CubeSats for Solar Soft X-ray Spectroscopy: MinXSS and CubIXSS

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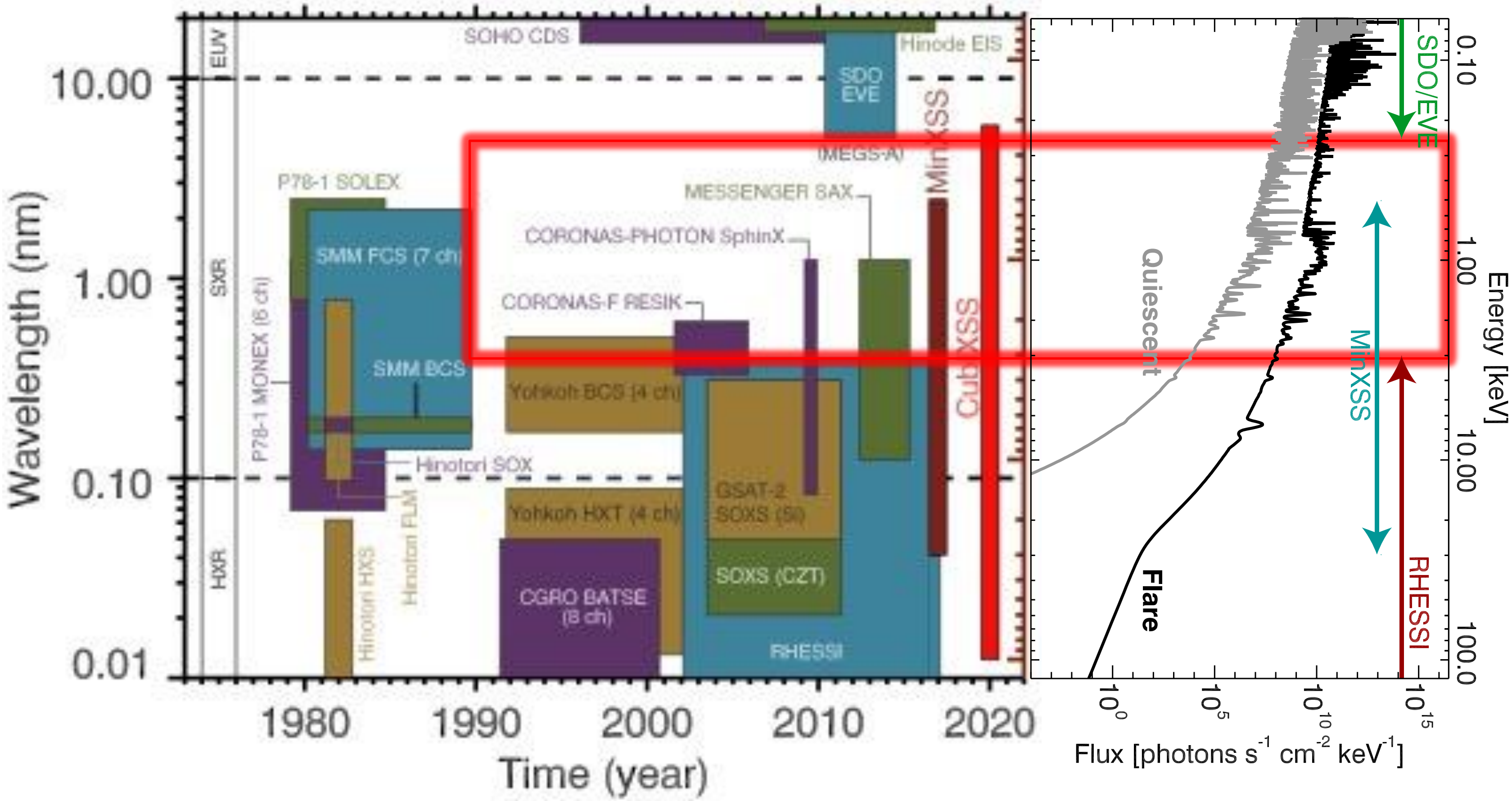
+ the MinXSS Team

+ the CubIXSS Team

Spectrally-Resolved SXR Observations

- Crucial observational gap from ~0.2 to ~3 keV (~0.4 to ~6 nm) with very few spectrally-resolved observations in previous decades

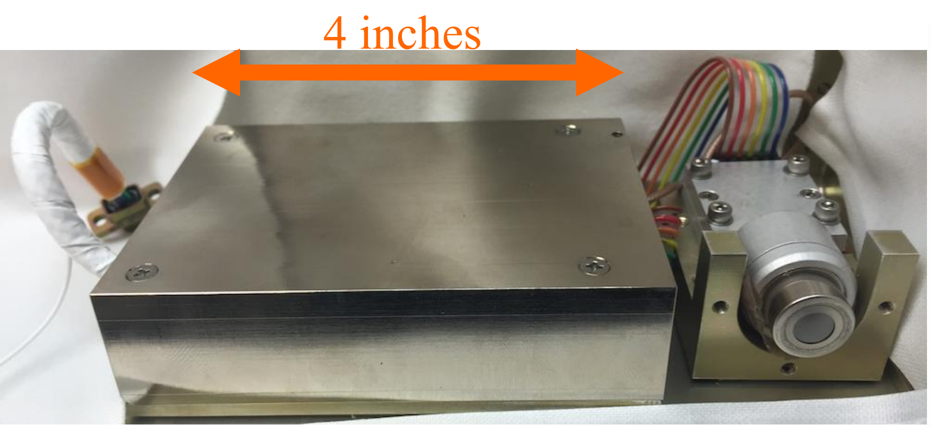


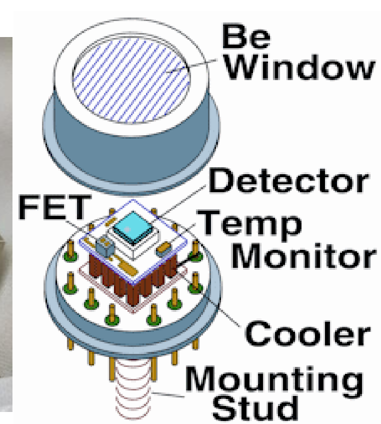
Spectrally-Resolved SXR Observations

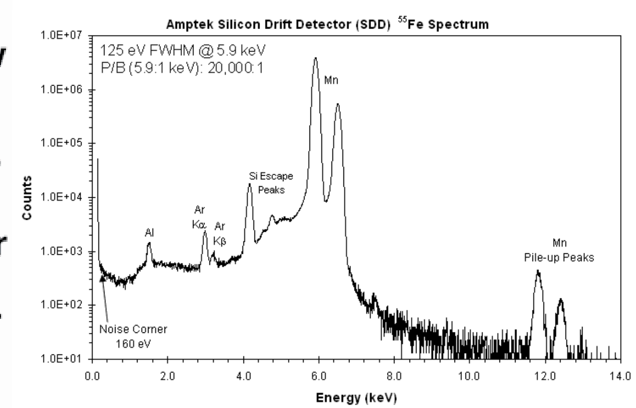
- Crucial observational gap from ~0.2 to ~3 keV (~0.4 to ~6 nm) with very few spectrally-resolved observations in previous decades
- Rich with med- and high-T lines and continuum for diagnostics of coronal plasma temperatures
- Extremely sensitive to temperature, esp. high T
- Especially important for non-flaring corona, where there is little >3 keV (<0.4 nm) emission
  - *Critical* for understanding heating and for interpreting nonthermal observations
- Large photon fluxes

