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A burst with double radio spectrum observed up to 212 GHz

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UK-Germany National Astronomy Meeting
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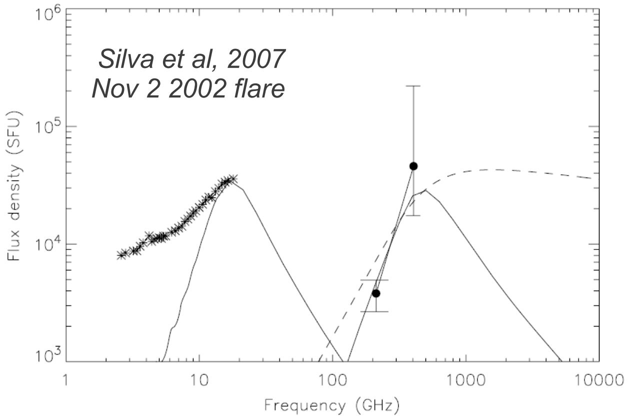
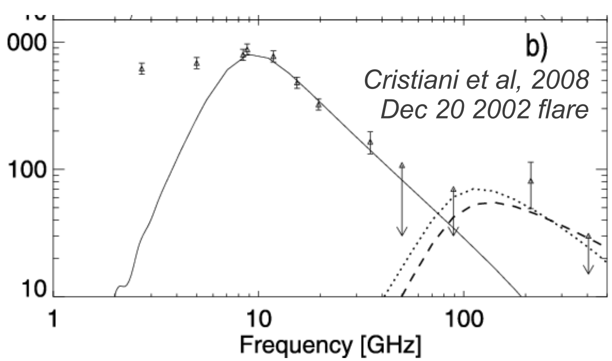
Typical solar flares
Radio range: peak frequency around 10 GHz (mildly relativistic electrons)
Above ~30 GHz: relativistic particles
Synchrotron theory: decreasing flux towards higher frequencies

Double radio spectrum events
X-class flares have shown a second component, optically thick at submillimeter range
Kauffman et al, 2004; Silva et al, 2007; Lüthi, Lüdi and Magun, 2004
M-class flare: 2nd component peaked around 200 GHz
Cristiani et al, 2008

Different mechanisms proposed
Kaufmann and Raulin, 2006; Fleishman and Kontar, 2010
Two synchrotron sources fit reasonably well the observations
Silva et al, 2007; Trottet et al, 2008





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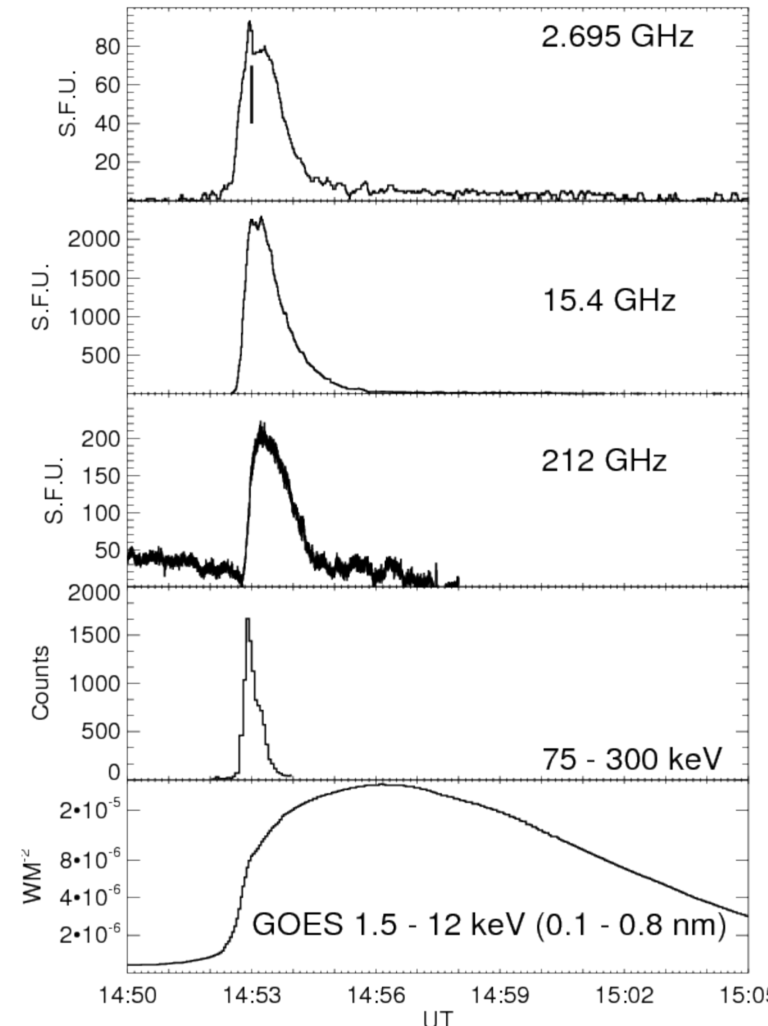
Observational Data

