Combining Broadband Irradiance Measurements and Plasma Temperature Approximations to Generate Solar EUV Spectra

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Abstract

Soft x-ray and EUV radiation from the Sun is absorbed by and ionizes the atmosphere, creating both the ionosphere and thermosphere. Temporal changes in irradiance energy and spectral distribution can have profound impacts on the ionosphere, impacting technologies such as satellite drag and radio communication. Because of this, it is necessary to estimate and predict changes in Solar EUV spectral irradiance. Ideally, this would be done by direct measurement but the high cost of solar EUV spectrographs makes this prohibitively expensive. Instead, scientists must use data driven models to predict the solar spectrum for a given irradiance measurement. In this study, we further develop the Synthetic Reference Spectral Irradiance Model (SynRef). The SynRef model, which uses broadband EUV irradiance data from the MAVEN EUVM at Mars, was created to mirror the SORCE XPS model which uses data from the TIMED SEE instrument and the SORCE XPS instrument at Earth. Both models superpose theoretical Active Region and Quiet Sun spectra generated by CHIANTI to match daily measured irradiance data, and output a modeled solar EUV spectrum for that day. We use the broadband EUVM measurements to estimate Active Region temperature. This will allow us to select from a library of AR reference spectra with different temperatures. We also investigate how the prevalence of solar minimum coronal holes affects our measurements and how to account for them. We present this updated SynRef model to more accurately characterize the Solar EUV and soft x-ray spectra.

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Summary

What is SynRef?

The Synthetic Reference Spectra Model, SynRef, (Thiemann et al. 2017) was developed to mirror at Mars what the SORCE XPS model does at Earth (Woods et al. 2008). It takes a broadband measurement of multiple wavelengths (either Channel B 0-7 nm or Channel A 17-22 nm from the MAVEN EUVM instrument) and combines that measurement with active sun and quiet sun spectra generated by CHIANTI to output a modeled solar Extreme Ultra-Violet (EUV) spectrum for that day.

Goal:
- Generate a predicted solar irradiance spectrum (0-105 nm) based on fundamental physics and broadband EUV (0.1-7, 17-22 nm) measurements

Problems:
- Our model has trouble predicting spectra during and around solar minimum, in part due to coronal holes.
- The model assumes temperatures of quiescent corona (QC) and active corona (AC) do not change.

Solution:
- Use a ratio method to determine solar plasma temperature and then separate out AC and QC temperatures

How does the model work?

The Math – Calculating a Spectrum

Irradiance from the solar disk (in soft x-ray and EUV) is a combination of irradiance from the quiescent corona plus that from its active corona regions, each scaled by their apparent fractional area of the solar disk.
A philter radiometer instrument's photocurrent due to the sun's irradiance can be approximated as

$$I_{measured} = f_{QC} * I_{QC} + f_{AC} * I_{AC}$$

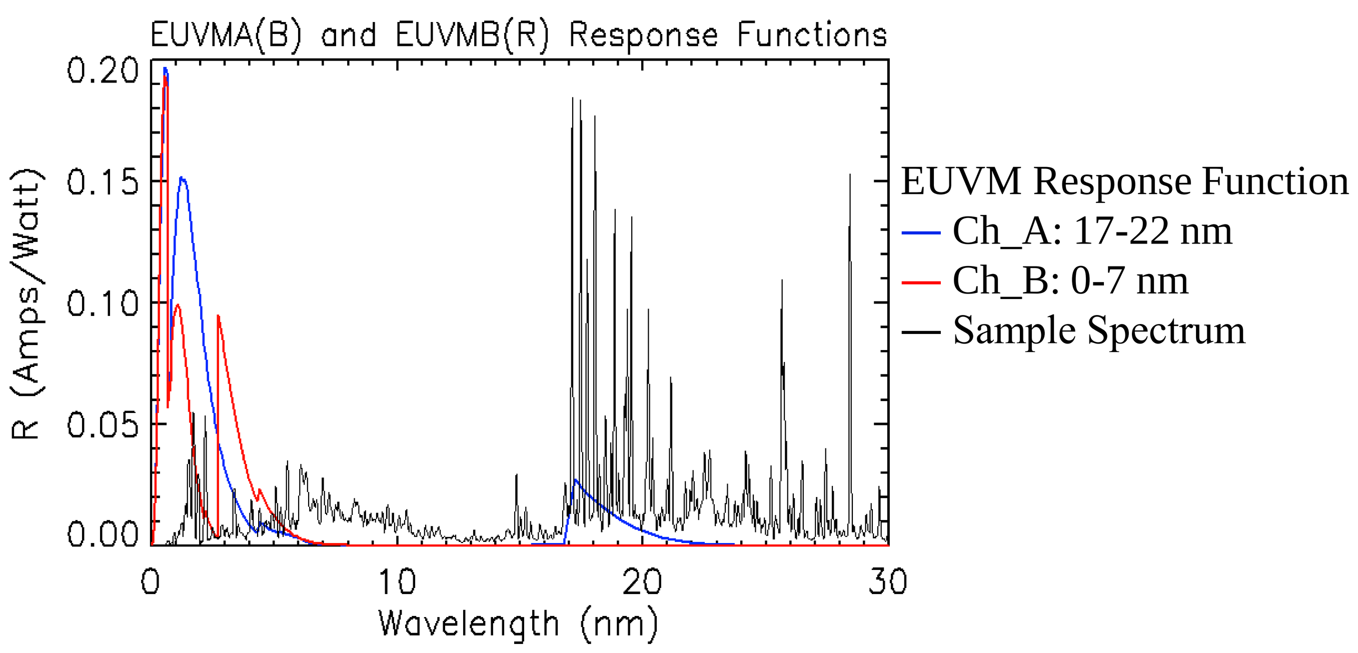
If $I_x = \int_0^\infty R(\lambda)E_x(\lambda)d\lambda$ where f represents the fraction of the solar disk covered by the feature, R is the response function of the instrument, and E is a modeled spectrum of the feature, then

