The QUIJOTE experiment: status and first views on radiosources with the Multifrequency Instrument

Marcos López-Caniego
for the QUIJOTE collaboration

Rencontres du Vietnam 2013: Cosmology in the Planck Era

Talk outline

- Project overview
  - Scientific objectives
  - Time baseline
- Instrumentation
  - Telescopes (QT1 and QT2)
  - Instruments (MFI, FGI, TGI)
- Science
  - MFI science (foregrounds, AME, synchrotron,...)
  - TGI science (B-modes)
- Observations
  - Calibration
  - Perseus complex
  - Wide survey

The QUIJOTE collaboration

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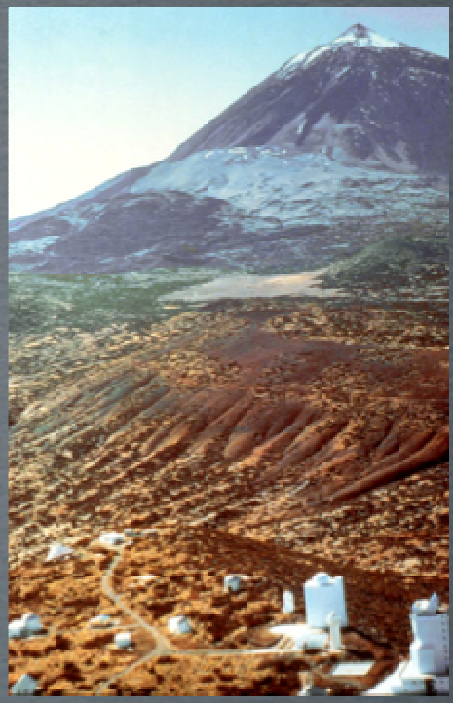
Goals:

- To obtain six polarization maps in the frequency range 10-40 GHz with sufficient sensitivity to correct foreground emission (synchrotron and AME) and constrain the imprint of B-modes down to r=0.05



- **Site:** Teide Observatory (altitude: 2400 m, latitude: 28º), Spain
- **Observability:** -32º<Dec.<88º (f_{sky} ~0.65)
- **Frequencies:** 11,13, 17, 19, 30 and 40 GHz
- **Angular resolution:** 1 degree (52 arcmin @ 11 GHz)

Telescope and instruments:

- Phase I:
  - First Telescope (QT1)
  - Equiped with a Multifrequency Instrument (MFI) with 4 polarimeters @ 10-20 GHz. Started operations Nov. 2012
  - Second Instrument (TGI) with 31 polarimeters @ 30 GHz. Funded; to start operations at the beginning of 2014
  - Polarized Source Subtractor (undergoing commissioning)
- Phase II:
  - Second Telescope (QT2). Under construction (beginning of 2014)
  - FGI with 40 polarimeters @ 40 GHz. Funded (mid 2014)

- **Scientific operation plan:** 2012-2018

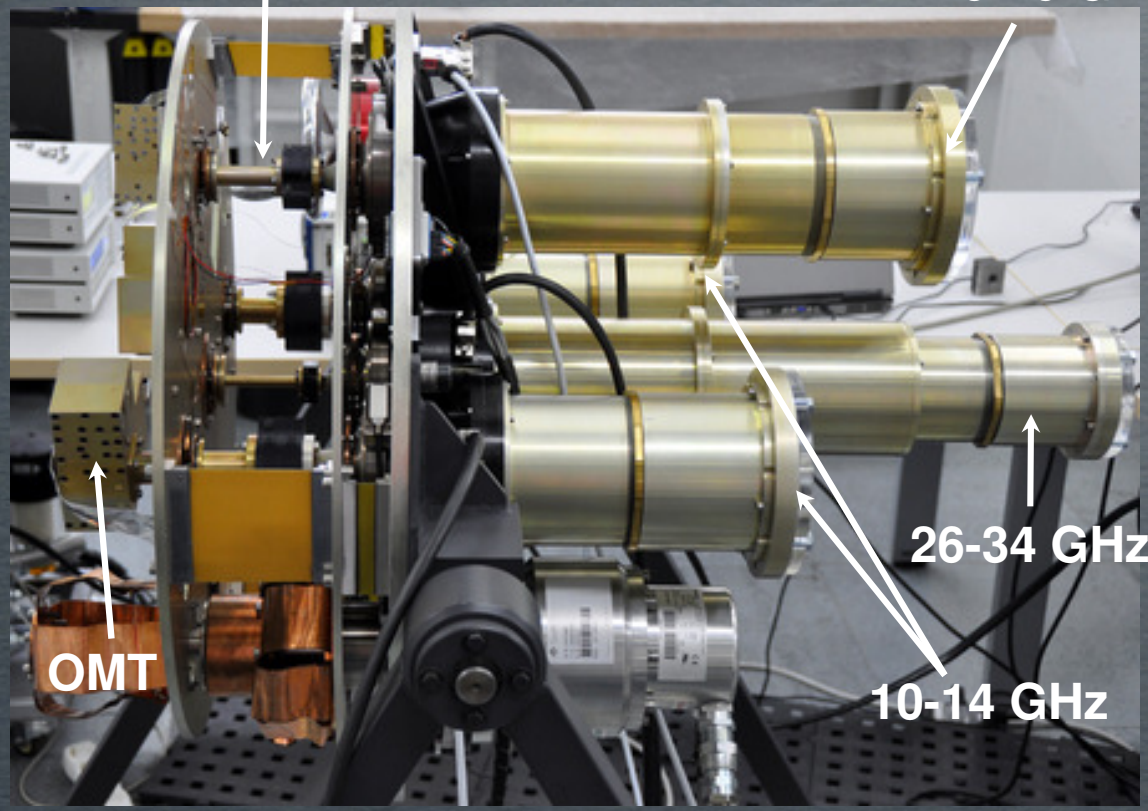
QUIJOTE telescope 1 (QT1)

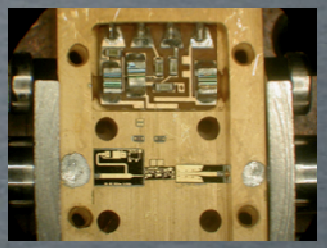
- Alt-azimuth mount
- Maximum rotation speed around AZ axis: 0.25 Hz
- Maximum zenith angle: 60º
- Cross-Dragonian design
- Aperture: 3 m (primary) and 2.6 m (secondary)
- Maximum frequency: 90 GHz (rms ≤20 μm and max deviation =100 μm)

- QT1 installed at the Teide observatory in May 3rd, 2012
- QT2 is a replica of QT1. Under construction

Multifrequency Instrument (MFI)

- 4 conical corrugated horns (2 at 10-14 GHz and 2 at 16-20 GHz)
- Polar modulator spinning at speeds up to 40 Hz
- Wide-band cryogenic Ortho-Mode-Transducer (OMT)
- MMIC 6-20 GHz Low Noise Amplifiers. Gain: 30dB
- Noise temperature: ~7-10 K (10-14 GHz), ~10-20 K (16-20 GHz)

