



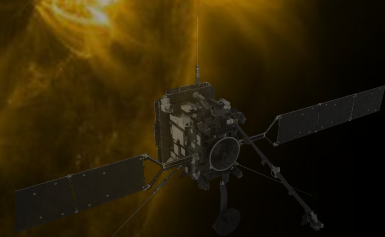
# Observing delayed emission of Type III bursts during the commissioning phase of Solar Orbiter

David Paipa

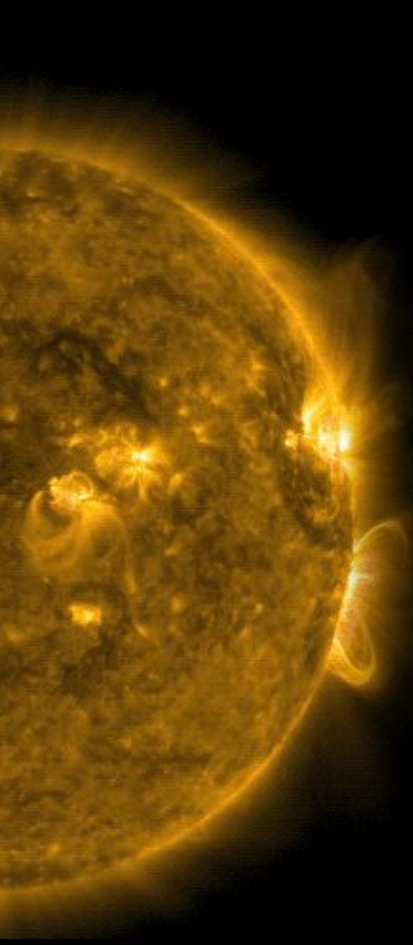
Advisors:

Dr. Milan Maksimovic

Dr. Nicole Vilmer



RPW consortium meeting 2023  
October 2, 2023



# Outline

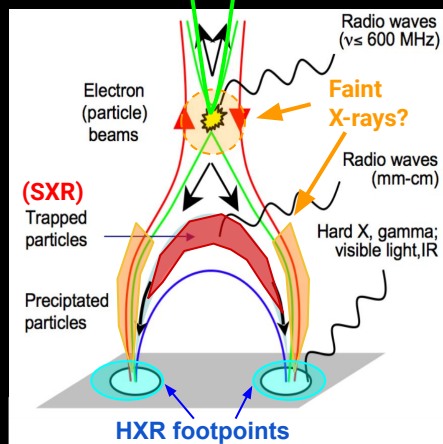
- Energetic particles in solar flares
- Context on Radio/X-ray observations
- Solar Orbiter
- Method of observation
- Recent Results
- The future

Solar flares Context Solar Orbiter Method Observations Future End

# Energetic particles in solar flares: Particle acceleration and transport

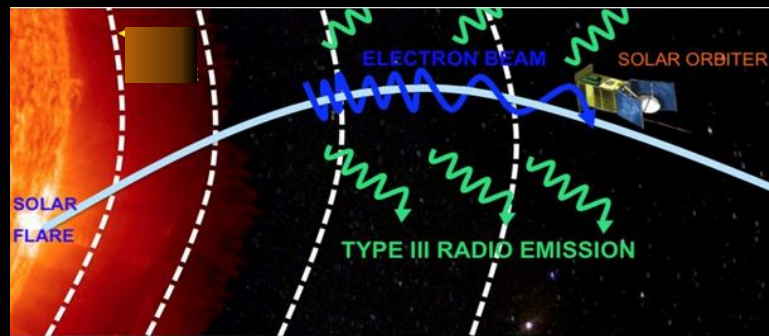
Release of the free magnetic energy contained in **complex** magnetic fields can occur through the process of magnetic reconnection

electrons escaping through open magnetic field lines

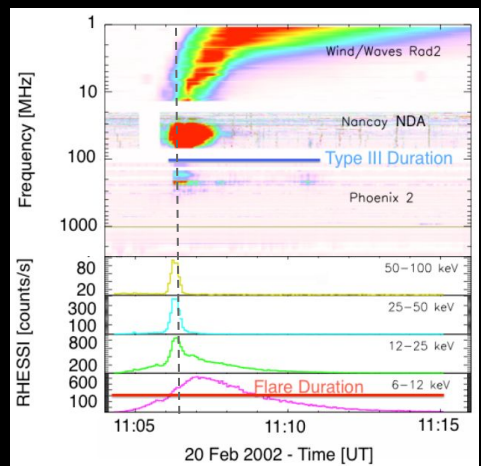


Adapted from Klein, 2006

electrons fall back into the chromosphere



Plasma emission mechanism  
Radio emissions in IP medium

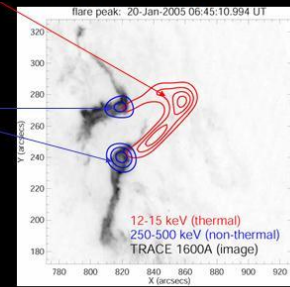
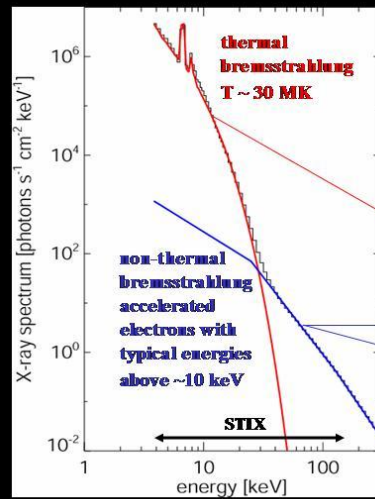


