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Fan region as seen by QUIJOTE MFI experiment

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Abstract

Microwave and radio observations exhibit some interesting features in the Galactic plane. One of those is the Fan region which it is an extended region located in the Perseus arm at a distance of $\sim$ 500 pc. Fan region has highly polarized emission from several MHz up to 353 GHz, which is ascribed to synchrotron but nowadays is largerly unexplained. Here we present new measurements in intensity and in polarization at the microwave frequencies 10-20 GHz coming from the Multi Frequency Instrument (MFI) of the Q-U-I-JOint Tenerife Experiment (QUIJOTE). From these new maps, we present recent results on spectral energy distribution of several sources embedded in the region (the SNR 3C58 and few molecular regions), as well as the caracterization of the spectral properties of the diffuse polarized emission.

1 Introduction

Radio observations of our galaxy show some local features with a strong emission in intensity and in polarization such as the North Polar Spur and the Fan region. The Fan Region is a notable feature that has a strong polarized synchrotron emission (up to a degree of polarization of $\approx 40\%$). This region is thought to be a large-scale structure rather than just a local feature, potentially extending beyond 2 kiloparsecs from our solar neighbourhood. Observations suggest that it is partially depolarized by ionized gas within the Perseus Arm, indicating that part of its emission originates at a significant distance from our solar neighbourhood [3].

Recent studies propose that the Fan Region may be linked to larger filamentary structures that also include the North Polar Spur. These structures may form a system of magnetized filaments that encircle the Local Bubble, the region in space where our solar system resides.

This model helps to reconcile observed differences in distances across various parts of the North Polar Spur and supports the idea that both it and the Fan Region are prominent parts of the local galactic magnetic environment [9]. Additional research using low-frequency radio telescopes has detected fluctuations in synchrotron emission in the Fan Region, which provide insights into the magnetic turbulence in interstellar space. These observations reveal a mix of ordered and random magnetic fields, which varies across the region, supporting the existence of multiple turbulent regimes within this part of the galaxy [4].

The QUIJOTE experiment[1] is a scientific collaboration between the Instituto de Astrofísica de Canarias, the Instituto de Física de Cantabria, the universities of Cantabria, Manchester and Cambridge, and the IDOM company. The QUIJOTE experiment is a comisc microwave (CMB hereafter) experiment composed with two different telescopes and three instruments devoted to measure the polarized sky between 10 and 40 GHz. The multifrequency instrument (MFI hereafter) observed the sky at 11, 13, 17 and 19 GHz and it was installed in the first telescope. The second telescope contains two instrument TFGI that observes at 30 and 40 GHz. QUIJOTE experiment is located at Teide observatory (Spain) which it is at 2400 m and latitude 28.3° N, 16.5° W. The Teide observatory has a huge experience in CMB experiments as Tenerife experiment, COSMOSOMAS or the Very Small Array (VSA).

Here we use the QUIJOTE MFI data to provide new insights on the properties of the diffuse emission and compact sources towards the Fan region. This contribution is organized as follows: In Section 2, it is described the characterization of the Fan region in two different aspects, describing the sources embedded in the region as well as the diffuse emission. In this section, which is also includes our preliminary results. Finally, in Section 3, it is described our preliminary conclusions.

2 Characterization of the Fan region

The Fan region is a located in the galactic plane, centered around galactic longitude $\ell \approx 140°$ and galactic latitude $b \approx 0°$. The region expands on $\ell \in [120°, 160°]$ and $b \in [-15°, 15°]$, i.e. its area is $\approx 40° \times 30°$. In Fig. 1 displays the Fan region in intensity seen by QUIJOTE MFI at 11 GHz.

The Fan region exhibits a diffuse emission in intensity and in polarization at frequencies between 100 MHz up to 353 GHz. It also contains different sources as supernovae remnants, molecular clouds or HI regions. There are some results for characterizing the polarized emission and the rotation measure of the region in [8], [4], [3] and [9].

