High Energy Solar Physics data in Europe

Paris Observatory

Final meeting Genova October 28-30 2013

WP3

Integration of multi-wavelength data

N.Vilmer

CNRS / LESIA Paris Observatory

- **CNRS situation for HESPE**

HESPE funding:

Hamish Reid: post-doc 03/11-12/13
left on January 2013 to go back to Glasgow

Rositsa Miteva: 3 months (04/05/06-13)
Catalog RHESSI/ EIT waves/

Permanent position:
Nicole Vilmer (DR2 CNRS) (25%)

Post-doc and student on related topics
(RHESSI and STIX Solar Orbiter)

S. Musset (master thesis) on RHESSI/SDO; RHESSI/Hinode
PhD thesis (CNES; ESEP/PSL) at LESIA/ Paris Observatory from October 2013
RHESSI analysis and preparation of STIX (science and software development)

R. Pinto (post-doc CNES)
MHD simulations and predictions of X-ray emissions; (STIX oriented)

Integration of multiwavelength data

Study of the energy release sites and particle acceleration mechanisms (WP3;task 2)

- Combination of X-rays and other wavelengths

  to derive the physical conditions of the energy release sites

  to better understand particle acceleration mechanisms:

  with radio observations

  with optical, SXR and EUV (SDO mission).
- D3.4: Specification of paradigms for multiwavelength interpretation (X-rays, EUV,radio) [month 36]

- Detailed comparisons with other non-thermal particle signatures including in-situ data and radio measurements,

  to understand the link between electrons accelerated into space, and those remaining localized at the Sun

Integration of multiwavelength data

- **Selected list of refereed papers**

  Reid, H., Vilmer, N., Kontar, E.P.

  Using the Low-High-Low Trend of Type III Radio Burst Starting Frequencies with X-ray Observations to Diagnose Flare Acceleration Region Characteristics, *Astronomy and Astrophysics, in revision, 2013*

  Reid, H., Vilmer, N., Aulanier, G., Pariat, E.

  X-ray and UV investigation into the magnetic connectivity of a solar flare , *Astronomy and Astrophysics, 547, A52, 2012*

  Reid, H**.,** Vilmer, N., E. Kontar,

  Characteristics of the flare acceleration region derived from simultaneous hard X-ray and radio observations, *Astronomy and Astrophysics*, *Volume 529, id.A66, 2011*

- **Selected list of invited reviews**

  Vilmer, N. Solar Flares and Energetic Particles , *CESRA WORKSHOP 2013: New eyes looking at solar activity, Challenges for theory and simulations, Prague, 24-29 Juin 2013*

  Vilmer, N**.** Radio diagnostics of Solar Flare Escaping Electrons, *STEREO/WAVES &WIND/WAVES workshop on Solar Radio Emissions, Santorin, 7-11 Octobre 2013*

- **Selected list of oral presentations:**

  Vilmer, N. ,Radio emissions in the upper corona , *ISSI Workshop: X-ray and radio diagnostics of energetic electrons in solar flares, Berne, 4-8 Février 2013*

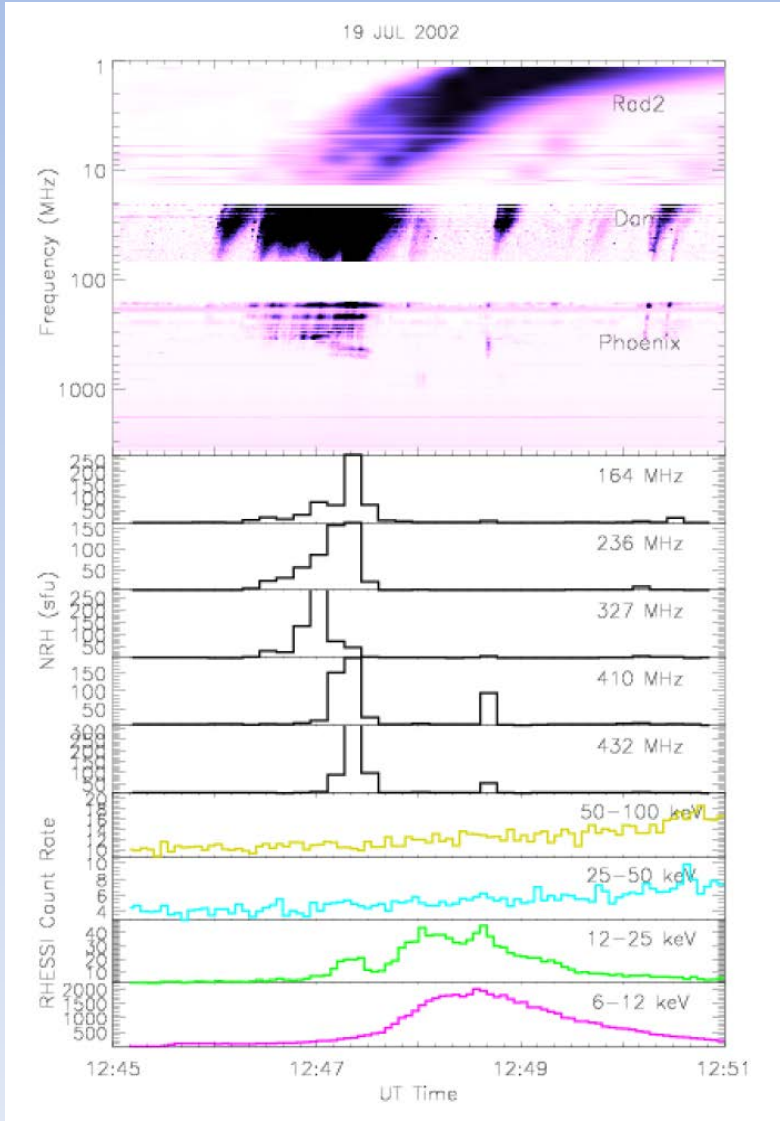
  Vilmer, N.; Reid, H.S. , Electron beams in the solar corona as diagnosed by combined spatially resolved Hard X-ray and radio decimetric/metric observations , *COSPAR, 39th Scientific Assembly, Mysore, India, 14-22 July 2012, E2.6-0017-12.*

  Reid, H.S., Vilmer, N., Kontar, E. Multi-flare study of acceleration region characteristics using combined X-ray and Radio Observations *COSPAR, 39th Scientific Assembly, Mysore, India, 14-22 July 2012, E2.6-0018-12.*

  H. Reid, N. Vilmer, E. Kontar Combining X-ray and Radio to diagnose spatial aspects of acceleration regions Solar in Sonoma, Tracing the connections in Solar Eruptive Events, 27 Novembre-2 Décembre 2012

  N. Vilmer, H. Reid , X-ray Flares and their Type III Radio Signature , AGU, San Francisco, 3-7 Décembre 2012

Radio diagnostics of Solar Flare Escaping Electrons:

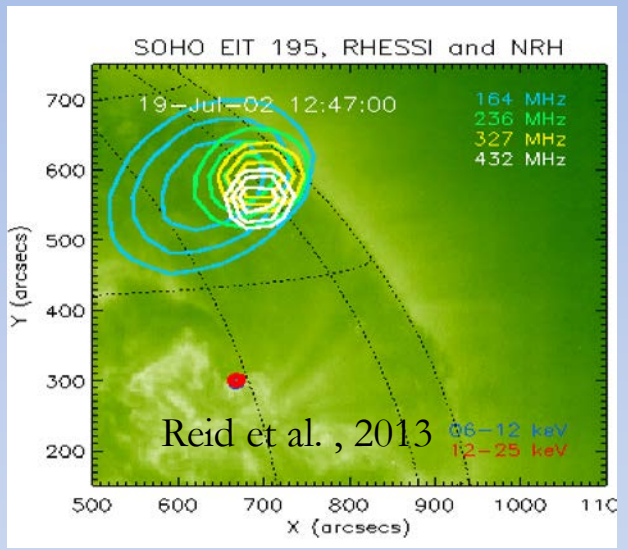


- ***The Sun: an efficient particle accelerator in connection to flares***

Particles escaping in the corona:

Energetic Electrons

Radio diagnostics of electron beams dm to km



Coherent radiations

Particles at the Sun:

Hard X-Ray/(gamma-ray)

Electrons / (Ions)

Acceleration: Where? How Many?

Link between X-ray and radio emitting electrons??

Combined HXR and radio observations: Electron acceleration and propagation in the low corona

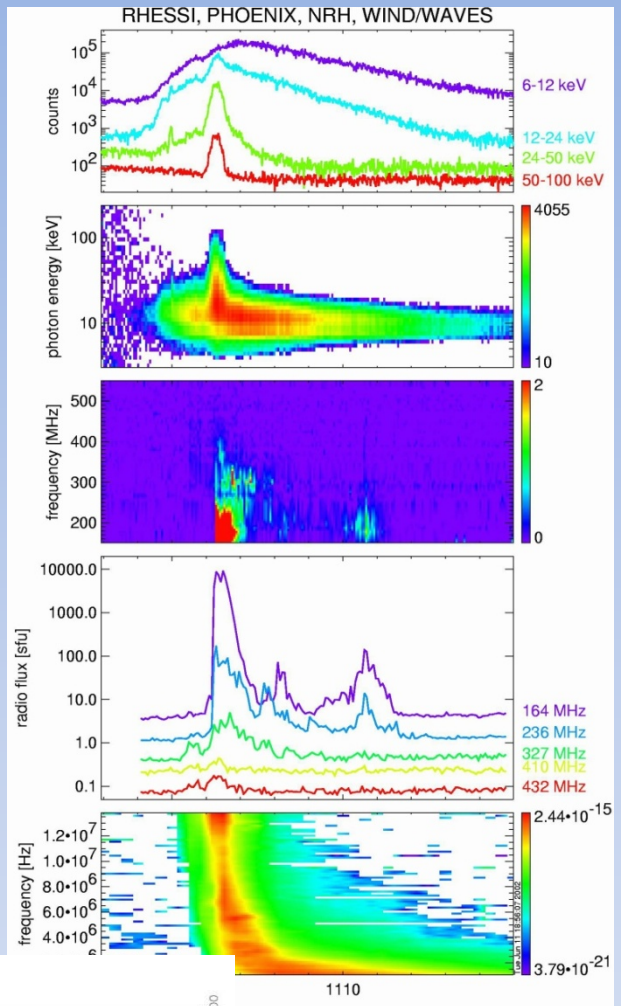
Standard picture

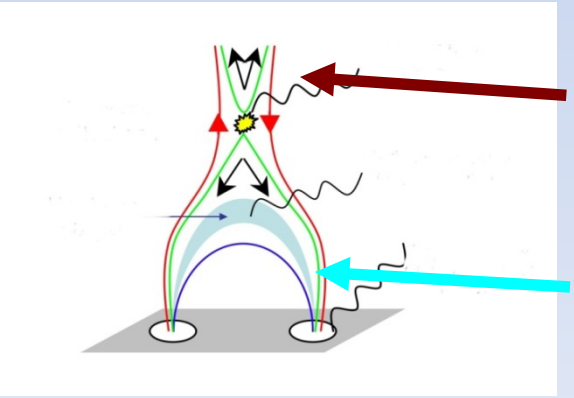
X-RAYS

Electrons travelling downwards into the chromosphere radiate X-rays in dense ($n_e=10^{12}$ cm^{-3}) plasma via Bremsstrahlung. Detected X-rays are usually in the 6-100 keV energy range

