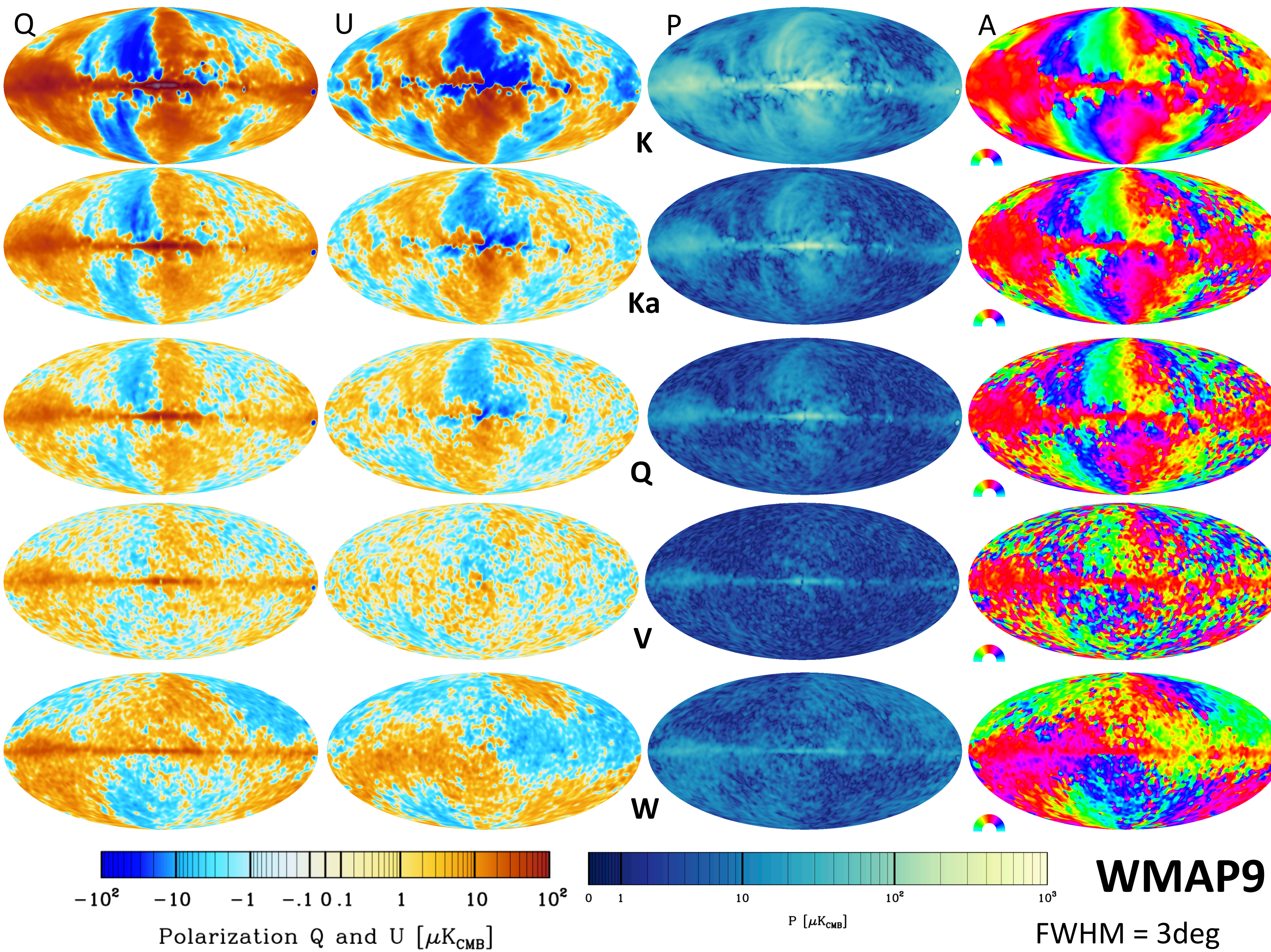
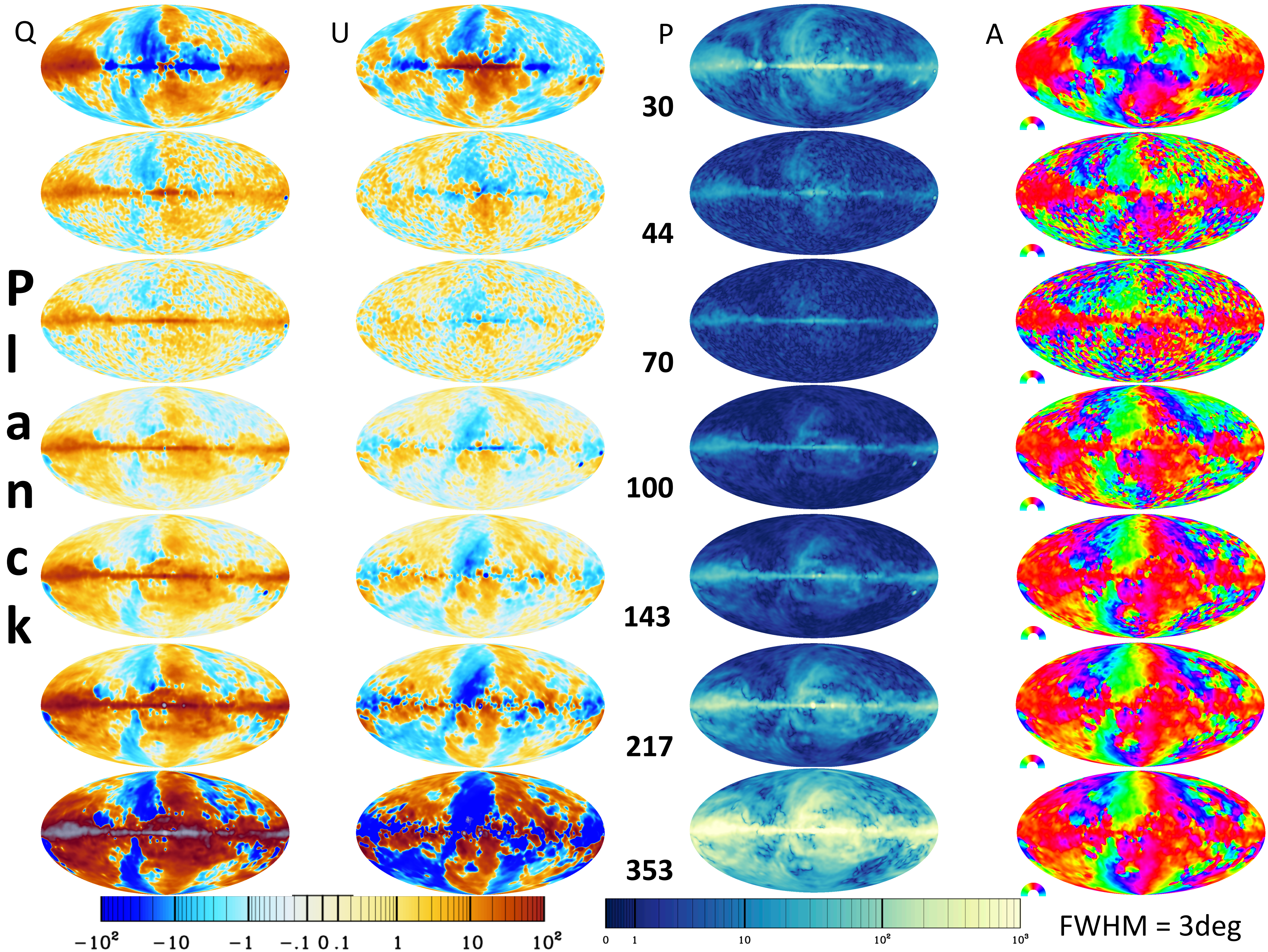
B-mode from Space

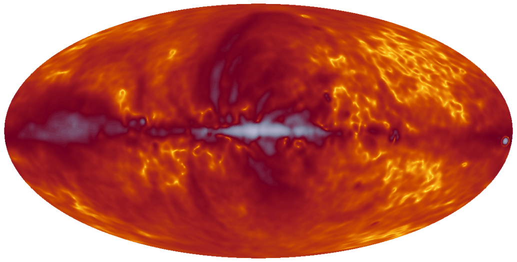
K.M. Gorski
KIPMU
Dec. 2015


Q
U
P
A
K
Ka
Q
V
W
−10²
−10
−1
−.1
0
.1
1
10
10²
Polarization Q and U [μK_CMB]
0
1
10
10²
10³
P [μK_CMB]
WMAP9
FWHM = 3deg

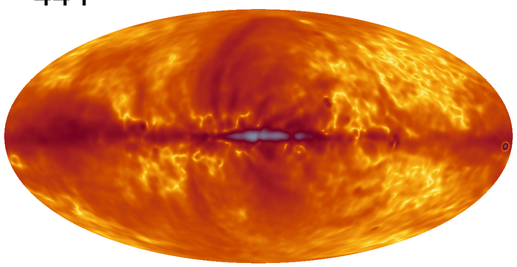


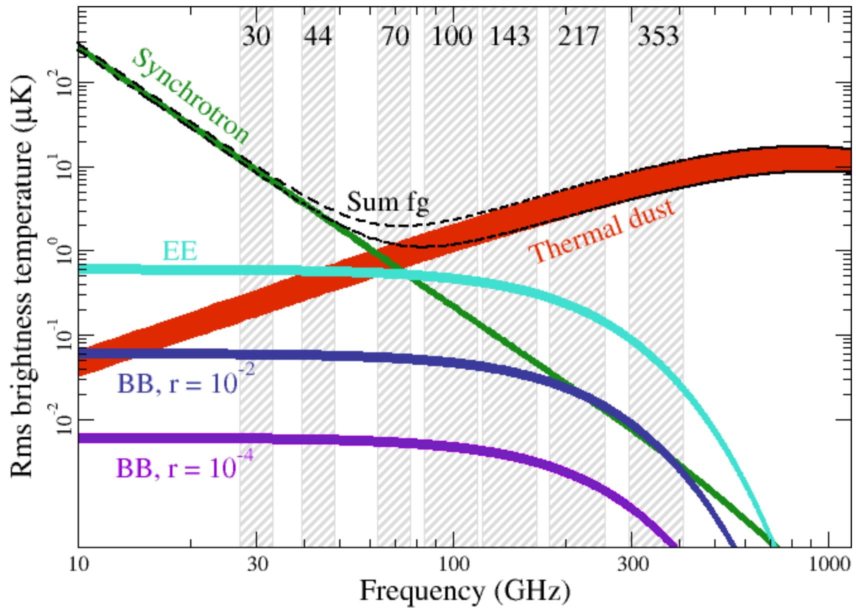
Q
U
P
A
Planck
30
44
70
100
143
217
353
−10² −10 −1 −.1 0 .1 1 10 10²
0 1 10 10² 10³
FWHM = 3deg

