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Flare parameters inferred with 3D loop models database

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Abstract. We characterize a solar flare based on key parameters of their microwave emission in a structured 3D geometry of a magnetic loop. Due to the high number of the parameters involved we propose a large database of pre-calculated elements (∼ 250.000) to better explore the range of those parameters that explain the observables. This database was constructed based on NoRP and NoRH observations (but not restricted to) including known general properties of a solar flare.

Resumo. Caracterizamos uma explosão solar baseado em parâmetros-chave de sua emissão em microondas usando uma geometria estruturada em 3D de um arco magnético. Devido ao elevado número de parâmetros envolvidos, propomos um banco de dados (∼ 250.000 elementos pré-calculados) para melhor explorar o intervalo desses parâmetros que explicam os observáveis. Este banco foi construído com base nas observações do NoRP e NoRH (não restritos a estas), incluindo propriedades gerais das explosões solares.

Keywords. Sun: radio radiation – Sun: flares, sun: magnetic fields – sun: atmosphere, catalogs.

1. Introduction

A solar flare is an energetic phenomenon in the solar atmosphere, manifested as a sudden and rapid enhancement of intensity in almost all electromagnetic wavelengths (Fletcher et al. 2011). The excess of energy in tens of seconds is on the order of 10^{32} ergs (e.g. see reviews by Bastian et al. 1998; Fletcher et al. 2011). The process occurs in a magnetic loop or arcades over active regions. Therefore, the lack of knowledge on the detailed coronal magnetic field usually leads to simple homogeneous source model to analyse the emission. This yields to incorrect inferred parameters as analysed in Costa et al. (2013).

To describe a spatially varying flare source, it is necessary to define the strength and geometry of the magnetic field, spatial distribution of the non-thermal electrons, and to a lesser importance for microwave emission, the thermal plasma density and temperature, which can be relevant to the free-free absorption and Razin effect.

Following the work of Costa et al. (2013), we constructed a database based on a simplified 3D loop geometry and distribution of the parameters. We calculated more than two hundred and fifty thousands elements to become a catalogue for flare analyses. In this current database, we upgraded their geometry by inserting two new parameters to describe the magnetic dipole model. Although we know the properties of the gyrosynchrotron emission (the theory); we know that we need information about the geometry and strength of B field in the corona B(x,y,z), and the distribution of the non-thermal electrons, in space and energy it is very complicated and time-consuming to implement in practice as reported in the literature (e.g. Alissandrakis & Preka-Papadema 1984; kucera et al. 1993; Lee et al. 1994). Therefore, past and current observations cannot constrain the models well, even the simplest, uniform source model. That makes the space of parameters for forward-fitting modelling huge. Thus, the proposed large pre-calculated database of 3D simplified models result into a faster search of the parameters in a flare analysis.

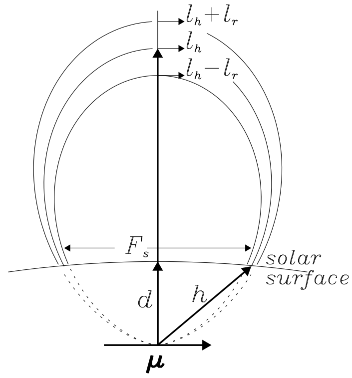

Figure 1. Magnetic dipole model

2. Model description

The loop is modelled as a dipole magnetic field. The magnetic induction of any voxel in space at position (**r**), from the dipole magnetic momentum (μ), is calculated by

$$B = \frac{3(\mu\mathbf{r})\mathbf{r} - \mu\mathbf{r}^2}{\mathbf{r}^5} \quad (1)$$

The absolute value of the magnetic moment is adjusted to give the desired magnetic field to the loop foot-point. The dipole is placed below the solar surface at some depth d as shown on Figure 1. The flaring volume is constructed around the central field line with a circular cross-section with radius at the apex (l_r). Thus, the geometrical free parameters are the loop height ($H_{arc} = l_h - d$, where l_h is the distance from the dipole momentum to the central field line at the loop apex), feet separation (F_s) and apex radius.

The electron distribution is defined by its energy distribution in the form of a power-law (with power index δ as a free param-

Table 1. Best database representation.

