

# QUIJOTE : a CMB Polarization experiment



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<https://www.iac.es/project/cmb/qu>



The Univ. of Manchester



Nordwijk, ESA April 4th, 2013

# Outline

- QUIJOTE
  - Basic features
  - Science goals
- Telescopes and Instruments
- Polarized source subtractor
- QUIJOTE Data processing
  - Beam reconstruction
  - MFI Noise estimation
  - Photometric calibration
  - Map making
- Preliminary maps
- Science Prospects



## The QUIJOTE collaboration

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### ❖ University of Cambridge



K. Grainge, M.P. Hobson, A. Challinor, A.N. Lasenby, R.D.E. Saunders, P.F. Scott, D. Titterton

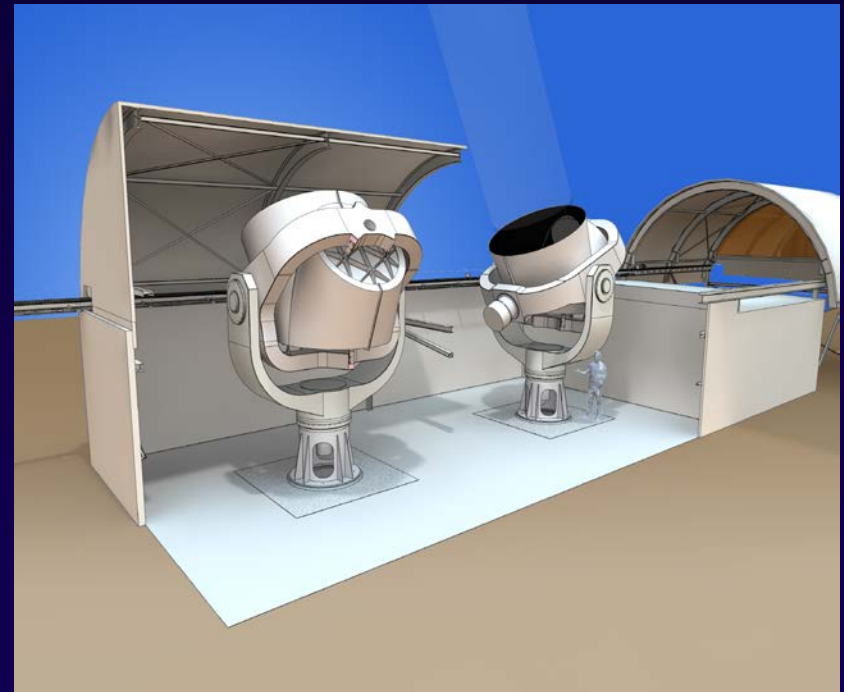
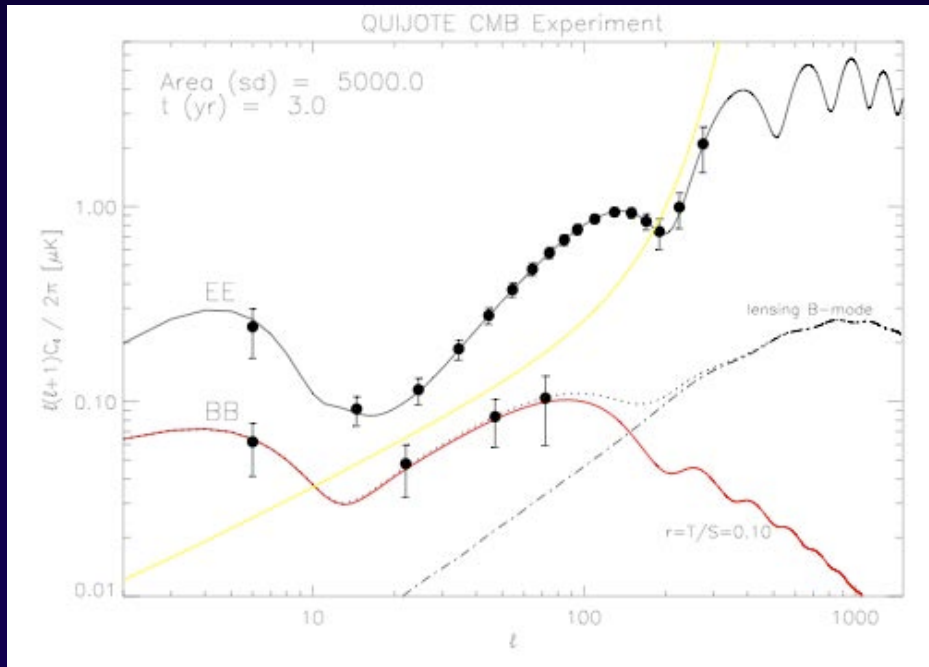
### ❖ IDOM



J. Ariño, B. Etxeita, A. Gómez, C. Gómez, G. Murga, J. Pan, R. Sanquircce, A. Vizcargienaga

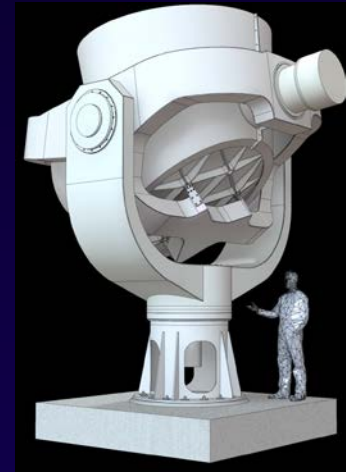
# *QUIJOTE (Q-U-I Joint Tenerife Experiment)*

The main goal is to obtain six polarization maps in the frequency range 10-40 GHz with sufficient sensitivity to correct the 30 and 40 GHz maps from foreground emission and detect the imprint of B modes if  $r > 0.05$ .



# ***QUIJOTE: Project basic features***

- **Site**: Teide Observatory (2400 m altitude, Tenerife)
- **Frequencies**: 11, 13, 17, 19, 30 and 40 GHz.
- **Angular resolution**: 54 arcmin @ 11 GHz
- **Telescopes and instruments**:
  - 2.3 meter – off axis microwave telescope.
  - Equipped with a multifrequency 11-20 GHz instrument (MFI) providing (started operation November 2012). **Polarization detection**: modulation
  - Second instrument with 32 polarimeters @ 30 GHz (currently under construction, it shall be completed at the end of 2013) .
  - Polarized Source Subractor (30 GHz): 2 antenna interferometer
  - **Phase II (funded)**
    - Second telescope (in construction, shall be ready end of 2013)
    - Third instrument with 40 polarimeters at 40 GHz (shall be completed by end 2014).
  - **Scientific operation plan: 2012-2018**



# First QUIJOTE Telescope (QT1)



Installed at Teide Observatory on  
May 3<sup>rd</sup>, 2012.



## Observing modes:

1. Nominal: fast spinning at fixed elevation. Earth rotation provides daily swaths of several thousand sq degrees.
2. Raster and Tracking observations are also possible.

# QUIJOTE EXPERIMENT

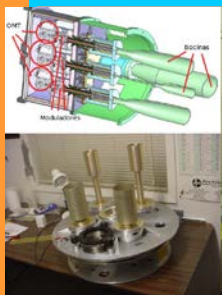
QT1 MFI

observing modes

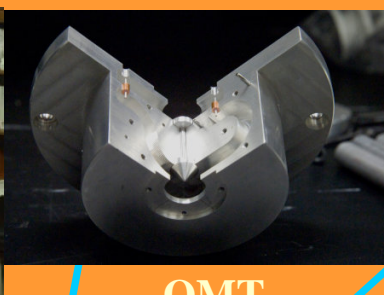
OBSERVATORIO DEL TEIDE. MARZO 2013

# QUIJOTE INSTRUMENTATION

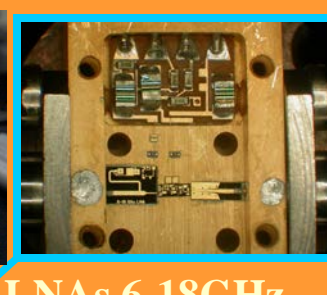
MFI



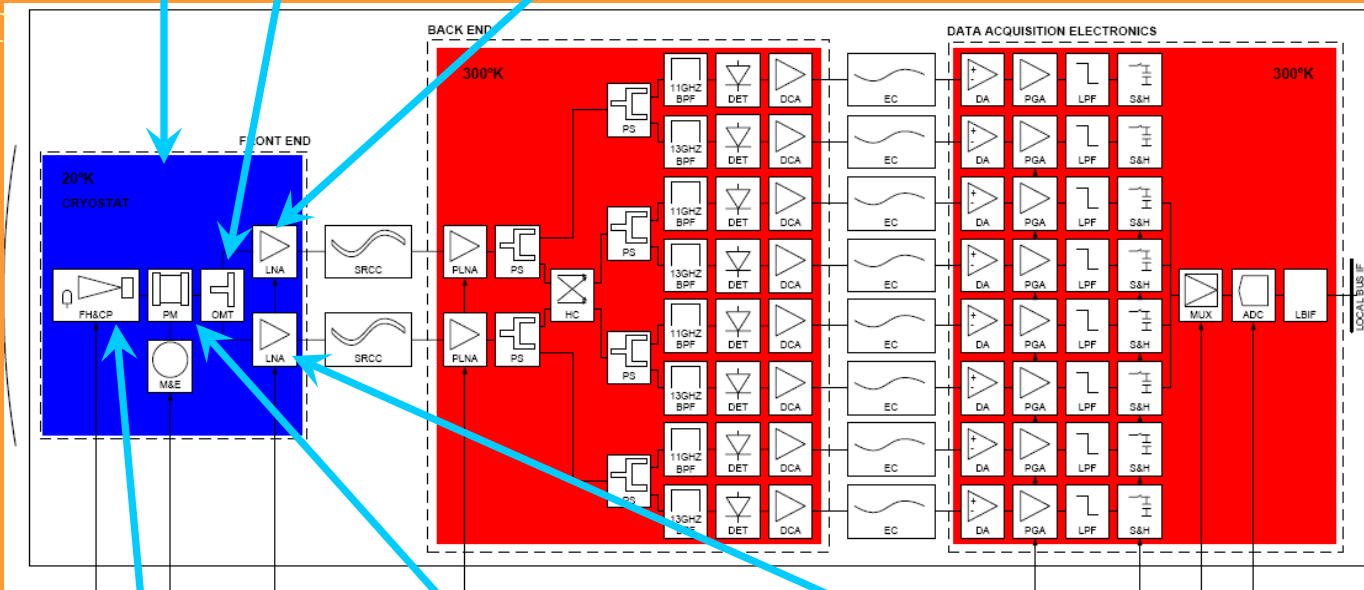
QUIJOTE CRYOSTAT



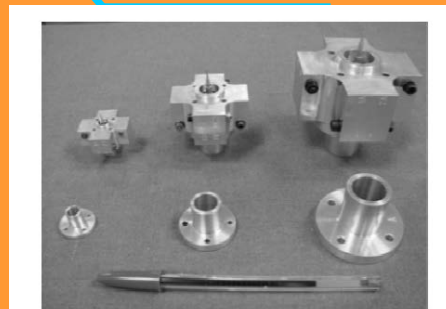
OMT



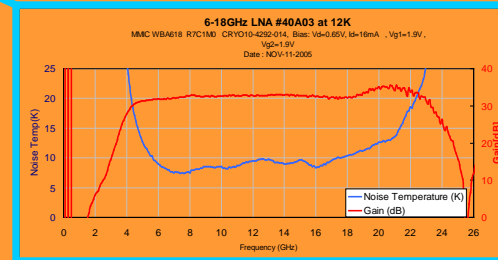
LNAs 6-18GHz



HORN



POLAR MODULATOR



LOW NOISE AMPS



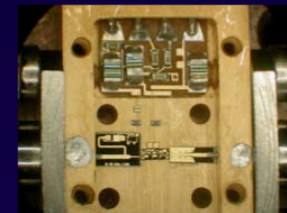
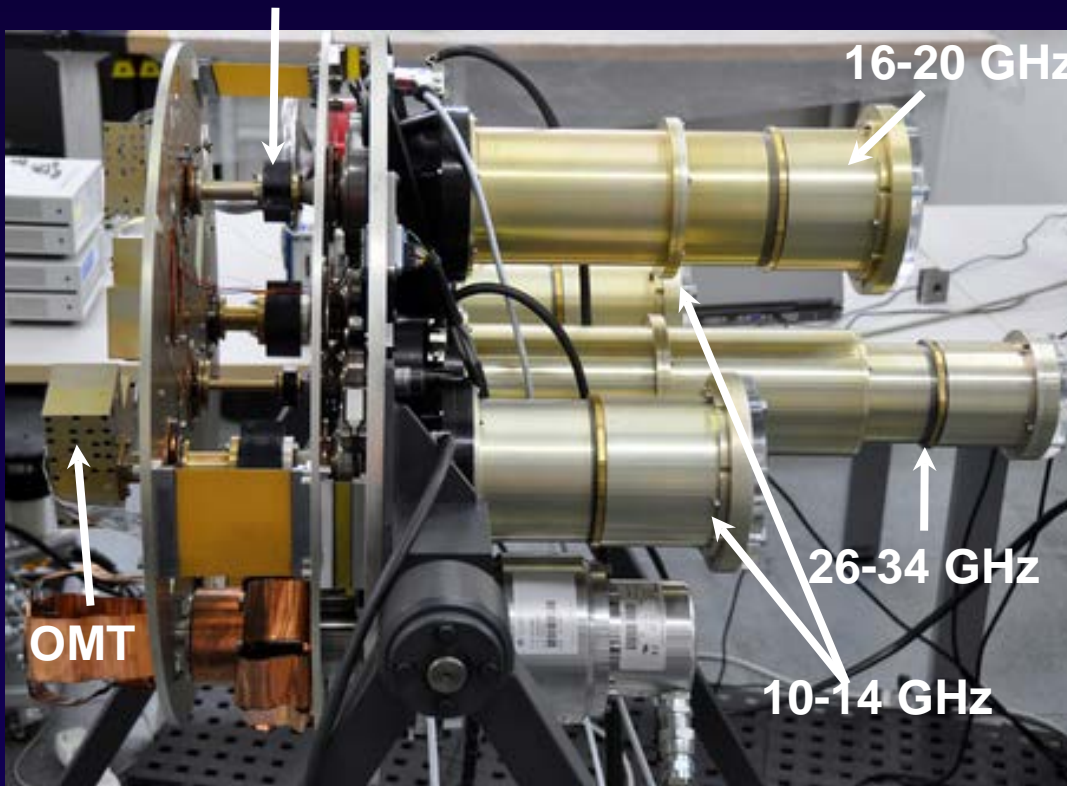
# QUIJOTE first instrument

