Statistical study of type III bursts and associated HXR emissions

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Solar Flare Electron Acceleration/ Propagation

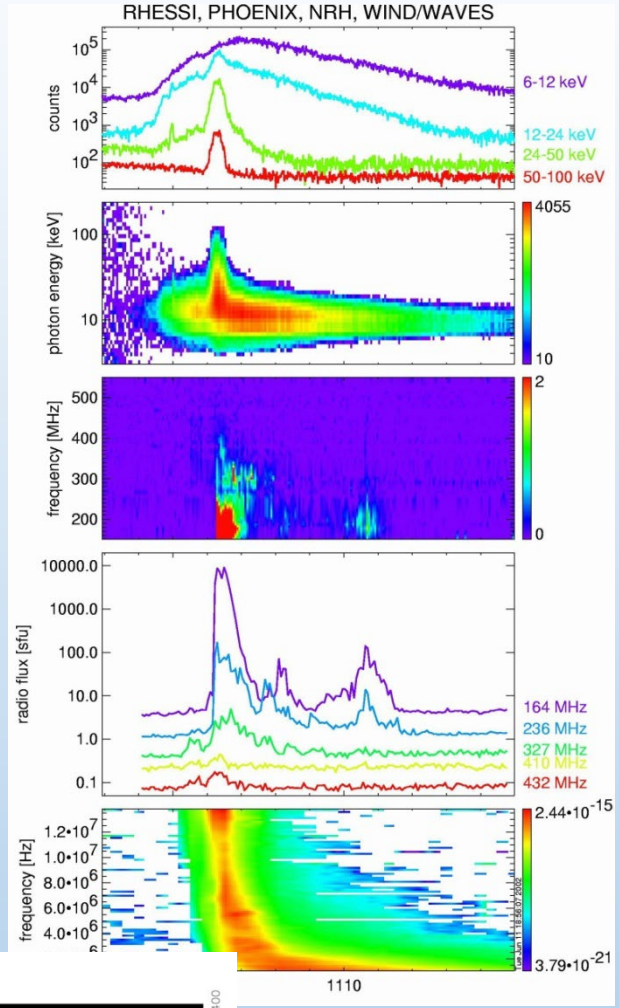
Standard (simple) picture

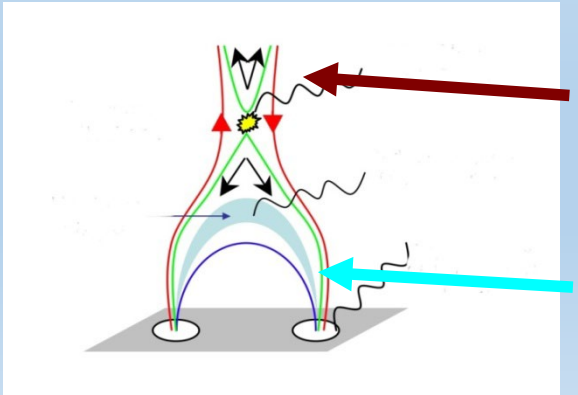
Electrons travelling downwards into the chromosphere radiate X-rays in dense
($n_e=10^{12}$ cm^{-3}) plasma via Bremsstrahlung. Detected X-rays are usually in the 6-100 keV energy range

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.

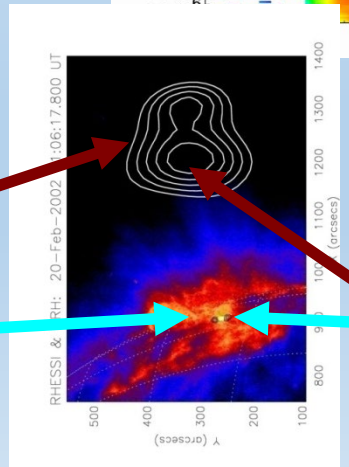
X-RAYS

RADIO





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



Vilmer et al. 2002

NRH and RHESSI observations

HXR – Type III Statistical Connection (a long history)

First studies by Kane (1972): good association between some HXR and type III radio emission, suggesting electrons can originate from a common acceleration site.

The first statistical study of HXRs and Type III emission was undertaken by Kane (1981):

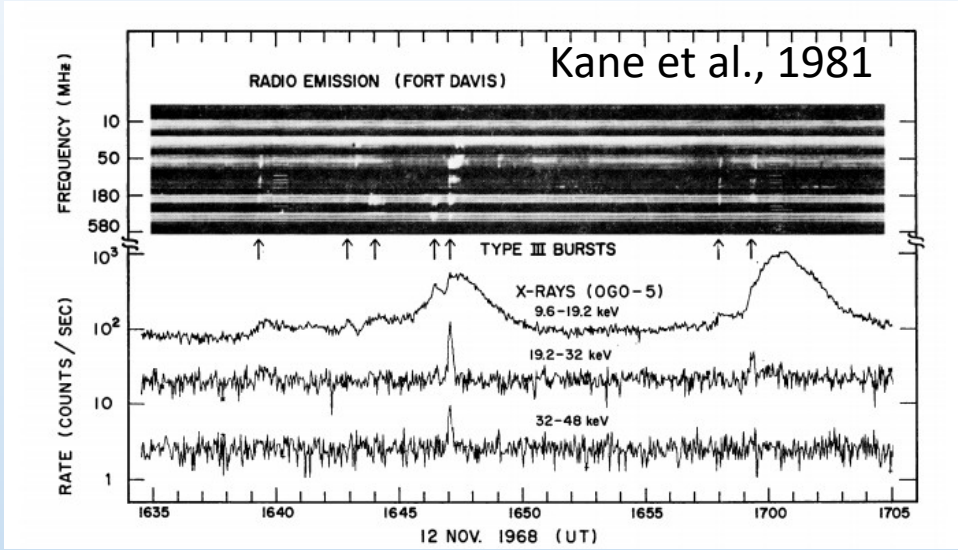
– 3% of type III emission at metric wavelengths associated with HXRs.

The more intense the type III burst, the more likely it would be associated with a HXR flare.

The harder the X-ray spectral index, the more likely it is associated with a type III radio burst.

Events which have associated HXR and Type III radio emission tended to have higher radio starting frequencies

The higher, the type III starting frequency, the stronger X-ray emission (Raoult et al., 1985)



HXR – Type III Statistical Connection

Hamilton et al (1990) : statistical analysis using SMM (X) and BLEN, WEIS,TRIESTE (R)
No correlation between the peaks of the X-ray and type IIIs.
[But a statistical dependence]

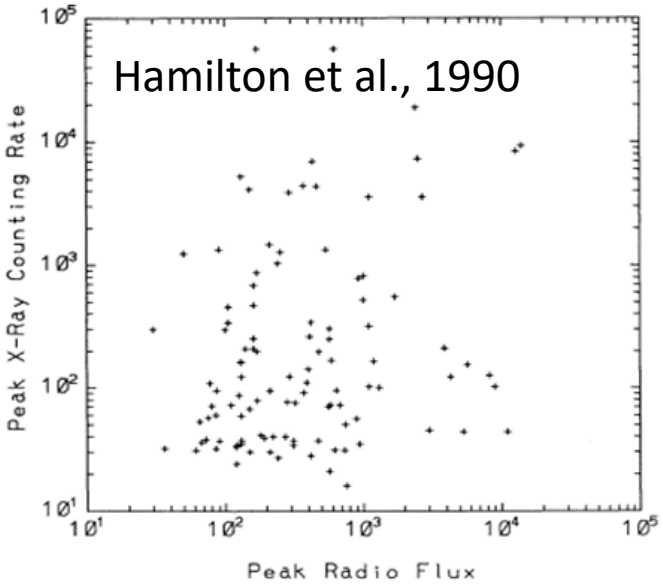
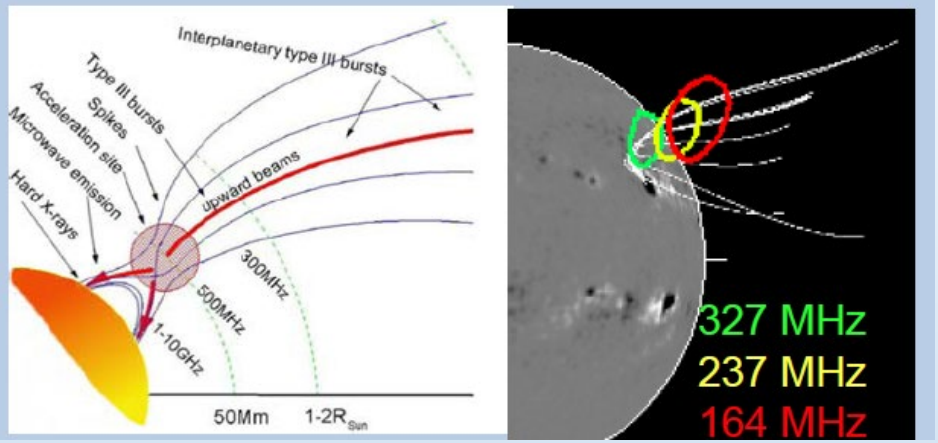


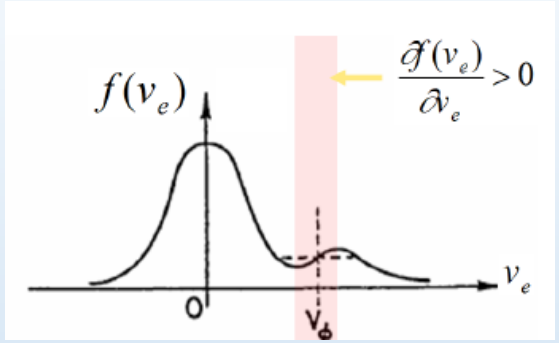
FIG. 1.—Distribution of the correlated events in the *R-X* plane

Aschwanden et al. 1995: 31% of HXR associated with Type III around 300 MHz

More recent surveys by Benz et al. 2005;2007 combining RHESSI HXR observations and radio observations by PHOENIX-2 (4 GHz-100 MHz)
-Xray flares with GOES class > C5
- Classic meter wave type III bursts associated with 33% of HXR flares
-Only in 4% the only emission

HXR- type III statistical connection

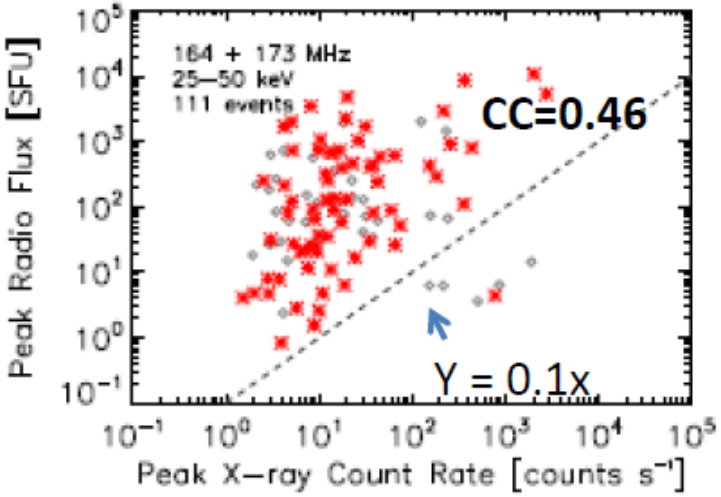




What kind of correlation between X-ray and radio intensities?

Do all coronal type III bursts have an interplanetary counterpart?

