PHYS 7810: Solar Physics with DKIST

Lecture 1: Course overview and Intro to the Solar Atmosphere

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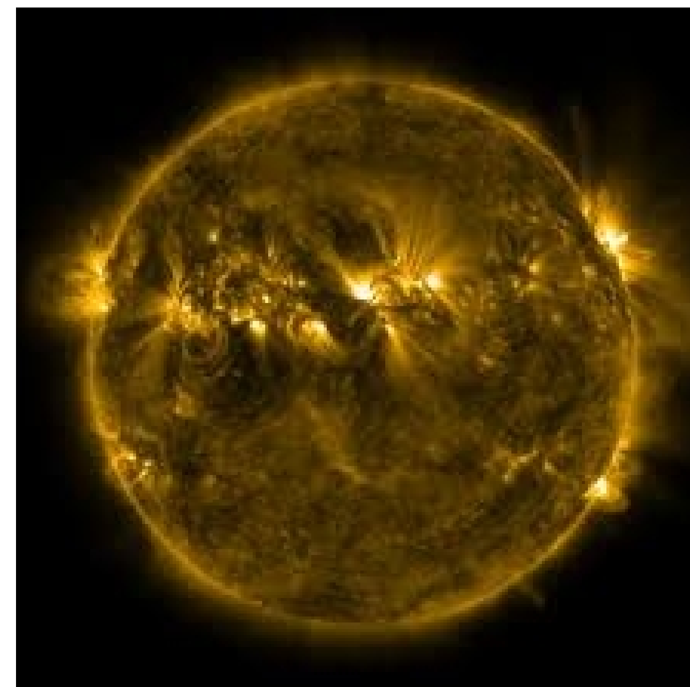


The course goals

- Ground based observations in general and DKIST in particular. The idea is to get **you** ready to use DKIST for **your** research
- Study the intricacies of the ground-based observations. Learn how the observations are made and reduced.
- Learn how to go from the reduced observations to the data we need to do science. Study the physics behind the observables so we know how to infer what we need.
- See how DKIST synergies with the rest of the instruments (PSP, SO, ALMA, etc.)
- Write a DKIST proposal!

Concept of the lectures and the student engagement

- We will try to have “blocks” of 3-4 lectures followed by 1-2 hands-on exercises.
- Homeworks will contain real-life problems grounded in the research, with relatively flexible deadlines.
- For hands-on, we will try to go from the very basics, developing our tools in **python,** whenever possible.
- We will not grade attendance per se. However, homework might be hard if you are not attending lectures + you can earn extra credit at the lectures.
- No final exam.
- We will have several guest lecturers: Kevin Reardon (NSO), Valentin Martinez Pillet (NSO), Gianna Cauzzi (NSO), Maria Kazachenko (CU), Steven Cranmer (CU) + some more (TBD).

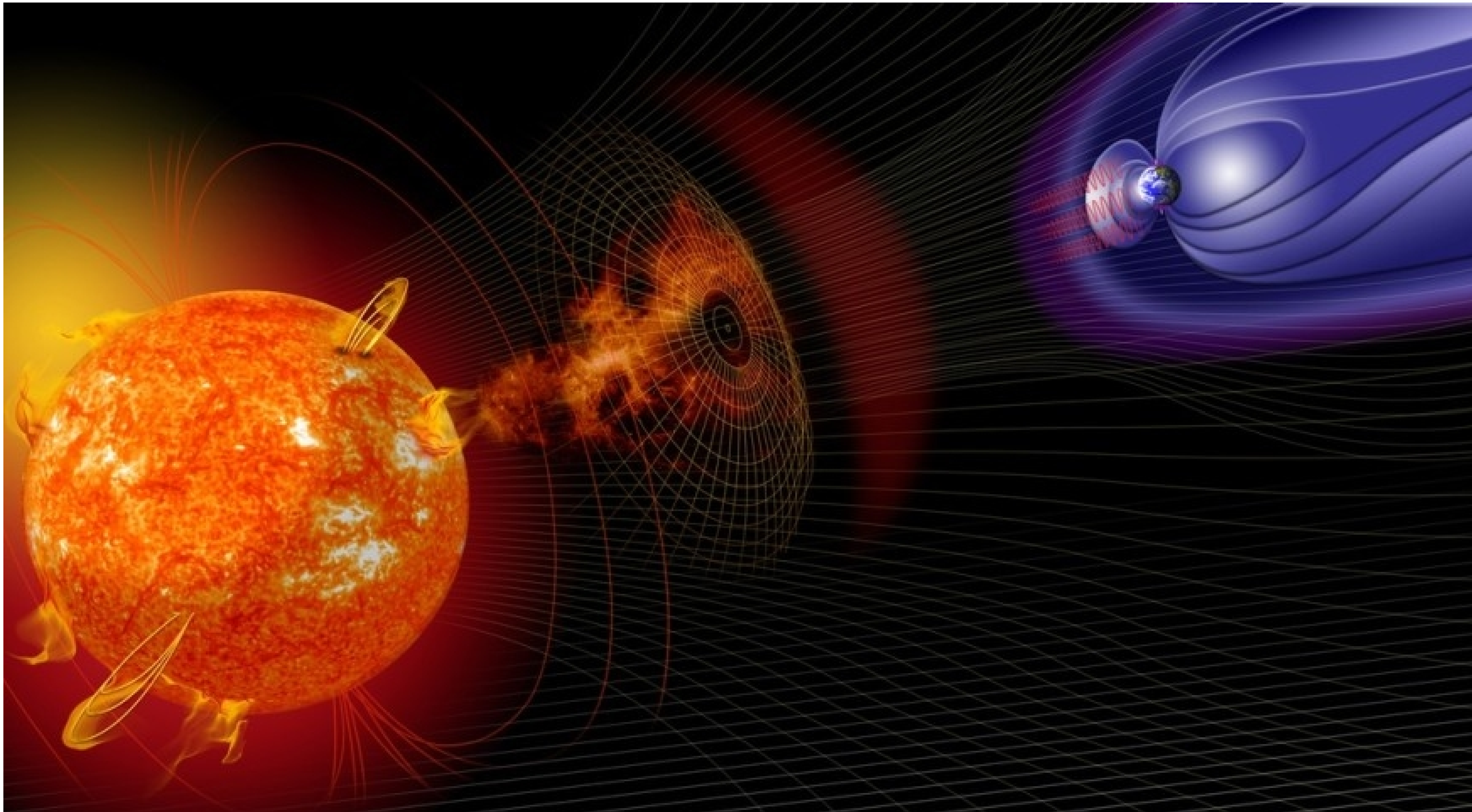
Materials, contact, webpage, etc.

- Lectures and exercises are streamed via Zoom (**681-878-8932)**
- Materials (slides, papers, codes) will be uploaded at: www.nso.edu/students/collage/collage-2020/
- You can always reach me at ivanzmilic@gmail.com or ivan.milic@colorado.edu
- Do not ever hesitate to ask for help, advice, etc. or to criticize and complain about the things you are finding non-optimal.

Some useful literature

- “The Sun” - M. Stix (2004) – good book on the Sun in general
- “Solar Astrophysics” - P.Foukal (2004) – similar approach
- “Introduction to Spectropolarimetry” - J.C. del Toro Iniesta (2003) – focus on spectropolarimetry methods, mostly interpretation but also the instruments
- “Observation and analysis of stellar photospheres” - David F. Gray (1992) – Excellent all purpose book on observational and diagnostics methods related to the atmospheres of the stars
- “Stellar Atmospheres” (3 editions) – D. Mihalas (& I. Hubeny) (1970, 1978, 2014) – Higher level “bible” on radiative transfer and modeling of stellar atmospheres. Great if you are in the field already.
- “Stellar Interiors” - Hansen, Kawaler, Trimble – best book on stellar physics ever ;)
- We will try to study some papers as we go. These will be linked at the course page.

Why is the Sun so special? Sun-Earth relationship(s)

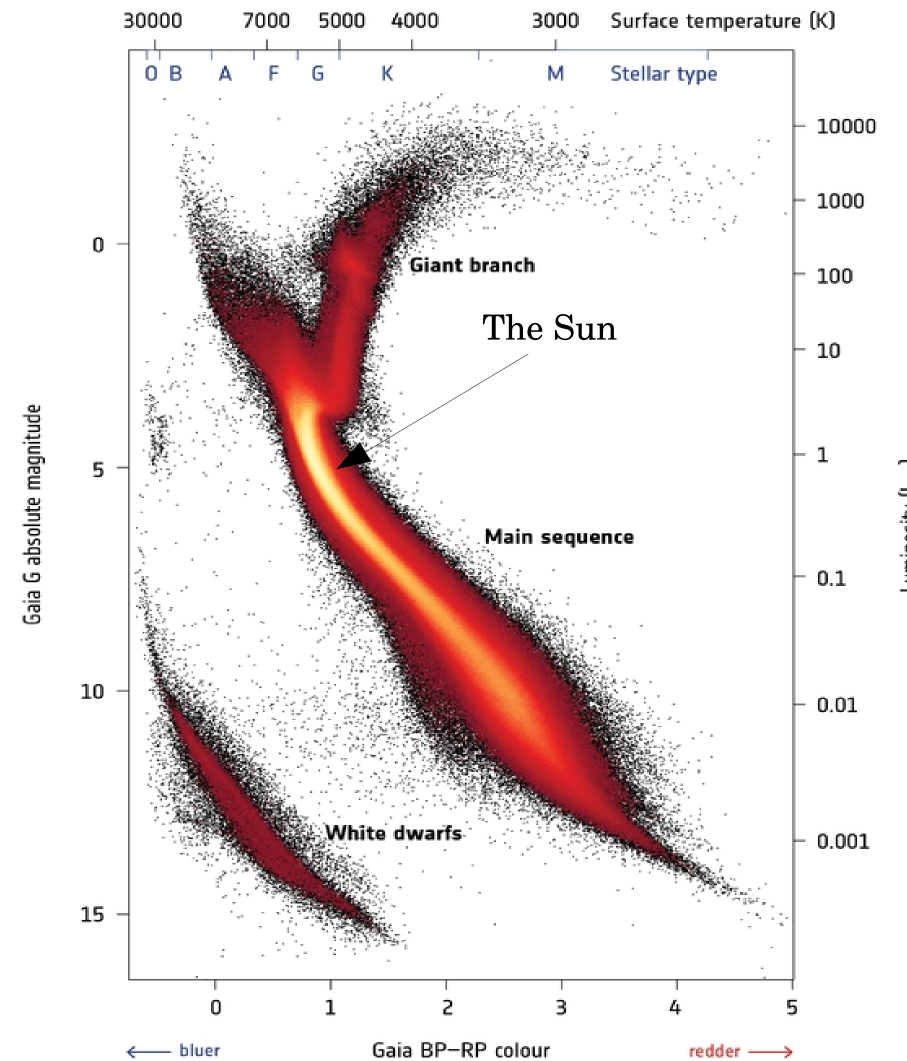


Credits: NASA

Astrophysical context

- A G2 V ‘yellow dwarf’
- Magnitude and color index (CI) depend on the atmospheric properties
- These depend on the effective temperature, which depends on the stellar properties (mass and composition)
  (Vogt-Russel theorem)
- Refresher / introduction:
  ‘Stellar Interiors’, ‘Observation and Analysis of Stellar Atmospheres’