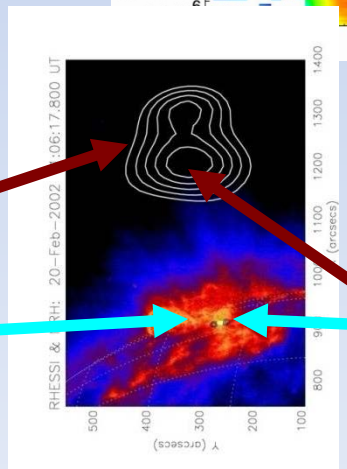
RADIO

Electrons travelling upwards can induce Langmuir waves which in turn produce coherent radio emission (type III) in the rarefied ($n_e<10^9$ cm^{-3}) coronal and interplanetary plasma. Detected radio frequencies are from around 400 MHz down to 2 MHZ





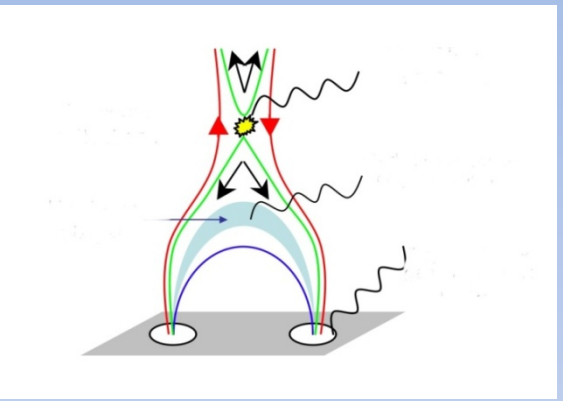
Simplified picture:
Electron acceleration in the corona
Propagation both upwards and downwards.



Vilmer et al. 2002

NRH and RHESSI observations

What are the characteristics of the acceleration region?



Assume a common acceleration region for upward and downward propagating energetic electron beams (e.g. Ashwanden et al 1995)

$$f_0(v,r,t=0) = g_0(v)\exp\left(\frac{-|r|}{d}\right)$$
$$g_0(v) \sim v^{-\alpha}$$

$$f(v,r,t) = g_0(v)\exp\left(\frac{-|r-vt|}{d}\right)$$

After propagation upwards (no collisions)

$$\gamma_c = \frac{\pi\omega_{pe}}{n} v^2 \frac{\partial f}{\partial v} > \nu_c$$

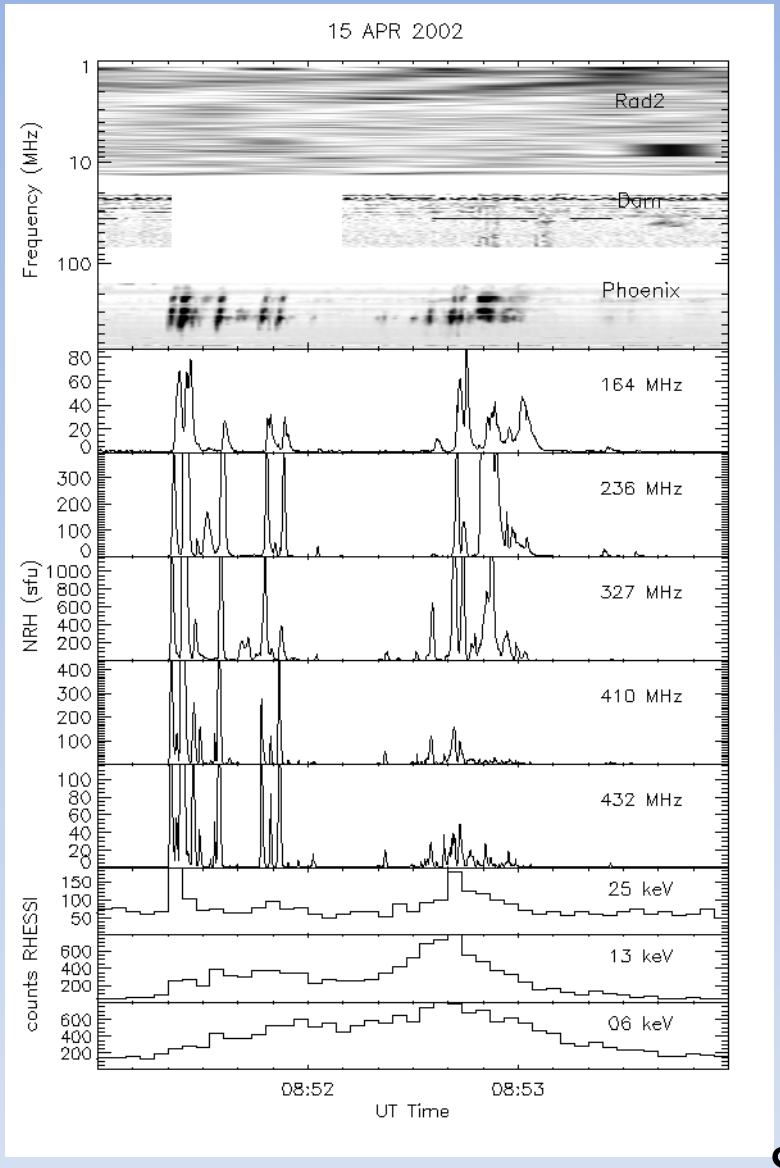
Growth rate of Langmuir waves

r = $h_{typeIII}$ – $h_{acceleration}$

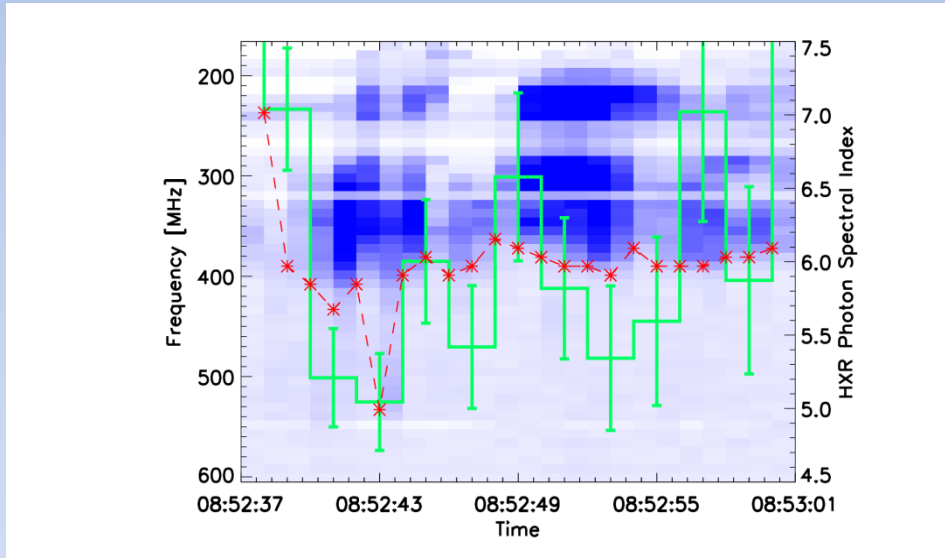
Distance travelled until Langmuir waves can grow:

$$h_{typeIII} = d\alpha + h_{acceleration}$$

Reid, Vilmer, Kontar, 2011



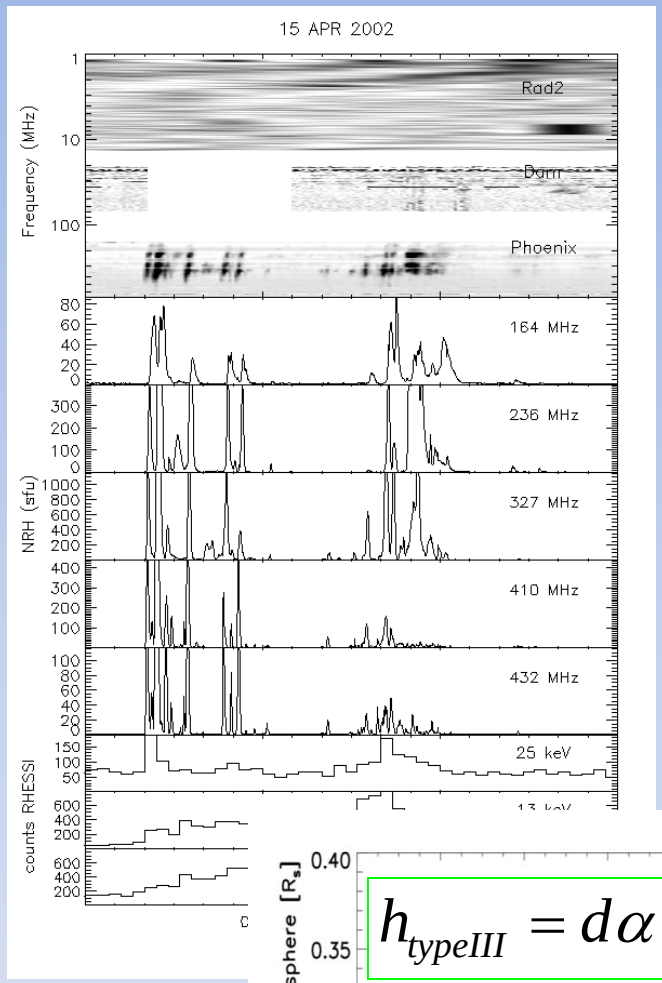
Deducing the characteristics of acceleration region: height and size using combined radio and X-ray observations and numerical simulations (Reid, Vilmer, Kontar, 2011)



