Solar Active Region Spectrum From EVE Lunar Transit

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Background

The total solar irradiance stays relatively constant. However, at shorter wavelengths the irradiance from the Sun varies significantly. The Extreme ultraviolet Variability Experiment (EVE) aboard the Solar Dynamics Observatory (SDO) measures the disk-integrated intensity of solar extreme ultraviolet (EUV) radiation. The EUV output of the Sun is especially effected by the number of active regions on the Sun. An active region is the area of strong magnetic activity above a sunspot that is observed in the outer layers of the solar atmosphere. The plasma in these active regions is hotter than that of the surrounding Sun. Plasmas at different temperatures will emit different spectra of light.

We used spectra from 6.5 nm to 38 nm taken with the Multiple EUV Grating Spectrometers (MEGS) on EVE. MEGS has a spectral resolution of 0.1nm and a time cadence of ten seconds. MEGS uses a series of filters and gratings to separate light into different wavelengths which are measured on a Charge Coupled Device (CCD).

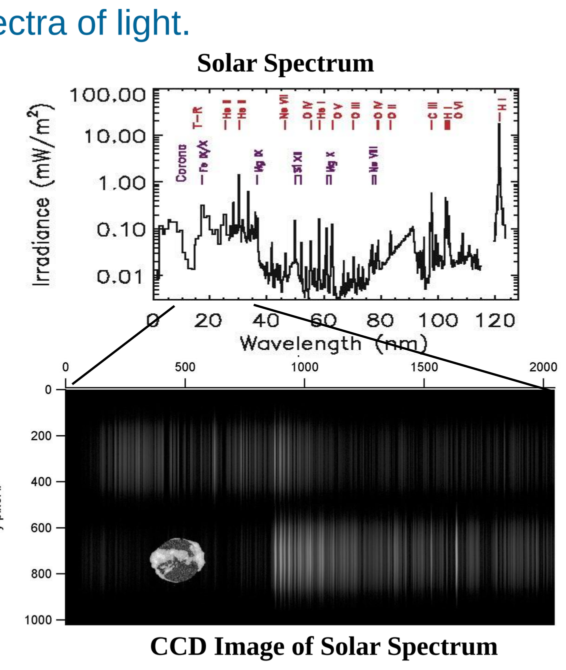

Figure 1: The CCD image from MEGS_A showing diffracted light as vertical lines. Wavelength range of 6nm to 38nm.

Introduction

The EUV Variability Experiment (EVE) observed several lunar transits during the first year of science operations. While the spectra taken during transits generally are not used for routine science because EVE is not measuring the full solar disk, this project used these observations to obtain the spectrum from a small segment of the Sun. EVE has a high time cadence but because it takes full disk measurements, it has no spatial resolution. Using a difference spectrum from outside and during a transit produces the spectrum from the area of the Sun covered by the Moon. This project focused on a transit that occurred on 6 November 2010, where an active region was covered. We produced a spectrum for that active region at the EVE spectral resolution. Using the CHIANTI Atomic Database, a database that can model stellar plasma and produce synthetic spectra, a differential emission measure (DEM) was calculated for this active region and compared to the DEM of a representative active region in CHIANTI.

