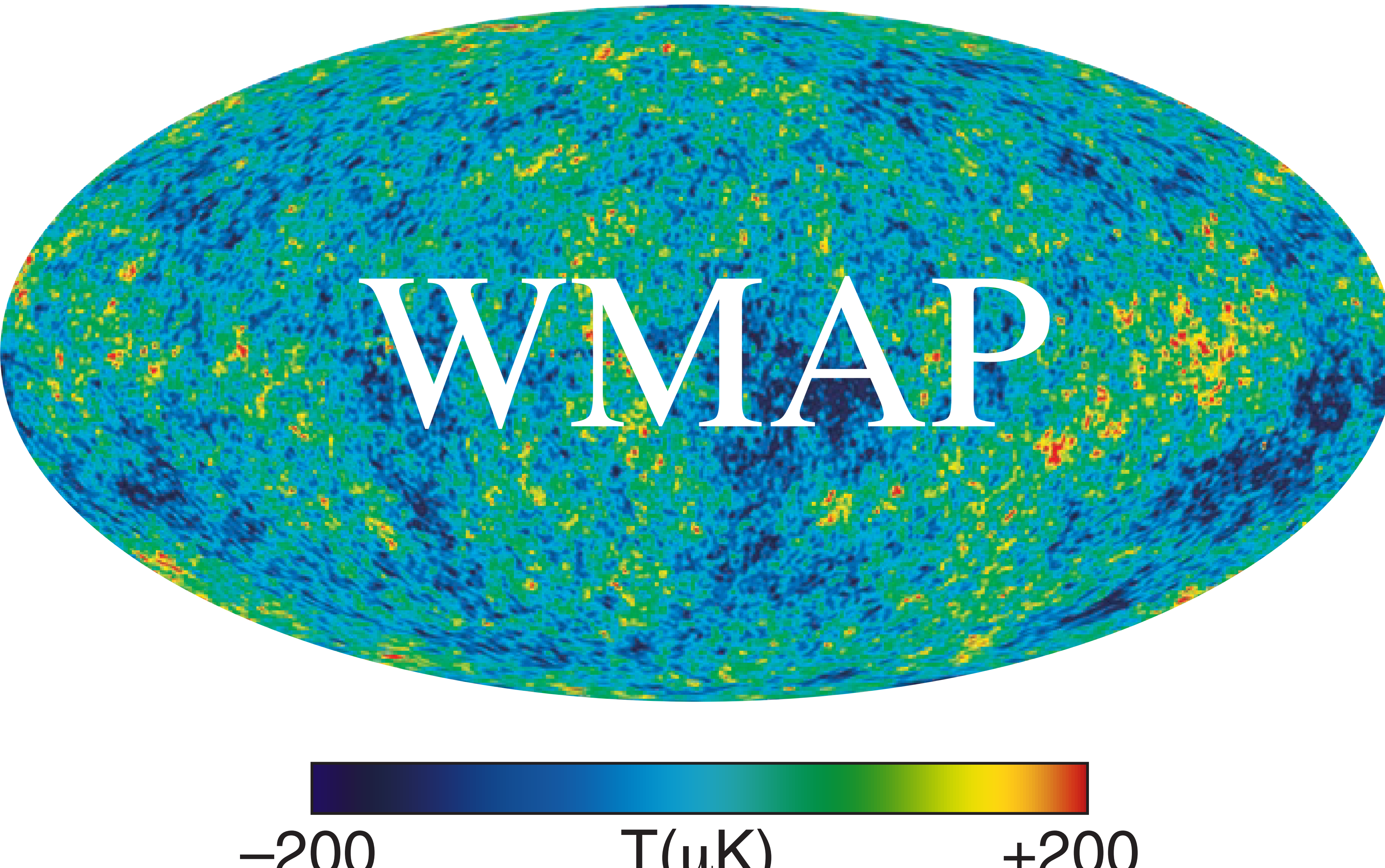

L. Page UC Davis May 2013

WMAP Science Team

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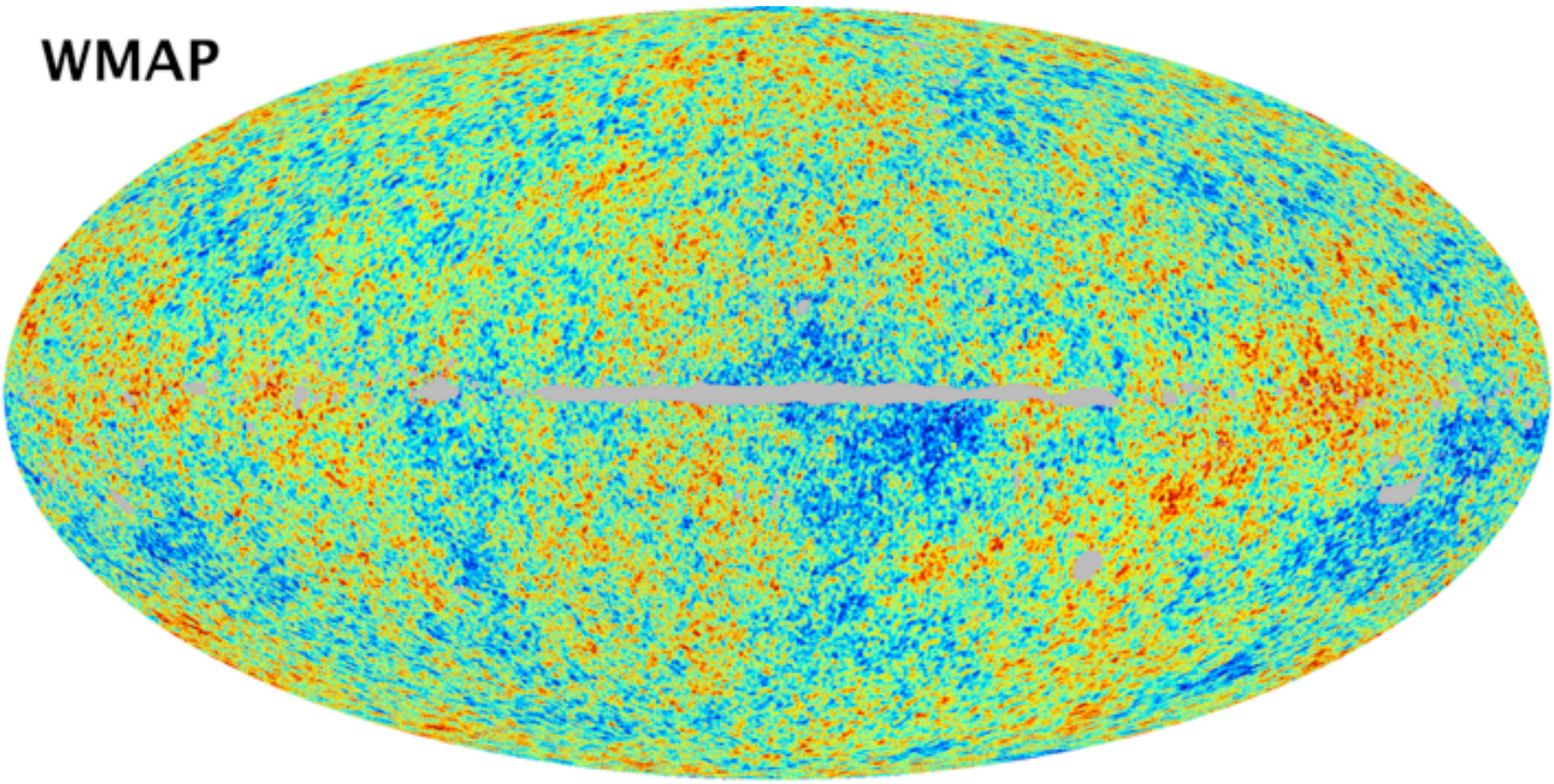
Licia Verde
Janet Weiland
Ed Wollack

WMAP1

Rachel Bean
Olivier Dore
Jo Dunkley
Ben Gold
Dave Larson
Kendrick Smith

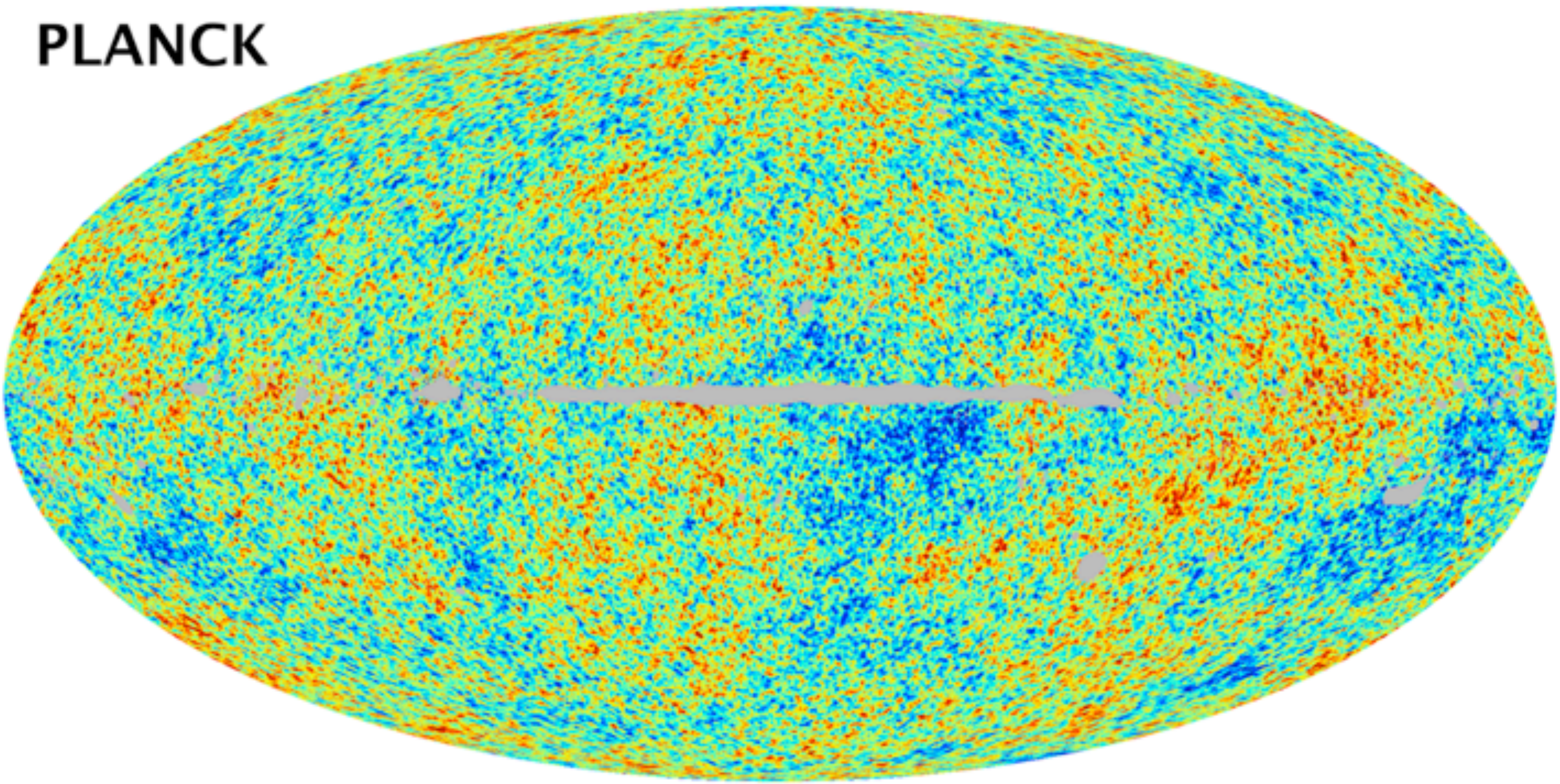
WMAP3
WMAP5
WMAP7
WMAP9

WMAP W-band, Template Cleaned



Cleaned with Planck 353 GHz dust map and low-frequency templates. 12’ resolution.

Planck SMICA Map



Planck/SMICA map, 5’ resolution.

WMAP

1 Established and tested the standard model of cosmology: Flat, adiabatic & Gaussian ptb., 6 parameters.

All you need are:

$\Omega_b h^2$ $\Omega_c h^2$ H_0 σ_8 τ n_s

Amazingly this hold true for Planck data.

