Identifying Emission Lines in the Solar Extreme Ultraviolet (EUV) Irradiance Spectrum

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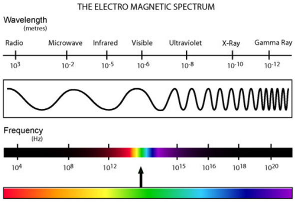
Advisors: Dr. Frank Eparvier and Rachel Hock

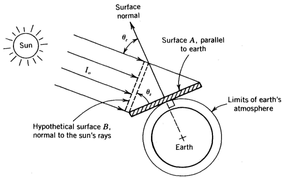
University of Colorado, Boulder

Laboratory for Atmospheric and Space Physics

August 4, 2010

Brief Background





Definition

Ultraviolet light is the portion in the electromagnetic spectrum which falls between X-Ray and Visible ranging between 10 nm - 400 nm. The Extreme Ultraviolet ranges between 10 nm - 120 nm.

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Spectral Irradiance is the absolute measure of the total amount of sunlight incident on a unit area at a specific distance from the sun per wavelength. Units: $\frac{W}{m^2 \cdot nm}$

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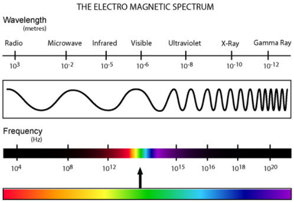

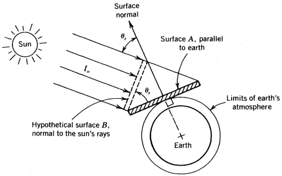

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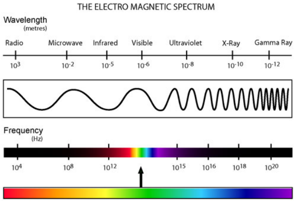

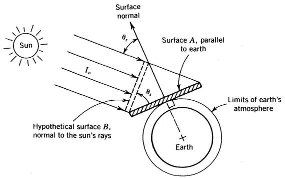

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EUV at Earth

Space Weather Effects

- Solar EUV is completely absorbed in the Earth's upper atmosphere.
  - Creates ionosphere, heats thermosphere, and initiates photochemistry.
- Variability in solar EUV causes variability in:
  - Amount and height of ionization.
  - Temperature and density distribution of atmosphere.
  - Composition of upper atmosphere.

What does it effect?

- Satellite Tracking, Satellite operations
- Navigation, GPS location
- Communication: Ground-Space and Ground-Ground

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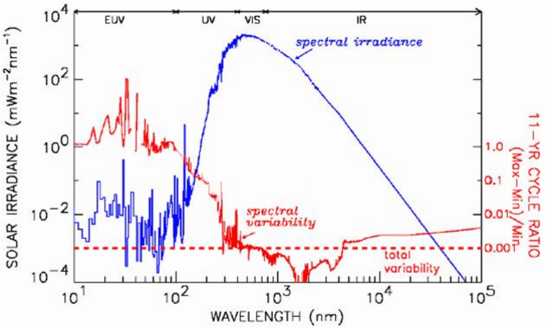

Primary Objectives

(1) Specify the solar EUV spectral irradiance and its variability on multiple time scales.
(2) Advance current understanding of how and why the solar EUV spectral irradiance varies.
(3) Improve the capability to predict the EUV spectral irradiance variability.
(4) Understand the response of the geospace environment to variations in the solar EUV spectral irradiance and the impact on human endeavors.

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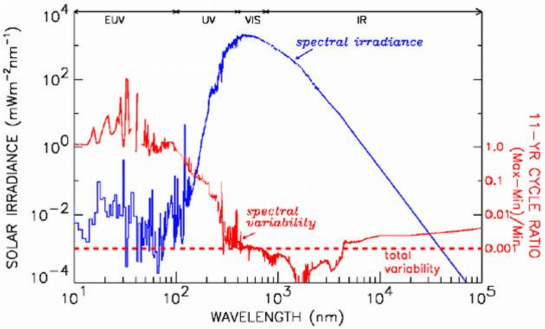