Adapted from Reid & vilmer, 2016

HXR emissions in the chromosphere

## HXR emission of a solar flare

RHESSI observations: Thermal and non-thermal components



Bremsstrahlung

Radio

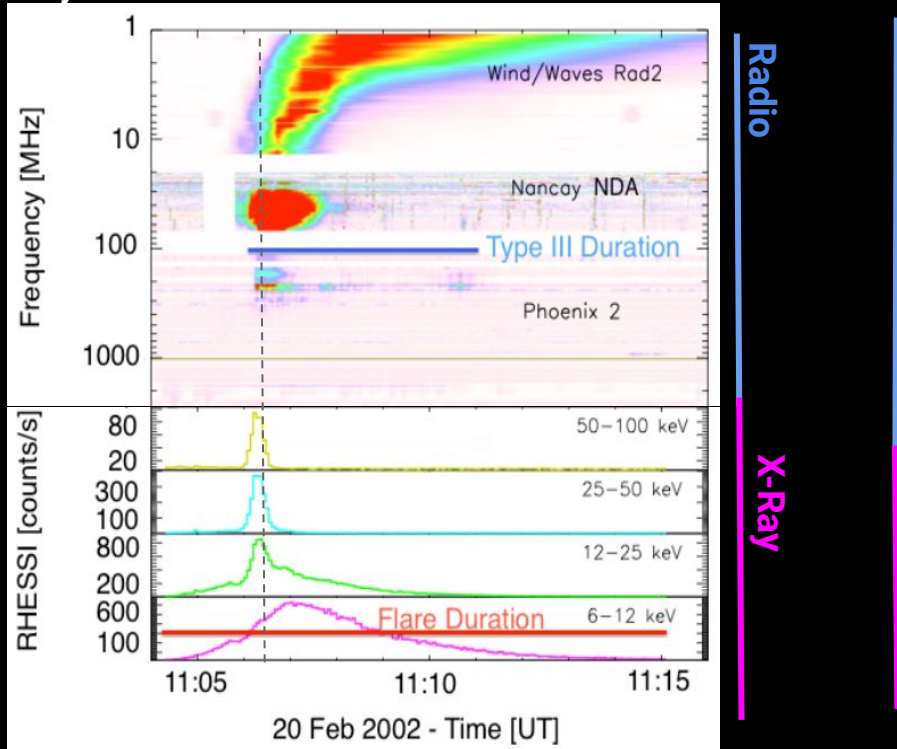
X-Ray



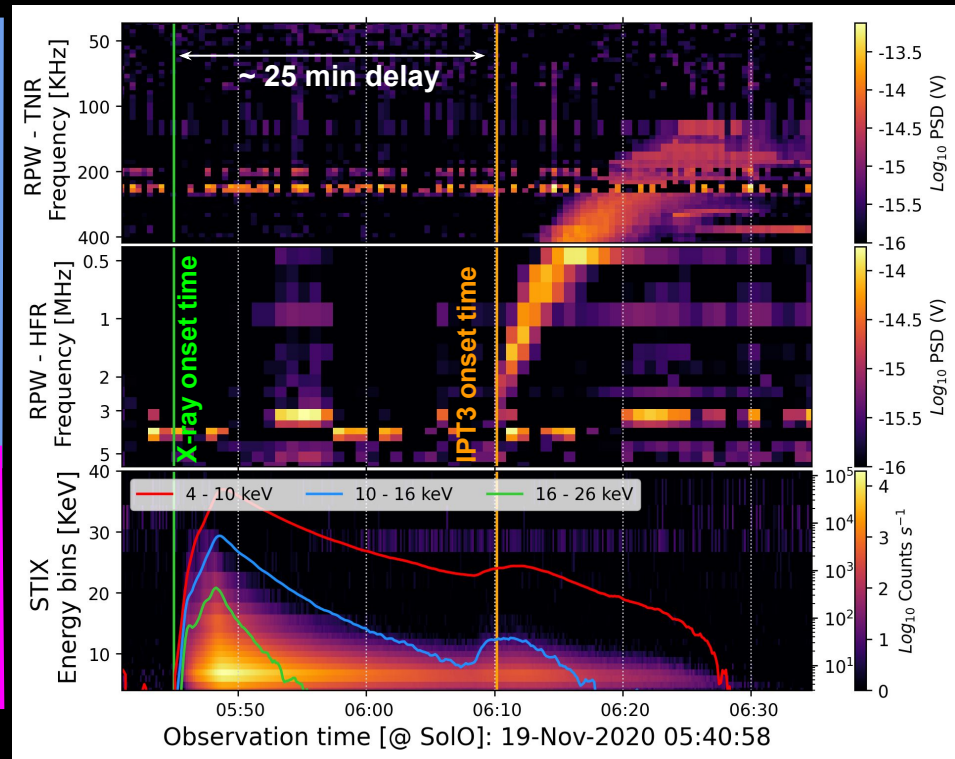
Solar flares      Context      Solar Orbiter      Method      Observations      Future      End

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

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



. . . BUT this is not always the case

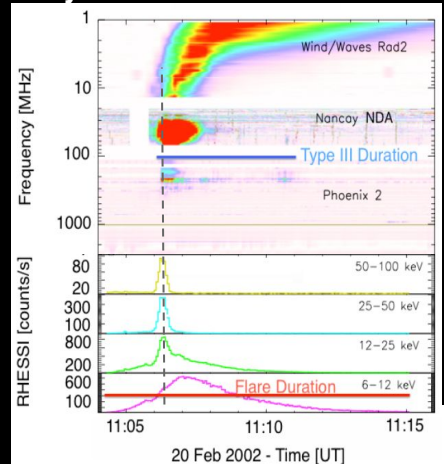


Solar flares      Context      Solar Orbiter      Method      Observations      Future      End

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

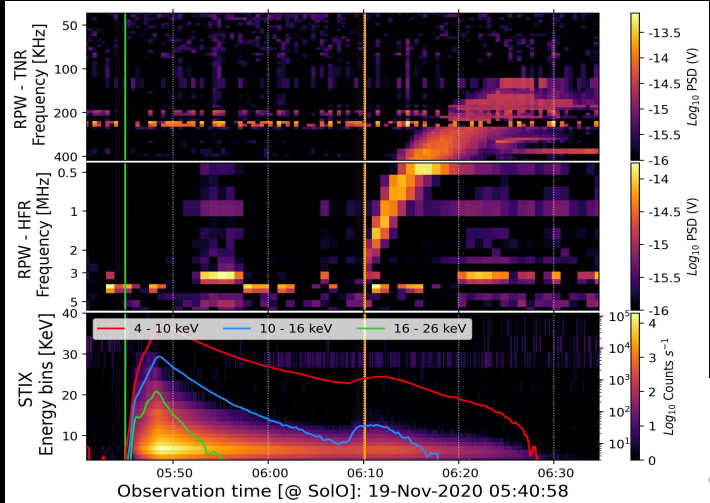
The onset time of X-ray and Radio emissions can be very similar . . .

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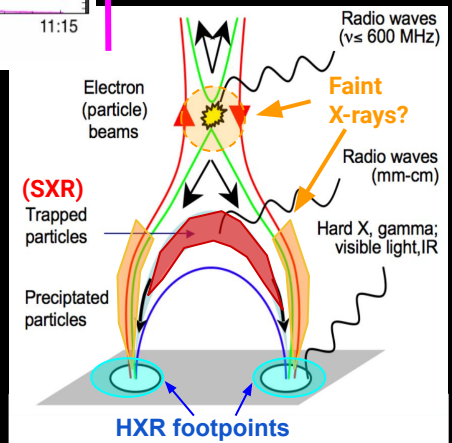
Radio

