Title: Mapping the polarized sky with WMAP: Methods and new cosmological insights

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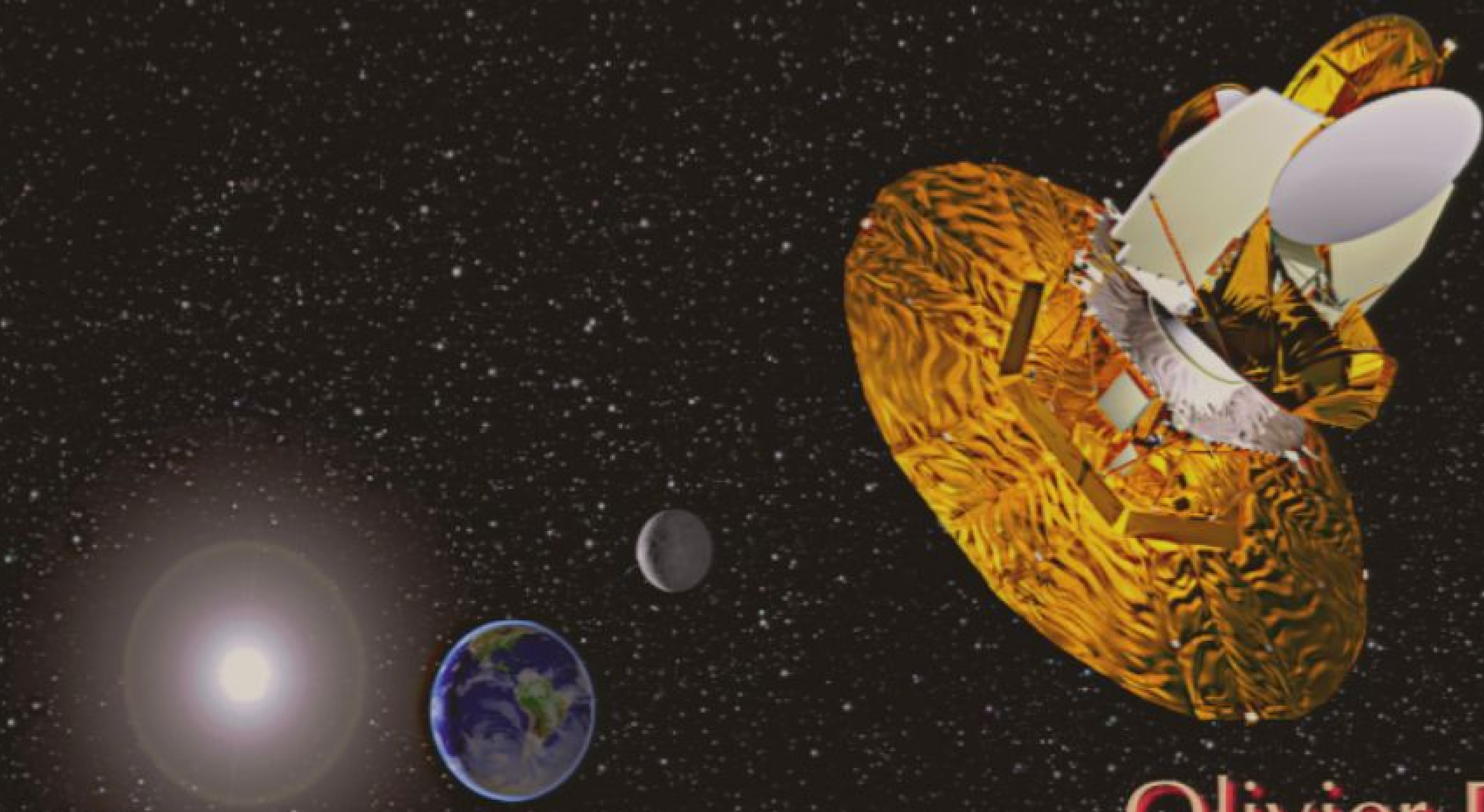
Abstract:

Mapping the polarized sky with WMAP: Methods and new cosmological insights



Olivier Doré

CITA / Princeton University

on behalf of the WMAP science team

WMAP Science Team

NASA - GSFC GODDARD

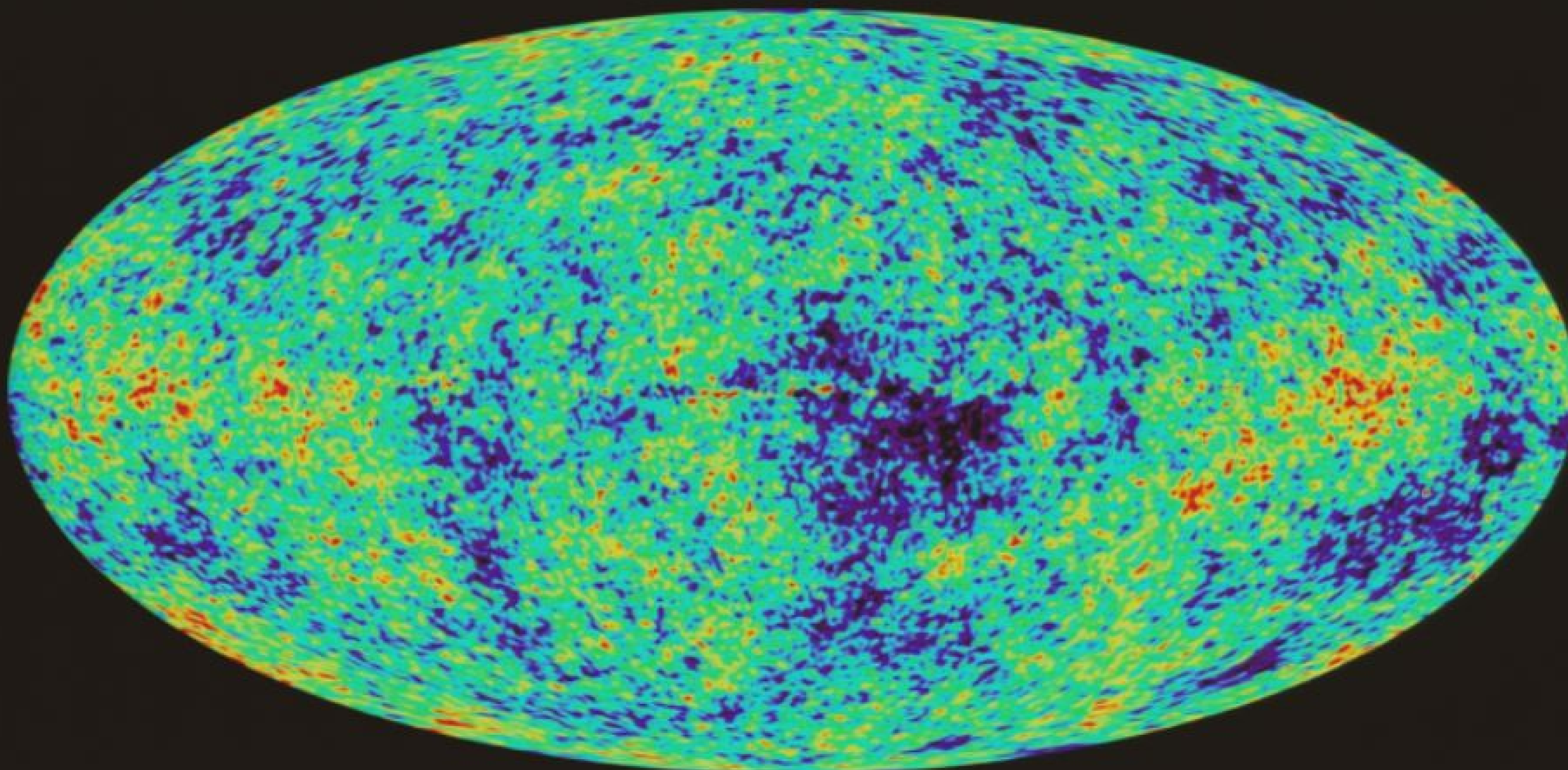
C.Bennett (JHU)
G. Hinshaw
R. Hill
A. Kogut
M. Limon
N. Odegard
J. Weiland
E. Wollack

PRINCETON

C. Barnes
R. Bean (Cornell)
O. Doré (CITA)
M. Nolta (CITA)
N. Jarosik
E. Komatsu (Texas)
L. Page
H. Peiris (Chicago)
L. Verde (Penn)
D. Spergel

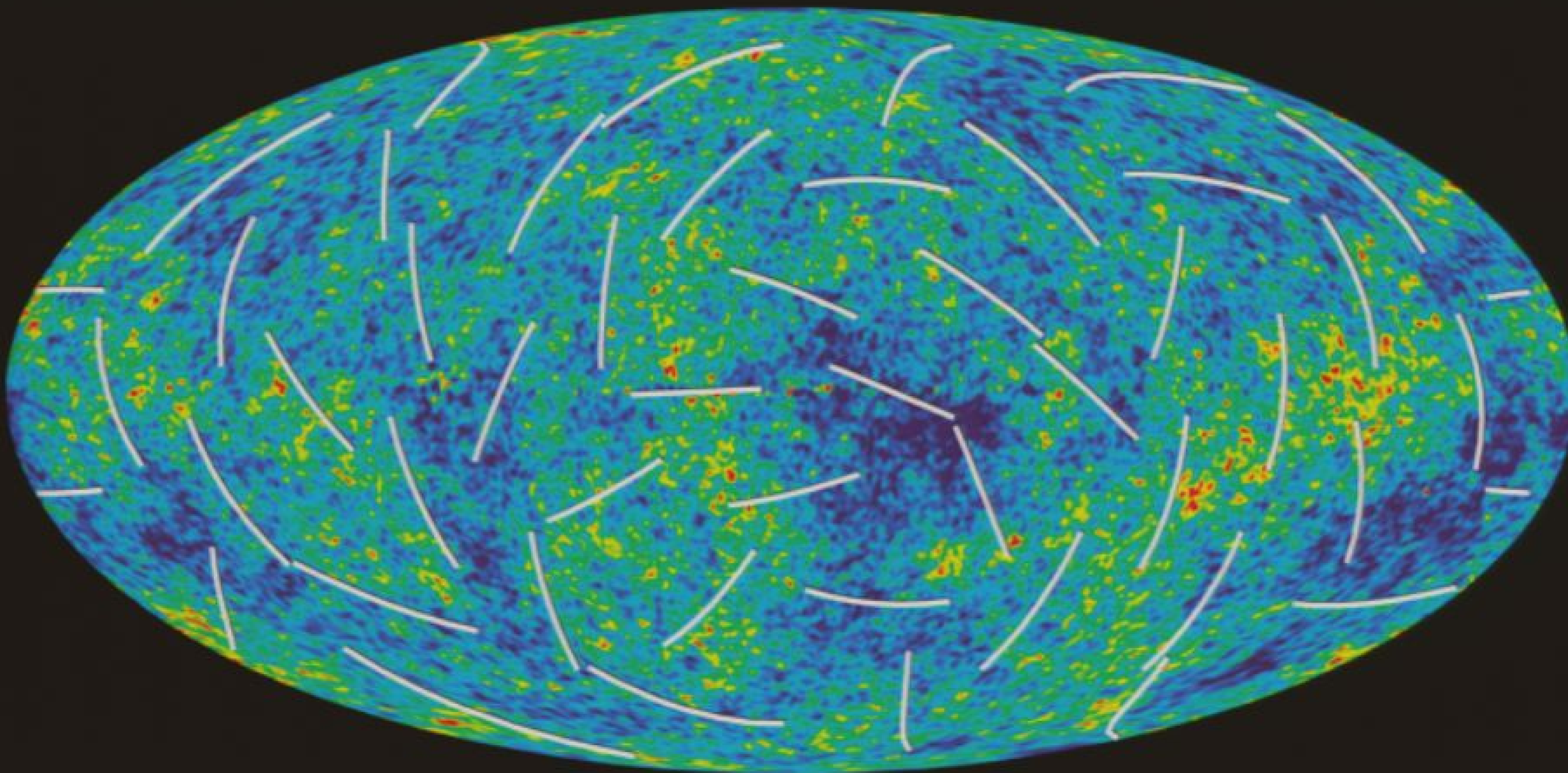
M. Halpern	(UBC)
S. Meyer	(Chicago)
G. Tucker	(Brown)
E. Wright	(UCLA)

What has WMAP-1 done for us ?

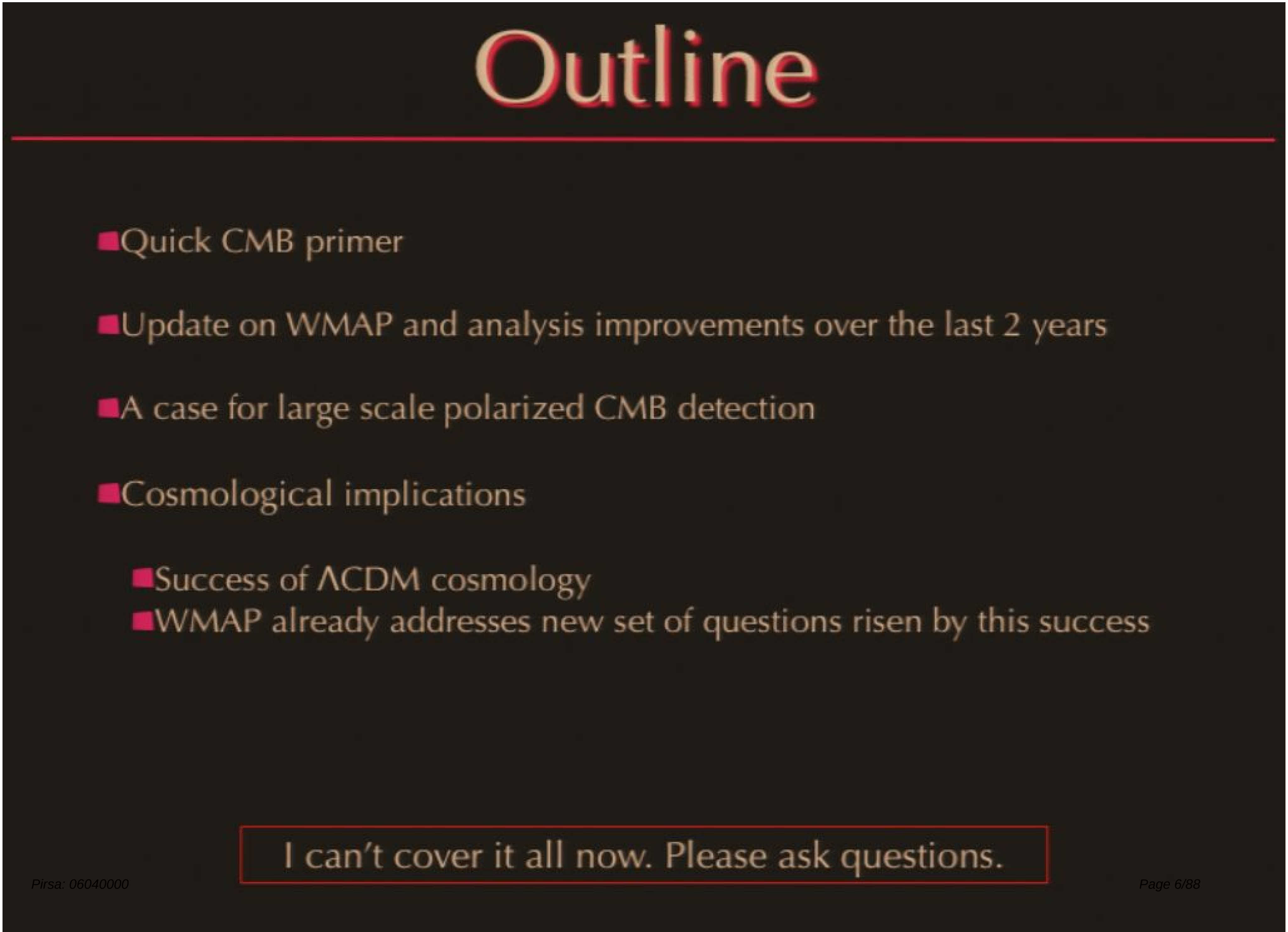


- WMAP-1 has improved over COBE by a factor of 45 in sensitivity and 33 in angular resolution
- Color codes temperature (intensity), here ±100μK
- Temperature traces gravitational potential at the time of recombination, when the Universe was 372 000 ±14000 years old
- The statistical analysis of this map entails detailed cosmological information
- The mission met all its requirements after the first year... "Mission Accomplished!"... but...

What has WMAP-3 done for us?



- ... but the insights expected on Inflation theory (~10^{-18}s after BB) and the Universe reionization (364+124/-74 Myr) from large scale polarization measurements were to tempting to not be pursued
- WMAP-3 has now improved over COBE by a factor of 77 in sensitivity and 33 in angular resolution
- WMAP-3 has measured the CMB polarization on very large angular scales
- To do so required us to improve control the systematics at a level 50 times higher than originally proposed!


Outline
Quick CMB primer
Update on WMAP and analysis improvements over the last 2 years
A case for large scale polarized CMB detection
Cosmological implications
Success of ΛCDM cosmology
WMAP already addresses new set of questions risen by this success
I can't cover it all now. Please ask questions.

The CMB is a leftover from when the Universe was 380 000 yrs old

- The Universe is expanding and cooling
- Once it is cool enough for Hydrogen to form, (T~3000K, t~3.8 10^5 yrs), the photons start to propagate freely *(the Thomson mean free path is greater than the horizon scale)*
- This radiation has the imprint of the small anisotropies that grew by gravitational instability into the large structures we see today

Confronting sky maps with theoretical predictions

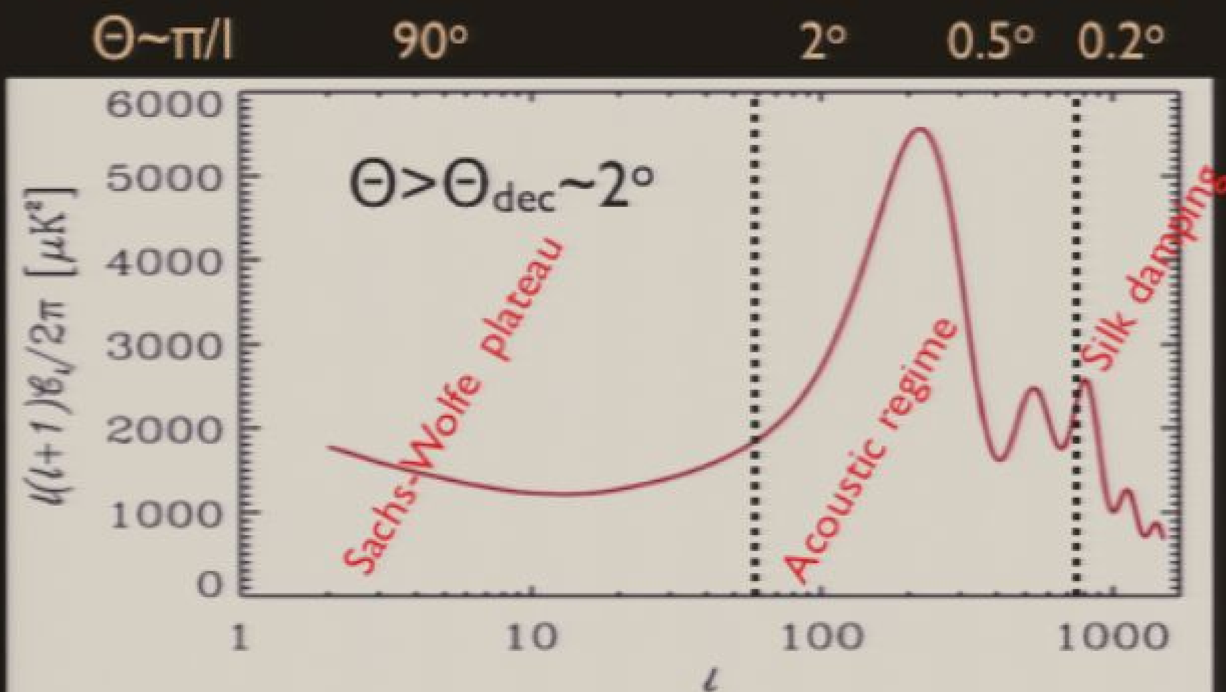
- It is both theoretically sound and observationally supported to consider the CMB temperature fluctuations as a gaussian random field so that a_{lm}'s are Gaussian random variables

$$T(\hat{n}) = \sum_{\ell m} a_{\ell m} Y_{\ell m}(\hat{n})$$

- Thus sufficient to consider the power spectrum

$$C_\ell = \frac{1}{2\ell+1} \sum_m a_{\ell m} a^*_{\ell m}$$

- Physics in the linear regime well described by a 3000K plasma photo-baryon fluid oscillating in dark matter potential wells



Sunyaev & Zeldovich 70
Peebles & Yu 70
Bond & Efstathiou 87
Hu & White 97

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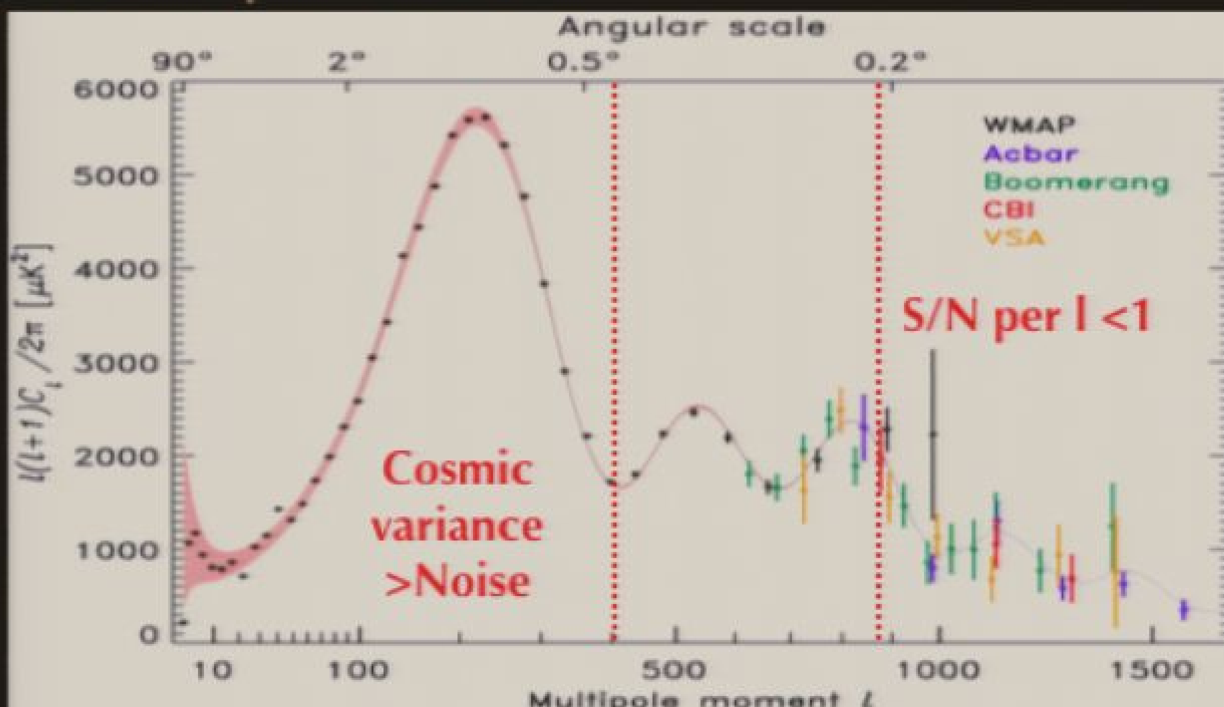

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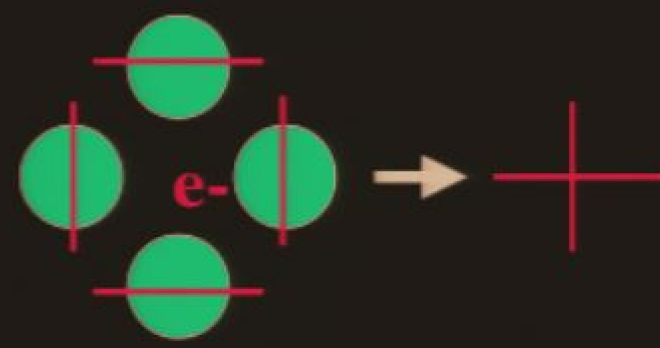
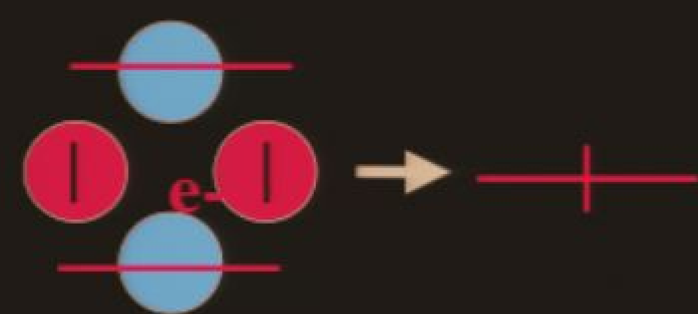
The CMB is weakly polarized

- Linear polarization of the CMB is:
  - Produced by Thomson scattering of a quadrupolar radiation pattern on free electrons
    $\Rightarrow$probe recombination and reionization
  - Partially correlated with temperature
    (velocity pert. correlates with density pert.)



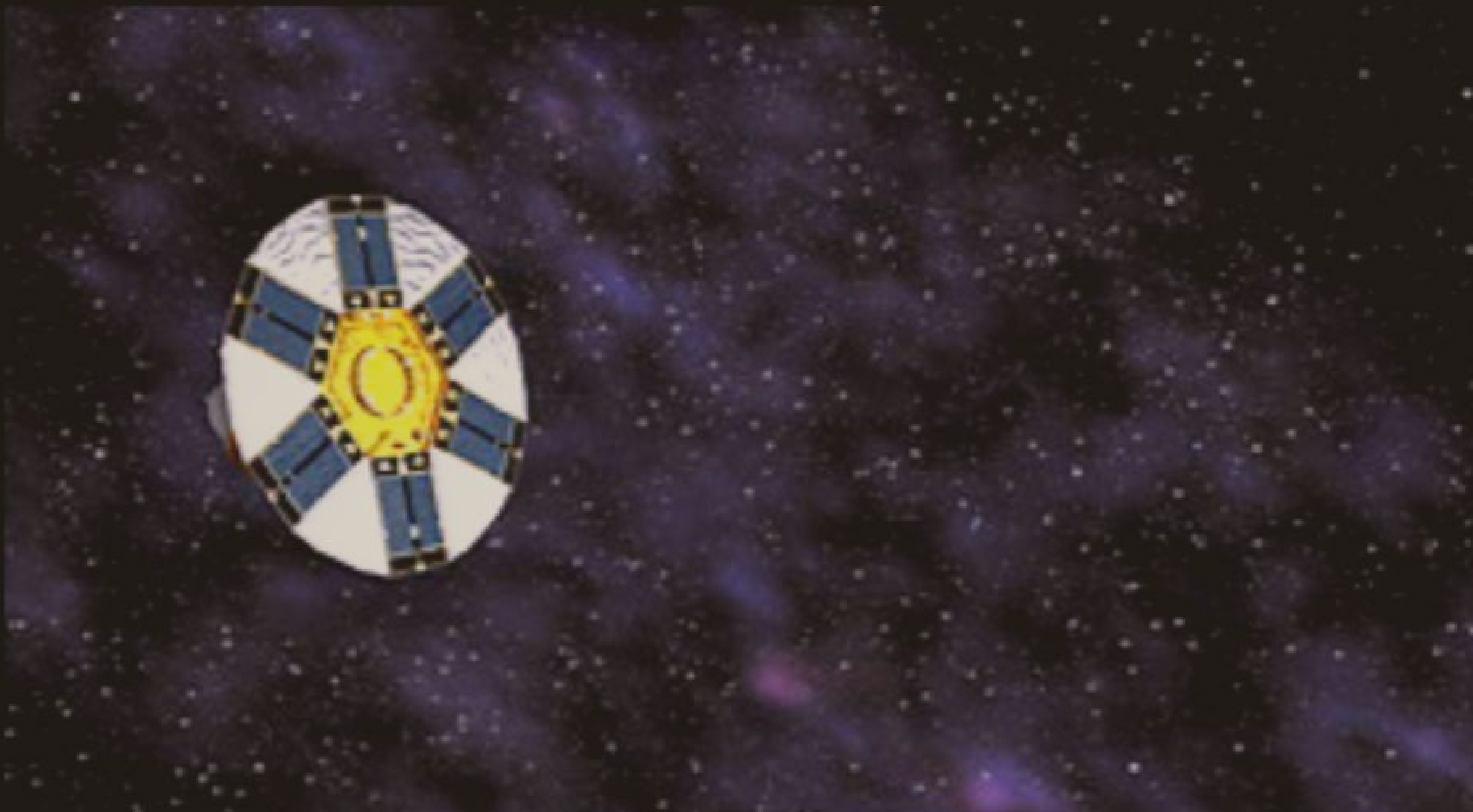
- Two types of Polarization
  - Scalar perturbation to the metric produce E-mode polarization
  - Tensor perturbations to the metric produce B-mode polarization, *i.e.* Gravity waves

