First radio evidence of impulsive heating in the quiet solar corona

Surajit Mondal[1], Divya Oberoi[1], Atul Mohan[2]

[1]: National Centre for Radio Astrophysics

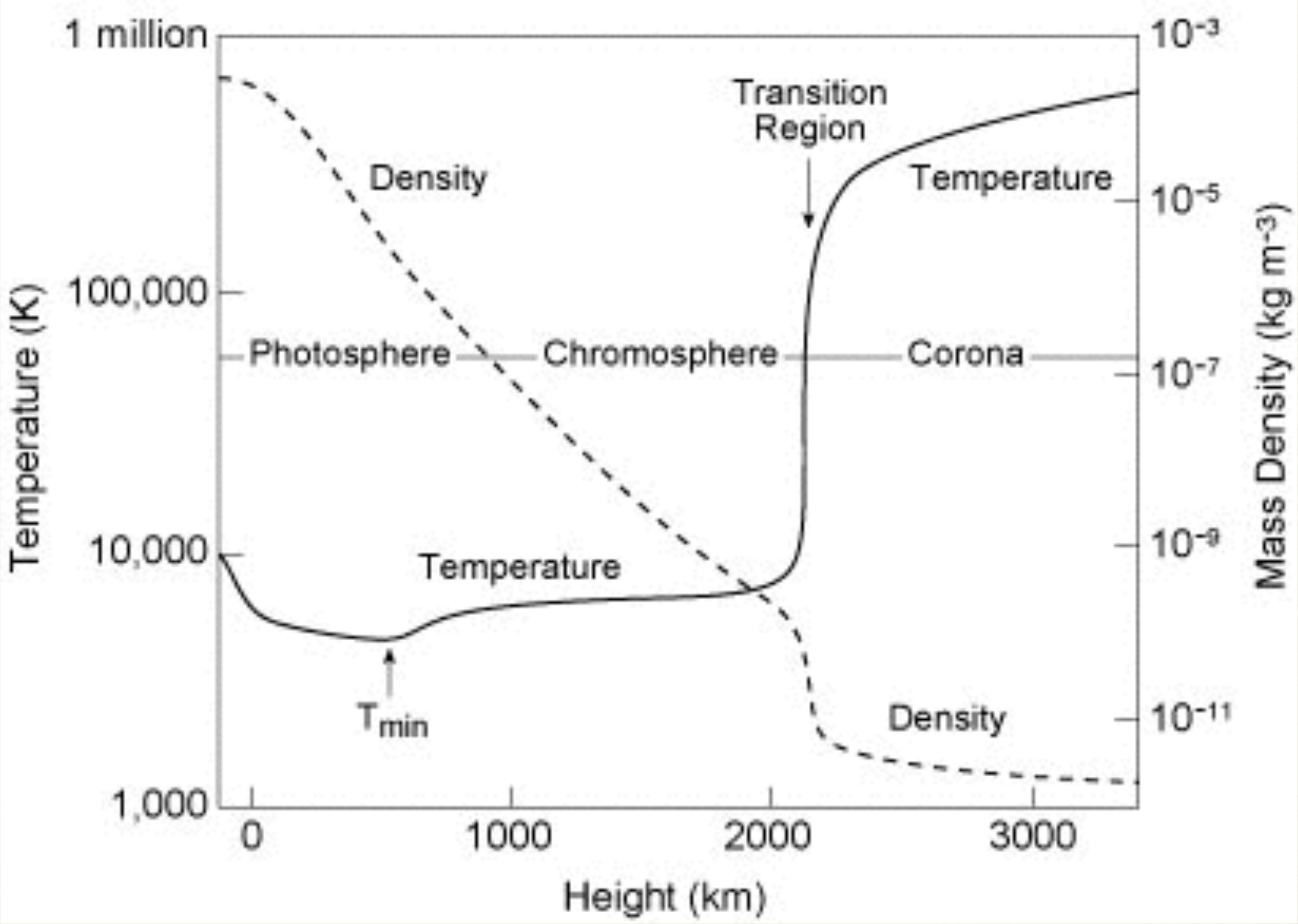
[2]: Rosseland Centre for Solar Physics

NCRA • TIFR

Mondal et al. 2020 b, "First radio evidence of impulsive heating in quiet solar corona", ApJ, 895L, 39M

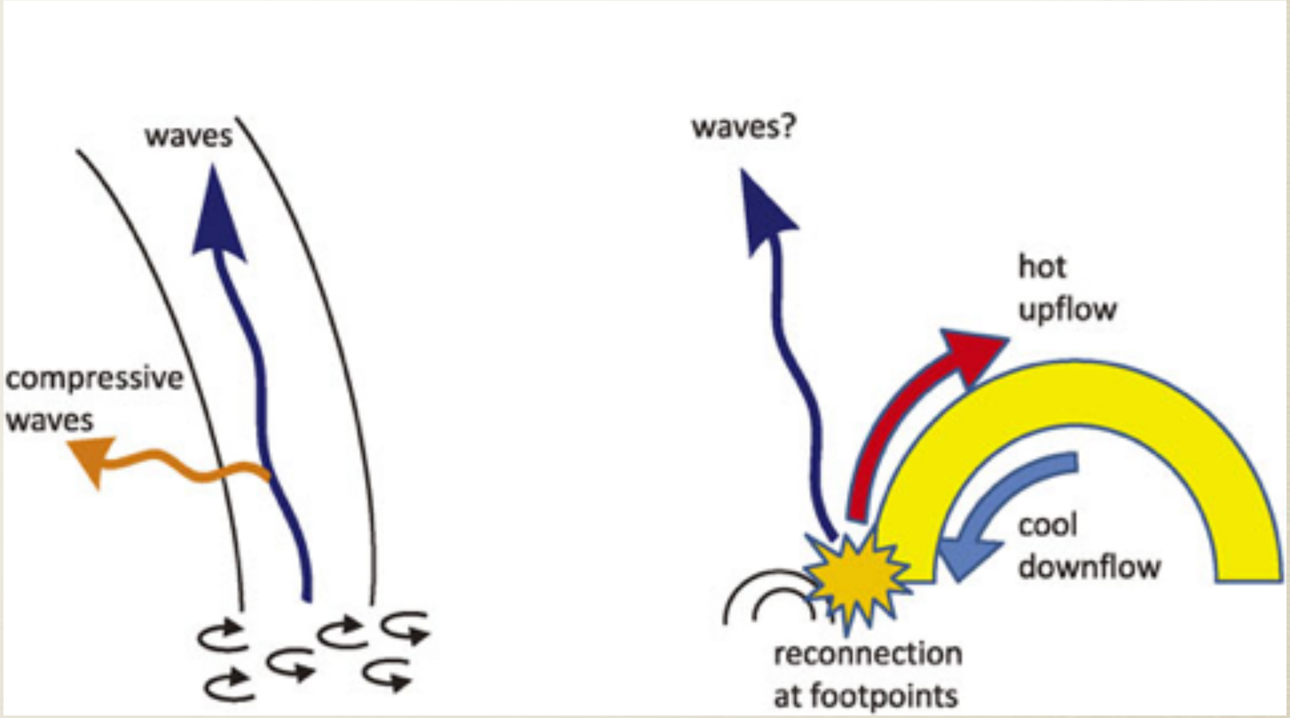
Coronal Heating problem

Random footpoint motion creates magnetic stresses which gets relieved in different ways. Depending on the exact mechanism, we have different theories.



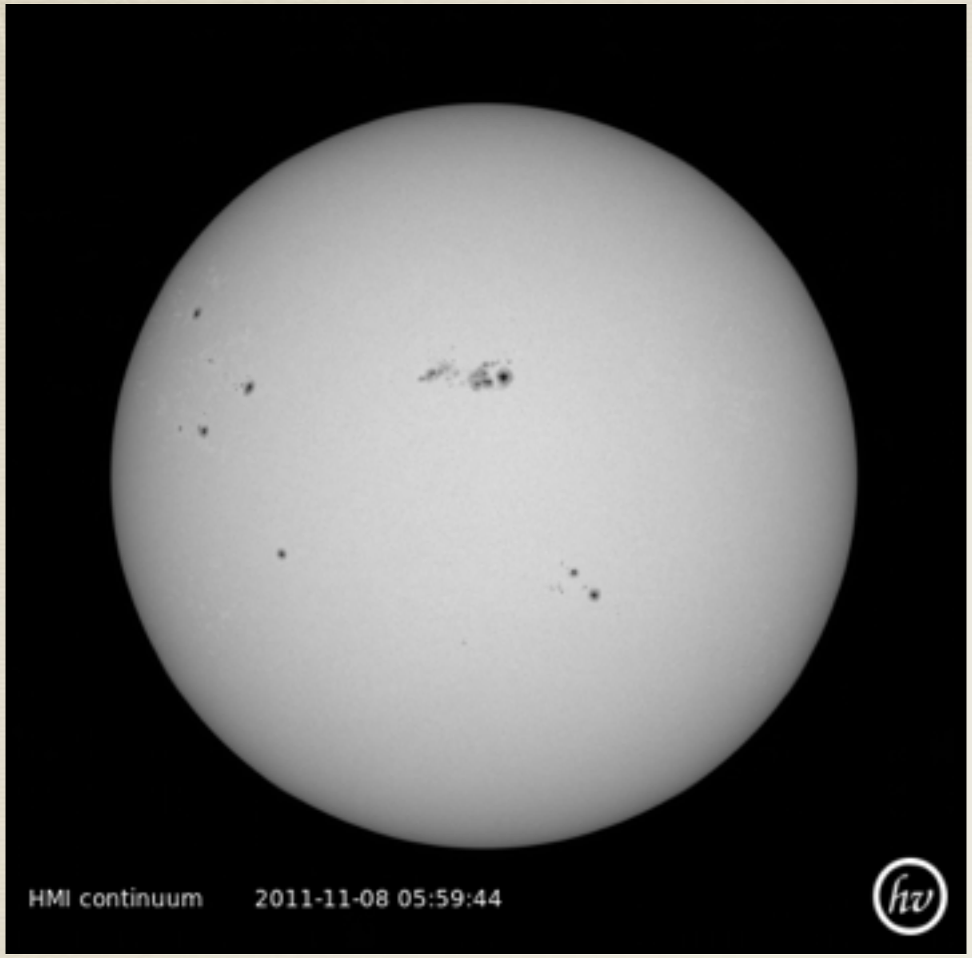
Theories of coronal heating

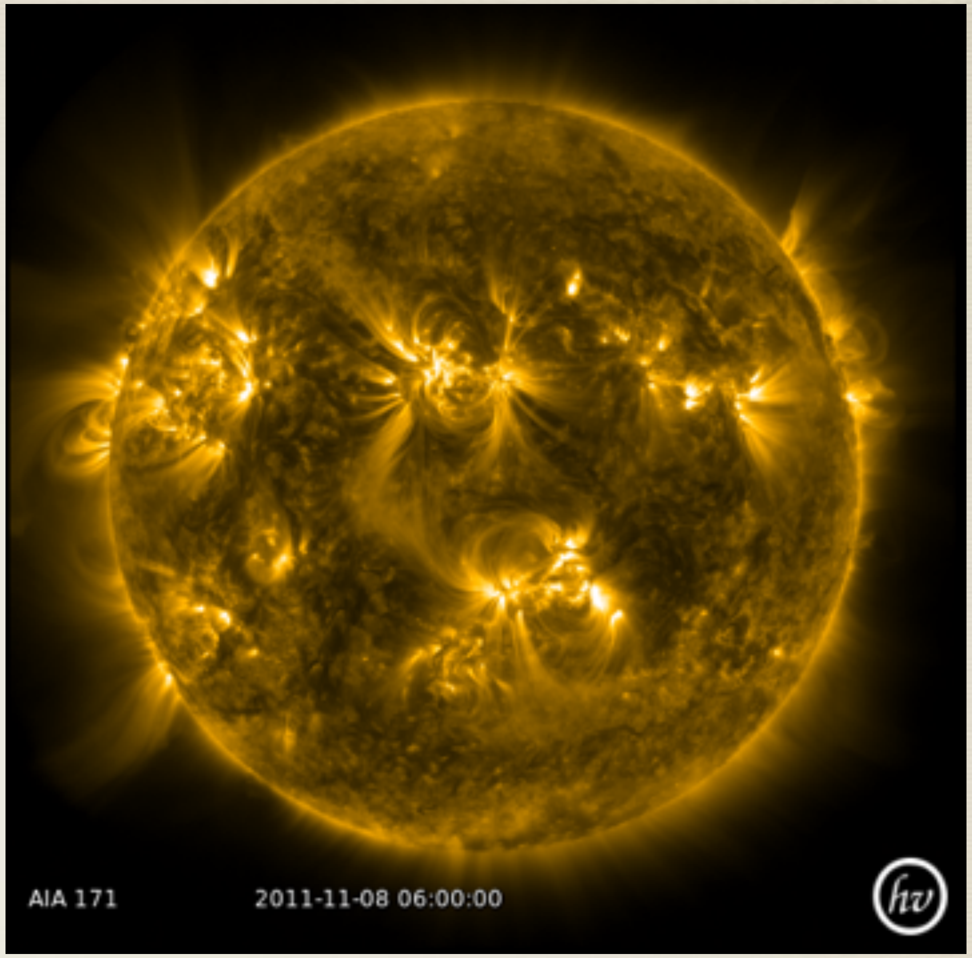
- In general, two types of theories:
    - By Alfven waves
    - By nanoflares
- Both are impulsive in nature and its exact details depend on the local plasma conditions.



