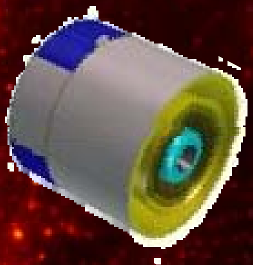
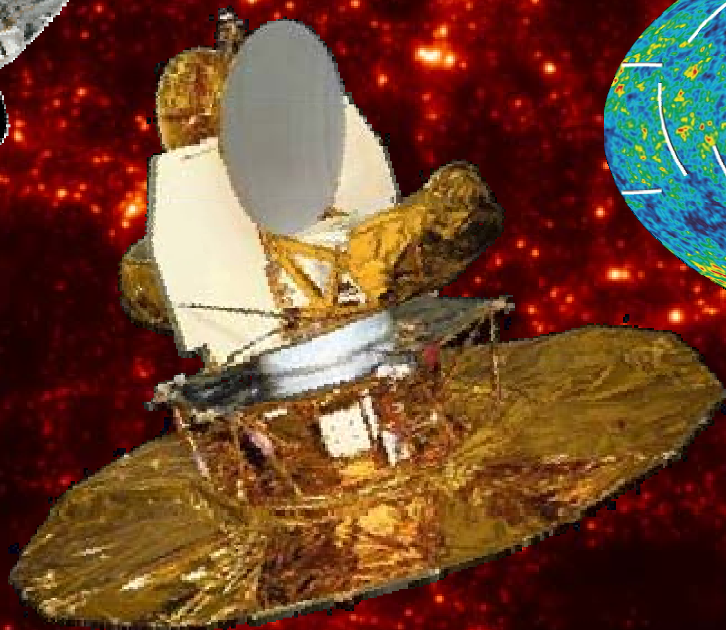
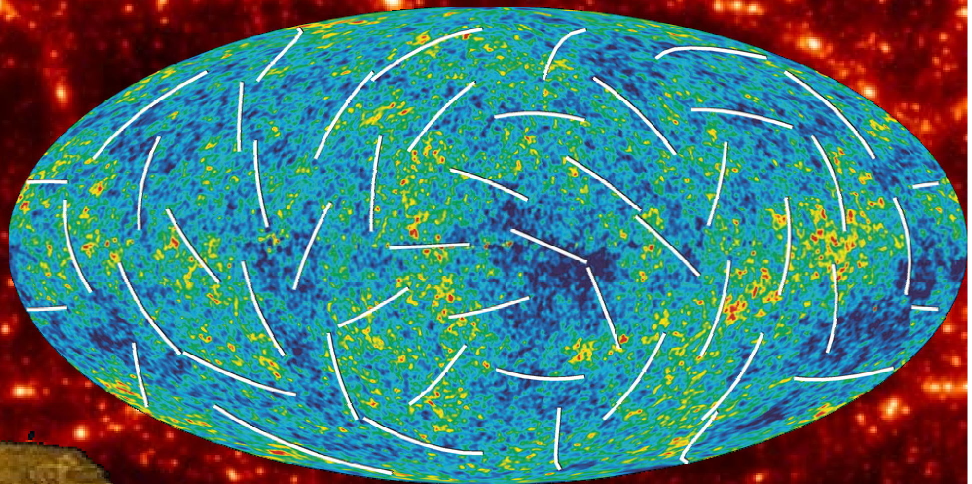
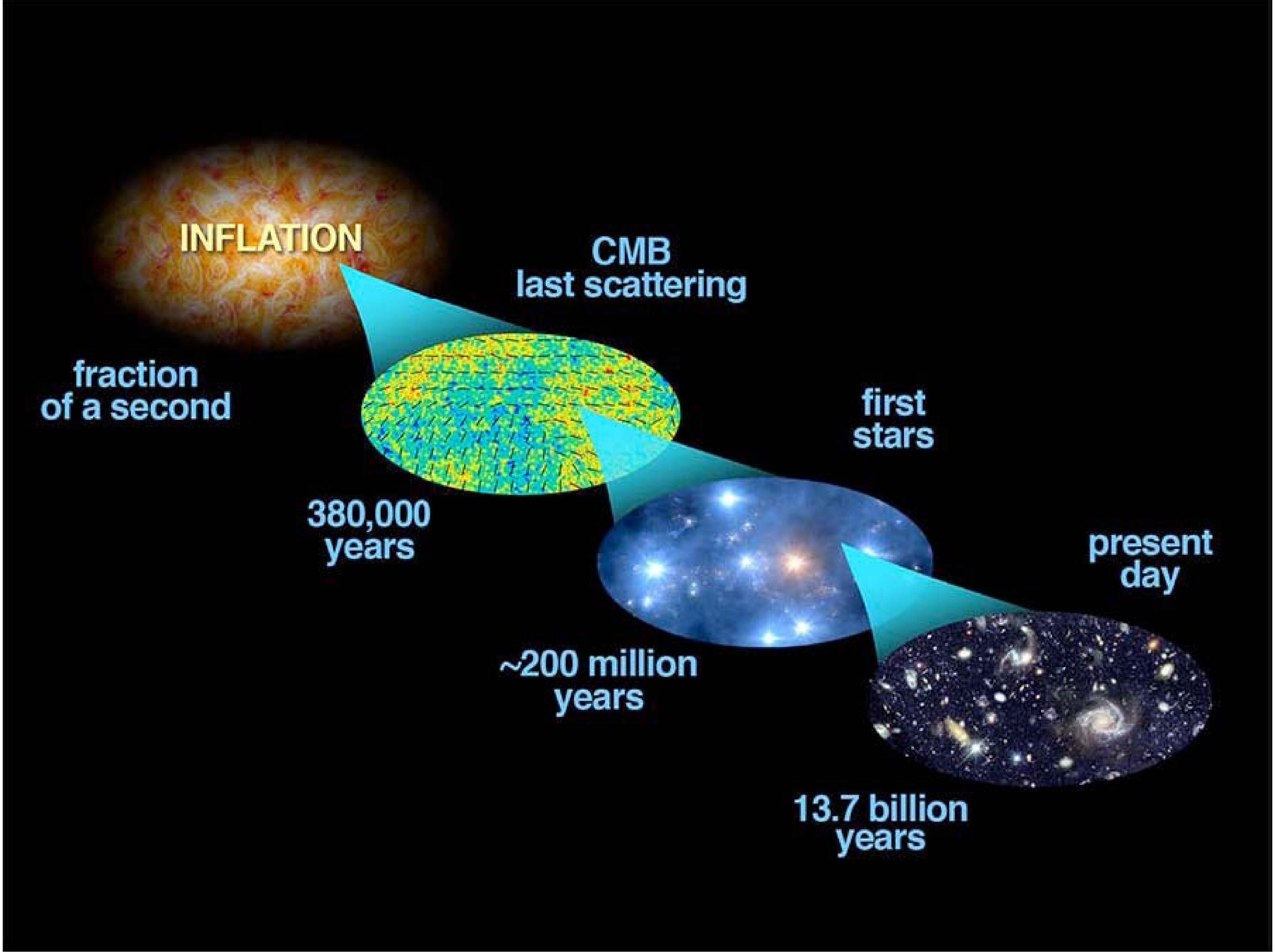
CMB ANISOTROPIES: CURRENT STATUS & PERSPECTIVES



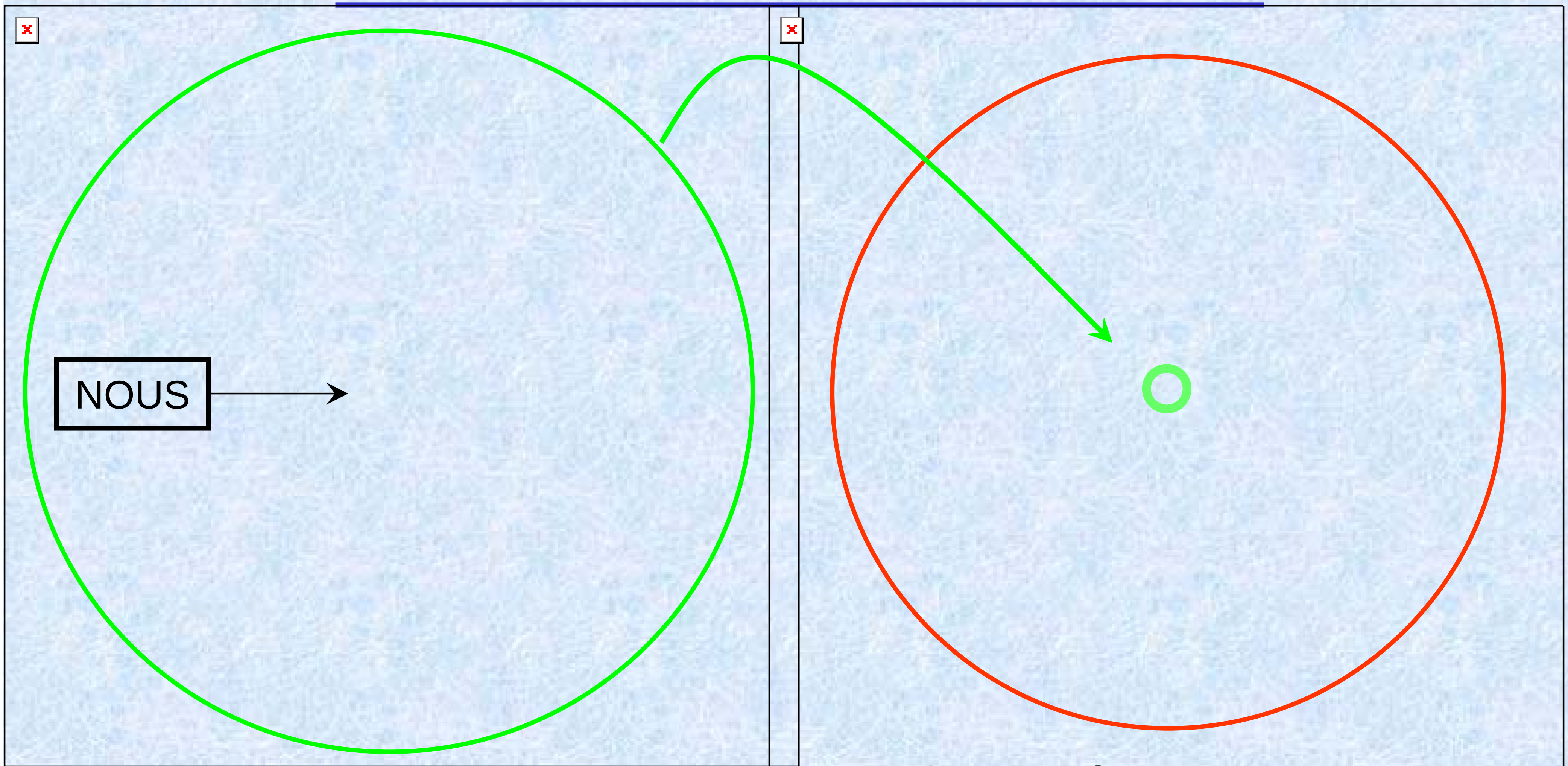




F. R. BOUCHET
INSTITUT D'ASTROPHYSIQUE DE PARIS, CNRS
IAP, PARIS, MAY 5TH 2006


INFLATION
CMB
last scattering
fraction
of a second
first
stars
380,000
years
present
day
~200 million
years
13.7 billion
years

VOIR LOIN, C'EST VOIR LE PASSÉ LOINTAIN !

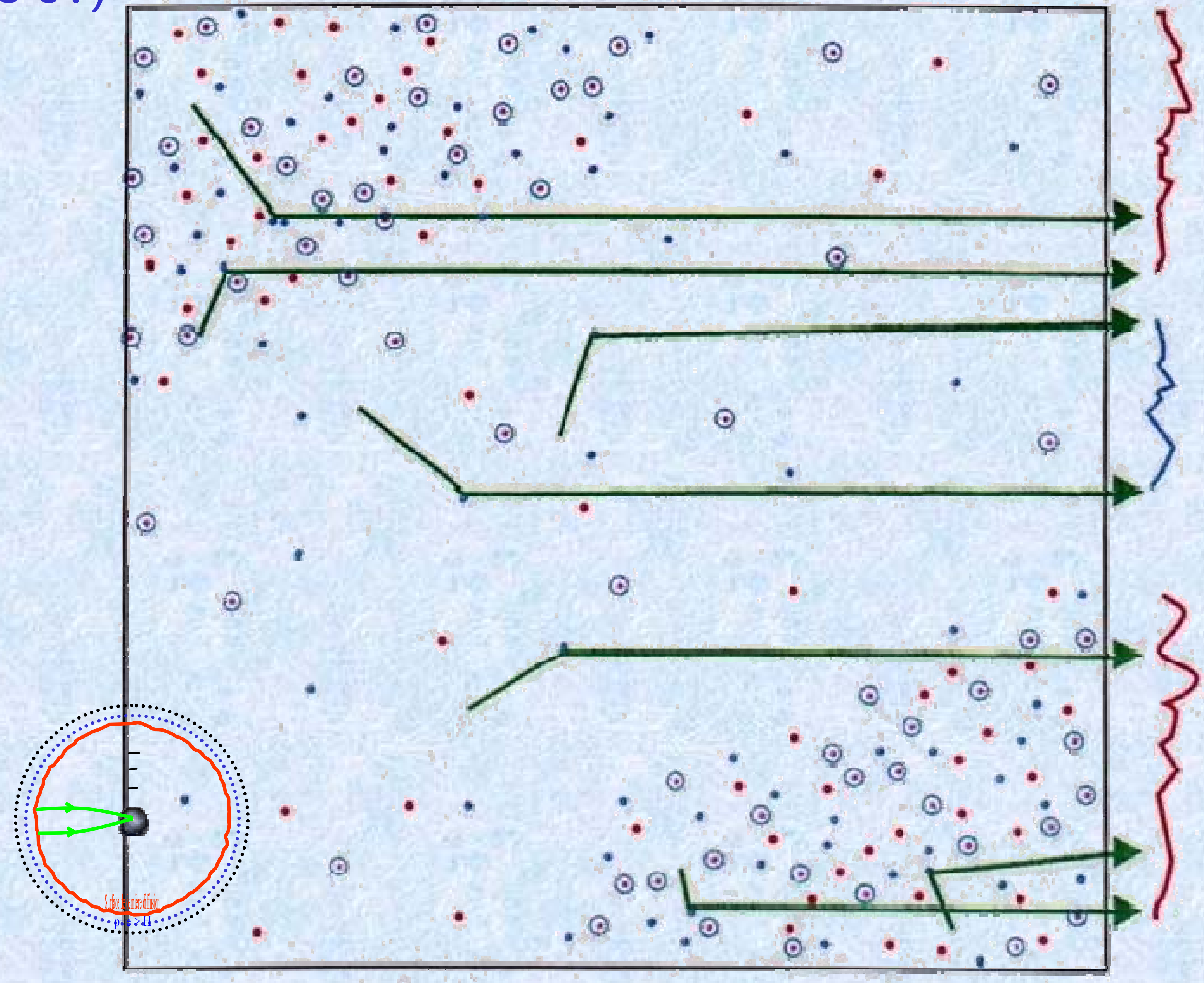


Chaque point est une galaxie comme la Notre. La plus proche, M31, est à ~2,5 Mal. Il faut 2,7 milliards d'années à la lumière d'une galaxie sur le cercle vert pour qu'elle nous parvienne.

La lumière **millimétrique** a mis environ 13 milliards d'années pour nous parvenir (cercle rouge).
C'est la trace intacte (comme fossilisée) de la fournaise primordiale, 400 000 ans après le Bang, quand l'Univers est devenu Transparent.

Quand l'univers devient transparent…

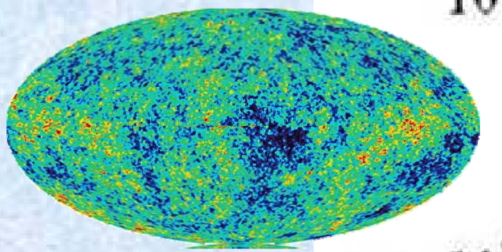
(at ~1/3 eV)



+ ISW…

$\Theta+\psi$
& v

« Cosmométrie »: spectre de puissance angulaire des anisotropies de température



Hauteur des vagues / longueur d'onde l

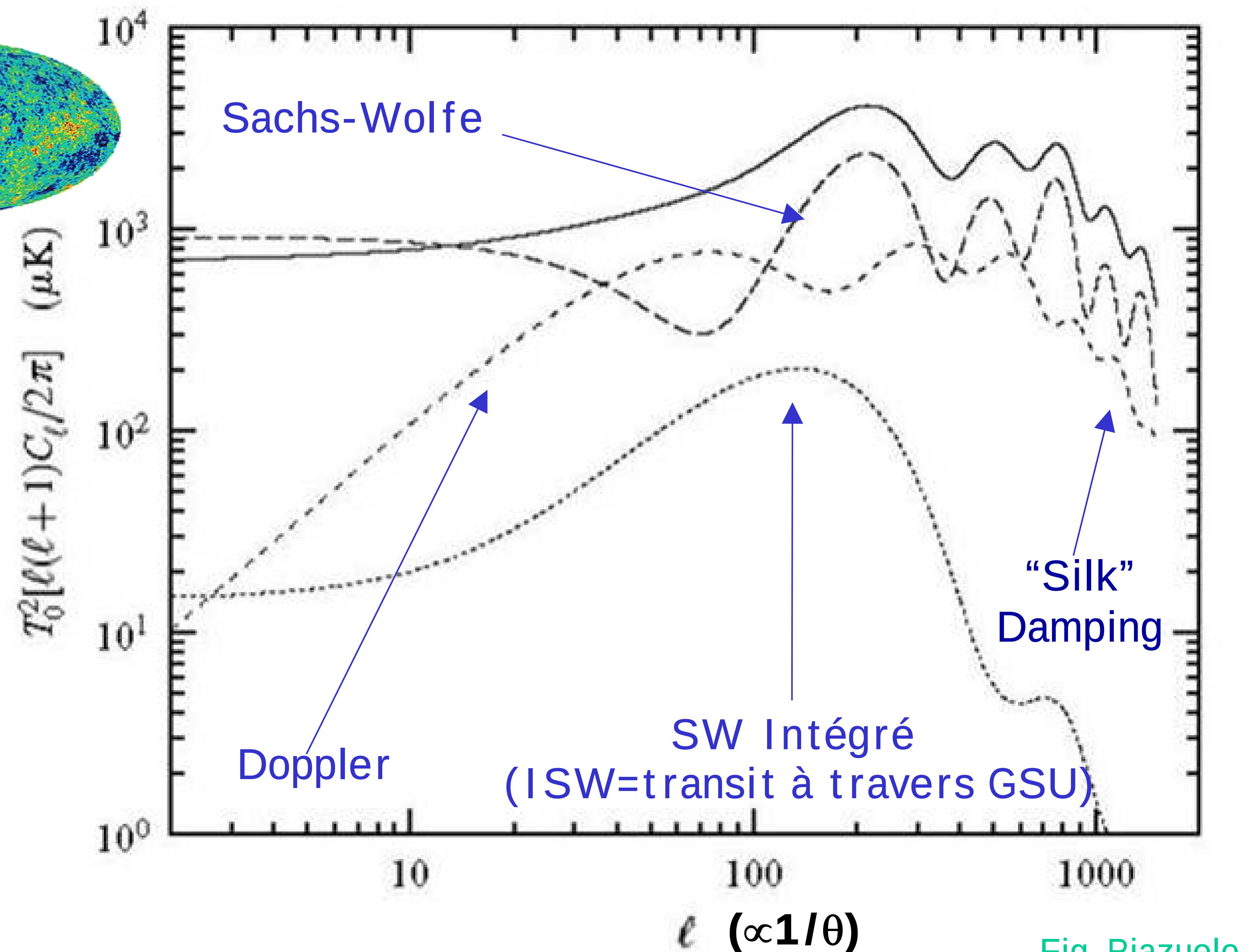
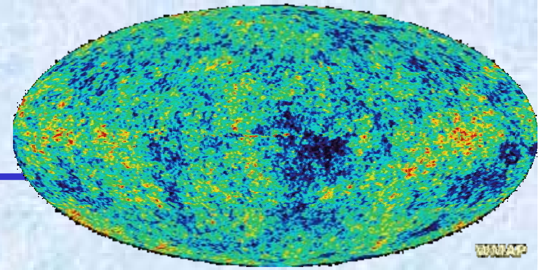
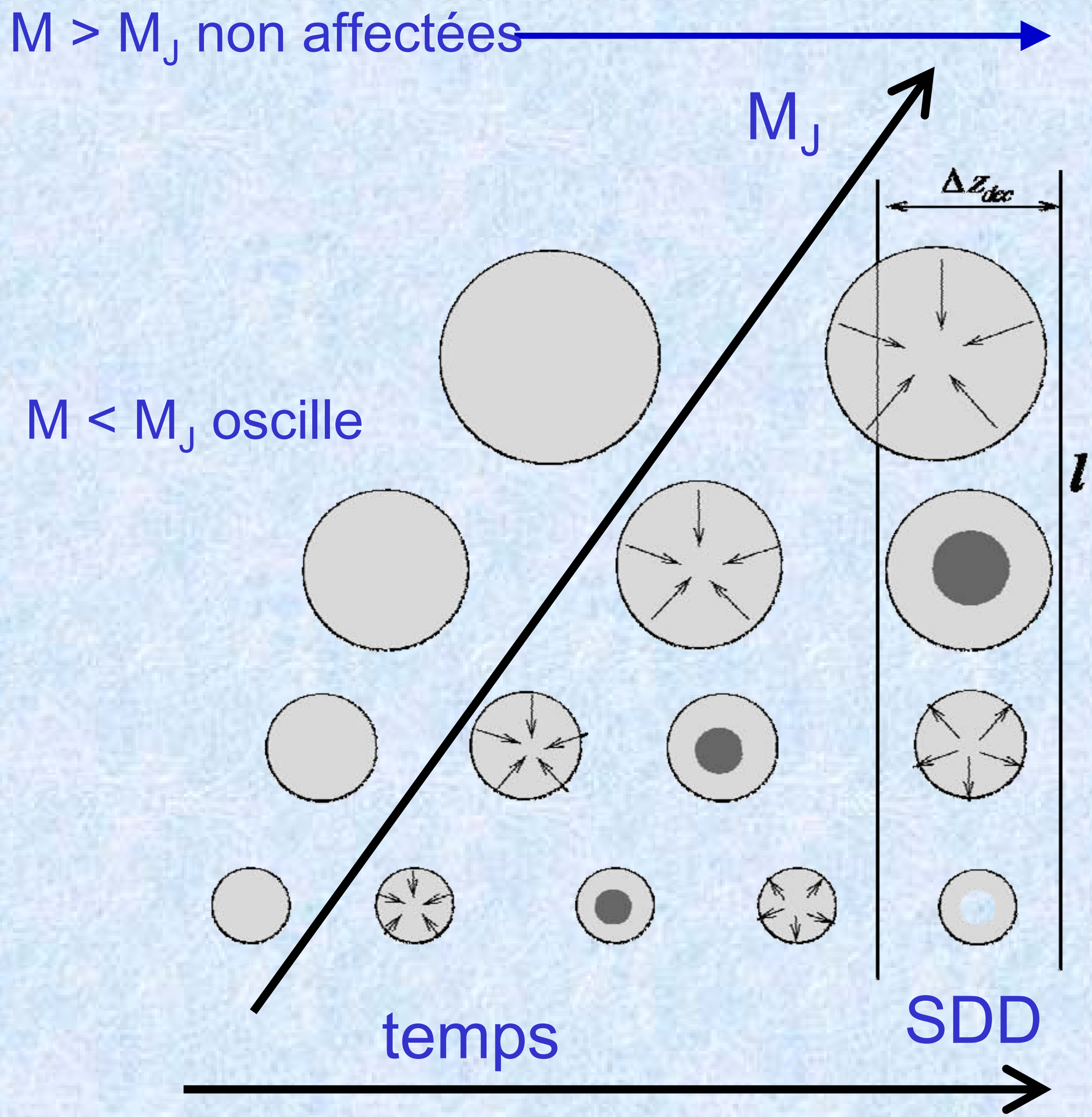


Fig. Riazuelo

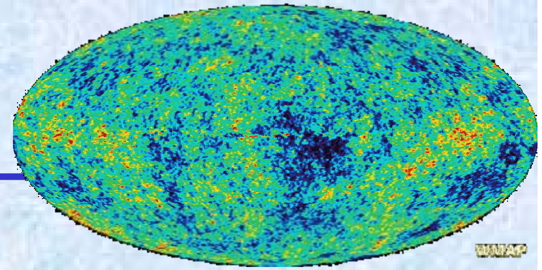
NB1 : Ici, cas restreint de fluctuations Scalaires uniquement (sinon il existe un terme additionnel)
NB2 : SW & ISW sont anti-corrélés

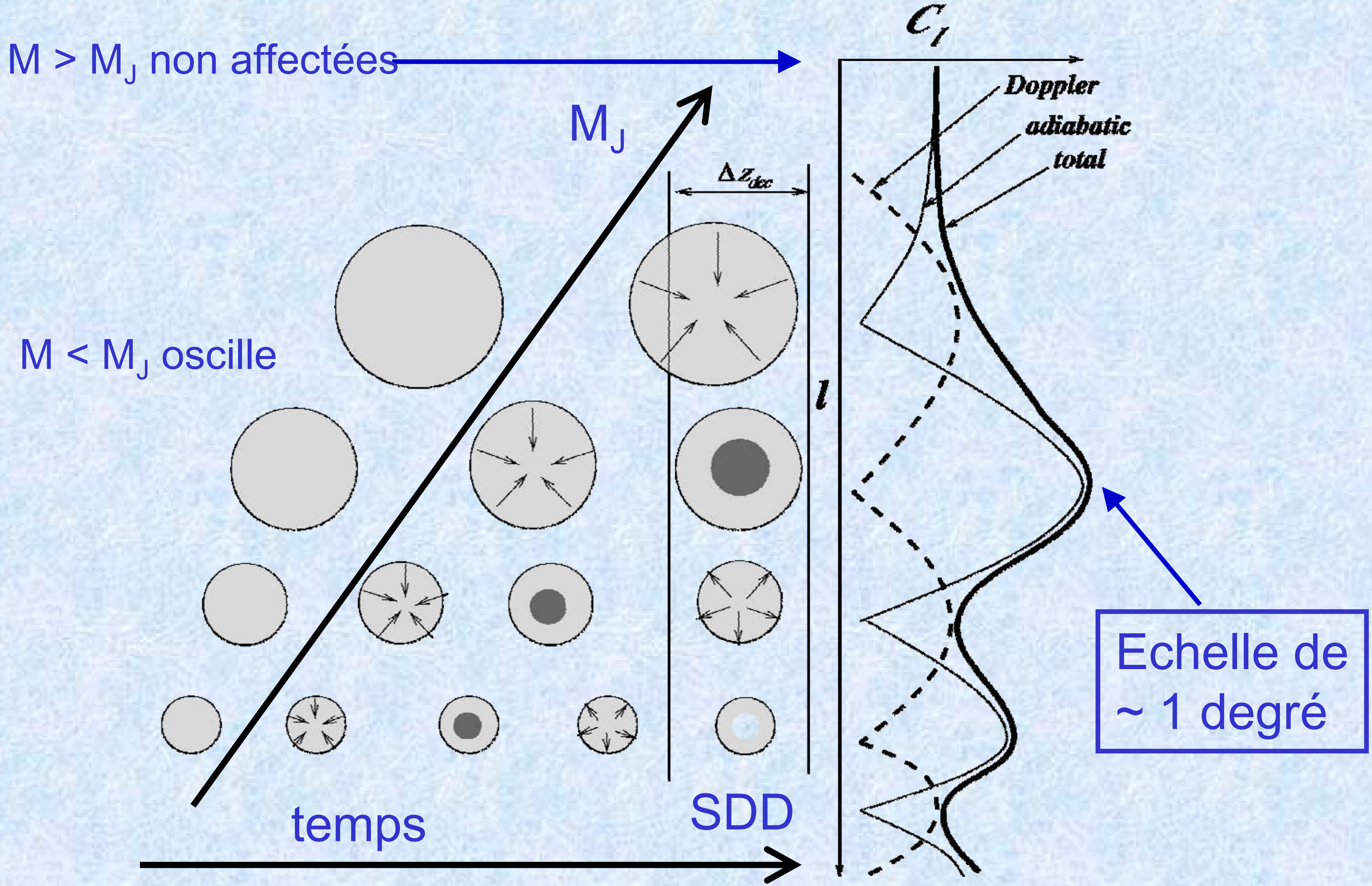
OSCILLATIONS ACOUSTIQUES





OSCILLATIONS ACOUSTIQUES

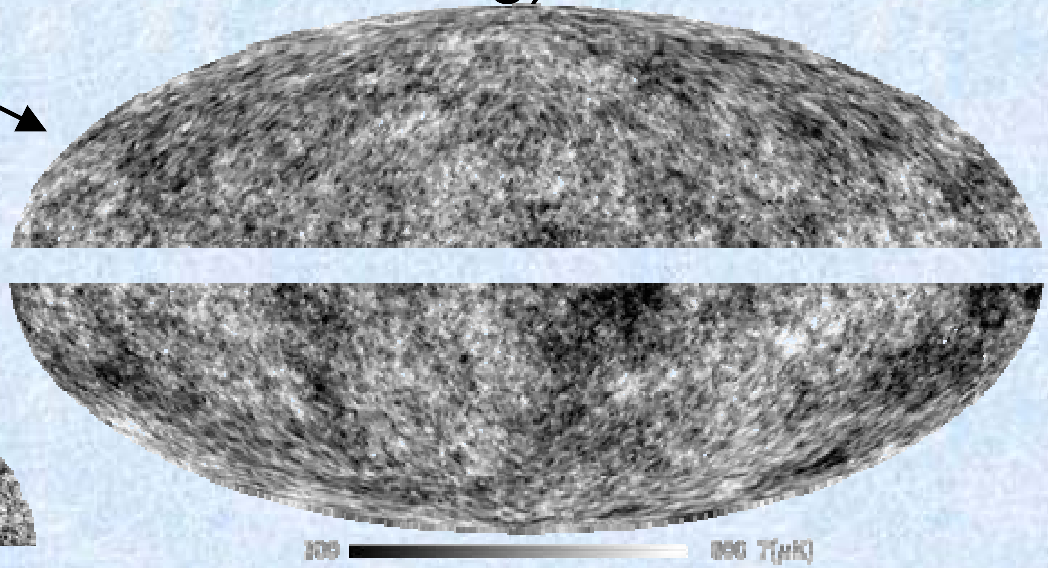


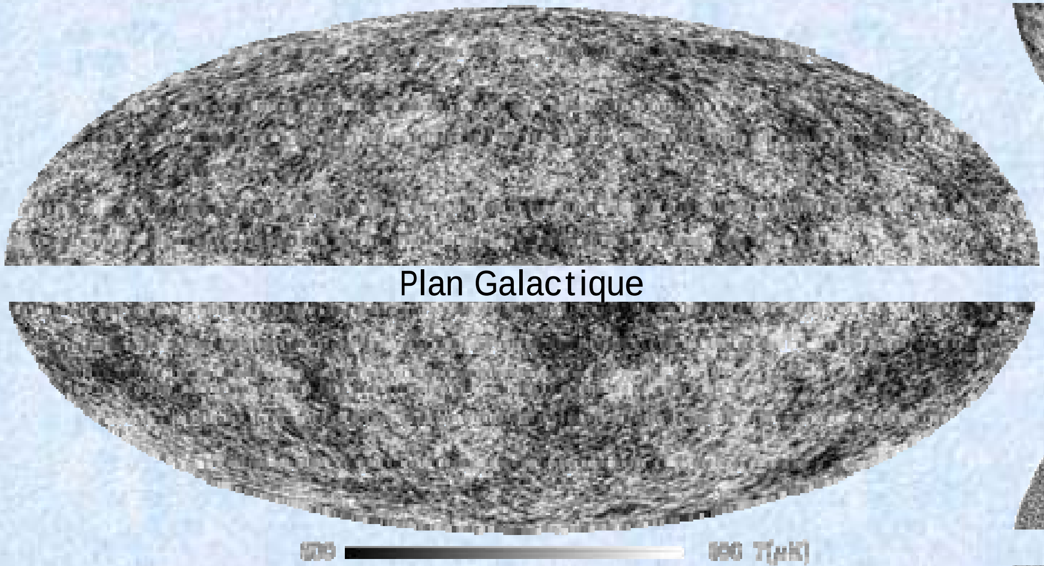


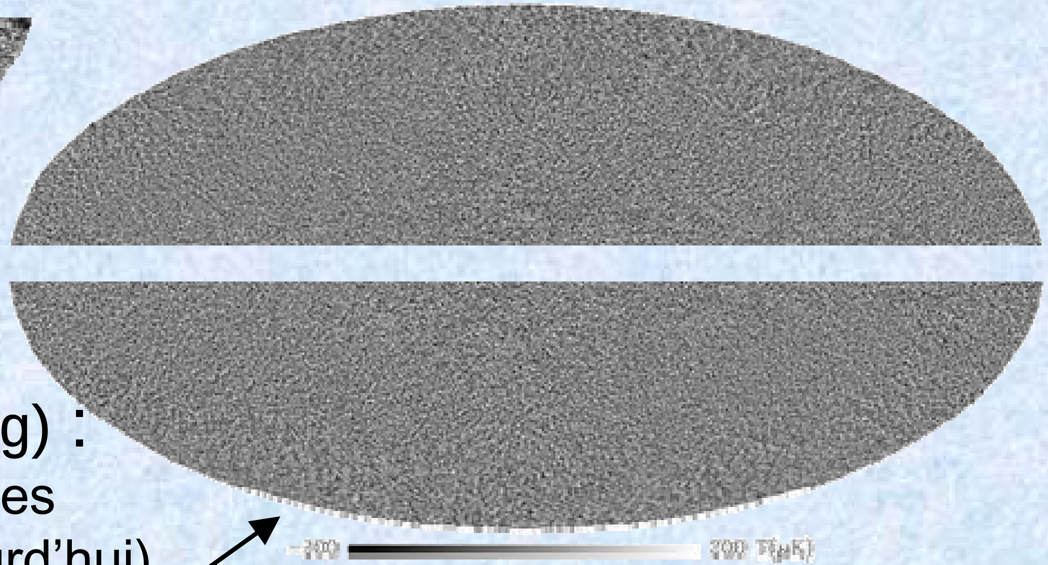
CE QU'ON OBSERVE

Carte lissée (suppression des échelles θ < 1 deg) :

Fluctuations Quantiques imprimées quand l'age de l'Univers était dans l'intervalle [10^{-43}, 10^{-12}] seconds





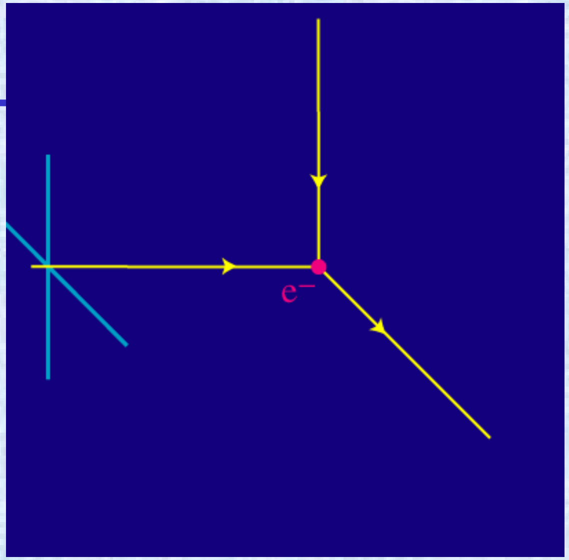


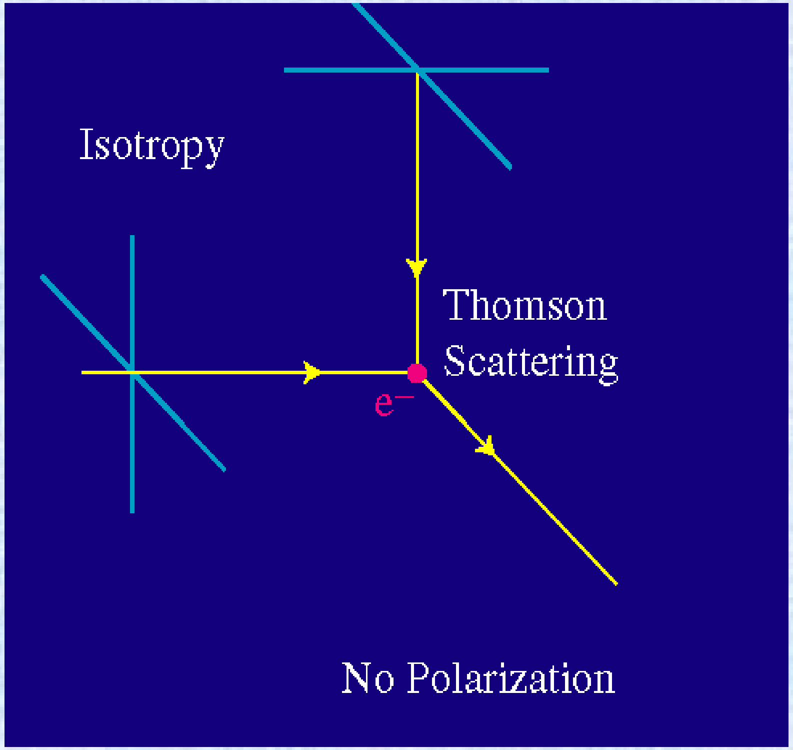
Carte différence (échelles θ < 1 deg) :

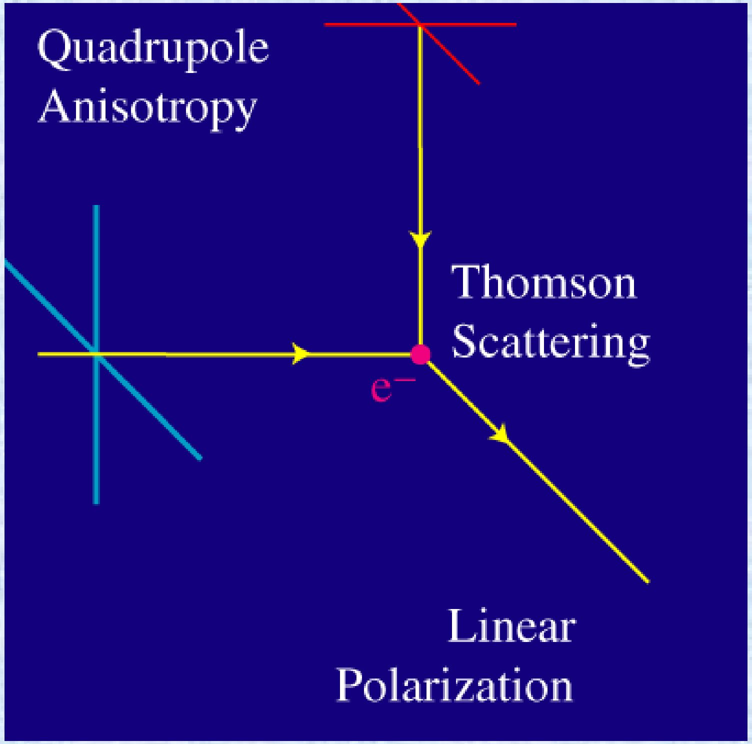
Oscillations acoustiques aux petites échelles < ct quand t=370 000 ans (~150Mpc aujourd'hui).