Event: September 10, 2002
GOES M2.9 (one of the weakest with sub-mm counterpart)
AR 10105 (S10E43)
Impulsive phase started at 14:52:30 UT

Instrument	Range	Time res.	Spatial res.
RSTN	1.415, 2.695, 4.995, 8.8, 15.4 GHz	1 s	Full sun
Solar polarimeter at Itapetinga Observatory	7 GHz	12 ms	Full sun
Solar patrol radiotelescopes (Bern University)	11.8, 19.6, 35, 50, 89.4 GHz	0.1 s	Full sun
Null interferometer (Bern University)	89.4 GHz	15 ms	Full sun
Solar Submillimeter Telescope	212 and 405 GHz	40 ms	4' and 2'
RHESSI	Up to 300 keV	4 s	0.5"



Spectral analysis
Electron evolution and source description

Source Position

HXR

Loop structure with 2 footpoints overlaying opposite magnetic polarities

Overlaps EIT 304 Å structure

212 GHz

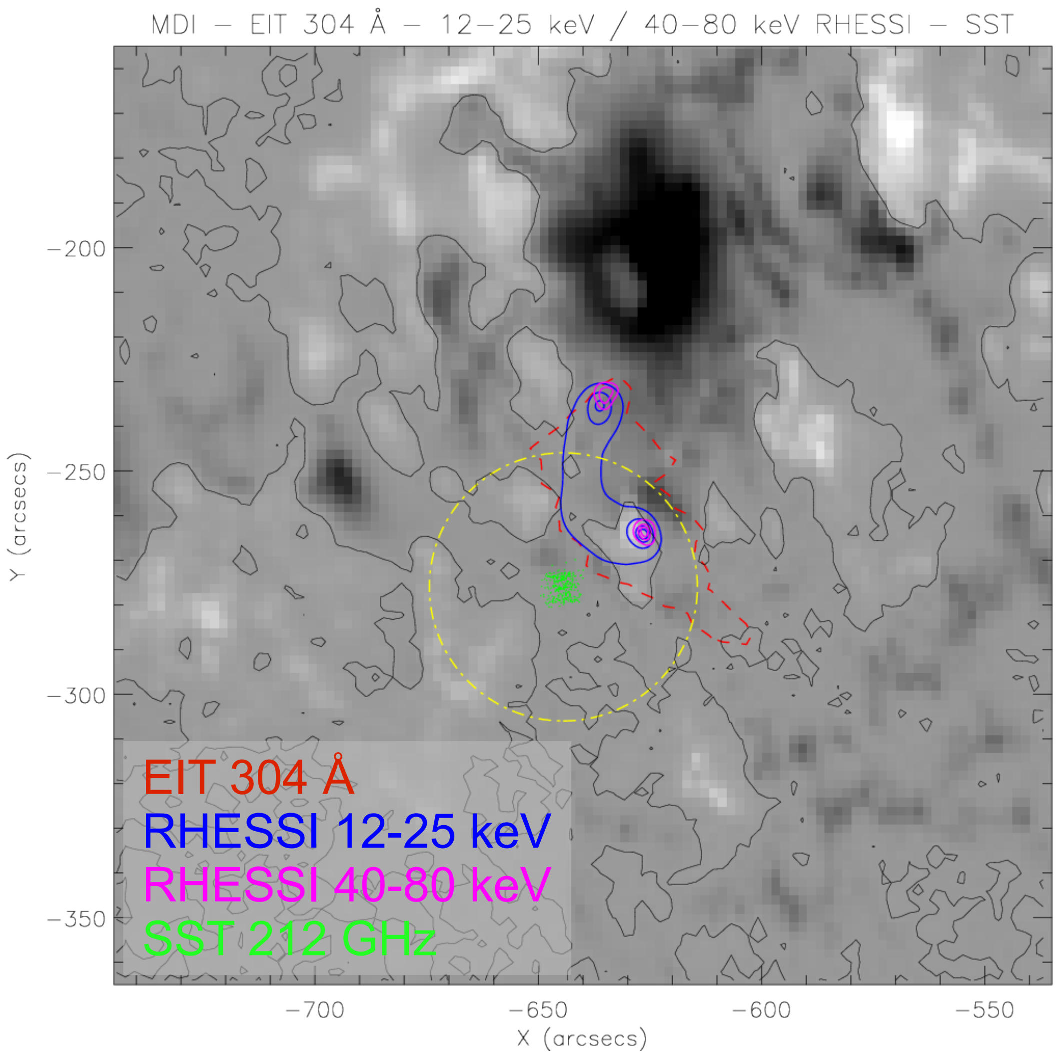
Stable and compact source ~10”
30” uncertainty (pointing accuracy)

