S-3(2b)

White-Light Emission and Related Particle Acceleration Phenomena

Conditions that Enhance White-Light Emission in Solar Flares

Kyoko Watanabe, Toshifumi Shimizu
ISAS/JAXA, Japan

Jun Kitagawa, Satoshi Masuda, Shinsuke Imada
STE Lab., Nagoya Univ., Japan

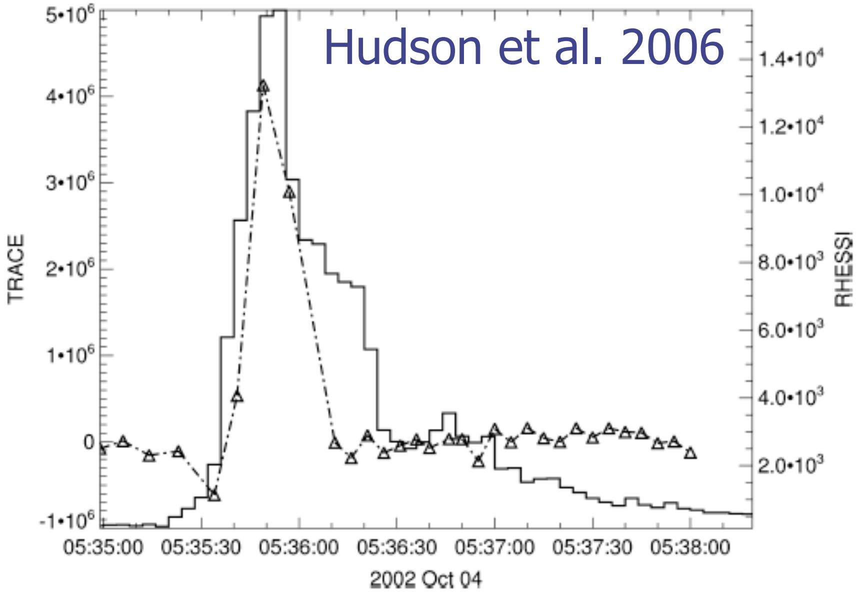
White-light flare

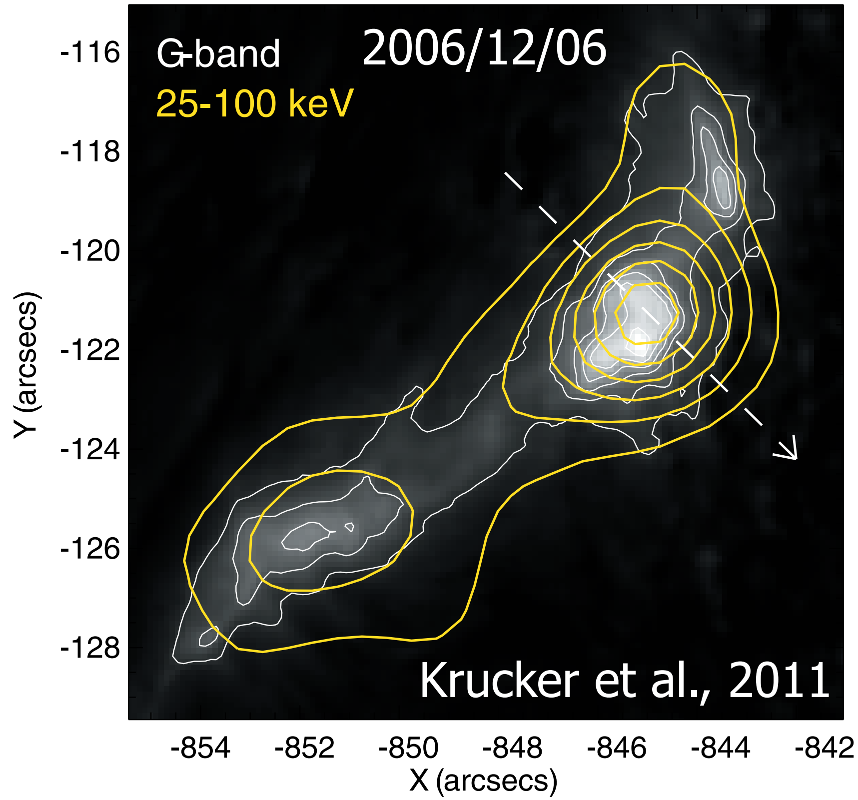
White-light (WL) flares are very rare events observed only from large & energetic solar flares (X-class etc.)

WL emission is well correlated with hard X-ray and radio emission (Location & Profile)
⇒ Non-thermal electrons

WL emission is related to strong particle acceleration, which might be connected to CMEs and SEPs as the original source.

We need to understand the conditions that produce enhancements of WL in solar flares.

