This work was supported by a NASA Space Technology Research Fellowship (NSTRF).

The Solar Corona viewed through the MinXSS (Miniature X-ray Solar Spectrometer) CubeSats

By: **Christopher S. Moore**
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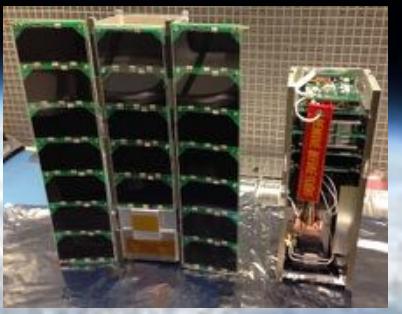
Mentors: Katharine Reeves and Ed Deluca

2017 IAU PhD Prize Recipient: University of Colorado Boulder
Advisors: Thomas Woods and Kevin France

Contributions by:
Amir Caspi
Brian Dennis
James Mason
Richard Schwartz
Kim Tolbert
Tom Woods

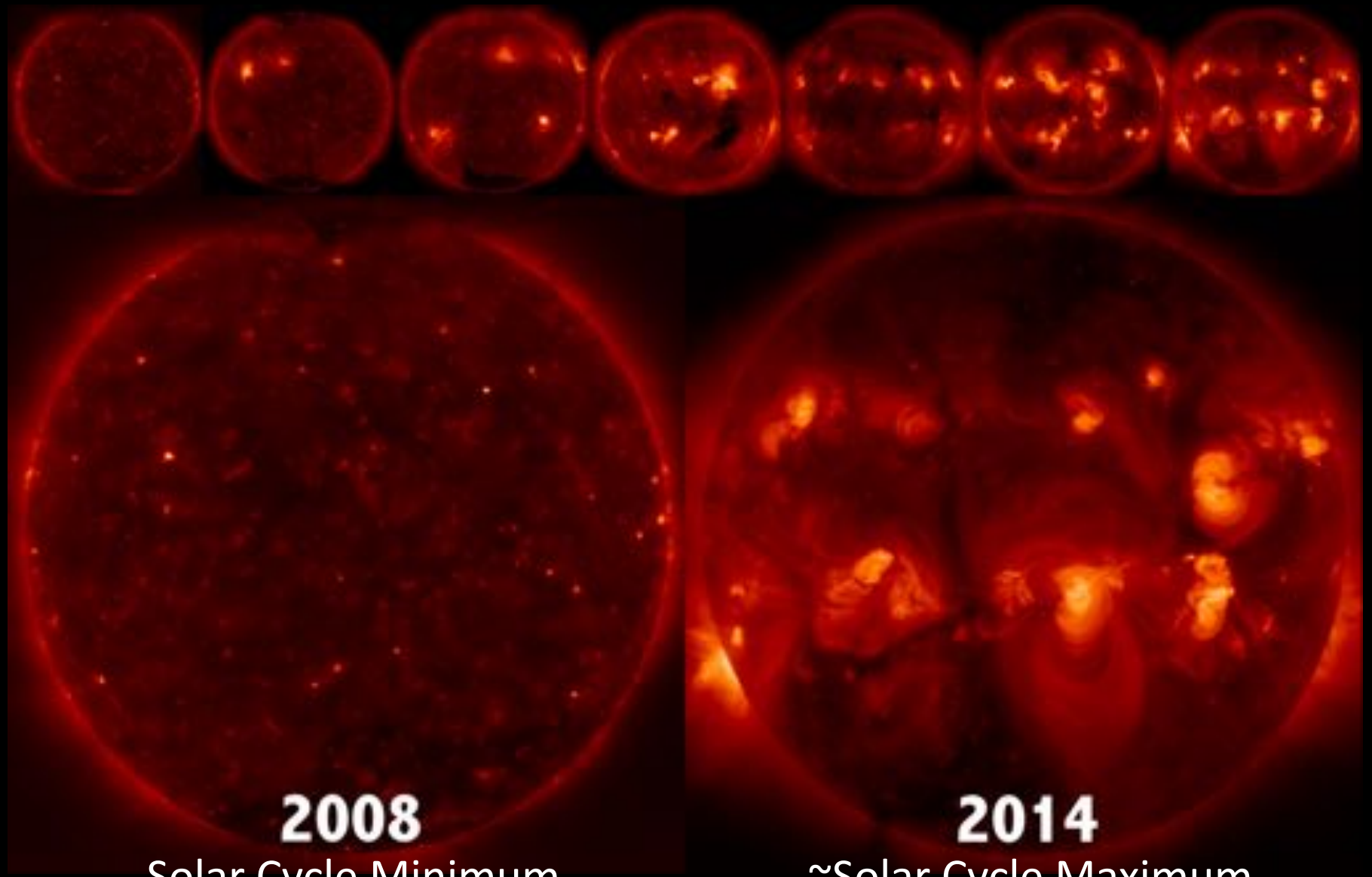


MinXSS CubeSat

Images courtesy of NASA and ESA astronaut Tim Peake

Solar Corona - Soft X-rays -

Increasing Magnetic Activity --→----------→----------→----------→

