Seconds to Centuries:
Chromospheric Variability (Part 1): Physics and Sun-Earth connection

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Who am I?

PhD thesis: Iron II asymmetries: the kinematics of the chromosphere of the cool supergiant alpha Orionis

Institutions:

South African National Space Agency (Research Chair in Space Weather)

University of Colorado Boulder, Laboratory for Atmospheric and Space Physics

University of the Western Cape, Cape Town, South Africa

Missions/Instruments

HST/GHRS, UARS/SOLSTICE I, SORCE/SOLSTICE II, GOES-R/EXIS,

TSIS-1/SIM, CSOL, CSIM

Hopefully: TSIS-2/SIM, SunCube, etc.

Hobbies:

Board games, cooking, travel, cats.

Outline

Physics background

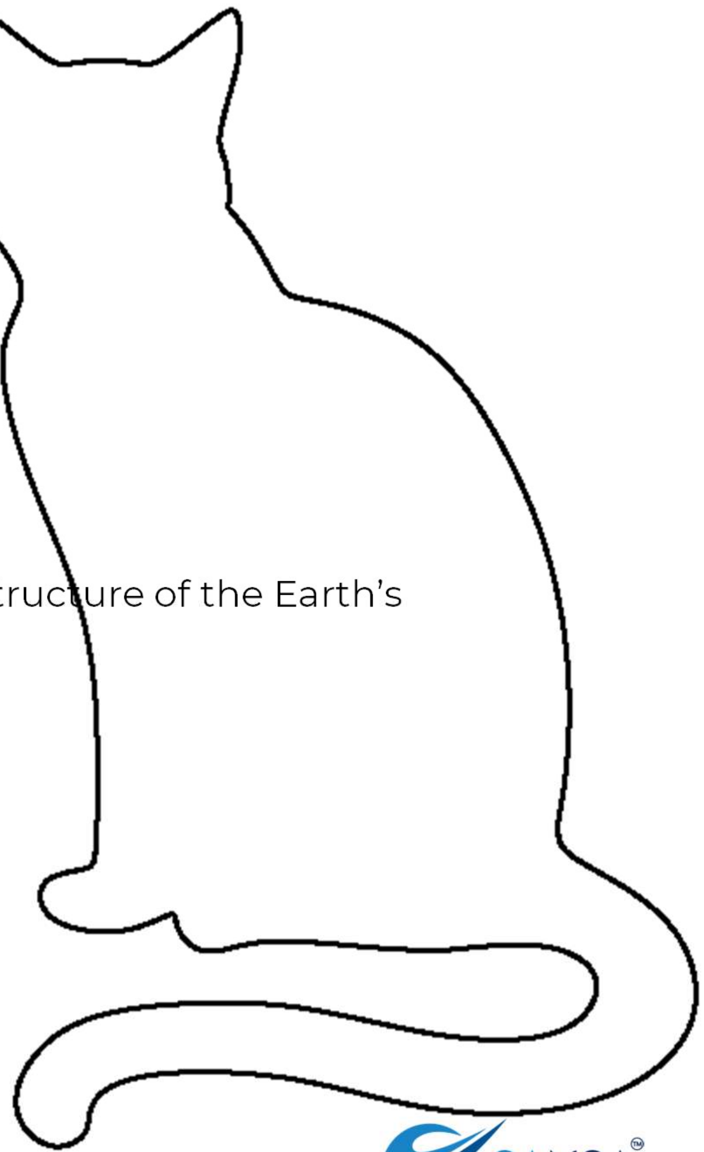
Radiative transfer – formation heights

Ionization as a function of temperature

Sun-Earth connection -- satellite drag, ionization, scintillation, temperature structure of the Earth's atmosphere

Short term variations in the atmosphere caused by space weather events

Part 2: instruments that measure the UV spectral irradiance



Physics review: Radiative Transfer – optical depth

Imagine a photon passing through a medium containing particles that can absorb of scatter that photon.

Let each absorber have a cross section, $\sigma = \pi r^2$

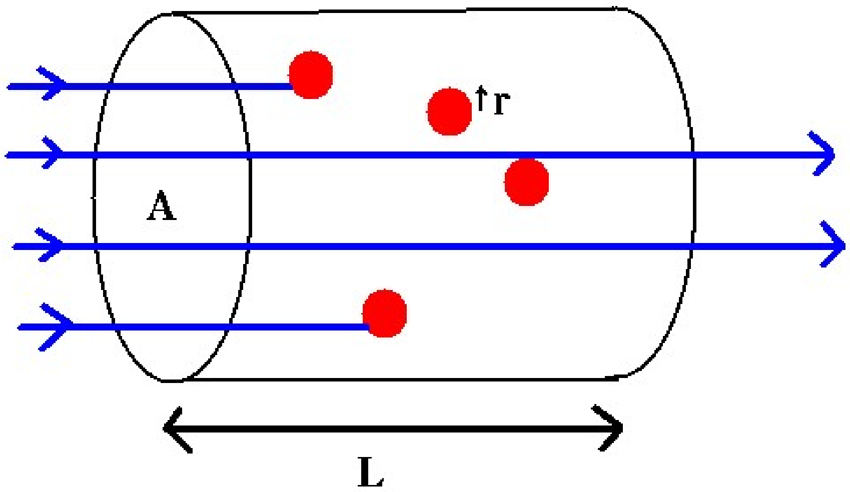
The area blocked by the absorbers will be

$$\sigma_{total} = nLA\sigma$$

The fraction of the light blocked would be

$$\frac{I}{I_0} = \frac{\sigma_{total}}{A} = \frac{nLA\sigma}{A} = nL\sigma = \tau$$

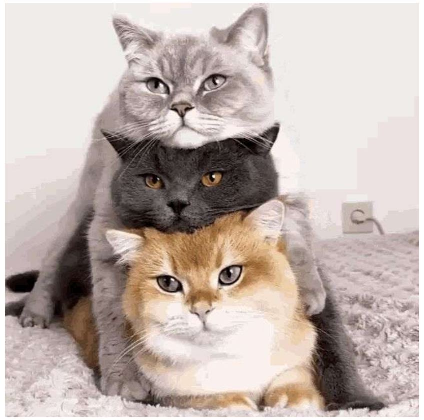
where τ is the optical depth.



Optical depth (2)

If we imagine a stack of these cylinders, each with thickness dL, the change in intensity would be:

$$dI = -(I)(n\sigma dL) = -I d\tau$$



Integrating over the stack

$$I_{out} = I_{in} e^{-\tau}$$

In a very dense medium (lots of absorbers)

$$\tau \gg 1 \; and \; I_{out} \approx 0$$

Deep in the sun, photons do not travel very far before being absorbed and then re-emitted in a random direction. Small parcels of gas/plasma are in equilibrium with their neighbors. This is referred to as Local Thermodynamic Equilibrium (LTE).

Optical Depth (3)

To first order (i.e. no turbulence or bulk flows), the atmospheric pressure decreases as a function of height

$$P = P_0 e^{-z^2/H}$$

Where z is the height above some “surface” and H is the scale height that depends on temperature, atomic mass of the plasma, force of gravity, etc.

For a given parcel of gas/plasma, the density will decrease with height. As the density decreases, the number of absorbers decreases, so the optical depth decreases.

Photons in a low-density plasma can travel much farther before encountering an absorber.

If the number of photons leaving is greater than the number arriving, energy is transported out of the parcel.

Optical Depth (4)

$$I_{out} = I_{in}e^{-\tau}$$

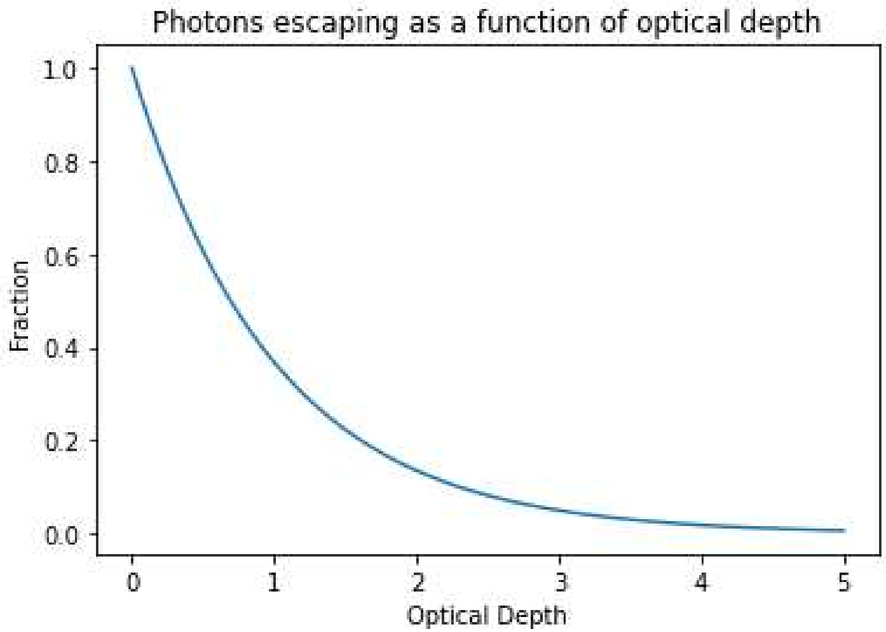
Instead of thinking of this as the photons escaping,

Think of it as looking in from the outside.

Where do those photons you see come from?

The photons that escape come from $\tau \leq 1$ (roughly)

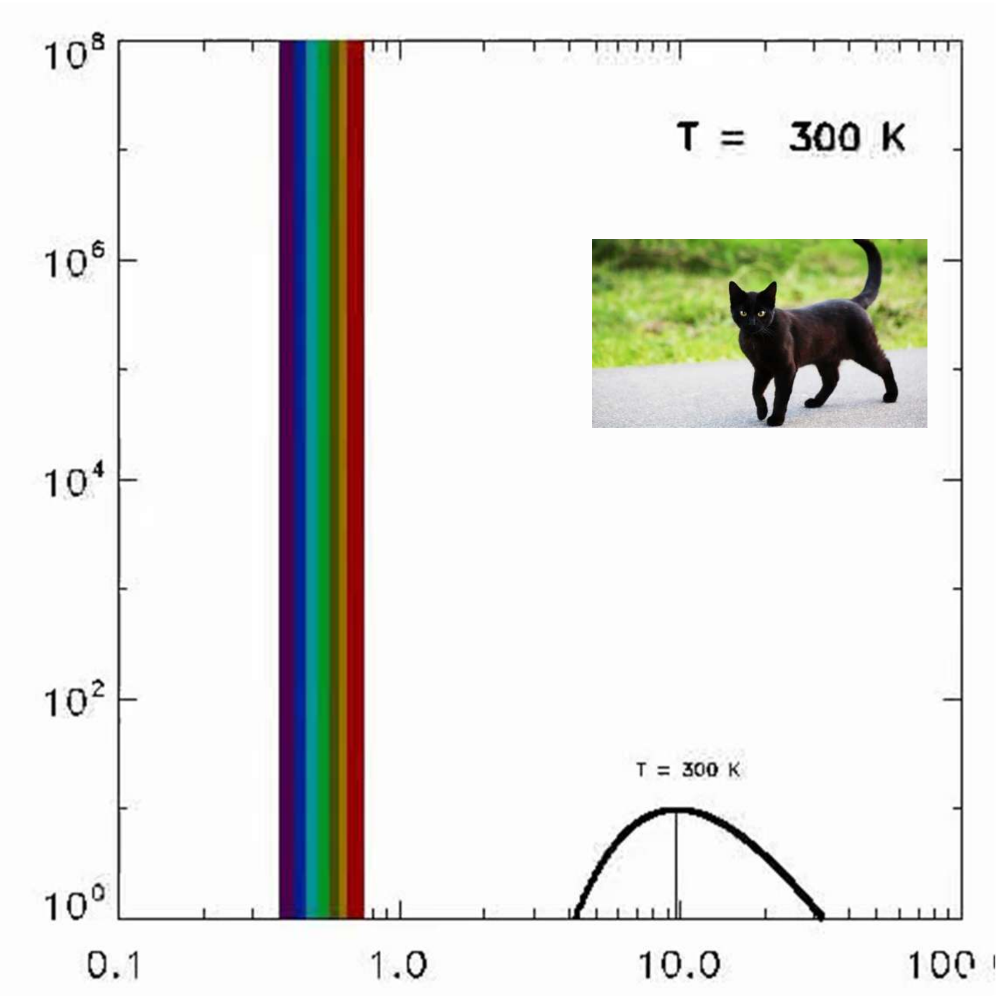
So that's how far into the atmosphere you can see.



Planck Function

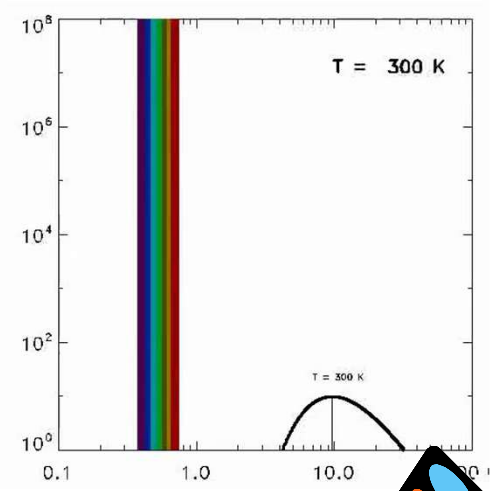
A medium in thermodynamic equilibrium, known as a black (cat) body, produces a spectrum as shown in the plot.

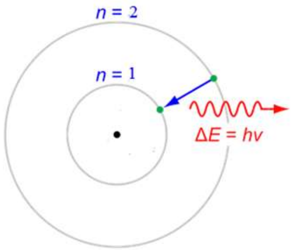
As the temperature rises, the emitted spectrum gets brighter, and also peaks at shorter and shorter wavelengths.

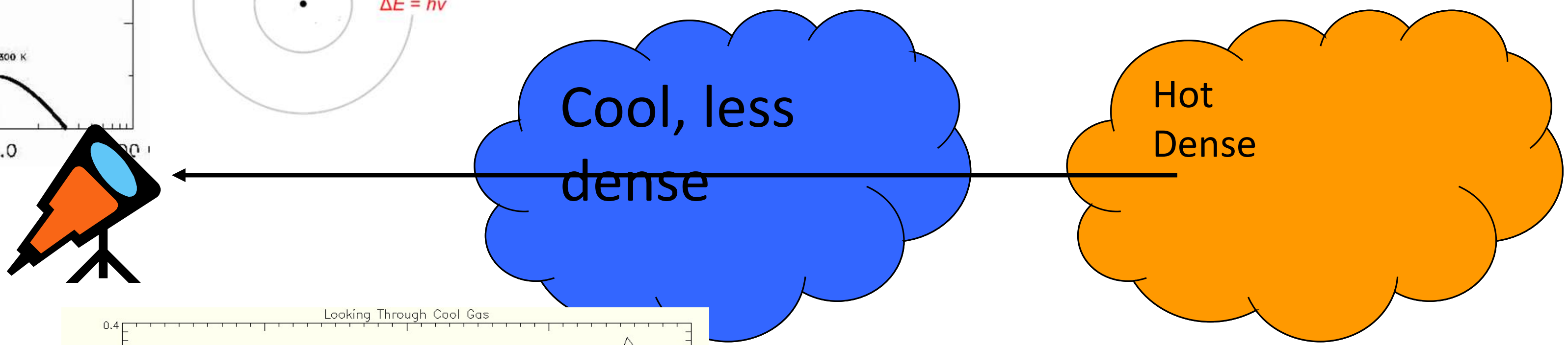


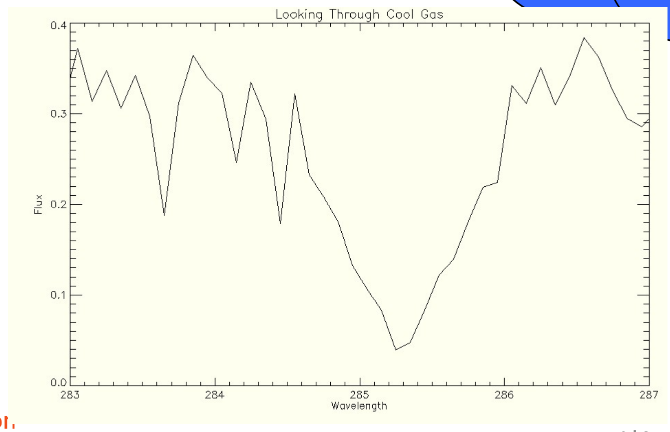
Two slide summary of radiative transfer

In all remote sensing (e.g. Astronomy and Heliophysics), we observe photons and then use physics to interpret the conditions that might have produced them.

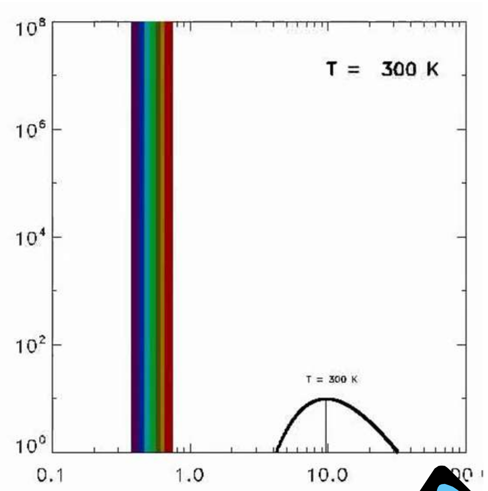


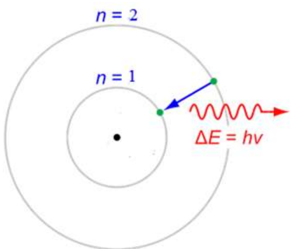


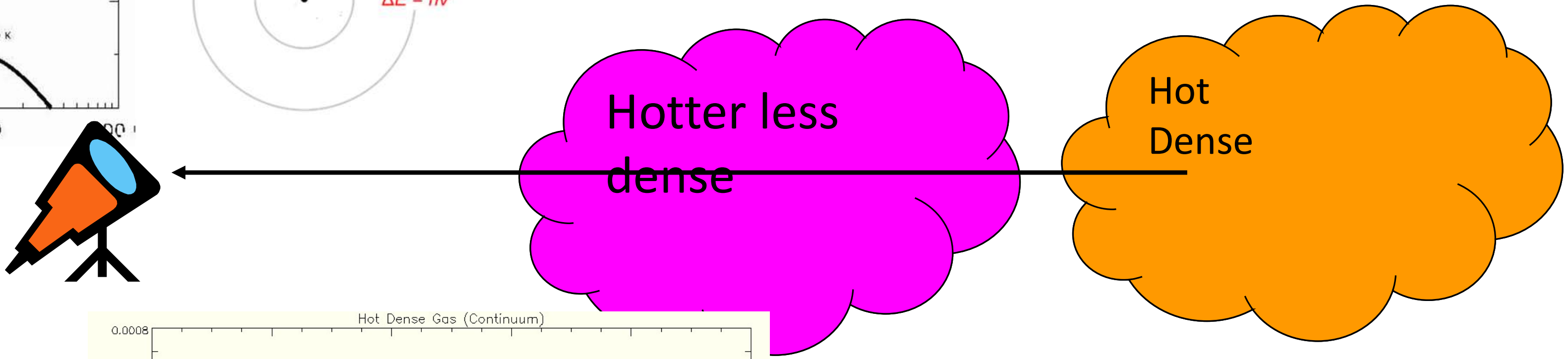


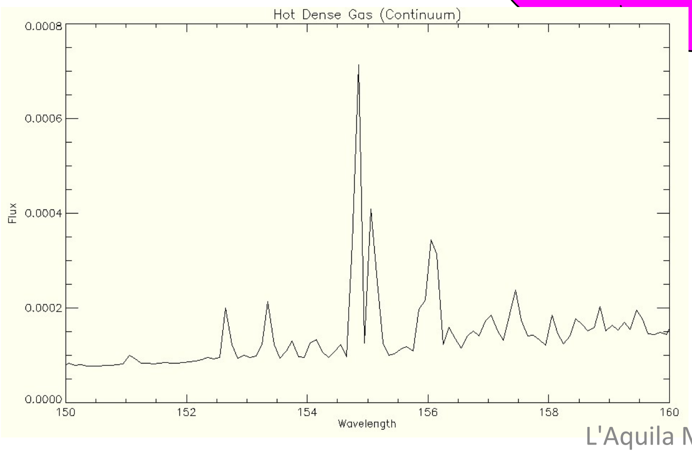


Planck curve for cooler material is not as bright.
At core of line, only see into atmosphere as far as the cool gas.
Absorption Line Spectrum



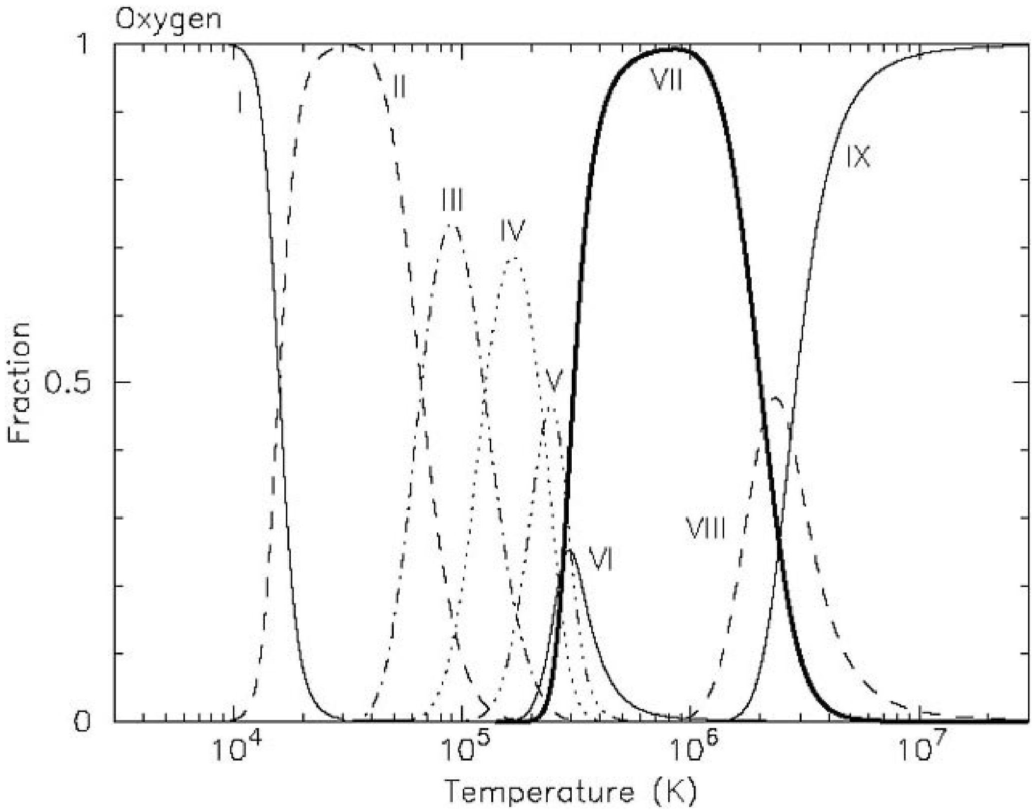






Planck curve for hotter material is brighter.
At core of line, only see in as far as hotter gas.
Emission Line Spectrum

