



The QUIJOTE experiment: status and first results

José Alberto Rubiño-Martín (IAC), on behalf of the QUIJOTE Collaboration



CMB foregrounds for B-mode studies

Tenerife, Spain, October 15-18, 2018



The QUIJOTE Collaboration

(<http://www.iac.es/project/cmb/quijote>)





The QUIJOTE experiment

(<http://www.iac.es/project/cmb/quijote>)



Teide Observatory (altitude 2400 m; 28.3° N, 16.5 W)
Median PWV=3.8mm (Garcia-Lorenzo et al. 2010). And 25% the PWV < 1.7mm.

The QUIJOTE experiment

QT-1 and QT-2: Cross-Dragone telescopes, 2.25m primary, 1.9m secondary.

QT-1. Instrument: MFI.
11, 13, 17, 19 GHz.
FWHM=0.92°-0.6°
In operations since 2012

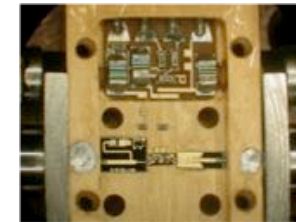
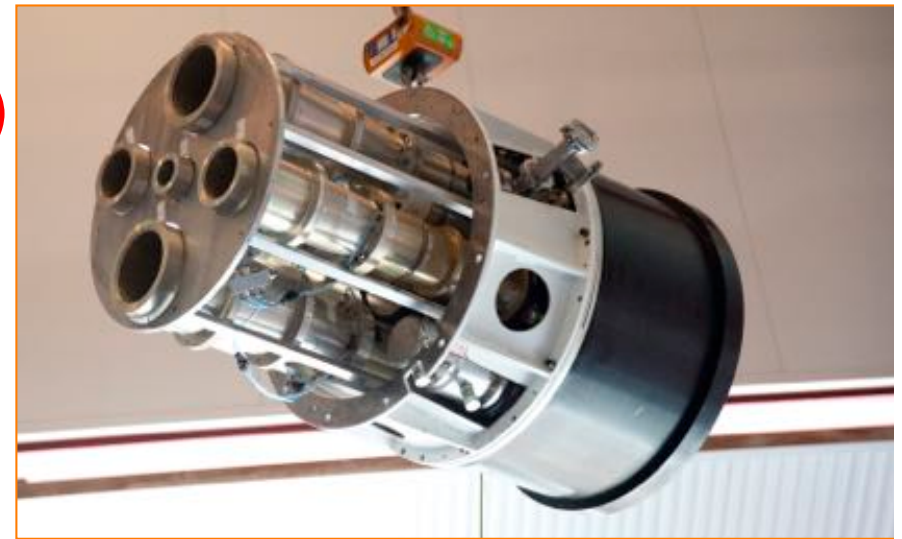
QT-2. Instruments: TGI & FGI
30 and 40 GHz.
FWHM=0.37°-0.26°
In operations since 2016.





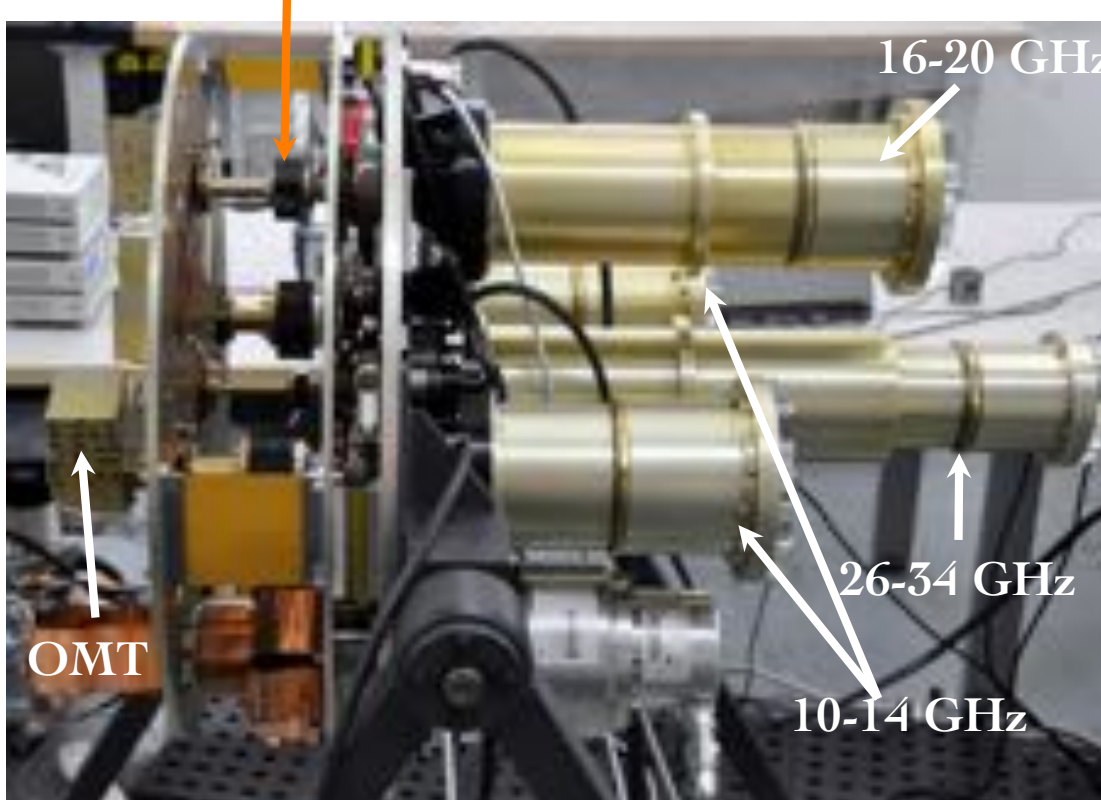
MFI Instrument (10-20 GHz)

- ❖ In operations since Nov. 2012.
- ❖ 4 horns, 32 channels. Covering 4 frequency bands: 11, 13, 17 and 19 GHz.
- ❖ Sensitivities: $\sim 400-600 \mu\text{K s}^{1/2}$ per channel.
- ❖ **MFI upgrade (MFI2)**. Funds secured. Aim: to increase the integration speed by a factor of 3.

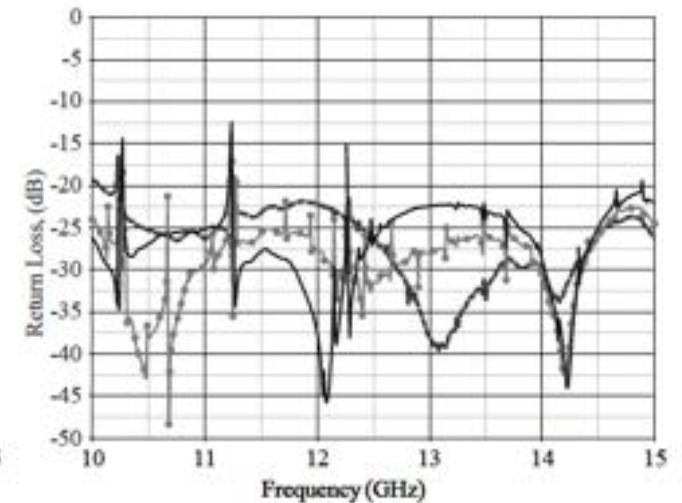
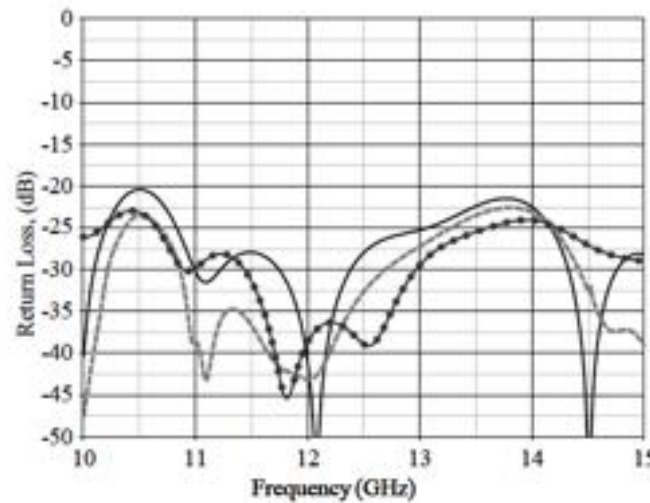
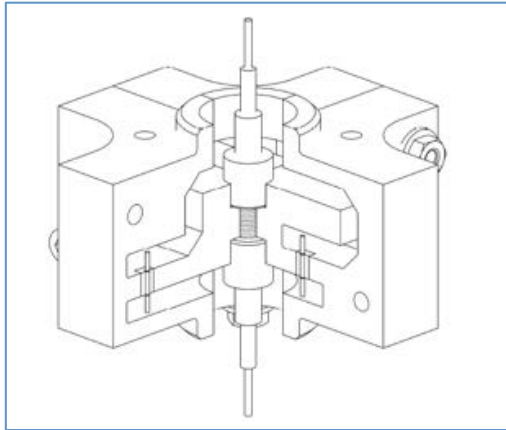