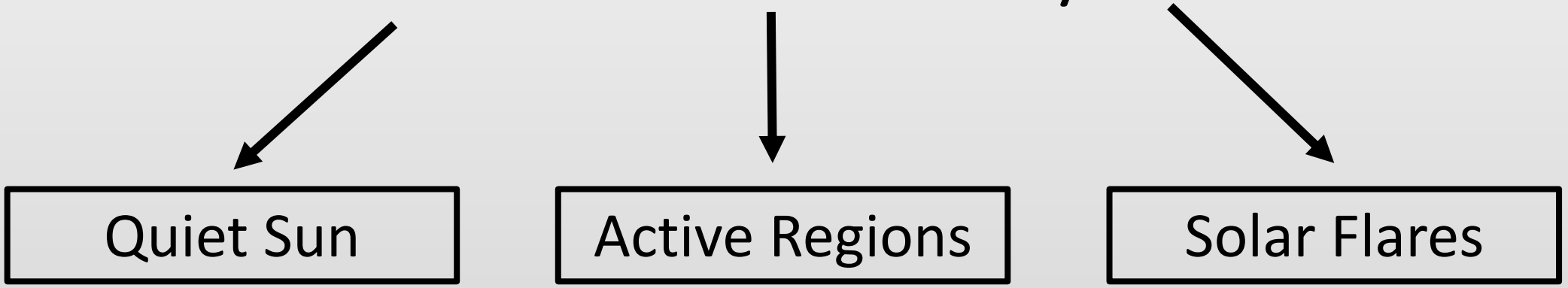


Solar Cycle Minimum

~Solar Cycle Maximum

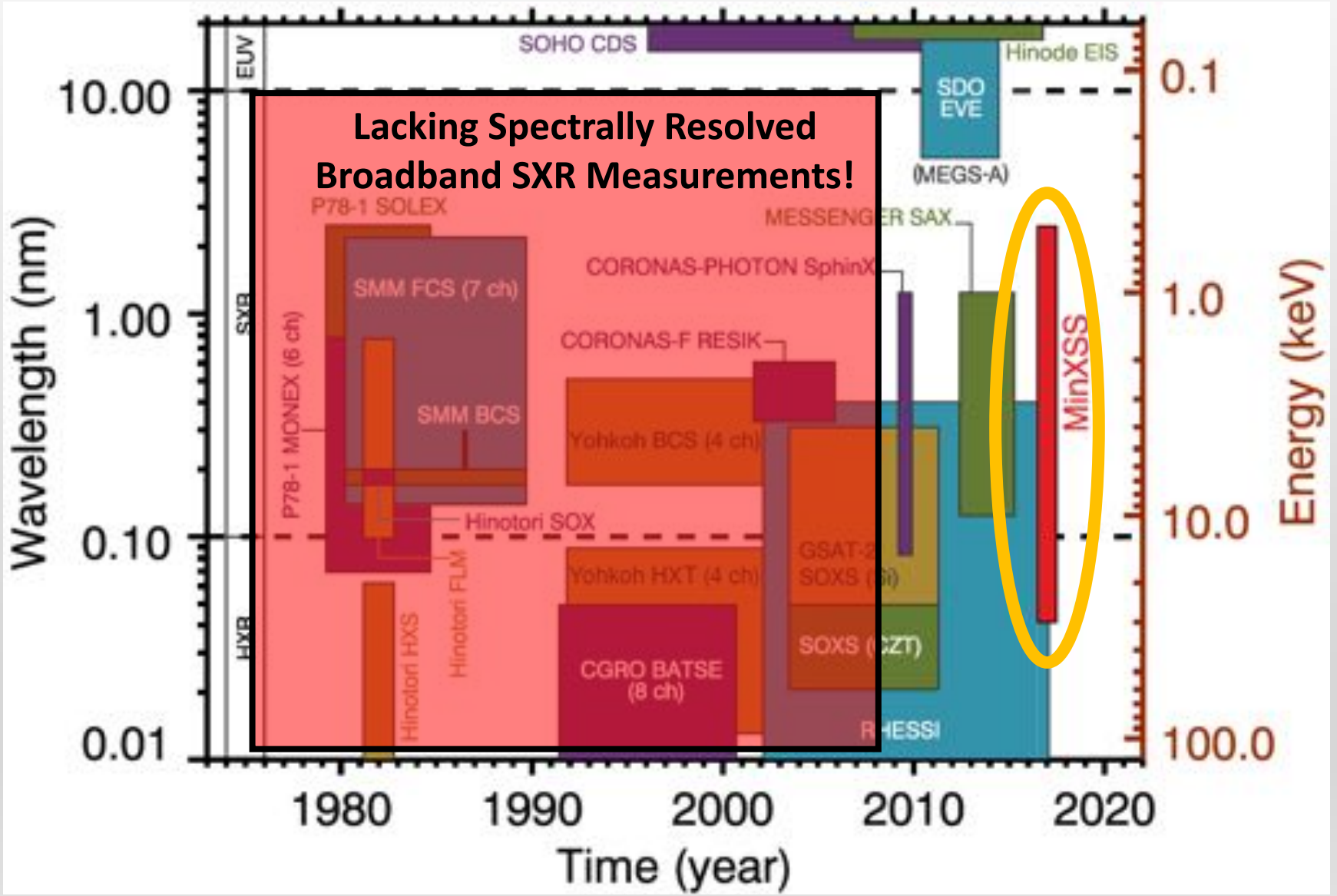
Image credit: Hinode

What is the Solar soft X-ray *spectral distribution* and how does it vary?



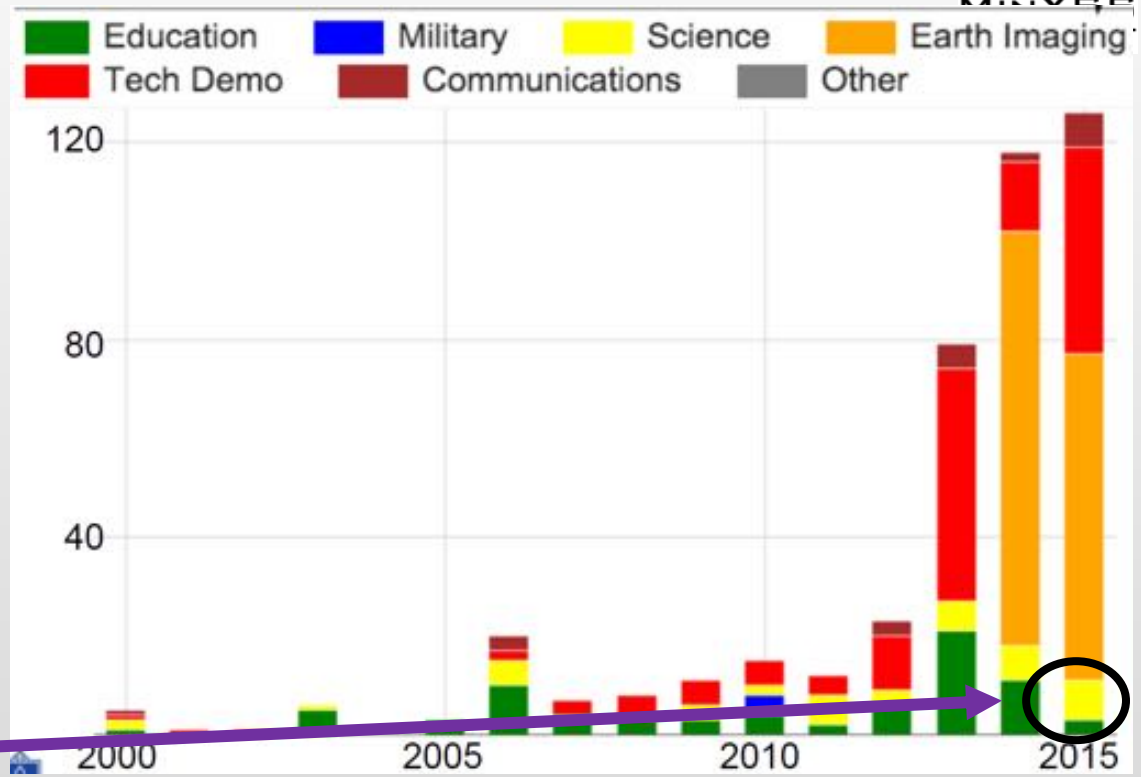
Solar X-rays can yield information on T, n, A, $\vec{B}$ and $\vec{v}$

Solar EUV and X-ray Instruments



CubeSats!!

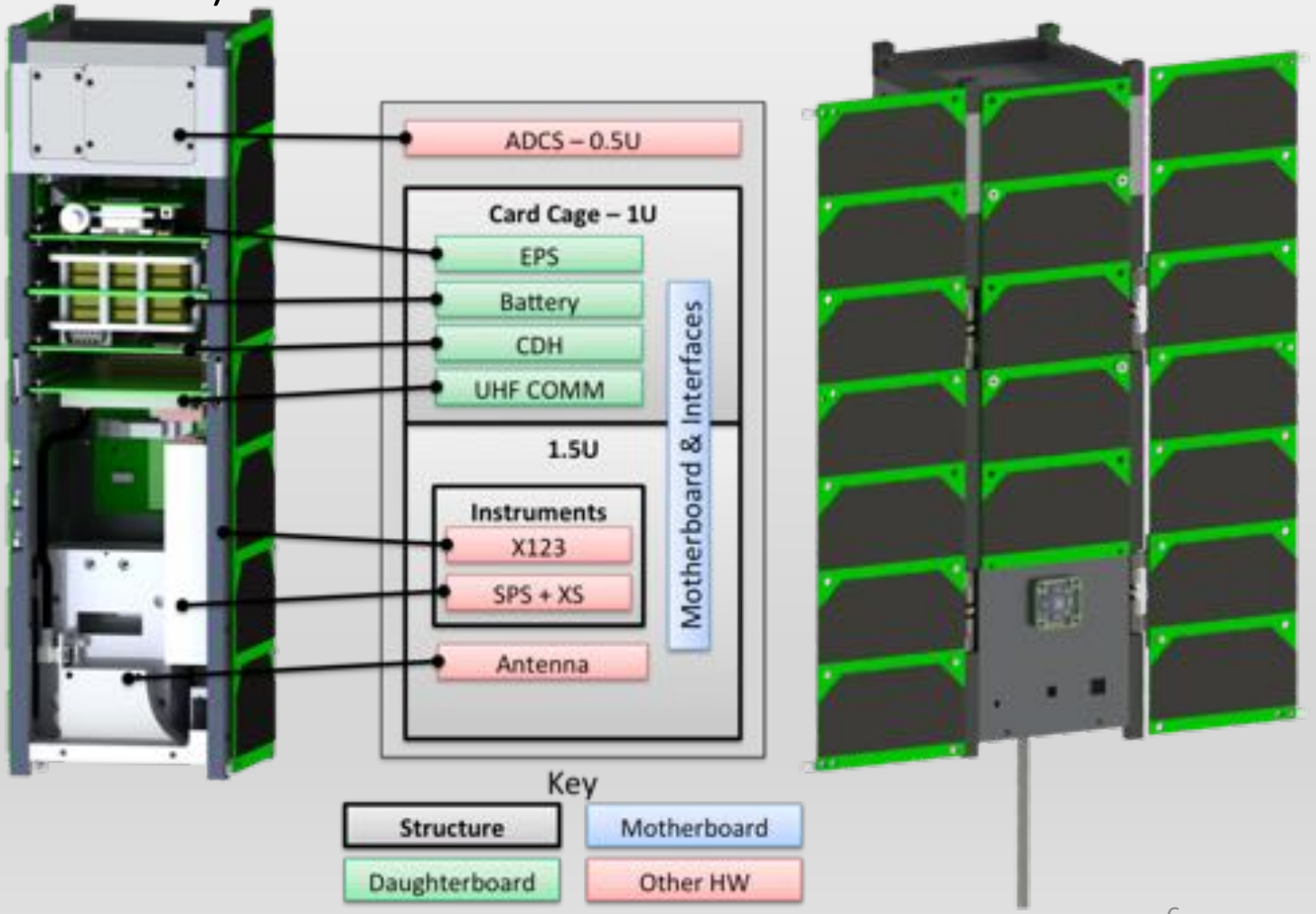
- Offer quick
  - ~3 year inception-to-launch
- Relatively cheap
  - MinXSS-1 budget ~$1 M
- Technology demonstration platform
- Conduct significant science
  - Colorado Student Space Weather Experiment (CSSWE) – Van Allen Belts + SEPs
  - MinXSS – Solar Corona X-ray spectra