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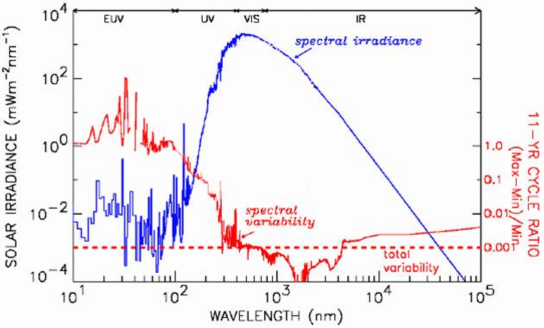

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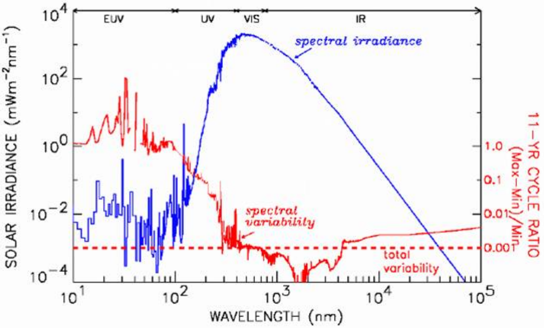

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- Identified solar emission lines between 17 nm and 37 nm using EVE data, IDL and CHIANTI.
- Extracted time series of individual ion emission lines.
- Compared and contrasted within species over a slow variation.

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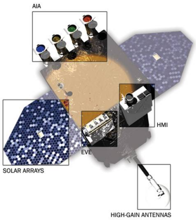

Solar Dynamics Observatory: Launched February 11, 2010

Helioseismic and Magnetic Imager (HMI)

Atmospheric Imaging Assembly (AIA)

Extreme Ultraviolet Variability Experiment (EVE)

EUV SpectroPhotometer (ESP)

Multiple EUV Grating Spectrograph (MEGS)

MEGS-A: Grazing incidence grating
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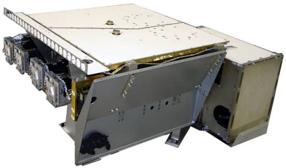
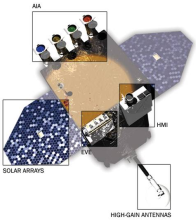
MEGS-SAM: Pinhole camera
MEGS-P: Photodiode





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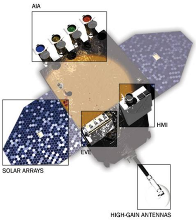

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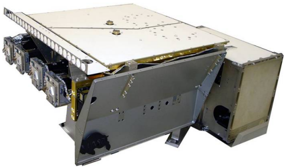

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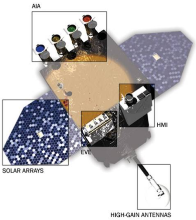

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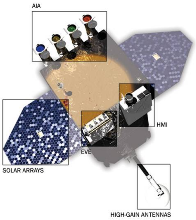

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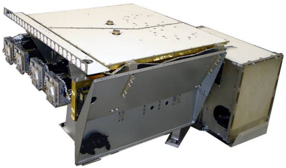

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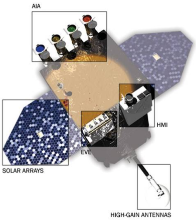

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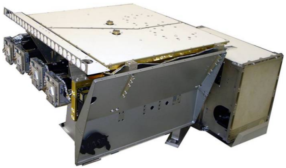

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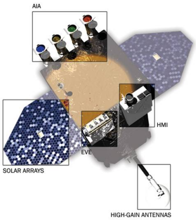

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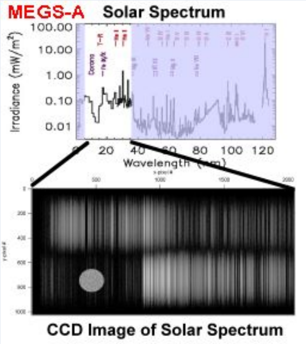
MEGS-A Data Product

