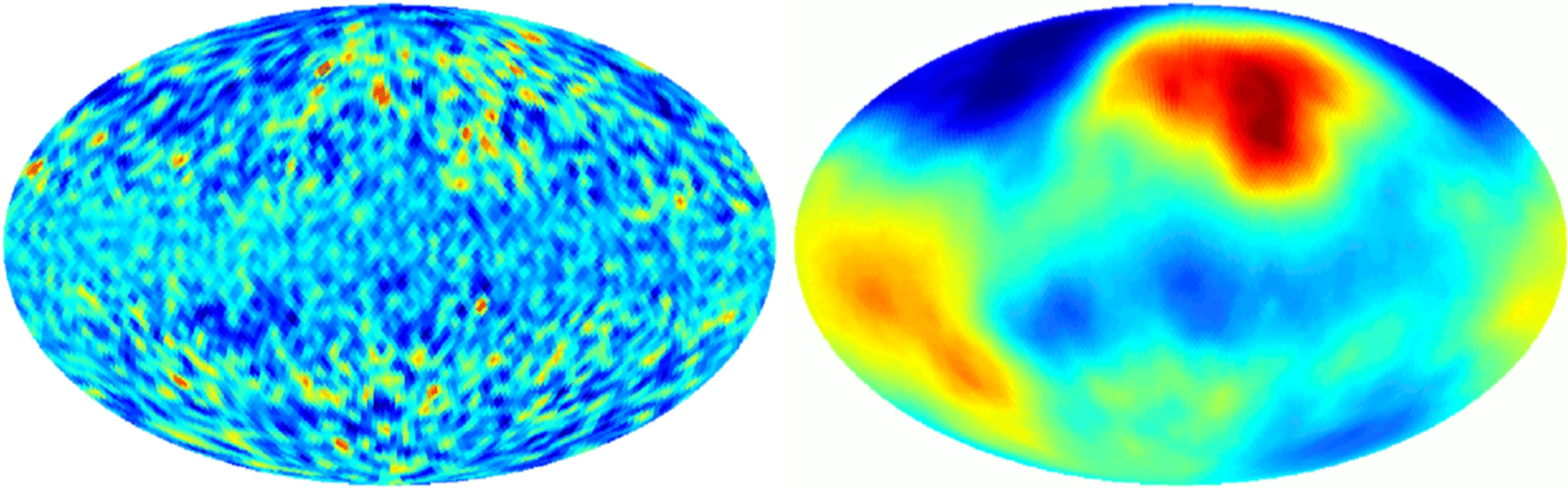
Dark information in the galaxy distribution



John Peacock Leopoldina Dark Energy Munich 10 Oct 2008

Outline

- Overview of probing DE with LSS
- Issues with photometric redshifts
- Example: ISW with 2MASS
- Digression

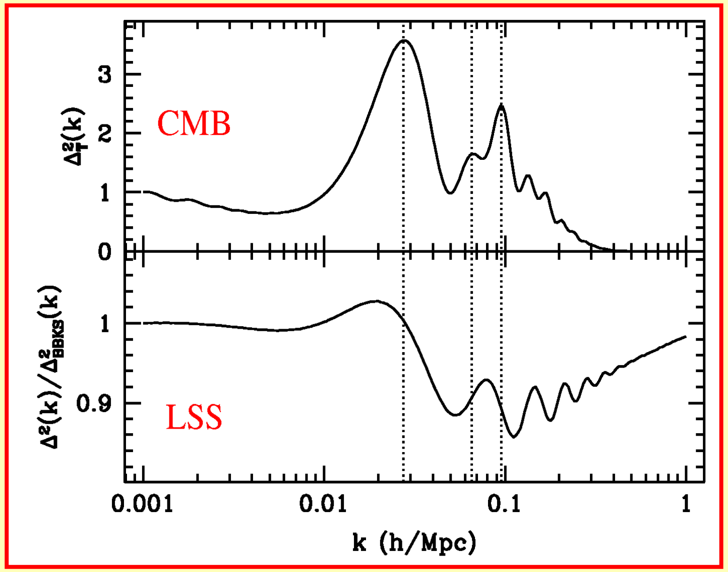
Signatures of DE in the matter distribution

(1) Matter-radiation horizon:

$123\ (\Omega_m h^2 / 0.13)^{-1}$ Mpc

(2) Acoustic horizon at last scattering :

$147\ (\Omega_m h^2 / 0.13)^{-0.25} (\Omega_b h^2 / 0.024)^{-0.08}$ Mpc



Observe angle in LSS/CMB via D(z):

$$D(z) = \frac{c}{H_0} \int_0^z \frac{dz}{[\Omega_v (1+z)^{3+3w} + \Omega_m (1+z)^3 + \Omega_k (1+z)^2]^{1/2}}$$

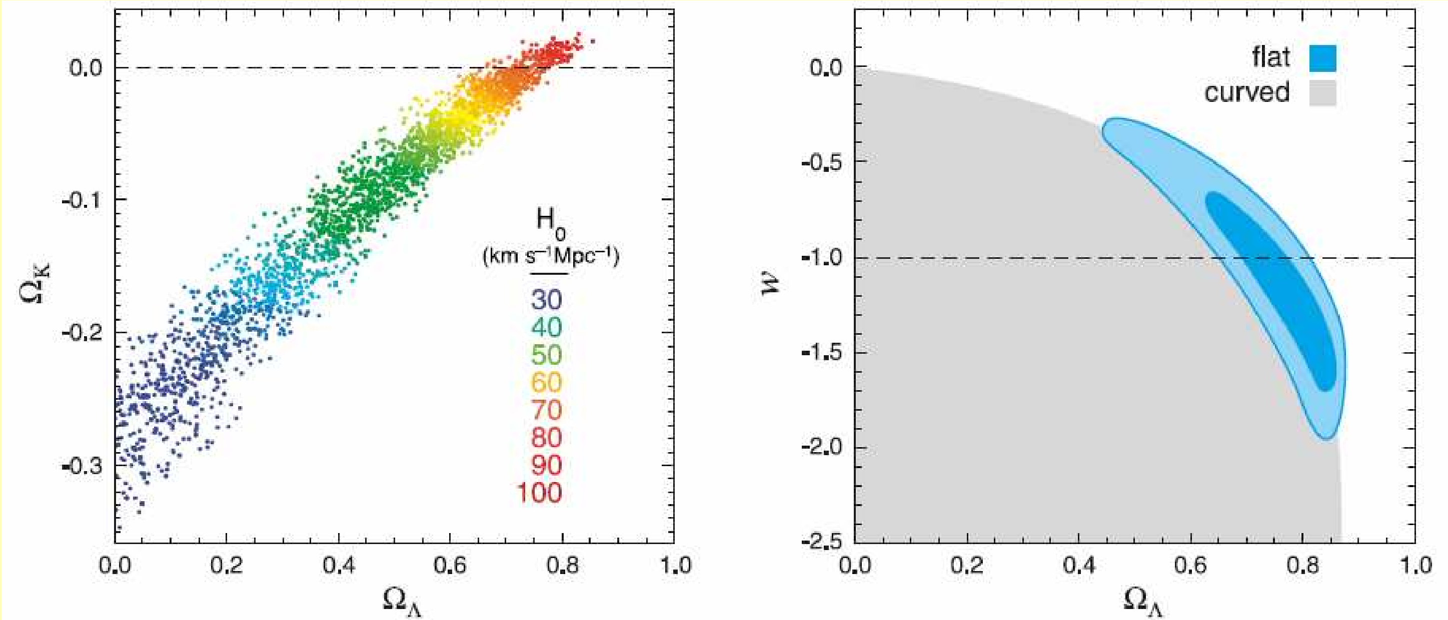
Depends on 5 parameters: CMB can fix 3 – need LSS @ 2 z's

– or empirical @ 5 z's

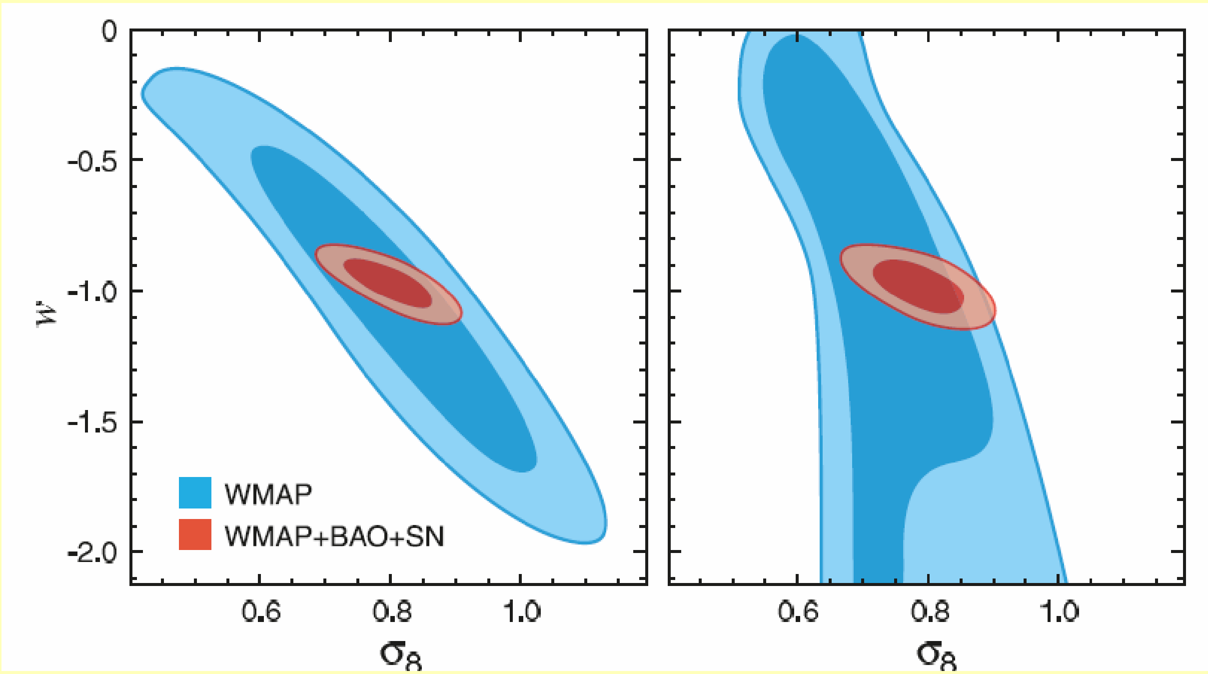
Also H(z) appears in growth $\ddot{\delta} + 2H(z)\dot{\delta} = 4\pi G\, \bar{\rho}_m\, \delta$

d ln δ / d ln a = $\Omega_m(a)^\gamma$ γ not = 0.6 indicates modified gravity

Breaking degeneracies



WMAP + h < 1 (Dunkley et al. 2008)



WMAP++ (Komatsu et al. 2008)

History: the CDM argument for Λ

The cosmological constant and cold dark matter

G. Efstathiou, W. J. Sutherland & S. J. Maddox

Department of Physics, University of Oxford, Oxford OX1 3RH, UK

THE cold dark matter (CDM) model[1–4] for the formation and distribution of galaxies in a universe with exactly the critical density is theoretically appealing and has proved to be durable, but recent work[5–8] suggests that there is more cosmological structure on very large scales ($l > 10\ h^{-1}$ Mpc, where h is the Hubble constant H_0 in units of $100\ \text{km s}^{-1}\ \text{Mpc}^{-1}$) than simple versions of the CDM theory predict. We argue here that the successes of the CDM theory can be retained and the new observations accommodated in a spatially flat cosmology in which as much as 80% of the critical density is provided by a positive cosmological constant, which is dynamically equivalent to endowing the vacuum with a non-zero energy density. In such a universe, expansion was dominated by CDM until a recent epoch, but is now governed by the cosmological constant. As well as explaining large-scale structure, a cosmological constant can account for the lack of fluctuations in the microwave background and the large number of certain kinds of object found at high redshift.