The data used for characterizing sources and diffuse emission comes from MFI wide survey (9000 hours for the whole north sky) and dedicated observations (561.4 hours) focused on the Fan region. The wide survey and QUIJOTE MFI data is extensively described in [7].

To characterize the flux and the spectral energy distribution (SED hereafter) of sources, ancillary data as Haslam (0.408 GHz), Stockert- Villa Elisa, DRAO (1.4 GHz), WMAP (23,33, 41, 61, 94 GHz), Planck (30,44, 70, 100, 143, 217, 353, 545, 857 GHz), DIRBE (1249, 2141,

[1] `https://research.iac.es/proyecto/quijote/pages/en/home.php`

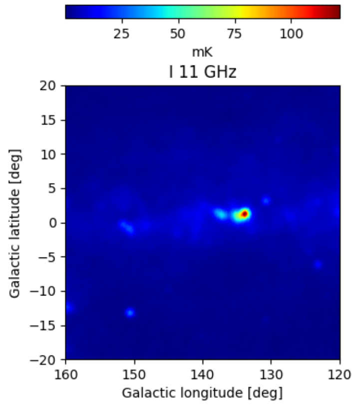

Figure 1: Emission of the Fan region observed by QUIJOTE MFI at 11 GHz in intensity. Units are mK.

Table 1: Sources in the Fan region

Name	l (deg)	b (deg)	Description
3C58	130.75	3.12	SN remnant
W3	133.8	1.2	Molec. cloud
W5	137.5	1.1	Molec. cloud
W4	134.7	0.9	Molec. cloud
LBN0679	141.0	-1.7	Molec. cloud
LBN0679	140.7	2.0	Molec. cloud
WD	123.2	-6.4	White dwarf(?)
Source1	150.7	-13.4	Unknown
Source2	151.1	-1.0	Unknown
Source3	151.8	-0.3	Unknown
Source4	159.7	-12.6	Unknown
3C10	120.1	1.4	SN remnant
HB9	160.9	2.6	SN remnant

2997 GHz) are considered in addition to QUIJOTE MFI frequencies. For the diffuse emission, data coming from WMAP and Planck at low frequencies (23, 30, 33 GHz) are considered. In next subsections, we describe preliminary results on sources and on diffuse emission.

2.1 Sources

Tha analysis of sources embedded within the Fan region is done through measuring the flux densities in intensity and in polarization and modelling their spectral energy distribution.

Table 1 lists the sources embedded within the Fan region studies such as 3C58 (supernova remnant) and molecular clouds W5, W3-W4 adn the Drumstick. Here we discuss the properties of the integrated spectral energy distribution in intensity and in polarization of these sources.

Flux measurement. For measuring the integrated flux densities in intensity and in polarization, i.e. the Q and U Stokes' parameter, it is performed aperture photometry (AP, hereafter). This technique has been applied through different by Planck and QUIJOTE collaborations [5, 2]. It consists in select the source and define a region where the flux is quantified as well as two different regions out of the source in order to subtract the background level by computing the median value of pixels in those outer regions. We apply AP to ancillary and QUIJOTE data. All maps are degraded at nside = 512 and smoothed with a Gaussian kernel of $FWHM = 1^o$. In Fig. 2, it is shown the definition of sources in intensity at 11 GHz (upper panel) and at 23 GHz (lower panel). The box shape is for defining the drumstick region, the circle next to this, it is the molecular cloud W5 and the circle of the right side of the plot, it is the molecular complex W3-W4. Black dashed lines represent the definition of the source and the grey ones, the region where the background is computed for each source. In the upper right side, it is the SNR 3C58, where the flux is computed by using a gaussian fitting [2].

