HEL1OS and its science objectives

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(On behalf of HEL1OS team)

ASI Aditya L-1 workshop

Participating institutes

Space Astronomy Group
ISRO Satellite Center

Udaipur Solar Observatory
Physical Research Laboratory

High Energy L1 Orbiting X-ray Spectrometer (HEL1OS)

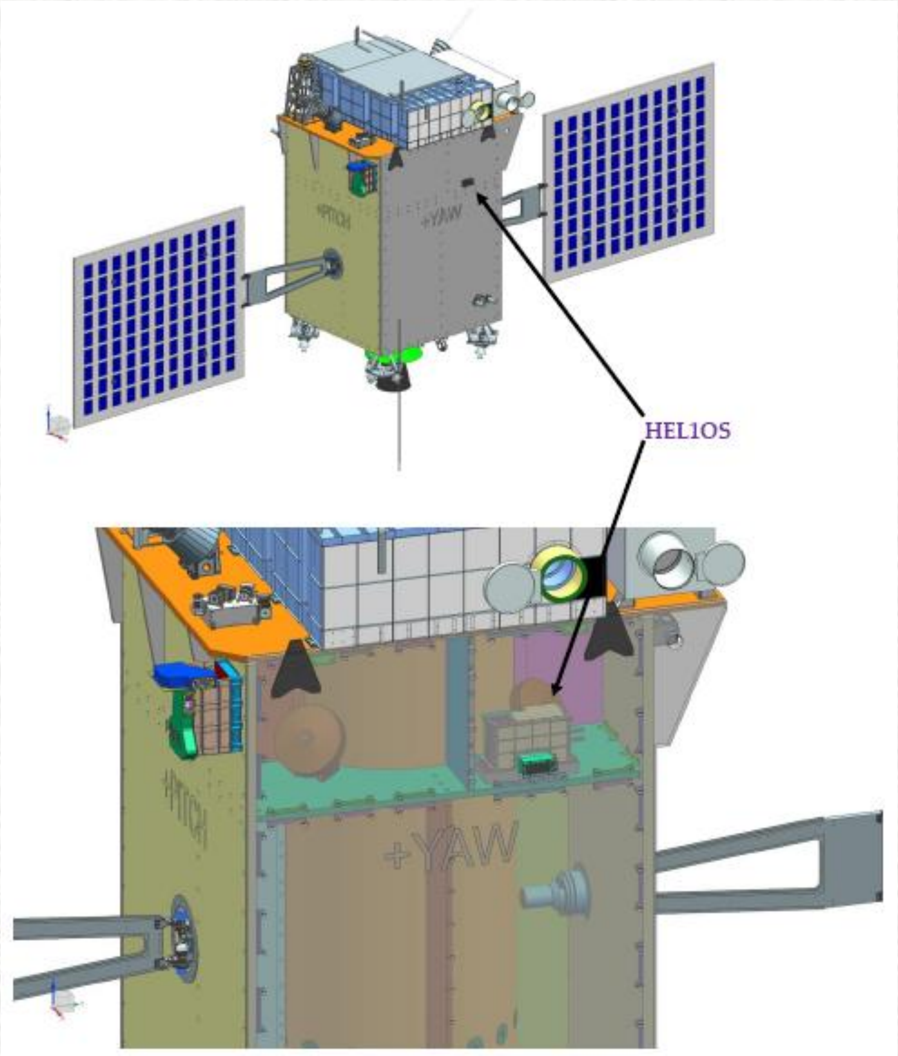
- Observations of hard X-ray (HXR) emission from the Sun in the energy range of 10 –150 keV.

- HEL1OS would provide integrated solar X-ray spectrum with high temporal and spectral resolutions.

- HXRs are emitted from the Sun during **solar flares**.

  ✓ ***Provide direct information of electrons accelerated in flares***
  HXR non-thermal emission typically > 10 keV

  ✓ ***Information about hot thermal plasma > 10 MK***
  Thermal emission typically < 25 keV



HEL1OS payload mounting location on the spacecraft

Science objectives for HELIOS

- **Particle acceleration and explosive energy release:** Hard X-ray bursts of energy > 20 keV are the most direct consequence of the basic flare energy release process.

  - *Evolution of **cut-off energy** between thermal and non-thermal emissions as a function of flare evolution.*

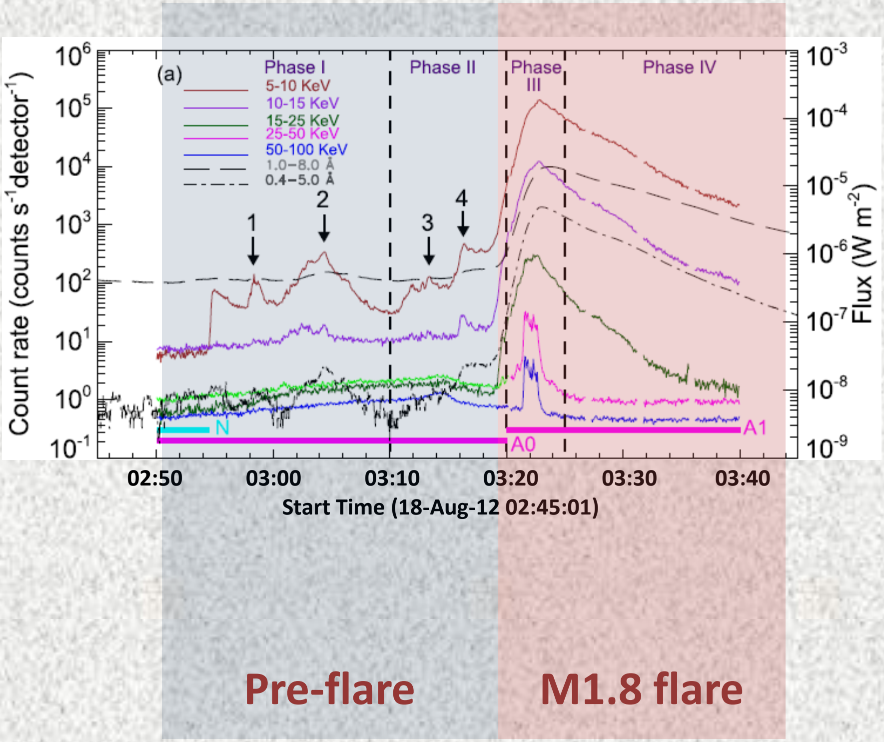
  - ***Quasi-periodic pulsations** in HXR during the impulsive phase of solar flares*