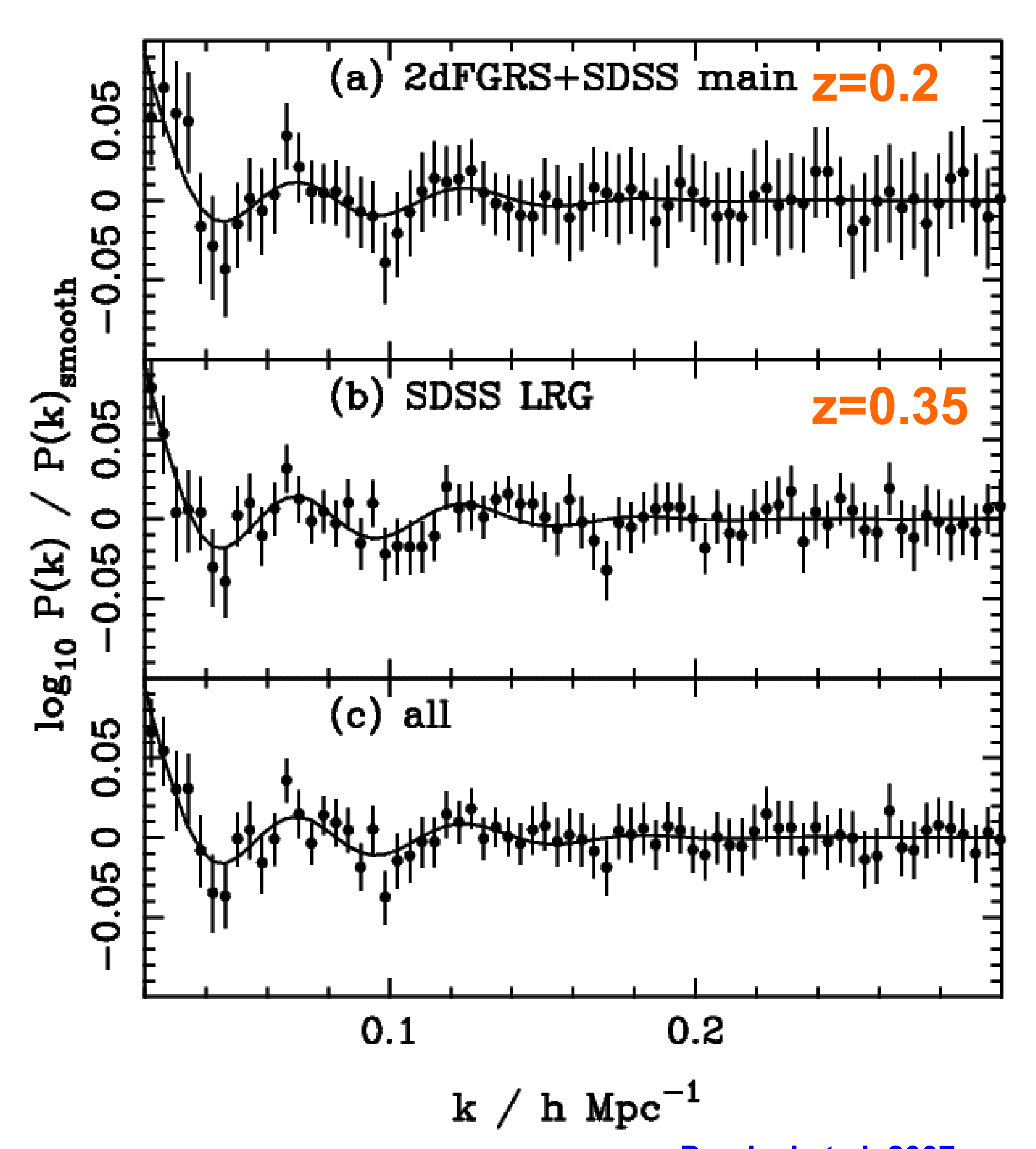
We can, however, simply accept that $\Omega_0 \approx 0.2$, while retaining the key ingredients of the CDM model, namely a flat universe with scale-invariant, adiabatic initial fluctuations. This requires a positive cosmological constant and is compatible with inflation[12]. Furthermore, spatially flat scale-invariant CDM models with $\Omega_0 h \approx 0.2$ are compatible with limits on the anisotropies of the microwave background radiation[23], whereas equivalent low-density models with $\Lambda = 0$ are firmly excluded by these limits[14].

Why wasn't this correct argument immediately accepted?

– Model dependence

– Denial

Dark Energy with BAO



Percival et al. 2007

In practice: % error in D = $(V / 5\ h^{-3}\ Gpc^3)^{-1/2}$ $\times\ (k_{max} / 0.2\ h\ Mpc^{-1})^{-1/2}$

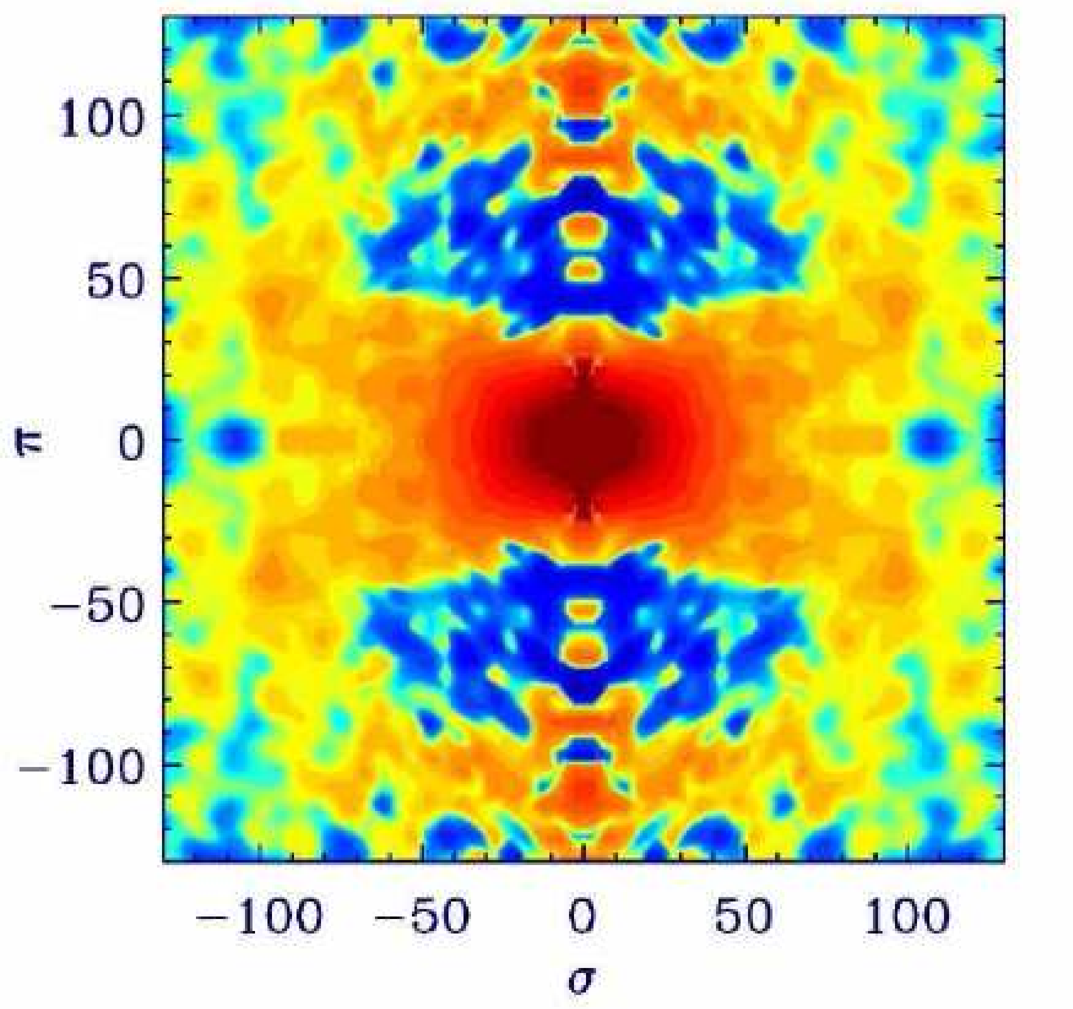
So at z ~ 1, 1% in D (= 5% in w) needs few X (1000 deg^2, 10^6 z's)

Main current/future BAO surveys

Name	Telescope	N(z) / 10^6	Dates	Status
SDSS/2dFGRS	SDSS/AAT	0.8	Now	Done
WiggleZ	AAT(AAOmega)	0.4	2007-2011	Running
FastSound	Subaru(FMOS)	0.6	2009-2012	Proposal
BOSS	SDSS	1.5	2009-2013	Approved
HETDEX	HET(VIRUS)	1	2010-2013	Part funded
WFMOS	Subaru	>2	2013-2016	Part funded
ADEPT	Space	>100	2012+	JDEM
EUCLID	Space	>100	2018	ESA
SKA	SKA	>100	2020+	Long term

Photometric redshifts

Redshift-space 2D $\xi(\sigma,\pi)$
Gaztanaga et al. 0807.3551



Radial convolution from photo-z gives change in effective volume by factor

$12(\sigma_z/1+z / 0.03)$

Pan-STARRS

Panoramic Survey Telescope and Rapid Reponse System

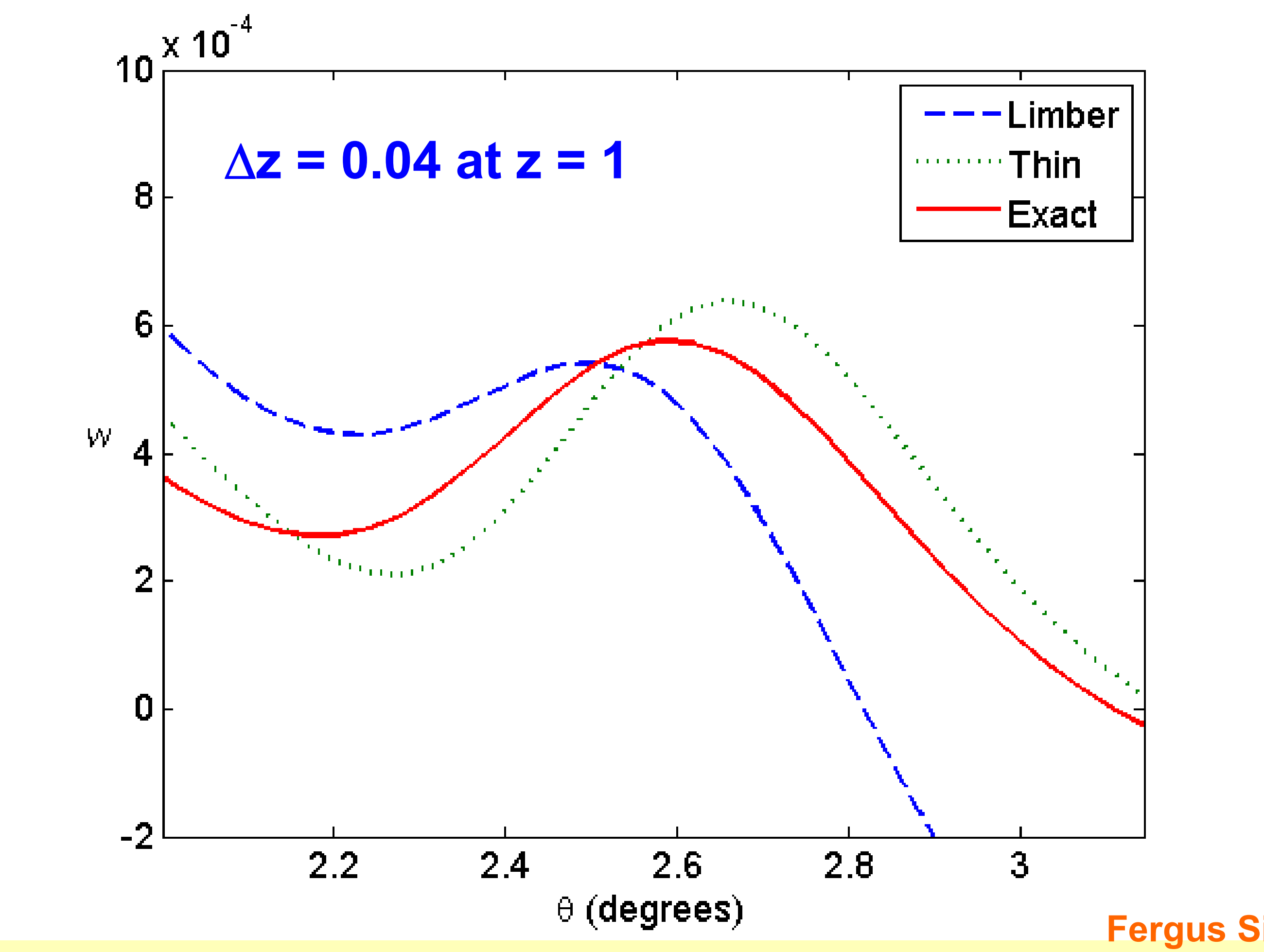
The world's leading survey telescope, sited on Haleakala, Maui, Hawaii

- 1.8m mirror
- 7 deg^2 fov and 1.4 Gpixel CCD

Survey (5-band grizy) operations from early 2009, for 3.5 years

- All-sky to r = 24.6 (above dec -30)
- 70 deg^2 to r = 27.4 (variability)