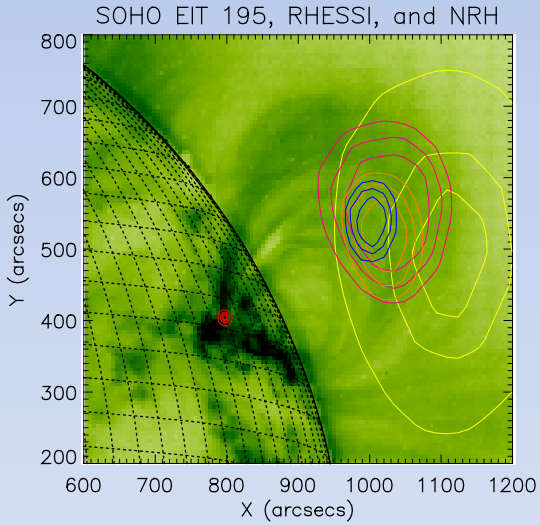
Starting frequency of the radio type III burst (red) and HXR spectral index

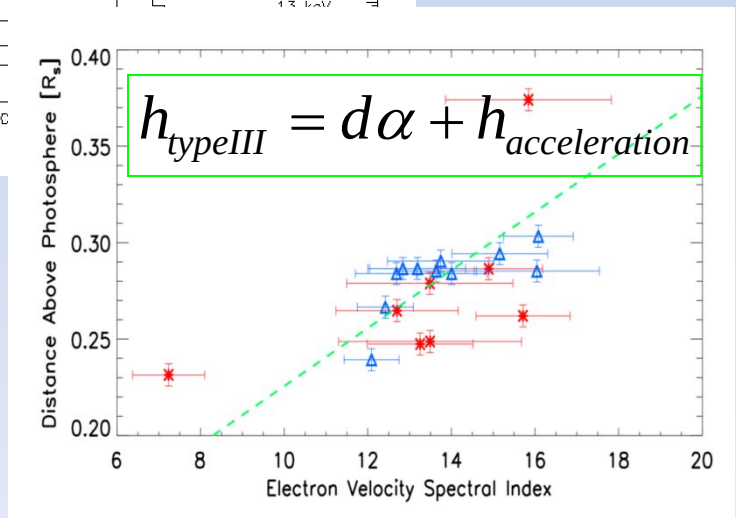
$$h_{typeIII} = d\alpha + h_{acceleration}$$

What are the characteristics of the acceleration region?



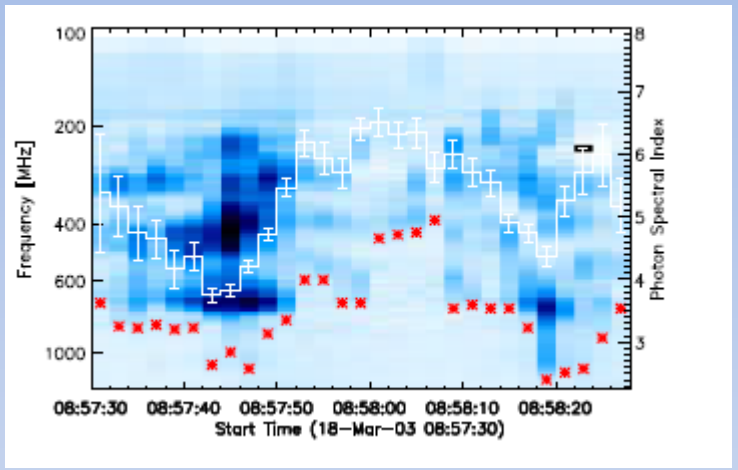
Deducing the characteristics of acceleration region: height and size d using combined radio and X-ray observations and numerical simulations (Reid, Vilmer, Kontar, 2011)

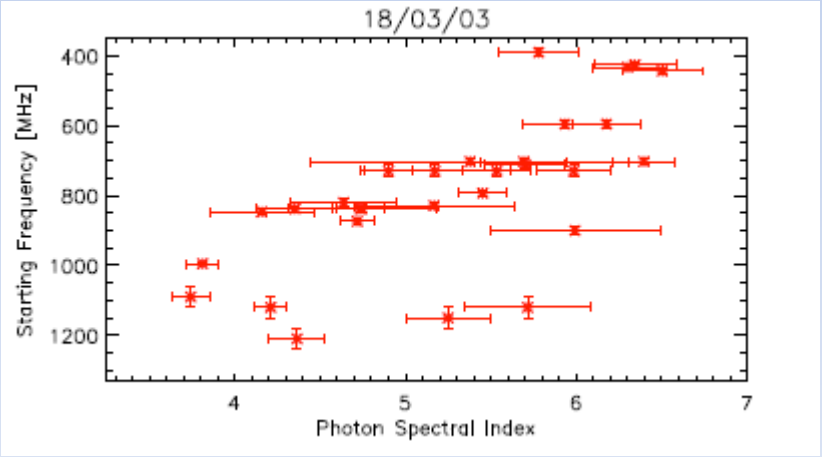




h_{acc} =50 Mm d=10 Mm

A statistical study of the link between HXR spectra and radio starting frequency



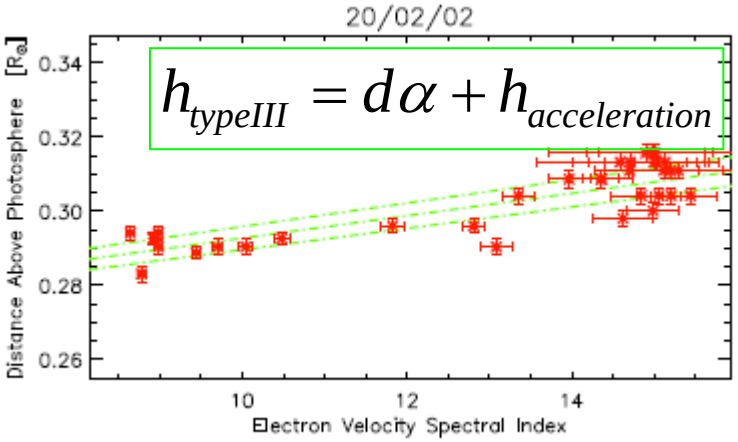


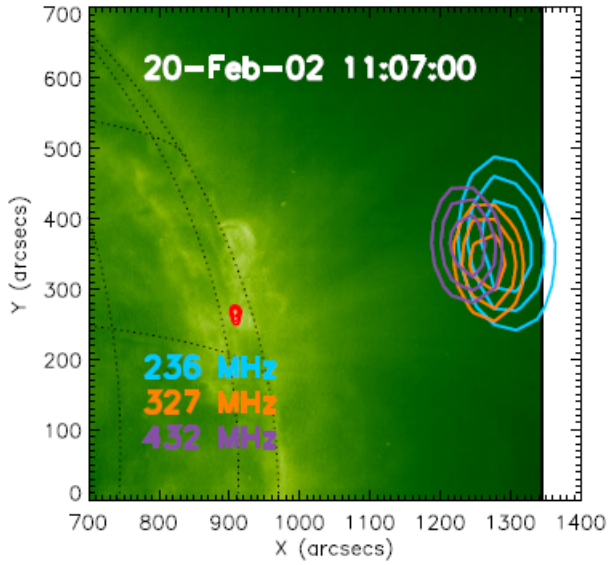
Study on 30 events derived from the RHESSI catalogue, the Phoenix 2 catalogue of type III radio bursts (simple events) and with NRH observations (To build radio images)
Type III bursts with starting frequency within 4GHz-100 MHz (duration of type III burst group >20s)
Impulsive X-ray emission with HXR detection above 25 keV

50%of the events: good correlation between starting frequencies and HXR spectra

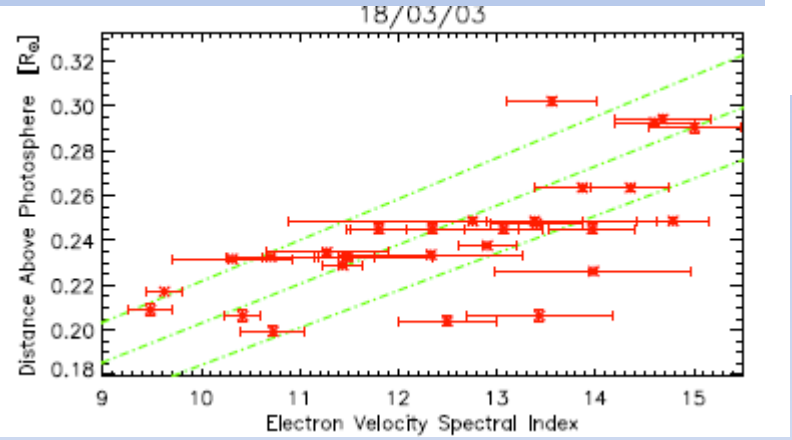
Low-high-low trend of starting frequencies: Soft-Hard-Soft evolution of the HXR spectrum during flares

