24 Oct 2001
A Cool, Dense Flare

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Owens Valley Solar Array

Radio Observations

OVSA: 1-14.8 GHz, 2 s cadence, total flux, Stokes I

NoRP: 1, 2, 3.75, 9.4, 17, 35, and 80 GHz, 0.1 s cadence, total flux, Stokes I/V

NoRH: 17 GHz, 1 s cadence, imaging (10”), Stokes I/V

34 GHz, 1 s cadence, imaging (5”), Stokes I

EUV/X-ray Observations

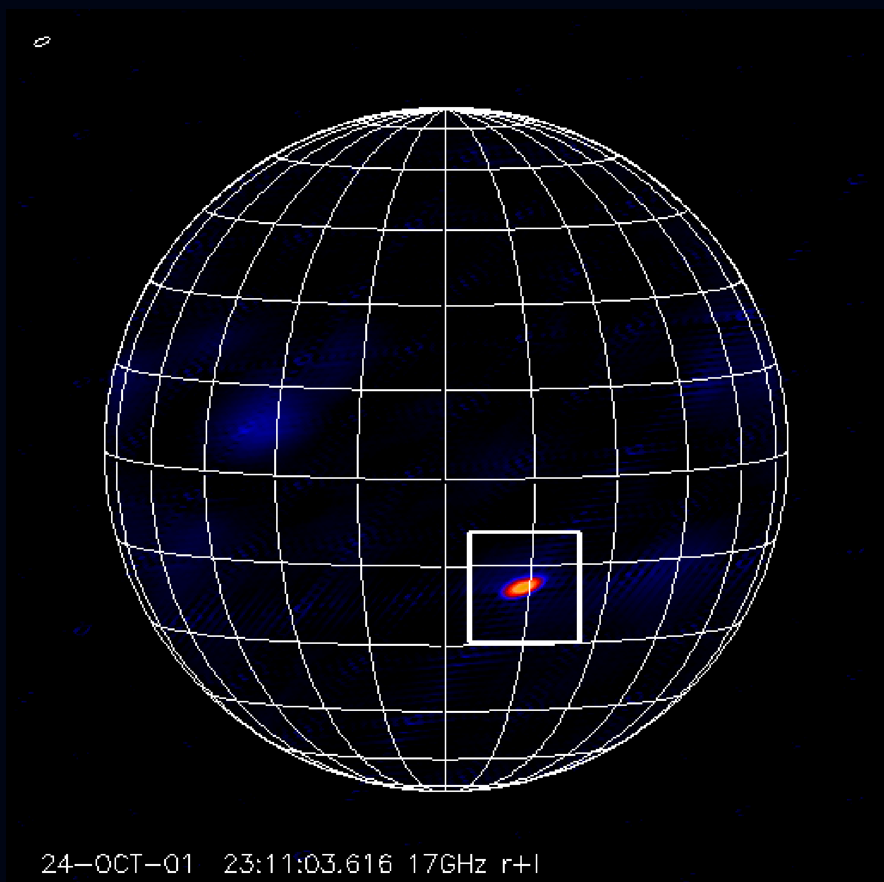
TRACE: 171 A imaging, 40 s cadence (0.5”)

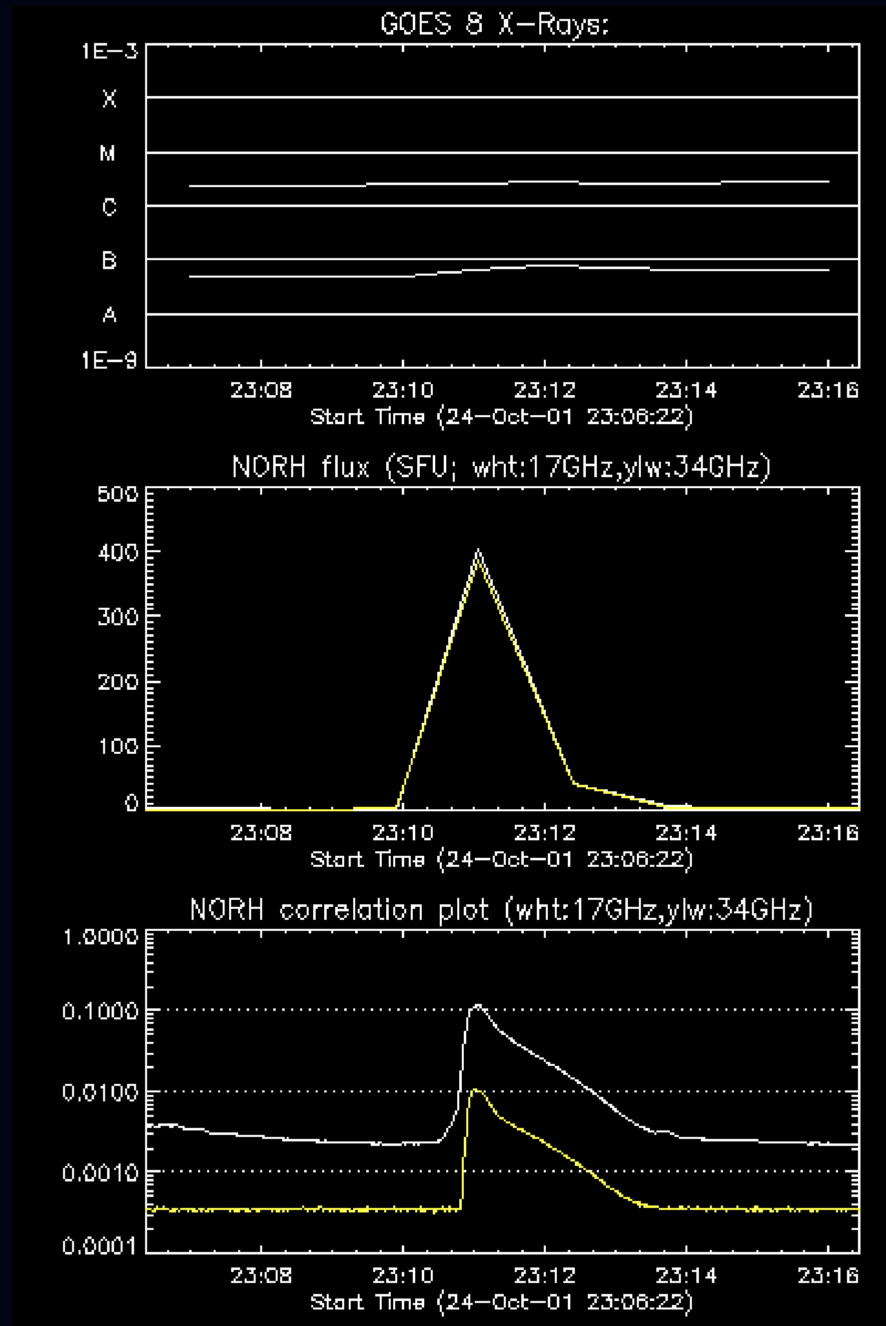
Yohkoh SXT: Single Al/Mg full disk image (4.92”)

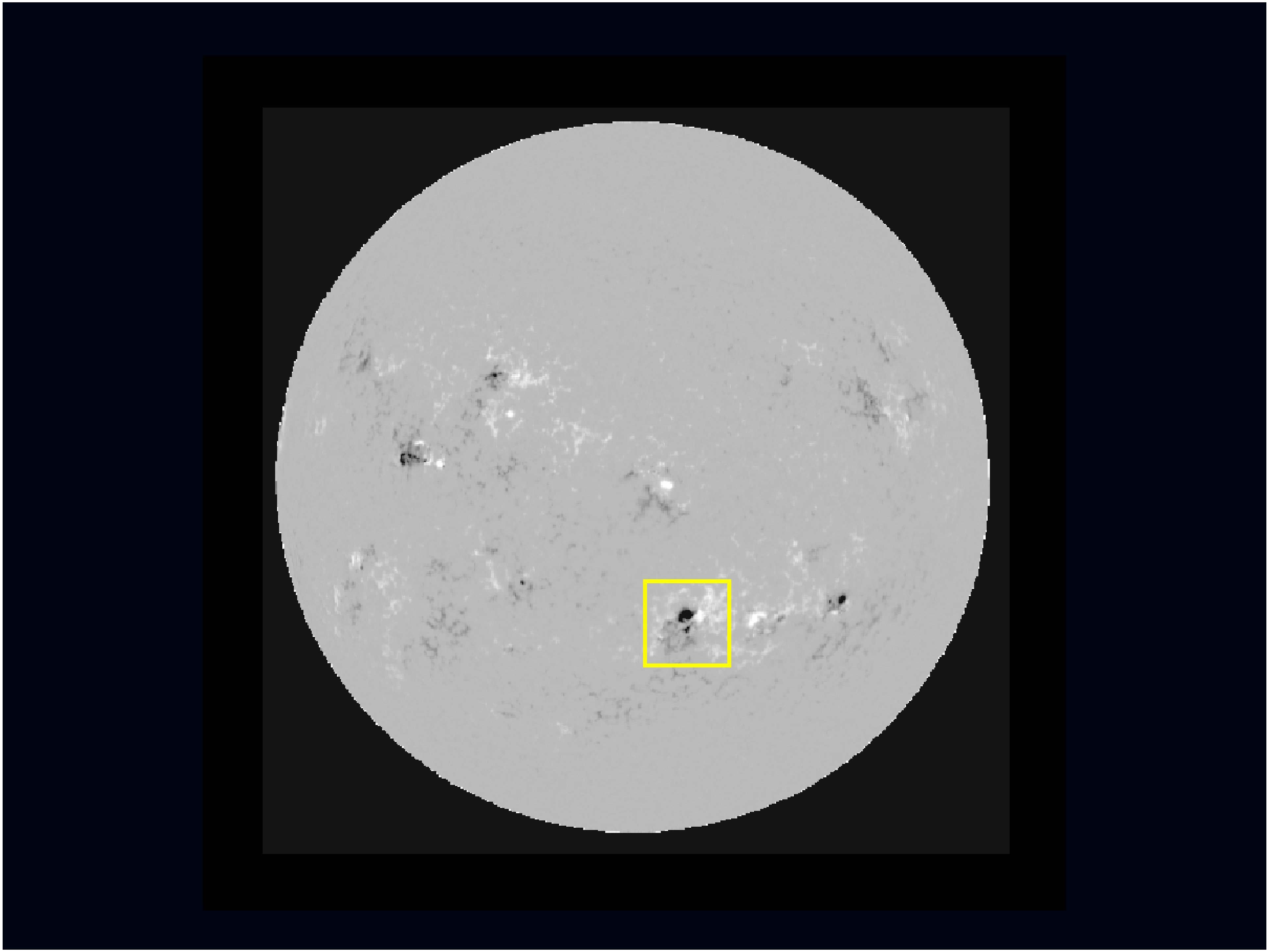
Yohkoh HXT: Counts detected in L band only

