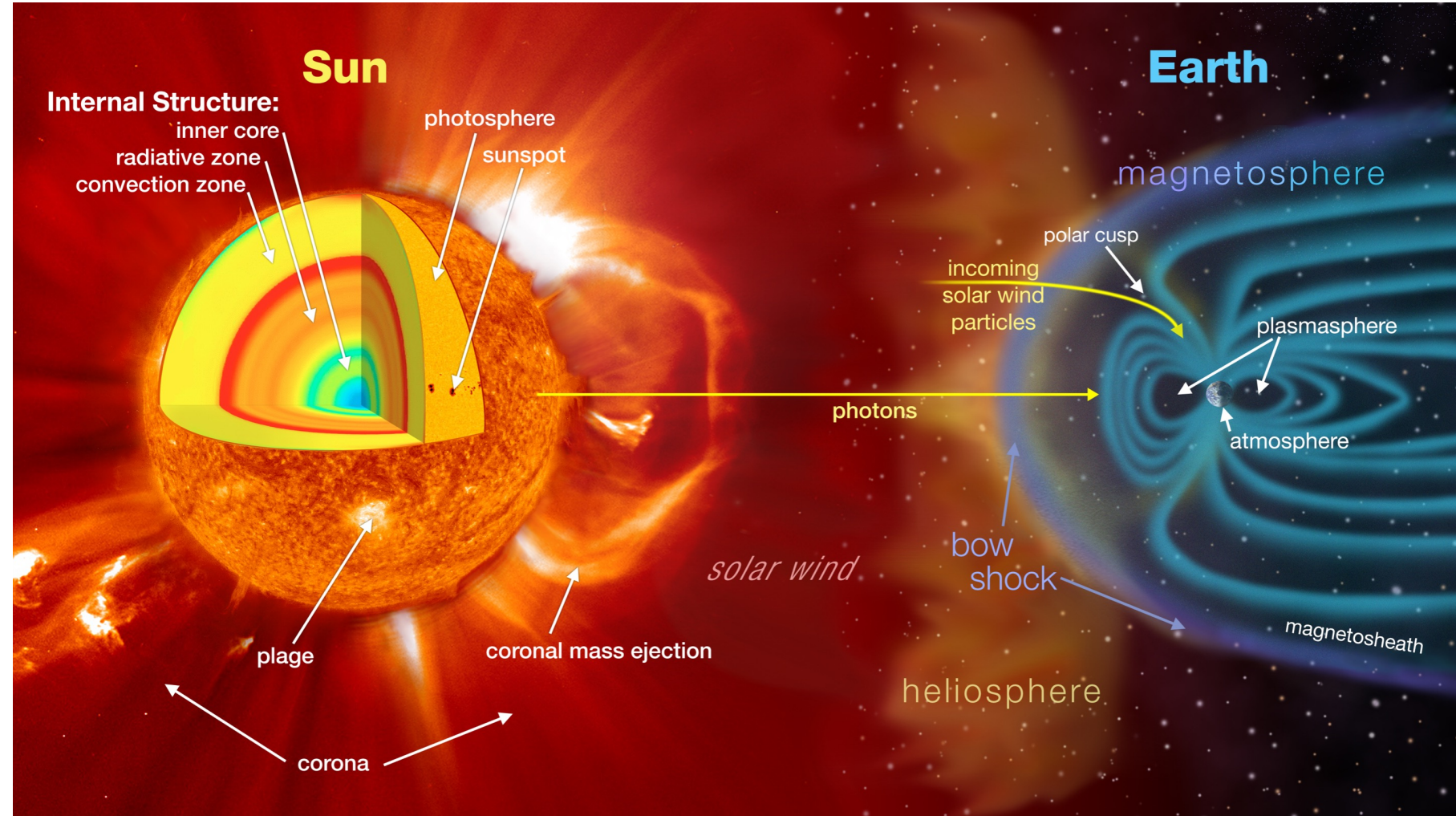


The Sun at the Source

COLLAGE 2023
ASEN-5519:
Space Weather Overview

Lecture #1
18 January 2023

Kevin Reardon
kreardon@nso.edu

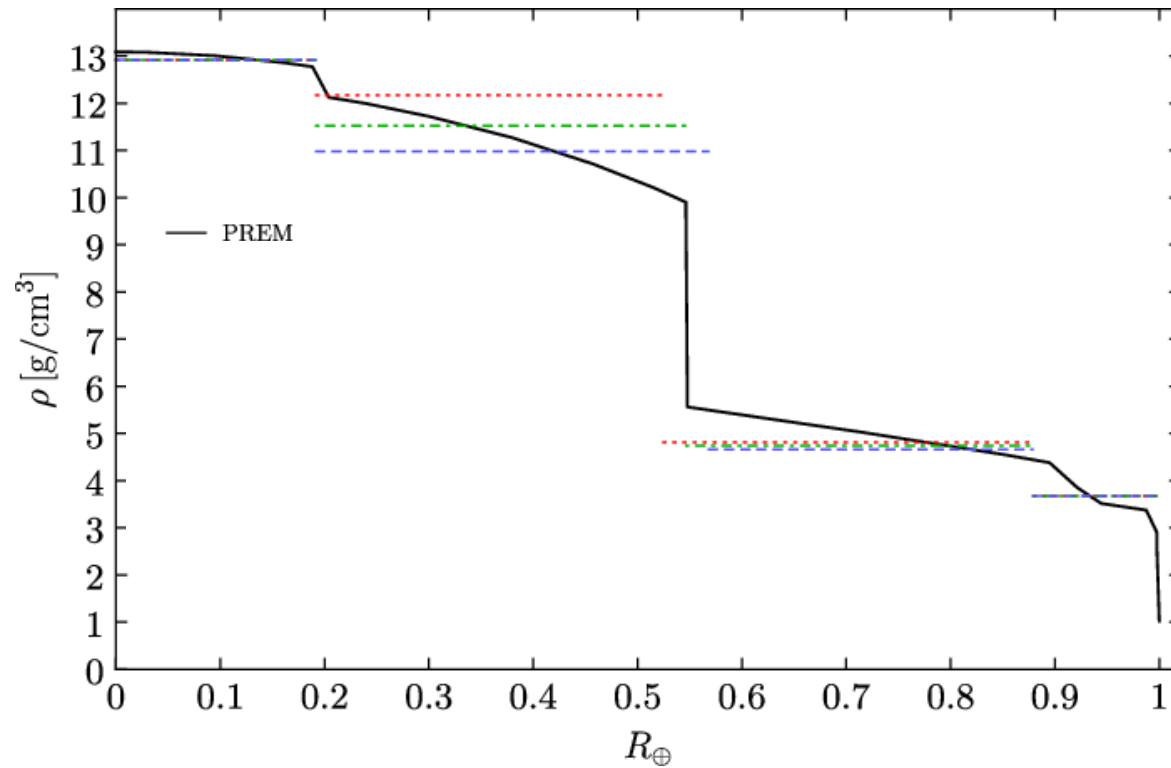


Key Concept: Energy Conversion

The Sun is an enormous cascade of processes converting different types of energy:

- Gravitational (Potential) – collapse of interstellar cloud
- Thermal – heating of plasma
- Nuclear – fusion in core
- Kinetic – convective flows, waves
- Electromagnetic – magnetic energy, waves
- Atomic – energy level transition, ionization

Key Concept: Density

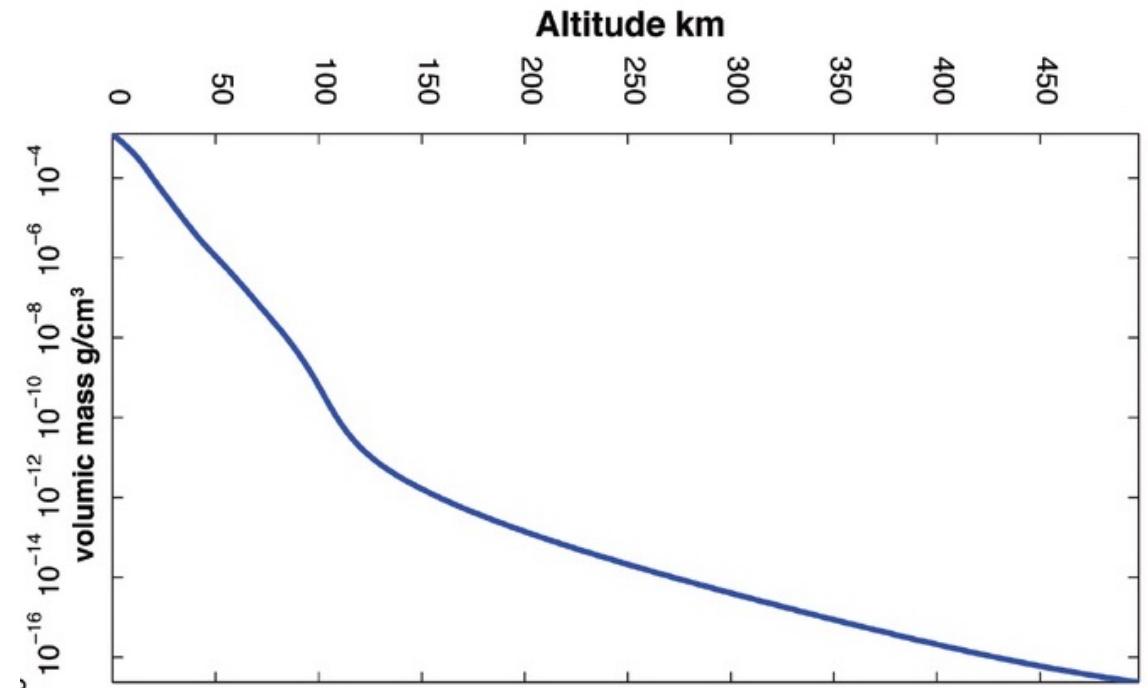


Density of Earth's Interior
with radius
Note linear scale
1 order of magnitude change

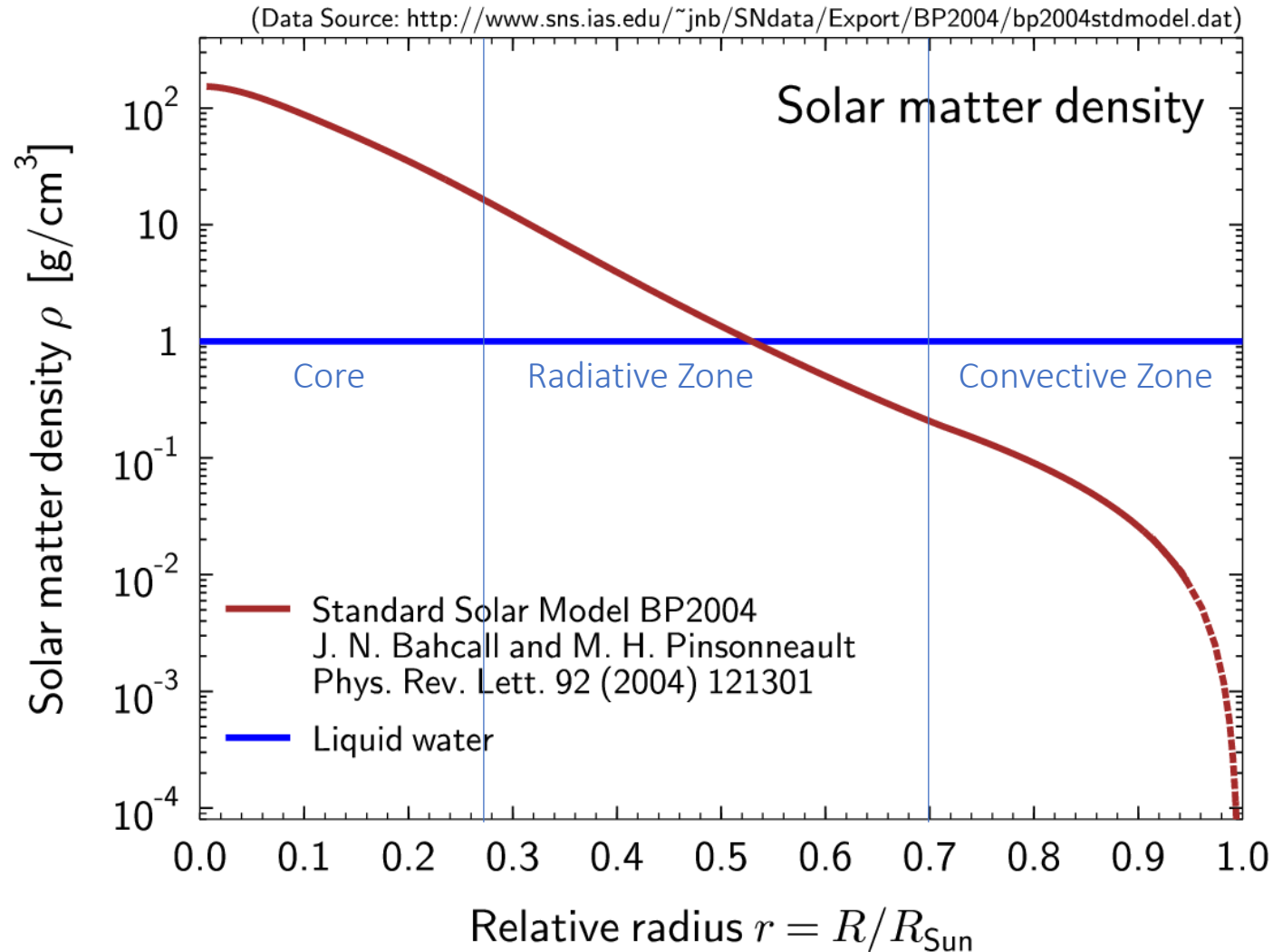
There is a continuous outward density gradient in the Sun.

For reference, compare the density profile of the Earth.

Density of Earth's Atmosphere
with height
Note logarithmic scale
12 orders of magnitude change



Solar Interior



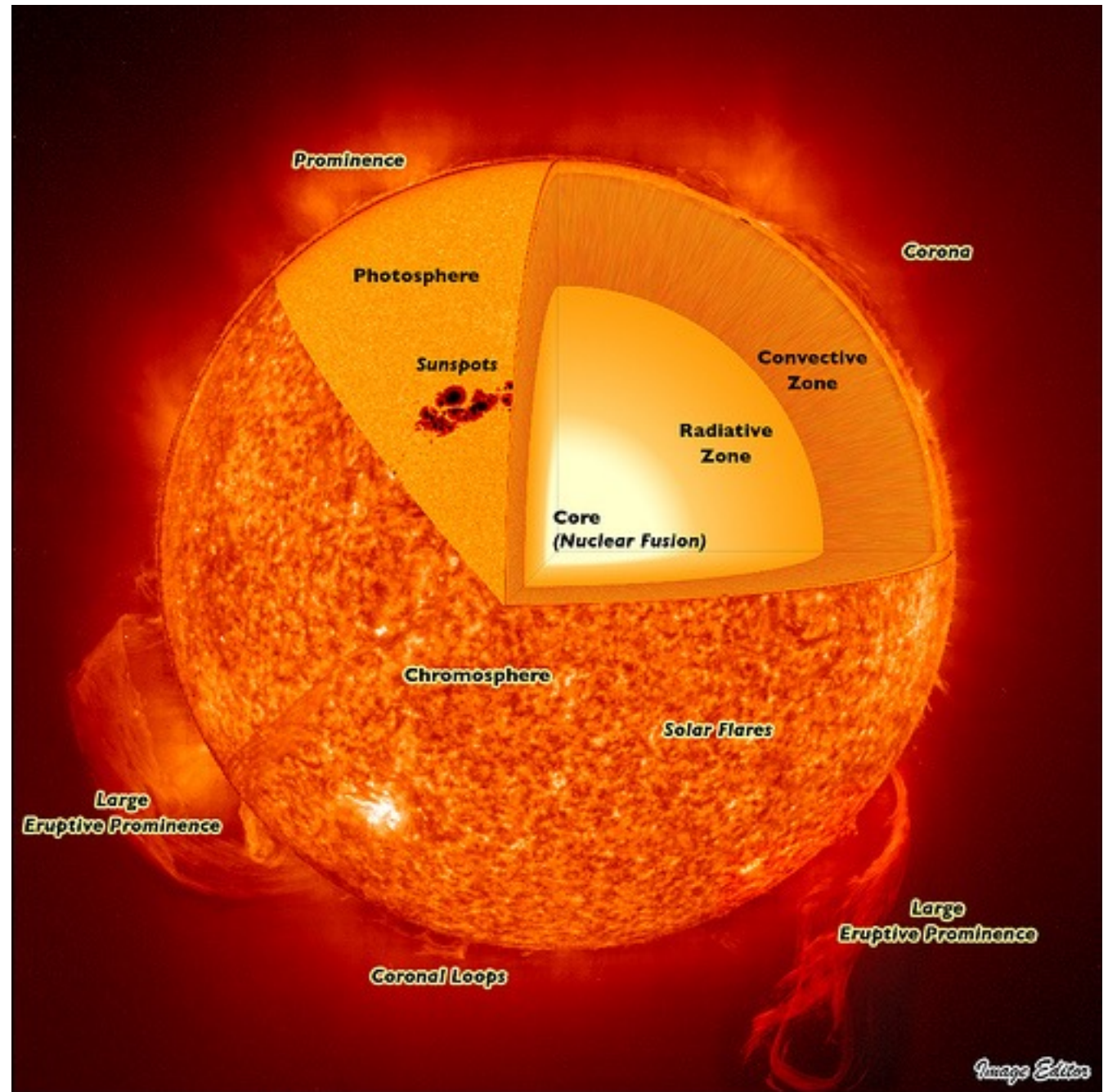
This instead is the density gradient in the Sun.

6 order of magnitude decrease from core to surface

Outer half of Sun (85% of volume) is less dense than water.

Solar Structure

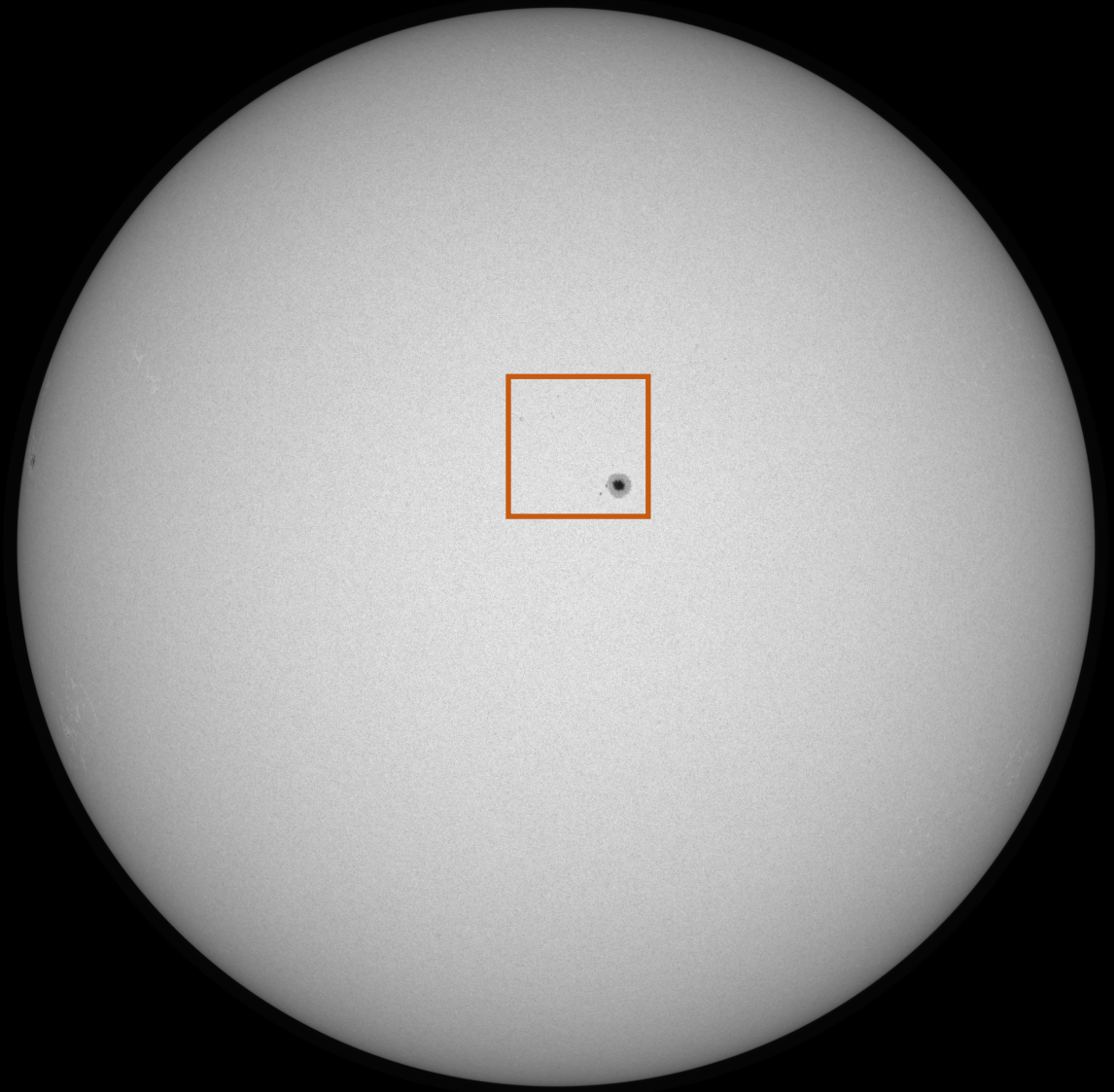
Different energy transport mechanisms at work as energy moves outward



Solar “Surface”

Called **Photosphere**

Radiative escape carries away most of solar energy as electromagnetic waves

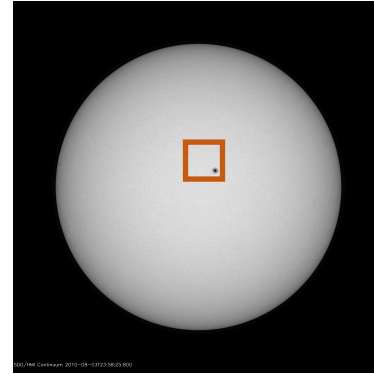


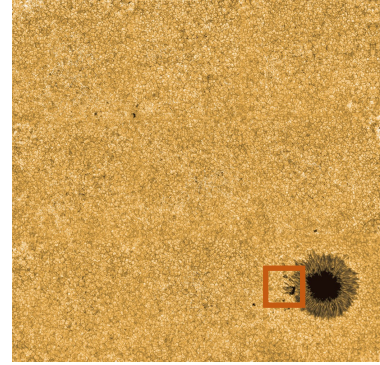
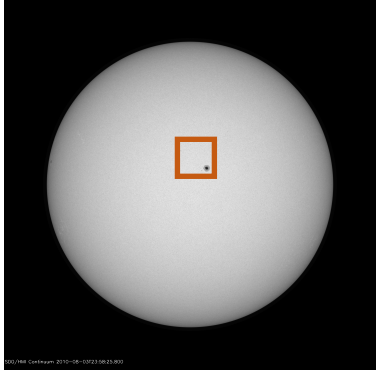
240 arcseconds = 170 Mm = 1/8th solar diameter