LNA

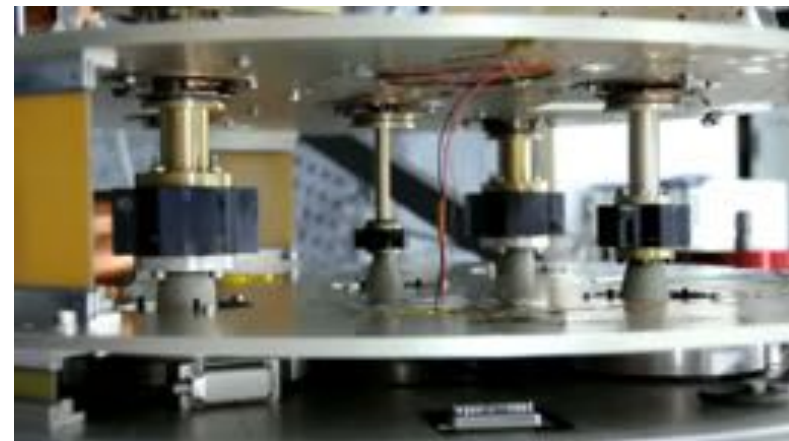
Polar Modulators



MFI Instrument (10-20 GHz). Polar modulator.



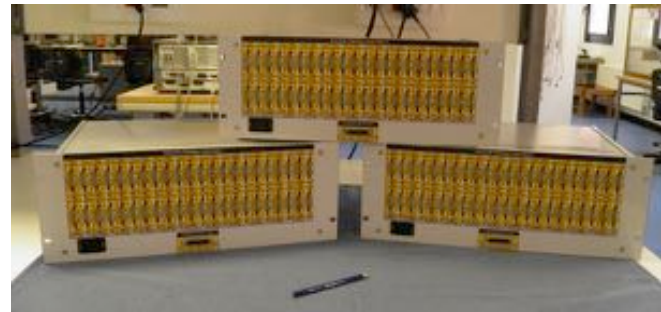
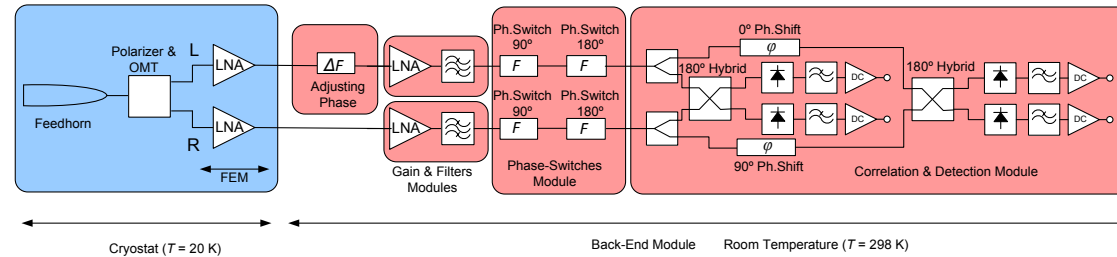
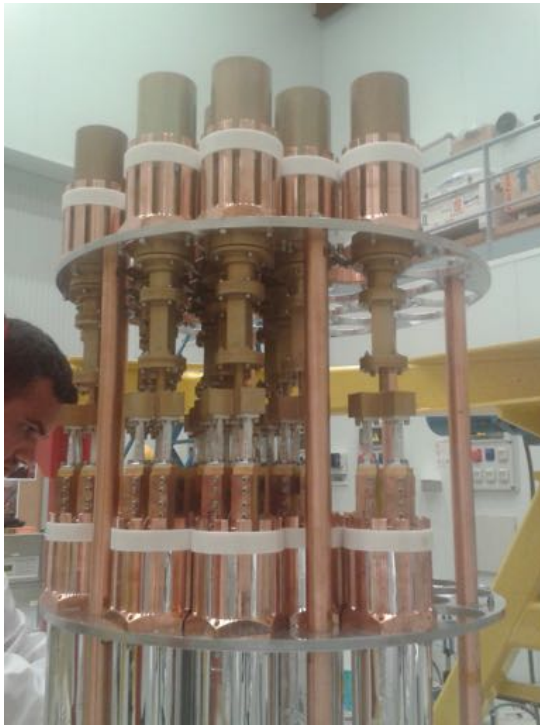
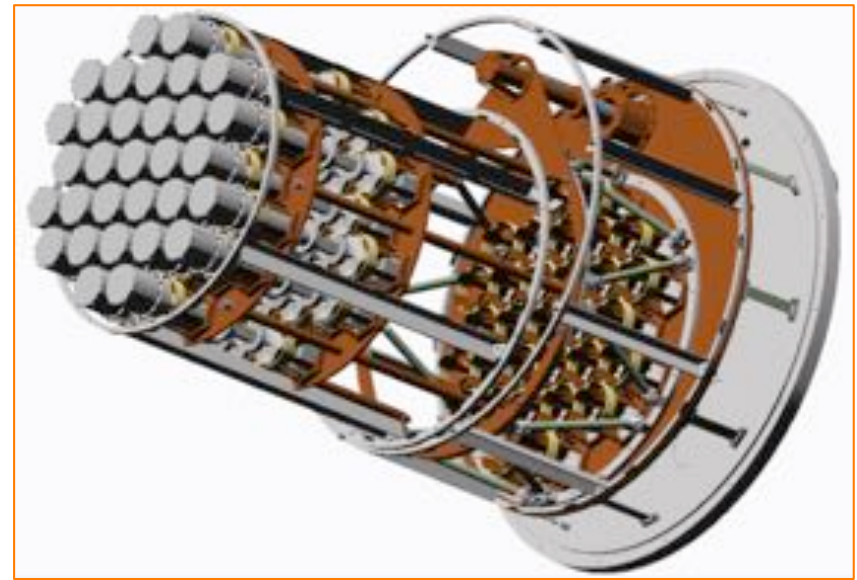
“HWP”: a polar modulator based on a turnstile junction, in waveguide. Advantages: broad band, cooled down in the criostat, and high performance (Return Losses < -20dB, insertion losses < -0.15dB, isolation < -40 dB) .





TGI (30 GHz) and FGI (40GHz) instruments

- ❖ **TGI:** 31 pixels at 30GHz. Measured sensitivity: $50 \mu\text{K s}^{1/2}$ for the full array. First light May 12th 2016.
- ❖ **FGI:** 31 pixels at 40GHz. Expected sensitivity: $60 \mu\text{K s}^{1/2}$ for the full array. In commissioning phase.