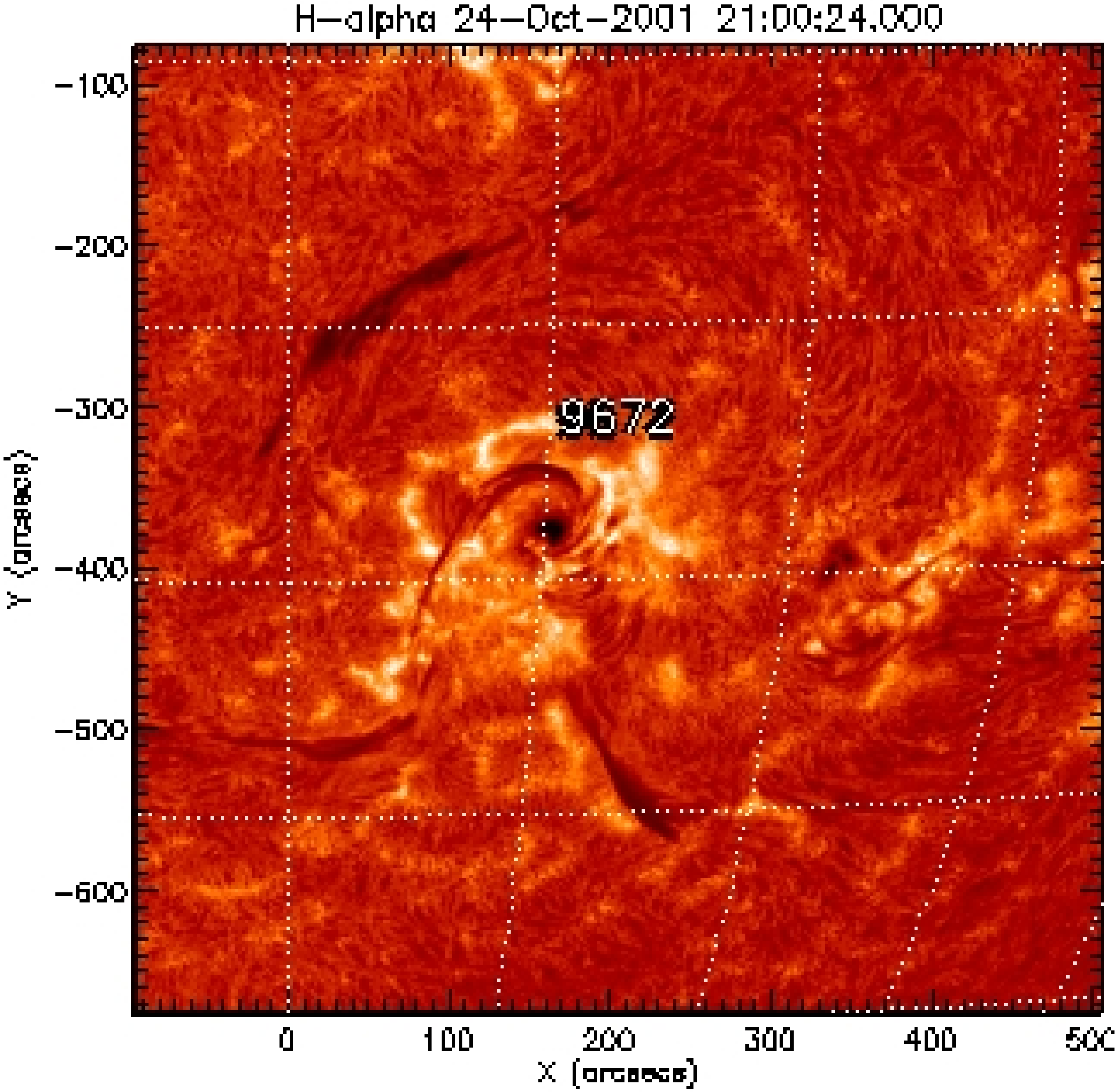
24 October 2001

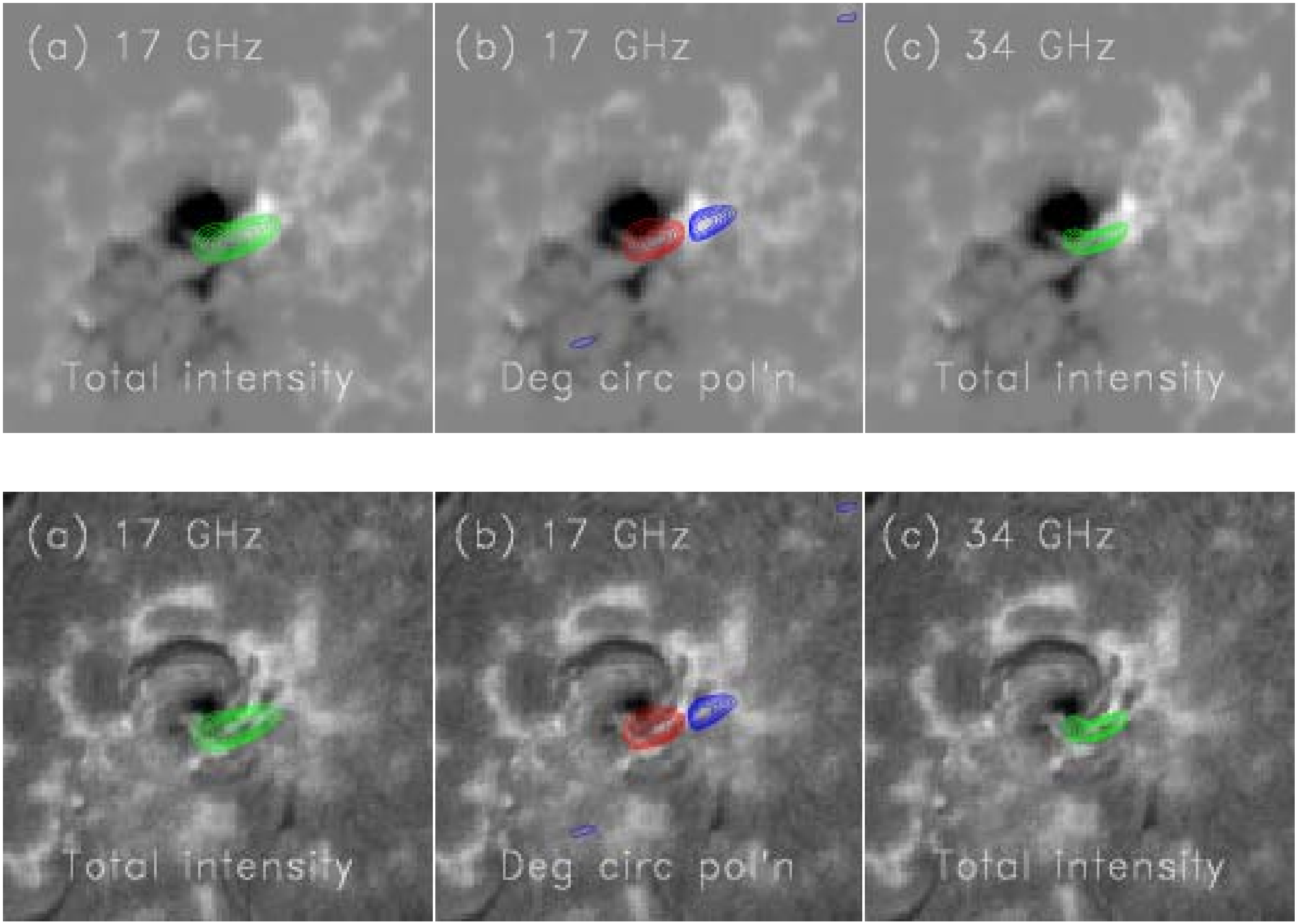
AR 9672



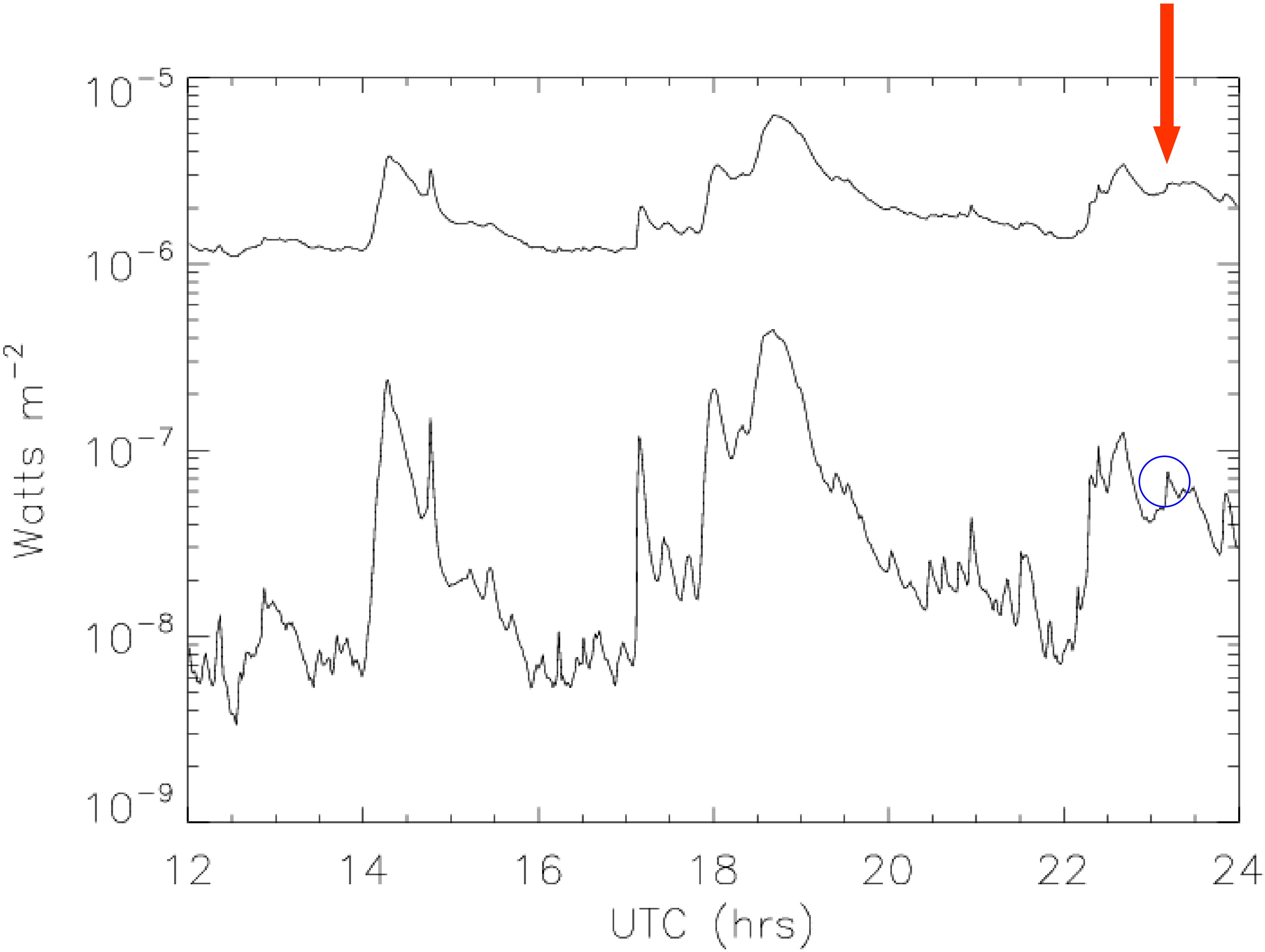




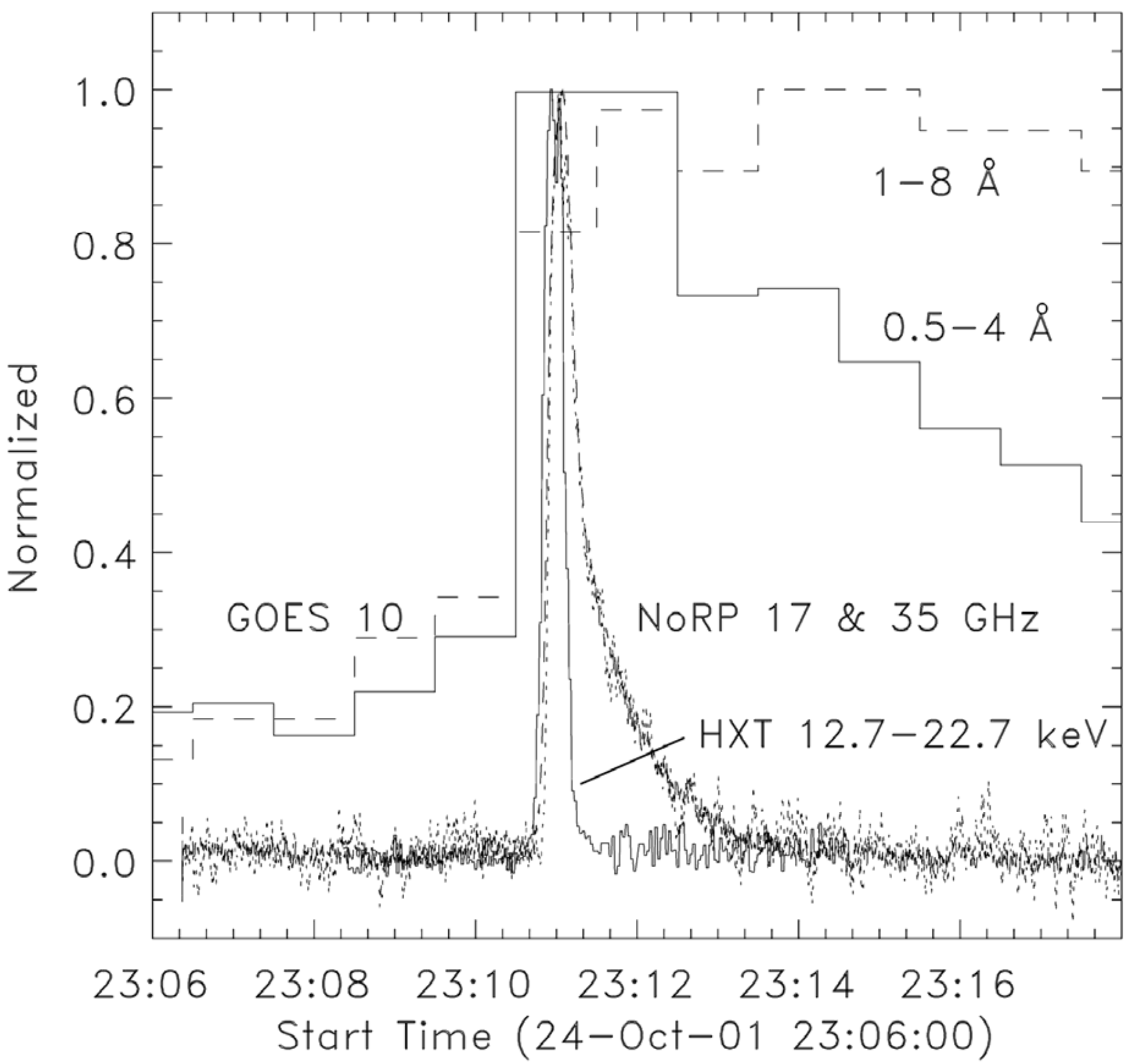

H-alpha 24-Oct-2001 21:00:24.000
9672
-100
-200
-300
-400
-500
-600
Y (arcsecs)
0
100
200
300
400
500
X (arcsecs)



