

Solar Flare Plasma Transport Inferred from Elemental Abundance Changes using soft X-ray Spectra

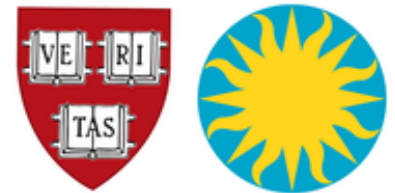
Crisel Suarez

Fisk-Vanderbilt Master's to PhD Program



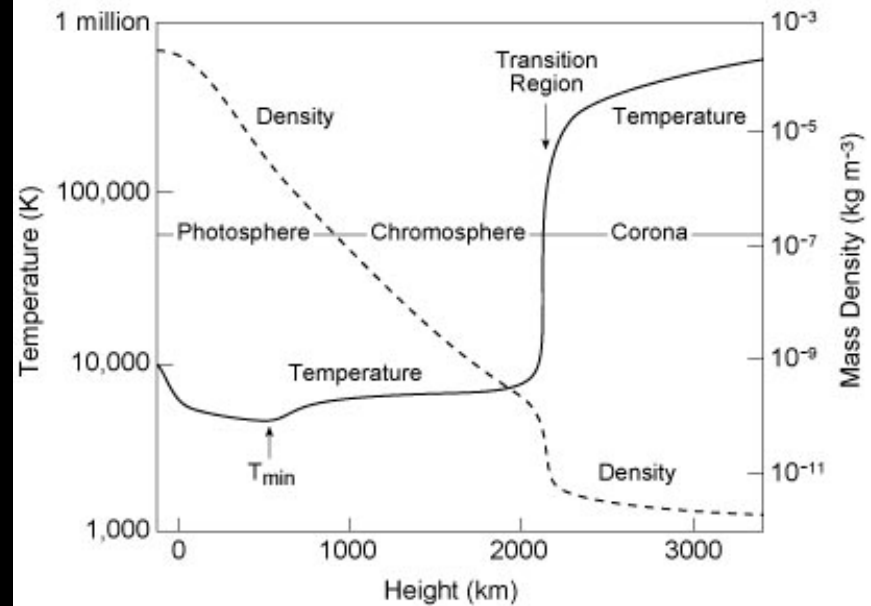
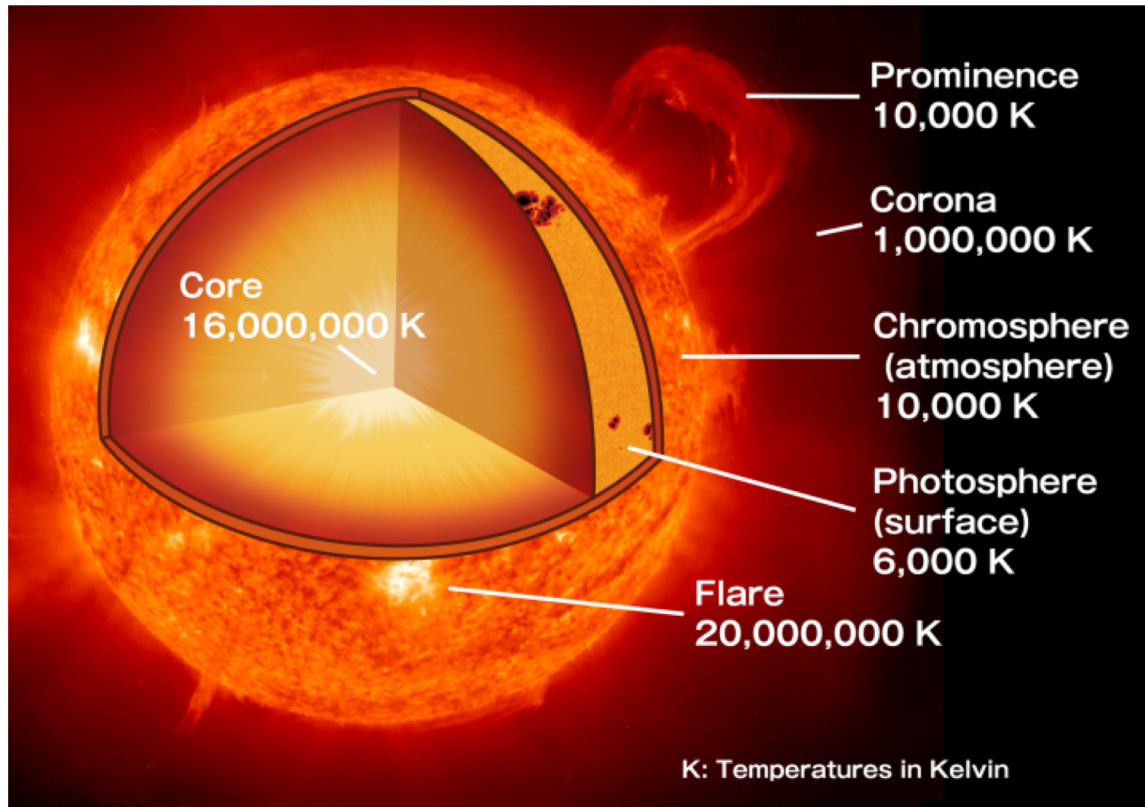
Mentored by: Dr. Chris Moore

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CfA Sun Background

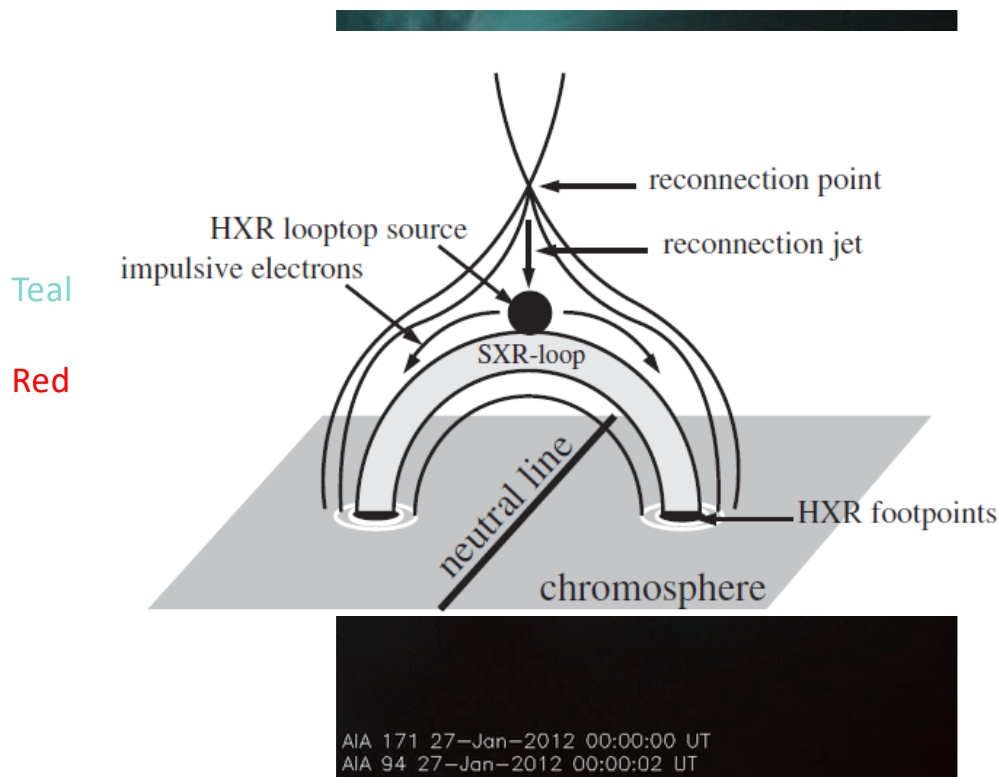


<https://aasnova.org/2018/07/25/shocks-in-the-solar-atmosphere/>
https://ase.tufts.edu/cosmos/view_picture.asp?id=174

