The Sun and the Heliosphere at Low Radio Frequencies

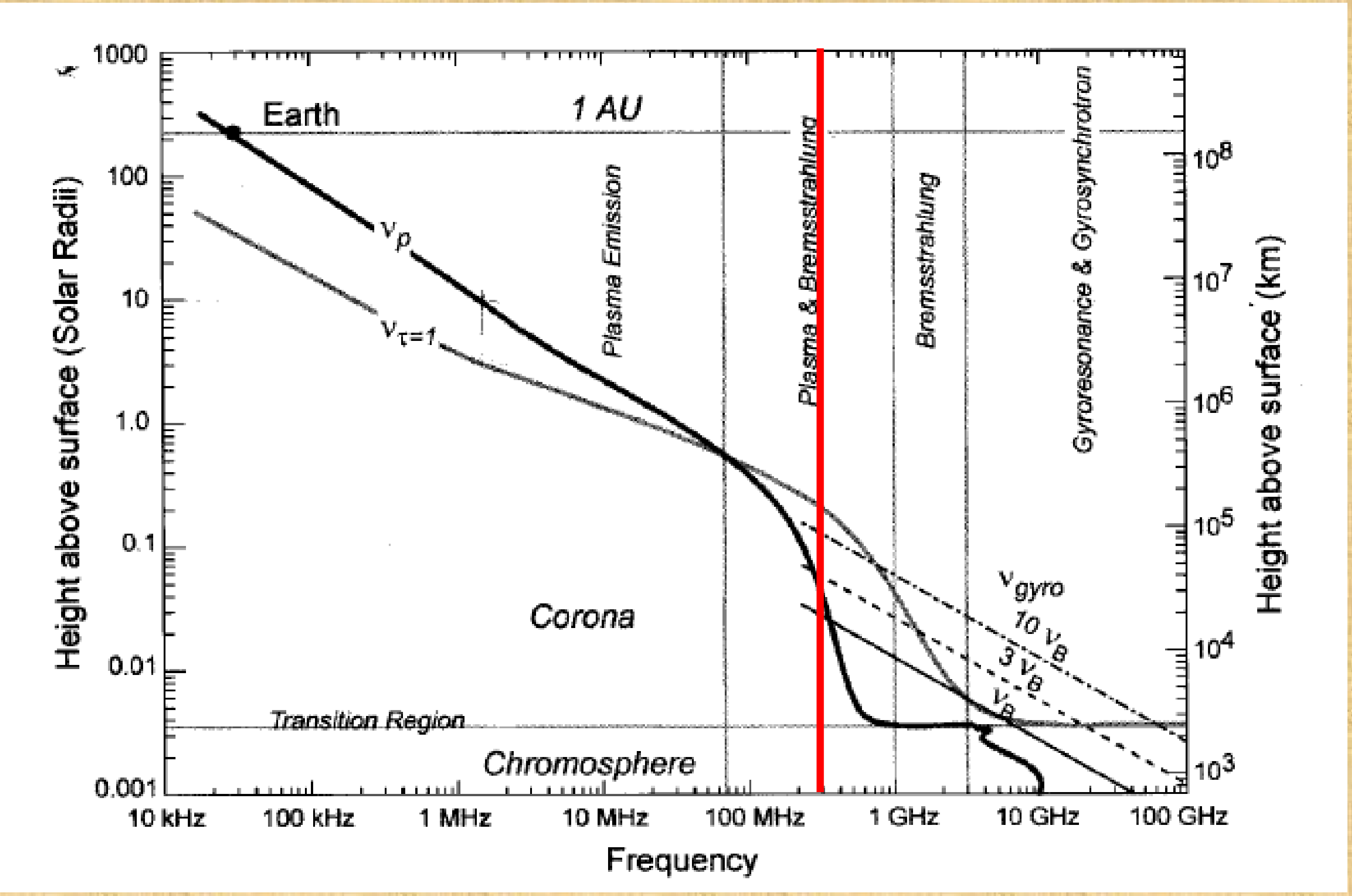
Divya Oberoi
National Centre for Radio Astrophysics
Tata Institute of Fundamental Research
Pune, India

div@ncra.tifr.res.in

Collaborators

- NCRA-TIFR
  - Rohit Sharma, Atul Mohan, Akshay Suresh (IISER-Pune)
- MIT Haystack Observatory
  - Colin Lonsdale, Leonid Benkevitch, Meagan Crowley (UMass)
- University of Sydney
  - Iver Cairns, Patrick McCauley
- Institute of Astronomy, Bulgarian Academy of Sciences
  - Kamen Kozarev
- Curtin University of Technology
  - John Morgan, Rajan Chhetri
- New Jersey Institute of Technology
  - Bin Chen
- MWA Collaboration

Characteristic frequencies and emission mechanisms



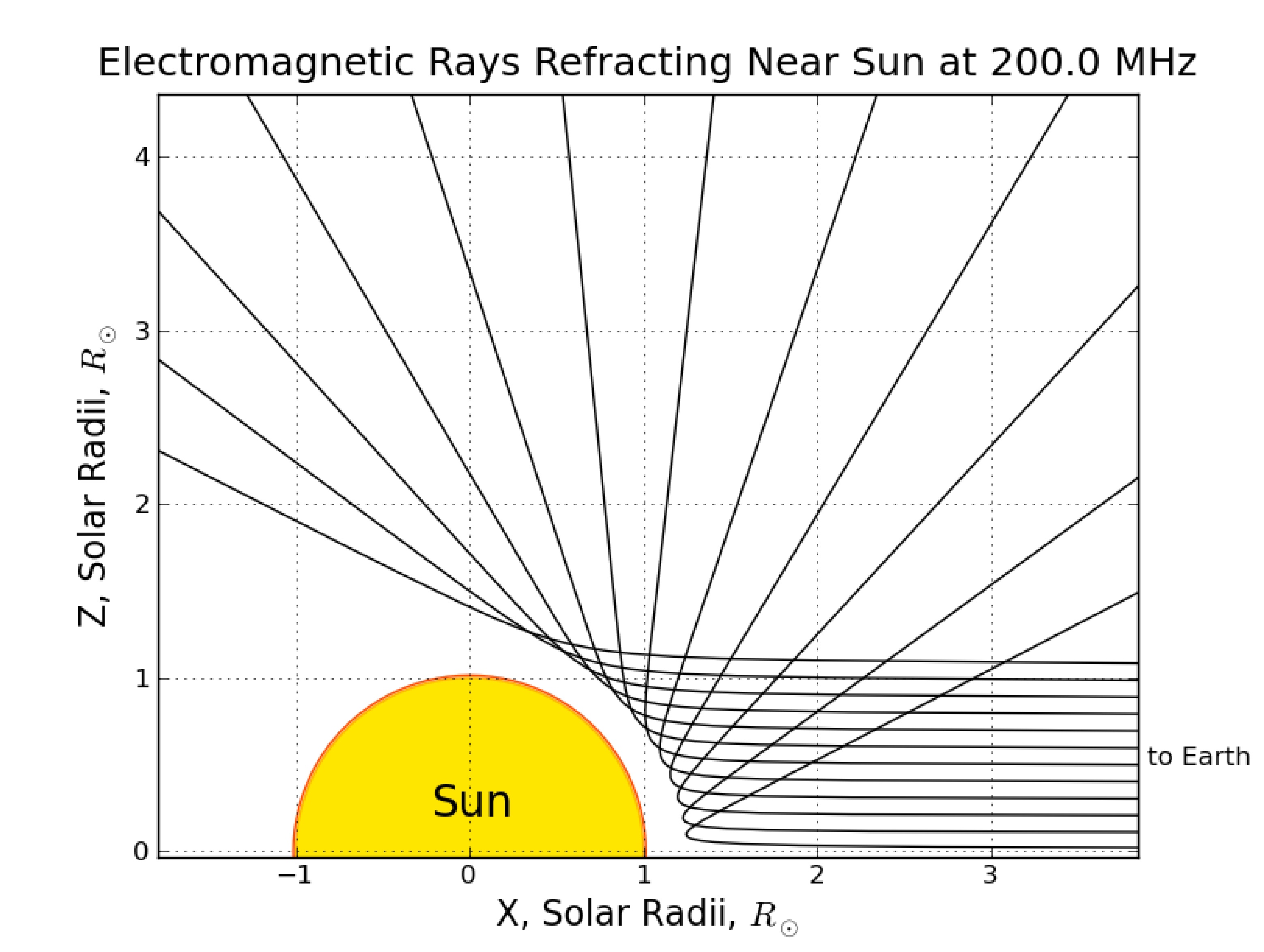
Plasma freq.
$\nu_p \approx 9x10^3\ N_e^{1/2}$

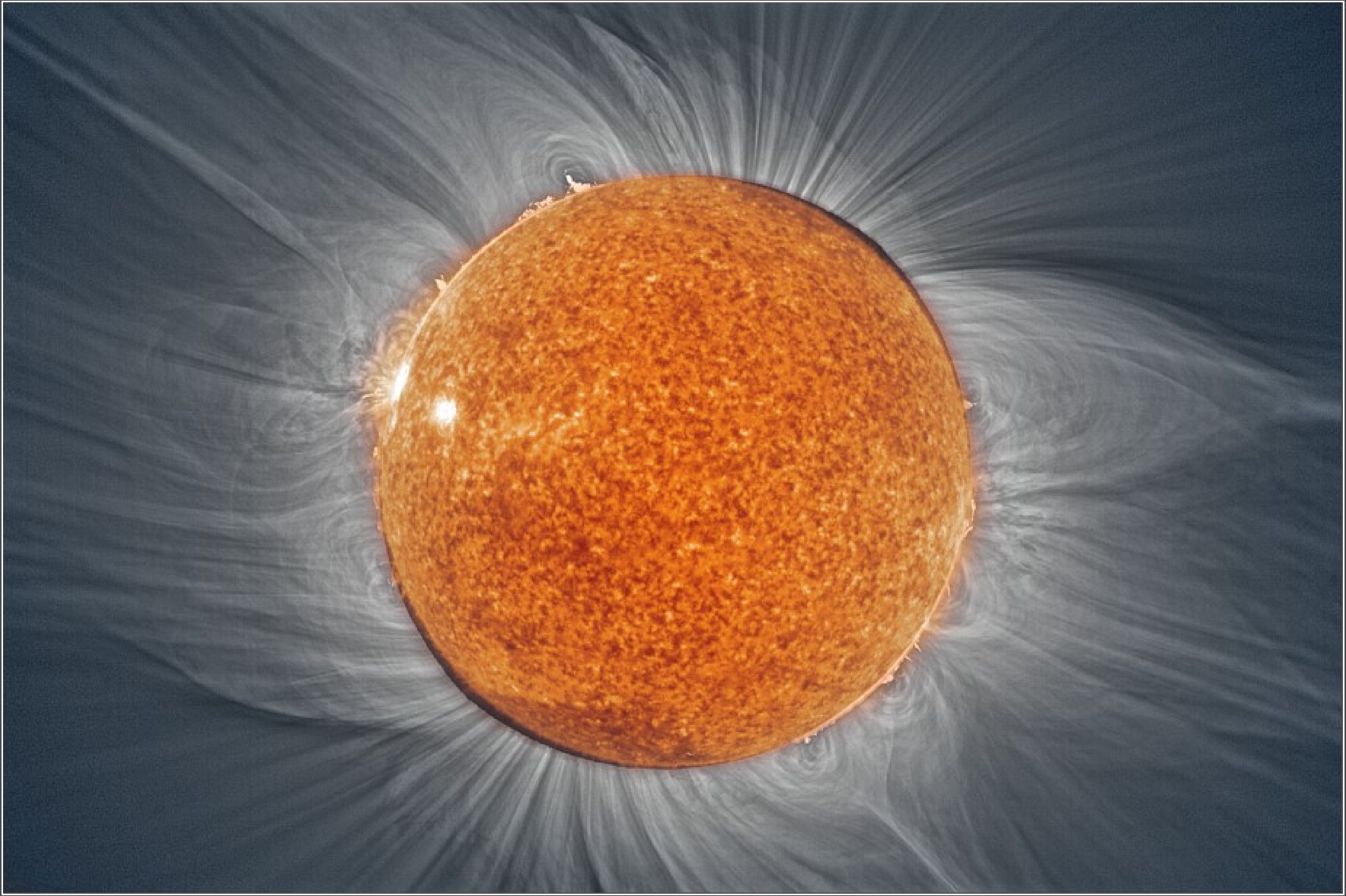
Free-free emission
$\nu(\tau_{ff} = 1) \approx$
$0.5\ N_e\ T_e^{-3/4}\ L^{1/2}$