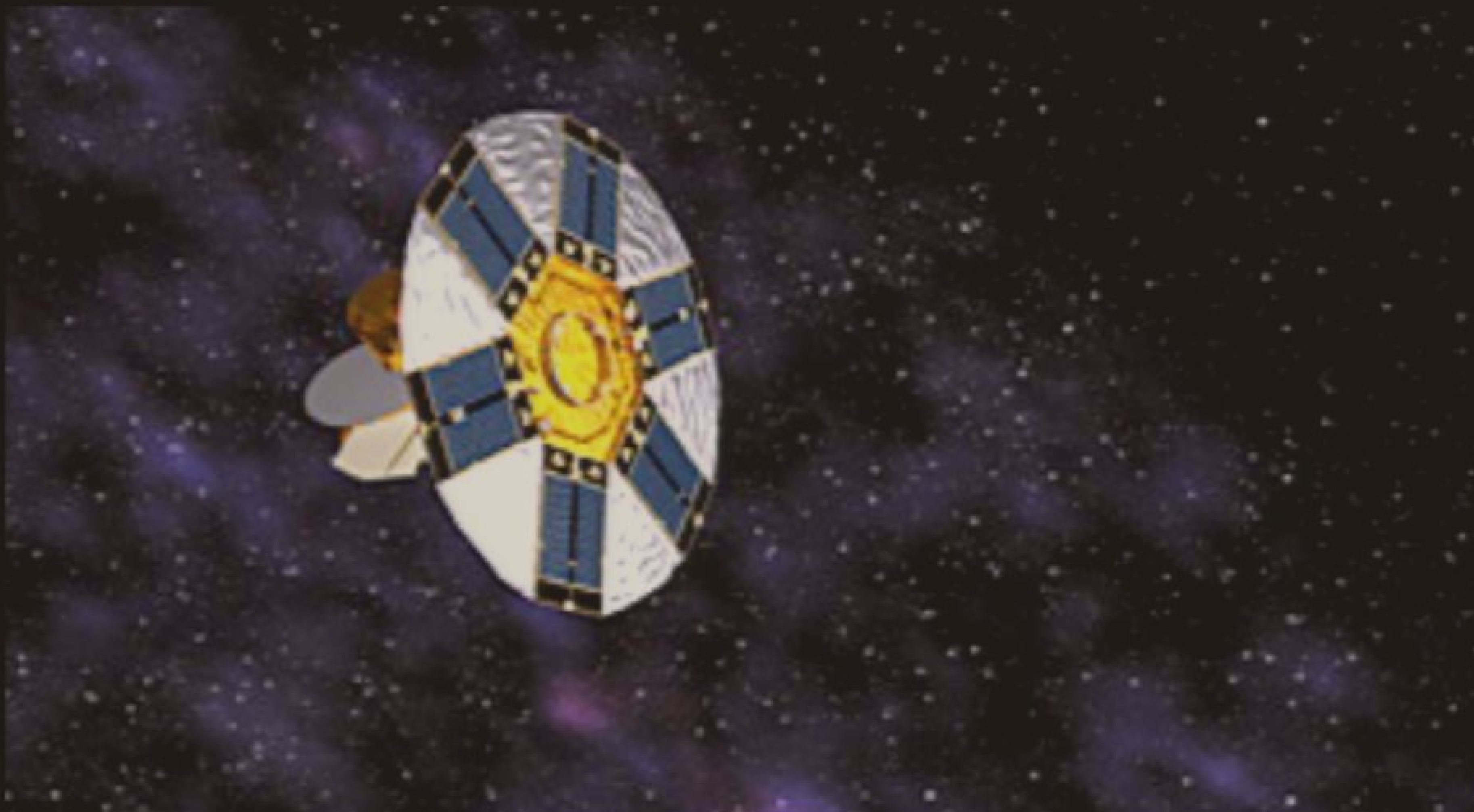


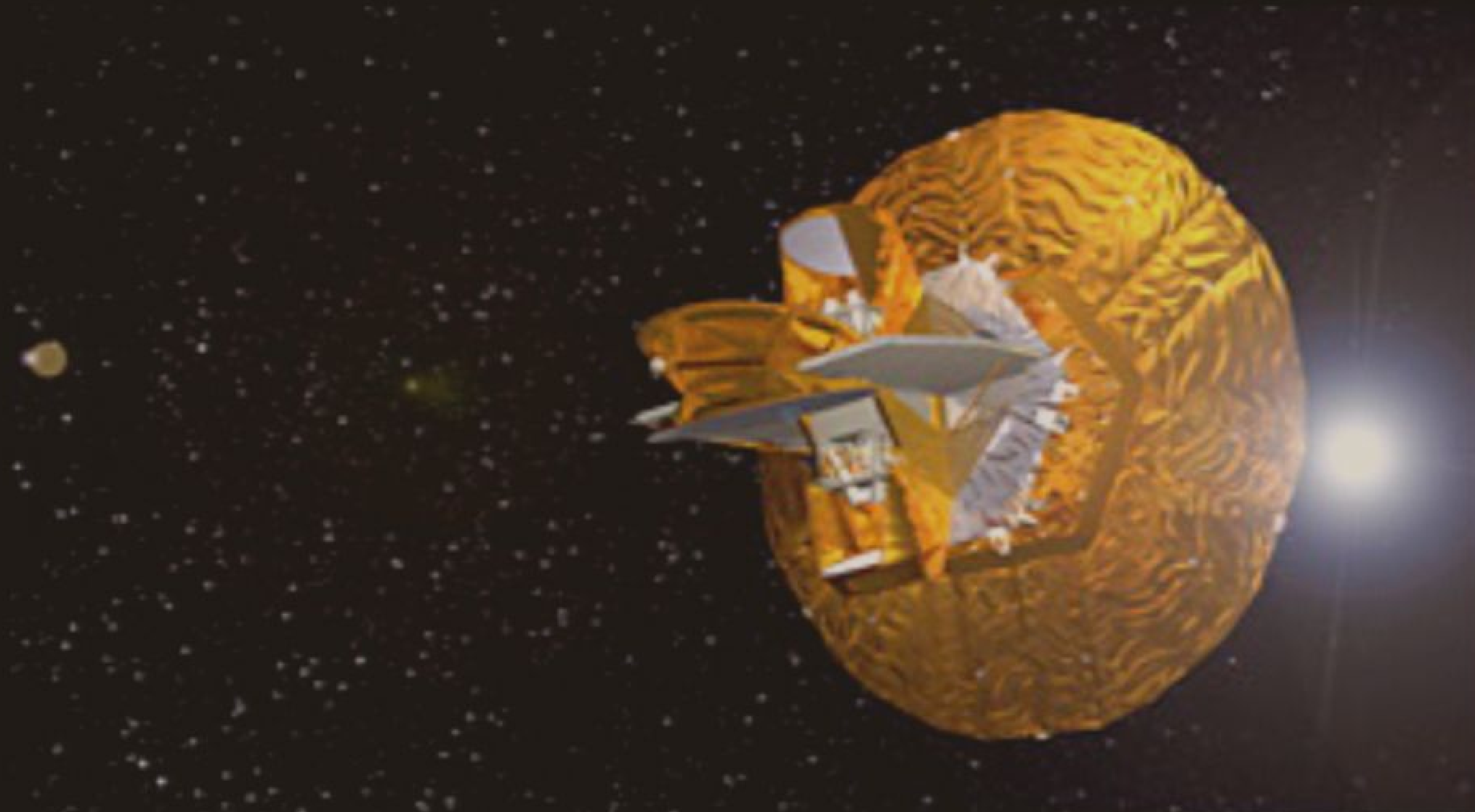
- Polarization probes both perturbations themselves and ionization history

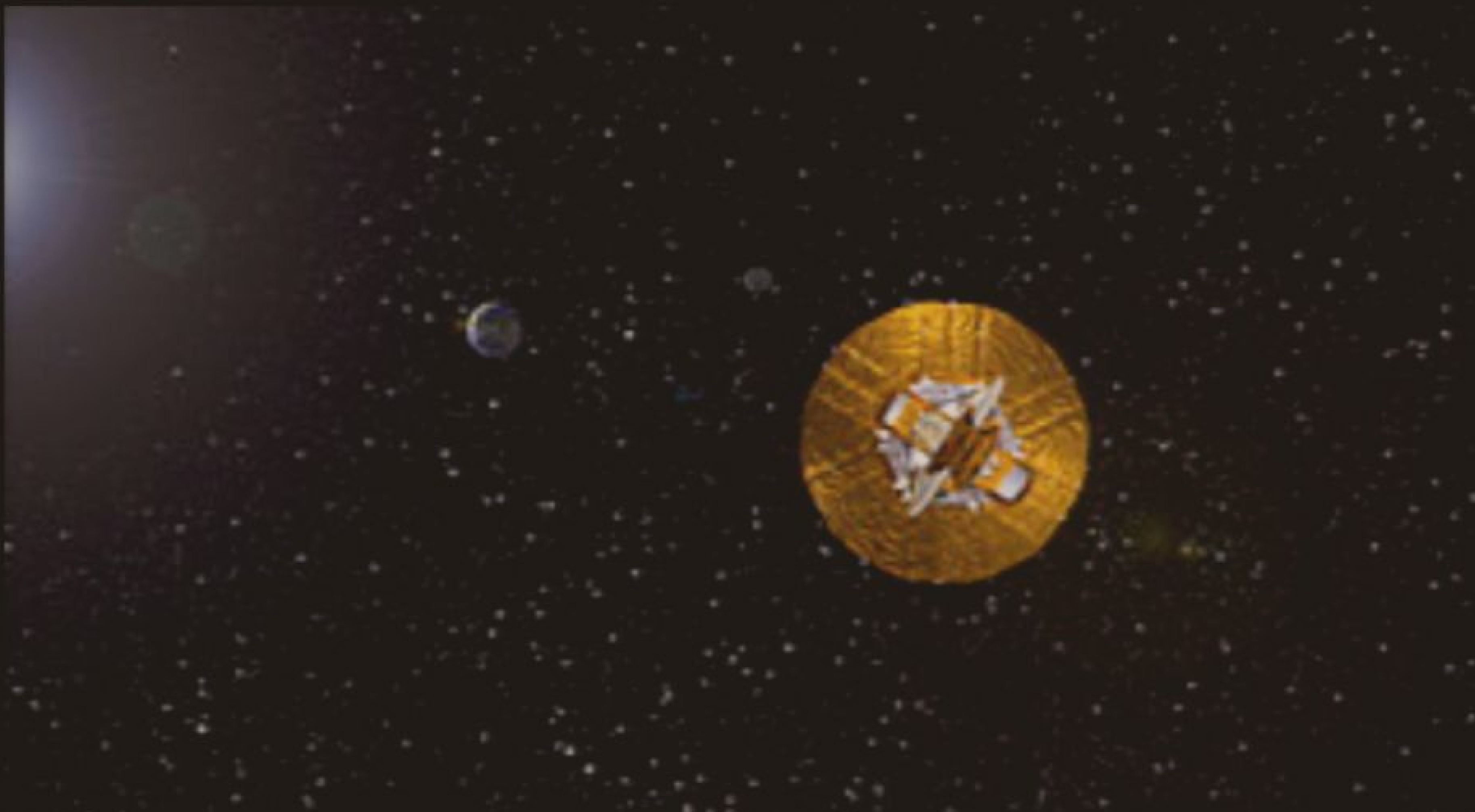
- Numerical calculation show that the

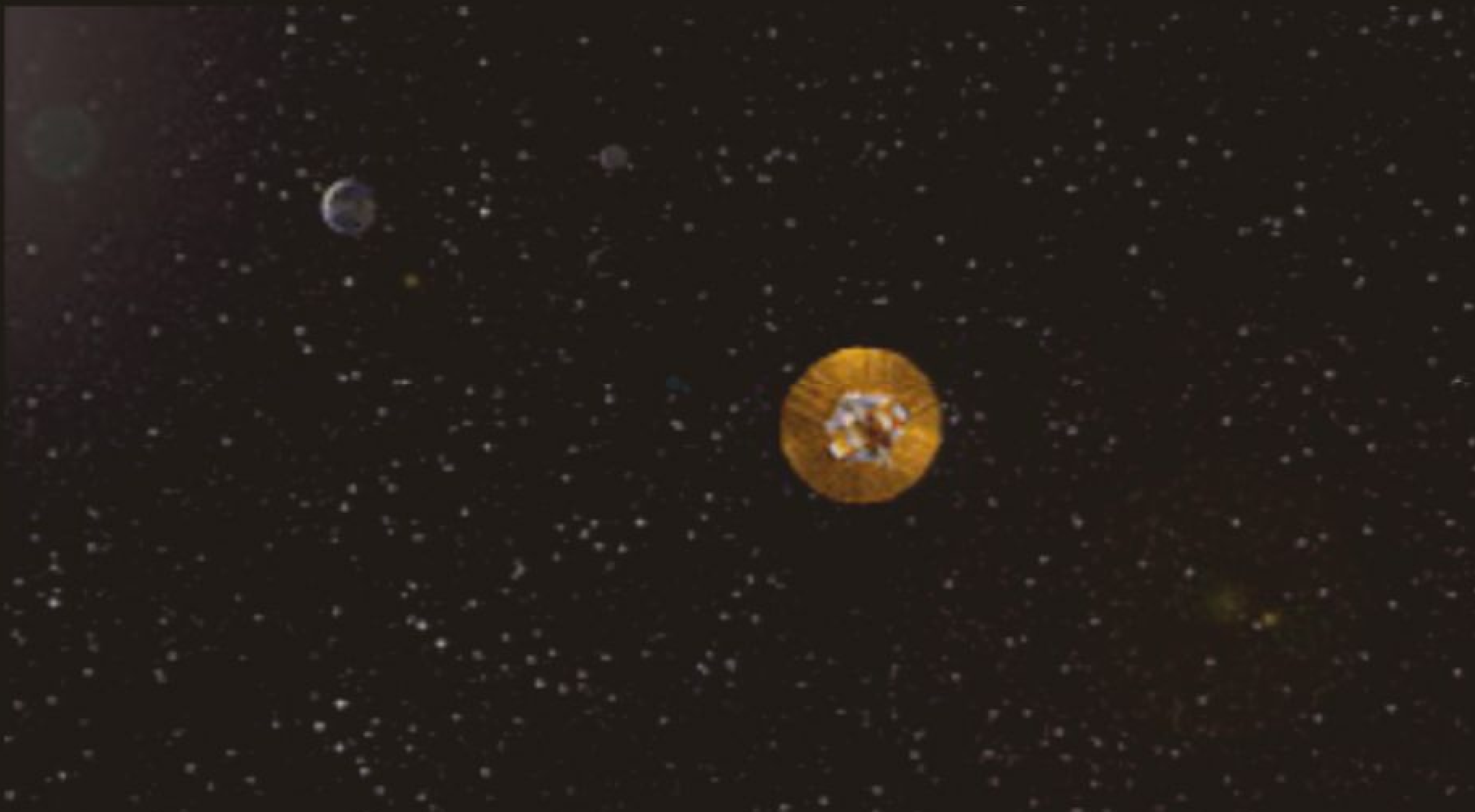
WMAP analysis over the last two years



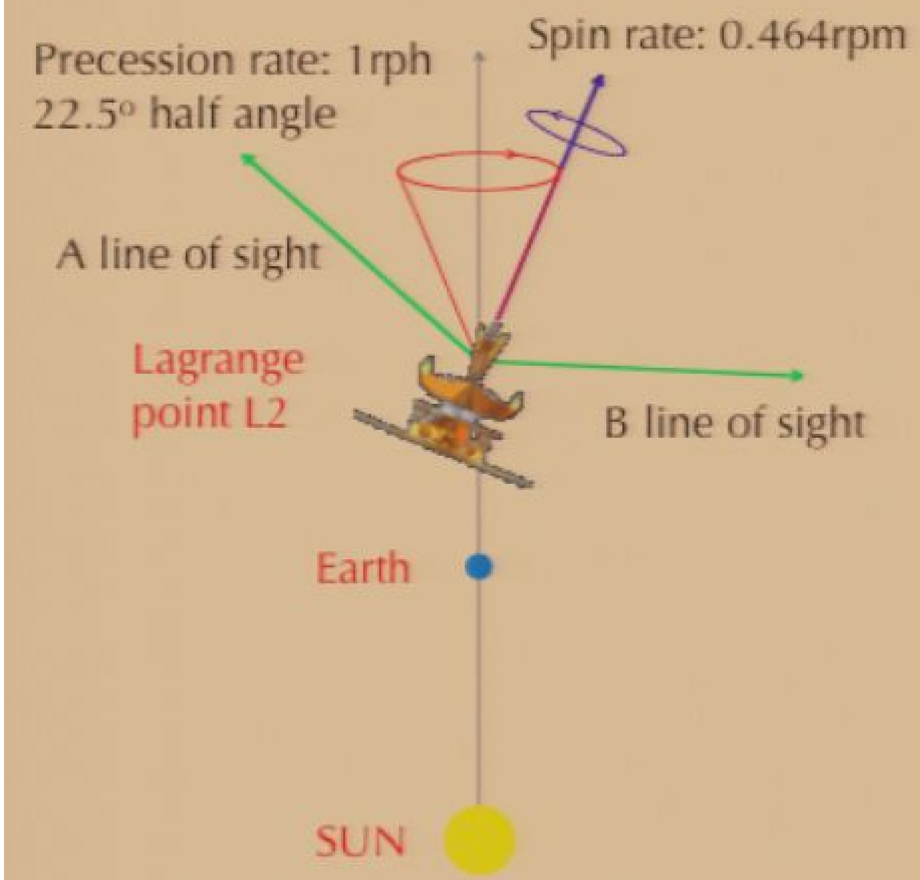








WMAP primer



- Differential measurement only
  - Most of the common modes cancel
  - Two radiometers per feed
    - $T_1+T_2 \propto$ Intensity
    - $T_1-T_2 \propto$ Polarization
  - 10 feeds, 20 DA total
- 5 microwave frequencies to monitor foregrounds
  - K, Ka, Q, V, W bands
  - 22, 33, 40, 60, 93 GHz
- Rapid and complex sky scan
  - Observe 30% of the sky every hour
  - Most of pixels are observed with evenly distributed orientations
- Accurate calibration on the cosmological dipole and beam measurements on Jupiter
- L2 orbit
  - Constant survey mode
  - Thermal stability/Passive cooling

Remarks on the analysis over the last 2 years

- Differential measurement and interlocked scanning strategy suppresses polarization systematics as for temperature.
- Still no corrections needed for spin synchronous systematics.
- No new systematics, but the weak nature of the spinorial polarized signal requires extra-care to avoid any coupling to the much stronger T field (100 times).
- Non-trivial interactions between the slow drift gain, non-uniform weighting across the sky, time series masking, 1/f noise, galactic foregrounds, band-pass mismatch, off-set sensitivity and loss imbalance.
- The handling of these effect had to be propagated from the map-making till the power-spectrum measurement. To understand them required numerous end-to-end simulations (enough to have good statistics). Most of 2005 was spent running those and realizing that the previous short-cuts did not work anymore.
- A new pipeline was eventually required and has been designed, written and optimized.
- We rely heavily on null tests in map and C_l space to assess the quality of this processing

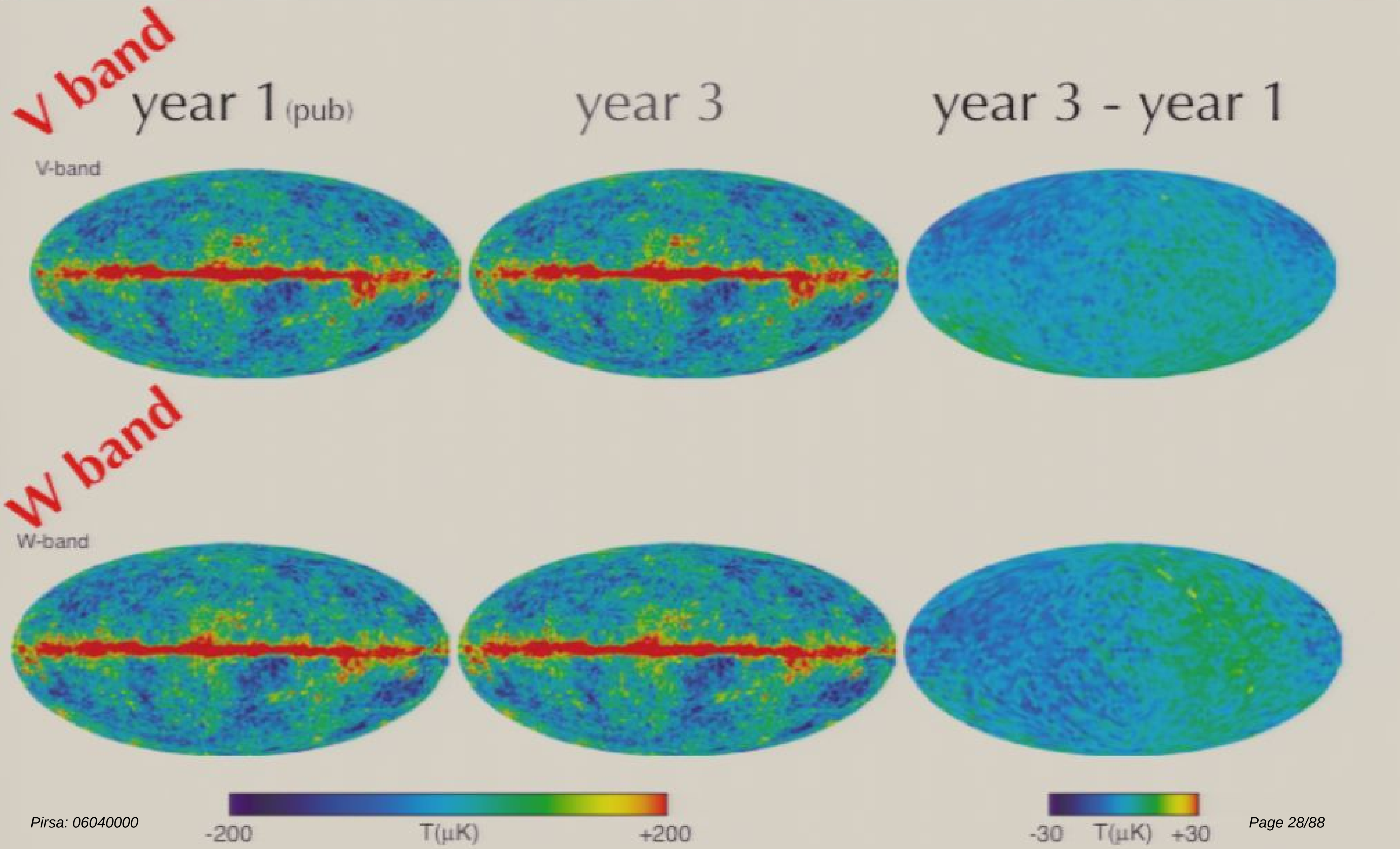
Improvement in the analysis over the last 2 years

- ☐ Corrected slight pointing error due to thermal stress on the spacecraft (1′)
- ☐ Improved gain model
- ☐ Better beam profile (helped by full physical model of the optics)
- ☐ Far-side beam correction applied now to all 10 DAs
- ☑ Exact handling of the beam asymmetry at the C_l level
- ☑ Map-making improvement including 1/f and other systematics and handling of the full N at res 4 (N_{side} =16)
- ☑ Better and physically motivated polarized foreground modeling
- ☑ New and exact methods to compute the lowest l C_l likelihoods for temperature and polarization (fast enough to be included in the parameter likelihood evaluation code)
- ☑ But also new methods to compute cosmological parameter likelihood from sky maps where noise properties are more easily described
- ☐ We now have systematic errors below the 200nK level, 50 times less than in the initial proposal, where polarization was not mentioned!
- ☐ WMAP is still working nominally as I speak...

So why did the analysis take so long? "It was gruesome detail day after day," says Bennett. "This was an enormous undertaking, I know people were anxious and wondered why we didn't put it out straight away, but they have no idea."

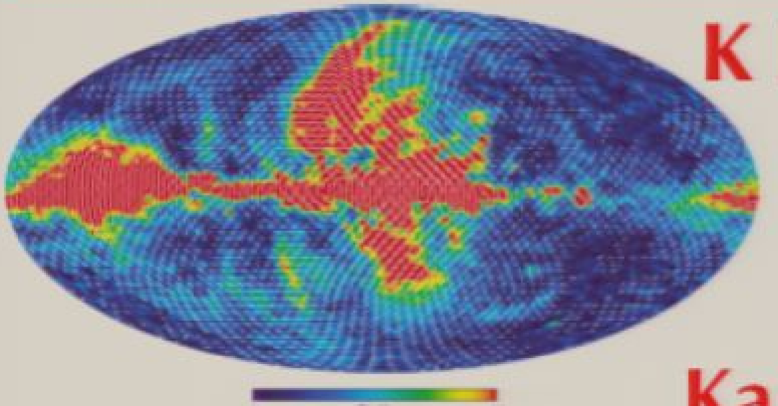
Chuck Bennett, Nature 03/17/06

Temperature maps

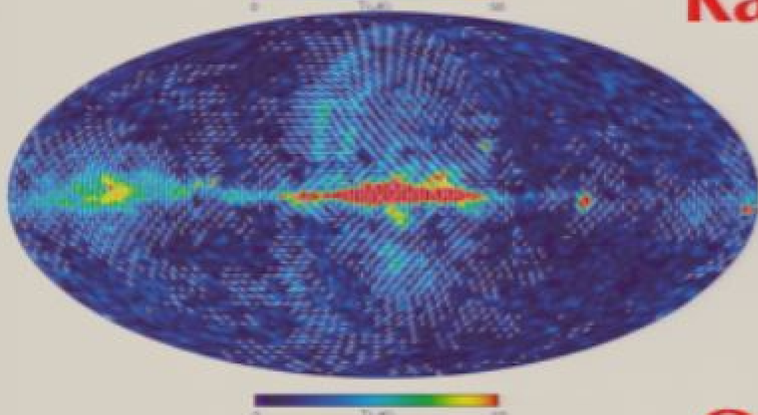


Polarization maps

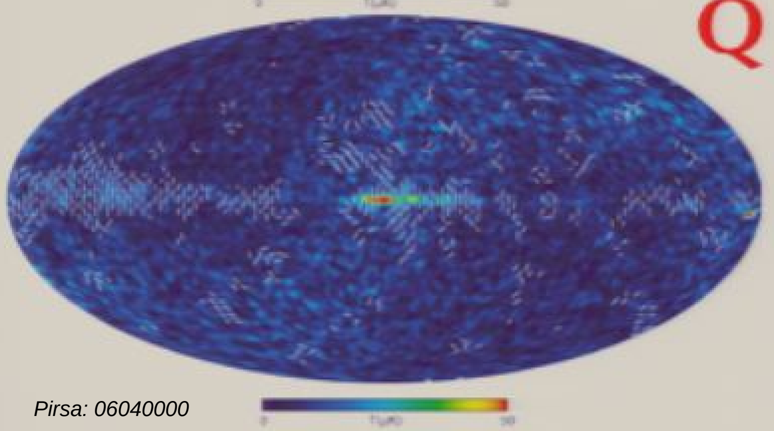
K band



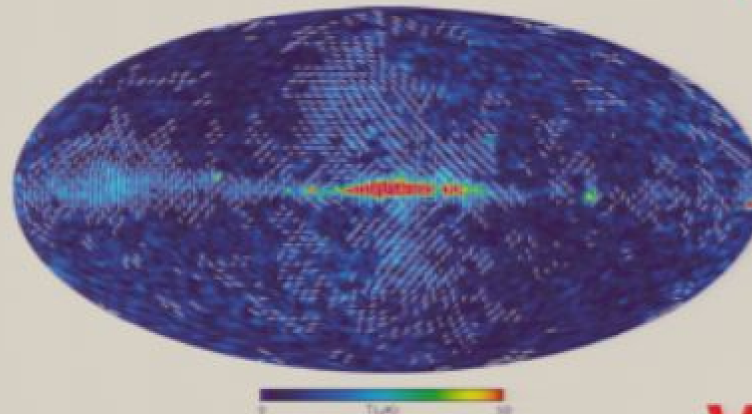
Ka band



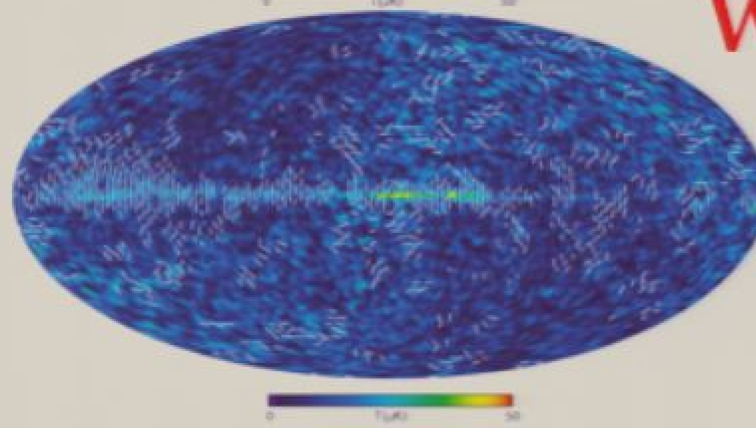
Q band



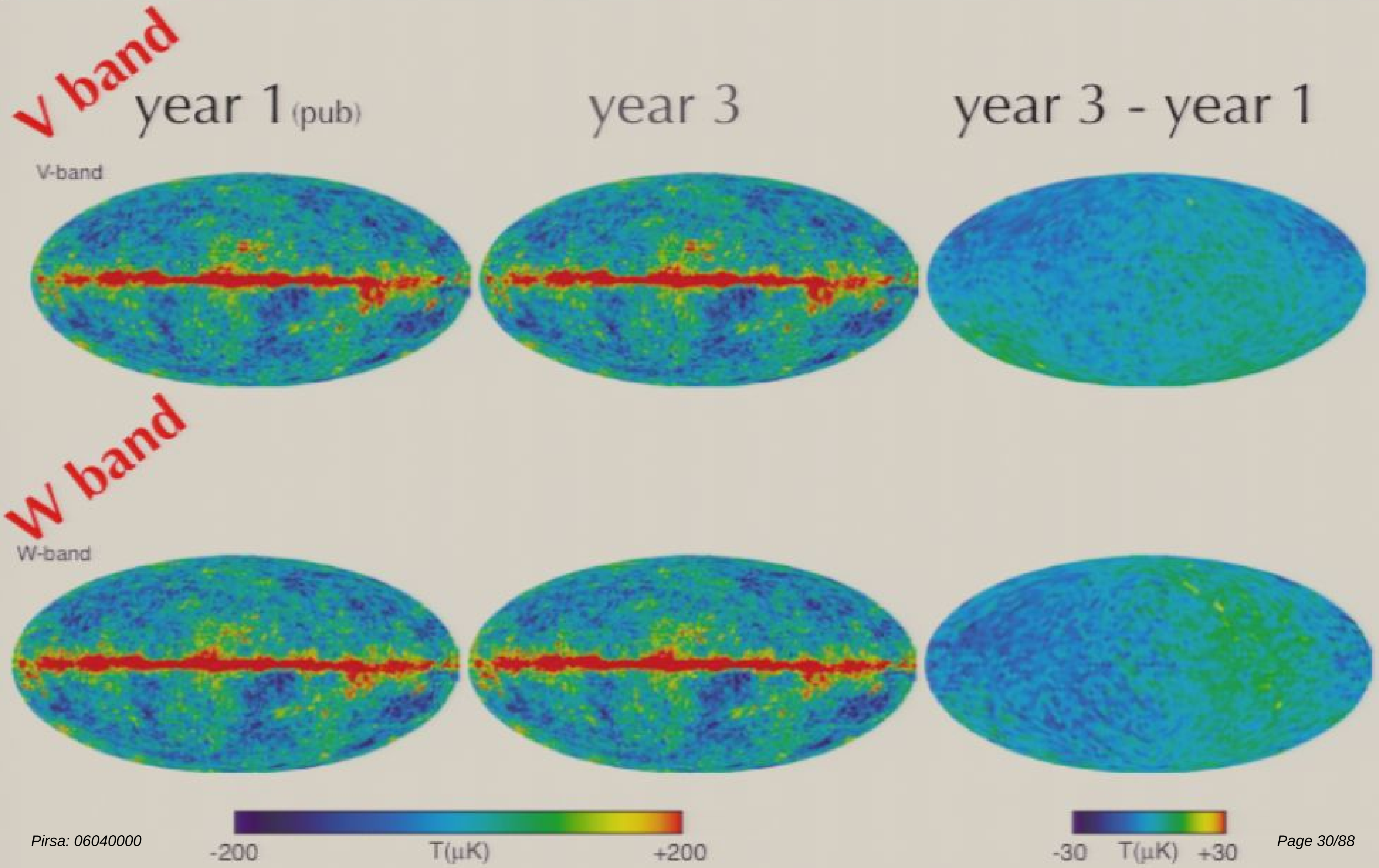
V band



W band

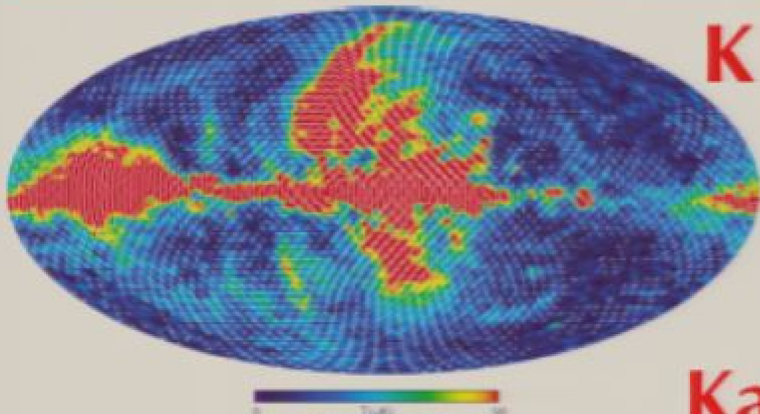


Temperature maps

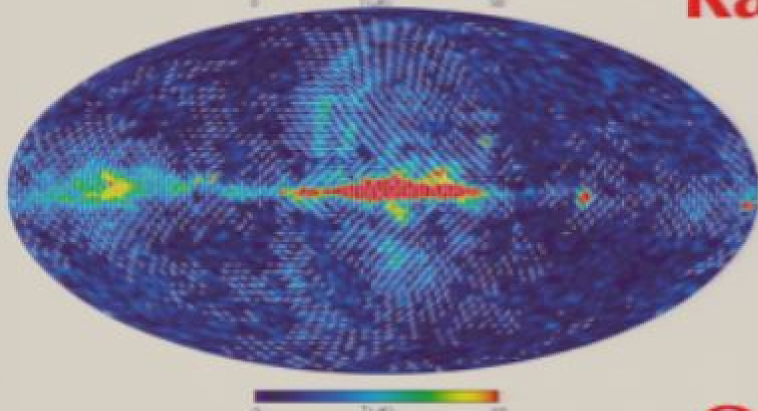


Polarization maps

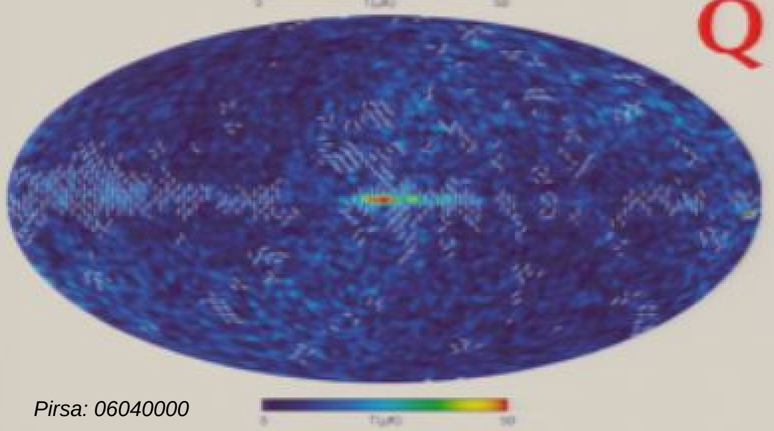
K band



Ka band



Q band



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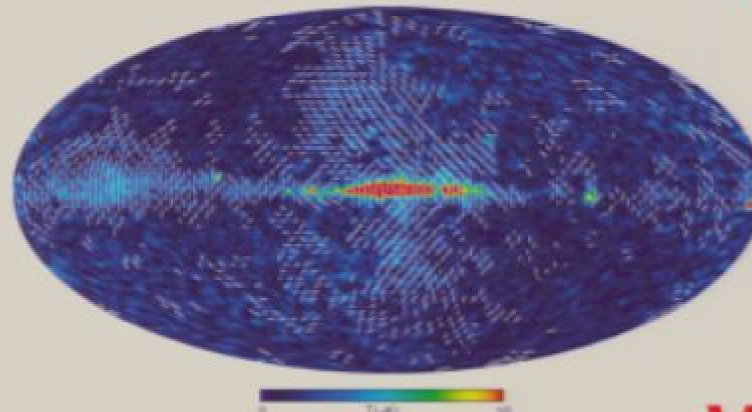