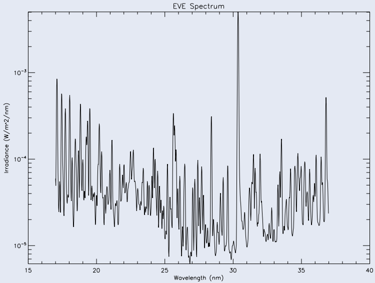


Level	Description	Components	Wavelength Coverage	Wavelength Sampling	Temporal Sampling	Time Span of Data File	Daily size (GB)	Latency of Availability
L0C	**Space Weather Product:** Crudely calibrated irradiances* (from Ka-Band data)	ESP bands + quads (flare)	0.1-7, 18.2, 25.6, 30.4, 36.6 nm	broadband ~4-nm	1-min	Latest 15-min and current 1-day (growing file)	0.004	<15 min
		MEGS-P	121-122 nm	1-nm				
		MEGS-A, B	5-105 nm	1-nm	1-min		0.005	
		MEGS-A, B, proxies	Select lines and bands**	Varies by band	1-min		0.01	
L0CS	**Fastest Space Weather Product**: Crudely calibrated irradiances* with least latency (from S-Band)	ESP bands + quads (flares)	0.1-7, 18.2, 25.6, 30.4, 36.6 nm	broadband ~4-nm	1-min	Latest 15-min and current 1-day (growing file)	0.005	< 1 min
		MEGS-P	121-122 nm	1-nm				
		XRS & SEM model	Proxies	Varies by band				
L1	**Photometer Data:** fully calibrated and corrected photometer irradiances	ESP	0.1-7, 18.2, 25.6, 30.4, 36.6 nm	~4-nm	1/4-sec	1-hour	0.03	1 Day
		SAM	0.1-7 nm***	0.1-1-nm	1- & 5-min		varies	
		MEGS-P	121-122 nm	~1-nm	1/4-sec		0.006	
L2	**Spectra**: fully calibrated and corrected spectral irradiances at instrument resolution	MEGS-A, B	5-105 nm	0.02 nm	10-sec	1-hour	1.2	1-2 Day
L2	**Lines & Broadband irradiances:** fully calibrated and corrected photometer irradiances and extracted spectral lines and bands	MEGS-A, B, P, ESP	select lines & bands	Varies by band	10-sec	1-hour	0.01	1-2 Day
L3	**Merged Spectra:** fully calibrated, corrected, and merged spectral irradiances	ESP, SAM, MEGS-A, MEGS-B, MEGS-P	0.1-105 nm	0.02, 0.1 & 1 nm	1-day	1-day	<0.001	1-2 Day

*All products are corrected to 1-AU except L0C and L0CS.
** Lines spanning Log T = 3.8-7.1, plus AIA and ESP bands.
*** SAM is a research project, L1A will have 4 element event list: time, location (x,y), and energy.

EVE Spectrum

May 5, 2010



L2 data product, averaged over 1 hour.

Definition

Interactive Data Language (IDL) is a programming language used for data analysis. It is highly used in the astronomical community due to its ability to handle large arrays of data.

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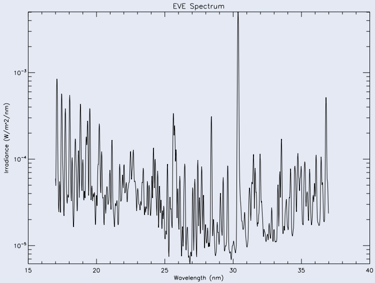

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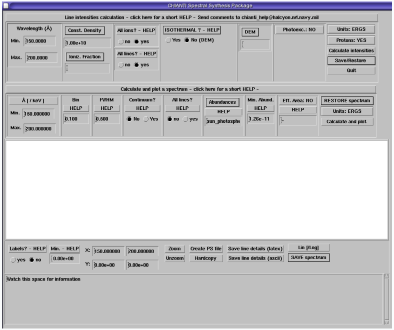
Critically evaluated set of atomic data (energy levels, wavelengths, radiative transition probabilities and excitation data) for a large number of ions of astrophysical interest.