Permet de recenser le contenu

LES DIFFUSIONS THOMSON SONT POLARISÉES

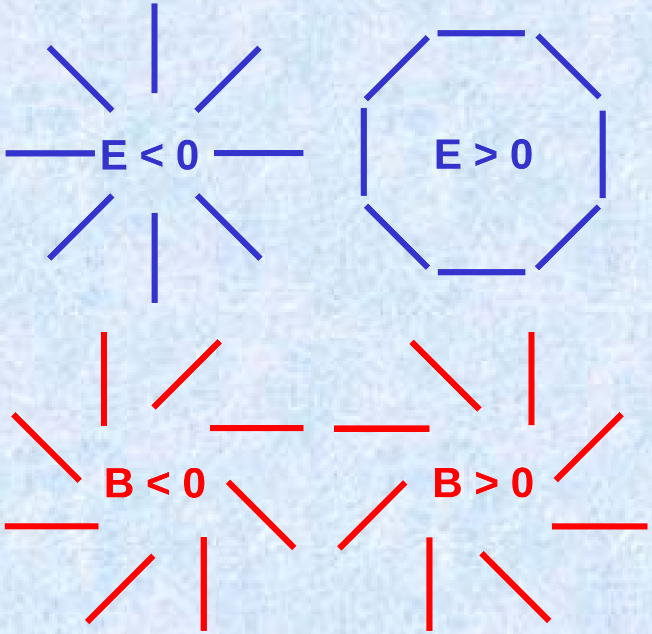


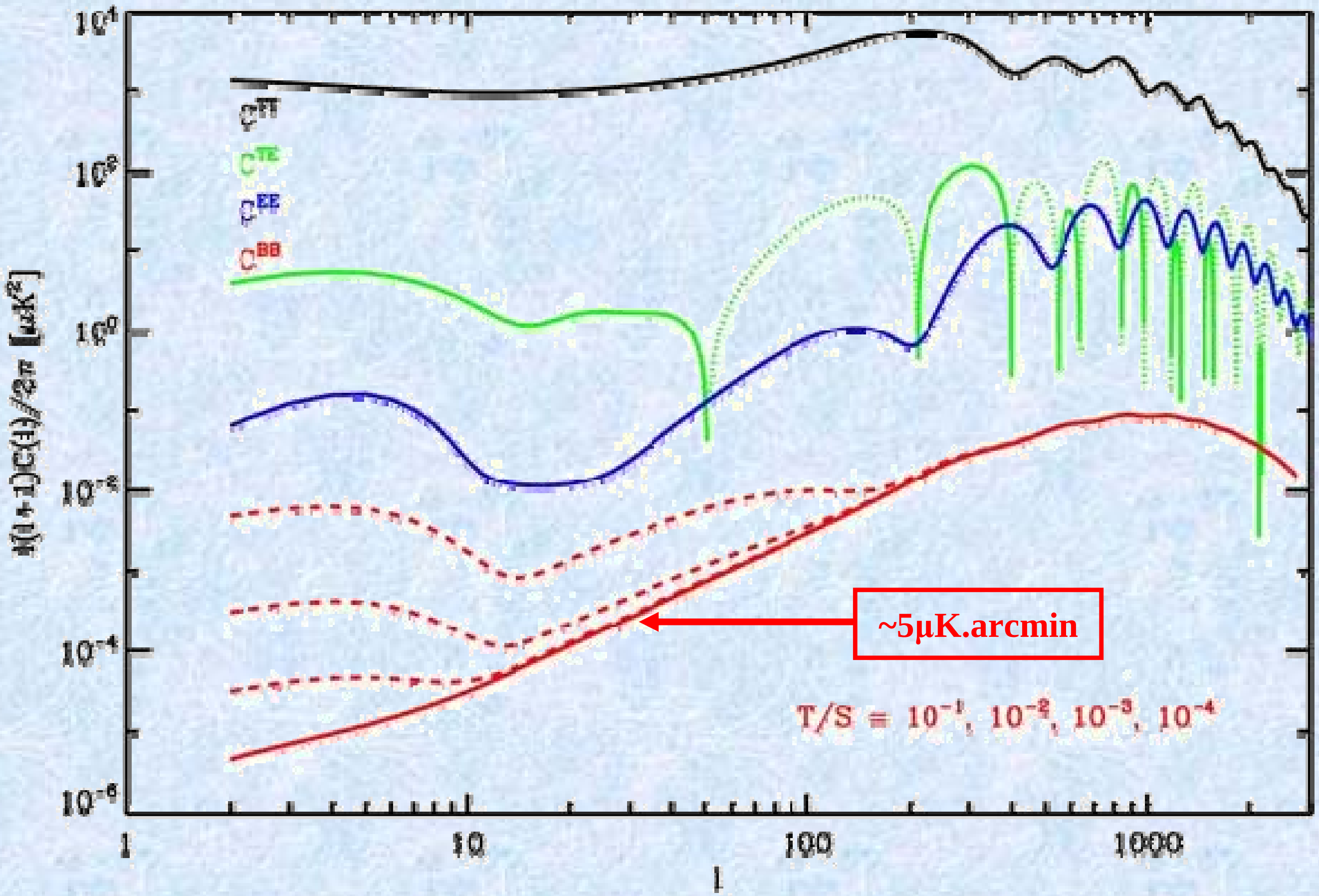




SPECTRES DE PUISSANCE DU RCF

- 3 observables : T, E, B



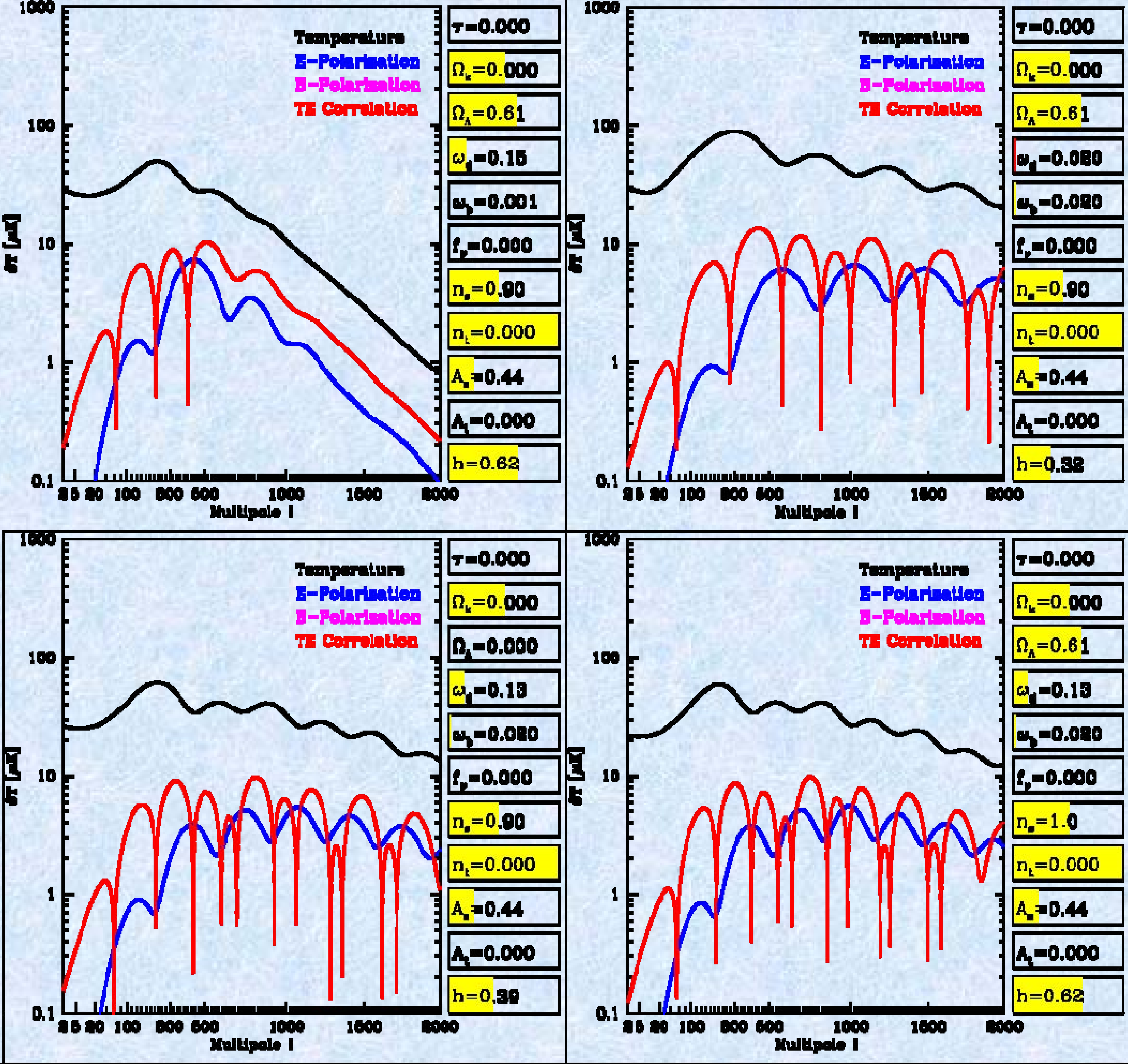


- Les modes B **ne peuvent pas** être générés par des fluctuations primordiales scalaires
  mais « lentillage » par les grandes structures transforme du E en B

($\propto 1/\theta$)

Ω_B (D/H)

Ω_Λ

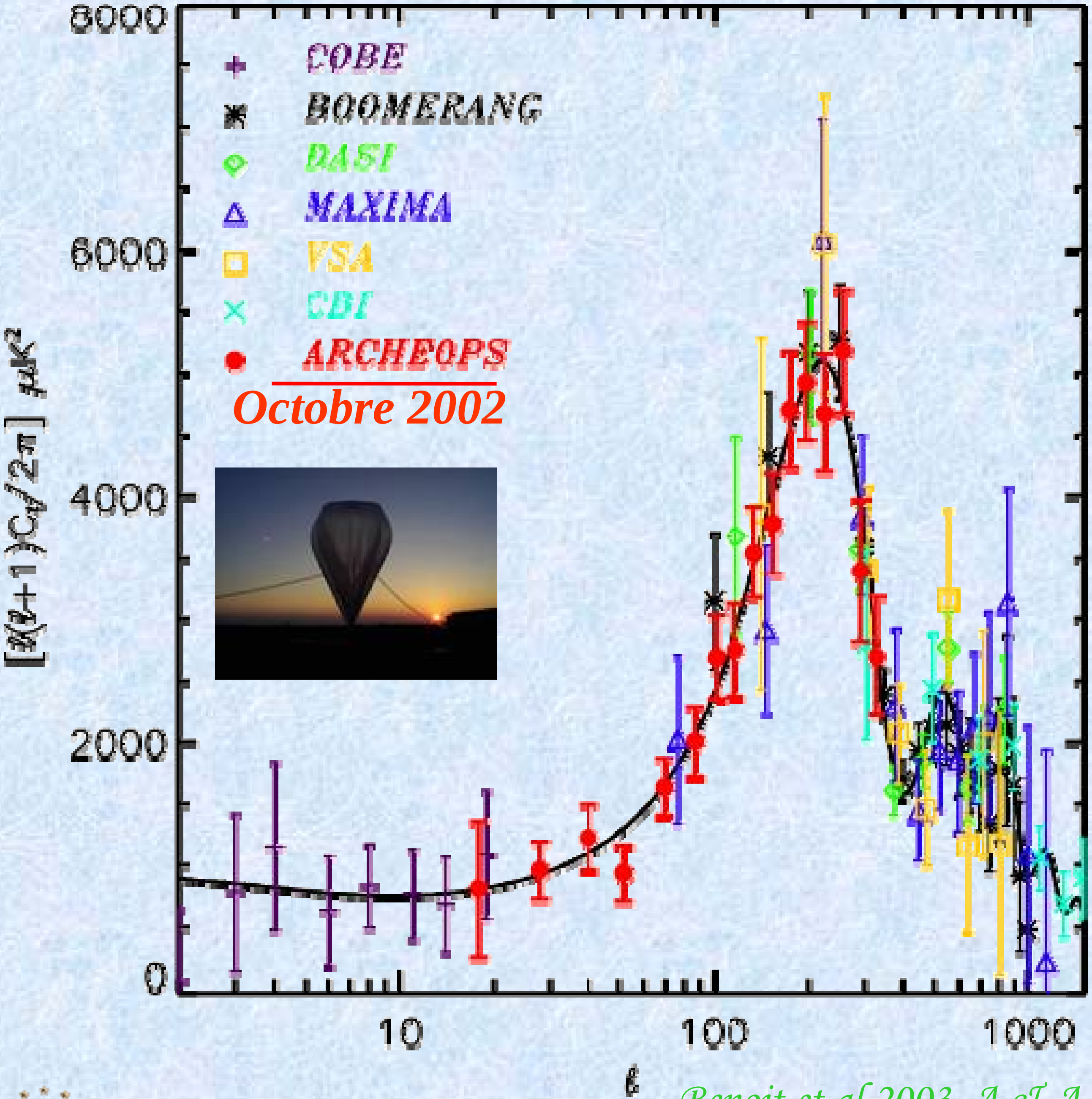


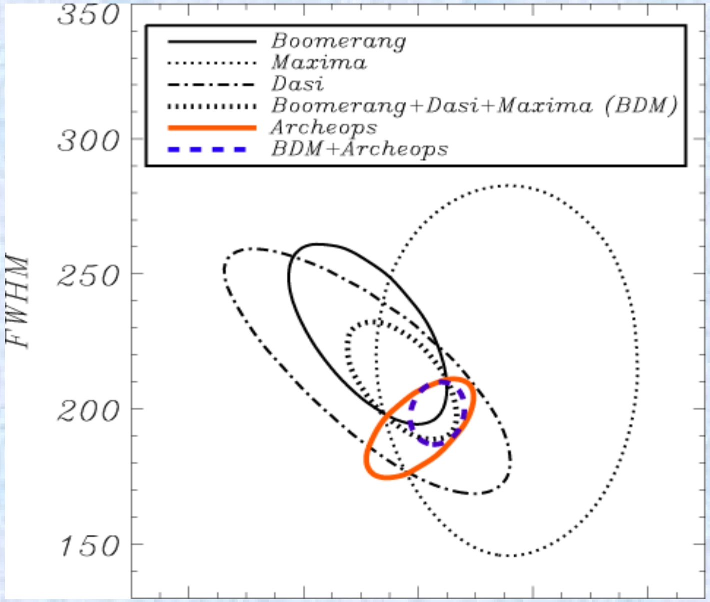
Ω_M (LSS, WL)

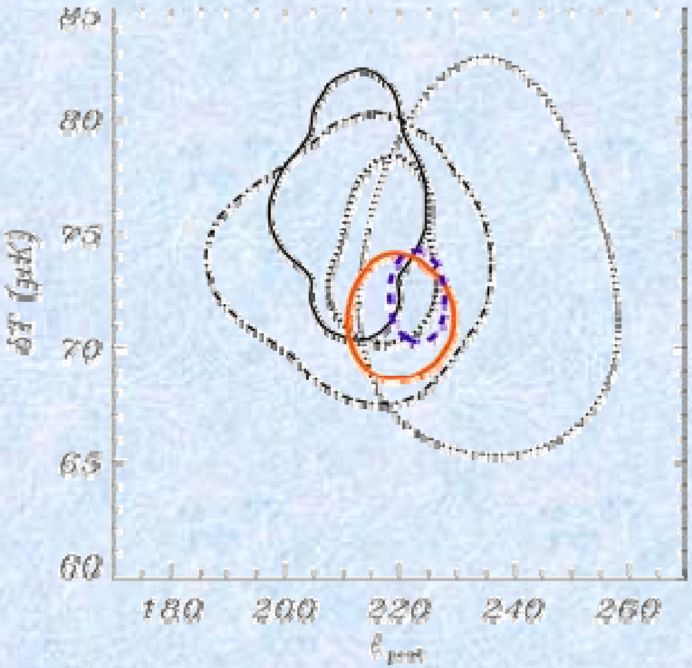
$f_\nu = \frac{\Omega_\nu}{\Omega_M}$

Tegmark's web site

END OF 2002 STATUS...



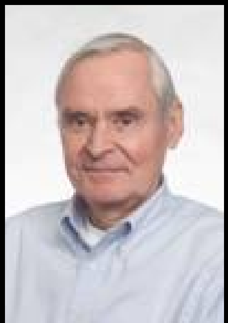


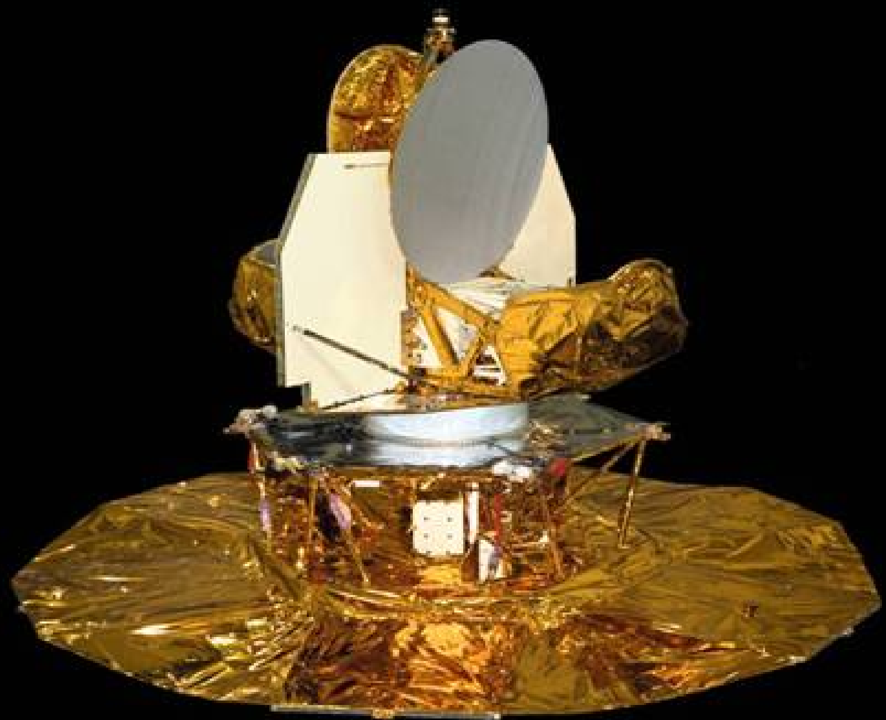


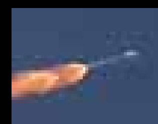
Benoit et al 2003, A & A, 399, L25

WMAP

Wilkinson Microwave Anisotropy Probe

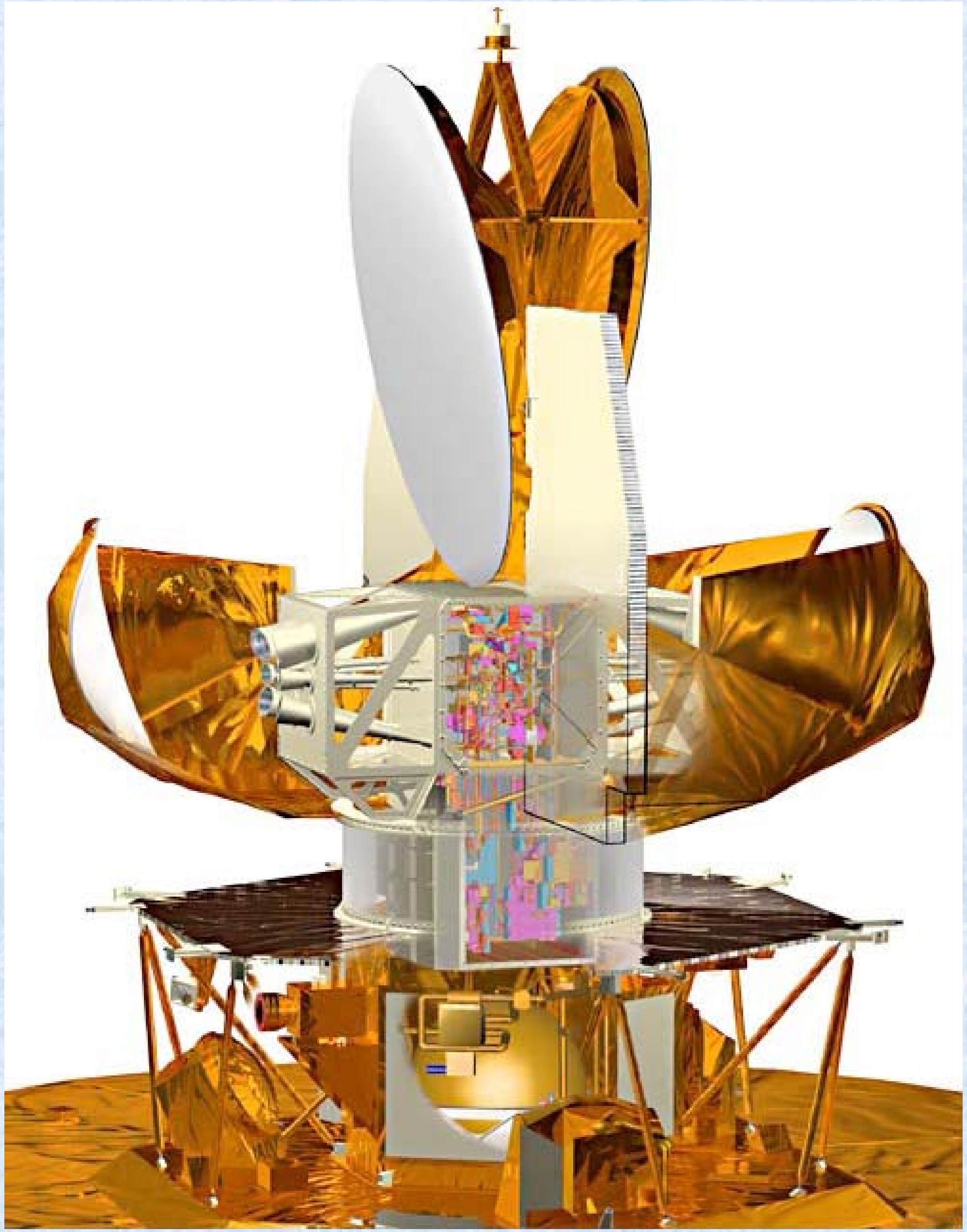




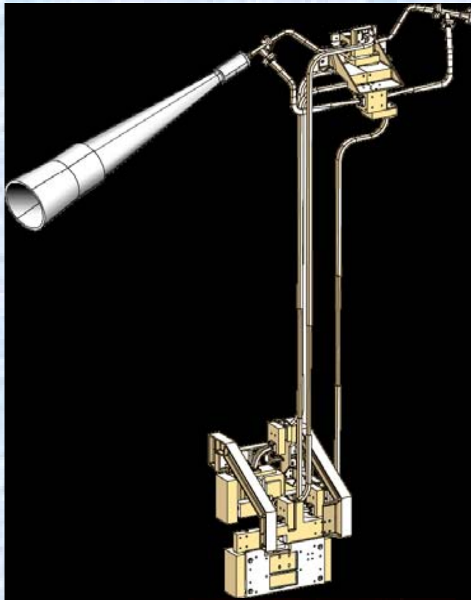


Launched on
June 30, 2001

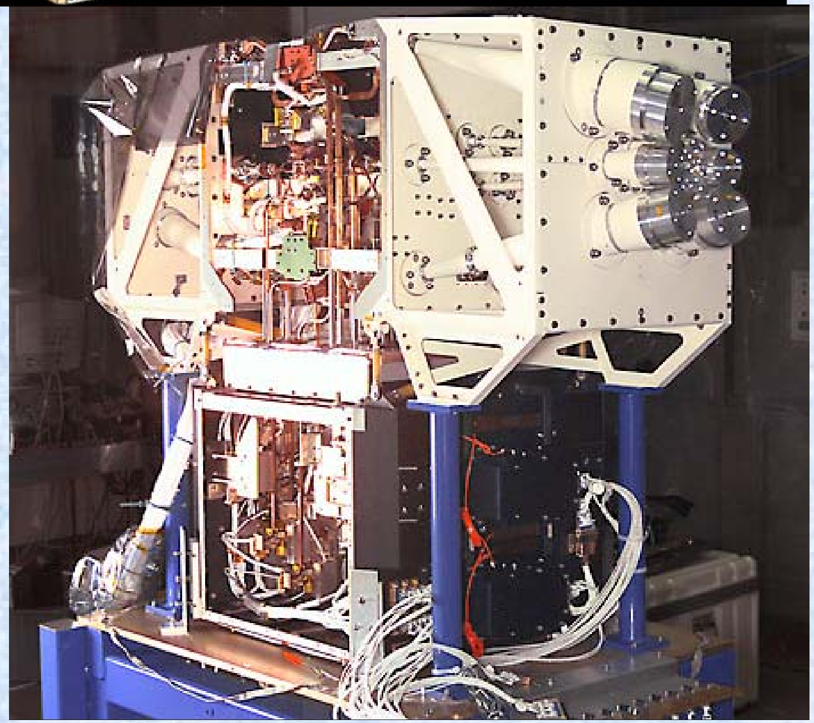
HEMT based differential measures



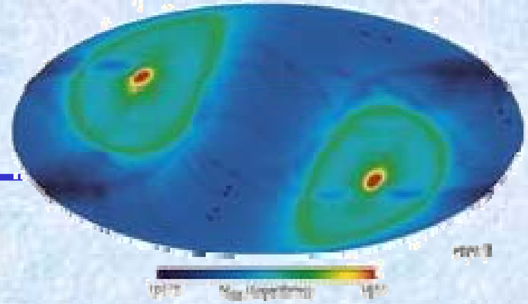
2 back-to-back telescopes

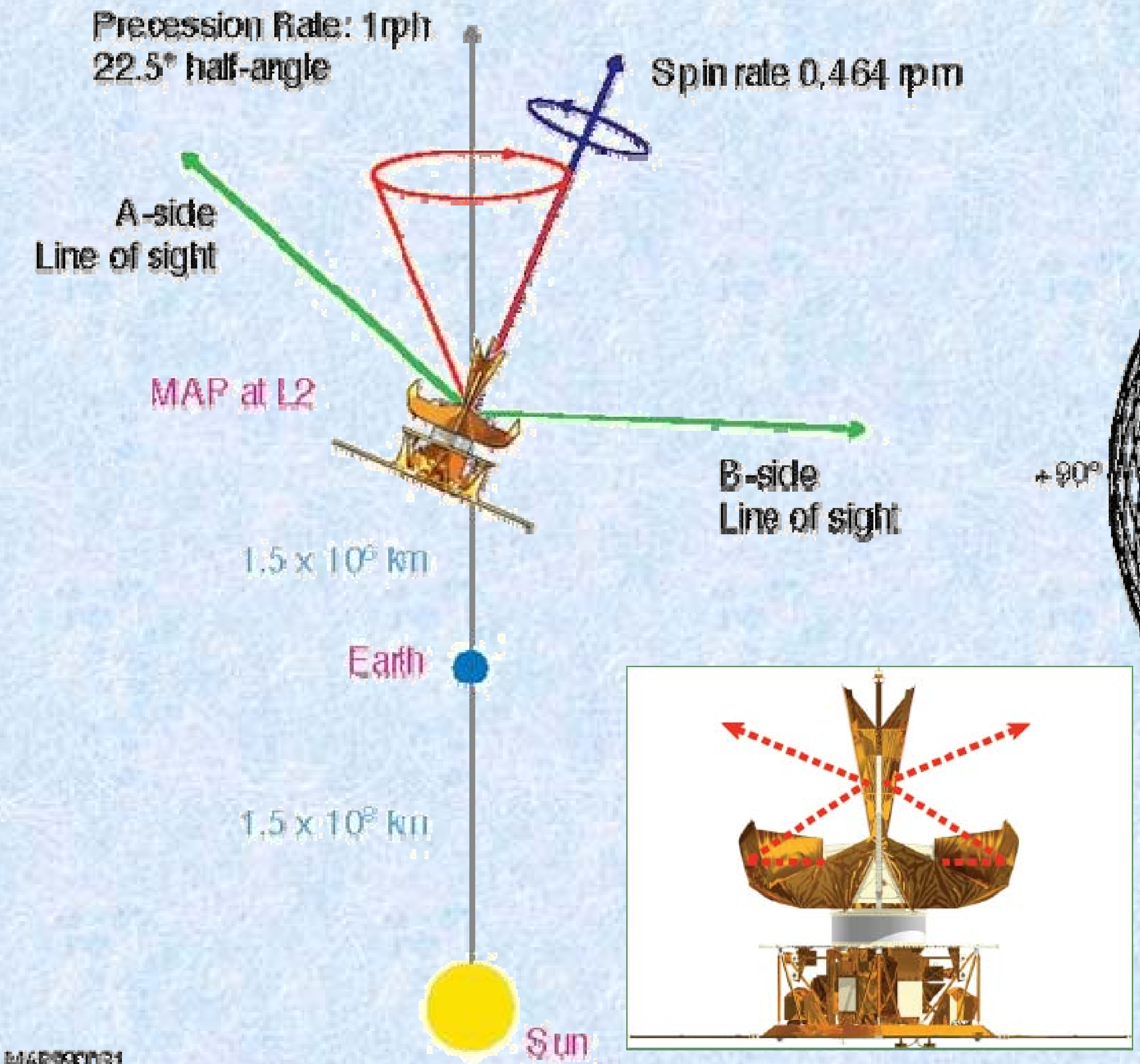


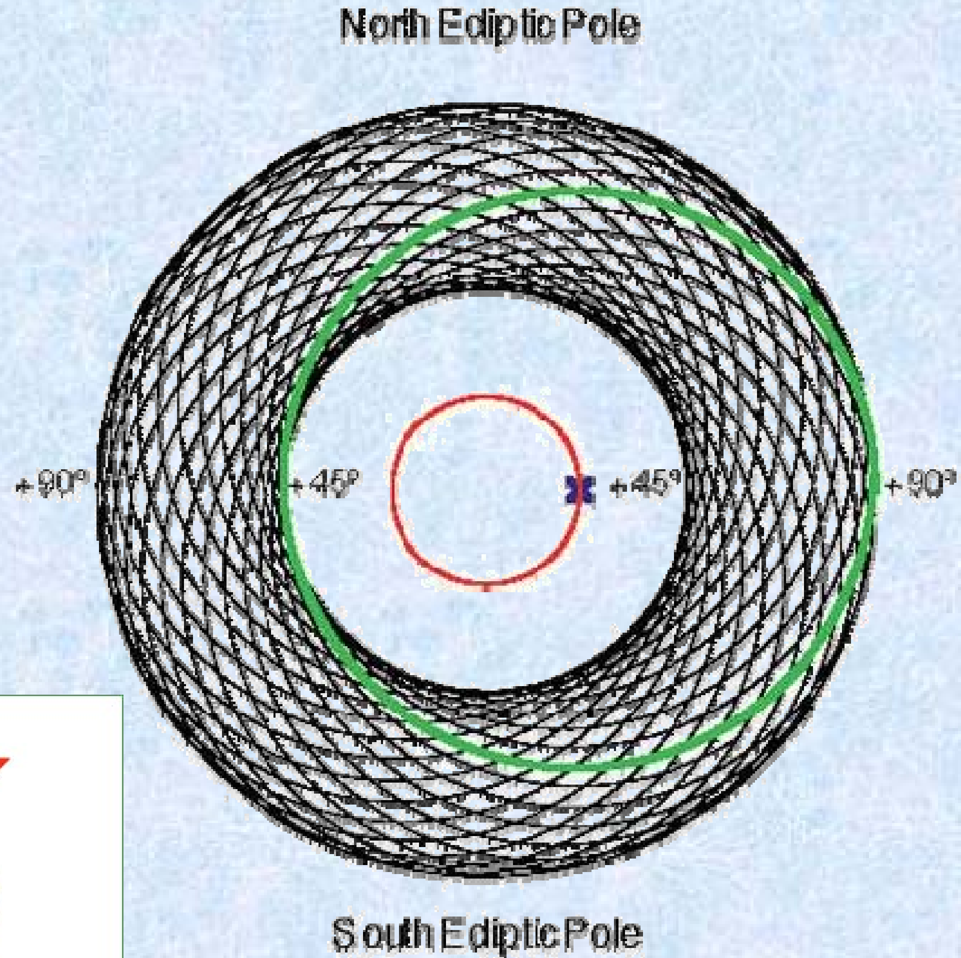
10 differencing assemblies:
1@23GHz (K band)
1@33GHz (Ka)
2@41GHz (Q)
2@61GHz (V)
4@94GHz (W)



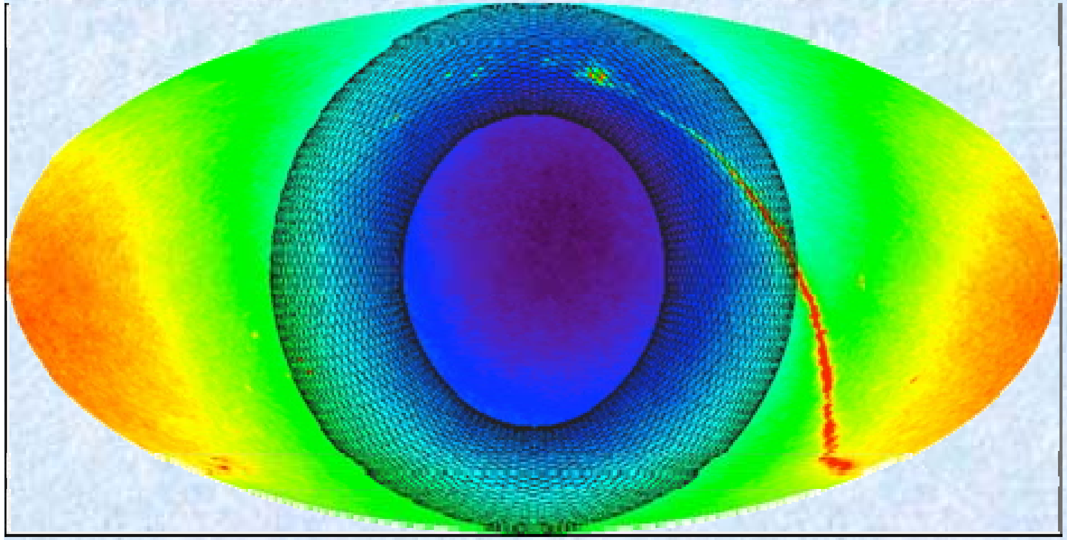
Scan Pattern

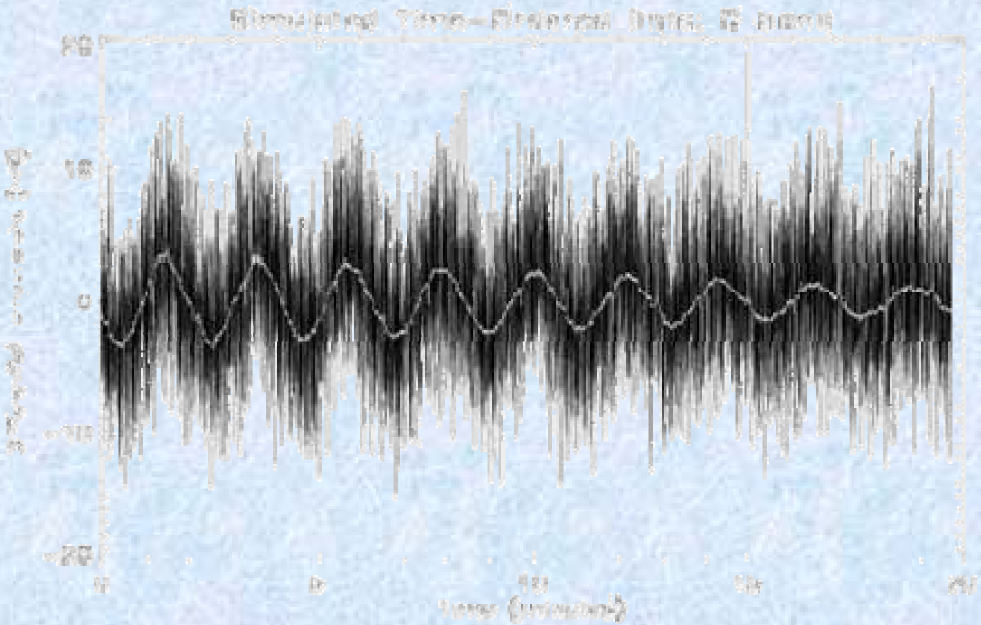




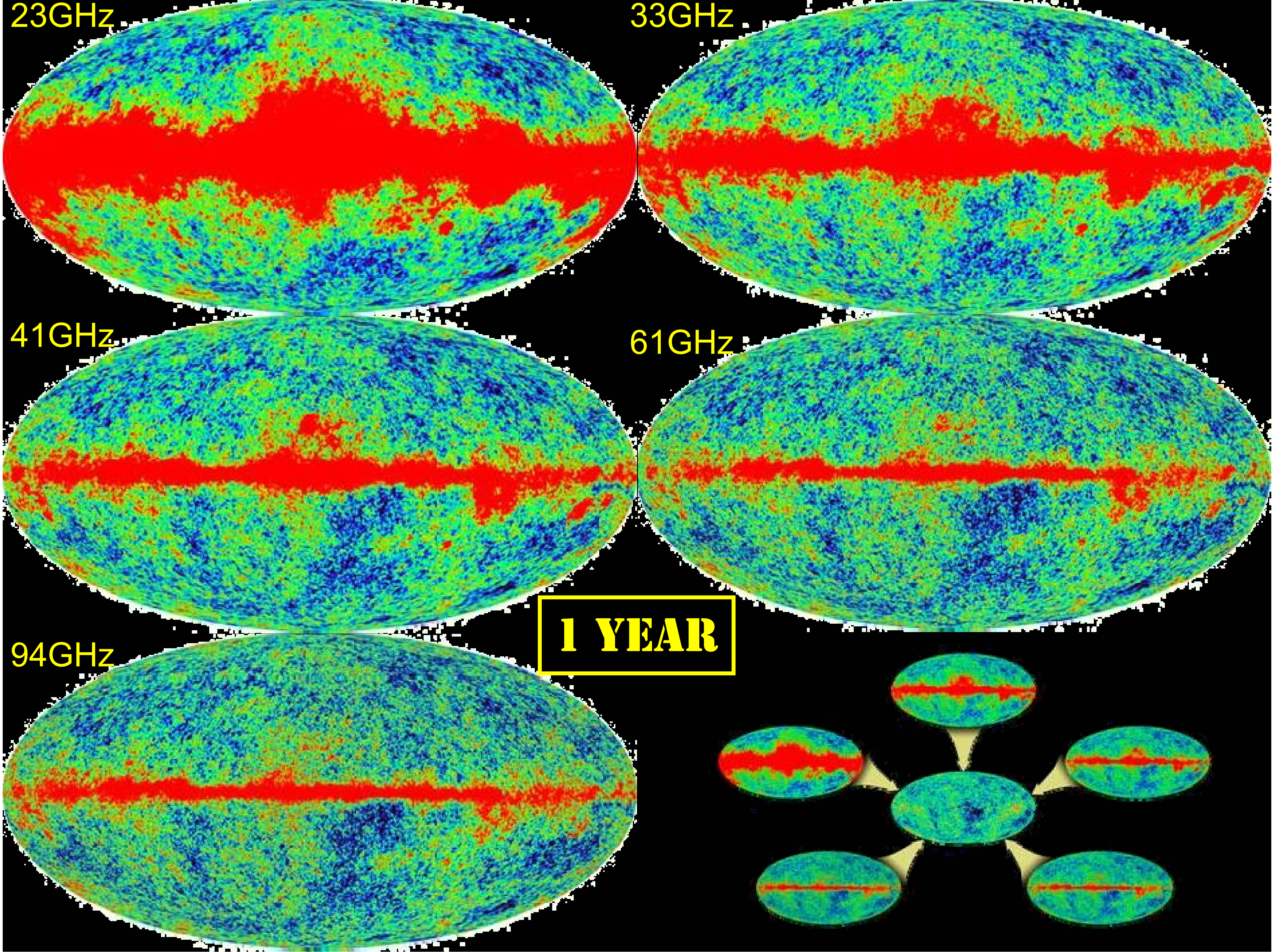


CONTINUOUS CALIBRATION FROM DIPOLE

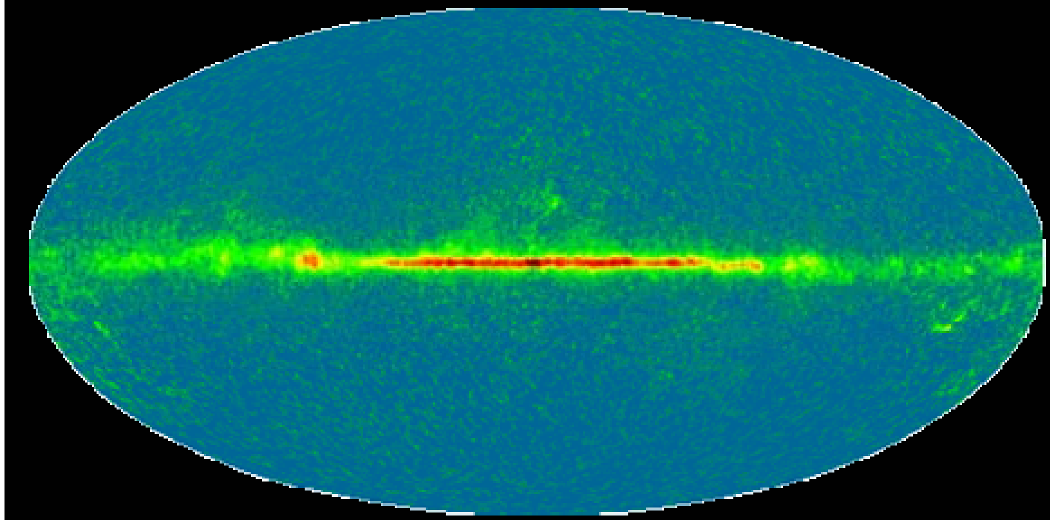




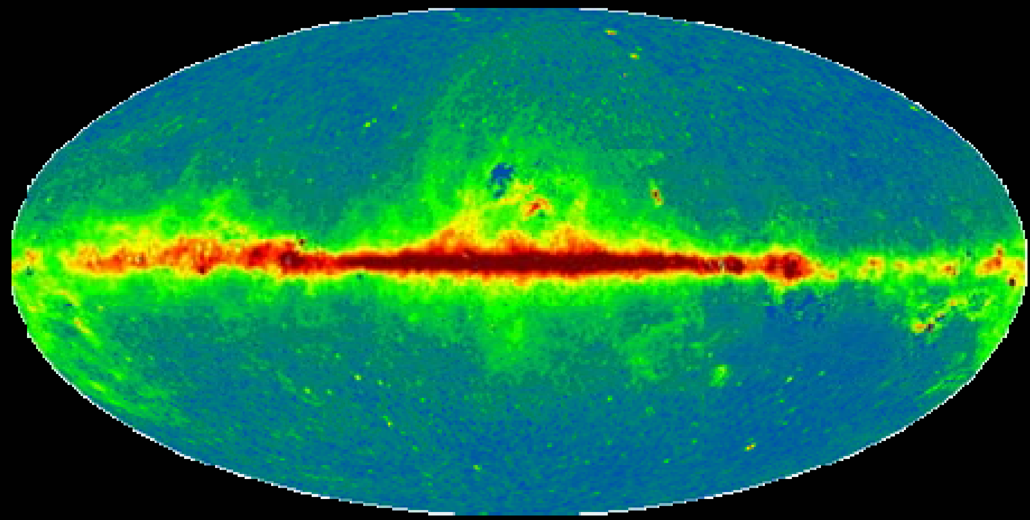
- Gain calibration based on known dipole modulation due to motion of WMAP around the Sun.
- CMB dipole provides short term transfer standard.
- Baseline (or offset) determination based on sky signal changing sign every half-spin.