Photosphere

Granulation covers surface, with occasional sunspots

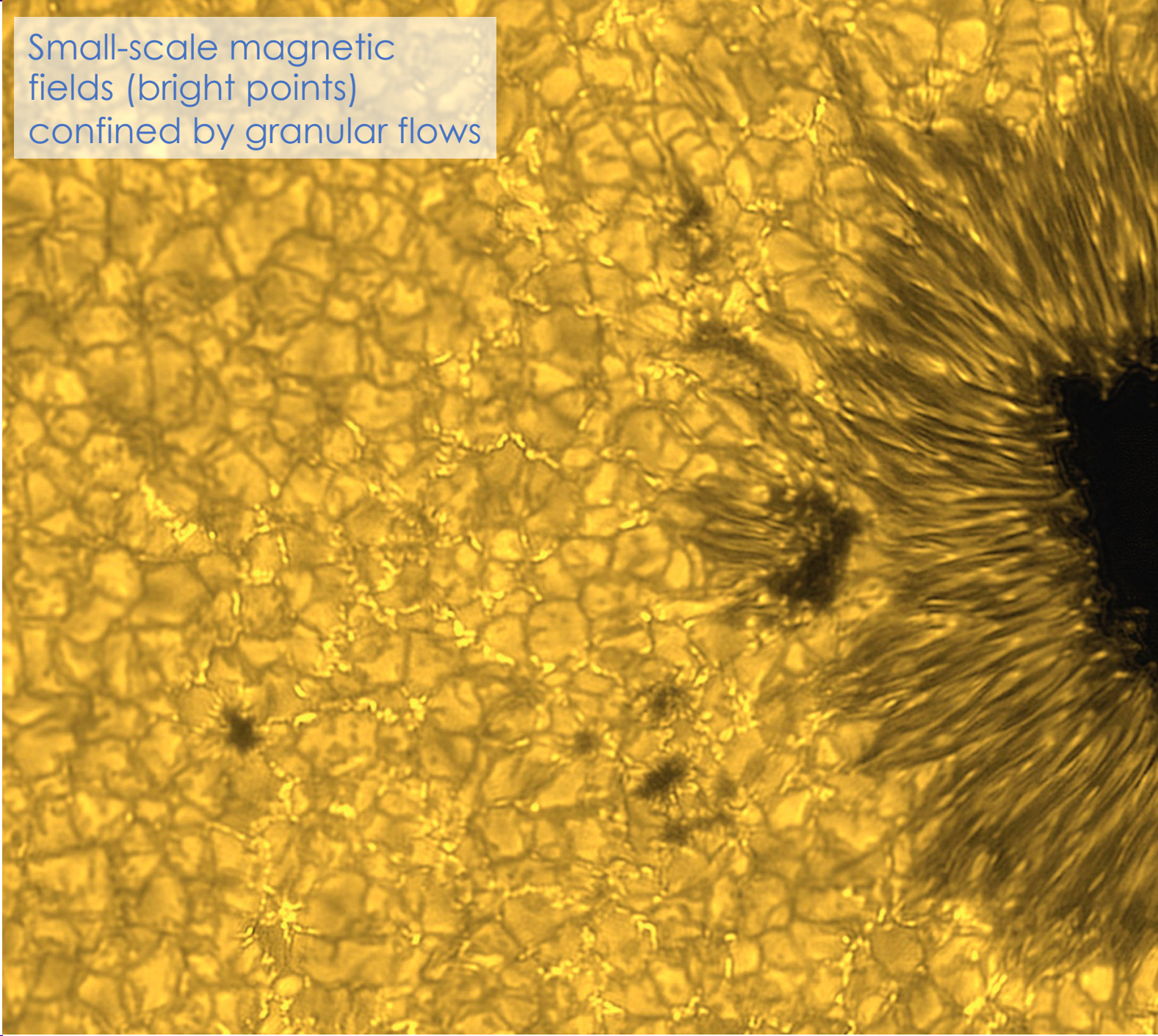
IBIS Mosaic – 03 August, 2010
Continuum





44 arcseconds = 32 Mm = 1/44th solar diameter

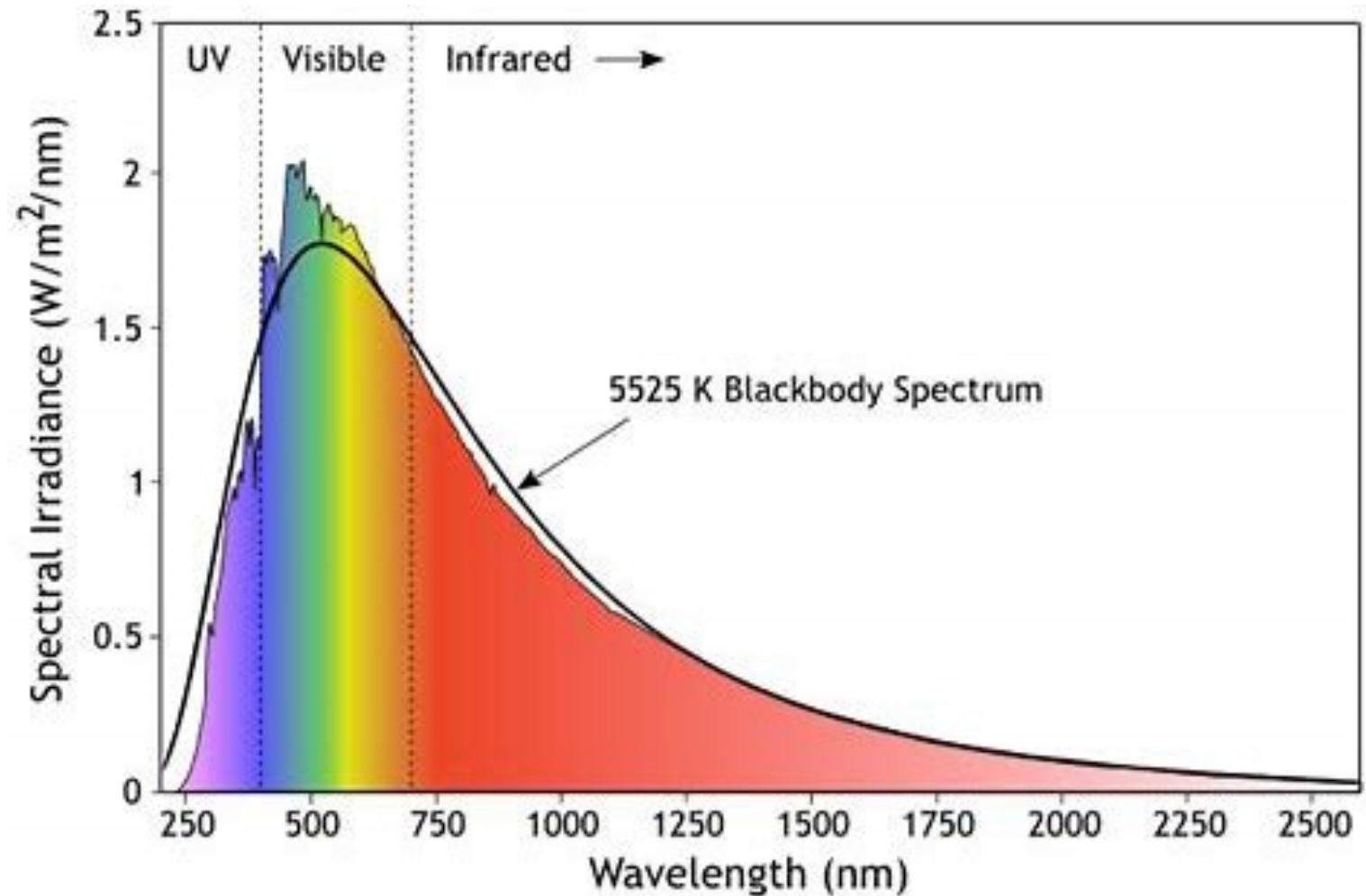
Small-scale magnetic fields (bright points) confined by granular flows



IBIS Mosaic - 03 August, 2010
G-band

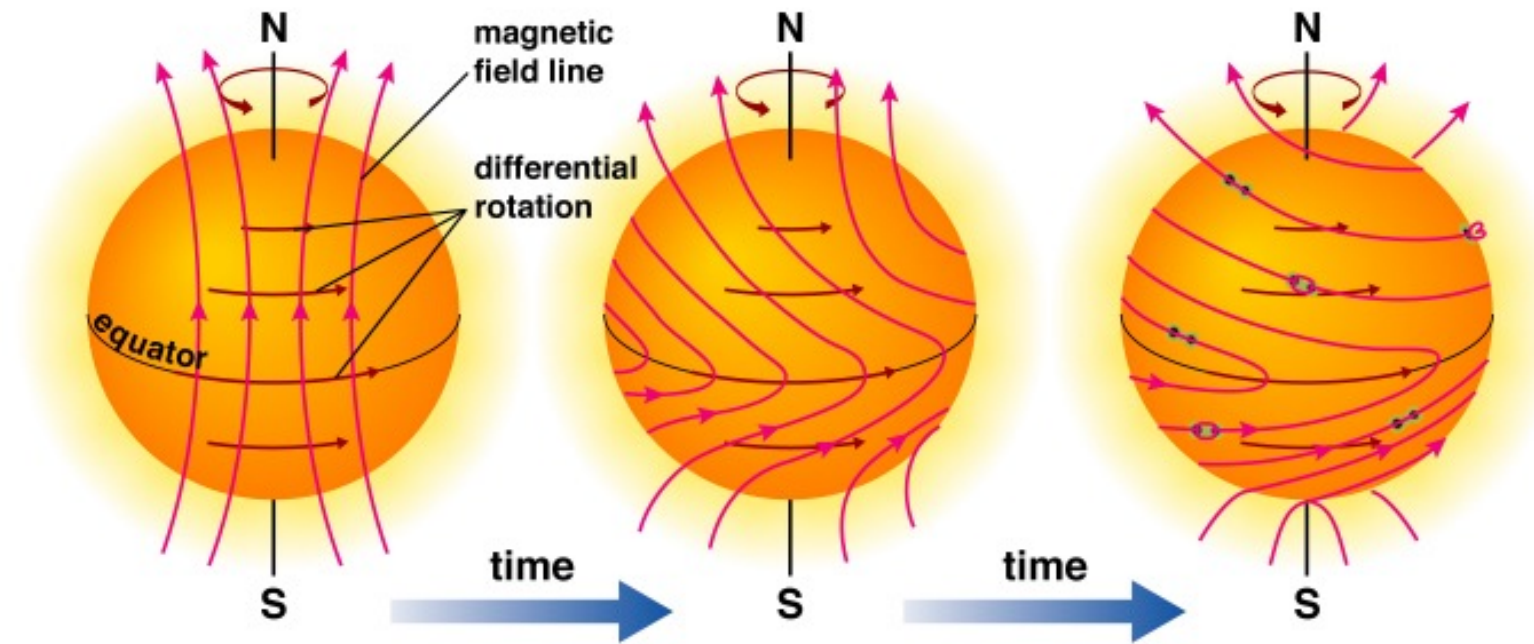
Black Body

Continuum spectrum of Sun is an approximate blackbody spectrum

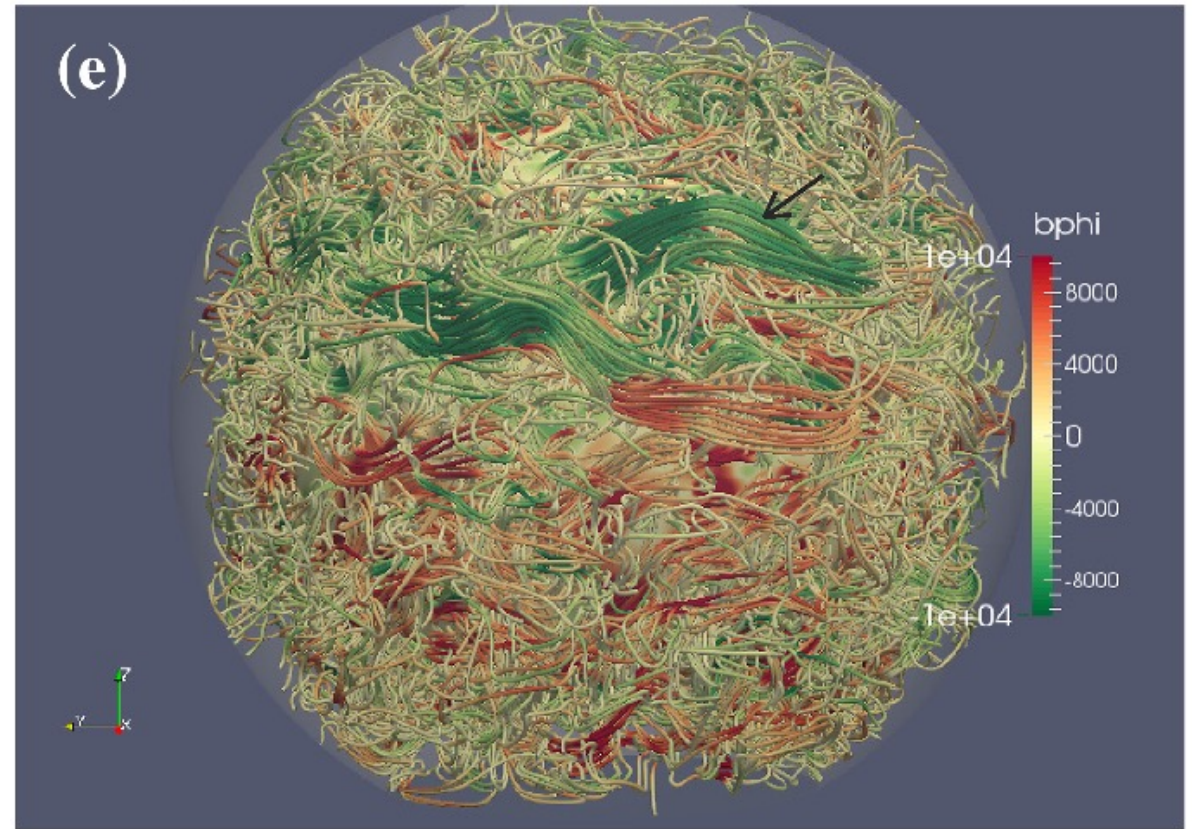
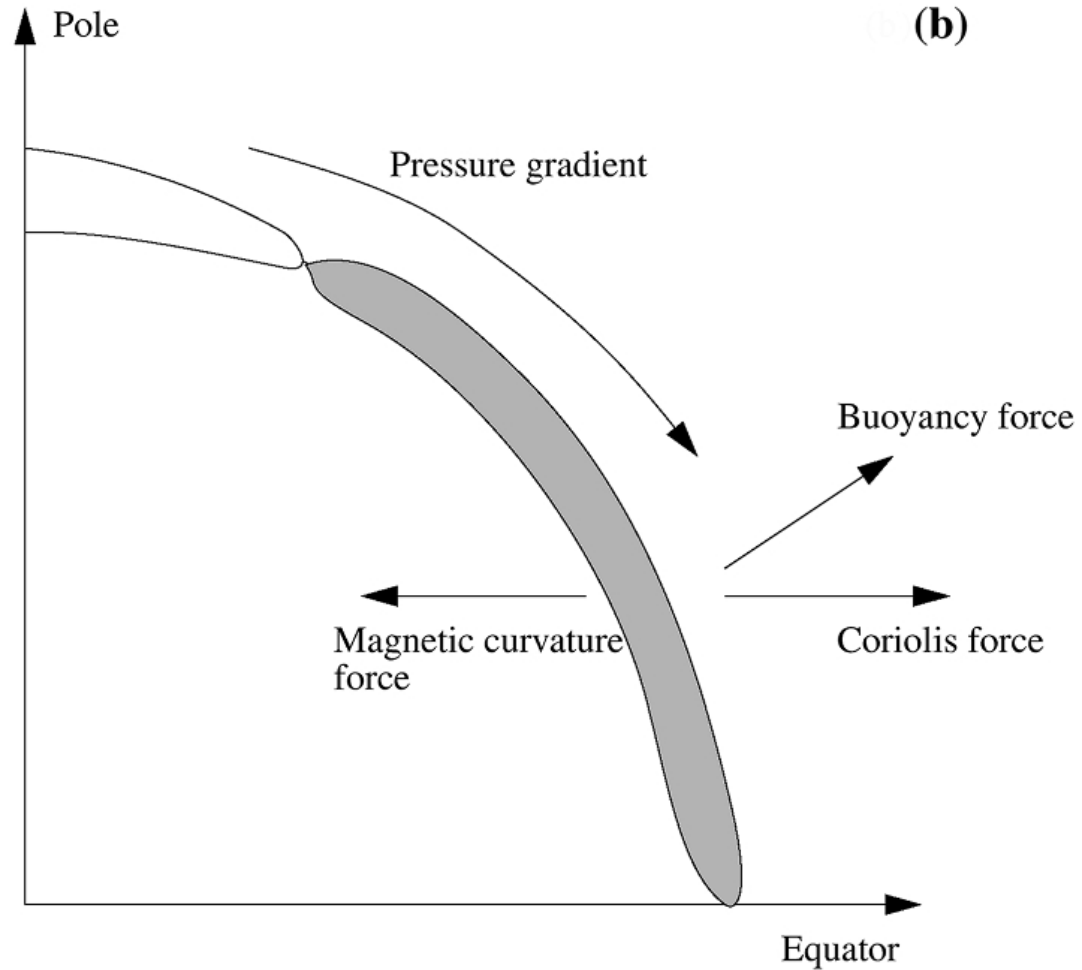


Magnetic Field Generation

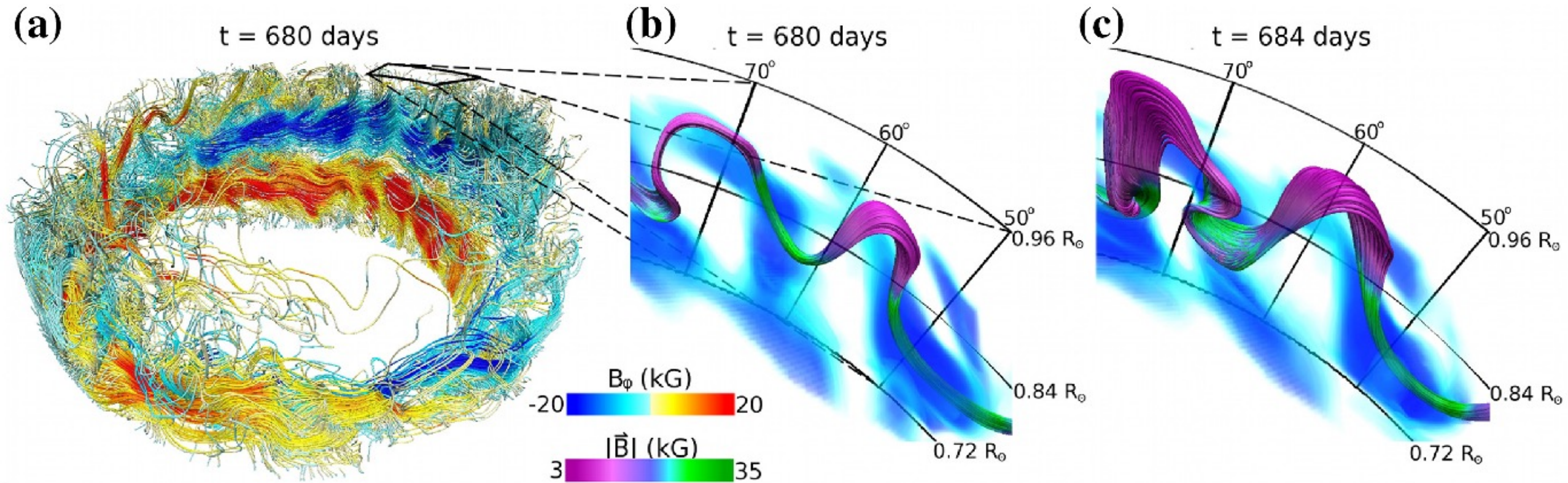
Differential rotation of Sun (higher latitudes rotate more slowly) twists up poloidal magnetic field.



Magnetic Field Generation



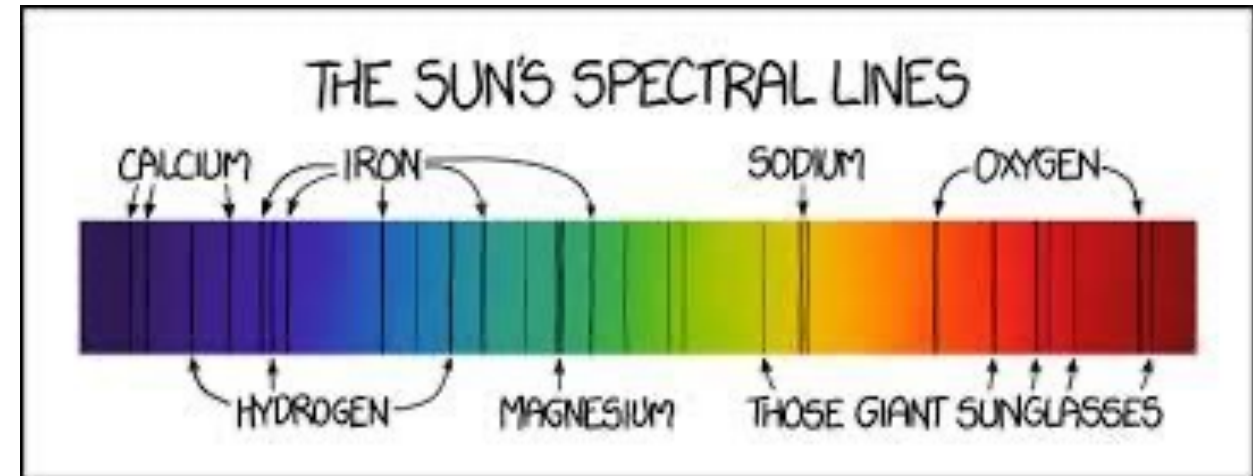
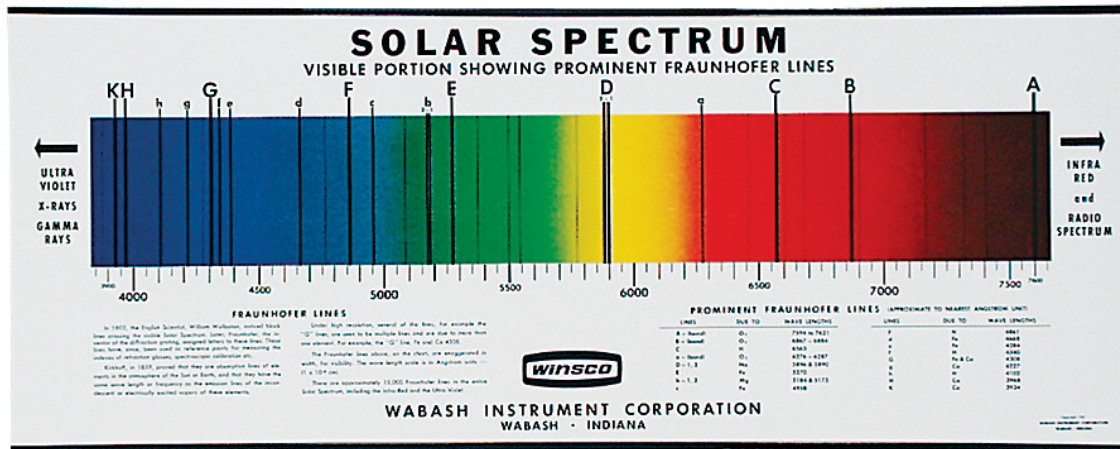
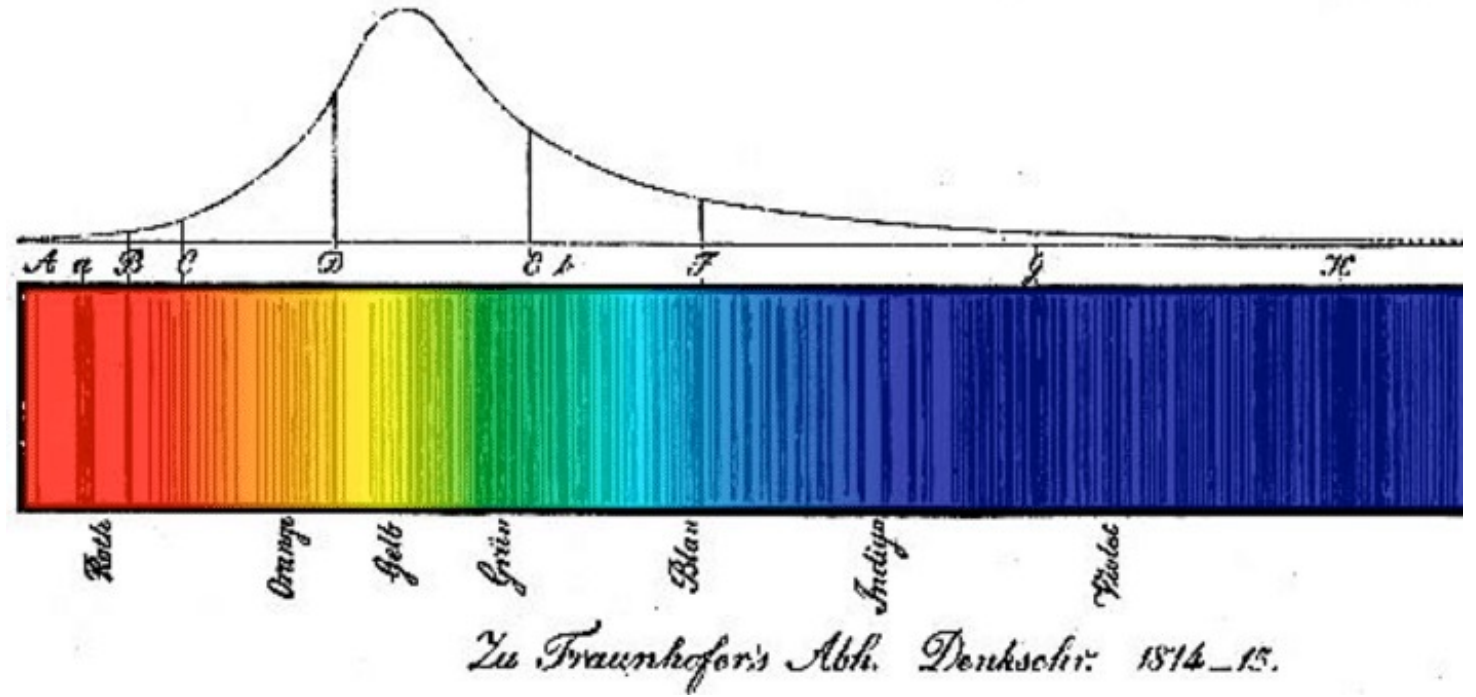
Magnetic Field Emergence



Nelson, *et al.*, 2013,
<https://arxiv.org/abs/1211.3129>

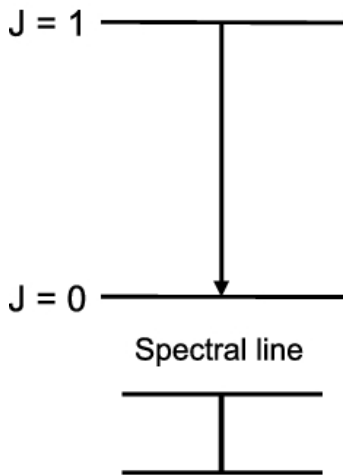
Solar spectrum through the years

In addition to the blackbody spectrum, many dark spectral lines

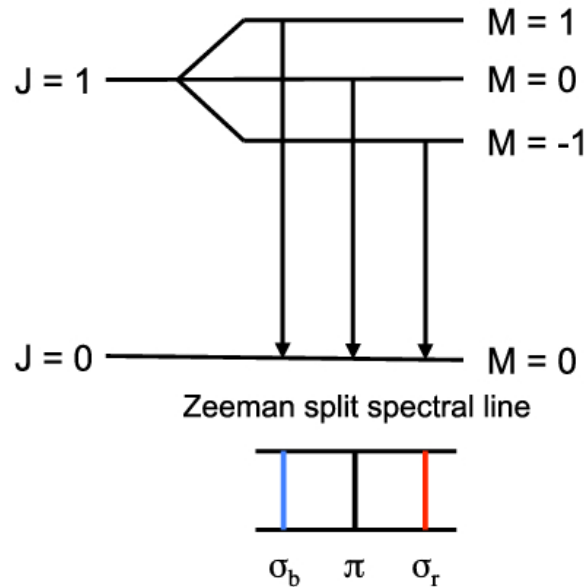


Magnetic Field Measurements (Zeeman)