Swartwort, 2014 + 2016

MinXSS-1 CubeSat

- **Min**iature **X**-Ray **S**olar **S**pectrometer
  - Dimensions ~ 34 x 10 x 10 cm (13.4 x 4 x 4”) ‘cube’
  - Mass ~ 3.5 kg



Mason et al. 2016

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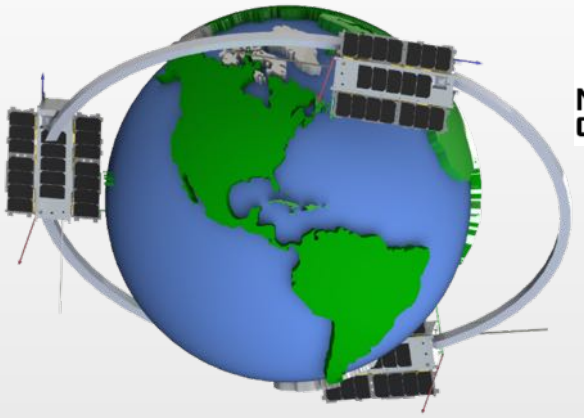
  - OA-4, Atlas V-401

MinXSS-1 CubeSat



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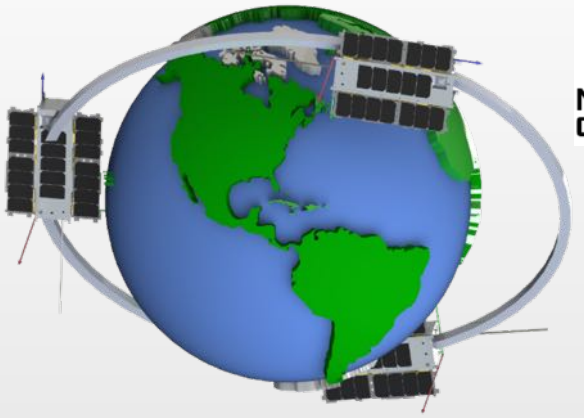
  - ISS, 1 m/s
  - 52º inclination
  - ~400 km altitude

Image courtesy of NASA and ESA astronaut Tim Peake

MinXSS-1 CubeSat



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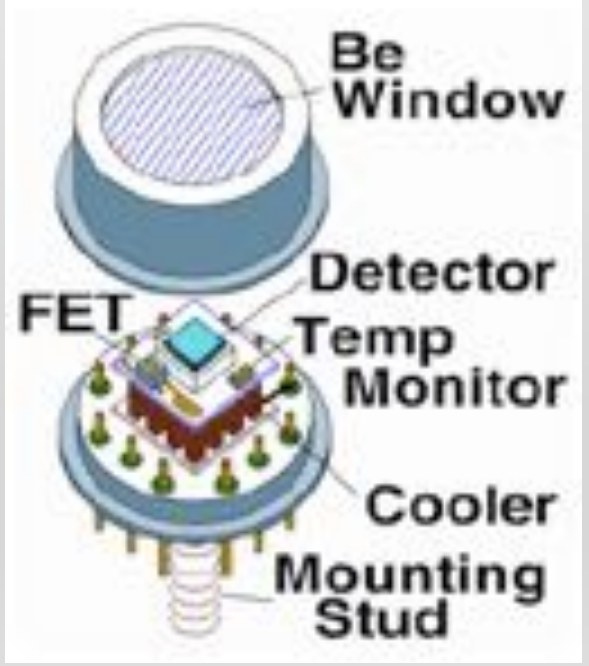
- **Operations:** MinXSS-1 ~12 months
  - UHF 437 MHz half duplex comm
  - LASP roof Yagi Antenna

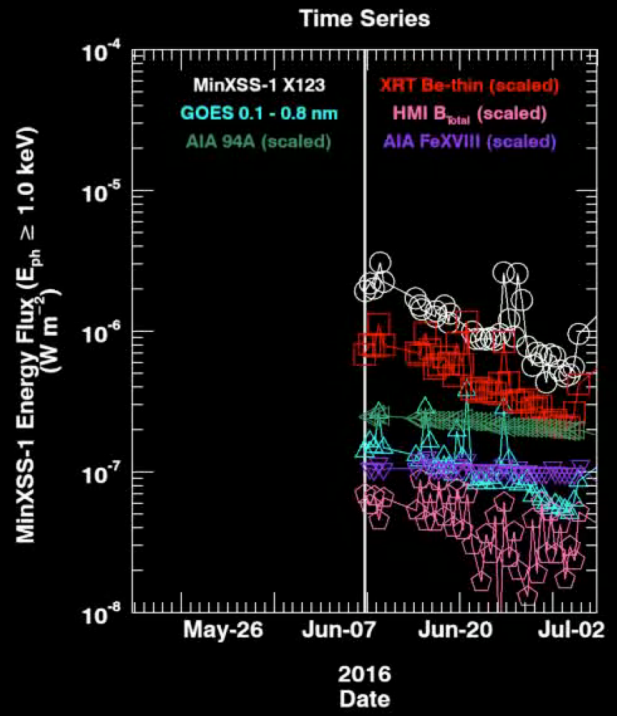
- MinXSS-2 scheduled to launch in 2018 for 4 year mission

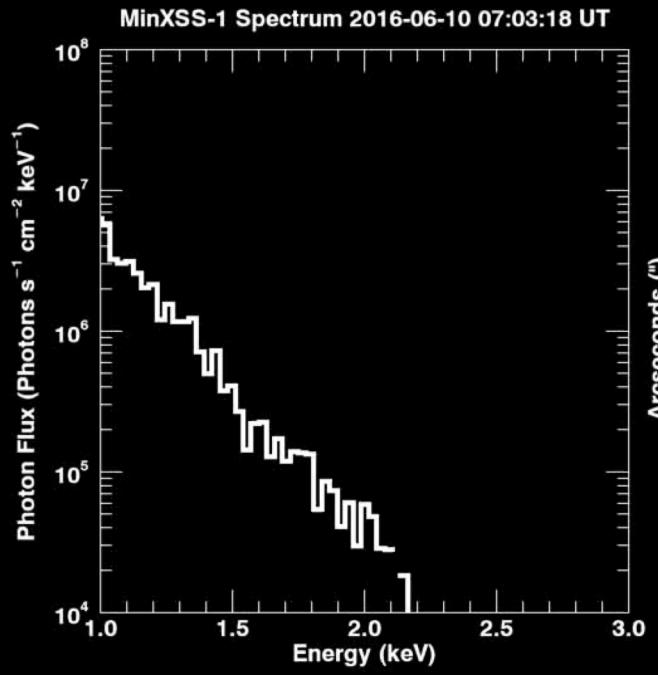
MinXSS Instruments

- **Sun Positioning System (SPS)**
  - Quad visible light Si-photodiodes
  - ND7 filter
- **X-ray Photometer (XP)**
  - Si-photodiode
  - Be window
- **X-ray Spectrometer (X123)**
  - Amptek X123 Silicon Drift Diode (SDD)
  - 0.8 – 12 keV bandpass
  - 0.03 keV bins -> 0.15 keV FWHM resolution
  - Δt = 10 seconds cadence
  - FOV = 4°
  - $\Delta V \sim E_{ph}$

