Viewing the Sun across the electromagnetic spectrum

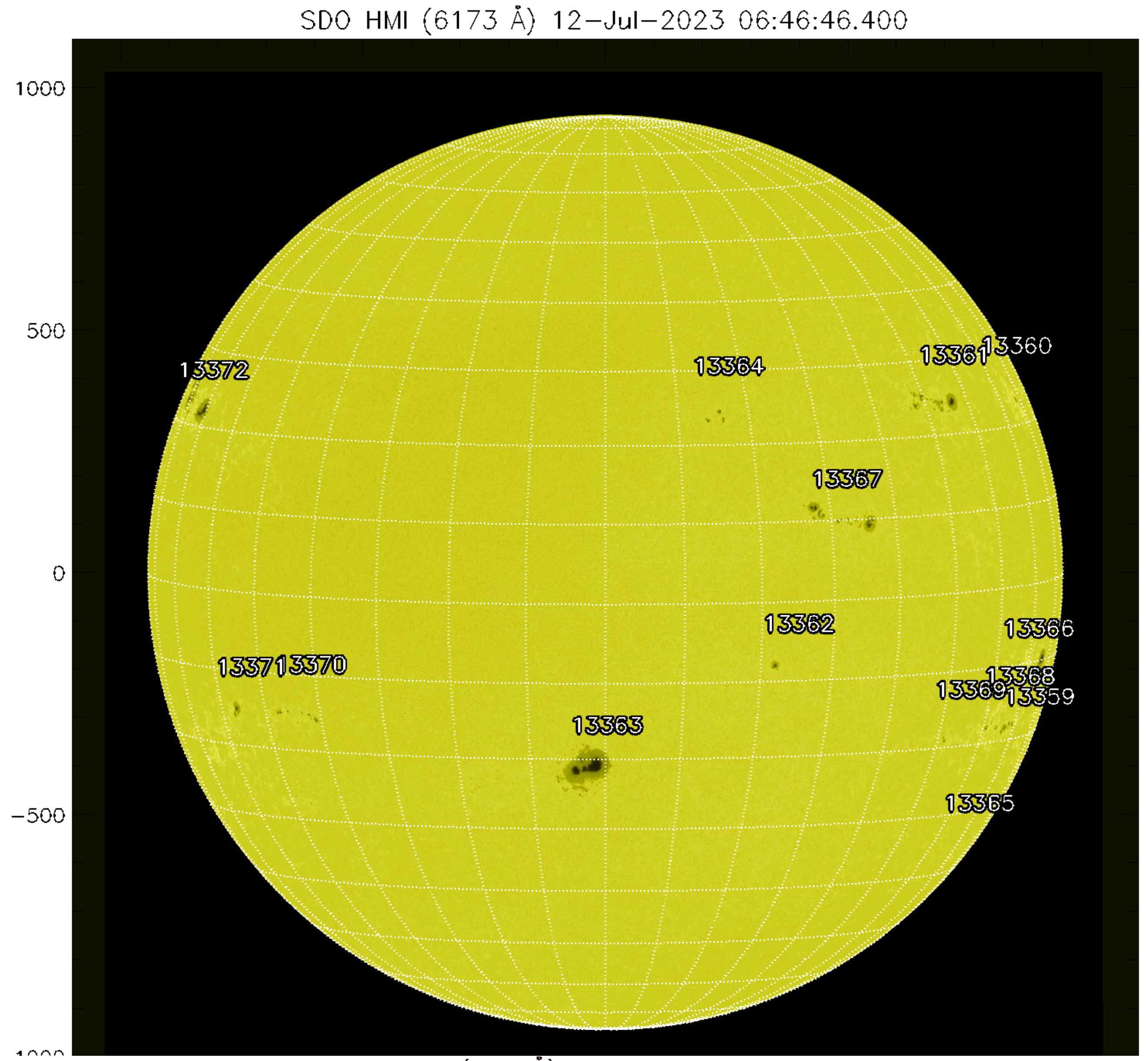
How does an imaging instrument work

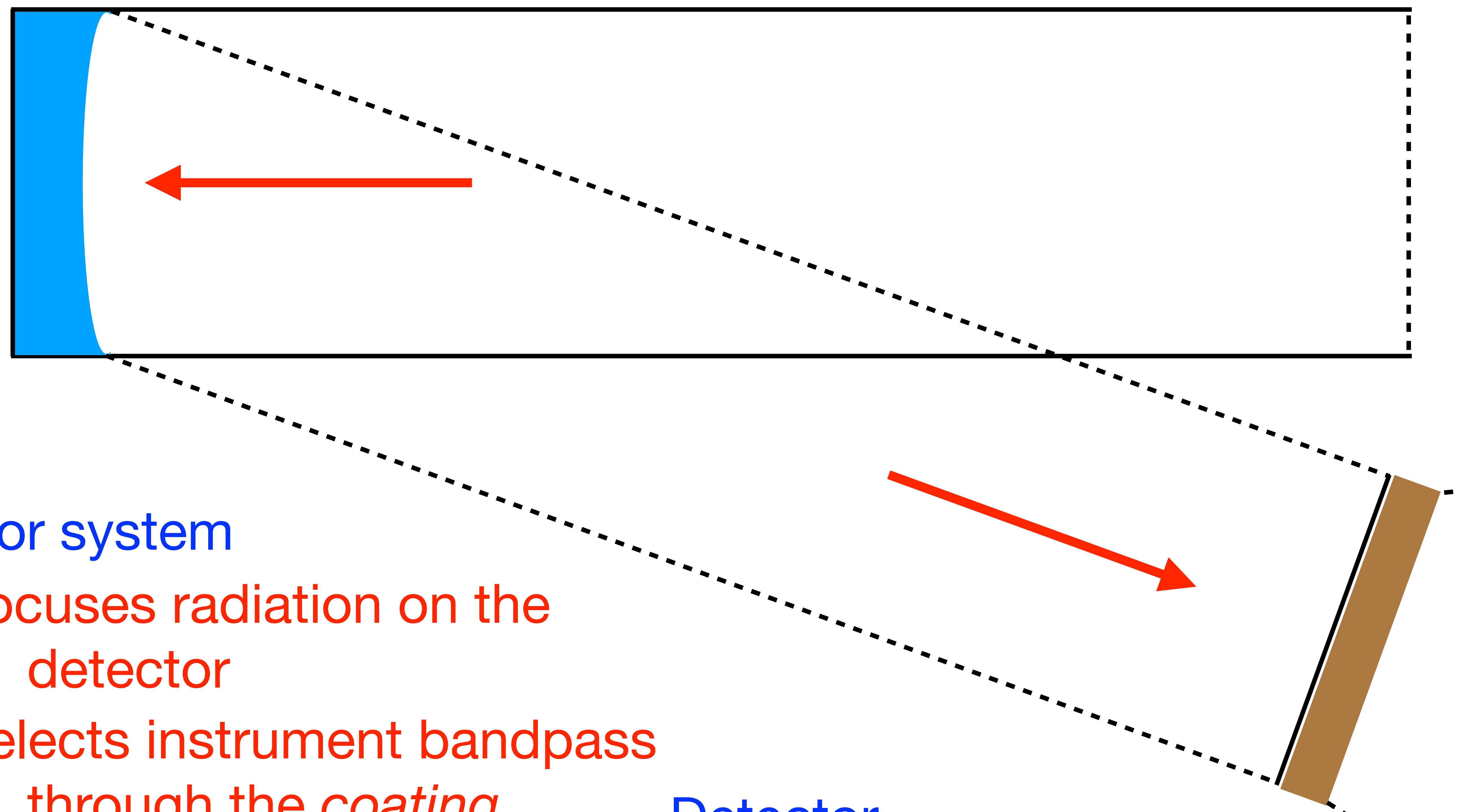
Main components

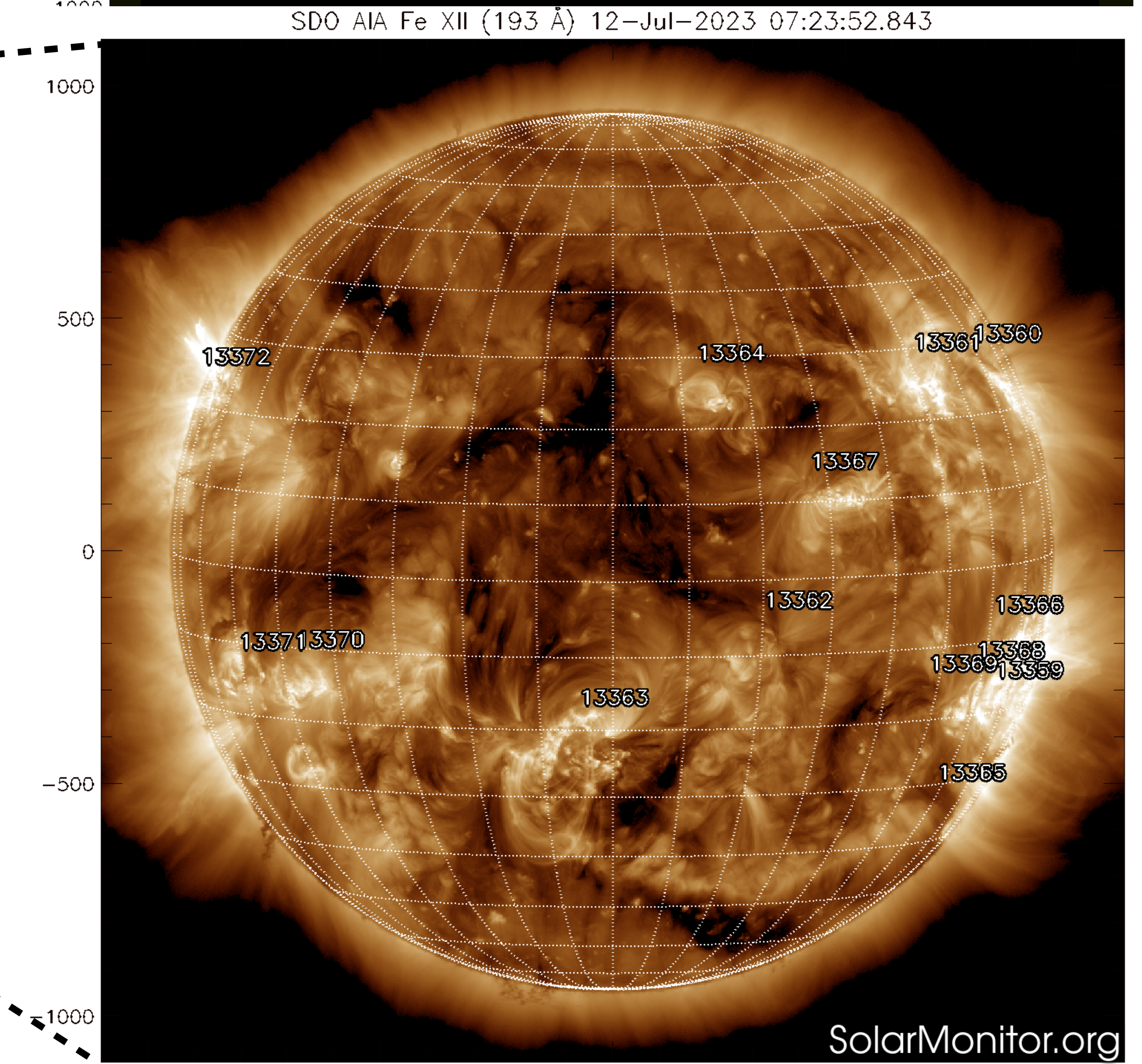
- Aperture
- Mirror system
- Detector

Aperture

- Determines amount of incoming light
- Rejects unwanted light







Mirror system

- Focuses radiation on the detector
- Selects instrument bandpass through the *coating*

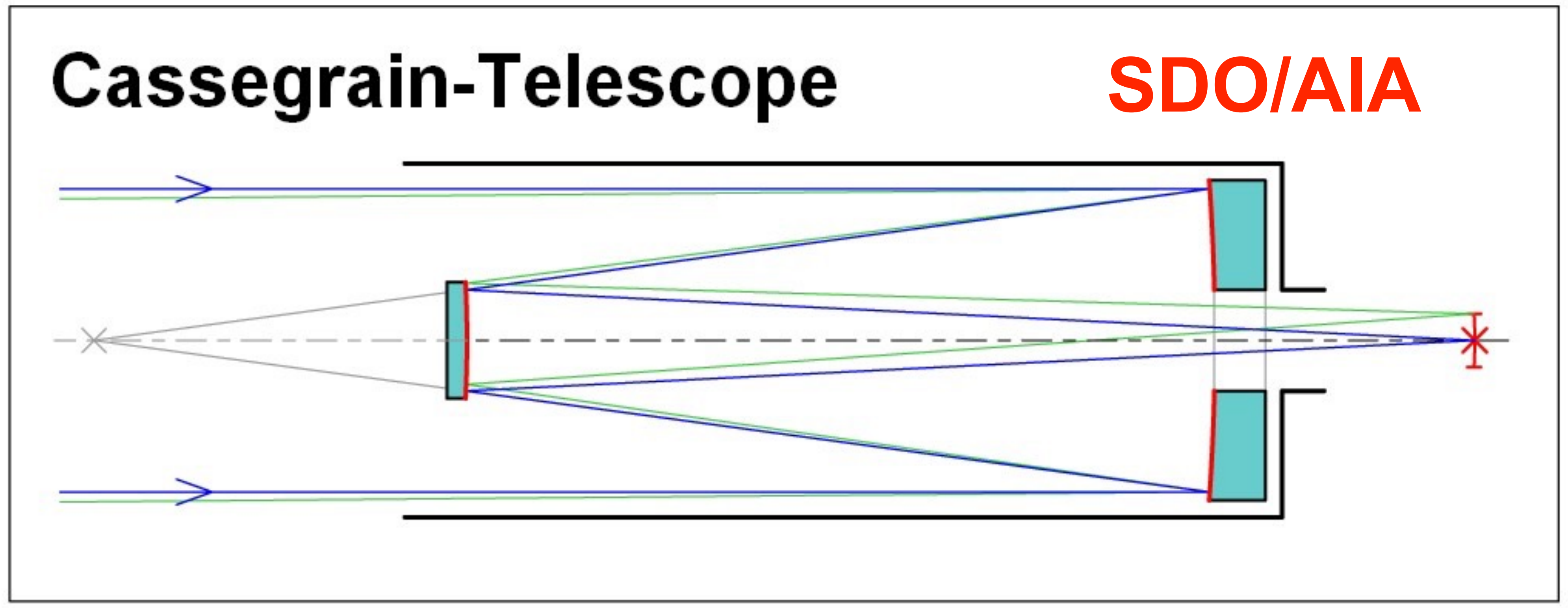
Detector

- Records radiation into array
- Reads and transmits image to electronics

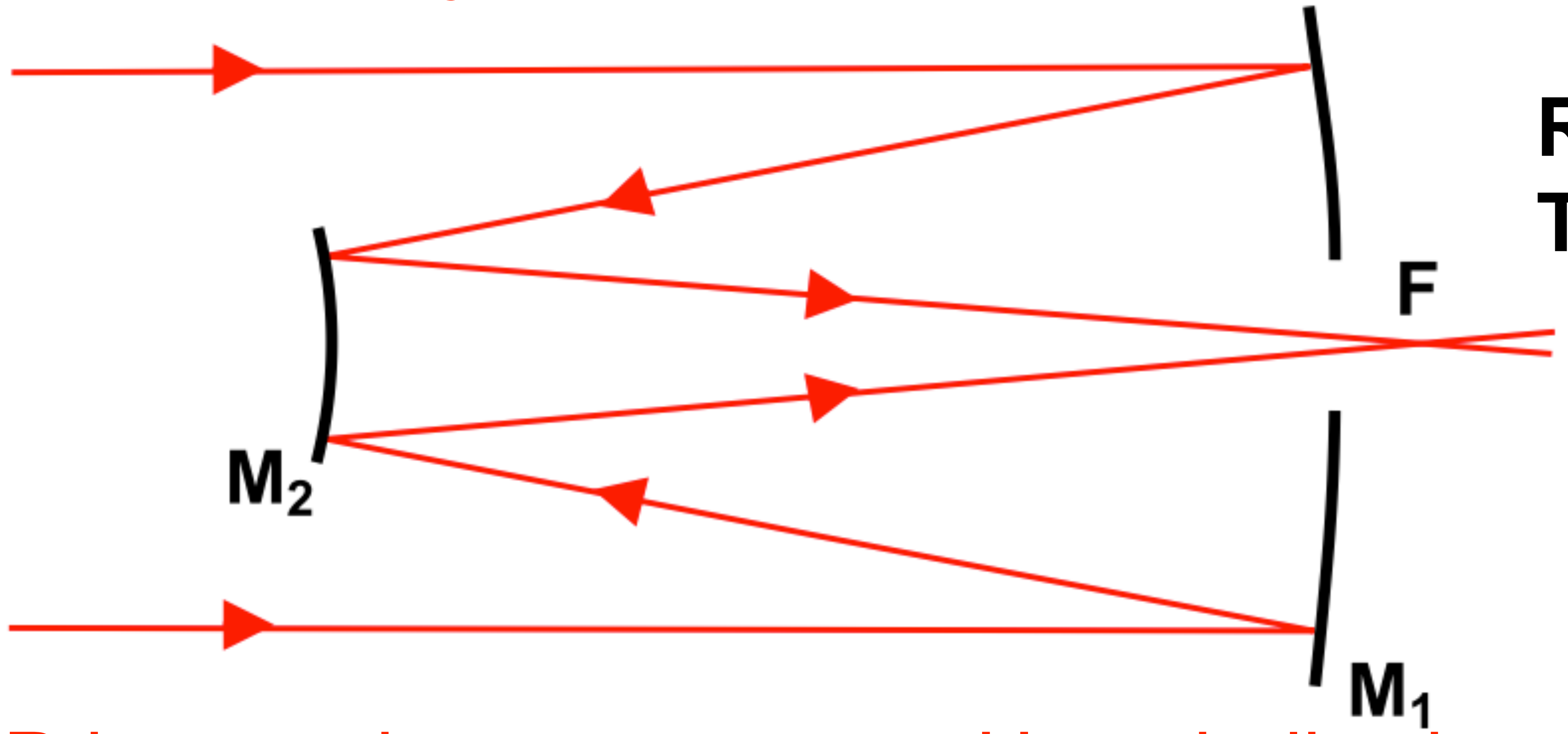
How does an imaging instrument work

Mirror system

Goals: Produce an image with as little aberrations as possible
Be compact, light, and sturdy