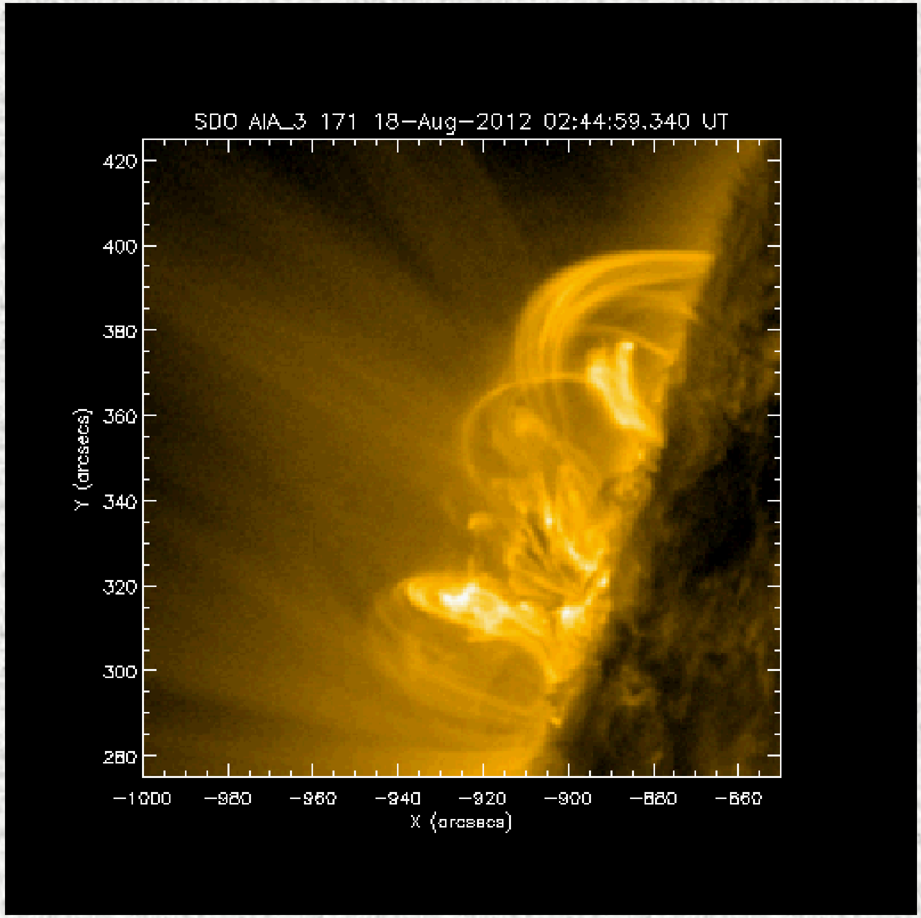
- **Pre-flare heating/ triggering of flares:** HXR observations of pre-flare and precursor emissions, pre-flare heating.

- **HXR Flare/CME associations:** Understanding the association of CME parameters (e.g., initial acceleration) with properties of X-ray emission (onset, duration and spectral index).

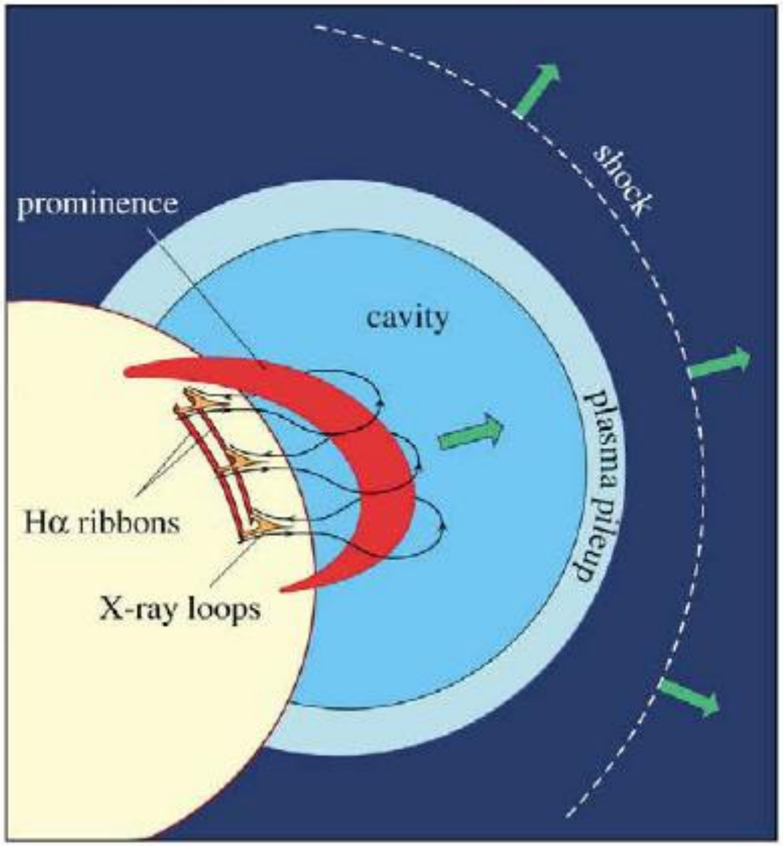
Flare X-ray light curves and energy release in active region corona