$$I_{measured}(t) = (1 - f_{AC}(t)) \int_0^\infty R(\lambda)E_{QC}(\lambda)d\lambda + f_{AC}(t) \int_0^\infty R(\lambda)E_{AC}(\lambda)d\lambda$$

Assuming quiescent corona and active corona areas sum to 1, our only unknown is f_{AC}.

Once we calculate the active corona fraction, we can generate a spectrum:

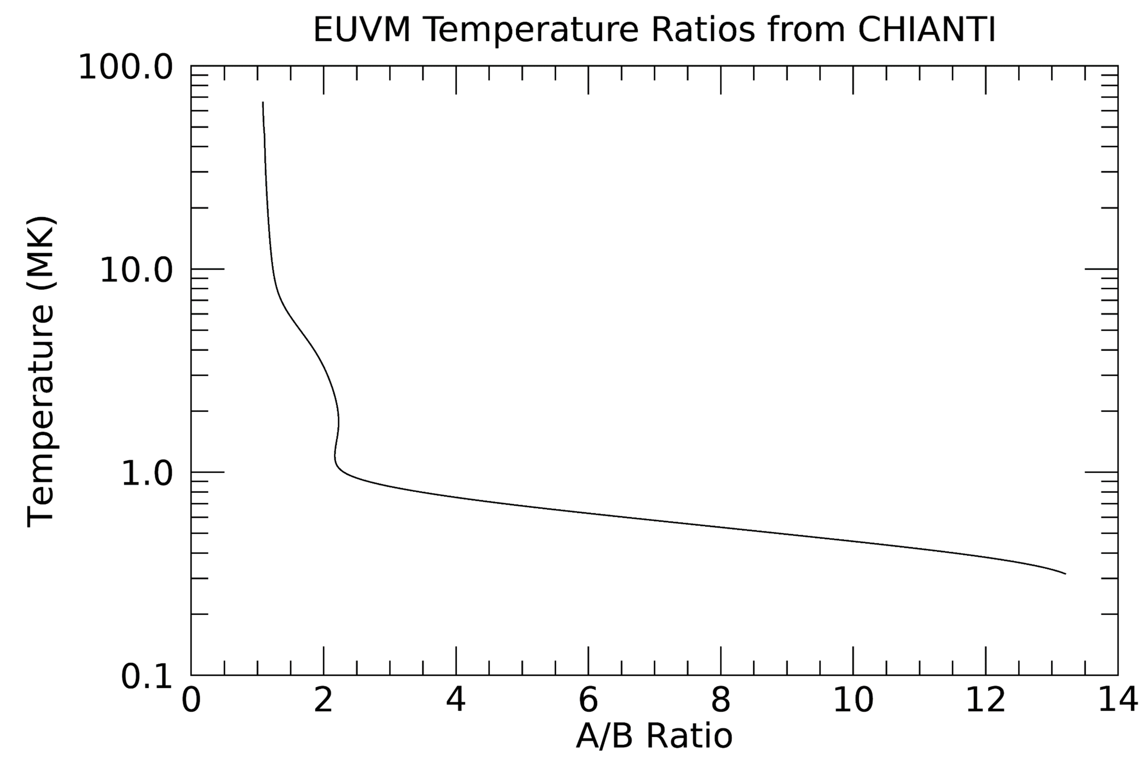
$$E_{solar} = (1 - f_{AC})E_{QC} + f_{AC}E_{AC}$$