Primary mirror — Parabolic shape
Secondary mirror — Hyperbolic shape

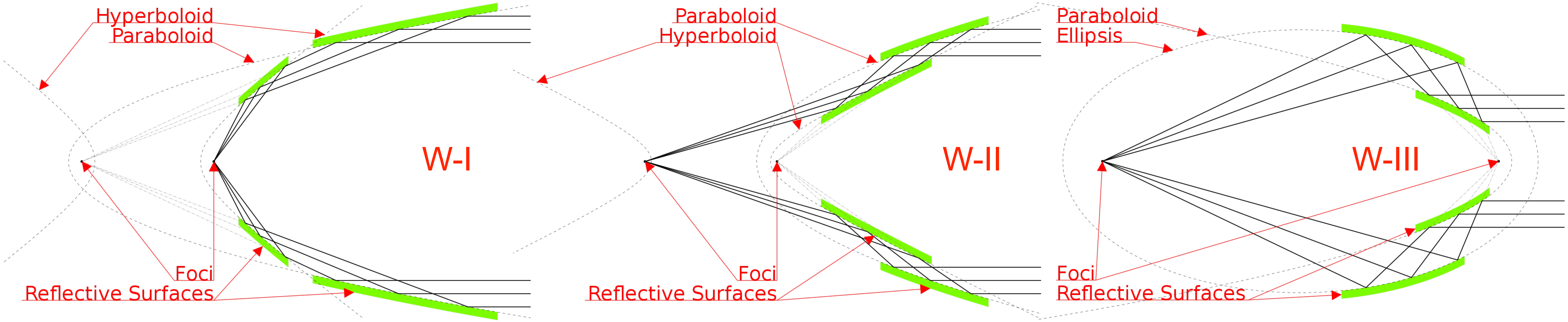


Ritchey-Chretien Telescope

SoHO/EIT
STEREO/EUVI

Primary mirror — Hyperbolic shape
Secondary mirror — Hyperbolic shape

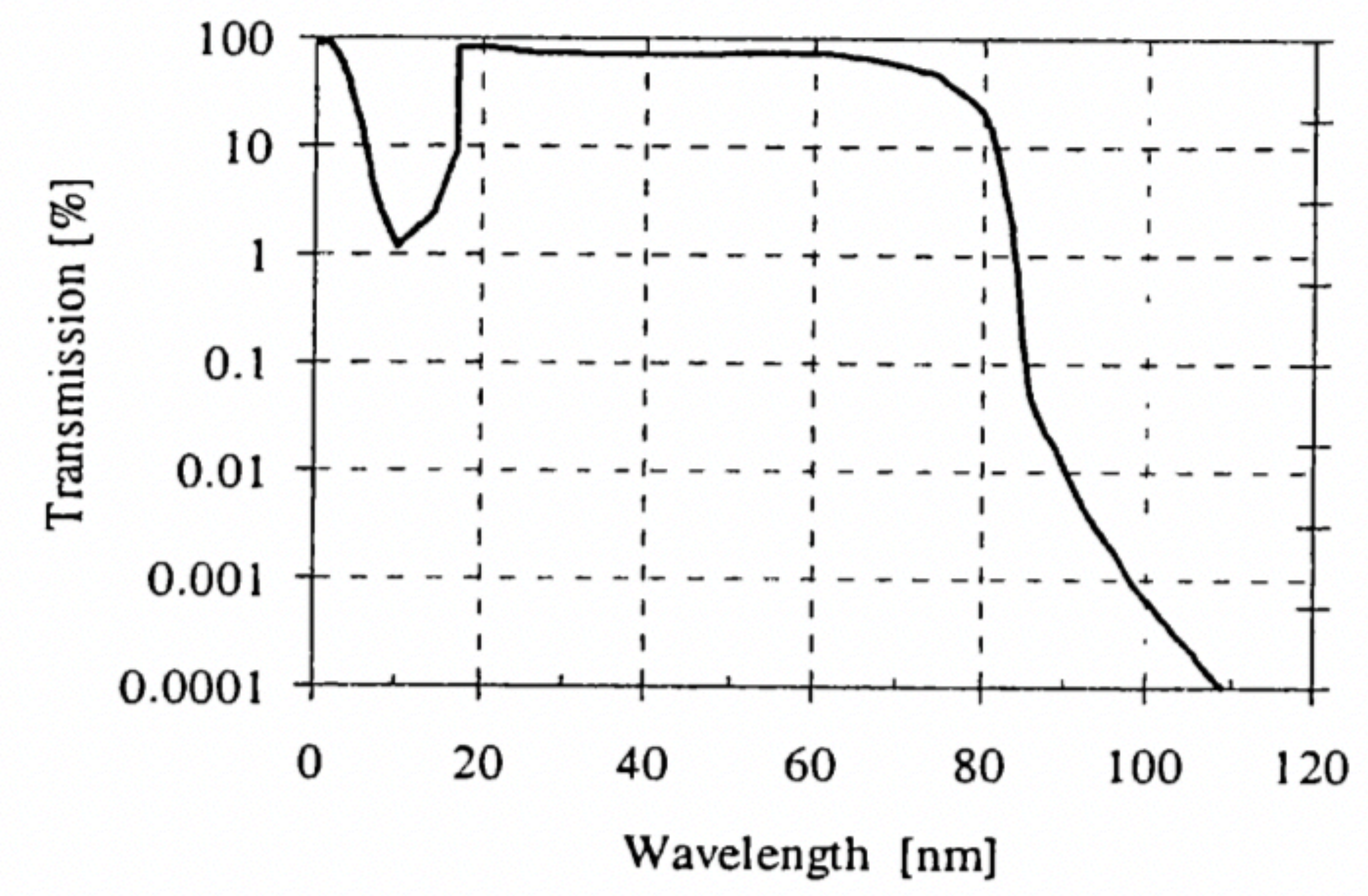
Wolter Telescope (grazing incidence)



How does an imaging instrument work

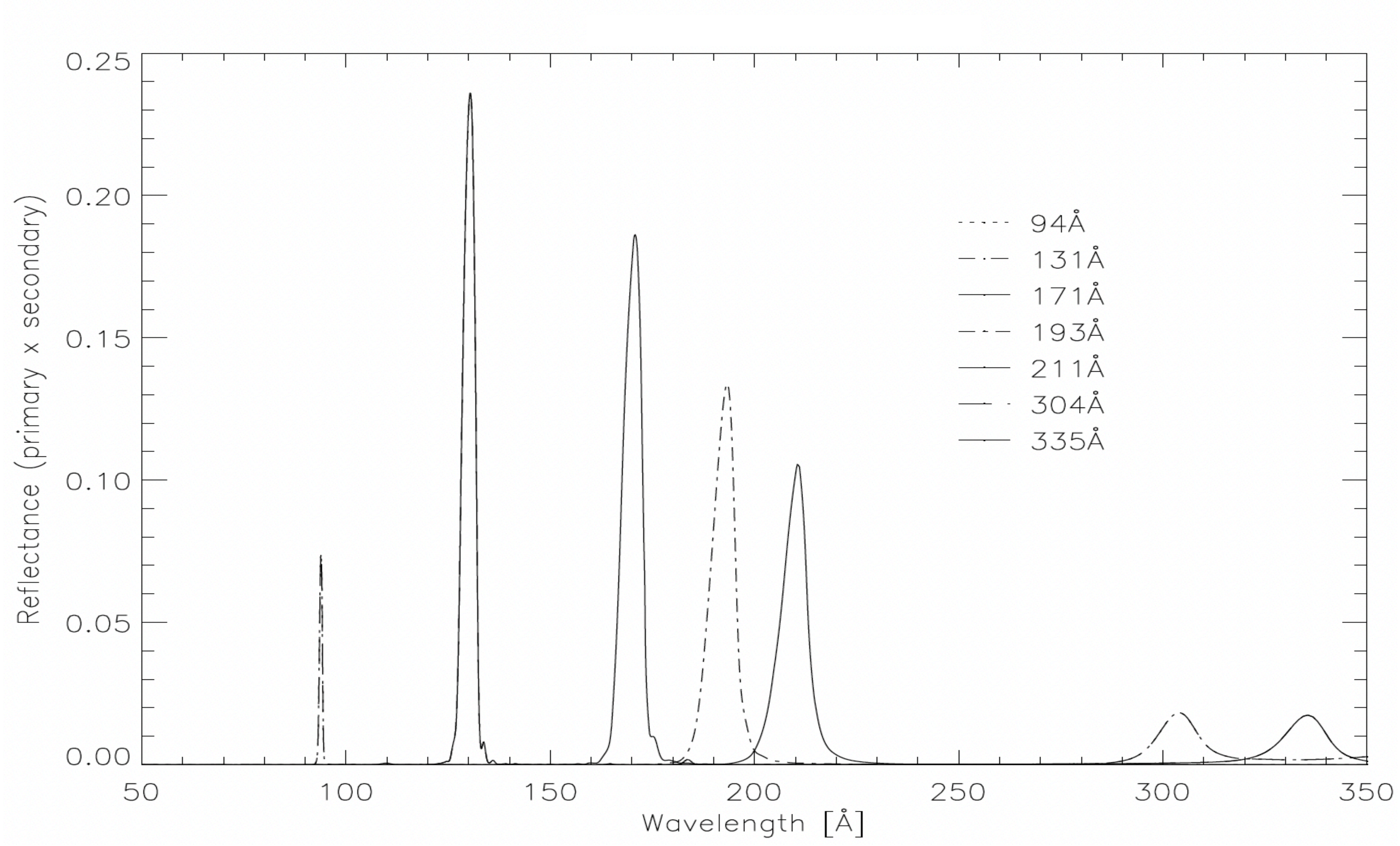
Selecting the wavelength range

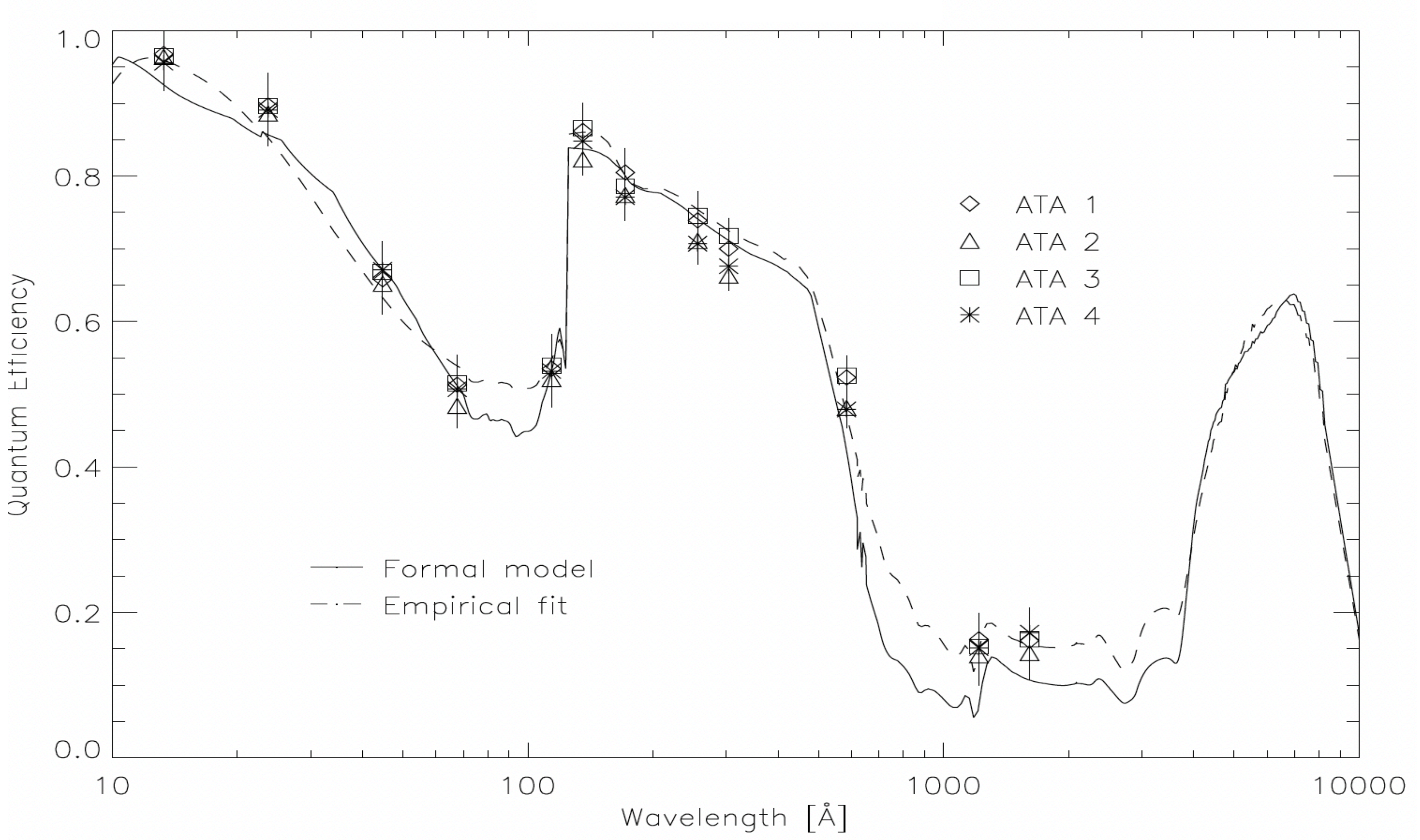
- Entrance filters transmissivity
  - Reject visible, IR light (keep instrument cool)
  - Transmit EUV radiation



- Mirror coatings reflectivity
  - Enhance reflectivity in desired narrow range
  - Suppress other ranges

