The Determination of Temperature and Emission Measure for GOES-R Series XRS Measurements

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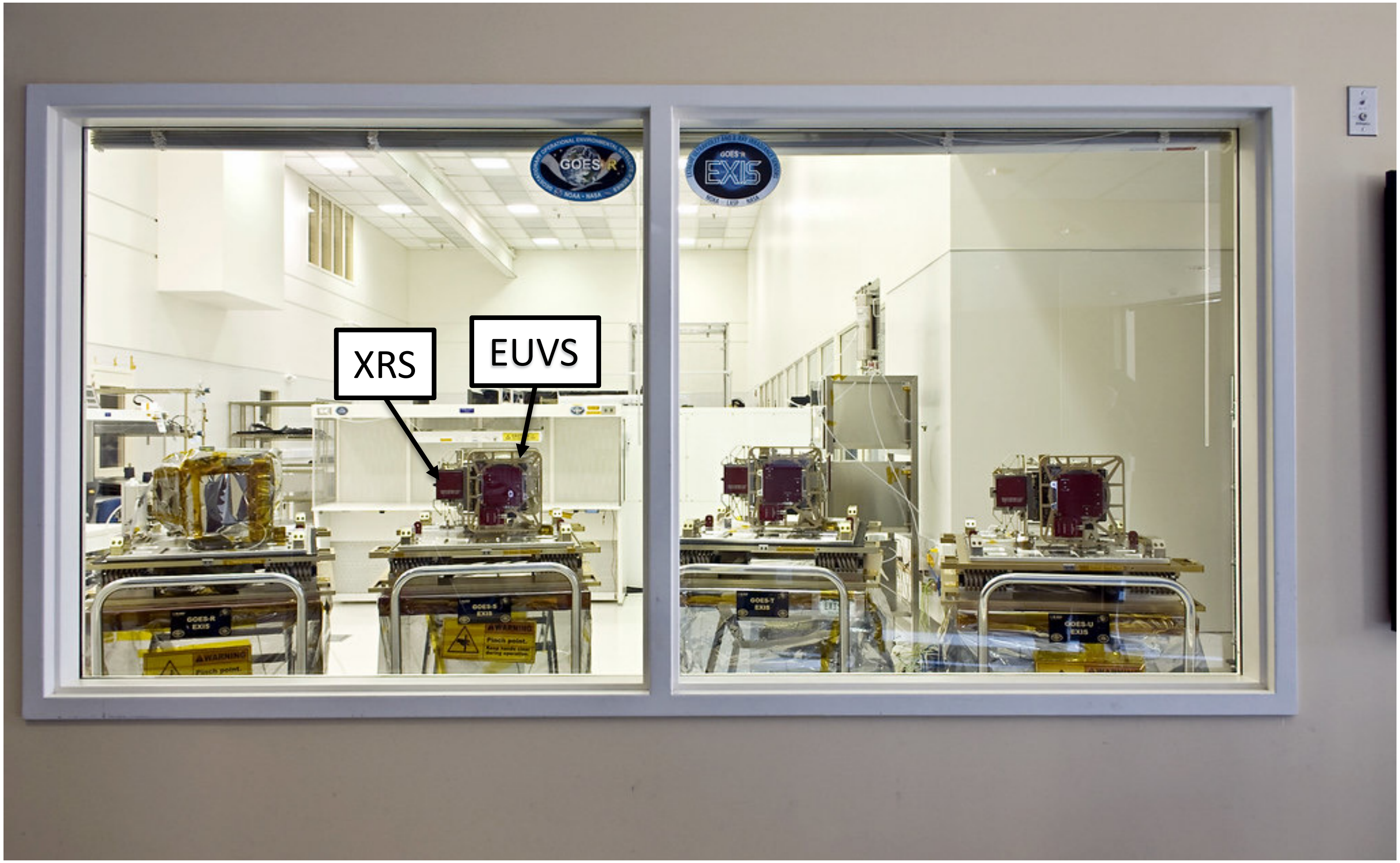
Overview

- Solar X-ray irradiance measurements made by the GOES-R XRS sensors have been transformed to coronal plasma temperature and emission measure following the work of Thomas, *et al*.*
- Detector technology had changed for the GOES-R Series XRS.
  - ➢ **Prior to GOES-R Series:** Ionization cells.
  - ➢ **GOES-R Series:** Silicon photodiodes.
- Synthetic CHIANTI (version 10.0.2) solar spectra were used.
- Detector responsivities for each GOES-R XRS as a function of wavelength were recently updated by Tom Woods and obtained directly from the NCEI website**.
- This work was reported in the recent DAXSS journal submission by Woods, *et al*.

*R.J. Thomas, R. Starr, and C.J. Crannell, *Solar Physics* **95** (1985) 323-329.
**https://www.ngdc.noaa.gov/stp/satellite/goes-r.html

GOES-R Series EXIS Instruments



A quadruplet set of flight instruments! All were designed and constructed here at CU/LASP. Prelaunch calibrations occurred at NIST SURF in MD.

Developing the Theoretical Response Ratio Under Isothermal Conditions

Thomas, Starr, and Crannell showed that a ratio of fluxes defined by the two XRS passbands could determine the radiating plasma temperature, then the emission measure in one of the XRS channels (usually the long channel) could be ascertained.