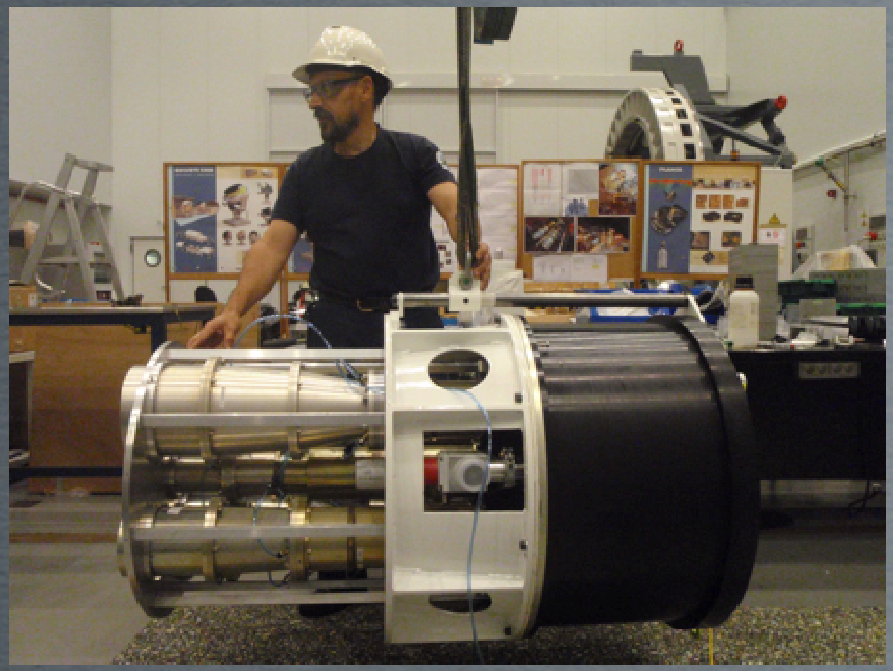


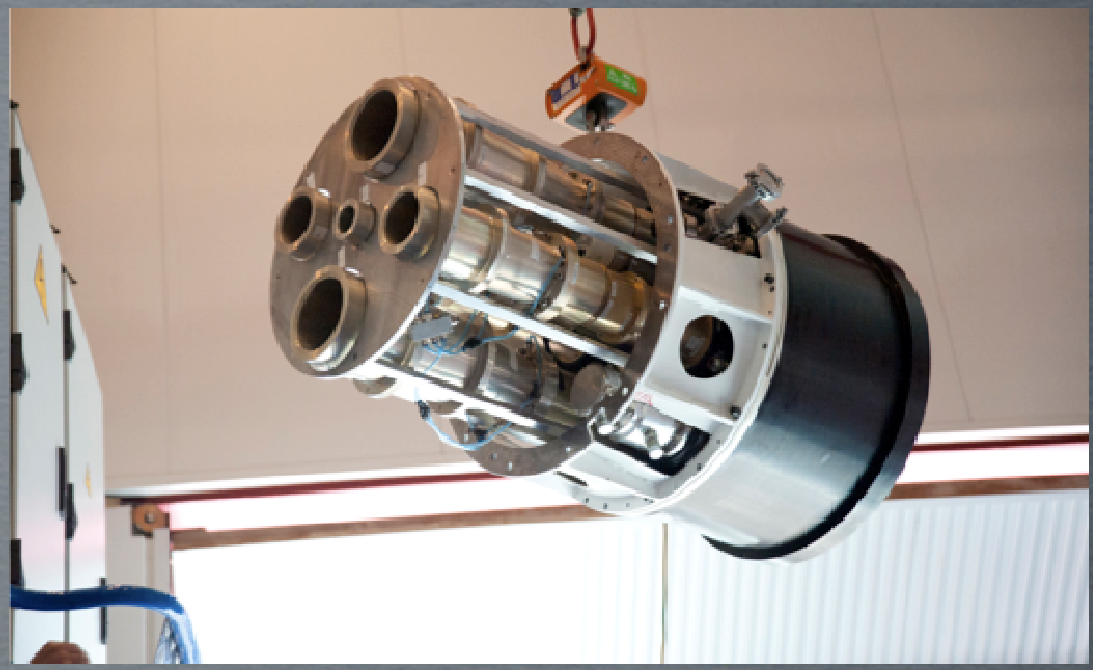


LNA

OMT and motor

Horns





- MFI integration tests on the QT1 at the AIV room. March 2012
- Currently on scientific operation (since Nov. 2013)

Polarized Source Subtractor

- Dedicated instrument at 30 GHz. VSA Source Subtractor converted to a polarimeter
- Installed a dielectrically embedded mesh-HWP
- Twofold subtraction strategy:

  - NVSS-GB6 extrapolation. ~300 sources with Stokes-I flux > 300 mJy at 30 GHz. Flux sensitivity per source ~2-3 mJy in ~100 days

  - Identify sources in the low-frequency channels by MHW filters (L-C et al. 2009)

- Interferometer of two 3.7m antennae with a 9m baseline
- Primary beam: 9’
- Synthesized beam: 4’
- Dec. range: $-5^{\circ}<\delta<+60^{\circ}$

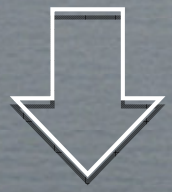
❖ Sensitivities:

	MFI				TGI	FGI
Frequency (GHz)	11	13	17	19	30	40
Bandwidth (GHz)	2	2	2	2	8	10
Number of horns	2		2		31	40
Channels per horn	2	2	2	2	4	4
Beam FWHM (deg)	0.92	0.92	0.60	0.60	0.37	0.28
T_{sys} (K)	25	25	25	25	35	45
NEP per channel (μK $s^{1/2}$)	456	370	663	1019	557	632
Sensitivity per channel (Jy $s^{1/2}$)	0.49	0.55	0.73	1.40	0.66	0.76

- Measured sensitivities for the MFI
- Nominal sensitivities for the TGI and FGI

❖ Main goals of QUIJOTE-CMB:

- To detect the imprint of the gravitational B-modes if $r \geq 0.05$
- To provide essential information of the polarization of the synchrotron and of the AME from our galaxy at low frequencies (10-40 GHz)



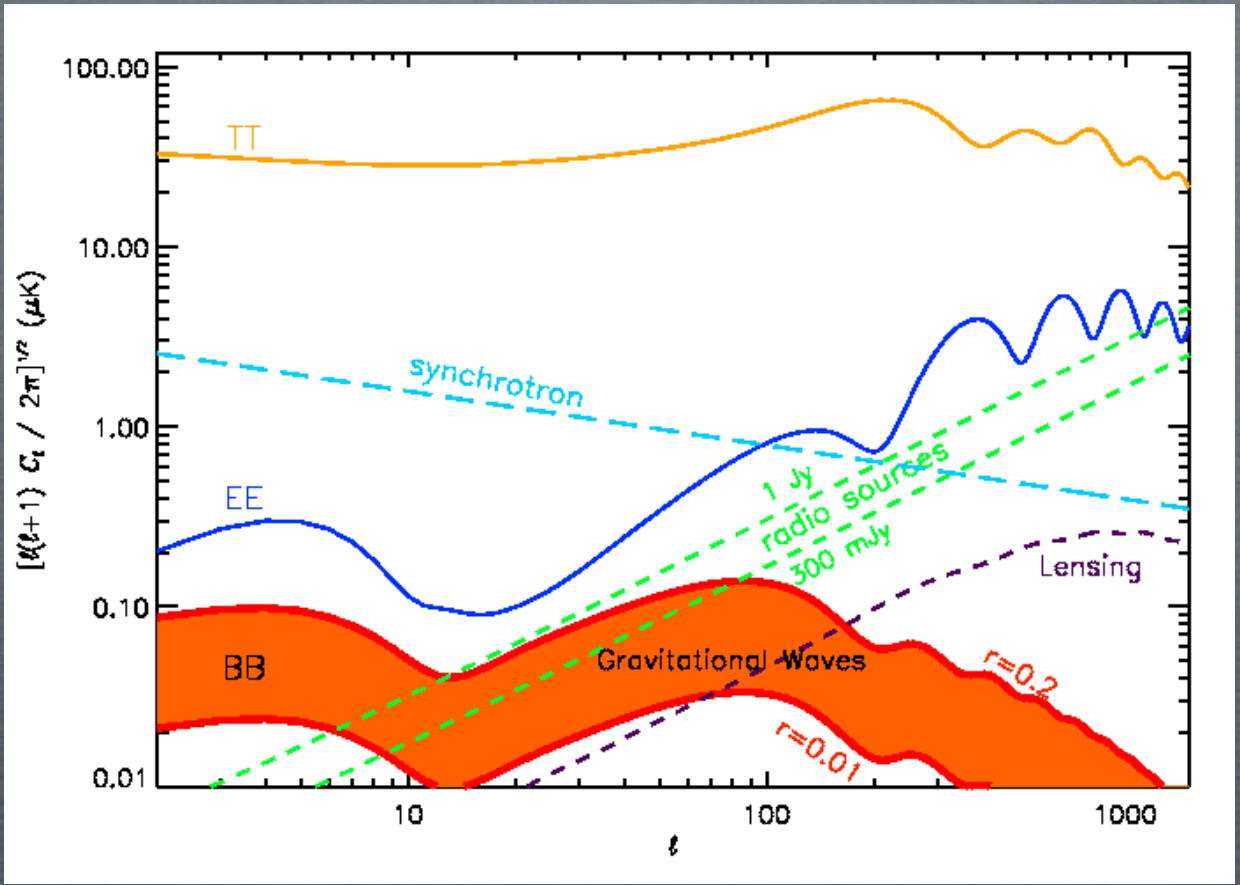
❖ Two large surveys in polarization

- **Wide Galactic survey.** It will cover 20,000 deg^2, and will be finished after 3 months of observations with each instrument (half-way through with the MFI). Expected sensitivities:
  - $\approx$ 14 μK/(beam 1º) with the MFI @ 11, 13, 17 and 19 GHz, in both Q and U
  - $\leq$ 3 μK/(beam 1º) with the TGI @ 30 GHz and with the FGI @ 40 GHz

- **Deep cosmological survey.** It will cover around 3,000 deg^2. Expected sensitivities after 1 year:
  - $\approx$ 5 μK/(beam 1º) with the MFI @ 11, 13, 17 and 19 GHz
  - $\leq$ 1 μK/(beam 1º) with the TGI @ 30 GHz and with the FGI @ 40 GHz