X123 Soft X-ray Spectrometer

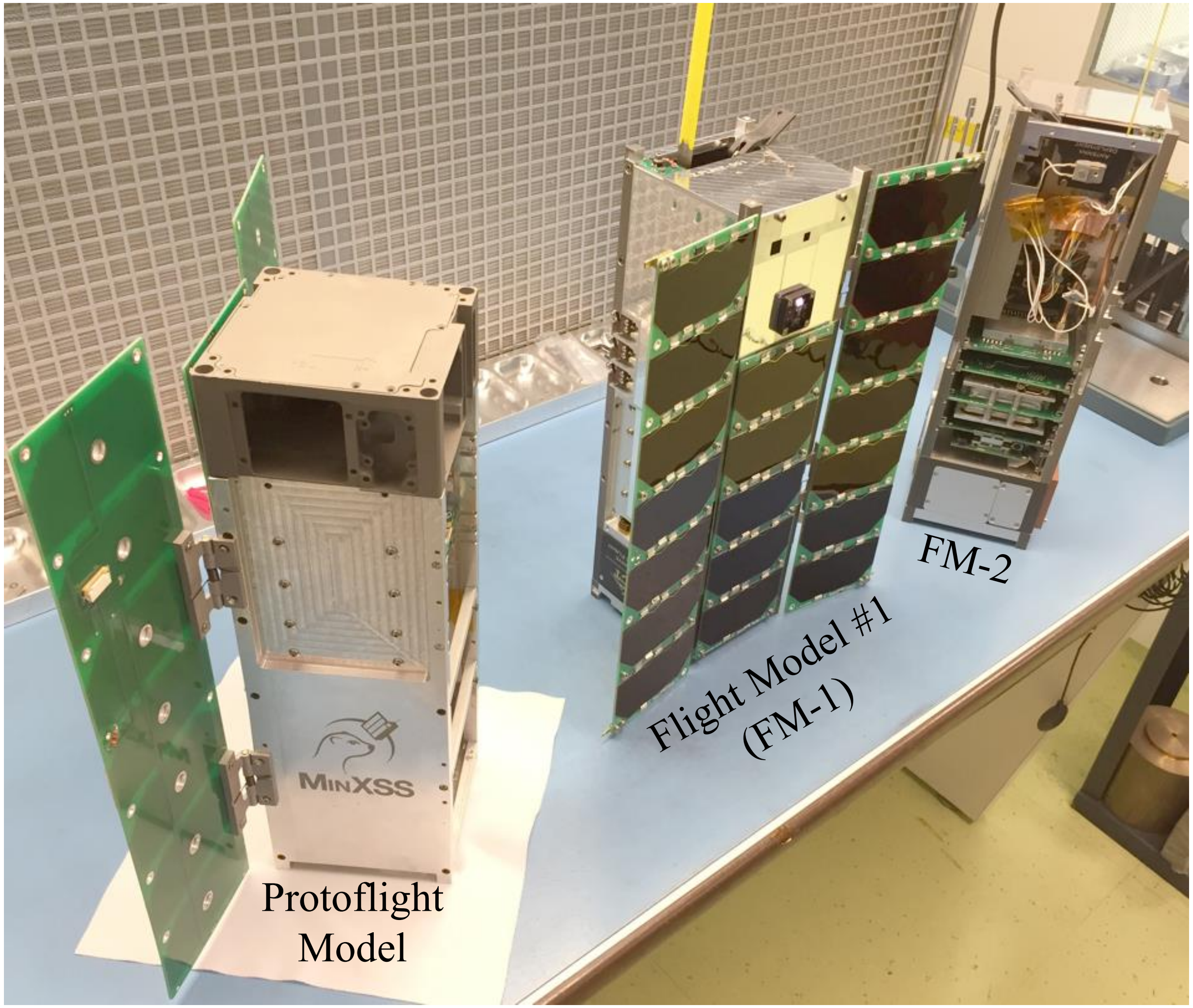
- Amptek X123-SDD X-ray spectrometer package:
  - 500 µm Silicon Drift Detector (SDD), 8 µm Be window
  - ~0.5–30 keV (~0.04–2.4 nm) @ ~0.15 keV FWHM
    - Up to ~200 kpcs, on-board pulse pileup rejection
  - All in one: TEC, HVPS, CPU included
  - 7 × 10 × 2.5 cm, ~300 g (with mods), ~2.5 W, $11K + mods







Miniature X-ray Solar Spectrometer



MinXSS-1 CubeSat

Deployed from ISS on May 16, 2016

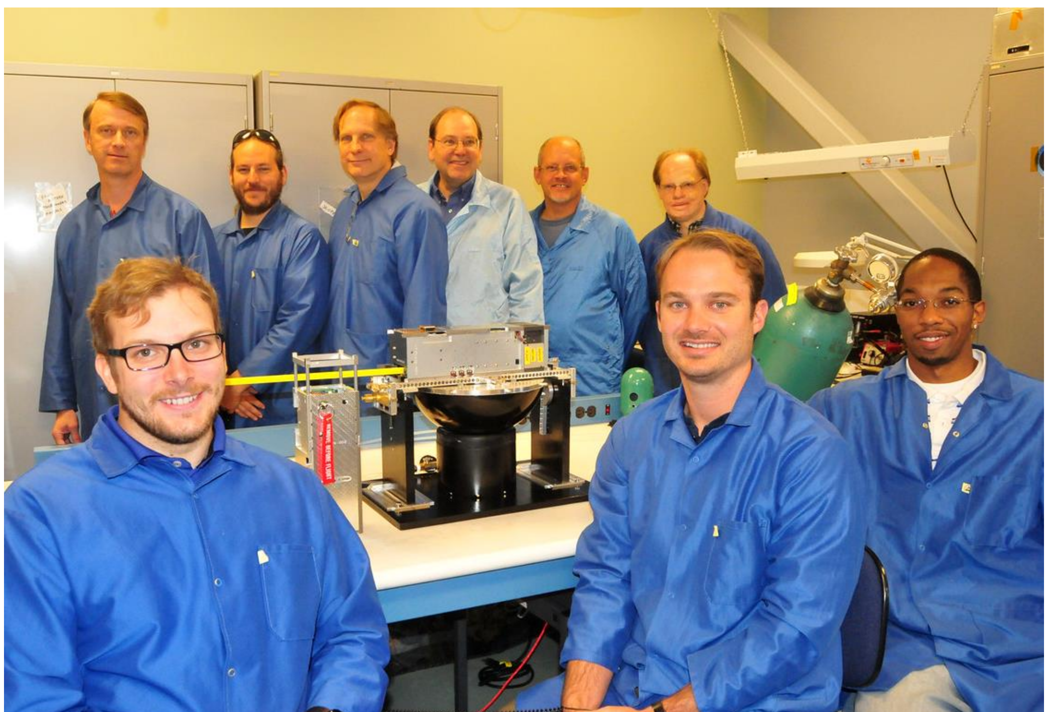
MinXSS Science Team: Tom Woods (PI, LASP), Amir Caspi (SwRI), Phil Chamberlin (GSFC), Andrew Jones (LASP), Rick Kohnert (LASP), James Mason (LASP), Chris Moore (CU-APS), Scott Palo (CU-AES), Stan Solomon (NCAR-HAO)

MinXSS is NASA Science Mission Directorate's *first* CubeSat in space!

MinXSS CubeSat

Led by CU Boulder's LASP, in collaboration with SwRI, NASA/GSFC, NCAR/HAO, and industry partners

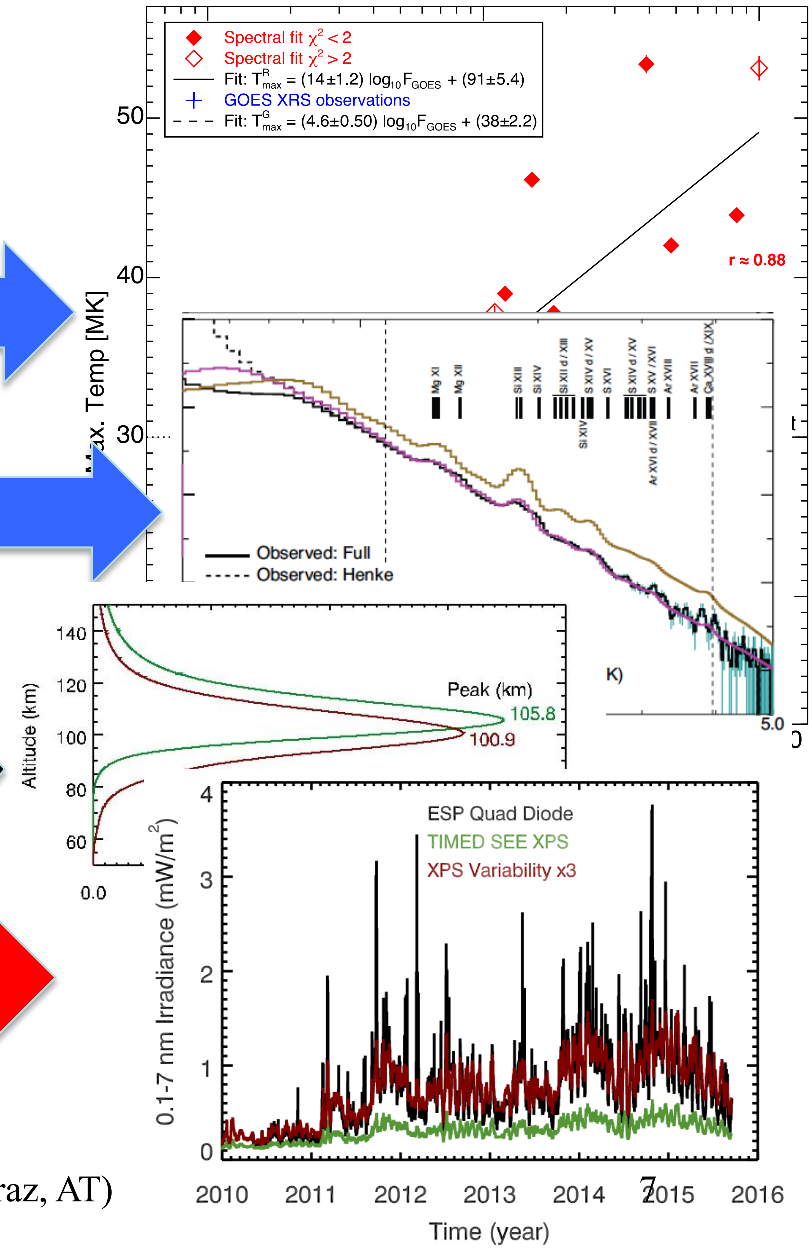
44 students and over 40 professional scientists and engineers involved



