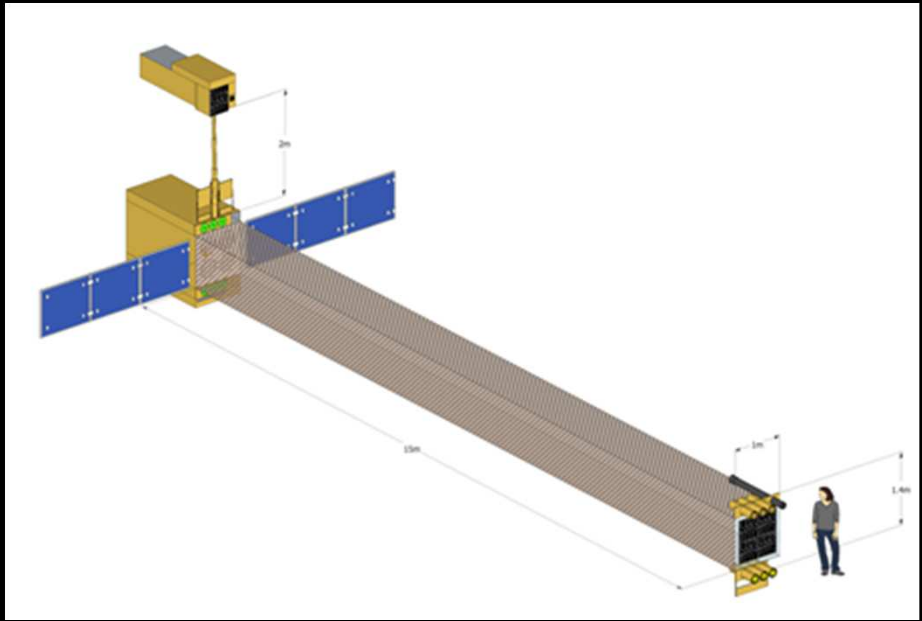
SEE (Solar Eruptive Events) 2020 Mission



R. P. Lin, A. Caspi, S. Krucker, H. Hudson, G. Hurford, (SSL/UCB);
S. Bandler, S. Christe, J. Davila, B. Dennis, G. Holman, R. Milligan,
Y. Shih (GSFC); S. Kahler (AFRL); E. Kontar (Glasgow);
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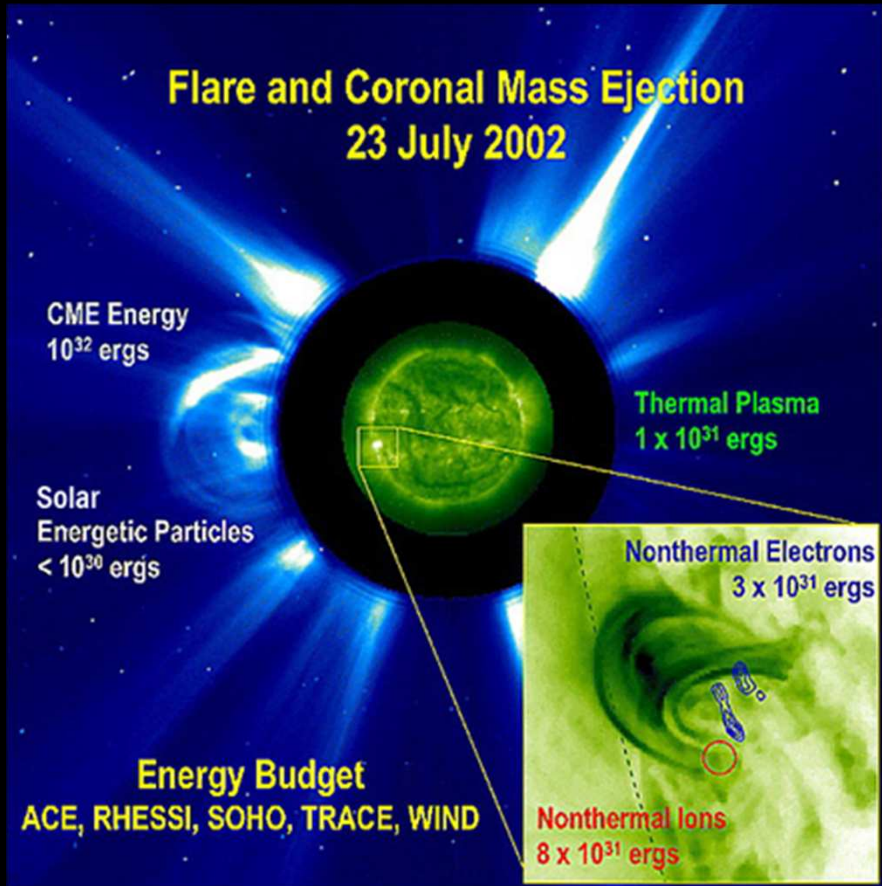
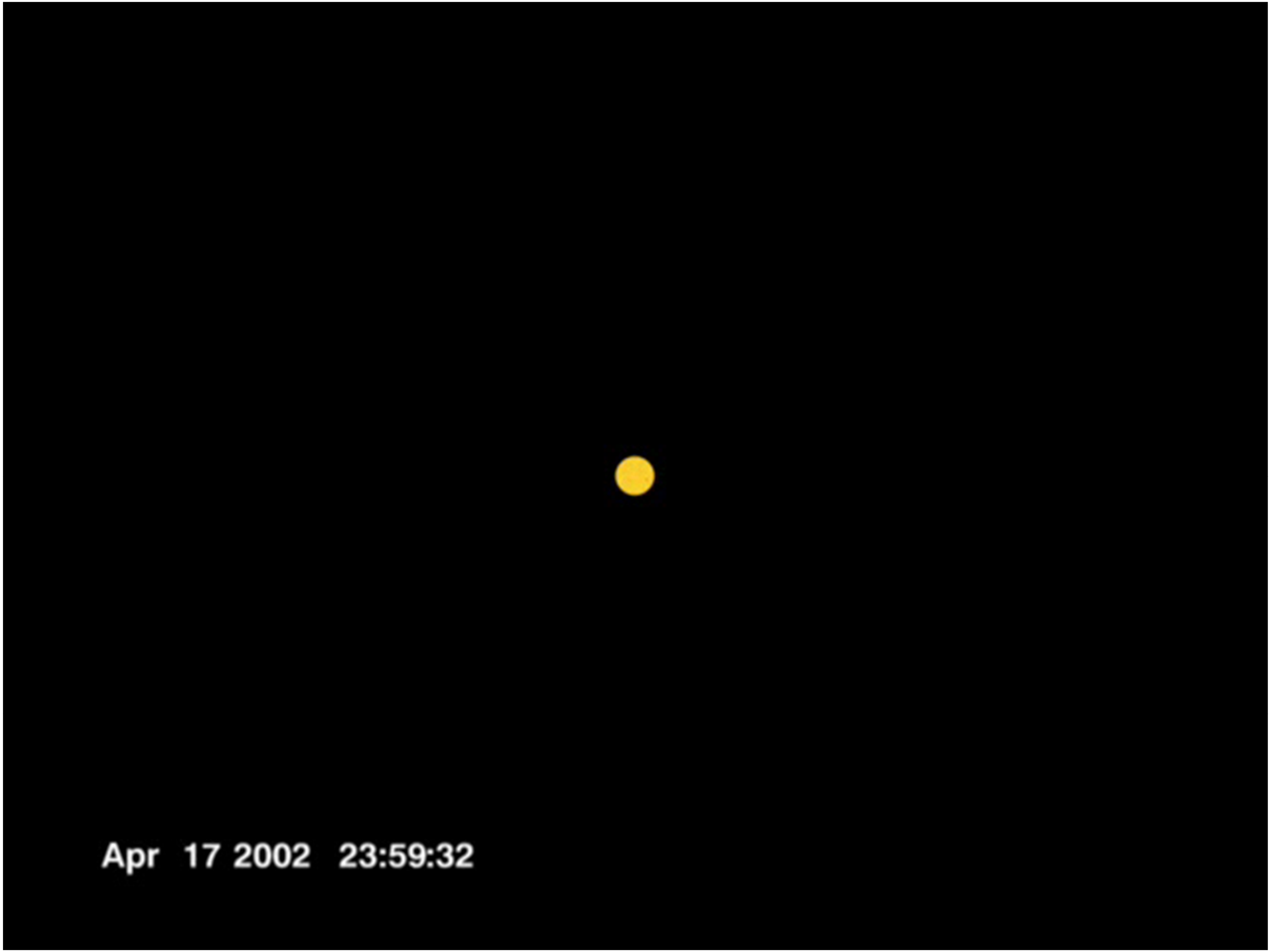
G. H. Share, A. Vourlidas (NRL); J. Raymond (SAO);
D. M. Smith (UCSC); M. McConnell, J. Ryan (UNH);
G. Emslie (WKU)