- CCD quantum efficiency
  - Enhance sensitivity in desired wavelength ranges



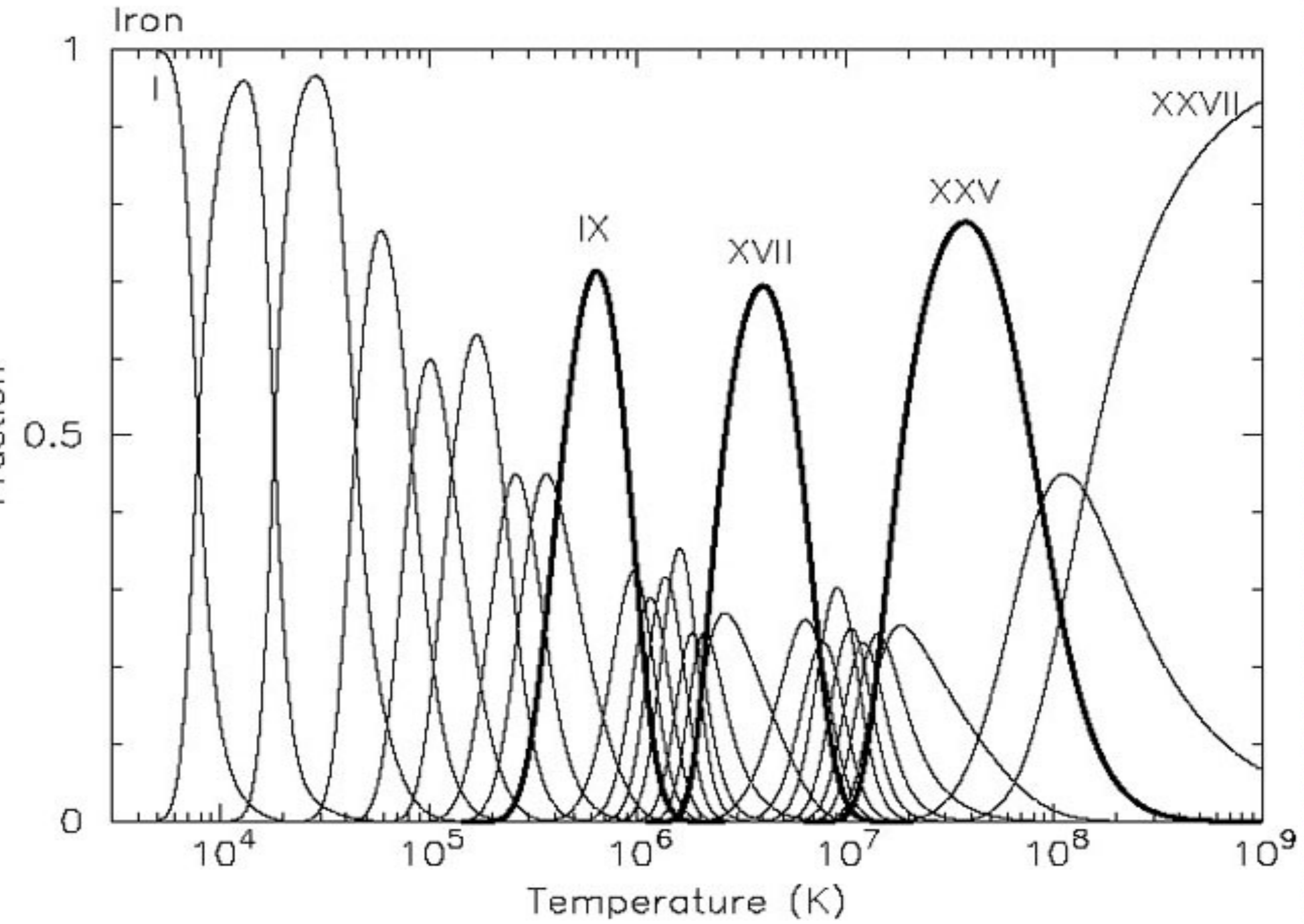


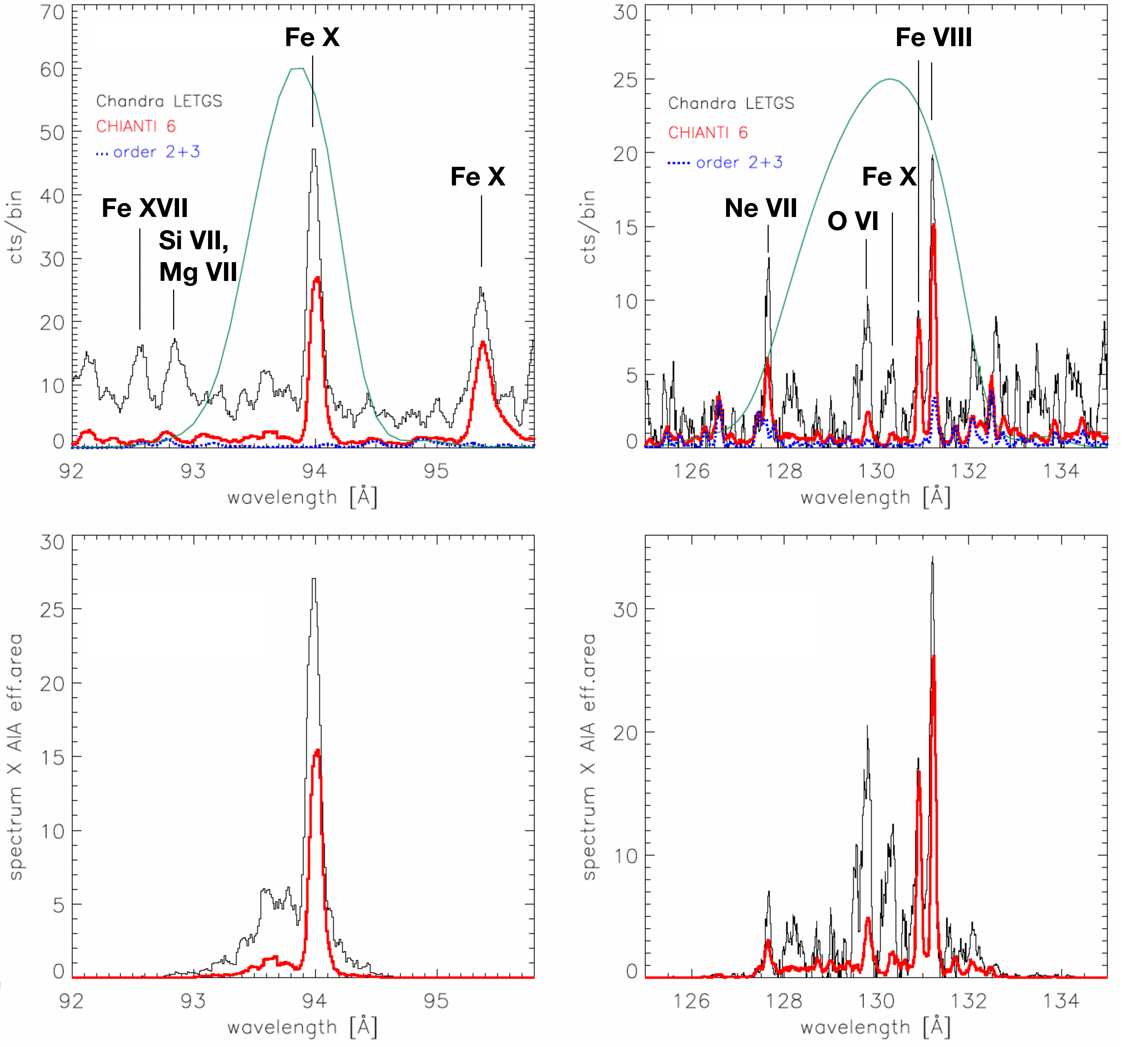
How does an imaging instrument work

Combined coating/filter effect selects the *Effective Area*

Make whole channel sensitive to very few lines/ions

Individual ions are formed in restricted temperature ranges





How does an imaging instrument work

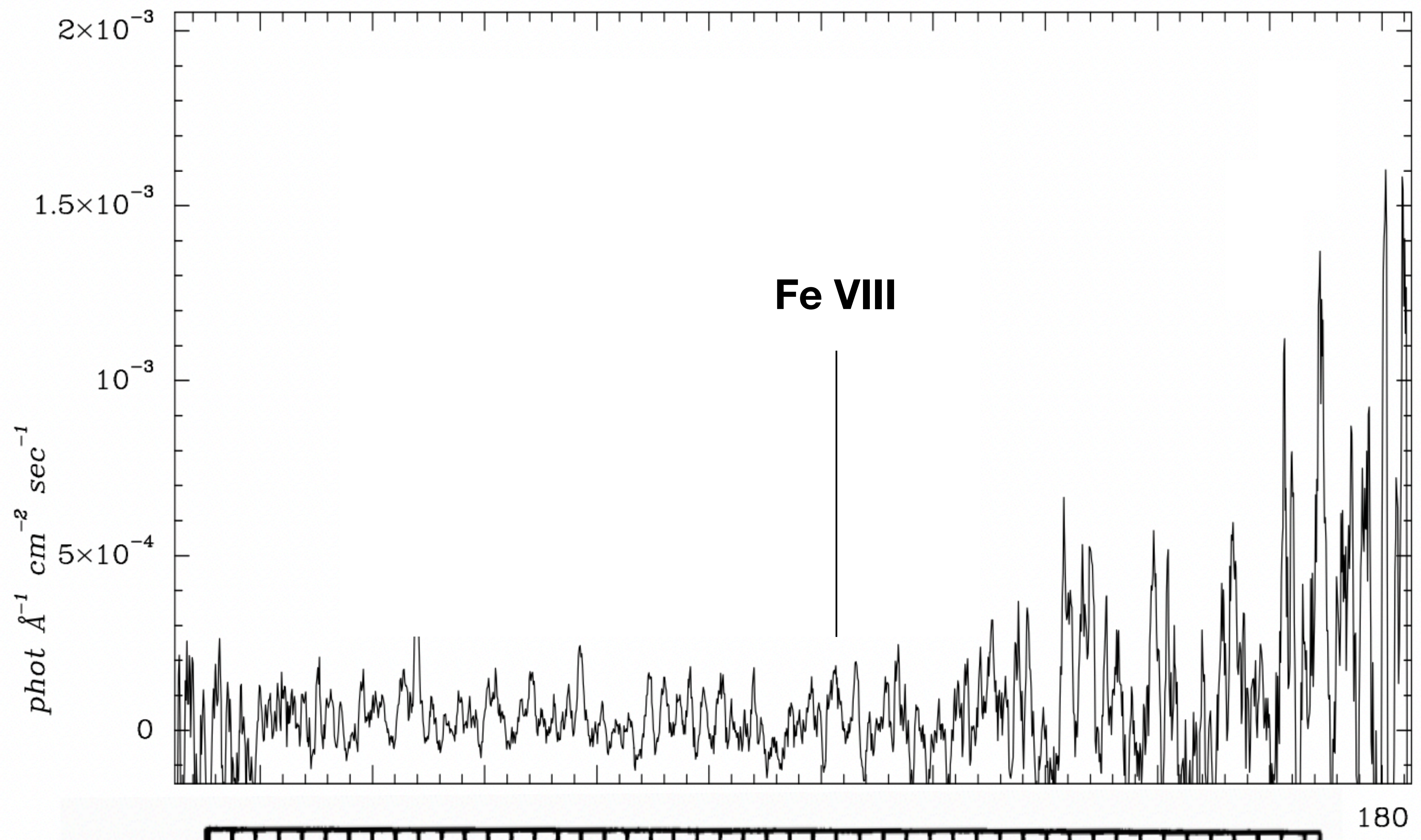
Pro and cons of filtering a spectrum

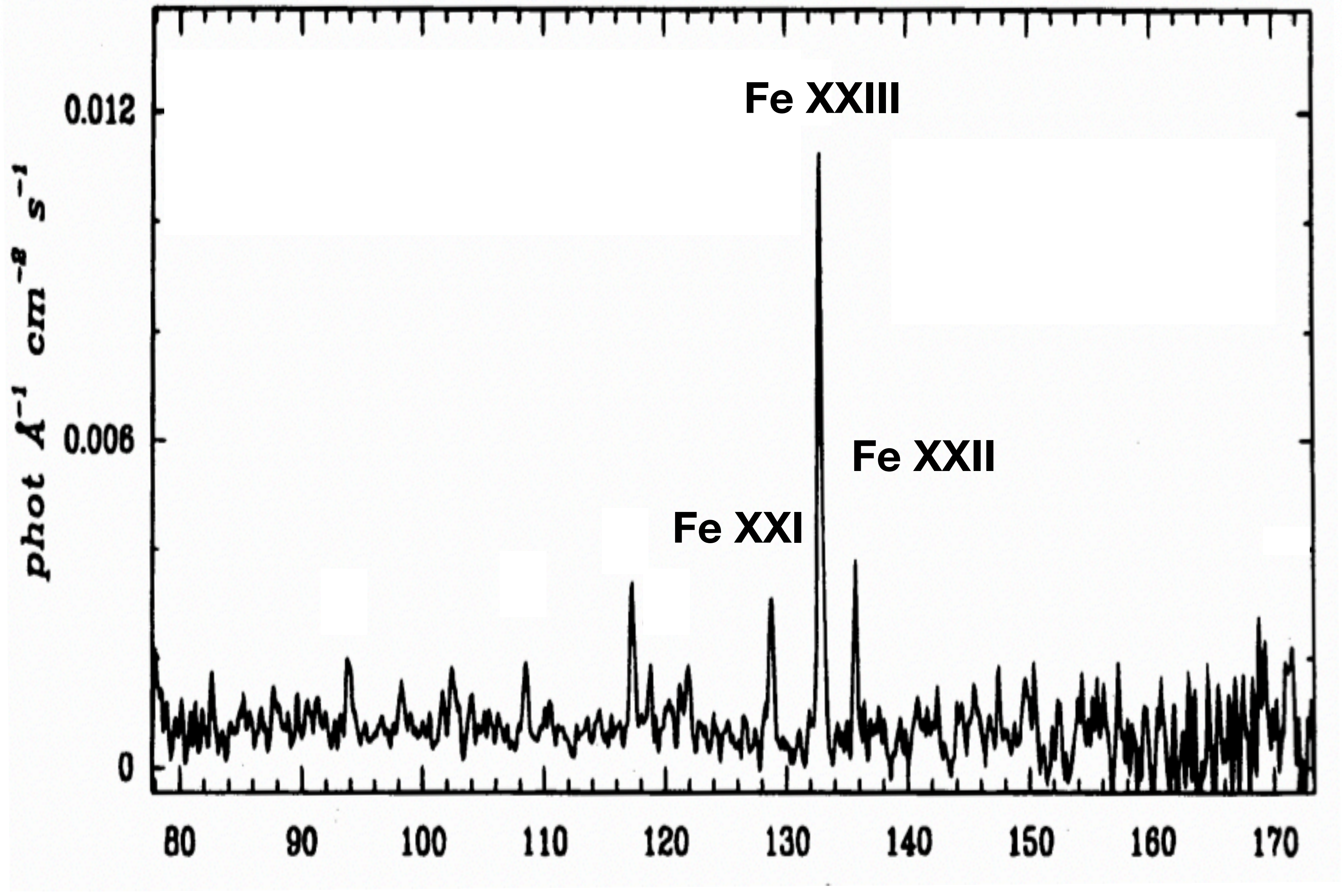
Pros:

- Improve temperature resolution over broadband imagers
- Create series of “temperature” movies
- Increase signal to noise ratio over spectrally resolved intensities

Cons:

- Contamination from other temperature regimes (presence of other lines/ions)
- Change of spectrum during solar activity (“dual” channels)

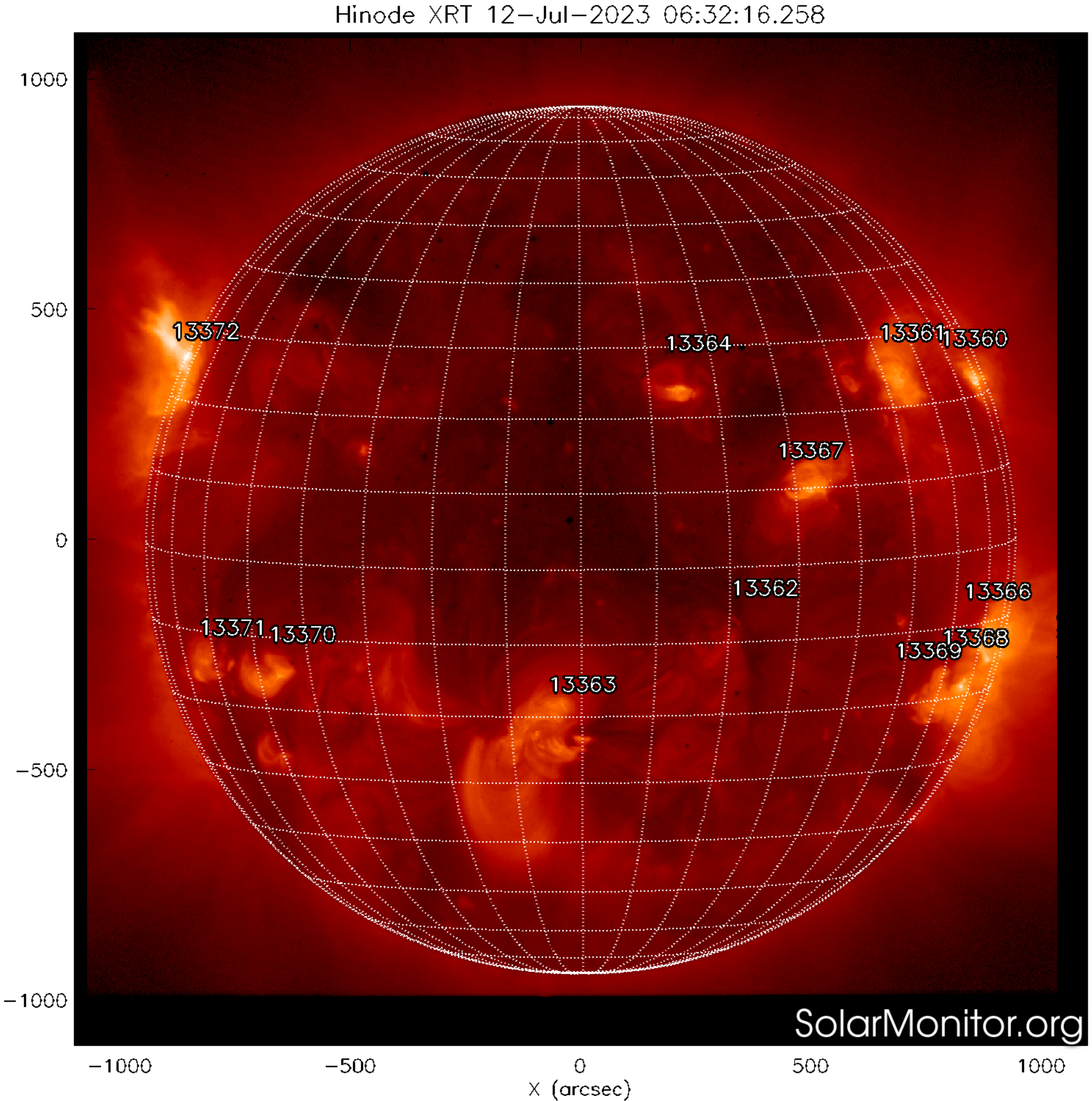




Making choices

Choosing the right lines

- Select the physics you would like
  - Quiescent vs. activity
  - Disk vs. limb vs. both
- Pick the right wavelength range
  - Activity suggests X-rays



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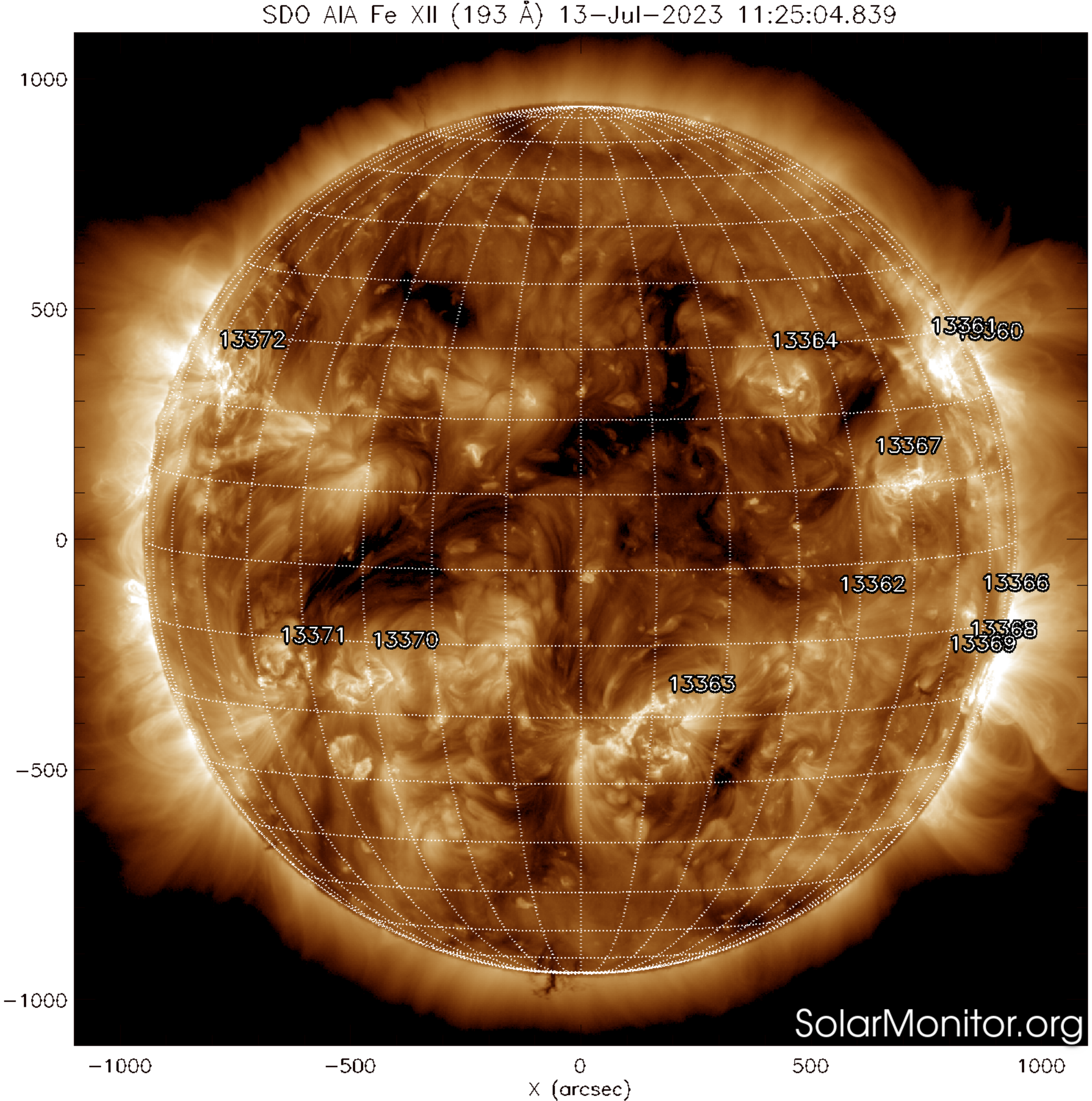

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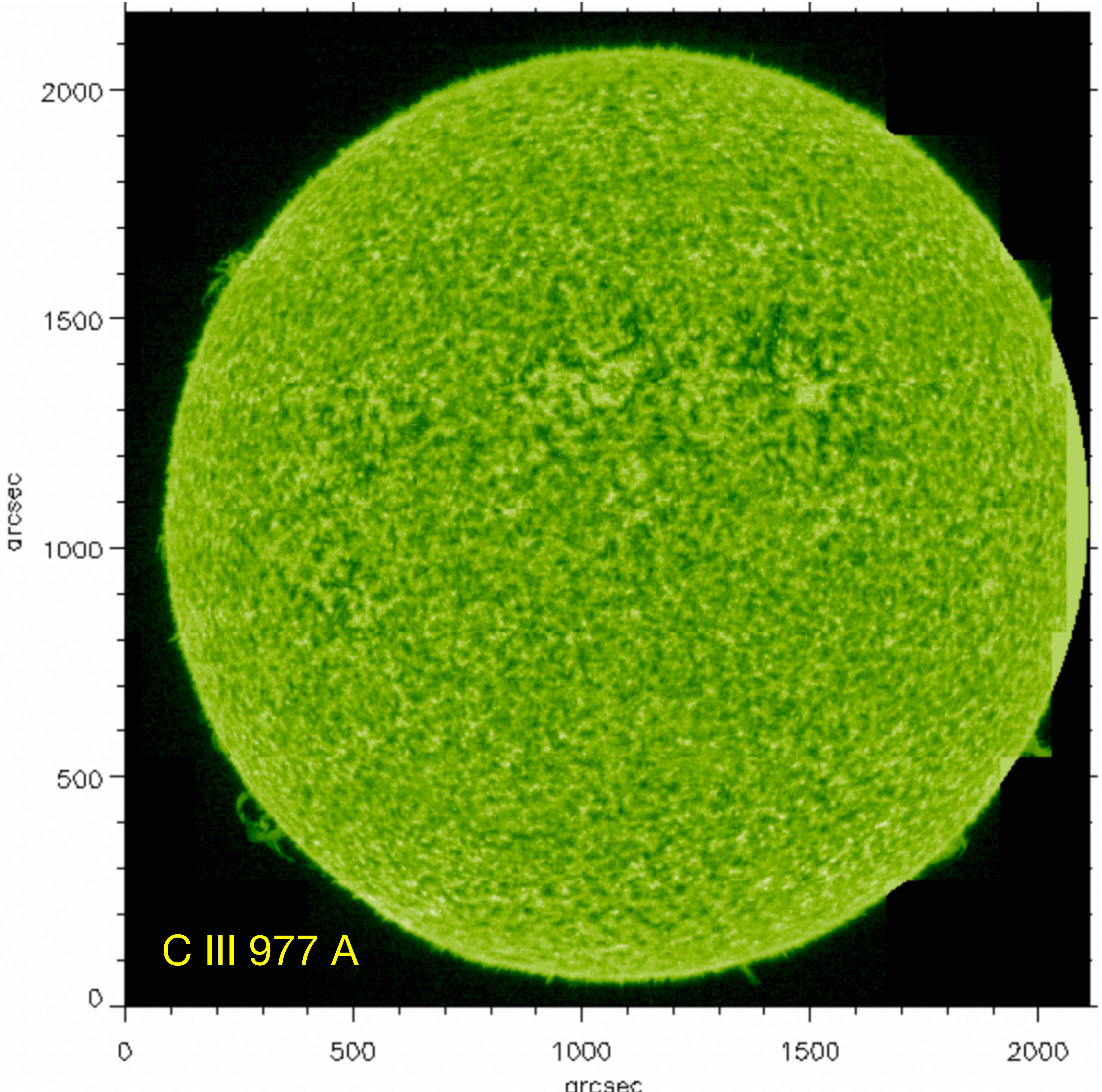
  - Colder stuff has several options