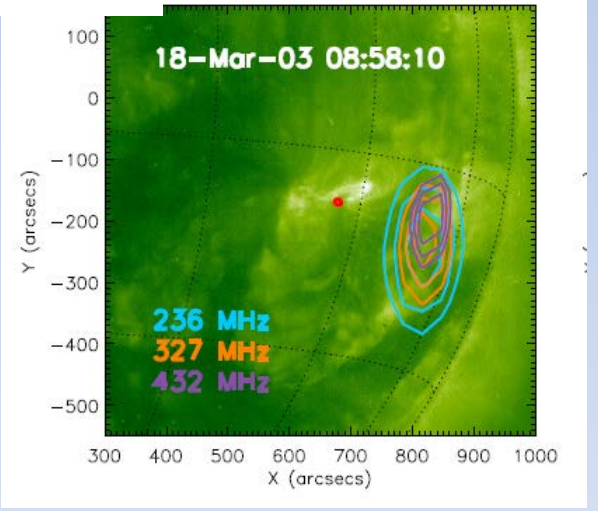
Reid, Vilmer, Kontar, 2013 in revision





Reid, Vilmer,Kontar 2013, in revision





10 events:

h_{acc} in the 25Mm to 180 Mm range

d in the 2.1 to 16 Mm

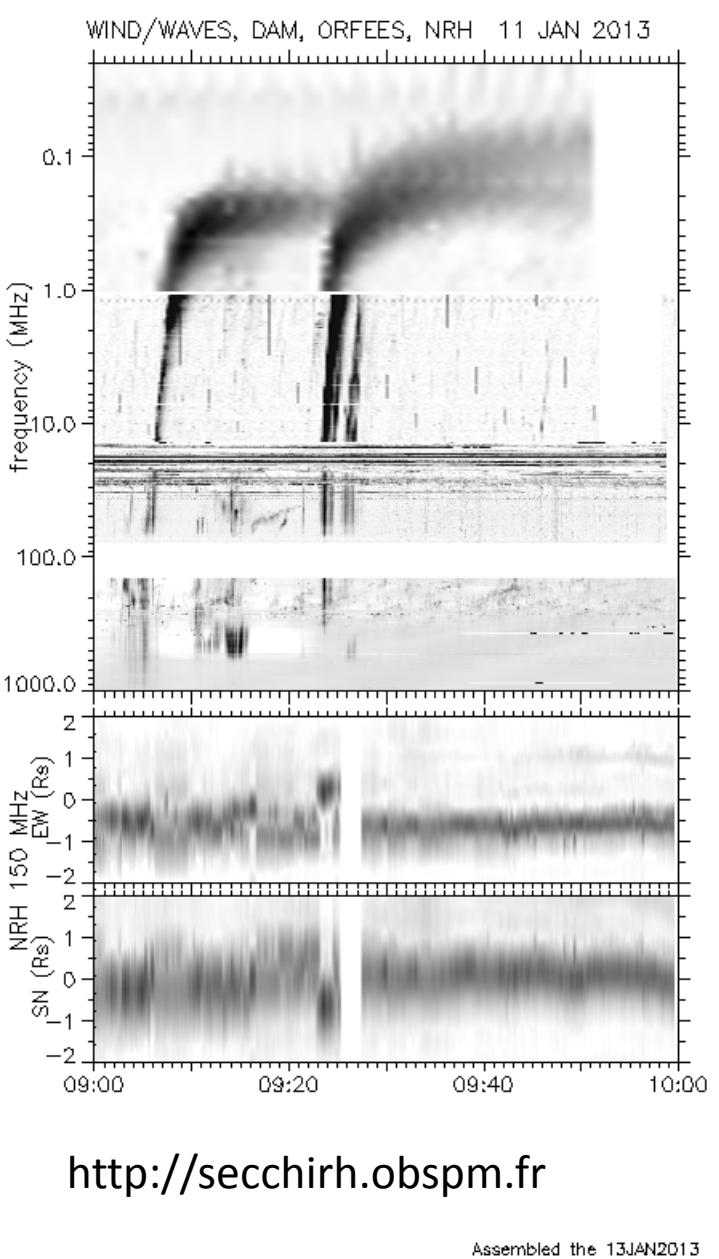
Note that these flares are NOT « confined » flares, that they have a simple morphology

Events with no correlation or no possibility to derive d and h_{acc}

Multiple acceleration regions

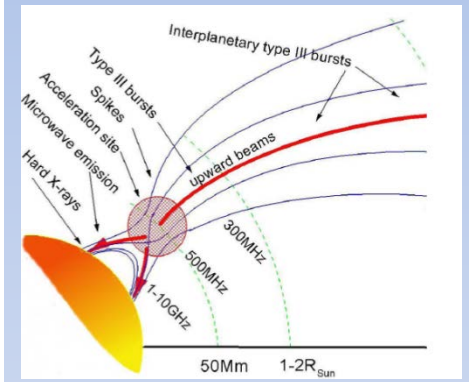
Complex magnetic field structure…

Radio observations in the GHz-MHz range: input to the understanding of electron acceleration and propagation in the corona towards the interplanetary medium



http://secchirh.obspm.fr

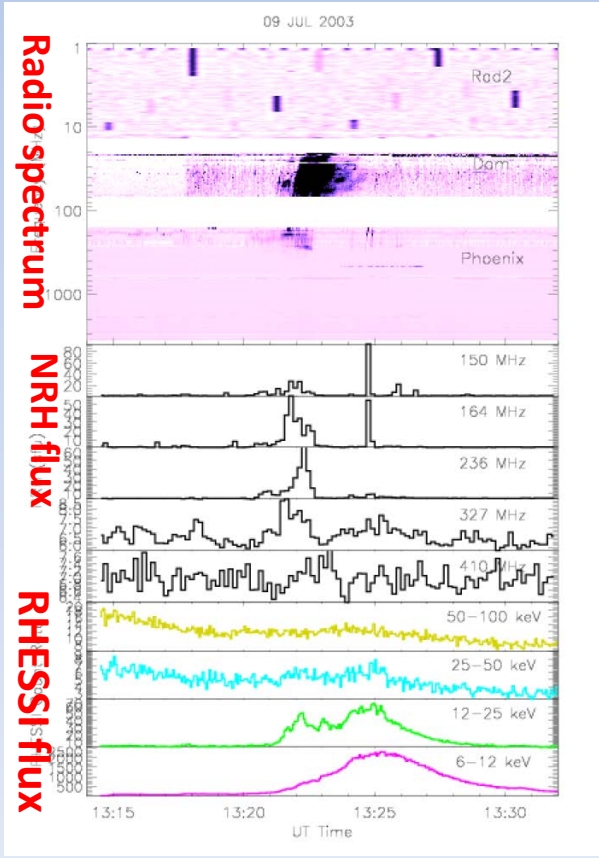
Assembled the 13JAN2013



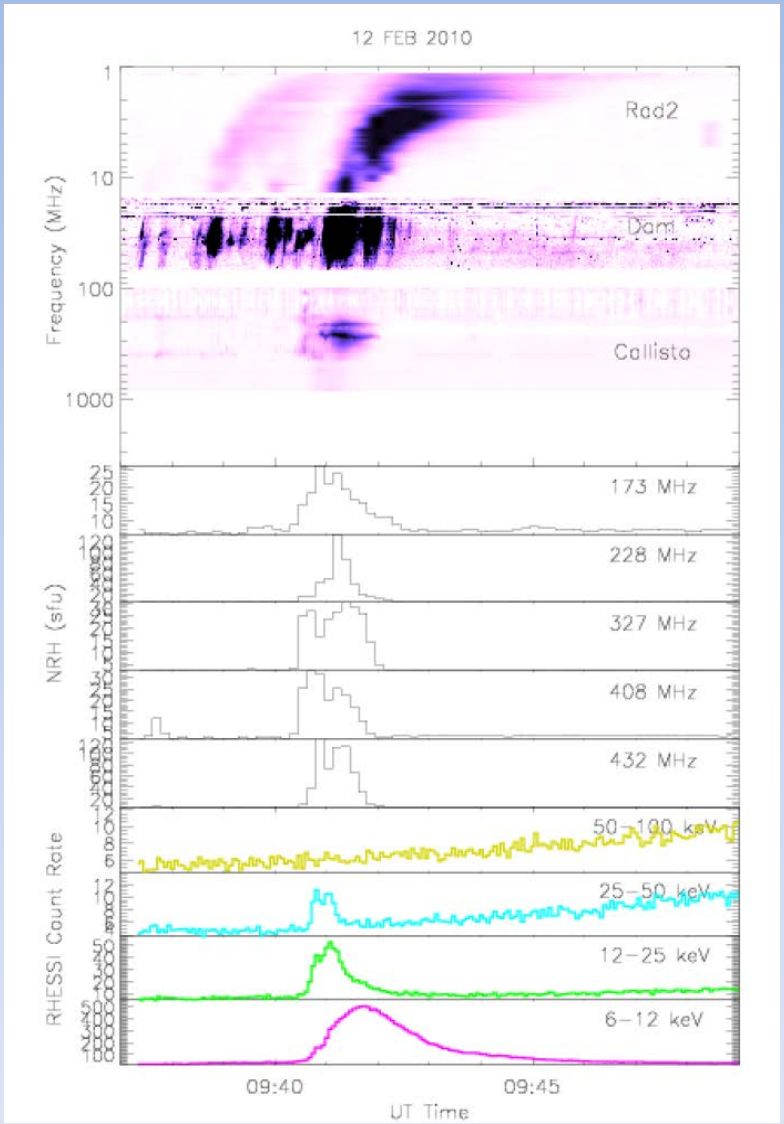
A too simple scenario ??

Link between X-rays and type IIIs
Do all metric type III have interplanetary counterparts?
(see Reid &Vilmer,)

Not always a simple morphology



HXR – Type III Statistical Connection



Reid, Vilmer, in preparation

-Re-examine the link between HXR emissions and type III emissions in the decimeter/meter range (>100 MHz)

-No limit on the class of GOES X-ray flares (not specifically large X-ray flares)

-Systematic study of the extension of the type III emission at lower frequencies (<100 MHz) in the higher corona towards the interplanetary medium

-Study of the « morphology » of the X-ray and radio sources combining spatially resolved HXR and radio observations (tracing the magnetic connection between the solar surface and the corona towards the interplanetary medium).