Science with the MFI

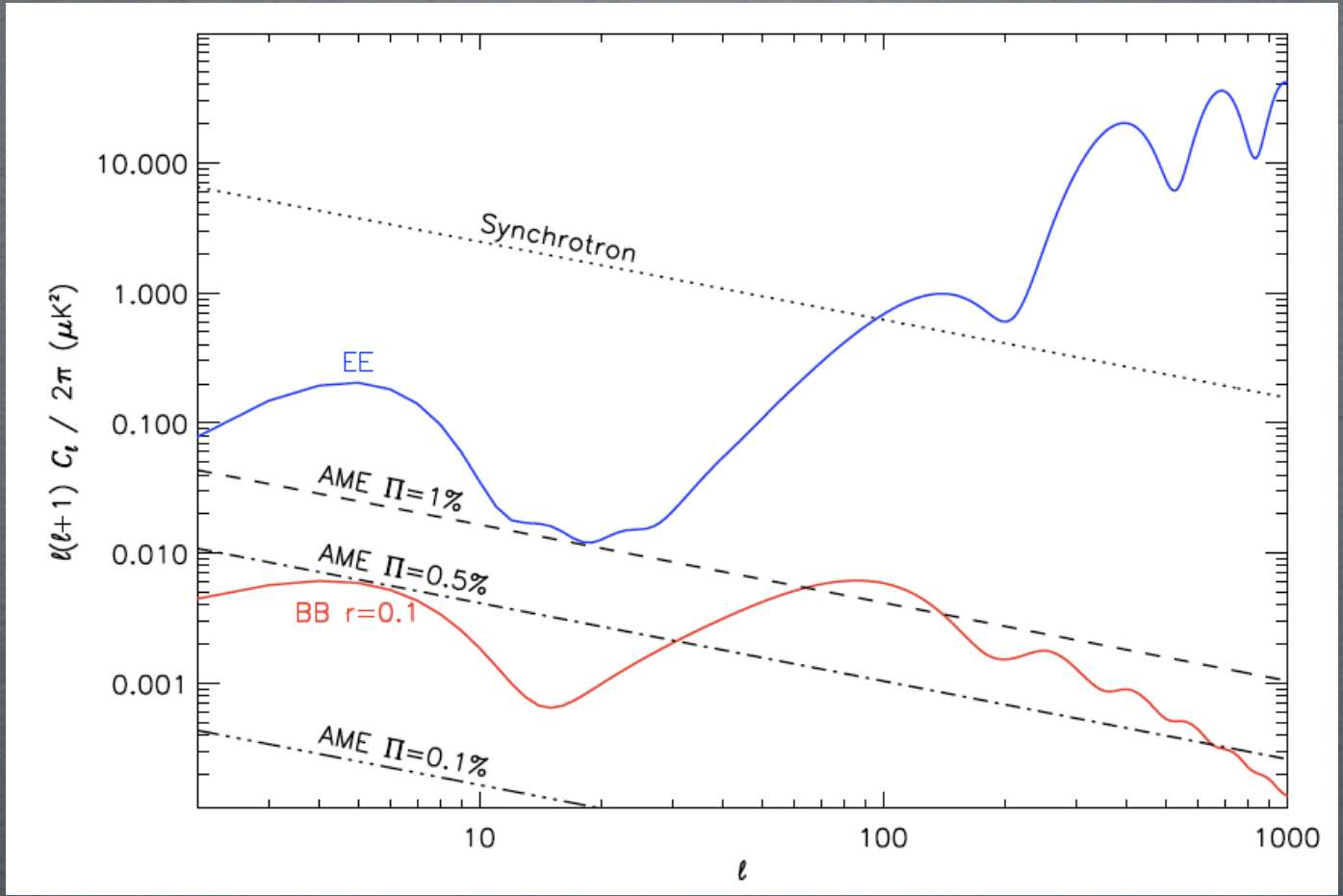
- Contamination introduced by synchrotron at 30 GHz:
  - MFI deep survey maps used to determine the synchrotron spectrum at 10-20 GHz
  - Extrapolation to higher frequencies. Pixel-by-pixel correction of the TGI and FGI maps



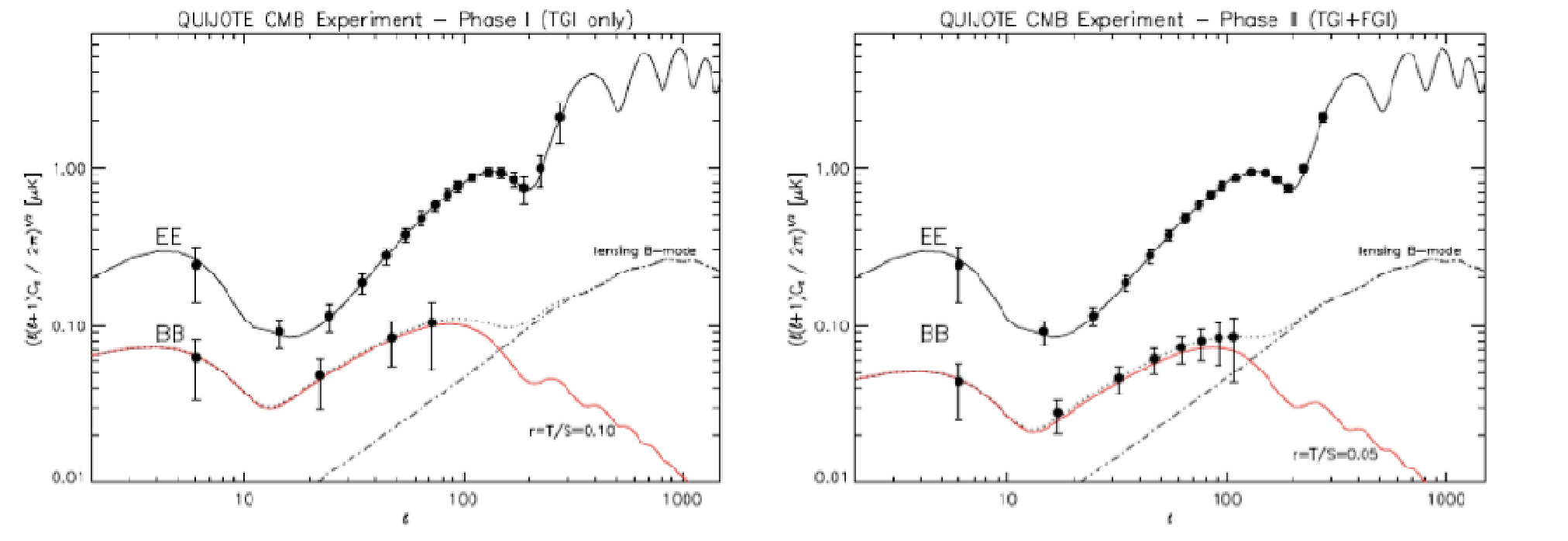
- The residual synchrotron will have a contribution to the total noise less than one order of magnitude with respect to the thermal noise of the TGI maps after 1 year

Science with the MFI

- Contamination introduced by AME at 30 GHz:



Science with the TGI and FGI

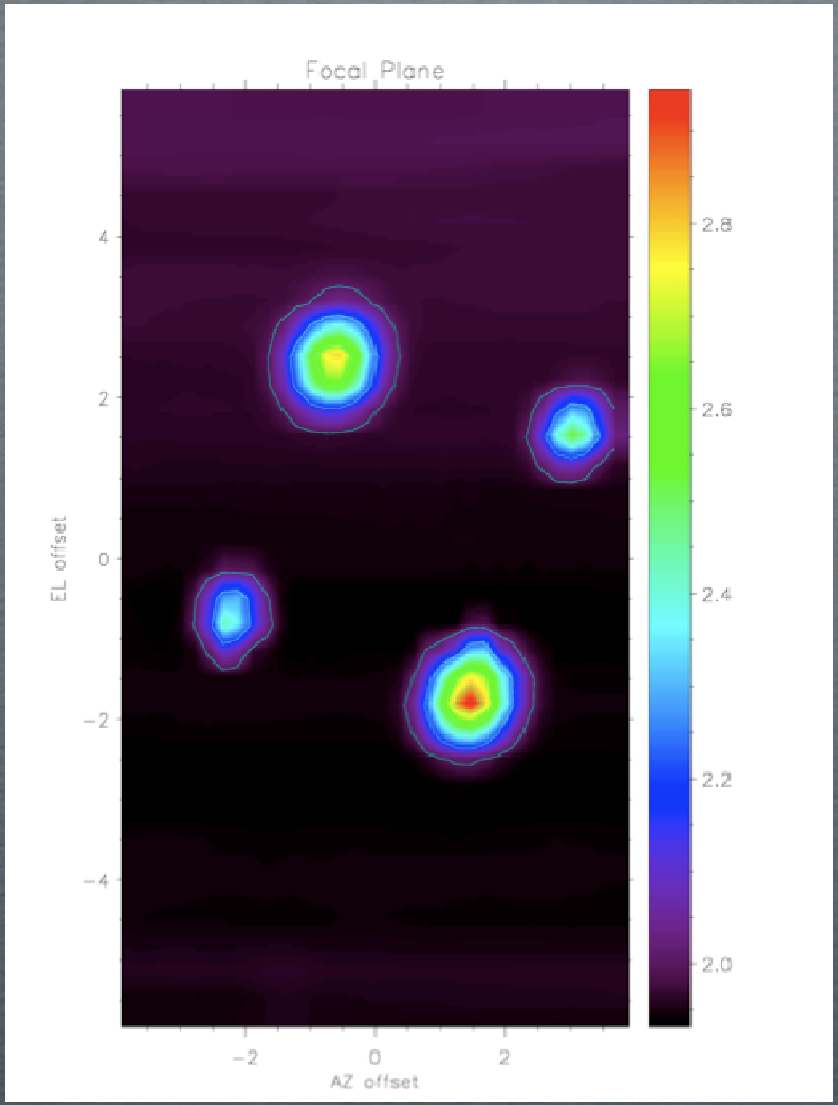


1 year effective time with the TGI over 3,000 deg^2

3 years effective time with the TGI and 2 years with the FGI over 3,000 deg^2

Observations

- Quijote focal plane using observations of the Moon



Calibrators

- Crab - used as calibrator

  <Q/I> = 5.79±0.2 %

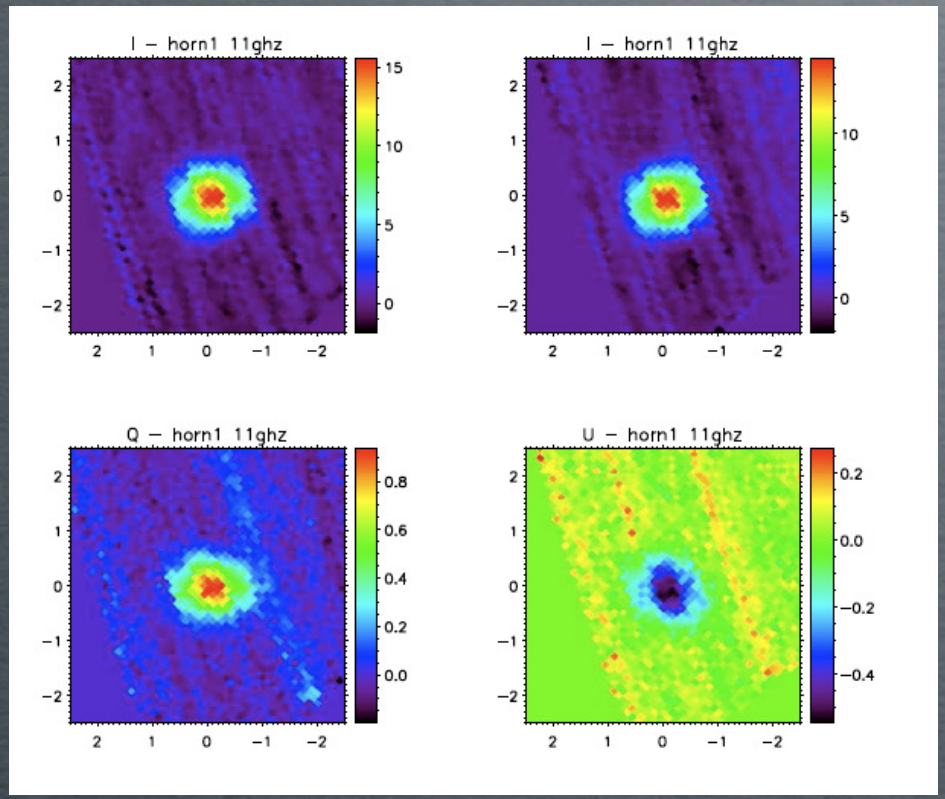
  <U/I> = -3.60±0.4 %

  <P/I> = 6.8±0.8 % at 11 GHz

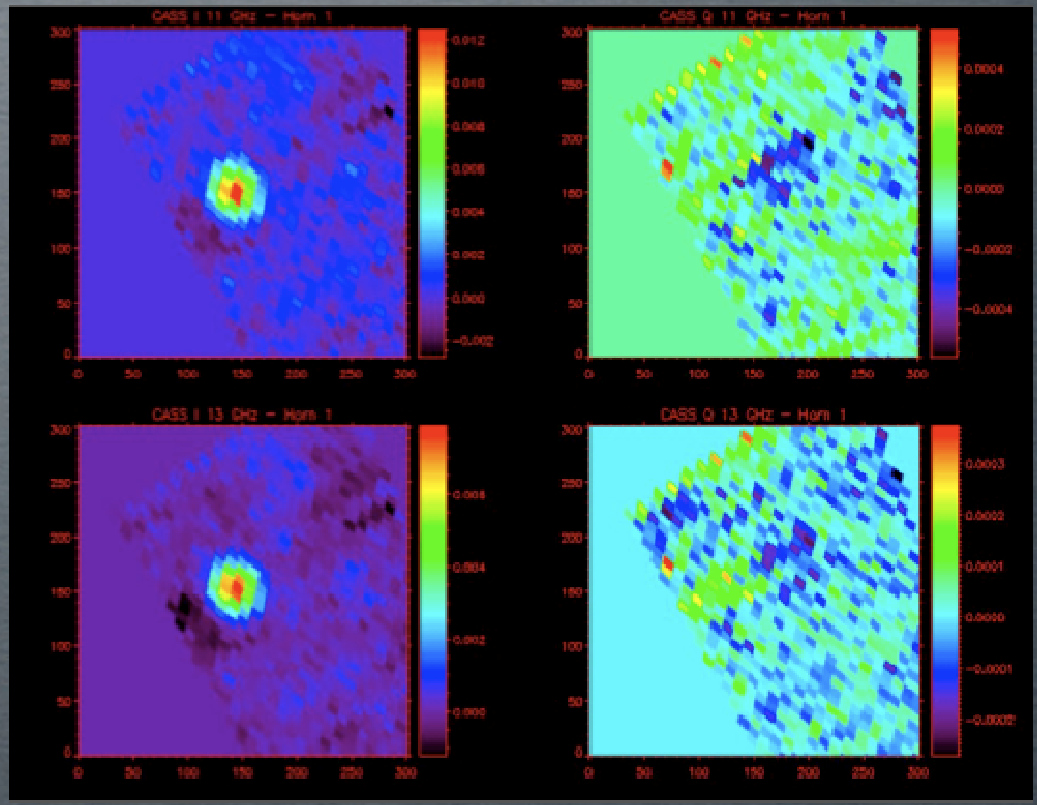
Consistent w, WMAP 23 GHz, 7.08 ± 0.25%

- Cas-A - null polarization calibrator to adjust the gain mismatch between pairs of channels

I P



Crab observation (30 s on source)



Cas A observation (30 s on source)

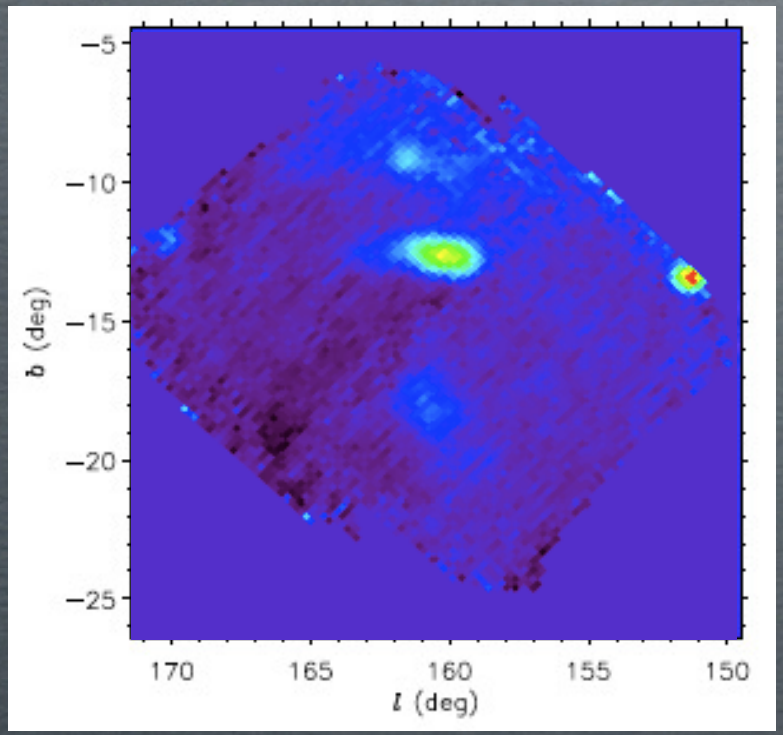
Perseus molecular complex

★ Large observation programme (~132 hours, 12/2012 to 04/2013), on an area covering ~200 deg^2 around the Perseus molecular complex. One of the brightest AME regions on the sky (Watson et al. 2005, Planck collaboration 2011)

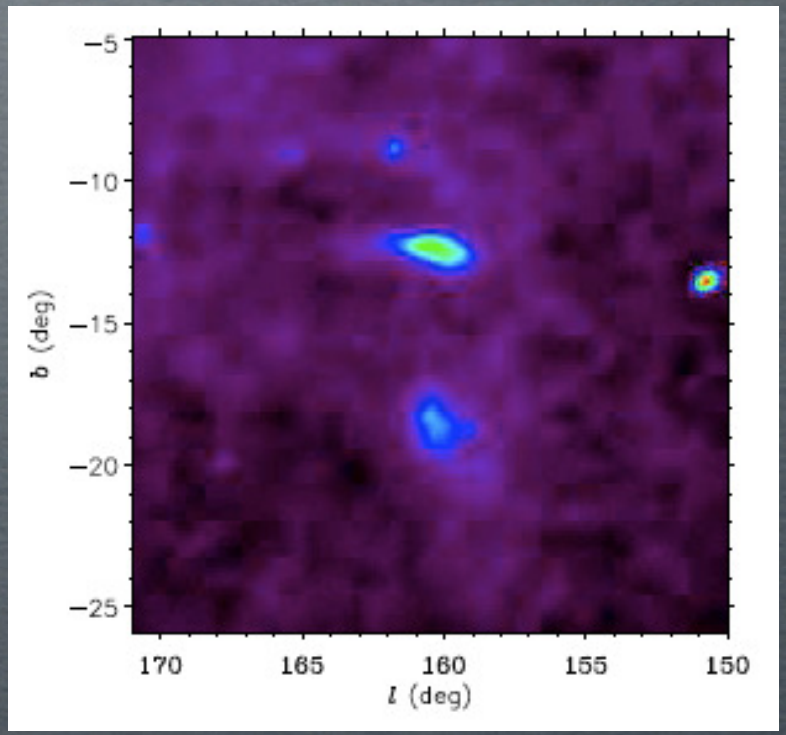
★ Also covering the California nebula (HII region - null polarization control region)

★ Final integration time of ~ 3300 s/beam, yielding a sensitivity of ~ 30 mJy/beam in Q and U