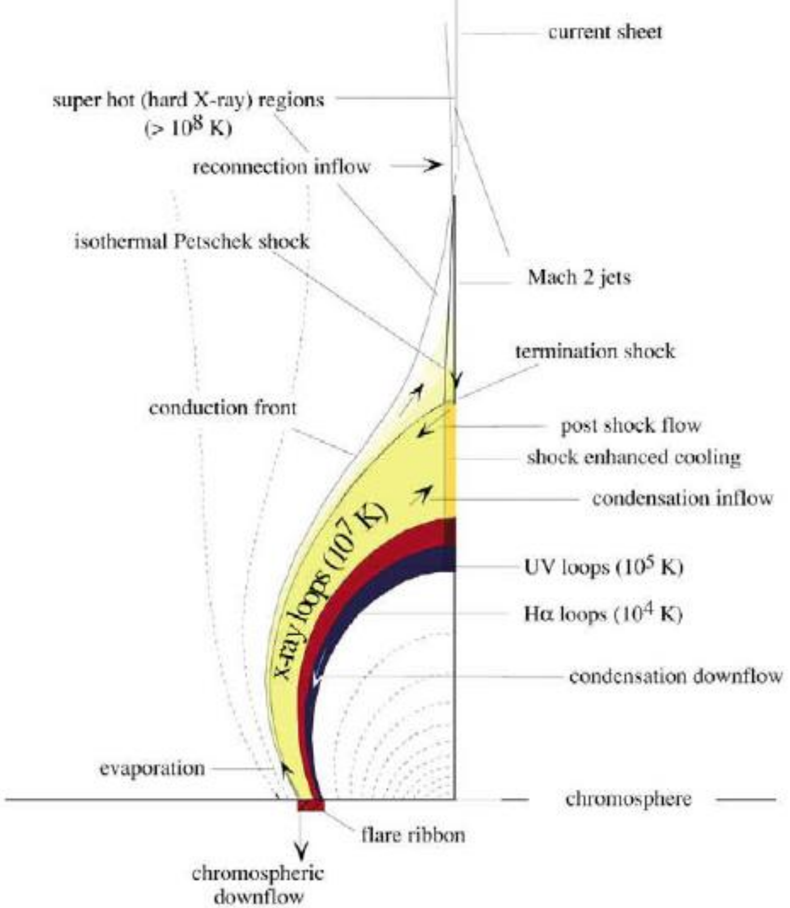
SOL2012-08-18 M1.8
(Joshi et al. 2016, ApJ, 832, 130)





➢ **A <u>solar flare</u> is a transient, explosive perturbations in the solar atmosphere. During a major flare energy in excess of 10^{32} erg is released within a few minutes.**





The standard flare scenario

See e.g., Joshi et al. 2012, ASSP series, Springer-Verlag (Chapter # 4)

Thermal Bremsstrahlung spectrum

$$F(\epsilon) \approx 8.1 \times 10^{-39} \int_V \frac{\exp\left(-\epsilon/k_B T\right)}{T^{1/2}} n^2 \, dV \qquad (\mathrm{keV\ s^{-1}\ cm^{-2}\ keV^{-1}})$$

