Polarization of solar flares at 45 and 90 GHz

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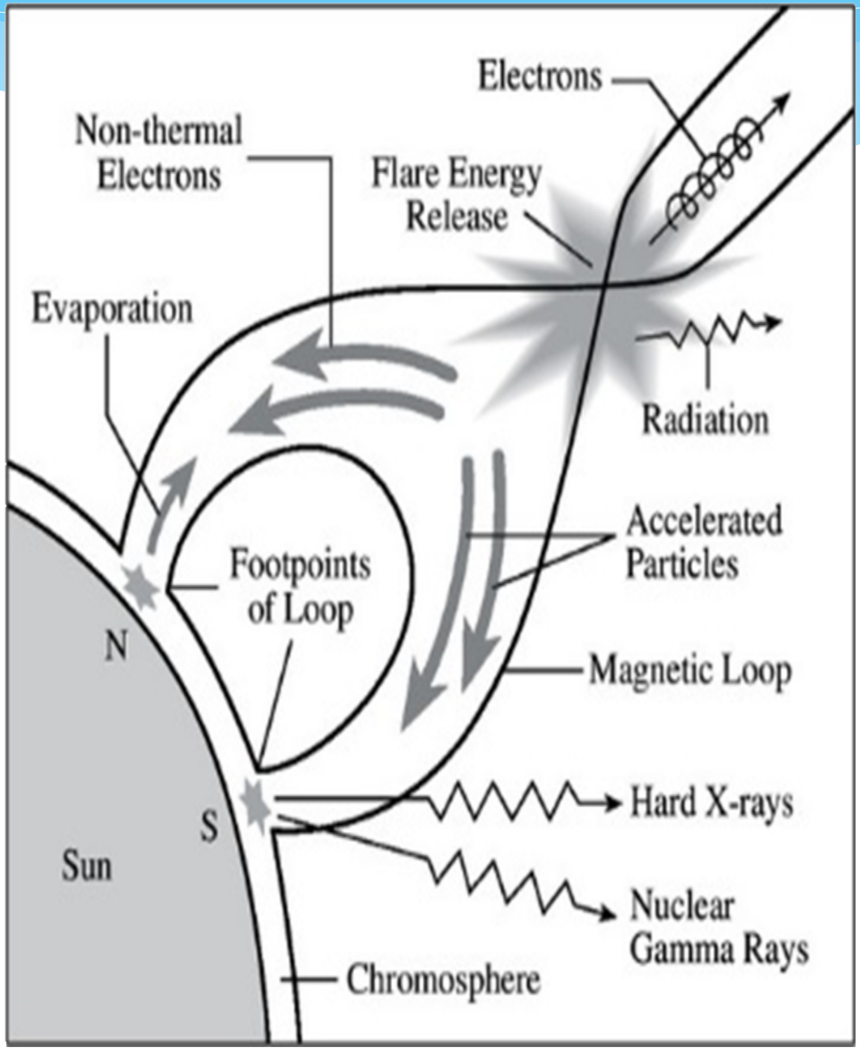
Chromo AID – March 15-18, 2016 – Boulder, CO (USA)

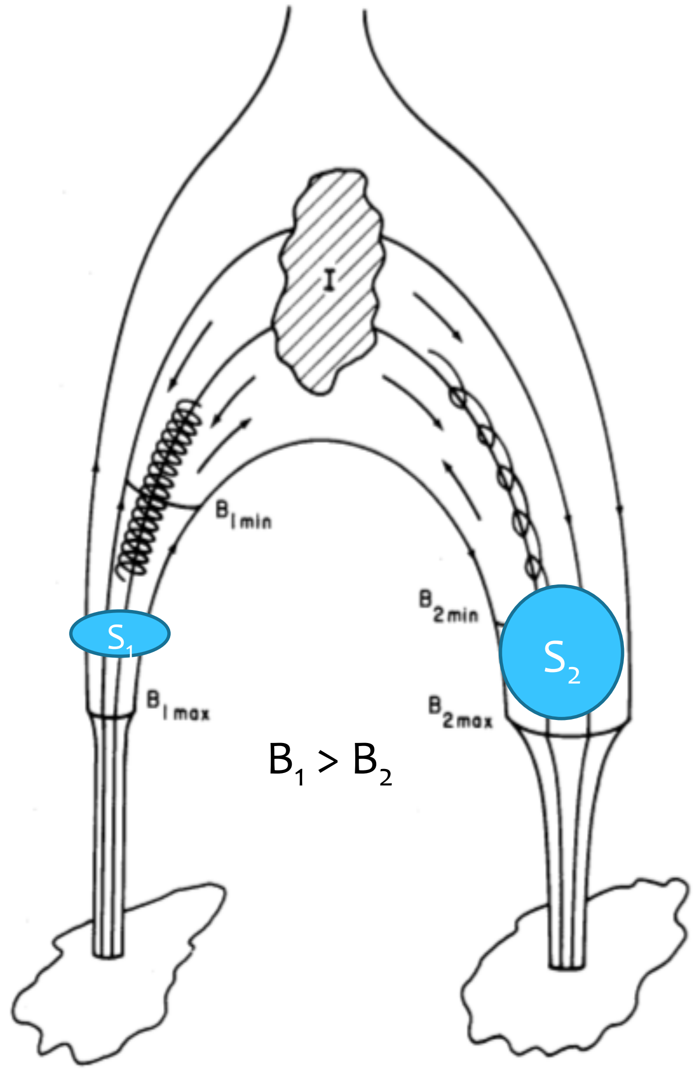
Flare radio emission and polarization

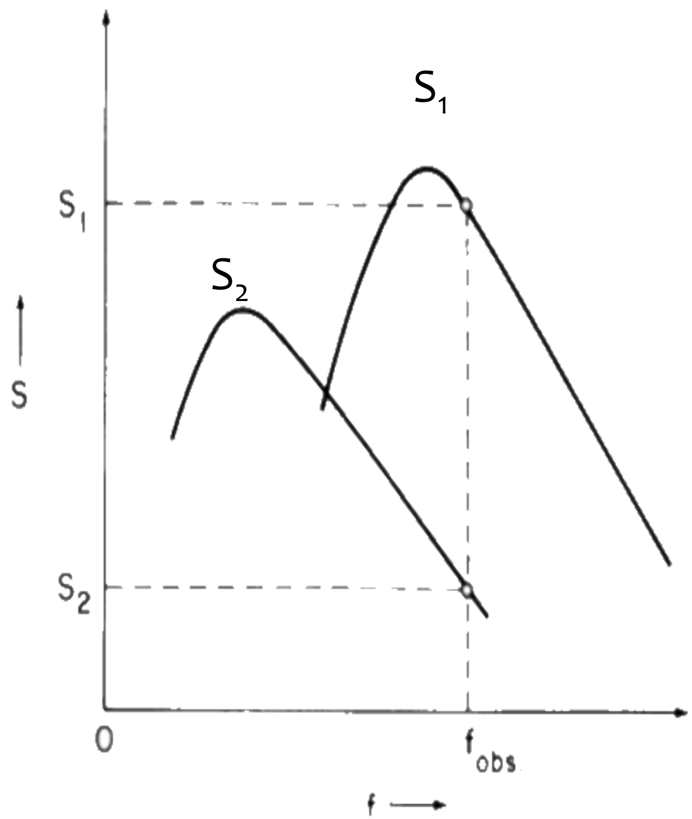
- Flare emission at mm due to gyrosynchrotron from accelerated electrons
- Wave propagation mode
    i. Ordinary
    ii. Extraordinary:
        i. RCP: N (+) B
        ii. LCP: S (-) B
- Strongly affected by the propagation conditions
- Observed circular polarization at 45 and 90 GHz with opposite sign



Asymmetric magnetic loop

* Kundu & Vlahos (1979): Relation between total flux and polarized flux depends on the ratio of the magnetic intensity at loop legs





Goal

Determine the magnetic field configuration and energy distribution of accelerated particles

* Radio observation of three solar flares:
    i. Radio spectra;
    ii. Polarization degree at 45 and 90 GHz.
* Complementary observations at other wavelengths:
    i. X Ray;
    ii. UV images;
    iii. Magnetograms.
* Qualitative comparison with numerical simulations of radio emission in flaring 3D magnetic loops (Simões 2009).

Radio observation

* RSTN: 2.7, 5, 8.8, and 15.4 GHz
* POEMAS (POlarized Emission of Millimeter Activity on the Sun): 45 and 90 GHz
* SST (Submillimeter Solar Telescope): 212 GHz

El Leoncito Observatory (CASLEO) in the Argetina Andes

POEMAS

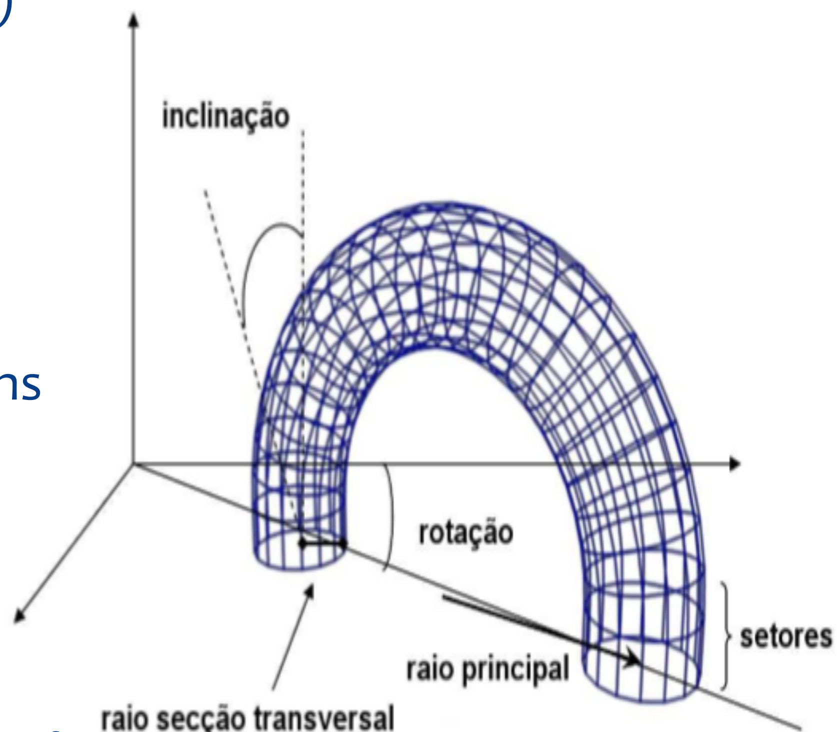
* Novelty: circular polarization measurements
* Frequencies: 45 and 90 GHz
* Whole solar disk (HPBW 1.5°)
* Time resolution: 10 ms
* Sensibility: 2 – 3 K
* CASLEO, Argentina
* Data: Nov 2011 – Dec 2013