Ionization state as a function of temperature



Energy levels in an atom depend on ionization state

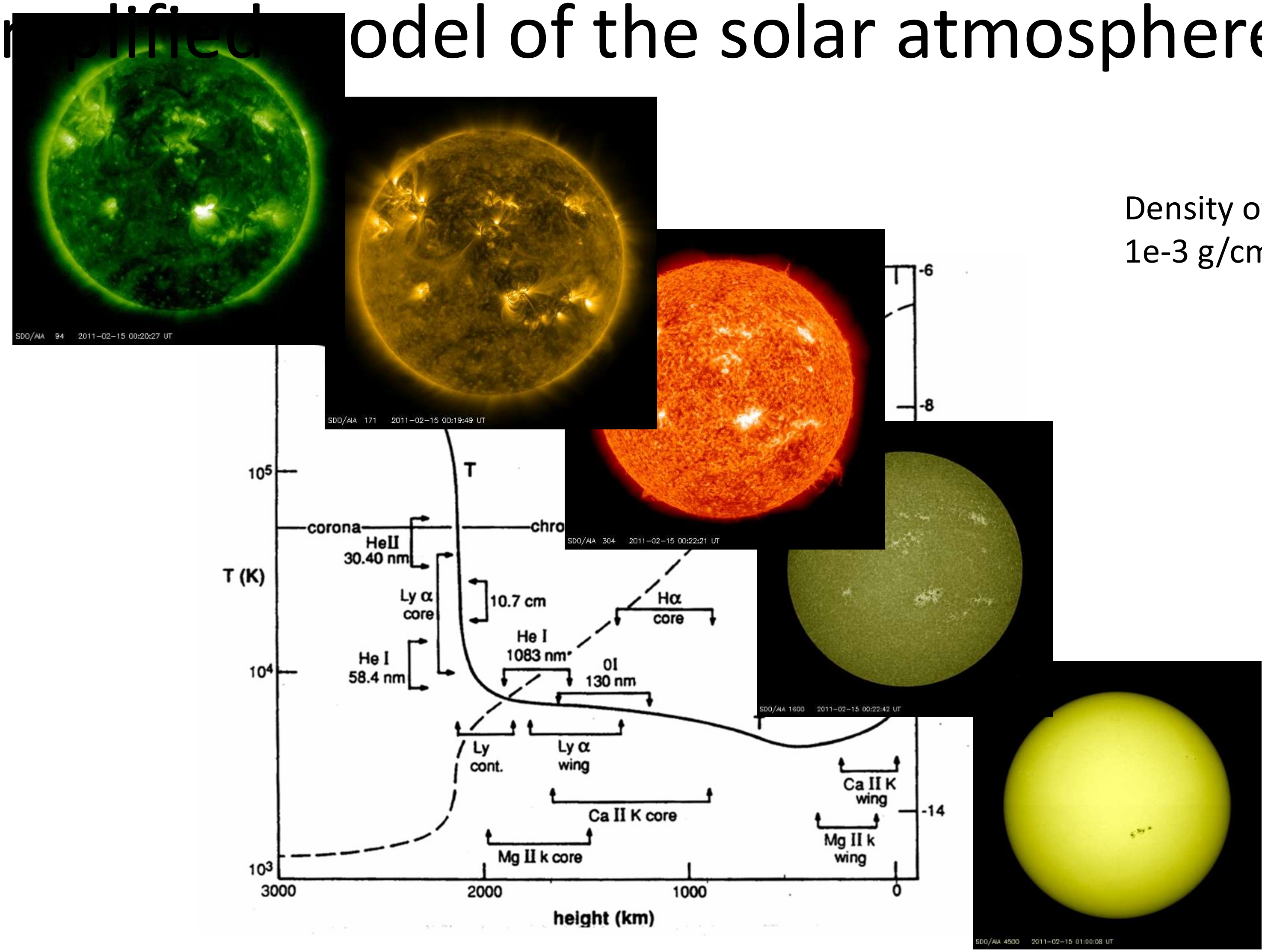
CHIANTI database – possible electronic transitions for each ionization state

So observed spectral lines can only come from certain atomic species, which can only exist in a small range of temperatures.

https://linelists.chiantidatabase.org/

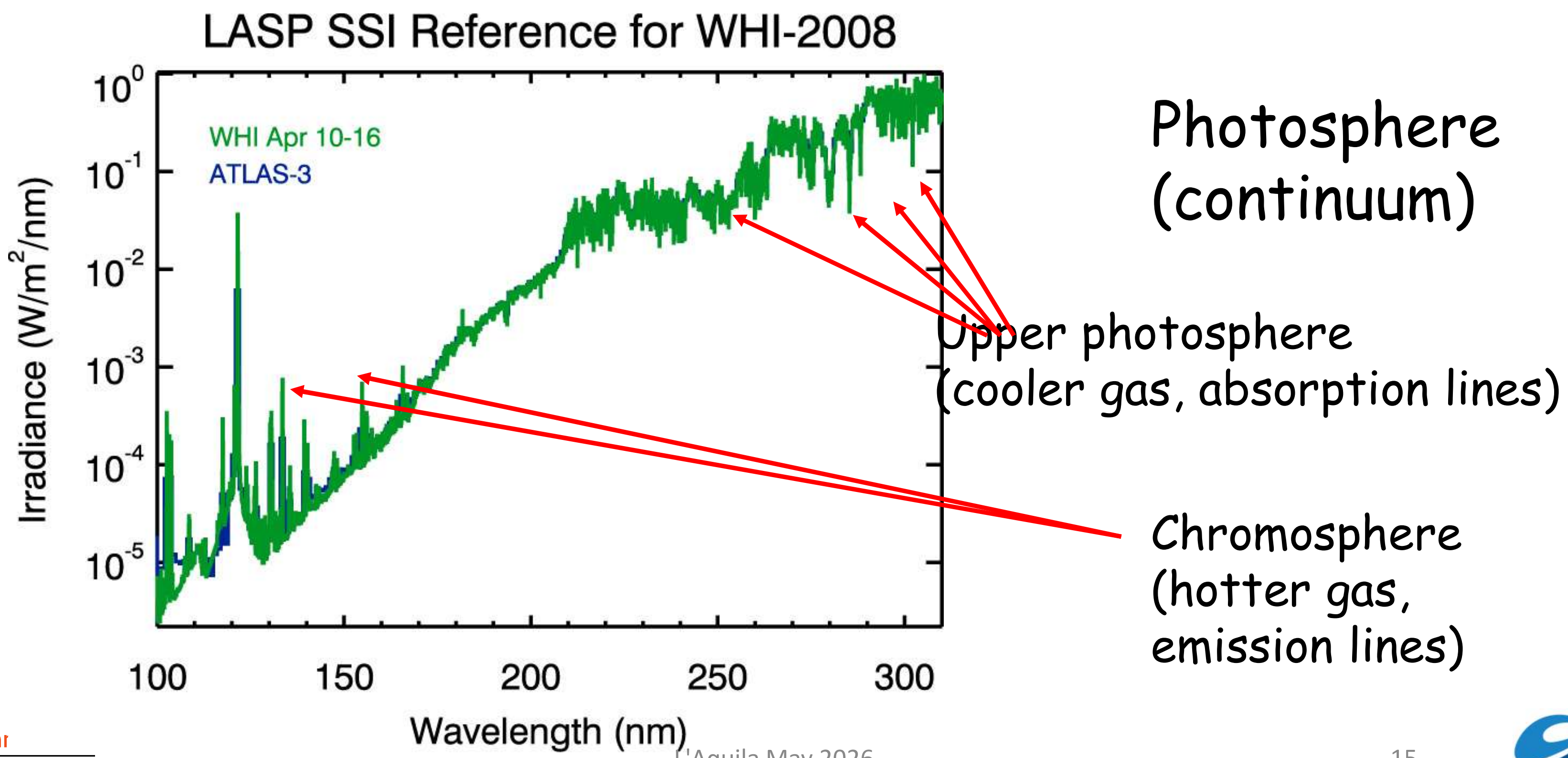
Ion	λ (Å)	Transition	T_{max}	Int
S III	1194.4410	$3s^2\ 3p^2\ ^3P_1$ - $3s\ 3p^3\ ^3D_1$	4.60	2.72e+03
S V	1199.1340	$3s^2\ ^1S_0$ - $3s\ 3p\ ^3P_1$	5.05	1.28e+04
S III	1200.9590	$3s^2\ 3p^2\ ^3P_2$ - $3s\ 3p^3\ ^3D_3$	4.60	1.47e+04
S III	1201.7180	$3s^2\ 3p^2\ ^3P_2$ - $3s\ 3p^3\ ^3D_2$	4.60	2.37e+03
Si III	1206.5000	$3s^2\ ^1S_0$ - $3s\ 3p\ ^1P_1$	4.60	5.06e+05
Si III	1206.5551	$3s\ 3p\ ^1P_1$ - $3s\ 3d\ ^1D_2$	4.70	4.31e+03
He II	1215.1710	$2p\ ^2P_{3/2}$ - $4d\ ^2D_{5/2}$	4.90	2.25e+03
He II	1215.1750	$2p\ ^2P_{1/2}$ - $4d\ ^2D_{3/2}$	4.90	1.25e+03
H I	1215.6680	$1s\ ^2S_{1/2}$ - $2p\ ^2P_{3/2}$	4.50	8.73e+05
H I	1215.6740	$1s\ ^2S_{1/2}$ - $2p\ ^2P_{1/2}$	4.50	4.36e+05
O V	1218.3440	$2s^2\ ^1S_0$ - $2s\ 2p\ ^3P_1$	5.25	5.74e+04
N V	1238.8210	$1s^2\ 2s\ ^2S_{1/2}$ - $1s^2\ 2p\ ^2P_{3/2}$	5.20	6.67e+04
N V	1242.8040	$1s^2\ 2s\ ^2S_{1/2}$ - $1s^2\ 2p\ ^2P_{1/2}$	5.20	3.33e+04
C III	1247.3820	$2s\ 2p\ ^1P_1$ - $2p^2\ ^1S_0$	4.75	3.65e+03
Si II	1264.7380	$3s^2\ 3p\ ^2P_{3/2}$ - $3s^2\ 3d\ ^2D_{5/2}$	4.50	1.19e+03
Si III	1294.5450	$3s\ 3p\ ^3P_1$ - $3p^2\ ^3P_2$	4.65	1.21e+04
Si III	1296.7260	$3s\ 3p\ ^3P_0$ - $3p^2\ ^3P_1$	4.65	9.72e+03
Si III	1298.8920	$3s\ 3p\ ^3P_1$ - $3p^2\ ^3P_1$	4.65	7.24e+03
Si III	1298.9460	$3s\ 3p\ ^3P_2$ - $3p^2\ ^3P_2$	4.65	3.58e+04
Si III	1301.1479	$3s\ 3p\ ^3P_1$ - $3p^2\ ^3P_0$	4.60	8.30e+03
Si III	1303.3220	$3s\ 3p\ ^3P_2$ - $3p^2\ ^3P_1$	4.65	1.18e+04
Si III	1312.5909	$3s\ 3p\ ^1P_1$ - $3s\ 4s\ ^1S_0$	4.70	2.55e+03
C II	1323.9060	$2s\ 2p^2\ ^2D_{3/2}$ - $2p^3\ ^2D_{3/2}$	4.50	1.48e+03
Fe XIX	1328.9041	$1s^2\ 2s^2\ 2p^4\ ^3P_2$ - $1s^2\ 2s^2\ 2p^4\ ^3P_0$	7.00	5.40e+03
C II	1334.5320	$2s^2\ 2p\ ^2P_{1/2}$ - $2s\ 2p^2\ ^2D_{3/2}$	4.50	9.99e+04
C II	1335.6620	$2s^2\ 2p\ ^2P_{3/2}$ - $2s\ 2p^2\ ^2D_{3/2}$	4.50	1.97e+04
C II	1335.7070	$2s^2\ 2p\ ^2P_{3/2}$ - $2s\ 2p^2\ ^2D_{5/2}$	4.50	1.70e+05

A simplified model of the solar atmosphere

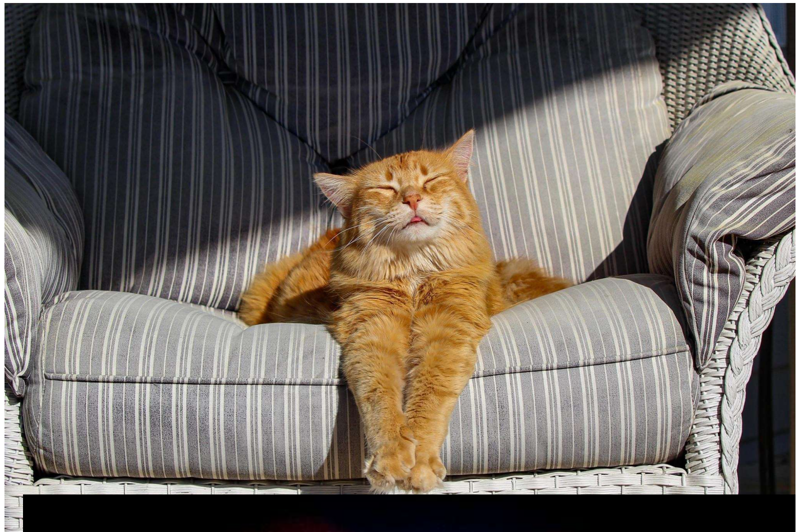


Density of air in this room?
1e-3 g/cm^3

Different wavelengths formed at different heights in atmosphere



Sun-as-a-star irradiance

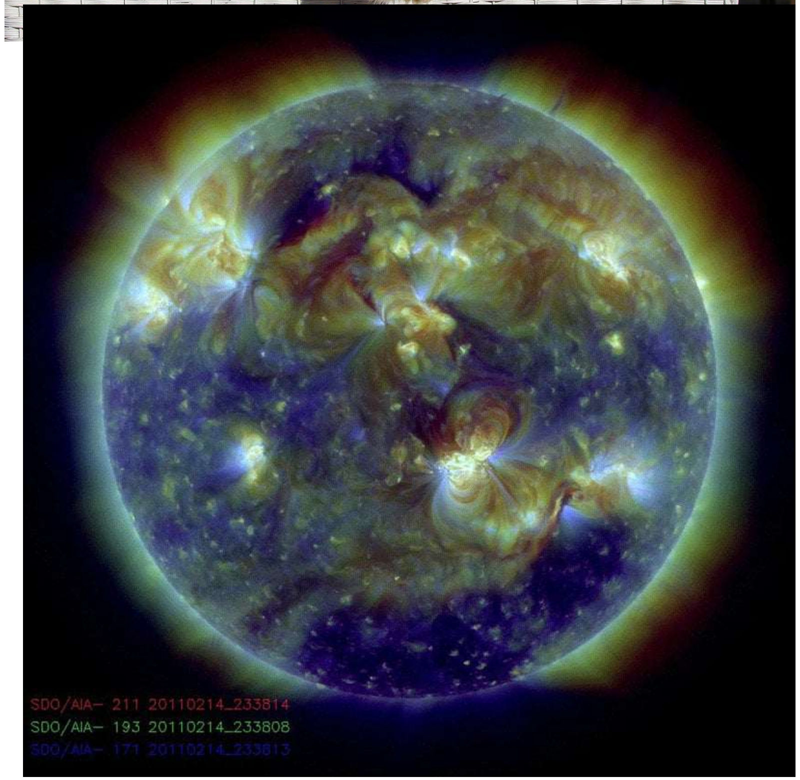


Most of the data that I will show is a disk-integrated solar spectral irradiance (SSI).

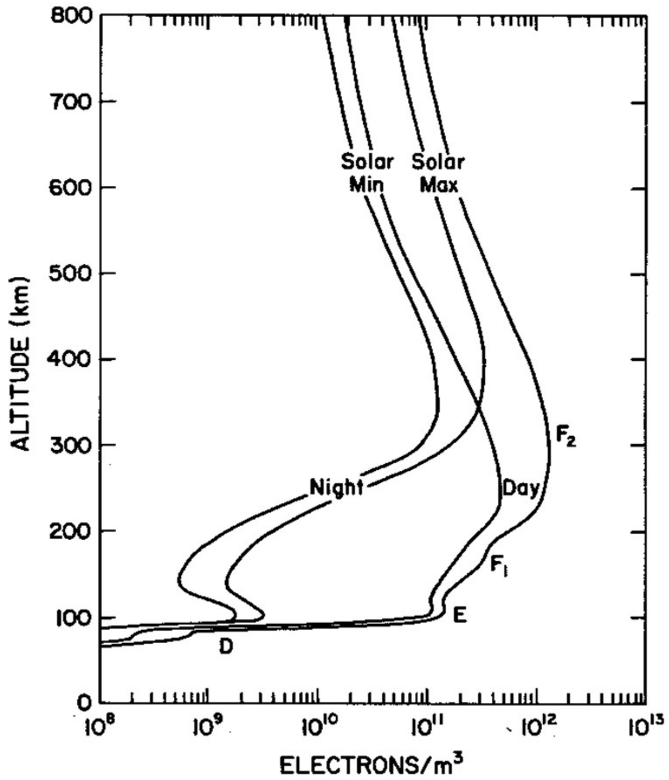
Why?

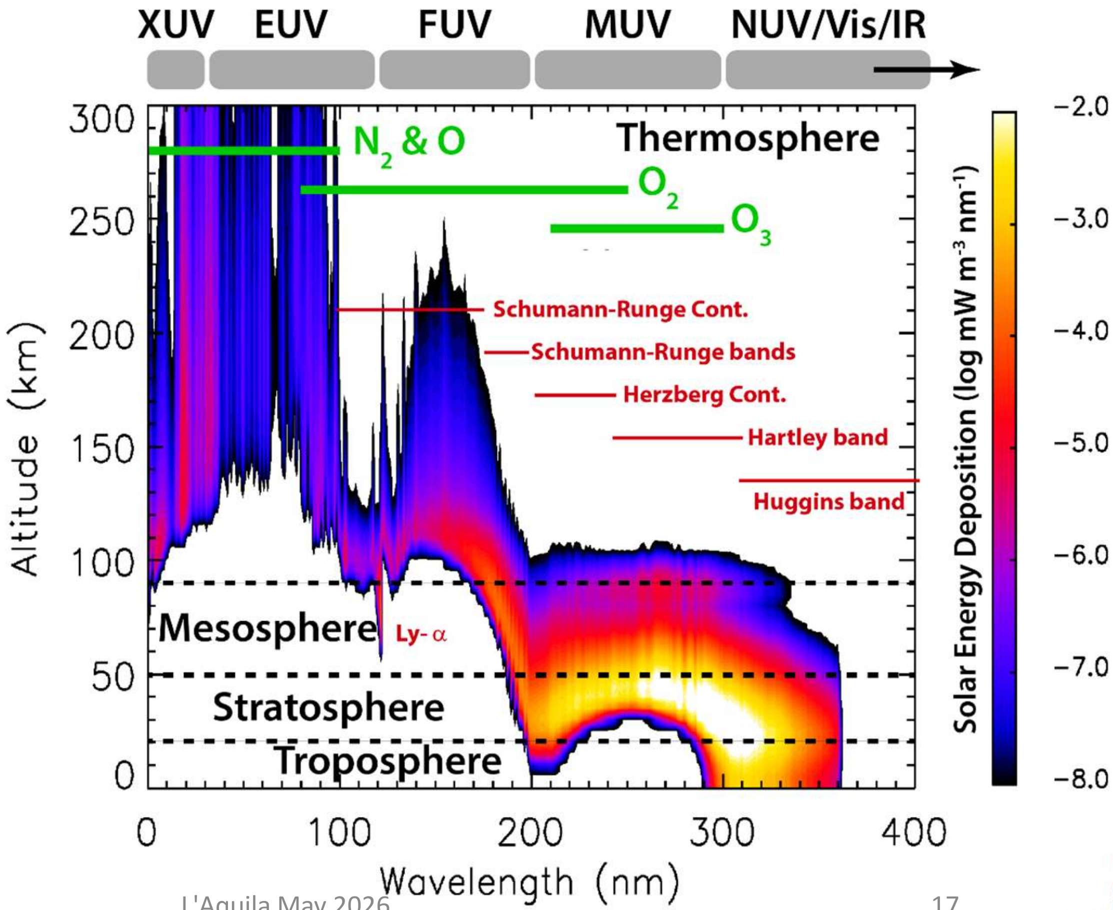
For the Sun-Earth connection (Space Weather and Climate), the Earth's atmosphere doesn't care what the surface features look like. It only cares about the integrated flux.

Don't worry, I'll include some images since our favorite star is very photogenic.

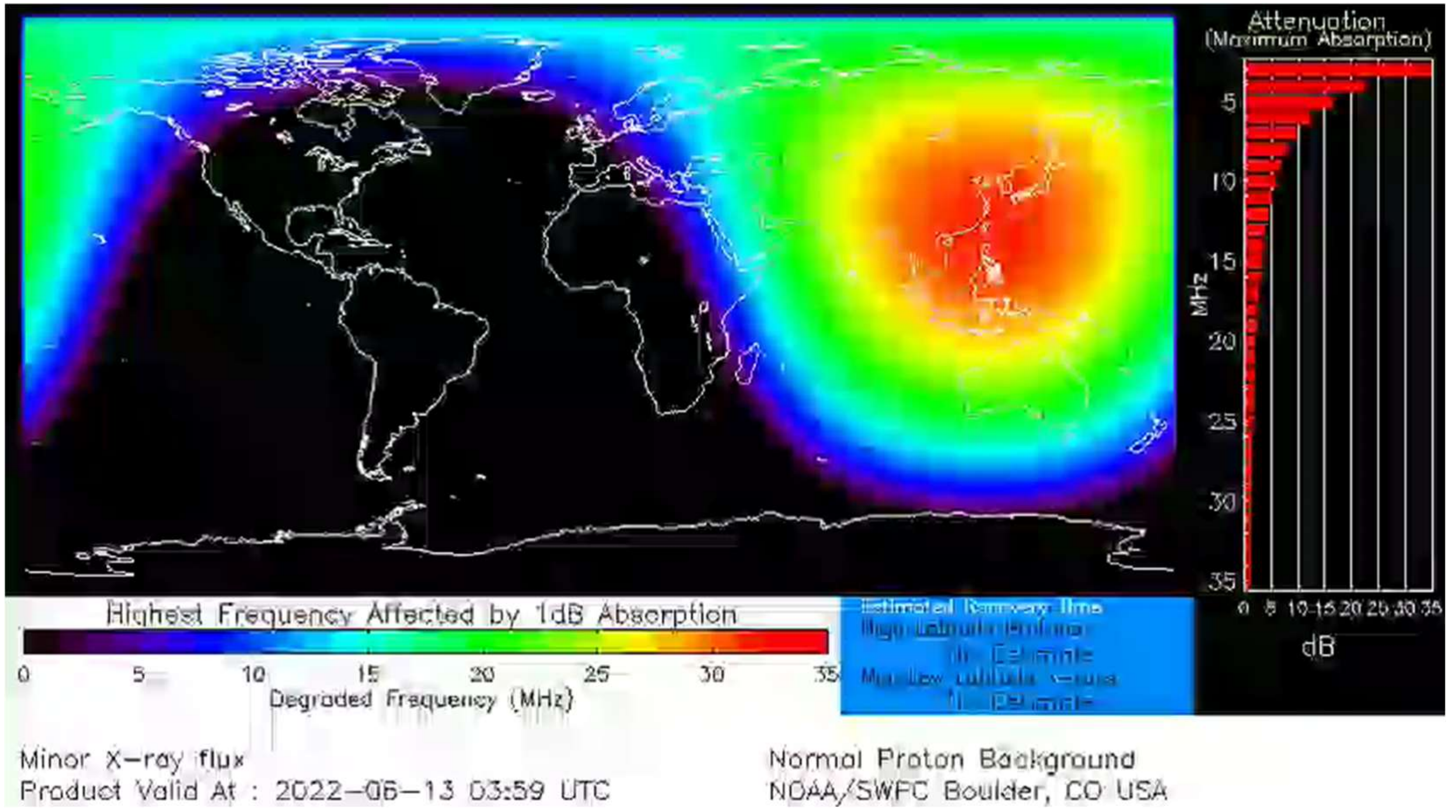


Where does UV SSI end up in the atmosphere?





Flare Ionization causing HF radio interference.