30 P

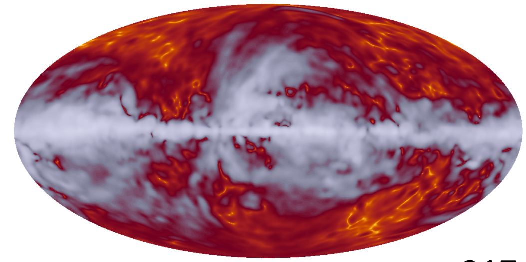


44 P

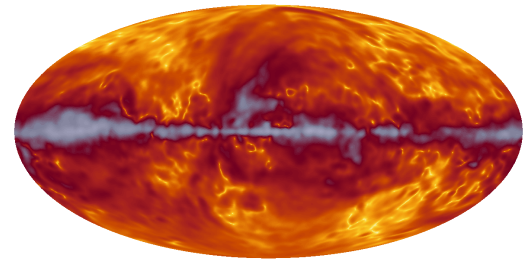




353 P



217 P

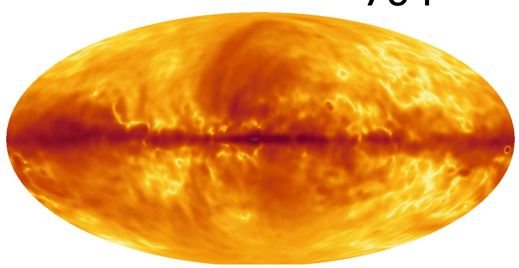


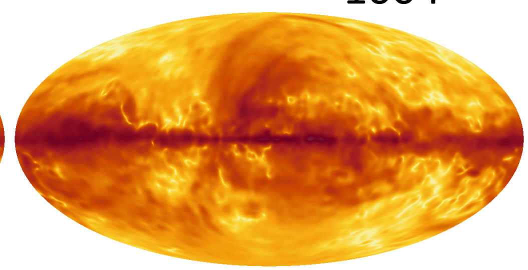
70 P

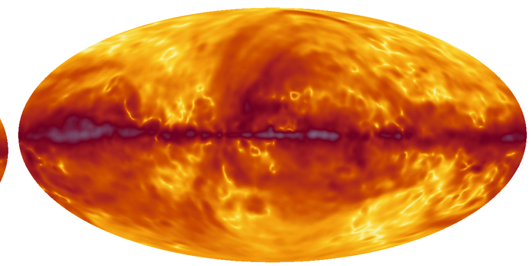
100 P

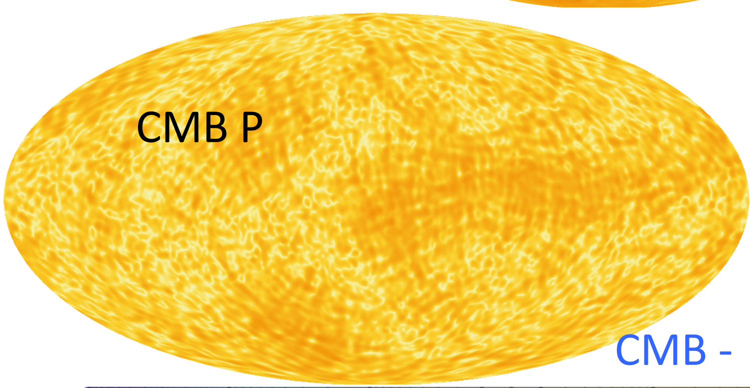
143 P

ALL PLOTS: Polarization Amplitude









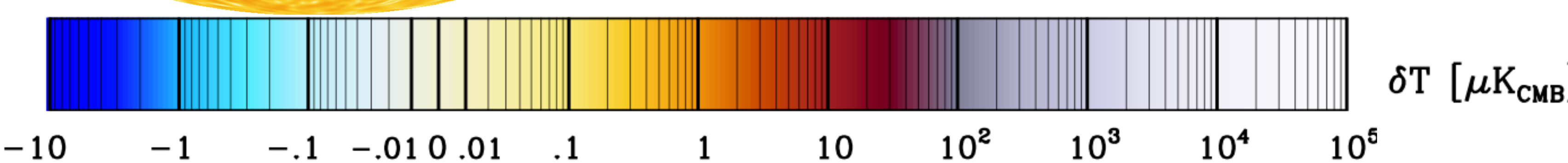
Commander polarized foreground maps:

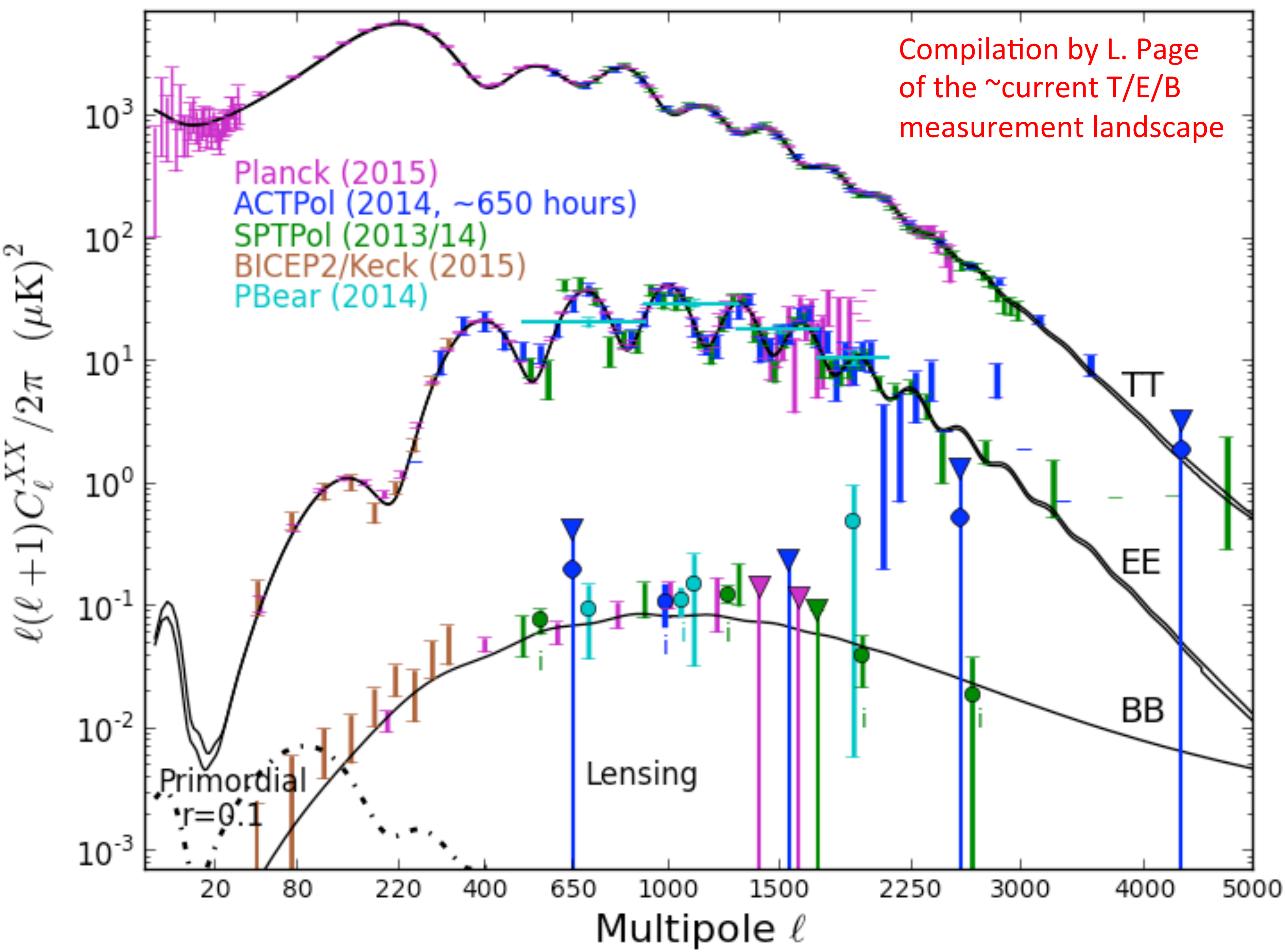
frequency scaled and added together

- WMAP-K synchrotron map plus
- Planck 353 dust map (only foregrounds shown)

All maps at FWHM = 3deg

CMB - a realization from the τ =0.06 and r=0.10 model





Compilation by L. Page
of the ~current T/E/B
measurement landscape
Planck (2015)
ACTPol (2014, ~650 hours)
SPTPol (2013/14)
BICEP2/Keck (2015)
PBear (2014)
TT
EE
BB
Lensing
Primordial
r=0.1
$\ell(\ell+1)C_\ell^{XX}/2\pi \ (\mu K)^2$
Multipole ℓ