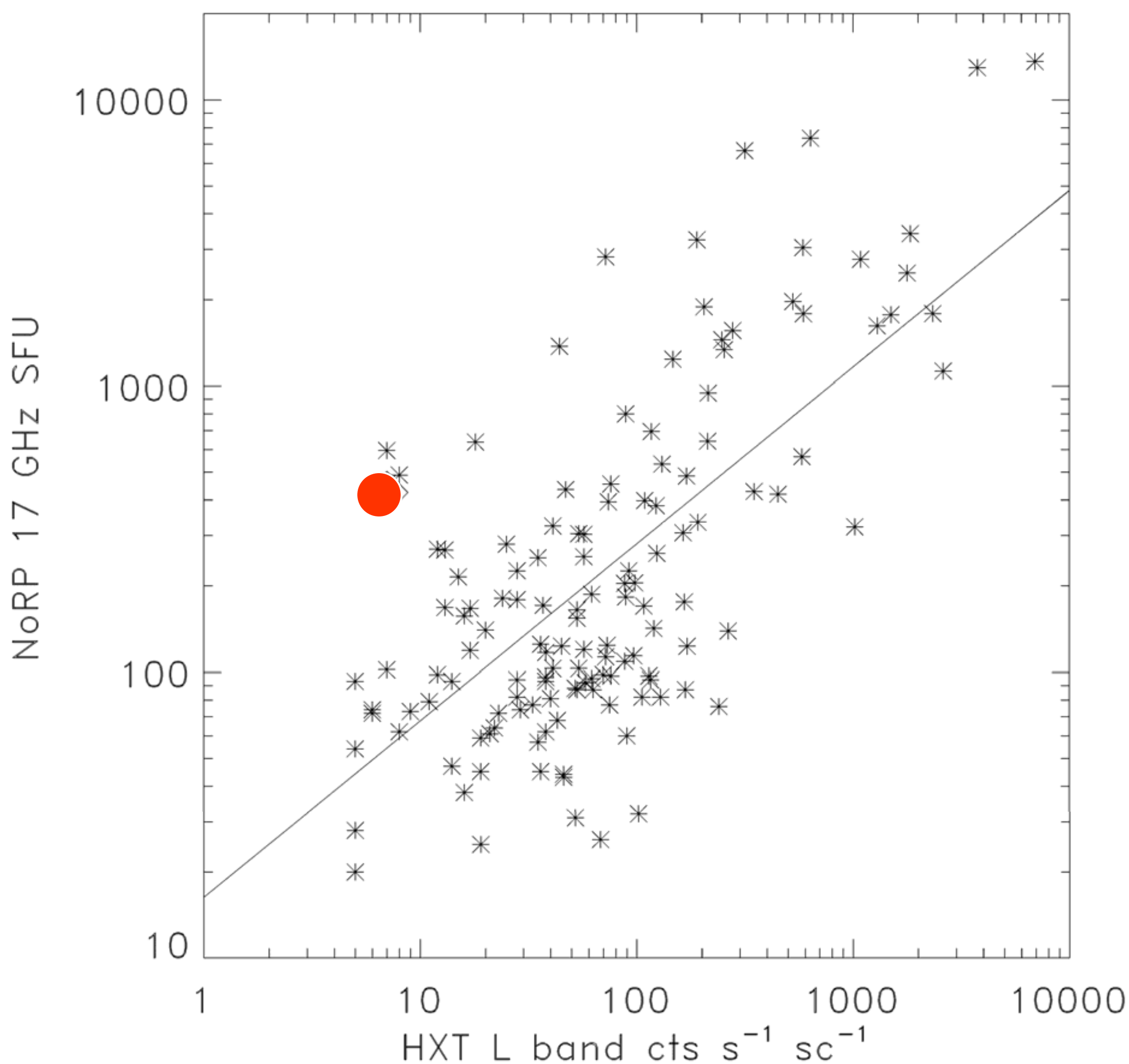
(a) 17 GHz
Total intensity
(b) 17 GHz
Deg circ pol'n
(c) 34 GHz
Total intensity
(a) 17 GHz
Total intensity
(b) 17 GHz
Deg circ pol'n
(c) 34 GHz
Total intensity

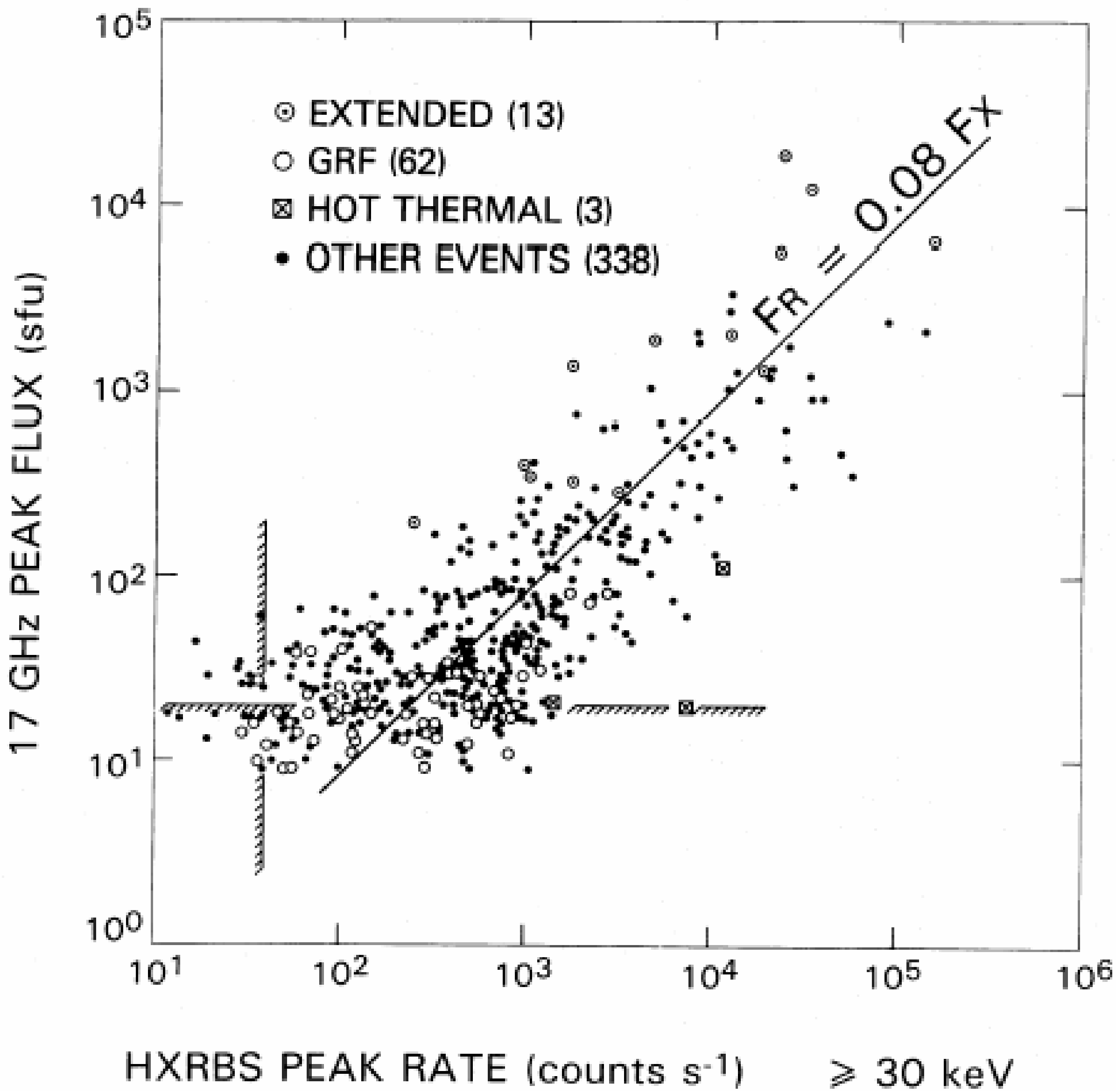


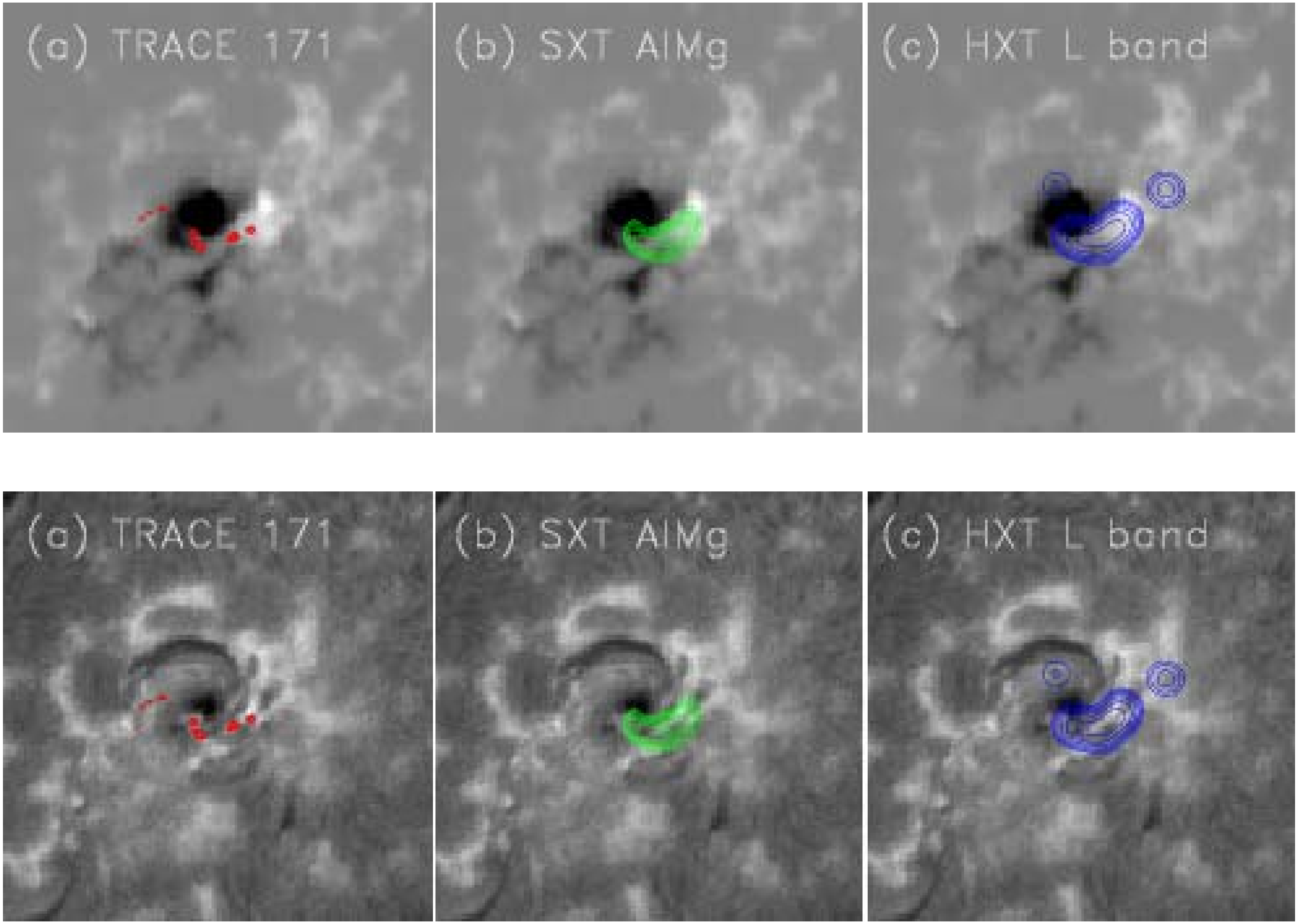
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
Watts m^{-2}
12
14
16
18
20
22
24
UTC (hrs)