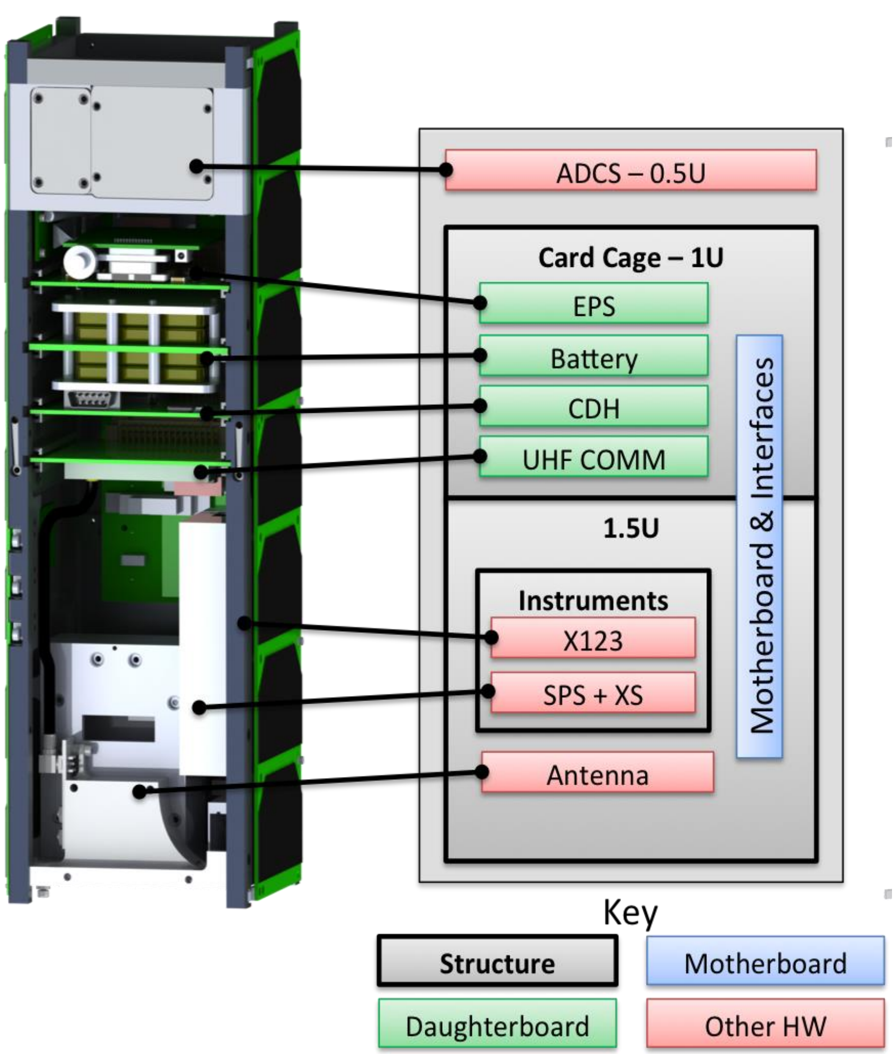
MinXSS Science Objectives

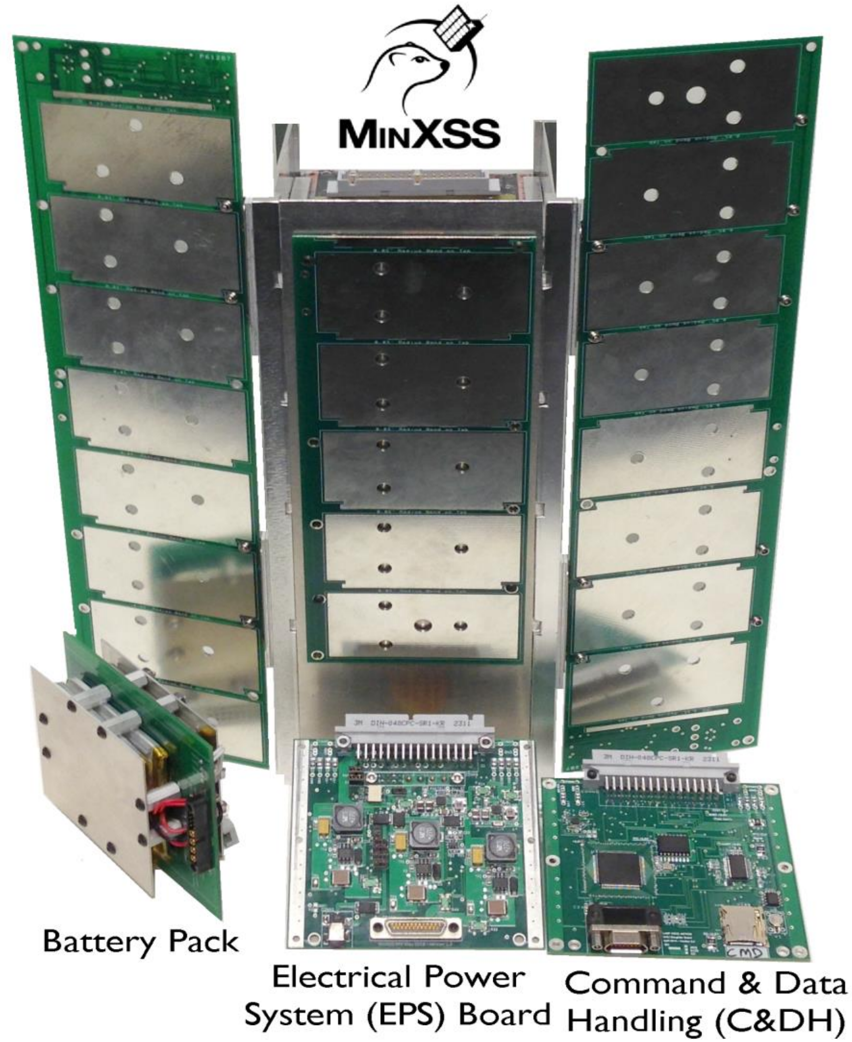
New Soft X-Ray (SXR) spectra measurements can address the following outstanding issues:

- Flare energetics (plasma heating mechanisms)
- Active region evolution (corona heating and abundances)
- Earth's E-region ionosphere energetics and variability
- Factor of 3 difference in irradiance from broad band SXR photometers



MinXSS CubeSat Design Overview





Acronyms: Command and Data Handling (CDH), Electrical Power System (EPS), Communications (COMM, Li-1 UHF Radio), Attitude Determination and Control System (ADCS, BCT), Solar Position Sensor (SPS), X-ray Sensor (XS), X123 is Amptek X-ray spectrometer.

