What's New in Cosmology

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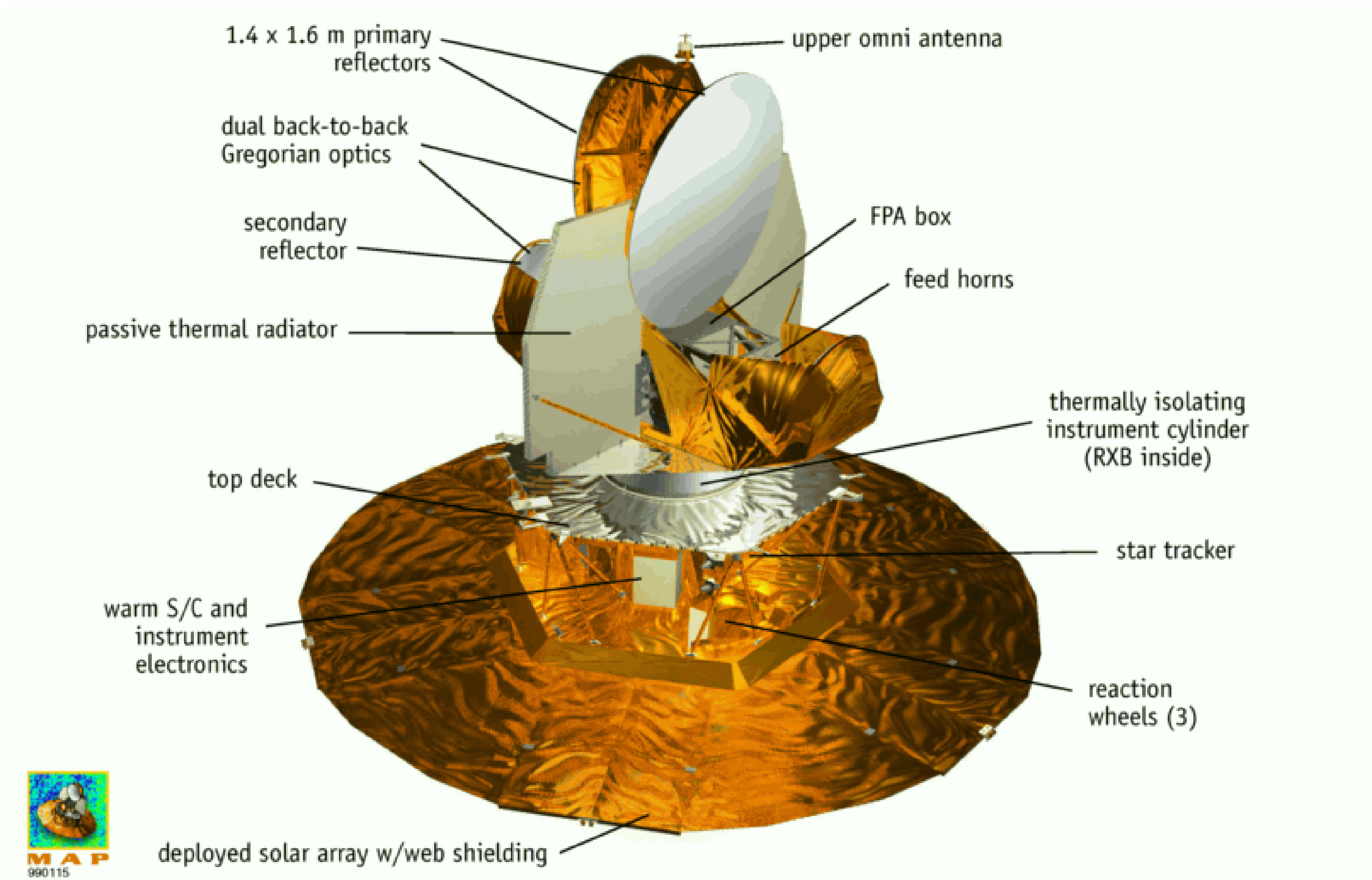
UCLA

12 May 2004

WMAP Briefly:

- The Microwave Anisotropy Probe has been renamed in honor of David T. Wilkinson
- Maps and power spectra from the first full year of WMAP data have been released. 2nd year soon.
- The TE temperature-polarization signal has been seen at large and small angles
  - $\tau = 0.17 \pm 0.04$
  - Reionization: $z \sim 17$, $t \sim 180$ Myr ABB
- ΛCDM is a good fit to the power spectrum

A New Cosmology Satellite

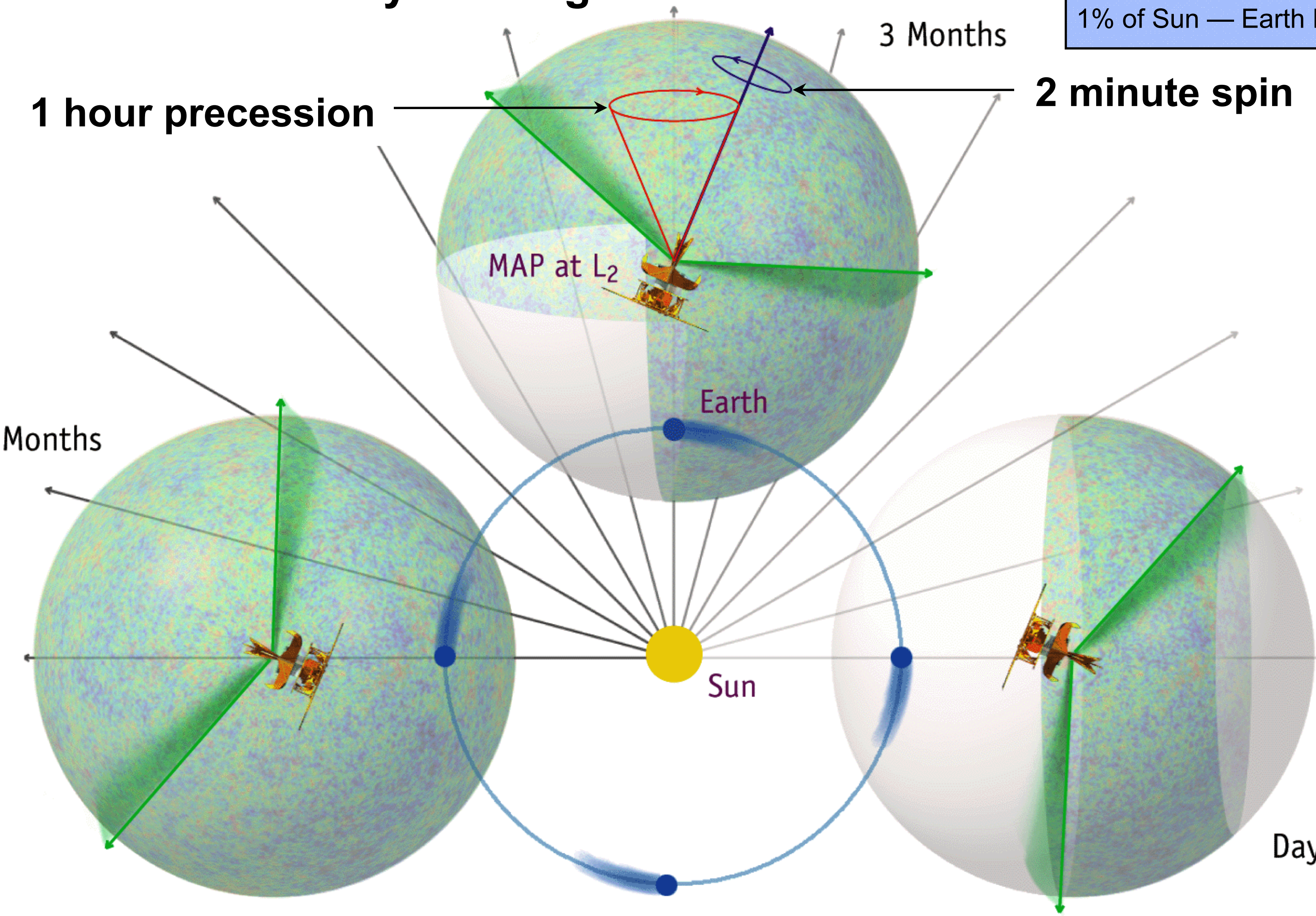


WMAP Science Working Group

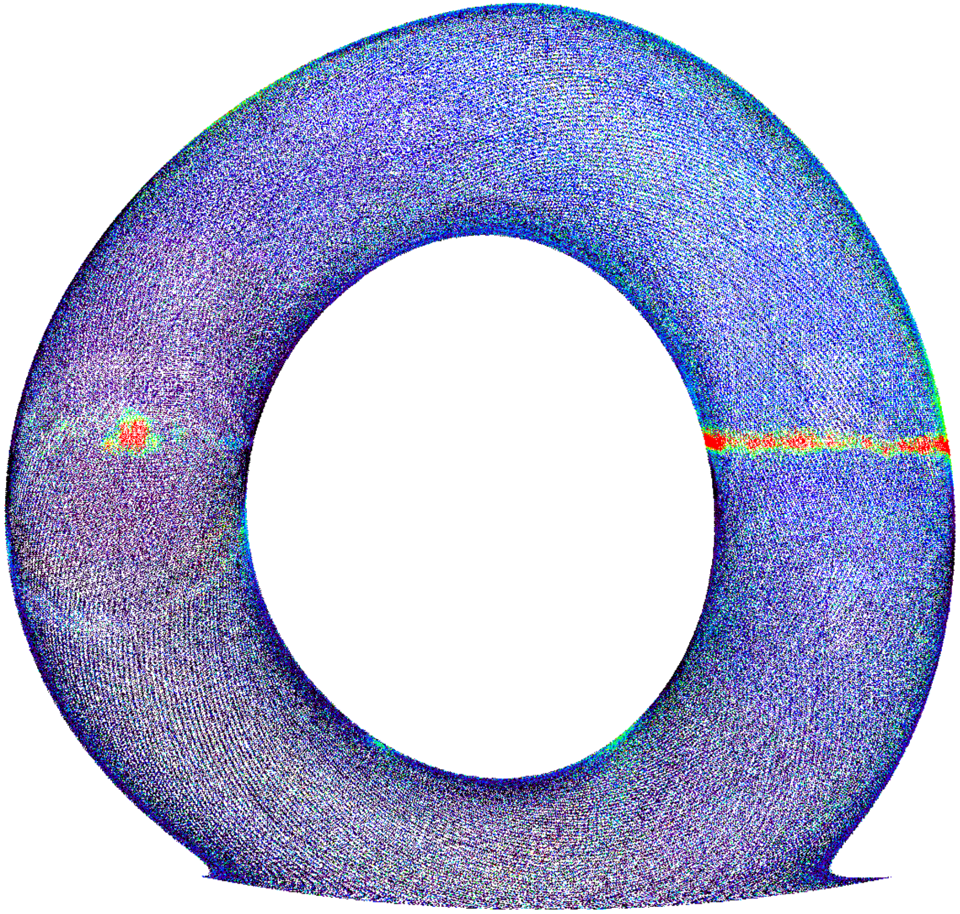
Scan Strategy

- **6 Months for full sky coverage**

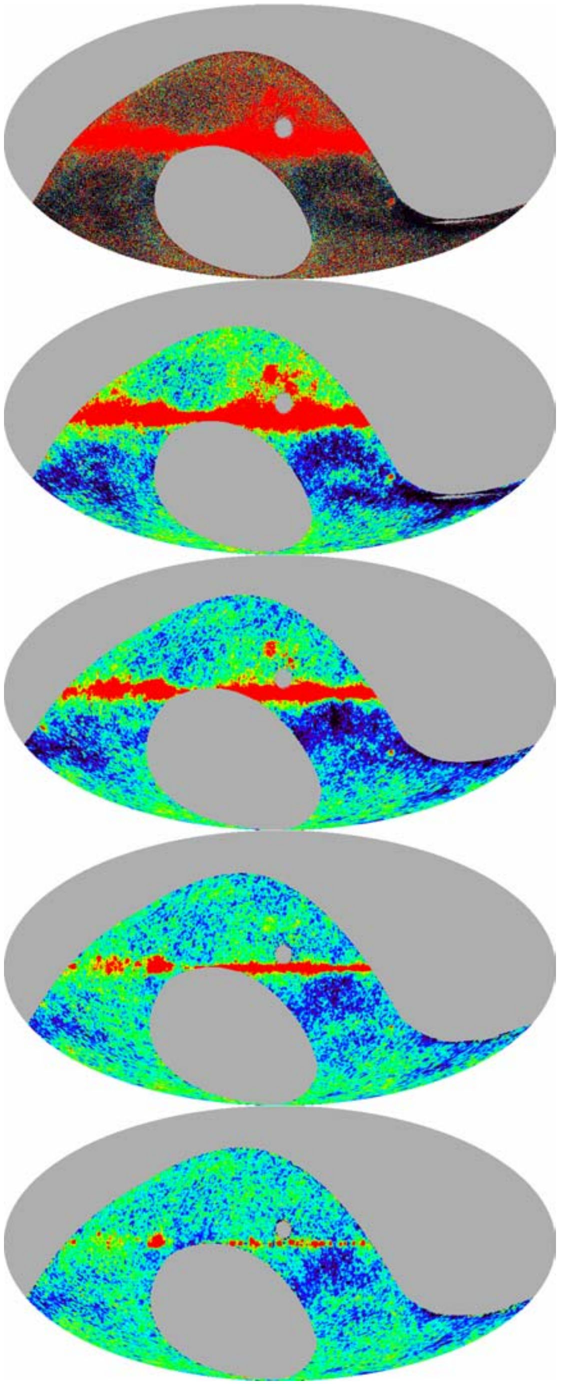
Not to scale:
Earth — L2 distance is
1% of Sun — Earth Distance



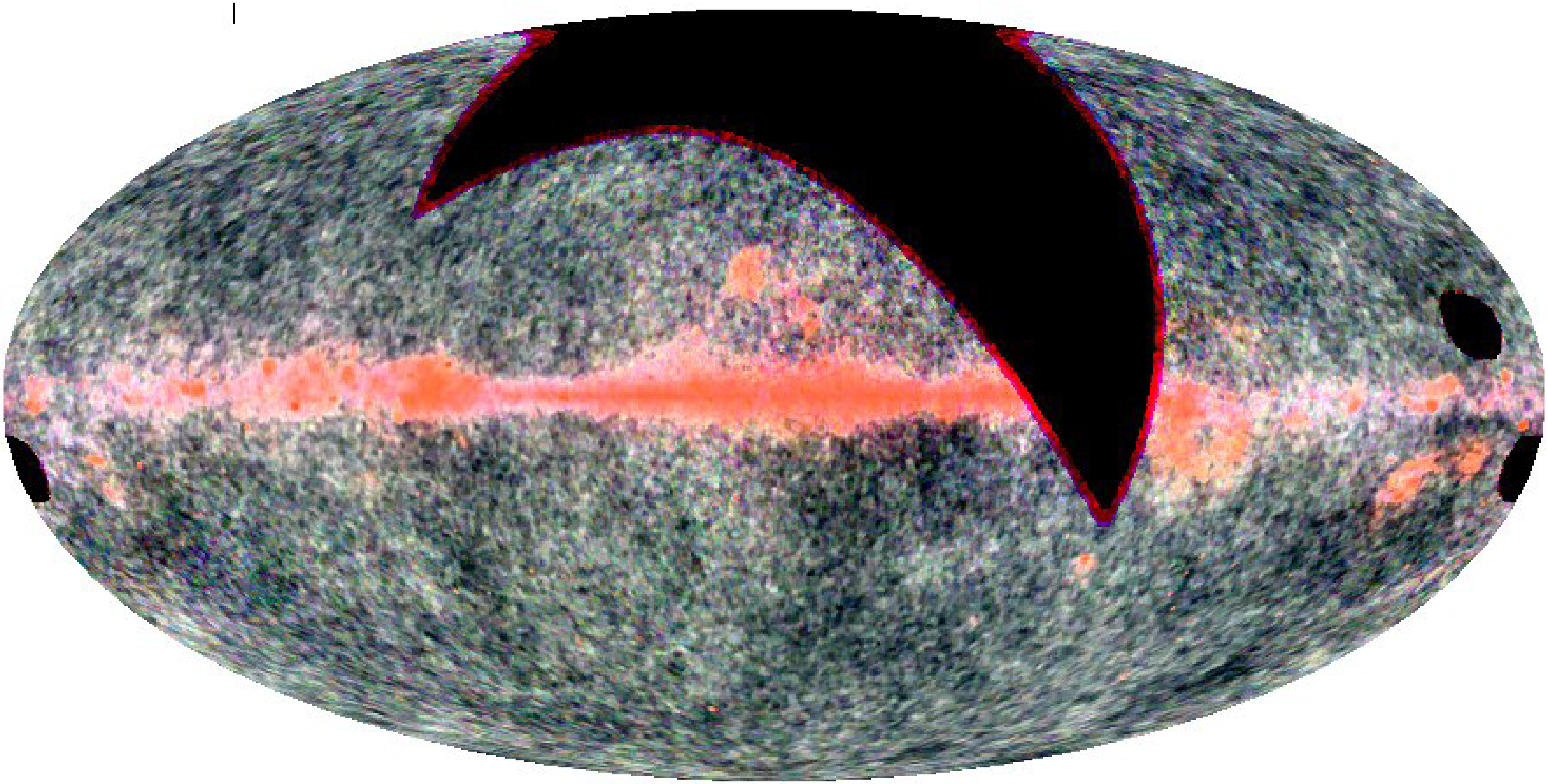
First map from WMAP, day 01186



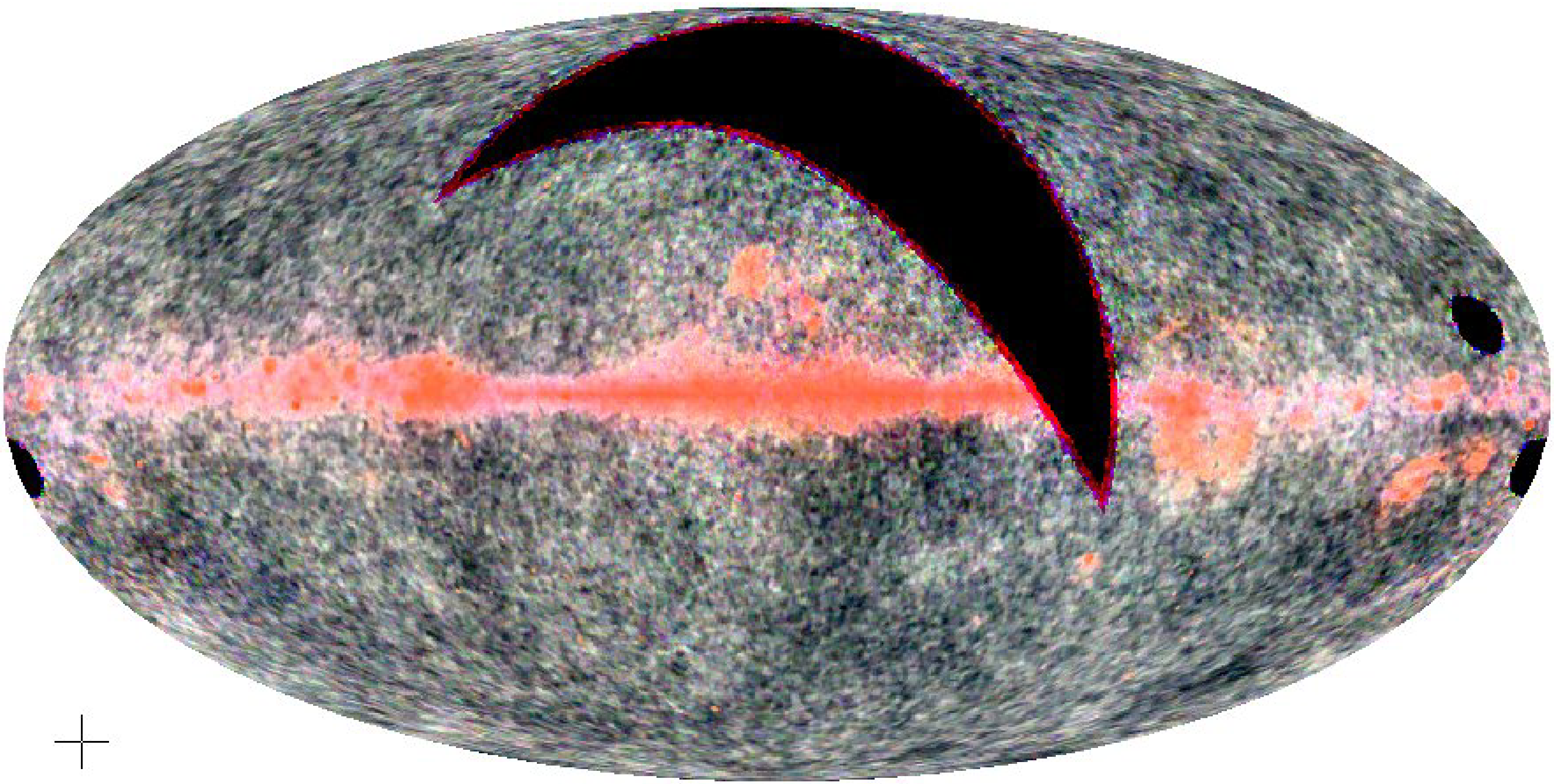
Before closing the donut hole: maps from August 2001



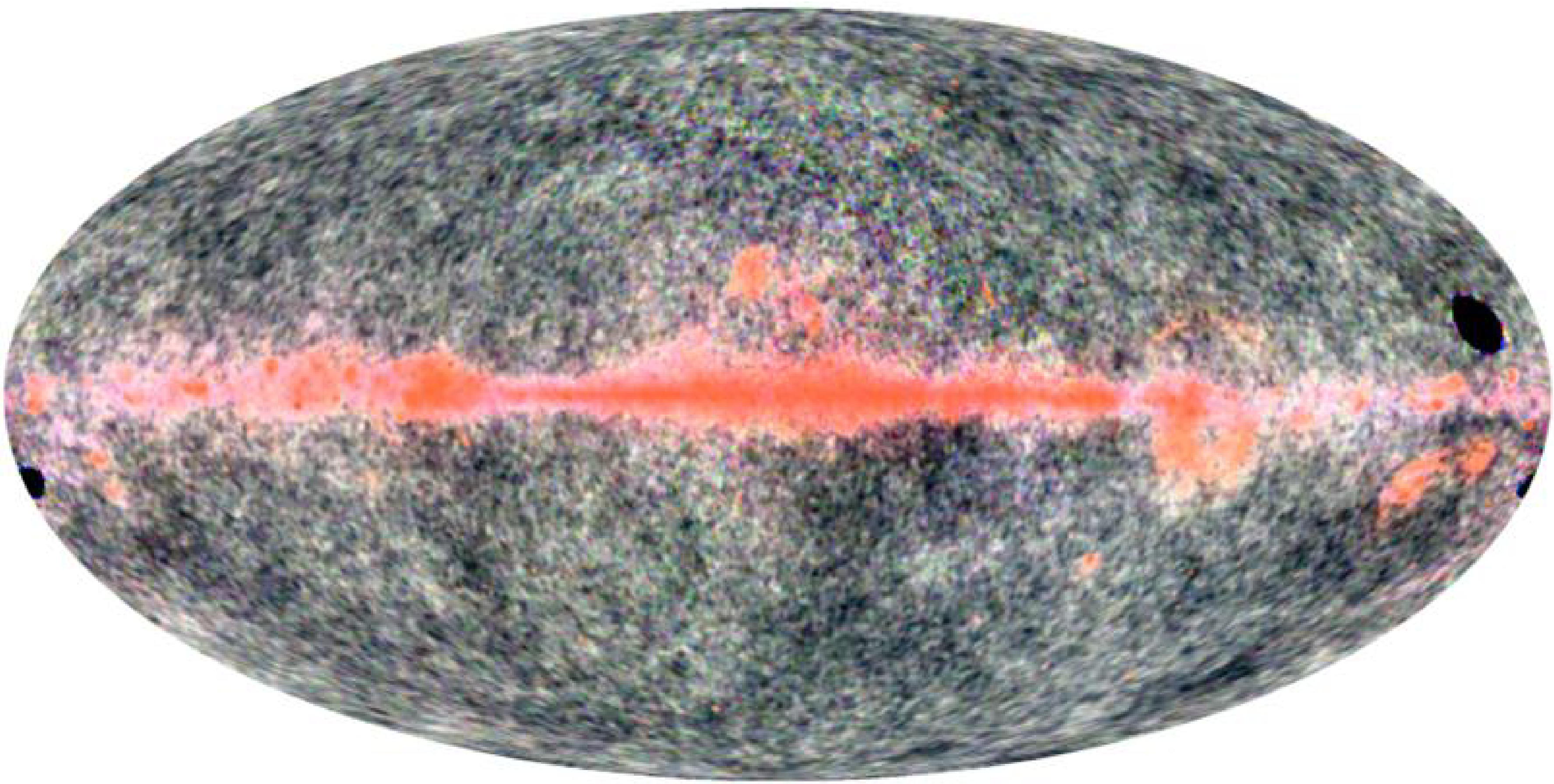
The gap disappeared slowly like...



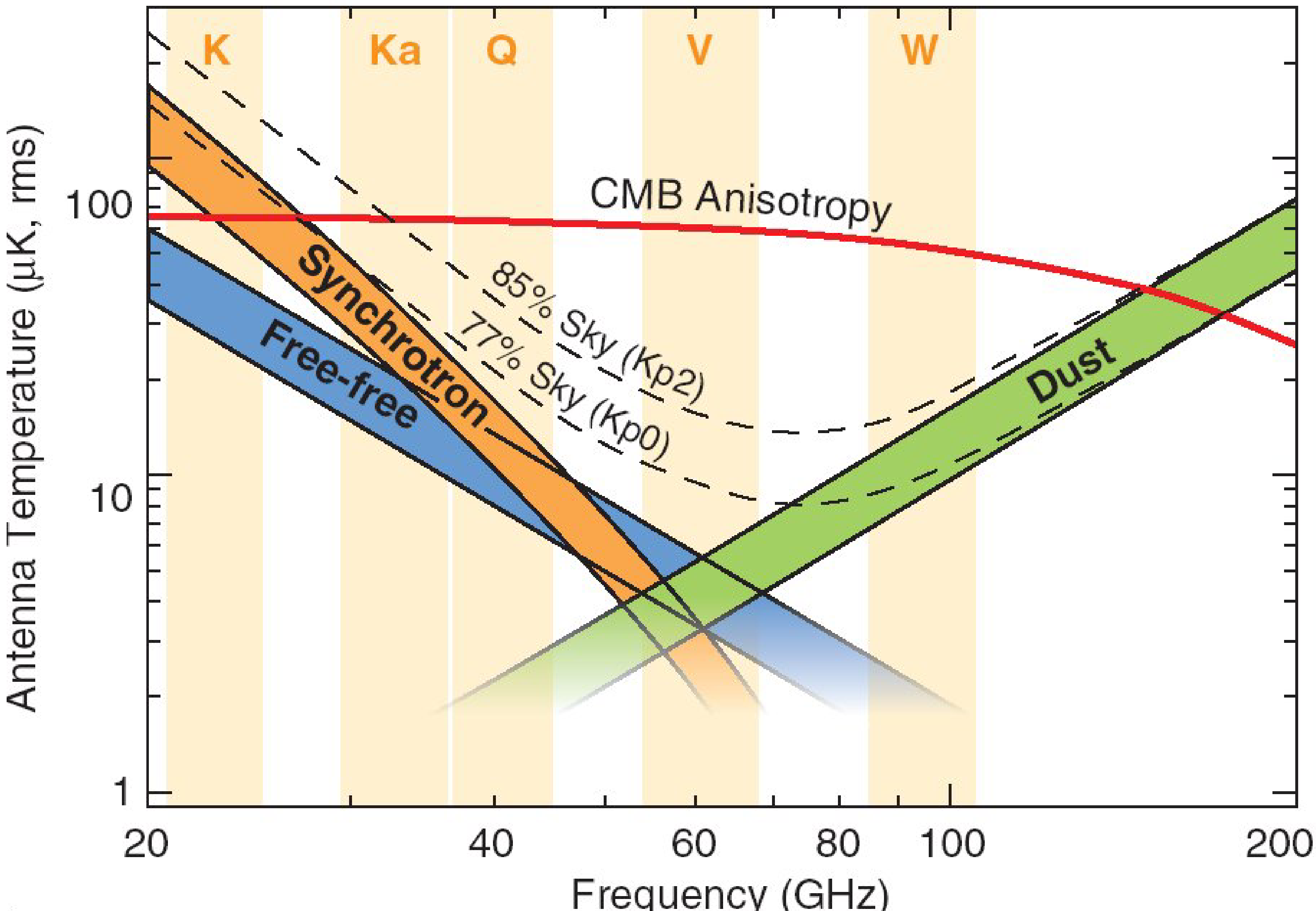
…the Cheshire cat's grin!



