CDAW2014　group 1
NoRH-RHESSI-Hinode-SDを用いた
フレア・フィラメント放出の多波長解析

増田　智 (名古屋大学太陽地球環境研究所)

Characteristics

- Increase in intensity of electromagnetic waves in various wavelengths

- duration

  A few minutes – a few hours

- temperature

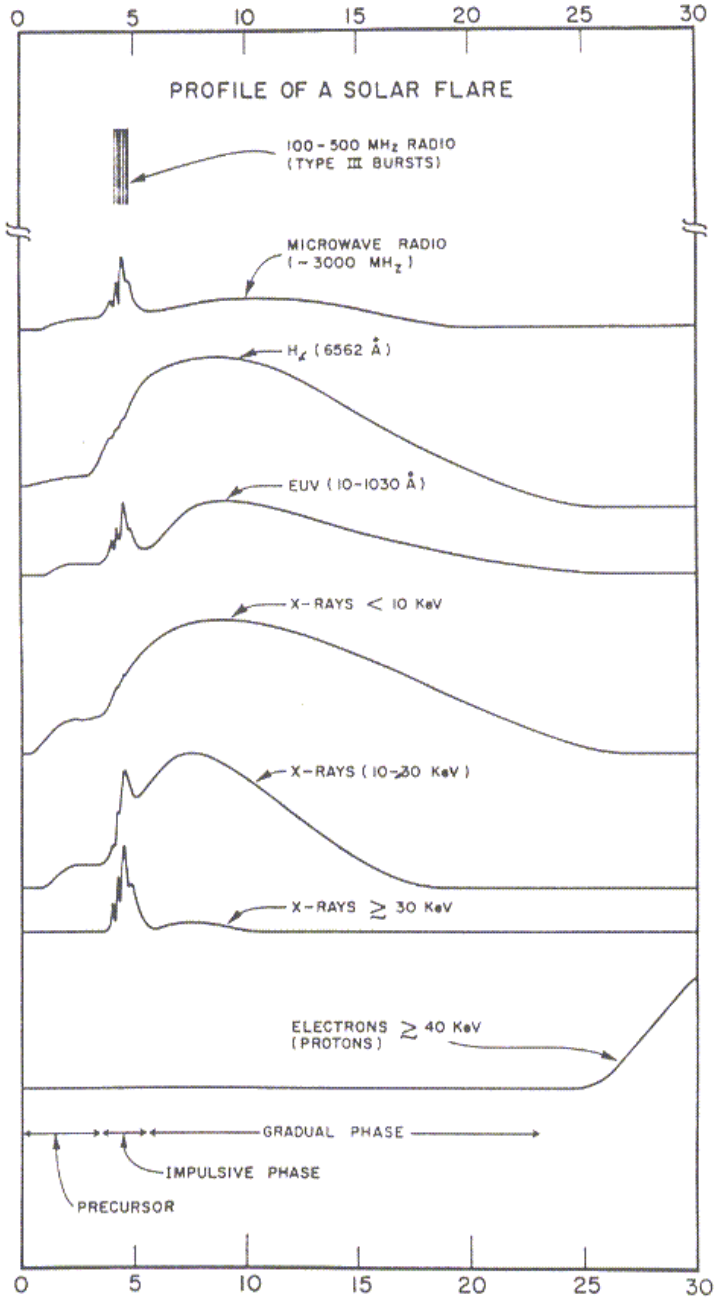
  > 10 MK

- Energy

  10^{27}-10^{33} ergs

- Occurrence

  1 event/month – 10events/day



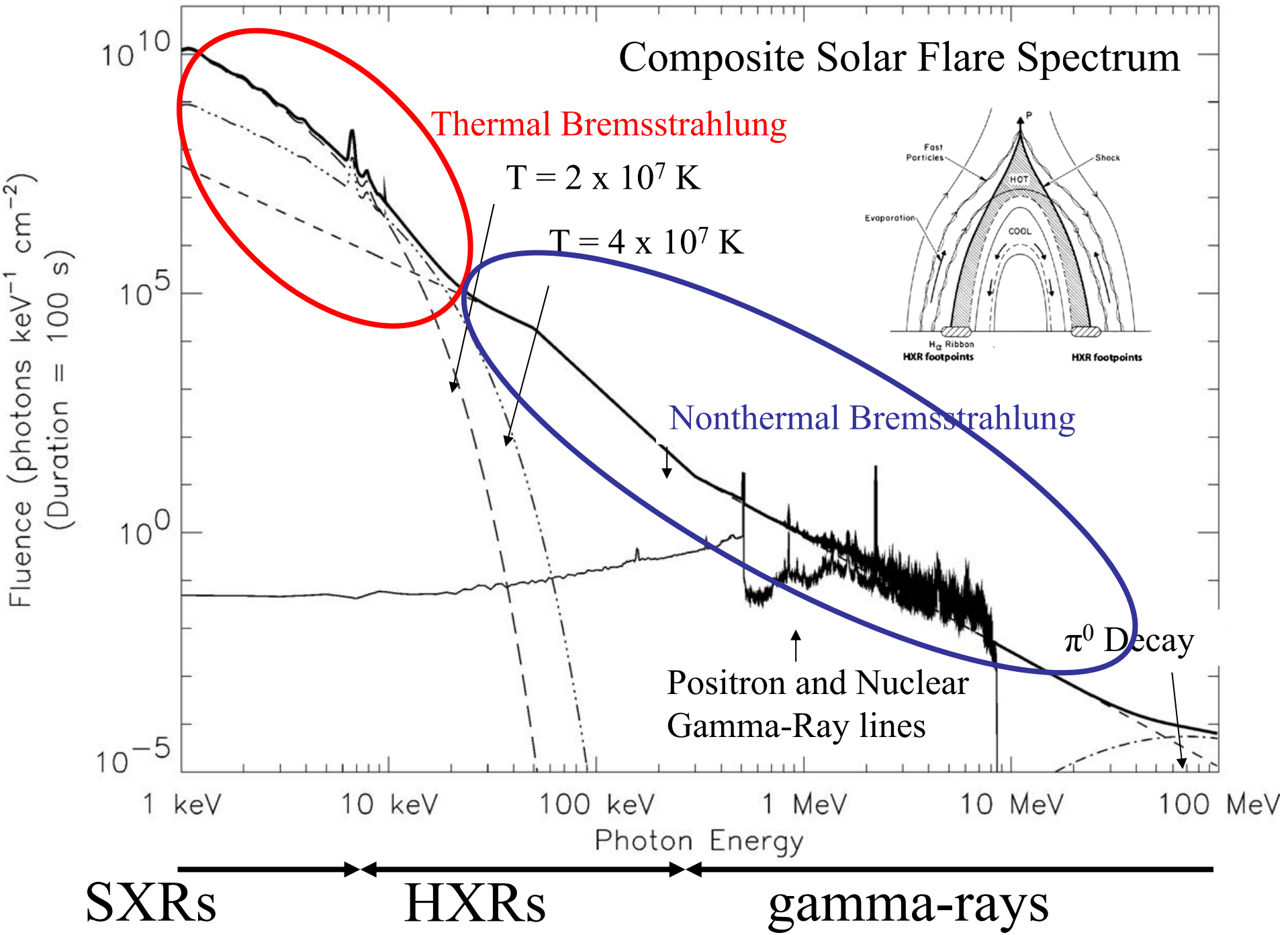
radio

Hα

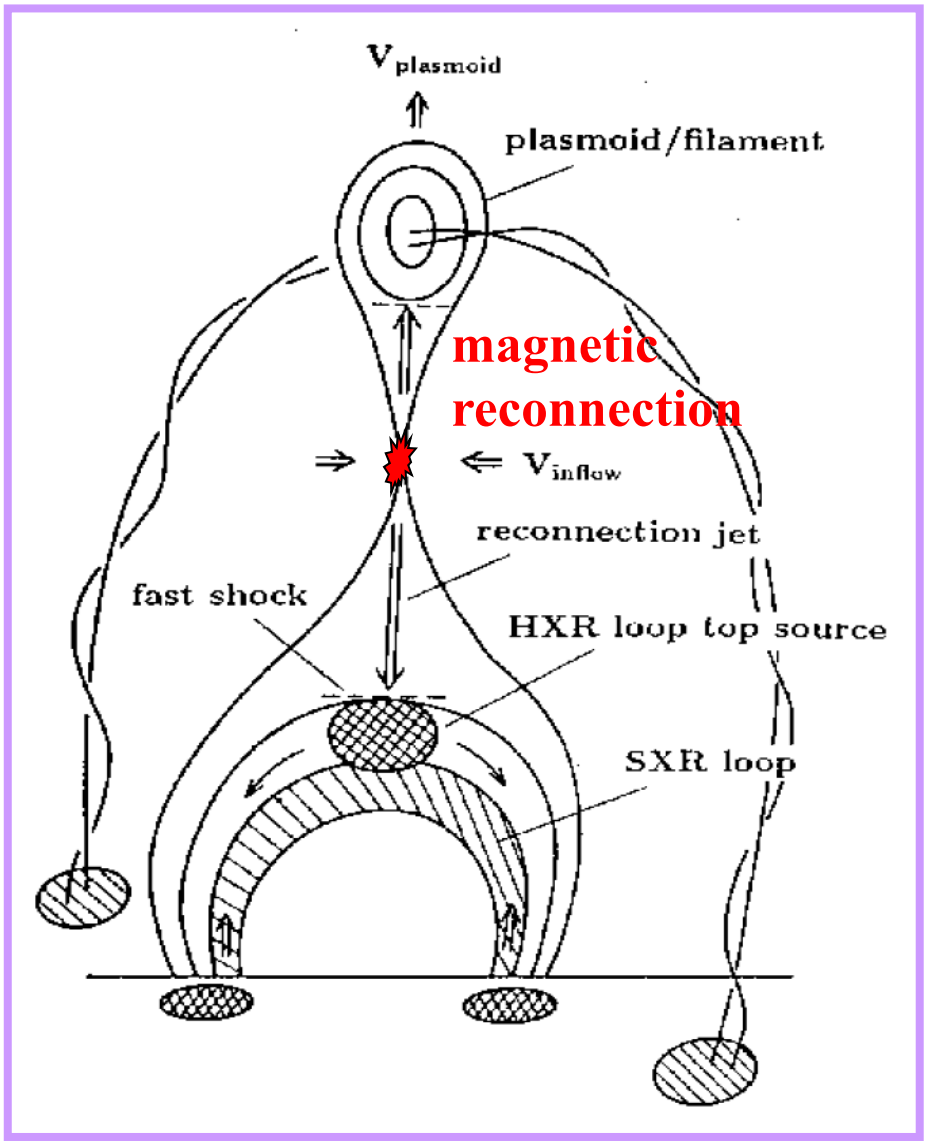
UV

X-rays

electrons


Composite Solar Flare Spectrum
Thermal Bremsstrahlung
T = 2 x 10^7 K
T = 4 x 10^7 K
Nonthermal Bremsstrahlung
Positron and Nuclear
Gamma-Ray lines
π0 Decay
Fluence (photons keV−1 cm−2)
(Duration = 100 s)
10^10
10^5
10^0
10^−5
1 keV
10 keV
100 keV
1 MeV
10 MeV
100 MeV
Photon Energy
P
Fast
Particles
Shock
HOT
Evaporation
COOL
Hα Ribbon
HXR footpoints
HXR footpoints
SXRs
HXRs
gamma-rays