Recall yesterday's lecture by F. Berrilli

Sources of heating in Earth's climate system

Heat Source	Heat Flux* [W/m^2]	Relative Input
Solar Irradiance	340.25	1.000
Heat Flux from Earth's Interior	0.0870	2.6E-04
Radioactive Decay	0.0550	1.6E-04
Geothermal	0.0320	9.4E-05
Worldwide Combustion of Coal, Oil, and Gas	0.0279	8.2E-05
Infrared Radiation from the Full Moon	0.0102	3.0E-05
Sun's Radiation Reflected from Moon	0.0037	1.1E-05
Energy Generated by Solar Tidal Forces in the Atmosphere	0.0017	5.0E-06
Dissipation of Magnetic Storm Energy	8.2E-04	2.4E-06
Radiation from Bright Aurora	4.8E-05	1.4E-07
Energy Dissipated in Lightning Discharges	2.0E-05	5.9E-08
Dissipation of Mechanical Energy of Micrometeorites	2.0E-05	5.9E-08
Energy Generated by Lunar Tidal Forces in the Atmosphere	2.0E-05	5.9E-08
Total Radiation from Stars	1.4E-05	4.1E-08
Energy of Cosmic Radiation	1.3E-05	3.8E-08
Radiation from Zodiacal Light	3.4E-07	1.0E-09
Total of All Non-Solar Energy Sources	*0.1315*	*3.9E-04*

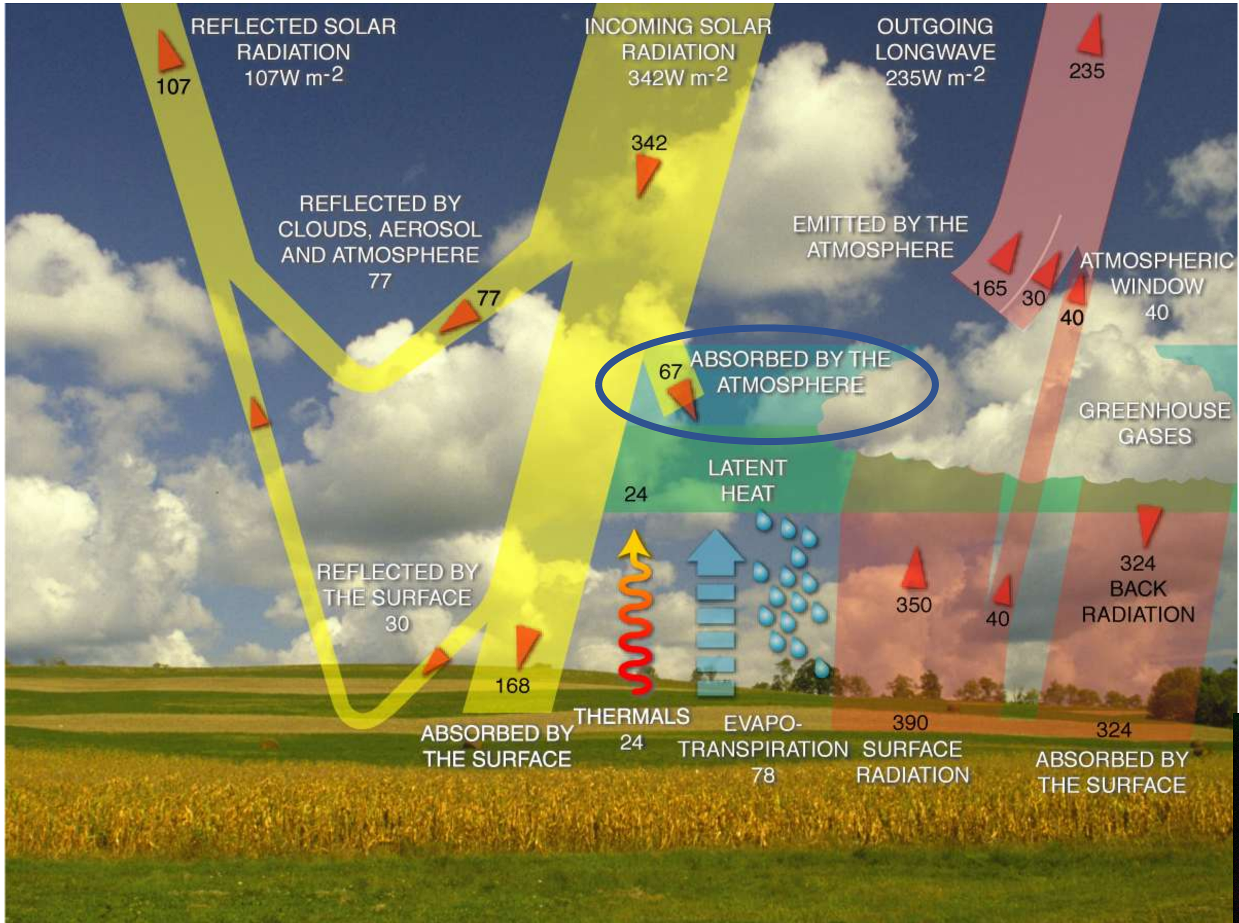
2500 X

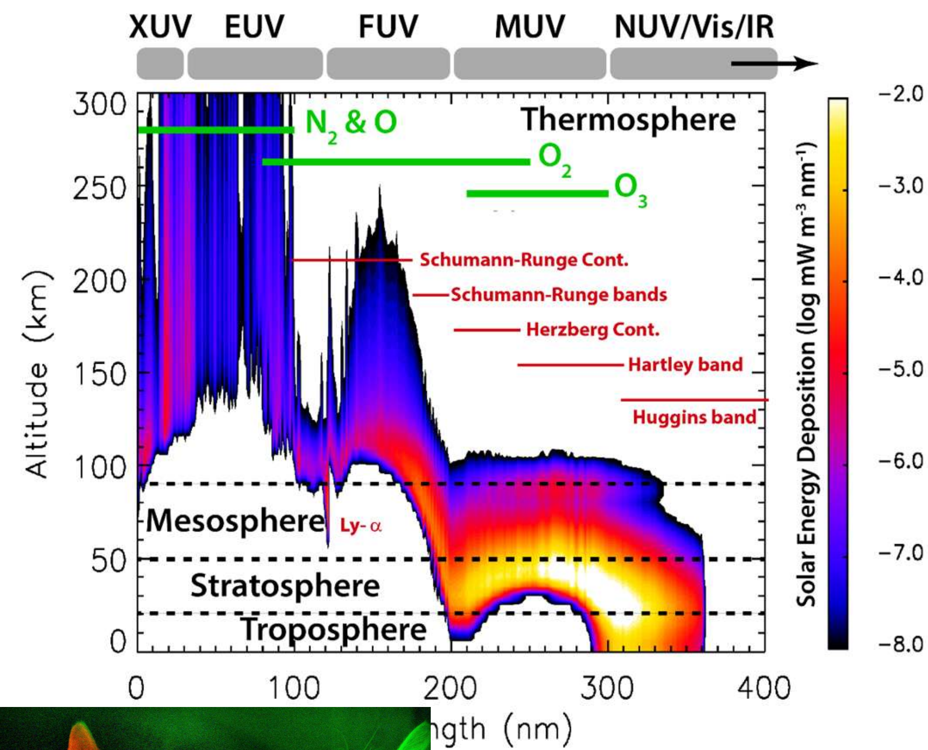
* global average

based on Physical Climatology, W.D. Sellers, Univ. of Chicago Press, 1965

Table 2 on p. 12 is from unpublished notes from
H.H. Lettau, Dept. of Meteorology, Univ. of Wisconsin.

Where does radiation end up in the atmosphere?





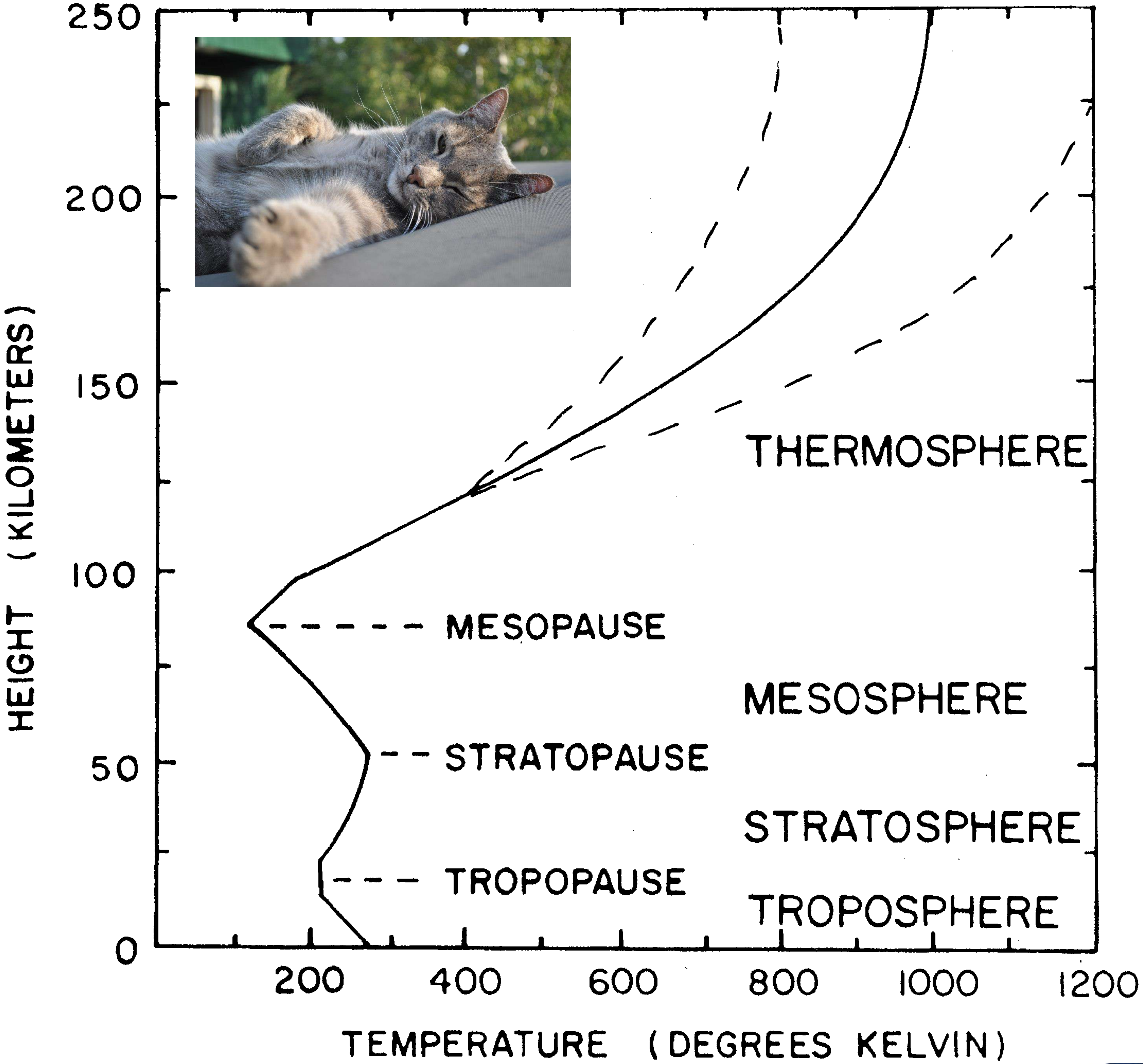
Typical Atmospheric Temperature Profile

EUV, FUV, Soft X-rays absorption
and ionization heating

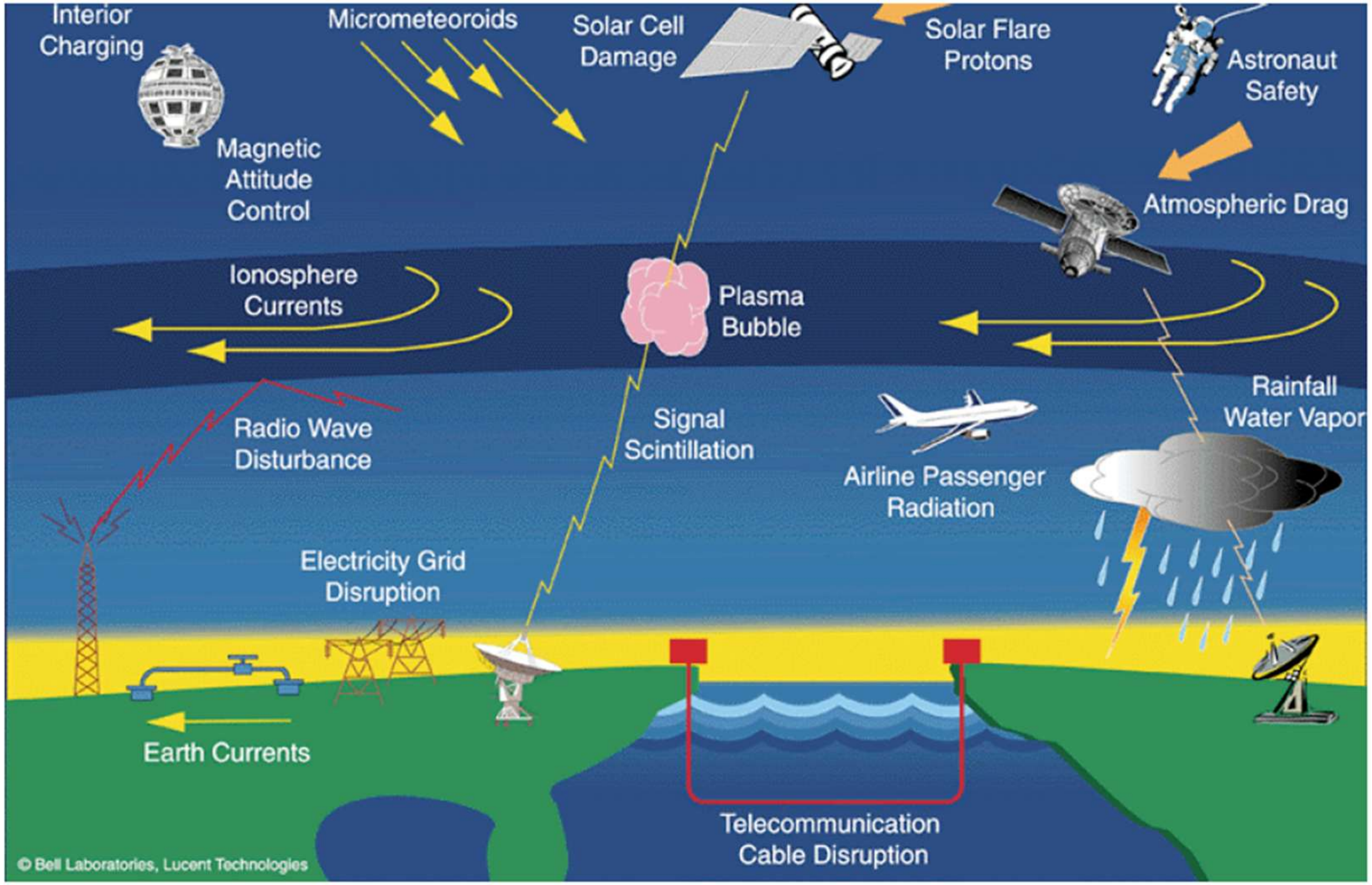
Primarily IR radiating to space cooling,
Some FUV absorption heating

MUV Sunlight absorption by O_3 heating

Visible, NIR, NUV absoprtion of sunlight
by air and surface, surface heats from below



Variations in solar output affect many technologies, not just radio reception



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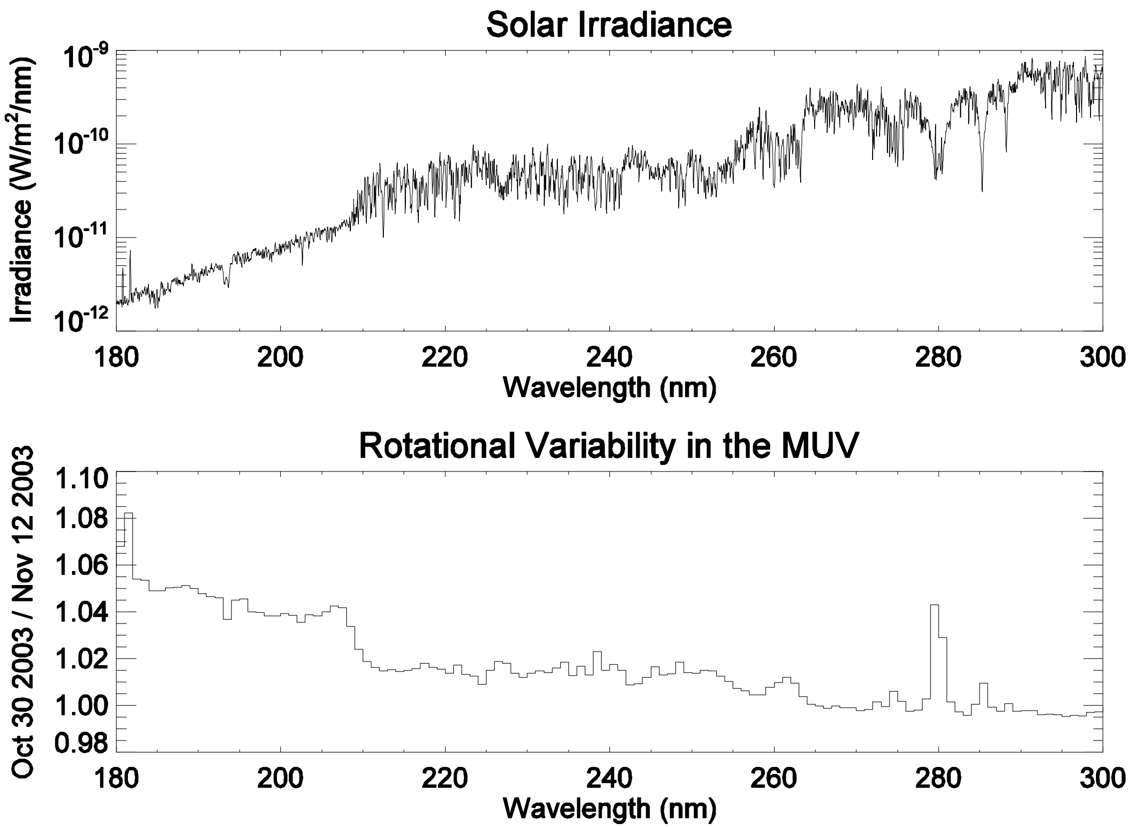
Now that we understand how the spectrum of the Sun gives clues about the solar atmosphere….

Is it always the same?
How often does it change?
How quickly?

Variability at 1 nm spectral resolution over one rotation (two weeks)



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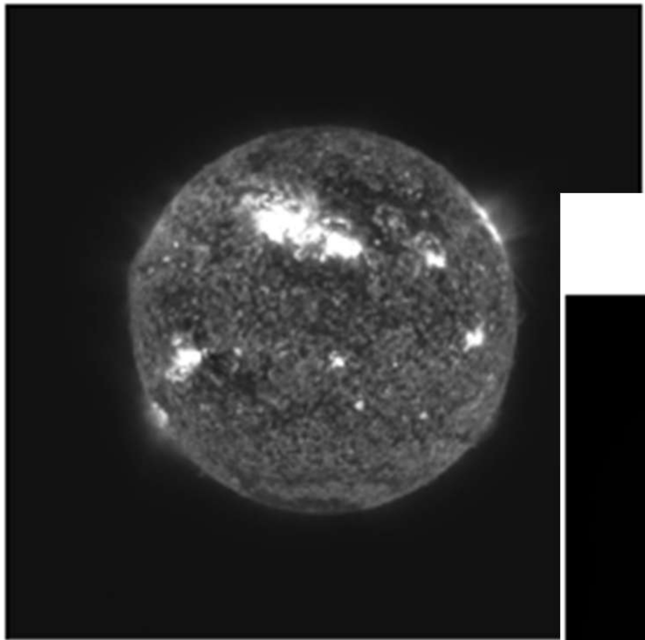
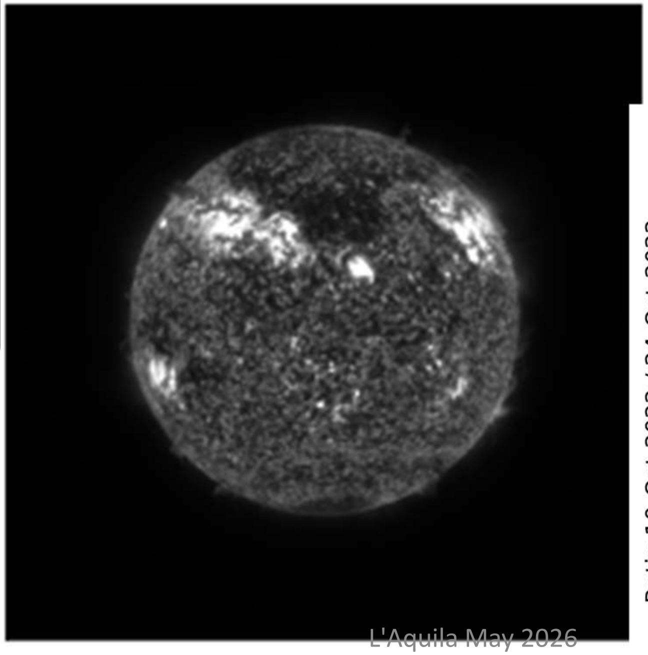
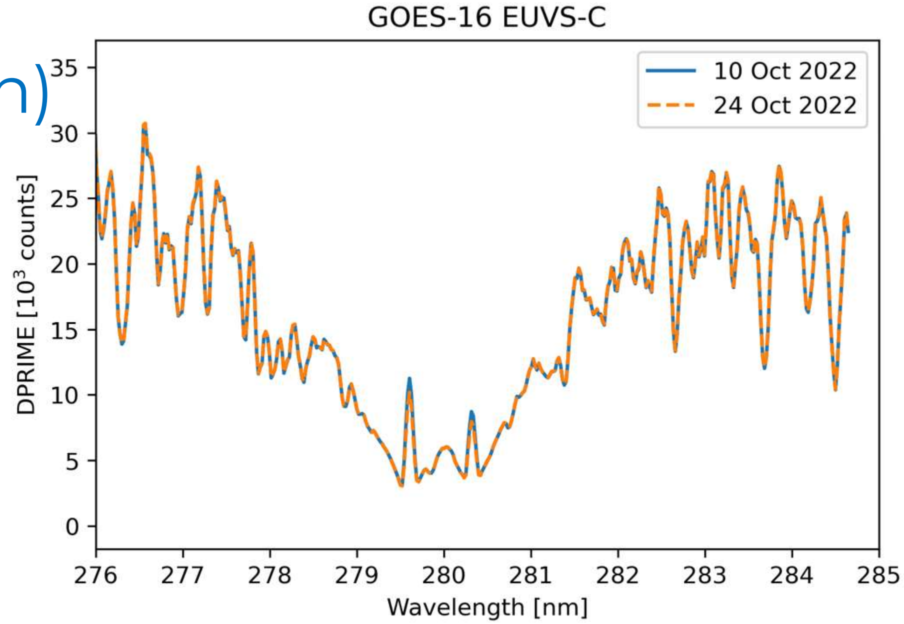
Rotational Variability (0.1 nm resolution)

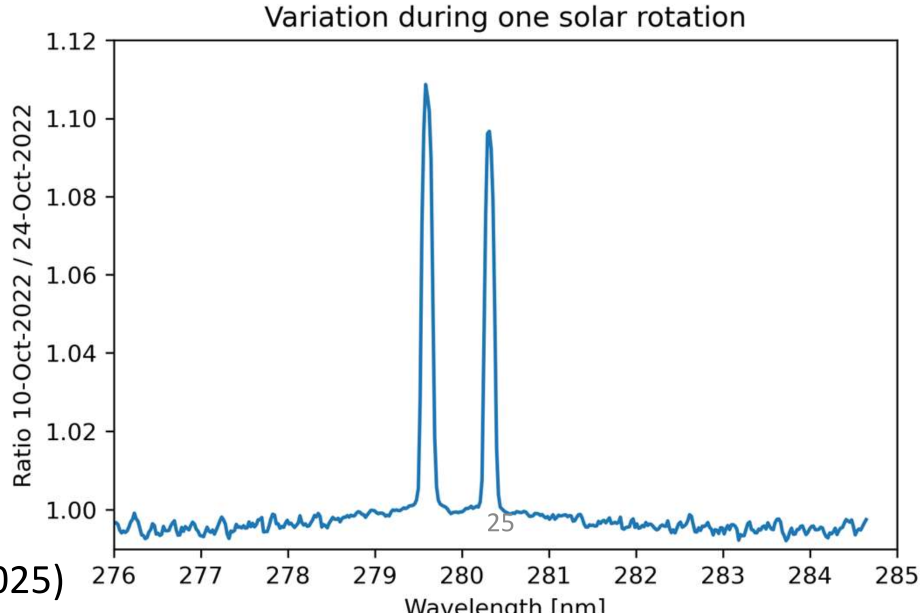
SUVI 26 September 2022



SUVI 10 Oct 2022







McClintock et al. (2025)

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This spectral region contains both Chromospheric and Photospheric emission.