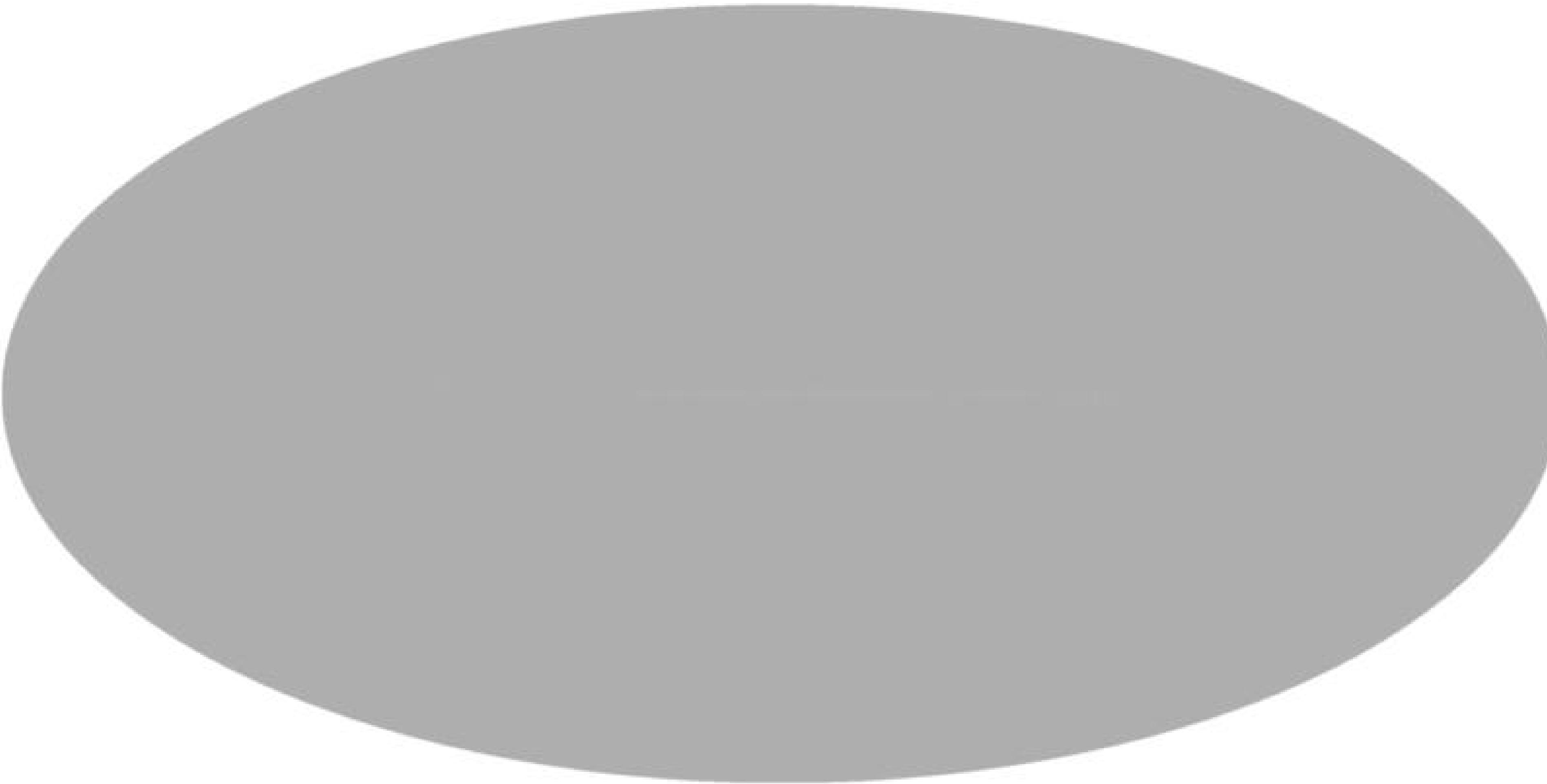
Closing the Gap after 6 Months



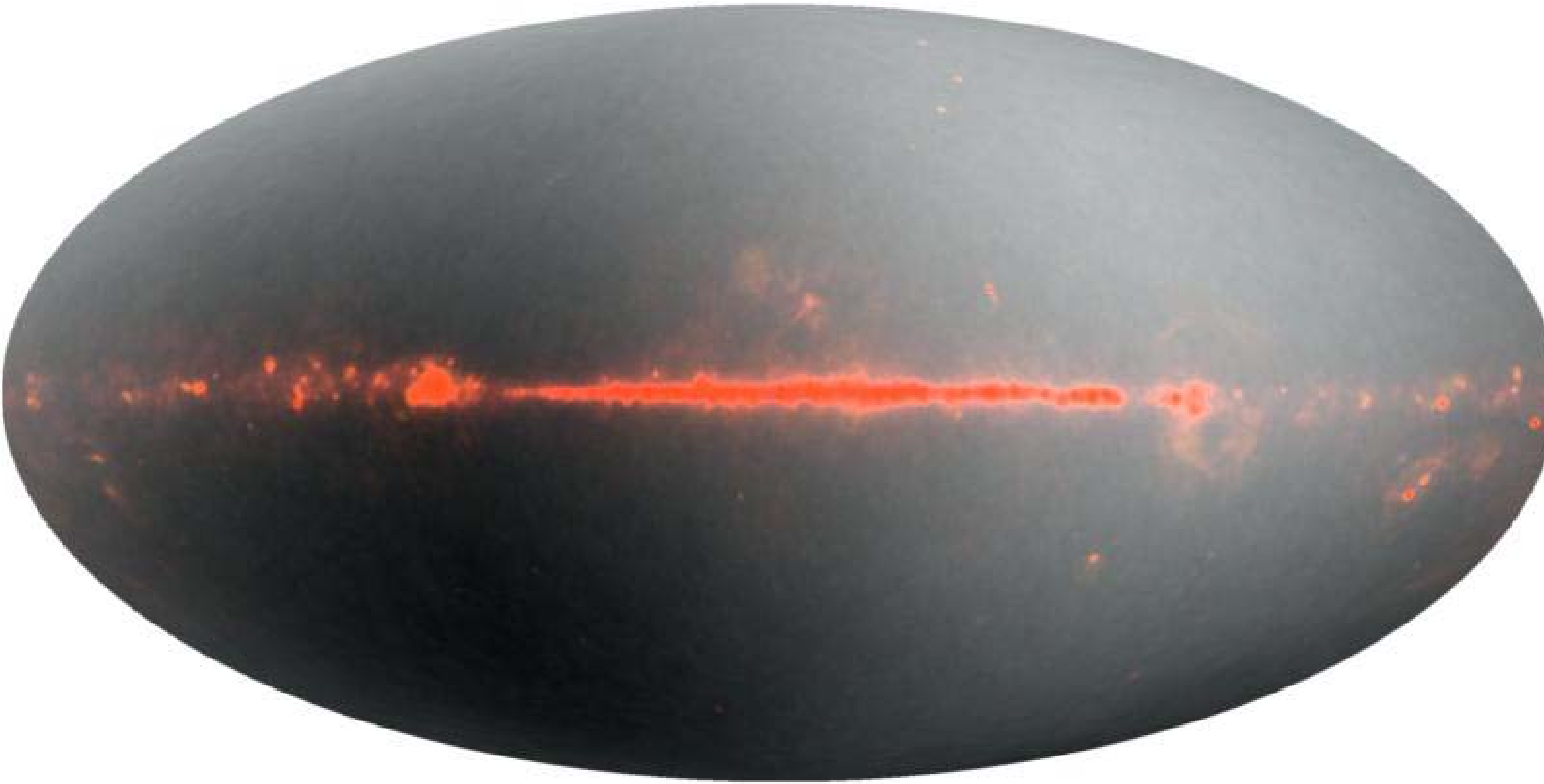
Foreground vs CMB Power



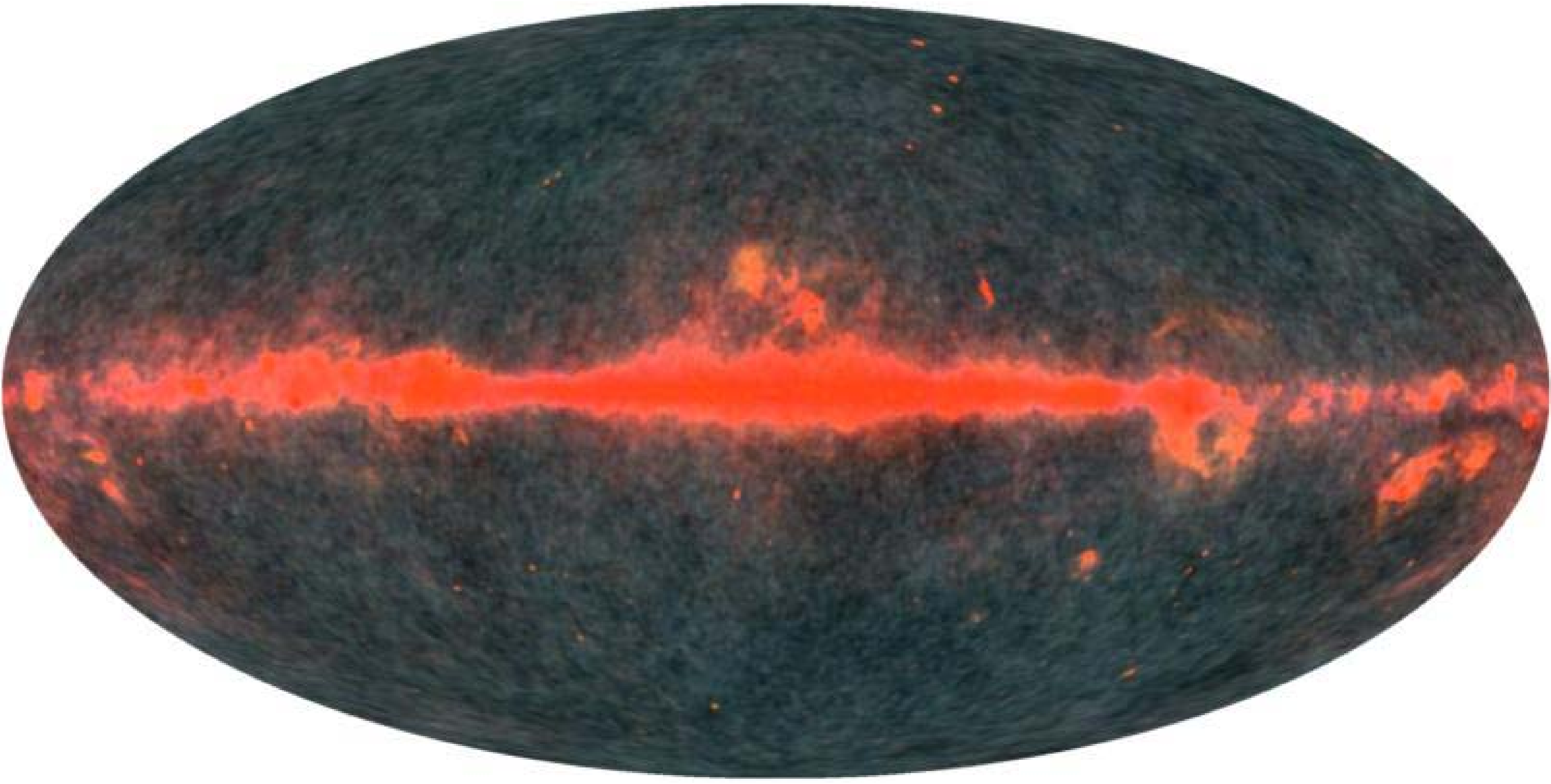
Normal Contrast CMB Sky



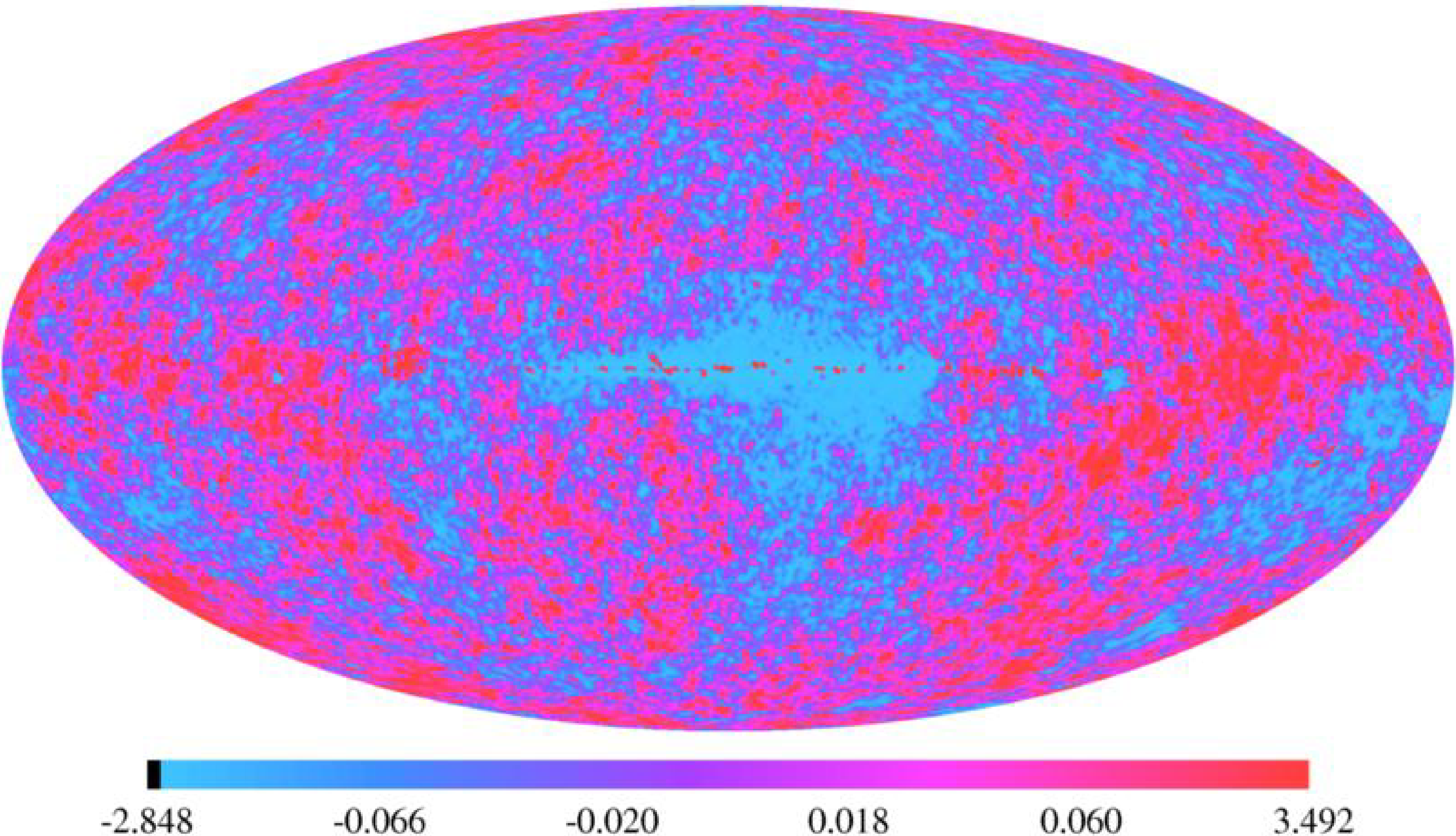
Remove T_o, 400x Contrast



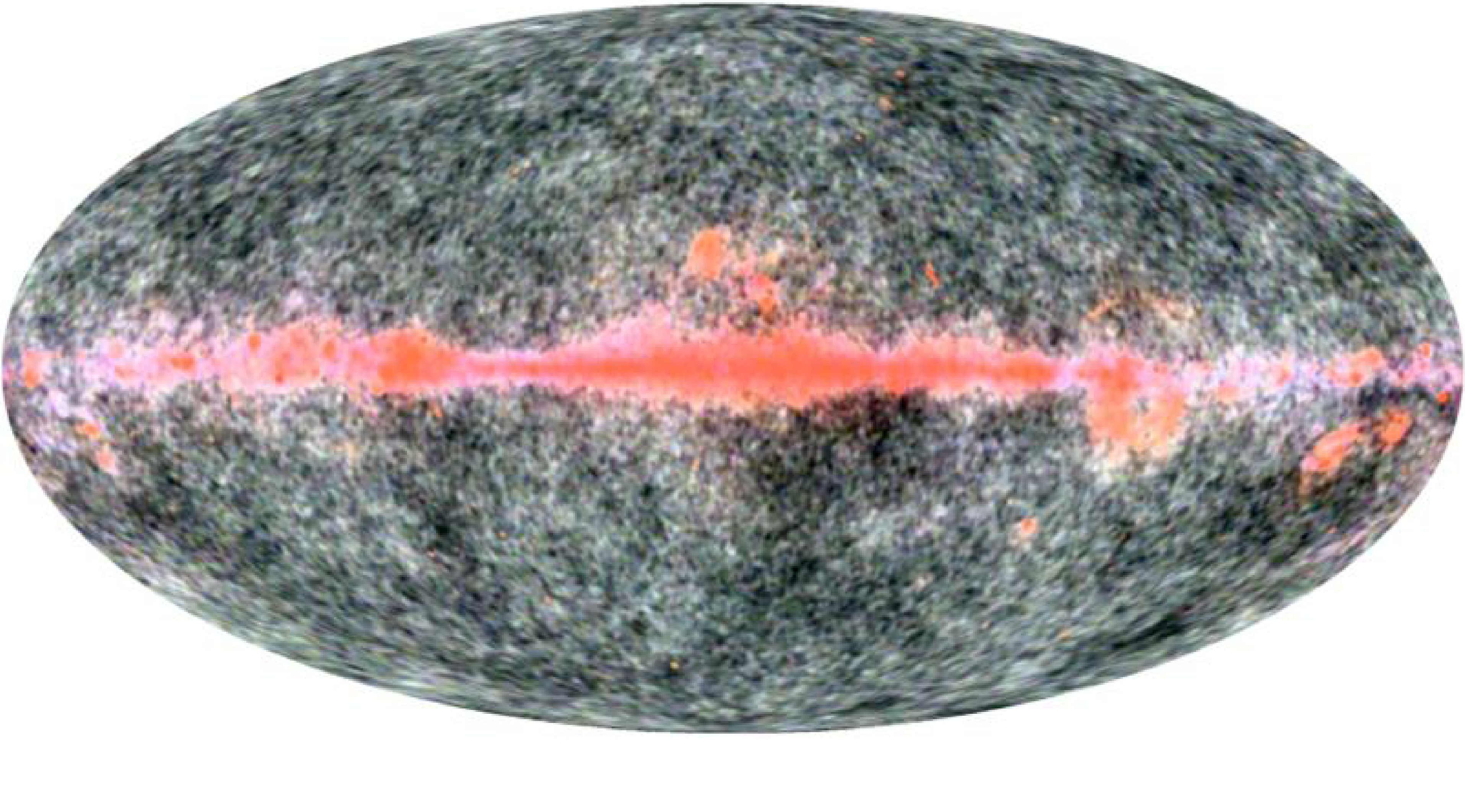
Remove v_{SS}, 2000x Contrast



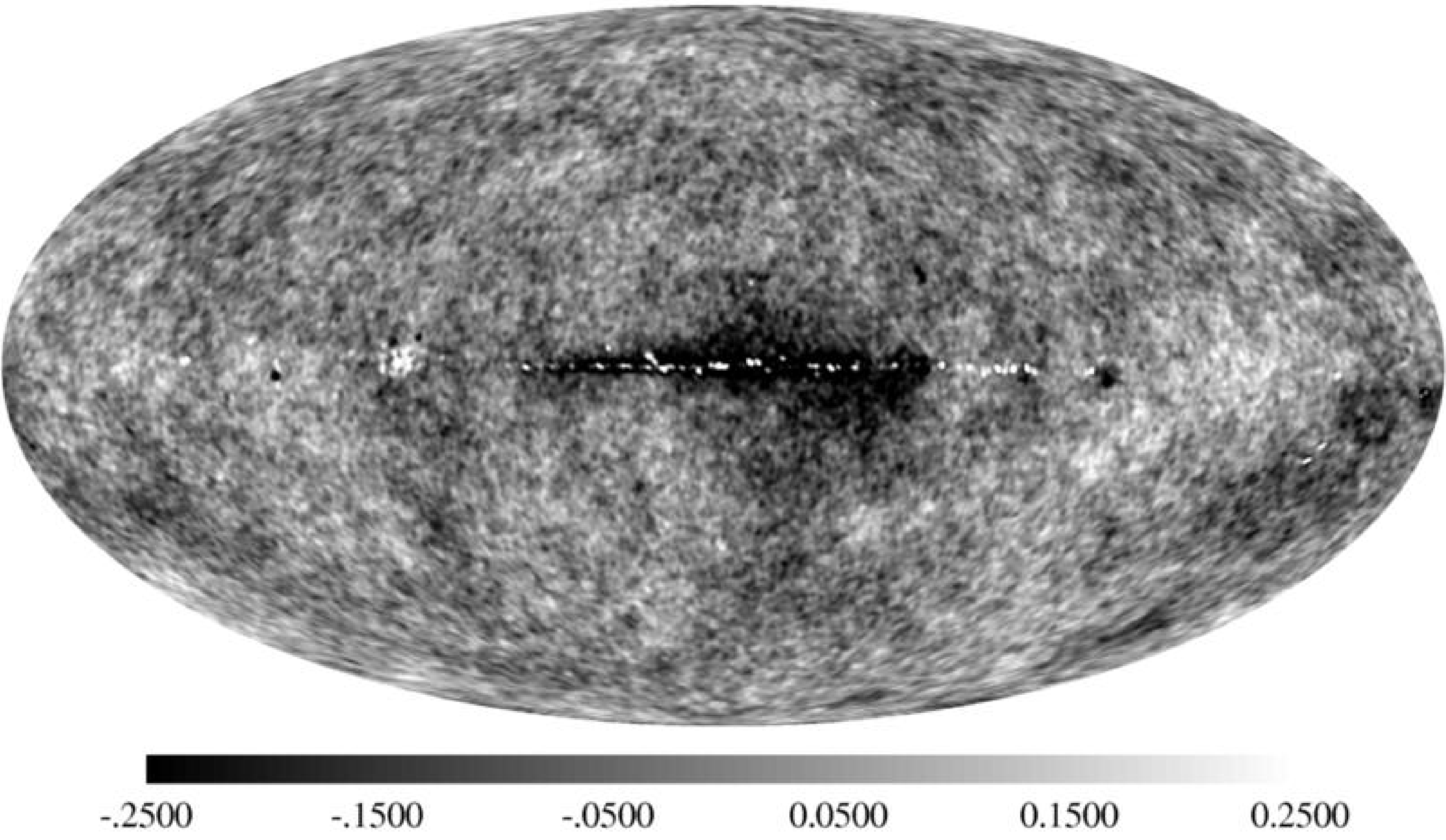
Remove Galaxy, 19000x Contrast



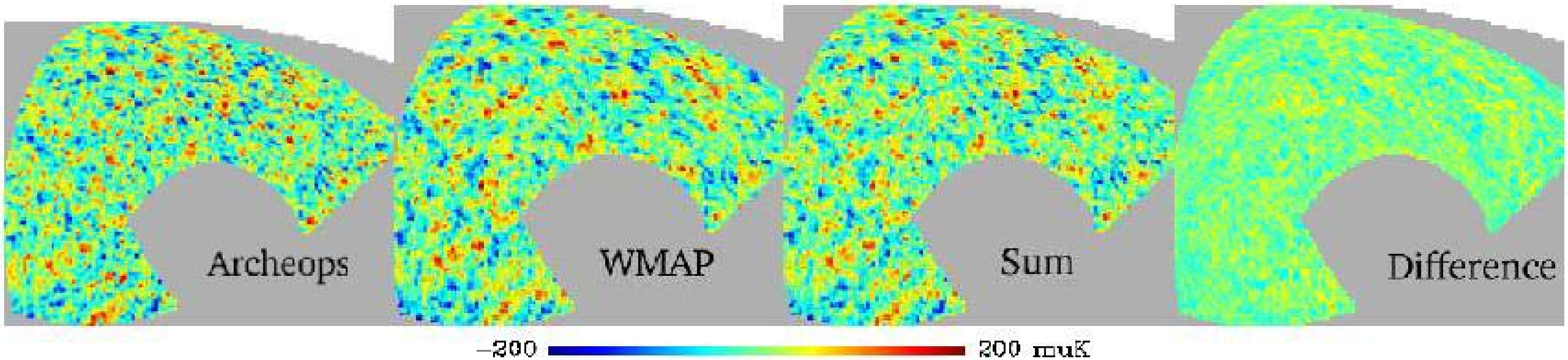
QVW as RGB



No Galaxy on same scale



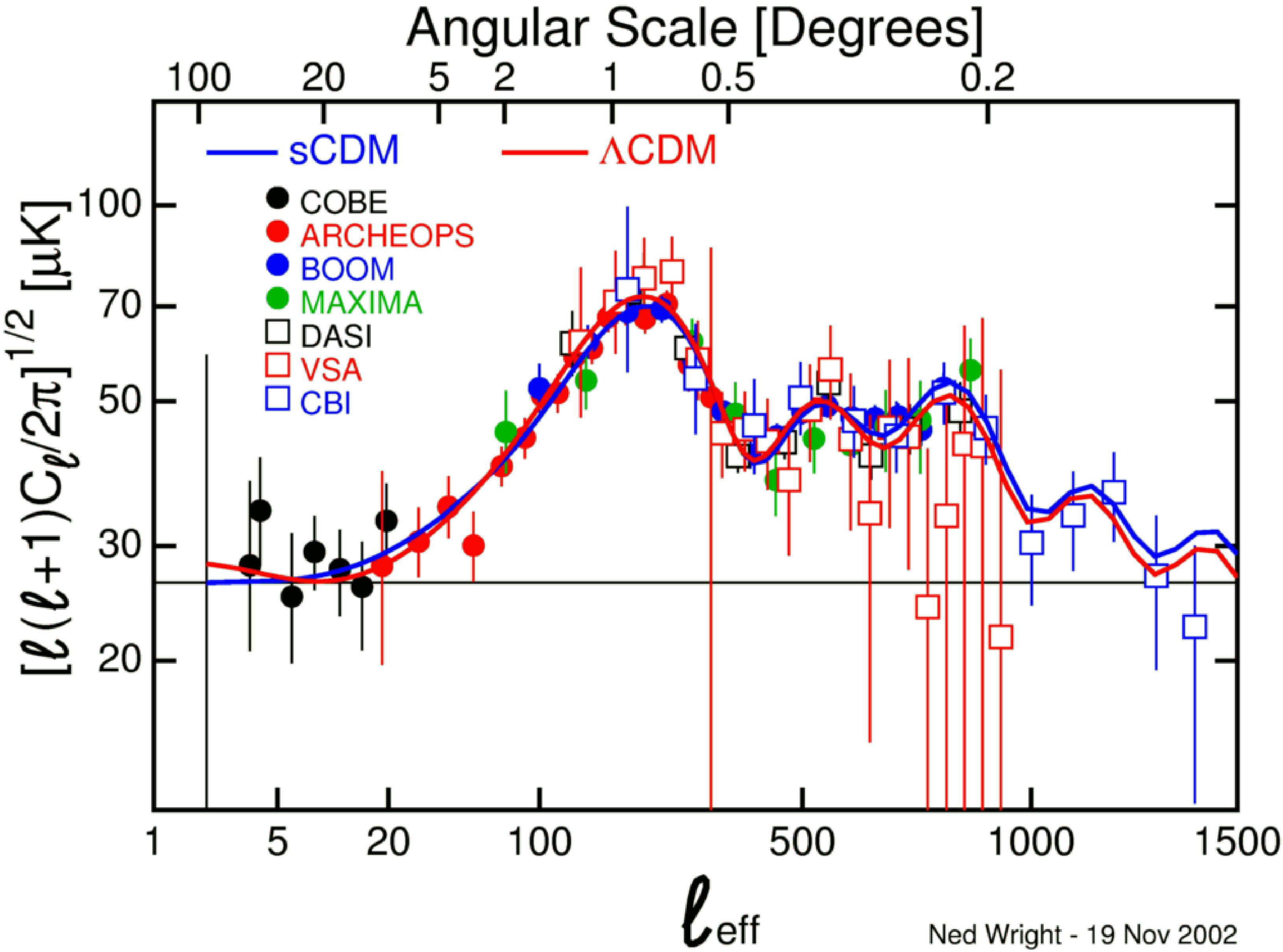
ARCHEOPS vs WMAP



- ARCHEOPS observed same ΔT at 143 & 217 GHz.
- Also consistent with WMAP at 94 GHz.
- THEREFORE thermal Sunyaev-Zeldovich effect is insignificant at l < 500.