Need to treat radial selection with care



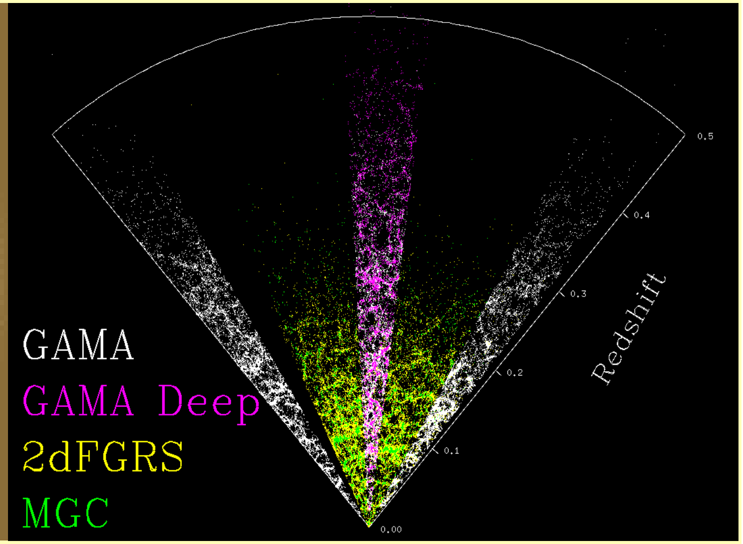
Fergus Simpson

Angular clustering in photo-z slices: Limber formula inadequate

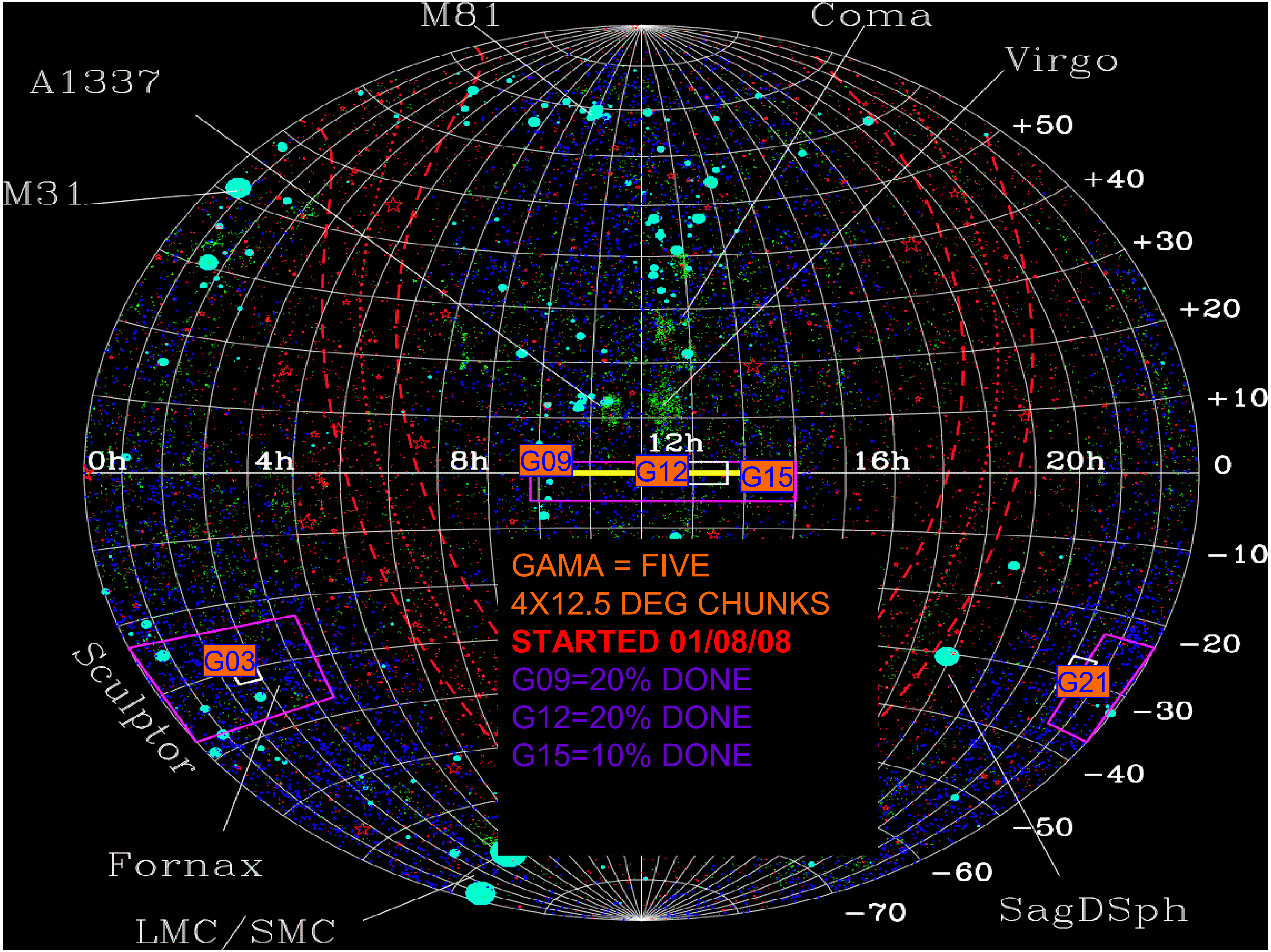
Other issues

- Need to understand photo-z systematics at << 1%
- Need to calibrate photo-z's: $>10^5$ spectroscopic z's over different sky regions, with extremely high success rate and confidence.

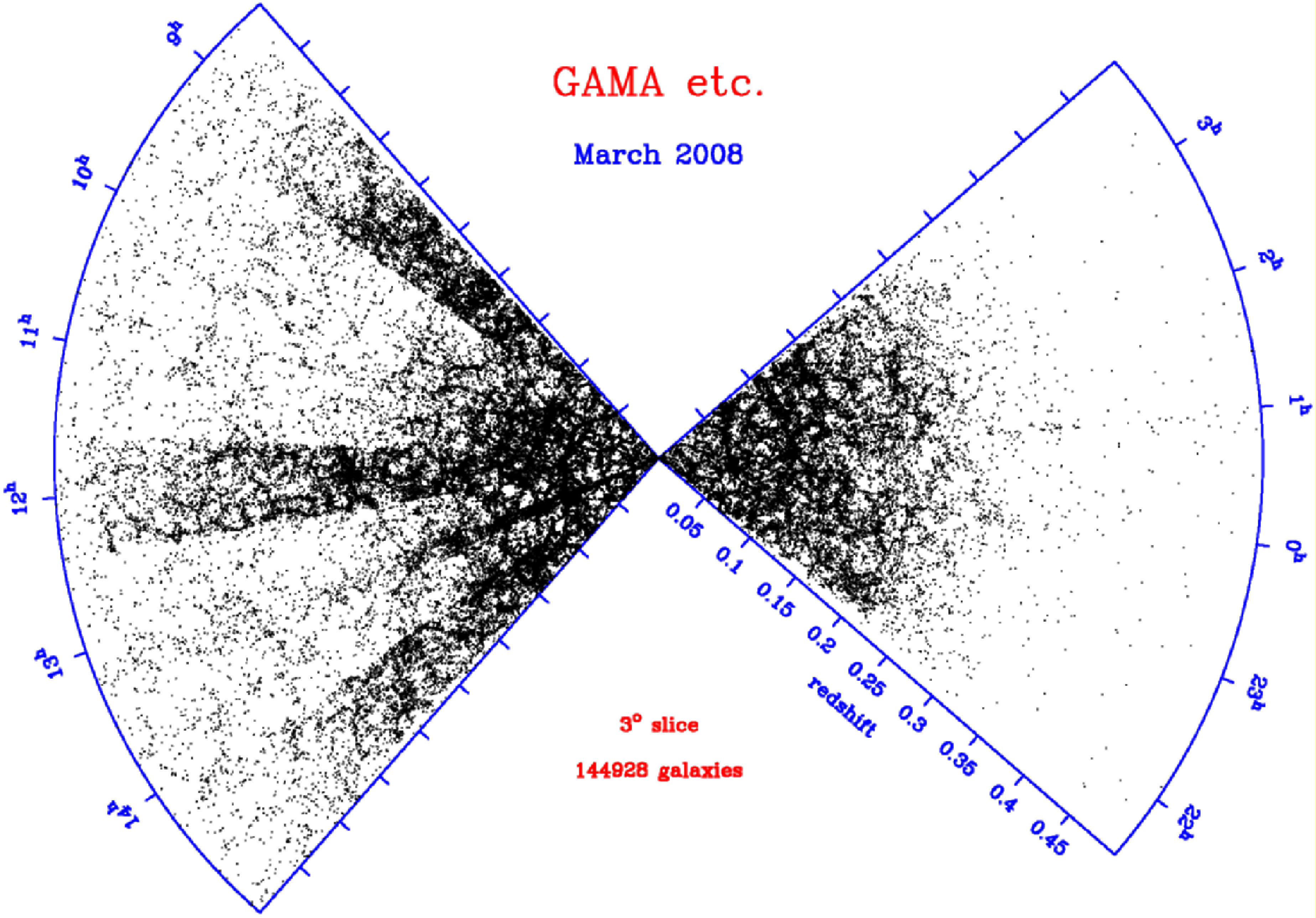
Galaxy Mass And Assembly – GAMA



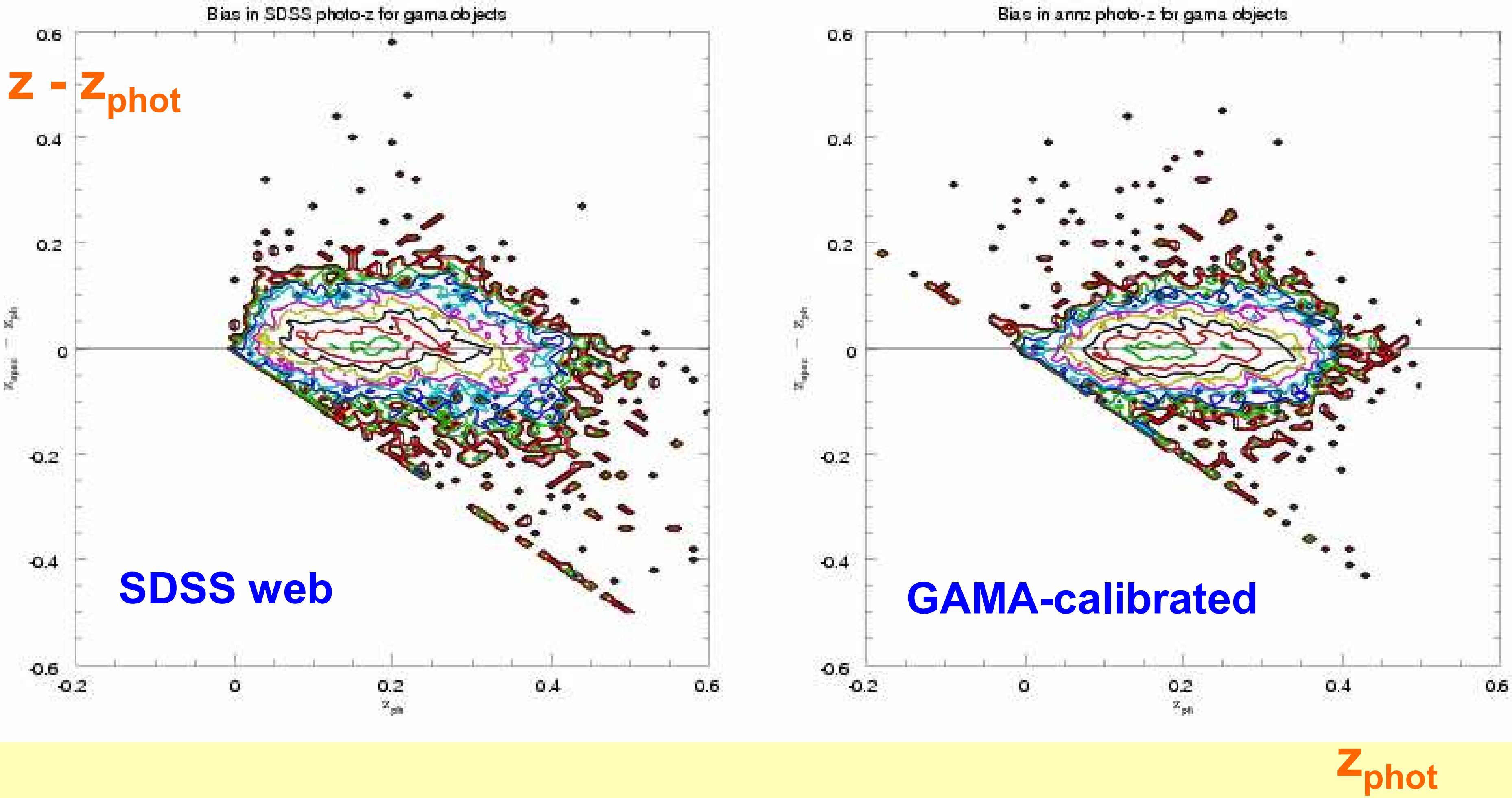
- 250 deg^2 in 5 fields
- to r < 19.4 / 19.8 (GAMA deep) in one field – cf. SDSS 17.8
- Aim for > 100,000 redshifts
- First season:
  - 22 nights mar/apr 08 – 20 clear
  - 50746 z's out of 52557 spectra: 96.6% success


M81
Coma
Virgo
A1337
M31
+50
+40
+30
+20
+10
0
−10
−20
−30
−40
−50
−60
−70
0h
4h
8h
12h
16h
20h
G09
G12
G15
G03
G21
Sculptor
Fornax
LMC / SMC
SagDSph
GAMA = FIVE
4X12.5 DEG CHUNKS
STARTED 01/08/08
G09=20% DONE
G12=20% DONE
G15=10% DONE