Enabling Technology – precision ADCS

- Blue Canyon Technology (BCT) XACT ADCS specification
  - Mass: 850 g   Size: 0.5 U
  - Power: < 2 W   using 5 V and 12 V DC
  - Pointing Accuracy: < 25 arc-sec
  - Pointing Stability: < 10 arc-sec
  - Slew Rate: > 10 deg/sec
  - ADCS components: star tracker, coarse sun sensor, 3 reaction wheels, 3 torque rods, magnetometer, IMU, ADCS processor

MinXSS Statistics

Deployed: 16 May 2016
Days in Orbit: 75
Orbit #: 1155

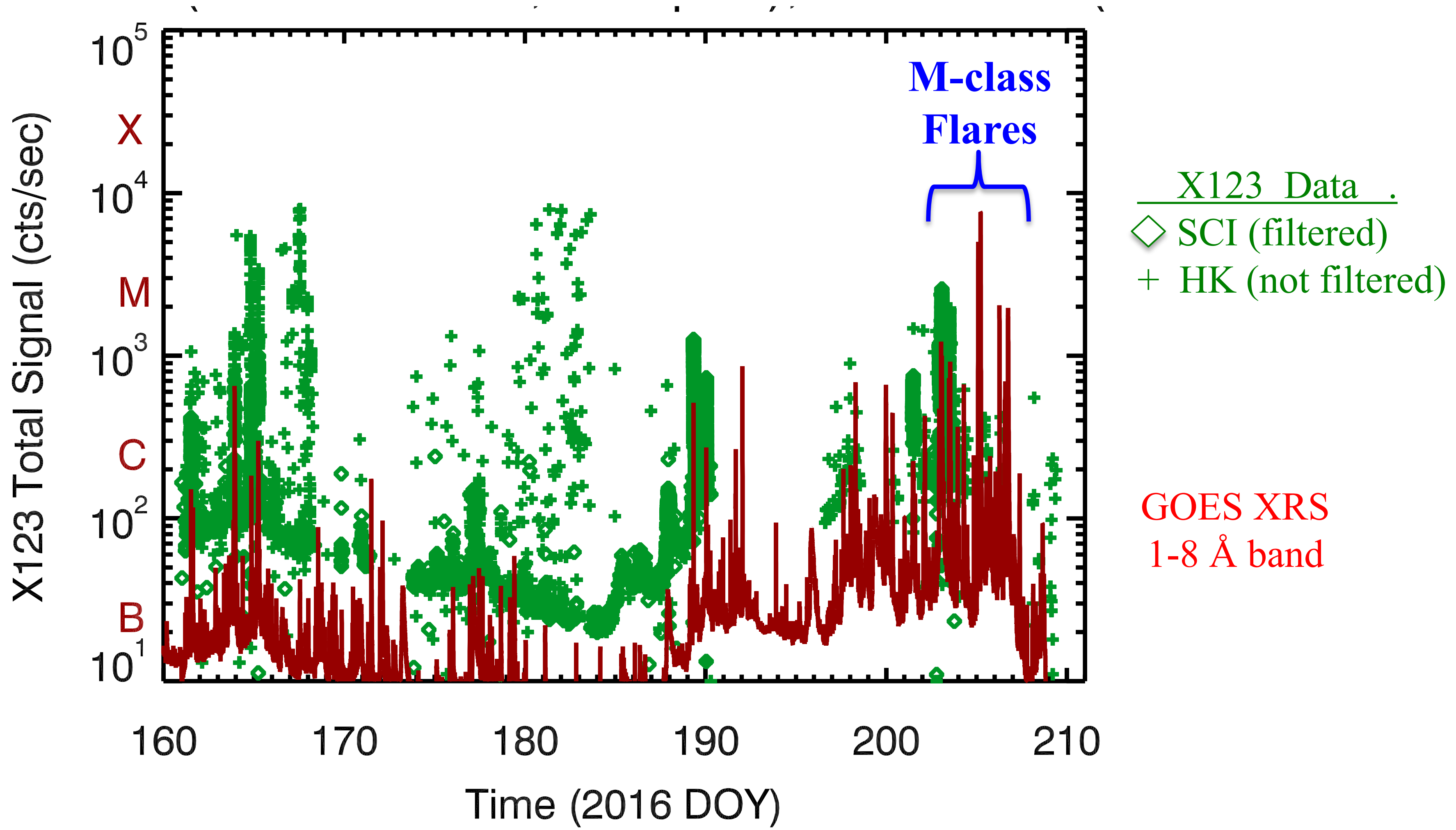
LEO, ~400 km
~1 yr lifetime

~10 W power consumption
Power-positive w/ 35% margin

Pointing: ~8” ± 2”

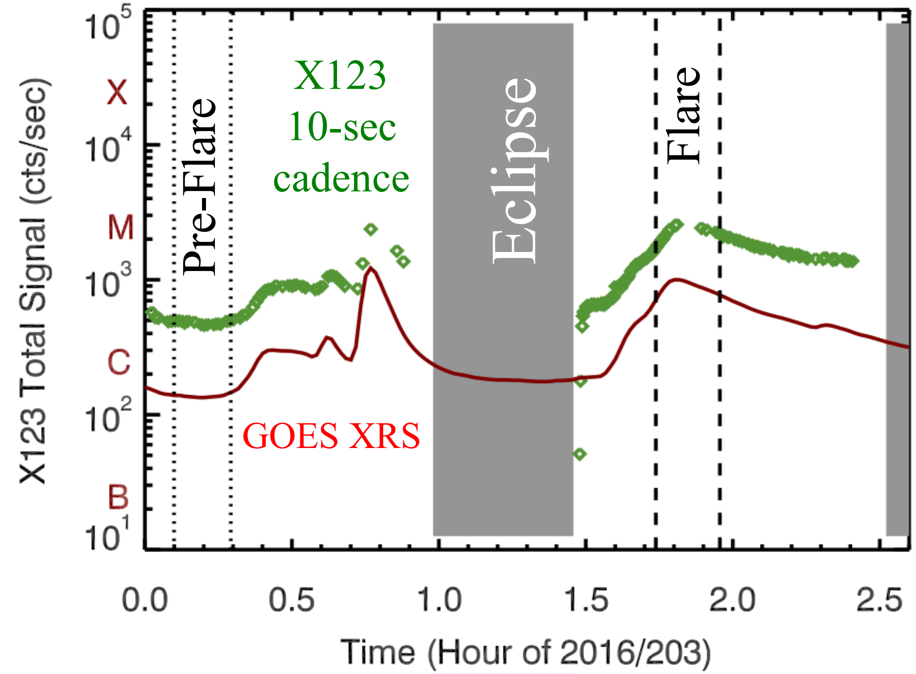
First light: 30 May 2016

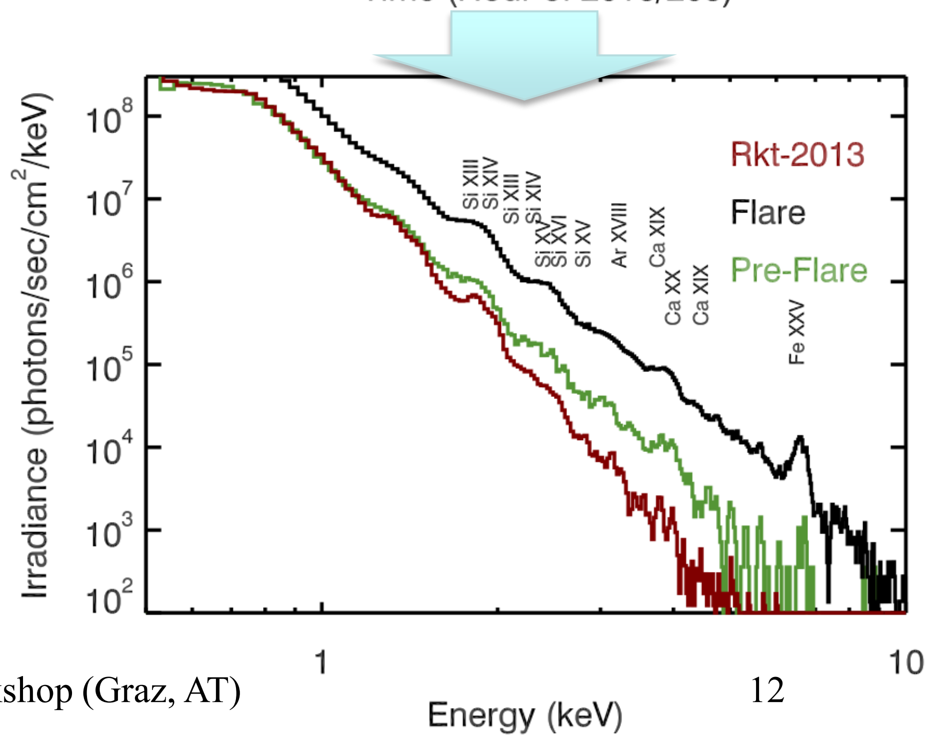
MinXSS June-July Observations
7 M-class flares and ~40 C class flares



