# Radio counterparts of a behind the limb flare detected by FERMI GBM:

## A coronal mass ejection magnetic field strength estimate.

Eoin P. Carley[1,2], Brían Ó Fearraigh[2], Nicole Vilmer[1] and Peter T. Gallagher[2]

[1] l'Observatoire de Paris, France.

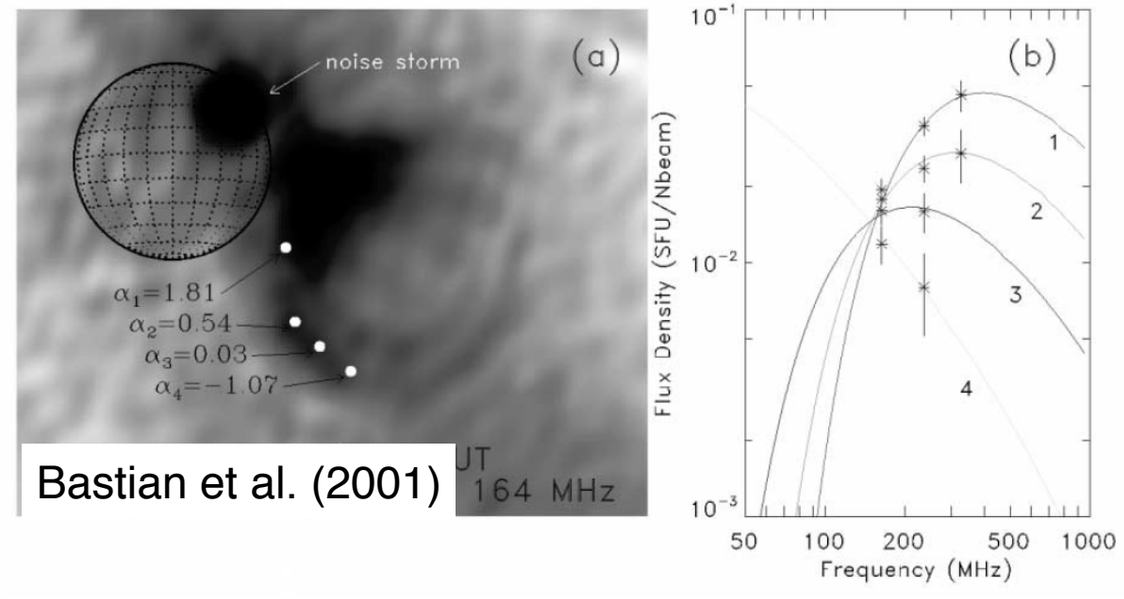
[2] Trinity College Dublin, Ireland.


TRINITY COLLEGE DUBLIN
COLÁISTE NA TRÍONÓIDE
THE UNIVERSITY OF DUBLIN

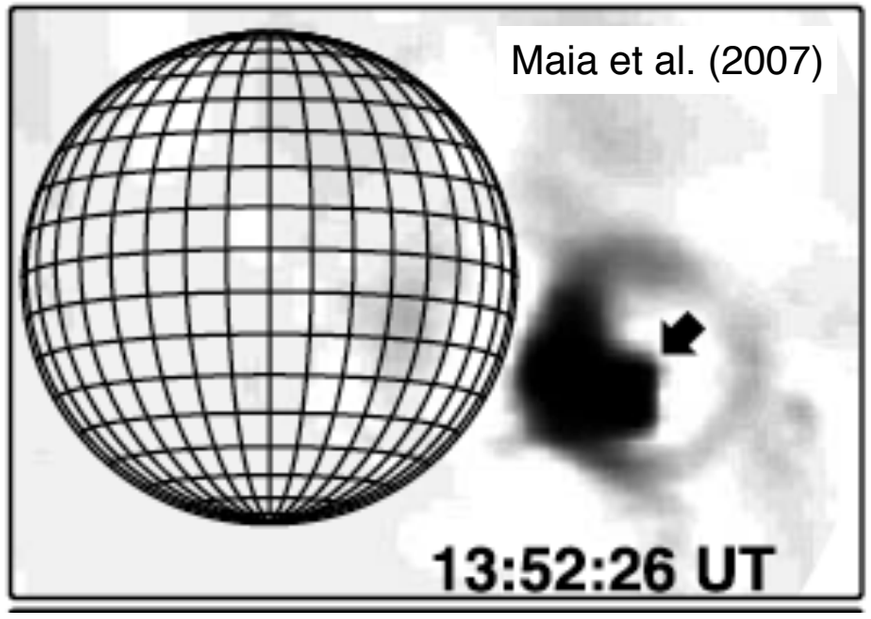
IRISH RESEARCH COUNCIL
An Chomhairle um Thaighde in Éirinn

eoincarley@gmail.com

# Introduction - Observing CMEs in radio



Bastian et al. (2001)

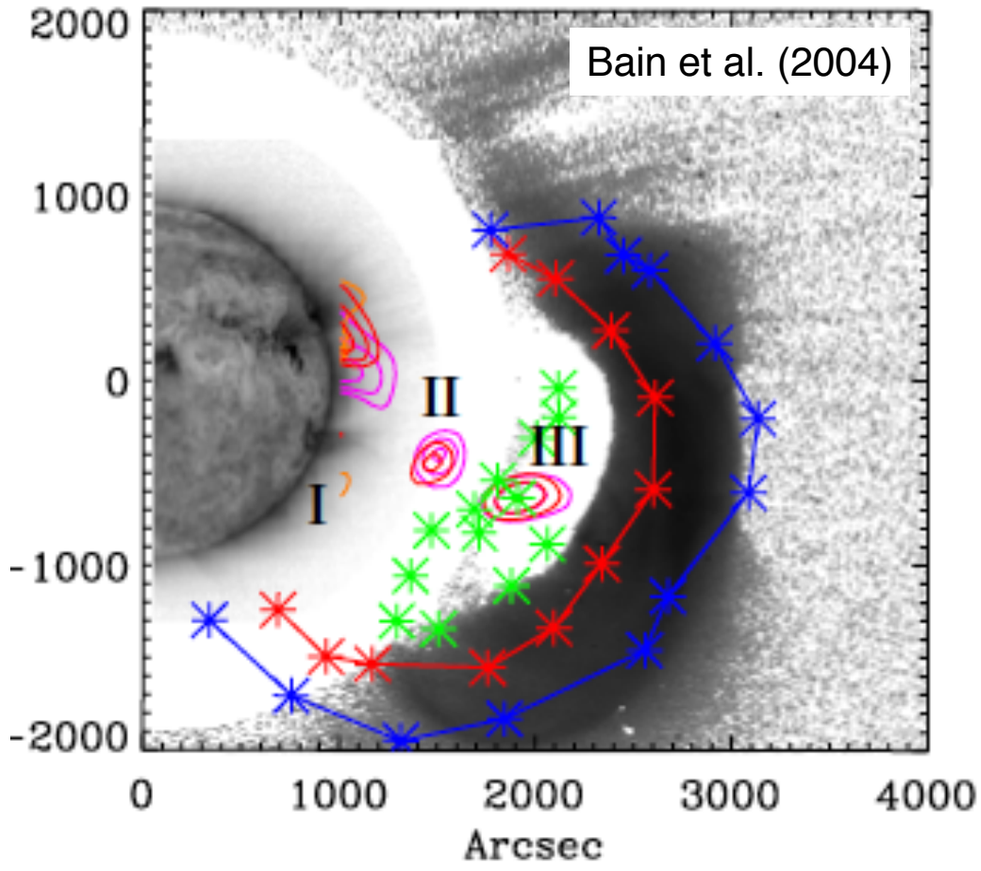


Maia et al. (2007)

- Observing CMEs in decimetric domain can show evidence for (gyro)synchrotron emission

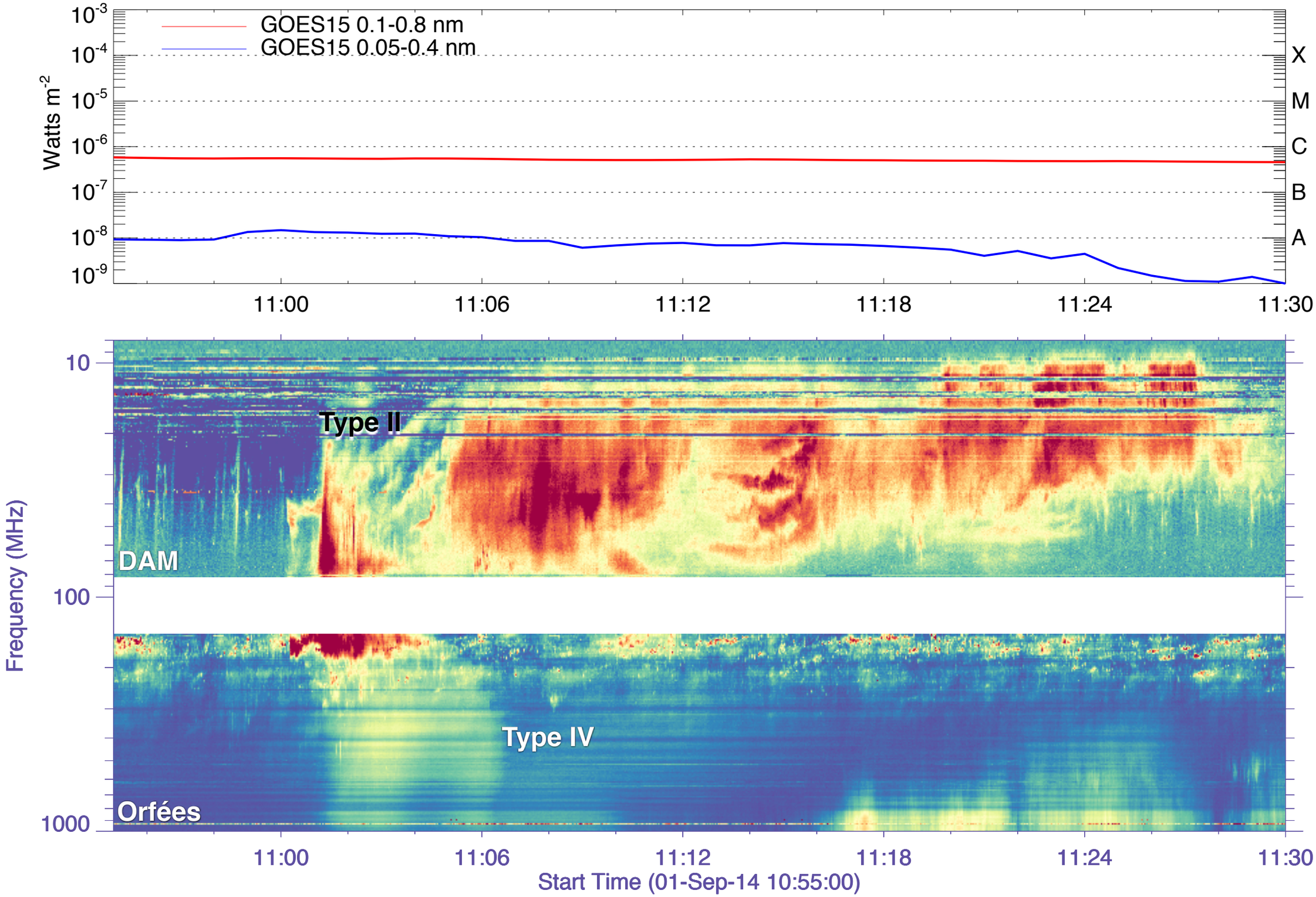
- Allows for rare diagnostic of CME magnetic field

- Bastian et al. (2001): 0.3-1.5 G
  Maia et al. (2007): 0.1-1.0 G
  Raja et al. (2014): 1.4-2.4 G
  Bain et al. (2014): 3-5 G
  Tun & Vourlidas (2013): 15 G

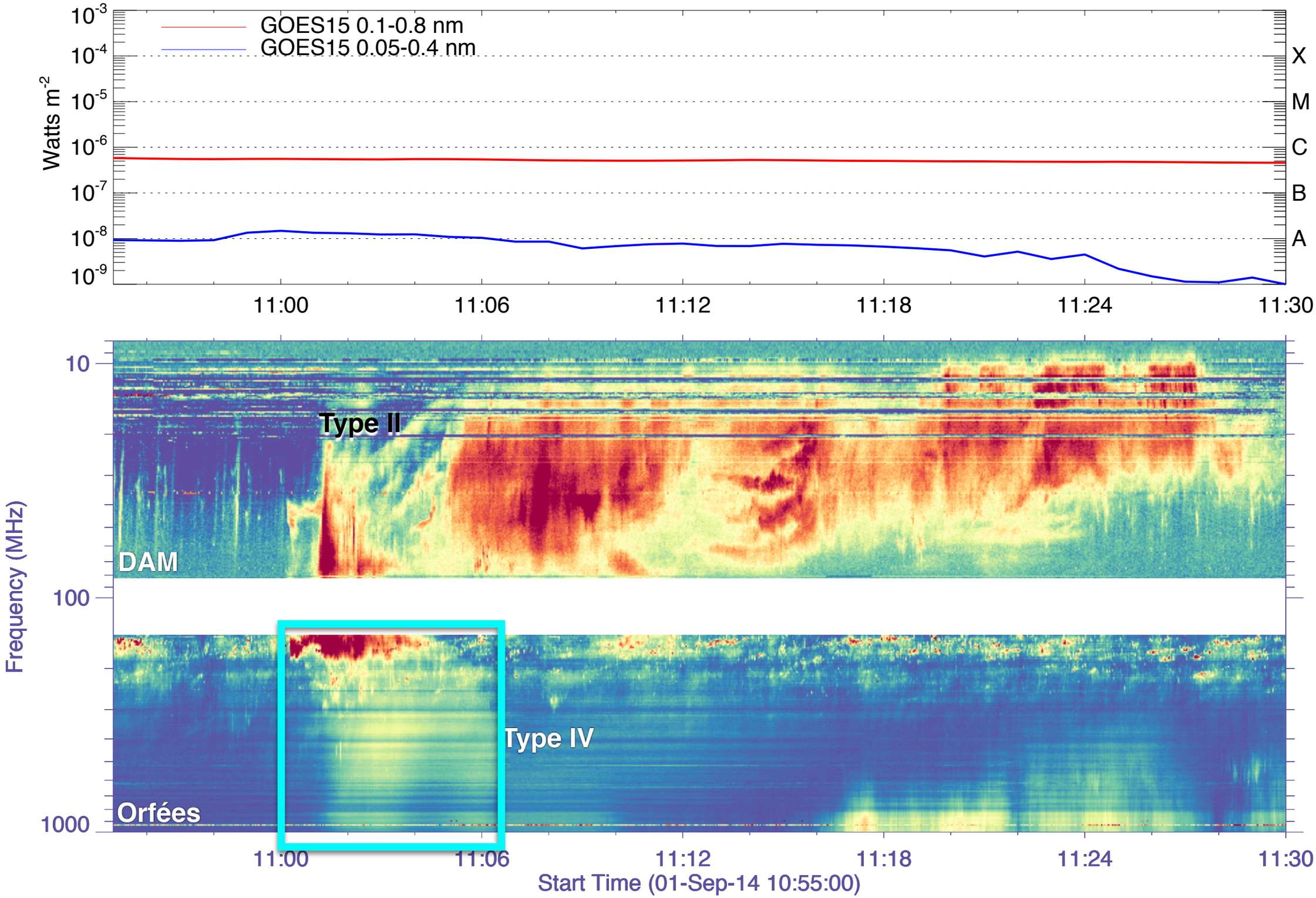


Bain et al. (2004)