Heliophysics Steering Committee Meeting, Feb. 1-3, 2011



Understanding the energy release and particle acceleration processes in the most powerful explosions in the solar system that also produce the most extreme space weather.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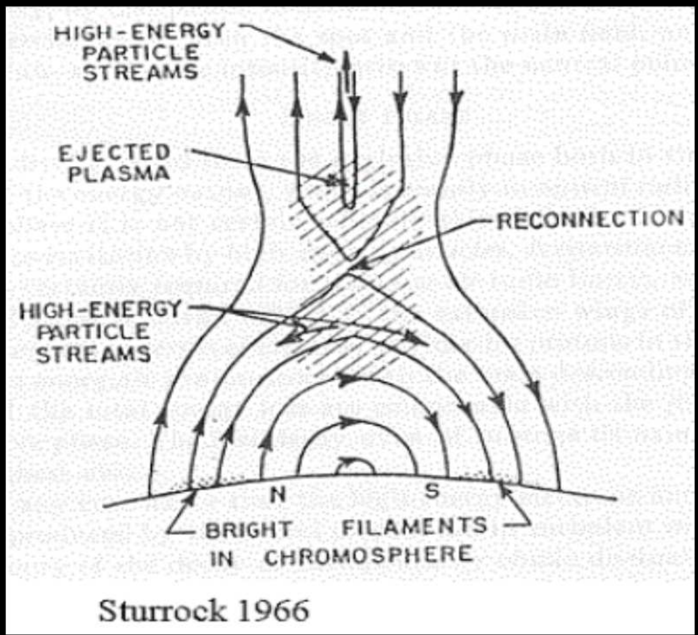
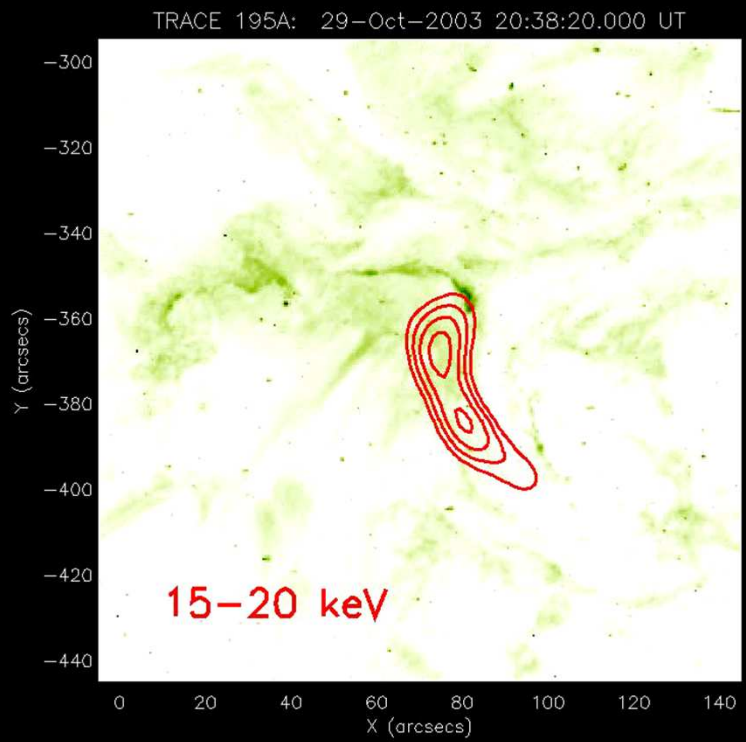
Large solar flares are the most powerful explosions in the solar system

Up to ~ 10^{32}- 10^{33} ergs released in ~ 10 – 1000 s
Flare-accelerated ~20-100 keV electrons contain ~10-50% of the total energy released
In large flares, >~1 MeV ions contain comparable energy

=> Particle acceleration is intimately related to flare energy release





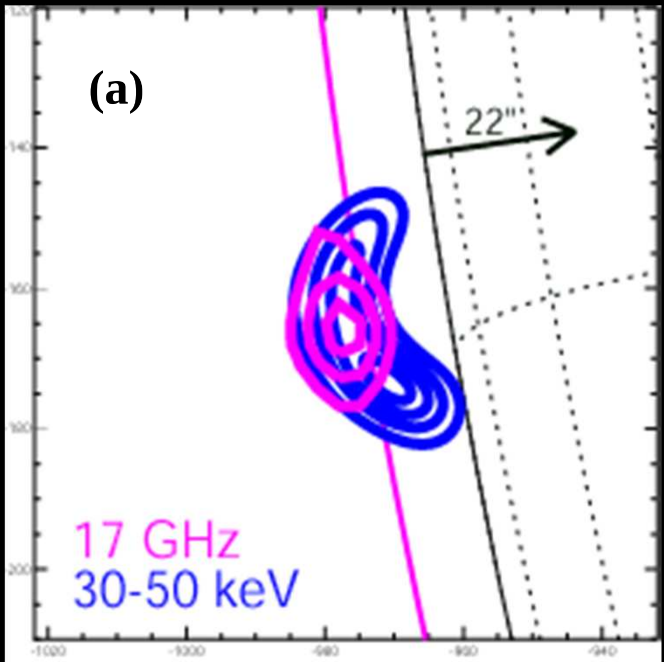
TRACE movie with RHESSI hard X-rays
29 October 2003 X17 Flare

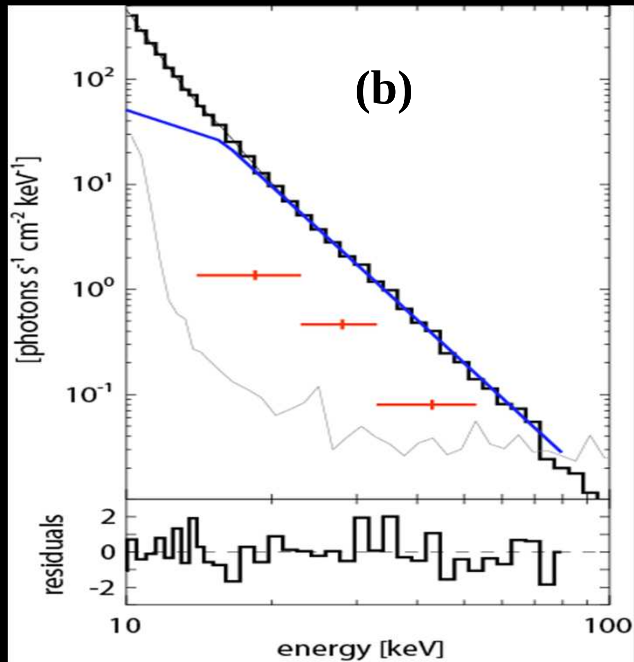
Imaging of the Flare Electron Acceleration/Energy Release Region in Corona

(a) Flare electron acceleration/energy release region potentially identified by RHESSI [blue contours] and in microwaves [pink contours] located above loops in occulted flare.

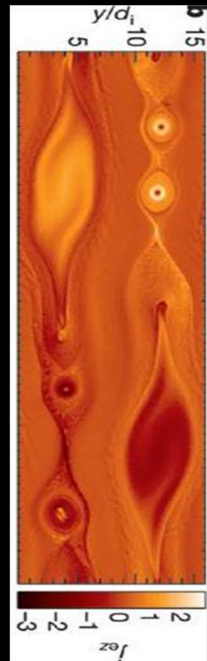
(b) Energetic electrons in this region with power-law spectrum and energy density comparable to magnetic field energy density.

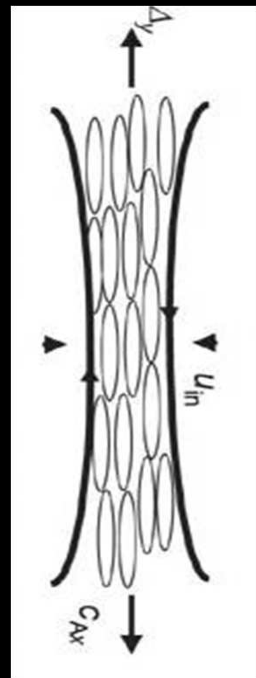
(c, d) Consistent with predictions of a flare model where magnetic reconnection produces volume-filling elongated islands that accelerate electrons as they contract until the two energy densities are comparable.





Krucker et al, 2010





(c) (d)