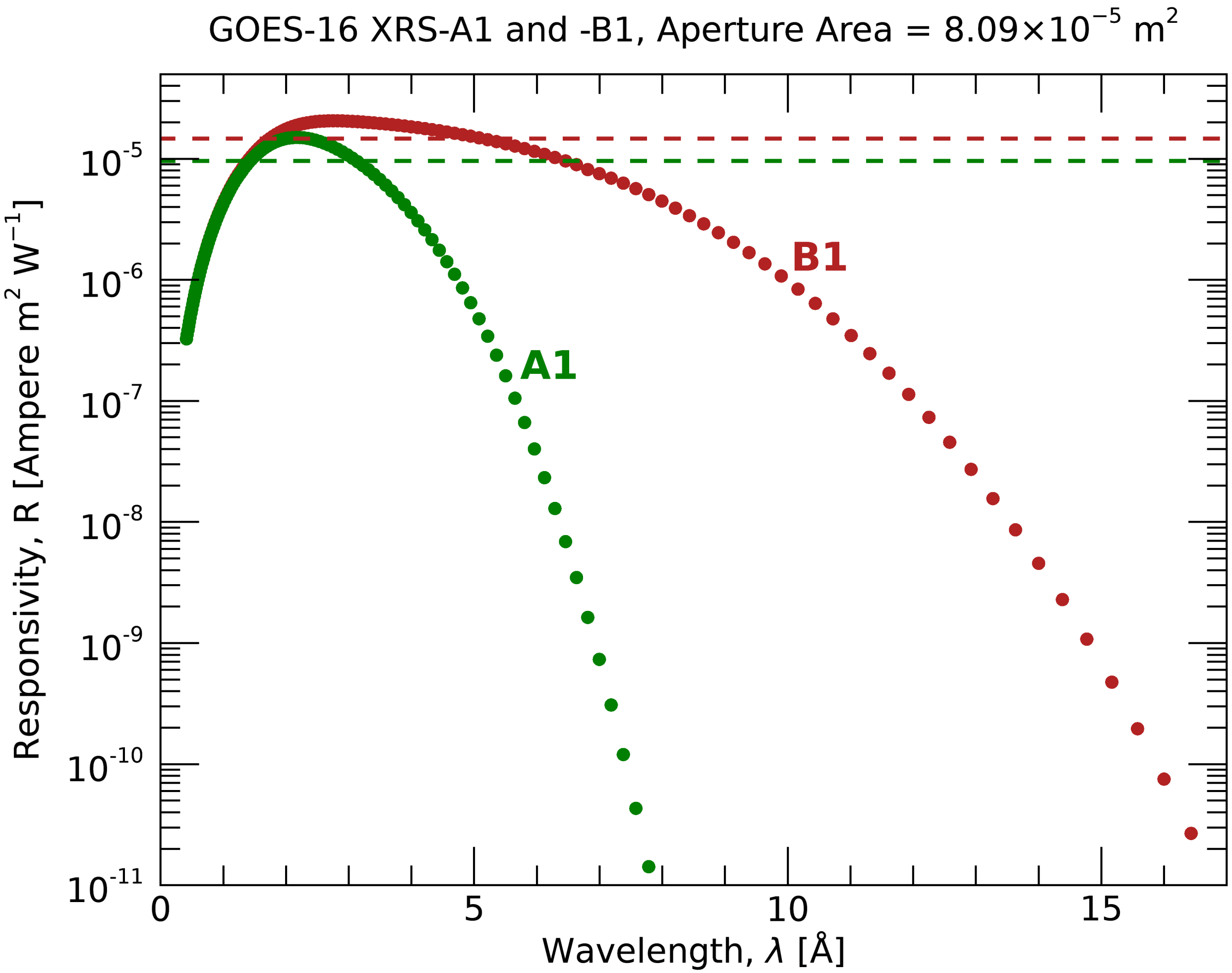
$$Ratio = \ b_4(T)/b_8(T)$$

Temperature dependent part to the detector response is given by:

$$b_i(T) = [\bar{R}_i]^{-1} \int_0^\infty R_i(\lambda)\phi(T,\lambda)d\lambda$$

Here, the subscript "i" refers to either 4 (XRS-A1) or 8 (XRS-B1), and $\phi(T,\lambda)$ is the theoretical CHIANTI solar spectrum for a given isothermal plasma temperature.

GOES-16 XRS Responsivities

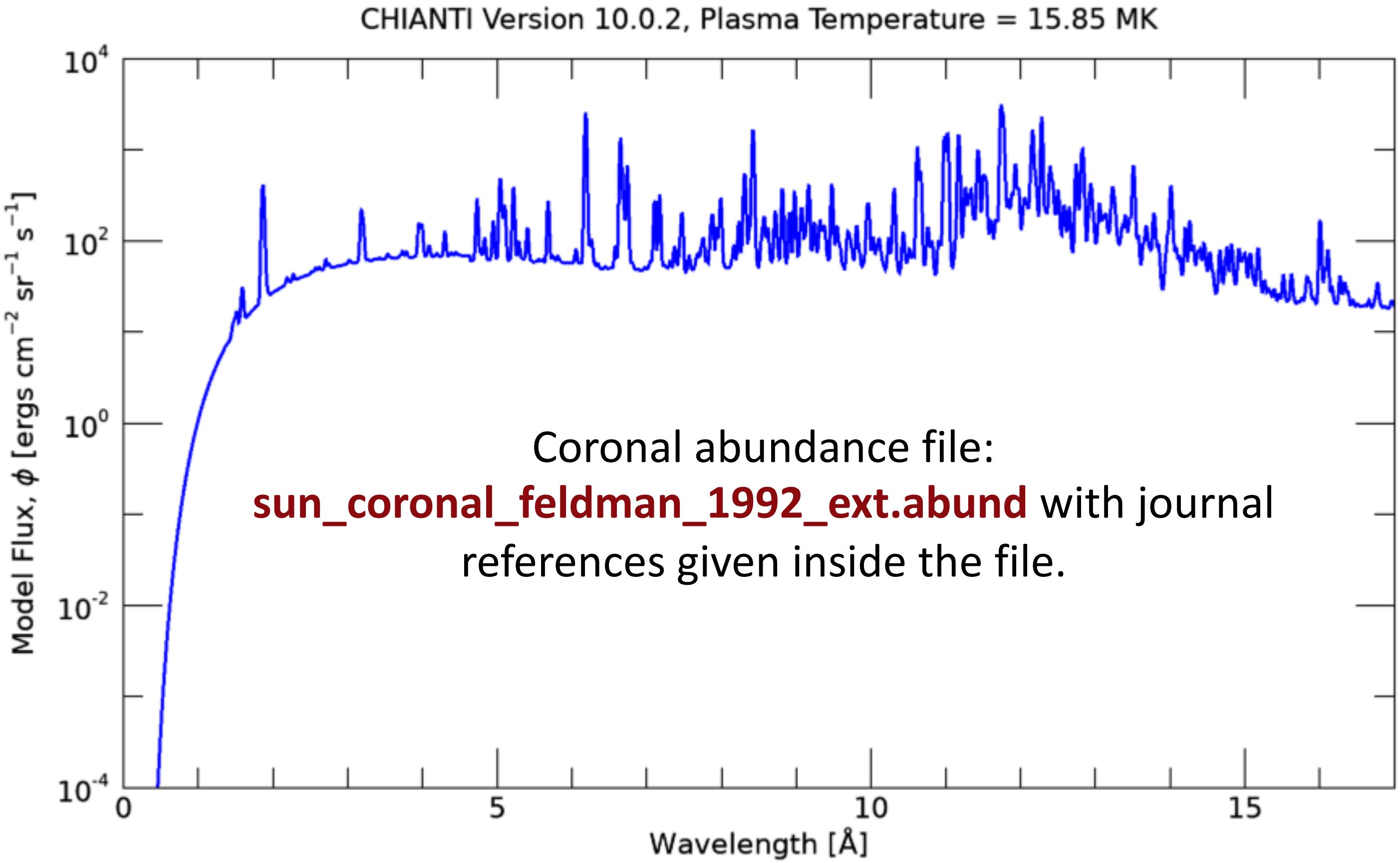


Horizontal dashed lines represent the *bandpass-normalized* responsivity that is used in science-data processing. Recall that for A1, the bandpass is 0.5-4 Å, and for B1, the bandpass is 1-8 Å.

$$\bar{R}(\lambda_2 - \lambda_1) = (\lambda_2 - \lambda_1)^{-1} \int_0^\infty R(\lambda) d\lambda$$

Other XRS flight models have nearly identical detector responsivities to FM-1.

Typical Model Solar Spectrum



Coronal abundance file:
sun_coronal_feldman_1992_ext.abund with journal references given inside the file.