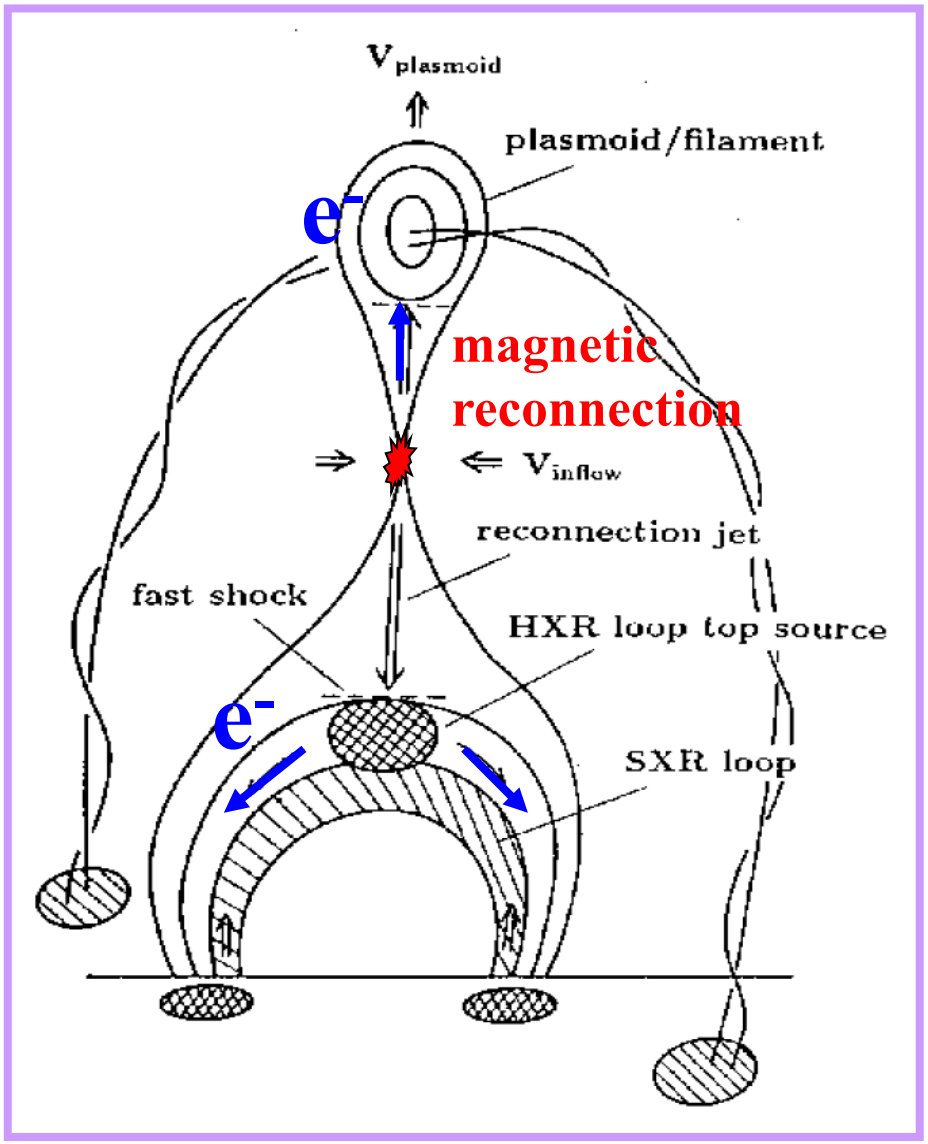
"Standard flare model"



1) Release of magnetic energy

from Shibata + Krucker

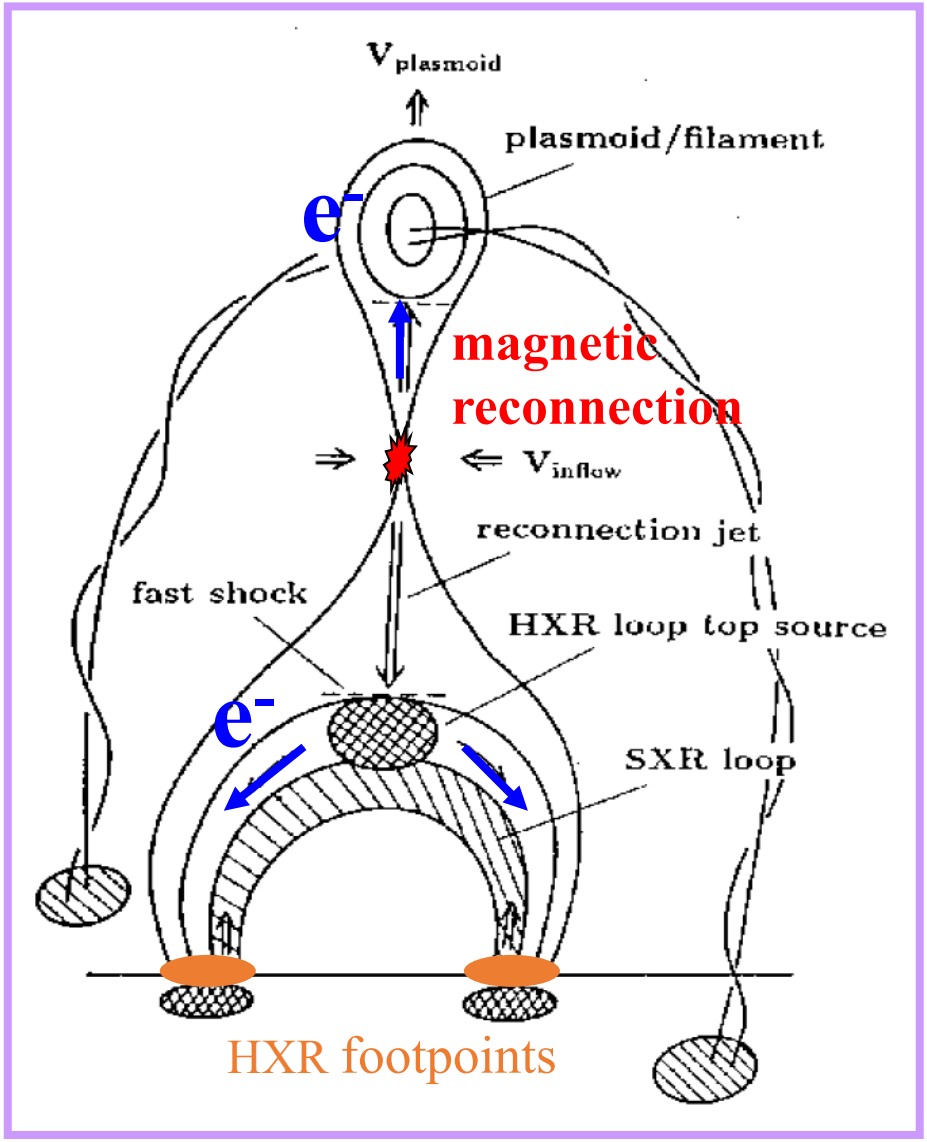
"Standard flare model"



1) Release of magnetic energy
2) particle are accelerated (not understood)

from Shibata + Krucker

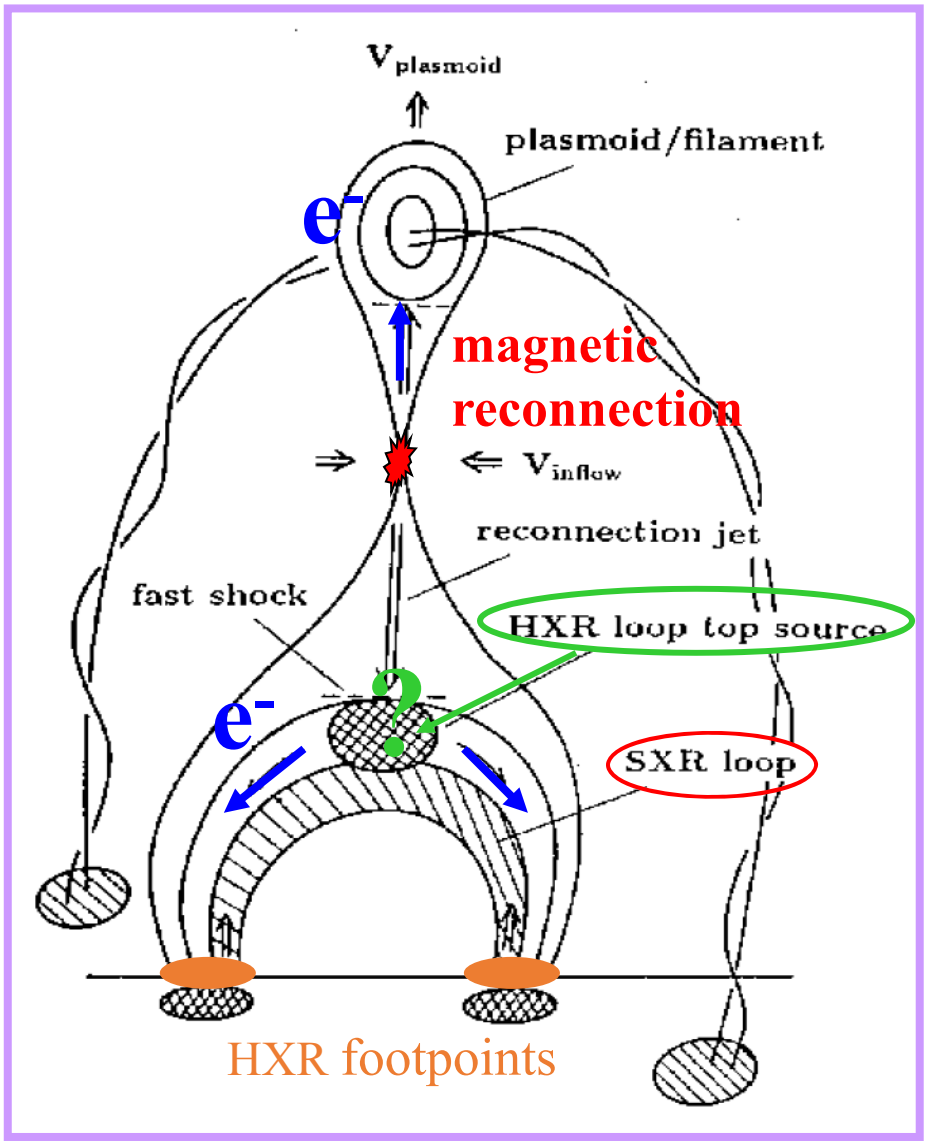
"Standard flare model"



1) Release of magnetic energy
2) particle are accelerated (not understood)
3) Acc. electrons produce HXR emission (mostly footpoints)

from Shibata + Krucker

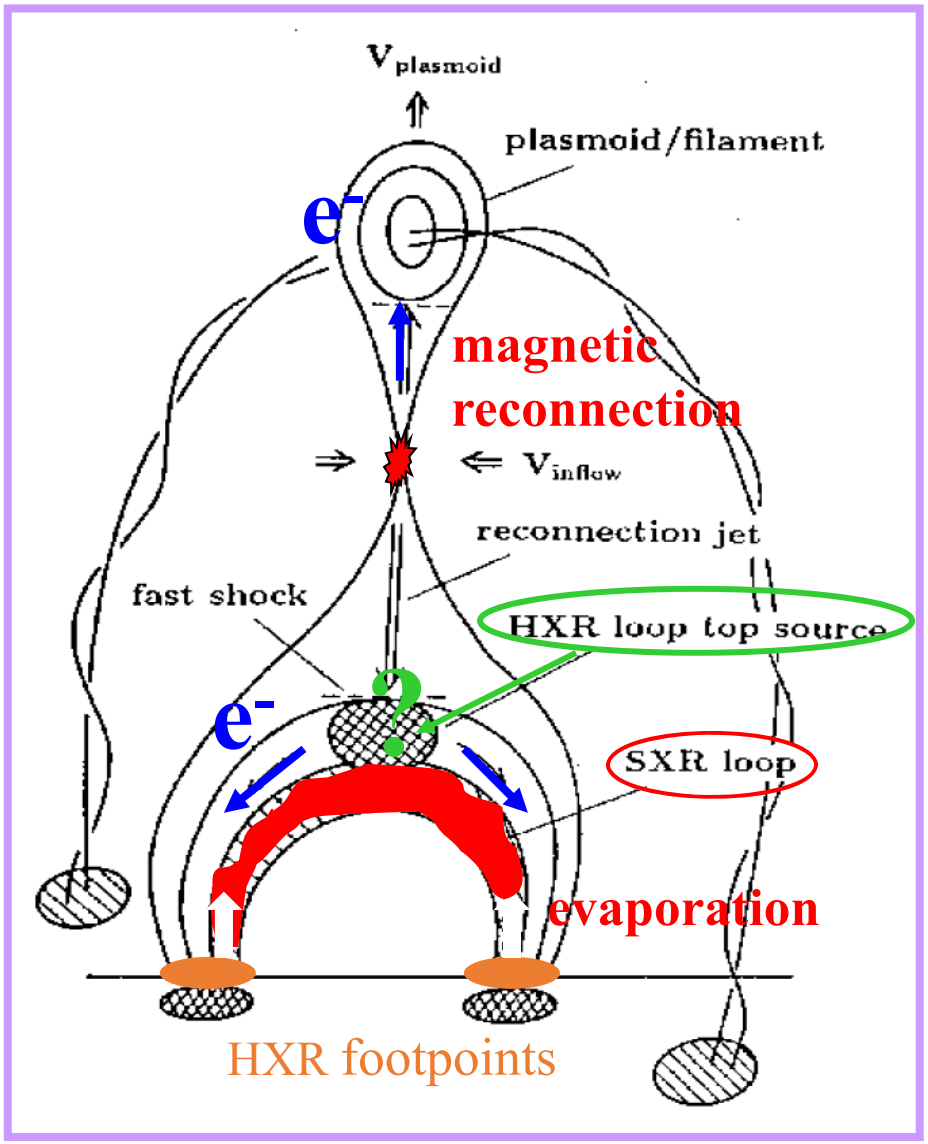
"Standard flare model"



1) Release of magnetic energy
2) particle are accelerated (not understood)
3) Acc. electrons produce HXR emission (mostly footpoints)
4) Above loop top HXR source not understood

from Shibata + Krucker

"Standard flare model"