Thick-target Bremsstrahlung

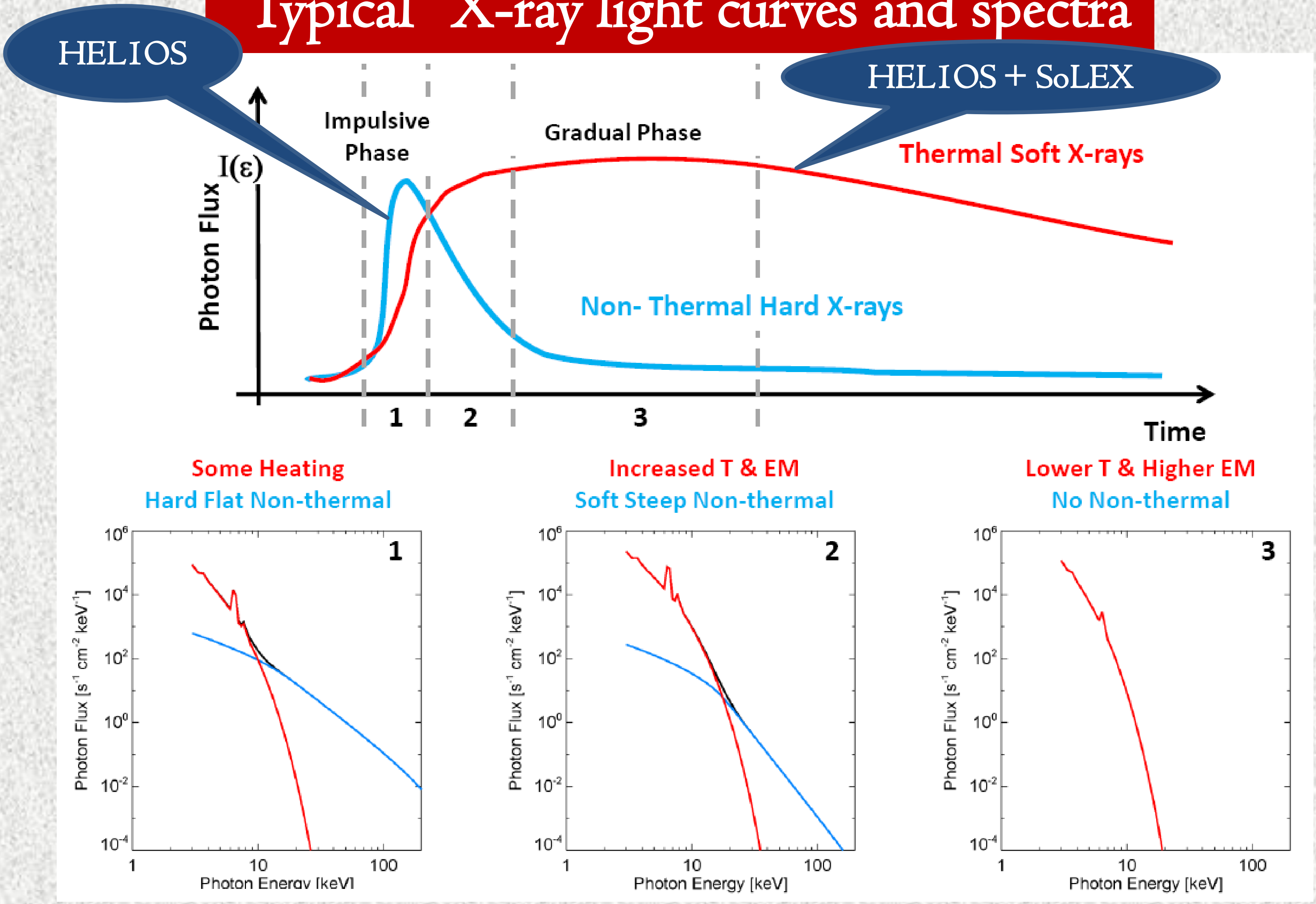
$$I(\epsilon_x) = A\, \epsilon_x^{-\gamma} \qquad (\mathrm{photons\ cm^{-2}\ s^{-1}\ keV^{-1}})\ ,$$

$$f_e(\varepsilon) = 2.68 \times 10^{33}\, b(\gamma) A \varepsilon^{-(\gamma+1)} \qquad (\mathrm{electrons\ keV^{-1}\ s^{-1}})$$

Thin-target Bremsstrahlung

$$f_e(\varepsilon) = 1.05 \times 10^{42}\, C(\gamma) A \frac{1}{n_0} \varepsilon^{-(\gamma-1/2)} \qquad (\mathrm{electrons\ keV^{-1}})$$

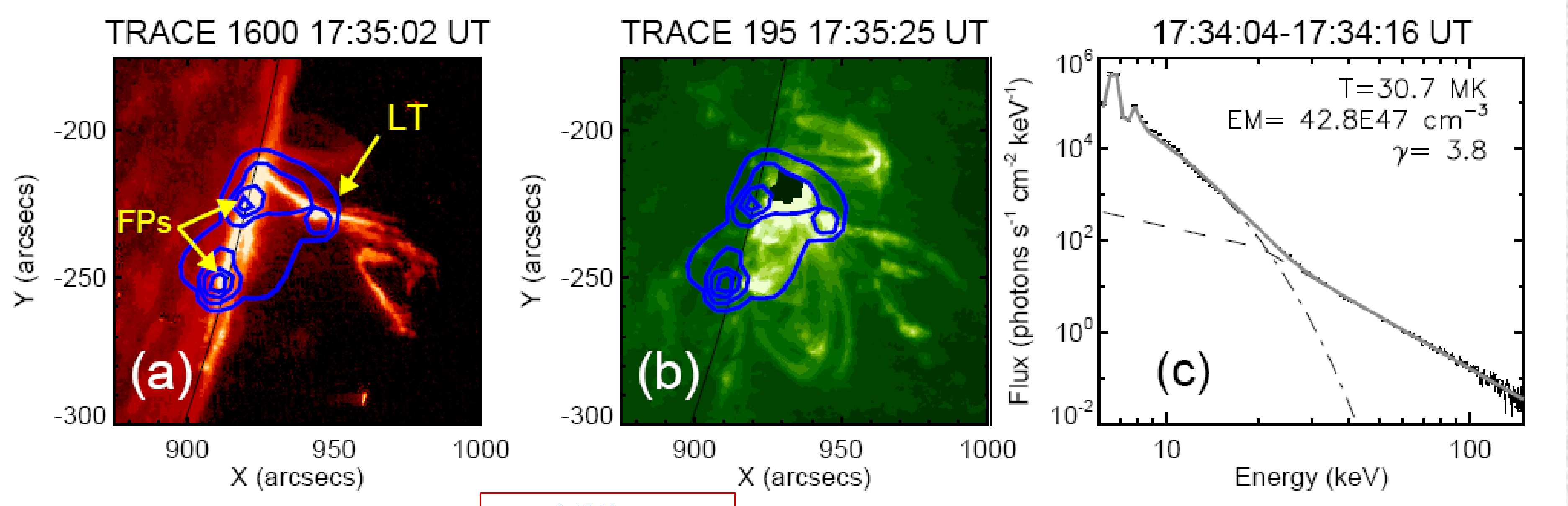
“Typical” X-ray light curves and spectra



"Loop-top" and "foot-point" HXR emission

SOL2004-08-18 (X1.8)

(Joshi et al. 2013, ApJ; Cho et al. 2009, ApJ)