Parameter	ie	δ	N_{nth} (log)	q (%)	Az (Deg)
Mean	1.91	3.12	6.72024	5.65	44.00
Solution	1.94	2.49	6.00277	1.00	-80.60
	R_{Arc} ($\times10^9$cm)	F_{sep} ($\times10^9$cm)	H_{Arc} ($\times10^9$cm)	t (Deg)	B (G)
Mean	0.58	2.20	2.97	4.33	2231
Solution	0.27	2.51	1.74	0.00	2297

eter) from 10 keV to 100 MeV, in a homogeneous pitch angle distribution. The spatial distribution of non-thermal electrons is symmetric in relation to the loop apex. The ambient density is defined as an exponential decay from 10^{13} to 10^8 cm^{-3}. Thus, for a given set of reference values of the parameters, the gyrosynchrotron is calculated following Ramaty (1969), using a code by Simões & Costa (2006); Costa et al. (2013) to obtain the emission and self-absorption coefficients and the 3D radiative transfer. Details are given in those papers.

3. Application to 20020531_000725 UT Flare

We analysed an M2.4 GOES class flare observed on the East limb of the Sun on May 31, 2002 with our 3D database. This M2.4 event clearly shows a loop-like geometry. The maximum peak in 9.4 GHz at NoRH were observed at 00:07:25 UT. We collected the four fluxes at 3.75, 9.4, 17 and 34 GHz at NoRP website without any additional calibration, and both images at 17 and 34 GHz at NoRH. From the magnetogram, we found that the maximum positive and negative B is ∼ 2200 G, that suggests low asymmetry. The inferred parameters of the observation (computed weighted mean) from our database search can be seen in Table 1. This Table 1 also shows the refined parameters (solution) obtained after calculating new elements that are not in the database using a genetic algorithm known as Pikaia (Charbonneau 1995) to improve the image and spectrum matches.

We found a microwave looptop emission that is quite clear from the image of this May 31, 2002, flare near the limb. This effect might be explained by an enhancement of energetic electrons at the top of the loop occurring as a result of a transverse pitch angle anisotropy caused by the accelerating mechanism as suggested in the work of Melnikov et al. (2002).

Figure 2 shows plots of the spectra. The asterisks show the observed spectrum obtained by NoRP website, the continuous line shows our refined solution.

Figure 3 shows the observed NoRH maps at 34 and 17 GHz on red scale, respectively. The maps are overlaid with white contour at 50% of NoRH image maximum and black contours plots of the model for comparison. It is clearly seen that the contours not perfectly match but it reproduces the shape of the observed loop. This may imply that many of the geometric parameters (see Table 1) of the model are roughly in the same range of the observable.

4. Conclusions

We conclude that, this database speeds up the search for the best geometrical representation of the observed brightness temperature of NoRH maps and the best spectral fit of NoRP, by using a reasonably large volume of pre-constructed models with different scenarios.

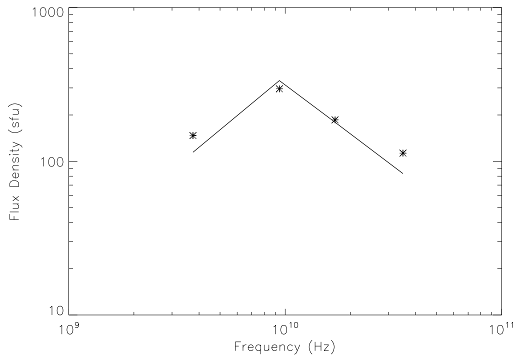

FIGURE 2. Plots of the calculated and observed spectra. The asterisks are the observed NoRP spectrum, thick line is the fitting.

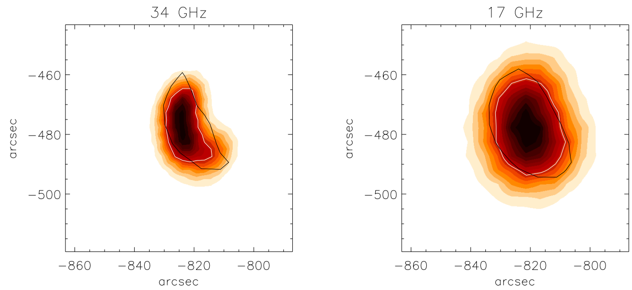

FIGURE 3. Images of NoRH 34 and 17 GHz (red scale) brightness temperature with contours overlaid (white) at 50% of image maximum and model (black) at 50%.

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