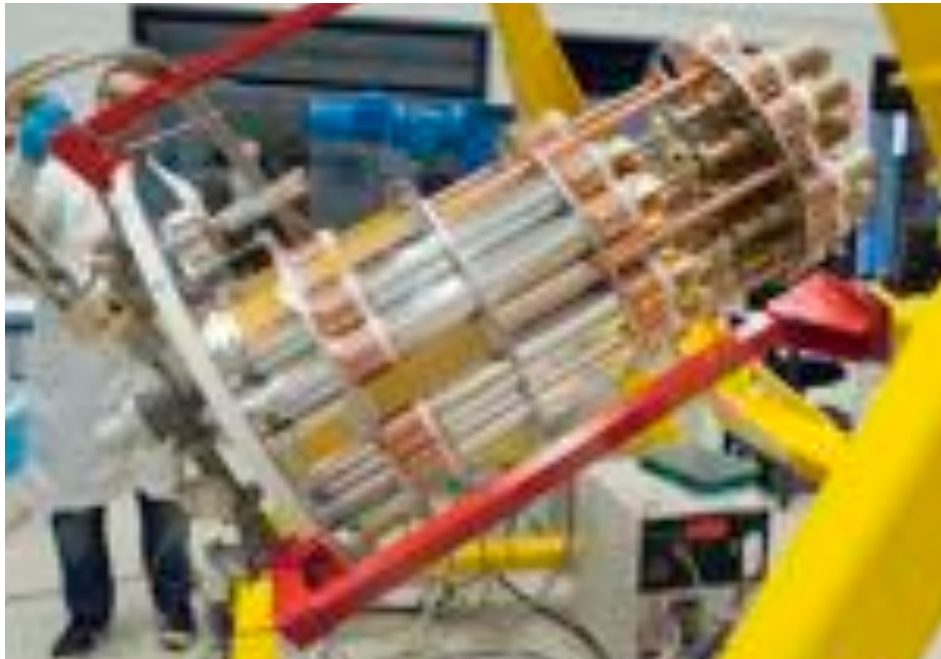




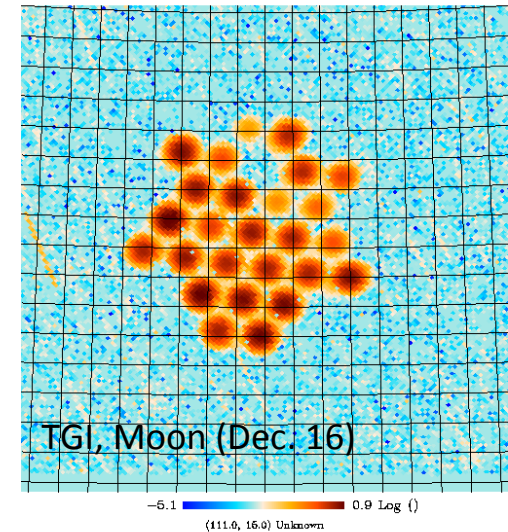
TGI (30 GHz) and FGI (40GHz) instruments

TGI instrument

- Instrument calibrated on lab during Feb-Apr 2016.
- Installed at QT2 focal plane on April 20th, 2016.
- First light on May 12th, 2016 (3 pixels).
- October 16th 2016: 28 pixels installed. Commissioning phase started.



TGI - Moon 27Pixels-161215-2132 (Median4) - Vd1



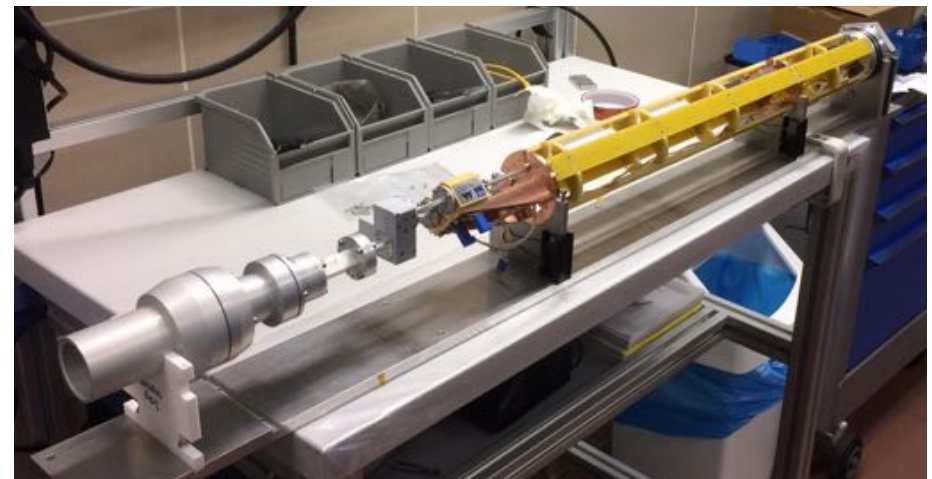
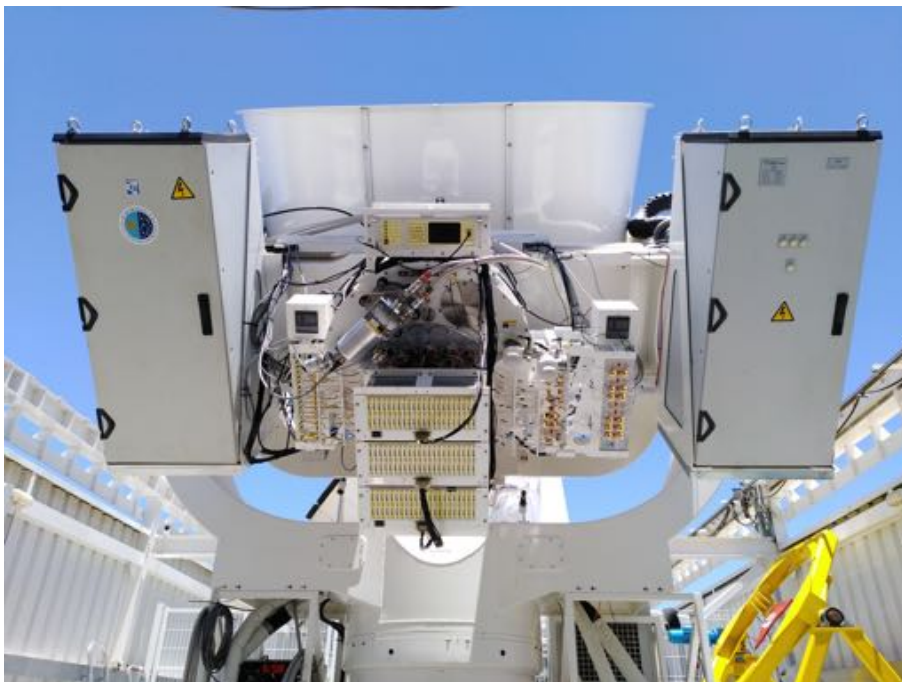
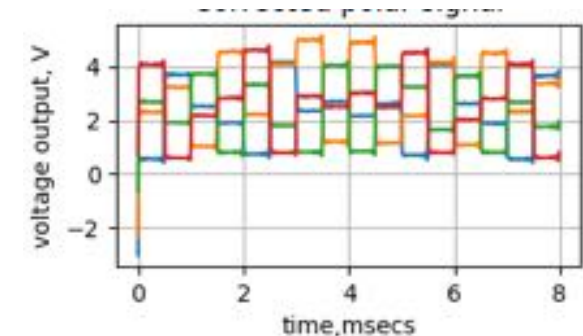
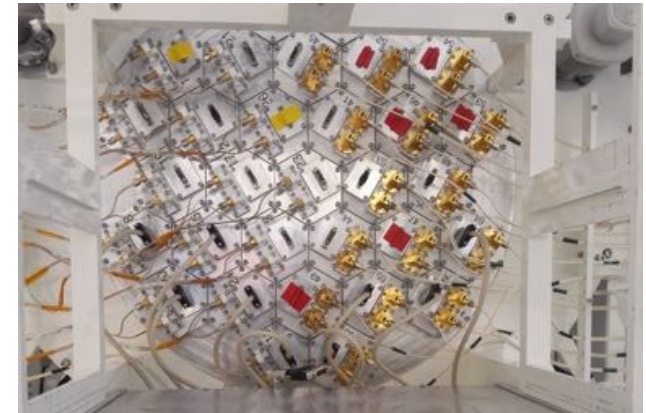
- Preliminary results with three pixels showed:
 - Good quality of beam.
 - Data acquisition tested at 16kHz and 8kHz.
 - $T_{\text{sys}} \sim 36\text{K}$, as expected.
 - $T_{\text{atm}}(\text{zenith})=5\text{K}$ for $\text{pwv}=3\text{mm}$ (expected from ATM model).
 - Knee frequencies for polarization measurements around 20mHz.
 - Extrapolated array sensitivities of $\sim 50\text{-}60 \mu\text{K s}^{1/2}$.



TGI (30 GHz) and FGI (40GHz) instruments

Joint TGI/FGI operation (May 2018-now)

- 14 FGI receivers integrated cryostat together with 15 TGI pixels. Full array sensitivity: $\sim 85 \mu\text{K}\cdot\text{s}^{1/2}$ at 30 GHz and at $\sim 71 \mu\text{K}\cdot\text{s}^{1/2}$ at 40 GHz.
- Observing plan for TGI/FGI science phase: cosmo survey in 3 effective years.
- Preliminary T_{sys} estimates for 40GHz show values according to expectations.
- Now in calibration and commissioning phase.