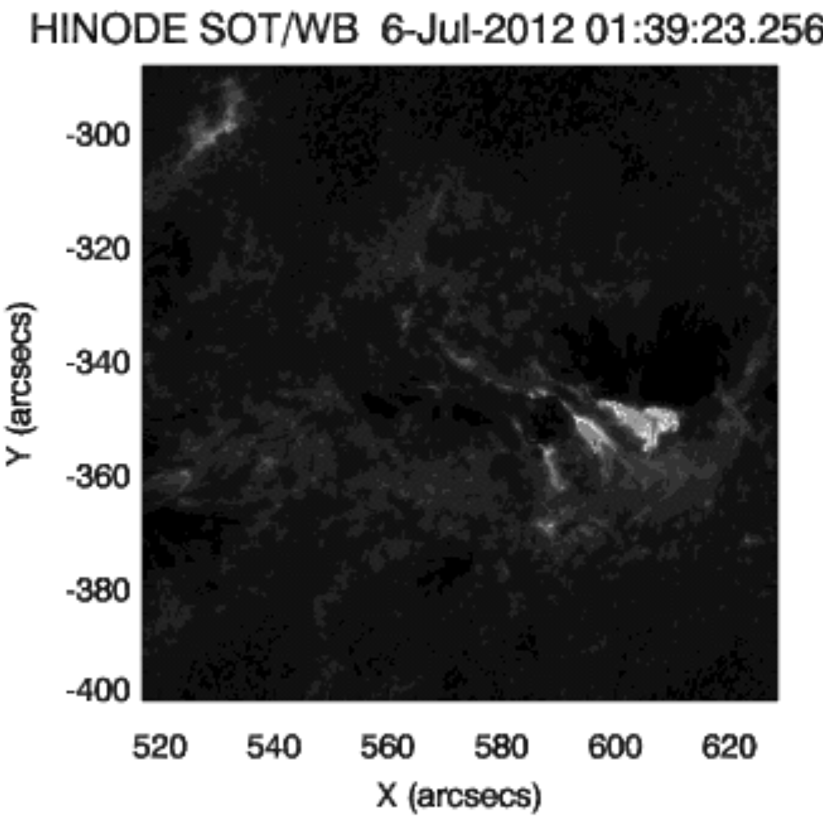


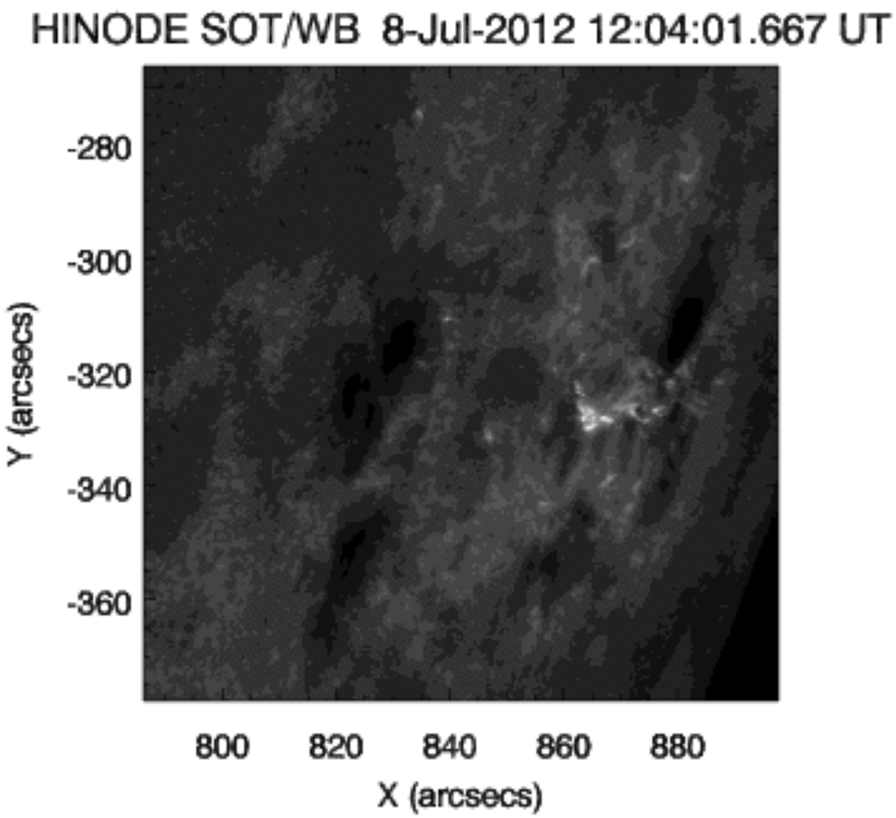


White-light flare observations

2012 Jul 6 1:37- M2.9 flare
S18W41 NOAA#11515

2012 Jul 8 12:05- M1.4 flare
S21W69 NOAA#11515



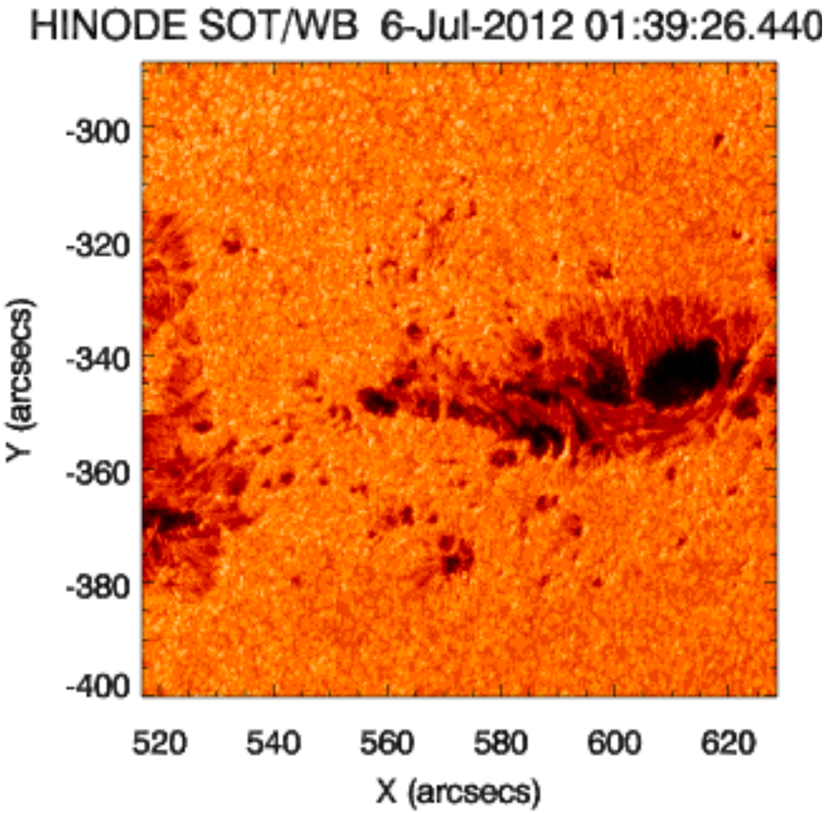


RHESSI: 50-100 keV

RHESSI: 50-100 keV

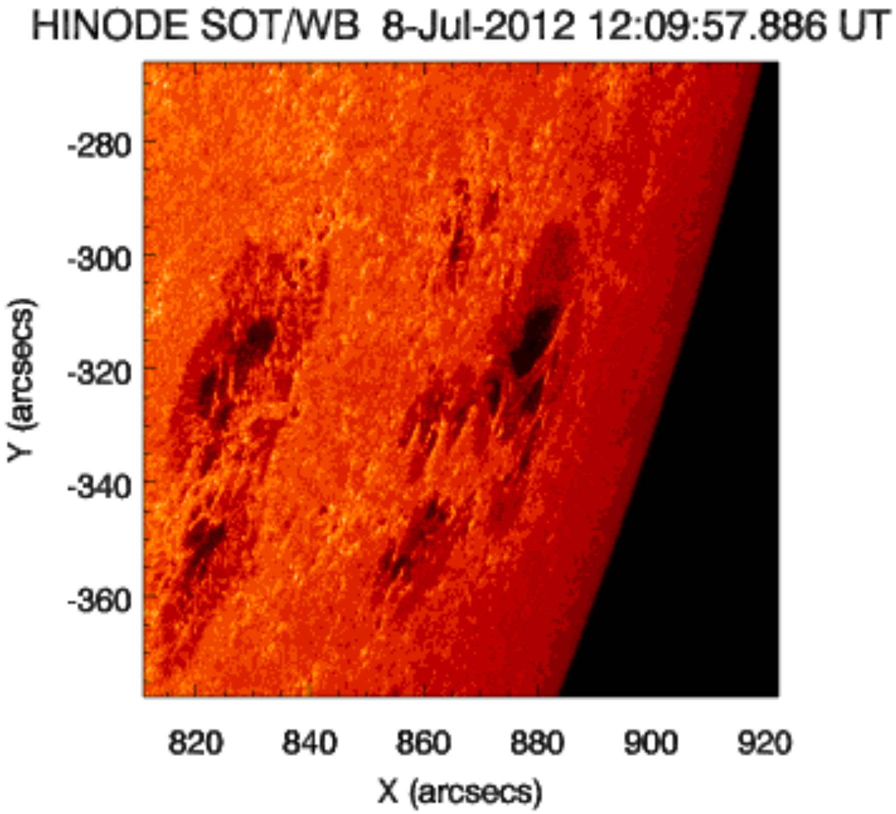
White-light flare observations

2012 Jul 6 1:37- M2.9 flare
S18W41 NOAA#11515



RHESSI: 50-100 keV

2012 Jul 8 12:05- M1.4 flare
S21W69 NOAA#11515

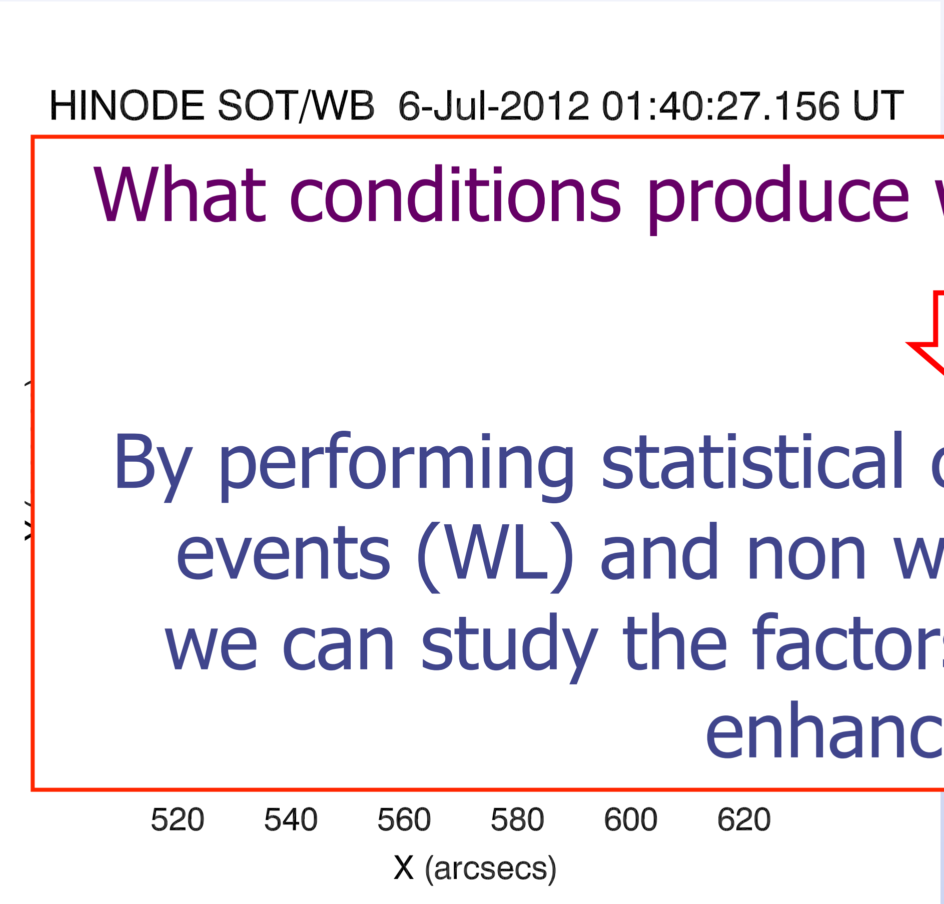


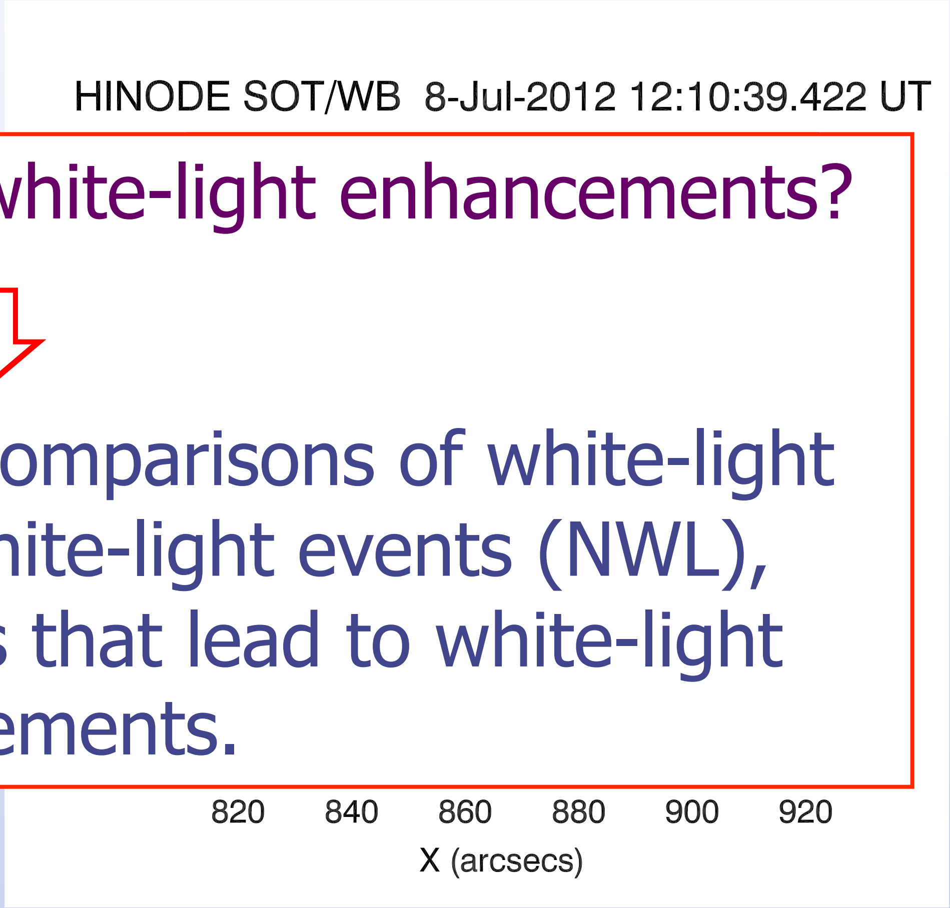
RHESSI: 50-100 keV

White-light flare observations

2012 Jul 6 1:37- M2.9 flare
S18W41 NOAA#11515

2012 Jul 8 12:05- M1.4 flare
S21W69 NOAA#11515





What conditions produce white-light enhancements?

⇩

By performing statistical comparisons of white-light events (WL) and non white-light events (NWL), we can study the factors that lead to white-light enhancements.

RHESSI: 50-100 keV
No white-light enhancement

RHESSI: 50-100 keV
white-light enhancement

Event Selection

Flare events from Jan 2011 to Aug 2013 — 5977 events — Hinode Flare Catalogue (Watanabe et al., 2012)

↓

GOES >M-class — 292 events — Flare mode observation (SOT/RGB data exists)

↓

SOT/RGB data exists

42 events

- WL: 19 events (4 X, 15 M)
- NWL: 23 events (3 X, 20 M)

