spot.



Cold Fingers of God



- The red line outlines “the” dark spot.
- Better called the “dark fingernail” of God

The Infamous “Dark Spot”

- Proposed by Cruz et al., astro-ph/0405341, “Detection of a non-Gaussian Spot in WMAP”
  - Of course it makes no sense to talk about “a non-Gaussian spot”: one has to show that the underlying random process is non-Gaussian. If I choose a value from N(0,1), say 1.37, then the observed pdf is $\delta(T-1.37)$ which is non-Gaussian but the underlying process is Gaussian.

Large Search Space

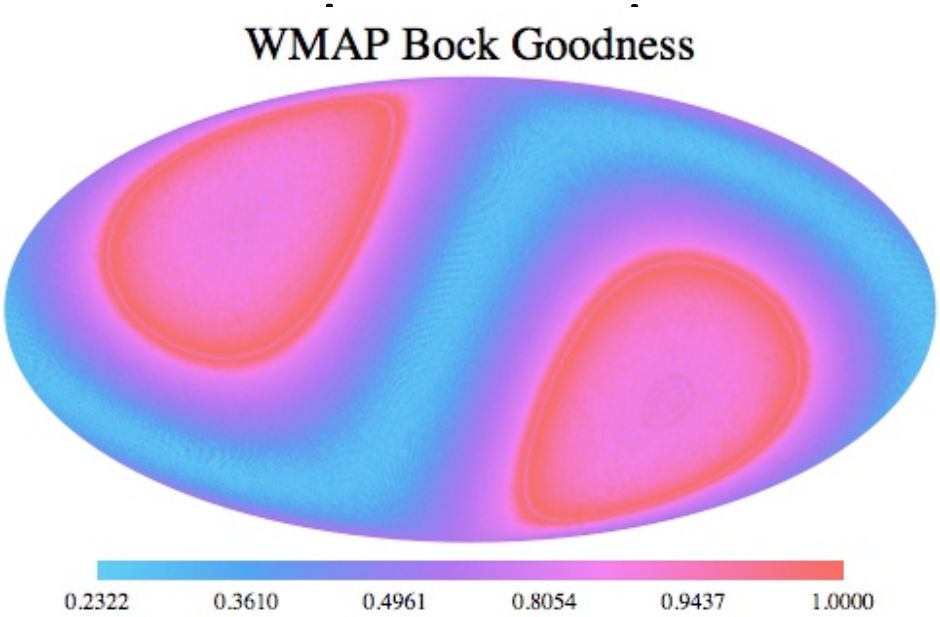
- 15 different circular Mexican hat wavelet sizes were used.
- For each size, the whole sky was searched for outliers.
  - A fair estimate for the number of cases searched has to be > 10^5.
- Claim that (l,b) = (209,-57) is a 4.7σ cold spot with a 5^o scale (8.75^o FWHM).
- But $\exp(-½ \times 4.7^2)$ is > 10^{-5}, so where's the beef?

