Coronal HXR Sources

Lindsay Glesener, Säm Krucker
Space Sciences Lab, UC Berkeley

Solar Cycle 24, Napa, CA

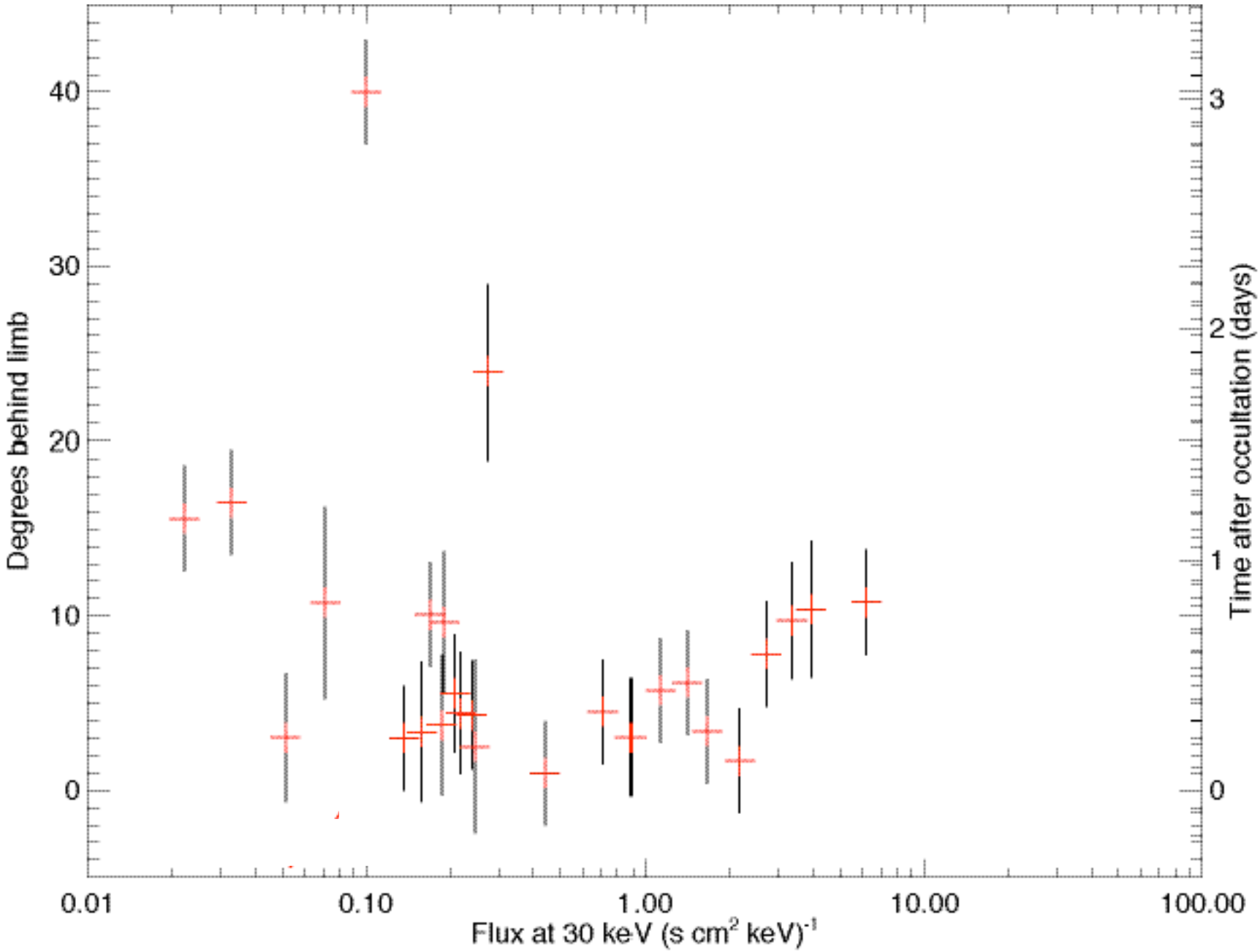
Coronal HXR Emission

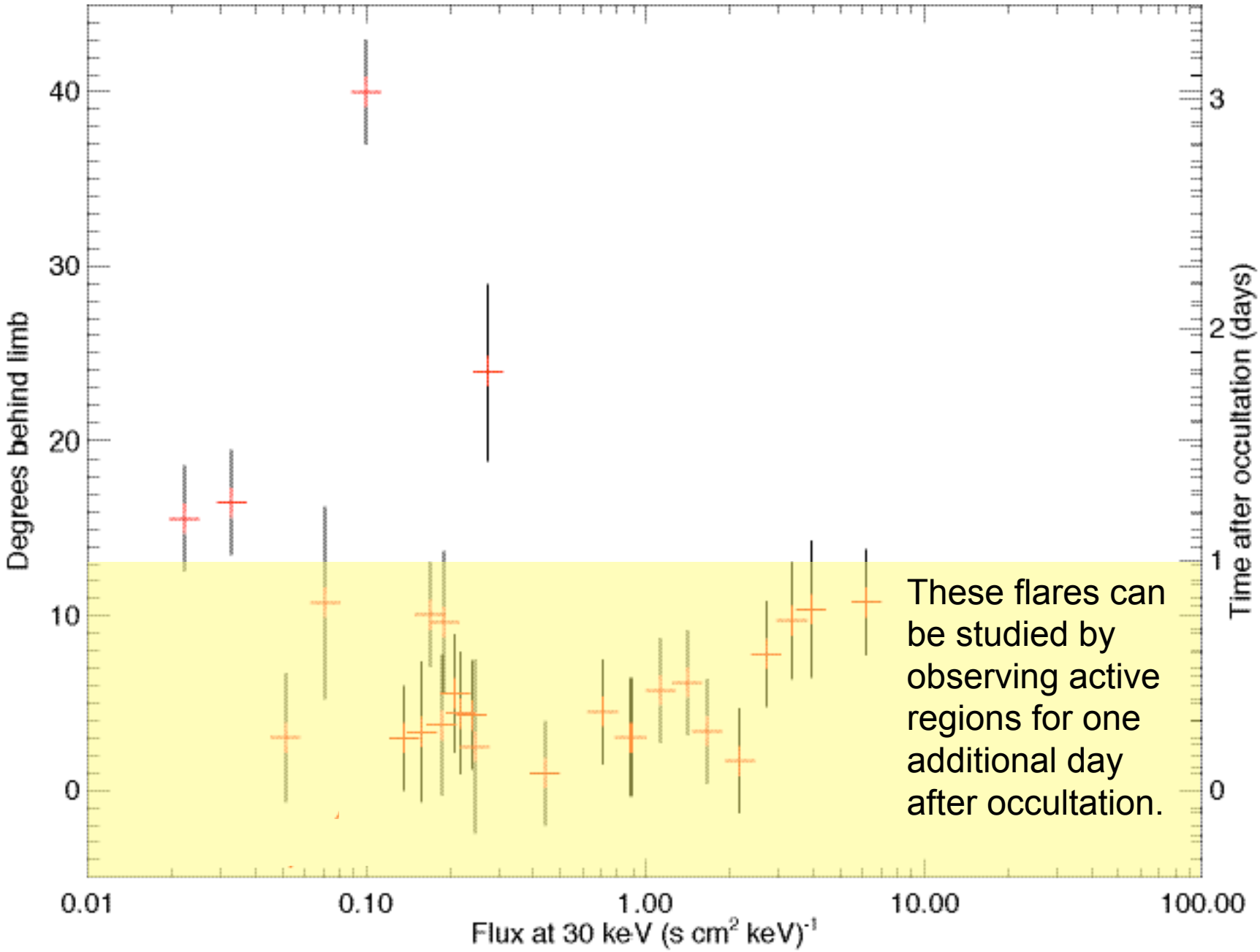
- Coronal HXR emission
  - Acceleration region
  - Paths away from acceleration region
  - Footpoints

- Footpoints
  - Saint-Hilaire et al (2008) found that flare footpoints emit up to 100 (s cm^2 kev)$^{-1}$ at 30 keV.
- Coronal sources
  - Almost always fainter by an order of magnitude
  - Studies are limited by instrument dynamic range.