e gyro freq
$\nu_B \approx 2.8x10^6\ B$

Gary and Hurford, 2004

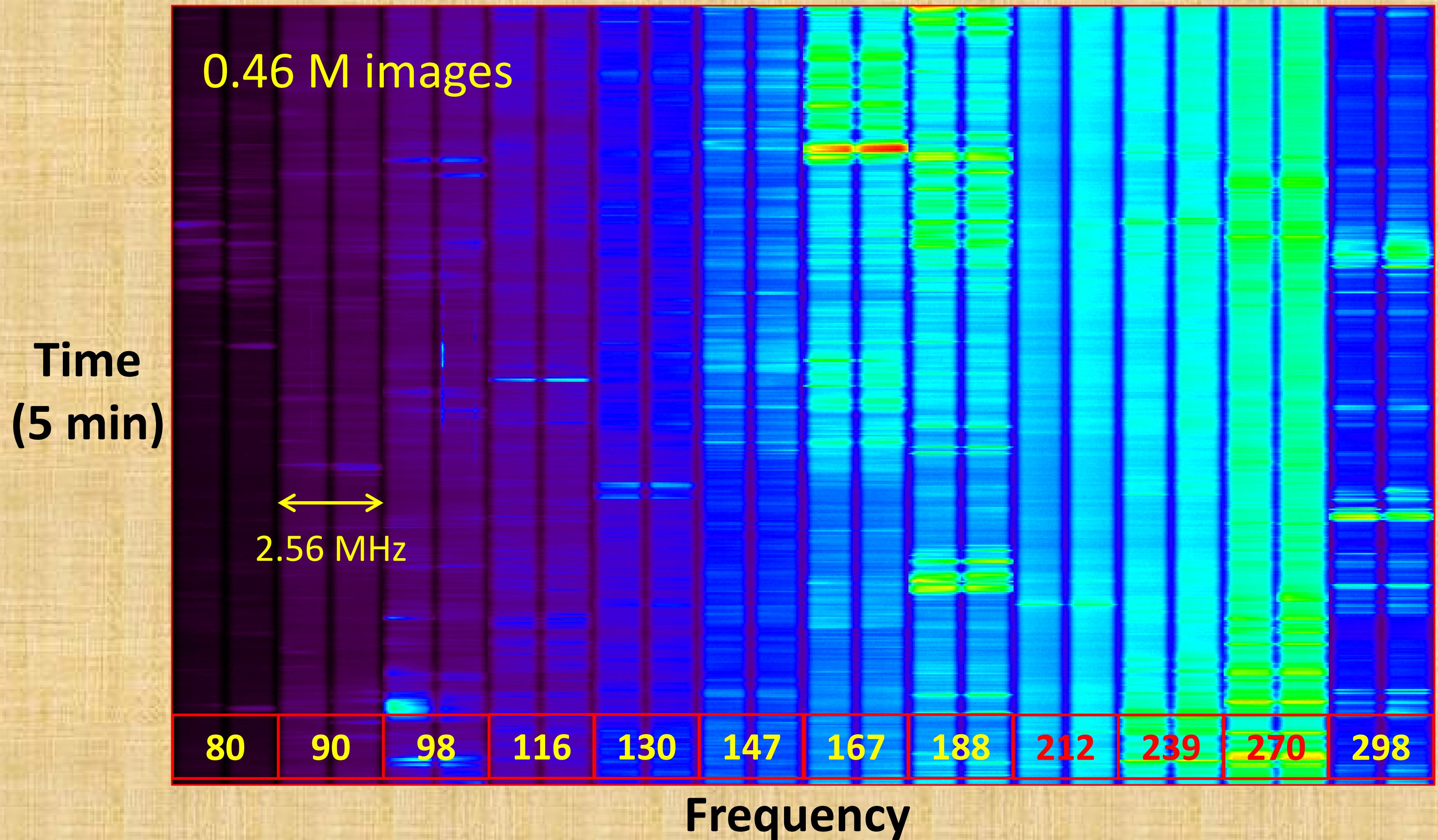
Refraction in the corona





Total Solar Eclipse 2006

Sample MWA Dynamic Spectrum

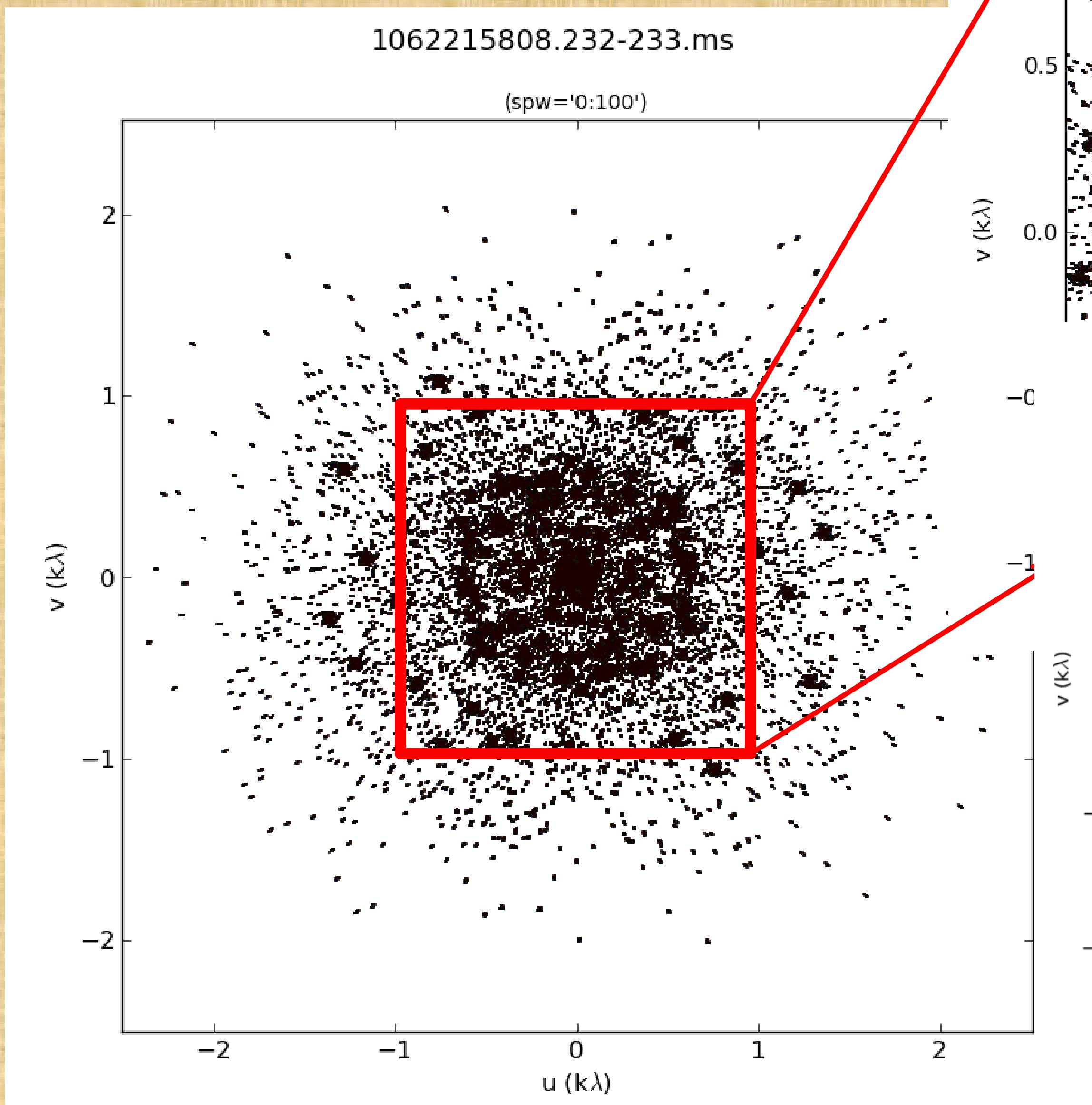


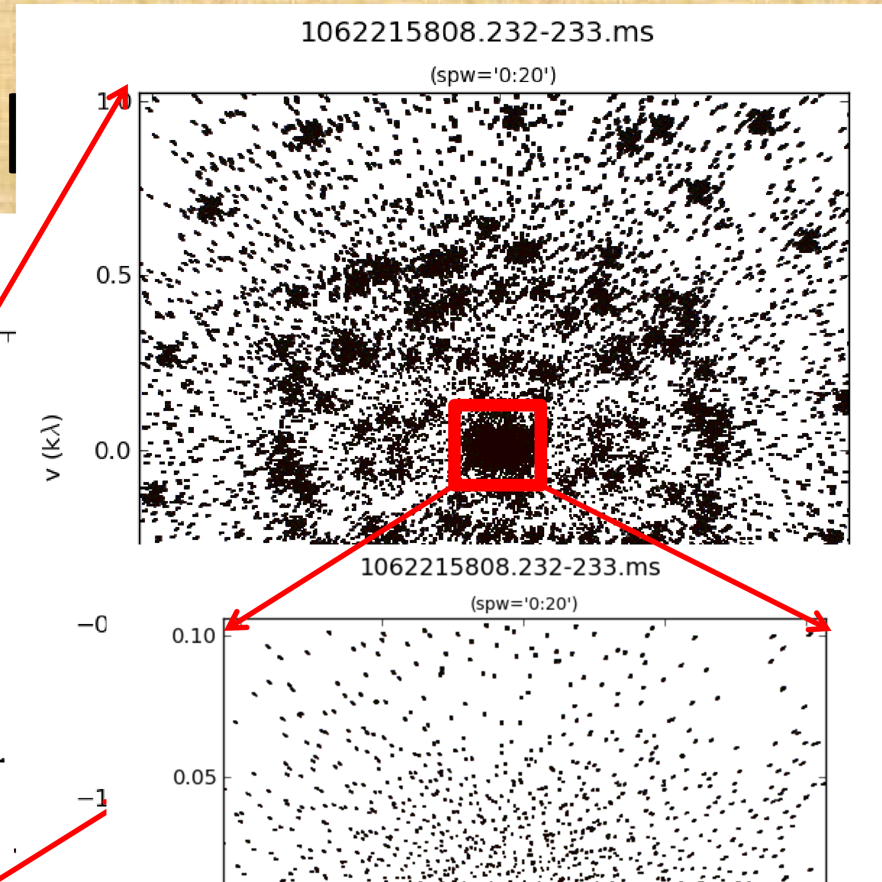
(12 log-spaced groups of 2.56 MHz spanning 80 – 300 MHz)

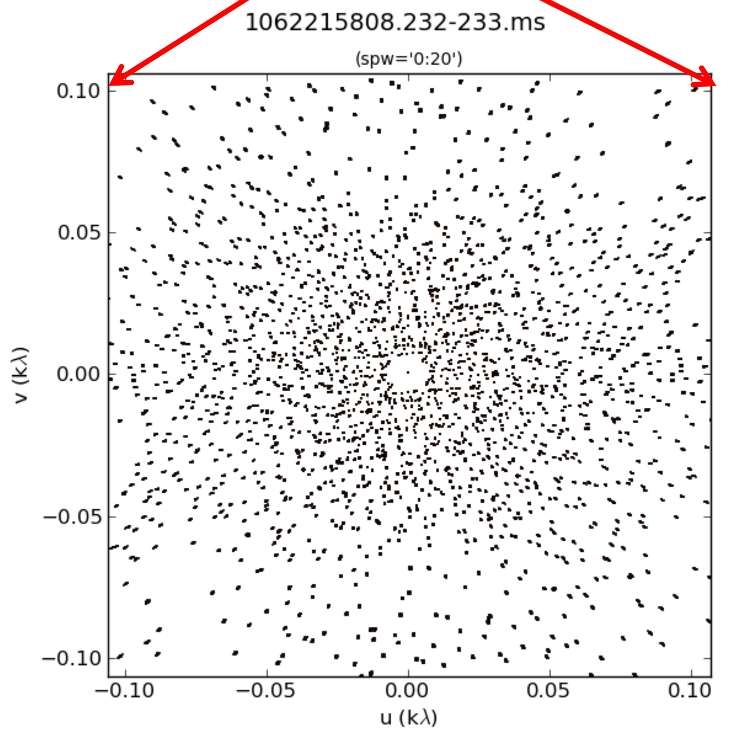
Needs of solar radio imaging

- More of everything
  - Time resolution (10s of ms)