3 Solar flares

Flare	GOES class	Location	Pol at 45 GHz	Pol at 90 GHz
17 Feb 2013	M 1.9	N12E17	-8 %	+9%
13 May 2013	X 2.8	N08E89	+7%	-10%
05 Nov 2013	M 1.0	S12E47	+35%	-10%

Numerical Simulation (Simões 2009)

* Gyrosynchrotron emission - Ramaty (1969) and Ramaty et al. (1994).
* Injection of accelerated electrons into the magnetic loop
* Energy distribution of accelerated electrons
* Radiative transfer
* Results for flaring source:
  * Radio spectra
  * Emission maps with total flux and polarization for several radio frequencies

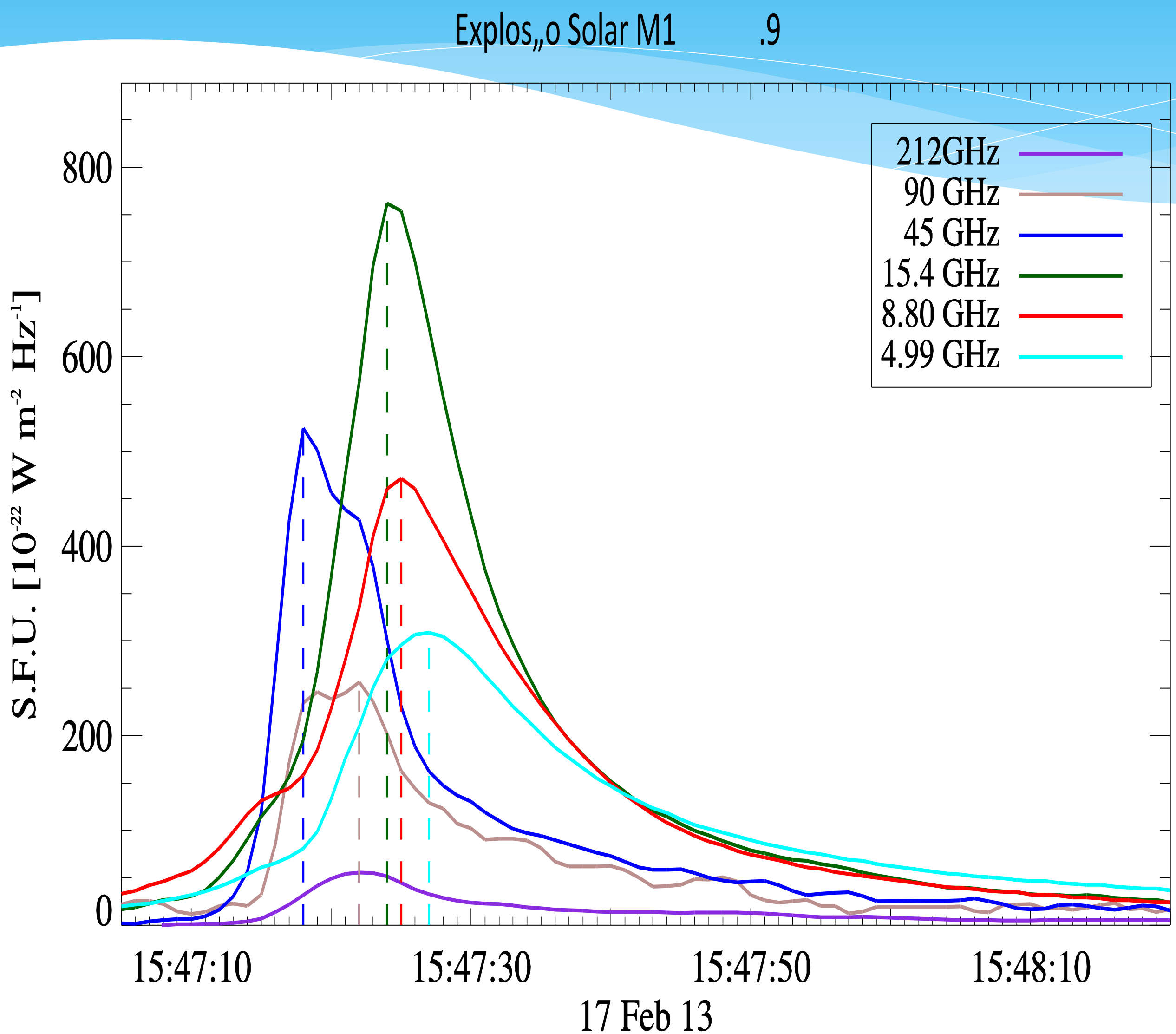


*

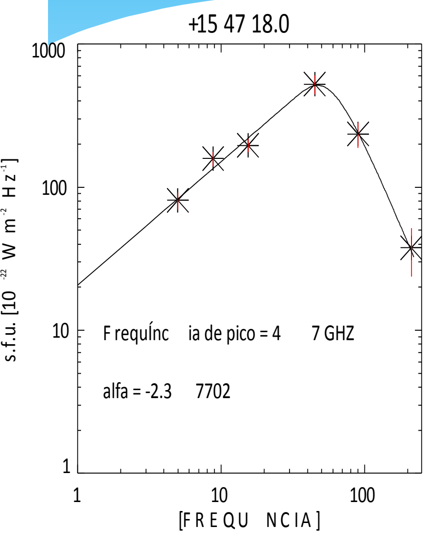
Numerical simulation INPUTS

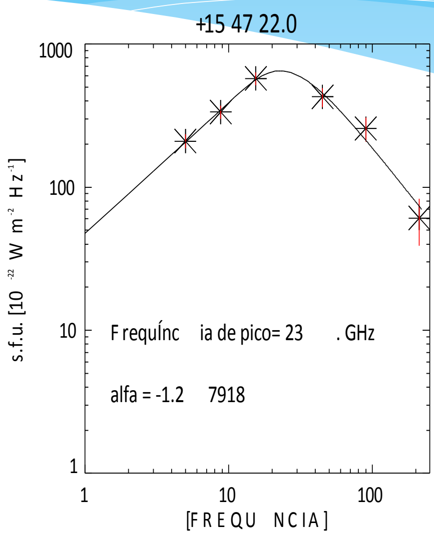
* Magnetic loop
  * Magnetic field intensity along the loop
  * Length: 1 - 3 x 10^9 cm
  * Position (longitude,latitude): location of flare in UV images
  * Azimuth (magnetograma): magnetic field
  * Inclination: 0º
* Ambient thermal electrons:
  * Density: 1 x 10^{10} cm^{-3}
  * Temperature: 10 MK
* Non thermal electrons:
  * Spectral index
  * Density: 5 x 10^7 cm^{-3}
  * Energy cutoffs: 10 keV – 20 MeV

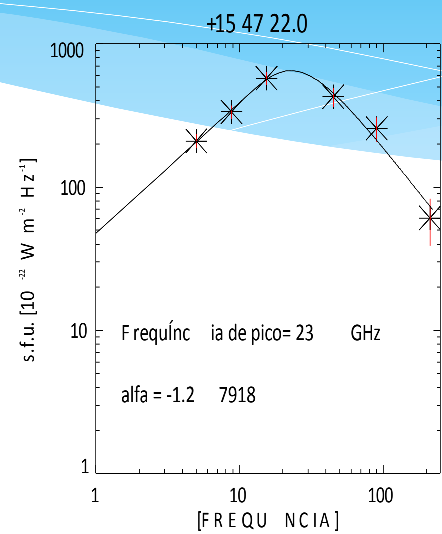
Flare – 17 Feb 2013 (M 1.9)