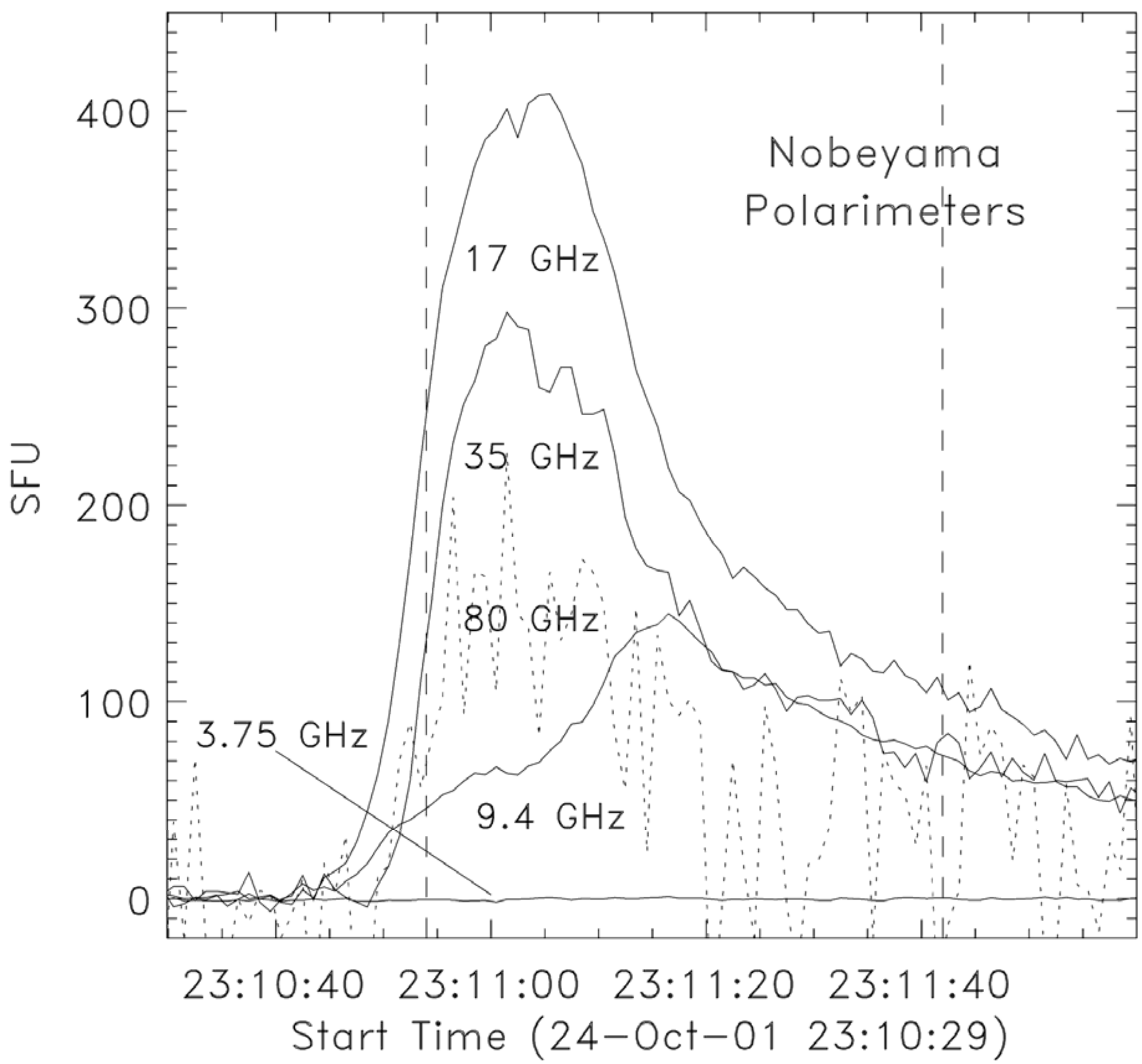


Normalized
1.0
0.8
0.6
0.4
0.2
0.0
1-8 Å
0.5-4 Å
GOES 10
NoRP 17 & 35 GHz
HXT 12.7-22.7 keV
23:06
23:08
23:10
23:12
23:14
23:16
Start Time (24-Oct-01 23:06:00)

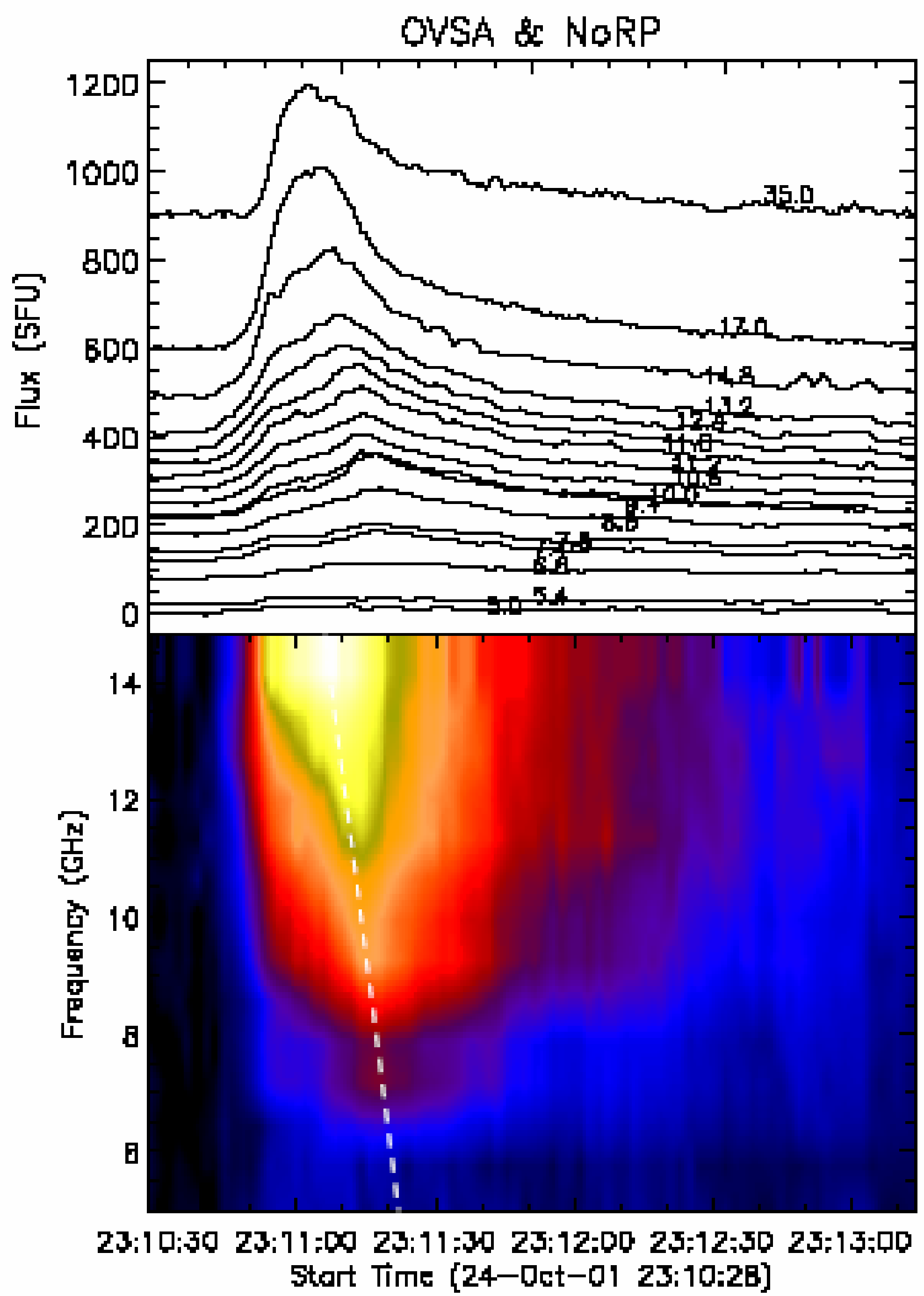

10000
1000
100
10
1
10
100
1000
10000
NoRP 17 GHz SFU
HXT L band cts s^{-1} sc^{-1}


EXTENDED (13)
GRF (62)
HOT THERMAL (3)
OTHER EVENTS (338)
FR = 0.08 FX
17 GHz PEAK FLUX (sfu)
HXRBS PEAK RATE (counts s-1) ≥ 30 keV
10^0
10^1
10^2
10^3
10^4
10^5
10^6

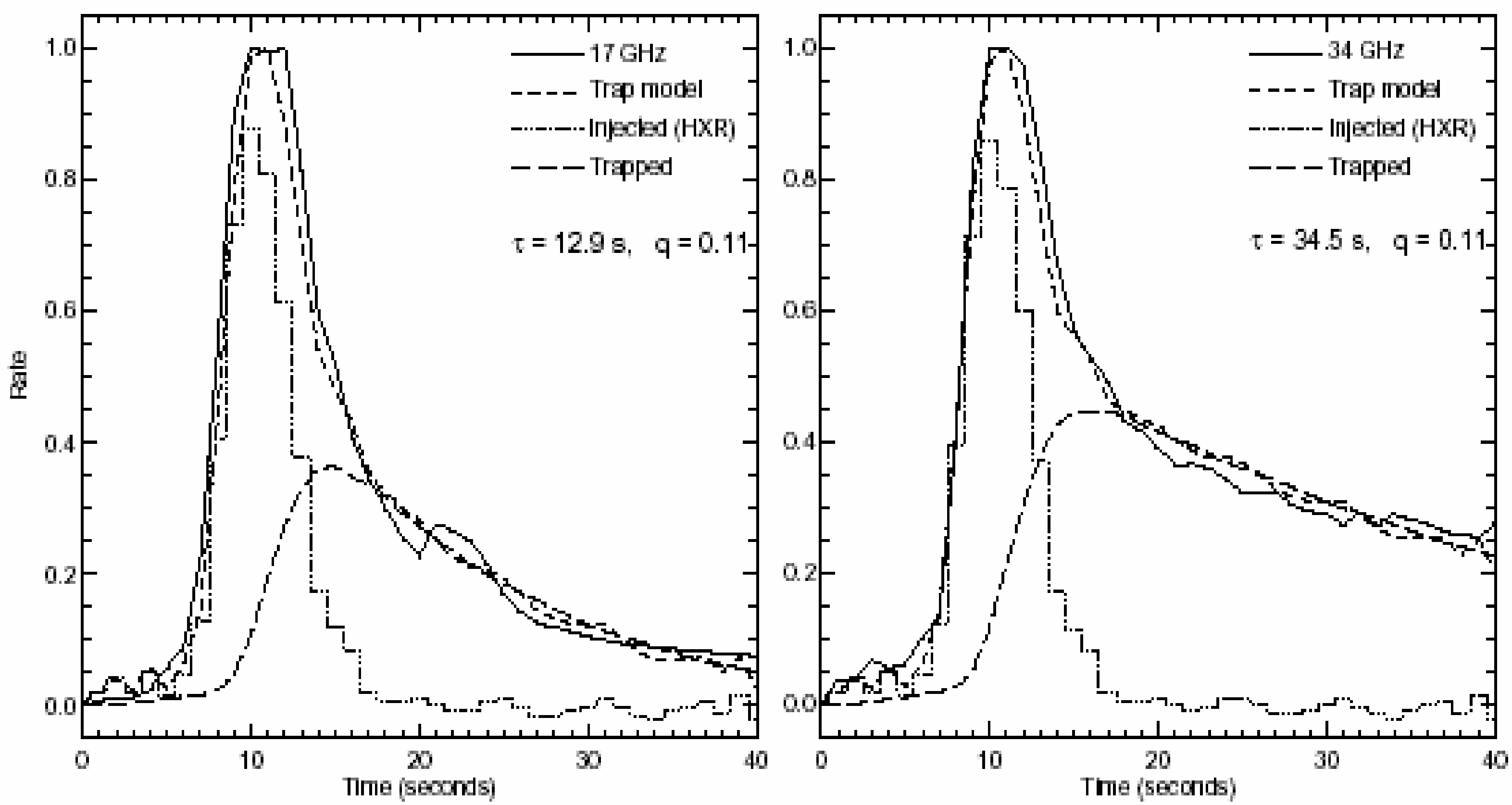

(a) TRACE 171
(b) SXT AlMg
(c) HXT L band
(a) TRACE 171
(b) SXT AlMg
(c) HXT L band