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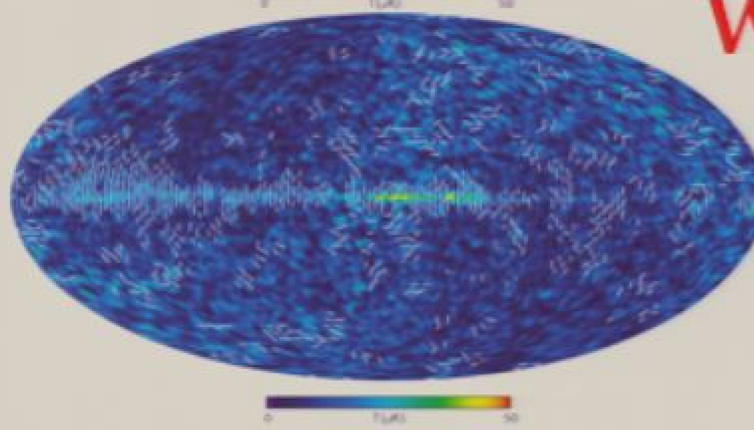

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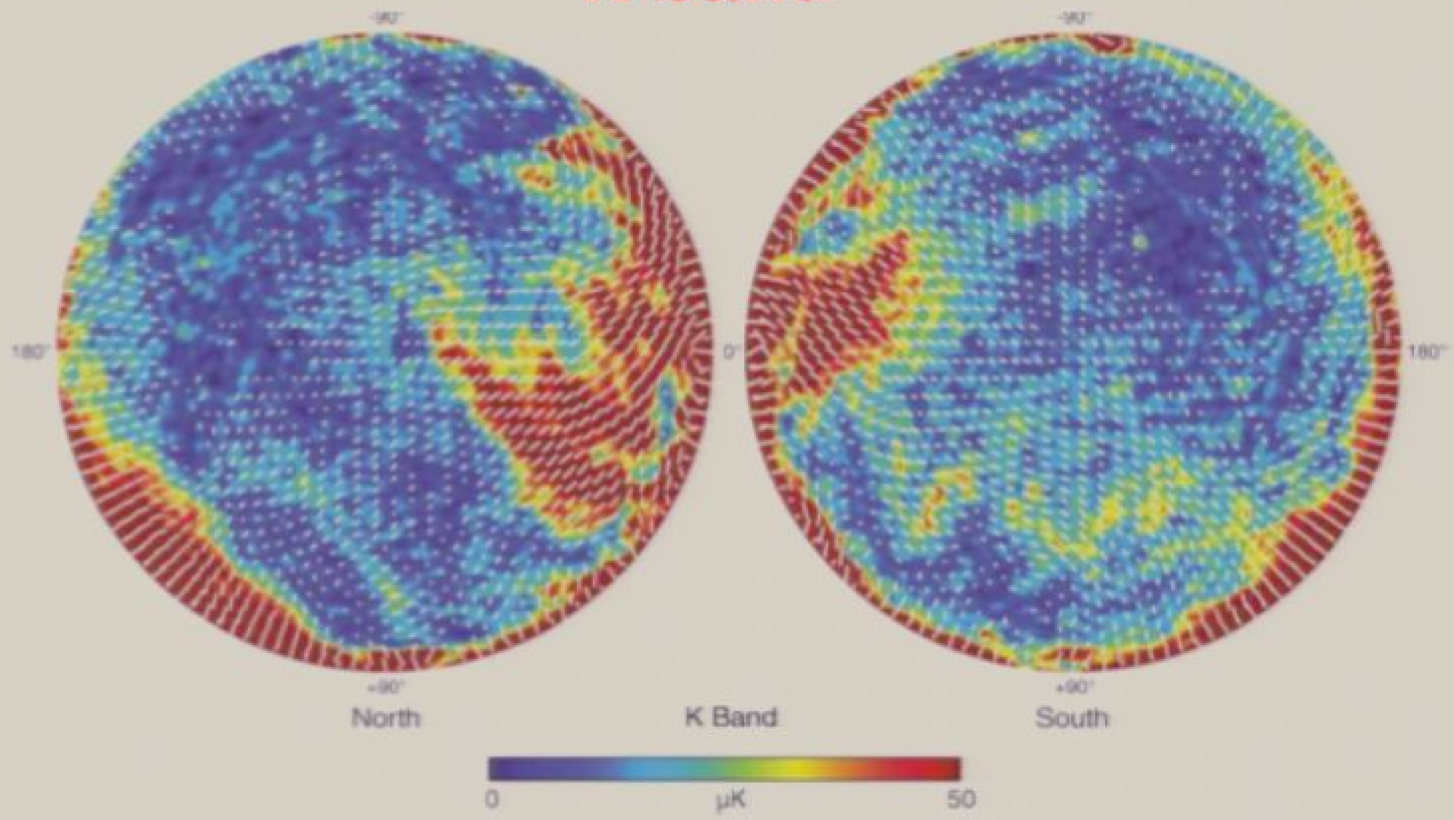
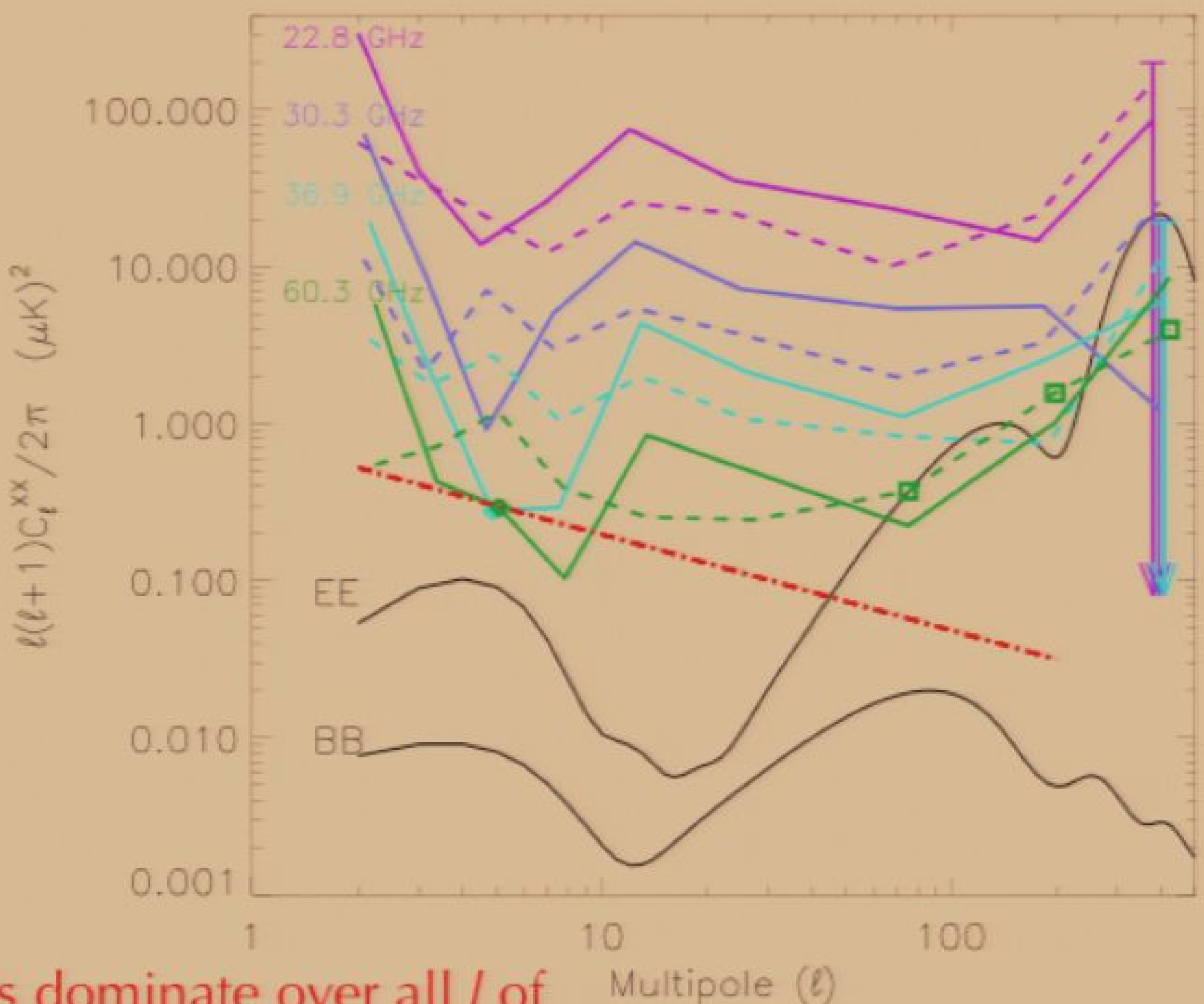


Lambert projection of galactic poles

Uncleaned power spectra

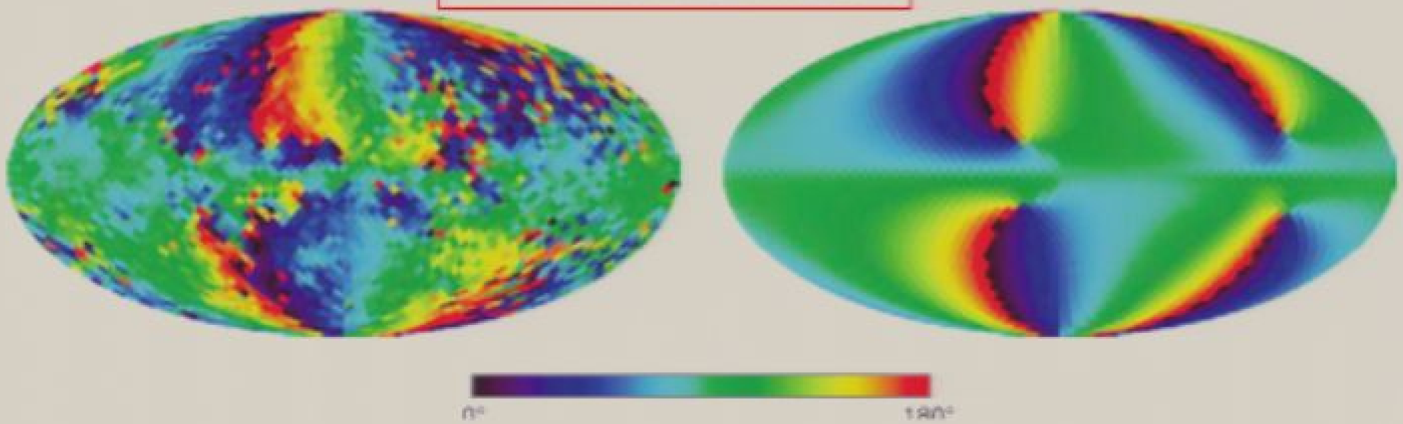


Foregrounds dominate over all *l* of interest and all frequencies unlike for temperature

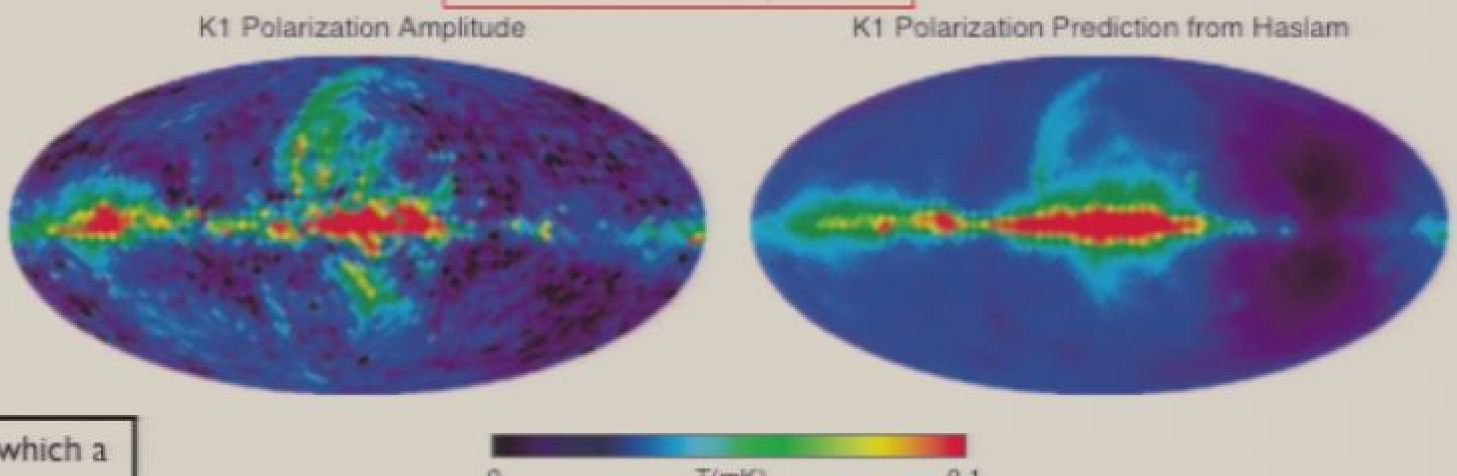
Outside p06 mask

Polarized foregrounds predictions: synchrotron radiation

Polarization directions

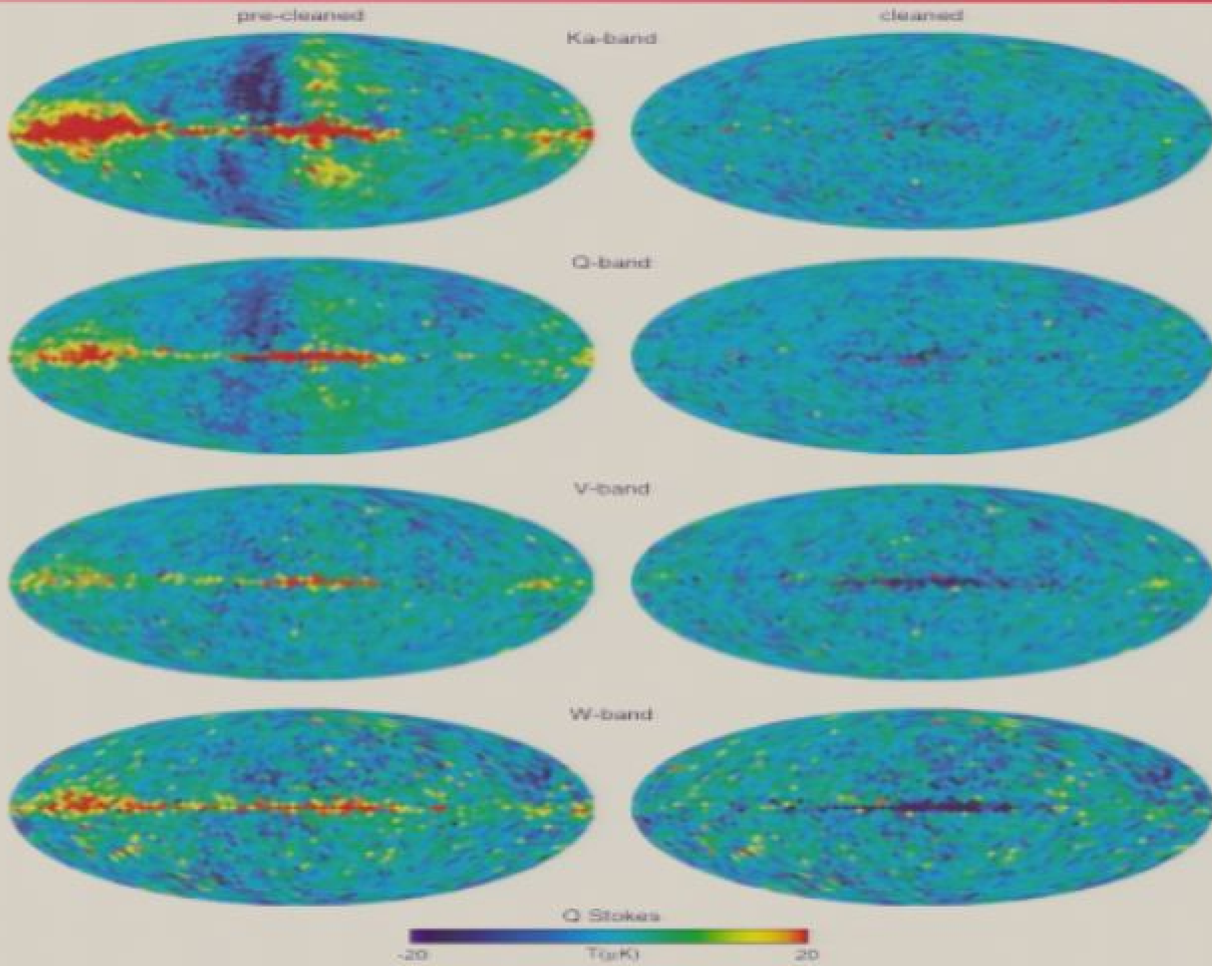


Polarization amplitude



Based on a model in which a gas of cosmic rays electrons interact with a magnetic field following a bisymmetric spiral arm pattern

Foreground cleaned maps



Due to correlations between foregrounds, a map based cleaning is more powerful

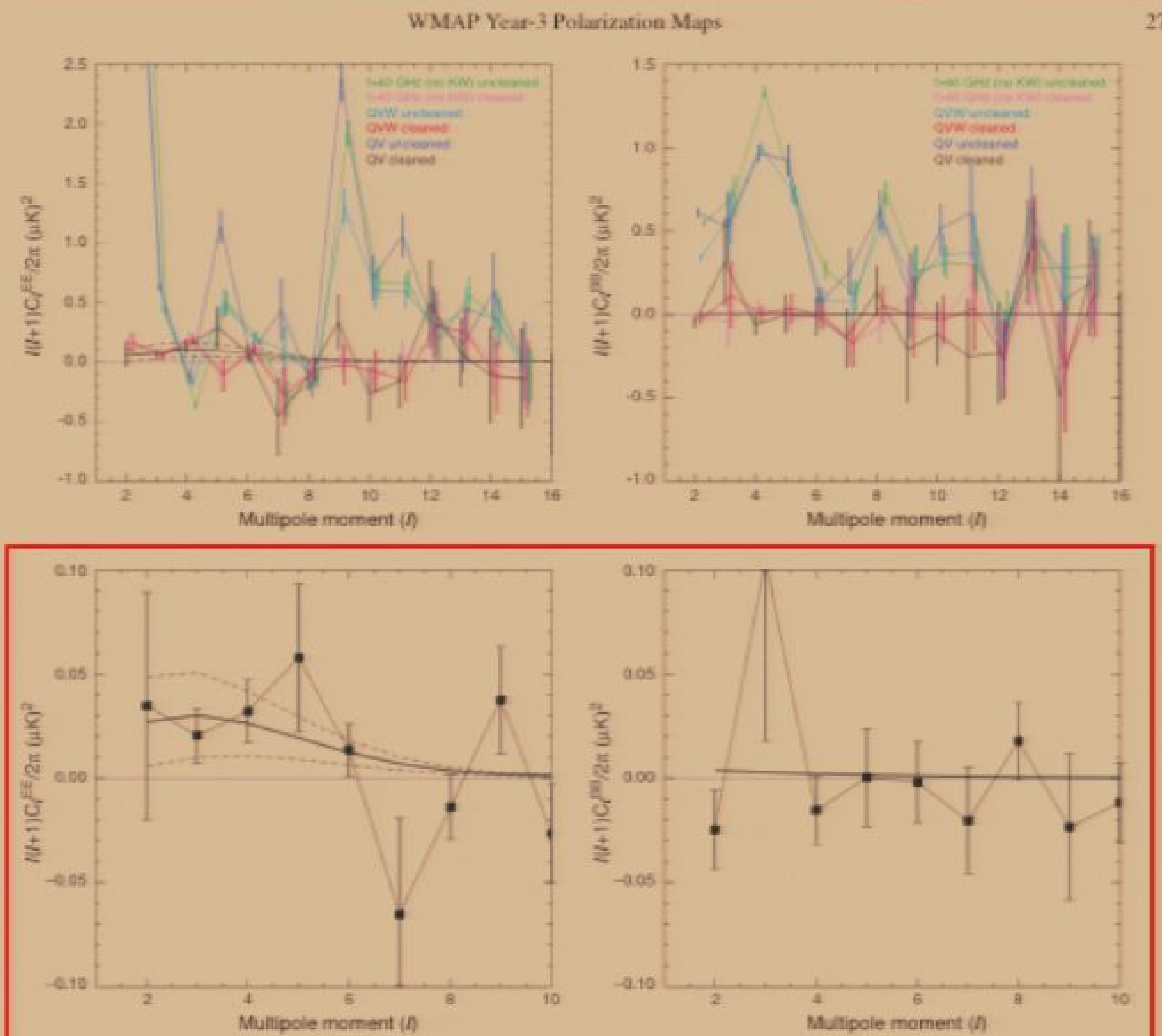
TABLE 4
COMPARISON OF χ^2 BETWEEN PRE-CLEANED AND CLEANED MAPS

Band	χ^2/ν Pre-cleaned	χ^2/ν Cleaned	ν	$\Delta\chi^2$
Ka	10.65	1.20	6144	58061
Q	3.91	1.09	6144	17326
V	1.36	1.19	6144	1045
W	1.38	1.58	6144	-1229
Ka	2.142	1.096	4534	[illegible]
Q	1.289	1.018	4534	1229
V	1.048	1.016	4534	145

Cleaned power spectra

EE

BB



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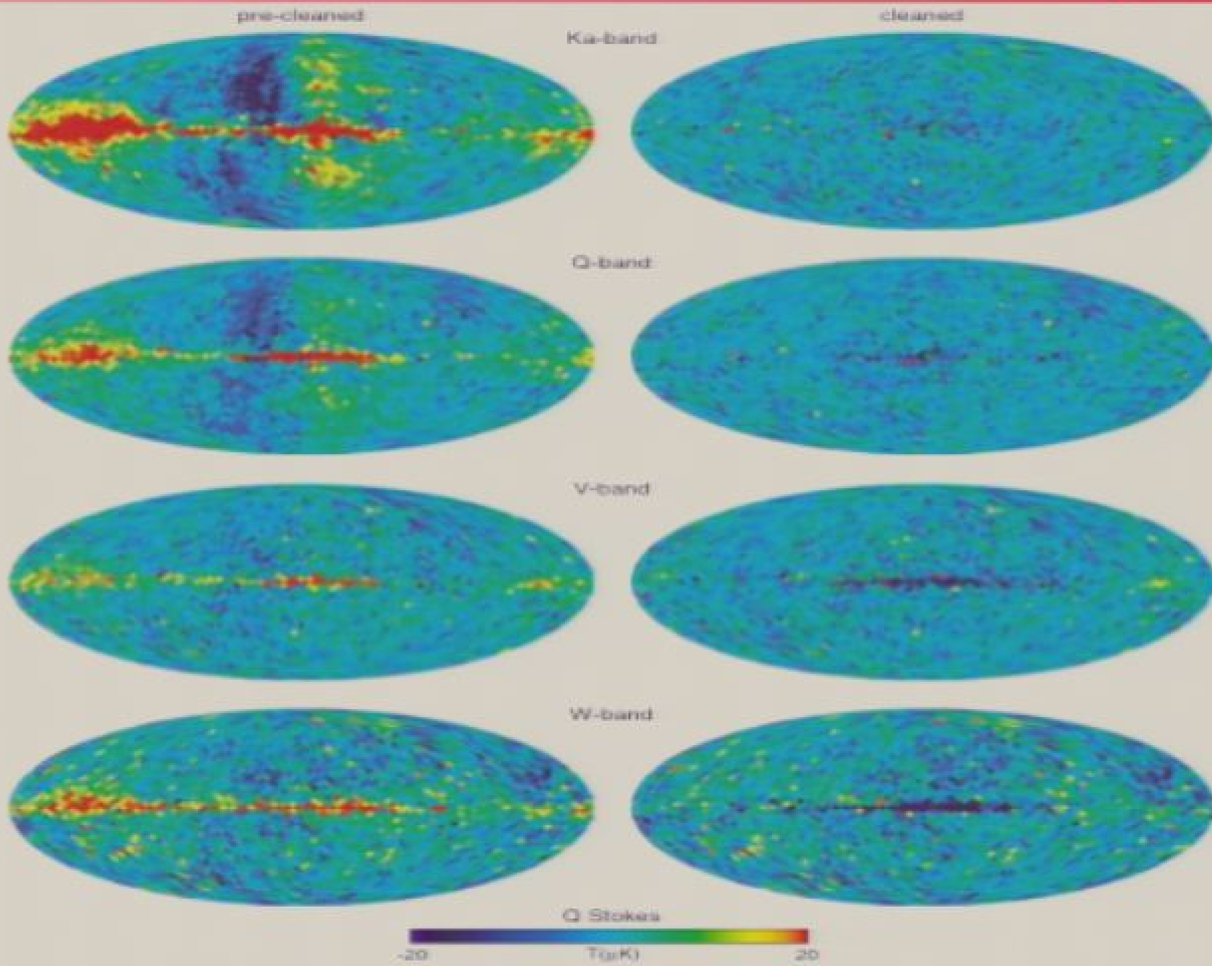

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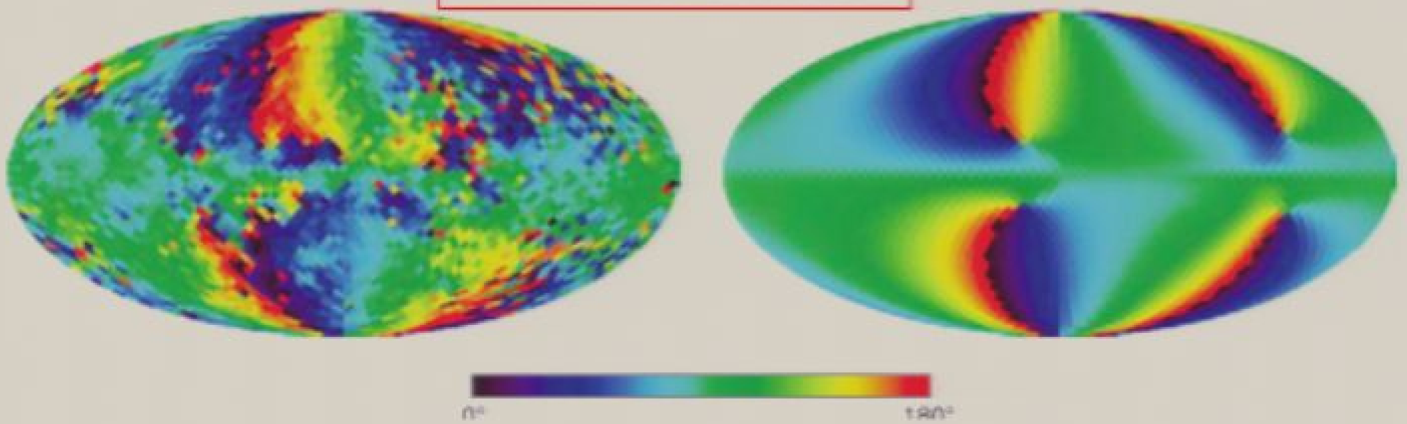

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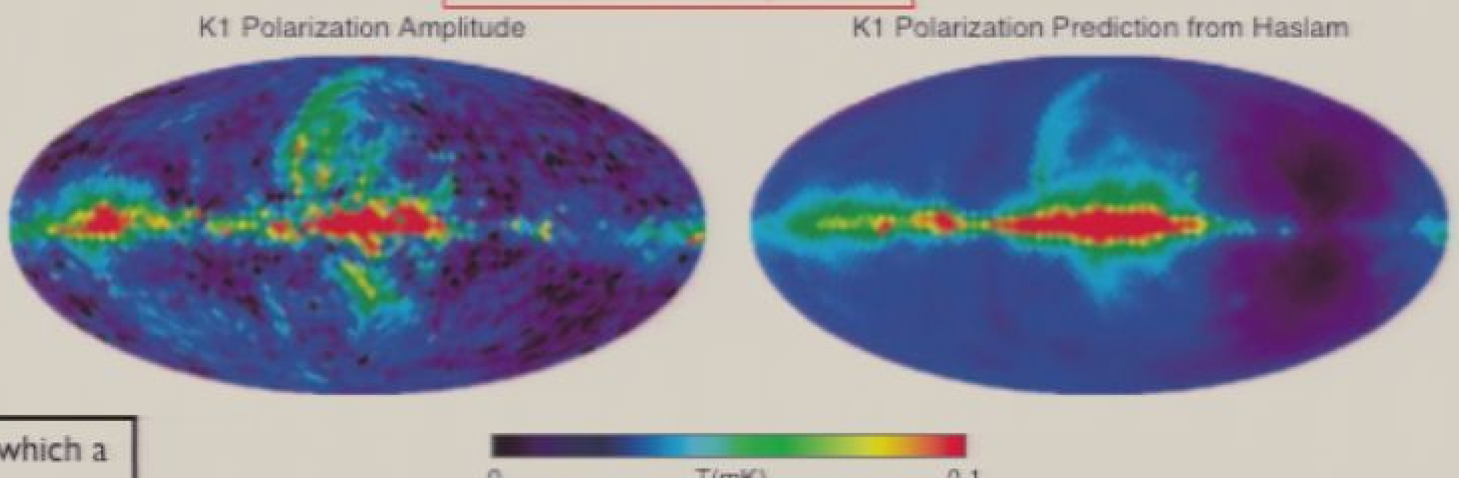