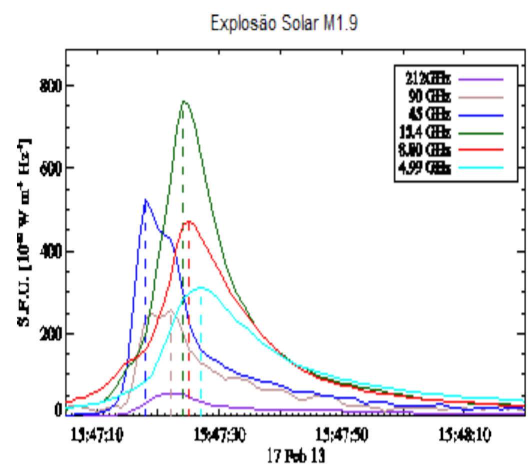


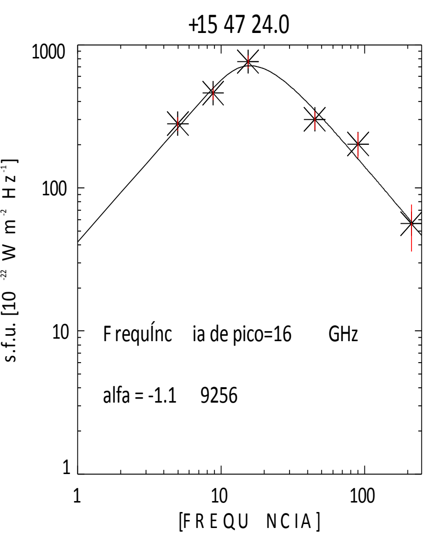
Radio spectra

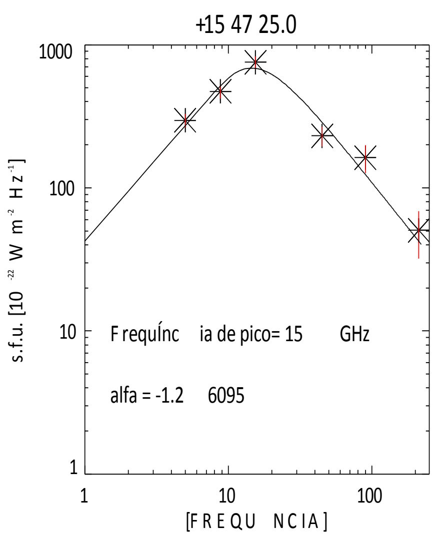


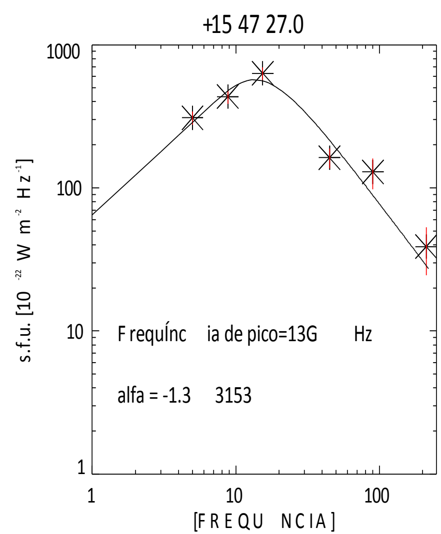




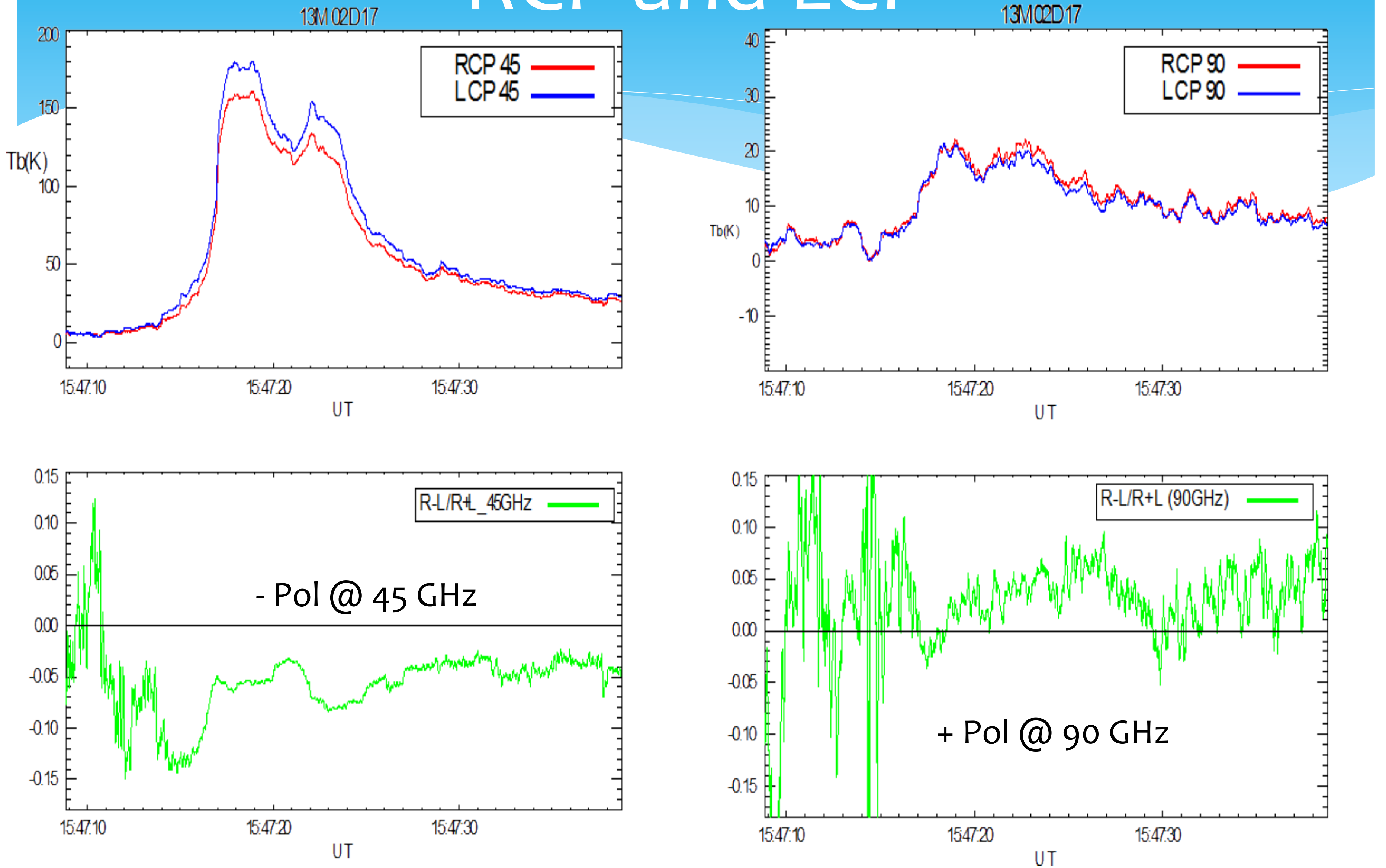






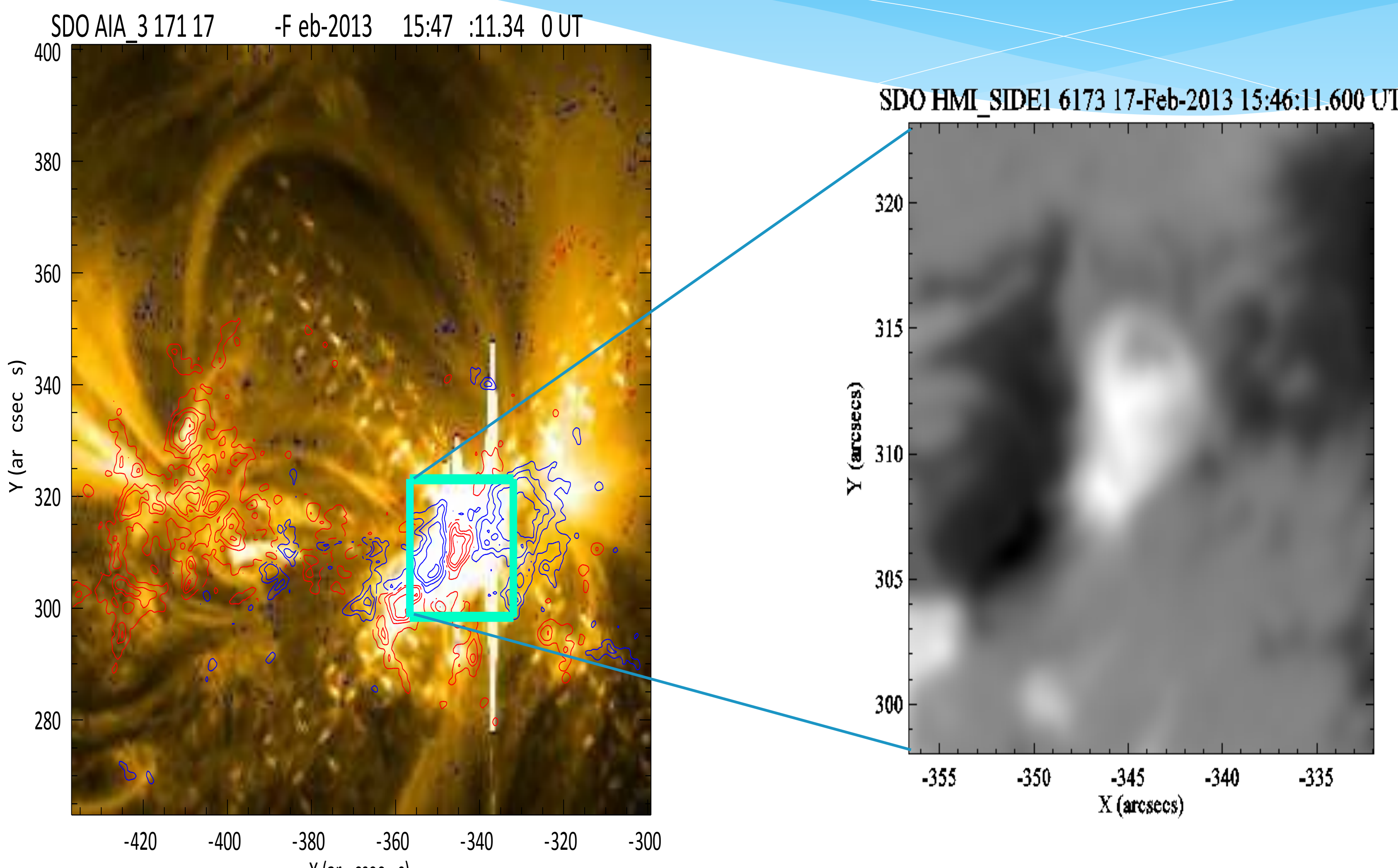


RCP and LCP

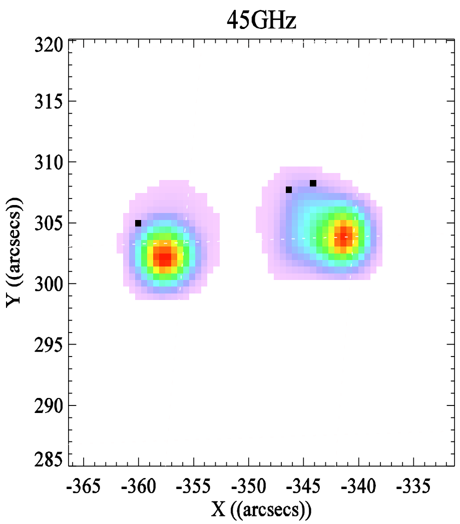


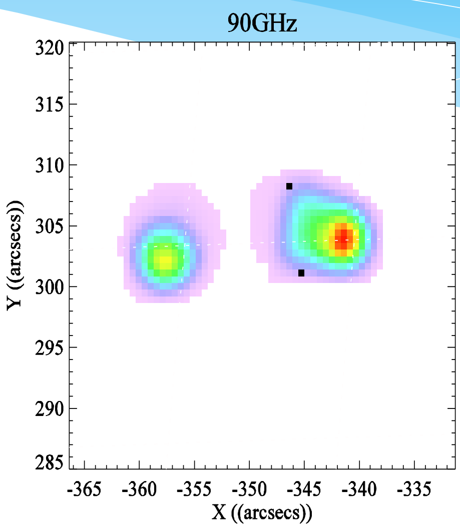
13M02D17
RCP 45
LCP 45
Tb(K)
200
150
100
50
0
15:47:10
15:47:20
15:47:30
UT
13M02D17
RCP 90
LCP 90
Tb(K)
40
30
20
10
0
-10
R-L/R+L_45GHz
- Pol @ 45 GHz
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
R-L/R+L (90GHz)
+ Pol @ 90 GHz