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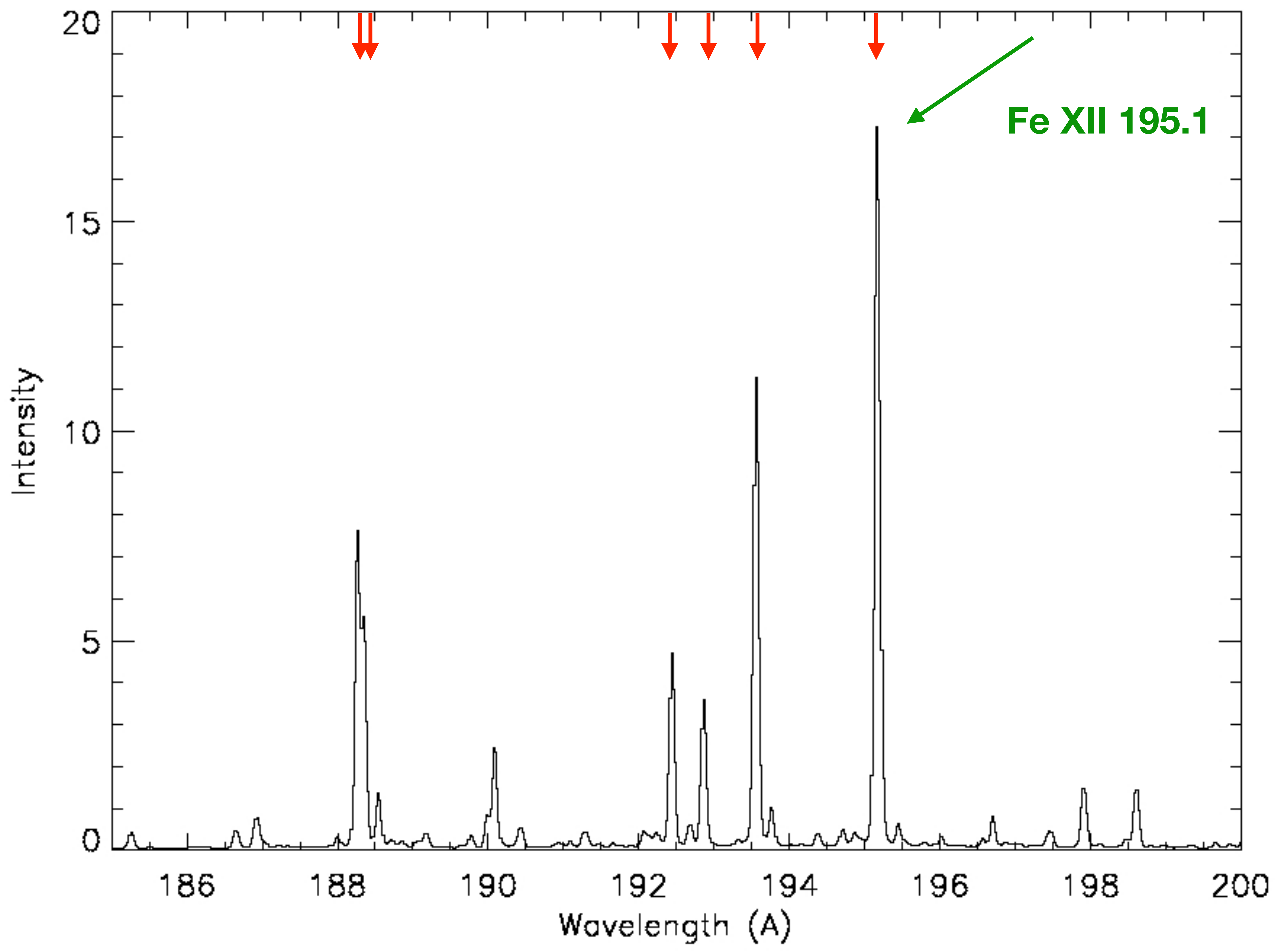
  - Colder stuff has several options
- Pick the right spectral lines
  - Bright
  - Isolated
  - Might choose “dual channels”



Making choices

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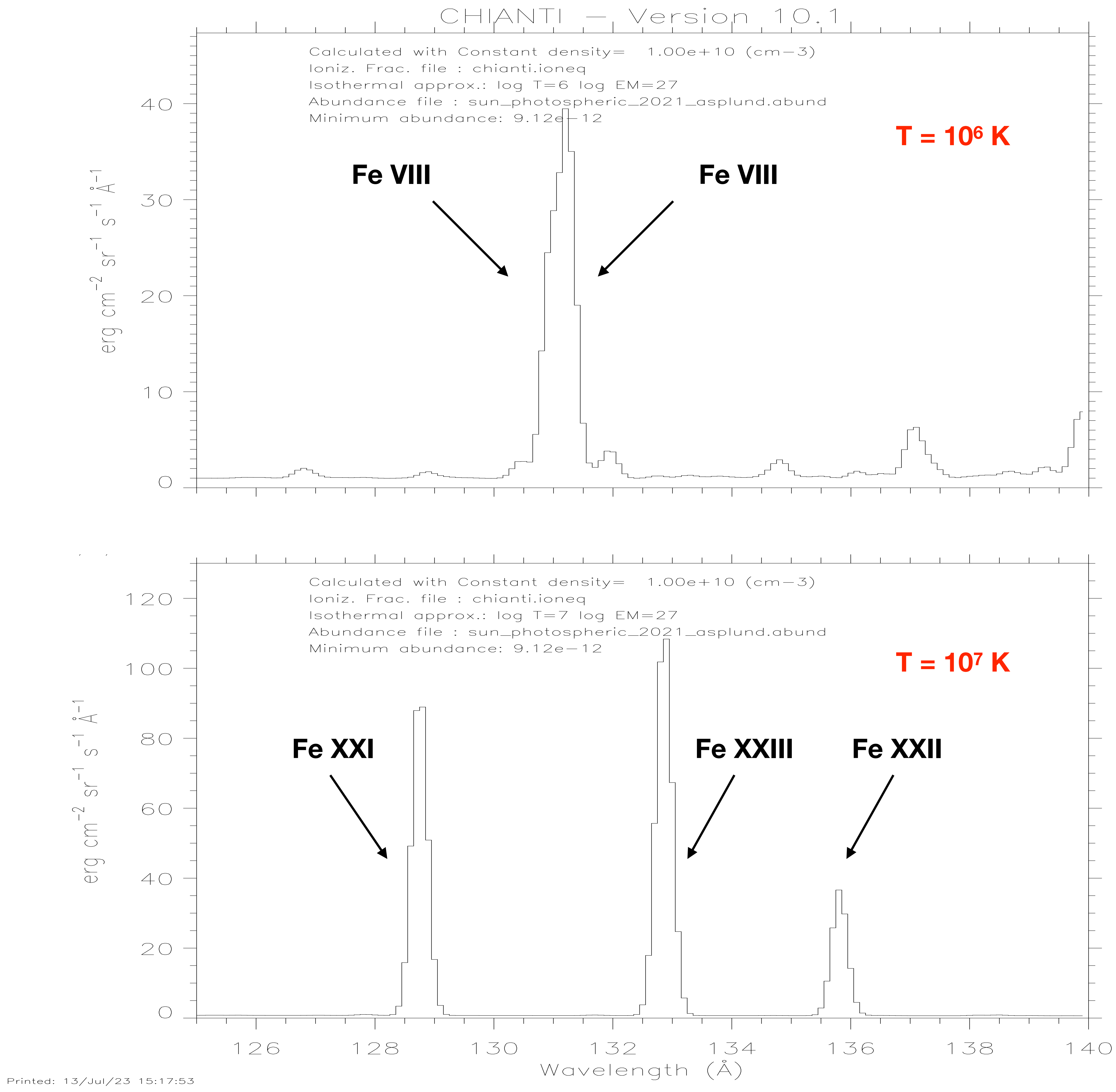
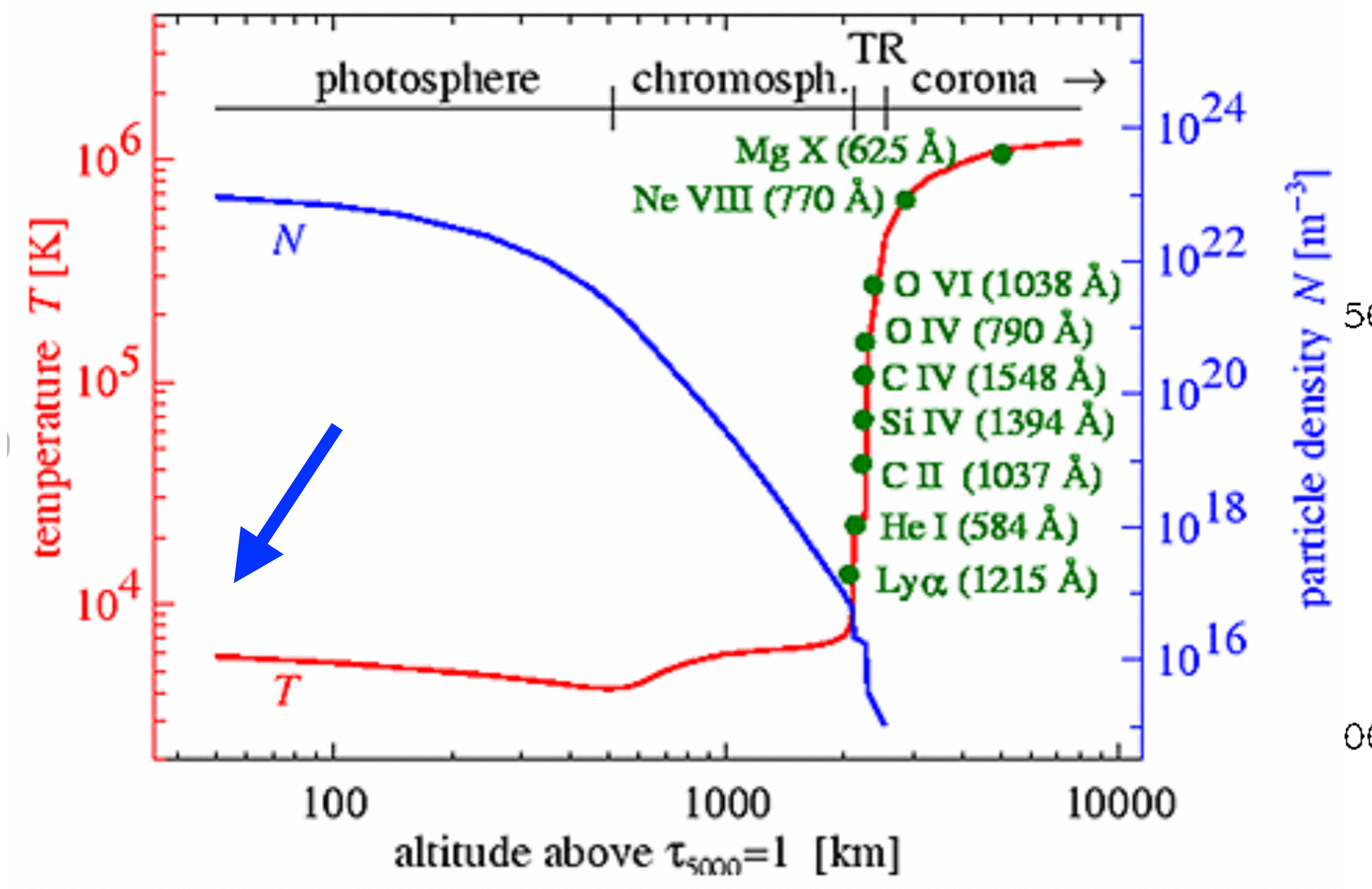
  - Colder stuff has several options
- Pick the right spectral lines
  - Bright
  - Isolated
  - Might choose “dual channels”
    - At different temperatures different lines dominate

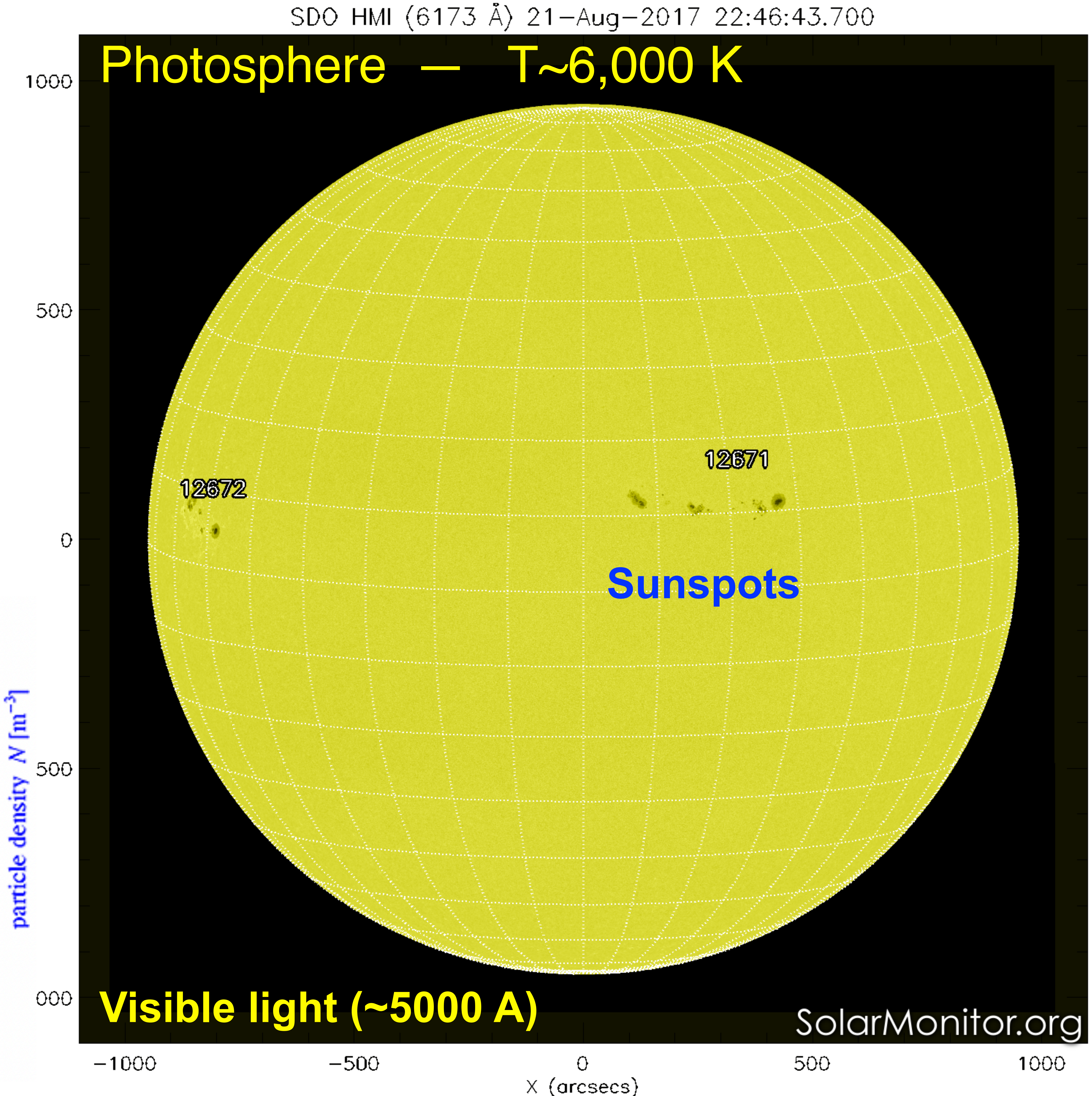


Viewing the Sun across the electromagnetic spectrum

Your everyday Sun

- Disk visible emission due to Black body radiation
- Cooler sunspots appear as dark spots
- Solar atmosphere can not be observed in the visible….





Viewing the Sun across the electromagnetic spectrum

Your everyday Sun

- Disk visible emission due to Black body radiation
- Cooler sunspots appear as dark spots
- Solar atmosphere can not be observed in the visible….
- ….except when it can
  - Need to block disk radiation Somehow
  - Coronal emission is around 1 million times fainter than solar disk
  - Thomson scattering, coronal spectral lines

Viewing the Sun across the electromagnetic spectrum

Your everyday Sun

Disk visible emission due to
Black body radiation

Cooler sunspots appear as
dark spots

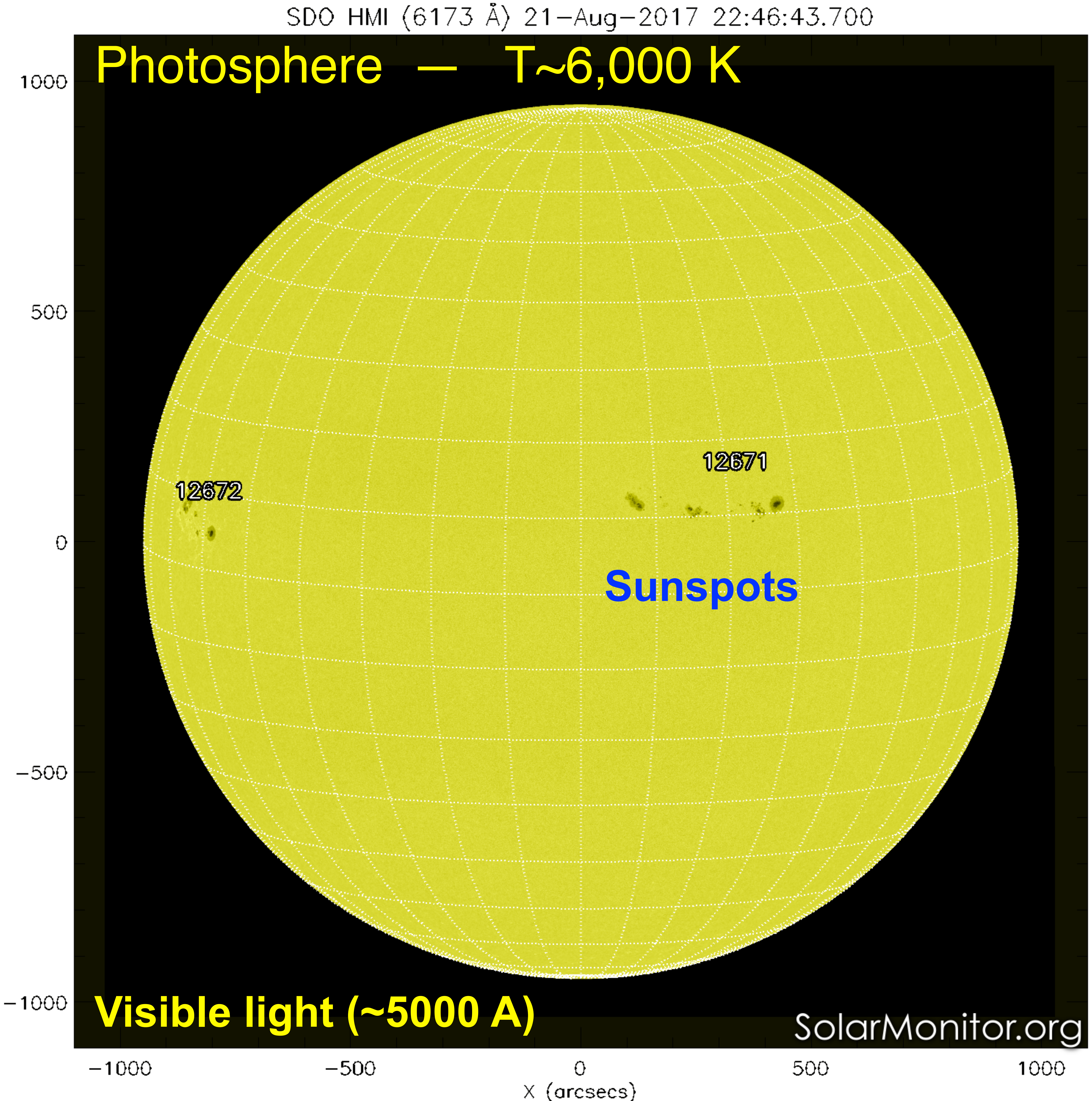
Solar atmosphere can not be
observed in the visible….

