Soft X-ray spectroscopy of the Solar corona during the deepest solar minimum of the past hundred years with the Solar X-ray Monitor (XSM) on-board the Chandrayaan-2 orbiter.

Biswajit Mondal [1,2*], **A. Sarkar**[1], **S. V. Vadawale** [1], **NPS. Mithun** [1], **P. Janardhan**[1], **G. Del Zanna**[3], **H.E. Mason**[3], **U. Mitra-Kreav**[3], **S. Narendranath**[4]

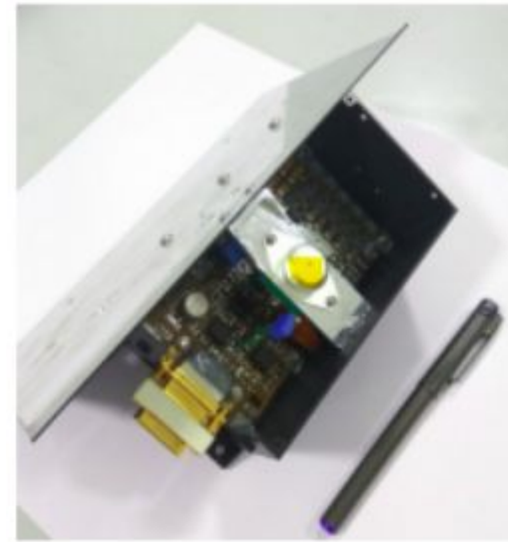
[1] PRL, Ahmedabad, India; [2]IIT Gandhinagar, India; [3]DAMTP, Cambridge, UK; [4]URRSC, ISRO, India.

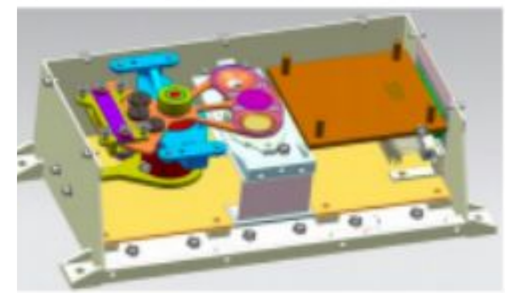
*Email: biswajitm@prl.res.in

16th European Solar Physics Meeting, 6-10 Sep 2021

Chandrayaan-2 Solar X-ray Monitor (XSM)

- XSM is a soft X-ray spectrometer, which is observing the Sun as a star from the lunar orbit and functional from mid of the year 2019, covering the minimum of solar cycle 24.
- It provides disk-integrated Solar spectrum at every second in the energy range of 1-15 keV (upto M5 class of solar activity) or 2-15 keV (> M5 solar activity).
- Very good energy resolution of 175 eV @ 5.9 keV for a broad band soft X-ray energies.