Sakurai 2017

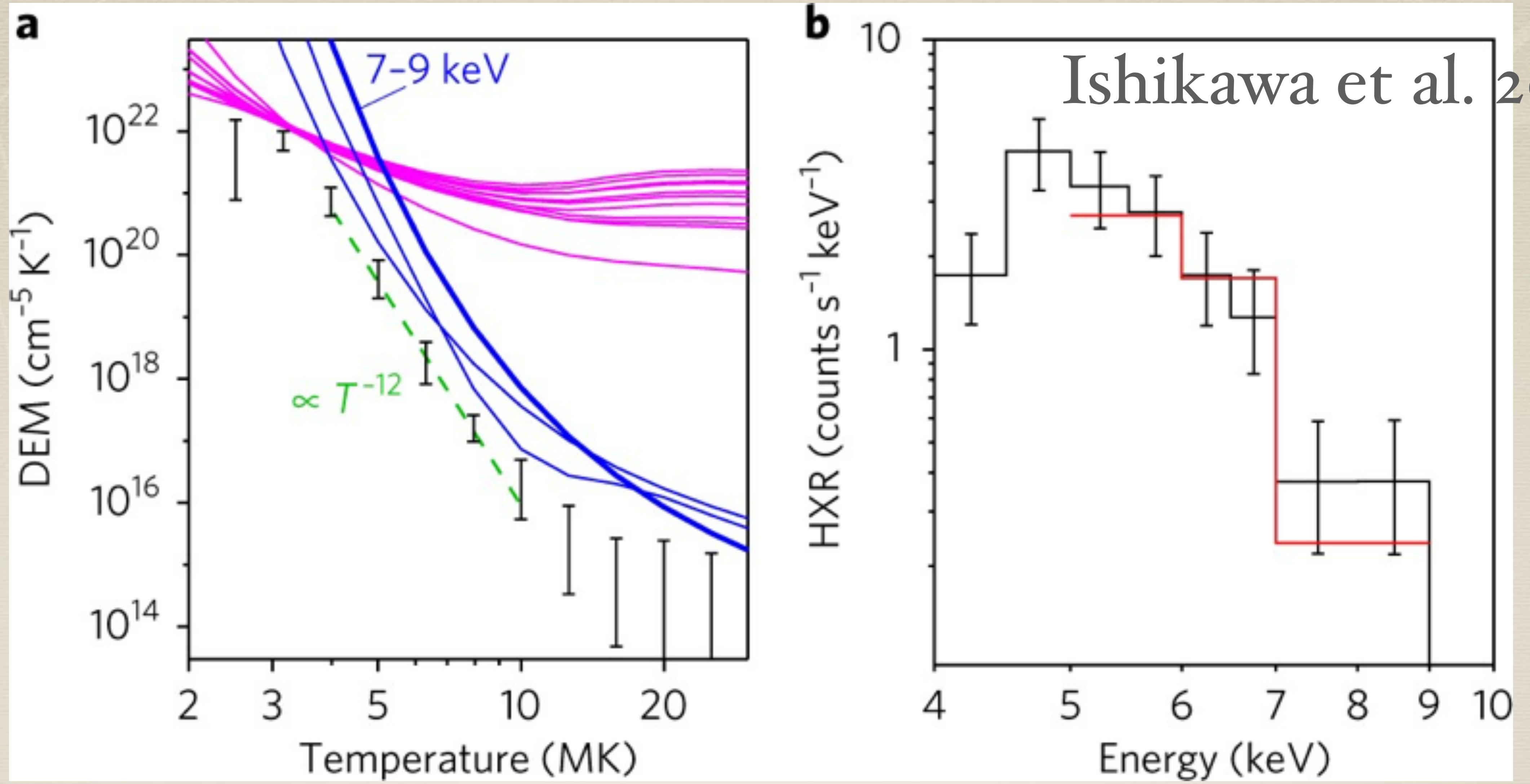
Heating the active regions





Some concensus that active regions are definitely heated, at least partially, by nanoflares. (e.g. Ishikawa et al. 2017).

Wave heating scenarios are also being studied.



Ishikawa et al. 2017

- Was done on quiscent active regions.
- Detected temperature > 10 MK. Cannot be explained without invoking the nanoflare theory.

Predictions

- Nanoflares should occur through out the corona as the temperature do not show huge variation across the corona.

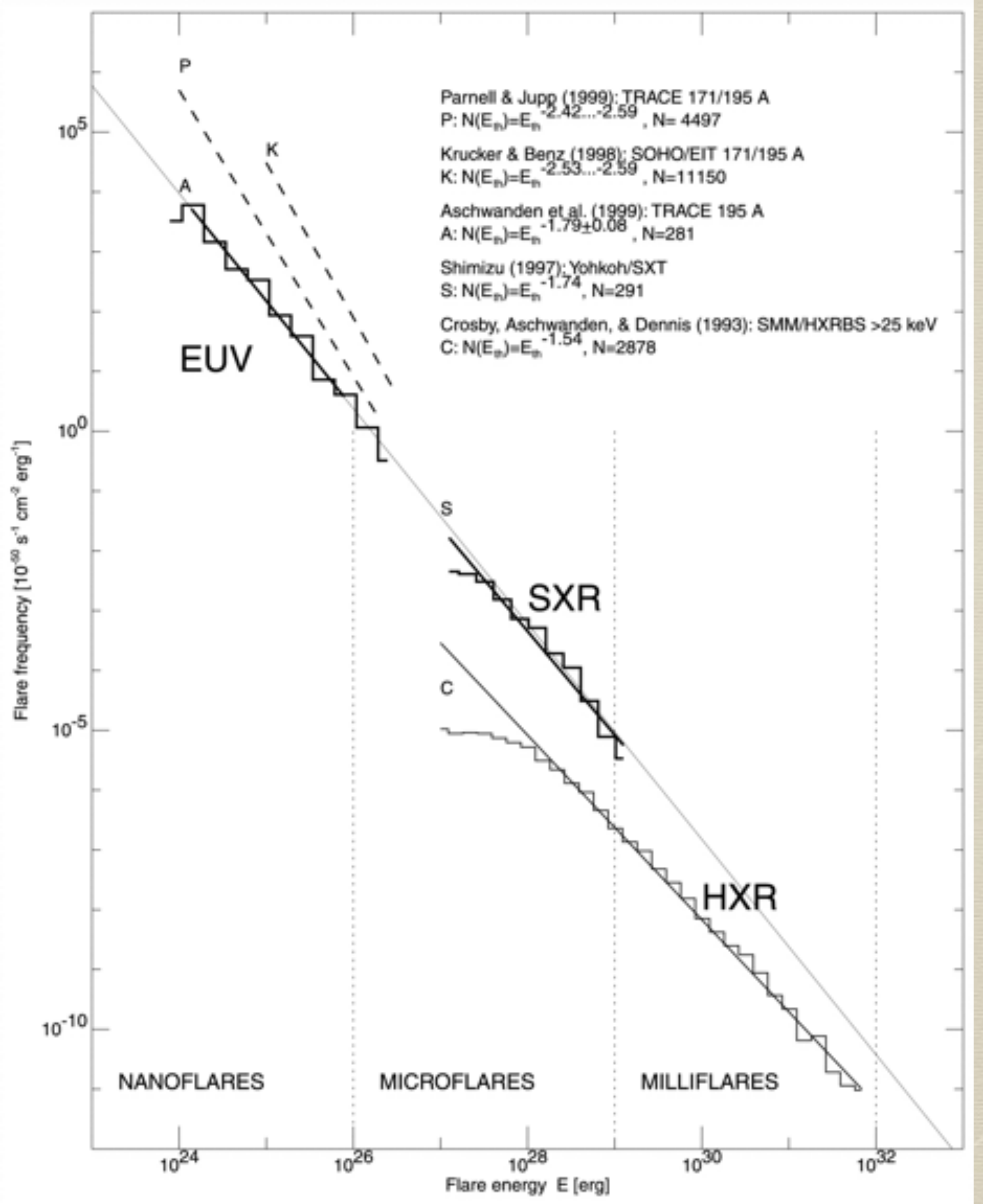
- The number distribution of nanoflares should satisfy the Hudson's criterion $N(E) \propto E^{-\alpha}, \alpha > 2$

$$E_{tot} = \int_{E_{min}}^{E_{max}} EN(E)dE = A \int_{E_{min}}^{E_{max}} E^{-\alpha+1} dE$$