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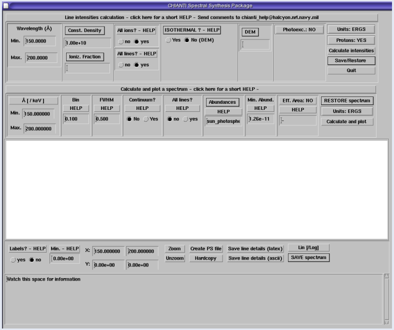

Making a Synthetic Spectrum

Assumptions

- Constant Density = $1.00e^{10}\ cm^{-3}$
- Ionization Fraction = CHIANTI
- Differential Emission Measure = quiet_sun
- Elemental Abundance = sun_photospheric
- Minimum Abundance = $3.98e^{-8}$
- Minimum Intensity = $1.26e^{-11}\ \frac{erg}{cm^2 \cdot sr \cdot s}$

Problems

- Making assumptions.
- CHIANTI is not complete.
  Not all atomic transition probabilities are known.

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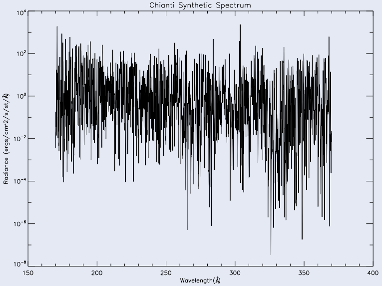

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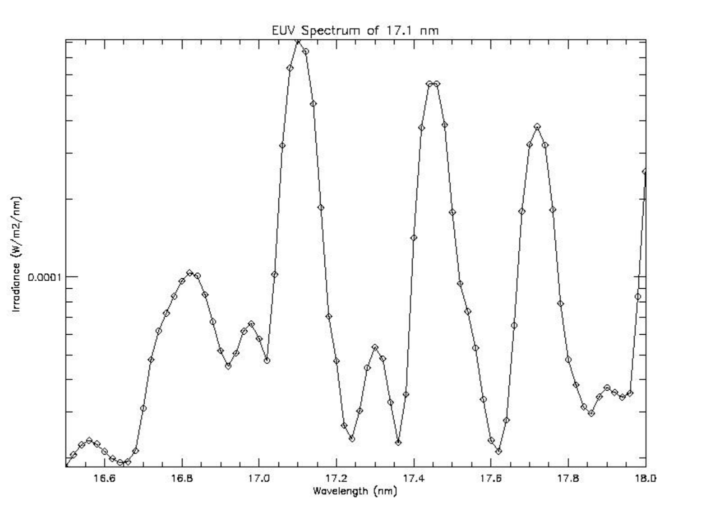