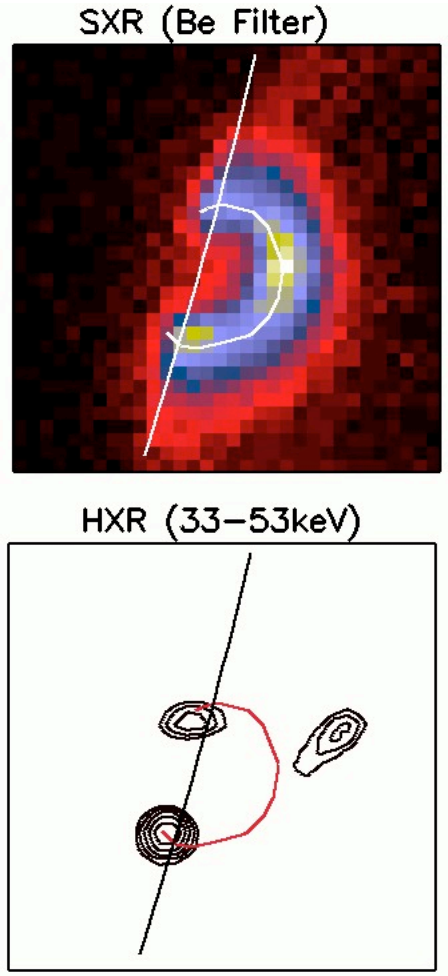
Occulted flares

- Active region has advanced beyond limb -- how far beyond?
- No bright footpoints -- fainter coronal HXR sources can be studied in detail.
- Krucker and Lin (2008) studied 55 occulted flares
  - Spectra, images, locations of thermal and nonthermal sources
  - Later, occultation heights were determined for most of these.


Degrees behind limb
40
30
20
10
0
Time after occultation (days)
3
2
1
0
0.01
0.10
1.00
10.00
100.00
Flux at 30 keV (s cm^2 keV)$^{-1}$


Degrees behind limb
40
30
20
10
0
Time after occultation (days)
3
2
1
0
0.01
0.10
1.00
10.00
100.00
Flux at 30 keV (s cm^2 keV)$^{-1}$
These flares can be studied by observing active regions for one additional day after occultation.