$$= A \frac{E_{max}^{-\alpha+2} - E_{min}^{-\alpha+2}}{-\alpha+2}$$

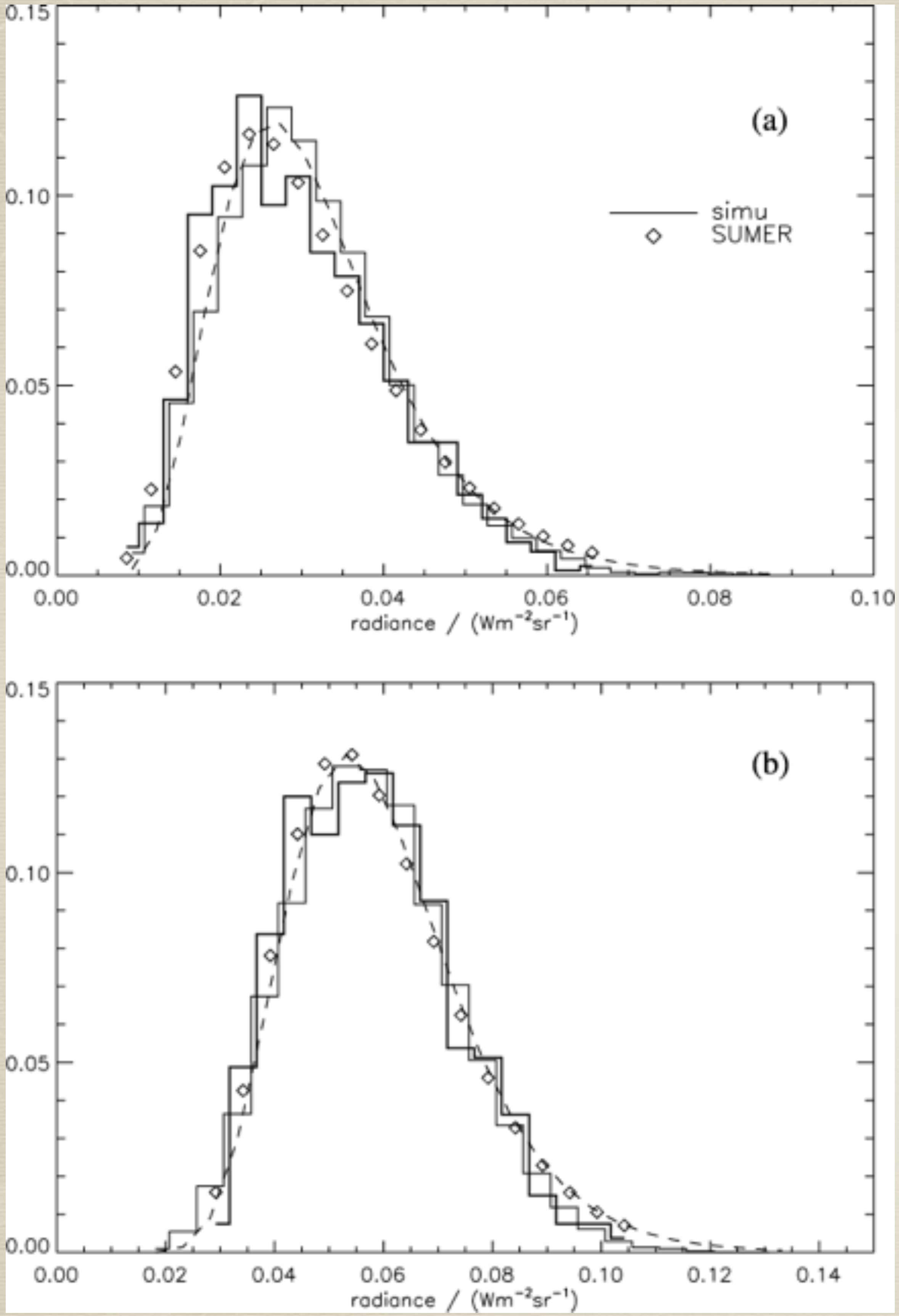
Related to quiet sun

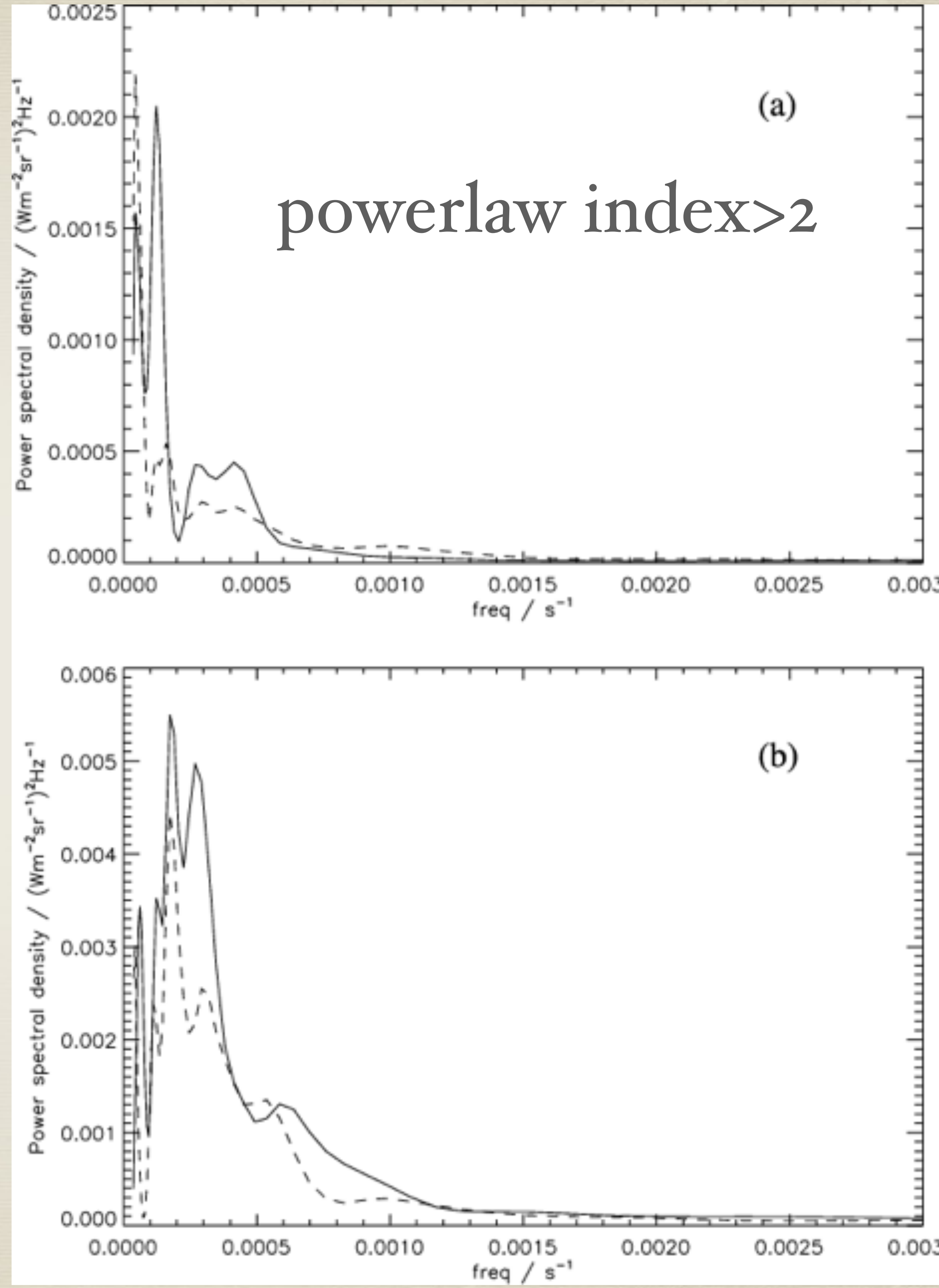
- Flare frequency over a large energy range well modelled by a powerlaw with powerlaw index 1.8 (Aschwanden et al. 2000)
- Nanoflares not important for coronal heating !!
- Problems:
  - Definition of flare
  - Instrumental resolution effects



New approach to old problem

- Pauluhn & Solanki (2007) tries to model quiet sun radiance timeseries using impulsive events with 5 free parameters:
    - maximum and minimum flare amplitude
    - powerlaw index of flare frequency distribution
    - damping time of flare
    - flaring probability



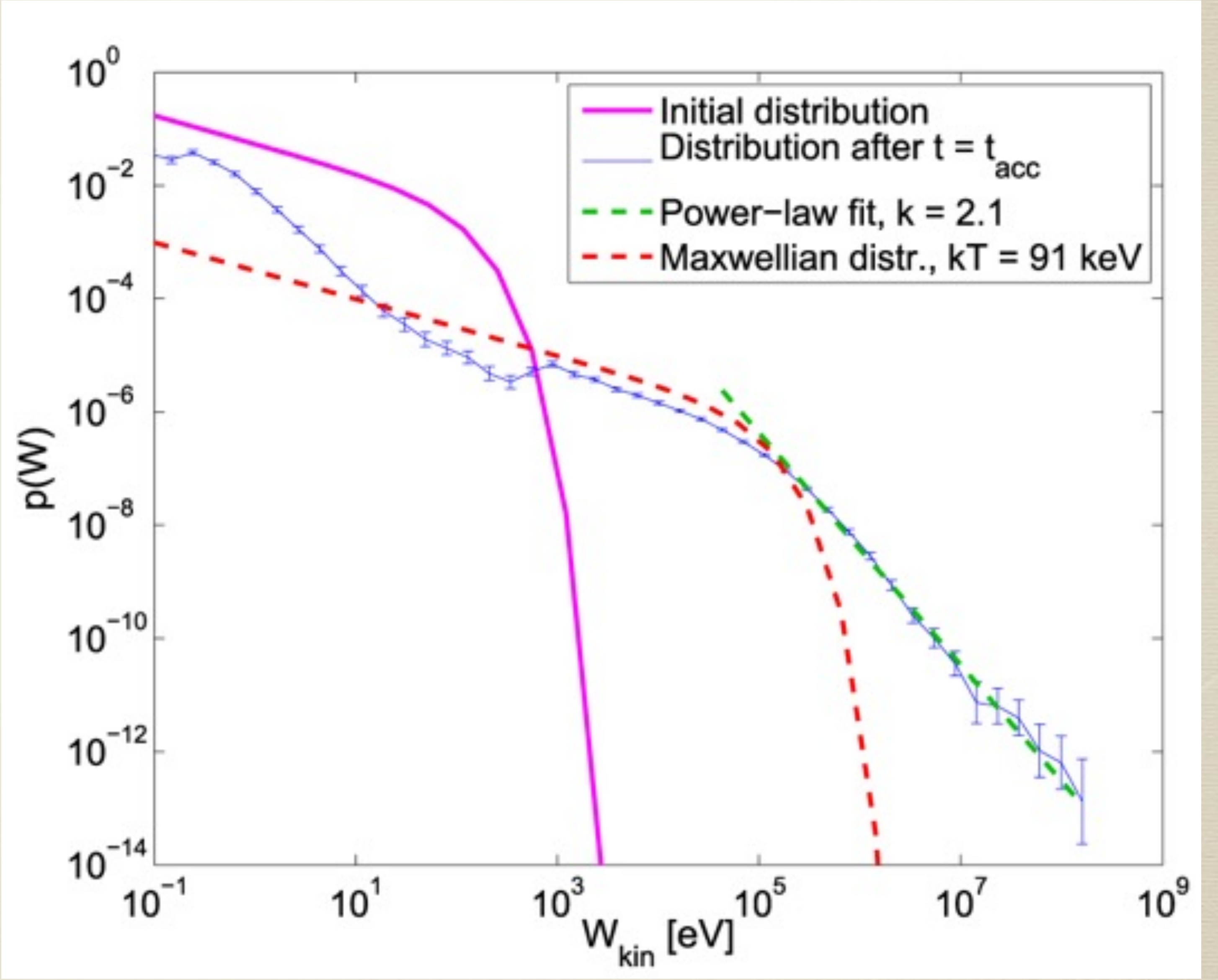


powerlaw index>2

Particle acceleration in quiet sun

- Turbulent reconnection can happen easily in the solar corona due to presence of multitude of Alfven waves and turbulent medium.

- Particle acceleration has been studied in such medium by several authors (e.g. Pisokas et al. 2017, 2018, Isliker et al. 2017)



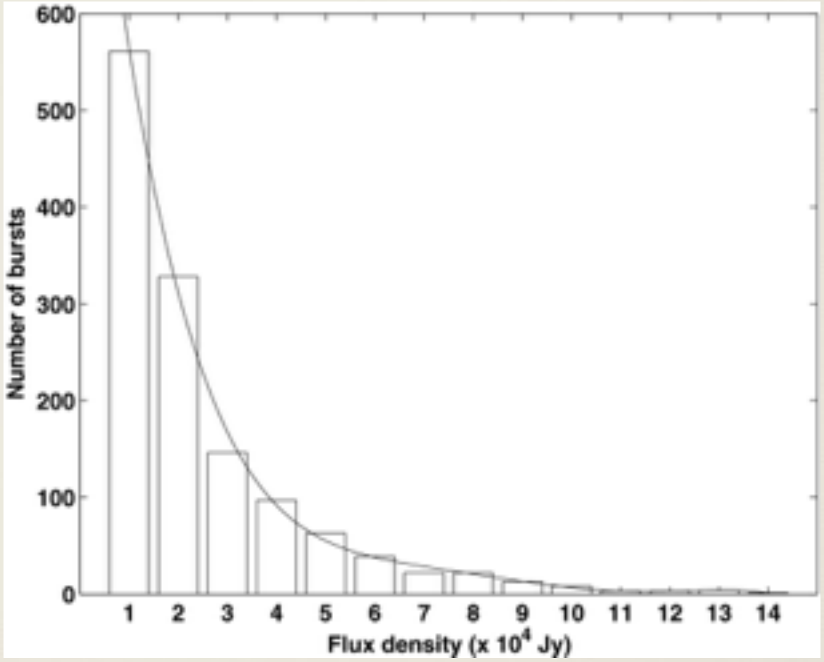
Pisokas et al. 2018

Solar radio emission

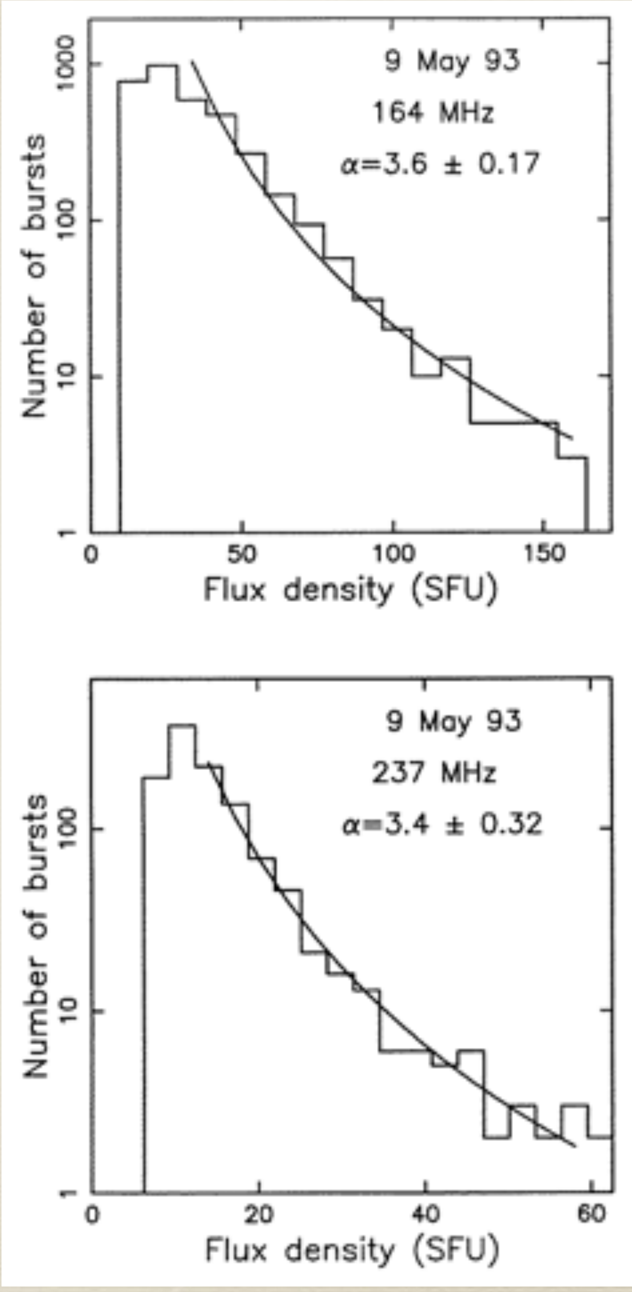
- Solar radio emission: a) thermal bremsstrahlung b) radio bursts
- Radio bursts: Coherent emission mechanism; caused by plasma instabilities due to the motion of a beam of energetic electrons
- Coherent emission results in high brightness temperature; easily detectable in radio

Past works in radio

- The powerlaw index is greater than 2.
- Concerned noise storms.