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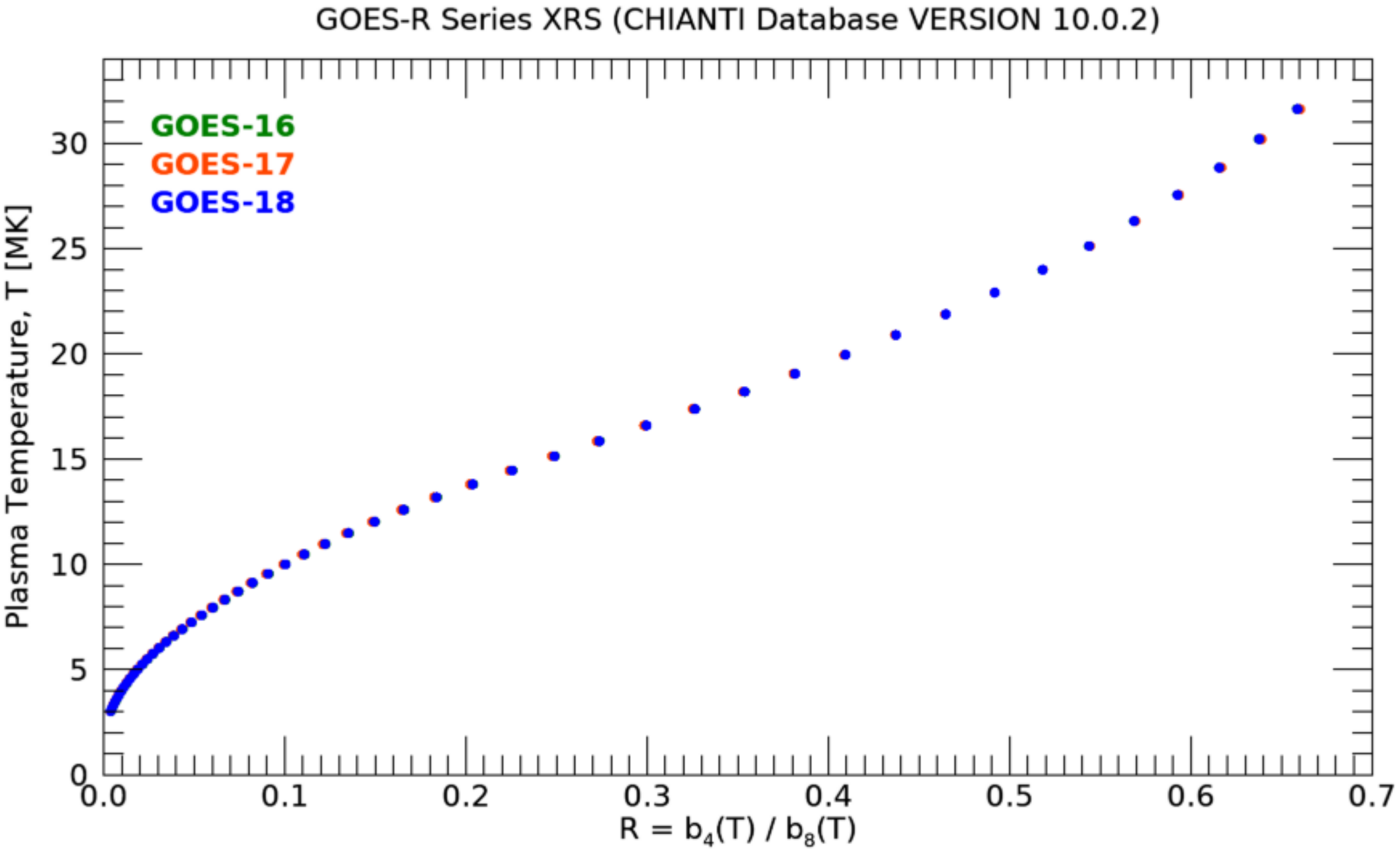
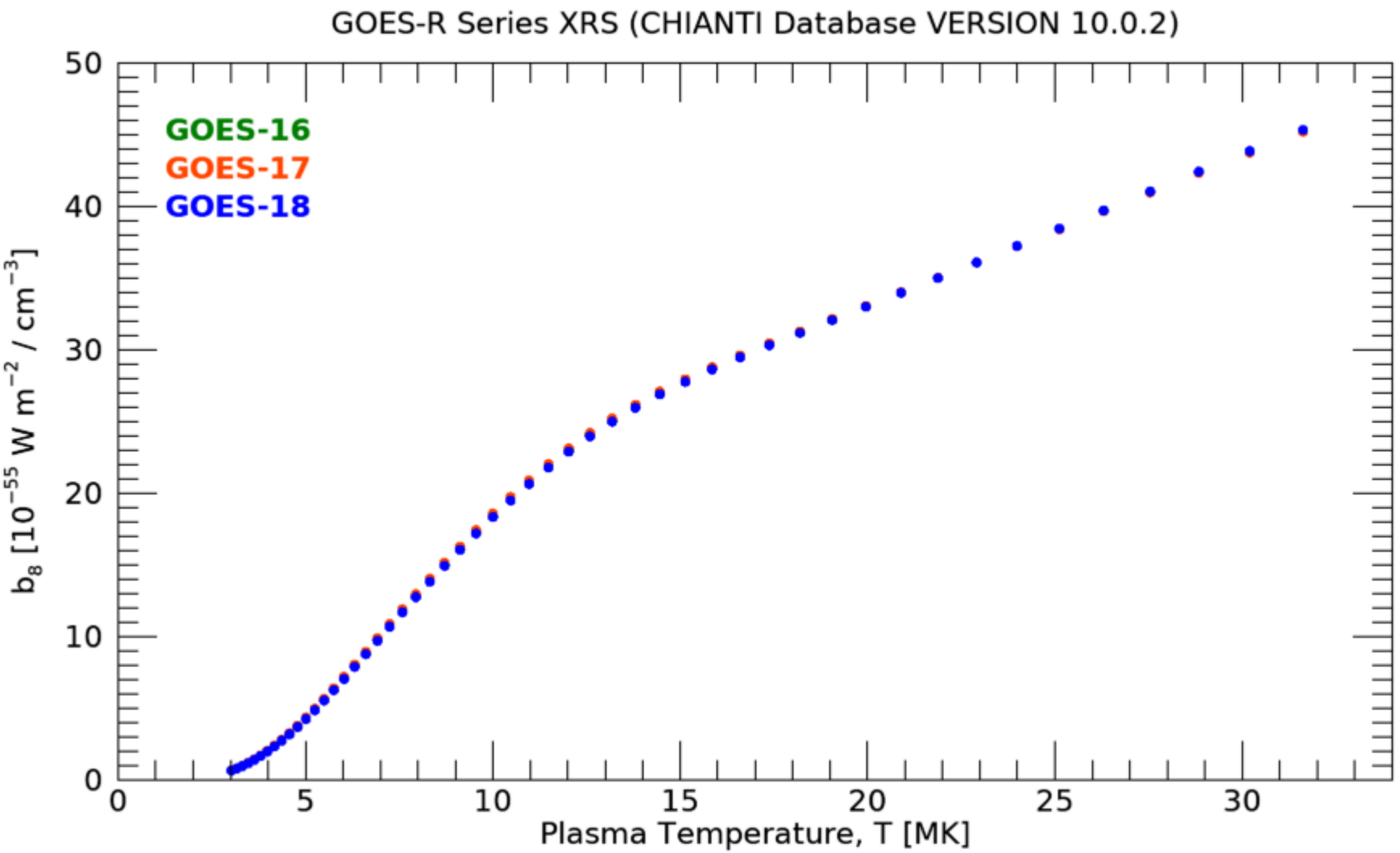
Developing the Response Ratio

- Synthetic isothermal CHIANTI solar spectra were generated for temperatures between 3-32 MK.
- These solar spectra were separately convolved with high-resolution renditions of the each XRS responsivity to render the model detector responses for each channel.
- The ratio, A1/B1, is then computed and the temperature as a function of this ratio is produced.
- For emission measure, the GOES-R XRS-B1 irradiance signal alone was used.

