Full Sun Spectrally Resolved Soft X-ray Measurements from the Miniature X-ray Solar Spectrometer (MinXSS) CubeSats

By: **Christopher S. Moore**

Postdoc – Harvard-Smithsonian CfA

Mentors: Katharine Reeves and Ed Deluca

PhD 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

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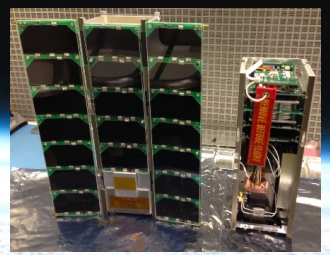
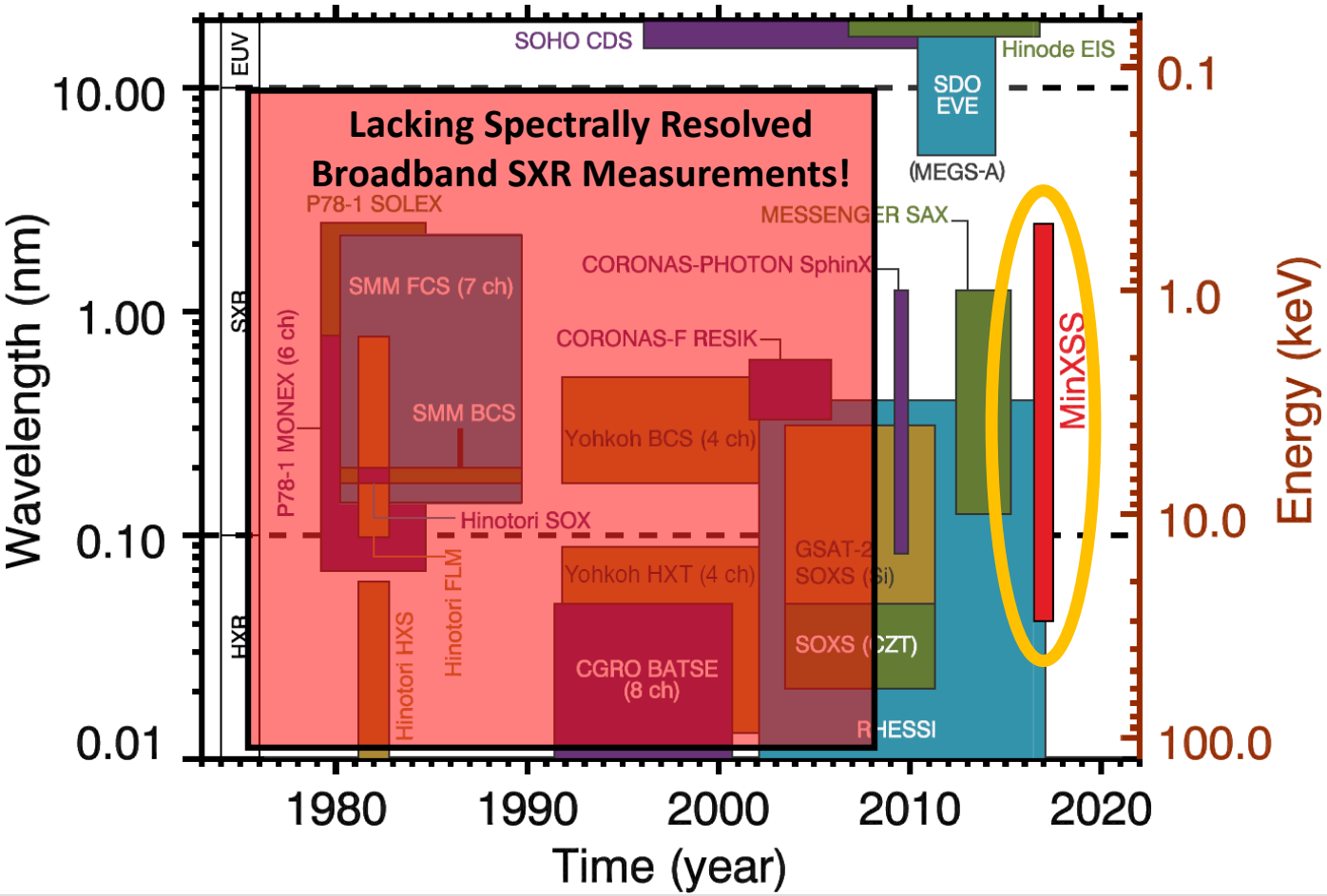


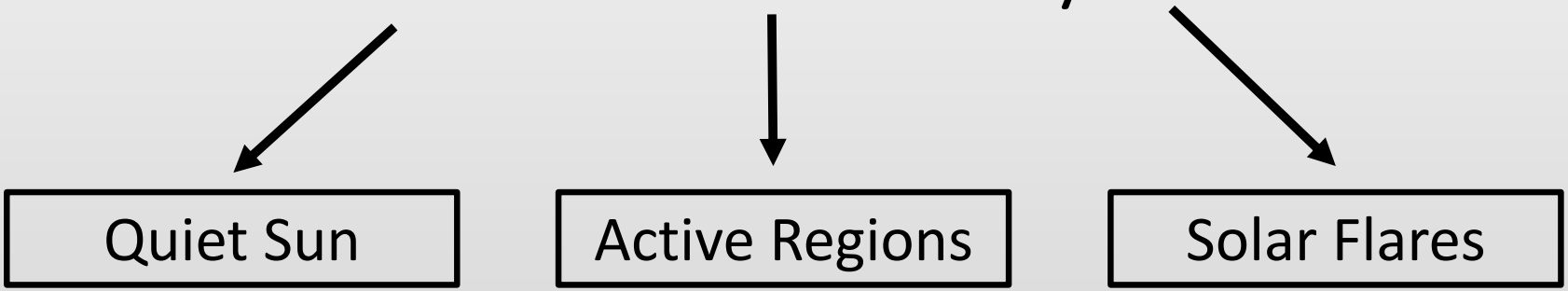
MinXSS CubeSat

Images courtesy of NASA and ESA astronaut Tim Peake

Solar EUV and X-ray Instruments

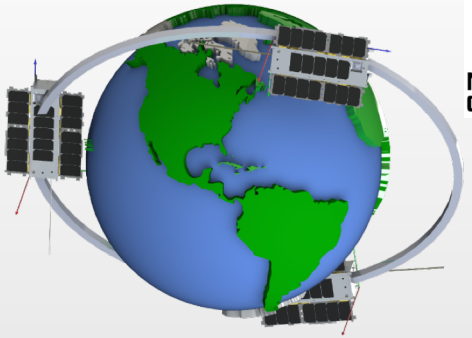


What is the Solar soft X-ray spectral distribution and how does it vary?