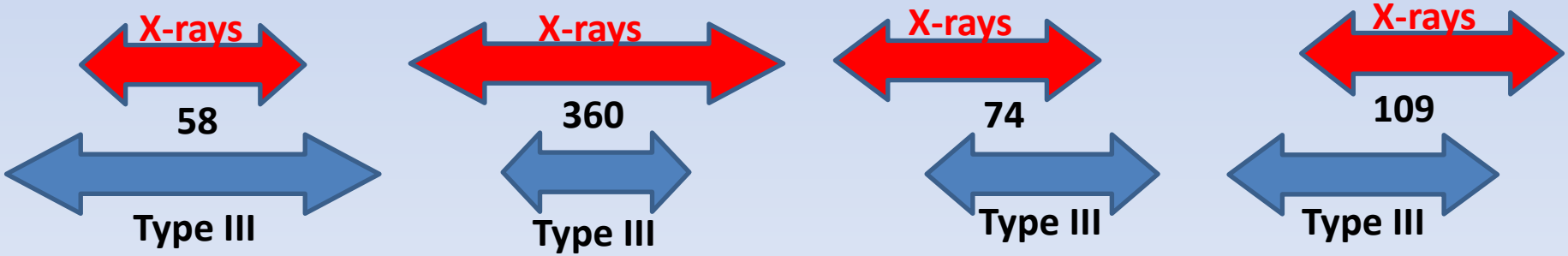
Radio and X-ray Events

A systematic work using data from **2002 to 2011**

Start from the list of RHESSI flares. Automatic detection in the **6-12 keV** band.
http://hesperia.gsfc.nasa.gov/hessidata/dbase/hessi_flare_list.txt

And the list of type III bursts observed with PHOENIX-2 in the **4 GHZ-100 MHz** between 2002 and 2009 and BLEN7M in the **900-100 MHz** range between 2010 and 2011. Between 08-16 UT (also for combination with NRH data).
http://soleil.i4ds.ch/solarradio/data/BurstLists/1998-2010_Benz/
http://soleil.i4ds.ch/solarradio/data/BurstLists/2010-yyyy_Monstein/

18,206 X-ray flares and **1,959** groups of type III radio bursts
Consider only events with the following morphologies: total: **601** events



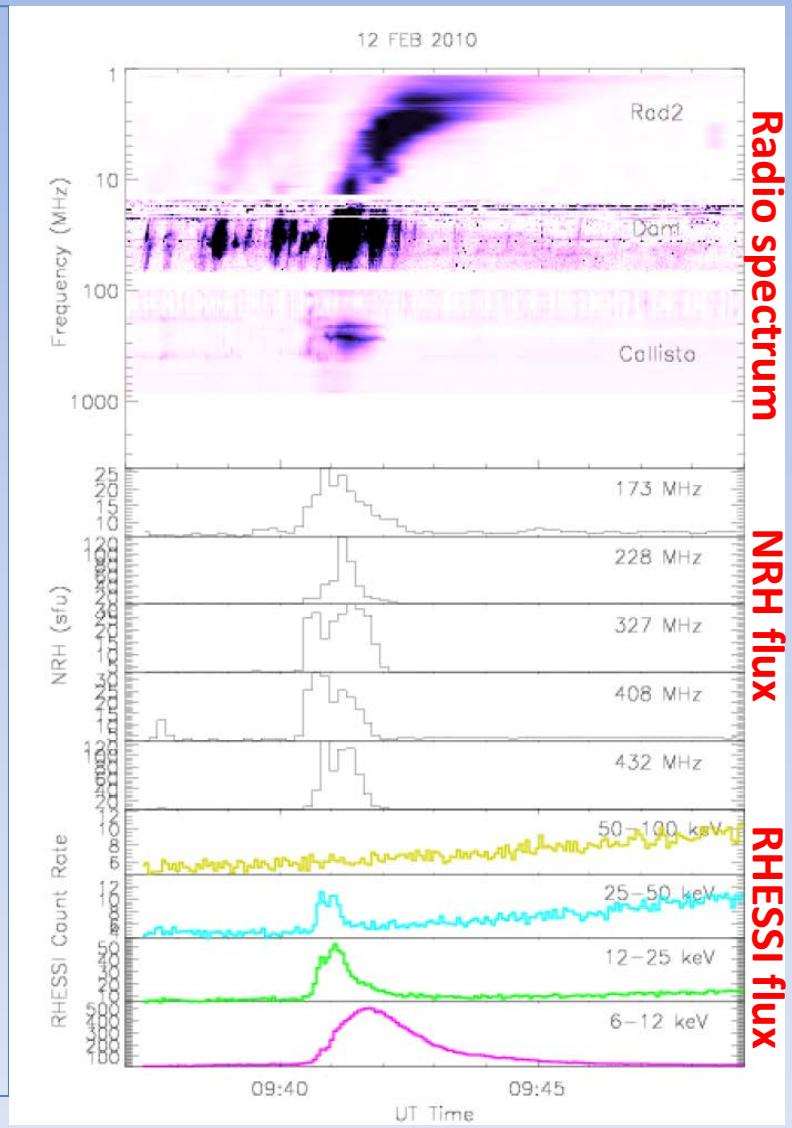
Radio and X-ray Events

We created spectra using different instruments.
RADIO: PHOENIX 2 / BLEN7M
Decametre Array (DAM)
Wind/Waves (RAD2)

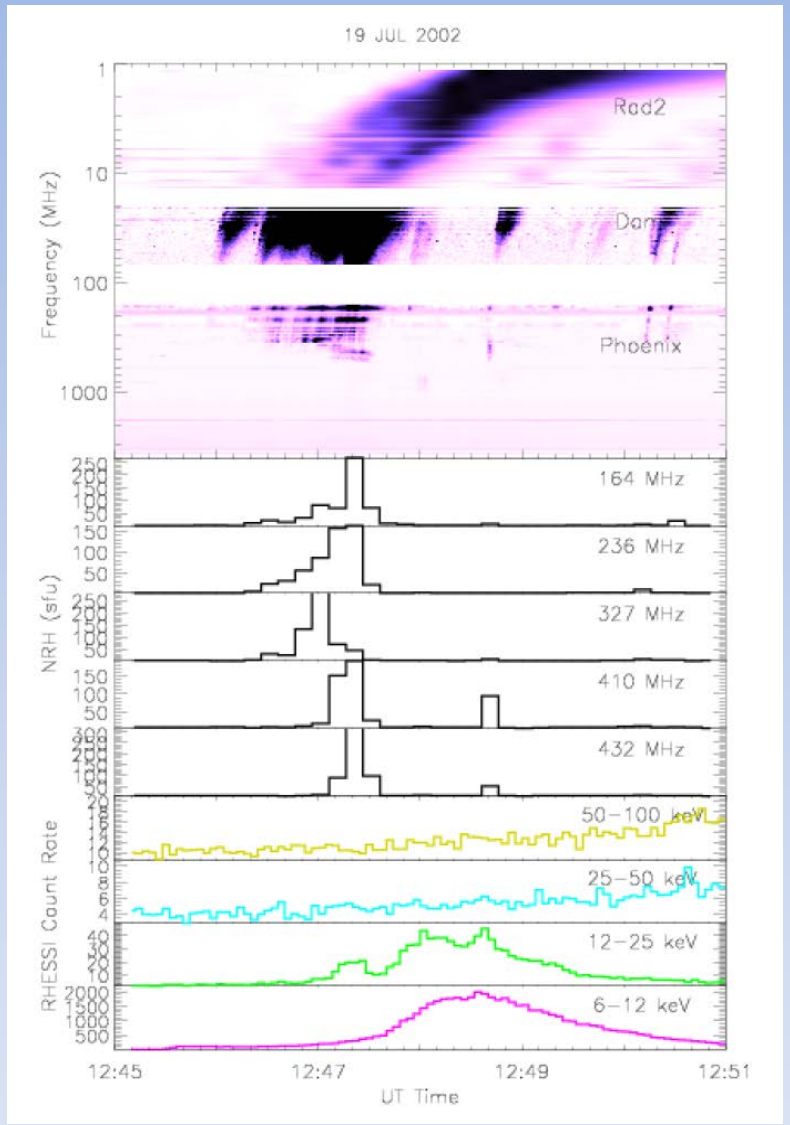
RADIO flux: Nançay Radioheliograph
XRAY flux: RHESSI

Automatic detection is great but far from perfect! Many false positives that have to be removed. We went through all of the 601 events and removed the events which had problems (bad data, duplicated events, RHESSI night time etc). We were left with **378 events** (321 of them showed associated X-ray and type III emission after a visual inspection.)

Flares are less intense than Benz et al 2005, 07
Between 2002 – 2007, the GOES class is M=13%, C=53%, B=34%



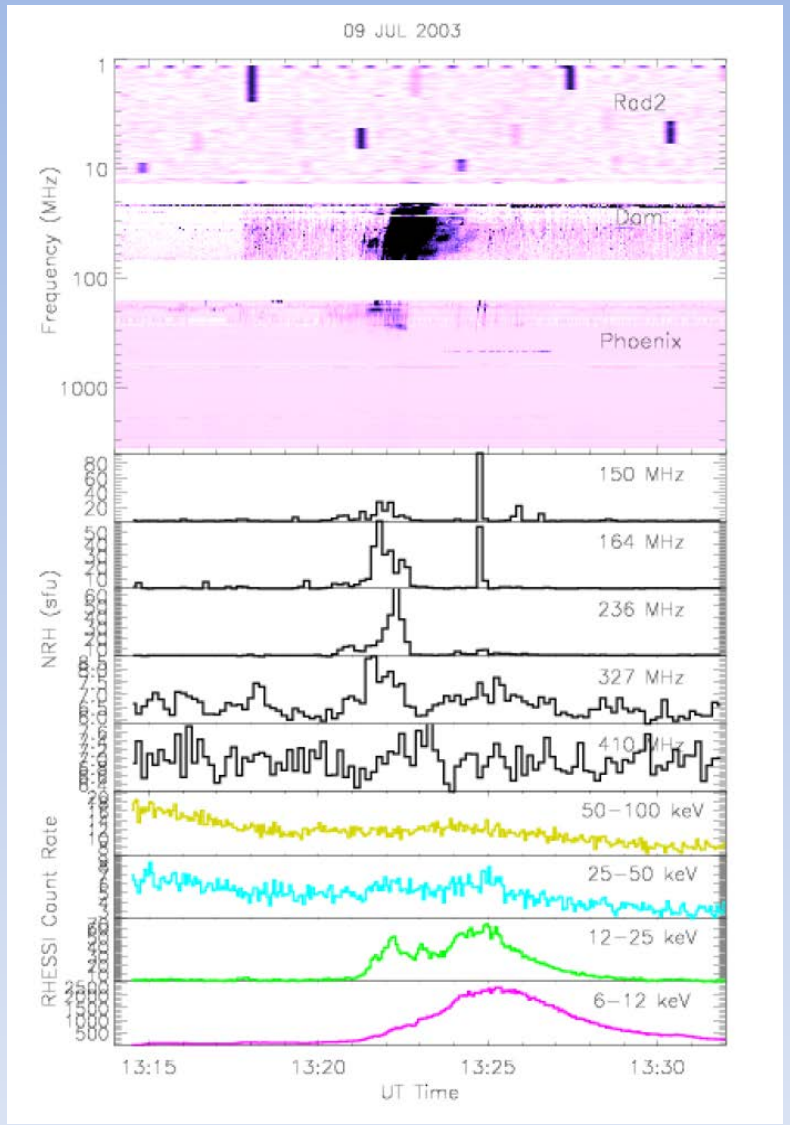
Radio and X-ray Events



Radio spectrum

NRH flux

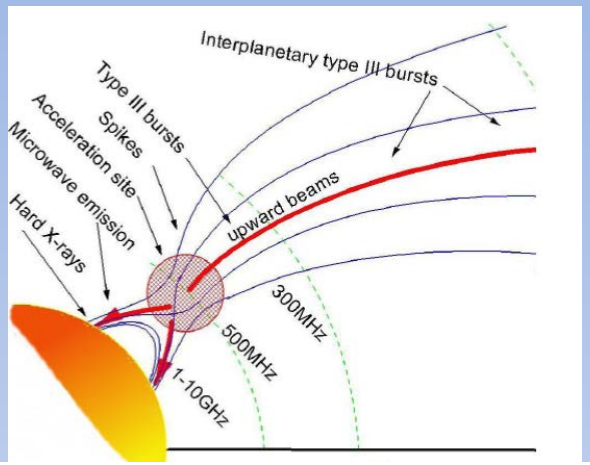
RHESSI flux



Overlap of type III and X-ray emissions but the peaks are not simultaneous.