  - Spectral resolution (10s of kHz)
  - Angular resolution (< arcmin)
  - Imaging dynamic range (> 10^5)
  - Full Stokes imaging

Sampling in th







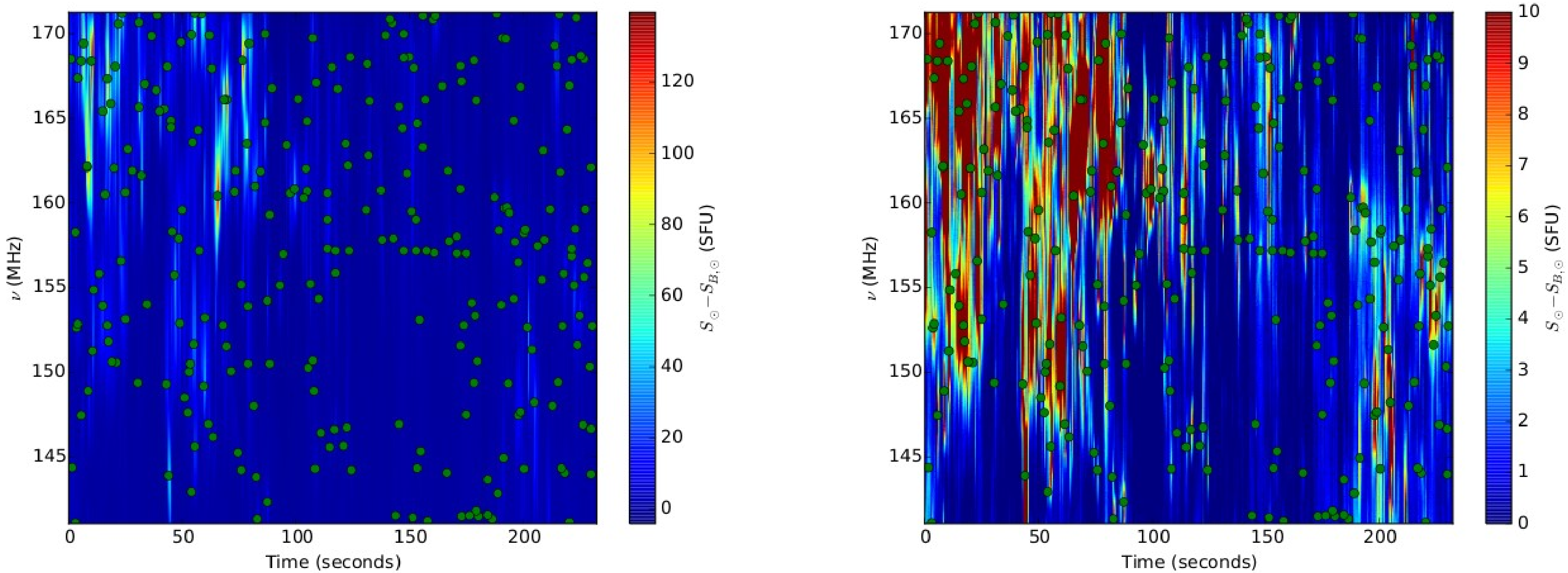
Snapshot uv coverage at 285 MHz

Plan

- The quiet Sun studies
- Event based solar studies
  - Type II bursts
  - Type III bursts
- High dynamic range solar imaging
- Heliospheric science
- Outlook

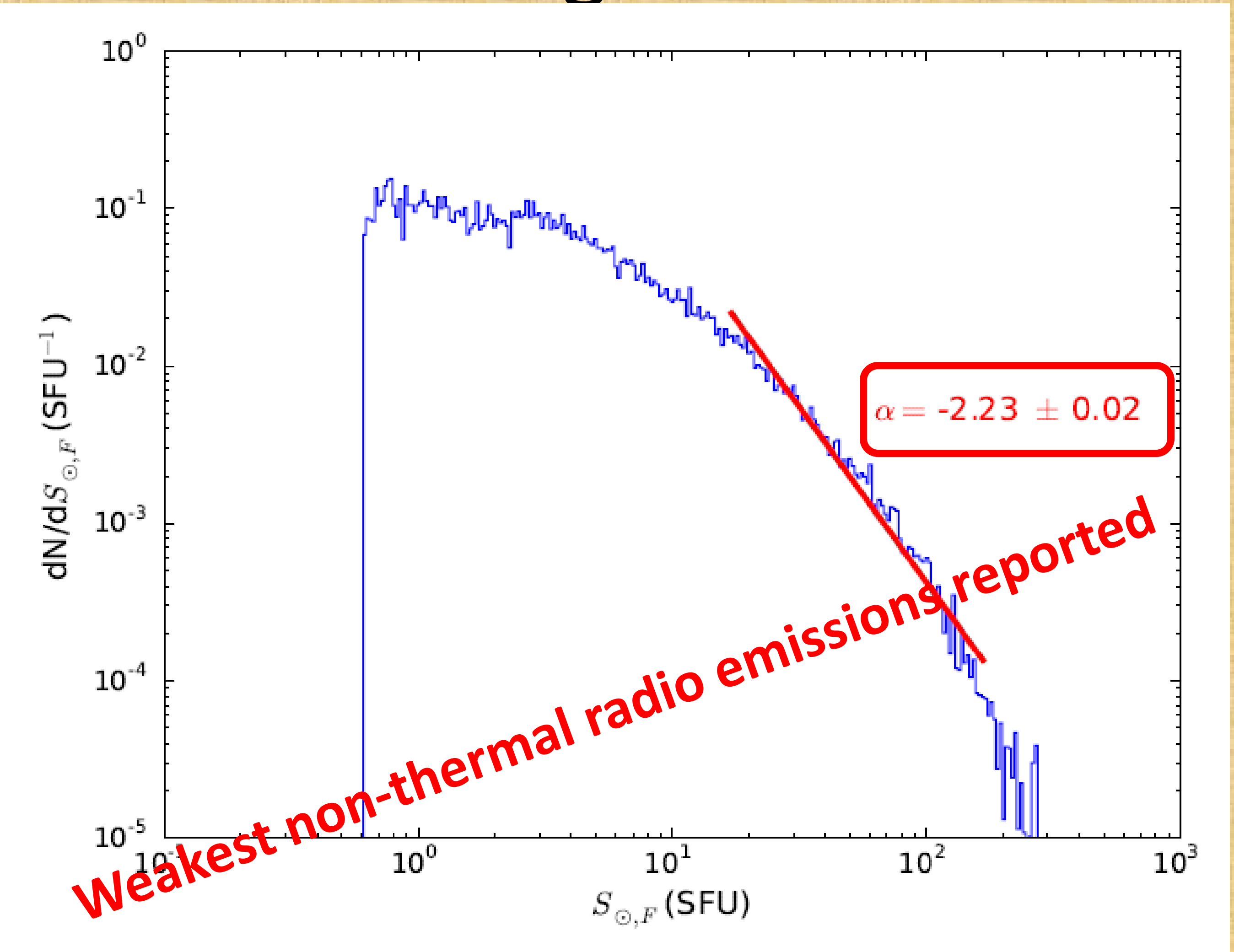
Characterizing weak features in solar dynamic spectra

