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# Polarized solar activity at mm-waves

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## 1 Introduction

The time development of active regions generates slow period variations in the solar flux, this is called the slowly varying component or S-component of radio emission. Thus, the study of structure and physical processes in active regions, estimation of plasma parameters referring to layer in solar atmosphere are accessible by radio methods [1]. Although the S-component is best known at centimeter wavelengths, their observations at millimeter wavelengths shall improve the understanding of the emission mechanisms involved in solar active regions. We show that emission from a quiescent solar active region observed by solar radio polarimeters at 45 and 90 GHz exhibits fluxes increasing with frequencies.

On the other hand, solar flares are the most important manifestations of solar activity and represent one of the big enigmas of solar physics. They occurs within the solar active regions, which give rise to the S-component. Radio emission from S-component and solar bursts are known to be partially polarized at microwaves. The polarization is usually attributed to the propagation of radio waves through the solar atmosphere, i.e. a magneto active plasma [2; 3]. We show the first results obtained at microwaves (45 and 90 GHz). During two years of operation 28 solar flares were identified. We report a reversal in the sense of polarization from the East to West solar disk that could be explained by magneto-ionic coupling modes. However, the evidence of non-inversion in polarization from North to South is an intriguing result.

## 2 Solar Radio Polarimeters

For the present work, we use observations obtained by two solar radio polarimeters, each one with right and left circular polarization independent channels, operating at 45 and 90 GHz (6.67 mm e 3.34 mm wavelengths, respectively) installed at El Leoncito observatory, in the Argentina Andes. The 45 GHz telescope uses a 44 cm aperture offset reflector and the 90 GHz telescope has a 16.5 cm lens. The field of view of both telescopes was designed to be larger than the solar disk $\sim 1.02^\circ$ and $\sim 1.4^\circ$ HPBW ($= 1.2\lambda/D$), at 45 and 90 GHz respectively. Data are obtained with 10 ms time resolution. Both radio telescopes have a high sensitivity of 4 and 20 SFU at 45 and 90 GHz, respectively [4].

## 3 Time development of S-component at 45 and 90 GHz

We have analyzed the time development of a quiescent region emission at the two mm-wavelengths. The S-component contribution to the total solar disk emission must be isolated in order to define the excess flux over the quiet Sun level. NOAA 11850 active region was chosen for this purpose, during the period between September and October 2013.

Figure 1 (top panel) shows the daily excess flux variation due to the transit of AR 11850 over the quiet Sun flux. Flux enhancements are observed as the active region appears on the solar disk, attaining mean daily values of about 100 SFU at 45 GHz and 600 SFU at 90 GHz, in approximate correspondence with the Zurich sunspot number shown at the bottom panel. The error bar represents the dispersion from the mean value of the four daily measurements (four daily sky-sun scans maneuvers). Changes in polarization degree are poorly significant due to the entrance of the active region (central panel).

A typical microwave spectra of the S-component have a maximum around 5 GHz, as evidenced statistically and during eclipses. This S-component decreasing flux for higher frequencies suggested a different behavior from a thermal spectra [5; 6]. Figure 2 shows the S-component spectra derived for 45 and 90 GHz frequencies, suggesting an increasing flux for shorter millimeter wavelengths. Thus, the observation of a "double" spectral structure may favour the "core-halo" model for the S-component [7].

## 4 Detection of mm-waves polarized solar bursts

The radio polarimeters started monitoring the Sun on 25 November 2011 and during two years of operation 28 solar flares were identified.