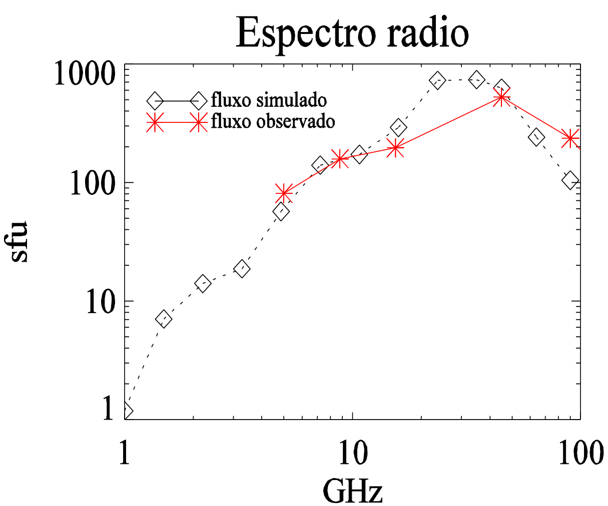
UV (171 A) and Magnetogram

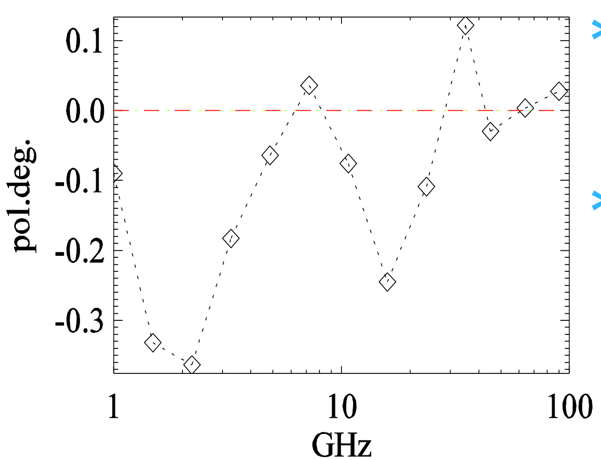


Simulation results



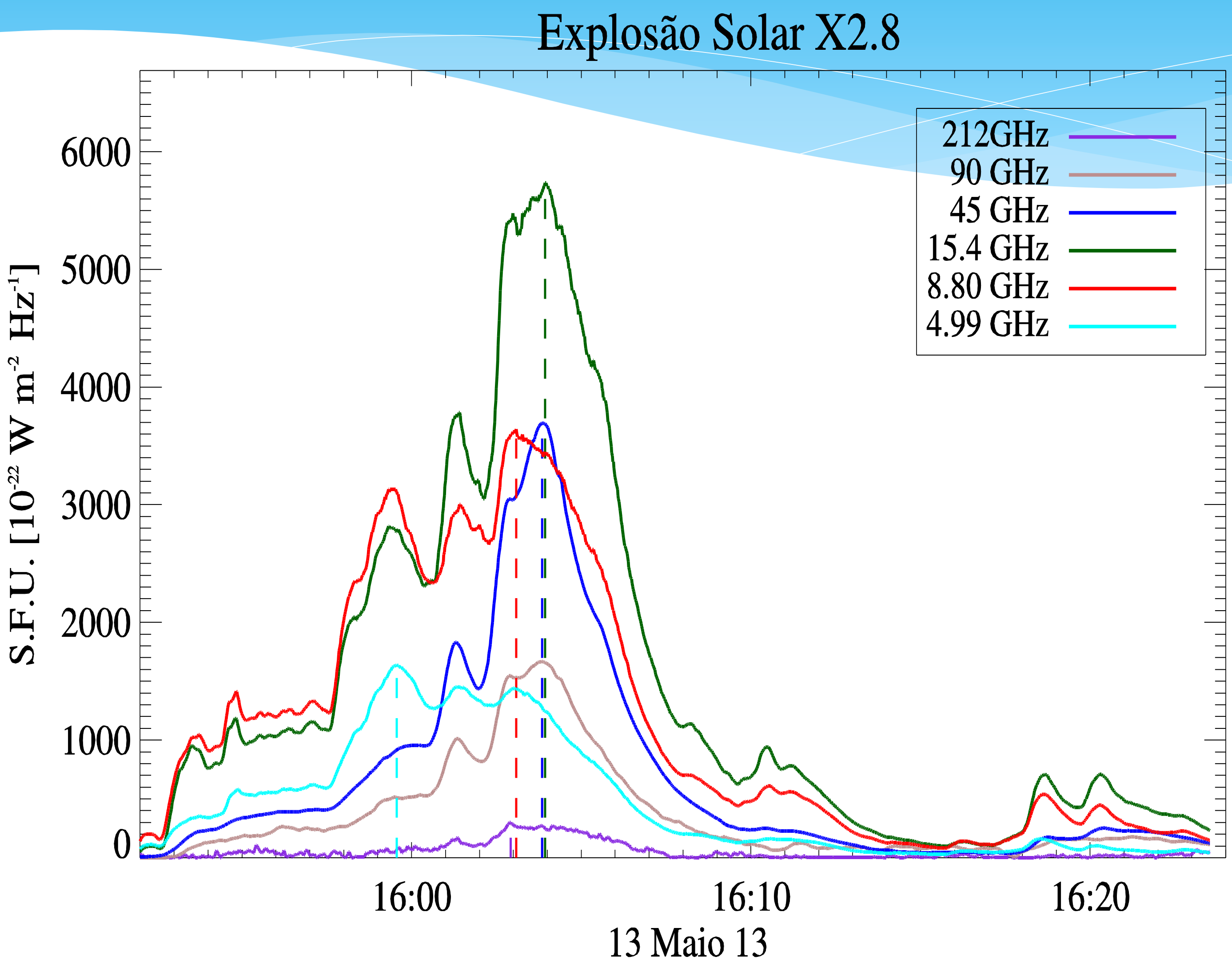




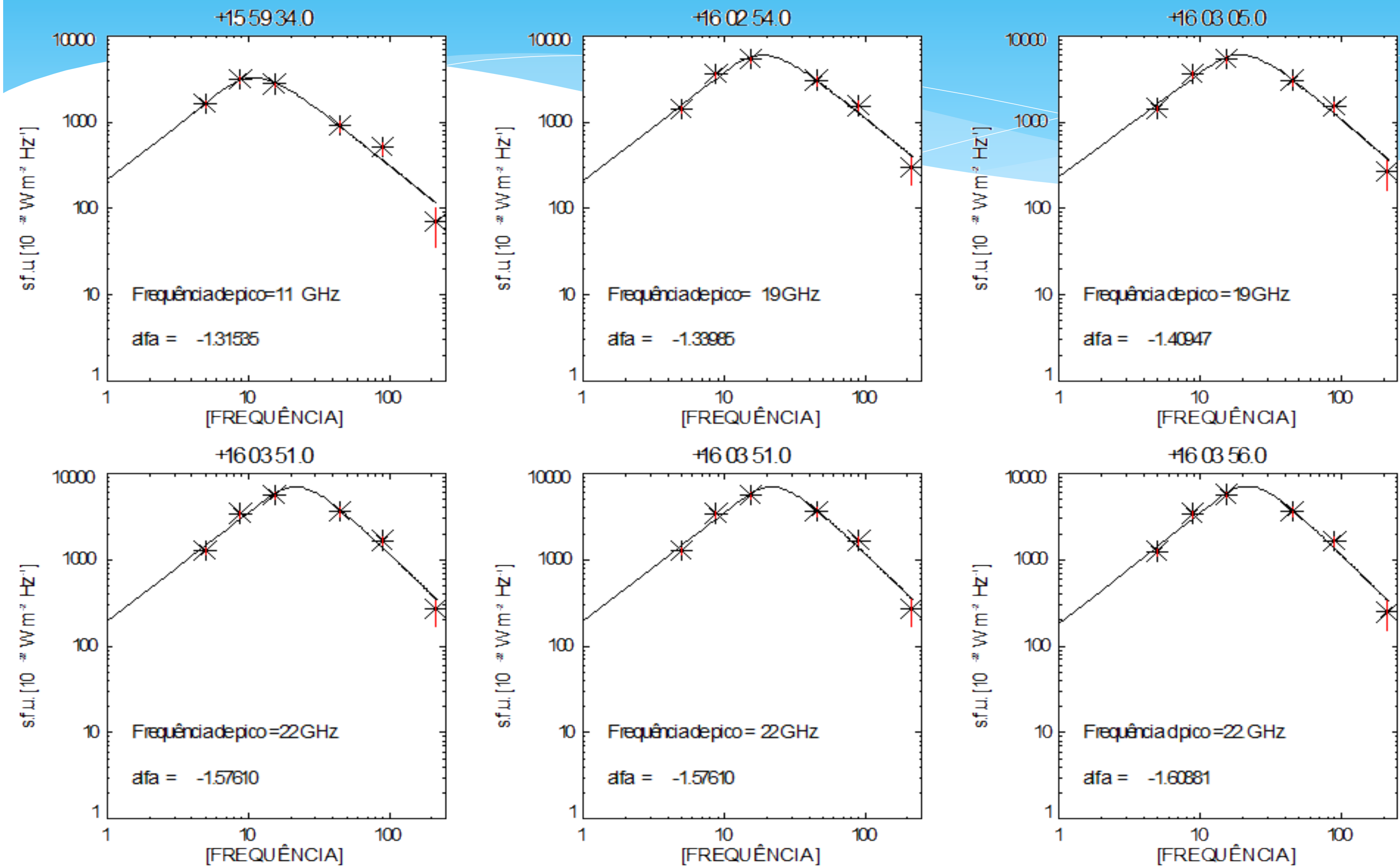


- Asymmetric magnetic field: -3100 G in one footpoint and 3800 G on the other.
- Position: Lat 18°, Long -22°
- Angle wrt solar equator: 5°