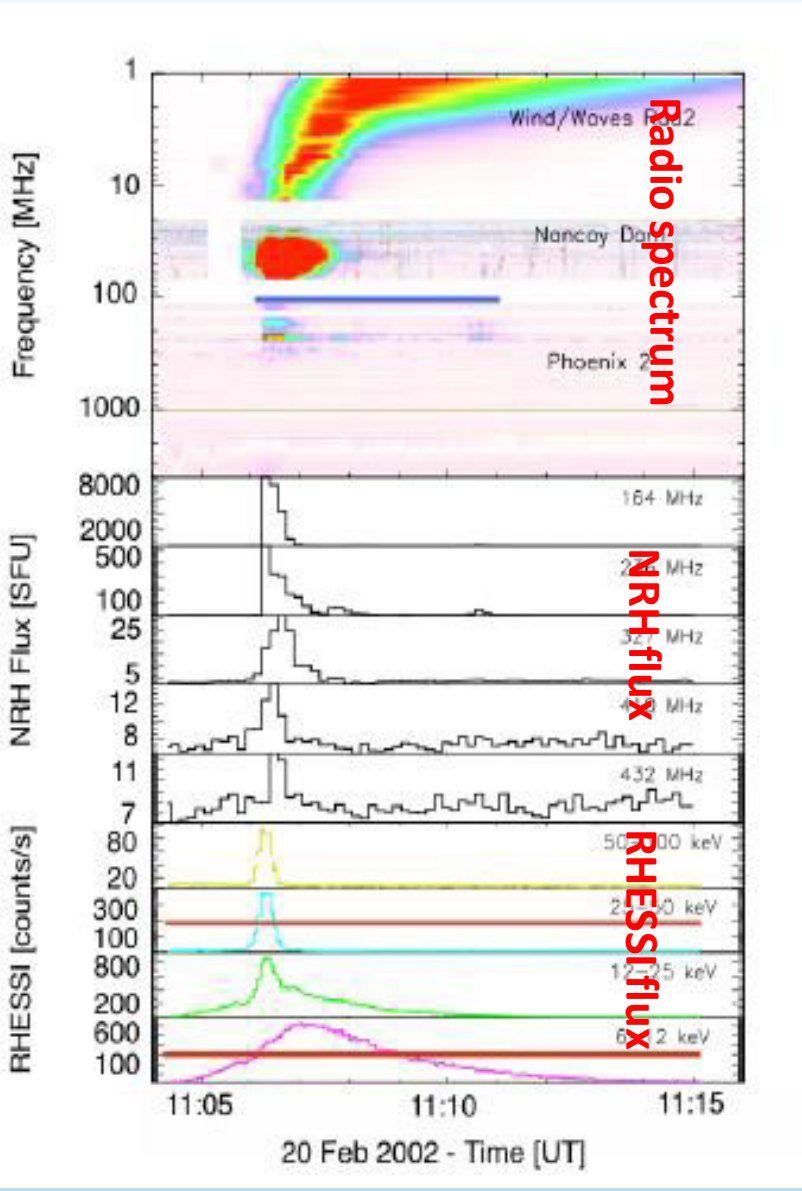
Study based on >1000 coronal type III bursts over 10 years of data (2002-2011) (Reid& Vilmer, 2017)



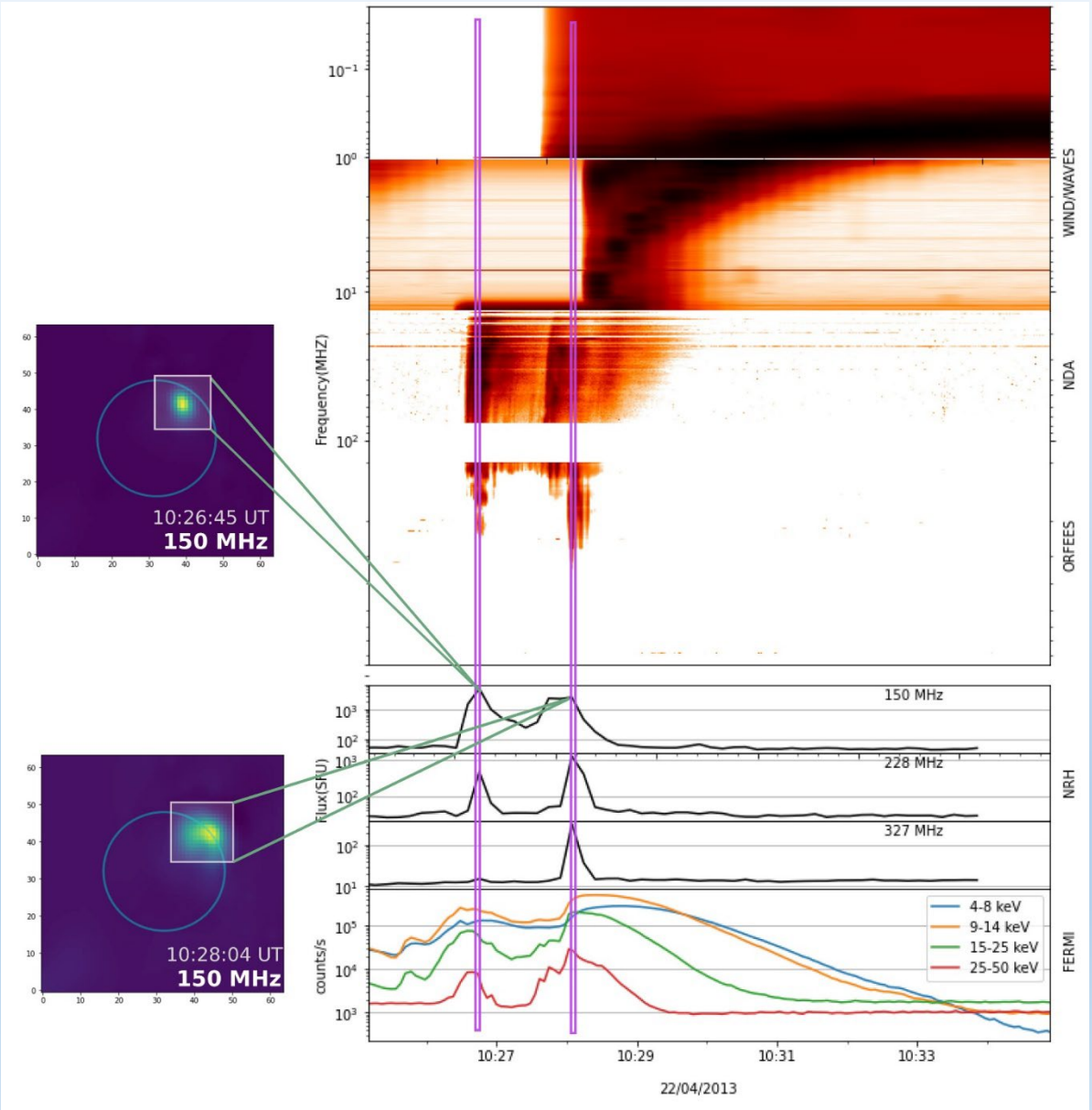
321 events with co-temporal HXR and radio emission (automatic selection of events)

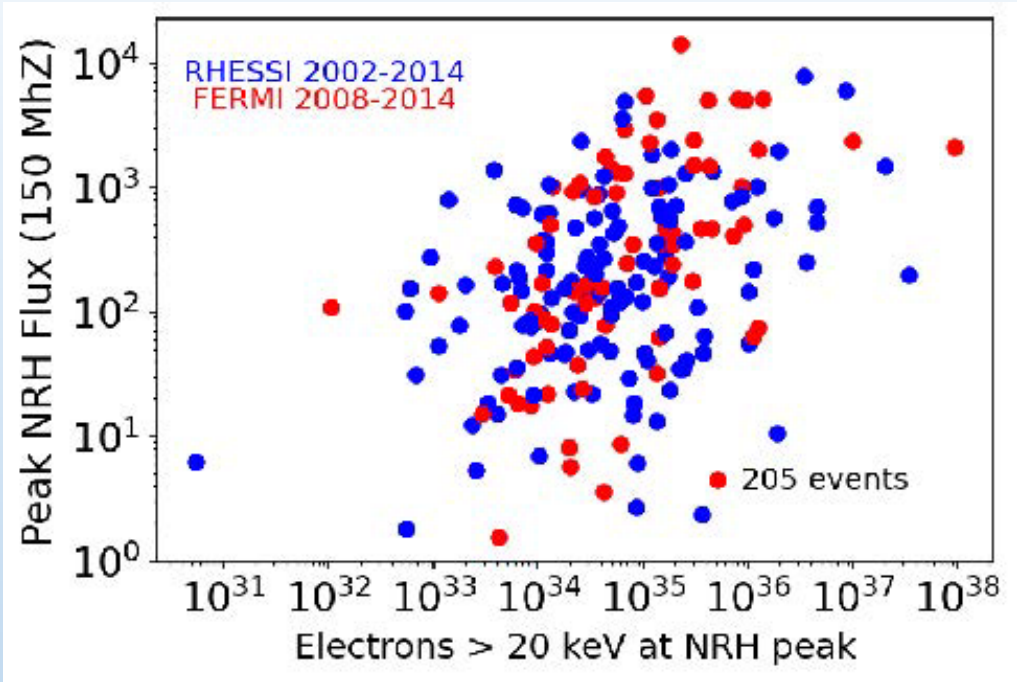
Peak radio flux vs peak X-ray count rates

No HXR spectral analysis



HXR- type III statistical connection (a new study)