- 2 horns providing 8 channels at 11 and 13 GHz
- 2 horns providing 8 channels at 17 and 19 GHz

## Spinning polar modulators



## Polar Modulators



LNA



OMT and motor



Horns



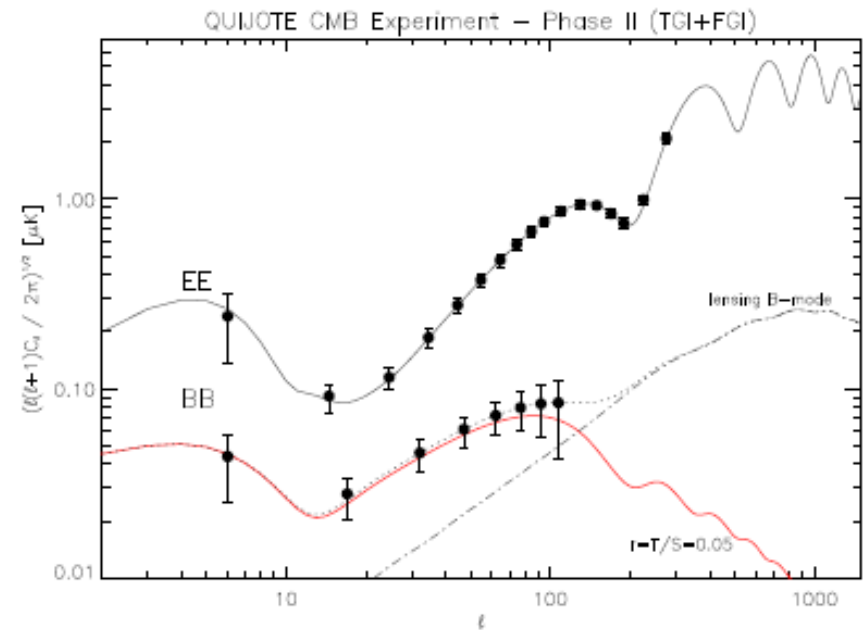
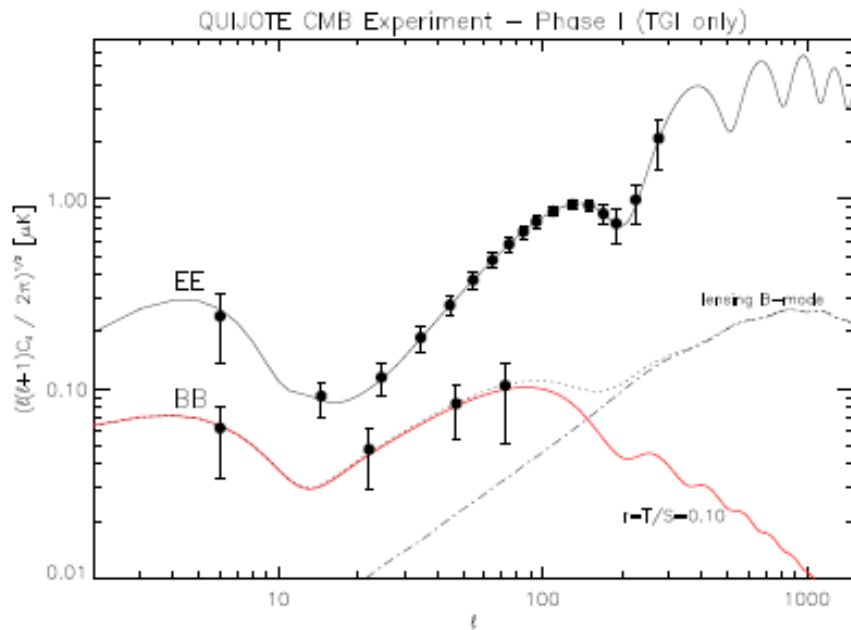
- MFI integration tests on the QT1 at the AIV room. March 2012
- Currently undergoing scientific commissioning



# The QUIJOTE-CMB project

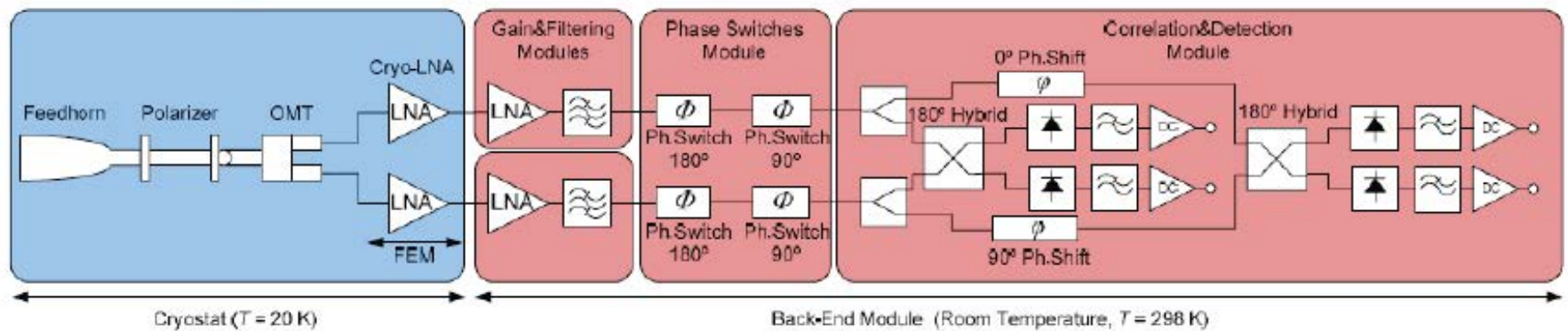
	MFI				TGI	FGI
Frequency (GHz)	11	13	17	19	30	40
Bandwidth (GHz)	2	2	2	2	8	10
Number of horns	2		2		31	40
Channels per horn	1	1	1	1	4	4
Beam FWHM (deg)	0.92	0.92	0.60	0.60	0.37	0.28
$T_{\text{sys}}$ (K)	25	25	25	25	35	45
NEP per channel ( $\mu\text{K s}^{1/2}$ )	456	370	663	1019	557	632
Sensitivity per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

# Science with TGI and FGI



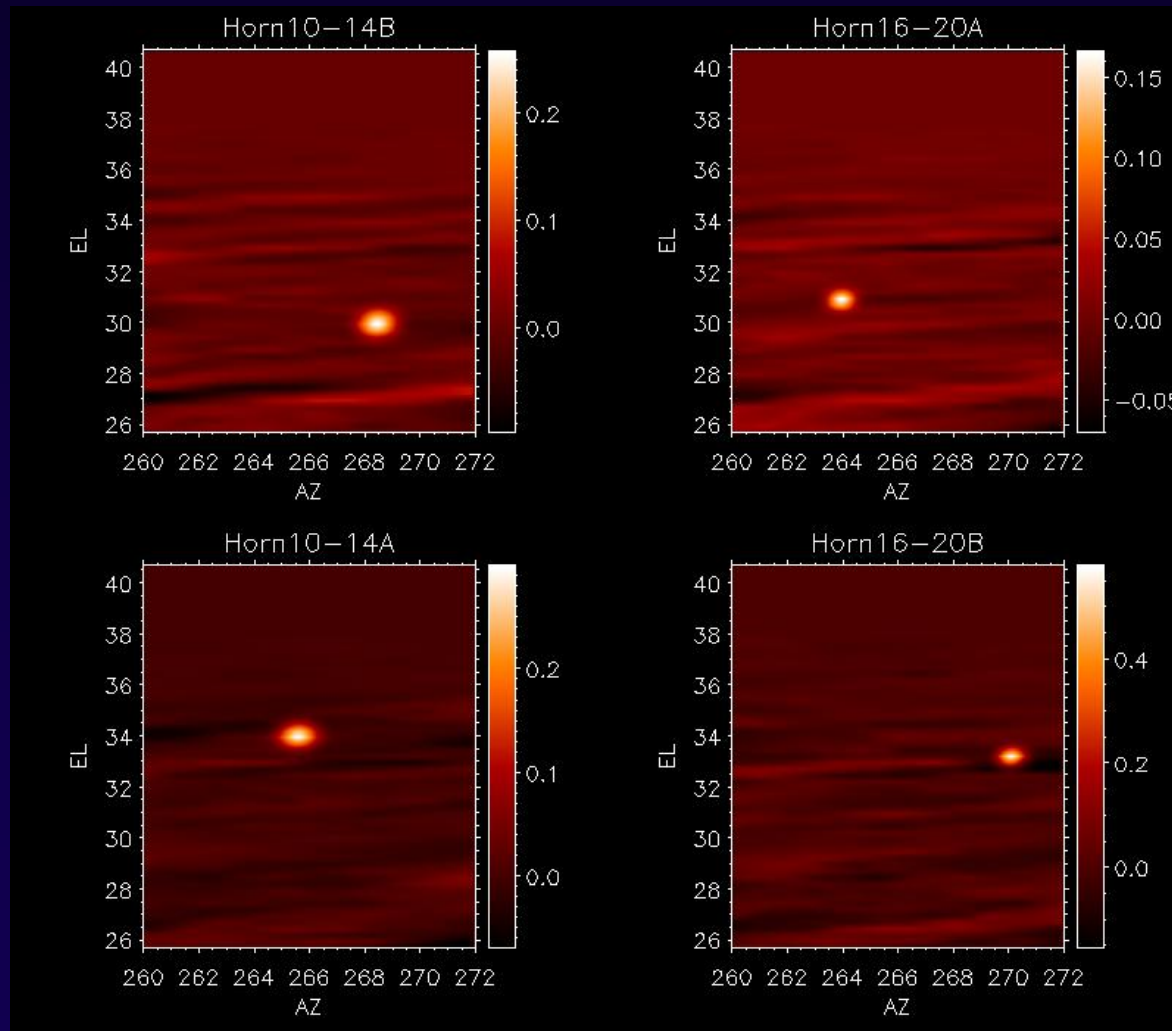
## Thirty Gigahertz instrument (TGI)

- 31 polarimeters at 30 GHz (4 channels each)
- Expected sensitivity:  $50 \mu\text{K s}^{1/2}$



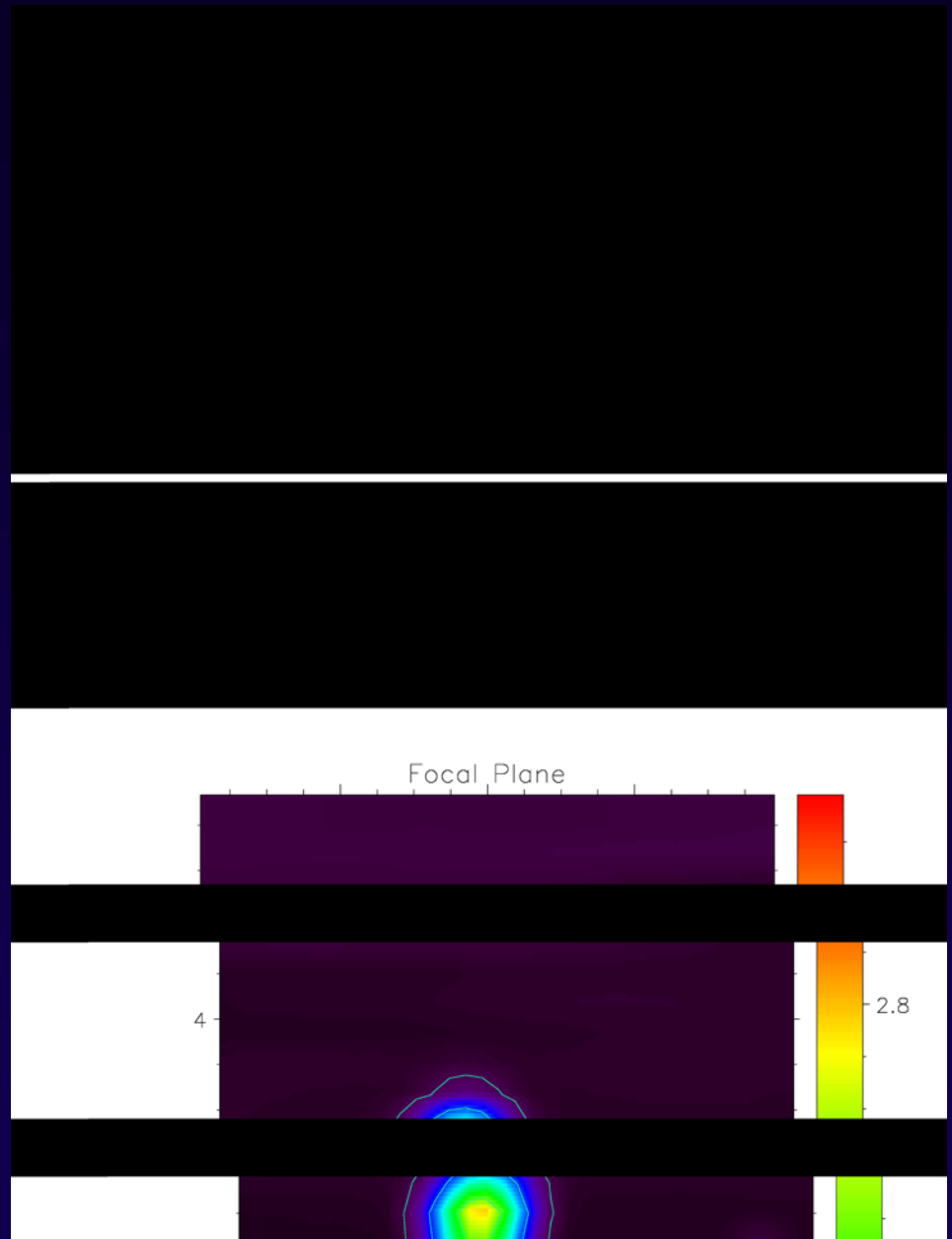
- MFI design (rotating polar modulator) not appropriate for the long-term operations required for the TGI
- Alternative design based on a fixed polarizer
- Fixed polarizer combined with two 90° and 180° phase switches to generate the four polarization states in each branch, to minimize the 1/f noise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