Some type III burst do not go to interplanetary medium

Some statistics on the extension towards interplanetary Type IIIs



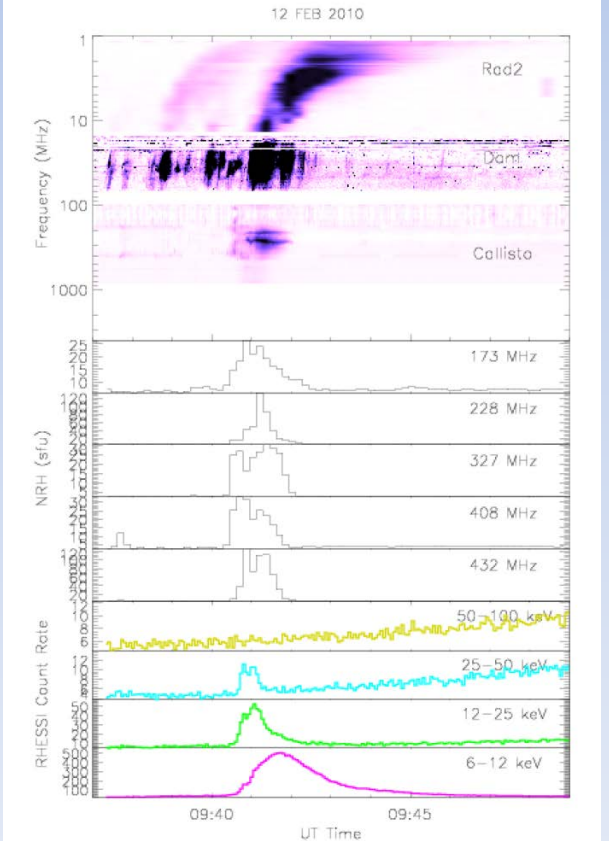
Interplanetary type III bursts:

174 of the 321 events had strong emission in RAD2, 14-1 MHz. (>50 %)

Among these events,
63% had significant HXR emission in 25-50 keV
29% were observed at 12-25 keV but not 25-50 keV
8% had the highest HXR emission in 6-12 keV

Events with higher starting frequencies tended to be more associated with events detected in RAD2?

RAD2 events have mean starting freq of 1640 MHz
Other events have mean starting freq of 1550 MHz
Only 11 events were observed in DAM, 80-10 MHz and not observed in RAD2



Peaks of X-ray and Radio events

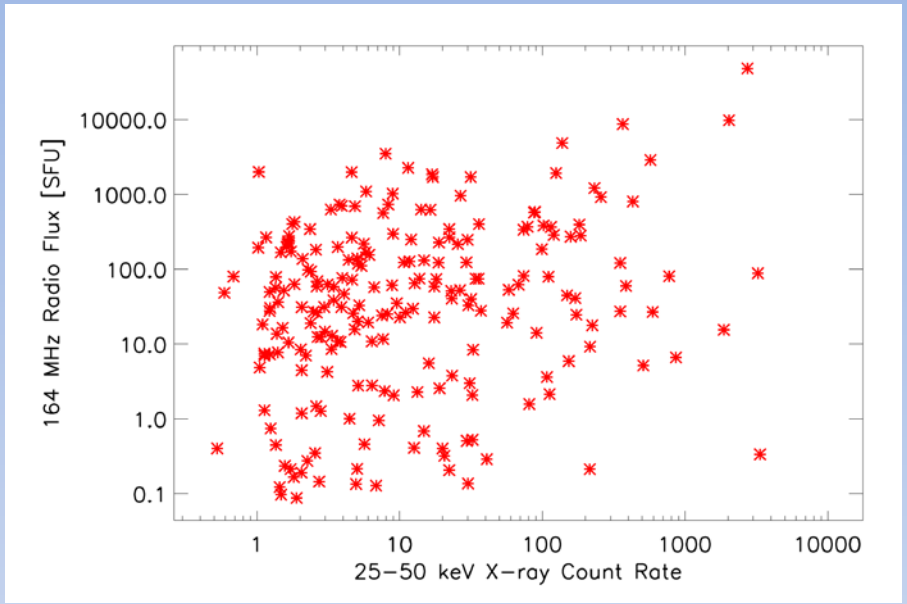
Peak count rate of the X-ray emission and
peak flux of the type III emission (background subtracted).

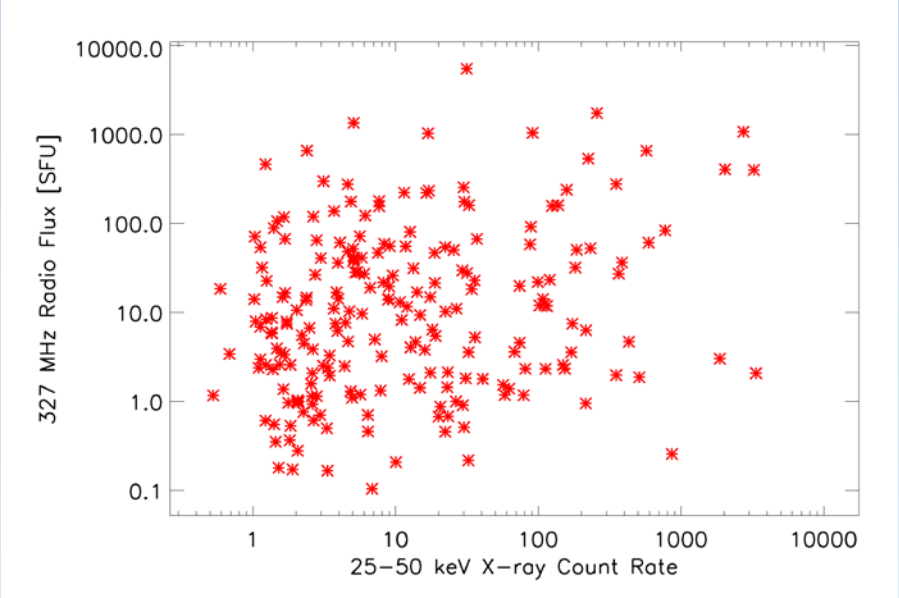
We found **NO** correlation between the peak flux of any radio frequencies with any of the X-ray energy channels.

These results agree with Hamilton et al 1990.

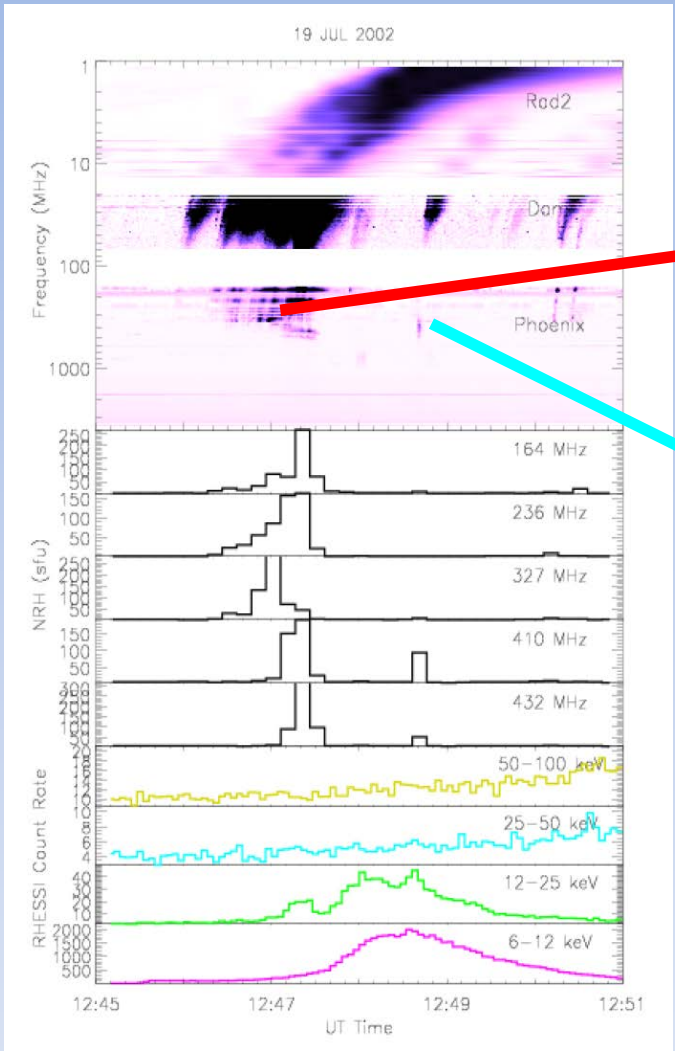
The lack of correlation is expected considering the nonlinear processes that generate the type III emission.