25” away from HXR footpoint

Trottet et al (2008) found an offset of 10” between 212 GHz centroid and HXR footpoint, but coincident with gamma-ray line 2.2MeV (protons >30MeV)

No gamma-rays detected for this flare

Magnetogram evolution suggests two-loop reconnection system



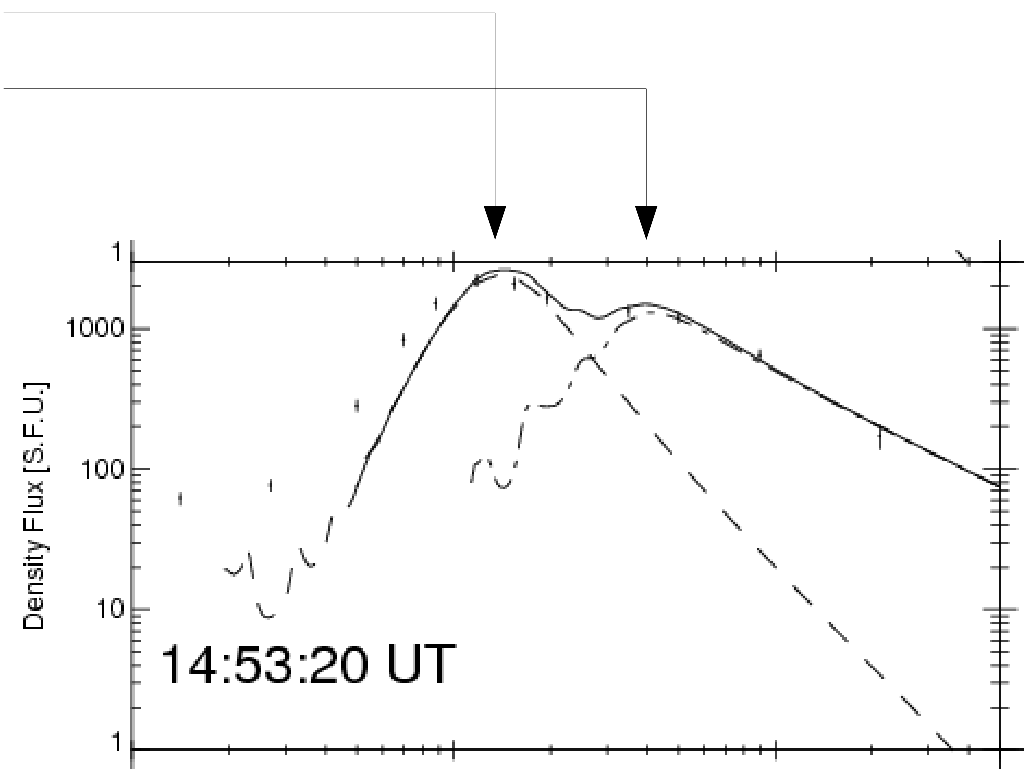
Spectral Analysis: radio

Radio spectrum

Low frequency component (peak 7-15GHz)
High frequency component (peak ~35GHz)

fitted with two homogeneous sources:
Gyrosynchrotron emission (Ramaty, 1969)