….except when it can

Need to block disk radiation
Somehow

Coronal emission is around
1 million times fainter than
solar disk

Thomson scattering, coronal
spectral lines



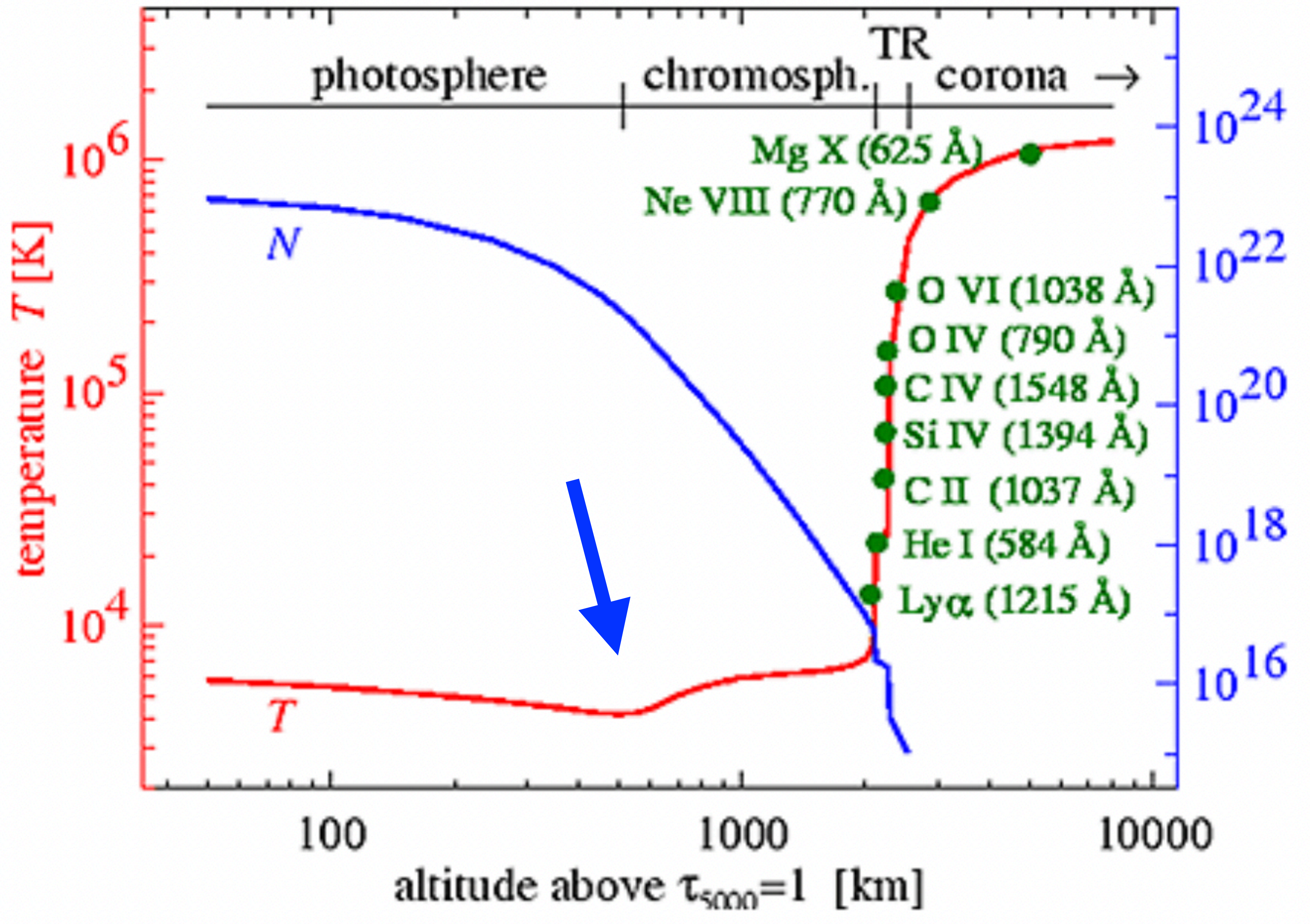
Viewing the Sun across the electromagnetic spectrum

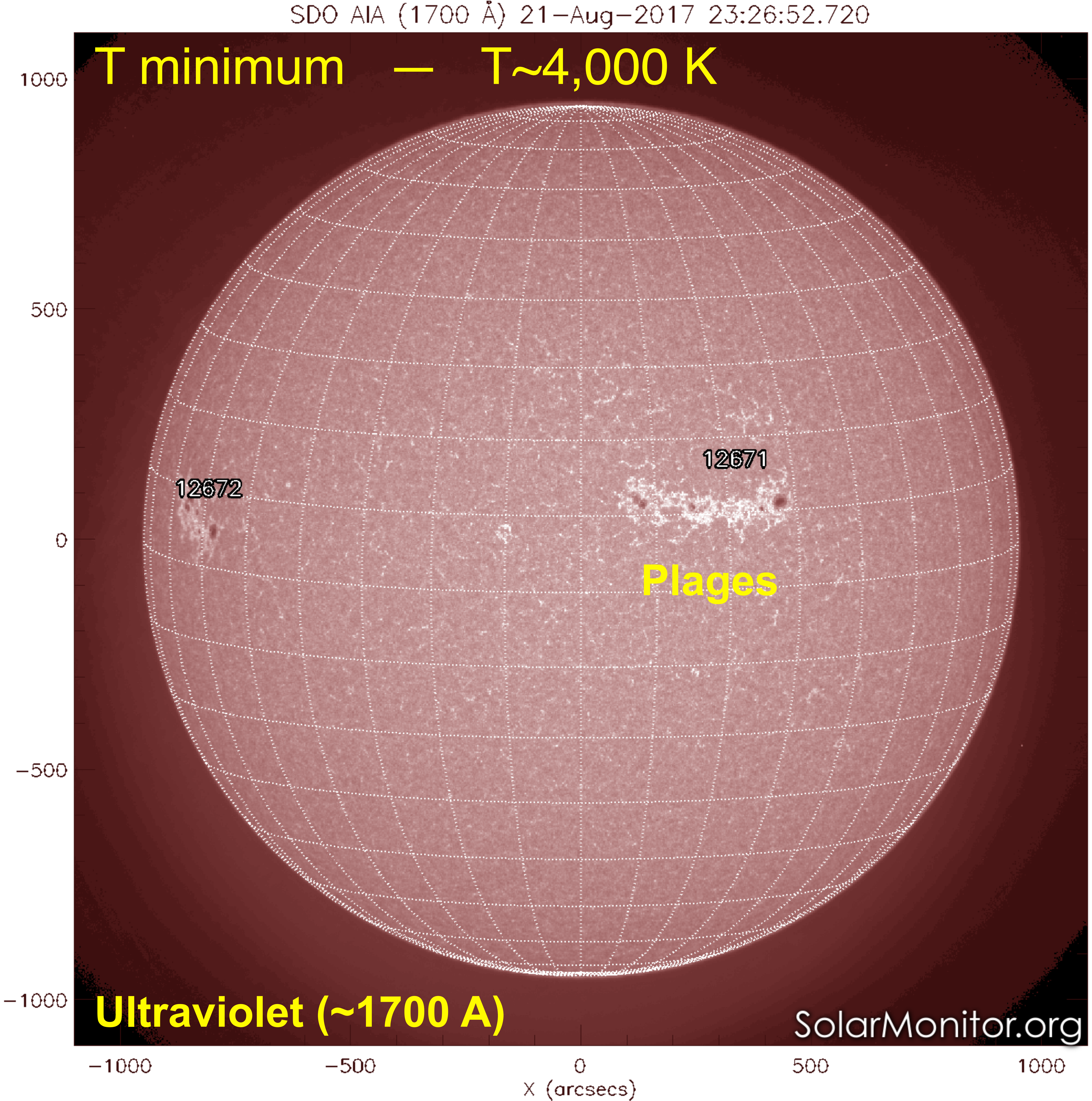
The temperature minimum

Temperature initially decreases above the photosphere

Some structuring is present

Recombination continuum contributes to emission





Viewing the Sun across the electromagnetic spectrum

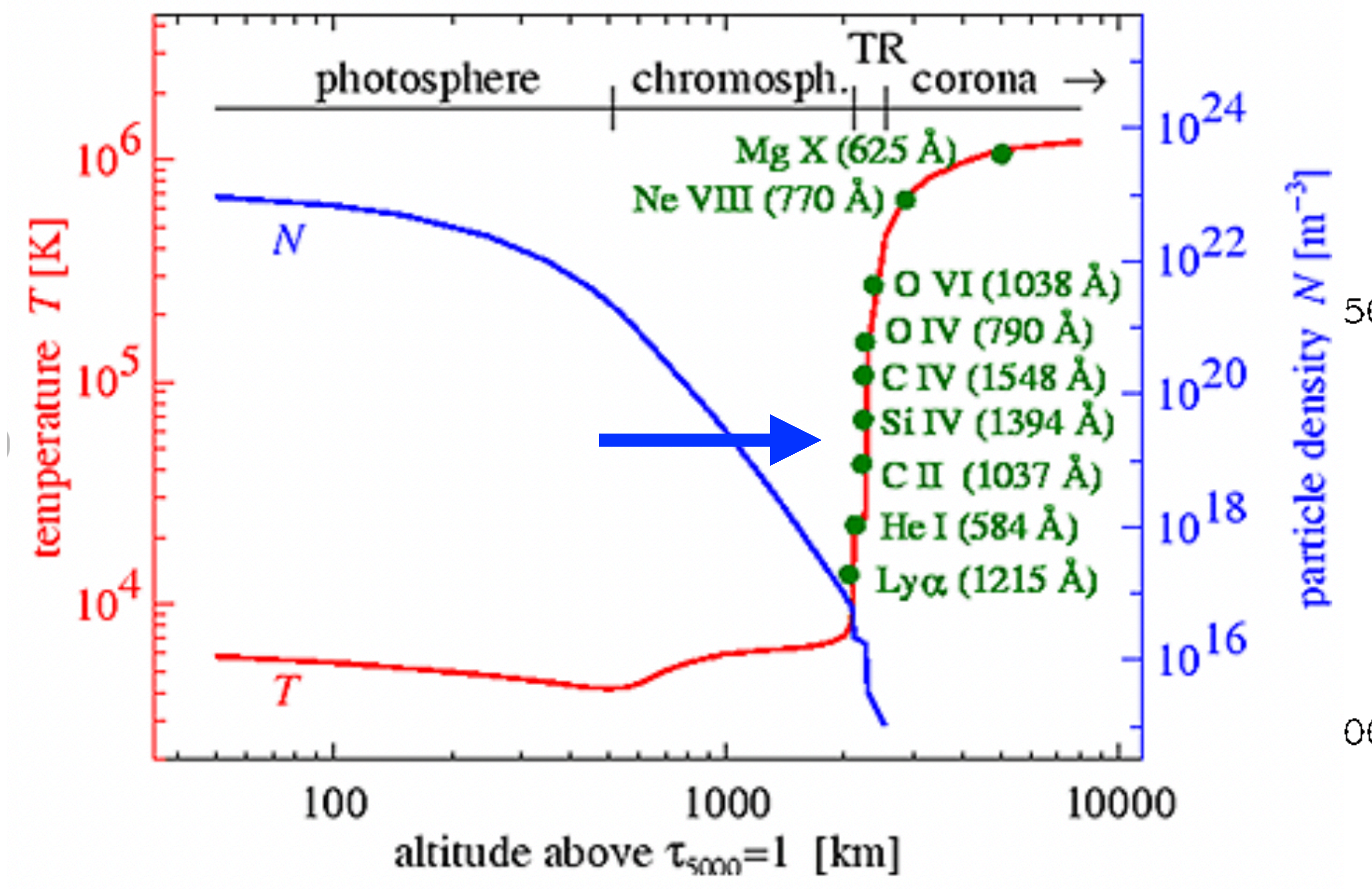
The Chromosphere

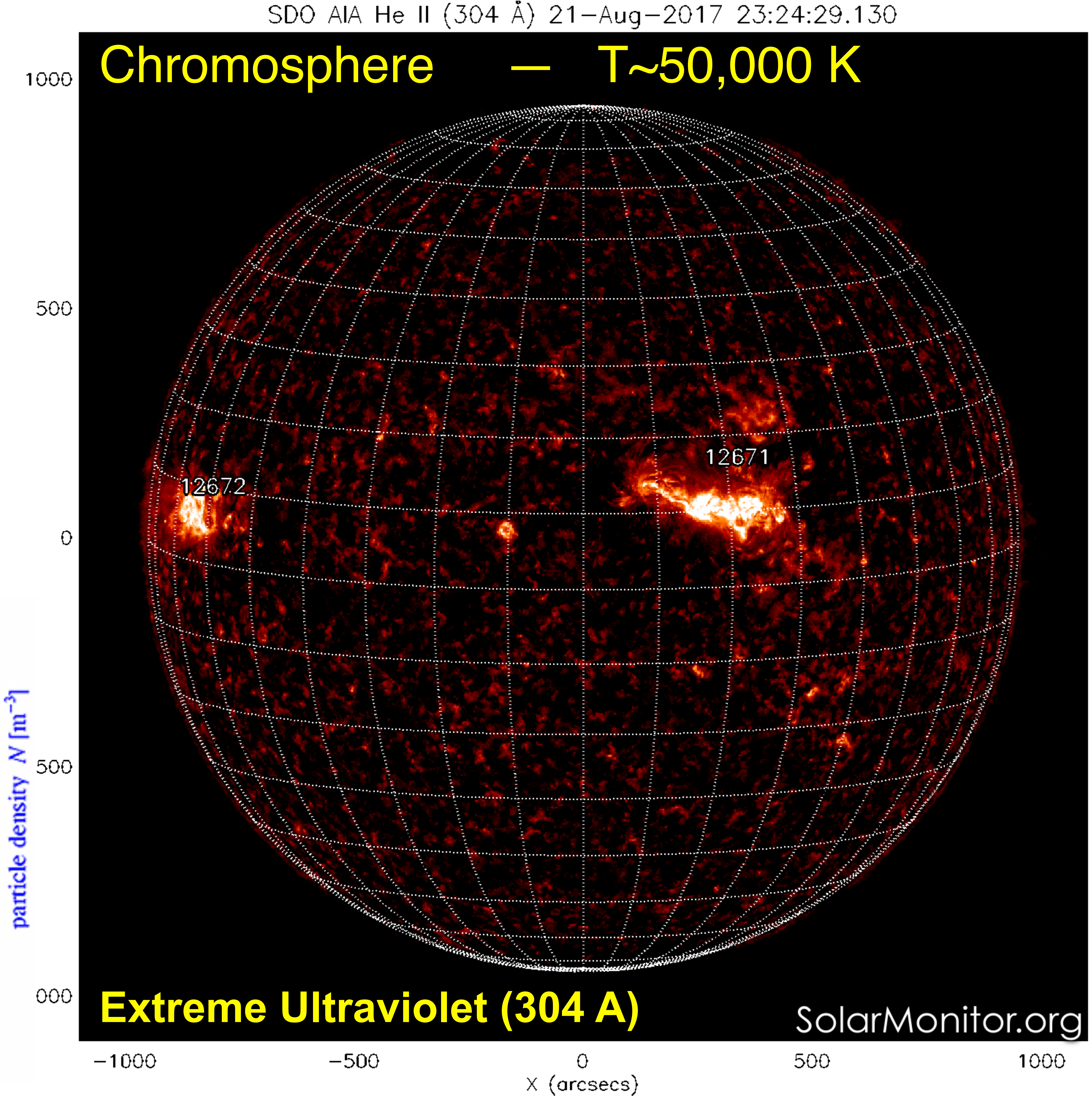
Temperature begins to increase

Highly structured region

Helium begins to be ionized

Very strong lines in the Lyman series of H I, He II





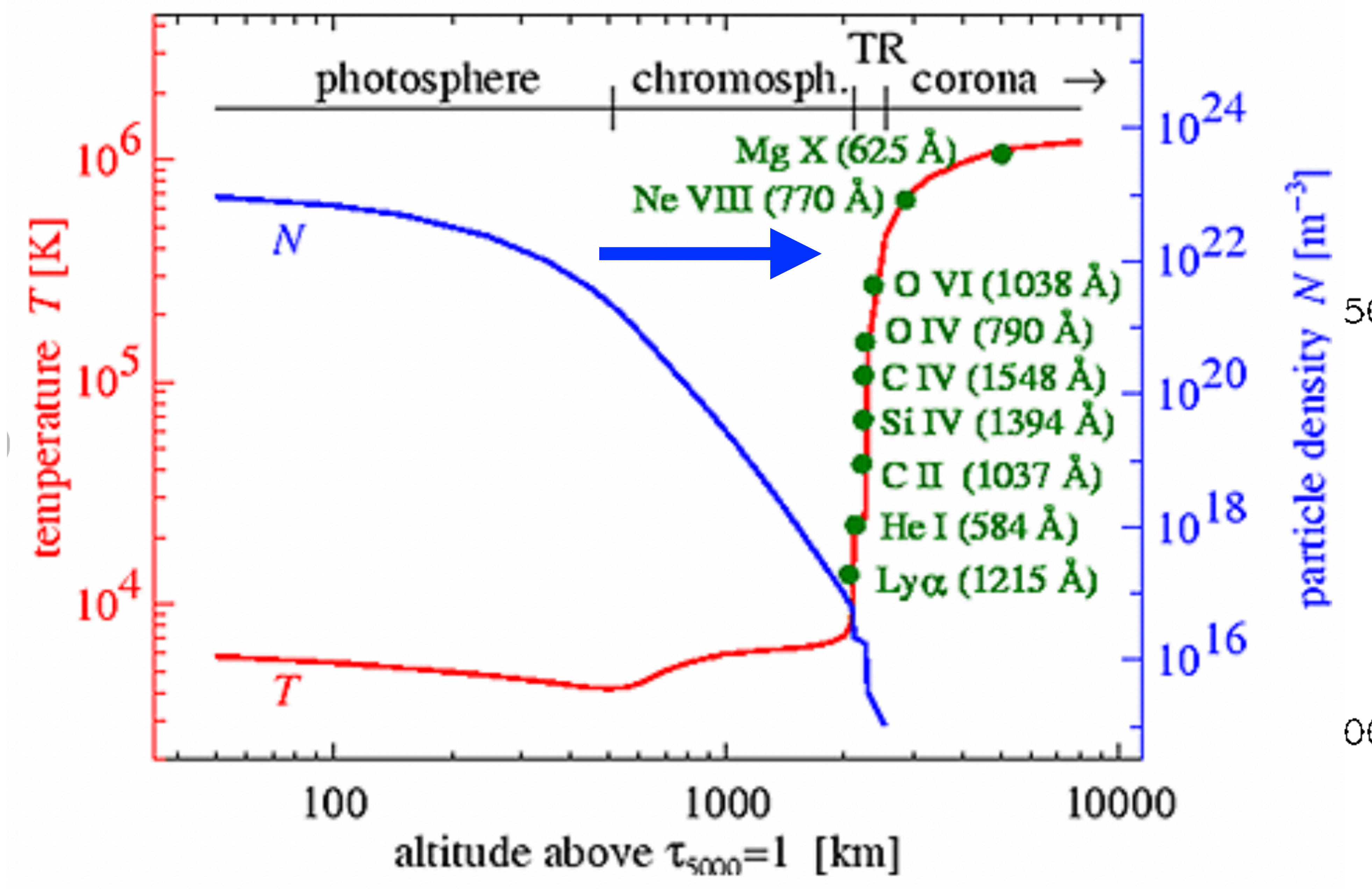
Viewing the Sun across the electromagnetic spectrum