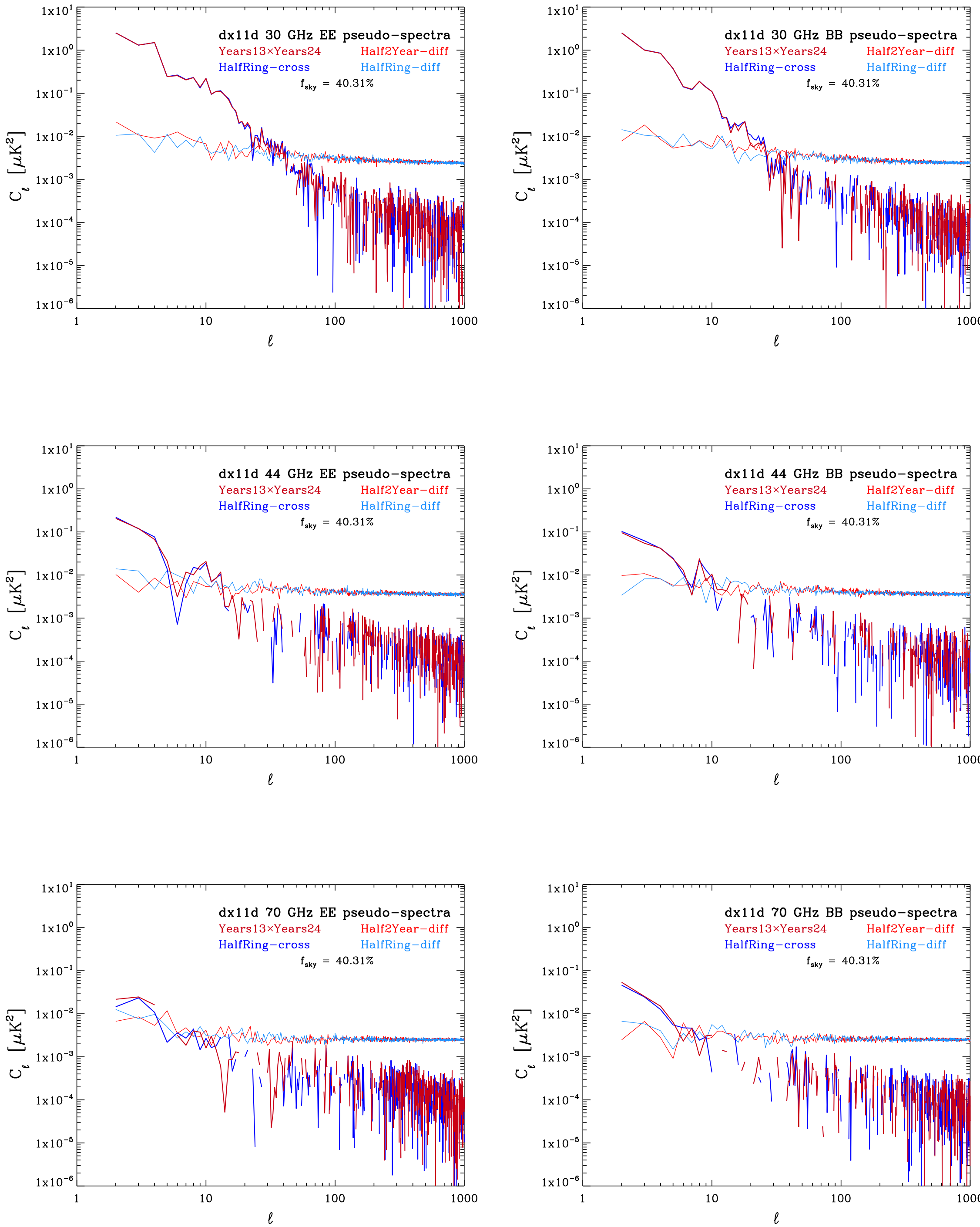
Planck LFI 2015

All pseudo-spectra computed on on the sky-mask of f_{sky}=~42% (identical for LFI, and HFI on next slides) using data splits available with Planck LFI sky maps.

Here – two cases:

- Half-ring splits of full mission data
- Half mission splits

Excellent noise properties (structurally; low level of residual correlated noise at low-l), but high amplitude, especially regrettable at the “cosmological” 70 GHz channel.



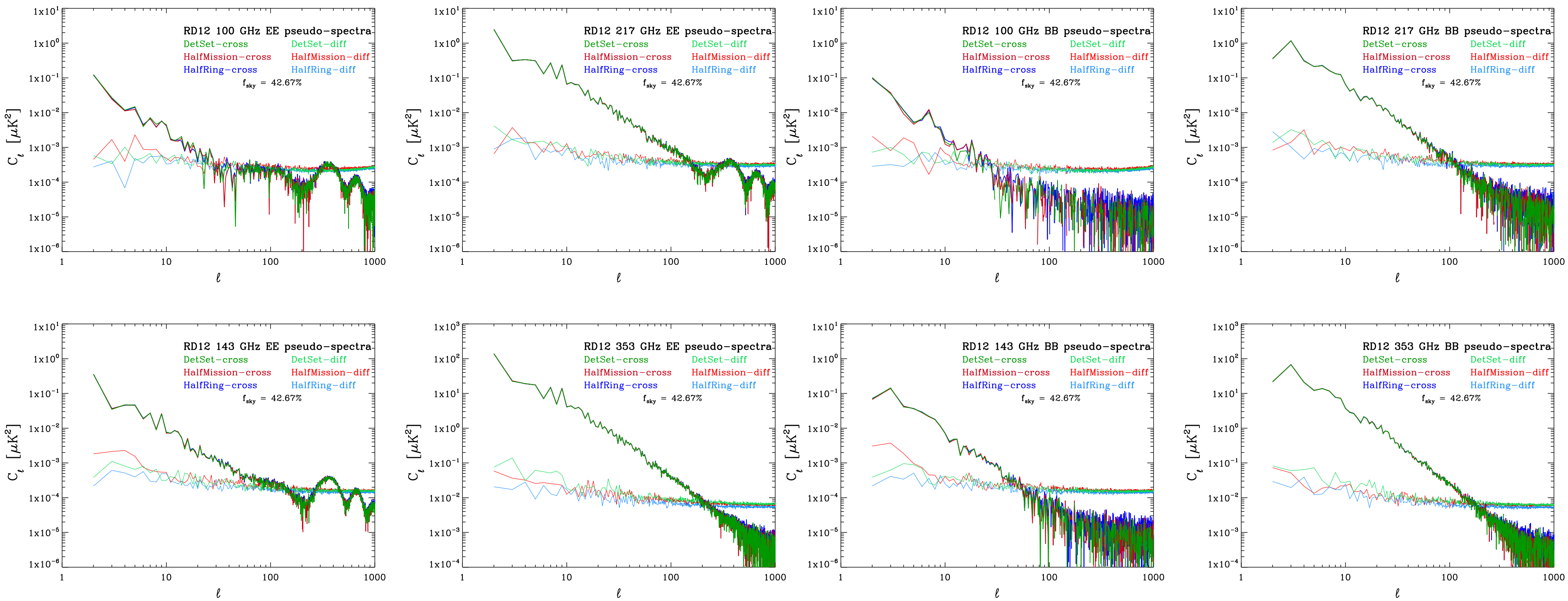
Some working version of the Planck HFI data
(not the data set in the Planck Legacy Archive, as explained in the 2015 papers)

All pseudo-spectra computed on on the sky-mask of f_{sky}=~42% (identical for HFI, and LFI on the next slides) using data splits available with Planck HFI sky maps.

Here – three cases:

- Half-ring splits of full mission data
- Half mission splits
- Detector set split (maps made from separate halves of the focal plane at each frequency)

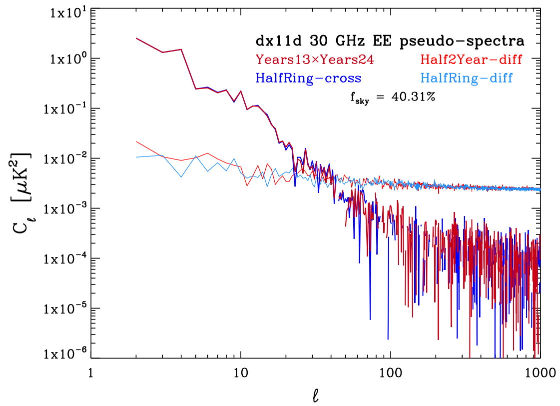
Agreeable noise properties are being achieved, systematics purge is ongoing, and a quest for higher fidelity τ estimates continues. 2016 results to be expected.

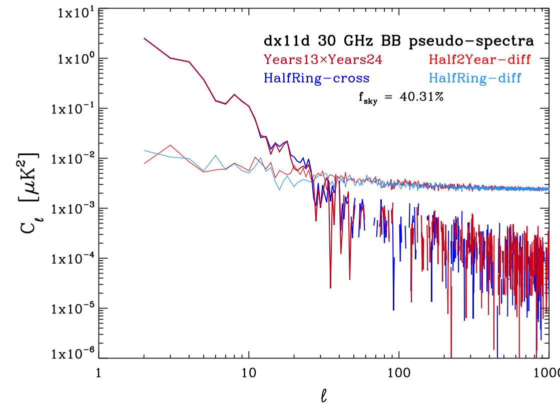


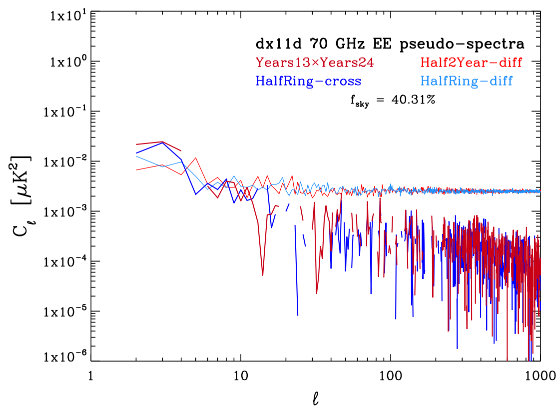
Quick illustration (qulitative only) of inputs to single frequency, foreground cleaned by far-out frequency data, analysis of low-l range.

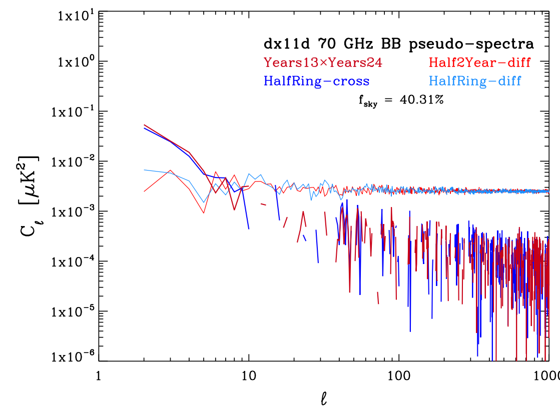
Here – “70 to be cleaned by 30 and 353”

