C6.2 class flare parameters inferred with a 3D geometry of flare database

Valente A. Cuambe[1,2,#], J. E. R. Costa[3], P. J. A. Simões[4]

valente.a.cuambe@a-raege-az.pt

[1]AIR CENTRE - Atlantic International Research Centre
[2]RAEGE - Rede Atlantica de Estacoes Geodinamicas e Espaciais
[3]INPE - Astrophysics Division, National Institute for Space Research
[4]CRAAM- Mackenzie, Escola de Engenharia, Universidade Presbiteriana Mackenzie
[#]CICGE, DGAOT, FCUP, Vila Nova de Gaia, Portugal

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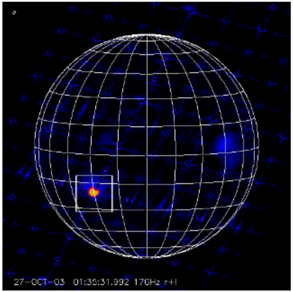
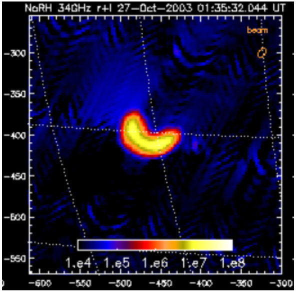
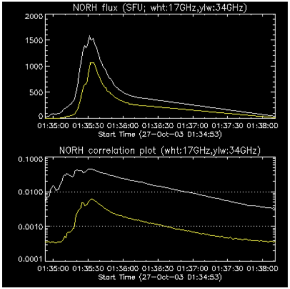
Motivation

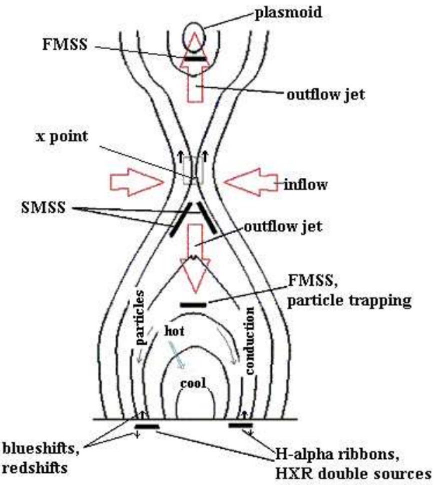
- GOES C6.2 class flare occurred on 27 October 2003 at heliographic position S20E29 in the active region NOAA 486. This flare shows a typical loop-like geometry and presents a simple structure.
- We aim to explore the unknown parameters by implementing the forward-fitting method using an optimised database of a 3D magnetic loop geometry.



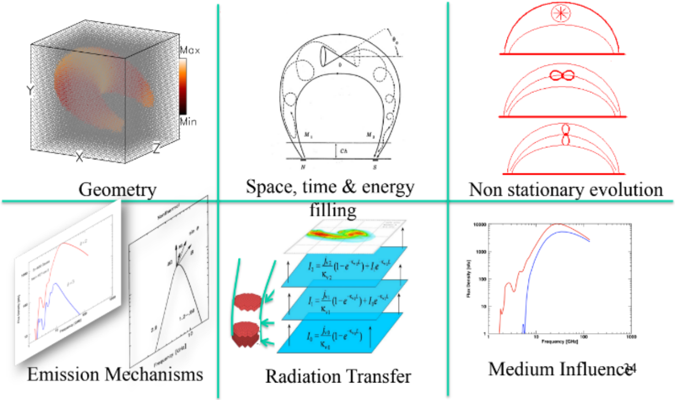




- The standard model [Kopp and Pneuman, 1976]
- Solar flares often exhibit two bright, elongated regions known as flare ribbons
- The reconnection of magnetic field lines occurs at the top of the loop
- Particles precipitates along magnetic loop and hit the chromosphere footpoints



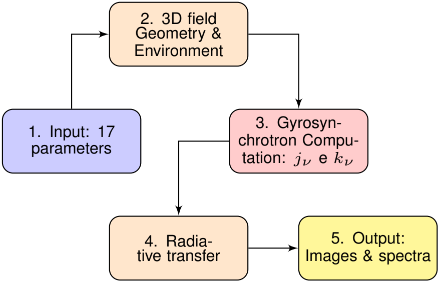
[Simões and Costa, 2006, Simões and Costa, 2010, Costa et al., 2013, Cuambe et al., 2018]