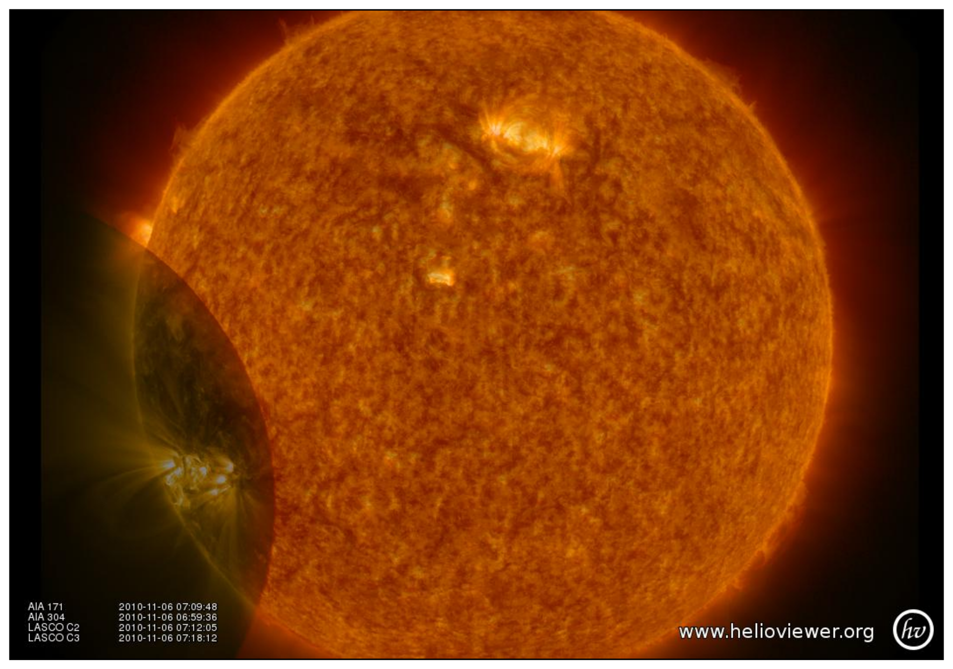

Figure 2: Overlay image of the Sun on 6 November, 2010 in AIA 171 and 304. AIA is an instrument aboard SDO. The shaded region on the South East limb of the Sun shows the area covered by the moon at 6:59:36 Universal Time(UT). The active region of interest is composed of the bright spots and loops above them in the shaded region. The EVE spectrum recorded at 6:59:55 was used to produce the difference spectrum for the active region. At this time the moon covered all of the active region with as little surrounding quiet sun as possible.

Methods

- **Created five minute average spectra for before and after the transit.**
  - Averaged together to create an average spectrum for outside the transit.
- **Subtracted the spectrum taken at 6:59:55 UT.**
  - Resulted in the spectrum from the shaded section in figure 2.
- **Applied a correction for the small area of quiet sun in that region.**
  - Resulted in a spectrum for the active region.

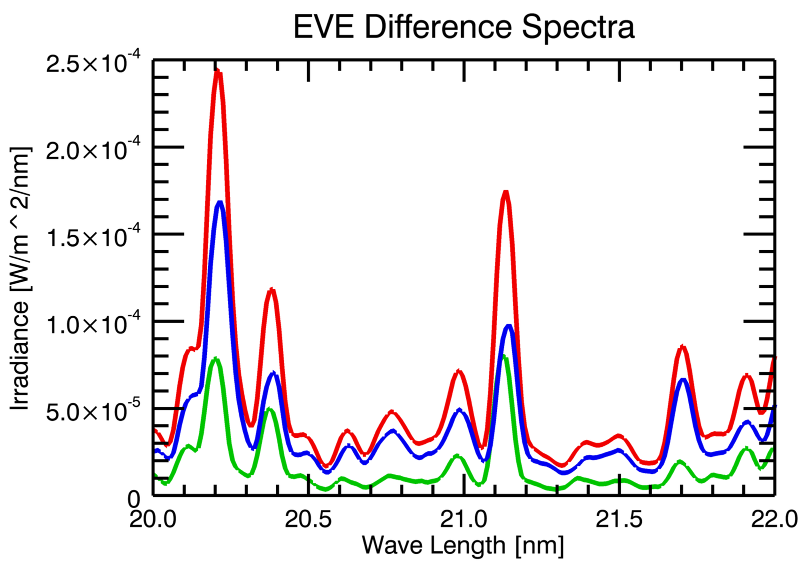

Figure 3: A two nm segment of the three spectra. The top line in red is the average outside the transit spectrum. The middle line in blue is the spectrum taken during the transit. Finally the bottom line in green is the difference between the first two spectra which is the spectrum from the area of the sun covered by the moon.

- **Extracted sixteen emission lines from active region spectrum.**
  - Fitted a Gaussian curve to a line.
  - Irradiance is the area under the Gaussian.
  - Clearly resolved lines were chosen without heavy blending with neighbors.
- **Used data from extracted lines to fit a Differential Emission Measure (DEM).**
  - A DEM describes the amount of plasma as a function of temperature along a line of sight. It is a tool that can be used to examine the temperature structure of the solar atmosphere.