23GHz
33GHz
41GHz
61GHz
94GHz
1 YEAR

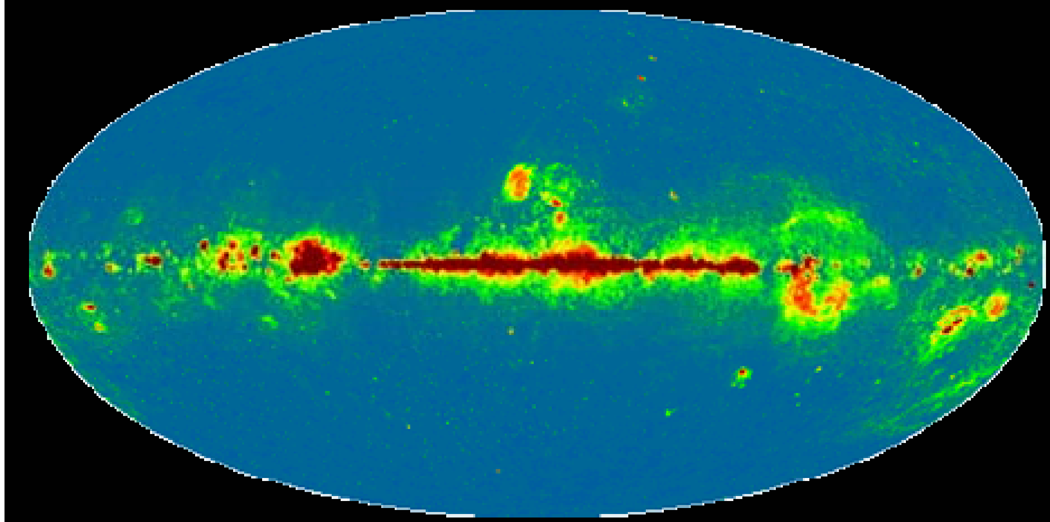
Cartes d’émission Déduites



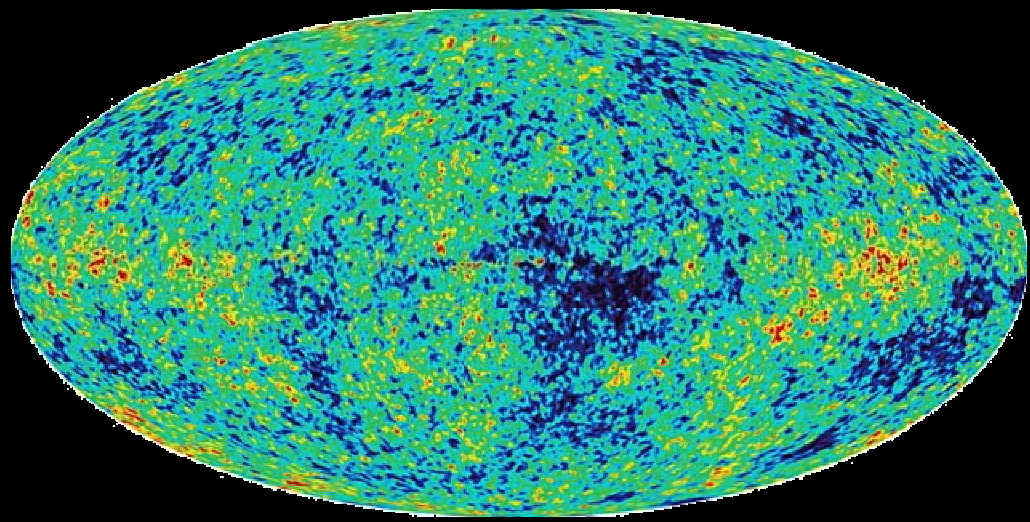
Poussière



Synchrotron

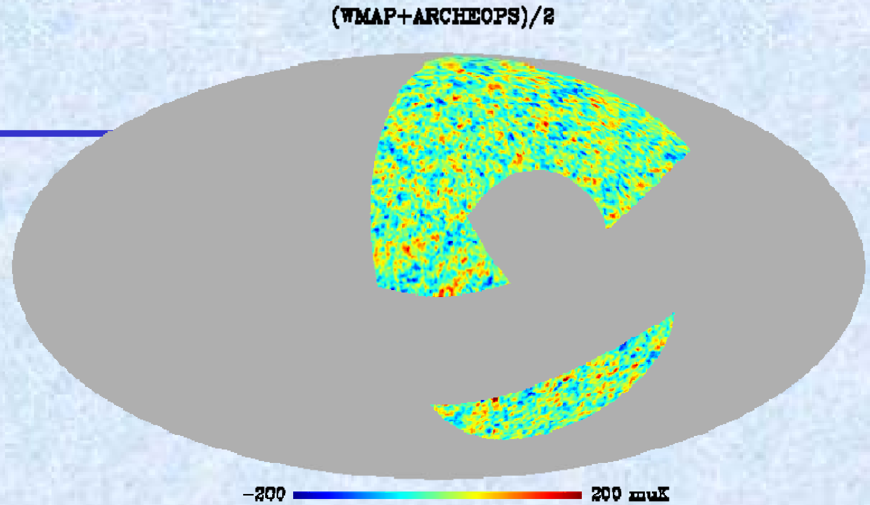


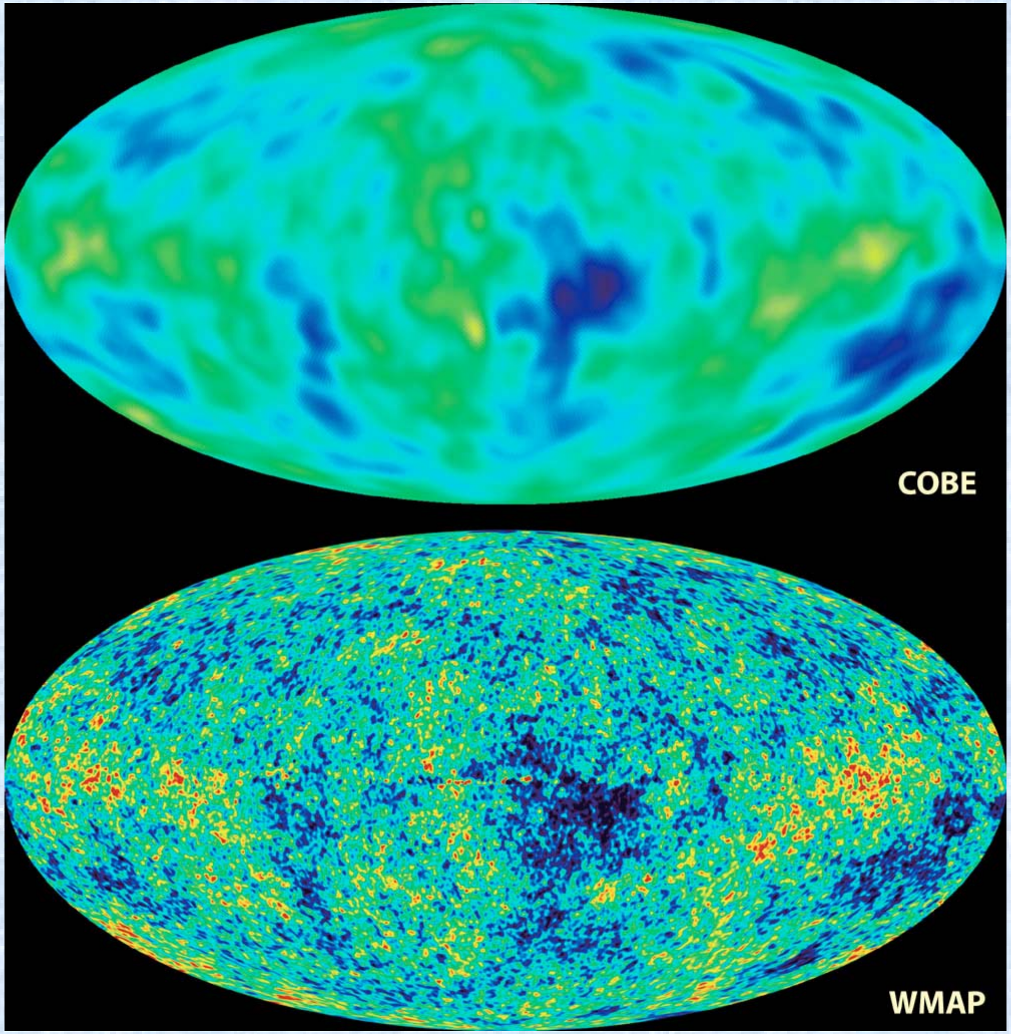
Bremstralhung

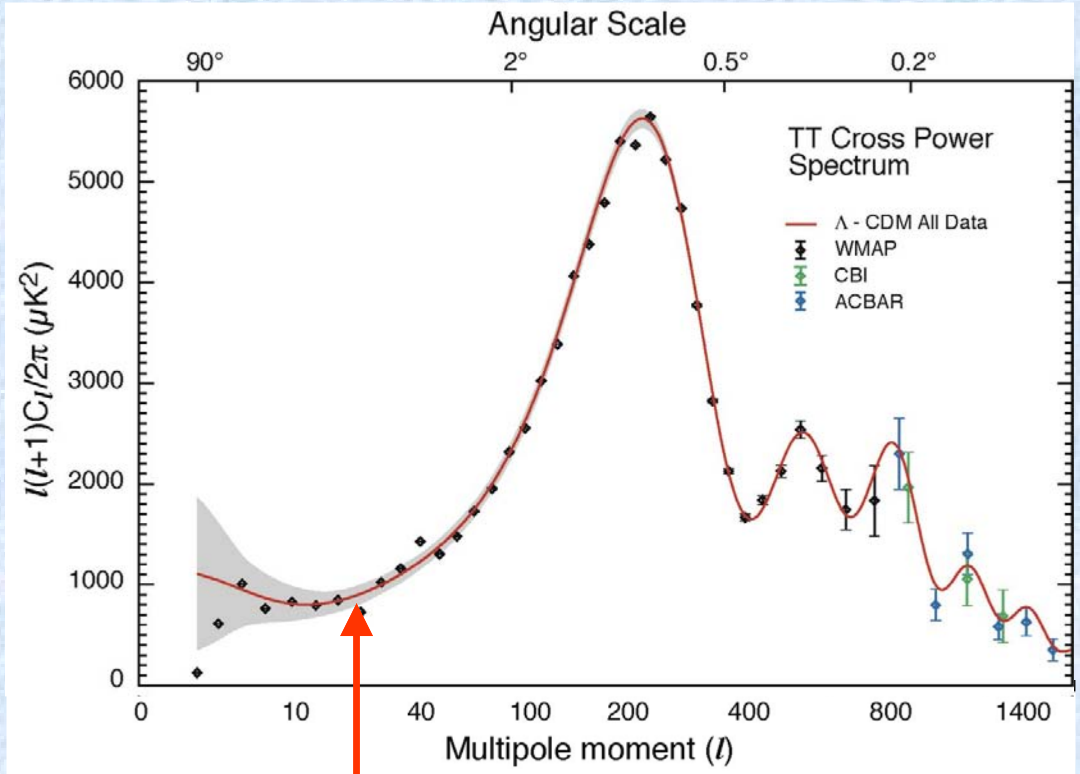


RCF

CARTE & SPECTRE DU RCF PAR WMAP-1



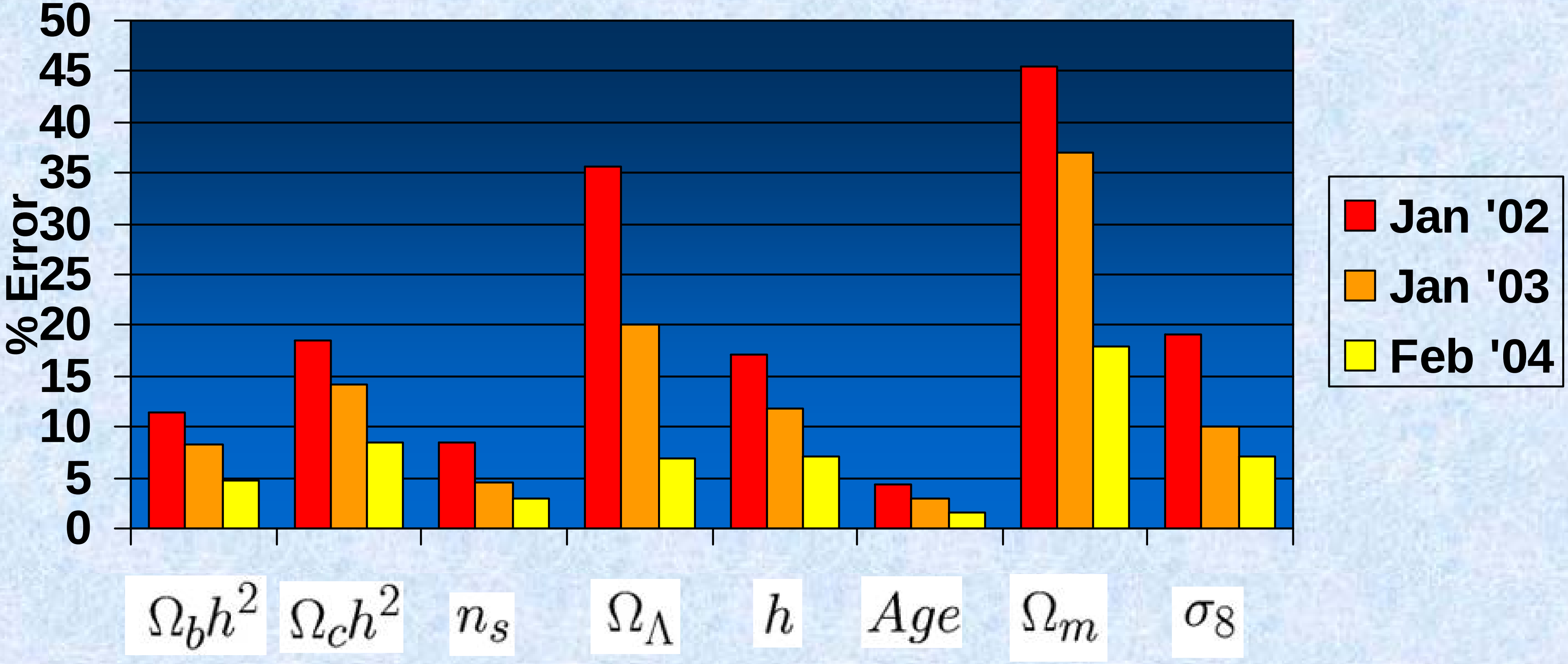




Courbe rouge =Théorie pour un univers avec 5% d'atomes, 25% de matière sombre, 70% d'énergie sombre

PRE-WMAP1 ⇔ POST-WMAP1

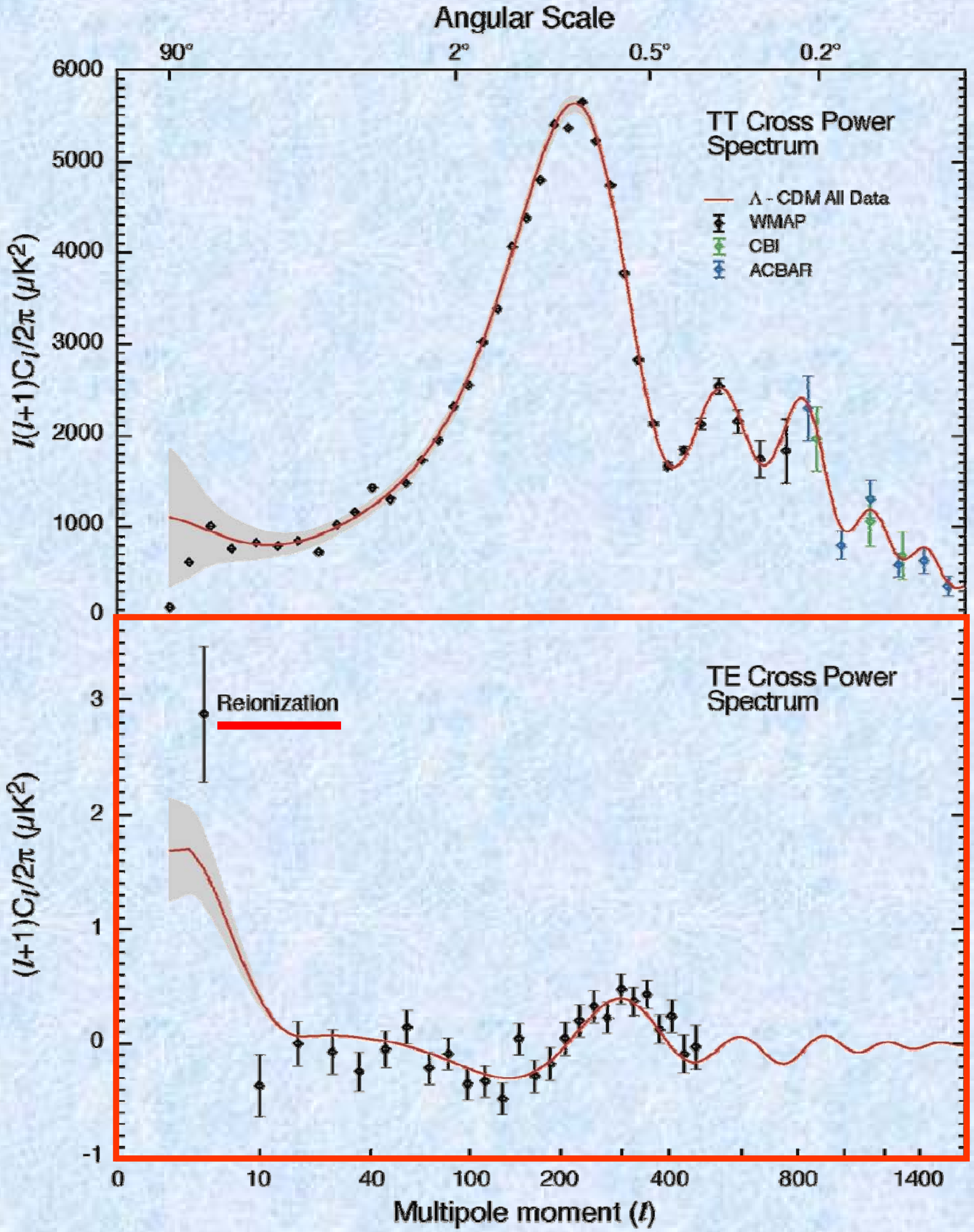
Parameters very similar. Precision +



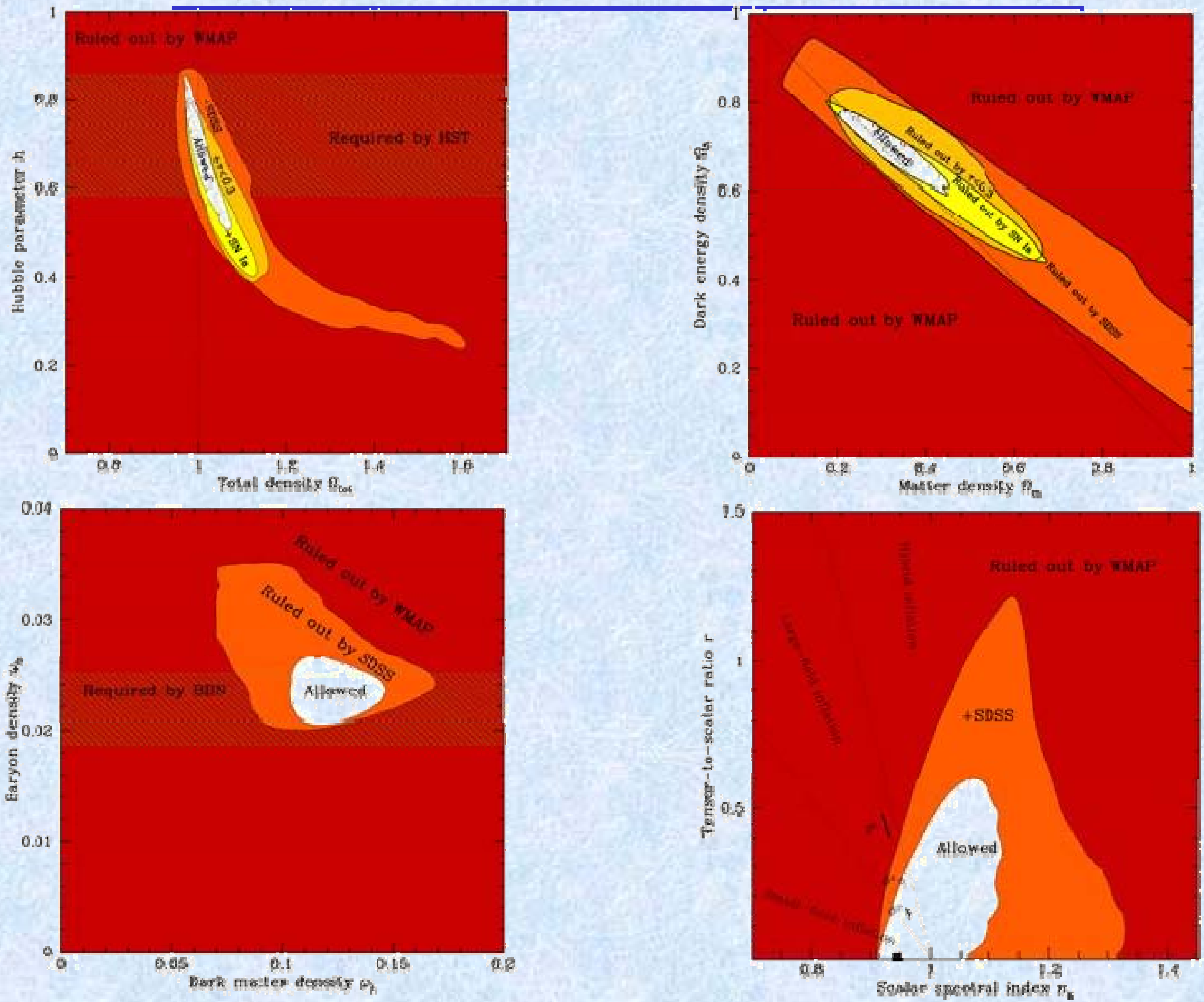
[Bond, Contaldi & Pogosyan astro-ph/0310735]

WMAP & LA POLARISATION

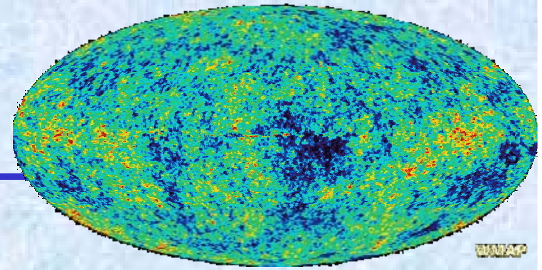
- 1ere mesure du spectre de la polarisation (partie corrélée avec la Température, dite TE)
- Oscillations / comparaison au même modèle théorique (courbe rouge): consolidation supplémentaire du paradigme
- Le pic à bas l (grandes échelles) est très haut : Réionisation de l'Univers plus tôt que prévu. Fortes contraintes sur la sortie de l'age sombre si confirmé
- Adiabaticité des fluctuations primordiales (phases TT/TE)

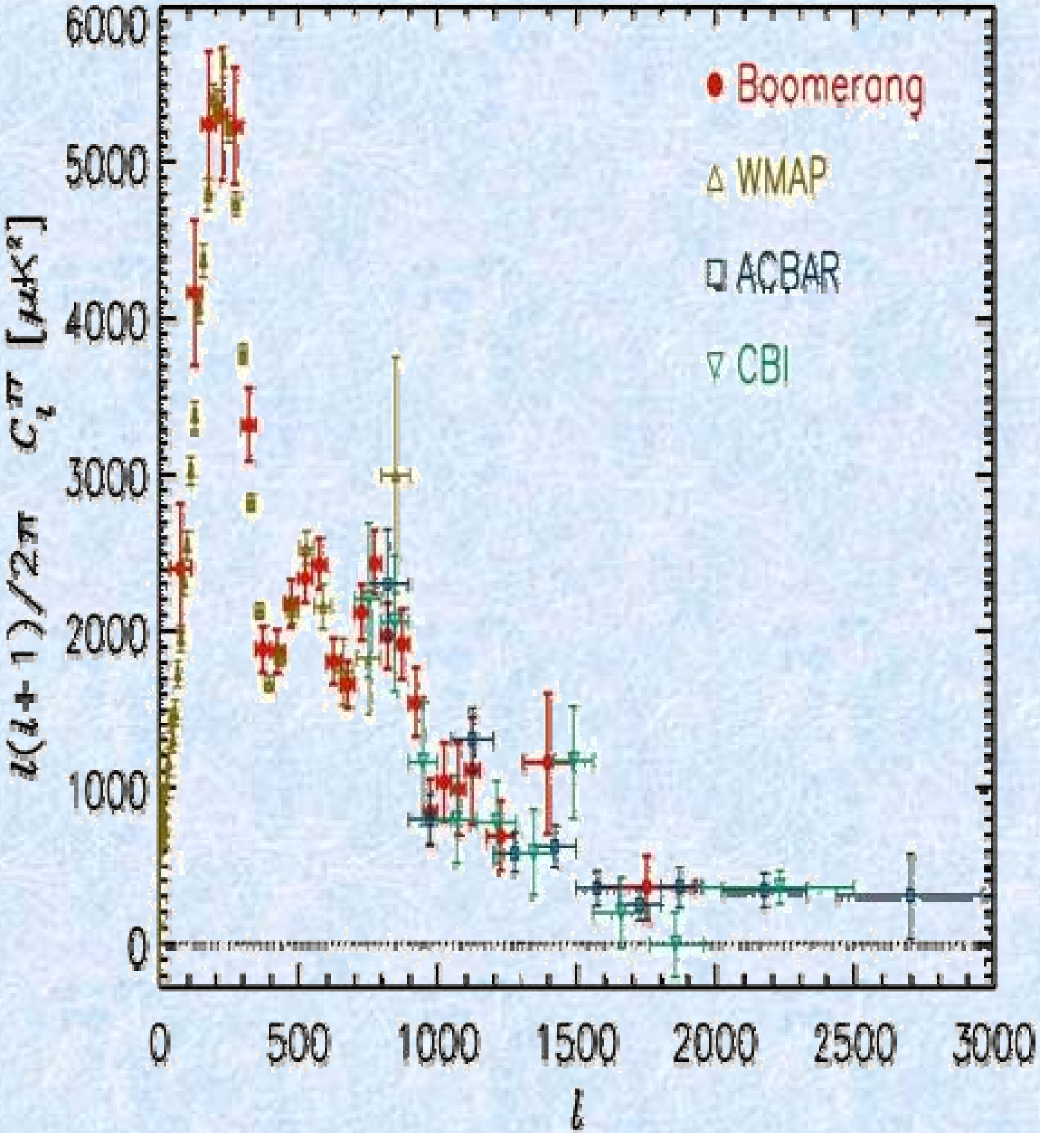


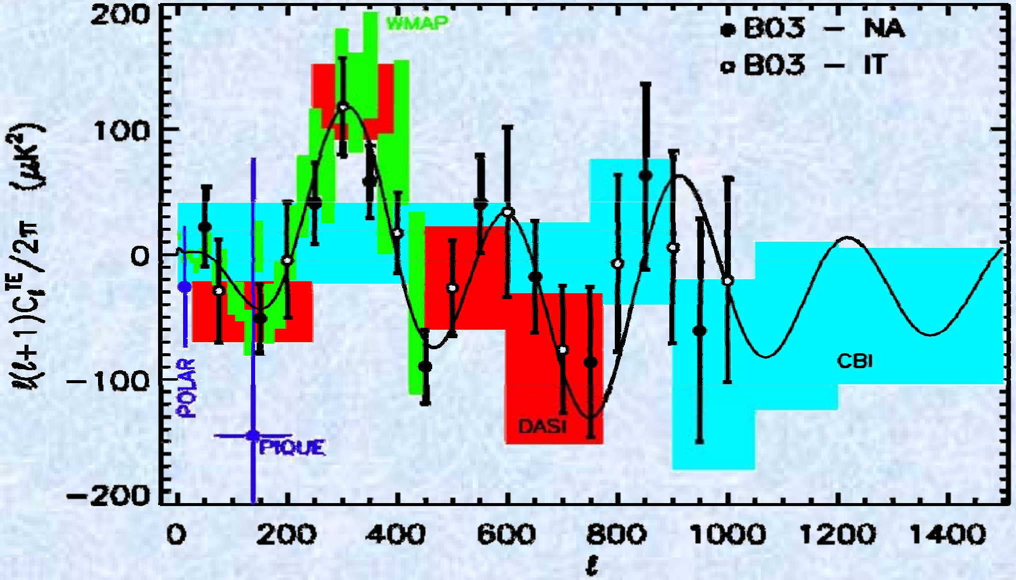
Consistency / Complementarity

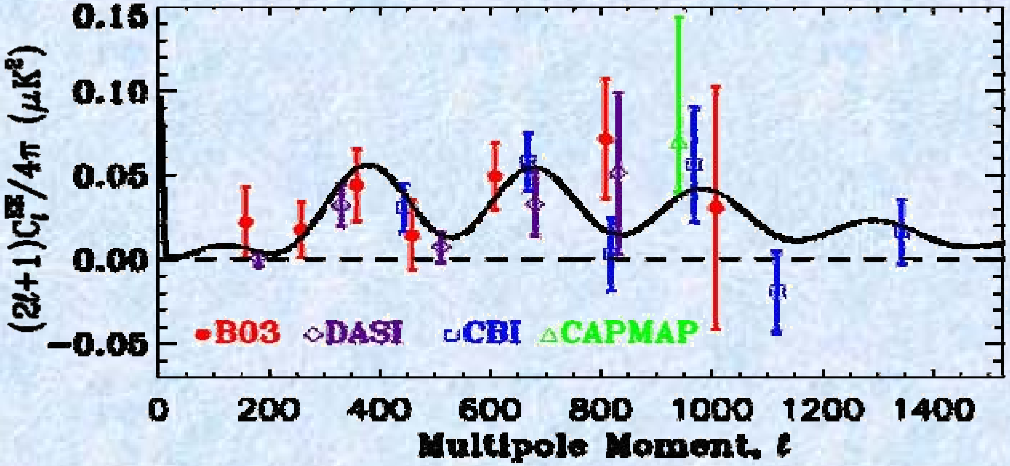


PRE-WMAP3 STATUS

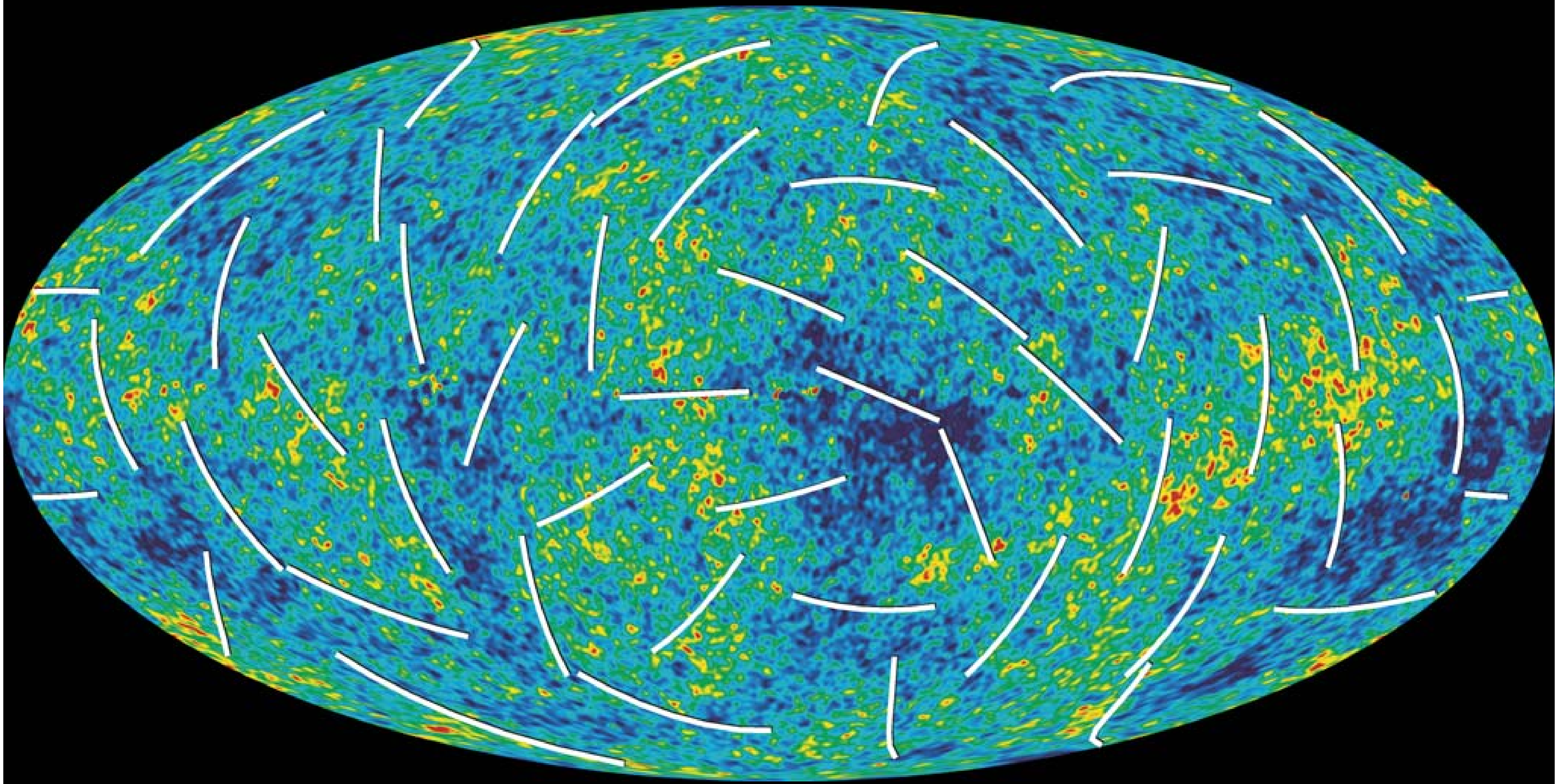








WMAP 3 YEARS



HIGHLIGHTS

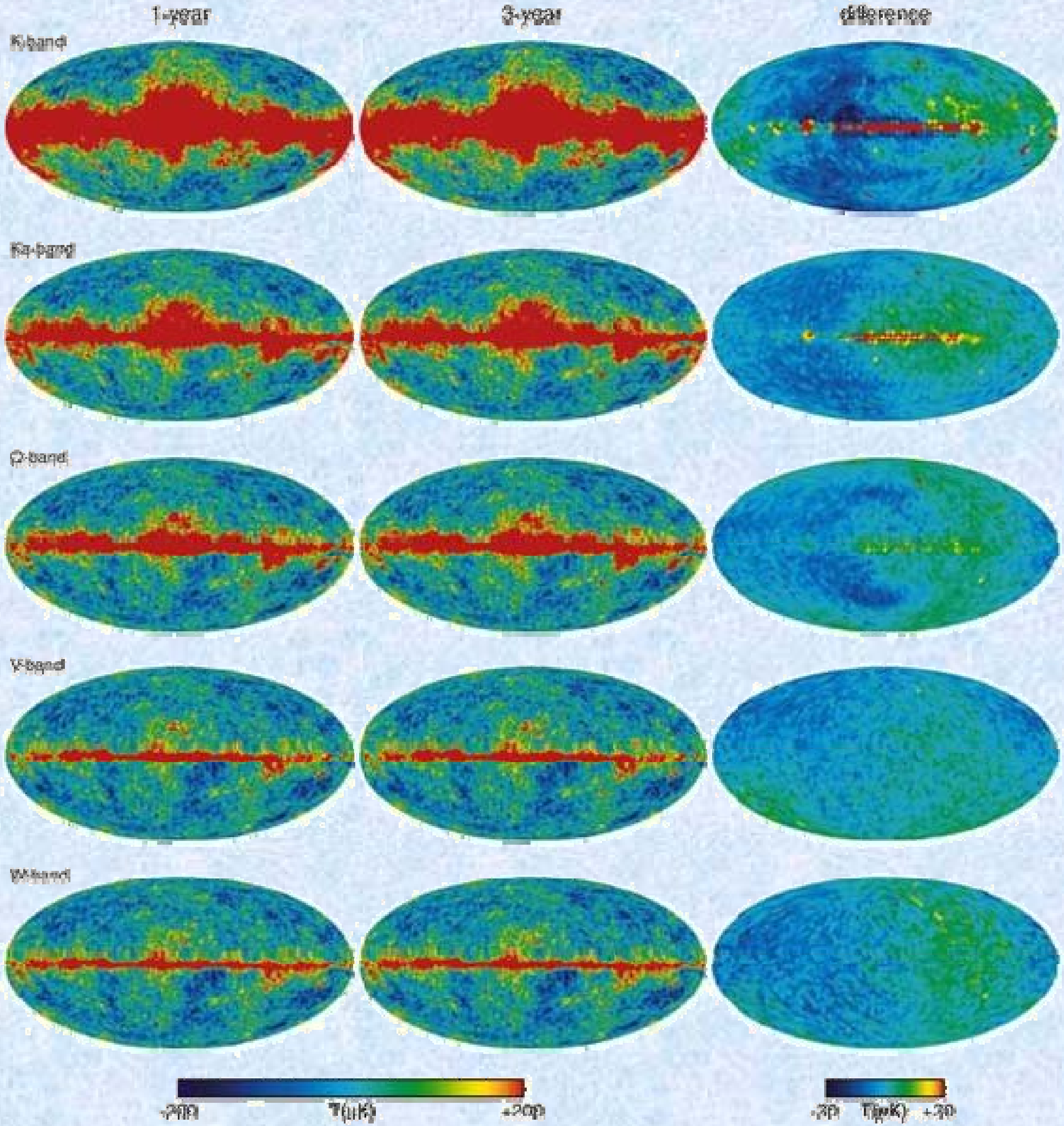
- Full sky polarisation measurements
  - Galactic foregrounds knowledge
  - Simple synchrotron emission model works well
- Minimal model - power-law CDM – with 6 parameters still fits well.
- χ2eff (TT)/dof = 1.068 (1.09 yr 1) & χ2eff (all)/dof = 1.04 (1.04 yr 1)
- Improvements in the constraints on parameters {Ωbh2, Ωmh2, h, τ, ns, As}
  - lower σ_8 and Ω_m (⇒ tension with lensing & Ly_a),
  - lower n_s and τ (⇒ hint on inflation, removes tension with Galaxy formation)