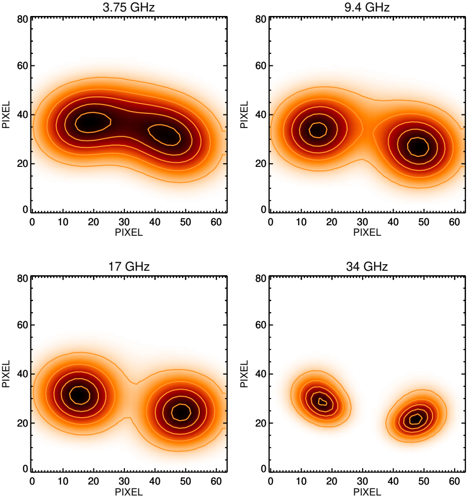


- Box with 16x16x16 voxels
- Z – viewer direction
- X – Solar equator
- Y – rotation axis

- Any heliographic position
- Top cross section variable
- Foot separation variable
- Loop height and inclination variable

- Magnetic field (dipole)
- Viewing angle
- Ambient temperature
- Ambient density
- Electron density (Nel)


2. 3D field Geometry & Environment
1. Input: 17 parameters
3. Gyrosynchrotron Computation: j_ν e k_ν
4. Radiative transfer
5. Output: Images & spectra


3.75 GHz
9.4 GHz
17 GHz
34 GHz
PIXEL

- **Energy**:
- $\Rightarrow$ 10 keV – 100 MeV
- **ambient density**:
- $\Rightarrow 10^9 - 10^{14}$ cm^{-3}
- **Nonthermal eletron number density** [Lee et al., 2009]:
- $\Rightarrow 7 \times 10^{34} - 3 \times 10^{42}$.

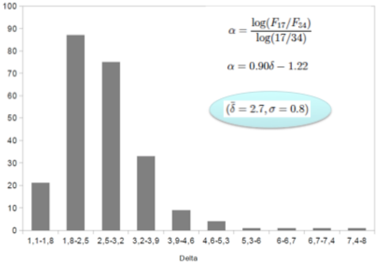
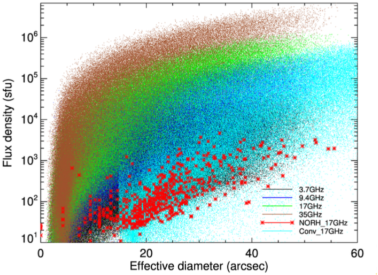


Tabela 6.1 - Intervalo de parâmetros no banco de modelos

No.	Parâmetro	min	max	Símbolo	Unidade
1	Preenchimento do arco	0.2	2	ω	-
2	Delta	1.	4.4	δ	-
3	Densidade dos elétrons	1×10^6	1×10^8	Nel	cm^{-3}
4	Assimetria	-50	50	As	%
5	Azimute	-90	90	Az	Grau
6	Raio do ápice	0.002	0.02	R_arc	$R\odot$
7	Separação dos pés	0.008	0.06	Foot_s	$R\odot$
8	Altura	0.008	0.06	H_arc	$R\odot$
9	Inclinação	-40	40	Inc	Grau
10	Campo magnético	800	3500	B	Gauss



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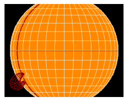
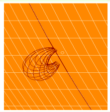
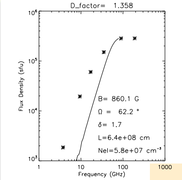
REPORT

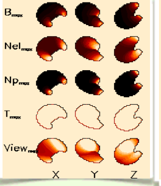


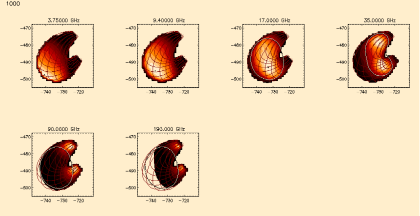


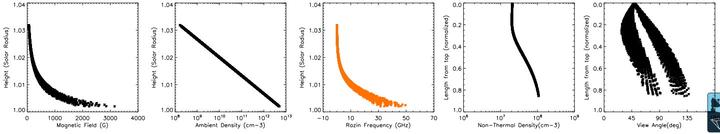


DATA	MIN	MAX	MEAN
B	63.	3152.	305.
Nel	2.03E+07	1.08E+08	3.00E+07
Np	1.66E+08	4.99E+12	1.61E+11
T	1.00E+08	1.00E+08	1.00E+08
View	28.	137.	63.
Energy	10.	100000.	347.0
δ	1.7	1.7	

Latitude	−30.0
Longitude	−60.0
Azimuth	−60.0
Height	0.020
Radius	0.010
Foot Sep.	0.020
Elect. Fill	Homog