# *Technical First Light: the Microwave Moon through clouds*



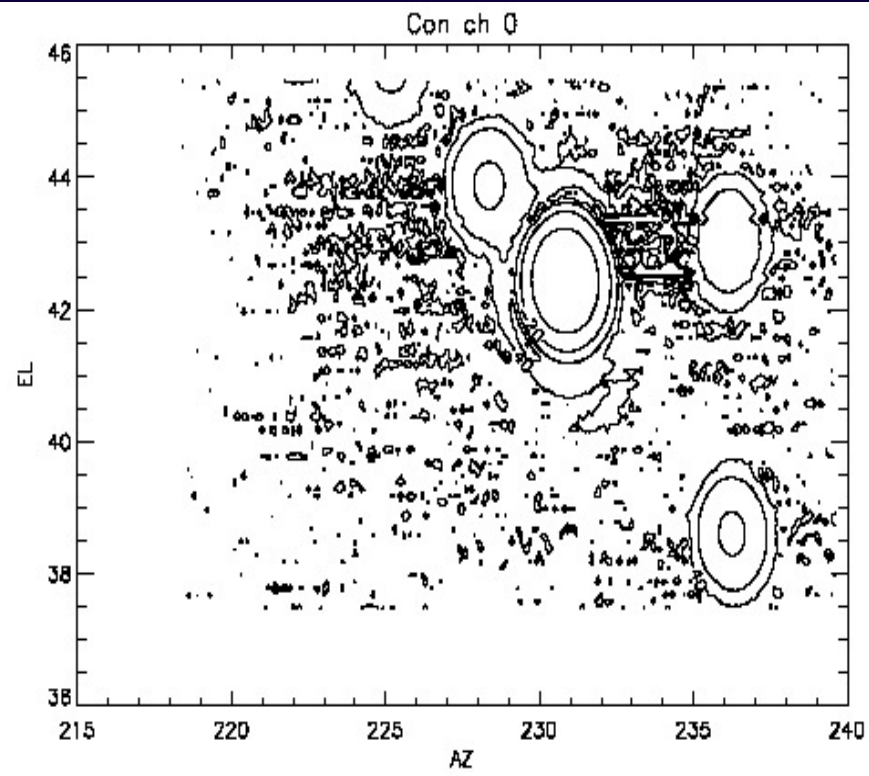
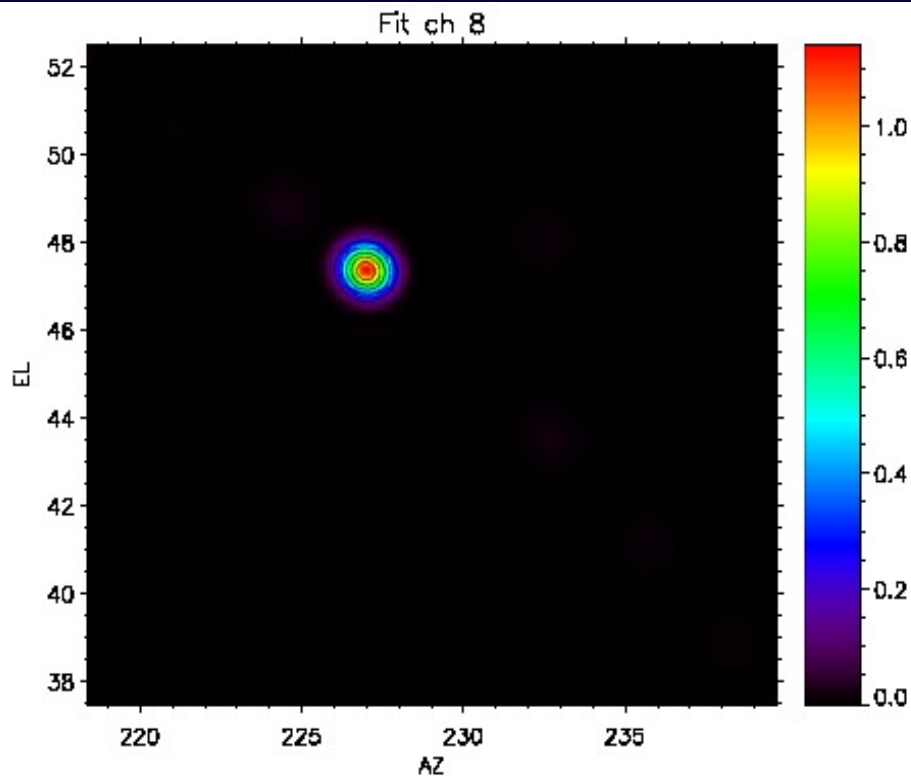
# *QUIJOTE* *focal plane*

- Detector pointing reconstruction can be determined with an error of  $\sim 1$  arcmin



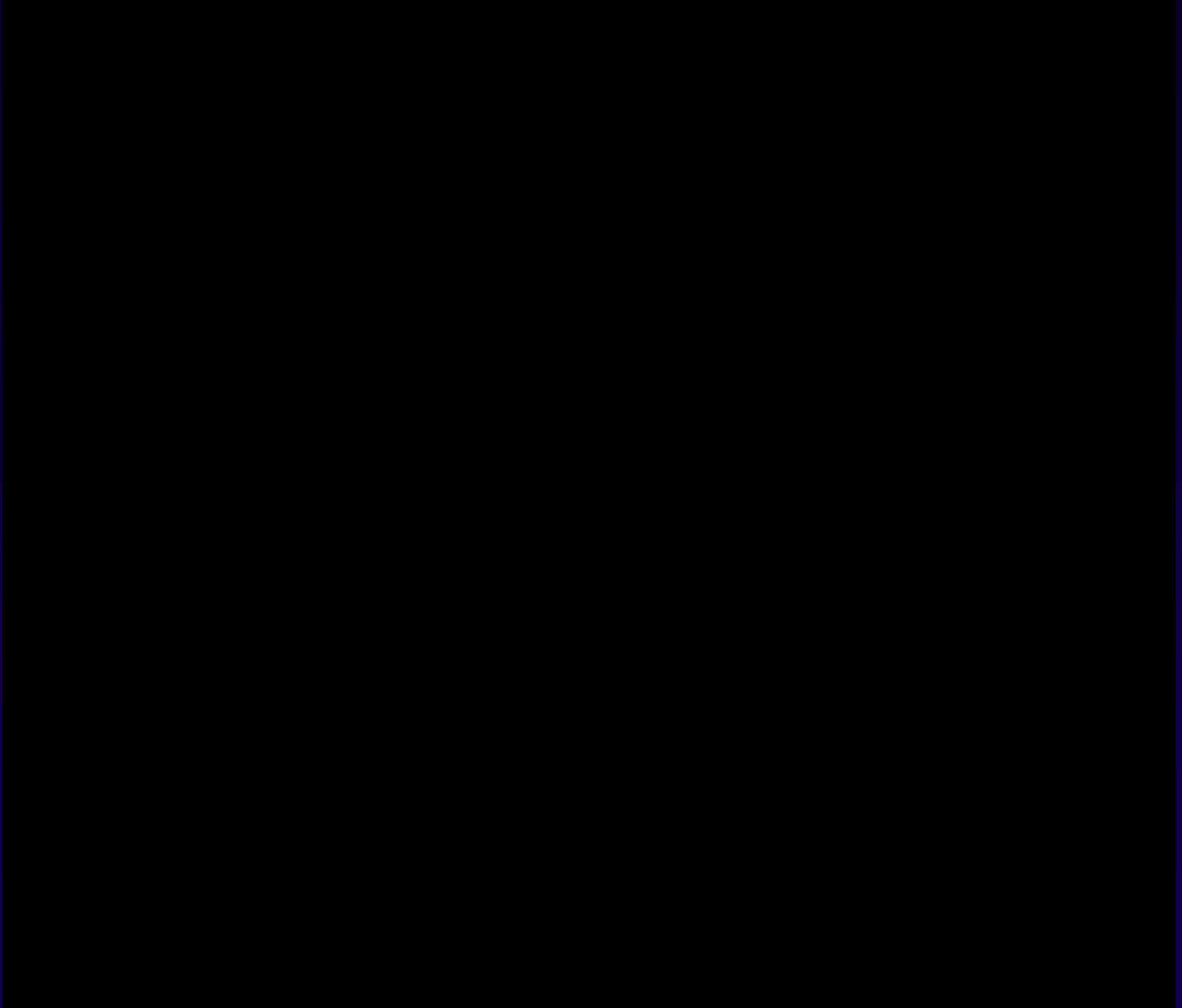
# Beams (deg)

Horn	Frequency	FWHM (Az)	FWHM (El)
1	11	0.89	0.88
1	13	0.89	0.89
2	19	0.66	0.67
3	11	0.81	0.85
3	13	0.82	0.88
4	19	0.63	0.66



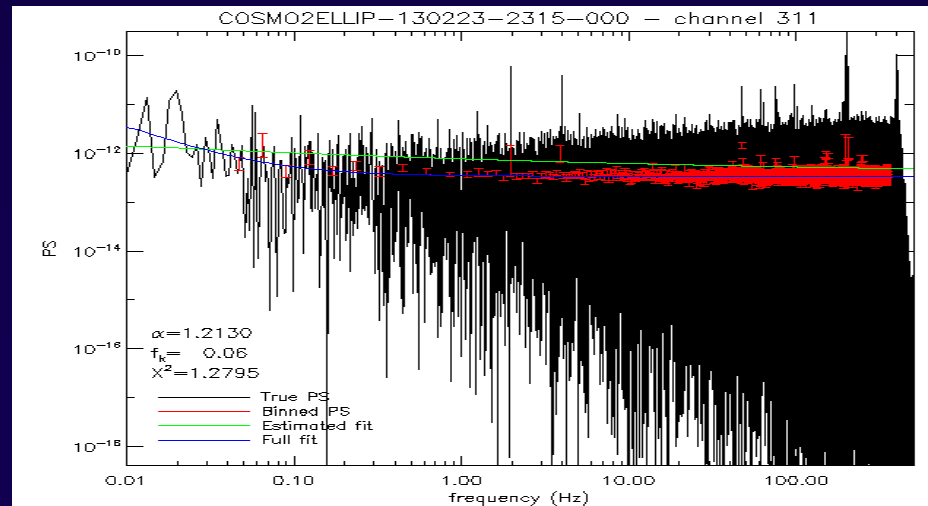
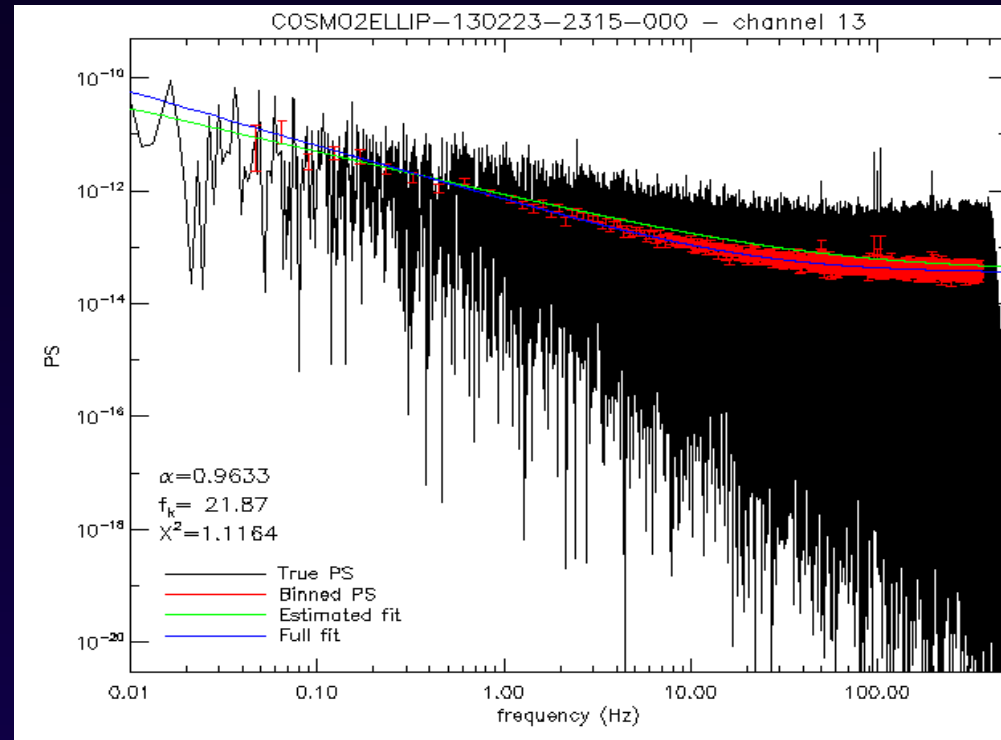


MFI: Beam Horn 1 (11 GHz)



# MFI - Noise properties

- Noise power spectrum is measured using long observations of blank fields.
- There is a 2Hz signal + harmonics which could be caused by the cooler system frequency. It is also present a 50Hz signal.
- The anti-aliasing filter cuts off at >400Hz.
- The 1/f noise knee frequency (in intensity) is generally < 10-20Hz.
- When subtracting correlated channels instantaneously, the knee frequency is effectively reduced.