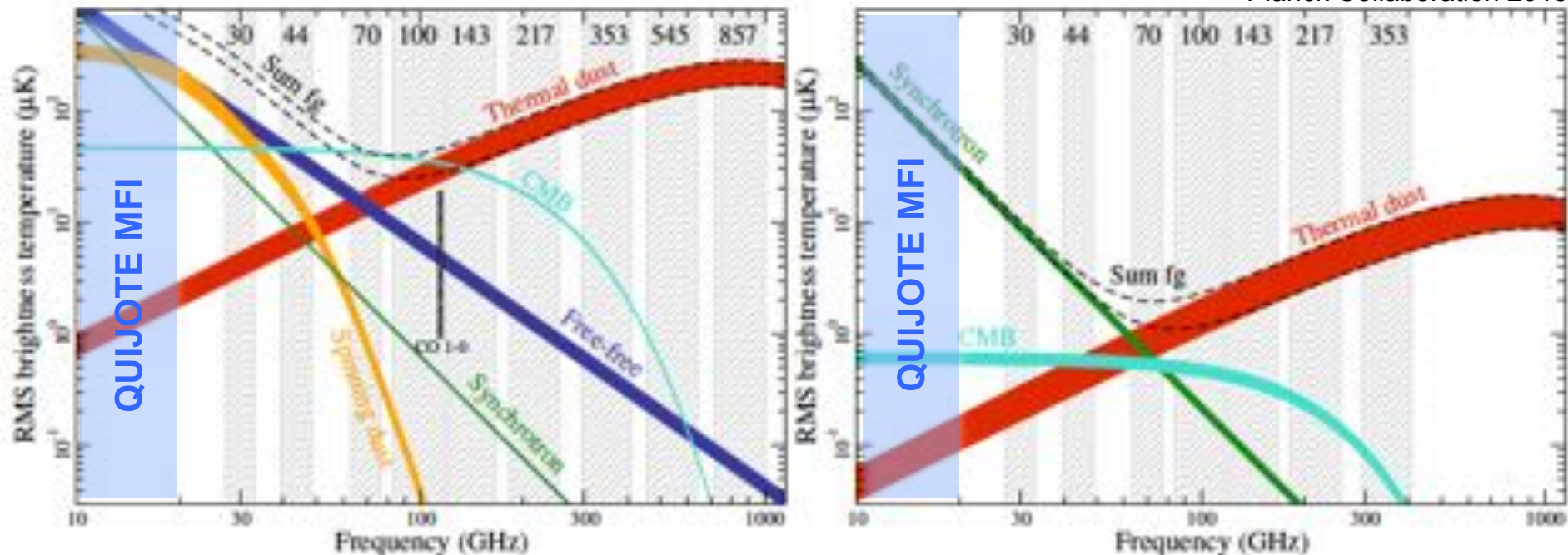


Science with QUIJOTE first instrument (MFI)

- ❖ **Shallow Galactic survey.** Covering 20,000 deg² (~10000 hrs completed)
 - $\approx 30 \mu\text{K}/(\text{beam } 1^\circ)$ with the MFI @ 11, 13, 17 and 19 GHz, in both Q and U.
- ❖ **Deep cosmological survey.** It will cover around 3,000 deg² in three separated fields.
 - $\approx 10 \mu\text{K}/(\text{beam } 1^\circ)$ after 1 year with the MFI @ 11, 13, 17 and 19 GHz.

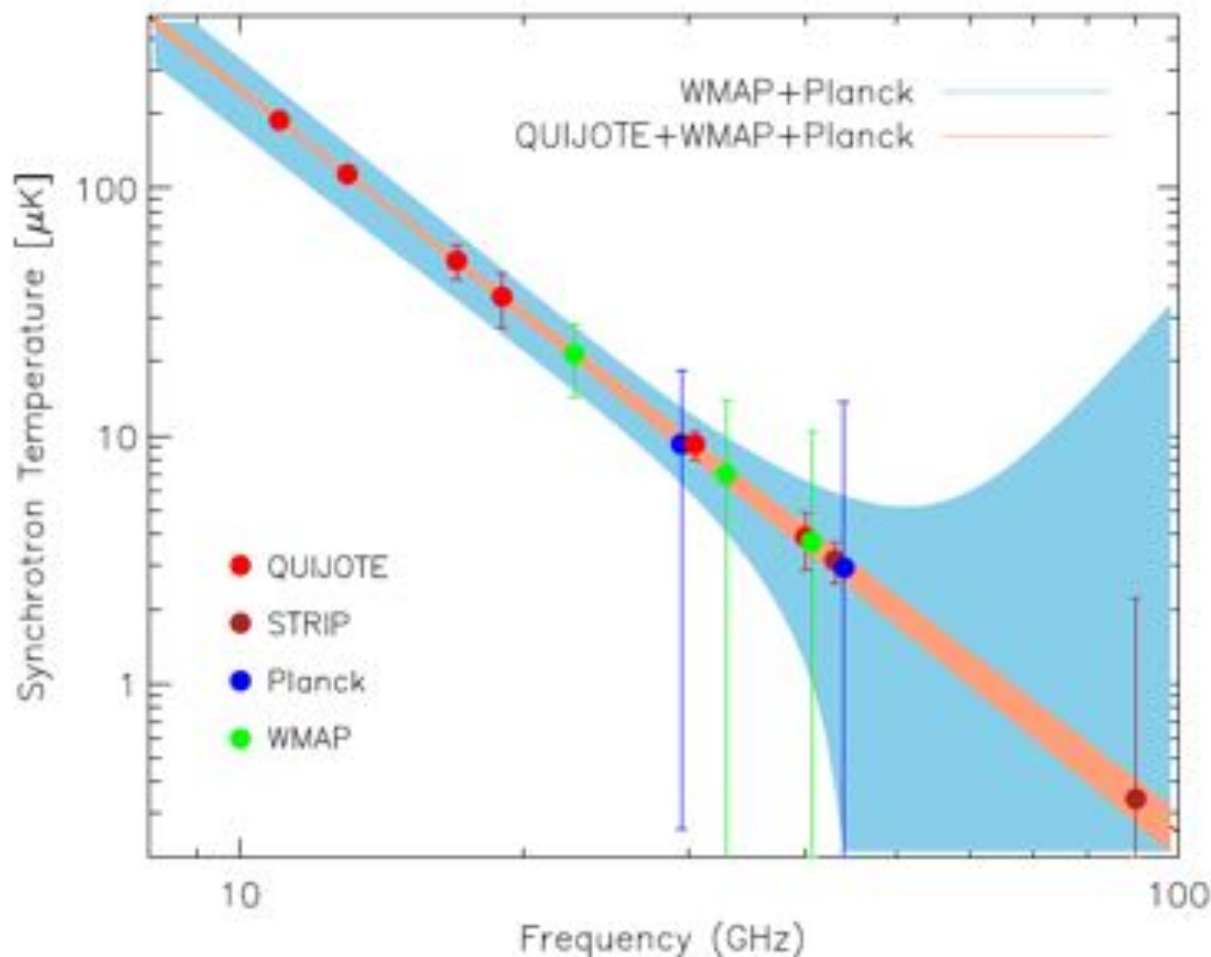
- ❖ These maps will provide valuable information about the **polarization** properties of:
 - Synchrotron: main emission mechanism at our frequencies.
 - Anomalous microwave emission (spinning dust?). Current best upper limits of polarization fraction are 0.2% (G nova-Santos et al. 2017) .
- ❖ Excellent complement to PLANCK at low frequencies. Legacy for future experiments.