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

MinXSS-1 CubeSat



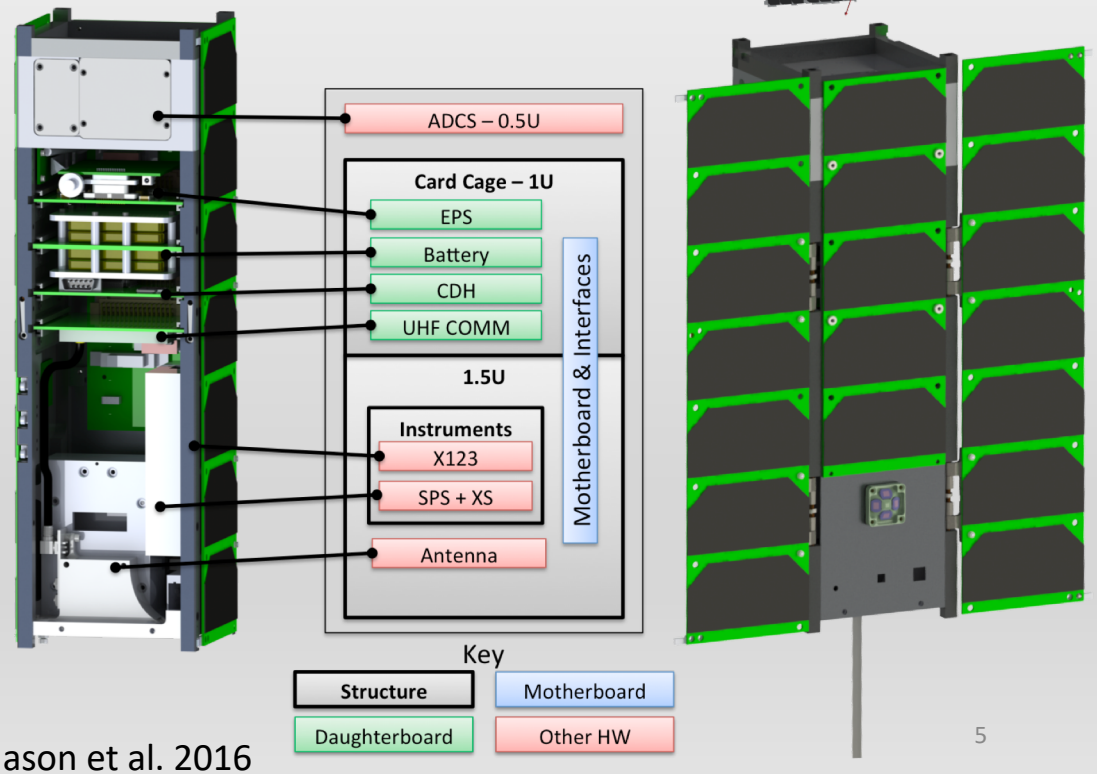
- **Min**iature **X**-Ray **S**olar **S**pectrometer
  - Dimensions ~ 34 x 10 x 10 cm (13.4 x 4 x 4”) ‘cube’
  - Mass ~ 3.5 kg

- **Launch:** MinXSS-1 2015/12/06
  - Cape Canaveral SLC-41
  - OA-4, Atlas V-401

- **Deployment:** MinXSS-1 2016/05/16
  - ISS, 1 m/s
  - 52º inclination
  - ~400 km altitude

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

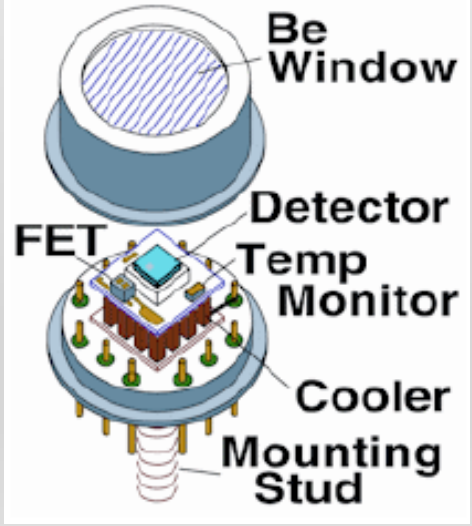
- MinXSS-2 scheduled to launch in 2018 for 4 year mission