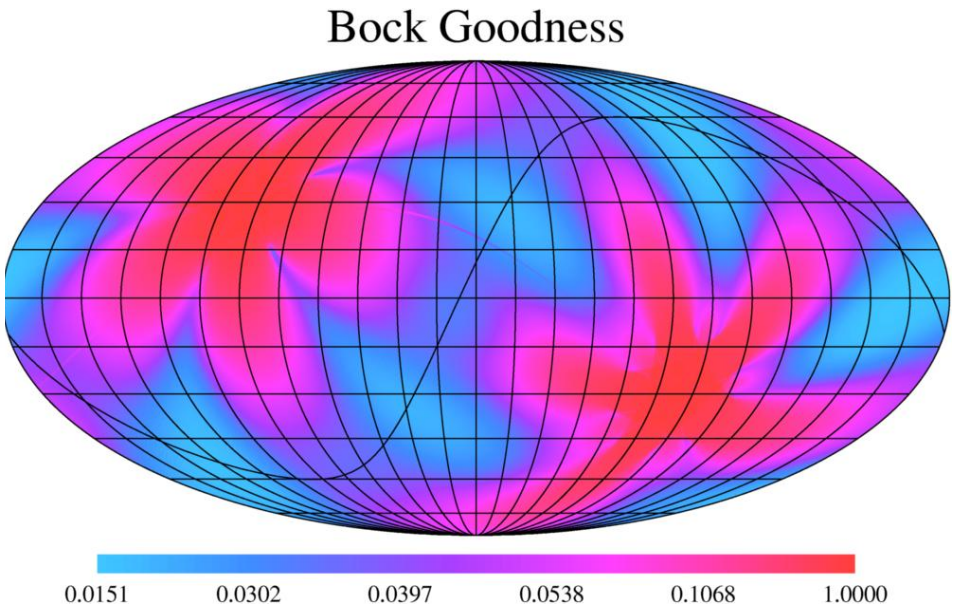
A Real Anomaly

- ``Imprints of a Primordial Preferred Direction on the Microwave Background''
  - Ackerman, Carroll & Wise, astro-ph/0701357
- Assumed that the 3D power spectrum is not isotropic: $$P(\mathbf{k}) = P(k)(1 + g(k)(\hat{\mathbf{k}} \cdot \hat{\mathbf{n}})^2).$$
- Then assumed g(k) is a constant g*. Estimated $g^* \sim 10^{-5}$ might be possible.

Search in WMAP data

- ``Bayesian analysis of sparse anisotropic universe models and application to the 5-yr WMAP data''.
  - Groeneboom & Eriksen, arXiv:0807.2242.
- They found a significant effect with g* ~ 0.12
  - 10,000 times too big but who's counting.
- Then with more data, Groeneboom, Ackerman, Wehus & Eriksen (arXiv:0911.0150) found a 9σ effect! But the preferred axis now very close to the ecliptic poles.
- Conclusion: a systematic error in the WMAP maps due to ellipticity of the beams.
- Remembering Shapley, always look for systematic errors.





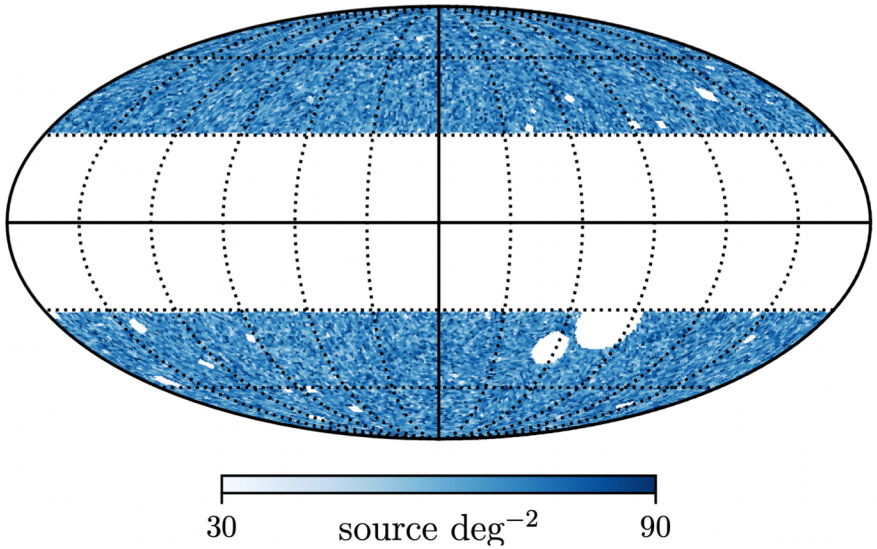
- It is best to observe the sky in all possible orientations. COBE did this well, WMAP did OK but Planck used a very limited range of scan angles.

  Quantify using Bock Goodness:$1-(\langle\sin(2\theta)\rangle^2+\langle\cos(2\theta)\rangle^2)$

- Median: WMAP 0.65, Planck 0.047

Quasar Number Count Dipole

- Large samples of “quasars” have been constructed using WISE colors: W1-W2 > 0.8 and W2 < 16.4 (Vega). (Secrest etal arxiv:2009.14828)
- |b| > 30 and other masks for bright sources
- Dipole of resulting map is too big for Compton-Getting effect.