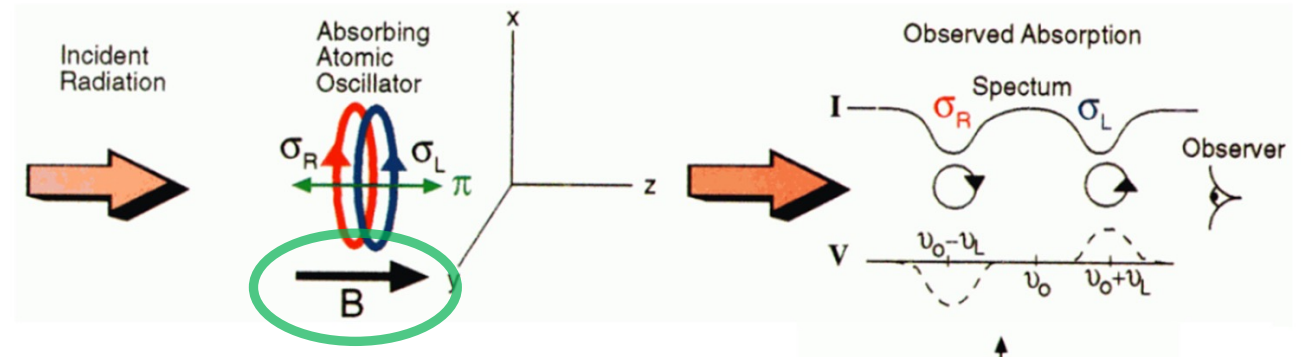
No magnetic field



Magnetic field is present

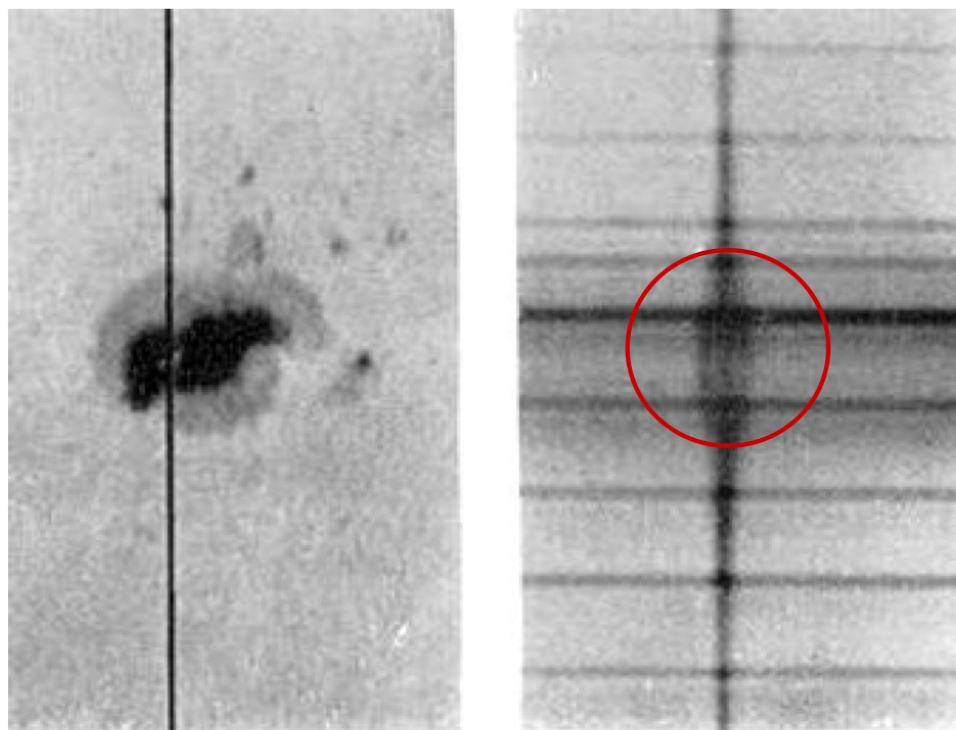


Longitudinal Zeeman Effect



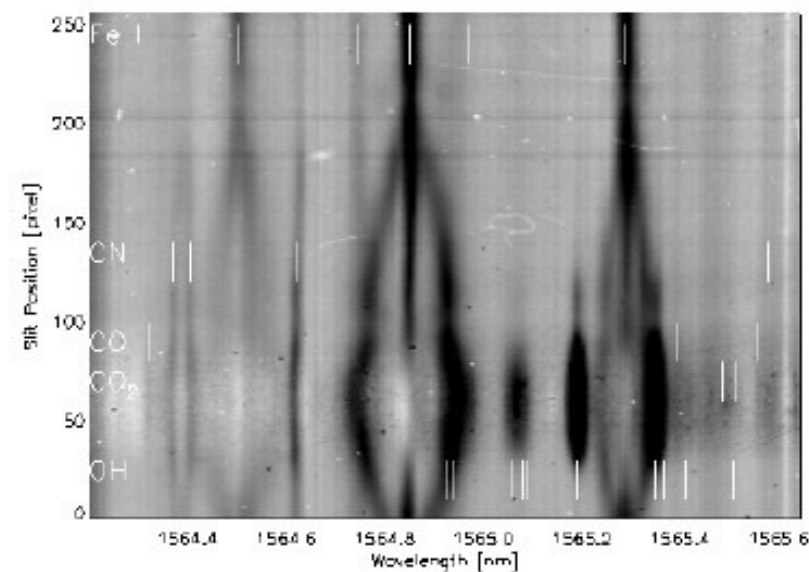
Properties of atomic transitions of certain spectral lines allow us to diagnose magnetic field in solar atmosphere (where line is formed)

Easiest measurement is the field strength along the line of sight

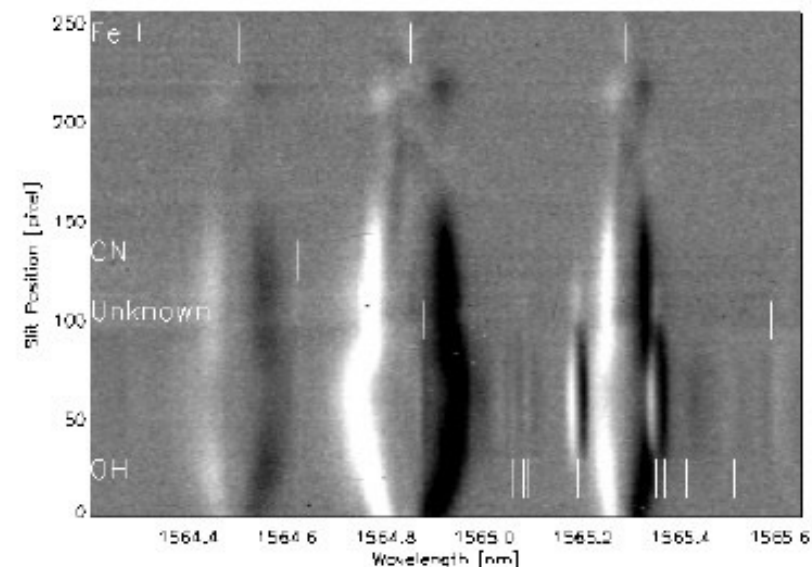


G.E. Hale, F. Ellerman, S.B. Nicholson,
and A.H. Joy (ApJ, 1919)

I



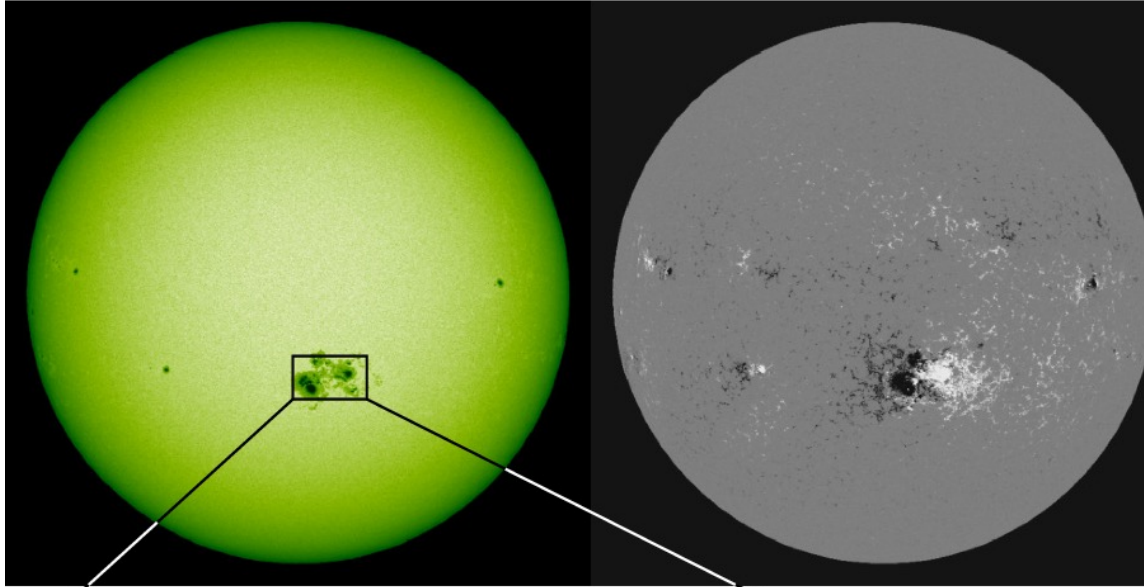
V



NOAA AR 12192 on 2014 Oct 24

NAOJ/SFT continuum

SDO/HMI magnetogram

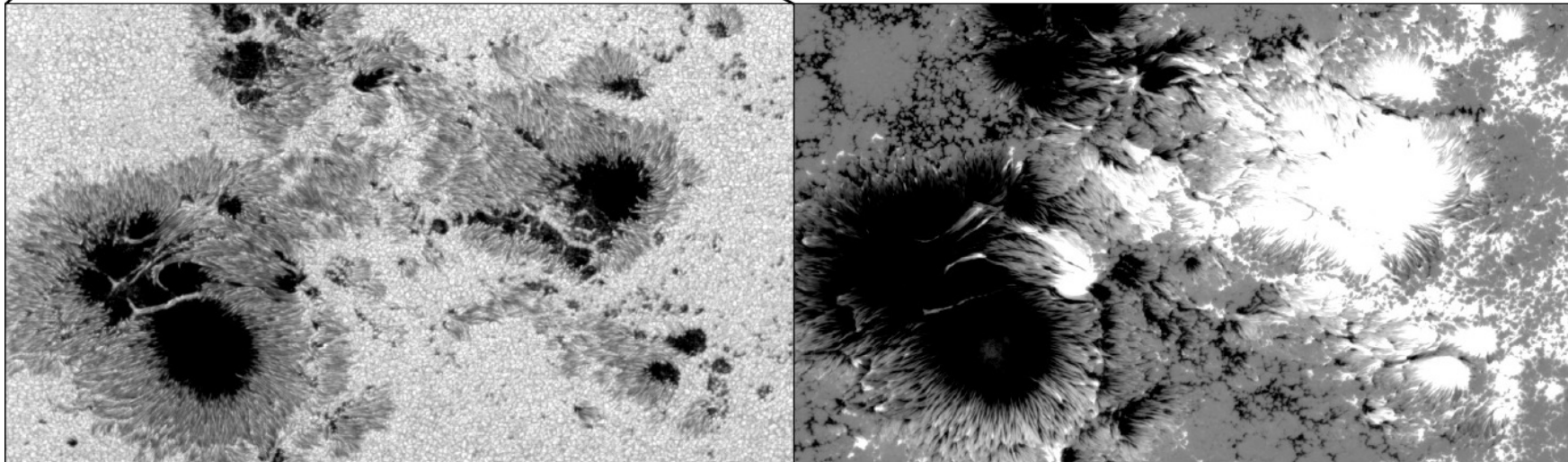


Sunspots, and the surrounding area (the active region) harbor strong magnetic fields of opposite polarities.

Sometimes these magnetic field are complex and intertwined

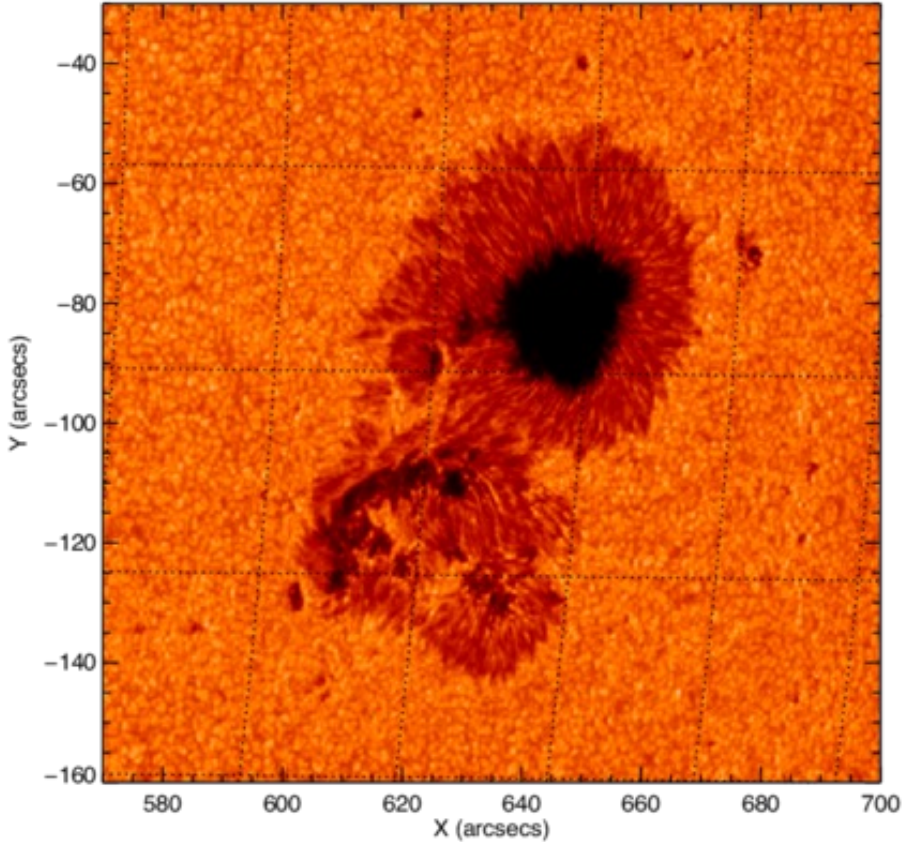
Hinode/SOT/SP continuum

Hinode/SOT/SP magnetogram

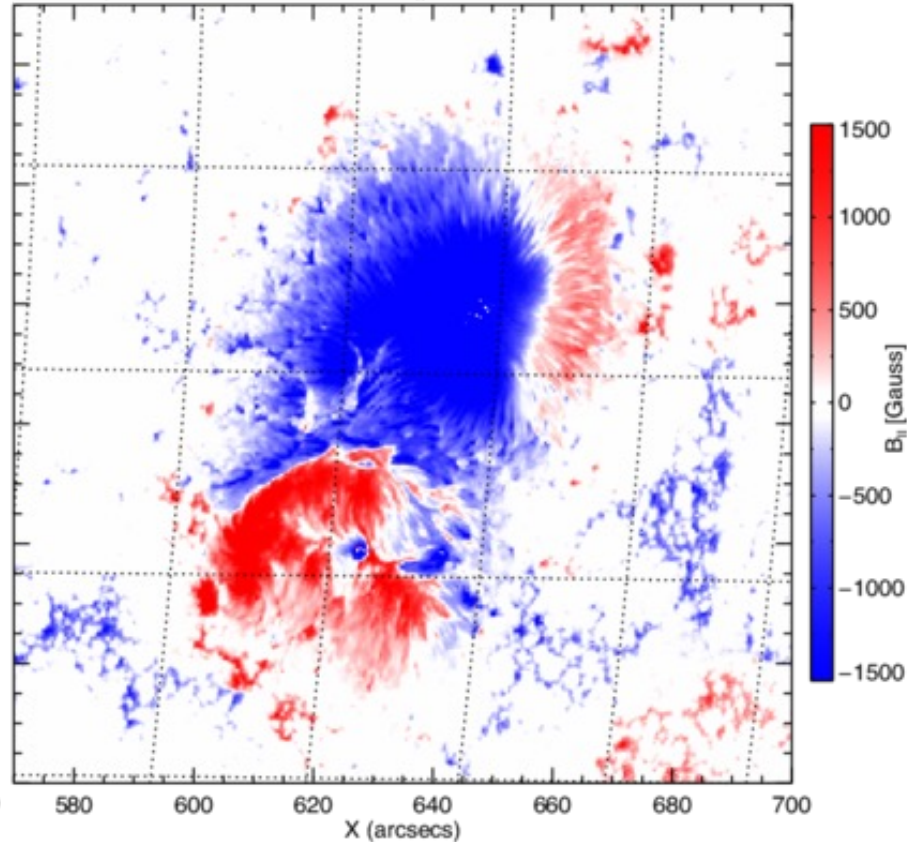


Sunspots and Magnetic Fields

A) Hinode/SOT SP Continuum Intensity – 14-Dec-2006 14:01



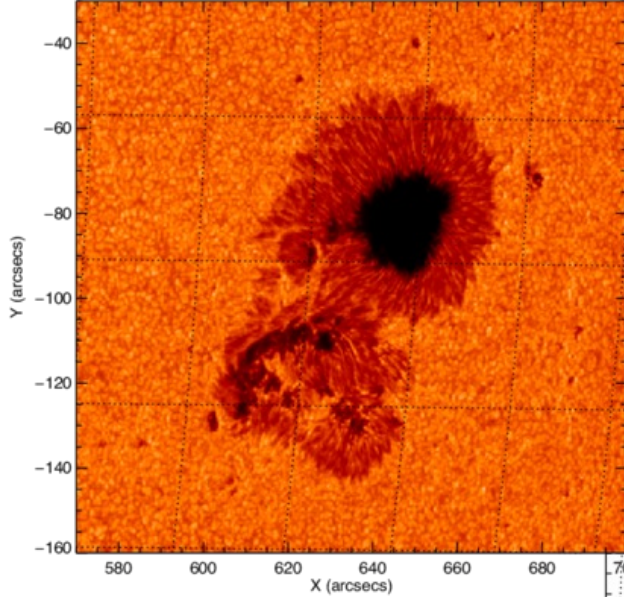
B) HAO/CSAC Inverted $B_{||}$ – 14-Dec-2006 14:01



Another example, with magnetic field polarities shown as red and blue. Notice sharp line between two polarities in some parts of the active region.

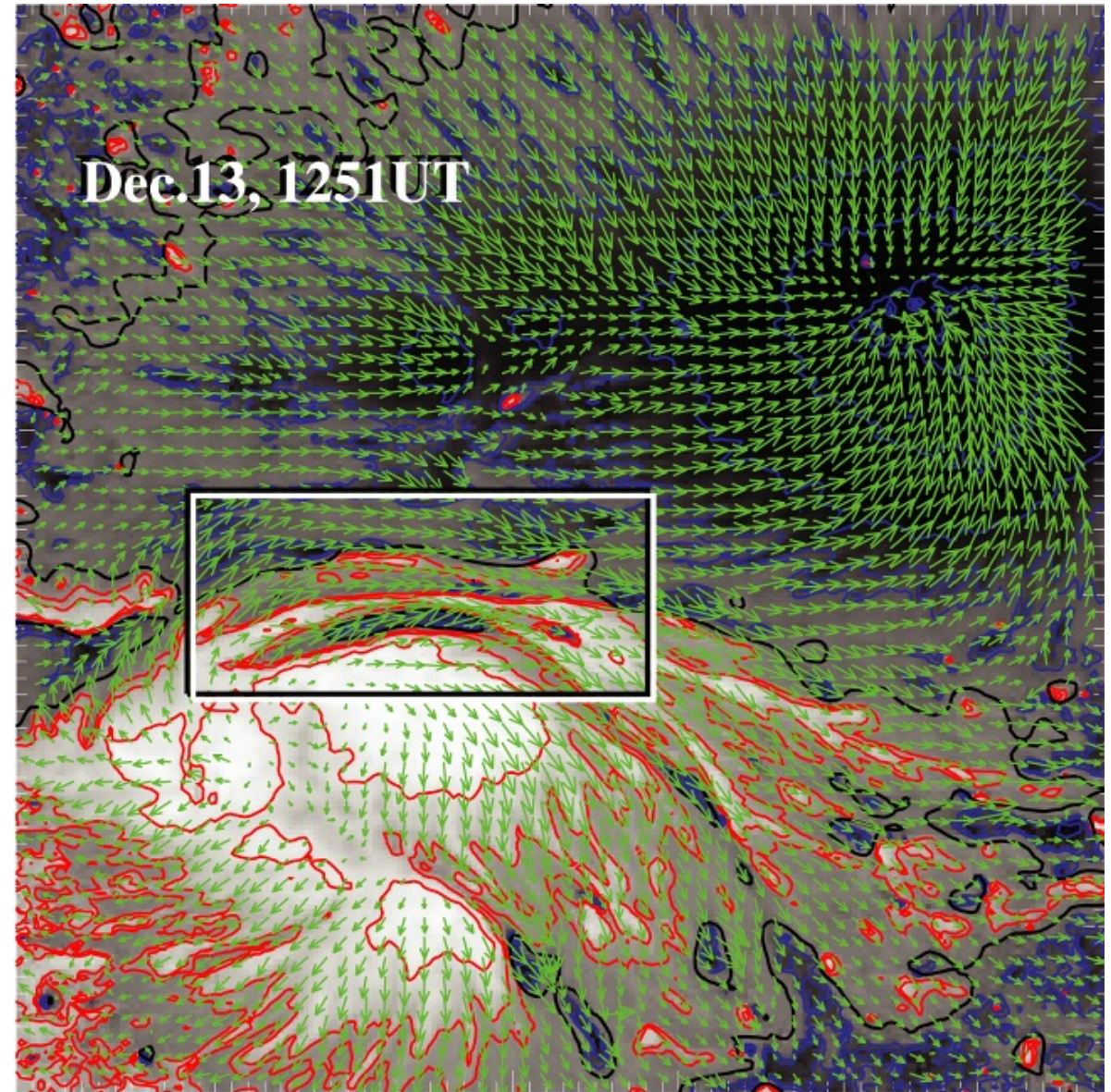
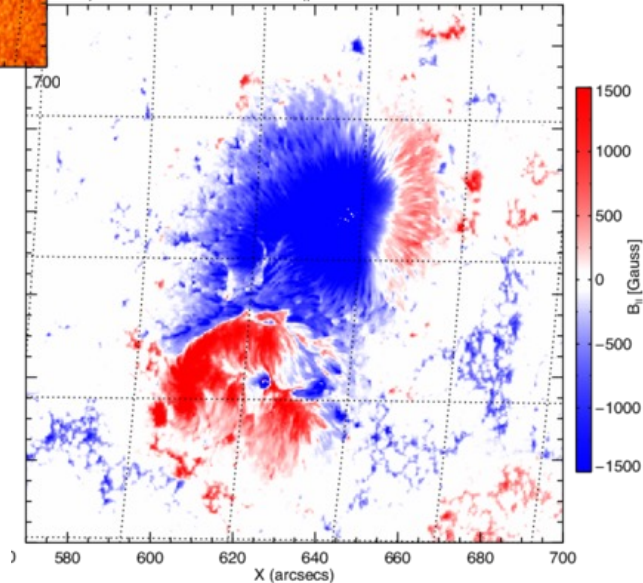
Polarity Inversion Lines (PIL) aka Neutral Lines

A) Hinode/SOT SP Continuum Intensity – 14-Dec-2006 14:01



There can be strong, sheared horizontal magnetic fields at the locations where the polarity changes.

B) HAO/CSAC Inverted $B_{||}$ – 14-Dec-2006 14:01

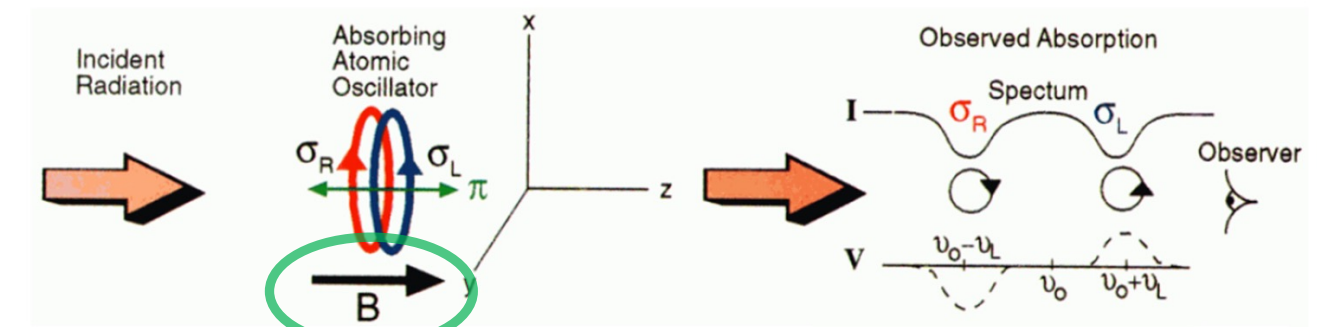


Magnetic Field Measurements (Transverse)

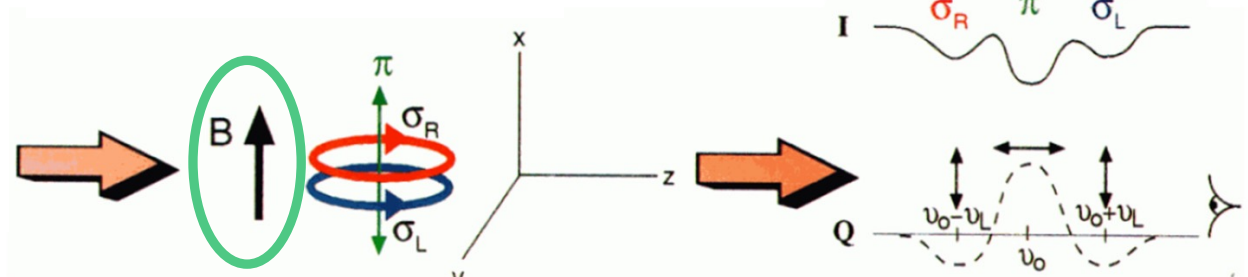
No magnetic field

Magnetic field is present

Longitudinal Zeeman Effect

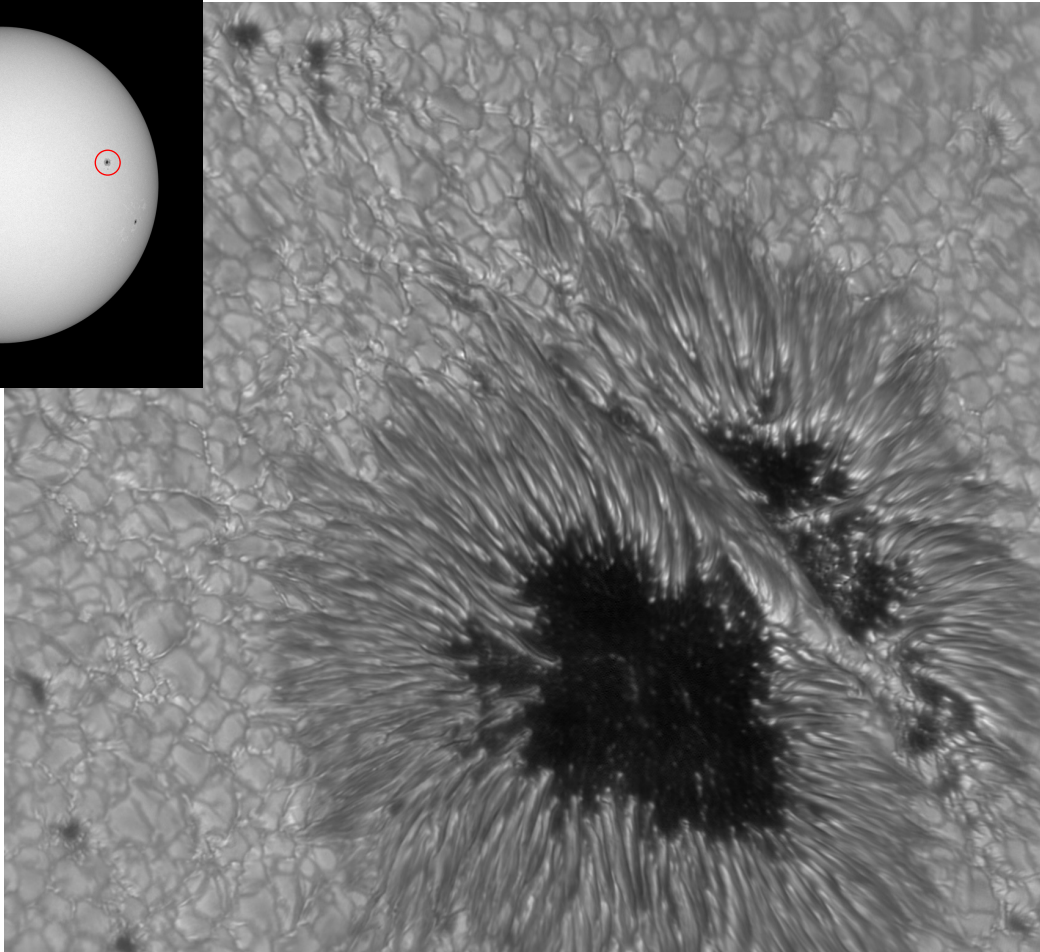
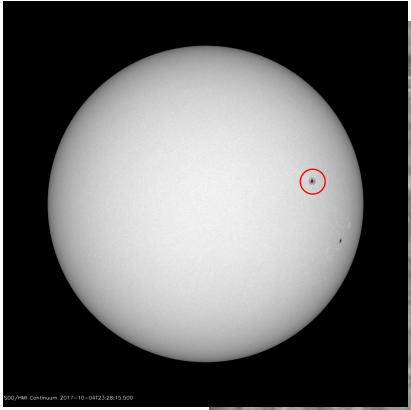