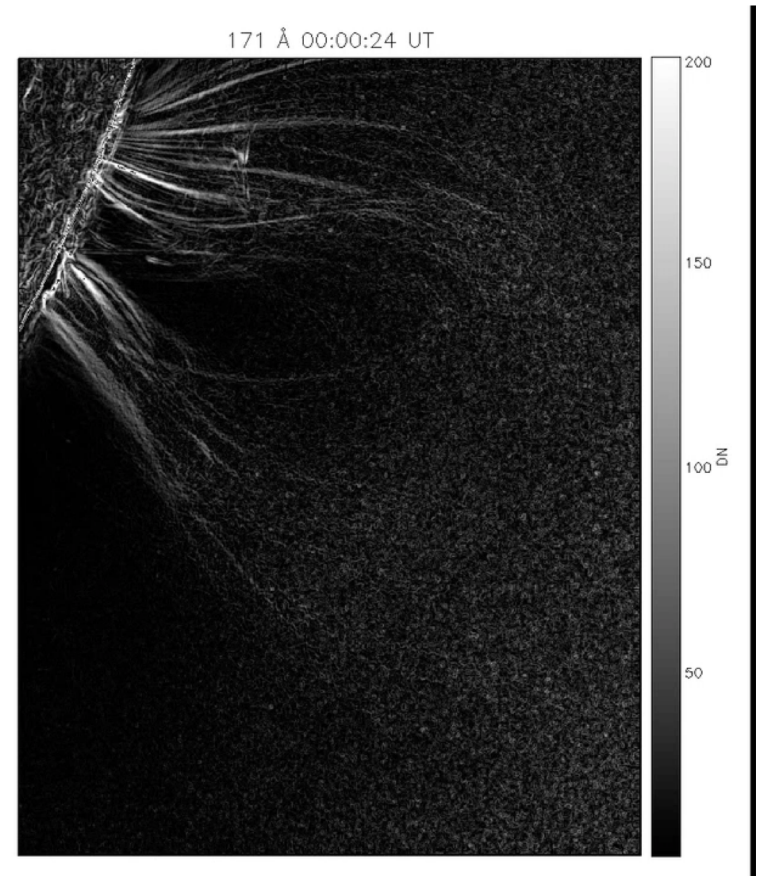


Flares are Magnetic Reconnection Events!

Composite Intensity Image



Difference Image

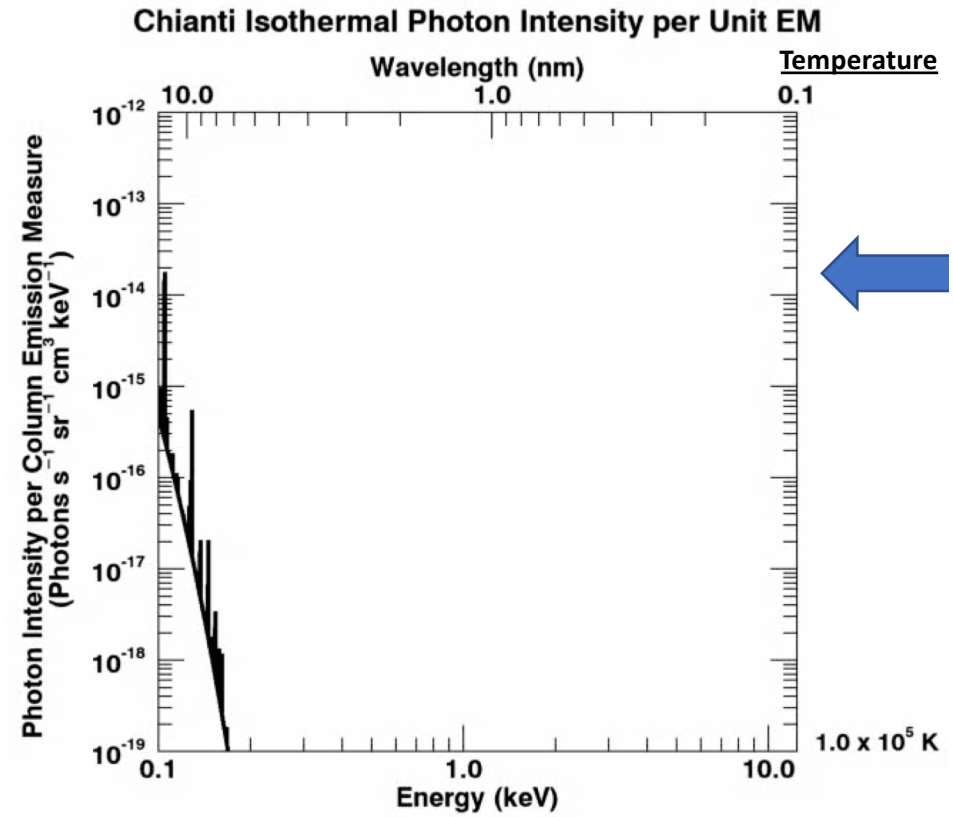
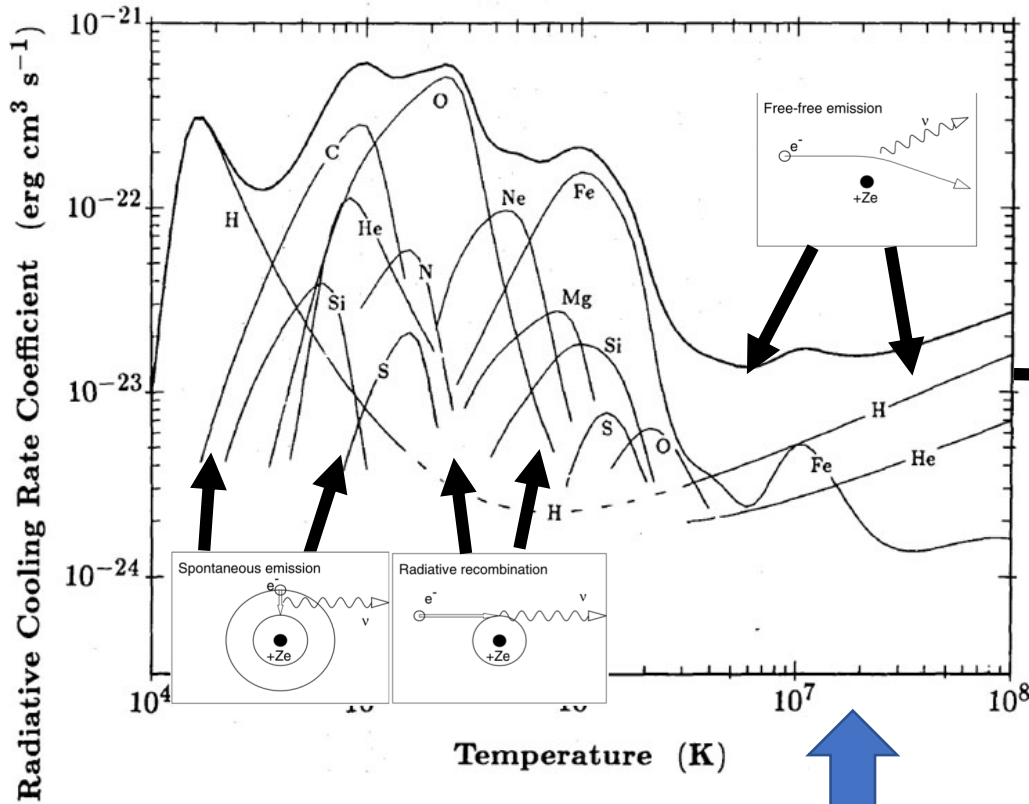


Slide courtesy of Chris Moore

Sun et al. 2015



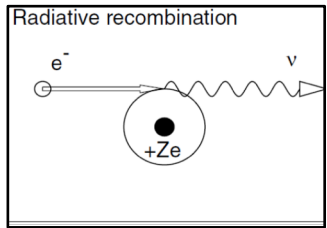
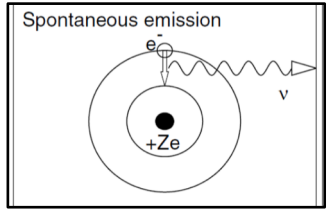
Radiative Cooling and Model Plasma Spectra