I too have struggled to use WISE number counts for cosmology

- Measurement of the Integrated Sachs-Wolfe Effect Using the AllWISE Data Release, Shajib & Wright, arxiv:1604:03939
- Luckily only needed intermediate angular scales
- Consistent with ΛCDM

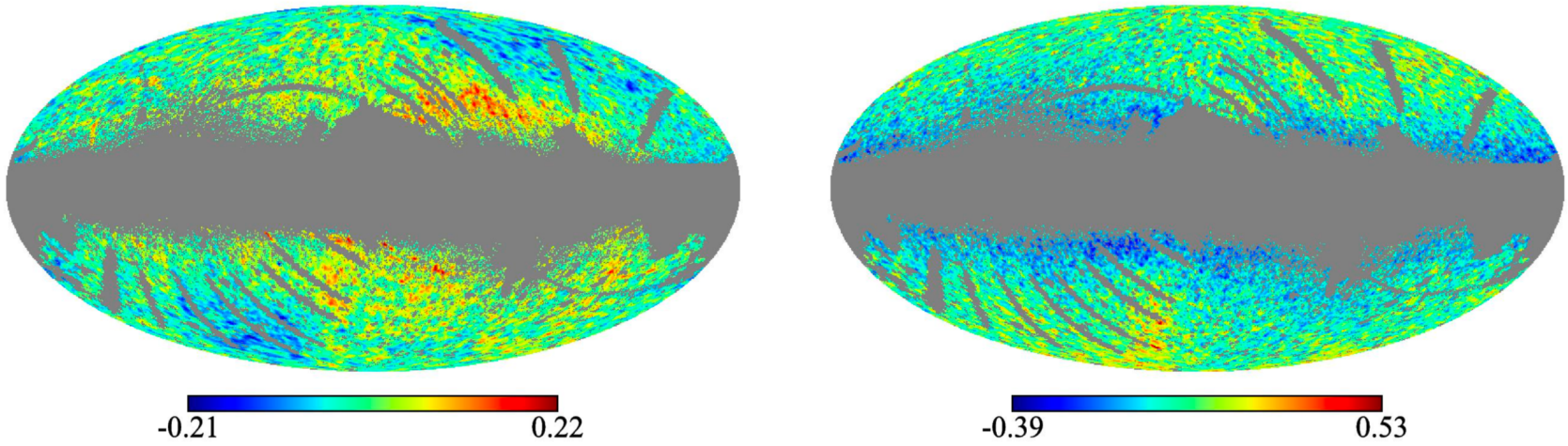
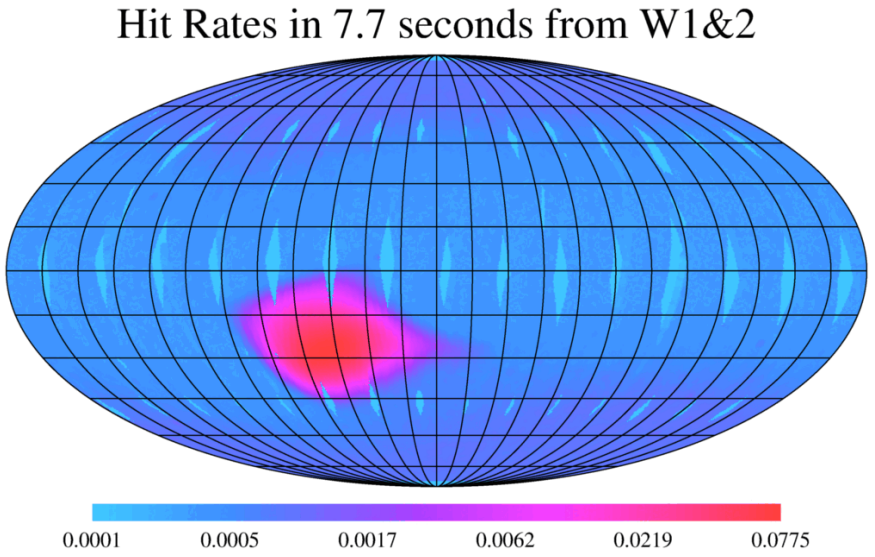