Nobeyama
Polarimeters
17 GHz
35 GHz
80 GHz
3.75 GHz
9.4 GHz
SFU
0
100
200
300
400
23:10:40
23:11:00
23:11:20
23:11:40
Start Time (24-Oct-01 23:10:29)



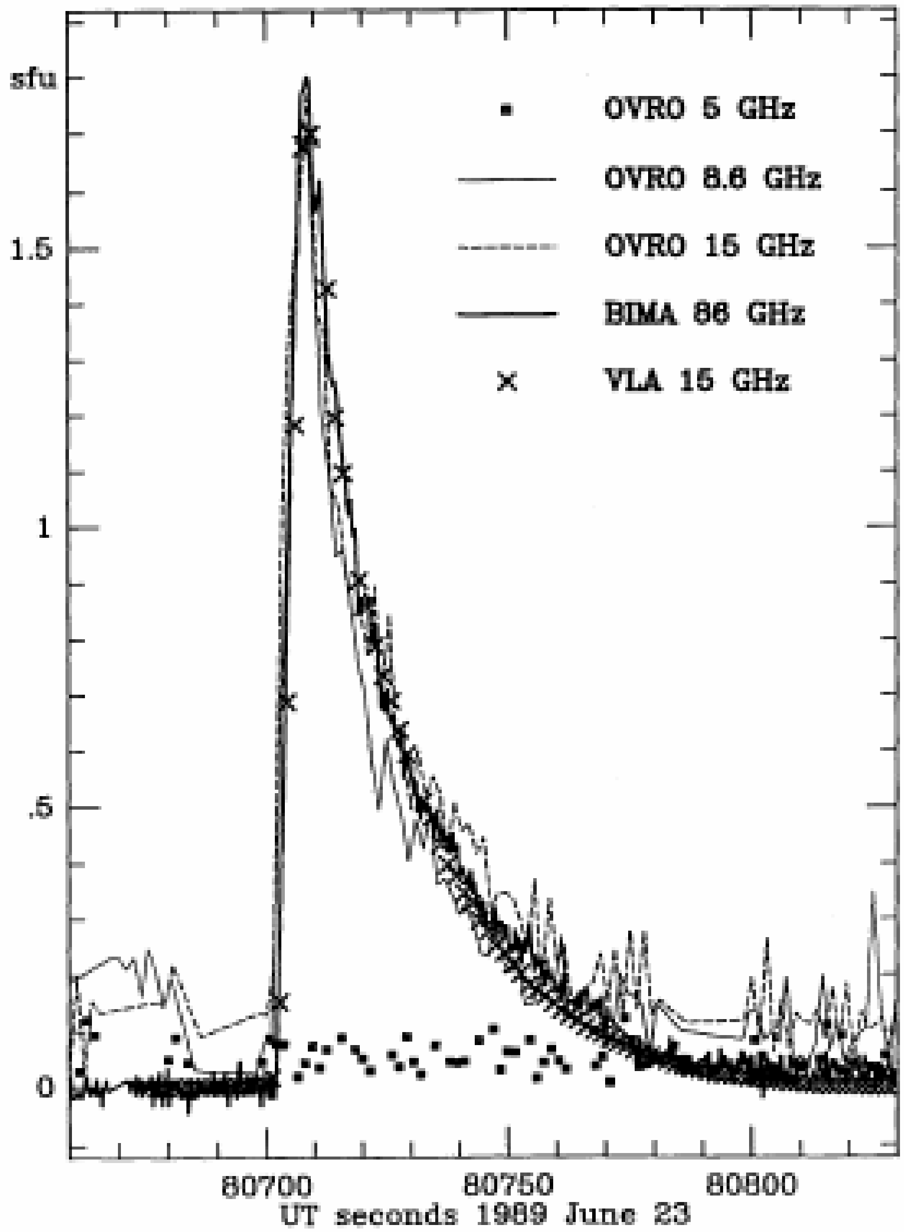
OVSA & NoRP
Flux (SFU)
1200
1000
800
600
400
200
0
35.0
17.0
14.8
13.2
12.8
11.8
10.6
10.0
9.4
8.6
7.8
6.6
5.4
5.0
Frequency (GHz)
14
12
10
8
6
23:10:30
23:11:00
23:11:30
23:12:00
23:12:30
23:13:00
Start Time (24-Oct-01 23:10:28)



Kundu et al. 2001

Observational Summary

- Impulsive, radio rich flare – little EUV, SXR, HXR
- Low frequency cut-off below ~10 GHz
- Flux maxima delayed with *decreasing* frequency
- Flux decay approx. frequency independent late in event



Hudson & Ryan's (1995) "Impulse response" flares

- First pointed out by White et al (1992).
- Simple impulsive profile
- Flat spectrum
- Sharp low frequency cutoff
- No SXRs!

from White et al 1992

Interpretation

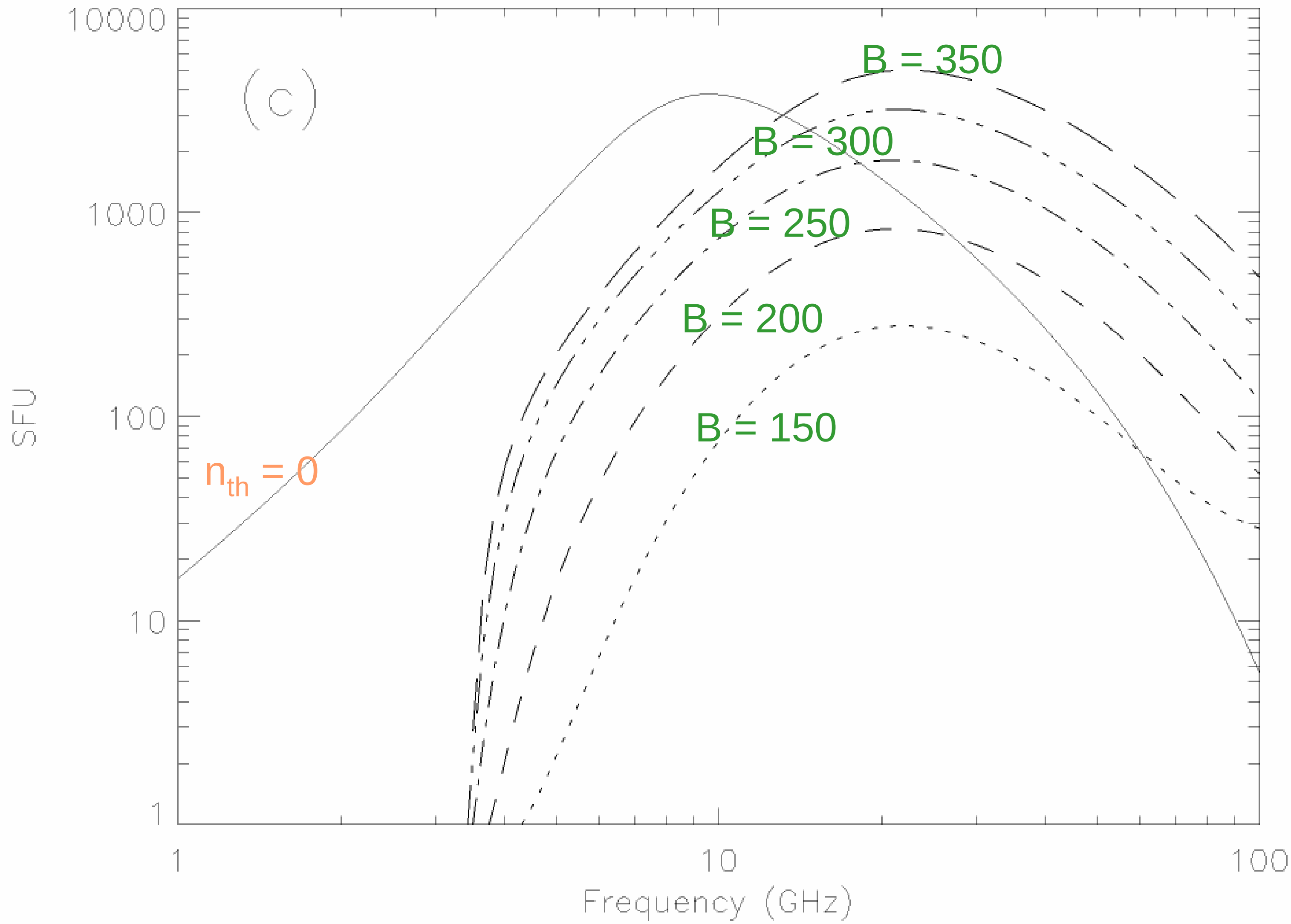
- Radio emission is due to GS emission from non-thermal distribution of electrons in relatively cool, dense plasma
- Ambient plasma density is high – therefore, Razin suppression is relevant
- Thermal free-free absorption is also important ($\sim n^2 T^{-3/2} \nu^{-2}$)

Include these ingredients in the source function (cf. Ramaty & Petrosian 1972)

The idea is that energy loss by fast electrons heats the ambient plasma, reducing the free-free opacity with time, thereby accounting for the reverse delay structure.

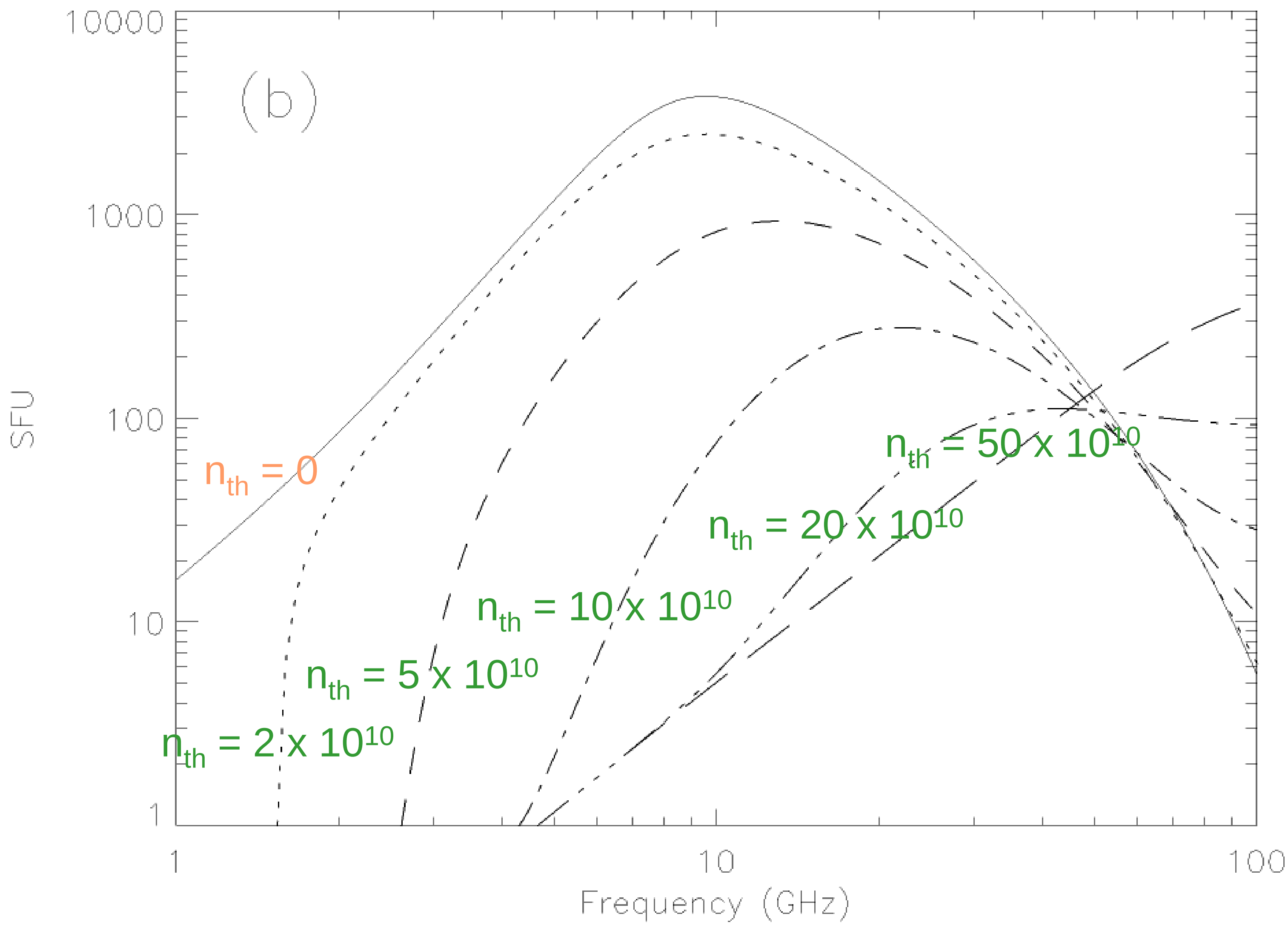
δ = 3.5, E_1 = 100 keV, E_2 = 2.5 MeV, n_{rl} = 5 x 10^6 cm^{-3}