Reid , Vilmer in preparation





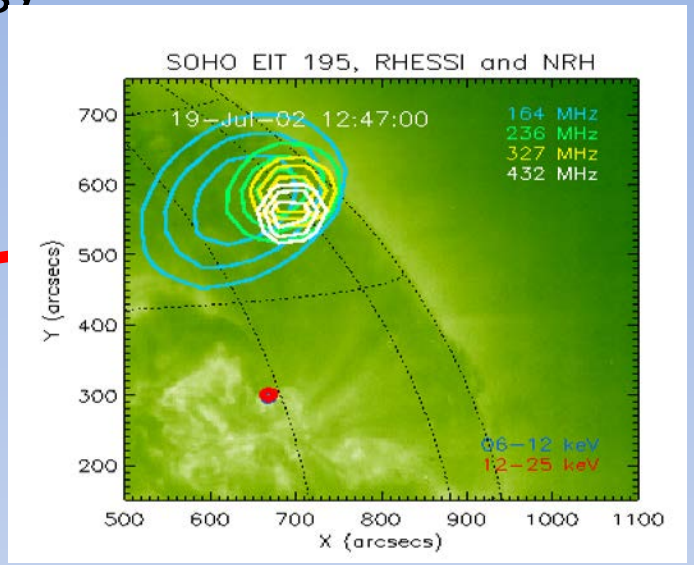
Flare Morphology

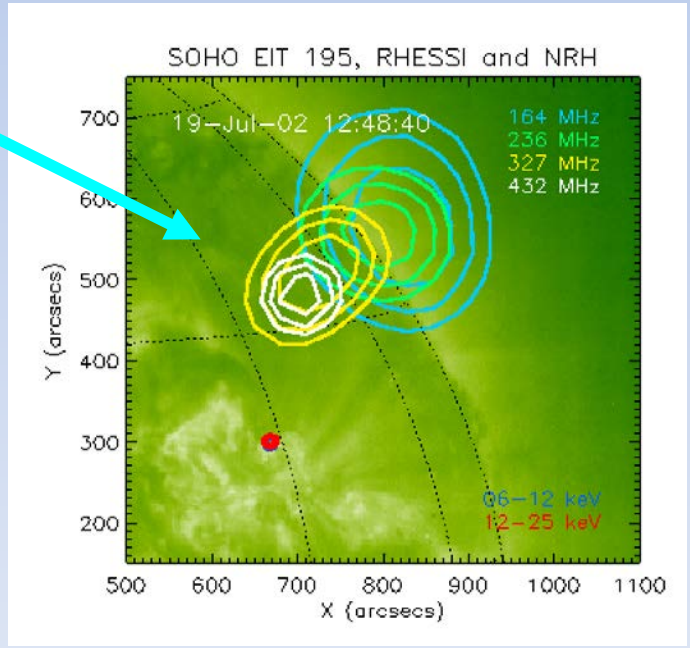


The standard flare model is very simplified. The reality is more complicated

Particles can be injected into different magnetic structures during the course of a flare.

This can influence whether the electron beam makes it into interplanetary space.

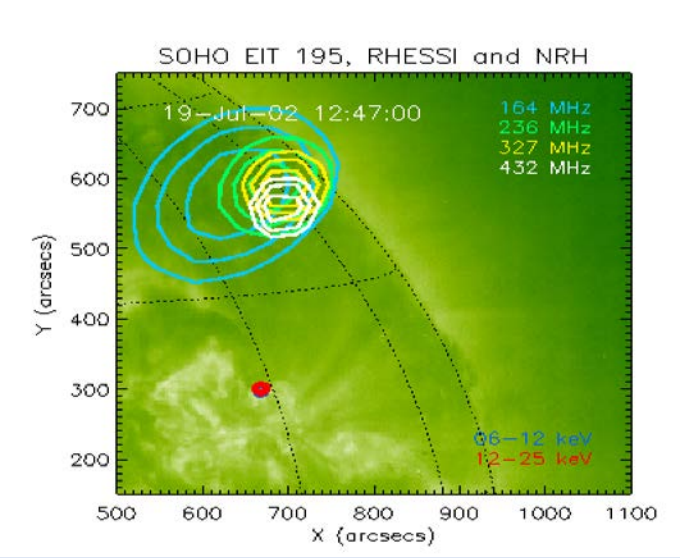


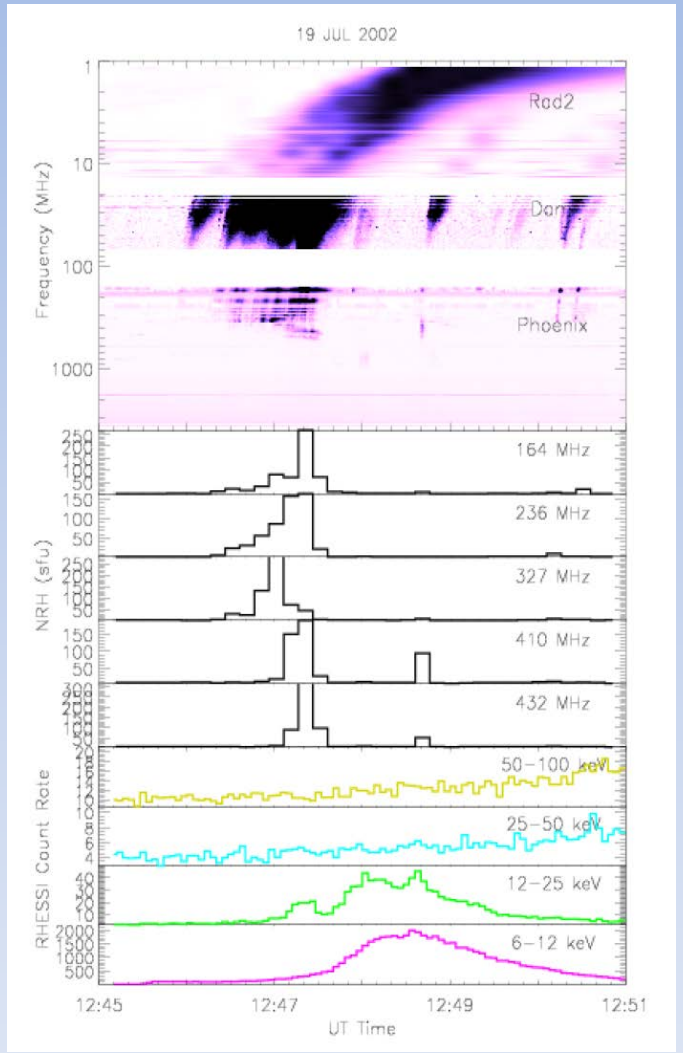


HXR – Type III Statistical Connection

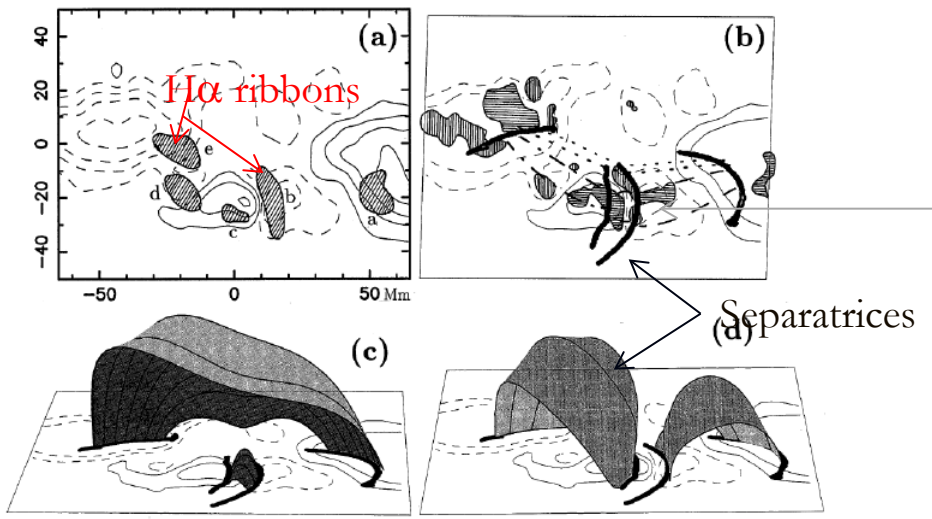
Future plans:

Provide combined plots for the different events (>300 events from 2002 to 2011)