XSM detector package

XSM Observed spectrum at different Solar activity in 1-15 keV

Peak of an M2 flare

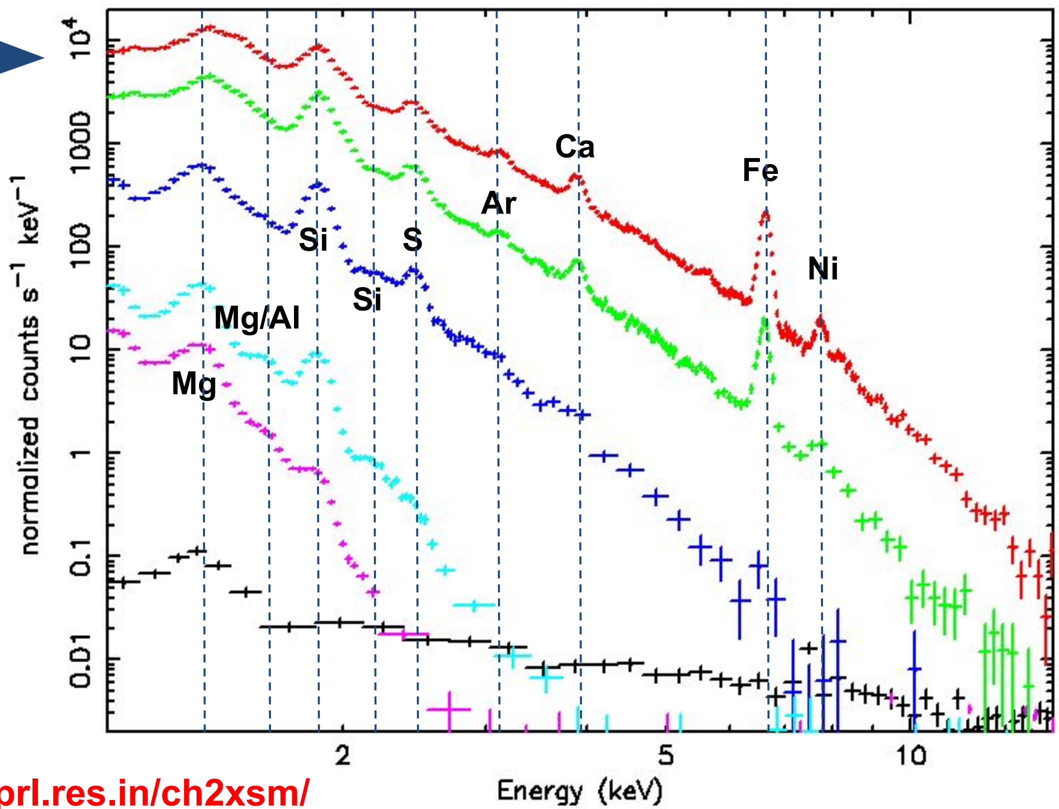
Peak of an C3 flare

Peak of an B4 flare

Active Region

Quiet Sun

Non-Solar background