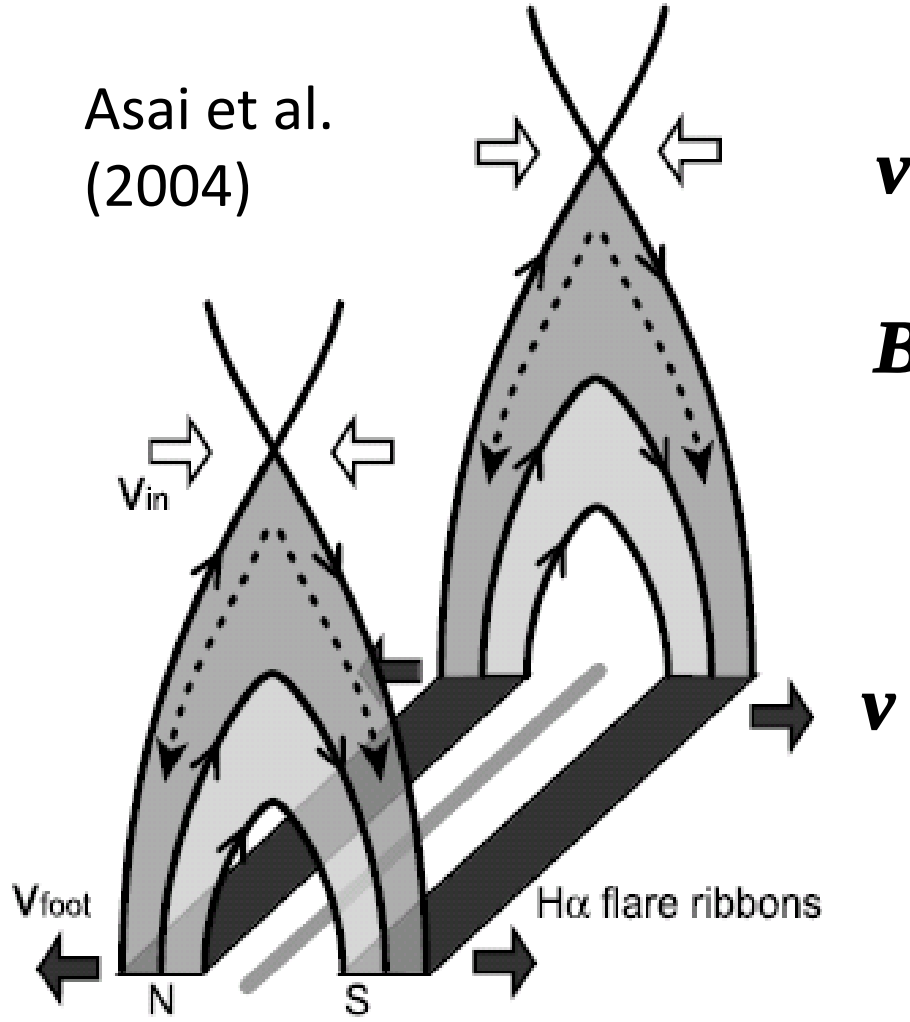
1) Release of magnetic energy
2) particle are accelerated (not understood)
3) Acc. electrons produce HXR emission (mostly footpoints)
4) Above loop top HXR source not understood
5) collisional loses of acc. electrons heat plasma
6) "evaporation" fills loop

from Shibata + Krucker

Relationships between electric field and particle acceleration

$E_{rec} = -v \times B$ is estimated from observations.

Asai et al. (2004)



***v*: ribbon expansion**

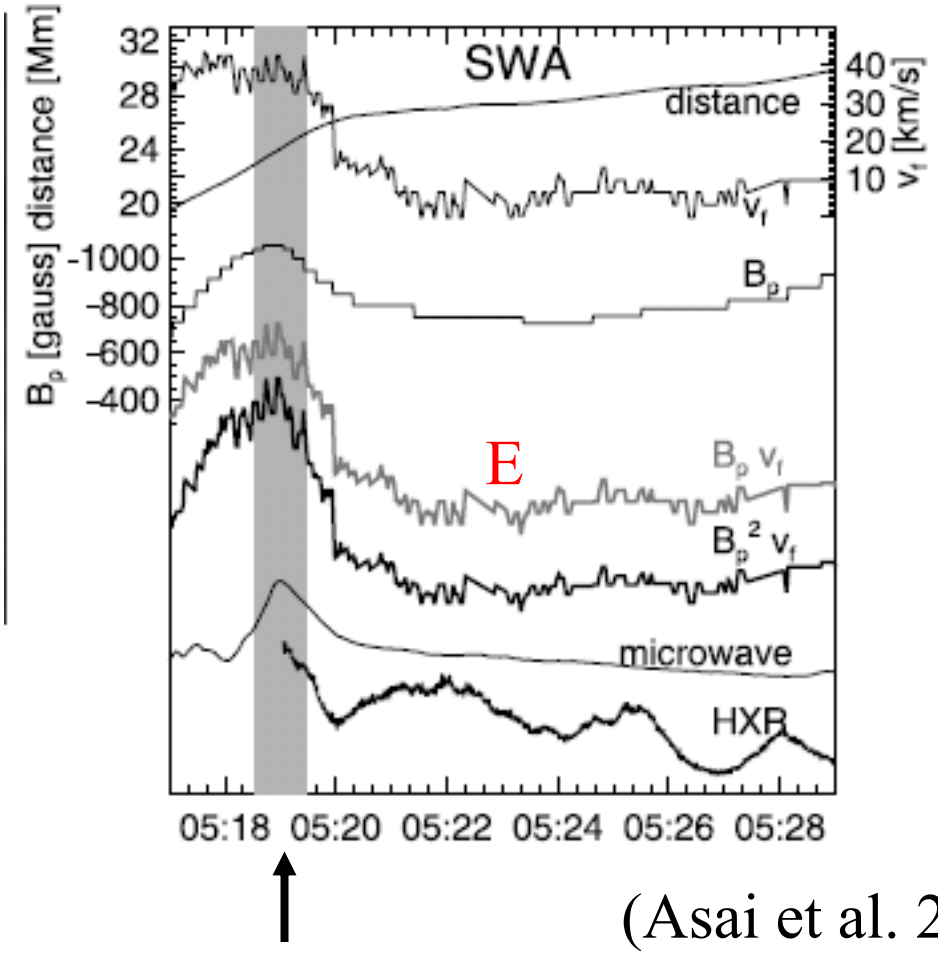
***B*: photospheric magnetic field**

v

Flare ribbon
(or footpoint HXR source)
= frontline of continuous reconnection in the corona

Relationships between electric field and particle acceleration

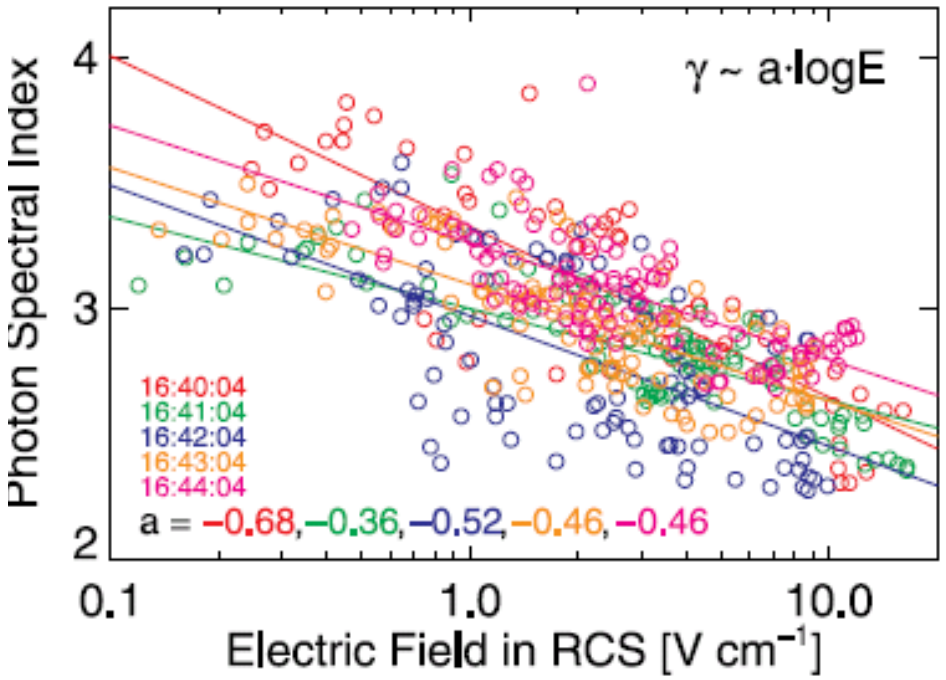
Electric field vs HXR intensity



HXR/microwave peak

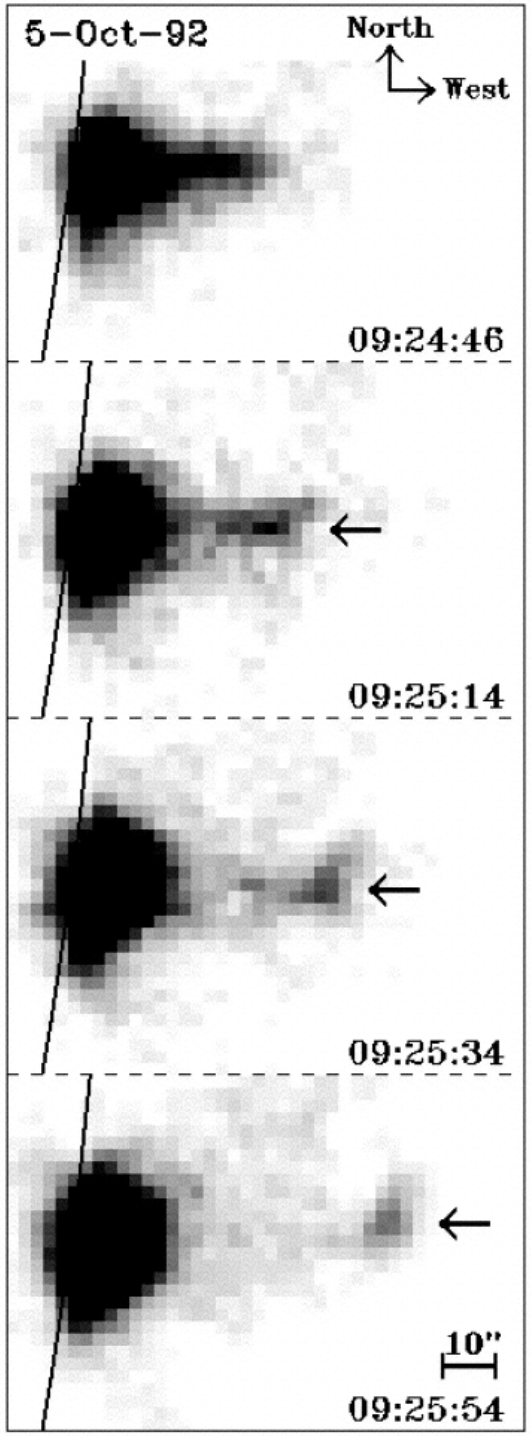
(Asai et al. 2004)

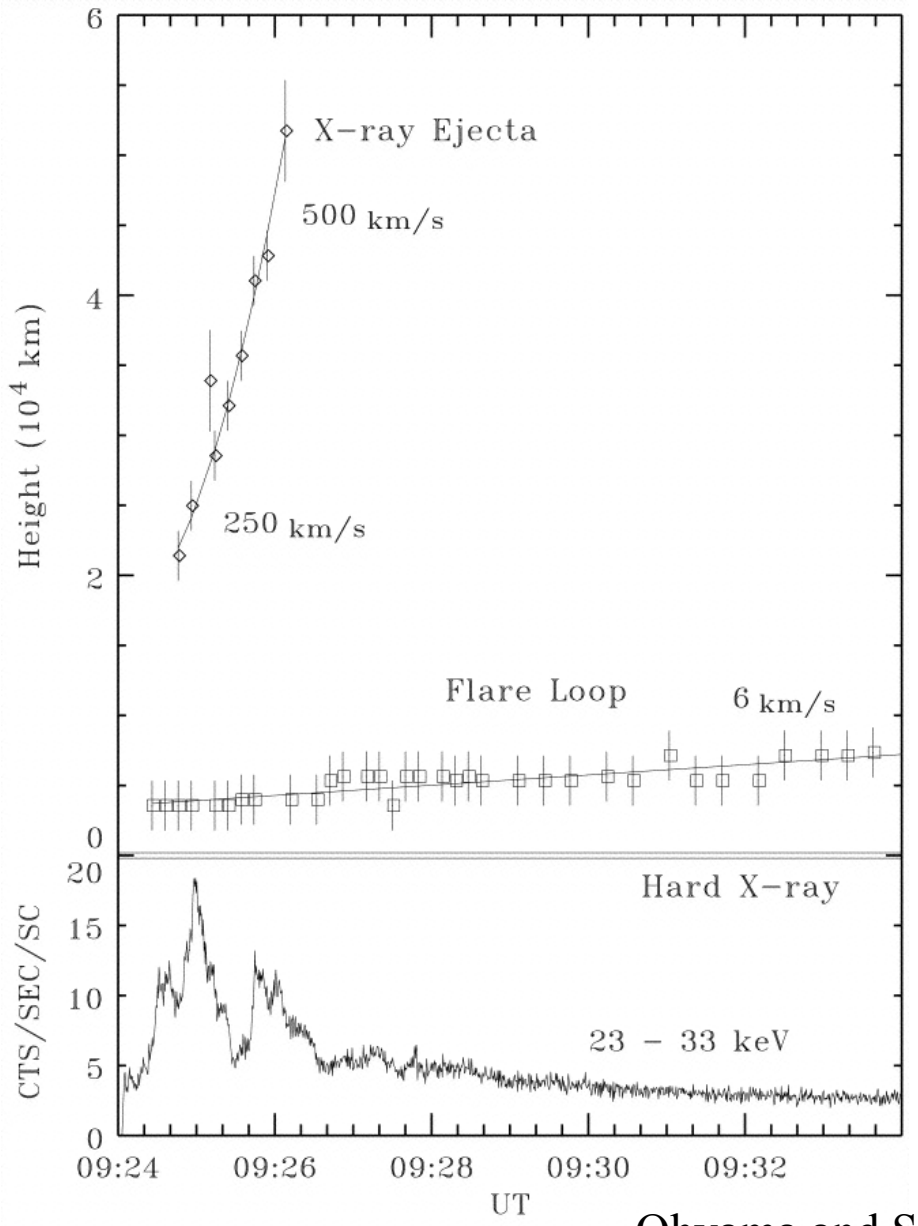
Electric field vs HXR spectral index



(Liu et al. 2008)

プラズマ放出現象と粒子加速(硬X線)





Ohyama and Shibata (1998)

Purpose

To understand the relationship between particle acceleration and magnetic reconnection in solar flares.