QUIJOTE 11 GHz

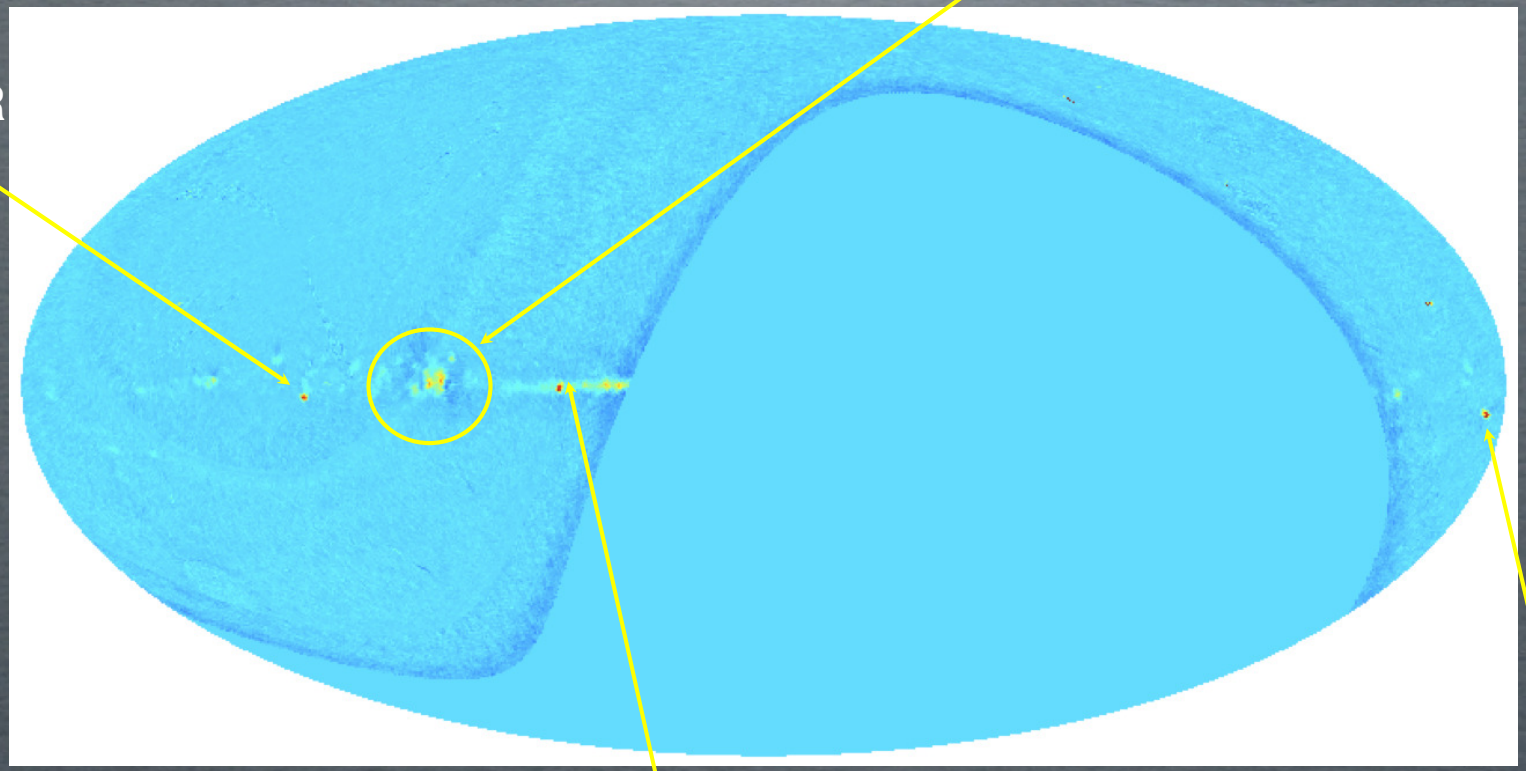


Planck 30 GHz

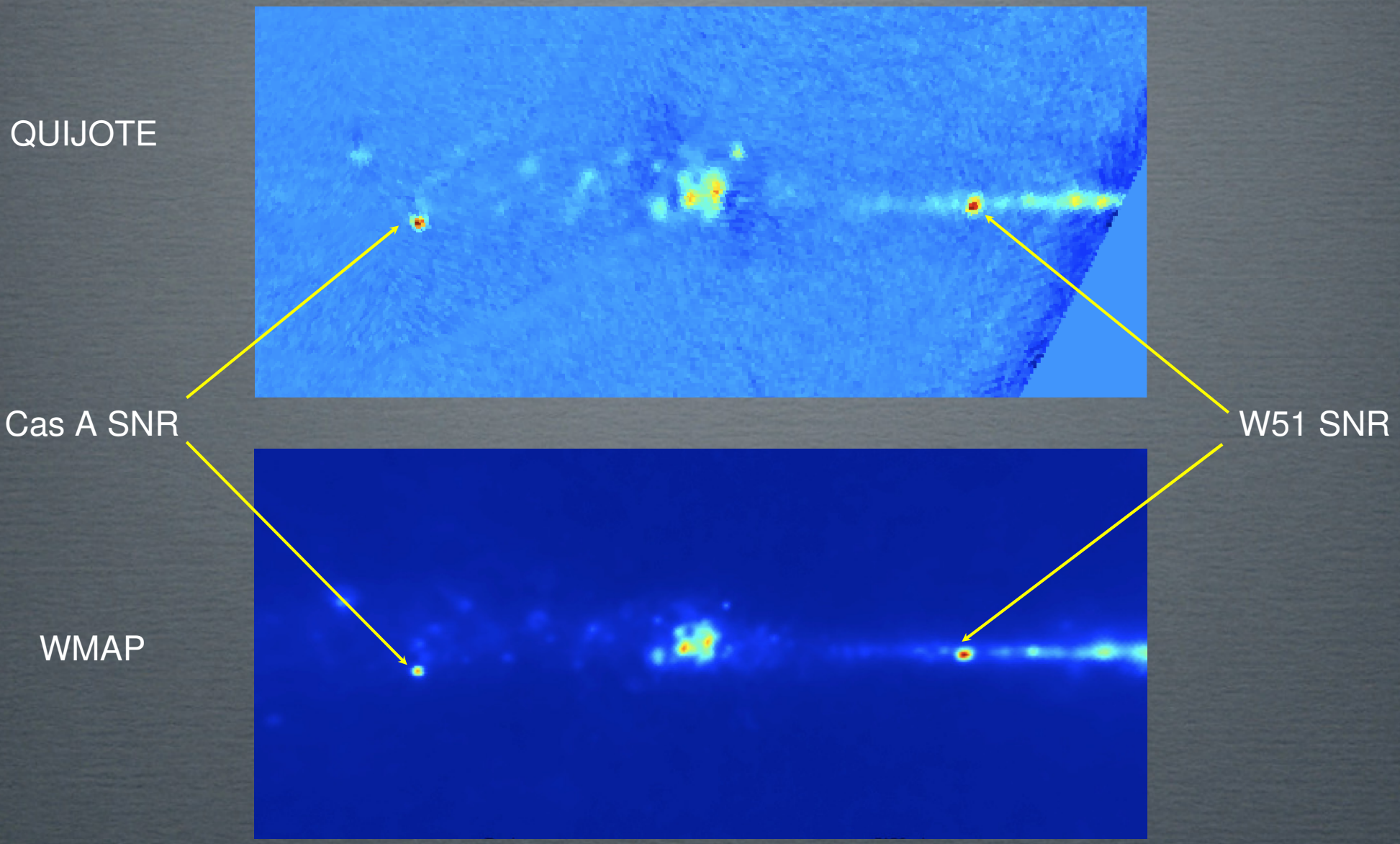


Quijote wide survey

- Northern hemisphere
- ~ 700h of data (ongoing)
- 20,000 deg^2, with sensitivity of ≈ 14 μK/(beam 1º)
- Four frequencies (11, 13, 17 and 19 GHz)



Quijote wide survey



★ Quijote-CMB is a new polarimeter operating at 10-40 GHz, dedicated to characterize the low-frequency (AME and synchrotron) Galactic foregrounds, and to set constraints on the B-mode signal down to r~0.05

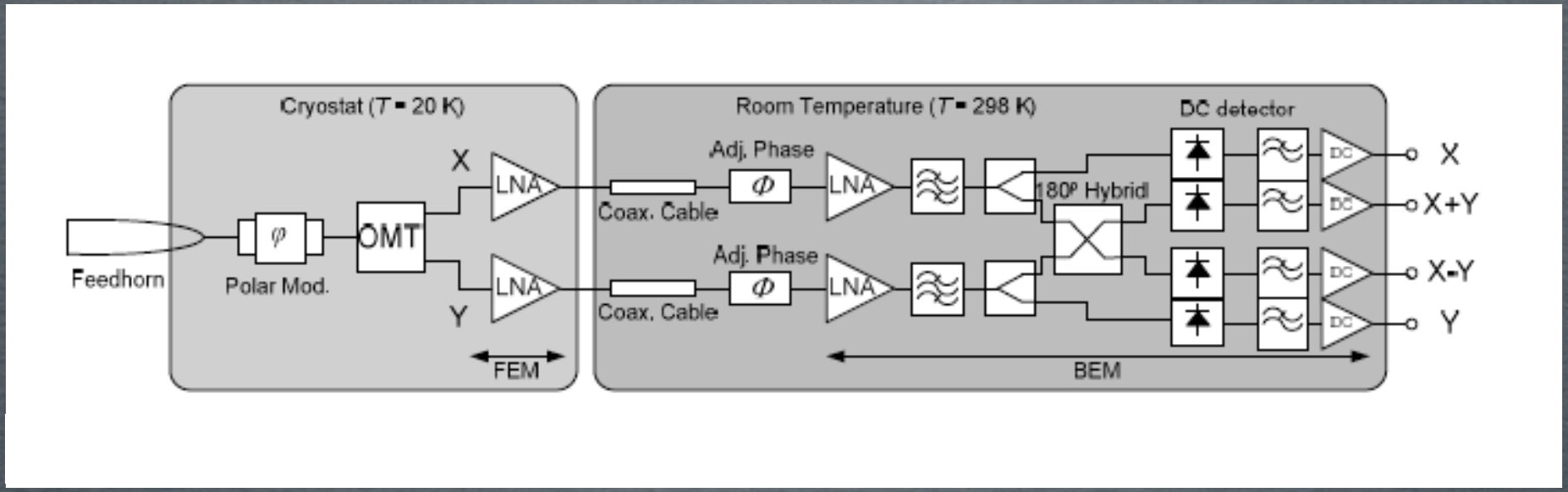
★ The MFI on the QT1 are currently under scientific operation and performing under specifications

★ Intensity and polarization maps are produced at each of the four frequencies

★ The second telescope and the second instrument (TGI) are currently under construction. The third instrument (FGI) will be manufactured during 2014

Thanks for your attention!