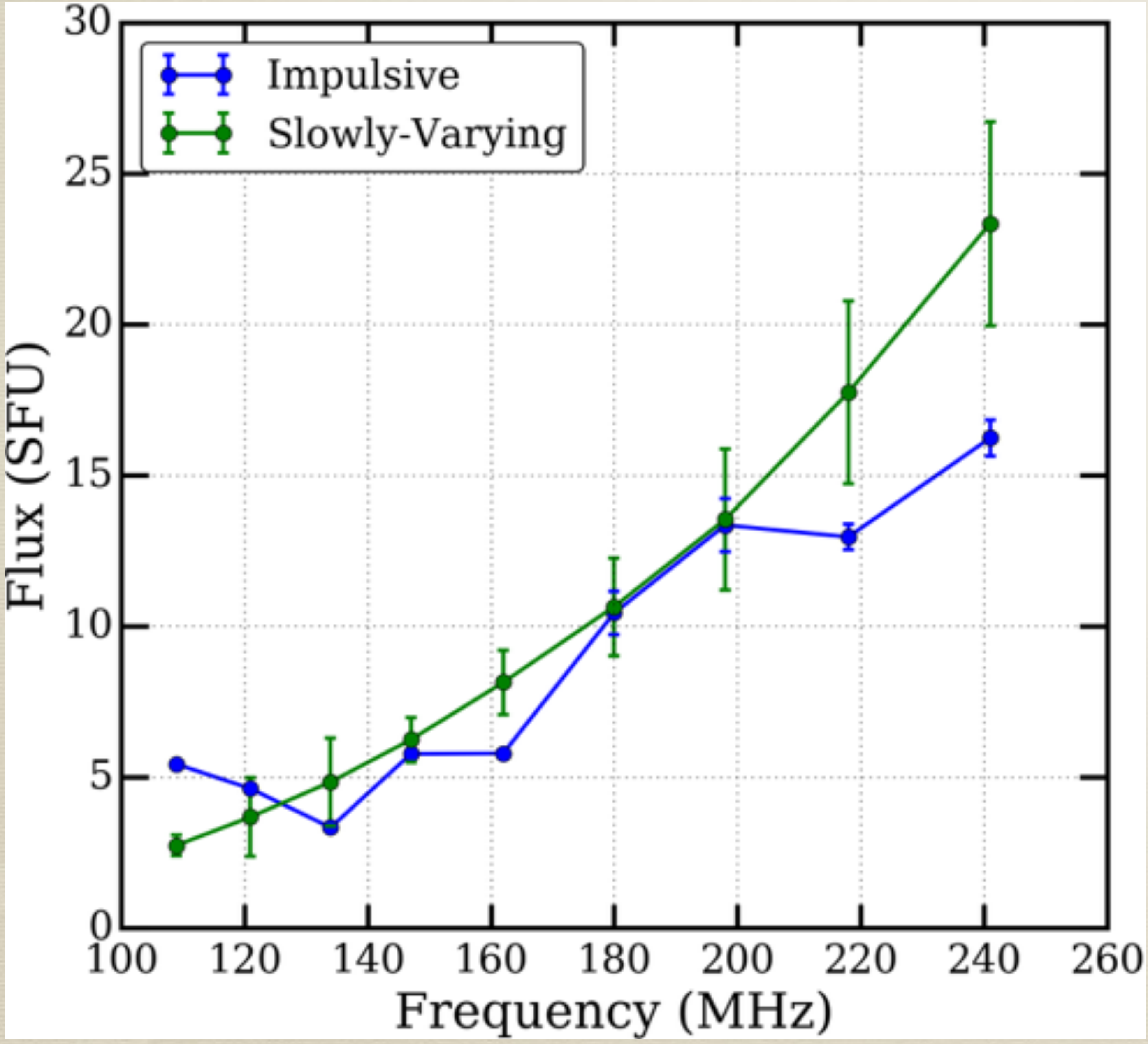
Ramesh et al. 2013



Mercier et al. 1998

Impulsive events in quiet sun

- Sharma et al. (2018) showed the presence of very small scale impulsive events in the quiet sun.



Impulsive events and slowly varying events have similar energies.

Sharma et al. 2018

Sharma et al. 2018

- Powerlaw index<2.
- Determination not robust.
- The authors themselves suggest that the fit is limited by the lack of data points at the high S_{Im} regime.

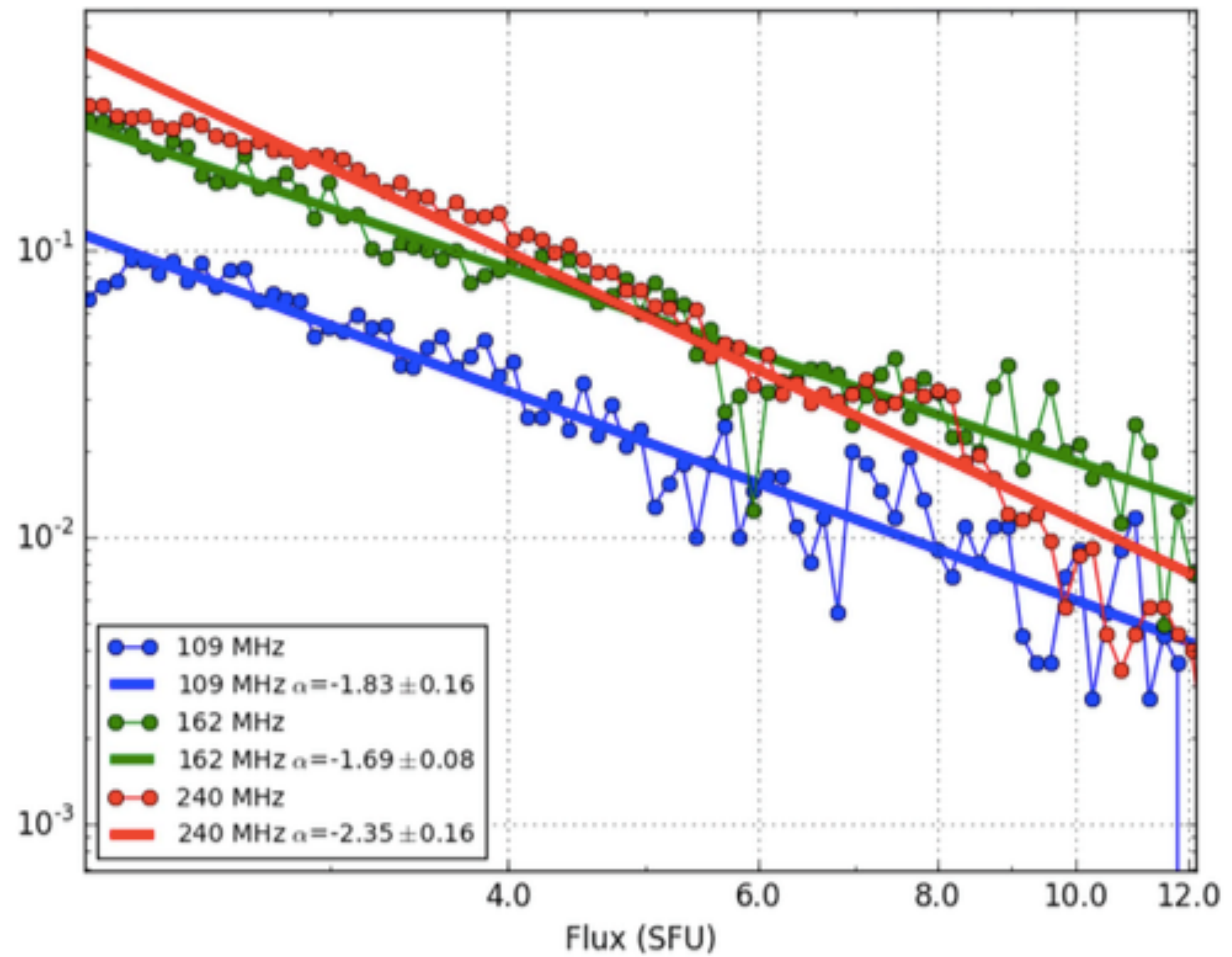


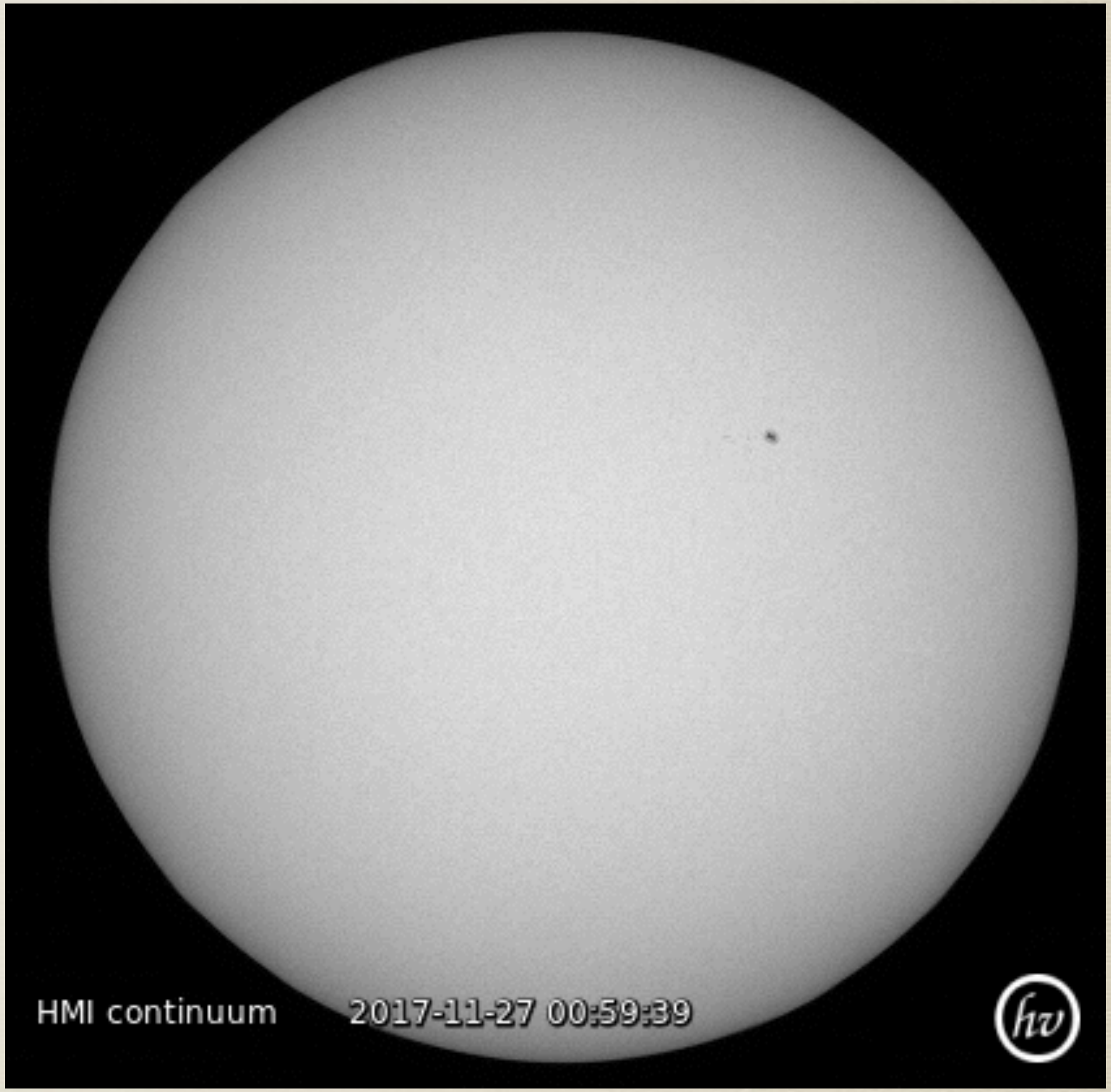
Figure 10. Histogram plot showing the power-law fit to the tail of the S_{Im} distribution for three of the frequencies for data from one of the baselines. The best-fit index, α, and the associated uncertainty are mentioned in the legend.

Our goal

- To look for any impulsive emission from the quiet sun.
- Investigate if the detected impulsive emissions satisfy the necessary conditions of coronal heating.

Solar conditions

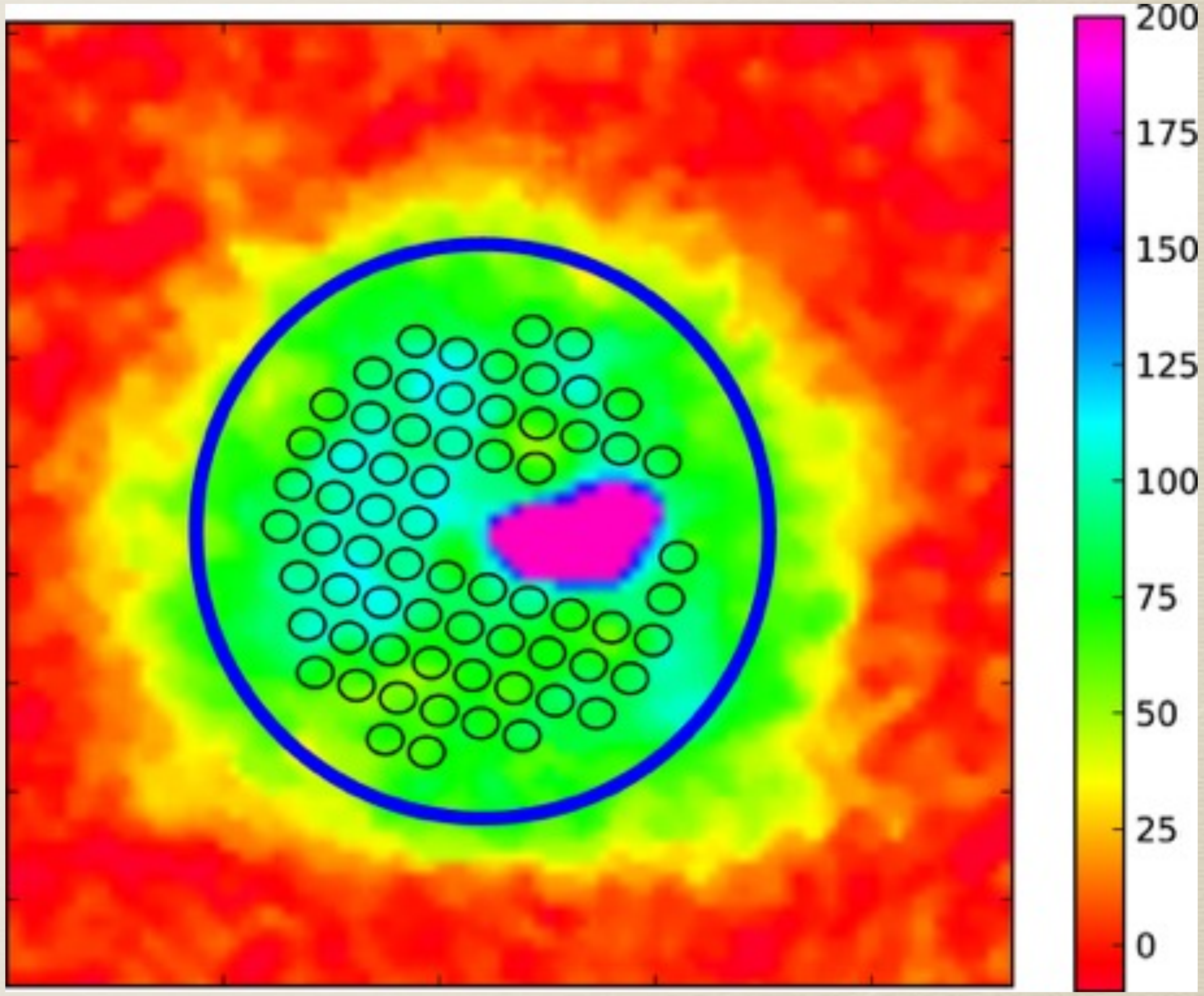
- Chose to work with MWA data from 2017/11/27.
- Very quiet.
- No X-ray flare, radio flare reported.
- Well suited for such an investigation.