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170.7753	$8.33e^{-07}$	S VIII	6.1	2s2 2p4 (3P) 3p 4P3/2 - 2s2 2p4 (1D) 4d 2P3/2
170.8420	$1.05e^{-02}$	Fe XI	6.1	3s2 3p4 1D2 - 3s2 3p3 (2P) 3d 1P1
170.9989	$4.74e^{-10}$	Fe XVIII	6.6	2s2 2p4 (3P) 3s 4P3/2 - 2s2 2p4 (3P) 3d 4F5/2
171.0080	$2.12e^{-07}$	Ne VI	5.7	2s 2p2 2P1/2 - 2s 2p (3P) 3s 4P3/2
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171.0570	$1.44e^{-08}$	Ti XVII	6.6	2s 2p3 3P2 - 2p4 3P2
171.0730	$2.05e^{+02}$	Fe IX	5.9	3s2 3p6 1S0 - 3s2 3p5 3d 1P1
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171.1540	$4.97e^{-08}$	Ar IX	6.1	2s2 2p5 3p 1D2 - 2s2 2p5 4p 3P1
171.1794	$4.27e^{-05}$	Ar X	6.2	2s2 2p4 (3P) 3s 4P5/2 - 2s 2p5 (3P) 3s 2P3/2
171.2420	$1.59e^{-07}$	Ar IX	6.1	2s2 2p5 3p 1D2 - 2s2 2p5 4p 1D2
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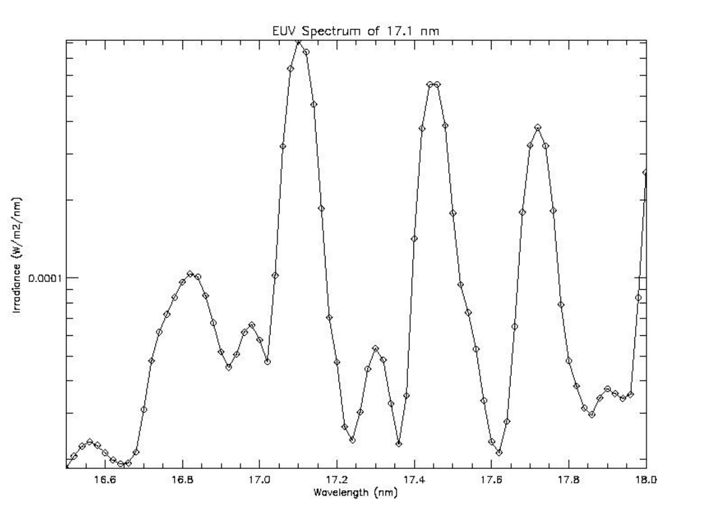
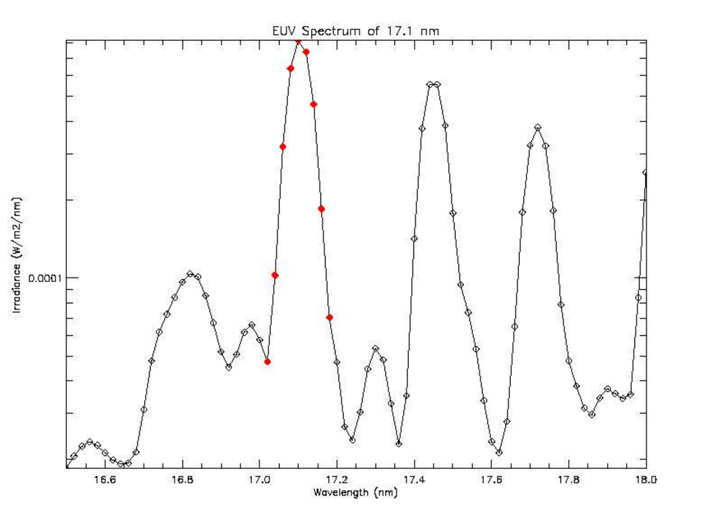
171.2620	$2.46e^{-03}$	Fe X	6.1	3s 3p5 (3P) 3d 2F7/2 - 3s2 3p4 (1D) 4d 2D5/2
171.3703	$1.36e^{+00}$	Ni XIV	6.3	3s2 3p3 4S3/2 - 3s2 3p2 (3P) 3d 4P5/2