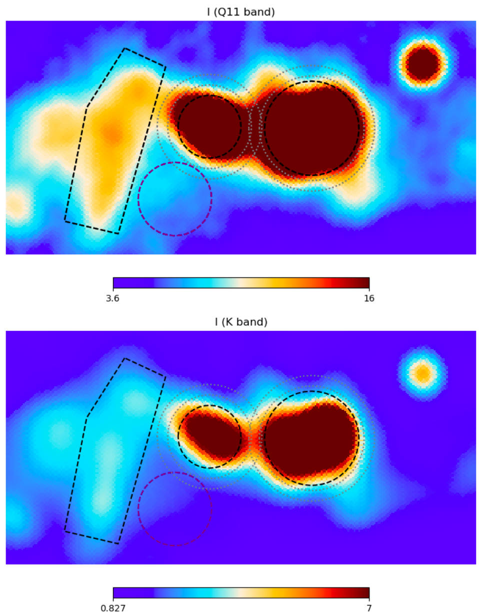

Figure 2: Sources embeded in Fan region: definition of the regions and annulus for background computations in measuring fluxes.

Spectral Energy Distribution (SED). The representation of the flux in intensity, Stokes' Q and U parameters versus the frequency are plotted and modelled by considering different components. The spectrum is modelled as a multi-component emission. In intensity, it is fitted free-free, synchrotron, anomalous microwave emission (AME, hereafter), thermal dust and CMB. For polarization, it is fitted synchrotron, thermal dust and CMB. In [6] are described the different components, laws used for modelling each one and the free parameters. Moreover it is described the fitting process by using Monte Carlo Markov Chains. Results on these fittings provide an insight on emission mechanisms acting on the SNR or on the molecular clouds.

In Fig. 3 is plotted the SED and the fitting for SNR 3C58 (left upper pannel), for the complex molecular cloud W3-W4 (right upper pannel), for the W5 region (left lower pannel) and for the drumstick (right lower pannel). For SNR 3C58, the SED shows that it is dominated by synchrotron emission with a turn over on the spectral index around 10-20 GHz. No AME is found for this SNR. For the molecular clouds, no polarization is found therefore our analysis is focus on intensity signal. The molecular complex W3-W4 is fitted with free-free (emission measure $EM = 1368.48^{+77.51}_{-97.15}$ cm^{-3}) and thermal dust (temperature of the thermal dust $T_d = 26.75^{+2.01}_{1.74}$ K and spectral index $\beta_d = 1.40 \pm 0.11$) emissions without significant AME and synchrotron. The W5 source is fitted with free-free, AME and thermal dust components. In particular, for the free-free, the emission measure is $EM = 663.50^{+40.24}_{-42.38}$ cm^{-3}; for the AME, the amplitude $A_{AME} = 13.22^{+3.35}_{-3.24}$ Jy, the width $W_{AME} = 0.83^{+0.17}_{-0.18}$ and the frequency $\nu_{AME} = 36.64^{+9.69}_{-6.34}$ GHz. For the thermal dust, the temperature $T_d = 25.05 \pm 1.01$ K and the spectral index $\beta_d = 1.34 \pm 0.12$. Finally, for the drumstick is also fitted free-free, AME and thermal dust. For the free-free is found a emission measure $EM = 394.47^{+27.01}_{-28.20}$ cm^{-3}; for the AME, the amplitude $A_{AME} = 24.93^{+2.31}_{-2.22}$ Jy, the width $W_{AME} = 0.50 \pm 0.04$ and the frequency $\nu_{AME} = 24.06^{+1.03}_{-0.98}$ GHz. For the thermal dust is found a temperature $T_d = 20.20^{+0.78}_{-0.75}$ K and a spectral index of $\beta_d = 1.48 \pm 0.07$.

2.2 Diffuse emission

Extended emission in the region observed at the QUIOTE MFI frequencies are useful to characterize the synchrotron emission. In Figure 3, it is shown the emission at 11 GHz in intensity, polarized intensity and the Stokes' Q and U parameters. The rectangle overplotted represents the Fan region for our analyses.