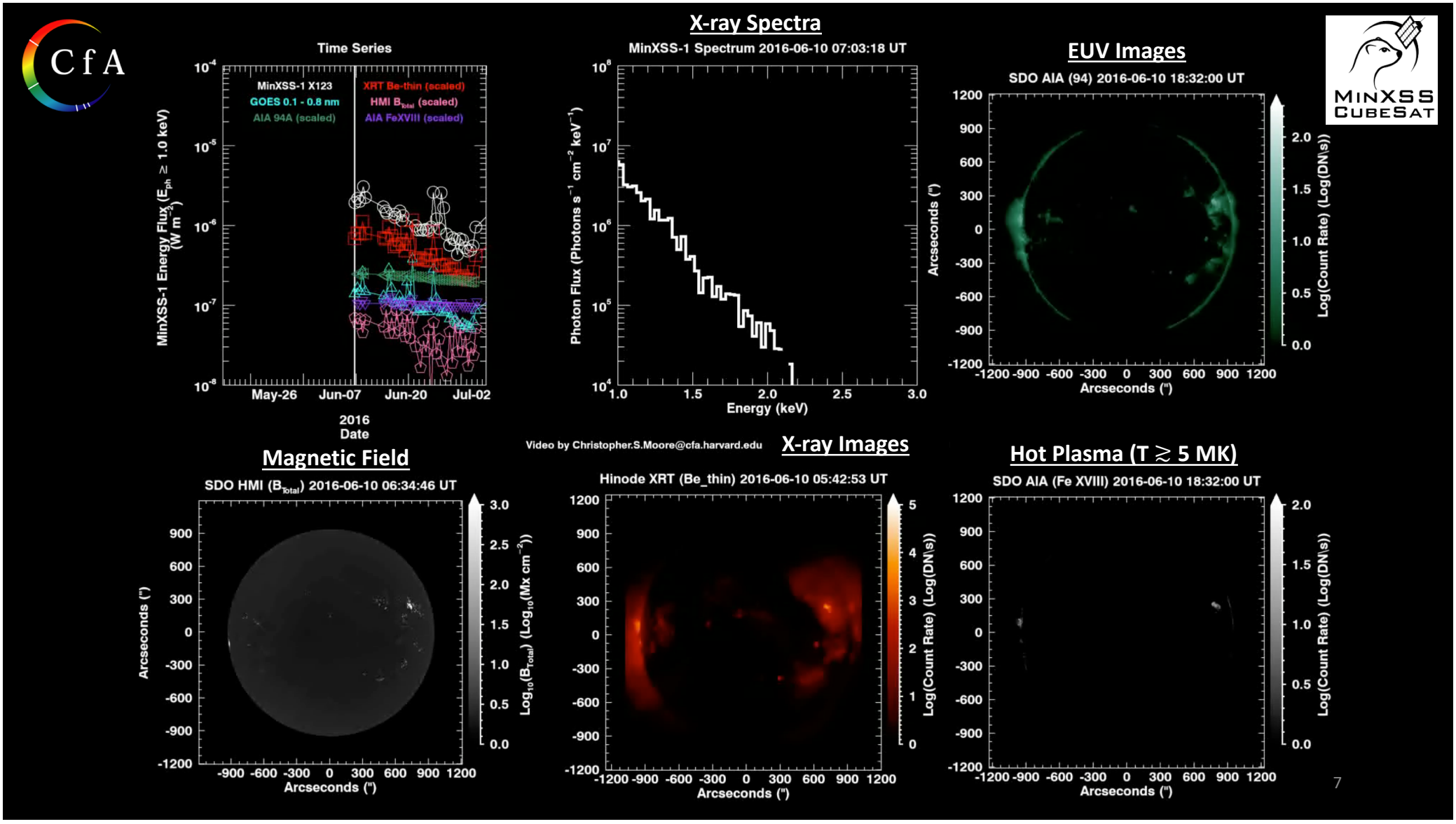


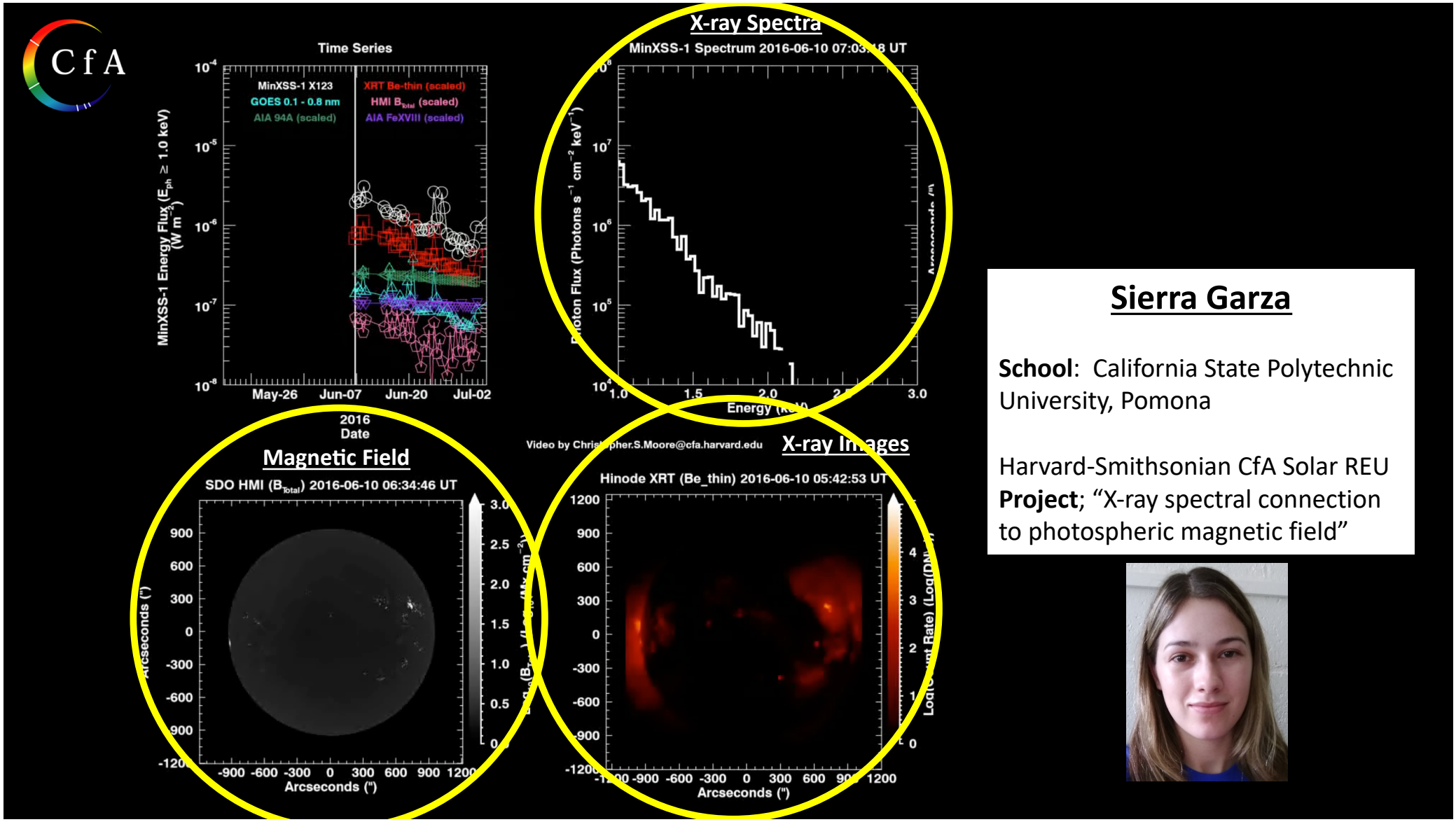
Mason et al. 2016

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
Time Series
MinXSS-1 X123
GOES 0.1 - 0.8 nm
AIA 94A (scaled)
XRT Be-thin (scaled)
HMI B_Total (scaled)
AIA FeXVIII (scaled)
MinXSS-1 Energy Flux (E_ph ≥ 1.0 keV) (W m^-2)
May-26
Jun-07
Jun-20
Jul-02
2016
Date
MinXSS-1 Spectrum 2016-06-10 07:03:18 UT
Photon Flux (Photons s^-1 cm^-2 keV^-1)
Energy (keV)
EUV Images
SDO AIA (94) 2016-06-10 18:32:00 UT
Arcseconds (")
Log(Count Rate) (Log(DN\s))
Video by Christopher.S.Moore@cfa.harvard.edu
Magnetic Field
SDO HMI (B_Total) 2016-06-10 06:34:46 UT
Log10(B_Total) (Log10(Mx cm^-2))
X-ray Images
Hinode XRT (Be_thin) 2016-06-10 05:42:53 UT
Log(Count Rate) (Log(DN\s))
Hot Plasma (T ≳ 5 MK)
SDO AIA (Fe XVIII) 2016-06-10 18:32:00 UT
MinXSS CubeSat