GAMA: year 1 cone diagram



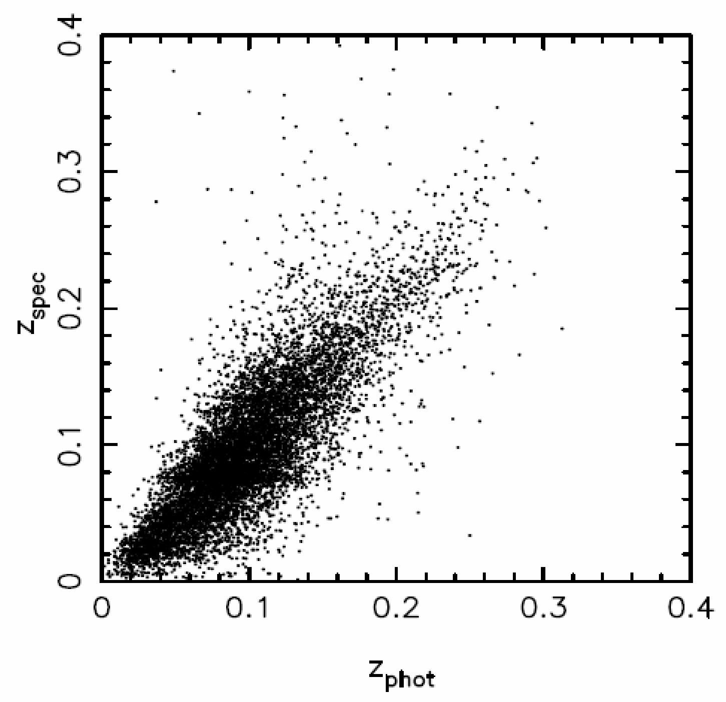
GAMA-improved SDSS photo-z's

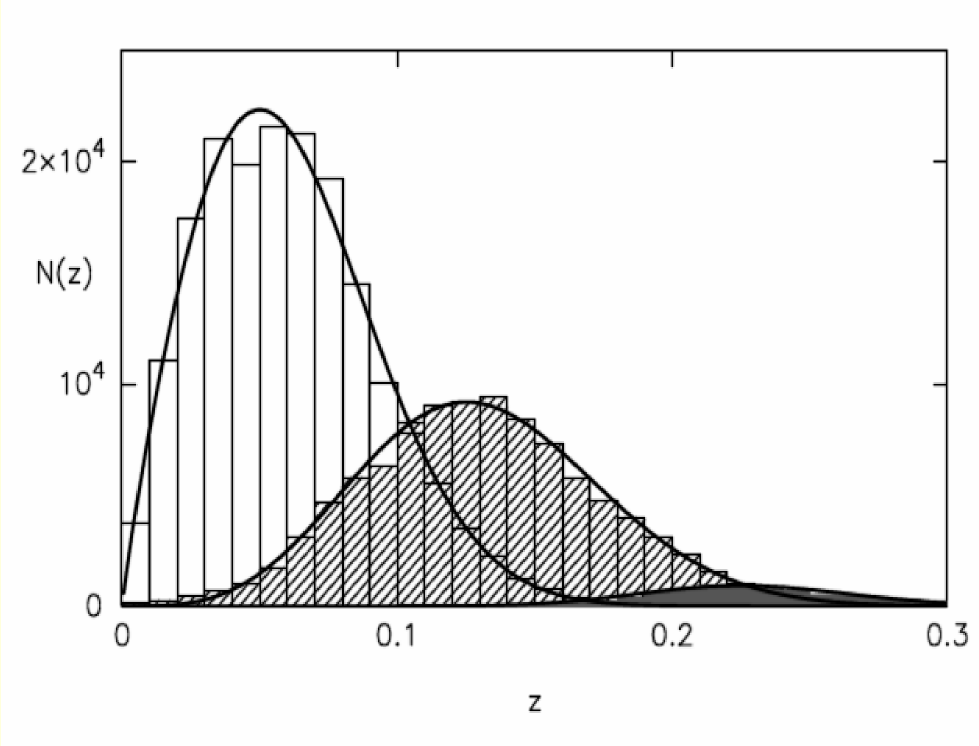


Hannah Parkinson

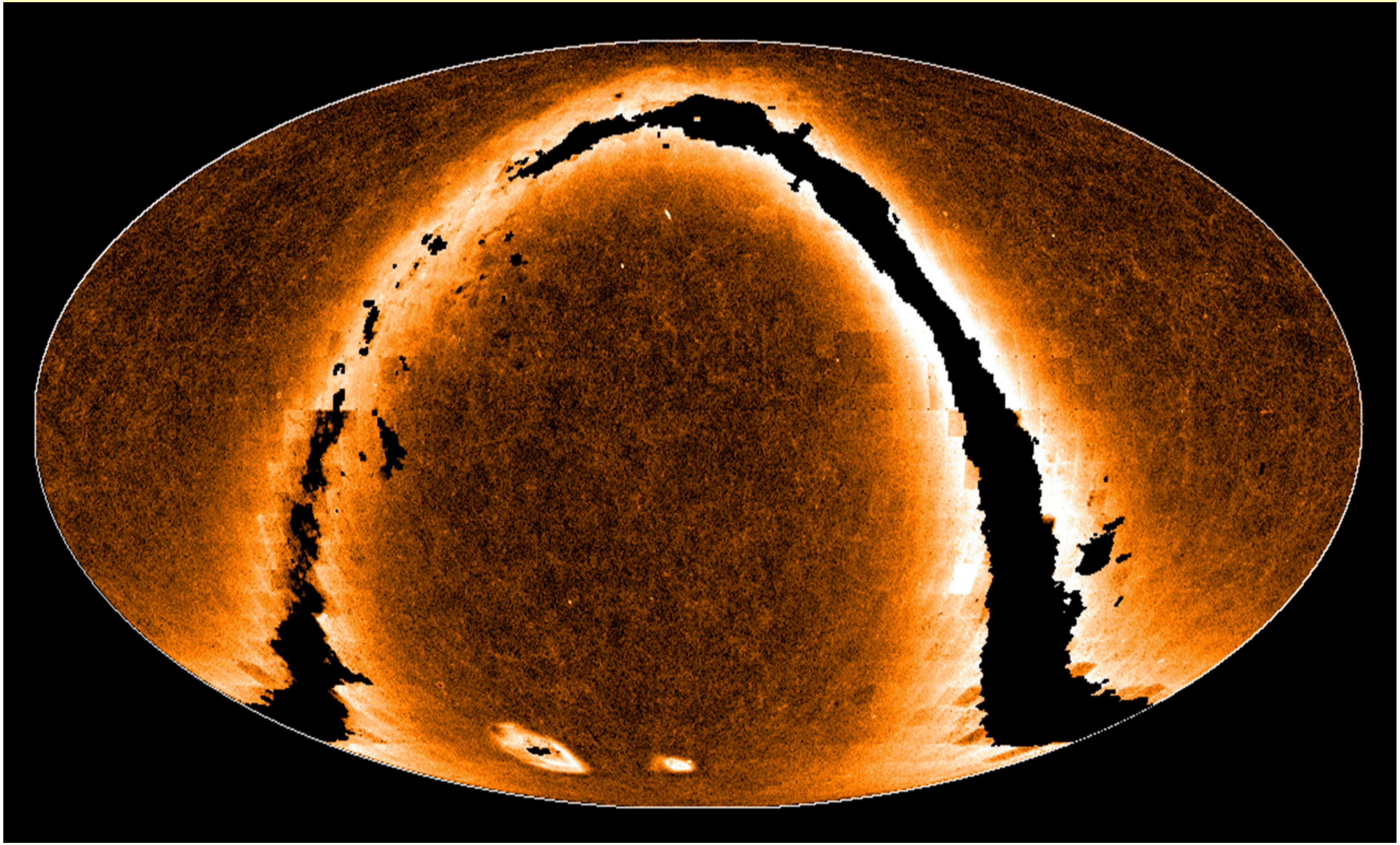
Worked example: 2MASS

- All-sky XSC: 1.6 million galaxies
- Match with SuperCOSMOS photographic photometry
- BRJHK $\Rightarrow \sigma_z / (1+z) = 0.033$

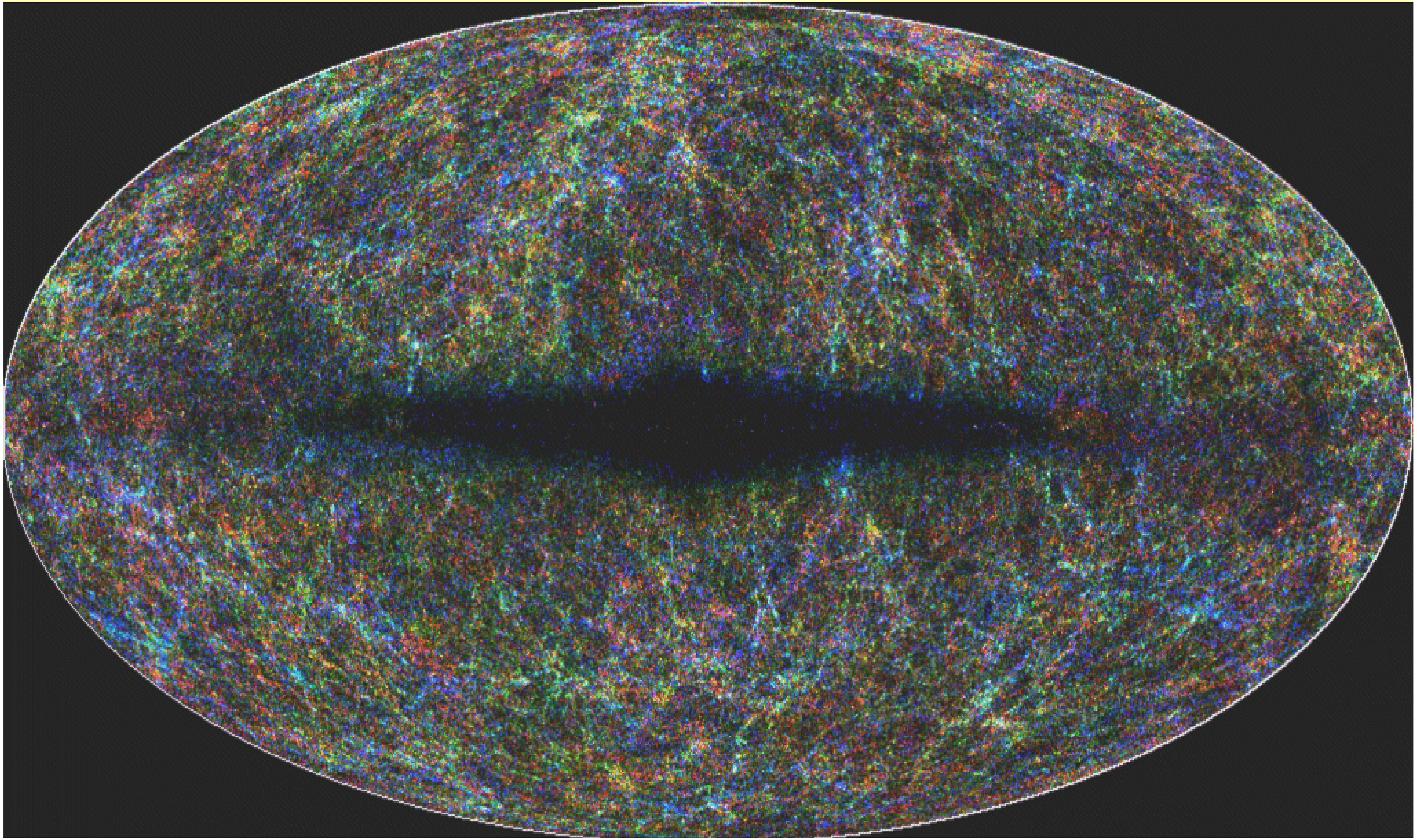




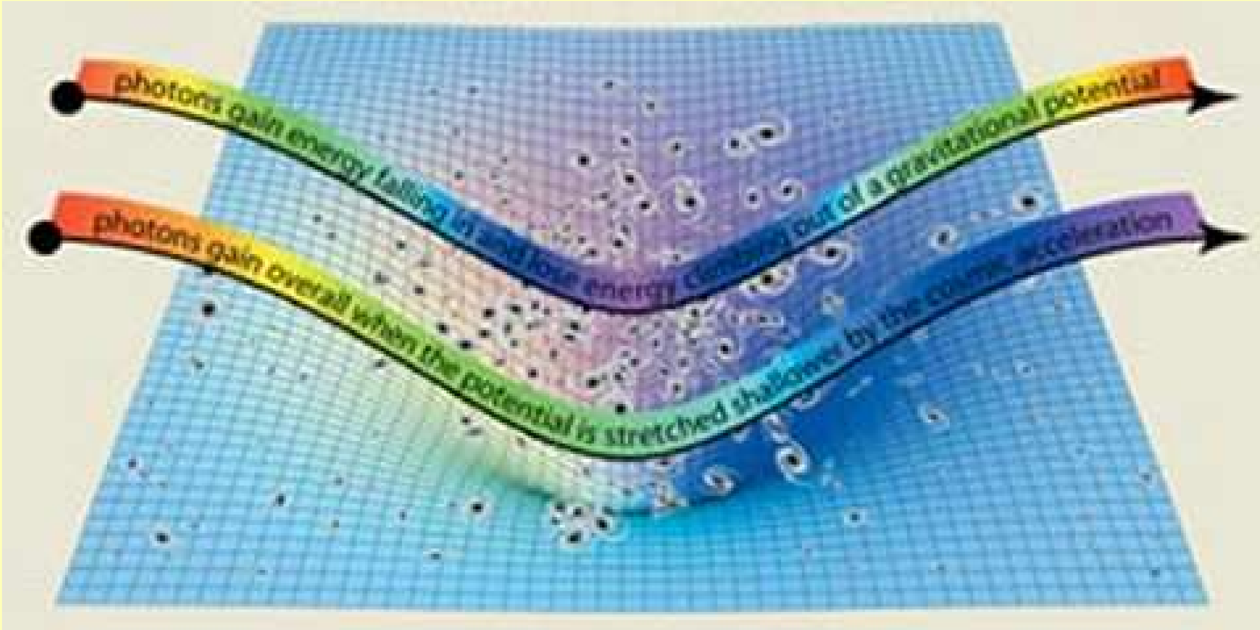
10^8 All-sky galaxies: SuperCOSMOS UKST + POSS2