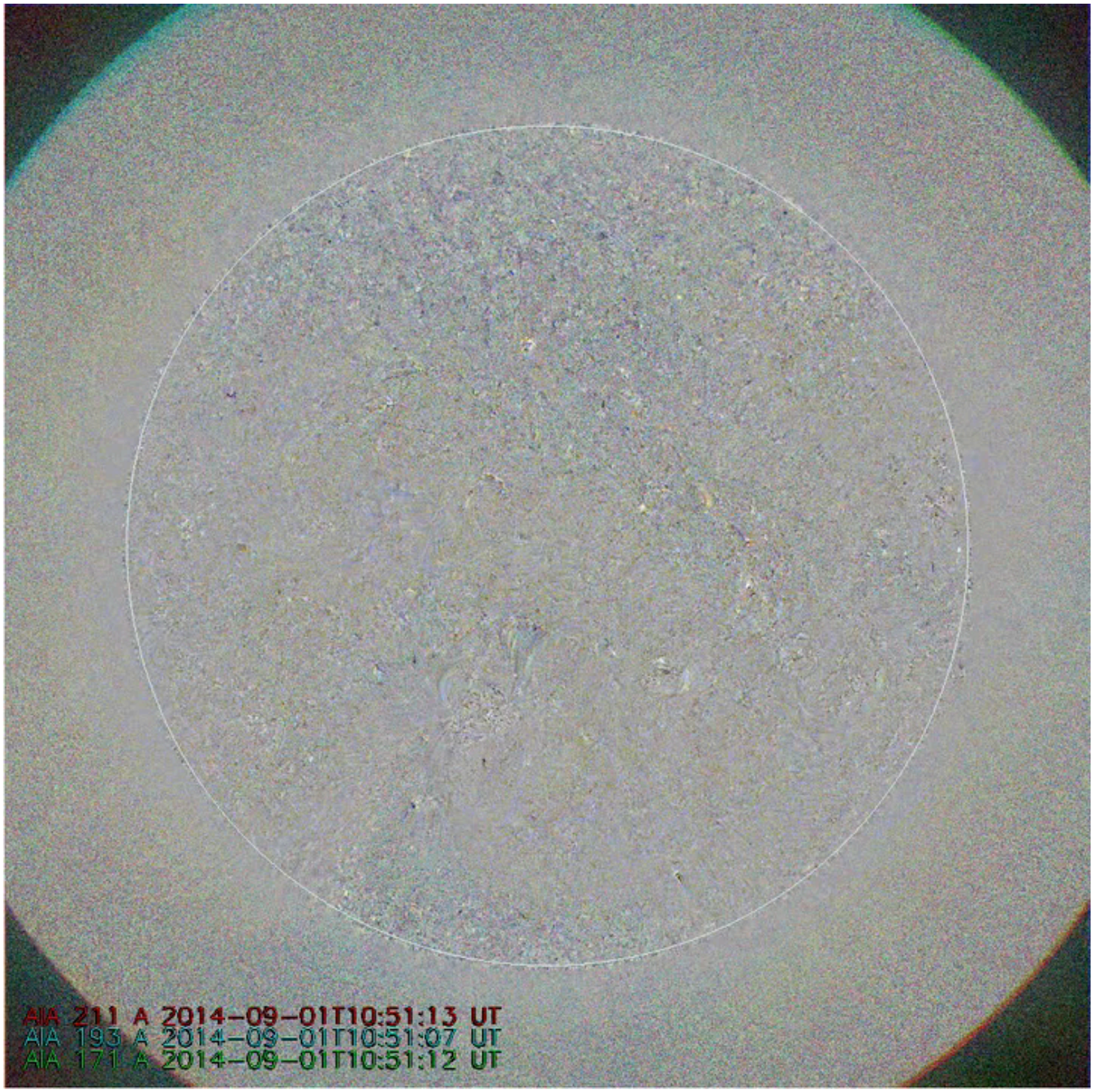
# 2014-September-01 Event - Radio event



# 2014-September-01 Event - Radio event

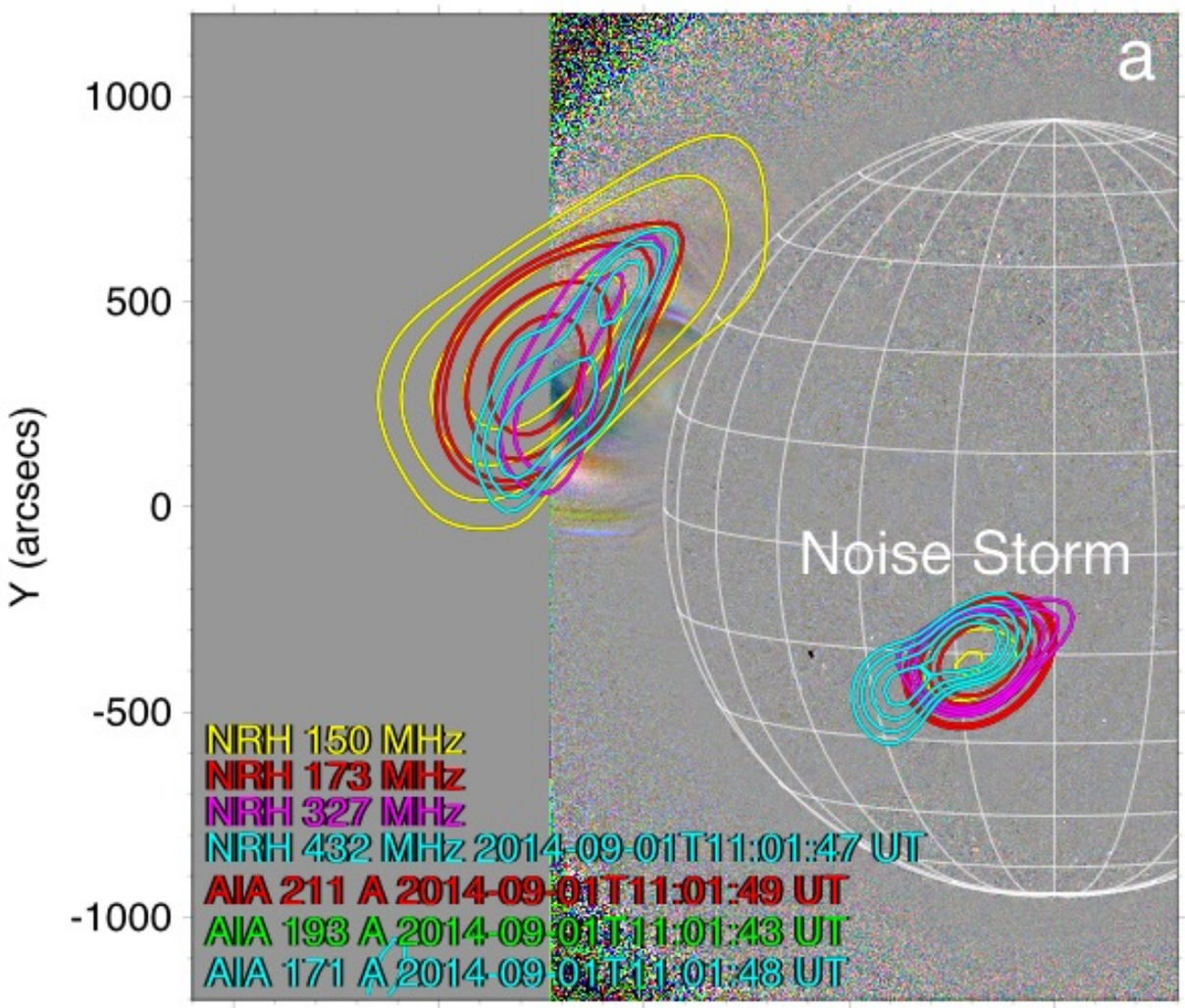


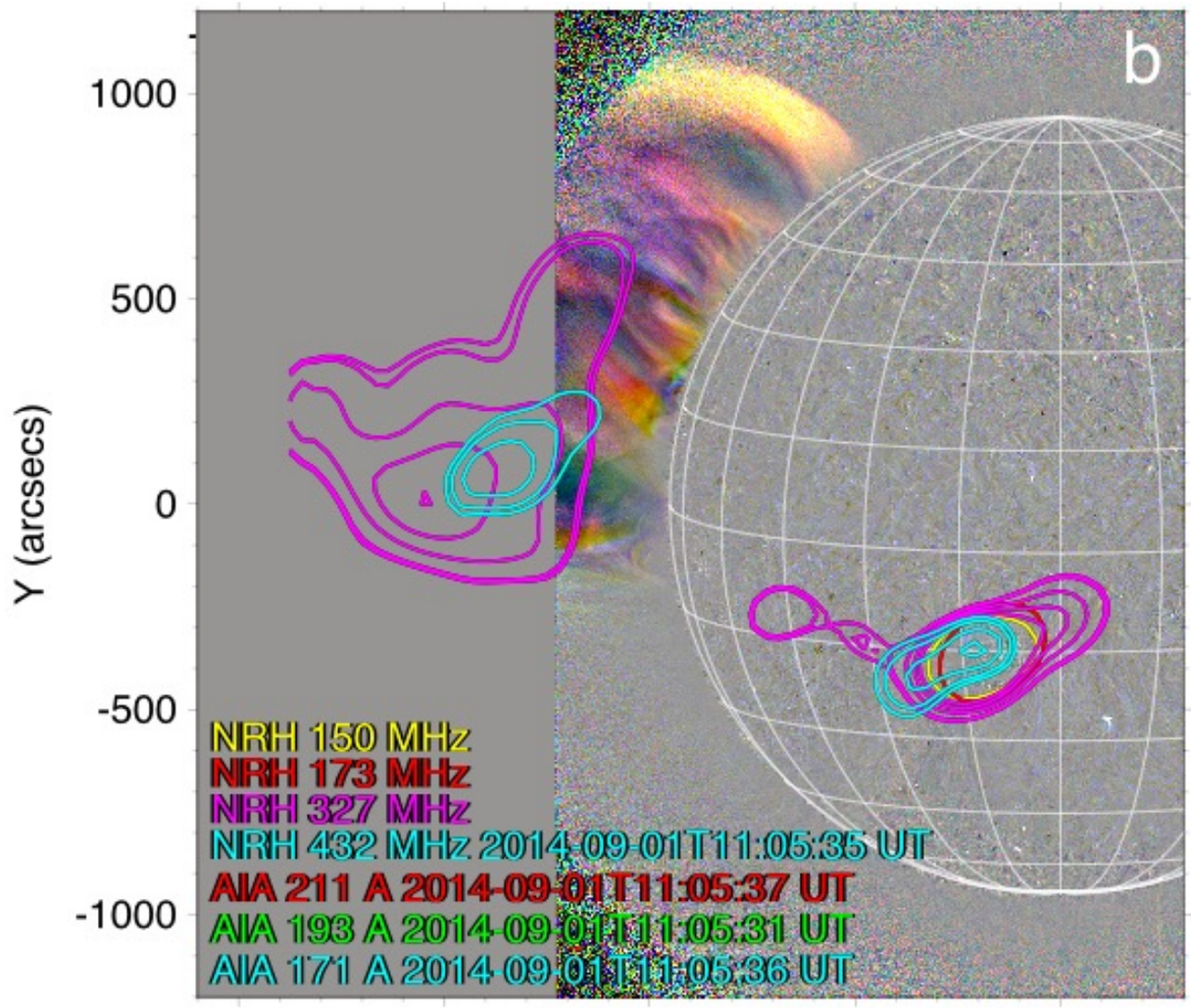
# 2014-September-01 Event




- AIA 21.1 nm (red), AIA 19.3 nm (green), AIA 17.1 nm (blue)
- Eruption off the east limb
- EUV wave propagating both north and South
- X2.1 flare 36 degrees beyond east limb. CME of ~2000 km $s^{-1}$ (Pesce-Rollins et al. 2015)

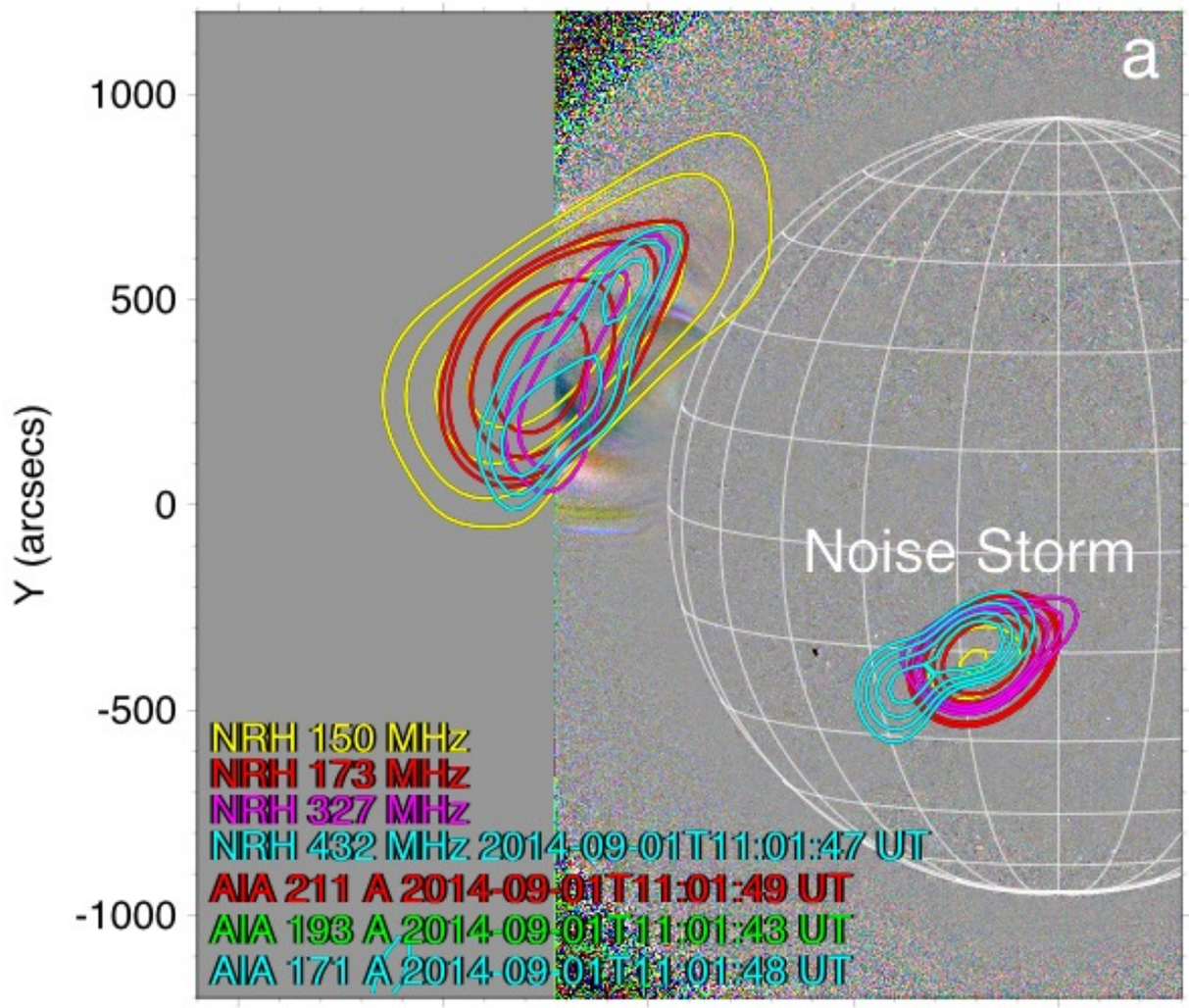
# 2014-September-01 Event - EUV + Radio Imaging