n_{th} = 10^{11} cm^{-3}, T = 2 x 10^6 K, A = 2 x 10^{18} cm^2, L = 9 x 10^8 cm



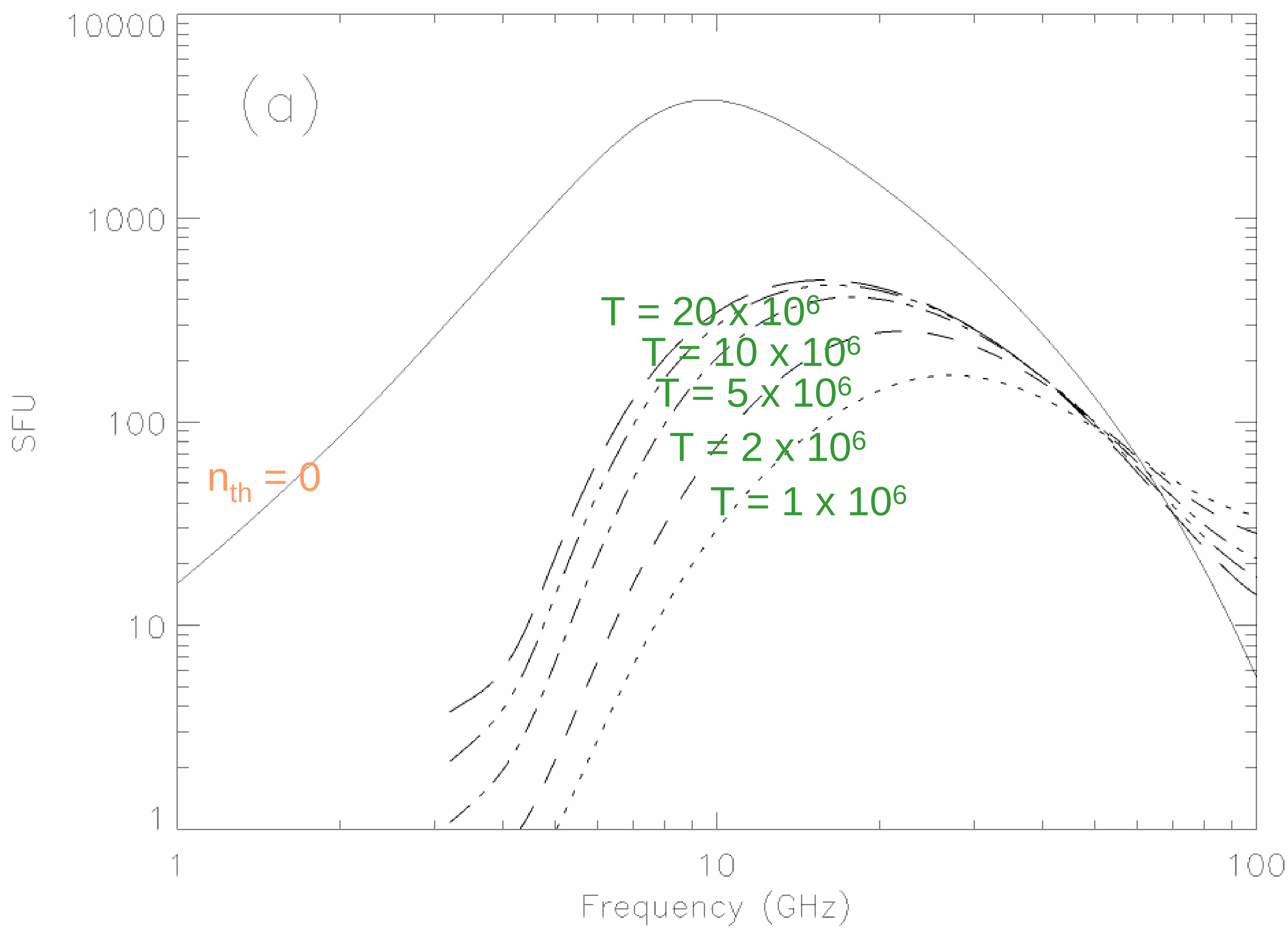
δ = 3.5, E_1 = 100 keV, E_2 = 2.5 MeV, n_{rl} = 5 x 10^6 cm^{-3}

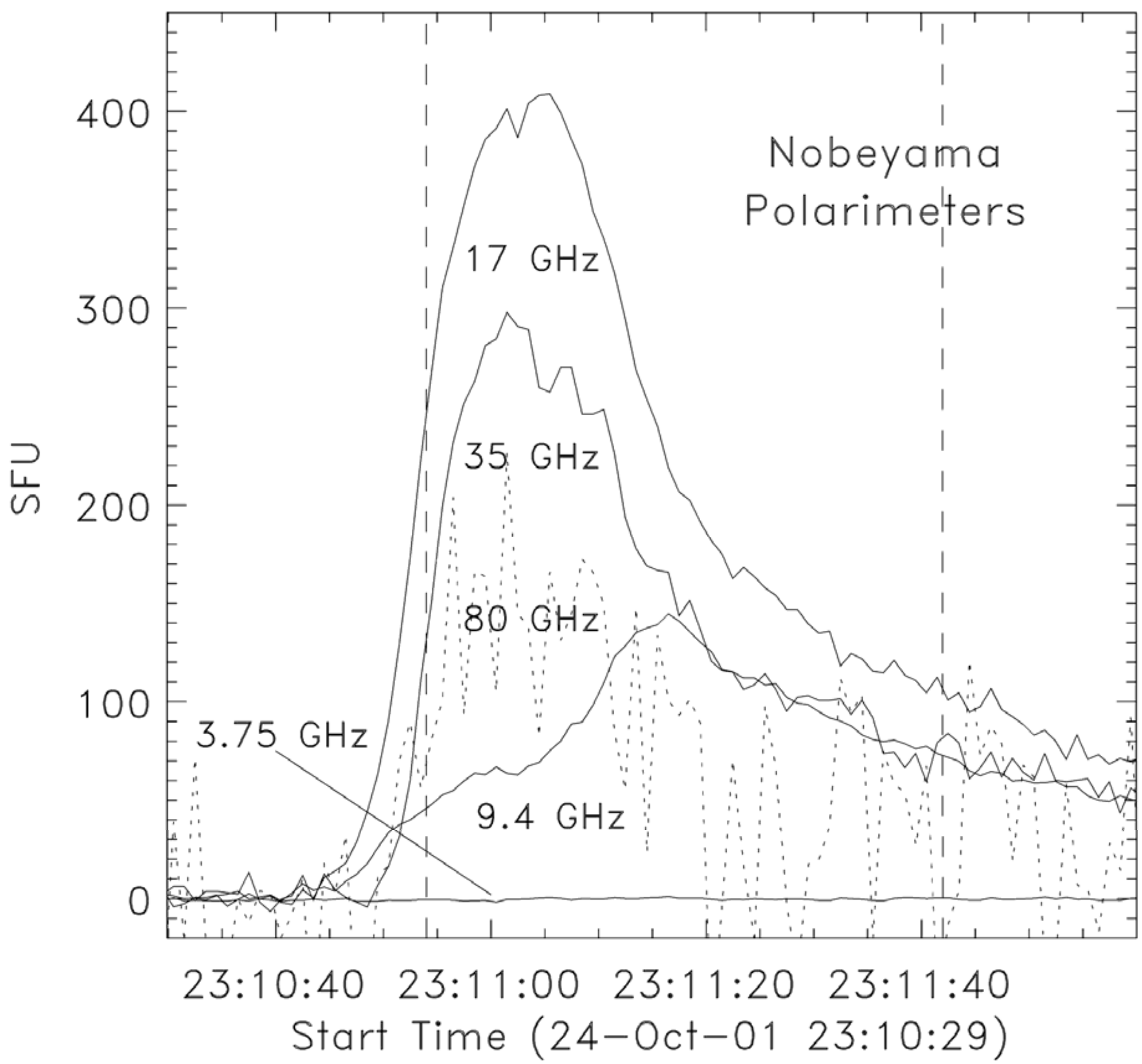
B = 150 G, T = 2 x 10^6 K, A = 2 x 10^{18} cm^2, L = 9 x 10^8 cm



$\delta = 3.5$, $E_1 = 100$ keV, $E_2 = 2.5$ MeV, $n_{rl} = 5 \times 10^6$ cm^{-3}

B=150 G, $n_{th} = 10^{11}$ cm^{-3}, $A = 2 \times 10^{18}$ cm^2, $L = 9 \times 10^8$ cm



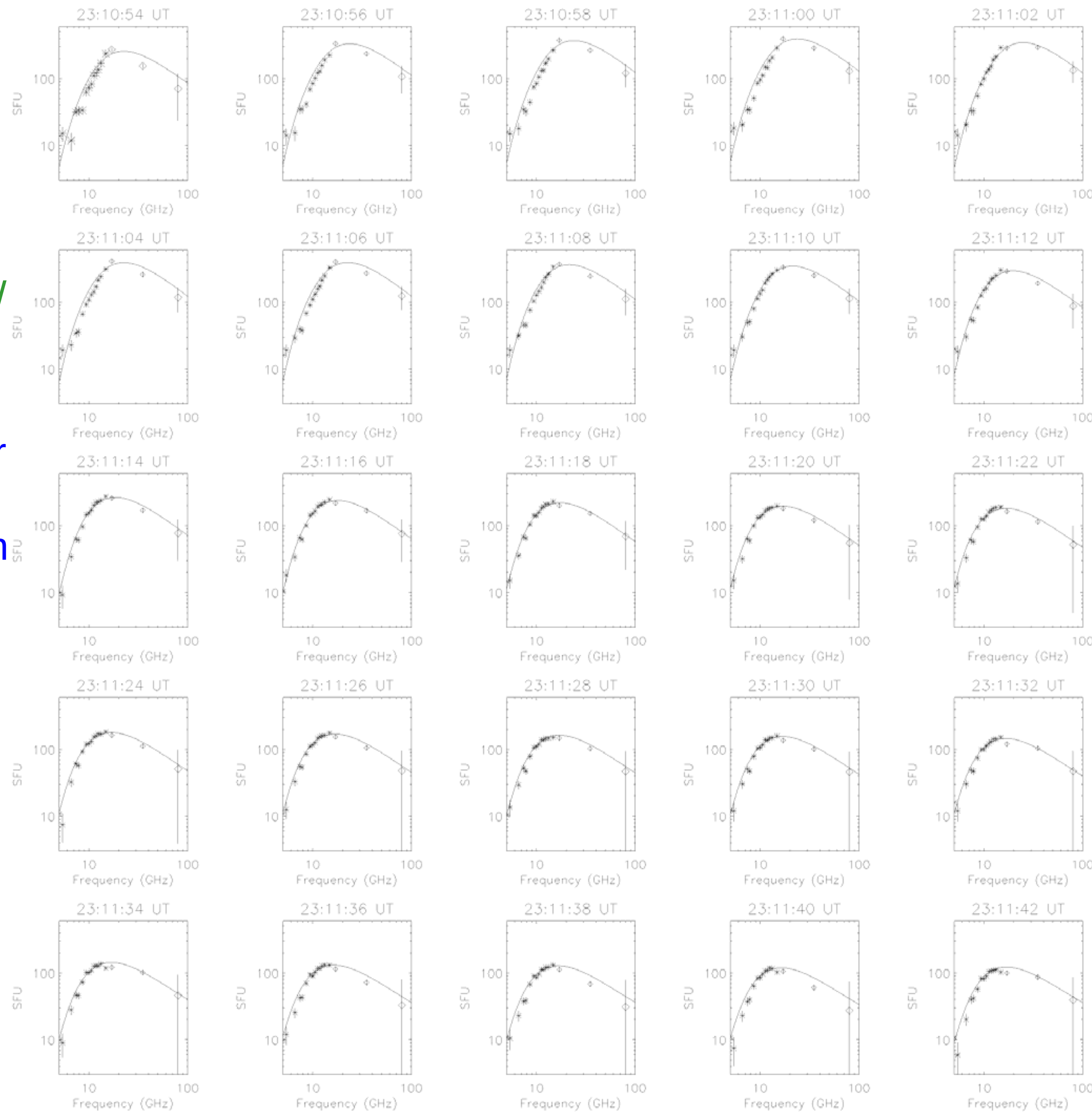

Nobeyama
Polarimeters
17 GHz
35 GHz
80 GHz
3.75 GHz
9.4 GHz
SFU
400
300
200
100
0
23:10:40
23:11:00
23:11:20
23:11:40
Start Time (24-Oct-01 23:10:29)