Transverse Zeeman Effect

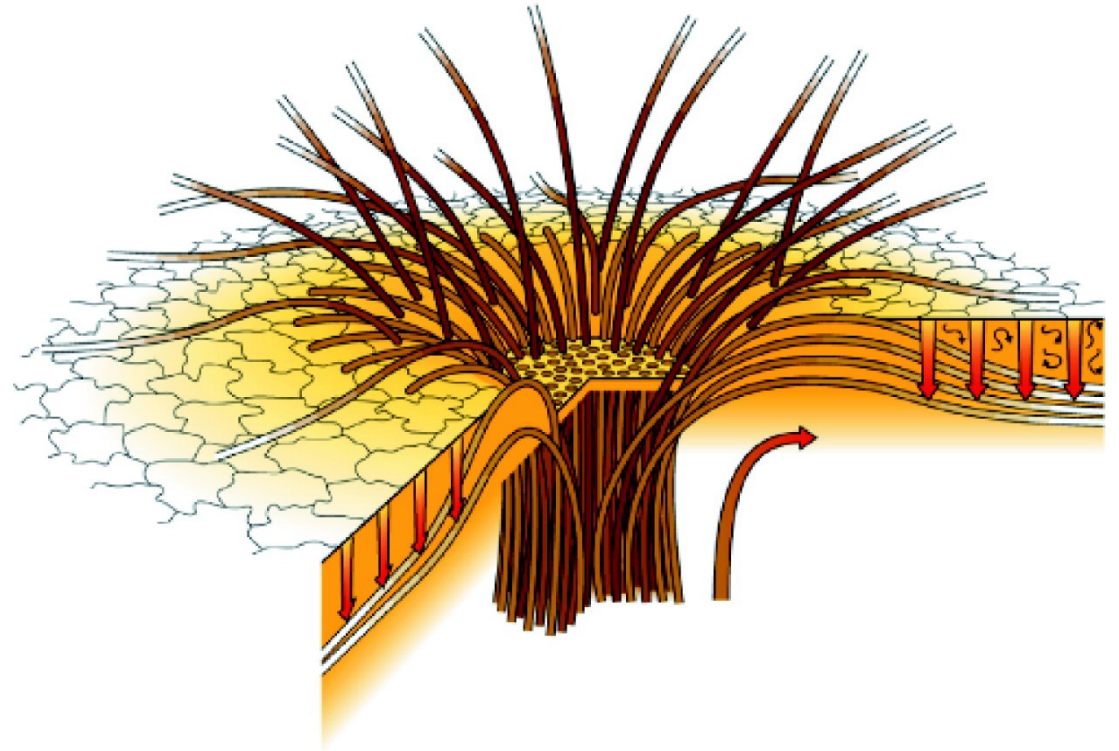


We can also measure the horizontal field with the Zeeman effect, but it is harder, noisier.

Sunspot Penumbra



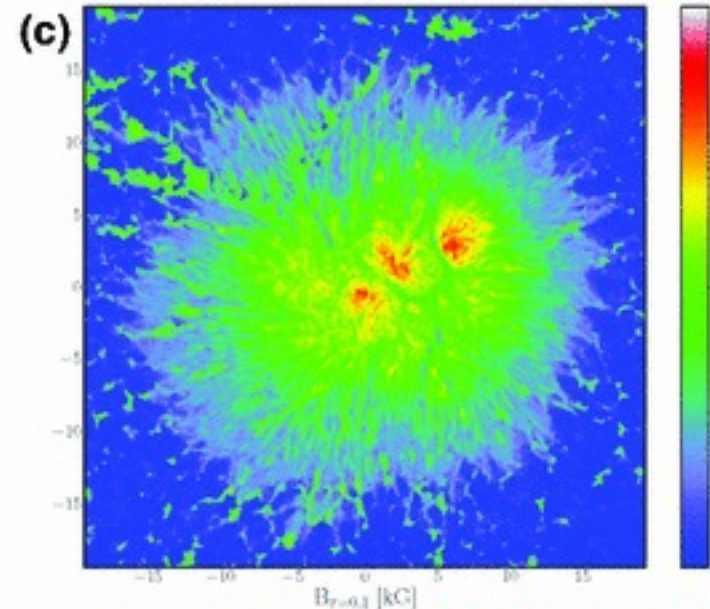
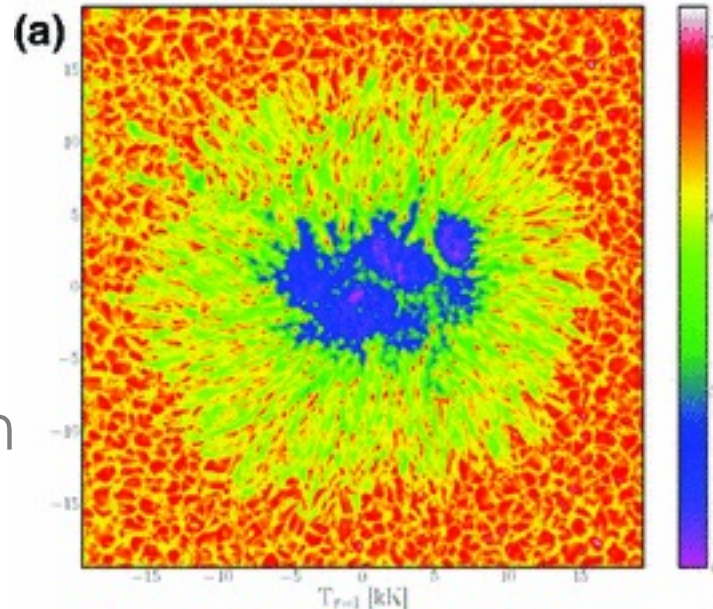
43'' = 31 Mm



Penumbra can be seen surrounding dark sunspot umbra – these are sites of complicated, predominantly horizontal fields

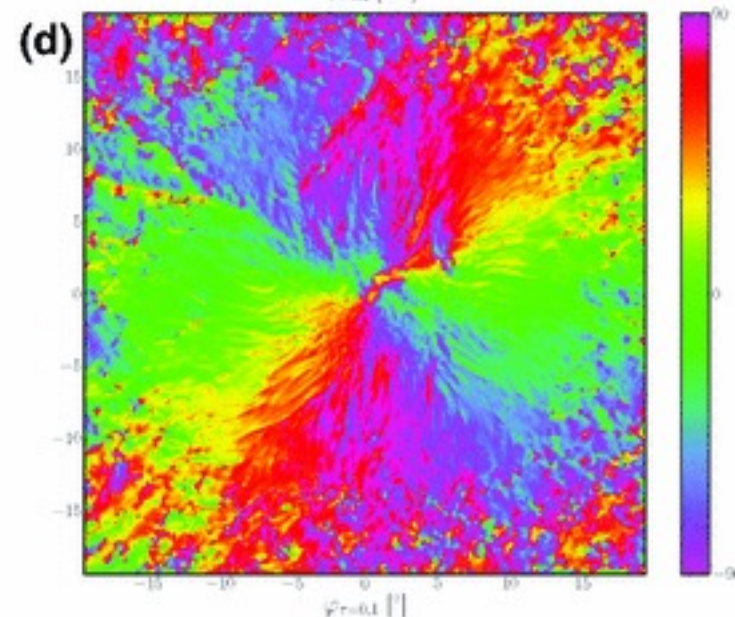
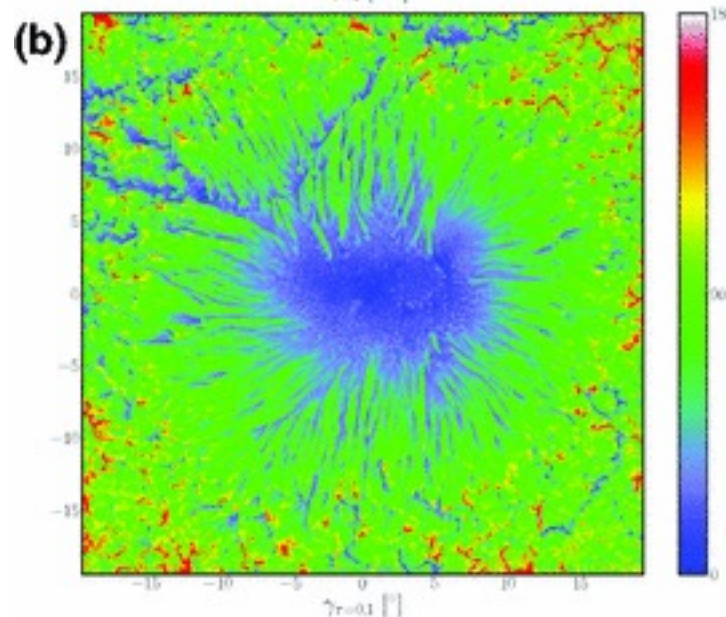
We can derive multiple parameters about the solar atmosphere with spectral lines.

Temperature



Magnetic Field Strength

Inclination



90° Azimuth

Note azimuth only goes from $\pm 90^\circ$

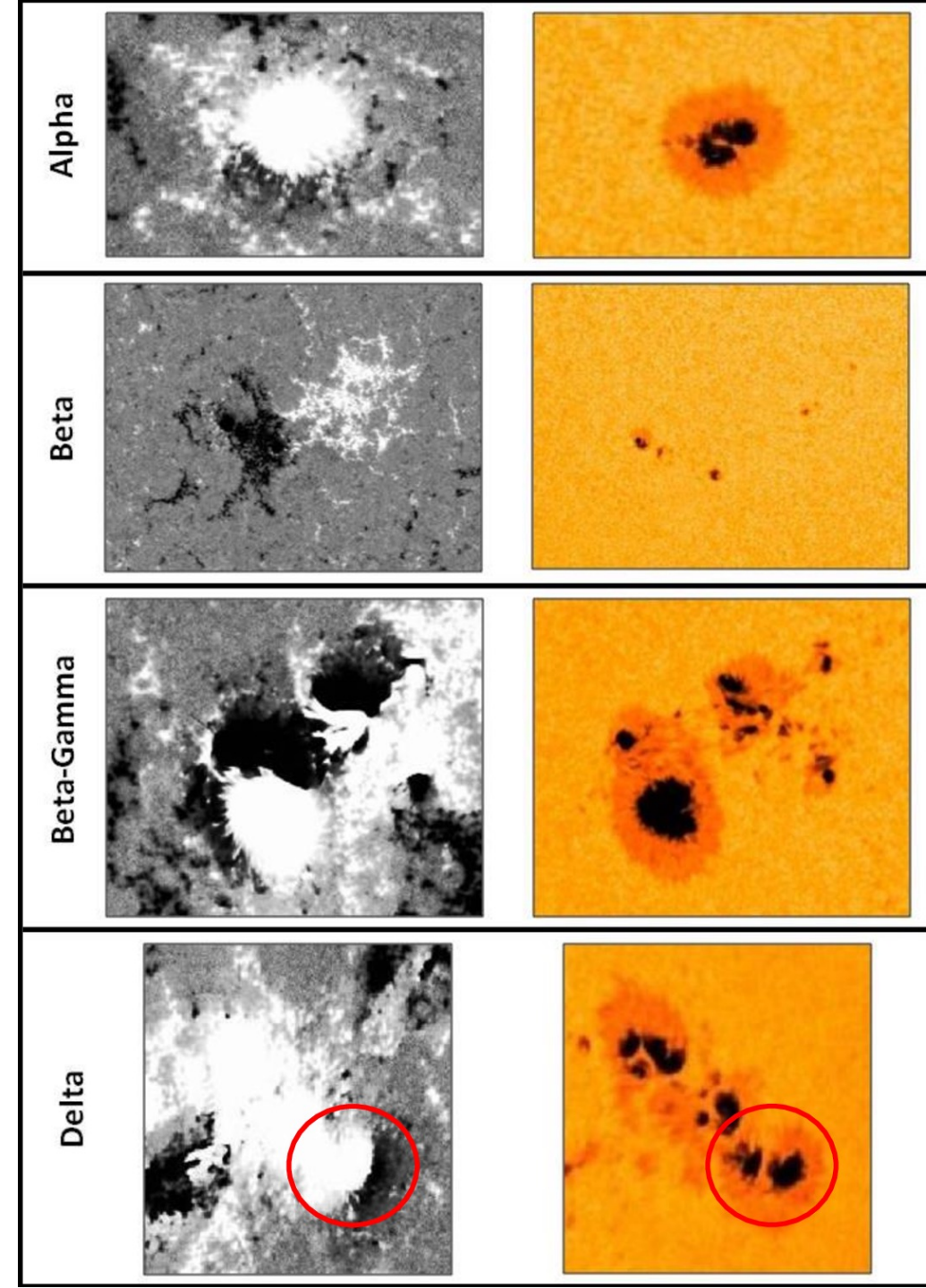
-90°

Mt. Wilson Classification

Flaring and CME activity may be related to complexity of magnetic field. How do we characterize different active regions?

Table 4. Mount Wilson Magnetic Classification Codes

Alpha	Unipolar (single magnetic pole) sunspot groups
Beta	Bipolar sunspot groups with a simple and distinct division between areas of opposite polarity
Beta-Gamma	Bipolar sunspot groups with no easily discernible dividing line separating areas of opposite polarity
Gamma	Complex sunspot groups with areas of opposite polarity completely intermixed, preventing classification as a bipolar group
*Delta	Denotes sunspot groups consisting of opposite polarity umbrae within the same penumbra
*Note that the classification code 'Delta' is not a standalone magnetic classification. It is simply a descriptor that can be affixed to the end of the 'Beta', 'Beta-Gamma', and 'Gamma' classification codes, allowing for a total of seven unique magnetic codes.	



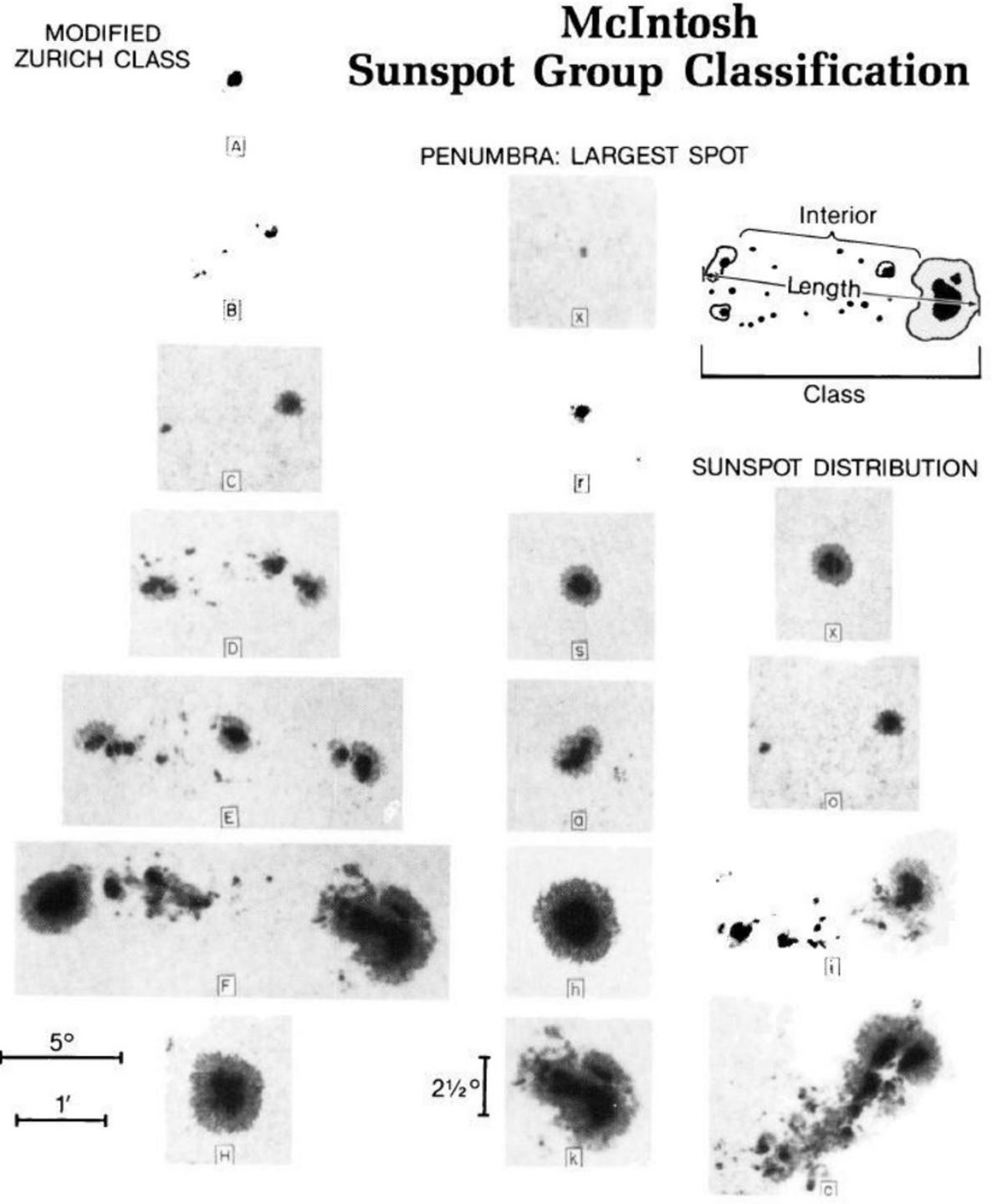
McIntosh Classifications

This classification scheme just uses distribution of sunspots, not magnetic field measurements.

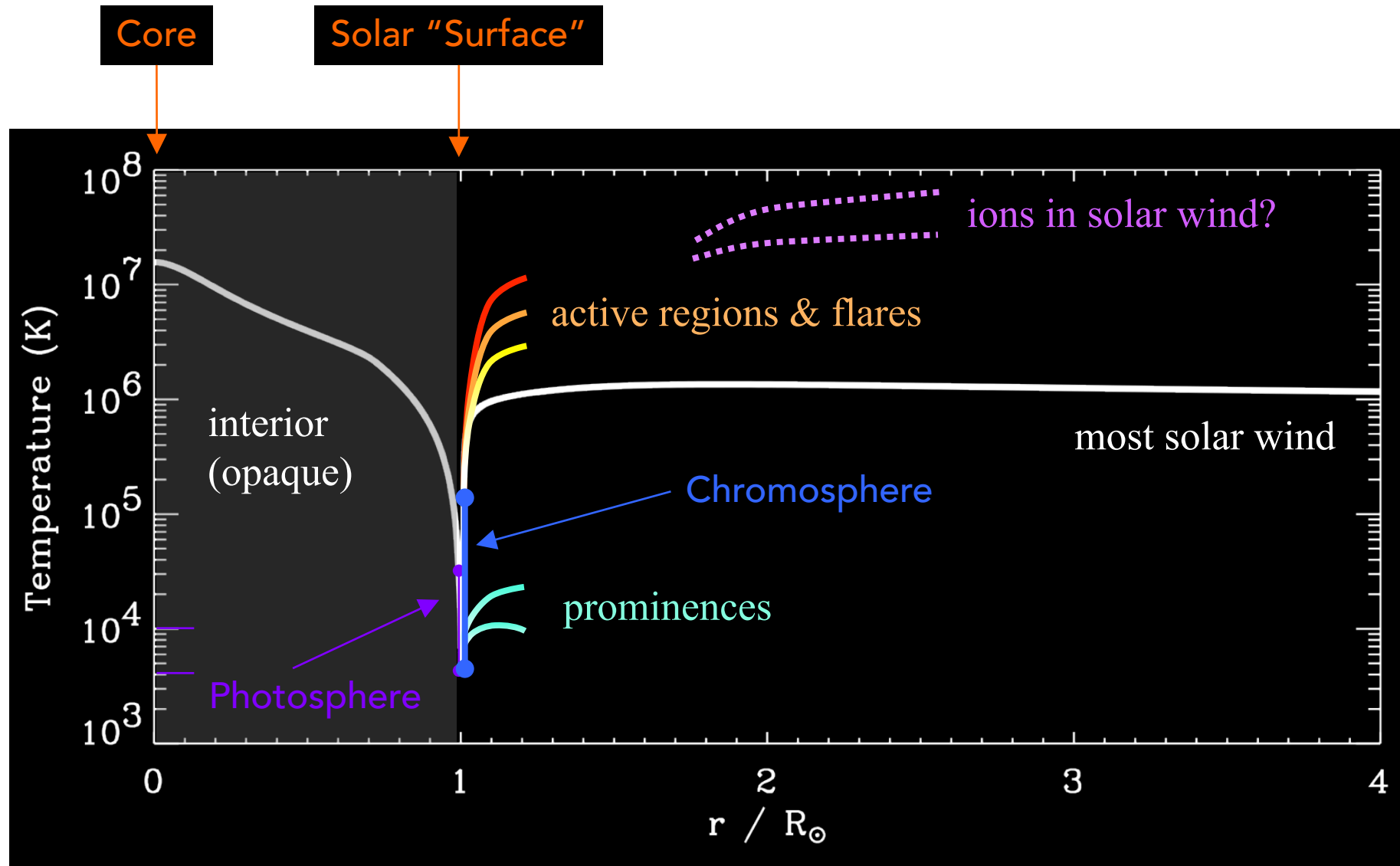
TABLE IV

Most flare-productive sunspot types 1969–1976 (from Kildahl, 1980)

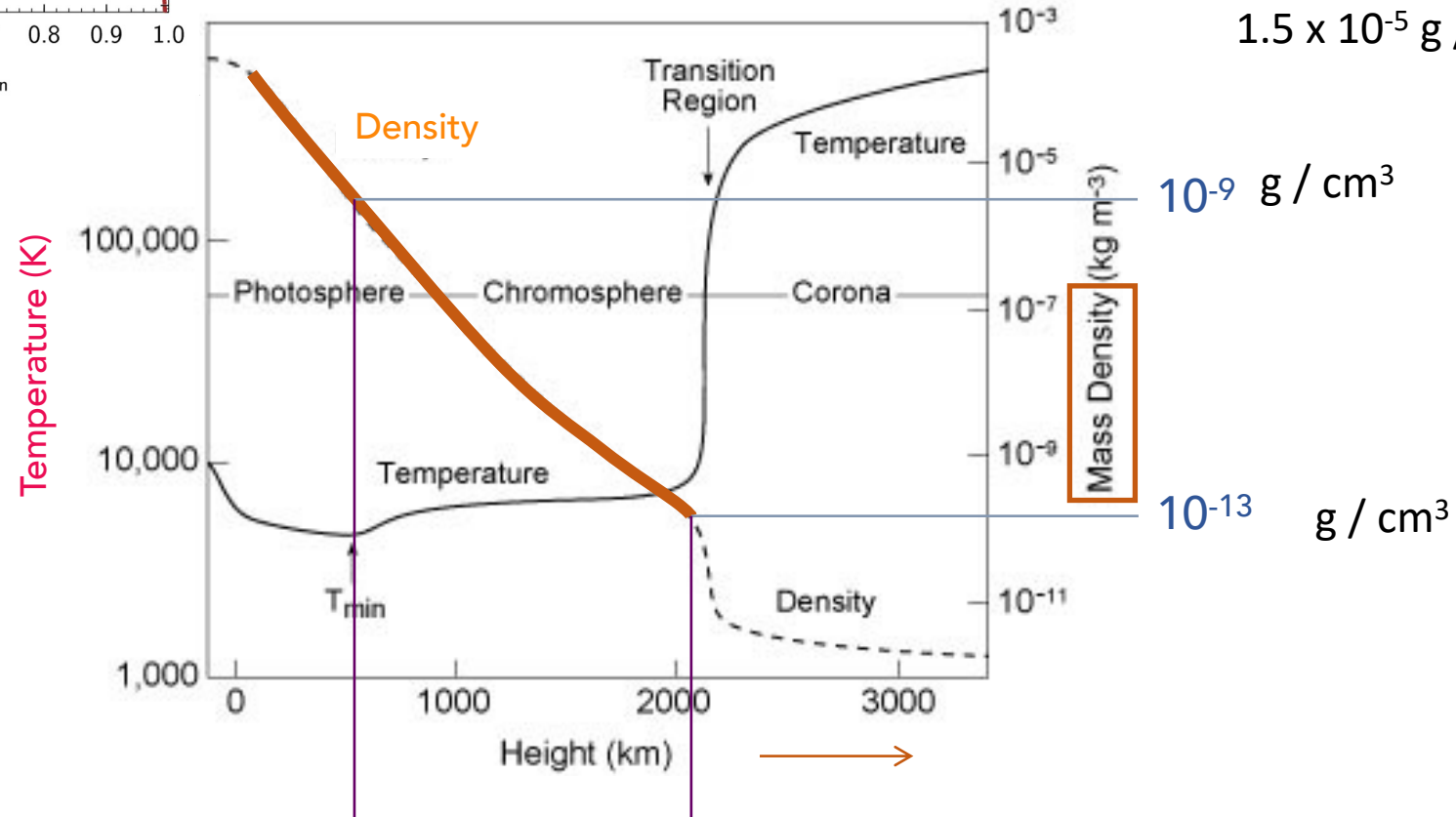
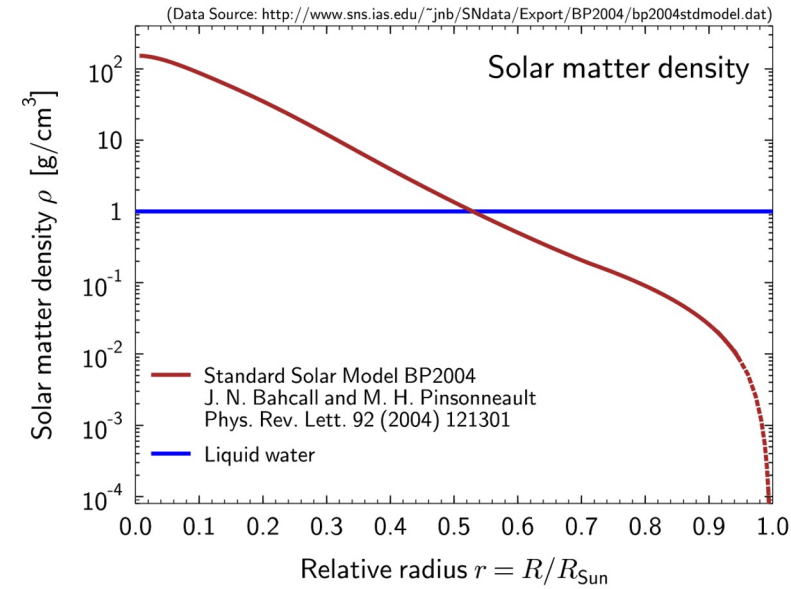
McIntosh type	Number of occurrences	Number of class M flares	Number of class X flares	Flares/occurrence per 24 hours	
				M	X
Hsx	1963	99	6	0.05	0.003
Dso	553	51	6	0.09	0.01
Dai	324	58	7	0.18	0.02
Dkc	100	72	10	0.72	0.10
Eki	81	103	11	1.27	0.14
Ekc	63	149	21	2.36	0.33
Fki	47	106	17	2.26	0.36
Fkc	27	39	13	1.44	0.48