Data Analyses

STEP 1

Electric field ← Hard X-ray source motion, photoshperic magnetic field
Ca II ribbon motion, photospheric magnetic field

STEP 2

Hard X-ray intensity, spectrum (power-law lindex) vs electric field
Microwave intensity, spectrum (power-law index) vs electric field
Eruption (SDO, STEREO) vs electric field

Hard X-rays 硬X線

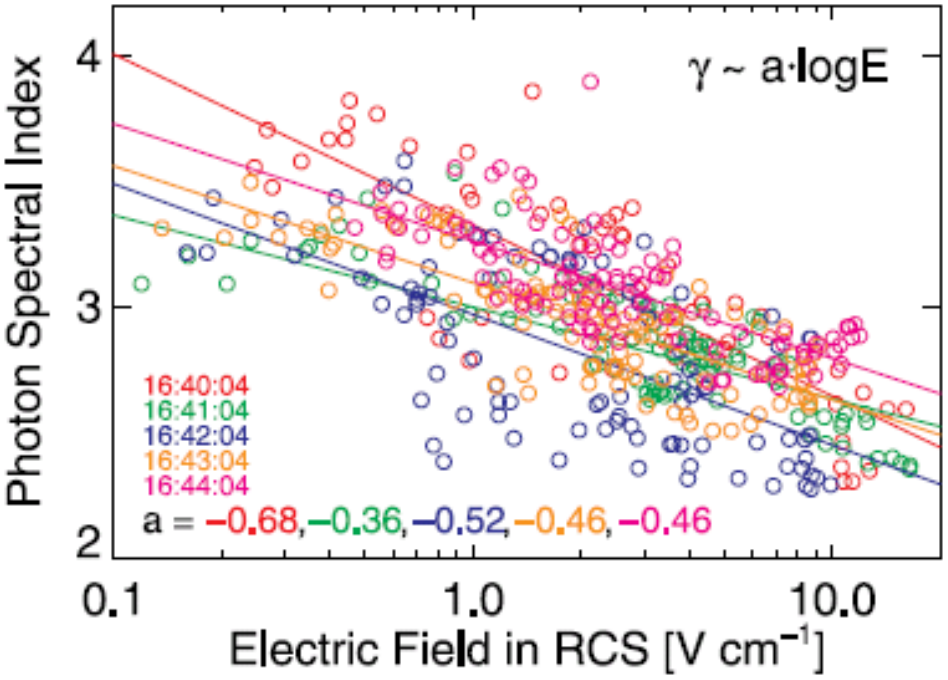
radiation mechanism 放射機構

Bremsstrahlung 制動放射 (or free-free emission)
same as soft X-rays
but by nonthermal electrons
or by super-hot (>30MK) plasma

Hard X-rays are detected only during a solar flare.

The solar corona is usually very dark in hard X-rays.

Electric field vs HXR spectral index



(Liu et al. 2008)

Only in this event, the relationship between hard X-ray spectral index and electric field was reported.
We must check if this relationship is valid or not in other events.

Event selection

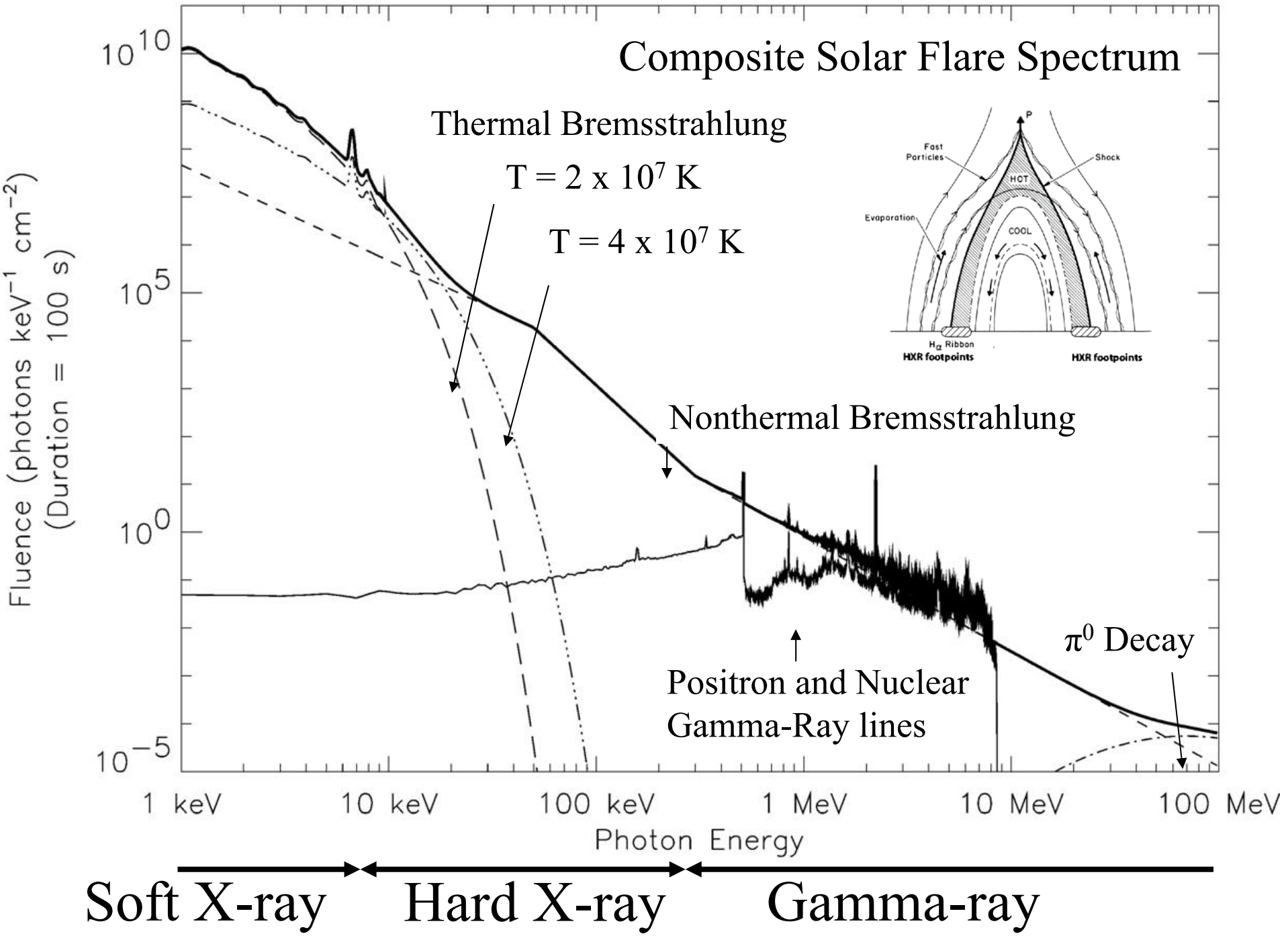
Criteria

(1) Reported in the NoRH event list
(2) Simultaneous observations with RHESSI
and RHESSI detected > 50 keV photons
(3) SDO data are available
(4) Occurred near the disk center (East 30 deg. to West 30 deg.)
(5) Hinode/SOT data are available

The selected events

20110215_0154	X2.2	S20W10
20120705_0337	M4.7	S18W29
20130502_0504	M1.1	N10W26

Hard X-ray Observations in solar flares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10^10
10^5
10^0
10−5
1 keV
10 keV
100 keV
1 MeV
10 MeV
100 MeV
Photon Energy
Soft X-ray
Hard X-ray
Gamma-ray

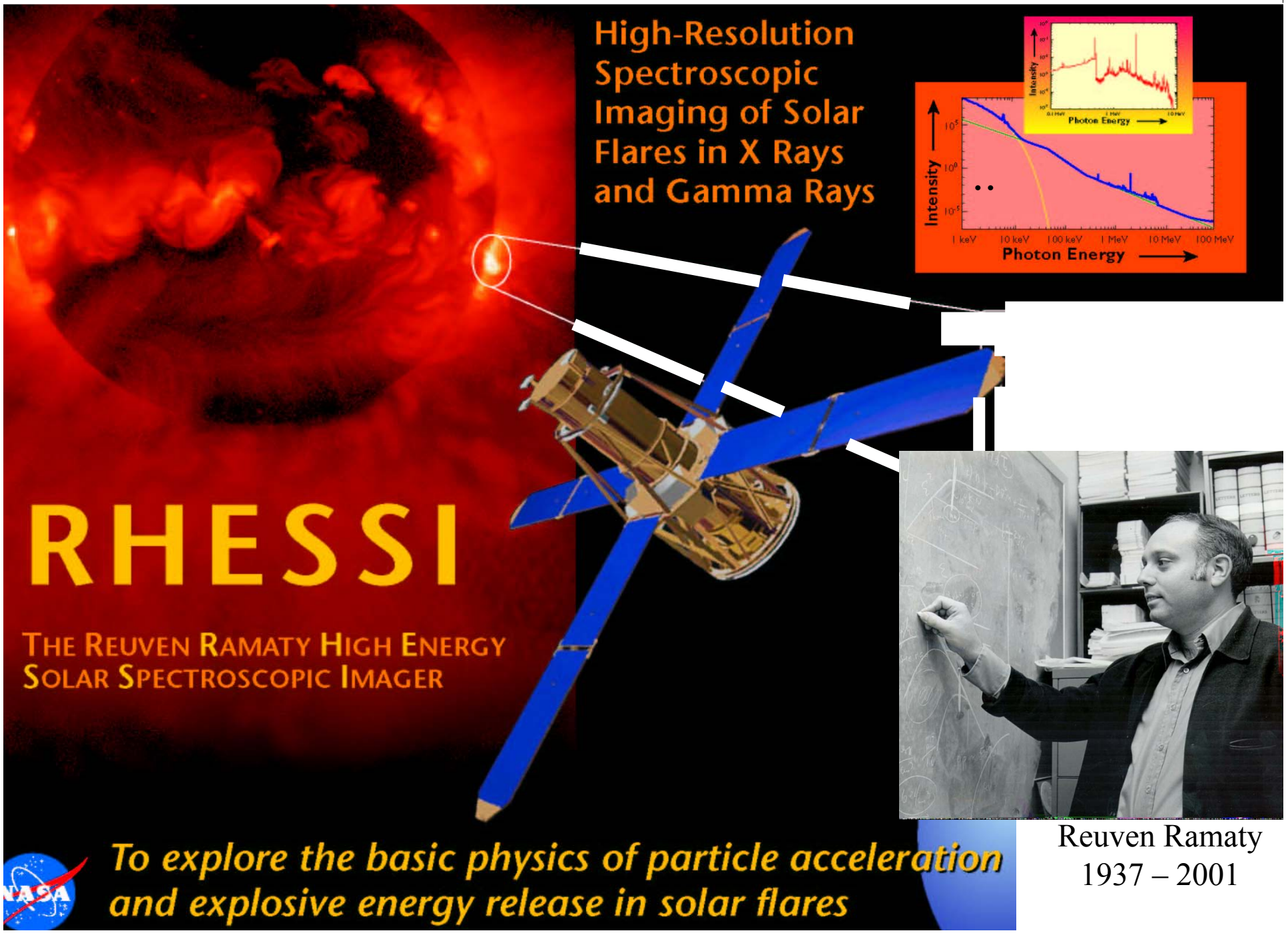
2.4.2 hard X-ray telescope 硬X線望遠鏡

It is very hard to reflect hard X-rays with a mirror optics.

modulation-collimator type telescope (すだれコリメータ)
proposed by Dr. Minoru Oda (小田　稔)