Above-the-loop-top HXR sources



Masuda et al. 1994, 2000

Ambient (thermal) density is low
$n \sim 10^9$ cm^{-3} or even smaller

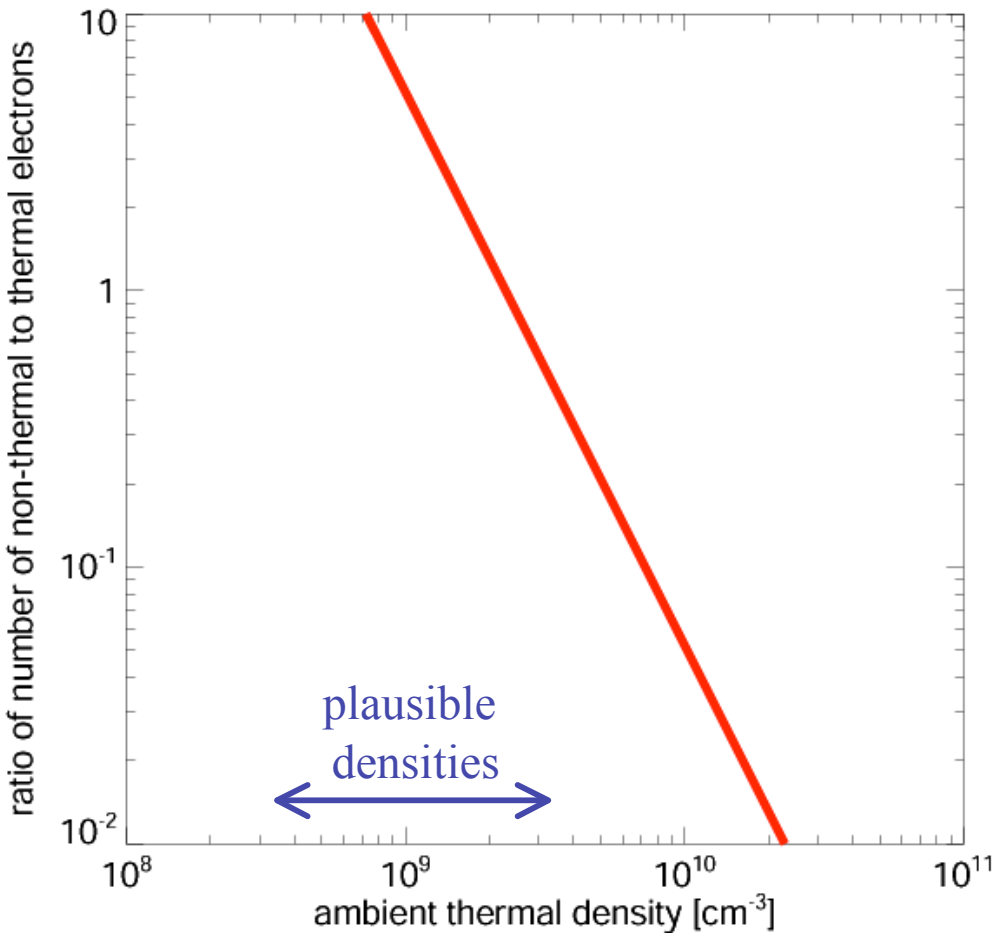
number of HXR producing electrons (instantaneous)
$N_{HXR} \sim n^{-1}$

Ratio number of accelerated to thermal electrons:

$R = N_{HXR}/N_{thermal} \sim n^{-2}$

$N_{HXR} \gtrsim N_{thermal}$

$R = N_{HXR}/N_{thermal} \sim n^{-2}$



Number of non-thermal (accelerated) electrons must be of the same order as ambient thermal electrons or larger.

HXR producing electrons are NOT a tail of a dominant thermal core population …

$N_{HXR} \gtrsim N_{thermal}$ means

- almost all energy is in accelerated electrons

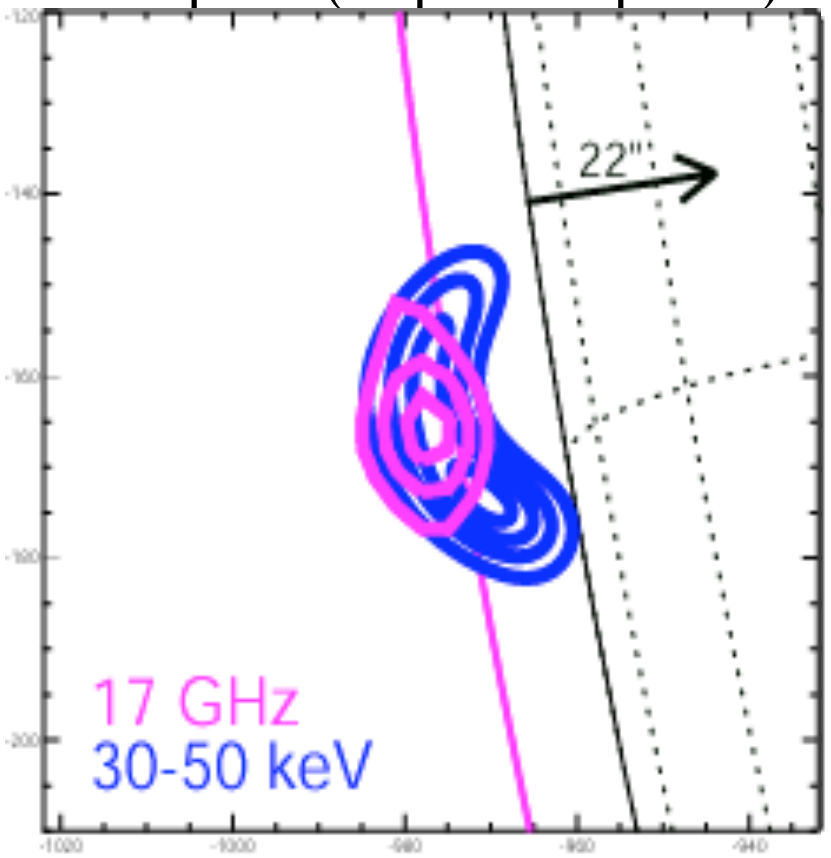
  ($<E_{acc}>$~20 keV vs $E_{thermal}$~0.2 keV)
- collisional heating is fast (~ 5 keV/s)
- accelerated electrons heat all thermal electrons to $< E_{acc}>$ within seconds