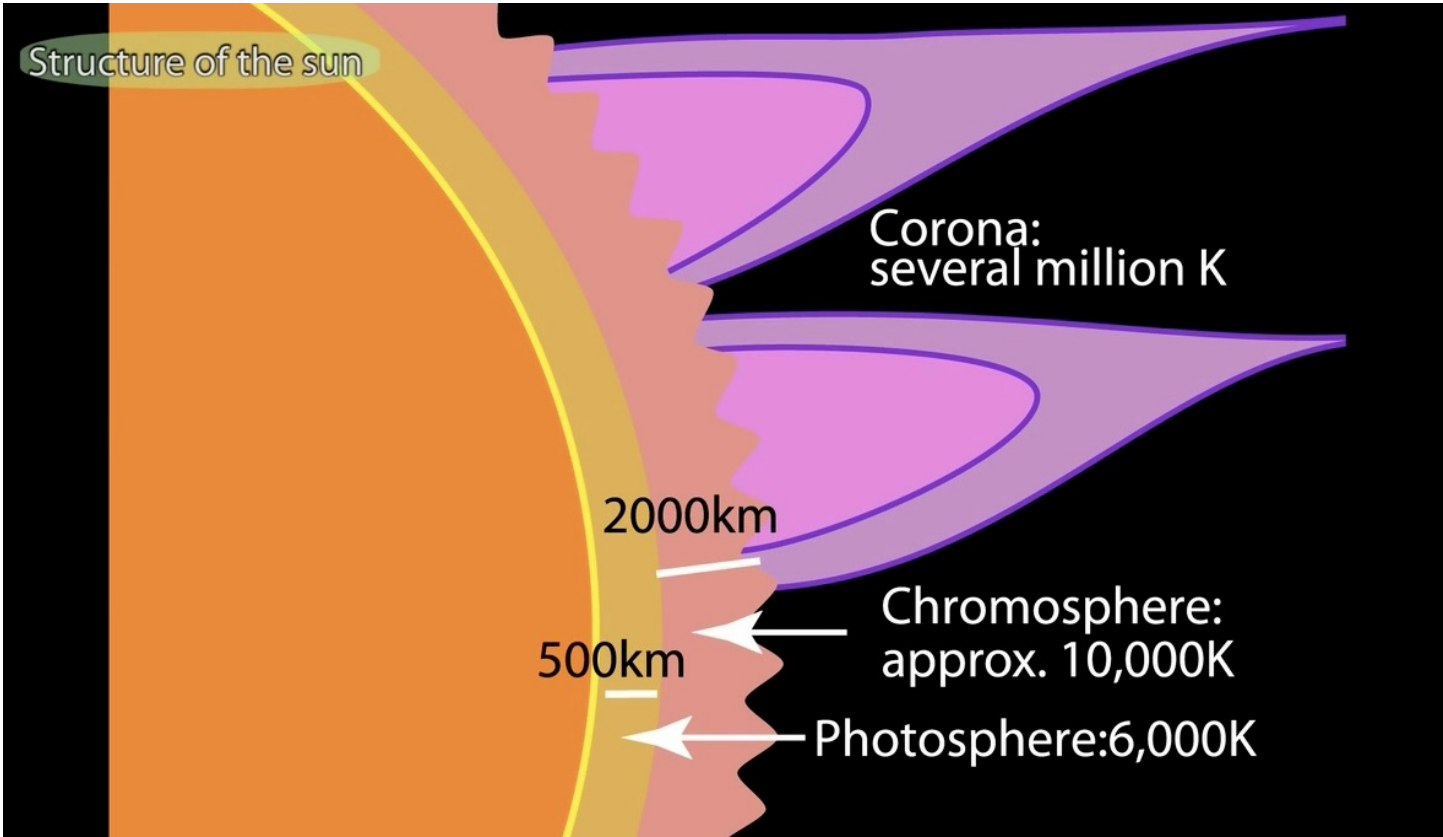
What happens higher in the solar atmosphere?



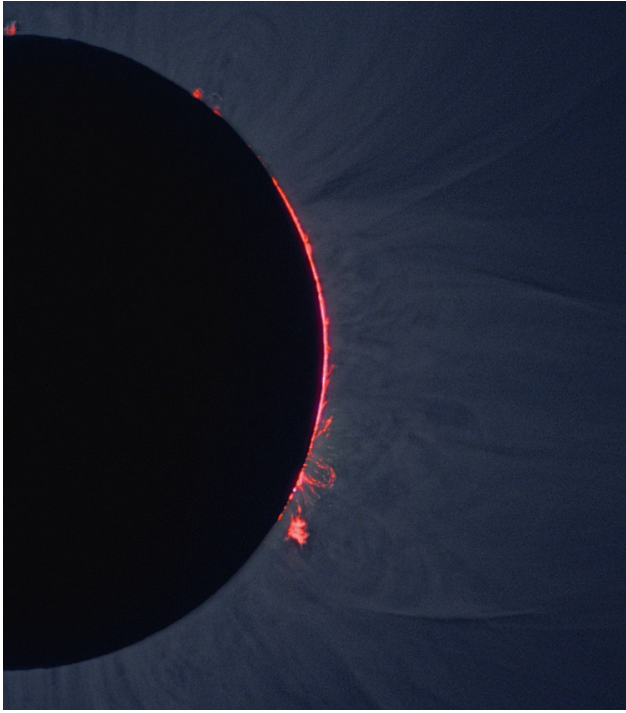
What happens higher in the solar atmosphere?



Solar (Stellar) Atmosphere



	Thickness	Density	Energy requirements	Mass
Photosphere	~500 km	$\rho_{ph} = 2 \times 10^{-5} \text{ gr/cm}^3$	$F_{ph} = 6 \text{ kW/cm}^2$	$4 \times 10^{20} \text{ kg}$
Chromosphere	~2000 km	$10^{-3} - 10^{-6} \times \rho_{ph}$	$10^{-4} \times F_{ph}$	$2 \times 10^{18} \text{ kg}$
Corona	$> 10^6 \text{ km}$	$10^{-8} \times \rho_{ph}$	$< 10^{-5} \times F_{ph}$	$6 \times 10^{15} \text{ kg}$



Chromospheric Radiation

Radiation from chromosphere comes in the form of continuum radiation (in the UV and millimeter wavelengths) and many emission lines in the visible and UV

Ca II
H & K

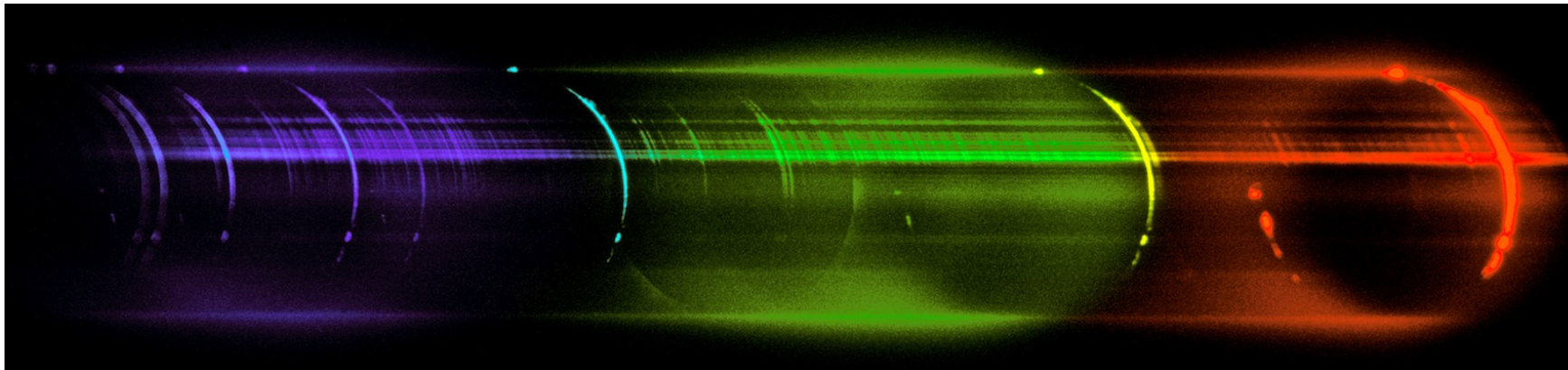
H γ

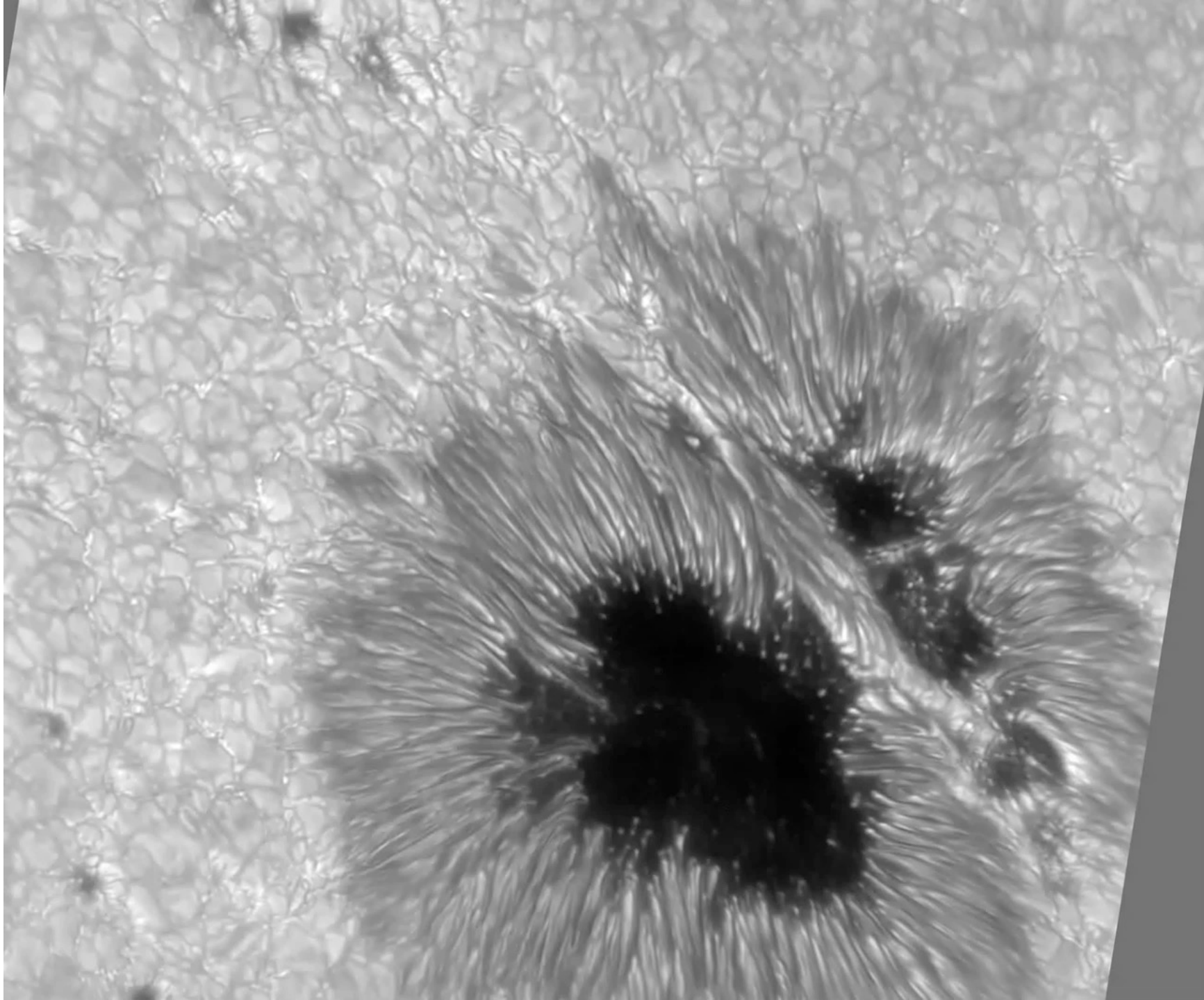
H β

Fe XIV
5303

Na D₁, D₂
He D₃

H α

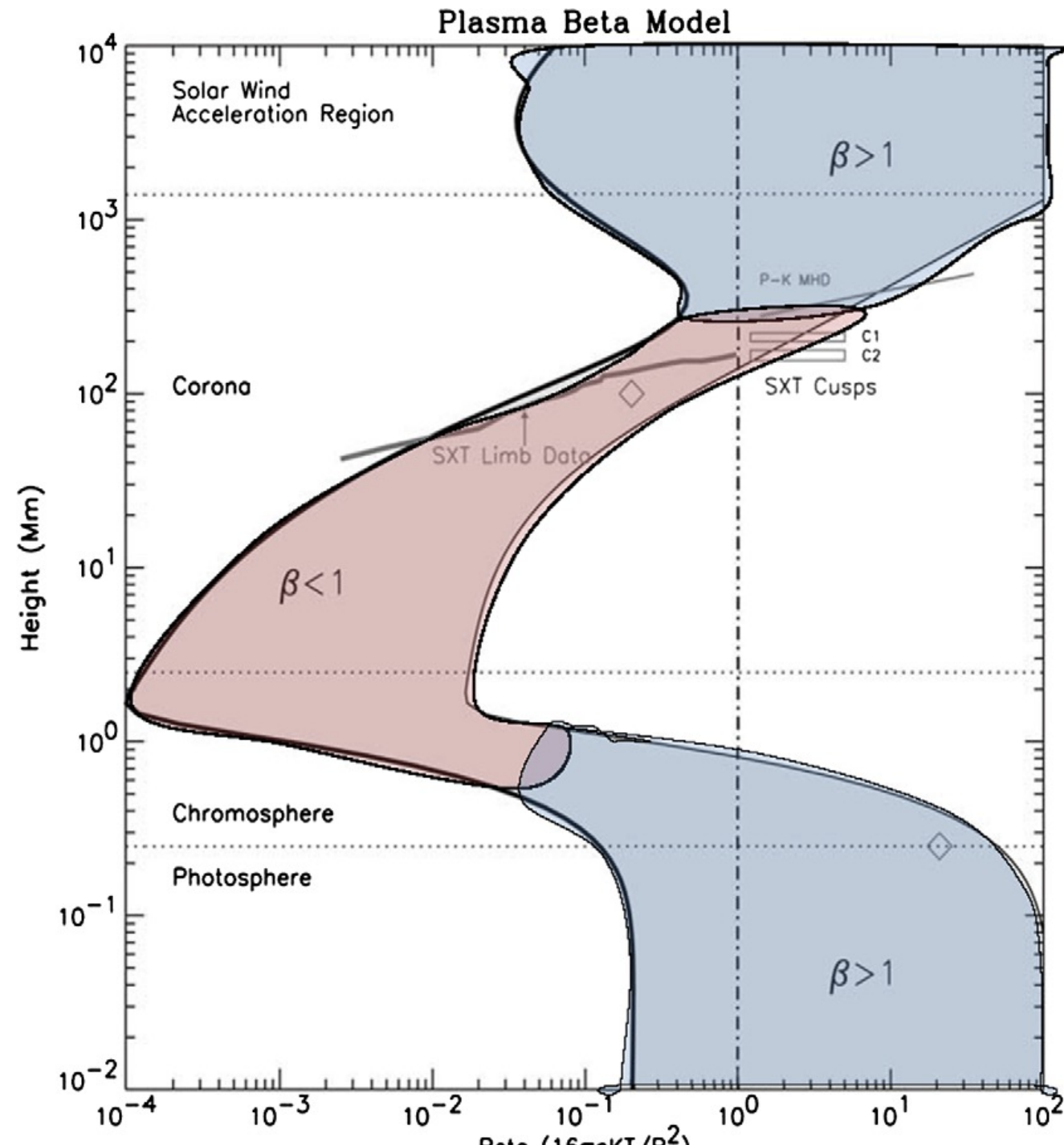




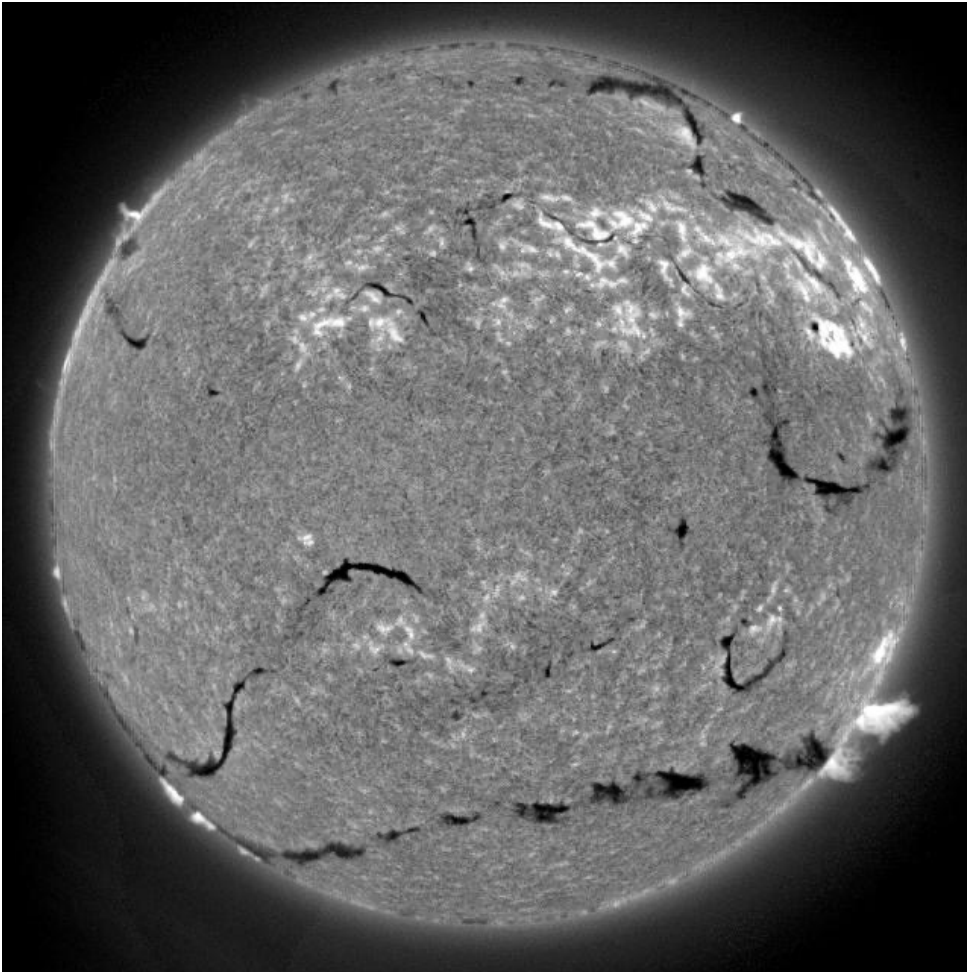
Magnetic Field Dominance

$$\text{plasma } \beta = \frac{\text{plasma pressure}}{\text{magnetic pressure}}$$

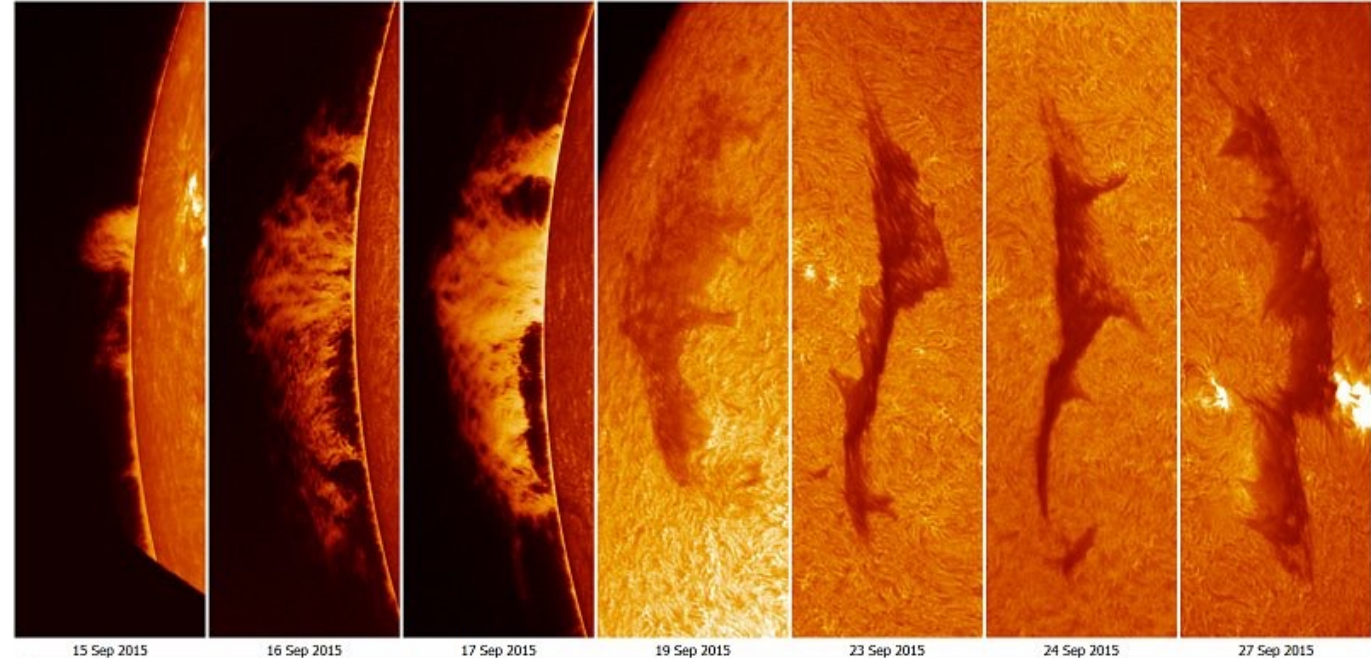
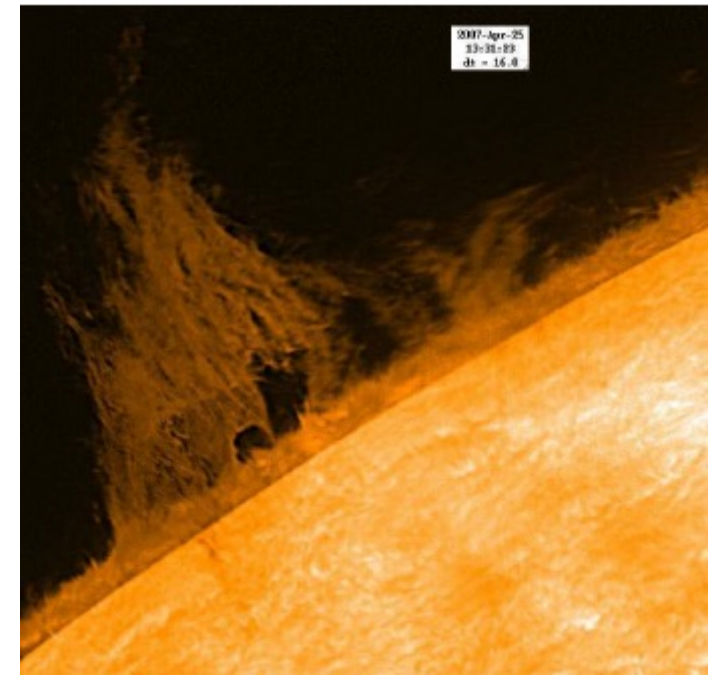
In the chromosphere and corona, because of the steep drop in density, the magnetic field begins to dominate the plasma motions.