- Wavelet based feature detection and characterization



Suresh, A. et al., 2017, ApJ

Interesting for nanoflare based coronal heating models

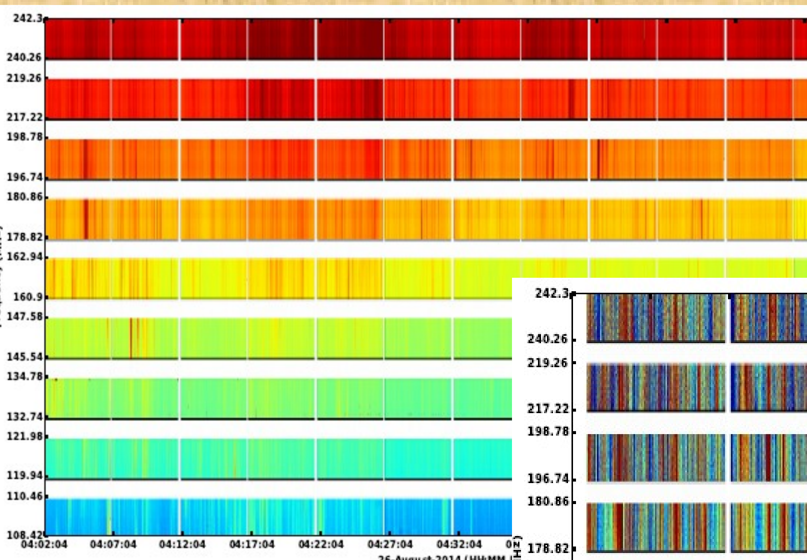


1 SFU = 10^4 Jy

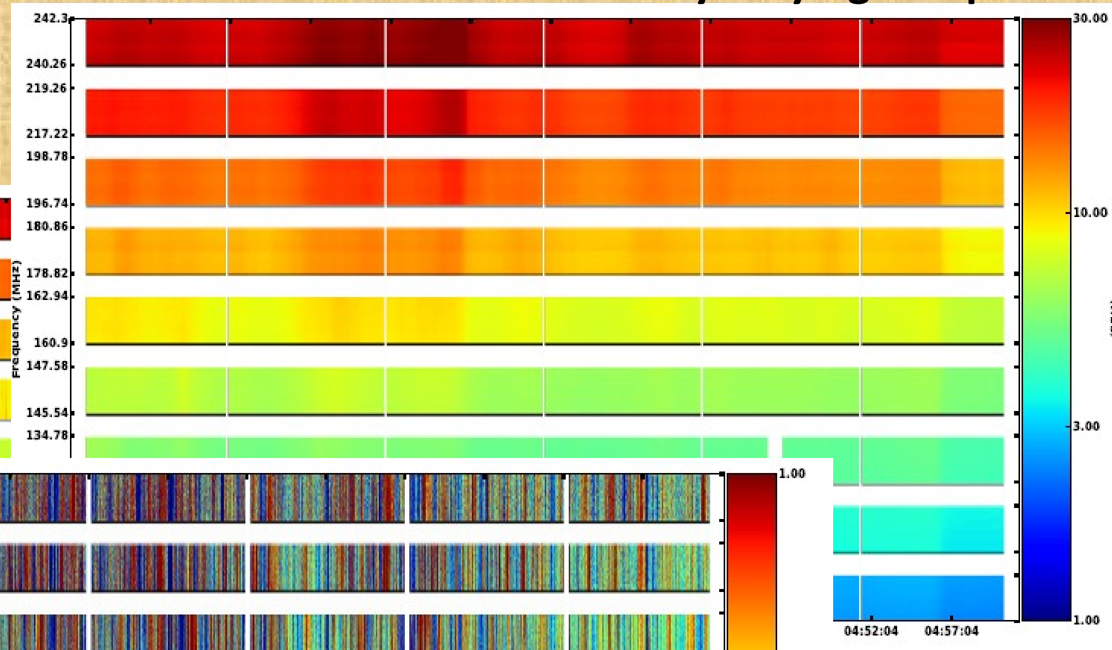
Suresh, A. et al., 2017, ApJ

Evidence for even weaker non-thermal emissions

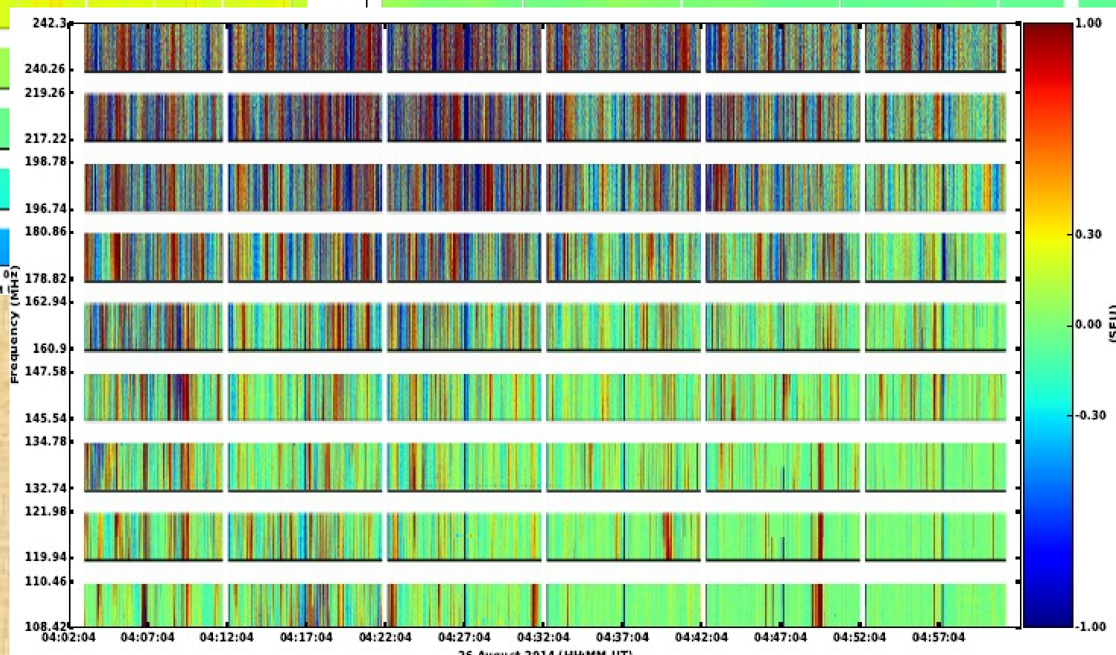
Observed DS



Slowly varying component

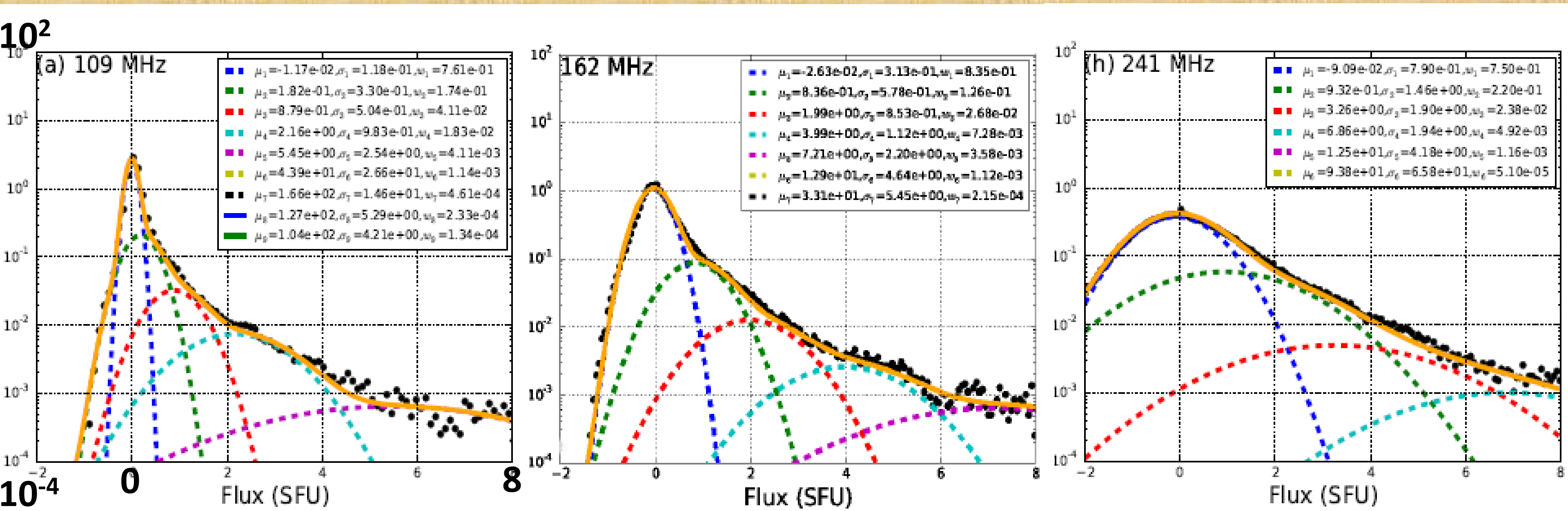


Impulsive component



Sharma, R. et al., 2017, In preparation

Gaussian Mixture Decomposition



- The 1st Gaussian – slowly varying component
- 1-w_1 = Impulsive (hence non-thermal) component