Statistical analysis with GOES & Hinode/SOT

→

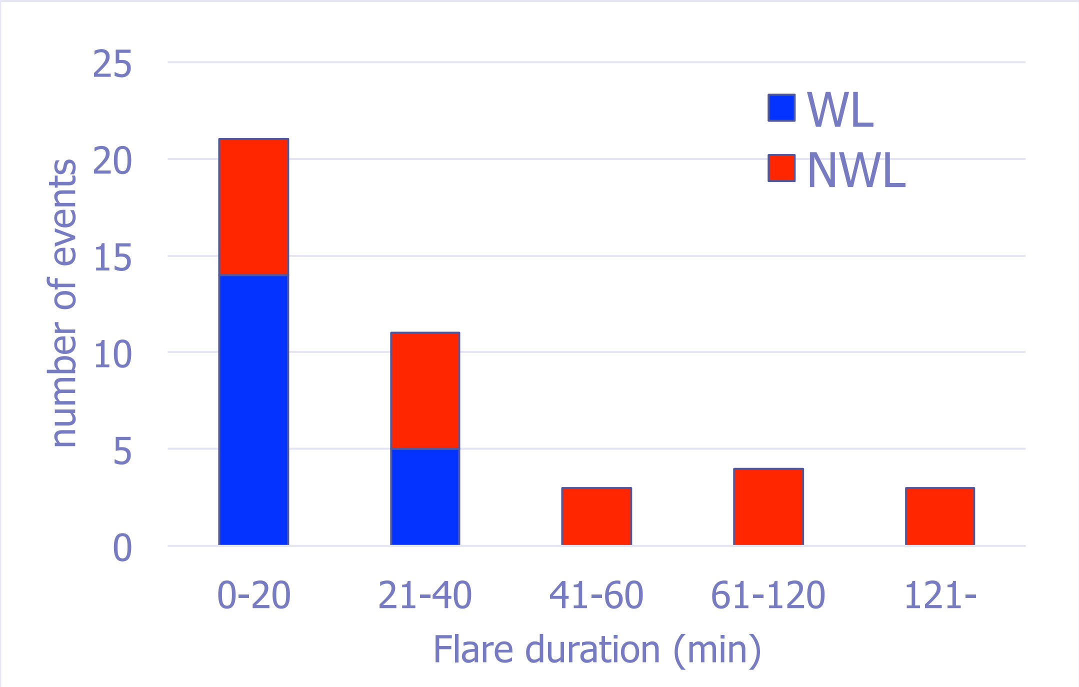
RHESSI data exists

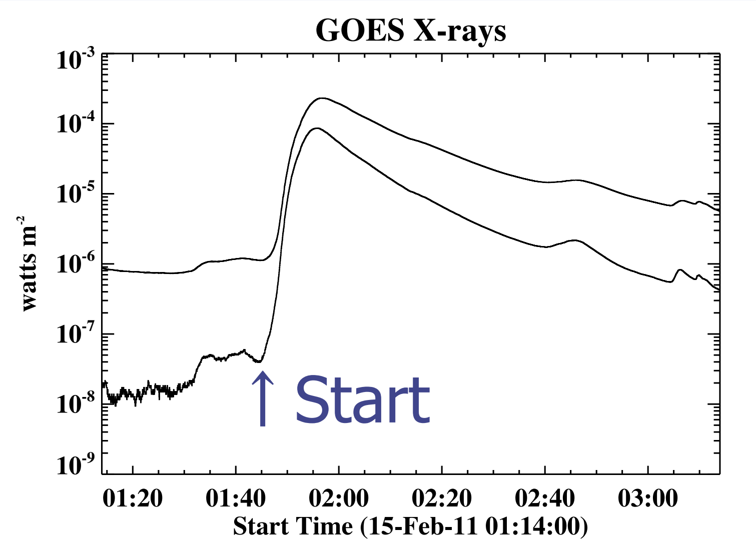
19 events

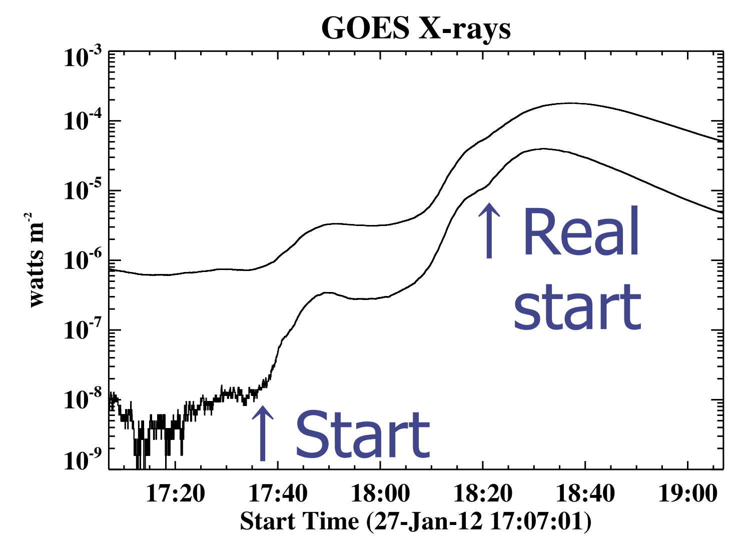
- WL: 10 events (2 X, 8 M)
- NWL: 9 events (2 X, 7 M)

Statistical analysis with RHESSI data

GOES X-ray Duration





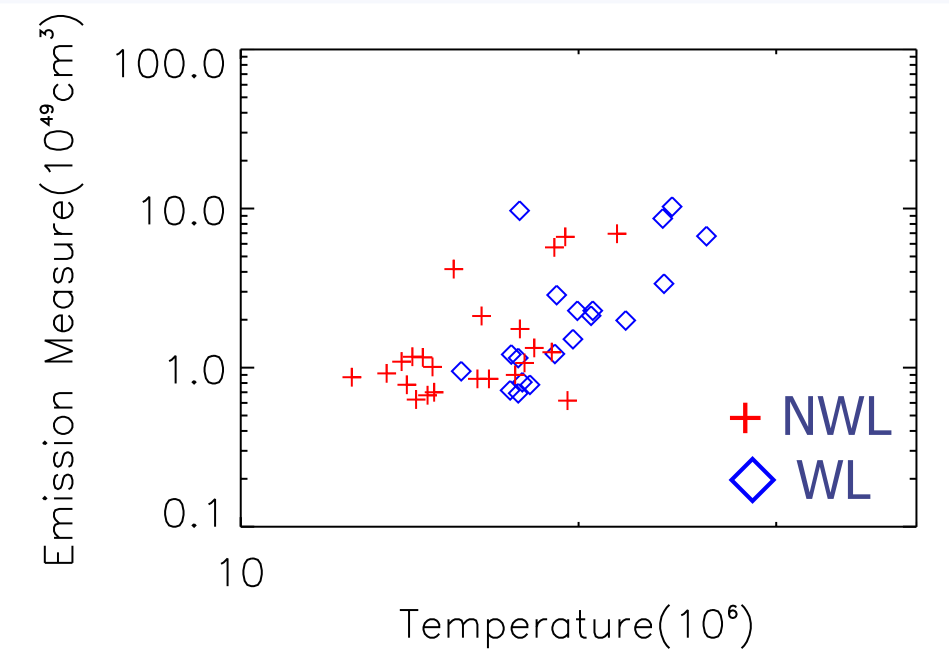


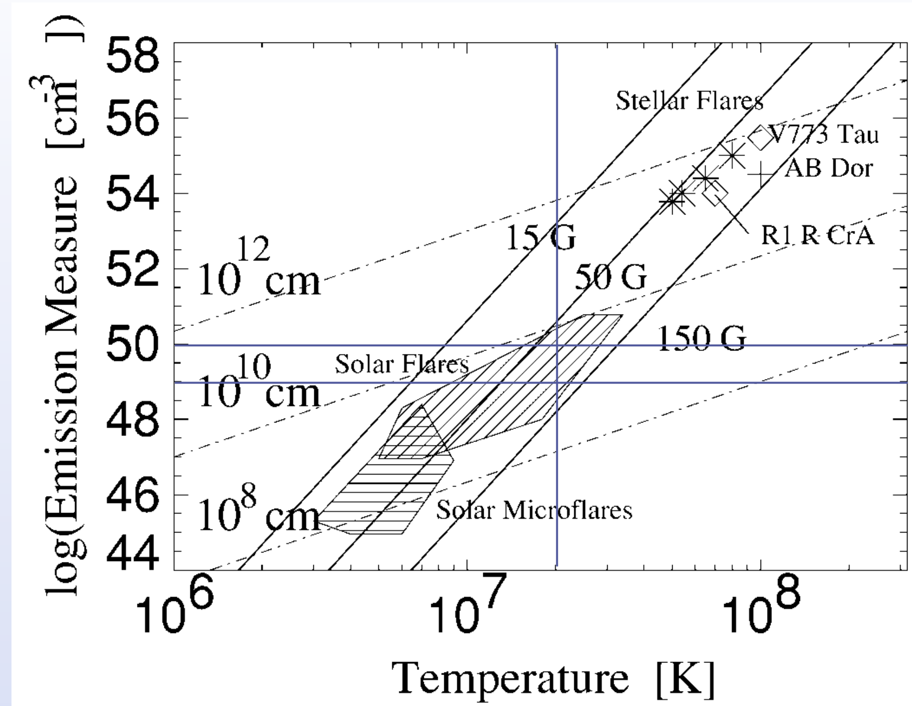
Comparison of X-ray duration from GOES start to end. (Start time is corrected.)

⇒ Durations of WL events are shorter than NWL events (most WL events <20 min.)

"Start – Peak" and "Peak – End" show the same features.

Temperature & Emission Measure





Comparison of temperature and emission measure ($n^2 V$).

Shibata & Yokoyama 1999

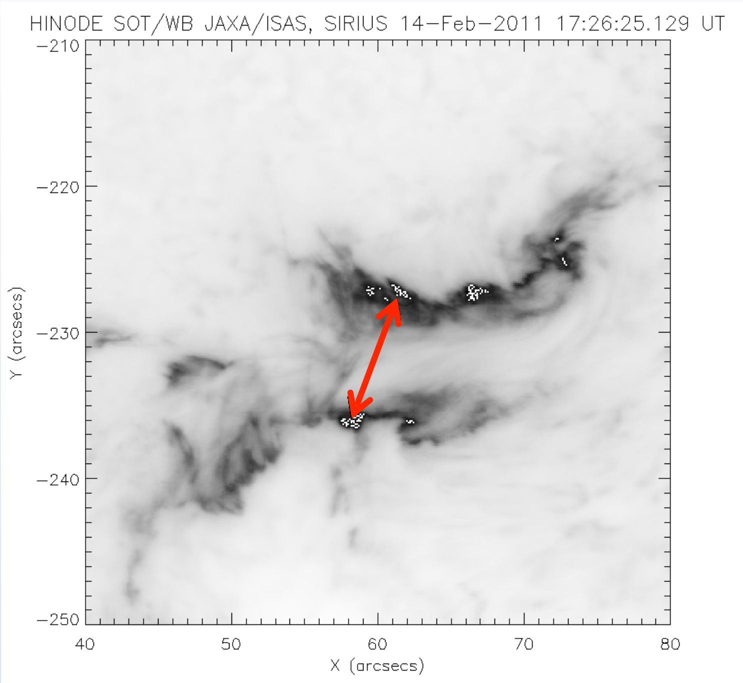
WL events:

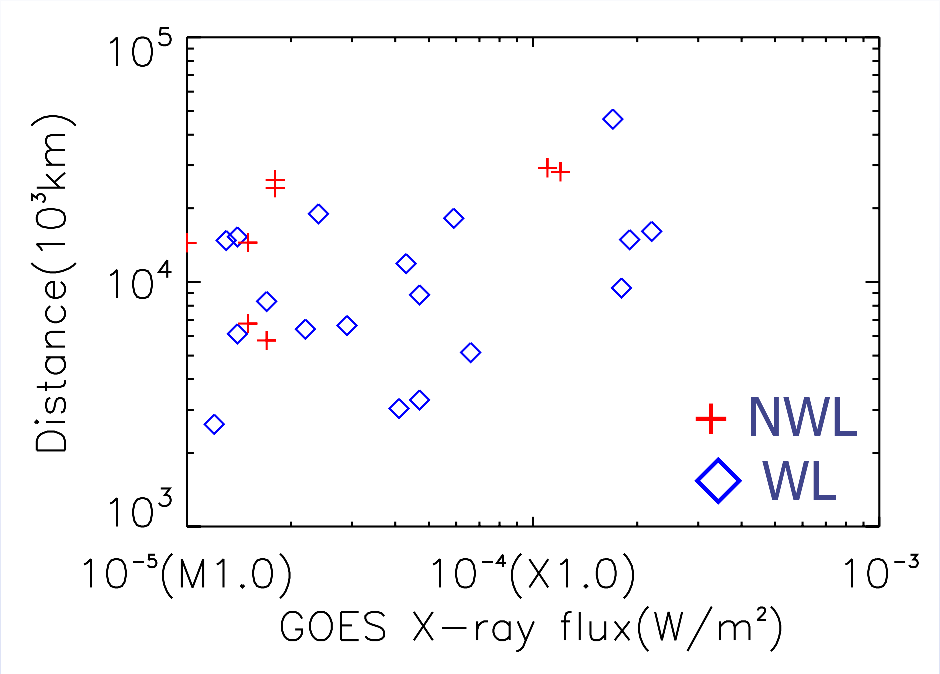
- Slightly higher temperature
- Lower emission measure for a given temperature

WL events are located in slightly stronger field strength regions.

⇒ Coronal field strength is one of the key factors in producing WL events?

Distance between flare ribbons





Measure the distance between the brightest points of the SOT/Ca II H ribbons. (18 WL and 8 NWL events)

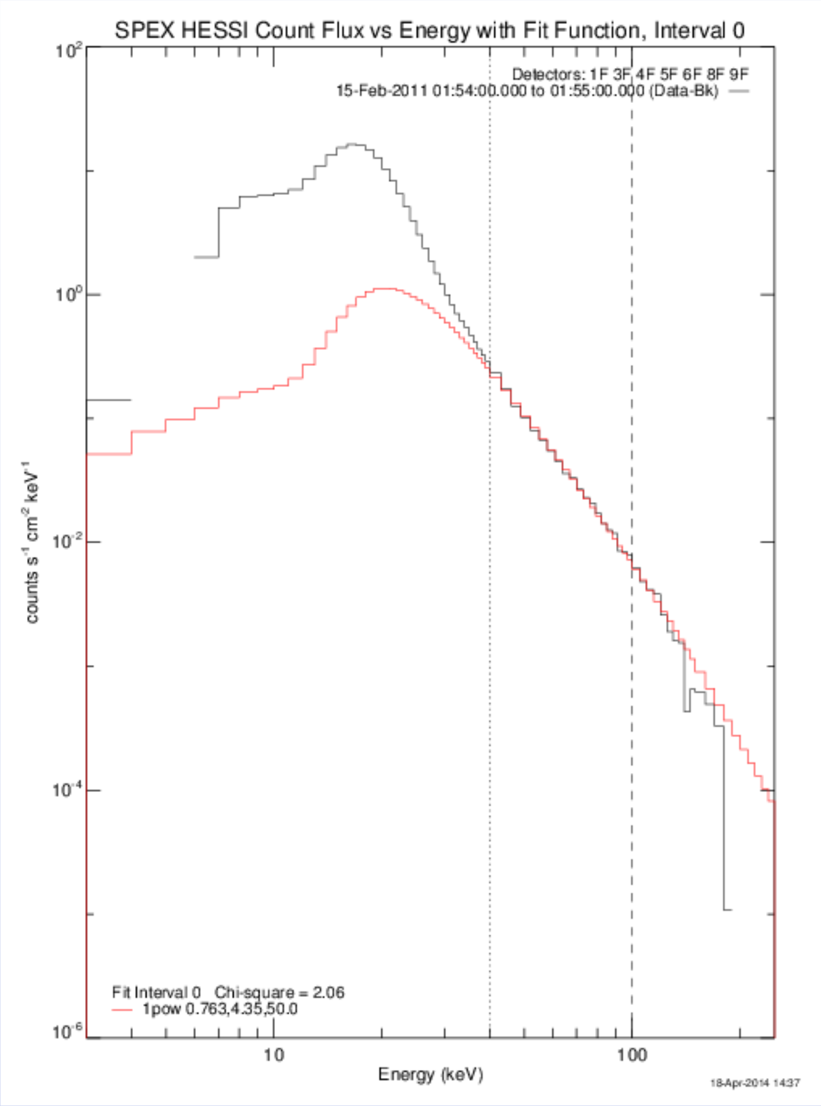
Average distance

WL: 11.7×10^{-3} km

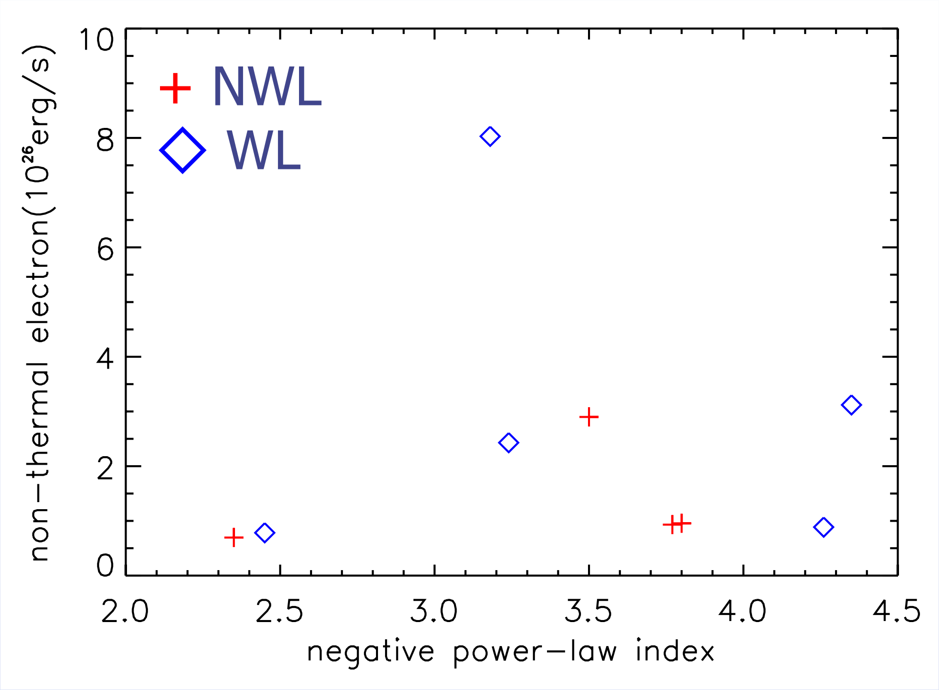
NWL: 18.7×10^{-3} km

⇒ Distances between flare ribbons for WL events are slightly shorter than in NWL events.