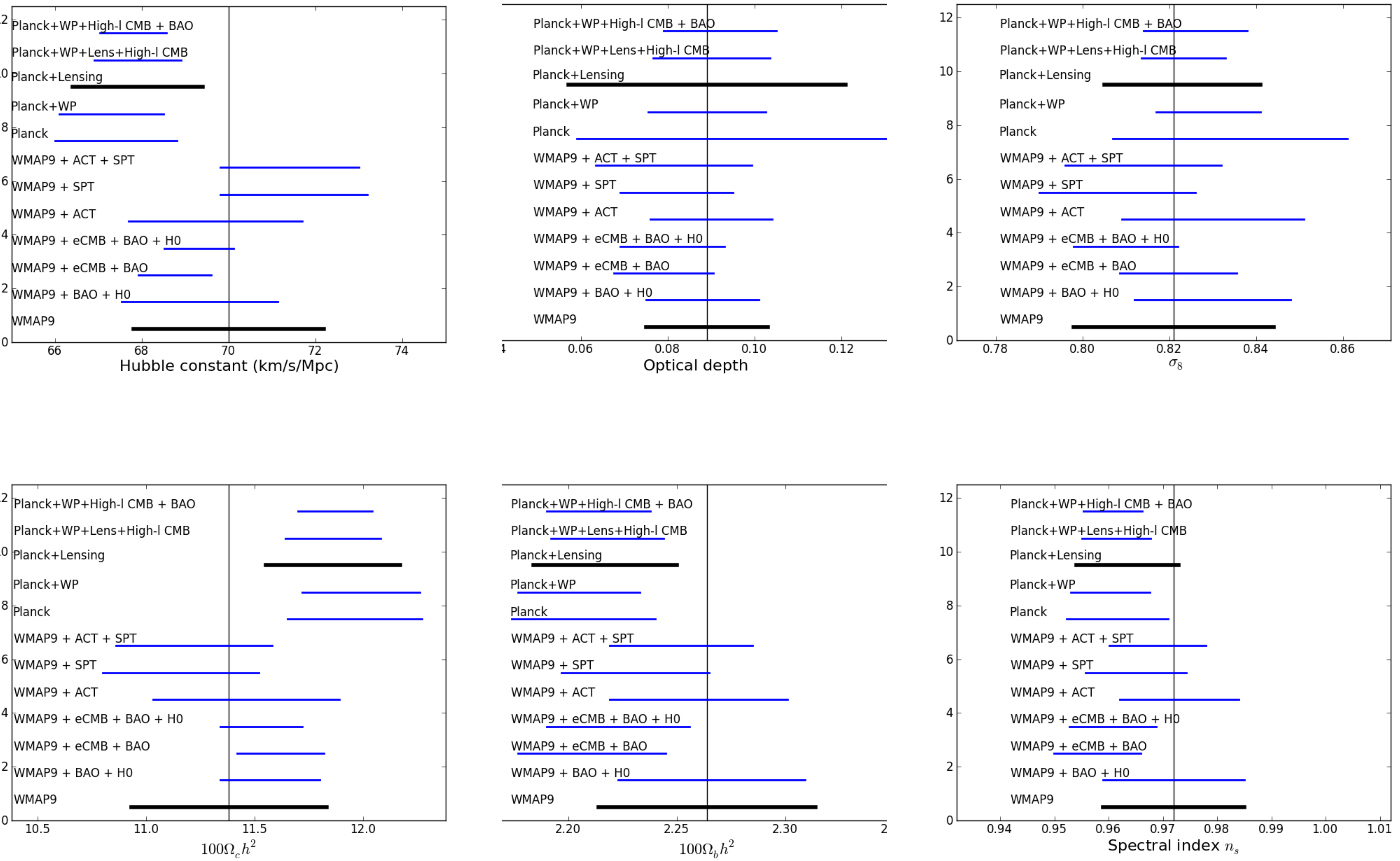
WMAP TT l : 33-1200, χ^2= 1200/1168 (PTE =0.251)

TE l : 24-800, χ^2= 815/777 (PTE =0.165)

All l: χ^2=3336/3115 (PTE =0.003)

Driven by low-l polarization.

Standard Model Parameters

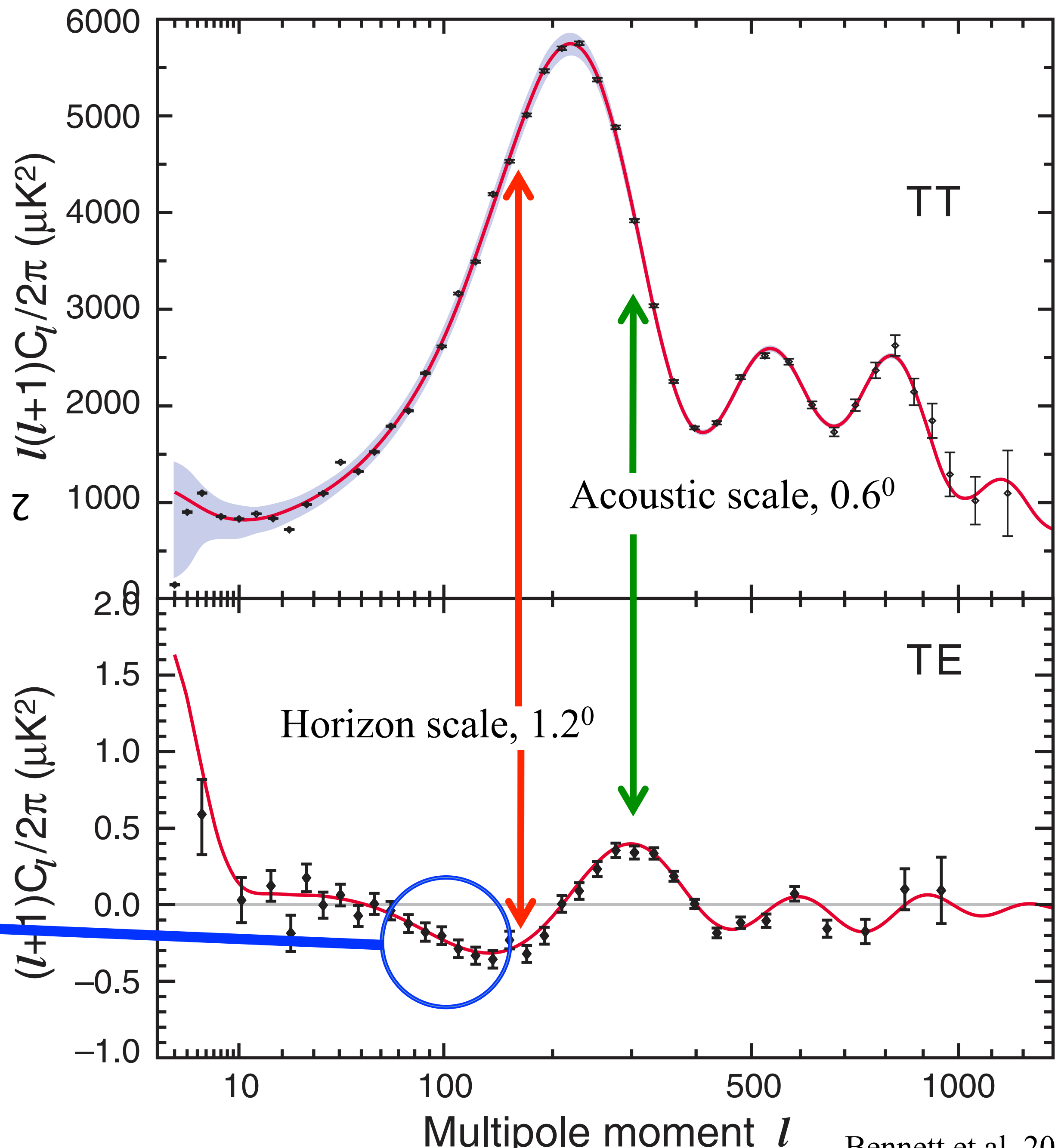


2 WMAP

Demonstrated superhorizon fluctuations.

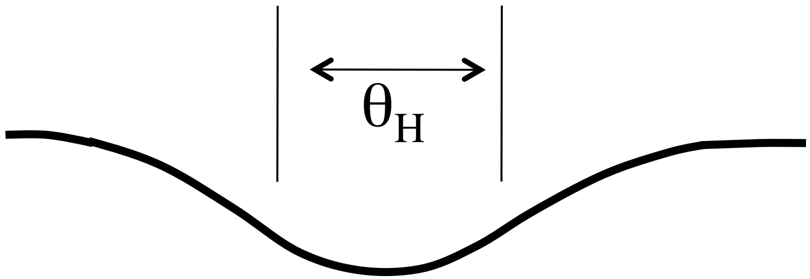
This TE anti-correlation is the best evidence for the existence of super horizon fluctuations, a key element of the standard model.

Spergel & Zaldarriaga (1997)
Peiris et al. (2003)

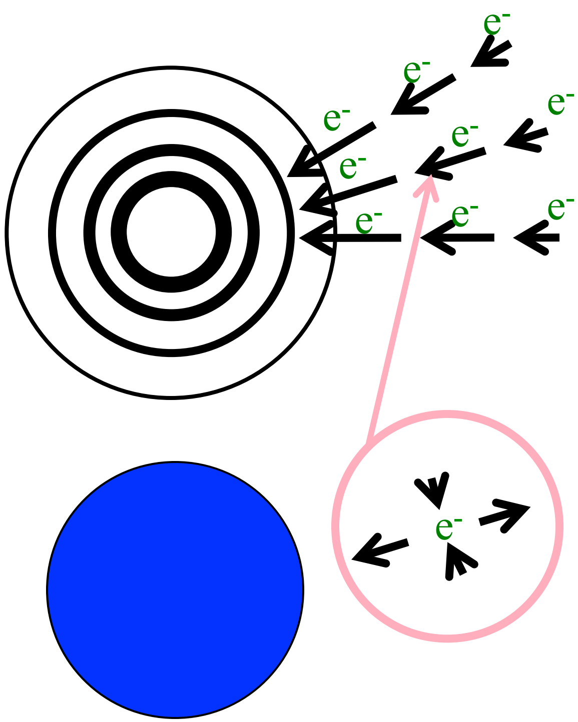


Bennett et al, 2013

Consider a fluctuation in potential at **large** angular scales.



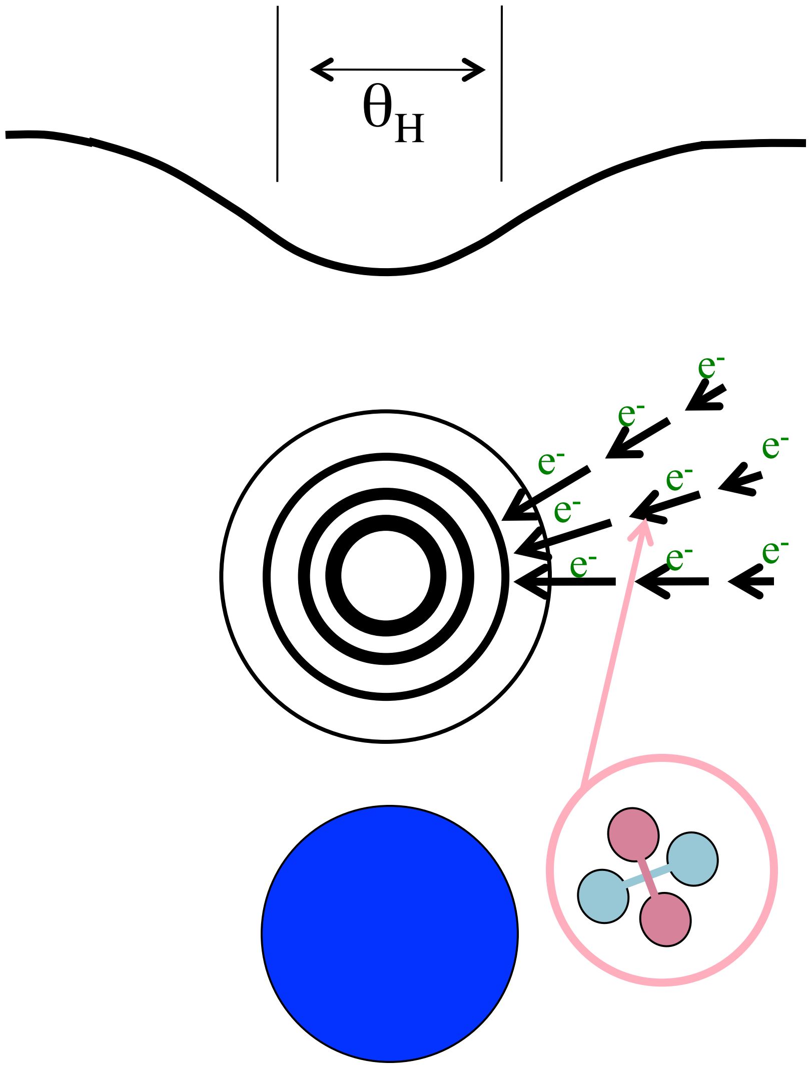
Photons climb out of well so this appears as a cold splotch on large angular scales.



The primordial plasma flows into the well.

An electron sees a local quadrupole and thus scatters polarized light towards us.

Consider a fluctuation in potential at **large** angular scales.



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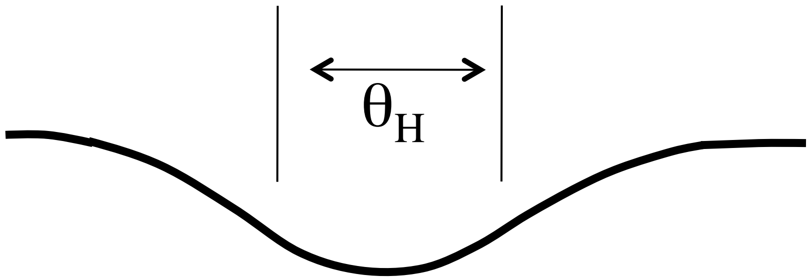
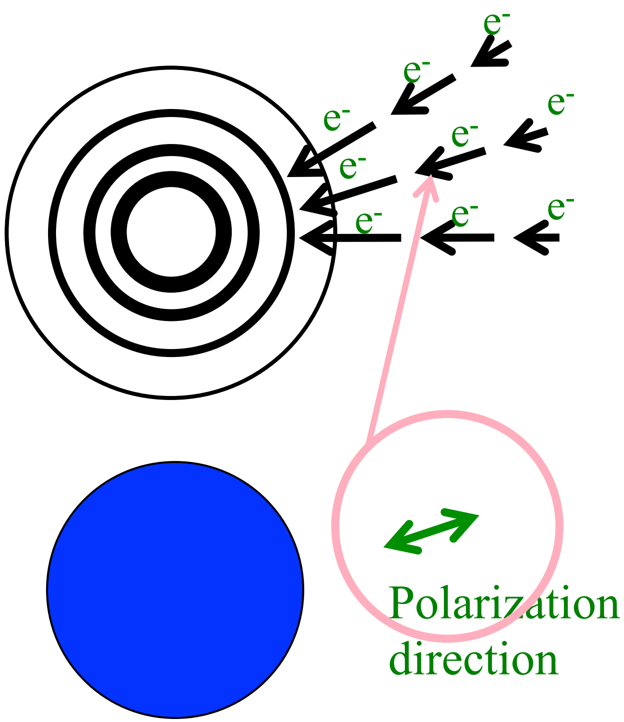


Photons climb out of well so this appears as a cold splotch on large angular scales.