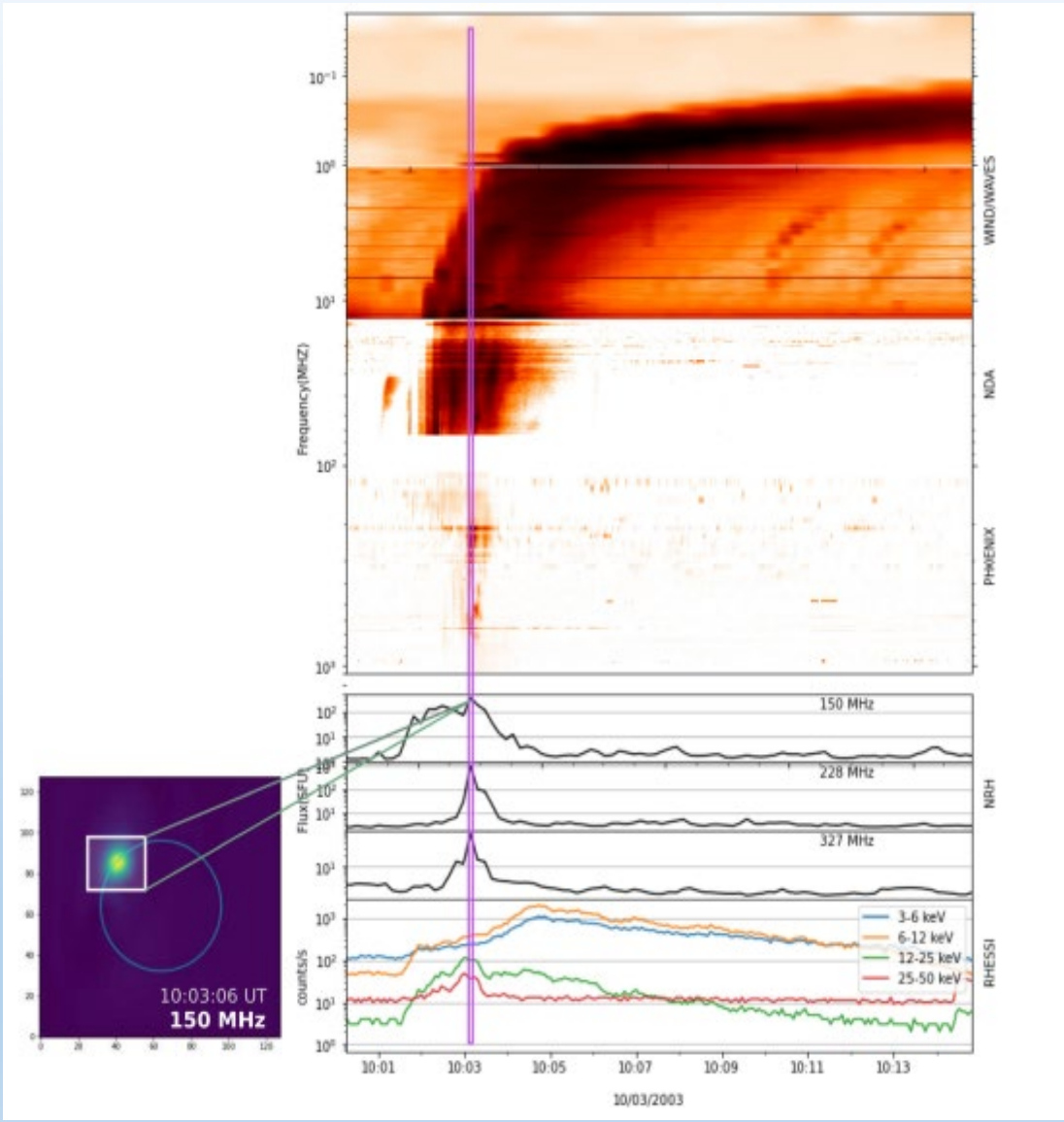
James and Vilmer, 2023A&A...673A..57J

More events (RHESSI and FERMI/GBM)
Different data selection

Radio flux and electron numbers (instead of X-ray flux)

Data selection

- 13 Years of observations: 2002-2014
- Start of RHESSI- End of NRH
- X-rays: RHESSI + FERMI/GBM
- NRH Observations: radio fluxes
- Solar radio spectra: 1 GHz-0.1 MHz
- PHOENIX-2; PHOENIX-3;-ORFEES 1 GHz-100 MHz
- NDA 80 MHz-10 MHz
- WIND/WAVES (<10 MHz)
- Production of daily QL plots for selection of HXR/ associated type III radio emissions (simple events) for event selection
- Production of more detailed plots for interesting events



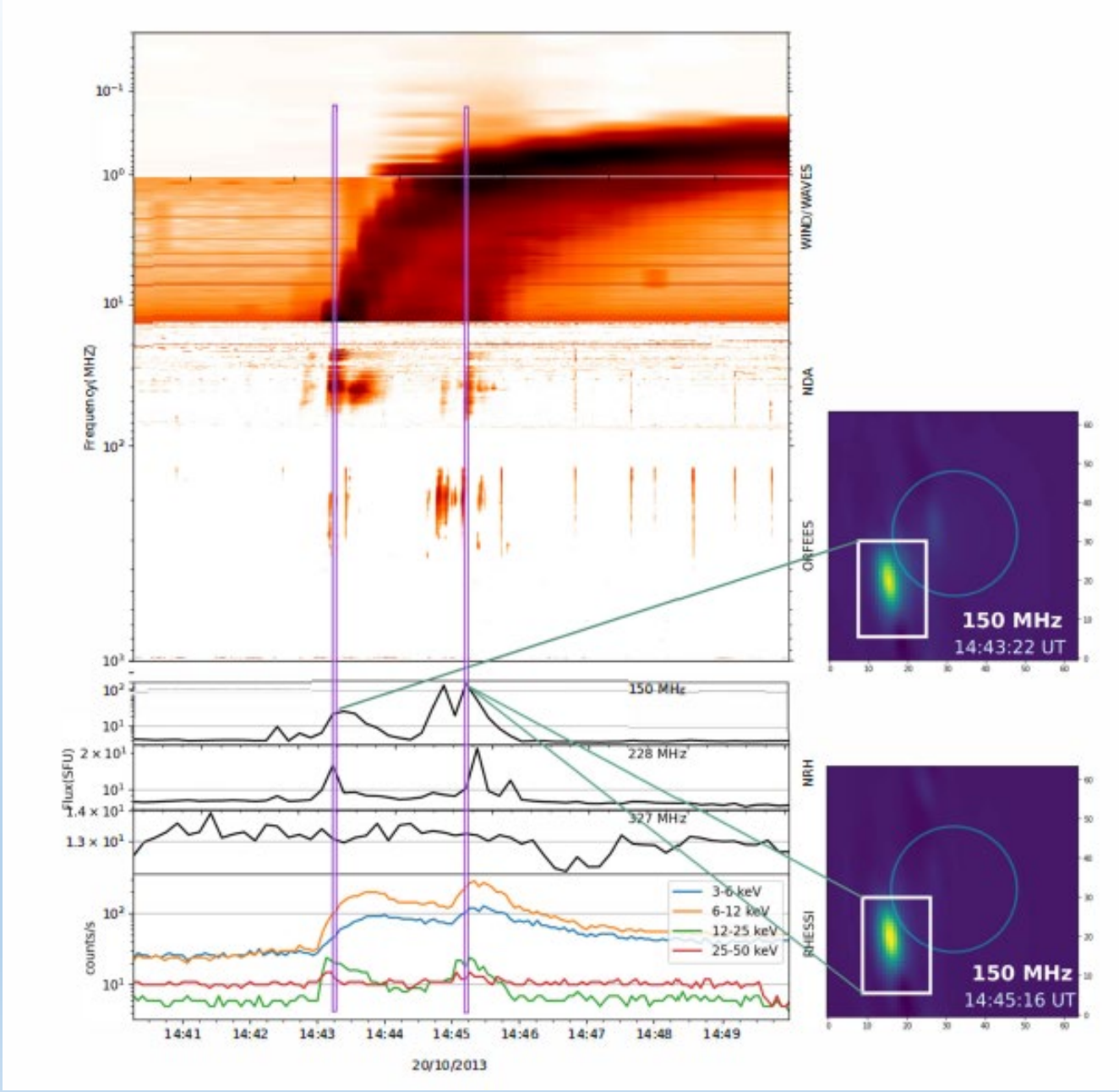
Data selection

- Selection criteria:
- Impulsive X-ray emission at least above 15 keV: (for HXR spectral fitting)
- No events with long HXR tails and complex radio emissions
- Type III emission clearly seen above 100 MHz
- Not necessarily extension below 10 MHz
- Clear type III emission observed at 150 MHz with the NRH (flux measurement)
- Only 205 events
- 89% association with GOES C &B class flares
- Output: radio flux

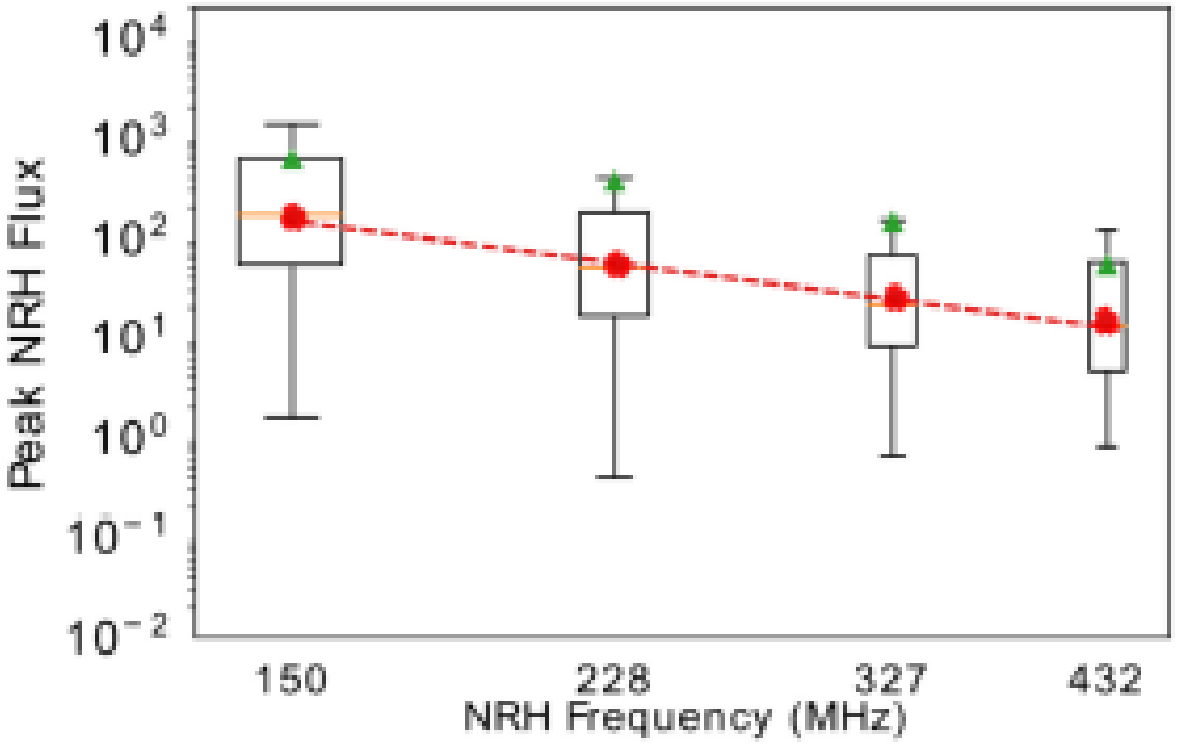
  starting and stopping frequencies

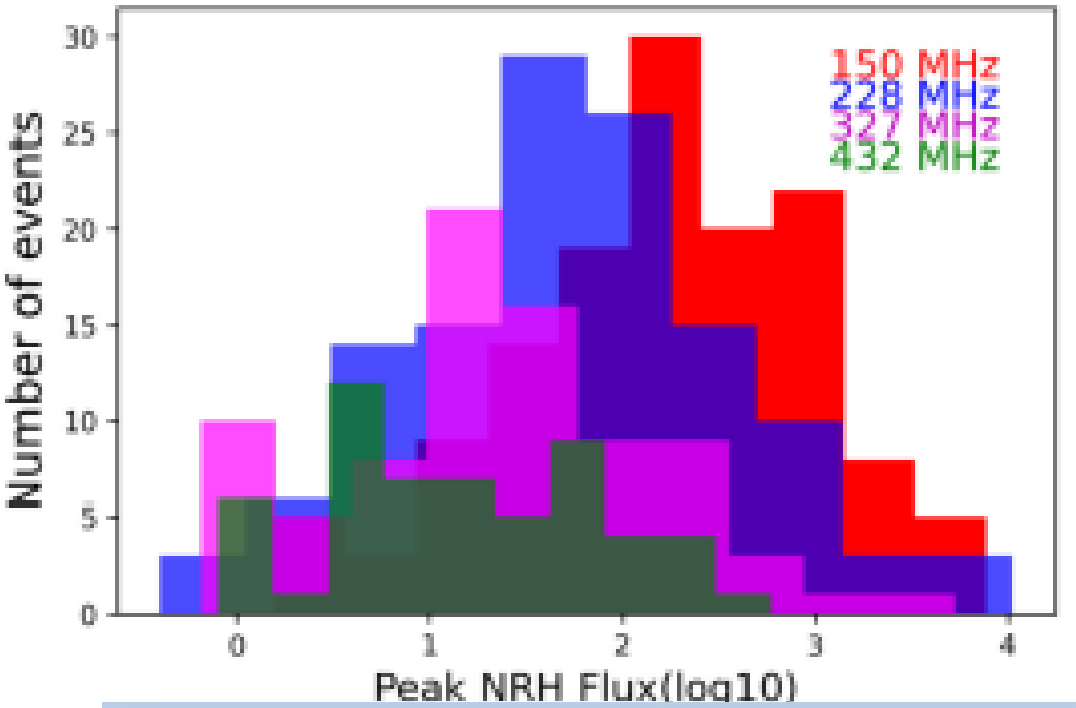
  electron number (HXR emissions)