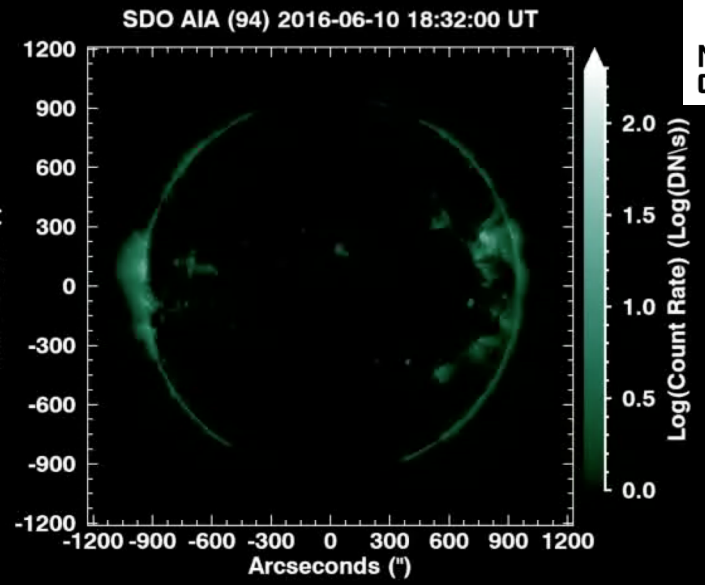


X-ray Spectra



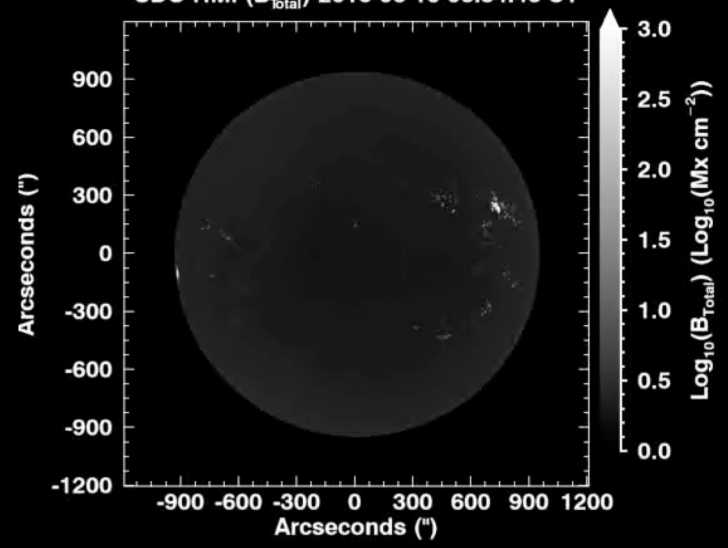


EUV Images

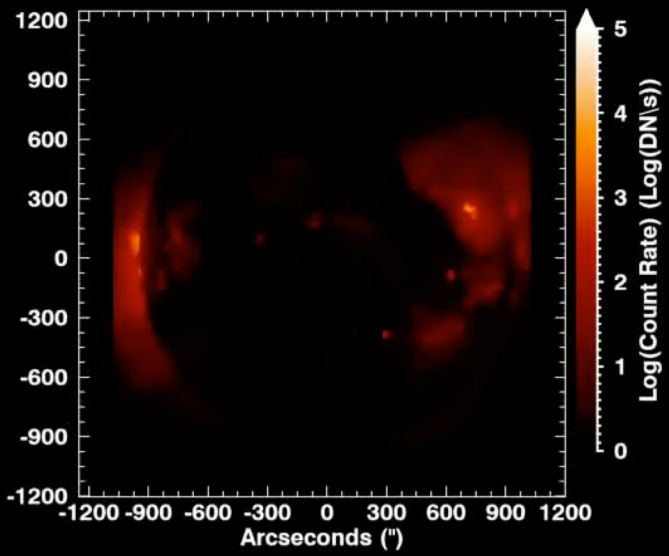


Video by Christopher.S.Moore@cfa.harvard.edu

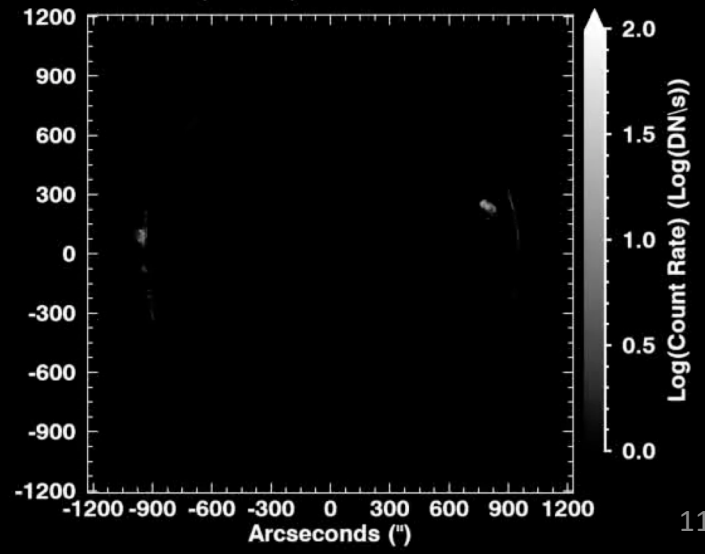
Magnetic Field



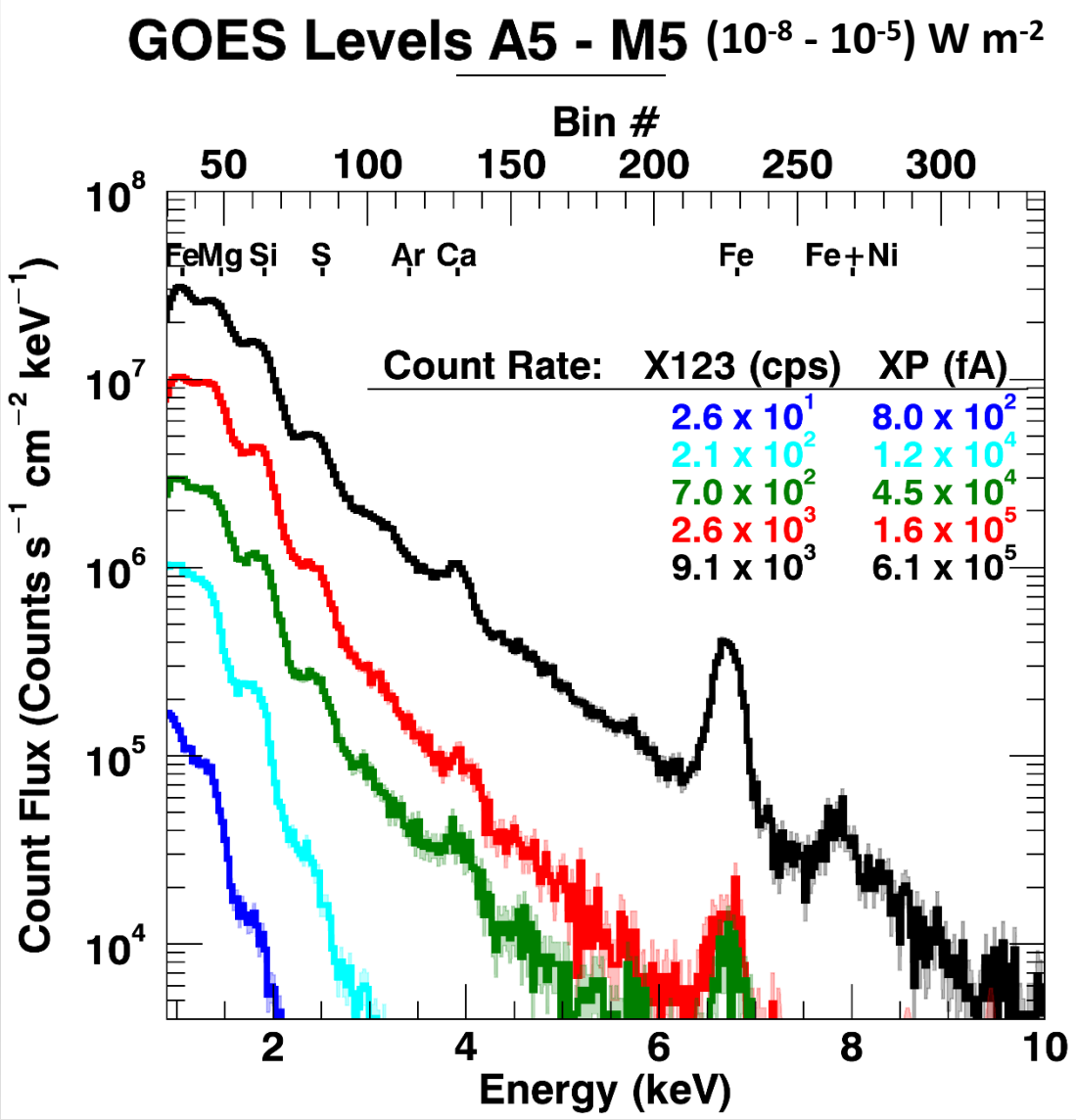
X-ray Images



Hot Plasma (T ≳ 5 MK)