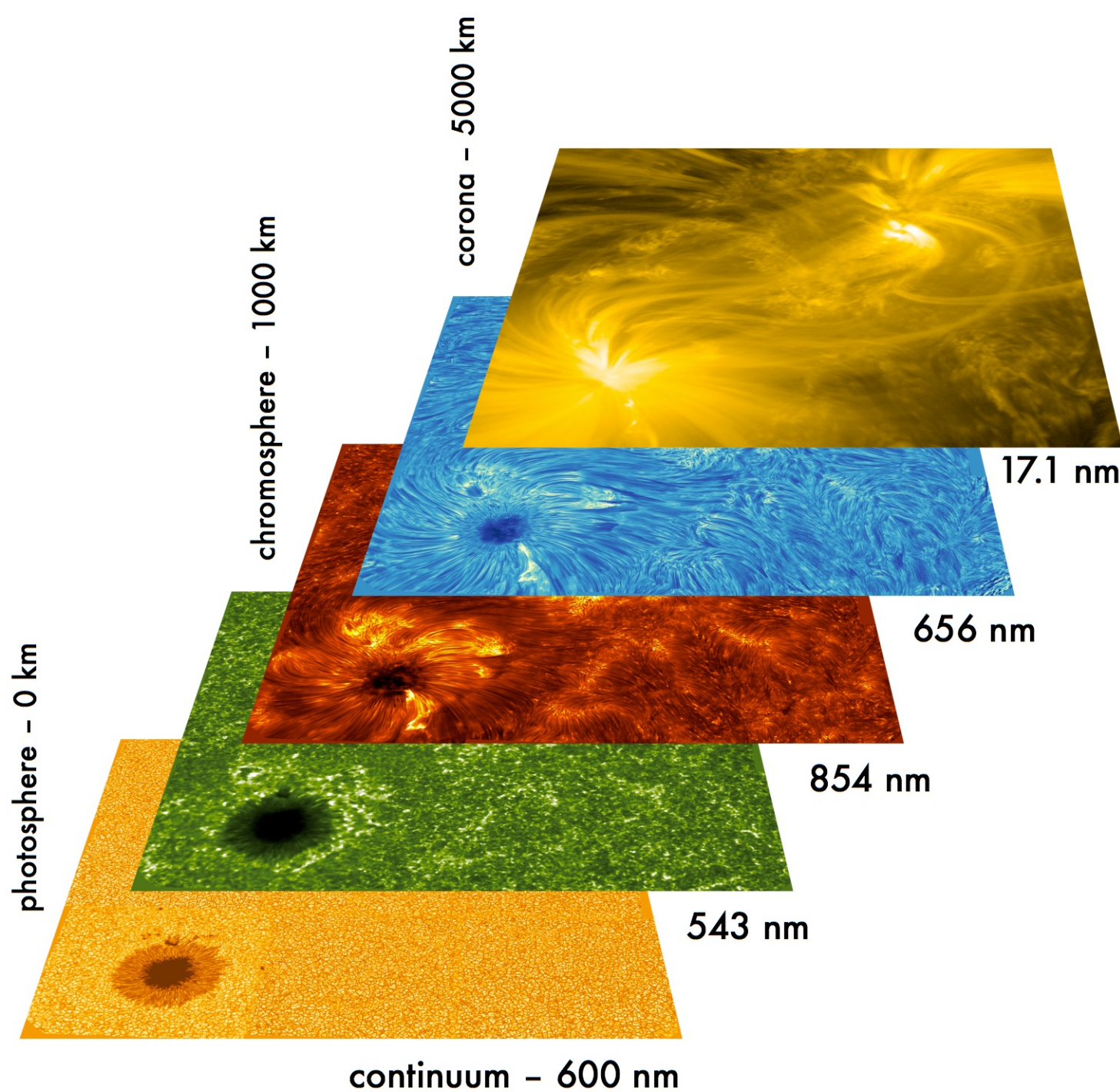


Filaments and Prominences



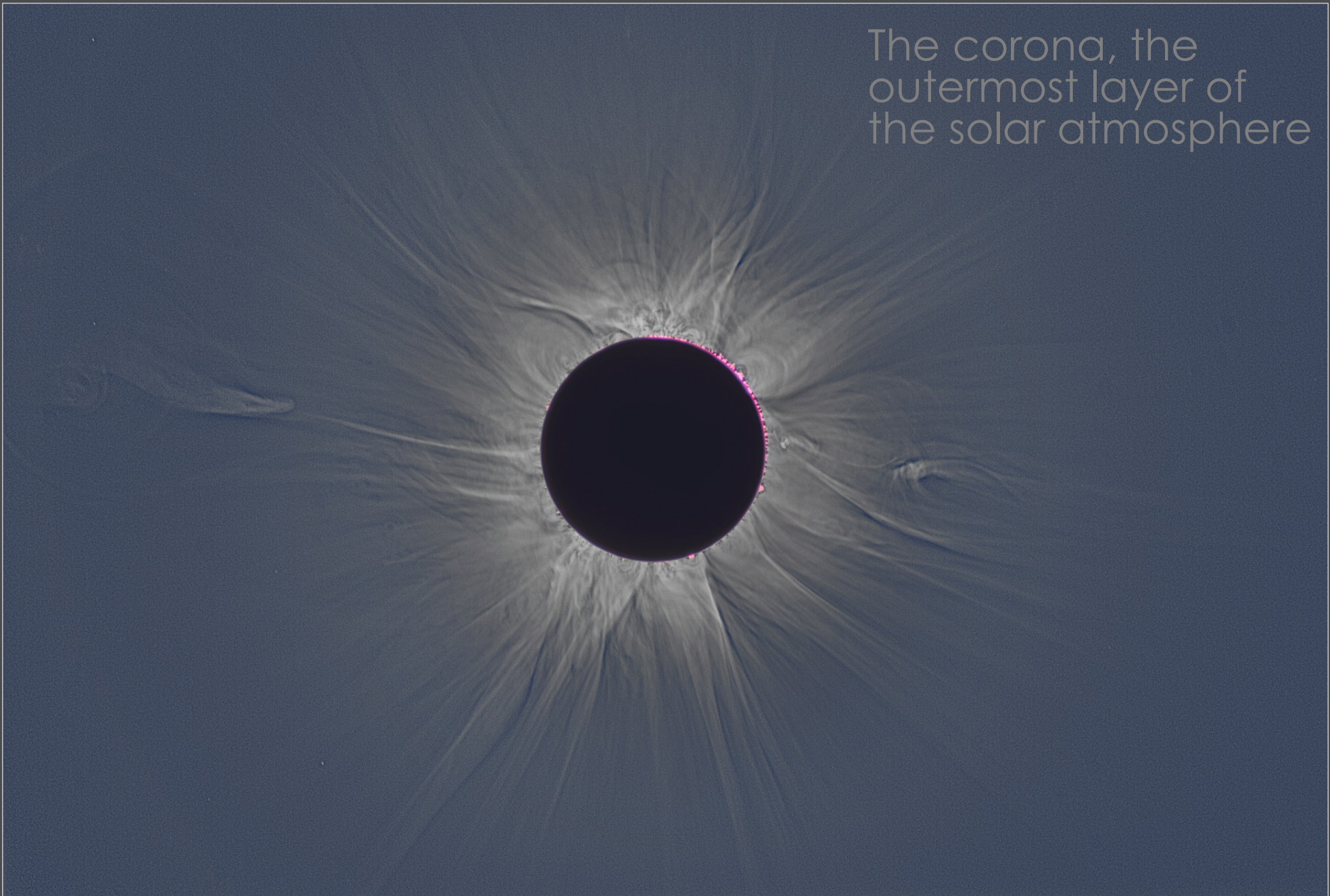
This creates neat things like prominences (seen at the limb) and filaments (same structures, but seen on the disk)

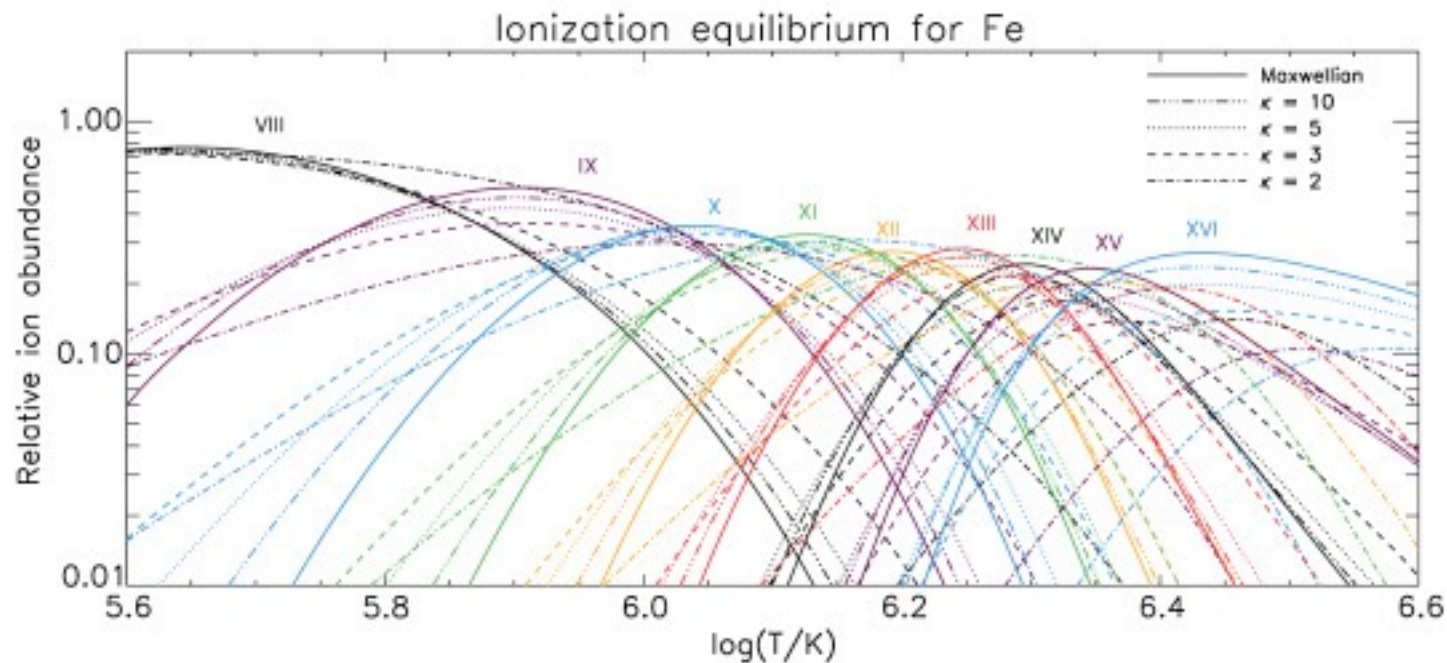
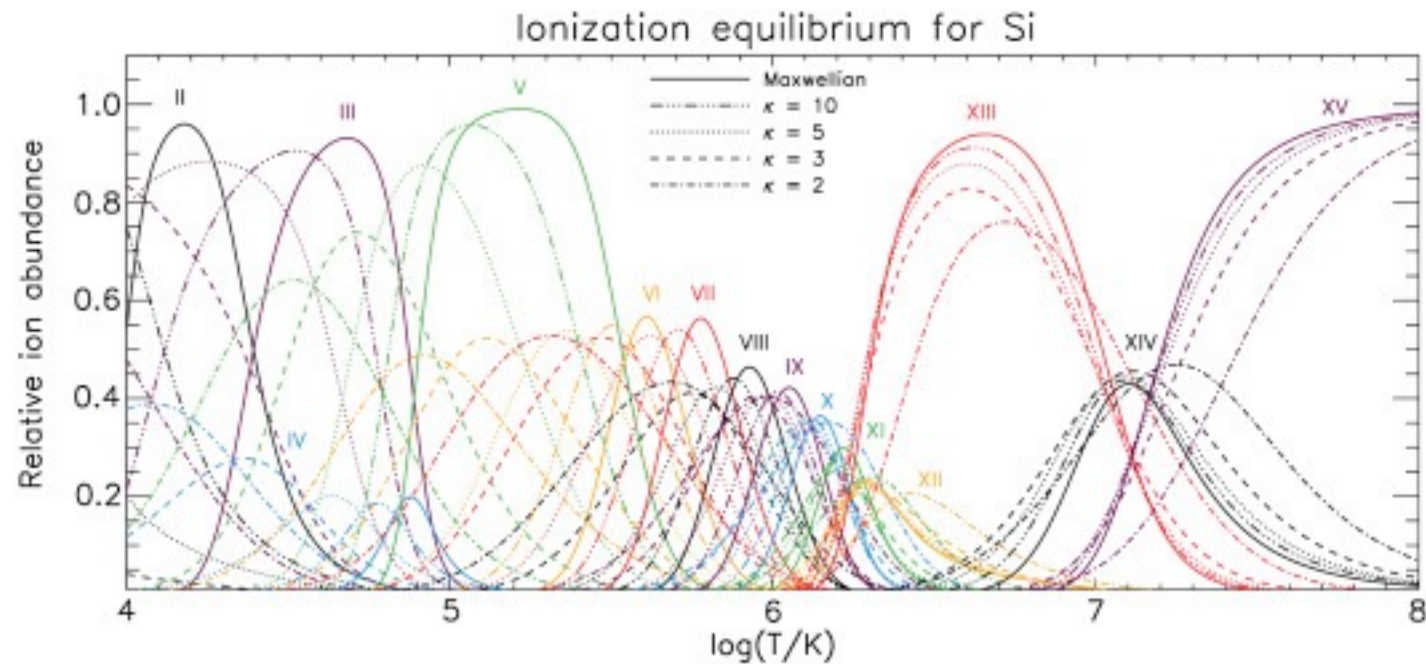




A view of how
structures connect
up through
different regions of
the atmosphere

The corona, the
outermost layer of
the solar atmosphere

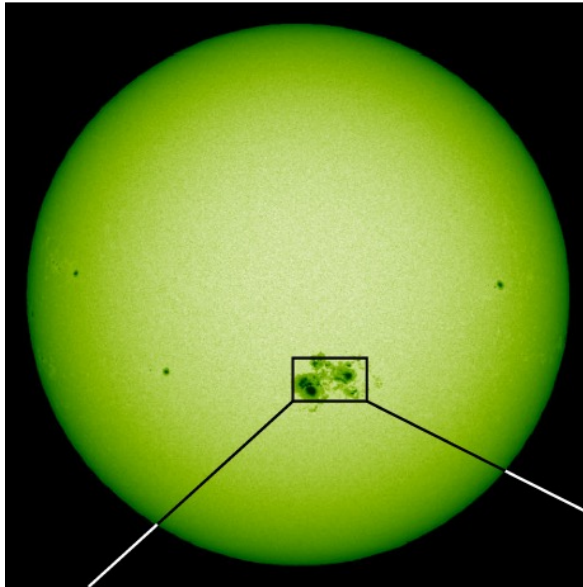




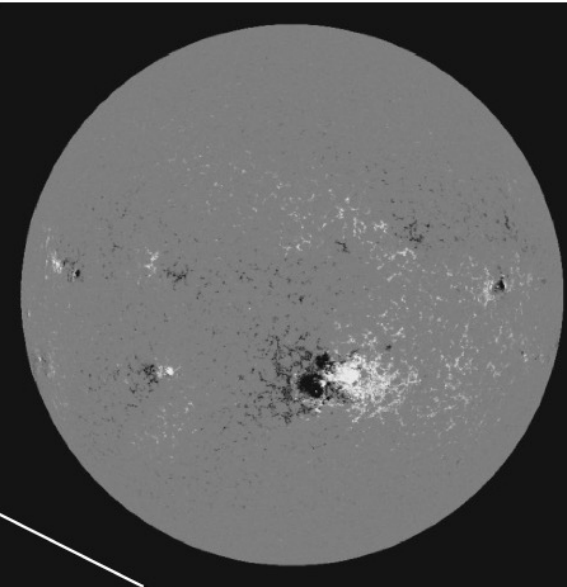
Again we also use spectral lines to diagnose the conditions in the corona – different ionization states indicate different ambient temperatures