  electron spectral indices

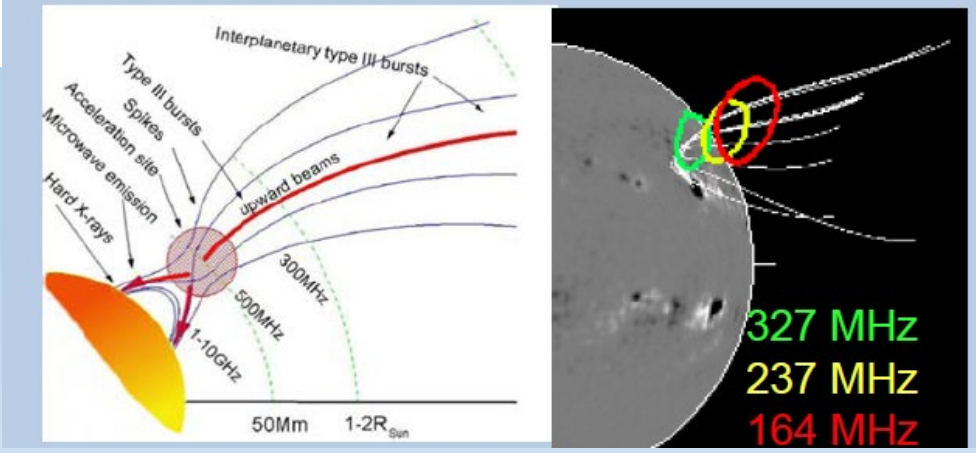


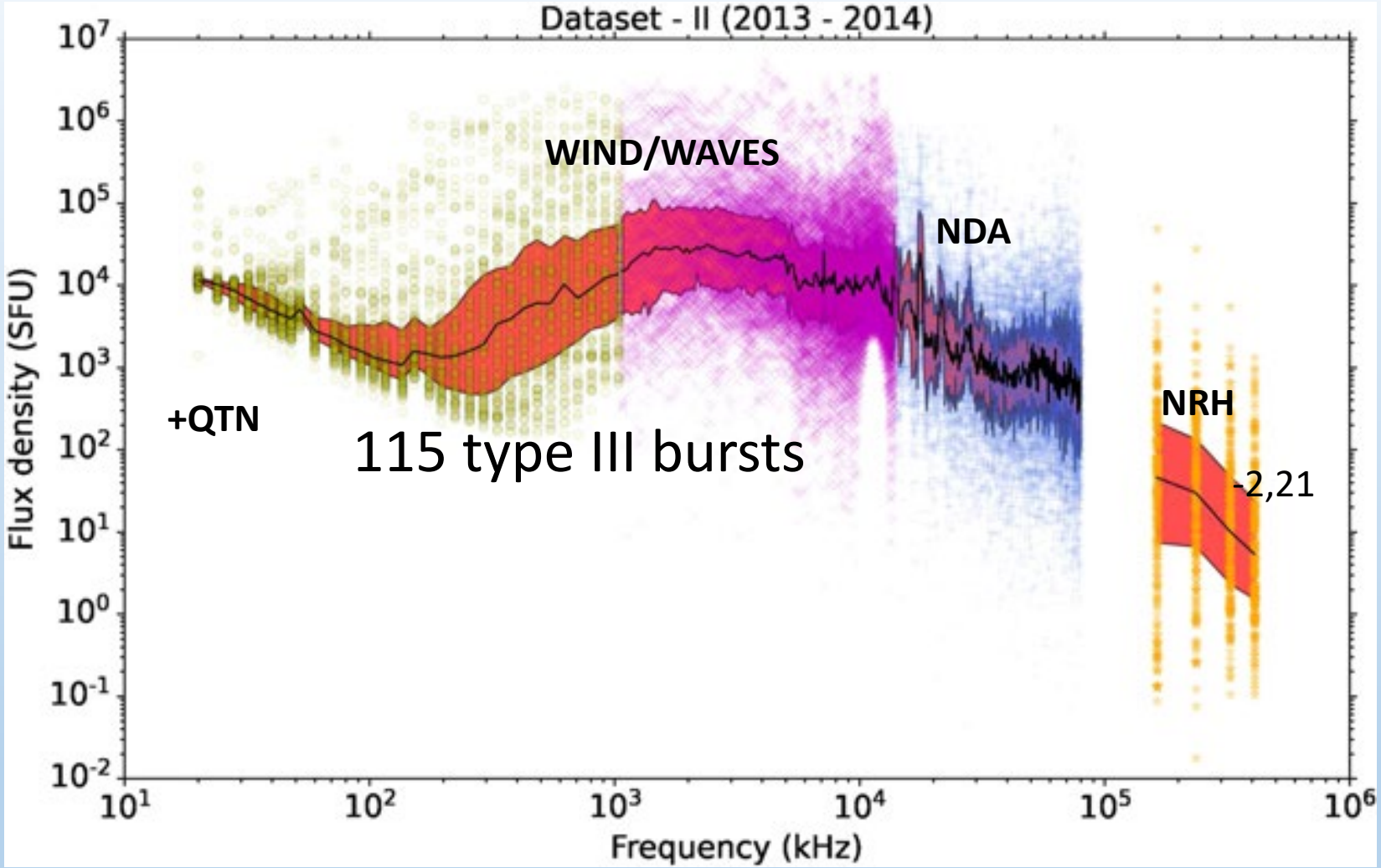
Radio type III burst distribution (in our sample)





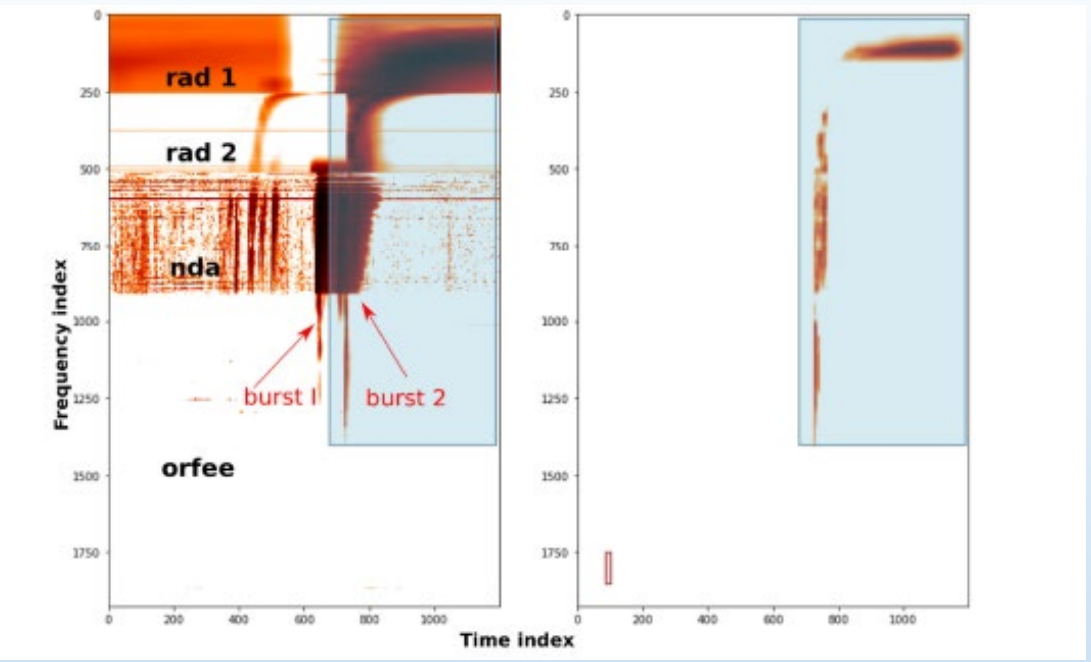
Peak radio flux as a function of frequency : decreasing as $\nu^{-2.43}$





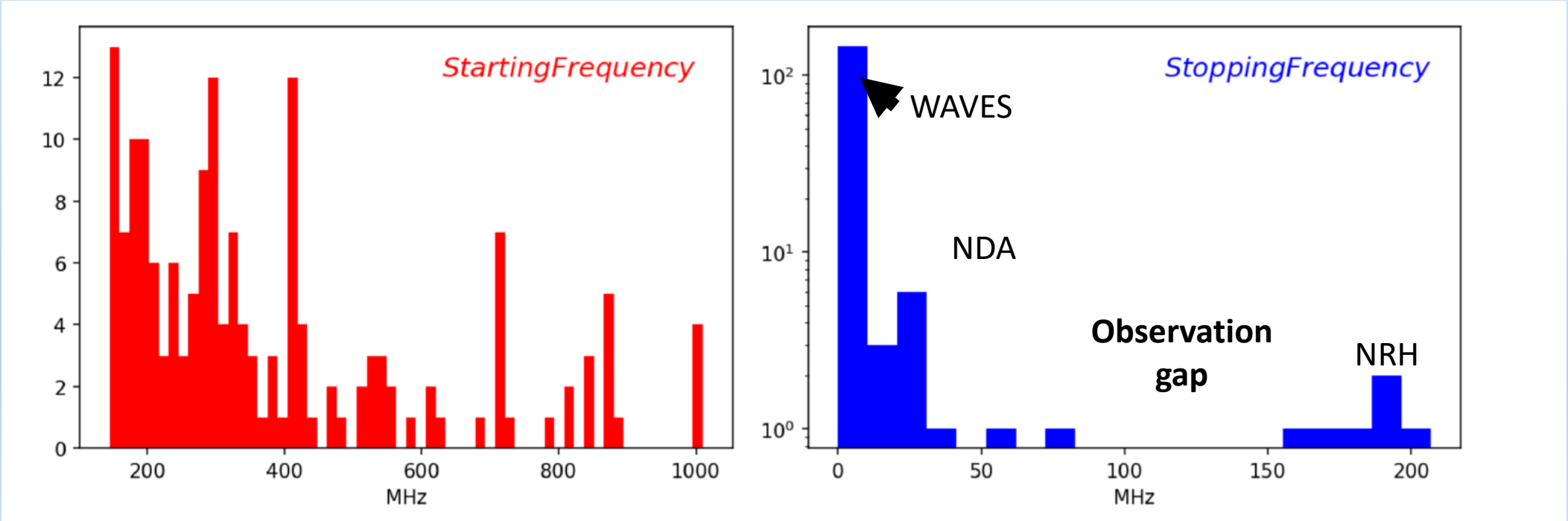
Sasikumar Raja, Maksimovic, M et al., 2022