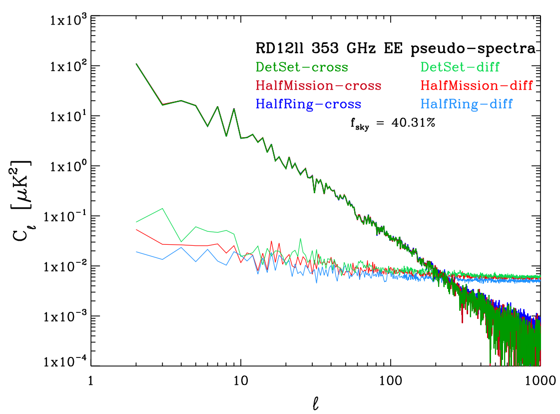
- Low foreground, high noise

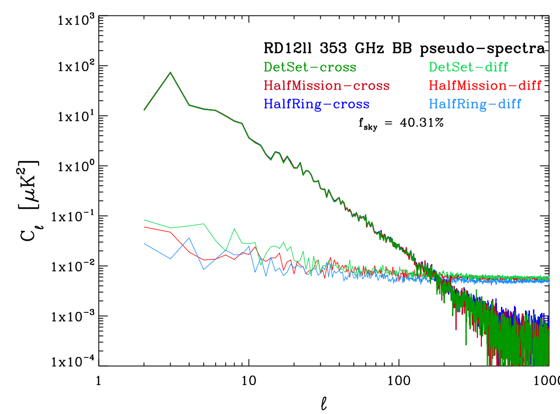






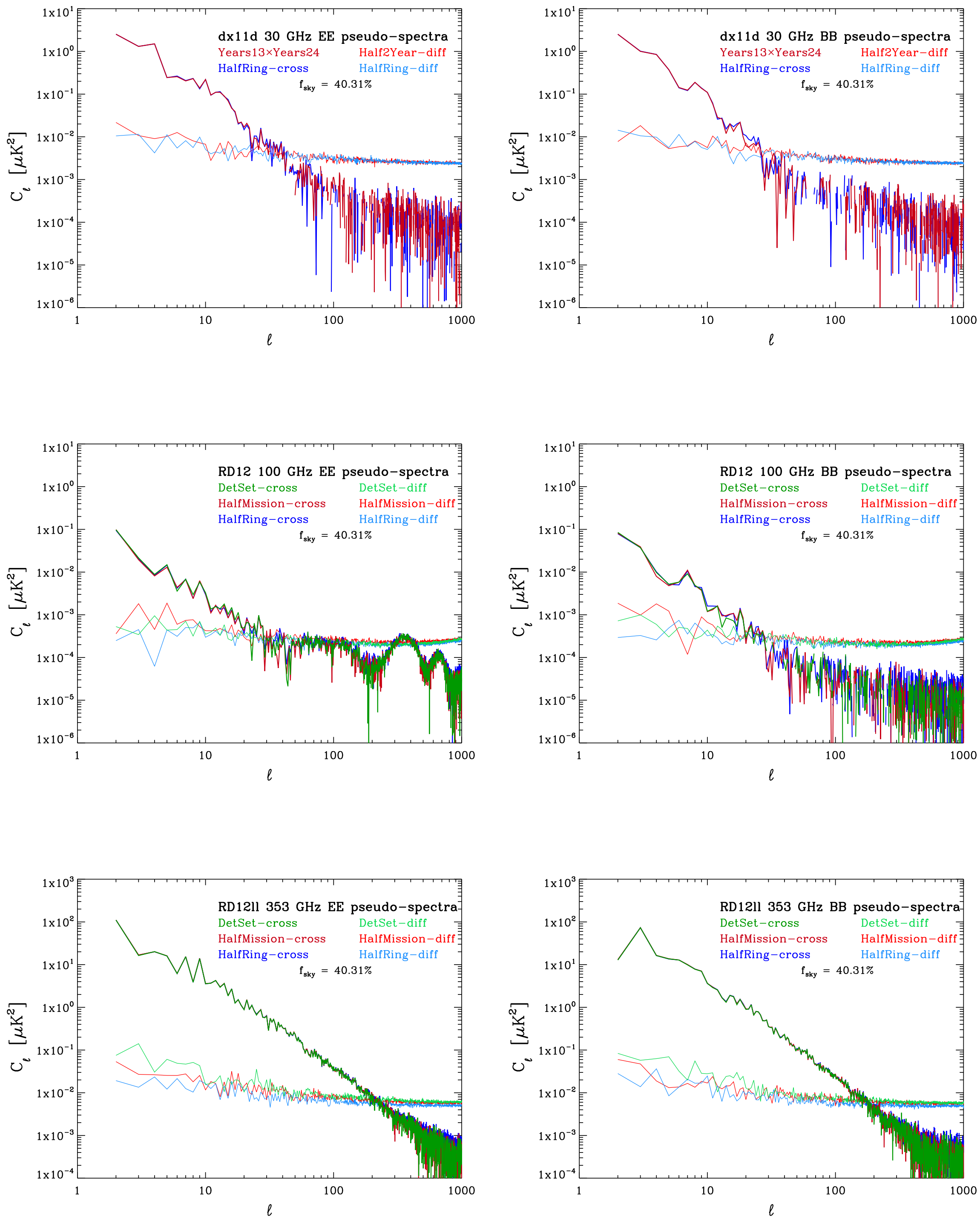






Here – “100 to be cleaned by 30 and 353”

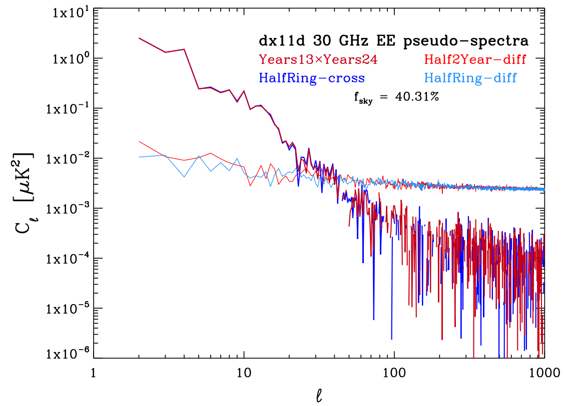
- Higher foreground, lower noise

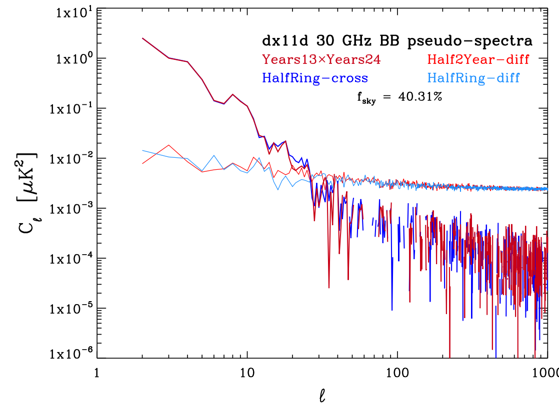


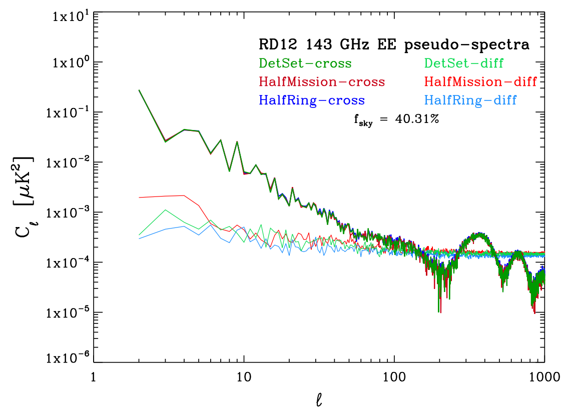
Here – “143 to be cleaned by 30 and 353”

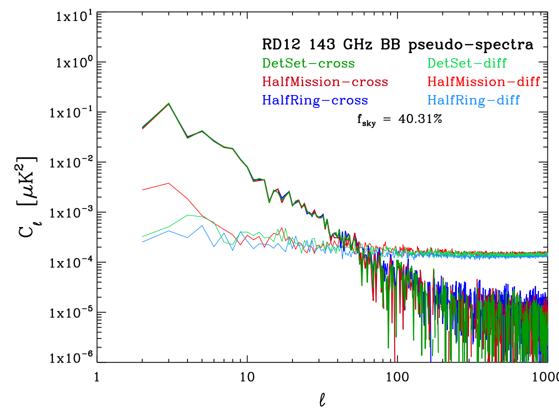
- Still higher foreground, lower noise – the lowest noise level amongst Planck frequency channels

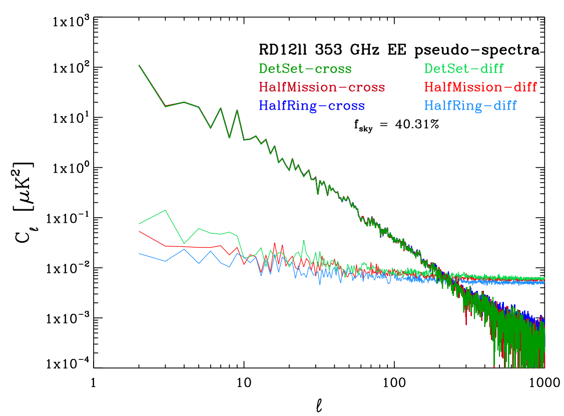
Just as Eichiro remarked correctly during his talk:
(and just in case it went unnoticed ☺)
there’s plenty of B-modes all over the place in these plots …

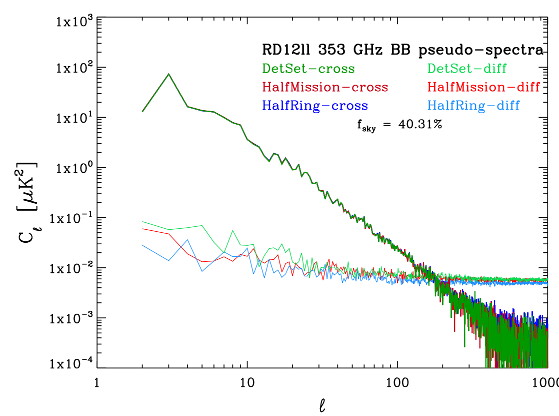












Some discussion questions

- What about other statistics to look for residual foregrounds?
- How should we simulate polarised AME?
- What is missing from current sims? (e.g., decorrelation, spatially varying dust index, silicon/carbon with different pol fraction, magnetic dust, turbulence at small scales)
- What data is it vital to have from space? (and do we want <40 GHz)
- ➔ Is the sensitivity balance right in current LiteBIRD design?
- Should we deal with decorrelation with lots of closely spaced bands?
- What is effective resolution/lmax of LiteBIRD (e.g 40 GHz beam is 80′)

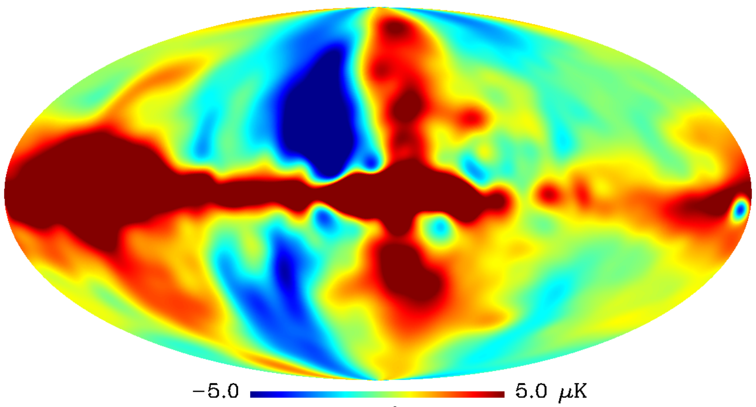
Of Elephants in the Room …

From Jo Dunkley's list: "What data is it vital to have from space? Do we need <40 GHz?"