Planck Collaboration 2015



Science with QUIJOTE first instrument (MFI)

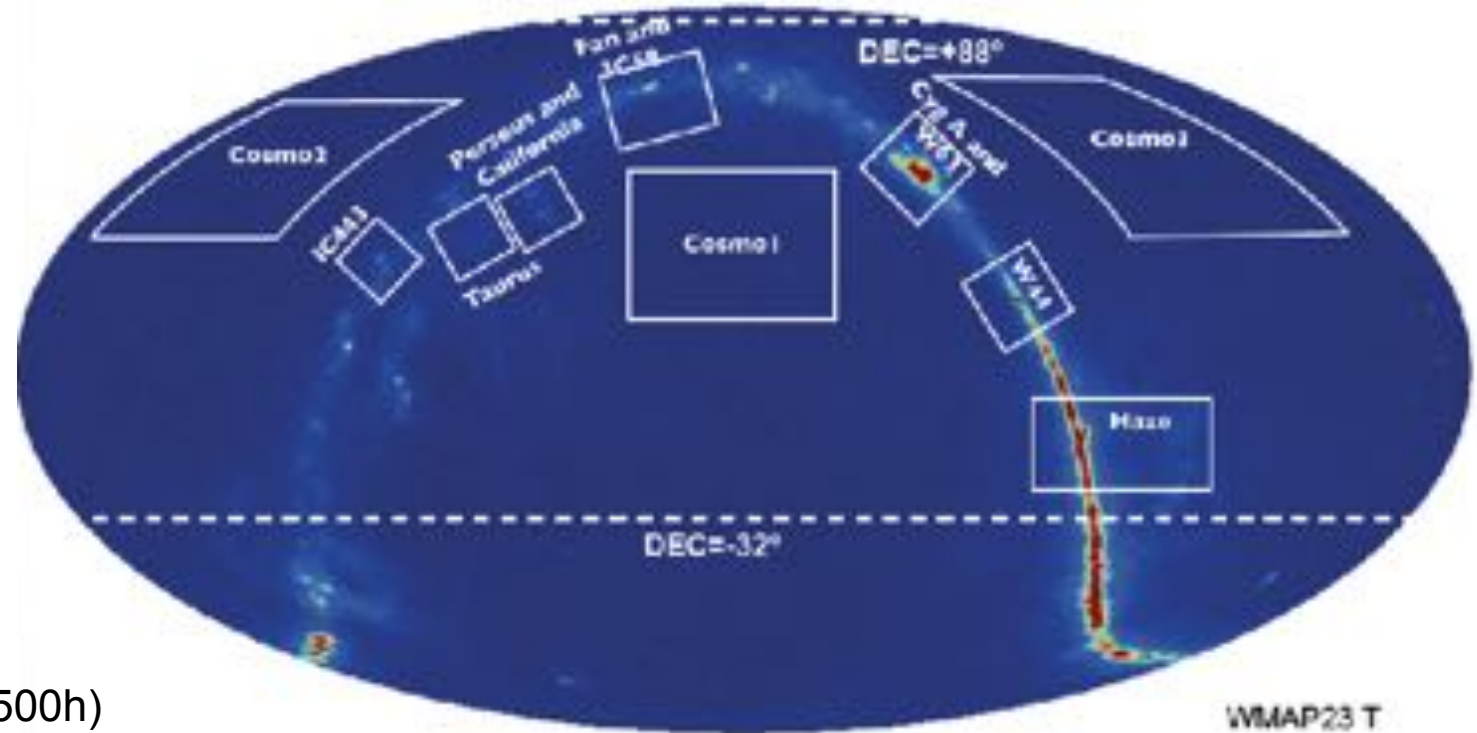
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- Improvement in the characterisation of the synchrotron spectrum thanks to the inclusion of QUIJOTE MFI data.
- QUIJOTE MFI frequencies are needed to separate AME and synchrotron curvature.

QUIJOTE cosmological and galactic fields

Observing strategy: Deep observations in selected areas using raster scans, plus wide survey.



MFI Science phase

(April 2013 - now)

- Wide survey (10,800h)
- Cosmological fields (6,500h)
- Daily calibrators (Crab, Cass A, Jupiter, sky dips)
- Galactic centre and Haze (930h)
- Perseus molecular cloud (600h)
- Fan region and 3C58 (460h)
- Taurus region (450h)
- SNRs (W44, W47, IC443, W63) (900h)

Total: ~25,500 h of MFI data (2.9 effective years), with ~50% efficiency.



Wide survey with the QUIJOTE MFI (10-20GHz)

- 10,800 hrs on a region of 20,000 deg² in the northern sky.
- Goal: ~30 $\mu\text{K}/\text{deg}$ in Q,U. Current sensitivities around 40-55 $\mu\text{K}/\text{deg}$.
- **Observing strategy:** “nominal mode”, consisting in continuous 360° AZ scans at constant elevation.
 - EL = 30°, 35°, 40°, 50°, 60°, 65° and 70°.
 - Data accumulated during 5 years, in different periods.
- **Data processing:**
 - Basic processing similar to other QUIJOTE data (Genova-Santos et al. 2015, 2017)
 - Primary flux calibration: CRAB. Also the polarization calibrator.
 - Gain model. Based on a (thermally stabilised) noise diode. Signal injected during 1s every 30s.
 - RFI correction. Mainly due to geostationary satellites. Objects are flagged, and the far sidelobe contamination (only detectable at 11 and 13GHz in intensity) is removed using signal templates based on data stacks in AZ.
 - Post-processing: removal of large scale residual by subtraction of a dipole component to the final maps.



Wide survey with the QUIJOTE MFI (10-20 GHz)

PRELIMINARY MAPS

HORN	Freq. [GHz]	Beam [deg]	σ_Q [$\mu\text{K}/\text{deg}$]	σ_U [$\mu\text{K}/\text{deg}$]	NET [$\text{mK s}^{1/2}$]
2	16.8	0.63	70.6	70.7	1.71
2	18.7	0.63	90.8	91.3	2.17
3	11.2	0.84	54.3	54.3	1.21
3	12.9	0.85	48.6	48.3	1.05
4	17.0	0.65	40.9	41.0	0.98
4	19.0	0.65	42.6	42.6	0.95

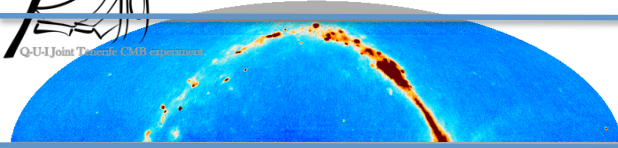
- Noise estimates based on null-tests, splitting the data in two epochs.
- Last column shows the instrument instantaneous (equivalent) sensitivity in polarisation, taking into account the integration time per pixel.
- Preliminary maps have
 - $\sim 50 \mu\text{K}/\text{deg}$ at 11, 13GHz
 - $\sim 40 \mu\text{K}/\text{deg}$ at 17, 19GHz.



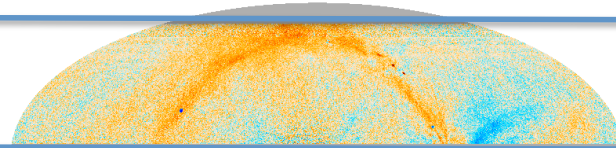
Wide survey with the QUIJOTE MFI (10-20 GHz)

PRELIMINARY MAPS

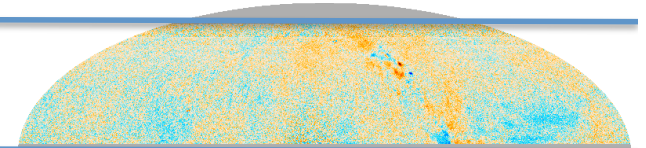
(Note: Q, U defined in Galactic coords.)