X-Ray



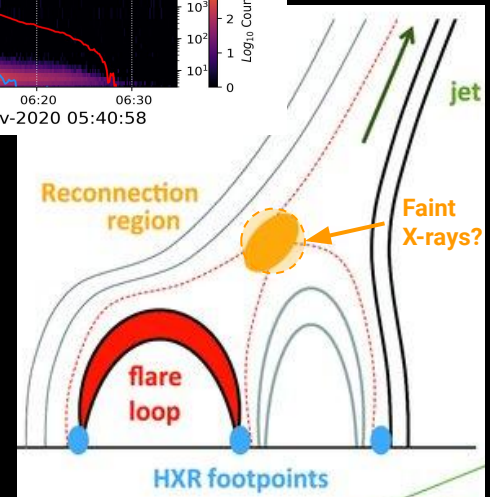
Co-temporal X-ray/IP radio emissions

simple scenario



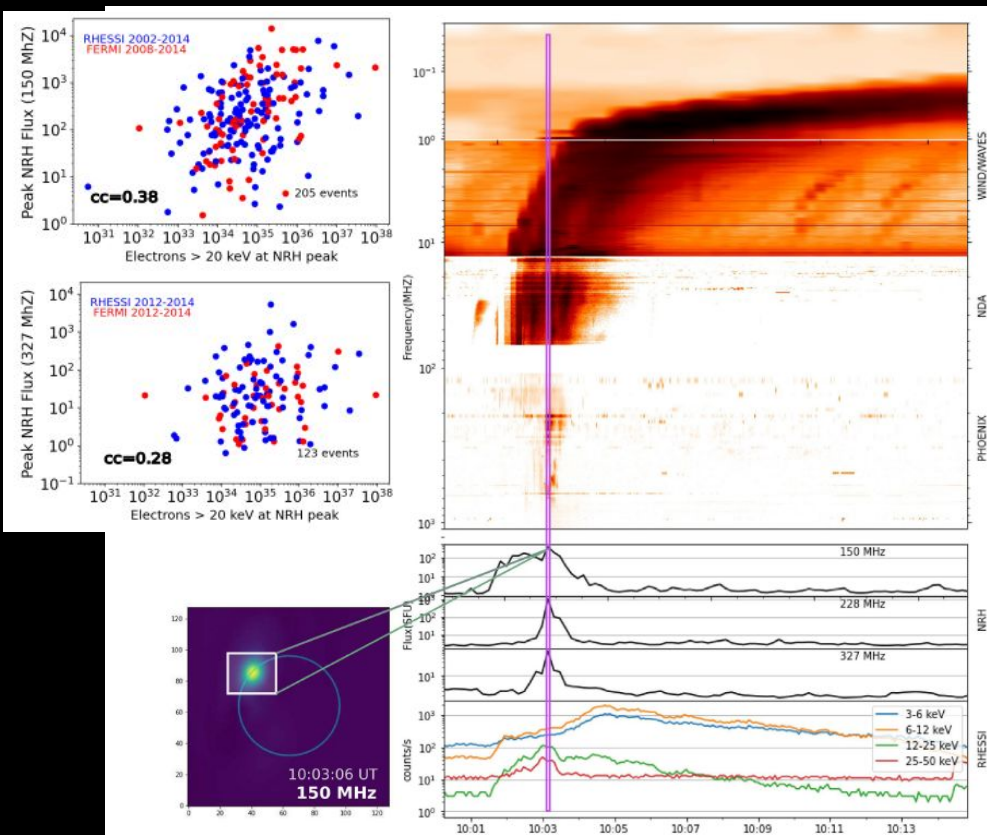
Delayed IP radio emissions w.r.t. X-ray onset

more complex scenarios e.g. Interchange reconnection.



# Context on Radio/X-ray observations: Previous studies

Previous statistical studies characterizing the correlation between HXR and radio emission intensities



← James, vilmer 2023

Correlation between non-thermal electron number with  $E > 20$  keV at HXR peak vs. peak NRH flux at different frequencies

~200 events analyzed in  
13 year interval



Radio

Combining observations from different observatories **limits the number of events**

Fortunately . . .

Solar Orbiter observes in X-ray and Radio from the same platform

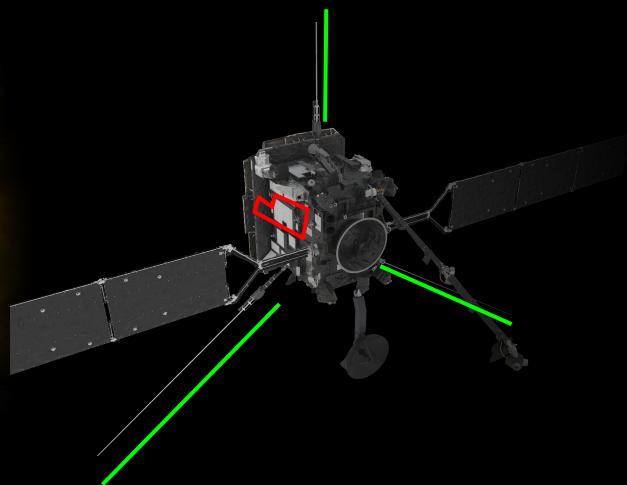
X-Ray

# The Solar Orbiter

Launched in February 2020  
Getting as close as  $\sim 0.28$  AU

**10 instruments** onboard

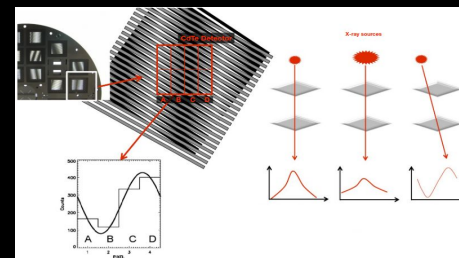
- 4 in-situ
- 6 remote sensing



## Spectrometer/telescope for imaging X-rays

STIX

- **Energy range:** 4 to 150 keV
- X-ray remote sensing
  - **bi-grid imaging (Indirect)**
  - spectroscopy