GOES-R Series Model Ratio



GOES-R Series Theoretical b_8 Response

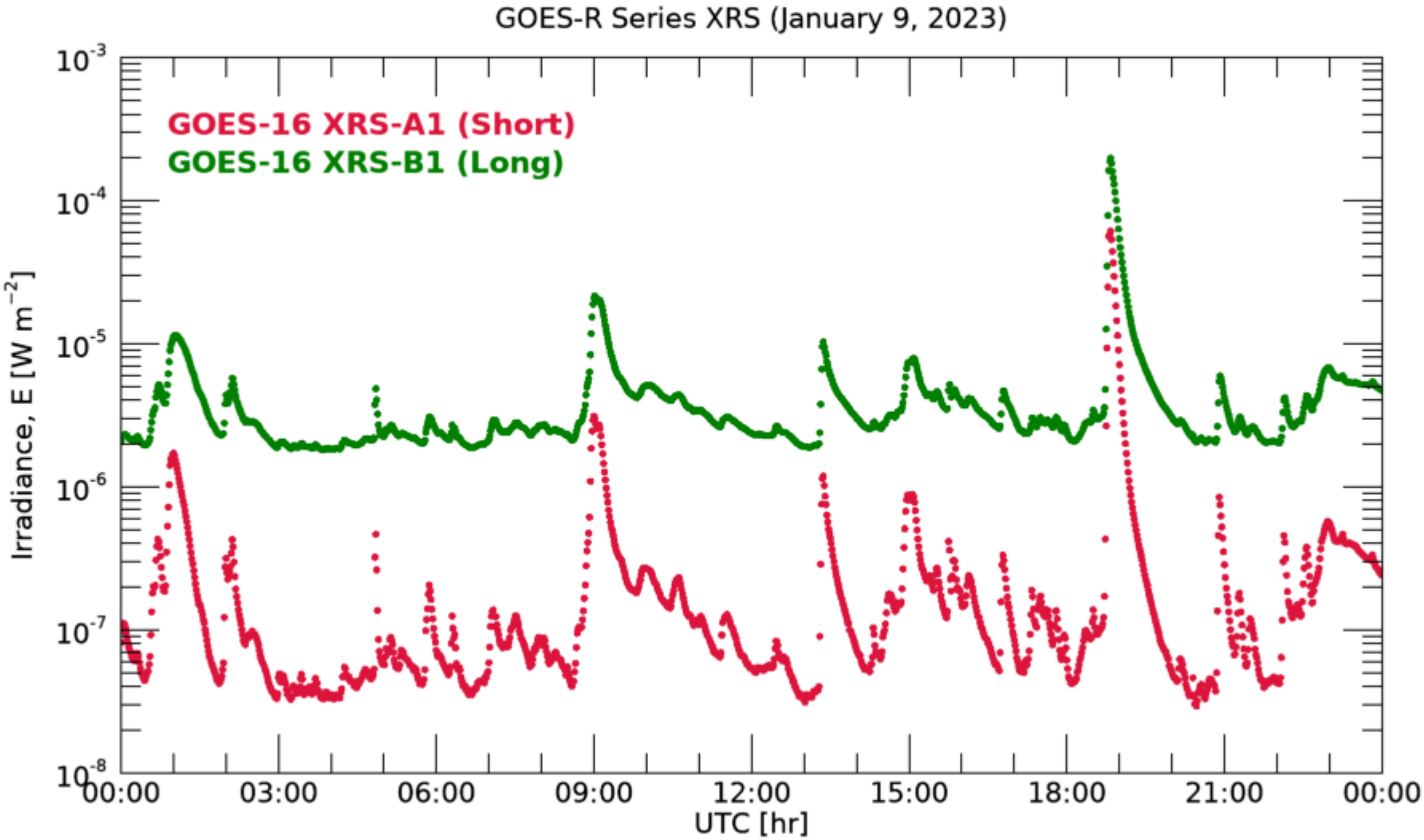


The units for b_8 have been converted and normalized to theoretical irradiance per unit emission measure for this analysis.