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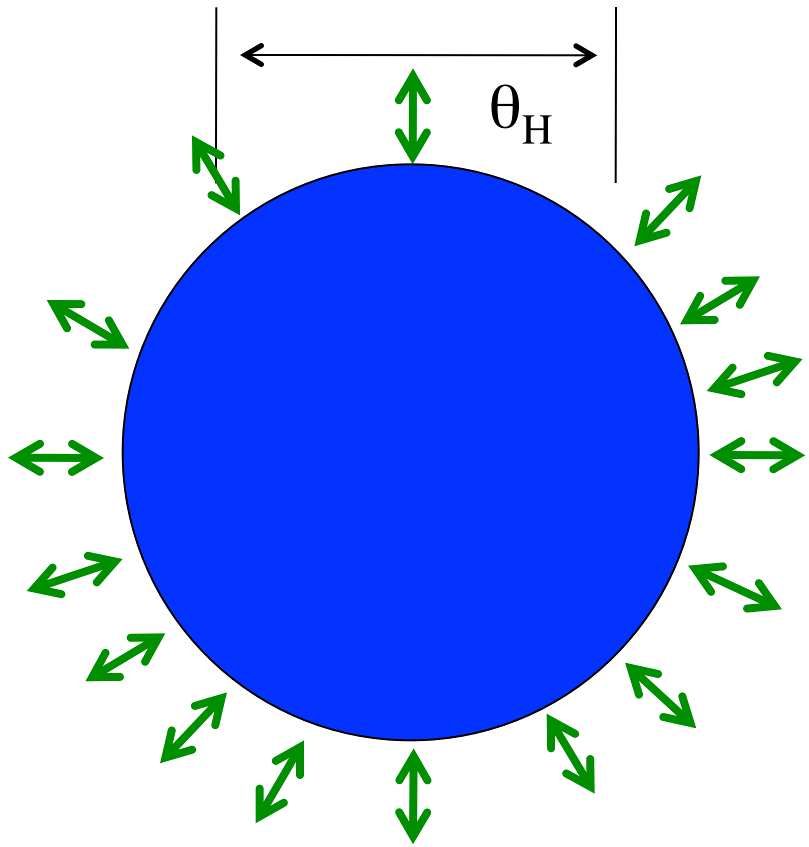
Consider a fluctuation in potential at **large** angular scales.



At **large** angular scales we expect the direction of the correlated component of the polarization to be **radial** around cold spots (or potential minima or over dense regions).

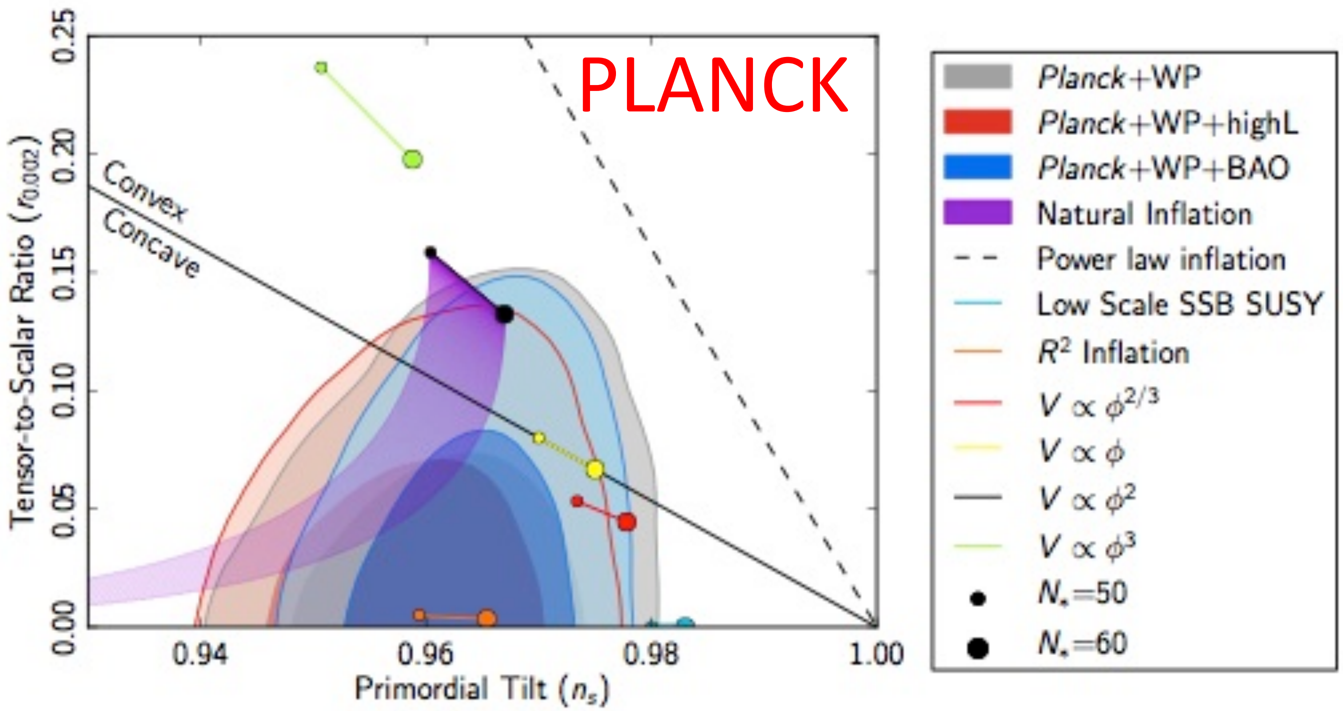
T here is negative, and the E polarization "positive" and so TE is negative.

If fluctuations are superhorizon there should be an anti-correlation for $\theta > 1.2^0$

3

WMAP

Got a good start on the early universe or "Inflation parameters": r, n_s, dn_s/dk, f_{nl}.

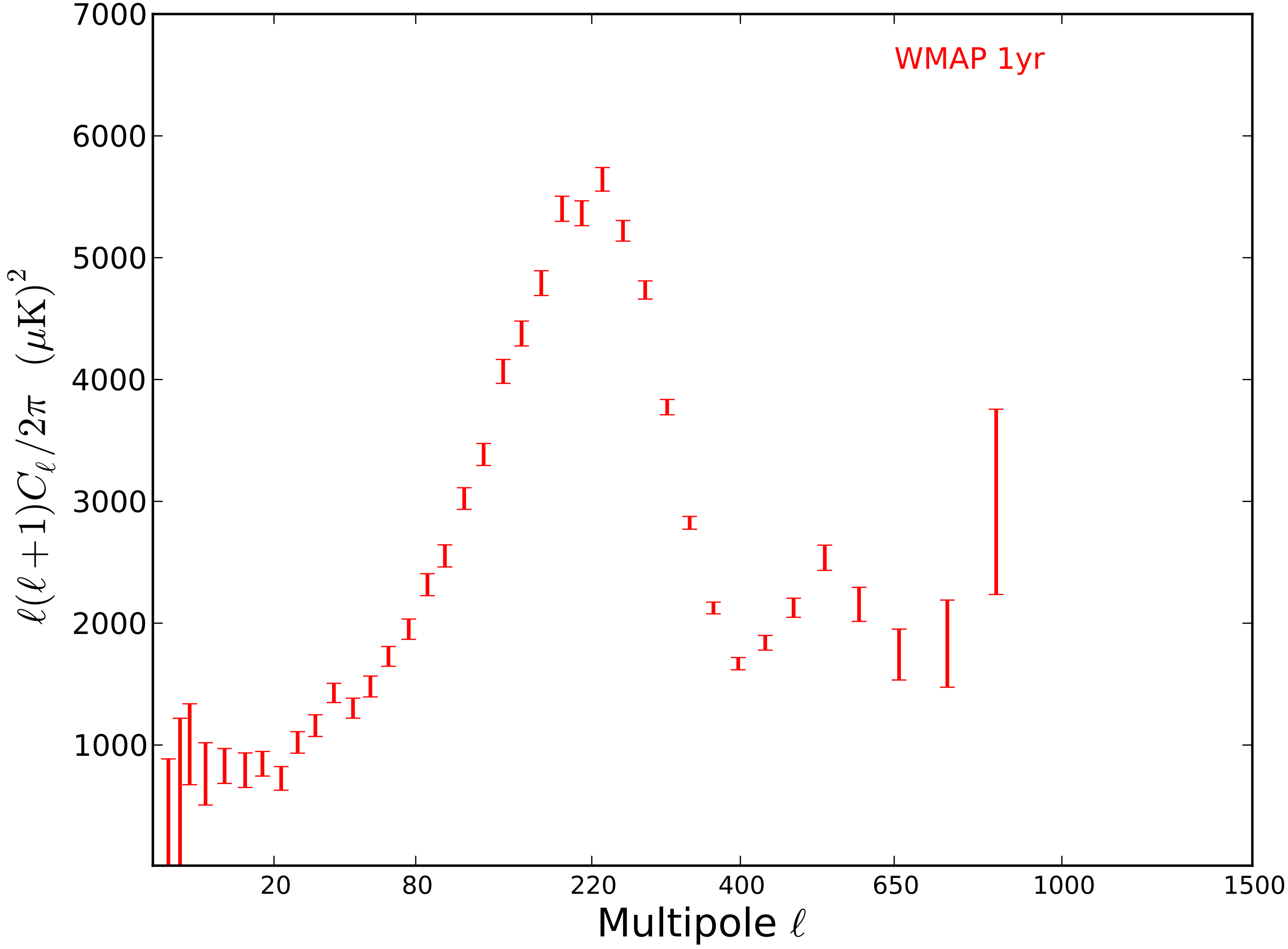


Current best B-mode limit, r<0.74 (BICEP/Chiang et al.)

More to r than inflation

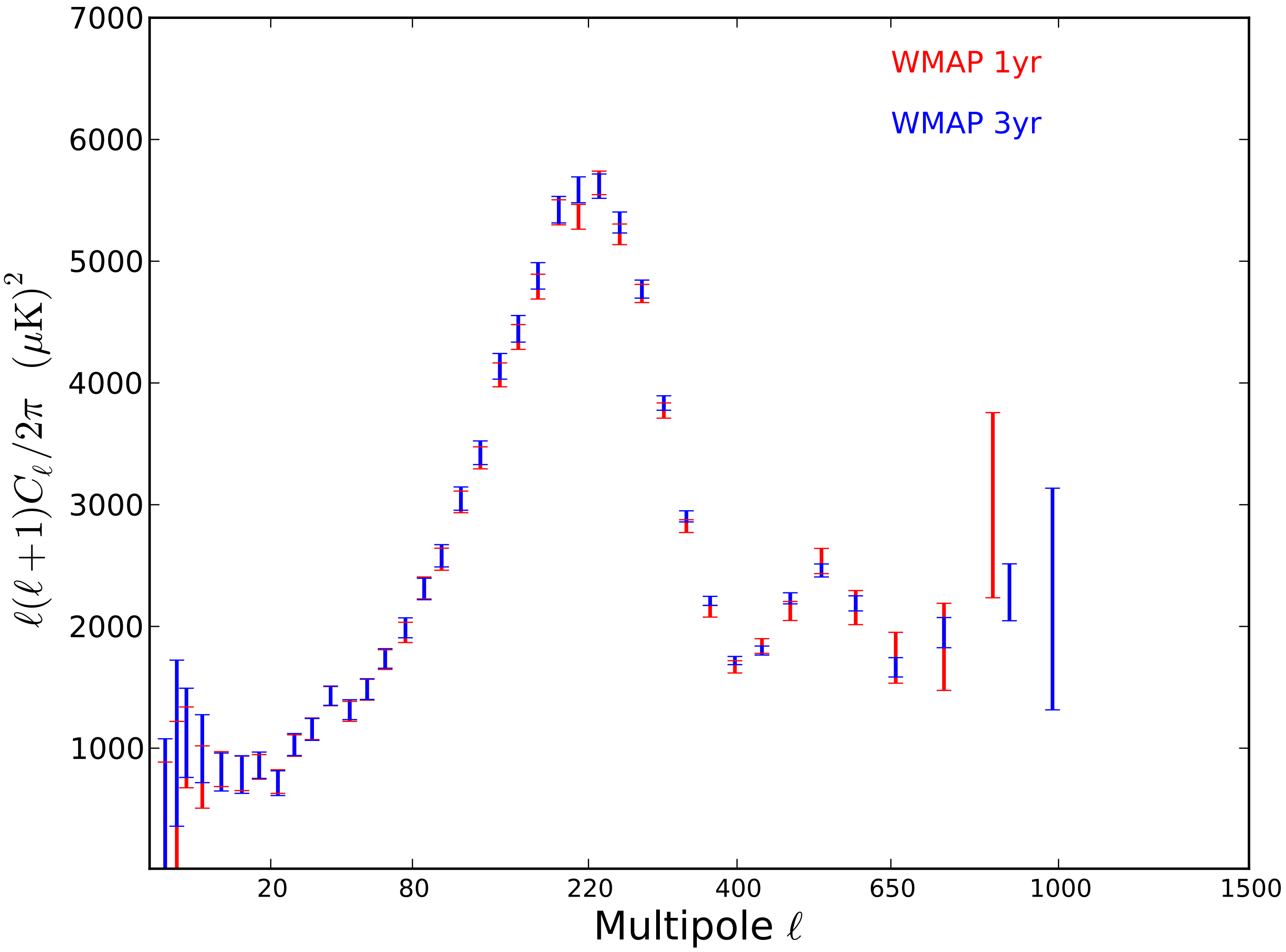
WMAP Observations

- 30% of the sky in 1 hour. Heavy cross linking.
- Just a few parameters for gain model for 9 years.
- 17 seasons of Nyquist-sampled Jupiter mapping to determine beams.
- Noise model independent of cosmology. Depends only on N_{obs}.
- Unity transfer function & low 1/f.
- Sidelobe mapping on the ground and in flight.