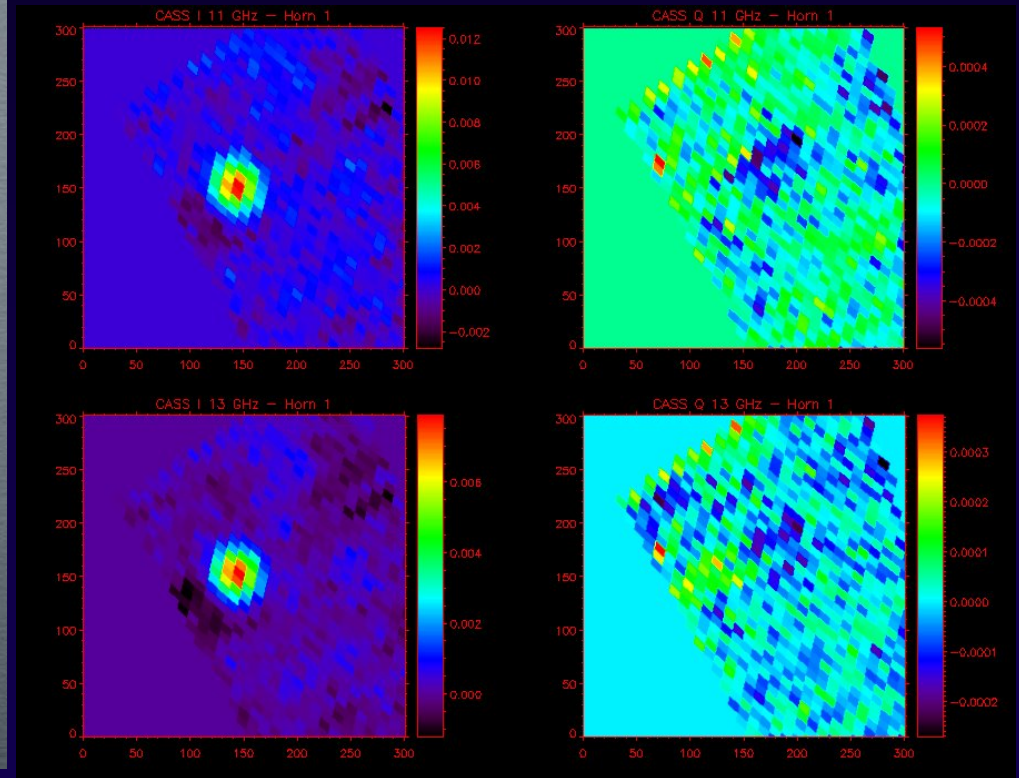
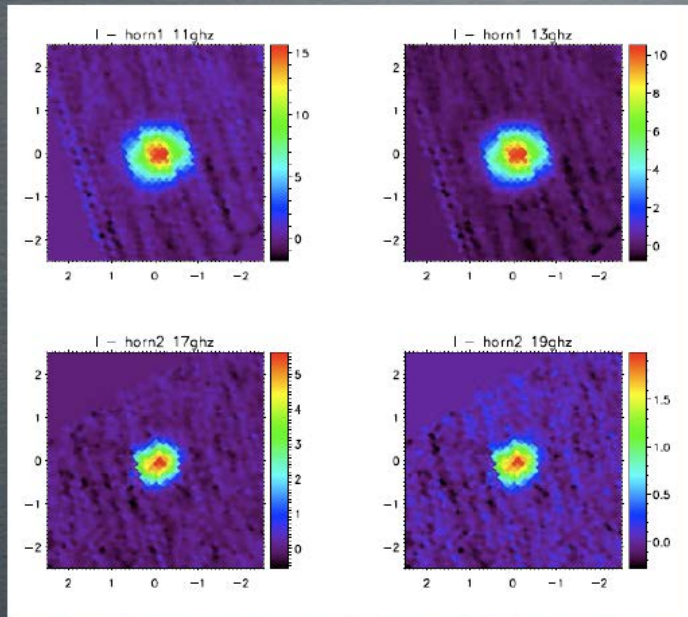


# Photometric Calibrators: Crab and Cass A

I

Q

- Crab maps (intensity):



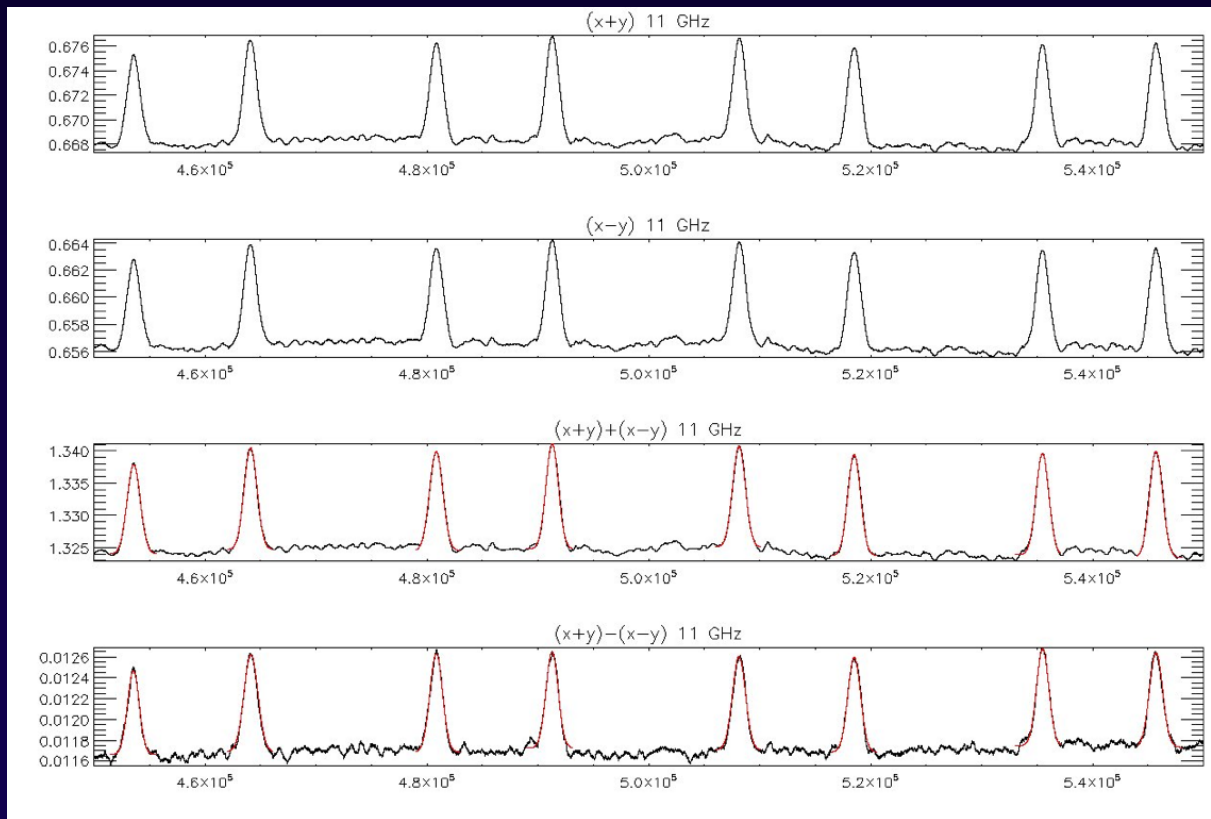
Typical integration on source: 10 s

$P=7\%$

$P=0.7\%$

- Crab observations on 15/11/2012:

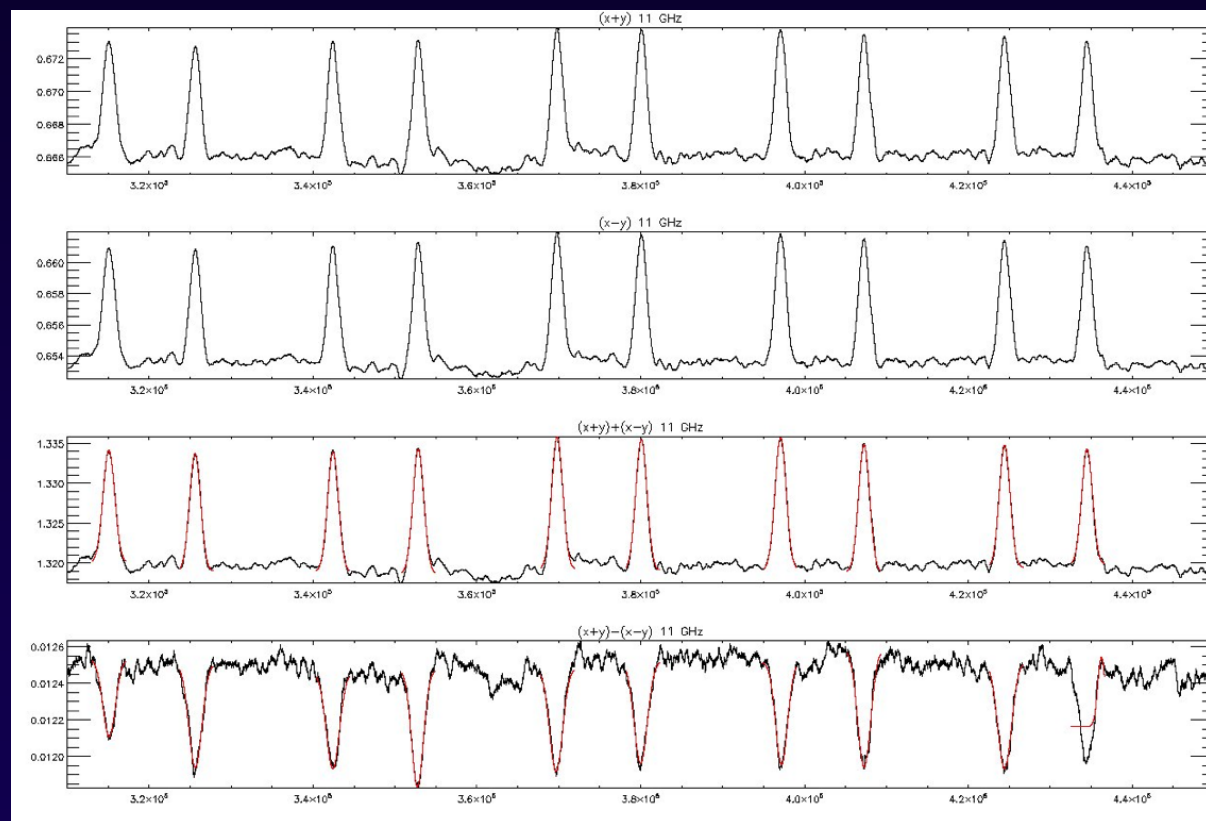
Modulators fixed at  $0^\circ$



$$\langle Q/I \rangle = 0.0579 \pm 0.002$$

- Crab observations on 15/11/2012:

Modulators fixed at  
22.5°

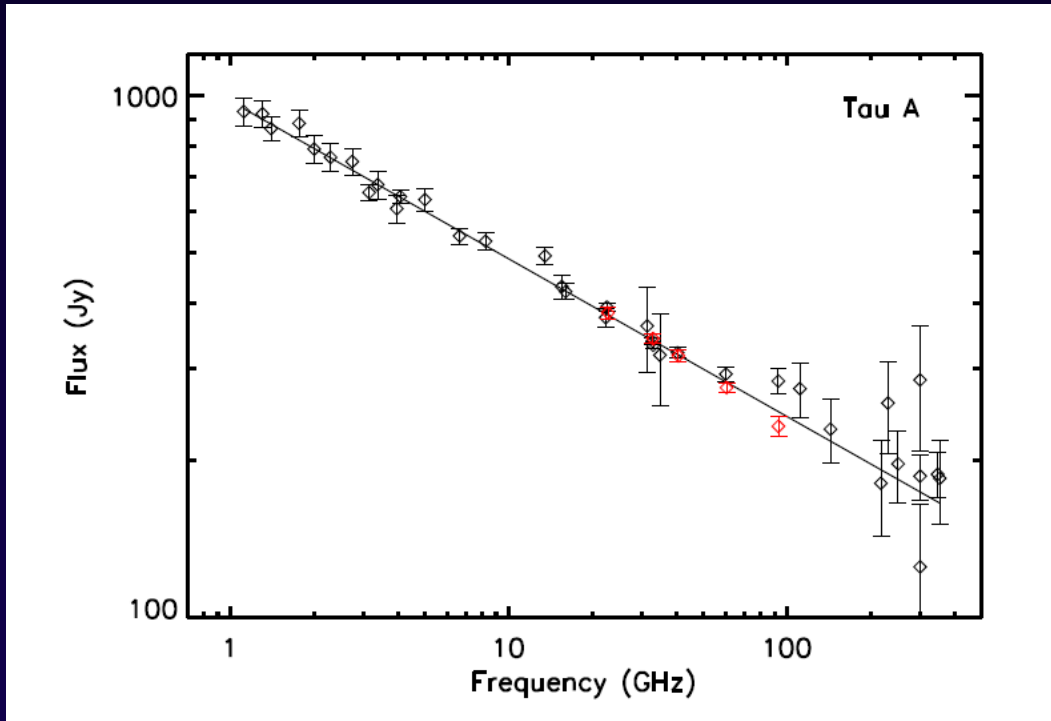


$$\langle U/I \rangle = -0.0360 \pm 0.004$$

$$\langle P/I \rangle = 6.8 \pm 0.8 \% \text{ at } 11 \text{ GHz}$$

(Consistent with WMAP 23 GHz,  
7.08 ± 0.25%)

# *Spectrum of Crab* (Weylan et al.)



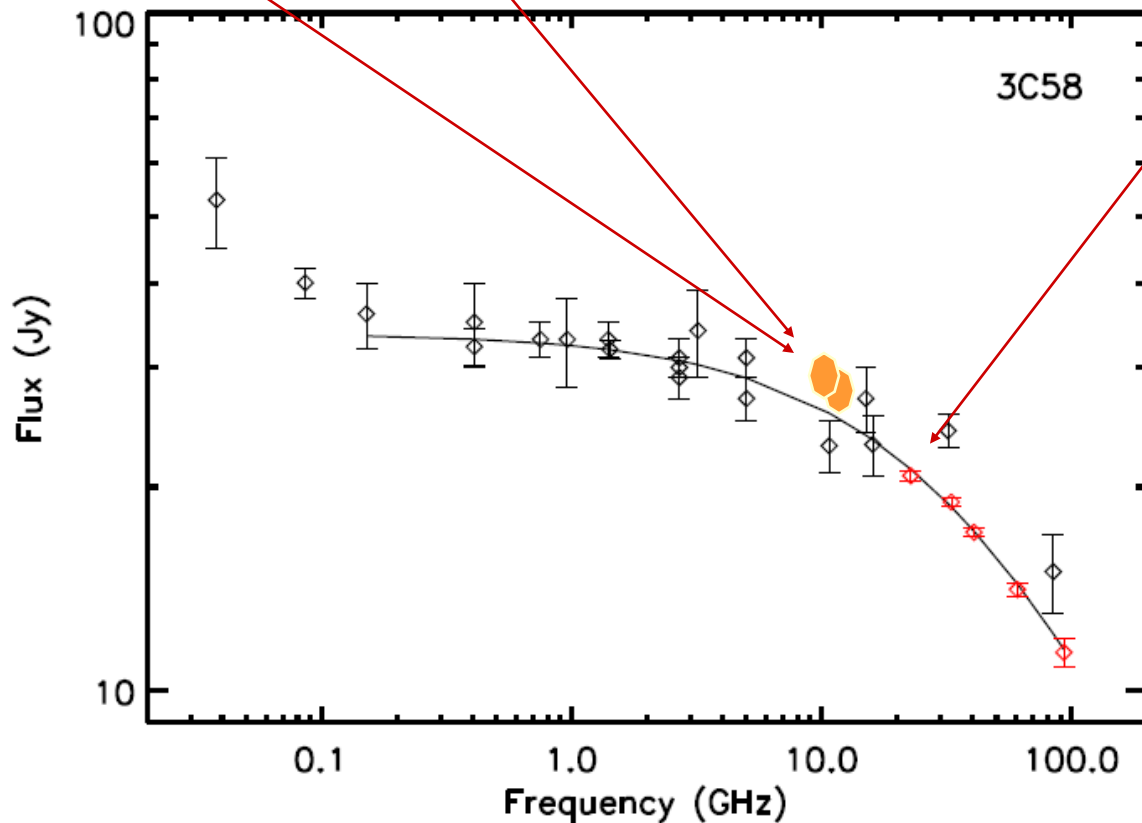
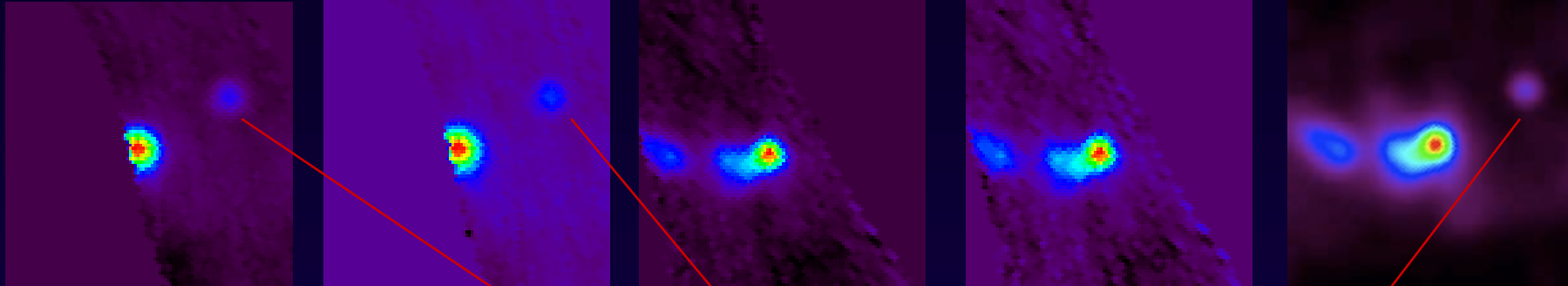
11 GHz

13 GHz

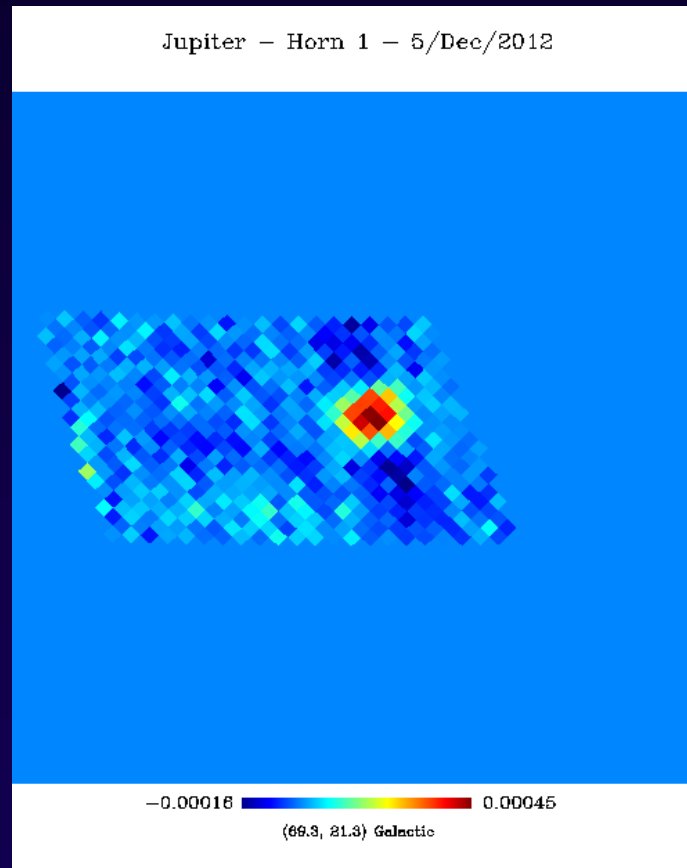
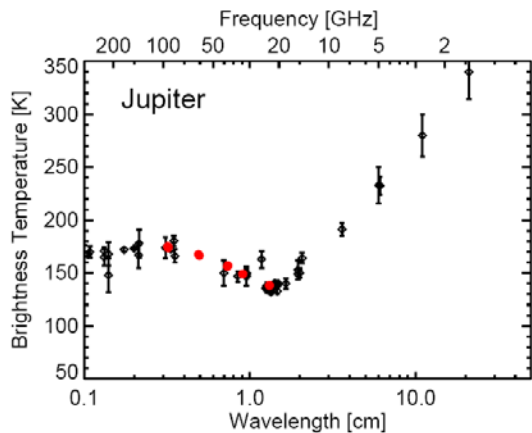
17 GHz

19 GHz

WMAP 23 GHz



# *Jupiter @ 11 GHz*

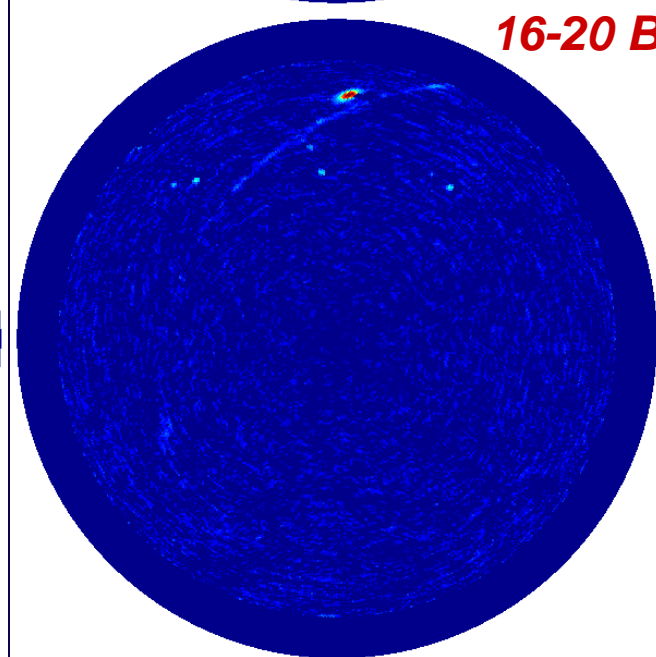
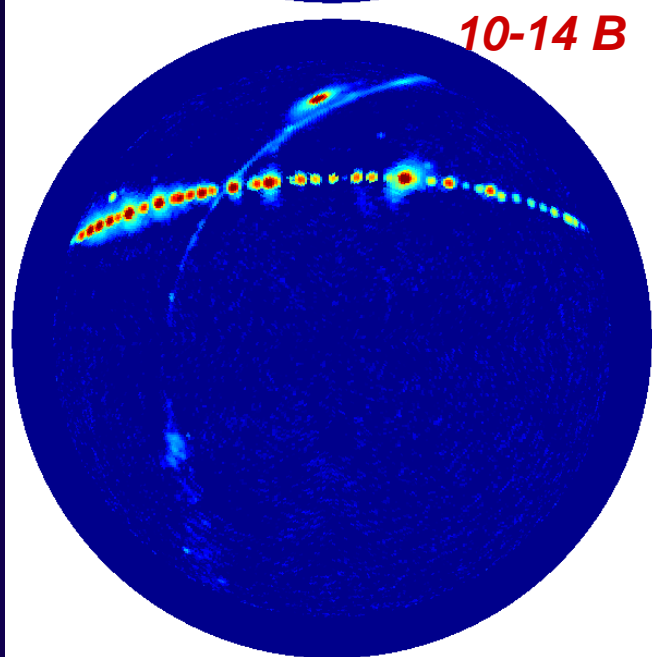
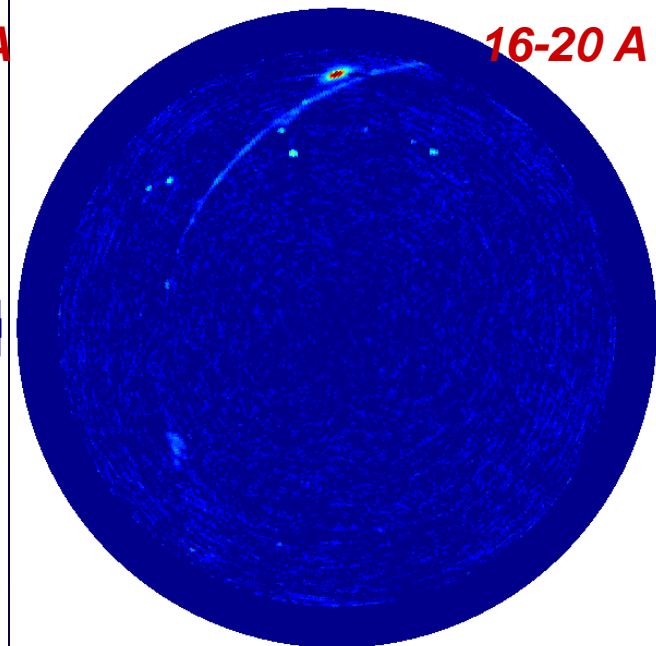
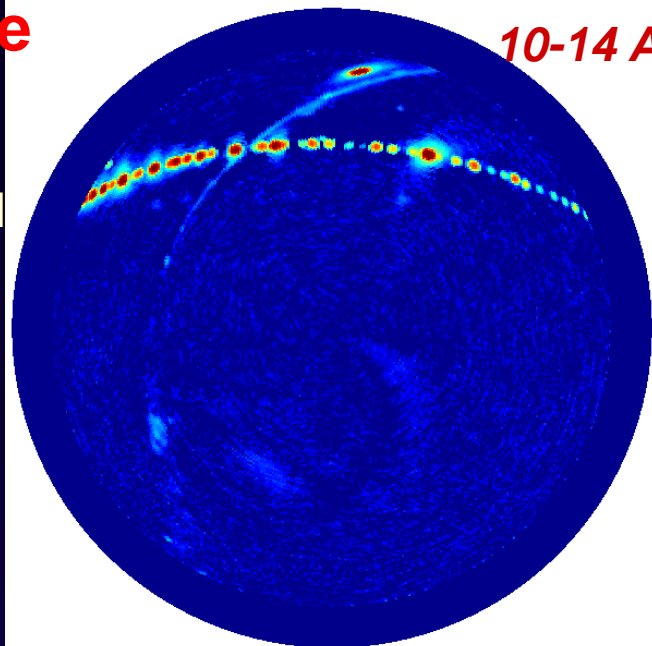


10 times fainter  
than Crab



# LOCAL interference maps

- Uses nominal mode, and it represents local coordinates centred at zenith (N is bottom, E is left).
- A full map is produced in 3hrs, covering from  $EL=30^\circ$  to  $90^\circ$  with steps of  $0.2^\circ$ , and telescope velocity of 4deg/s.
- This example was taken on Dec 27<sup>th</sup> 2012, during the morning (the Sun is visible).
- Stripe of geo-stationary satellites at declination  $0^\circ$  is seen in the 10-12GHz band.