Data analysis

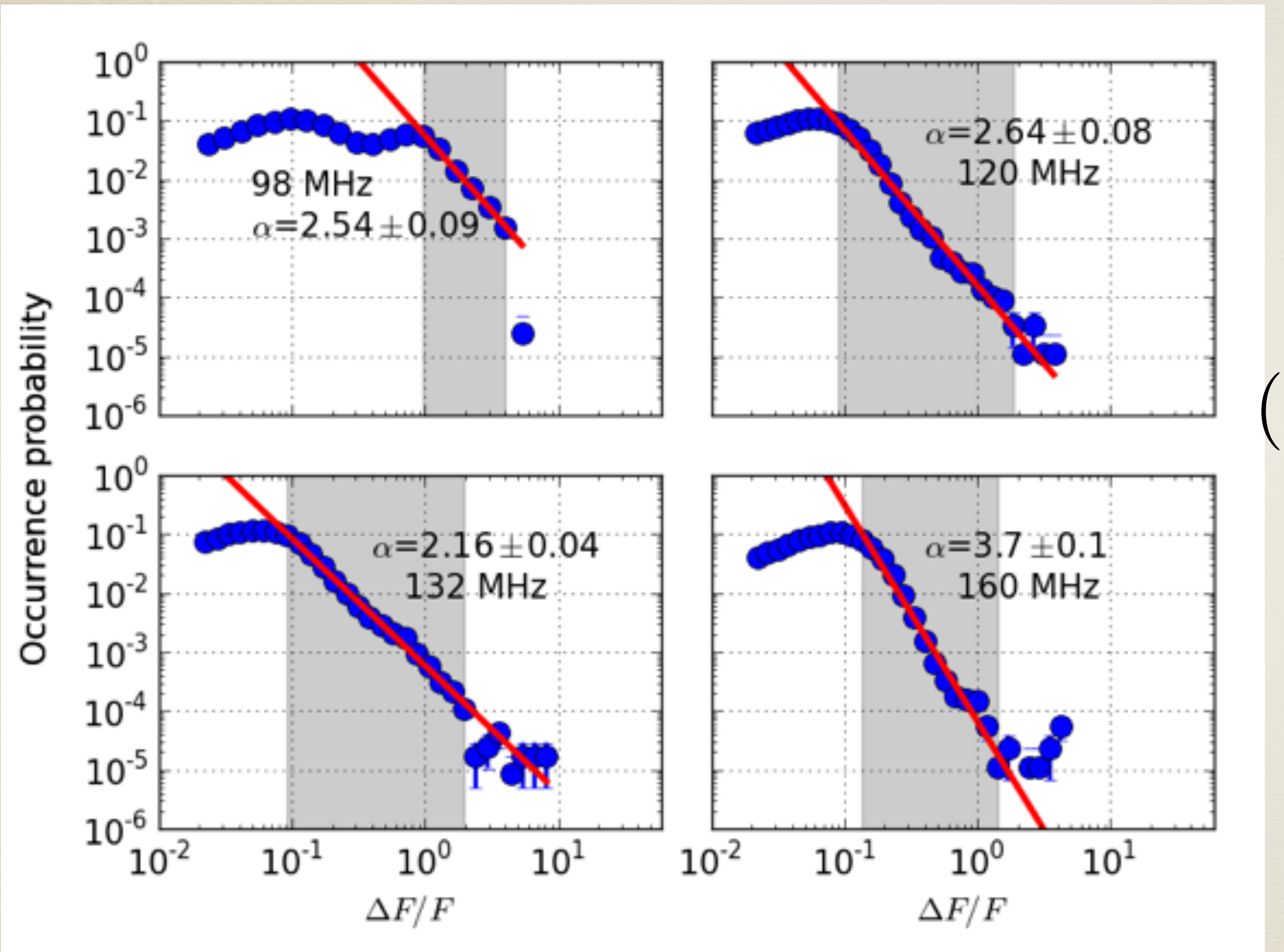
- Imaged 70 minutes of data at 4 frequencies near 98, 120, 132 and 160 MHz at 0.5s cadence.

- Imaging was done in a completely automated manner using the Automated Imaging Routine for Compact Arrays for Radio Sun (AIRCARS, Mondal et al. 2019); ~33000 images made



Mondal et al. 2020b

Normalised flux density histogram



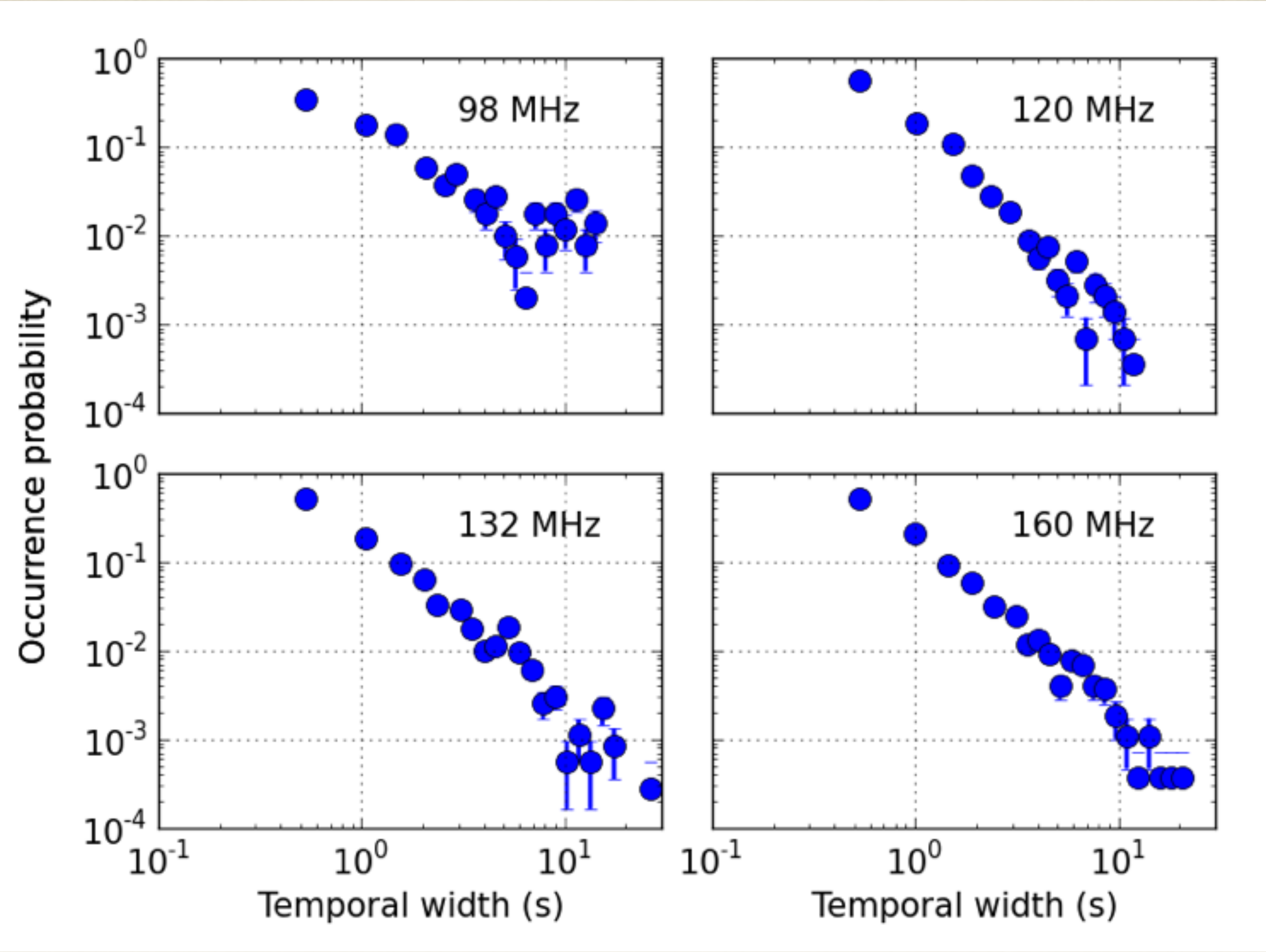
$$(\Delta F/F)_{i,t} = \frac{F_{i,t} - \langle F_i \rangle}{\langle F_i \rangle}$$

~1mSFU flux detected

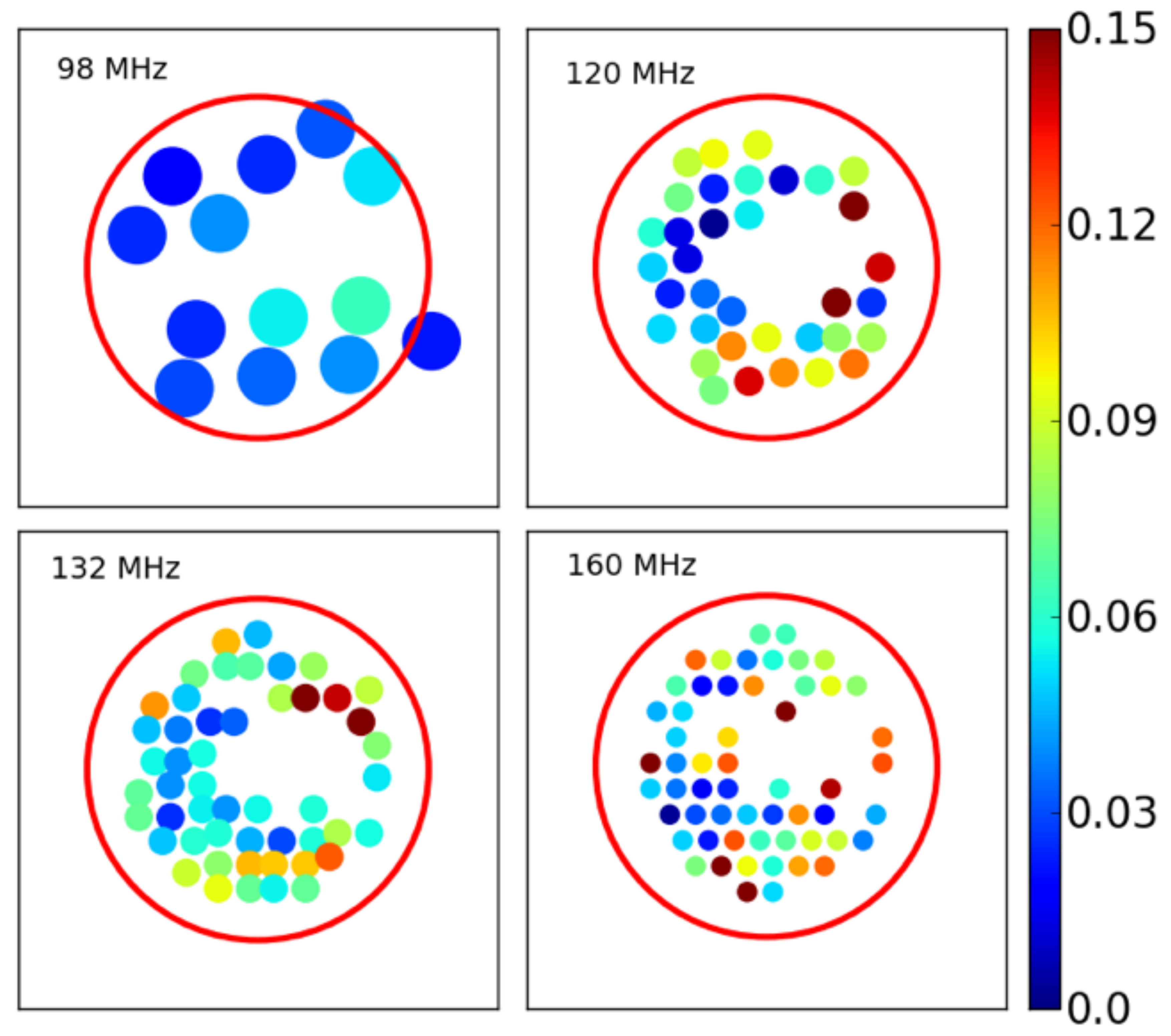
What is different?