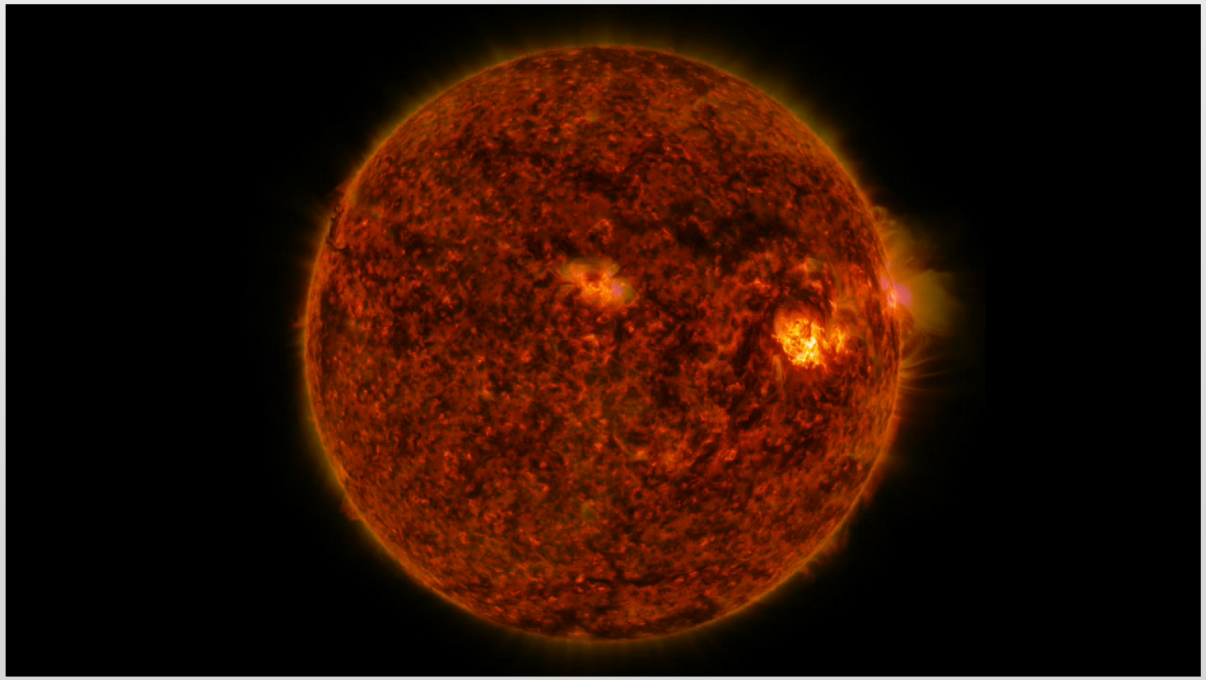


MinXSS-1 Measurements



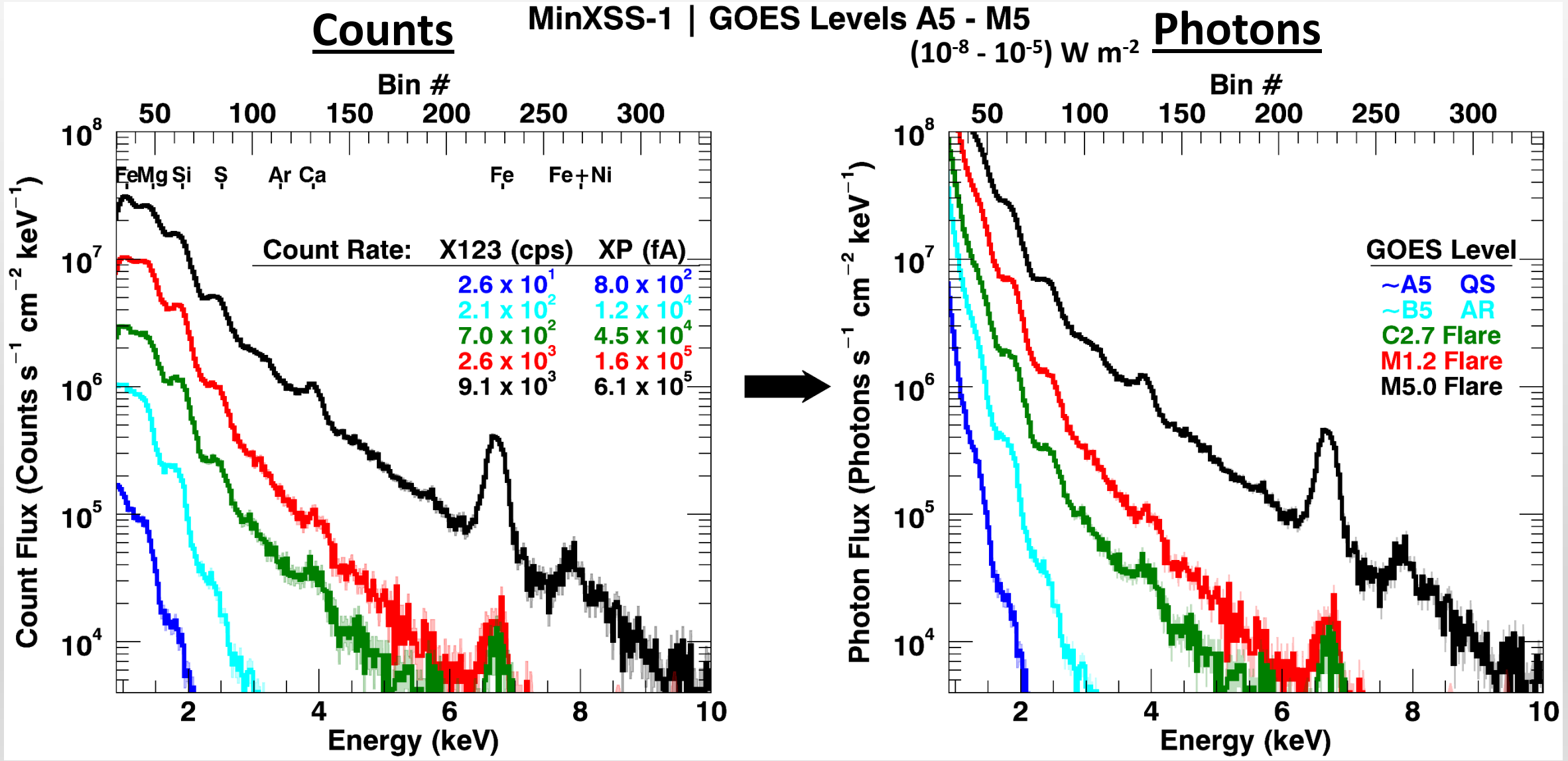
GOES Level

~A5	QS
~B5	AR
C2.7 Flare	
M1.2 Flare	
M5.0 Flare	



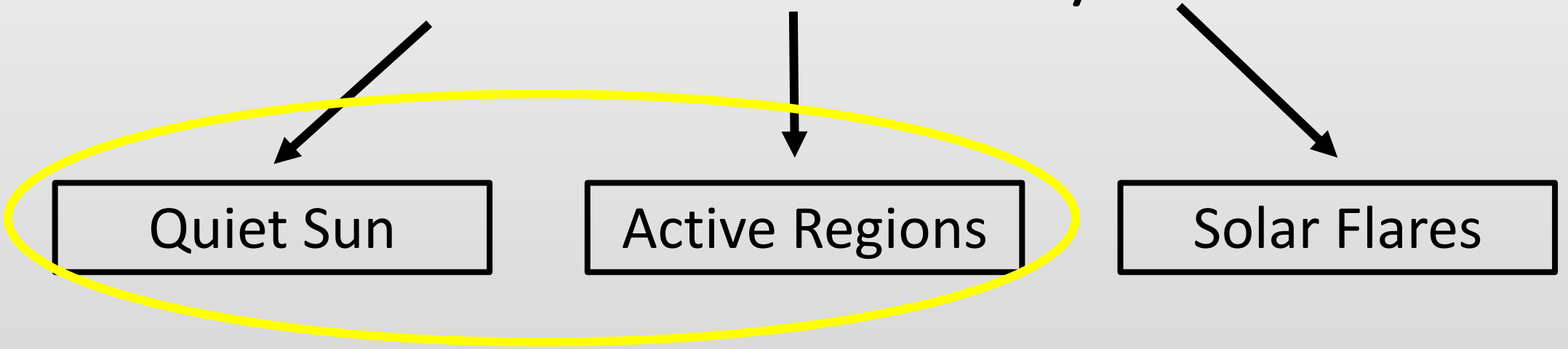