RPW

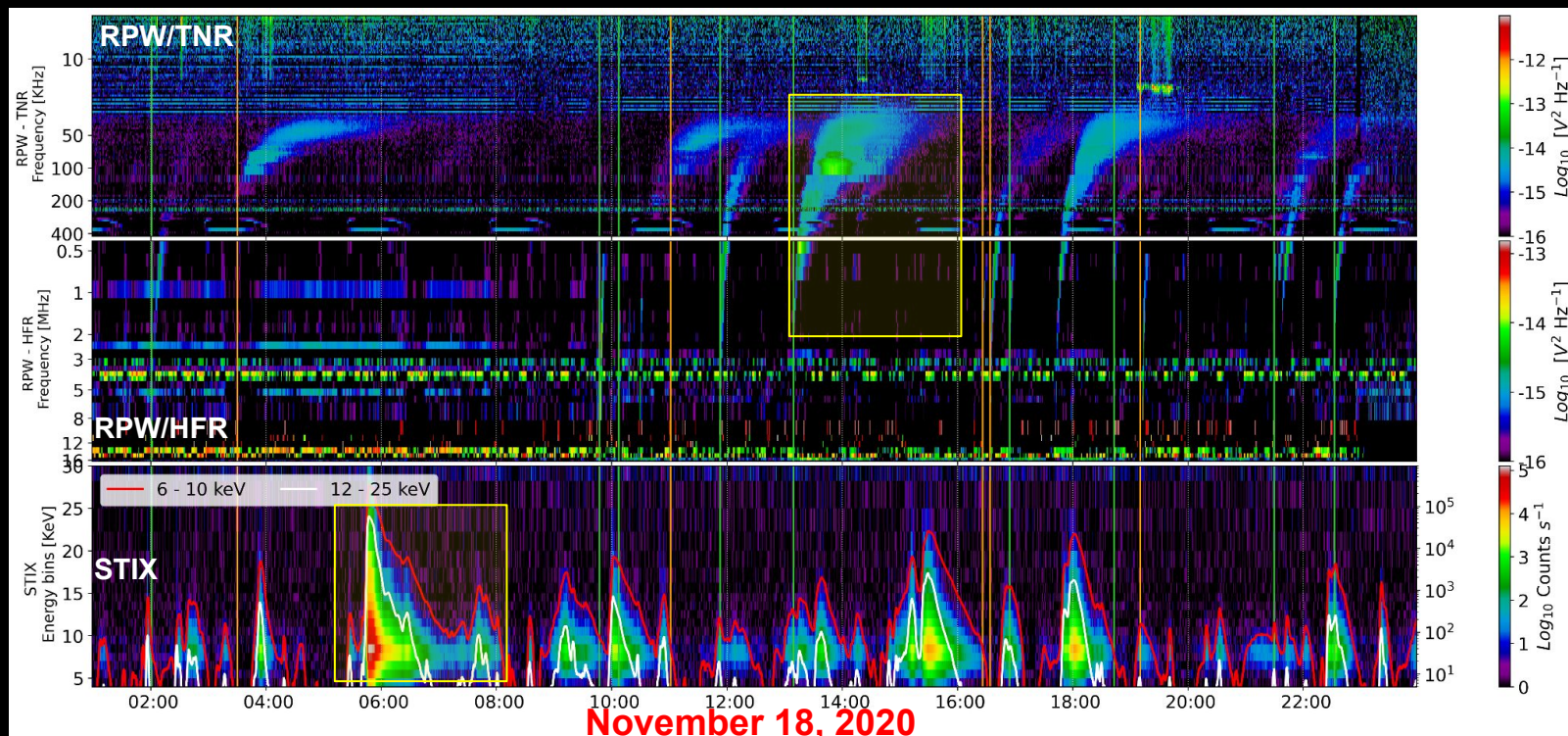
## Radio and Plasma Waves Instrument

- 3 antennas , Radio waves measurements
- **Frequency range:**  $\sim$ DC to 16.4MHz

How do solar eruption produce energetic particle radiation that fills the heliosphere?



# First available interval for STIX/RPW combined observations between 17 and 21 November 2020



What conditions determine the presence of IPT3s in solar flares?



Solar flares   Context   Solar Orbiter   Method   Observations   Future   End

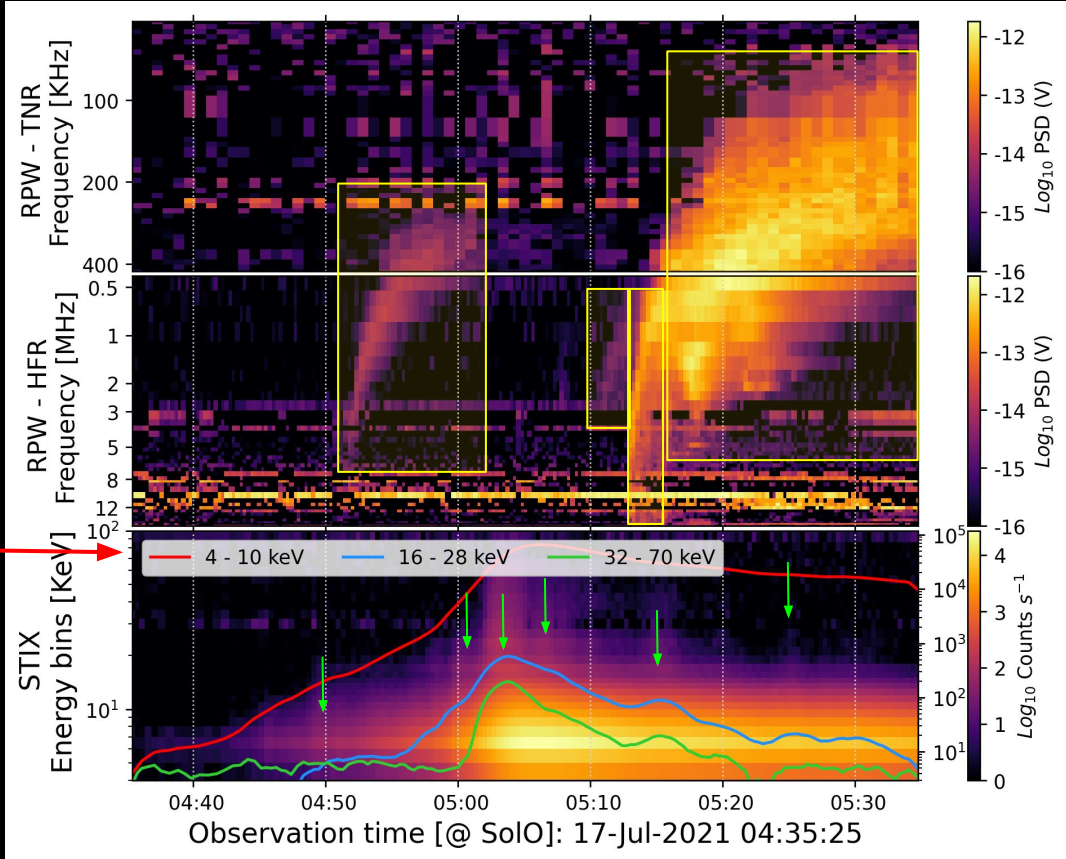
# Method for X-ray and Radio Diagnostics: Nice example of delay in Type III bursts