from Hamilton *et al.*, astro-ph/0310788

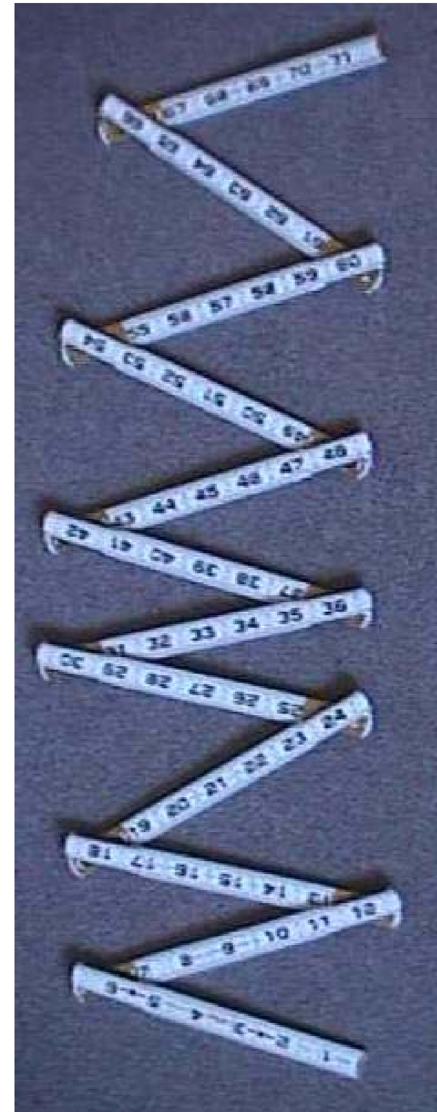
Pre-WMAP: ΛCDM & EdS both fit



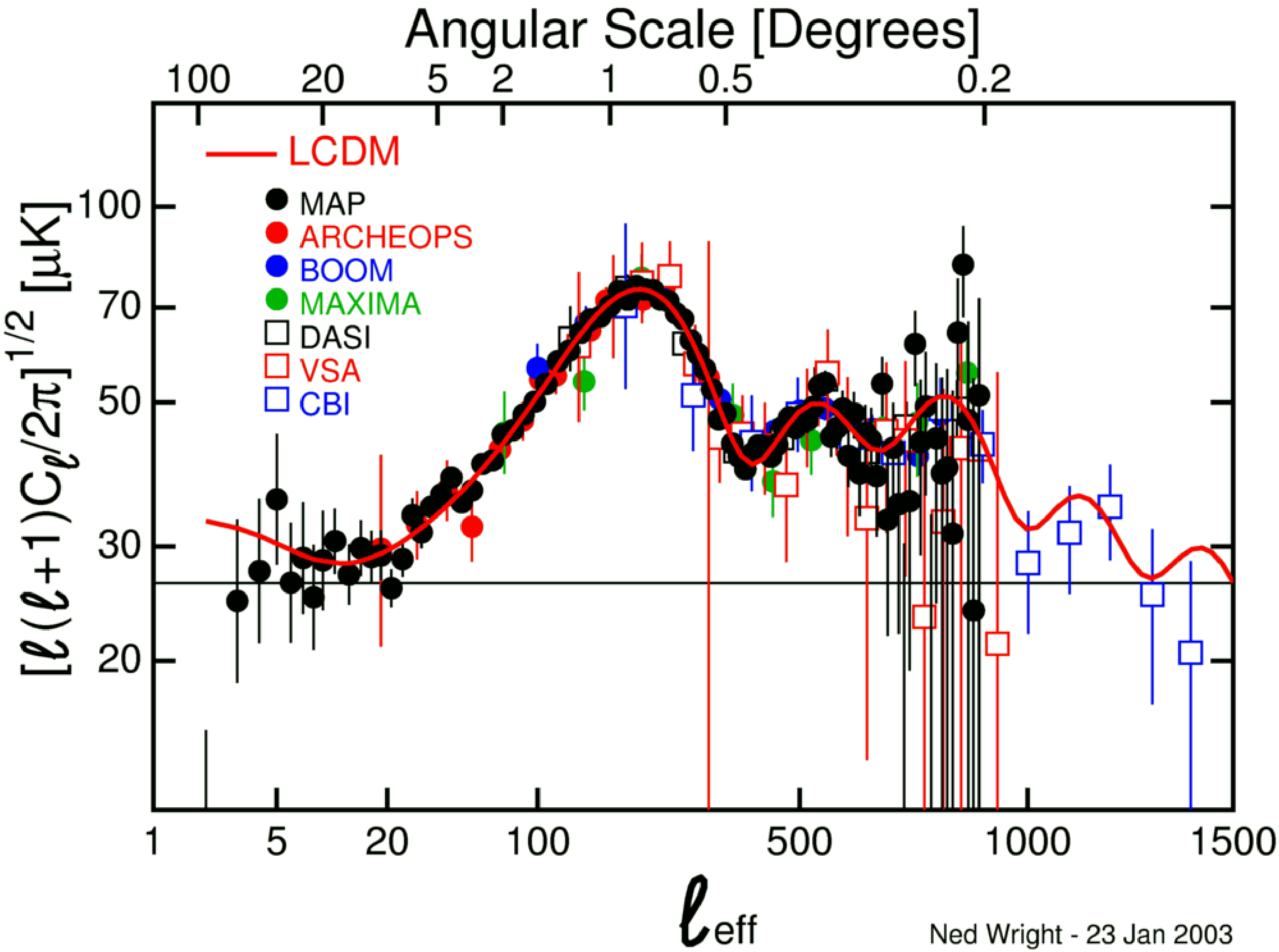
Flat, n=1; ω_b = 0.021, ω_c = 0.196, H_o = 47; ω_b = 0.022, ω_c = 0.132, H_o = 68, Λ = 2/3

A Solid Calibration is Vital

- Prior to WMAP, calibration errors between experiments allowed a great flexibility is peak heights.
- WMAP provided a rigid calibration from low *l* through the peaks.



Post WMAP: ΛCDM is a Good Fit

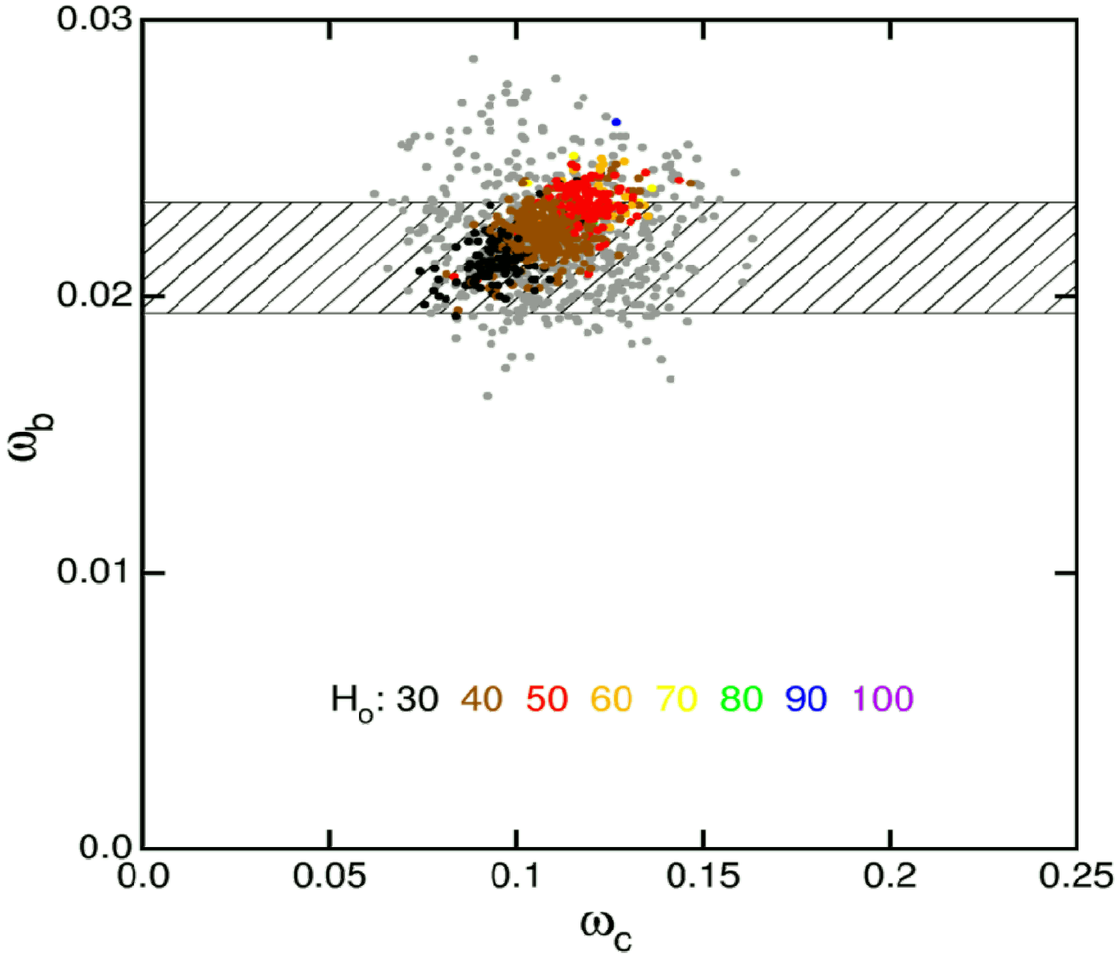


$H_o = 71$, $\Omega_\Lambda = 0.73$, $\Omega_b h^2 = 0.0224$, $\Omega_m h^2 = 0.135$, $\Omega_{tot} = 1$

WMAP pinned down the densities

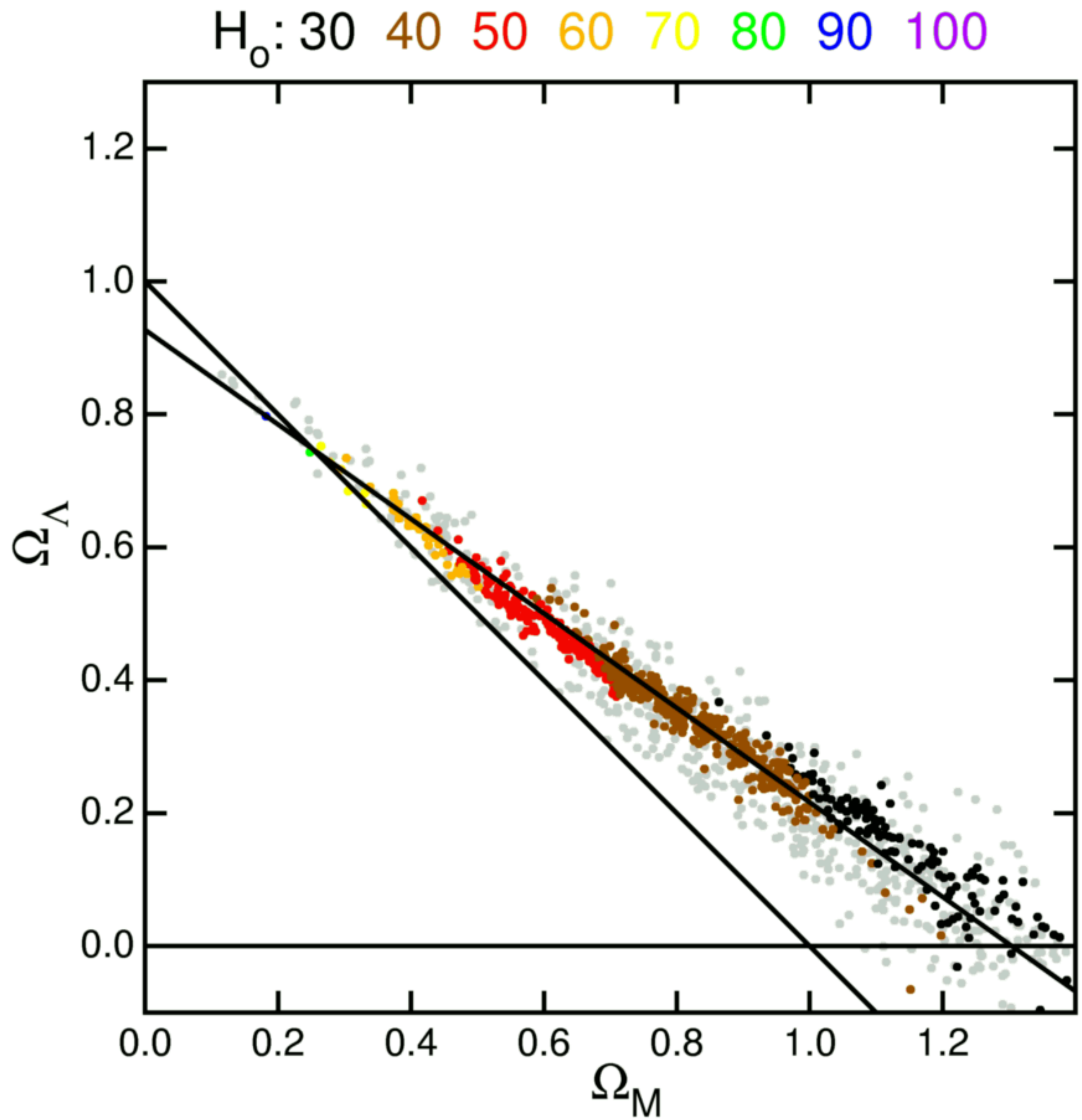
Note the new BBNS value from astro-ph/0302006

Vacuum energy is 3.9 keV/cc for the flat model but is not well determined by the CMB data alone.

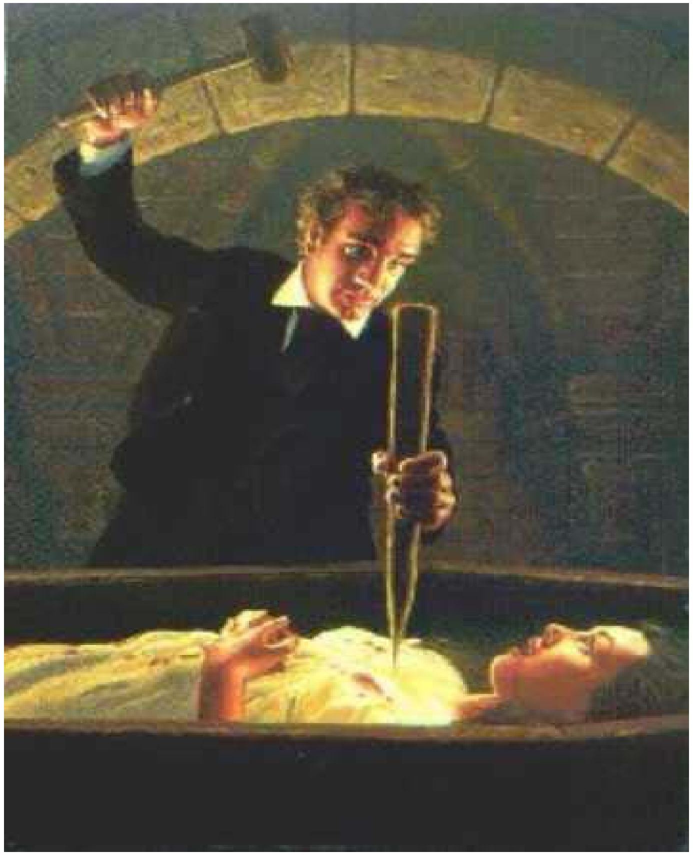


Ω_M-Ω_Λ degeneracy is narrower but not shorter

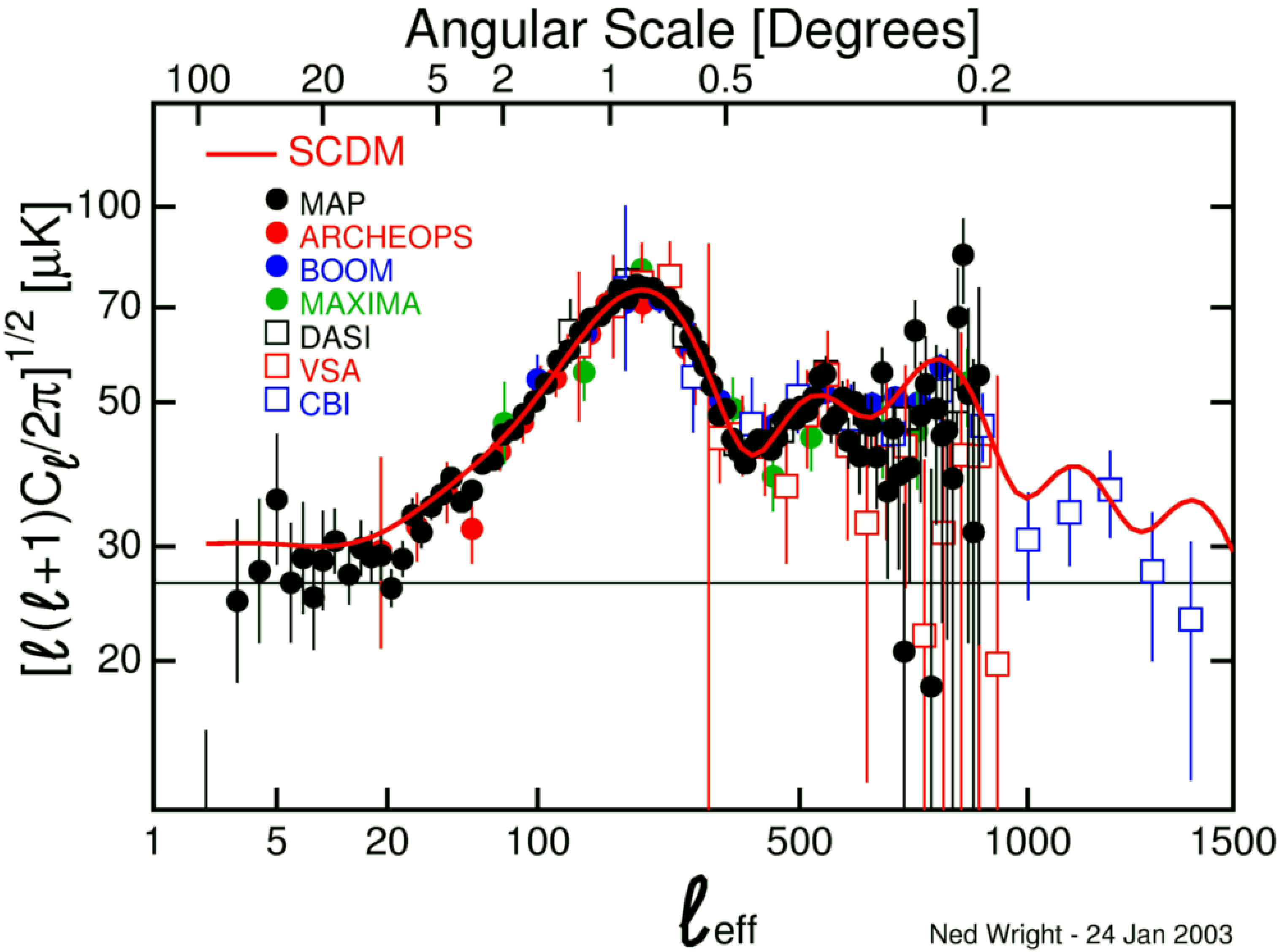
- Degeneracy is broken by:
  - supernova data
  - H_o data
  - Large scale structure data: Γ
  - Late integrated Sachs-Wolfe effect



But What Can We SLAY?



Einstein – de Sitter Model Fails



$H_o = 50, \Omega_\Lambda = 0, \Omega_b h^2 = 0.0236, \Omega_m h^2 = 0.25, \Omega_{tot} = 1$

Is the Universe Really Flat?

- CMB data alone give some limits but adding H_o and SNe priors gives much better limits.
- Replacing COBE by WMAP does not dramatically change the limits on Ω_{tot}.

	CMB only	CMB+SNe	CMB+H_o	All
Pre-WMAP	1.18(11)	1.04(4)	1.02(3)	1.02(2)
With WMAP	1.16(9)	1.04(3)	1.03(3)	1.02(2)

Some good suggestions

- Efstathiou recommends using likelihood of low l a_{lm}'s instead of pseudo-C_l's in astro-ph/0307515 & 0310207. He claims low l deficit is less significant (about 2σ).
- Lewis (astro-ph/0310186) found that the neglect of radiometer noise at low l's led to an overestimate of χ^2 by about 16 units.

Corrupted Echo of Big Bang?

- Tom Shanks press release 2 Feb 04
- Picked up by *The Economist*
- But pre-contradicted by data from April 2000!

Astronomy.com

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Cluster confusion

Do galaxy clusters distort the Big Bang's echo? New research suggests they do.

by Francis Reddy

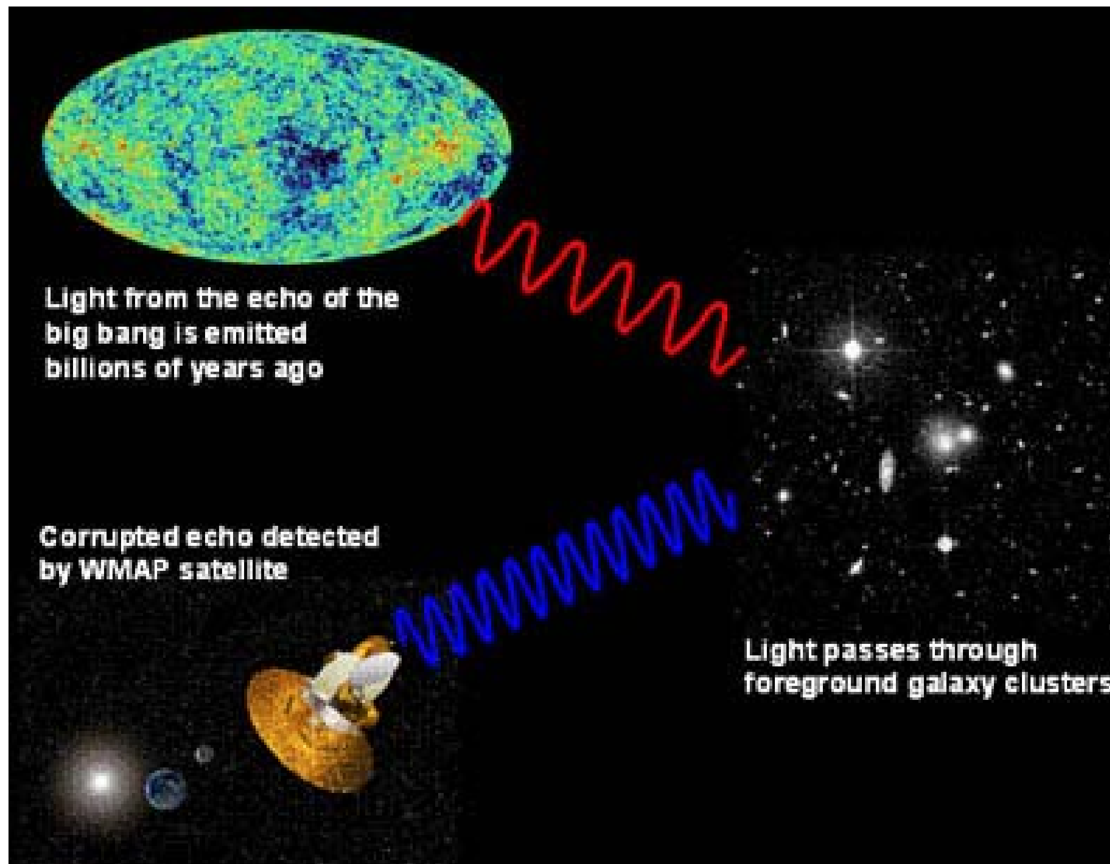
Detailed measurements of the cosmic microwave background radiation — the "echo" of the Big Bang — appear to validate the idea that we live in a cosmos dominated by "cold dark matter" and "dark energy." But earlier this month, a group of astronomers at the University of Durham, England, published evidence that gas in nearby galaxy clusters may have altered the microwave signal during its 13 billion-year journey to Earth. If more distant galaxy clusters have the same effect, they say, our current ideas about the evolution of the cosmos may need substantial revision.

Foreground galaxy clusters corrupt the cosmic microwave background.
T. Shanks / WMAP / NASA

The team, led by Tom Shanks, compared data from NASA's Wilkinson Microwave Anisotropy Probe (WMAP) to the positions of nearby galaxy clusters in three well-known catalogs. The clusters lie in regions of the sky where WMAP recorded lower-than average microwave temperatures. The average temperature of the microwave background is just 2.73 kelvins.

Sunyaev-Zeldovich Effect

- Hot electrons scatter cool photons making low frequency deficit and high frequency excess.

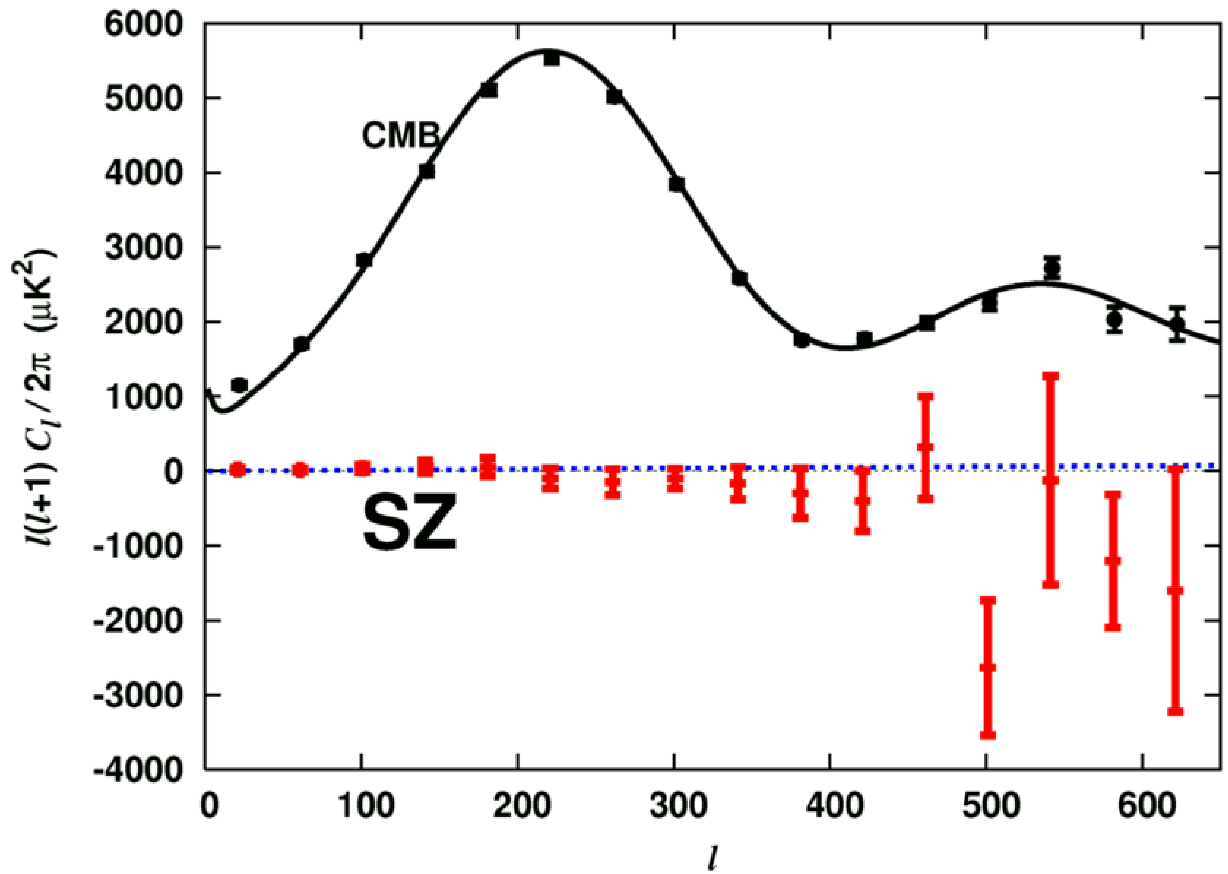


WMAP only observed low frequencies.

But BOOMERanG, MAXIMA & ARCHEOPS observed both low & high frequencies & saw no difference.

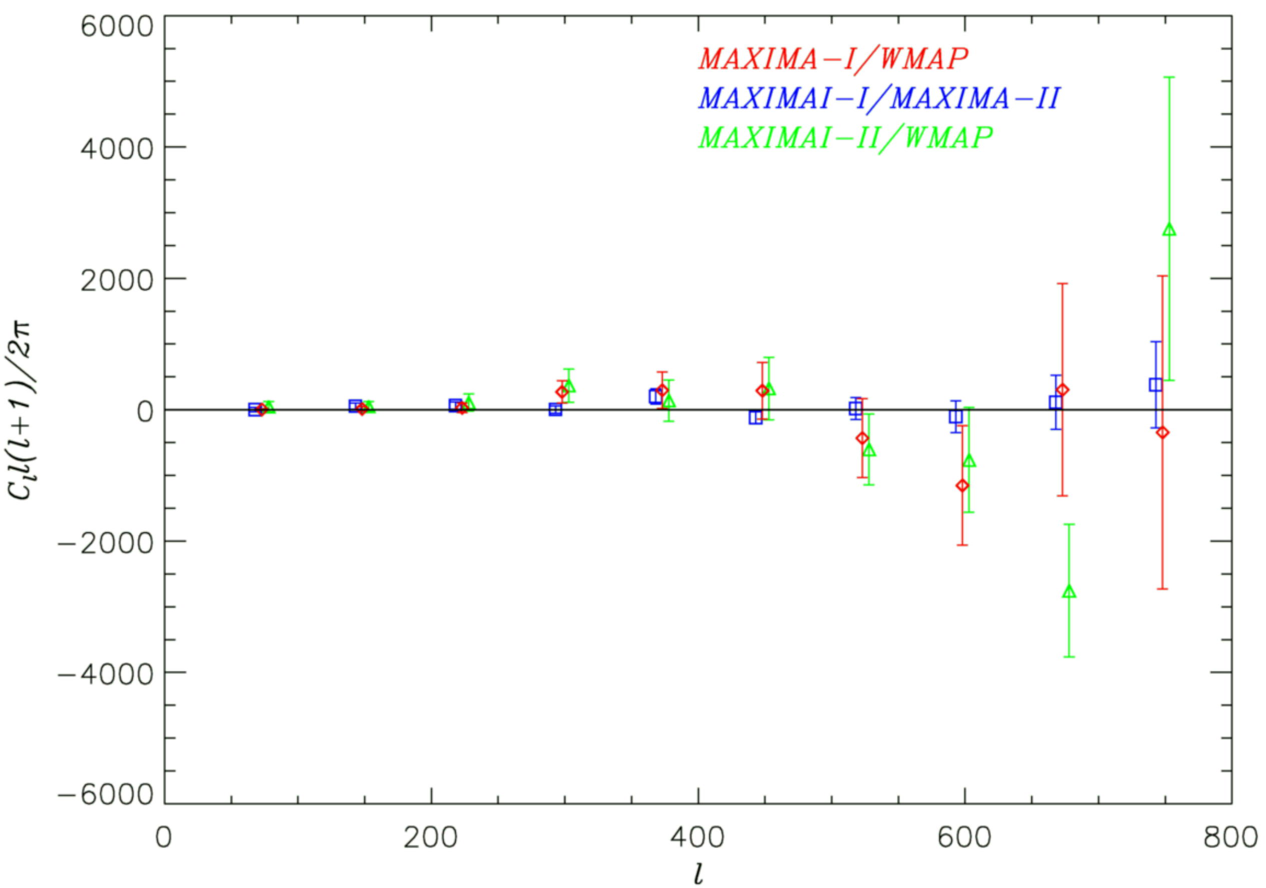
This claim is WRONG, of course

- Huffenberger, Seljak & Makarov (astro-ph/0404545) combined WMAP cross-power spectra to get a “CMB-free” SZ power spectrum, which is negligible.