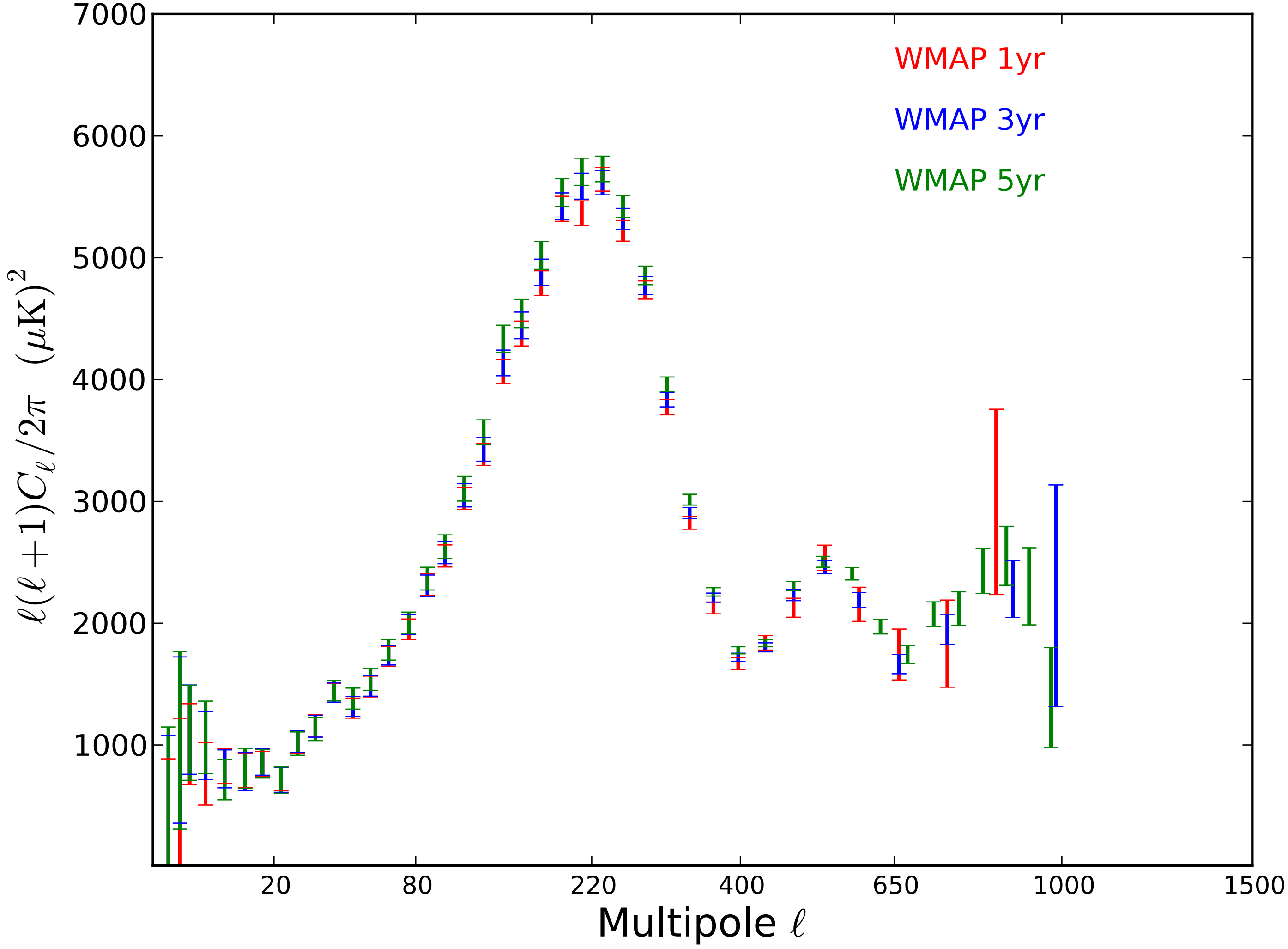


WMAP 1yr
7000
6000
5000
4000
3000
2000
1000
$\ell(\ell+1)C_\ell/2\pi \quad (\mu K)^2$
20
80
220
400
650
1000
1500
Multipole ℓ

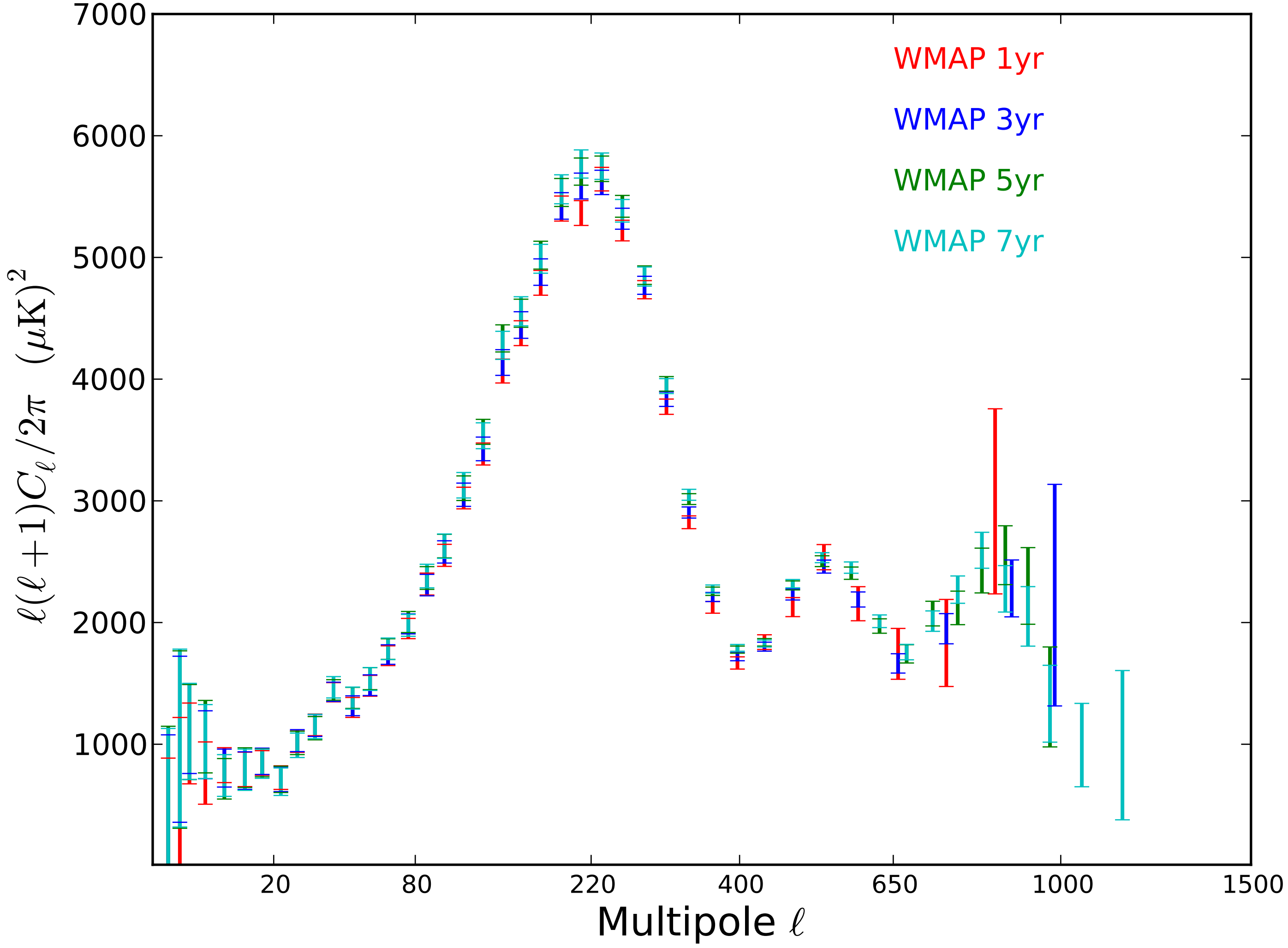
New dipole and gain model. ** Small pointing error corrected.
Physical optics model the beams on A side. Use K and Ka bands for foreground cleaning.
Maximum likelihood for l<30, pseudo C_l for l>30



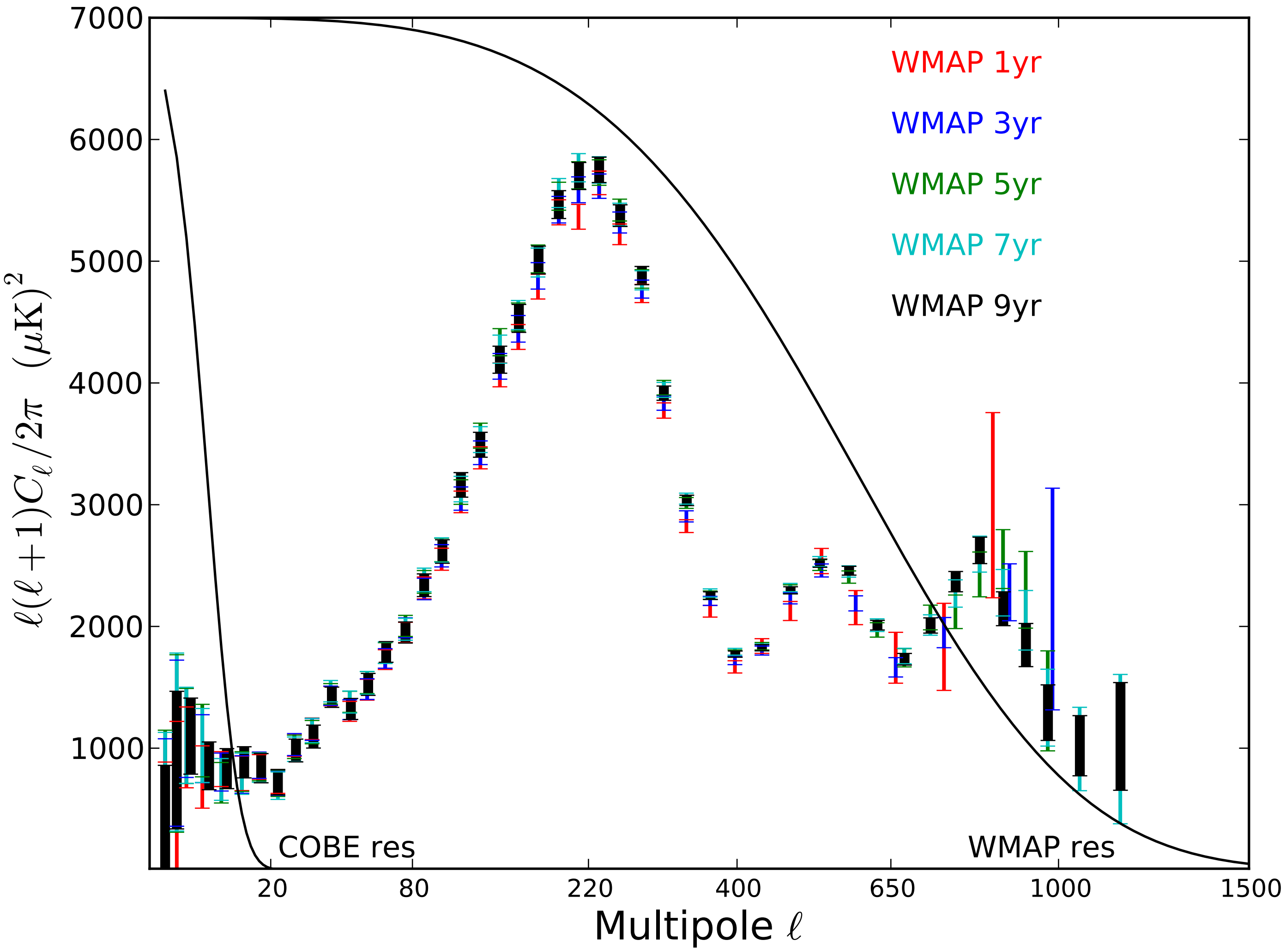
Reassess gain model, 0.2% ** 10 seasons for beam. Measure at -44dB, 0.5% Omega beyond that. ** Full physical optics model. ** Reassess far sidelobes, enlarge transition radius, mode sidelobe accounting into time line. ** Improved likelihood at l<32