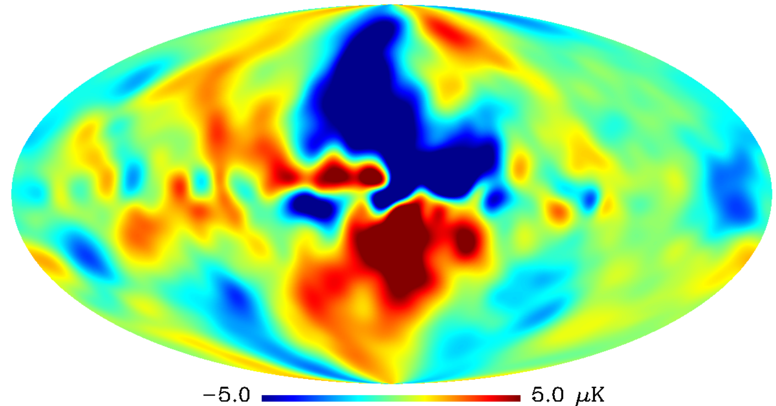
Well, let's take a look.

Comparison of K-band with Ka – FWHM=8deg

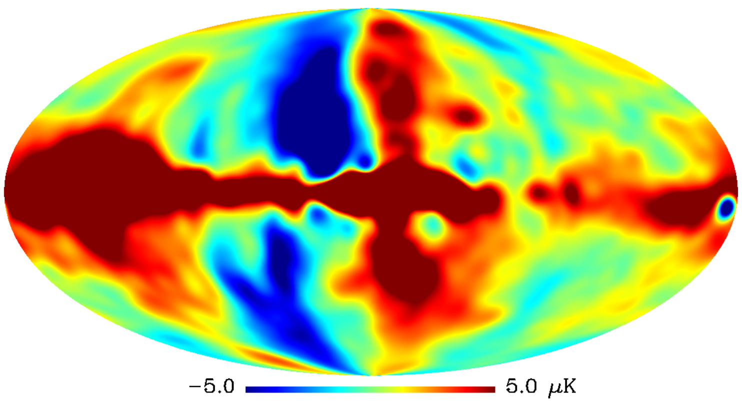
WMAP Q @ K_band ν^{-3}–scaled to Q_band



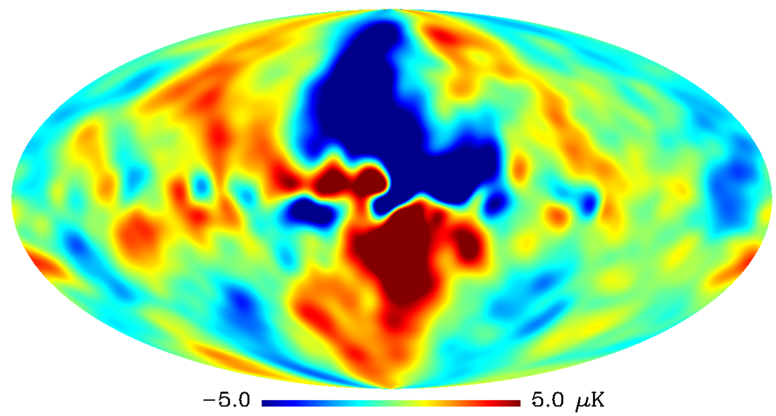
WMAP U @ K_band ν^{-3}–scaled to Q_band



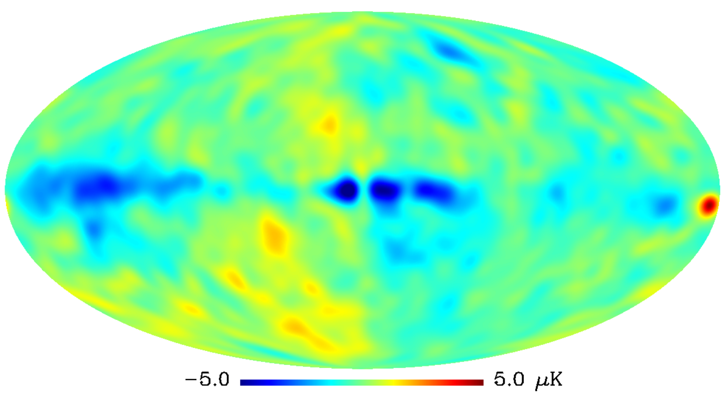
WMAP Q @ Ka_band ν^{-3}–scaled to Q_band



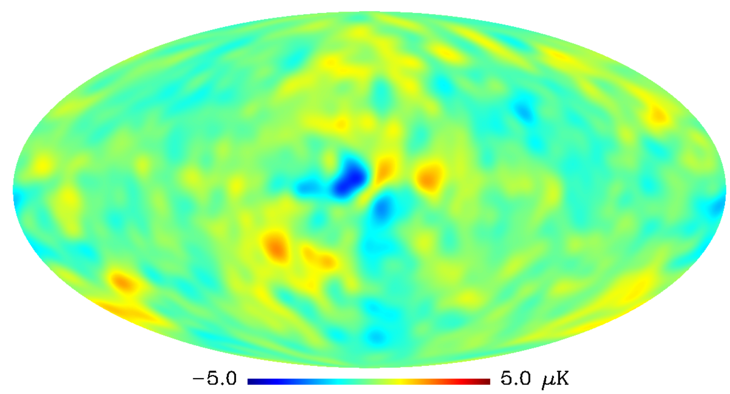
WMAP U @ Ka_band ν^{-3}–scaled to Q_band