Hard X-ray Spectra – Spectral index



Fit 40 – 100 keV
with a single power law



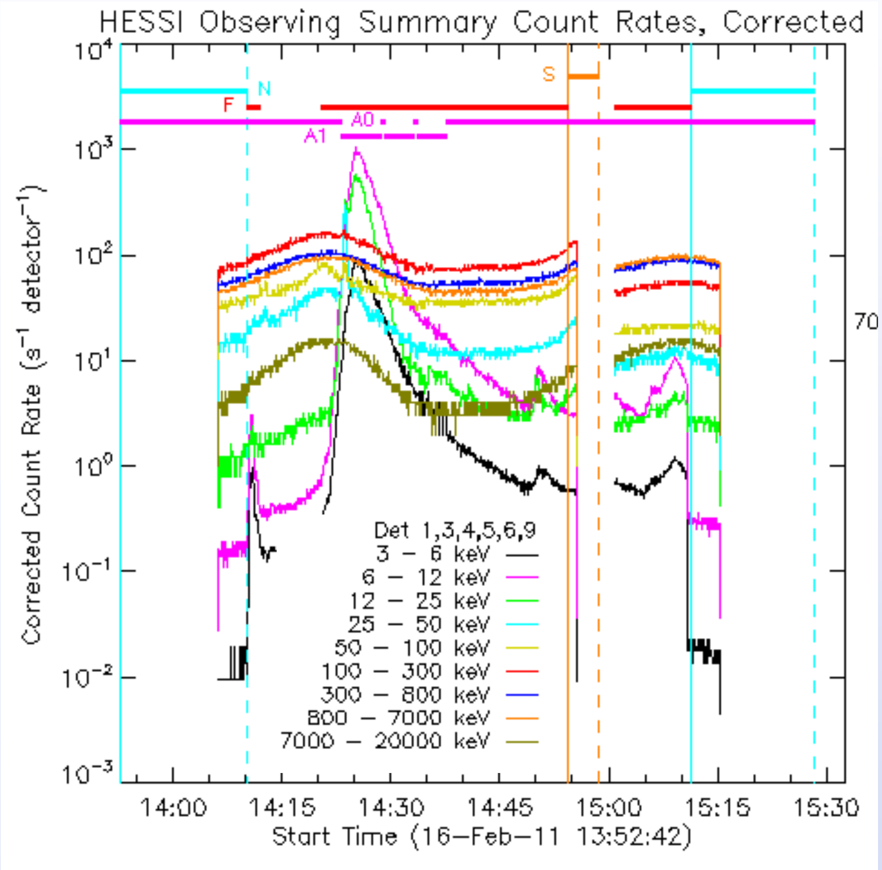
Comparison of power-law index and number of non-thermal electrons from 40 to 100 keV.

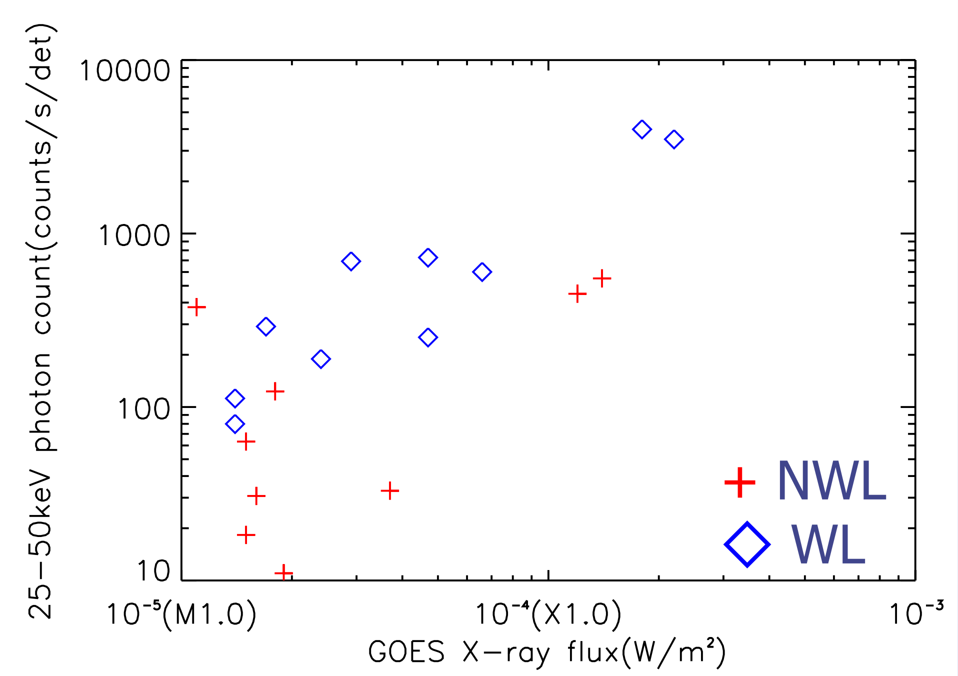
(5 WL and 4 NWL events)

⇒ No difference in power index

⇒ e- number: WL > NWL ?

Hard X-ray Flux @ 25-50keV





Comparison of GOES X-ray flux and 25-50 keV peak photon counts. (10 WL and 9 NWL)

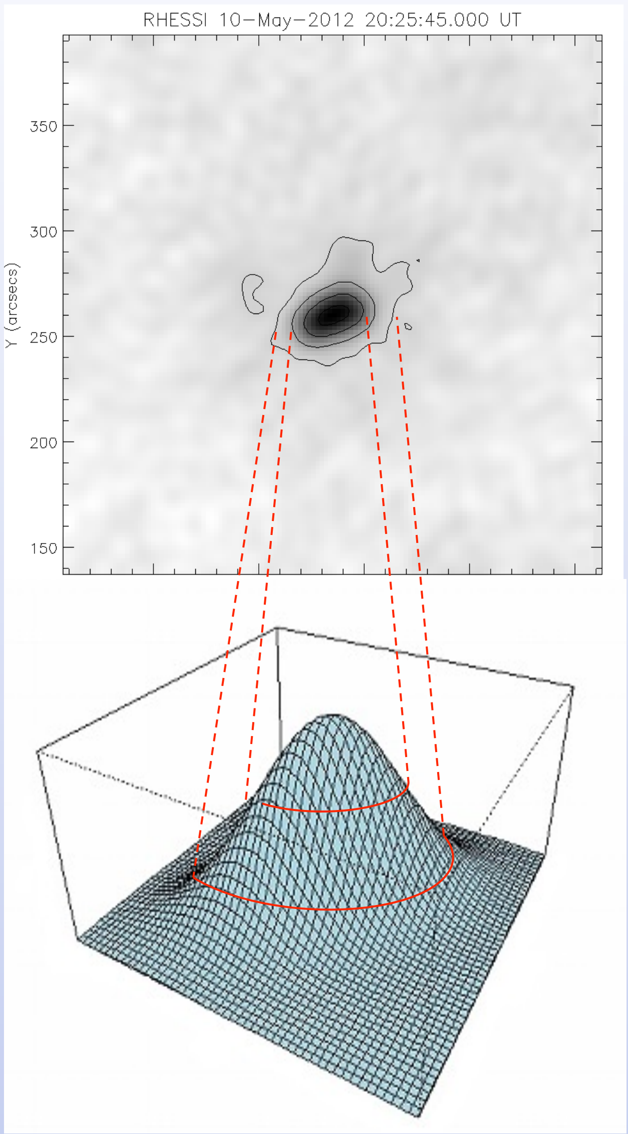
Usually, non-thermal emission is greater than 20keV, all of the >M-class flares have some emission in the 25-50 keV energy range.