- Data from the Murchison Widefield Array
- Automated Solar Imaging pipeline for Compact Arrays for Radio Sun (Mondal et al. 2019)
    - High dynamic range images
    - Produce thousands of images in manageable time

Temporal width distribution

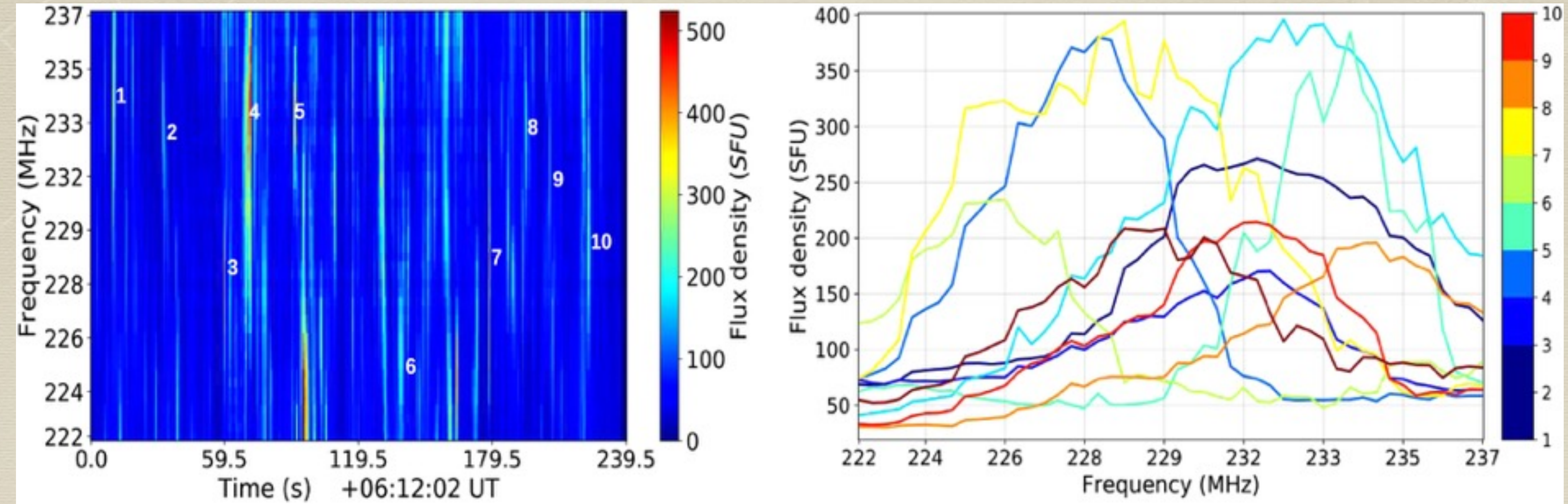


Spatial distribution



Characteristics

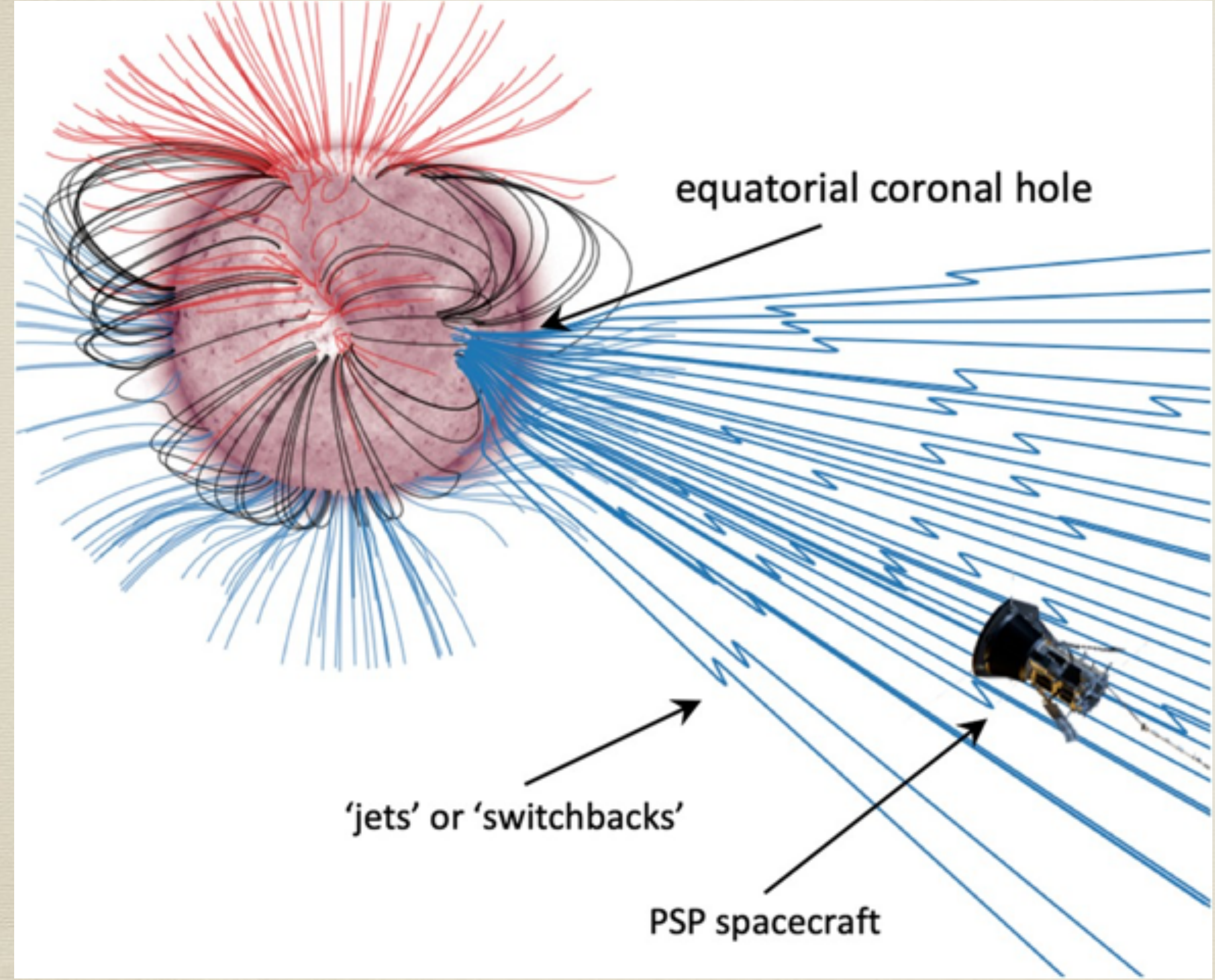
- Clearly show up as a powerlaw tail in histogram.
- Impulsive in nature, Median duration: ~1s; Powerlaw distribution in widths.
- Present everywhere on the Sun. No evidence of clustering along both time and location.
- No correlation observed between frequencies: Narrow band.



Mohan et al. 2019

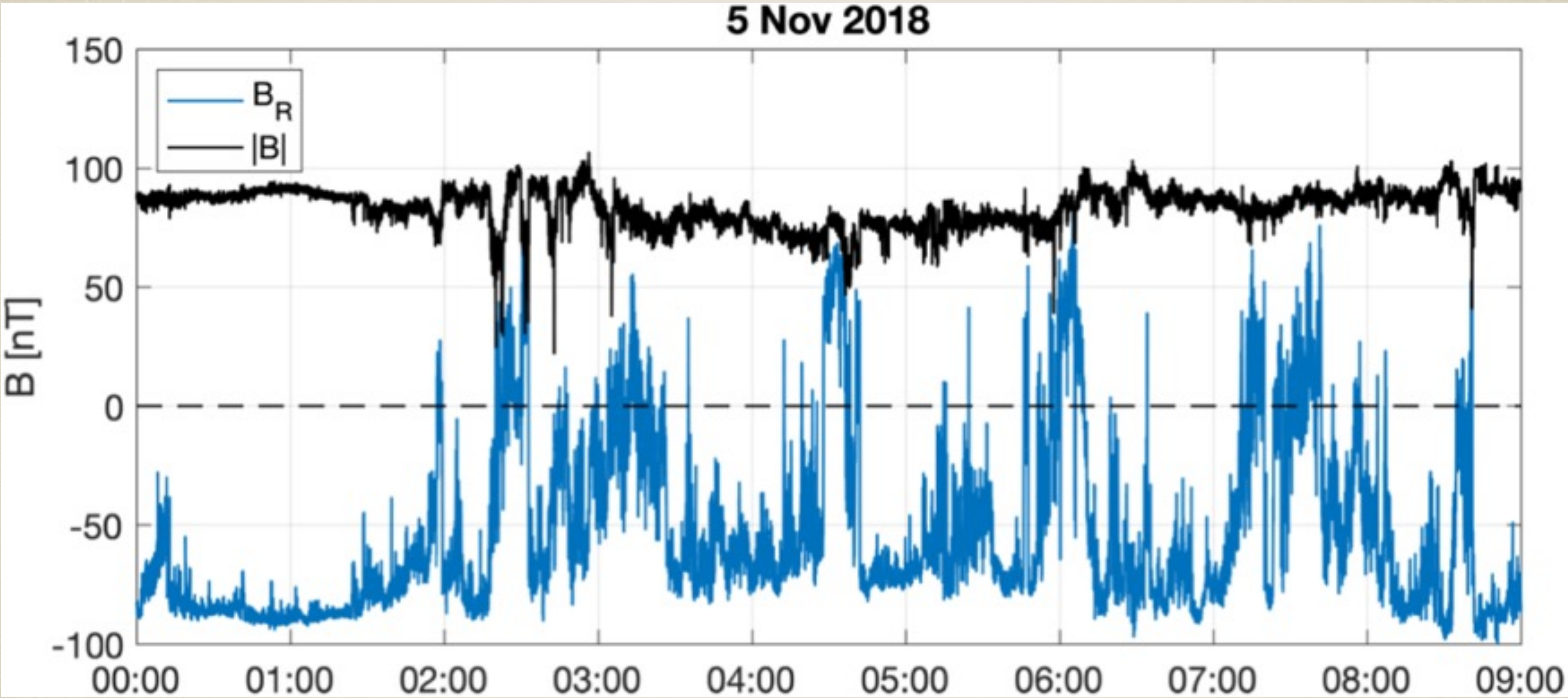
- Evidence of small scale reconnections
- Electrons beam emits radiation and gets dissipated very close to site of origin.
- Energy dumped into the corona satisfies the coronal heating budget.