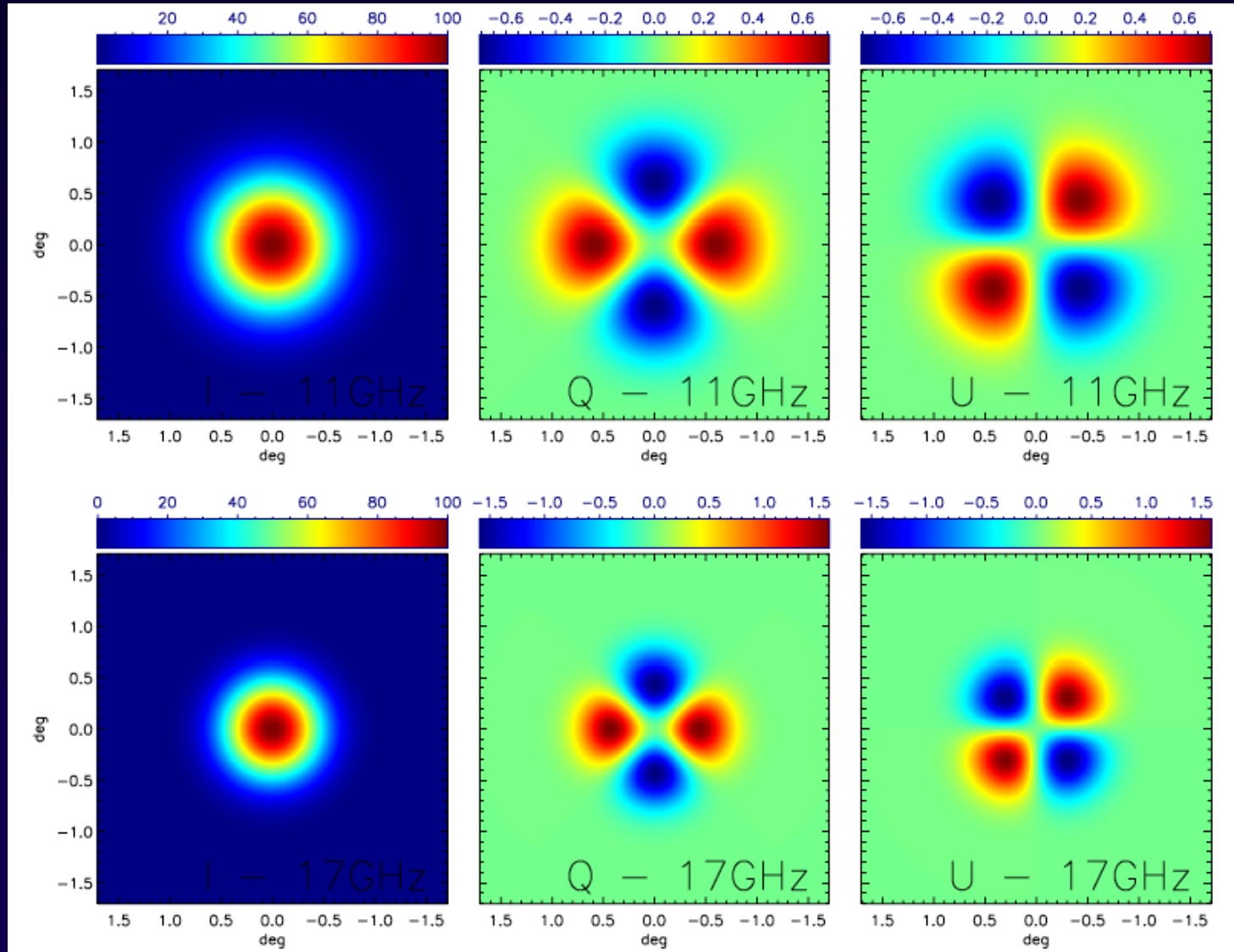


0.0 5.2 Log (S/N)

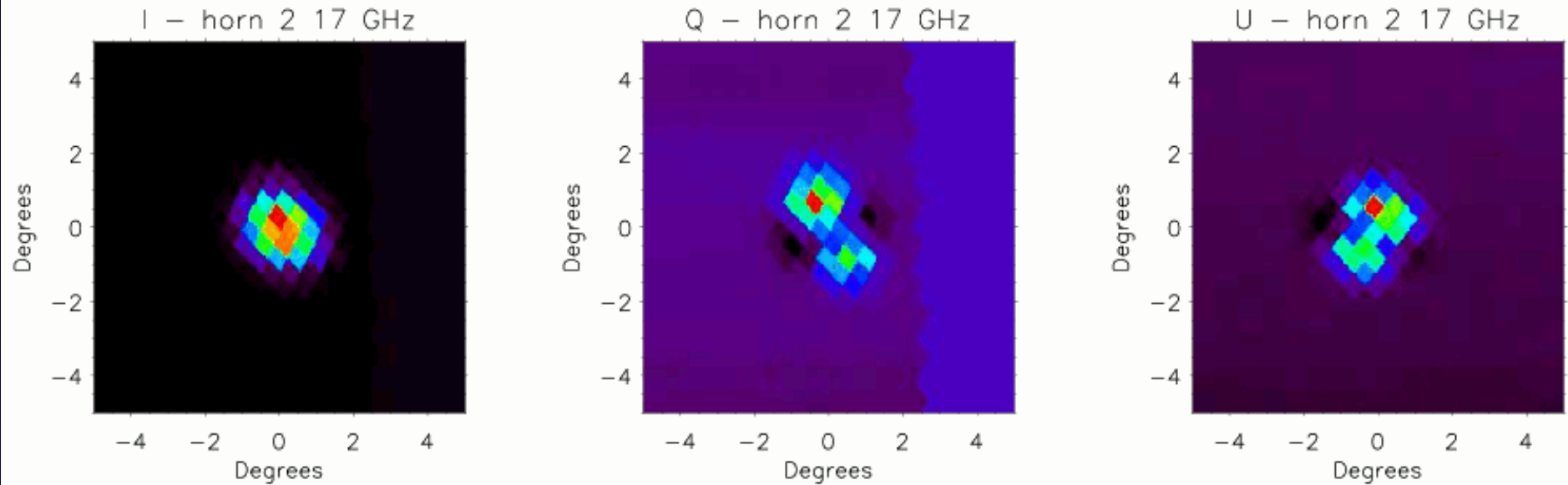
0.0 5.0 Log (S/N)

# Moon model

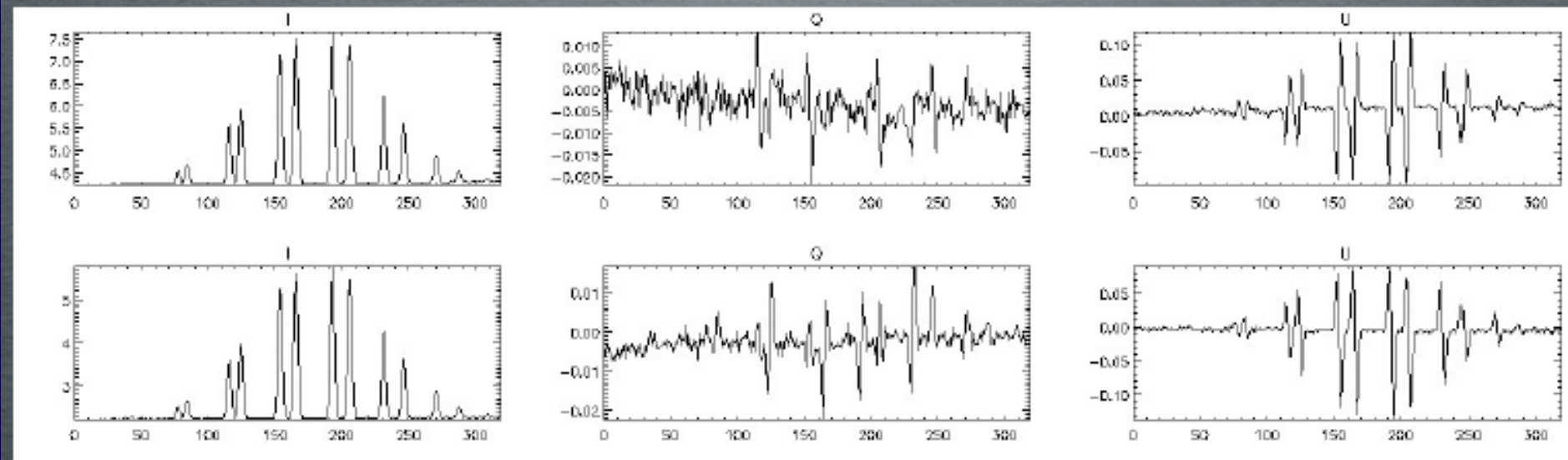
- Dielectric sphere of refractive index  $n_i=1.8$  at uniform temperature (see Davies & Gardner 1966; Bischoff 2010).



# Moon Maps at 17 GHz of Stokes I, Q and U (integration time of 1 min on source)



- Moon observations on 22/11/2012 (continuous movement of the modulators):



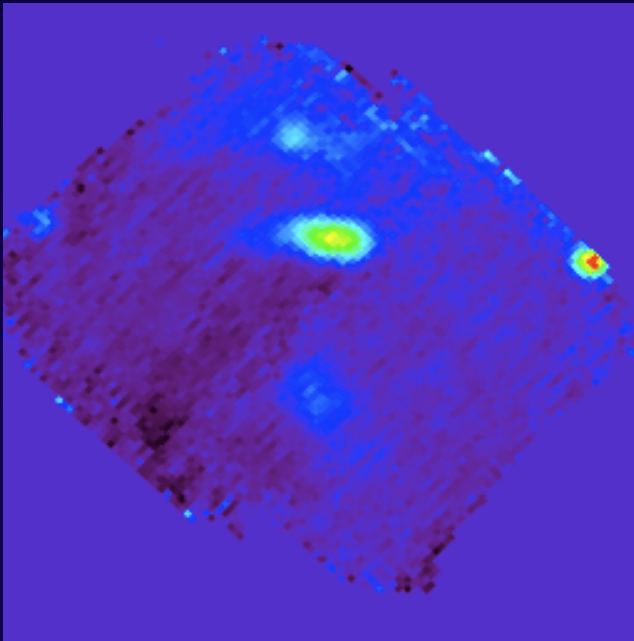
## QUIJOTE: first science observations

★ Large observation programme (~100 hours, from december 2012, still ongoing), on an area covering ~200 deg<sup>2</sup> around the Perseus molecular complex. One of the brightest AME regions on the sky (Watson et al. 2005, Planck collaboration 2011)

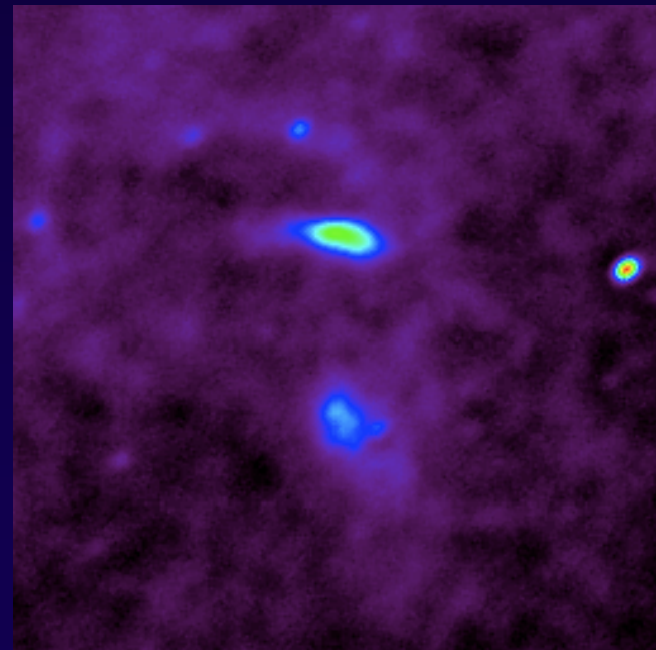
★ Also covering the California nebula (HII region - null polarization control region)