Drake et al, 2006

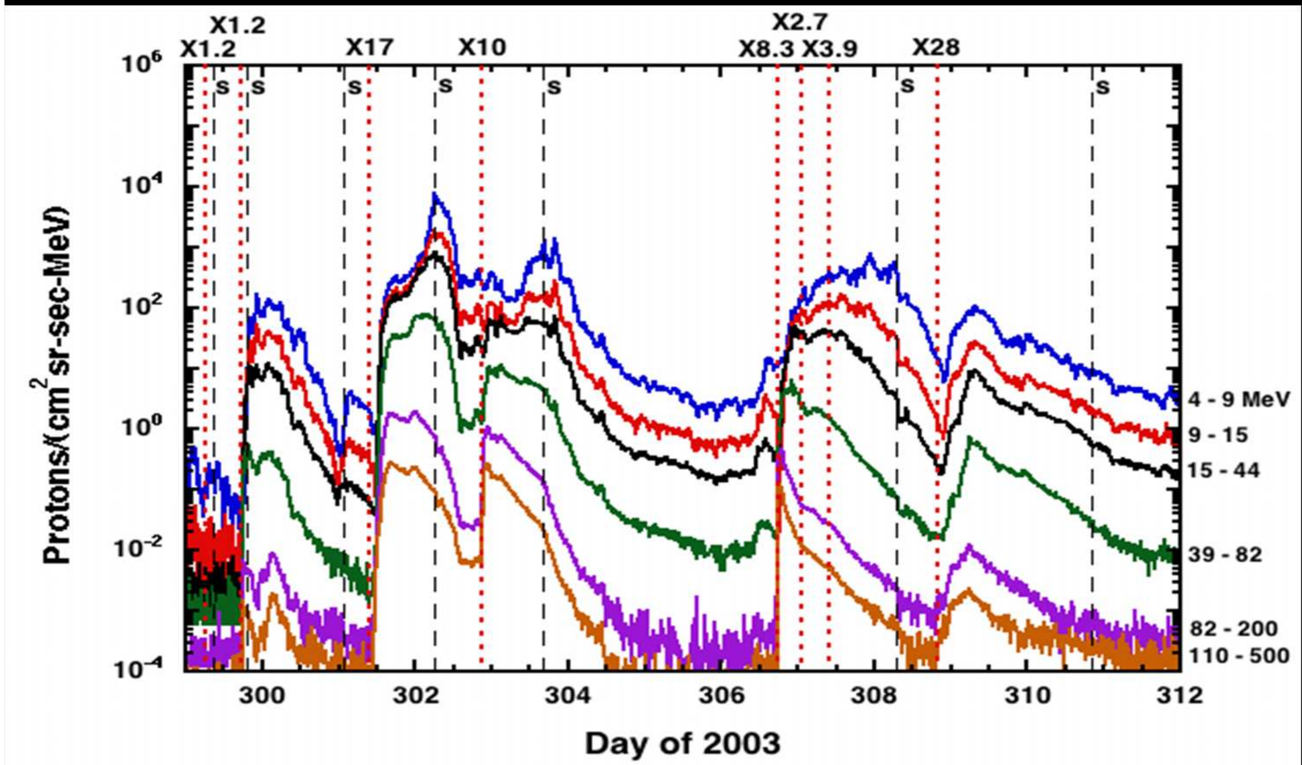
The Sun is the most energetic particle accelerator in the solar system:

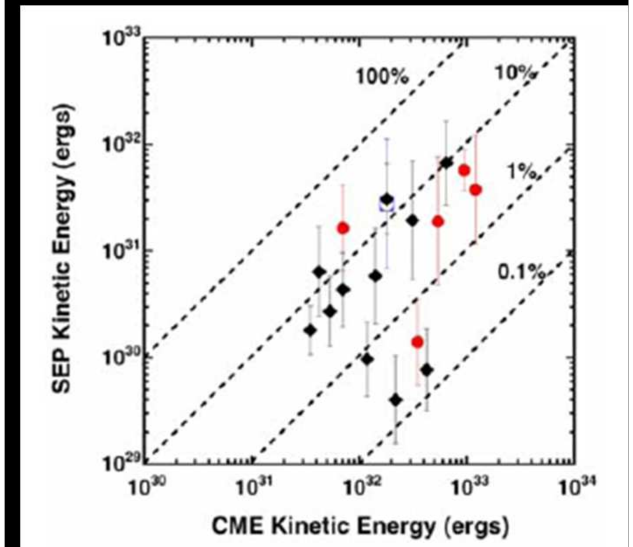
- *Ions up to ~ GeV*
- *Electrons up to ~10s of MeV*

Acceleration to these energies occurs in two (!) processes in SEEs:

- *Large Solar Flares, in lower corona*
- *Fast Coronal Mass Ejections (CMEs), at ~2-40 R_{sun} in inner heliosphere*

~10% of the total energy in fast CMEs goes to accelerating SEPs (solar energetic particles)



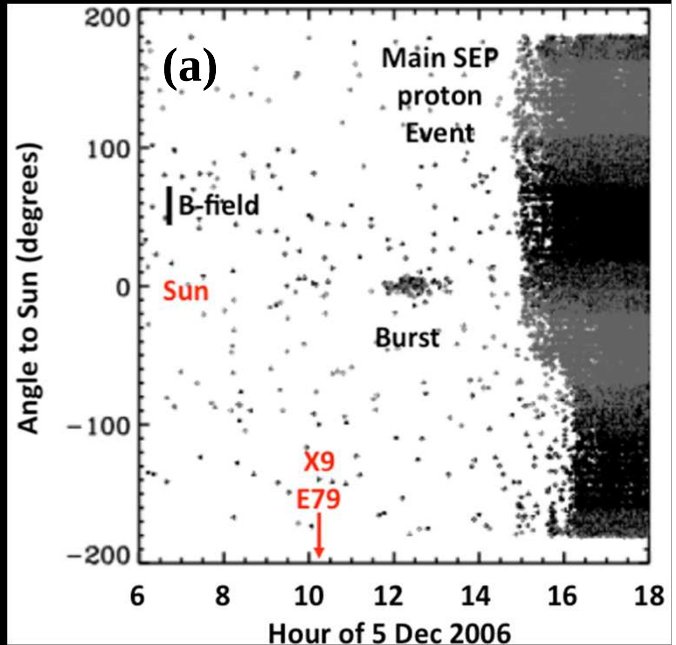


First detection of *neutral* solar energetic particles (SEPs)
First gamma-ray line imaging of energetic ions in flares

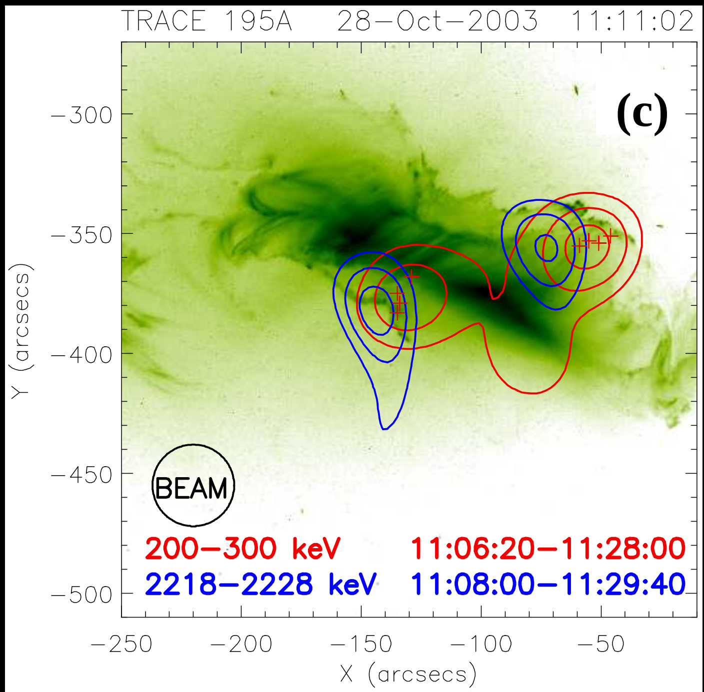
(a, b) STEREO discovery of *neutral* solar energetic particles (SEPs) with a flare-like emission profile but likely from CME-shock accelerated SEPs.

(c) First imaging of flare-accelerated >~30 MeV ions by RHESSI using the 2.223 MeV gamma-ray line showing two ion footpoints displaced from the electron footpoints.

These discoveries enable the remote imaging of energetic ion acceleration in both flares and CMEs.



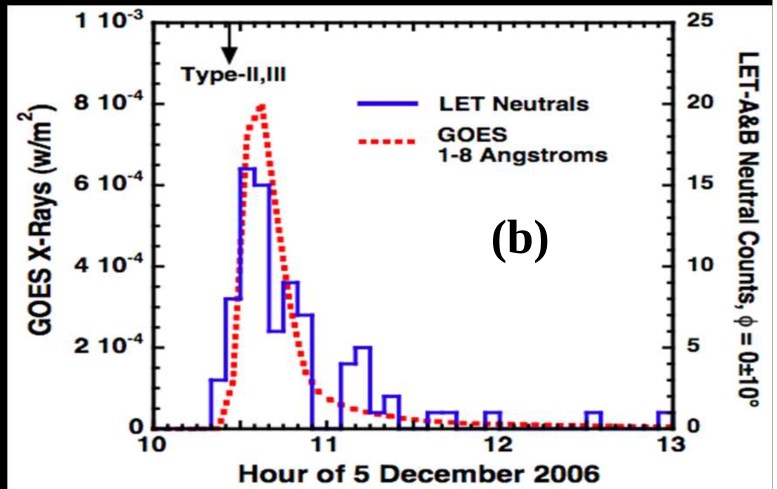
Mewaldt et al. (2009))

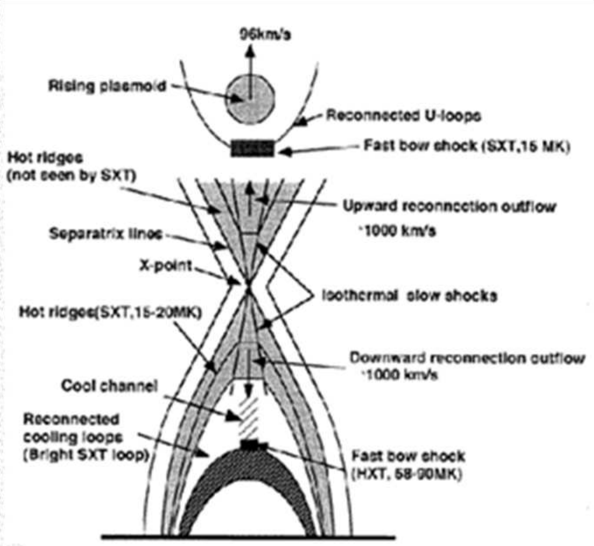


>~30 MeV protons (2.223 MeV neutron-capture line)