→ above-the-loop-top source is entirely non-thermal (all electrons are accelerated)

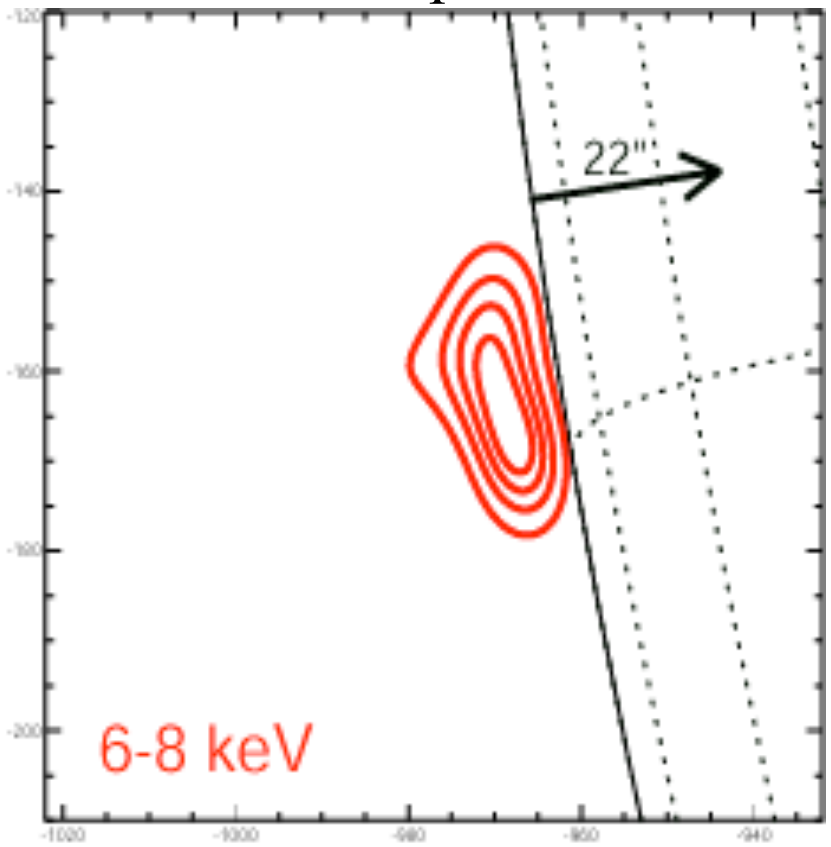
→ above-the-loop-top source is acceleration region

Partially disk-occulted flare of 2007Dec31

HXR peak (impulsive phase)