Final integration time of ~ 2500 s/beam, yielding a sensitivity of ~ 40 mJy/beam in Q and U

Quijote 11 GHz



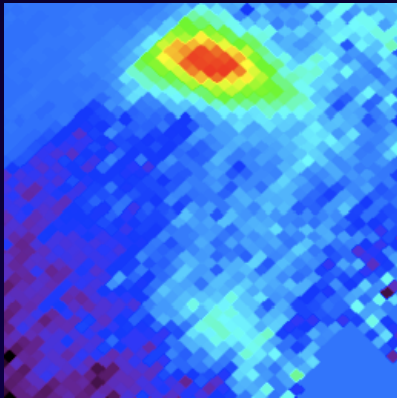
Planck 30 GHz



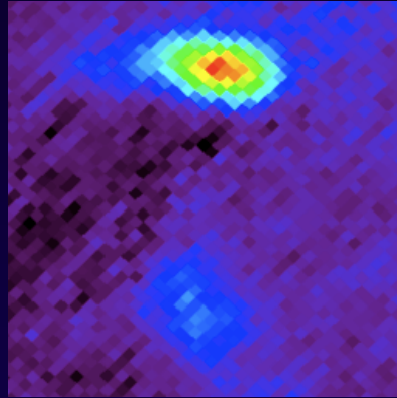
# Perseus intensity maps

Preliminary

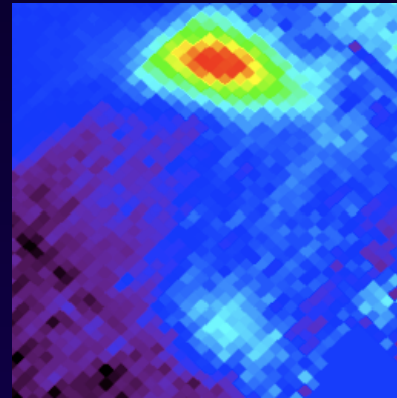
Horn 1 11 GHz



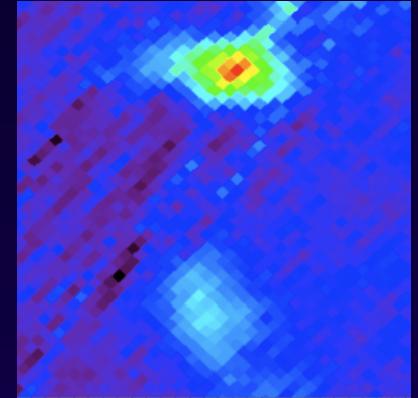
Horn 3 11 GHz



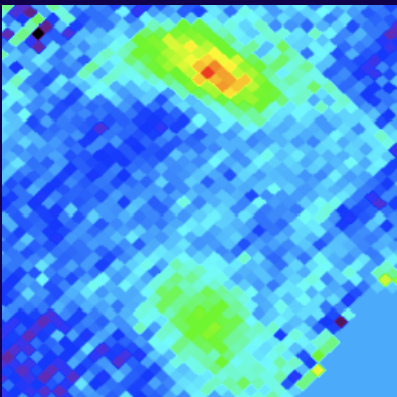
Horn 1 13 GHz



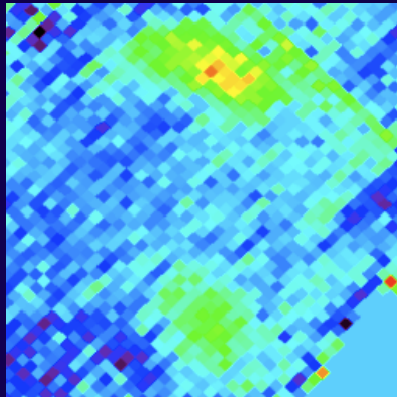
Horn 3 13 GHz



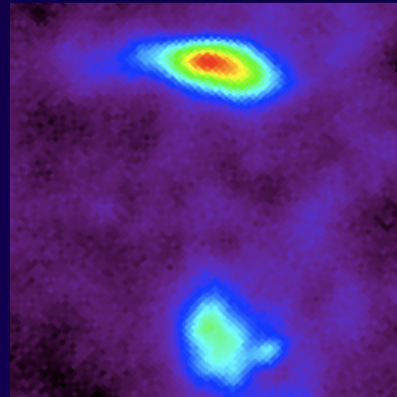
Horn 2 17 GHz



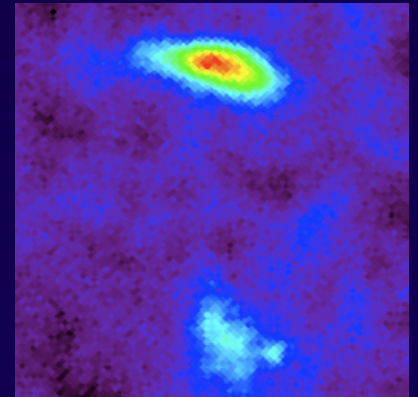
Horn 2 19 GHz



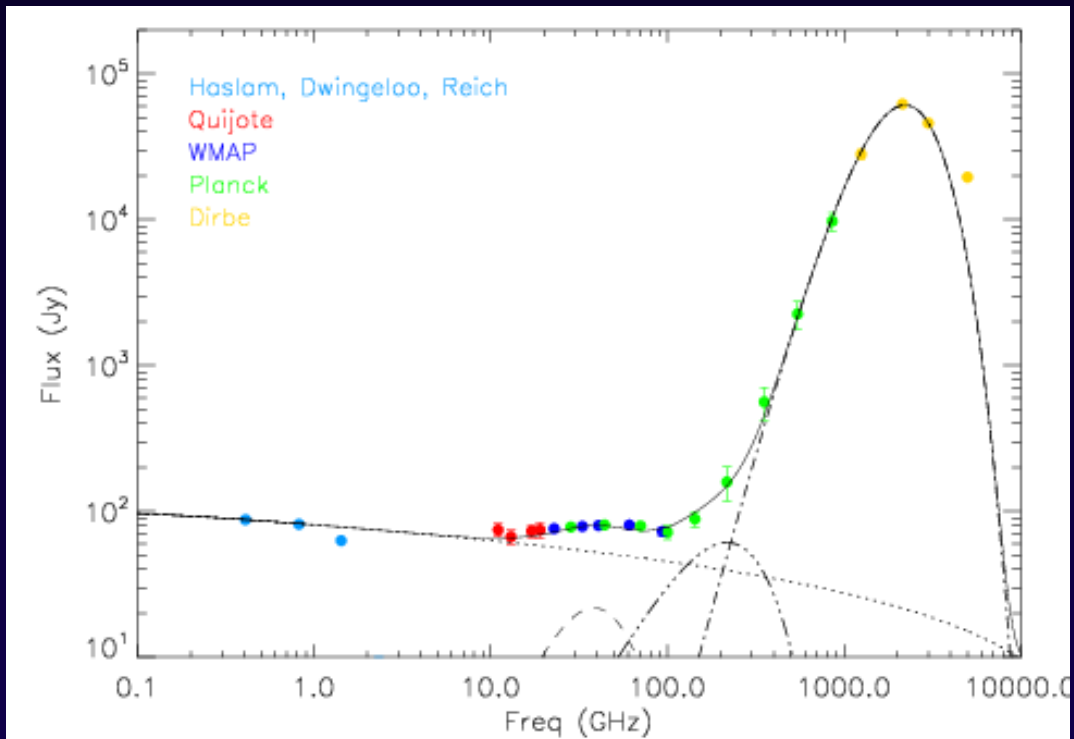
LFI 30 GHz



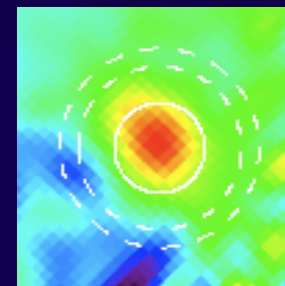
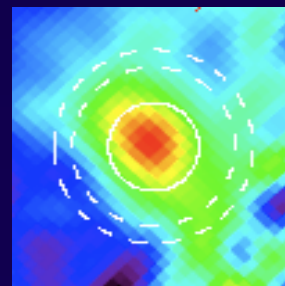
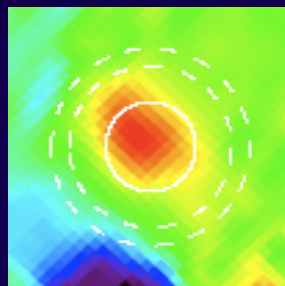
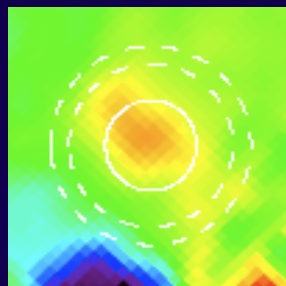
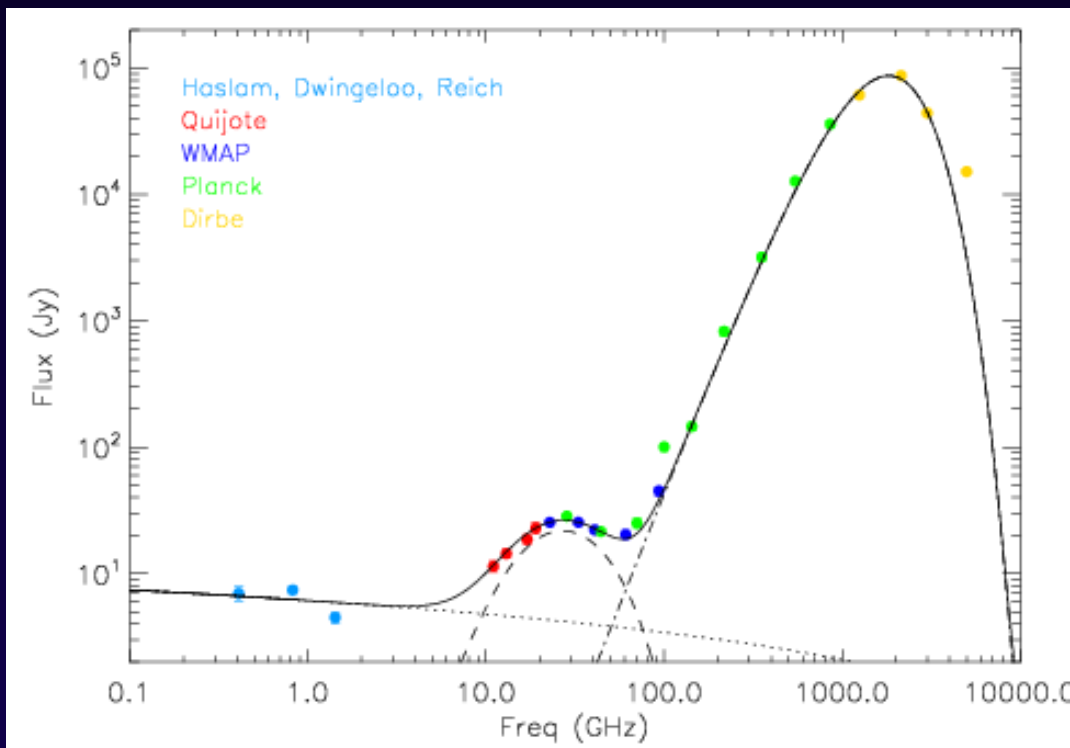
LFI 44 GHz



# Perseus and California intensity SED



# Perseus and California intensity SED



# Polarization maps

## PRELIMINARY

No sources in the field with flux  $> 0.6$  J

Q maps

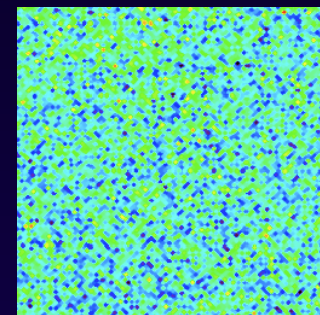
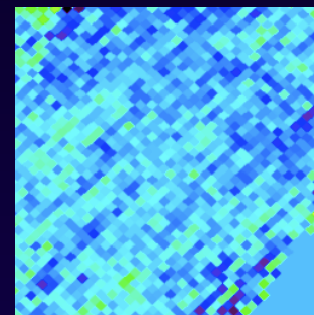
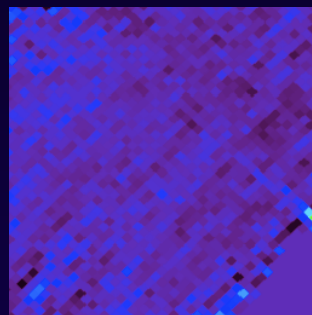
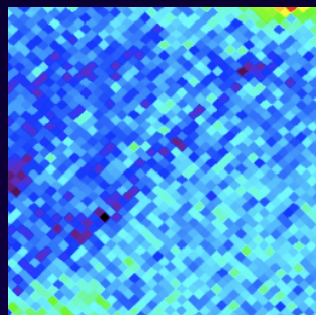
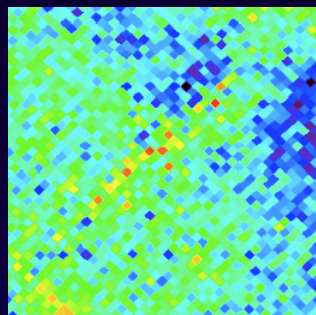
11 GHz