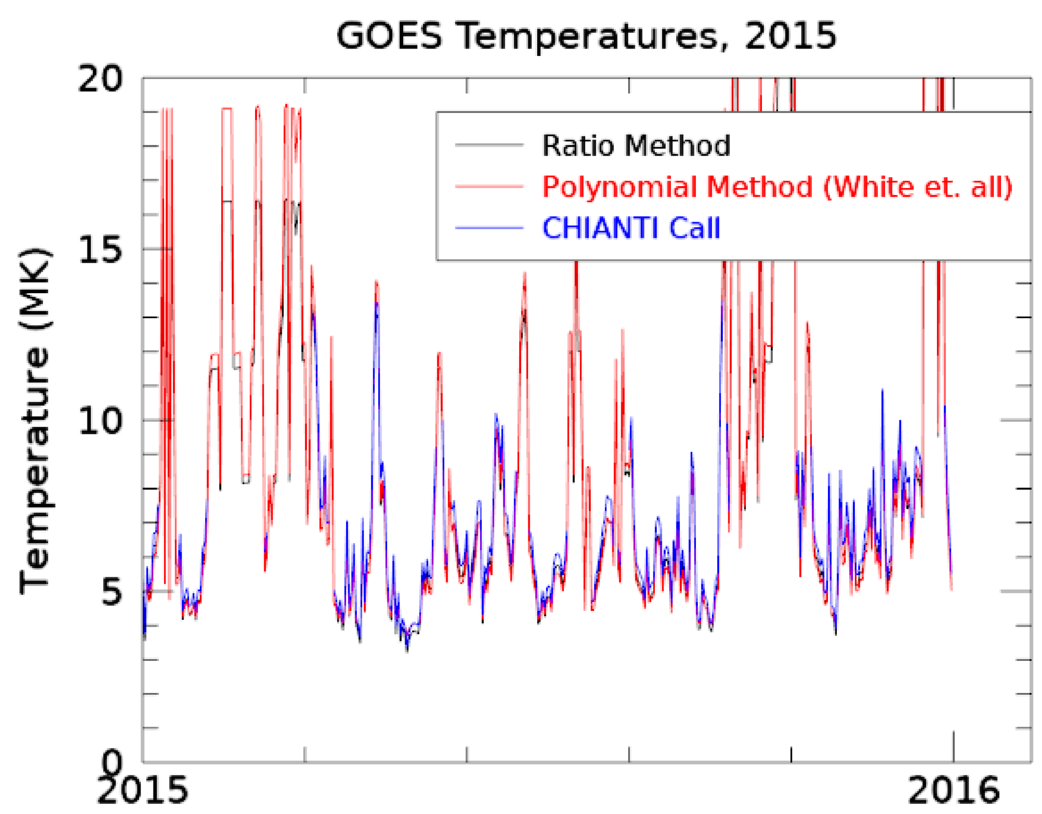
Full-Disk Temperatures

Finding the Temperature

EUV and Soft X-ray emissions are highly sensitive to temperature. If two broadband measurements are made and temperature is increased, the shorter-wavelength measurement will see total irradiance increase compared to the longer-wavelength measurement. This means most temperatures have a unique corresponding ratio which can be used to find that temperature.



When comparing our Ratio Method using GOES data to the *goes_chianti_tem* call and the polynomial method proposed by White et. all., we produce similar temperature results.
Conclusion: Our full-disk method produces similar results to other accepted methods.