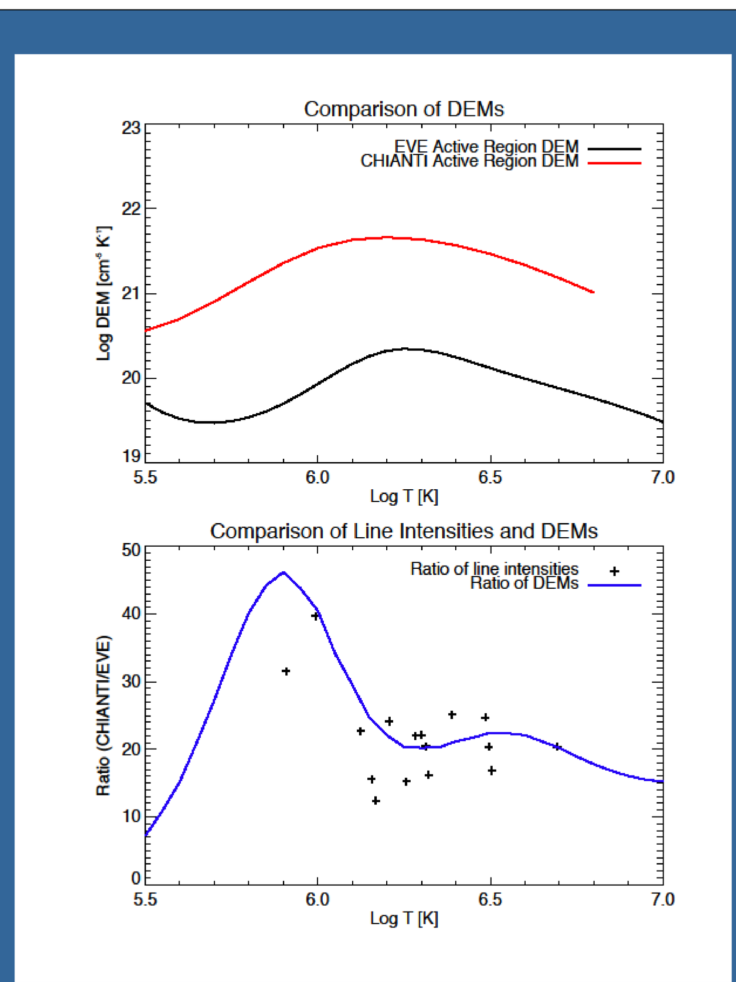

Figure 4: Top graph shows the calculated DEM (Black) with a DEM from a representative active region stored in the CHIANTI atomic database (Red). Bottom graph shows the ratio of CHIANTI data over EVE data as a function of temperature. The blue line is the ratio of the DEMs from the top plot. The crosses are the ratios of the irradiances of the extracted lines plotted at the emission weighted average temperature.

Results

Sixteen emission lines were extracted from both the observed active region spectrum and the representative active region found in the CHIANTI atomic database and are as follows:

Ion	Log T (K)	Ion	Log T (K)
Si VII 27.53nm	5.91	Fe XIV 27.420nm	6.30
Fe IX 17.107nm	5.99	Fe XIV 21.132nm	6.31
O VI 15.01nm	6.12	Fe XIV 26.479nm	6.32
Al X 33.27nm	6.16	Fe XV 28.416nm	6.39
Si X 27.20nm	6.17	Fe XVI 33.541nm	6.48
Fe XII 19.512nm	6.21	Fe XVI 36.07nm	6.50
Ni XII 15.41nm	6.26	Fe XVI 26.2984nm	6.50
Fe XIV 27.052nm	6.28	Fe XVIII 9.393nm	6.69

- **Figure 4 shows the DEM that was calculated using these lines with the DEM of a representative active region.**
- **CHIANTI DEM is higher than the observed DEM as a result of scaling.**
- **More significant are the shapes of the lines.**
  - Overall the shapes of the two lines are very similar.
  - **A noticeable difference is the shape at cooler plasmas**, this can be seen by the peak at log T=5.9 (K) in the ratio of CHIANTI over EVE in the bottom plot of figure 4. This peak means there is more plasma at cooler temperatures in the representative active region than in the observed active region.
- **DEM is an accurate fit for the data.**
  - Line passes closely through the ratio data points in the bottom plot of figure 4.