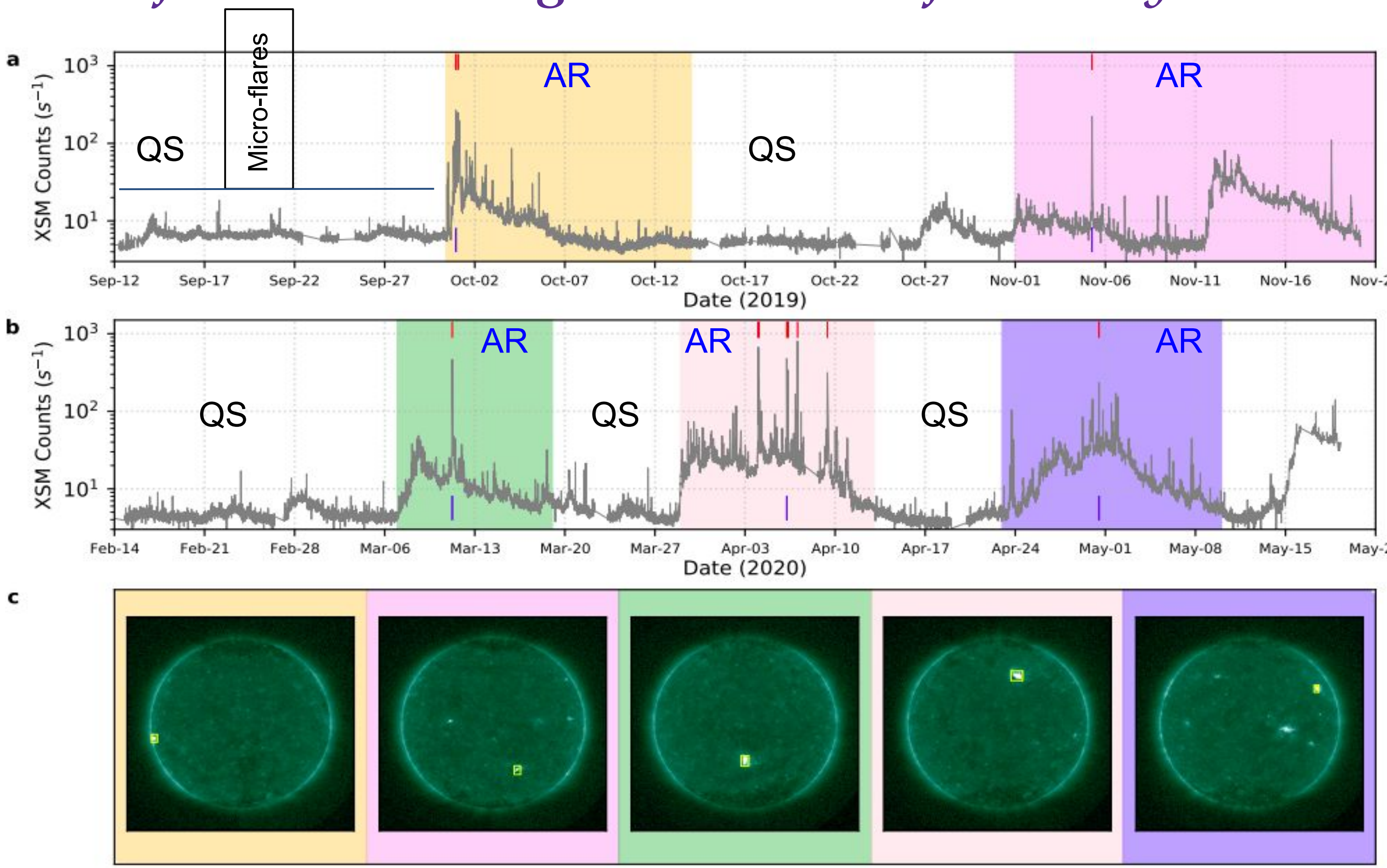


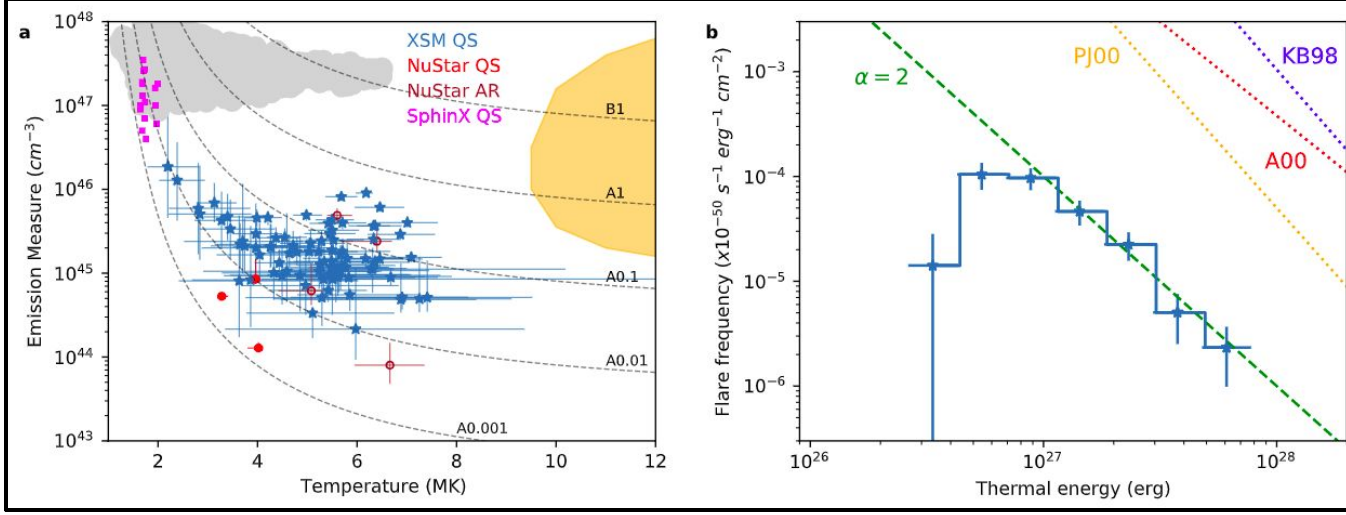
- Spectral modeling will tell us the emitting plasma parameters, e.g., temperature, emission-measure and abundances of the elements.