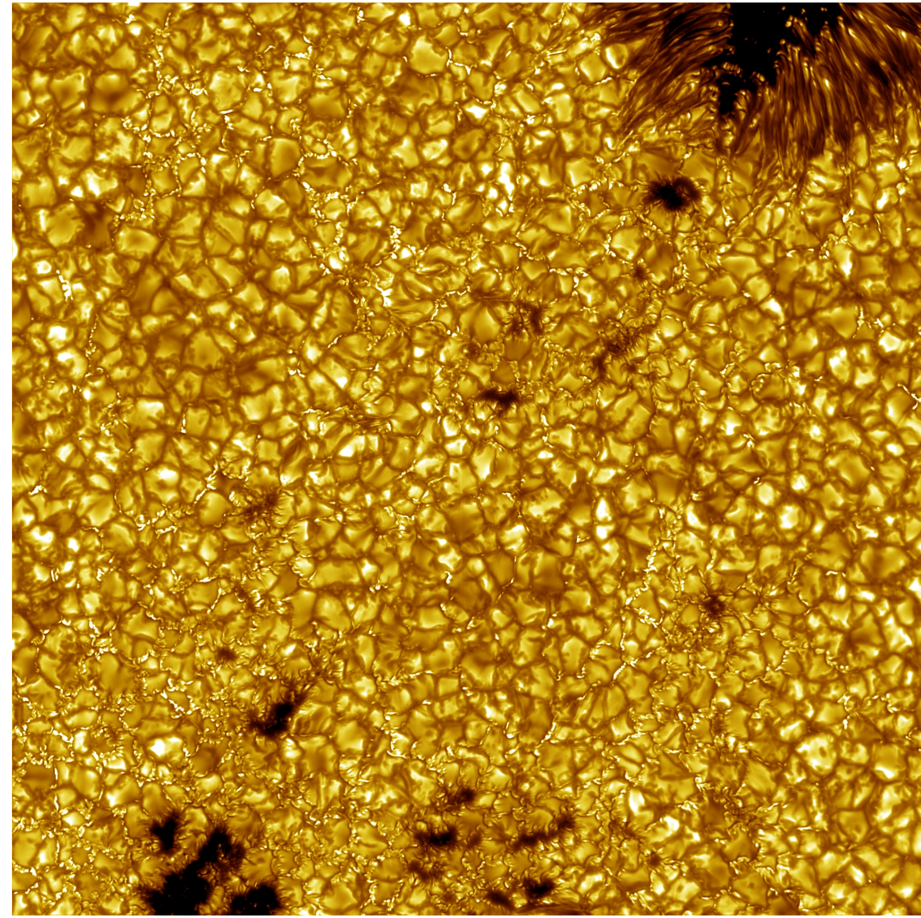
→ GAIA’S HERTZSPRUNG-RUSSELL DIAGRAM



Why is the Sun so special for us? Because it is a fantastic plasma laboratory.

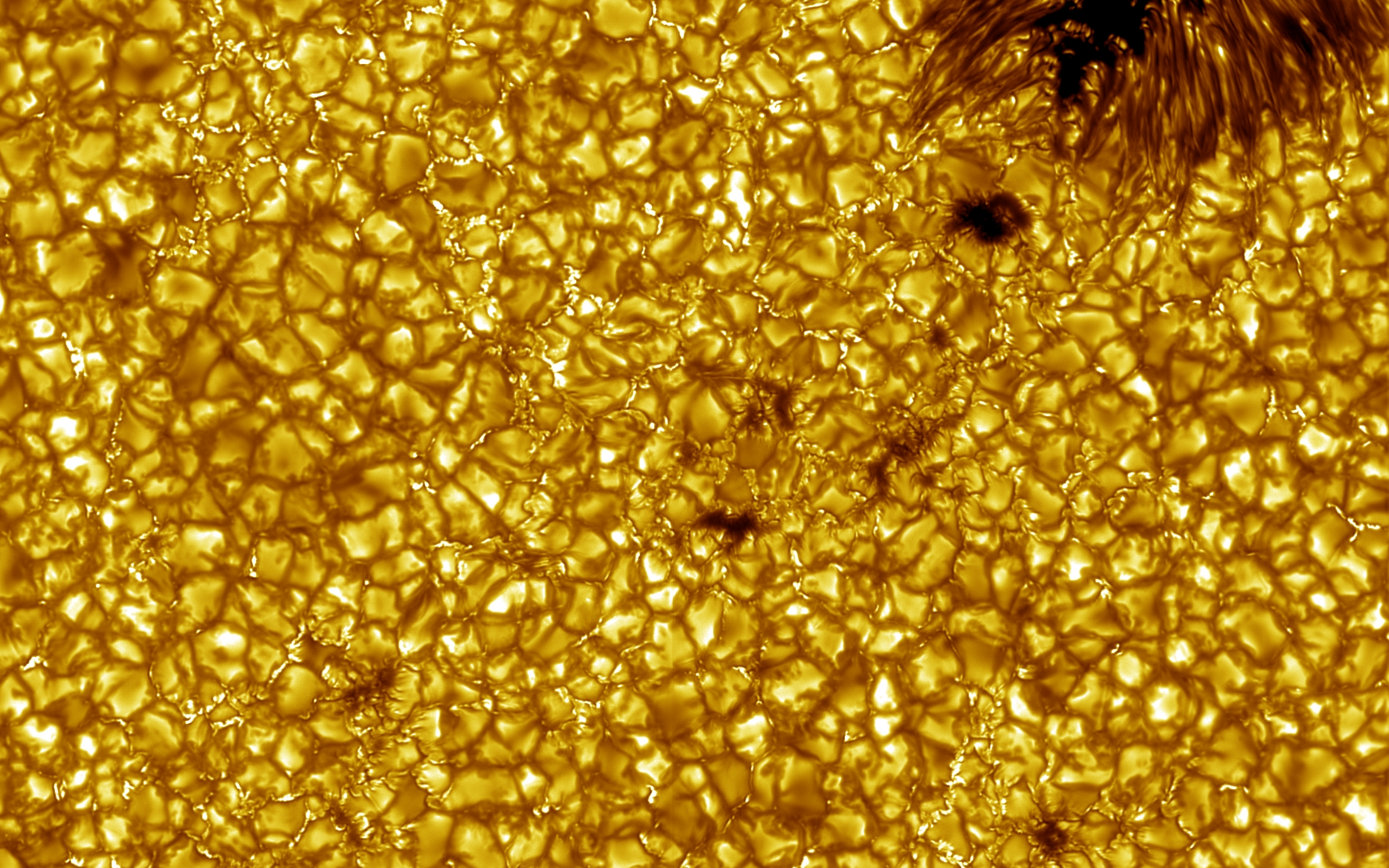
$$\theta = 1.22\frac{\lambda}{D} = 0.012\,''$$

$$\rho = R_\odot/d = 0.004''$$



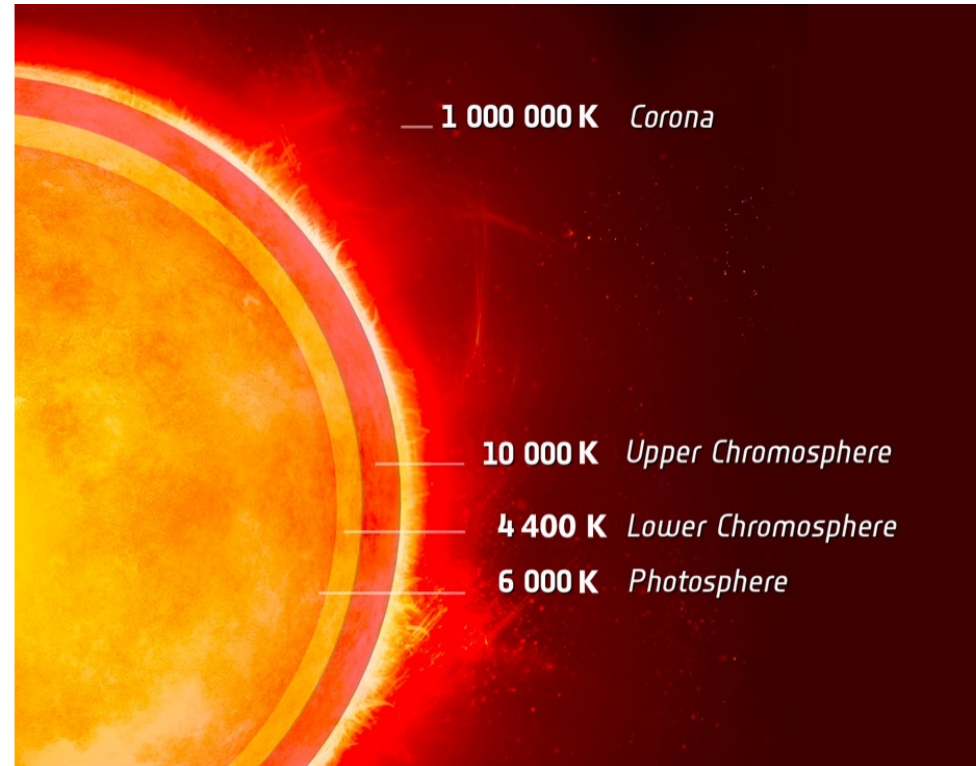
$$\theta = 1.22\frac{\lambda}{D} = 0.083\,''$$

$$\Delta x = \theta \times 1\mathrm{AU} = 61\,\mathrm{km}$$



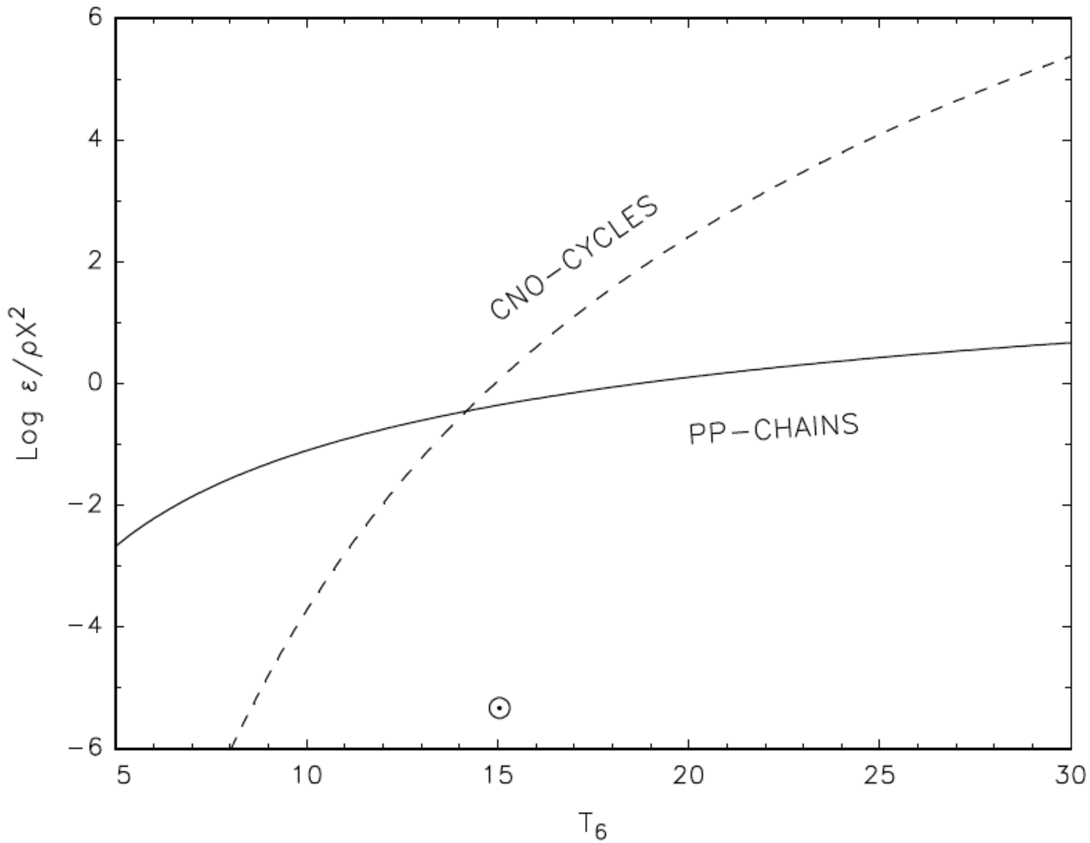
When we observe, we see the solar **atmosphere.**