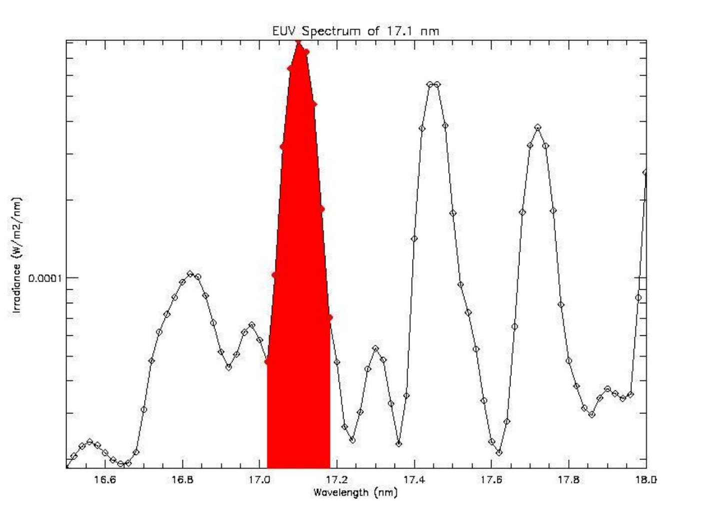
Identifying Lines



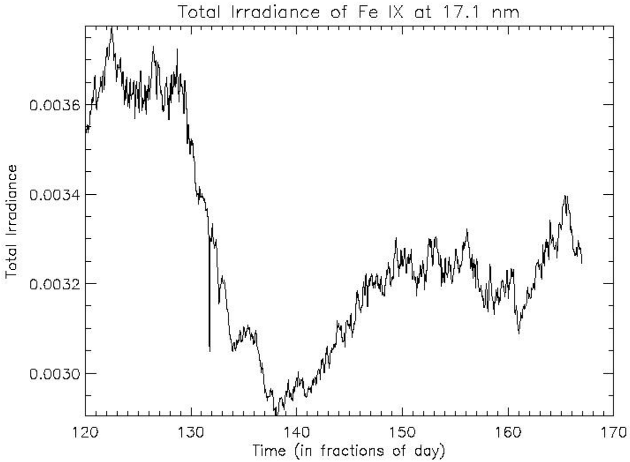
Identifying Lines



Identifying Lines



Time series of 17.1 nm Fe IX

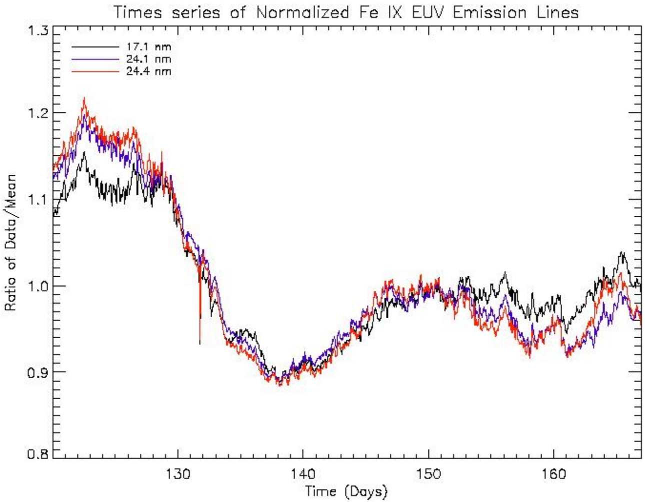


Fe IX

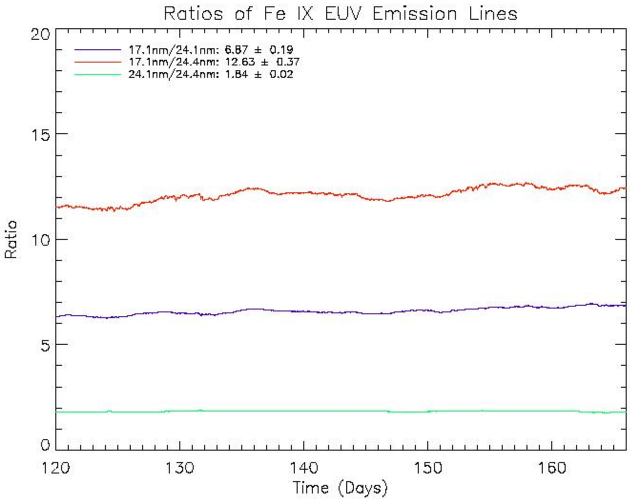
Table: Fe IX emission lines between 17 nm and 37 nm

Wavelengths(Å)	*Ratio*	*Stand.Dev.*	*Percent*	*Pearson*
171./171.	1.0000	0.000000	0.000000	1.000000
171./188.	2.0168	0.069886	0.034652	0.906477
171./190.	8.2293	0.224910	0.027330	0.951956
171./191.	20.3197	0.874443	0.043034	0.895725
171./197.	21.1571	0.782183	0.036970	0.932942
171./217.	8.3959	0.298466	0.035549	0.949570
171./219.	12.7881	1.028338	0.080414	0.902604
171./230.	11.4787	0.303932	0.026478	0.937031
171./241.	6.8751	0.186593	0.027140	0.959386
171./244.	12.6288	0.365976	0.028979	0.966897
171./341.	22.1180	0.998897	0.045162	0.852954
188./219.	6.3364	0.375403	0.059245	0.967875
188./241.	3.4112	0.090832	0.026628	0.951427
188./244.	6.2651	0.156928	0.025048	0.966654
191./341.	1.0892	0.037211	0.034165	0.926662
230./197.	1.8432	0.050085	0.027173	0.974626
241./190.	1.1971	0.021267	0.017766	0.978145
241./244.	1.8369	0.023265	0.012665	0.992566