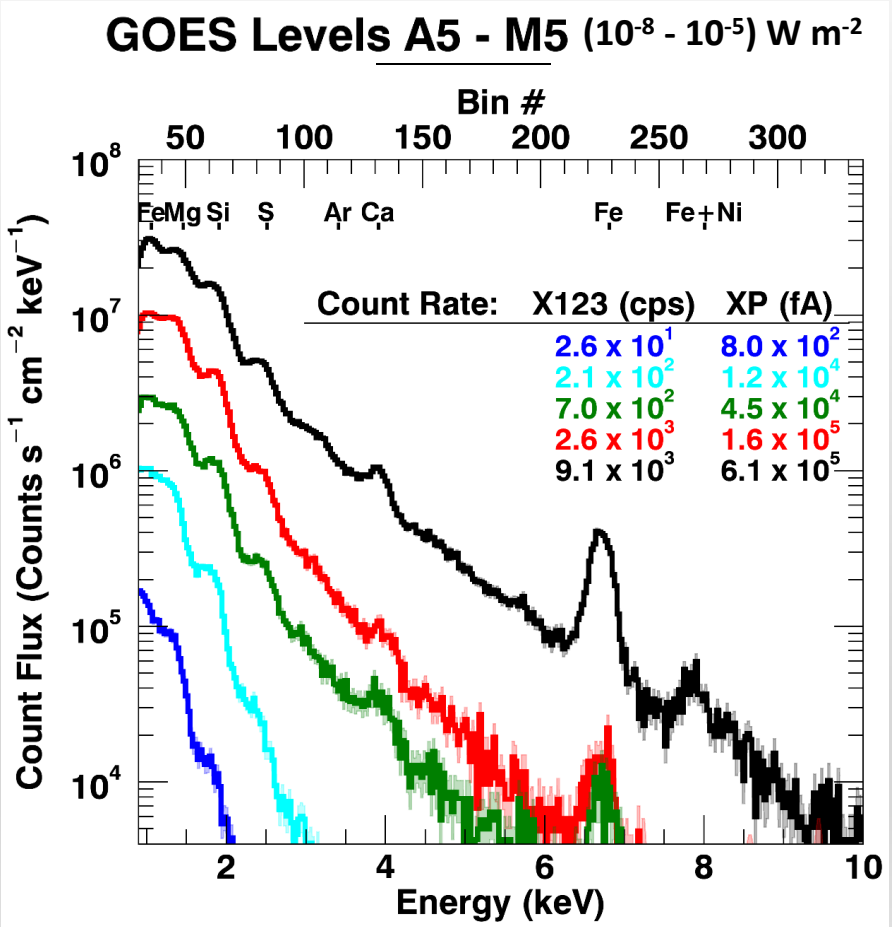


Sierra Garza

School: California State Polytechnic University, Pomona

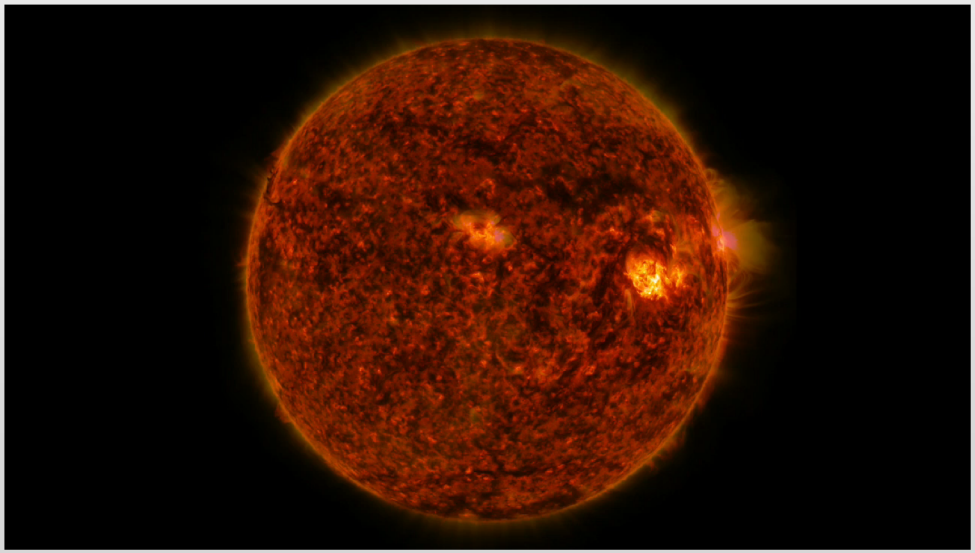
Harvard-Smithsonian CfA Solar REU **Project**; "X-ray spectral connection to photospheric magnetic field"