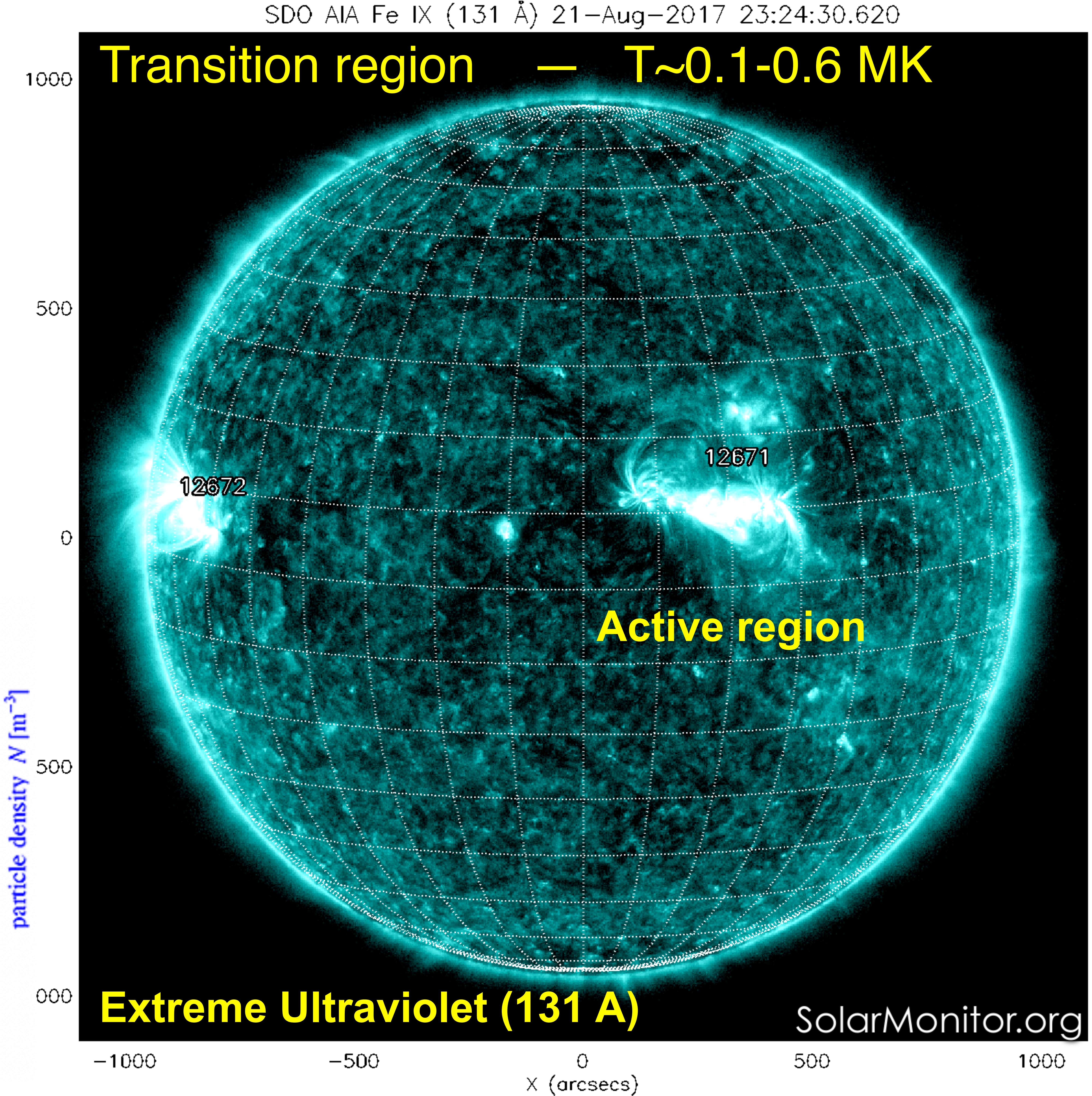
The Transition Region

"Dual" filter:

Structured transition region with Fe VIII

Very hot corona with Fe XXI-XXIII

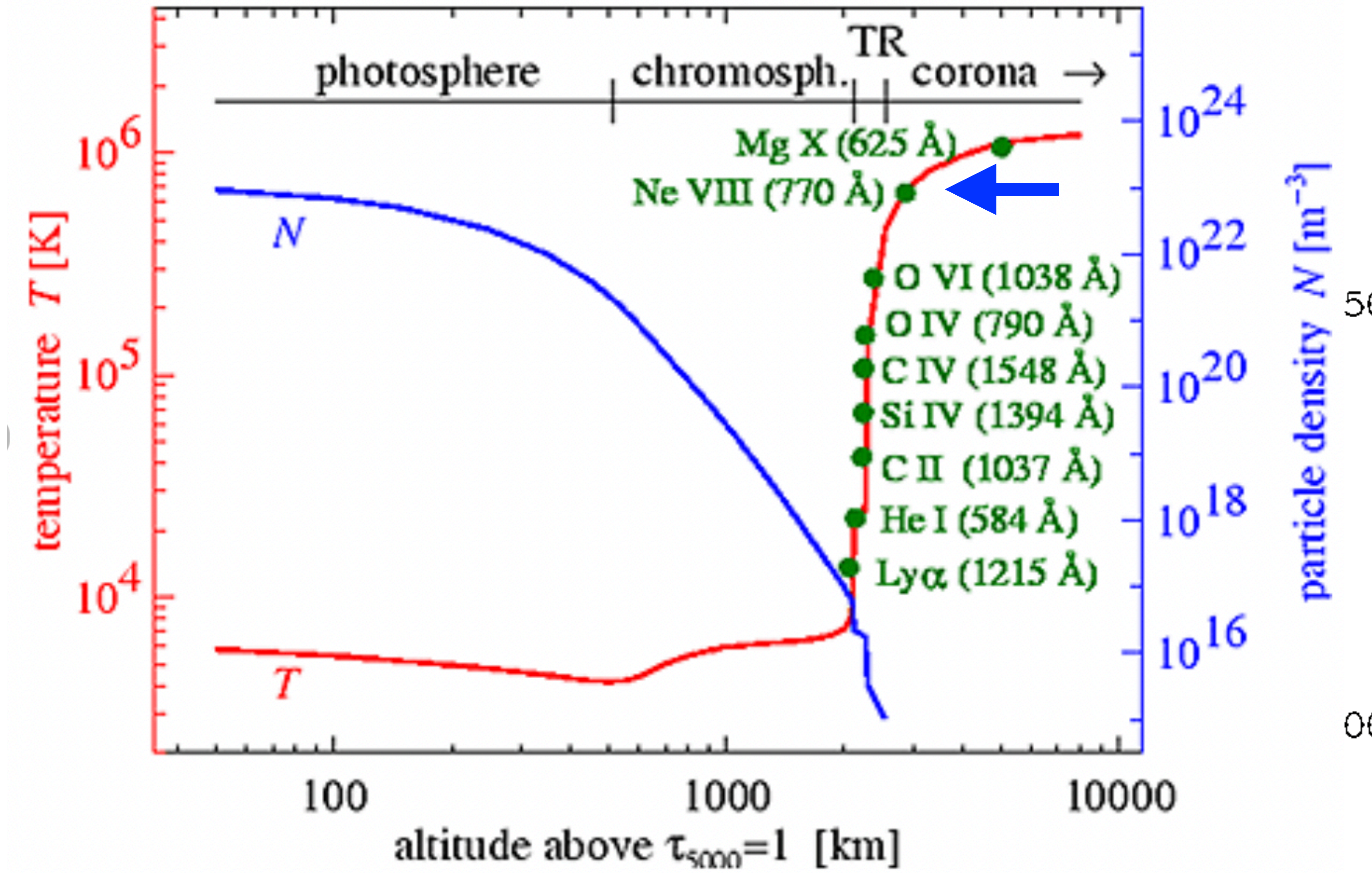


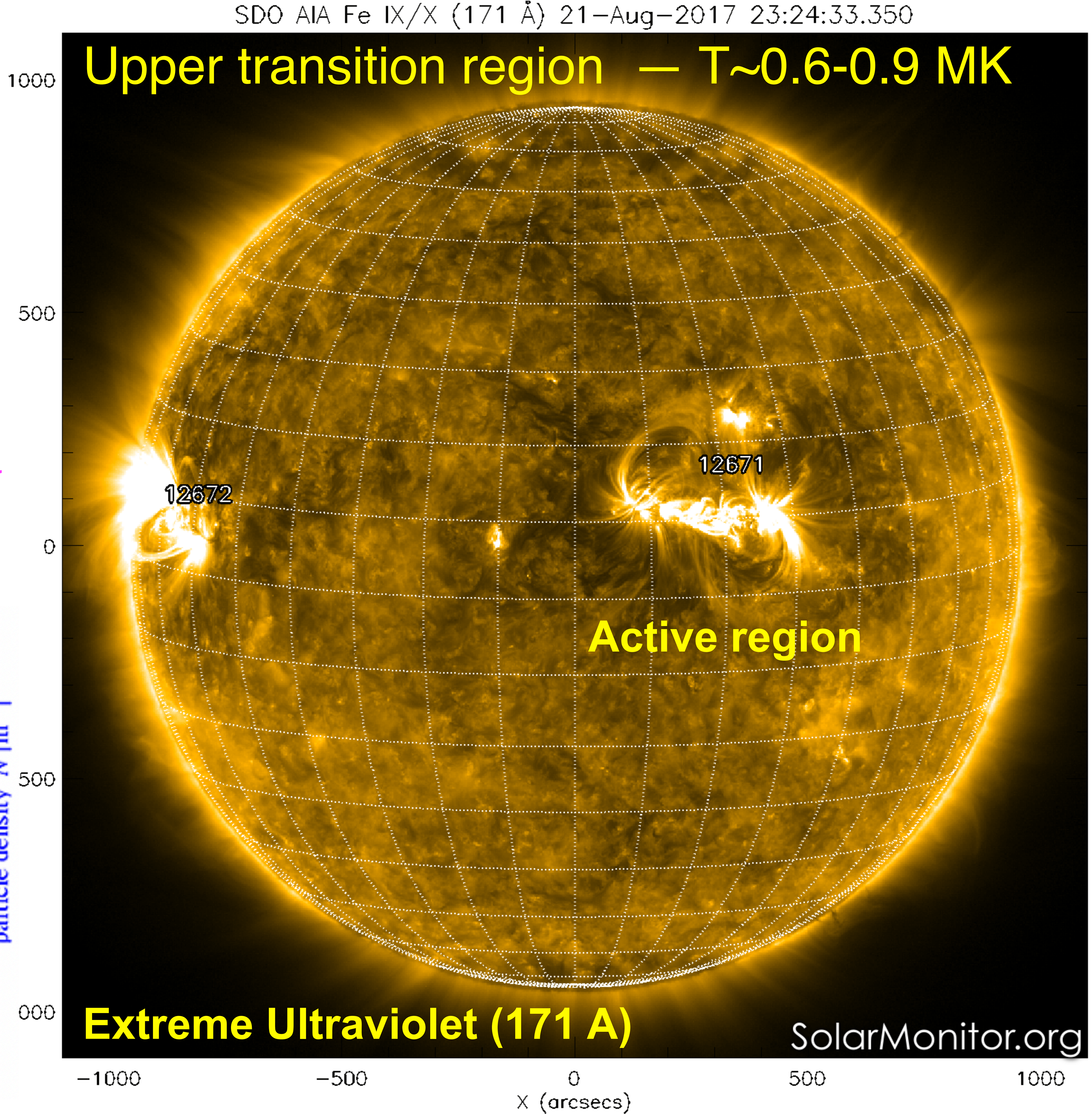


Viewing the Sun across the electromagnetic spectrum

The Upper Transition Region

- Fe IX is formed *both* in transition Region and corona
  - Structured transition region
  - More diffuse quiescent corona
  - Population of colder active region loops

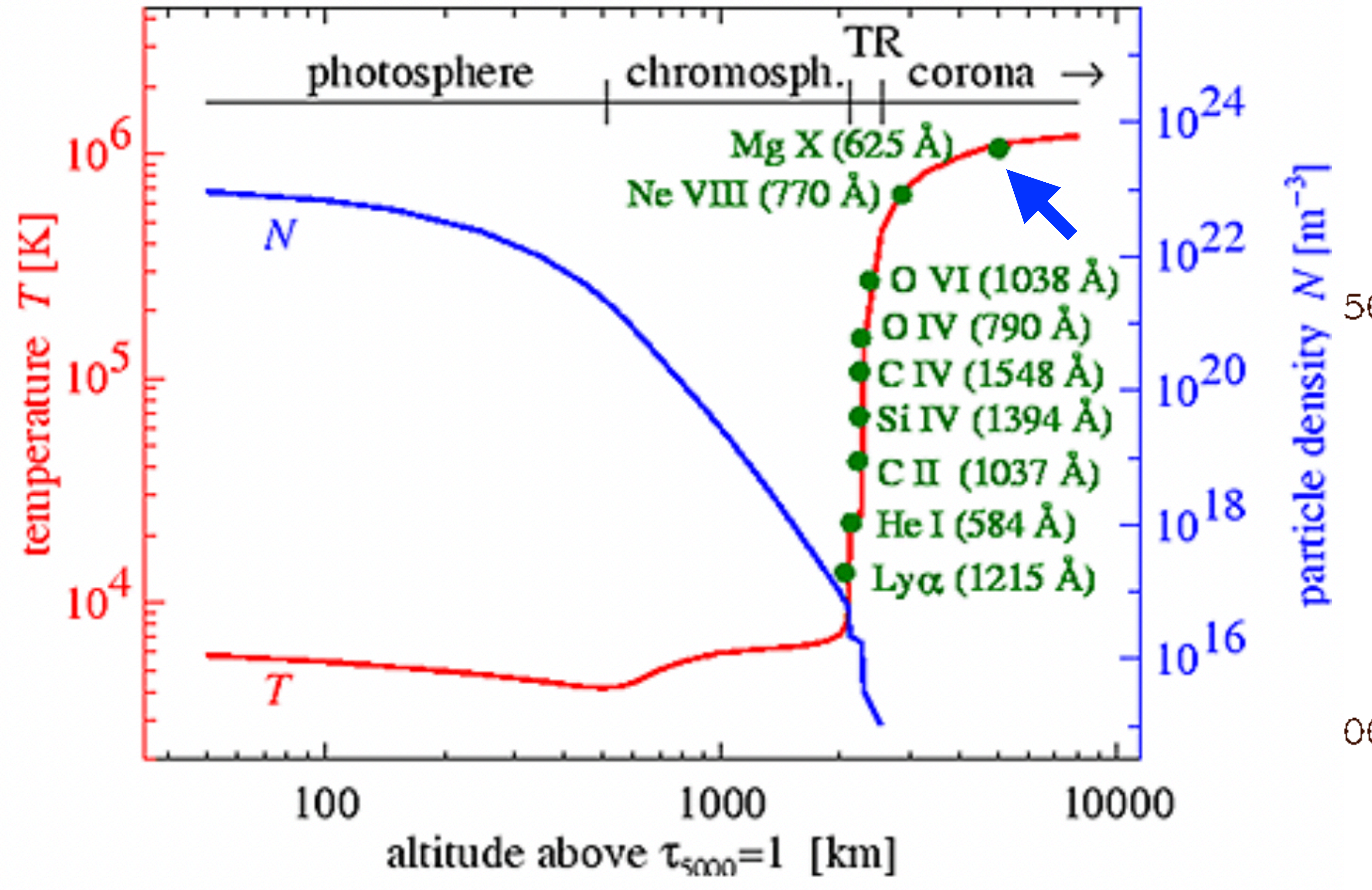


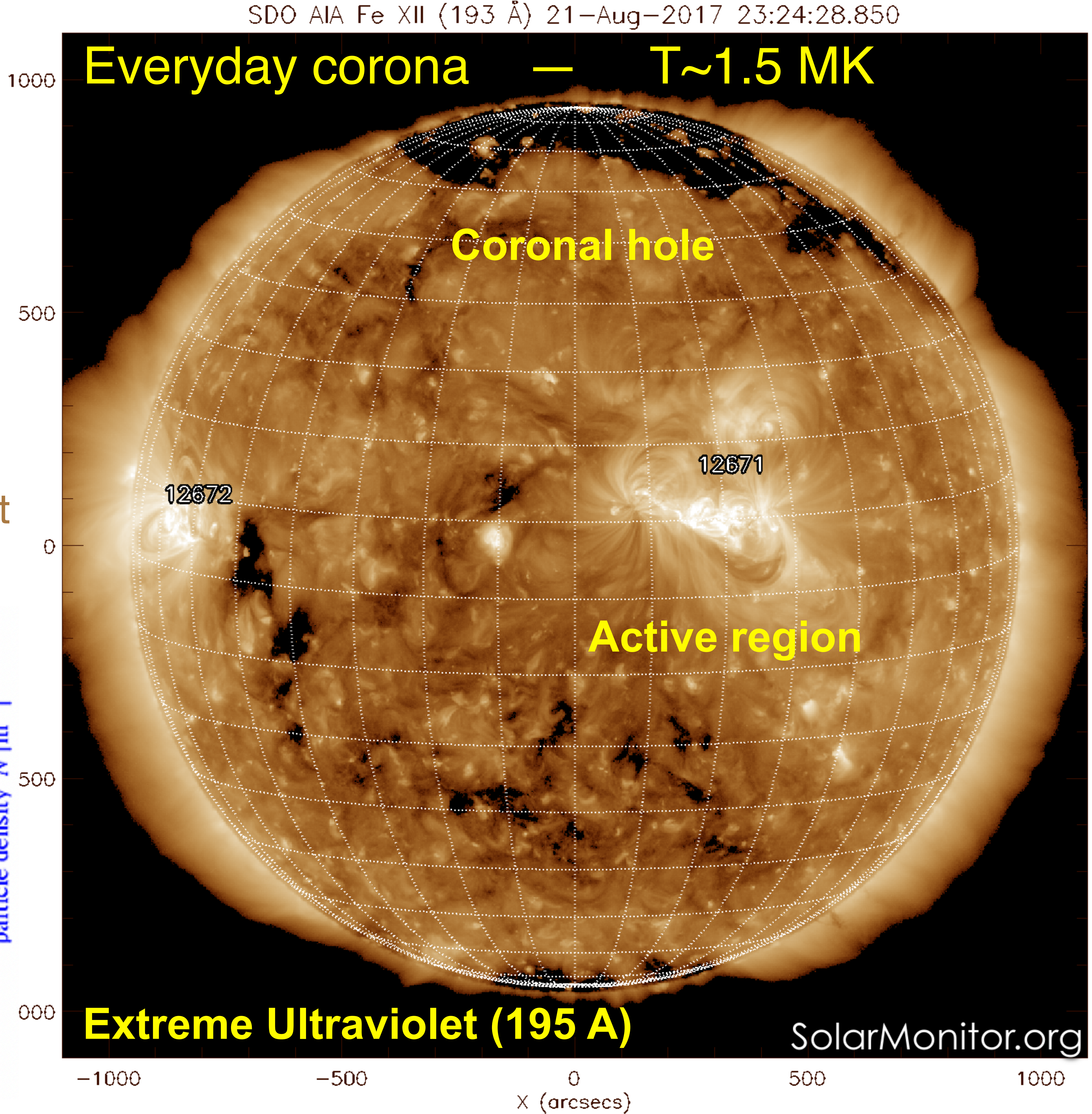


Viewing the Sun across the electromagnetic spectrum

The “everyday” corona:

- Fe XII is the typical coronal ion
  - Diffuse quiet Sun regions
  - Active region loops
  - Dark coronal holes:
    - Colder plasma emits less at Fe XII temperatures