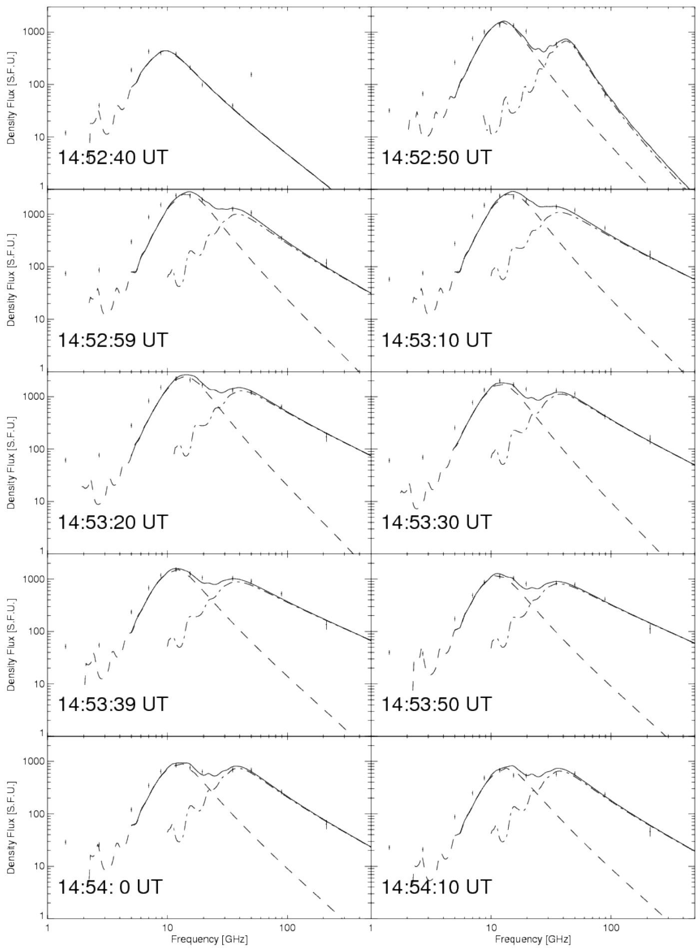
Free parameters:
Electron spectral index and number



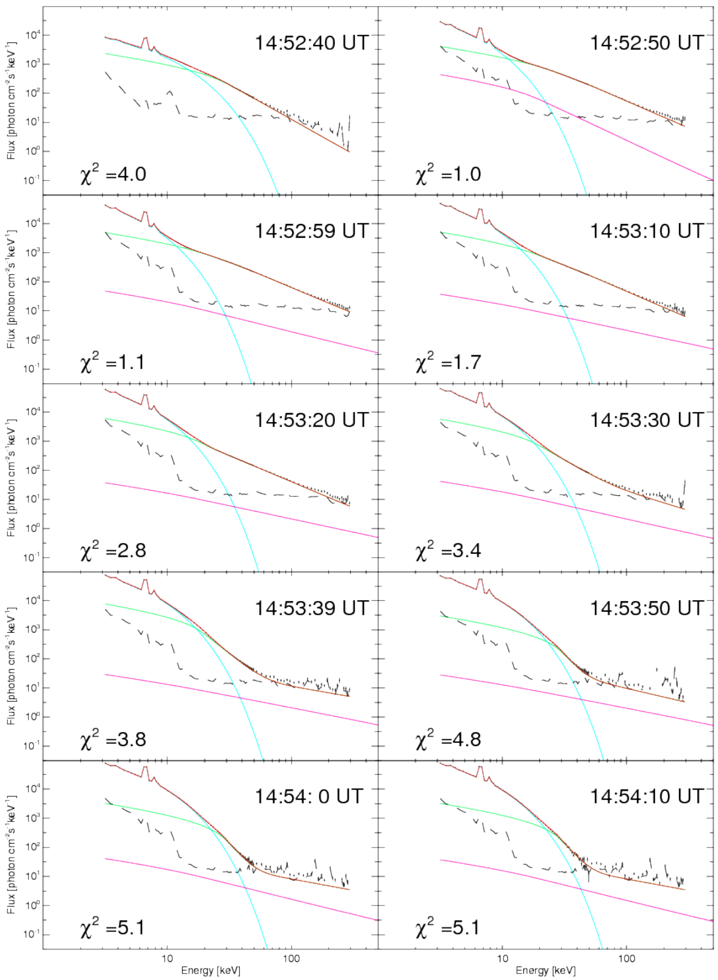
Parameter	Low freq	High freq
Mag. Field [G]	380	2000
Diameter [“]	18	5
Column [cm]	10^9	10^8
E_low [keV]	20	20
E_high [MeV]	10	10