MinXSS-1 Measurements



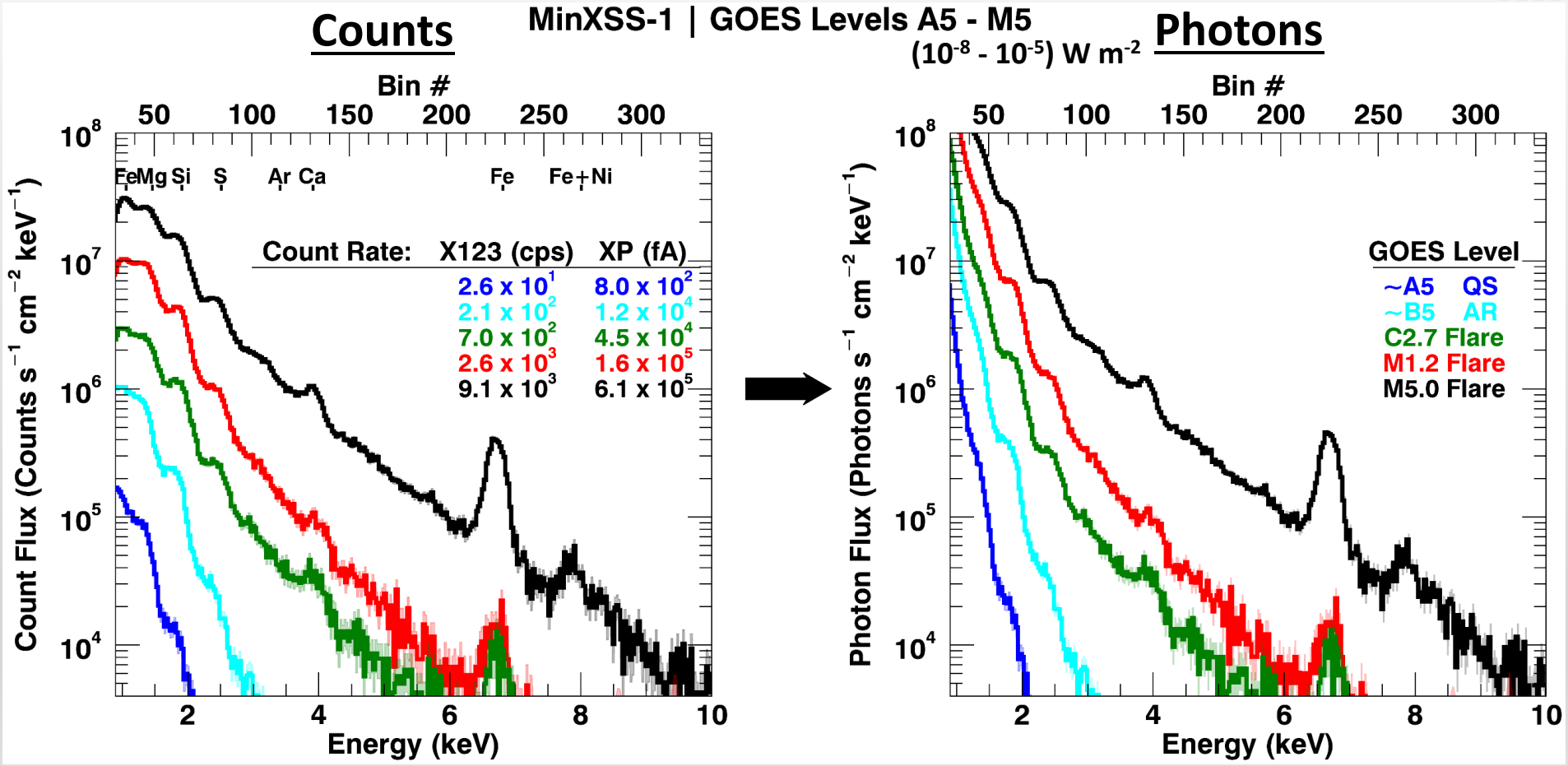
GOES Level

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



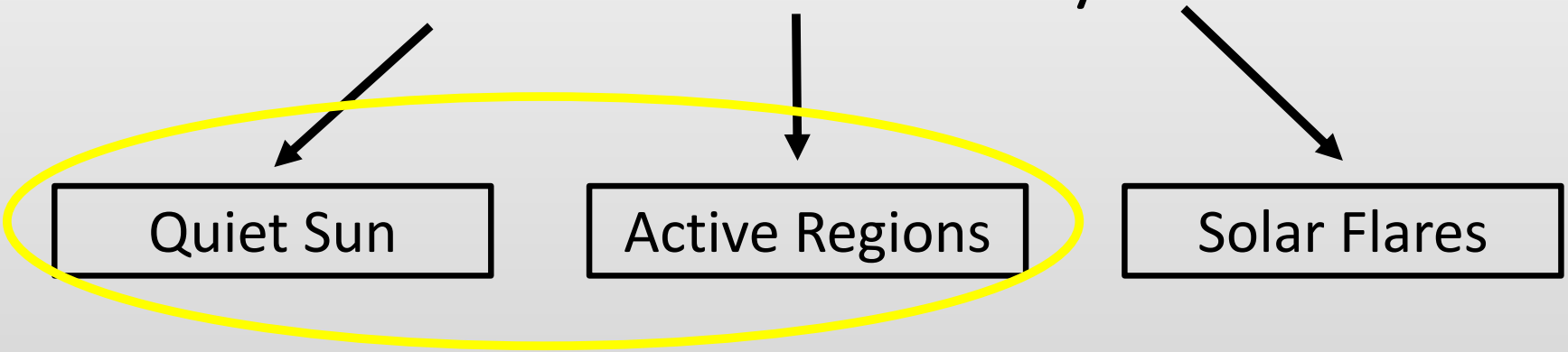
Moore et al. 2018

MinXSS-1 Measurements



Moore et al. 2018

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



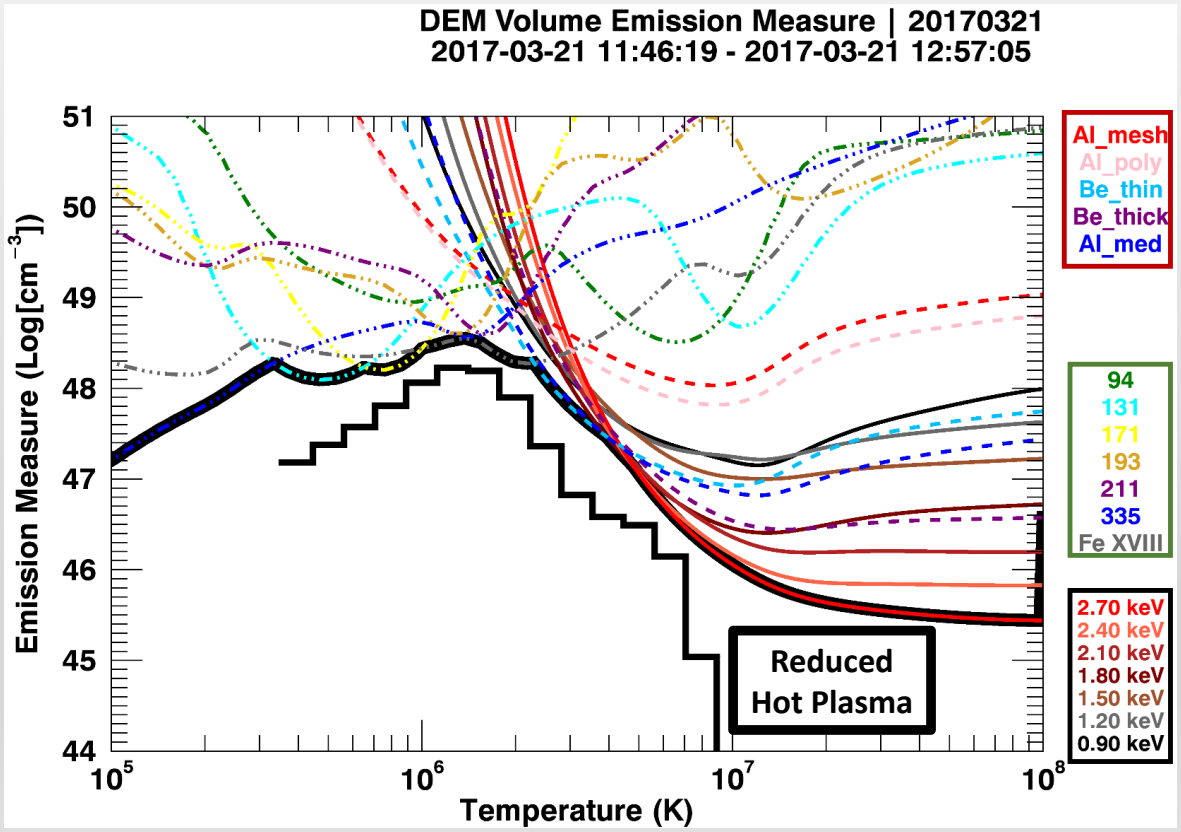
Data: MinXSS-1/X123 + SDO/AIA + Hinode/XRT