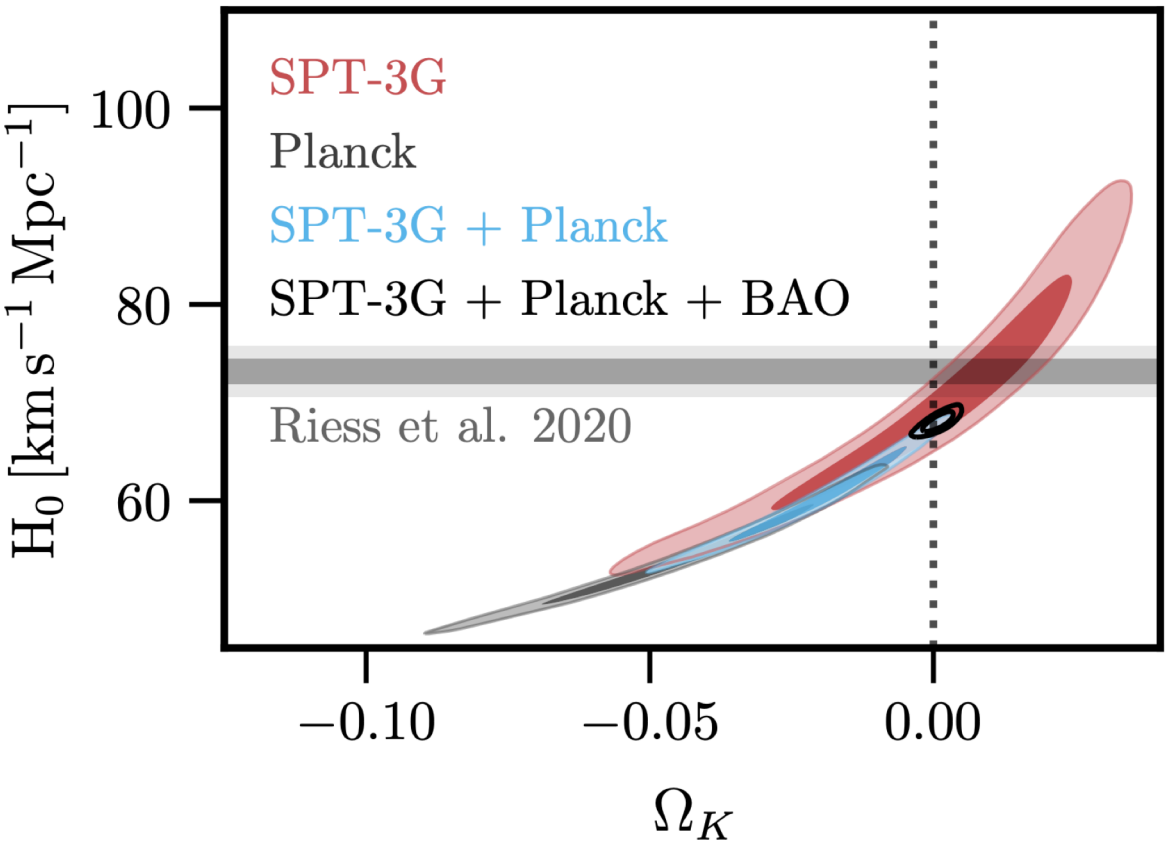
Figure 2. Overdensity maps in galactic coordinate with HEALPIX resolution parameter $n_{side} = 128$ for galaxies (left) and AGNs (right). These maps are smoothed with a Gaussian window of standard deviation $\sigma = 0.5°$. The grey area is the mask where the overdensity is zero. The mask leaves the unmasked sky fraction $f_{sky} = 0.46$.