## Flare on July 17, 2021 UT 05:05

Presence of (IP) **Type III bursts**

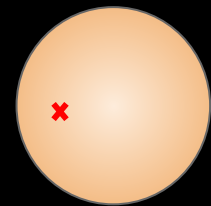
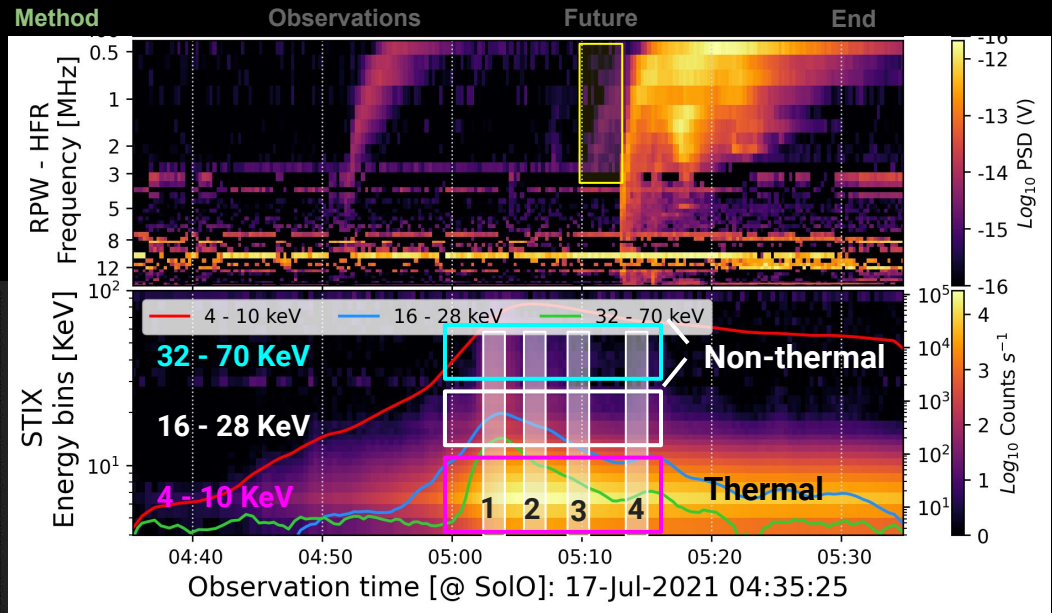
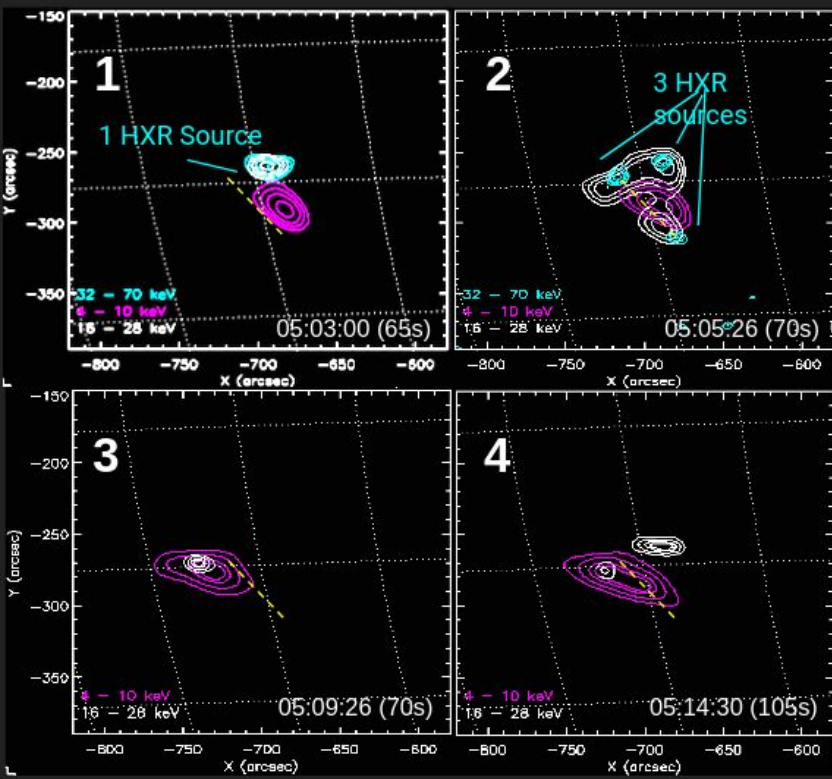
Flare counts in energies up to 84 KeV

several impulsive **HXR emission peaks**, some of them temporally associated with **IPT3s**



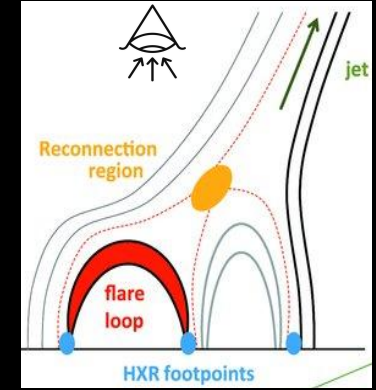
# X-ray Diagnostics: Timing and Imaging

## Imaging of 4 time intervals close to the IPT3 onset time (Before and during)



Flare position on solar disk

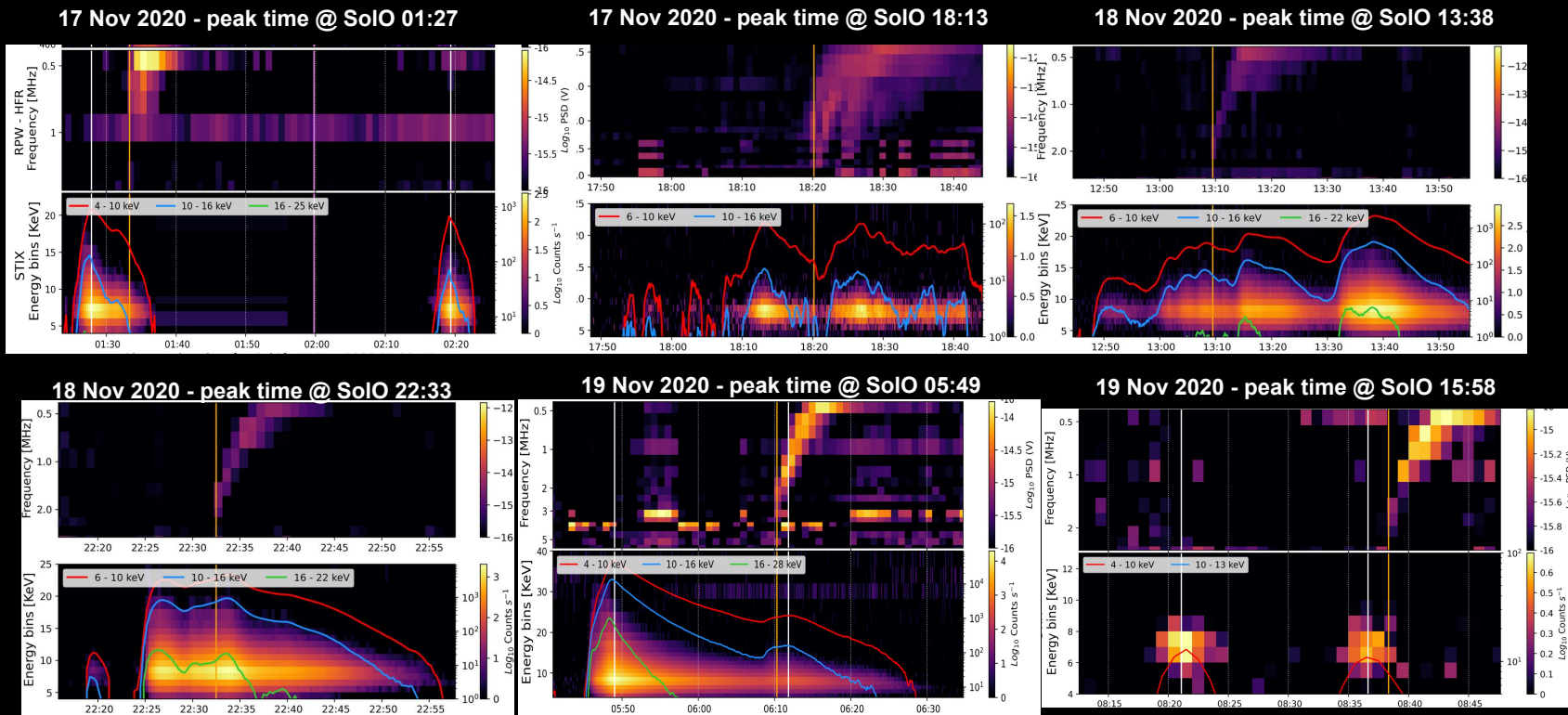
Adapted from Krucker, Kontar et al. 2011



Solar flares      Context      Solar Orbiter      Method      Observations      Future      End

# Preliminary results: Observation of the November 2020 period

Events from first available interval for STIX/RPW combined observations between 17 and 21 November 2020