13 GHz

17 GHz

19 GHz

WMAP 23 GHz



U maps

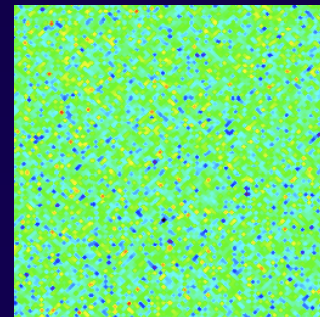
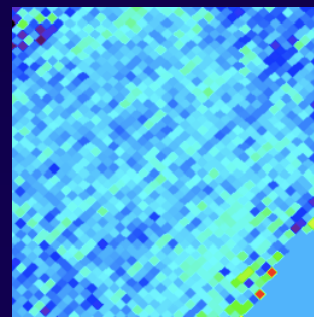
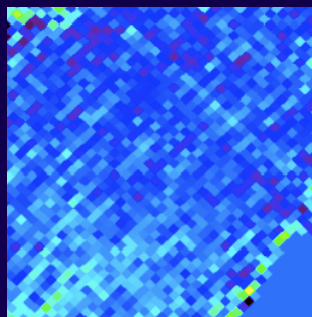
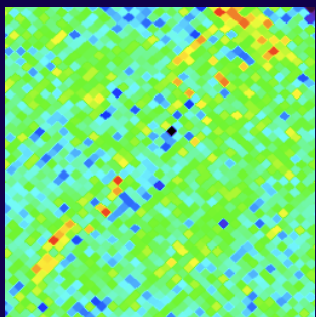
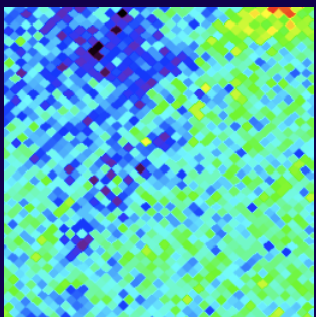
11 GHz

13 GHz

17 GHz

19 GHz

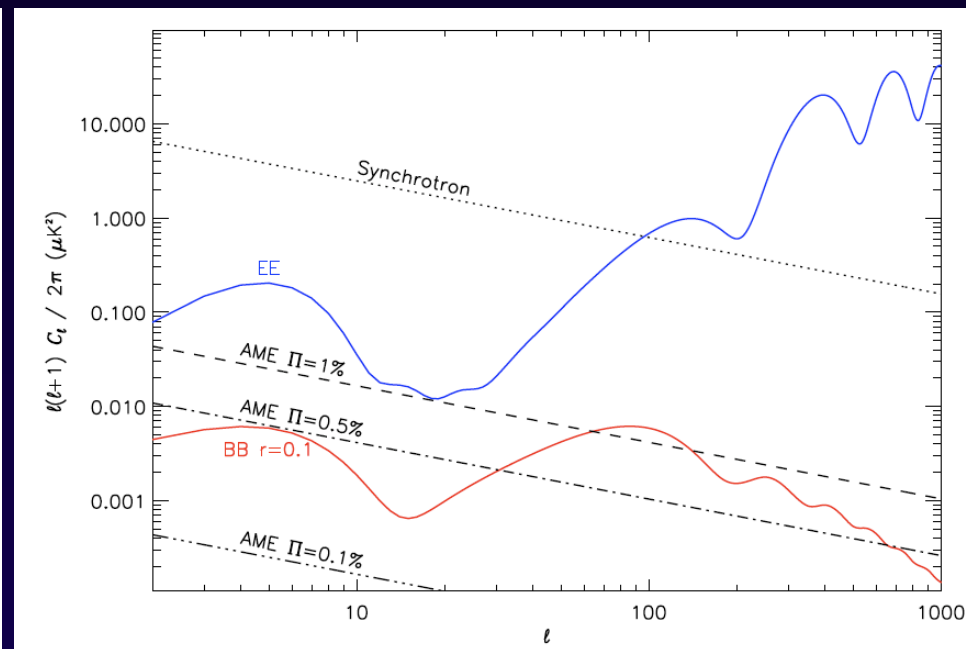
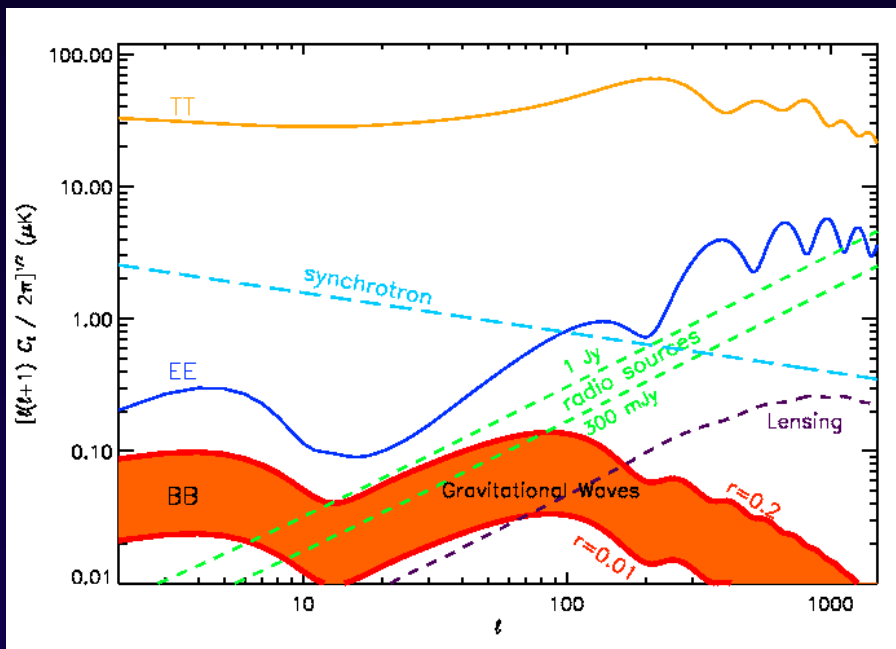
WMAP 23 GHz





## Science with the MFI

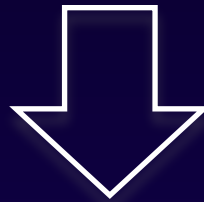
- Contamination introduced by synchrotron and AME at 30 GHz:



- Maps of the MFI deep survey at will be 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 total noise of the TGI maps after 1 year

## ❖ Main objectives of QUIJOTE-CMB:

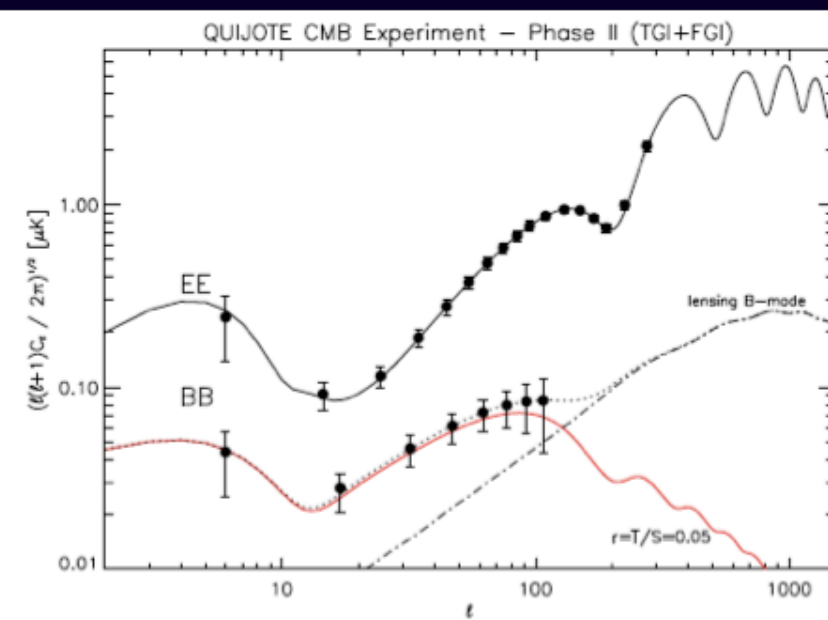
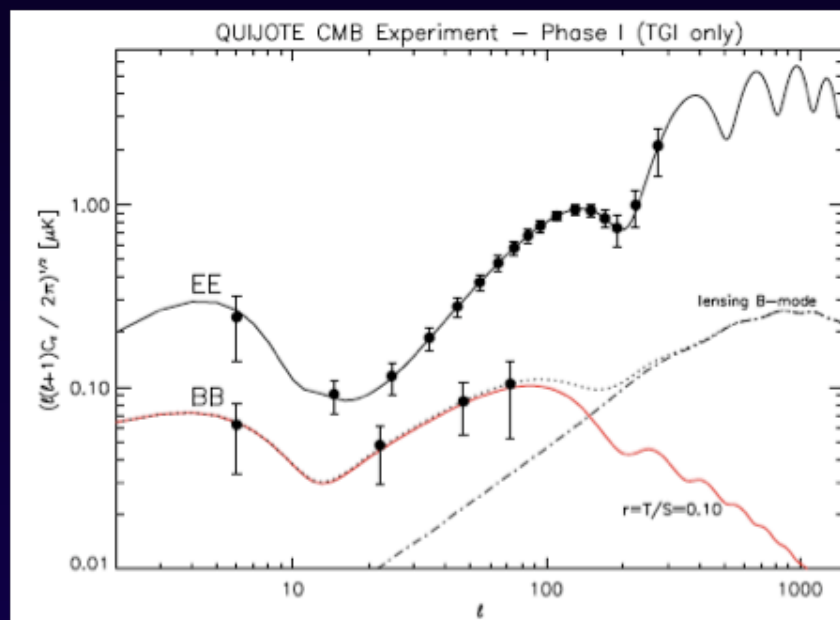
- To detect the imprint of the gravitational B-modes if  $r \geq 0.05$
- To provide precise information of the polarization of the synchrotron and of the AME from our galaxy at low frequencies (10-40 GHz)



## ❖ Two large surveys in polarization

- **Shallow Galactic survey.** It will cover 10,000 deg<sup>2</sup>, and will be finished after 3 months of observations with each instrument. Expected sensitivities:
  - $\approx 10 \mu\text{K}/(\text{beam } 1^\circ)$  with the MFI @ 11, 13, 17 and 19 GHz, in both Q and U
  - $\leq 2 \mu\text{K}/(\text{beam } 1^\circ)$  with the TGI @ 30 GHz and with the FGI @ 40 GHz
- **Deep cosmological survey.** It will cover around 3,000 deg<sup>2</sup>. Expected sensitivities after 1 year:
  - $\approx 5 \mu\text{K}/(\text{beam } 1^\circ)$  with the MFI @ 11, 13, 17 and 19 GHz
  - $\leq 1 \mu\text{K}/(\text{beam } 1^\circ)$  with the TGI @ 30 GHz and with the FGI @ 40 GHz

# PROSPECTS of Science with the TGI and FGI



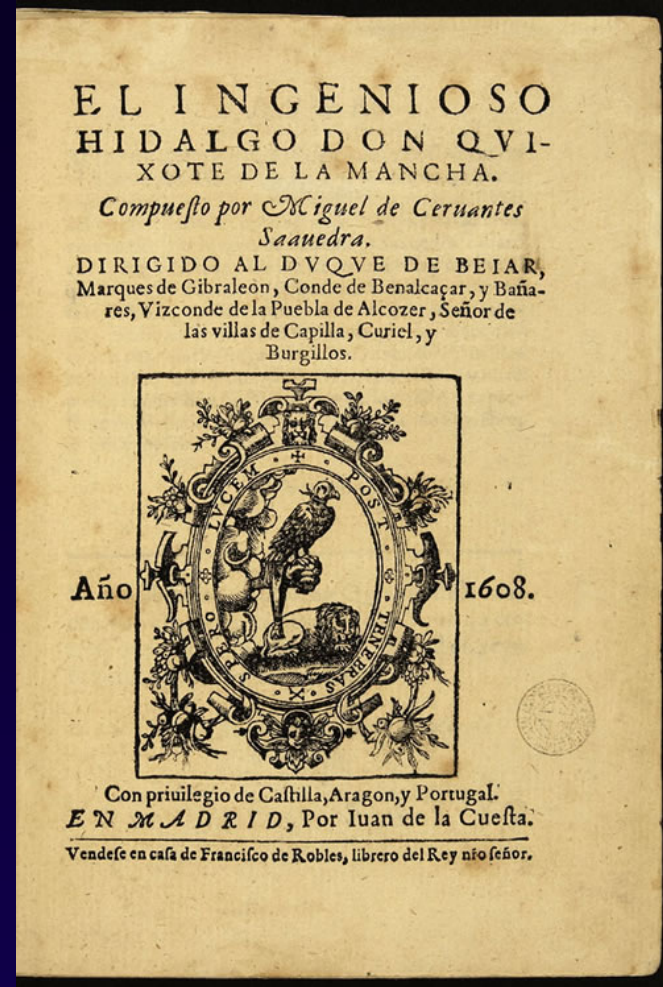
1 year effective time with the TGI  
over 3,000  $\text{deg}^2$



3 years effective time with the  
TGI and 2 years with the FGI  
over 3,000  $\text{deg}^2$



Dalí 1945



We are riding...

Thanks for your attention!