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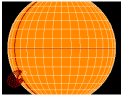
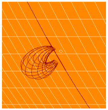
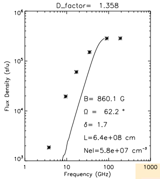
REPORT







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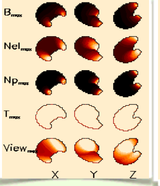
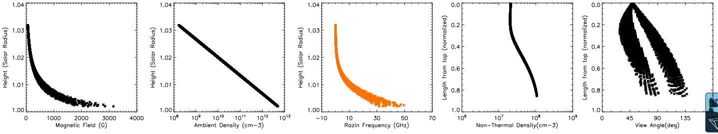
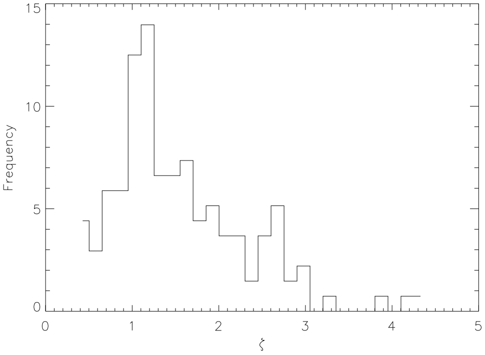


$$\chi^2 = \sum \frac{1}{\sigma^2_{\psi_{Obs_i}}} (\psi_{Mod_i} - \psi_{Obs_i})^2 \quad (1)$$

$$\zeta = \sum_{i=1}^{10} \left(\frac{|Par_i^{Sim} - Par_i^{Res}|}{|Par_i^{max} - Par_i^{min}|} \right) \quad (2)$$

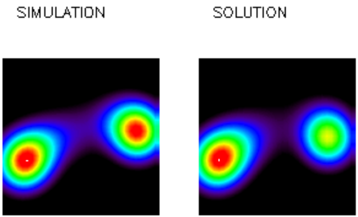


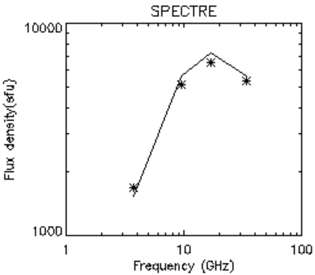
- The parameters recovering in the database were tested in randomly simulated flares.
- 56% of the simulations shows satisfactory results.
- More than 50% of the parameters were recovered with $\zeta \leq 10\%$.



We evaluate the following:

- Simulations with $|\zeta| < 1.2$
- Simulations with $|\zeta| \sim 1.2$
- Simulations with $|\zeta| > 1.2$

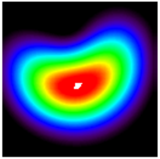




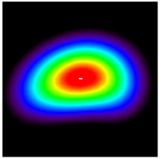
COMPARED PARAMETERS

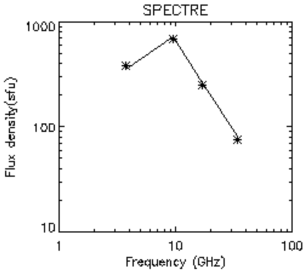
ie= 0.30	ie= 0.30	ie= 0.00
Delta= 3.98	Delta= 3.59	Delta= 0.11
Assim= −0.05	Assim= 0.00	Assim= 0.05
Ne= 9.333e+06	Ne= 1.778e+06	Ne= 7.631e−02
Azim= 0.00	Azim=−15.00	Azim= 0.17
Raio= 0.01	Raio= 0.01	Raio= 0.11
Foot= 0.03	Foot= 0.03	Foot= 0.00
h_arc= 0.02	h_arc= 0.02	h_arc= 0.00
Incl=−40.00	Incl=−40.00	Incl= 0.00
Bmag=1716.43	Bmag=1389.58	Bmag= 0.12
		yy= 0.640