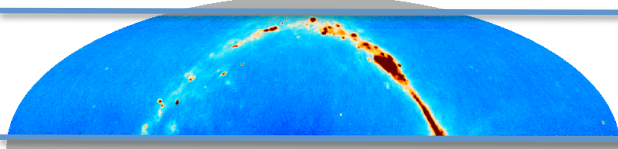
QUIJOTE I 11GHz



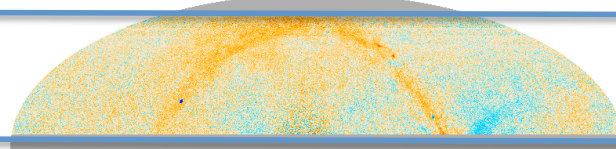
QUIJOTE Q 11GHz



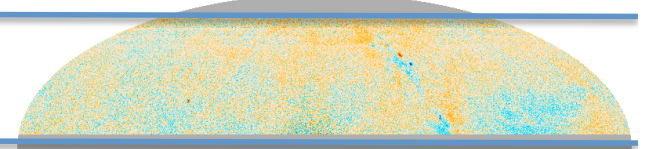
QUIJOTE U 11GHz



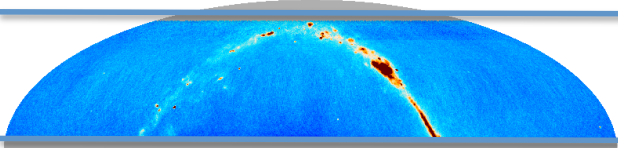
QUIJOTE I 13GHz



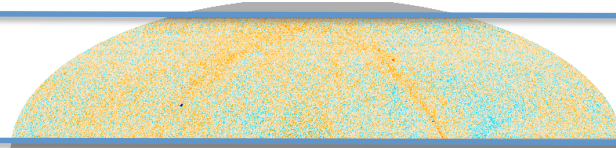
QUIJOTE Q 13GHz



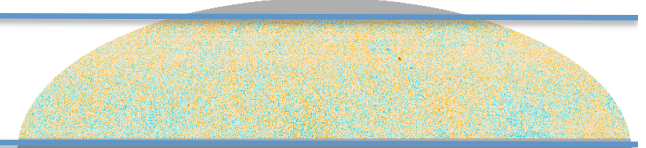
QUIJOTE U 13GHz



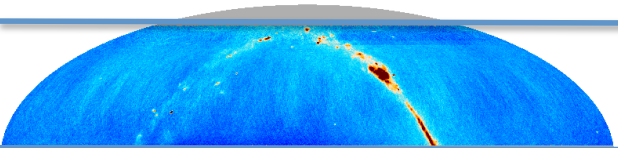
QUIJOTE I 17GHz



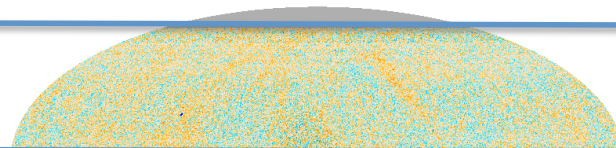
QUIJOTE Q 17GHz



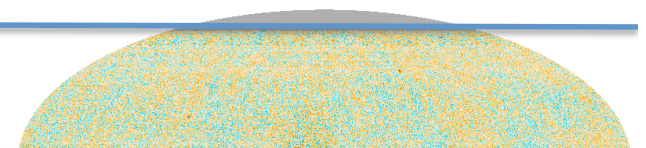
QUIJOTE U 17GHz



QUIJOTE I 19GHz



QUIJOTE Q 19GHz



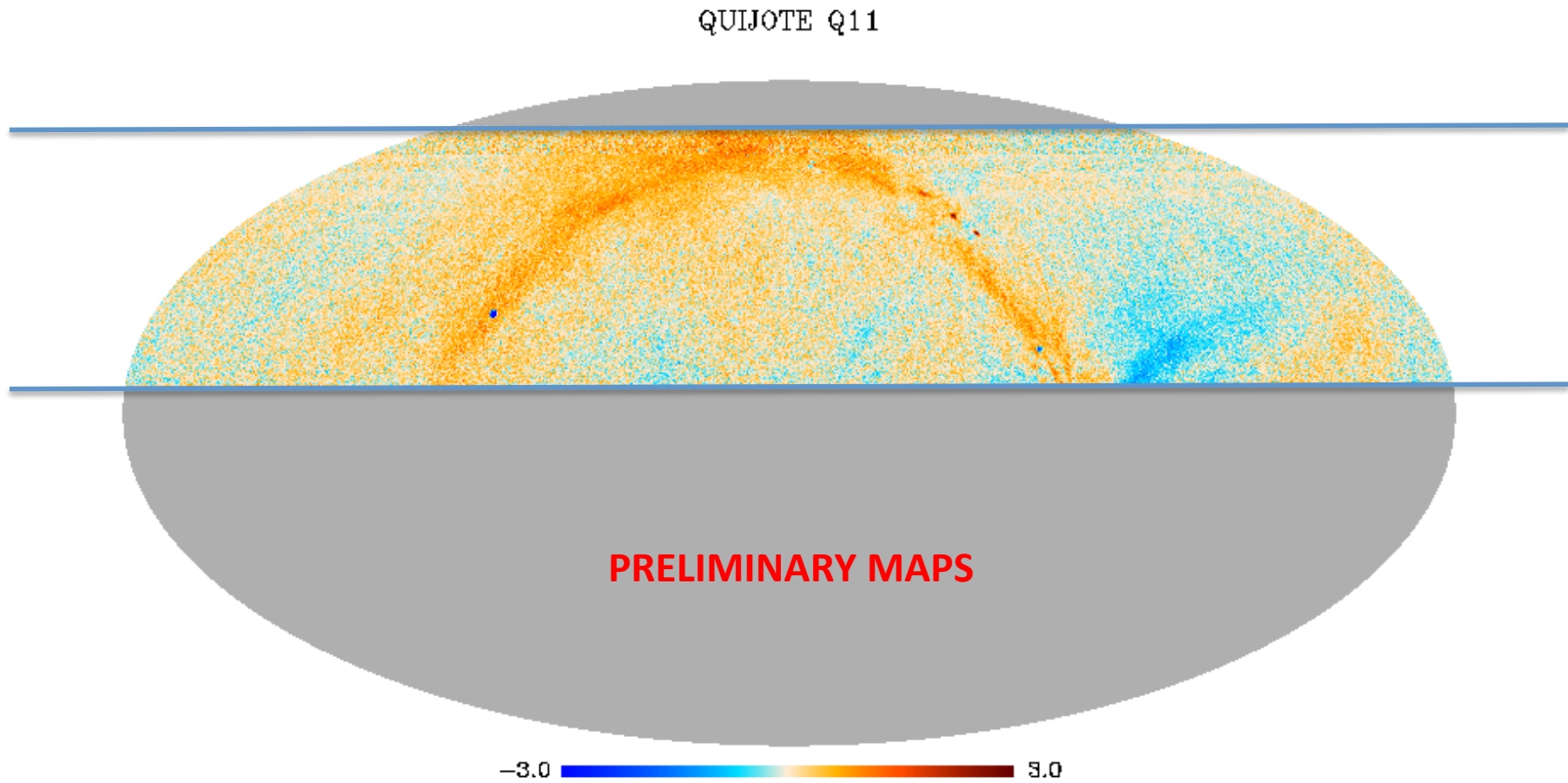
QUIJOTE U 19GHz





Wide survey with the QUIJOTE MFI (10-20GHz)

- Example of polarization maps at 11GHz from one horn (using Equatorial projection).