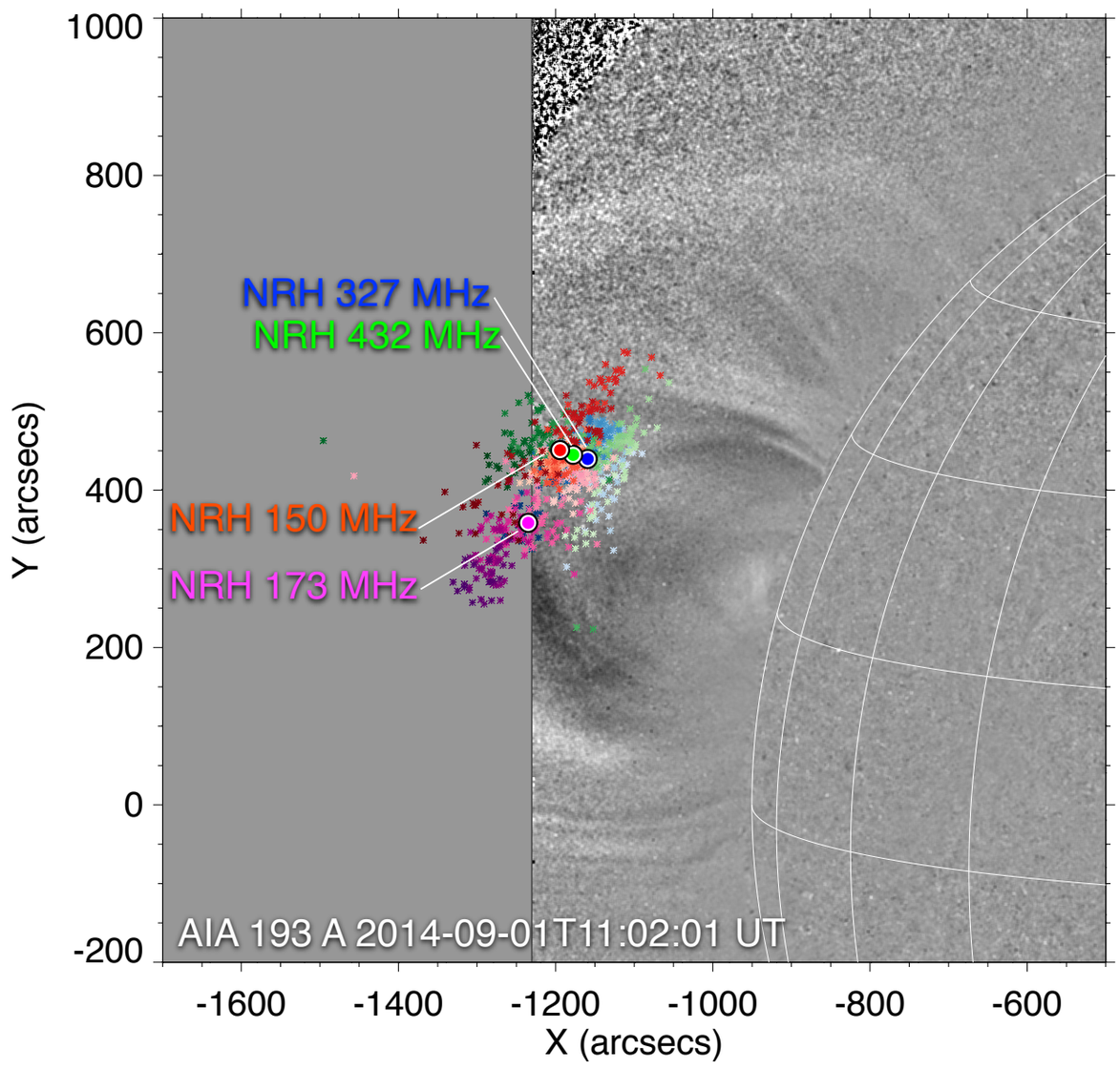



- Eruption off the east limb
- Large radio sources ~0.7 $R_{sun}$ along major axis.

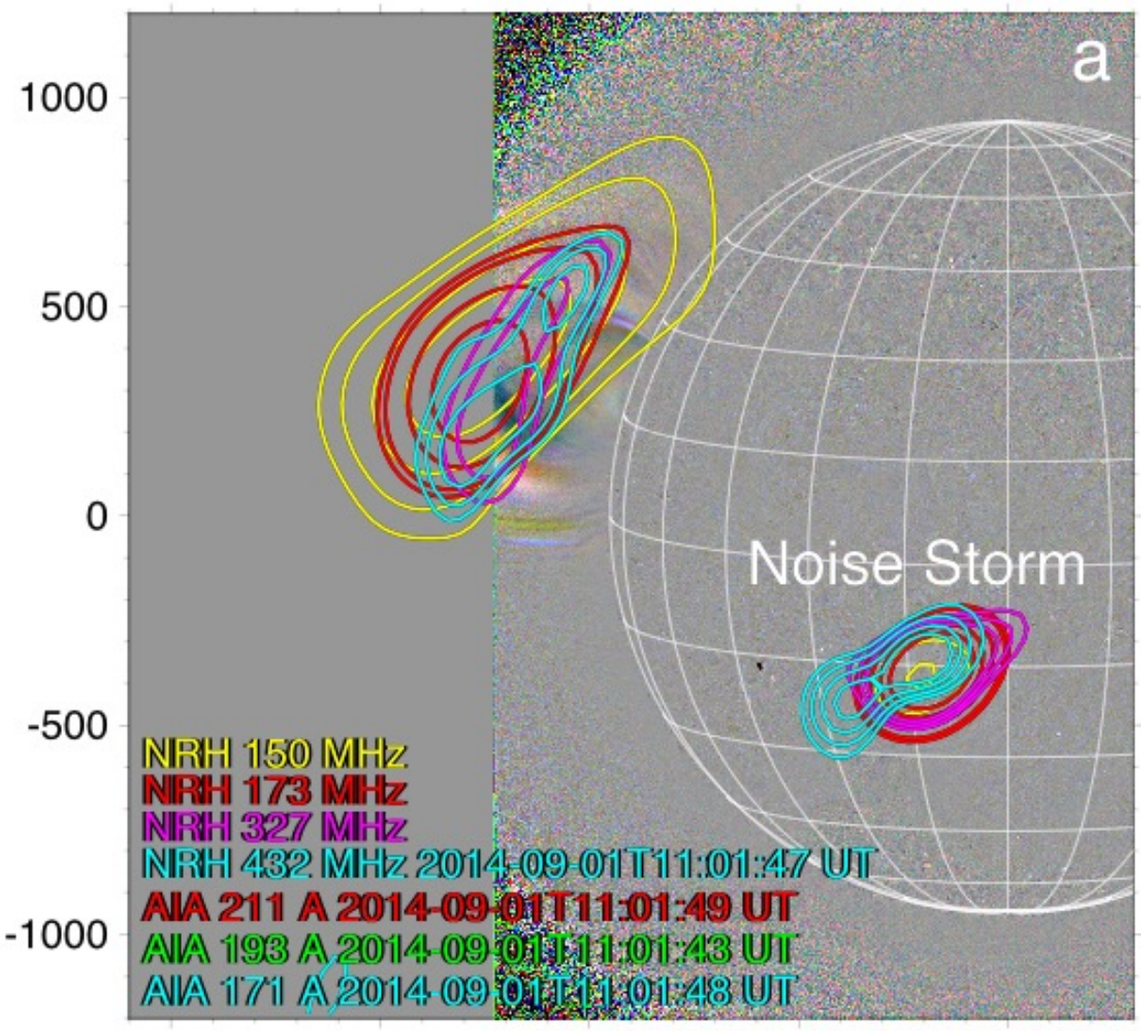
# 2014-September-01 Event - EUV + Radio Imaging

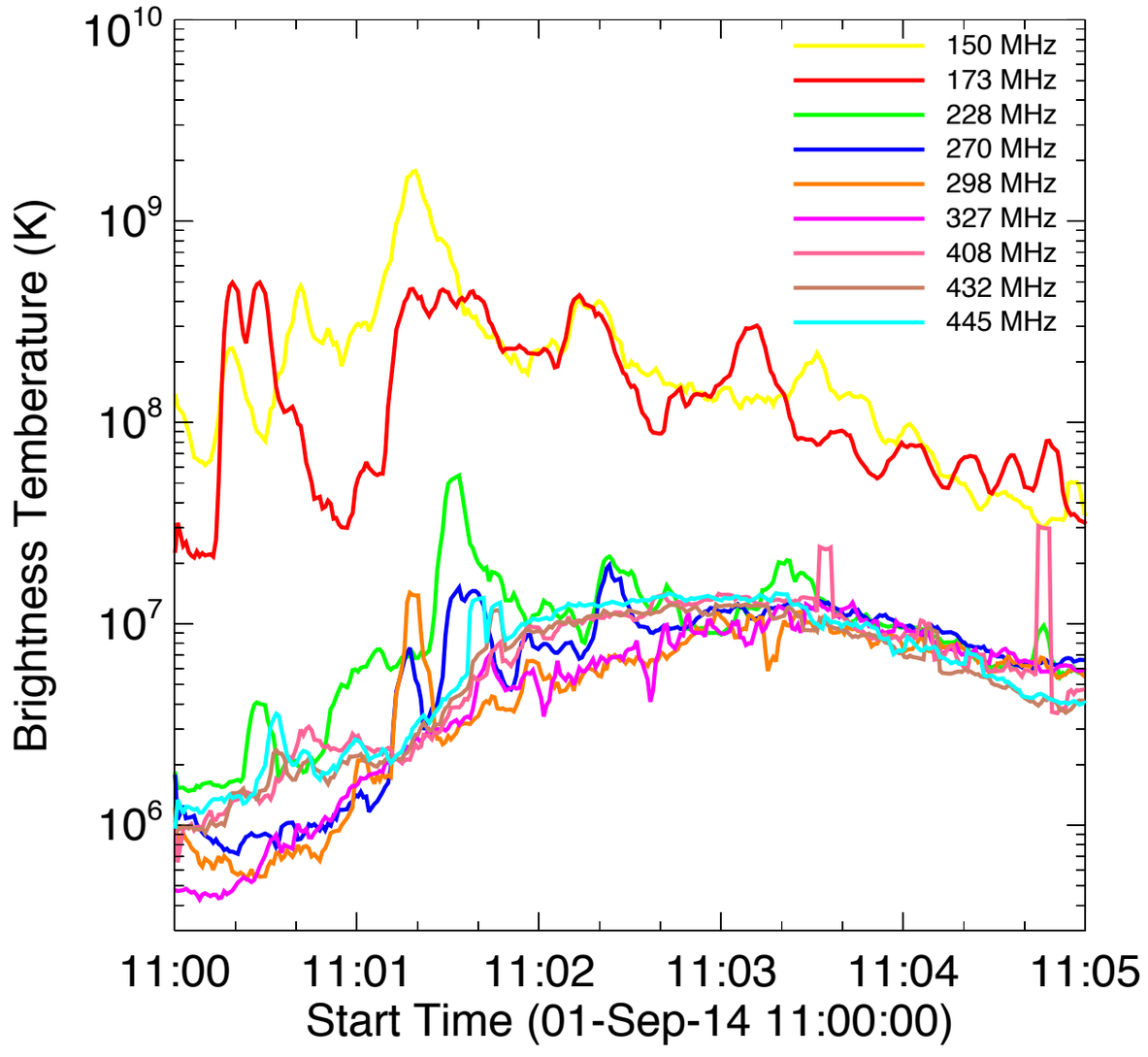



- Eruption off the east limb
- Large radio sources ~0.7 $R_{sun}$ along major axis.
- Nearly all frequencies at same position.