Spectral Analysis: fitting radio and HXR

Radio spectrum fitted with
two gyrosynchrotron sources



HXR spectrum fitted with a
thick-target model plus thermal component



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Spectral Analysis

Mildly relativistic electrons

Spectral index derived from low freq. radio and HXR

constant $\delta_X \sim \delta_{lf} \sim 5$

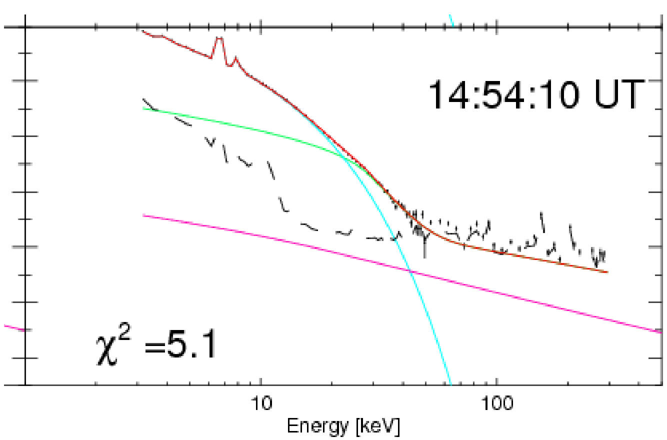
Relativistic electrons

Soft-hard-soft behaviour $2.5 < \delta_{hf} < 3.5$

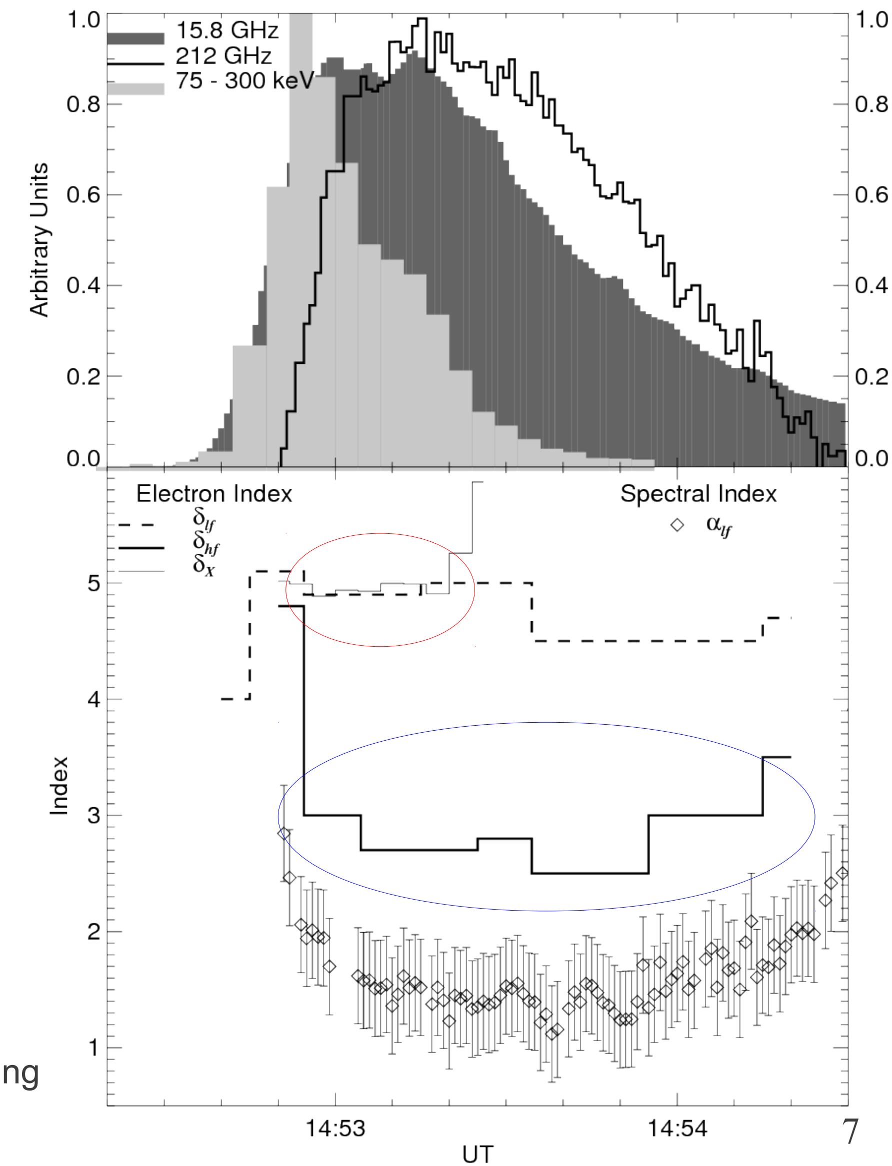
Suggests two different electron populations