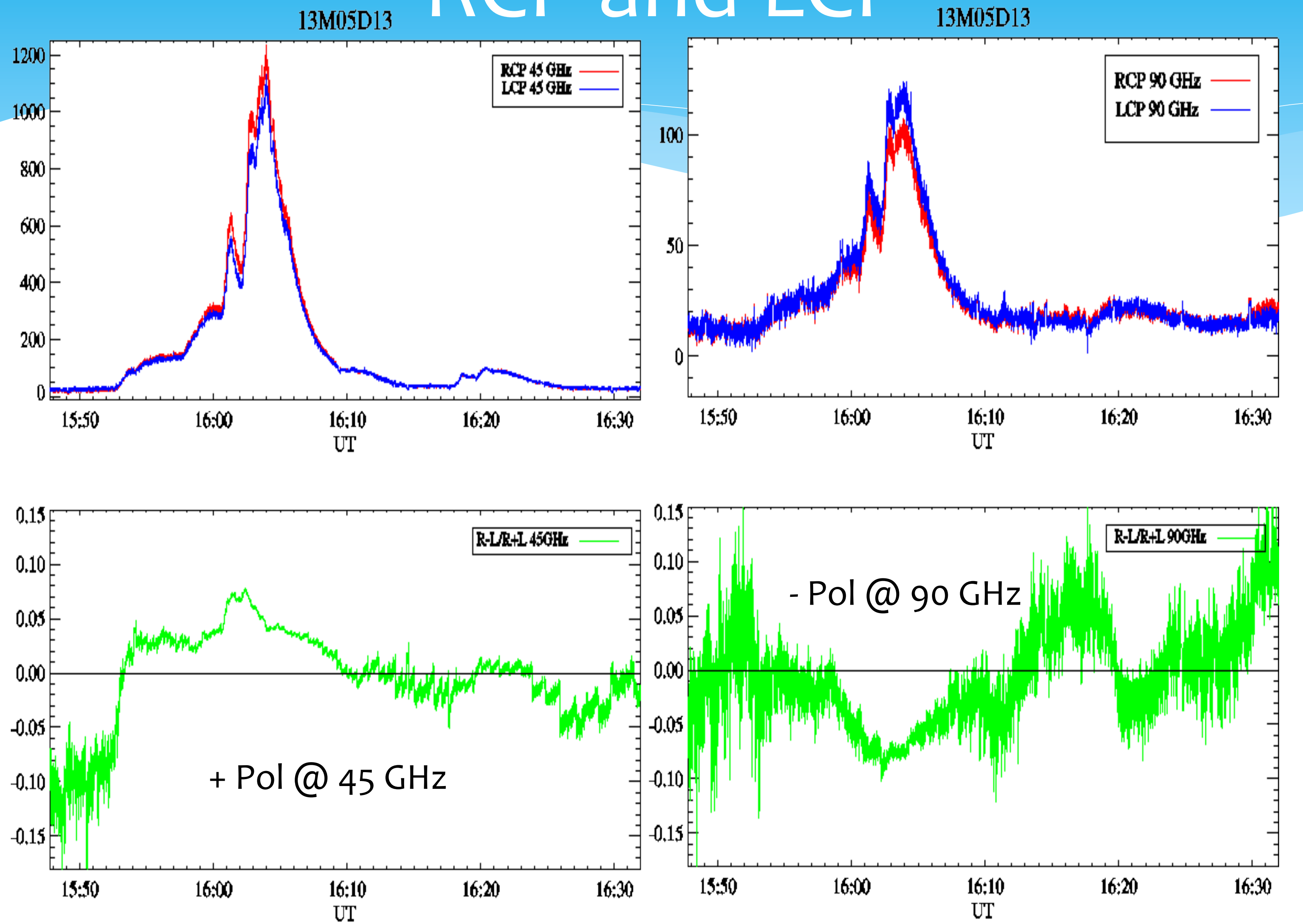
Flare – 13 May 2013 (X 2.8)



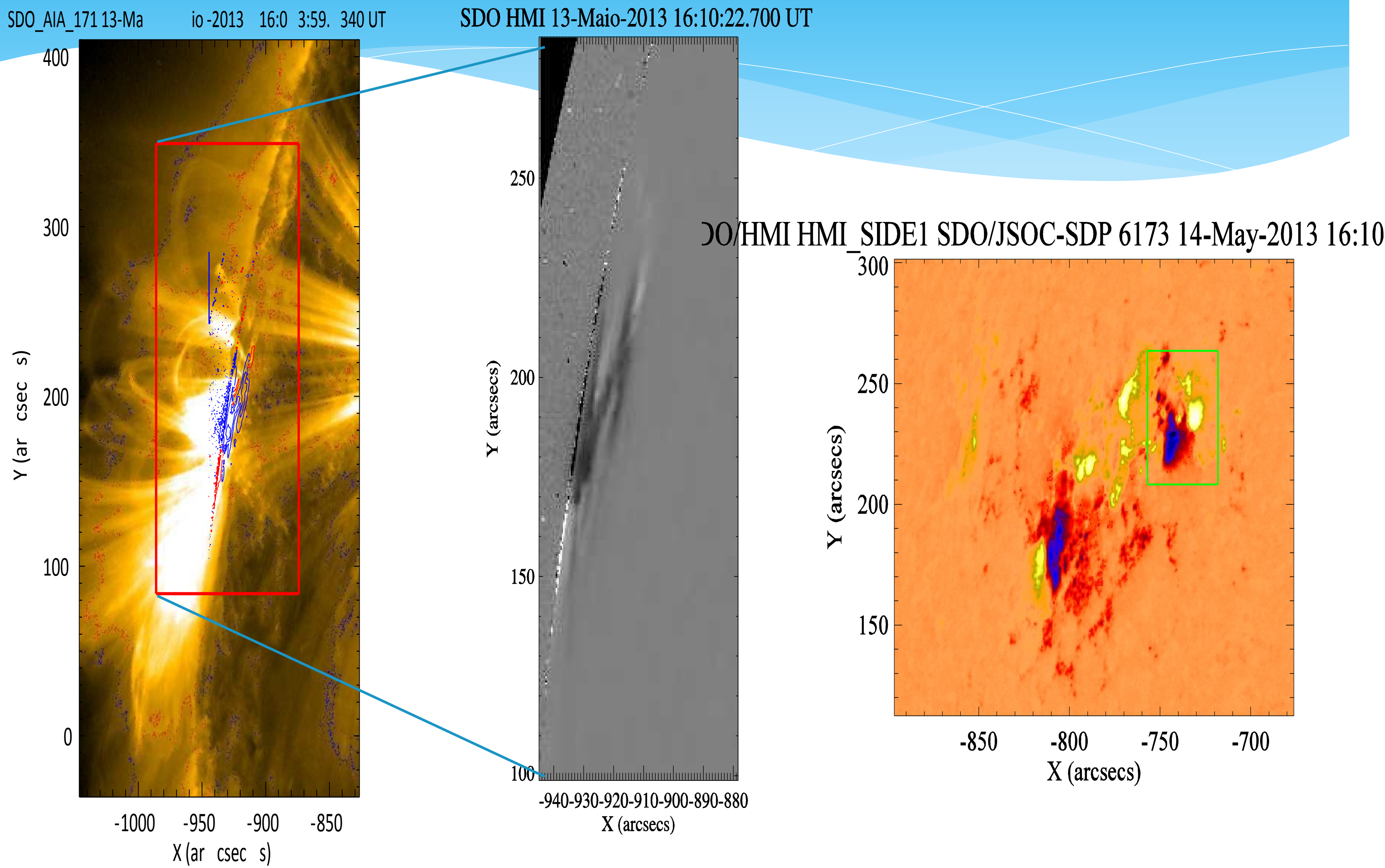
Radio spectra



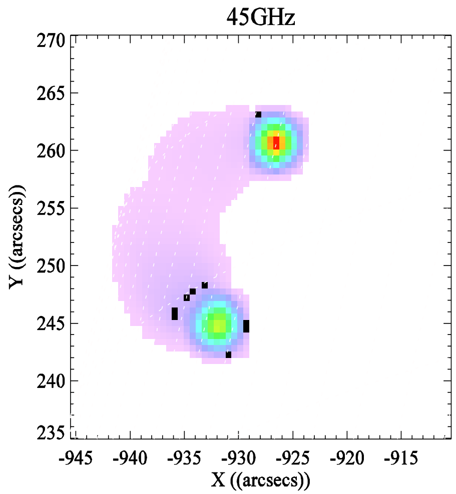
RCP and LCP

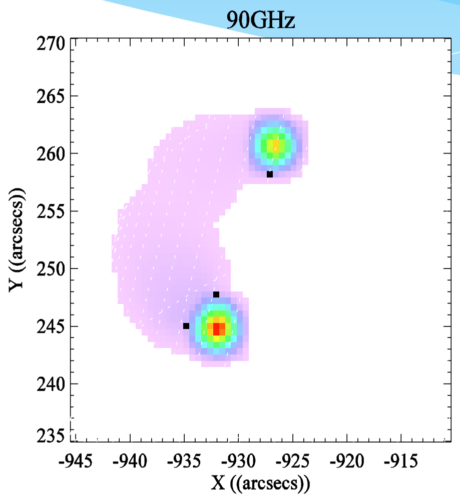

13M05D13
RCP 45 GHz
LCP 45 GHz
1200
1000
800
600
400
200
0
15:50
16:00
16:10
16:20
16:30
UT
13M05D13
RCP 90 GHz
LCP 90 GHz
100
50
0
15:50
16:00
16:10
16:20
16:30
UT
R-L/R+L 45GHz
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
+ Pol @ 45 GHz
15:50
16:00
16:10
16:20
16:30
UT
R-L/R+L 90GHz
- Pol @ 90 GHz
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
15:50
16:00
16:10
16:20
16:30
UT