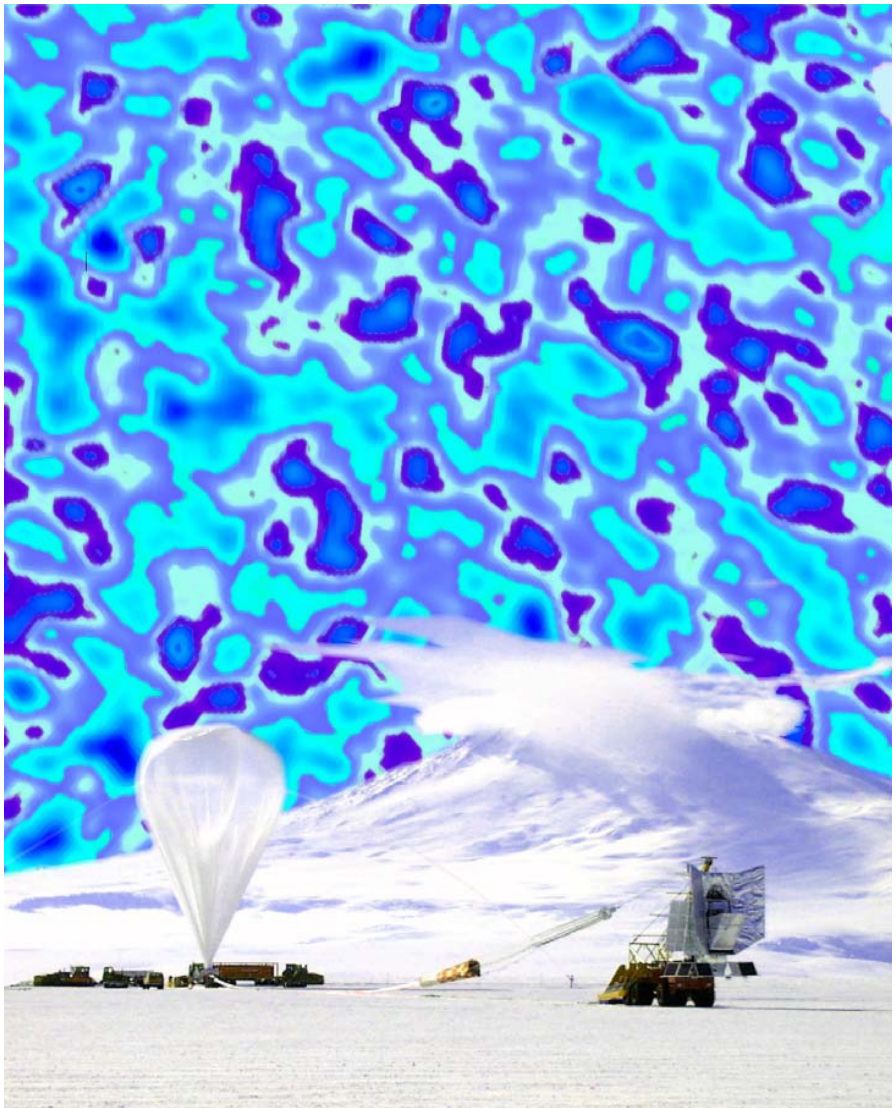


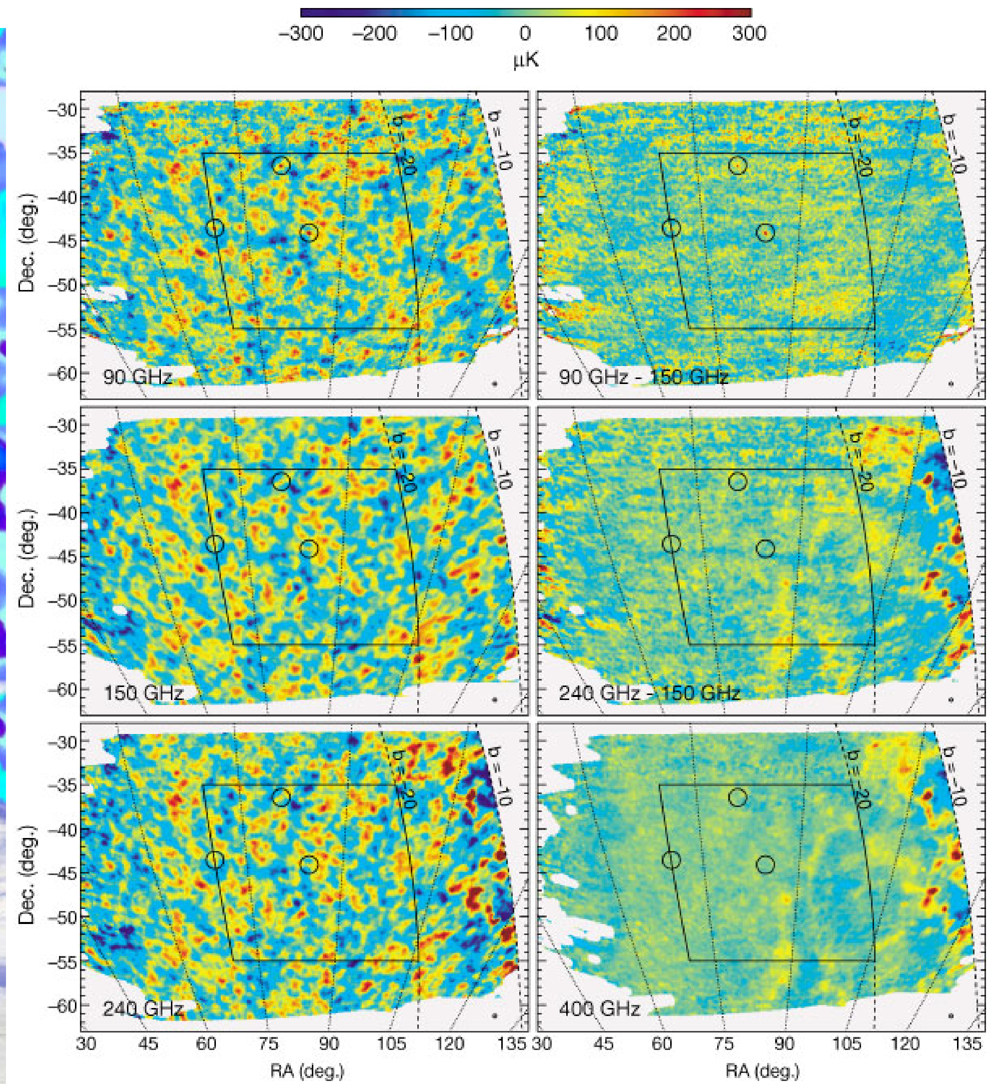
But Shanks was obviously wrong before he issued his Press Release:

- Abroe etal (astro-ph/0308355) compared WMAP to MAXIMA: substantial SZ not possible.



Cover Story of 27 Apr 2000 *Nature*





BOOMERanG !

- Cover story in that obscure journal *Nature*.
- Made a big point that the 90, 150 & 240 GHz maps were perfectly consistent.
- Therefore, Sunyaev-Zeldovich effect is negligible at BOOMERanG scales (and WMAP scales).

Cosmic Background Imager

- Chile @ 5.08 km
- 13 antennae
- 26-36 GHz
- 10 GHz band
- 0.75^o FOV
- 0.075^o res
- Mosaic many FOV's together

Cosmic Background Imager

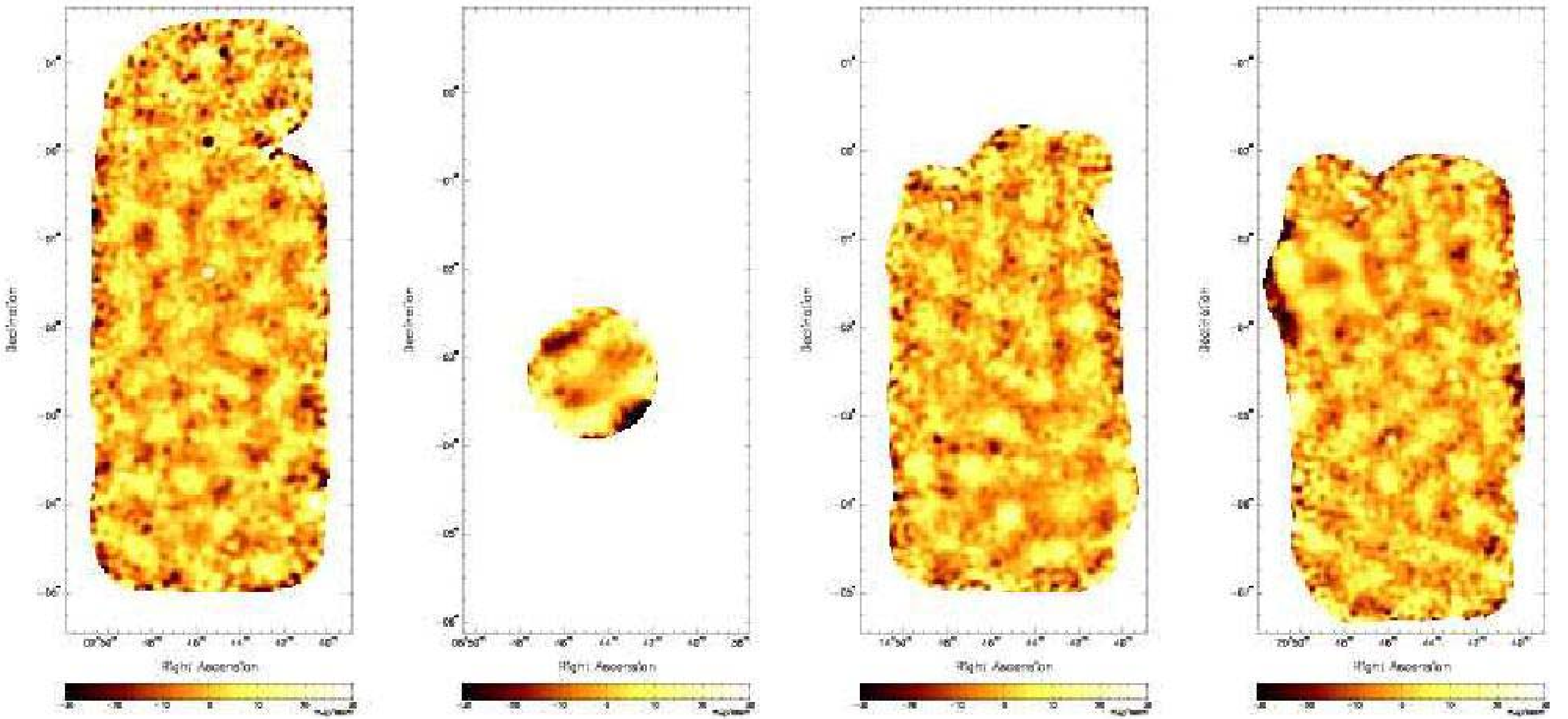
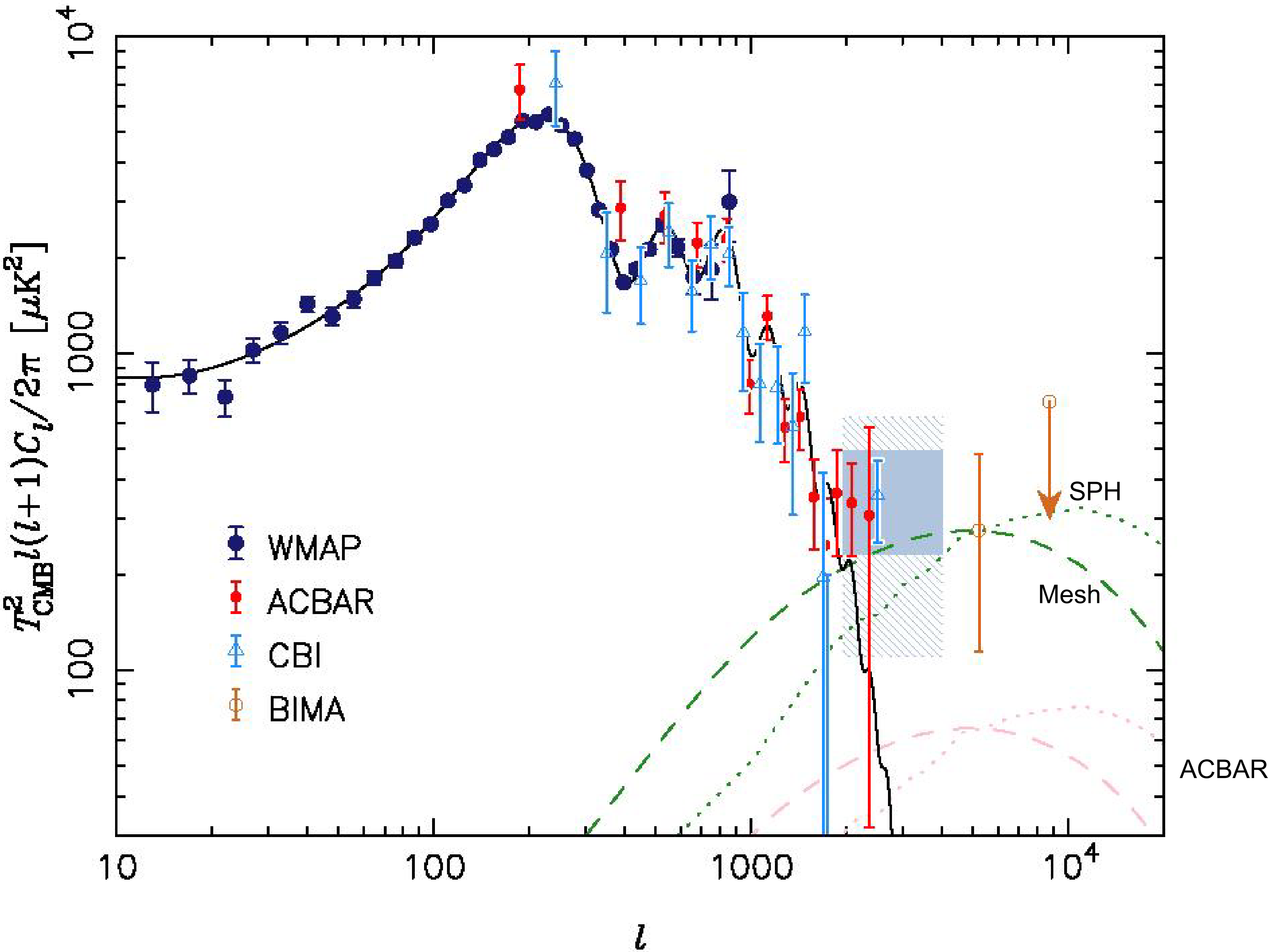


FIG. 1.— The extended mosaic images from the combined 2000+2001 observations. The angular resolution of these observations is $\sim 5'$ (FWHM).

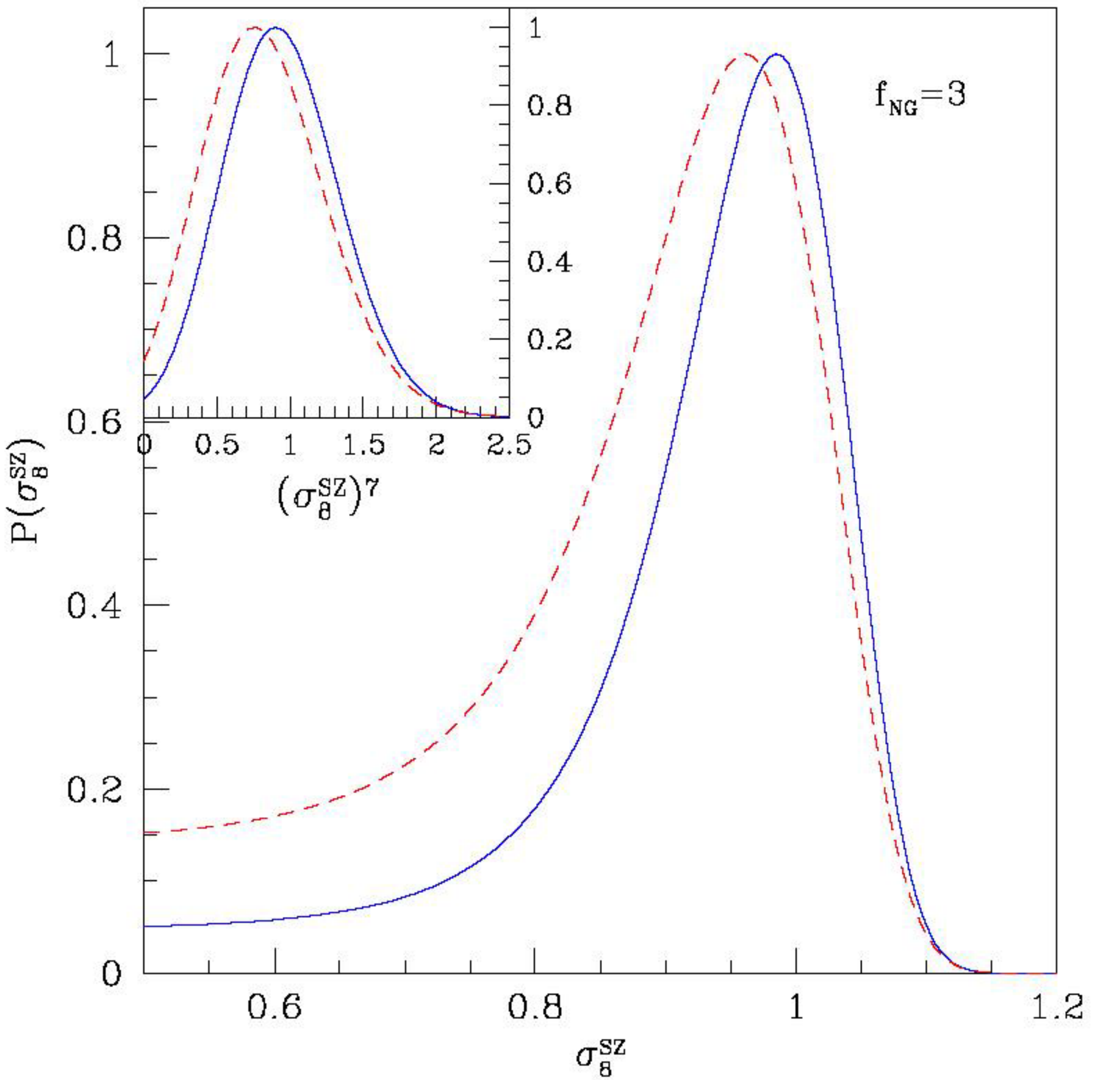
- From Readhead *et al.*, astro-ph/0402359
- 0.1% of sky mapped

CBI High l Excess



If SZ, a high σ_8 is wanted

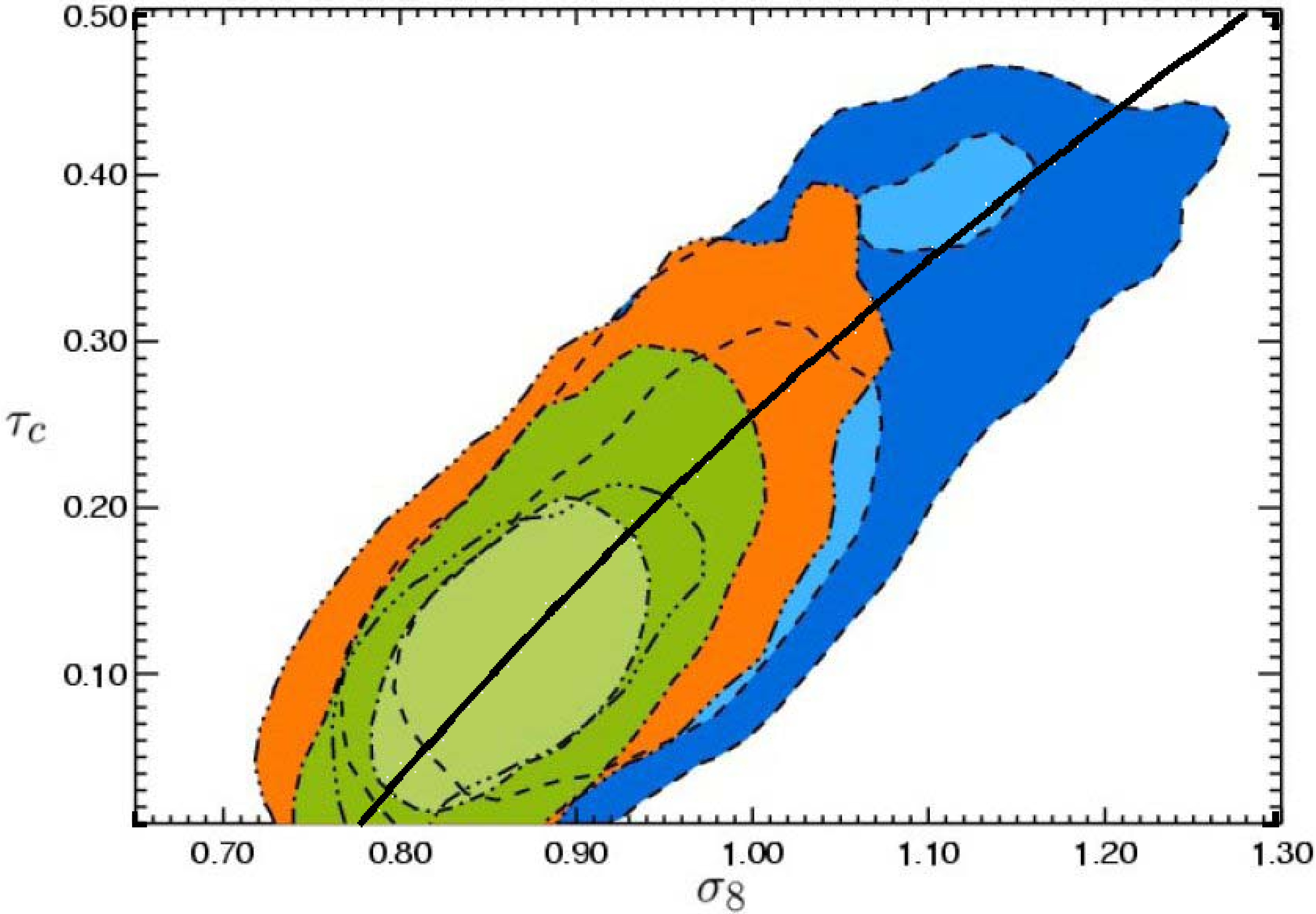
- CBI:ACBAR ratio is now wrong for SZ but the errorbars allow an SZ model.
- Predicted SZ C_l is insignificant at $l < 500$.



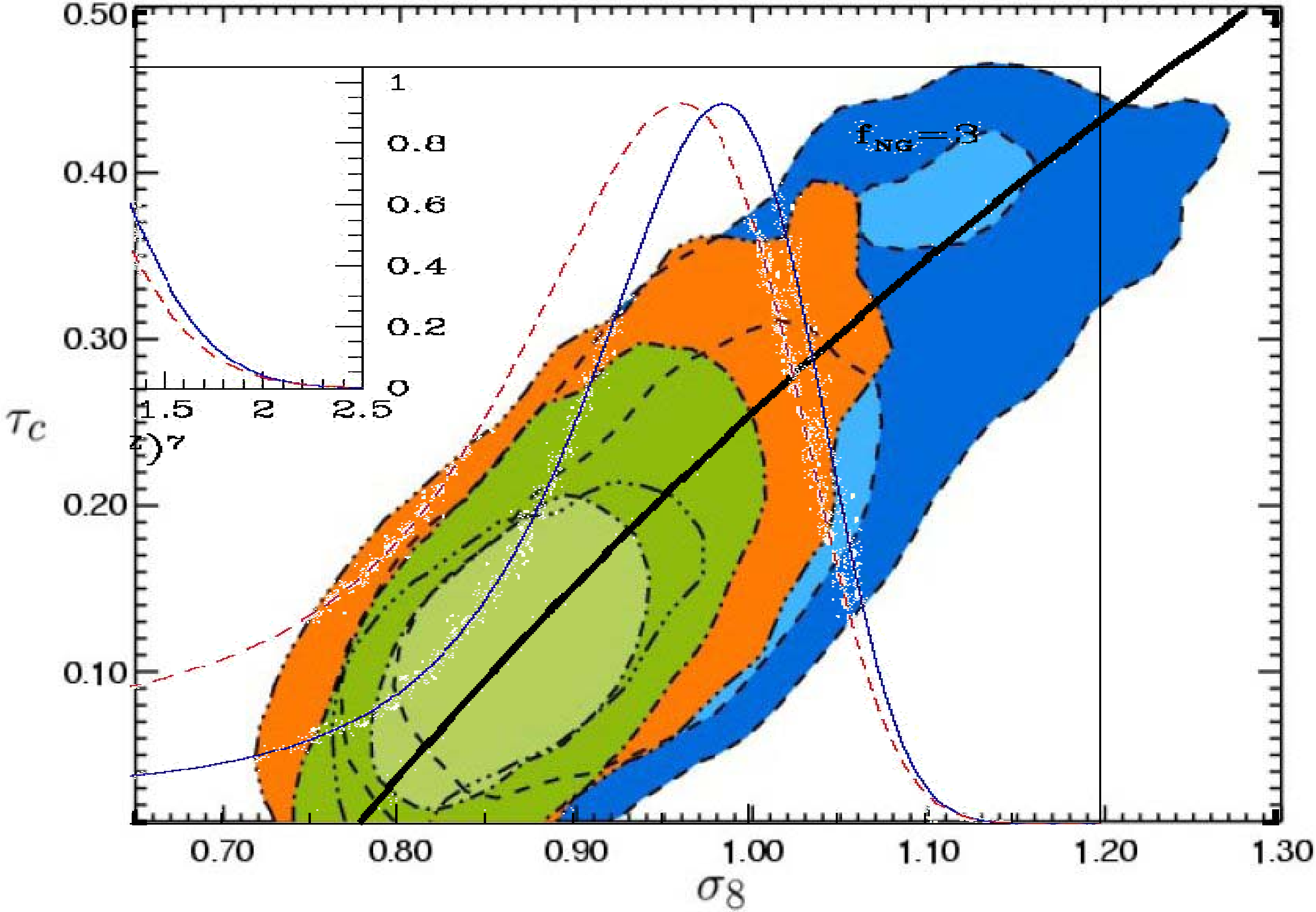
CBI CMB only "flat model" fits

Parameter	*WMAP* only	CBI + *WMAP*	CBI + ALL
$\Omega_b h^2$	$0.0243^{+0.0016}_{-0.0016}$	$0.0232^{+0.0012}_{-0.0012}$	$0.0228^{+0.0009}_{-0.0010}$
$\Omega_c h^2$	$0.123^{+0.017}_{-0.018}$	$0.113^{+0.014}_{-0.014}$	$0.118^{+0.010}_{-0.010}$
Ω_Λ	$0.71^{+0.08}_{-0.08}$	$0.74^{+0.06}_{-0.06}$	$0.71^{+0.05}_{-0.05}$
τ_C	$0.184^{+0.031}_{-0.057}$	$0.152^{+0.023}_{-0.041}$	$0.117^{+0.019}_{-0.033}$
n_s	$1.01^{+0.05}_{-0.05}$	$0.98^{+0.03}_{-0.03}$	$0.96^{+0.02}_{-0.02}$
$10^{10} A_S$	$27.7^{+5.5}_{-5.1}$	$24.2^{+3.5}_{-3.5}$	$22.9^{+2.4}_{-2.5}$
H_0	$72.1^{+6.4}_{-5.8}$	$72.9^{+5.2}_{-5.1}$	$70.5^{+3.7}_{-3.9}$
Age (Gyr)	$13.3^{+0.3}_{-0.3}$	$13.5^{+0.3}_{-0.2}$	$13.6^{+0.2}_{-0.2}$
Ω_m	$0.29^{+0.08}_{-0.08}$	$0.26^{+0.06}_{-0.06}$	$0.29^{+0.05}_{-0.05}$

High l excess not used in these fits.