- Results from much more sophisticated data analysis

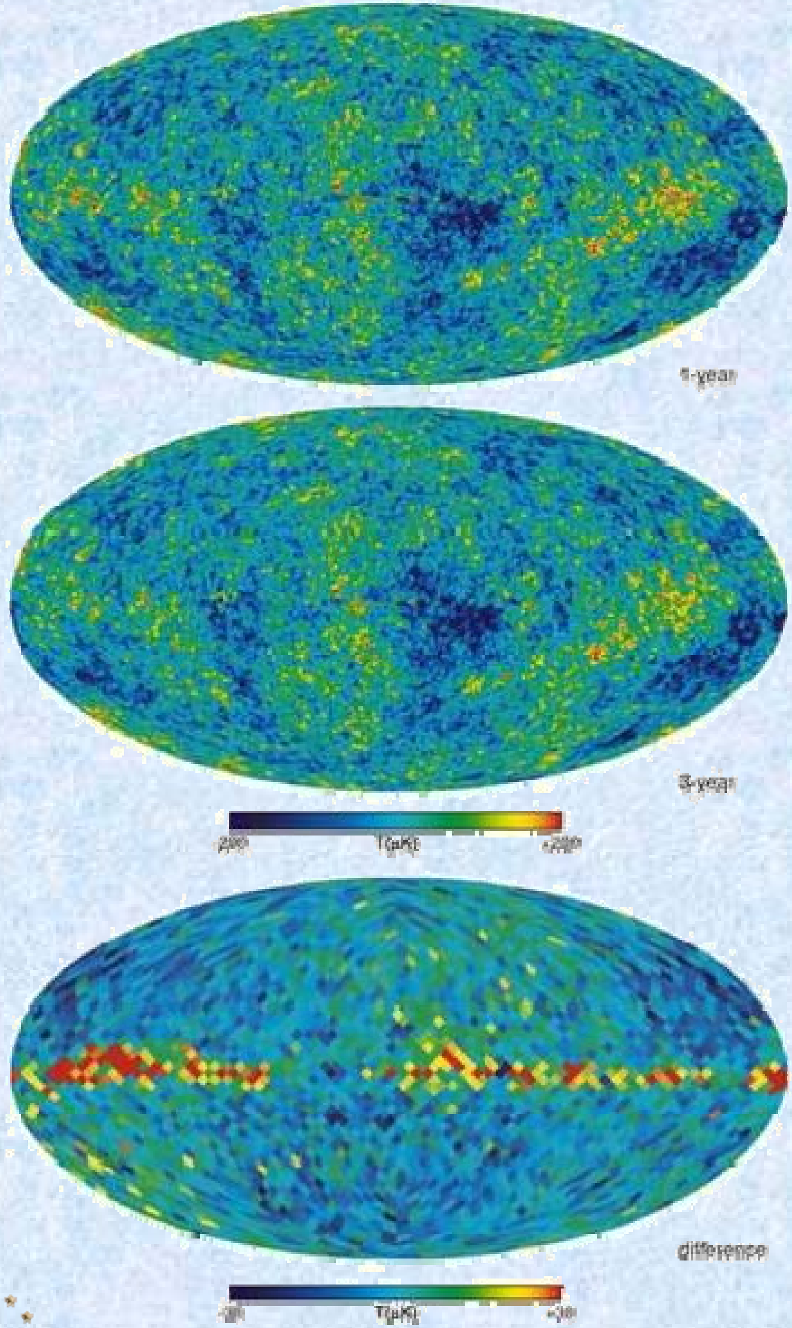
1 YEAR VERSUS 3 YEARS COMPARISON

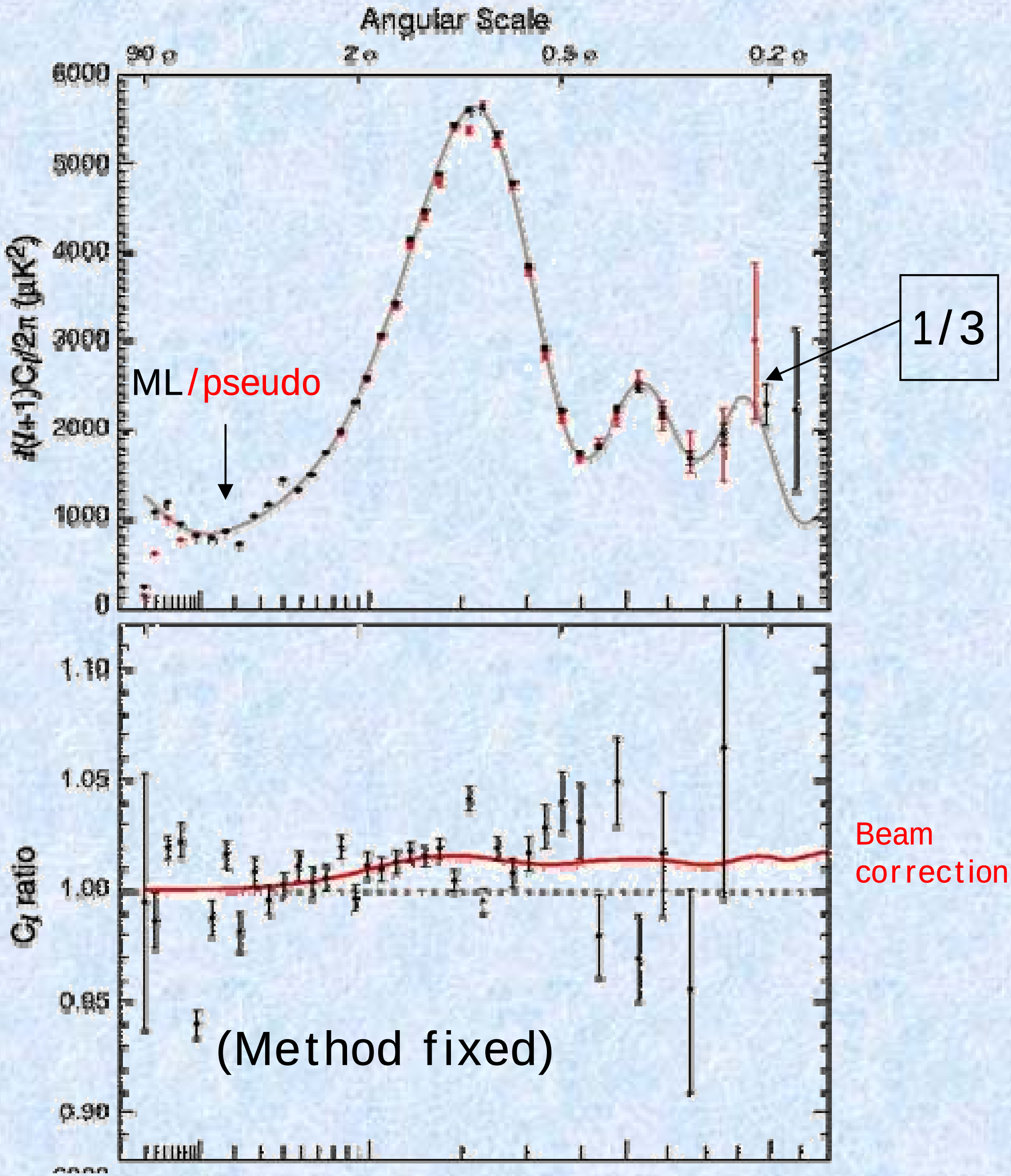
- Data smoothed to 1◦ resolution, scaled to ±200 μK
- The difference maps (right) degraded to pixel resolution 4 (~3.7◦) & scaled to ±20 μK.

- Small difference in low-l power, mostly due to improvements in the gain model vs. t



WMAP 1 > WMAP 3


1-year
3-year
T(μK)
difference
T(μK)


Angular Scale
90°
2°
0.5°
0.2°
$l(l+1)C_l/2\pi$ (μK²)
C_l ratio
ML/pseudo
1/3
Beam correction
(Method fixed)

LOW QUADRUPOLE POWER

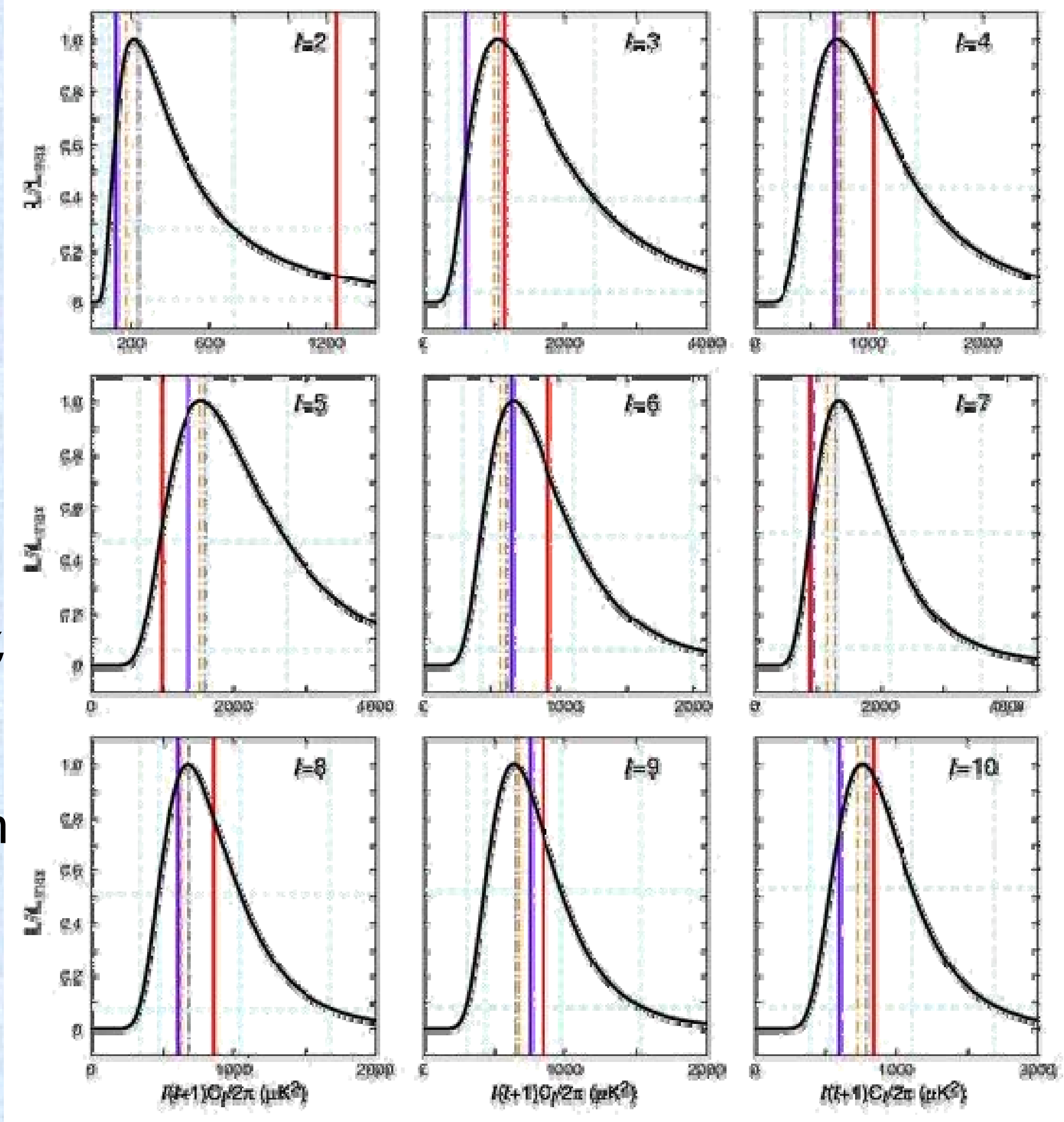
- Expected (mean) values for selected best-fit LCDM models -
  - Pure power-law, WMAP+CBI+ACBAR: 1221 mK^2*
  - Running index, WMAP+CBI+ACBAR: 870 mK^2
  - Power-law, CMB+2dF+Ly-a: 1107 mK^2
- Measured value(s) of quadrupole -
  - Quadratic estimator, V+W band, galaxy template & cut: 123 mK^2
    (Hinshaw, et al., ApJS, 148, 135, 2003)
  - Full-sky estimate, Galaxy-cleaned map: 184 mK^2
    (Tegmark et al, astro-ph/0302496)
  - Full-sky estimate, Linear Combination map: 154 ± 70 mK^2
    Error based on spread of values by galaxy cut and frequency
    (Bennett, et al., ApJS, 148, 1, 2003)
  - Max. likelihood estimate, Galaxy-cleaned map(s): 176-250 mK^2
    (Efstathiou, astro-ph/0310207)
  - Max. likelihood estimate, Galaxy template marginalization: < 300 mK^2
  - (Bielewicz, astro-ph/0405007; Slosar & Seljak, astro-ph/04??)

- Likelihood of low quadrupole given power-law LCDM model –
  ~2% - 10%
- Fine print: estimates of significance depend on
  1) quadrupole estimation method,
  2) handling of foreground errors,
  3) handling of cosmic variance errors,
  4) handling of cosmological parameter errors.

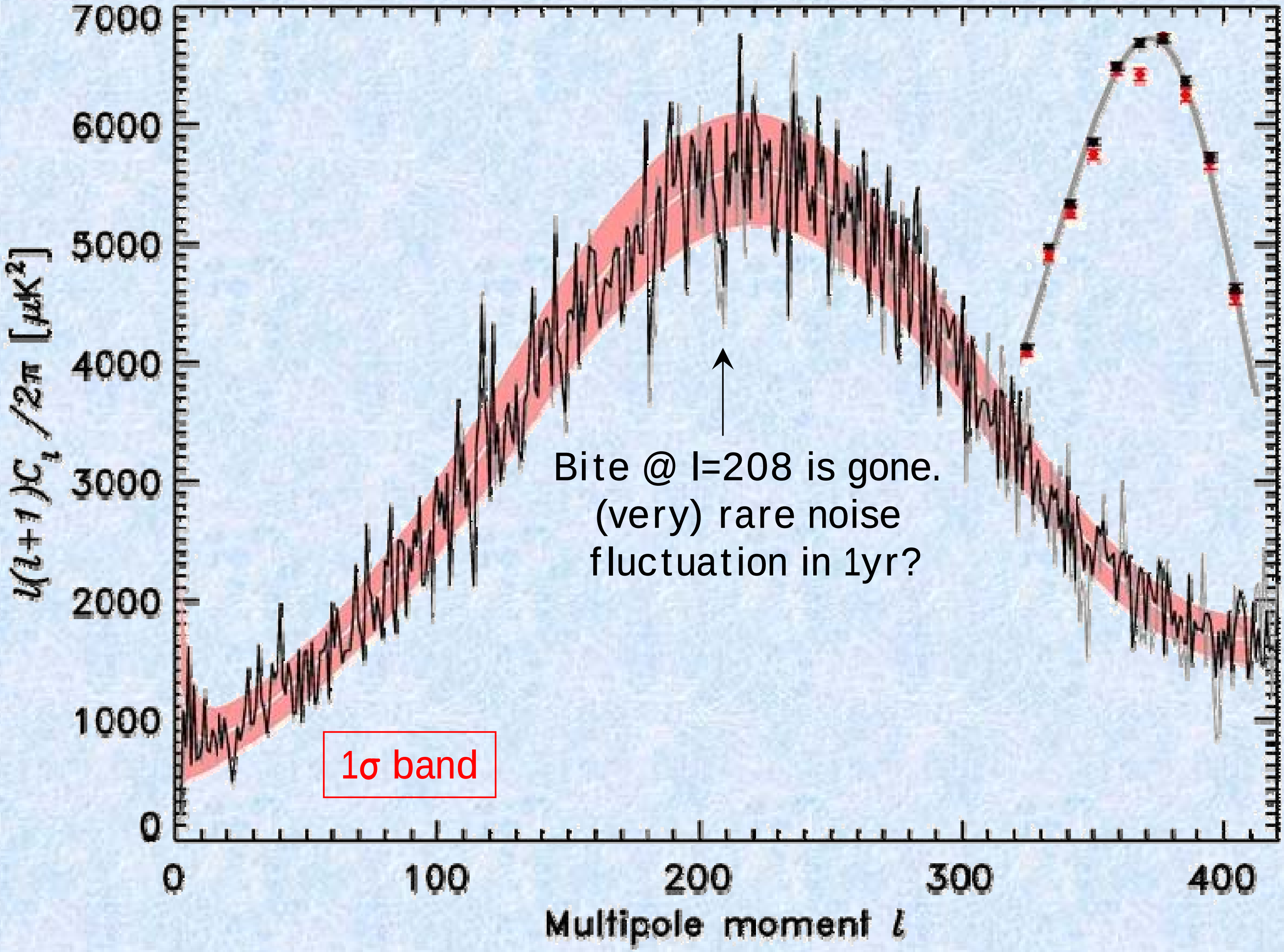
LOW-L (NEW, ML) ANALYSIS

- Black= posterior distribution of l(l + 1)Cl/2π from the ILC map outside the Kp2 sky cut
- Vertical red = Mean for best fit CDM to WMAP
- Purple=pseudo-C(l) estimate, tend to be lower than peak at l = 2, 3, 7
- *Quadrupole still rather low, but now the only one*

- NB: Vertical black dot-dash =maximum with no sky cut; orange – with Kp2 V-band only



“LOOKS” OK?


7000
6000
5000
4000
3000
2000
1000
0
0
100
200
300
400
Multipole moment l
l(l+1)C_l /2π [μK²]
Bite @ l=208 is gone.
(very) rare noise
fluctuation in 1yr?
1σ band

SUMMARY OF IMPROVEMENTS IN THE POLARIZATION ANALYSIS

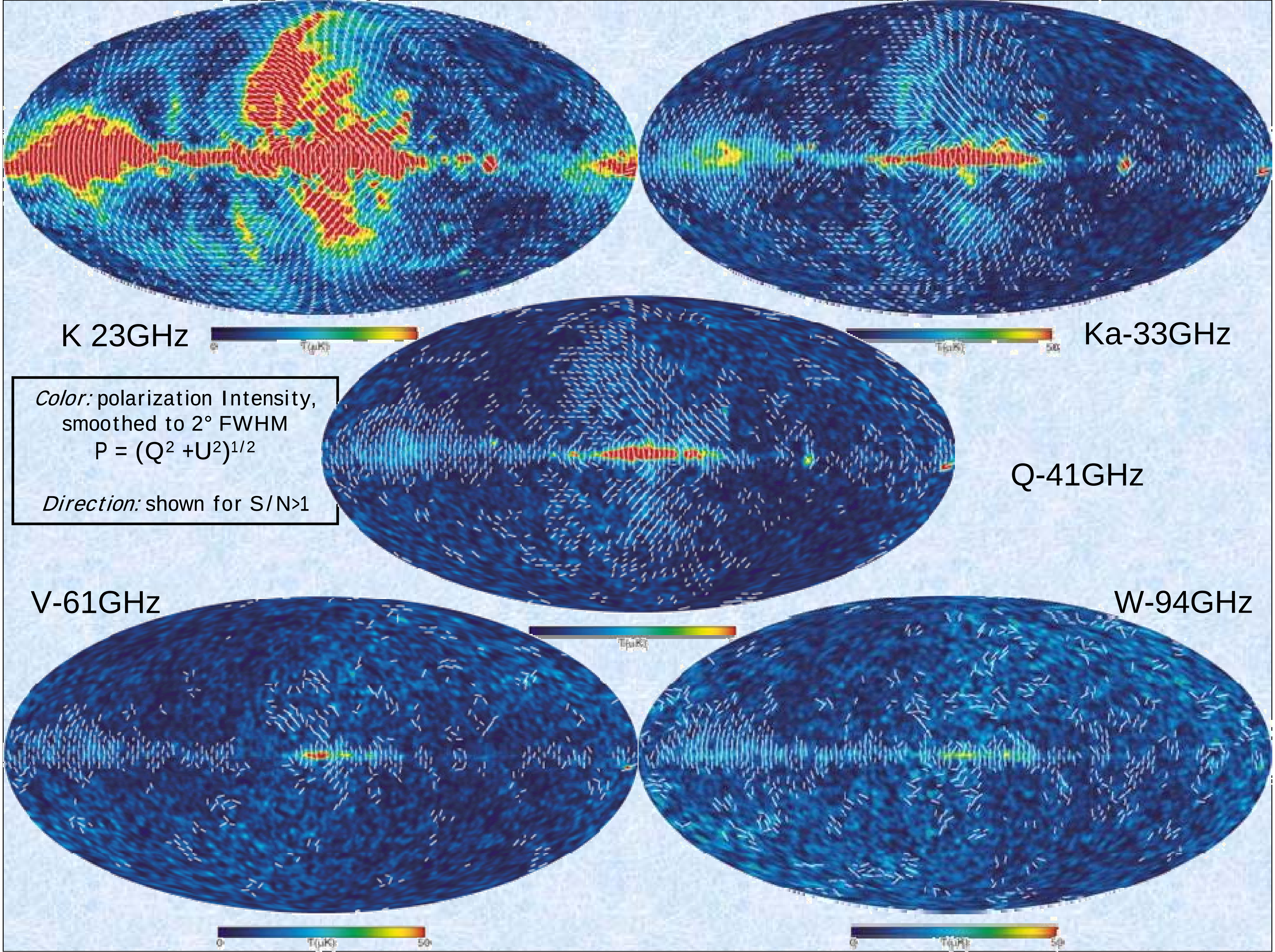
First Year (TE)

- Foreground Removal
  - Done in harmonic space
- Null Tests
  - Only TB
- Data Combination
  - Ka, Q, V, W are used
- Data Weighting
  - Diagonal weighting
- Likelihood Form
  - Gaussian for C_l
  - C_l estimated by MASTER

Three Years (TE,EE,BB)

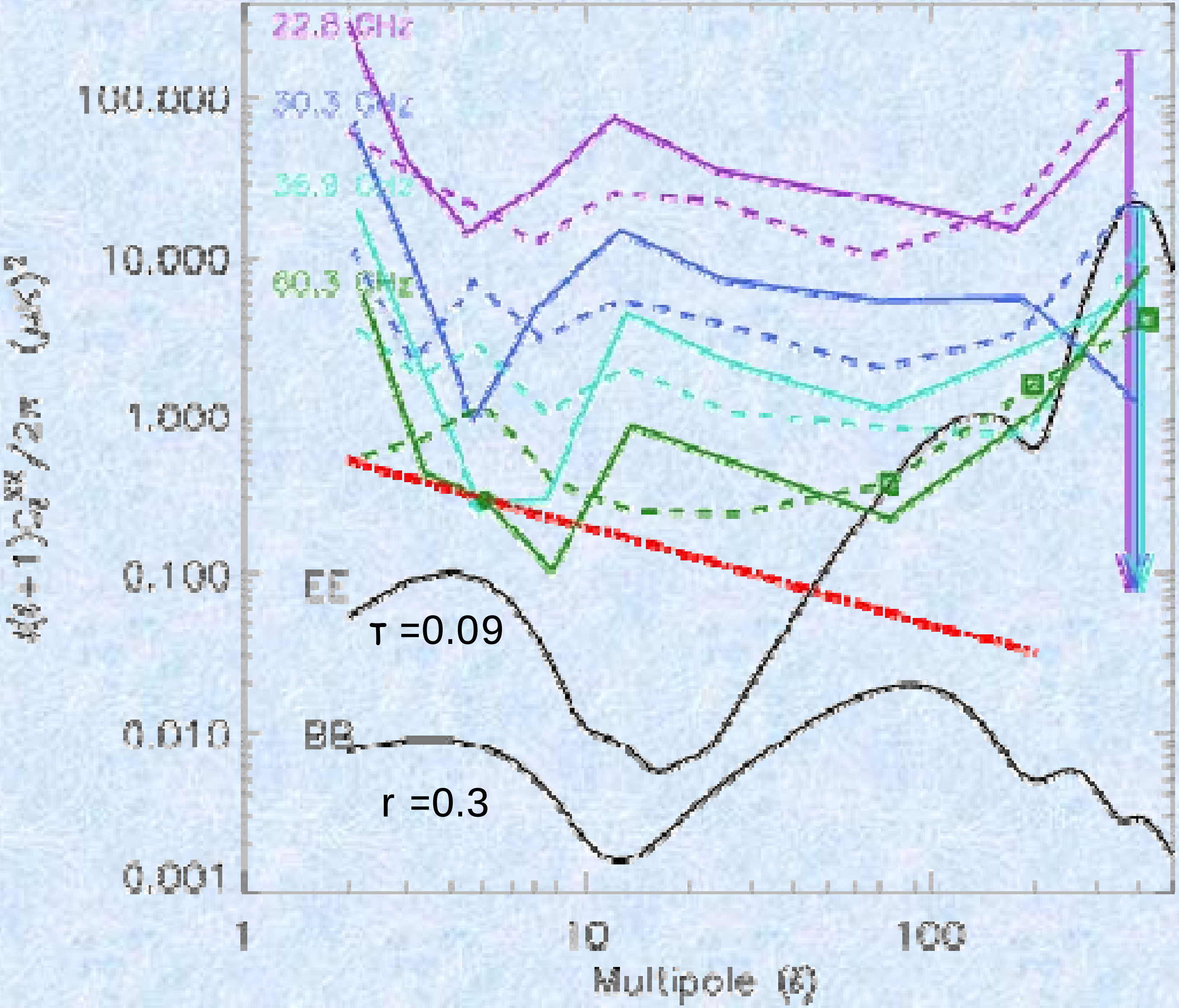
- Foreground Removal
  - Done in pixel space
- Null Tests
  - I Year Difference & TB, EB, BB
- Data Combination
  - Only Q and V are used
- Data Weighting
  - Optimal weighting (C-1)
- Likelihood Form
  - Gaussian for the pixel data
  - C_l not used at l<23

These are improvements only in the analysis techniques: there are also various improvements in the polarization map-making algorithm. See Jarosik et al. (2006)


K 23GHz
Ka-33GHz
Color: polarization Intensity,
smoothed to 2° FWHM
P = (Q2 +U2)1/2
Direction: shown for S/N>1
Q-41GHz
V-61GHz
W-94GHz
0
T(μK)
50

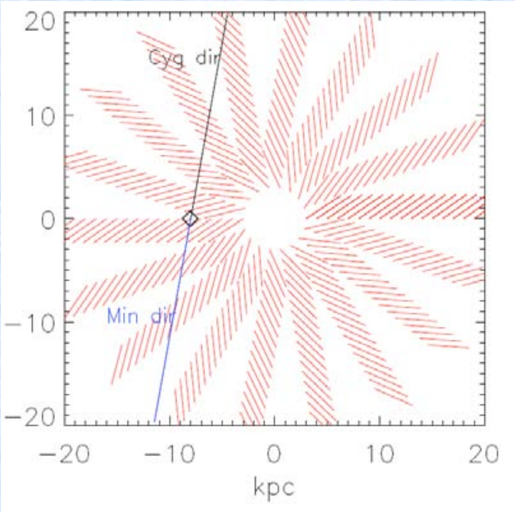
POLARISED FOREGROUNDS (OUTSIDE P06)

- EE Solid
- BB Dashed
- Frequency = geometric mean of data used for the spectra
- Red = estimate of FG level for BB at 60 GHz
- High-l rise <> noise



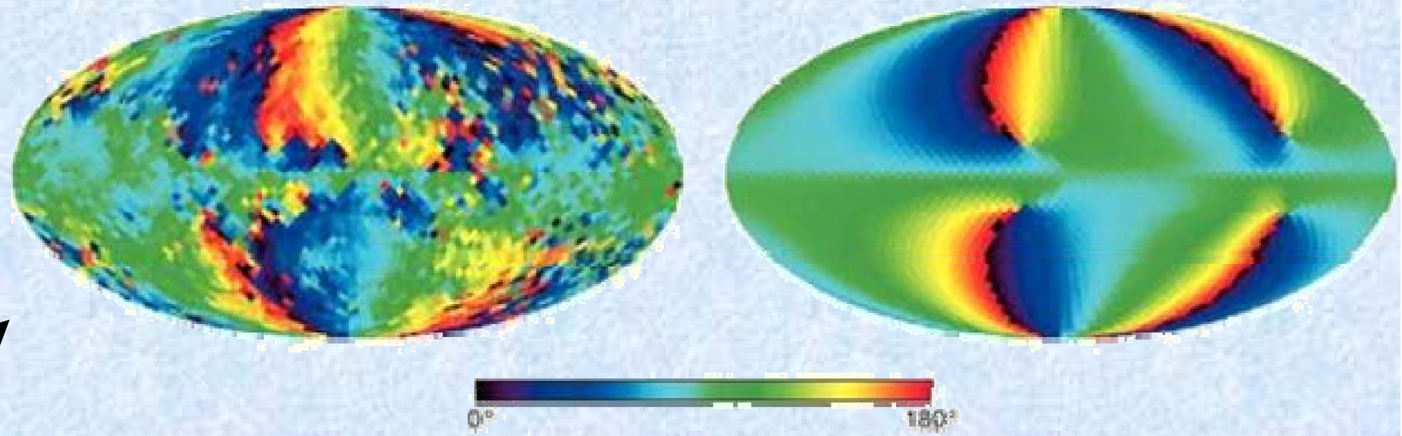
MUST BE CLEANED…

SYNCHROTRON EMISSION



Bisymmetric Spiral
Magnetic Field Model
+ electron distribution:
$n_e = n_0 \exp(-r_5) \sec h^2(z)$

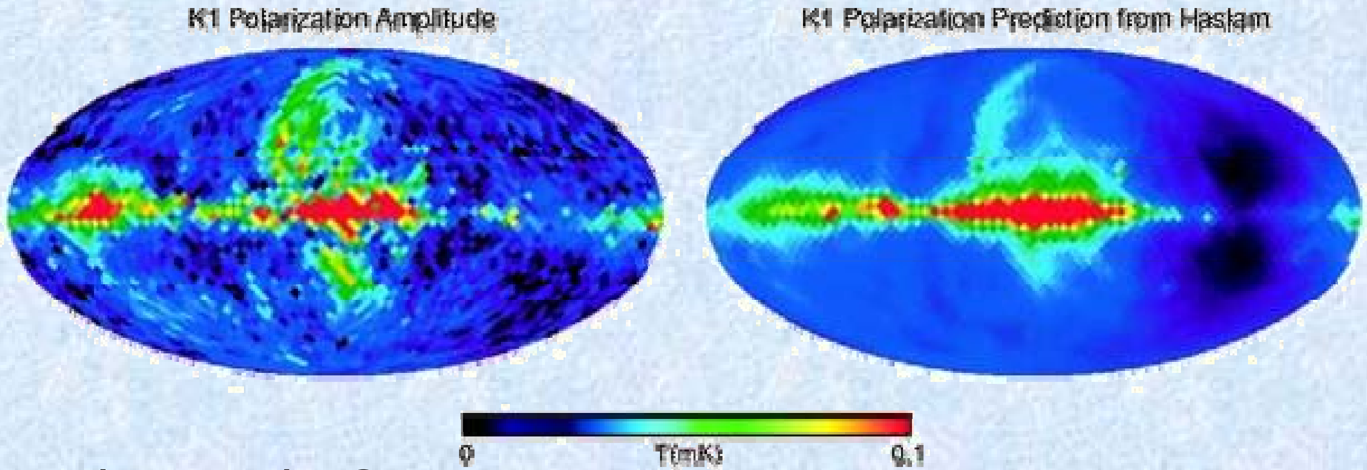
Rotation angle



B field from K band

B field from model

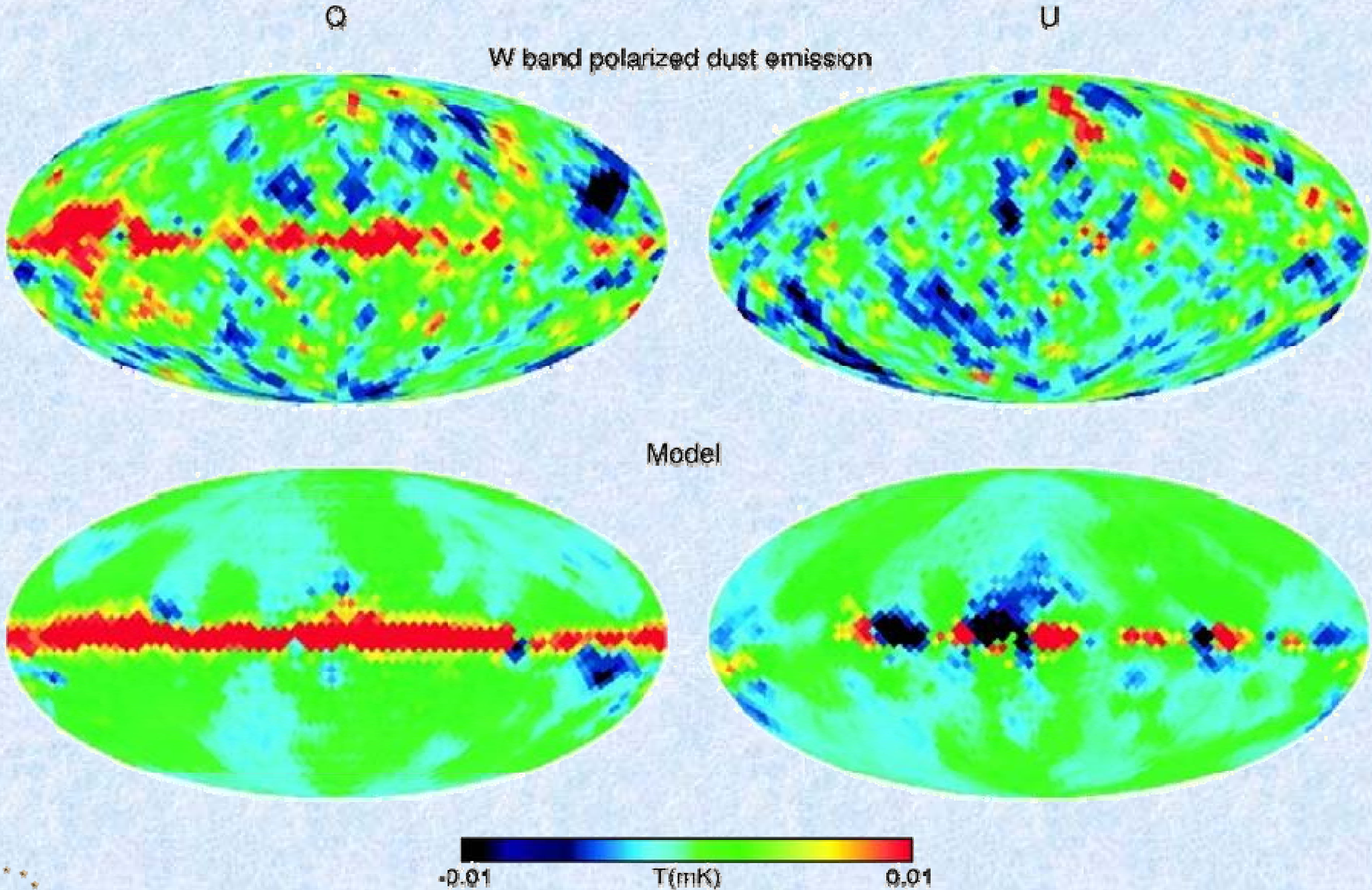
Polarisation amplitude



Observed P@23GHz

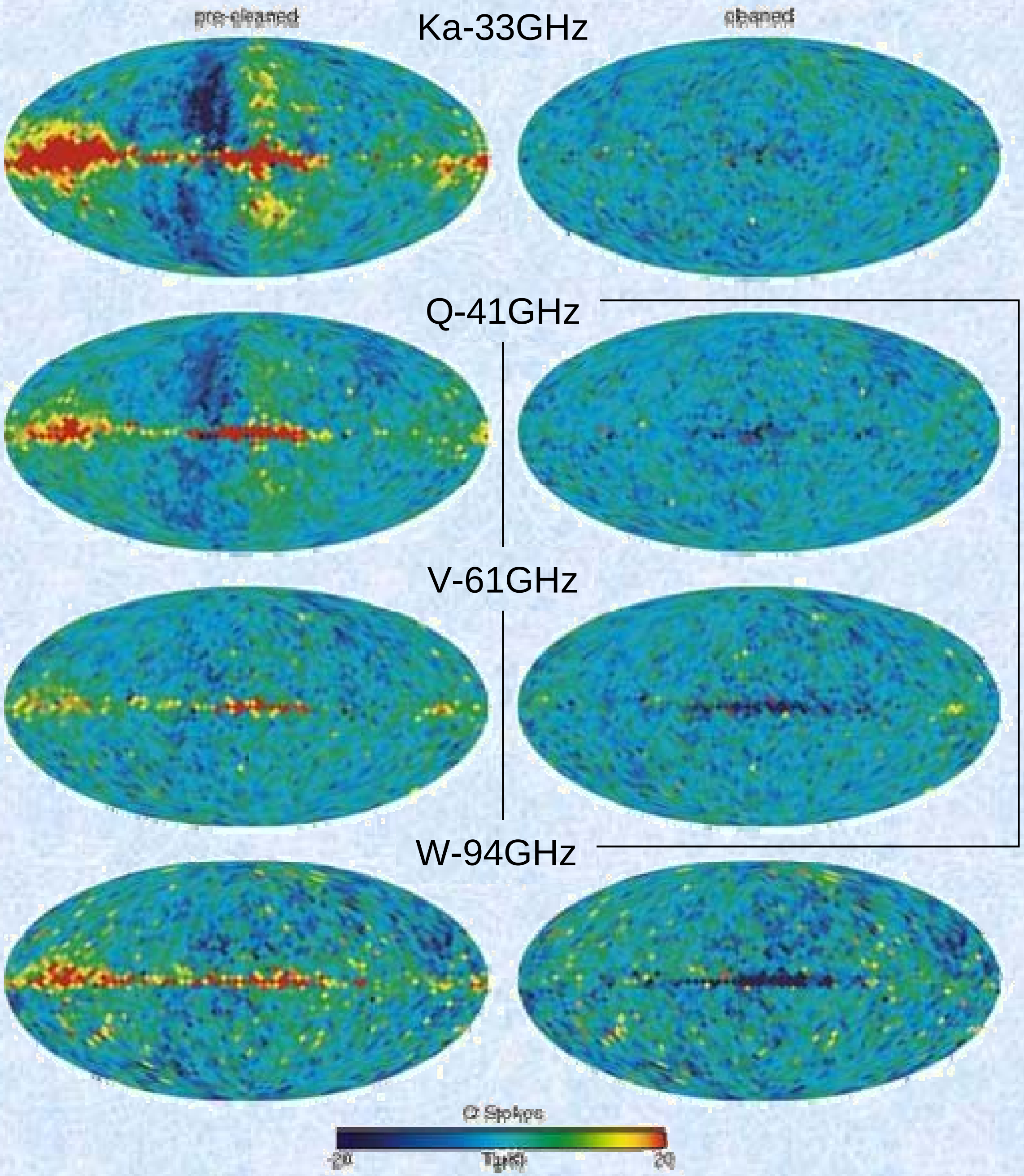
Predicted P@23GHz

EXPECT PROGRESS IN DUST MODELLING



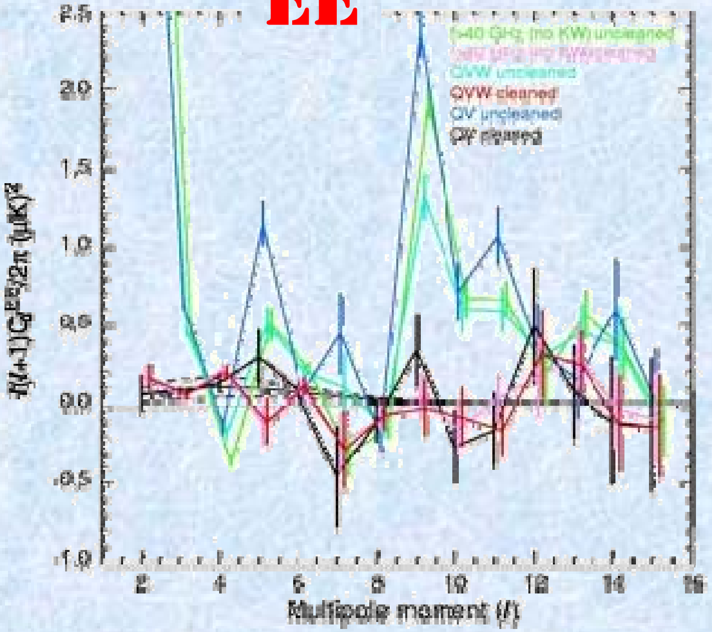
POLARISED FOREGROUNDS SUBTRACTION

- Fit & subtract 2 spatial templates of Galactic emission (Q is shown)
- Synchotron: 23 GHz Q & U
- Dust: Intensity COBE/IRAS-FDS plus Sparse polarisation angle data from starlight absorption