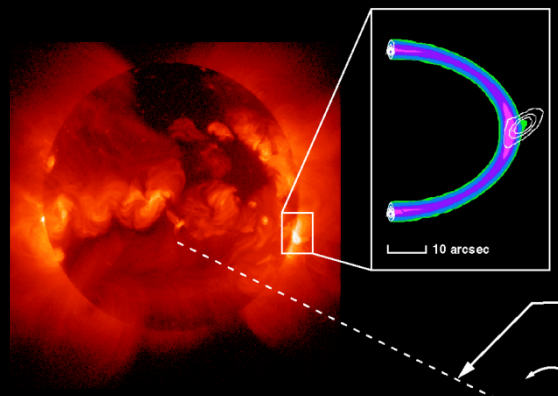
Characteristics of hard X-rays:
high transmission, low diffraction
(高い透過性、低い回折性 = 高い直進性)

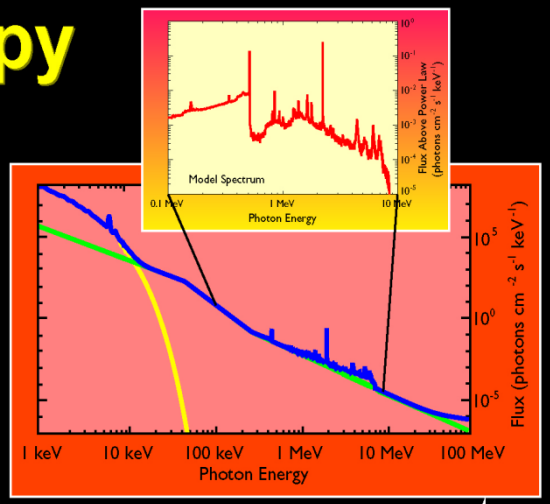
Hinotori/SXT (1981 – 1982) rotating bigrid
Yohkoh/HXT (1991 – 2001) multi-element bigrid
RHESSI (2002 – present) rotating multi-element bigrid



Reuven Ramaty
1937 – 2001

RHESSI Imaging Spectroscopy





Spin Axis
(to Sun Center
within 0.2 degree)

Spin Rate
~15 RPM

Metering Structure
1.5 m long x 45 cm dia.

Roll Angle
System (RAS)

Flexure Mo
to Spacecra
(1 of 3)

PMT

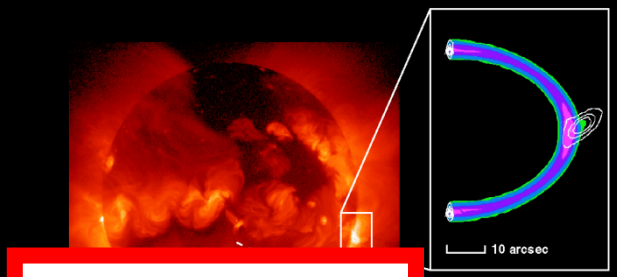
Germanium
detectors

nium
Detector
(1 of 9)

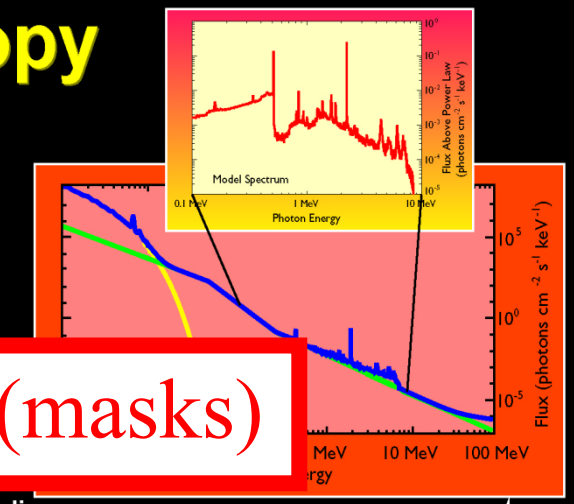
Sunpower
Cooler

F1309_18.ai

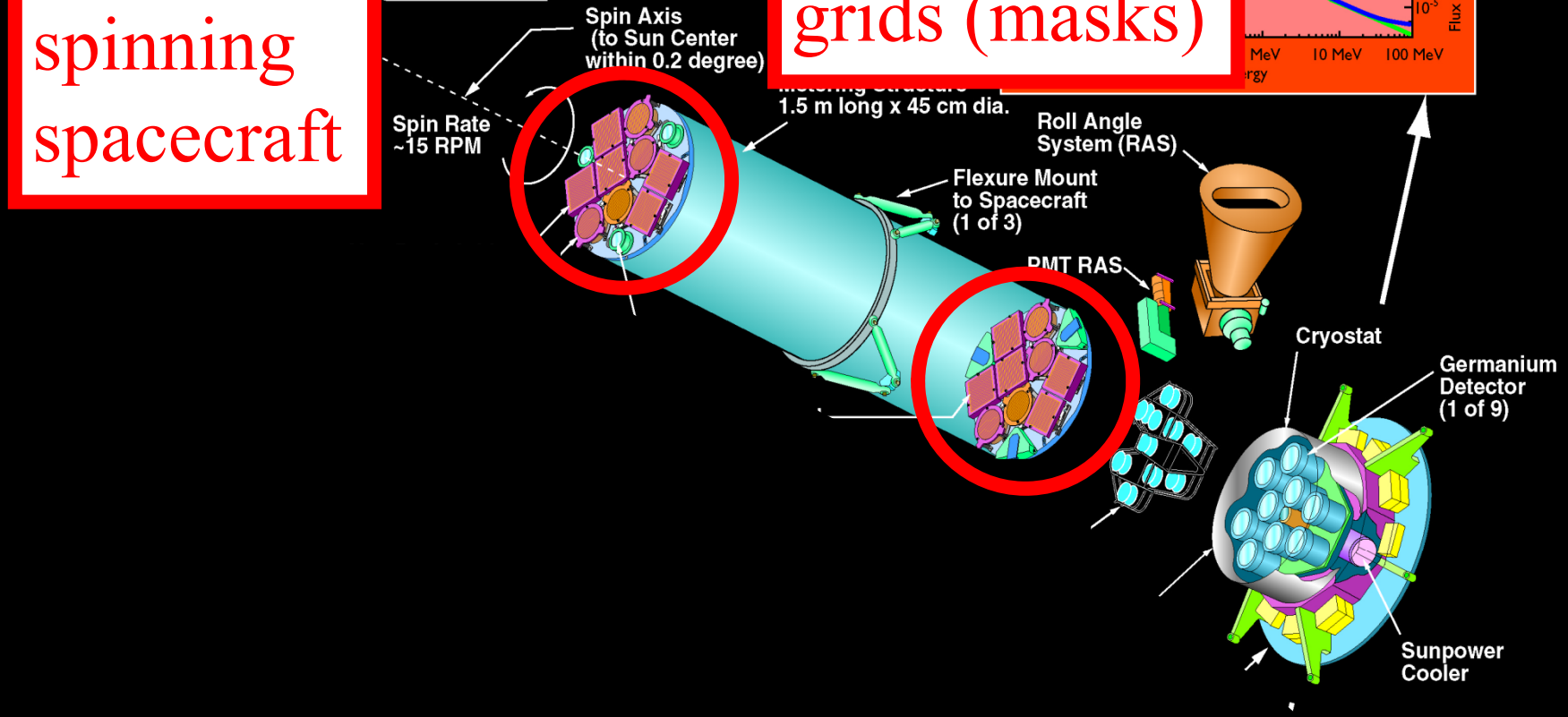
RHESSI Imaging Spectroscopy



spinning spacecraft

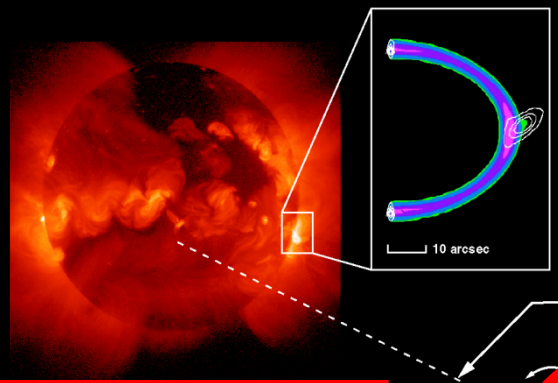


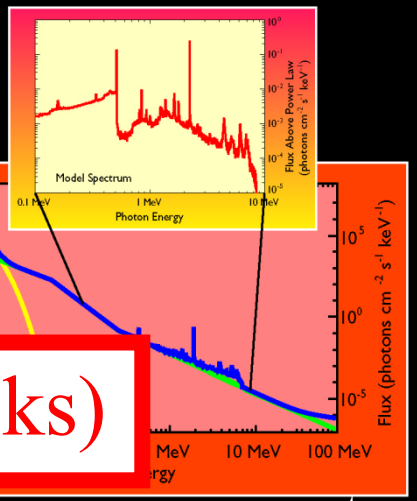
grids (masks)



F1309_18.ai

RHESSI Imaging Spectroscopy





grids (masks)

Modulated signal

Spin Axis (to Sun Center within 0.2 degree)

Spin Rate 15 RPM

1.5 m long x 45 cm dia.

Roll Angle System (RAS)

Flexure Mount to Spacecraft (1 of 3)

Beek Grid 5)

met Grid (1 of 4)

PMT RAS

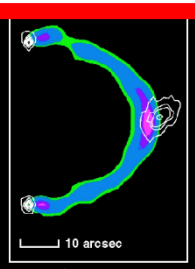
Solar Aspect System (SAS) Lens 4-cm dia. (1 of 3)

Cryostat

Germanium Detector (1 of 9)

Rear Grid (1 of 9)

SAS Linear Diode Array (1 of 3)



Count Rate ... for One Rotation

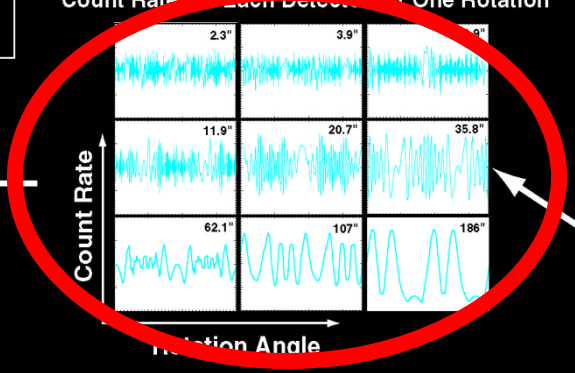


Image Reconstruction

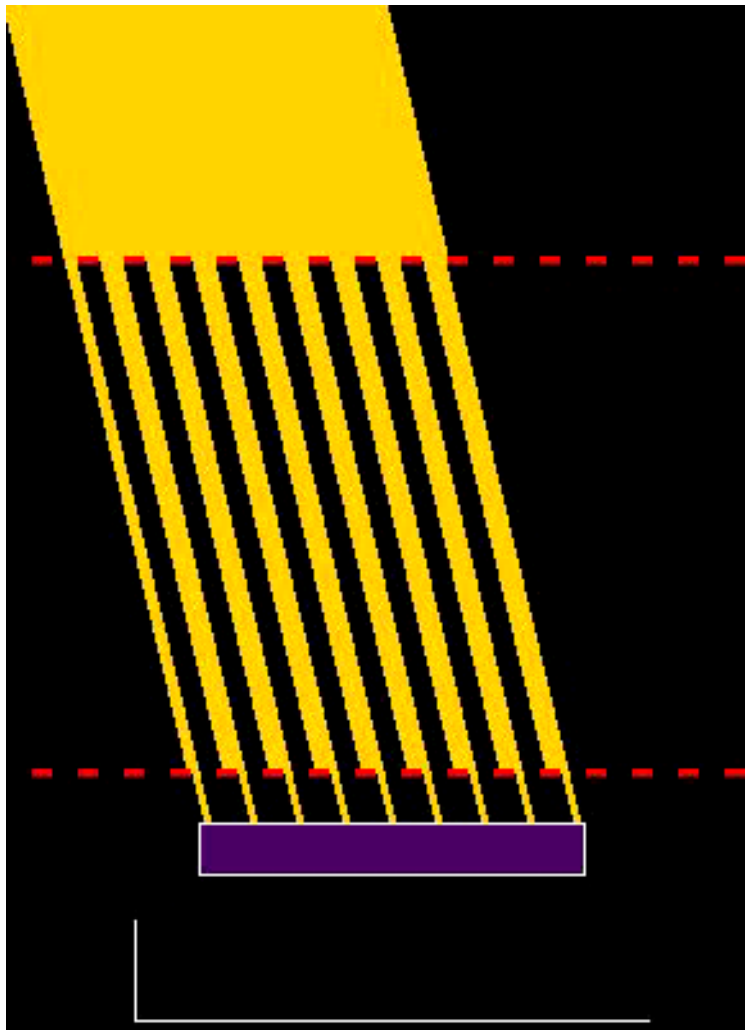
image information is stored in modulations