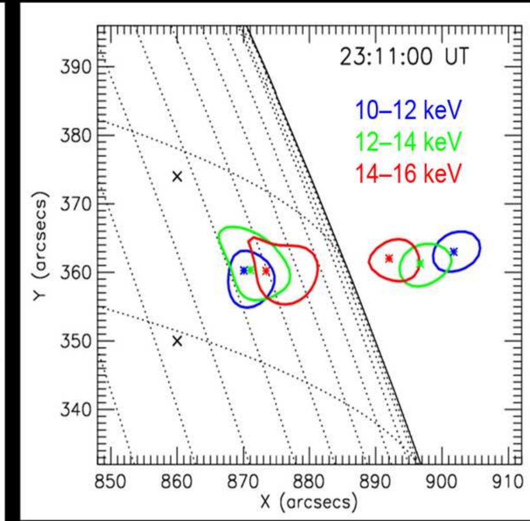
>0.2 MeV electrons (bremsstrahlung X-rays)

Hurford et al. (2006)

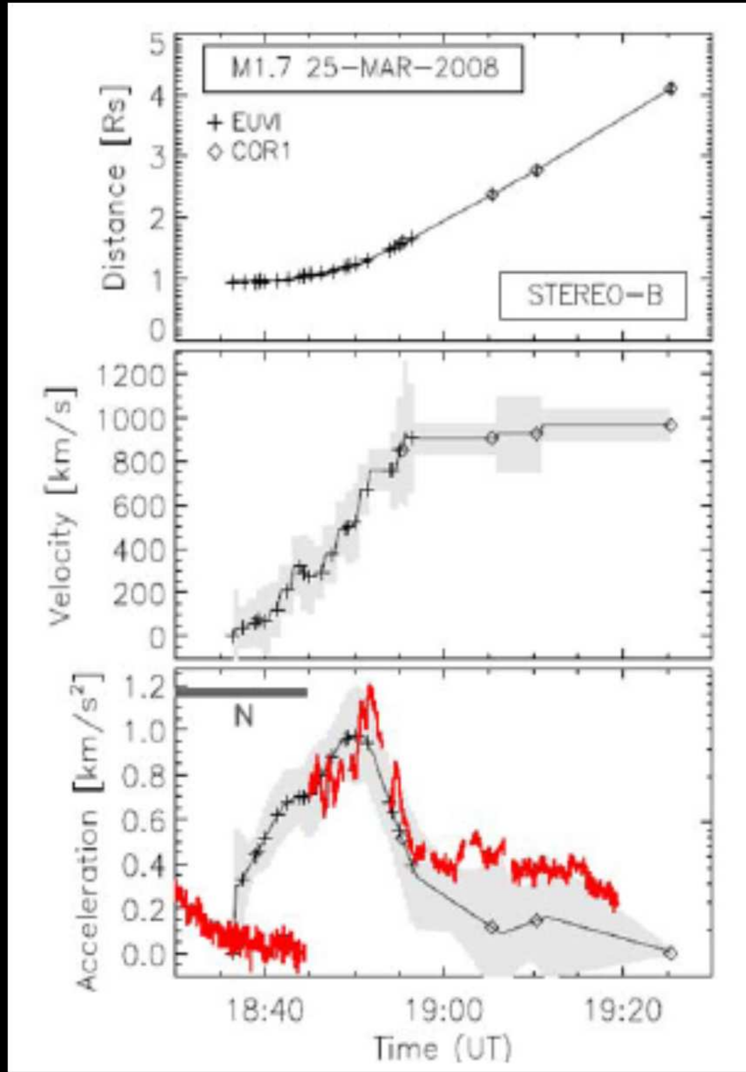




Tsuneta 1997



RHESSI observation of two coronal thermal X-ray sources that are believed to bracket the flare energy release site high in the corona. (Hard X-ray footpoints indicated with an x).

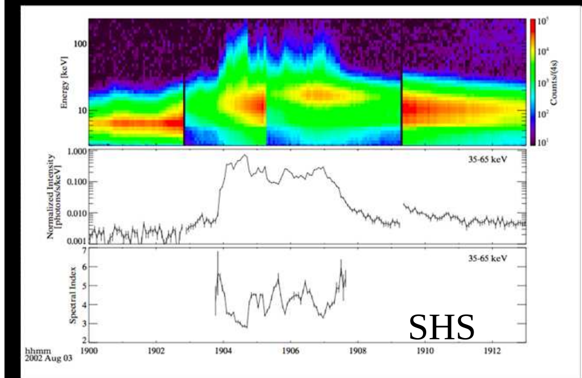


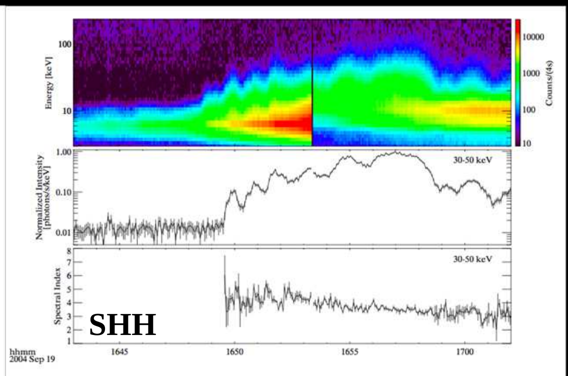
CME acceleration (bottom, black trace) is closely correlated to flare hard X-ray flux (red) (Temmer et al., 2008, 2010)

Solar Energetic Particles (SEPs) predicted by soft-hard-harder (SHH) behavior of flare hard x-ray burst!

	SHH?	
SEPs?	***Yes:***	***No:***
Yes:	*12*	*0*
No:	*6*	*19*

Flare, CME, and SEPs are closely related in SEEs (Solar Eruptive Events)!





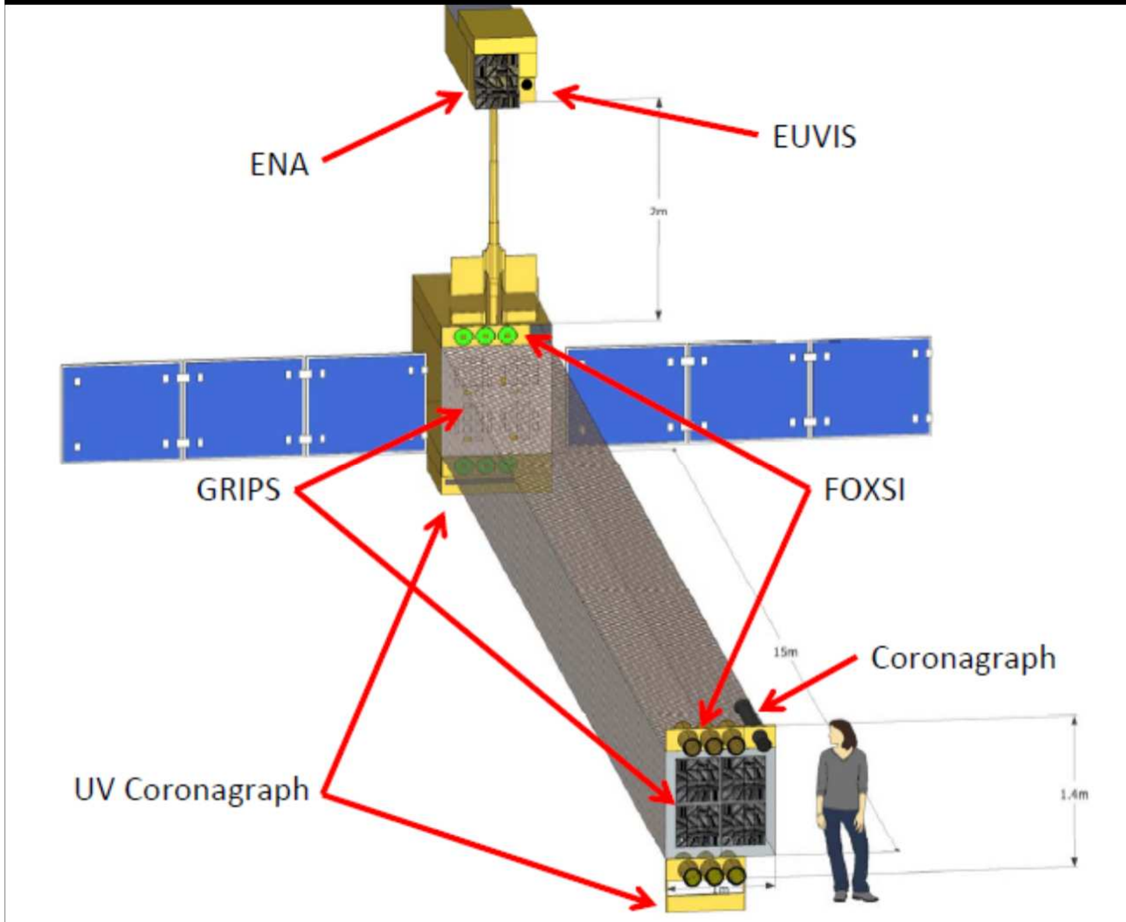
SEE (Solar Eruptive Events) 2020 Mission