HXR from relativistic electrons

Total number found: $8x10^{34}$ electrons
Not enough to produce HXR to be detected by RHESSI



Calculated HXR
thick-target bremsstrahlung



Electron evolution

Electron trapping

duration of HXR is shorter than the radio
HXR peak occurs before the radio peak

HXR does not necessarily represent the injected electrons
May represent the injected electrons that precipitate directly

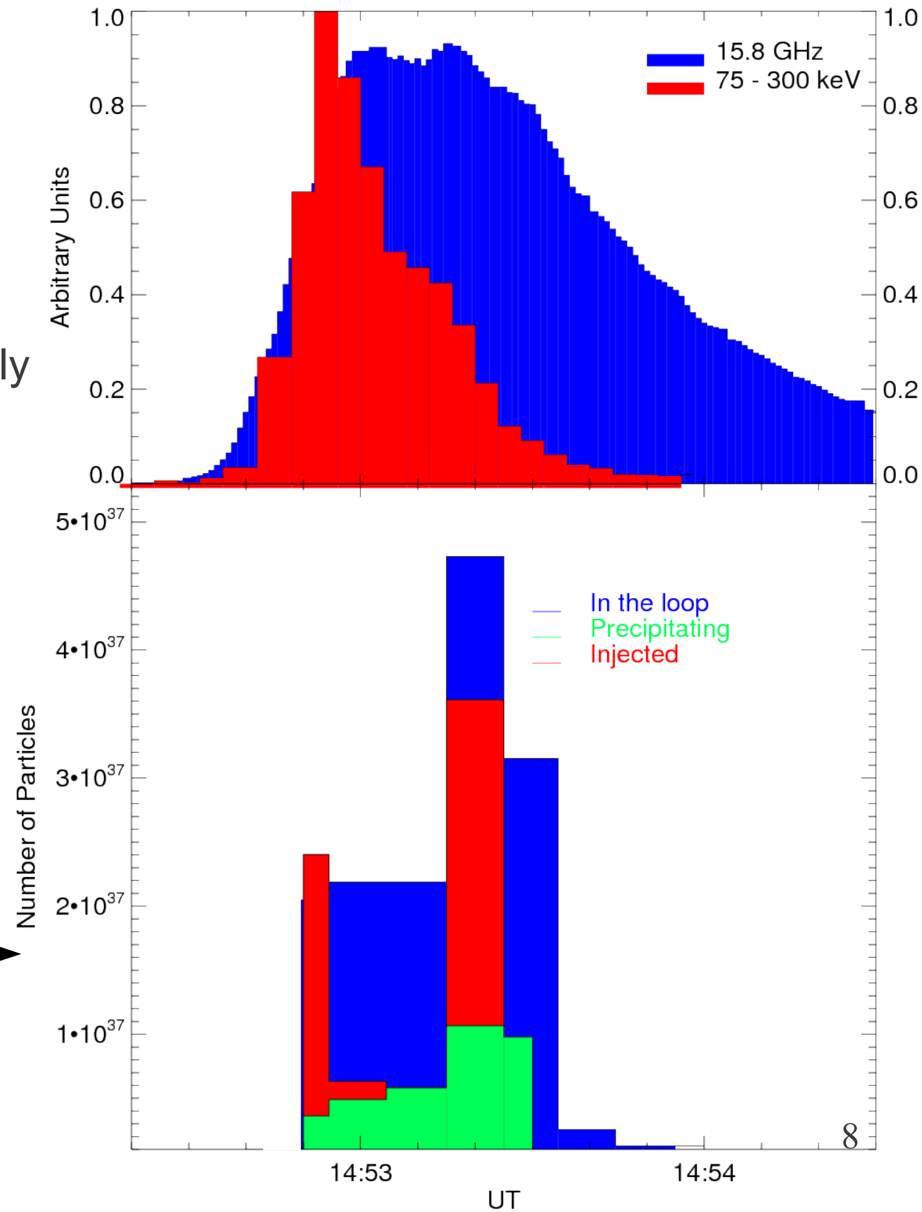
Simple continuity equation

Electrons in the loop (*N*), injected (*Q*) and precipitated (*P*)