50-100 keV: blue contours

Non-thermal hard X-ray emission

- The bremsstrahlung free-free photon flux at the Earth $\mathrm{I}(\varepsilon)$ is related to the source electron distribution $\mathrm{F(E)}$ as:

$$I(\varepsilon) = \frac{1}{4\pi R^2} \int_{\varepsilon}^{\infty} \int_{V} n(r) F(E, r) Q(\varepsilon, E) dE d^3 r$$

Photon Flux
ph s^{-1} cm^{-2} keV^{-1}

1 AU

Density of background plasma e- interacting with

e- distribution
e^- cm^{-2} s^{-1} keV^{-1}

Bremsstrahlung cross-section

ε =Photon Energy
E =Electron Energy

- Assume non-thermal emission from a power-law of electrons accelerated out of Maxwellian, spectral index δ above E_c $\quad F(E) \propto E^{-\delta}$

- Total Number of accelerated electrons s^{-1} above E_c [keV] $\quad N(E > E_C) = \int_{E_C}^{\infty} F(E) dE$

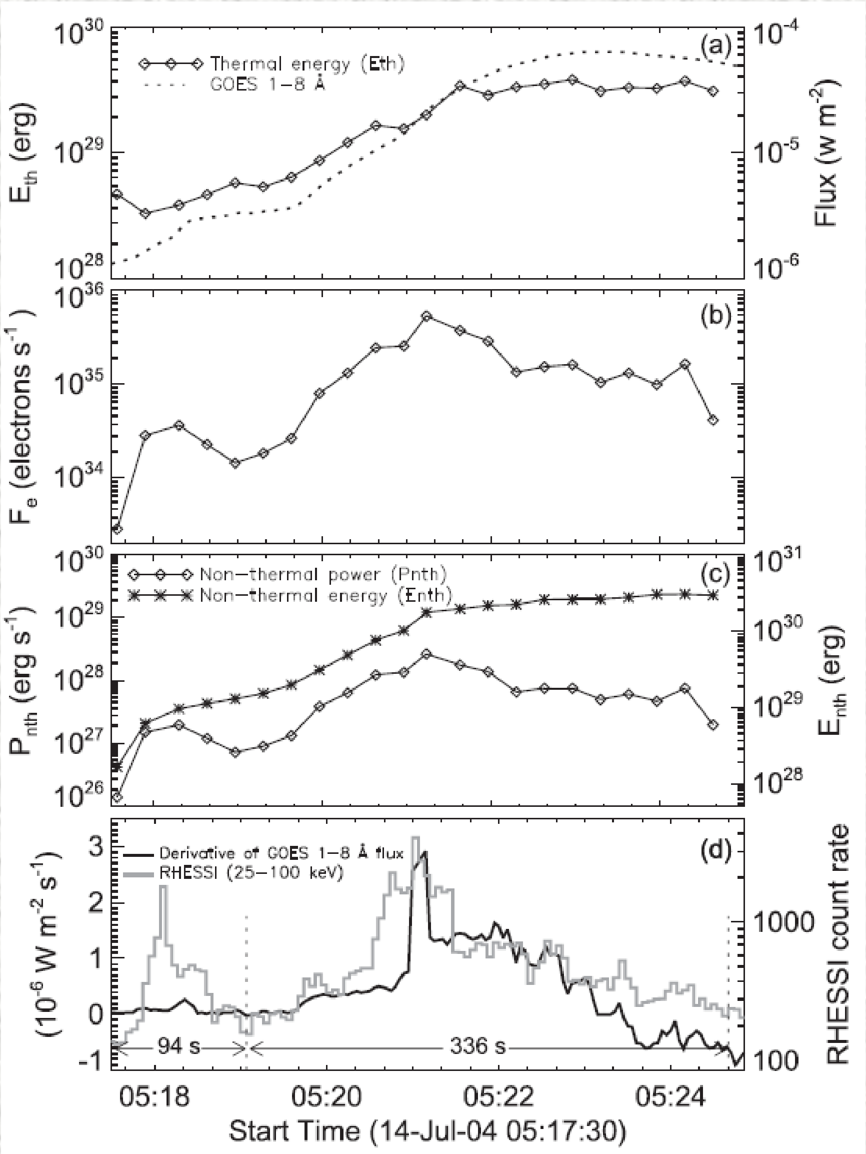
- Power in these electrons in erg s^{-1} $\quad P(E > E_C) = \int_{E_C}^{\infty} F(E) E dE = 1.6 \times 10^{-9} \frac{\delta - 1}{\delta - 2} N E_C$

- Non-thermal Energy in erg $\quad U_N(E > E_C) = P(E > E_C)\Delta t$

Estimations of non-thermal energy from RHESSI data

SOL2004-07-14 M6.2
(Kushwaha, Joshi et al. 2015, ApJ, 807, 101)

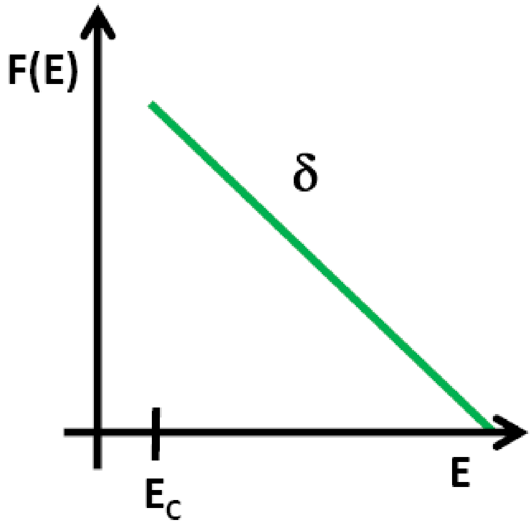
- ❑ **Estimations of E_{nth} highly depends on election spectral index and cut-off energy.**
- ❑ **Energy partition between thermal and non-thermal components.**