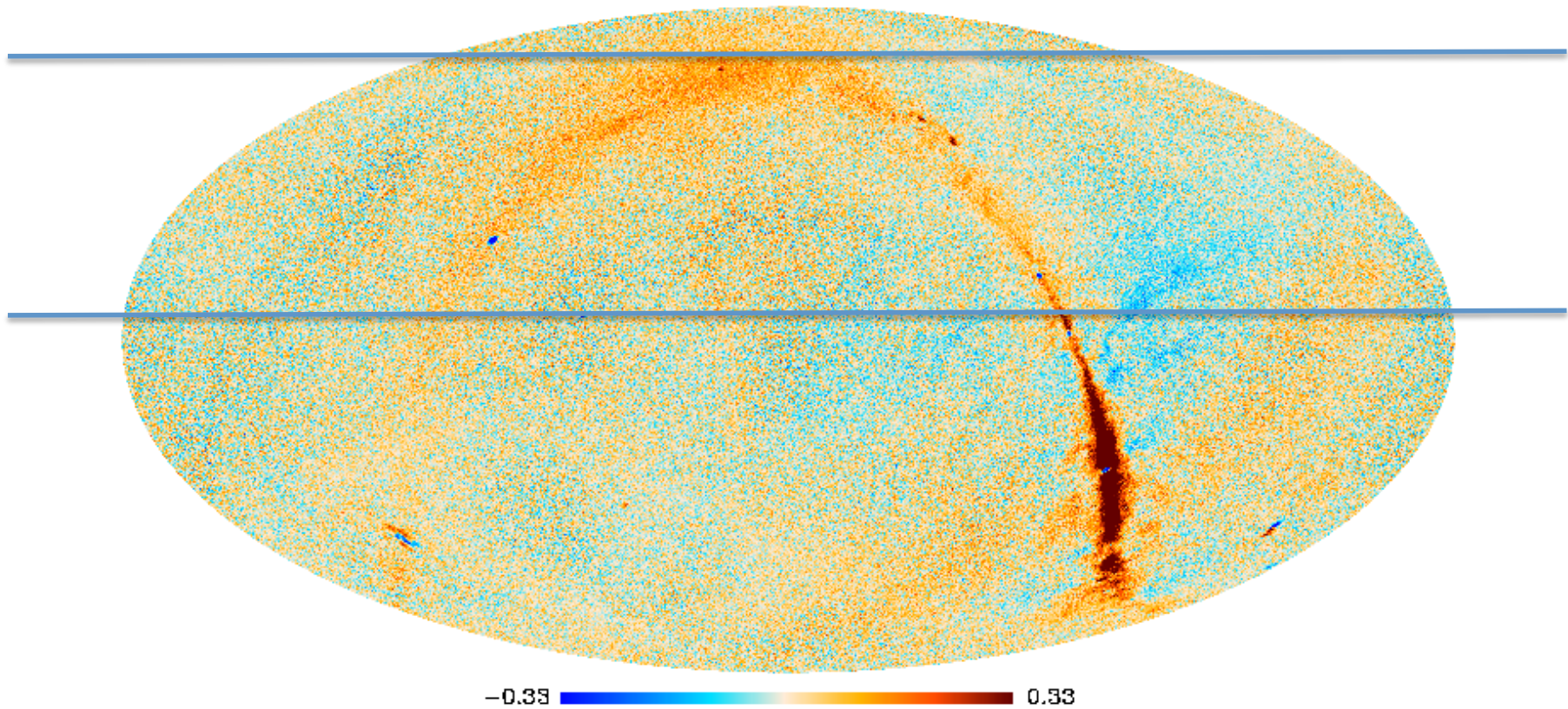


(scaled to preserve the same color
for a signal with $\beta=-3$)

Wide survey with the QUIJOTE MFI (10-20GHz)

- Example of polarization maps at 11GHz from one horn (using Equatorial projection).

WMAP Q23

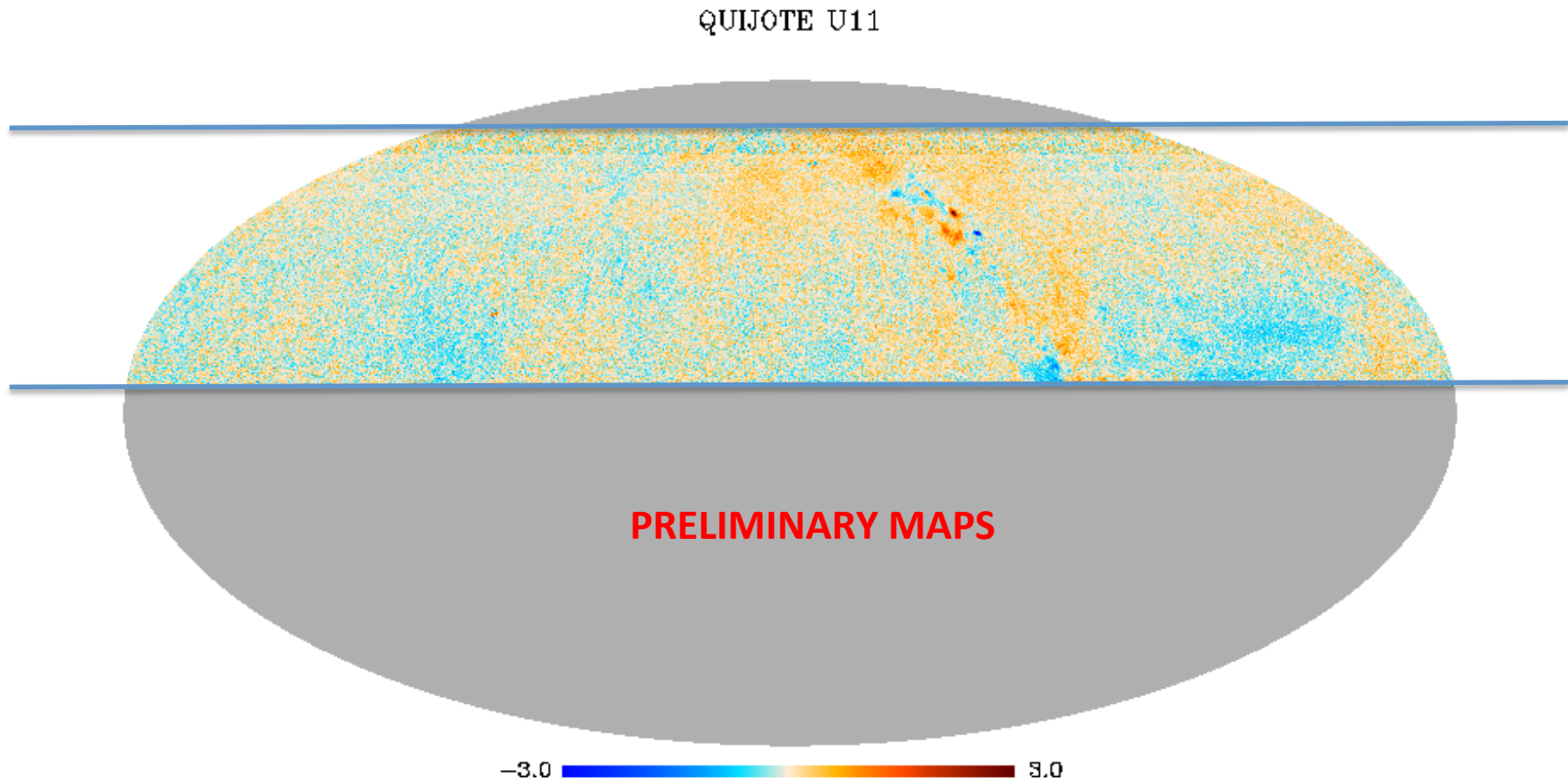


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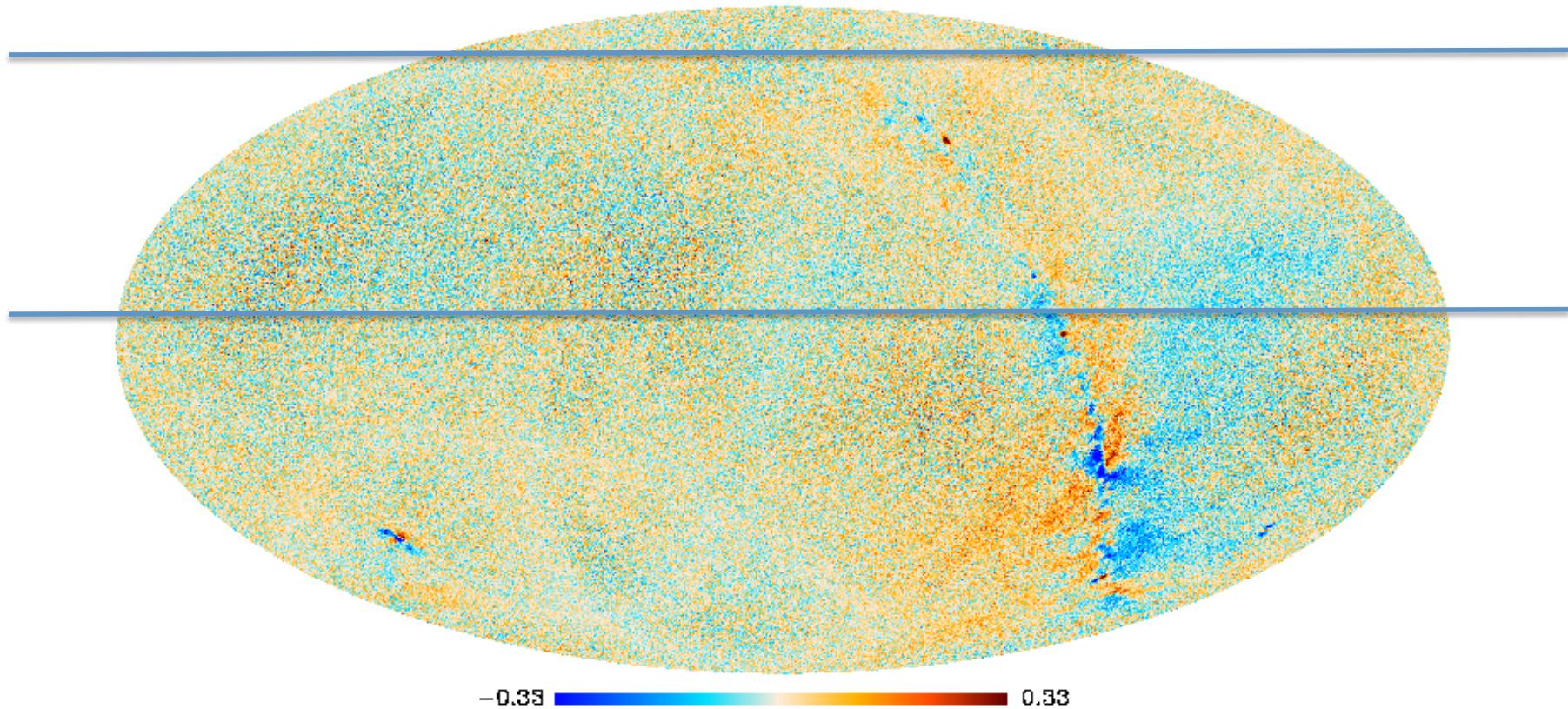


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Wide survey with the QUIJOTE MFI (10-20GHz)

- Example of polarization maps at 11GHz from one horn (using Equatorial projection).