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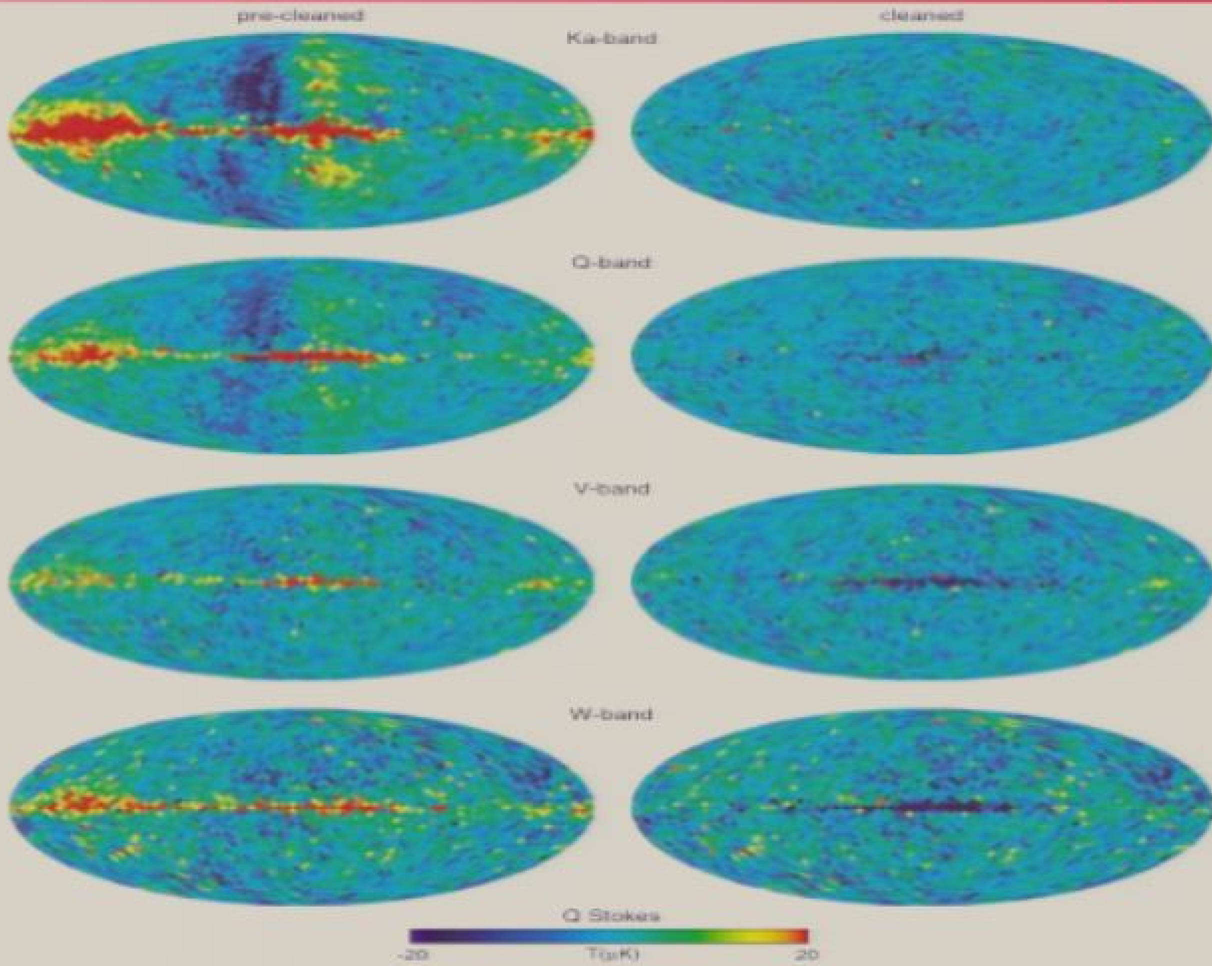

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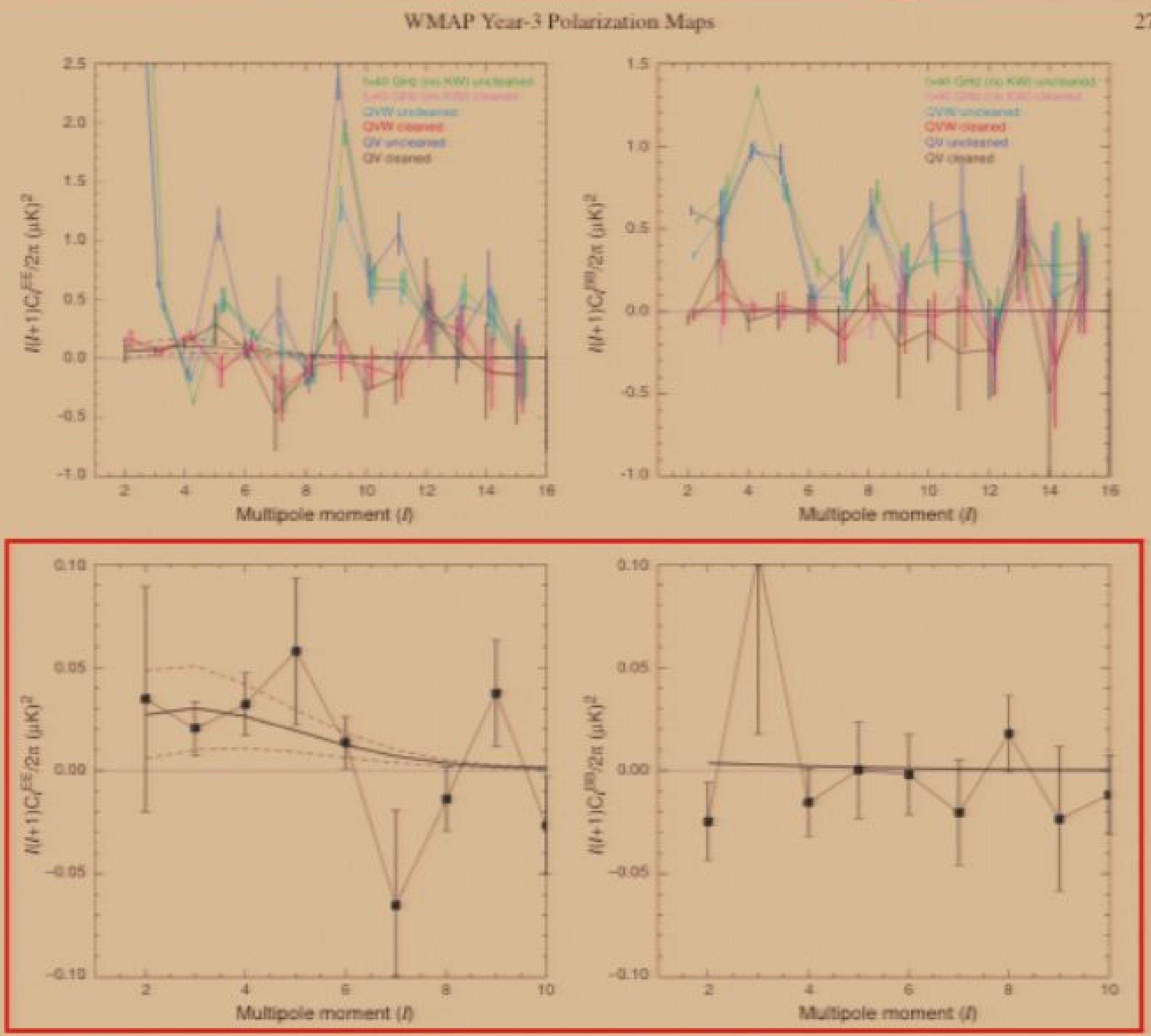

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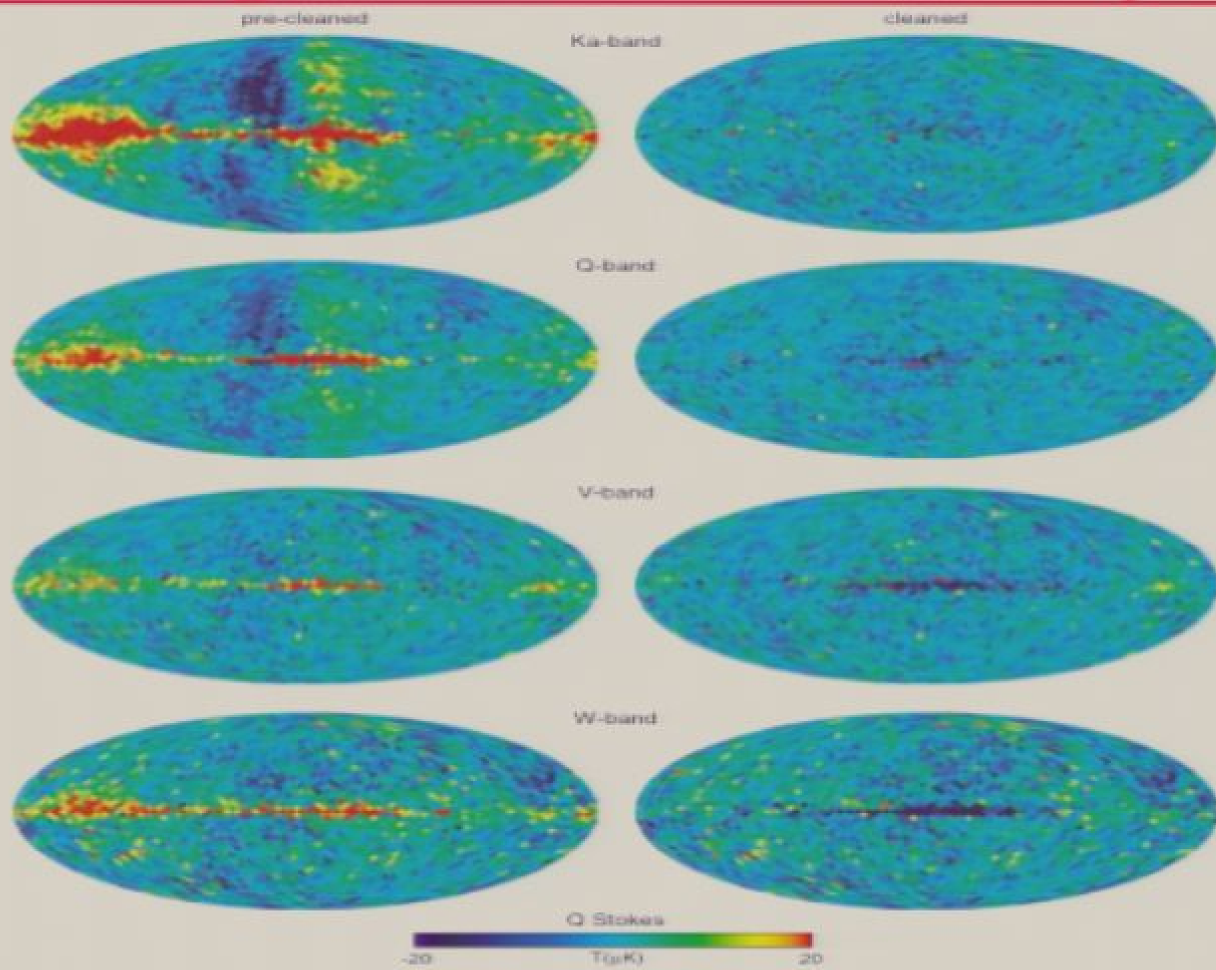

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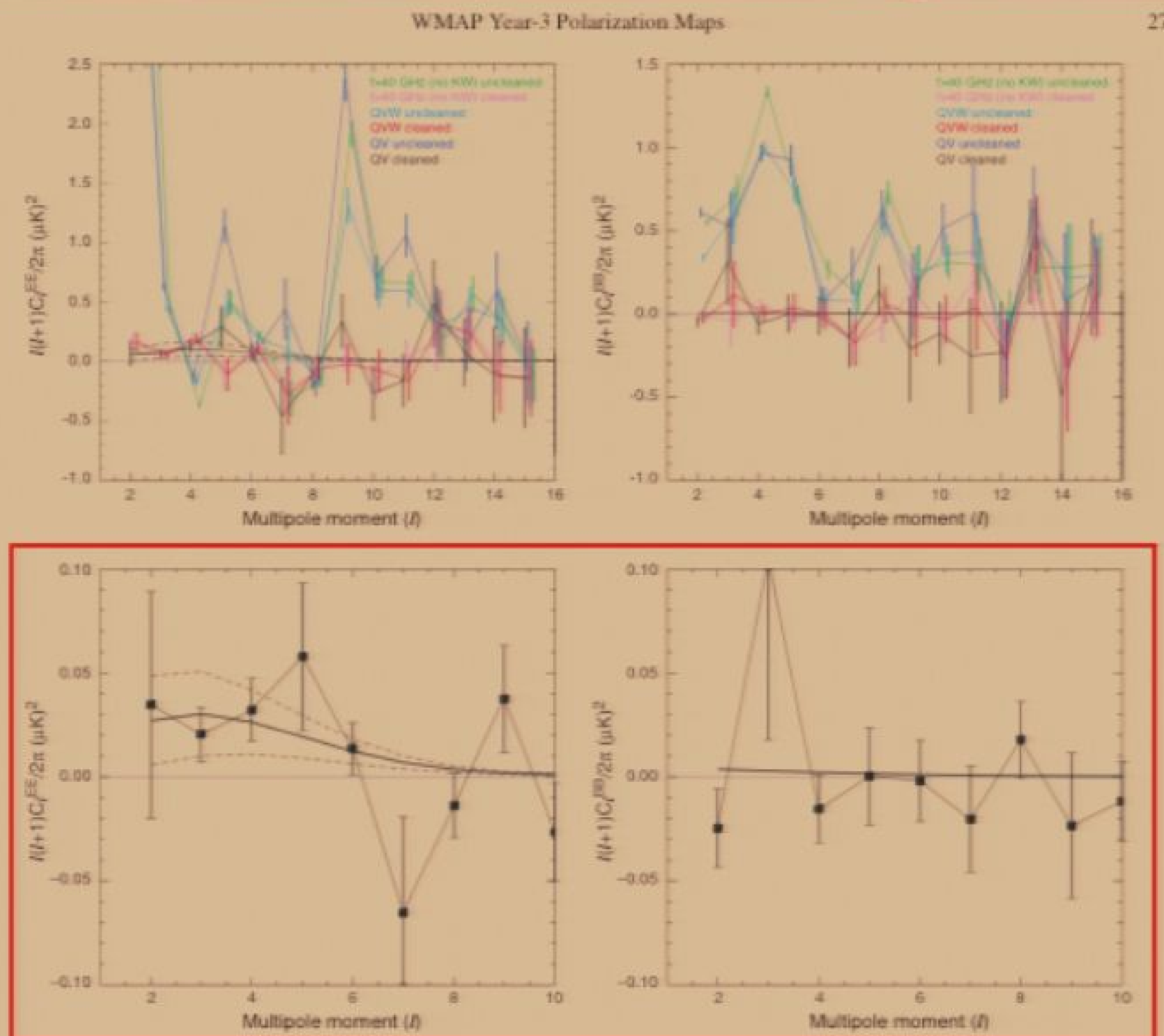

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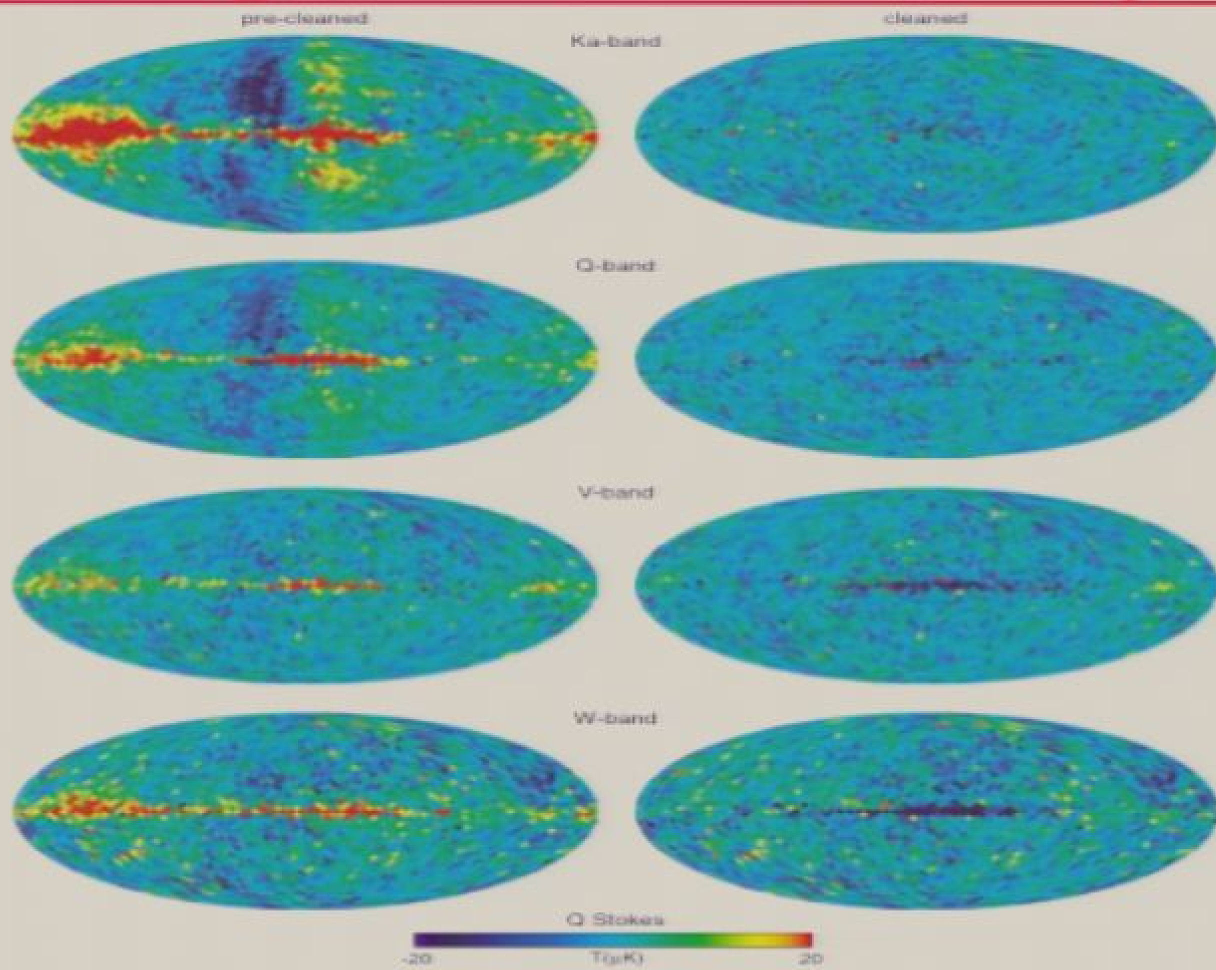

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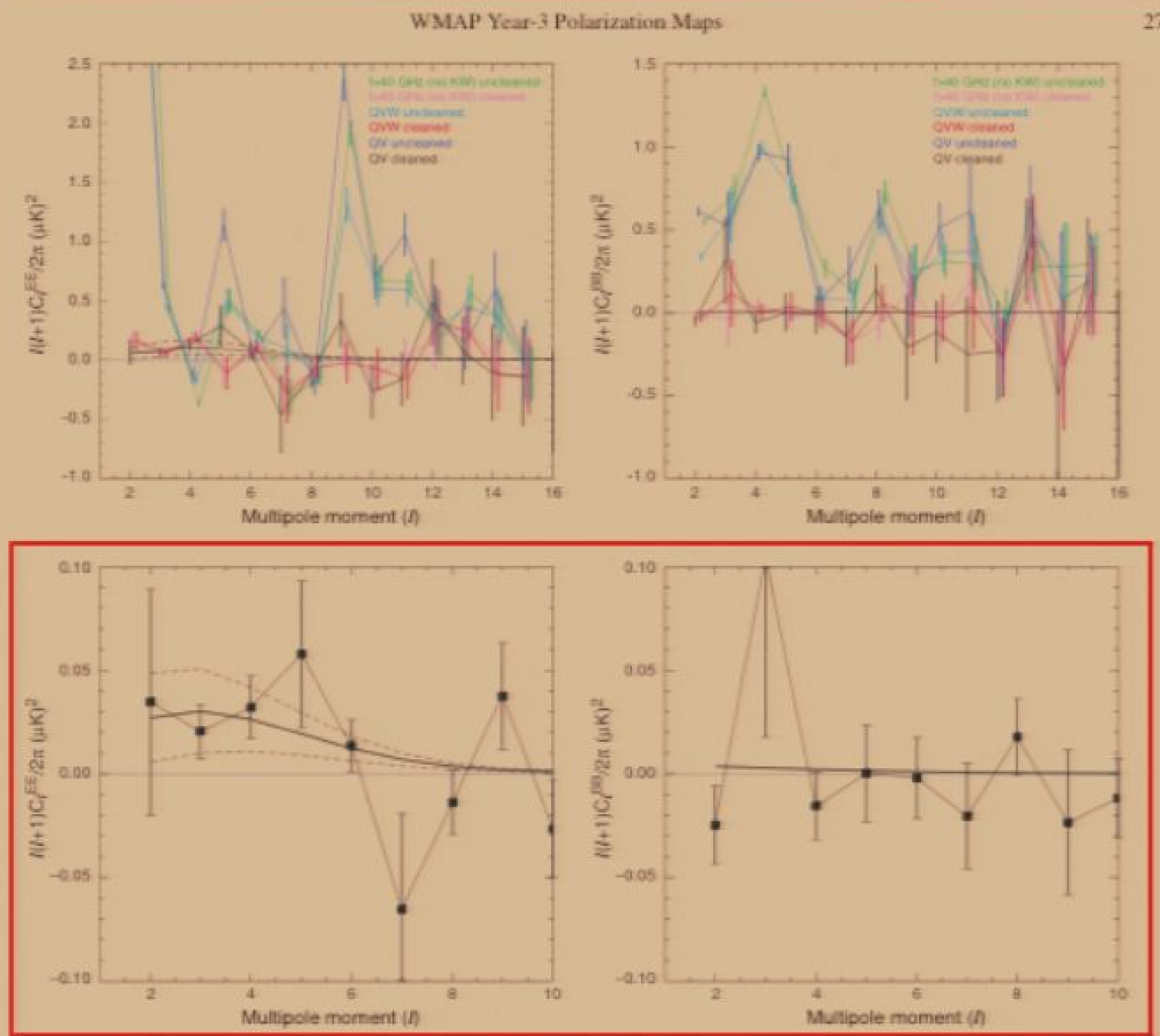

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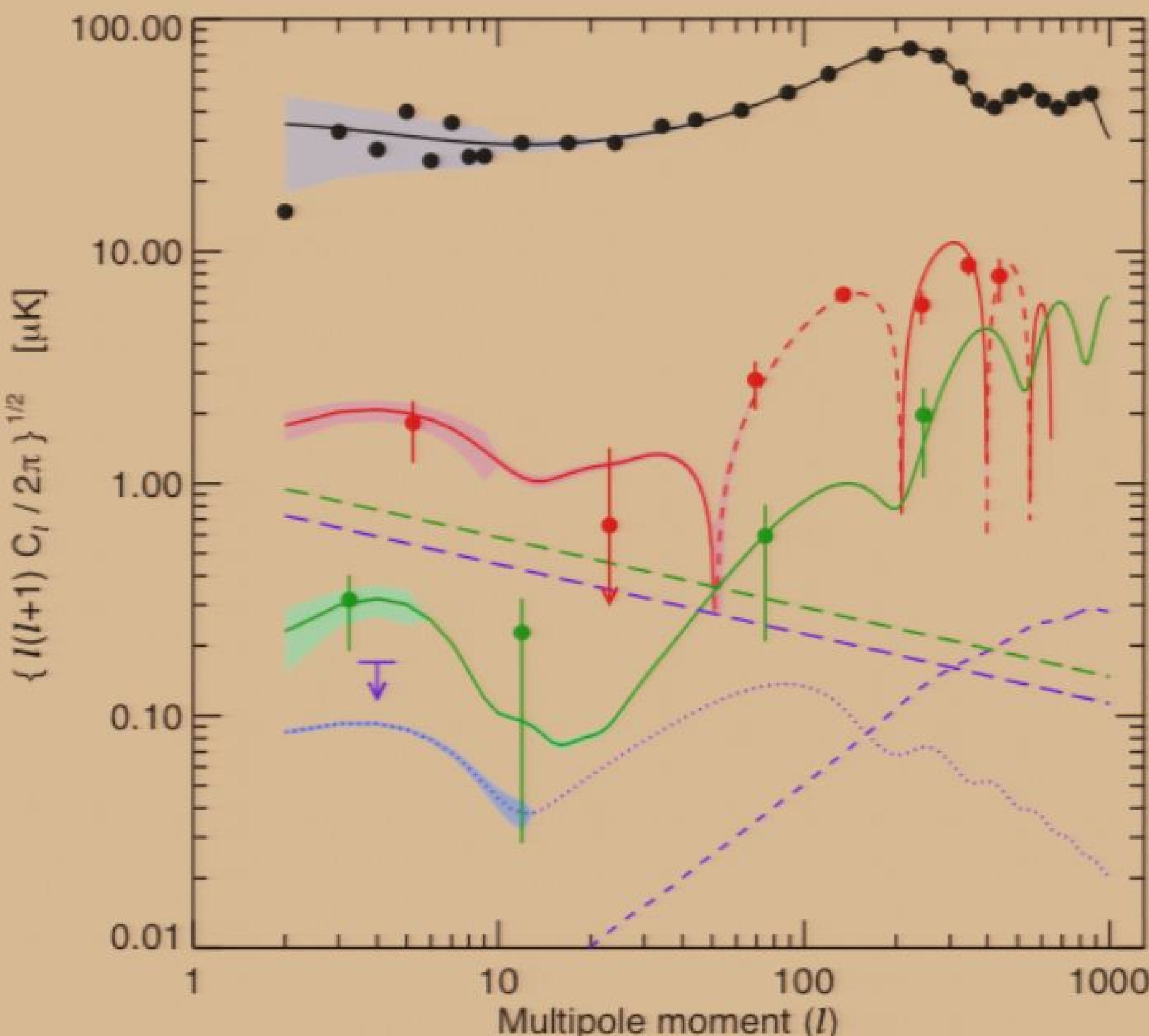
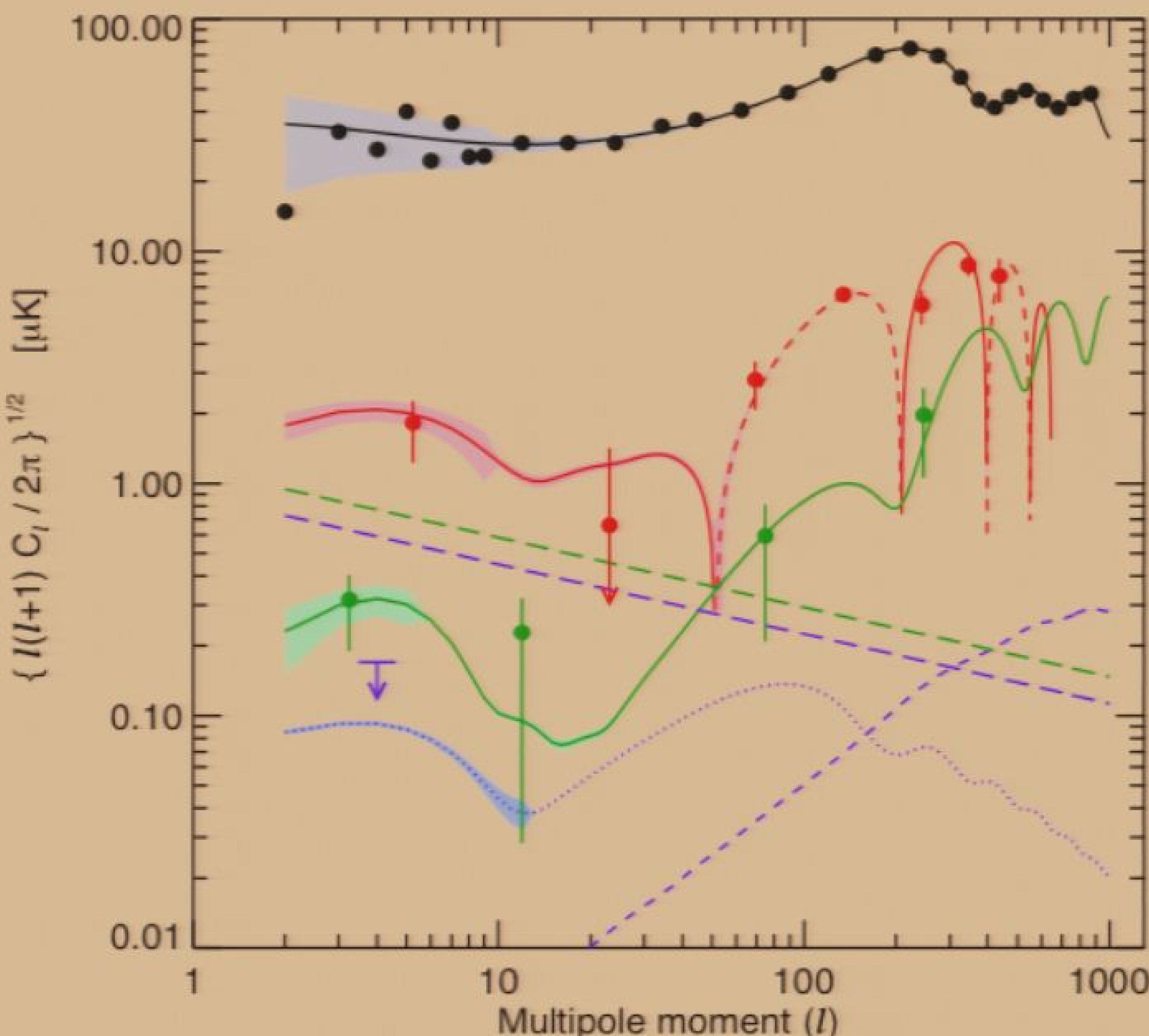
Final CMB spectra