Using Real XRS Data

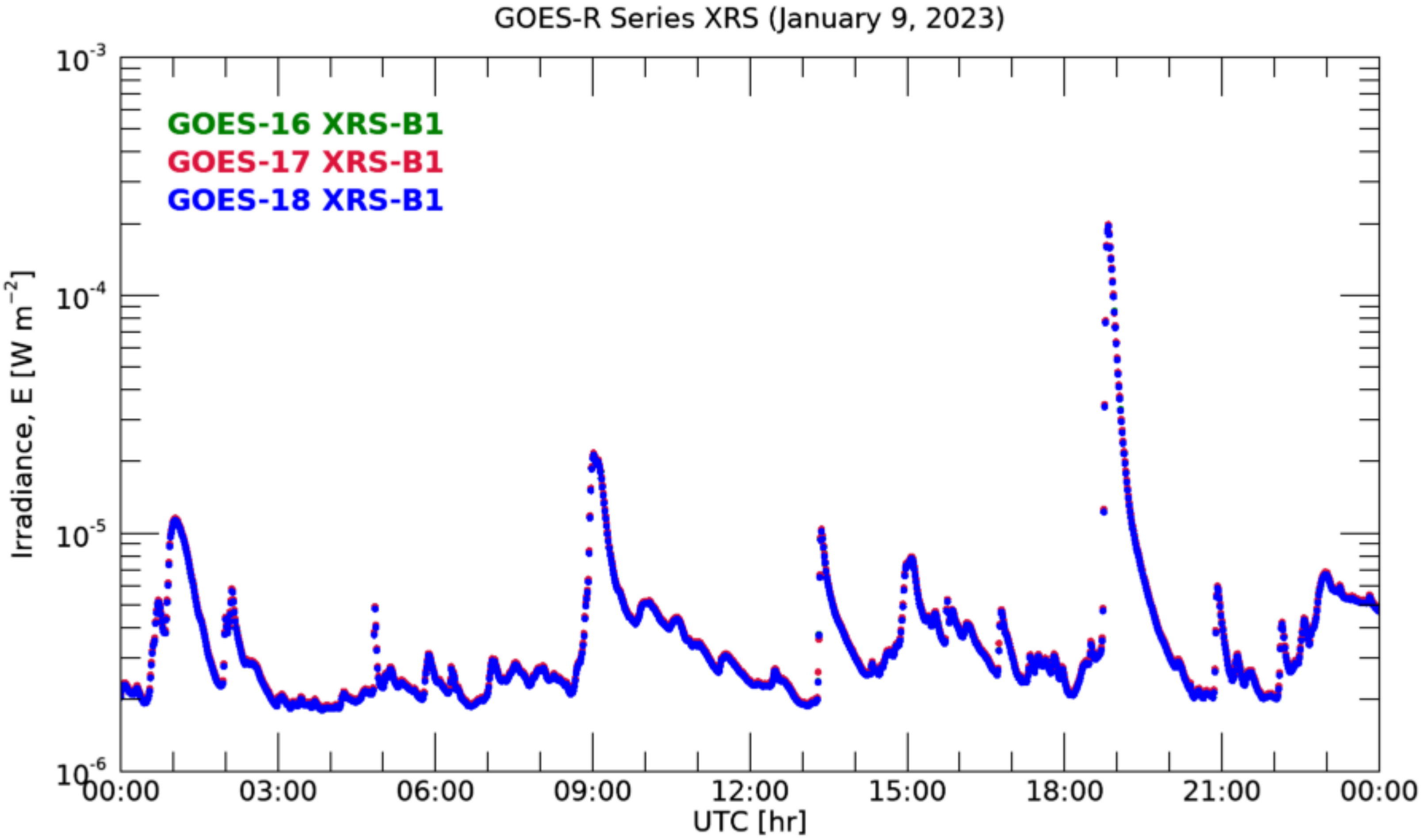
- Used **NCEI L2** XRS irradiance data from January 9, 2023. I believe these data are V2.2.
- These data are 1-min averaged data, with any signal made by electrons removed.
- All three inflight XRS sensors were active on this day.
- For emission measure, the GOES-R XRS-B1 irradiance signal alone was used.

GOES-16 XRS Irradiances (2023/009)

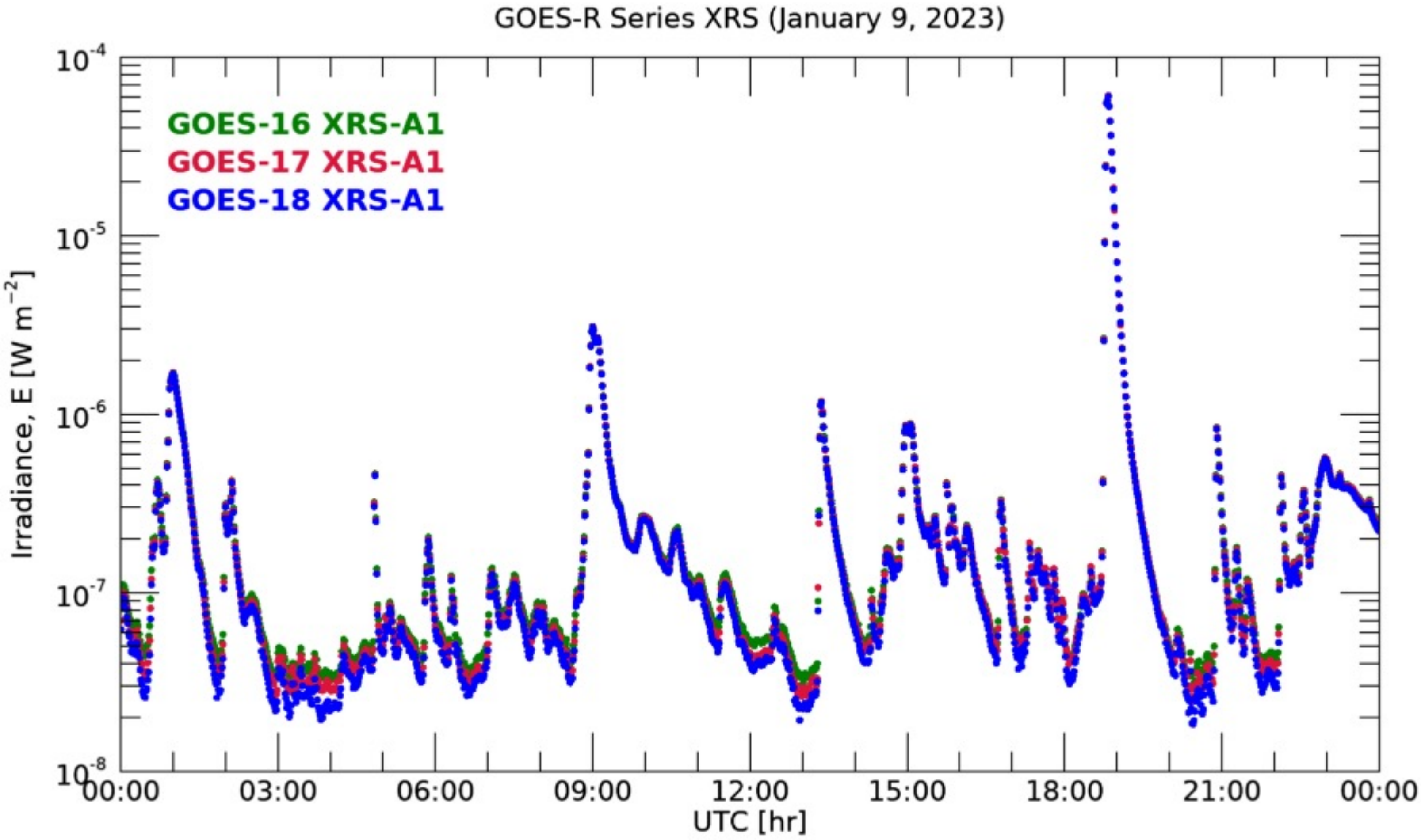


Solar activity was quite high on this day. Three GOES-R Series satellites (16-18) were powered and collecting data on this day.