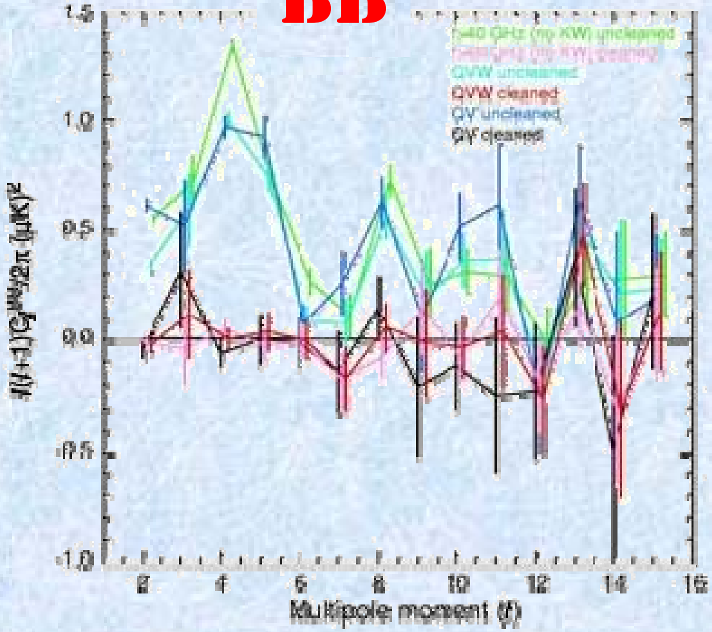


Low-l polarisation spectra

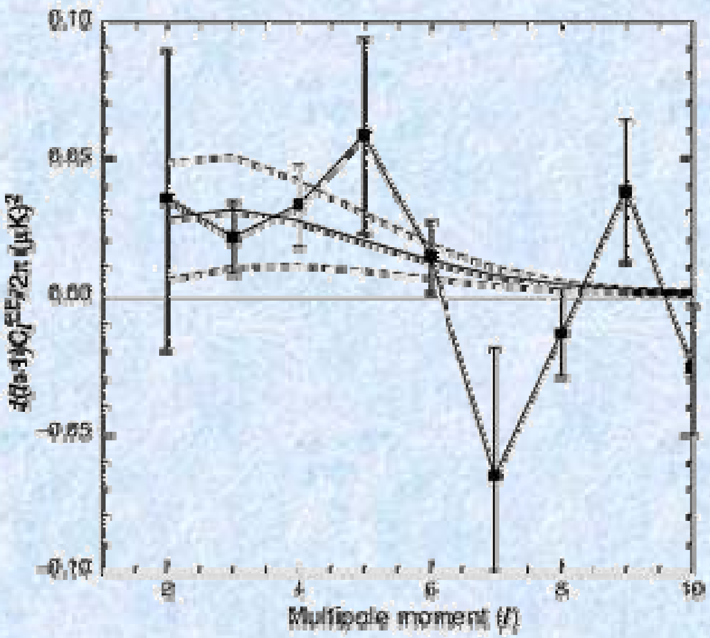
EE

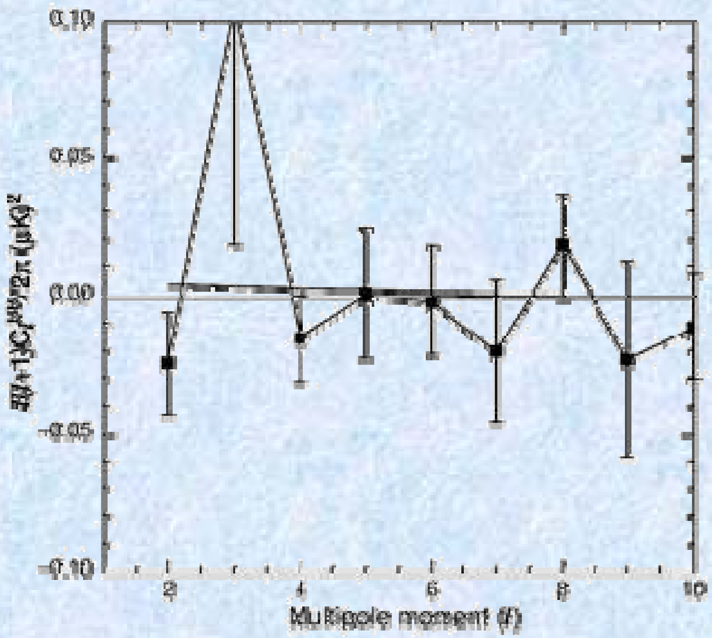


BB



What the cleaning does…



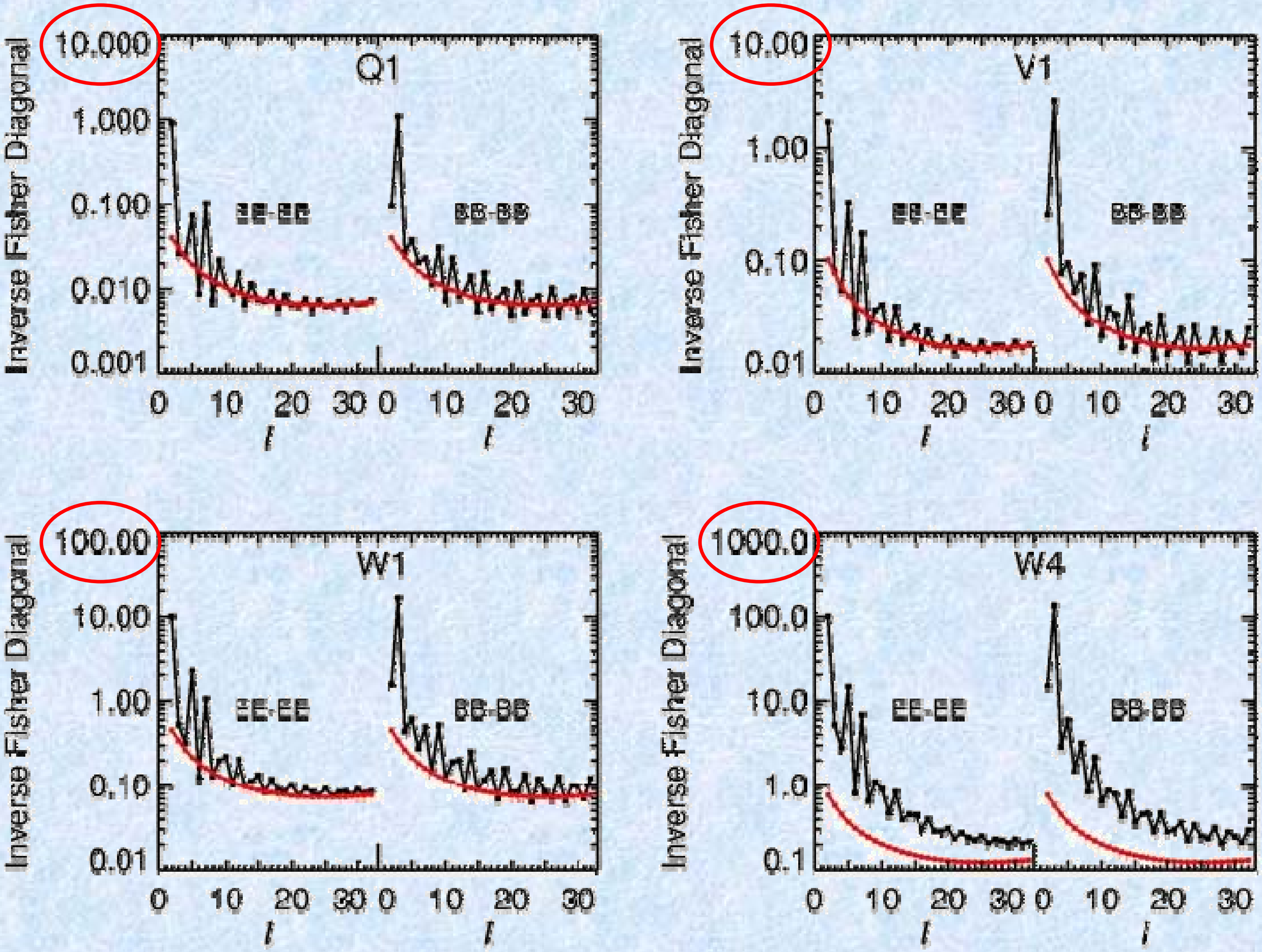


About all reionisation information comes from that bump…

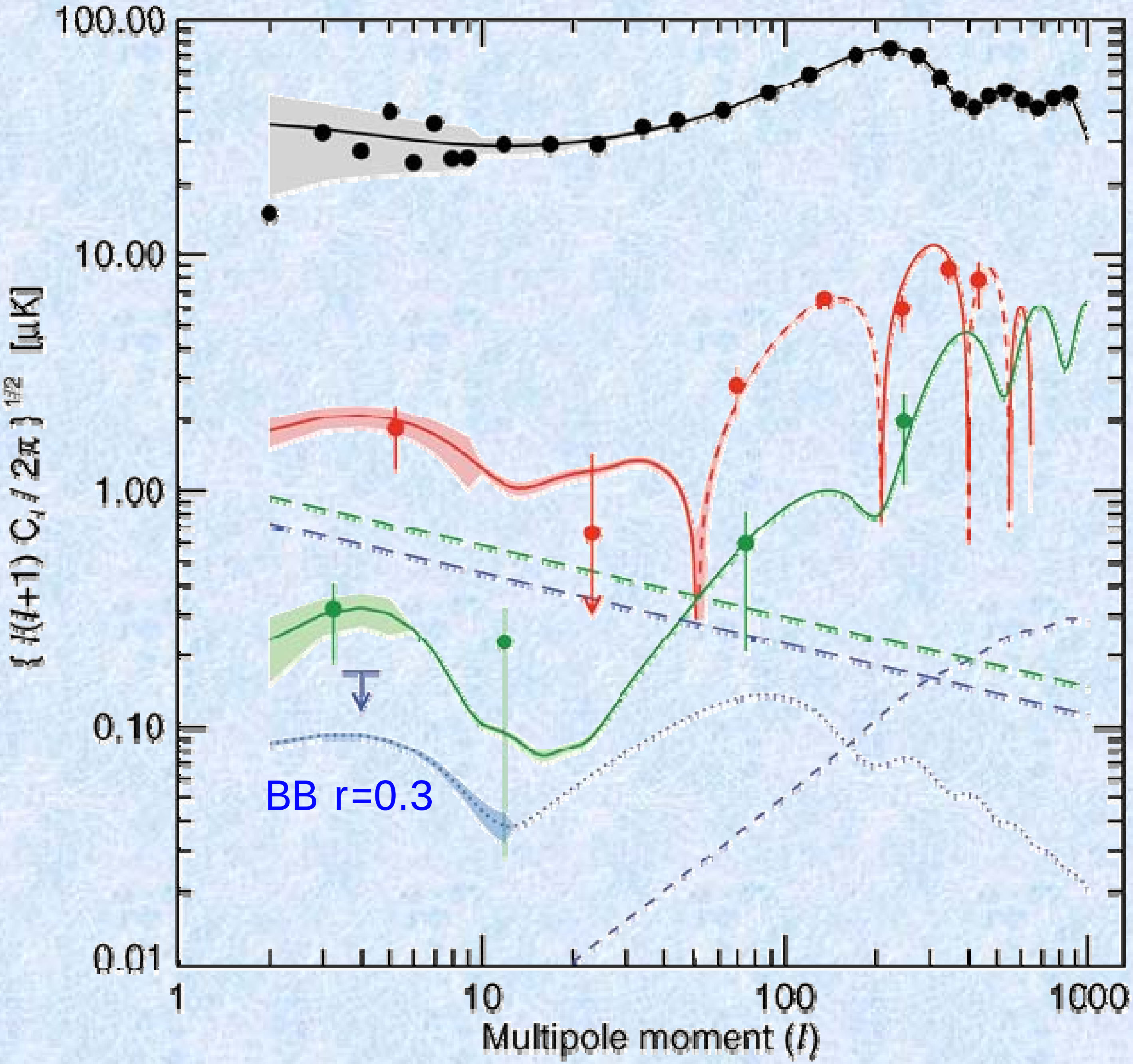
l^2C^E<2-6>/2pi =
0.09+-0.03μK^2

PREDICTED C(L) ERRORS (IN μK^4)

- variations in the N^{-1} weighting are due to the scan pattern combined with the sky cut.
- W data 3 years still not good enough at l=5,7!

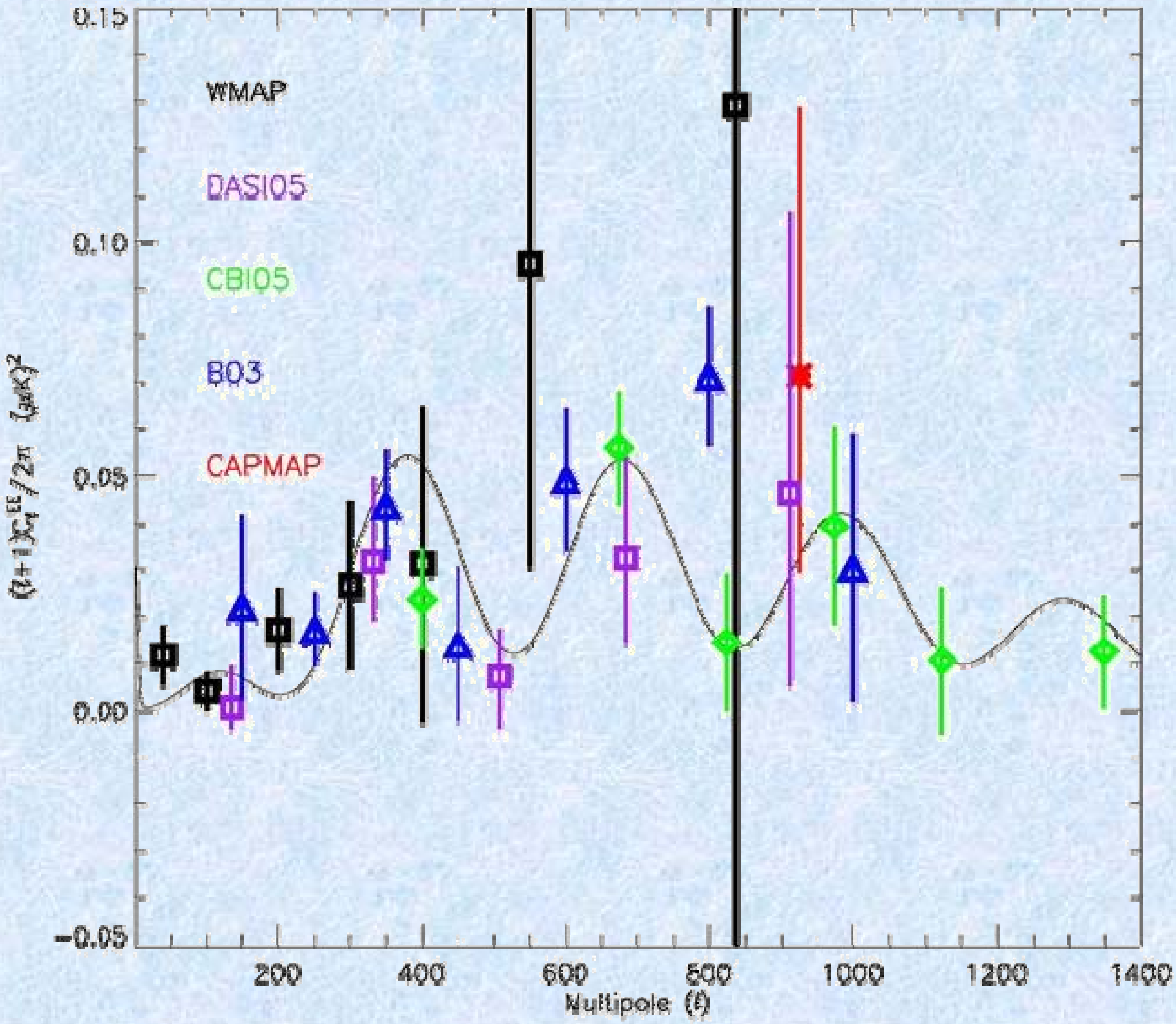


WMAP3 SPECTRA



Approx EE/BB foreground

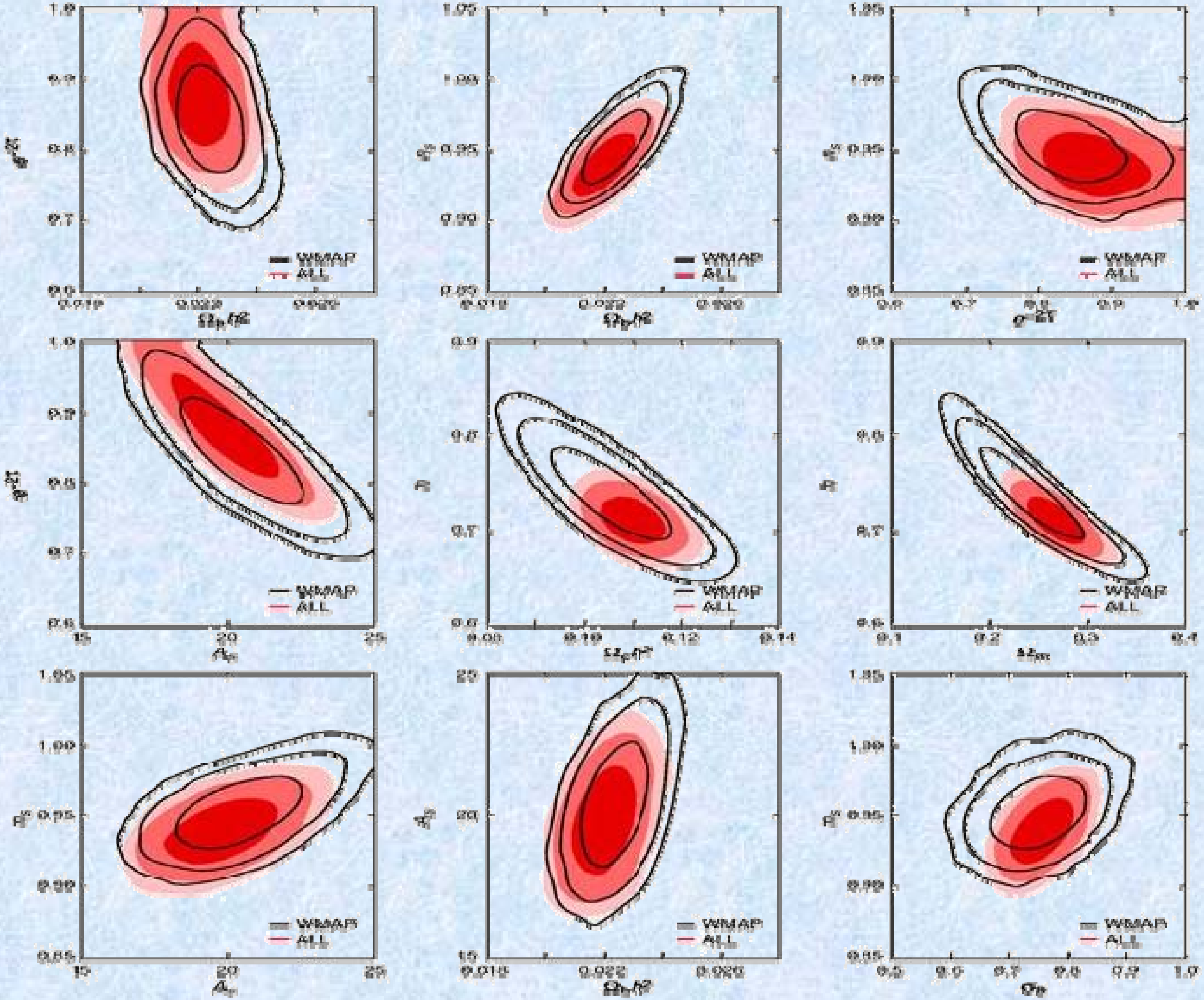
EE spectrum at ℓ > 40 (all today)



3 YEARS RESULTS

WMAP3 ONLY/ALL

ALL=WMAP+2dFGRS+SDSS+ACBAR+BOOMERanG+CBI+VSA+SN(HST/GOODS)+SN(SNLS)



CONSISTENCY WITH LSS

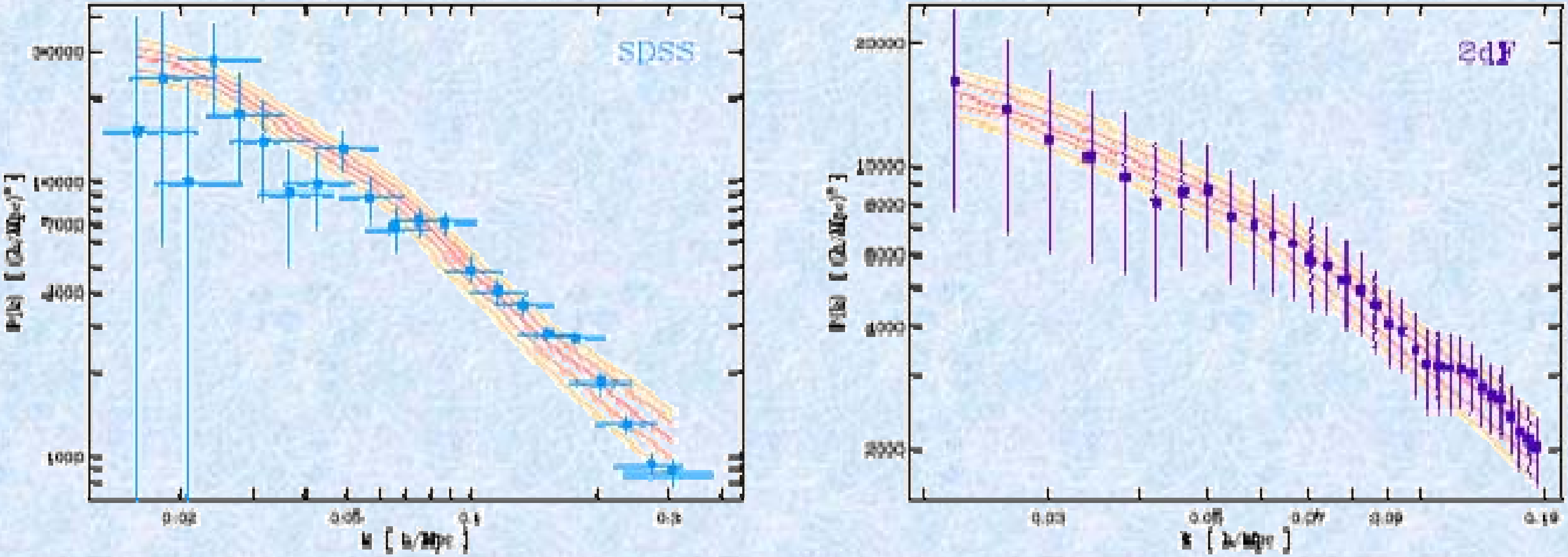
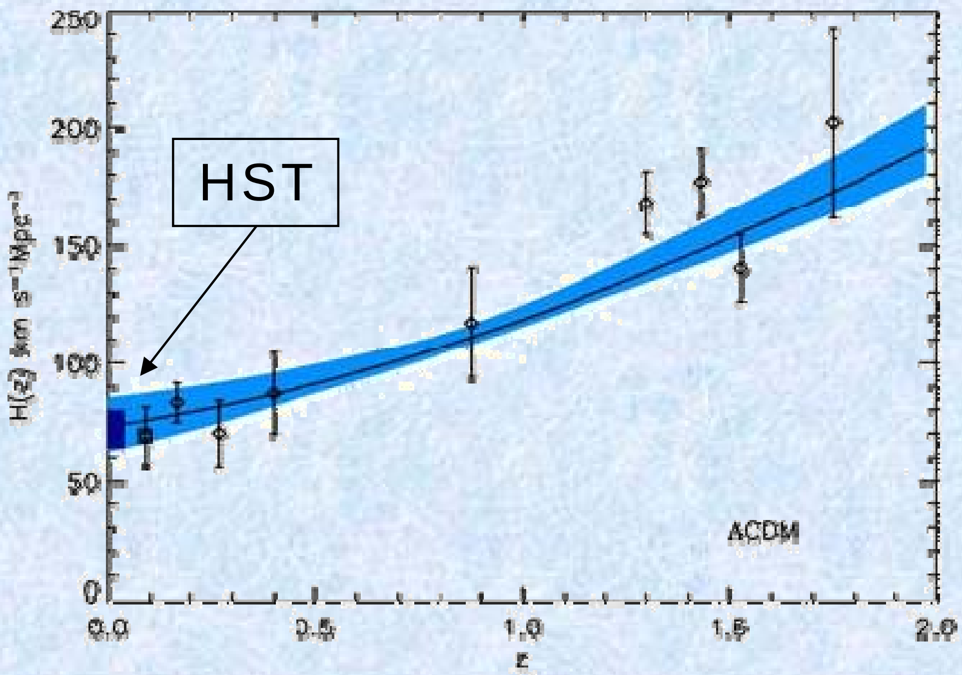
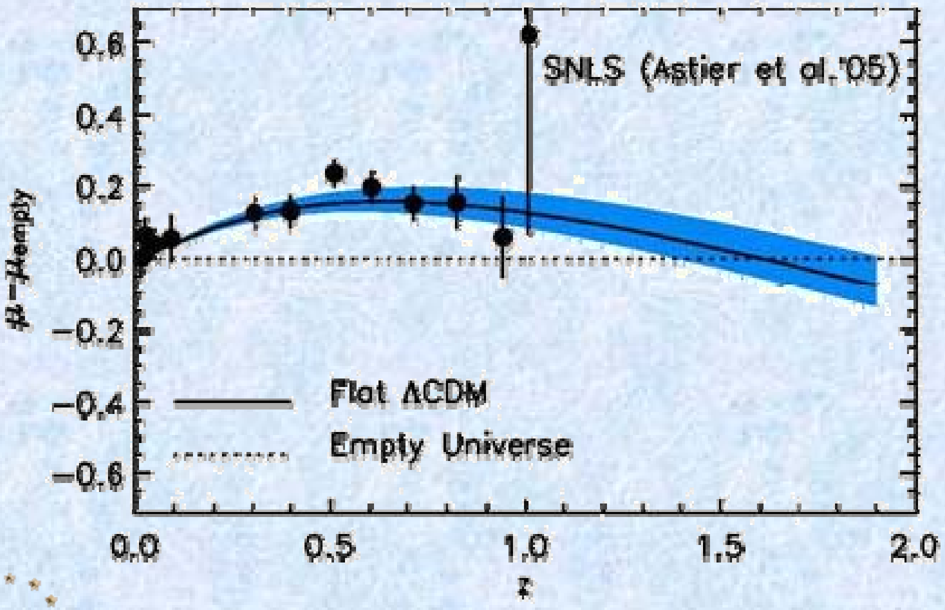
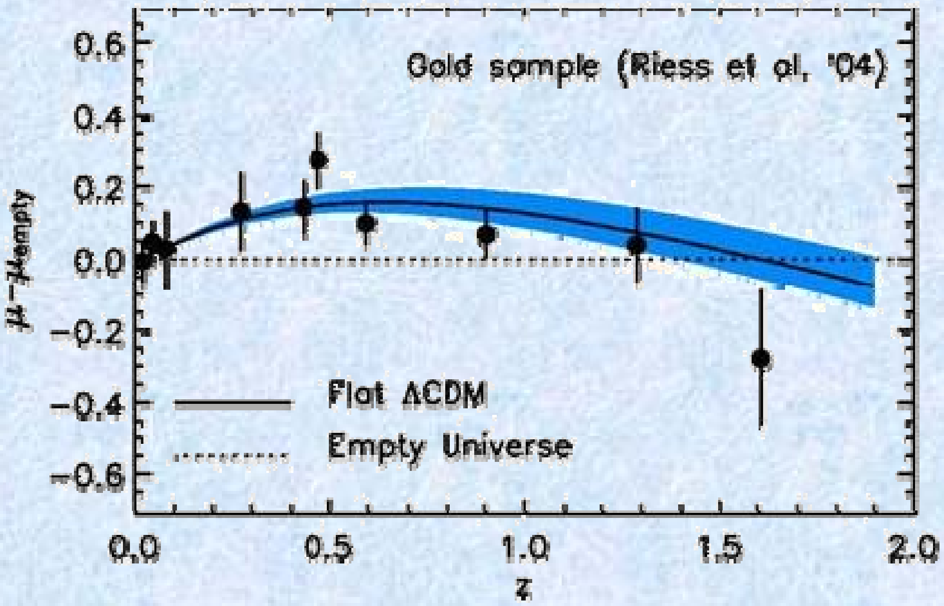


Fig. 6.— The prediction for the mass fluctuations measured by galaxy surveys from the ΛCDM model fit to the WMAP data only. (*Left*) The predicted power spectrum (based on the range of parameters consistent with the WMAP-only parameters) is compared to the mass power spectrum inferred from the SDSS galaxy power spectrum (Tegmark et al. 2004b) and normalized by weak lensing measurements (Seljak et al. 2005b). (*Right*) The predicted power spectrum is compared to the mass power spectrum inferred from the 2dFGRS galaxy power spectrum(Cole et al. 2005) with the best fit value for b_{2dFGRS} based on the fit to the WMAP model. Note that the data points shown are correlated.

Further predictions

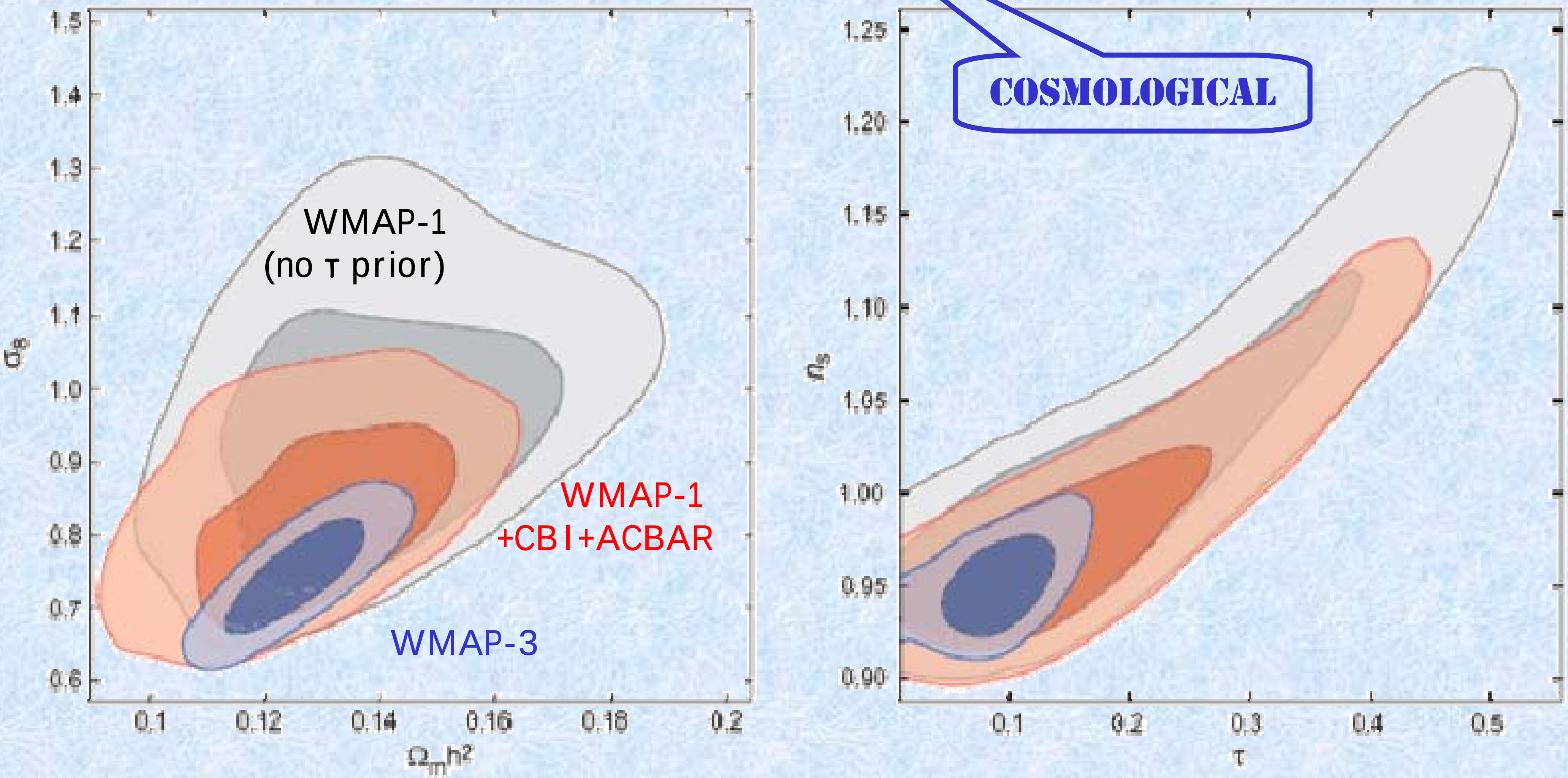






WMAP MAIN RESULTS

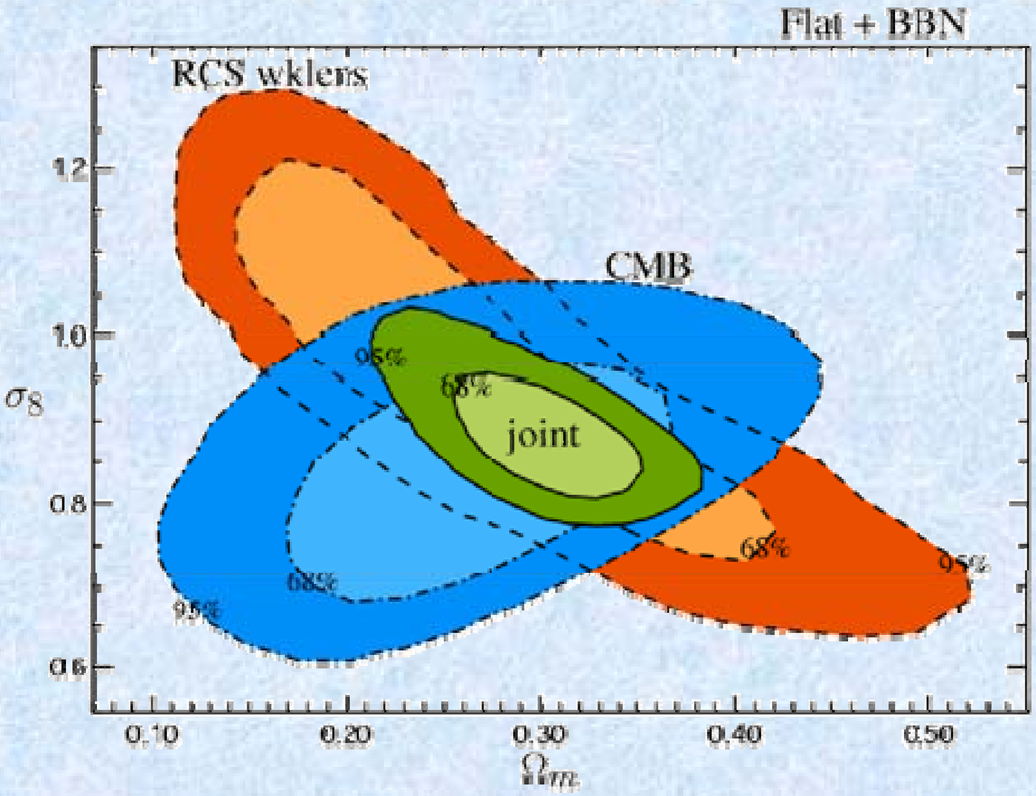
COSMOLOGICAL



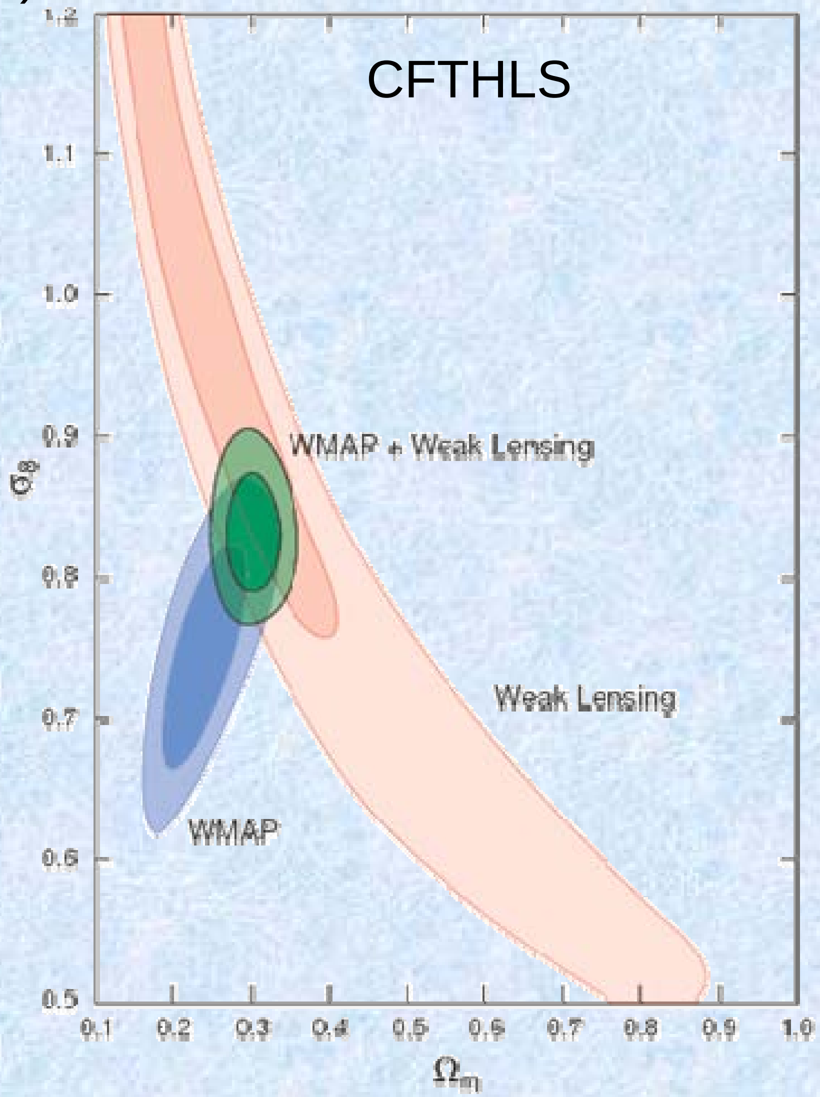
Improvement in parameter constraints for the power-law CDM model (6 pars).
$\{\Omega_b h^2, \Omega_m h^2, h, \tau, n_s, A_s\}$
χ2eff (TT)/dof = 1.068 (1.09 yr 1) & χ2eff (all)/dof = 1.04 (1.04 yr 1)