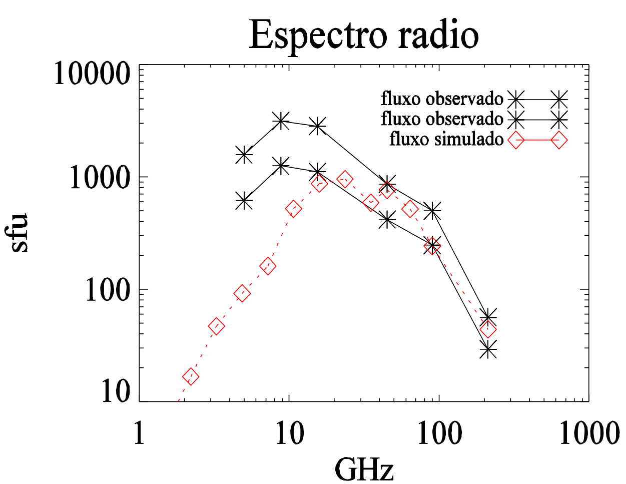
UV (171 A) and Magnetogram

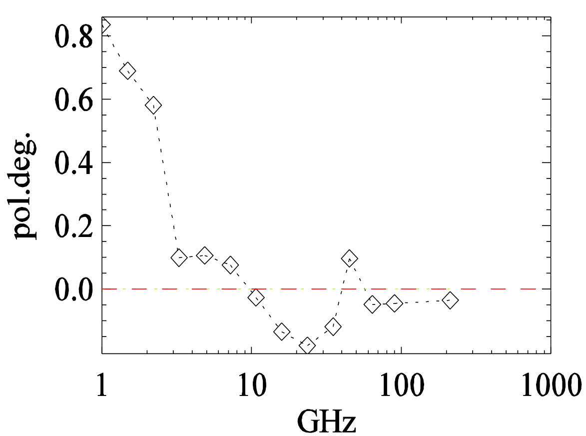


Simulation results



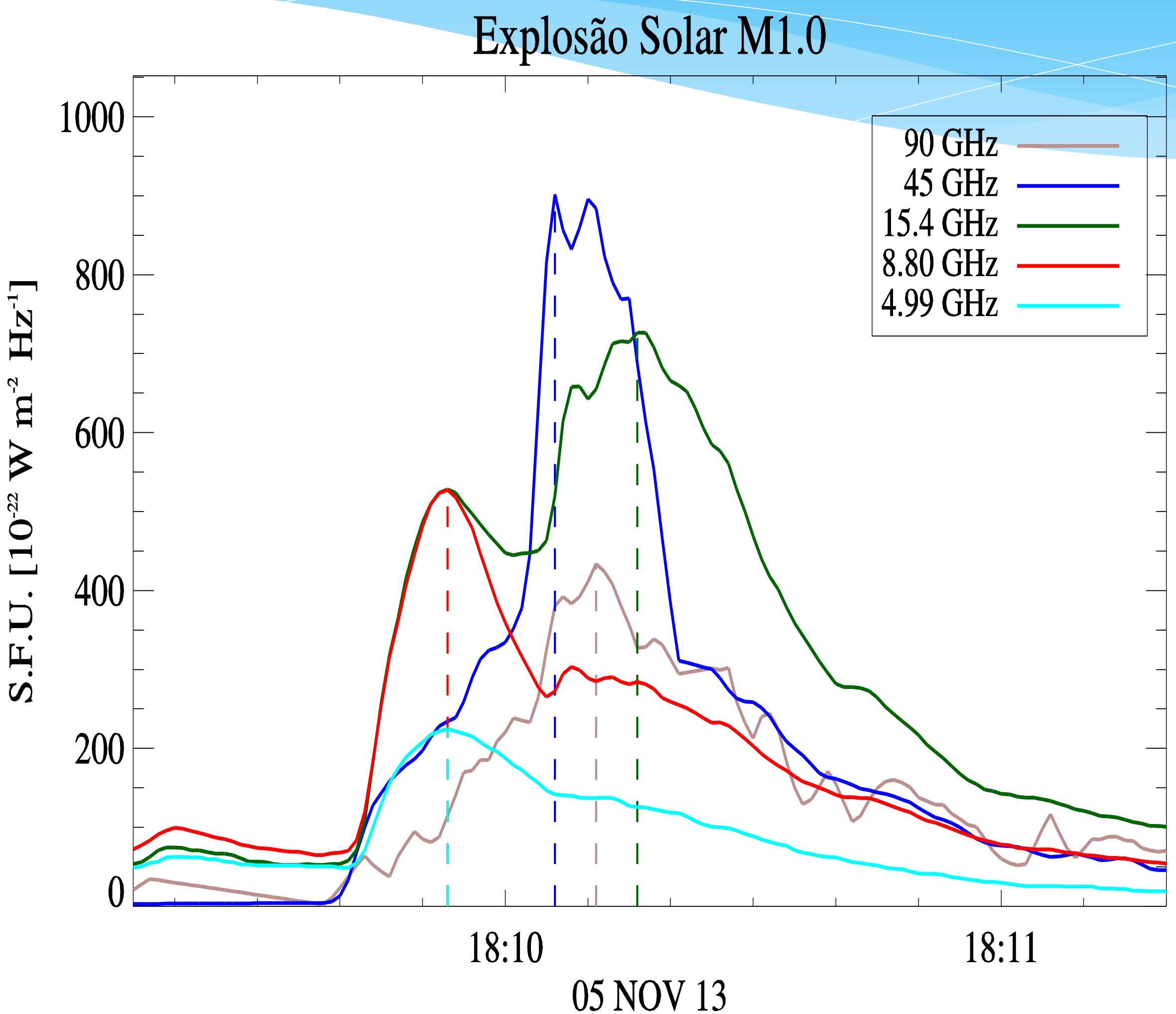




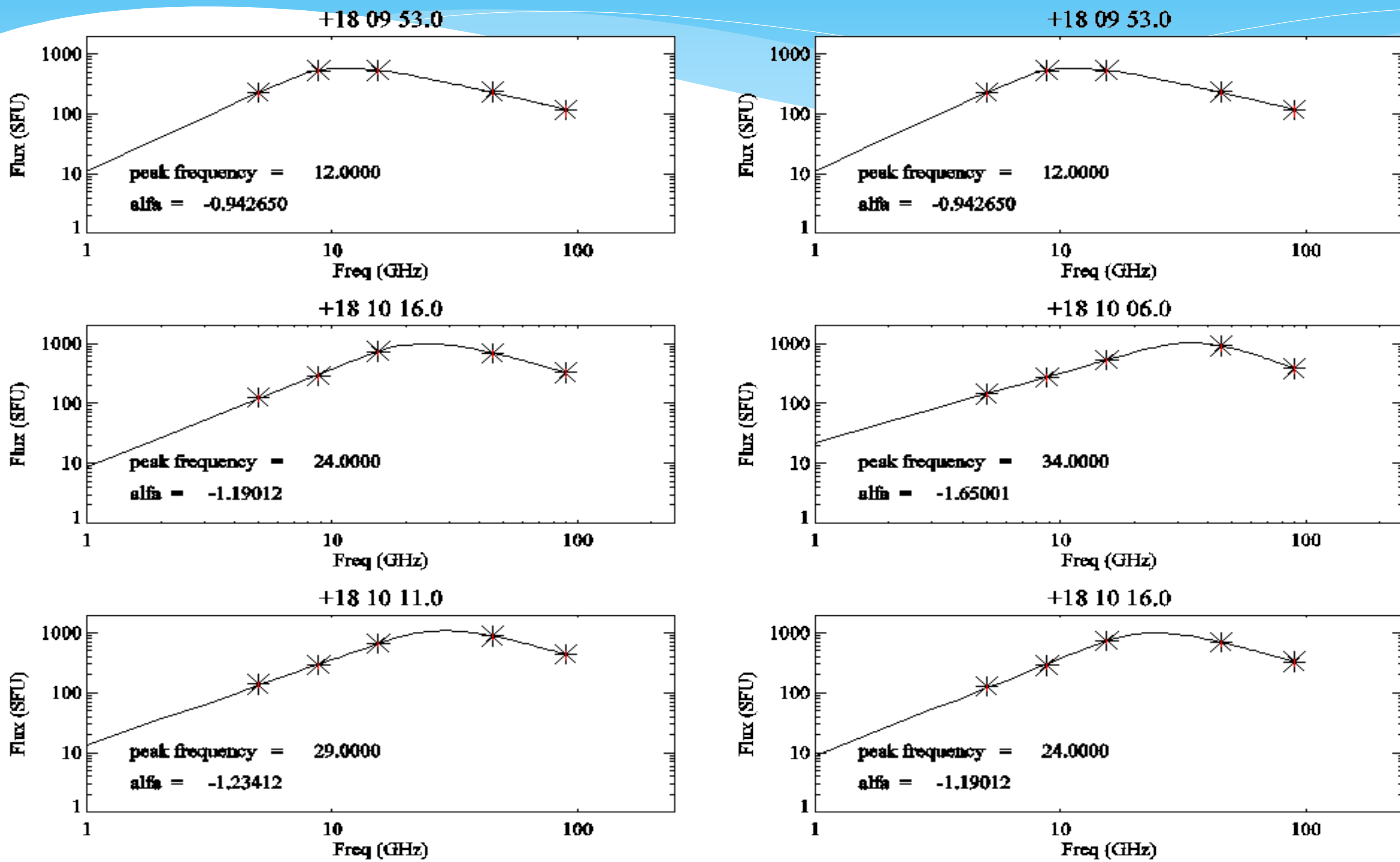


* Asymmetric magnetic field: 3200 G in one footpoint and -3420 G on the other.
* Position: Lat 15°, Long -80°
* Angle wrt solar equator: 70°