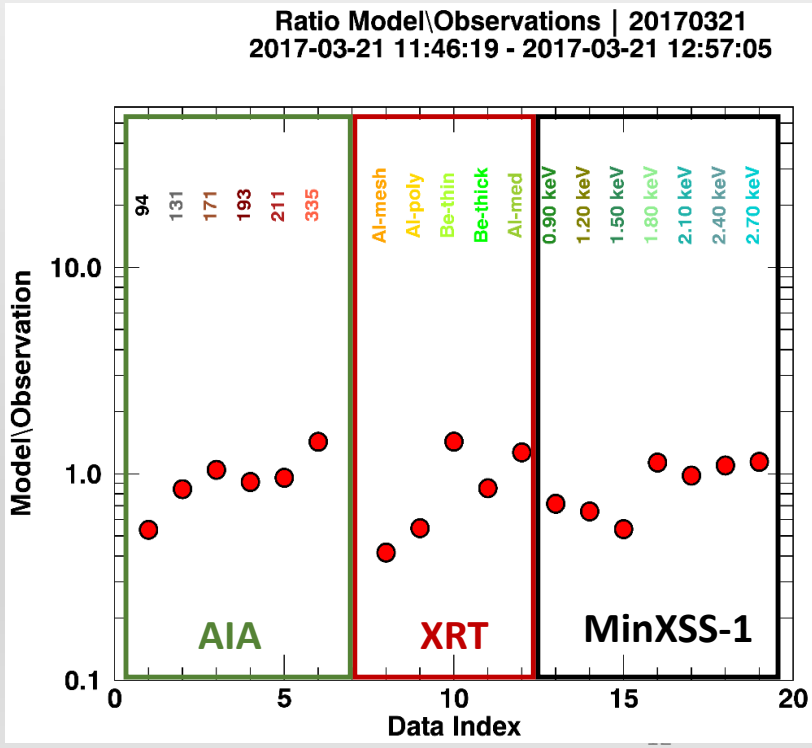
DEMs of QS, AR and full Sun

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

- **20170321 full sun**

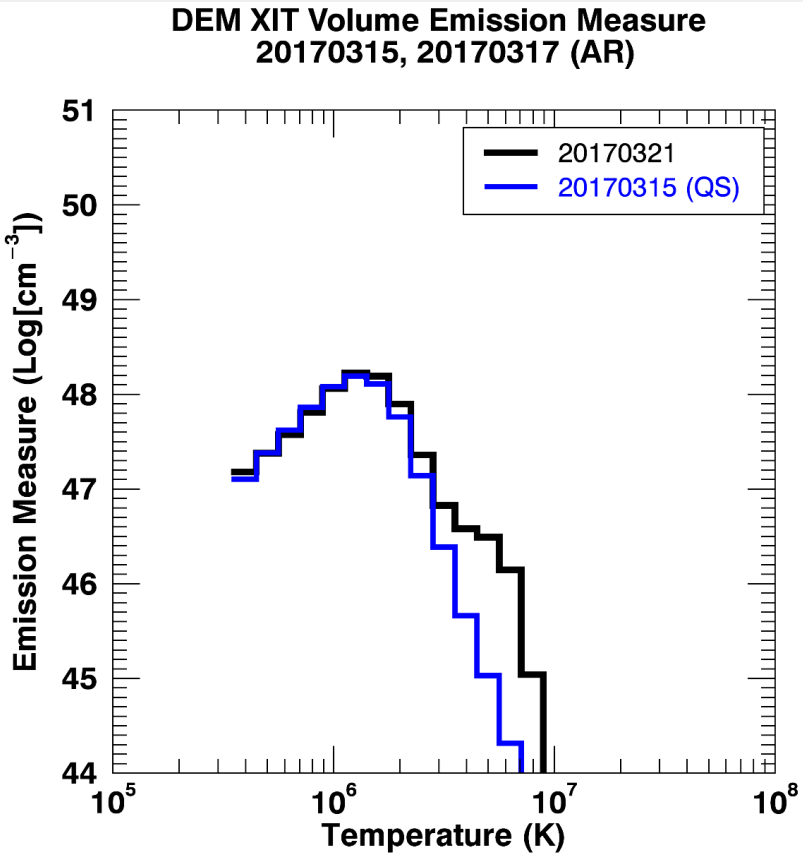
$$C_i = \int_T DEM(T)F(T)dT$$
$$= \sum_j DEM(T)_j F_{ij}(T)\Delta T_j$$



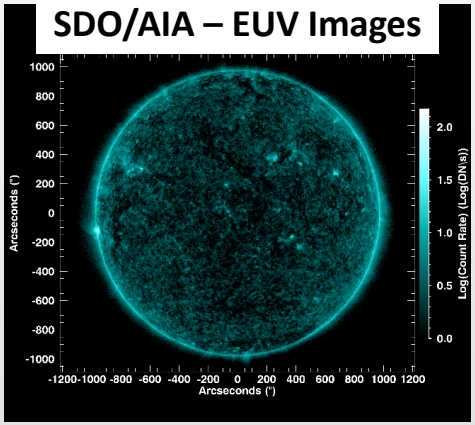


DEMs of QS, AR and full Sun

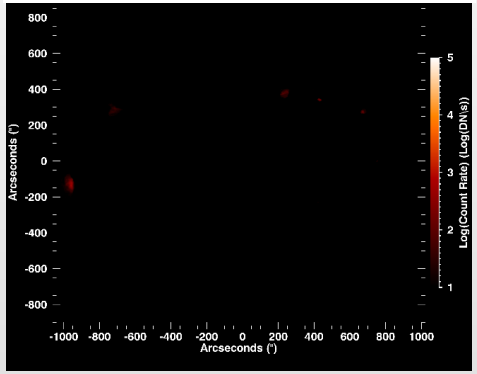
- **20170321 full sun,** separate **QS (20170315 full sun)**



SDO/AIA – EUV Images



Hinode/XRT – X-ray Images

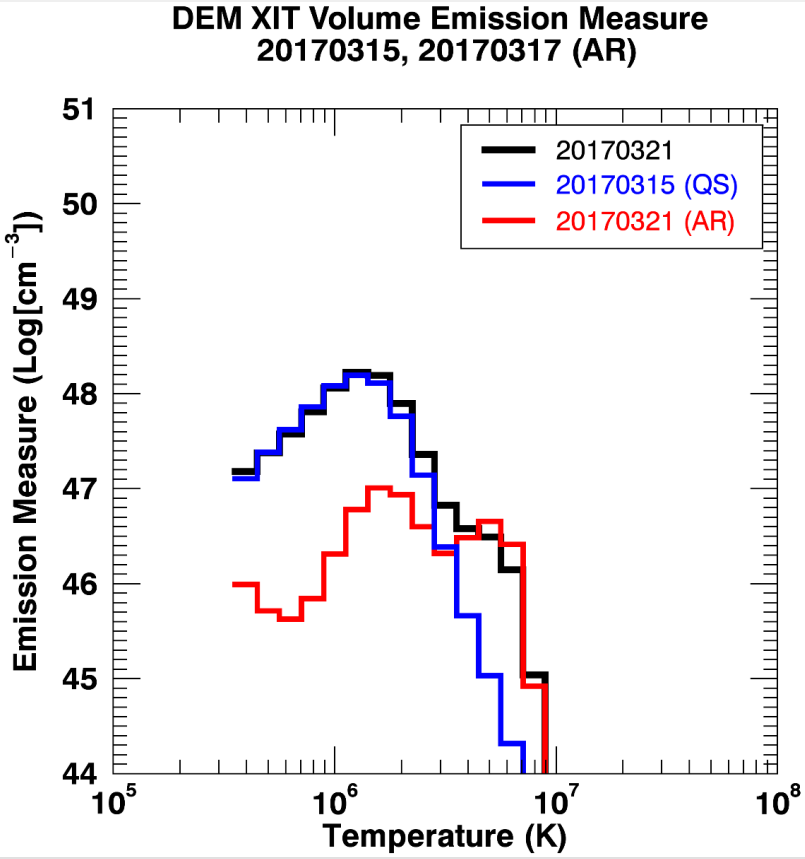


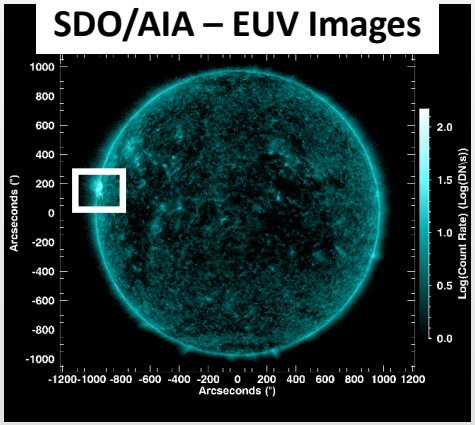
- **QS** consistent with temperatures predicted by **Alfvén wave heating models (1 – 3 MK)**[1,2].