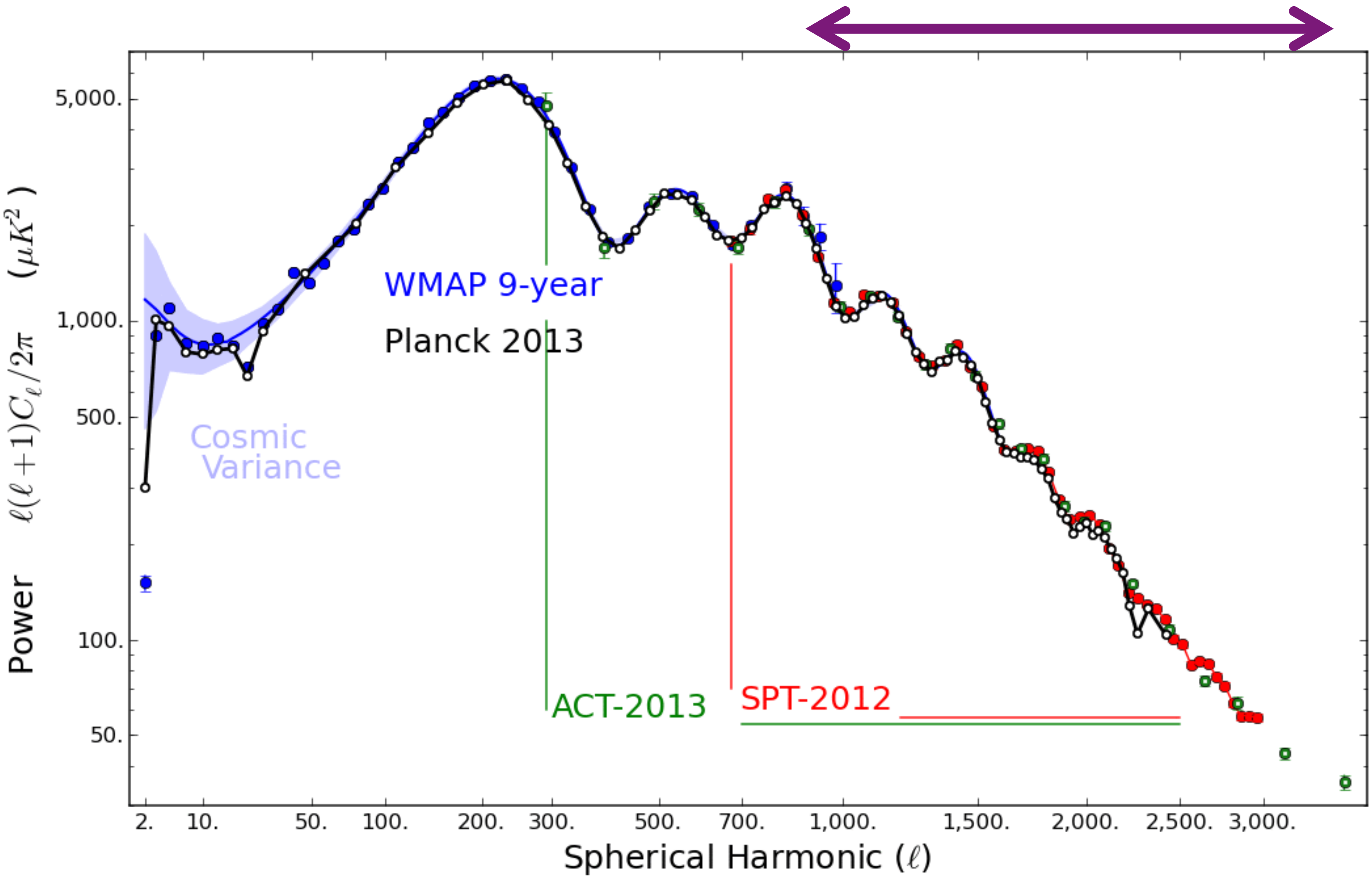
Continued improved improvement in beams. A and B separately



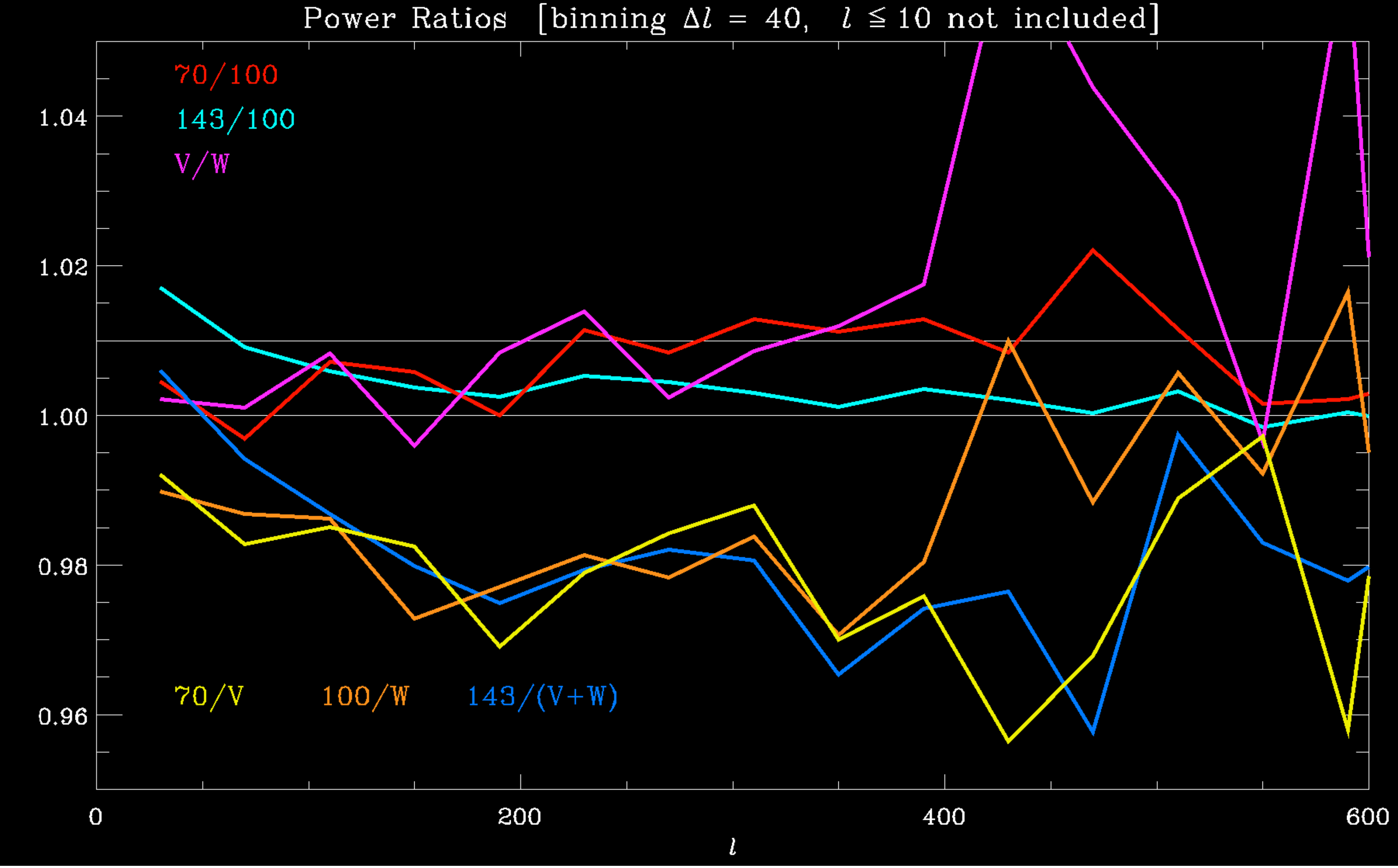
Reassess ILC and move to optimal C_l estimator.



Silk damping tail



From Mark Halpern



Spectra and maps do not agree at 1.2% level in temperature

From Kris Gorski

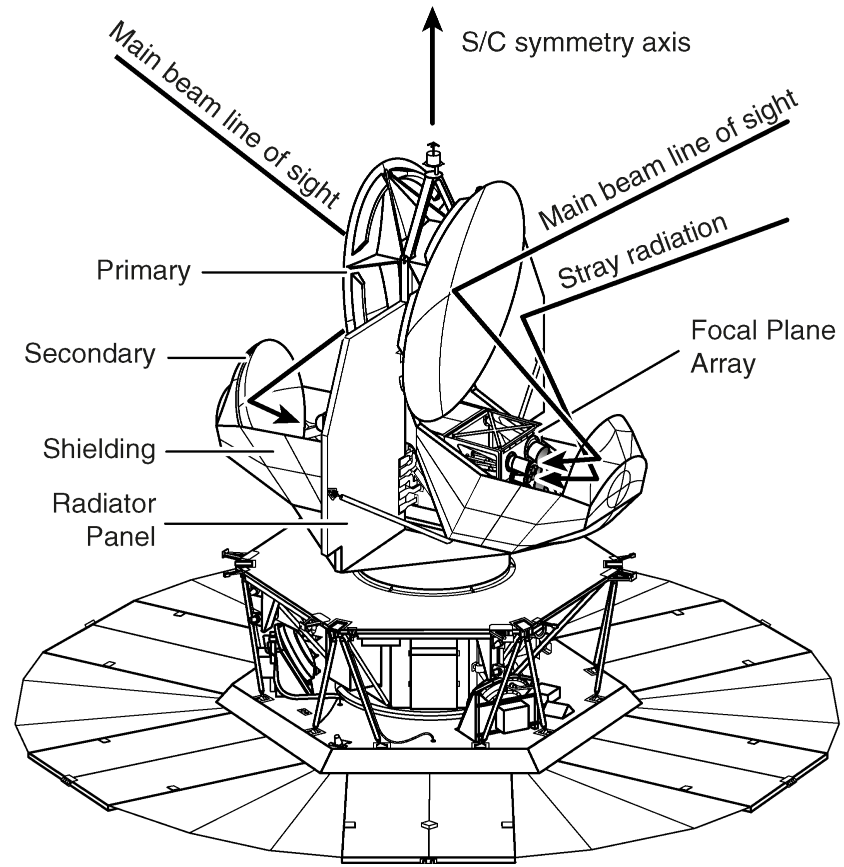
Difference does not depend on the masking or the foregrounds.

Some possible systematic errors

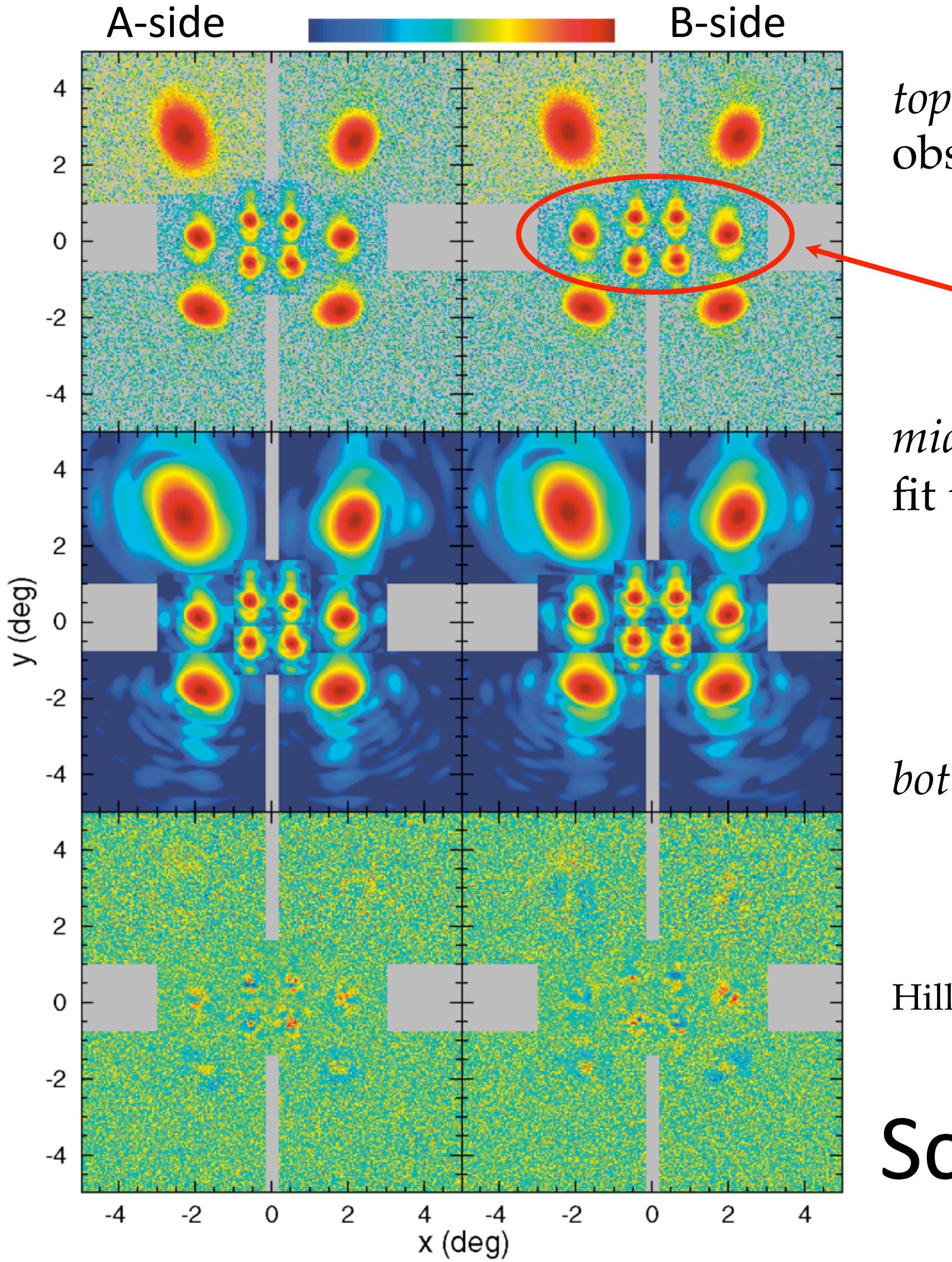
Beams

Sidelobes

Calibration



Beam Mapping & Modeling



top - beam maps constructed from in-flight observations of Jupiter.