XSM website: https://www.prl.res.in/ch2xsm/

XSM Observation of the Sun during the minima of Solar cycle 24

- **AR** → Isolated active regions are present on the solar-disk.
- **QS** → quiet Sun period, without the presence of ARs.
- **Microflares** → XSM observed a large number of microflares (sub-A class) on the QS.





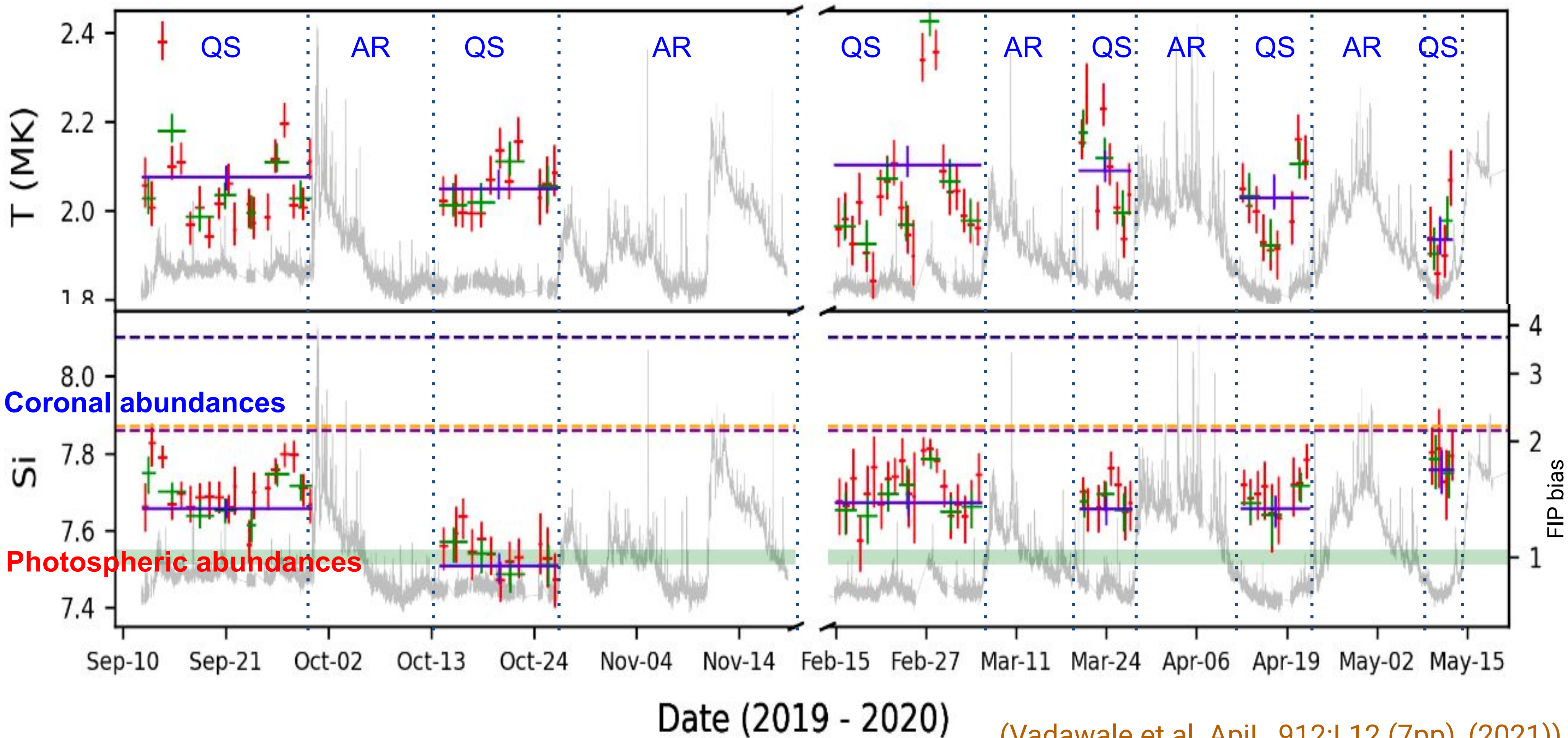
Panel a: XSM QS microflares (blue points) EM-T distribution on the isothermal flux lines. A very few QS microflares were observed earlier by NuStar (red) and SphinX (pink) are overplotted.