Sharma, R. et al., 2017, In preparation

Impulsive Emission: Fraction & Strength

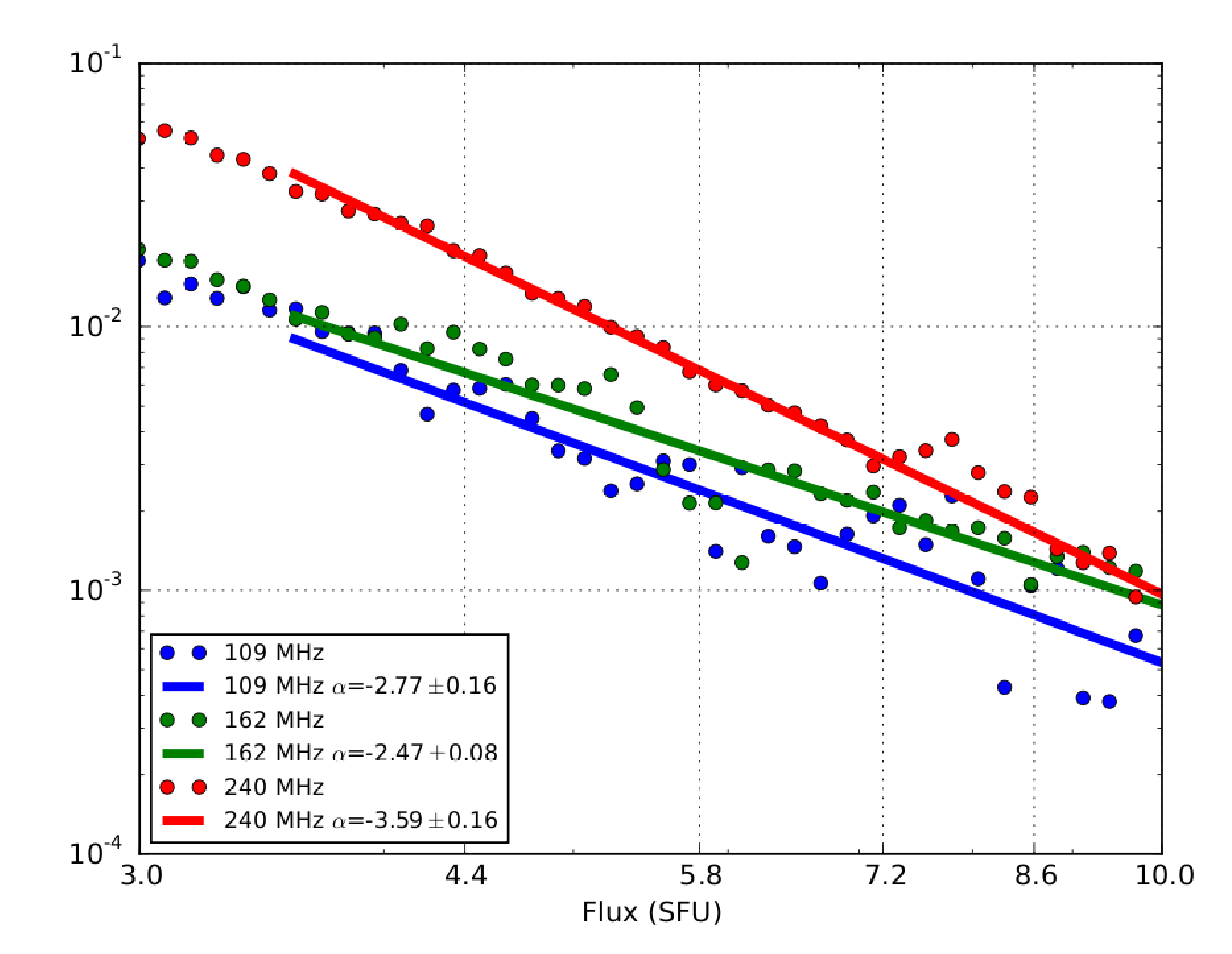
$$S_{Im}(SFU) = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu_1)y_i$$

x_i and y_i are the coordinates of the histogram for i^{th} bin and N is the number of histogram bins.

Frequency (MHz)	Continuum Flux (SFU)	Impulsive Flux (SFU)	Impulsive Fracti	PSF Area (arcmin^2)	T_b (K)
109.0	2.74 ± 0.34	5.43 ± 0.07	0.25 ± 0.01	47.3	3.7e+07
121.0	3.68 ± 1.31	4.62 ± 0.13	0.24 ± 0.0	38.4	3.2e+07
134.0	4.84 ± 1.46	3.33 ± 0.13	0.26 ± 0.02	31.3	2.3e+07
147.0	6.24 ± 0.74	5.77 ± 0.13	0.42 ± 0.07	26.0	3.9e+07
162.0	8.14 ± 1.07	5.79 ± 0.03	0.17 ± 0.0	21.4	4.0e+07
180.0	10.65 ± 1.62	10.44 ± 0.71	0.31 ± 0.03	17.3	7.3e+07
198.0	13.54 ± 2.34	13.35 ± 0.89	0.33 ± 0.02	14.3	9.2e+07
218.0	17.75 ± 3.02	12.96 ± 0.43	0.45 ± 0.05	11.8	8.9e+07
241.0	23.35 ± 3.38	16.24 ± 0.6	0.28 ± 0.04	9.7	1.1e+08

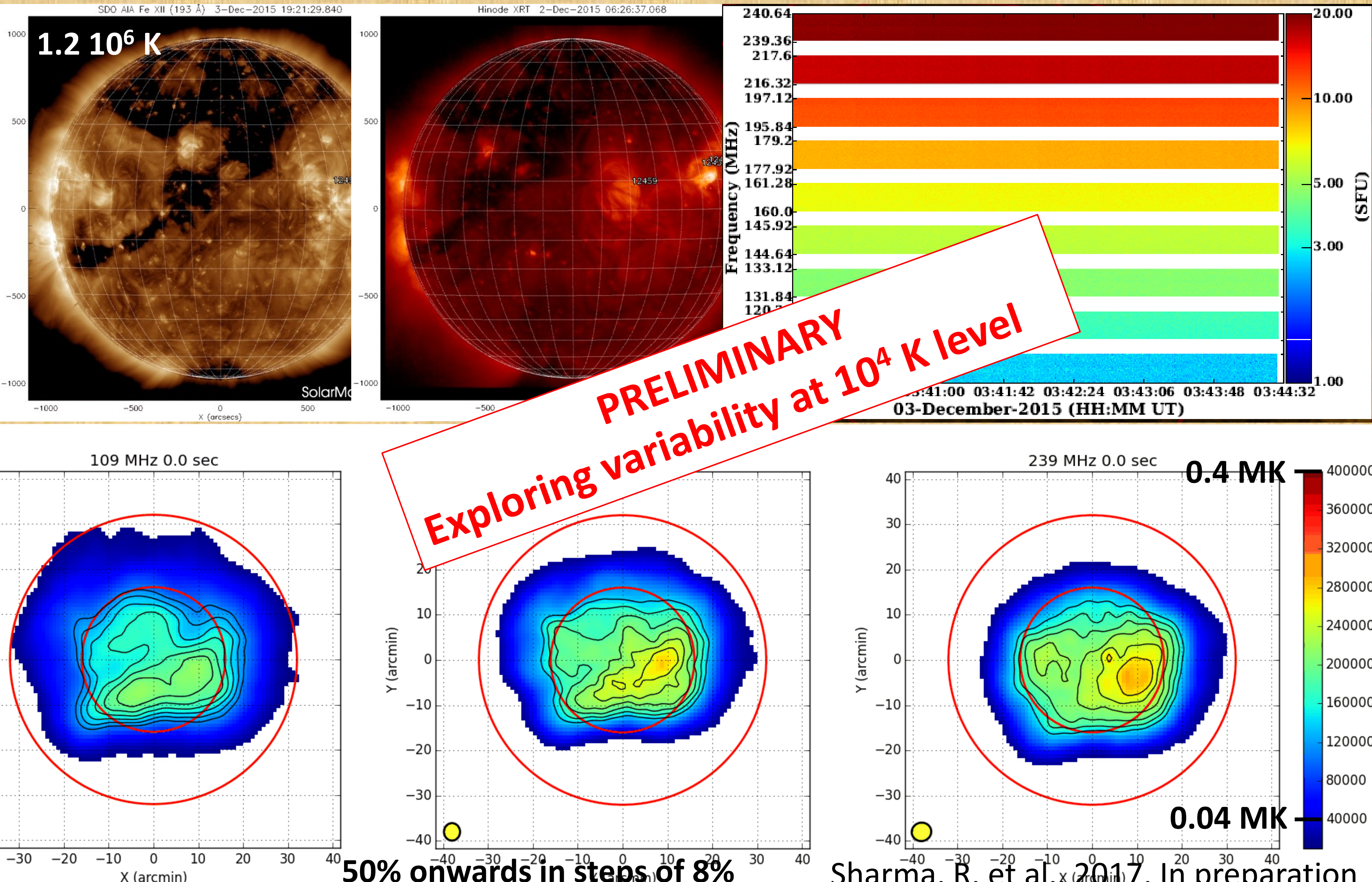
Sharma, R. et al., 2017, In preparation

More evidence for nanoflare heating



Sharma, R. et al., 2017, In preparation

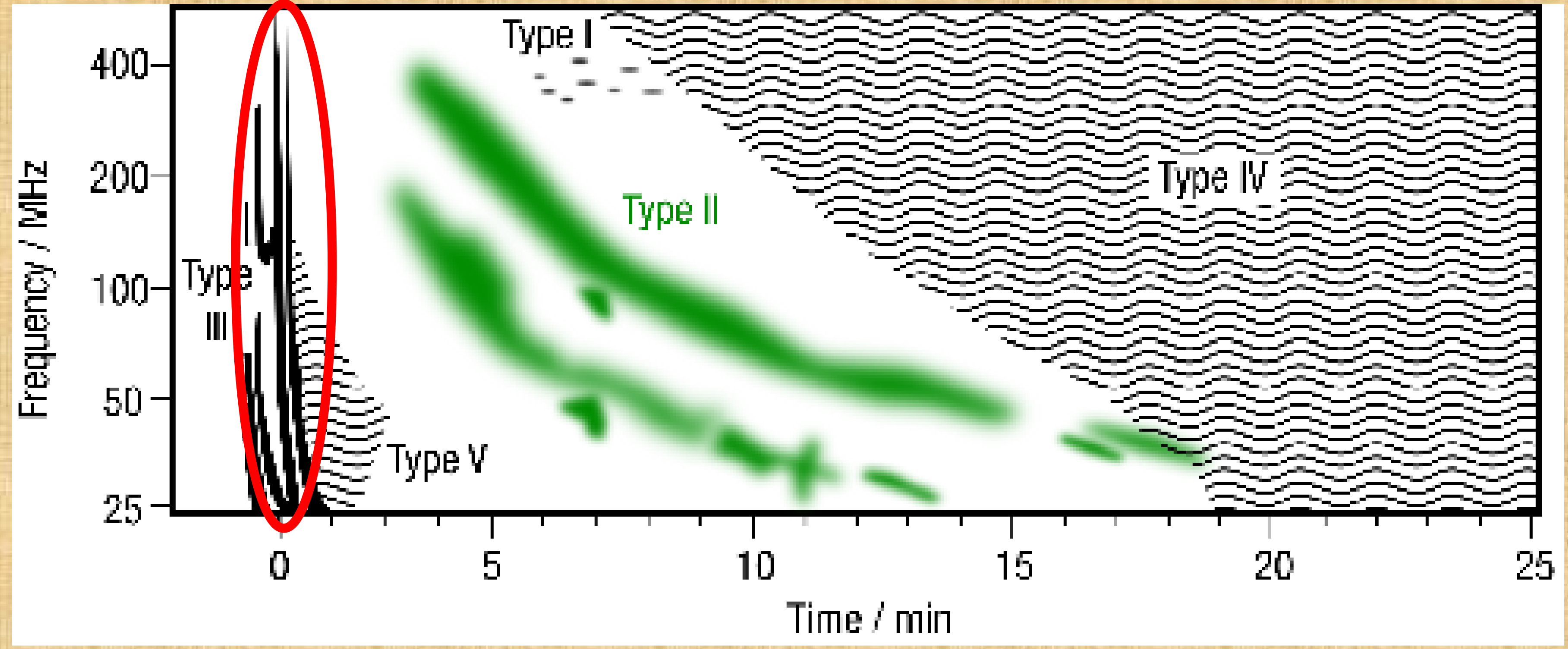
Evidence for nanoflare heating: Image plane