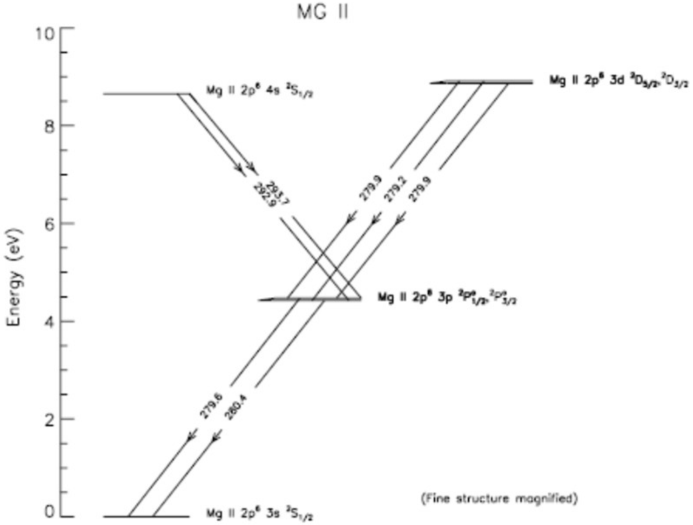
Optical depth at line center is very high, so τ=1 occurs high in the Chromosphere.

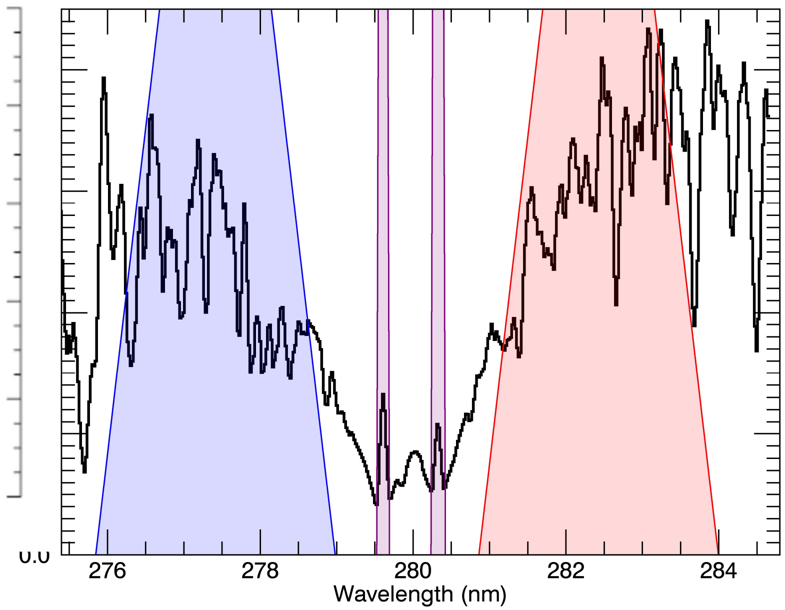
Away from line center, the cross section quickly decreases, so τ=1 occurs near the top of the Photosphere.

The ratio of the irradiance at line center to the "wings" of the Mg II line is known as the Mg II Index, or core-to-wing ratio.

Heath & Schlesinger (1986)

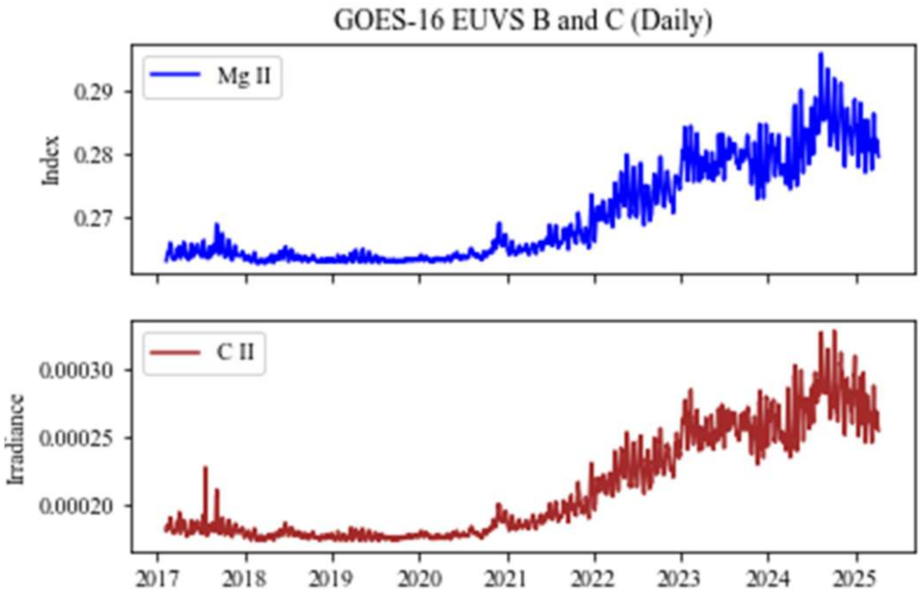
Snow et al. (2005)

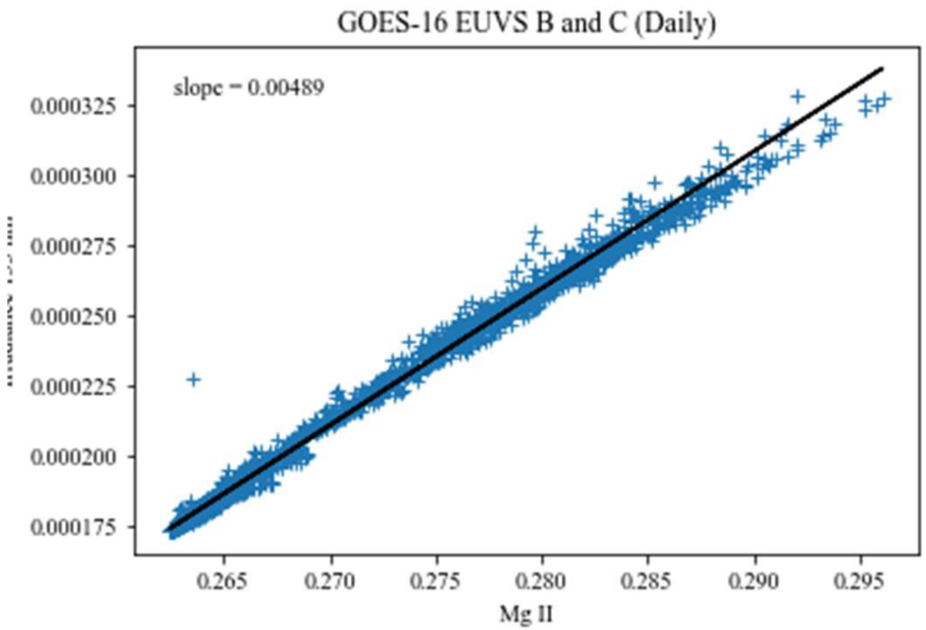




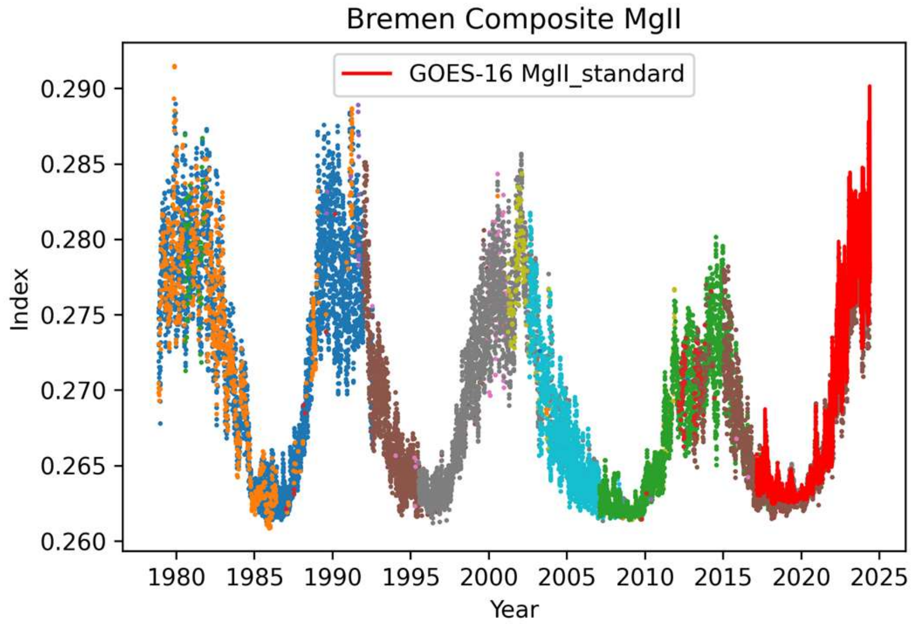
Mg II index highly correlates with variability at other wavelengths throughout the solar cycle

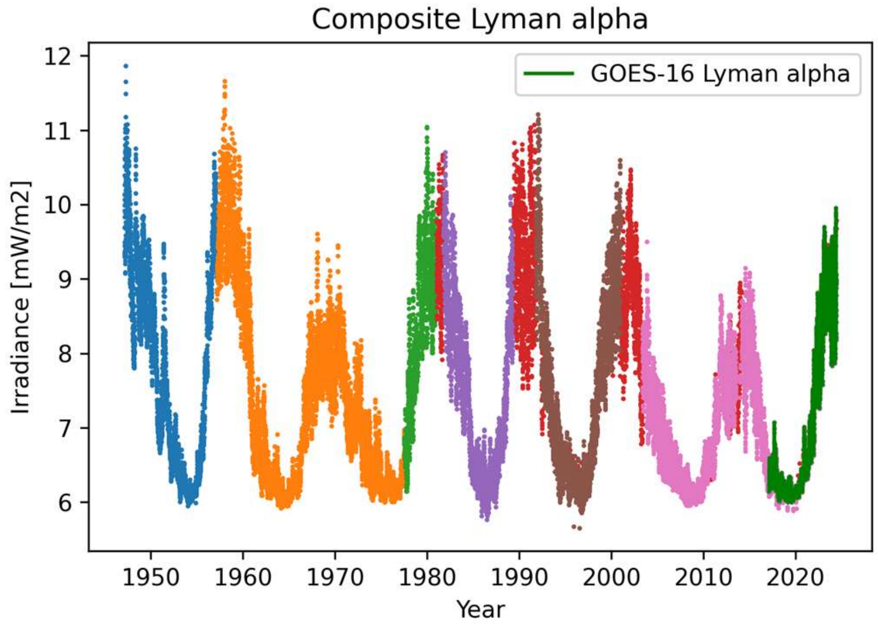
Activity changes in the Chromosphere affect all spectral features that are formed there. The observed slope of the correlation depends on many factors (i.e. all the magnetic factors described in the other lectures this week).





Long-term measurement composites, Mg II – direct measurements Lyman alpha – extending back to 1947 using F10.7 cm correlation





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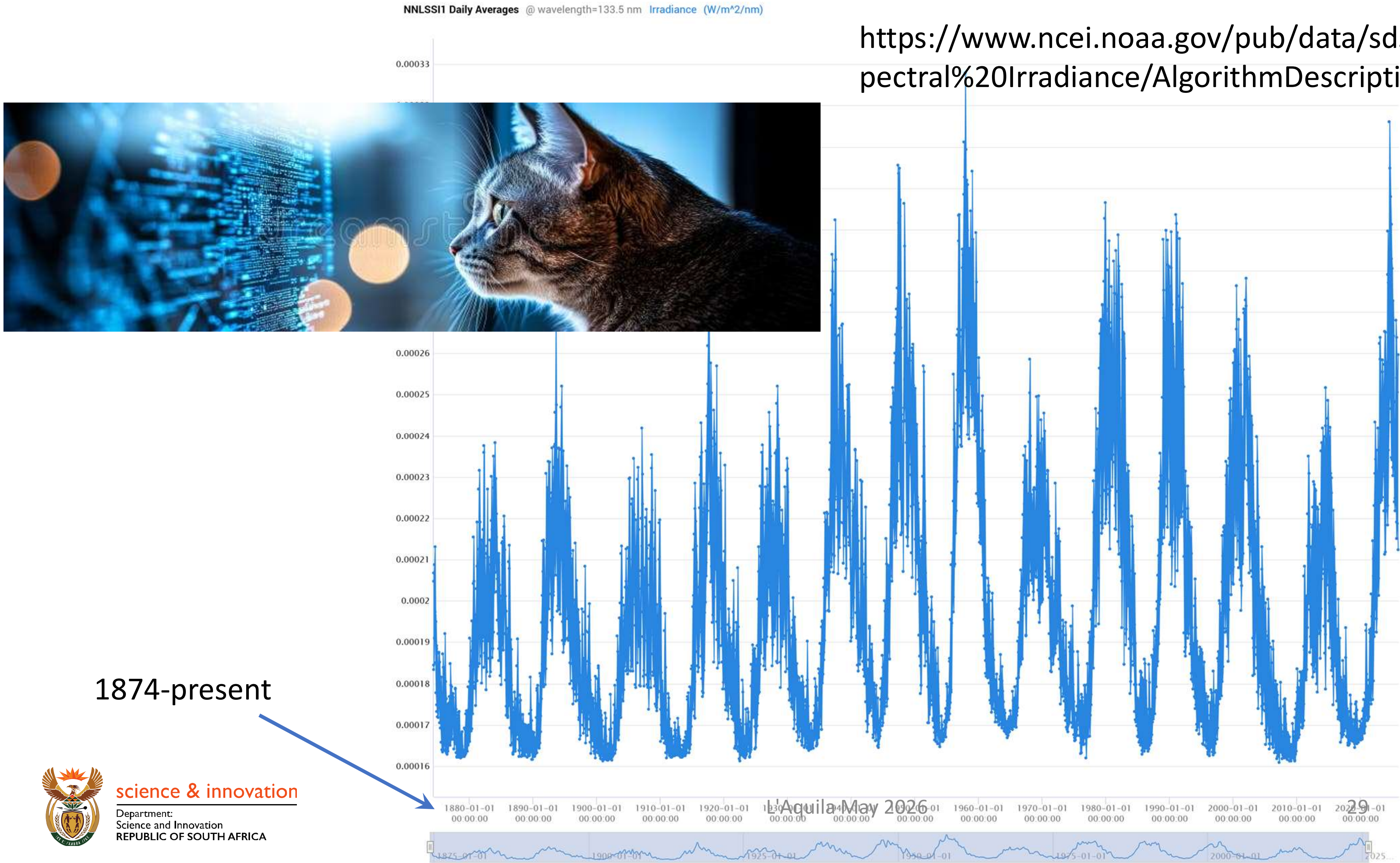
Correlation model can be extended further back using proxies

https://www.ncei.noaa.gov/pub/data/sds/cdr/CDRs/Solar%20Spectral%20Irradiance/AlgorithmDescription_01B-33.pdf



1874-present

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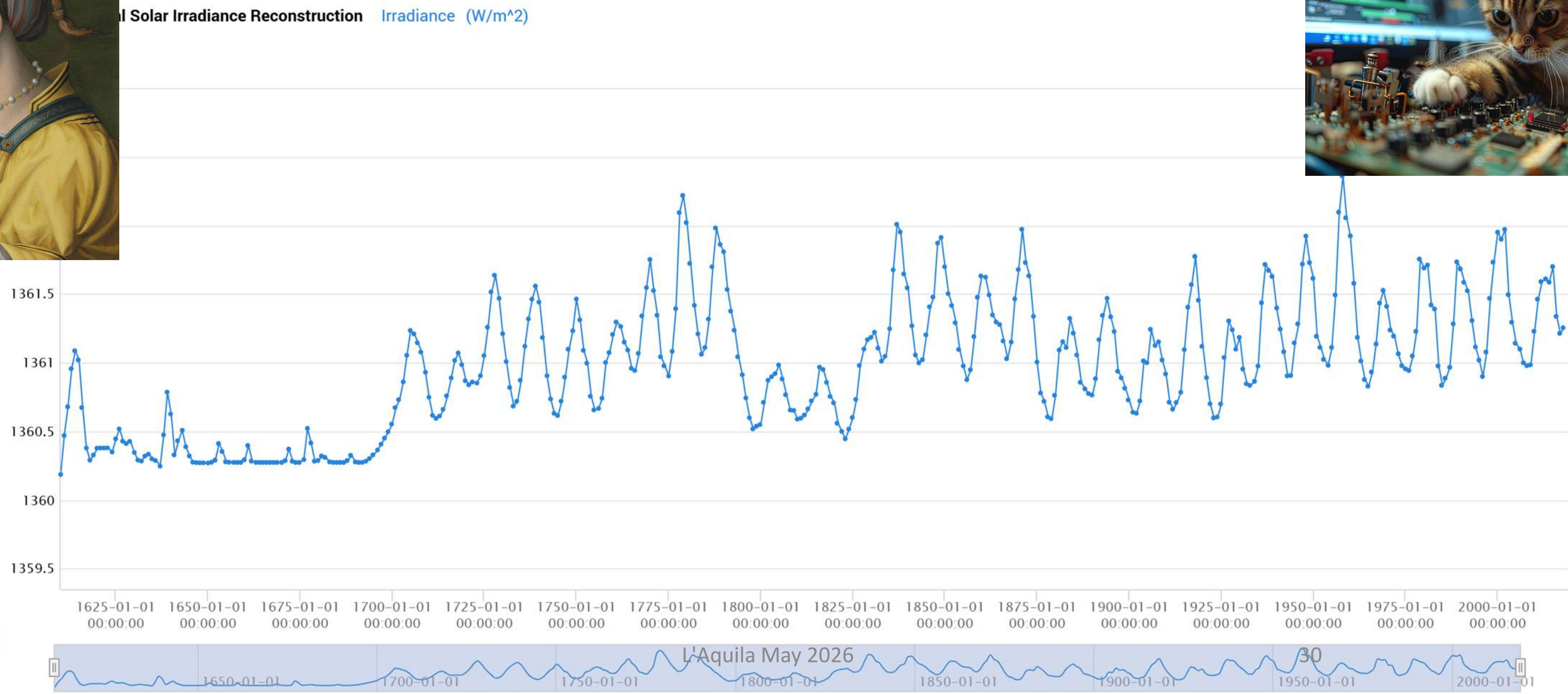
The integral of the solar spectral irradiance (SSI) is known as total solar irradiance (TSI).
It is the total radiative energy at the top of the Earth's atmosphere.
Models can be used to estimate its value to the beginning of the sunspot record in the 1600's



Summary of Part 1

- How do we know about the solar atmosphere?
  - Physics background
  - Interpretation of the solar spectrum
- Solar radiation’s affect on the Earth’s atmosphere
- Variation on long timescales
- Variation on short timescales will be in part 2

End of Part 1
Questions?

Seconds to Centuries:
Chromospheric Variability (Part 2): Measurements

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South African National Space Agency

University of Colorado Boulder/LASP

University of the Western Cape, South Africa

Current Instruments that measure UV SSI

GOES/EXIS

IRIS

TSIS-1/SIM

Calibration

Aditya-L1 SUITS (I have not yet seen data from this mission)

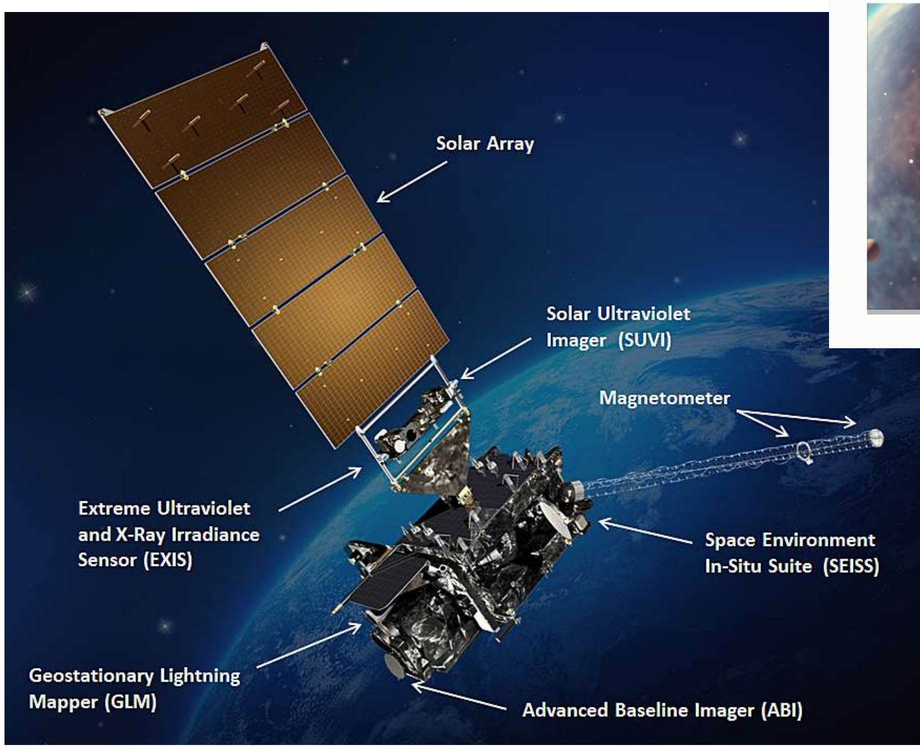
Geostationary Operational Environmental Satellites (GOES)

The GOES-R series of four spacecraft began observations in January 2017.

There are currently four in orbit (GOES-16, 17, 18, and 19). These satellites occupy geostationary orbit positions above the east and west parts of the United States, with the third satellite in on-orbit storage between them.

Each satellite has a 10-year expected lifetime.

GOES-16 and 17 have been placed in on-orbit storage. 18 and 19 are the current operational satellites.



EXTREME ULTRAVIOLET AND X-RAY IRRADIANCE SENSORS
GOES-R
EXIS
NOAA · LASP · NASA

Snow et al. (2025) Operational Solar Spectral Irradiance Measurements from the Extreme Ultraviolet Sensor (EUVS) on the GOES-R Series..IOP Conference Series: Earth and Environmental Science 1522. doi:10.1088/1755-1315/1522/1/012035

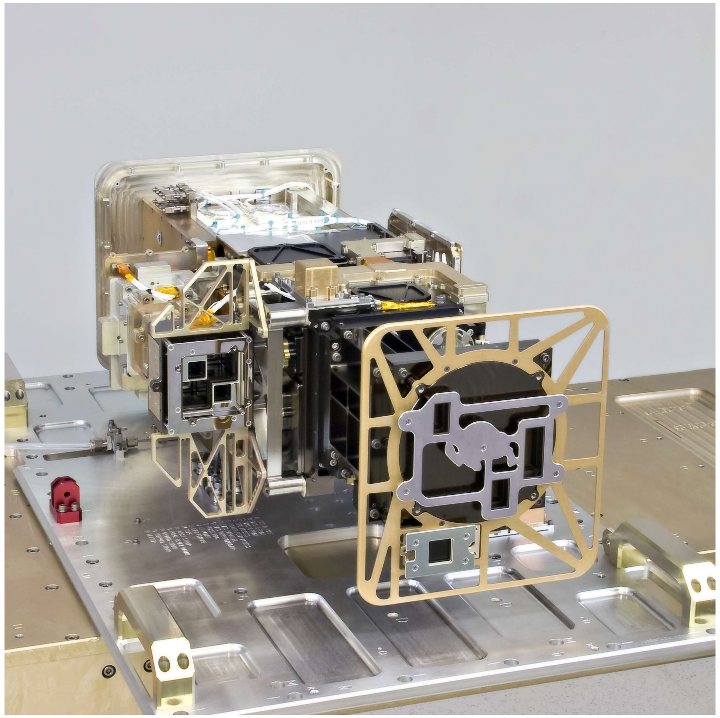
Extreme Ultraviolet Irradiance Sensor (EUVS)

The EUVS consists of three spectral channels (A, B, C) to sample the Sun's chromosphere, transition region, and corona.

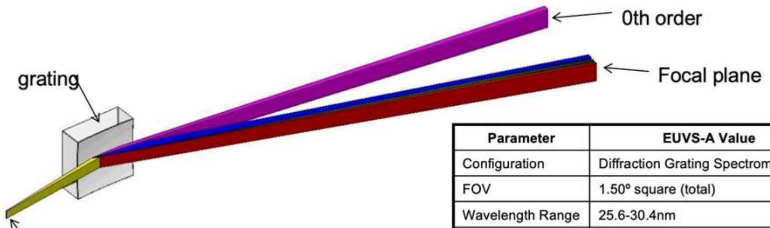
The instrument package also includes the X-ray Sensor (XRS) and the Solar Position Sensor (SPS) which is sensitive to visible light.