NOAA AR 12192 on 2014 Oct 24

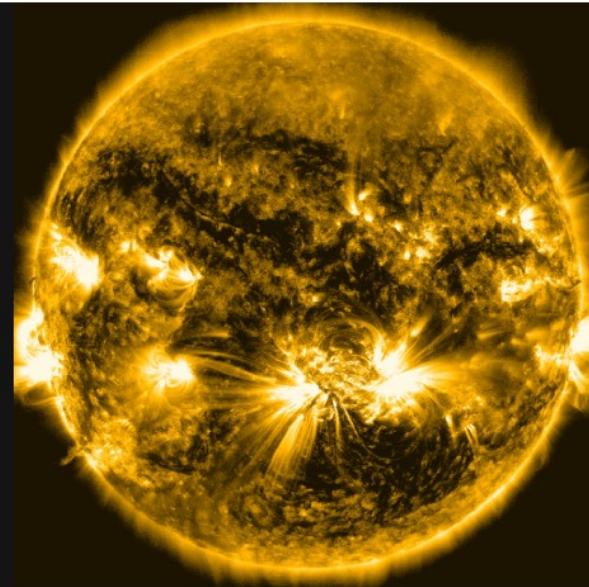
NAOJ/SFT continuum



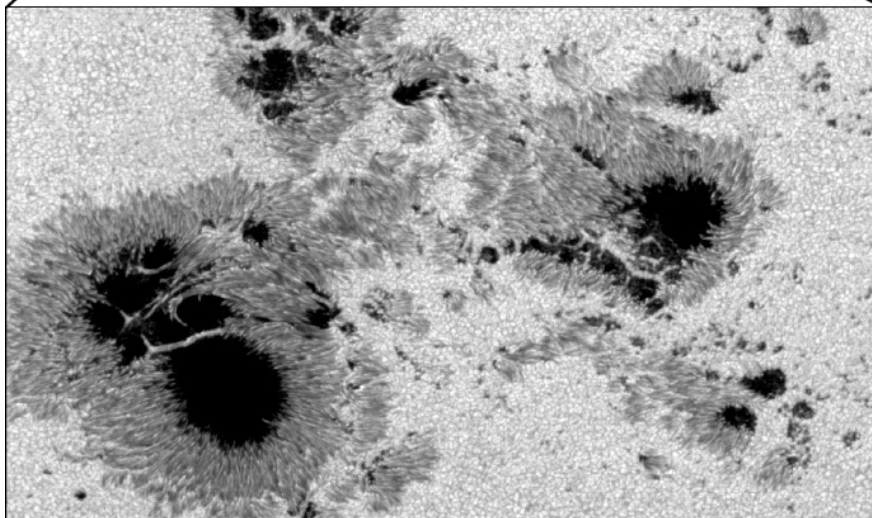
SDO/HMI magnetogram



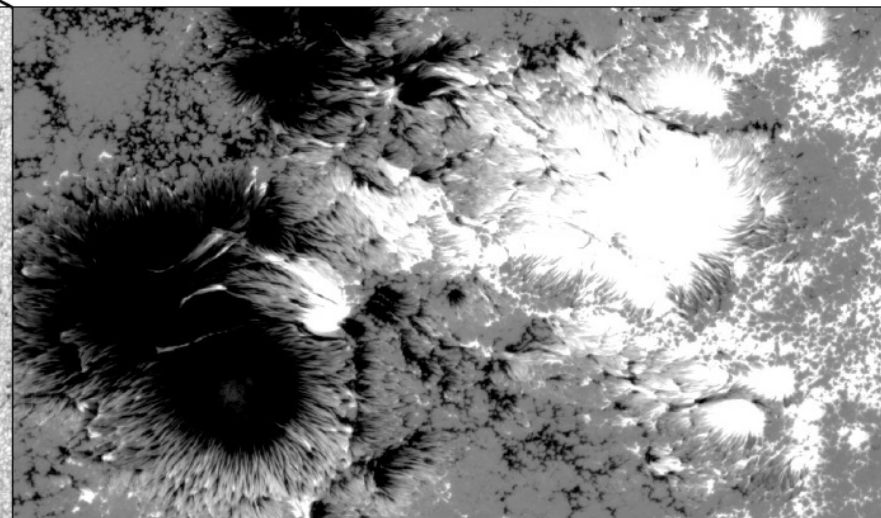
SDO/AIA 171 Å



Hinode/SOT/SP continuum

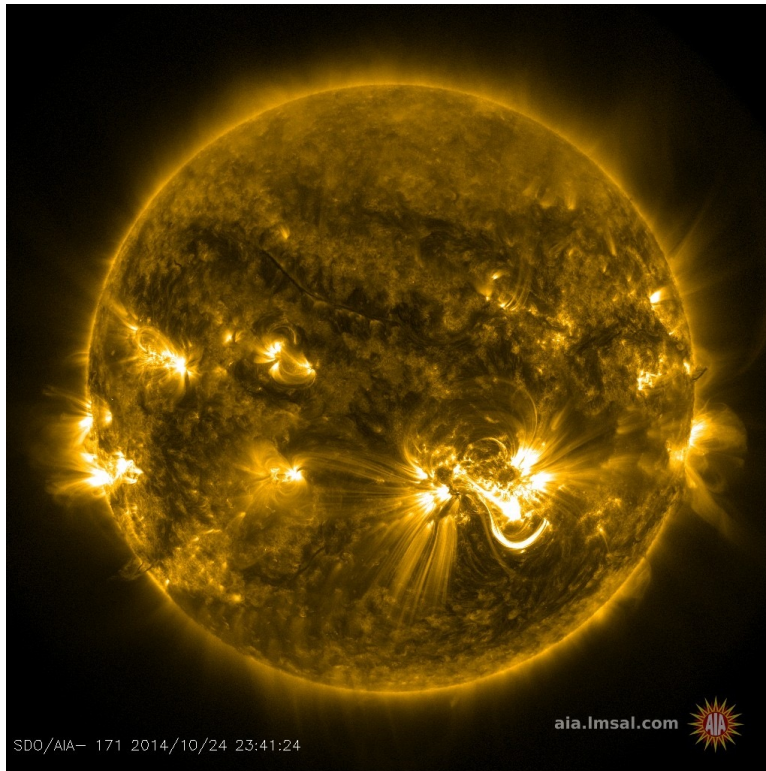


Hinode/SOT/SP magnetogram

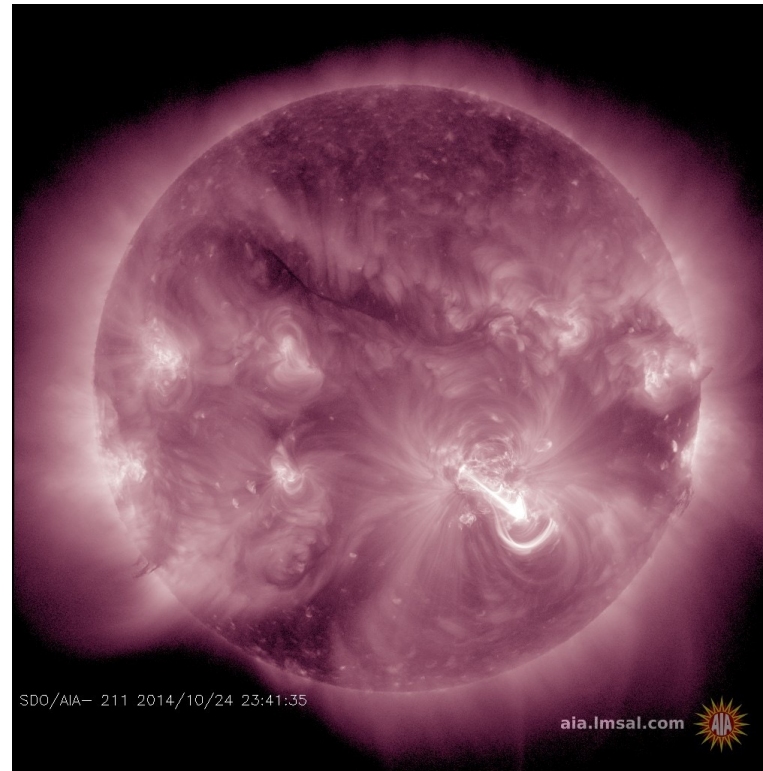


SDO EUV Images

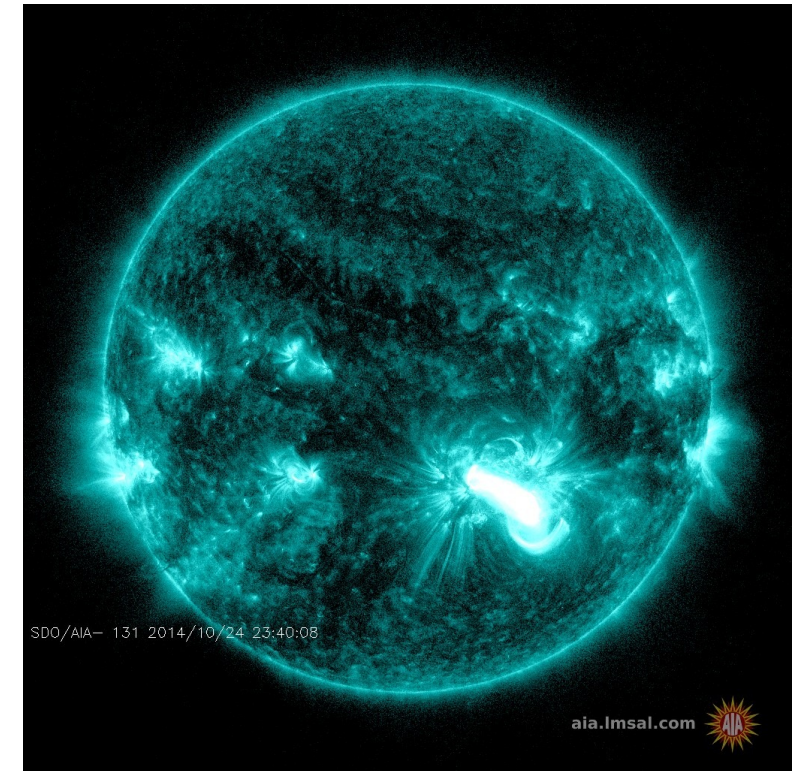
171 Å
Fe IX
 $10^{5.8}$ K



171 Å
Fe XIV
 $10^{6.3}$ K

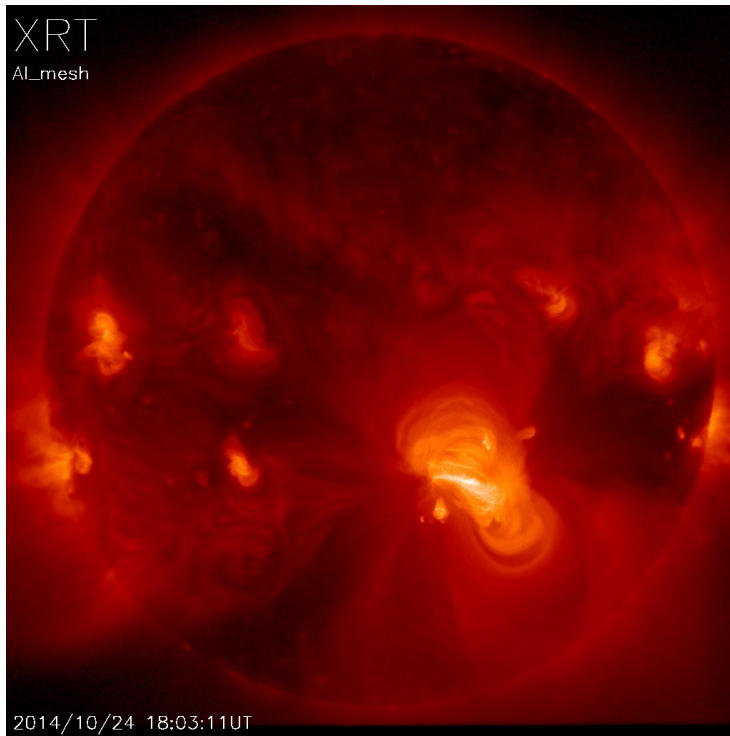


171 Å
Fe XX, XXIII
 10^7 K



XRT X-ray Images

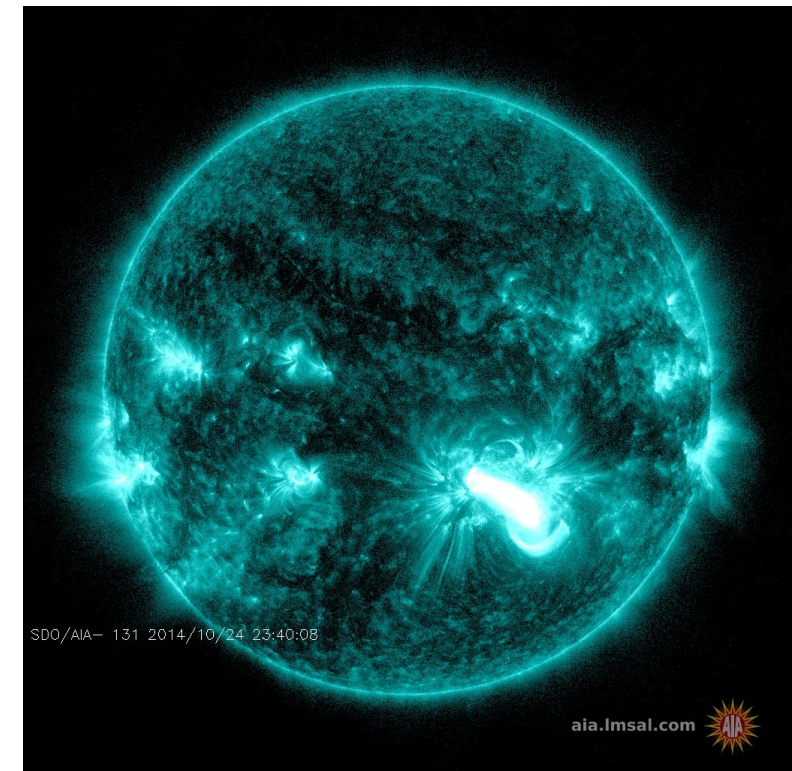
Al-Mesh
 $10^{6.9}$ K



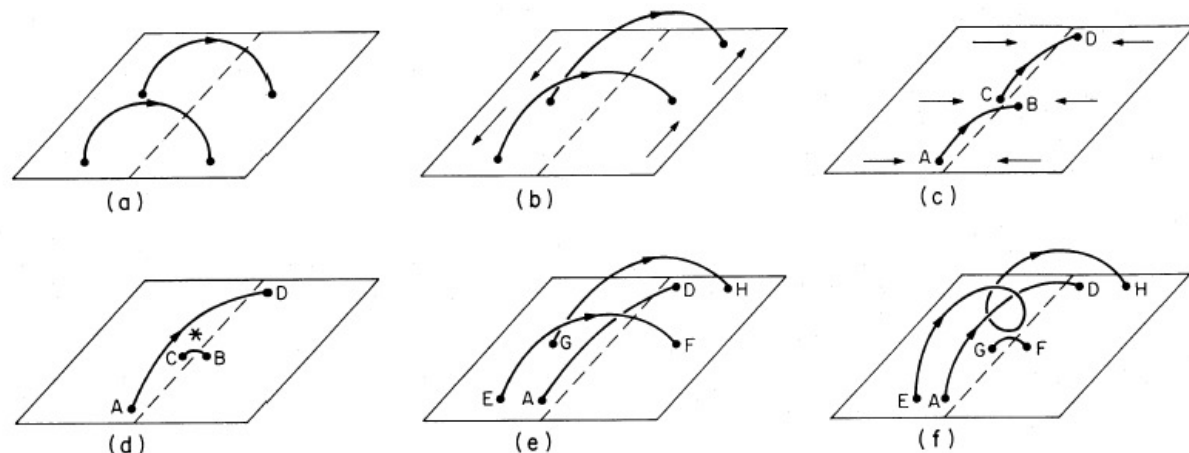
Be-Thin
 $10^{7.1}$ K



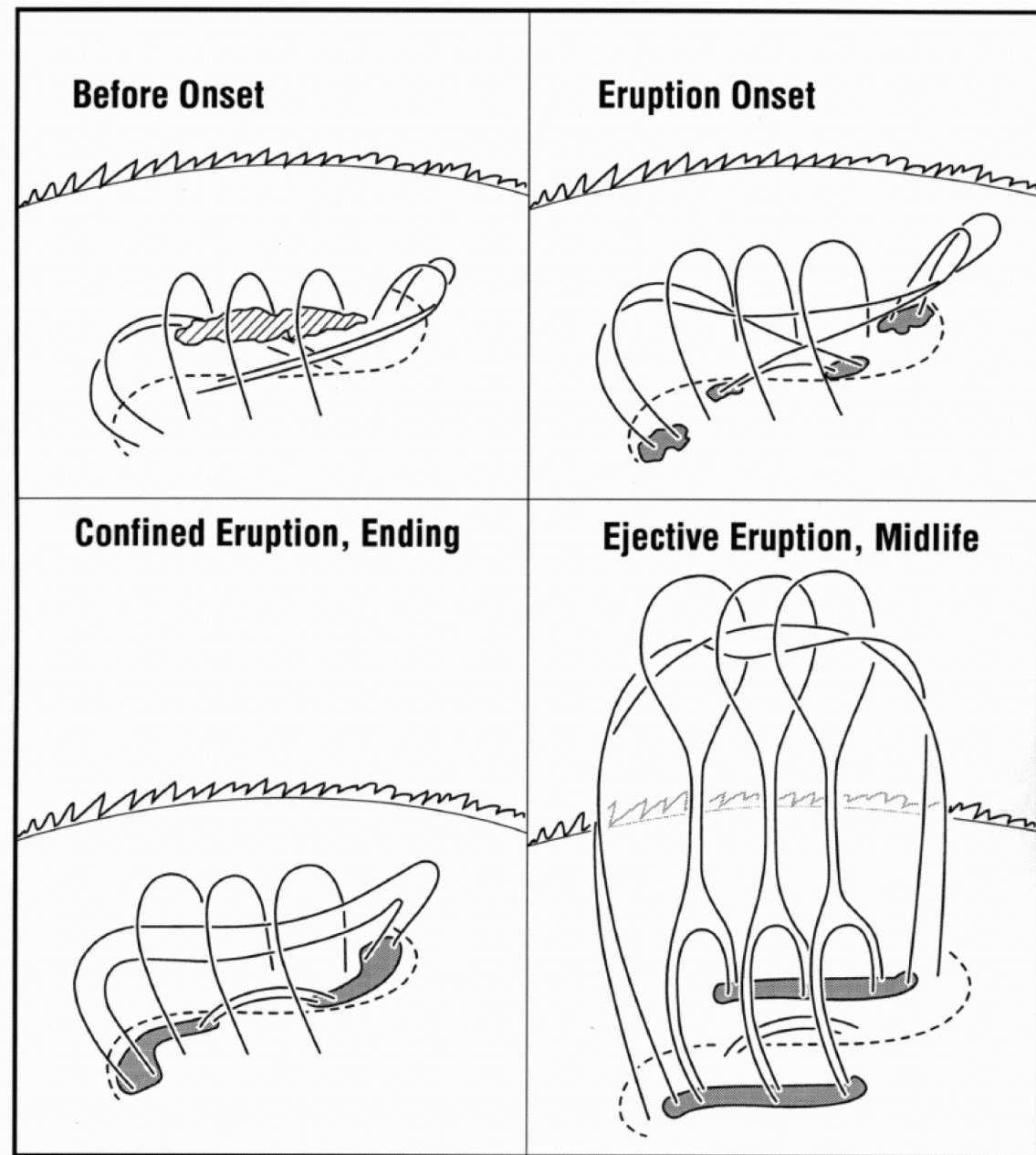
171 Å
Fe XX, XXIII
 10^7 K



Magnetic Energy Storage

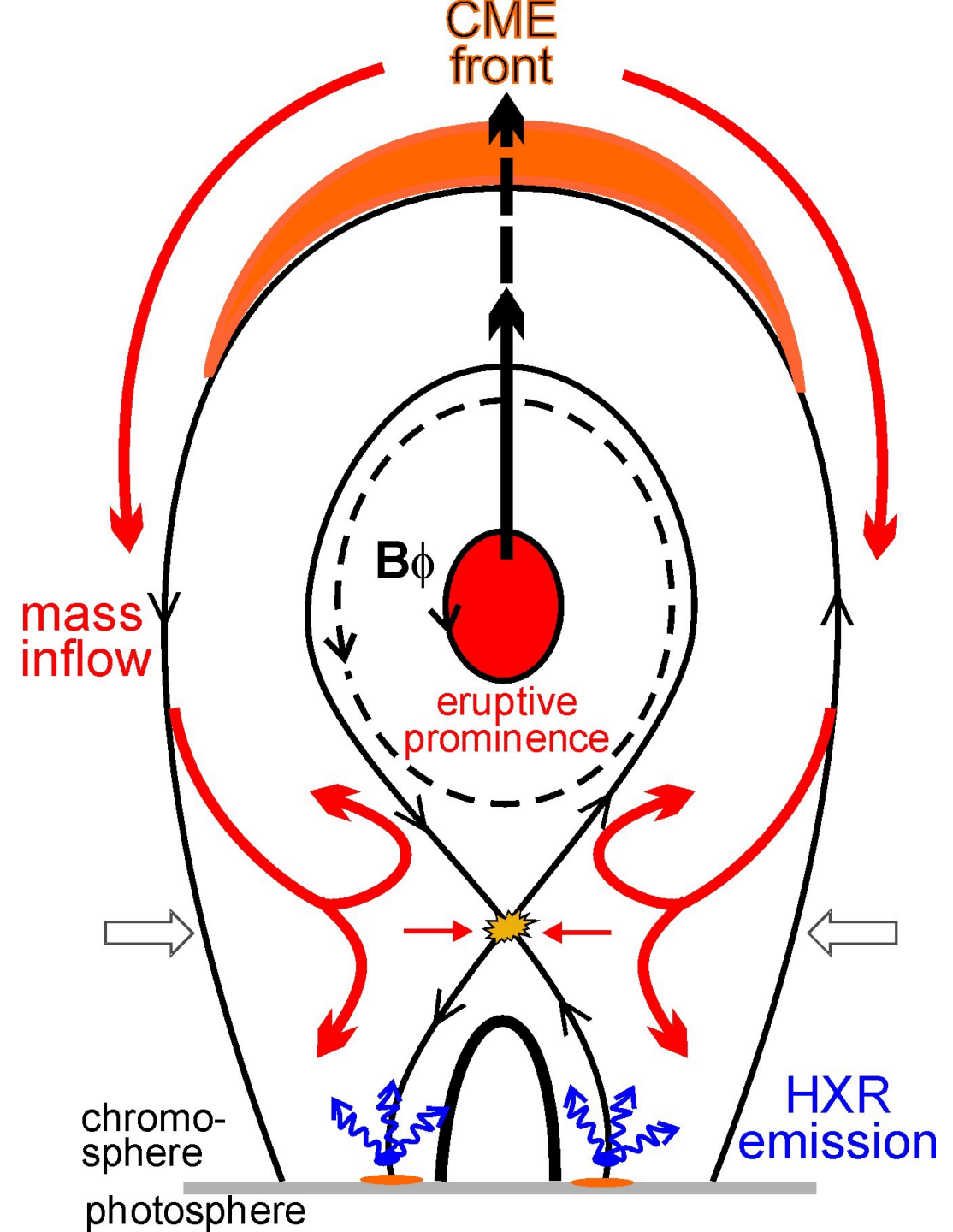


Driven by the plasma motions in the photosphere, the magnetic field in the photosphere can become intertwined and store energy in an unstable state

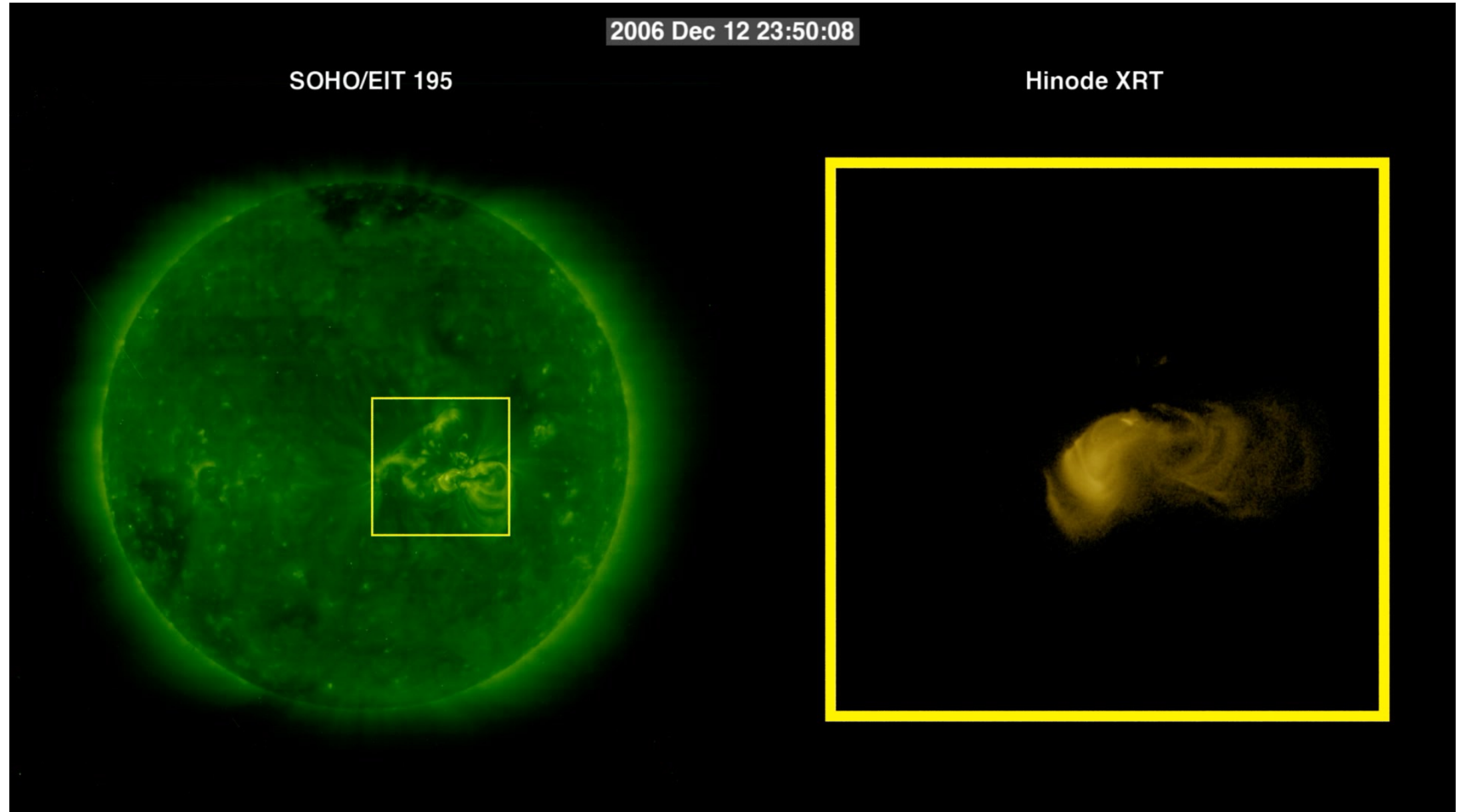


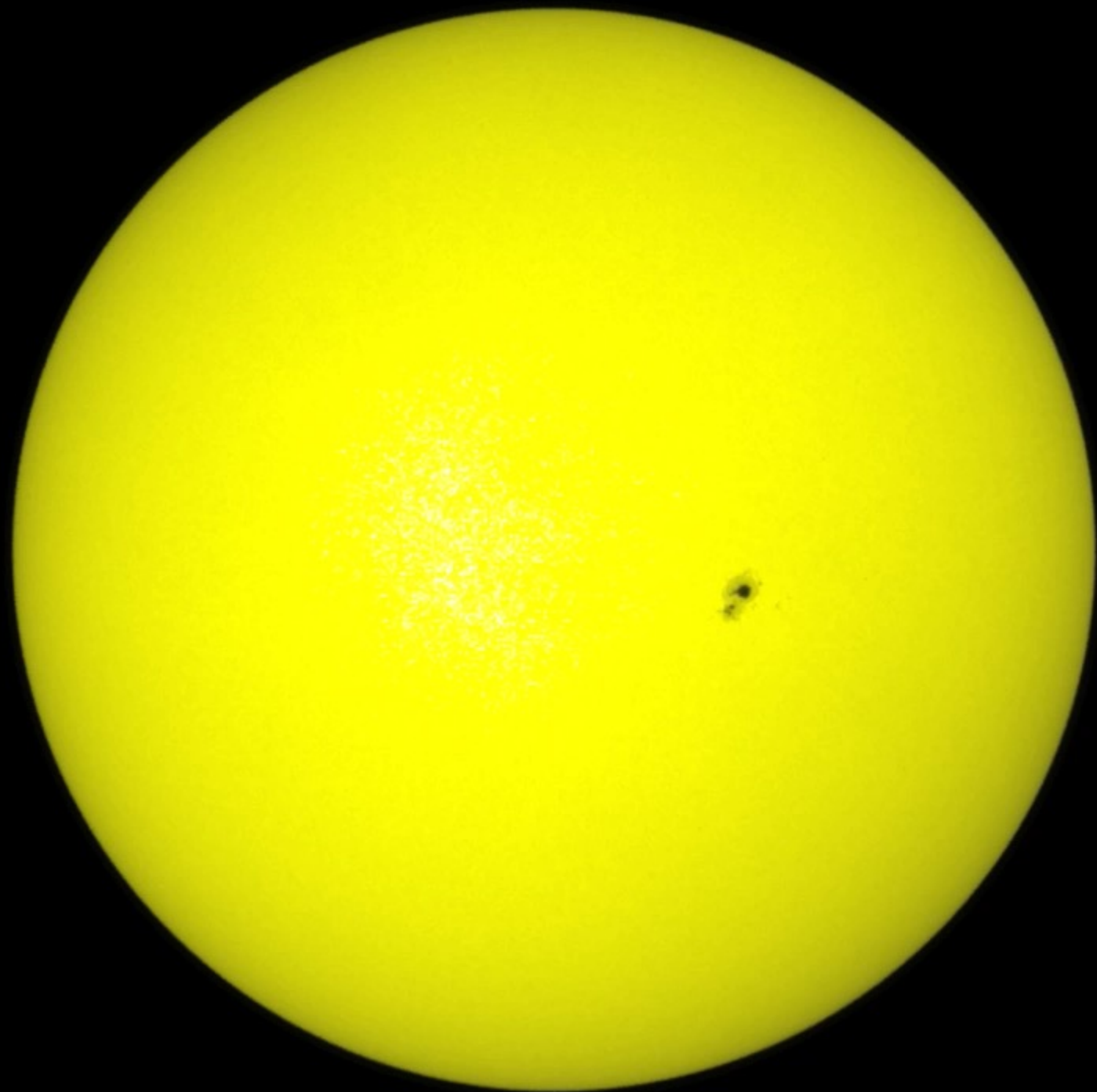
Magnetic Energy Release

The magnetic energy can then be impulsively released, resulting in the release of high-energy photons, heating of the solar chromosphere, and outward flux of high-energy particle and mass ejections (CME).

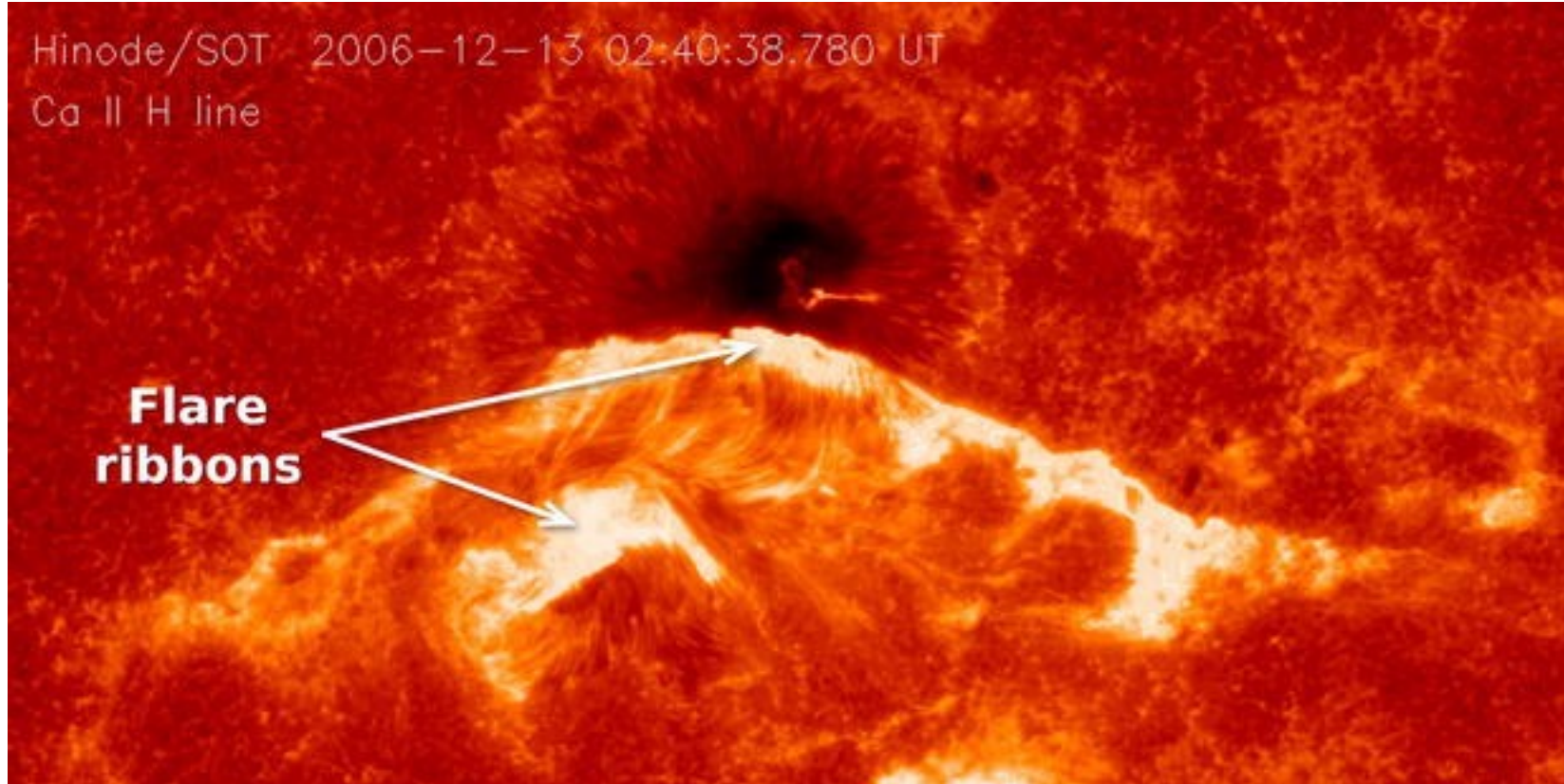


Example Flare (movie)





Chromospheric Response

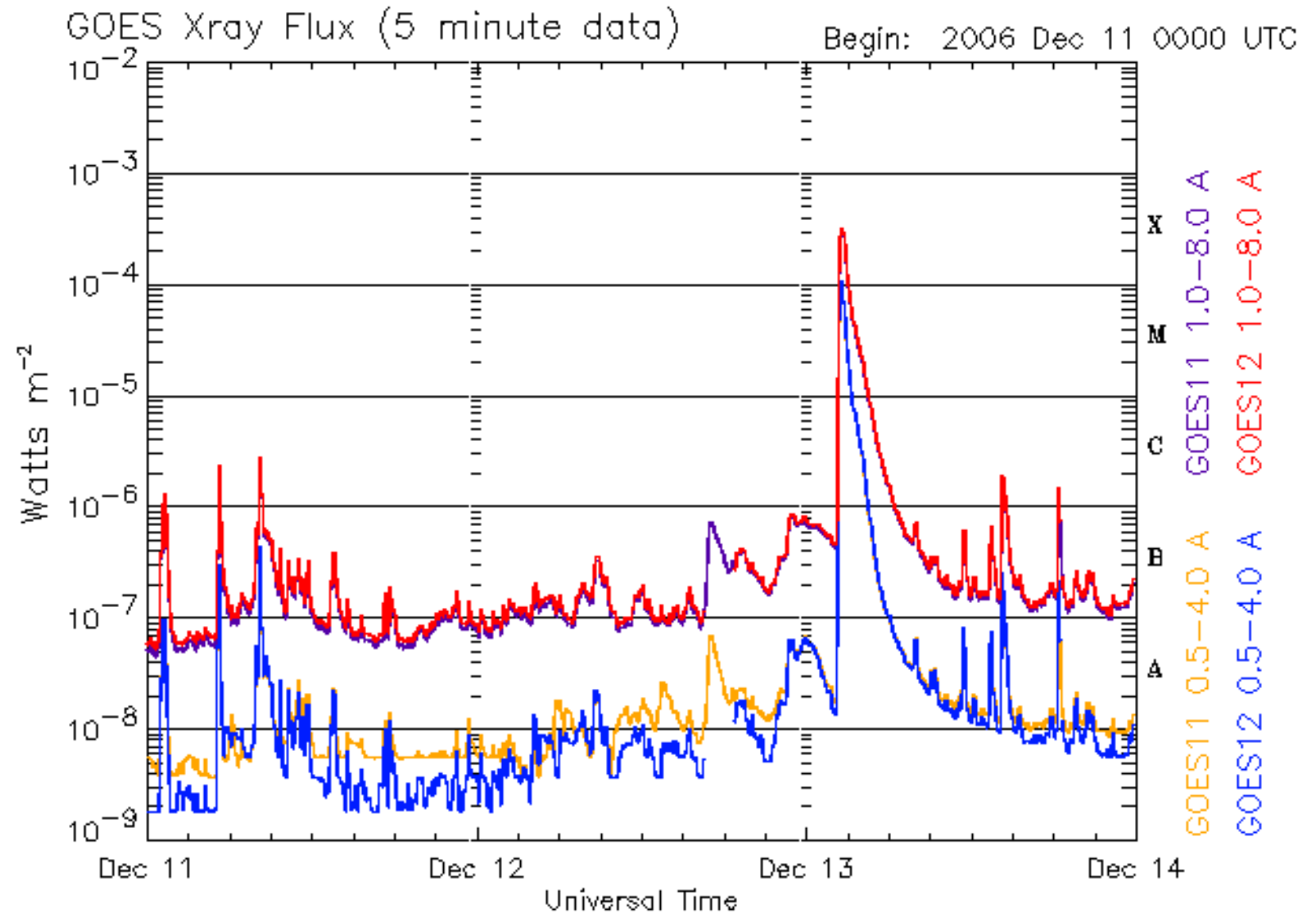


Flares generate energy propagation down to loops of magnetic loops, heating their footpoints in the chromosphere, which tend to fall on either side of the polarity inversion line

Activity Indicators

Integrated, full-sun X-ray flux shows solar flare activity, with the flares showing up as sharp rises and slower decays.