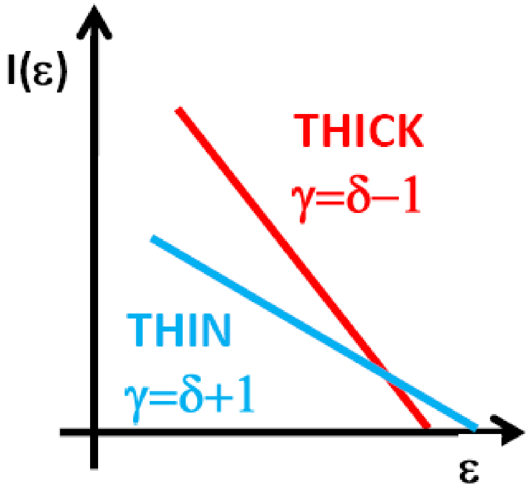


HXR solar spectra: Thin target and thick target

- **We normally investigate the emission within 2 limits**
  1. Thin target: energy losses not significant dU/dt≈0
     - Tenuous coronal emission => not observed
  2. Thick target: electrons stopped completely dU/dt=Coulomb rate
     - From dense chromosphere => bright footpoints emission

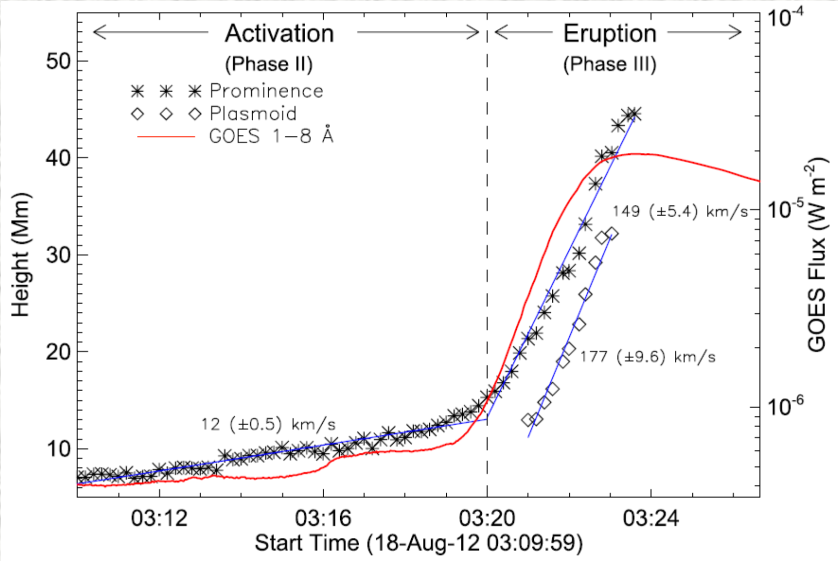
- **If take simpler non-relativistic form of Q(ε,E) find analytically** $I(\varepsilon) \propto \varepsilon^{-\gamma}$
  – Kramers or Non-relativistic Bethe-Heitler (see Brown 1971, Holman 2009)





Precursor and Pre-flare phase studies with HELIOS

- In X-rays, week emission is often observed prior to a major flare.
- Pre-flare activity is especially important when it is associated with filament eruptions.



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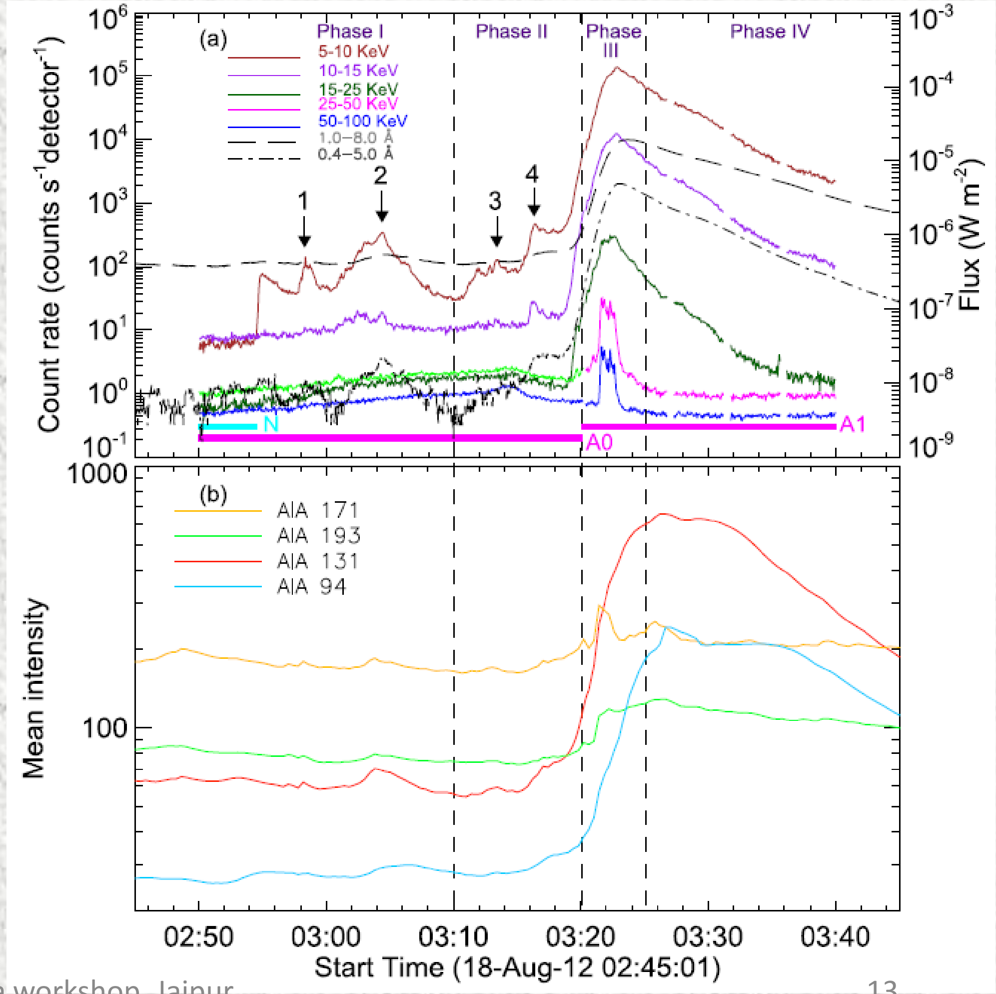