Figure 3a and 3b show the heliographic coordinates indicating the position of each active region and its polarization trend at the time of each solar burst. As we can see in Figure 3 all bursts located on the east solar hemisphere have left handed sense of polarization (blue points), except for one (red point), while on the west, all the bursts have right

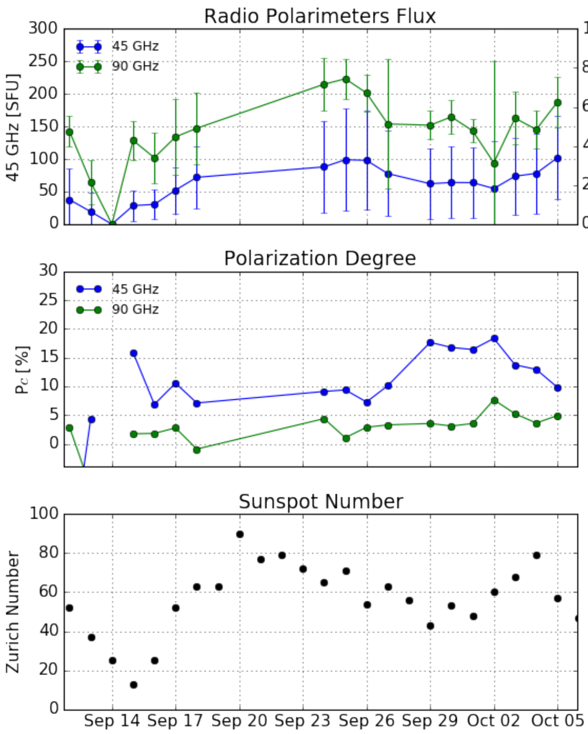



**Figure 1.** Daily 45 and 90 GHz flux time development (top) corresponding to NOAA 11850 active region transit in the solar disk in the period September 13 - October 05, 2013; the respective polarization degree (middle); and Zurich sunspot number (bottom)

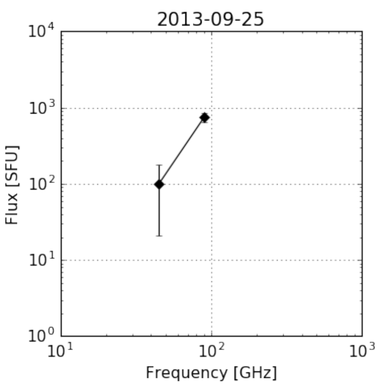
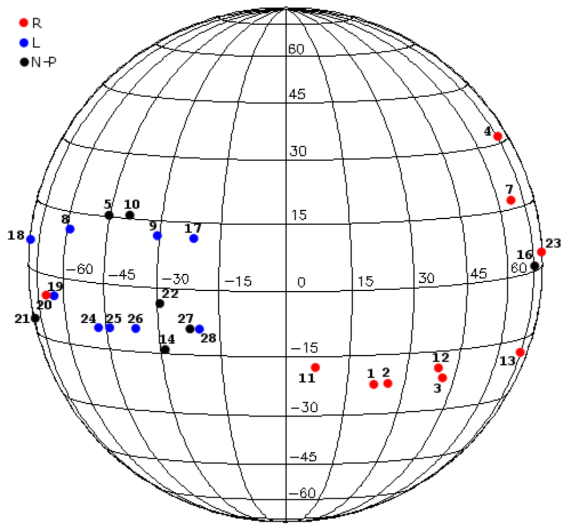


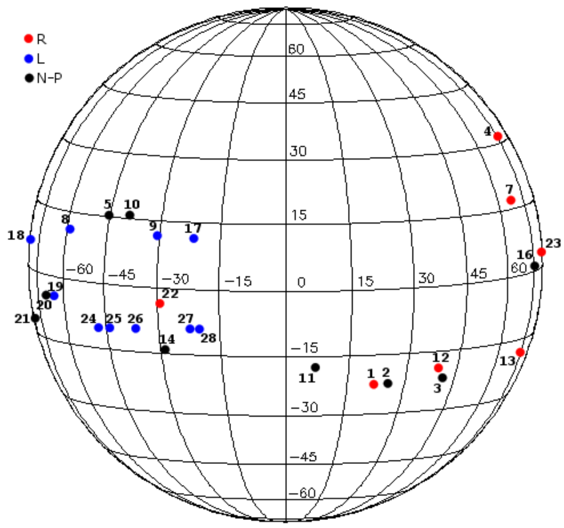

**Figure 2.** Flux spectrum for the maximum excess S-component level attained on September 25, 2013

handed sense of polarization (red points). The non polarized bursts are represented by the black points. Thus, we can notice a reversal sense of polarization for solar flares occurring from the East to West and this could be explained by magneto-ionic coupling modes. However, the evidence of non reversal sense of polarization from North to South is an intriguing result.