Panel b: shows the microflare frequency distribution.

(Vadawale et al. ApjL, 912:L13 (11pp), (2021))

Abundance measurements of X-ray Bright Points (XBP)

- Usually low FIP elements are 3-4 times more abundant in the core of the ARs than that of the photosphere known as FIP effect.
- Abundances of XBPs were not well known yet.
- It has been found that most of the X-ray emission during the quiet Sun (QS) is originated from the XBPs.
- By modeling the XSM spectra during the QS period, we have estimated the temperature, emission measure as well as the abundances of Mg, Al, and Si for the XBPs.



(Vadawale et al. ApjL, 912:L12 (7pp), (2021))

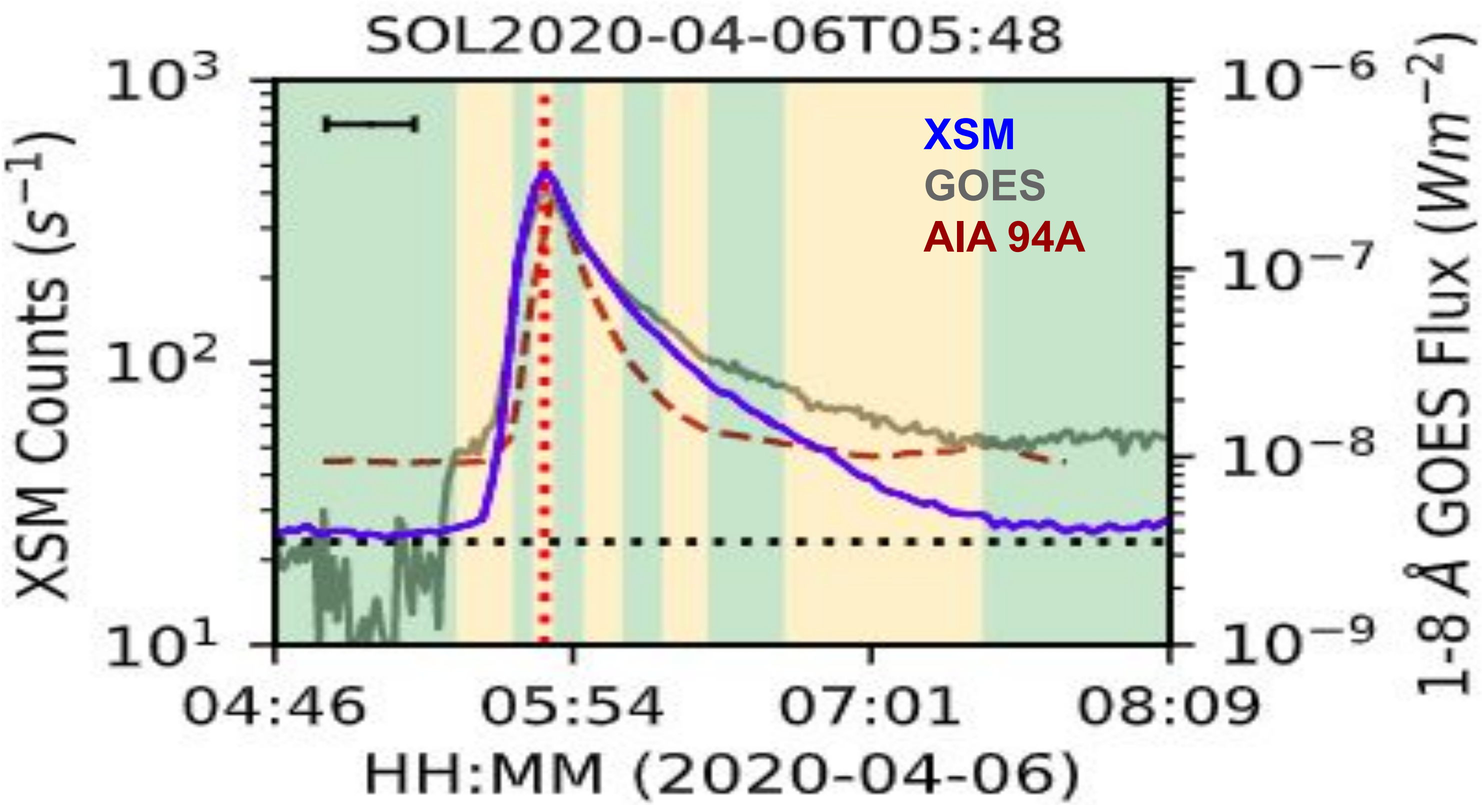
Abundances during solar transients

- Flare peak abundances are found to be photospheric (e.g., Feldman and Widing (1990), Feldman (1992), Warren et al. (2014)).

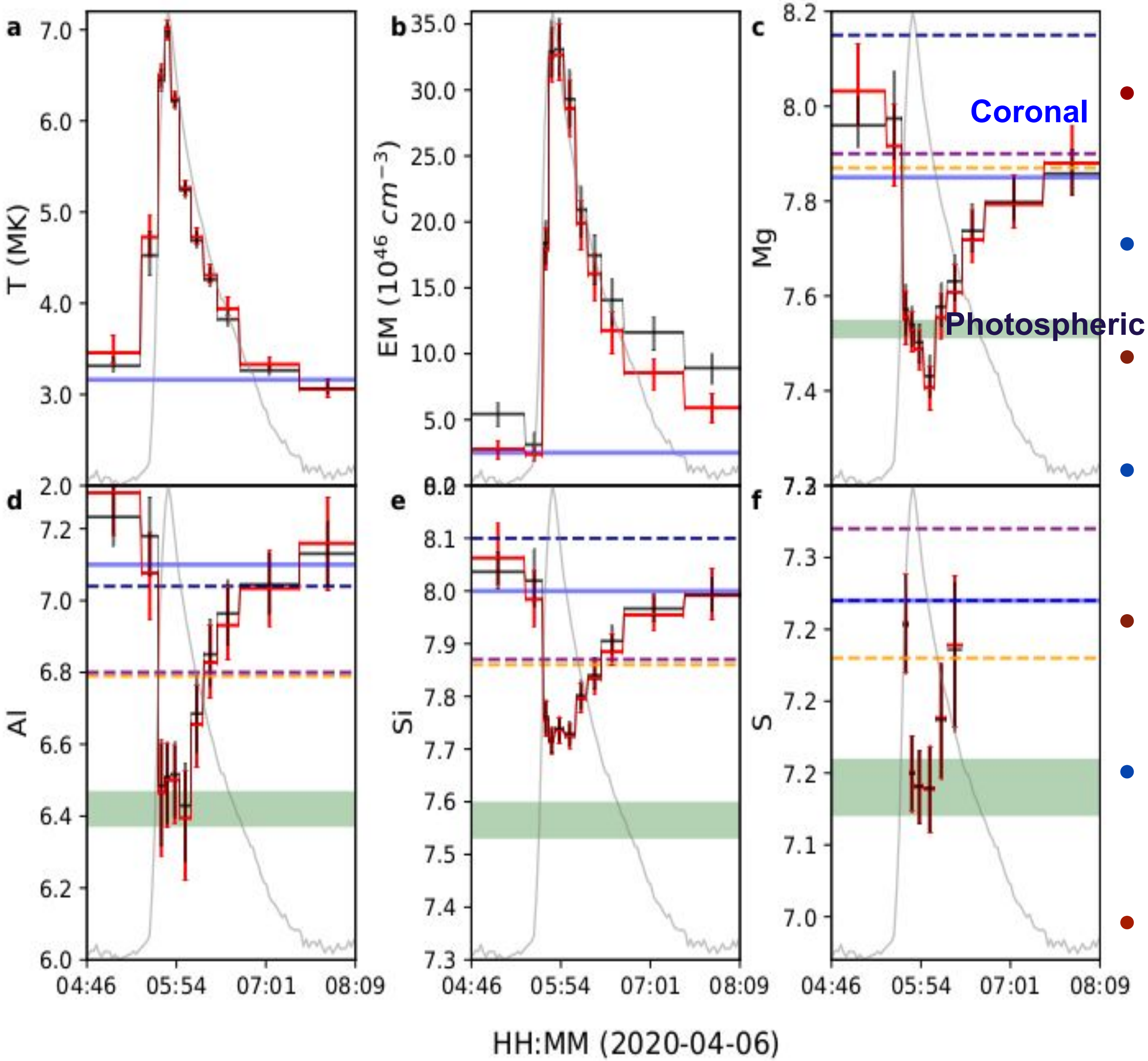
- Some attempts have been made to measure the abundance evolution during the large (e.g, X/M/C) flares, e.g., Katsuda et al.(2020), or Narendranath et al. (2020).