From Reid &Vilmer , 2017

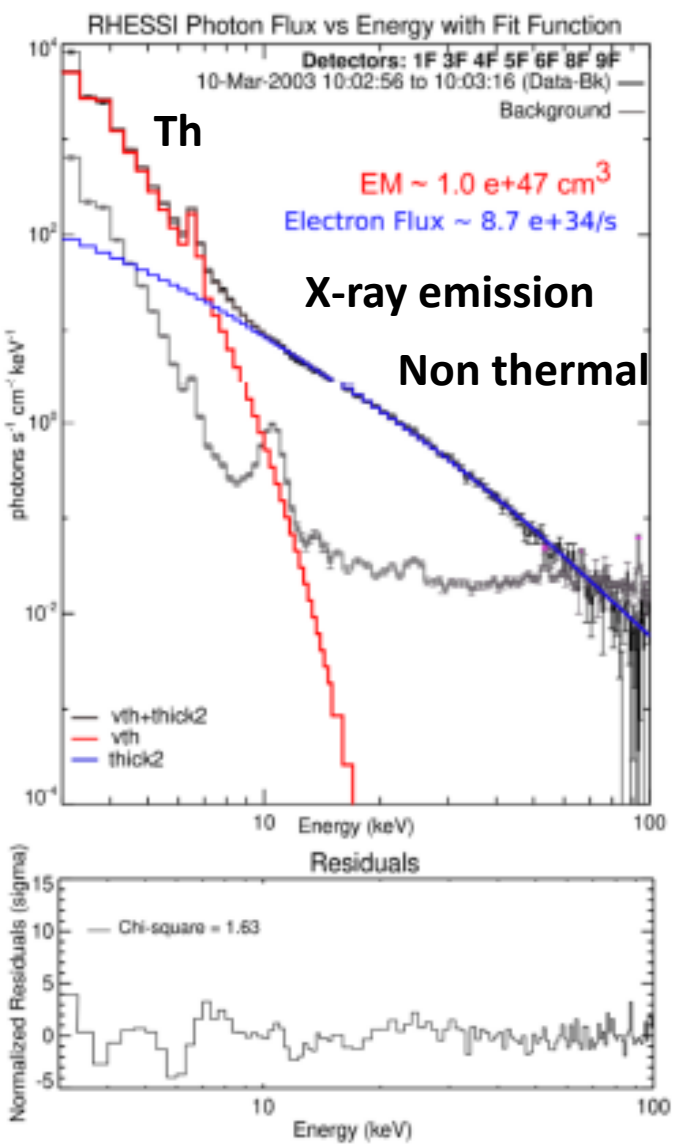


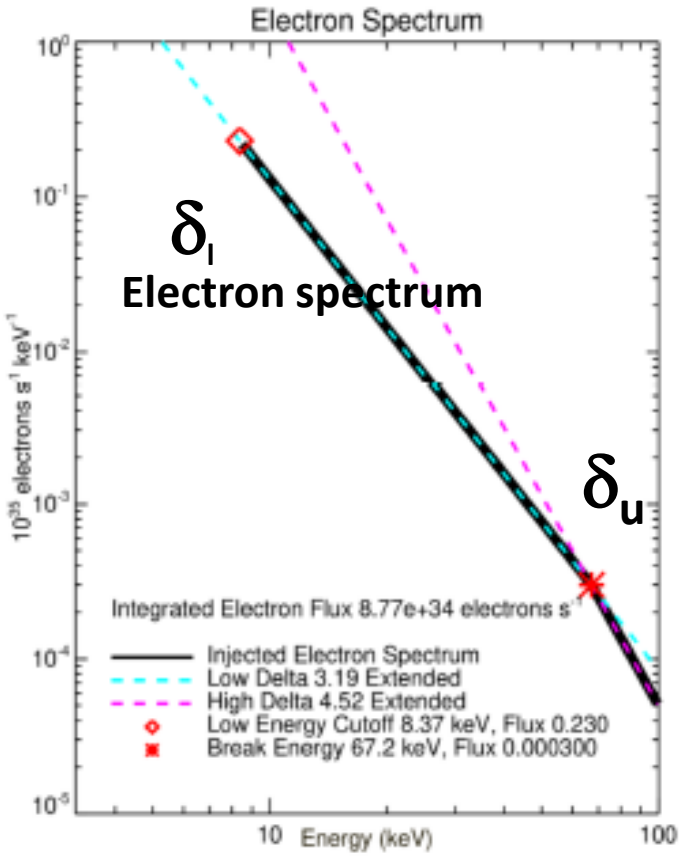
Automatic detection of starting and stopping frequencies

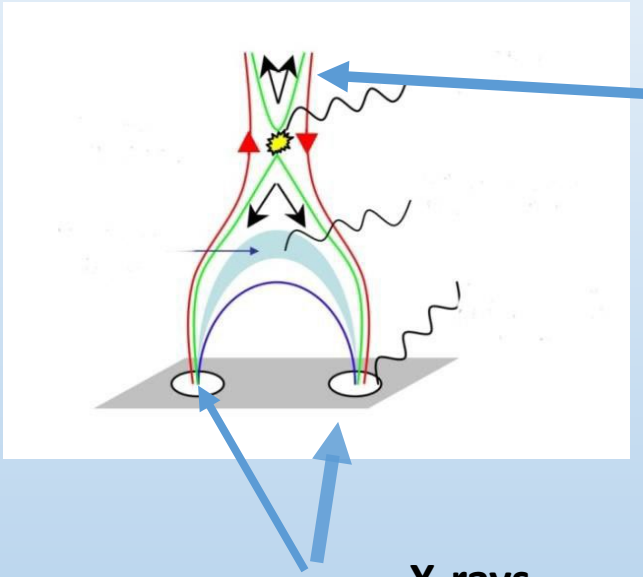
Most of the type III bursts start below 400 MHz
Most of the events in our sample extend to less than 10 MHz (are observed by WIND)