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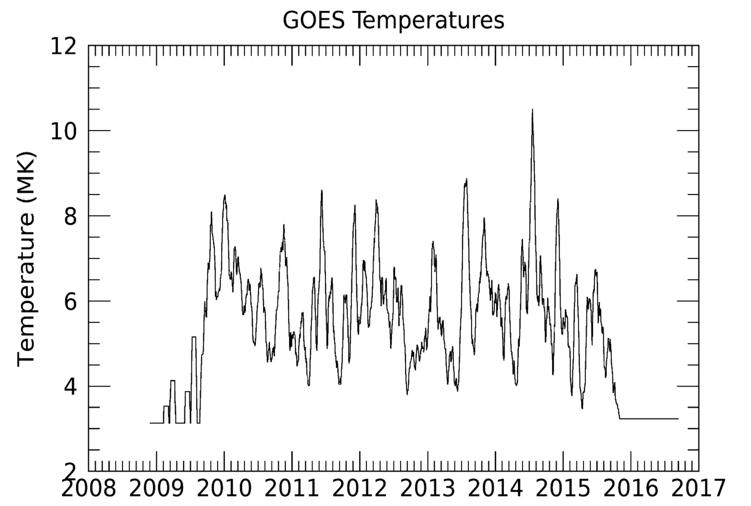
Region-Specific Temperatures

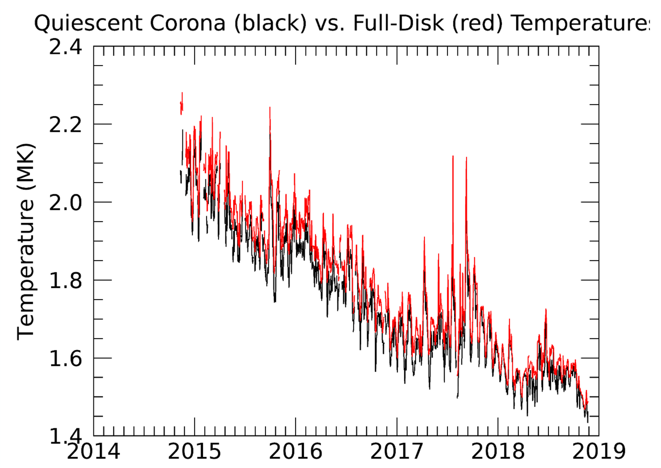
Separating Active and Quiet Corona Temperatures

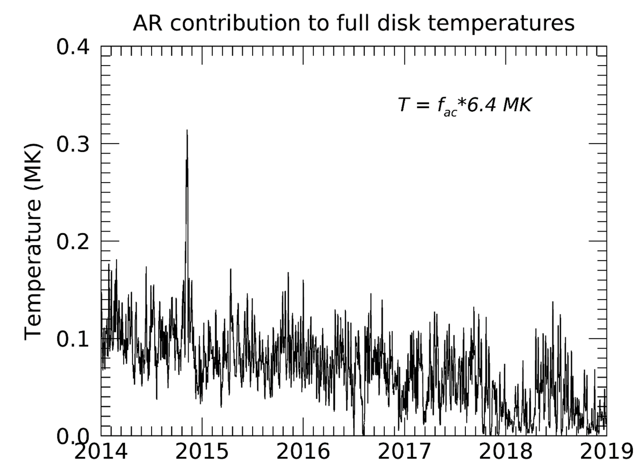
To separate the quiescent and active coronal temperatures, we assume that the measured full-disk temperature is the average of the active and quiescent coronal temperatures, scaled by their relative area.

$$T_{full\ disk} = (1 - f_{AC}) * T_{QC} + f_{AC} * T_{AC}$$



Based on MINXSS and GOES data, hot plasma during the most recent solar cycle appear to hold steady at a temperature of about 6.4 MK. Using the assumption that the active corona plasma is relatively constant and incorporating active corona area information from the Heliophysics Events Knowledgebase (HEK), we can calculate the quiet coronal temperatures, which dominate the full-disk measurements and change with solar cycle.





Applying this, we can calculate the approximate contribution of active regions to the total measured temperature, as well as the approximate quiescent corona temperature.
The quiescent corona shows a decreasing trend from 2 MK to 1.5 MK as we approach solar minimum, while the active corona regions contribute 0.1 MK to the average temperature.

Conclusions

- The full-disk temperature can be accurately measured using a ratio of the two measurement channels and comparing them to modeled spectral ratios based on temperature.
- This method of measuring full-disk temperature produces results in agreement with other accepted methods.
- The quiescent coronal temperature decreases as we approach solar minimum, while the active corona temperature does not (for this solar cycle).

Next Steps:
- Iterate the AC and QC temperature method to determine changes in AC temperature over time.
- Use calculated AC and QC temperatures to select appropriate temperature-based spectra
- The model doesn't account for coronal holes, which appear frequently during solar minimum. Determine a way for the model to account for coronal holes.