Diffuse emission is highly polarized from frequencies of few MHz up to 353 GHz. In Fig. 4, it is shown QUIJOTE MFI data at 11 GHz. The black retangle show high polarization in polarized intensity of the Fan region. As can be seen, the Stokes' Q parameter signal is the main contribution to the polarized intensity. This means that there are a ordered magnetic field perpendicular to the line of sight. The emission is compatible with the synchrotron emission as indicated by the spectral index. To characterize the emission, the spectral index is computed by using TT-plots [1]. The QUIJOTE 11 GHz is cross-correlated with WMAP 23 and 33 GHz and with Planck 30 data. Finally, the spectral index for WMAP 23 and 33 GHz are computed also. Our preliminary results are on spectral index of the region is in Tab. 2.

In Fig. 5, it is shown the correlation plots for QUIJOTE 11 GHz vs WMAP 23 GHz and QUIJOTE 13 GHz vs WMAP 23 GHz, respectively.

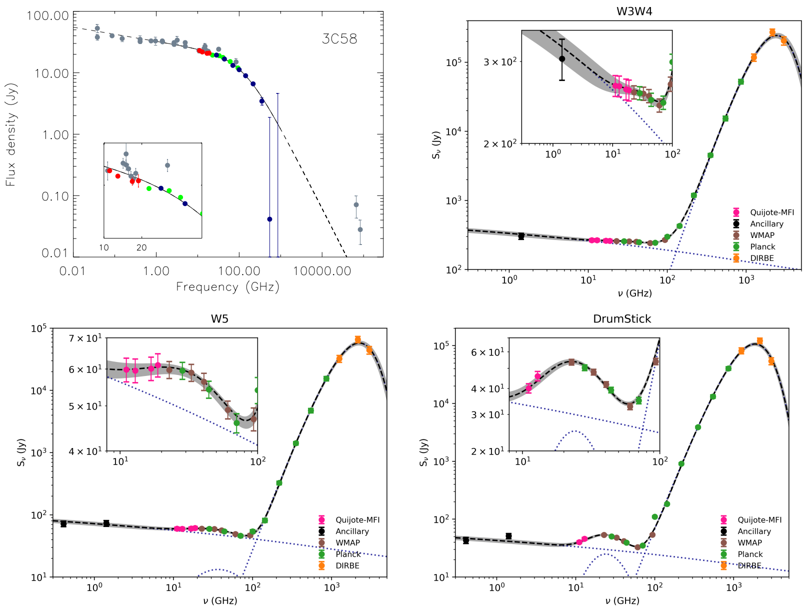

Figure 3: Spectral energy distribution for SNR 3C58, molecular clouds W3-W4, W5 and the Drumstick.

Table 2: Spectral index from the Stokes' Q parameter with QUIJOTE 11 and 13 GHz

Bands/Frequencies	**Spectral index β_s**
QJ11-WMAP23	-3.03±0.02
QJ11-Planck30	-2.94±0.02
QJ11-WMAP33	-2.98±0.03
QJ13-WMAP23	-3.41±0.04
QJ13-Planck30	-3.17±0.03
QJ13-WMAP33	-3.21±0.04
Average	-3.19± 0.08
WMAP23-WMAP33	-2.79± 0.03

3 Conclusions

Our preliminary conclusions on sources and diffusion emission of the Fan region by analysing QUIJOTE MFI observations joint to ancillary data are shown in what follows.

Sources. Four different sources are analysed through their spectral energy distribution. For molecular clouds as the complex W3-W4 and W5, no polarization are found. In both cases, no significant AME signal is detected. For the drumstick, our result show a clear AME detection. Finally, for the supernova remanant SNR 3C58, it is found a turnover spectrum for the synchrotron emission.