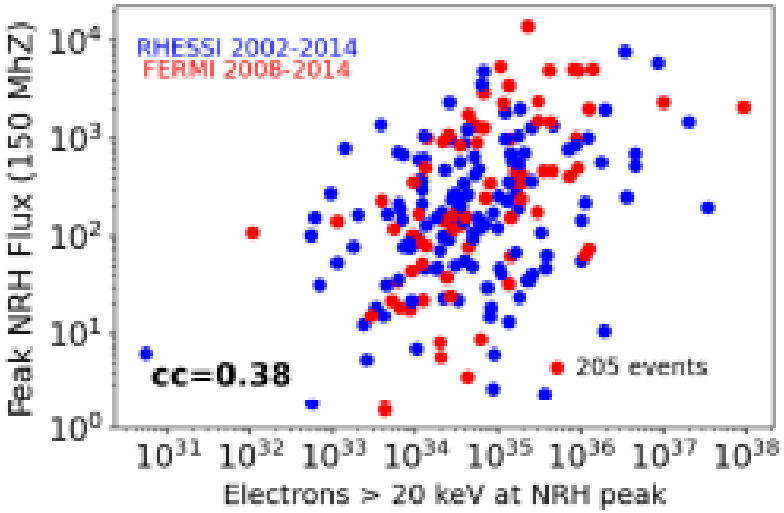
Deriving HXR producing electrons

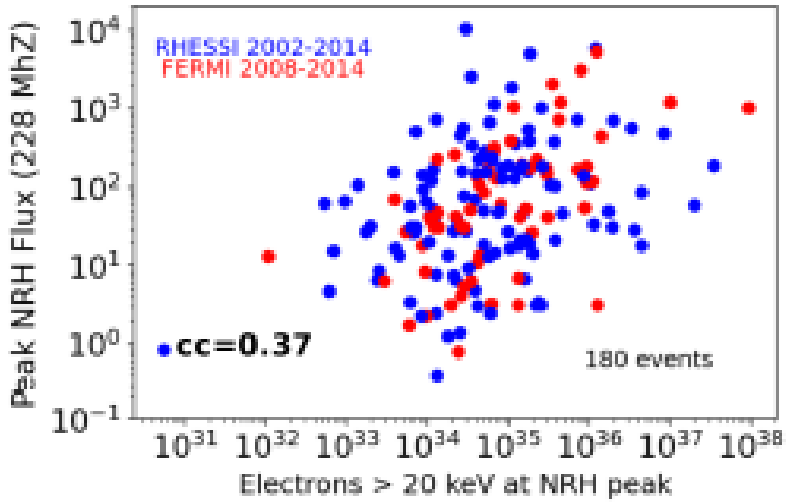


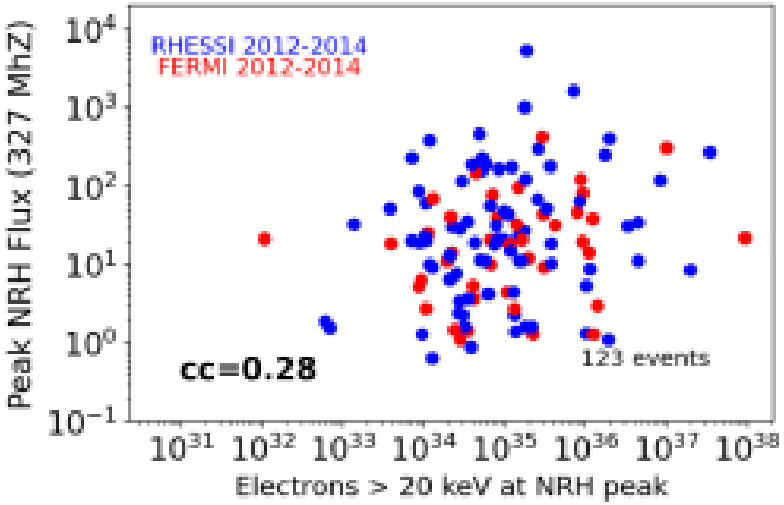


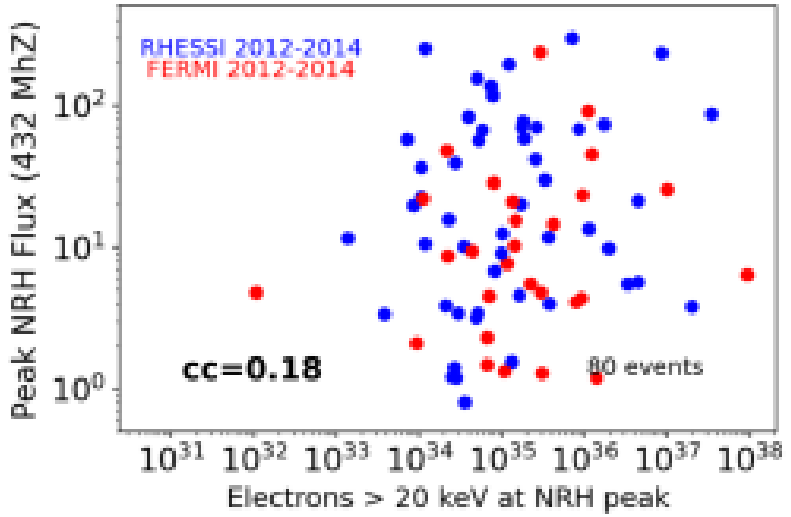


Radio flux and HXR emitting electrons





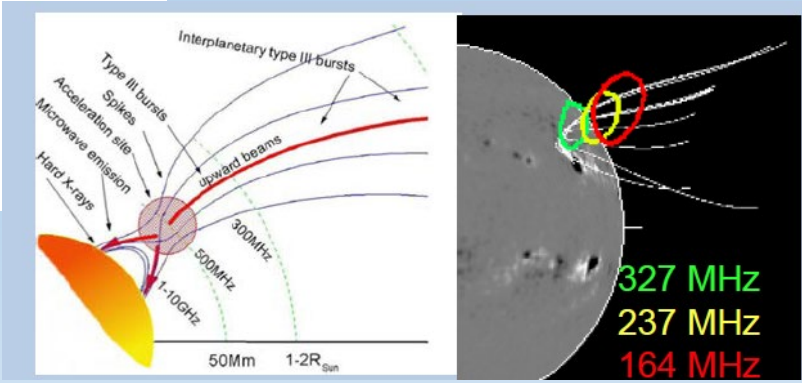




Rough correlation
of peak radio fluxes with
electron number > 20 keV

Correlation increases with
decreasing frequency

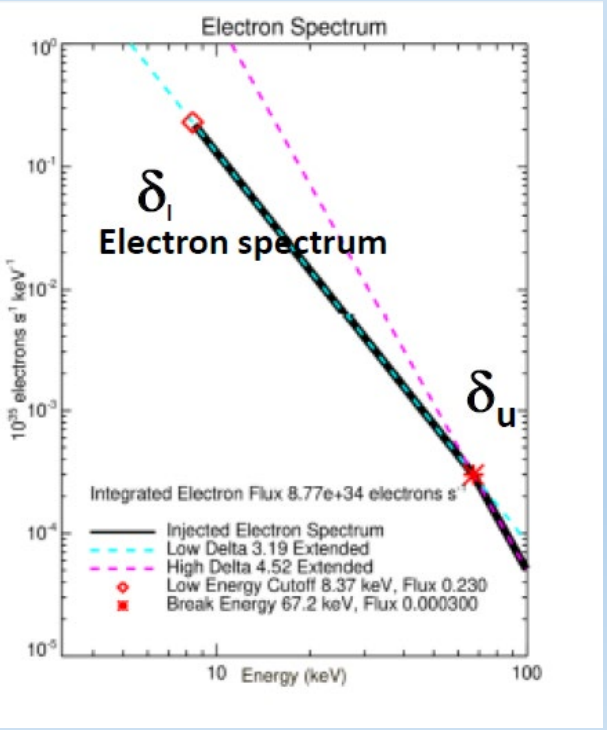
Better correlation for electron
number > 20 keV than for
electron number >10 keV



Radio flux and HXR emitting electrons

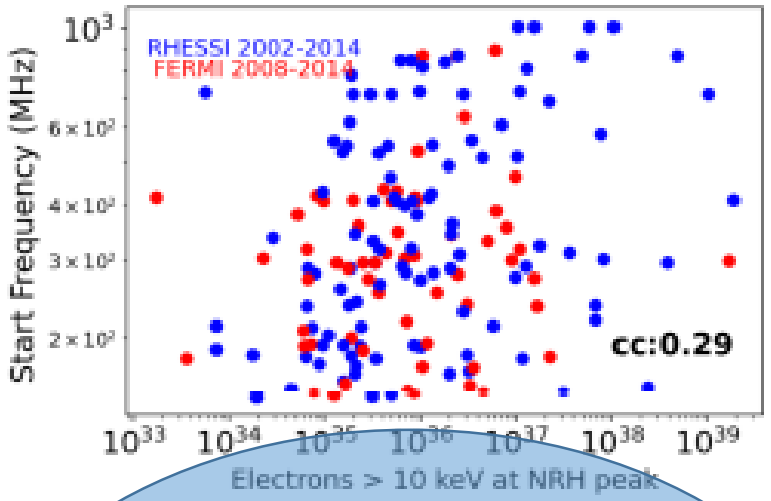
NRH frequency(MHz)	Number of events	Electrons above 10 keV vs NRH peak flux	Electrons above 20 keV vs NRH peak flux
150	205	0.29±0.001	0.38±0.001
228	180	0.26±0.002	0.37±0.001
327	123	0.21±0.002	0.28±0.002
432	80	0.16±0.002	0.18±0.002

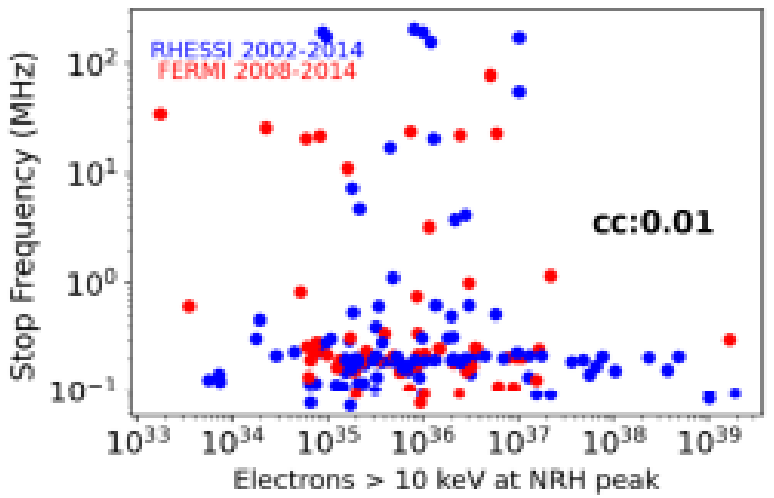
NRH frequency(MHz)	Number of events	δ_{low} vs NRH peak flux	δ_{high} vs NRH peak flux
150	205	-0.10±0.001	0.05±0.002
228	180	-0.16±0.001	0.09±0.002
327	123	-0.01±0.002	0.13±0.002
432	80	-0.04±0.002	0.04±0.002

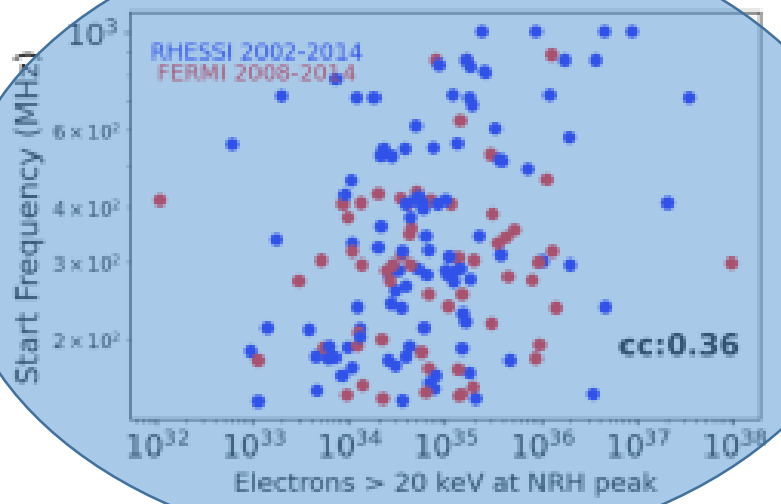


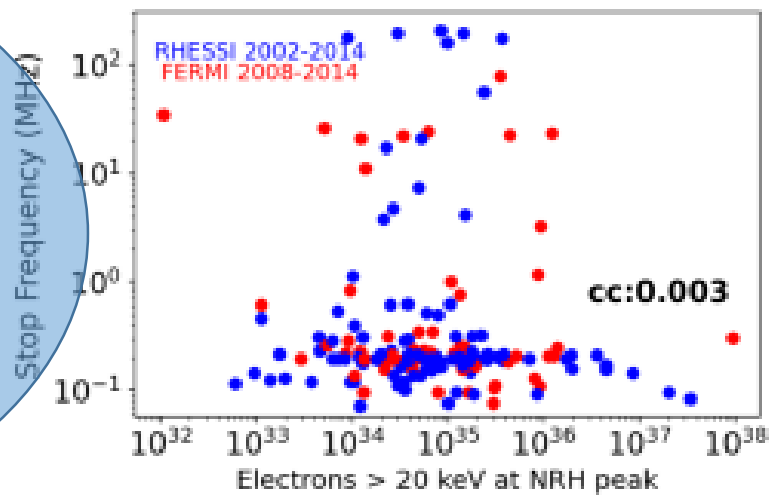
Better correlation of the radio flux with the electron number than with the spectral indices
(relation with bump in tail unstability?)

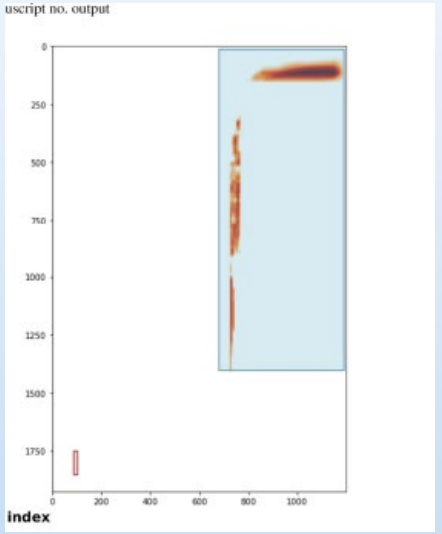
Starting and stopping frequencies and HXR emitting electrons

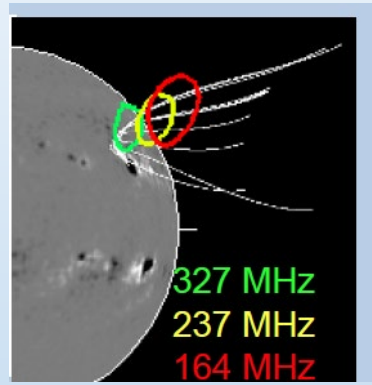












Some correlation between the starting frequency and the electron numbers above 20 keV

(relation with the production of bump-in tail instability?)

No correlation between stopping frequency and electron numbers (most bursts reach IP medium)

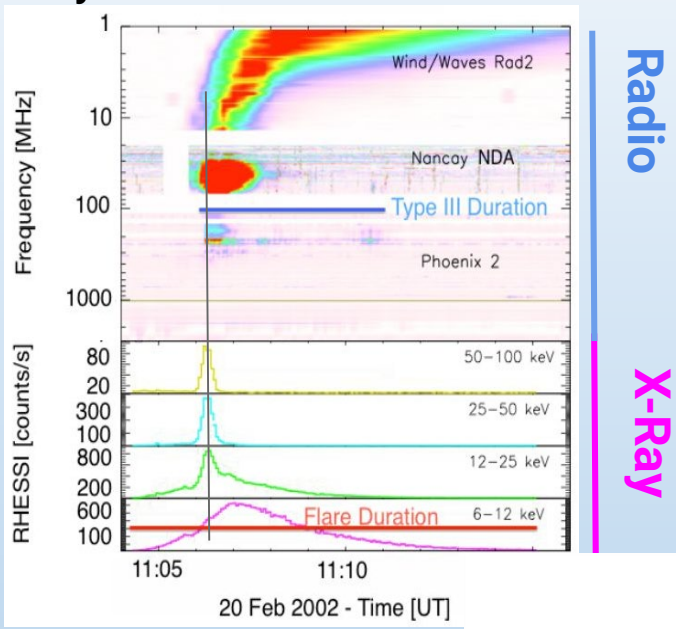
Statistical study of type III bursts and HXR bursts

- **Peak radio flux as a function of frequency in the 450 -150 MHz range: decreasing as $\nu^{-2.43}$**
- **Some correlation between the electron number > 20 keV deduced from X-rays and the peak type III radio flux (and not with the HXR electron spectral index)**
- **Correlation increases with decreasing frequency (further away from the beam production?)**
- **Some correlation between the starting frequency and the electron number > 20 keV**
- **Constraints for simulations of type III radio bursts in the corona**
- **Would be better constrained if directly measuring X-ray emission from the beam**
- **(would need some direct imaging in X-rays… see FOXSI's type of instrumentation)**

- A few additional slides from the work of David Paipa

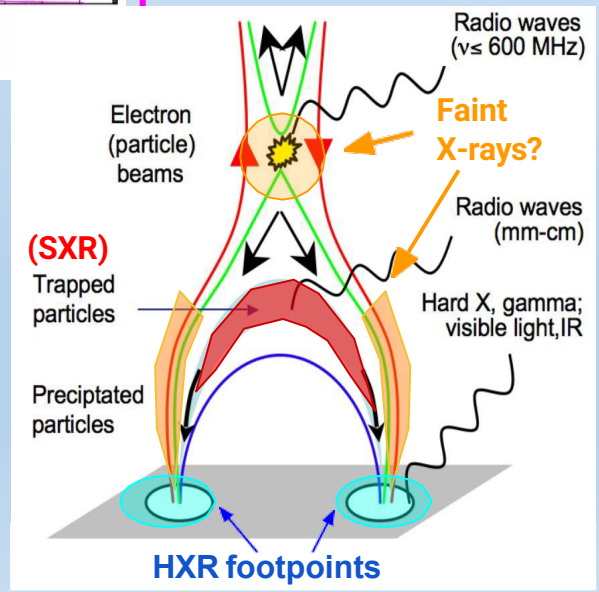
Context on Radio/X-ray observations: IPT3 delayed emission

The onset time of X-ray and Radio emissions can be very similar . . .