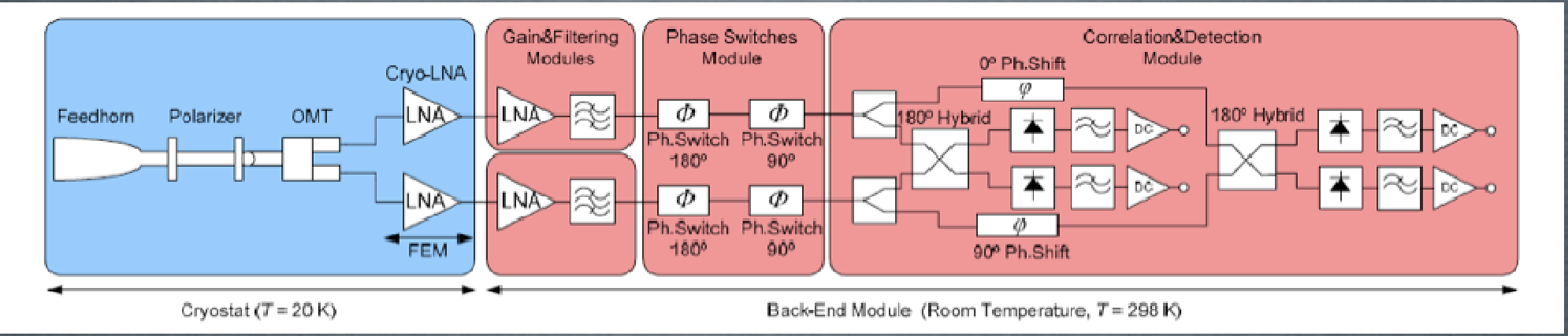
- MFI polarimeter configuration
- FEM: partially-cooled feed-horn, polar modulator, OMT and LNAs
- BEM: phase adjuster, further amplification, band pass filter and correlation
- Output: two channels (x) and (y) measuring Q (un-correlated), two channels (x+y) and (x-y) measuring U (correlated)



- Continuous spinning of the polar modulators allows independent measurement of I, Q and U for each channel, while switching out the 1/f noise
- Each of the four outputs are divided into a lower frequency and an upper frequency band

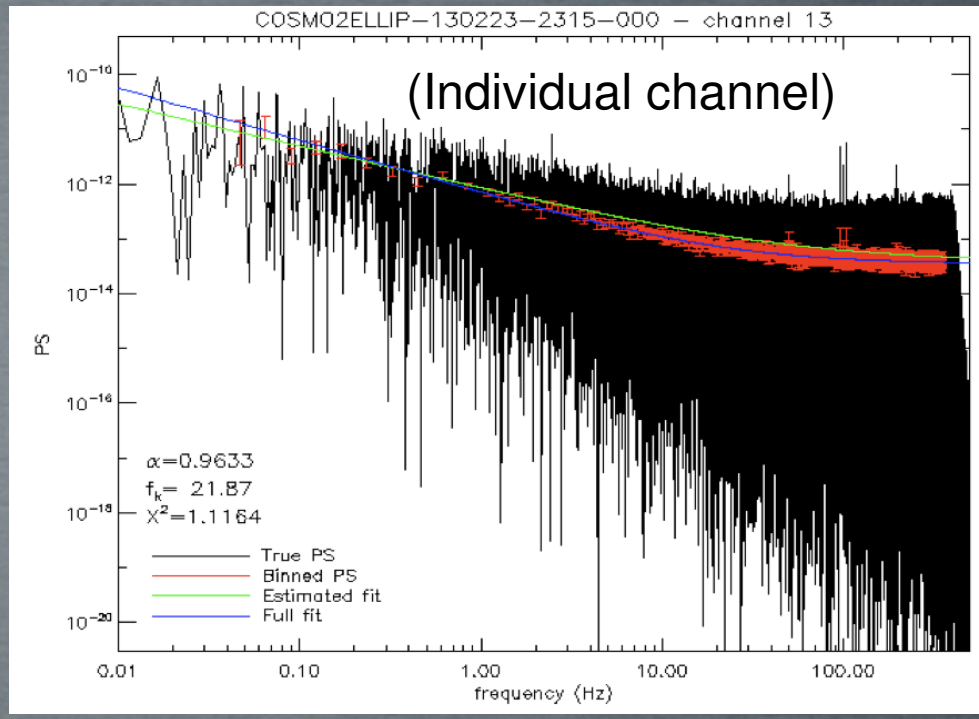
Thirty Gigahertz instrument (TGI)

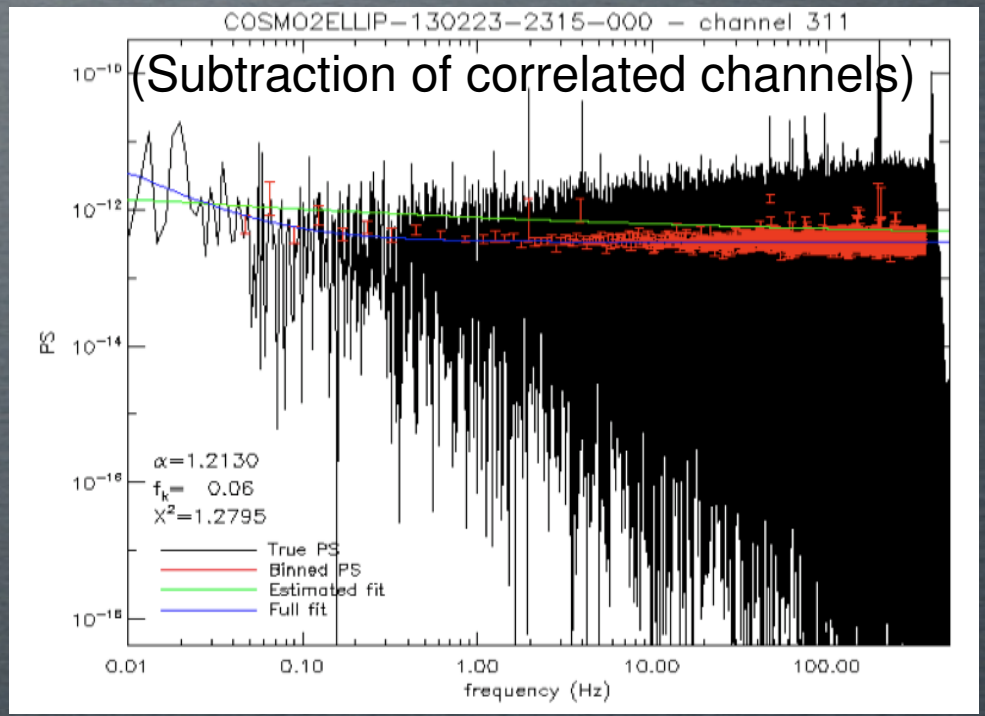
- 31 polarimeters at 30 GHz (4 channels each)
- Nominal sensitivity: 50 μK $s^{1/2}$