2MASS XSC: BRJHK photoz map



Application: ISW effect

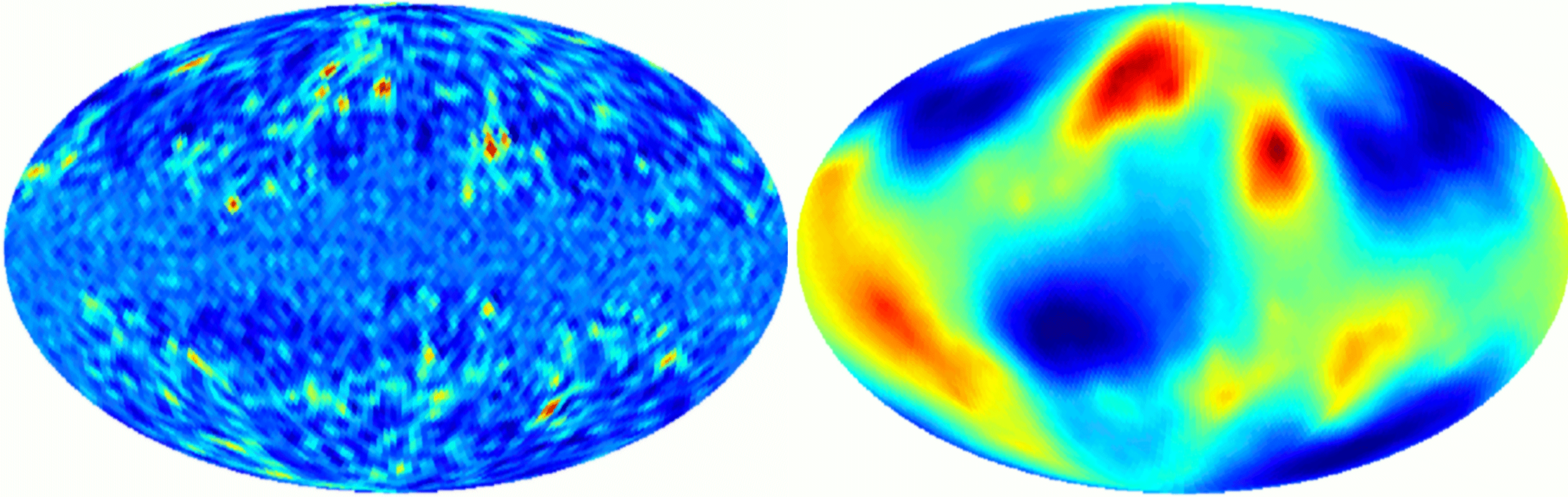


$$\frac{\Delta T^{\mathrm{ISW}}}{T_{\mathrm{CMB}}} = 2\int_{t_{\mathrm{LS}}}^{t_0} \frac{\dot{\Phi}(\vec{x}(t),t)}{c^2}\,\mathrm{d}t$$

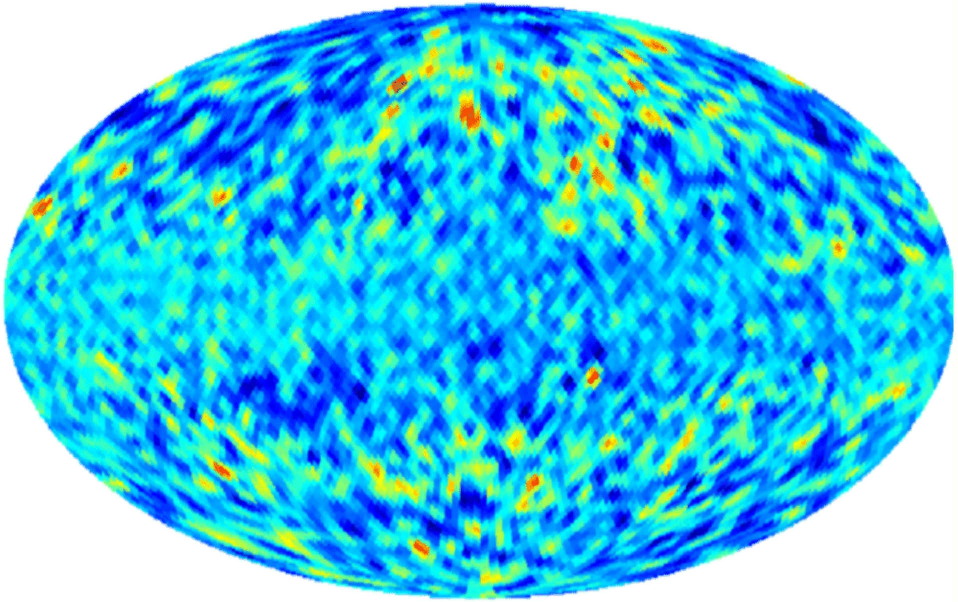
$$\frac{\Delta T_{\ell m}}{T} = -2\int \frac{d}{dt}\left[\frac{g(a)}{a}\right] \frac{a^2\Phi_{\ell m}(a)}{g(a)}\,\frac{dr}{c^3}$$

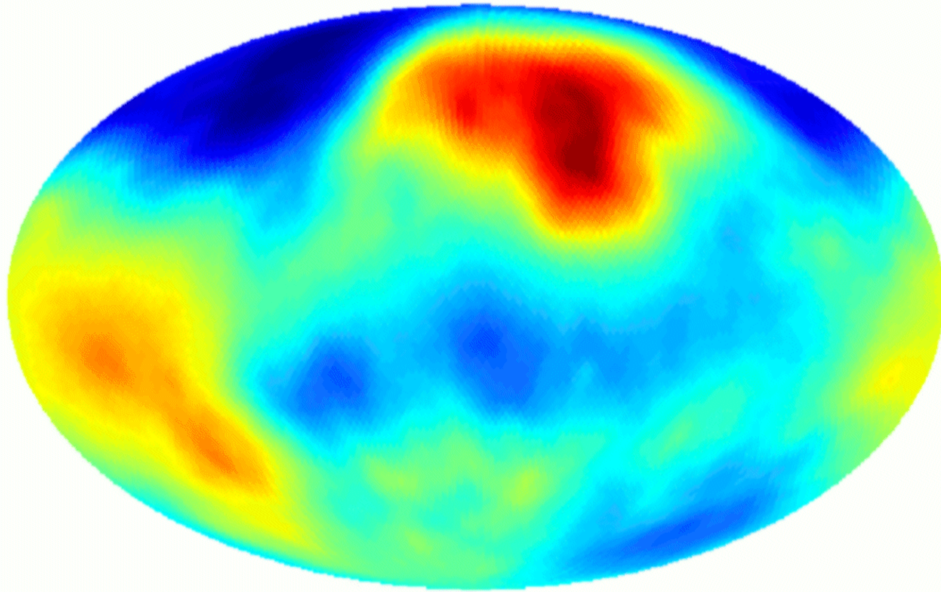
Integrate potential through shell, using Poisson to relate to density field