- Stars are gaseous, there is no sharp distinction.
- *„Why in the world would anyone want to study stellar atmospheres? They contain only 10^{-10} of the mass of a typical star. Surely such a negligible fraction of a star's mass cannot affect the overall structure and evolution!"*
  (Edward Salpeter to Dmitri Mihalas)
- A quick answer: We can't see deeper!
- But also, the atmosphere responds to the 'inner' processes

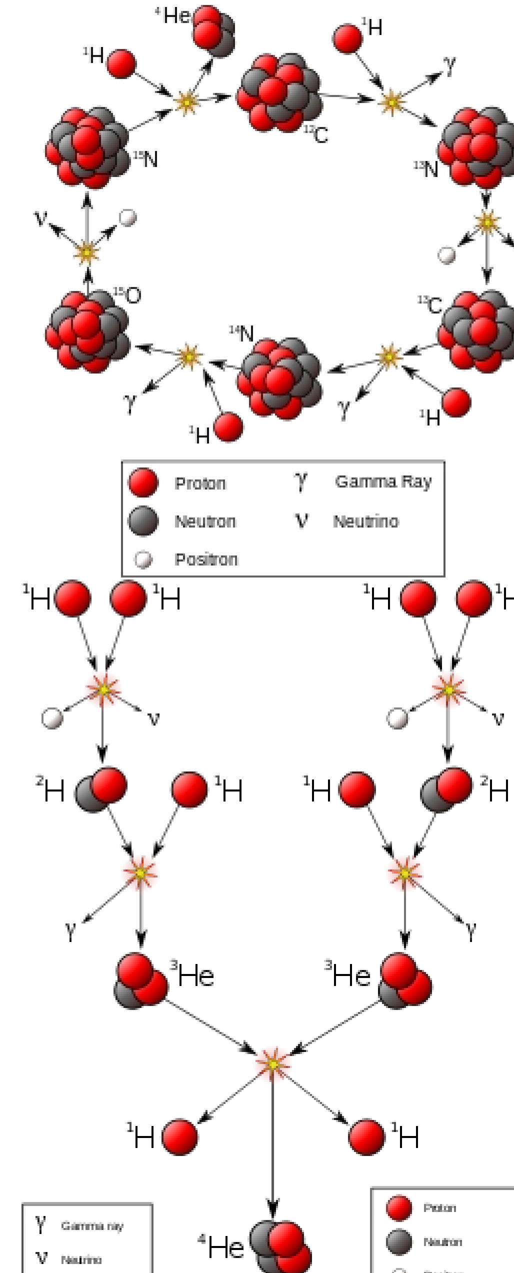


Credits: ESA

Energy sources: pp chain and CNO cycle

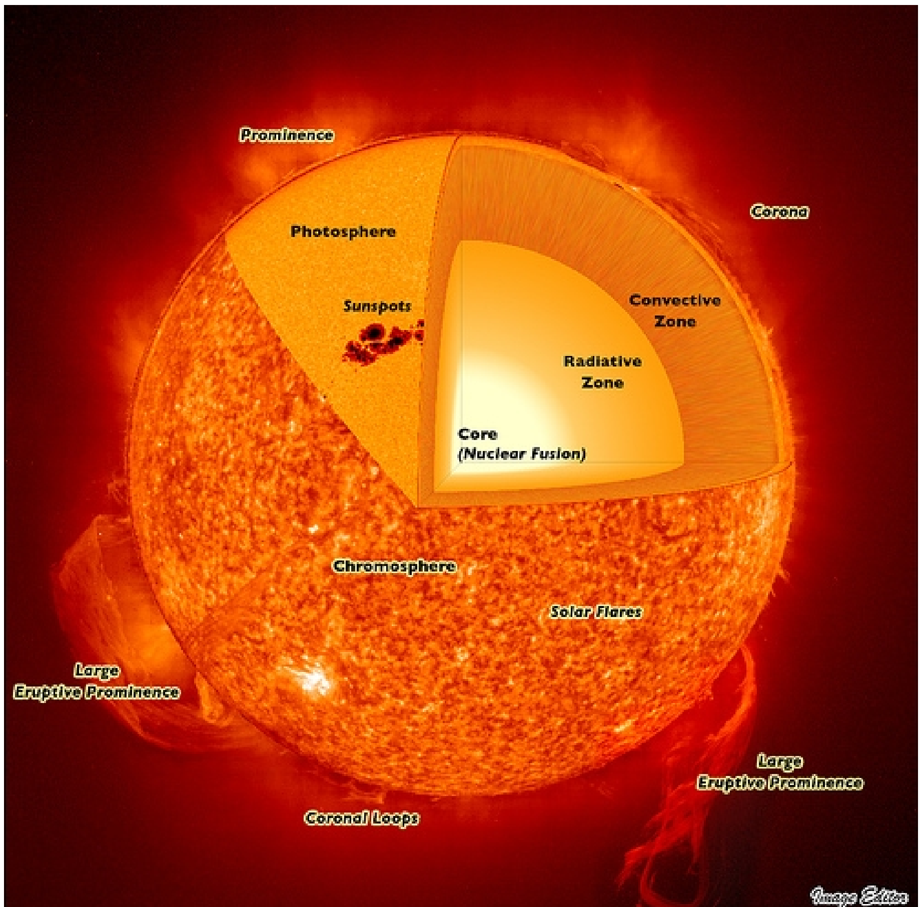


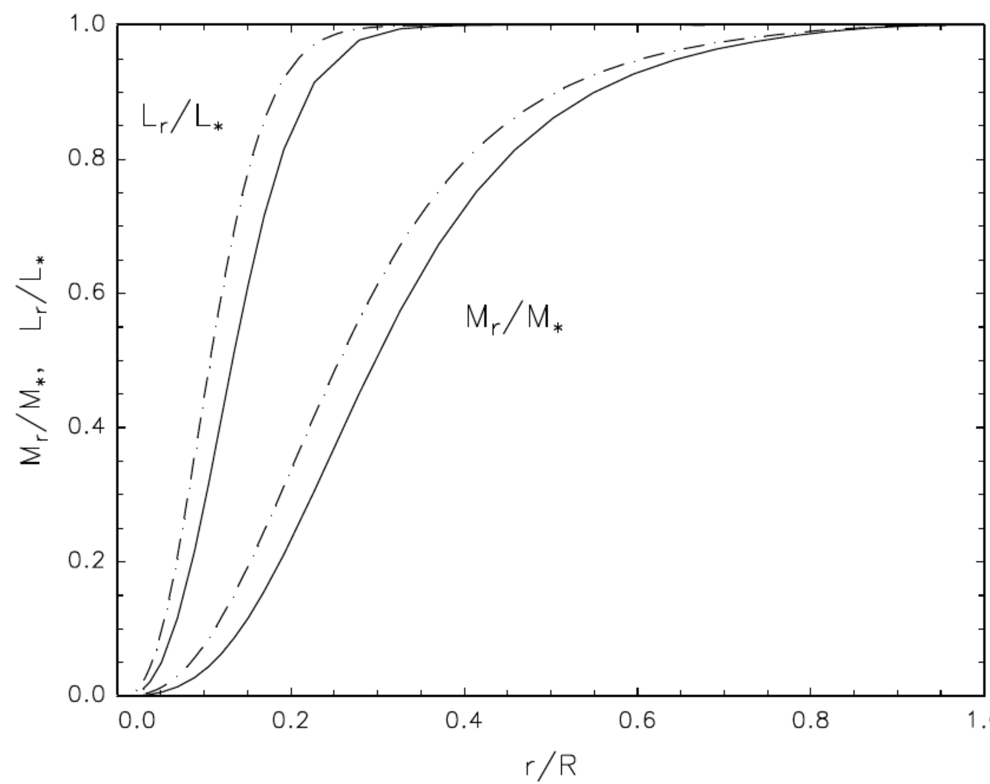
From "Stellar Interiors" , chapter 6



So, temperature in the core + composition → Luminosity

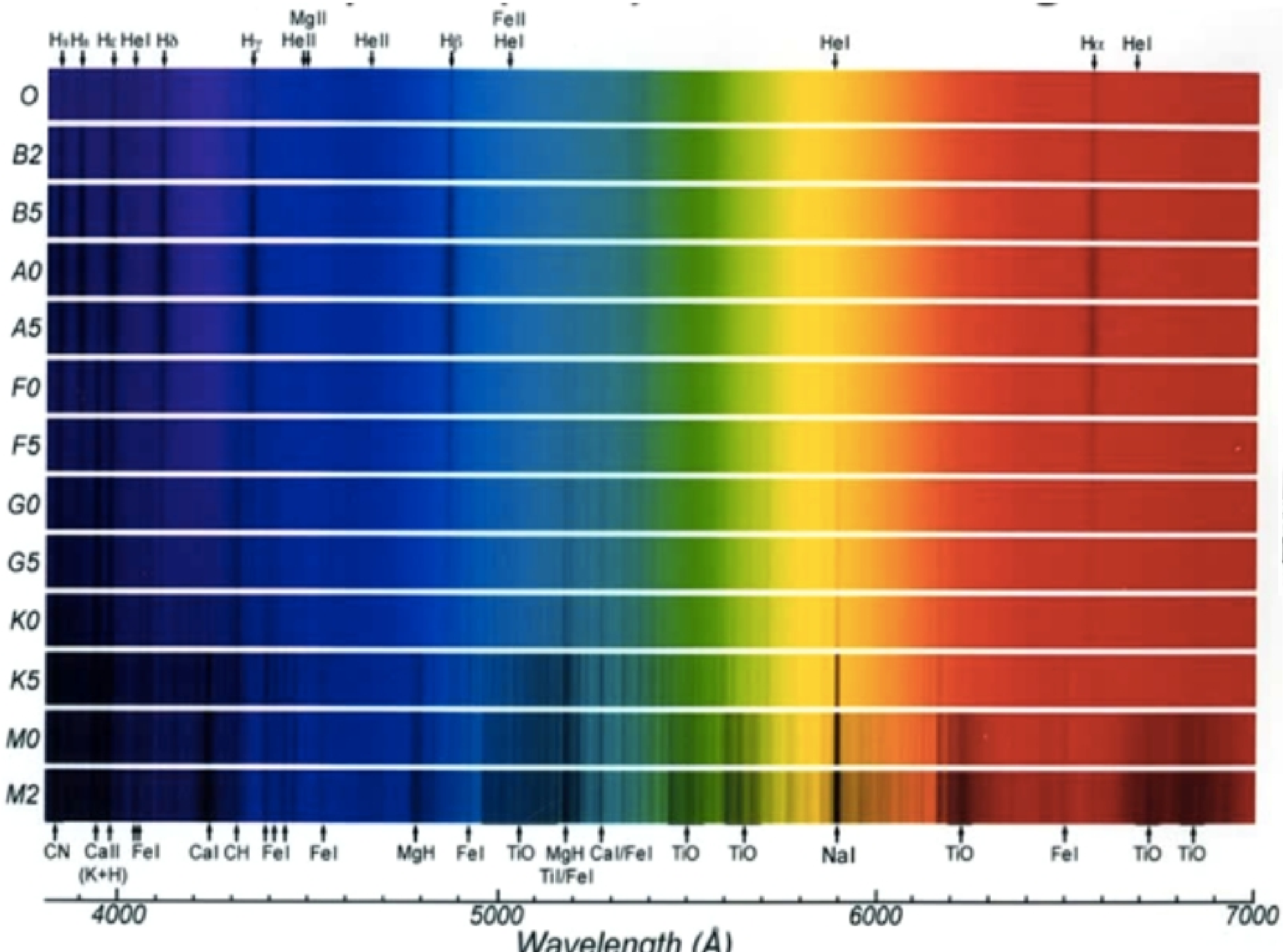
Canonical 1D picture of the solar interior:





From "Stellar Interiors" , chapter 9

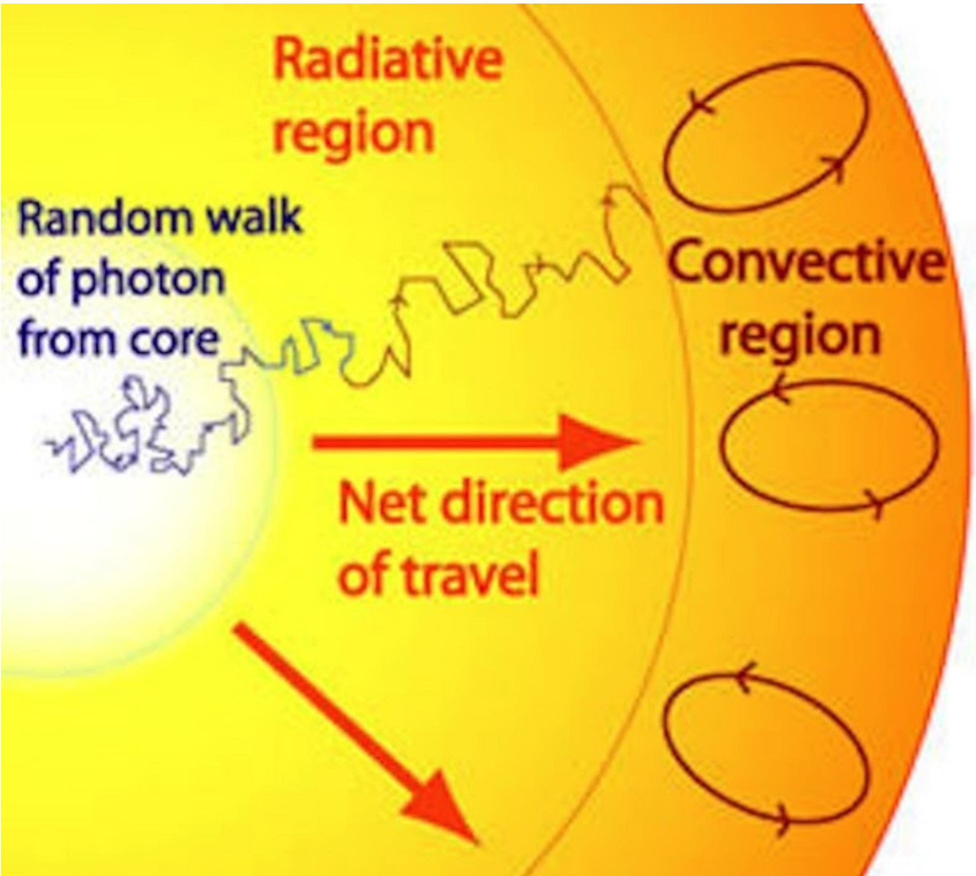
Finally, the atmosphere, where the spectrum is formed:



Credits: NOAO/AURA/NSF

Annie Jump Cannon,
Harvard classification.

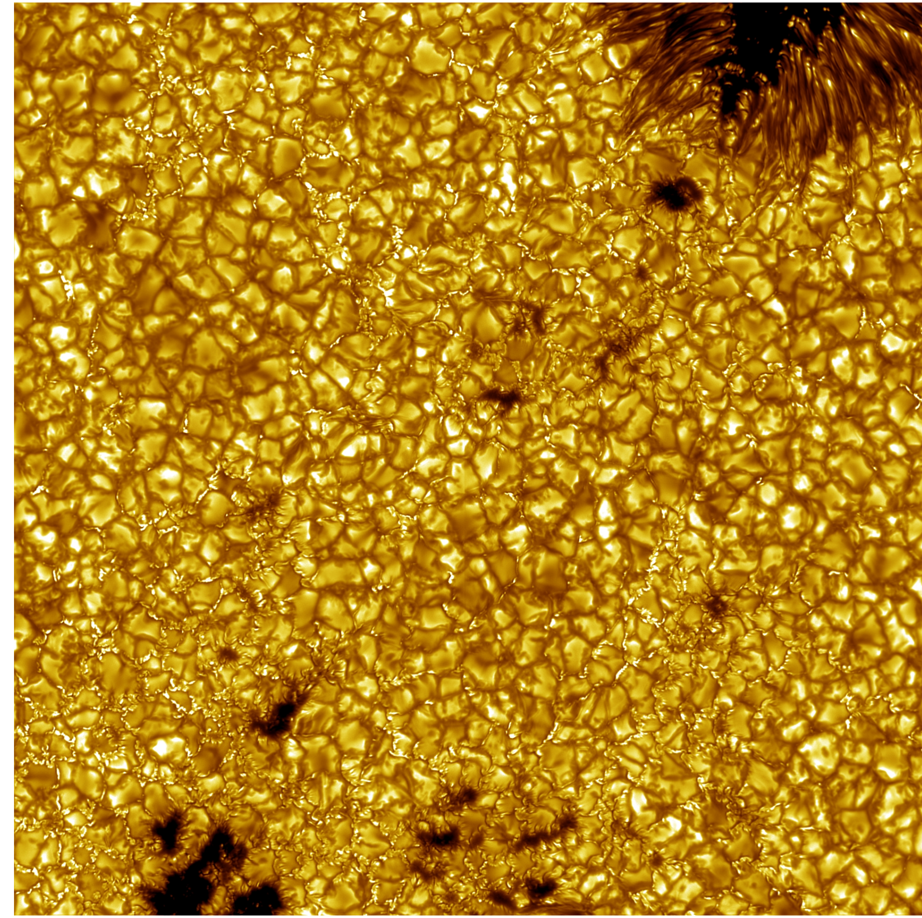
A common misconception: photons random-walking in the Sun



- Let's brainstorm together, what happens with the photons as they travel through the plasma?
- Absorption / emission/ scattering processes. Know any examples of these?
- What do these processes determine - spectral distribution.
- What do we detect in the end? Original photons or something else?
- Can we probe the interior by observing something else?

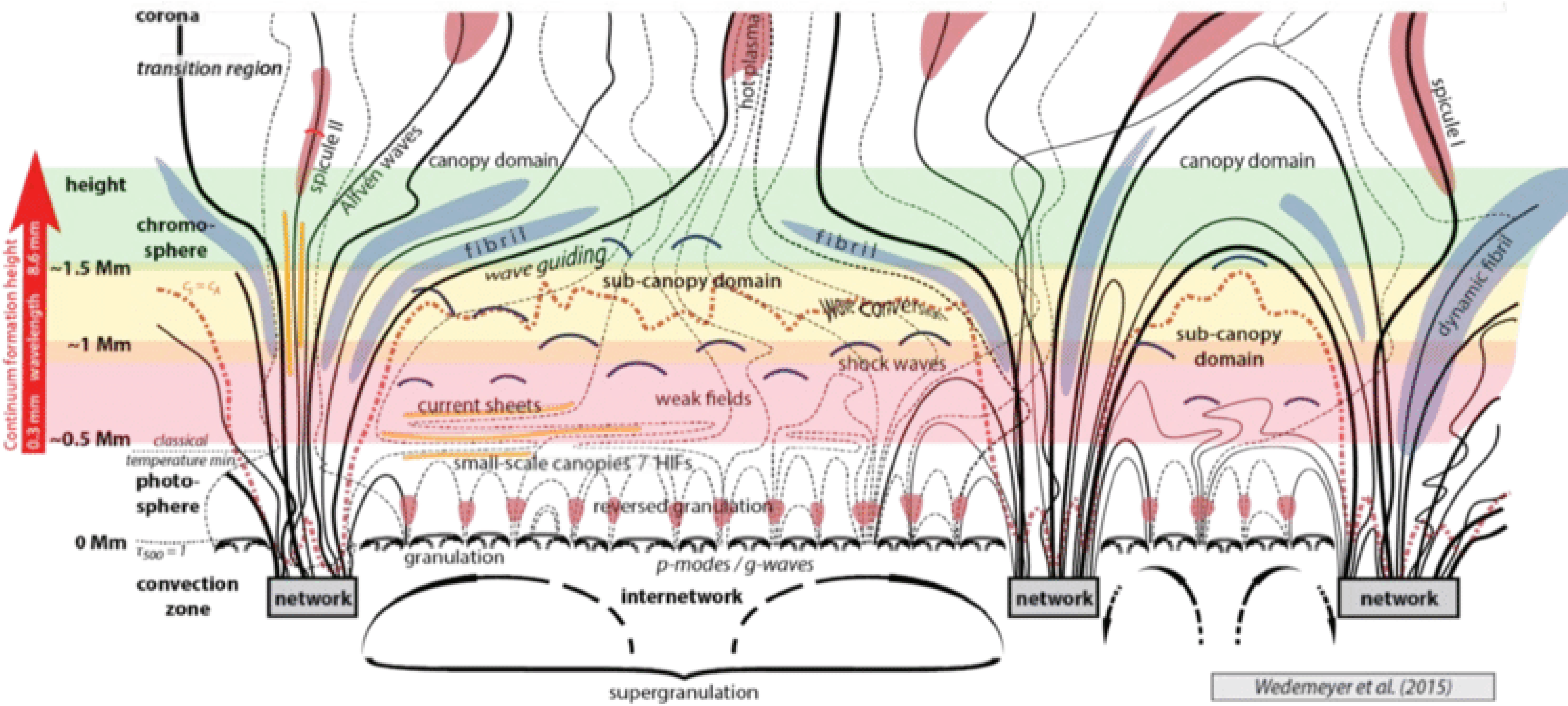
So, in both of these we see only the atmosphere!