A_S-Ω_M

CMB (WMAP1ext) with galaxy lensing (+BBN prior)



Contaldi, Hoekstra, Lewis: astro-ph/0302435



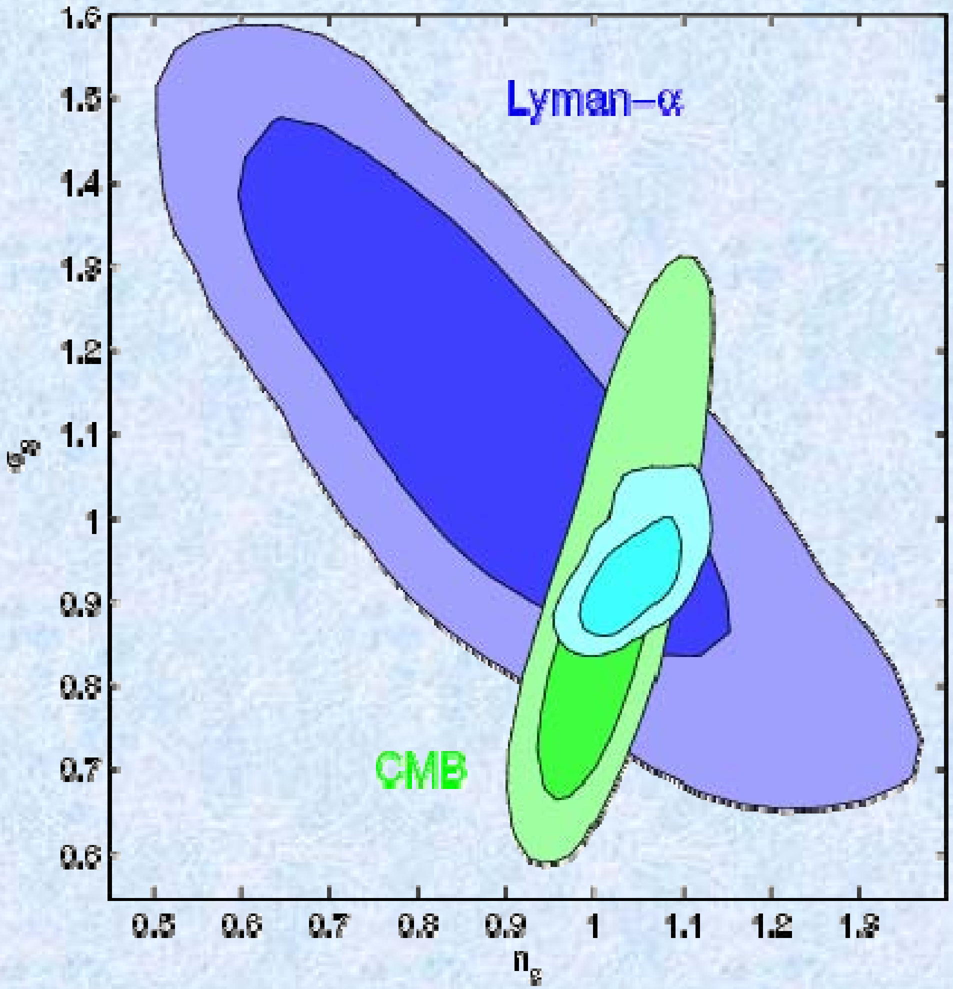
Spergel et al 2006

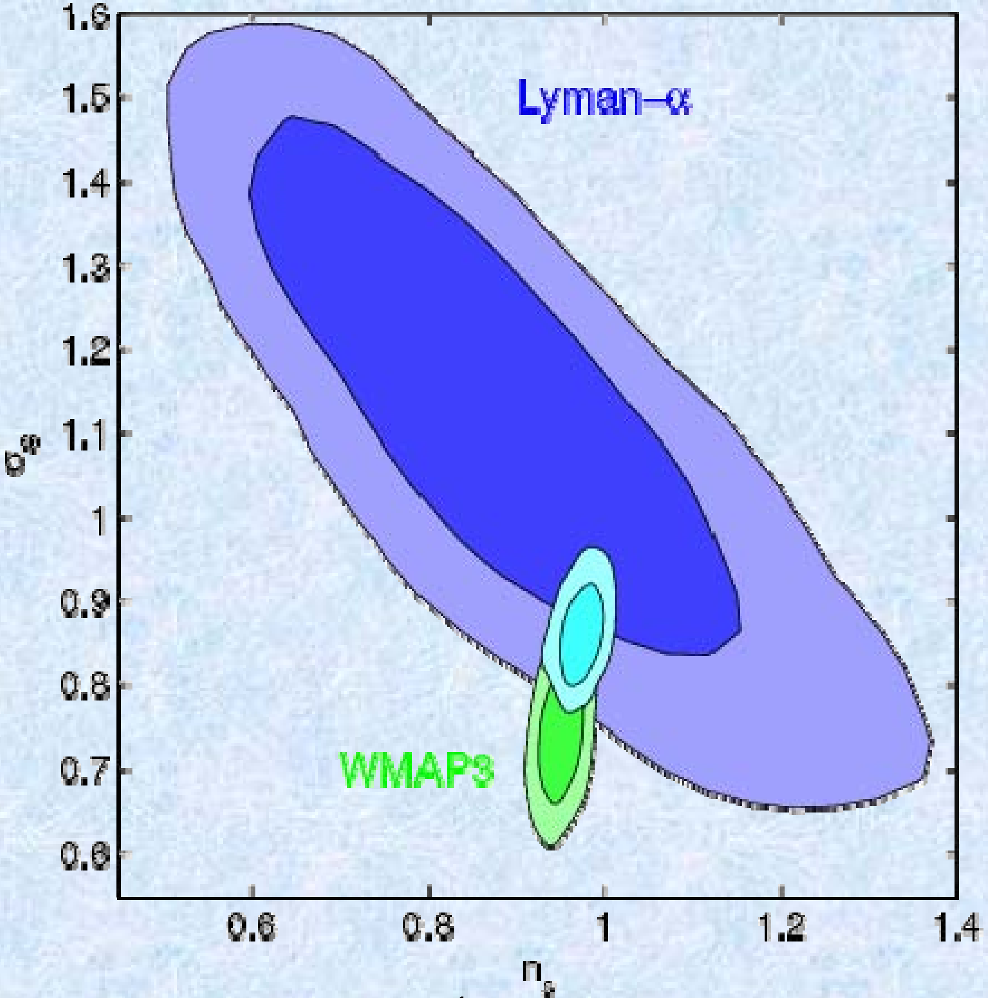
NB: σ_8 and A_S are just different normalisation of the (scalar) power spectrum

LYMAN ALPHA + WMAP

WMAP 1

WMAP 3 bfp: n_s=0.97, s_8=0.88





(both +HST)

n_{run} (0.002 Mpc^{-1})= 0.005 ± 0.030

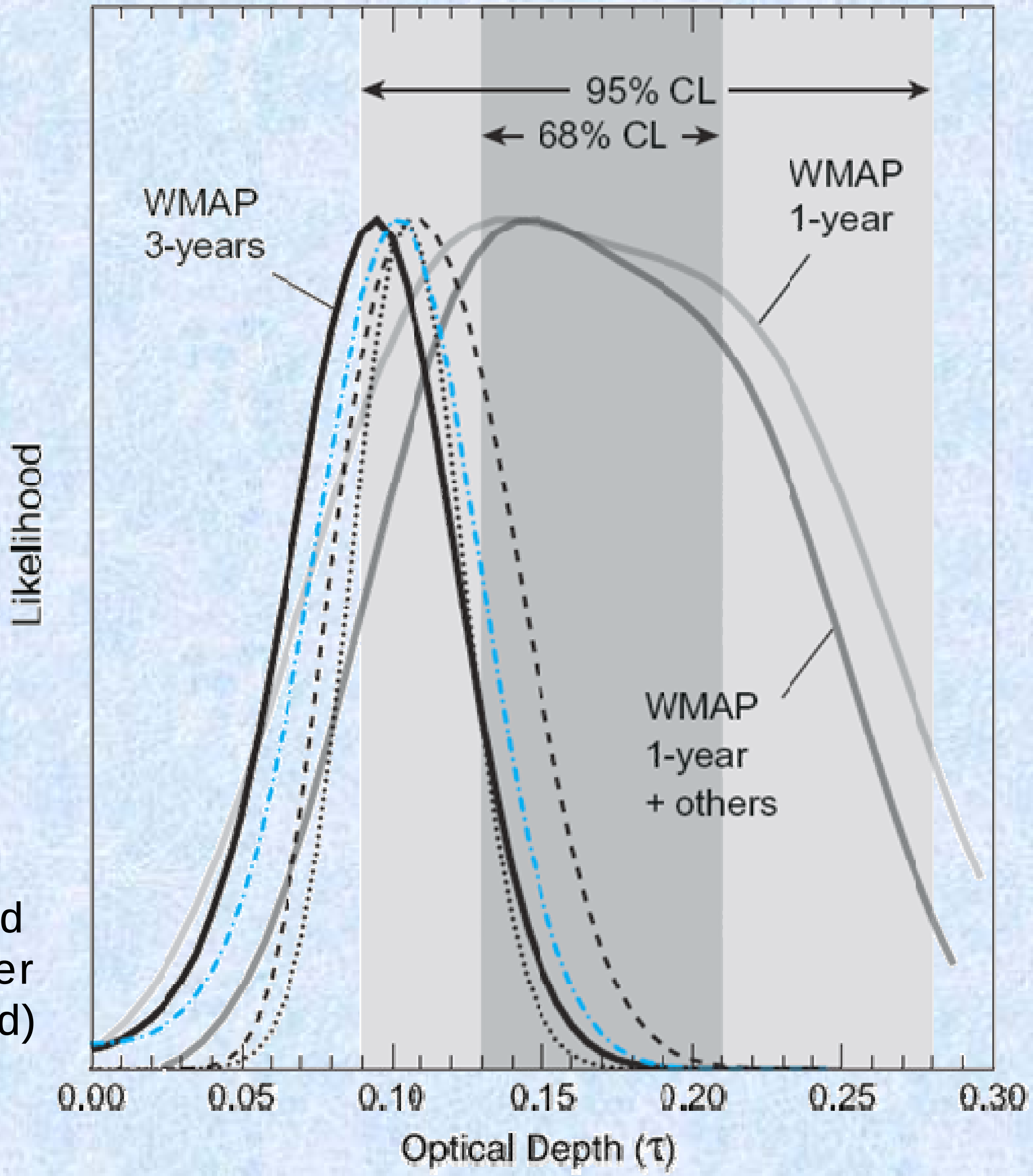
Does not favour running: 0.005 ± 0.03

Ly-alpha: Viel Matteo, Haehnelt Martin G., Springel Volker, 2004, MNRAS, 354, 684

OPTICAL DEPTH

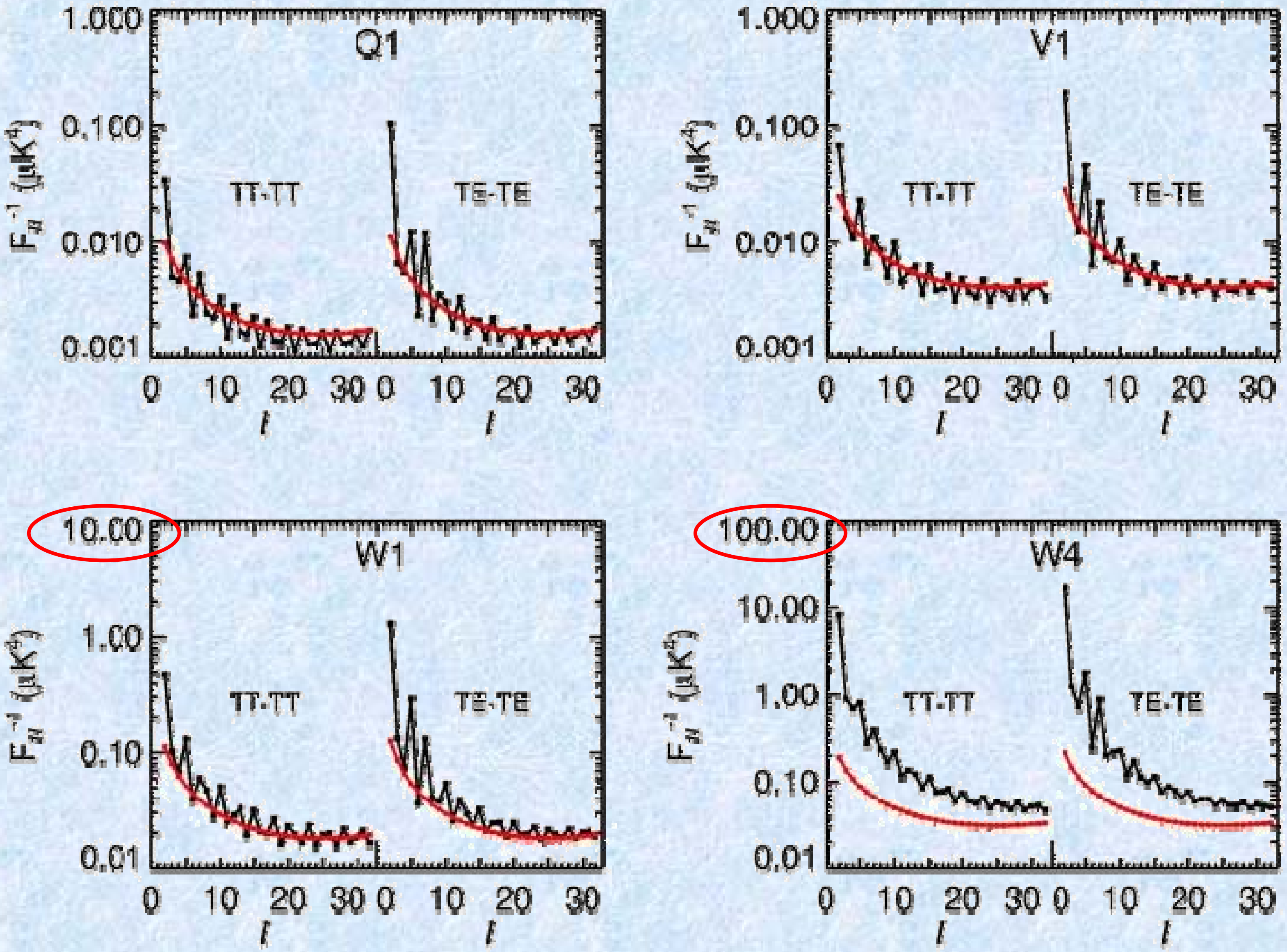
- TE-3 years contributes very little
- Alone would be an upper limit on tau
- New noise estimation is the reason
- tau from (EE-) 3yr is compatible at 2σ level with 1 yr data

(likelihood plotted keeping all other parameters fixed)



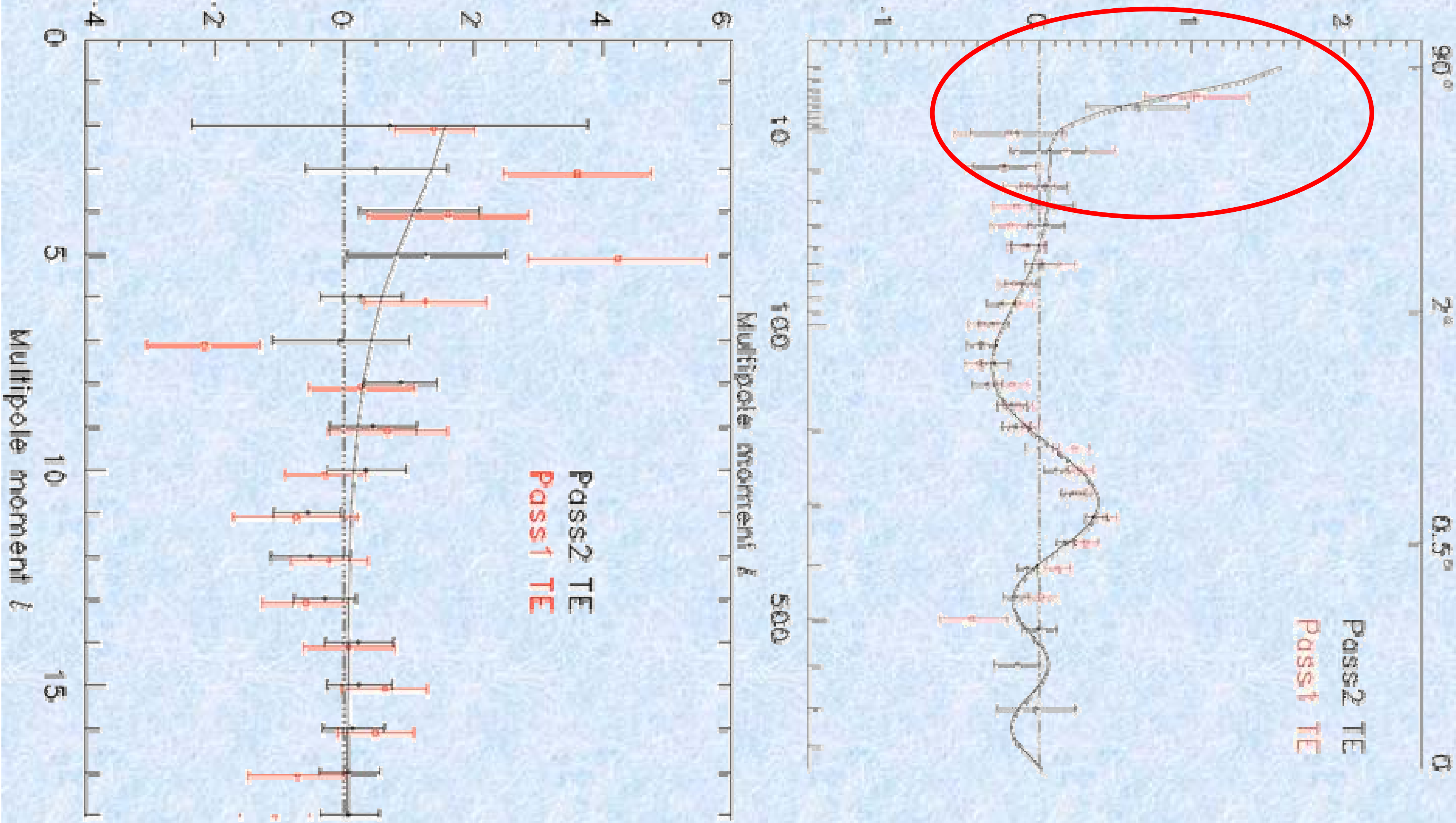
PREDICTED CL UNCERTAINTY AT LOW L

- Black = inverse Fisher Matrix
- Red = pixel-pixel noise correlations (after map-making) are ignored
- Low-l rise from 1/f noise (in time)



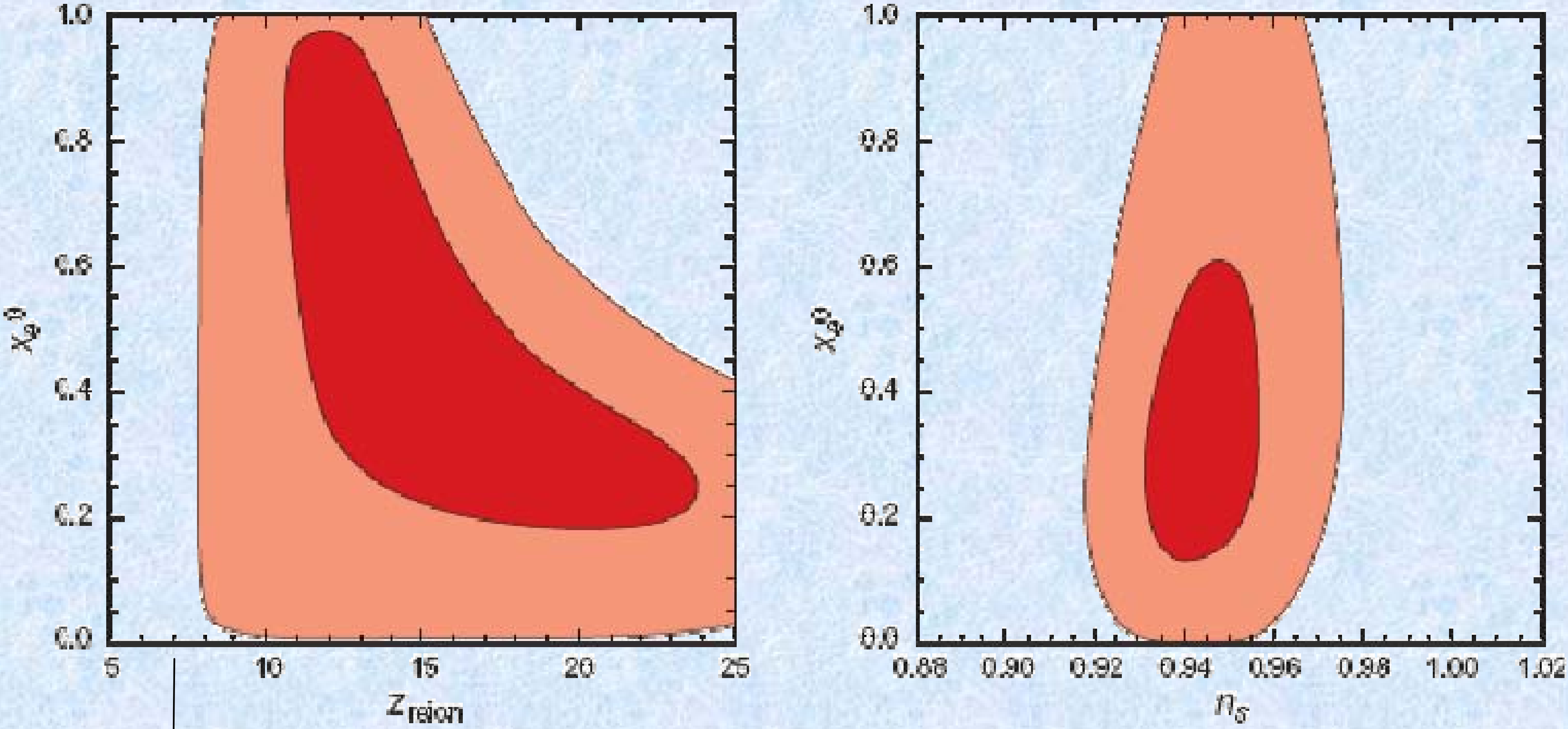
- NB: Noise negligible / signal for TT, but TE analysis must take the structure into account

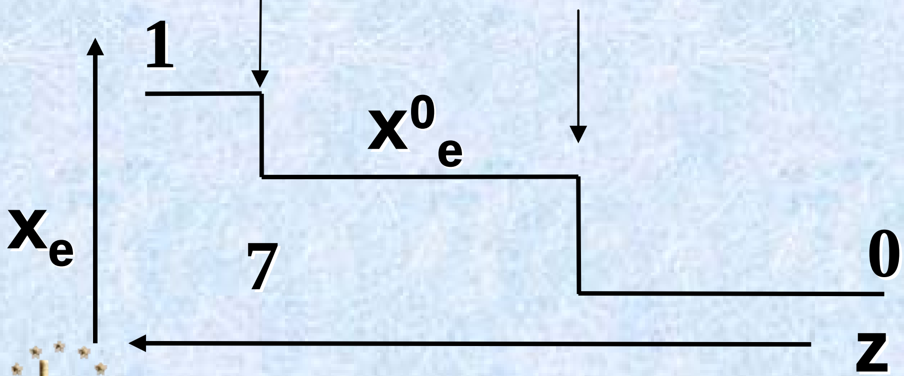
TE COMPARISON 1 VS 3 YEARS



From Hinshaw @ Irvine Conference

WMAP3 CONSTRAINTS ON REIONISATION





68% and 95% joint 2-d marginalized confidence level contours for x0e – zreion for a power law LCDM

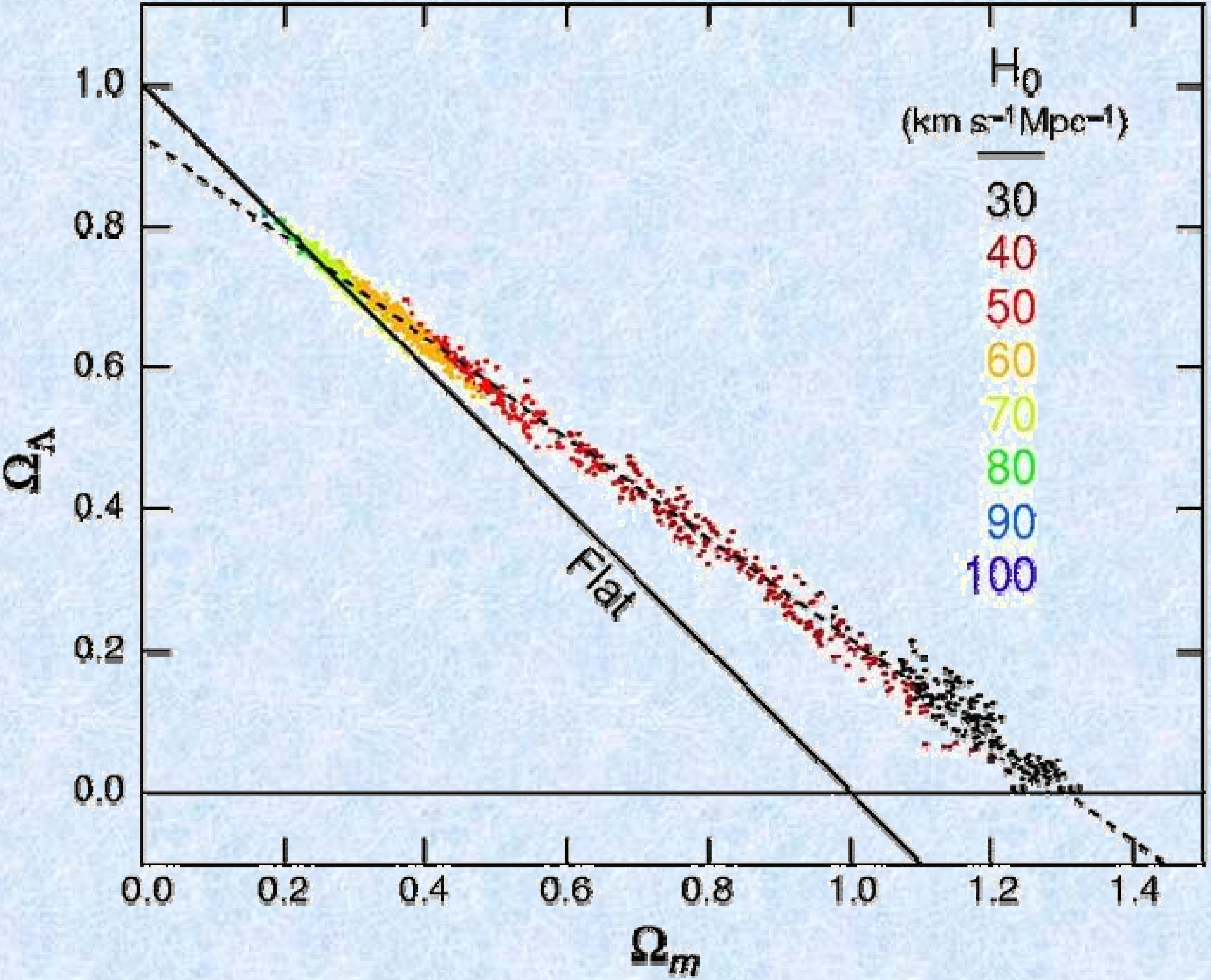
NB: If instantaneous,
z_r=10.9 +2.7-2.3

WHAT'S NEEDED!

WMAP Collaboration (Spergel & al), 2006:

Ω/H Degeneracy Track

(Setting Ω=1 is not innocuous)



CONSTRAINING IC

Epsilon, eta et ksi correspond to successive derivatives of the inflation potential

$$\begin{cases} r = 16\varepsilon \\ n_s = 1 - 6\varepsilon + 2\eta \\ dn_s / d\ln k = -2\xi + 16\varepsilon\eta - 24\varepsilon^2 \end{cases}$$

Measurement of the amplitude of tensor modes fixes Hubble parameter H during inflation when relevant scales are leaving horizon; alternatively, fixes scalar field potential and first derivative.

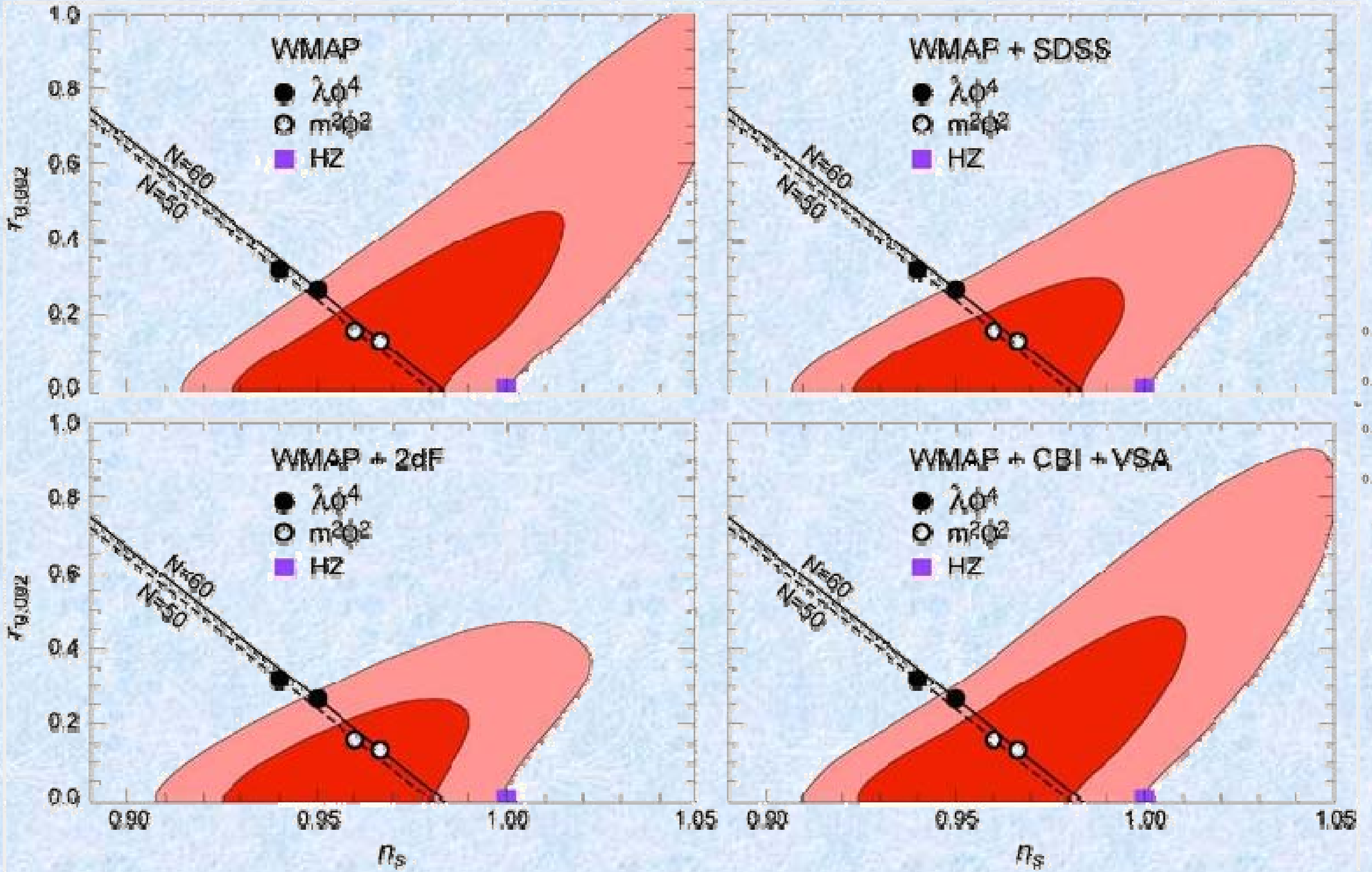
$$H \equiv \dot{a}/a \approx \frac{1}{M_{Pl}}\sqrt{\frac{V}{3}}$$

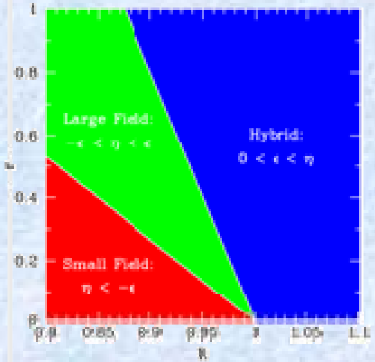
$$r = \frac{2V}{3\pi^2 M_{Pl}^4 \Delta_R^2(k_0)} = 8 M_{Pl}^2 \left(\frac{V'}{V}\right)^2$$

$$V^{1/4} \leq 3.3 \times 10^{16}\, r^{1/4}\ \mathrm{GeV}$$

e.g. Liddle & Lyth (1993), Copeland et al. (1993), Liddle (1994)

IMPLICATIONS (FOR INFLATION)





$\lambda\varphi^4$ is out, but a simple $m^2\varphi^2$ is still in…

*NB: this is **not** the astroph plot*

Tendencies:
ns < 1
or τ is high
or there are tensors
or the model is wrong
or we are quite unlucky…

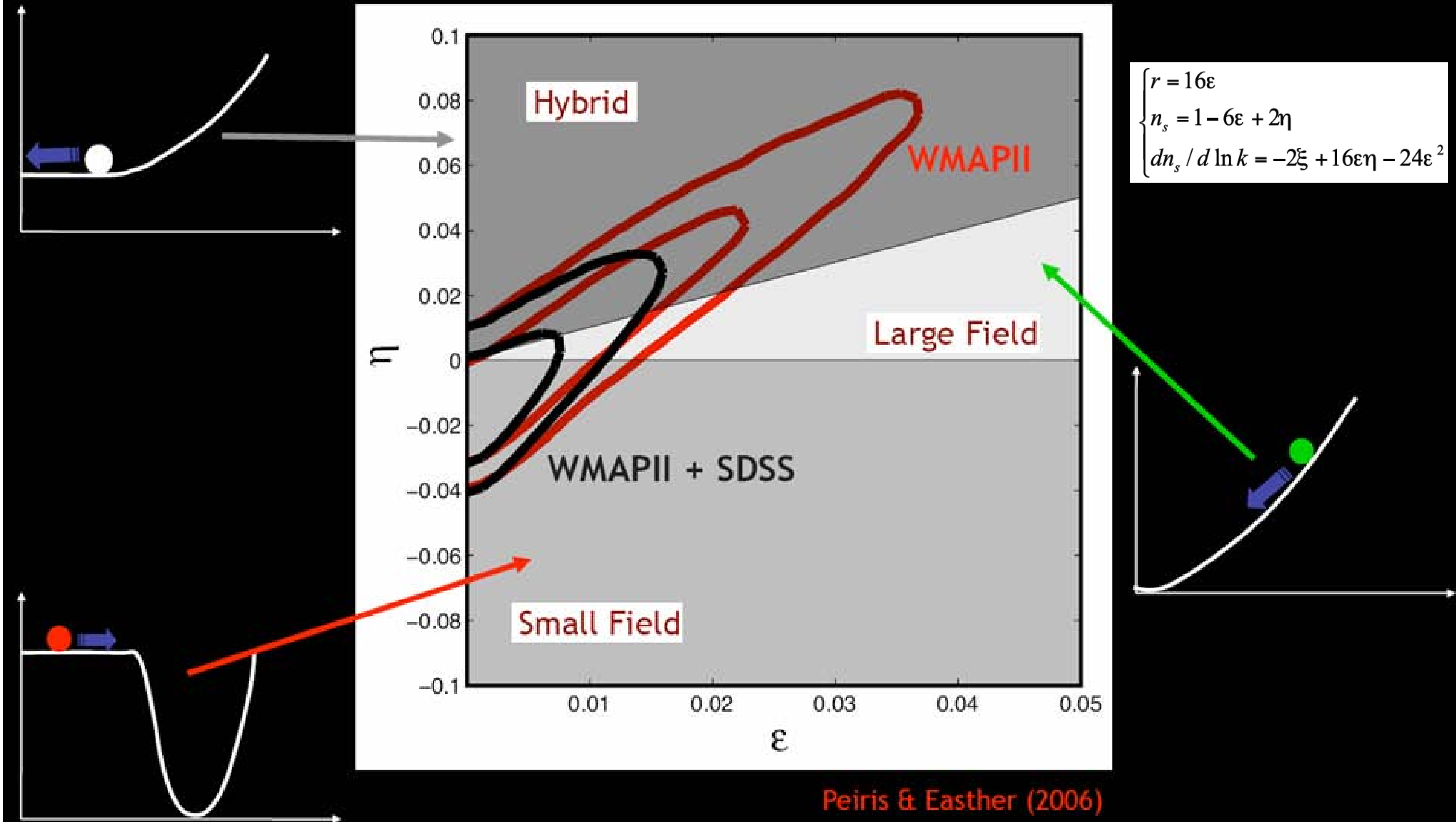
LIMITS ON TENSOR-TO-SCALAR RATIO

Table 8: Constraints on r, Ratio of Amplitude of Tensor Fluctuations to Scalar Fluctuations (at $k = 0.002$ Mpc^{-1})

Data Set	r (no running)	r (with running)
WMAP	0.55 (95% CL)	1.5 (95% CL)
WMAP+BOOM+ACBAR	0.63 (95% CL)	1.4 (95% CL)
WMAP+CBI+VSA	0.55 (95% CL)	1.1 (95% CL)
WMAP+2df	0.30 (95% CL)	1.0 (95% CL)
WMAP+SDSS	0.28 (95% CL)	0.67 (95% CL)