Example X123 Soft X-ray Spectra

M1.2 Flare on DOY 203 (7/21/16)



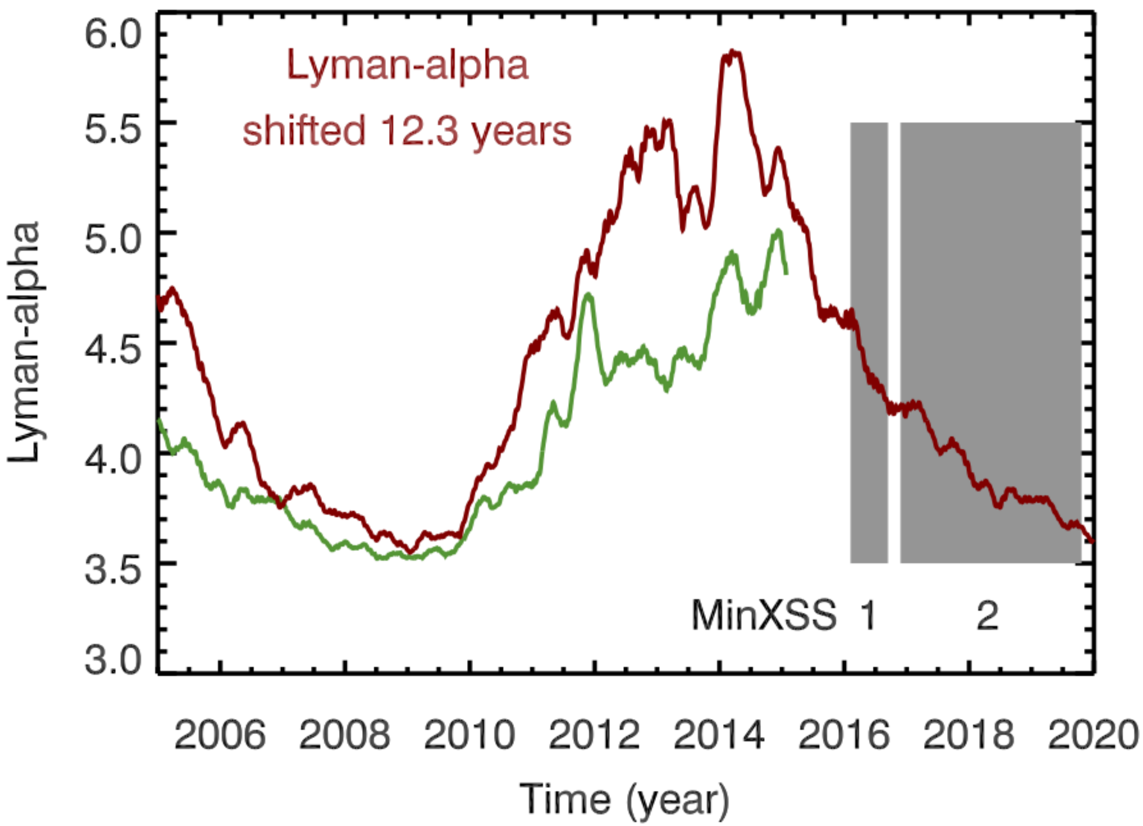


The rocket 2013 X123 measurement for active (non-flaring) sun is included for comparison as the red spectrum [Caspi, Woods, & Warren, *ApJ Lett*, 2015].

MinXSS Level 1 Irradiance Spectra will be released in August at http://lasp.colorado.edu/home/minxss/

Two MinXSS Missions

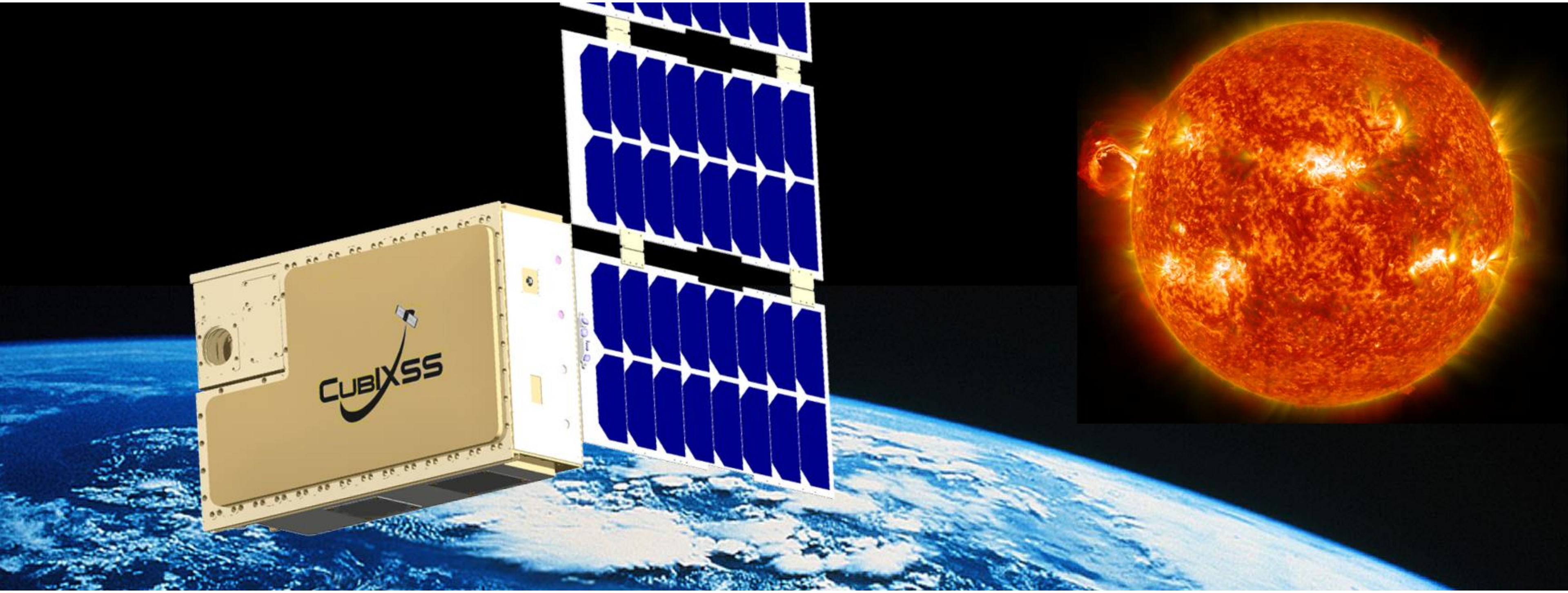
- MinXSS-1 will observe moderate solar activity
- MinXSS-2 will observe into the next minimum



MinXSS-1: May 2016
(6-month mission)

MinXSS-2: Dec 2016
(5-year mission)

New Proposed Mission



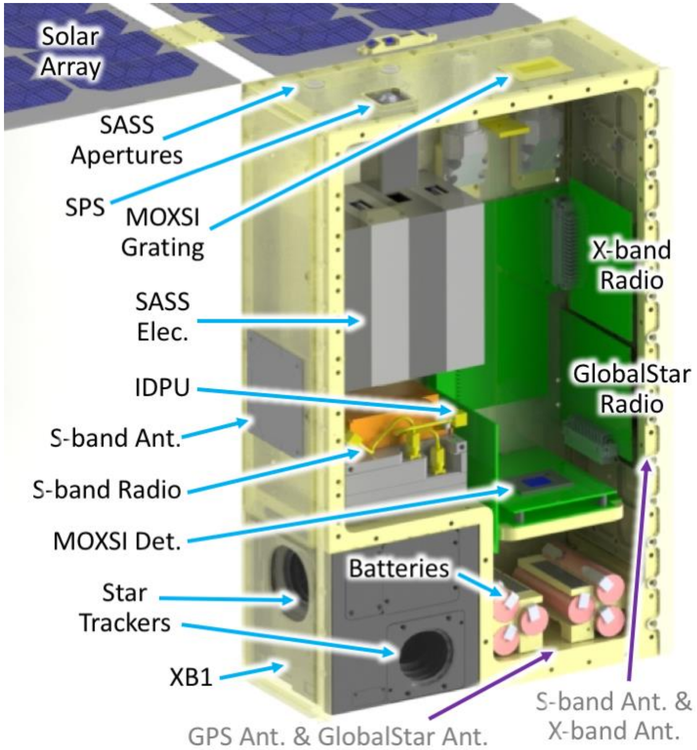
CubIXSS:

CubeSat Imaging X-ray Solar Spectrometer

- Goal: Improve physical understanding of thermal plasma processes and impulsive energy release in the solar corona, from quiescence to flares

CubIXSS: Spectroscopy & Imaging

- 6U CubeSat, proposed to H-TIDeS
- 2019 launch, LEO
  - *Optimized for solar minimum*
- Novel instrument suite includes:
  - Soft and hard X-ray spectrometers (spatially-integrated)
  - Soft X-ray imaging spectrograph (first solar imager on a CubeSat)

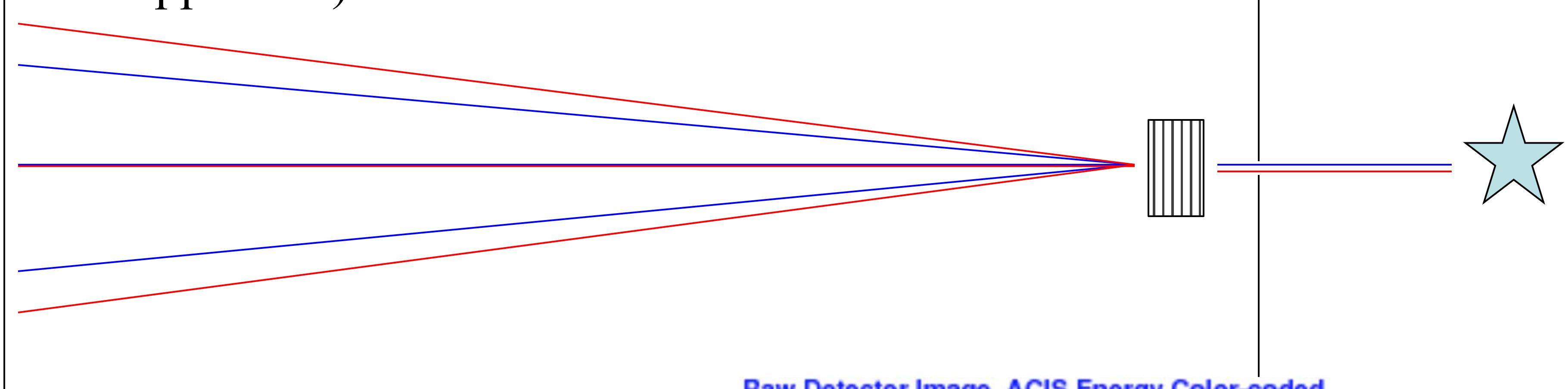


CubIXSS Instrument Summary

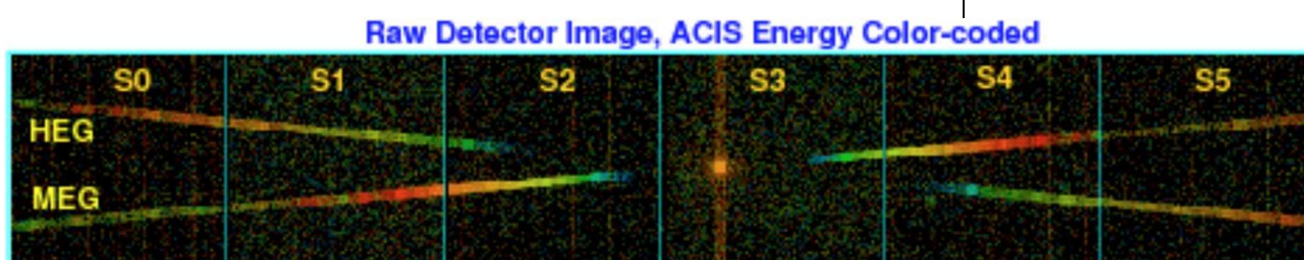
	Small Assembly for Solar Spectroscopy (SASS)	Multi-Order X-ray Spectral Imager (MOXSI)
Spectral range	SASS-S: ~0.5–30 keV SASS-H: ~5–100 keV	~1–55 Å (~0.22–12 keV)
Spectral res.	SASS-S: ~0.15 keV FWHM SASS-H: ~1 keV FWHM	~0.25 Å FWHM (~0.06 Å/pixel detector scale)
Spatial res.	N/A (spatially-integrated)	~25 arcsec FWHM (~6 arcsec/pixel detector scale)
Cadence	~1 s	~20 s

Multi-Order X-ray Spectral Imager

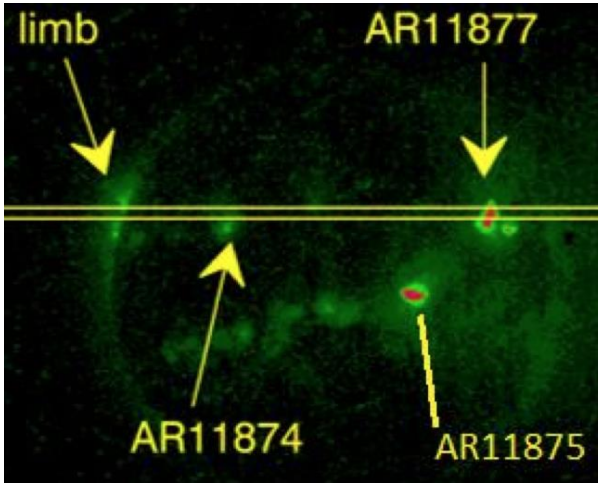
- For < 0.5 keV, single-photon measurement is impractical
- Dispersed spectra via transmission grating provide a solution
- Pinhole provides spatial resolution at low cost/mass/complexity (limited photon throughput NOT a problem)
- Combination yields full-Sun “overlappograph” with 0^{th} order and odd dispersed orders (±1, ±3, etc.) on same detector (even orders suppressed)



Chandra HETG image for point sources (stars)



MOXSI Prototype Results



Pinhole image

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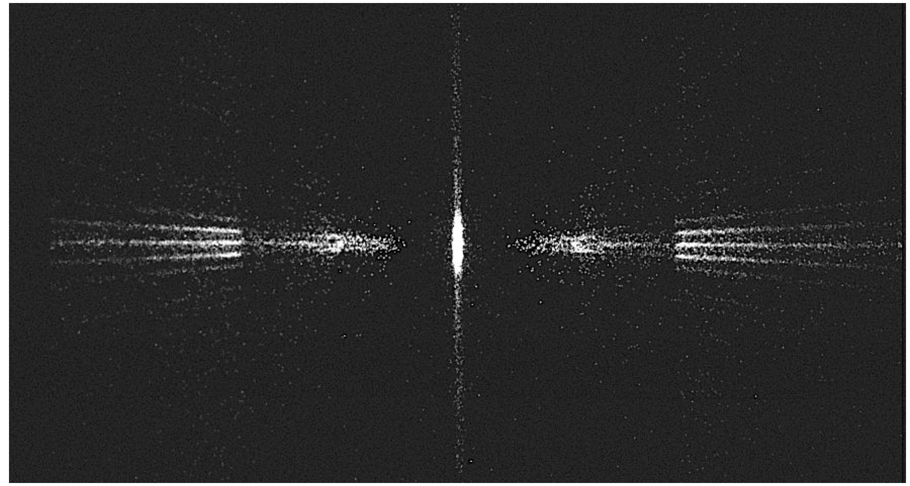