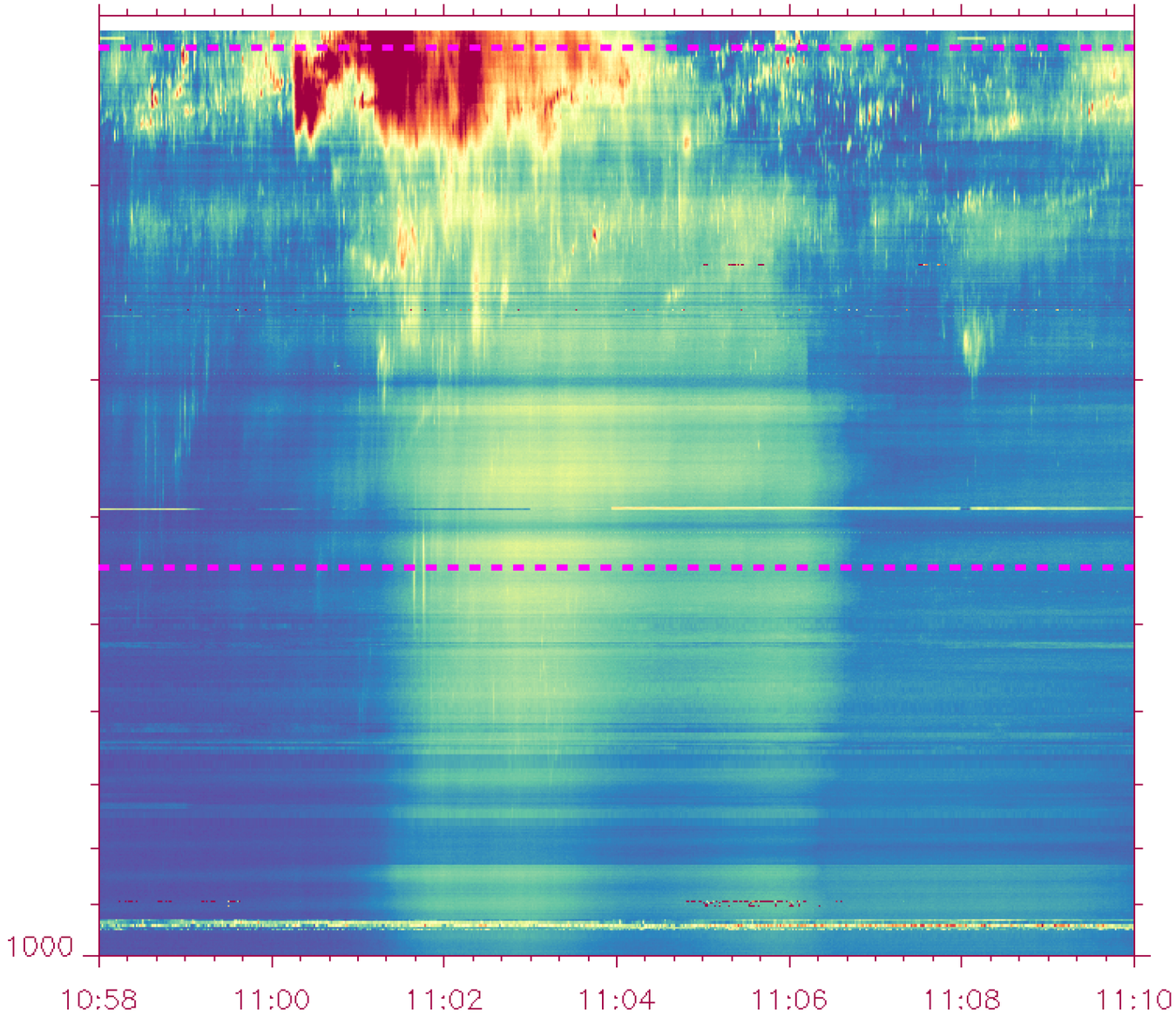
# 2014-September-01 Event - Brightness Temperatures

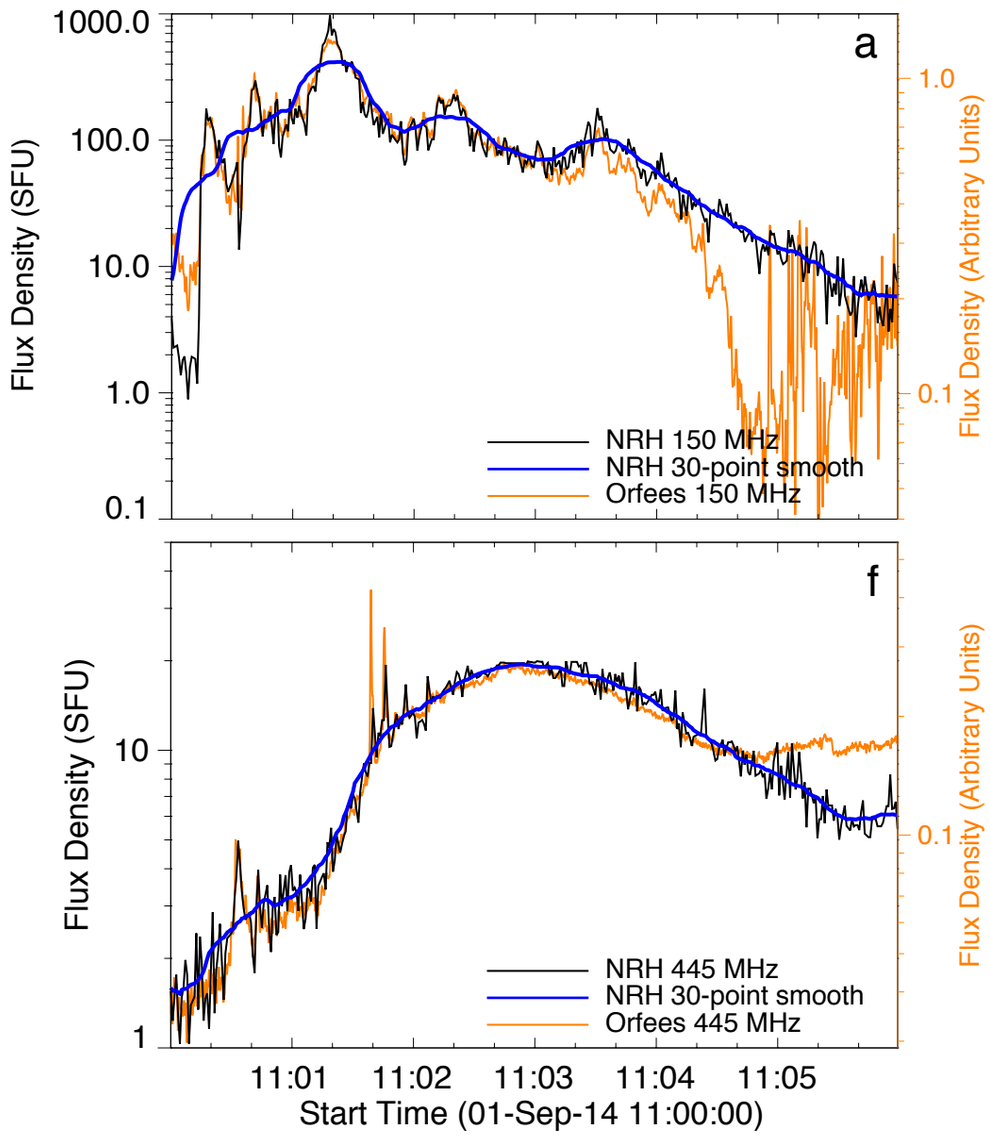



- Eruption off the east limb
- Large radio sources ~0.7 $R_{sun}$ along major axis.
- Separate emission mechanism above 173 MHz?

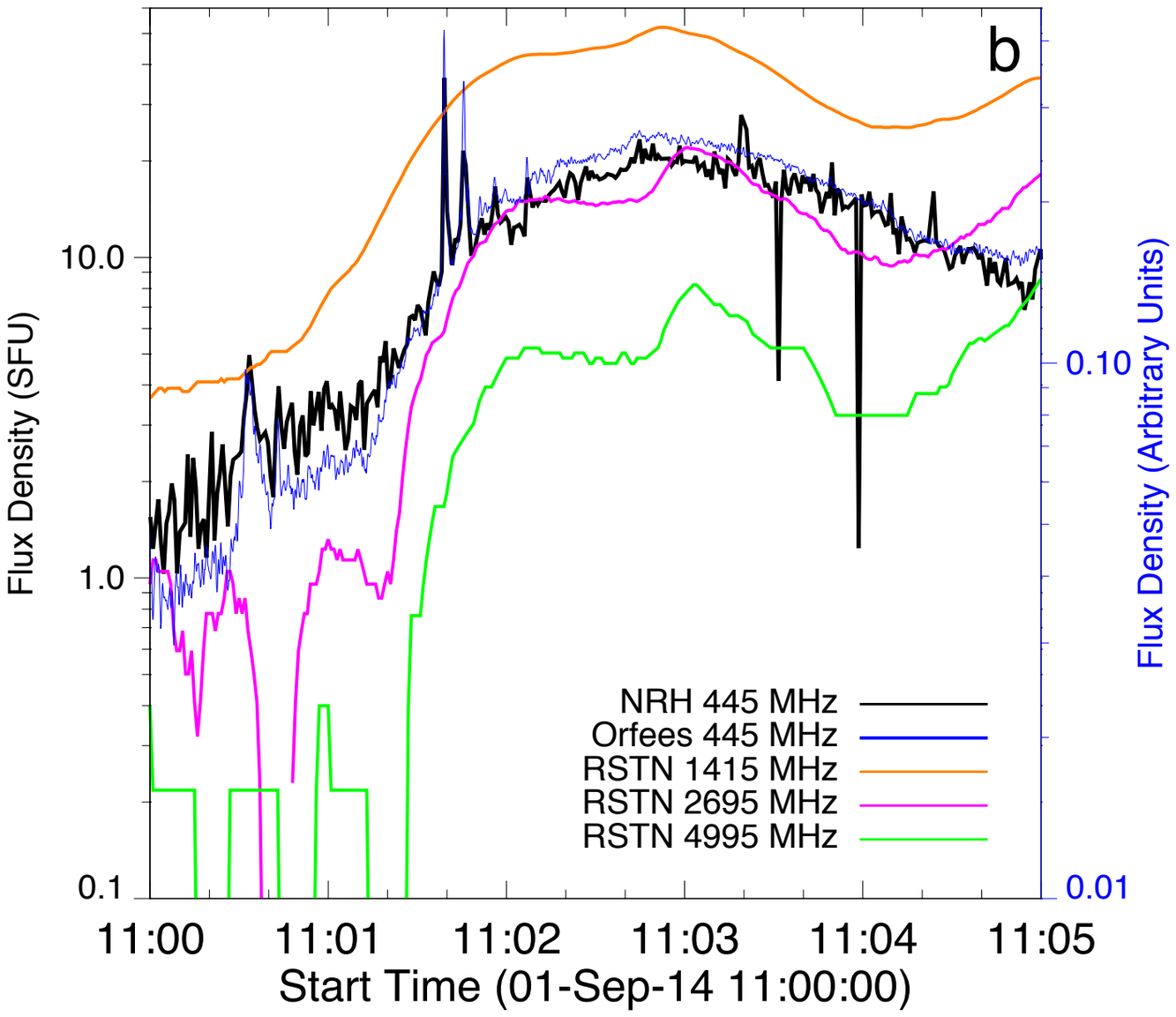
# 2014-September-01 Event - Flux Densities (NRH)



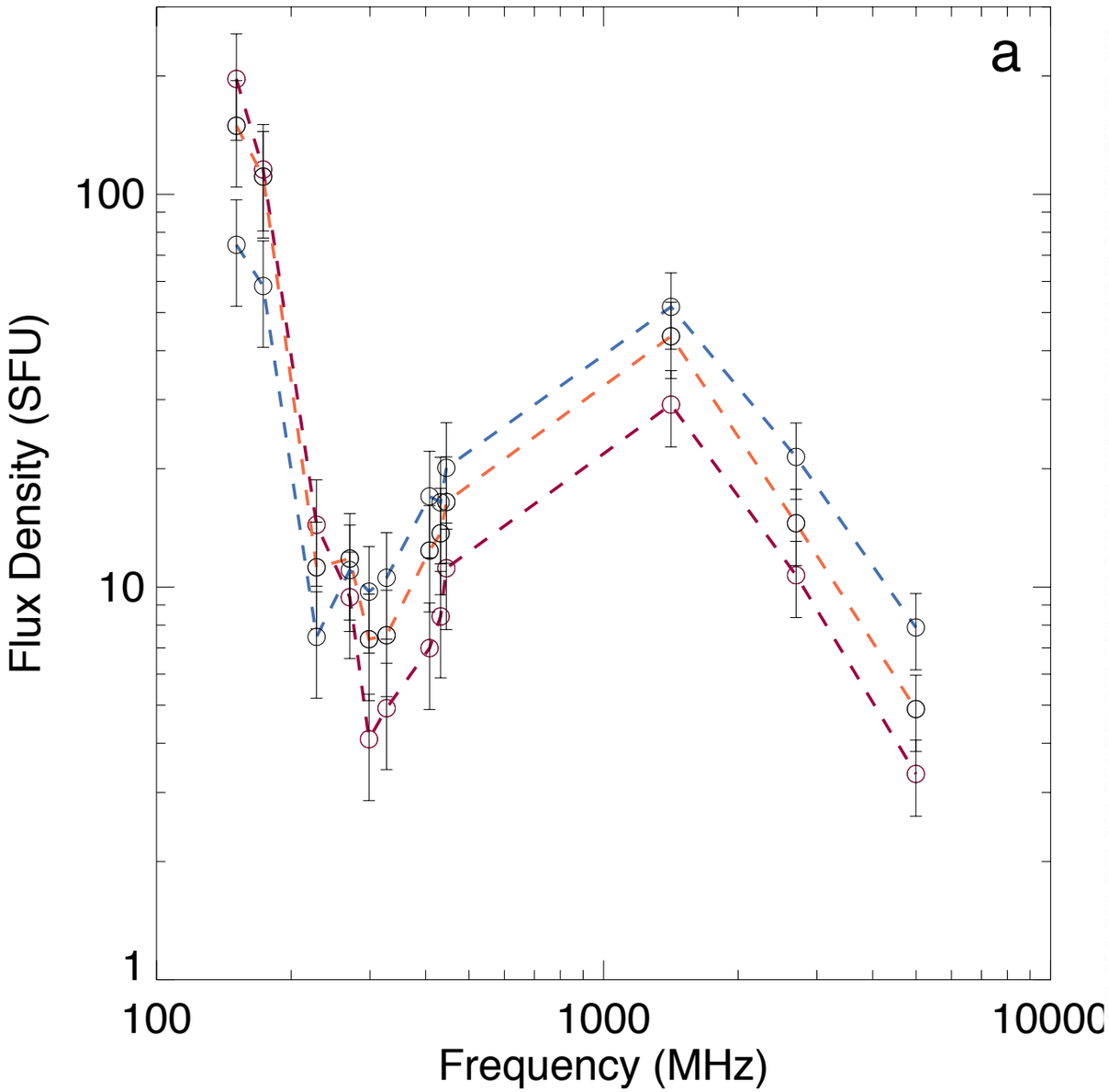

- Low NRH frequencies: higher SFU, bursty.
- High NRH frequencies: lower SFU, smooth.