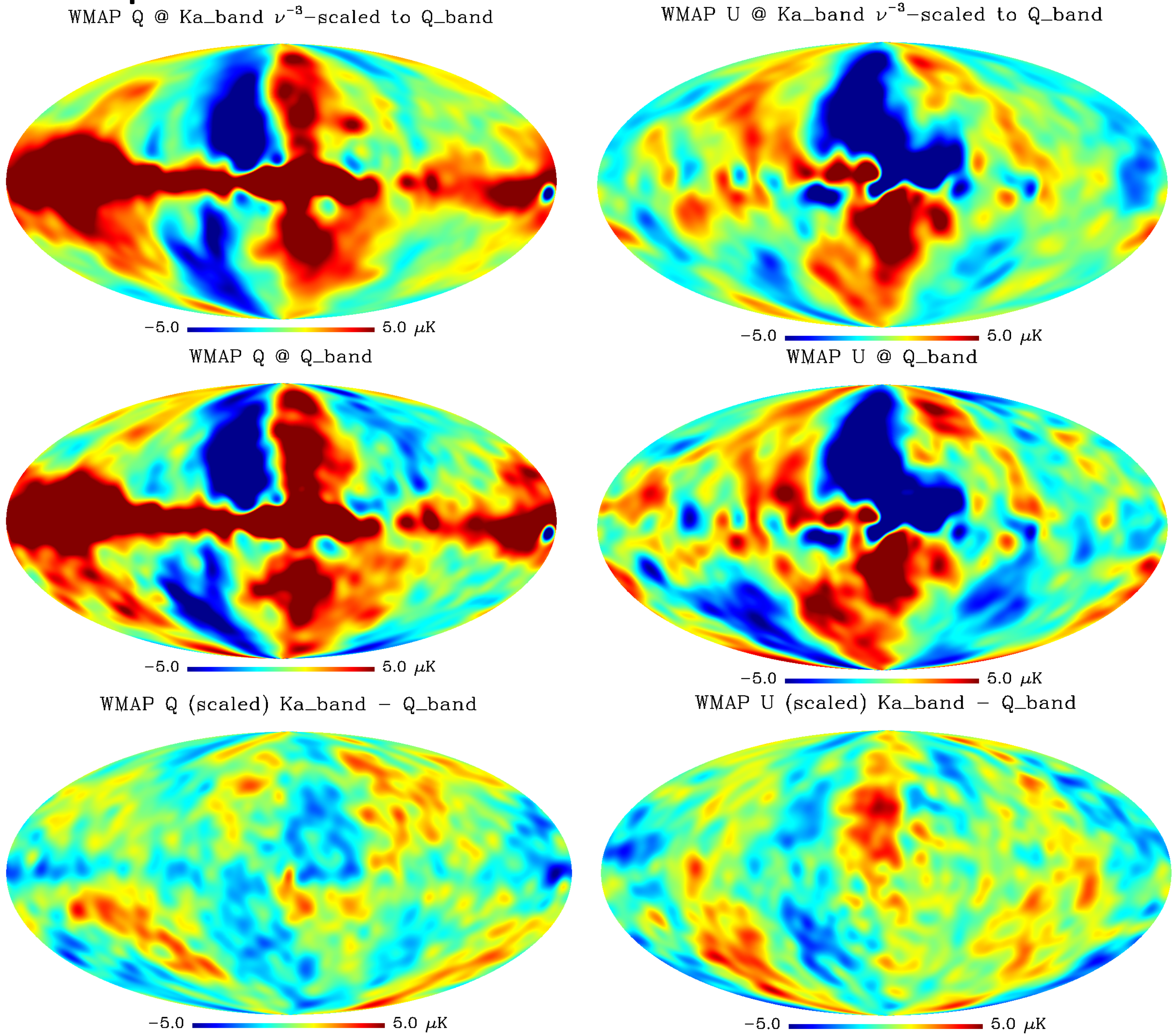
WMAP Q (scaled) K_band − Ka_band



WMAP U (scaled) K_band − Ka_band

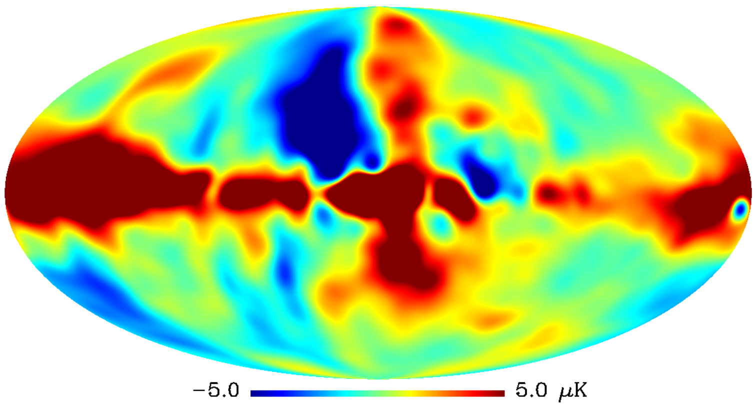


Comparison of Ka-band with Q-band – FWHM=8deg

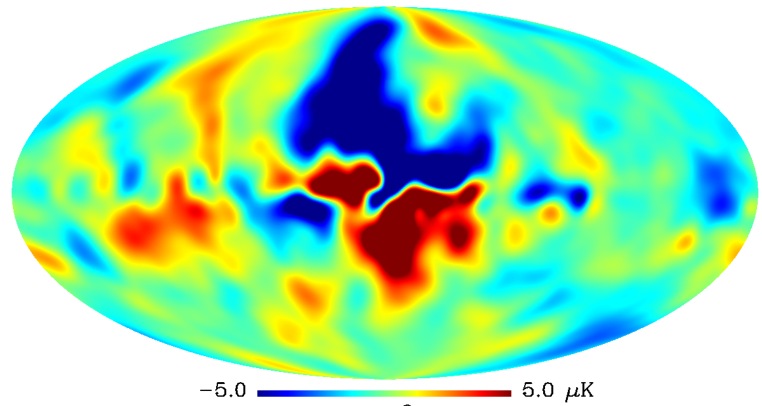


Comparison of 30 GHz with 44 GHz – FWHM=8deg

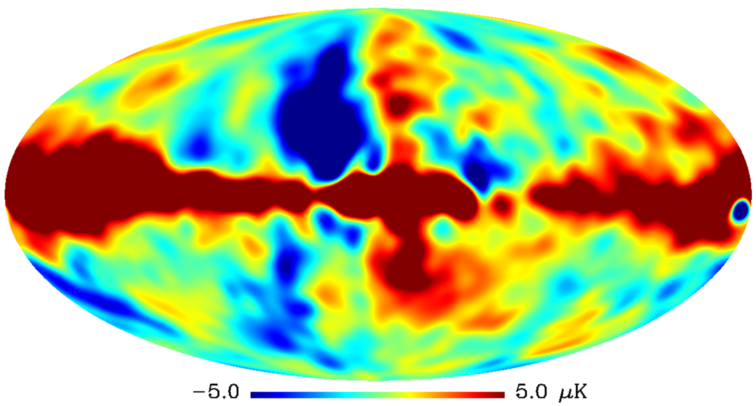
Planck Q @ 30GHz ν^{-3}−scaled to Q_band



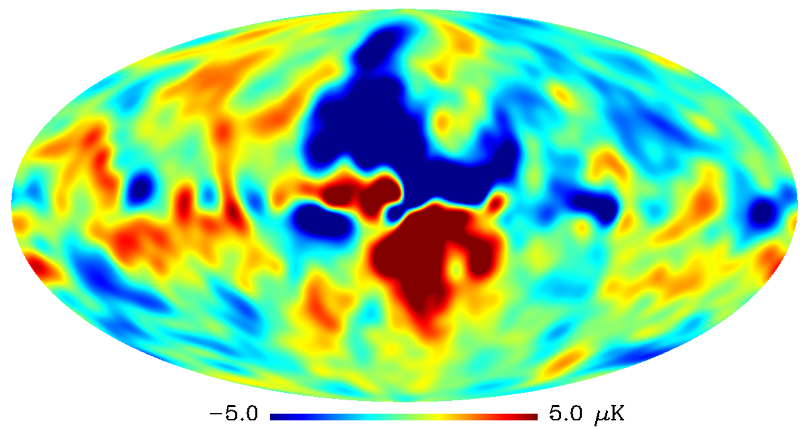
Planck U @ 30GHz ν^{-3}−scaled to Q_band



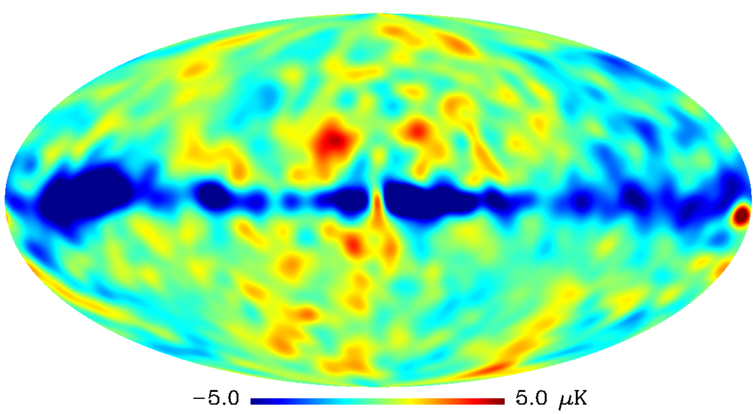
Planck Q @ 44GHz ν^{-3}−scaled to Q_band



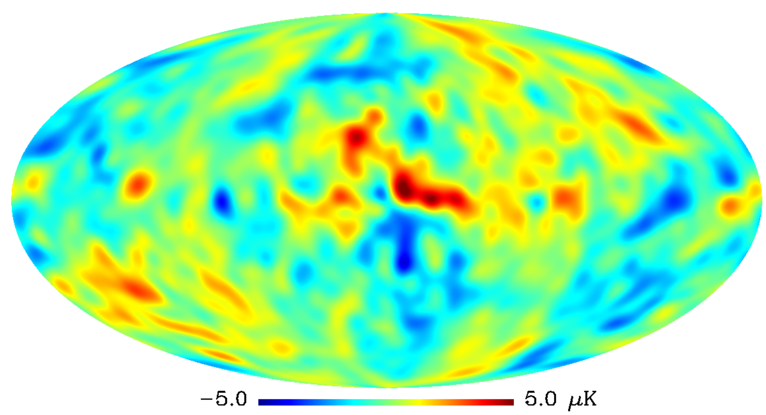
Planck U @ 44GHz ν^{-3}−scaled to Q_band