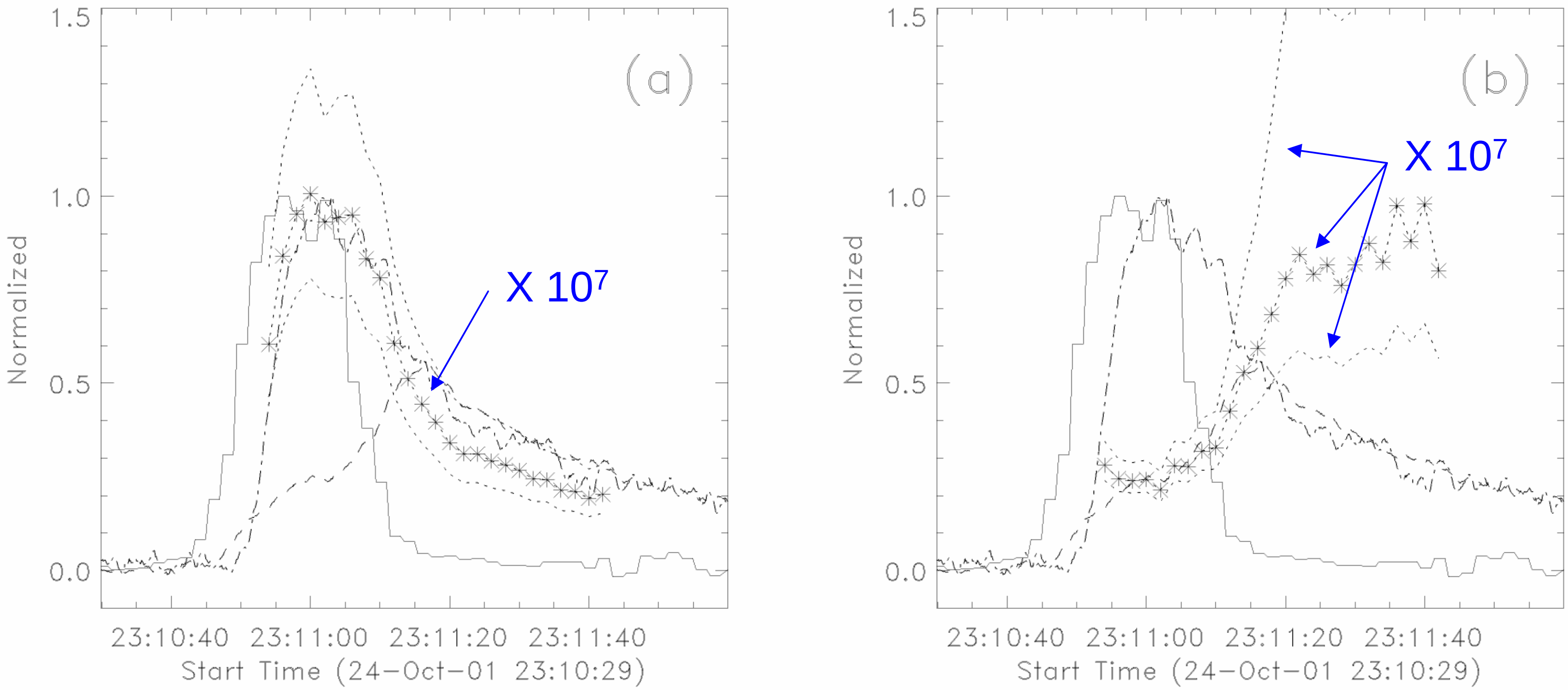
1 spectrum/
2 sec

2-parameter fits via χ^2-minimization

n_{rl}, T

B, θ, n_{th}, A, L, E_1, E_2, δ fixed




(a)
X 10^7
(b)
X 10^7
1.5
1.0
0.5
0.0
Normalized
23:10:40 23:11:00 23:11:20 23:11:40
Start Time (24-Oct-01 23:10:29)

Essential features of the flare are adequately described by the proposed scenario.

An outstanding issue that has not been addressed is the fact that all frequencies appear to decay with a similar time scale beyond the time of spectral maximum.

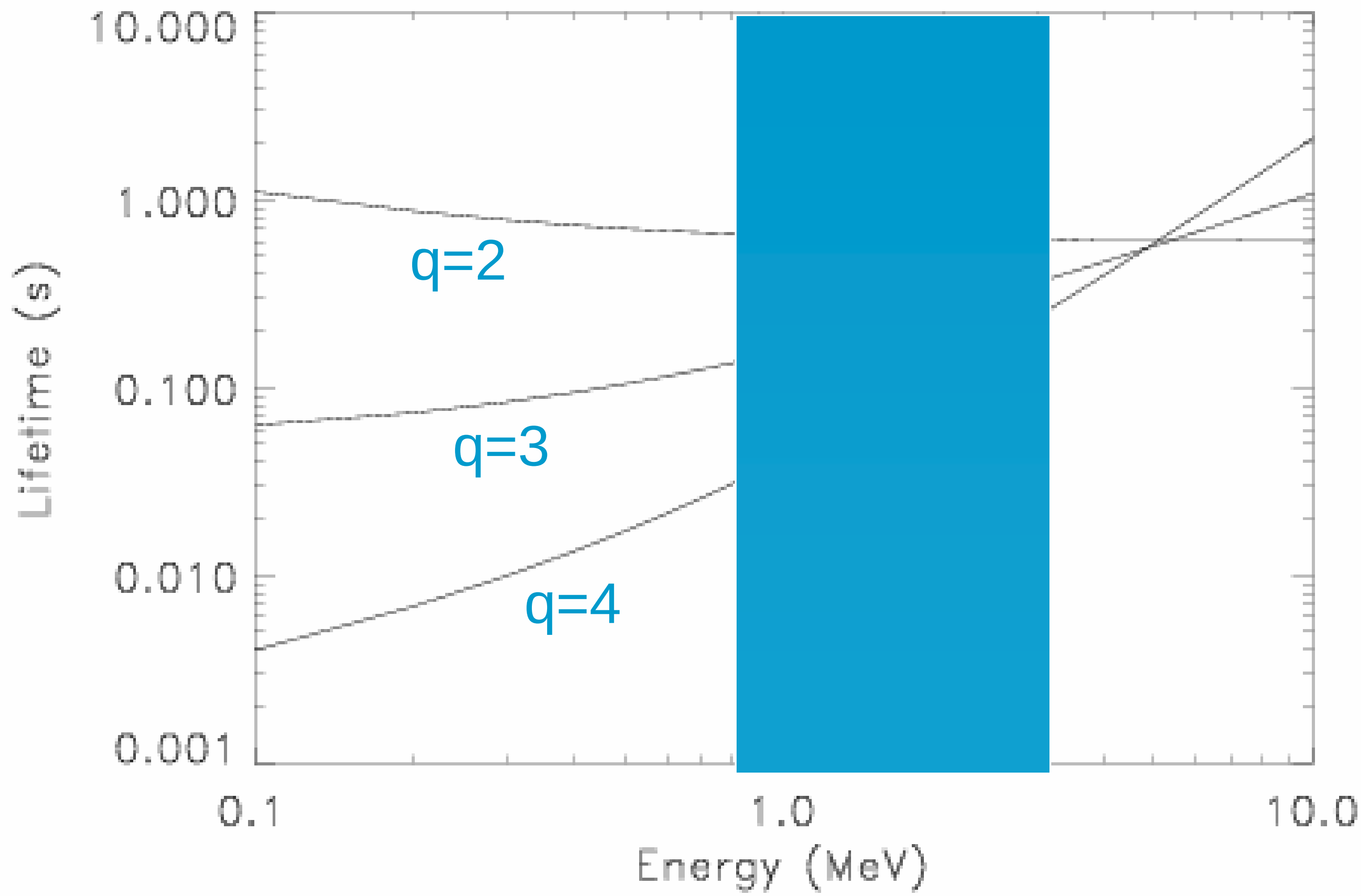
Possible explanations:

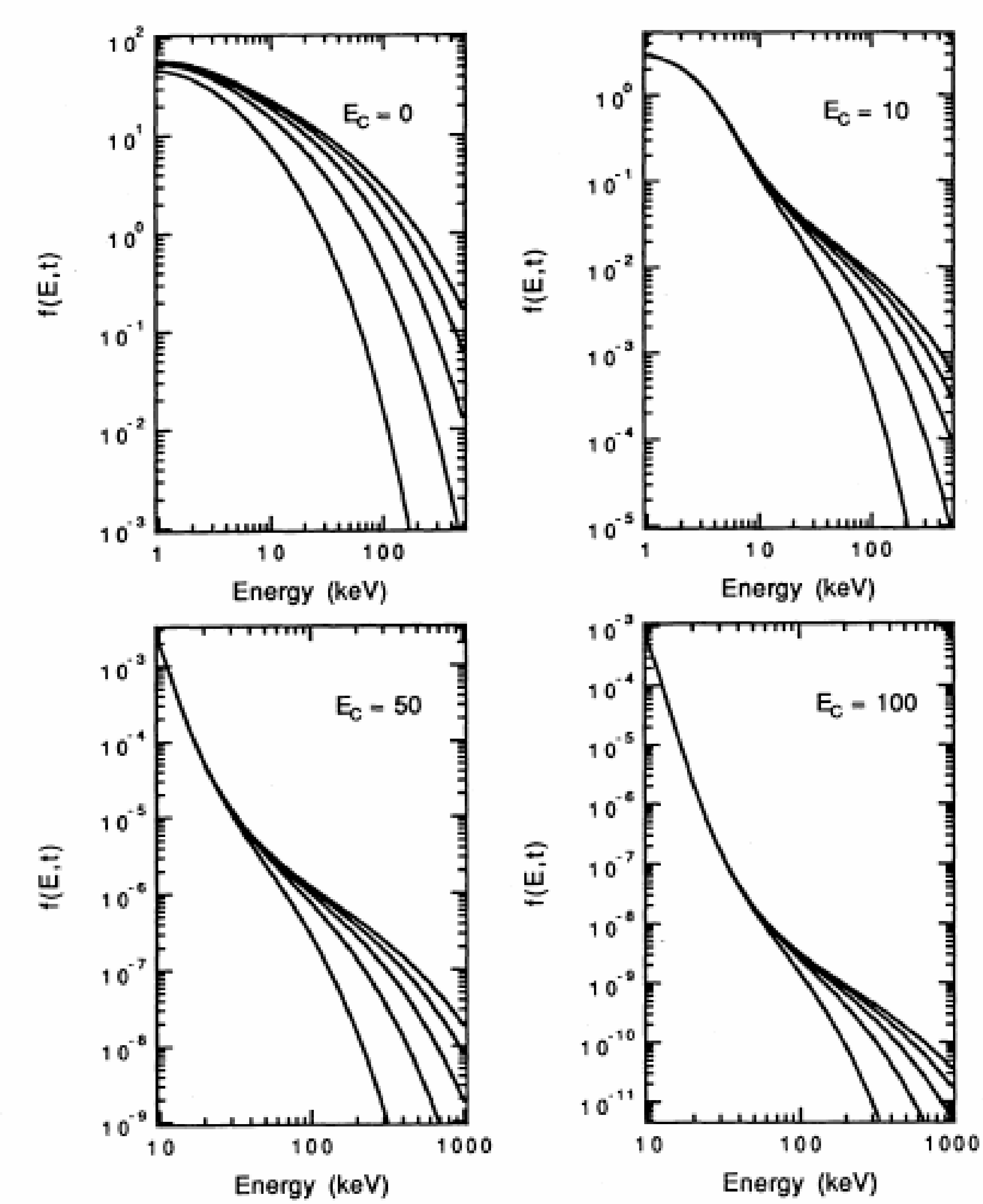
High energy cutoff E_2– discounted by spectral fits