WISE Made NO Attempt at Uniform Sky Coverage

- What could make a confounding pattern in the counts? Here are two effects:
  - The scan density is 7% larger around aphelion (July) than perihelion (Jan) due to the eccentricity of the Earth's orbit.
  - There is a South Atlantic Anomaly but no North Atlantic Anomaly



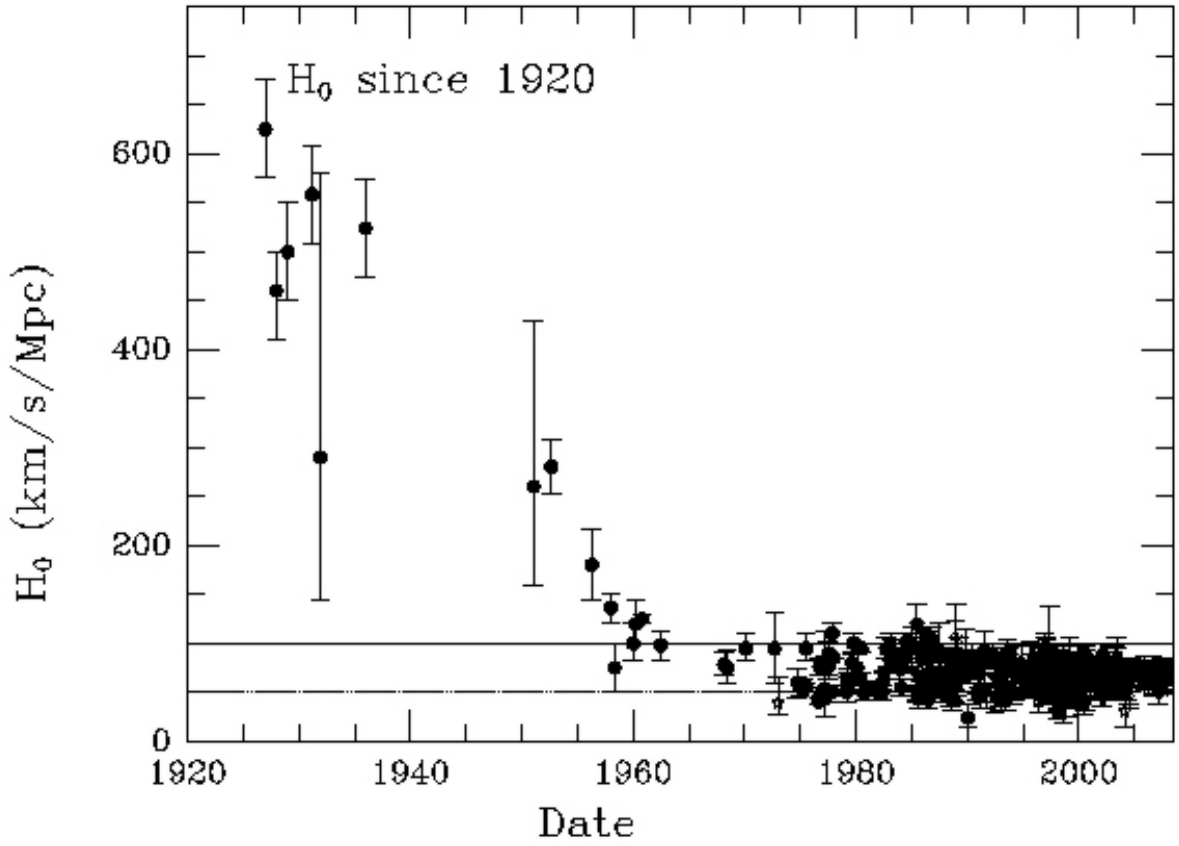
Is Space Flat?



- Planck slightly favors a closed space with a very low H_0.
- The South Pole Telescope is OK with flat space.
- Combining CMB with BAO, flat space is good and H_0 is higher.