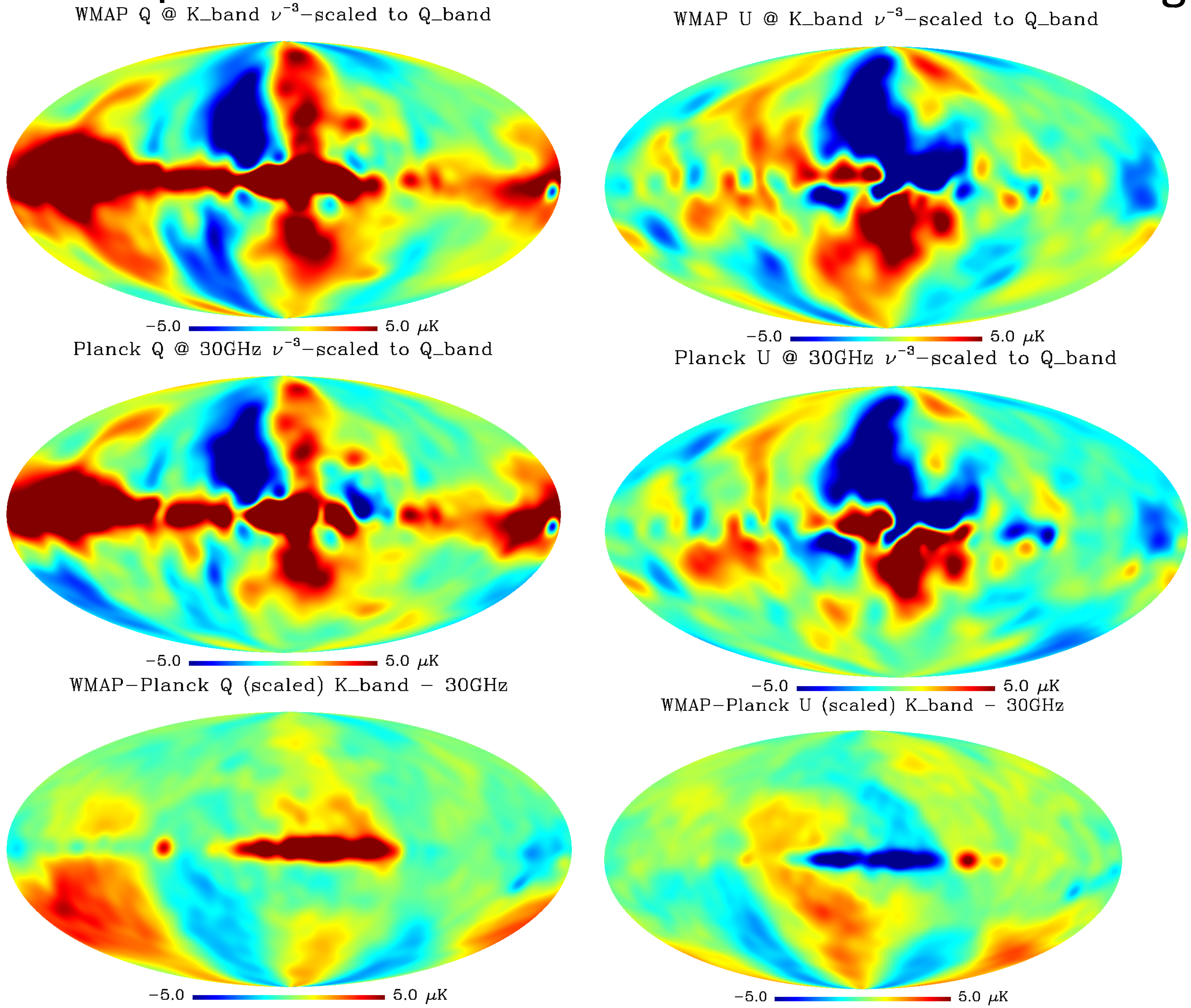
Planck Q (scaled) 30−44



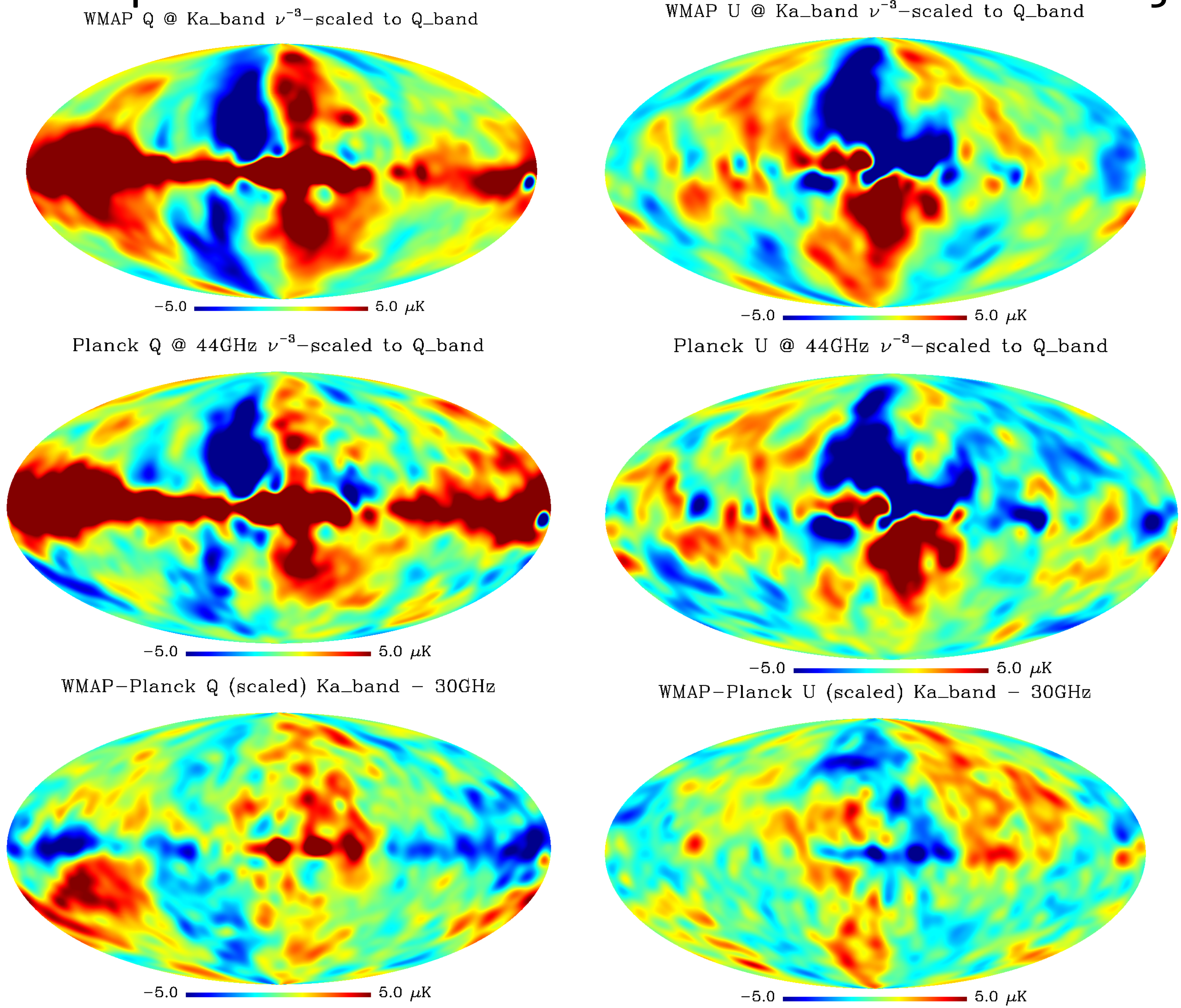
Planck U (scaled) 30−44



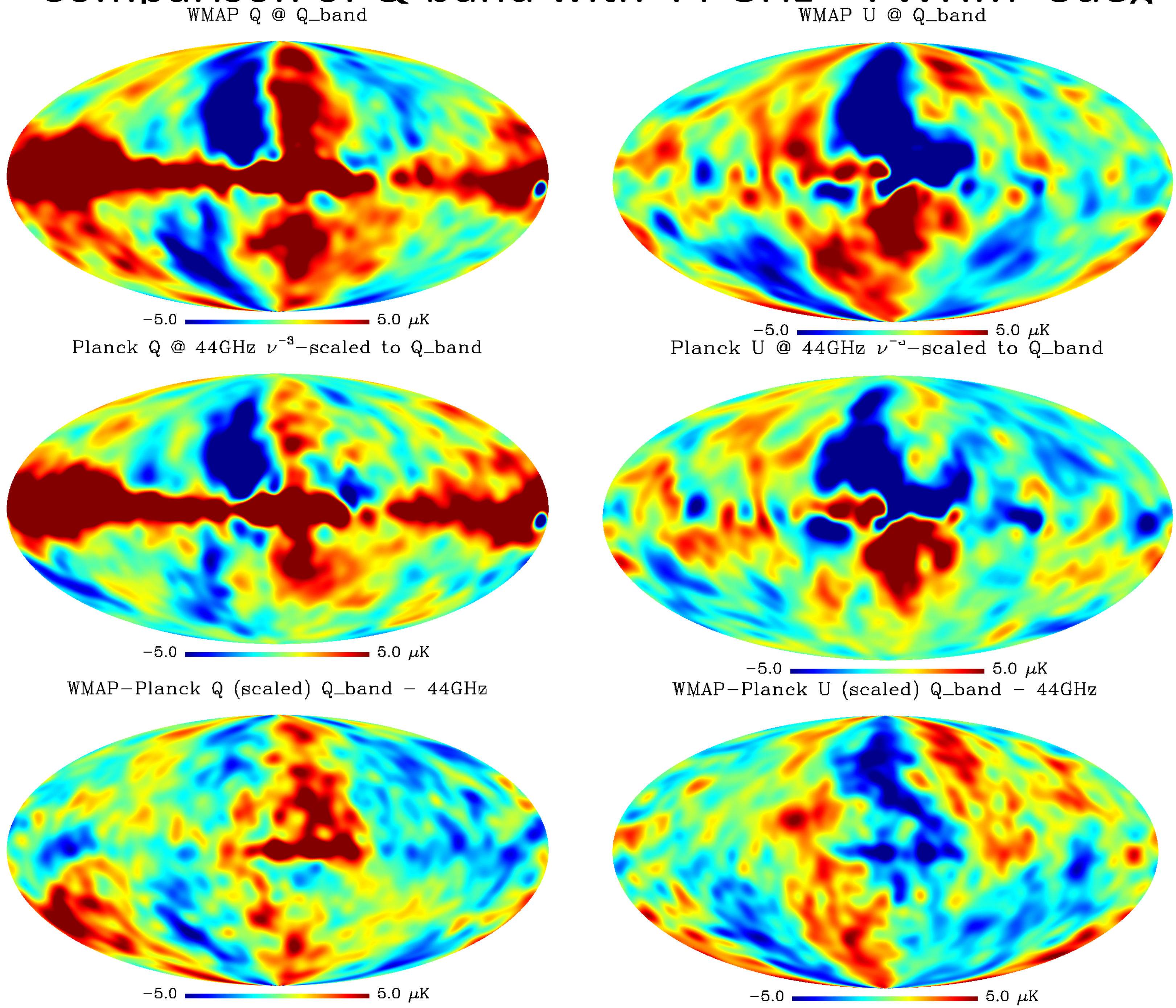
Comparison of K-band with 30 GHz – FWHM=8deg