Overlaid curve is $\sigma_8 = 0.78 \exp[\tau_c]$



Overlay σ_8 likelihood from S-Z

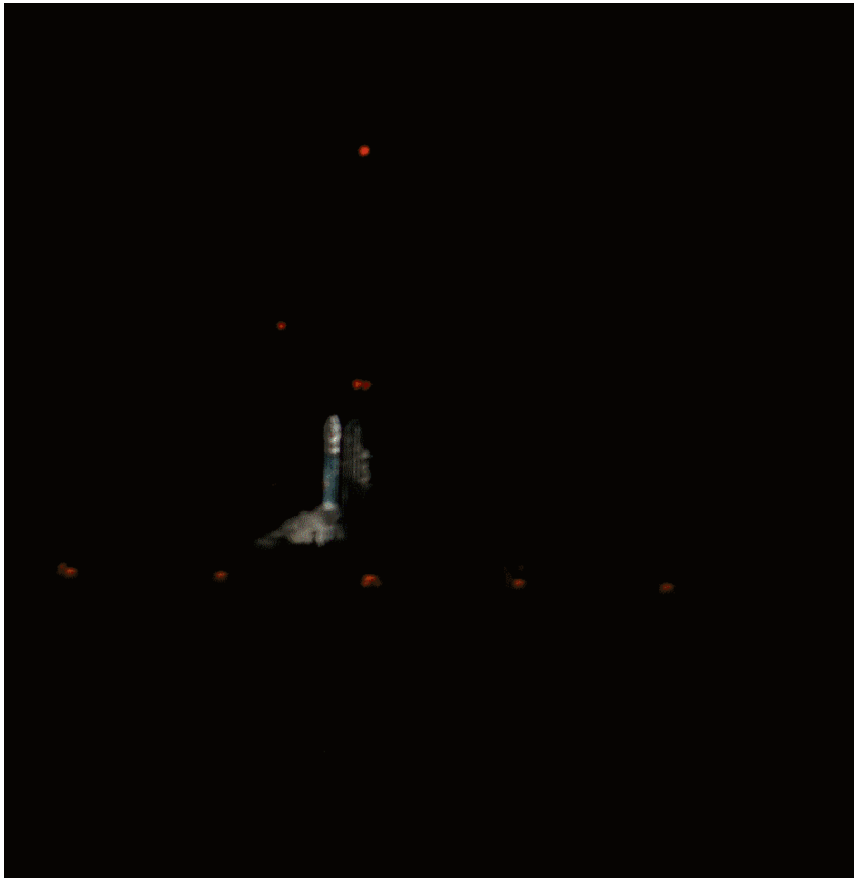
S-Z models need good hydro

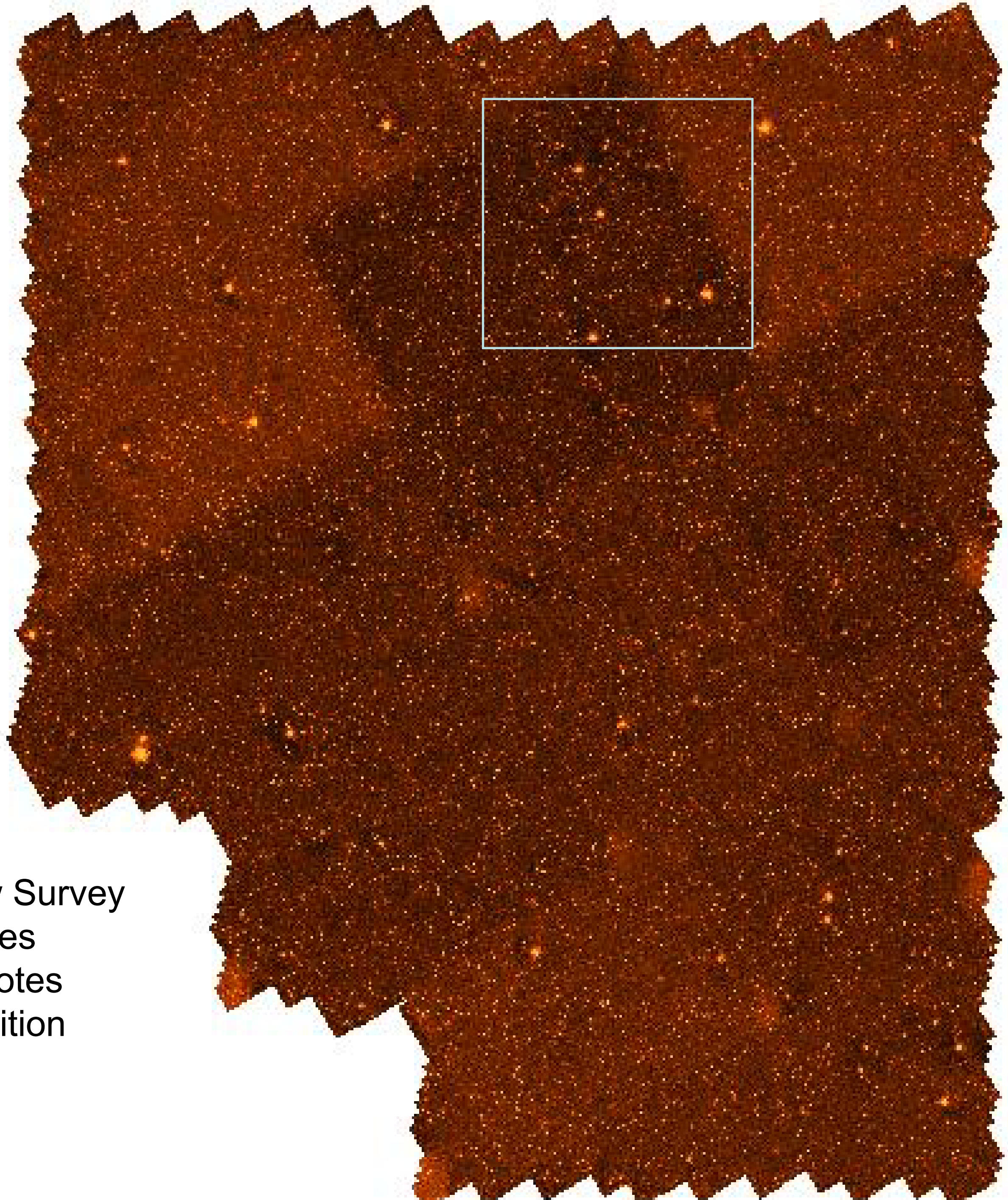
- I am a bit skeptical about using the S-Z effect to do this kind of fitting.
- But soon we should have a lot of good high SNR data from SZ surveys and we will be able to assess the complexities.

Running Spectral Index?

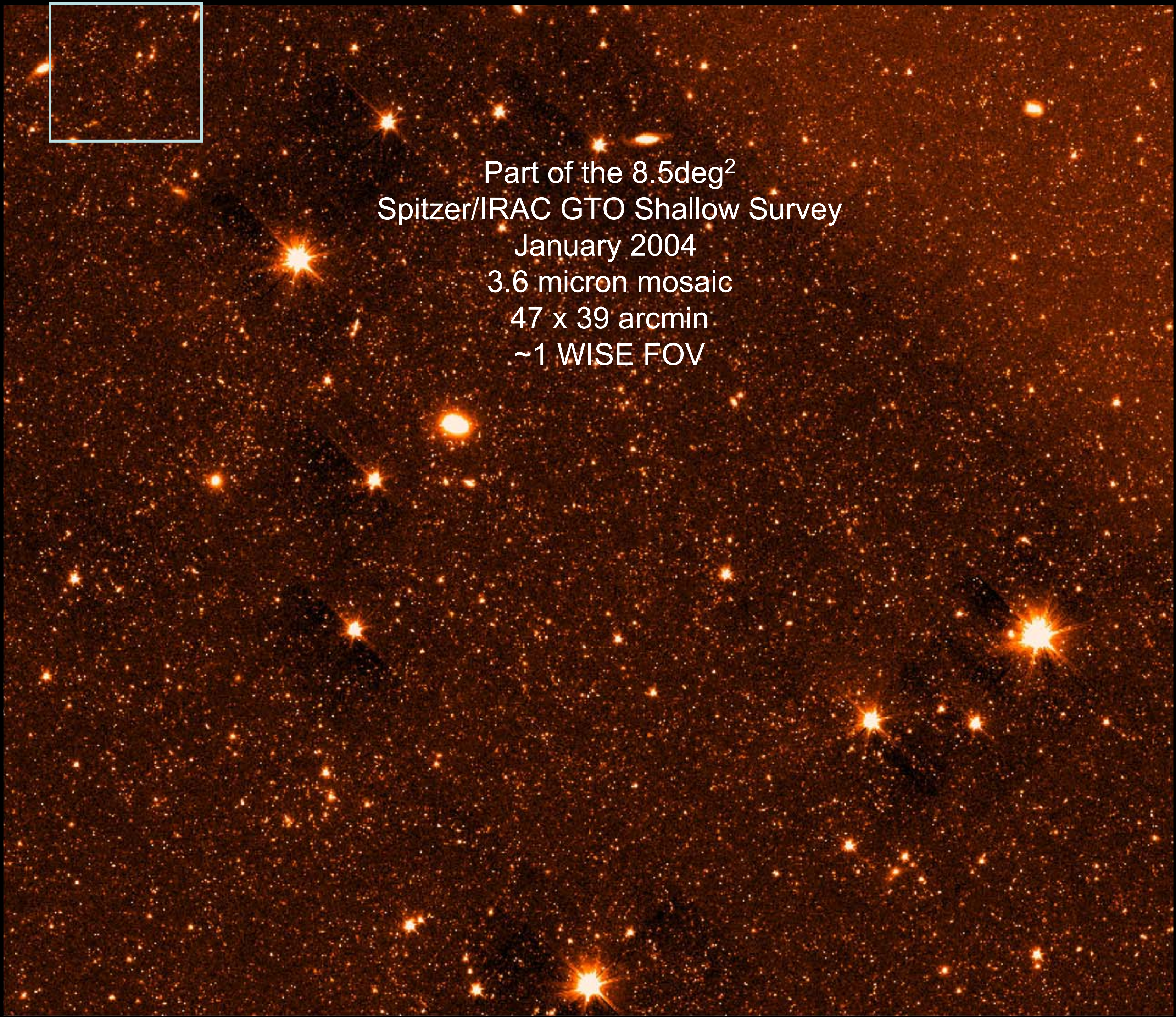
- $dn_s/d\ln k$ =
  - -0.031±0.016 in WMAP papers from Keck & Croft
  - +0.015±0.020 (Dodelson, 2003, SDSS)
  - -0.027±0.007 (Seljak, 2003, SDSS)
  - -0.074±0.030 (Readhead, 2004, CBI)
  - -0.017±0.006 (Seljak, 2004, SDSS, talk at TAMU)
- I haven't checked with Dodelson to see if the SDSS "team" disagreement has been settled.

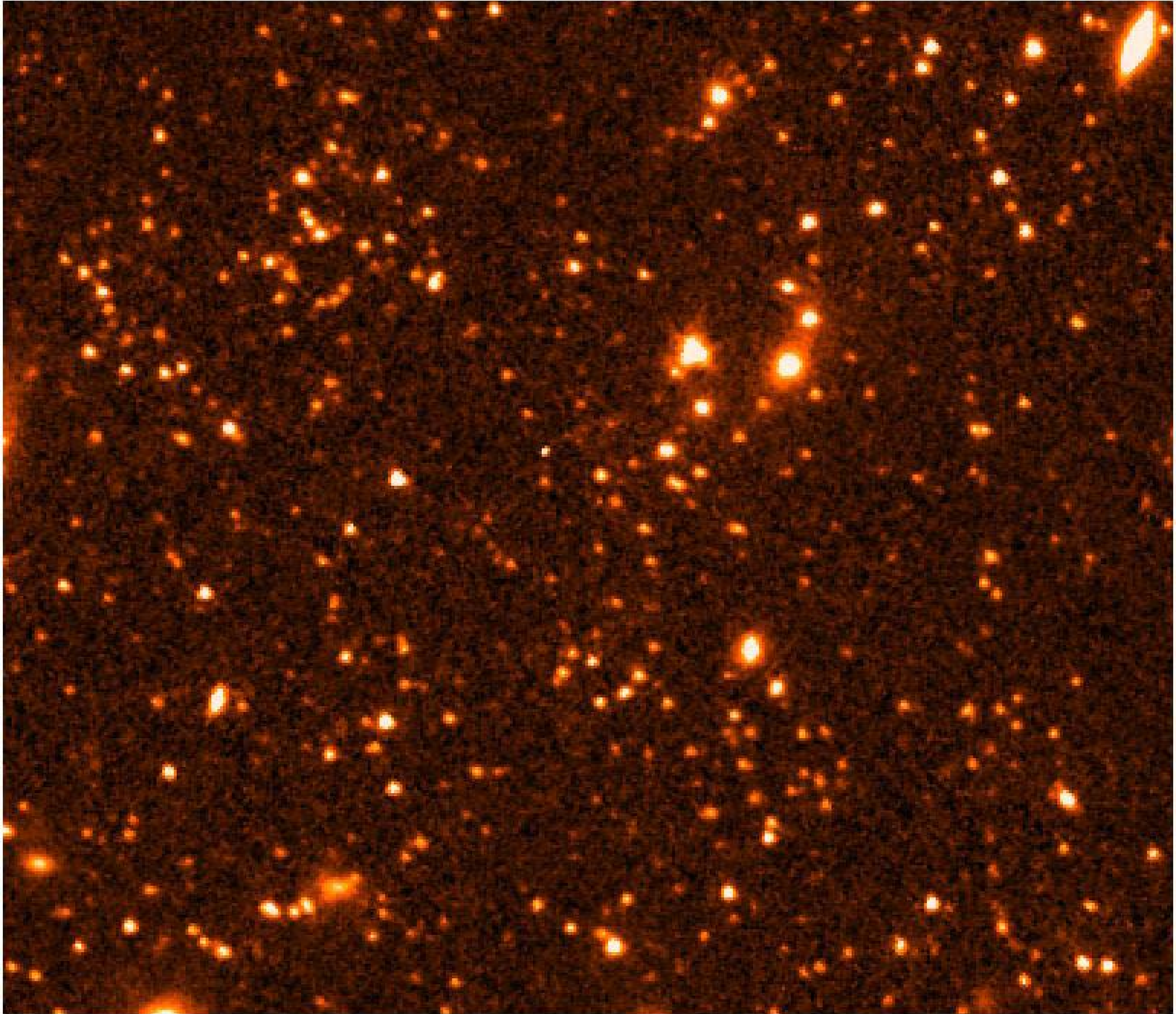
SIRTF Launch: 25 Aug 2003, 26+ yrs after I started.





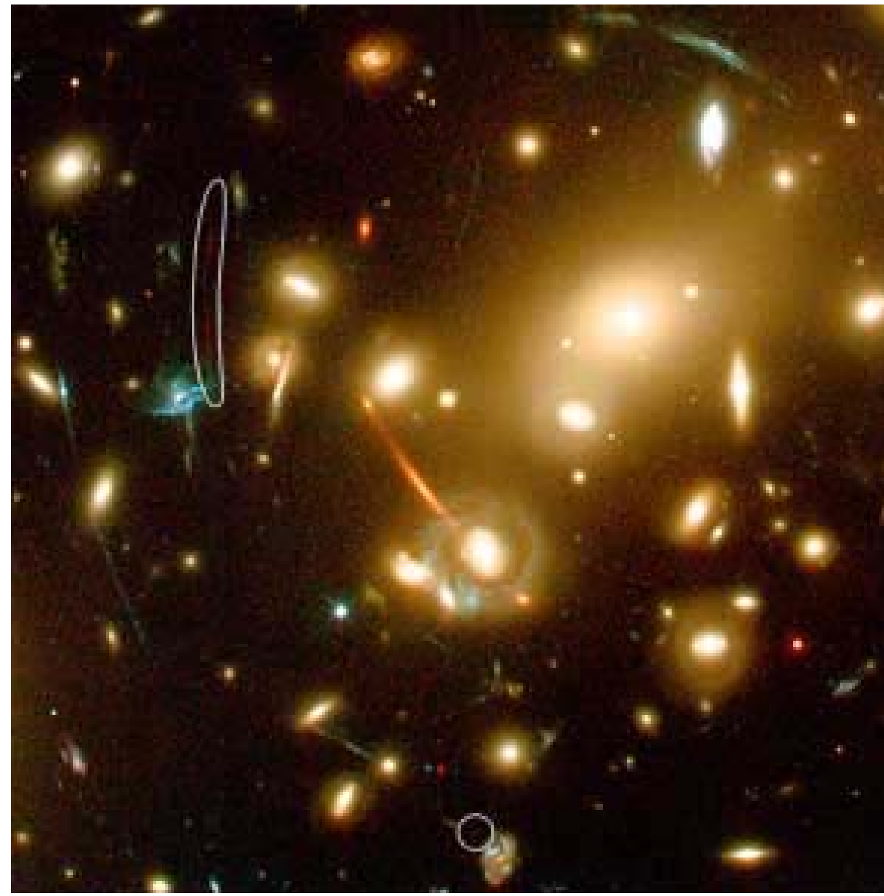
The IRAC Shallow Survey
8.5 sq degrees
in NDWFS Bootes
3 x 30 sec/position


Part of the 8.5deg^2
Spitzer/IRAC GTO Shallow Survey
January 2004
3.6 micron mosaic
47 x 39 arcmin
~1 WISE FOV



Most Distant Object?

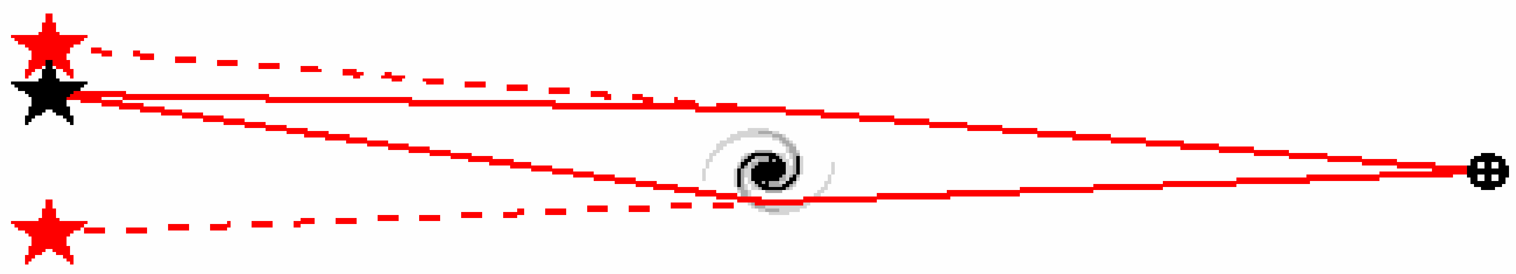
- Alleged redshift z=7
- No lines in spectrum
- Colors OK
- Gravitationally lensed by Abell 2218.
- The long arcs are highly magnified distant galaxies.



Kneib *et al*., astro/ph/0402319

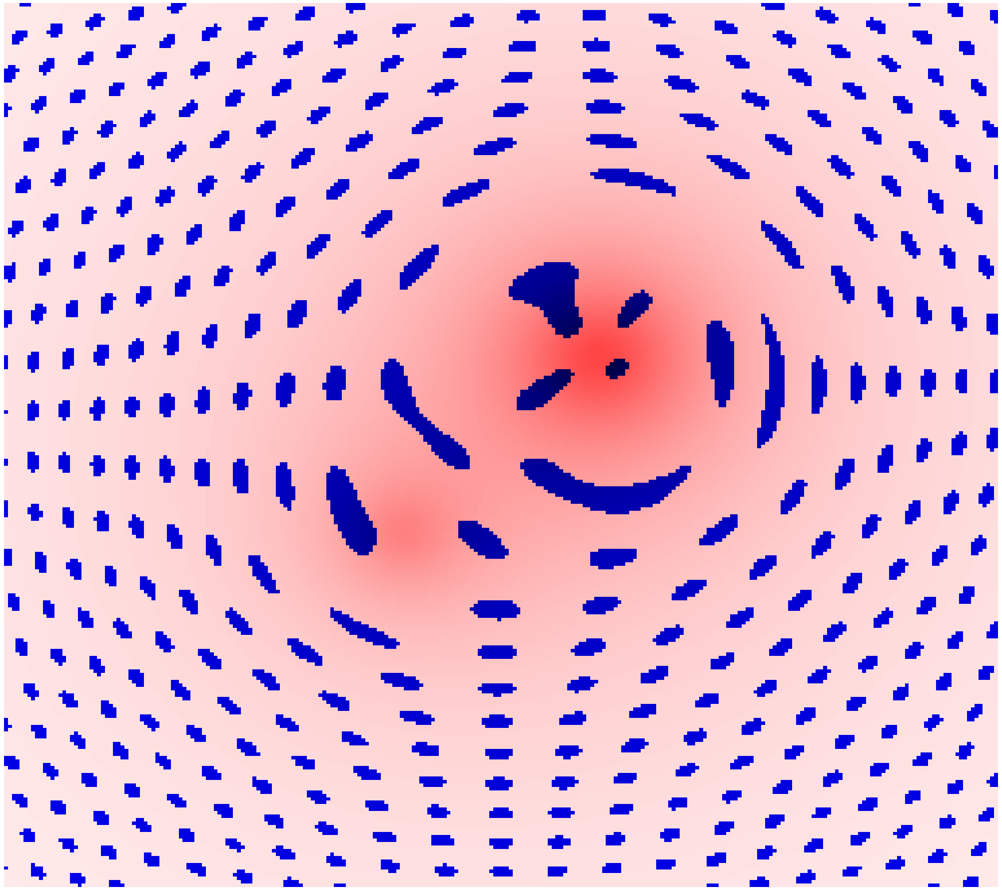
Gravitational Lensing

- Light is bent by a cluster of galaxies.
- For a symmetric cluster a small faint galaxy can be made into a long and much brighter arc or even a complete ring: the “Einstein ring”



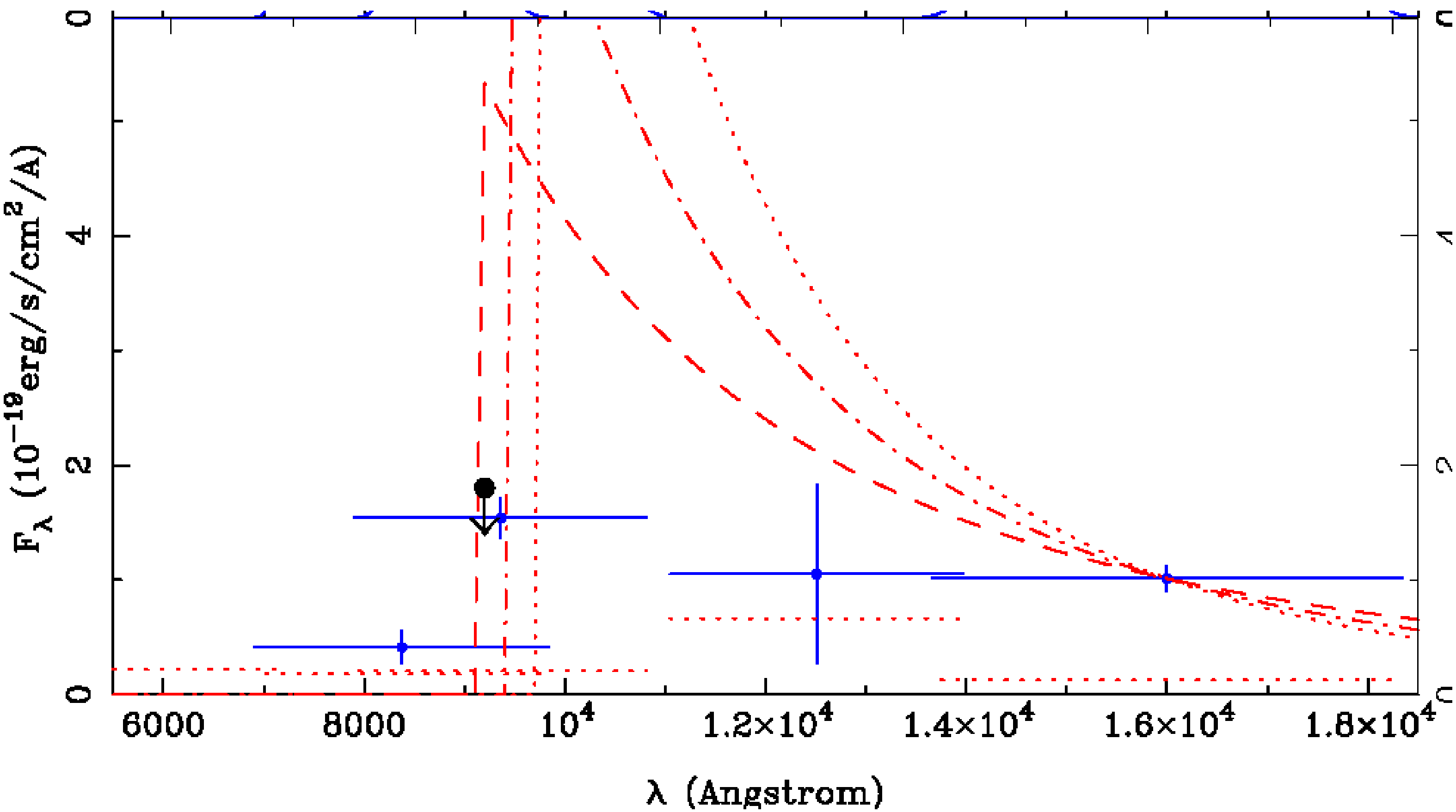
Cluster Lensing

- This animation shows a foreground cluster of galaxies with the pink showing the projected mass density. It has two separate clumps.
- The blue background galaxies slide behind the cluster to illustrate the range of images that can be produced.



Colors to redshift

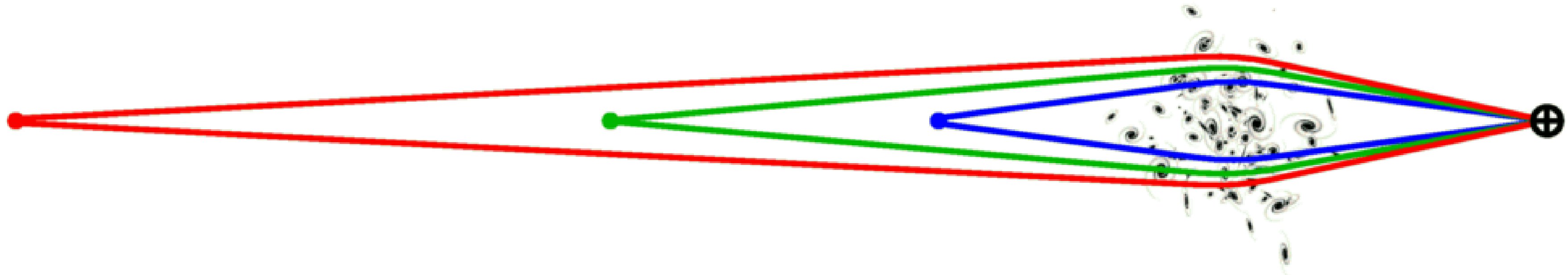
- No visible flux
- Only near-IR



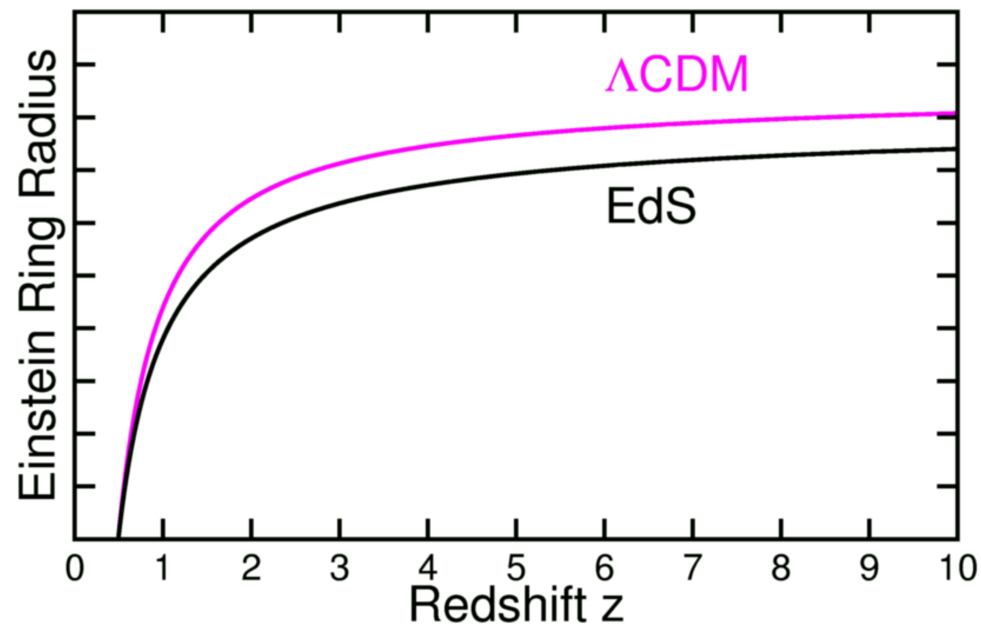
Guessing the redshift

- Redshift 7 chosen to hide Ly α in an atmospheric absorption band.
- Not really enough evidence for conviction except perhaps a conviction for hyperbole.
  - Lots of press coverage
  - Richard Ellis got the publicity in the US, not the lead author Jean-Paul Kneib

Einstein Ring Radius vs Distance

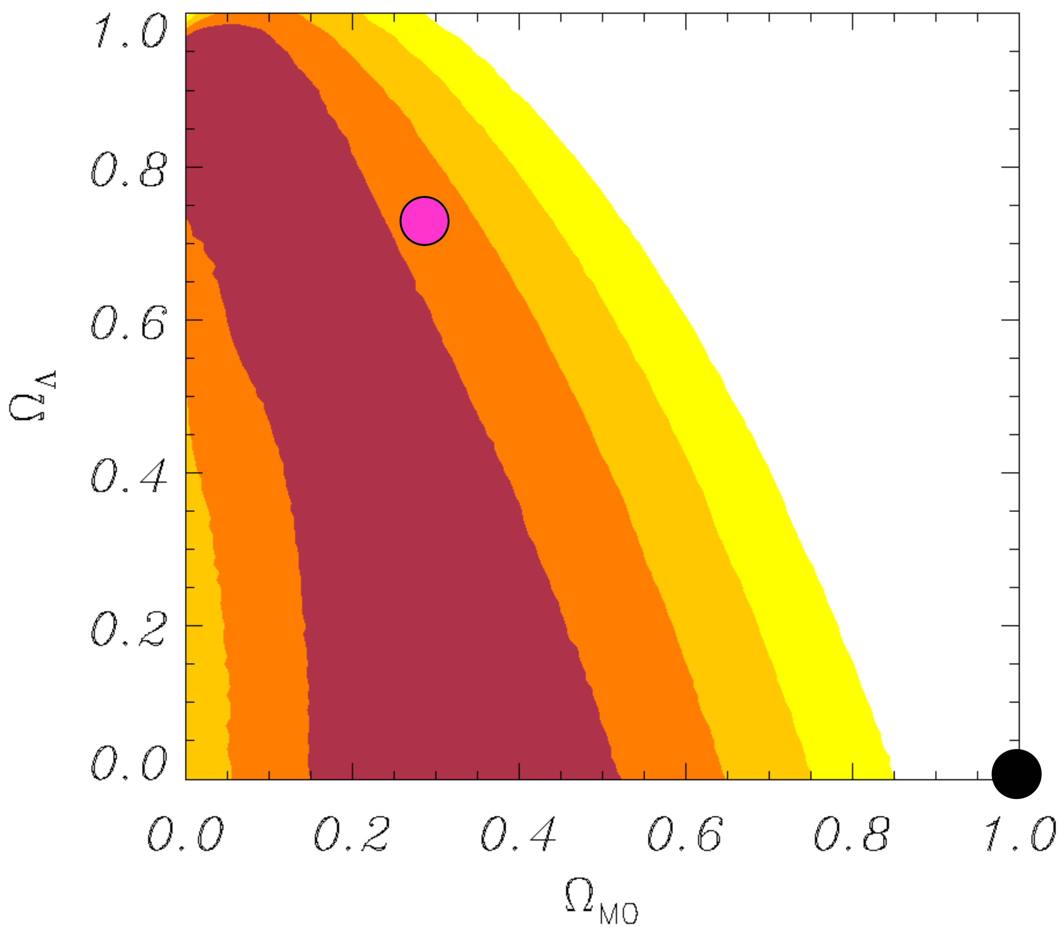


- Radius depends on distance.
- Distance depends on redshift and the geometry of the Universe.