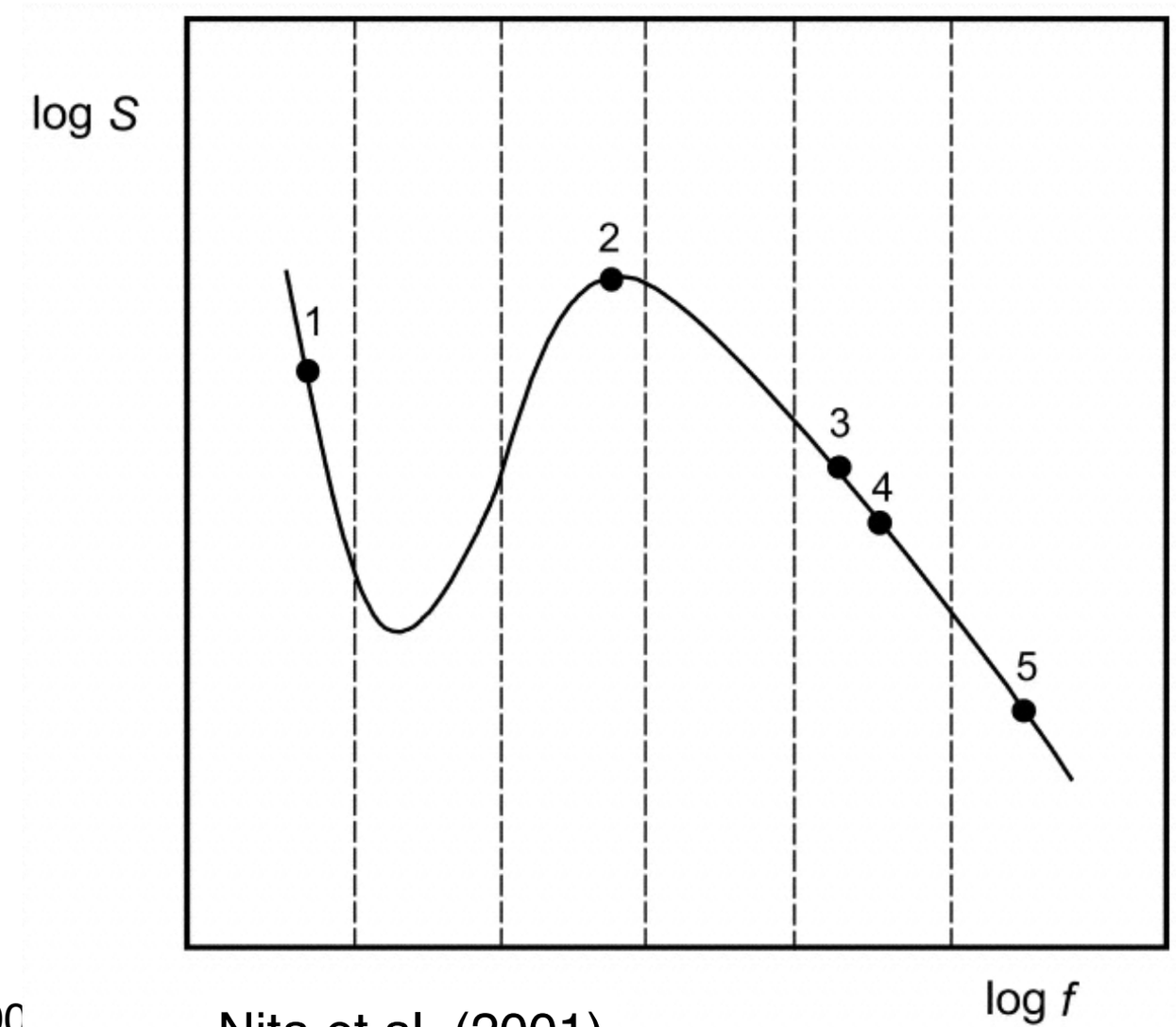
# 2014-September-01 Event - Flux Densities (RSTN, San Vito)




- Flux increase in Radio Solar Telescope Network (RSTN) San Vito site at time of event.
- 3 flux density measurements from 1.4 - 5.0 GHz
- NRH + RSTN: Flux density measurements from 150 - 5000 MHz.

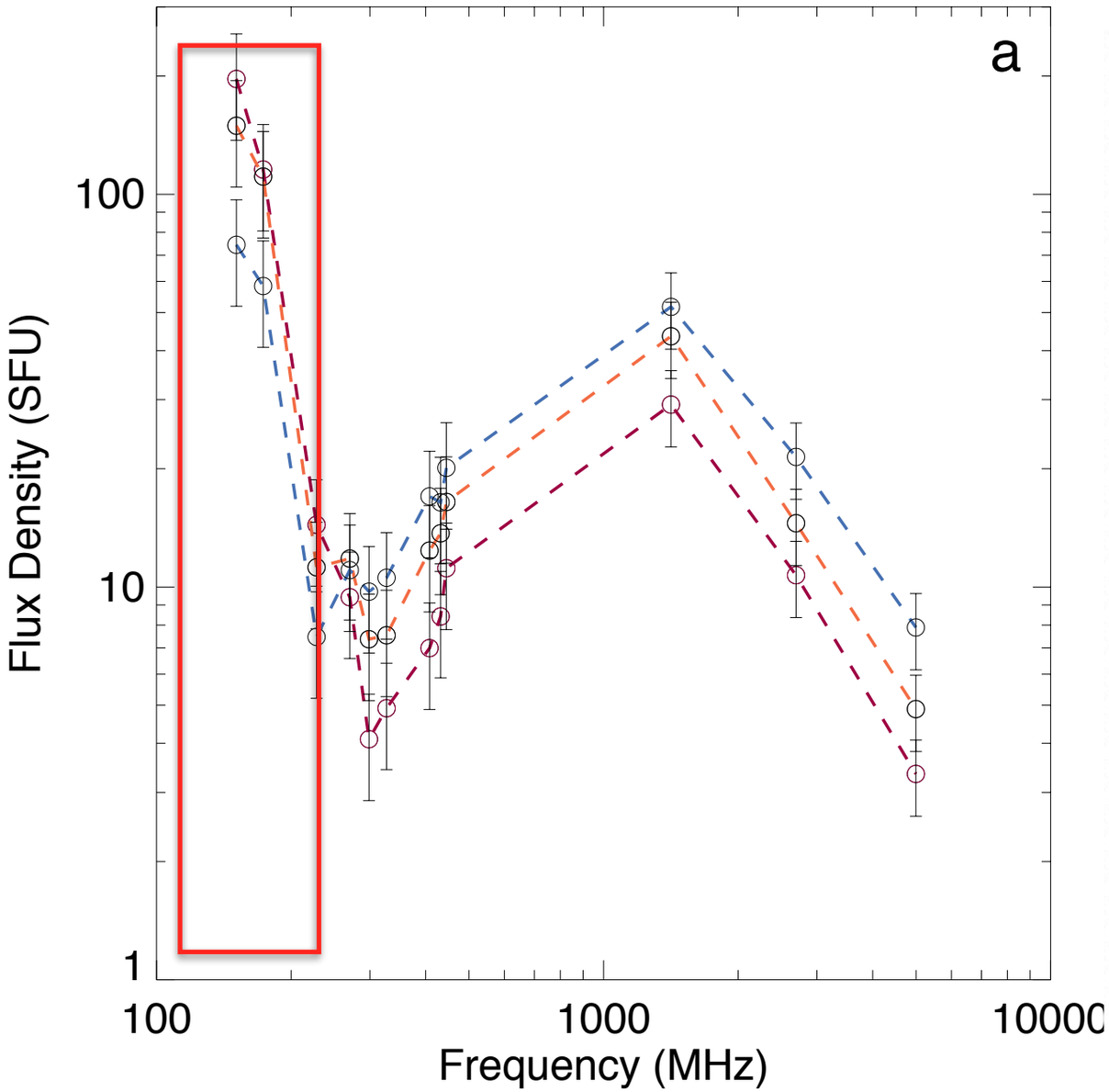
# 2014-September-01 Event - Flux Density Spectrum



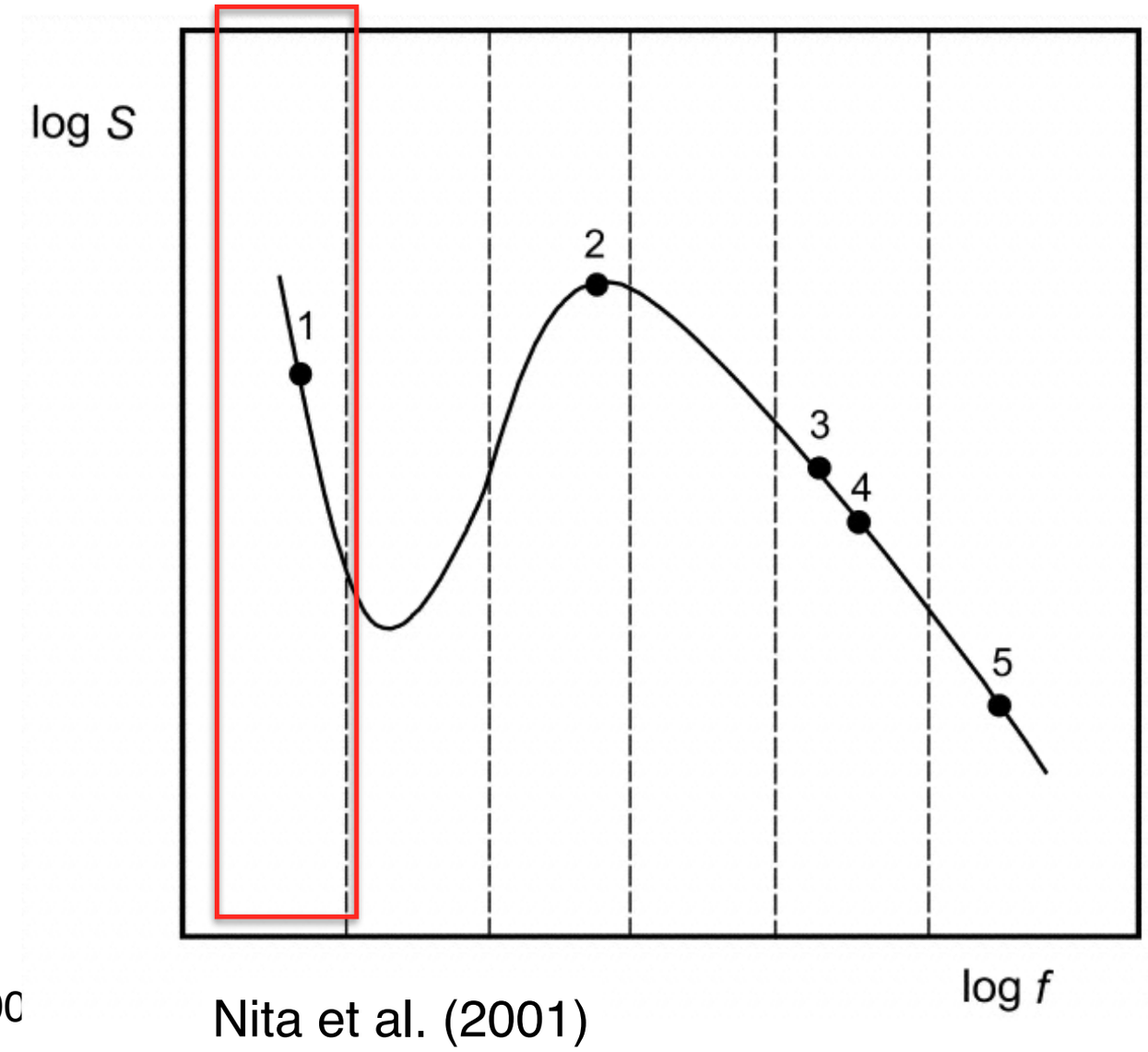




Nita et al. (2001)