Prime Instruments

FOXSI (Focusing Optics hard X-ray Solar Imager)
GRIS (Gamma-Ray Imaging Spectrometer)
ENA imager for neutral solar energetic particles

Context Instruments

EUVIS (EUV imaging Spectrometer)
UV Coronagraph Spectrometer
White light Coronagraph

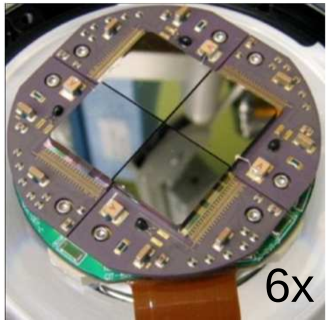


PAYLOAD

Mass	1300 kg
Power	1700 W
Bit rate	22 GB/day
Attitude	Sun-pointed 3-axis stabilized
Orbit	Low Earth Orbit, ~600 km altitude
Launch	~2022 for next solar maximum
Lifetime	~3-5 years
Total Cost	~$600 or 700M, based on launch vehicle cost of $100 or 200M

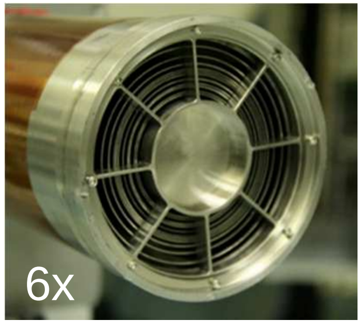
FOXSI (Focusing Optics X-ray Solar Imager)

- FOXSI will provide the sensitivity and dynamic range necessary to directly observe electrons where they are accelerated in the solar corona.



CZT detectors

Focal length = 15 m



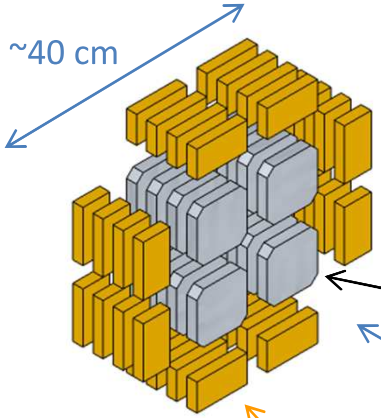
6 sets of telescope and detector pairs.

Ni replicated grazing-incidence optics

Technology	TRL	Heritage
CZT Detectors	6	NuStar
Grazing-incidence Optics	6	FOXSI, HERO

Parameter	Value
Focal Length	15 m
Energy Range	1-80 keV
Energy Resolution	~1 keV
Spatial Resolution	8 arcsec
Field of View	512 x 512 $arcsec^2$
Effective Area	250 cm^2 @ 25 keV 60 cm^2 @ 50 keV
Background Rate	7×10^{-4} cts/s (>10,000 lower than RHESSI)
Dynamic Range	Up to 100 x RHESSI
Sensitivity	~100 x RHESSI
Mass	130 kg
Power	80 watts
Cost	$50M

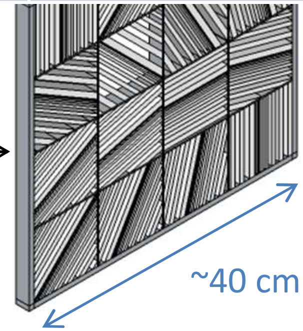
Gamma-Ray Imaging Spectrometer



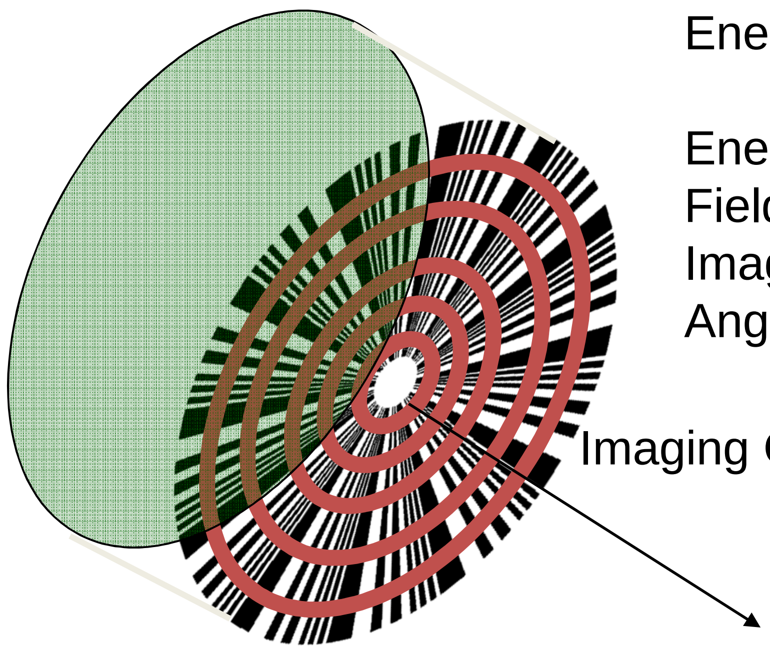
- Four modules, each with four 2×2 layers of 3D position-sensitive germanium detectors (3D-GeDs)
  - High-resolution spectroscopy
  - Position information to 0.5 mm allows reconstruction of Compton-scatter tracks for imaging reconstruction and background rejection
  - Mechanically cryocooled
- Tungsten mask for modulation
  - Quasi-continuous range of slit/slat pitches to give 7” to 3’ angular coverage
  - Great image quality virtually free of sidelobes

Instrument details	
Angular Resolution	7” to 3’ (5× *RHESSI*)
Spectral Resolution	~4 keV at 2.2 MeV
Geometric Area	~850 cm^2
Effective Area for Imaging	~50 cm^2 at 2.2 MeV (>10× *RHESSI*)
Mass	~450 kg
Power	~800 W
Data	~3 GB/day
Cost	~$70 M
Heritage	*RHESSI*, *NCT*, *GRIPS*

separated by 15 meters



Energetic Neutral Atom (ENA) Imager for Neutral SEPs (Solar Energetic Particles)



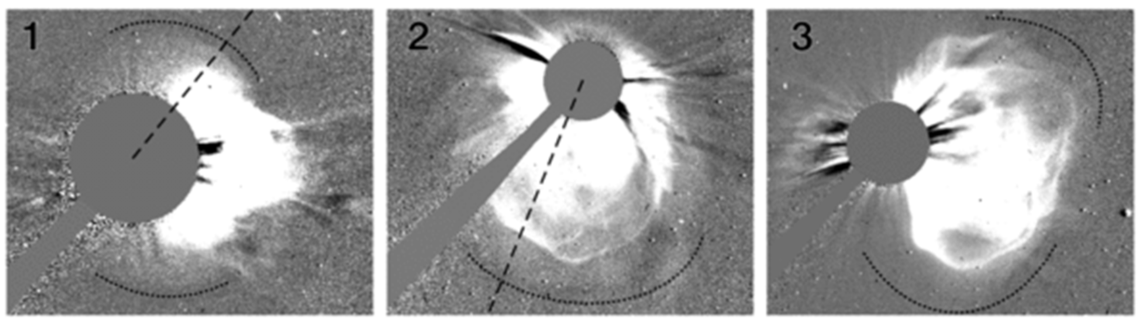
Specifications:

Effective area: ~500 cm^2 (100 x STEREO)
Energy range: ~0.4 to 20 MeV - dE/dx vs E
~4 to 400 keV - silicon detectors
Energy resolution: ($\Delta E/E$) = ~0.25
Field of View: ~10º (2 to 10 R_{sun})
Imaging Method: GRIPS-like Fourier transform
Angular Resolution: ~1 arcmin (<0.1 R_{sun})

Mass	**50 kg**
Power	**50 W**
Bit Rate	**1GB/day**
Cost	**$25 M**
Heritage	**STEREO LET & STE, RHESSI**

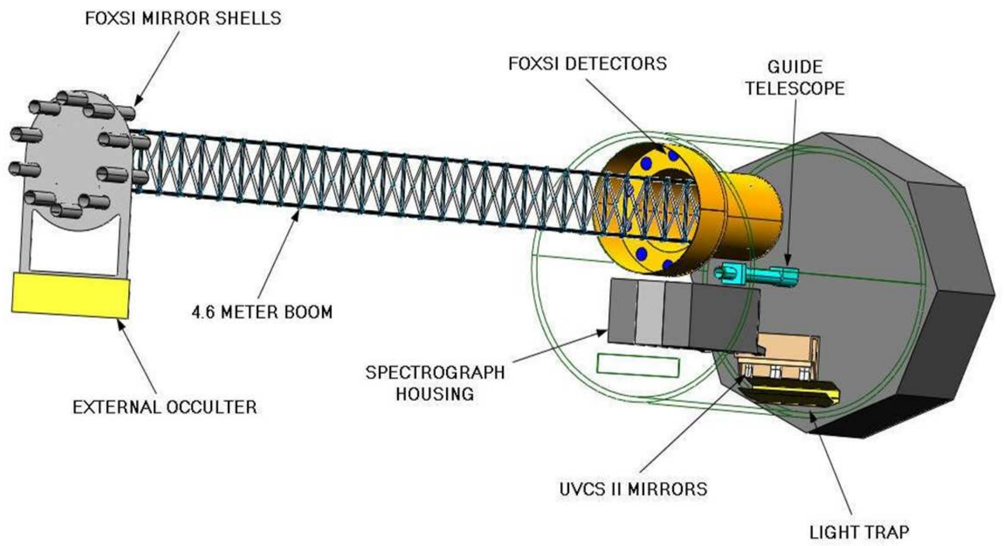
GOALS OF ENA IMAGING: SEP VARIATIONS AT SHOCK FRONTS

SEP distributions may show big variations at shock fronts leading to important advances in shock physics and SEP forecasting