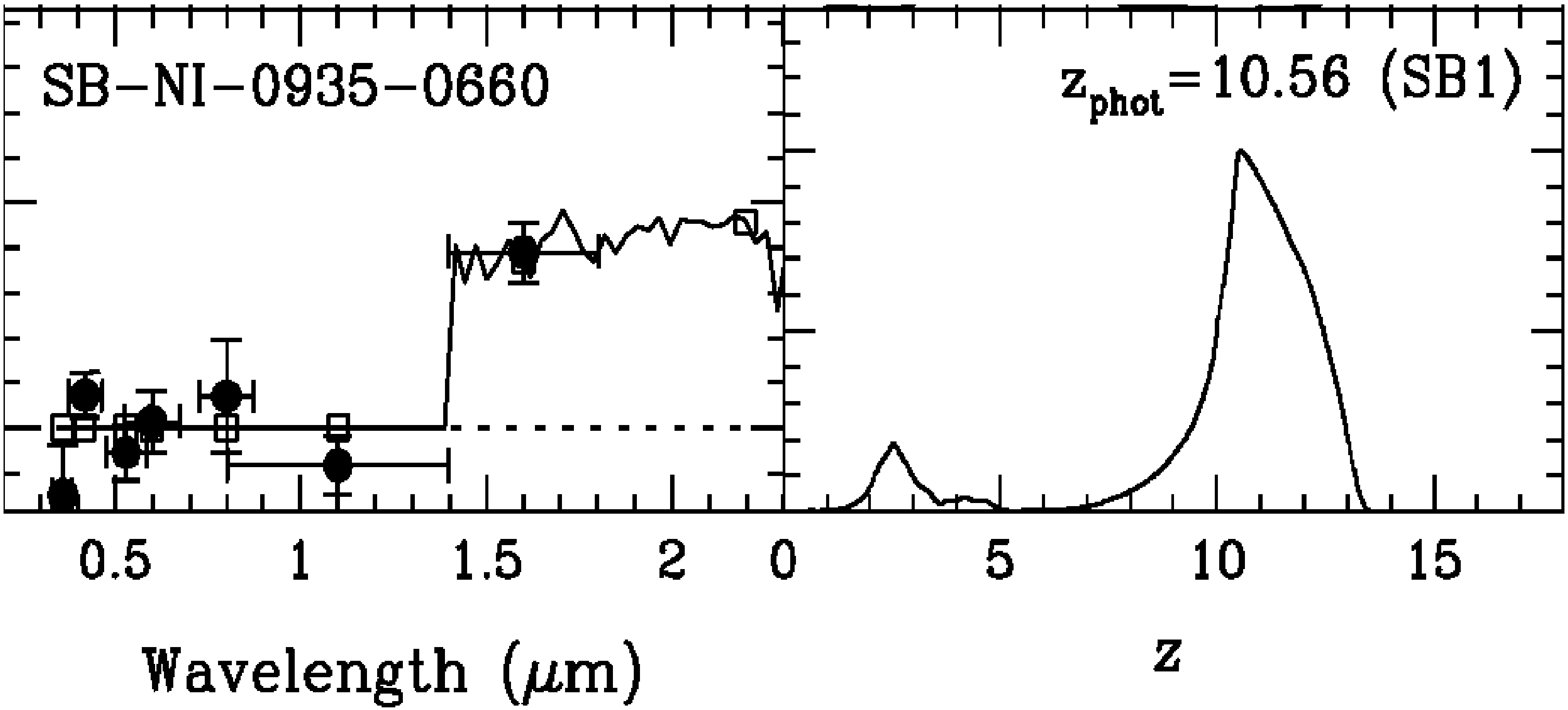
Can be used to measure Universe

- 4 arcs with well-known redshifts in Abell 2218.
- These arc radii agree more-or-less with the accelerating Universe from SNe.



Soucail et al., 2004, astro-ph/0402658

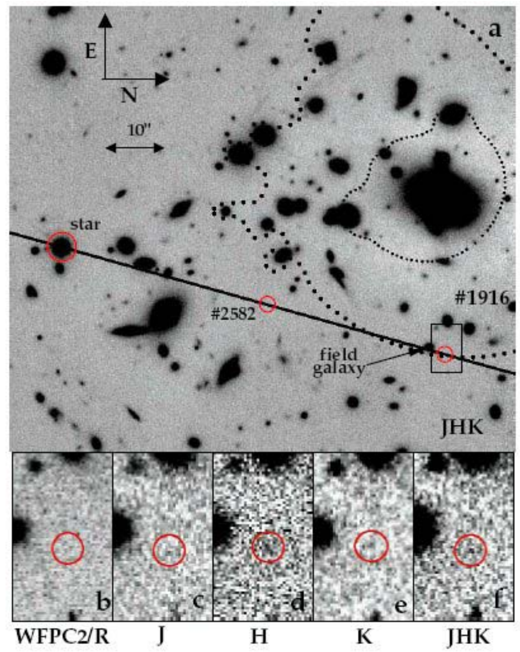
Past claims for z>10

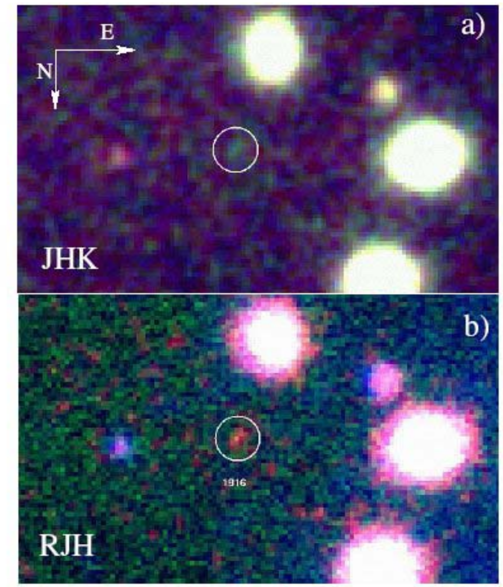


- Lanzetta group claimed z>10 for some objects in the Hubble Deep Field.
- Not widely accepted.

A More most distant Object

- Alleged redshift z=10
- One line in spectrum
- Not an HST press release.
- Different cluster: A1835.

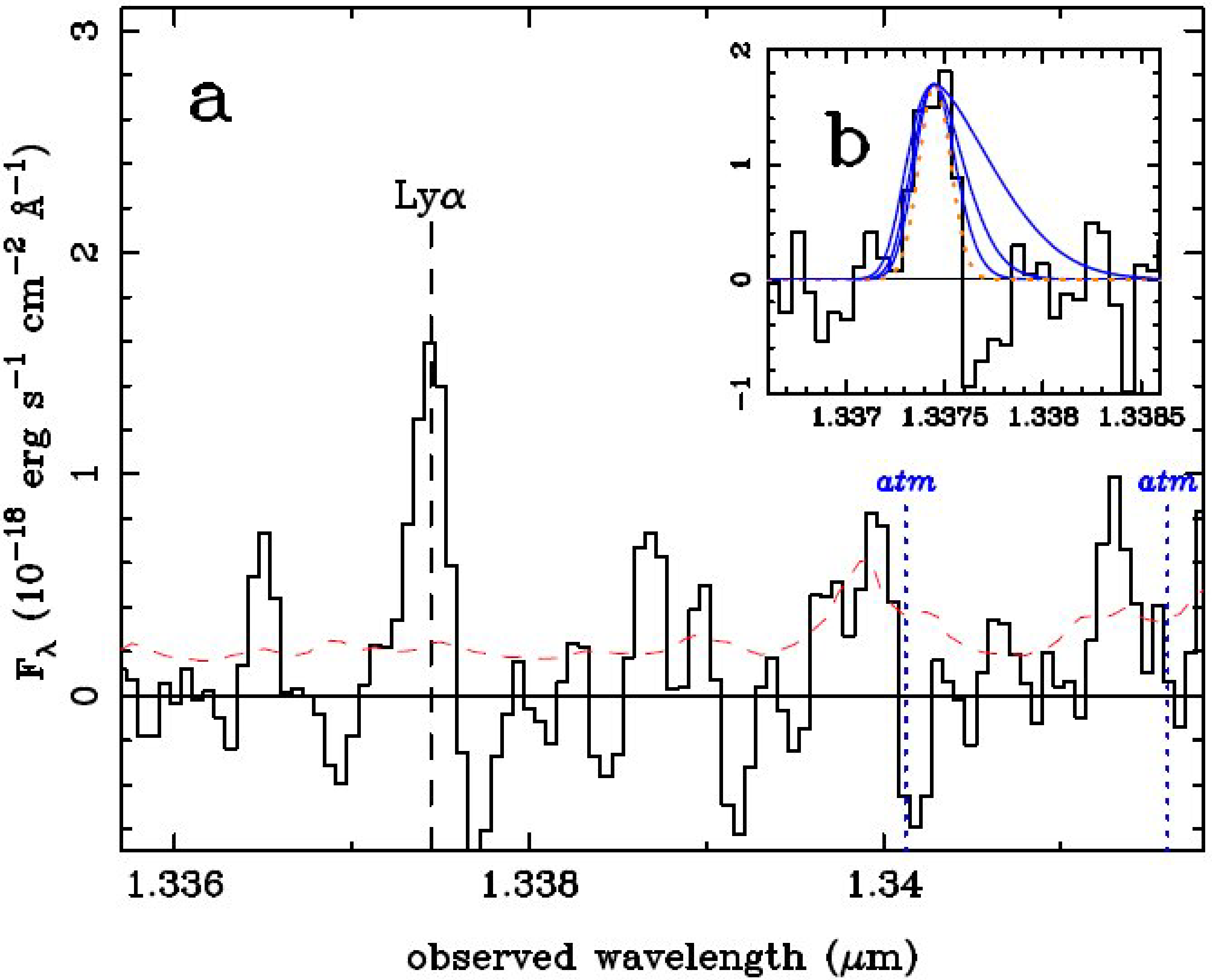




Pello et al., astro-ph/0403TBD

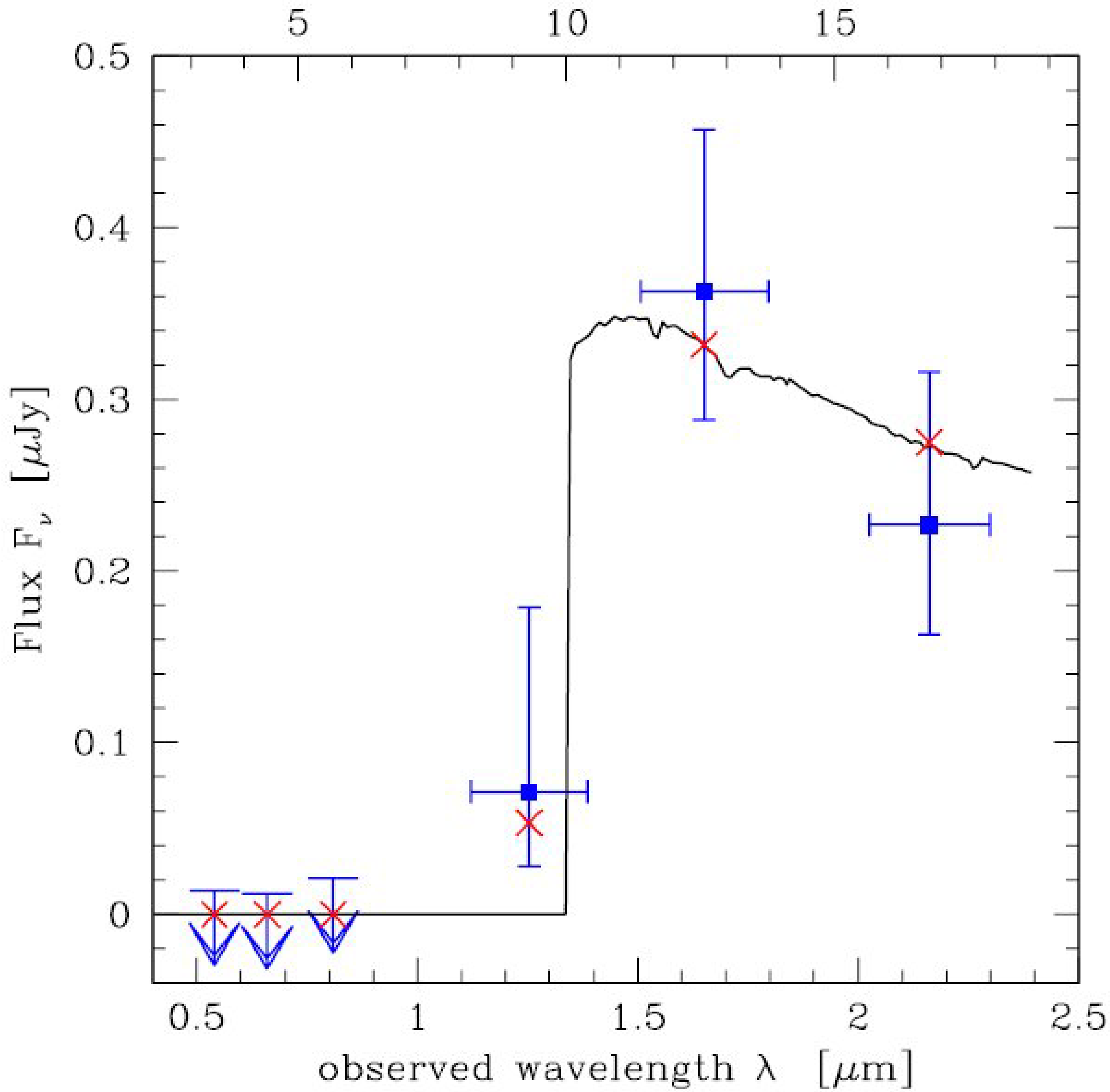
One line in spectrum

- λ_{obs} = 1.3375 μm, interpreted as Lyman α at λ_{em} =121.5 nm.
- Redshift = $\lambda_{obs}/\lambda_{em}$-1 = 10.01
- Symmetry & width are worrisome.



Colors Match Too

- No optical light, but visible in the infrared.
- Optical limits may be overstated.



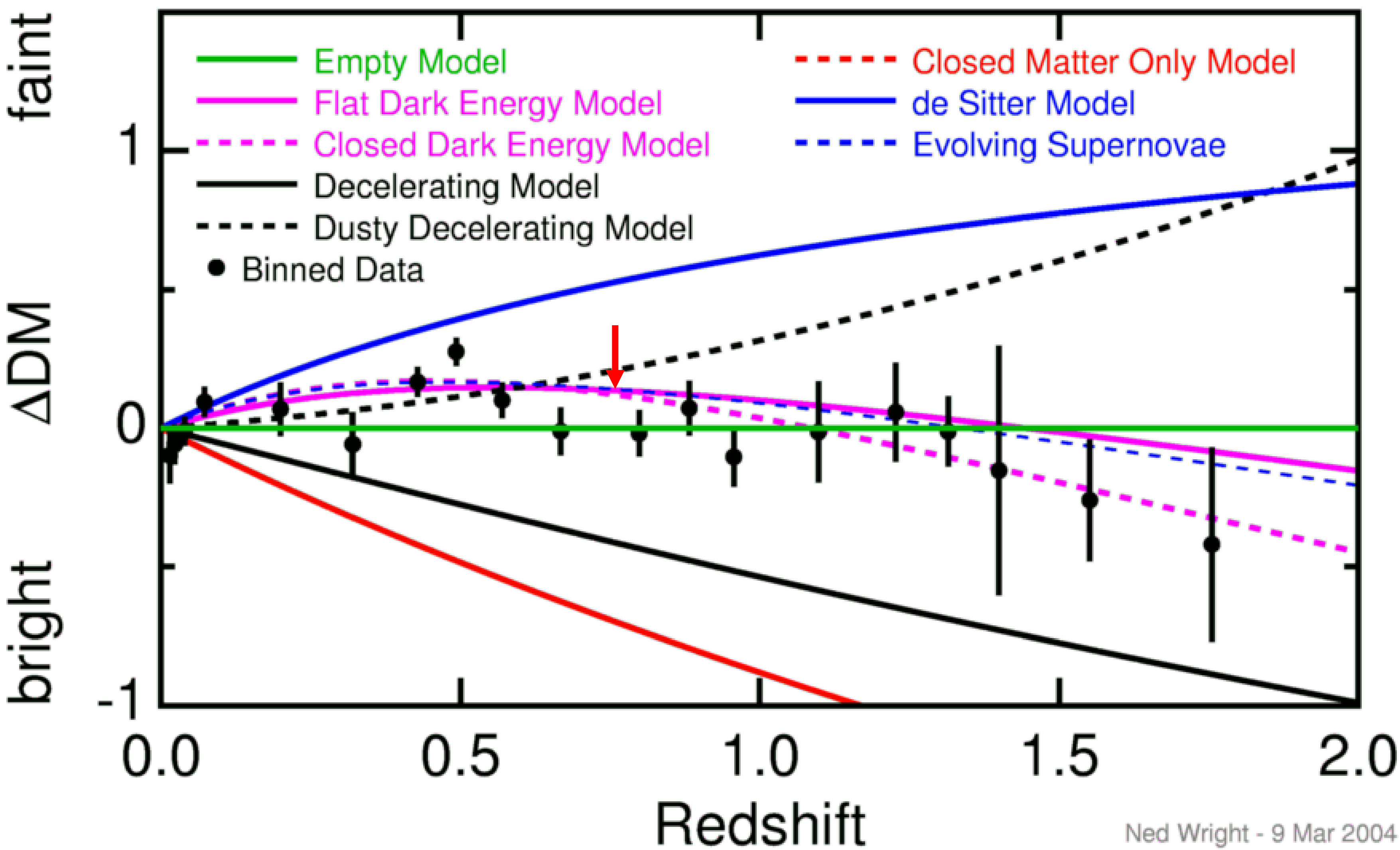
3 types of evidence

- A spectral line, identified with the strongest line from the most abundant element, Hydrogen Lyman α.
- The colors.
- The position on the critical line where redshift 10 objects should be most strongly magnified by gravitational lensing.
- Best case yet for $z = 10$ or more.
- But not well covered in the press.

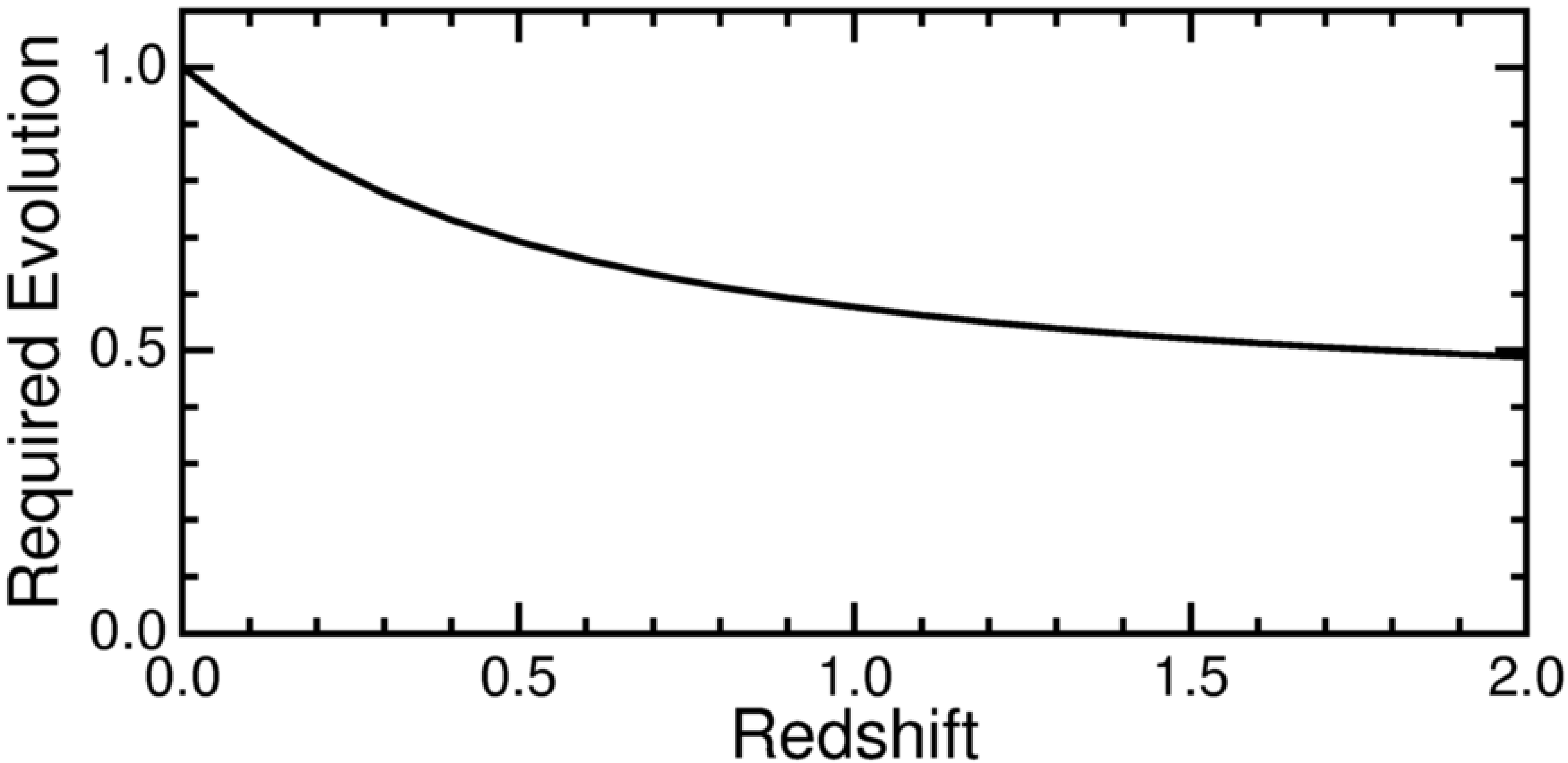
The latest from supernovae

- Several new z>1 SNe, and a great data table in Riess *et al*., astro-ph/0402512
- Contrary to STScI propaganda, these do not rule out evolution models. Evolution as an exponential of cosmic time in an EdS model is a nearly perfect match to ΛCDM.
- Furthermore, supernovae are fainter than expected in any model with matter, and high-z SNe are “more fainter”. There is no “cross-over” when q changes sign.