50% onwards in steps of 8%

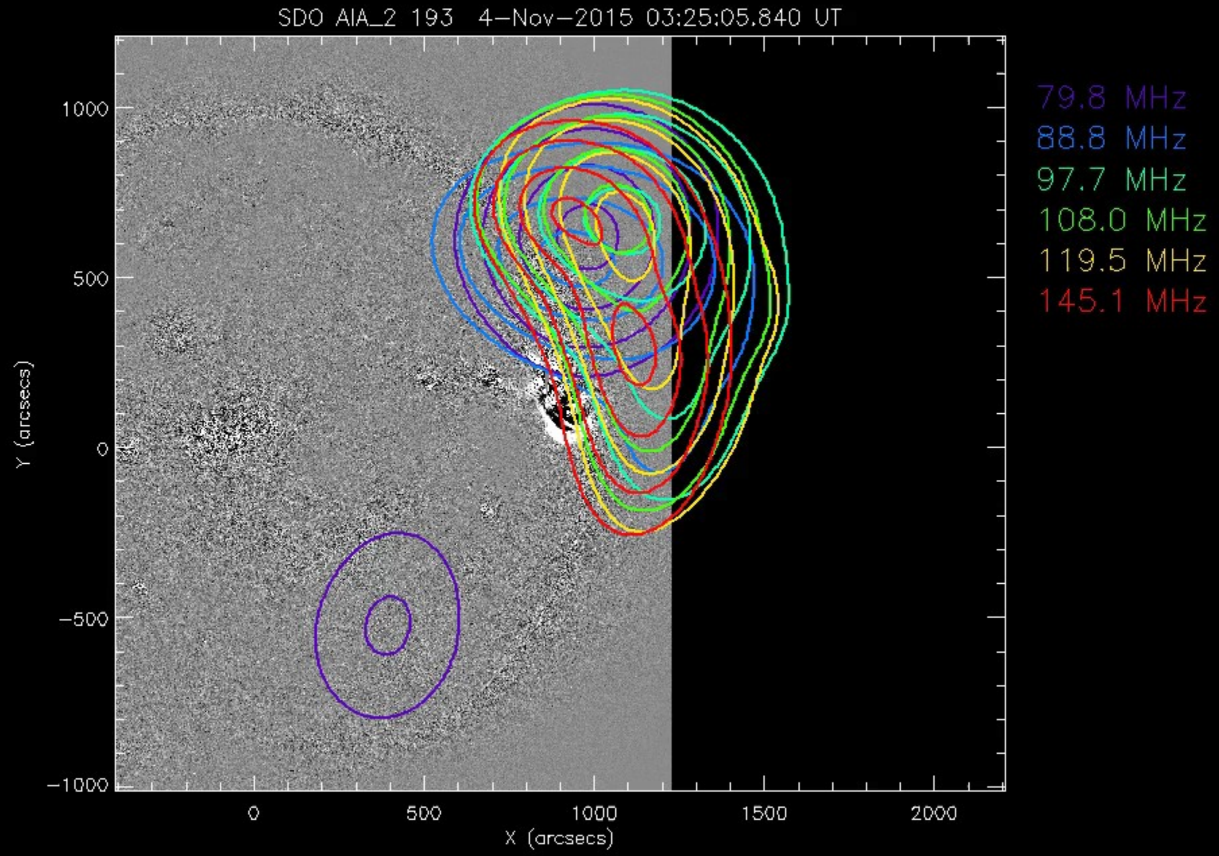
Sharma, R. et al., 2017, In preparation

Solar radio bursts : Classification



Ganse et al., 2012

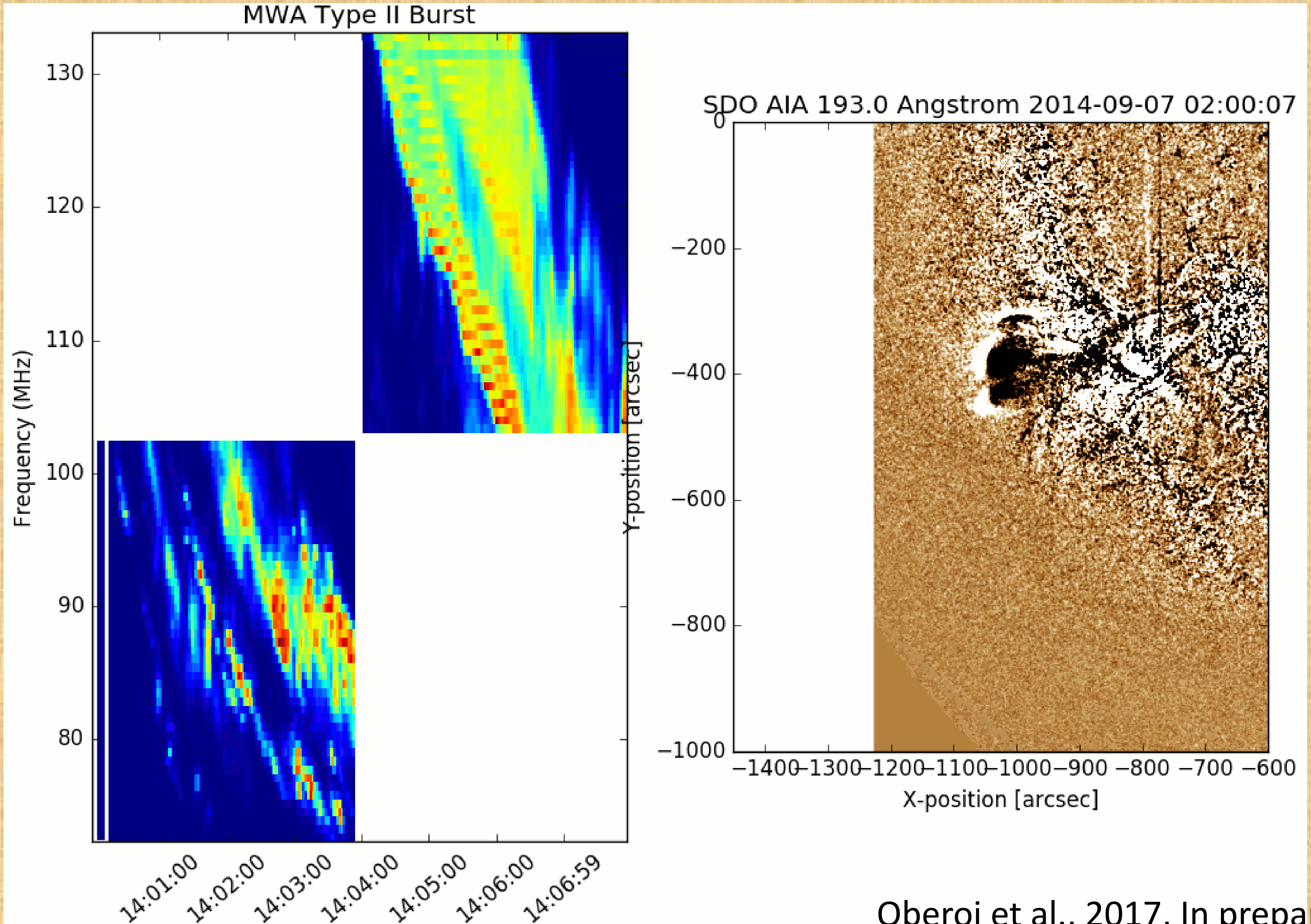
CME and Type II: Time evolution of sources



See poster by Kozarev et al.

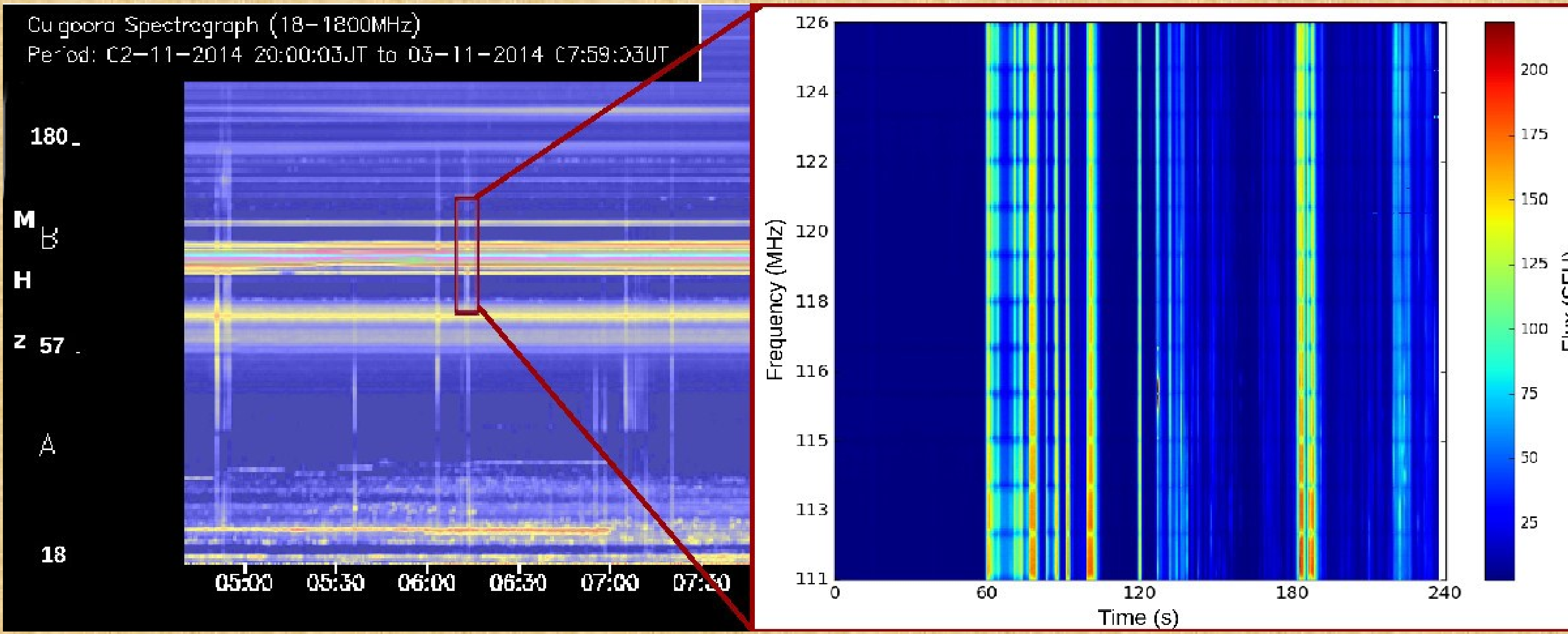
Kozarev, K. et al., 2017, In preparation