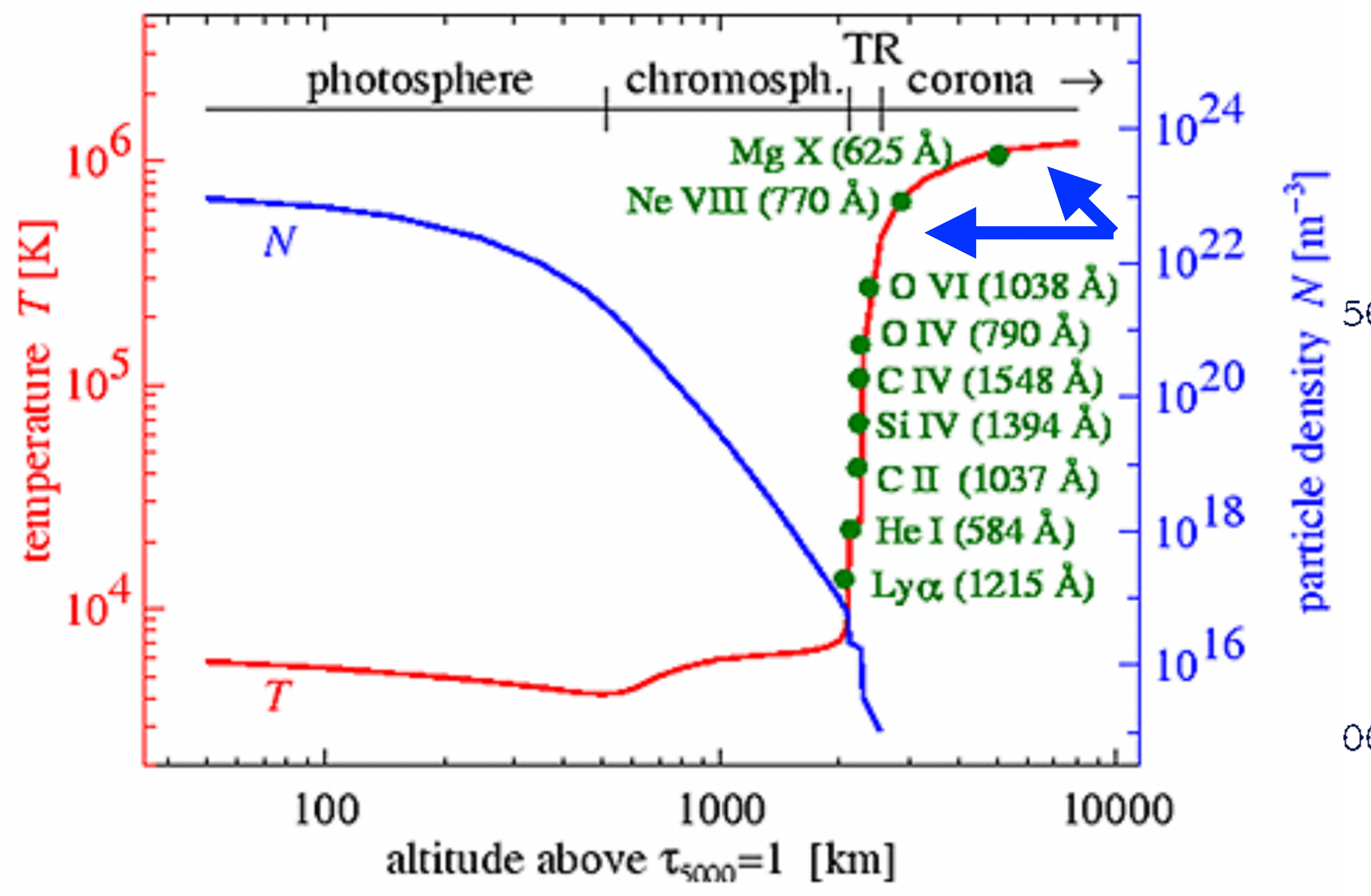
Viewing the Sun across the electromagnetic spectrum

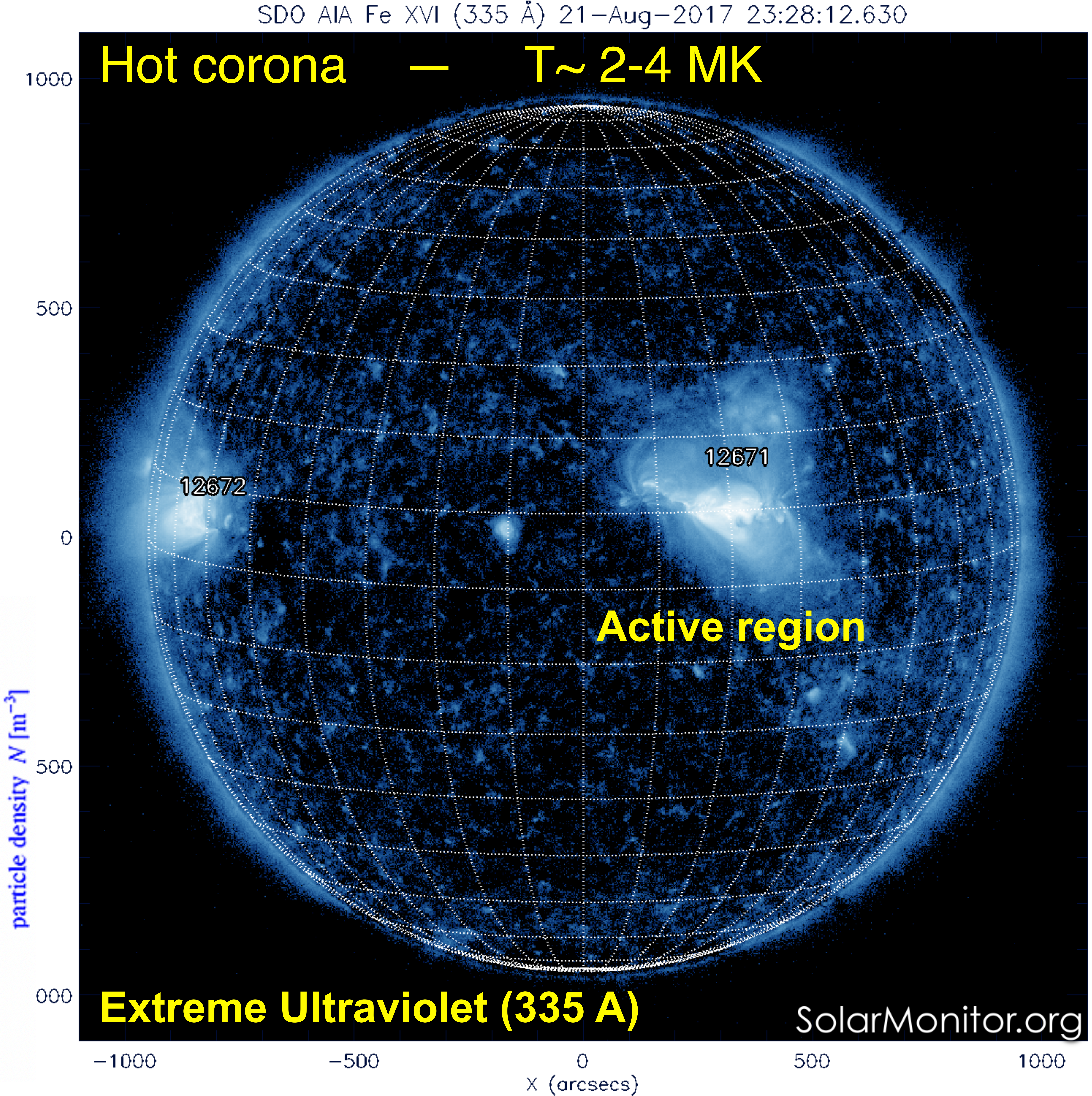
Another hybrid filter

"Dual" filter:

Structured transition region with Si IX, Mg VIII, Fe IX

Hot active region loops with Fe XIV, Fe XVI





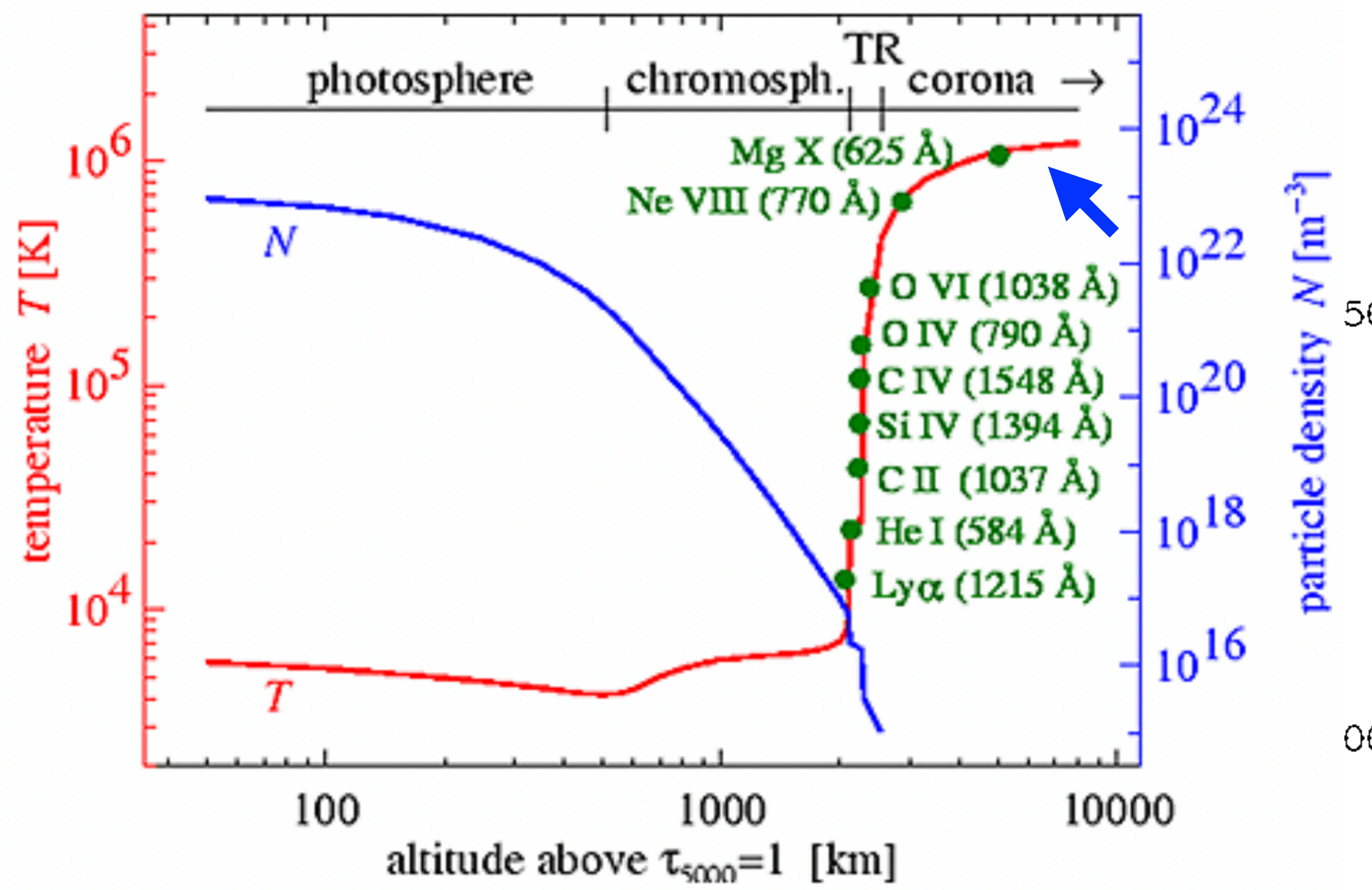
Viewing the Sun across the electromagnetic spectrum

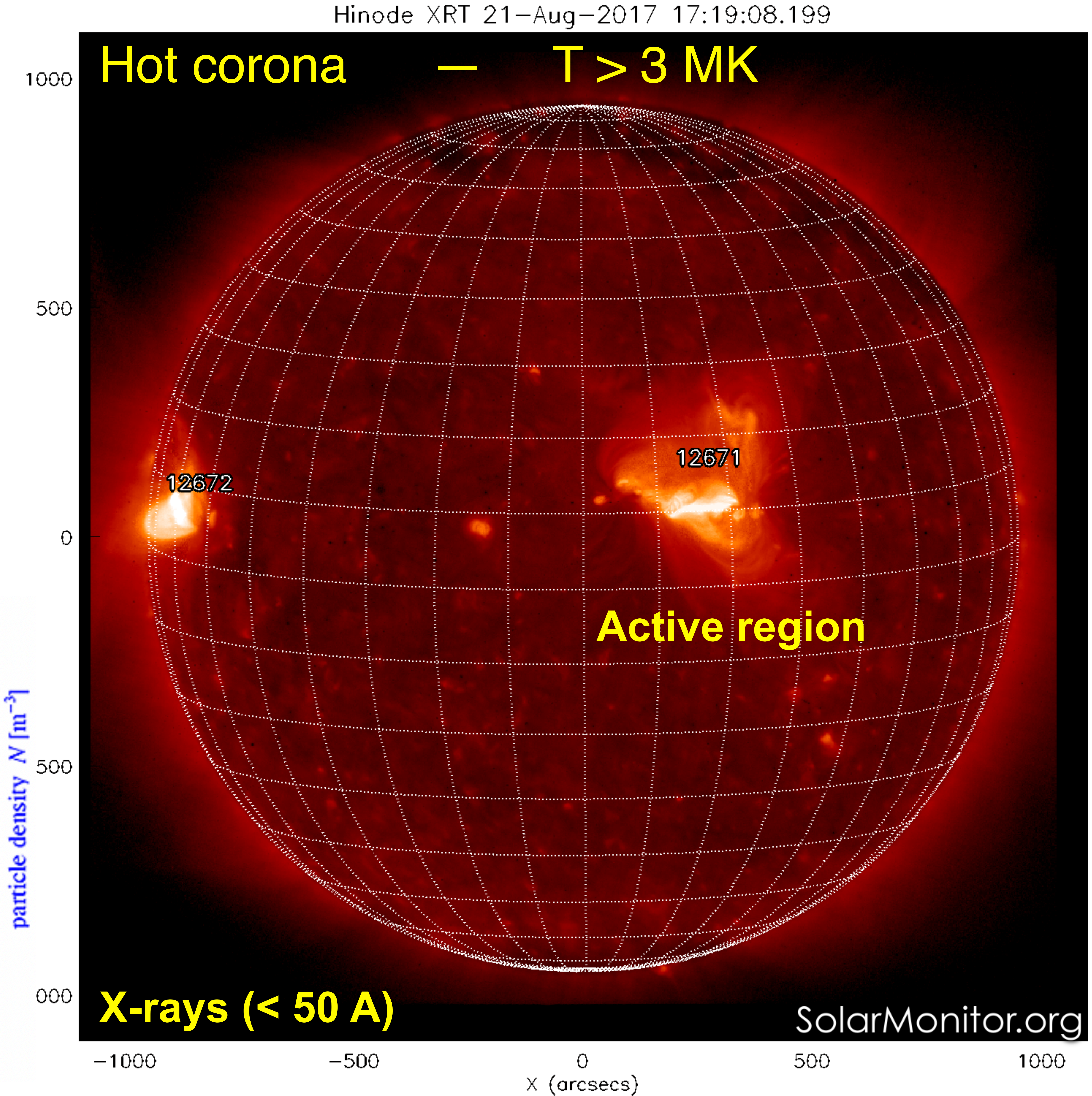
The broadband X-rays

Filter samples larger wavelength Range

Emission from hot plasmas (Fe XVII-XXIII)

Some coronal stuff may be Included (O VII, VIII)





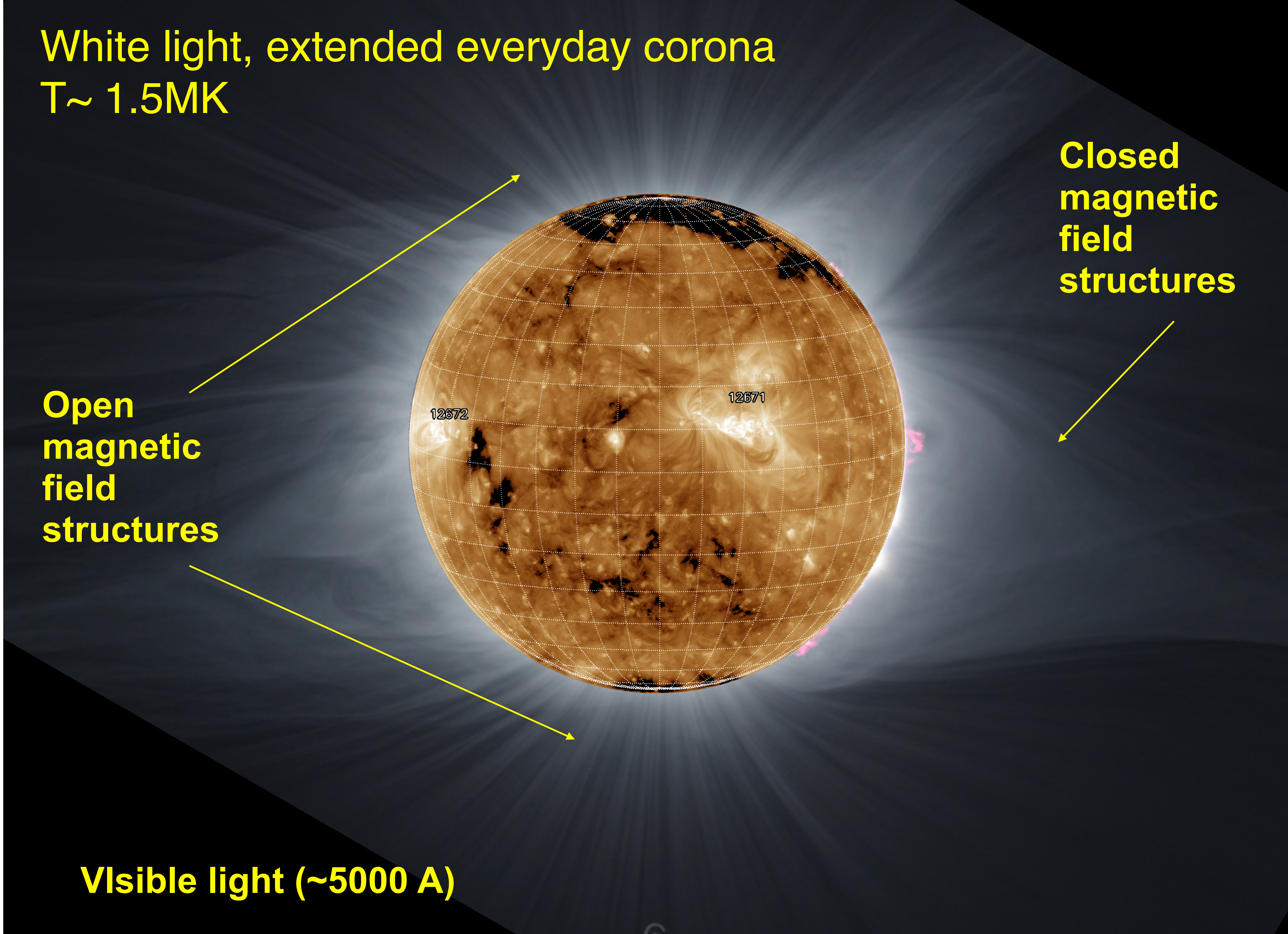
Eclipses

A rare glimpse into the extended corona

Moon shadow eliminates atmospheric scattering

Thomson-scattered Disk visible light;
Lines from coronal ions

Coronal structures can be visible for much larger heights



How can we use imaging instruments

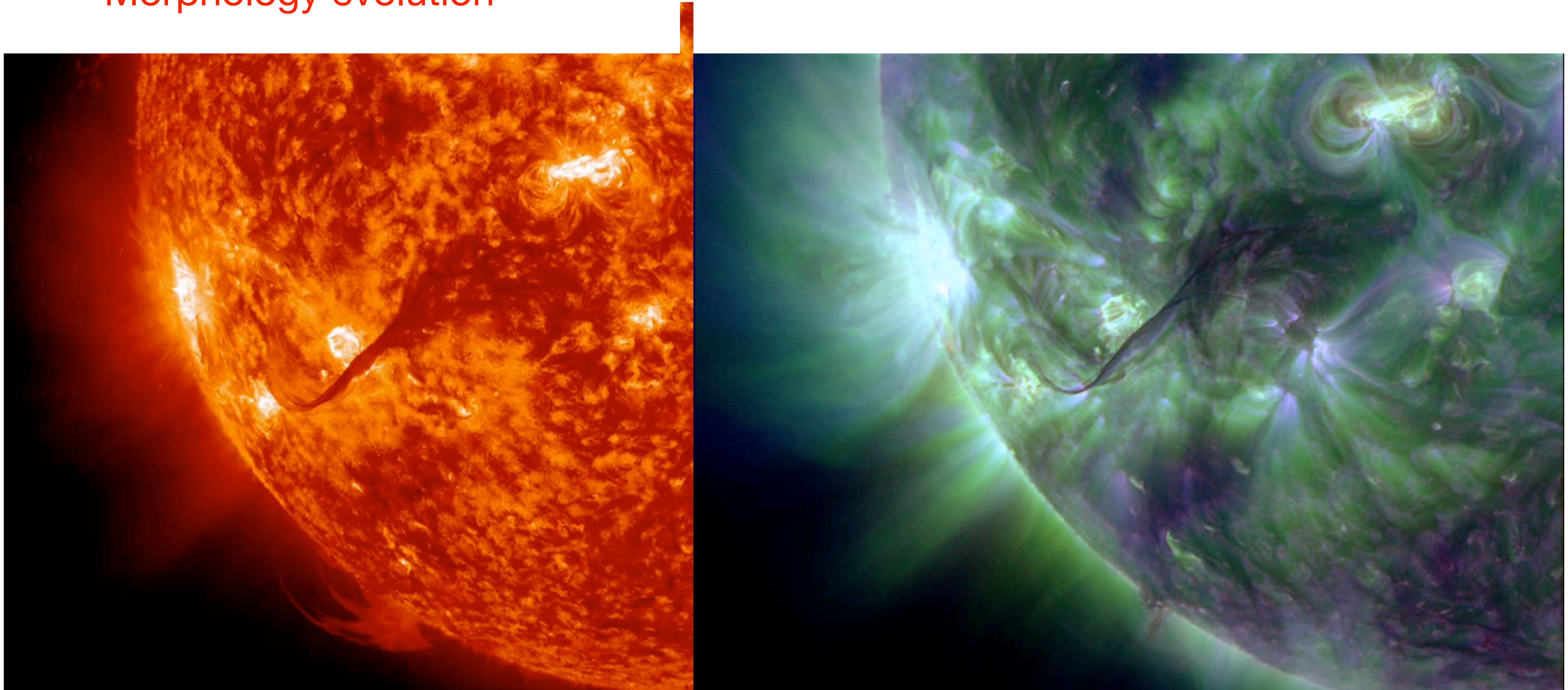
1 - Movies

Fast and easy way to monitor time evolution

- Activity events
- Connection between different structures
- Morphology evolution