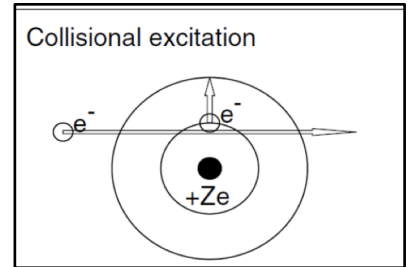
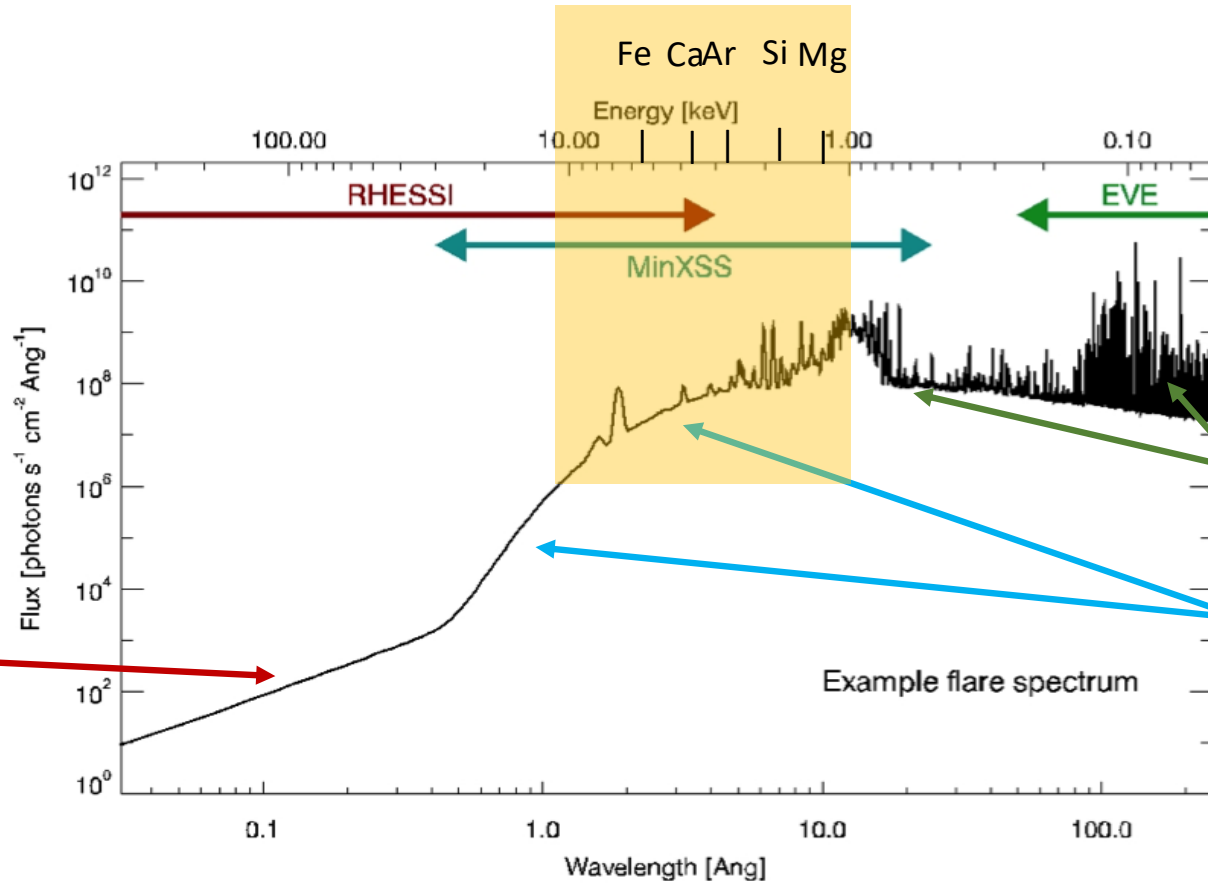
Slide courtesy of Chris Moore



Models X-Ray Spectra

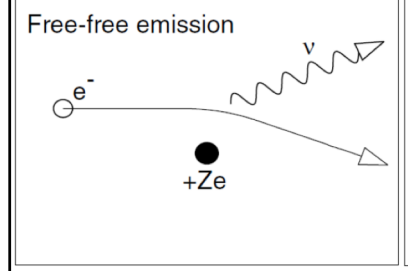


**- Free-Free Emission -
Non-Thermal
Bremsstrahlung
(Accelerated Electrons)**



**- Bound-Bound Emission -
- Free-Bound Emission -
(Ions)

- Free-Free Emission -
Thermal Bremsstrahlung**





MinXSS CubeSats



- **Miniature X-Ray Solar Spectrometer**
 - Dimensions ~ 34 x 10 x 10 cm (13.4 x 4 x 4") 'cube'
 - Mass ~ 3.5 kg
- **X-ray Spectrometer (X123)**
 - Amptek X123 Silicon Drift Diode (SDD)
 - 0.8 – 12 keV bandpass
 - 0.03 keV bins -> **0.15 keV FWHM resolution**
 - $\Delta t = 10$ seconds cadence
 - FOV = 4°
 - $\Delta V \sim E_{ph}$

Pivotal Professionals

P.I.: Tom Woods
Chris Moore
Amir Capsi
Phil Chamberlin
Rich Kohnert
James Mason
Scott Palo





Previous elemental abundance results in Soft X-ray Flare

- *Elemental Abundances in the Solar Corona as Measured by the X-ray Solar Monitor Onboard Chandrayaan-1* -Narendranath et al. 2014
- *Solar Flare Element Abundances from the Solar Assembly for X-Rays (SAX) on Messenger* - Dennis et al. 2015
- Distinctive Results!!!



SAX and XSM- Results

Messenger Solar Assembly for X-rays (SAX)

- Six-year mission- 2007 to 2013
- 526 large flares
- Analyzed Messenger SAX solar flare data ($\Delta E \sim 0.6 \text{ keV @ } 5.9 \text{ keV}$)
 - Estimate elemental abundance enhancement
 - 1 – 10 keV

Chandrayaan-1 X-ray Solar Monitor (XSM)

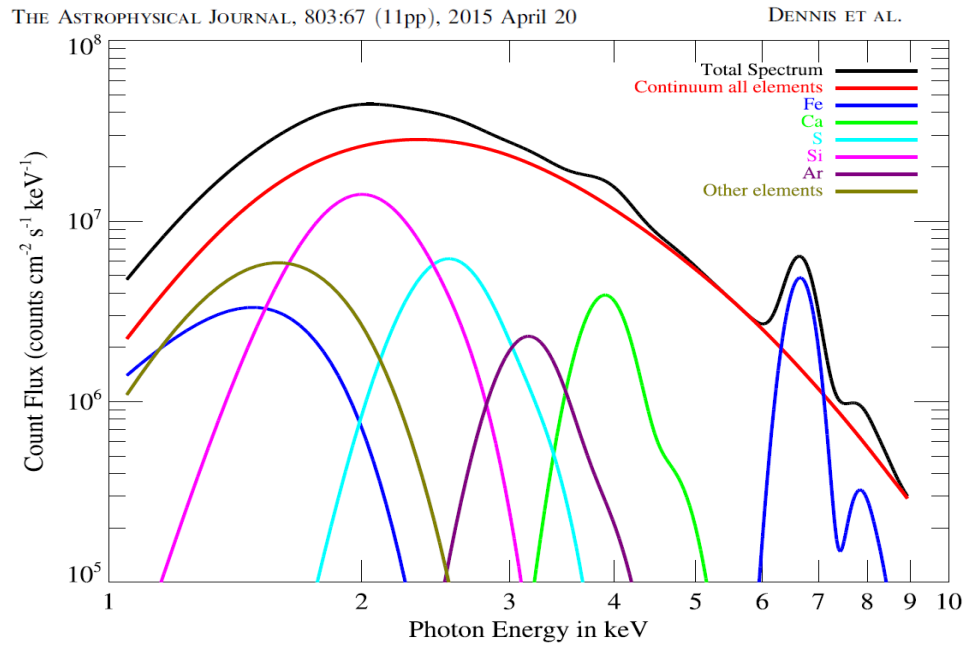
- Nine-month mission- November 2008 to 29 August 2009
- ~23 A, B, C class flares
- Analyzed Chandrayaan-1 XSM ($\Delta E \sim 0.2 \text{ keV @ } 5.9 \text{ keV}$)
 - Estimate elemental abundance enhancement
 - 1.8 – 8 keV

MinXSS- spectral resolution ($\Delta E \sim 0.15 \text{ keV}$), >40 potential flares C and M flares, enhance previous solar flare abundance studies, broader spectral coverage (0.8 – 12 keV bandpass)