Cosmological Implications

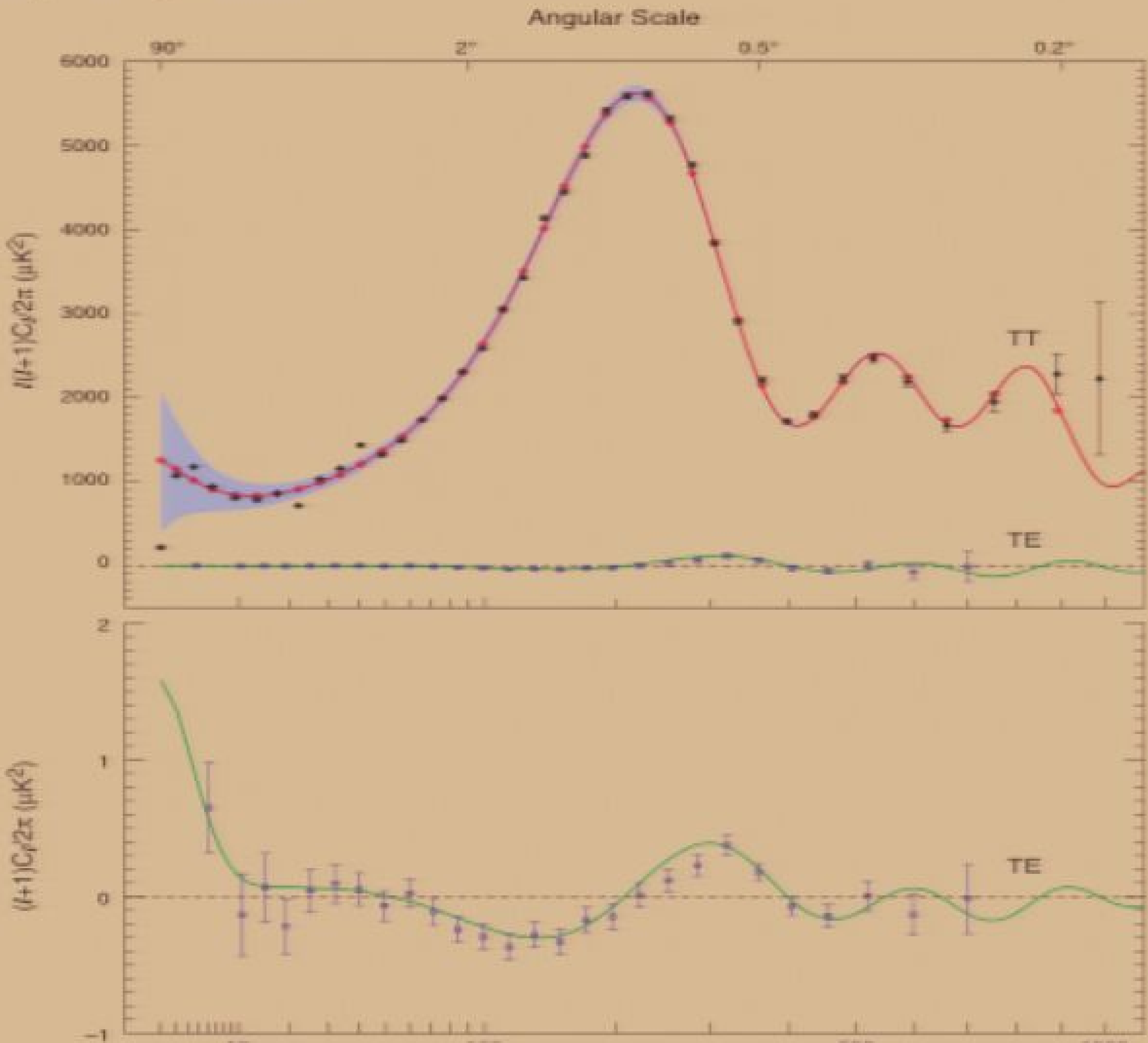
Final CMB spectra



Cosmological Implications

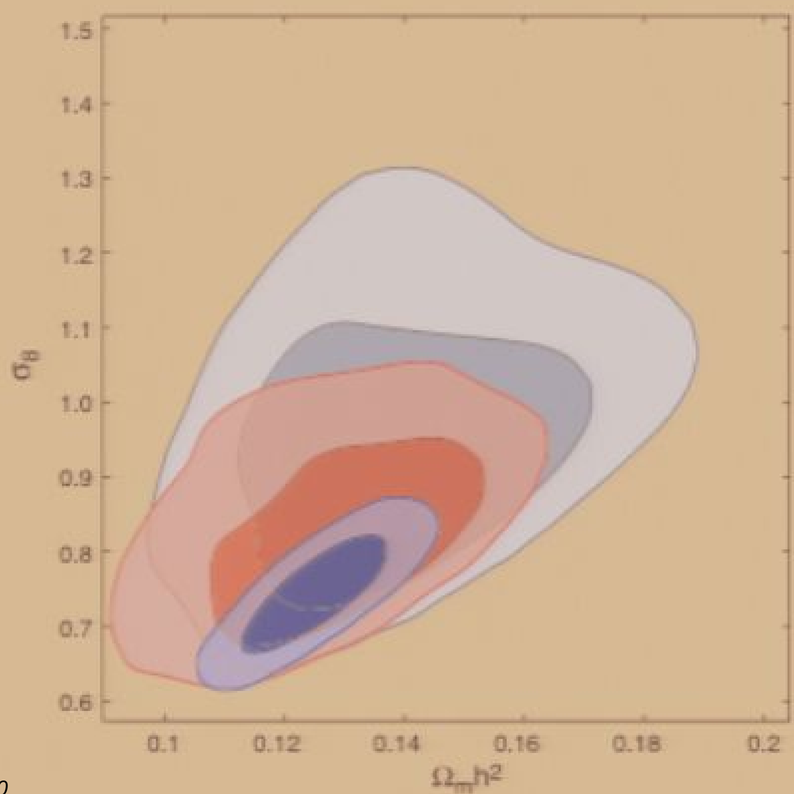
Simple ΛCDM model fits

- Simple flat ΛCDM model with 6 parameters ($\Omega_{cdm}, \Omega_b, n_s, A_s, h, \tau$) still excellent fits
- Despite smaller error bars, the χ^2_{eff} for TT improves from 1.09 (893 dof) to 1.068 (982 dof) and from 1.066 (1342 dof) to 1.041 for TT+TE (1410 dof)
- For T, Q, U maps, we have $\chi^2_{eff}=0.981$ for 1838 pixels
- Previously discrepant points get closer

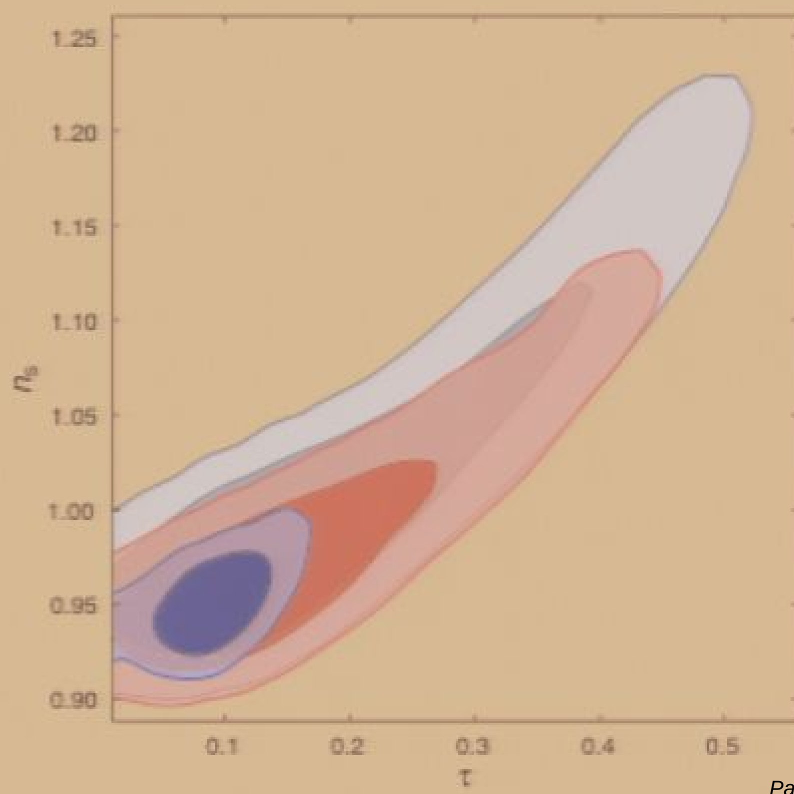


Improvement in parameter space

Parameter	First Year Mean	WMAPext Mean	Three Year Mean	First Year ML	WMAPext ML	Three Year ML
$100\Omega_b h^2$	$2.38^{+0.13}_{-0.12}$	$2.32^{+0.12}_{-0.11}$	2.23 ± 0.08	2.30	2.21	2.22
$\Omega_m h^2$	$0.144^{+0.016}_{-0.016}$	$0.134^{+0.006}_{-0.006}$	0.126 ± 0.009	0.145	0.138	0.128
H_0	72^{+5}_{-5}	73^{+3}_{-3}	74^{+3}_{-3}	68	71	73
τ	$0.17^{+0.08}_{-0.07}$	$0.15^{+0.07}_{-0.07}$	0.093 ± 0.029	0.10	0.10	0.092
n_s	$0.99^{+0.04}_{-0.04}$	$0.98^{+0.03}_{-0.03}$	0.961 ± 0.017	0.97	0.96	0.958
Ω_m	$0.29^{+0.07}_{-0.07}$	$0.25^{+0.03}_{-0.03}$	0.234 ± 0.035	0.32	0.27	0.24
σ_8	$0.92^{+0.1}_{-0.1}$	$0.84^{+0.06}_{-0.06}$	0.76 ± 0.05	0.88	0.82	0.77

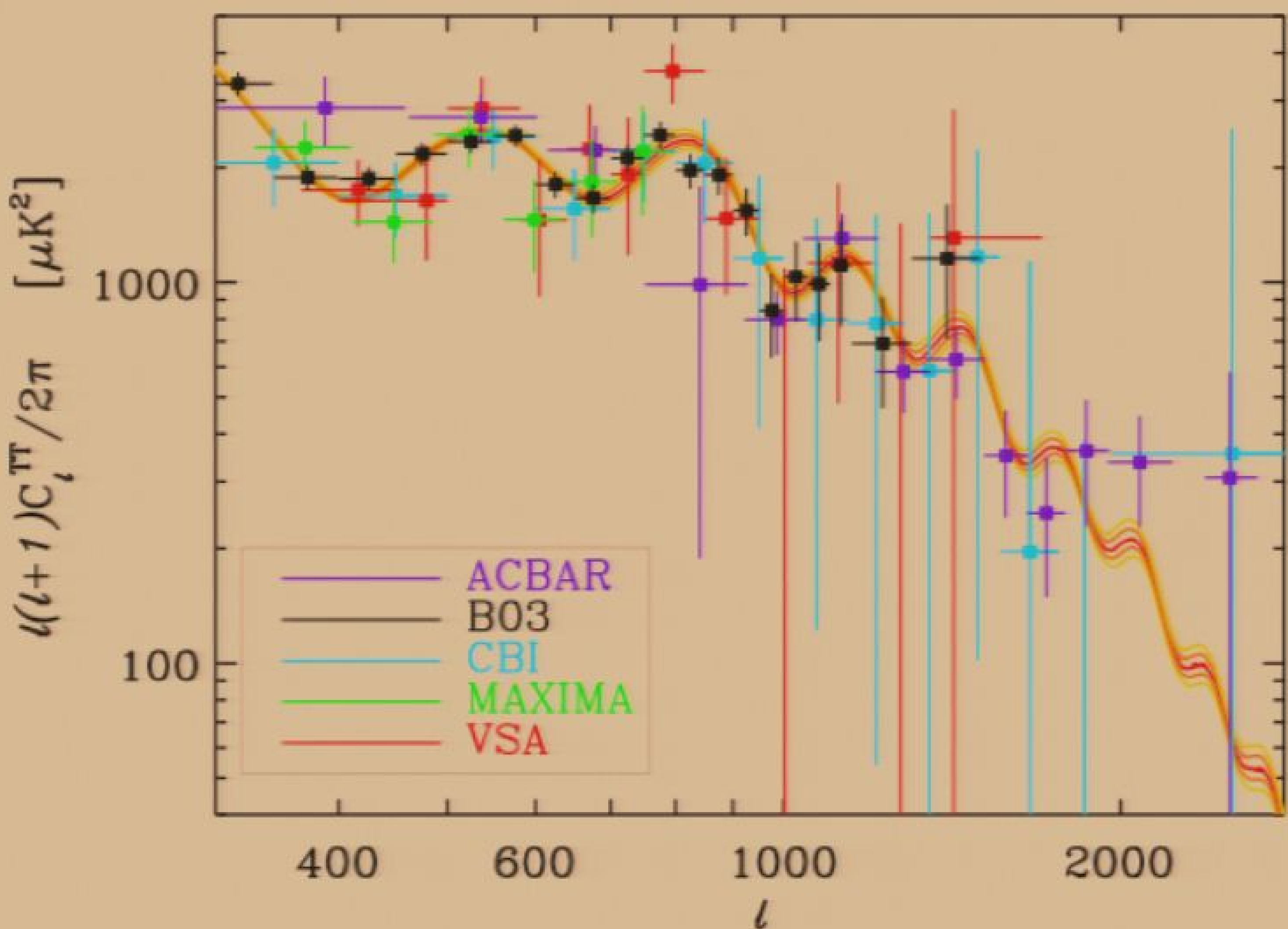


Driven by 3d peak



Driven by EE

Cosmological contrasts… and yet concordance



WMAP "predicts" small scale CMB experiments

Improvement in parameter space

Parameter	First Year Mean	WMAPext Mean	Three Year Mean	First Year ML	WMAPext ML	Three Year ML
$100\Omega_b h^2$	$2.38^{+0.13}_{-0.12}$	$2.32^{+0.12}_{-0.11}$	2.23 ± 0.08	2.30	2.21	2.22
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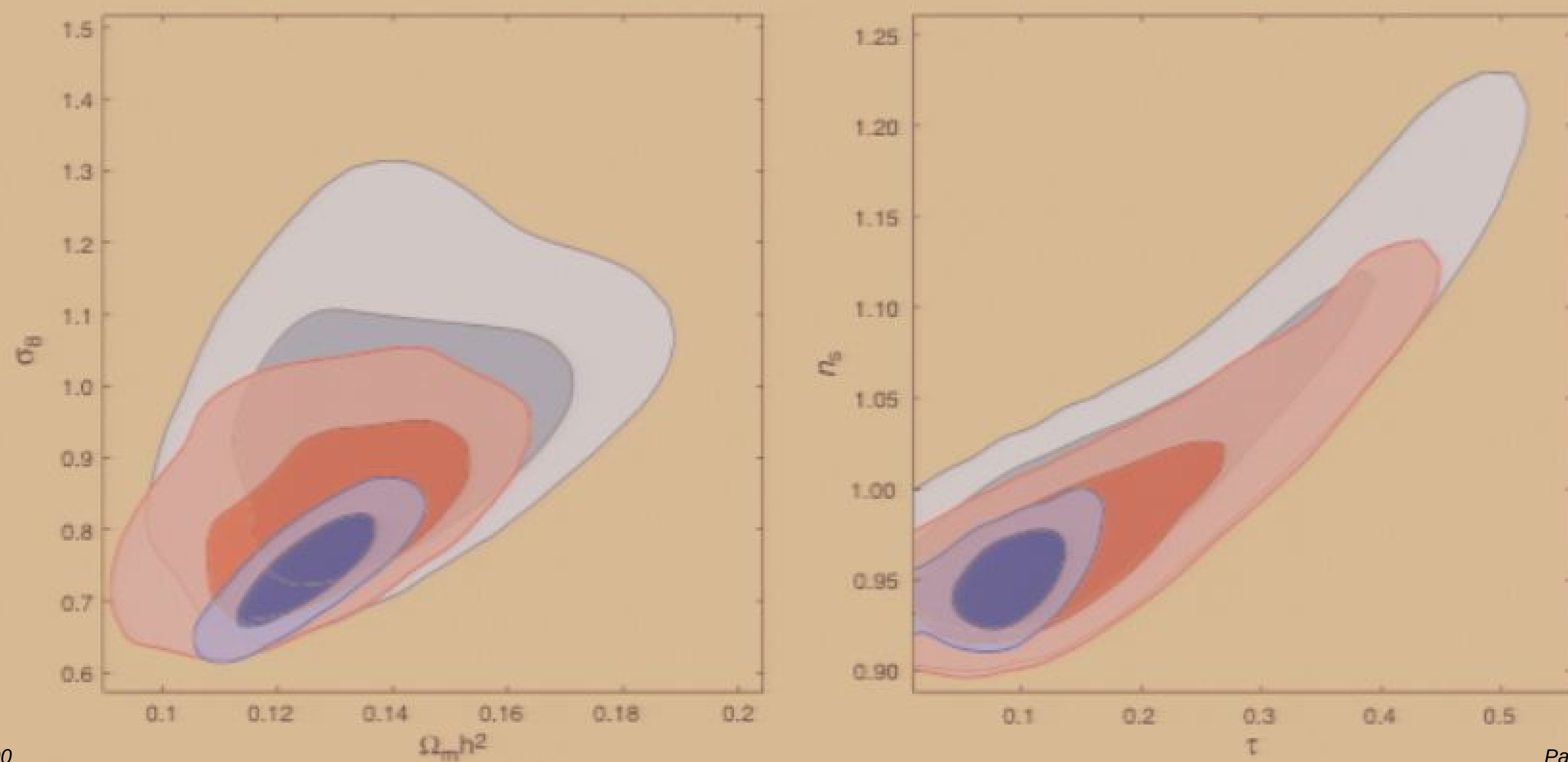
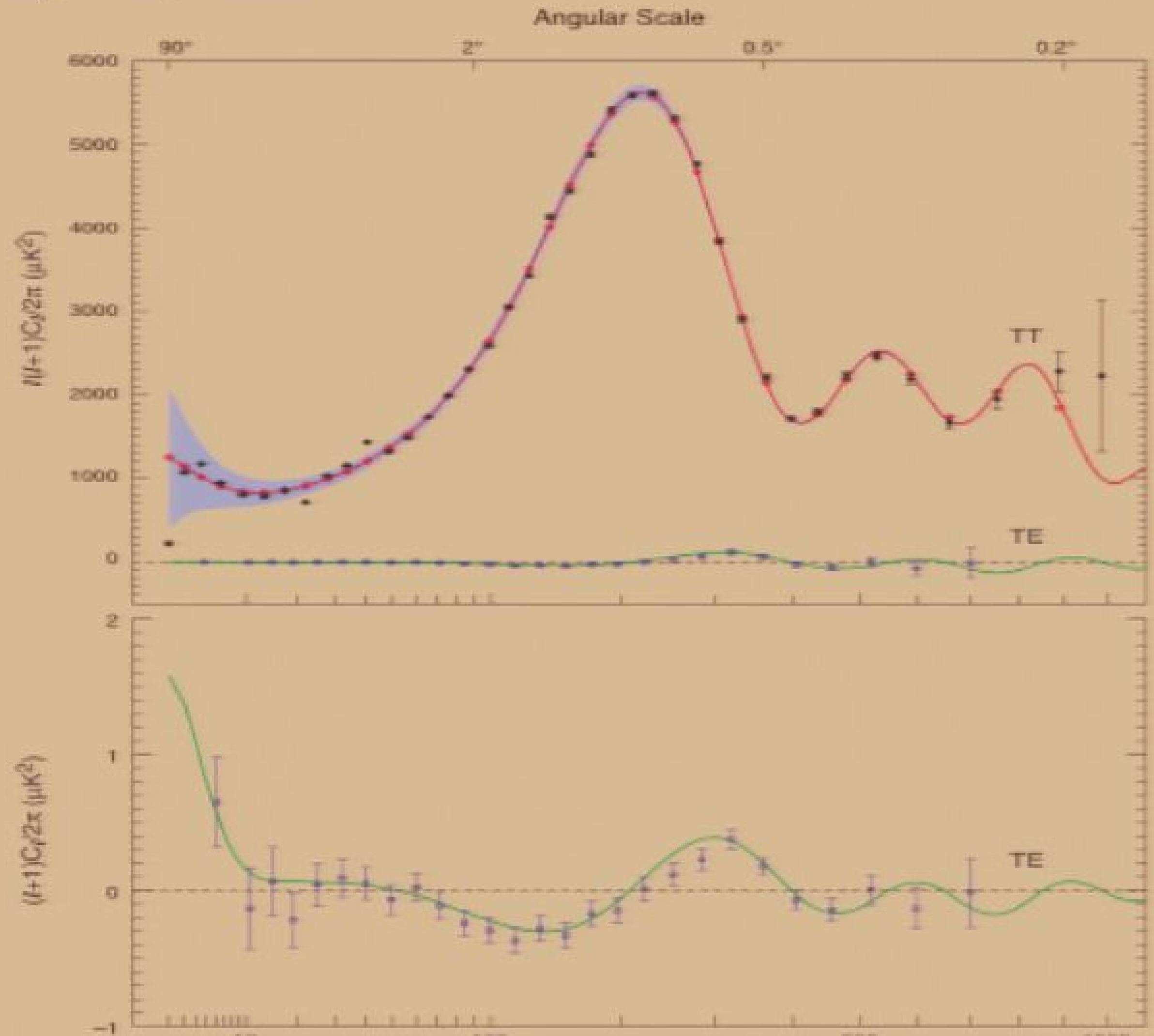


Driven by 3d peak

Driven by EE

Simple ΛCDM model fits

- Simple flat ΛCDM model with 6 parameters ($\Omega_{cdm}, \Omega_b, n_s, A_s, h, \tau$) still excellent fits
- Despite smaller error bars, the χ^2_{eff} for TT improves from 1.09 (893 dof) to 1.068 (982 dof) and from 1.066 (1342 dof) to 1.041 for TT+TE (1410 dof)
- For T, Q, U maps, we have $\chi^2_{eff}=0.981$ for 1838 pixels
- Previously discrepant points get closer



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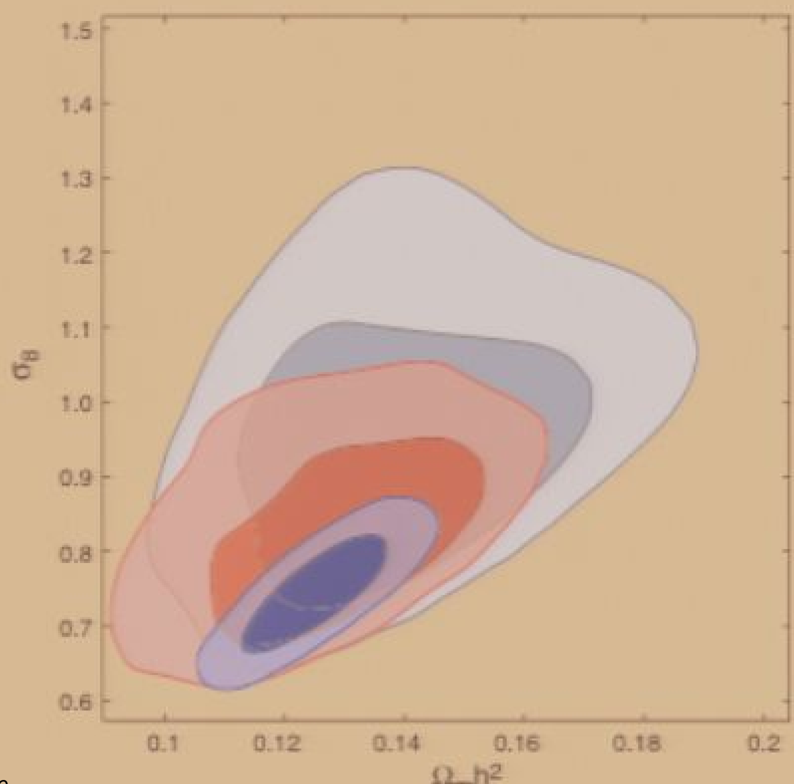
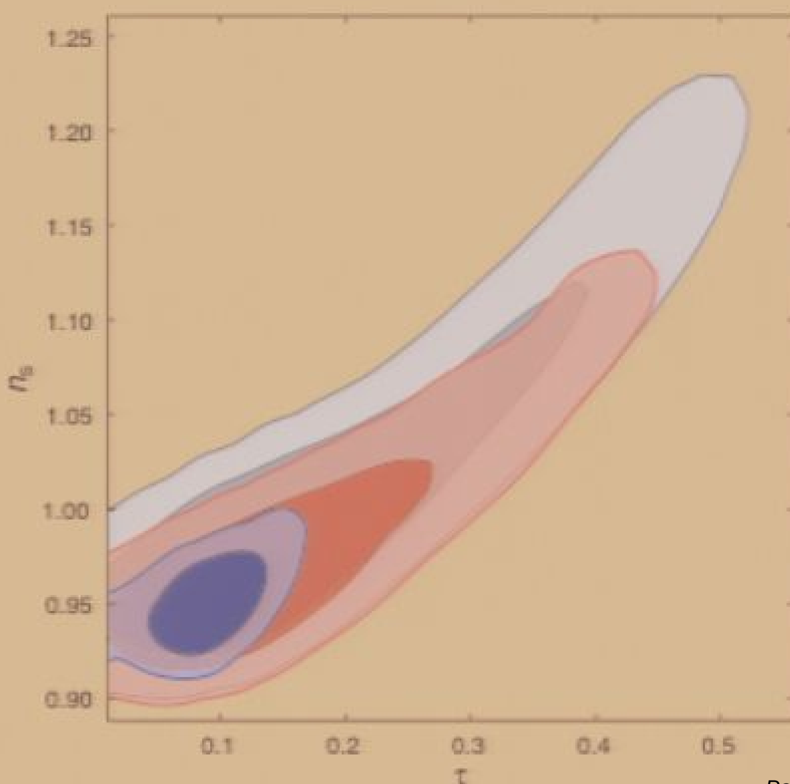
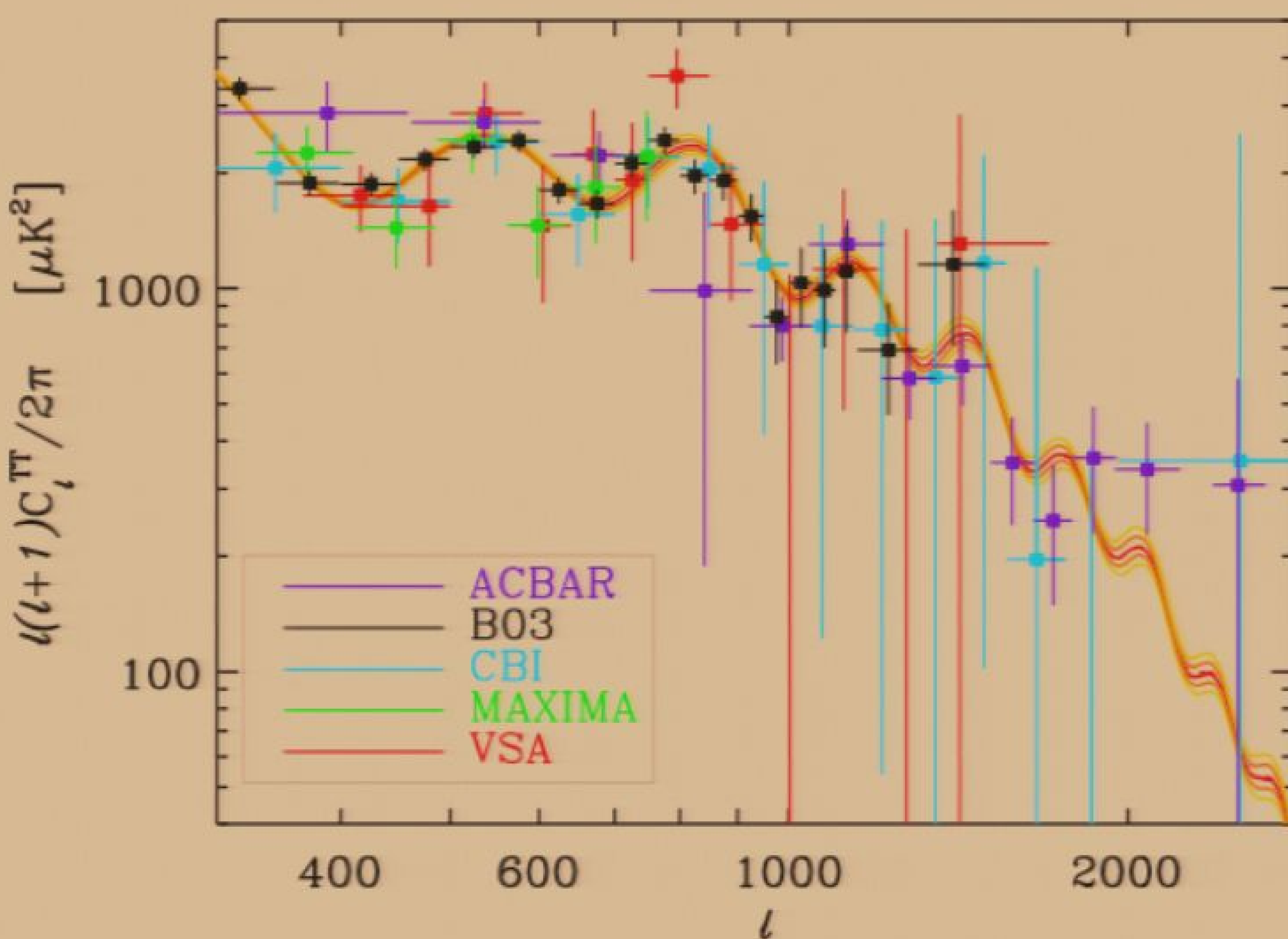




Driven by 3d peak

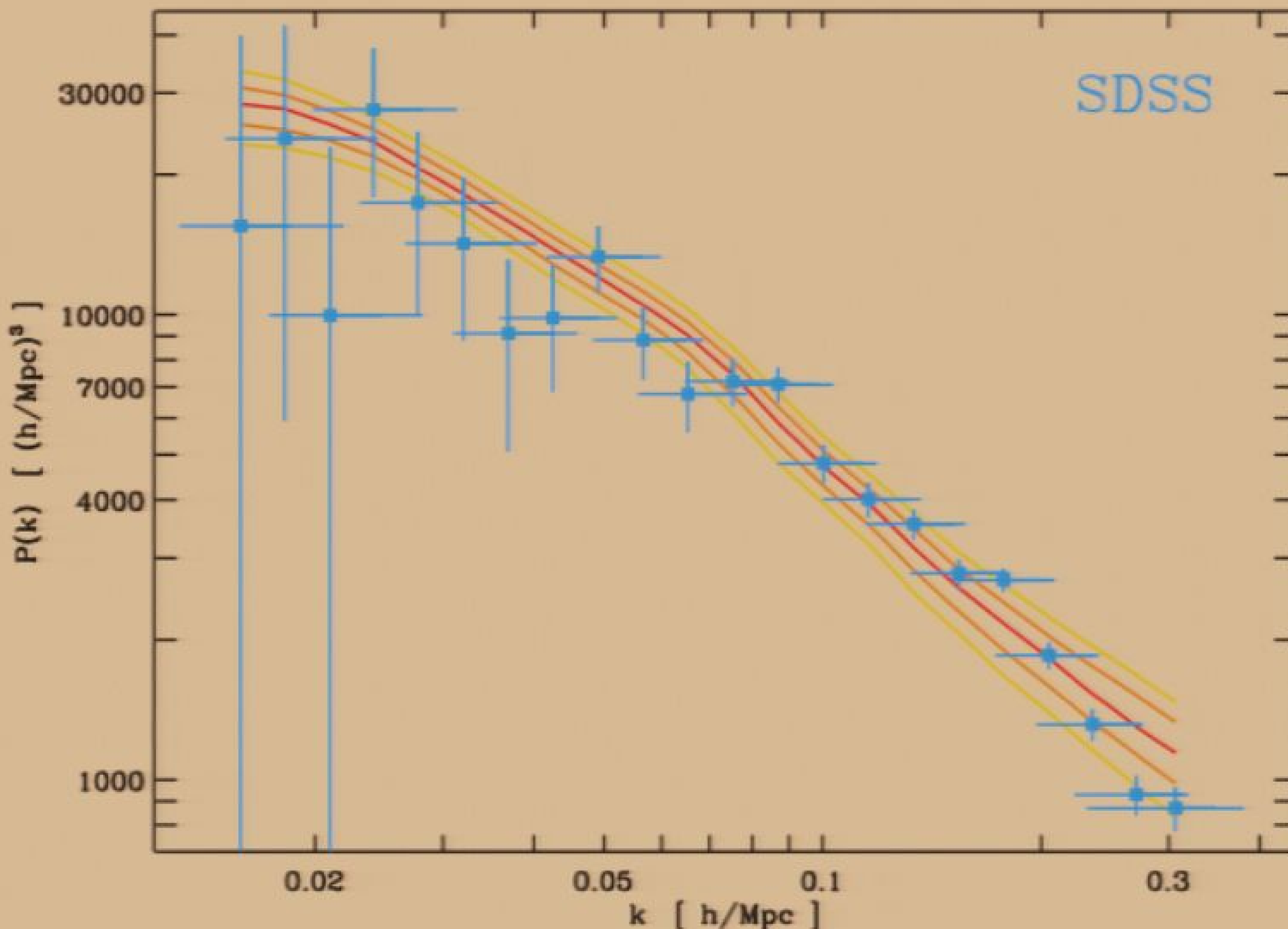
Driven by EE

Cosmological contrasts... and yet concordance



WMAP "predicts" small scale CMB experiments

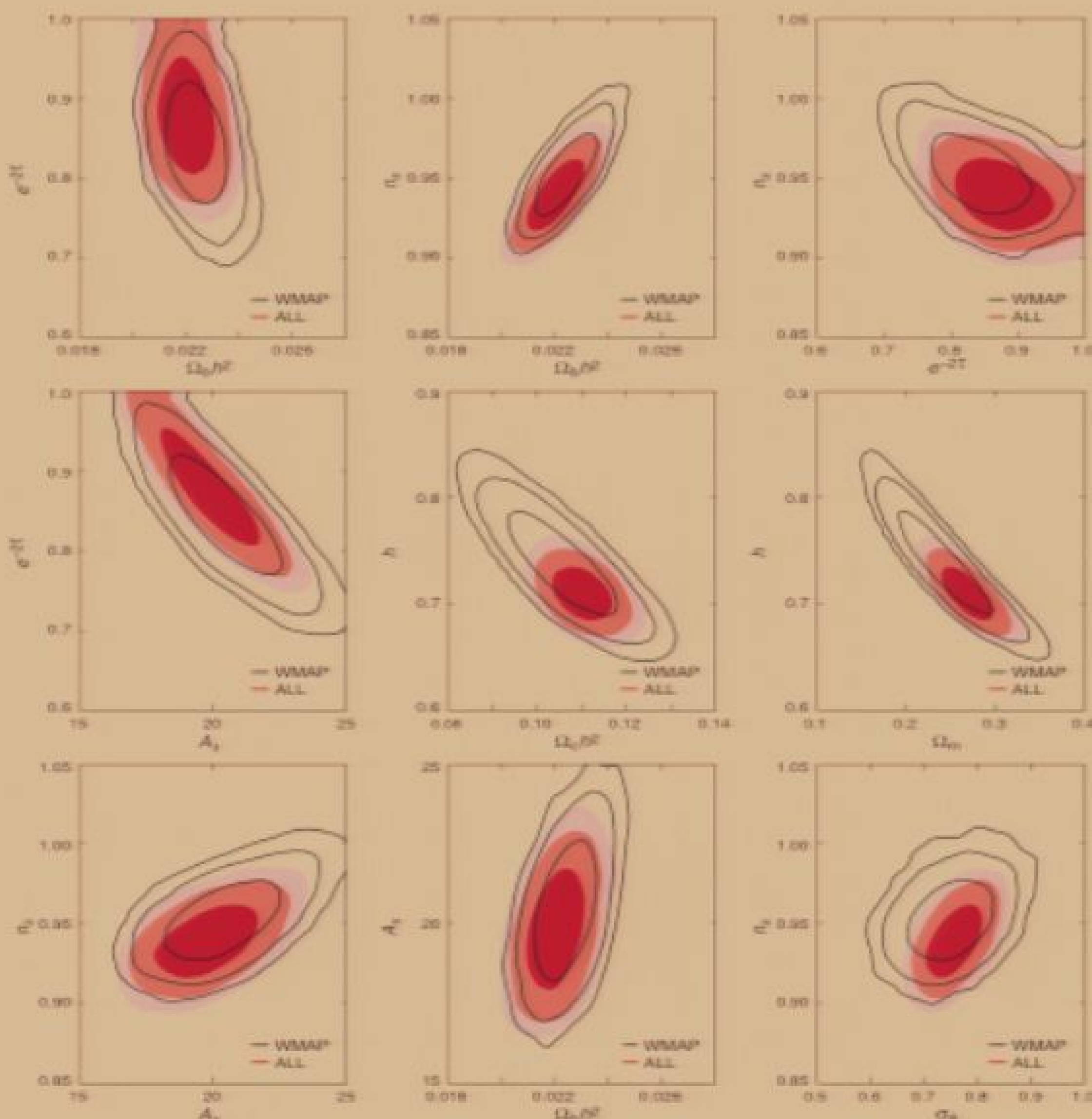
Cosmological contrasts... and yet concordance



WMAP "predicts" low z mass distribution

(same for 2dF)

LCDM model



All includes WMAP+HST+2dF+SDSS+SNLS+SN(Gold)+CBI+VSA+B03+ACBAR

Where are we now?