Stars: We see the whole atmosphere, unresolved

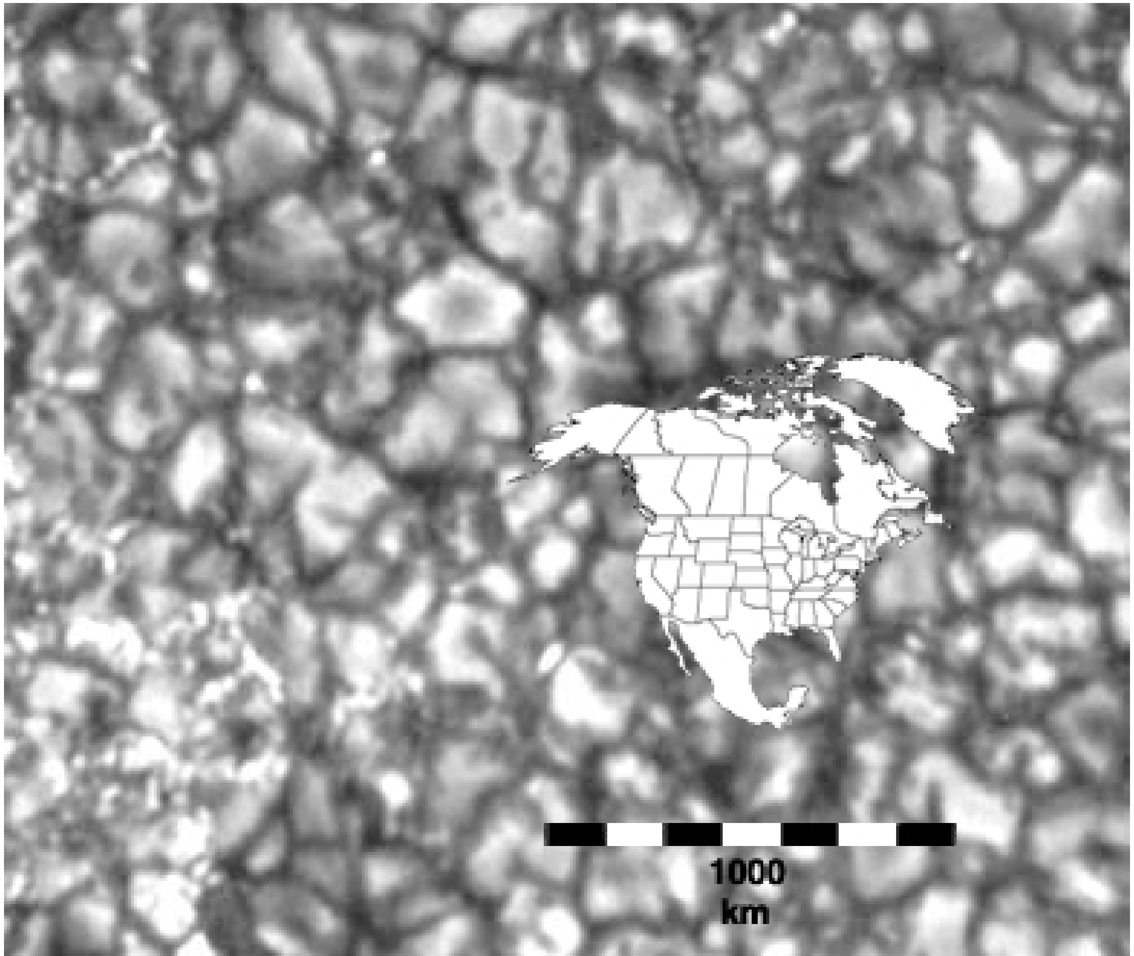


The Sun: We see the atmosphere resolved. In both images, the light comes from a 100 km thick layer.

There is physics happening the solar atmosphere

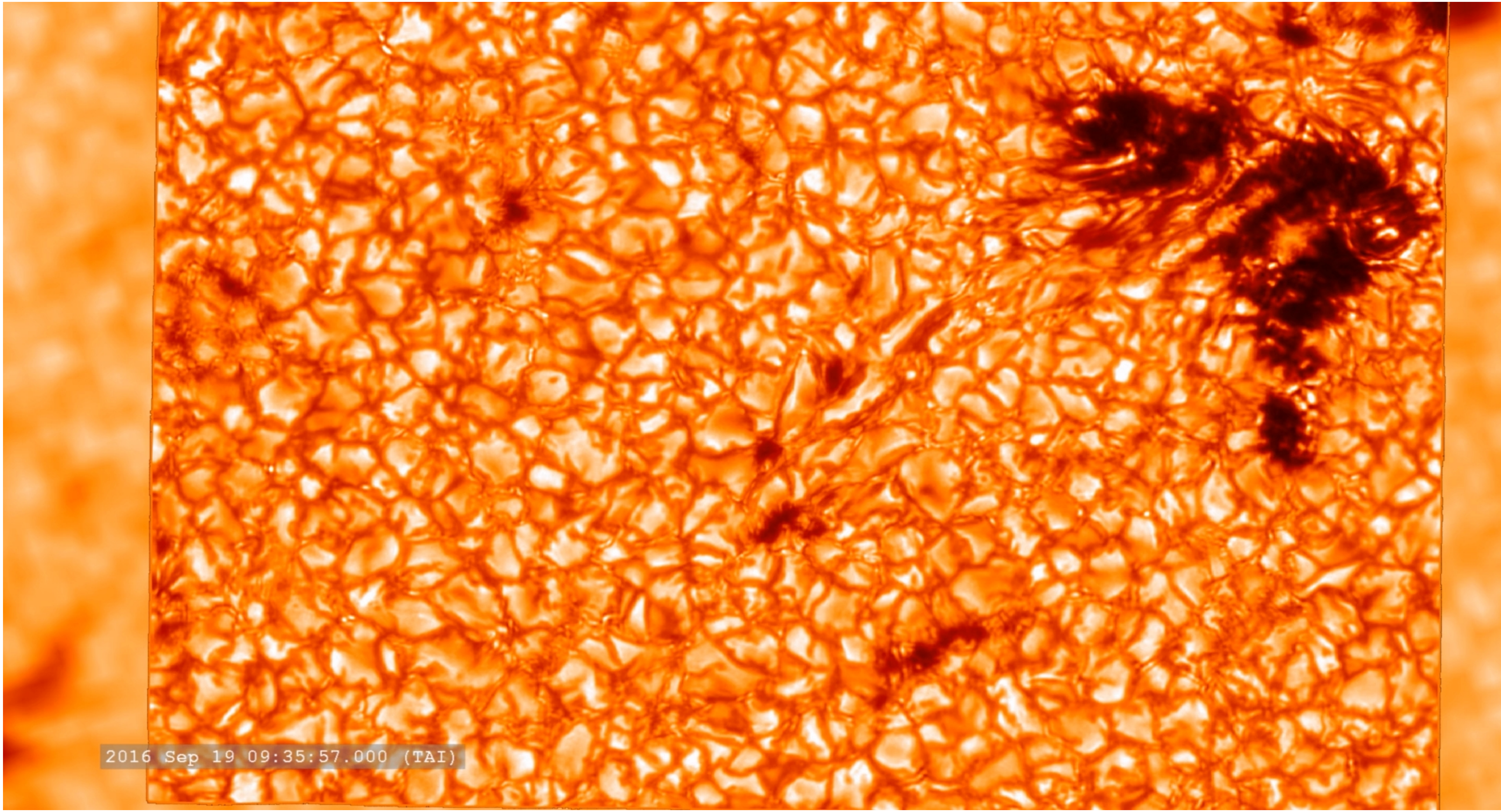


Granulation in the photosphere



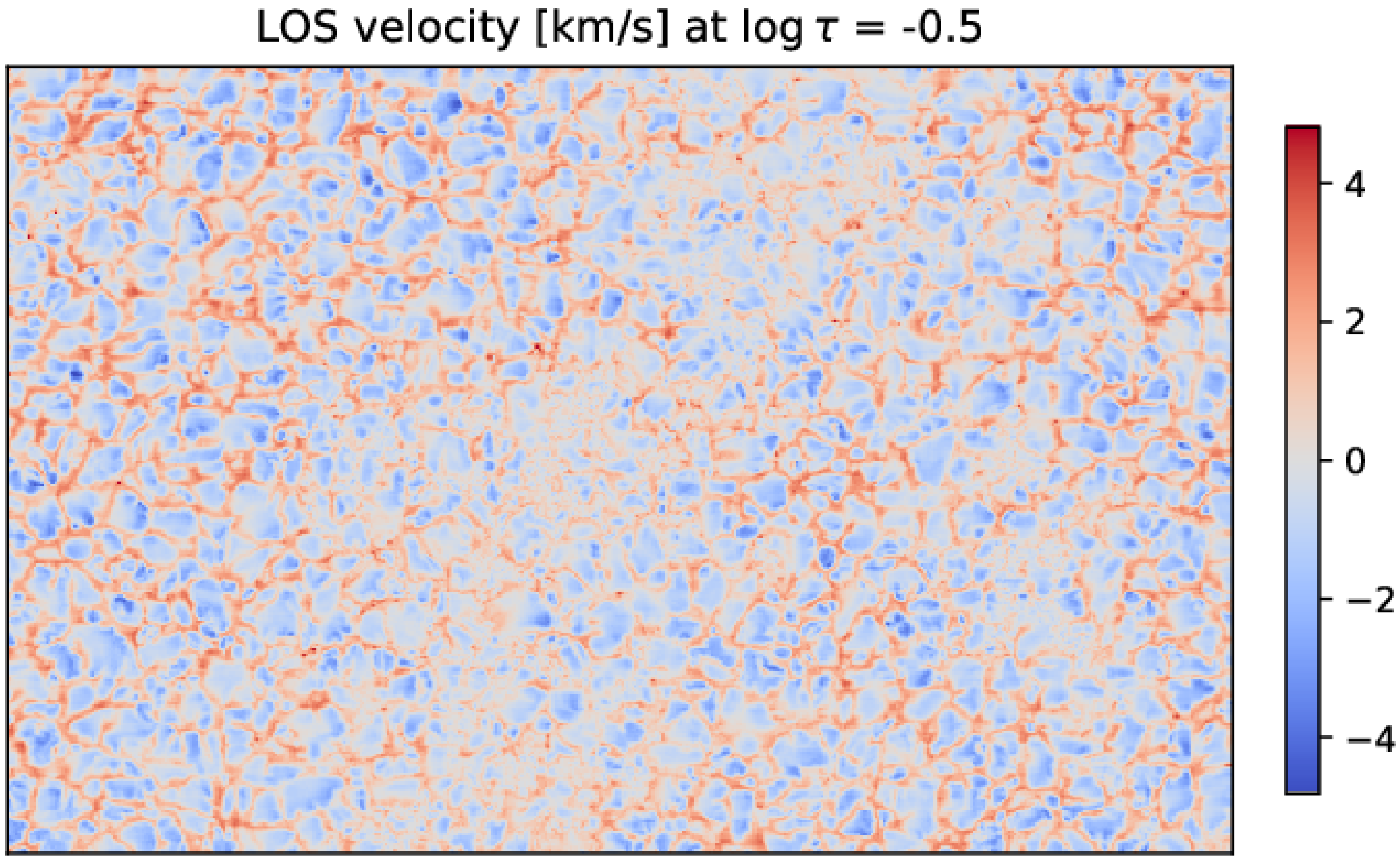
Credits: Wikipedia

- This is how Solar surface looks at “most” (very ambiguous term) wavelengths in the optical domain
- Why are the granules bright and intergranules dark?
- What else happens there?