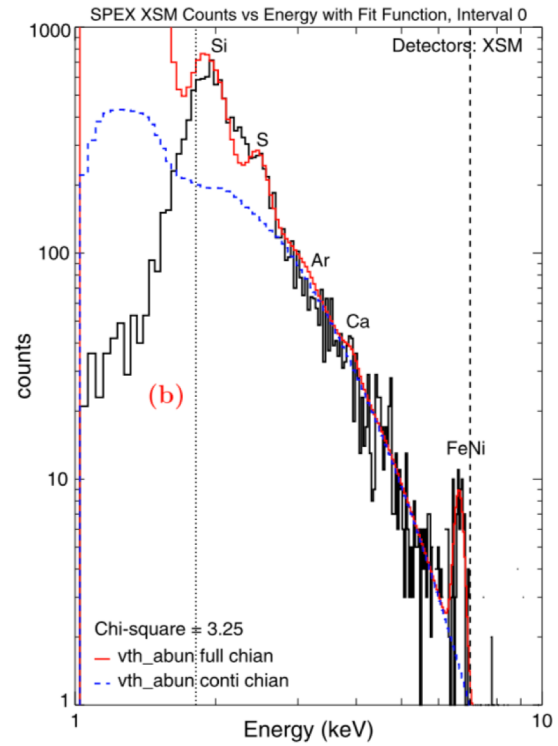
SAX and XSM- Analysis

Messenger Solar Assembly for X-rays (SAX)



Dennis et al. 2015

Chandrayaan-1 X-ray Solar Monitor (XSM)

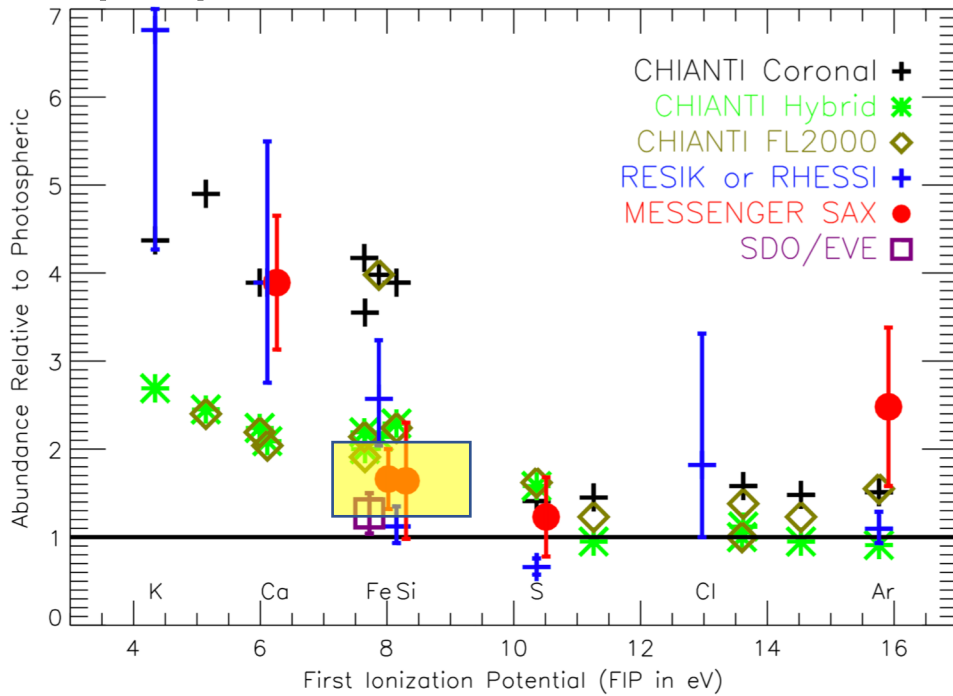


Narendranath et al. 2014



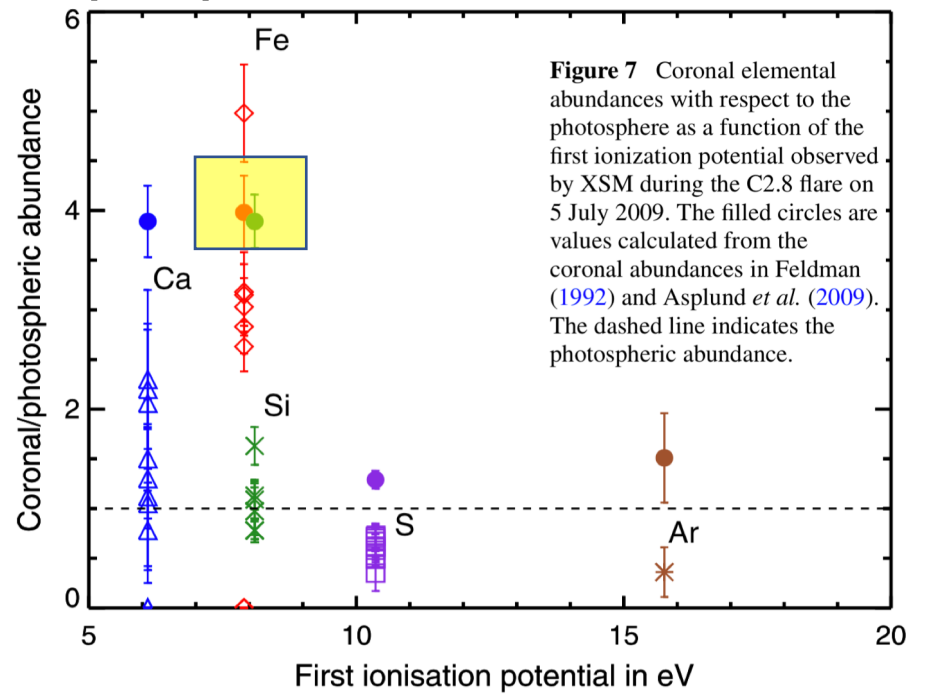
SAX and XSM- Results

Messenger Solar Assembly for X-rays (SAX)



- Ar shows anomalous behavior
- Seems self-consistent
- Fe and Si photospheric

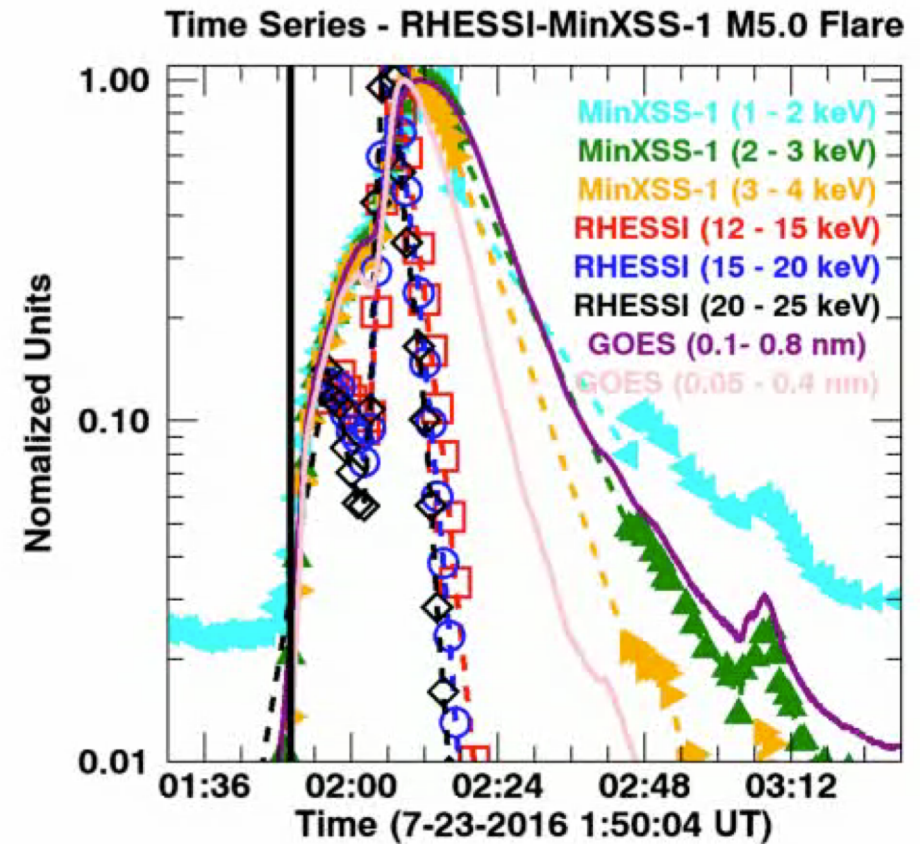
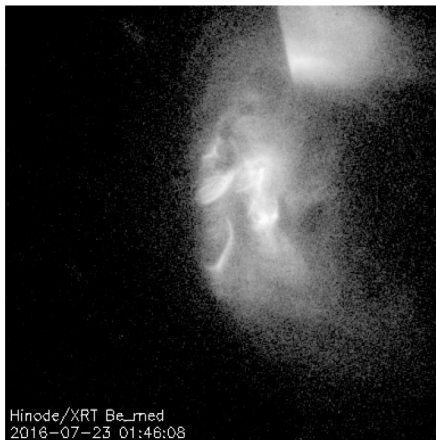
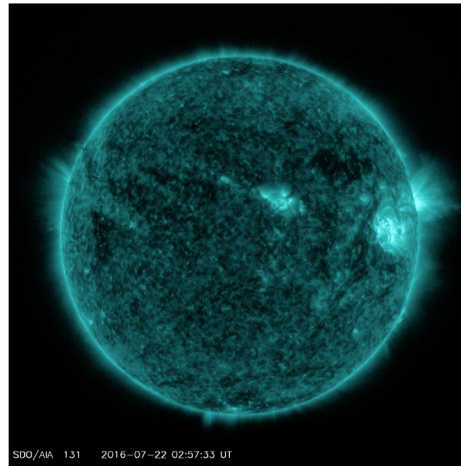
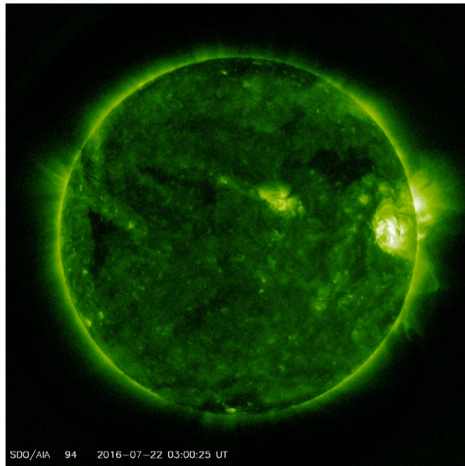
Chandrayaan-1 X-ray Solar Monitor (XSM)