Type II: Tracking emission in 4D



Oberoi et al., 2017, In preparation

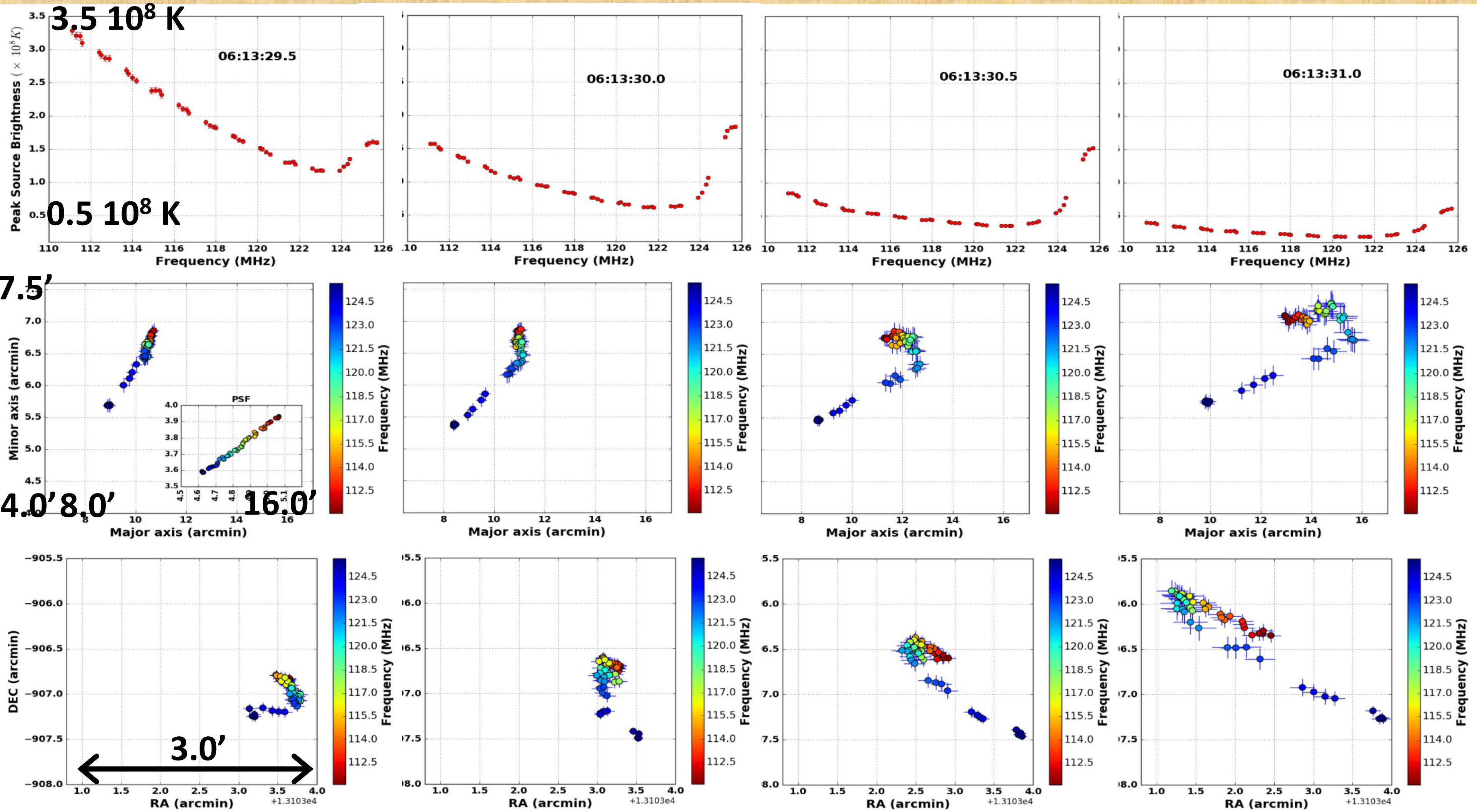
Study of a weak type III



- 02 Nov, 2014, observed in F (111-126 MHz) and H mode
- 10^9-10^{12} K (10,000 type IIIs from Nançay, Saint Hillaire, 2013)
- 10^8 K

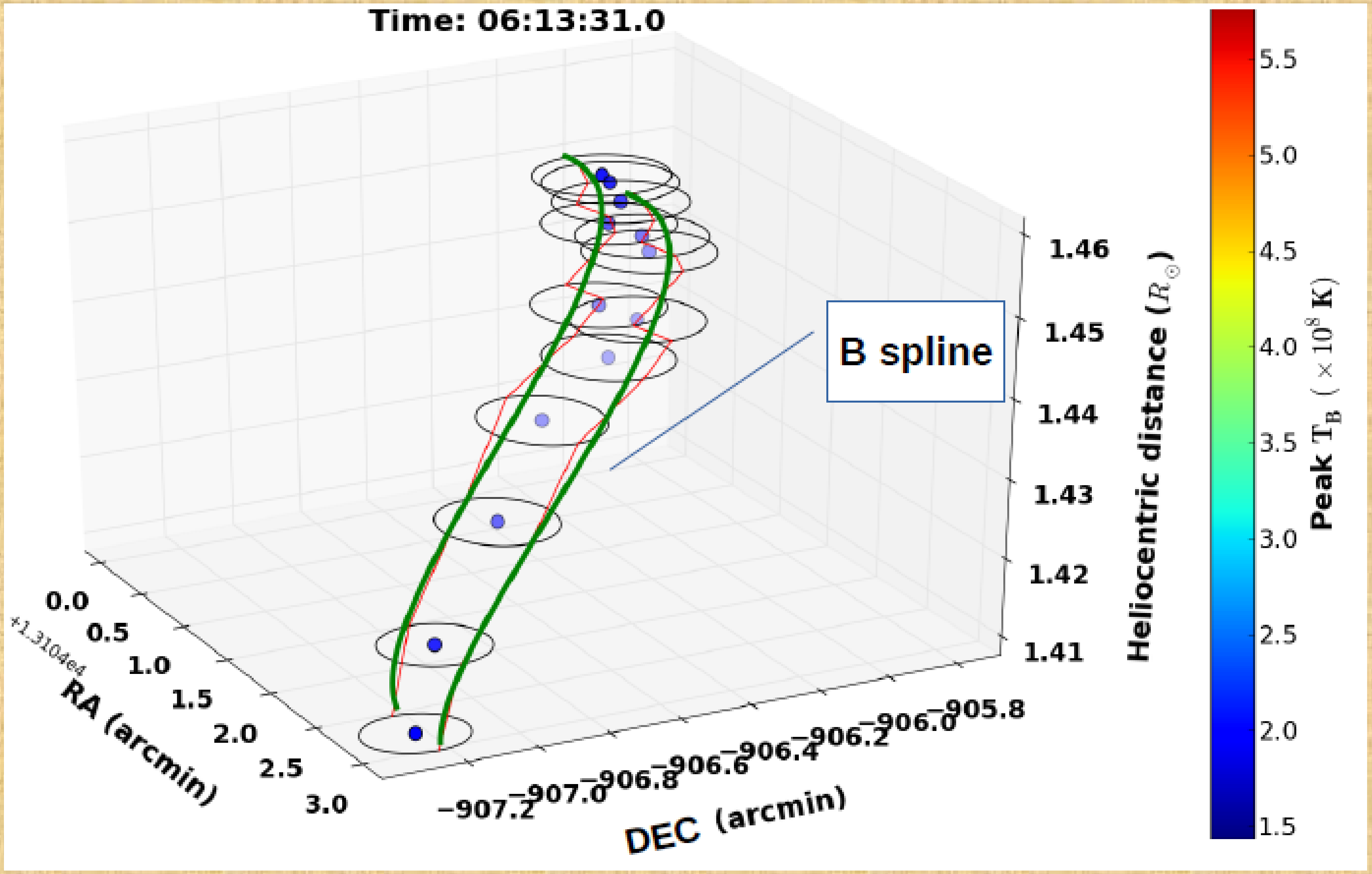
Mohan, A. et al., 2017, In preparation

Amazing dynamics!