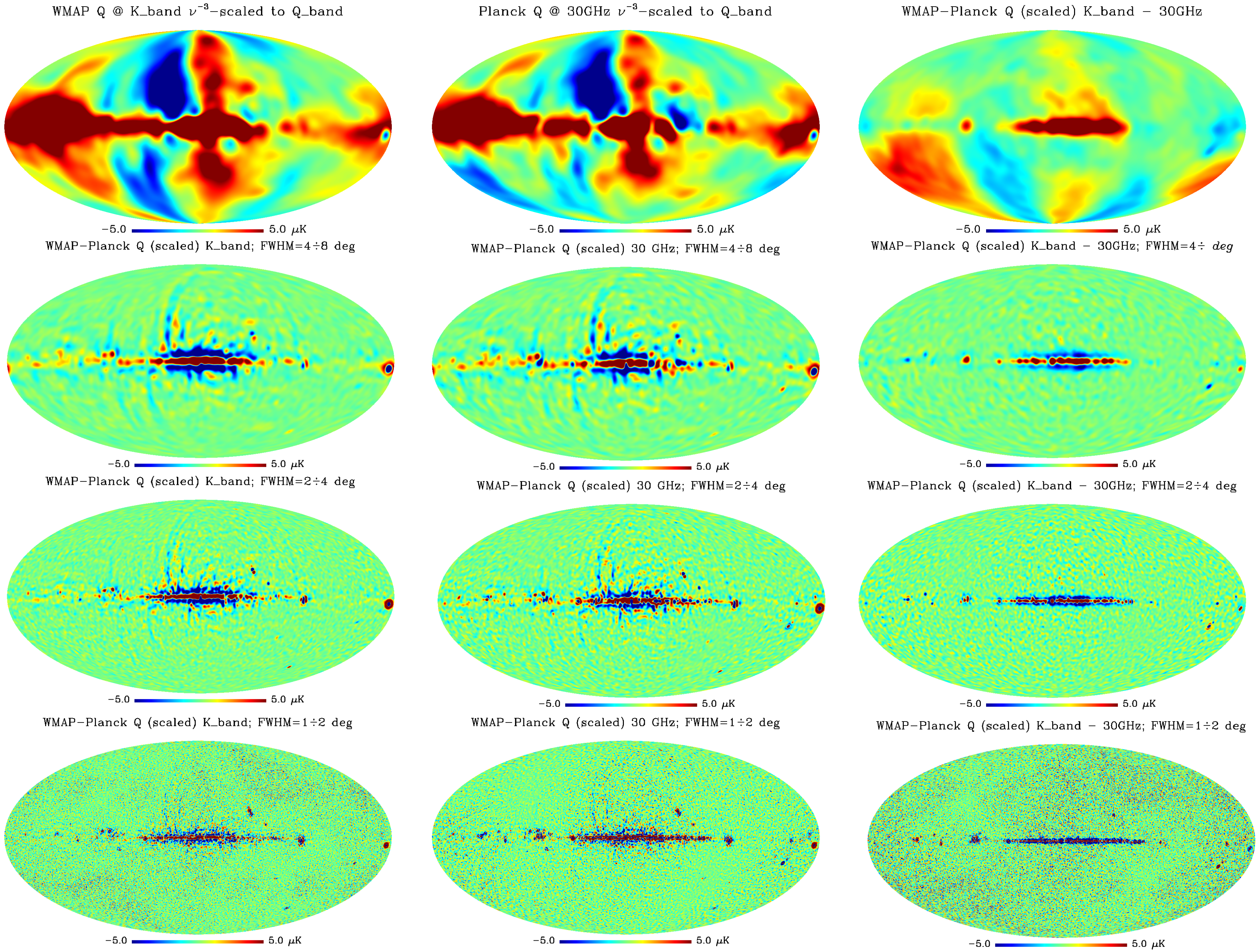


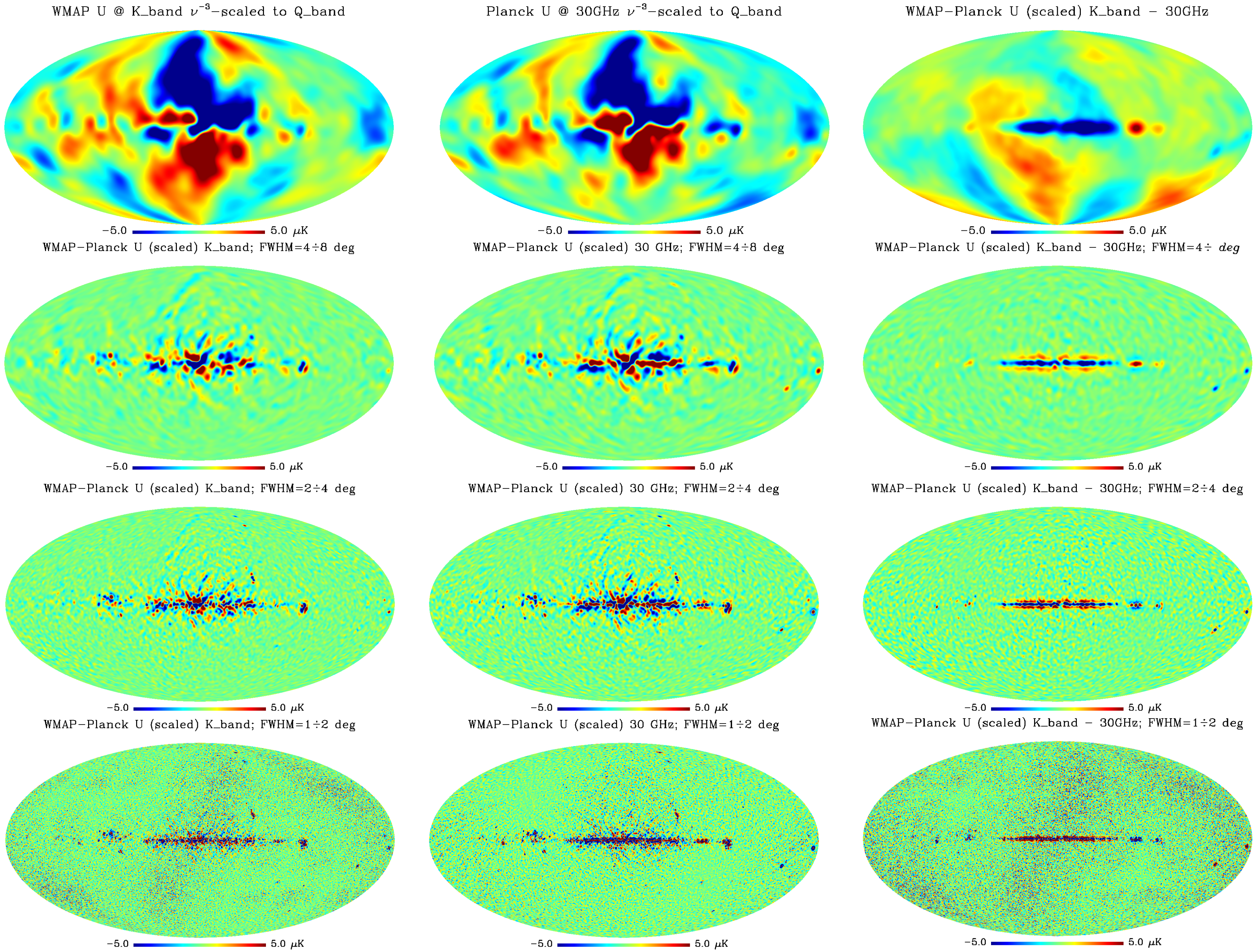
Comparison of Ka-band with 44 GHz – FWHM=8deg



Comparison of Q-band with 44 GHz – FWHM=8deg




WMAP Q @ K_band ν^-3-scaled to Q_band
Planck Q @ 30GHz ν^-3-scaled to Q_band
WMAP−Planck Q (scaled) K_band − 30GHz
−5.0 5.0 μK
WMAP−Planck Q (scaled) K_band; FWHM=4÷8 deg
WMAP−Planck Q (scaled) 30 GHz; FWHM=4÷8 deg
WMAP−Planck Q (scaled) K_band − 30GHz; FWHM=4÷ deg
WMAP−Planck Q (scaled) K_band; FWHM=2÷4 deg
WMAP−Planck Q (scaled) 30 GHz; FWHM=2÷4 deg
WMAP−Planck Q (scaled) K_band − 30GHz; FWHM=2÷4 deg
WMAP−Planck Q (scaled) K_band; FWHM=1÷2 deg
WMAP−Planck Q (scaled) 30 GHz; FWHM=1÷2 deg
WMAP−Planck Q (scaled) K_band − 30GHz; FWHM=1÷2 deg

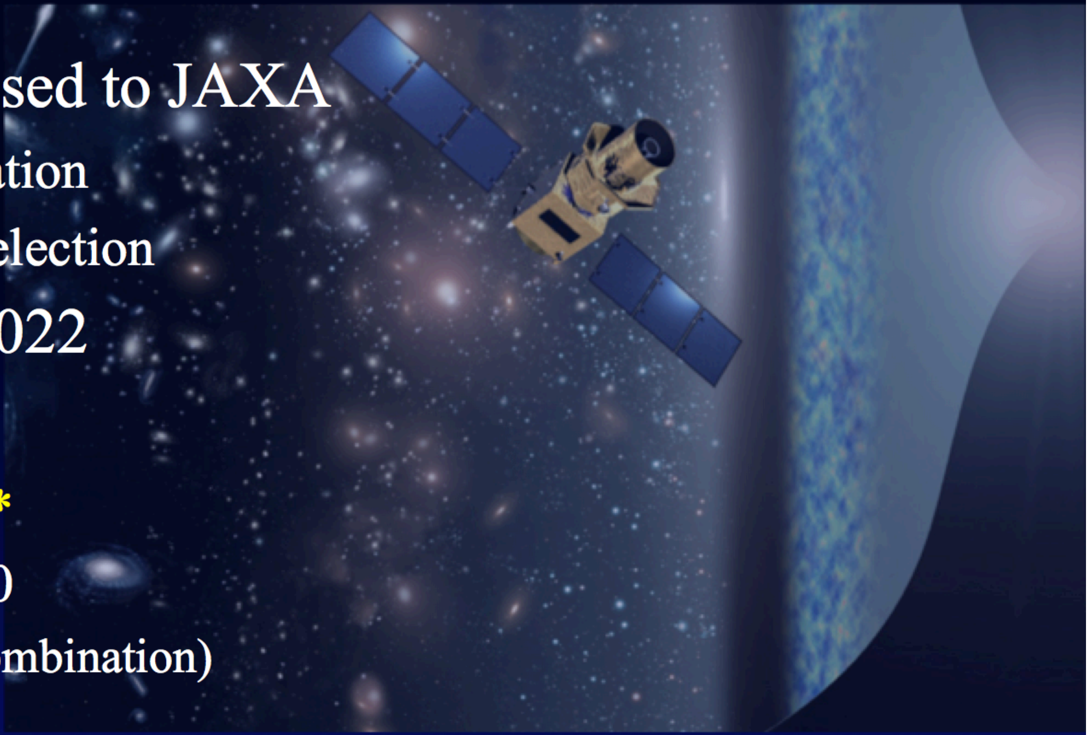

WMAP U @ K_band ν^{-3}-scaled to Q_band
Planck U @ 30GHz ν^{-3}-scaled to Q_band
WMAP-Planck U (scaled) K_band - 30GHz
WMAP-Planck U (scaled) K_band; FWHM=4÷8 deg
WMAP-Planck U (scaled) 30 GHz; FWHM=4÷8 deg
WMAP-Planck U (scaled) K_band - 30GHz; FWHM=4÷ deg
WMAP-Planck U (scaled) K_band; FWHM=2÷4 deg
WMAP-Planck U (scaled) 30 GHz; FWHM=2÷4 deg
WMAP-Planck U (scaled) K_band - 30GHz; FWHM=2÷4 deg
WMAP-Planck U (scaled) K_band; FWHM=1÷2 deg
WMAP-Planck U (scaled) 30 GHz; FWHM=1÷2 deg
WMAP-Planck U (scaled) K_band - 30GHz; FWHM=1÷2 deg
-5.0
5.0 μK

So?

- **In general, low-frequency range is seriously "under-measured" compared to the (presently) bolometric frequency-range, especially viz. the demanding measurement fidelity requirements characteristic of the inflationary B-mode targets**
- **Should this be rectified?**
  - Yes,
  - Yes, because all l<20 very large angular scale work, including on E-mode, is affected
  - If possible, definitely yes, as for r<0.005 (?) synchrotron residuals cannot be neglected at >110 GHz (?) (you cannot veto synchrotron just because you don't like it ☺ …)
- **How would it be done?**
  - Arbitration between the results of two space missions seems required
  - CAN THIS BE DONE FROM THE GROUND?
    - That would be cheaper than from space (somebody would still have to pay for it, and do it), but
      - It better be identified by the community as a goal QUICKLY, and acted on
      - BUT – can one ever achieve requisite fidelity of such measurements on full sky to be useful in the inflationary B-mode work?
        - » IMHO – this is very doubtful (serious community discussion is necessary)
  - **Inclusion of lower frequency (<40GHz) channel(s) in LiteBIRD instrument concept would be very valuable, and would close the very real potential liability of having to rely on auxilliary, most likely sub-par data, rather than fully autonomous measurements (angular resolution of lesser concern as issues in available data are mostly at the very largest scales)**

LiteBIRD Overview

Lite (Light) Satellite for the Studies of **B**-mode Polarization and **I**nflation from Cosmic Background **R**adiation **D**etection



- CMB B-mode satellite proposed to JAXA
  - Also to NASA for US participation
  - Both proposals passed initial selection
- Proposed launch year: JFY 2022
- Requirements
  - Total uncertainty on r < 0.001*
  - Multipole coverage: $2 \leq \ell \leq 200$
    - Each bump (reionization, recombination) with >5sigma if $r > 0.01$
- Orbit: L2
- Observing time: 3 years

*Our current studies yield $\sigma(r) = 2 \times 10^{-4}$ (for $r=0$) for 3 year observation