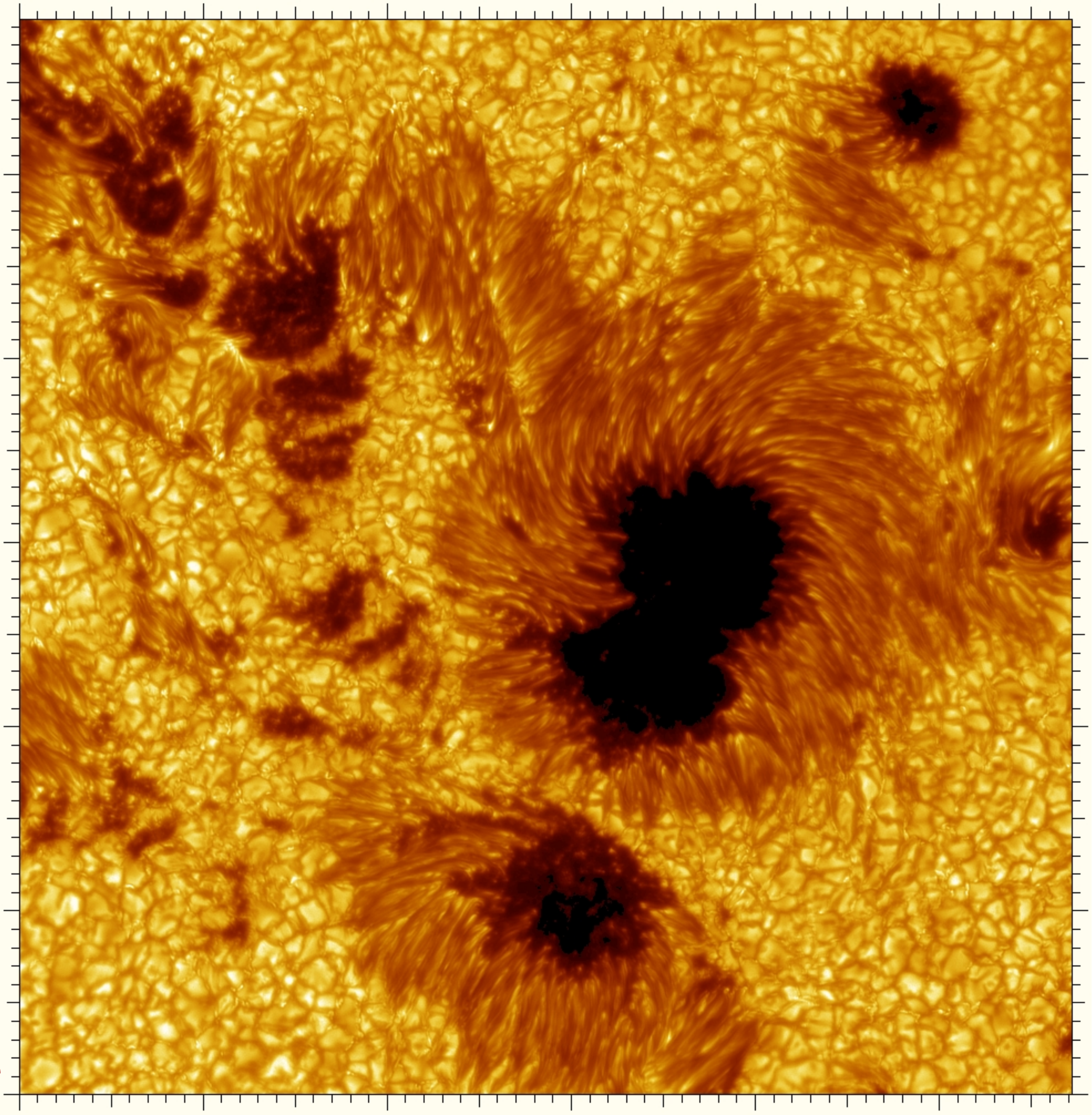
Credits: Swedish Solar Telescope

Granular velocities – an example from SST data



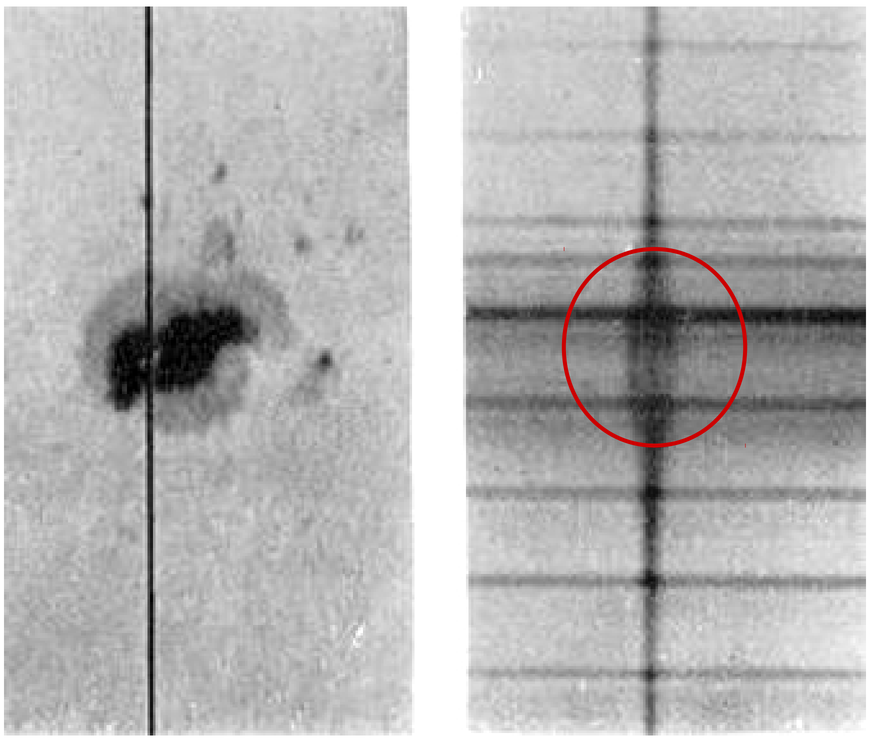
How do we obtain this kind of data?
We can't infer velocity from a picture, can we?

Sunspots – bundles of magnetic field protruding out of photosphere

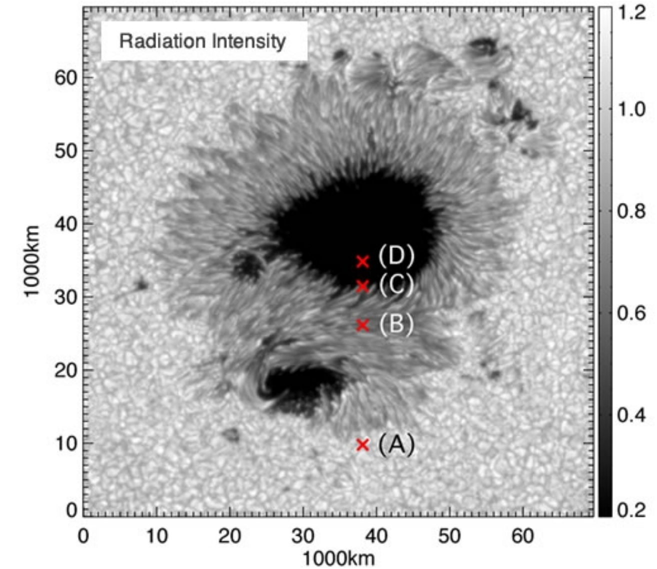


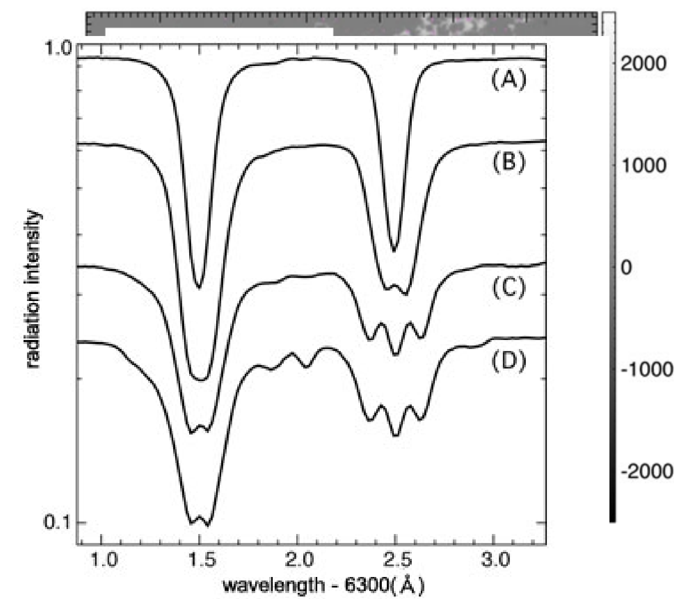
Credits: Swedish Solar Telescope

How do we know sunspots harbor magnetic fields?



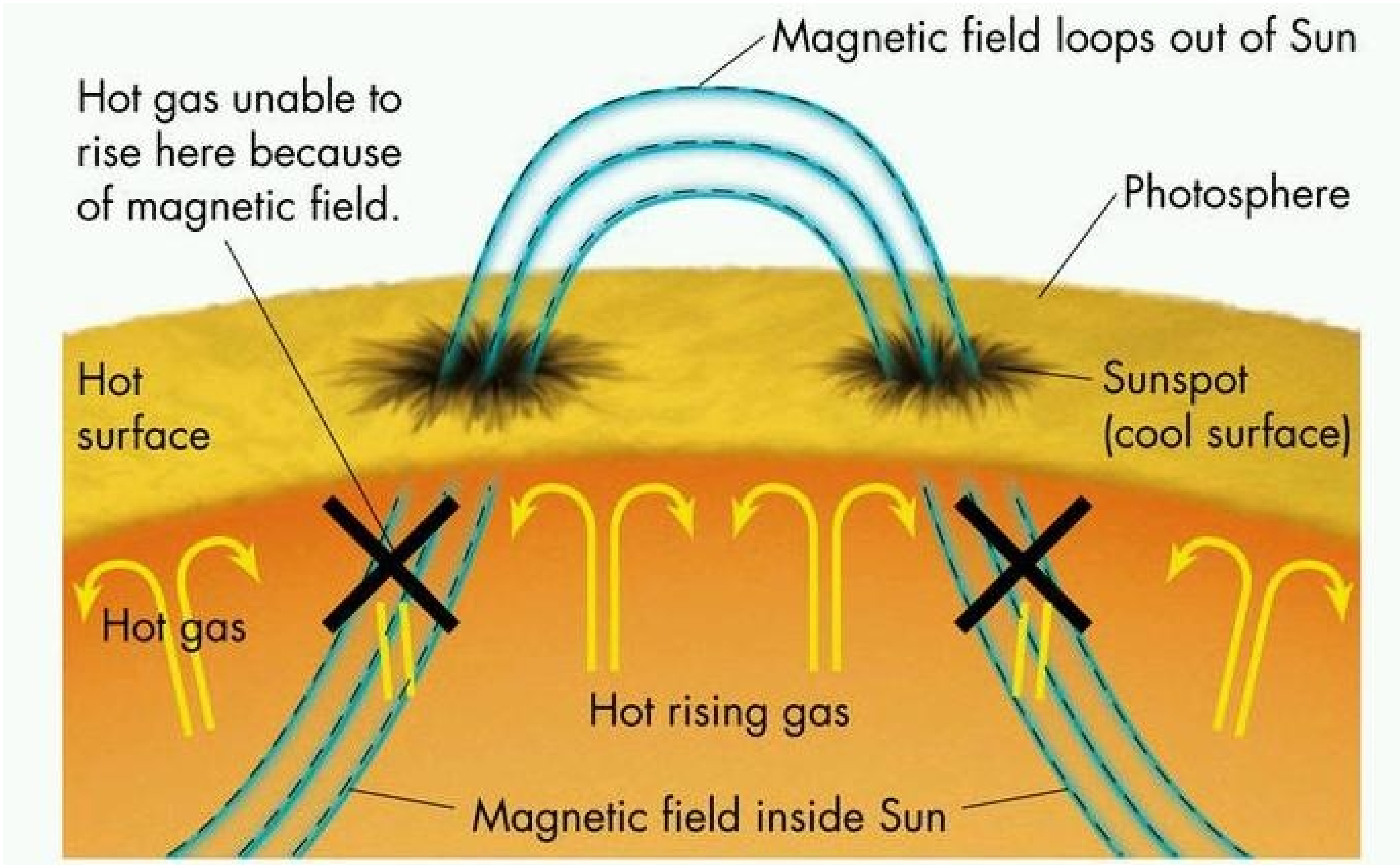
G.E. Hale, F. Ellerman, S.B. Nicholson, and A.H. Joy (ApJ, 1919)