# 2014-September-01 Event - Flux Density Spectrum



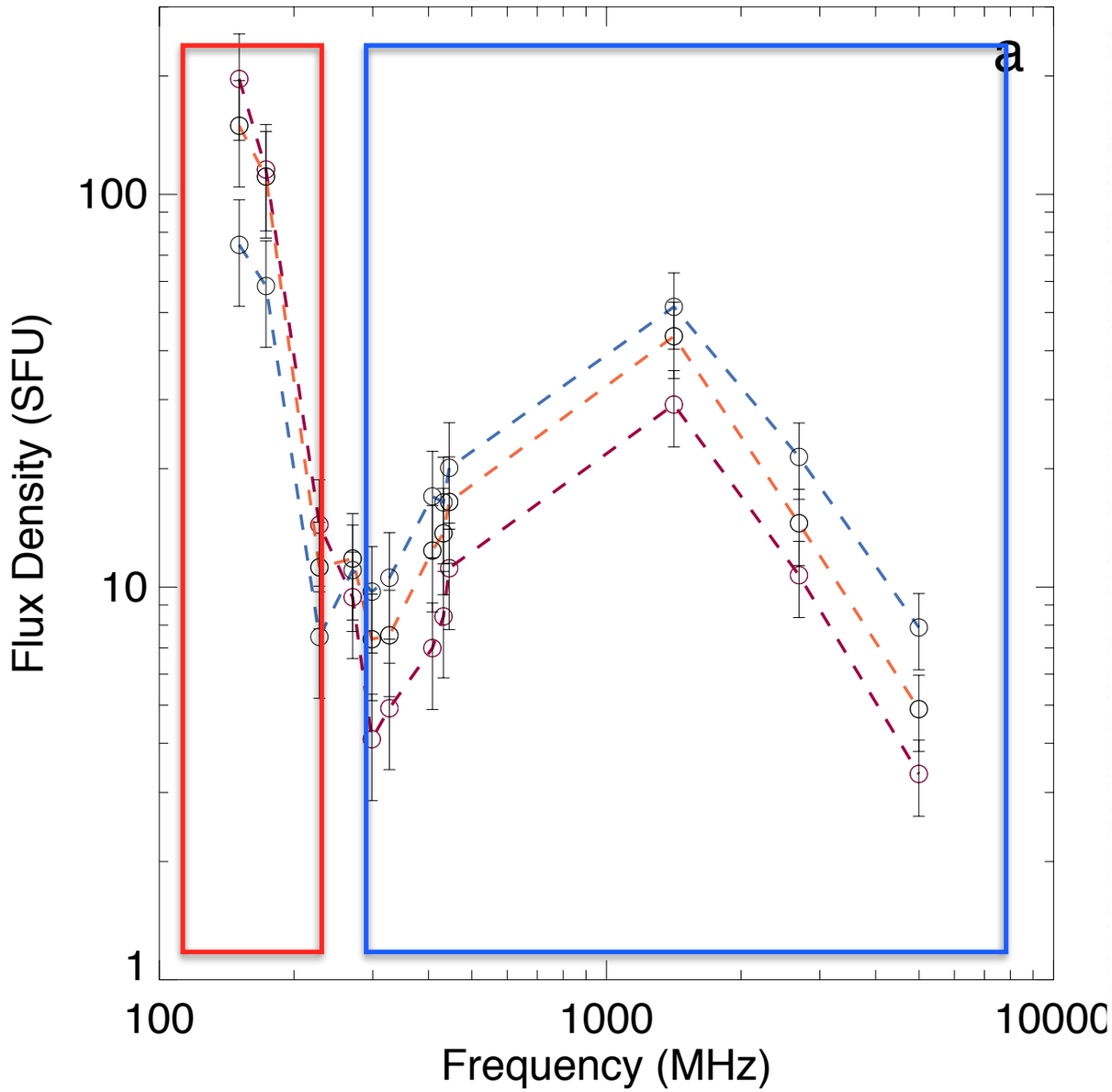

Plasma emission

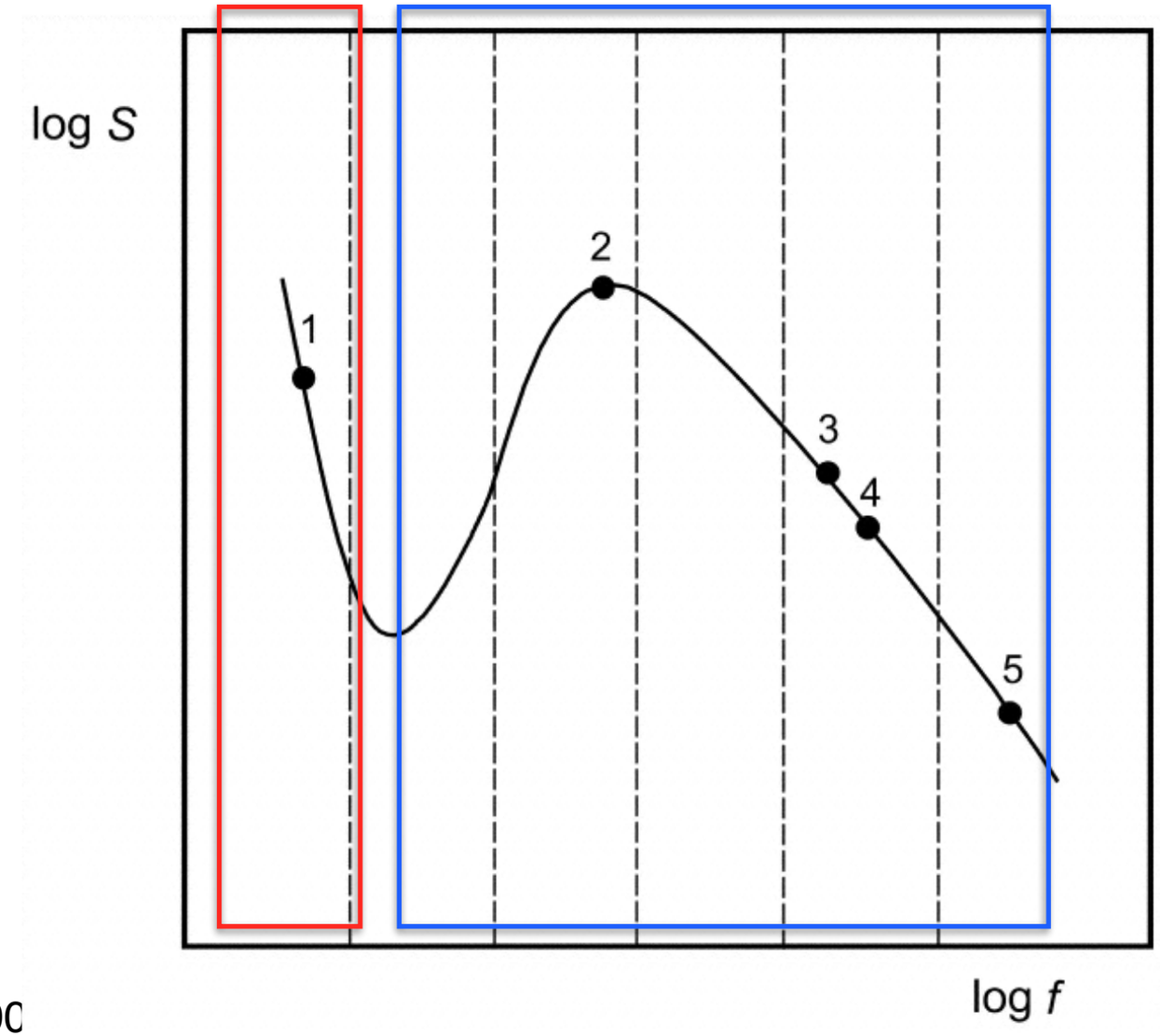



Nita et al. (2001)

Plasma Emission

# 2014-September-01 Event - Flux Density Spectrum



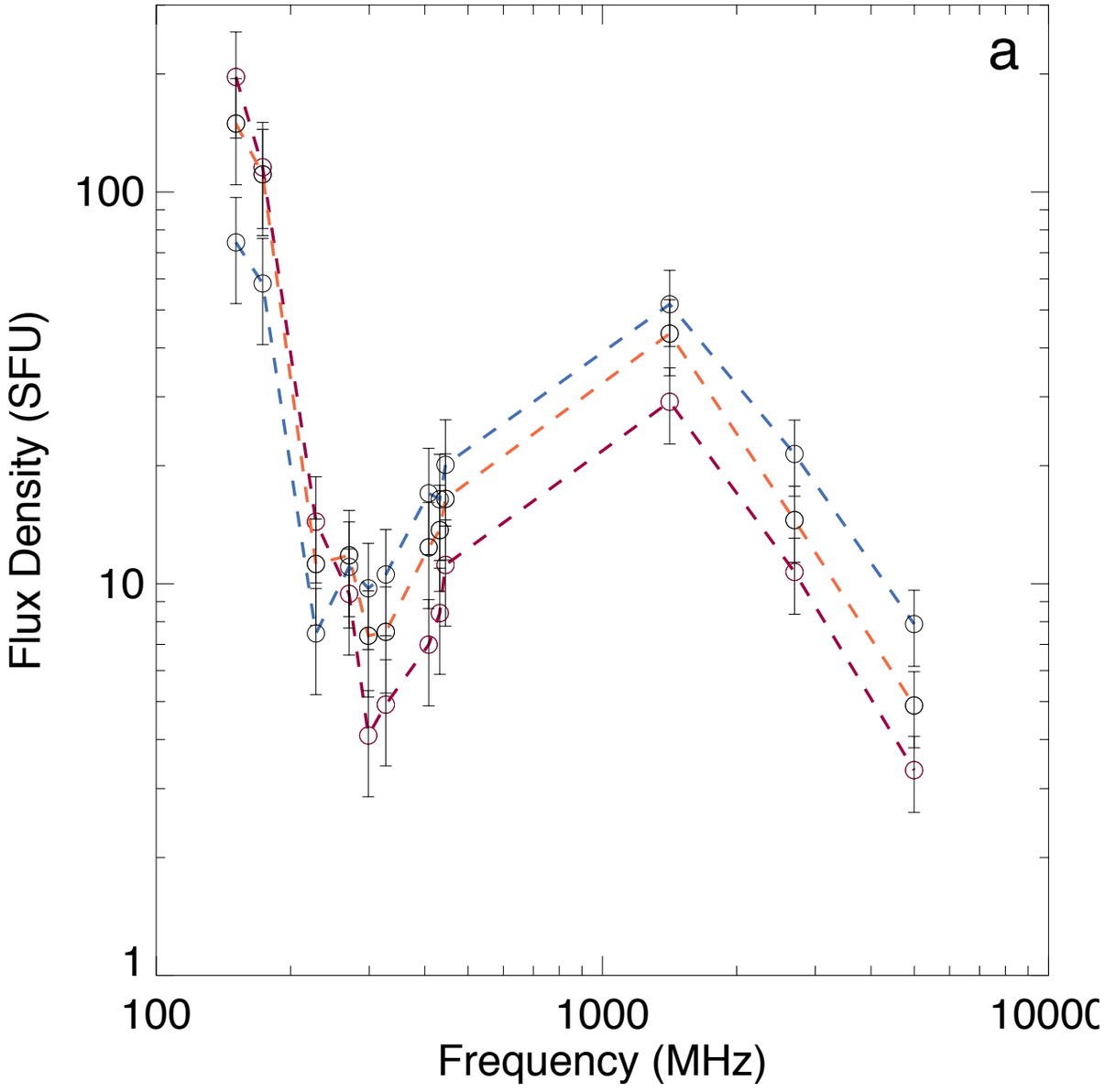

Plasma emission

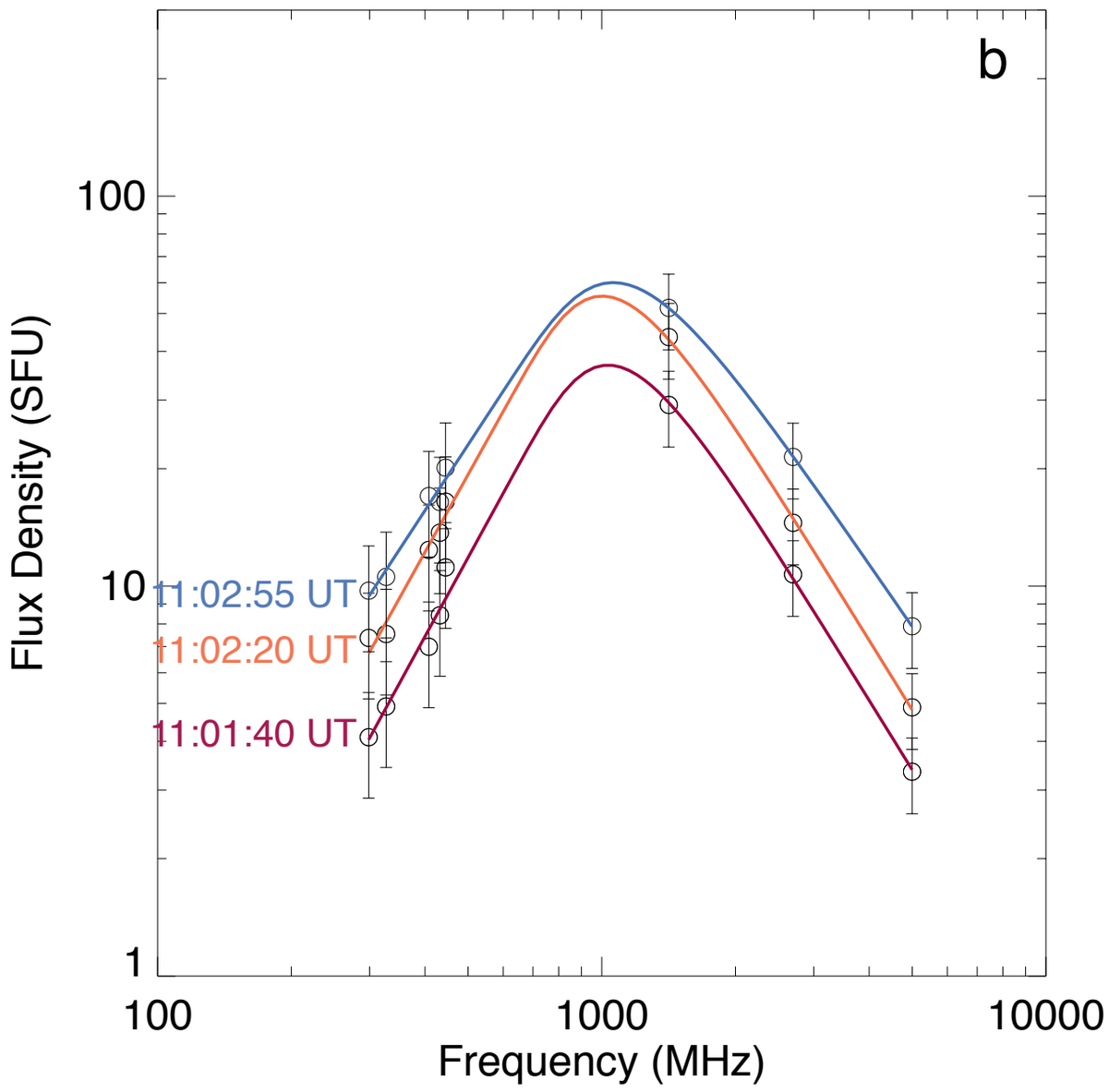
Gyrosynchrotron emission

Plasma Emission

Gyrosynchrotron emission

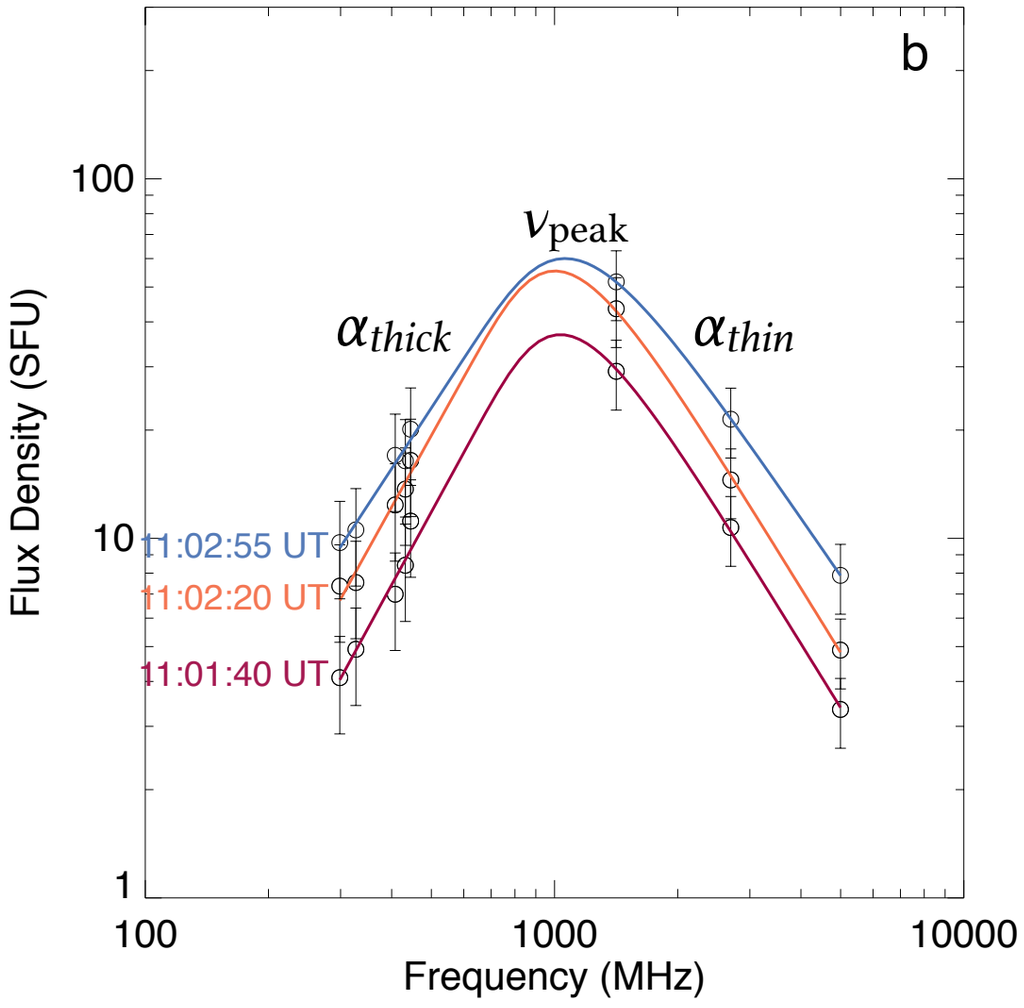
# 2014-September-01 Event - Flux Densities Spectrum




$$F_\nu = F_\nu^{max}\left(\frac{\nu}{\nu_{to}}\right)^{\alpha_{thick}}\left\{1 - exp\left[-\left(\frac{\nu}{\nu_{to}}\right)^{\alpha_{thin}-\alpha_{thick}}\right]\right\}$$

# 2014-September-01 Event - Flux Densities Spectrum




$\alpha_{thin}$= 1.8

$\delta = -1.1(\alpha_{thin} - 1.2)$ (Dulk & Marsh, 1982)