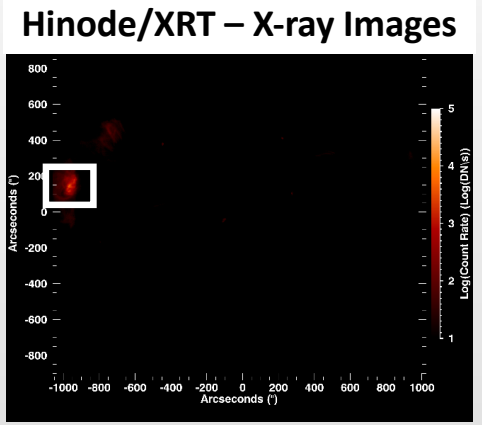
[1]van Ballegooijen et al. 2014, [2]van der Holst et al. 2014,

DEMs of QS, AR and full Sun

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





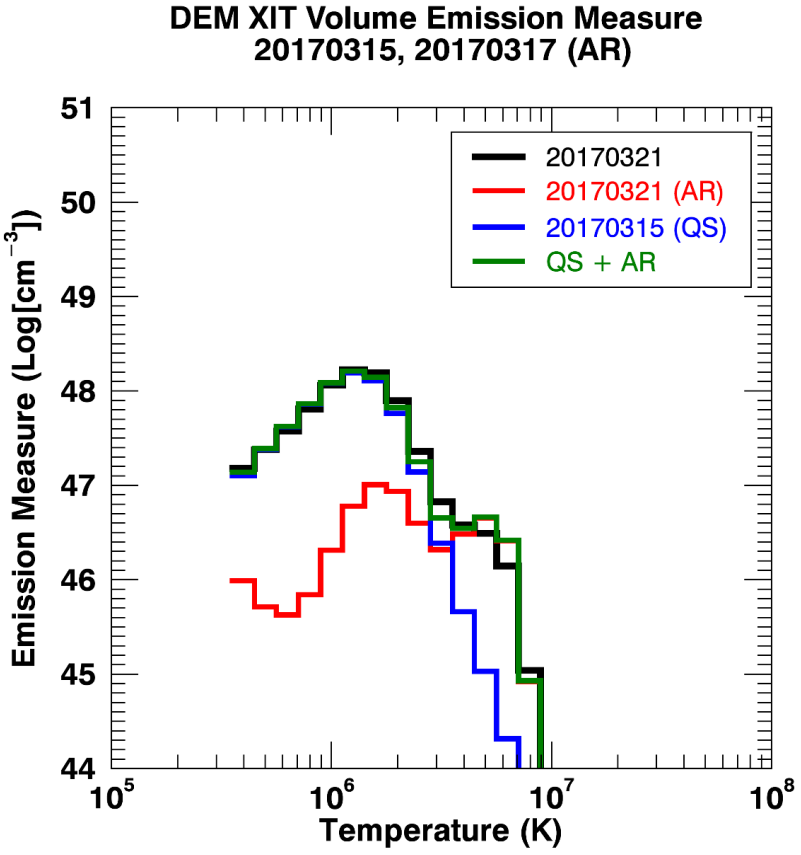


- **QS** consistent with temperatures predicted by **Alfvén wave heating models (1 – 3 MK)**[1,2].
- **AR** hot temperature component **(T >5 MK) inline with impulsive heating possibilities**[3].
  - **This is not observed for every case!!**

[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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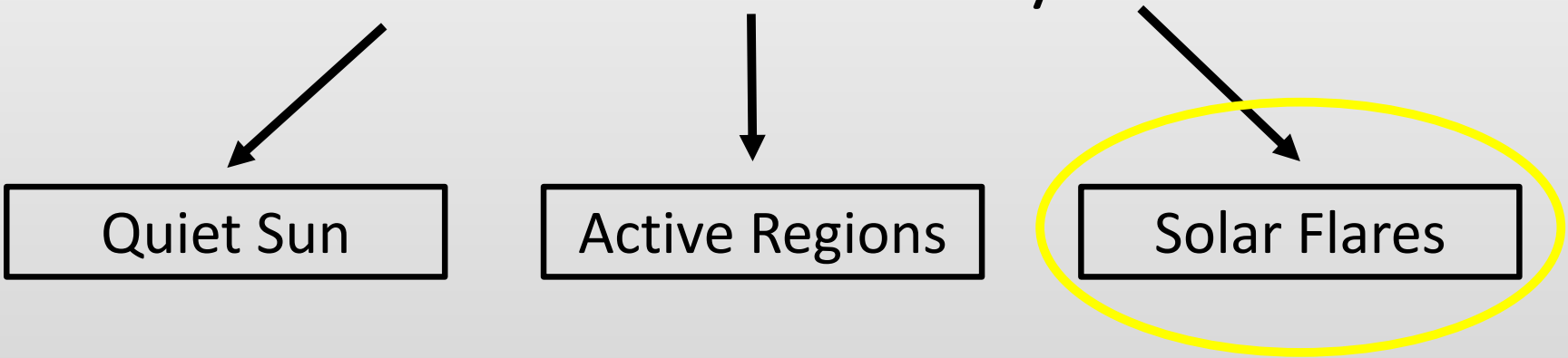
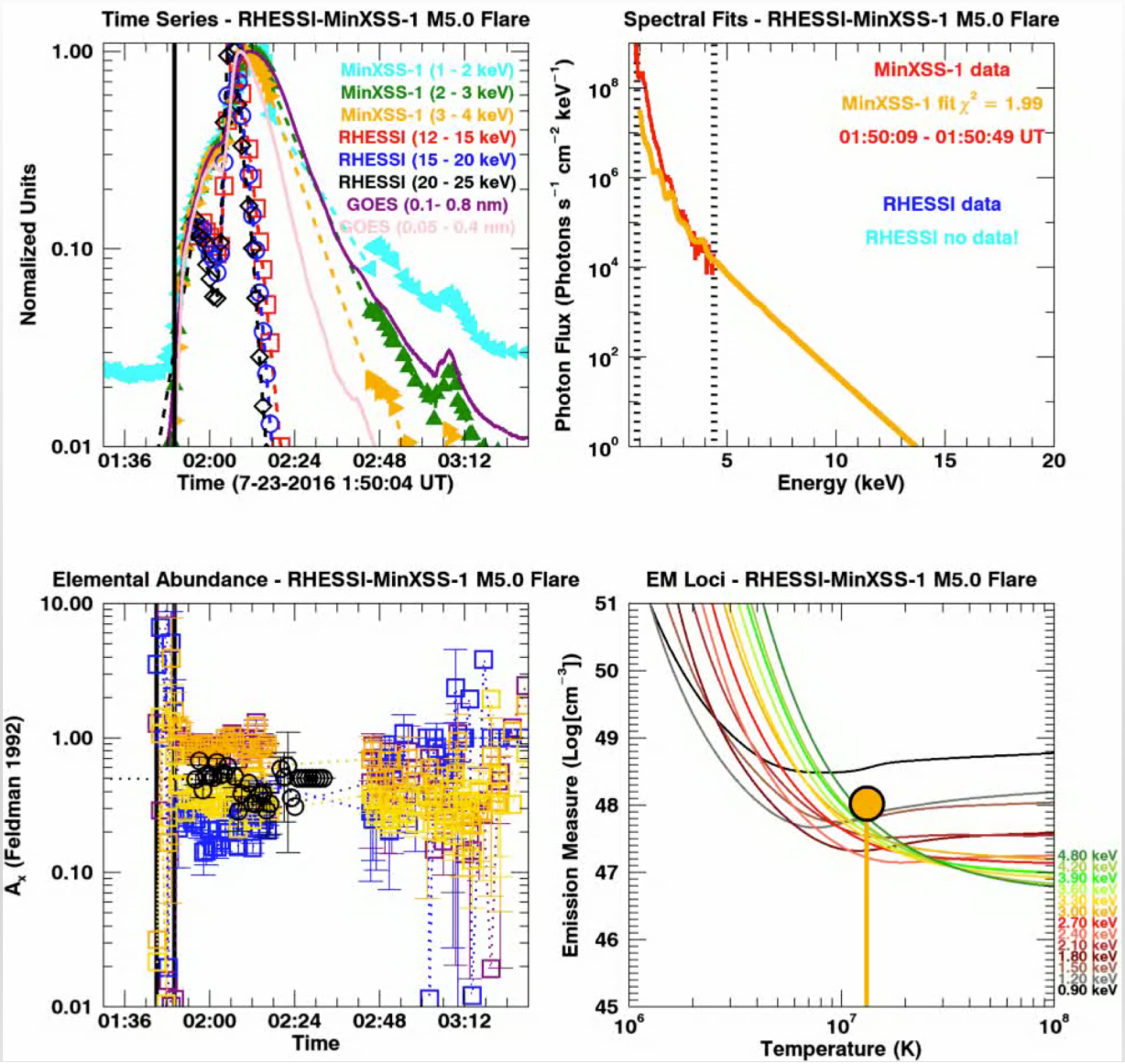