This instrument package produces operational solar spectral irradiance observations on a 1-second cadence which are averaged over 30 second intervals to produce an empirical model in 5 nm intervals from 5-115 nm.

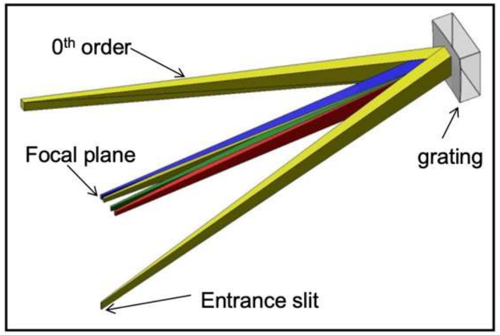
Thiemann et al. (2019) JSWSC doi:10.1051/swsc/2019041



EUVS Optiocal Paths.
All three channels use gratings to disperse the light

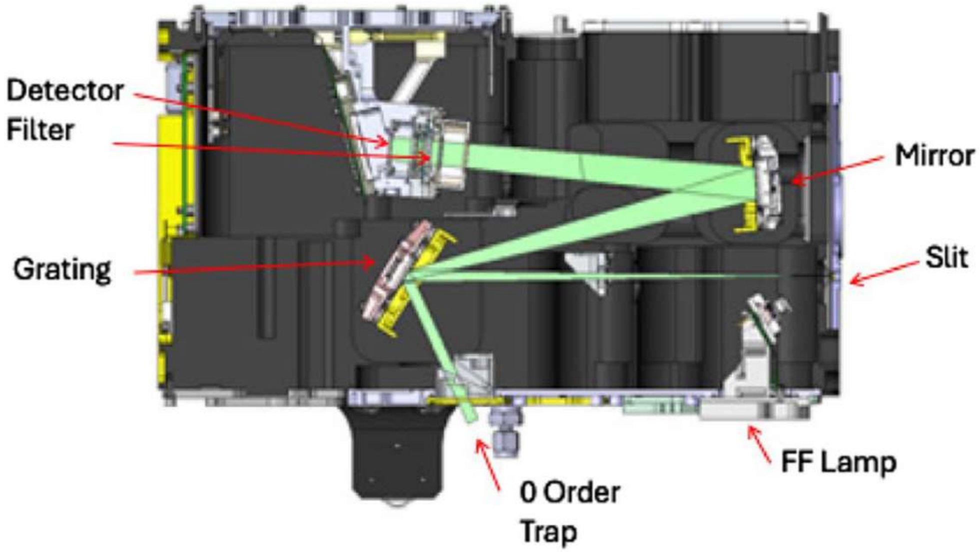


Parameter	EUVS-A Value
Configuration	Diffraction Grating Spectrometer
FOV	1.50° square (total)
Wavelength Range	25.6-30.4nm
Resolution	0.6nm
Slit	0.4mm x 4.0mm
Filter	Custom Luxél thin-foil
Detector	Custom IRD 24-element diode array
Slit sampling	3 pixels / slit image width



Parameter	EUVS-B Value
Configuration	Diffraction Grating Spectrometer
FOV	1.50° square (total)
Wavelength Range	117.5-140.5nm
Resolution	0.6nm
Slit	0.6mm x 5.0mm
Filter	Barr interference filter
Detector	Custom IRD 24-element diode array
Slit sampling	3 pixels / slit image width

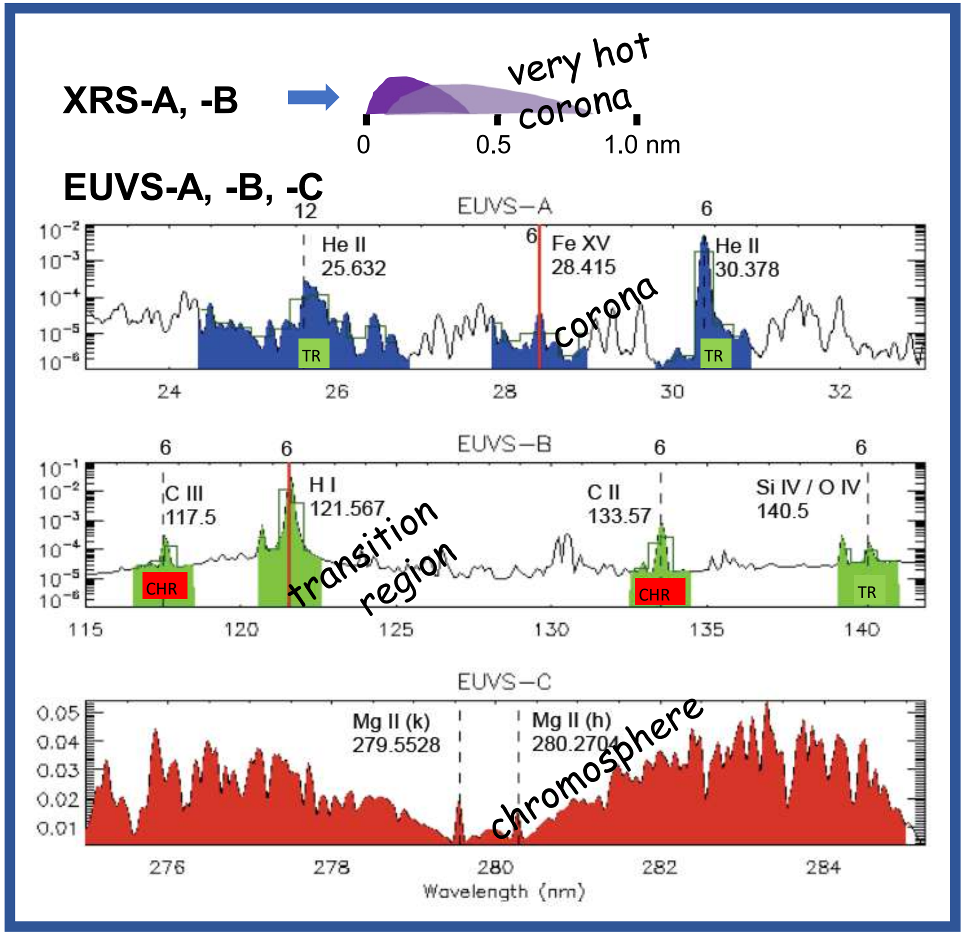
EUVS-C



Detectors are photodiode arrays.
A, B use 24-element arrays from IRD
C uses 512-element array from Hamamatsu

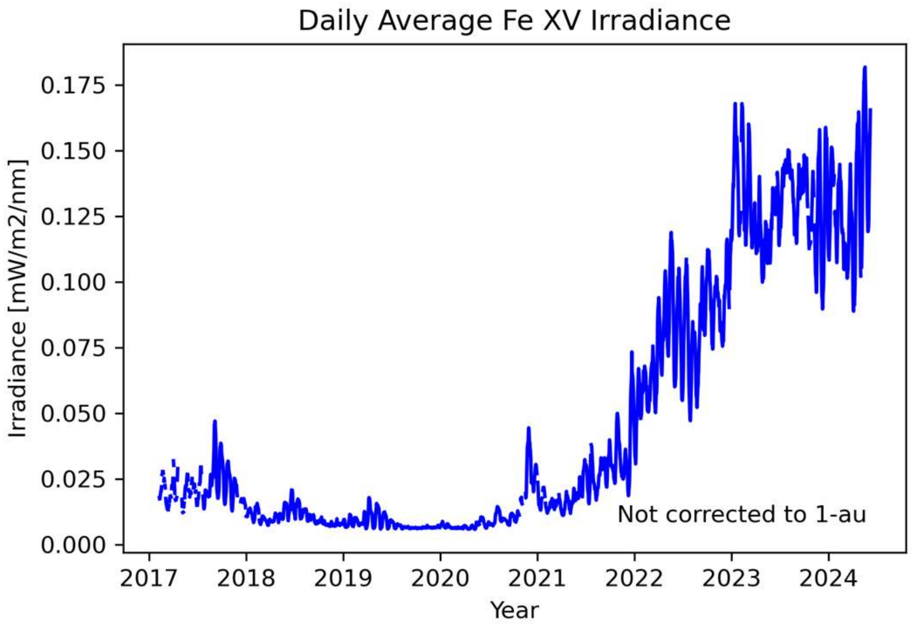
EXIS Bandpasses

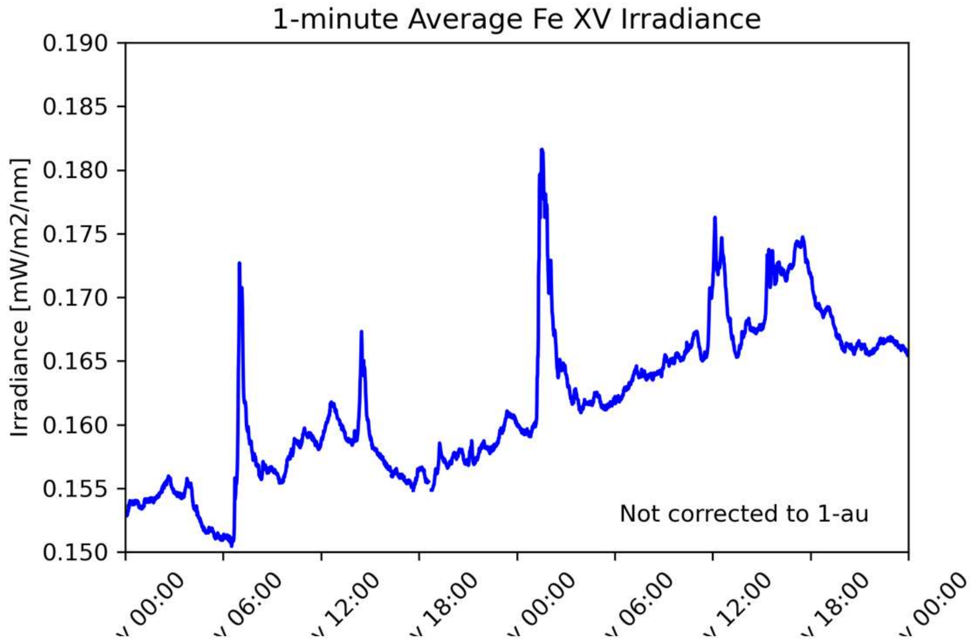
- X-ray Sensor (XRS)
  - Short (0-0.4 nm)
  - Long (0-0.8 nm)
- Extreme ultraviolet Spectrograph
  - A Coronal 28 nm Fe XV
  - B Transition Region 120 nm Ly-a
  - C Chromosphere MgII
- Channels A & B include lines from other solar layers for degradation corrections.



EUVS-A Corona

The Fe XV line at 28.4 nm is formed at log T= 6.3

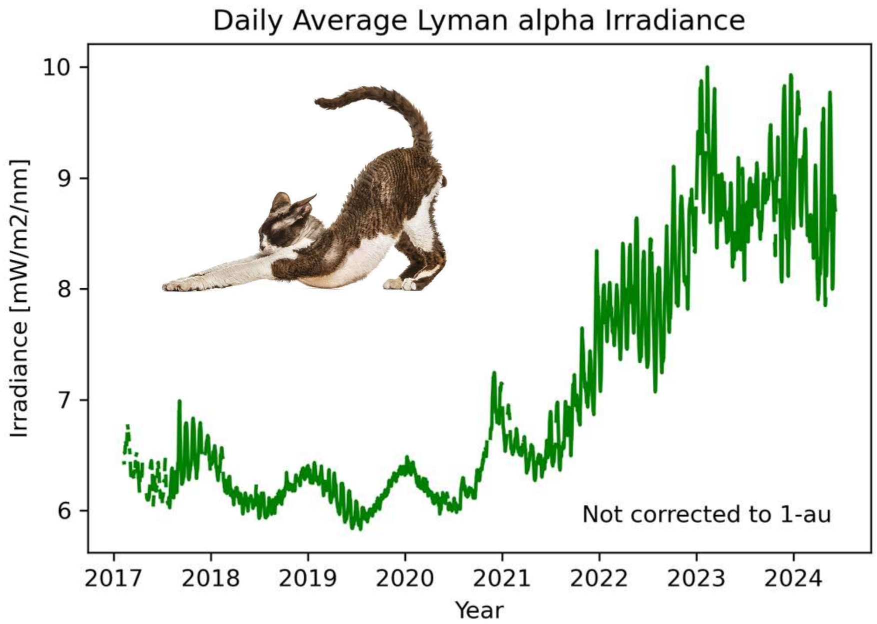


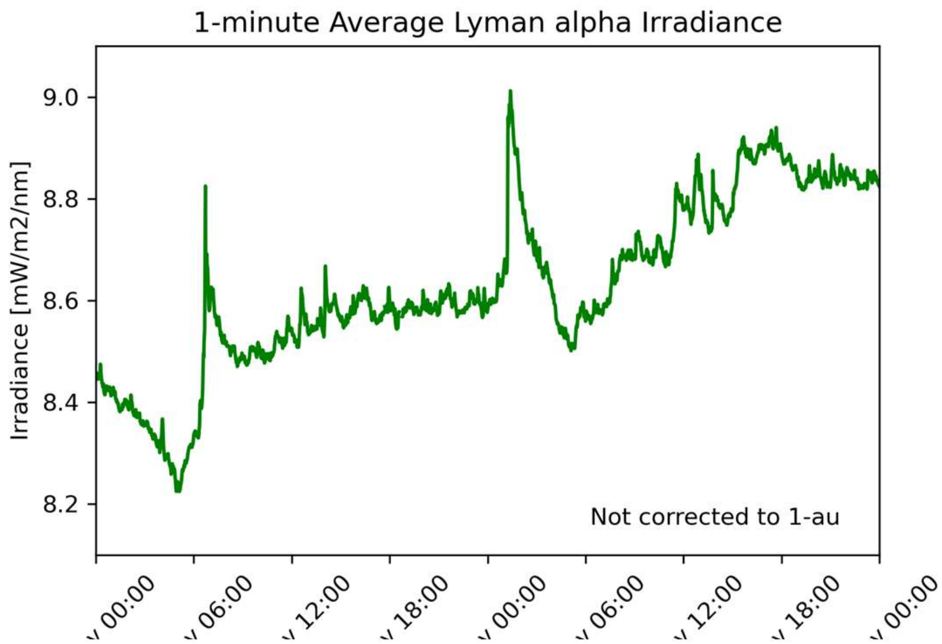


10-12 May 2024

EUVS-B Transition Region

H I (Lyman alpha)

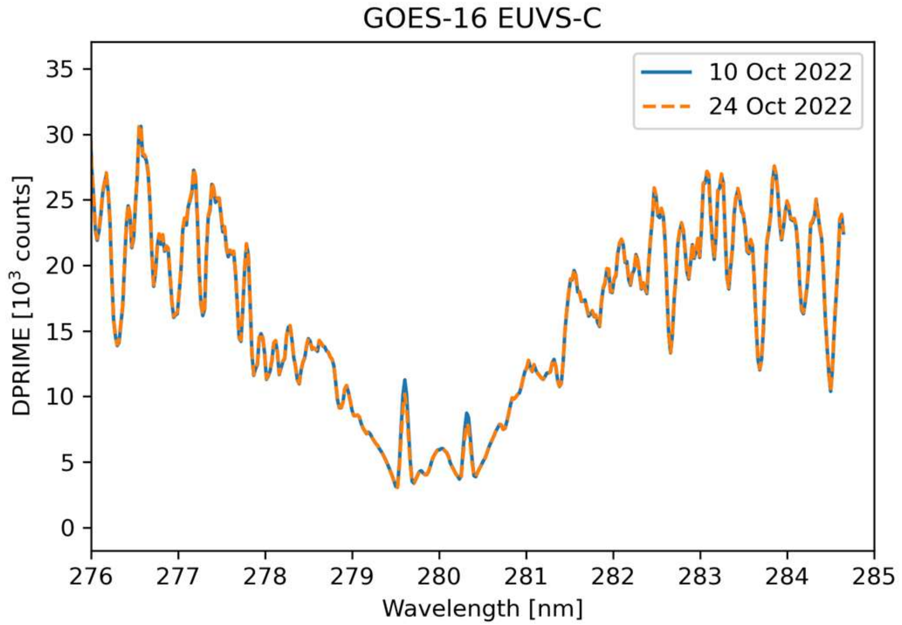


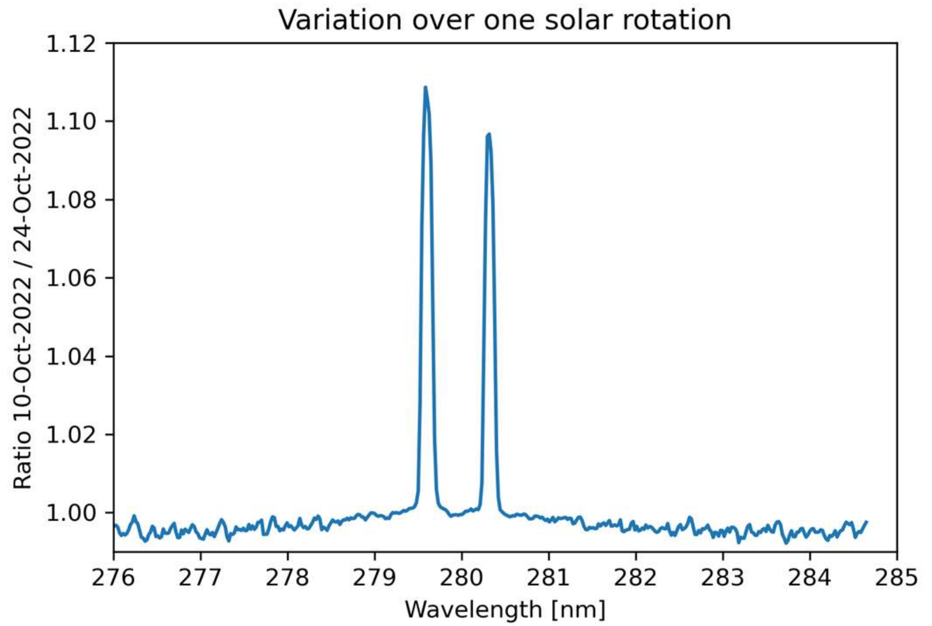


10-12 May 2024

EUVS-C Chromosphere (1)

The Mg II emission near 280 nm is used to create a proxy for chromospheric activity by taking the ratio of the emission cores relative to the nearby photospheric continuum.





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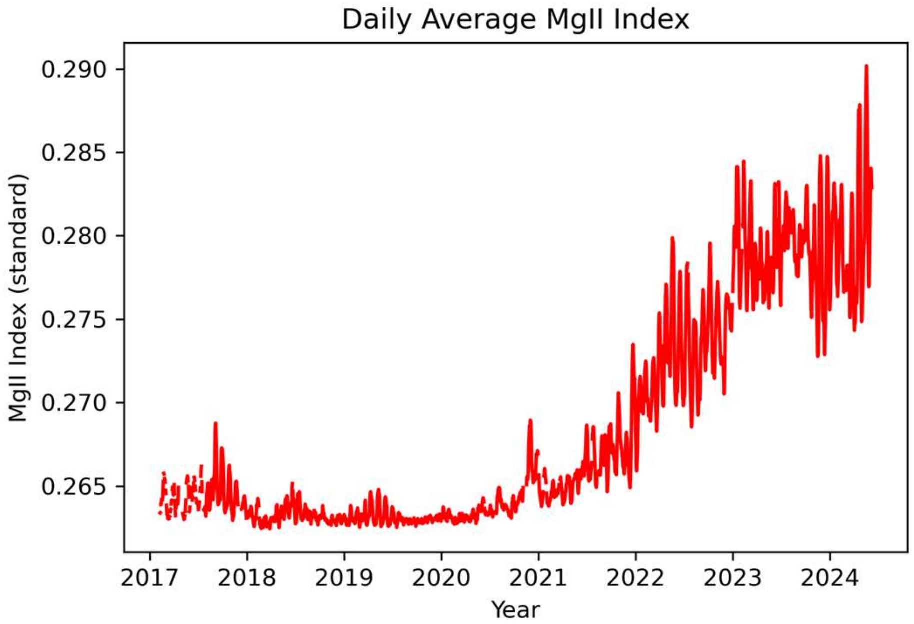
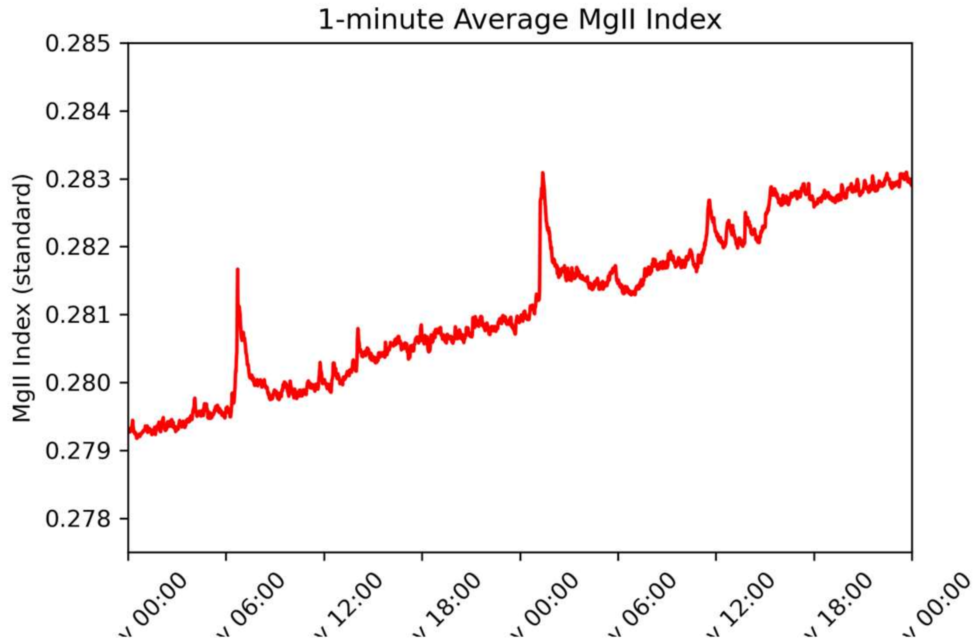
EUVS-C Chromosphere (2)





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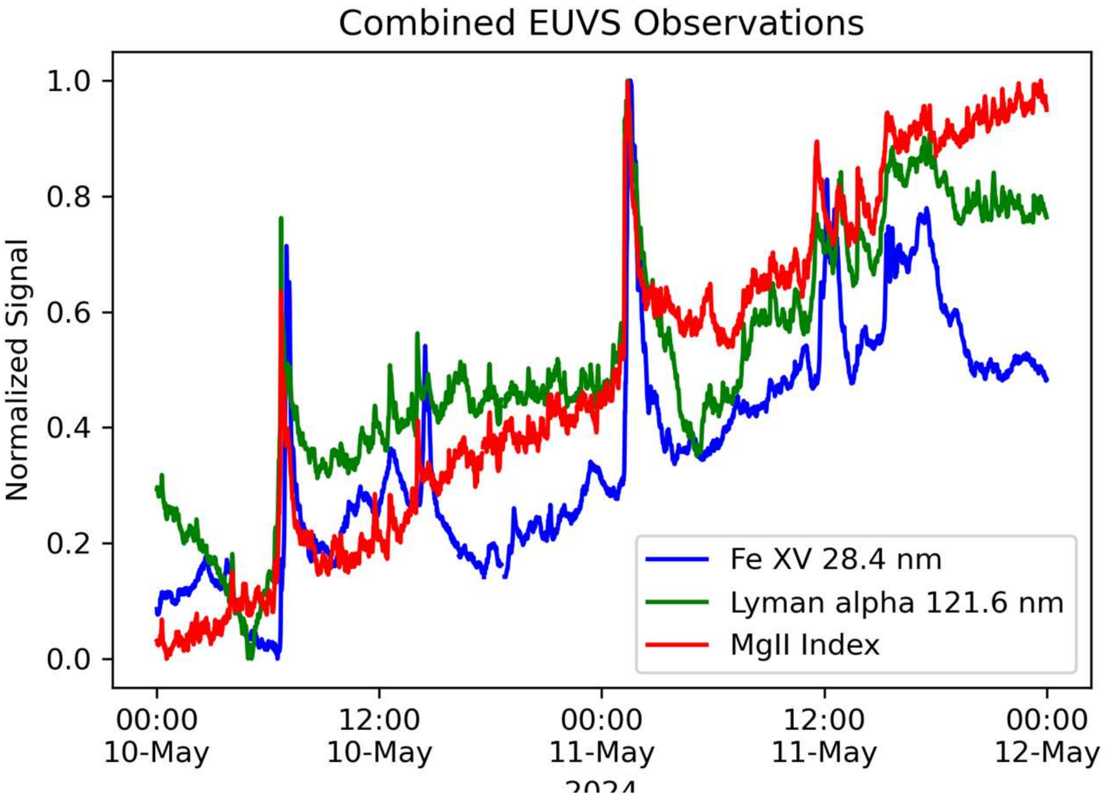
Combined EUVS bands

The plot shows a period of recent solar activity in various layers of the solar atmosphere.