Time-Tagged Detector Counts

F1309_18.ai

RHESSI imaging

incoming X-rays



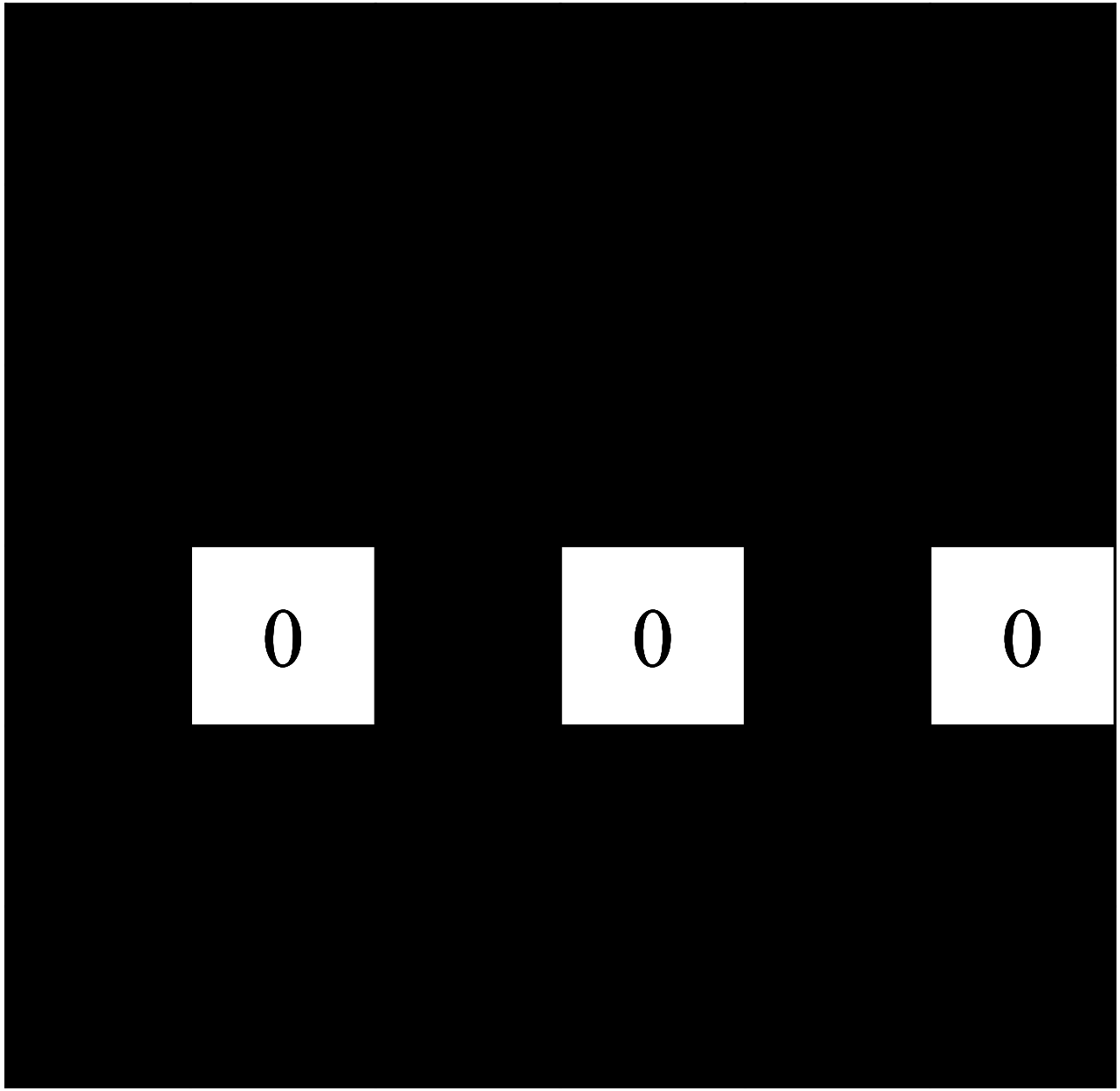
grid

grid

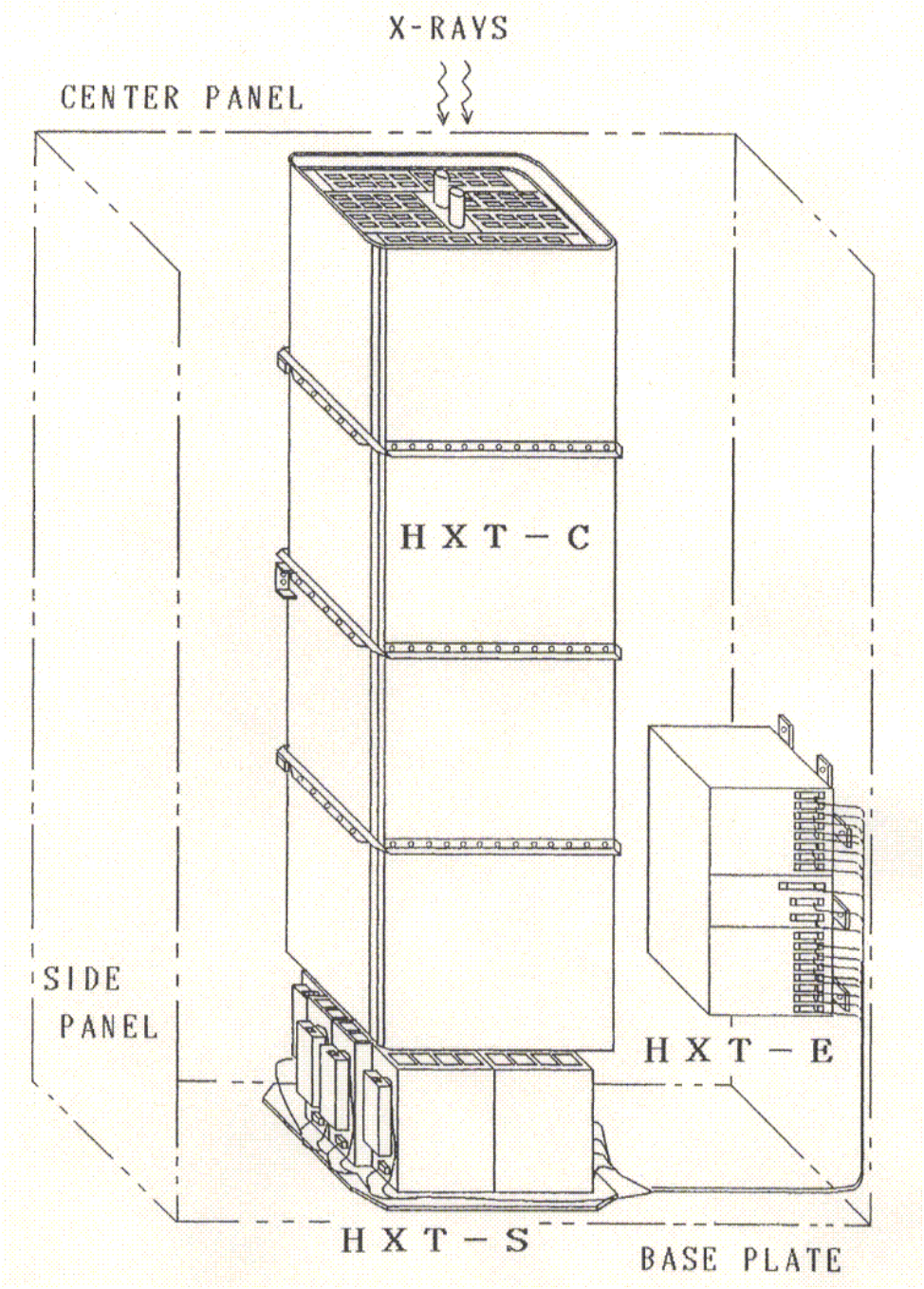
detector

detected signal
is modulated

Spatial distribution of hard X-ray sources (硬X線源の分布)