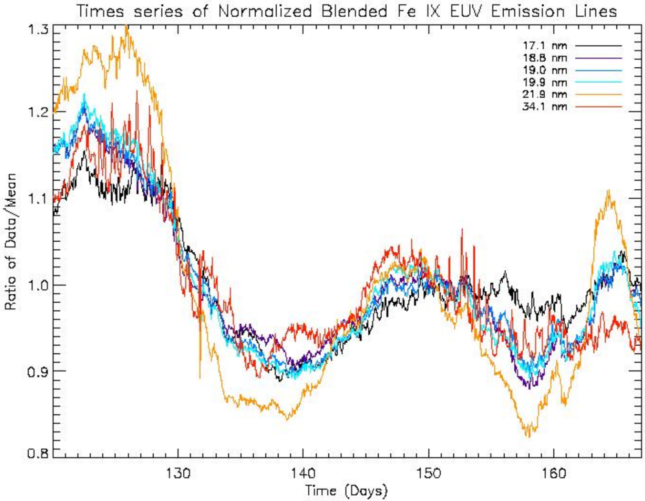
Squiggly Line Plots



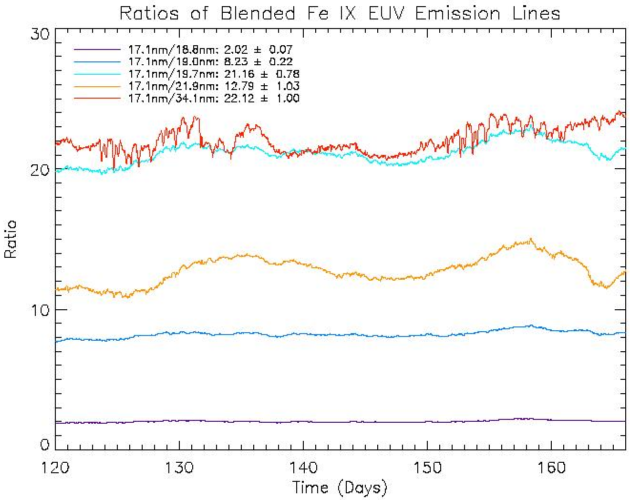
Squiggly Line Plots



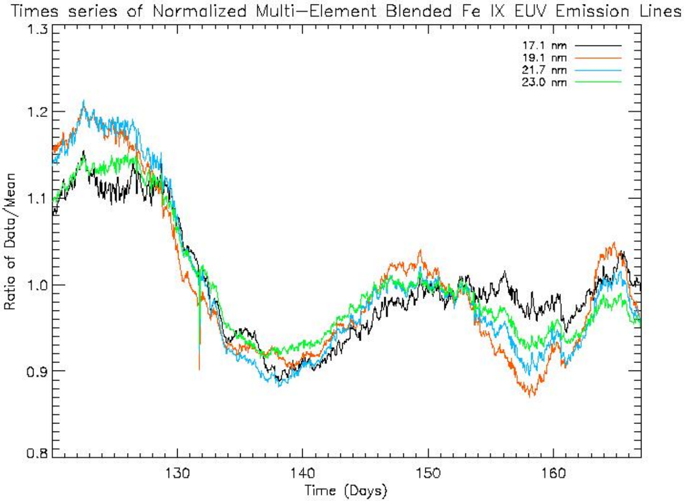
Squiggly Line Plots



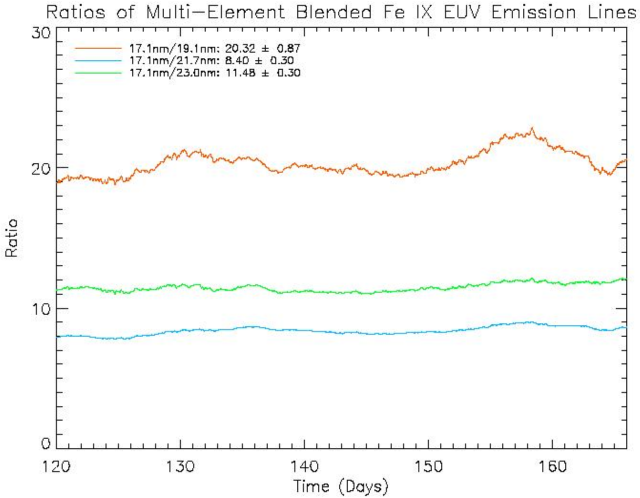
Squiggly Line Plots



Squiggly Line Plots



Squiggly Line Plots



Conclusions

Ions Analyzed

- Fe IX, Fe X, Fe XI, Fe XII, Fe XIII
- He II
- O IV, O V, O VI
- Mg VI, Mg VII

Magnesium

- Total of 3 usable lines.
- For both Mg ions, there wasn't sufficient data to suggest non-blends.
- All three Mg VII lines are all composed of different elements and ions.