SIMULATION



SOLUTION



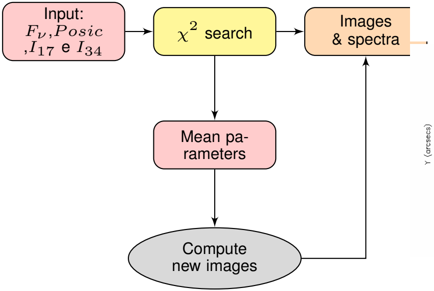


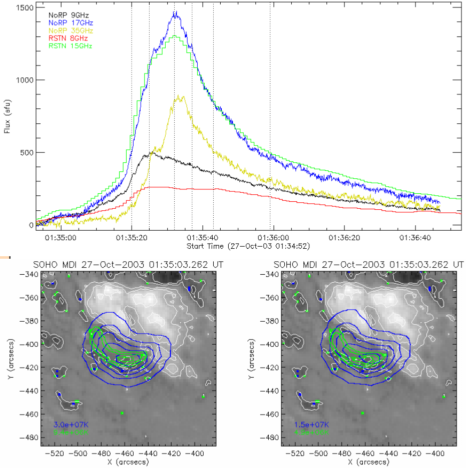
COMPARED PARAMETERS

ie= 1.20	ie= 0.30	ie= 0.50
Delta= 2.47	Delta= 2.74	Delta= 0.08
Assim= −0.05	Assim= −0.50	Assim= 0.45
Ne= 1.349e+07	Ne= 1.778e+07	Ne= 4.337e−02
Azim= 0.00	Azim= 0.00	Azim= 0.00
Raio= 0.01	Raio= 0.01	Raio= 0.11
Foot= 0.05	Foot= 0.05	Foot= 0.00
h_arc= 0.04	h_arc= 0.04	h_arc= 0.00
Incl= 0.00	Incl= 0.00	Incl= 0.00
Bmag=1492.45	Bmag=1244.98	Bmag= 0.09
		yy= 1.275

Table: Fitting parameters for flux calculations.

Time (UT)	Peak (GHz)	α_{thick}	α_{thin}
01:35:20	12.44	1.35	-2.32
01:35:25	12.84	1.52	-1.14
01:35:32	17.76	1.95	-0.82
01:35:37	17.01	1.98	-0.81
01:35:43	11.43	1.57	-0.67
01:35:59	10.19	1.09	-0.49





$$S = A\nu^{a}(1 - e^{-B\nu^{-b}}) \qquad (3)$$

[Stahli et al., 1989]

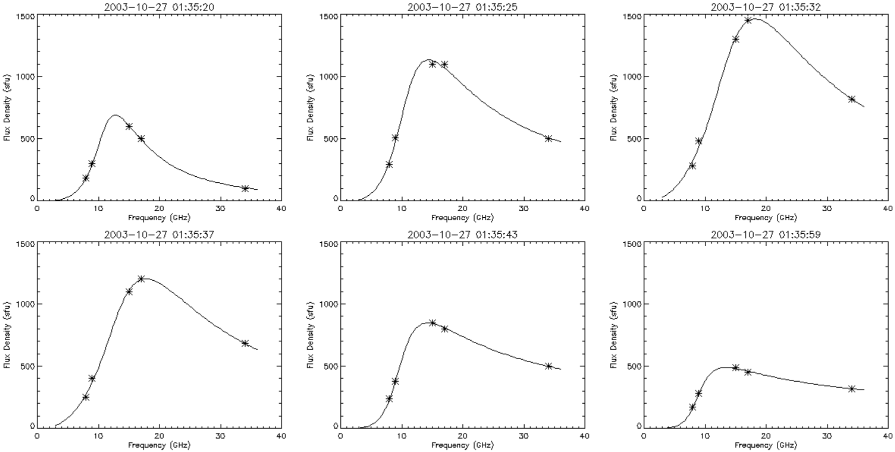
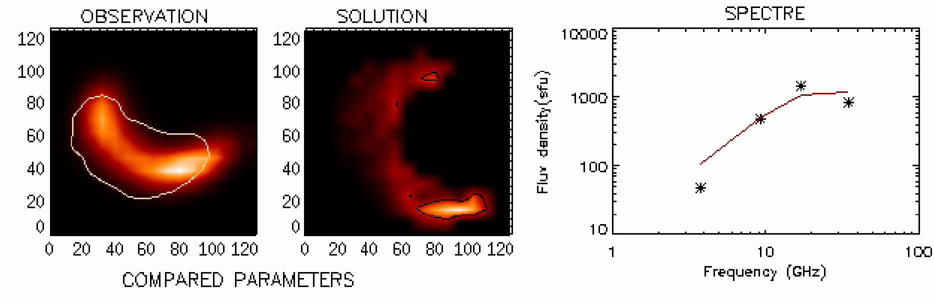
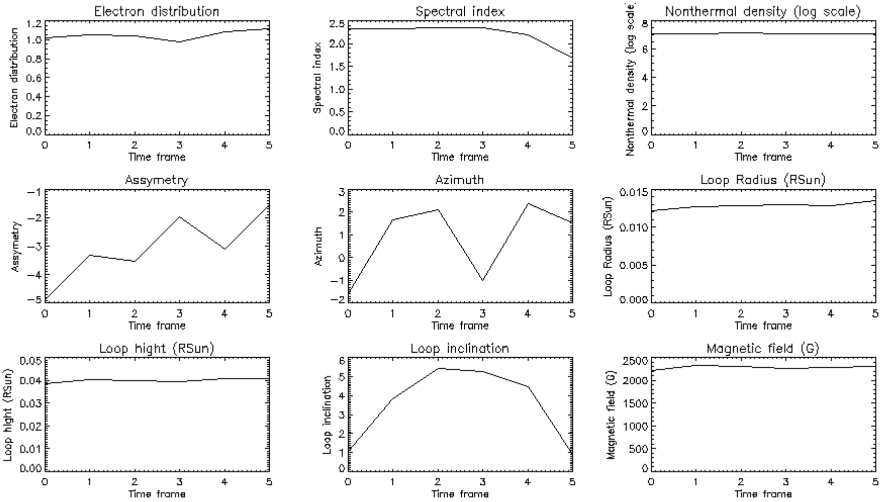