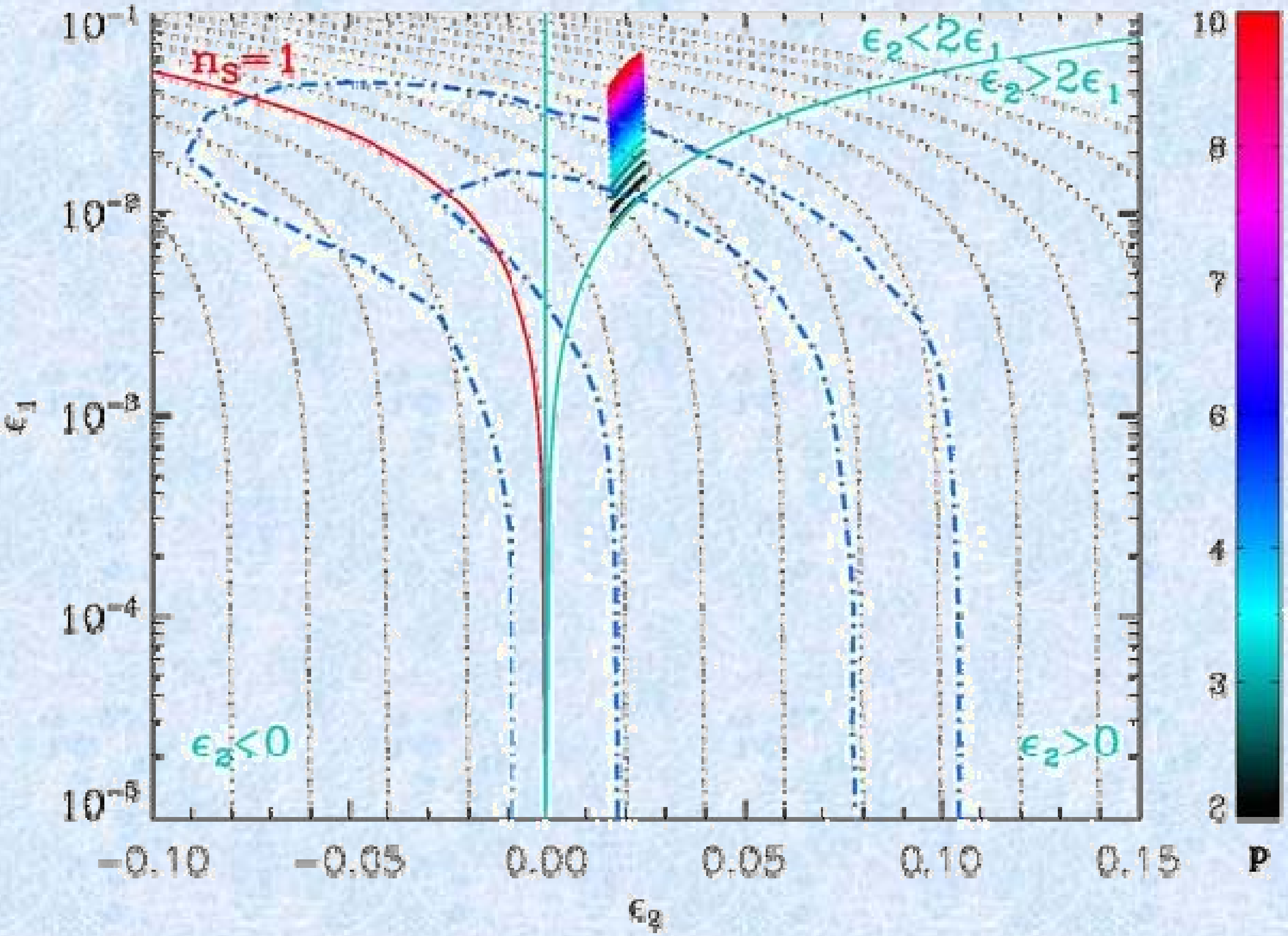
$r < 0.55$ @ 95% CL $\Rightarrow$ $\Omega_{GW}h^2 < 1.\ 10^{-12}$ (@95% CL)

The Inflationary Zoo



Constraints on first two HSR parameters at k=0.002 Mpc^{-1}

CONSTRAINTS ON LARGE-FIELD MODELS



marginalised

Likelihood)

- Models $V \propto \Phi^p$
- Dotted = constant spectral index lines
- P>4 are in trouble (one start constraining the potential shape)

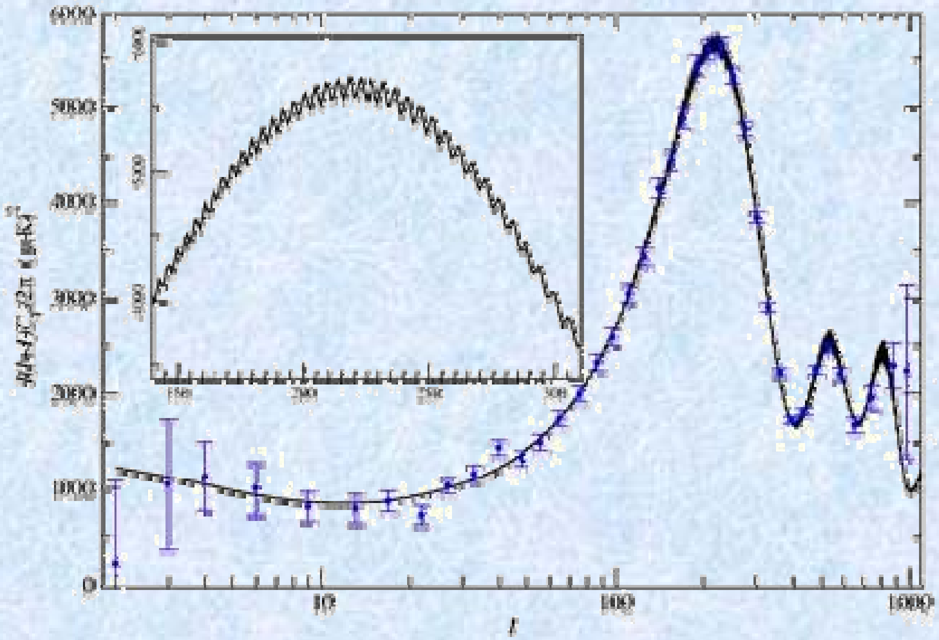
Martin & Ringeval 2006 (to be submitted to JCAP)

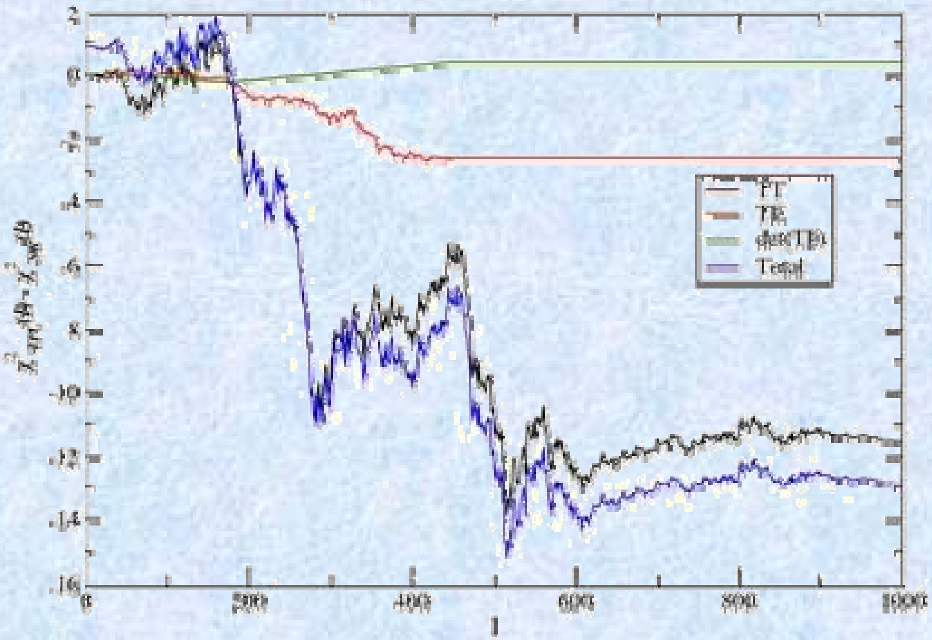
A SIGN OF TRANS-PLANCKIAN PHYSICS?

- Probleme theorique trans-Planckien
  J. Martin and R. Brandenberger, PRD 63 123501, 2001 (hep-h/0005209)

- WMAP et les oscillations :
  - J. Martin & C. Ringeval, PRD 69 064406, 2004 (astro-ph/0310382);
  - J. Martin & C. Ringeval, PRD 69 127303, 2004 (astro-ph/0402609);
  - J. Martin & C. Ringeval, JCAP 0501 007, 2004 (astro-ph/0405249)

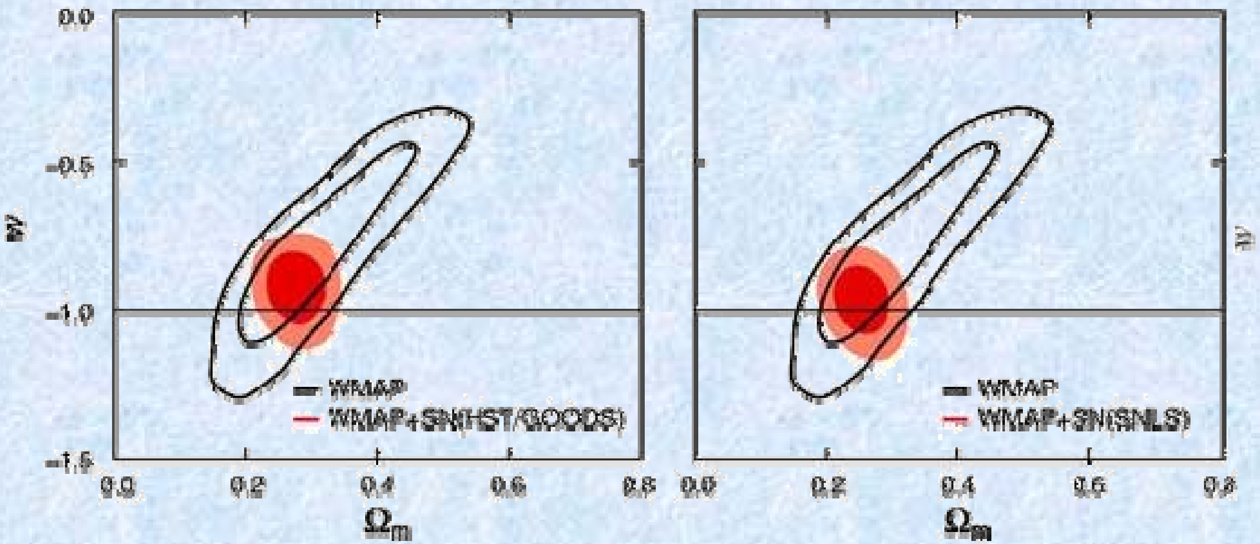
- Ongoing discussions with WMAP team, stay tuned…



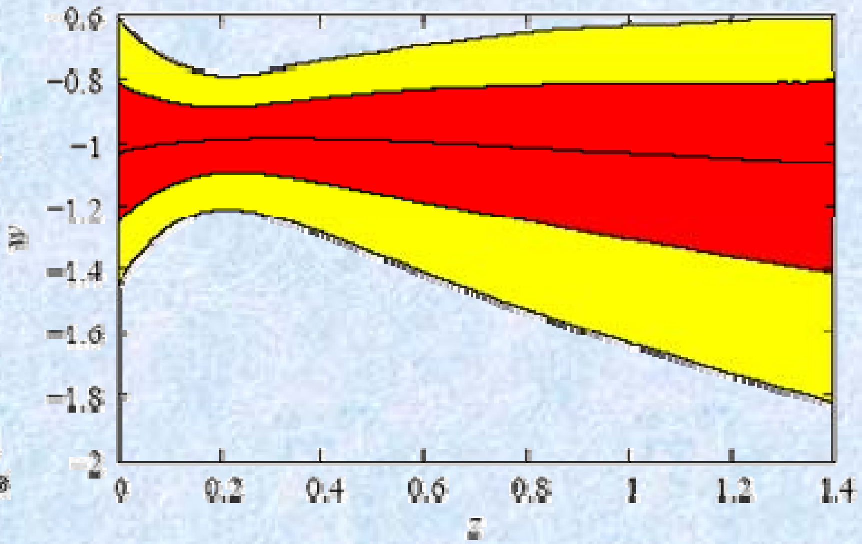


INVESTIGATING DARK ENERGY

- The equation of state parameter $w(z) = p/\rho$
  - $w = -1$
  - $w = \text{const} \neq -1$
  - $w(z)$



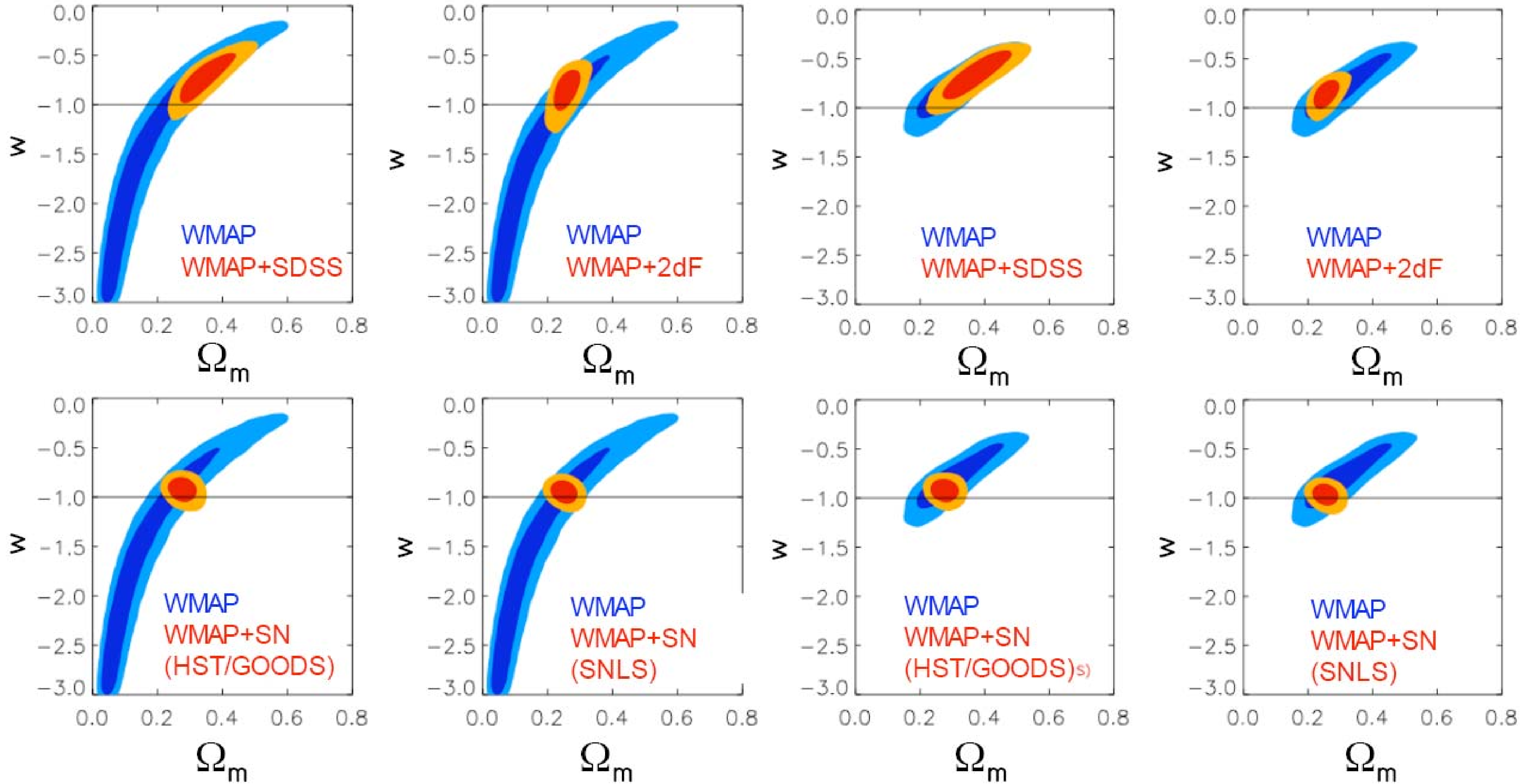
Spergel et al 2006



Seljak et al 2005

DARK ENERGY

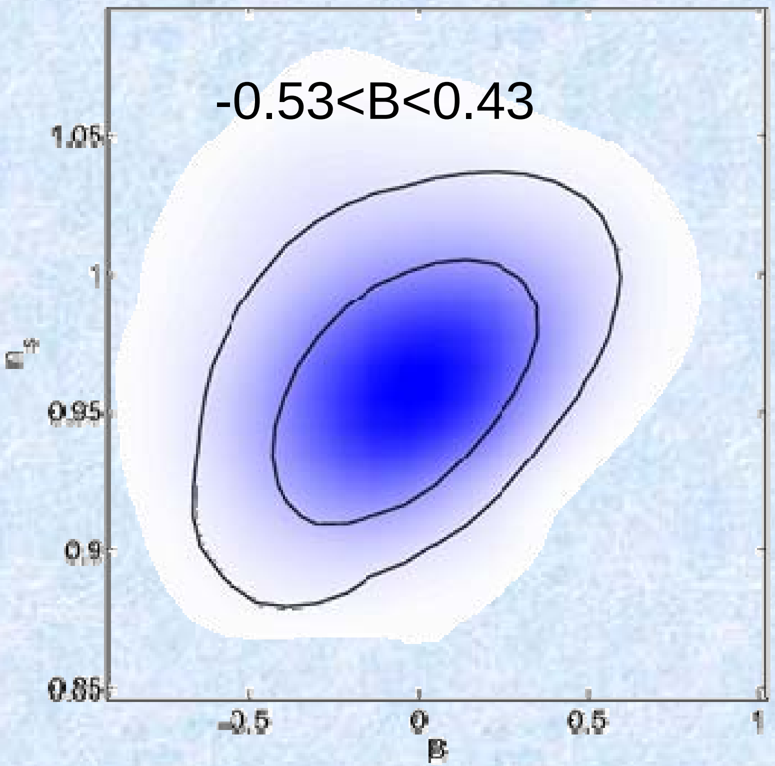
Clustering dark energy $c_s^2=1$ $w\neq-1$ — Ignoring fluctuations in DE



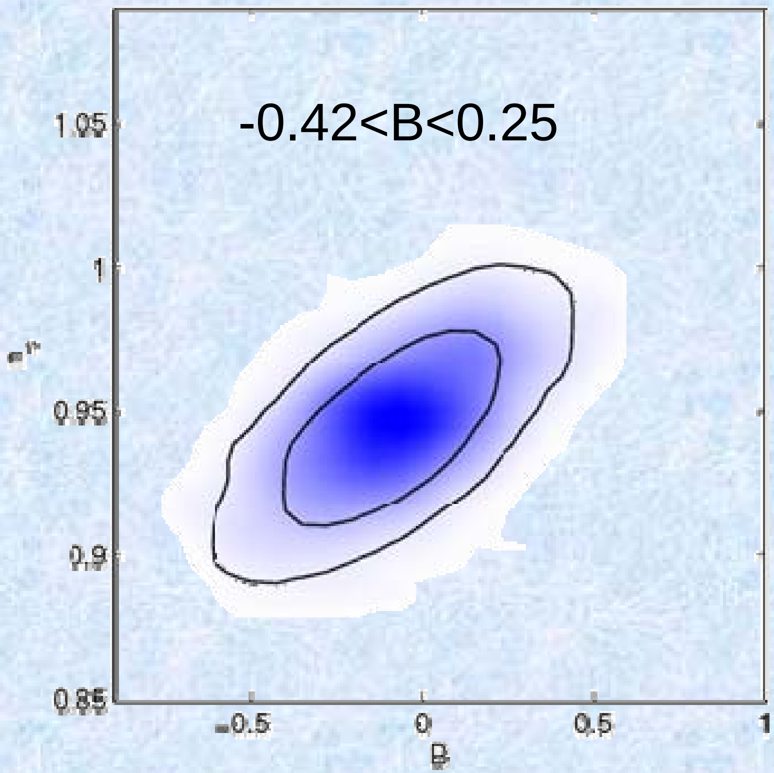
Matter Isocurvature Modes

- Possible in two-field inflation models, e.g. ‘curvaton’ scenario
- Curvaton model gives adiabatic + correlated CDM or baryon isocurvature, no tensors
- CDM, baryon isocurvature indistinguishable – differ only by cancelling matter mode

Constrain B = ratio of matter isocurvature to adiabatic



WMAP1+2df+CMB+BBN+HST

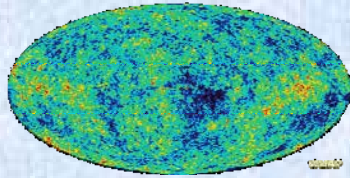


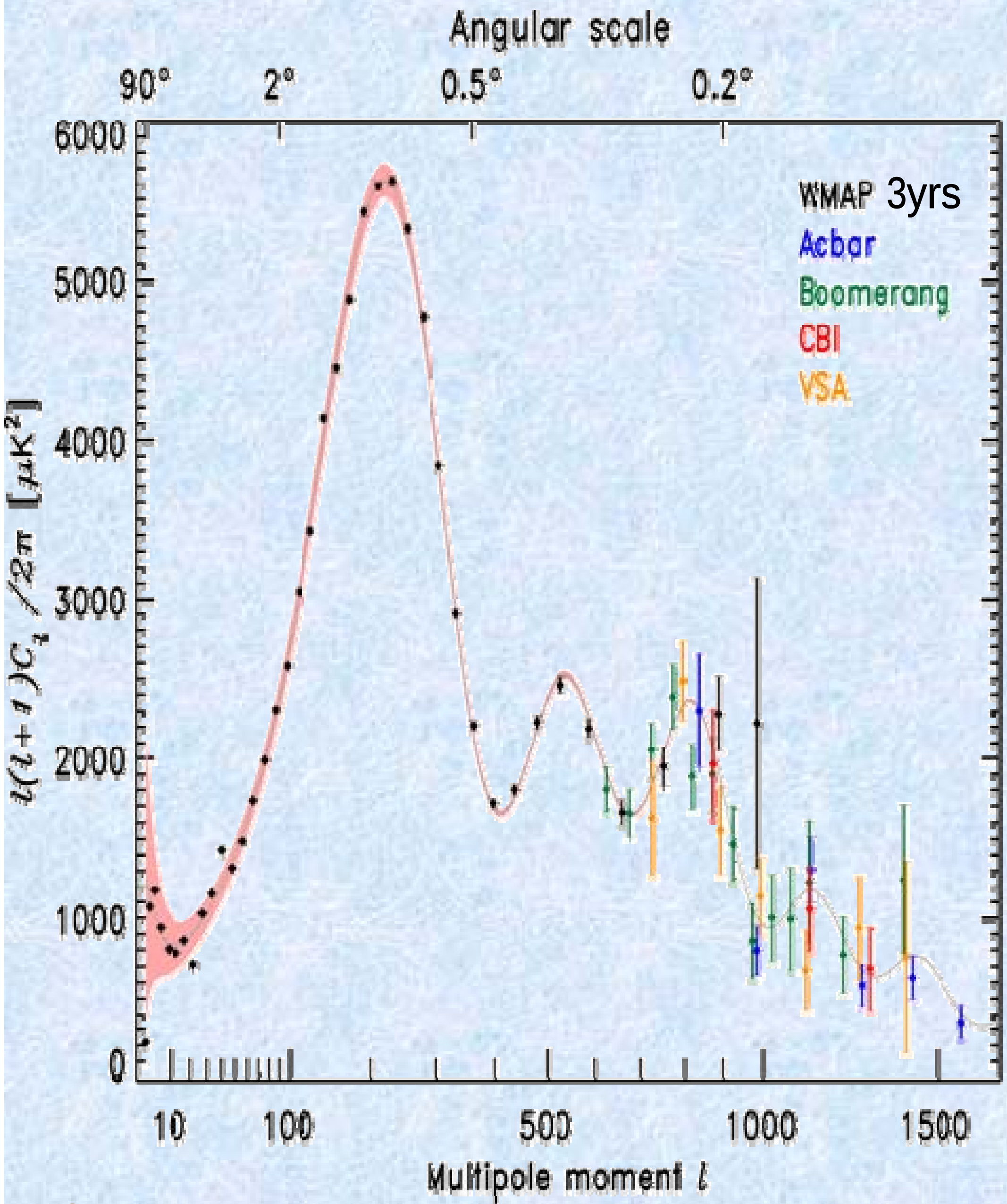
WMAP3+2df+CMB

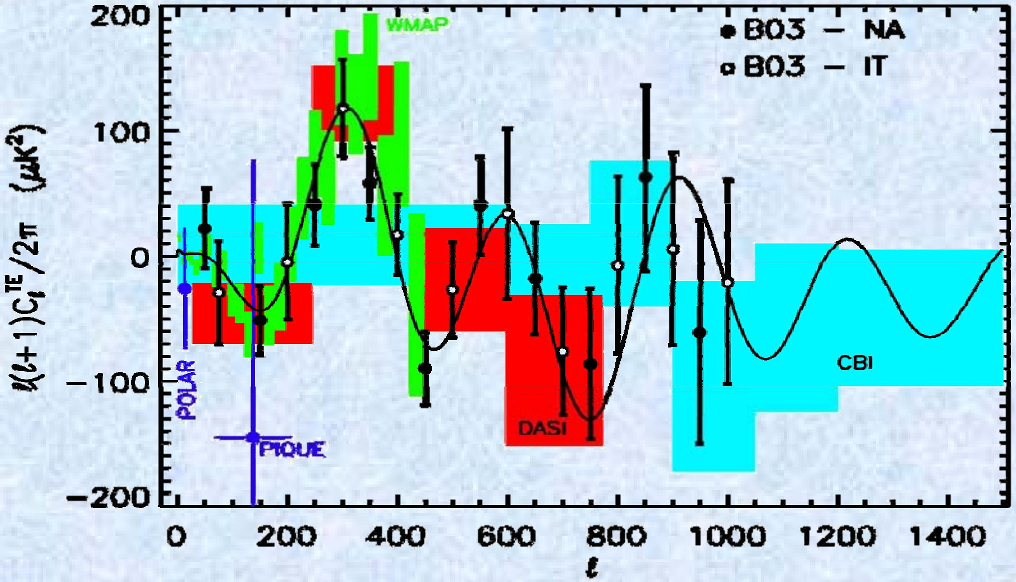
Gordon, Lewis: astro-ph/0212248

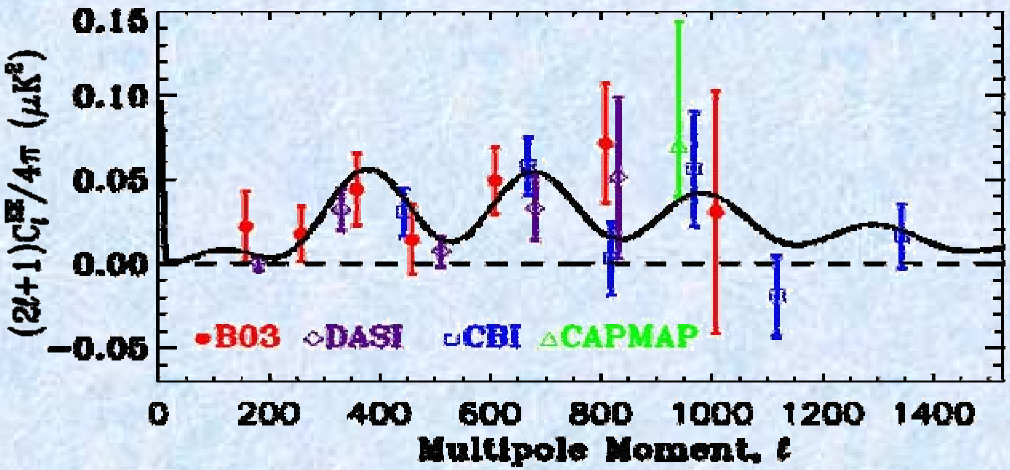
Lewis @ Moriond-march06

WHAT WE NOW KNOW

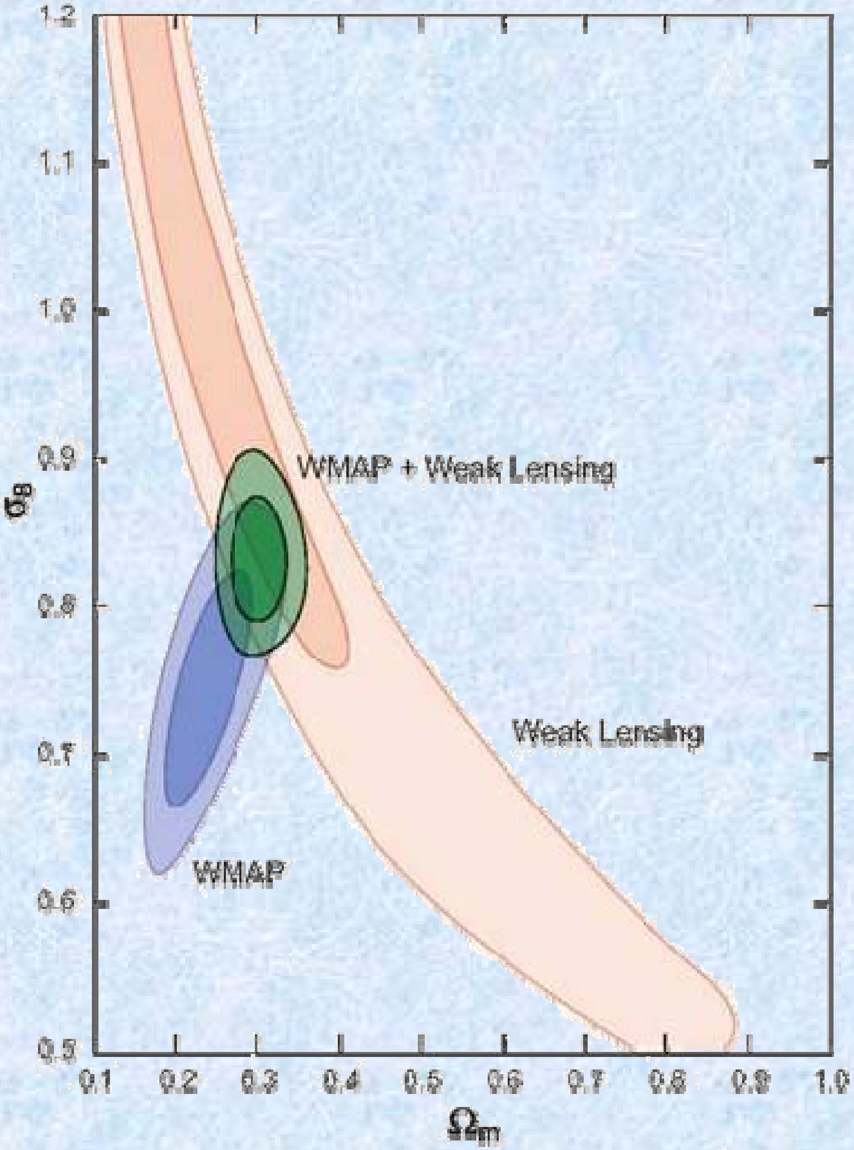


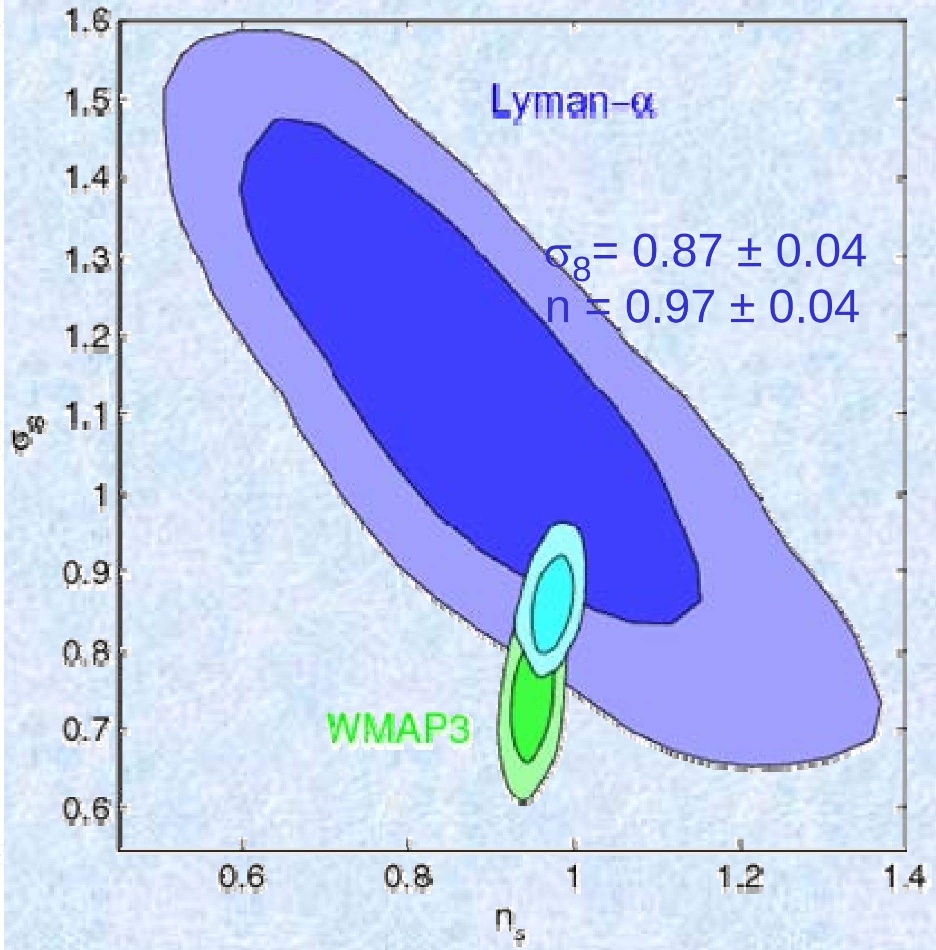






With some interesting tensions…





+ Li7…

THE FUTURE

Launch
in 2008

THE PLANCK CONCEPT

- An Instrument able to perform the “ultimate” measurement of the CMB temperature anisotropies:
  - full sky coverage and angular resolution covering all scales at which the CMB primary anisotropies contain information (~5’)
  - sensitivity essentially limited by ability to remove the astrophysical foregrounds, implying enough sensitivity combined with a large frequency coverage from 30 GHz to 1 THz (provided by the two instruments: HFI+LFI)
- get the best performances possible on the polarization of the CMB with the technology available

⇒ can be achieved with a small number of detectors in each frequency band, limited by the photon noise of the background (for the CMB ones)

PLANCK VS WMAP: 1 YEAR SENSITIVITY GOALS

Center Freq. (GHz)	30	44	70	100	143	217	353	545	857
Angular Resolution (FWHM, arcmin)	33	24	14	9.5	7.1	5	5	5	5
Average $\Delta T/T_I$ per pixel[#]	2.0	2.7	4.7	2.5	2.2	4.8	14.7	147	6700
Average $\Delta T/T_{U,Q}$[*] per pixel[#]	2.8	3.9	6.7	4.0	4.2	9.8	29.8		
Sensibilité in I [μK] per pixel (FWHM)	5.5	7.4	12.8	6.8	6.0	13,1	40,14		
Sensibilité in I [μK.deg] [$\sigma_{pix}\ \Omega_{pix}^{1/2}$]	2.7	2.6	2.6	0,96	0,63	0,97	2,9		
Sensibilité in Q or U [μK.deg] [$\sigma_{pix}\ \Omega_{pix}^{1/2}$]	4.5	4.6	4.6	1.85	1.45	2.39	7.26		

WMAP Center Freq.	23	33	41	61	94
Angular resolution (FWFM arcmin)	49	37	29	20	12,6
μK per 3,2 10^{-5} sr pixel (22'x 22')	38.9	39,9	41	48	46
Sensibilité en I [μK.deg], 1 yr (8 yr)	12.6 (4.5)	12.9 (4.6)	13.3 (4.7)	15.6 (5.5)	15.0 (5.3)

The aggregated sensitivity of the 3 core CMB channels of Planck, @ 100, 143, 217GHz (~0.5μK.deg in T, 1 μK.deg QU) will be unprecedented and quite challenging in terms of control of systematics

PLANCK NEEDED BREAKTHROUGHS

- The sensitivity goals of Planck requires 5 technological performance never achieved in space before
  - Sensitive & fast bolometers with
    - NEP< 2 10^{-17} W/$Hz^{1/2}$ & time constants typically < 5 msec

    (thus cooling them to 100 mK, very low heat capacity and charged particles sensitivity)
  - total power read out electronics with very low noise
    - < 6nV/$Hz^{1/2}$ from 10 mHz to 100 Hz
  - temperature stability for detector plate
    - < 40 nK 10nV/$Hz^{1/2}$ from 10 mHz to 100 Hz
  - temperature stability for 4K box
    - < 10 µK/$Hz^{1/2}$ from 10 mHz to 100 Hz
  - 100 GHz low noise HEMT amplifiers (⇒ cooled to 20K) & very stable cold reference loads (4K)

- Additionally:
  - low emissivity very low side lobes telescope (strongly under-illuminated)
  - no windows, minimum warm surfaces between detectors and telescope
  - active cooling
    - 4K, 1.6K and 100mK for HFI
    - 20K for LFI with large cooling power K (0.7W)
  - NB: 100mK cooling by dilution cooler does not tolerate micro-vibrations at sub-mg level or 7.10^{10} He atoms accumulated on dilution heat exchanger (typically He pressure 1.10^{-10} mb)

PLANCK-HFI PERFORMANCE

Tested flight bolometers

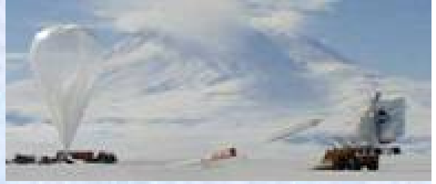
		100	143	217	353
beam size	arcmin	9,5	7,1	5	5
n pixels		1,65E+06	2,95E+06	5,94E+06	5,94E+06
system sensitivity to T	μK rt s	28,8	16,4	26,1	93,9
system sensitivity to Q,U	μK rt s	43,8	38,1	58,9	262
avg time/pixel	s	19,2	10,7	5,3	5,3
ΔT/pixel	μK	6,587279	5,021682	11,32264	40,76182
ΔT/T/pixel	10^{-6}	**2,4**	**1,9**	**4,2**	**15,0**
ΔT/T/pixel bluebook	10^{-6}	2,5	2,2	4,8	14,7
Δ(Q,U)/pixel	μK	10,0	11,6	25,6	114
Δ(Q,U)/T/pixel	10^{-6}	**3,7**	**4,3**	**9,4**	**41,9**
Δ(Q,U)/T/pixel bluebook	10^{-6}	4	4,2	9,8	29,8