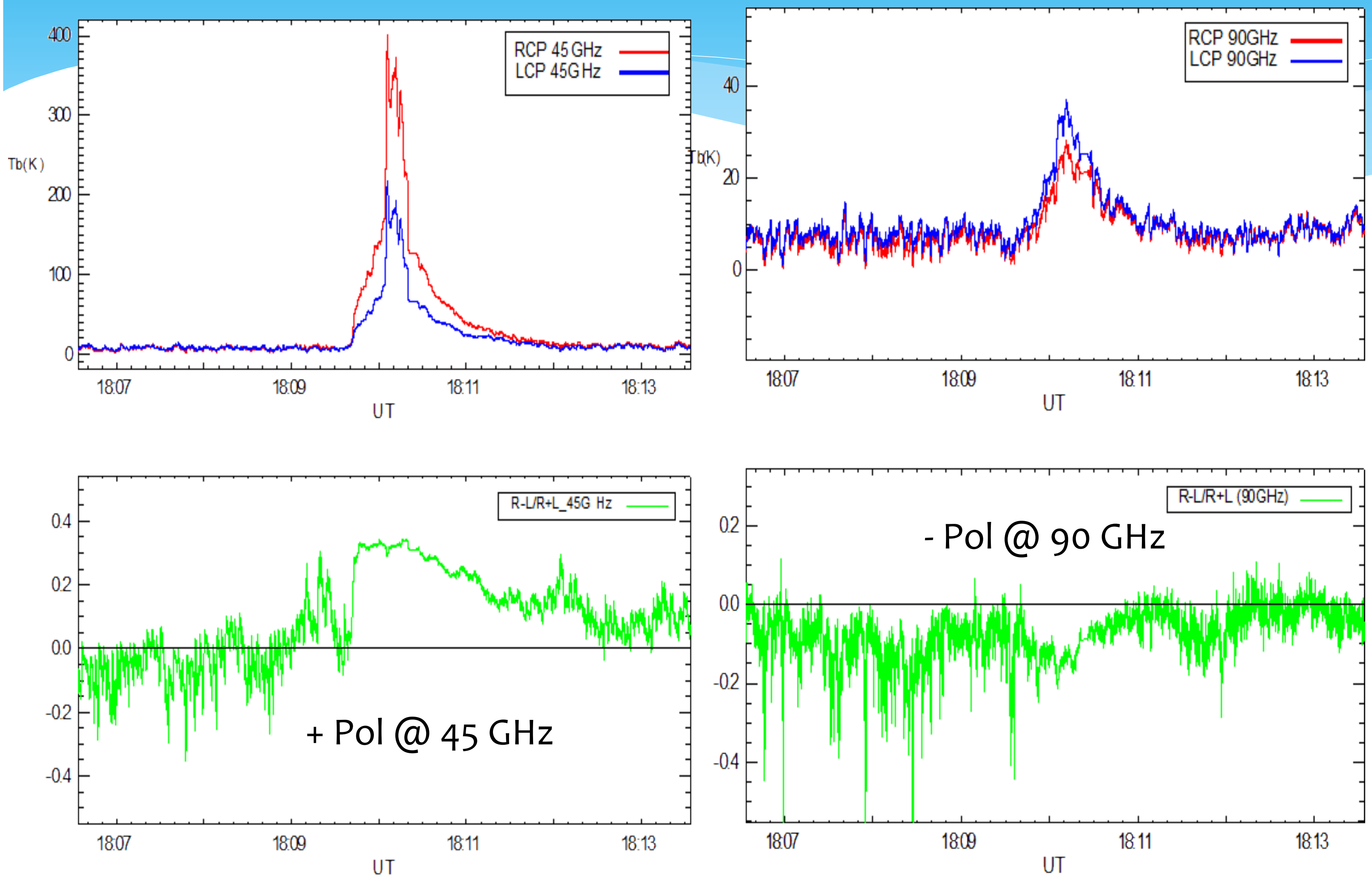
Flare – 5 Nov 2013 (M 1.0)



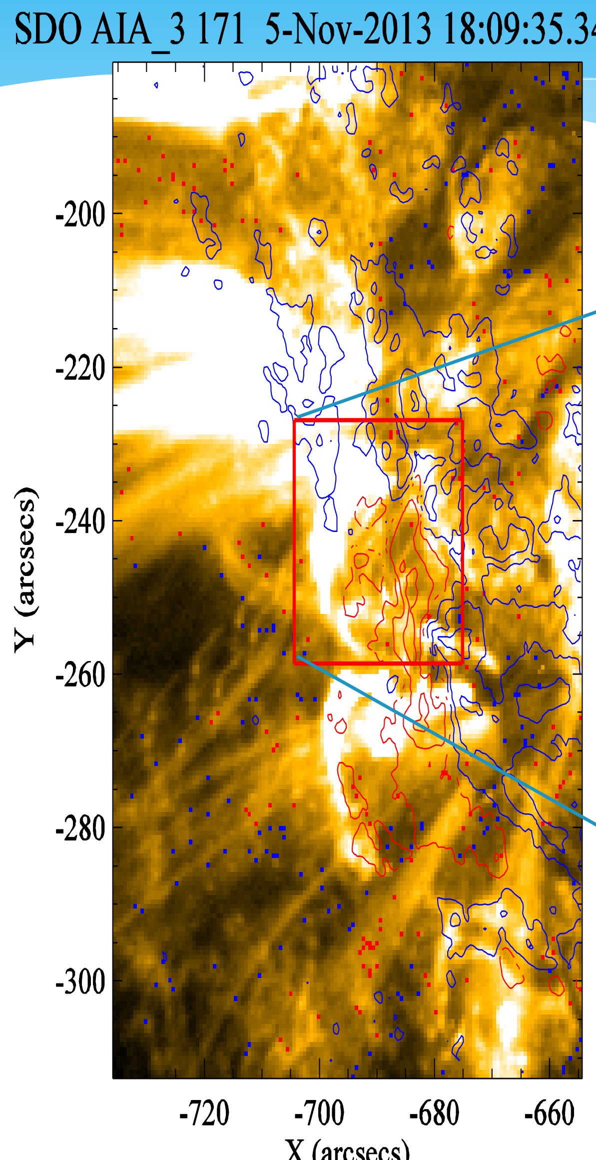
Radio spectra

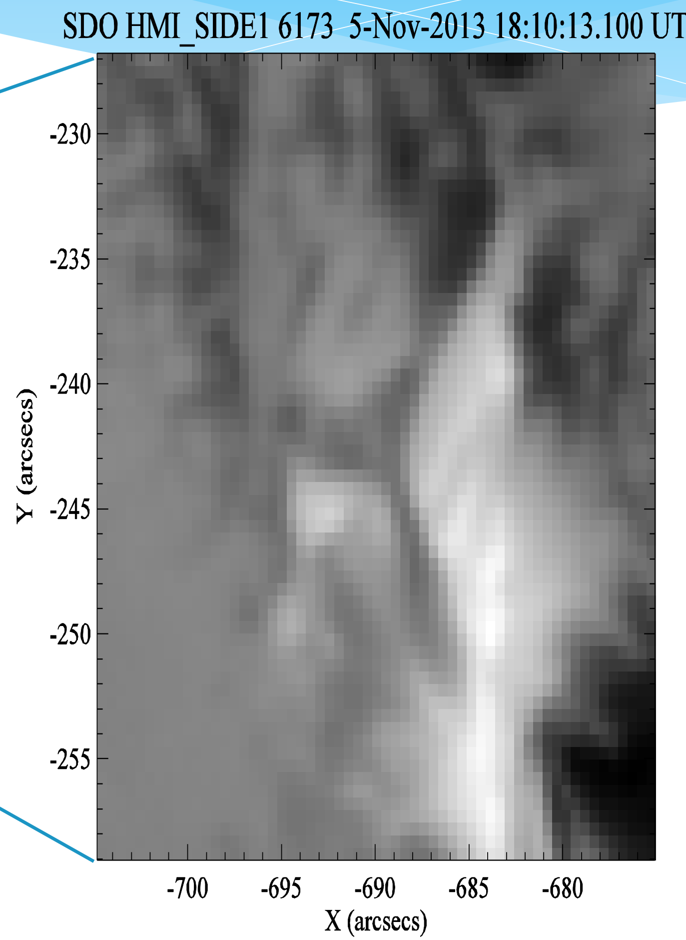


RCP and LCP

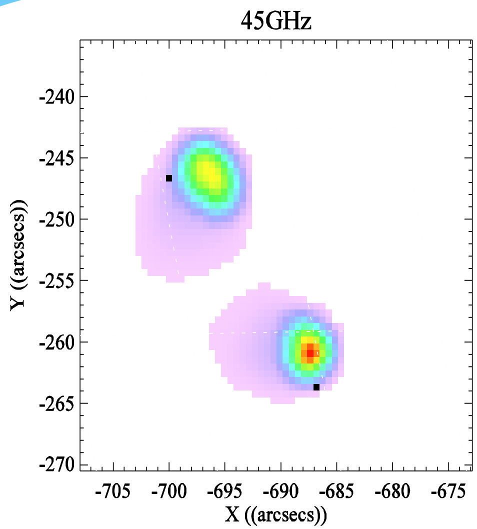

RCP 45 GHz
LCP 45GHz
Tb(K)
400
300
200
100
0
18:07
18:09
18:11
18:13
UT
RCP 90GHz
LCP 90GHz
Tb(K)
40
20
0
18:07
18:09
18:11
18:13
UT
R-L/R+L_45G Hz
0.4
0.2
0.0
-0.2
-0.4
+ Pol @ 45 GHz
18:07
18:09
18:11
18:13
UT
R-L/R+L (90GHz)
- Pol @ 90 GHz
0.2
0.0
-0.2
-0.4
18:07
18:09
18:11
18:13
UT