‘Observed’ ISW map: z < 0.1

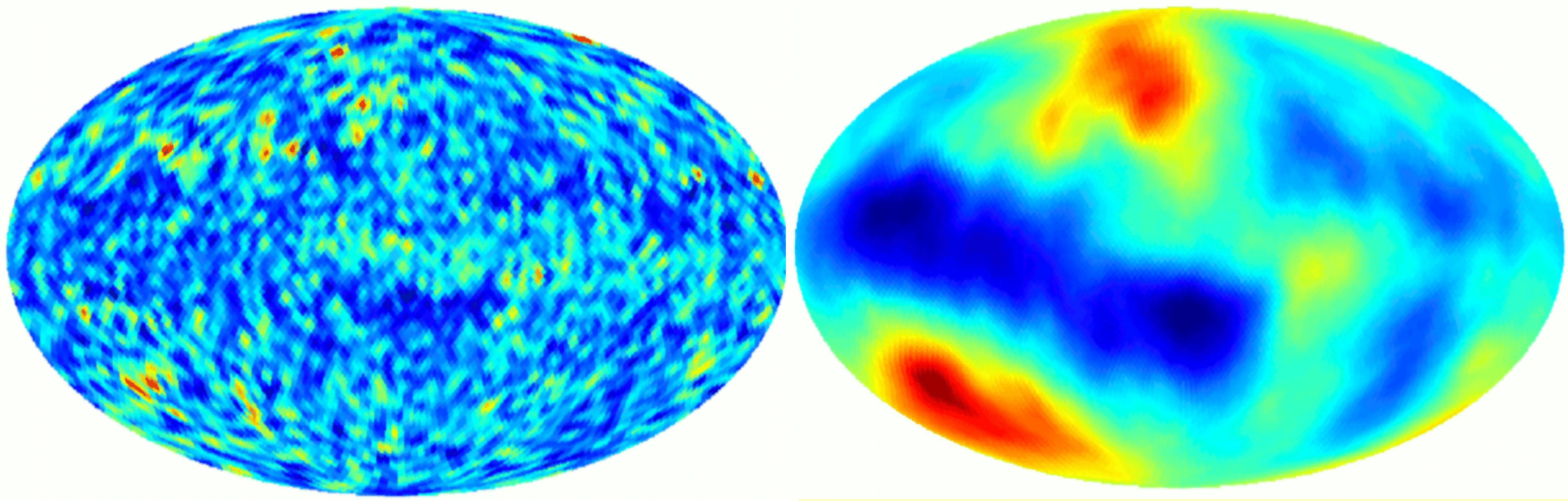


‘Observed’ ISW map: $0.1 < z < 0.2$

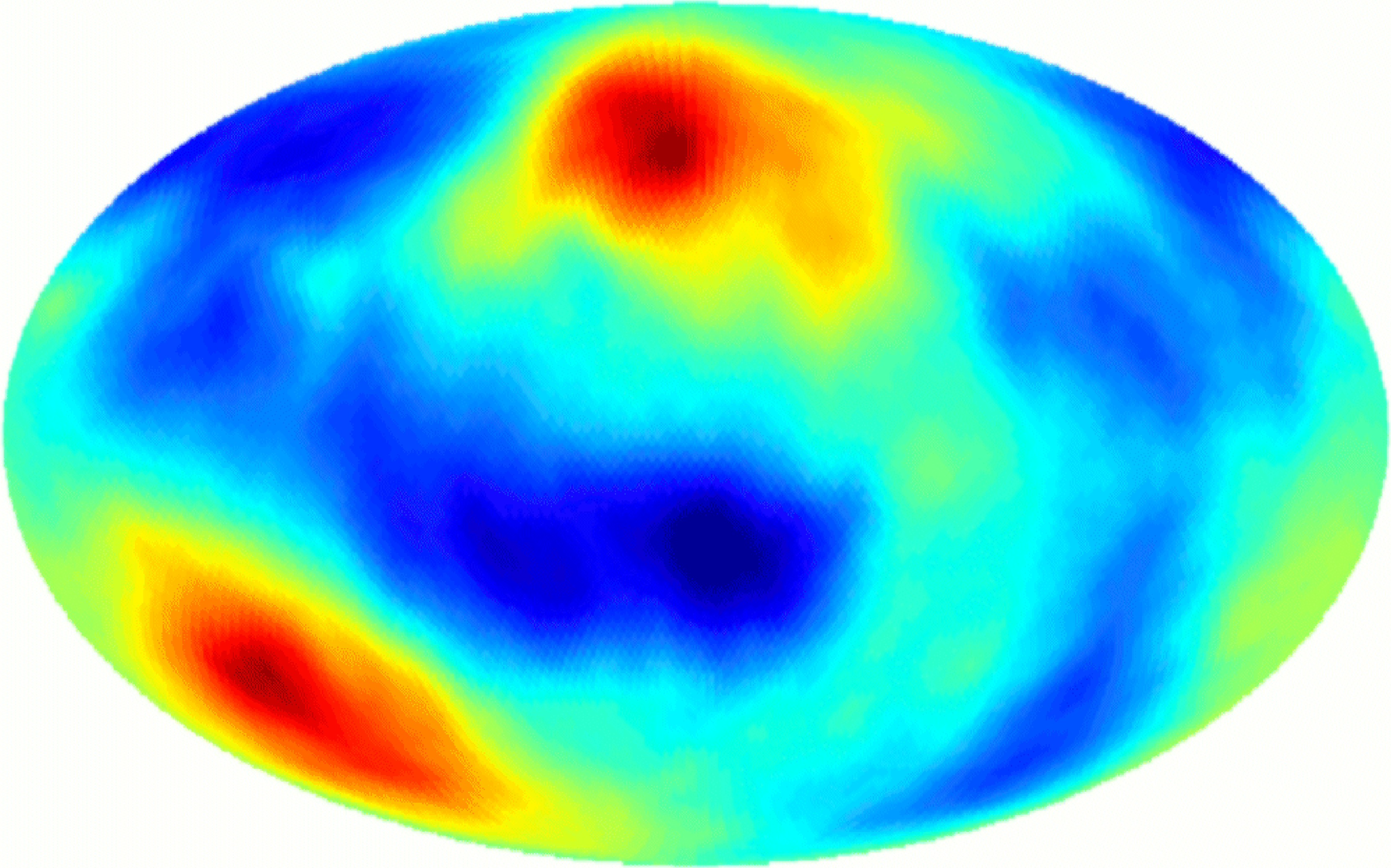


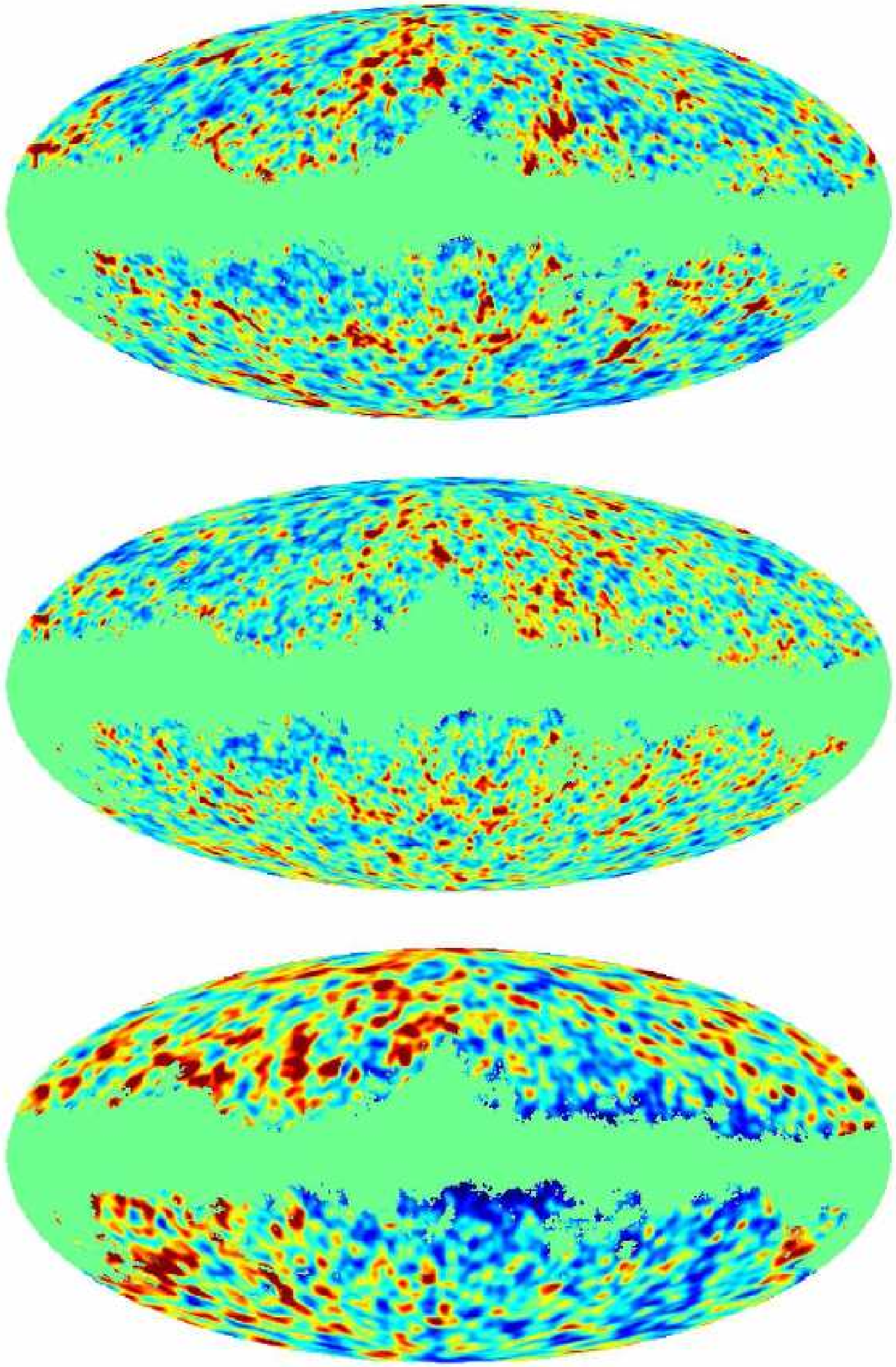


‘Observed’ ISW map: 0.2 < z < 0.3



‘Observed’ ISW map: z < 0.3

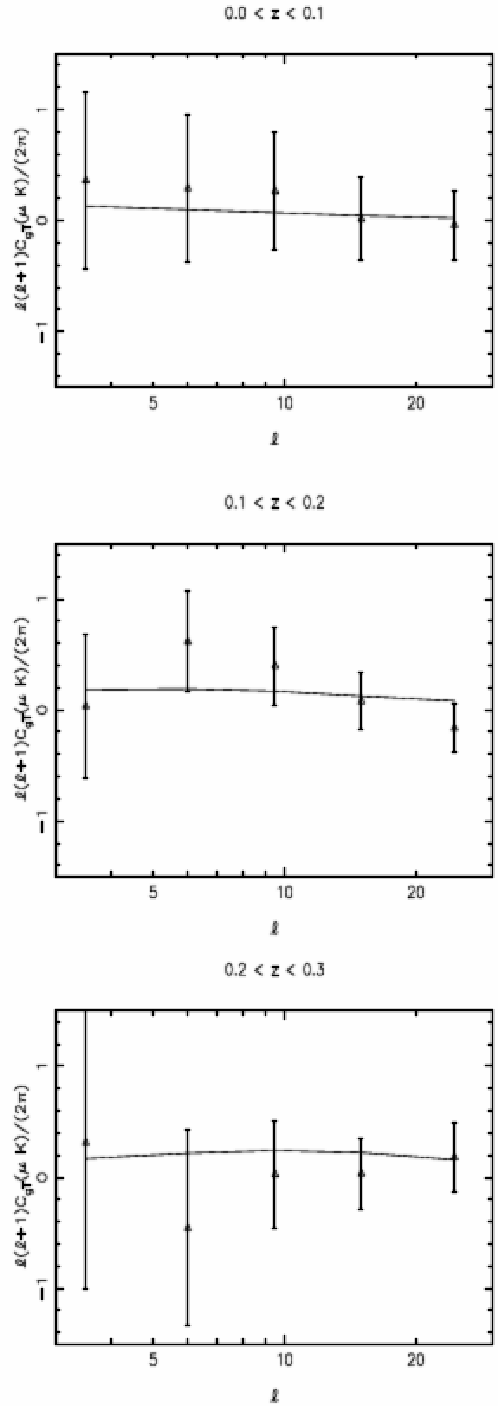




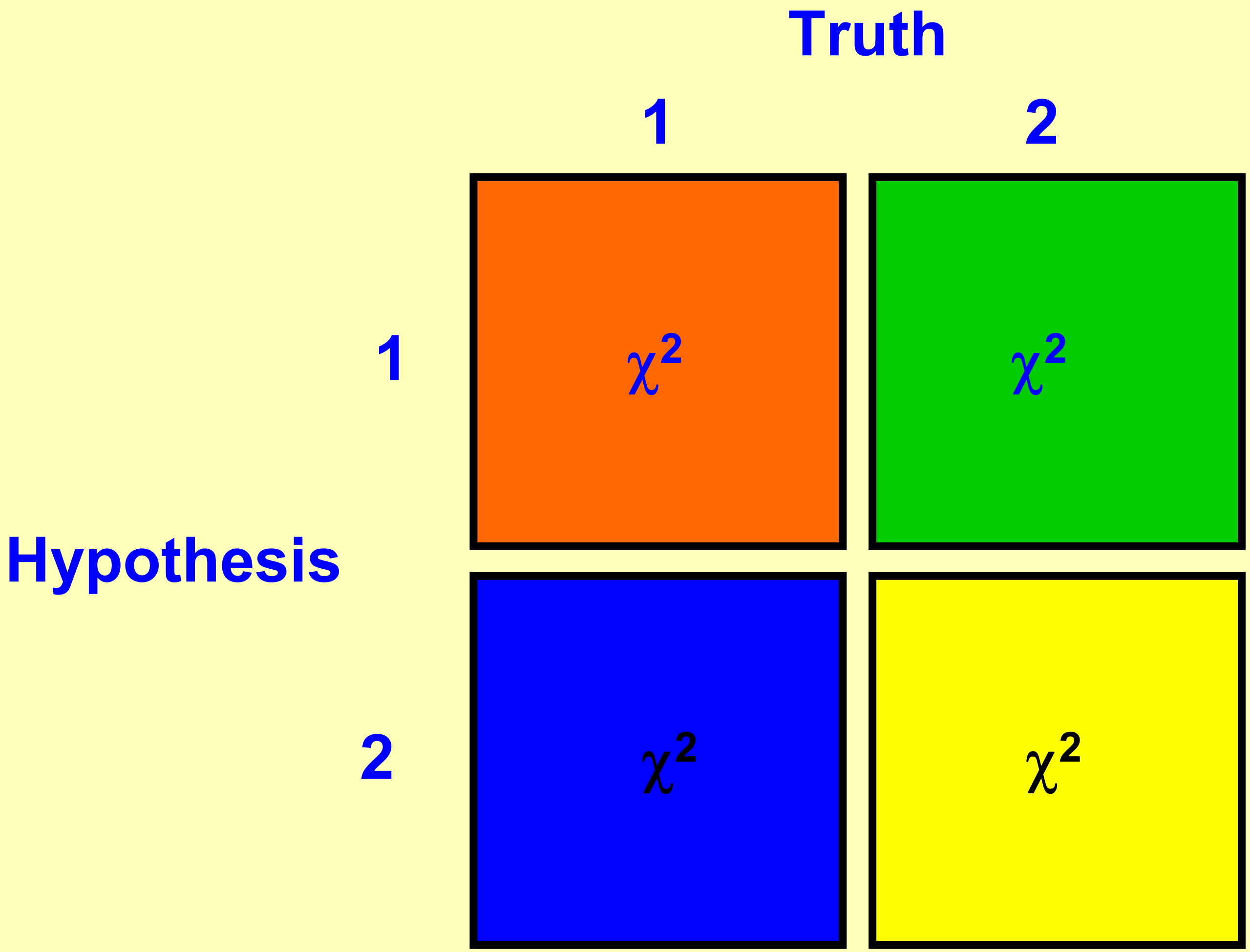
2MASS:

no detection from harmonic space cross-correlation in redshift bands

(Caroline Francis); see also Rassat et al. 2006



Type I vs Type II errors

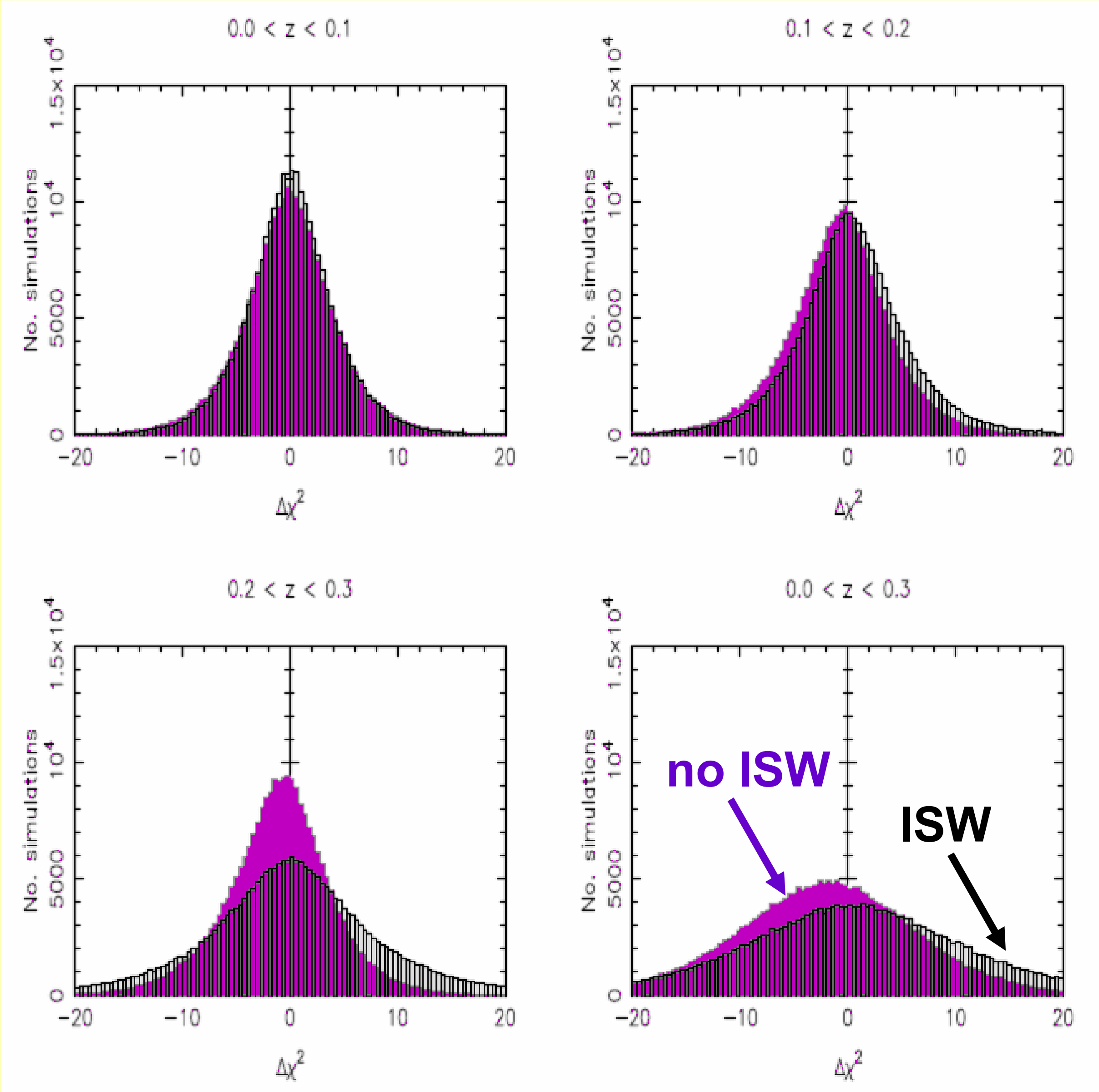


1 = ISW

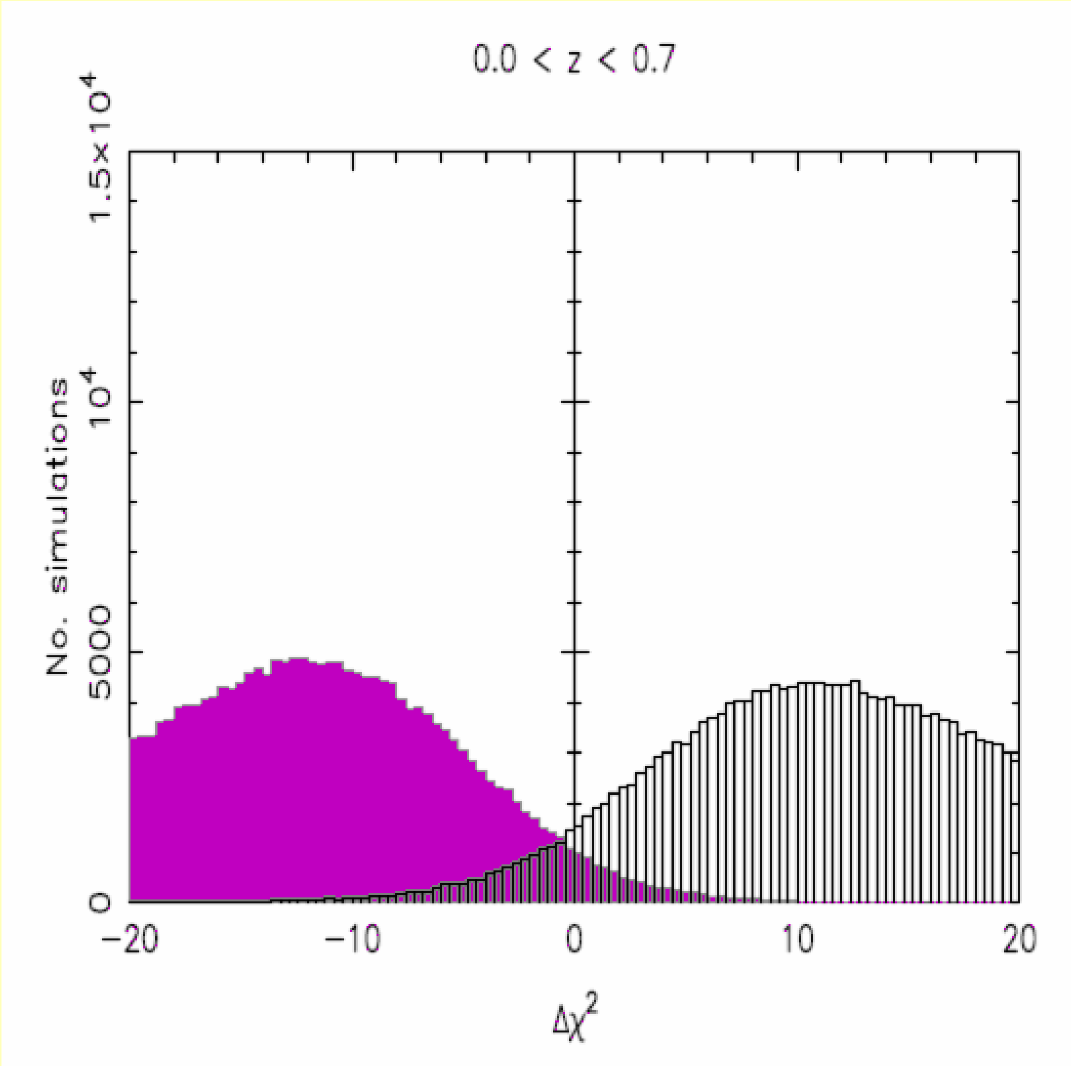
2 = no ISW

A powerful experiment would have $\Delta\chi^2$ favouring 1 if 1 is true and 2 if 2 is true