- Fe > Ca > Si



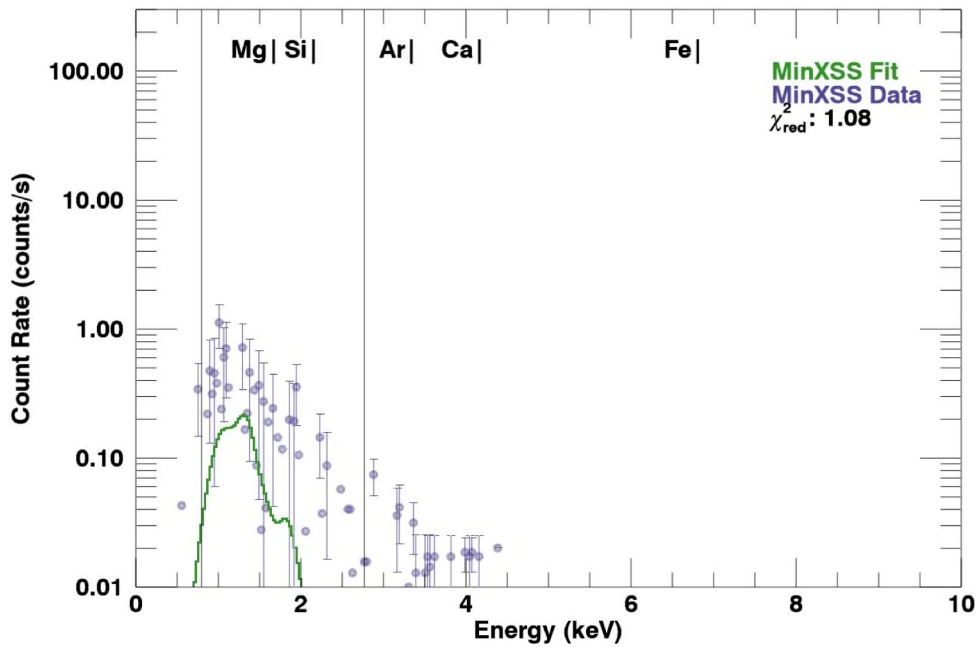
Start own study of MinXSS M5.0 Flare July 23, 2016



