EPSC Abstracts
Vol. 6, EPSC-DPS2011-500, 2011
EPSC-DPS Joint Meeting 2011

Simulation of generation and transfer of polarized gyrosynchrotron radiation in the solar corona

A.A. Kuznetsov (1,2)
(1) Armagh Observatory, Armagh, Northern Ireland (aku@arm.ac.uk), (2) Institute of Solar-Terrestrial Physics, Irkutsk, Russia

Abstract

We perform 3D simulations of gyrosynchrotron emission from solar flaring loops. The full polarization transfer equation is solved; the radio brightness maps and spectral dependences of the Stokes parameters of the emission are obtained. We discuss the conditions required to detect the linear polarization of the solar microwave emission by the existing and perspective instruments, as well as the information that could be inferred from such observations. The numerical codes for calculating the radio emission are available online.

1. Introduction

Gyrosynchrotron microwave emission contains highly important information about the energetic electrons, plasma, and magnetic field in solar flares. A number of new multiwavelength radioheliographs (EOVSA, USSRT, EVLA, CSRH) are currently being constructed and we can expect that the new data with unprecedented spectral, spatial, and temporal resolution will soon become available. In order to understand the observations and infer the source parameters, we need realistic simulations of the microwave emission taking into account 3D structure of the active region.

Mode coupling and Faraday rotation during propagation significantly affect the emission properties. In particular, crossing the regions of transverse magnetic field can reverse the sign and/or reduce the degree of the circular polarization. Thus the propagation effects must be included into the simulation model.

Linear polarization of the solar microwave emission has been detected only occasionally (e.g., [1]), since the spatial and spectral resolution of most of the existing instruments is believed to be insufficient for such observations. Realistic 3D simulations of the linear polarization are required to better estimate the necessary instrument parameters and to interpret the observations of the future instruments (e.g., EOVSA) capable to measure the full set of the Stokes parameters.

2. Radiation transfer equation

In this work, the transfer of polarized radiation is described in terms of the Stokes parameters (I, Q, U, V). The transfer equation may be written in the form [2, 3]

$$\frac{\mathrm{d}}{\mathrm{d}z}\begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} = \begin{pmatrix} S_I \\ S_Q \\ S_U \\ S_V \end{pmatrix} - \begin{pmatrix} \mu_I & \mu_Q & \mu_U & \mu_V \\ \mu_Q & \mu_I & r_V & -r_U \\ \mu_U & -r_V & \mu_I & r_Q \\ \mu_V & r_U & -r_Q & \mu_I \end{pmatrix}\begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}, \quad (1)$$

where the coefficients $S_{I,Q,U,V}$ describe the process of spontaneous emission, the coefficients $\mu_{I,Q,U,V}$ describe the radiation absorption, and the coefficients $r_{Q,U,V}$ describe the change of the polarization state due to Faraday rotation. We developed a numerical code for integrating the transfer equation (1) in an inhomogeneous medium. The spontaneous emission and absorption coefficients are computed using fast gyrosynchrotron codes [4].

The mentioned code has been used to calculate the emission from a coronal flaring loop with the dipole-like magnetic field. The energetic electrons in the loop are assumed to have the loss-cone distribution; their density decreases exponentially with the distance from the loop axis. The thermal plasma is assumed to have different densities, temperatures, and height scales inside and outside the loop.

3. Results

An example of the simulation results is shown in Figs. 1-2. Simulations for the different parameters and orientations of the flaring loop have shown that:

– The circular polarization is strongly affected by the regions of quasi-transverse magnetic field, in accordance with the mode-coupling theory.

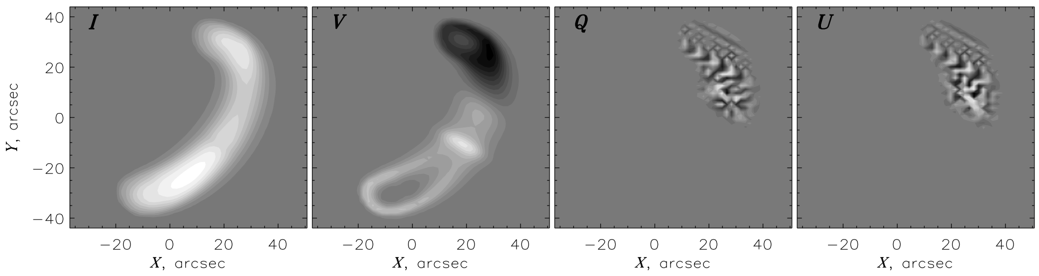

Figure 1: Two-dimensional radio brightness maps (the Stokes parameters) of a flaring loop at a fixed frequency. The areas which are brighter or darker than the background correspond to the positive or negative values, respectively.

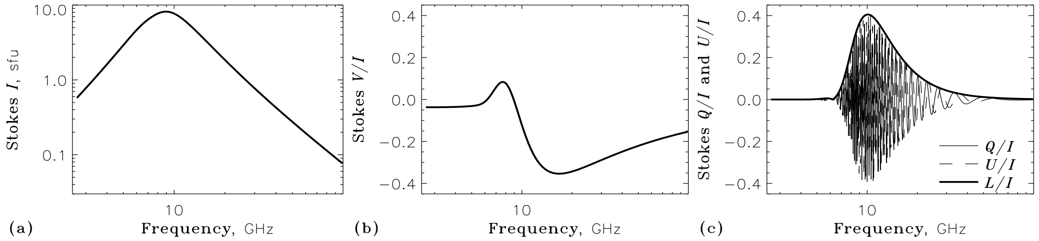

Figure 2: An example of spatially resolved emission spectrum (corresponding to the point in Fig. 1 where the total linear polarization is the highest). a) Emission intensity (Stokes I). b) Circular polarization degree V/I. c) Characteristics of the linear polarization Q/I and U/I and the total linear polarization degree $L/I = \sqrt{Q^2 + U^2}/I$.

– The linear polarization can be non-negligible only in the regions around the magnetic neutral lines.

– The linear polarization degree reaches its maximum near the emission intensity spectral peak.

– The linear polarization oscillates rapidly with both the frequency and the spatial coordinates.

– Although the total linear polarization degree at a given point and frequency can be rather high ($> 50\%$), the averaging in frequency and/or spatial coordinates can significantly reduce the observed polarization.

– In particular, the spatial resolution required to detect the linear polarization in the case shown in Fig. 1 is about 1” or better. However, for some orientations of the flaring loop, the Stokes parameters Q and U can be relatively constant in larger areas thus making the polarization detectable by the instruments with lower resolution (e.g., in the event reported by [1]).

4. Conclusions

The code for integrating the radiation transfer equation is implemented as the binary libraries callable from IDL or Python. These libraries together with the respective documentation are available at the web site `star.arm.ac.uk/~aku/transfer/`. The code can be used not only for solar flares, but also for active stars, planetary magnetospheres, etc.

Acknowledgements

The author thanks the Leverhulme Trust for financial support.

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