The spikes are flares of various sizes. There is also a continuous stream of micro-flare events.

Cadence shown is 1-minute averages.



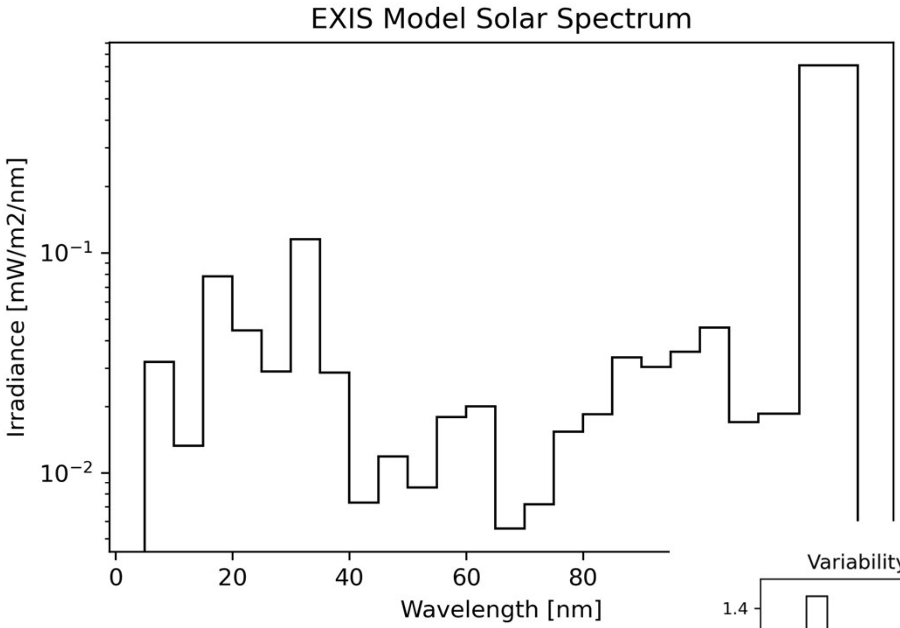
EXIS Solar Model

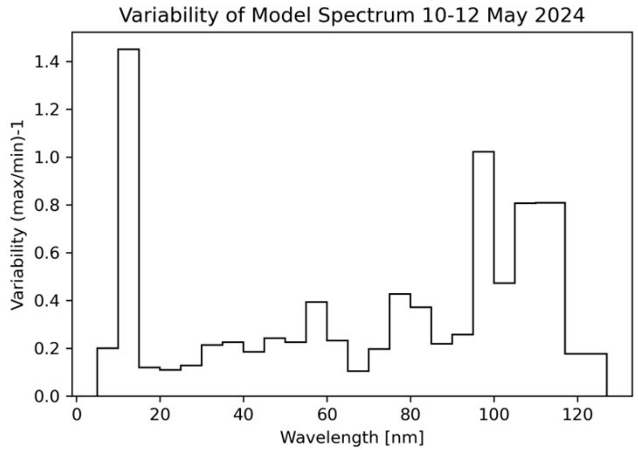
Combining the two XRS channels with the three EUVS channels, EXIS produces a model solar spectrum with 30-second cadence.

The model includes 5-110 nm in 5 nm bands, plus two additional bands at 117 and 121 nm.

The 117 bandpass is primarily C III, but also includes several additional lines (Avrett, Kurucz, & Loeser 2006).

The 121 nm band is primarily Lyman alpha.





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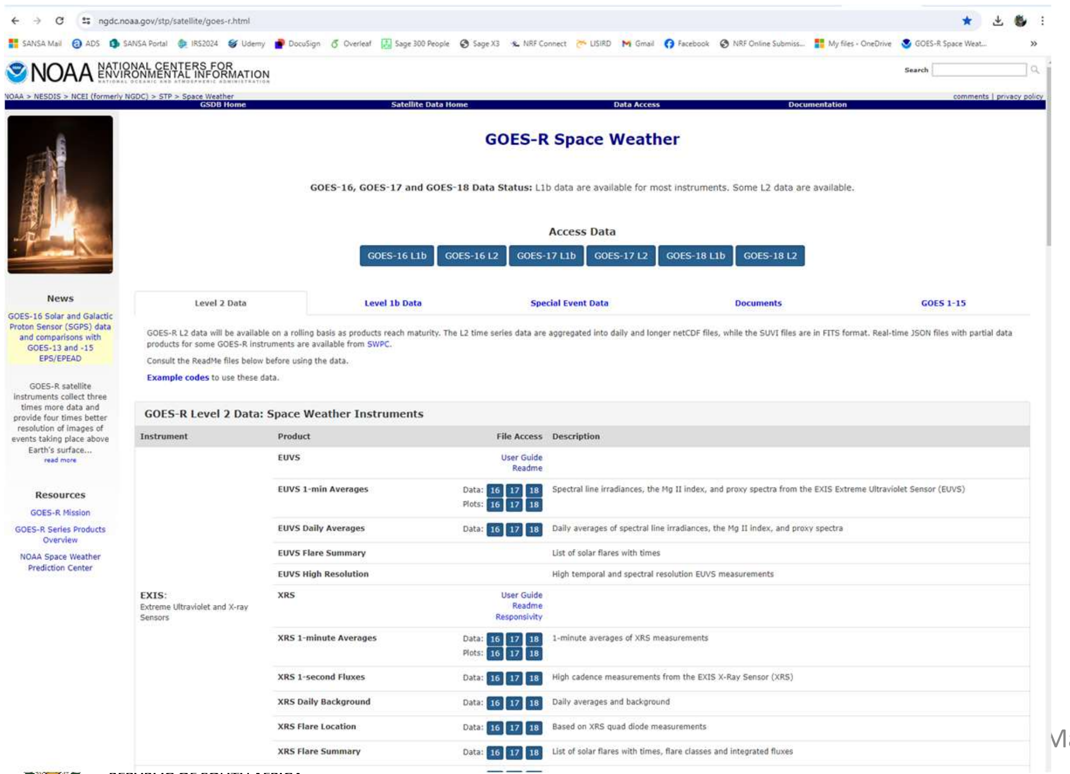
Data Access
https://www.ngdc.noaa.gov/stp/satellite/goes-r.html



Data is available in two modes:

- Operational (low latency, rough calibration)
- Science Quality (longer latency, high quality calibration)

Level 1b: 30-second averages

Level 2: both 1-minute and 1-day averages

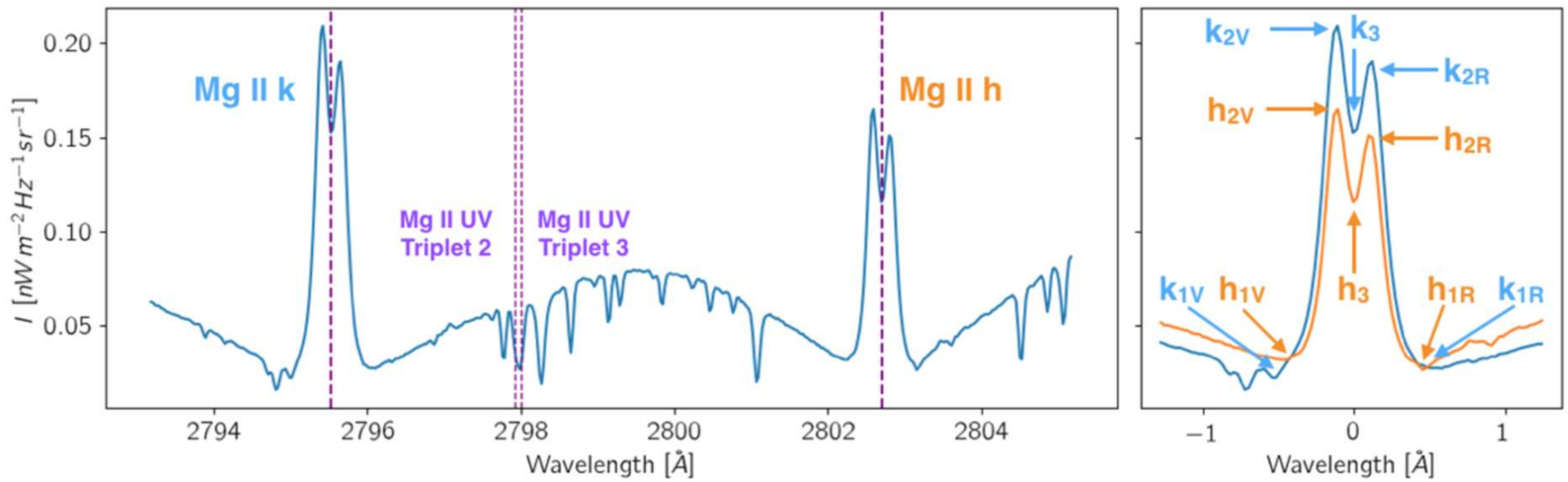
Interface region imaging spectrograph

IRIS obtains UV spectra and images with high resolution in space (0.33-0.4 arcsec), time (1-2s), and wavelength (26 and 53 mA).

The IRIS telescope feeds light from three passbands into the spectrograph box:

- Far Ultraviolet (FUV1): 1331.56–1358.40 Å
- Far Ultraviolet (FUV2): 1390.00–1406.79 Å
- Near Ultraviolet (NUV): 2782.56–2833.89 Å

Sample spectrum from IRIS NUV observation near Mg II h & k



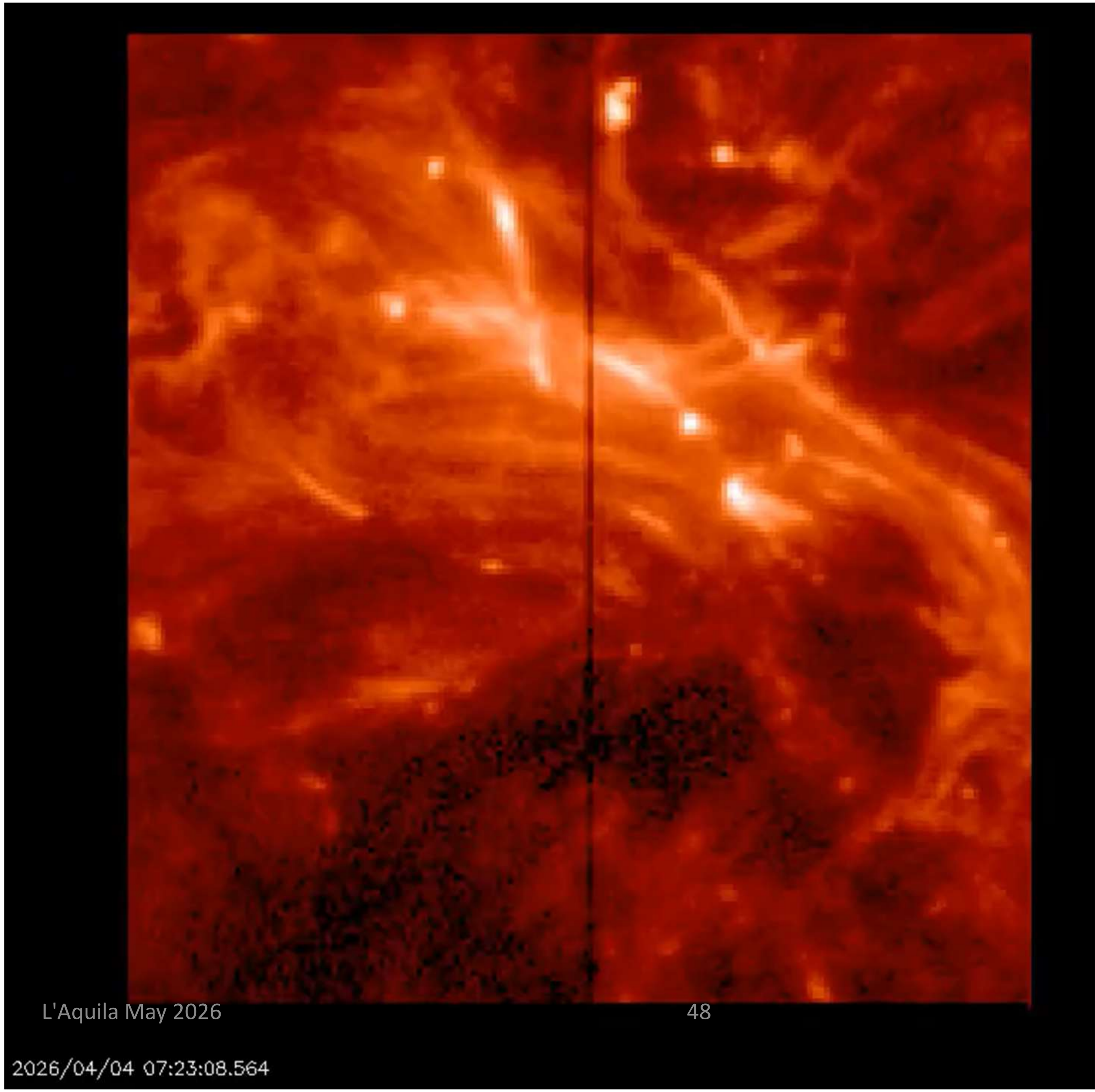
IRIS Movie of the Day

Lazy Flare

Credit: IRIS, LMSAL/NASA, Juraj Lorincik

The Sun's activity turned up the heat over the Easter holiday, with active region AR14409 producing a series of flares and eruptions. Flares are usually rapid events, but on April 4, IRIS caught an M-class flare taking its time and unfolding with unusual patience. It seems that even the Sun likes to slow down over a long weekend.

https://iris.lmsal.com/mod?cmd=view-pod&pubDate=2026-04-08

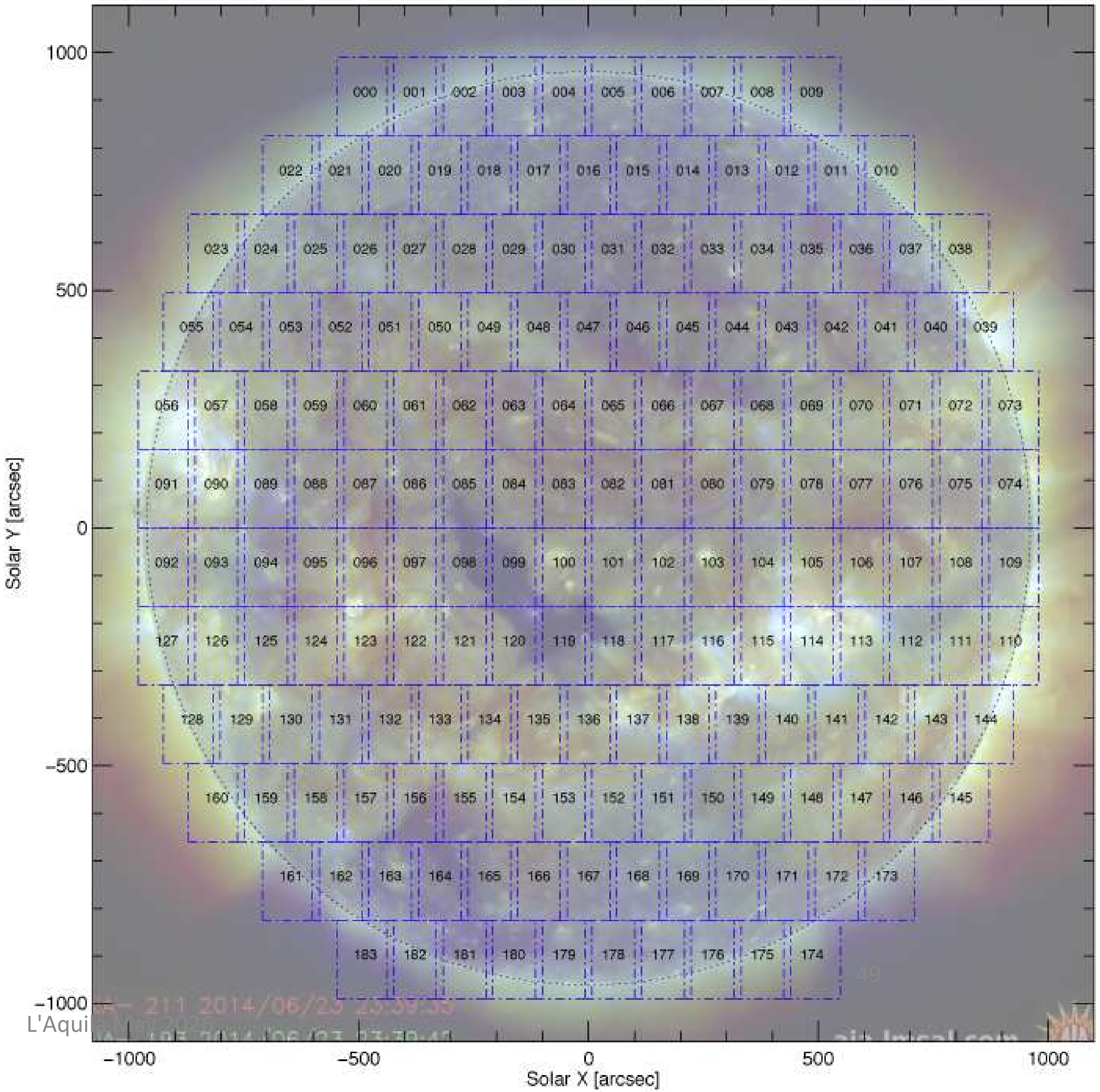


IRIS mosaics

About once per month, IRIS makes a raster map of the full disk of the Sun, producing a hyperspectral image.

“Hyperspectral” means that there is a spectrum at every pixel of the image.

These 174 separate observations take about half a day to complete.



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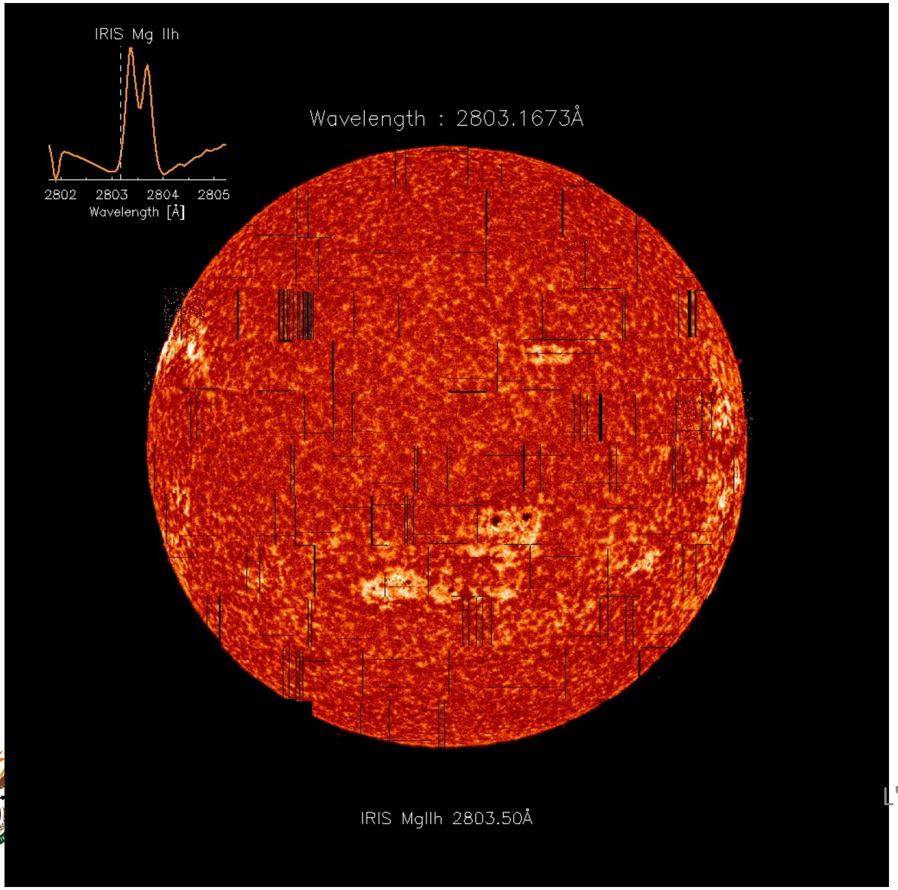
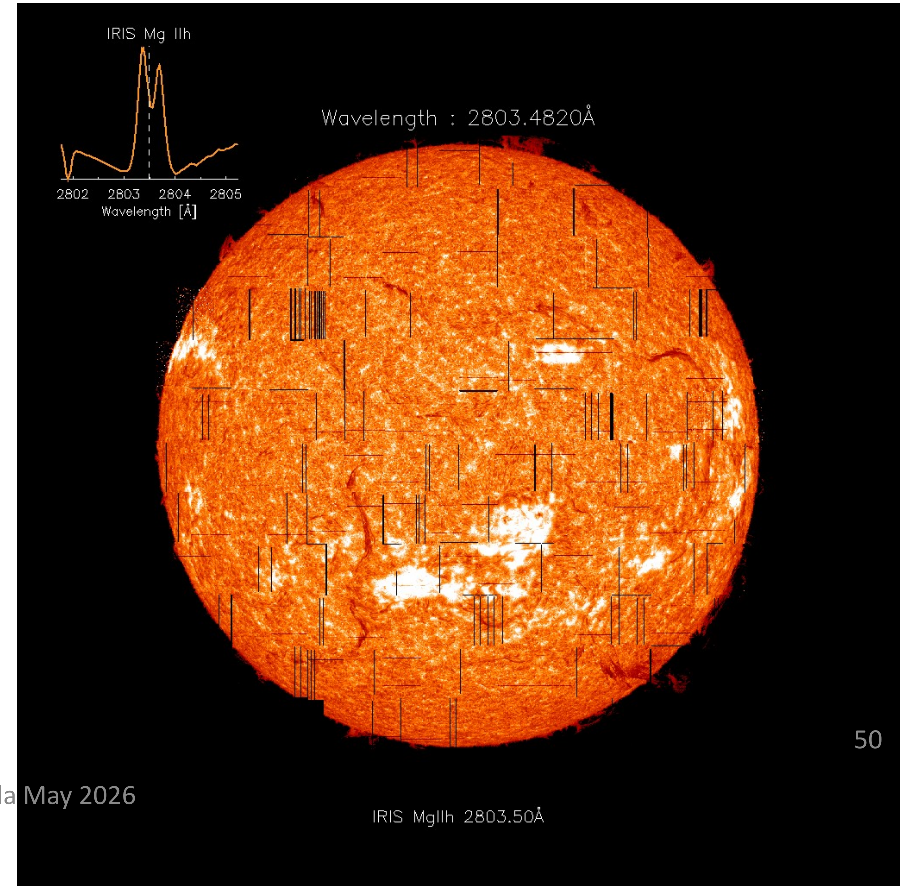
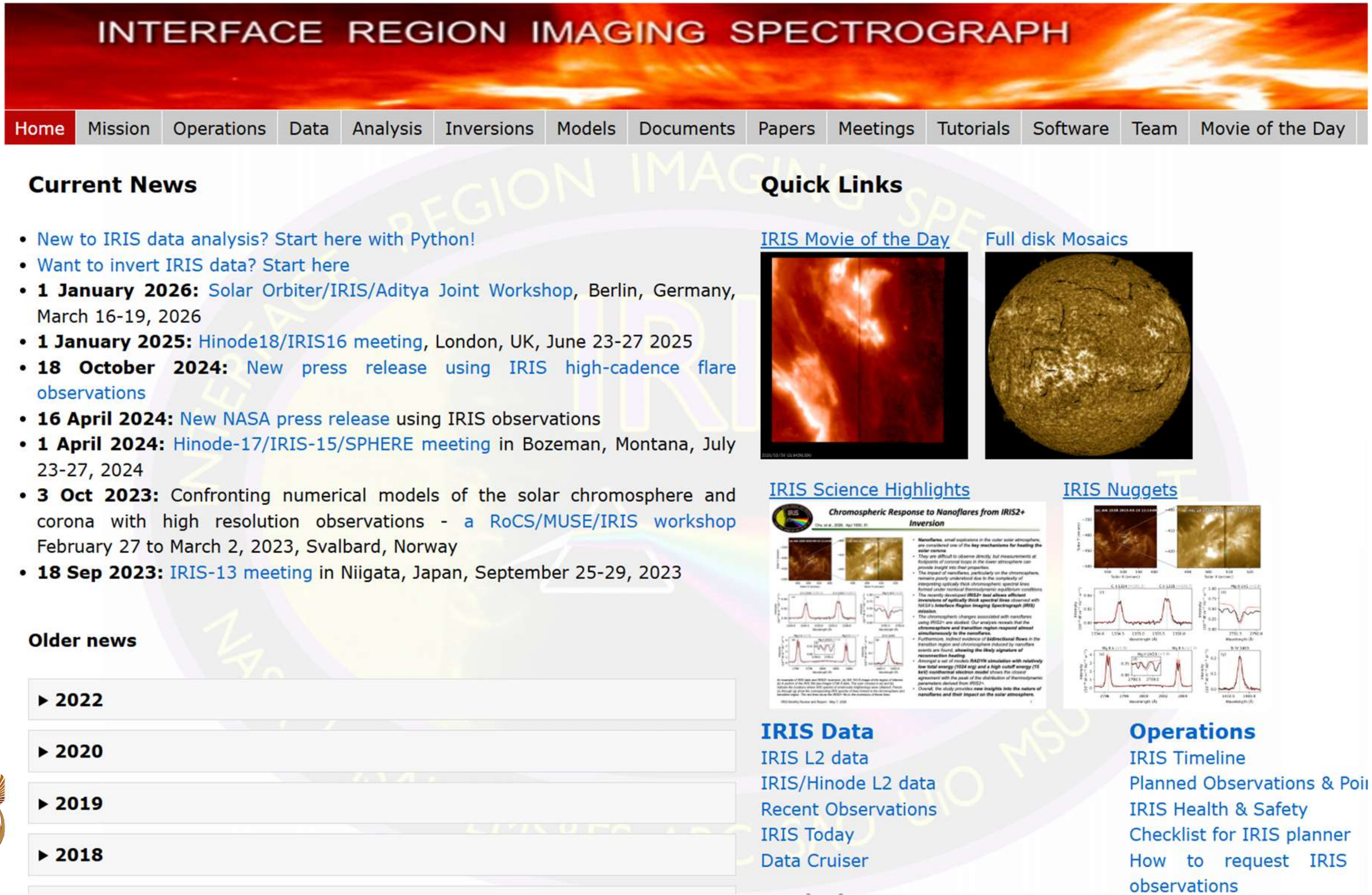
Sample images at wavelengths near Mg II h





IRIS Data access

https://iris.lmsal.com/



Accessing IRIS data with Python: irispy

`irispy` documentation

`irispy` is an open-source Python package that provides tools to read, manipulate, and visualize Interface Region Imaging Spectrograph (IRIS) data. The data is publicly available and provides access to co-aligned SDO/AIA data and more.