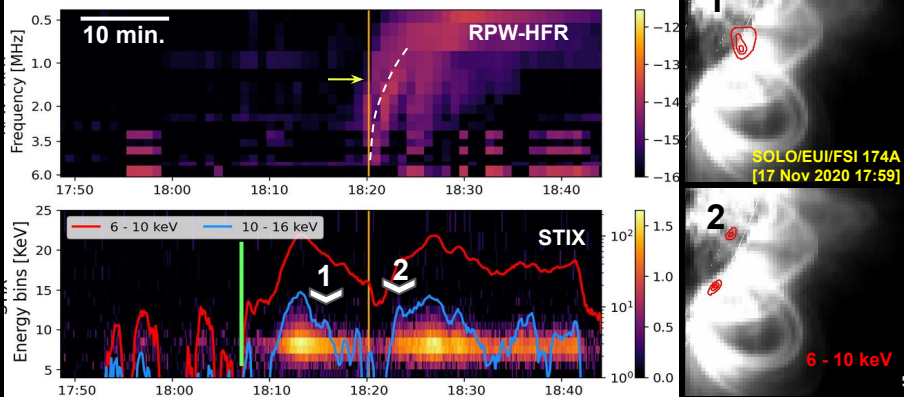
RPW/STIX data availability to study **16 flares** with IPT3 associated  
**UV images (EUI/FSI 174A)** available for some of them



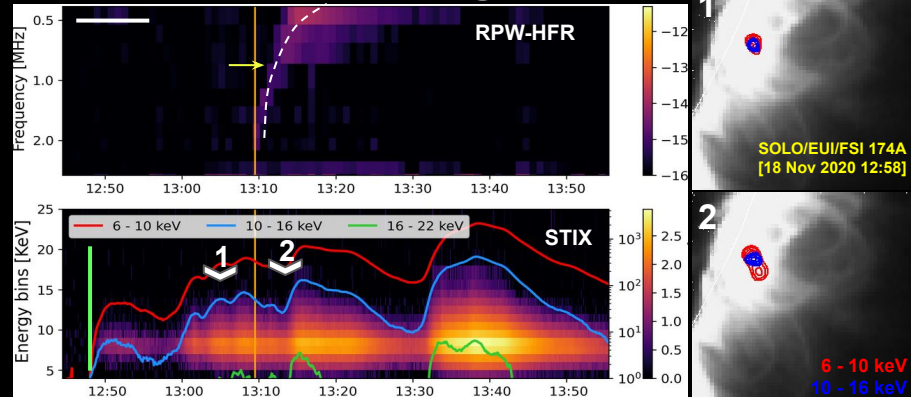
Solar flares      Context      Solar Orbiter      Method      Observations      Future      End

# Preliminary results: Systematic study

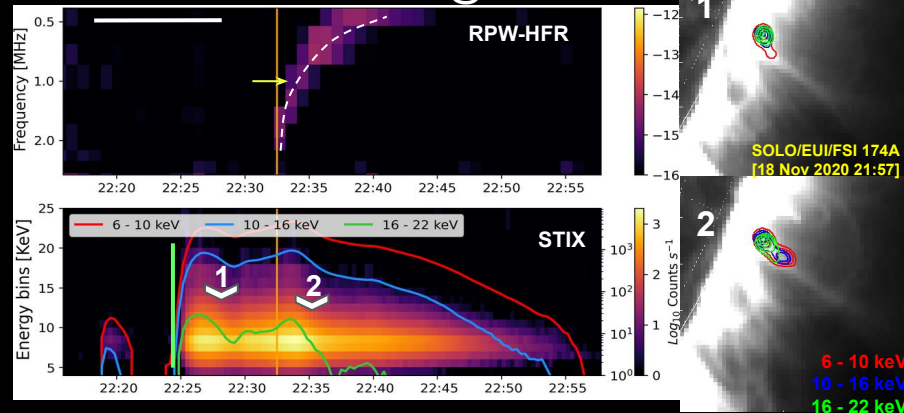
17 Nov 2020 - Obs. time @ SoLO 17:49



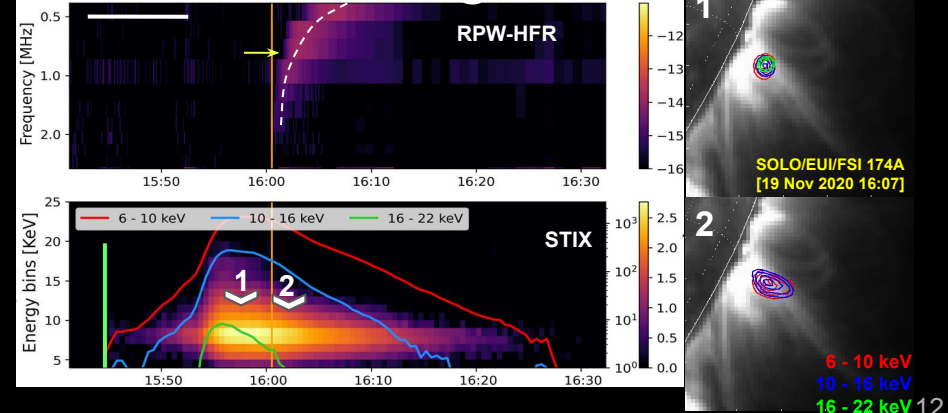
18 Nov 2020 - Obs. time @ SoLO 12:46



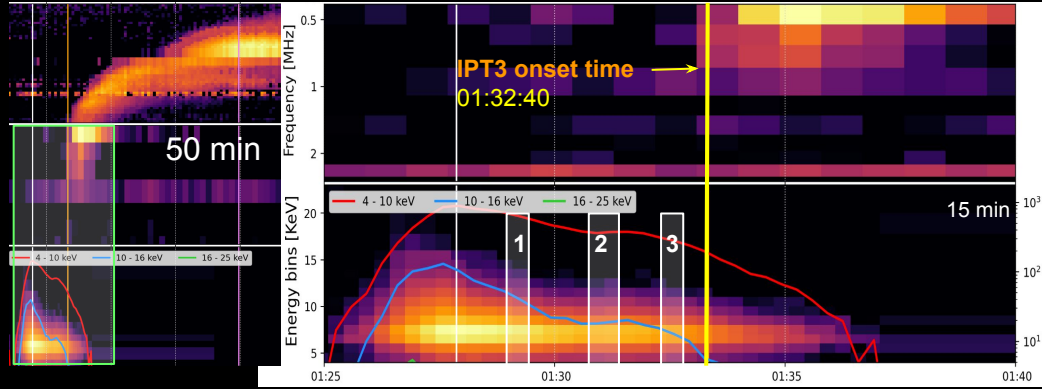
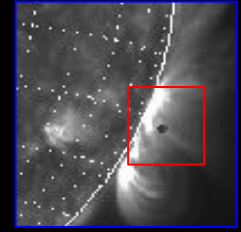
18 Nov 2020 - Obs. time @ SoLO 22:15



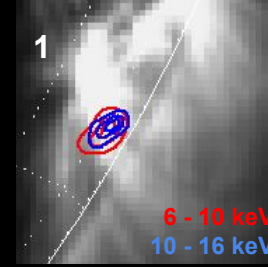
19 Nov 2020 - Obs. time @ SoLO 15:40



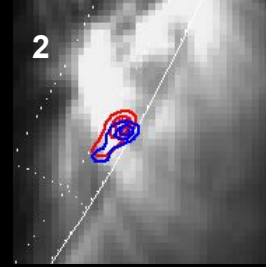
## 3 cases: appearance of new X-ray sources before/during IPT3 onset time