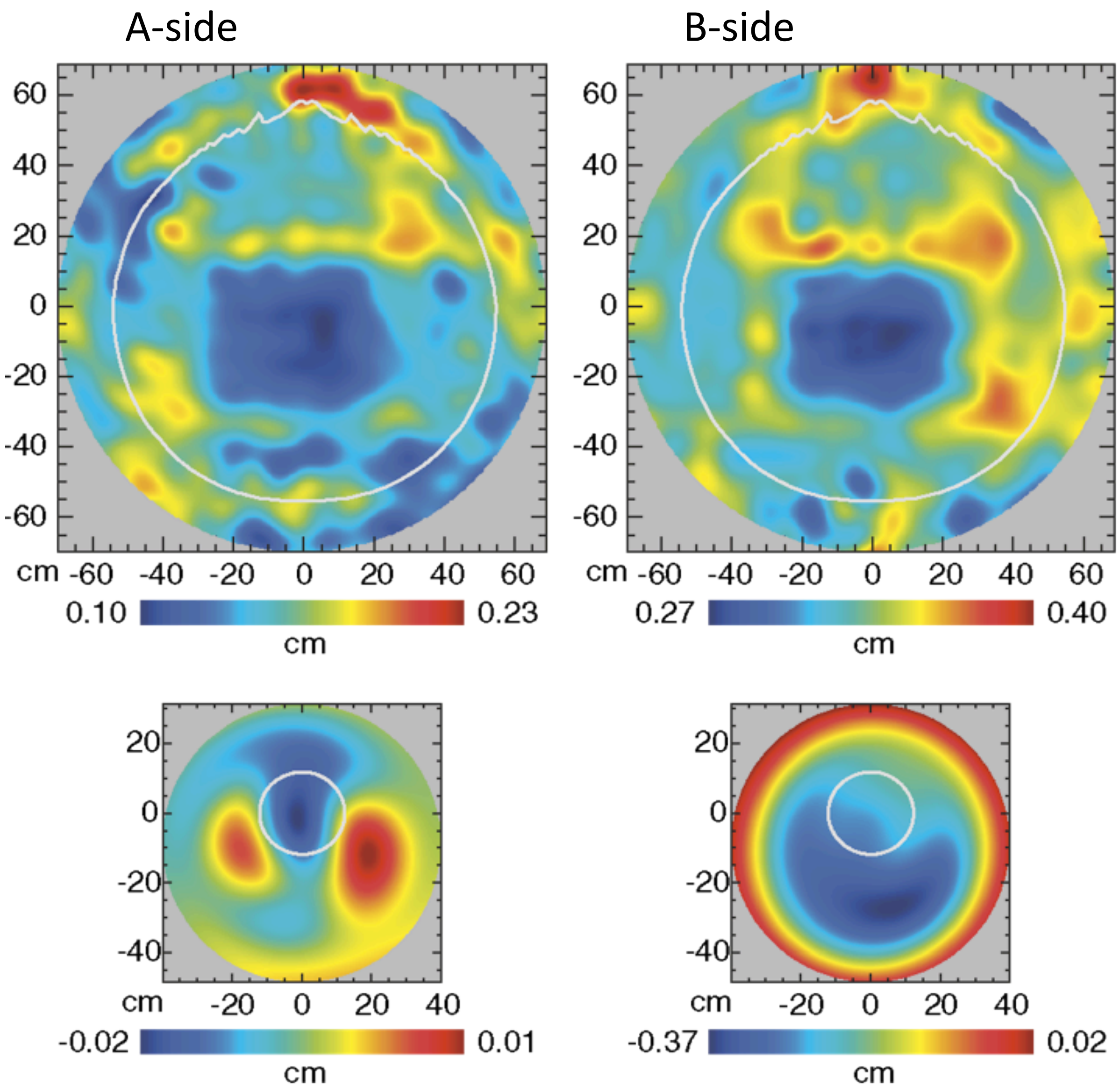
middle - physical optics model; mirror figure fit to in-flight beam maps.

bottom - residual: data – model.

Hill et al., ApJS, 2009, 180, 246

Scan symmetrizes beam.

Mirror Distortion Fits



top - primary mirror distortions inferred from fits to in-flight observations of Jupiter.

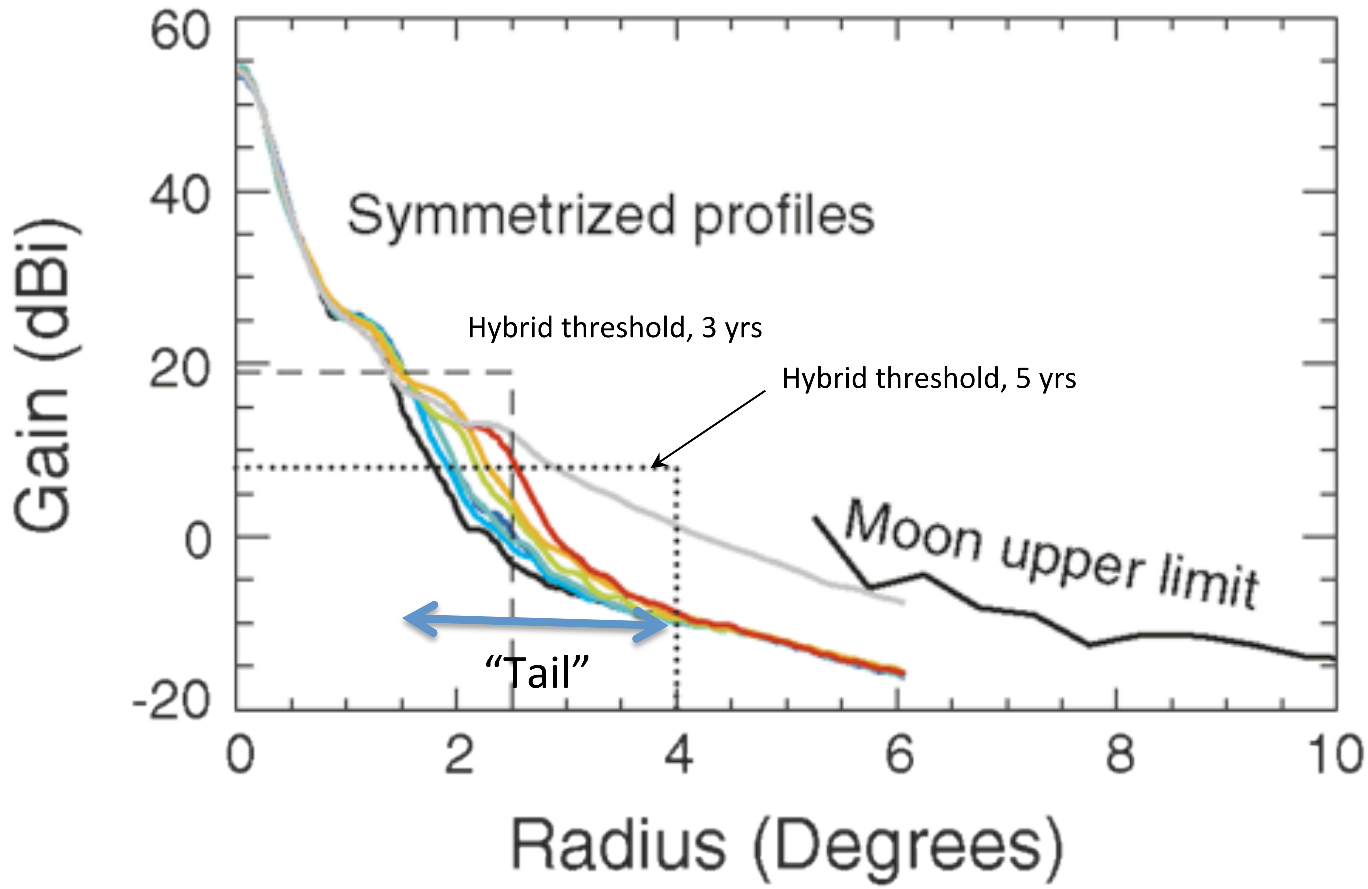
Grey curves indicate the mean radius at which W band illumination reaches −15 dB.

Note ~1.3 mm p-p and 0.6 mm over illuminated region.

bottom - same for secondary mirror.