WMAP U23



(scaled to preserve the same color
for a signal with $\beta=-3$)



RADIOFOREGROUNDS project

<http://www.radioforegrounds.eu>



H2020-COMPET-2015. Grant agreement 687312: “Ultimate modelling of Radio Foregrounds” (RADIOFOREGROUNDS).

3-year grant 2016-18 (IAC; IFCA; Cambridge; Manchester; SISSA; Grenoble; TREELOGIC).

This project will provide specific products:

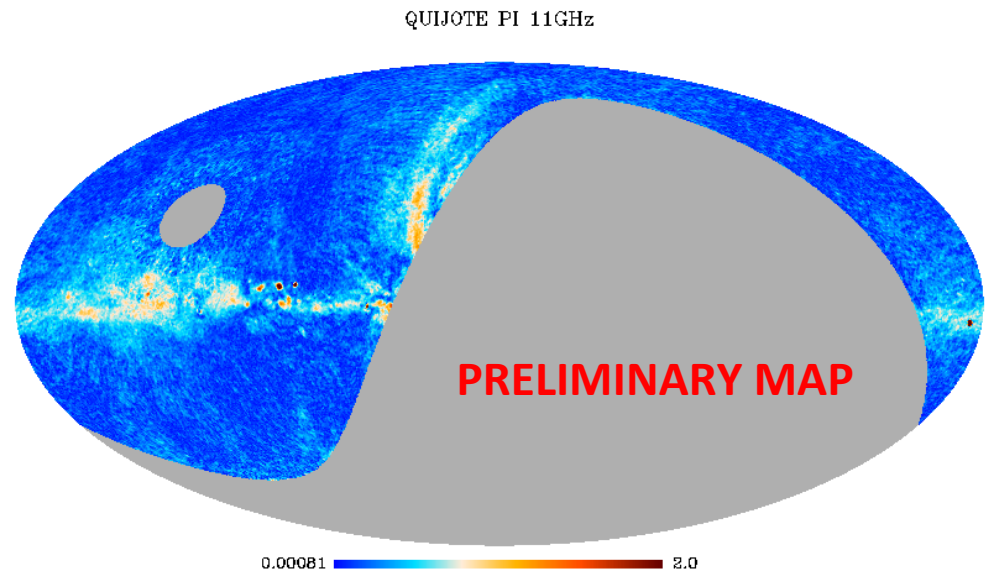
- a) state-of-the-art legacy maps of the synchrotron and the anomalous microwave emission (AME) in the Northern sky;
- b) a detailed characterization of the synchrotron spectral index, and the implications for cosmic-rays electron physics;
- c) a model of the large-scale properties of the Galactic magnetic field;
- d) a detailed characterization of the AME, including its contribution in polarization; and
- e) a complete and statistically significant multi-frequency catalogue of radio sources in both temperature and polarization.
- f) specific (open source) software tools for data processing, data visualization and public information.



Wide survey with the QUIJOTE MFI (10-20GHz)

PRELIMINARY RESULTS presented in this conference:

- Synchrotron spectral index, curvature and correlation with dust. → talk by Vansyngel.
- Component separation of the polarised synchrotron, combining PLANCK+WMAP+QUIJOTE → talks by Casaponsa and Poletti.
- AME in more than 40 regions → talks by Poidevin and Génova-Santos.
- Radiosources in the QUIJOTE maps → talk by Herranz.
- Synchrotron in the North Polar Spur → talk by Watson.
- Synchrotron emission in the FAN region → talk by Ruiz-Granados.
- Tools for visualization of maps and models.





QUIJOTE project: current status

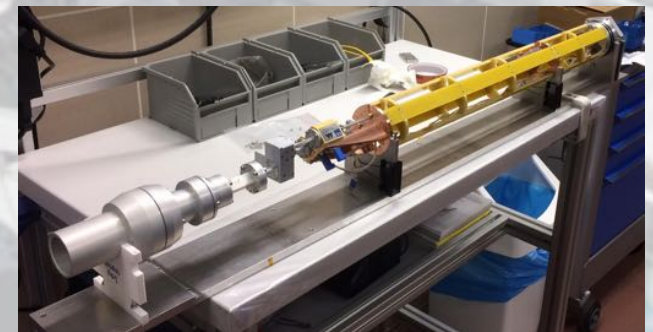
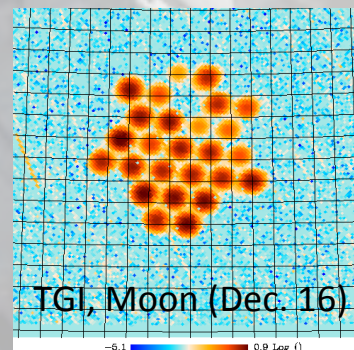
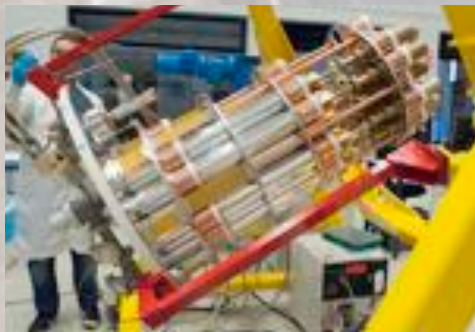
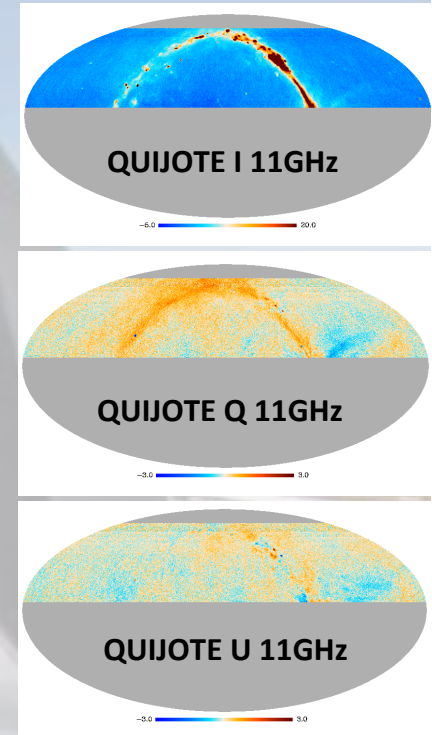


MFI (10-20 GHz). In operations since Nov 2012.

- 4 horns, 32 chan, 4 bands: 11, 13, 17, 19 GHz, $400-600 \mu\text{K s}^{1/2}$ per channel.
- Observations (> 24,000 hrs completed): COSMO fields (> 5,200 h), Wide survey (>10,000 h), galactic fields (Taurus, W49, IC443, W63, FAN, galactic center). Results published in Perseus and W43 (Genova-Santos et al. 2015; 2017). Best upper limit to date on AME pol fraction (0.2%).
- **MFI upgrade (MFI2)**. Funds secured. Aim: to increase the speed by at least a factor of 3.
- Extension of QUIJOTE to Southern hemisphere is being studied.
- **RADIOFOREGROUNDS** project (public results by end of 2018) → see results presented during this conference!

TGI (30 GHz) and FGI (40 GHz)

- All 30 TGI receivers integrated during 2016.
- Commissioning of 27 TGI pixels started early 2017.
- All 30 FGI receivers integrated during 2017.
- 2018: **Joint TGI/FGI operation** in the same cryostat (14/15)
- Observing plan for TGI/FGI science phase: cosmo survey in 3 effective years.





Thank you!