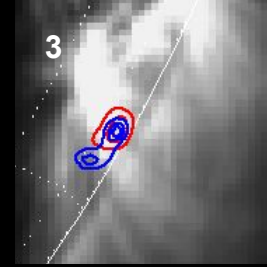
EM 01:27 (35s)



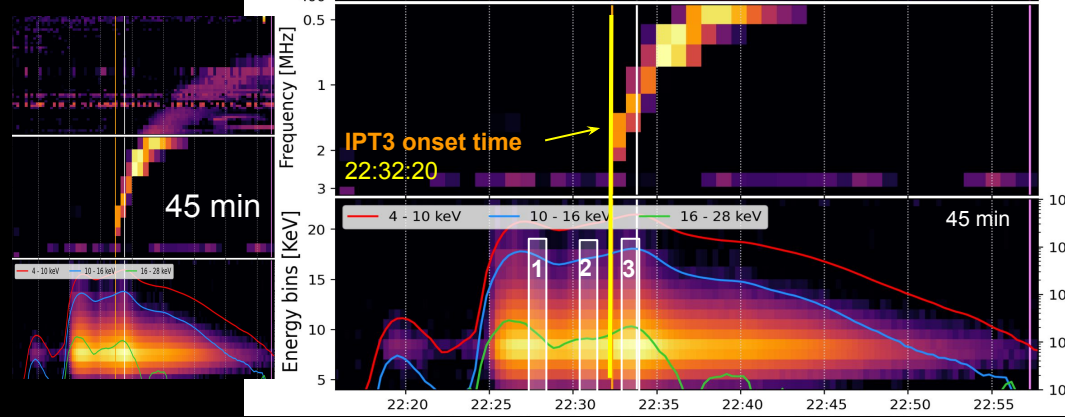
EM 01:31 (35s)



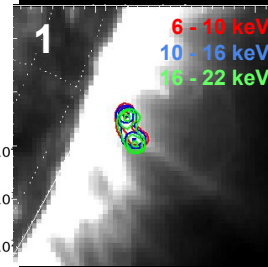
EM 01:33 (35s)



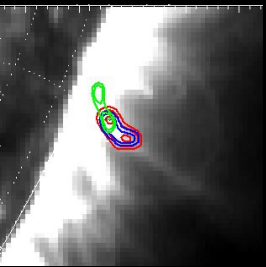
## 13 cases: change in the X-ray source shape before/during IPT3 onset time



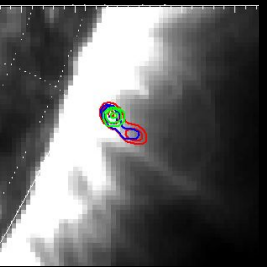
EM 22:27 (25s)



EM 22:31 (25s)



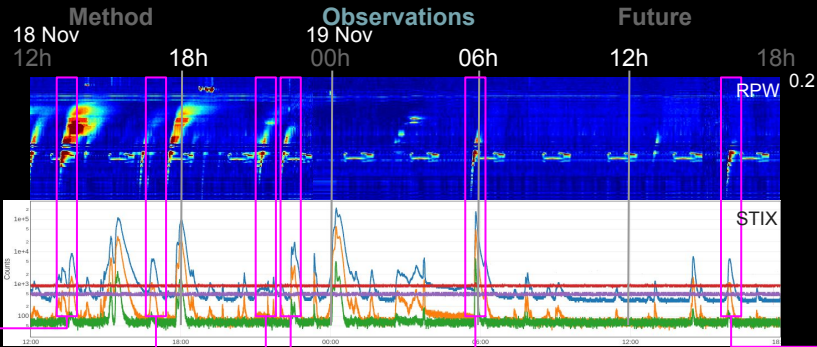
EM 22:33 (25s)



EUI/FSI 174A 22:58

Solar flares Context Solar Orbiter  
**Preliminary results: Observations**

**8 cases:** X-ray sources change morphology close to the same “open-like” plasma structure before/during the **IPT3 onset time**