Pro: Quick and easy
Provides connections between distant structures

Con: No quantitative diagnostics



How can we use imaging instruments

2 - Multitemperature images

Fast and easy way to figure out dominant plasma temperature

Coronal holes are seen in 171

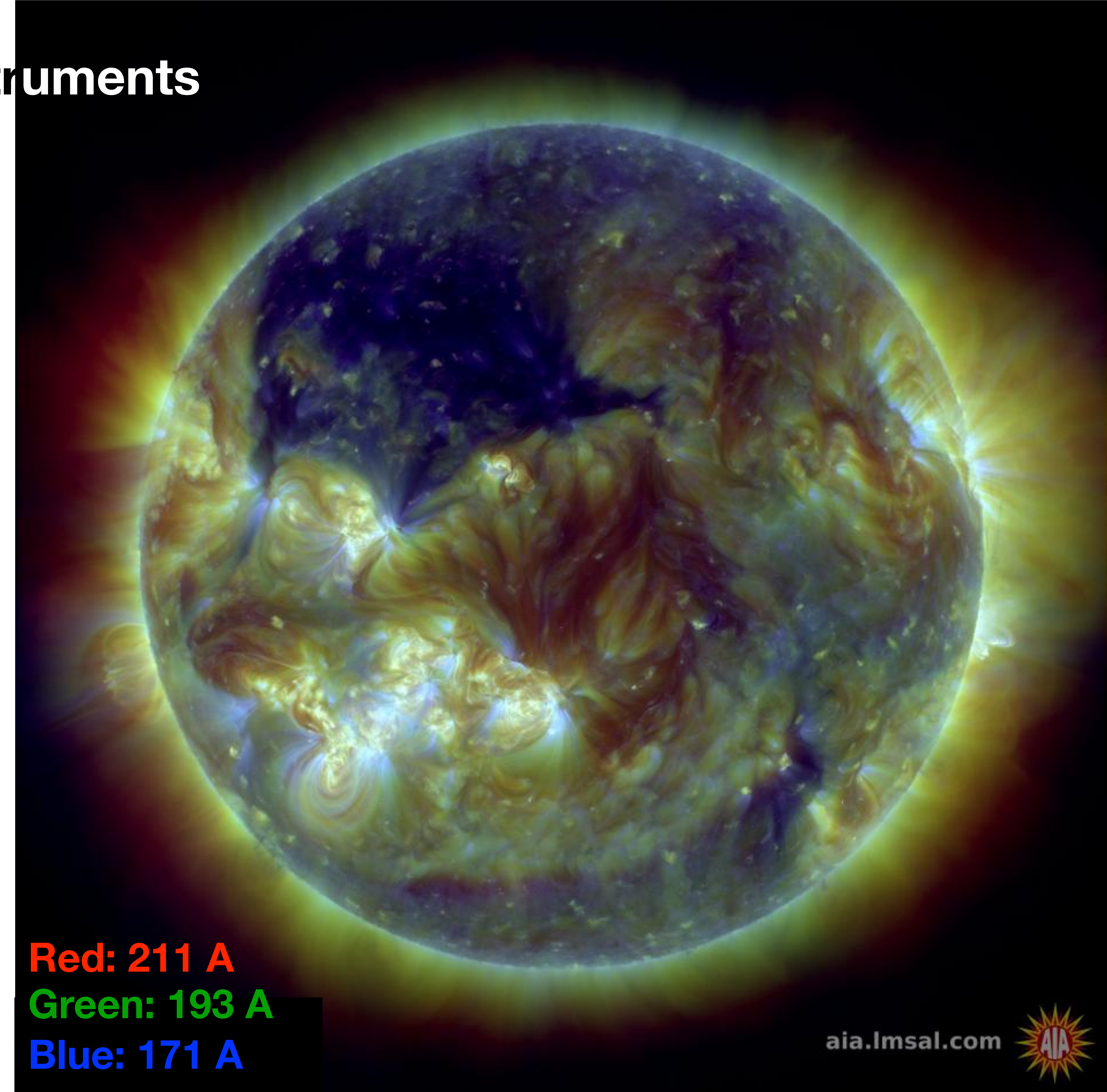
Quiet Sun is superposition of
171 bright points,
193 coronal diffuse structures

Active region mixes all channels

Contaminating structures give different hues

Pro: Quick and easy
Provides connections between different temperatures

Con: No quantitative diagnostics



How can we use imaging instruments

3 - Temperature ratios

Capitalizes on channel different temperature sensitivity

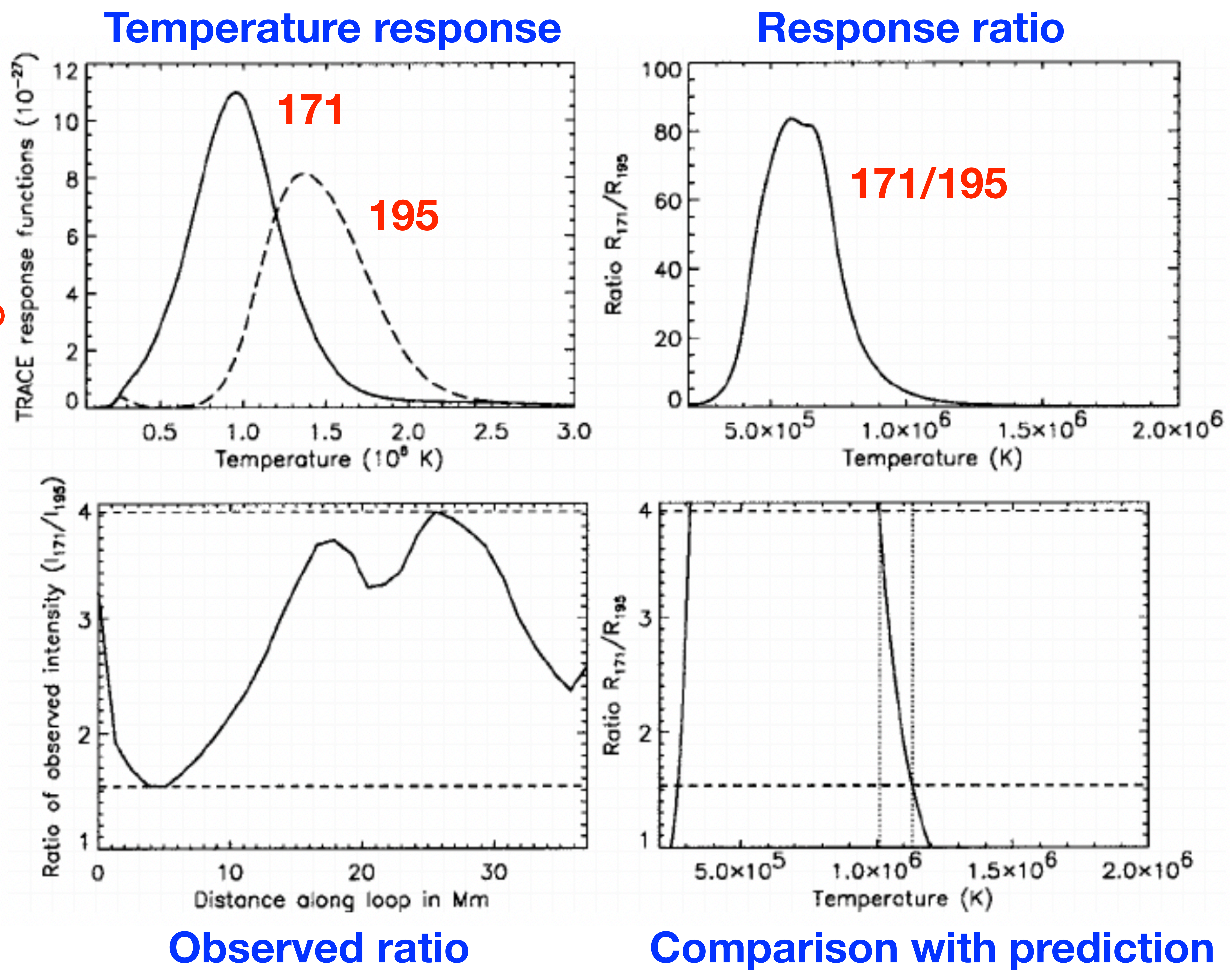
Assume plasma is isothermal

Predict channel intensity ratio As f(T)

Comparison provides measurement

Pro:
- Temperature maps
- Quick and easy
- Apparently very small uncertainties

Con:
- Isothermal assumption Is usually risky
- Non-unique solutions



How can we use imaging instruments

4 - DEM diagnostics

DEM measures plasma T distribution

Optically thin plasma:

$$F = \frac{1}{4\pi d^2}\int G(N_e,T_e)\varphi(T_e)\,dT$$

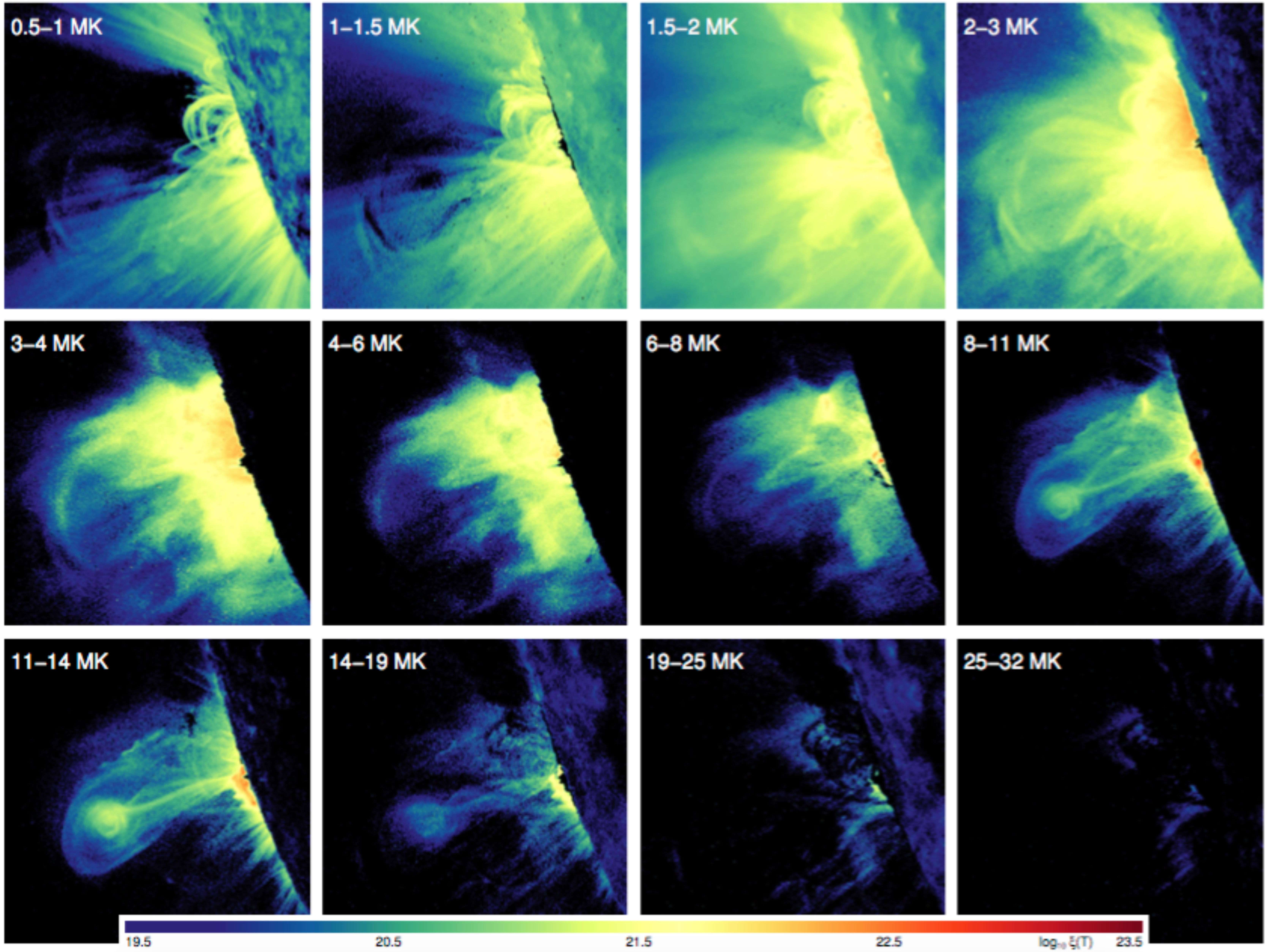
Plasma Emissivity

Plasma DEM

Determine $\varphi(T_e)$ using many channels

Pro: T distribution maps
Time evolution
Full sun coverage

Con: More limited accuracy than with spectra



How can we use imaging instruments

5 - Tomographic reconstructions

Series of 2D images of rotating corona can be used to retrieve 3D distribution of channel emission

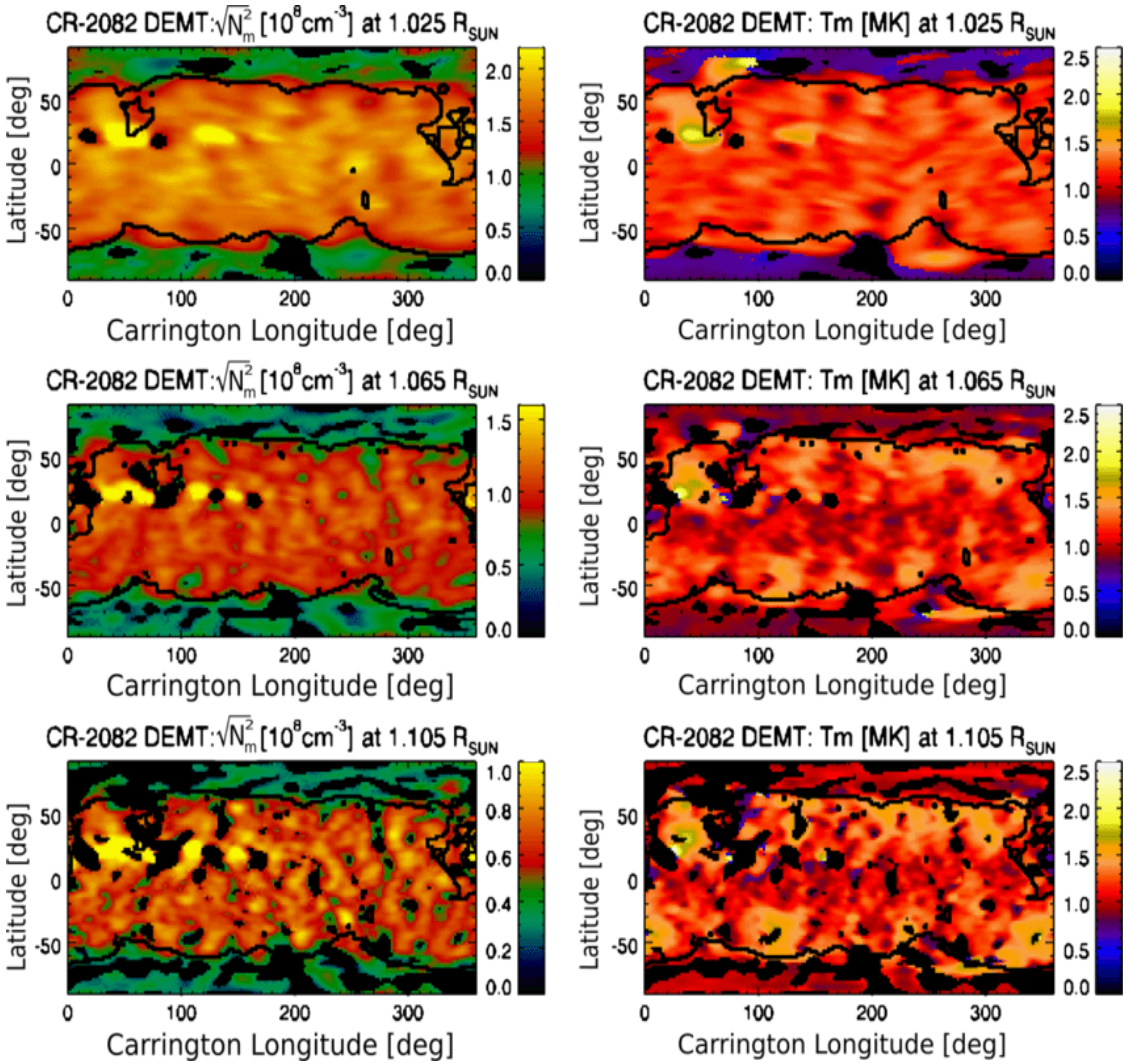
Can apply previous diagnostics to obtain 3D distribution of measured quantities

Pro:

- Remove Line of Sight ambiguities
- Provide formidable tool for *local* plasma diagnostics

Con:

- Need long time series (at least 15 days)
- Need quiescent corona
- Need high S/N ratio



How can we use imaging instruments

6 - Density diagnostics

At different T, effective spectra may be different from nominal ones

For 171, 195 channels, O ions dominate at CME ejecta temperatures

O lines in different channels form density sensitive line pairs

Can use channel ratios for density diagnostics

Pro: CME density distribution maps
CME density time evolution

Con: Need to know temperature beforehand
Need to remove background/foreground
Somehow limited sensitivity

Log T = 6.15

Log T = 5.45