Moore et al. 2018

MinXSS-1 Measurements



Moore et al. 2018

What is the Solar soft X-ray spectral distribution and how does it vary?



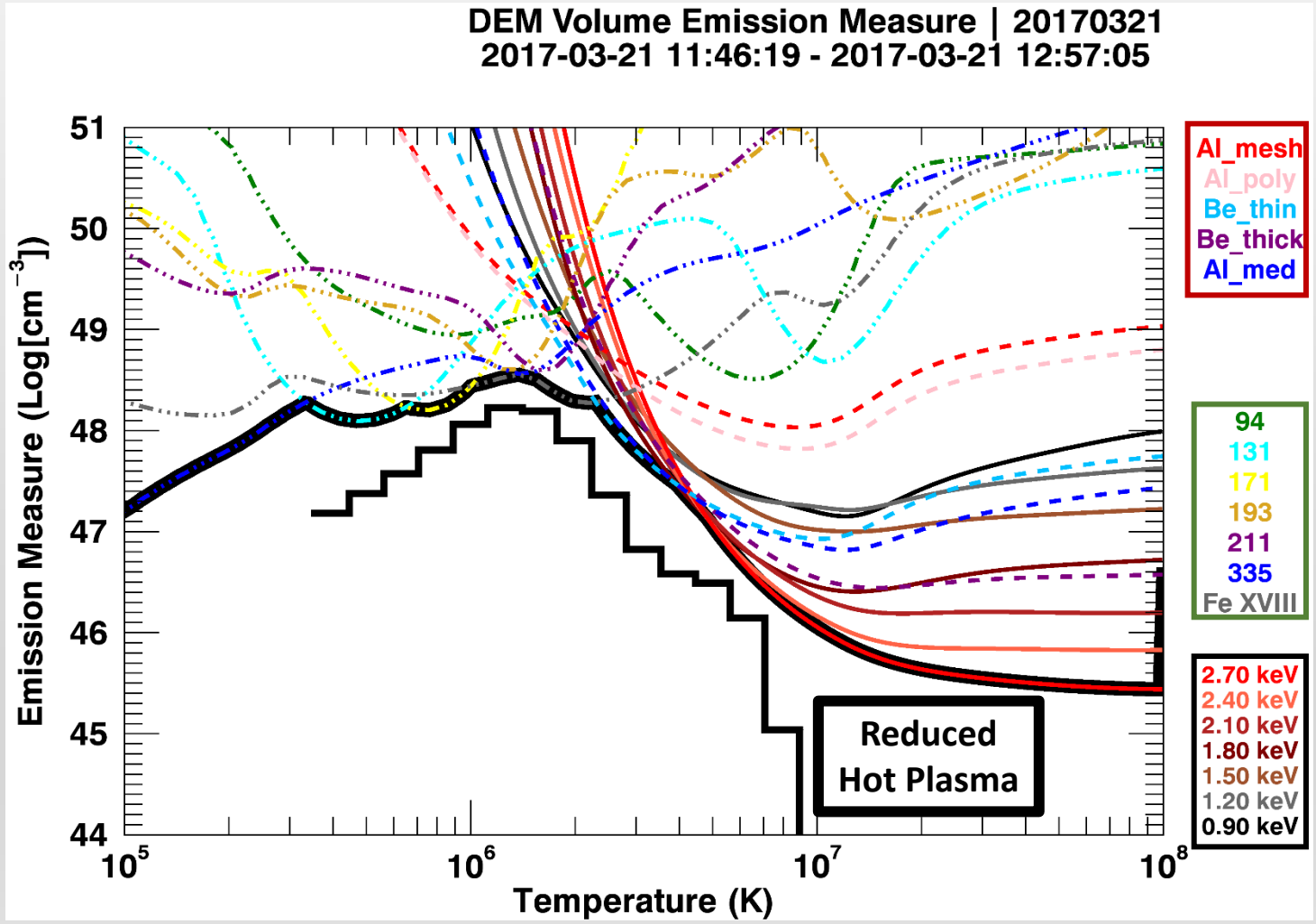
Data: MinXSS-1/X123 + SDO/AIA + Hinode/XRT