SXR peak

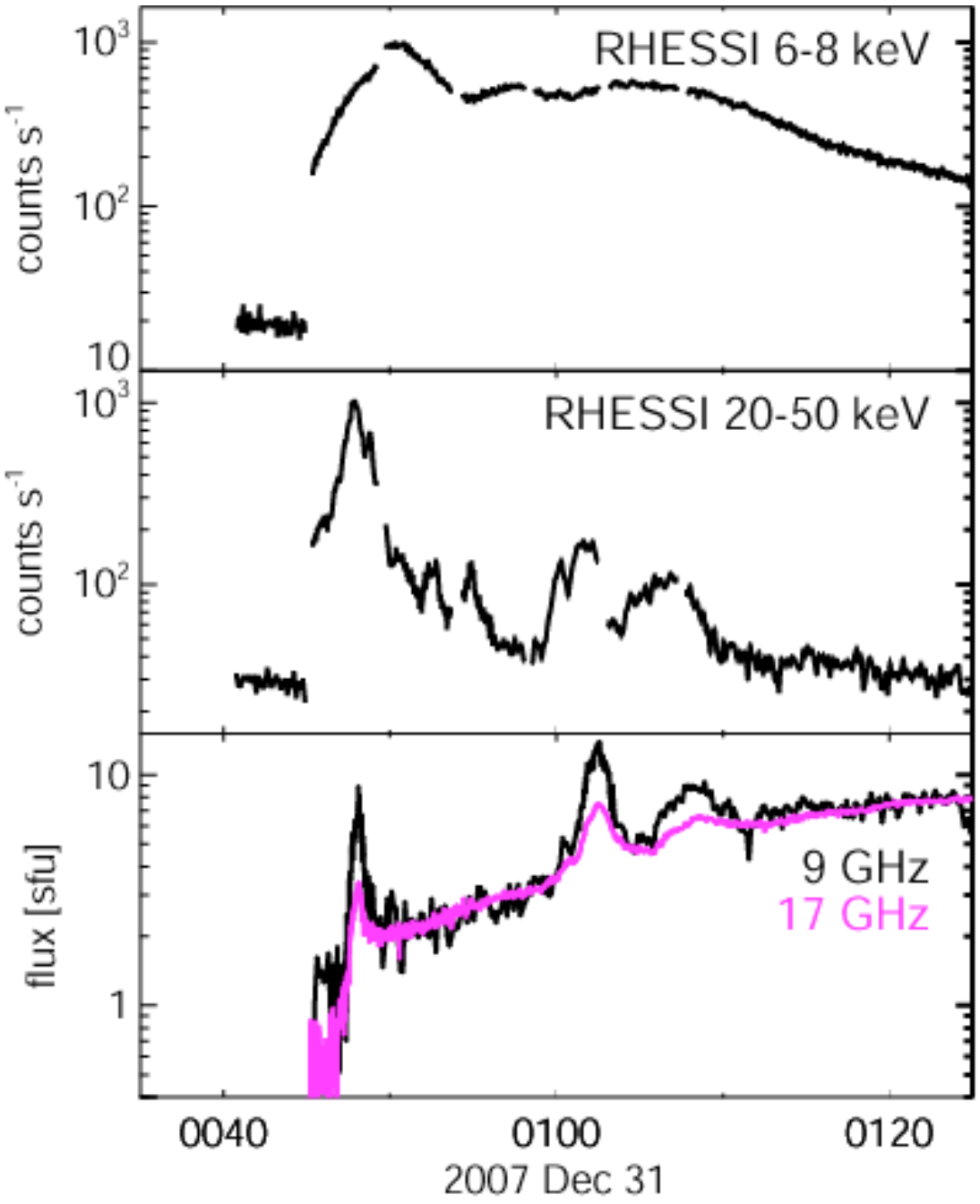


microwave limb is higher up, 17 GHz source is co-spatial.

Summary: measured parameters

pre-flare density	$\sim 2 \cdot 10^9$ cm^{-3}
volume	$\sim 8 \cdot 10^{26}$ cm^3
magnetic field strength B	~ 30-50 G
pre-flare β (T=2 MK)	~ 0.01
acc. electron density	$\sim 2 \cdot 10^9$ cm^{-3}
number of acc. electrons	$\sim 10^{36}$
power law distribution with δ	~3.4
from ~15 keV up to a few MeV	
β during HXR burst	~1

→ energy density of the accelerated electrons is comparable to that of the magnetic field



time series

thermal emission

rapid time variations

Nobeyama observations:
thermal component
(constant spectrum)
gyro-synchrotron emission
(decreasing spectrum)

HXR and microwave spectra