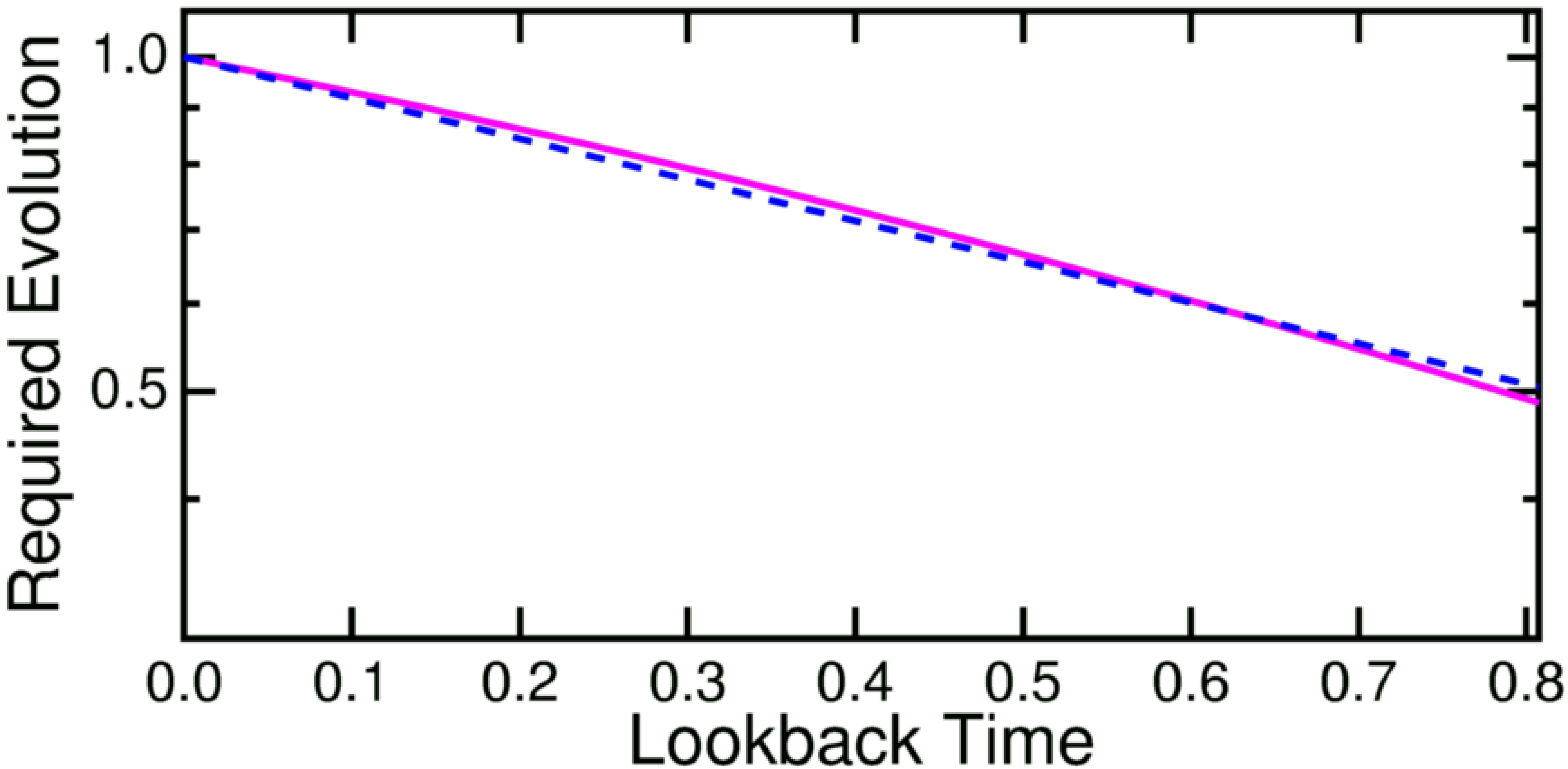
DM relative to empty model



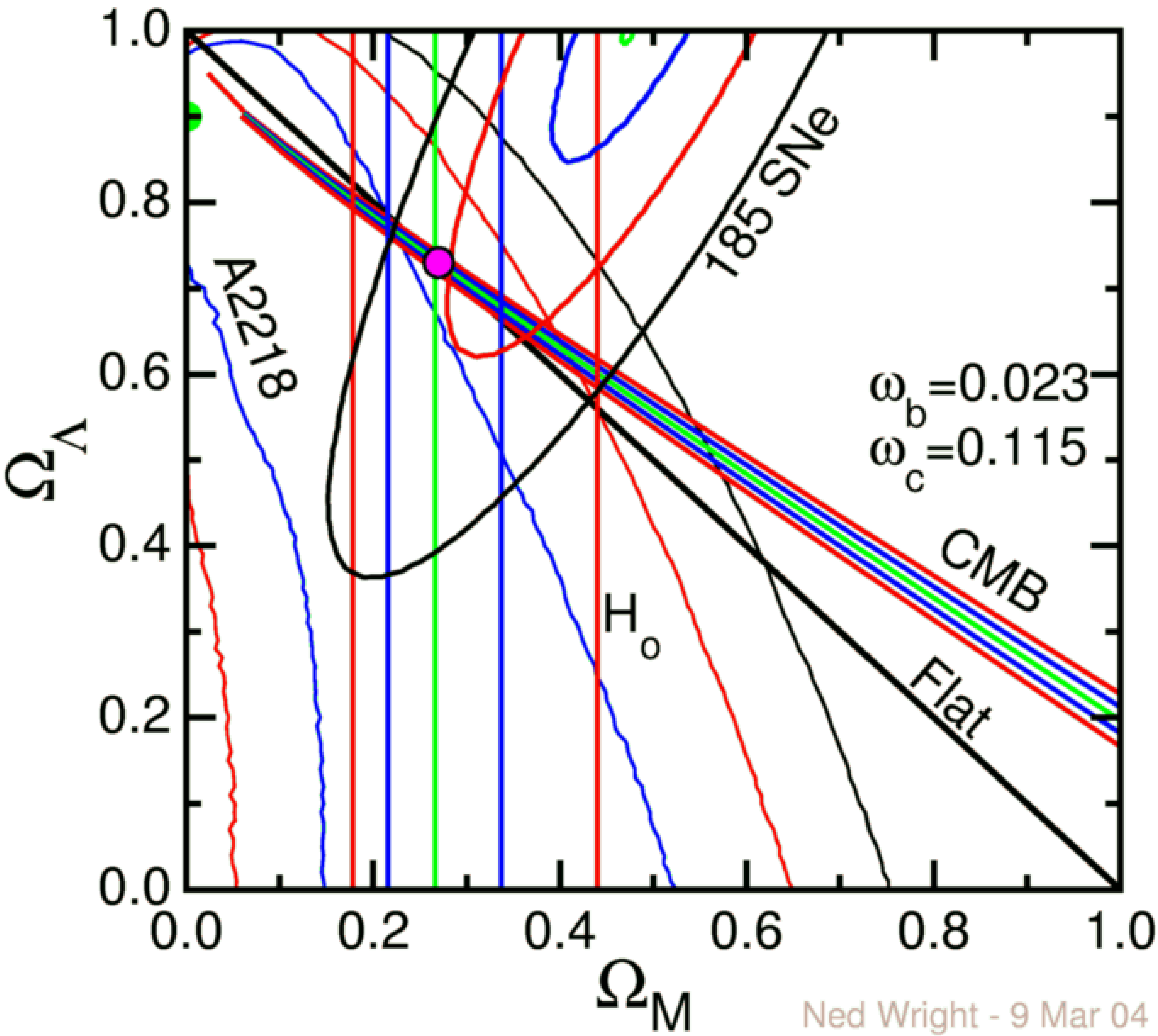
Dimming relative to Ω_m=1



Dimming relative to Ω_m=1



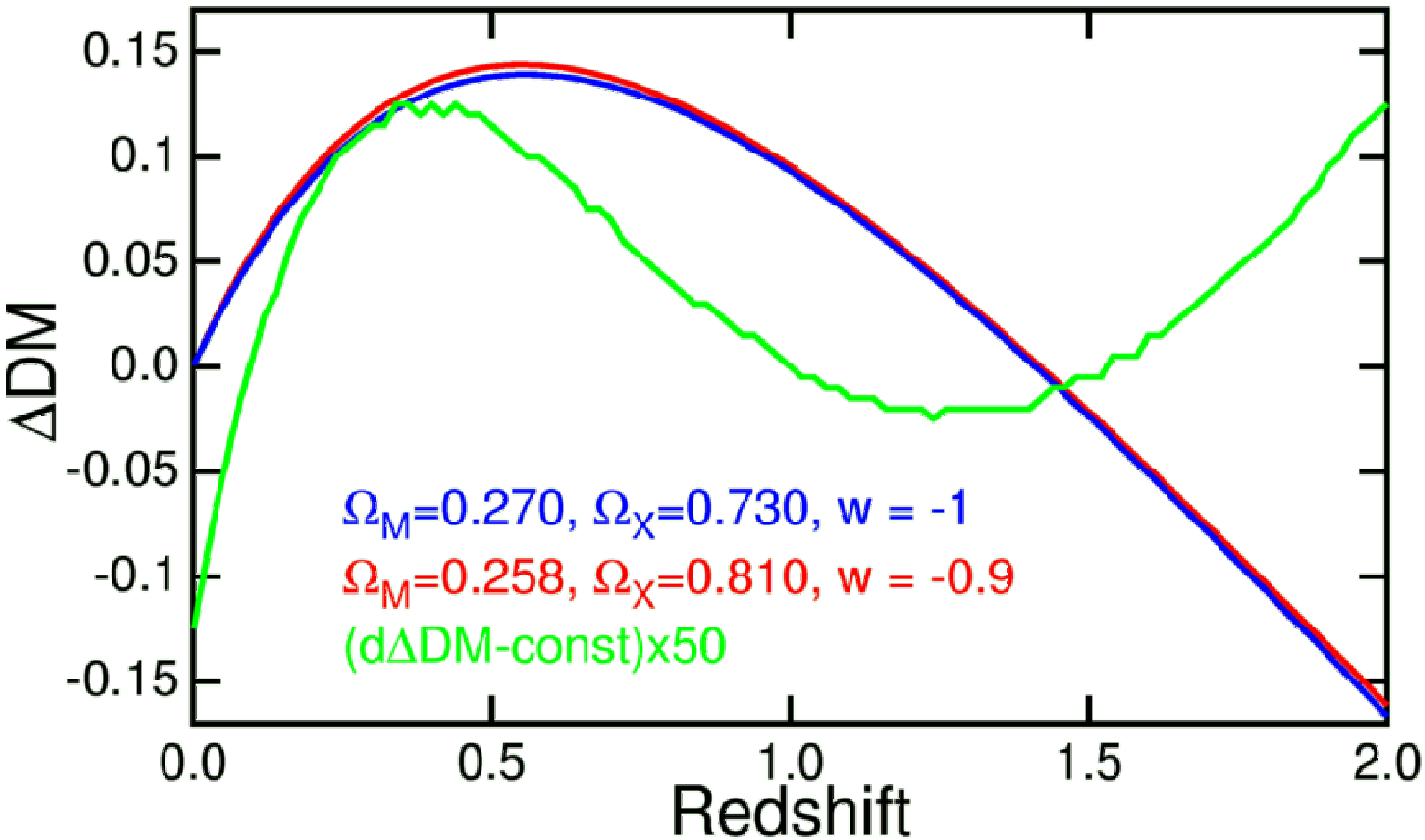
With known baryon & DM density



$\Omega_m h^2$ is known, not Ω_m

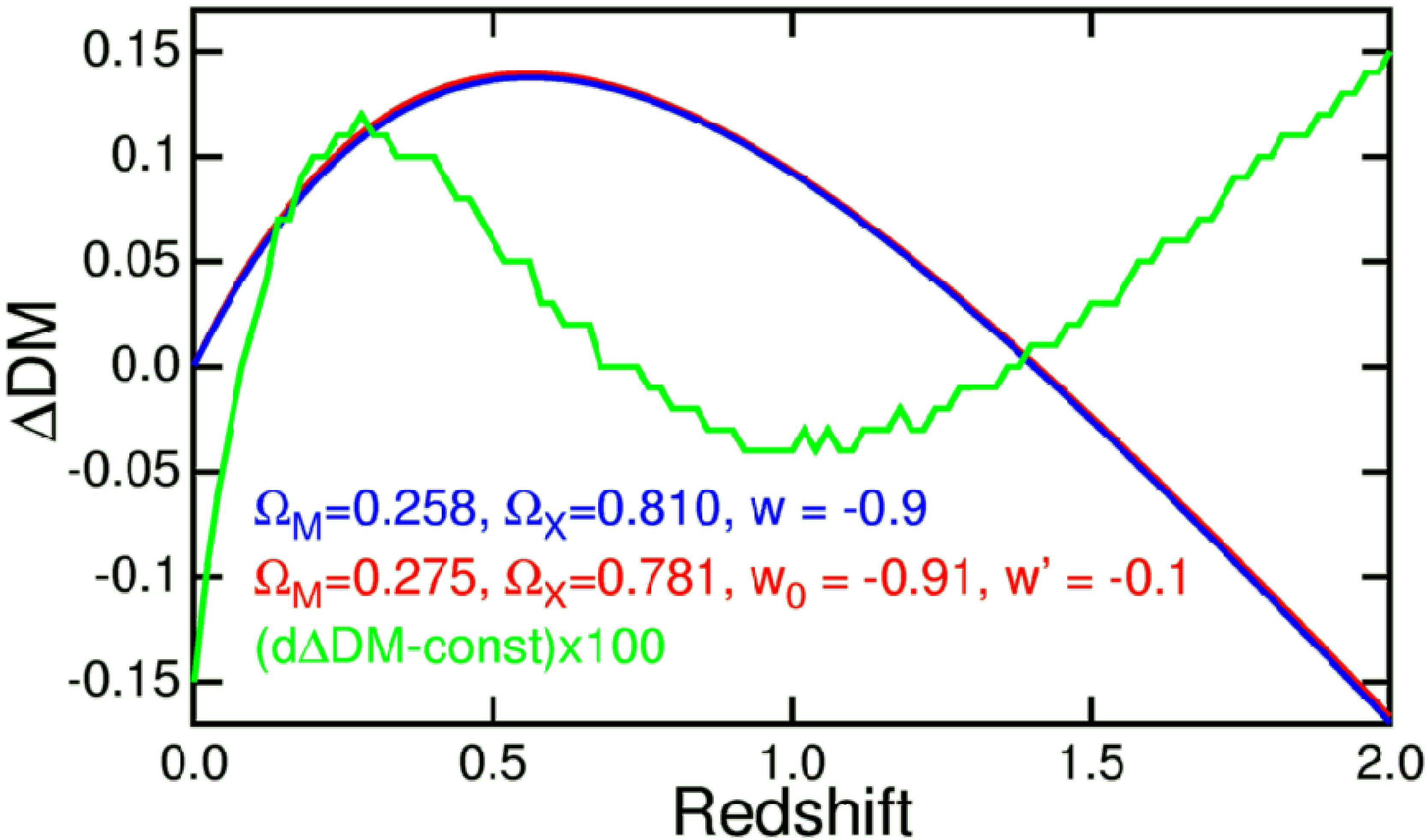
- This makes the H_o contours vertical lines
- Contours of $\Gamma = \Omega_m h$ are also vertical lines which are consistent with the HST Key Project Hubble constant.

SNe alone can't measure w



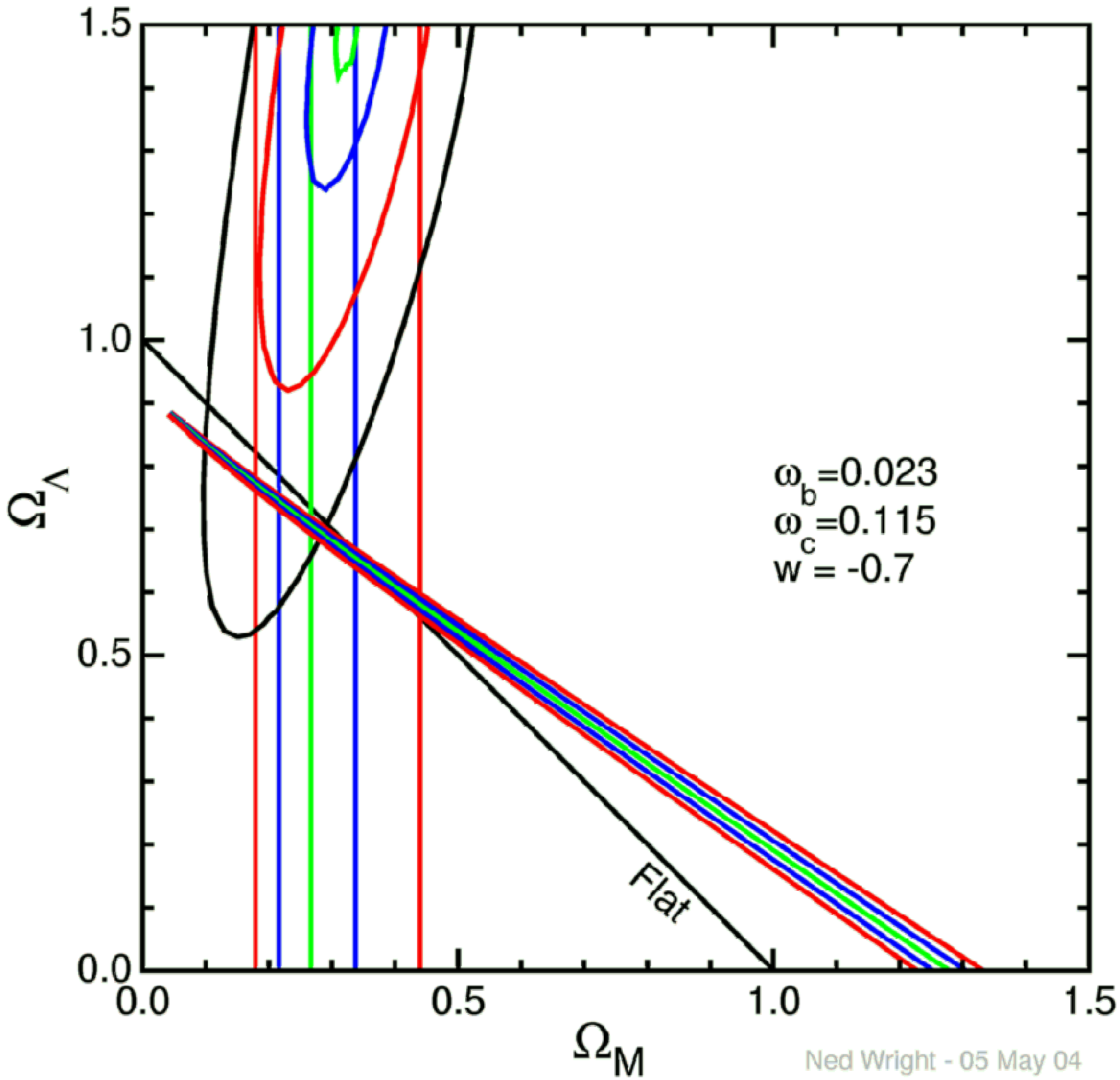
- Model with w = -1 and w = -0.9 agree to within ± 2 millimag

SNe alone can't measure w'

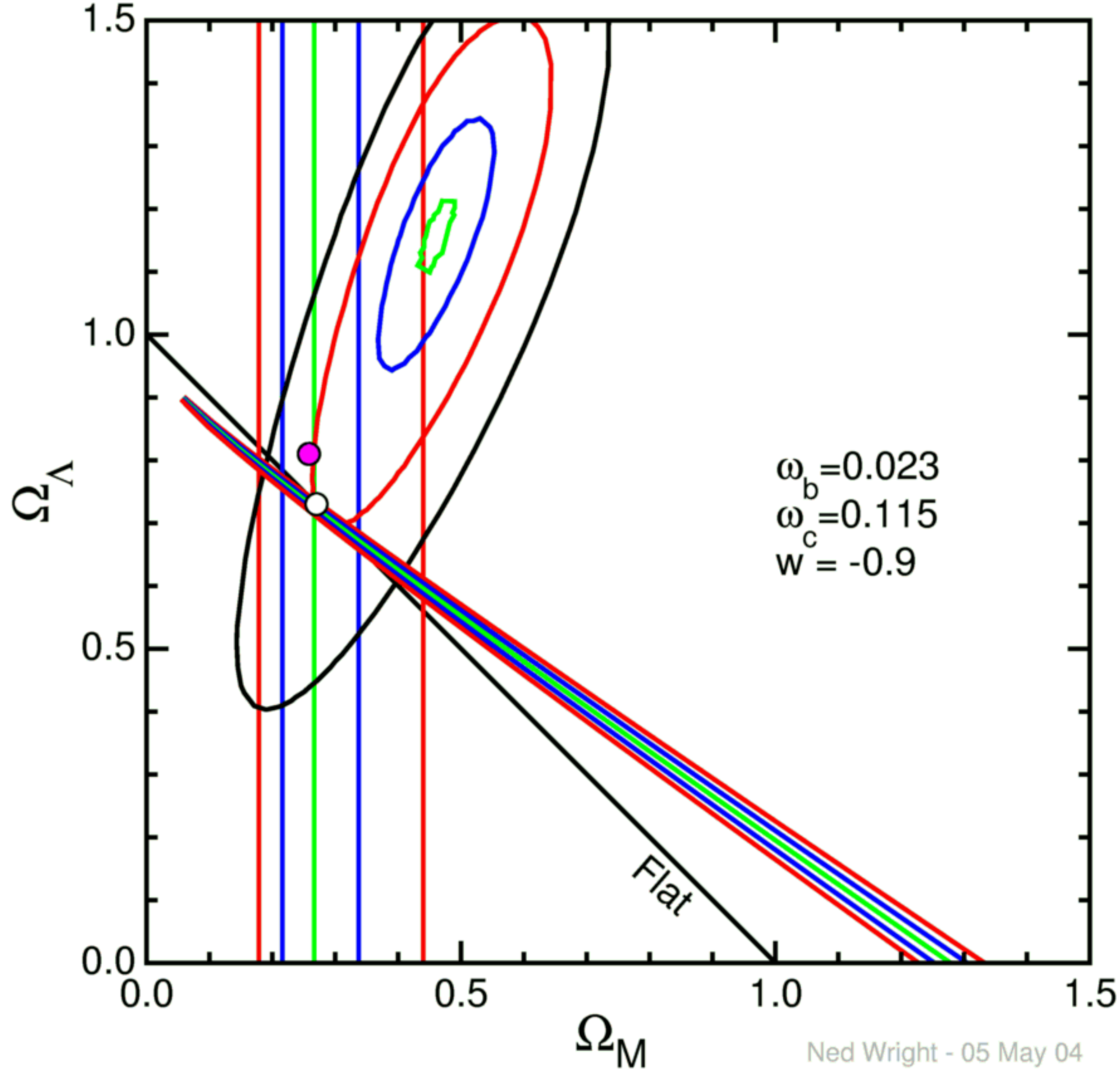


- Model with w' = 0 and w' = -0.1 agree to within ± 1 millimag

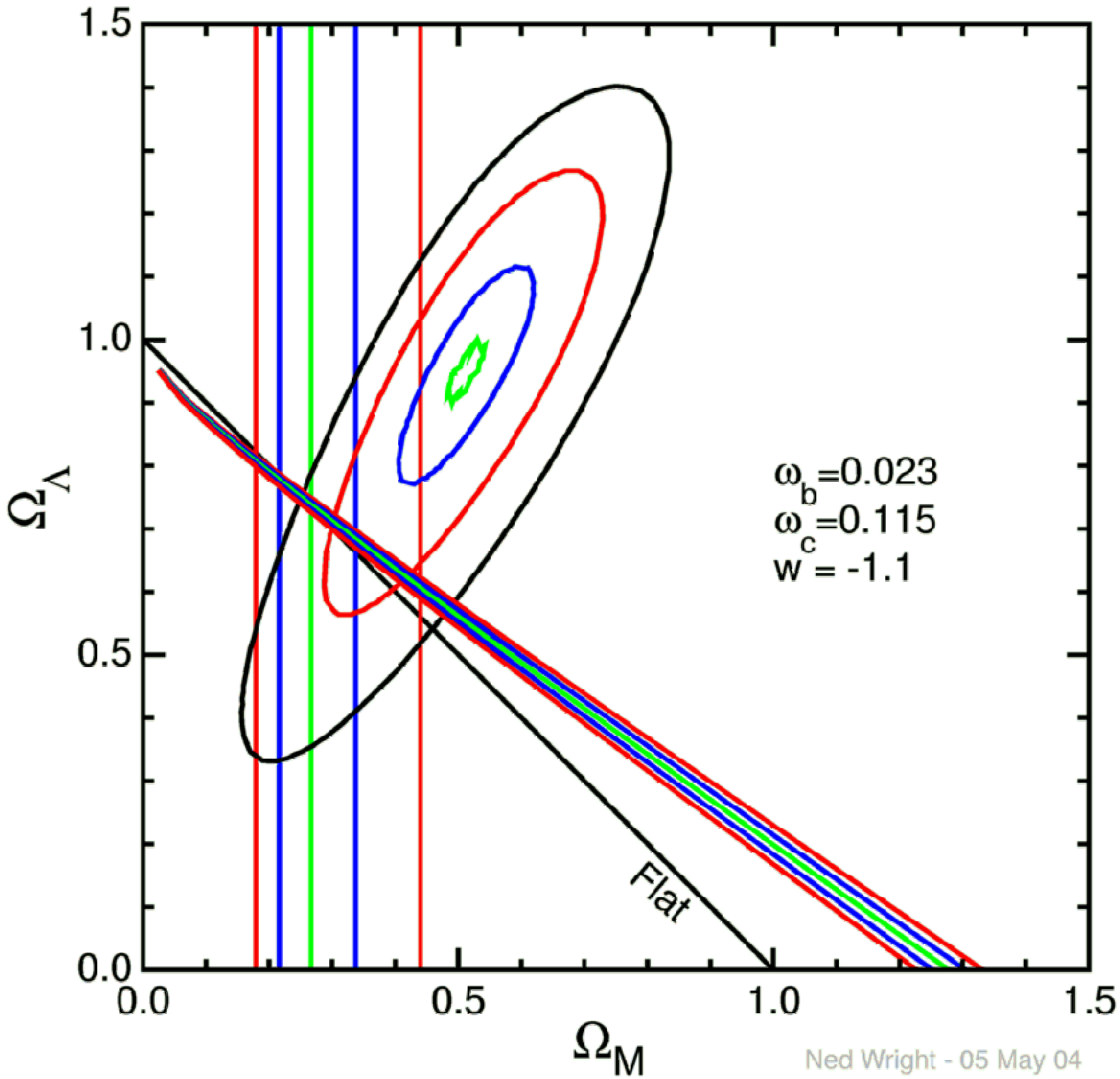
Can we measure $w = P/\rho c^2$?



Can we measure w?



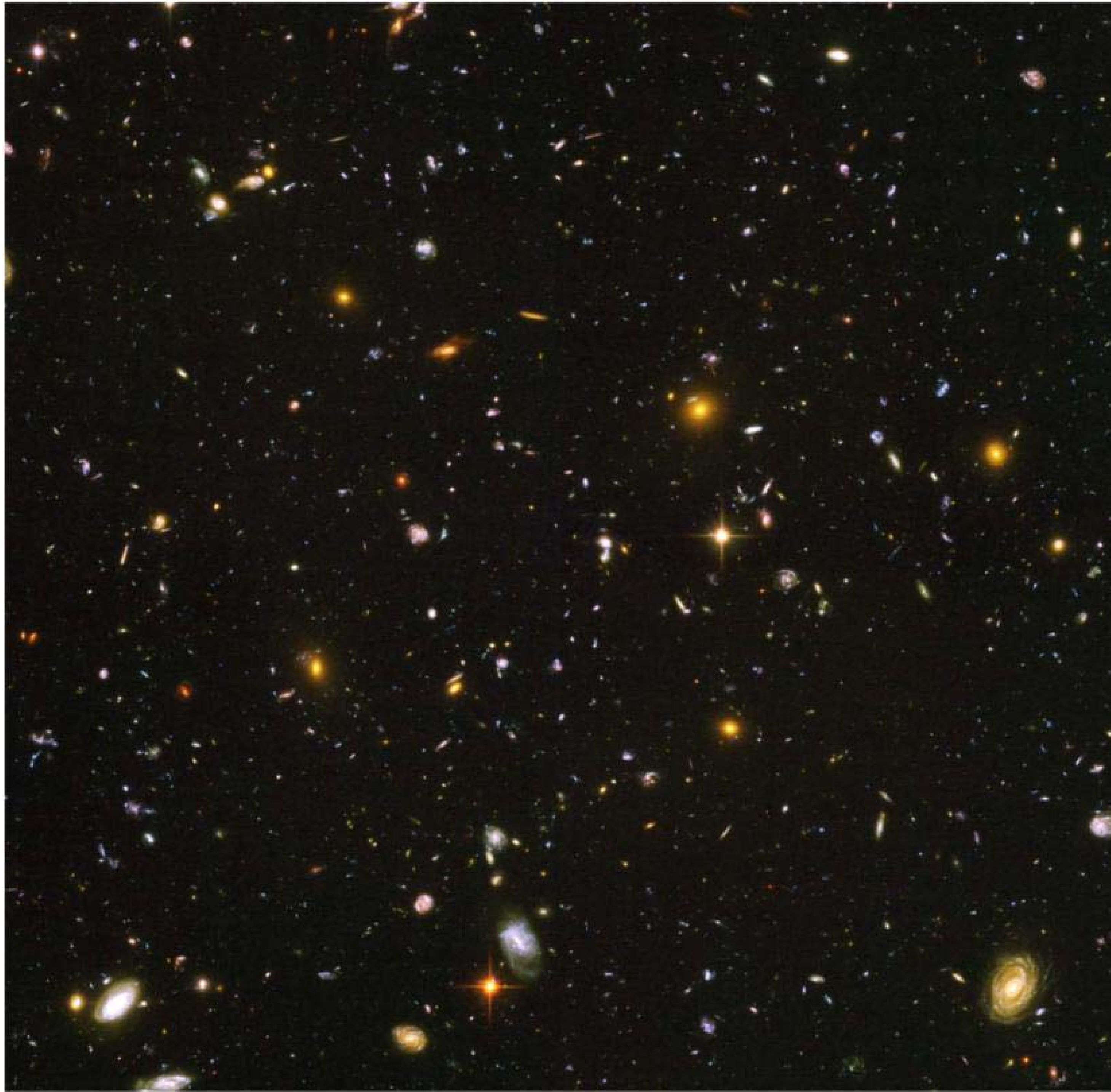
Can we measure w?



Should not assume flatness

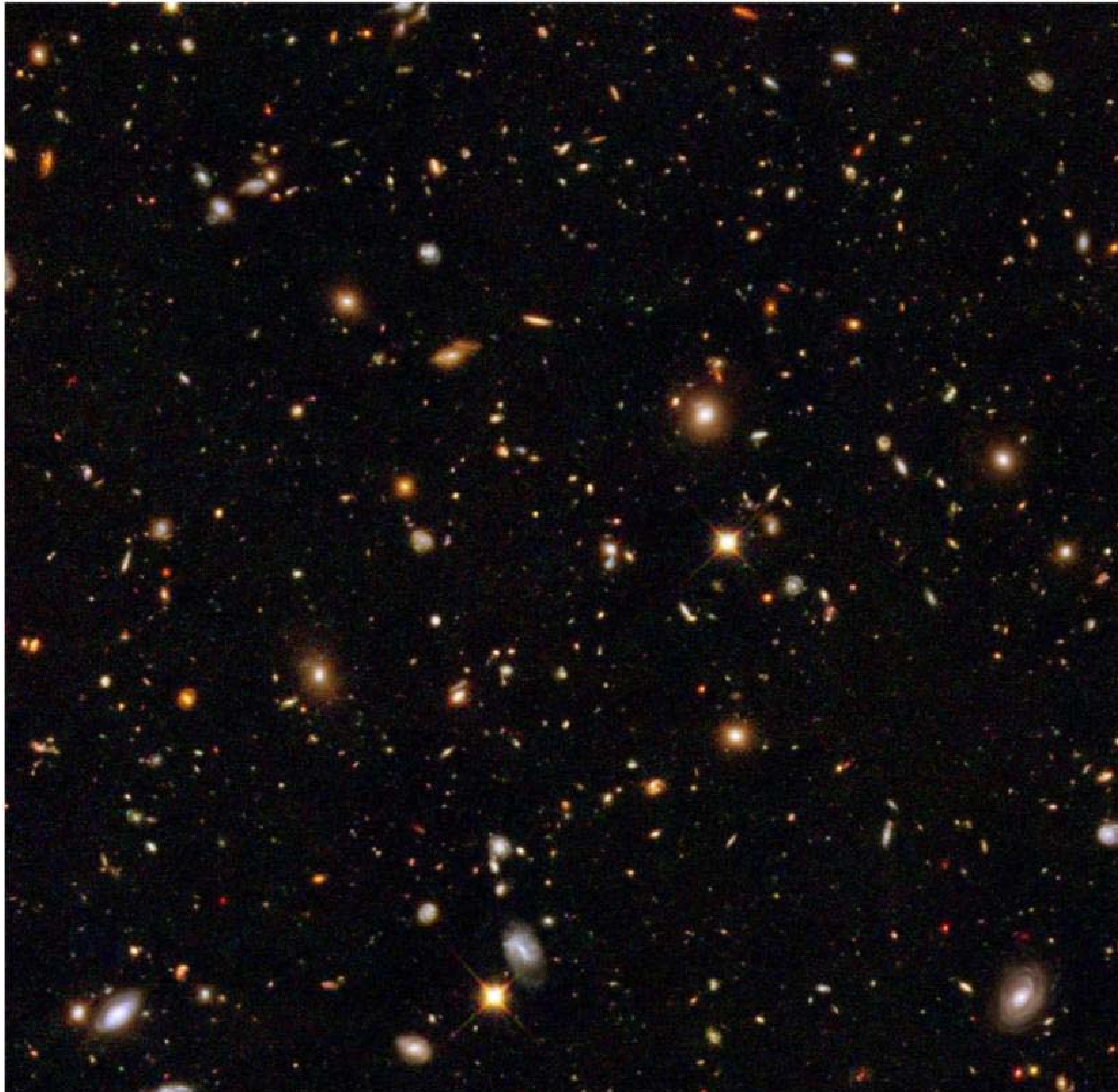
- The success of the flat model with w = -1 can not be used to justify assuming flatness when trying to find w and w'.
- Certainly Ω_{tot} = 1 is simpler, but
  – Ω_X = 0 is simpler, no CDM is simpler & w = -1 is simpler
- But the model consistent with both the CMB and SNe data moves as w is varied, and is most consistent with the Hubble constant from the HST Key Project when w is close to -1. So w can be measured ***using all data combined*** but be suspicious of priors on Ω_{tot} or Ω_M.