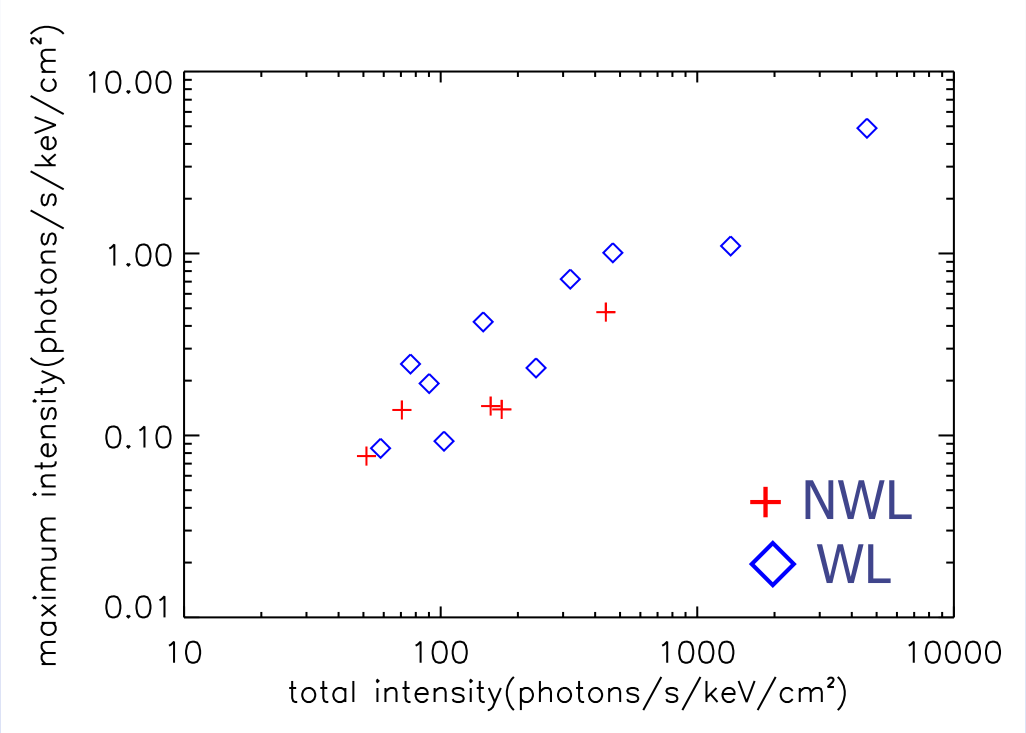
⇒ the non-thermal photon counts for the WL events are larger than for the NWL events.

⇒ Large energy injection

Hard X-ray emission area

25-50keV HXR image





Comparison of total HXR photon number and HXR peak. (10 WL and 5 NWL)

⇒ For events with the same total number of counts, the peak photon number for the WL event is slightly larger than for the NWL events. ⇒ WL injection is concentrated.

Summary – Statistical Comparison

	WL	NWL
① Flare duration	<20 min	>20 min
② EM vs Temperature	Slightly low	Slightly high
③ Flare ribbon distance	Short	Long
④ HXR energy	Large	Small
⑤ HXR area	Slightly small	Slightly large

WL events are;

③⑤ ⇒ Small size

① ⇒ Short duration

④ ⇒ Large energy injection

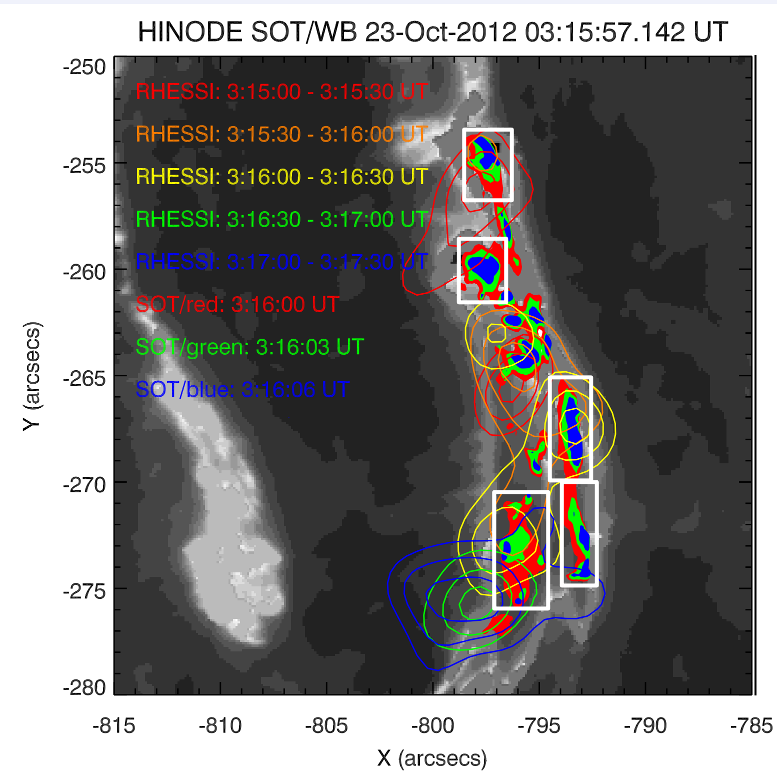
② ⇒ Strong magnetic field

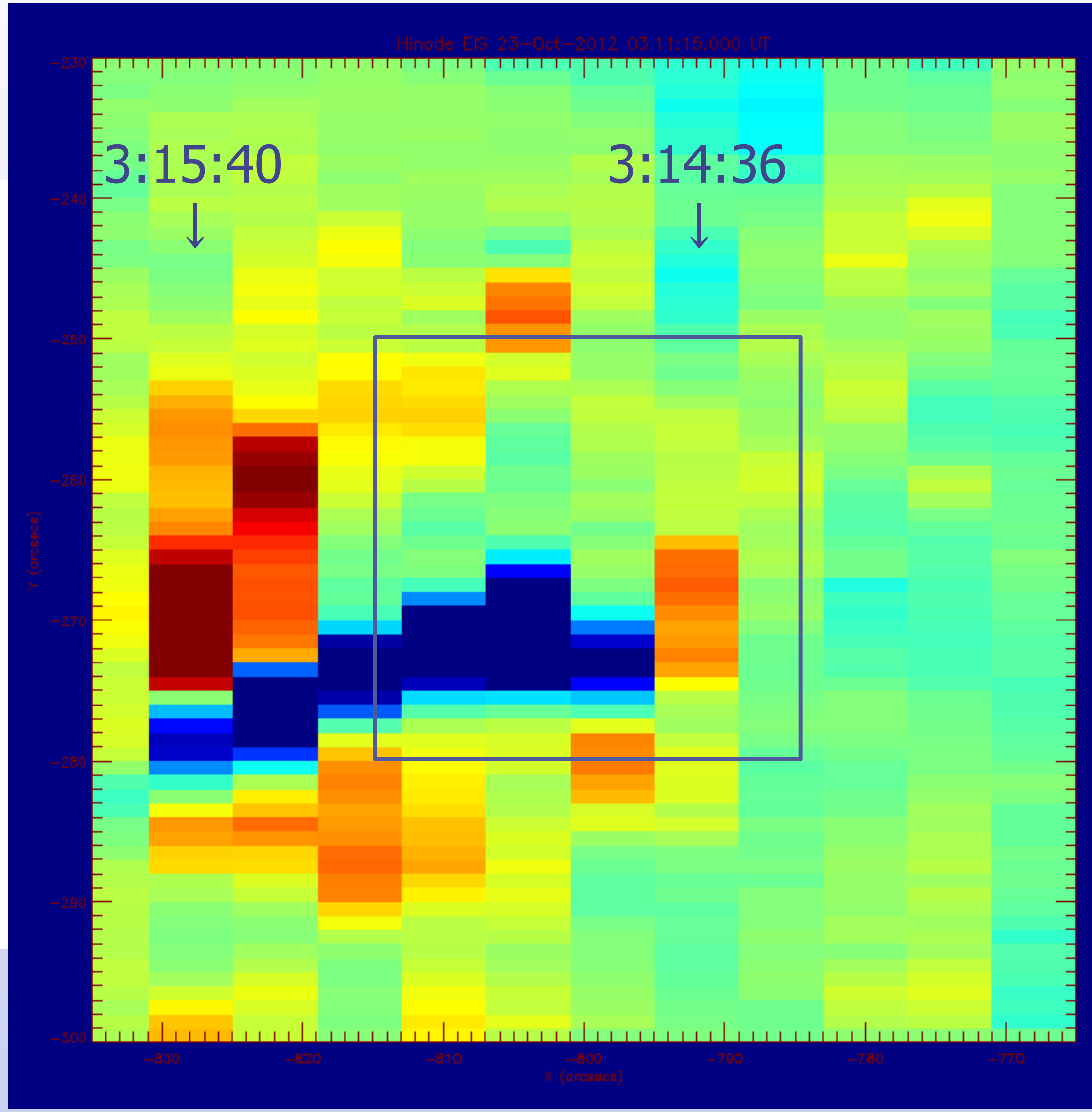
⇒ Injection of large amount of accelerated electrons into a compact region in a short time is the key feature that produces WL enhancements.