The current "phenomenological" success means:

- The primordial inhomogeneities are mostly adiabatic with a nearly scale invariant power spectrum
- We have a successful GR based theory of linear perturbations to evolve them
- We have a good description of the main components even if we do not know what they are

We can now ask various sets of questions:

- Ask question within the model
  - What else can we learn about the components of the model?
  - What is Dark Energy?
  - What is Dark Matter?
  - Did the Universe really undergo an Inflationary phase?
  - First stars and how did the Universe get reionized?
- Explore further the data and look for "anomalies"

Fundamental
Physics we don't know yet

Physics we don't know
to compute

Constraining neutrino mass

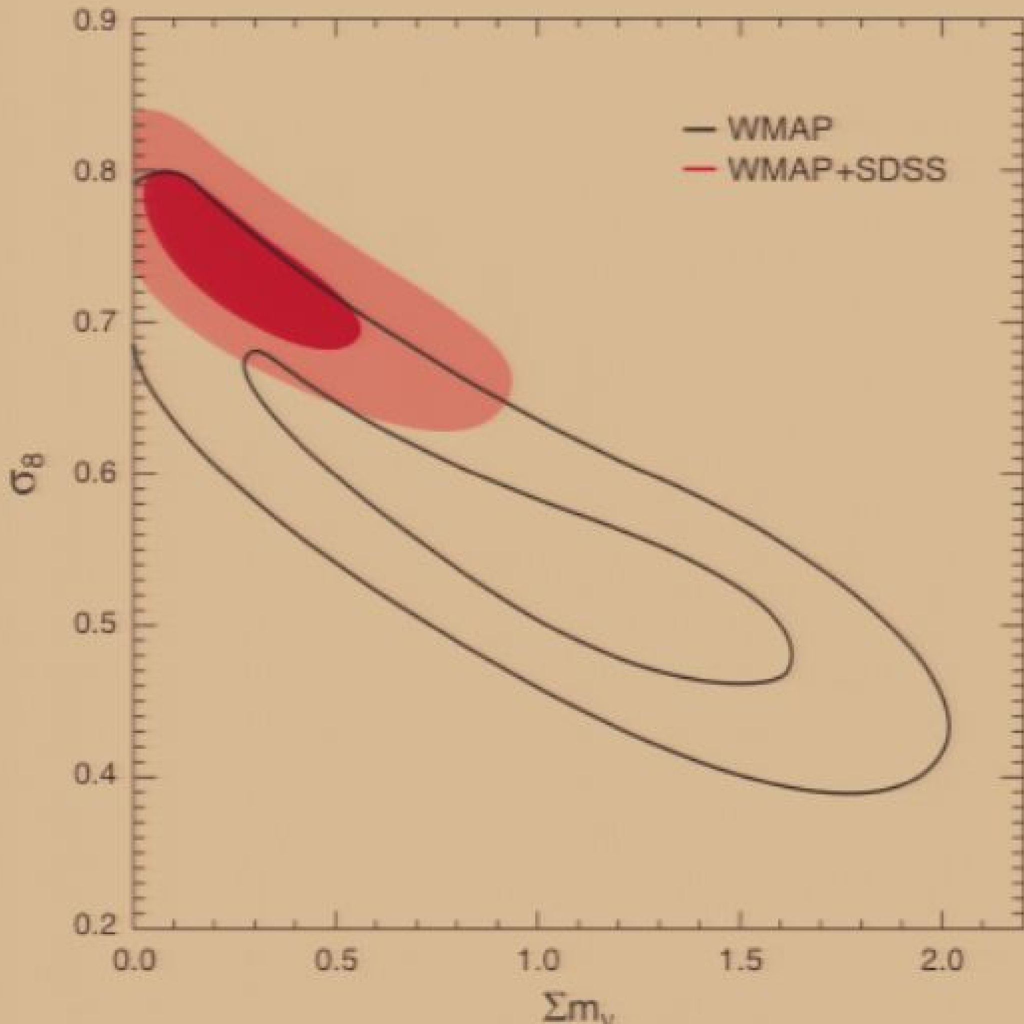
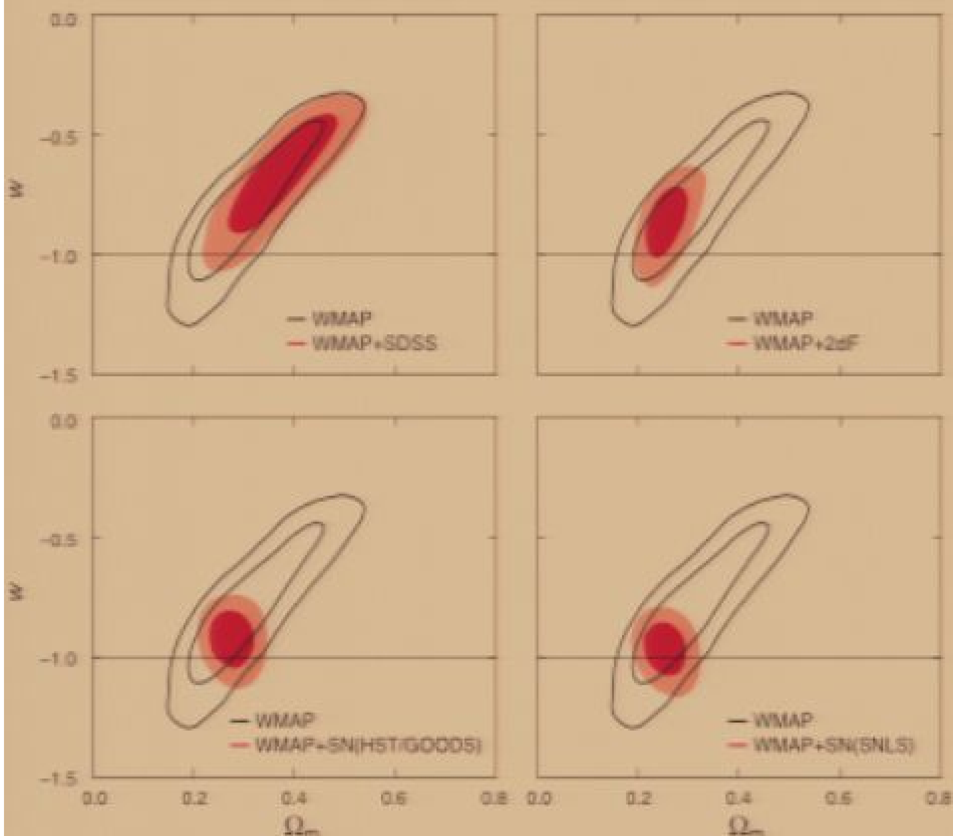


Table 10: Constraints on Neutrino Properties

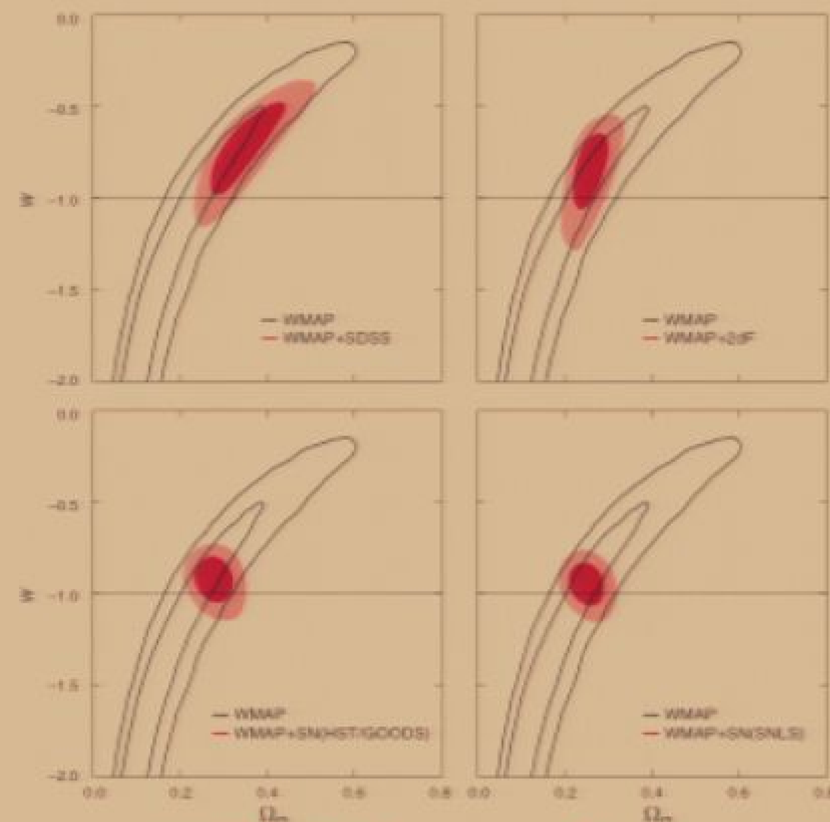
Data Set	$\sum m_\nu$ (95% limit for $N_\nu = 3.02$)	N_ν
WMAP	2.0 eV(95% CL)	
WMAP + SDSS	0.91 eV(95% CL)	[illegible]$92^{+0.25}_{-1.45}$
WMAP + 2dFGRS	0.87 eV(95% CL)	$2.68^{+0.26}_{-1.67}$

Dark Energy

Constraints on constant DE equation of state $w=p/\rho$



Without DE perturbations

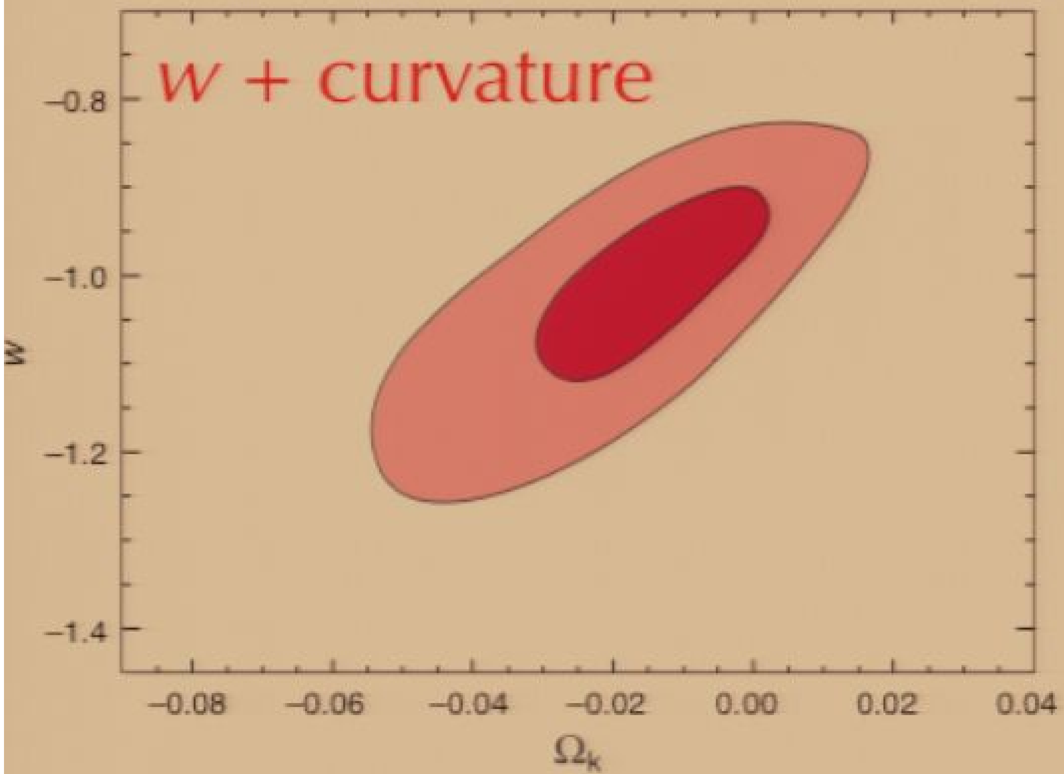


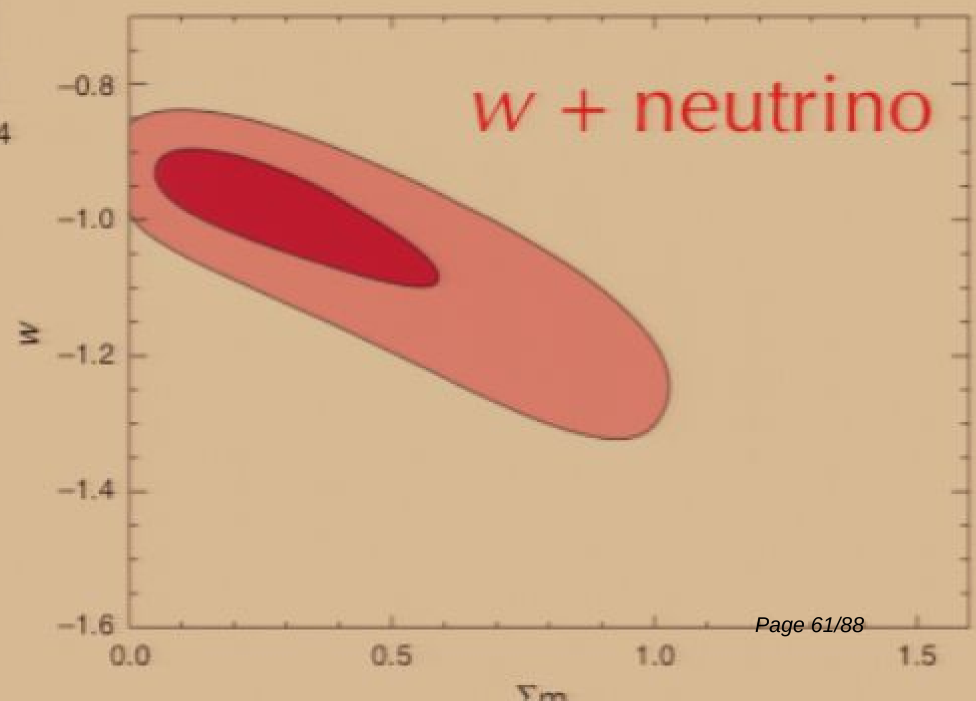
With DE perturbations

but fixed c_s^2 (cf Bean & Doré 03)

Data Set	with perturbations	no perturbations
WMAP + SDSS	$-0.75^{+0.18}_{-0.16}$	$-0.69^{+0.19}_{-0.18}$
WMAP + 2dFGRS	$-0.914^{+0.193}_{-0.099}$	$-0.877^{+0.094}_{-0.110}$
WMAP + SNGold	$-0.944^{+0.076}_{-0.094}$	$-0.940^{+0.071}_{-0.092}$
WMAP + SNLS	$-0.966^{+0.070}_{-0.090}$	$-0.984^{+0.066}_{-0.085}$

Robustness of DE constraints





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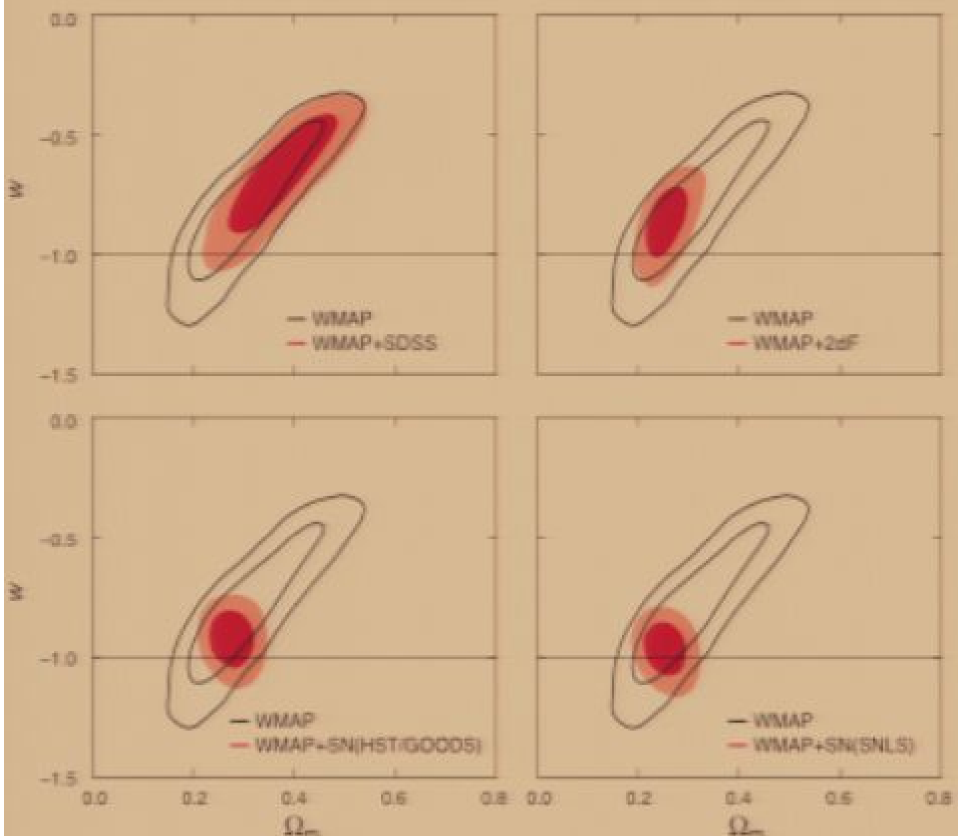
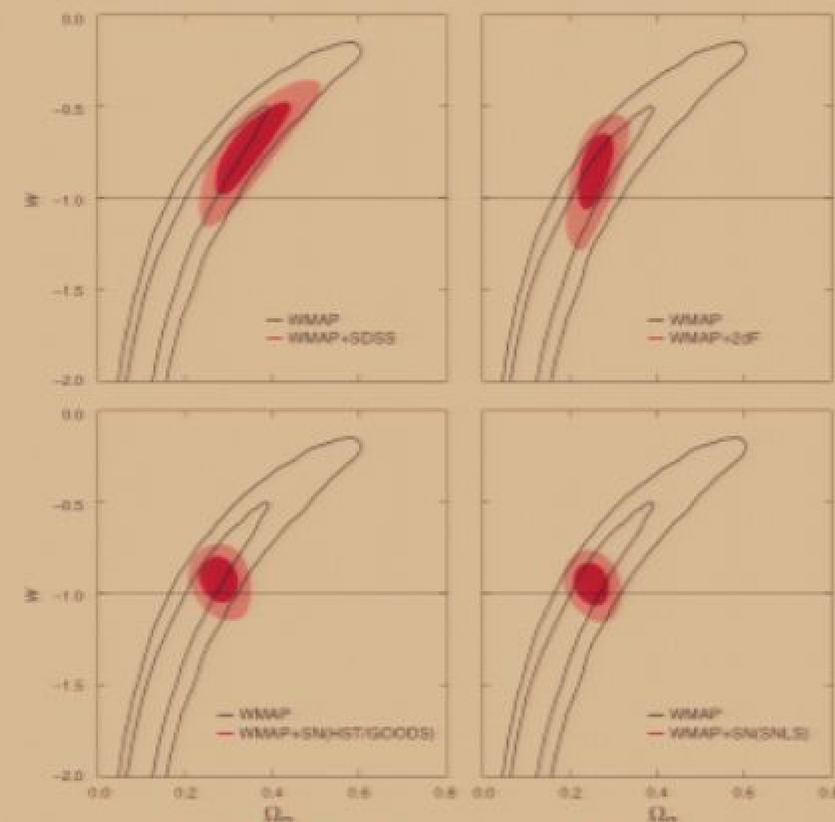


Without DE perturbations



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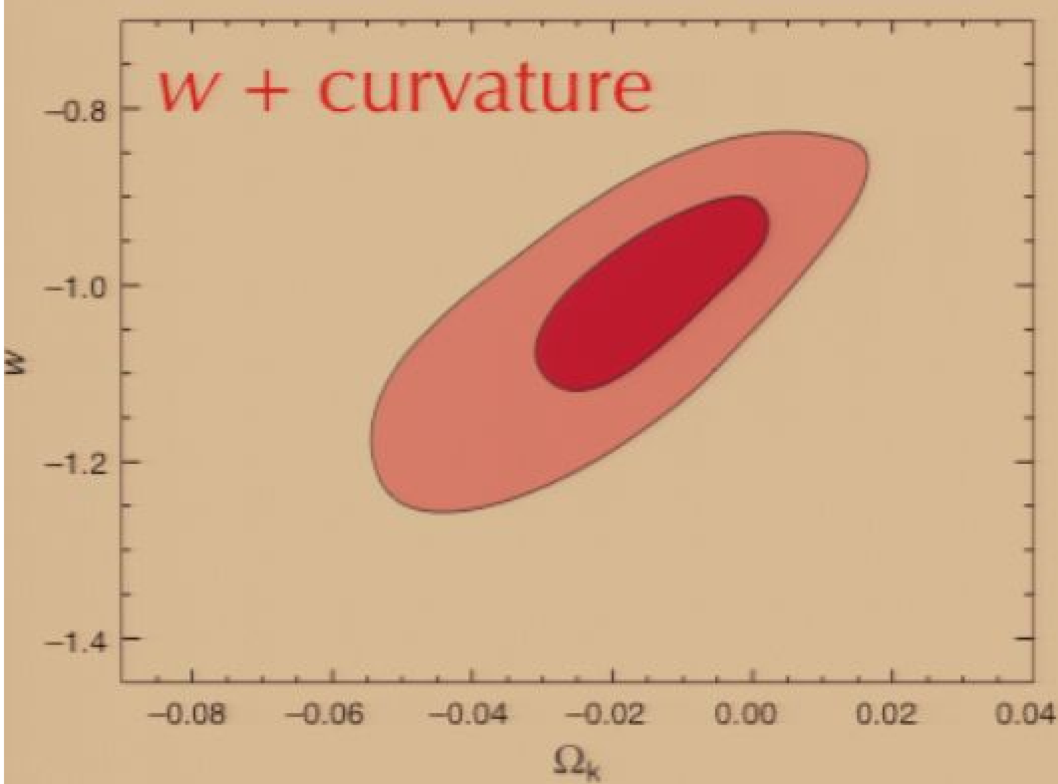
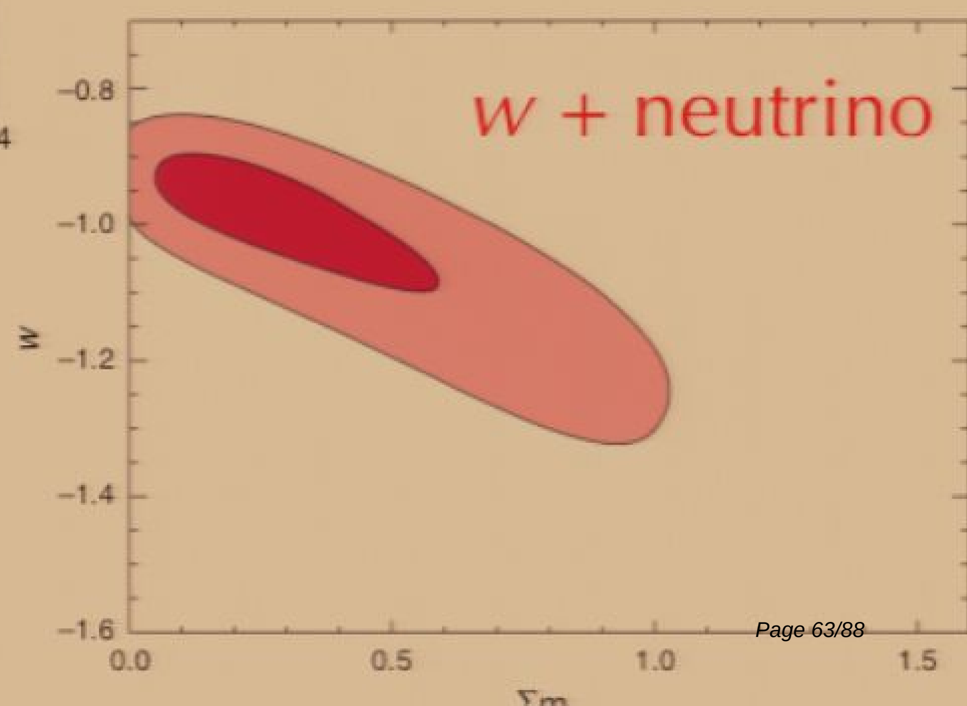




What is Inflation?

- Inflation was introduced to solve the problems of the "standard Big Bang" model like *flatness* and the *horizon problem*

- Key feature: during an extended period of time, the universe is expanding exponentially (superluminally). Fluctuations are generated during this phase

- This is achieved by introducing in the matter sector (a) new scalar field(s) Φ with a well chosen potential $V(\Phi)$

- For a given $V(\Phi)$ there are relations between derivatives of V and observables like n_s , r and $dn_s/d\ln k$

- Testing Inflation is mostly testing these consistency relations

- If you read this far, you HAVE to go and listen to Will Kinney's talk this afternoon

Guth 81, Sato 81, Linde 82, Albrecht & Steinhardt 82
Guth & Pi 82, Starobinsky 82, Mukhanov & Chibisov 81, Hawking 82, Bardeen et al. 83

What are Inflation predictions?

Most of Inflation predictions, in the 80s, when there were few evidences for any of those idea

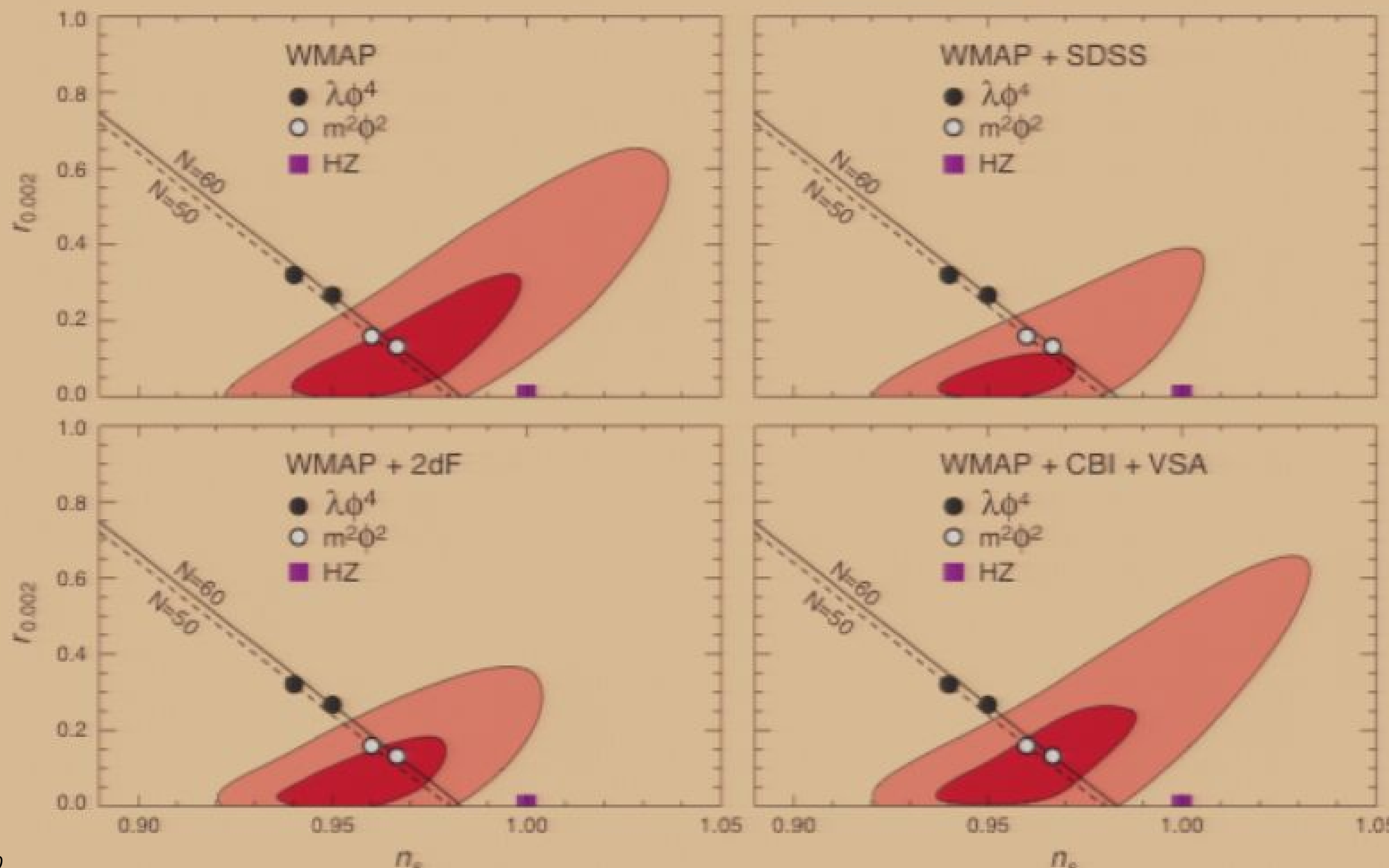
- Flatness ⇒ TOCO, MAXIMA, BOOMERANG, WMAP...
- Primordial perturbations nearly scale invariant ⇒ COBE (n_s = 1.2±0.3 -Gorski et al. 96)
- Gaussianity of fluctuations ⇒WMAP-1
- Adiabatic initial perturbations: ⇒WMAP-1
- Super-Horizon perturbations ⇒ WMAP-1 (TE at l~100)
- Deviation from scale invariance ⇒ WMAP-3
- Tensor perturbations, *i.e.* Gravity Wave Background (WMAP-8 ?, Planck?, Spider?, Biceps?...)