Dispersion from grating

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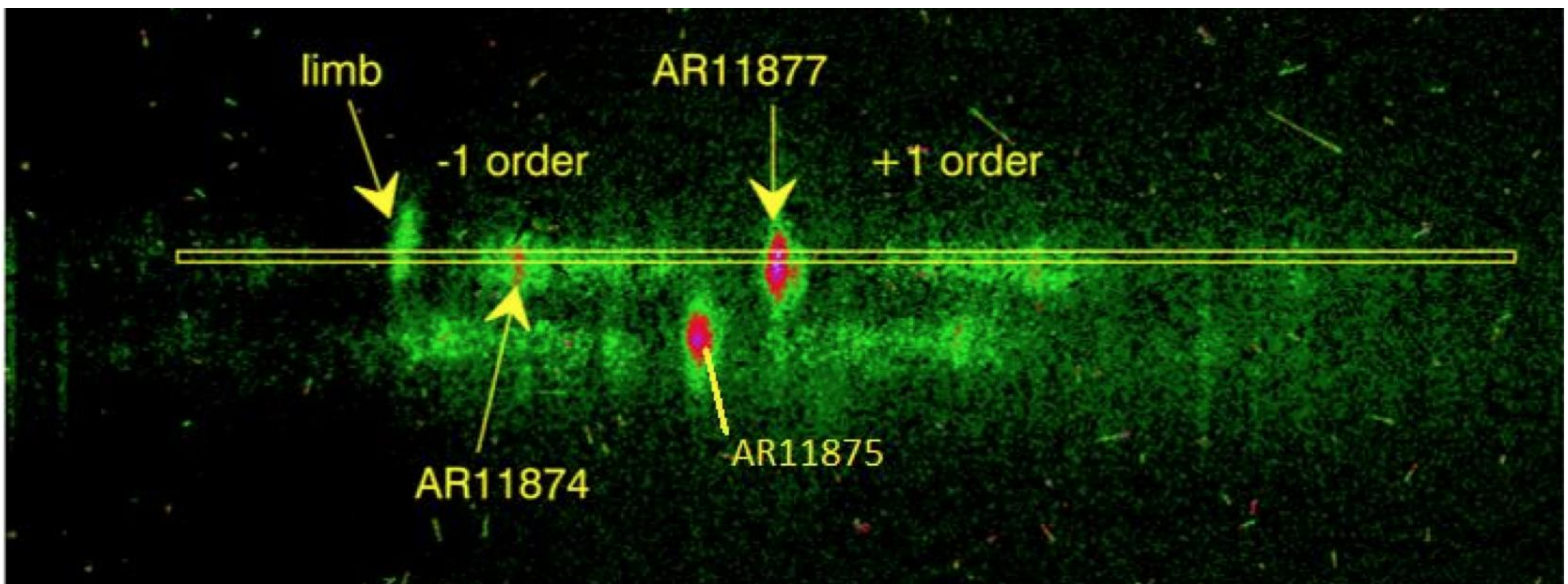
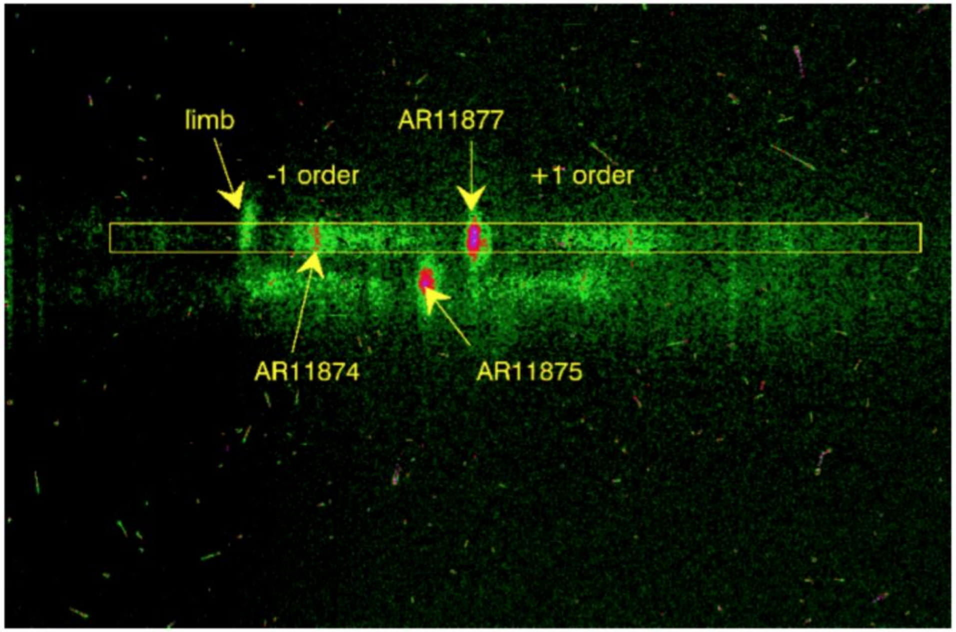
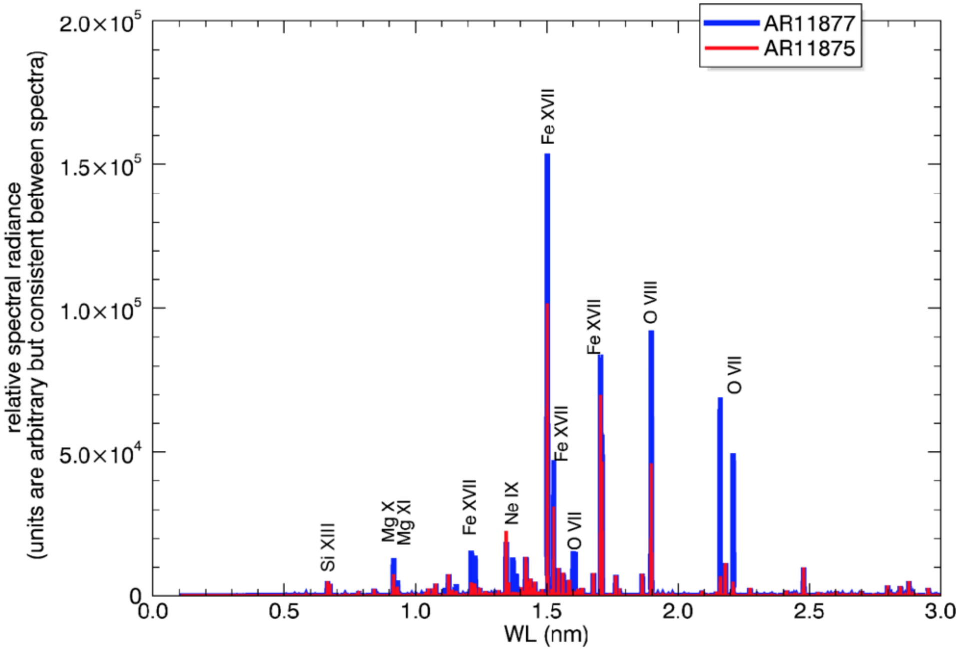


Dispersed multi-order spectral image

Prototype MOXSI Results



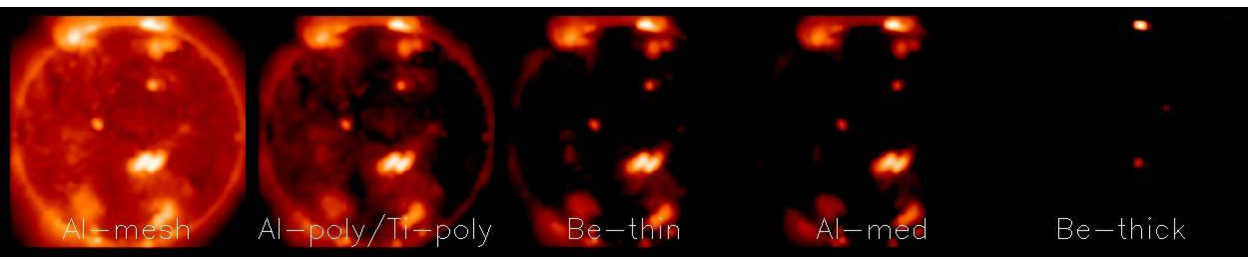


- Spectra from two ARs isolated, prominent lines observed
  - Preliminary analysis shows decidedly different spectra, indicates differences in DEM and/or abundances

- Optimized design improves sensitivity, resolution, and coverage, reduces noise and source confusion

MOXSI for CubIXSS

- Dispersed spectrum is rich, but complex to analyze alone
- Non-dispersed images w/ coarse spectral information provide spatial kernel *and* initial spectrum for forward modeling
- MOXSI has 5 additional pinholes to create *Hinode*/XRT-like filtergrams to provide this spatial kernel and spectral seed
  - Filters optimized for temperature coverage and dynamic range