Transport not determined by Coulomb collisions

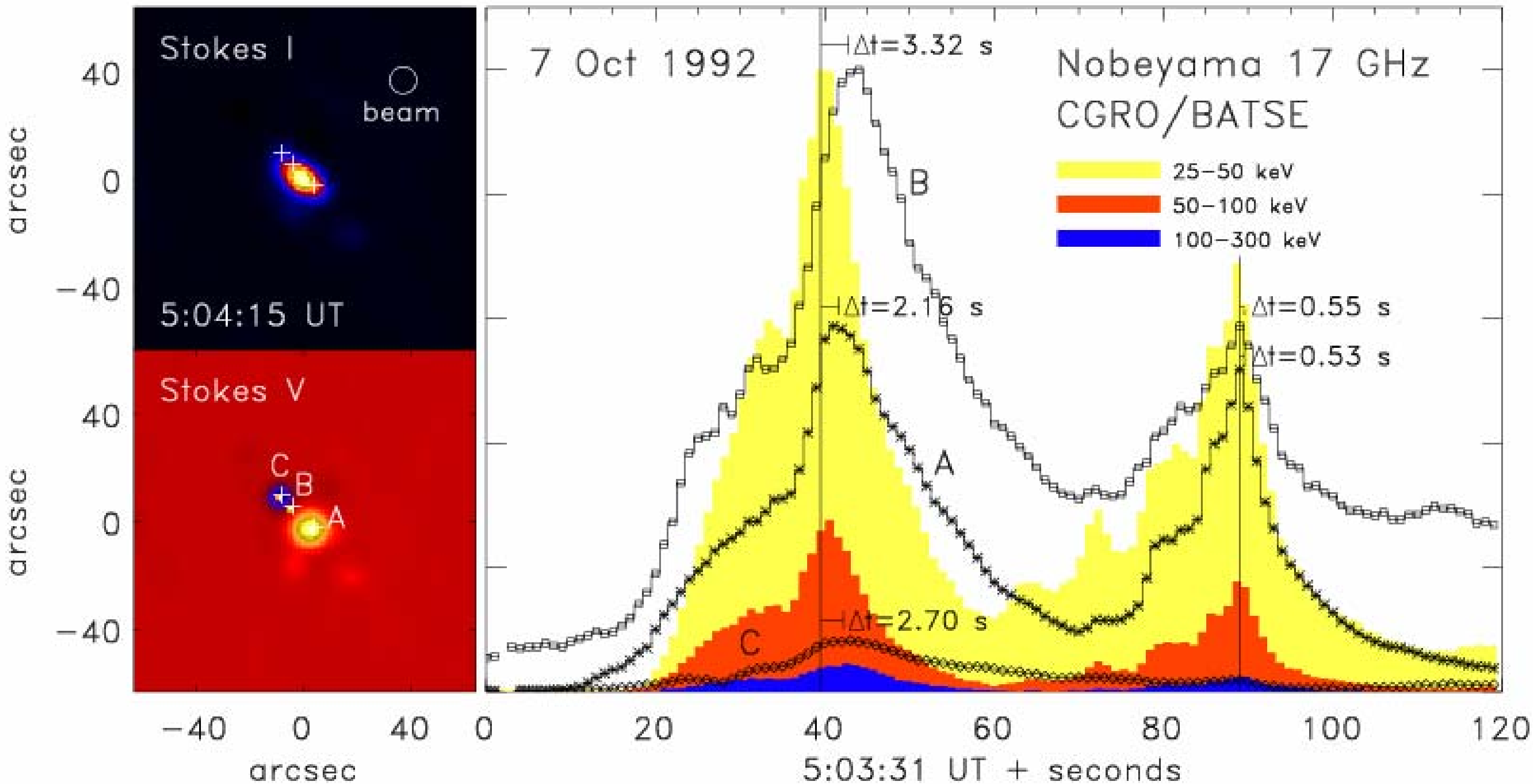
Scattering by turbulence – e.g., Whistlers (Hamilton & Petrosian 1992), fast-mode MHD waves (Miller et al. 1996)

$$W(q) = W_{tot} \frac{q-1}{k_o} \left(\frac{k_o}{k} \right)^q \qquad W_{tot} = \int_{k_o}^{\infty} W(k)dk; \qquad k_o = \frac{\Omega_p}{v_A}$$





Hamilton & Petrosian 1992

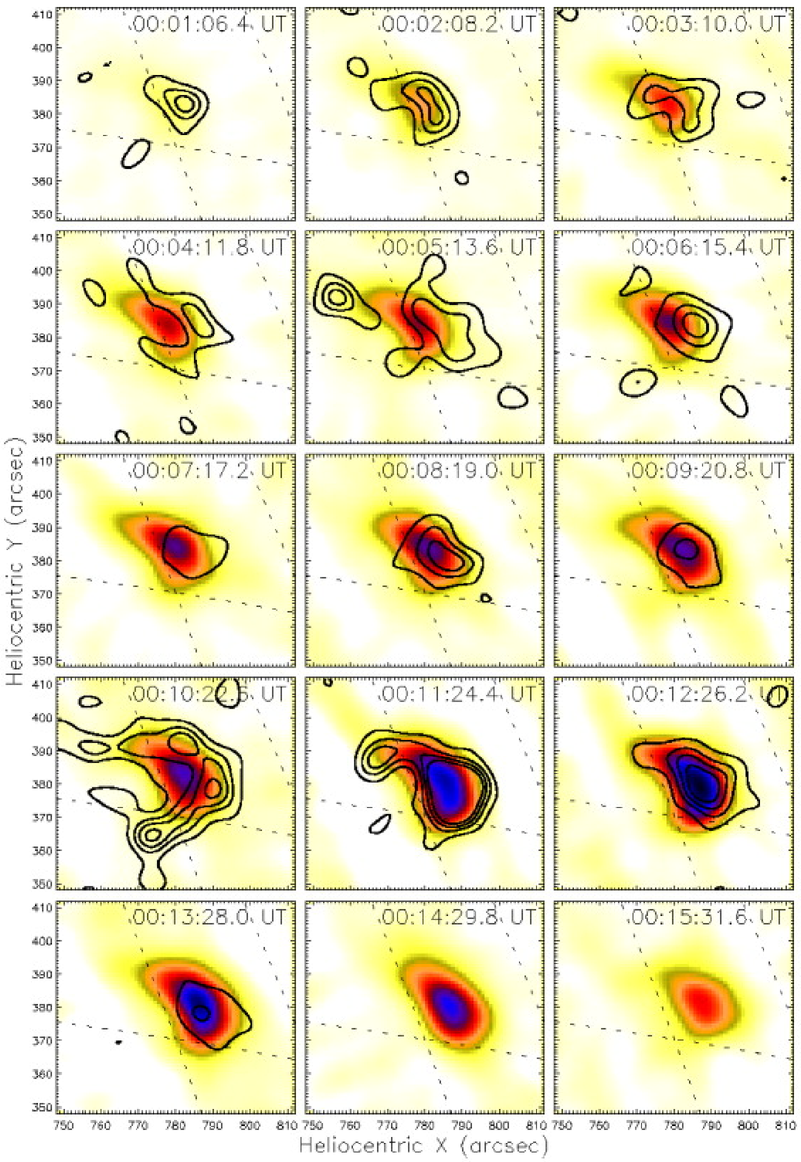


Bastian et al 1998

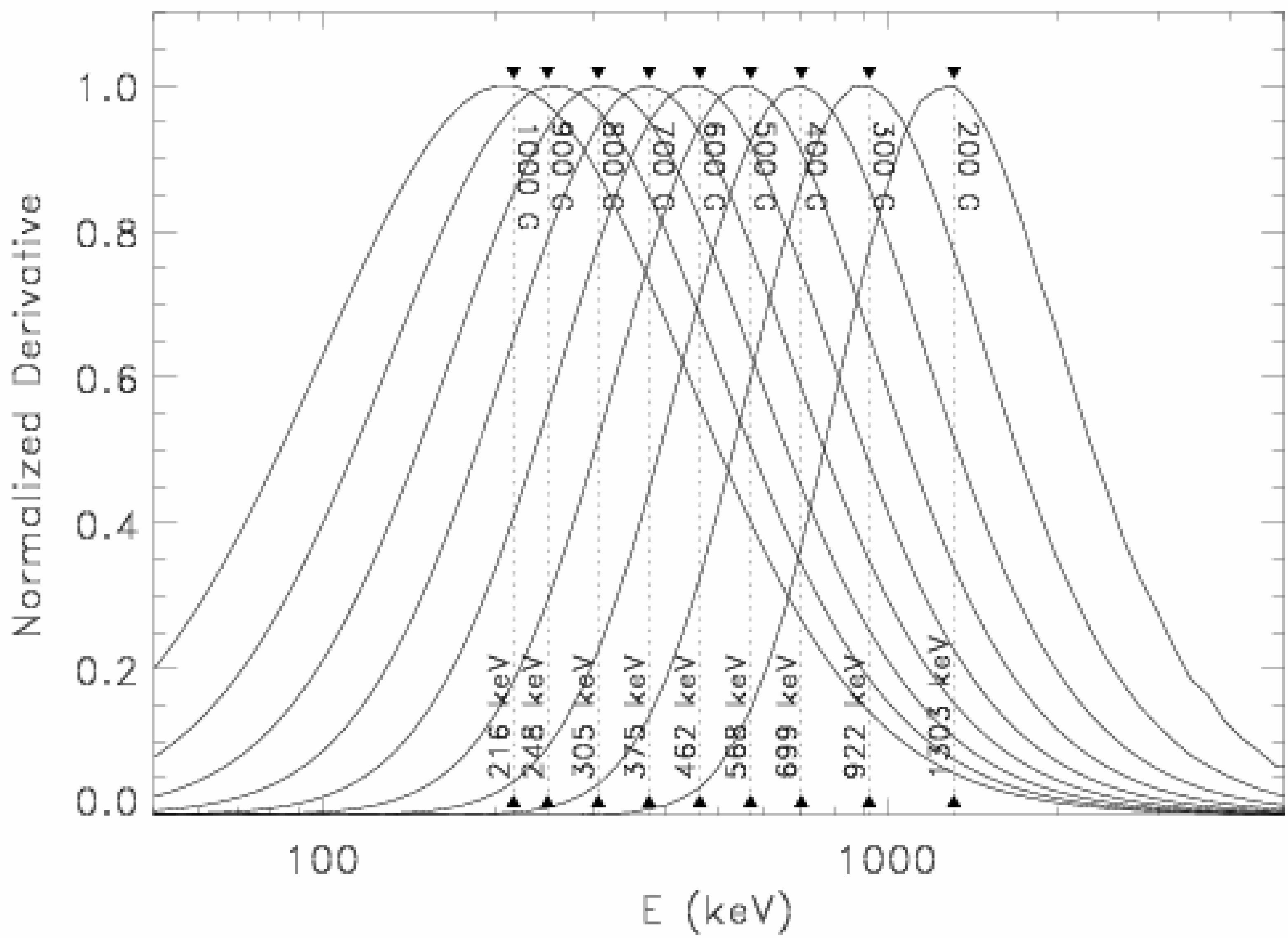
Coronal thick-target flares

Veronig & Brown 2004

- Two examples presented of gradual flares wherein the corona is collisionally thick.
- Electron distribution function, while steep (δ = 6-7) is definitely non-thermal (NoRH)
- Column depth $\phi \sim 5 \times 10^{20}$ cm^{-2}
- $E_{loop}=8.8\ \phi_{19}^{1/2}$ (keV)
- These flares have E_{loop}=50-60 keV!
- The implied coronal density of thermal plasma is $n_{th} \sim 2 \times 10^{11}$ cm^{-3}



Color:-12 kev; Contours: 25-50 keV



Normalized Derivative
E (keV)
1000 G
900 G
800 G
700 G
600 G
500 G
400 G
300 G
200 G
216 keV
248 keV
305 keV
375 keV
462 keV
588 keV
699 keV
922 keV
1303 keV