Flare/CME associations

- ❖ Association between CMEs and solar flares (Harrison 1995).
- ❖ Relation between CME parameters with properties of soft X-ray emissions during solar flares (Zhang & Dere 2006; Vrsnak et al. 2007).
- ❖ **CME acceleration and HXR spectral parameters (Temmer et al. 2008, 2010).**

VELC, HELIOS, SoLEX , SUIT in same platform…
Aditya L1 mission will have unique advantage to establish flare-CME associations.

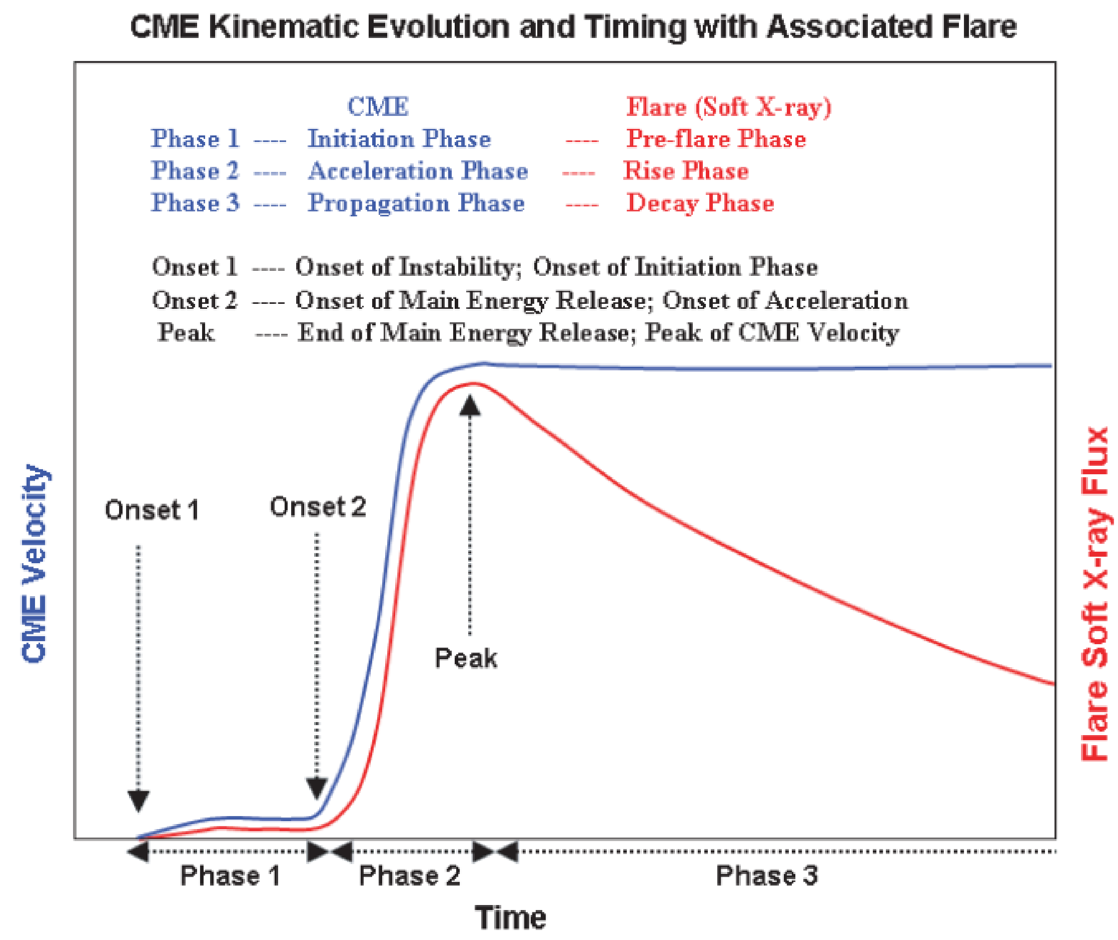


Fig. 1.—Schematic plot of CME kinematic evolution and its relation with temporal evolution of *GOES* soft X-ray flare. CME evolution may have three distinct phases: initiation phase, acceleration phase, and propagation phase, which correspond to the preflare phase, rise phase, and decay phase of the associated flare, respectively.