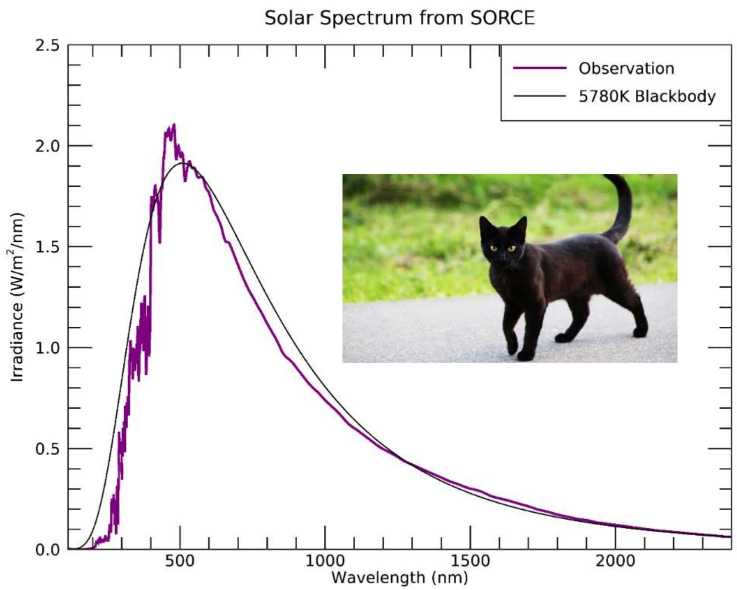
The goal of `irispy` is to provide a set of classes for handling both imaging (slit-jaw) and spectral observations (spectrograph). The classes link the observations with various forms of supporting data including: measurement uncertainties; units; a data mask to mark pixels with unreliable or unphysical data values; WCS (World Coordinate System) transformations that describe the position, wavelengths, and times represented by the pixels; and general metadata. These classes also provide methods for applying a number of calibration routines including exposure time correction and conversion between data number, photons, and energy units, referred to as radiometric calibration.

> **Warning**
>
> Please be aware that the package name on pypi and conda-forge is irispy-lmsal to avoid name clashes with other packages. However, the package is imported as `irispy` and is referred to as `irispy` in the documentation.

Solar Irradiance Monitor(s)

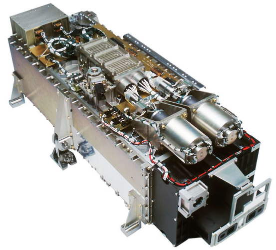
In addition to measuring ultraviolet SSI from the chromosphere, climate models need SSI from the photosphere.

The Spectral Irradiance Monitor (SIM) on the Solar Radiation and Climate Experiment (SORCE) was the first instrument to measure both UV and Visible/IR irradiance on a daily basis.



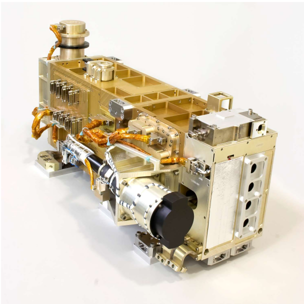
Maybe the Sun isn’t really a blackbody with a single temperature….

SIM Evolution



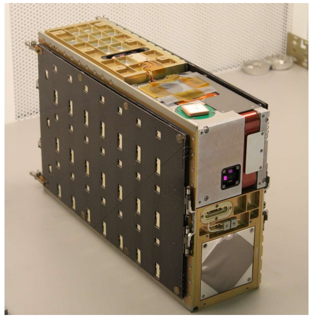
SORCE SIM (launched 15 Jan 2003)

- Two channel instrument (duty-cycled for stability corrections)
- Absolute ESR detector (NiP bolometer)
  - First generation (Noise 3 nW @ 40 sec.)
  - Diamond substrate
  - NiP black absorber
  - Kapton™ thermal link
- Abs. accuracy: 2-10% wavelength dependent (no-SI validation)



TSIS SIM (launched 15 Dec 2017)

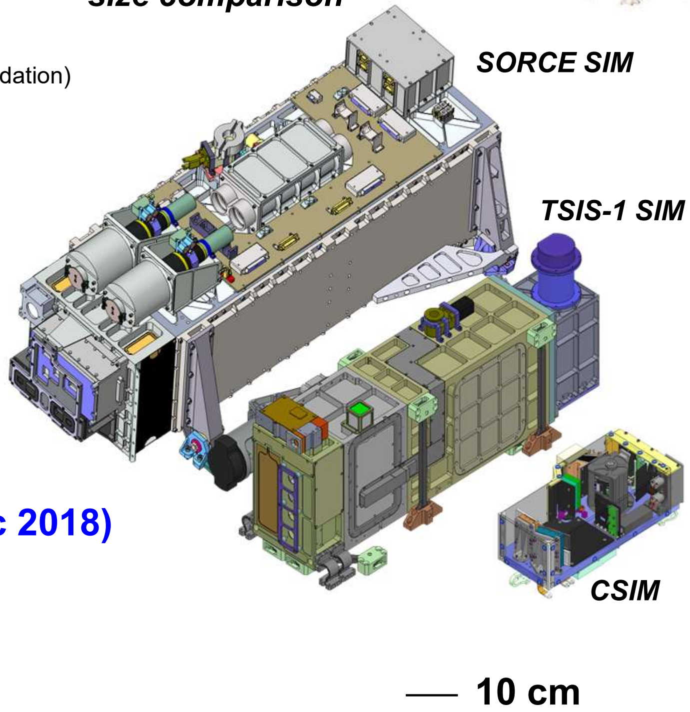
- Three channel instrument
  - For long-term stability validation of duty-cycling
- Absolute ESR detector (NiP bolometer)
  - Second gen. (Noise 1.6 nW @ 40 sec.)
  - Diamond substrate
  - NiP black absorber
  - Kapton™ thermal link
- Abs. accuracy – 0.2 % (SI-traceable validation)



CSIM 6U CubeSat (launched 3 Dec 2018)

- ✓ Two channel instrument (duty-cycled)
- ✓ Absolute ESR detector (VACNT bolometer)
  - Third gen. (Noise 0.2 nW @ 40 sec.)
  - Silicon substrate
  - VACNT black absorber
  - SiNx thermal link
- ✓ 200-2400 nm (continuous)
- ✓ Abs. accuracy – 0.2 % (SI-traceable validation)

Relative instrument size comparison



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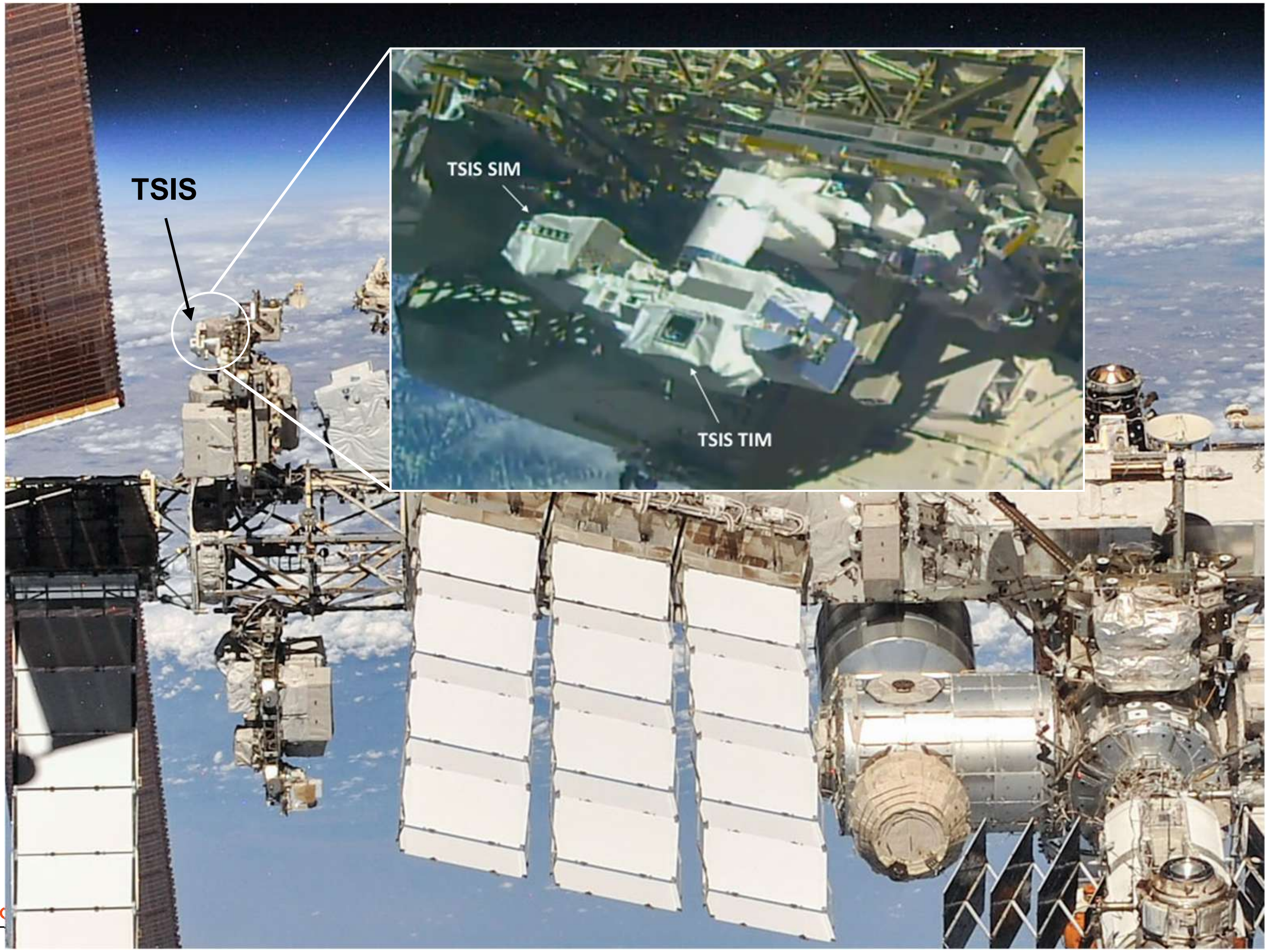
Thanks to E. Richard for these slides.

The Total and Spectral Solar Irradiance Sensors (TSIS) on ISS



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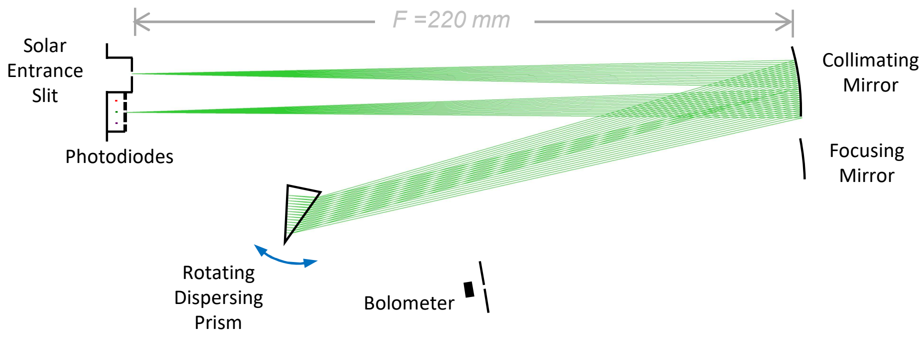
CSIM Optical Layout: Prism Spectrometer

Photodiode scan mode

Fast, high SNR detectors Full spectrum (200-2400nm) in < 30 min.

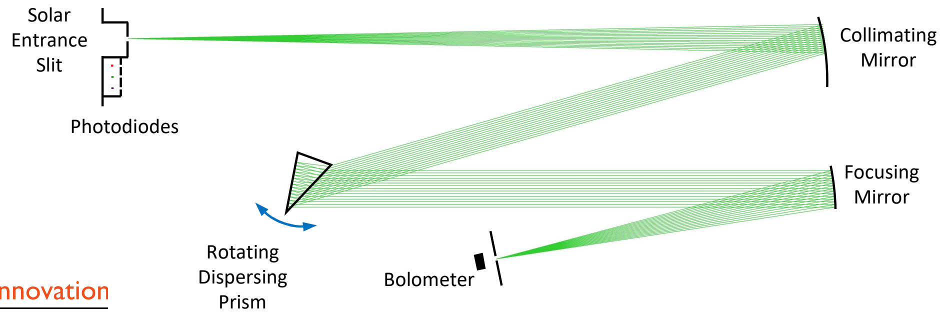


- *"Step and Stare" with the prism to take a spectra*
- *0.5 seconds per point with photodiodes*
  - Full Spectrum in ~25 minutes
- *10-50 Seconds per point with ESR*
  - Full range in ~14 orbits

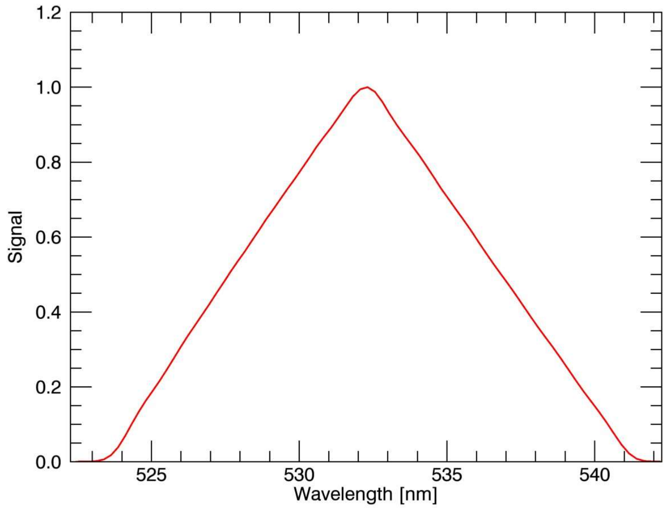
ESR scan mode

Slow, robust absolute detector

Photodiode channel irradiance calibration, degradation tracking



Measured Instrument Line Shape at 532 nm



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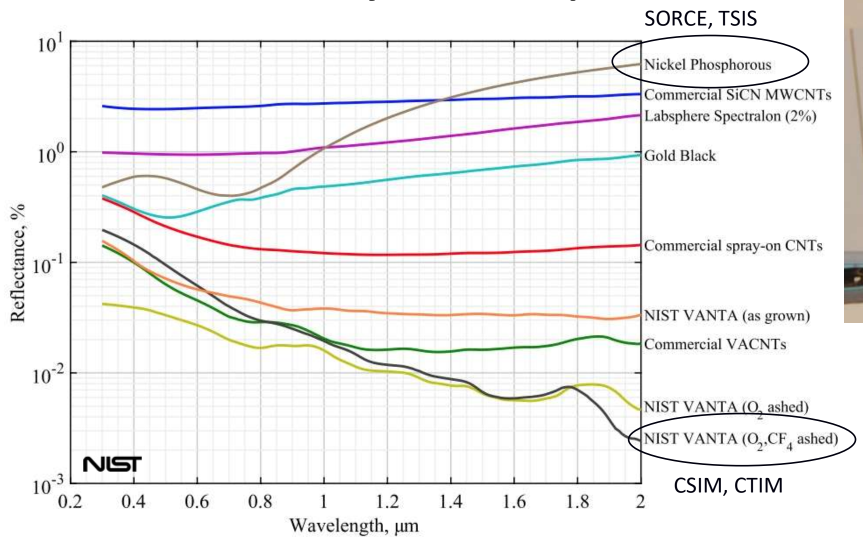
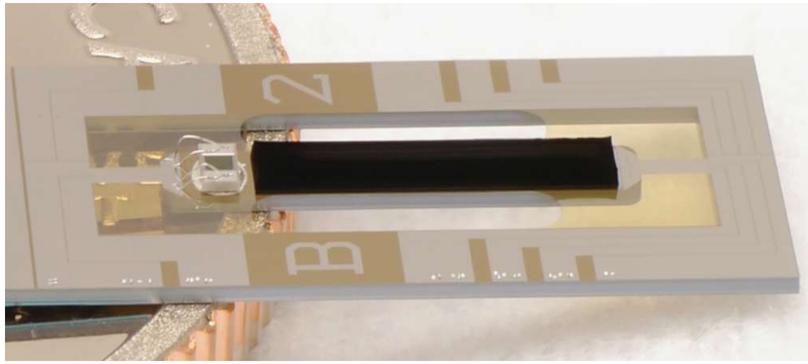
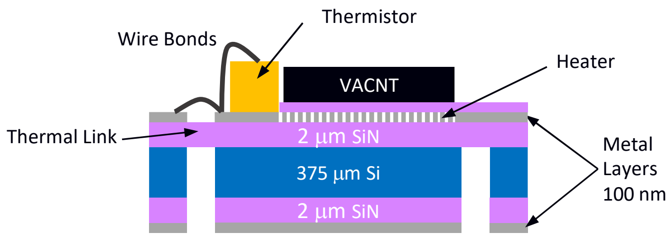
Silicon Substrate Vertically Aligned Carbon Nanotube (VACNT) Bolometers

VACNTs are currently the best optical absorber

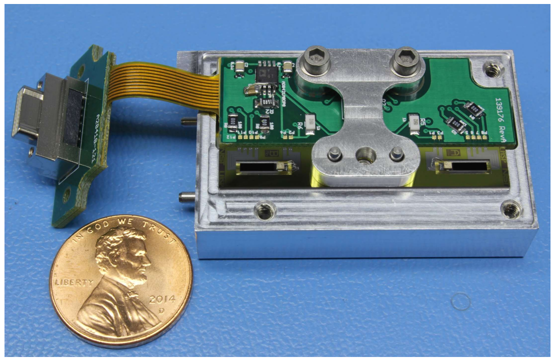


Lehman, *et al.* ***Appl. Phys. Rev***. 5, 011103 (2018)

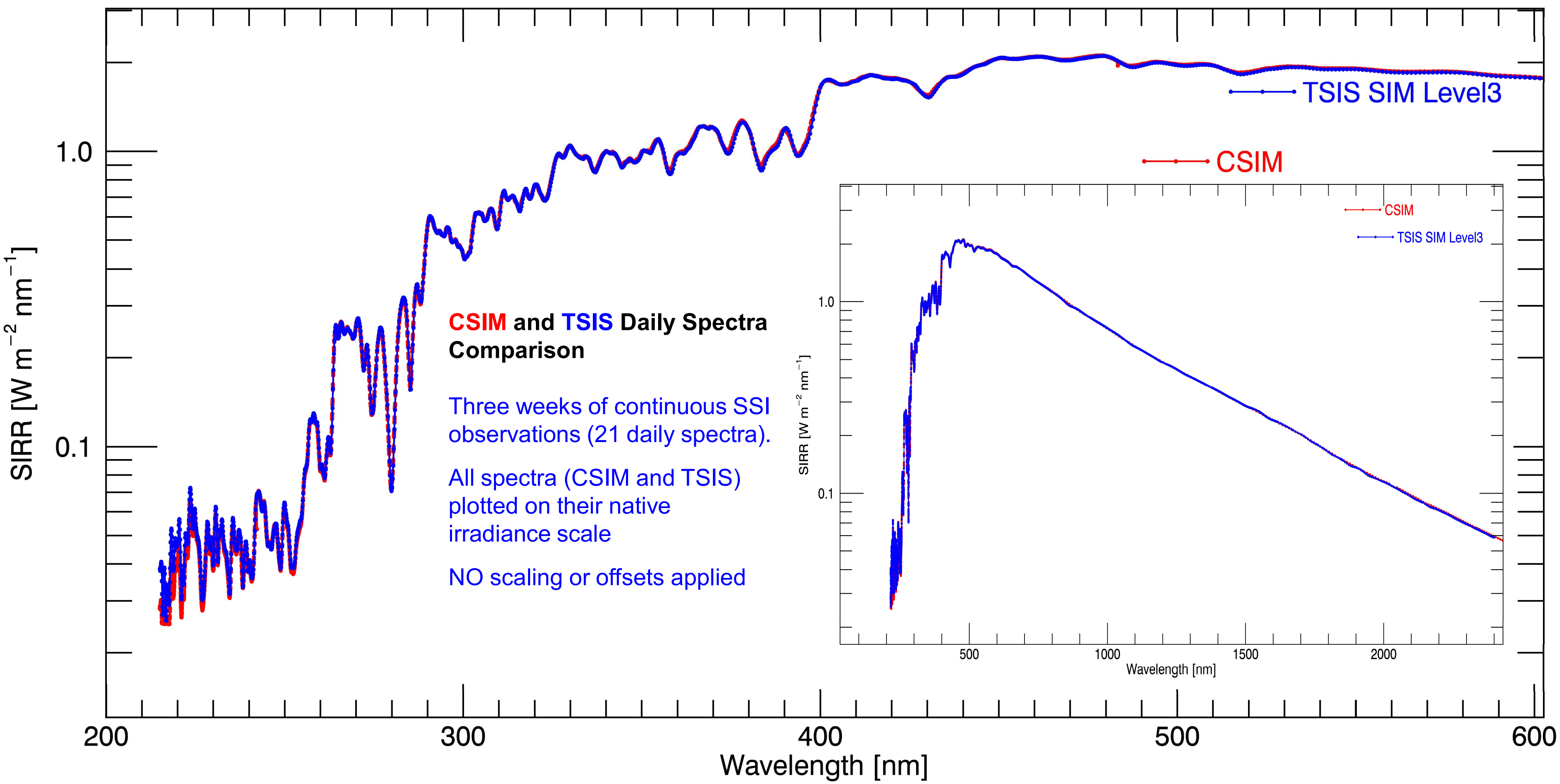




- Developed with NIST Boulder
- Silicon micro fabrication allows a nearly arbitrary 2D geometry to be fabricated with micron-level precision
- Conductive traces and integrated heaters can be fabricated on silicon
- Weak thermal links can utilize integrated thin SiN films



TSIS/SIM and Compact SIM observed spectra



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Calibration

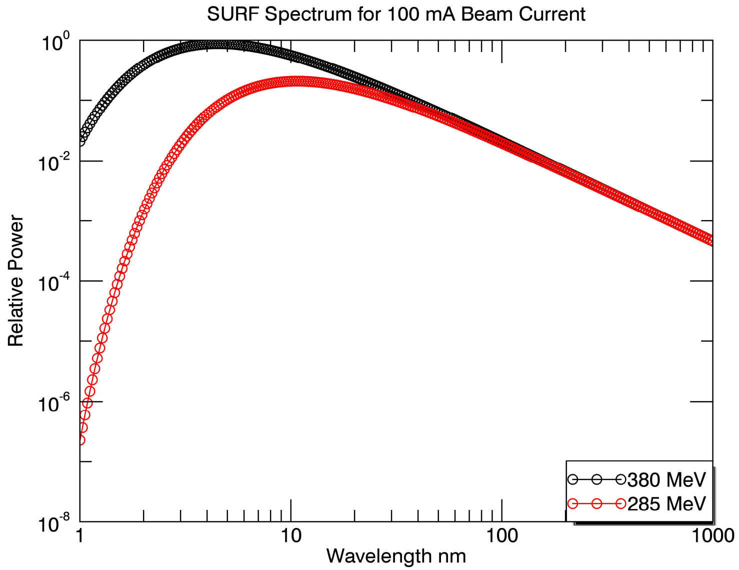
Measurements of SSI need accurate calibration in order to maintain records over long timespans and to allow the creation of composite datasets from multiple instruments.