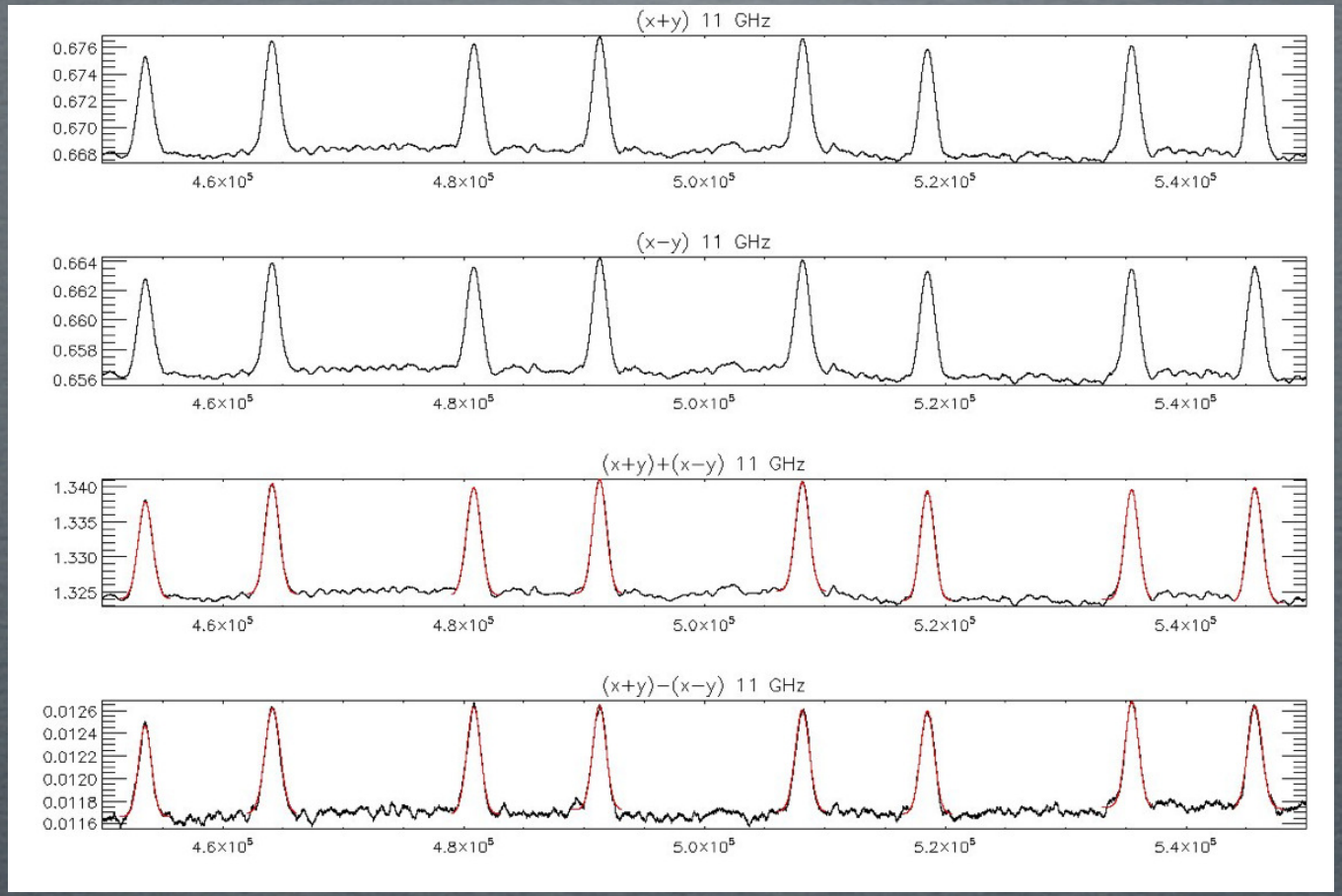
- MFI design (rotating polar modulator) not appropriate for the long-term operations required for the TGI
- Alternative design based on a fixed polarizer
- Fixed polarizer combined with two 90º and 180º phase switches to generate the four polarization states in each branch, to minimize the 1/f noise and other systematics
- To be commissioned in 2014
- The TGI (40 polarimeters at 40 GHz) will be based on the same design

- MFI noise characterization:
  - Noise power spectrum is measured using long observations on blank fields
  - 2 Hz signal + harmonics that could be caused by the coolying system frequency. It is also present a 50 Hz signal
  - The anti-aliasing filter cuts off at > 400 Hz
  - The 1/f noise knee-frequency (in intensity) is typically ~10-20 Hz
  - When subtracting correlated channels the knee-frequency is consistently reduced





- Crab observation:
  - AZ scans at 1 deg/s (1 second on source)
  - Modulators fixed at 0º

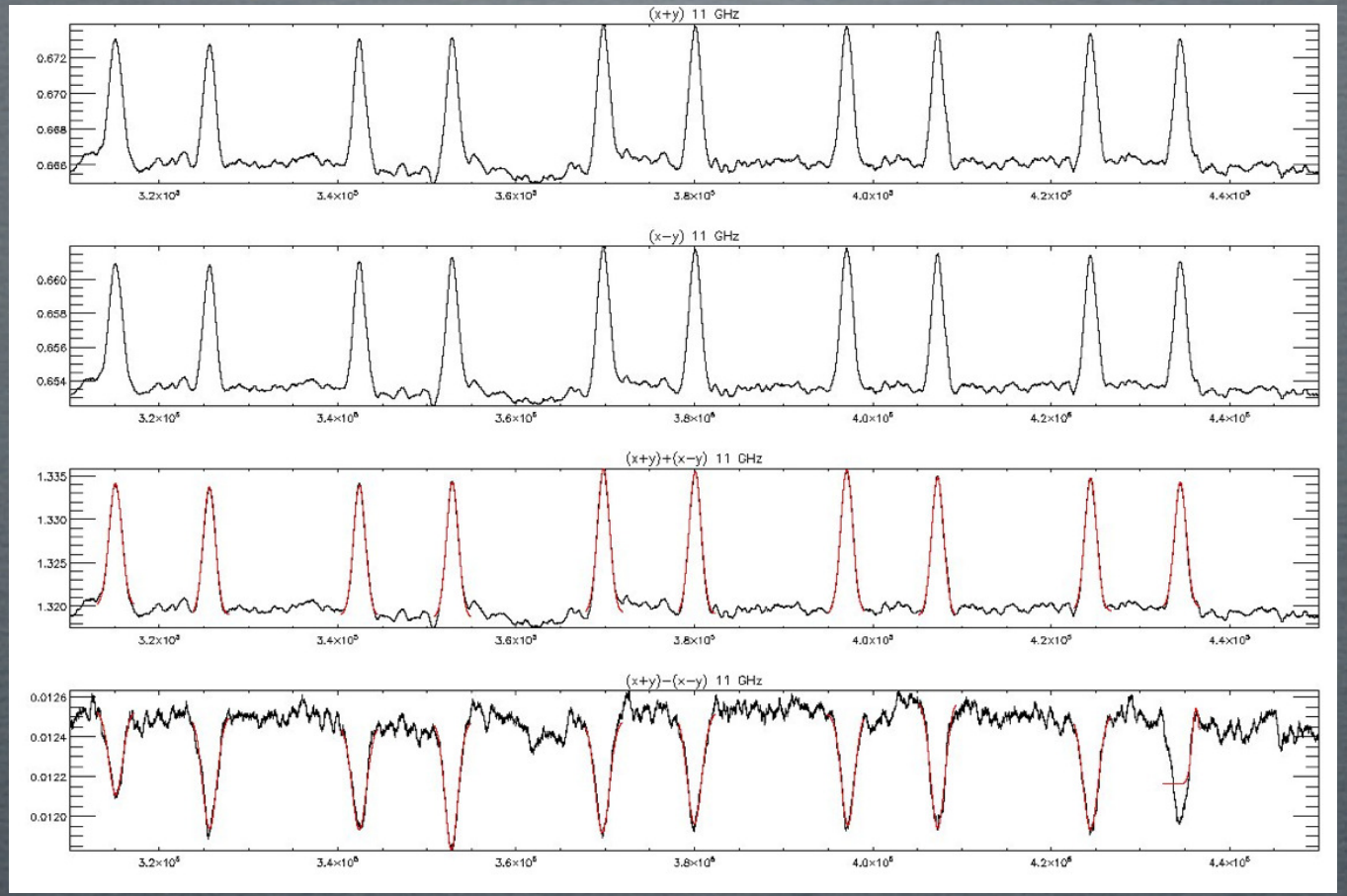


I

Q

$\langle Q/I \rangle = 5.79 \pm 0.2\ \%$

- Crab observation:
  - AZ scans at 1 deg/s (1 second on source)
  - Modulators fixed at 22.5º