Zhang & Dere 2006

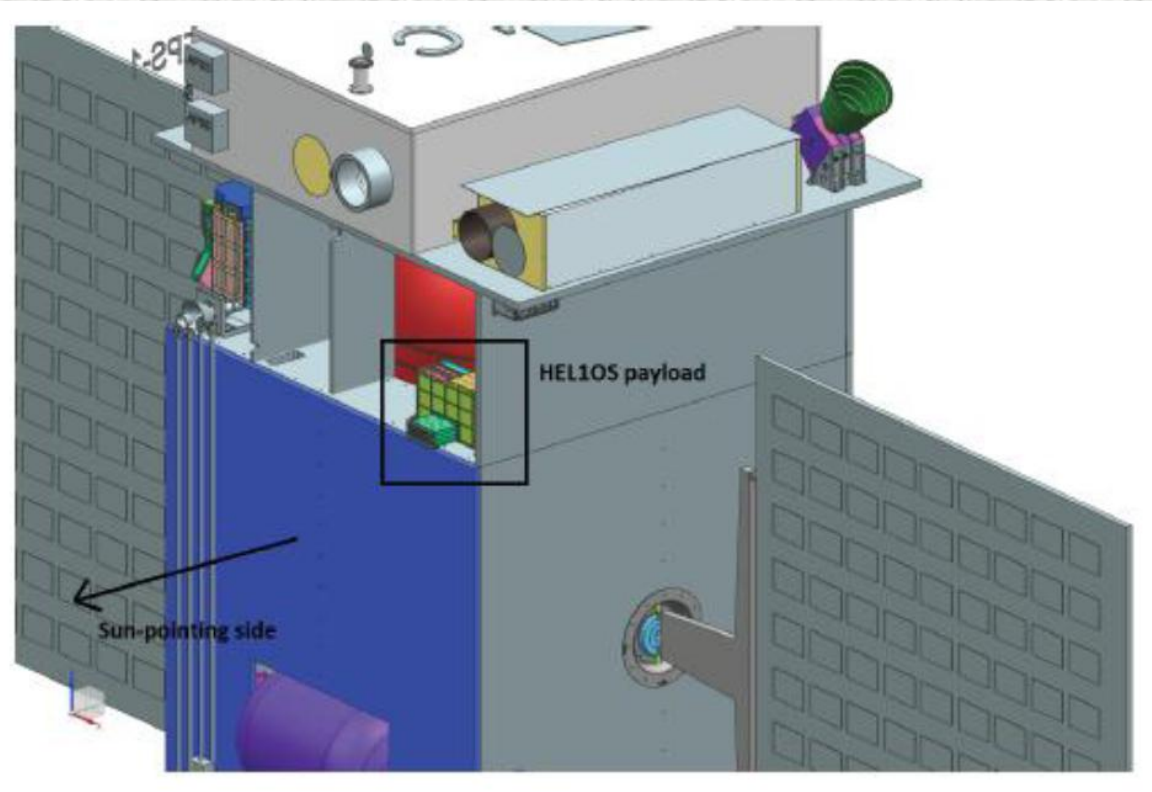
HELIOS: Detectors specifications

(Sankarasubramanian et al., 2017, Current Sciences)

Parameter	Specifications
Number of detectors	4
Detector type	CZT (2 modules) CdTe (2 modules)
Detector dimensions	**CZT:** 40 mm x 40 mm x 5 mm per module 256 pixel per module 2.46 mm x 2.46 mm pixel pitch **CdTe:** 5 mm x 5 mm x 1 mm per module Non-pixelated detector
Geometric Area	CZT: 32 cm^2 (both detectors) CdTe: 0.5 cm^2 (both detectors)
Detection efficiency	CZT: >90 % for 20 keV to 90 keV CdTe: > 90% for 10 keV to 40 keV
Energy range	CZT: 20 keV to 150 keV CdTe: 10 keV to 40 keV
Energy resolution	CZT: ~10% @ 60 keV (10 ^{0}C) CdTE: ~3 % @ 22 keV (-25 ^{0}C)
Operating temperature	CZT: 5 ^{0}C to 20 ^{0}C CdTe: -25 ^{0}C to -35 ^{0}C (in built TEC)

Views of CZT detectors

Views of CdTe detectors



Mounting location of HEL1OS payload on the top deck of spacecraft

Science	Desired Requirements	HEL1OS Capabilities	Remarks
Particle Acceleration	HXR Emission > 10 keV with energy resolution < 1 keV between 10 to 40 keV.	Energy Range 10 to 150 keV. Energy Resolution < 1 keV @ 22 keV (10-40 keV) and 5 keV @ 60 keV (20 – 150 keV).	Evolution of thermal and non-thermal spectral components as a function of energy and time.
	Timing Accuracy of the order of 10s of seconds to study QPPs (typical pulse duration few minutes). Temporal resolution better than 1 second for HXR bursts.	Time tagged event data ~32 milliseconds; based on flare class and statistics, binning of the light curves can be optimized.	QPPs and HXR bursts observed in HXR has implications on particle acceleration.
	Angular resolution of a few arc-seconds.	Not an imaging instrument.	Spectral and timing information will be complemented by ground based Hα imaging, radio observations, GOES SXI images and SUIT (on-board ADITYA-L1) full disk images.
Pre-heating and precursor phase studies	HXR observations between 5 and 25 keV with ~ 1 keV nergy resolution.	10 keV onwards with < 1 keV energy resolution @ 22 keV (10 – 40 keV band).	SoLEXS on-board ADITYA-L1 will complement for energies < 10 keV.
Relationship between Flare and early CME evolution.	Energy range ~5 keV to 150 keV.	10 keV to 150 keV.	Adequate to examine non-thermal parameters and early acceleration of CMEs. CME parameters will be estimated from VELC on-board ADITYA-L1.

Concluding remarks...

- HEL1OS has the capability in terms of spectral and temporal resolutions to address the problems of particle acceleration and explosive energy release in solar flares at 10-150 keV.

- HEL1OS and SoLEX will form an ideal combination to understand X-ray emission processes in solar flares over a broad range of X-ray energies.

- By combining HEL1OS measurements with VELC, we would be able to explore the relationship between CME acceleration and strength of magnetic reconnection.