2012 Oct 23 White-light flare

Hinode/EIS FeXII (195Å)

Hinode/EIS also observed this flaring region.

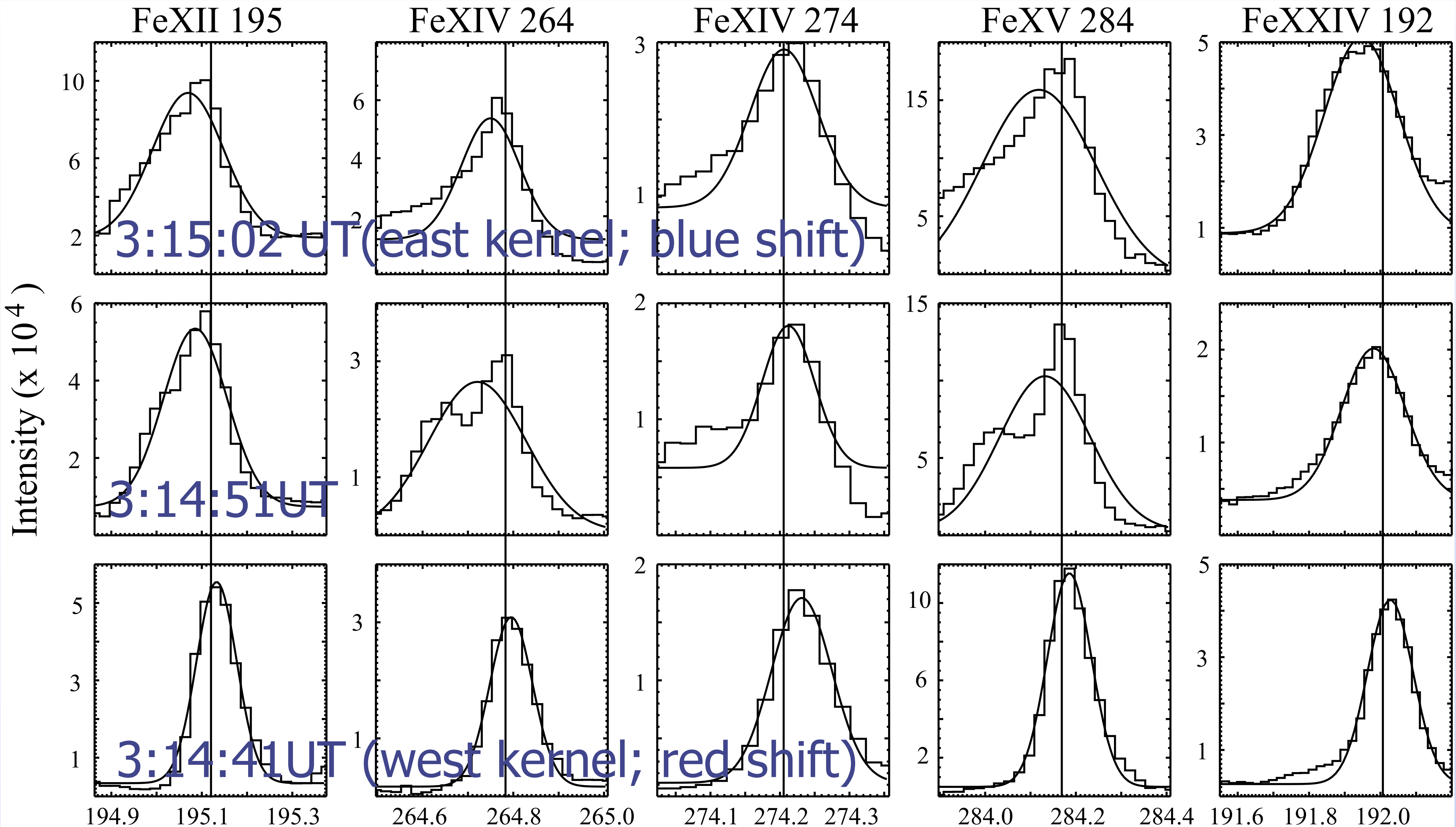




Red shifts can be seen around the western kernel, and blue shifts on the eastern kernel.

2012 Oct 23 White-light flare

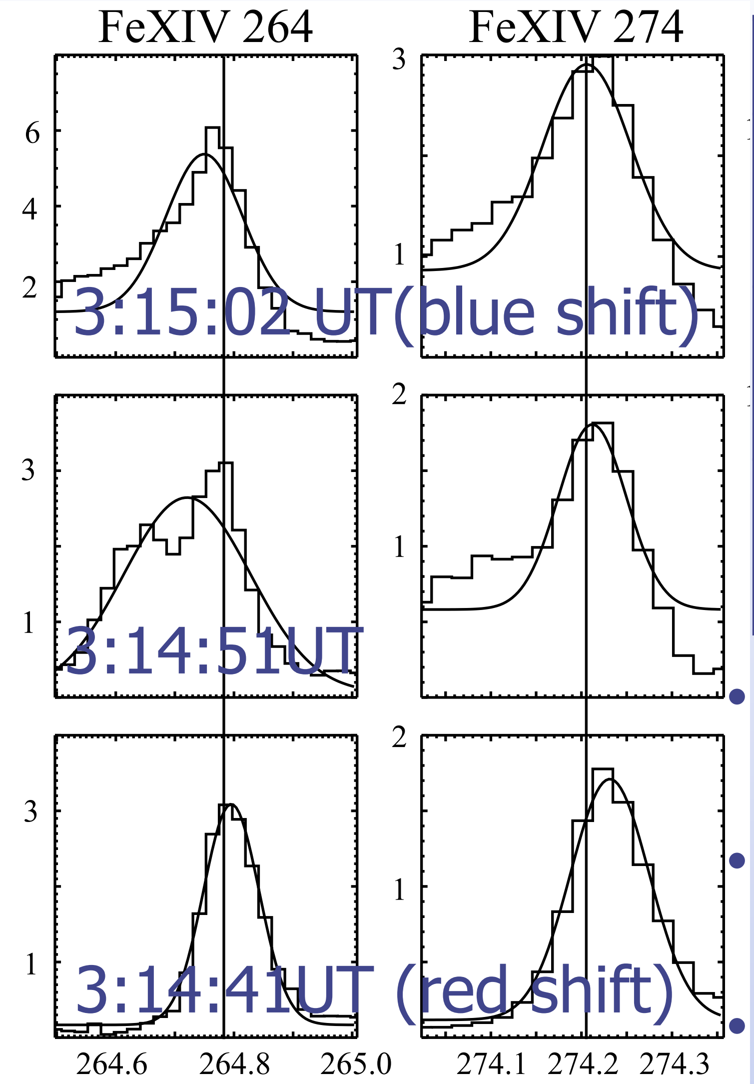
Hinode/EIS



Using two FeXIV lines, we can determine the electron density, and the time variation for these positions.

2012 Oct 23 White-light flare

Hinode/EIS



Density [cm^{-3}]	blue	between	red
Before flare @ 3:10 UT	$10^{9.8}$	$10^{9.8}$	$10^{9.8}$
Start flaring @ 3:15 UT	$10^{10.4}$	$10^{10.3}$	$10^{10.2}$
Flaring (~peak) @ 3:20 UT	$10^{10.2}$	10^{12}	$10^{11.2}$

- Most of the accelerated e- are stopped in a region with a density of 10^{12} cm^{-3}.
- The accelerated e- could not reach the photosphere @ the flare peak
- There is a possibility that the accelerated particles could enter the photosphere @ the flare start time

Summary

	WL	NWL
① Flare duration	<20 min	>20 min
② EM vs Temperature	Slightly low	Slightly high
③ Flare ribbon distance	Short	Long
④ HXR energy	Large	Small
⑤ HXR area	Slightly small	Slightly large

WL events are;
③⑤ ⇒ Small size
① ⇒ Short duration
④ ⇒ Large energy injection
② ⇒ Strong magnetic field

⇒ Injection of a large amount of accelerated electrons into a compact region in a short time is the key feature that produces WL enhancements.

- Electron density was small at the flare start time.

  ⇒ Density changes in the chromosphere also play a key role in producing WL emission.