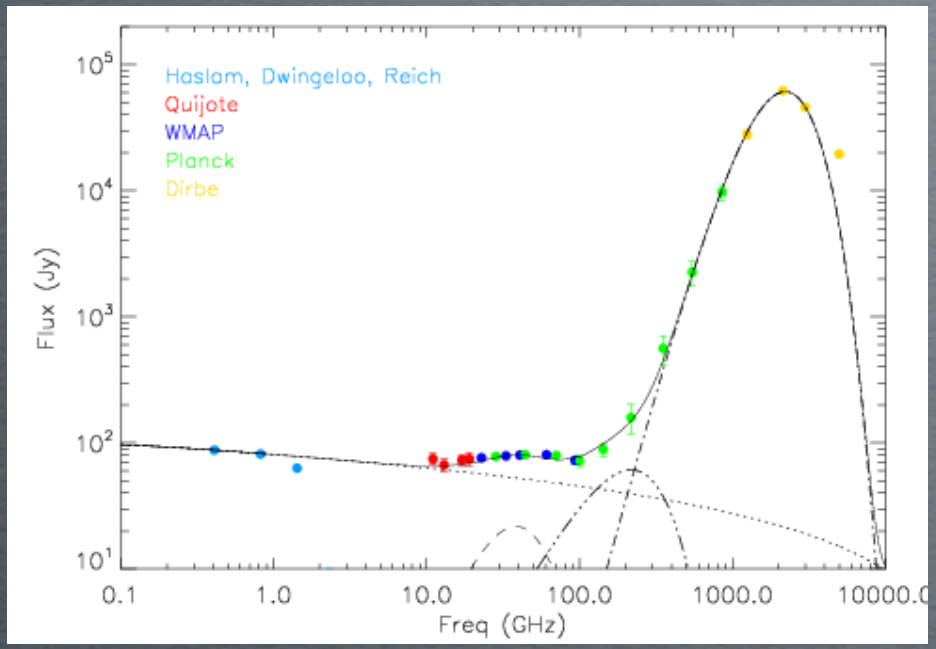
I

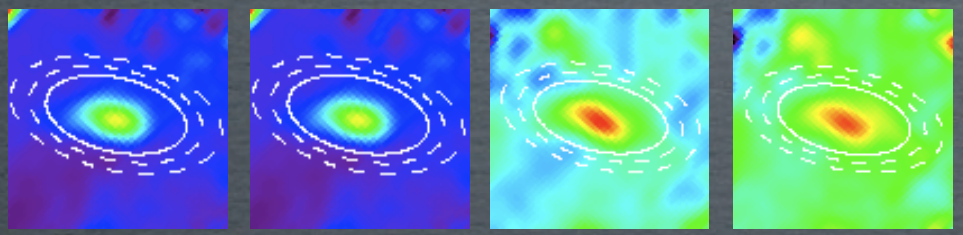
U

<U/I> = -3.60±0.4 %

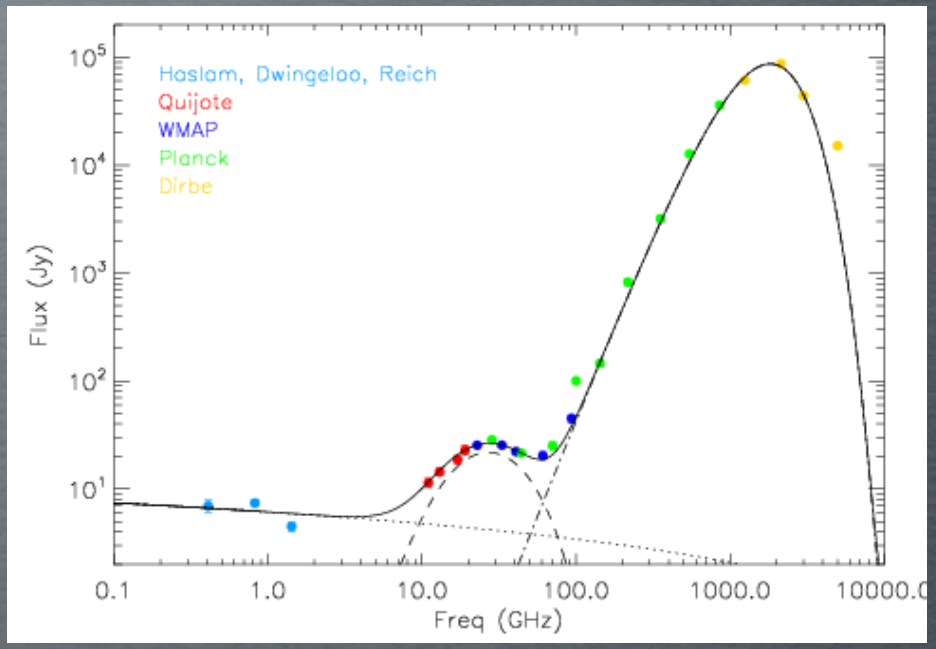
<P/I> = 6.8±0.8 % at 11 GHz (Consistent with WMAP 23 GHz, 7.08 ± 0.25%)

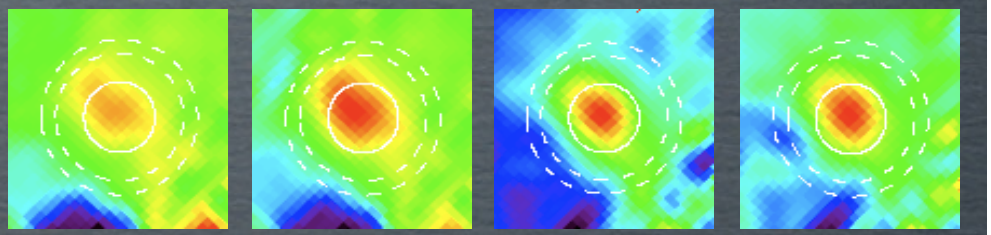
California HII region





Perseus G160.26-18.62

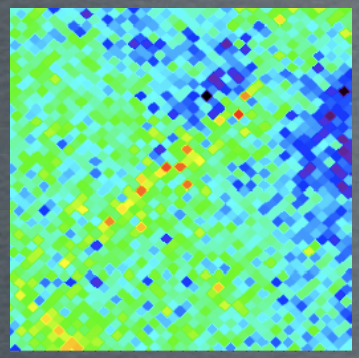




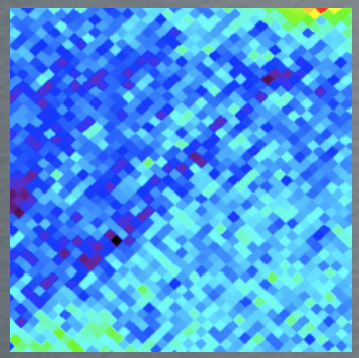
Perseus G160.26-18.62 polarization maps

Q maps

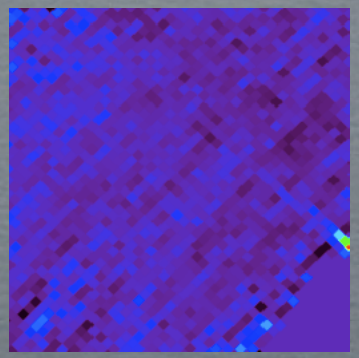
11 GHz



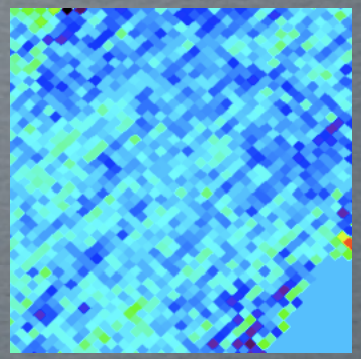
13 GHz



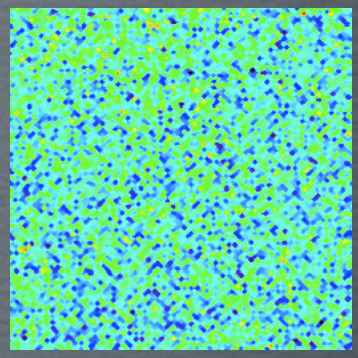
17 GHz



19 GHz

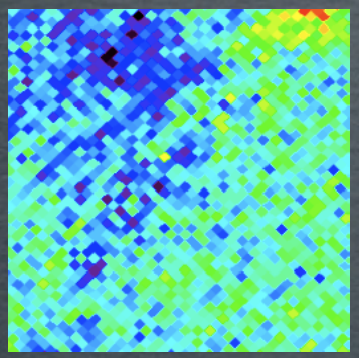


WMAP 23 GHz

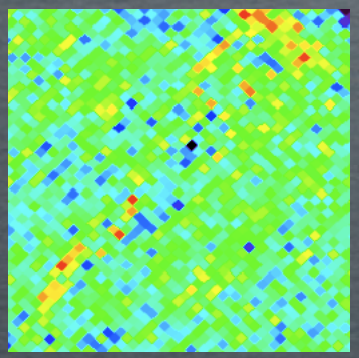


U maps

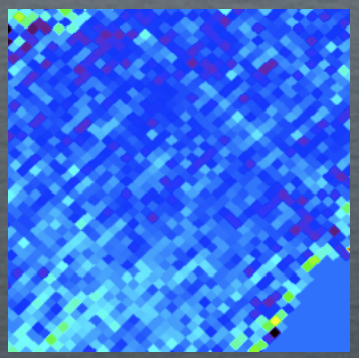
11 GHz



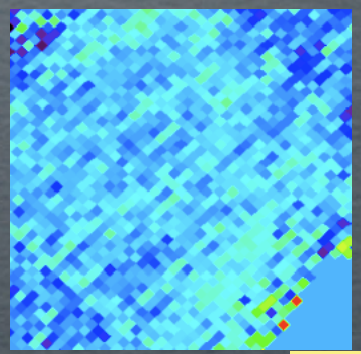
13 GHz



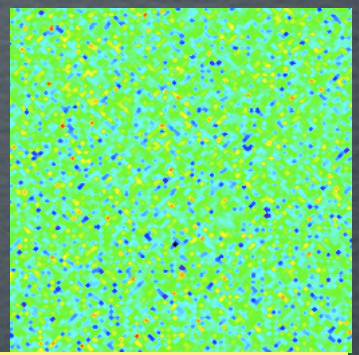
17 GHz



19 GHz



WMAP 23 GHz



These maps are 8x8 deg

- Polarization upper limits:

ν (GHz)	I (Jy)	Q (Jy)	U (Jy)	P (Jy)	$P_{\rm db}$ (Jy)	Π (%)	$\Pi_{\rm db}$ (%)
11	11.4 ± 1.1	0.12 ± 0.23	-0.075 ± 0.27	0.14 ± 0.24	< 0.27	1.26 ± 2.11	< 2.35
13	14.4 ± 1.1	-0.05 ± 0.22	-0.19 ± 0.27	0.19 ± 0.27	< 0.29	1.34 ± 1.87	< 1.98
17	18.7 ± 1.6	-0.10 ± 0.42	-0.19 ± 0.46	0.21 ± 0.45	< 0.47	1.14 ± 2.43	< 2.49
19	22.9 ± 2.4	0.41 ± 0.72	-0.06 ± 0.54	0.42 ± 0.71	< 0.70	1.83 ± 3.11	< 3.05