GOES-R XRS-B1 Irradiances (2023/009)

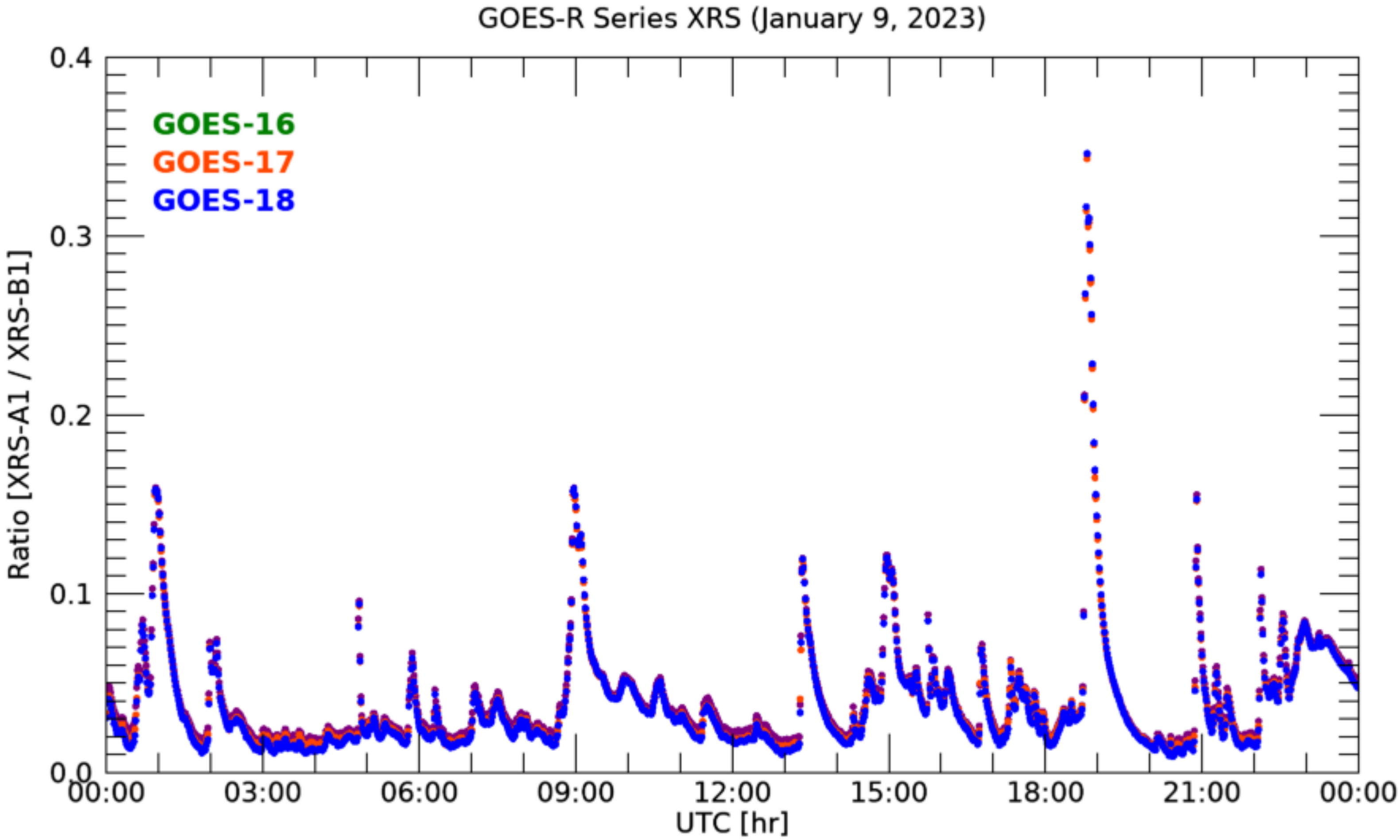


GOES-R XRS-A1 Irradiances (2023/009)



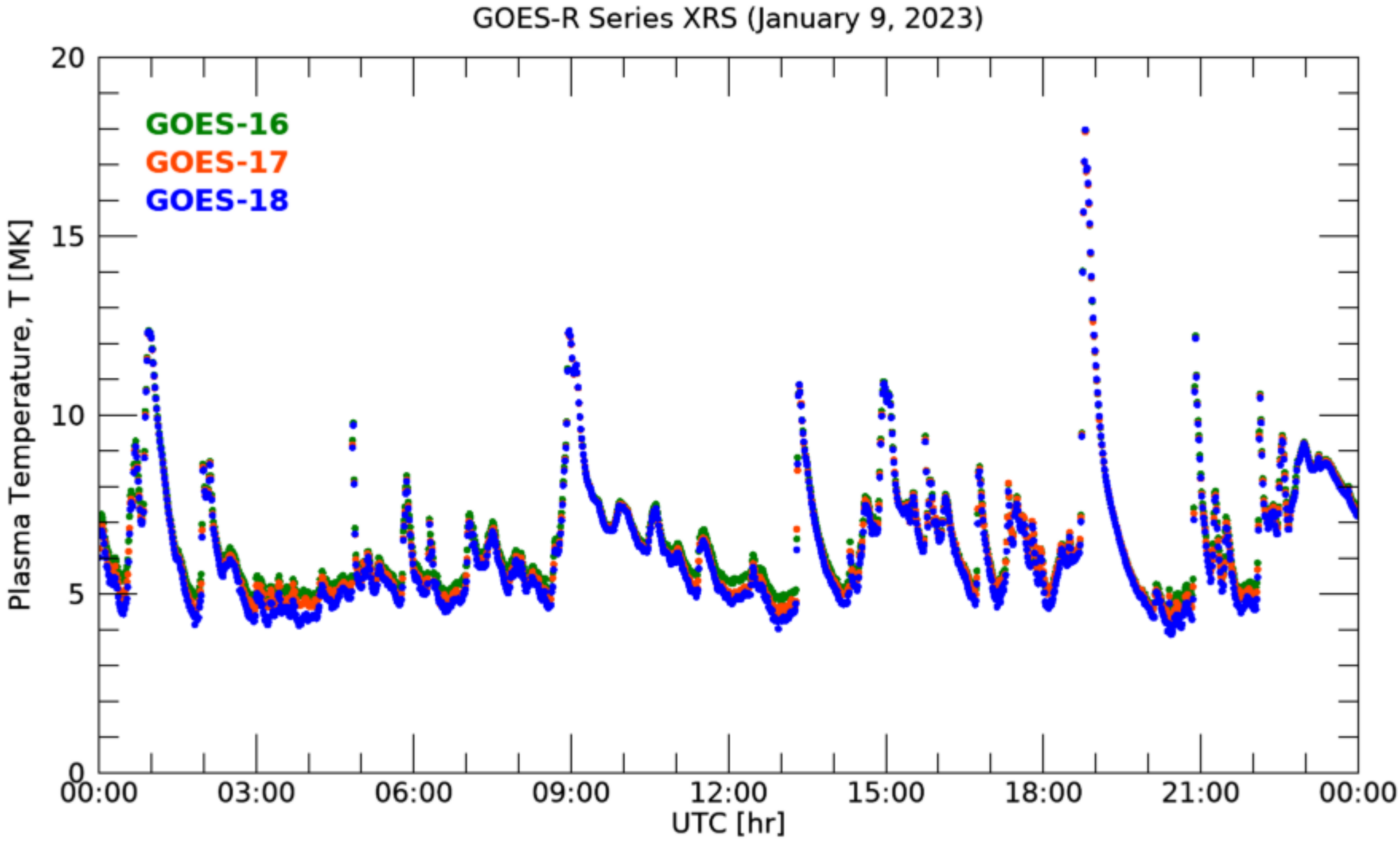
During periods of low solar X-ray flux (< ~4.0 x 10^{-7} W m^{-2}) and elevated electron flux, electrons can bias the X-ray signal high, so removing this component (done in L2) is critical and is flight-model dependent.