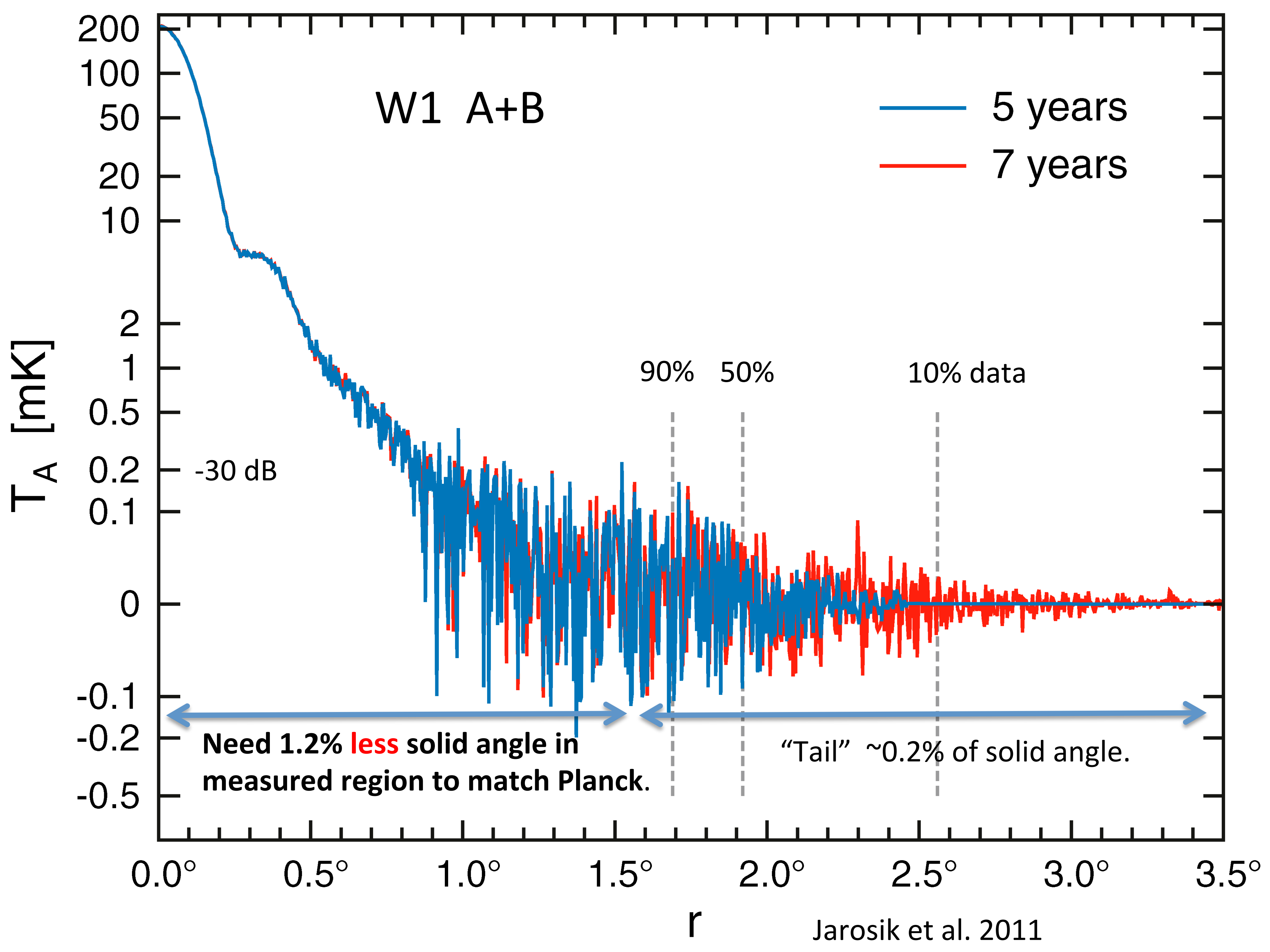
Hill et al., ApJS, 2009, 180, 246

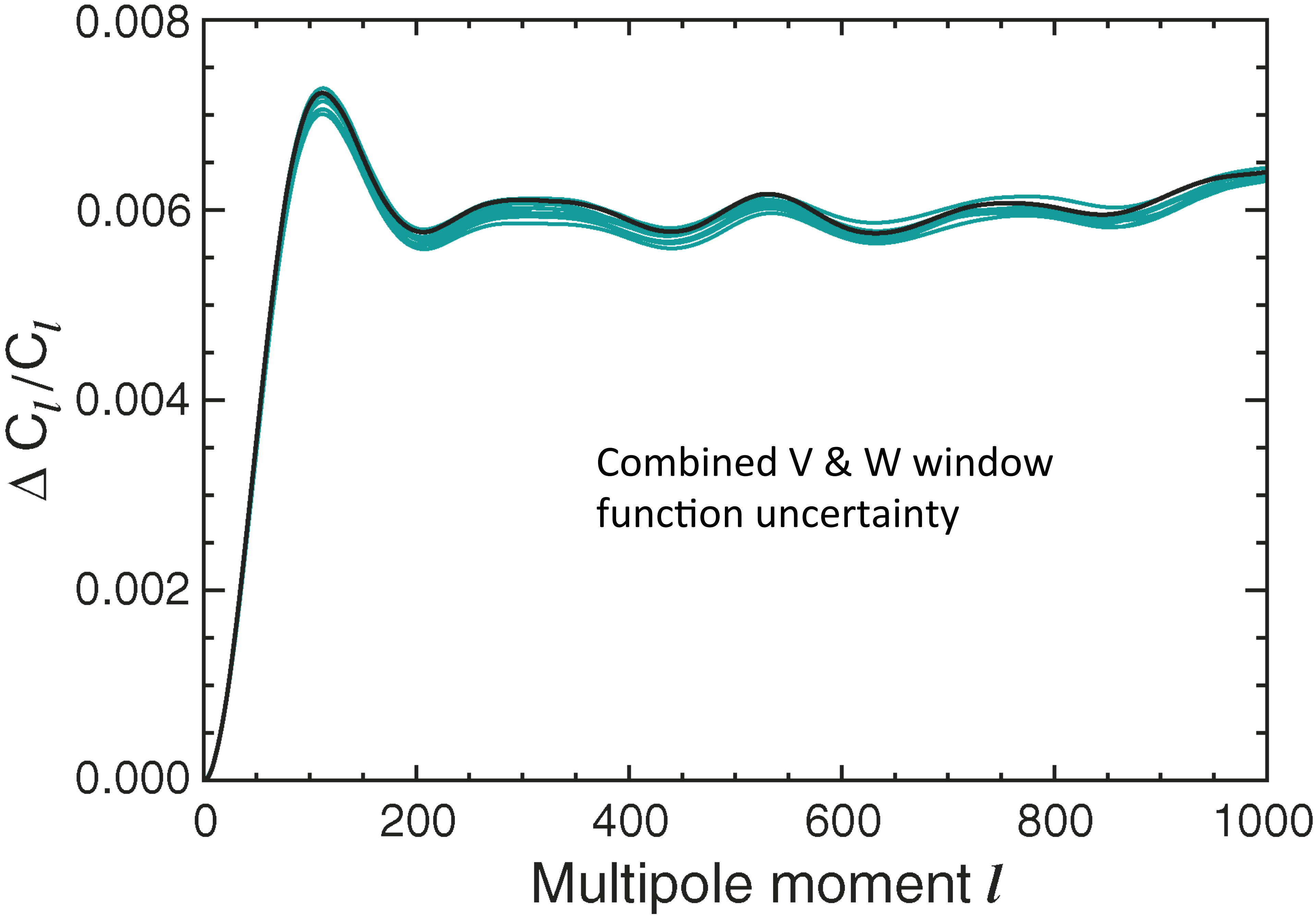
Determination of Model Threshold



V-band beam profiles for different maximum k values in the model of the primary reflectors. In going from indigo to red is an increase of 0.1% in sold angle.

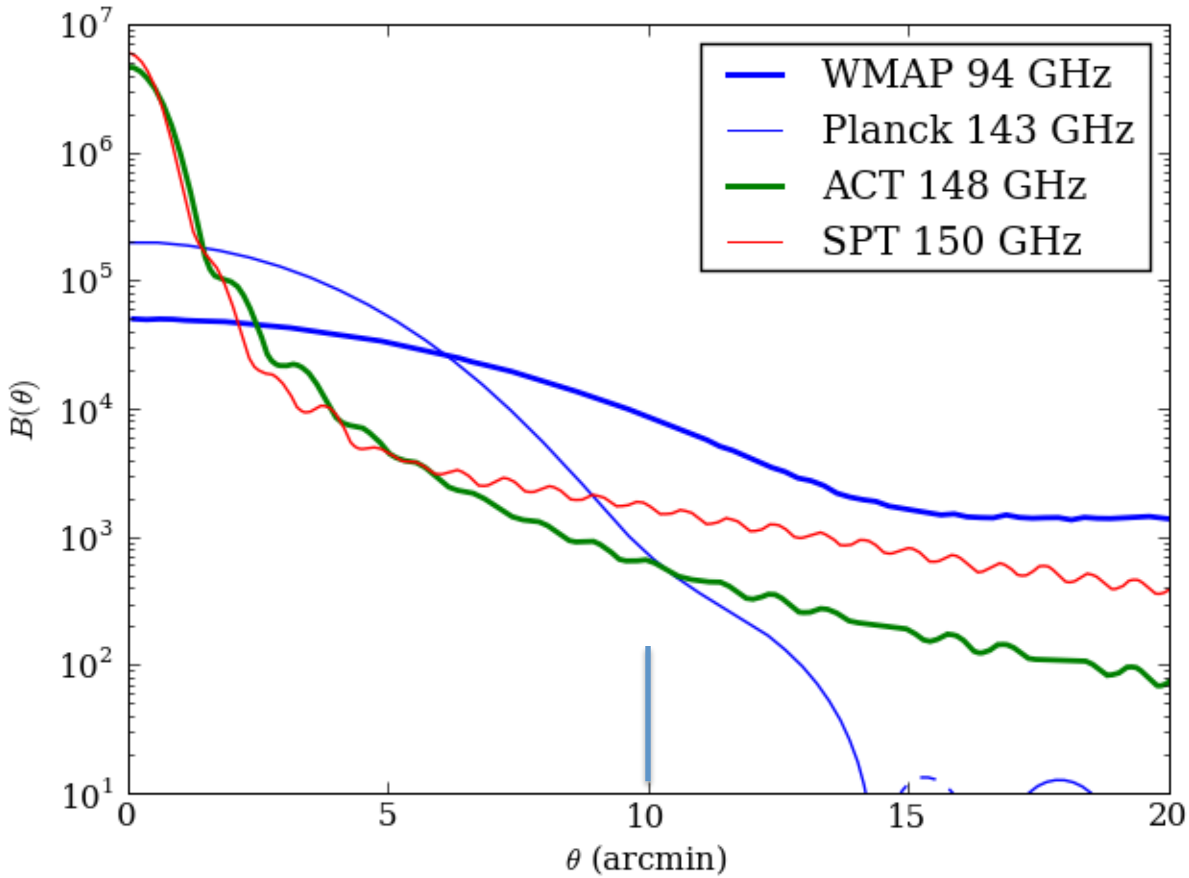
Hill et al., ApJS, 2009, 180, 246


W1 A+B
5 years
7 years
200
100
50
20
10
2
1
0.5
0.2
0.1
0
-0.1
-0.2
-0.5
T_A [mK]
-30 dB
90%
50%
10% data
Need 1.2% less solid angle in
measured region to match Planck.
"Tail" ~0.2% of solid angle.
0.0°
0.5°
1.0°
1.5°
2.0°
2.5°
3.0°
3.5°
r
Jarosik et al. 2011

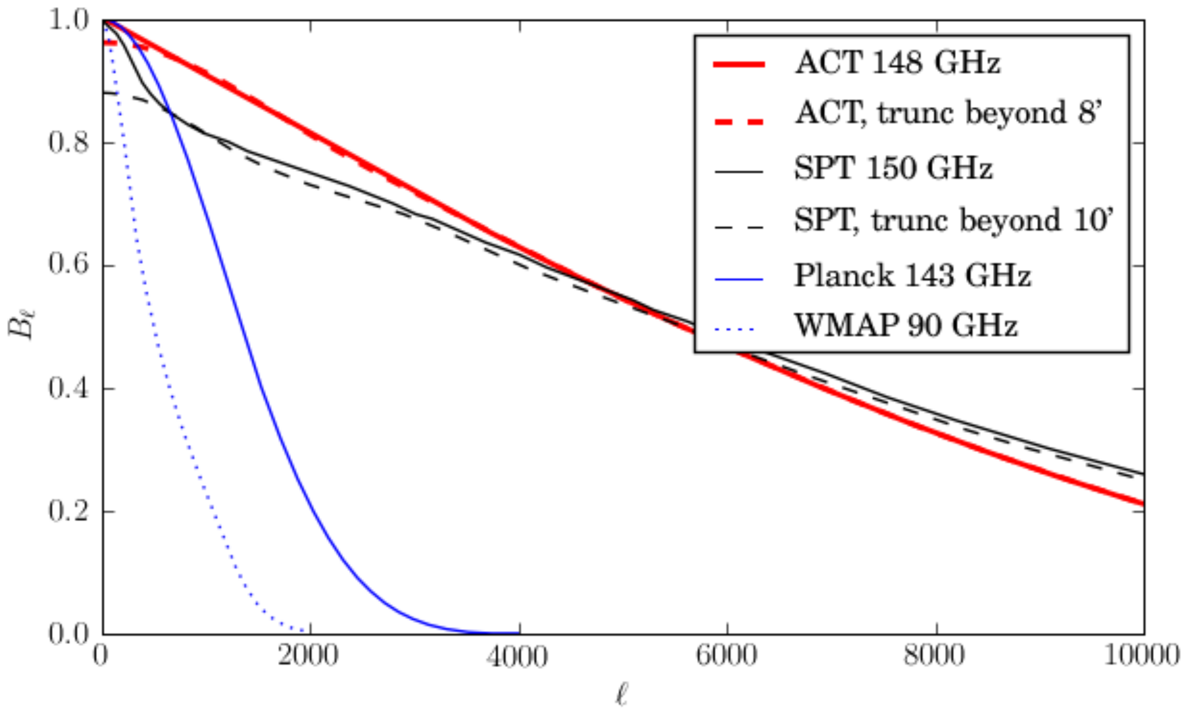


Hill et al., ApJS, 2009, 180, 246

Beam aside: ACT and SPT



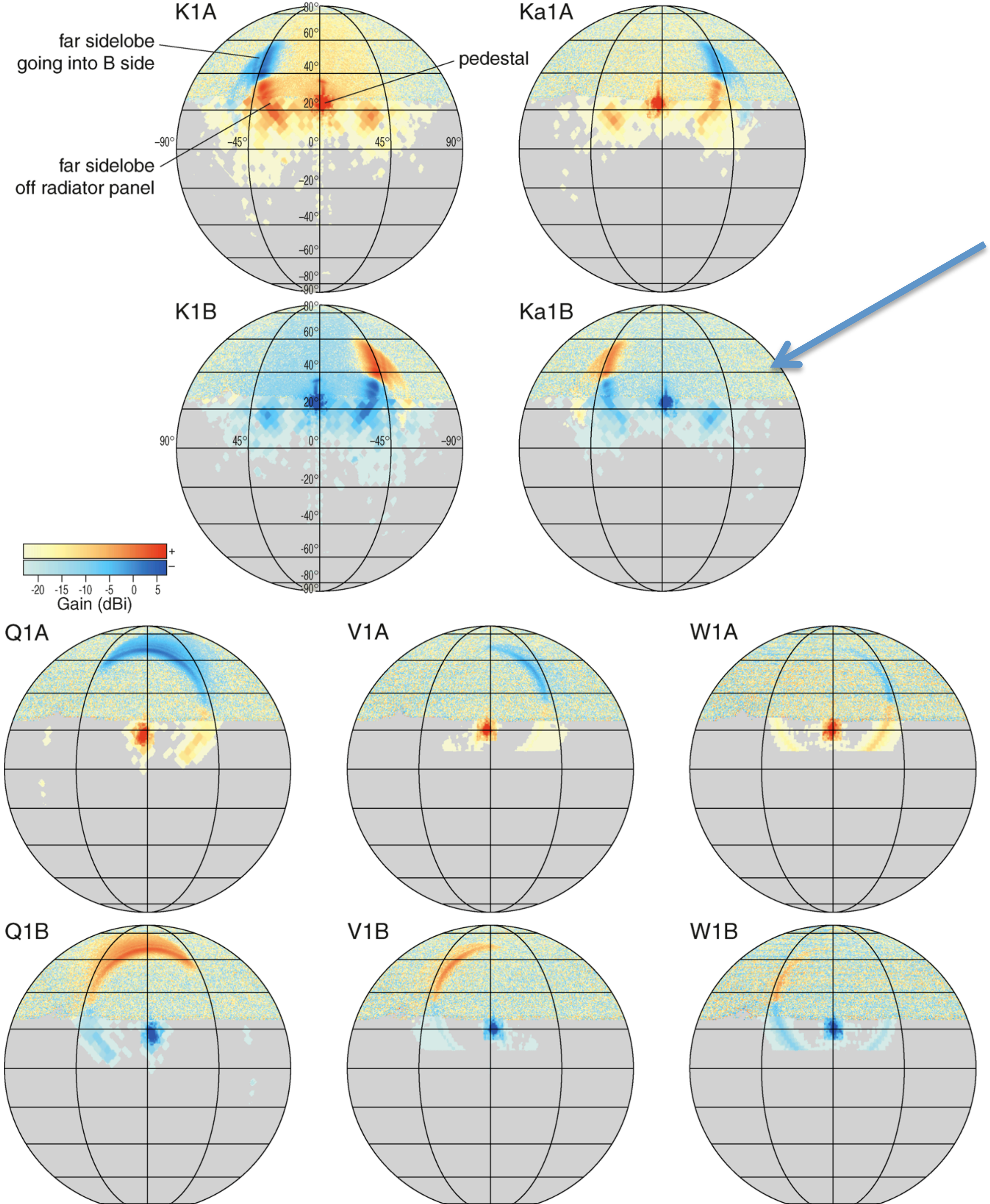
From Matthew Hasselfield



Note sensitivity to measurements at <0.001 of the peak.

From Matthew Hasselfield

Sidelobes



1.2π measured off moon in flight.

Agree in V and W band to with ground based measurements to 15% & 10%.

0.25% of Ω, corrected to a limit 0.05% in analysis.

Not sole cause.

Barnes et al. 2003

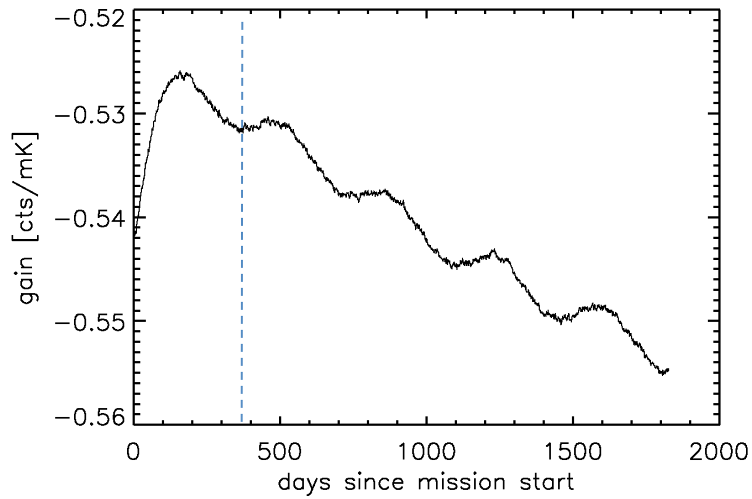
WMAP Calibration

- Calibration is done on the CMB dipole from the annual modulation of WMAP's L2 orbit around the solar barycenter.
- A baseline and gain model are iteratively solved for with 1 hr averages.
- Sidelobe contribution removed at this step.