Yohkoh
Hard X-ray Telescope



Yohkoh/HXT: concept of modulation collimators

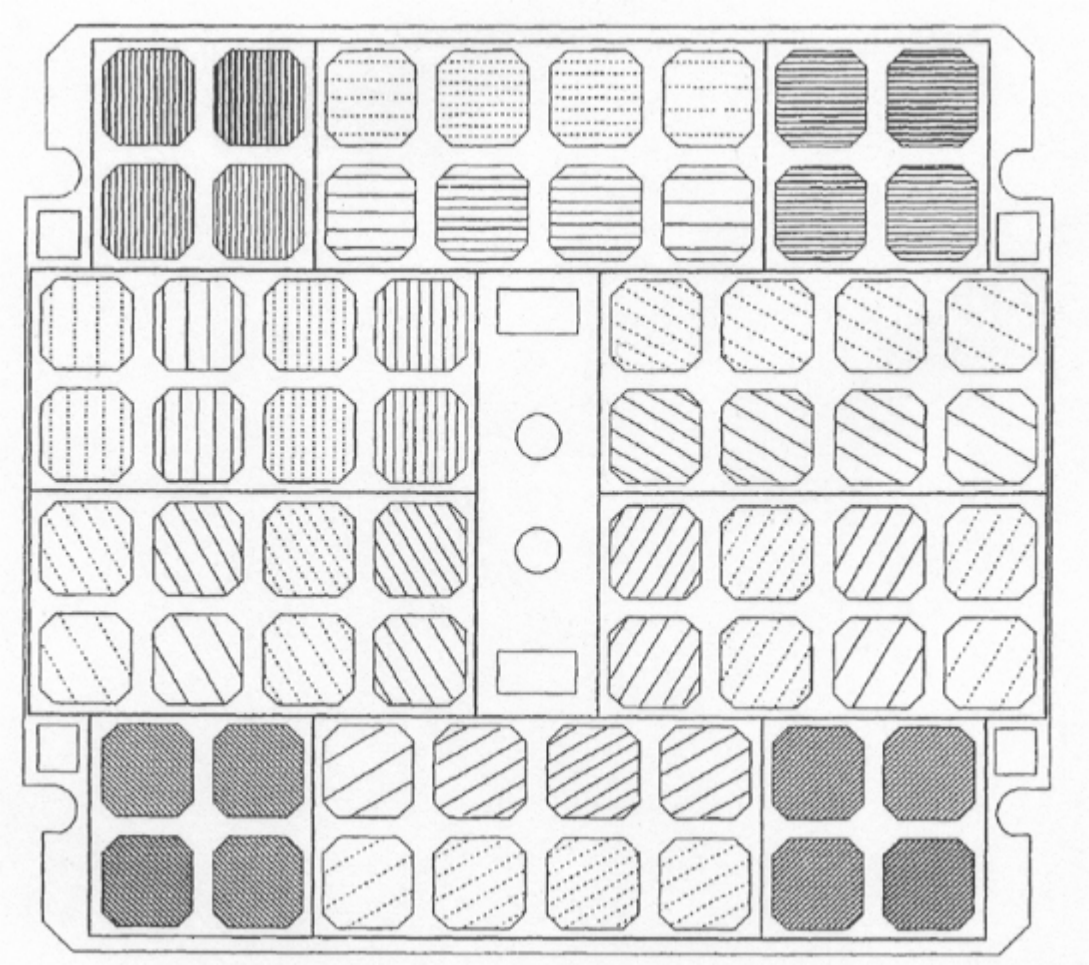
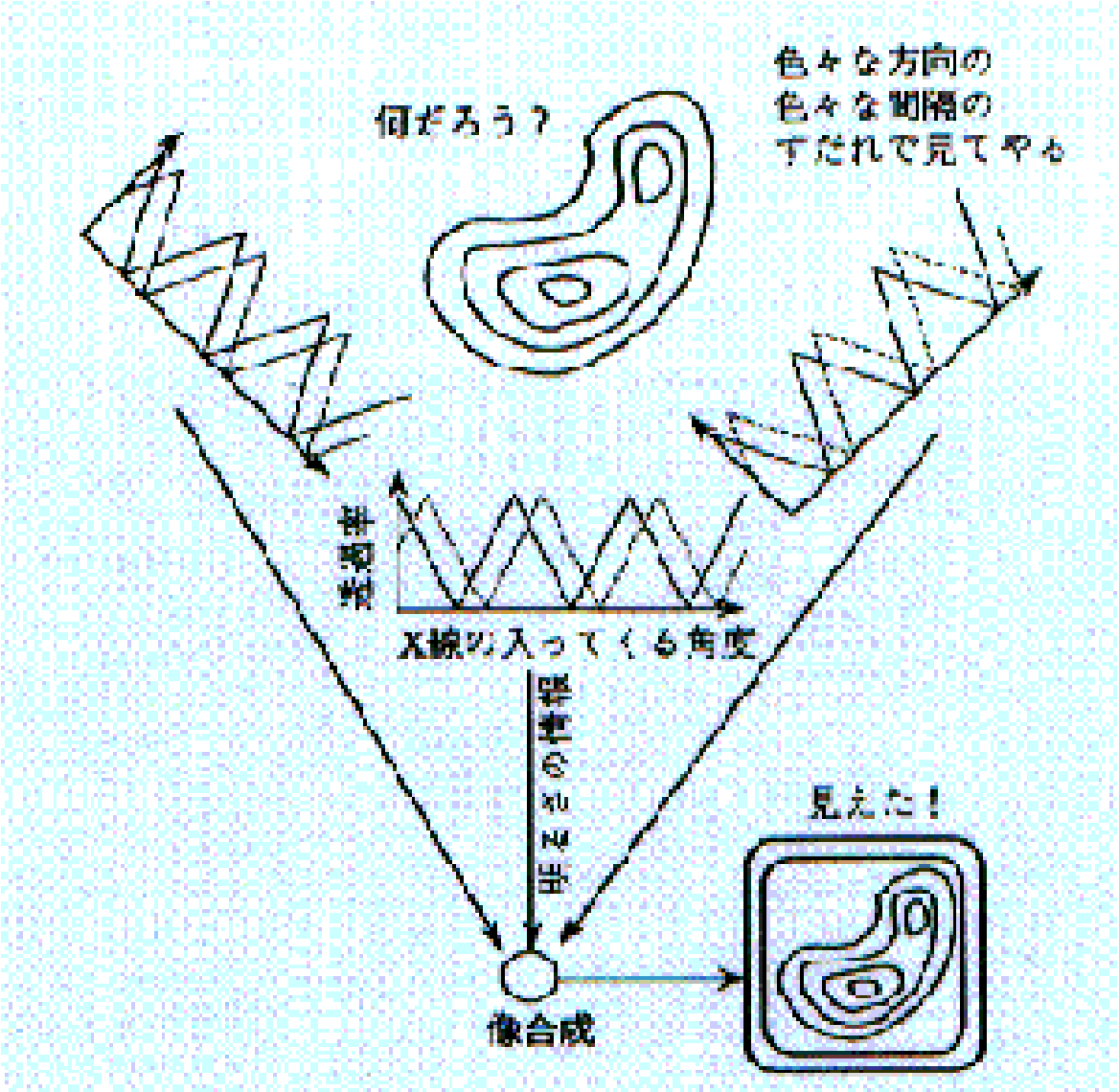
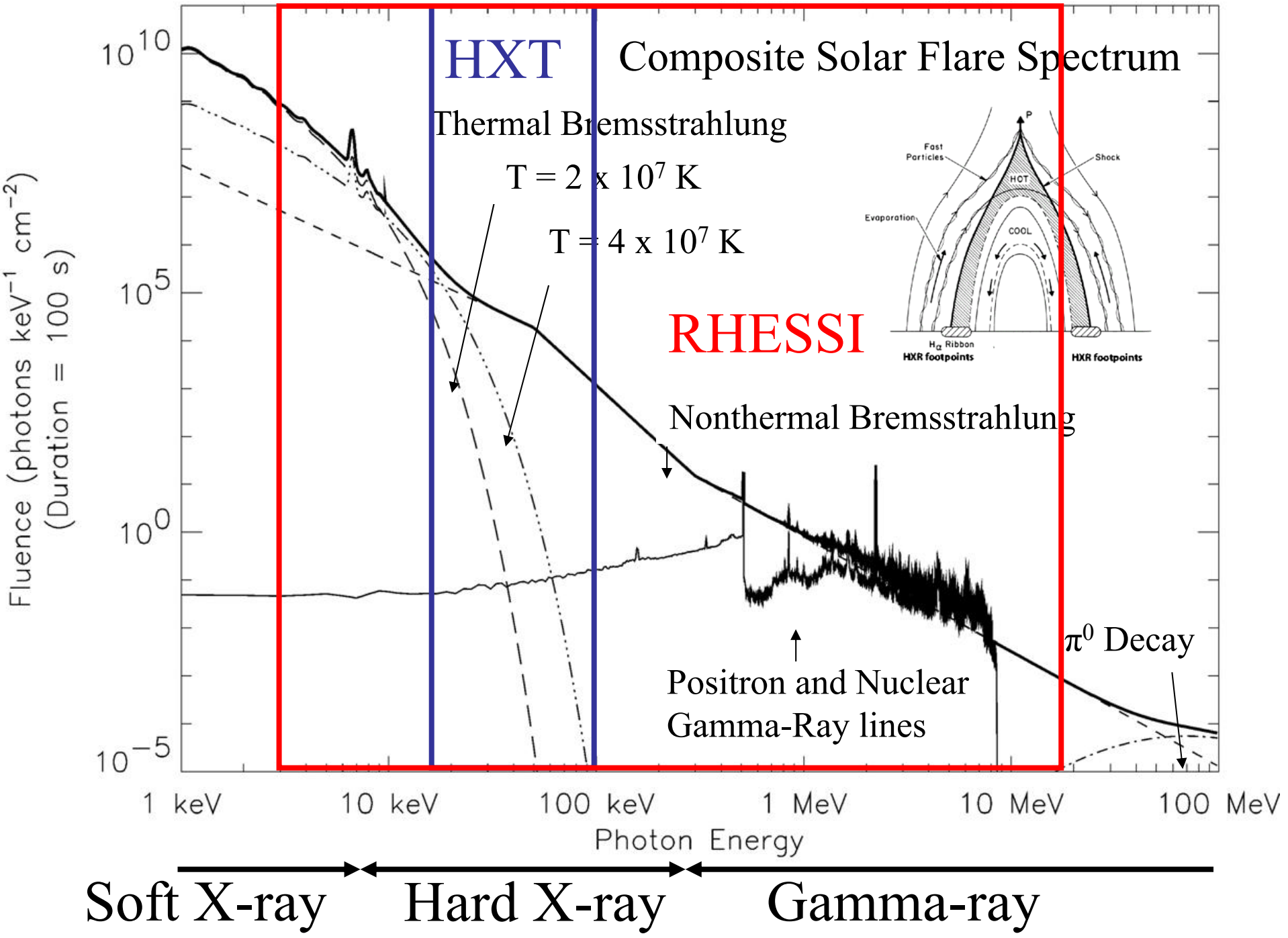


Image synthesis by modulation collimators
すだれコリメータによる像合成の概念図

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10^10
10^5
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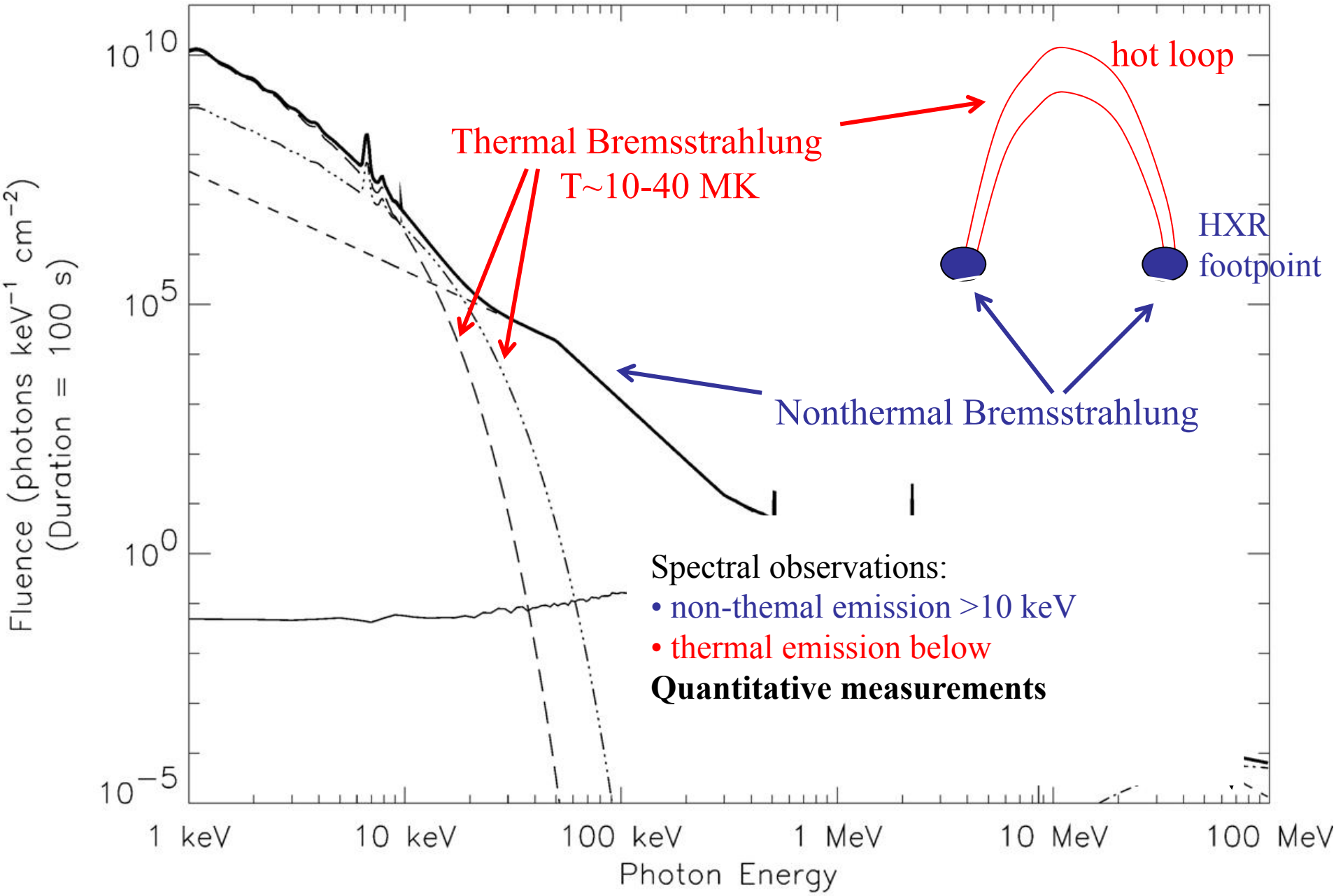
10−5
1 keV
10 keV
100 keV
1 MeV
10 MeV
100 MeV
Photon Energy
Soft X-ray
Hard X-ray
Gamma-ray