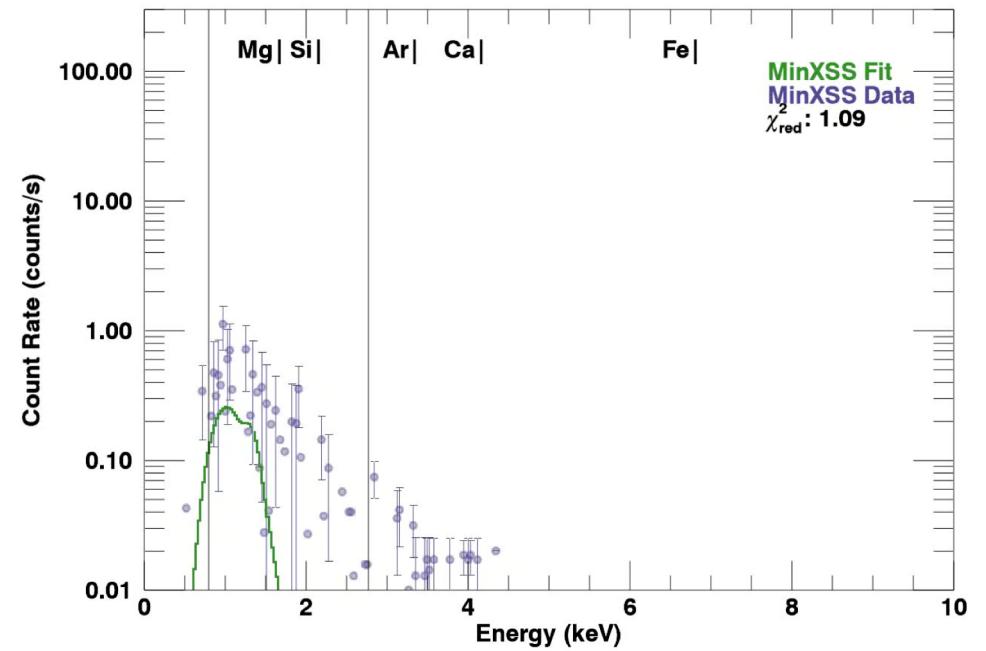


MinXSS Spectra- Fix Elemental Abundance

Spectral Fit of M5.0 Flare 1TCoronal



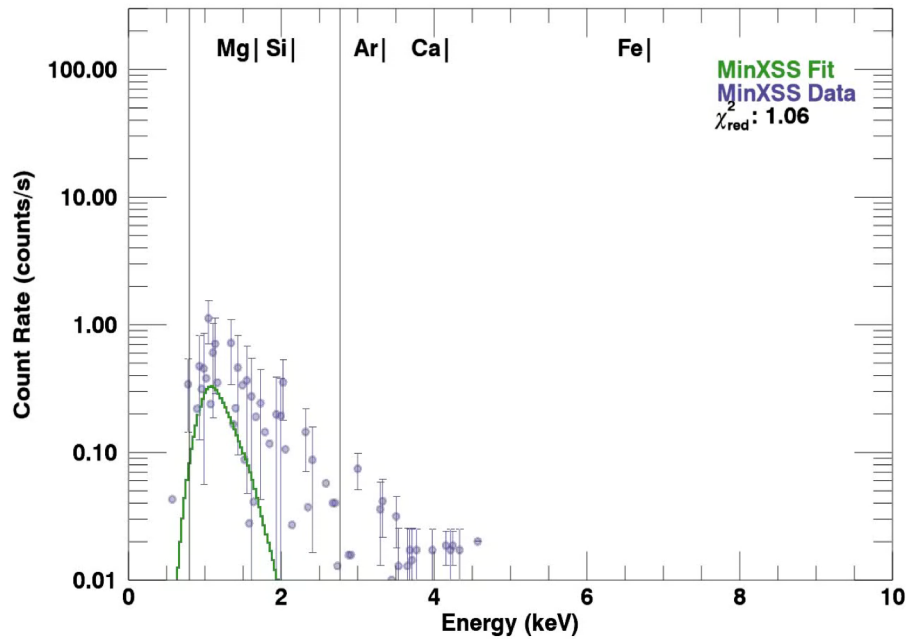
Spectral Fit of M5.0 Flare 2TCoronal



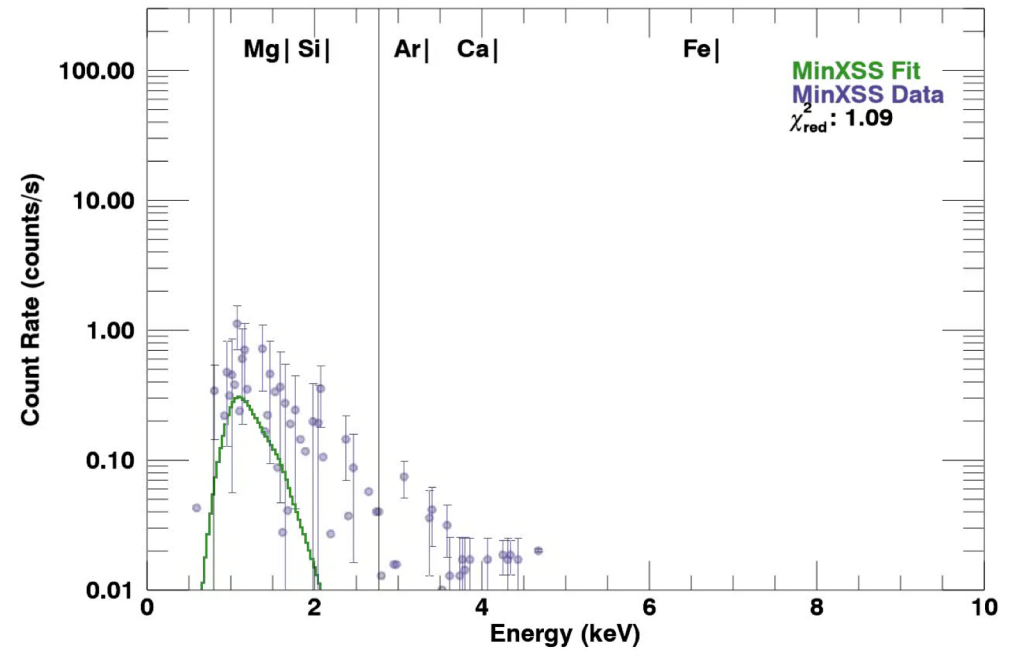


MinXSS Spectra- Single Scale Factor for Low FIP

Spectral Fit of M5.0 Flare 1TFree

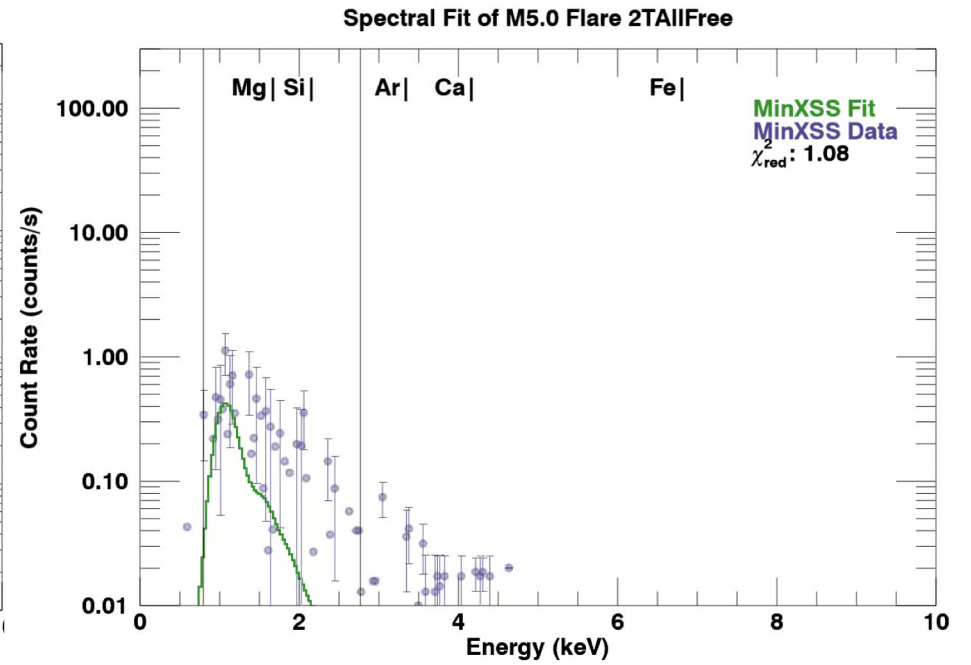
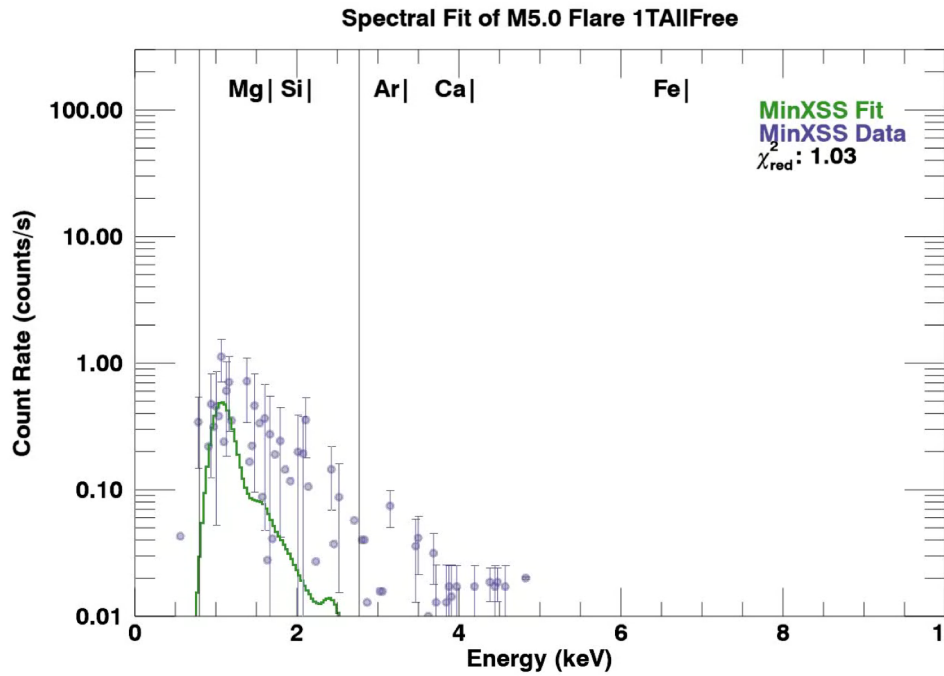