$\delta$ = 3.3

$\nu_{\rm peak}$ = 1.1 GHz

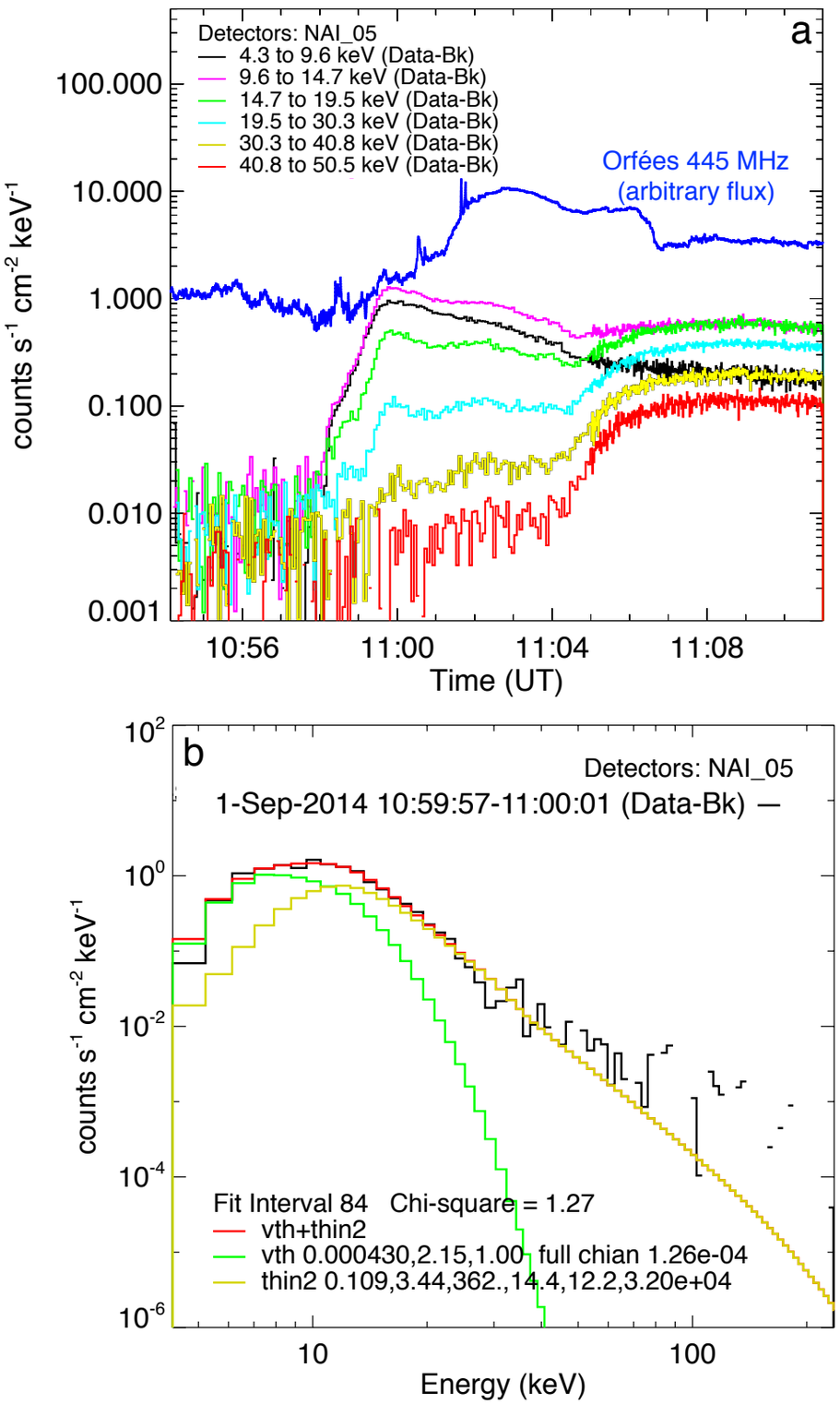
$$\nu_{peak} \approx 2.72\times10^{3}\,10^{0.27\delta}(sin\theta)^{0.41+0.03\delta}(NL)^{0.32-0.03\delta}\times B^{0.68+0.03\delta}$$

- $\theta$ ~ 80 degrees: Very low polarization -> assume high LOS angle.

$L$ ~0.5-0.6 $R_{sun}$ : estimated from radio source size.

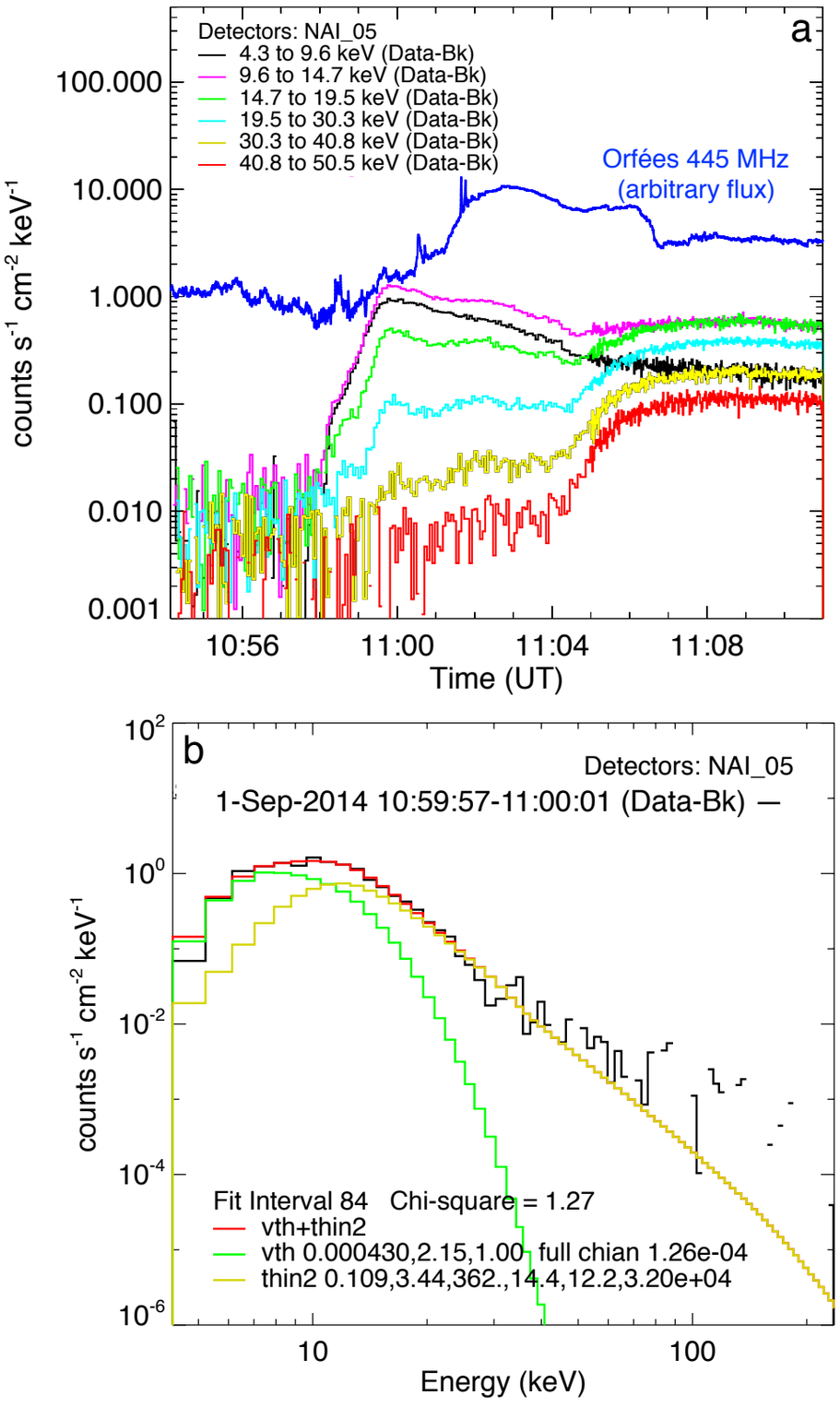
$N$: No independent estimate with radio

# 2014-September-01 Event - FERMI GBM

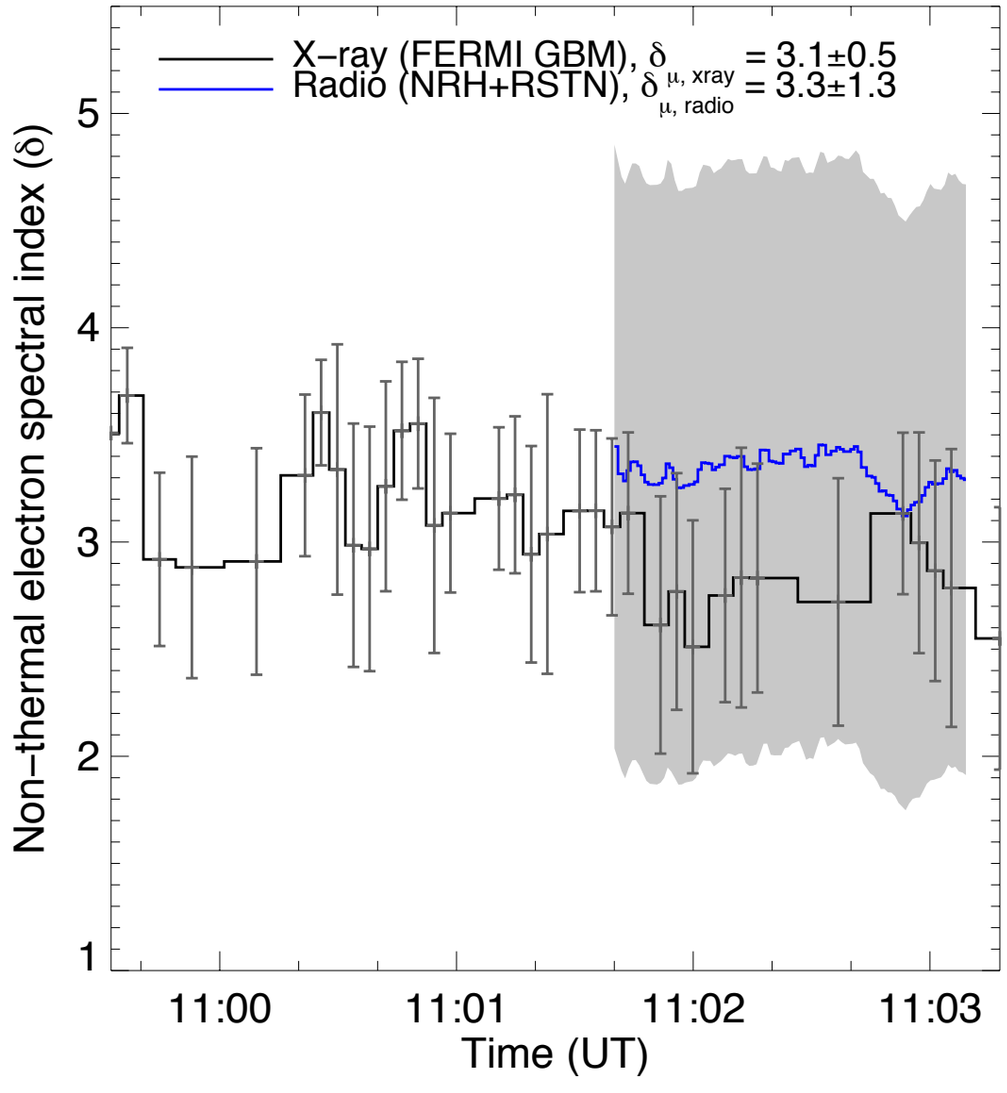



- From behind the limb flare: Fit FERMI GBM spectrum thermal + thin target source model.

# 2014-September-01 Event - FERMI GBM

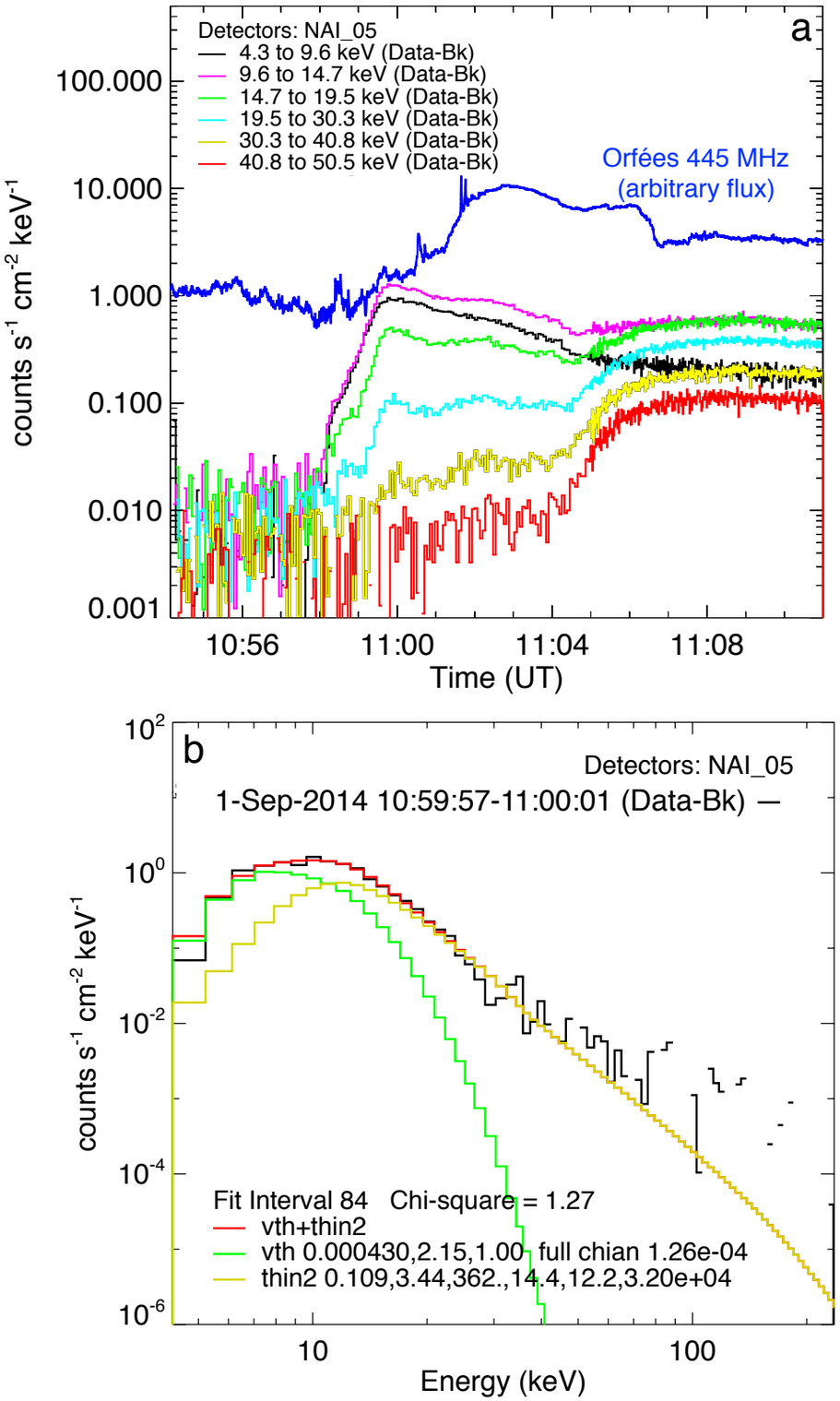



- From behind the limb flare: Fit FERMI GBM spectrum thermal + thin target source model.