Conclusions

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Conclusions

Oxygen

- Total of 7 usable lines.
- Insufficient data to analyze O VI
- 24.8 nm O V line is a non-blend
- 19.3 nm and 22.0 nm O V lines are blends and of different ions.
- 23.9 nm and 26.7 nm O IV lines are blends

Helium

- Total of 4 usable lines.
- 24.3 nm and 25.6 nm He II lines are blends.
- 30.4 nm and 23.7 nm He II lines are non-blends.

Conclusions

Oxygen

- Total of 7 usable lines.
- Insufficient data to analyze O VI
- 24.8 nm O V line is a non-blend
- 19.3 nm and 22.0 nm O V lines are blends and of different ions.
- 23.9 nm and 26.7 nm O IV lines are blends

Helium

- Total of 4 usable lines.
- 24.3 nm and 25.6 nm He II lines are blends.
- 30.4 nm and 23.7 nm He II lines are non-blends.

Conclusions

Iron Thirteen

- Total of 10 usable lines.
- 20.0 nm, 20.2 nm 21.4 nm lines are non-blends.
- 19.7 nm, 20.4 nm, 21.0 nm, 24.1 nm, 24.6 nm, 25.2 nm, 36.0 nm and 36.8 nm are blends.

Iron Twelve

- Total of 15 usable lines.
- 19.4 nm and 19.5 nm lines are non-blends.
- Not sure about 20.6 nm line.
- 18.9 nm, 19.1 nm, 19.3 nm, 19.7 nm, 20.4 nm, 21.9 nm, 23.2 nm, 24.1 nm, 24.9 nm, 29.1 nm, 35.2 nm and 36.4 nm lines are all blends.

Conclusions

Iron Thirteen

- Total of 10 usable lines.
- 20.0 nm, 20.2 nm 21.4 nm lines are non-blends.
- 19.7 nm, 20.4 nm, 21.0 nm, 24.1 nm, 24.6 nm, 25.2 nm, 36.0 nm and 36.8 nm are blends.

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Conclusions

Iron Eleven

- Total of 9 usable lines.
- No non-blends
- 18.2 nm, 18.4 nm, 18.8 nm and 19.0 nm all vary the same which suggests they are made of the same blend of ions.

Iron Ten

- Total of 9 usable lines.
- 17.4 nm and 17.7 nm lines are non-blended.
- Not sure about 20.8 nm line.
- 18.0 nm, 18.5 nm, 19.0 nm, 22.0 nm, 22.7 nm, 25.7 nm lines are blends.

Conclusions

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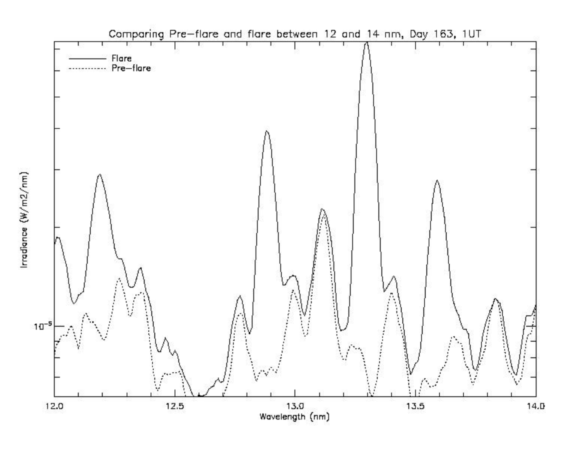
Flares



Comments

While the shorter EUV wavelengths are very active and interesting during a flare, preliminary analysis doesn't show any new usable lines between 17 and 37 nm.

Future Work

- Analyze more ion species.
  Fe XIV, Fe XVI, Si IX, Si X, ...
- Look at other parts of the EUV.
- Further suggest blends and which elements make up the blend.
- Further look at flare vs non-flare (fast variation).

Acknowledgments

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