XRS Irradiance Ratio (2023/009)



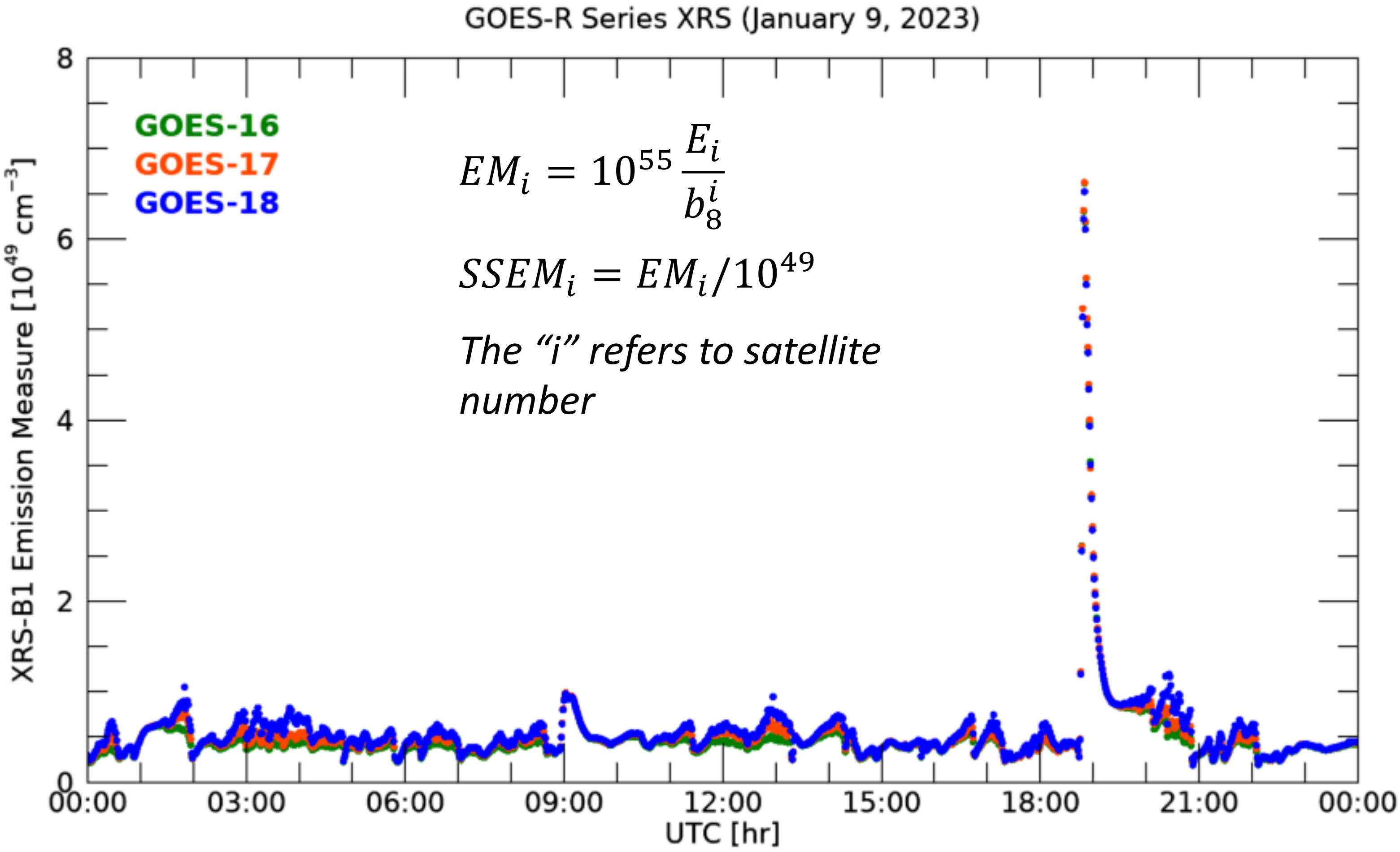
By interpolation to the model data (temp vs. response ratio) shown in Slide 8, these data can now be used to infer the radiating plasma temperatures. For the DAXSS paper, a polynomial fit was used to map the ratio data to temperature.

Coronal Plasma Temperatures



Because electron removal is flight-model dependent, deviations mostly occur at lower temperatures, where the percentage of the signal at low solar X-ray fluxes is higher.

GOES-R XRS-B1 Emission Measure



$$EM_i = 10^{55}\frac{E_i}{b_8^i}$$

$$SSEM_i = EM_i/10^{49}$$

The "i" refers to satellite number

Because electron removal is flight-model dependent, deviations mostly occur at lower temperatures, where the percentage of the signal for electrons at low solar X-ray fluxes is higher.

Conclusions

- Theoretical coronal plasma temperatures were inferred for the GOES-16, -17, and -18.
- CHIANTI solar spectra for a suite of isothermal plasma temperatures were used as the theoretical source of solar photons.
- The mapped temperatures are very close for all flight models, though when the solar X-ray signal is low, electron removal can cause deviations.
- Emission measures were also calculated for the XRS-B1 sensor. Because the mapping of b_8 relies on the plasma temp, similar behavior with electron removal at low fluxes is observed.

***Any Questions*?**

Extra Slide (Ratio of XRS Channels)

Irradiance of a detector is related to the incident radiant flux:

$$E_i = [\bar{R}_i]^{-1} \int_0^\infty R_i(\lambda)\phi(EM, T, \lambda) d\lambda \qquad (1)$$

For an isothermal plasma, the radiant flux can be factored:

$$\phi(EM, T, \lambda) = EM \times \phi(T, \lambda)$$

Now, Eq.(1) can be rewritten as:

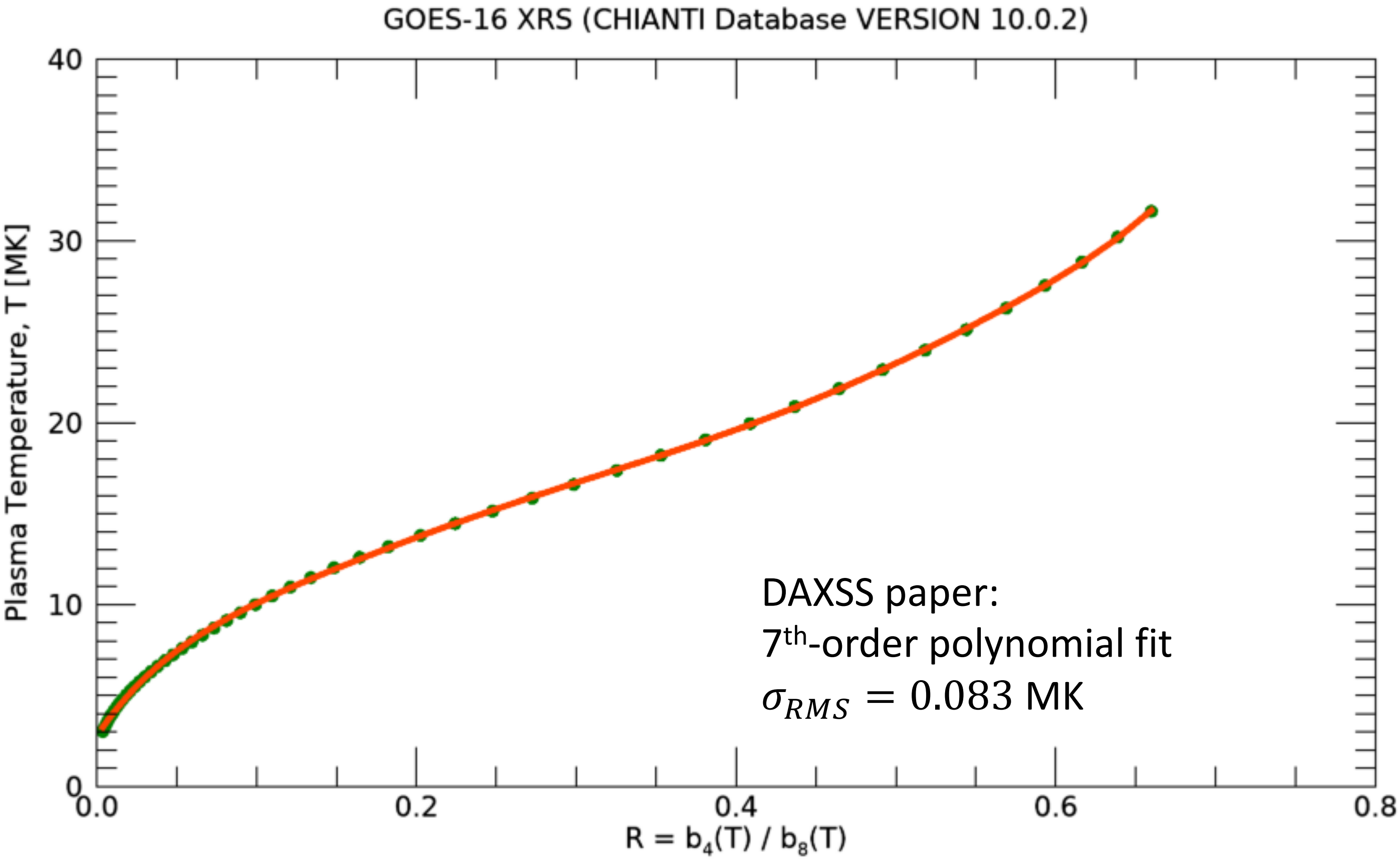
$$E_i = EM \times [\bar{R}_i]^{-1} \int_0^\infty R_i(\lambda)\phi(T, \lambda) d\lambda \equiv EM \times b_i(T)$$

Form the ratio, $R = E_4/E_8$:

$$R(T) = \frac{E_4}{E_8} = \frac{EM \times b_4(T)}{EM \times b_8(T)}$$

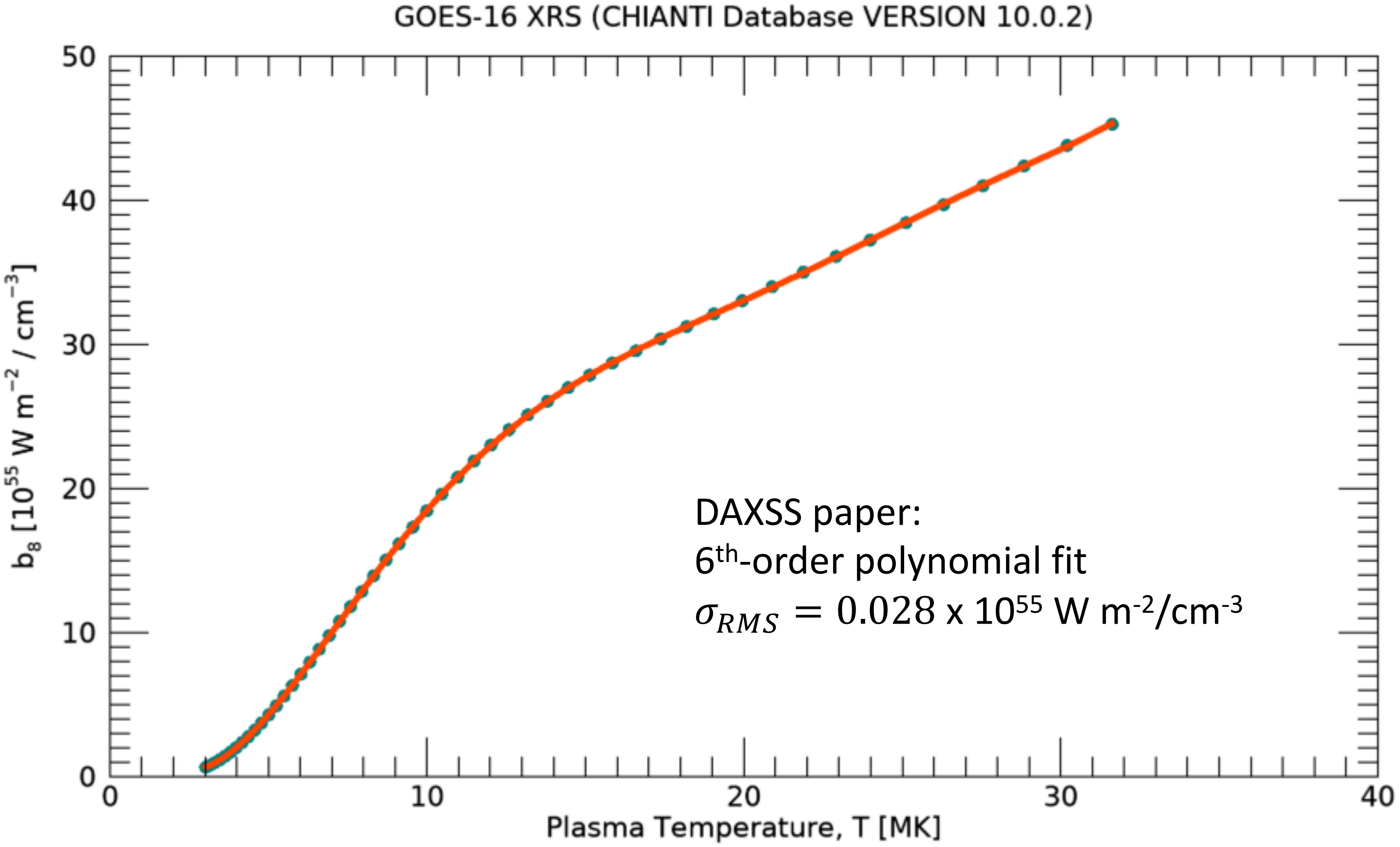
Ratio is independent of emission measure!

Extra Slide: Fit to G16 Temp vs. Ratio



DAXSS paper:
7th-order polynomial fit
$\sigma_{RMS} = 0.083$ MK

Extra Slide: Fit to G16 *EM* vs. b_8



DAXSS paper:
6^{th}-order polynomial fit
$\sigma_{RMS} = 0.028$ x 10^{55} W m^{-2}/cm^{-3}