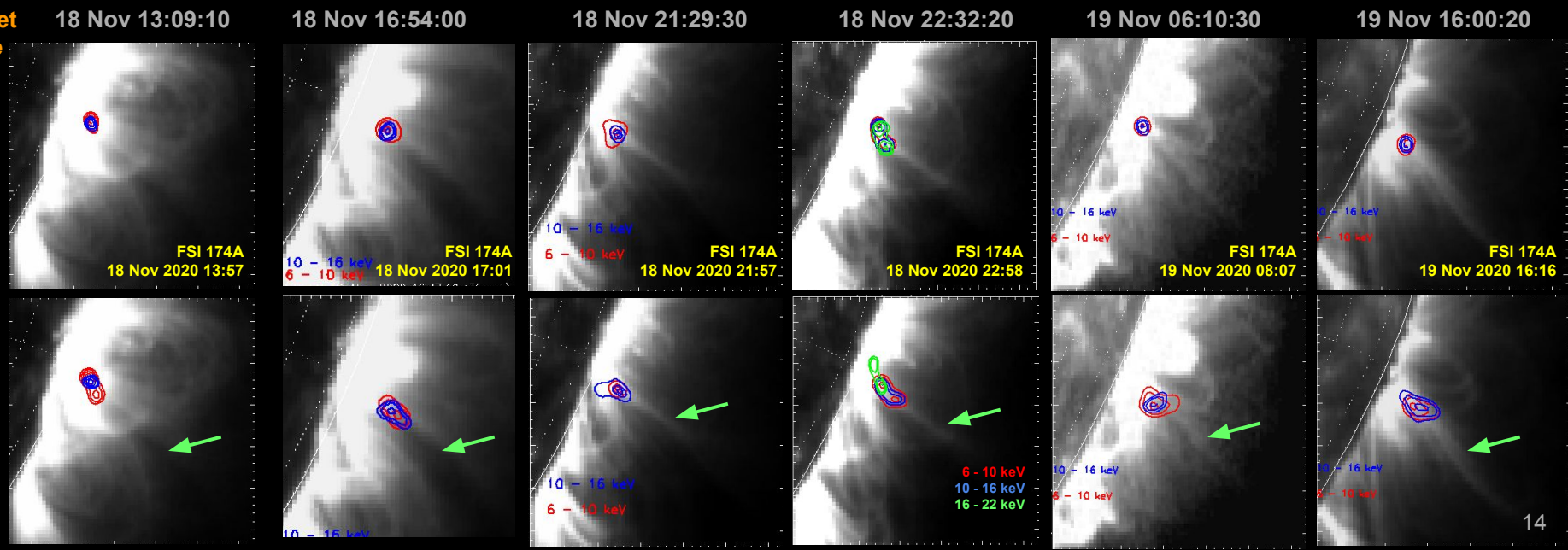


All the observed IPT3s within a 30h time lapse

**IPT3 onset time**

**Before IPT3 onset**

**During IPT3 onset**



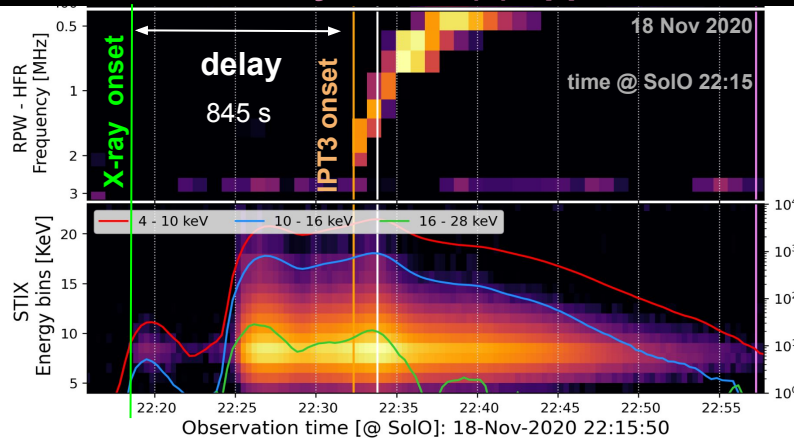


# Preliminary results: Summary

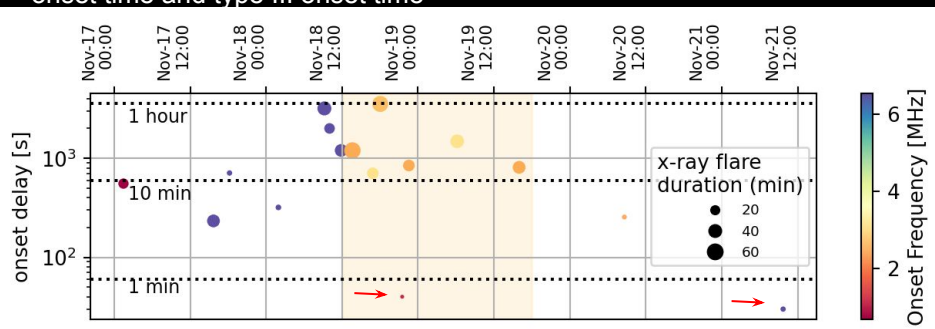
All of the 16 studied flares present **changes in X-ray source morphology** close to IPT3 onset time

**13 cases** changes in X-ray source shape

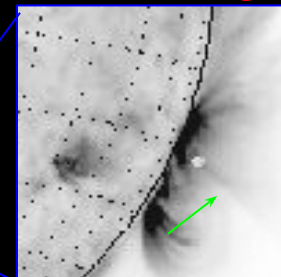
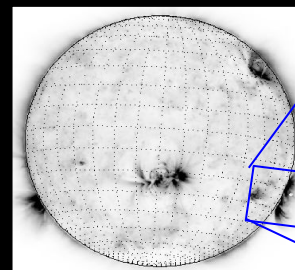
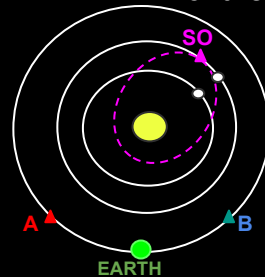
**3 cases** new X-ray source(s) appear



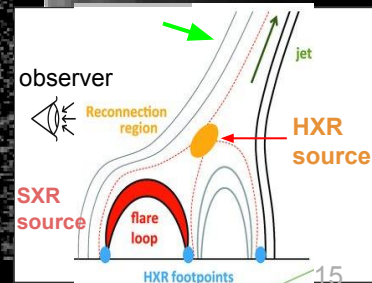
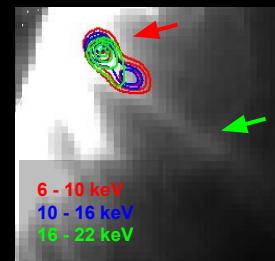
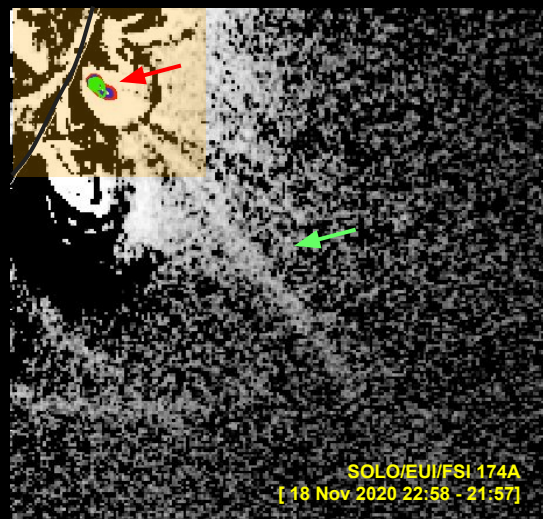
Except for two cases there is a delay  $>1$  min between X-ray flare onset time and type III onset time



All of the 16 flares with IPT3s in the **same active region**

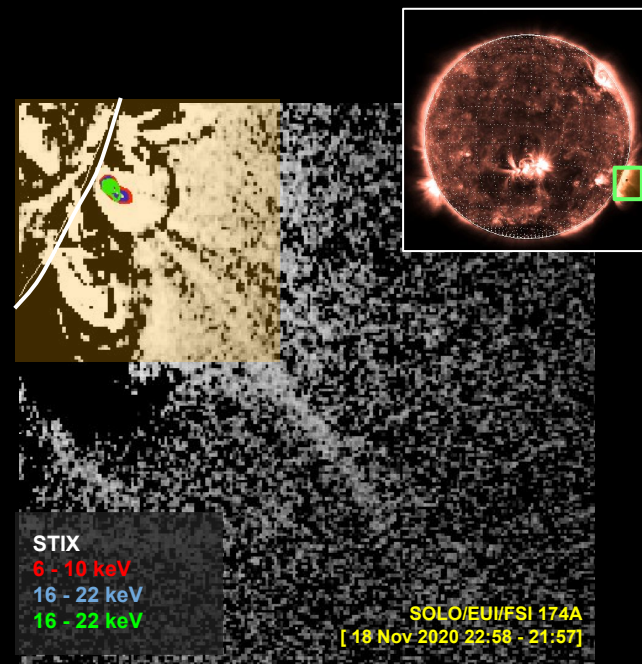


“open-like” magnetic feature favoring the production of IPT3 in this active region?



## A work in progress: Paper on November 2020 events

- **Continue the observation of X-ray flares in the November 2020 period**
  - same active region? what is different?
  - New data products
- **Integrate the frequency drift analysis and spectroscopy to the study of these flares**
  - what can we say about the energy content of the accelerated electrons? any relation with appearance of IPT3?
- **Use data of other instruments when possible**
  - EUI FSI 174/304 A
  - in-situ particle detections with EPD
  - Ground-based Radio
- **Robust statistical analysis with a larger population of events**



## Main ideas to take home

Analysis of **16 flares** with IPT3 associated during the first period with availability for STIX/RPW combined observations

**Delays in Type III onset** w.r.t. X-ray flare onset + **change in the x-ray source morphology** close to the IPT3 onset time suggests complex reconnection scenarios

All of them were located **close to the same active region**, transiting through and behind the limb in the observation period

**UV images** suggest that for some events the HXR source site had connection with **open magnetic field lines**.



# Thanks :) )

Questions? comments?  
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