Parker Solar Probe’s solar encounter



Bale et al. 2019

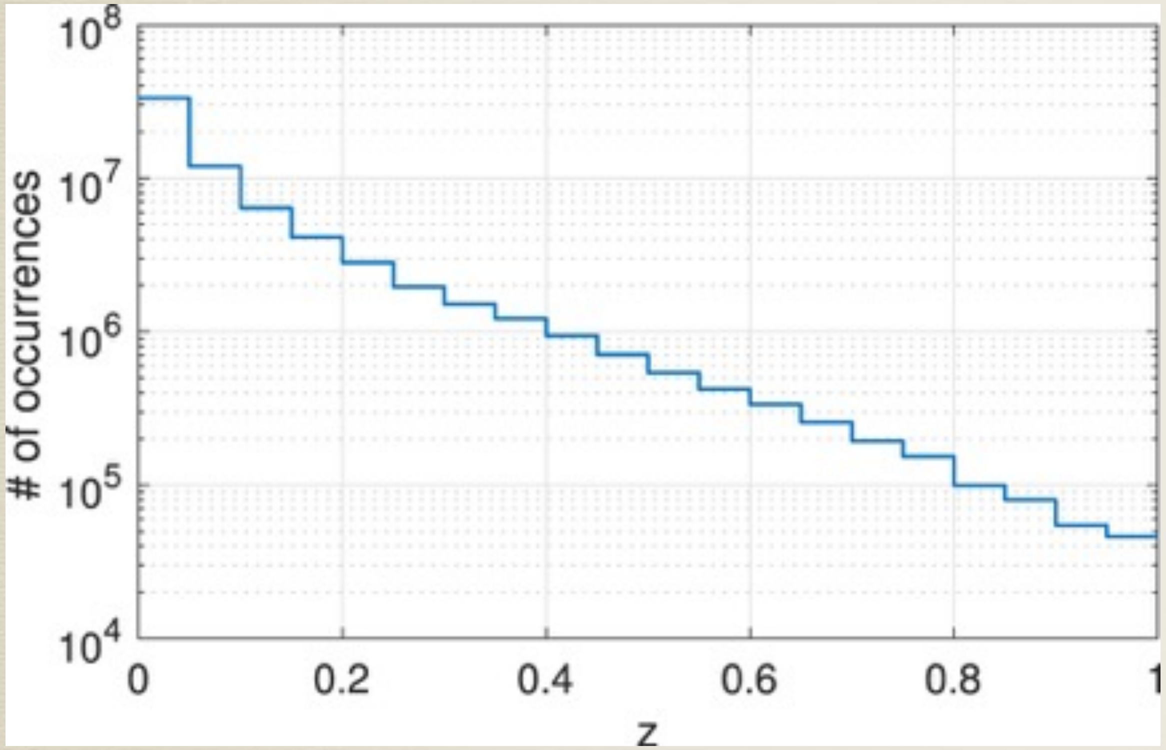
Magnetic switchbacks



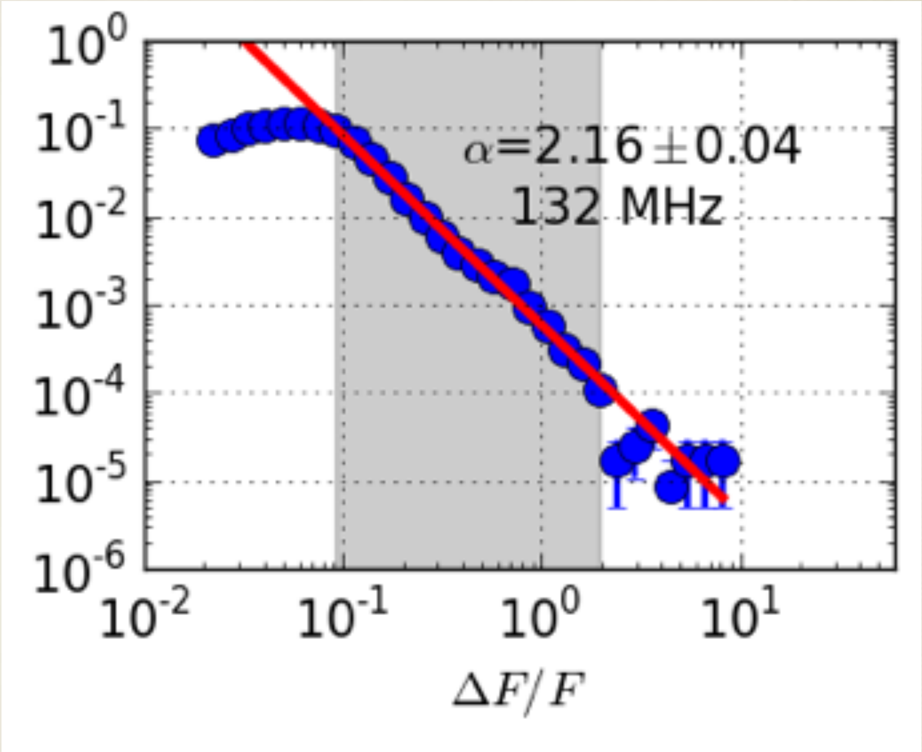
Krasnoselskikh et al, 2020

Similarities

Magnetic switchbacks



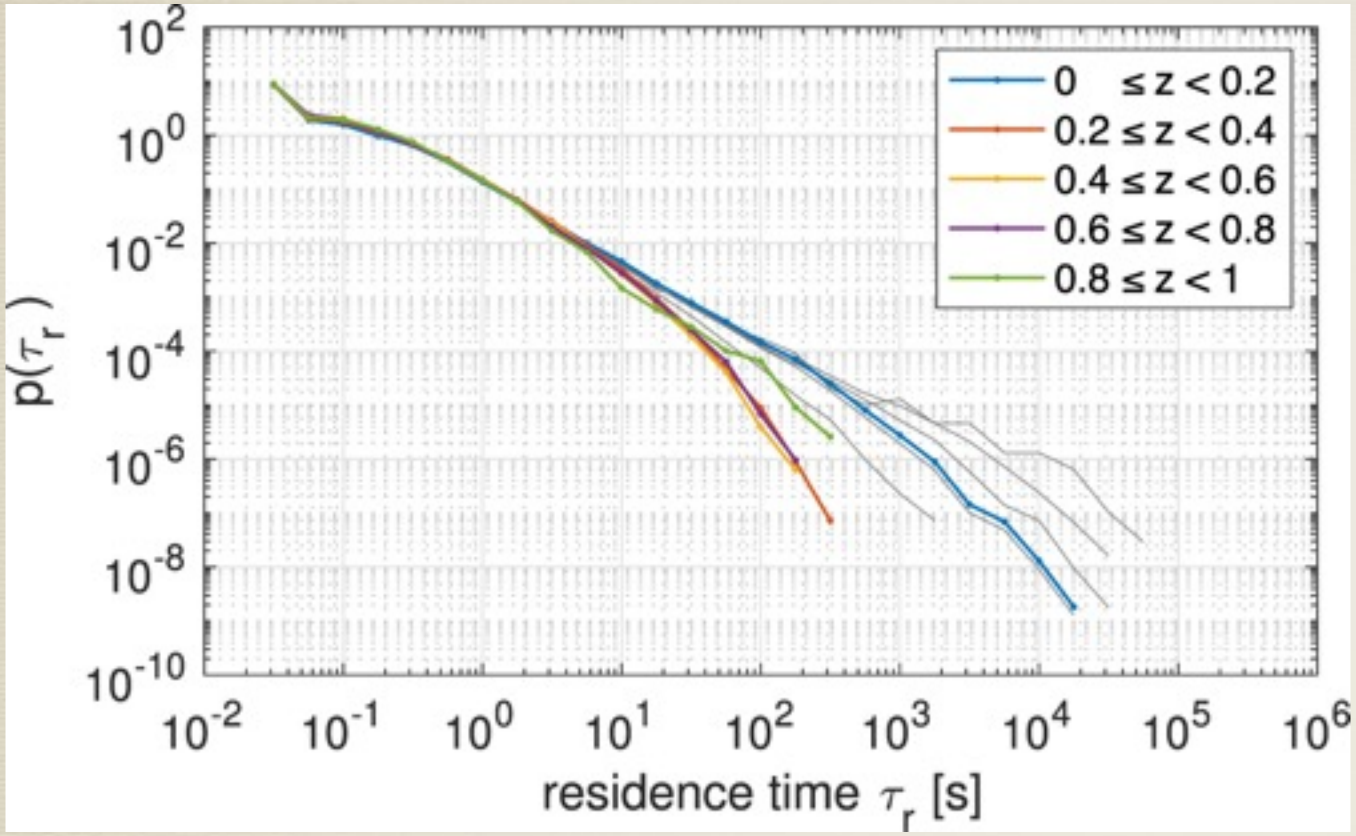
Impulsive emissions



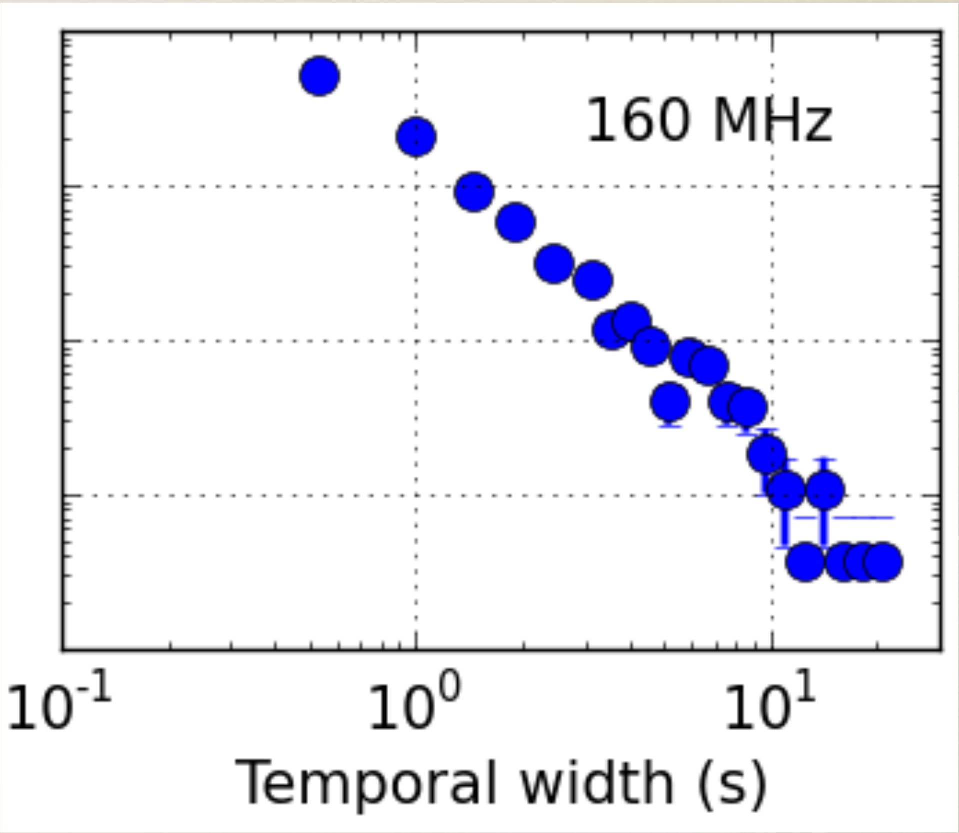
Dudok de Wit et al. 2020

Similarities

Magnetic switchbacks

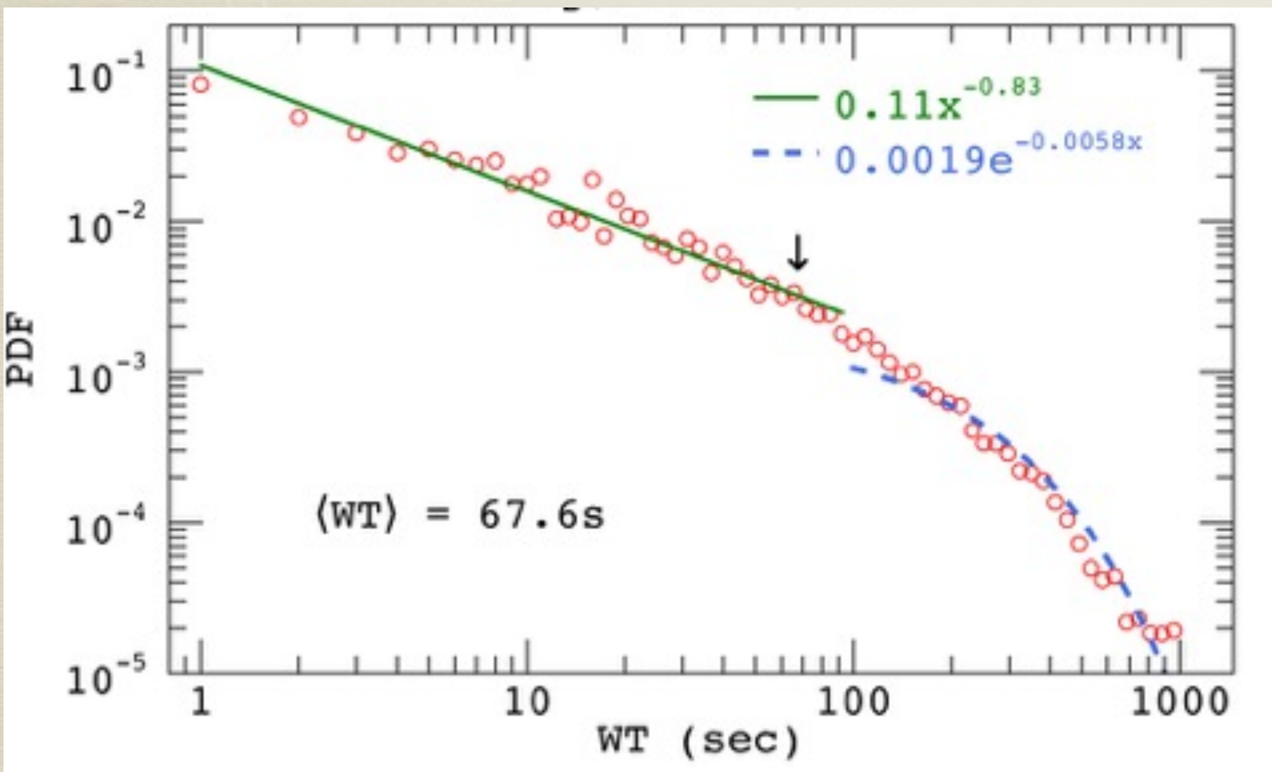


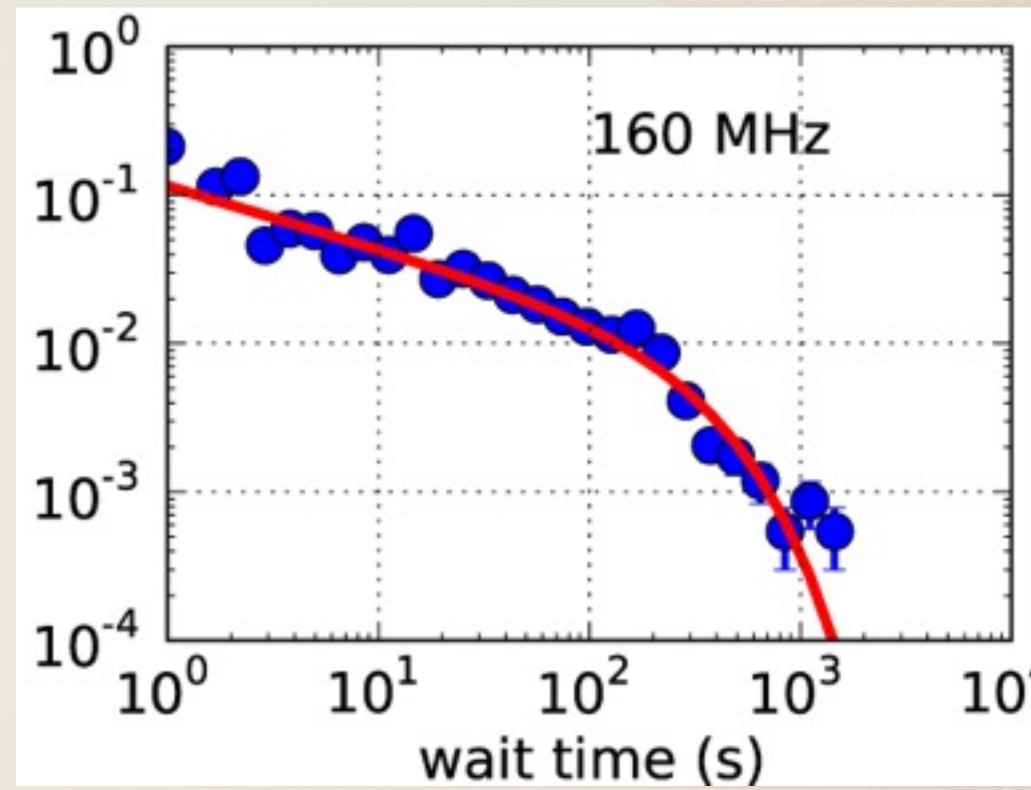
Impulsive emissions



Dudok de Wit et al. 2020

Similarities



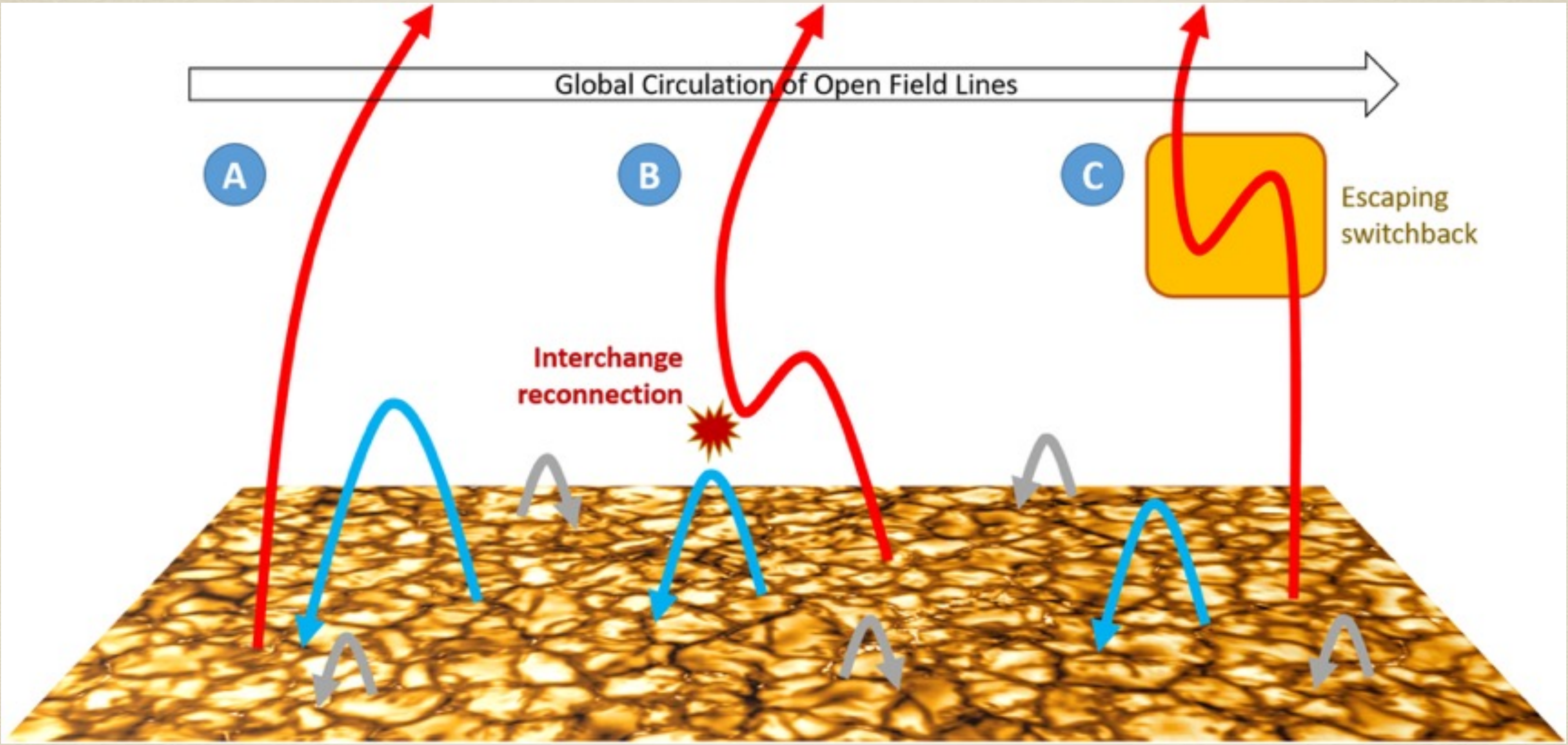


Chhiber et al. 2020

Similarities

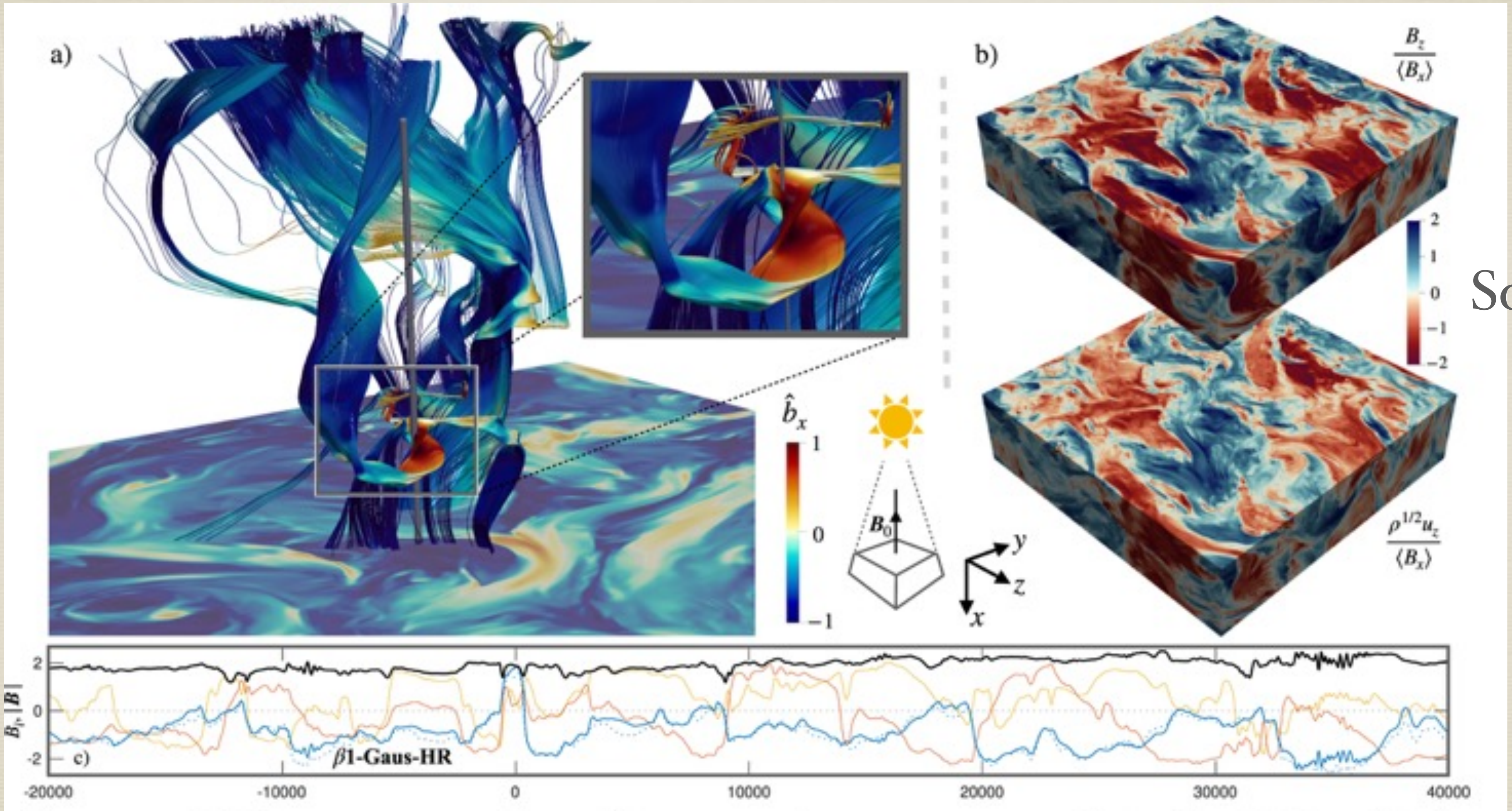
- Bale et al. 2019 noted that the magnetic switchbacks were detected in *~6%* of the observation duration.
- Very similar to the fractional time impulsive events are detected in our work.