Discussion

- **A difference spectrum during a transit can be used to produce the spectrum for an active region.**
  - The DEMs in figure 4 have similar shapes which supports the conclusion that the spectrum we found was produced in an active region.
  - This is important because few measured EUV spectra for active regions exist that have as wide of a wavelength range as this one. Spectra are key tools that solar physicist use to study the Sun. This spectrum could be used by other scientists to study the properties of solar active regions.
- **There is a difference in the temperature distribution between the observed active region and the representative active region.**
  - The representative active region contains more cooler plasma.
  - The observed DEM peaks slightly hotter than the representative DEM.
    - EVE peaks at 6.25 Log T and CHIANTI peaks at 6.20 Log T.
  - The observed active region is hotter than the representative active region.
- **These results indicate that not all active regions are the same**
- **DEM represents a possible fit to data and not a unique solutions.**
  - Since the lines I extracted range in temperature from 5.9 to 6.7 log T the shape of the DEM outside this range is not significant as it is not fit to any data. More extracted lines over a wider wavelength range would be necessary to improve the accuracy of our DEM.
  - Even with more data points, the DEM is still based on assumptions such as electron density and elemental abundance. A DEM is a good tool to evaluate a spectrum but it is not an absolute truth.

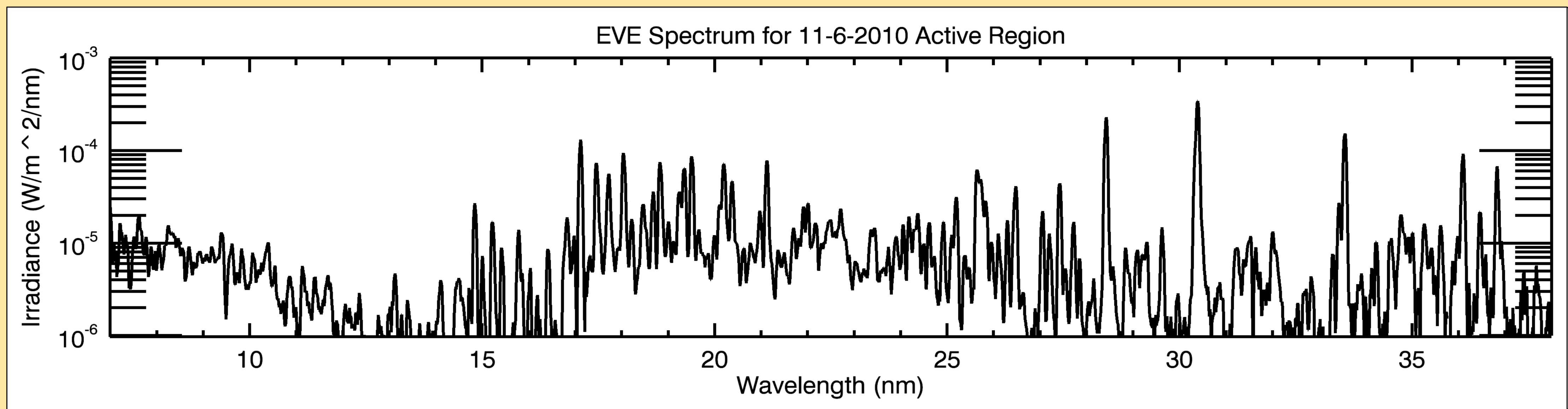

Figure 5: Spectrum for active region observed from 6 November 2010 lunar transit. Spectrum is a difference spectrum with a correction factor for quiet sun applied. Includes full wavelength range of EVE's MEGS-A.

References

"Differential Emission Measure for a Solar Minimum Irradiance Spectrum", Rachel A. Hock, 2008, Masters Thesis.

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