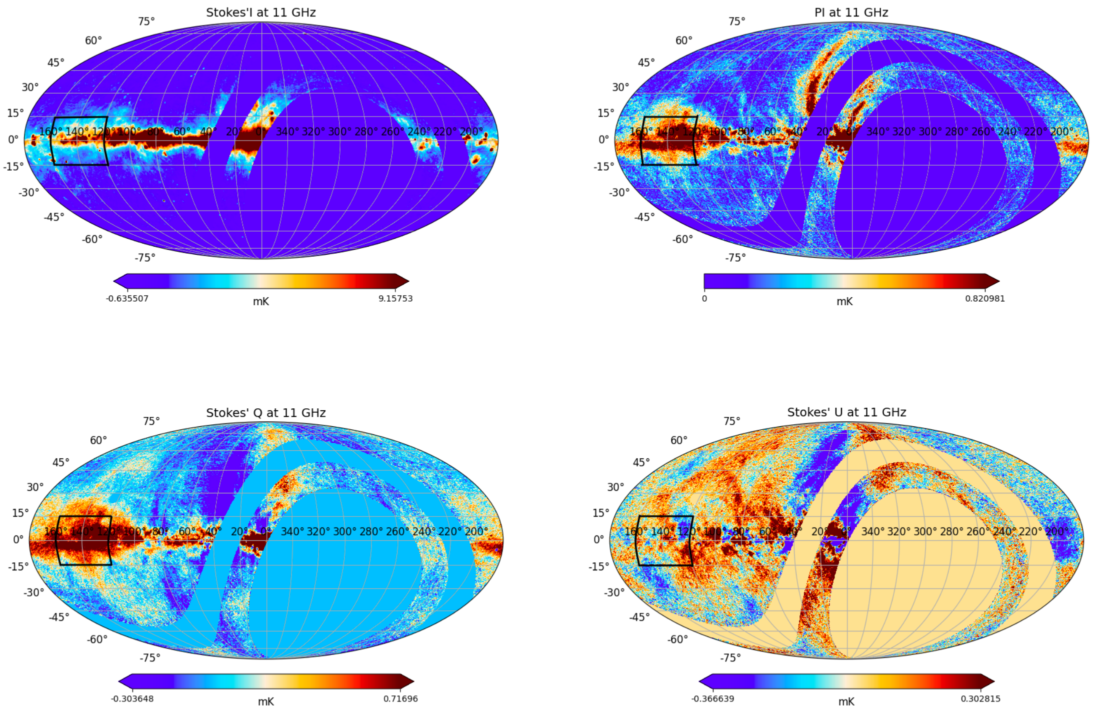

Figure 4: QUIJOTE MFI data at 11 GHz in intensity (I map) and in polarization (polarized intensity PI, U and Q maps). The black rectangle indicates the Fan region. Mapas are smoothed to 1 degree and in units of mK.

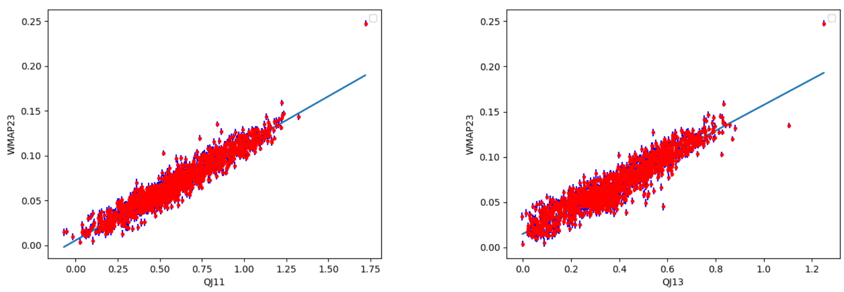

Figure 5: Correlation plots for the Stokes' Q parameter between QUIJOTE 11 GHz and WMAP 23 GHz (left pannel) and QUIJOTE 13 GHz and WMAP 23 GHz (right panel).

Diffuse emission. It is characterized by computing correlation plots in intensity and in polarization. In intensity, emission is dominated by free-free emission. Our preliminary analysis of the Stokes' Q parameter by using correlation plots shown a change of the spectral index for synchrotron emission. In particular, the flattening of the spectral index observed between 23 and 30 or 33 GHz could point out to a two electron populations.

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