Mohan, A. et al., 2017, In preparation

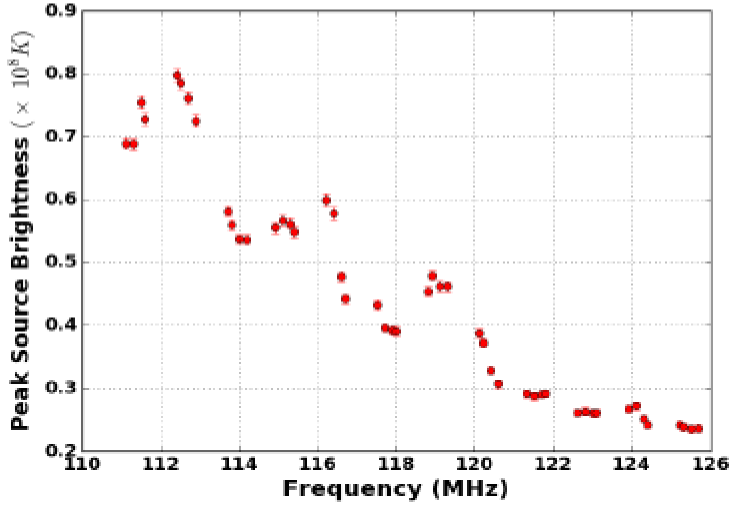
3D structure of B field

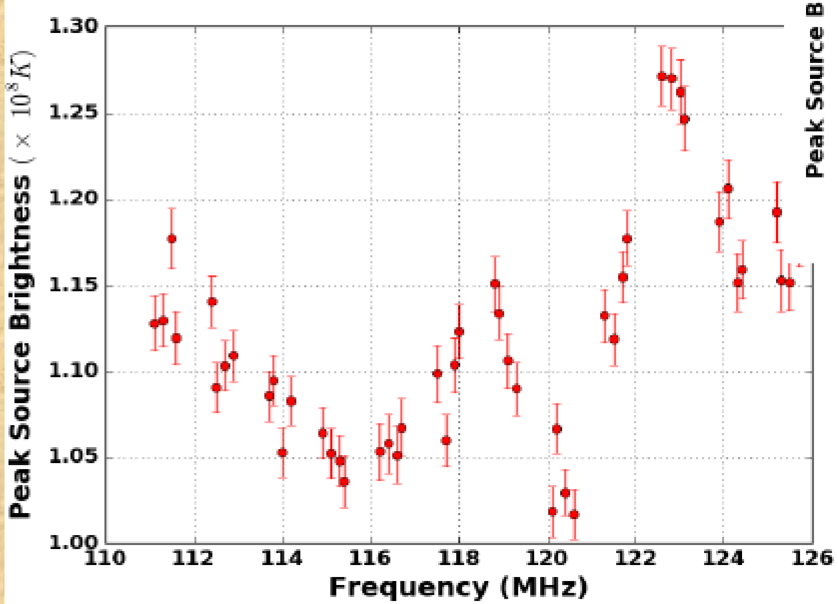


Mohan, A. et al., 2017, In preparation

Amplitude oscillations

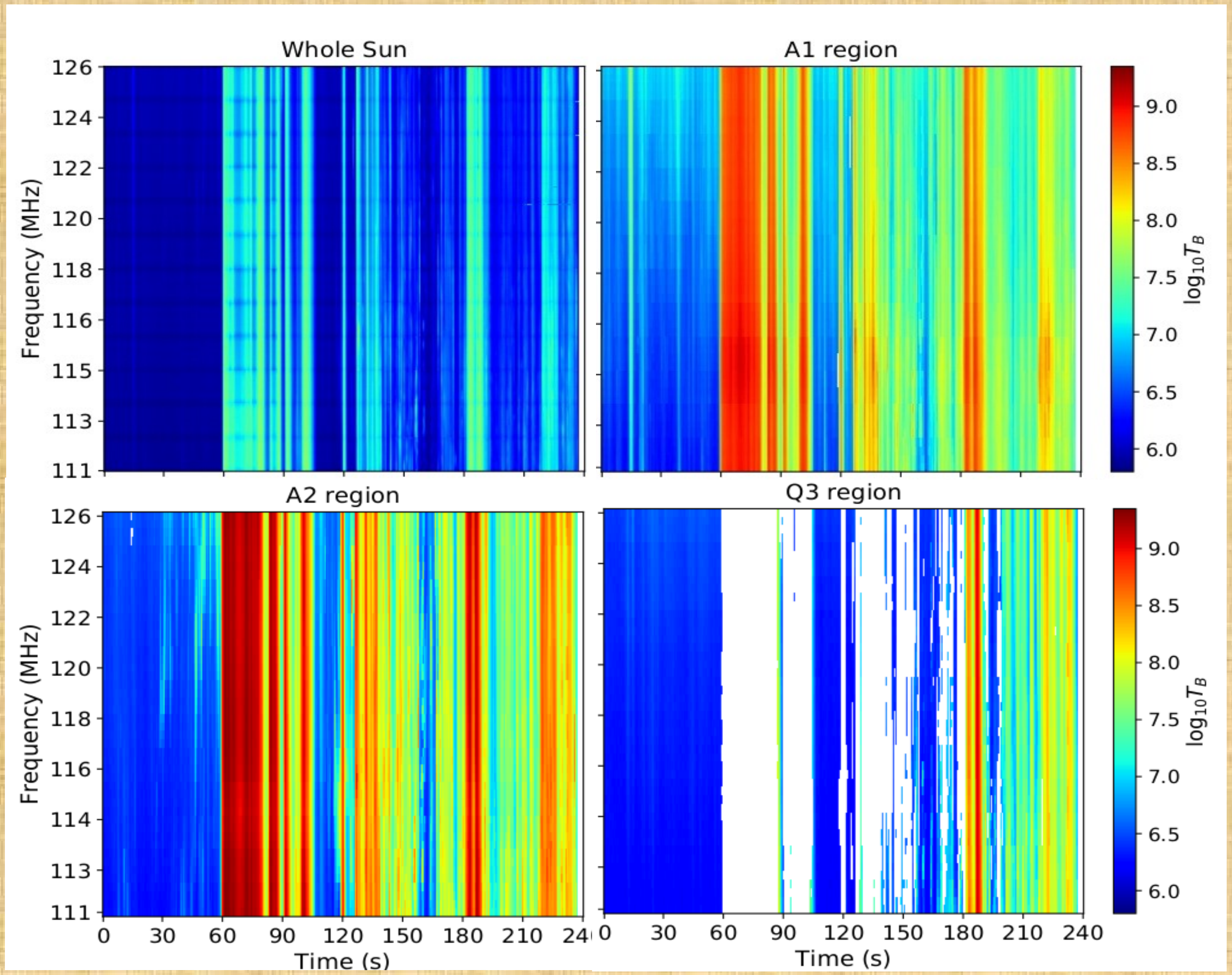
- Time variability
  - Could be loop MHD modes
  - Episodic jet?
  - Need more analysis





Mohan, A. et al., 2017, In preparation

Spatially resolved T_B dynamic spectra
$T_B(\theta,\phi,\nu,t)$



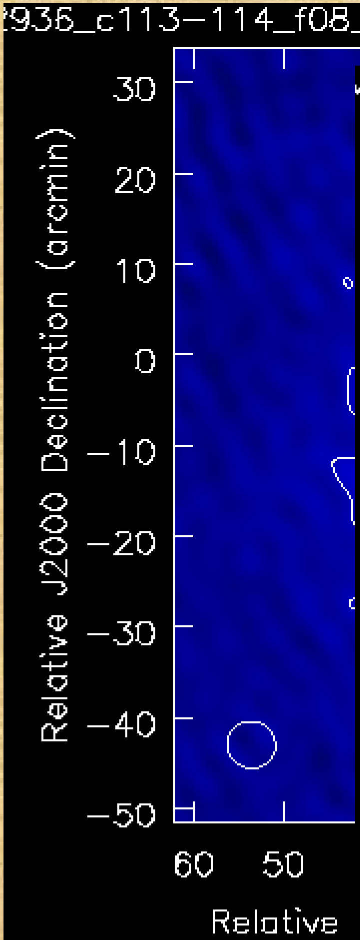
Mohan, A. et al., 2017, In preparation

High dynamic range imaging

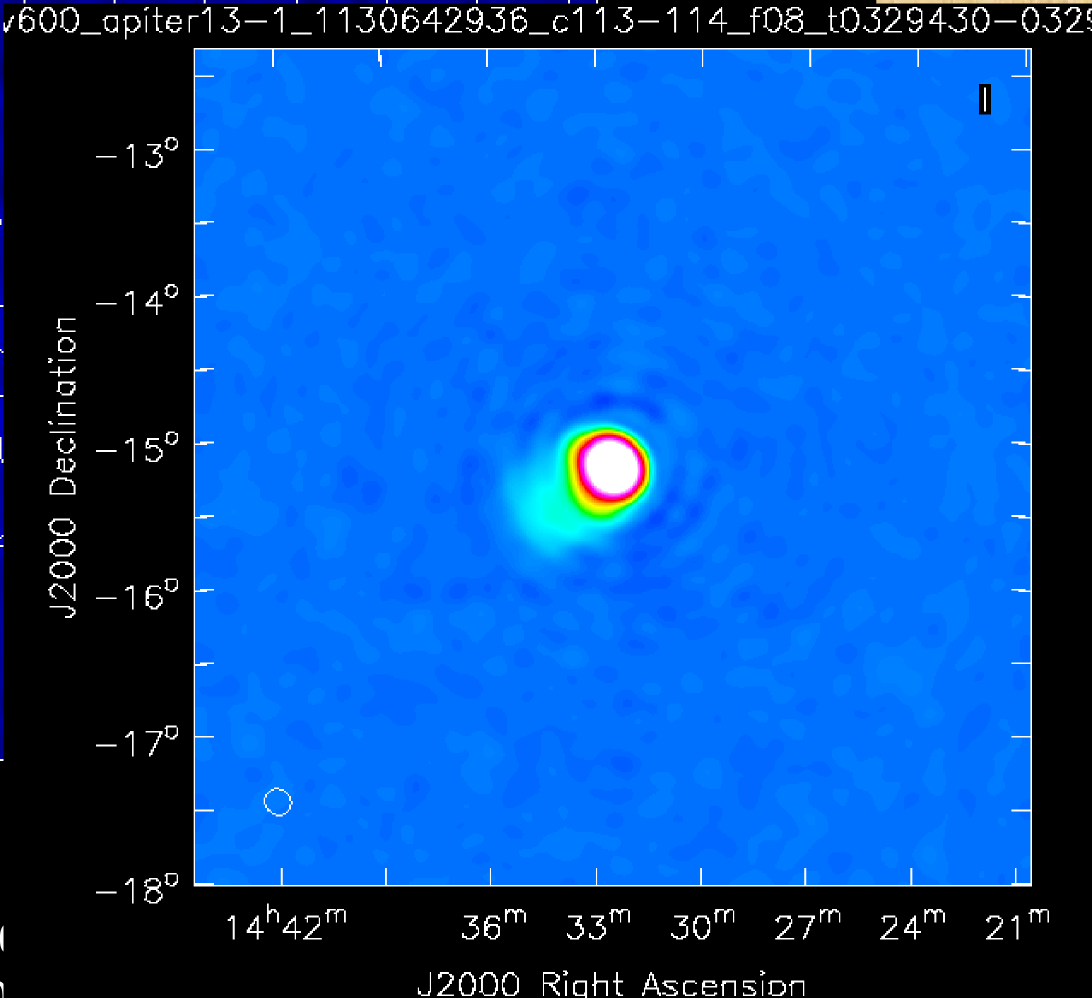
Extremely bright compact source during a type II burst

ν_0 = 144.9 MHz
$\Delta\nu$ = 40 kHz
Δt = 0.5 s

Quiet Sun ~5 10^4 Jy
Burst source ~10^6 Jy



Contour levels: ±(
0.0972, 0.2916, 0
B_{MAX} 1



Dynamic range ~38,600; B_{MAX} 600 m

Lonsdale et al., 2017

CME Physics

- Direct radio detection of CME plasma
  - Type II emission – 10^{10}-10^{12} K
  - Persistent non-thermal solar emission – 10^{7}-10^{8} K
  - CME synchrotron emission – 10^{4} K
  - Few published instances (e.g., Bastian et al., 2001)
- Strength of radio measurements
  - Direct measurements of CME magnetic field
  - Fraction of relativistic and thermal plasma

Space Weather

- Faraday rotation of linearly polarized background (Galactic) radiation due to the passage of the magnetized CME plasma across the LoS
  - Handle on CME B field – Holy grail of Space Weather physics
- Use of Interplanetary Scintillation (IPS) for constraining size, speed and turbulence properties of CMEs and solar wind
  - Rajan Chhetri – Thu morning; AGN Physics
  - Richard Fallows – Thu late afternoon; Ionosphere

Outlook

- We are only picking up the shiniest pebbles on the beach yet.
- Build the tools and techniques to analyse larger volumes of data in great detail.
- Build tools to condense the information from the above analysis into humanly intelligible forms!
- New generation instruments have really opened up new and pristine phase space for studying both the quiet and the active Sun.
  - Expect surprises and fascinating new science