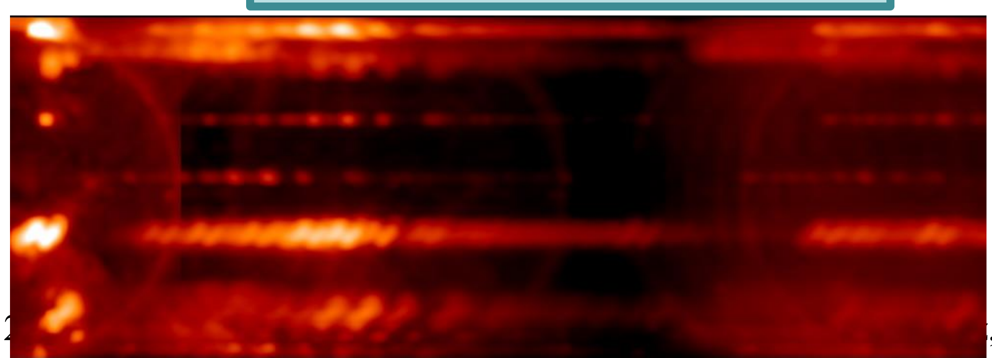


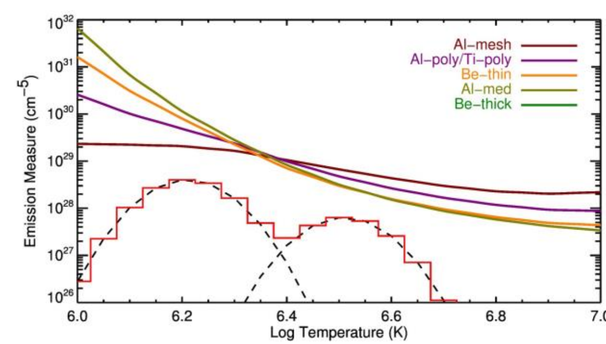
MOXSI data analysis: forward fit 2D map of DEM and FIP bias.

Seed DEM with filter images
Iterate with dispersed images

North →

MOXSI records the 5 filtergram images and the "overlappogram" on the same detector *simultaneously*





Scaling Up to Larger Missions

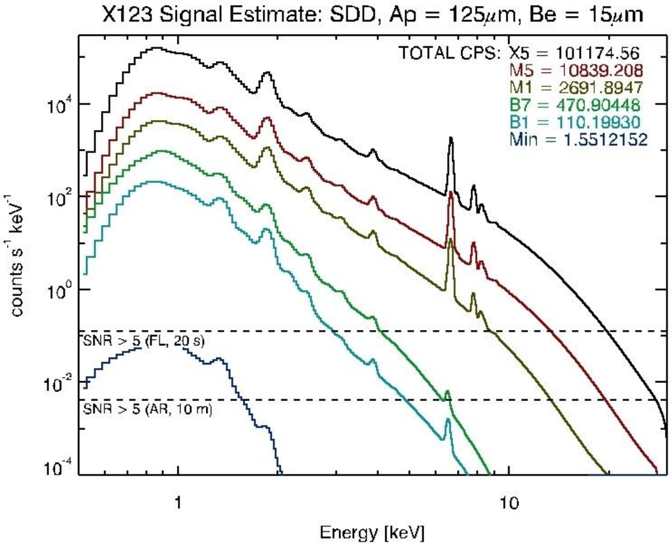
- Better spatial resolution enables spectroscopy *within* sources
- ~7” achievable in 1.5m distance (e.g., SMEX or MoO)

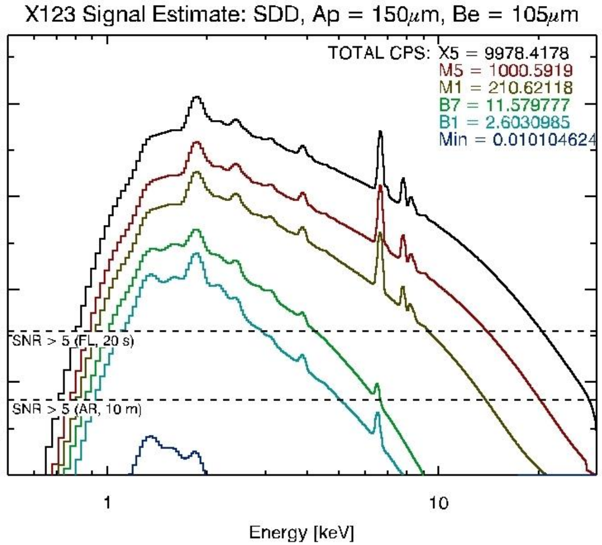
- SASS-S can easily scale: multiple detectors, potentially with coded aperture or rotation modulation imaging
- SASS-H will use larger-format detectors

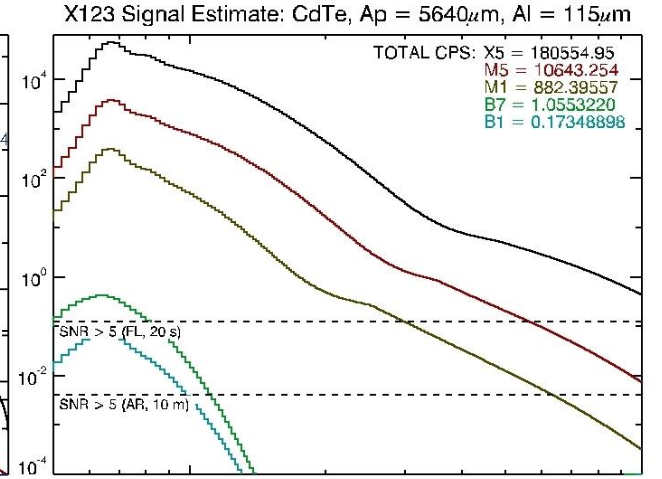
➡ Synergistic pairing with FOXSI SMEX mission concept for simultaneous, high-sensitivity HXR and SXR imaging spectroscopy

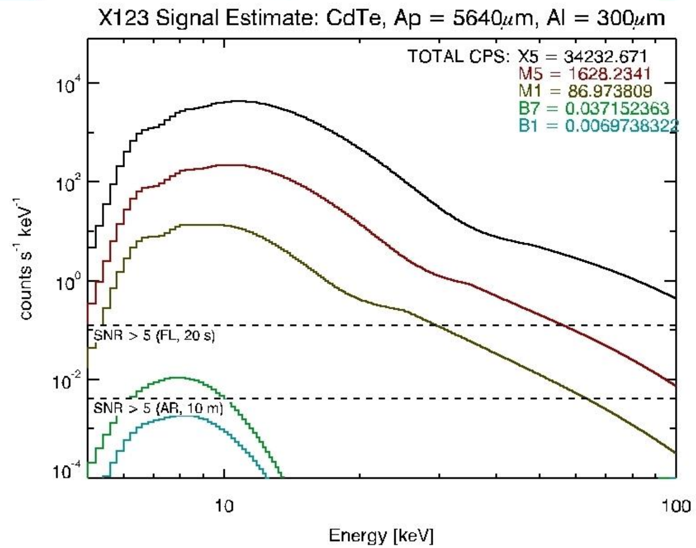
EXTRA SLIDES

SASS for CubIXSS









- 4 channels: 2 × SDD, 2 × CdTe
  - Apertures, windows optimized
  - Dynamic range from solar min to >X5
  - Spectroscopic coverage: ~0.5–100 keV
- 5 bins per FWHM, 1 s cadence
  - Resolves prominent line clusters, T/NT transition

MOXSI for CubIXSS

- e2v CIS115 CMOS detector (hardened): 7 µm pitch, 1500 × 2000 pixels
- 44 µm pinhole, 25.5 cm focal distance, 5000 lpm grating: 6"/pix, 0.06 Å/pix; 25", 0.25 Å FWHM; 1–55 Å range
  - Fills the critical wavelength gap
- 5 additional pinholes with filters (Be, Al, etc.) provide non-dispersed images on second half of detector
- 1^{st} order dynamic range from solar minimum to >X5
- Expected 20 s cadence
  - Multiple 1s integrations co-registered and summed to mitigate jitter, improve contrast