Arcs show the locations of shock fronts in fast (V > 1500 km/s) CMEs

UV Coronagraph Spectrometer



Measure:

n_e, T_e and T_i , Suprathermal tails, Ionization state and composition, $V_{DOPPLER}$, $\Delta V_{TURBULENT}$

In:

Pre-eruption Corona
CME acceleration region
Coronal Shock Waves
Current Sheets
CME core filaments

Mass	**90 kg**
Power	**70 W**
Bit rate	**3GB/day**
Cost	**$40M**
Heritage	**SoHO UVCS**

Specifications:

Spatial resolution 5” Wavelengths: 270–330, 500–700, 800–1300 Å
Spectral resolution 50 km/s
Cadence 10 sec Multi-slit capability: 3 heights
Temperature coverage 0.1 to 10 MK Effective Area: 10-100 times UVCS
Height range 1.1 to $10R_{SUN}$
Slit length 2.6 R_{SUN} Share 15m boom with FOXSI & GRIPS

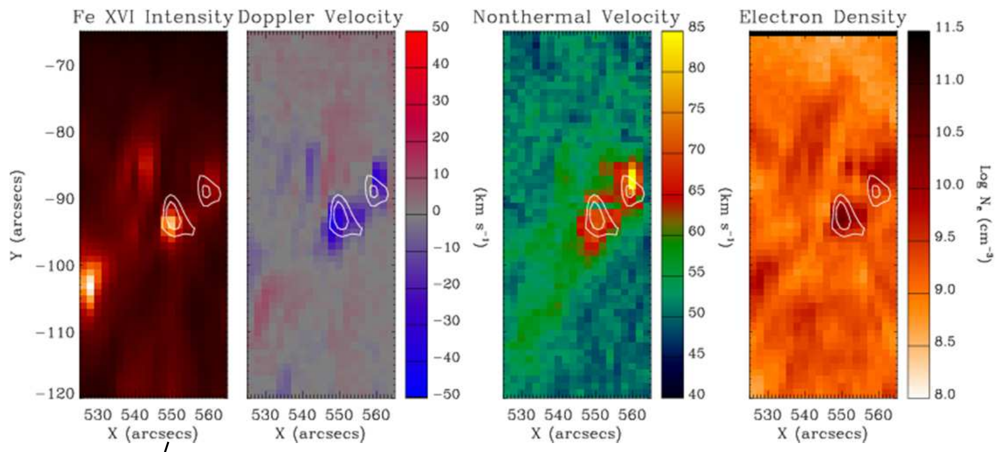
EUVIS (UV/EUV Imaging Spectrometer

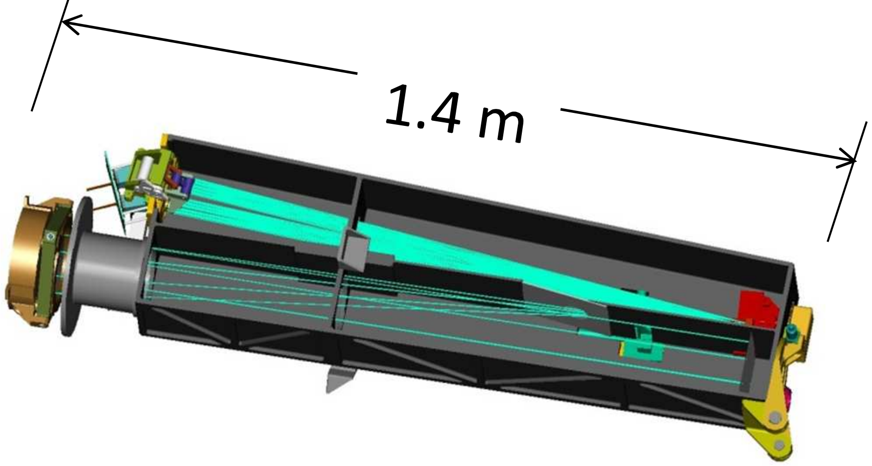
Purpose

1. Detect signatures of magnetic reconnection, such as jets
2. Detect sub-MeV accelerated ions
3. Determine physical properties of flare plasma
4. Detect and characterize pre- and post-impulsive-phase energy release
5. Distinguish direct plasma heating from heating by accelerated particles

Instrument Characteristics

1. Observe spectral lines sensitive to 10^4 K < T < 10^7 K including H Ly-α and He II 304 Å
2. Active region field of view (~$3' \times 3'$)
3. <10 s cadence
4. $\lambda/\Delta\lambda > 3000$
5. 10″ spatial resolution & better (multiple slits)
6. Observe solar disk out to ~1.2 RSun

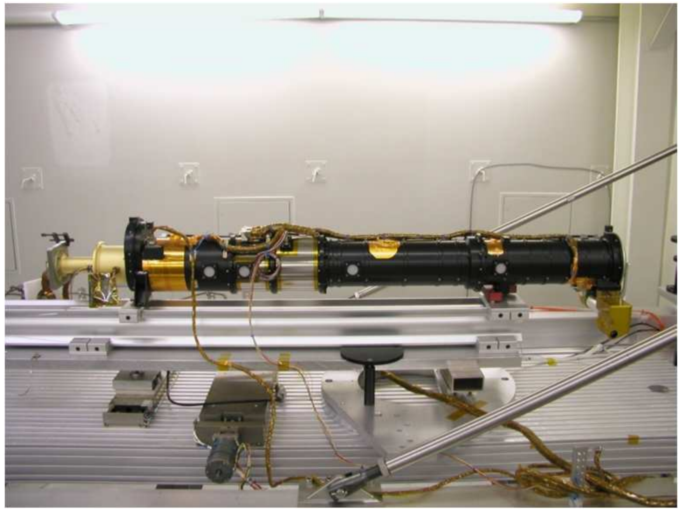


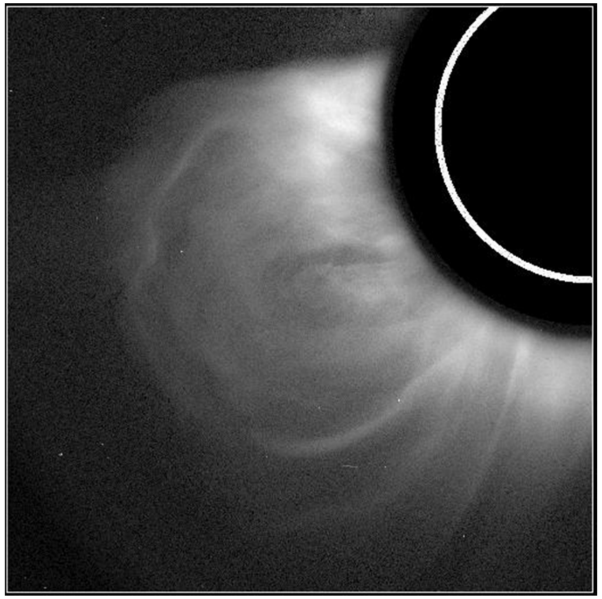


Mass	**55 kg**
Power	**100 W**
Bit rate	**3GB/day**
Cost	**$40 M**
Heritage	**Hinode EIS**

SEE Coronagraph

Item	Value
Field of View	1.5 – 4.0 Rsun or 2.5-15 Rsun
Volume	120 mm dia x 1.4 m
Mass	20 kg
Power	25 W
Data Rate	3 GB/day
Cost	$25 M
Heritage	LASCO, SECCHI





SEE (Solar Eruptive Events) 2020 Mission

Instrument	Heritage	Mass (kg)	Power (W)	Av. Data Rate (GB/day)	Cost ($M)
Focussing Optics hard X-ray Solar Imager	FOXSI HERO NuStar	130	100	3	50
Gamma-ray Imaging Spectrometer (HPGe)	RHESSI GRIPS	400	800	3	70
ENA Imaging Spectrometer	STEREO RHESSI	50	50	1	25
UV Coronagraph Spectrometer	SoHO UVCS	90	70	3	40
EUV Imaging Spectrometer	Hinode EIS	55	100	3	40
White-light Coronagraph	SoHO LASCO	20	25	3	25
Instrument totals		745	1145	16	250
Spacecraft		250	150	1	100
Contingency		300	400	5	100
Observatory TOTALS		1300	1700	22	450

Complementary space missions:

SDO
Solar Orbiter
Solar Probe Plus

Ground-based:

FASR
CoSMO
ATST
Flare Optical

Launch Vehicle (Taurus or Atlas) **$100 or 200 M**
MO & DA (5 years) **$ 50**

SEE 2020 Mission - Total Cost **$600 or 700 M**

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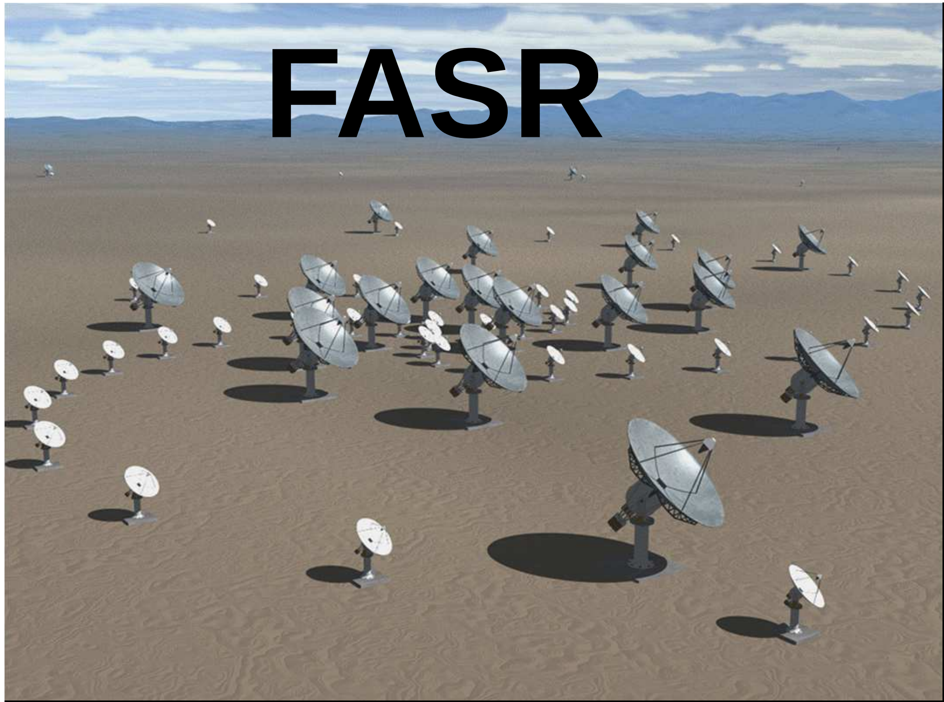
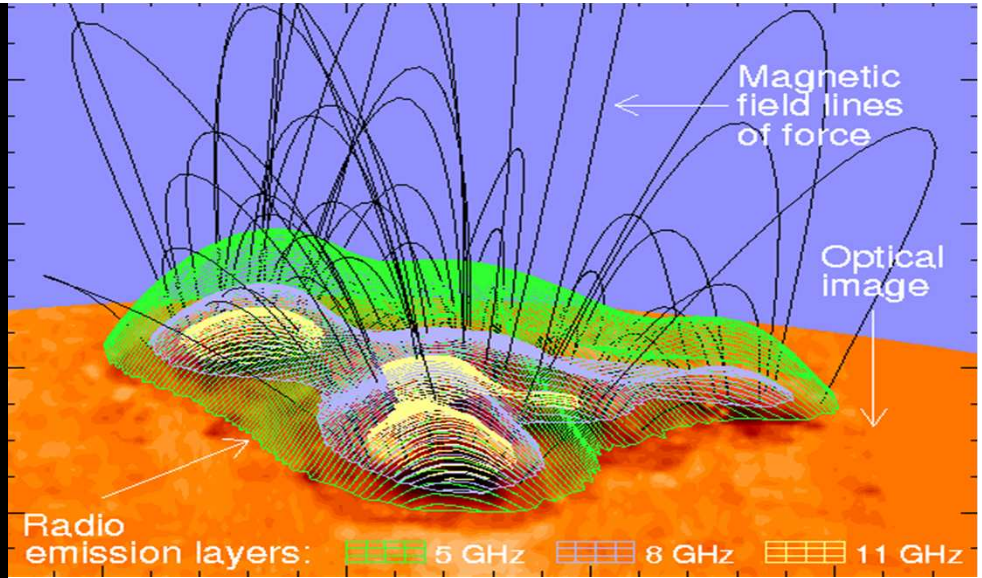
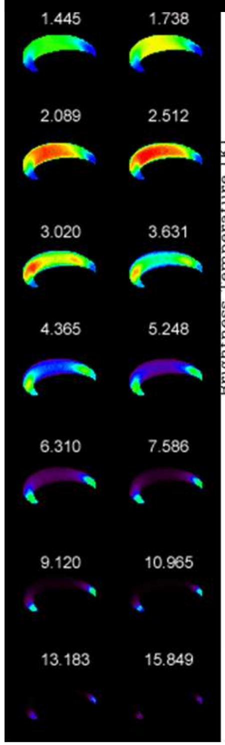
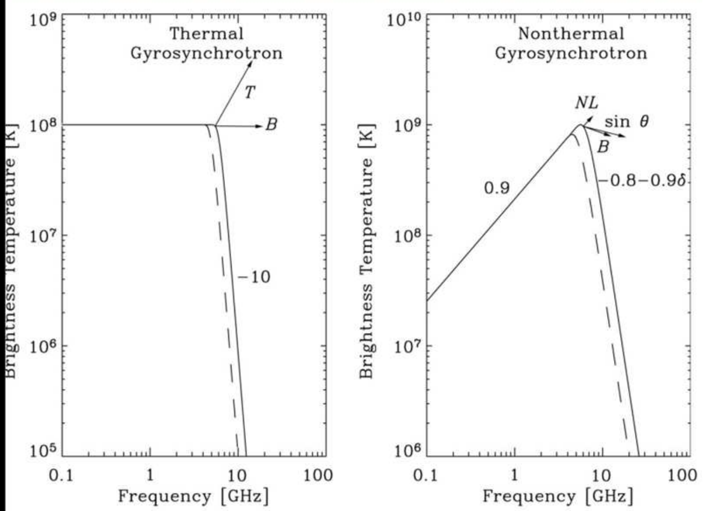