Table: Parameters of the database solutions.

					Parameters					
Time (UT)	ie (1)	δ (2)	$N_{\mathrm{nth}}(log)$ (3)	q (4)	Az (5)	R_{Arc} (6)	F_{sep} (7)	H_{Arc} (8)	t (9)	B (10)
01:35:20	1.02	2.32	7.08	-4.90	-1.58	0.01	0.03	0.04	1.07	2223.20
01:35:25	1.05	2.31	7.08	-3.33	1.66	0.01	0.03	0.04	3.84	2328.55
01:35:32	1.04	2.34	7.11	-3.55	2.08	0.01	0.03	0.04	5.43	2308.15
$**$	1.74	5.74	9.67	37.32	7.42	0.01	0.04	0.03	55.32	2543.60
01:35:37	0.97	2.34	7.10	-1.95	-1.00	0.01	0.03	0.03	5.27	2263.58
01:35:43	1.08	2.19	7.07	-3.10	2.34	0.01	0.03	0.04	4.47	2289.33
01:35:59	1.11	1.67	7.08	-1.56	1.52	0.01	0.03	0.04	0.89	2299.85

$**$ — The refined parameters with the pikaia algorithm.




Electron distribution
Electron distribution
Time frame
Spectral index
Spectral index
Time frame
Nonthermal density (log scale)
Nonthermal density (log scale)
Time frame
Assymetry
Assymetry
Time frame
Azimuth
Azimuth
Time frame
Loop Radius (RSun)
Loop Radius (RSun)
Time frame
Loop hight (RSun)
Loop hight (RSun)
Time frame
Loop inclination
Loop inclination
Time frame
Magnetic field (G)
Magnetic field (G)
Time frame

- Accelerates the search for the best geometric representation of brightness distribution maps from NoRH and the search for the best representation of NoRP spectra.
- The probability of success in the results is directly linked to the growth of the database.
- Additionally, using additional information in different observation bands contributes positively to success.
- The weighted mean solutions are an improvement to address the degeneracy on a single solution with the lowest χ^2 value.
- The weighted mean solutions are employed as an initial guess in different Monte Carlo methods to refine the fitting.

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Costa, J., Simões, P., Pinto, T., and Melnikov, V. (2013).
Solar burst analysis with 3d loop models.
Publication Astronomy Society Japan, 65:5.

Cuambe, V. A., Costa, J. E. R., and Simões, P. J. A. (2018).
Flare parameters inferred from a 3d loop model database.
Monthly Notices of the Royal Astronomical Society, page 12.

Kopp, R. and Pneuman, G. (1976).
Magnetic reconnection in the corona and the loop prominence phenomenon.
Solar Phys., 50:85–98.

Lee, J., Nita, G., and Gary, D. (2009).
Electron energy and magnetic field derived from solar microwave burst spectra.
APJ, 696:274–279.

Simões, P. and Costa, J. (2006).
Solar bursts gyrosynchrotron emission from three-dimensional sources.
Astronomy & Astrophysics, 453:729–736.

Simões, P. and Costa, J. (2010).
Gyrosynchrotron emission from anisotropic pitch-angle distribution of electrons in 3-d solar flare sources.
Solar Phys., 266:109–121.

Stahli, M., Gary, D., and Hurford, G. (1989).
High-resolution microwave spectra of solar bursts.
Solar Phys., 120:351–368.

Thank you !!