Credits: Yukio Katsukawa

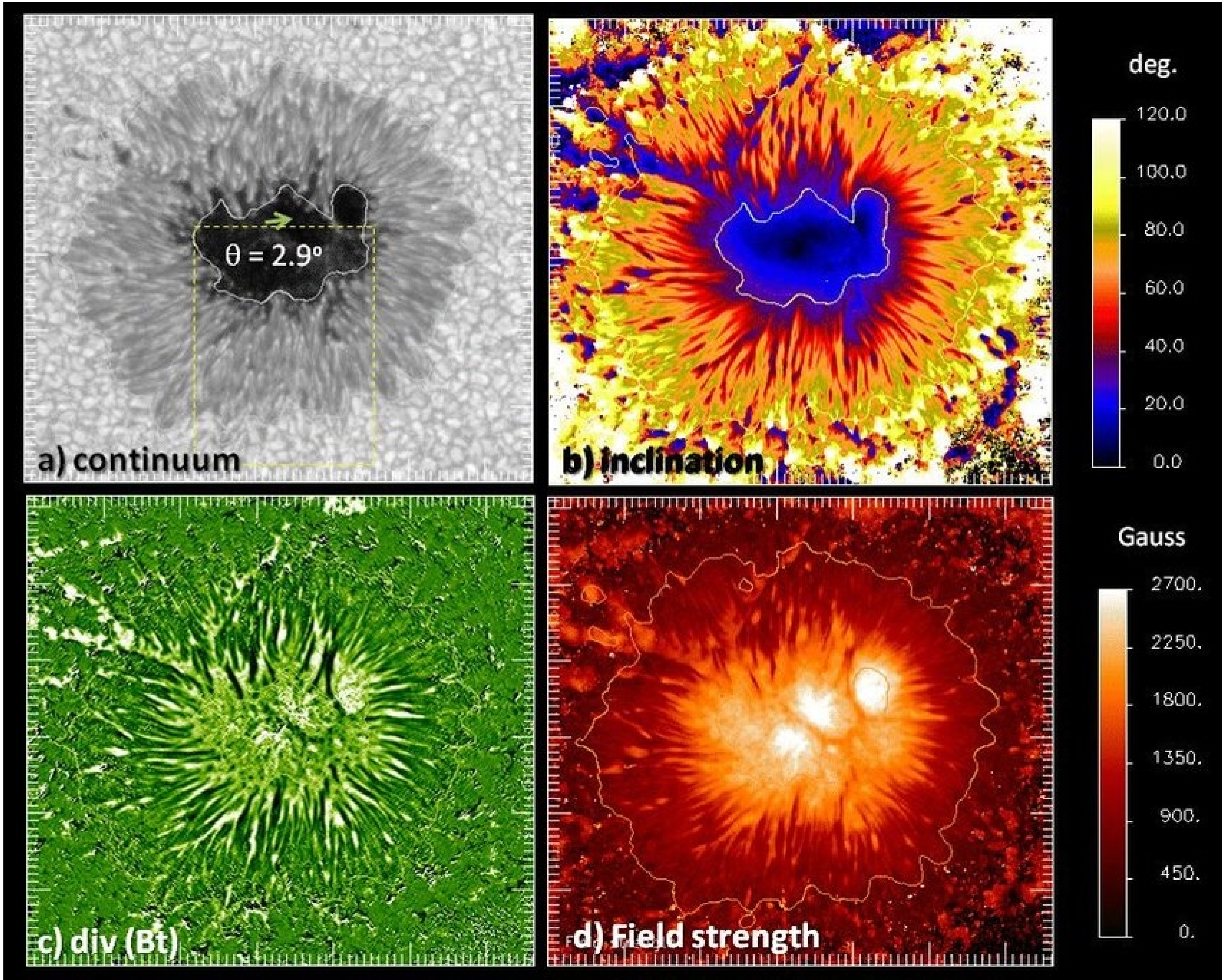
How do we imagine physics of the sunspots looks like



Credits: Prof. Min S. Yun

Sunspot magnetic fields

- Could we infer the magnetic structure of a sunspot from images only?
- What do **you** think?

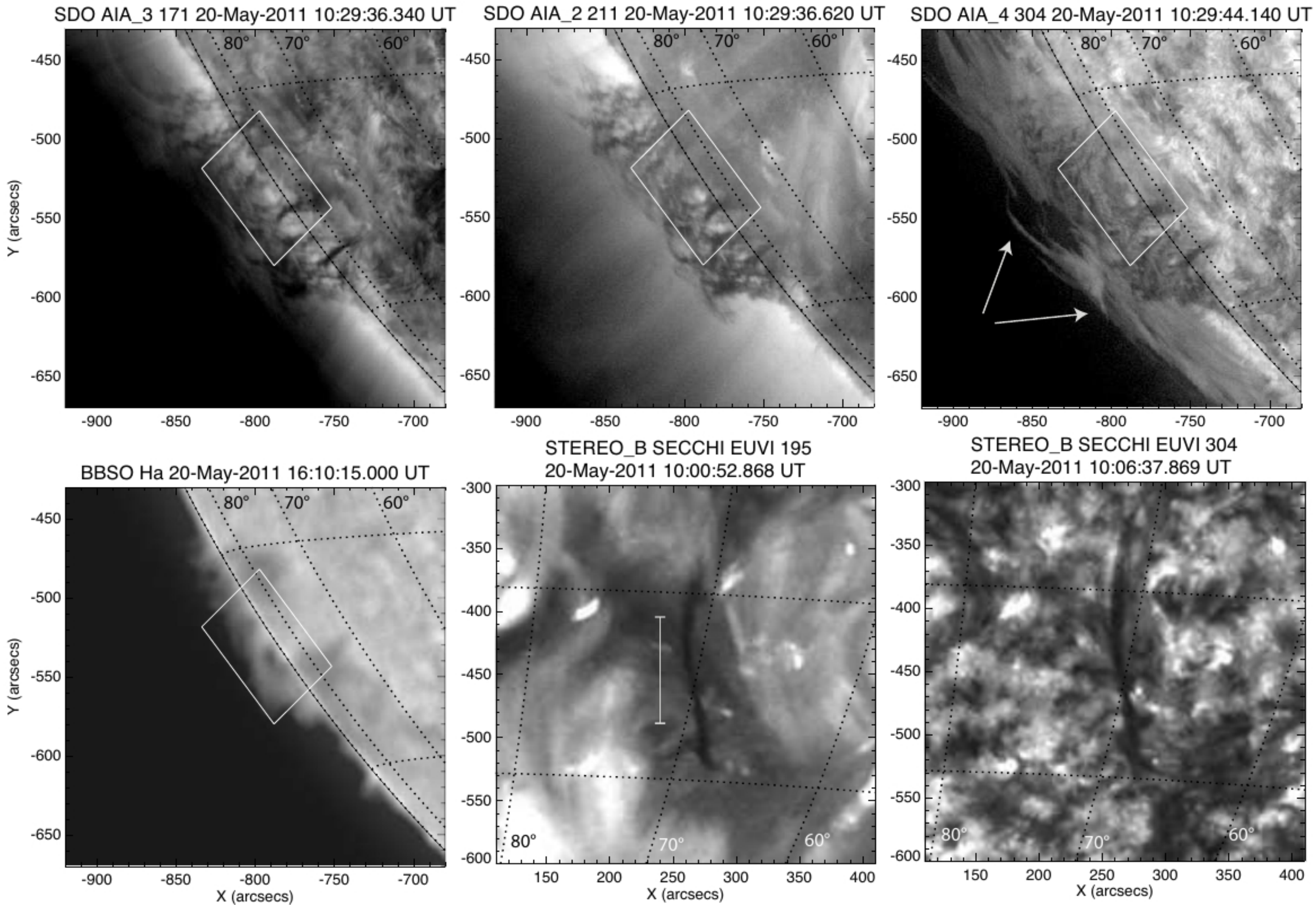


From Borrero & Ichimoto (2011)

Solar prominences and filaments

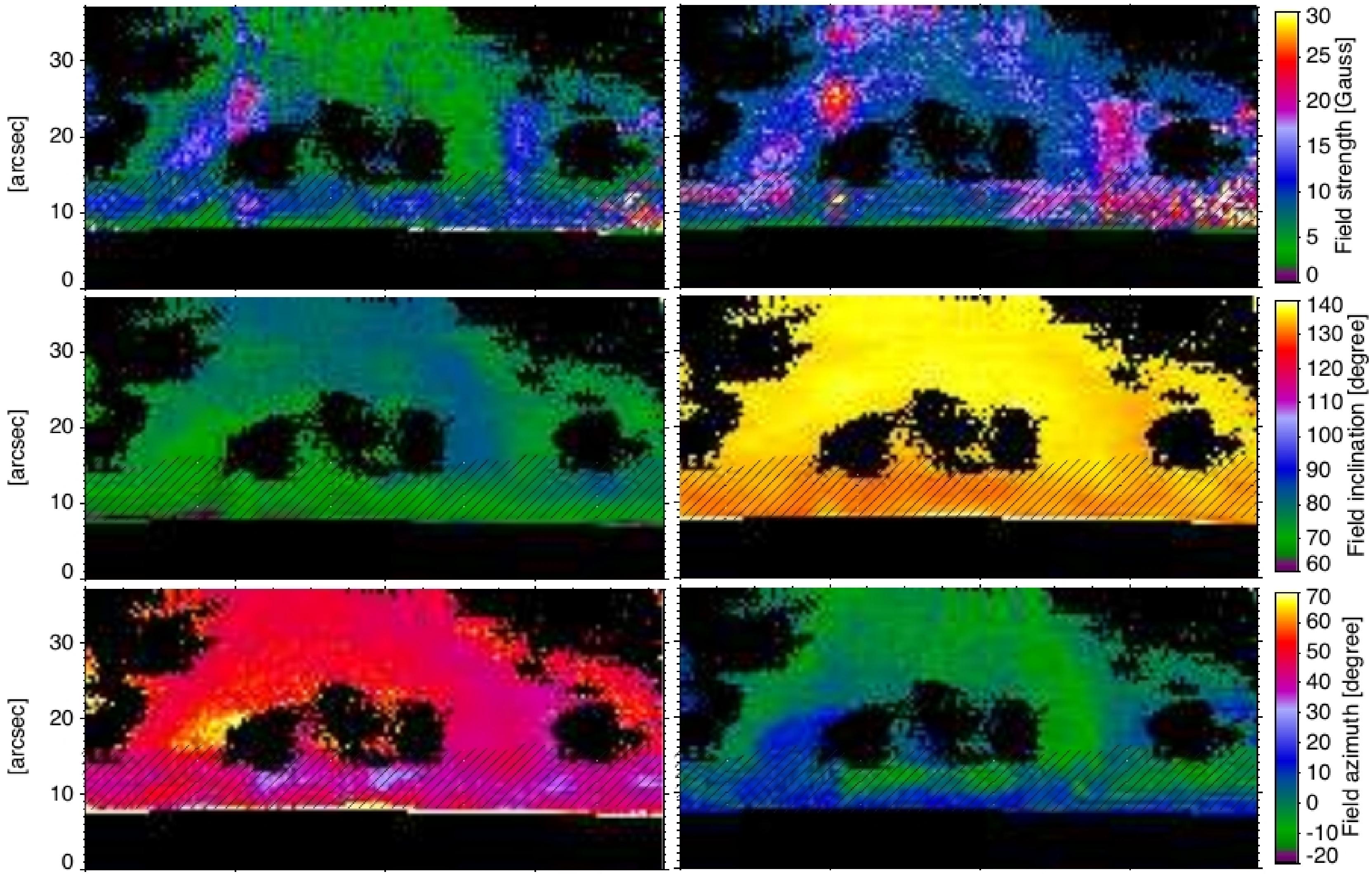
How does the Sun look here? What are differences w.r.t previous images we saw. Let's discuss a bit.