Data: MinXSS-1/X123 + RHESSI

M5 Flare
Spectral Fits vs. Time

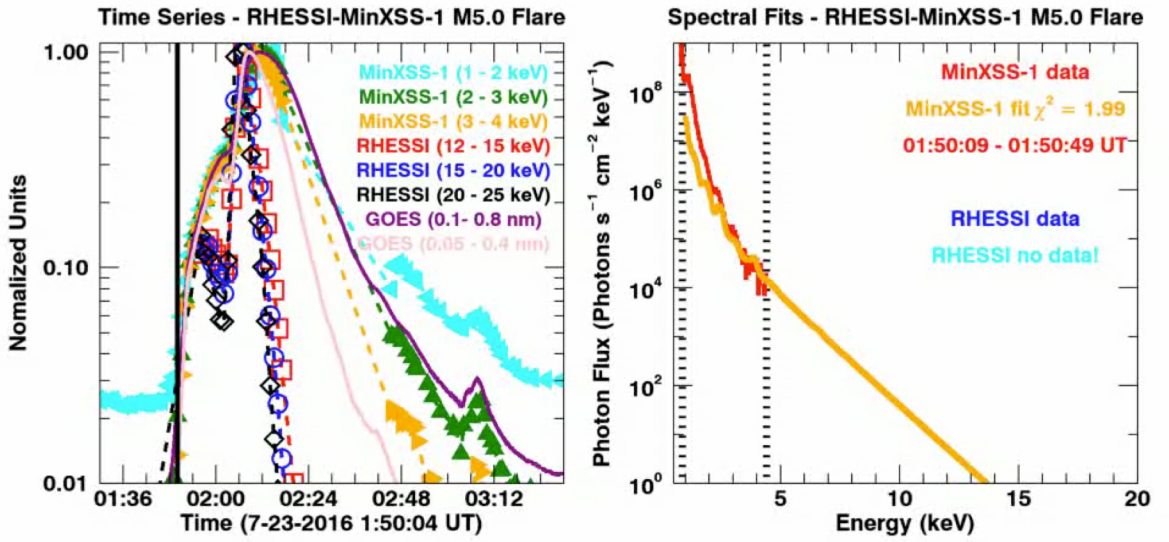


Elemental Abundance Symbols

Fe (RHESSI) – **Black** Circles

Fe (MinXSS-1) – **Purple** Squares
S (MinXSS-1) – **Blue** Squares
Mg (MinXSS-1) – **Orange** Squares
Si (MinXSS-1) – **Gold** Squares

M5 Flare Spectral Fits vs. Time



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Crisel Suarez-Bustantamente

School: Fiske-Vanderbilt Bridge Program

Harvard-Smithsonian CfA Solar researcher
Project; "Solar flare X-ray Abundance Variations"

Science Data on MinXSS Website

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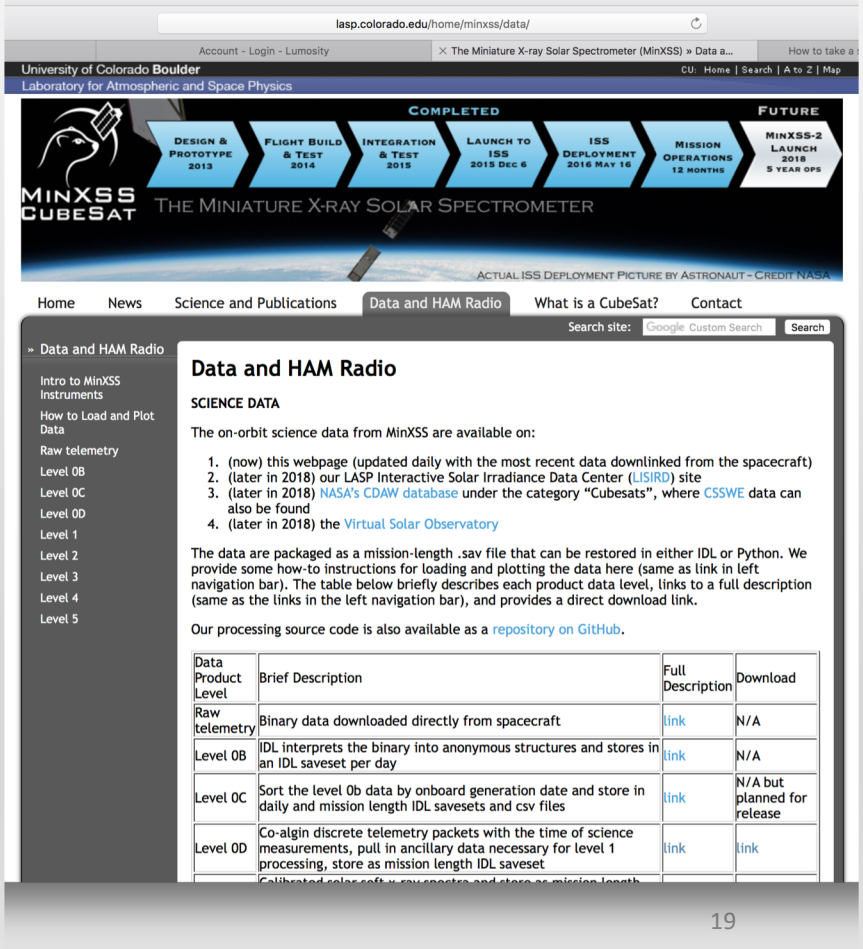
- Amir Caspi
  - amir@boulder.swri.edu



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