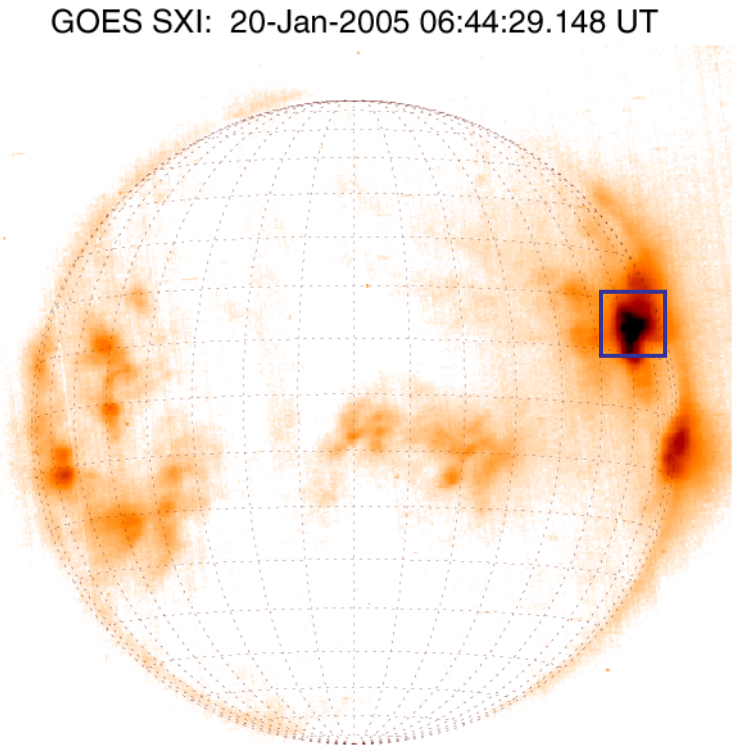
Yohkoh/HXT vs RHESSI

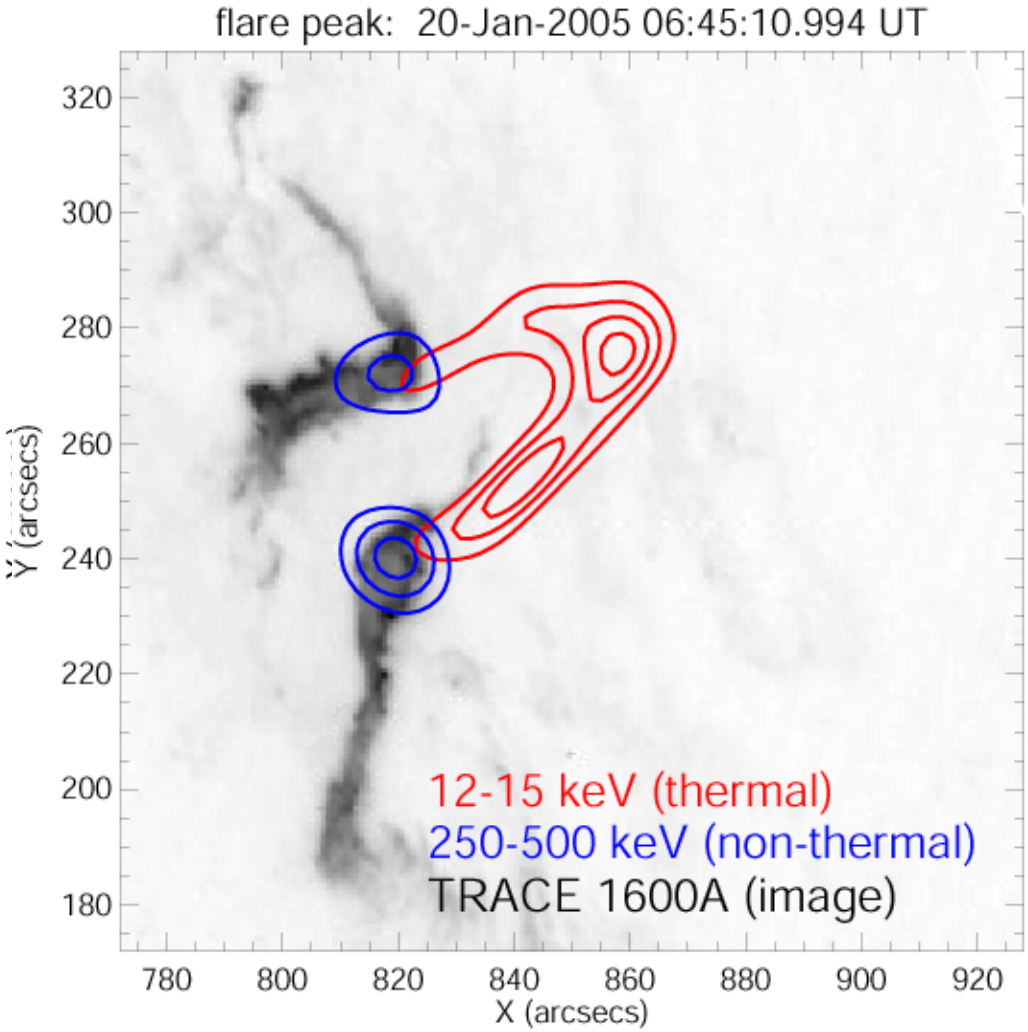
	Yohkoh/HXT	RHESSI
Effective area	~60cm^2 (64 detectors)	~100cm^2 (9 detectors)
Energy range	14-93 keV	3 keV – 15 MeV
Energy resolution	2 keV at 10 keV 10 keV at 100 keV	< 1 keV at 3 keV 5 keV at 15 MeV
Field of view	full sun	full sun
Spatial resolution	~5 arcsec	2 arcsec < 100 keV 7 arcsec < 400 keV 36 arcsec > 400 keV
Time resolution	0.5 sec	2 sec
Dynamic range	~10:1	50:1– 100:1


Thermal Bremsstrahlung
T~10-40 MK
hot loop
HXR
footpoint
Nonthermal Bremsstrahlung
Spectral observations:
• non-themal emission >10 keV
• thermal emission below
Quantitative measurements
Fluence (photons keV^{-1} cm^{-2})
(Duration = 100 s)
10^{10}
10^{5}
10^{0}
10^{-5}
1 keV
10 keV
100 keV
1 MeV
10 MeV
100 MeV
Photon Energy

X-ray imaging

Example:
very large flare occurring near solar limb (side view)





Two ribbon flare with 2 HXR footpoints (blue) and thermal loop (red)

flare near solar disk center (view from above)

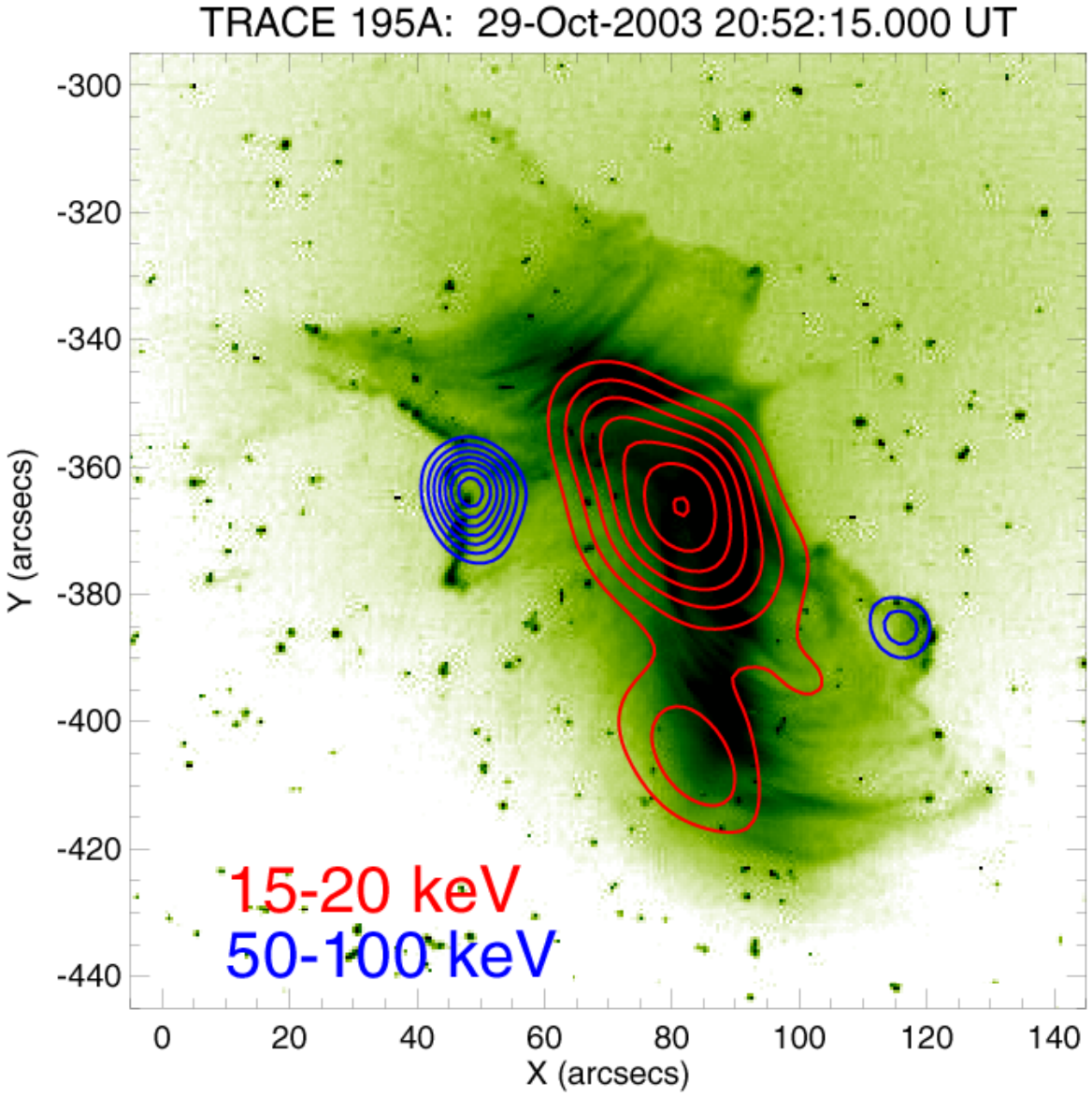
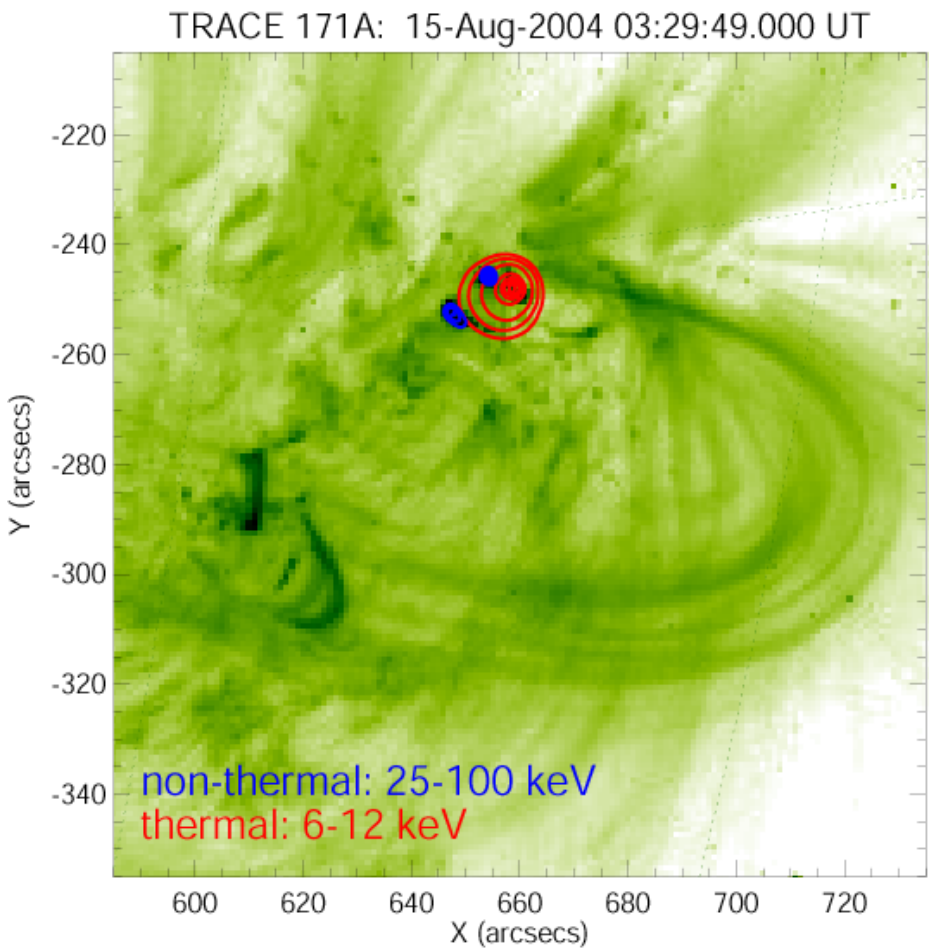


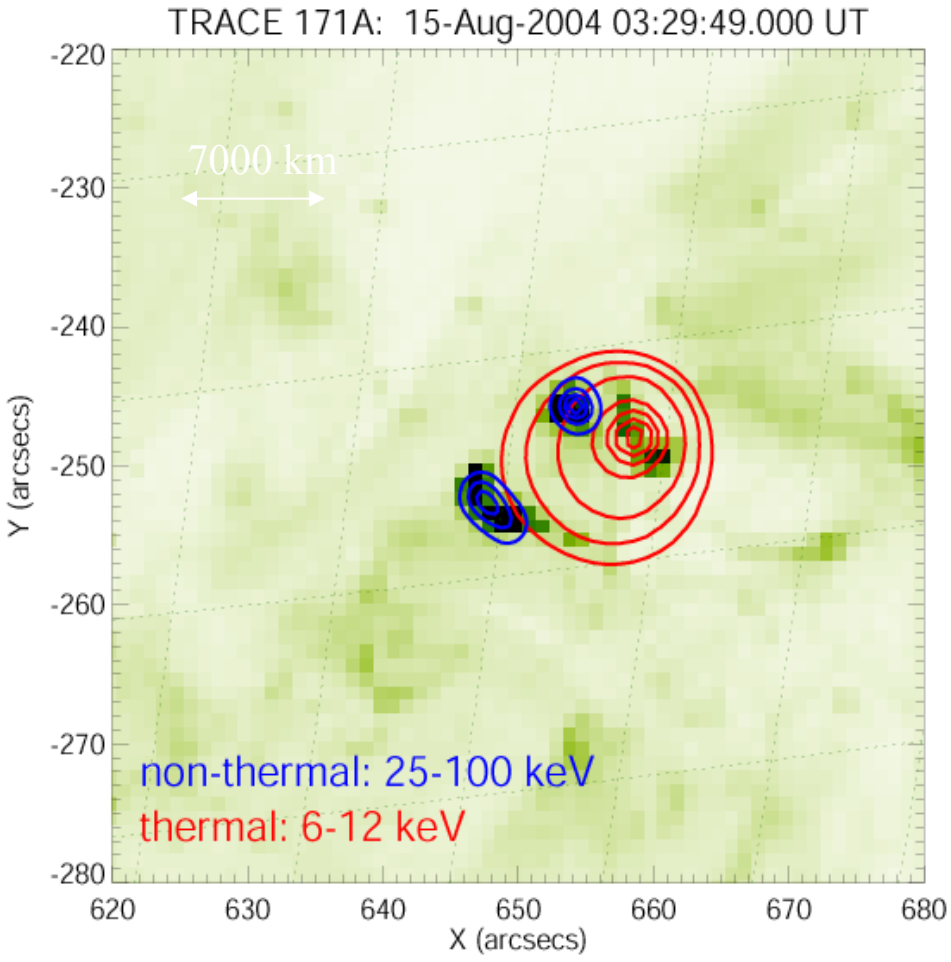
IMAGE:
TRACE EUV emission
~1.5MK

blue contours:
HXR footpoints
(non-thermal
Bremsstrahlung)

red contours:
thermal X-ray emission

Very compact flare





2” (1500 km) spatial resolution