Fig 5 from Balkenhol arxiv:2103.13618

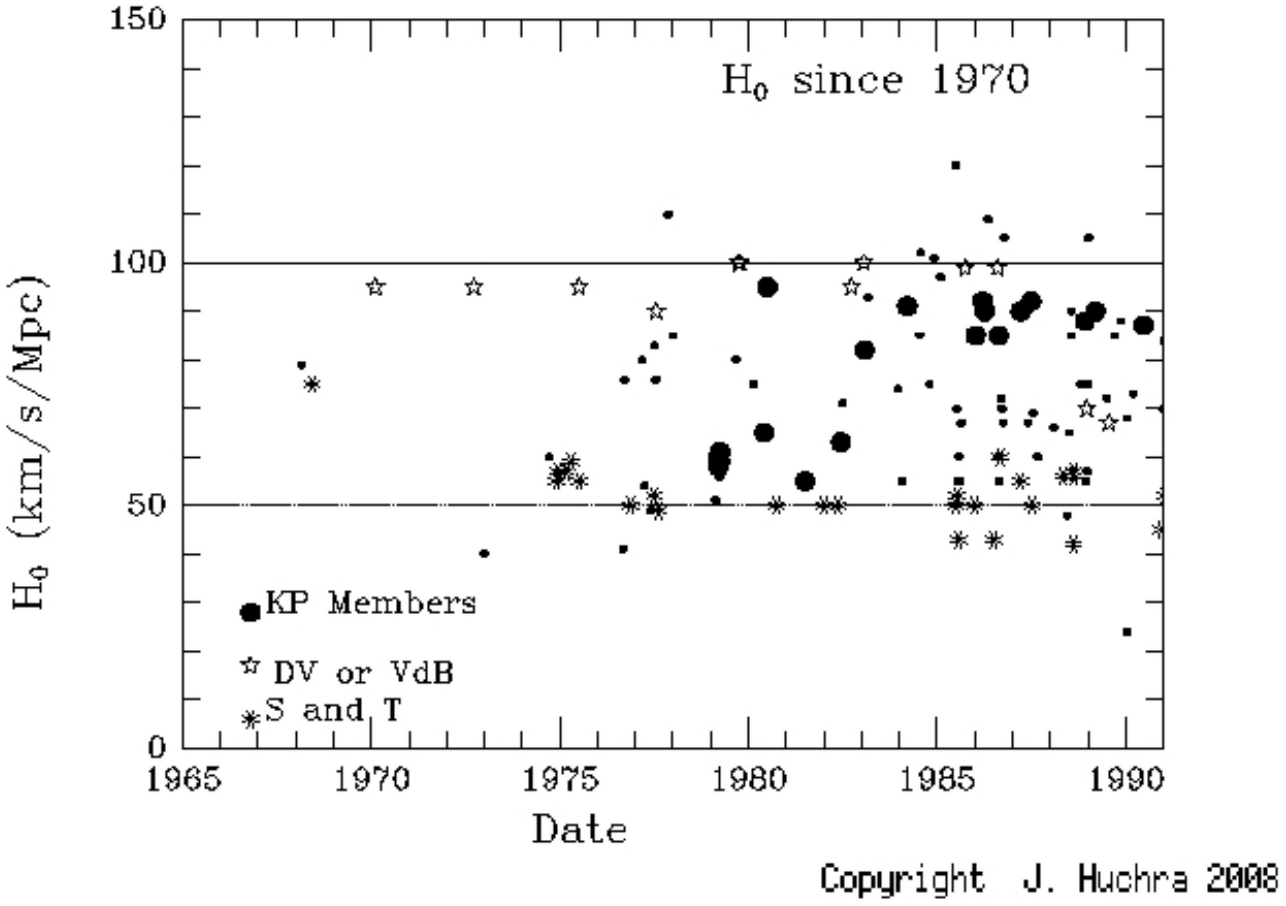
Hubble "Constant" is H(t)