The “size” of a flare is defined by the maximum value of the emission, and labeled by letters (B, C, X, M) indicating order of magnitude changes in flare emission.

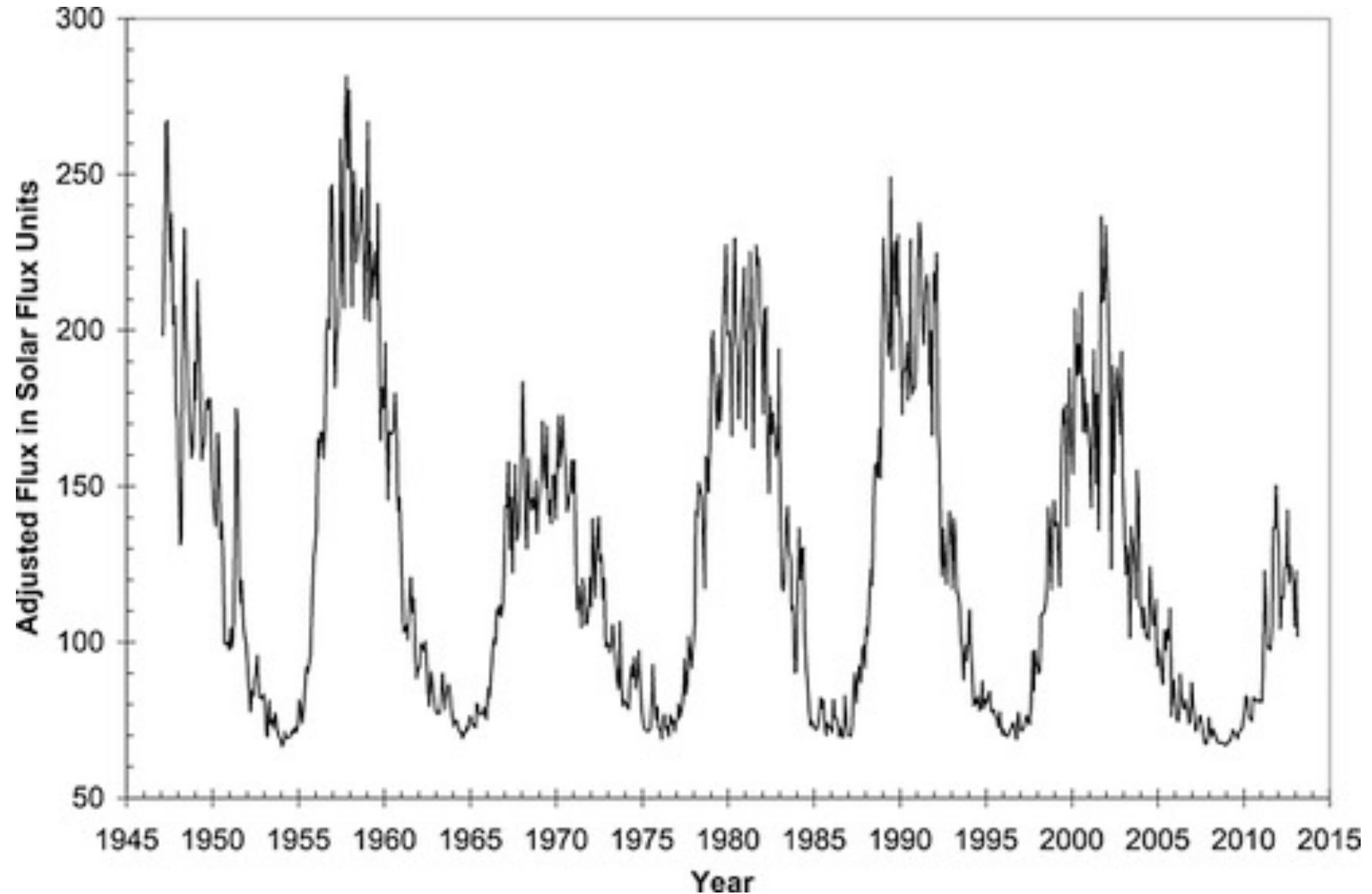


Updated 2006 Dec 13 23:56:06 UTC

NOAA/SEC Boulder, CO USA

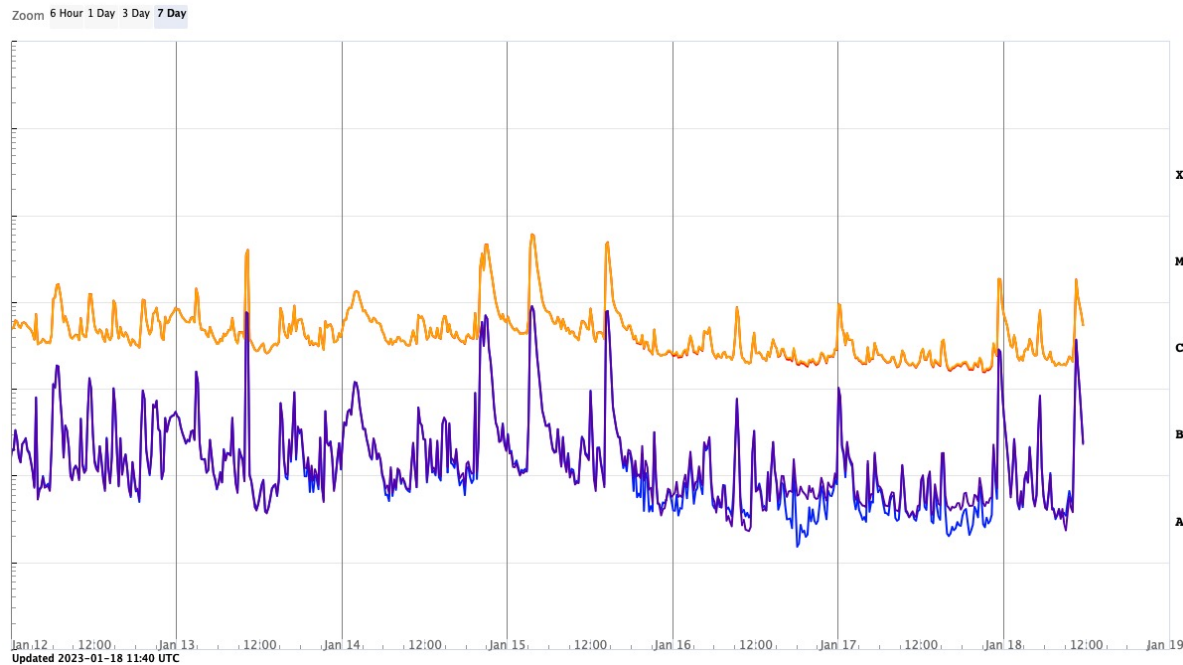
Radio 10.7 cm flux

Radio flux (10.7 cm wavelength) provides a good proxy for solar activity, and can be obtained from the ground, resulting in a long, continuous series of observations

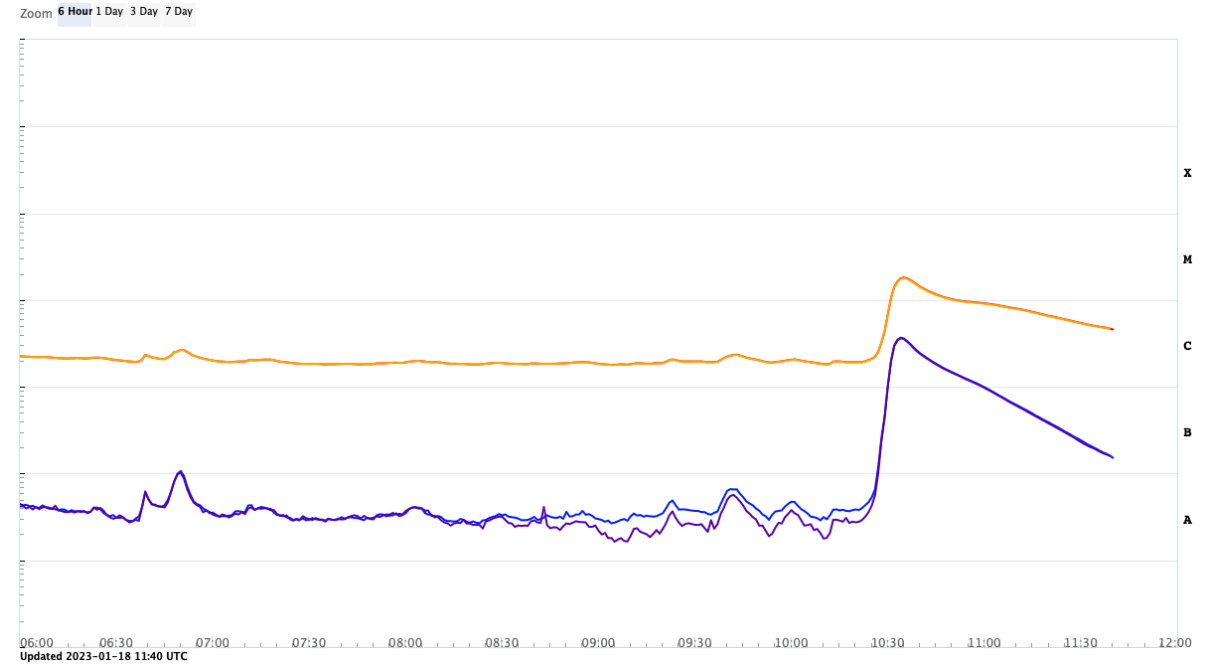


NOAA Web Pages

7-day X-ray Flux



6-hour X-ray Flux



<https://www.swpc.noaa.gov/products/goes-x-ray-flux>

ATMOSPHERIC IMAGING ASSEMBLY

AIA HOME | SOLAR INFO AND SPACE WEATHER | RESULTS - PUBLICATIONS | RELATED LINKS | CONTACT US

SCIENCE INVESTIGATION | INSTRUMENT | OPERATIONS | DATA | TEAM SITE

Sun In Time: 2023-01-18

← Prev. Day

Next Day →

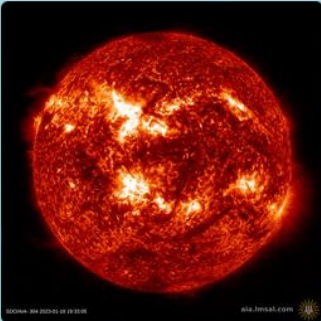
Today

Calendar

What's this webpage?

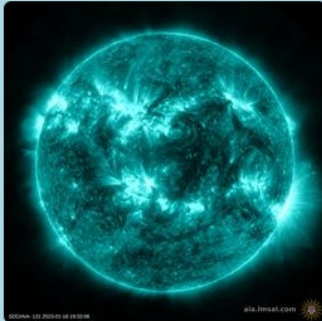
Image Channels

When were these taken?




1K4KPFSSNo Lines

30416001700304-211-171



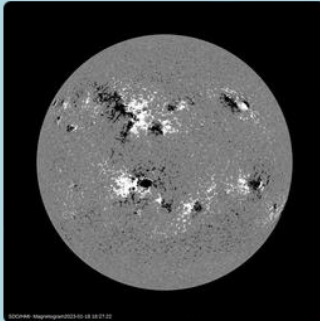
1K4KPFSSNo Lines

094-335-193094335131



1K4KPFSSNo Lines

211-193-171211193171



1K4KPFSSNo Lines

HMI contHMI B(los)171-B(los)

Tip: Hover over the wavelength labels underneath the set of images to change the thumbnail image.

FITS files (for planning purposes): 4500 | 1700 | 1600 | 335 | 304 | 211 | 193 | 171 | 131 | 94 | B(los)

Movie links:

Daily movies: Not Yet Available

304-171 movies: Not Yet Available

211-193-171 movies: Not Yet Available

211-193-171 running-ratio movies: Not Yet Available

AIA and STEREO/EUVI-A+B movies: Not Yet Available

Other resources:

Image data request form: [click here](#)

SolarMonitor for this date: [click here](#)

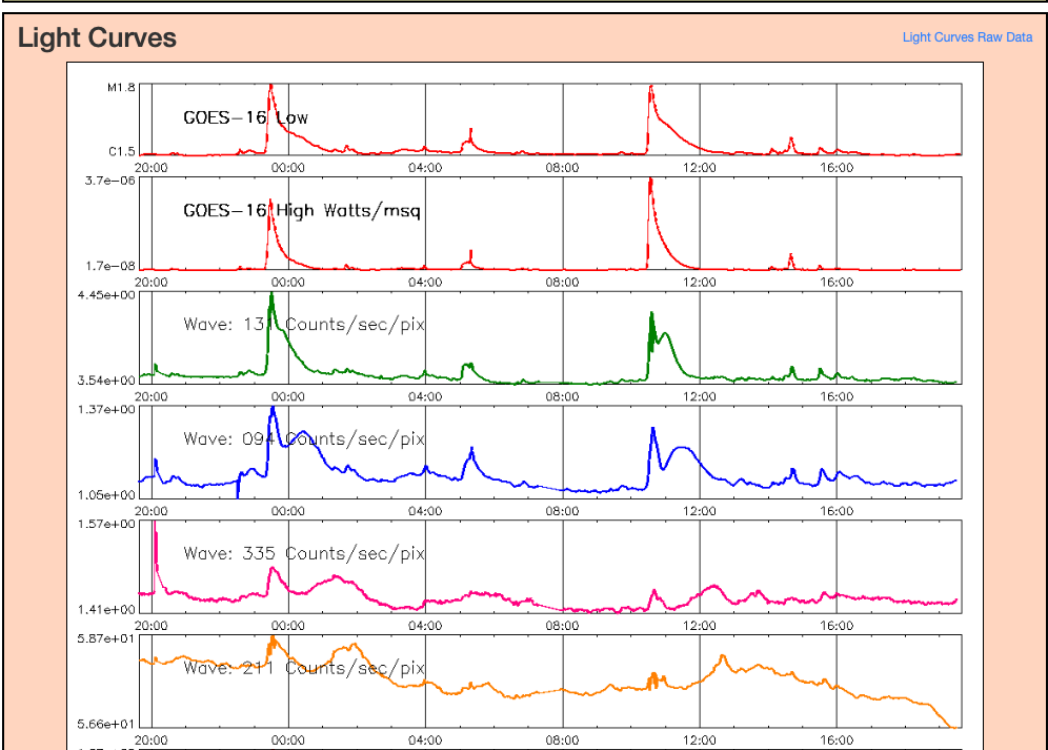
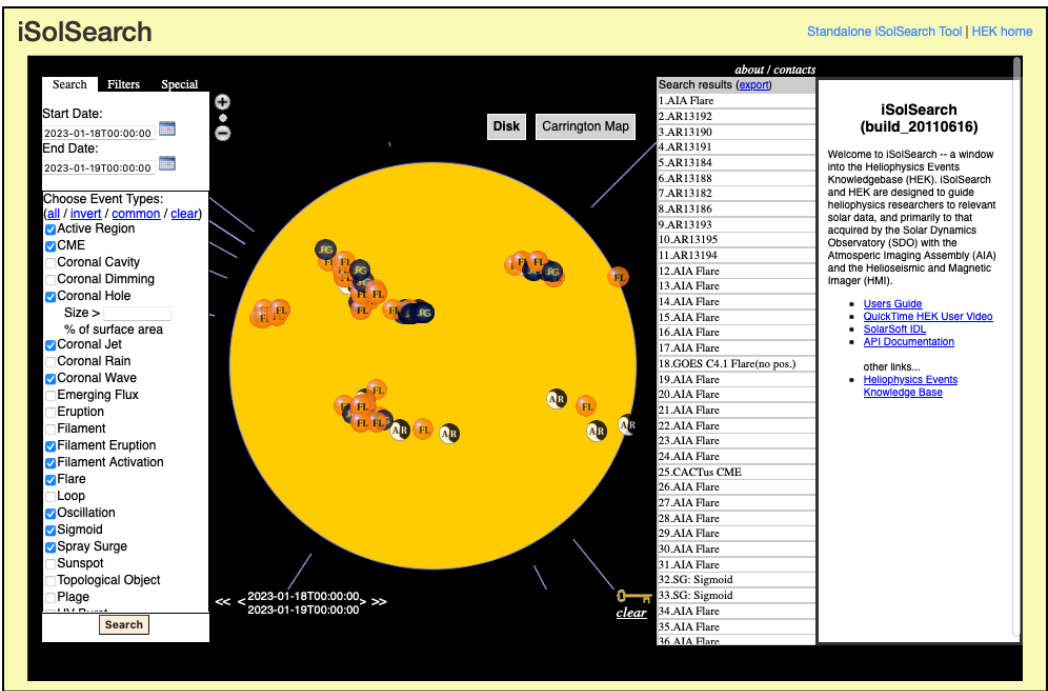
IRIS pointing summary for this date: [click here](#)

Interactive PFSS model for this date: [click here](#)


STEREO Science Center daily browse data for this date: [click here](#)

AIA emission measure data: [click here](#) (image) or [click here](#) (movie) or [click here](#) (genx cube) or [click here](#) (source code)

sdowwww.lmsal.com



gong2.nso.edu



GONG Data Archive


Status: **ONLINE**

210,756,834 Files -- 137.59 Terabytes
Current Time: **2023/01/18 19:51 UTC**
Archive Updated: **2023/01/18 19:49 UTC**

[Reference | Documentation Science](#)

SUPPORT: nispdata@nso.edu

[Data Use Acknowledgement](#)



Welcome to the GONG Data Archive.

Use this page to access most GONG data products from 1995* to present.

** Note that observations from before February-July 2001 (depending on the site) were made with lower-resolution 256x256 pixel cameras.*

Data Access Steps :

- **Step 0** : Review [reference](#) documentation, and data use [acknowledgement](#). Contact nispdata@nso.edu for assistance if needed
- **Step 1** : Select Product Set
- **Step 2** : Select Data From Product Set And Select Time Period


Step 1 : Choose Product Set

Select one of the links below to proceed to step 2 :

Full Calibration Products:	Magnetogram_Velocity & Intensity Global Helioseismology Local Helioseismology Magnetic Field Products
QuickReduce Near Real Time Products:	Magnetogram & Intensity H-Alpha Farside Images Zero Point Corrected Magnetic Field Products Uncorrected Magnetic Field Products


Step 2 : Select Data From Product Set And Select Time Period

Products for H-Alpha Product Set :


Instructions: Click the calendar icon  below for a quick view of availability. -OR- Select a product and date range to search. The Search results page will appear along with directions for staging and download your data request.

GONG Network H-Alpha Images

These options will search all GONG sites for a given time.




☐ GONG Network (un-merged) H-Alpha FITS Data




☒ GONG Network (un-merged) H-Alpha JPG Preview


GONG Site-specific H-Alpha Images




☐ Big Bear Reduced H-Alpha FITS Data




☐ Cerro Tololo Reduced H-Alpha FITS Data




☐ Learmonth Reduced H-Alpha FITS Data




☐ Mauna Loa Reduced H-Alpha FITS Data




☐ Teide Reduced H-Alpha FITS Data




☐ Udaipur Reduced H-Alpha FITS Data




☐ Big Bear Reduced H-Alpha JPG Preview




☒ Cerro Tololo Reduced H-Alpha JPG Preview




☐ Learmonth Reduced H-Alpha JPG Preview



☐ Mauna Loa Reduced H-Alpha JPG Preview



☐ Teide Reduced H-Alpha JPG Preview



☐ Udaipur Reduced H-Alpha JPG Preview

Select Date: (YYMMDD HHMM)

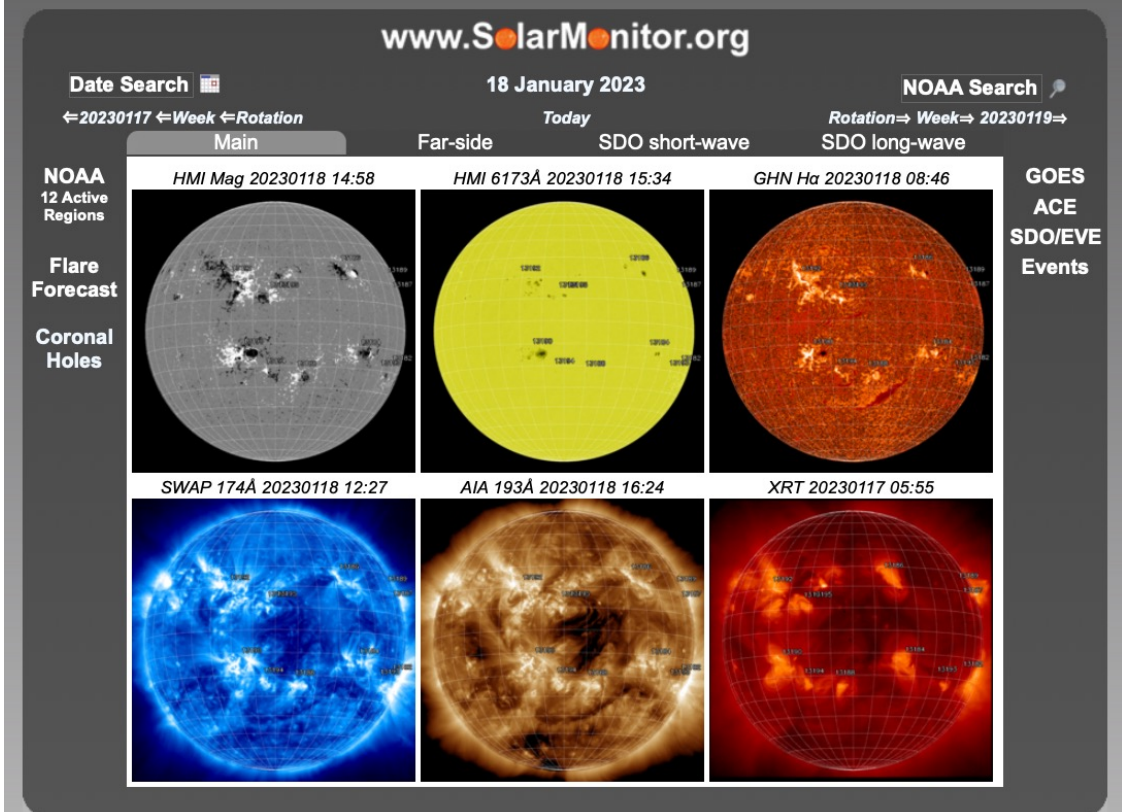
[Note: Date ranges should not cross the 1999-2000 boundary.]

Data Start: 230101 0000

Data Stop: 230118 0000

Search

solarMonitor.org



Today's/Yesterday's NOAA Active Regions						
NOAA Number	Latest Position	Hale Class	McIntosh Class	Sunspot Area [millionths]	Number of Spots	Recent Flares
13182	S17W91 (931",-285")	α/β	Axx/Cro	0000/0020	01/05	-
13184	S13W48 (708",-165")	α/β	Hsx/Cso	0190/0210	05/07	-
13186	N25W39 (557",470")	β/βγ	Eho/Eho	0430/0440	11/14	-
13188	S24W15 (231",-323")	β/β	Bxo/Dro	0010/0030	07/10	- / C3.2(22:29)
13190	S14E10 (-164",-156")	βγ/βγδ	Eki/Ehi	0900/0880	20/21	-
13191	N11W02 (33",267")	β/β	Dsi/Dkc	0320/0360	13/13	-
13192	N19E16 (-255",392")	β/βγ	Fki/Fki	0380/0400	13/13	-
13193	S21W69 (850",-320")	β/β	Cro/Dso	0030/0060	03/06	-
13194	S23W00 (0",-304")	β/β	Bxo/Bxo	0000/0010	04/07	-
13195	N11W06 (100",267")	β/-	Dro/---	0030/---	08/---	-
13187	N16W90 (936",267")	/	/	/	/	-
13189	N23W91 (896",378")	/	/	/	/	-

Class (HH:MM) -Today
Class (HH:MM) -Yesterday

helioviewer.org

Helioviewer.org

Observation Date

Date:

2023/01/18

20:05:45

UTC

NEWEST

Jump:

1 day

Images

AIA 304

2023/01/18 19:36:05 UTC

Opacity:

Observatory:

SDO

Instrument:

AIA

Measurement:

304

Difference:

No difference in

Features and Events

HEK

2023/01/18 20:05:45 UTC

check all

check none

Active Regions (10)

NOAA SWPC Observer (10)

Coronal Cavities

Coronal Dimmings

Coronal Holes

Coronal Jets

CMEs

Coronal Rains

Coronal Waves

Emerging Fluxes

Eruptions

Filaments

Filament Activations

Filament Eruptions

Flares

Loops

Oscillations

Plages

Sigmoids

Spray Surges

Sunspots

Celestial Bodies

SOHO

check all

check none

Mercury

Venus

Mars

Jupiter

Saturn

Uranus

Neptune

Parker Solar Probe

Label

Trajectory

STEREO_A

check all

check none

Mercury

Venus

Earth

Earth Scale

Welcome to Helioviewer.org, a solar data browser. First time here? Be sure to complete our Interactive Tutorial.

Virtual Solar Observatory

Search VSO Help or enter Cart Id:

Search for Solar Physics Data Products:

If you're new to the VSO, see [How To Search](#), the [FAQ](#) or click the  icons for online help.


Please select which values you wish to use to search for data products:

☒ **Time**



Search by time interval.

[Derive time intervals from event catalogs](#)

☐ **Observable**

Search based on physical observables 

☐ **Instrument / Source / Provider**

Search based on instruments  or data archives 

☐ Compact listing

☐ Instrument / Source (not provider dependent)

☐ Instrument Only (not source or provider dependent)

☐ **Spectral Range**

Search based on a spectral range

☐ **Nicknames**

Search based on common terms used to describe data products

Note: Nicknames generate an intersection with other search terms, so searching for a nickname, and a physical observable (or other parameter) when a nickname defines other physical observables will result in no matches.

☐ Show Nickname Definitions

Searching against current VSO instances

VSO Documentation

Documentation for Scientists, Programmers and Data Providers, including [Changes](#), [FAQs](#), and [contact info](#).

Help us improve VSO

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- Other [suggestions / comments / criticism](#)
- [Contact information for VSO team members](#)

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Automatically Generated at : Wed Jan 18 20:08:11 2023