Spectral index and Inflation

$V(\phi) \propto \phi^{\alpha}$ Consistency relations $\Rightarrow$

$$r \simeq \frac{4\alpha}{N}$$
$$1 - n_s = \frac{\alpha+2}{2N}$$

where $\Delta_R^2(k) = \left(\frac{k}{k_0}\right)^{n_s-}$

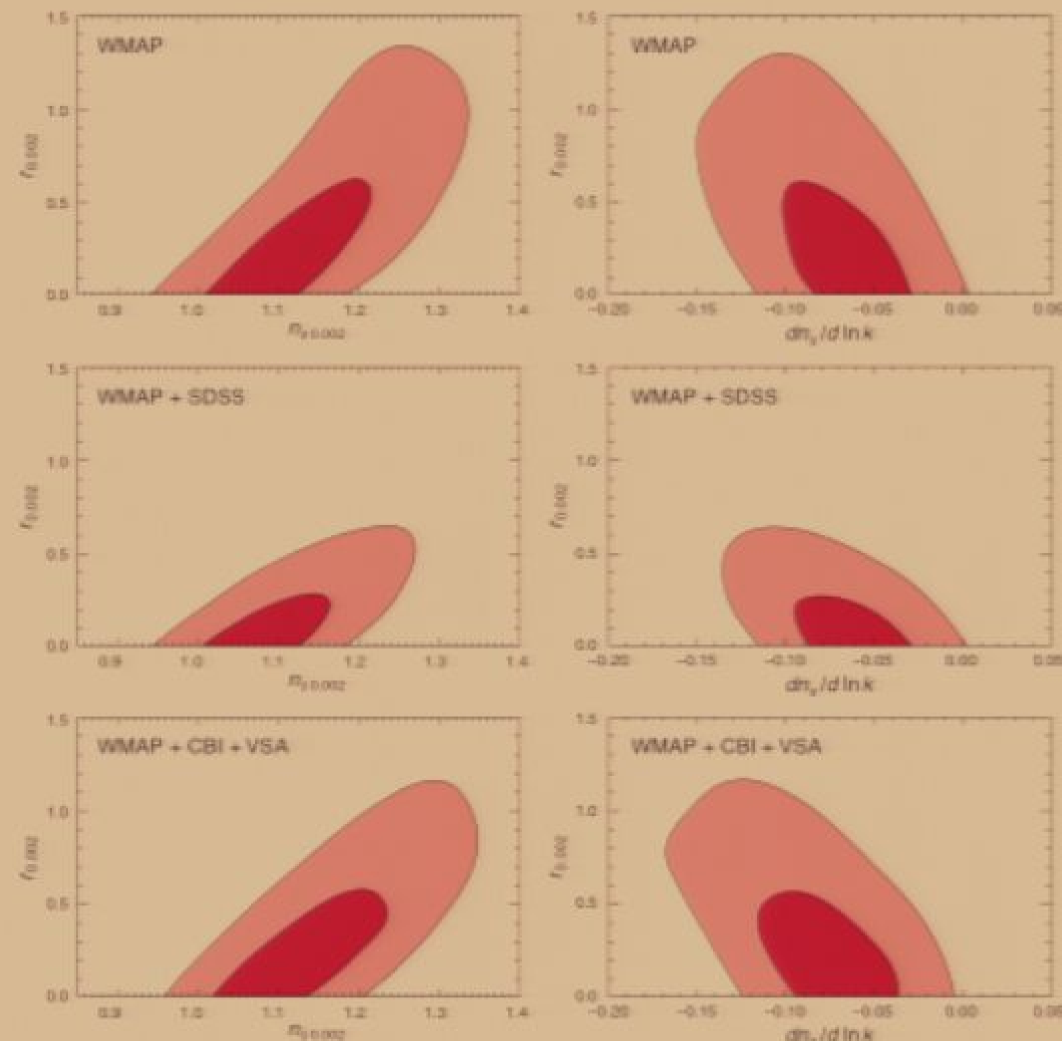


Similar constraints for B03+ACBAR

These models predict almost no running

Do we see a running spectral index?

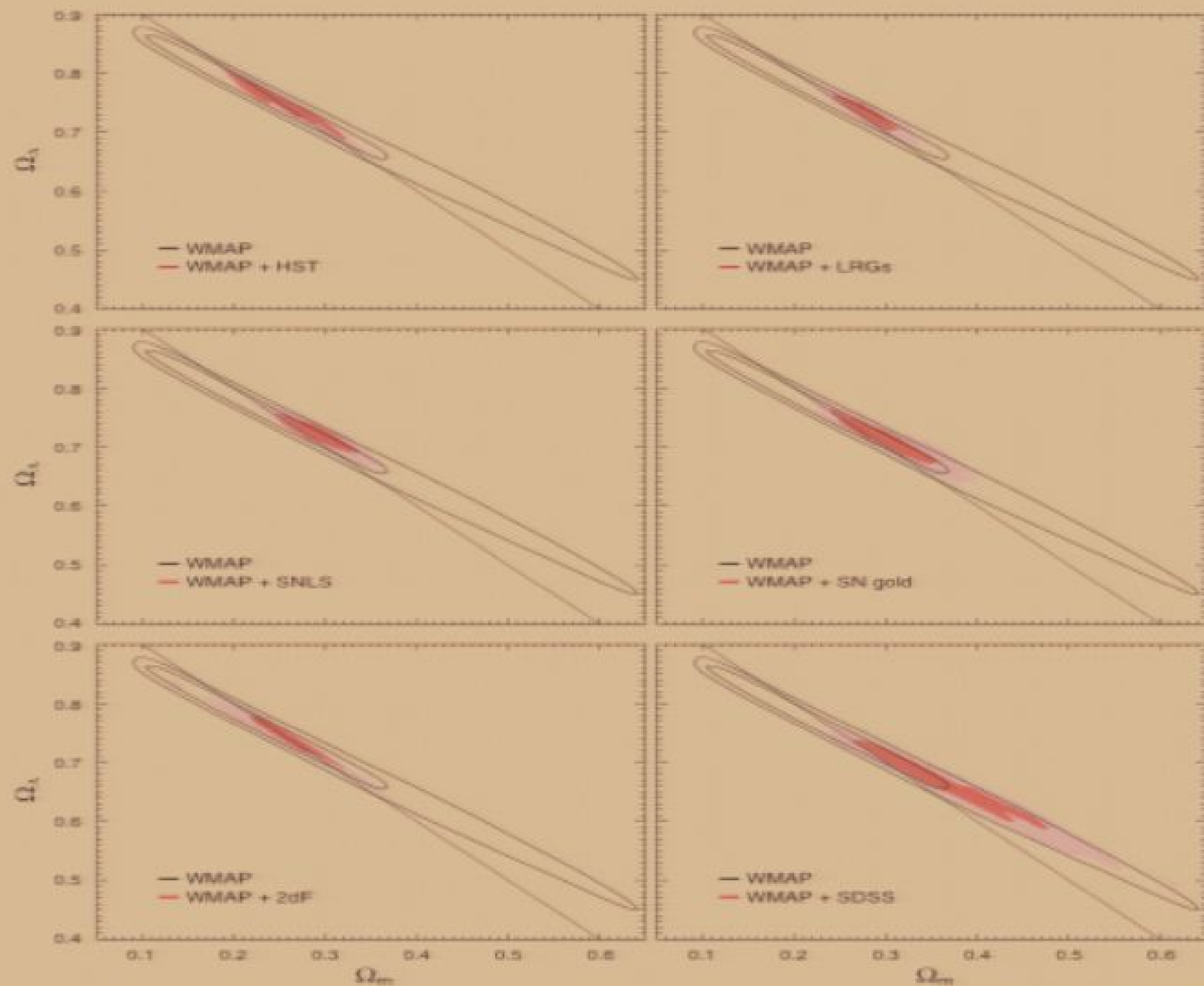
$$\frac{d \ln \Delta_R^2(k)}{d \ln k} = n_s(k_0) - 1 + \frac{dn_s}{d \ln k} \ln(k/k_0)$$



Similar constraints for B03+ACBAR

- Consistent trend but weak signal so far
- WMAP and LSS probe almost the same scales currently

Testing flatness



Data Set	Ω_K	Ω_Λ
WMAP + $h = 0.72 \pm 0.08$	$-0.003^{+0.013}_{-0.017}$	$0.758^{+0.035}_{-0.058}$
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WMAP + 2dFGRS	$-0.0057^{+[illegible]}_{-0.0064}$	[illegible]9 ± 0.028
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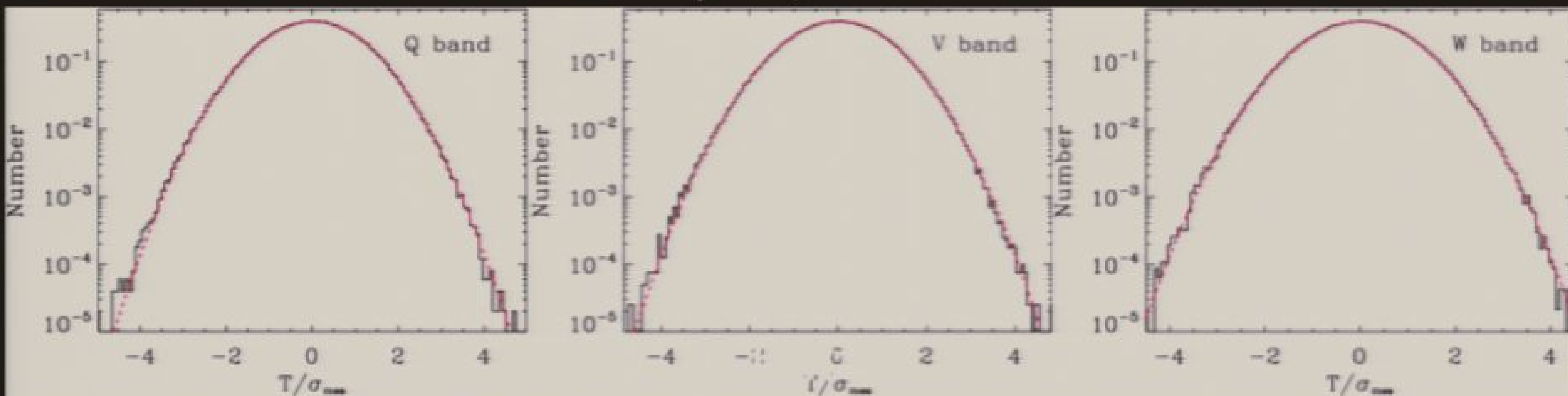
Testing Gaussianity: pdf distribution

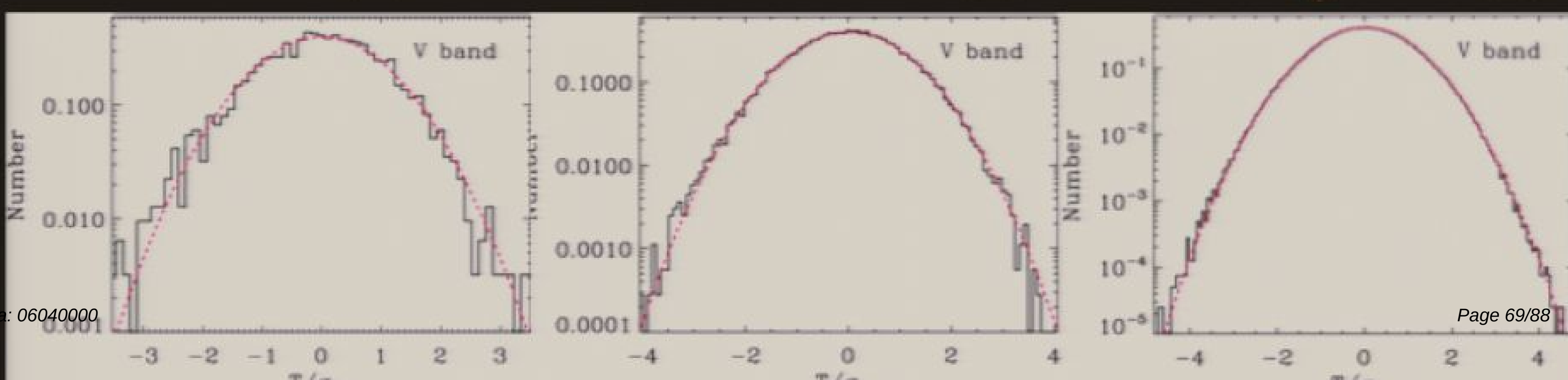
Various bands

$$u_p = \frac{T_p}{\sqrt{\frac{\sigma_0^2}{Nobs_p} + \sigma_{CMB}^2}}$$



V band at various resolution

Low res (4) Medium res (6) High res (8)



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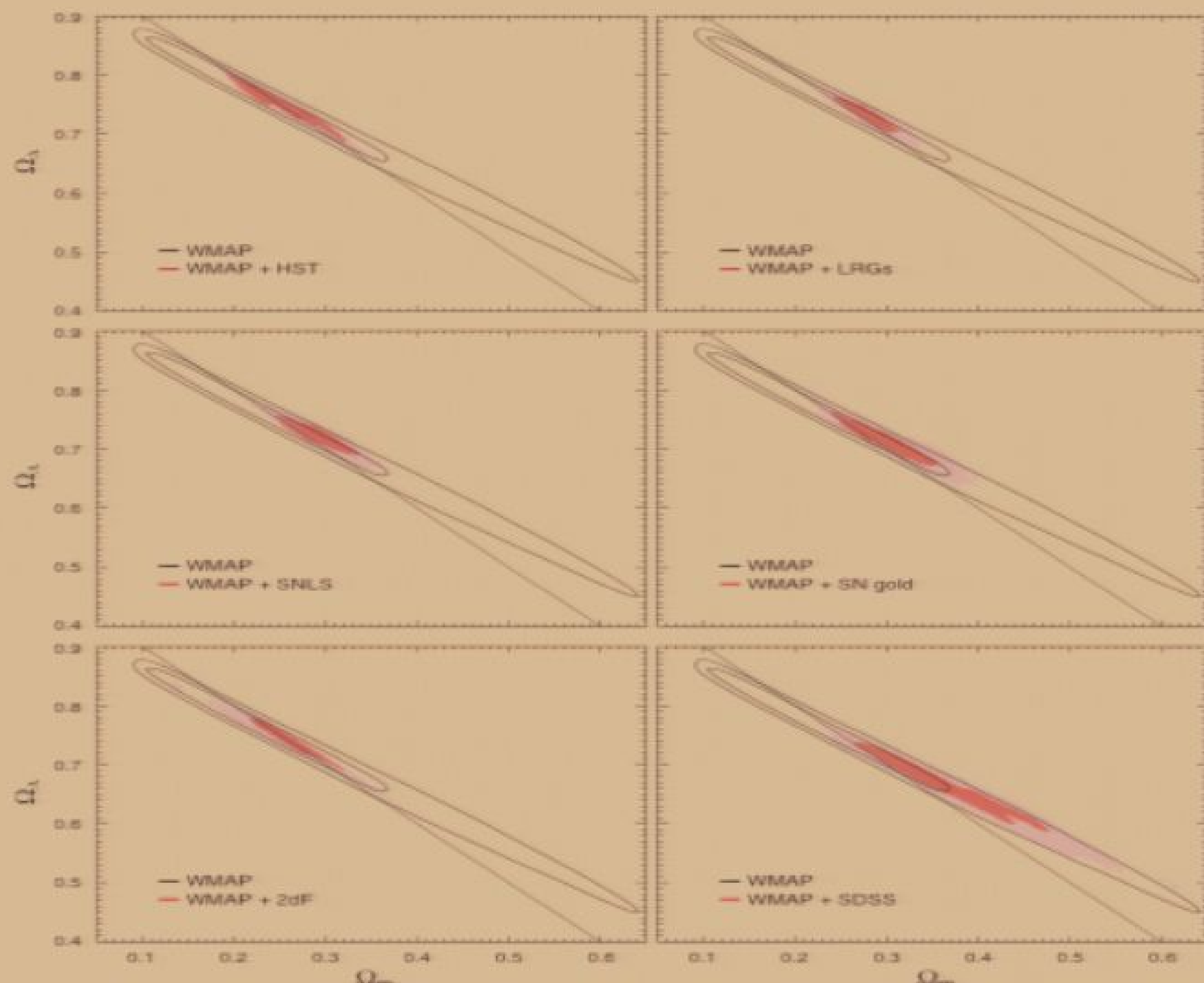

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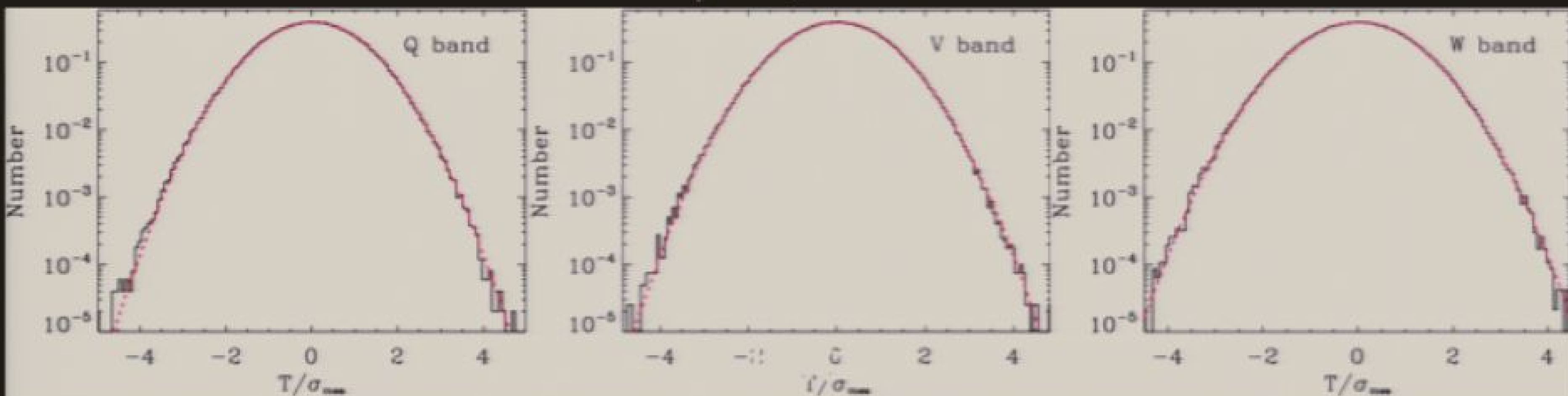

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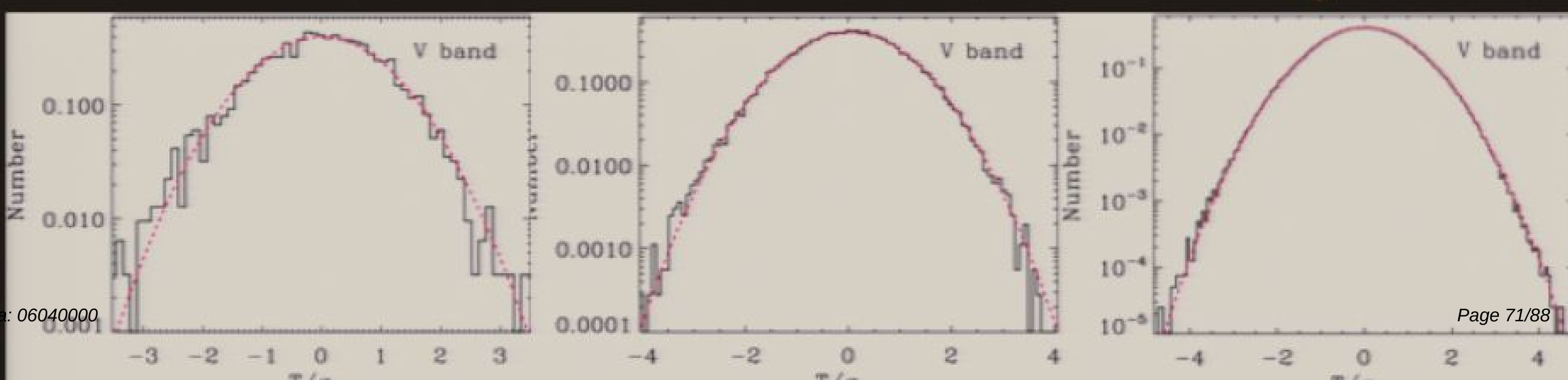
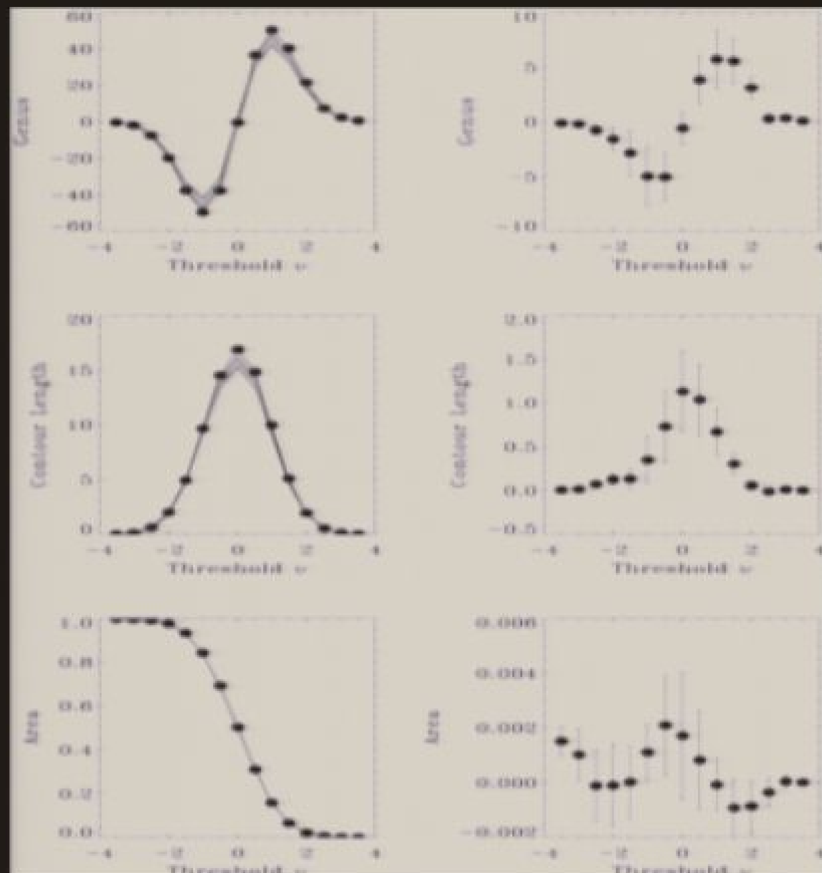


Testing Gaussianity: Minkovsky functionals & bispectrum

Comparison
to simulations



Residuals
(correlated)

Res 7 (28′ pix.)

Constraints on f_{NL} from bispectrum leads are
$-58 < f_{NL} < 137$ (1 year) (95%)
$-54 < f_{NL} < 114$ (3 years)

$$\Phi(\hat{x}) = \phi(\hat{x}) + f_{NL}\phi^2(\hat{x})$$

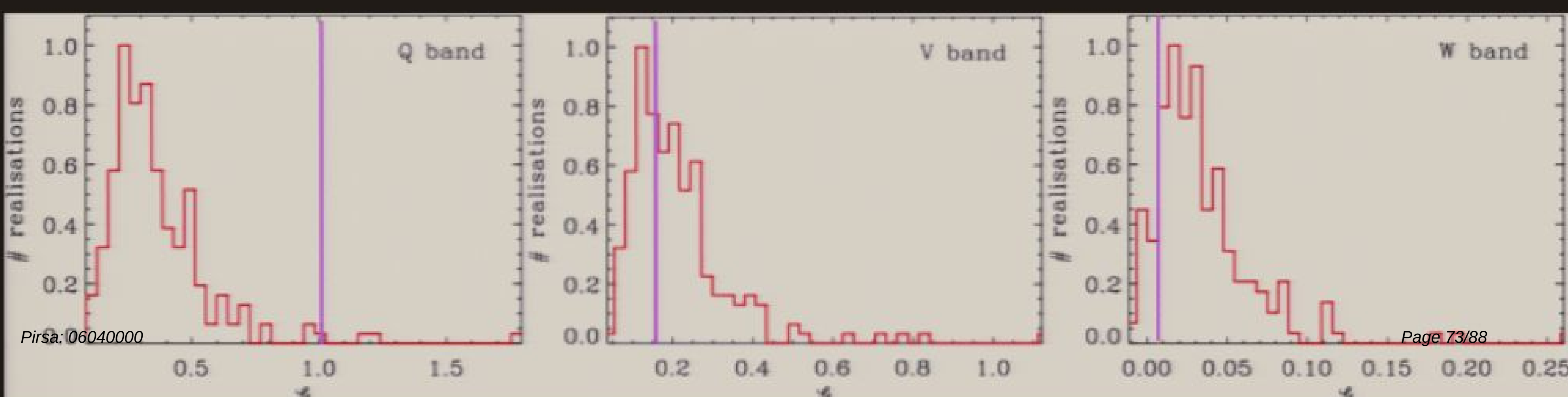
Testing Gaussianity: 4 points function

- Claims of large scale deviation from Gaussianity on large scales but no 3 point signal
- Could we have a NG signal without a 3 point (bispectrum) signal?
- Yes if *e.g.* Bardeen curvature modeled

$$\Phi(\hat{x}) = \phi(\hat{x})[1 + g_{NL}\psi(\hat{x})]$$

- The optimal estimator can be written as

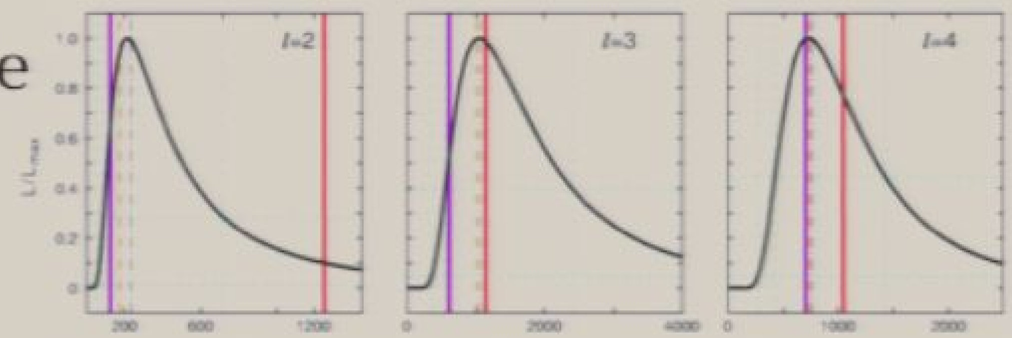
$$G = \sum_p \left(T_p^f \nabla^2 T_p^f - N_p^2\right)^2$$