- Looks like the Universe formed in 1920 and dark energy dominates after 1965

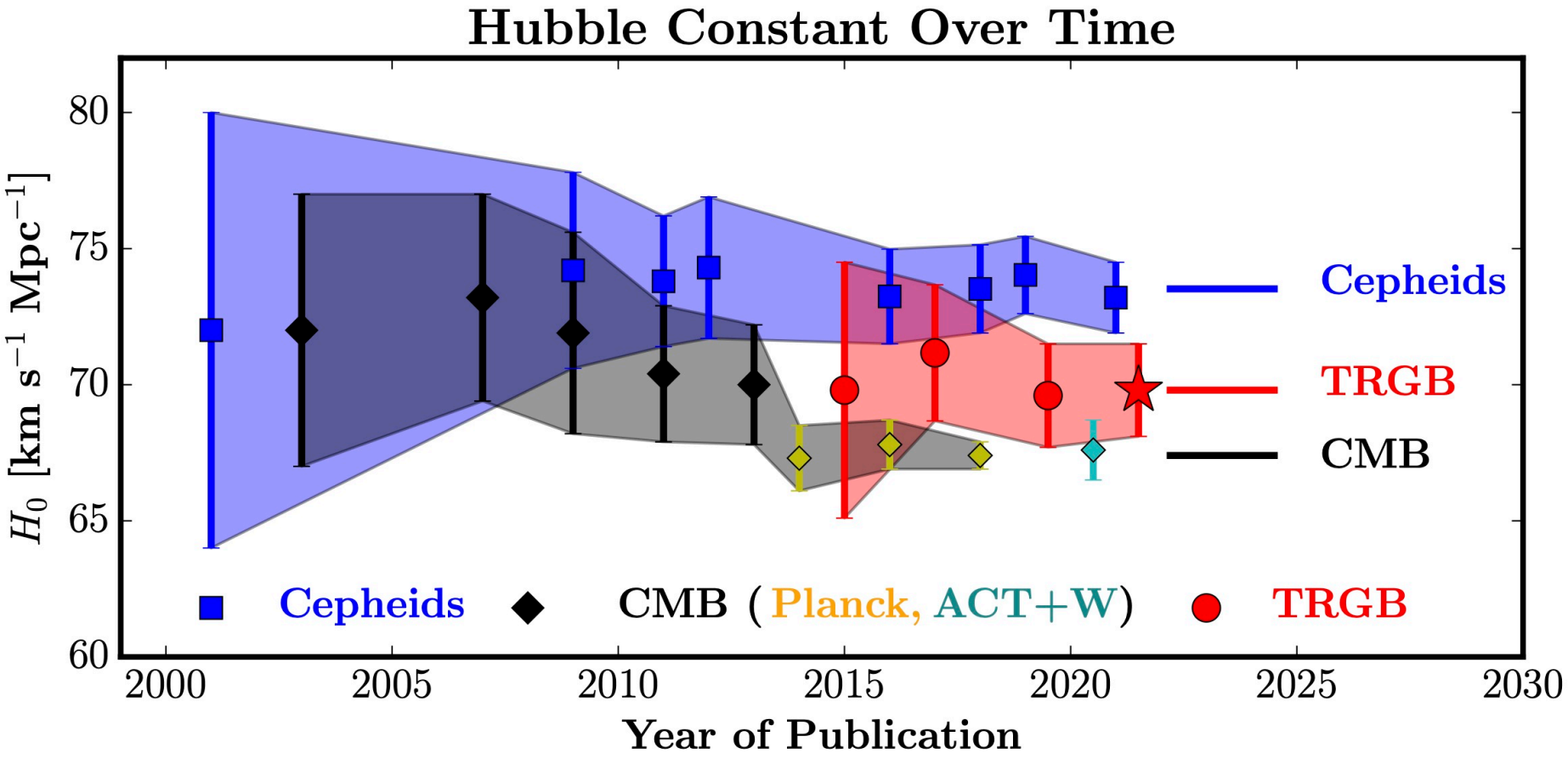
Figure credit: John Huchra

Past Hubble Tension



- Remember $H_0 = 100h$? I do

Current Hubble Tension



- Old 50 vs 100, 5 sigma; New 68 vs 73, 5 sigma

Credit: Wendy Freedman arxiv: 2106.15656

My Conclusion

- Cosmology is now data rich.
- With lots of data, outliers are inevitable.
- The 6 parameter Lambda-CDM model is still an adequate fit.
- Tensions are to be expected with a large number of number of data sets. They are worth tracking but hardly worth a press release.