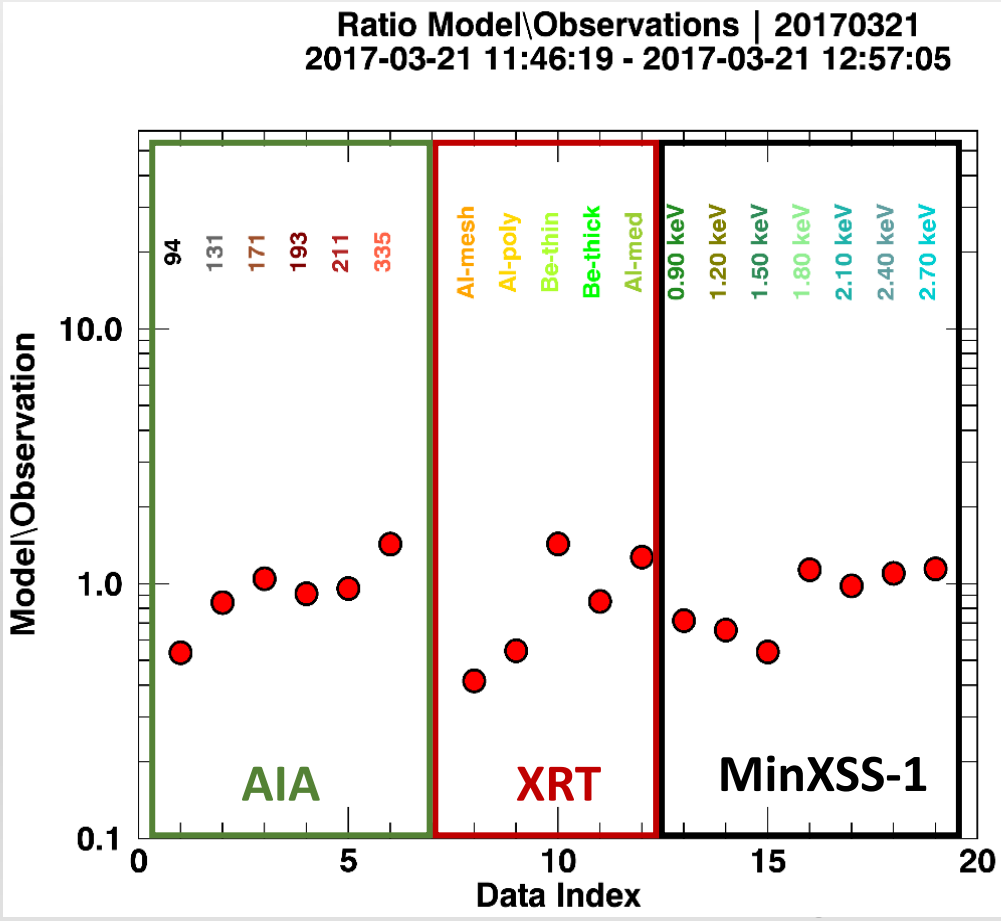
DEMs of QS, AR and full Sun

DEM result fits MinXSS-1, XRT and AIA data *simultaneously* within a factor of 3

- **20170321 full sun**

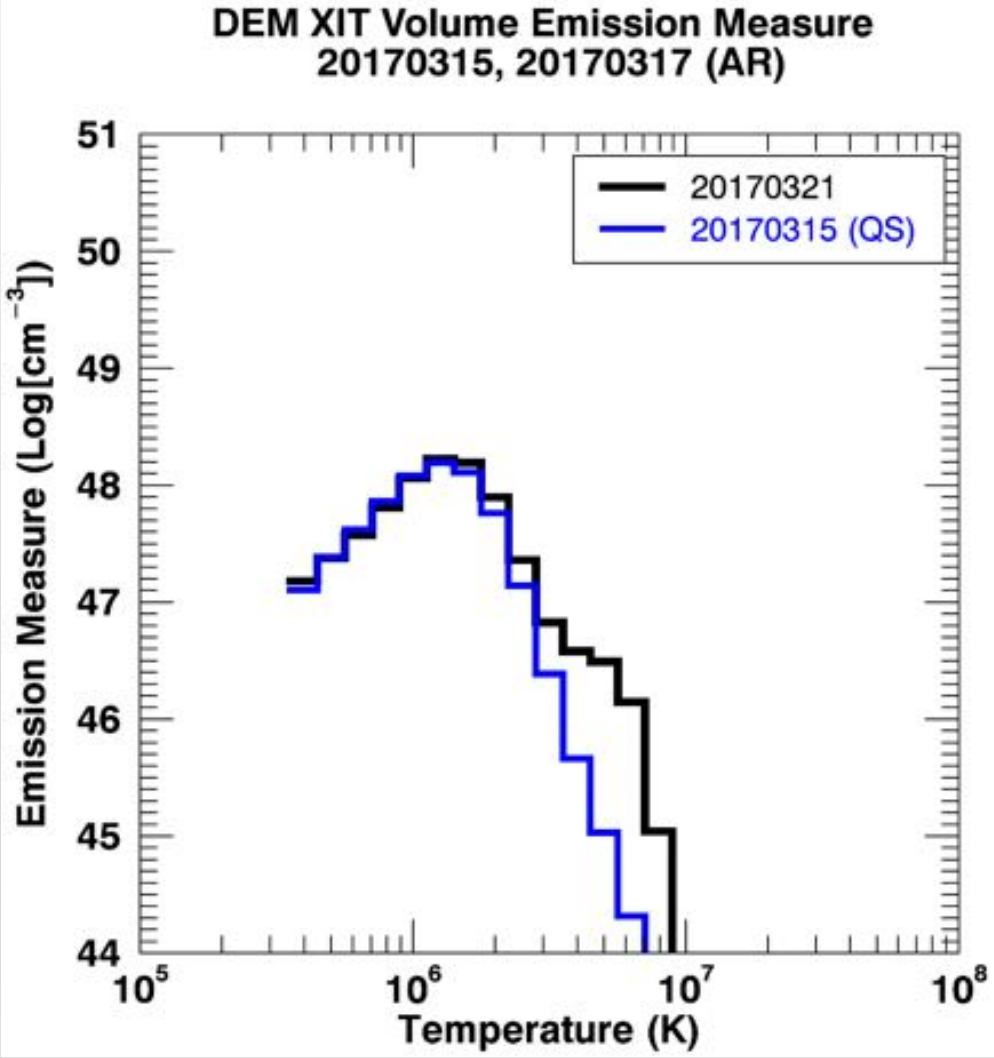
$$C_i = \int_T DEM(T)F(T)dT$$
$$= \sum_j DEM(T)_j F_{ij}(T)\Delta T_j$$



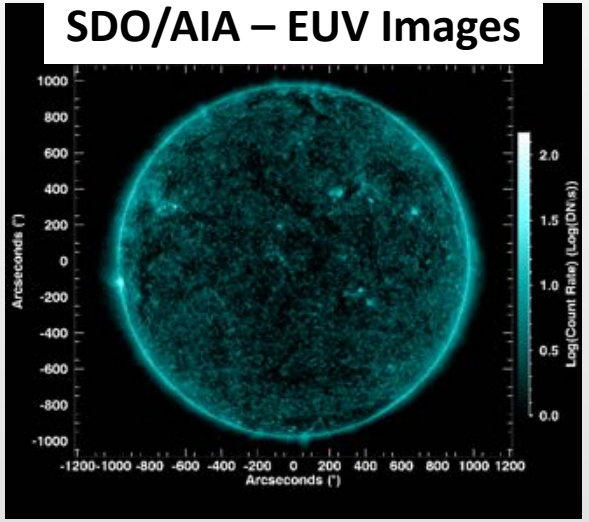


DEMs of QS, AR and full Sun

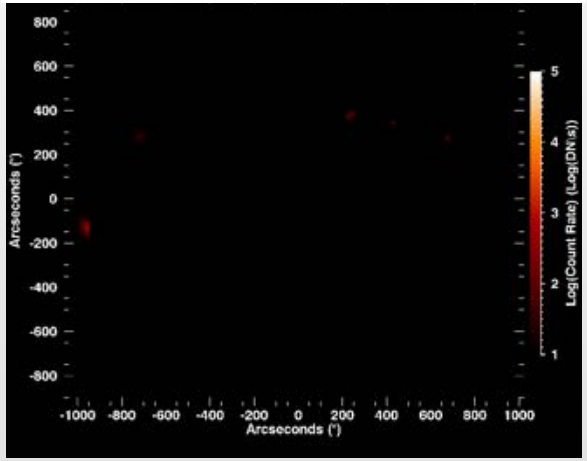
- **20170321 full sun,** separate **QS (20170315 full sun)**