Spectral Fit of M5.0 Flare 2TFree



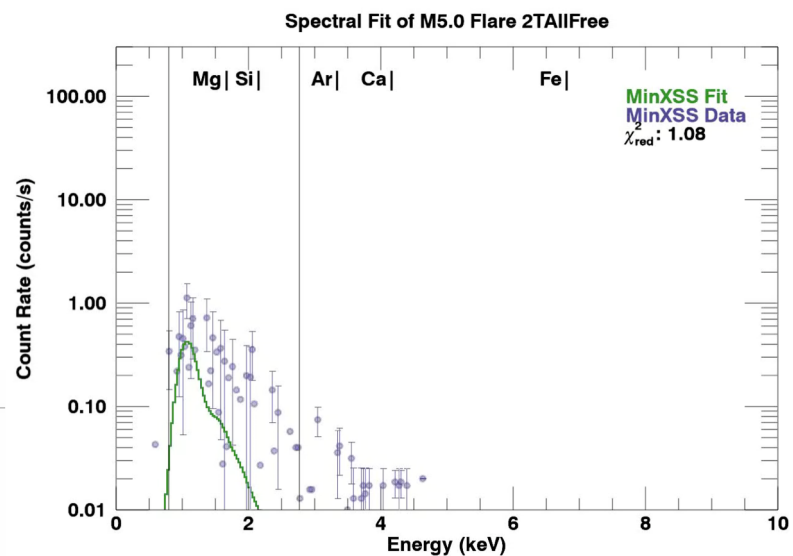
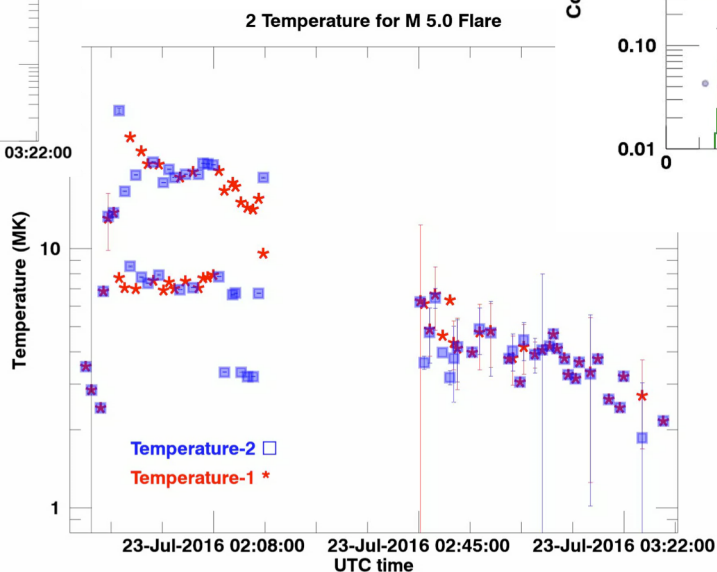
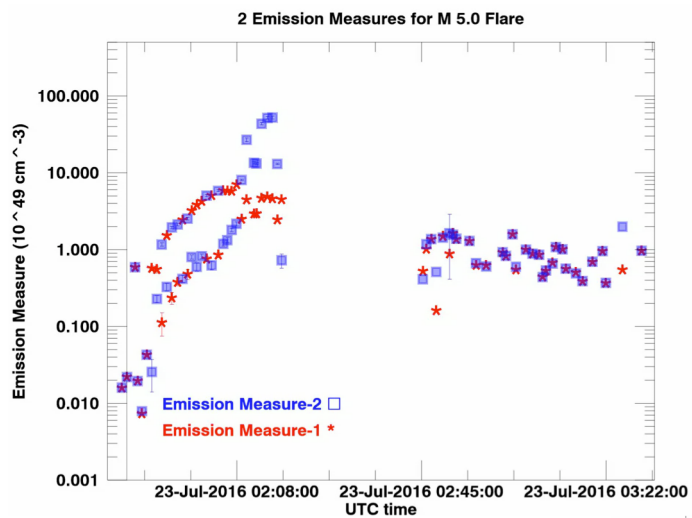


MinXSS Spectra- All Elemental Abundance Varies





MinXSS-2T-All Free Temperature & Emission Measure

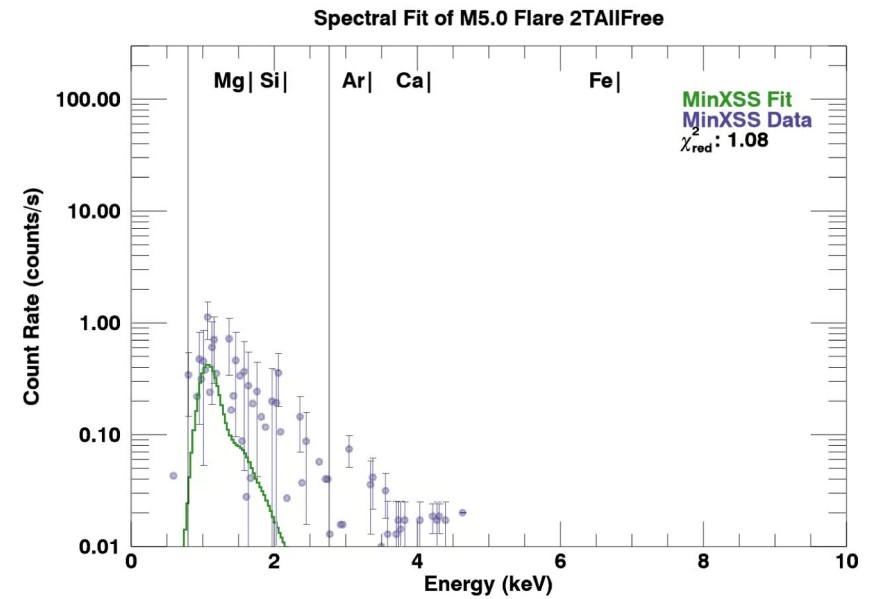
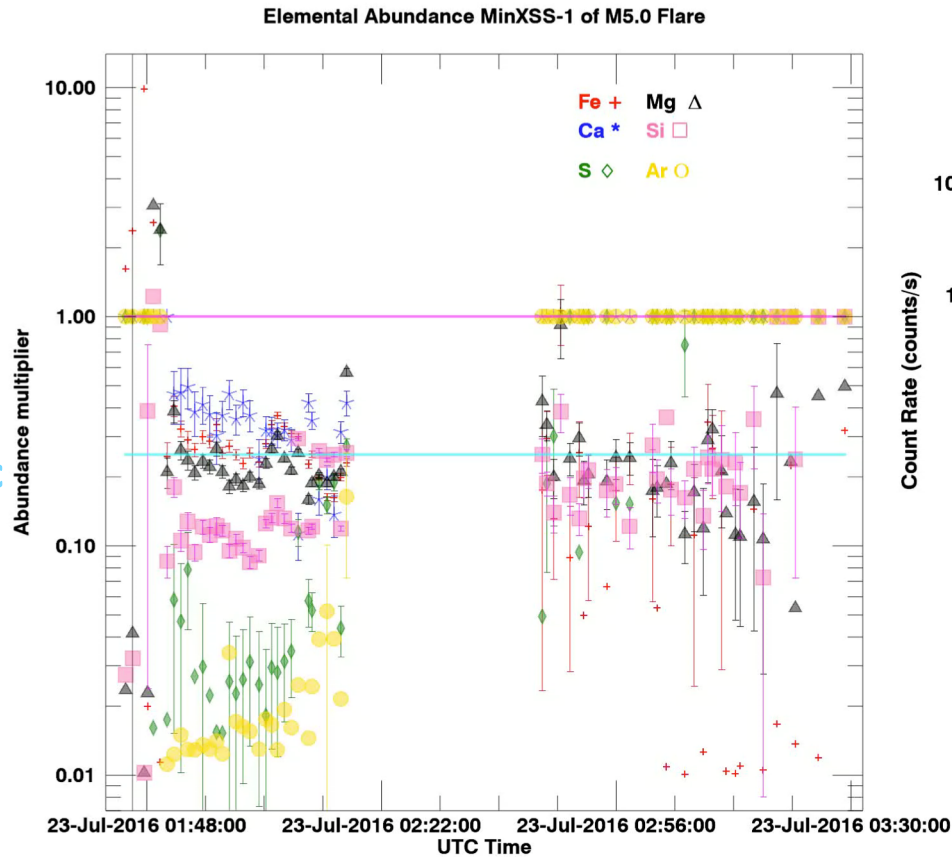


MinXSS-2T-All Free Abundances



Coronal Abundances

Photospheric Abundances



Results

- Fit M5.0 Flare with several fits
- Consistent 20 MK temperature
- Need more temperature components to fit data
- Low fip match Dennis et al. results – photospheric abundance

Future Work

- Analyze more MinXSS Flares
 - Compare results to other soft X-Ray studies

- Differential Emission Measure
 - Use other instruments like XRT to constrain temperature sensitivity



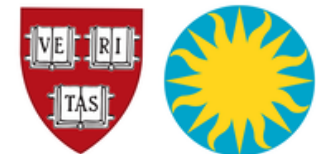
Summary

Soft X-Rays spectra is sensitive to temperature, emission measure and elemental abundance



Acknowledgments

- Chris Moore, Kathy Reeves, Rodolfo Montez, Solar REU Interns, SSXG
- Smithsonian Latino Center.
- NSF-REU Solar Physics program at SAO, grant number AGS-1560313.
- NSF- Fisk-Vanderbilt Master's-to-Ph.D. Bridge Program Grant No. HRD-1547757.
- MinXSS-1 CubeSat mission is supported by NASA Grant NNX14AN84G.