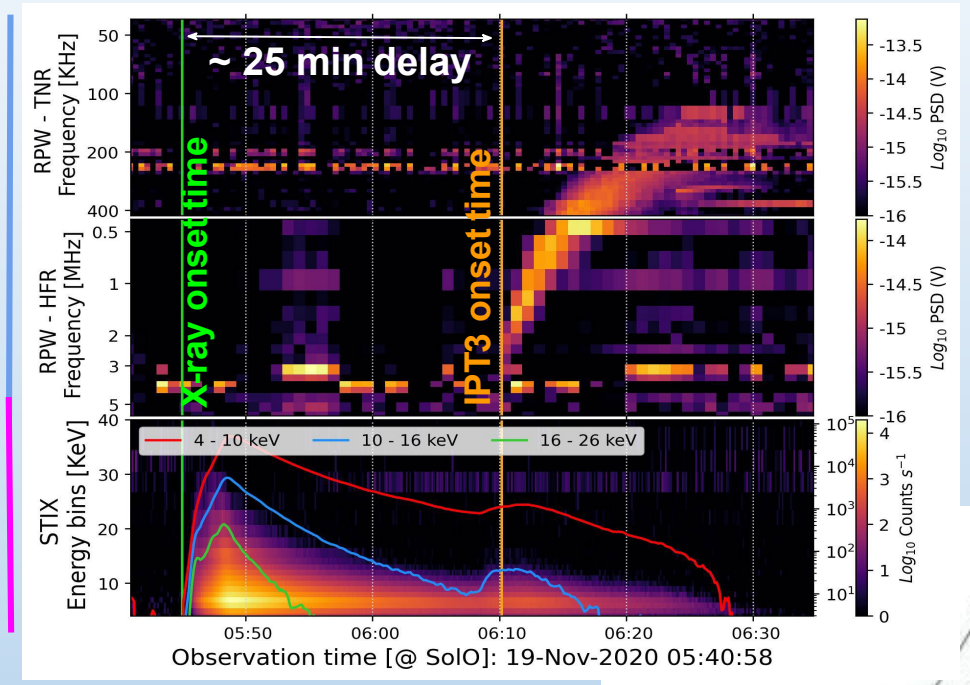


Co-temporal X-ray IP radio emissions

"simple" scenario



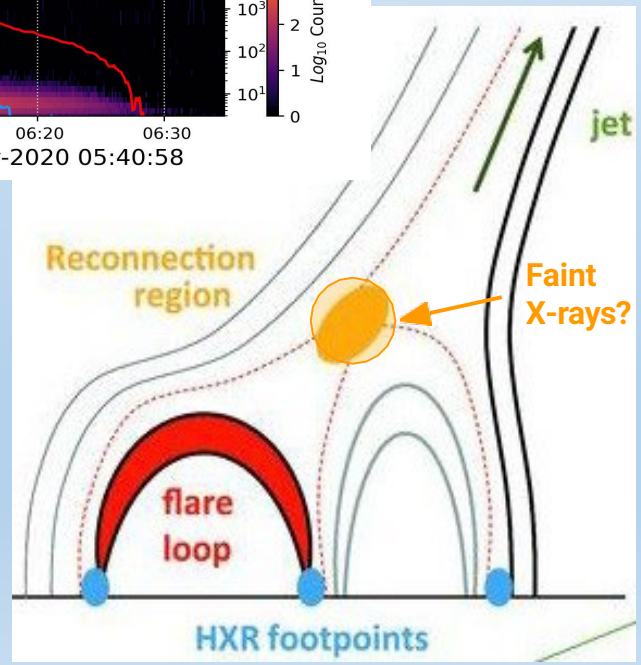
. . . BUT this is not always the case



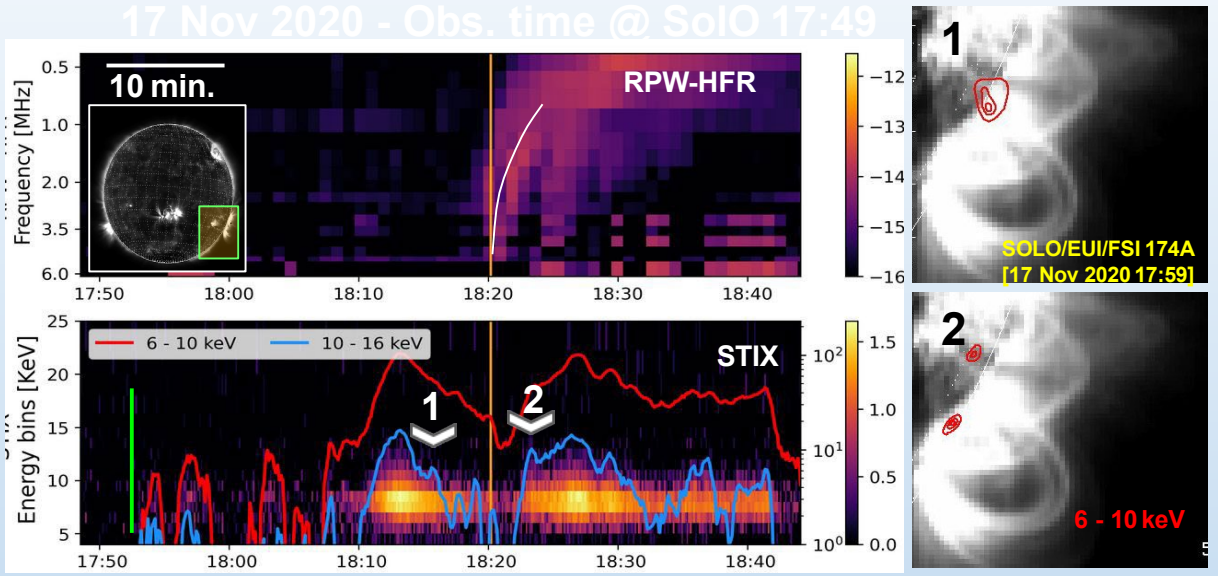
From Paipa et al., in preparation

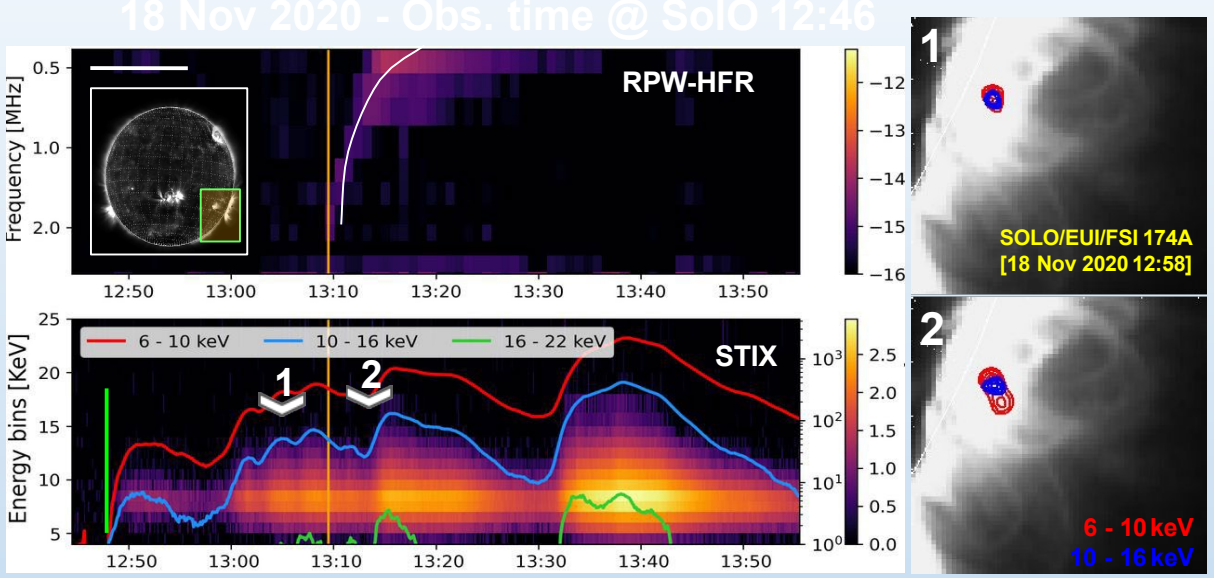
Delayed IP radio emissions w.r.t. X-ray onset

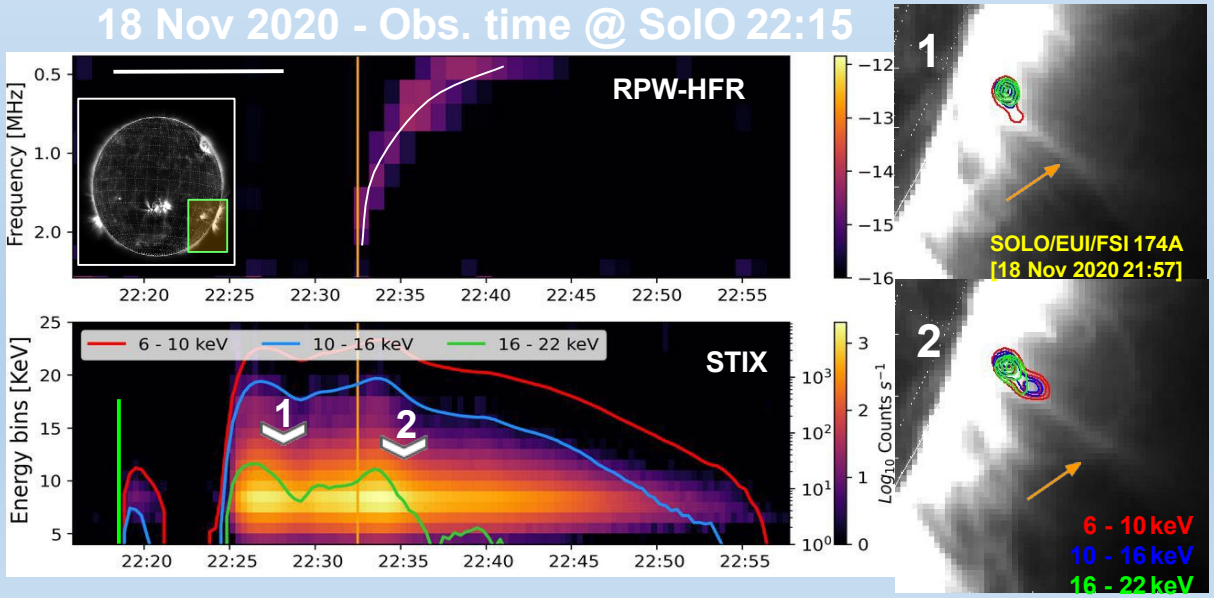
more complex scenarios **e.g. Interchange reconnection**