Figure 4 shows the 2013 May 13 event. Top panel depicts the GOES-SXR flux (red filled curve) and its derivative (black filled curve), that mimics the HXR emission. Next




**(a)** 45 GHz




**(b)** 90 GHz

**Figure 3.** Heliographic coordinates indicating the position of each active region and its polarization trend at the time of each solar burst. E-W polarization inversion may be explained by magneto-ionic coupling, while N-S non inversion is an intriguing effect. Red points indicate right handed sense of polarization, blue points indicate left handed sense and black points indicate non polarized bursts.

panels show the flux emission at microwaves and millimeters wavelengths from RSTN at 2.7, 4.9, 8.8 and 15.6 GHz and radio polarimeters at 45 and 90 GHz, respectively. The bottom panel shows the degree of polarization for 45 and 90 GHz emissions. Analysis of all these events could contribute to increase the poor knowledge on the polarization of solar radio emission at millimeter wavelengths.

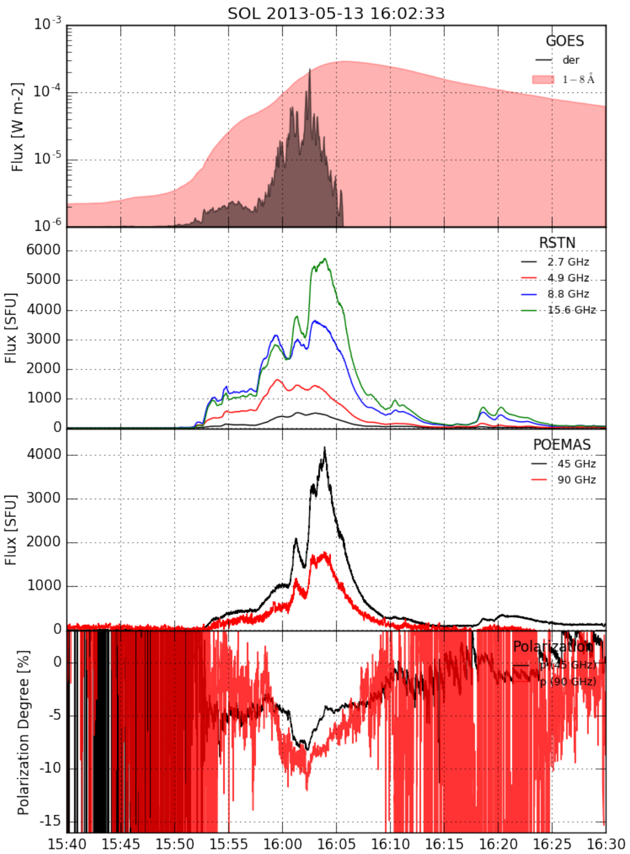



**Figure 4.** Time profile of GOES SXR emission (top panel), microwave emission from RSTN, millimeter emission from radio polarimeters and the degree of polarization for 45 and 90 GHz emissions.

## 5 Concluding Remarks

Solar flux and circular polarization observations were obtained at 45 and 90 GHz by two recently installed telescopes. It has been shown that emission from a quiescent solar active region, also called S-Component, exhibits fluxes increasing with frequencies, complementing previously known microwave spectra which have a maximum somewhere in the 5-15 GHz range. This "double" spectral structure may favour the "core-halo" model for the S-component [7].

From the solar bursts statistics, we have was observed a reversal in the sense of polarization from the East to West that could be explained by magneto-ionic coupling modes. On the other hand, the evidence of non reversal in the sense of polarization from North to South is a result that need to be investigated more rigorously.


## Acknowledgment

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