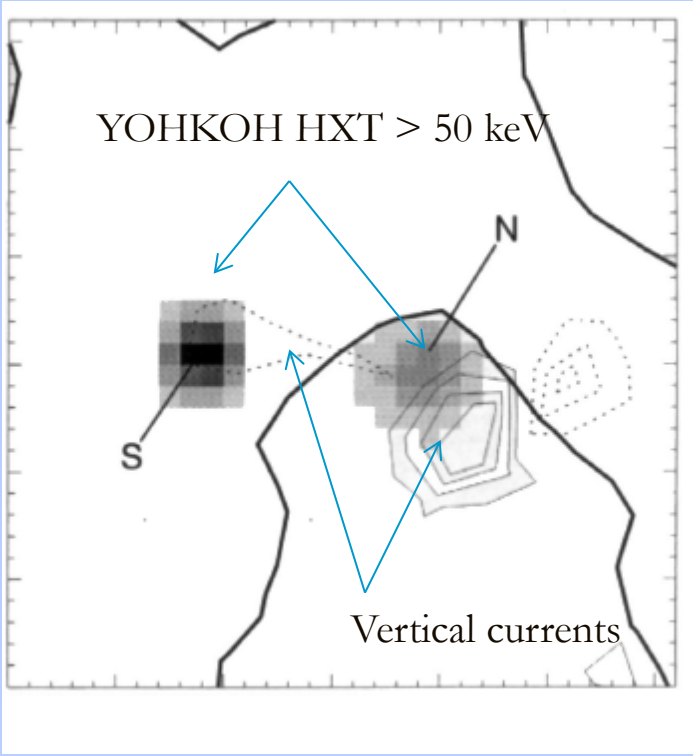


Particle acceleration/interaction sites and magnetic environment



From Démoulin et al., 1997

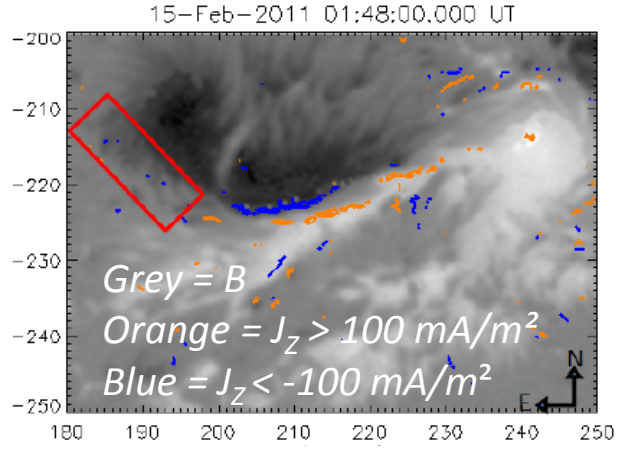
J> 10 mA/m^2

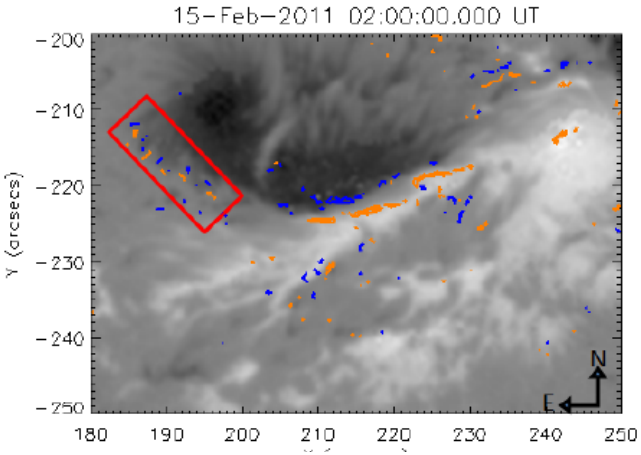


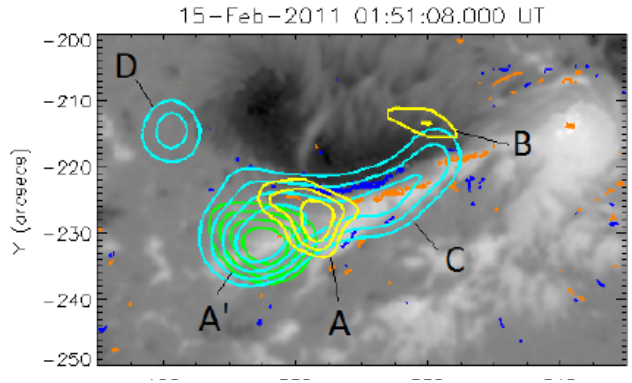
Finally, how to relate the location of hard X-ray sources to vertical current densities
(Li et al. 1997)

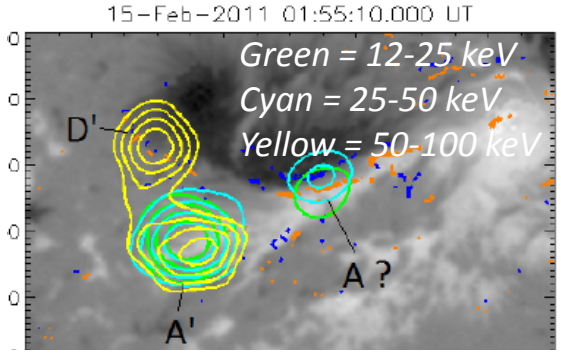
New possibilities combining SDO/HMI and RHESSI observations

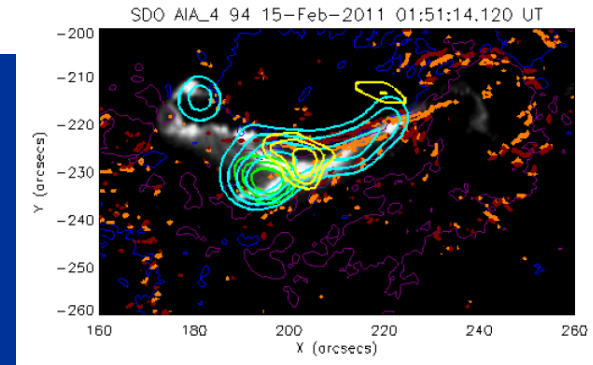
Particle acceleration/interaction sites and magnetic environment

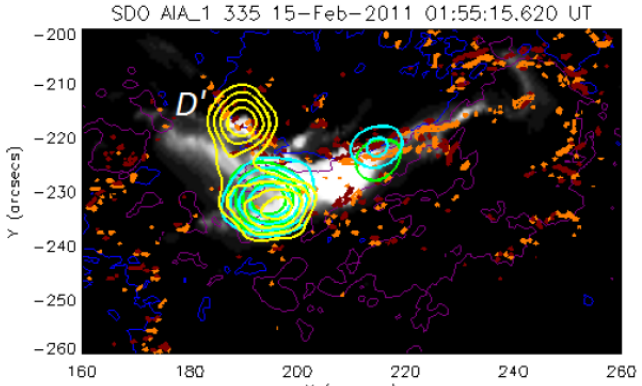










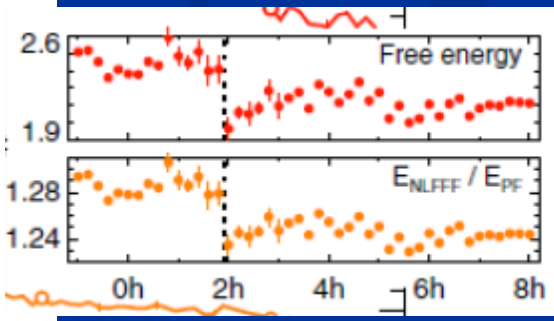


X2.2 flare SDO/HMI/AIA RHESSI
Musset, Vilmer, Bommier
In prep

X-ray emissions overlying strong concentrations of electric currents
Evolution of electric currents in the red box: appearance of new sources (evolution of reconnection sites)
Eth= 2 10 ^{30} erg
Enth= 6 10 ^{31} erg
Compared to values from Sun et al. 2012

- E_f =2 10^{32} erg

$$\Delta E_f = 3\ 10^{31} erg$$

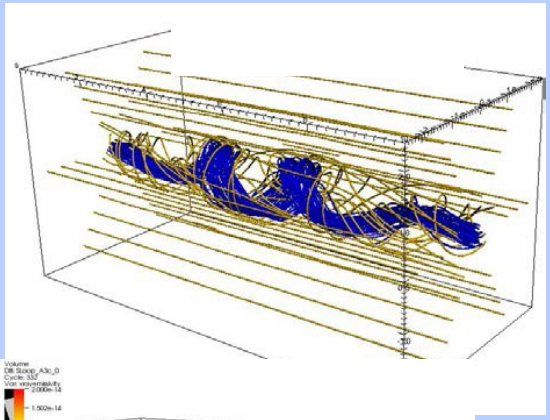


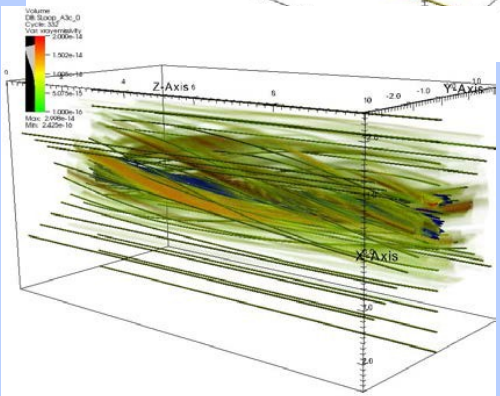
- MHD numerical simulation of a twisted flux tube (code PLUTO)

  Loop parameters :

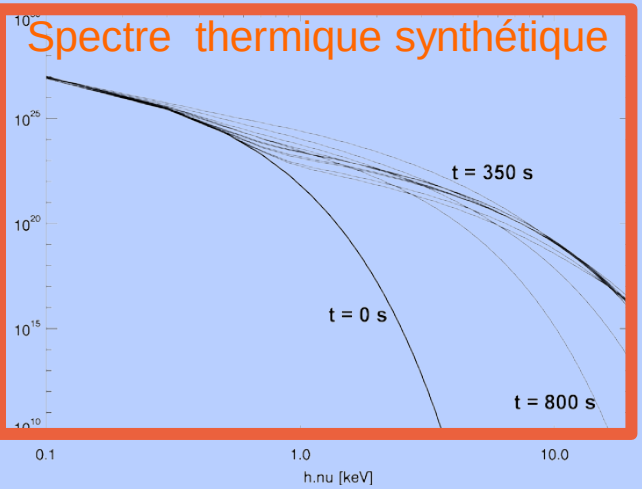
  L = 50 Mm, T_{init} = 1 MK, B_0 = 100 G, n_0 = 10^{10} cm^{-3}

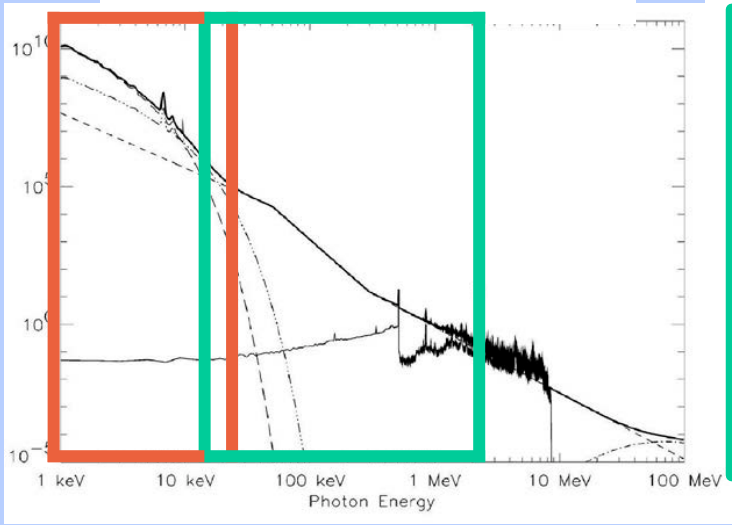
- Predicted thermal X-ray emission
  - **Pinto, Vilmer & Brun 2013**
- Non thermal emission: test particles

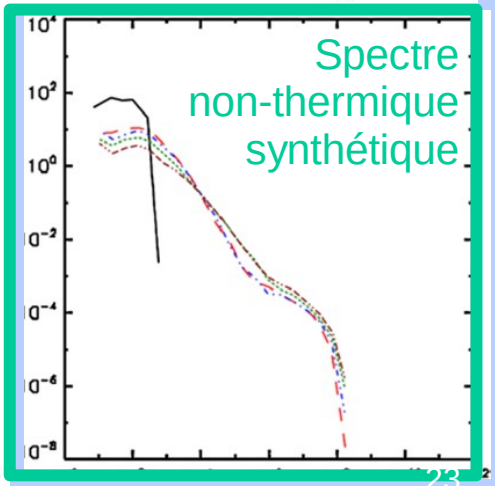




Spectre observé RHESSI







THANKS!!