Realizations of type I & Type II errors

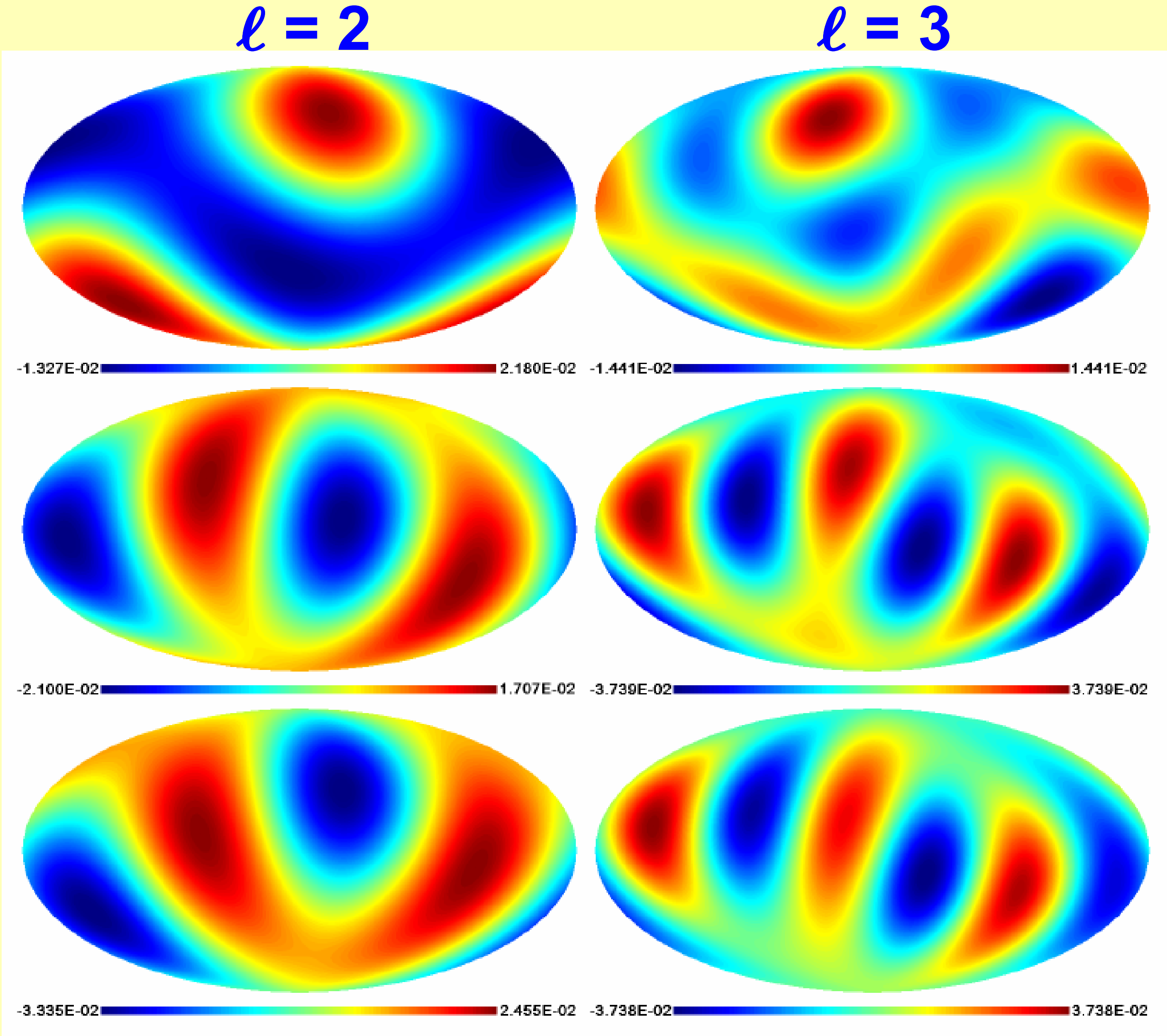


Almost perfect (masked) data



Probability of non-detection ~ 15%

Effect on low-ℓ anomalies

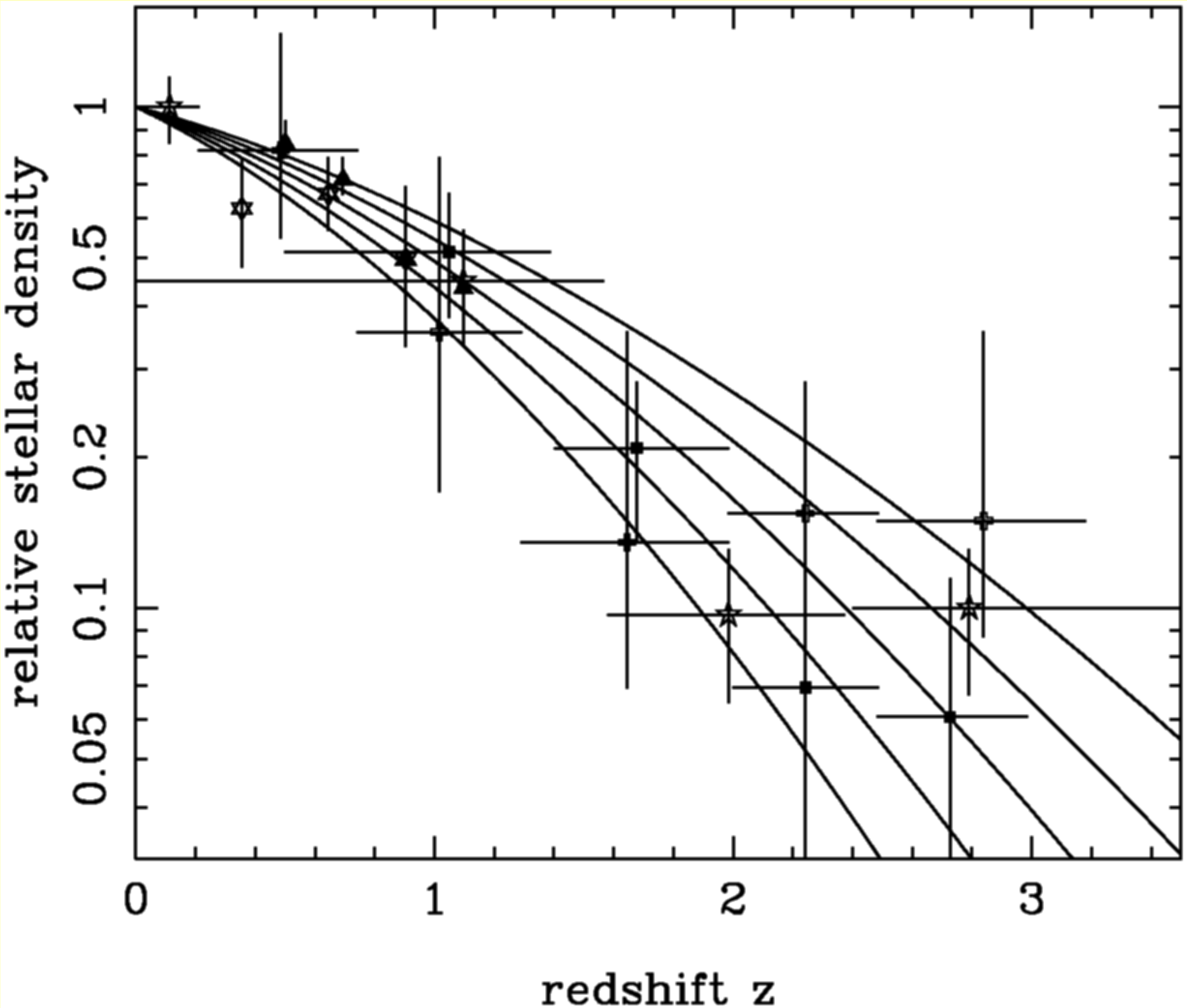


ISW

WMAP

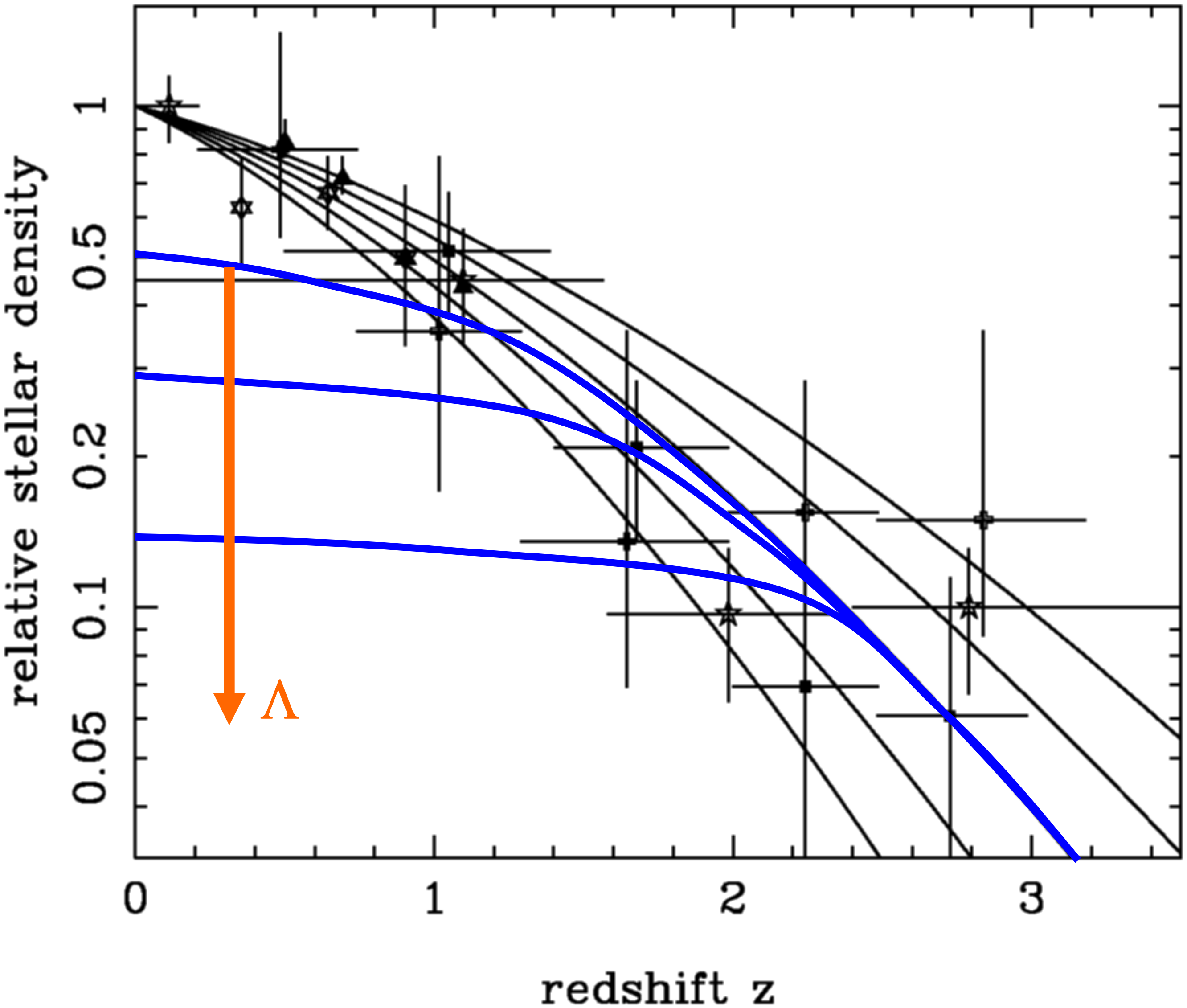
$P < 1\% \rightarrow$
$P \sim 10\%$

Build-up of stellar mass



Well modelled by collapse fraction into haloes of mass $2 \times 10^{12}\ M_{\odot}$

What if Λ were bigger?

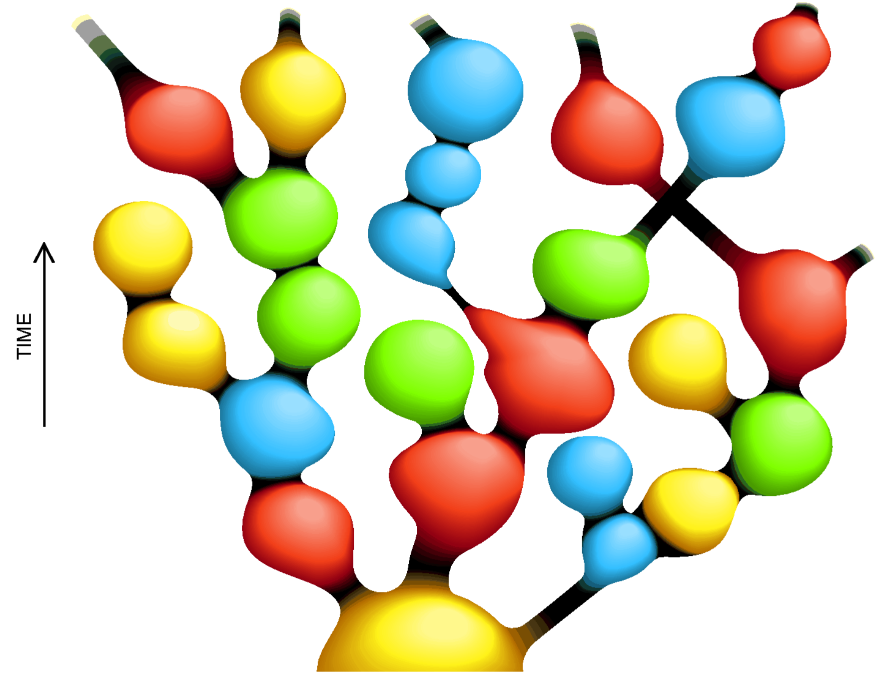


Growth of structure freezes out at vacuum domination

The answer to ‘why now’ must be anthropic

- One-universe anthropic
  - Life (structure) only after matter-radiation equality
  - Not controversial
  - k-essence would do
  - But need to solve classical Λ=0 problem

- Many-universe anthropic
  - Predates landscape, but requires new physics for variable Λ
  - Sound logic (exoplanets)
  - Is it testable?



Weinberg's prediction

The cosmological constant problem*

Steven Weinberg

Theory Group, Department of Physics, University of Texas, Austin, Texas 78712

Astronomical observations indicate that the cosmological constant is many orders of magnitude smaller than estimated in modern theories of elementary particles. After a brief review of the history of this problem, five different approaches to its solution are described.

Reviews of Modern Physics, Vol. 61, No. 1, January 1989

A large cosmological constant would interfere with the appearance of life in different ways, depending on the sign of λ_{eff}. For a large *positive* λ_{eff}, the universe very early enters an exponentially expanding de Sitter phase, which then lasts forever. The exponential expansion interferes with the formation of gravitational condensations, but once a clump of matter becomes gravitationally bound, its subsequent evolution is unaffected by the cosmological constant. Now, we do not know what weird forms life may take, but it is hard to imagine that it could develop at all without gravitational condensations out of an initially smooth universe. Therefore the anthropic principle makes a rather crisp prediction: λ_{eff} must be small enough to allow the formation of sufficiently large gravitational condensations (Weinberg, 1987).

This result suggests strongly that if it is the anthropic principle that accounts for the smallness of the cosmological constant, then we would expect a vacuum energy density $\rho_V \sim (10-100)\rho_{M_0}$, because there is no anthropic reason for it to be any smaller.

Is such a large vacuum energy density observationally allowed? There are a number of different types of astronomical data that indicate differing answers to this question.

Bayesian mediocrity

Assume you are a randomly-selected member of all observers ever generated in the multiverse

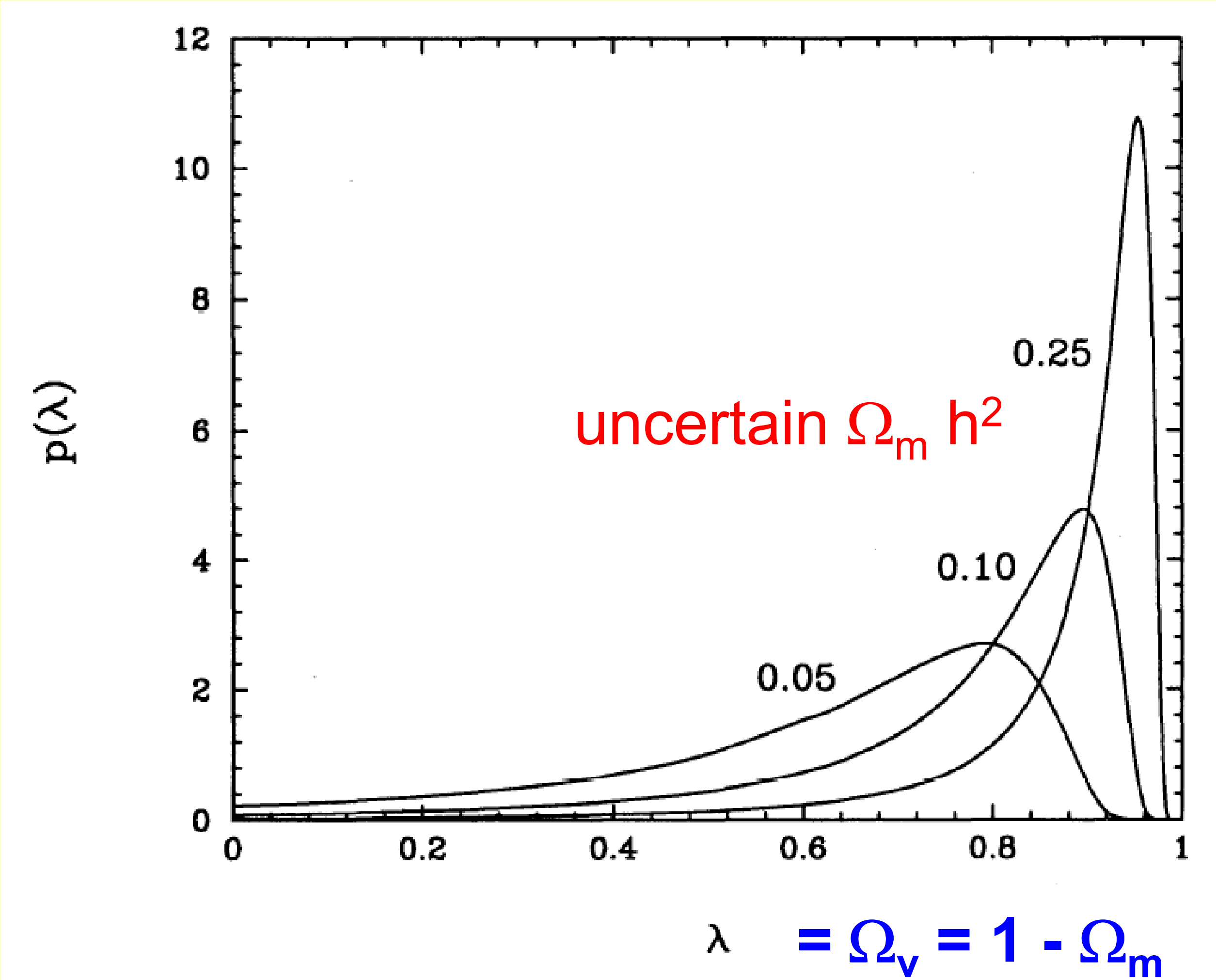
$$\boxed{\text{Bayes:} \quad P(\Lambda \mid \text{observer}) \propto P_{\text{prior}}(\Lambda)\, N_{\text{gal}}(\Lambda)}$$

Take prior on vacuum energy constant over small range around zero (not a special value)

Number of galaxies depends on fraction of universe collapsed into characteristic mass

$$M_G \sim \alpha^5 \left(\frac{\hbar c}{G m_p^2} \right)^2 \left(\frac{m_p}{m_e} \right)^{1/2} m_p$$

Efstathiou 1995



Fixes
T = 2.73 K

OK if we want to predict Λ in our universe

Conclusions

- We are well on the way to at least a photometric redshift for every galaxy in the visible universe

- Which will either rule out Λ or demonstrate $w = -1$ to <1%, and will test GR up to 100 Mpc

- Either way, need a solution to the classical Λ problem, or will have to accept an ensemble picture