SDO/AIA – EUV Images



Hinode/XRT – X-ray Images

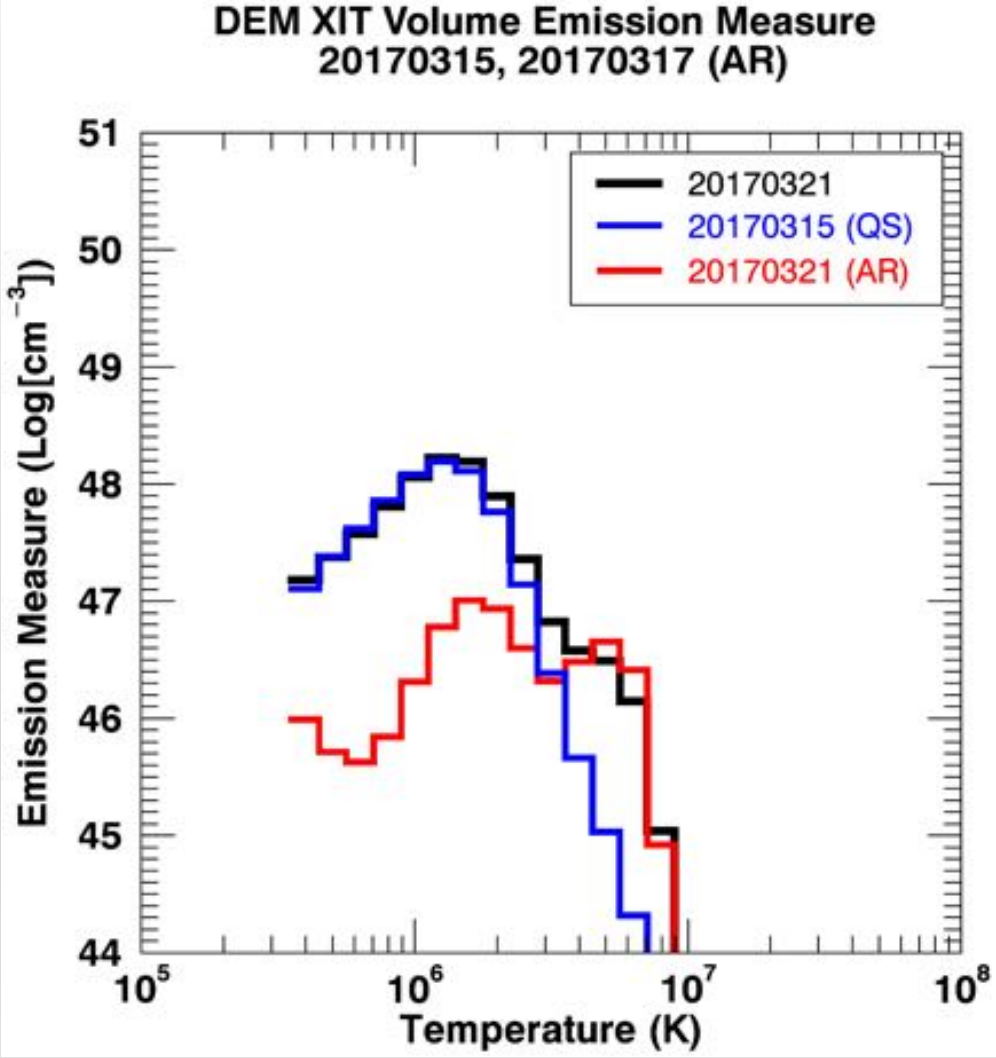


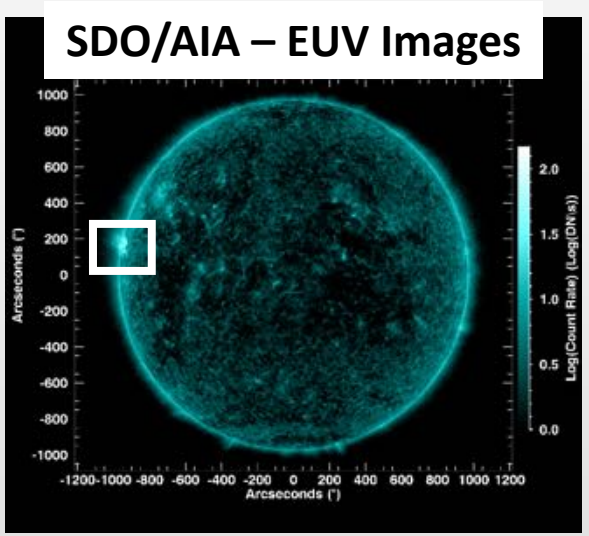
- **QS** consistent with temperatures predicted by **Alfvén wave heating models (1 – 3 MK)**[1,2].

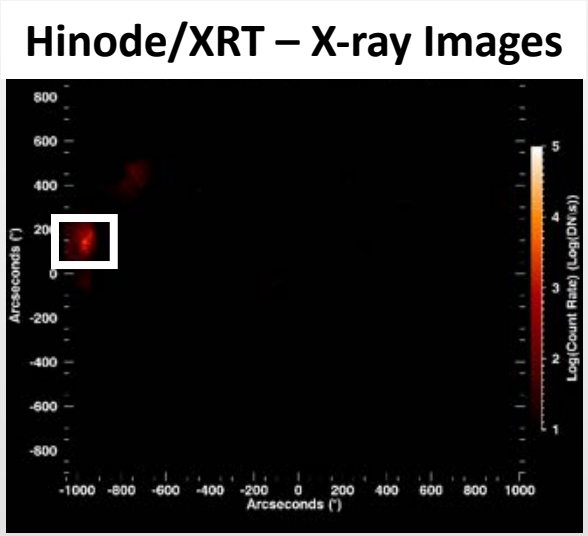
[1]van Ballegooijen et al. 2014, [2]van der Holst et al. 2014,

DEMs of QS, AR and full Sun

- **20170321 full sun,** separate **QS (20170315 full sun)** and **AR enhancement (20170321)**.





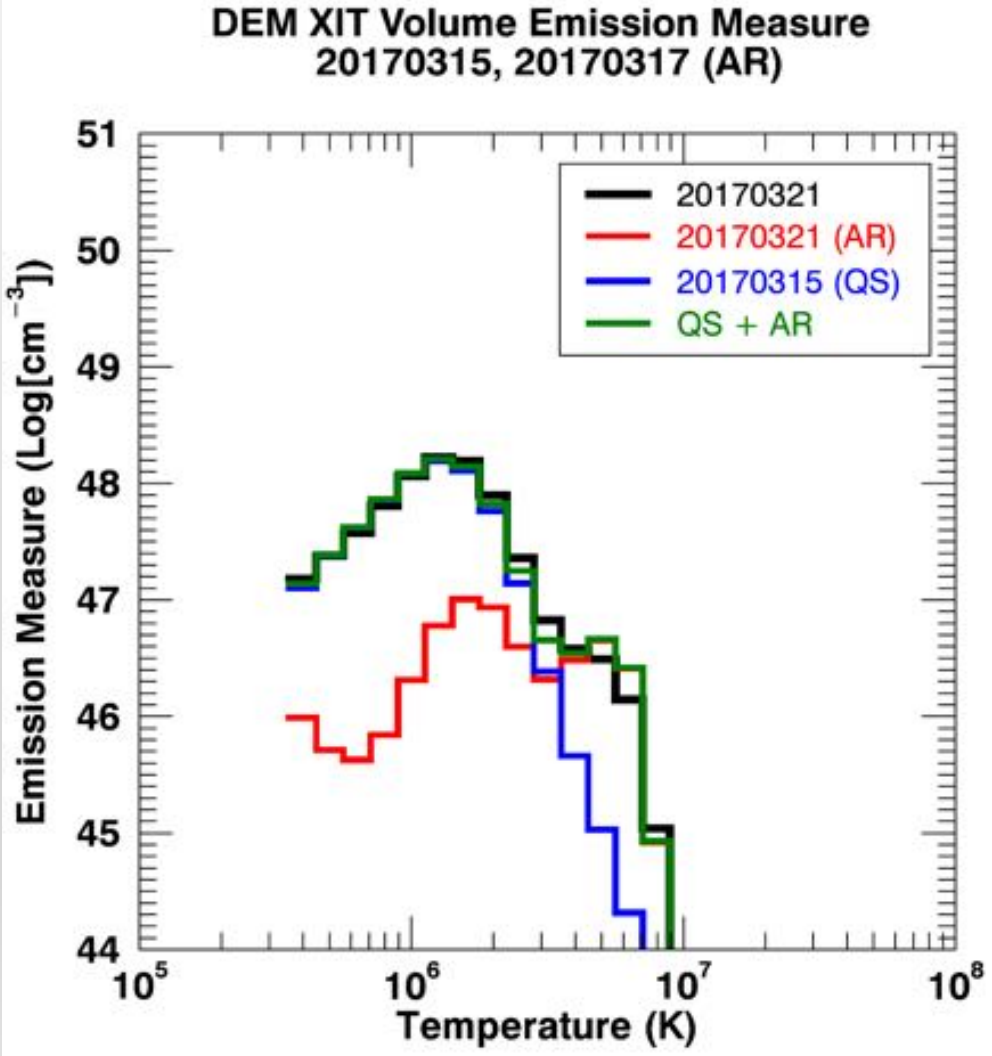


- **QS** consistent with temperatures predicted by **Alfvén wave heating models (1 – 3 MK)**[1,2].
- **AR** hot temperature component **(T >5 MK) inline with impulsive heating possibilities**[3]**.**
  - **This is not observed for every case!!**

[1]van Ballegooijen et al. 2014, [2]van der Holst et al. 2014, [3]Barnes et al. 2016

DEMs of QS, AR and full Sun

- **20170321 full sun,** separate **QS (20170315 full sun)** and **AR enhancement (20170321)**.
- **QS + AR** DEM demonstrate plasma inference consistency.



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Summary

1. MinXSS-1 quality measurements from GOES A5 – M5 without substantial post processing
   - Can estimate (QS, AR and Flare)
     - Chemical Abundances
     - Emission Measures
     - Temperatures (1T, 2T and DEMs)

2. MinXSS-2 scheduled to launch in 2018 for 4 year mission

3. Data is (will be) on the MinXSS Website.

Special Thanks to:
Entire MinXSS Team and over 40 graduate students

This work was supported by a NASA Space Technology Research Fellowship (NSTRF).

THE END

Thank You !

MinXSS CubeSat