HUDF Visible

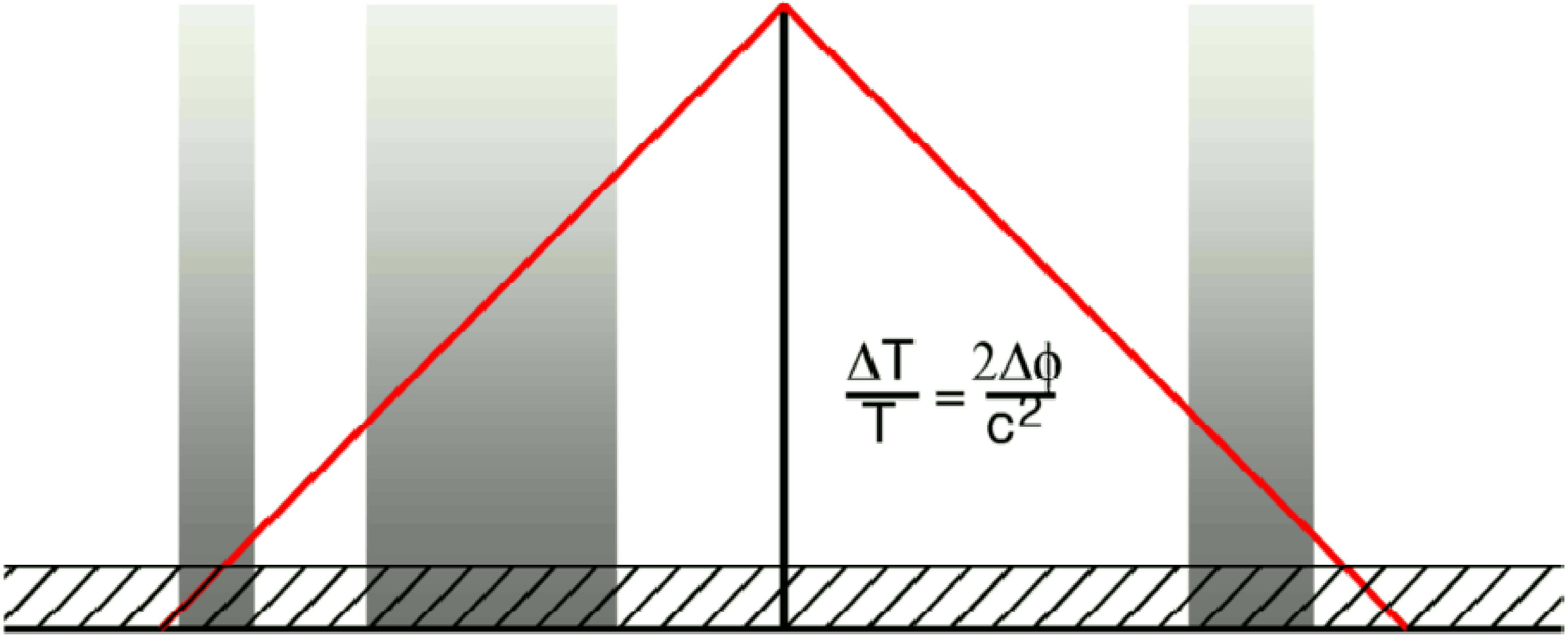


HUDF Infrared

Note that the IR image has a smaller total exposure time and very much less time on each pixel. But it still goes to higher redshift.

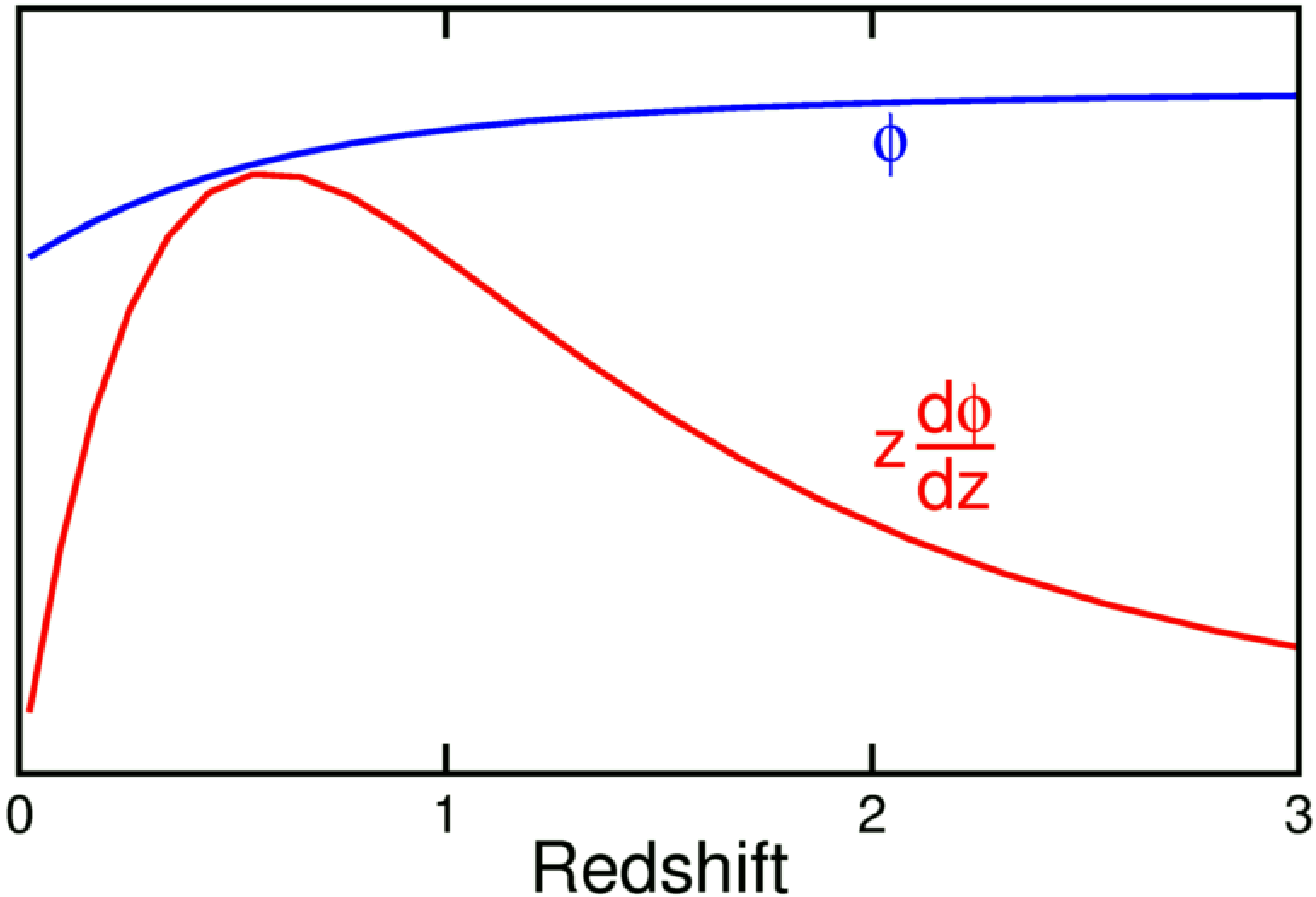


Late ISW Effect



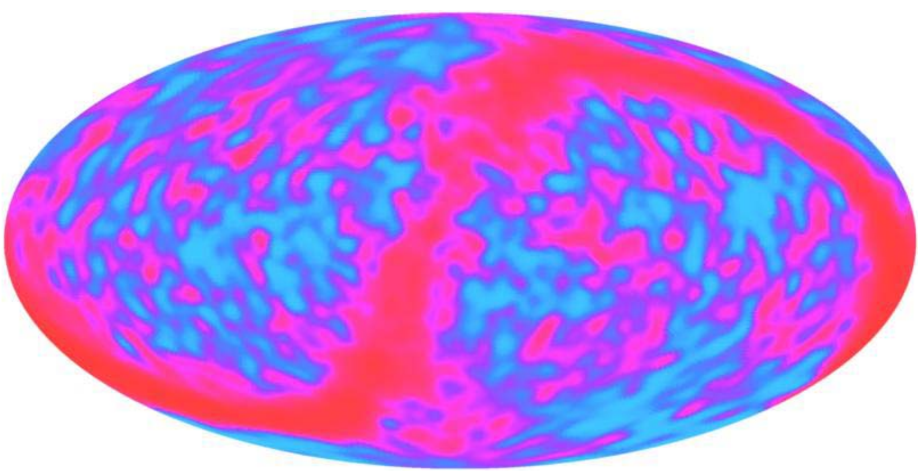
Potential only changes if $\Omega_m \neq 1$ (or in non-linear collapse, but that's another story [Rees-Sciama effect]).

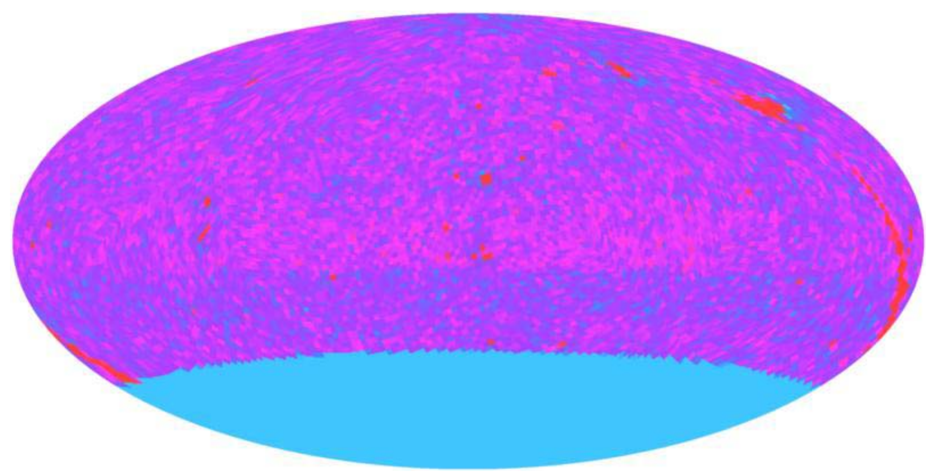
Potential decays at z ≈ 0.6



Correlated with Observed LSS

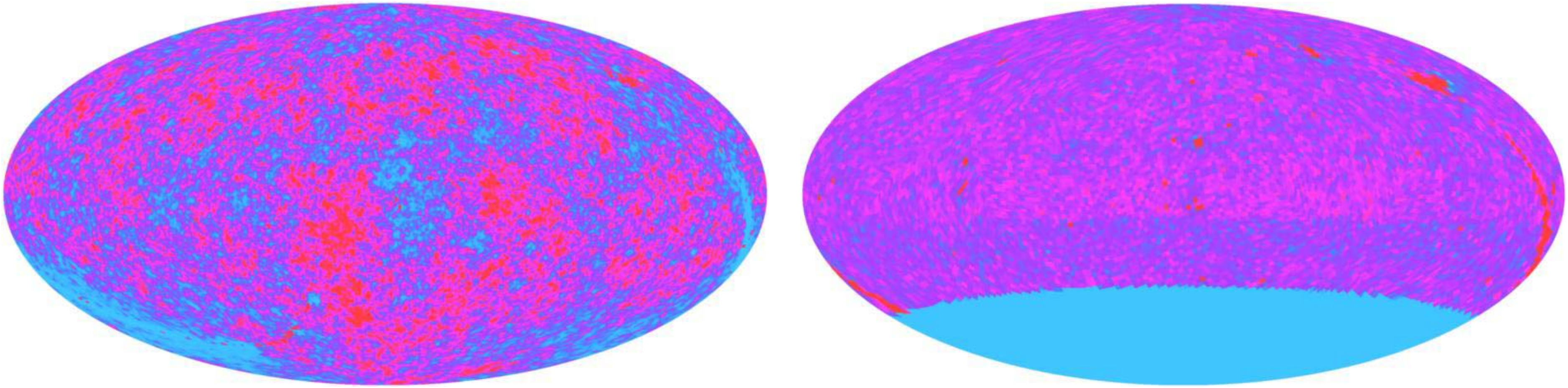
- This late ISW effect occurs on our past light cone so the ΔT we see is due to structures we also see.
- Search for correlation between LSS at z=0.6 and the CMB anisotropy: see Boughn & Crittenden, astro-ph/0111281
  - Expected 0.035 cross-correlation between NVSS sources and COBE DMR
  - observed -0.003 ± 0.025



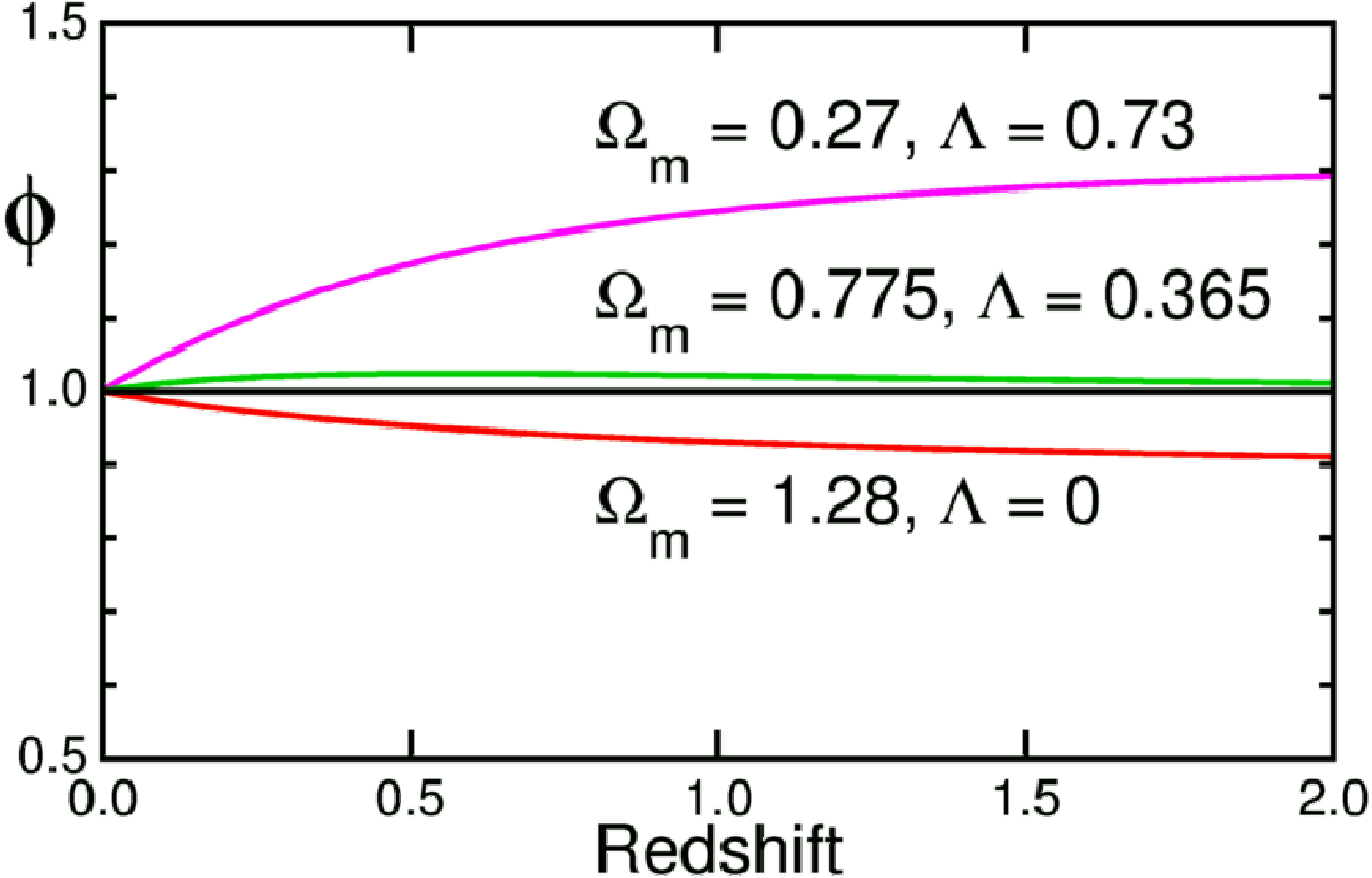


Correlation is seen with WMAP

- Correlation between WMAP and LSS seen by:
  - Boughn & Crittenden (astro-ph/0305001) at 2.75σ with hard X-ray background and 2.25σ with NVSS
  - Nolta et al. (astro-ph/0305097) at 2σ with NVSS

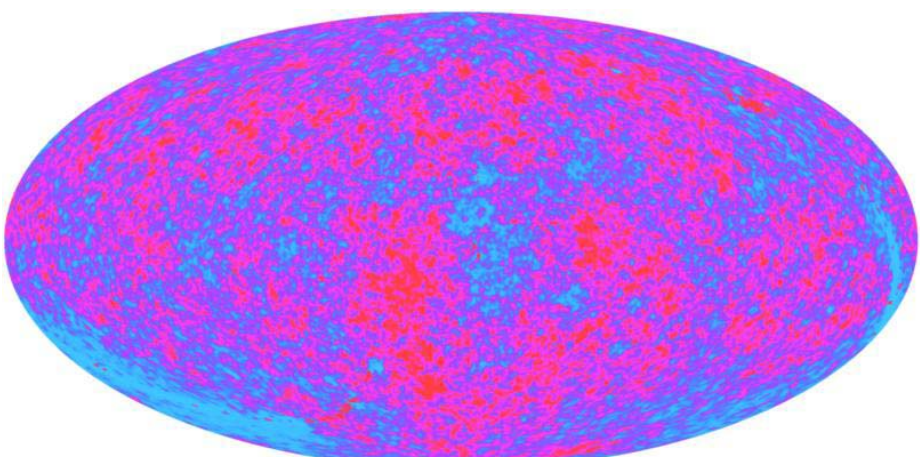


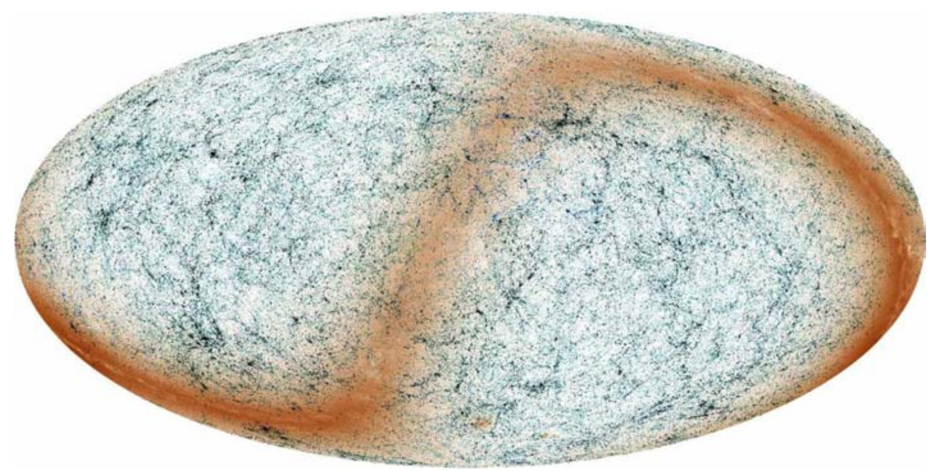
ΛCDM is OK, sSCDM fails at 3σ



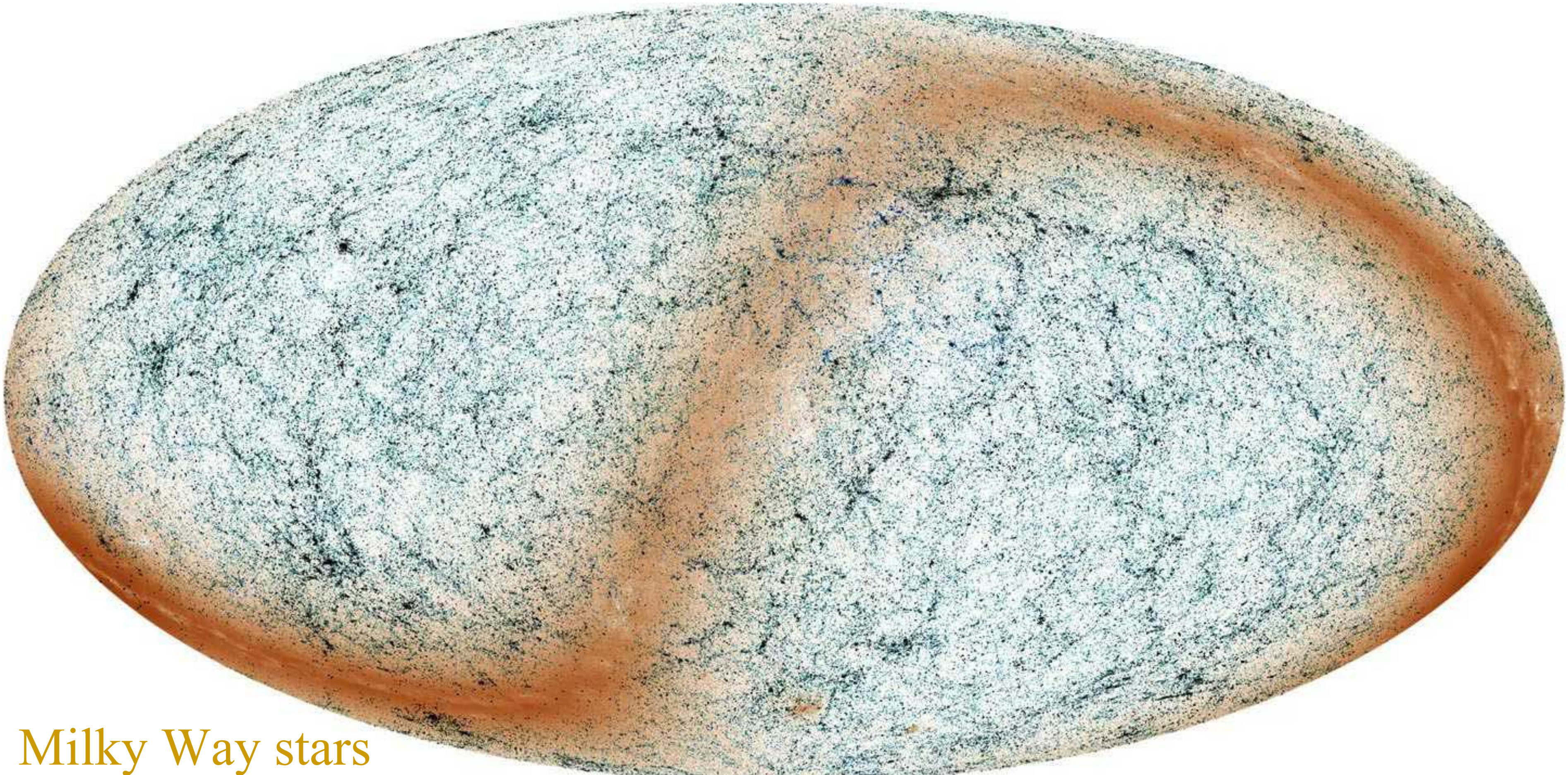
Possible Improvements?

- ✓ Less noisy and higher resolution CMB data.
  - WMAP is correlated with NVSS & XRB.
- Use a better tracer of LSS. IR surveys trace old stars and thus are close to a mass survey.
- Ashfordi et al (astro-ph/0308260) found 2.5σ ISW correlation between WMAP & 2MASS.



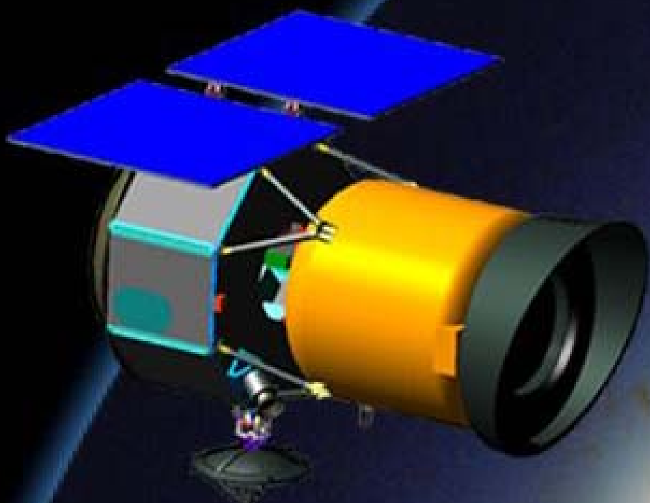


2MASS Galaxies at $z \leq 0.15$



To get a deeper sample, use:

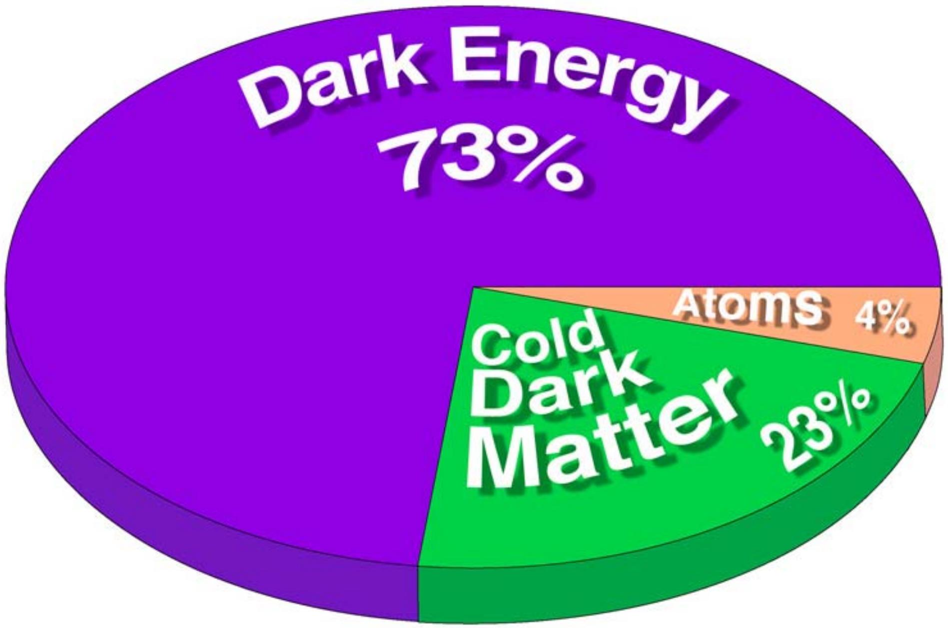
WIDE-FIELD INFRARED SURVEY EXPLORER

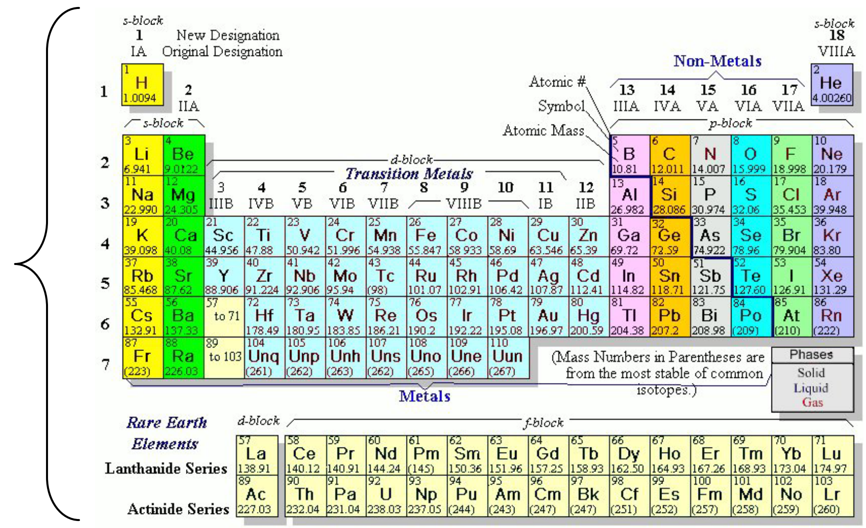


I am the PI on a MIDEX proposal for WISE, an all-sky survey in 4 bands from 3.5 to 23 μm. WISE will find and study the closest stars to the Sun, the most luminous galaxies in the Universe, and also map the large-scale structure out to redshift z=0.7, covering the era when the late ISW effect should be generated.

If confirmed WISE will fly in 4 years.

We (and all of chemistry) are a small minority in the Universe.





CONCLUSION

- MAP is now the Wilkinson Microwave Anisotropy Probe.
- Early reionization has been seen.
- The basic ΛCDM model for the Big Bang with inflation is confirmed:
  - The baryon density is measured to an accuracy of 4% from the CMB and agrees with the value from BBNS (9% accuracy) to within 5%.
  - Flat model fit only to CMB data matches the Hubble constant, supernova and large scale structure data.
  - Age of the Universe in flat model is 13.7 ± 0.2 Gyr
- Get more information at http://map.gsfc.nasa.gov

He knew in ’92?

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.”