Testing Gaussianity: Large scale temperature fluctuations

- Low COBE-WMAP quadrupole

Efstathiou 04
Slozar *et al.* 04
Bielewicz *et al.* 04

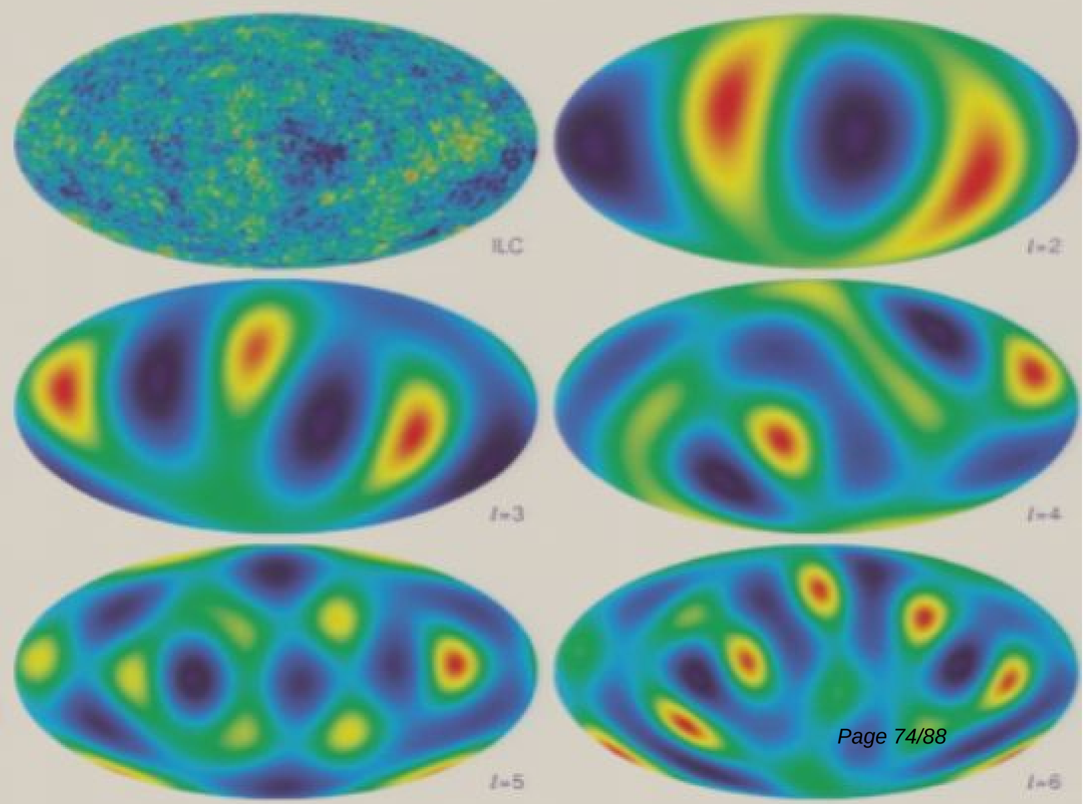


- Low *l* alignments

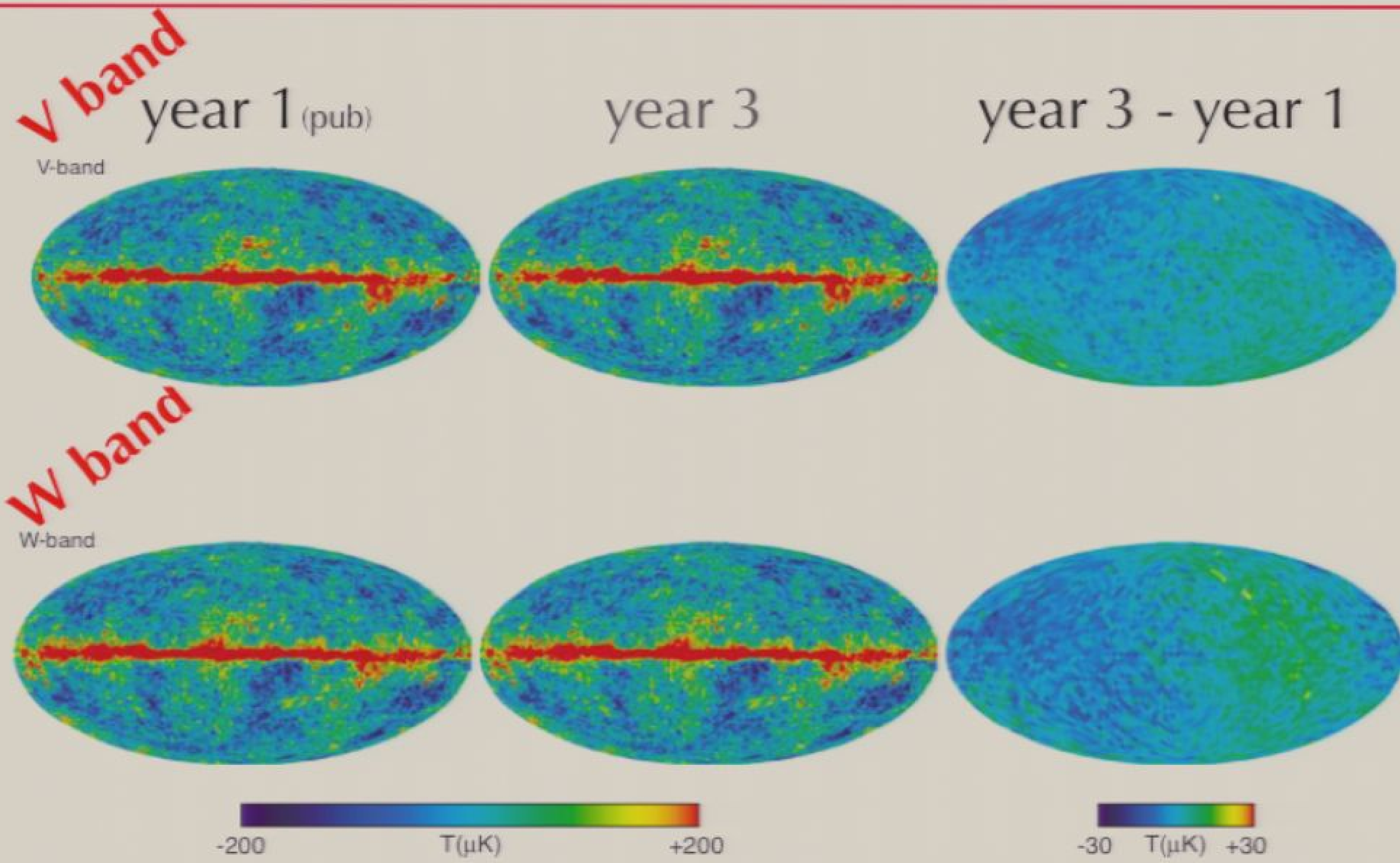
Tegmark *et al.* 04
de Oliveira-Costa *et al.* 04
Eriksen *et al.* 04
Copi et al. 04
Land & Mageuijo 04

- Low *l* power + alignment probability was estimated at ~4.10^{-5}
- This result is *a posteriori* so potentially strongly biased, but also potentially significant

- The yr3 temperature maps are almost unchanged at these scales



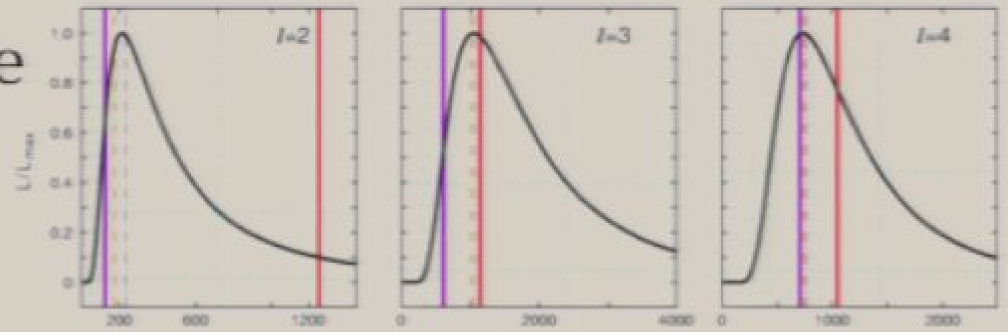
Unchanged Temperature maps on large scales



The previously mentioned analysis are very unlikely to be altered

Testing Gaussianity:
Large scale temperature fluctuations

- Low COBE-WMAP quadrupole



Efstathiou 04
Slozar *et al.* 04
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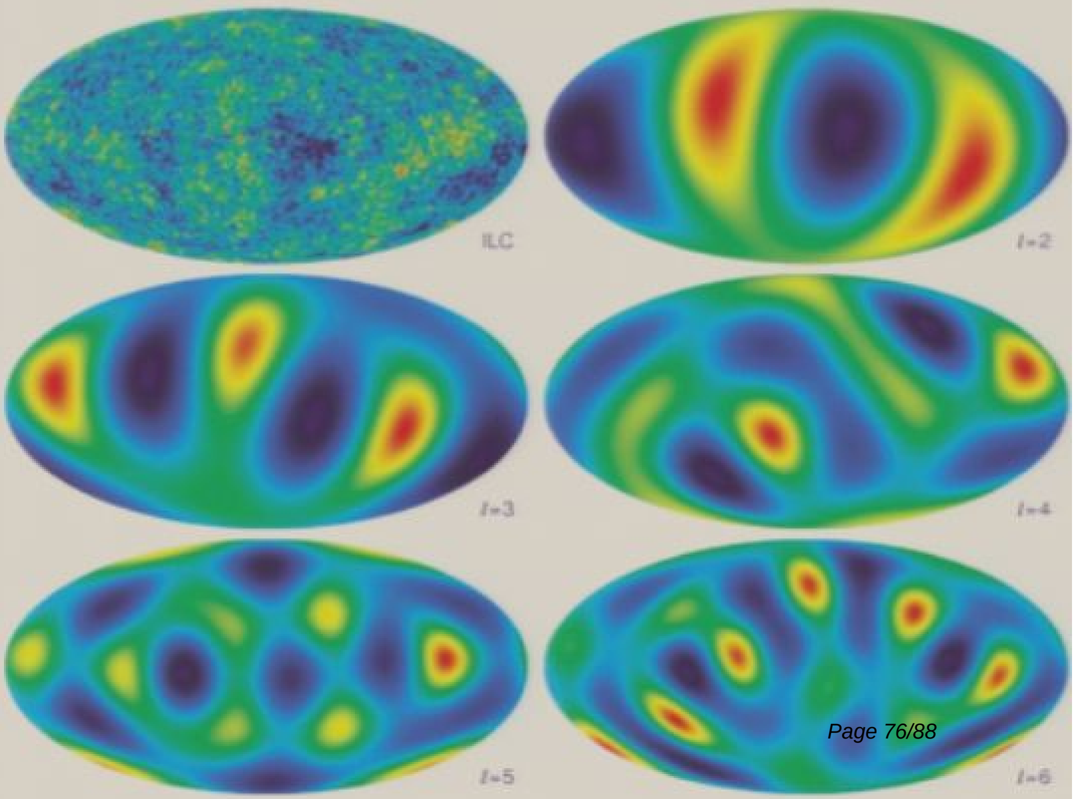

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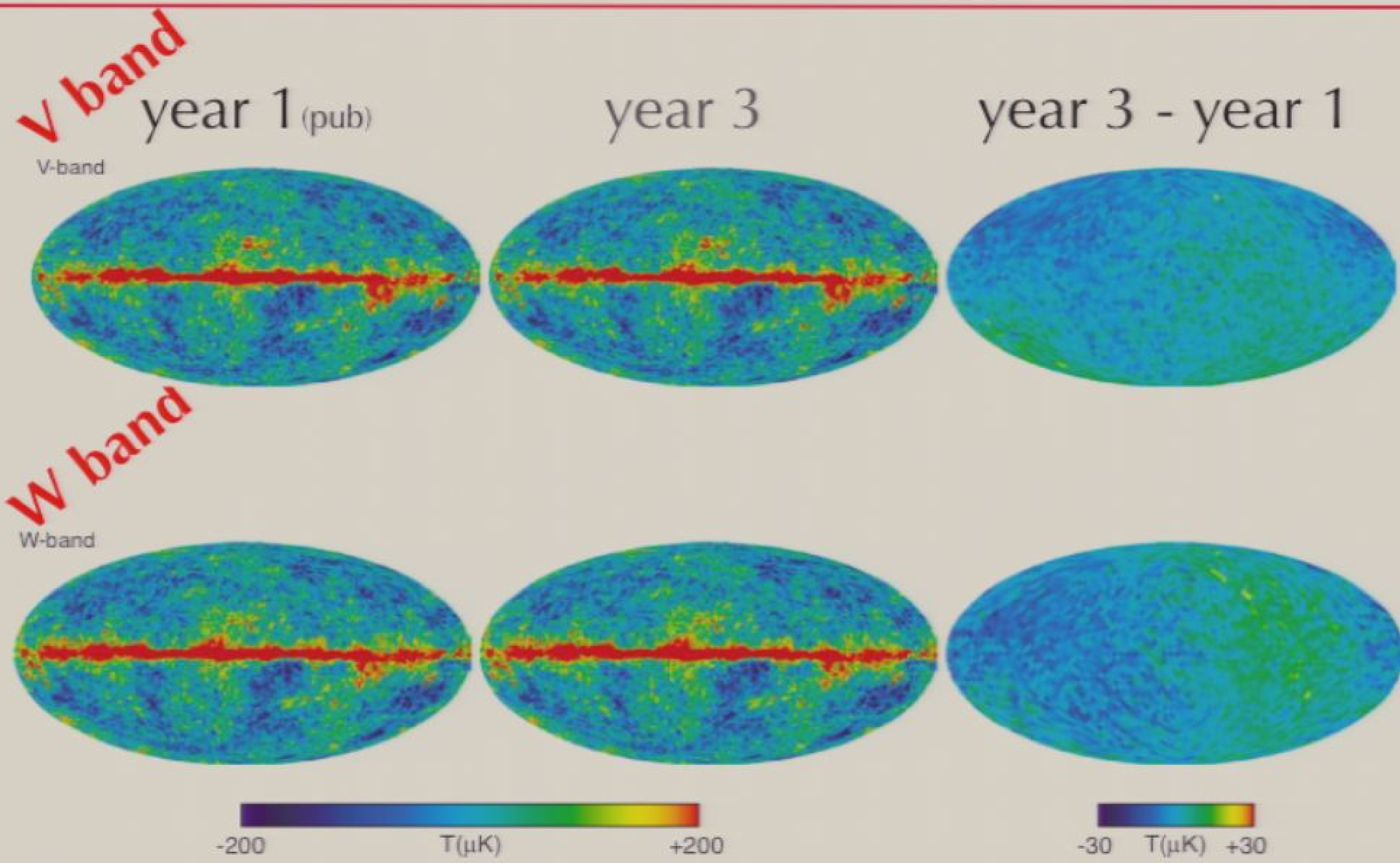

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Testing Isotropy
Large scale modulation

- We choose to address these 3 issues in a unifying manner by asking a simple question:

Can we describe the observed temperature field as a Gaussian isotropic field, T, modulated by an arbitrary (deterministic) field f ?

$$\tilde{T}(\hat{n}) = T(\hat{n})[1 + f(\hat{n})]$$

- Although the theoretical motivations are still weak, this phenomenological description is appealing since we can address and quantify in a Bayesian context the "alignment", low *l* power and asymmetry simultaneously
  - f = 0 is the usual assumption
  - If f was dipolar, it could lead to an asymmetry and potentially to some modifications to C_l of T
  - If f was quadrupolar, it would tend to align the observed quadrupole and octopole independantly of T and alter the C_l
  - etc.

$$f(\hat{n}) = \sum_{\ell=0}^{1\ or\ 2} \sum_{-\ell}^{+\ell} f_{\ell m} Y_{\ell m}(\hat{n})$$

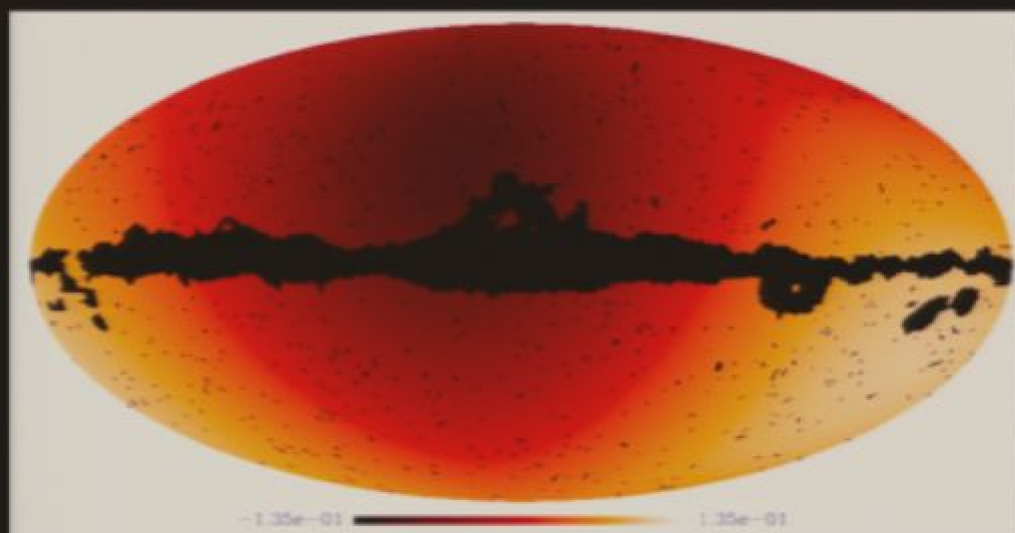
- We can compute the exact likelihood $L\left(\hat{T}|C_\ell, f_{\ell m}\right)$

Gordon *et al.* 04
Hajian *et al.* 04
Tomita *et al.* 03

Testing Gaussianity
Large scale modulation

$$\tilde{T}(\hat{n}) = T(\hat{n})[1 + f(\hat{n})]$$

f map



$l_{max}=1$

Testing Isotropy
Large scale modulation

- We choose to address these 3 issues in a unifying manner by asking a simple question:

Can we describe the observed temperature field as a Gaussian isotropic field, T, modulated by an arbitrary (deterministic) field f ?

$$\tilde{T}(\hat{n}) = T(\hat{n})[1 + f(\hat{n})]$$

- Although the theoretical motivations are still weak, this phenomenological description is appealing since we can address and quantify in a Bayesian context the "alignment", low *l* power and asymmetry simultaneously
  - f = 0 is the usual assumption
  - If f was dipolar, it could lead to an asymmetry and potentially to some modifications to C_l of T
  - If f was quadrupolar, it would tend to align the observed quadrupole and octopole independantly of T and alter the C_l
  - etc.

$$f(\hat{n}) = \sum_{\ell=0}^{1\ or\ 2} \sum_{-\ell}^{+\ell} f_{\ell m} Y_{\ell m}(\hat{n})$$

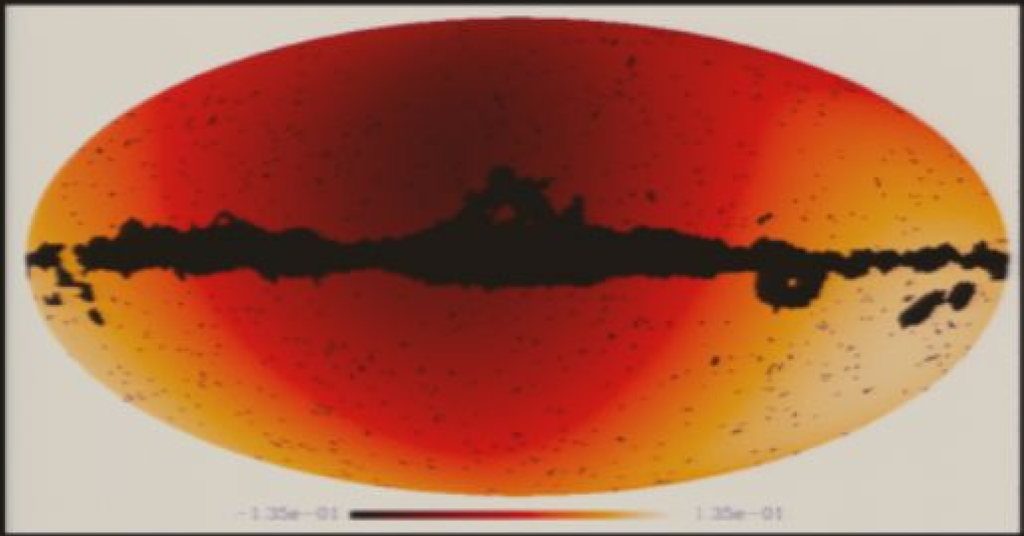
- We can compute the exact likelihood $L\left(\hat{T}|C_\ell, f_{\ell m}\right)$

Gordon *et al.* 04
Hajian *et al.* 04
Tomita *et al.* 03

Testing Gaussianity
Large scale modulation

$$\tilde{T}(\hat{n}) = T(\hat{n})[1 + f(\hat{n})]$$

f map

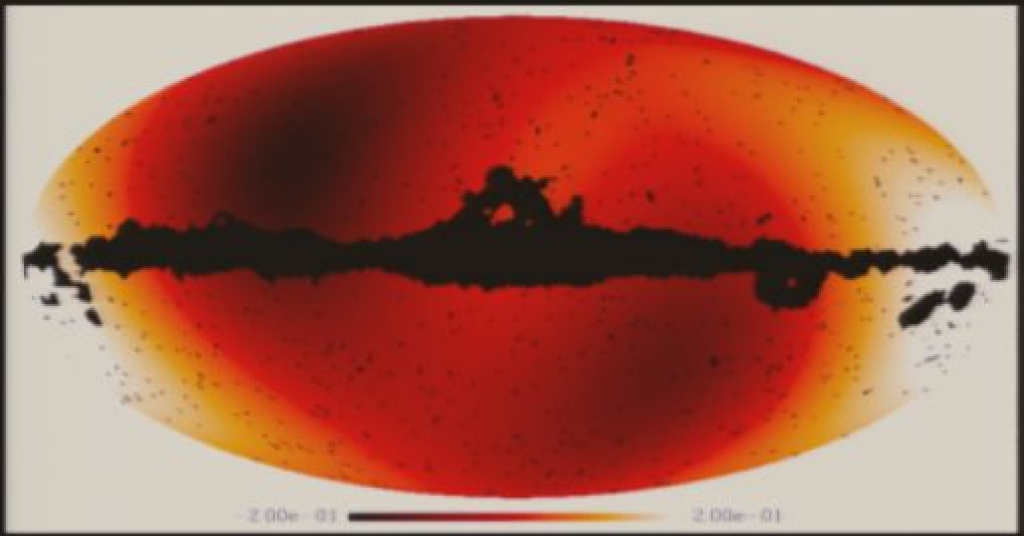


$l_{max}=1$

Testing Gaussianity
Large scale modulation

$$\tilde{T}(\hat{n}) = T(\hat{n})[1 + f(\hat{n})]$$

f map

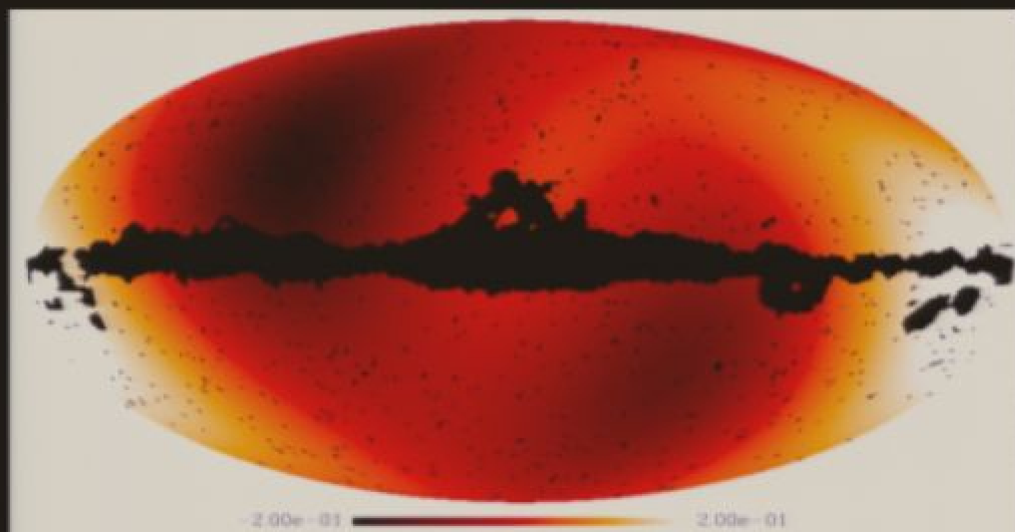


$l_{max}=2$

Testing Gaussianity
Large scale modulation

$$\tilde{T}(\hat{n}) = T(\hat{n})[1 + f(\hat{n})]$$

f map



l_{max}=2

Significance

- Dipolar modulation (*l_{max}=1*), Δ(-2ln L) =-3.4 for 3 extra parameters
- Quadrupolar (*l_{max}=2*), Δ(-2ln L) =-8.0 for 8 extra parameters
- The low *l* C_ls are unaffected as are the multipole modes of T
- Note that we could easily boost the significance were we to choose *a posteriori* a direction, but no physical motivations so far
- We conclude that more evidences are required for such a radical reinterpretation of our data

Testing Gaussianity
Large scale modulation

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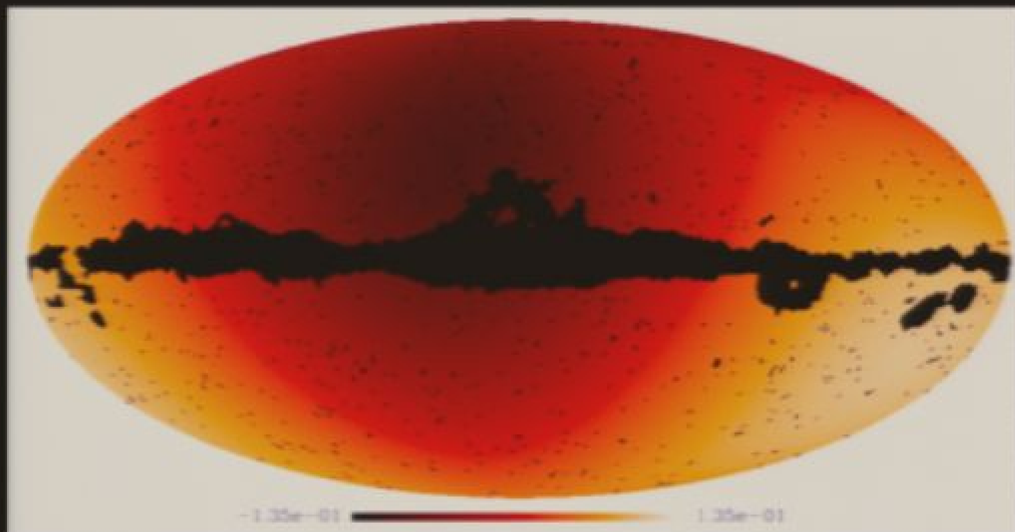

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Testing Gaussianity
Large scale modulation

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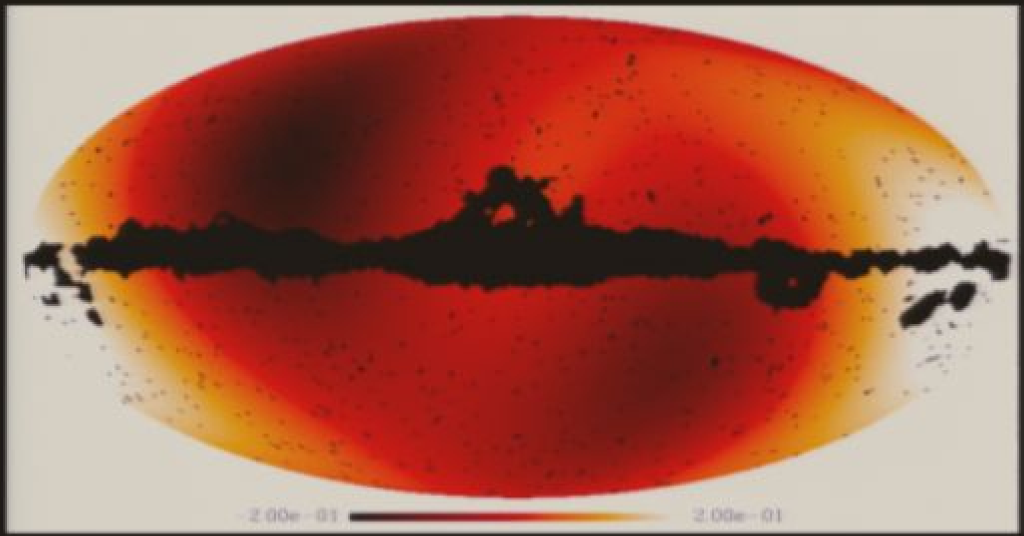

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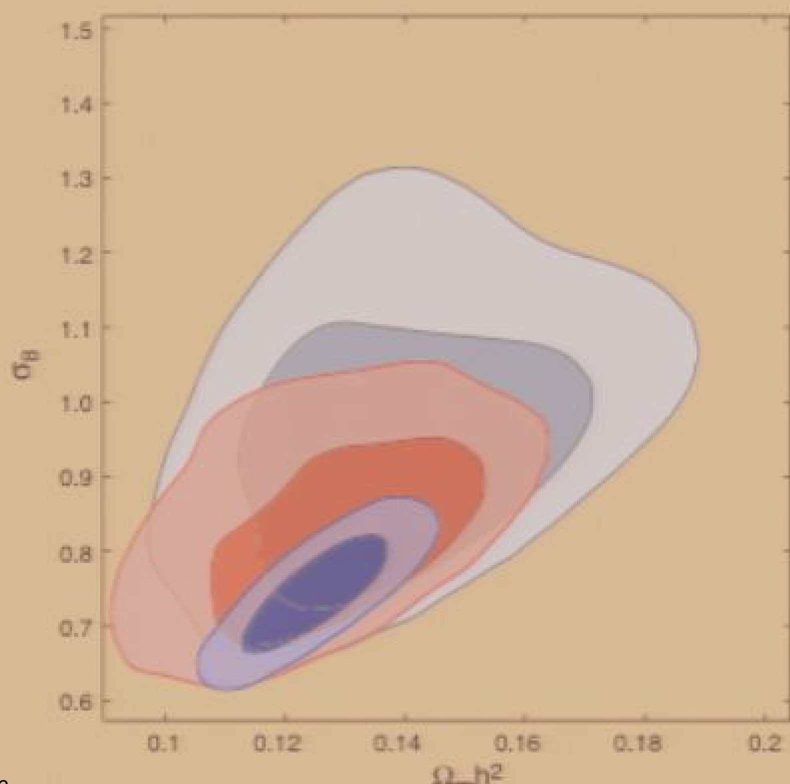
Conclusions

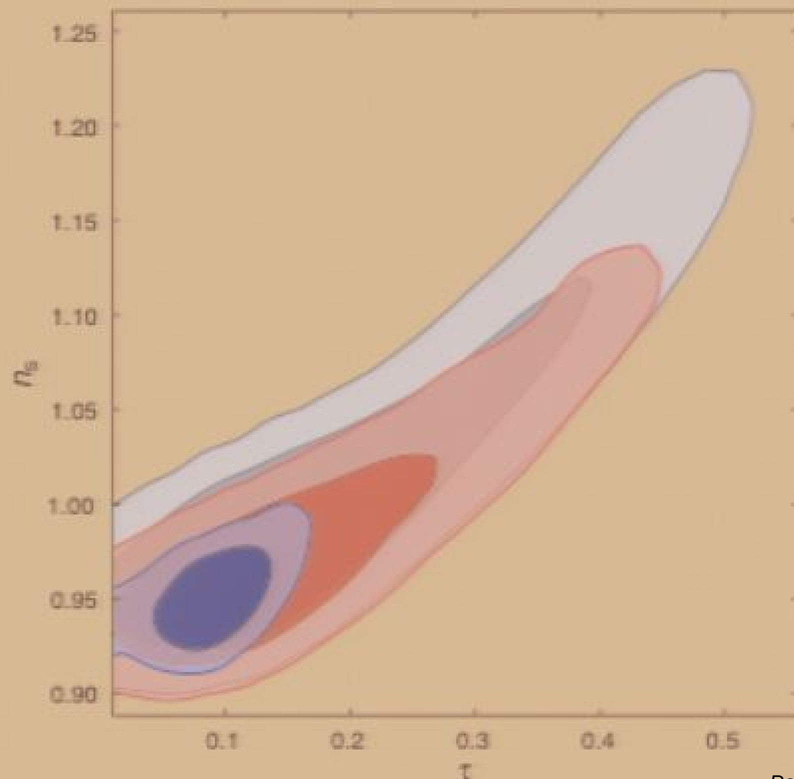
- WMAP has now produced well characterized temperature and polarization maps
- After removing the galactic foregrounds, WMAP has detected EE and TE signatures of reionization with optical depth of 0.09
- Simple flat ΛCDM cosmological model has survived its most rigorous test
- Data favors red spectral index (with values consistent with simple inflationary models) over Harrison-Zeldovich Peebles spectrum
- More complex initial power spectrum does not significantly improve the fit to the data
- The combination of WMAP data and other astronomical data now places even stronger constraints on the density of dark matter and dark energy, the properties of neutrinos, the properties of dark energy and the geometry of the Universe
- All the data and the derived products (time ordered data, maps, noise covariance matrices, simulations, likelihood codes, Markov chains) are all available on Lambda http://lambda.gsfc.nasa.gov . We are looking forward your analysis!

Improvement in parameter space

Parameter	First Year Mean	WMAPext Mean	Three Year Mean	First Year ML	WMAPext ML	Three Year ML
$100\Omega_b h^2$	$2.38^{+0.13}_{-0.12}$	$2.32^{+0.12}_{-0.11}$	2.23 ± 0.08	2.30	2.21	2.22
$\Omega_m h^2$	$0.144^{+0.016}_{-0.016}$	$0.134^{+0.006}_{-0.006}$	0.126 ± 0.009	0.145	0.138	0.128
H_0	72^{+5}_{-5}	73^{+3}_{-3}	74^{+3}_{-3}	68	71	73
τ	$0.17^{+0.08}_{-0.07}$	$0.15^{+0.07}_{-0.07}$	0.093 ± 0.029	0.10	0.10	0.092
n_s	$0.99^{+0.04}_{-0.04}$	$0.98^{+0.03}_{-0.03}$	0.961 ± 0.017	0.97	0.96	0.958
Ω_m	$0.29^{+0.07}_{-0.07}$	$0.25^{+0.03}_{-0.03}$	0.234 ± 0.035	0.32	0.27	0.24
σ_8	$0.92^{+0.1}_{-0.1}$	$0.84^{+0.06}_{-0.06}$	0.76 ± 0.05	0.88	0.82	0.77



Driven by 3^{d} peak



Driven by EE

Final CMB spectra