$$\frac{dN(t)}{dt} = Q(t) - P(t)$$

Integrating in time and rearranging to calculate *Q(t)*

$$Q(t_i)\Delta t = N(t_{i+1}) - N(t_i) + P(t_i)\Delta t$$



N(t) taken from radio spectrum fitting
P(t) taken rom HXR spectrum fitting

Discussion

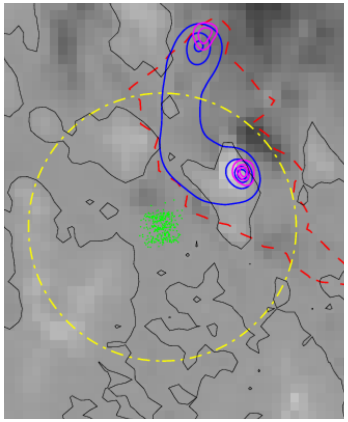
Injection of the mildly relativistic electrons

Continuous injection with two pulses 30 sec apart
1st: produces HXR and initiates the LF radio
2nd: slightly stronger, builds up into the radio emission but does not contribute to HXR emission

Suggests that the two pulses have different pitch-angle distributions
1st: electrons aligned with the magnetic field, allowing trapping (radio) and precipitation (HXR)
2nd: wider pitch-angle distribution, keeping most of the electrons trapped

Position of the radio high frequency component source

Two-loop reconnection system

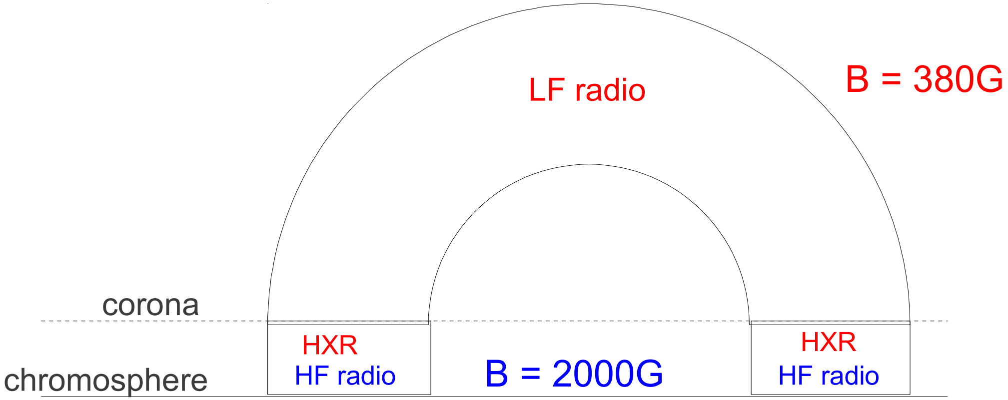


Supported by:
212 GHz centroid position
MDI evolution

Lacks:
X-rays emission
(RHESSI dynamic range)

EUV
EIT 12 min cadence
No images during the flare

One loop (Melnikov, Costa, Simões, 2012, in prep.)



Relativistic electrons reach deeper into the chromosphere

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Summary

Presented an analysis of a flare with double radio spectrum

Two spectral peaks: typical ~10GHz and ~35GHz
Not as extreme as the sub-THz events (peaks ~200GHz and >400GHz)
Need better spectral coverage in the range 10-80GHz and above 400GHz

Two different electron populations:

Mildly relativistic electrons:

Low frequency radio component and HXR (>75 keV)

Continuous injection with two pulses

1st: partially trapped: radio + HXR
2nd: mostly trapped: radio

Relativistic electrons:

High frequency radio component
Didn't produce enough HXR to be detected
Two possible source locations

Submitted
Giménez de Castro, C.G.; Cristiani, G.D.; Simões, P.J.A.; Mandrini, C.H.; Correia, E.; Kaufmann, P. "*A burst with double radio spectrum observed up to 212 GHz*", Sol. Phys.