- Possibility radio and X-ray are from same energetic electron distribution?

# 2014-September-01 Event - FERMI GBM




$$n_0 = \sqrt{\frac{\xi}{V_0}}$$

$$N = \frac{[n_0 V_0 \overline{F}]}{n_0 V_{nth}} \frac{\delta_{thin} - 1}{\delta_{thin} - 0.5} E_{min}^{1/2} \sqrt{\frac{m}{2}} \left( \frac{E_0}{E_{min}} \right)^{\delta_{thin} - 1}$$

- $\xi$ = 2.2x10$^{45}$ cm$^{-3}$

  $\delta$ = 3.1

$[n_o V_o F]$ = 1.0x10$^{54}$ electrons s$^{-1}$

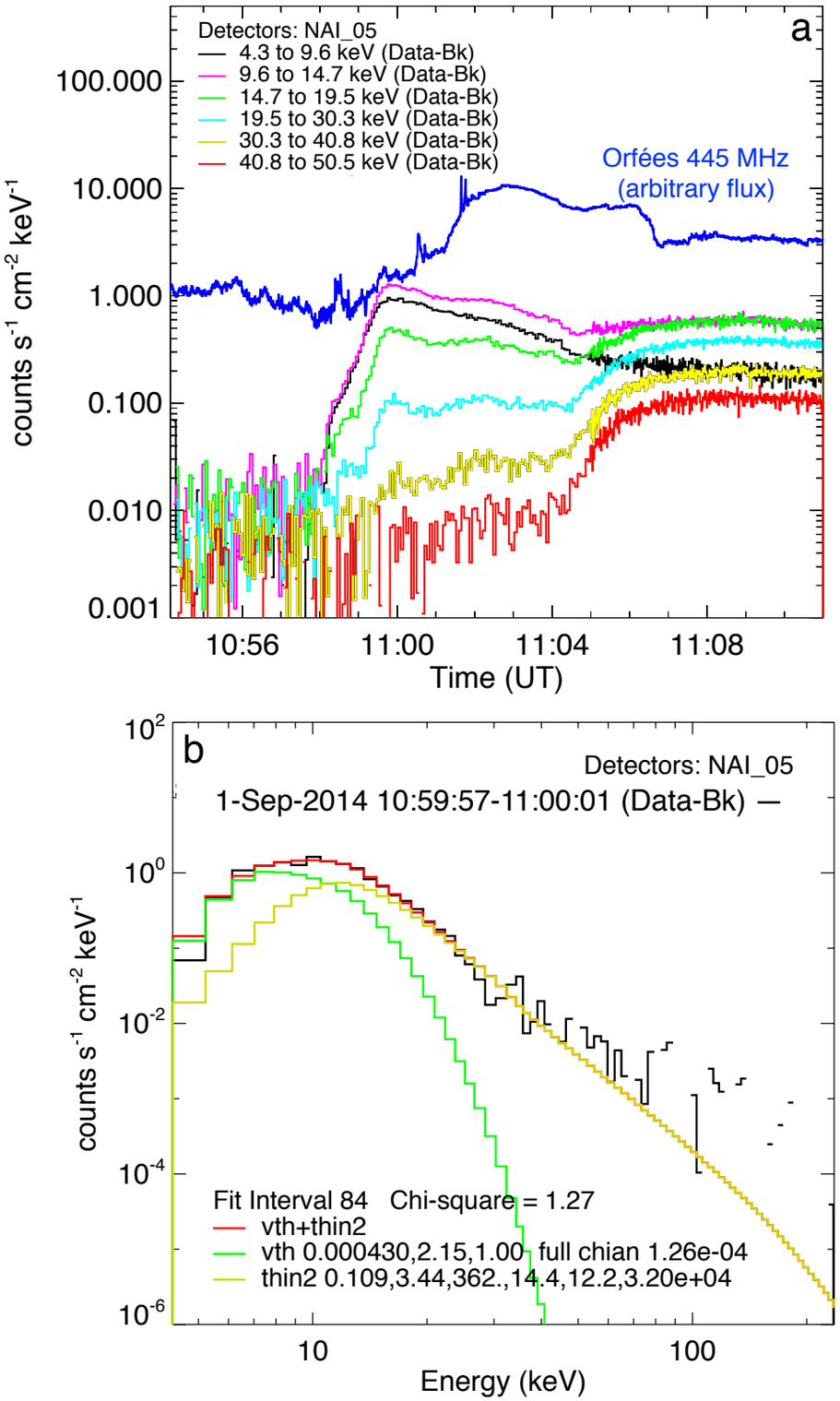
$E_o = E_{min}$ = 9.1 keV

$m$ = electron mass

$V_o$ = ? Distribution of volumes from Warmth and Mann (2013). Estimate of 10$^{27}$ cm$^3$

$V_{nth}$ = ? Assumed the same as $V_o$

# 2014-September-01 Event - FERMI GBM




$$n_0 = \sqrt{\frac{\xi}{V_0}}$$

$$N = \frac{[n_0 V_0 \overline{F}]}{n_0 V_{nth}} \frac{\delta_{thin} - 1}{\delta_{thin} - 0.5} E_{min}^{1/2} \sqrt{\frac{m}{2}} \left( \frac{E_0}{E_{min}} \right)^{\delta_{thin}-1}$$

$$\nu_{peak} \approx 2.72 \times 10^3 \, 10^{0.27\delta} (sin\theta)^{0.41+0.03\delta} (NL)^{0.32-0.03\delta} \times B^{0.68+0.03\delta}$$

- $\xi = 2.2 \times 10^{45}$ cm$^{-3}$

$\delta = 3.1$

$[n_o V_o F] = 1.0 \times 10^{54}$ electrons s$^{-1}$

$E_o = E_{min} = 9.1$ keV

$m$ = electron mass

$V_o = 10^{27}$ cm$^3$, $V_{nth} = 10^{27}$ cm$^3$

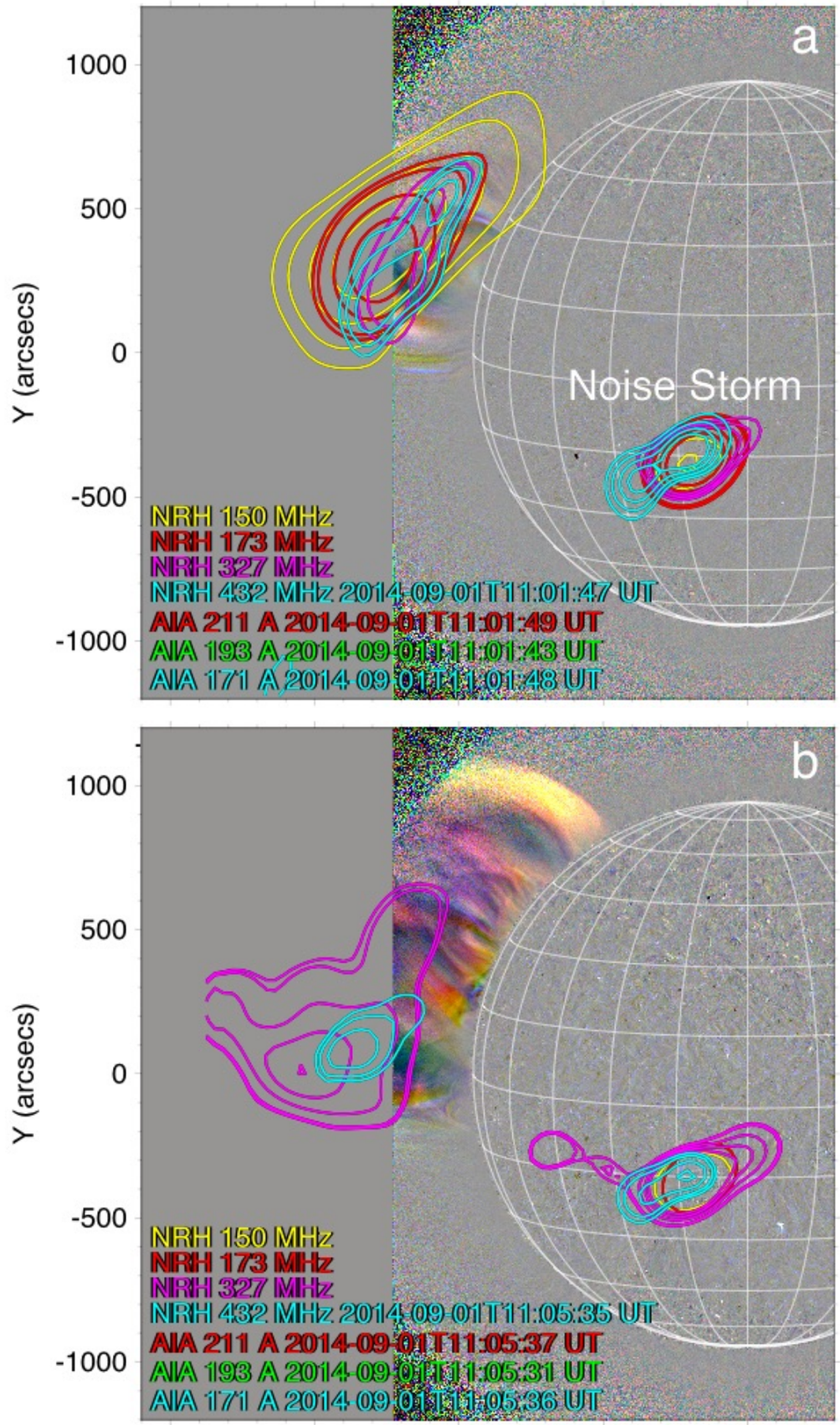
$N = 9.0 \times 10^7$ cm$^{-3}$ (6% of background density).

$\Theta = 80°$, $L = 0.5$ R$_{sun}$, $\nu_{peak} = 1.1$ GHz

**$B = 5$ G at 1.2 R$_{sun}$**

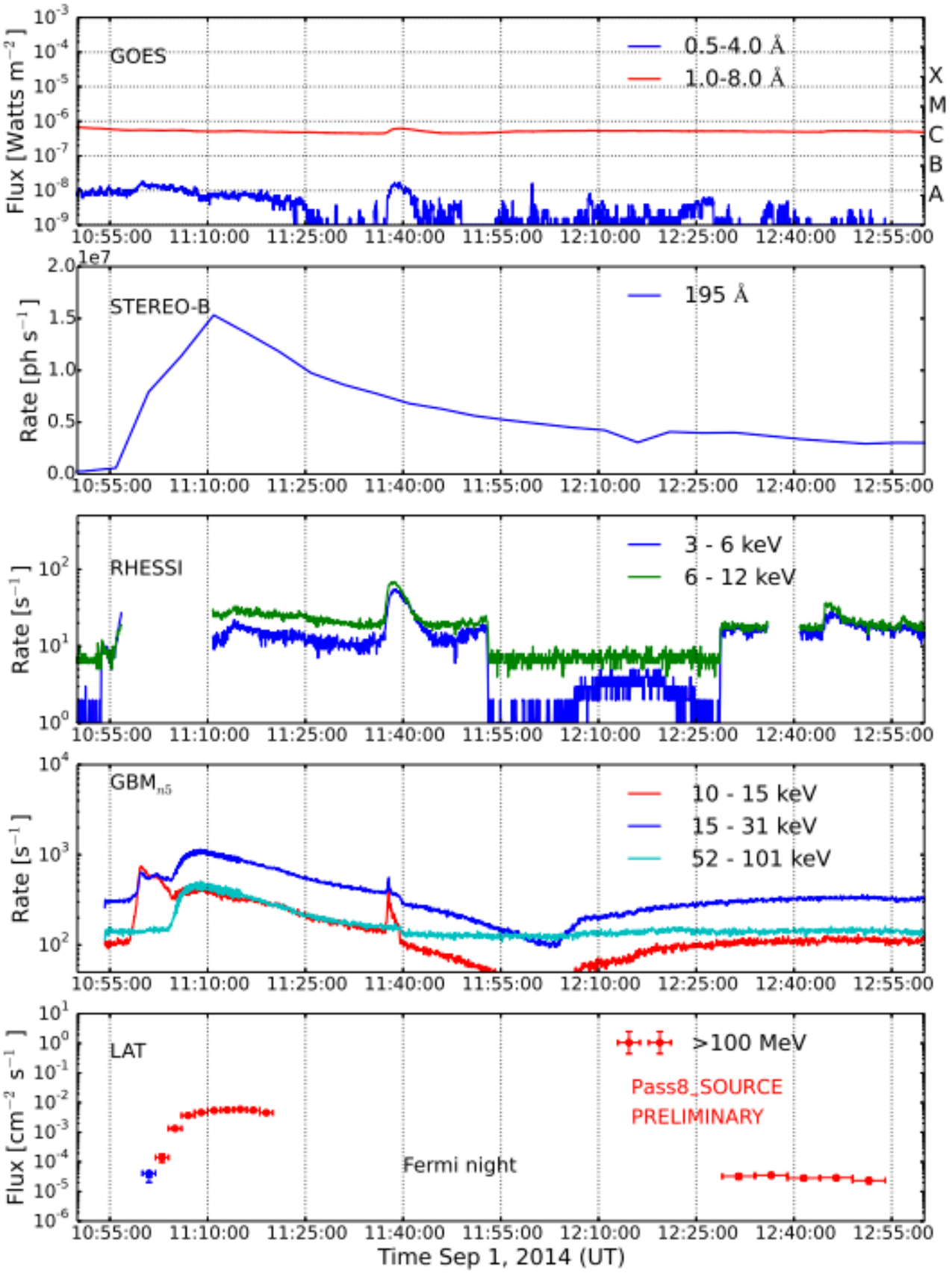
# Conclusions

- Eruption off the east limb with large radio sources.
- Type IV with a gyrosynchrotron spectrum
- FERMI GBM burst detected
- X-ray and radio both give same non-thermal electron spectral index of 3.1-3.3
- Estimate of non-thermal electron number density from X-ray
- X-ray and radio parameters allow for CME B-field strength of 5 G




eoincarley@gmail.com

# 2014-September-01 Event




- Pesce-Rollins et al. (2015): Study of FERMI-GBM observations of behind the limb events

# 2014-September-01 Event - SFU ‘burstiness’