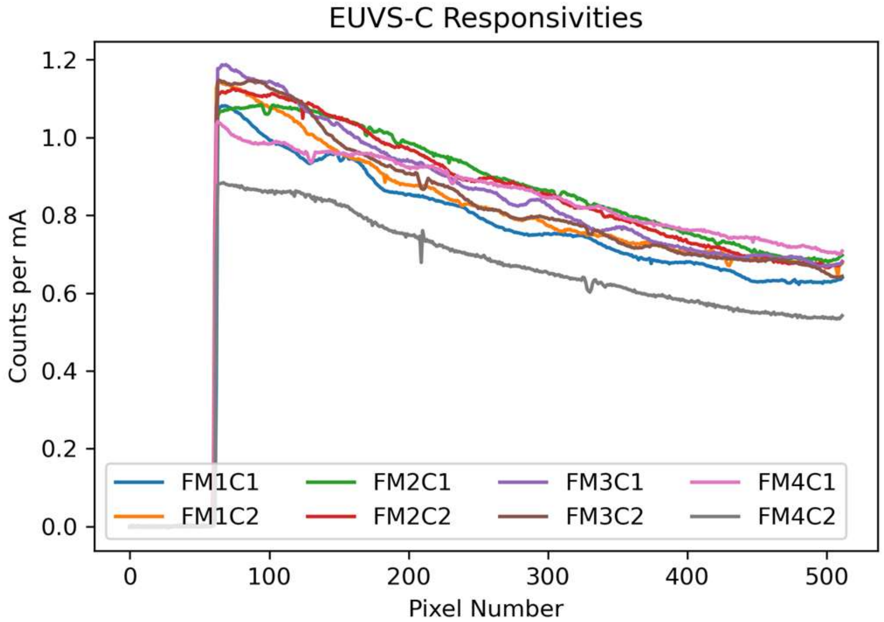
We use several calibration facilities depending on wavelength and optical configuration. Here a few that were used on the instruments described here.

How to calibrate in the Extreme Ultraviolet?

Surfing!

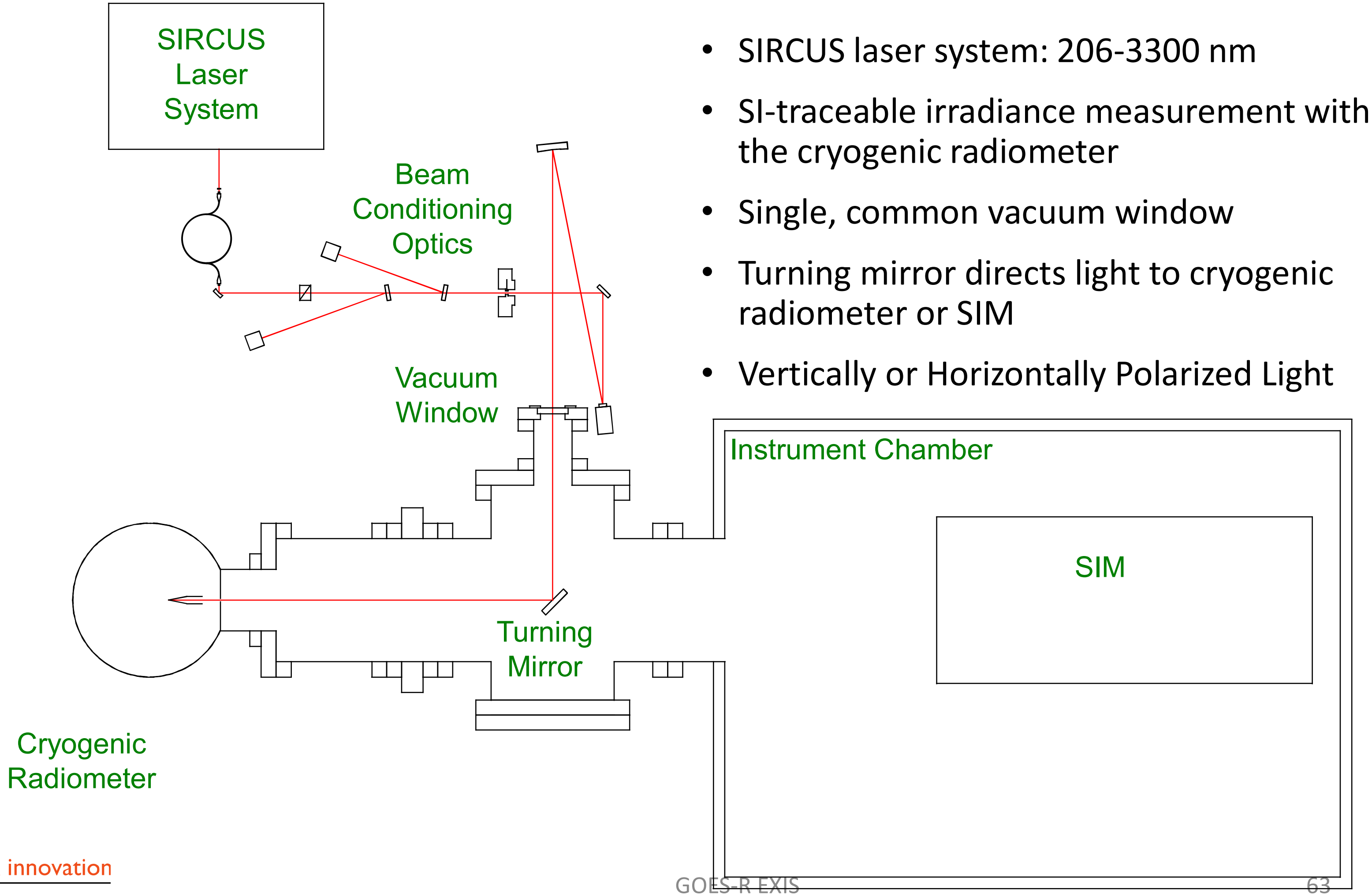
All channels of EXIS were calibrated at the Synchrotron Ultraviolet Radiation Facility (SURF-III) at the National Institutes of Standards and Technology in Gaithersburg MD, USA. Preflight uncertainties ~1%





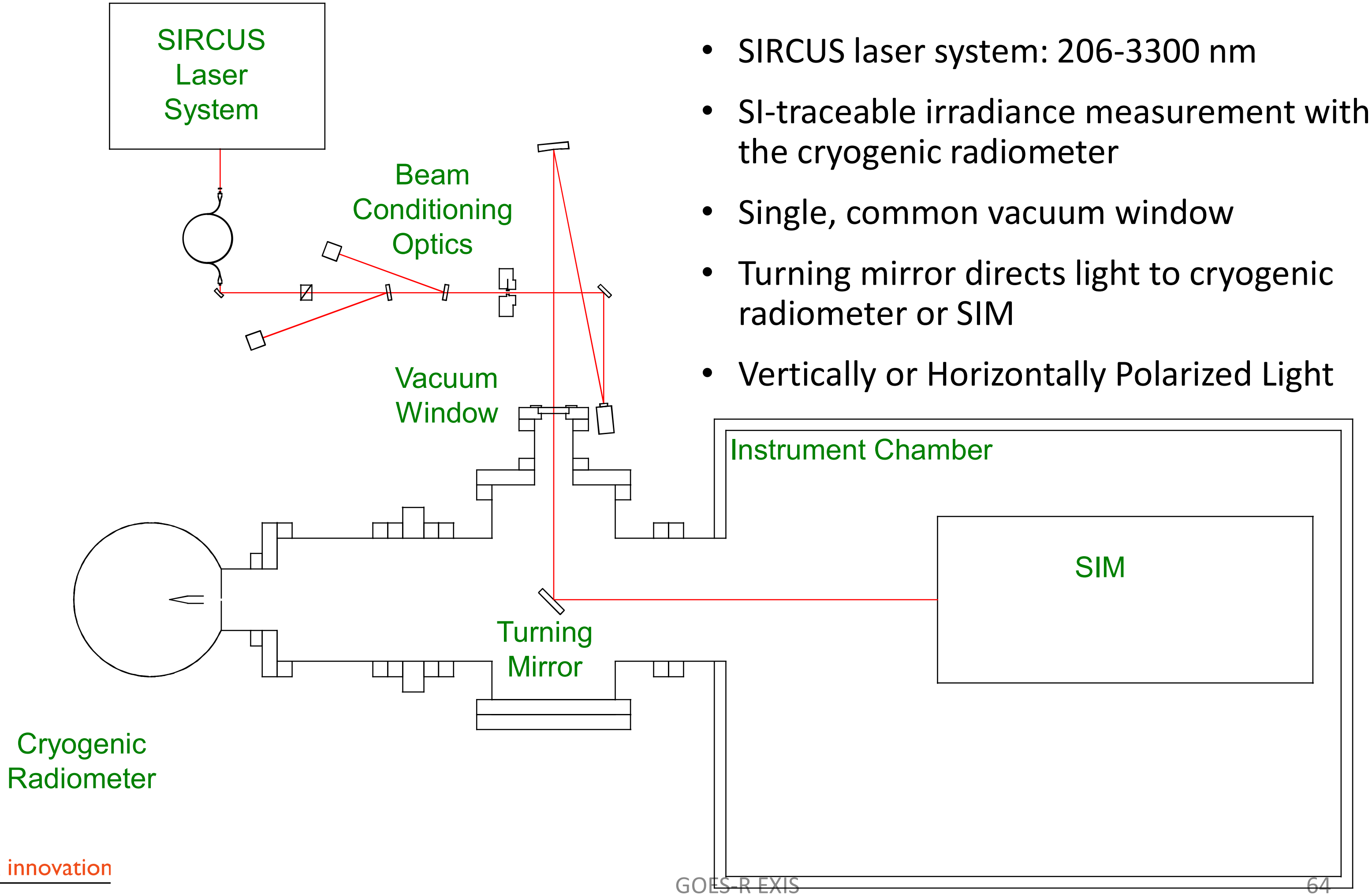
NIST SIRCUS –> LASP Spectral Radiometer Facility (SRF)

LASP Spectral Radiometry Facility: Overview



- SIRCUS laser system: 206-3300 nm
- SI-traceable irradiance measurement with the cryogenic radiometer
- Single, common vacuum window
- Turning mirror directs light to cryogenic radiometer or SIM
- Vertically or Horizontally Polarized Light

LASP Spectral Radiometry Facility: Overview

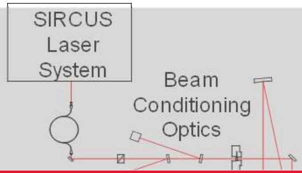


- SIRCUS laser system: 206-3300 nm
- SI-traceable irradiance measurement with the cryogenic radiometer
- Single, common vacuum window
- Turning mirror directs light to cryogenic radiometer or SIM
- Vertically or Horizontally Polarized Light

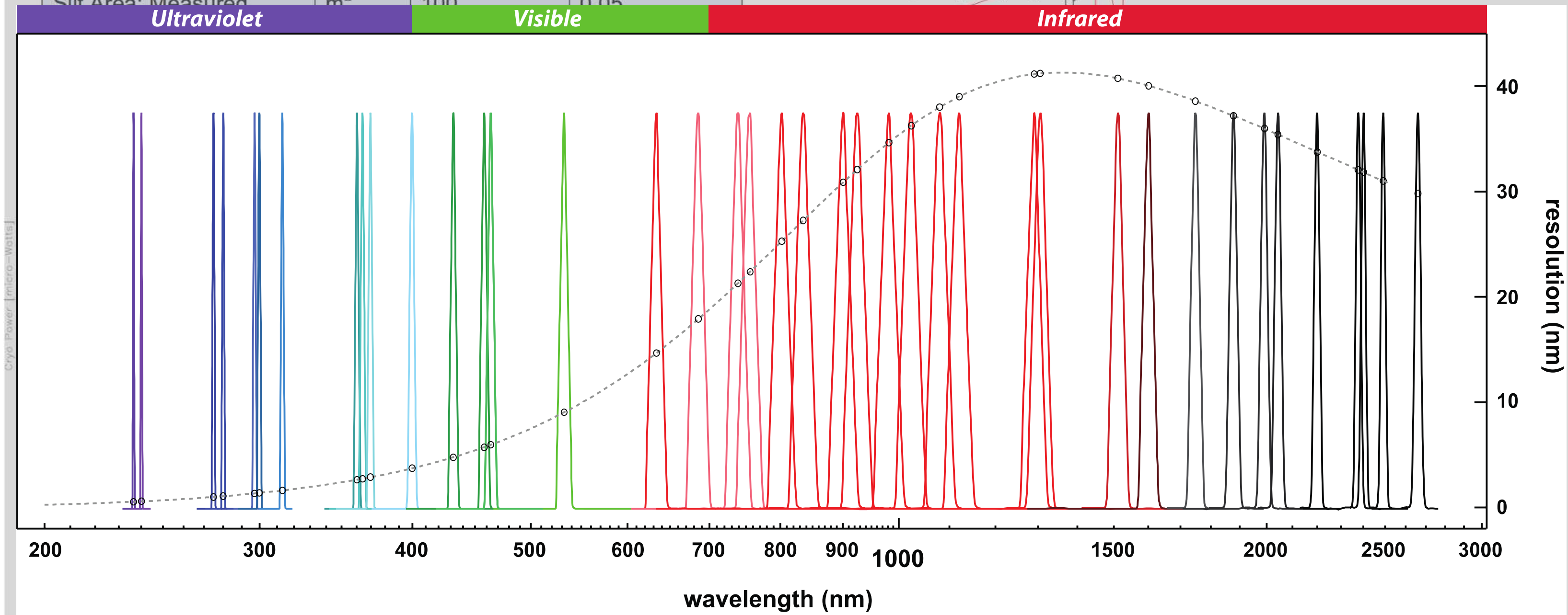
Absolute Irradiance Scale
(LASP-SRF)

Cryogenic Radiometer Uncertainty Budget

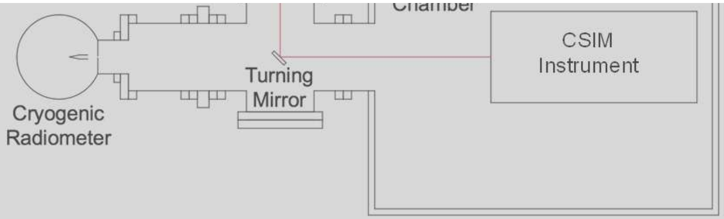
Parameter	Unit	% Effect	% Unc. (k=1)
Power	W	100	0.015
Cavity Reflectance	-	0.01	0.004
Cavity Non-Equiv.	-	0	0.01
Slit Area: Measured	m^2	100	0.05



Cryo Measurement (Static)



Parameter	Unit	% Effect	% Unc. (k=1)
Cryo Measurement	W/m^2	100	0.07
Turning Mirror Repeatability	-	0	0.004
Laser: Stability	-	0	0.060
Laser: Pattern Uniformity	-	0	0.023
Path Length Correction	-	0	0.0002
CSIM Spectral Integration	W/m^2	100	0.1
Total			**0.14**

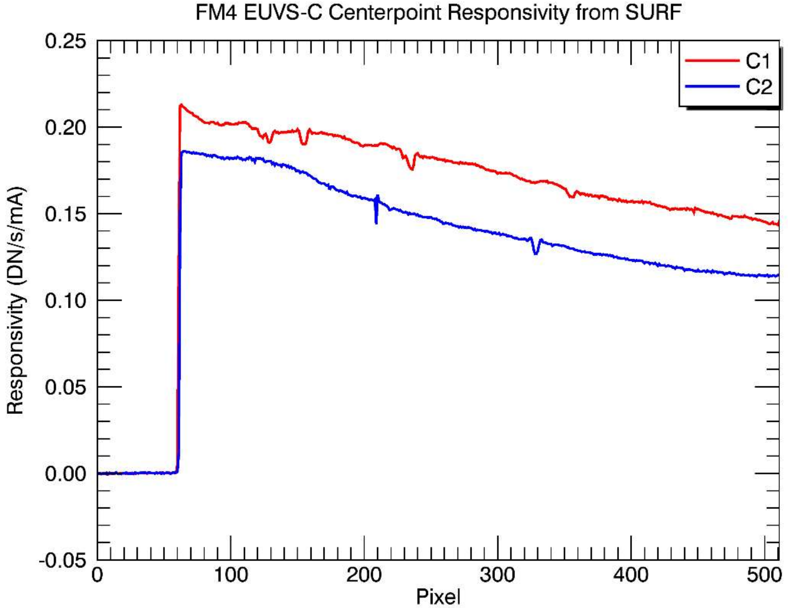


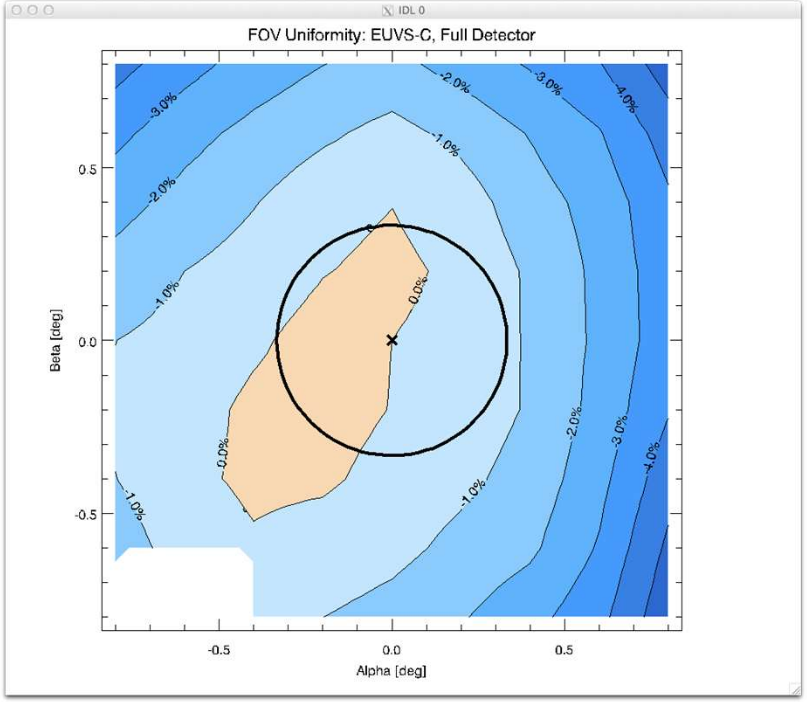
EXIS Laser Facility (ELF)
The best of both worlds

SURF beam is f/700 (point source)

Solar observations are f/100 (0.5 degree diverging beam).

ELF allows us to map the FOV with an f/100 beam in the UV.





Rocket Underflights

How to maintain calibration in orbit?

EUVS bootstrap method will use calibration-free MgII core-to-wing ratio. See Snow et al. (2019) for issues related to degradation. Current NOAA method will be described in Snow et al. (2024) in preparation.

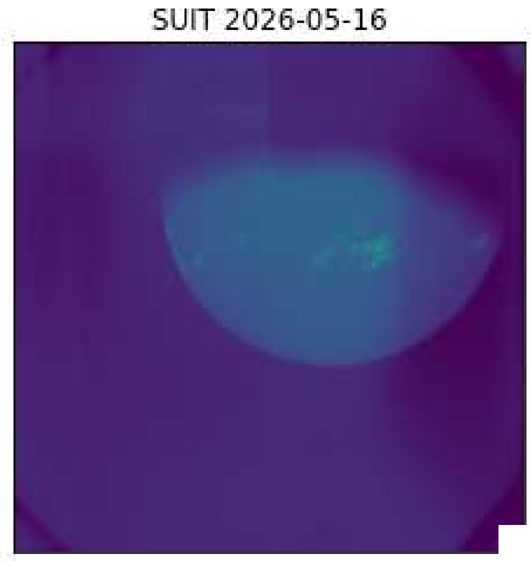
For EUV and x-rays, it's not practical to use any onboard source, so we fly an identical instrument on a rocket for a simultaneous solar observation.

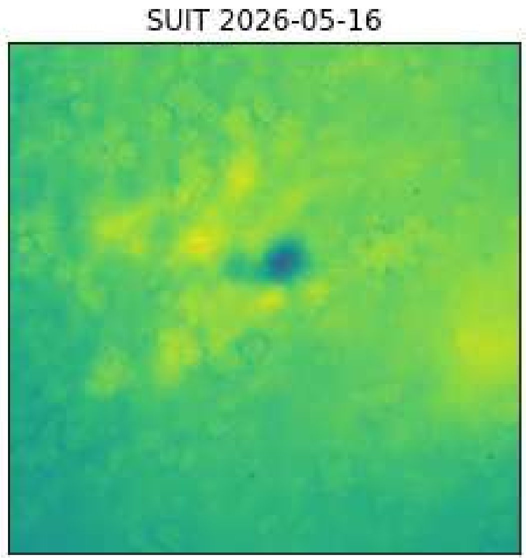
Aditya-L1

Launched a few years ago by the Indian Space agency to L1. Includes an instrument called Solar Ultraviolet Imaging Telescope (SUIT).

One of the filters is 280 nm (MgII)

Data is now available to the public.





Summary part 2

- Instruments that measure chromospheric irradiance
  - Geostationary Operational Environmental Satellites
  - Interface Region Imaging Spectrograph
  - Spectral Irradiance Monitor
- Instrument Calibration
  - Synchrotron for X-ray through ultraviolet
  - Lasers for near UV through infra-red
  - Rocket Underflights

THANK YOU
Questions on Parts 1 or 2?

SUVI: Six Bands

Wavelength Log (Te)	94 Å 6.8	131 Å 7.0,7.2	171 Å 5.8	195 Å 6.1,7.3	284 Å 6.3	304 Å 4.7
Filaments						
Coronal Holes						
Active Region Complexity						
CMEs (e.g. dimming)						
Flare Location and Morphology						
Quiet Regions