0.2% calibration uncertainty from sims.

Cosmic dipole remains in timeline and is expressed in the mapmaking.

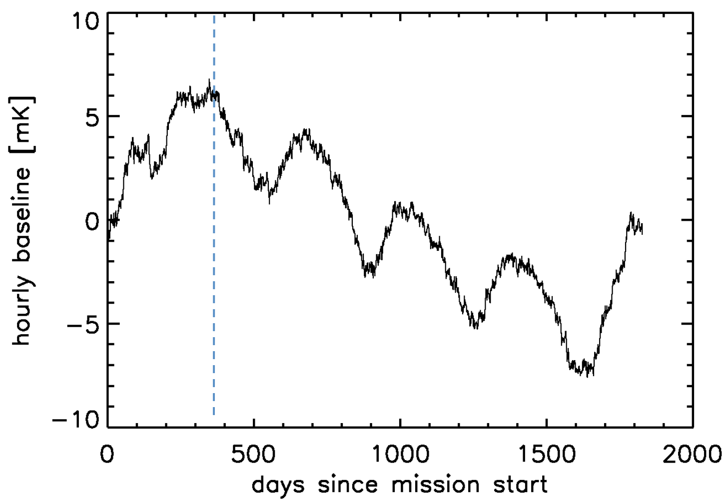
Instrument Performance over the Years



Raw gain factors ($g=dV/dT$) change by ~2% over 9 years. Due to changes in spacecraft temperature and amplifier properties.

Multiple years of data help to separate these effects and improve uncertainty in the gain model.

A few parameters per DA describe the gain for entire mission.

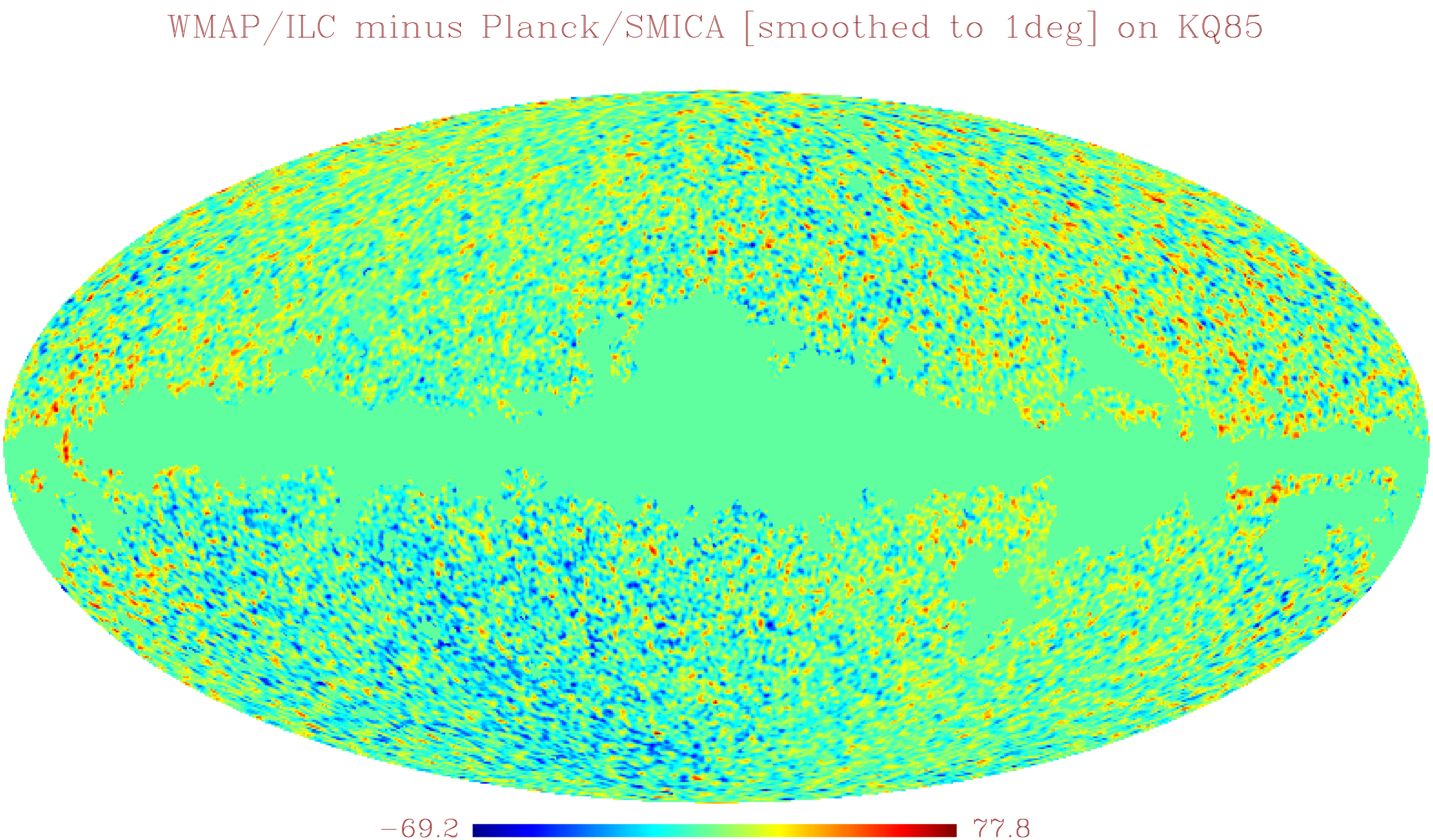


Change in instrument offset, b, vs. time,

$\Delta V = g\Delta T + b \qquad \langle \Delta T \rangle = 0$

Drifts < ~5 mK over 9 years.

< 1% of data flagged as unusable.



From Eiichiro Komatsu. There is a 6.3 uK residual dipole in the ILC-SIMCA map that points in the CMB dipole direction. Quadrupolar residual about 10x larger.

May account for 0.2% of the difference.

$T = T_J\Omega_J/\Omega_B$ a possible inconsistency

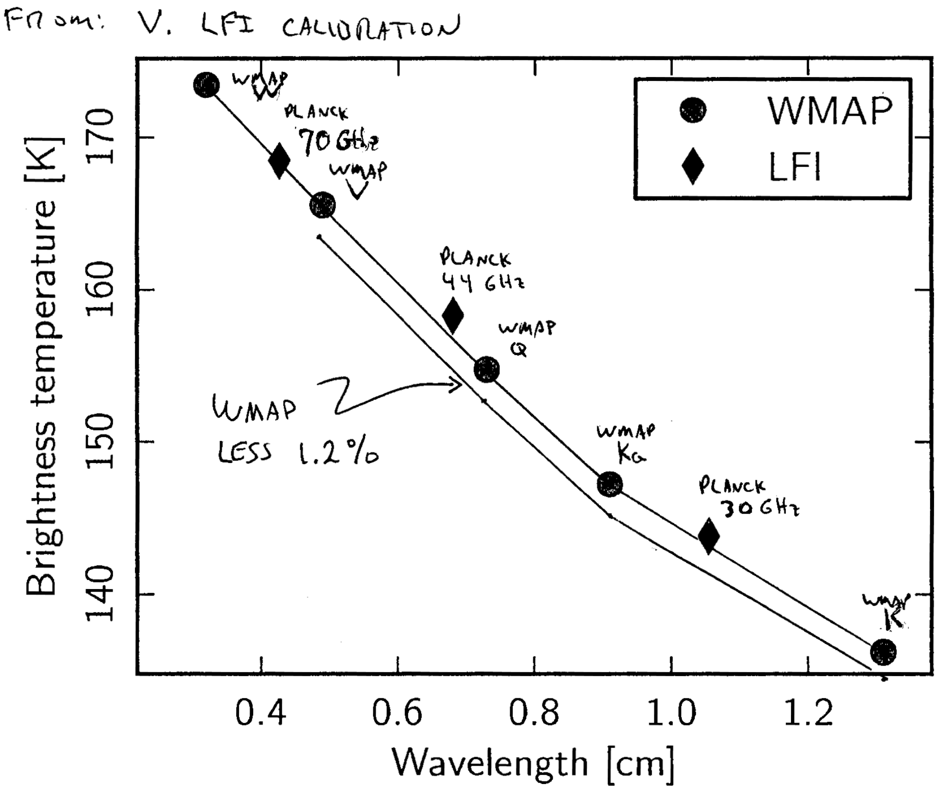
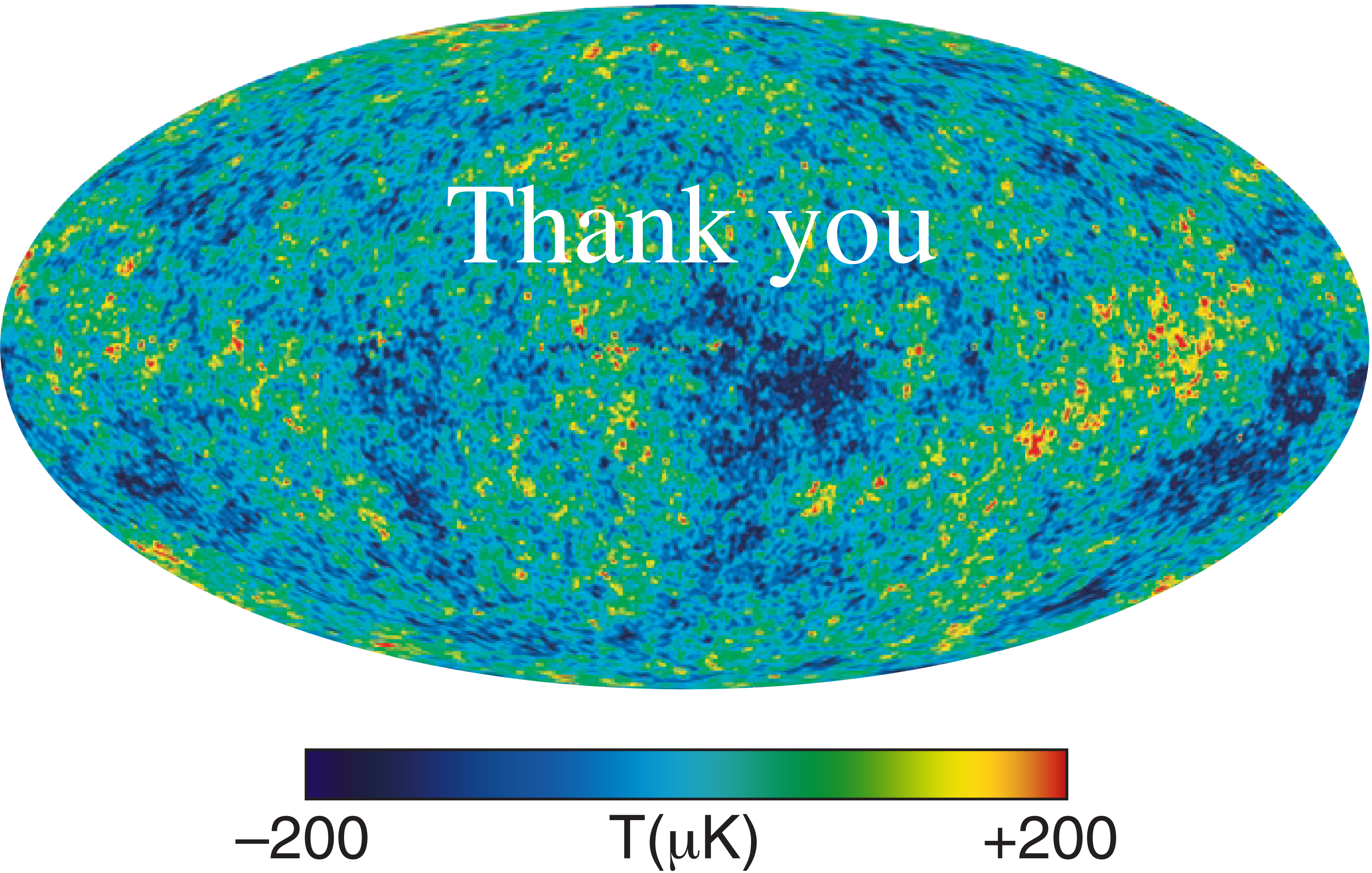


Fig. 18. The Jupiter spectrum for LFI compared to the *WMAP* spectrum (Weiland et al. 2011). In both cases, measurement errors are smaller than the size of the symbols.

Table 12. Averaged brightness temperatures for planets[a] .

6. Conclusions

In this paper we have (
Planck/LFI's data and
of our calibration. We
in the maps is quite gc
at 44 and 70 GHz, and
However, we belie
cantly improve our ur
fore produce a better c
(see sects. 4.1 and 4.2
noise temperature of t
need to concentrate ou
analysis methods for t
to provide a sound pol
An important poir
of a full characterizat
WMAP. This would in
radiometers absolutely
to obtain some encour
using *WMAP*'s charac
pipeline. We aim to dc
Another important
optical systematics on
volver (Sect. 4.2) is a


Thank you
–200
T(μK)
+200