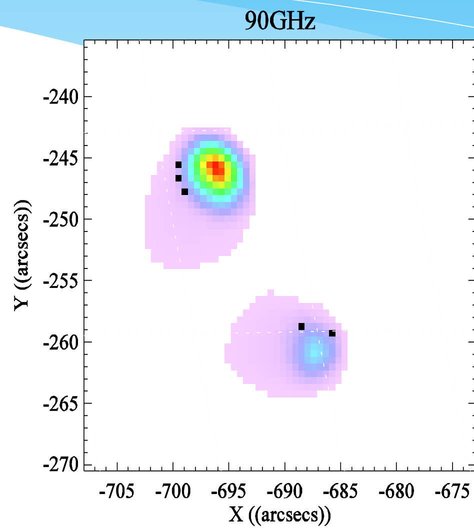
UV (171 A) and Magnetogram

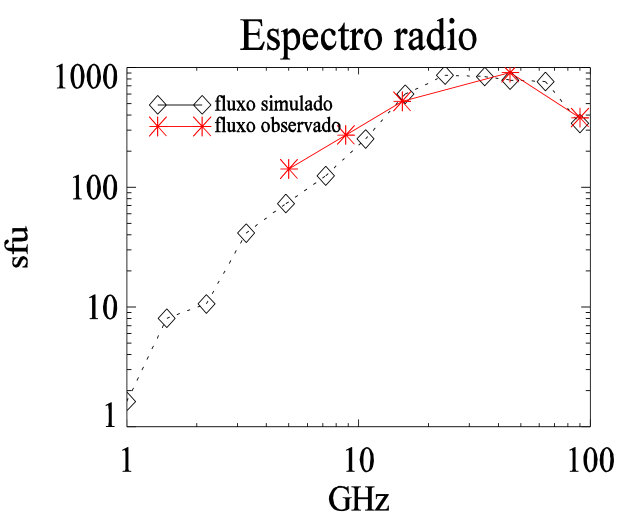


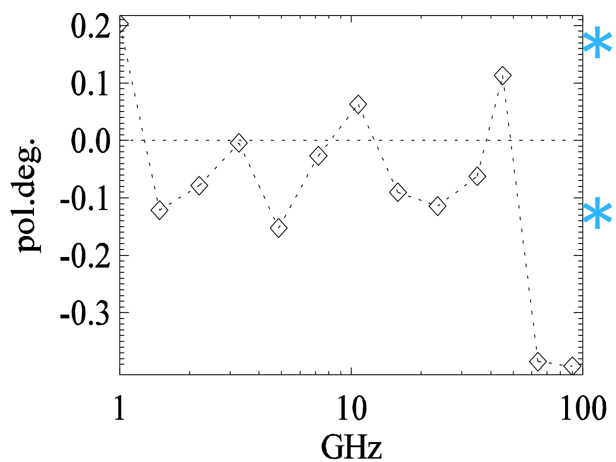


Simulation results









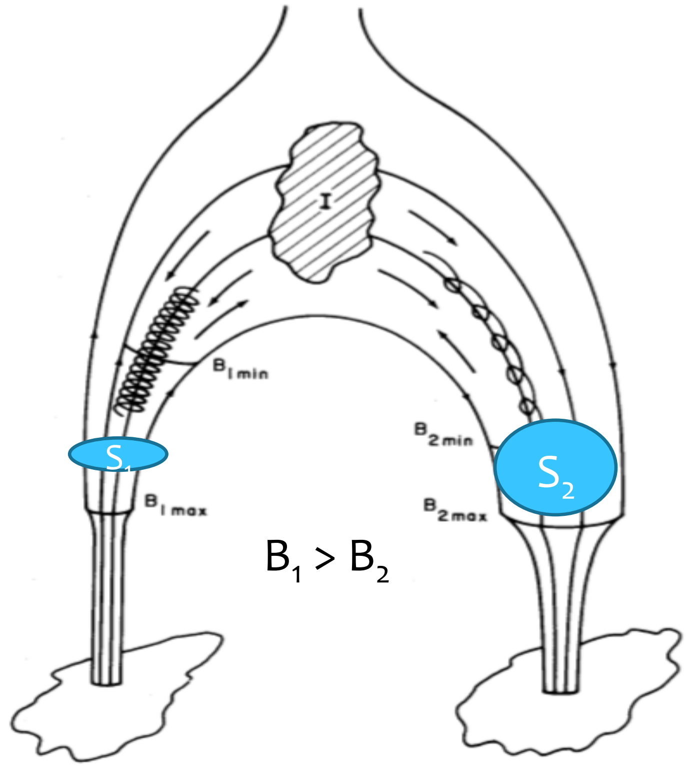
- Asymmetric magnetic field: -4500 G in one footpoint and 3000 G on the other.
- Position: Lat -15°, Long -47°
- Angle wrt solar equator: -60°

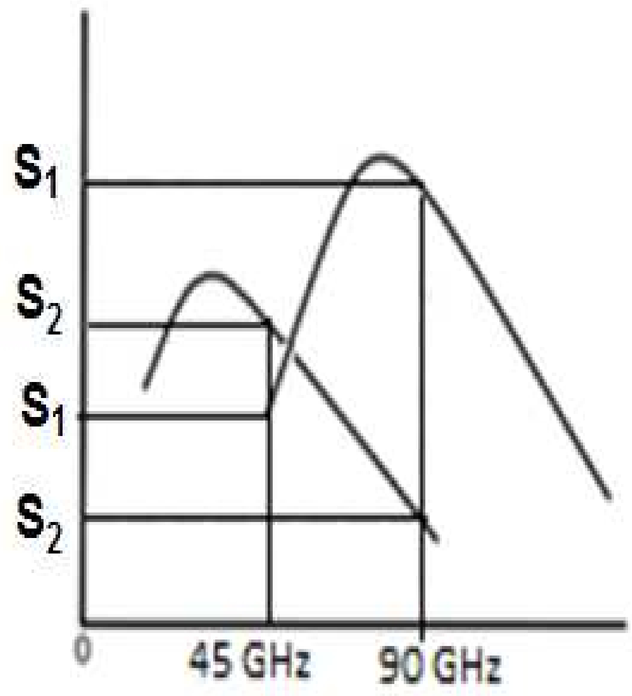
Summary

Parameter	17 Feb 2013		13 May 2013		5 Nov 2013	
	Obs	Model	Obs	Model	Obs	Model
Magnetic field	-1500 and 1400 G	-3100 and 3800 G	-1300 and 1200 G	3200 and – 3480 G	-1300 and 1200 G	3000 and -4500 G
Latitude & Longitude	12°, -17°	18°, -22°	8°, -89°	15°, -80°	-12°, -47°	-15°, 47°
Pol 45 GHz	- 0.08	-0.03	+ 0.07	+0.096	+ 0.35	+ 0.11
Pol 90 GHz	+ 0.09	+ 0.027	- 0.10	-0.045	- 0.18	- 0.39
Spectral index	2-3	3.5	2 - 3.4	3.5	1.8 – 3.5	3.5

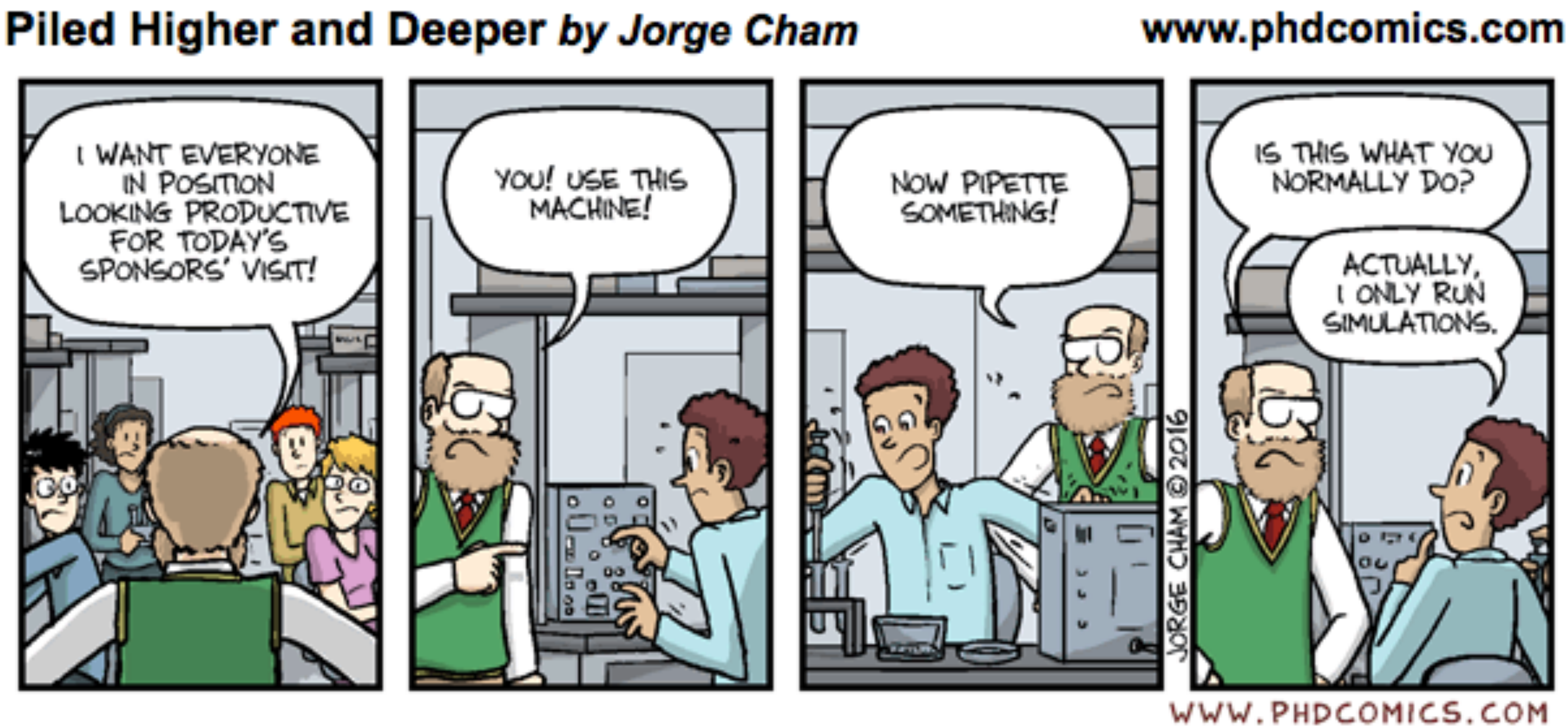
Conclusions

* Opposite sign of polarization at 45 and 90 GHz due to asymmetric magnetic loop
* Sources at different loop legs





Thank you!



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