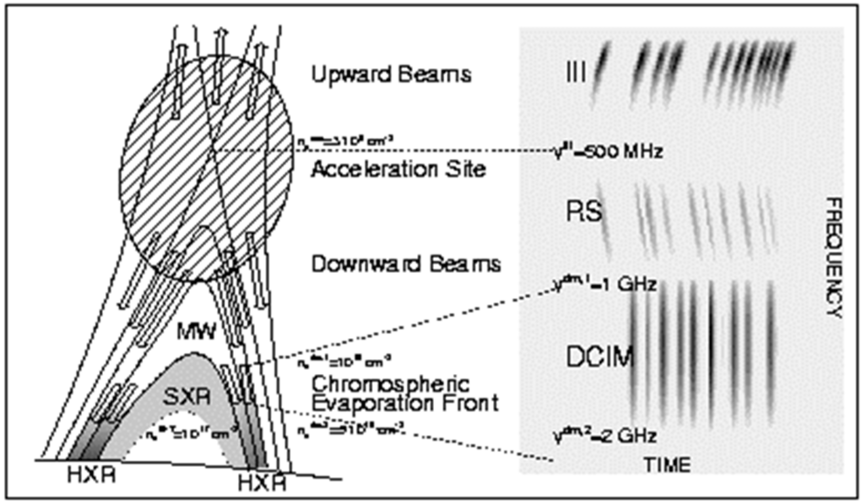


Gyroresonance-based measurement of coronal magnetic fields in active regions



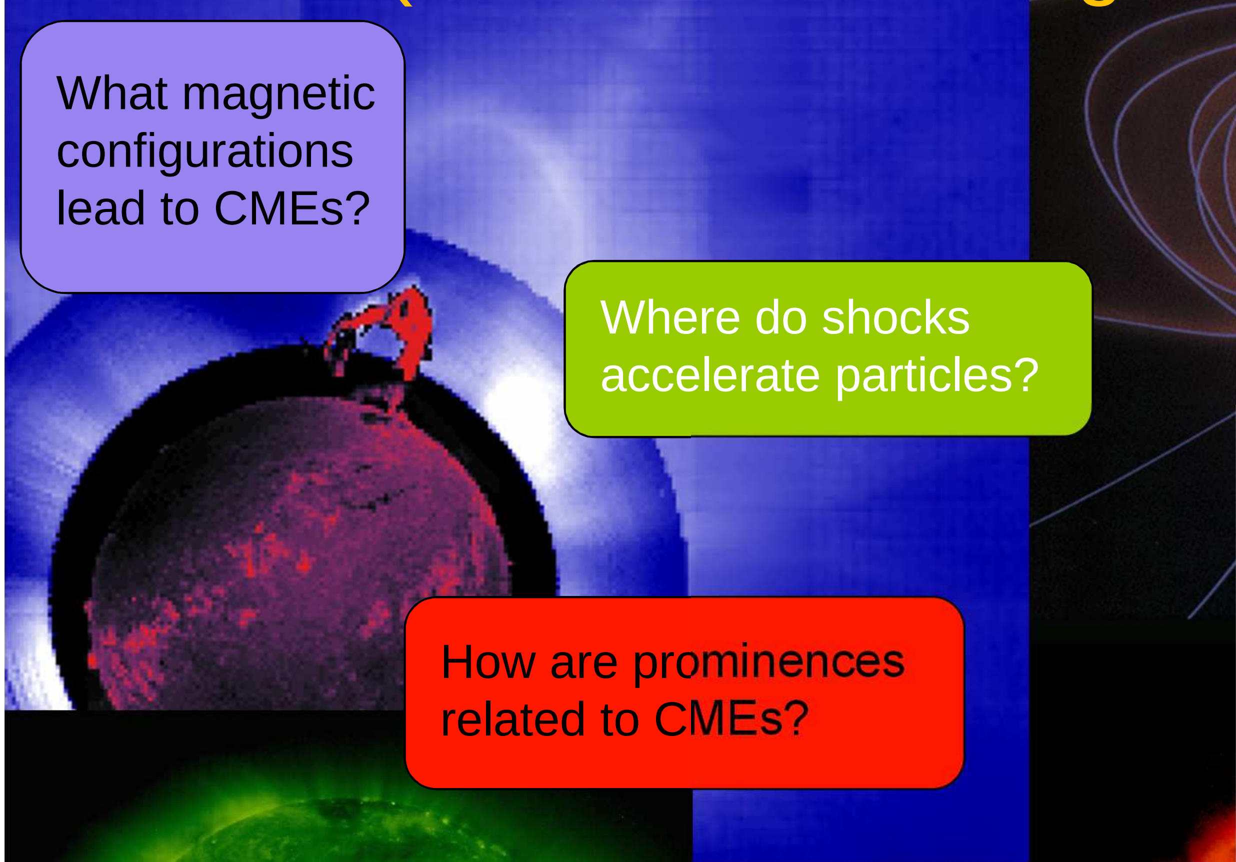


Microwave Imaging spectroscopy ➔ magnetic fields and electron parameters in flaring loops



Decimetric imaging/spectroscopy ➔ 3-D view of electrons at / near reconnection sites

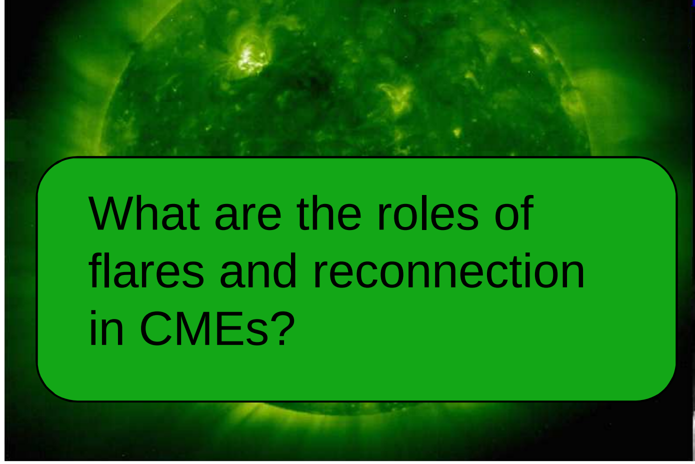
COSMO (Coronal Solar Magnetism Observatory)



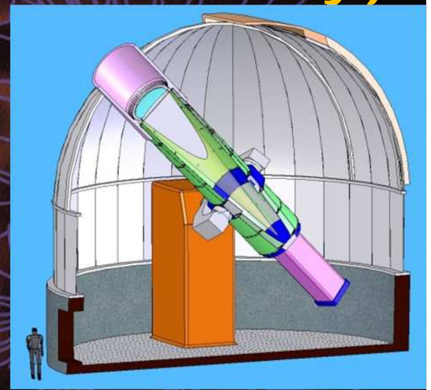
What magnetic configurations lead to CMEs?

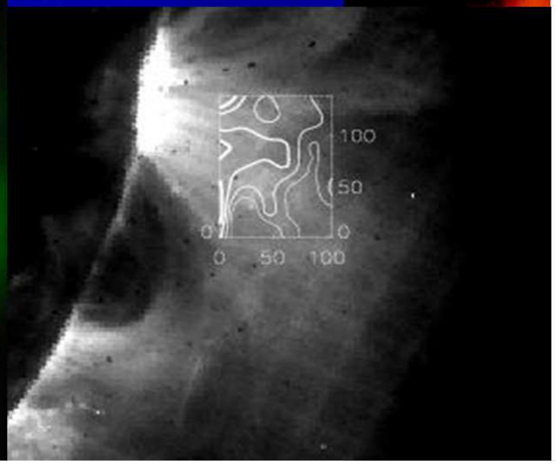
Where do shocks accelerate particles?

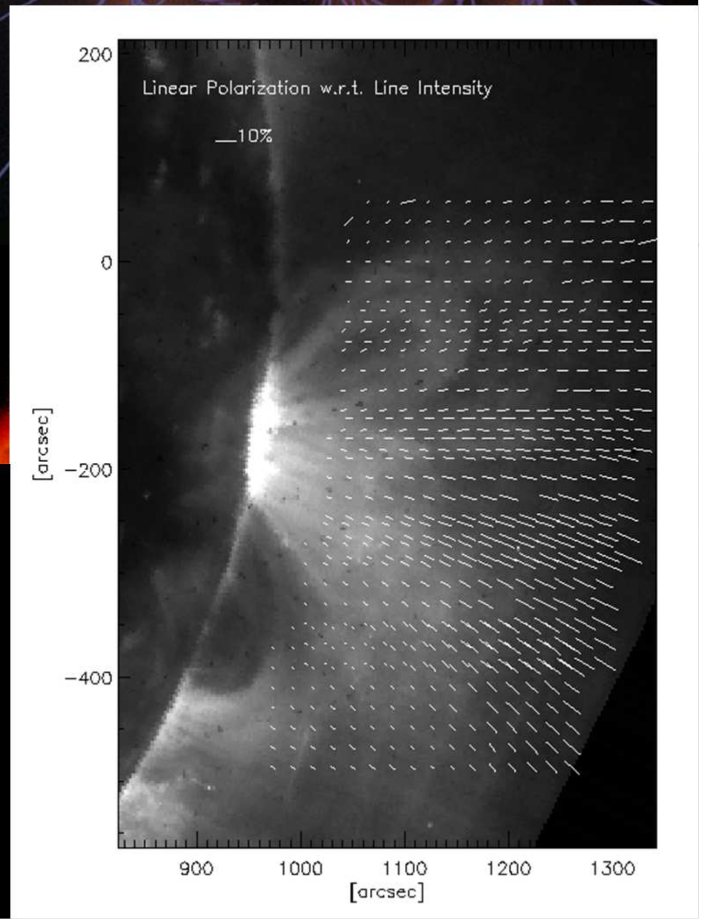
How are prominences related to CMEs?



What are the roles of flares and reconnection in CMEs?







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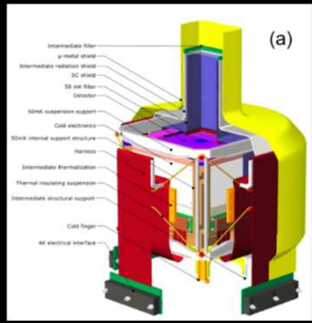
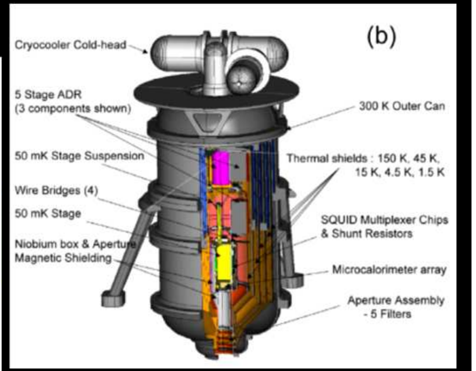
Microcalorimeter Array for Coronal Spectroscopic Imaging (MACSI)





Comparison of MACSI vs EUV Rastering Spectrometer

- True imaging spectroscopy. No rastering (millisecond timing, photon counting).
- Observe T, n, and, v for hot plasmas (>15 MK) in the corona (Flare-heated plasmas, Super-hot plasmas directly heated by the energy release process, CME-heated plasma)
- Observe lines and continuum simultaneously (abundances).
- Observe the transition between thermal and nonthermal plasma with high resolution.
- Does NOT access not chromospheric/transition region (lines < 1MK) or Lyman alpha (low energy ions).
- **Fundamentally new observations and science!**

Parameter	Value*
Pixel size	75 um, 4 arcsec
Number of pixels	48 x 48 (~200 x 200 arcsec)
Resolution	1.5 eV (~3000 to 1 @ 6 keV)
Energy Range	0.2 to 15 keV
Max Count rate	1000 cts/s/pixel
Data Rate	~5 Gb/day
Focal length	4 m
Weight	300 kg
Power	650 W
Cost	$100M

*Values do not include contingency

Alternative technical approach

- Array of closely packed $LaBr_3$ scintillator detectors
  - Moderate-resolution spectroscopy
  - Good photopeak efficiency >10 MeV
  - Active shielding for background rejection
- Bi-grid collimators to produce moiré fringes
  - A limited number of Fourier components
  - Grid separation of 3 meters

Instrument details	
Angular resolution	7” to 3’ (5× *RHESSI*)
Spectral resolution	~30 keV at 2.2 MeV
Geometric area	~1600 cm^2
Effective area for imaging	~50 cm^2 at 2.2 MeV (>10× *RHESSI*)
Mass	~350 kg
Power	~125 W
Data	~3 GB/day
Cost	~$40 M
Heritage	*SMM/GRS, RHESSI*