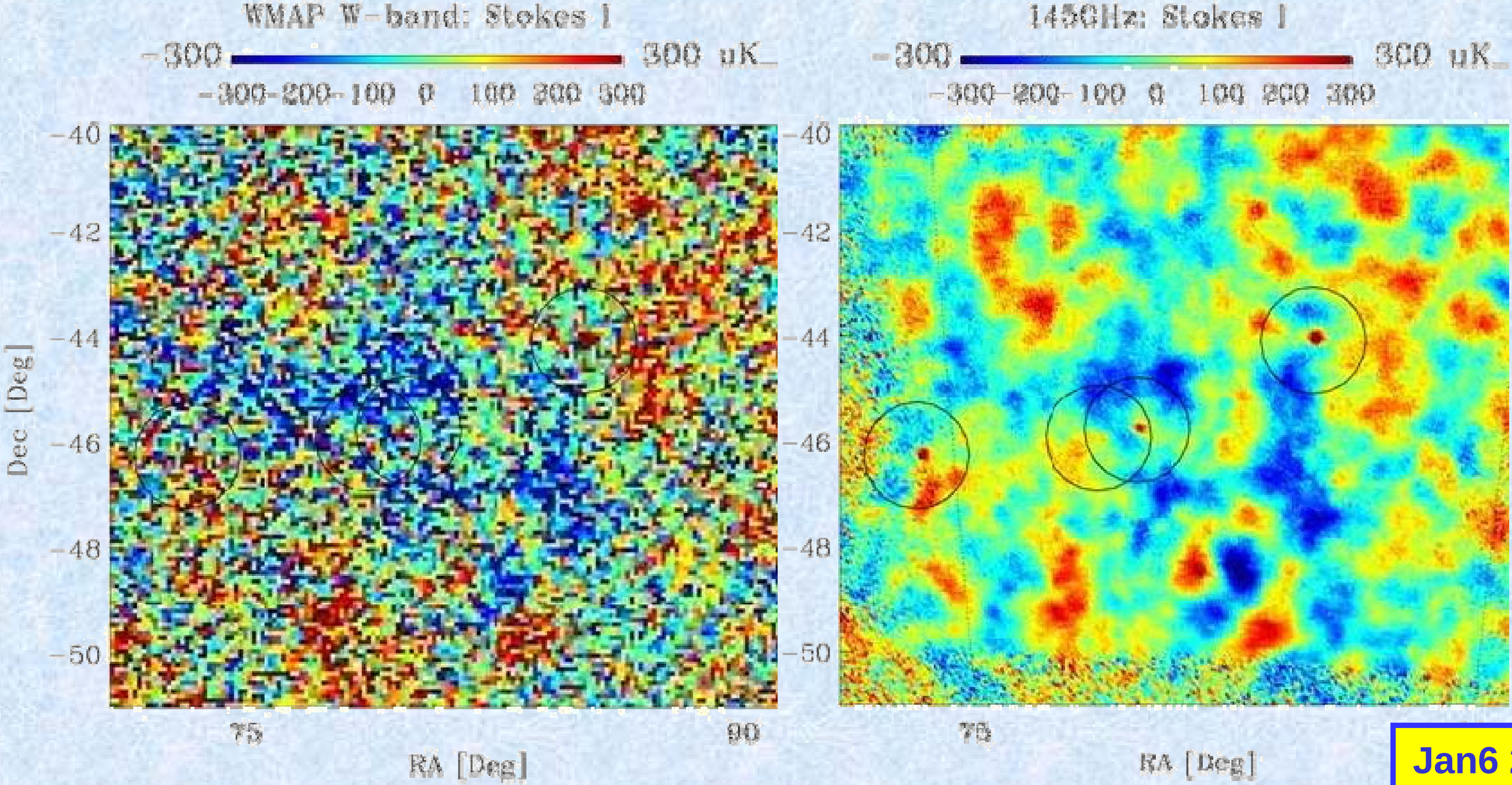
Survey Time years 1

T Sens (muK.arcmn)		63	36	57	204
T Goals Blue Book		65	42	65	200
Q, U Sens (muk.arcmin)		95	83	128	568
Q, U Goals Blue Book		104	81	134	406

As of 17 February 2006

B03 DEEP SURVEY





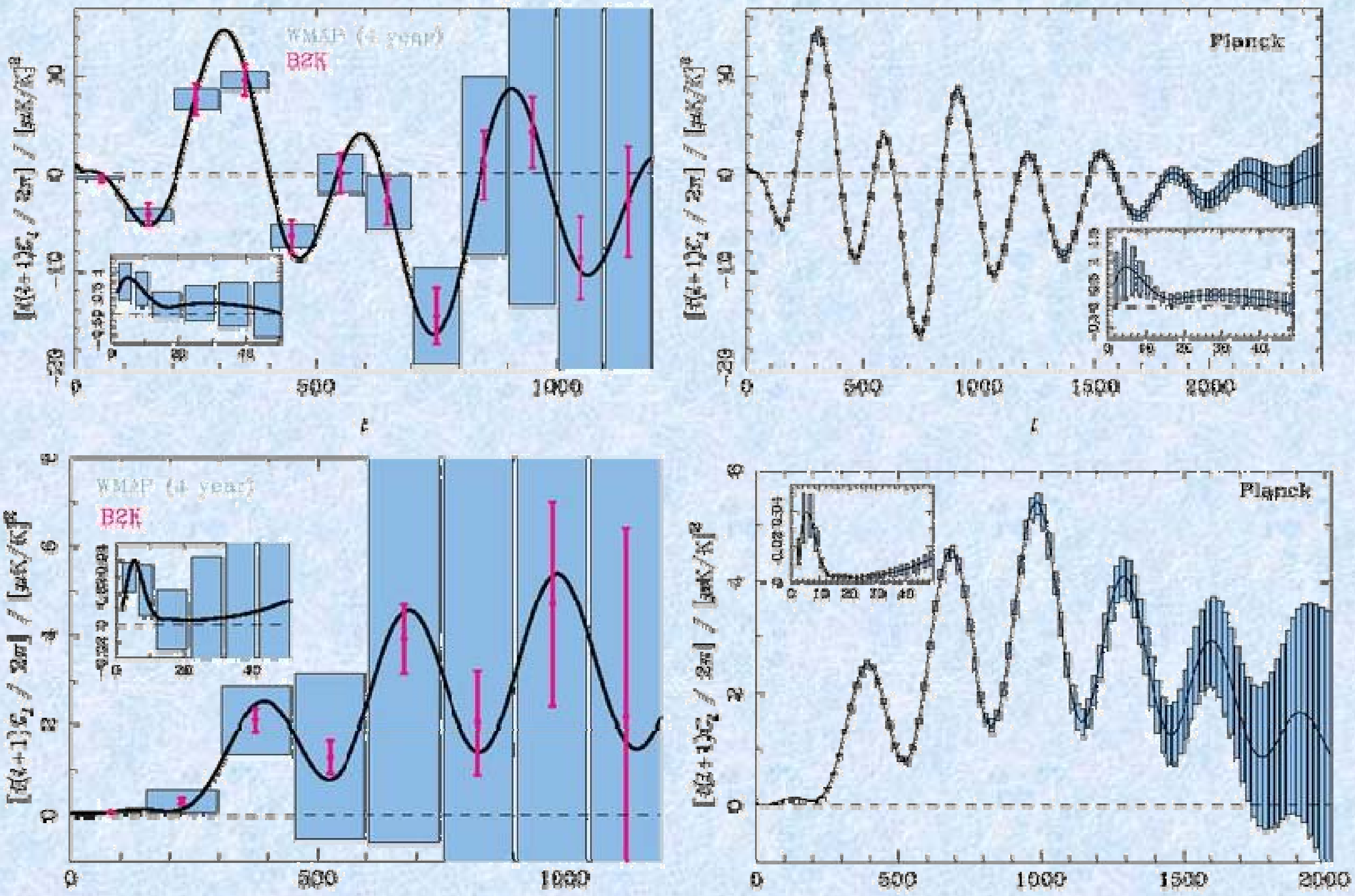
Masi et al. astroph/0507509

Jan6 2003 + 10 days

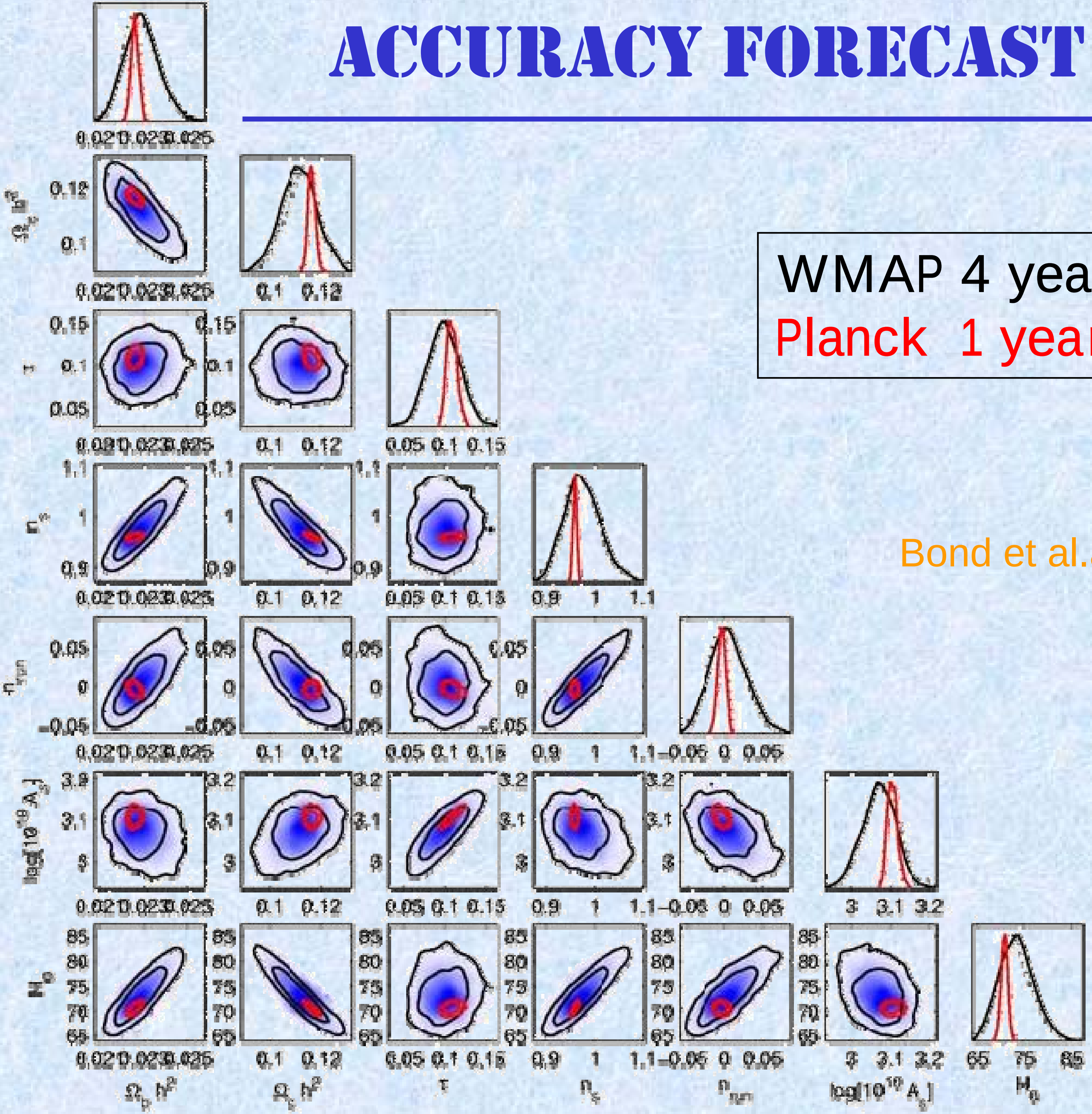
A foretaste of Planck-HFI @ 145 GHz but:

- w_I =82μK.arcmin, while HFI goal is w_I =42μK.arcmin @ 143GHz (OK FM bolos delivered~36)
- Planck has matching sensitivities in 9 frequency bands, e.g. ~60 μK.arcmin @ 100 & 217 GHz
- 90 deg², i.e. 0.2% of the sky covered, instead of 100% (and deep surveys in Planck too)

TE & EE FORECASTS



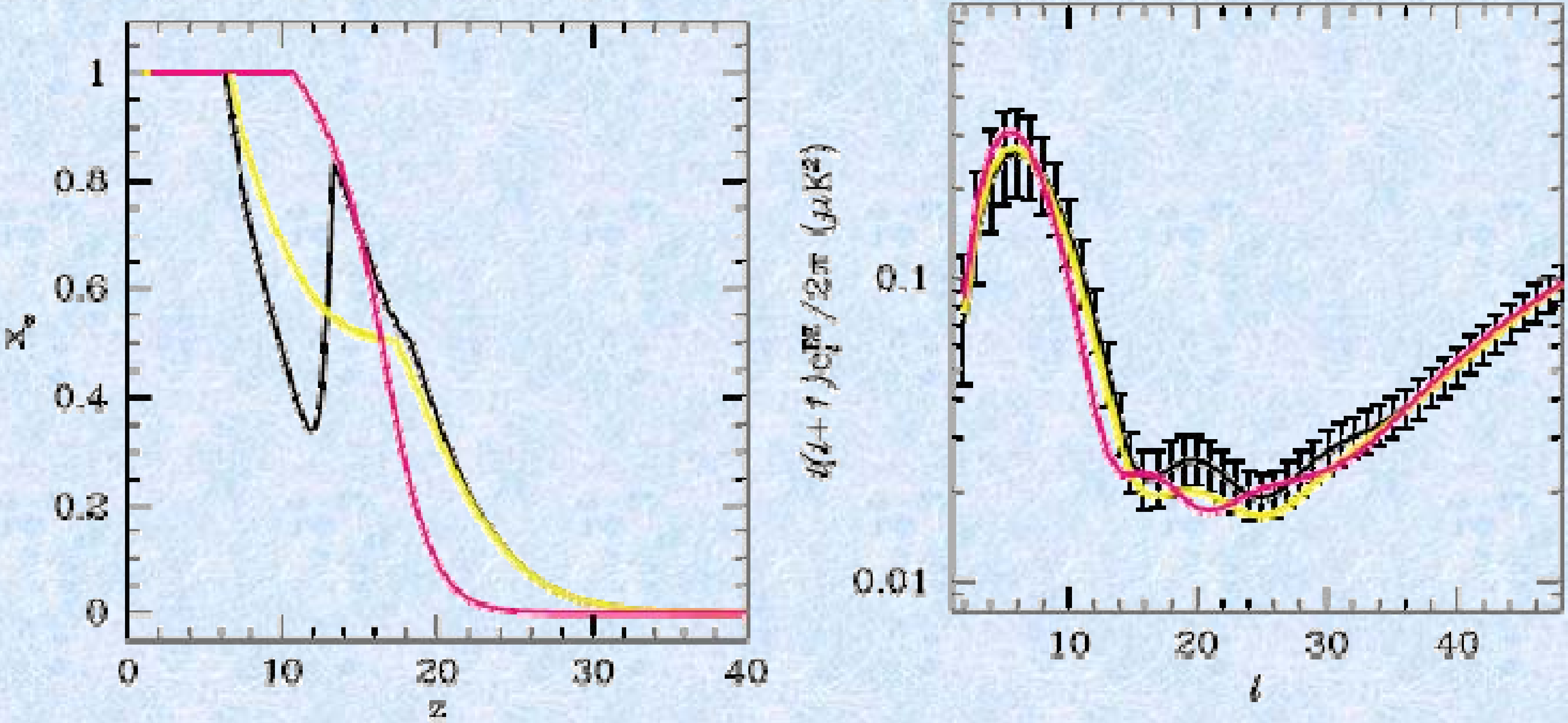
ACCURACY FORECAST



WMAP 4 years (94 GHz)
Planck 1 year (143 GHz)

Bond et al.astroph/0406195

REIONISATION



- Different reionisation histories leave a slightly different imprint (in low-l polarisation bump) which can be detected …

WHAT'S NEXT?

- Planck-HFI FM is right now at IAS in Orsay, cooling down in Saturne tank…
- To be delivered this summer to ALCATEL.
- Then CSL system level tests
- Current launch date is ~ early 2008

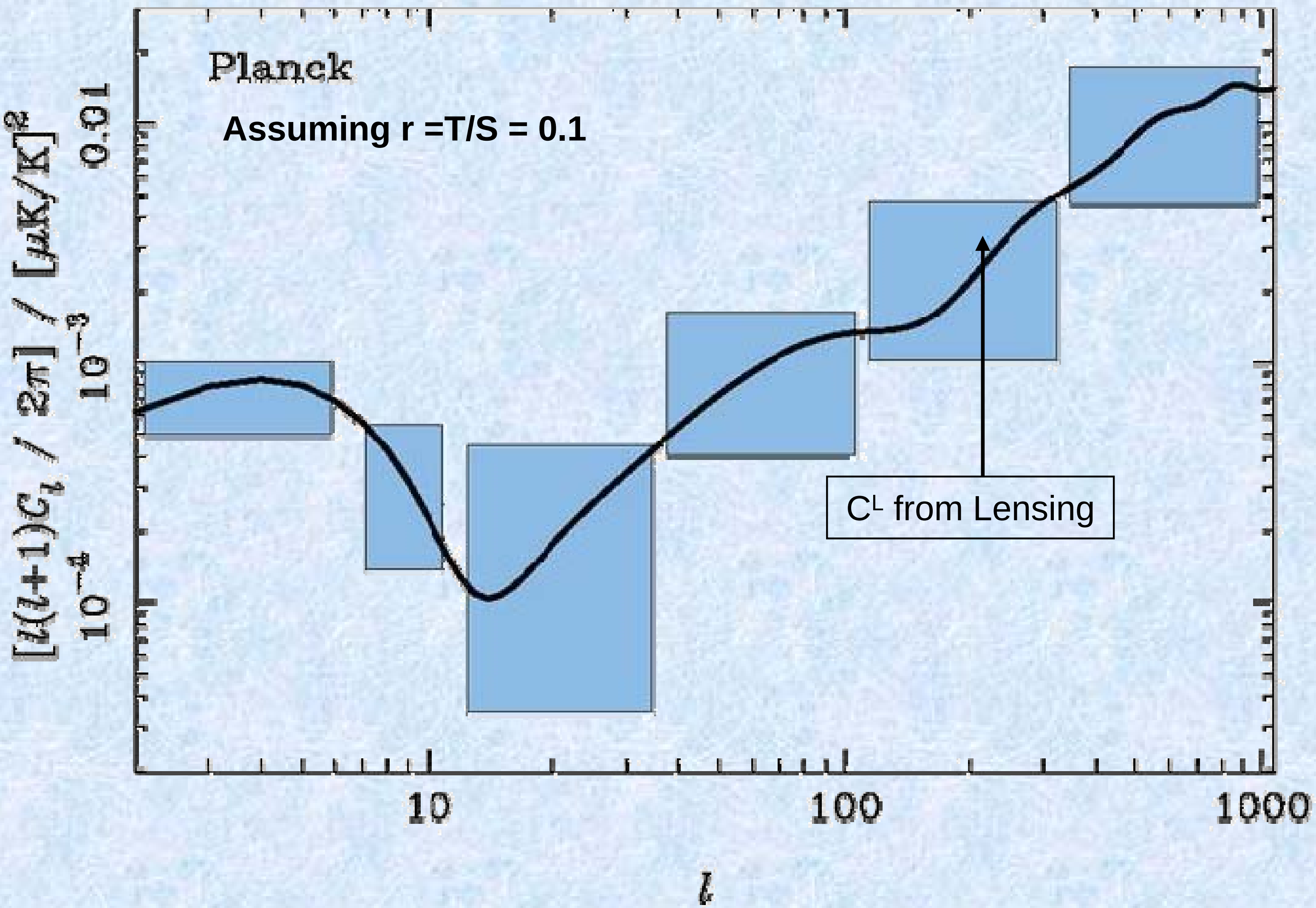
- Then 4 month to go to L2
- 2 month of PV phase (> survey starts ~ Sep 2008)
- 1 year nominal operation
- 1 year Data analysis
- 1 year proprietary > Public data deliveries ~ end of 2010

- Another year of operations might be doable (to keep Planck DPC team of IAP busy longer…some started ~1993)

CMBPOL

SAMPAN

PLANCK & THE B MODES



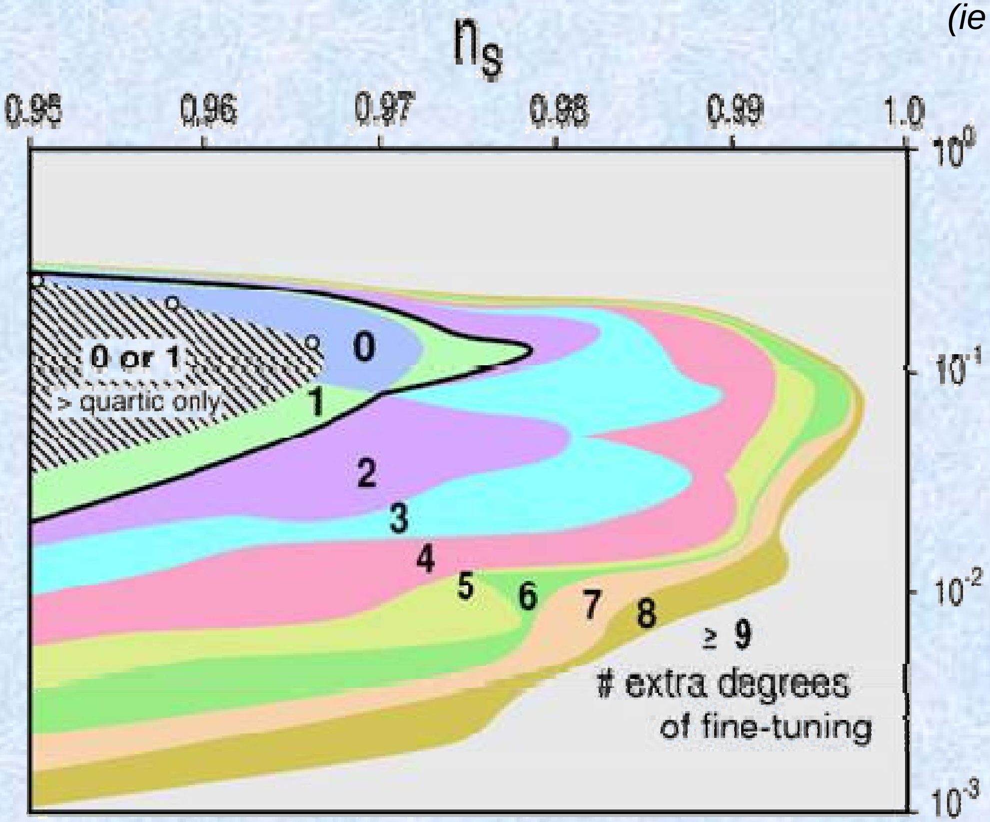
Planck will be limited by its (polarisation) sensitivity (~60 μK.arcmin at best)

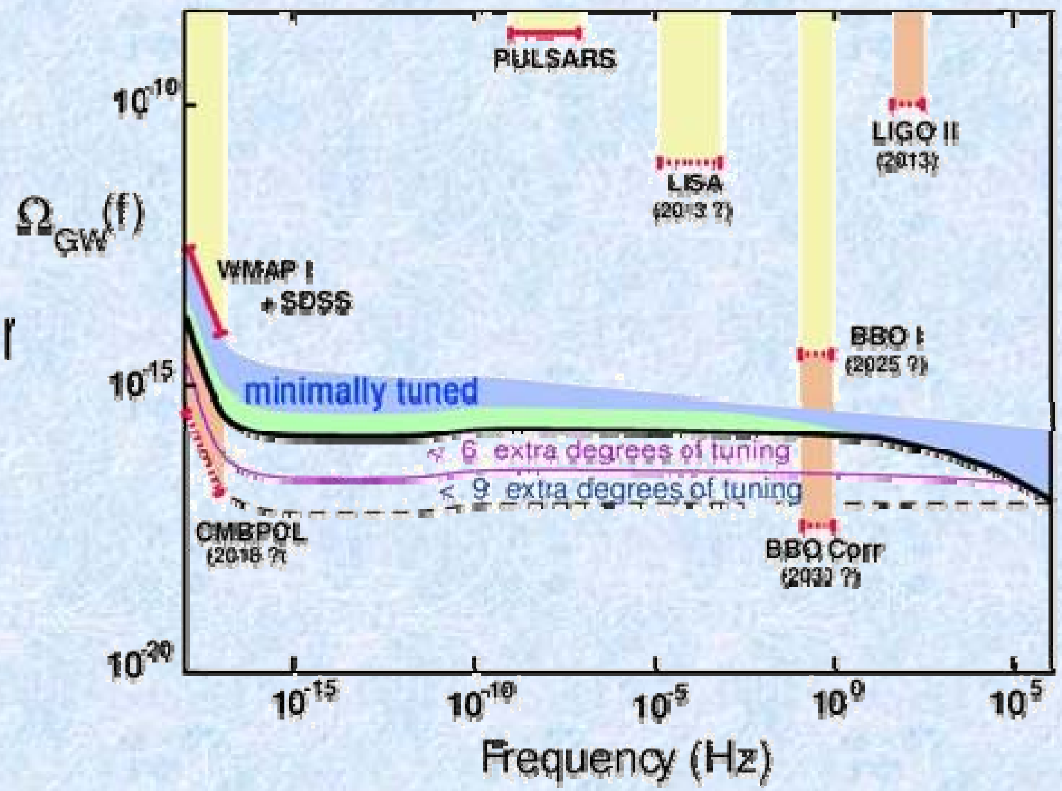
Indeed, it was conceived to be limited by unpolarised foregrounds confusion

GENERIC INFLATION

What is the value of r = T/S?

Take a few simple monomial potentials (quadratic, cubic, quartic), count unnecessary features introduced during 60-e fold of inflation to get a particular (ns, r)
(ie measure number of derivatives of slow-roll parameters to adjust)





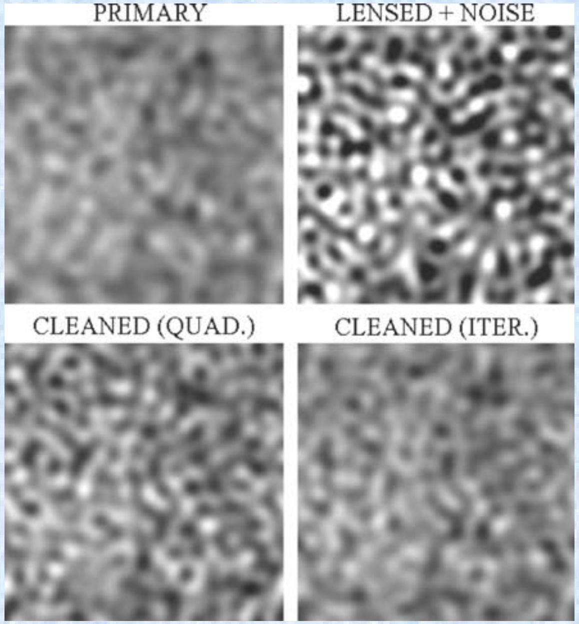
r=T/S < 10^{-3} would be rather unnatural

But of course no real measure on "theory space"

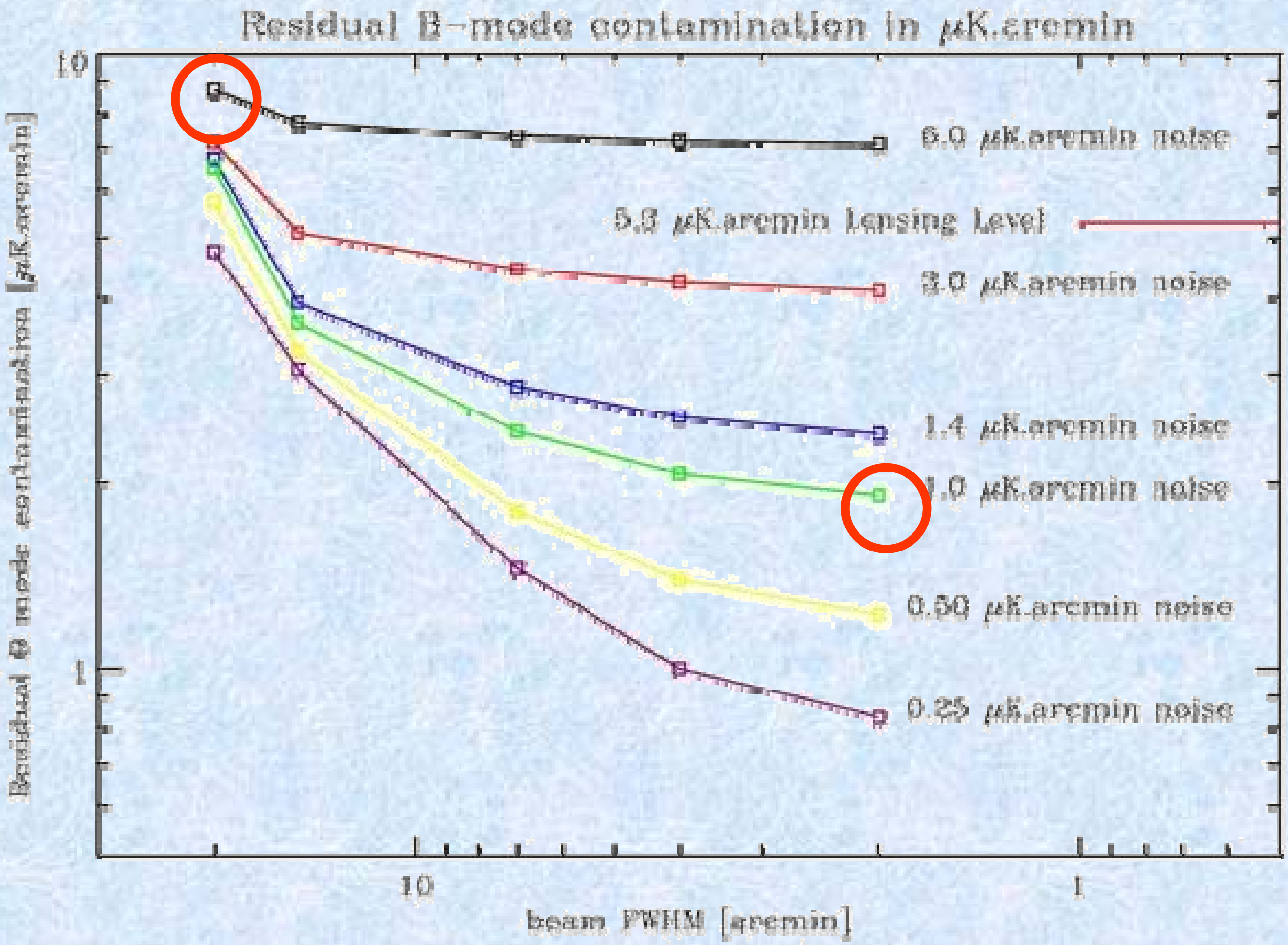
Boyle, Steinhardt, Turok - astroph/0507455

LENS "CLEANING" EFFICIENCY

By using quadratic estimators of displacement field



Seljak & Hirata astro-ph/0310163

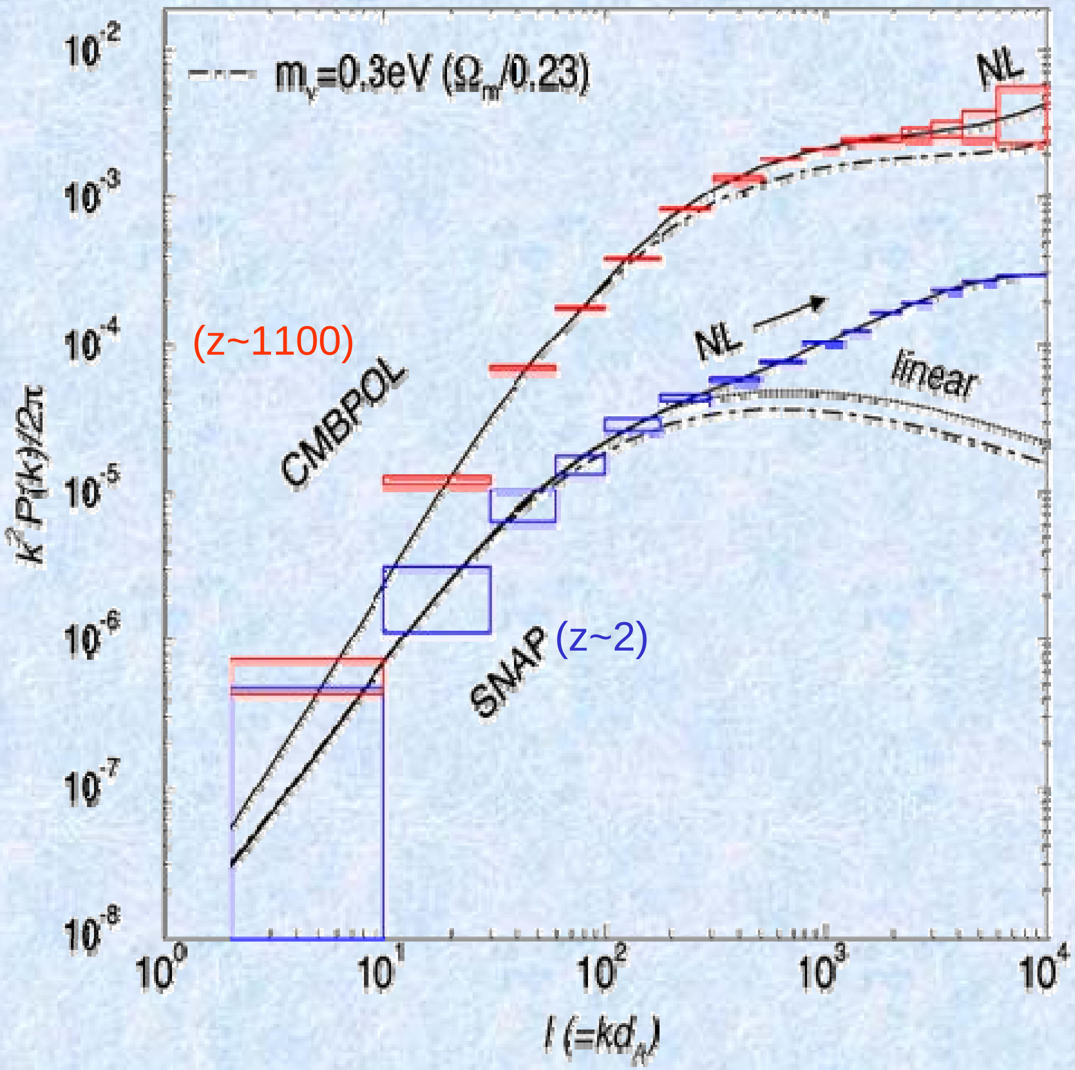


2 possible bounding cases:

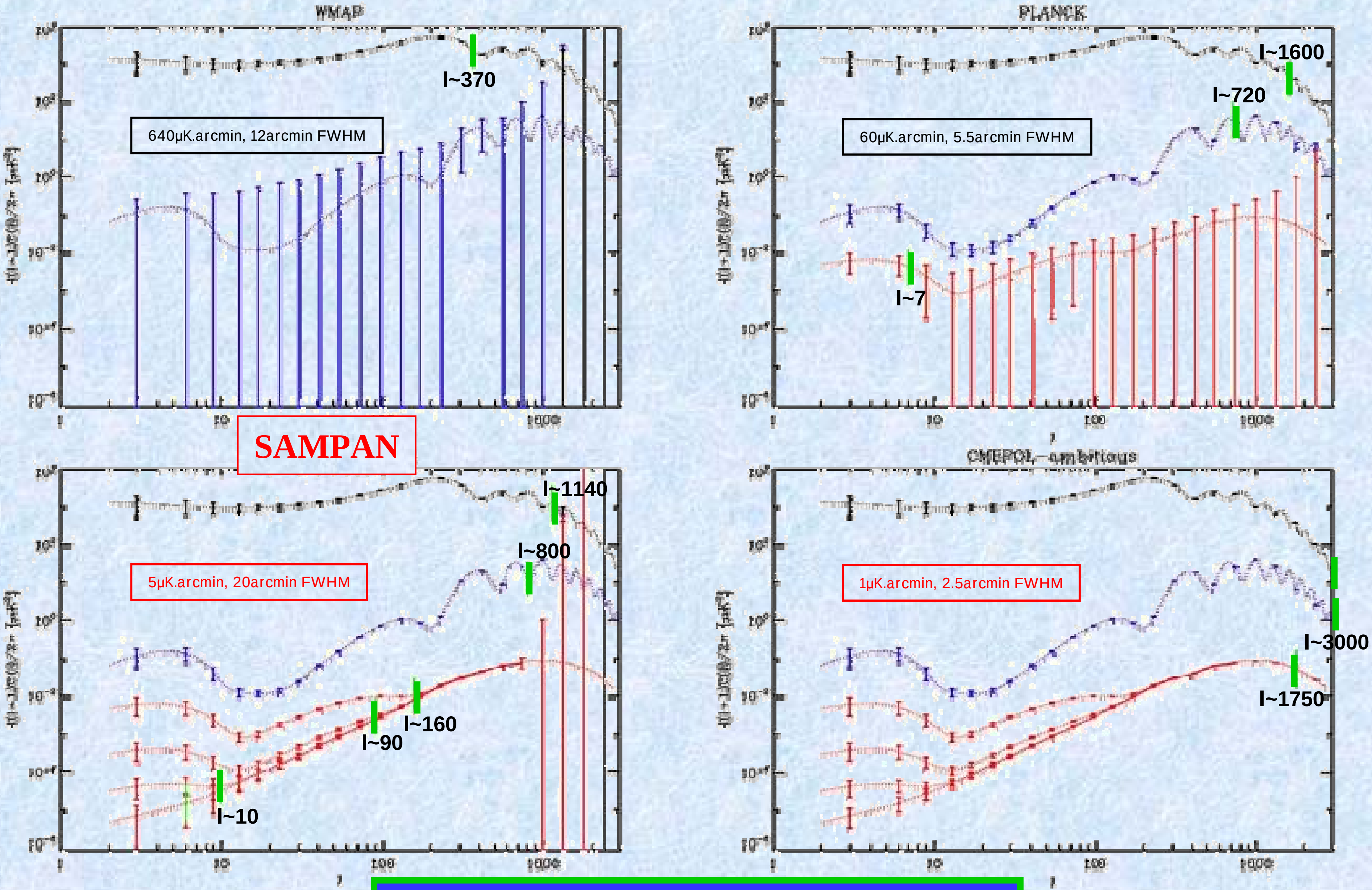
- SAMPAN: 5 μK.arcmin & 20 arcmin FWHM (i.e. no cleaning)
- CMBPOL : 1 μK.arcmin & 2 arcmin FWHM (lots of further science at high res)

CMB AS A WEAK LENSING EXPERIMENT

- plotted is the deduced convergence power spectrum (related to the integrated mass responsible for lensing) in the ambitious case
- Interest:
  - Source redshift is known (recombination)
  - Linear power spectrum - (easy calculations)
  - Test growth rate of structures accurately
  - Check precisely the consistency of the paradigm



MEASUREMENTS IN PERSPECTIVE



l bounds region (at left) with modes measured @ S/N >1

CONCLUSIONS

- From Hinshaw :
- WMAP three-year data includes full-sky polarization maps
- Analysis of EE + BB power spectra
- Improved measurements of many degenerate parameter pairs, especially (τ, *ns*)
- New limits on dark energy eq. of state, flatness.
- Spacecraft continues to function well.

- NB: many indications of non-gaussianity and/or anisotropies at large scale. Much work, but nothing has changed much after yet (large scales are already well known)

CONCLUSIONS (½)

- La cosmologie dispose d'un modèle minimal, cohérent, robuste, surprenant, à 6 (7) paramètres (concordance).
- Le RCF fournit les tests cosmologiques les plus précis; mais d'autres méthodes (e.g. SDSS, SN-Ia…) sont essentielles pour lever certaines dégénérescences.
- Un grand nombre d'"extensions" du modèle minimal, et la plupart de modèles d'inflation, sont encore possibles ou peu contraints aujourd'hui…
- Planck va fournir la mesure définitive des anisotropies de température, une mesure précise de la partie E de la polarisation et une première analyse de la partie B (grâce aux PSBs). Planck va ouvrir une nouvelle fenêtre sur la physique de l'Univers primitif.
- Un satellite post-Planck (au moins 10 fois plus sensible) est à l'étude partout dans le monde pour caractériser le fond d'onde gravitationnel primordial.
- Beaucoup d'opportunité de trouver des failles de notre compréhension

- NB: En dépit de ces grands progrès, nous ne connaissons pas la nature de la matière sombre, ni celle de l'énergie sombre !
- Les difficultés rencontrés (eg formation galaxies) indiquent-elles les limites de notre compréhension « gastrophysique », demande des propriétés plus complexes de DM et/ou DE, ou constituent t elle les premières traces d'une nouvelle physique?