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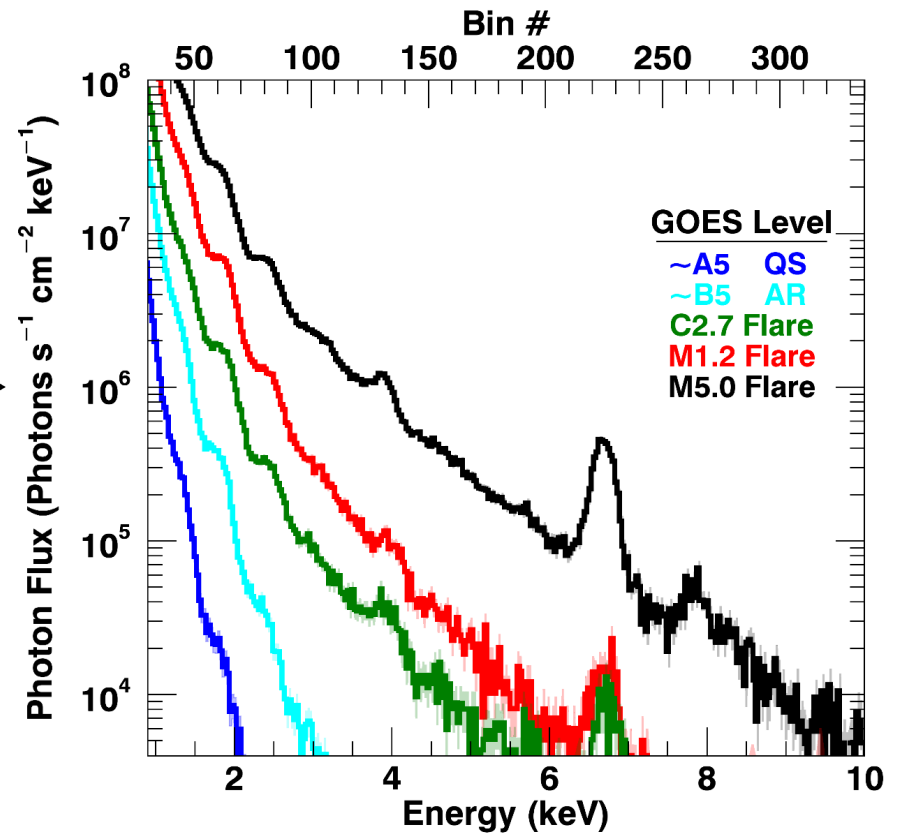
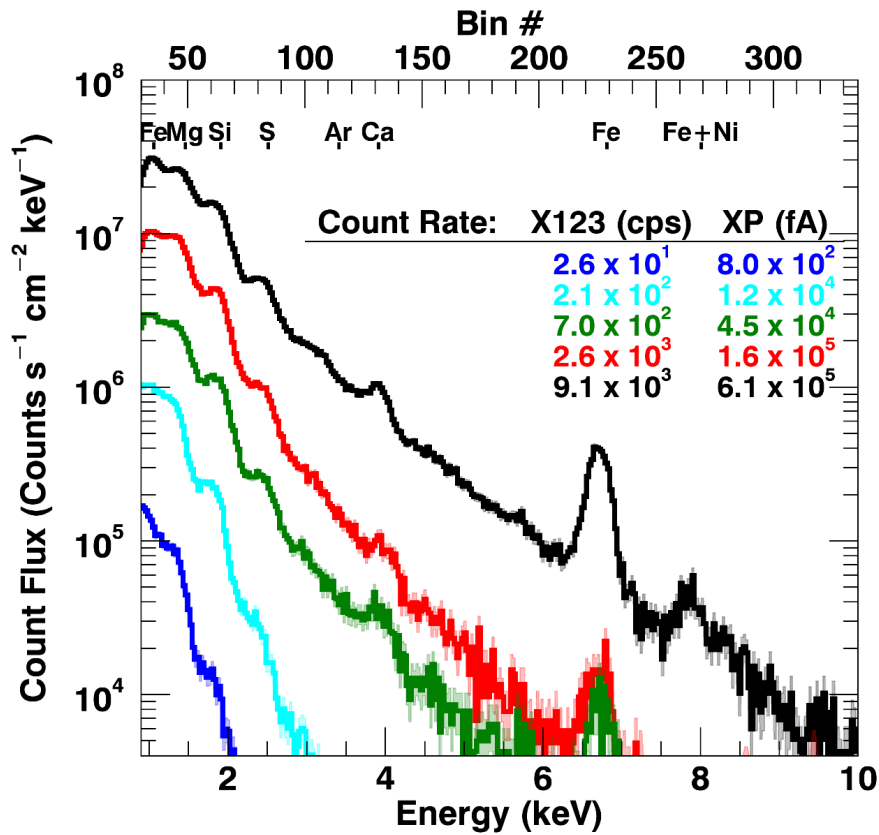
Thank you!





Models X-Ray Spectra

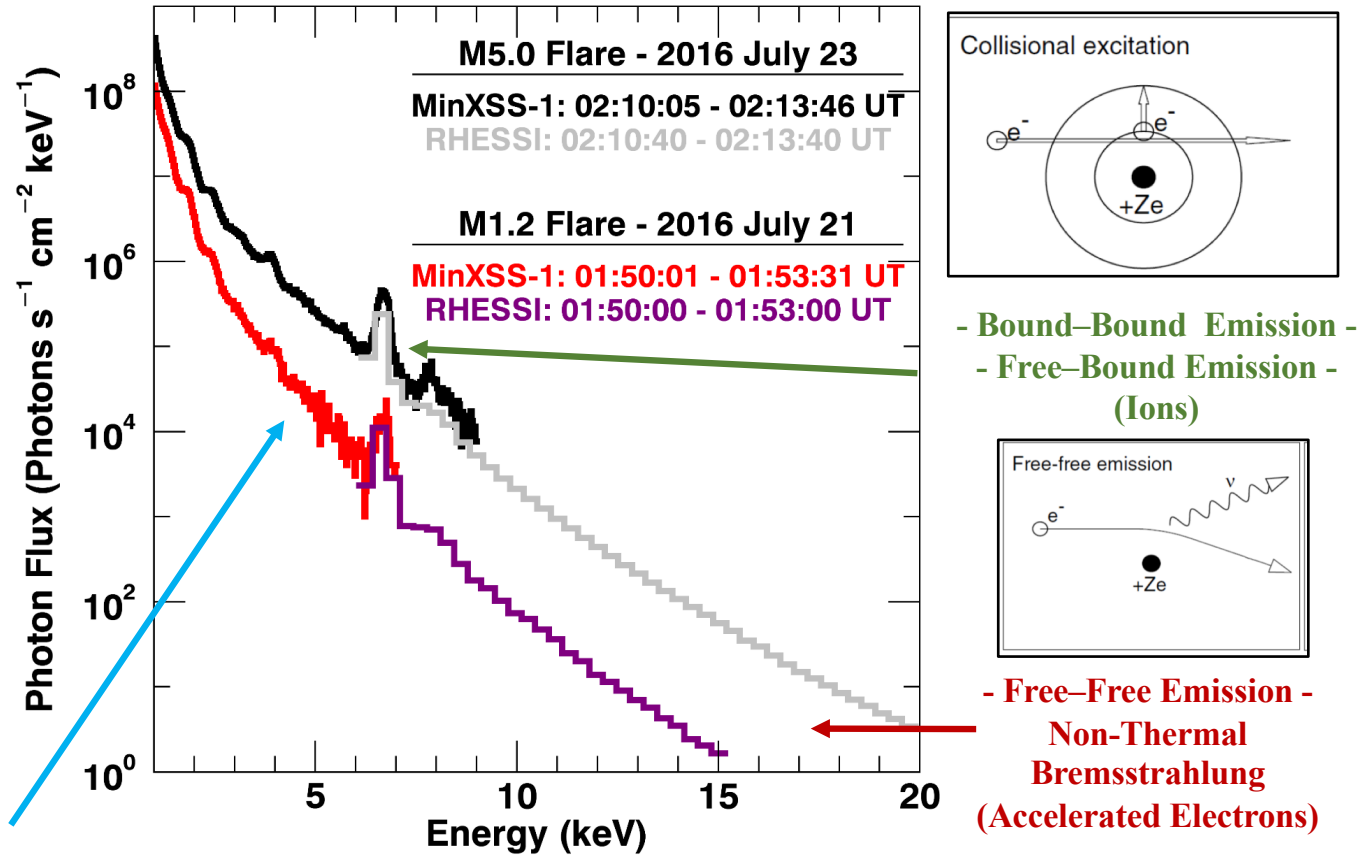
MinXSS-1 | GOES Levels A5 - M5





MinXSS-1 + RHESSI Flare Spectra

MinXSS-1 + RHESSI Spectra



Slide courtesy of Chris Moore

Moore et al. 2018 (published in Solar Physics)