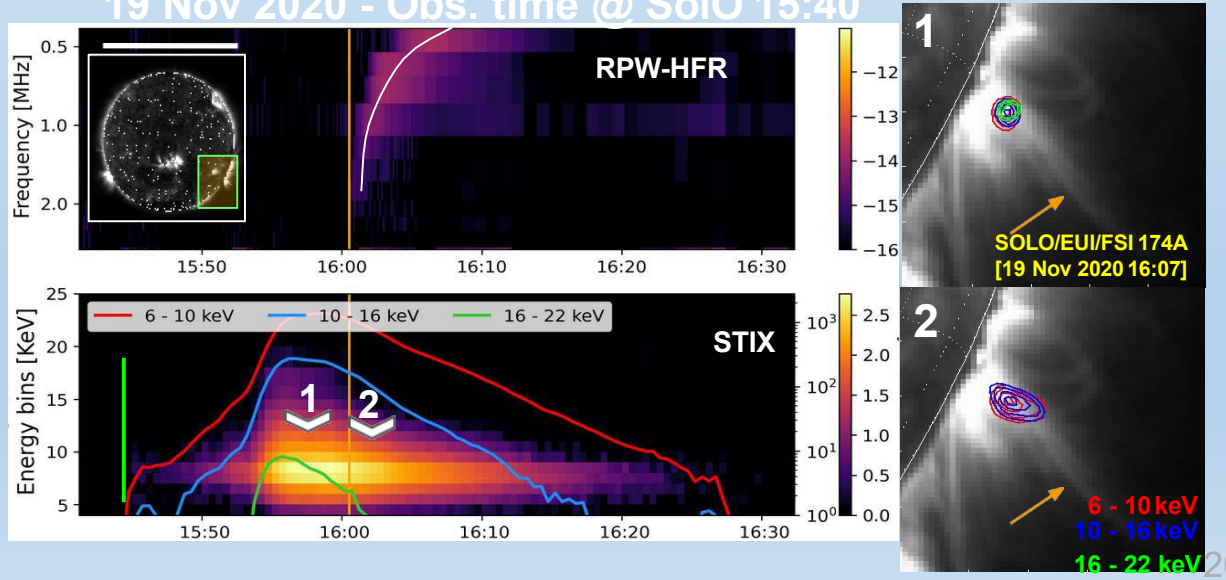


Preliminary results: Systematic study





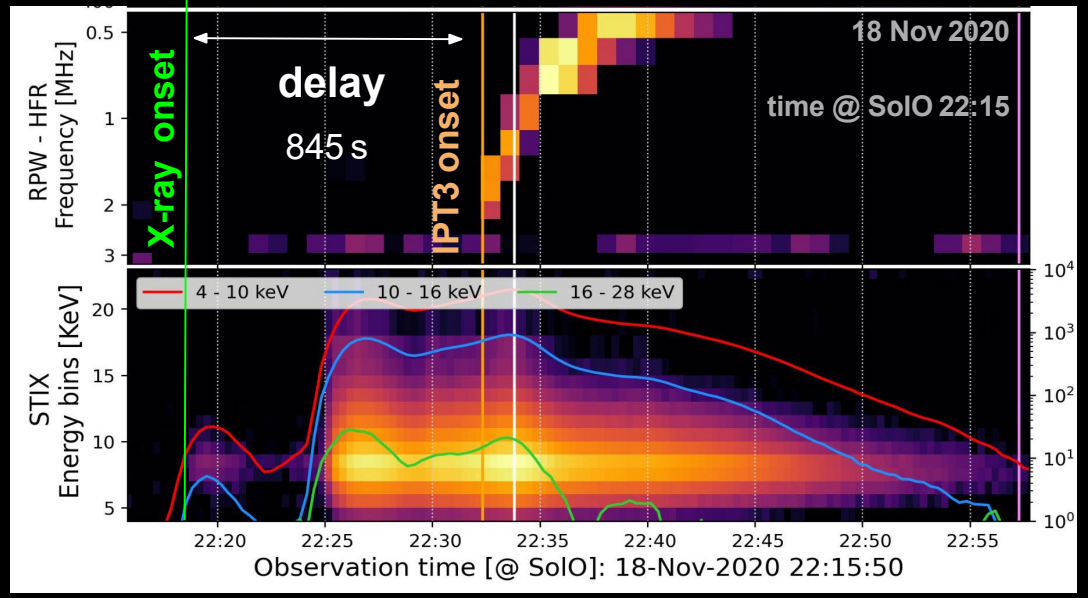




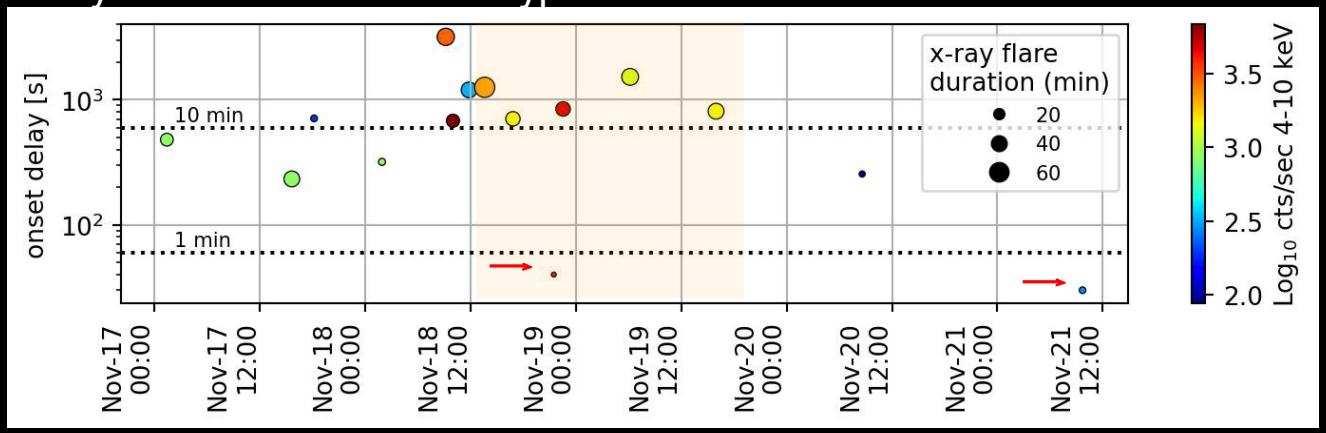
Paipa et al. In preparation

Preliminary results: Summary

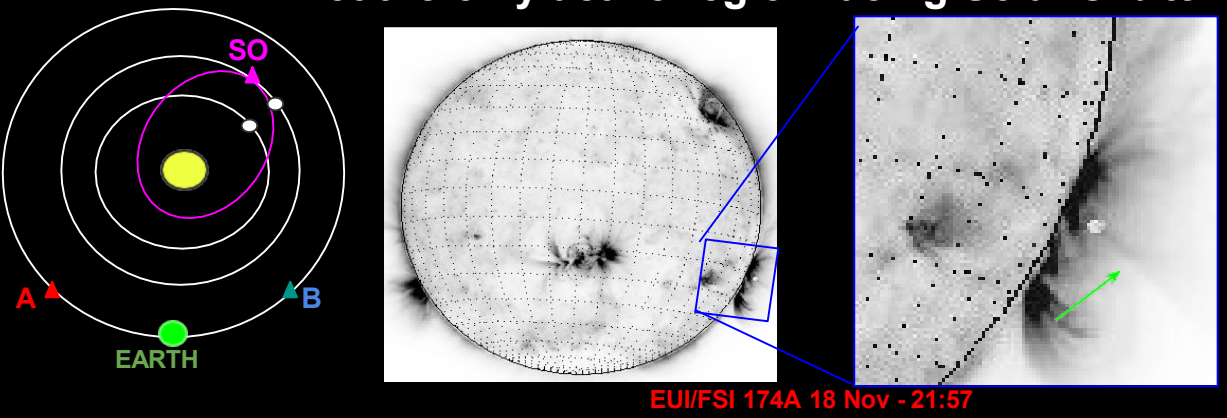
All of the 15 flares with IPT3s located close to the **same active region, all** present changes in X-ray source morphology close to IPT3 onset time



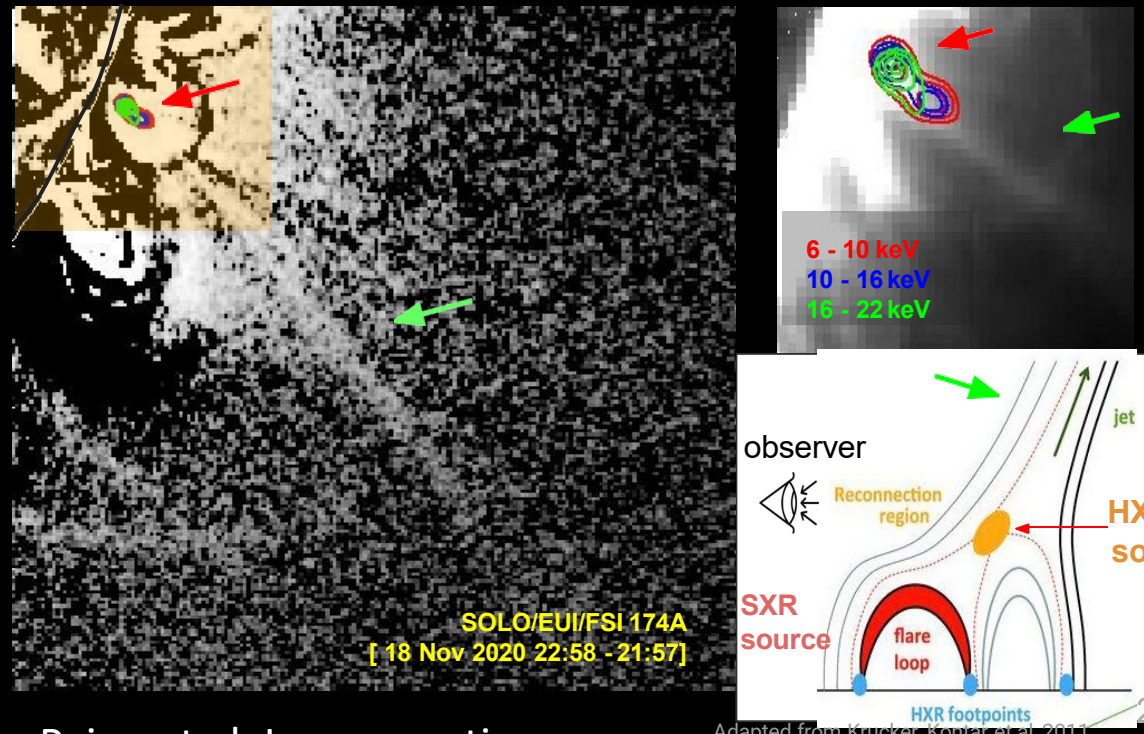
Except for two cases there is a delay >1 min between X-ray flare onset time and type III onset time



Not the only active region facing Solar Orbiter



"open-like" magnetic feature favoring the production of IPT3 in this active region?



Paipa et al. In preparation