- Due to high sensitivity, cadence, and energy resolution of the XSM, it was possible to measure the time evolution of abundances during small flares.

- We have selected ten B (B1.3-B4.0) class flares Though these are the largest events during the 24th solar minimum observed by XSM, their energies are much small compared to X/M class flares.



Evolution of elemental abundances during B-class solar flares



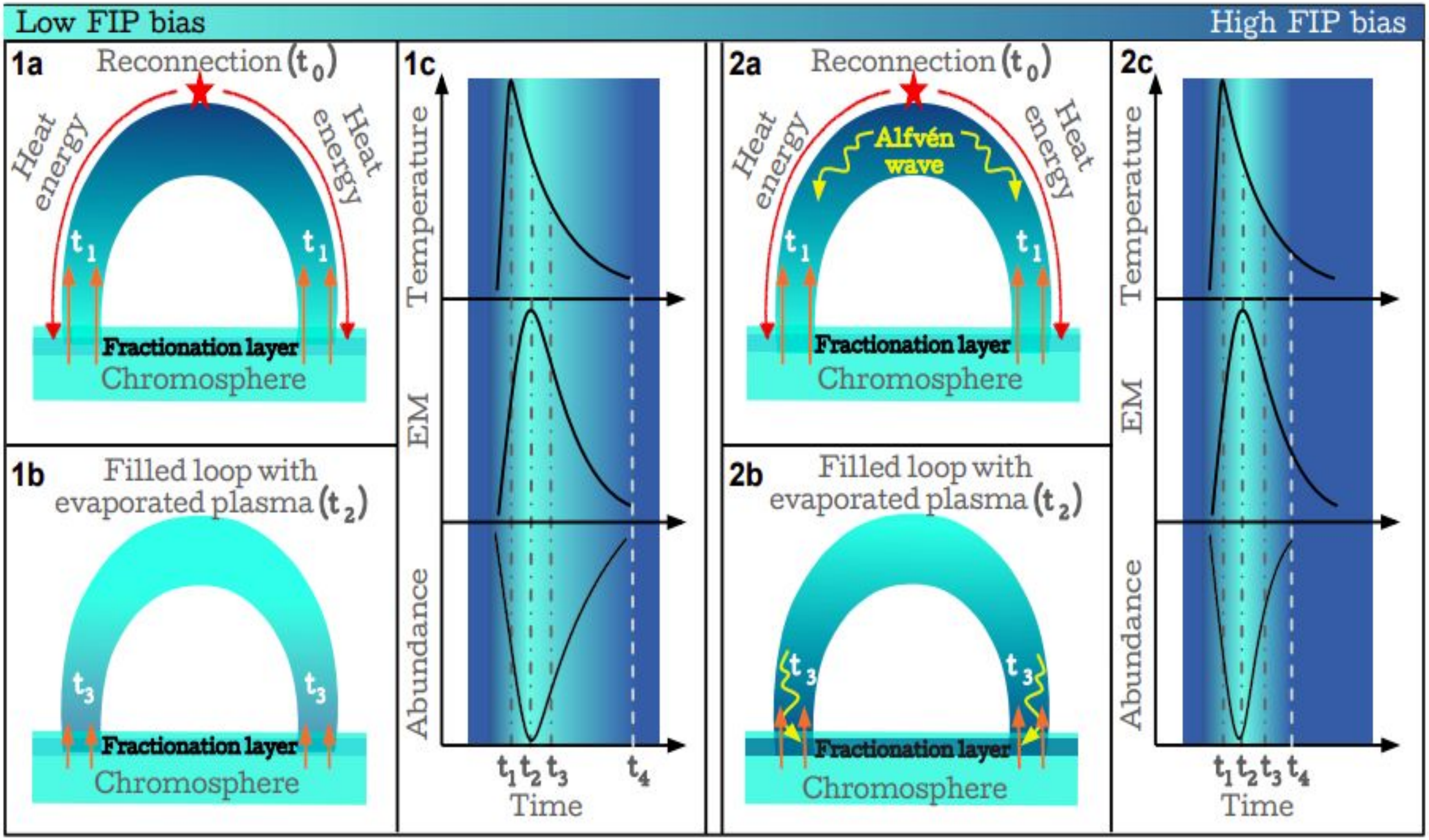
- Temperature, emission measure, and abundances are derived at each time bin for a particular flare
- Panels a-b, represent the evolution of the temperature (T) and EM
- Panels c-f, represent the evolution of the abundances of Mg, Al, Si, and S.
- Evolution of T and EM follows the flaring activity whereas the abundance evolve differently.
- A transition from the coronal to near photospheric abundances occurs during the impulsive phase of the flare.
- Quick recovery of the coronal abundances are observed during the decay phase of the flare.
- The transition of abundances from the coronal to photospheric values can be explained by chromospheric evaporation.

Mondal et. al, in press, ApJ (2021), (https://arxiv.org/abs/2107.07825)

Discussion: Abundance evolution

- An emerging AR takes about 1-2 days to establish the coronal FIP bias from the photospheric values (Widing et al. (2001)). On the contrary, our observations demonstrate that the coronal abundances are regained within minutes timescale after the flare.

- To explain our observation, we propose two scenarios, as explained in the following cartoon.



Scenario-1 (Figure 1a-1c): Relies on the evaporative plasma velocity

Scenario-2 (Figure 2a-2c): Bashed on flare driven Alfven waves, generated at the flaring site,

Mondal, et. al, in press, ApJ (2021), (https://arxiv.org/abs/2107.07825)

Acknowledgements: The XSM was primarily developed at PRL, while Chandrayaan-2 is funded by ISRO. Research at PRL is supported by the Department of Space, Govt. of India. GDZ and HEM acknowledge funding from STFC (UK). We acknowledge the funding from the Royal Society international exchanges grant.

Thank you!