Producing these simultaneously



Fisk et al. 2020

Switchbacks through turbulence

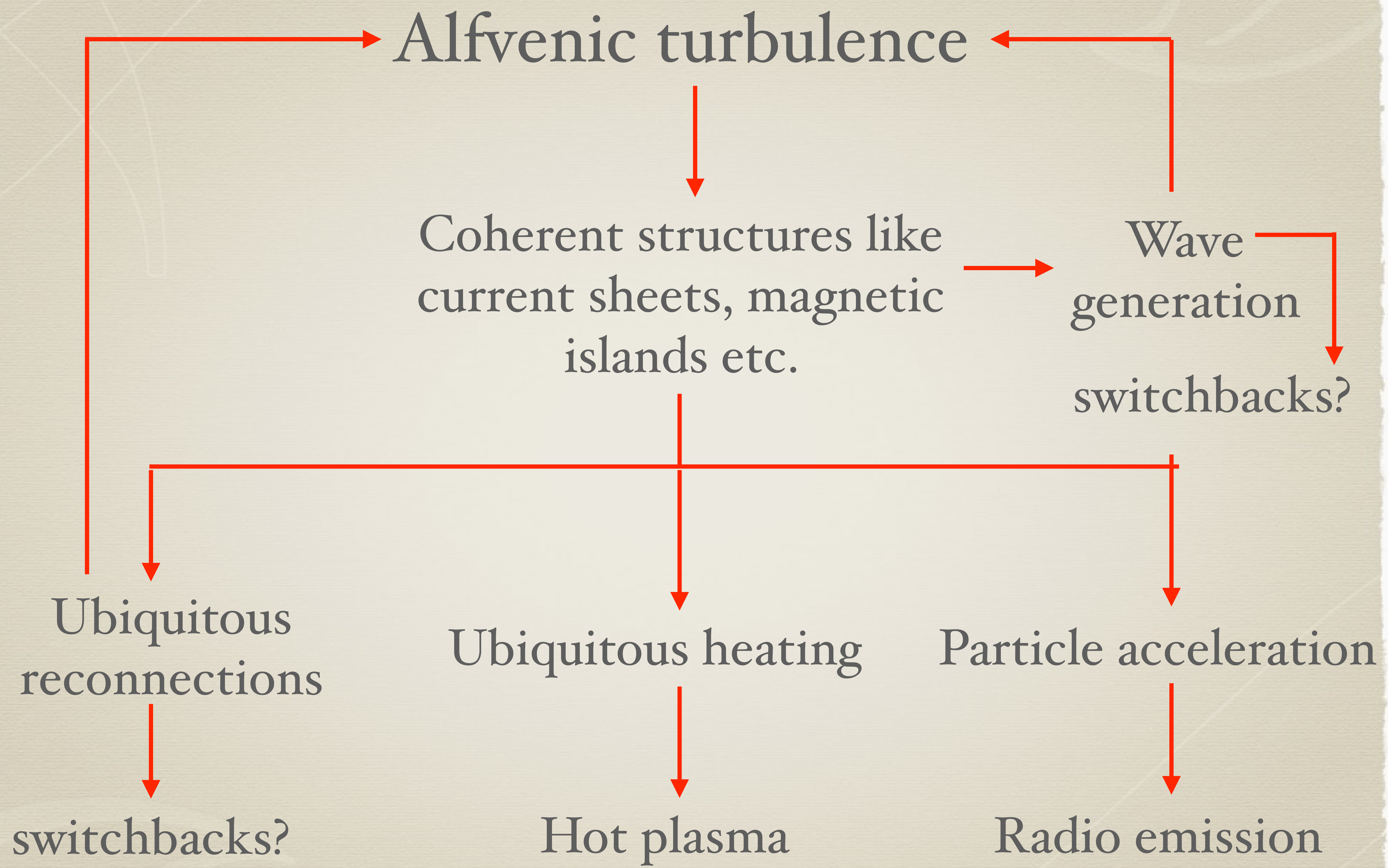


Squire et al. 2020

Switchbacks can be produced by spectrum of Alfvenic fluctuations advected by a rapidly expanding flow.

Summary

- For the first time found evidence of ubiquitous impulsive emissions in the quiet sun.
- Energy enough to maintain the high temperature of the corona.
- Properties consistent with being produced by magnetic reconnection.
- these impulsive emissions and the magnetic switchbacks observed by the Parker Solar Probe, might have similar origin.


Alfvenic turbulence
Coherent structures like current sheets, magnetic islands etc.
Wave generation
switchbacks?
Ubiquitous reconnections
Ubiquitous heating
Particle acceleration
switchbacks?
Hot plasma
Radio emission