Solar Prominences and Filaments



Orozco Suarez et al. 2011

Solar Prominences and Filaments



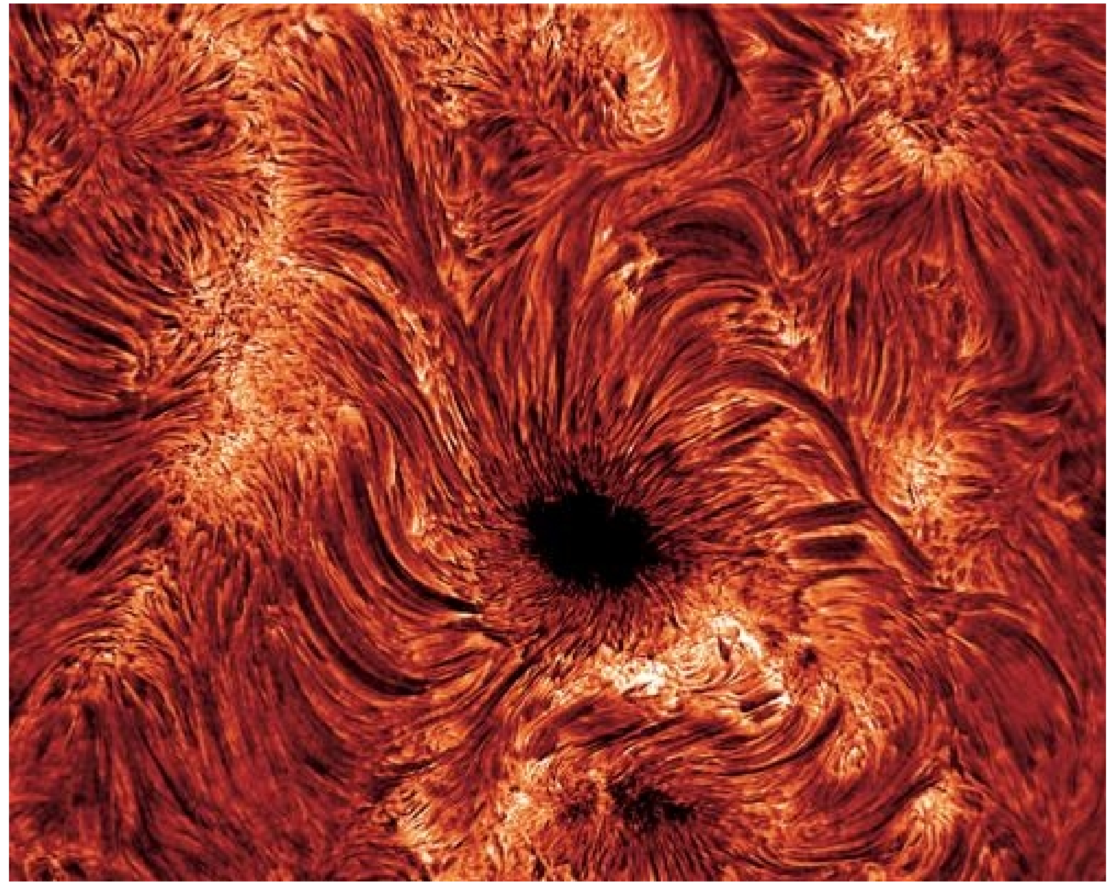
Orozco Suarez et al. 2011

Solar Chromosphere

- **Textbook definition:** a thin layer visible during the eclipse that has specific color and so on ...
- We see here the chromosphere during the eclipse (DKIST will be able to make an eclipse for you, not quite like this one but still)
- What if I told you we can look at the chromosphere “from the top”?

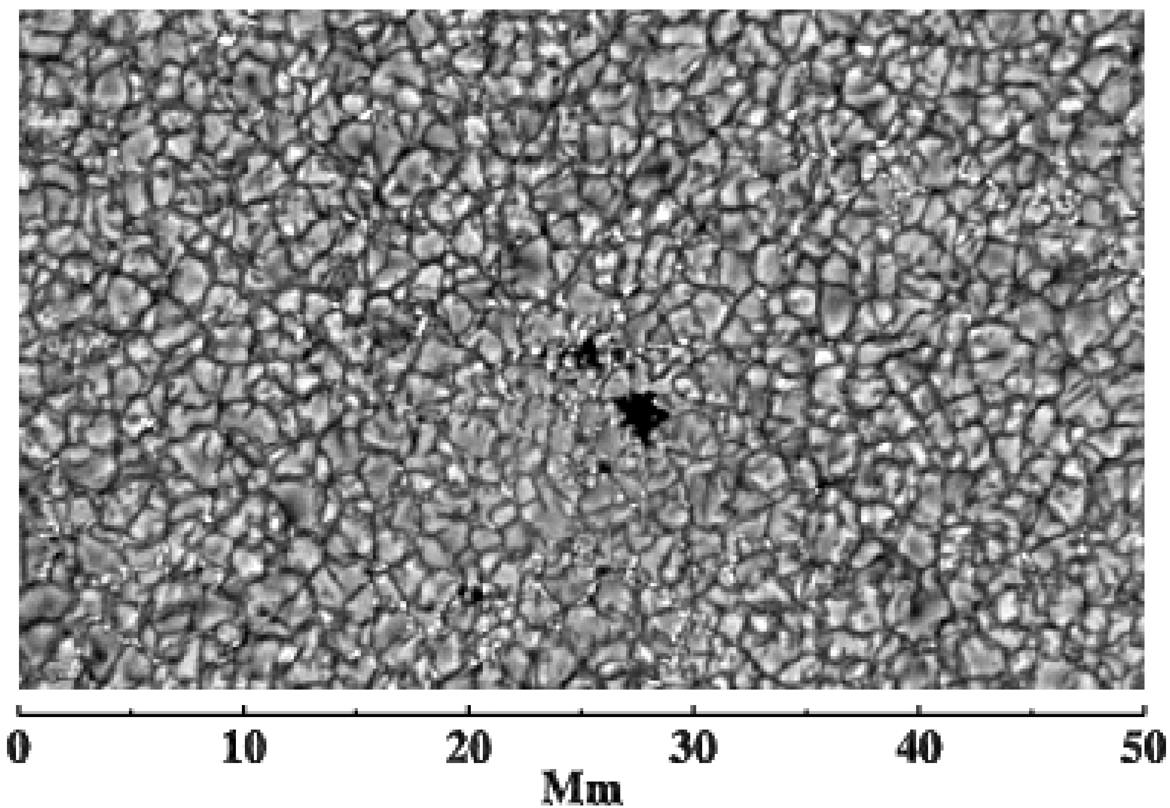
Solar Chromosphere

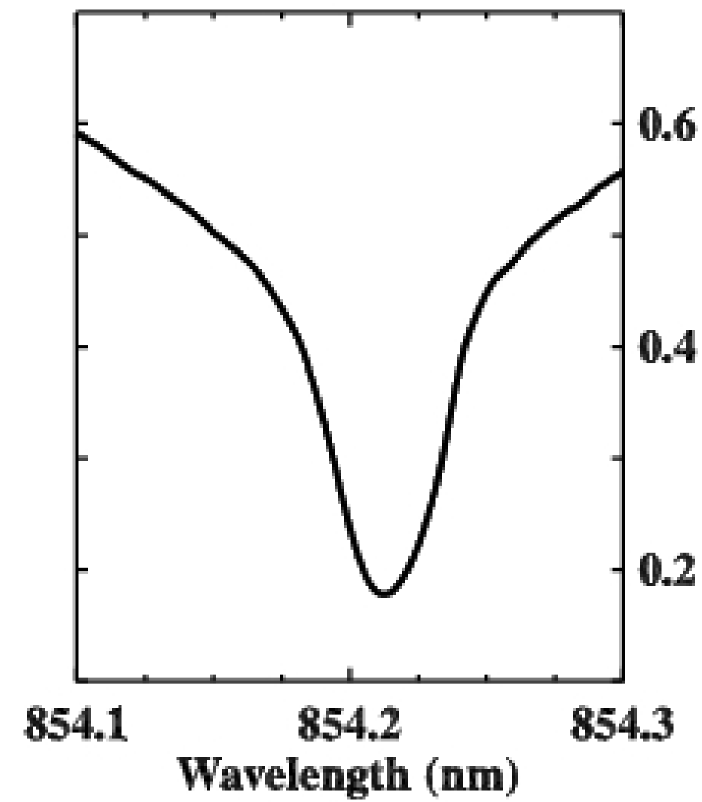
- This is again, a ground based, high resolution picture.
- What is this now? How come the atmosphere now looks completely different?
- In the center there is a sunspot, but what are these things around?



Credits: SST

Solar Chromosphere



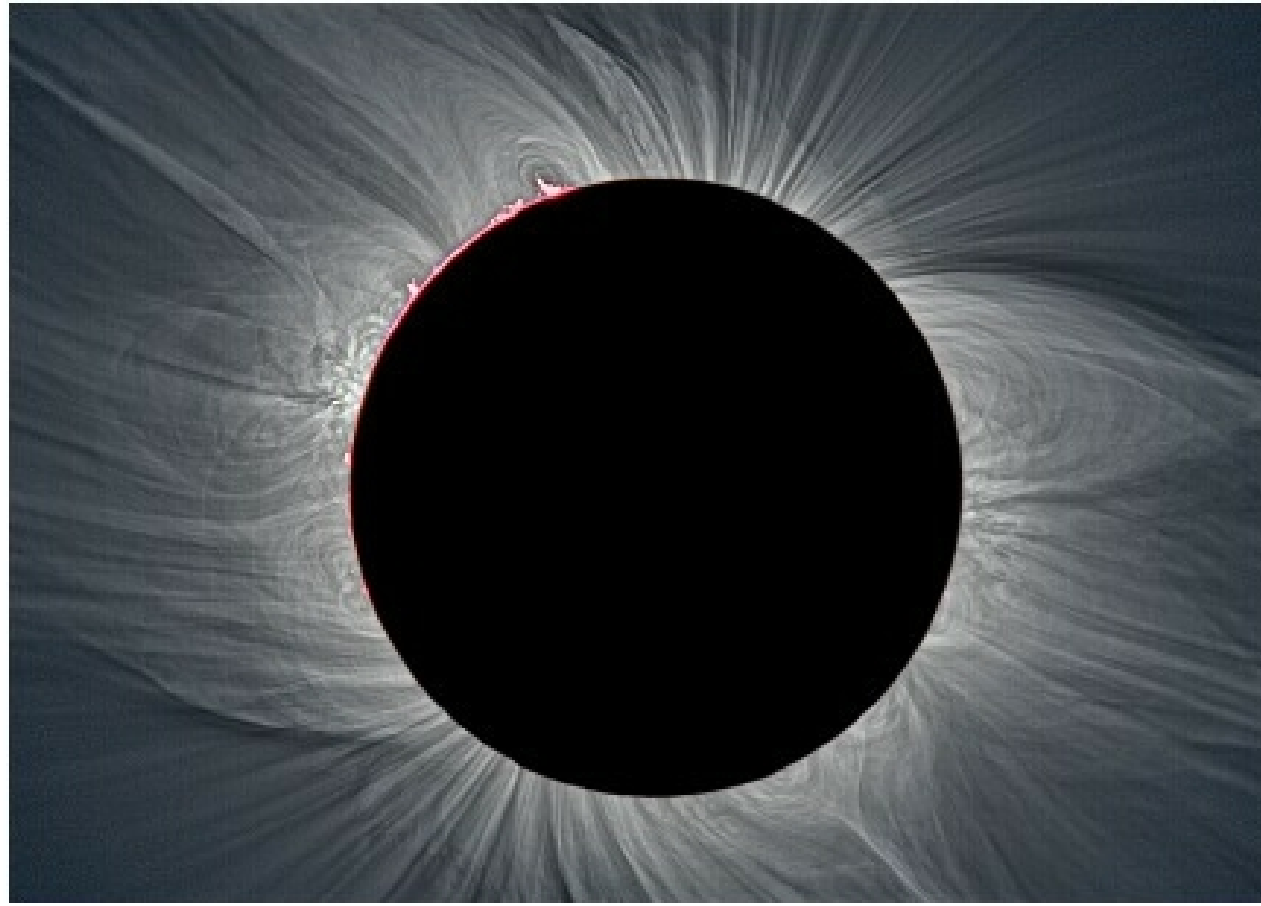


And here? What does this video represent?
Why does the image change completely?

Credits : DST/ IBIS

Solar Corona

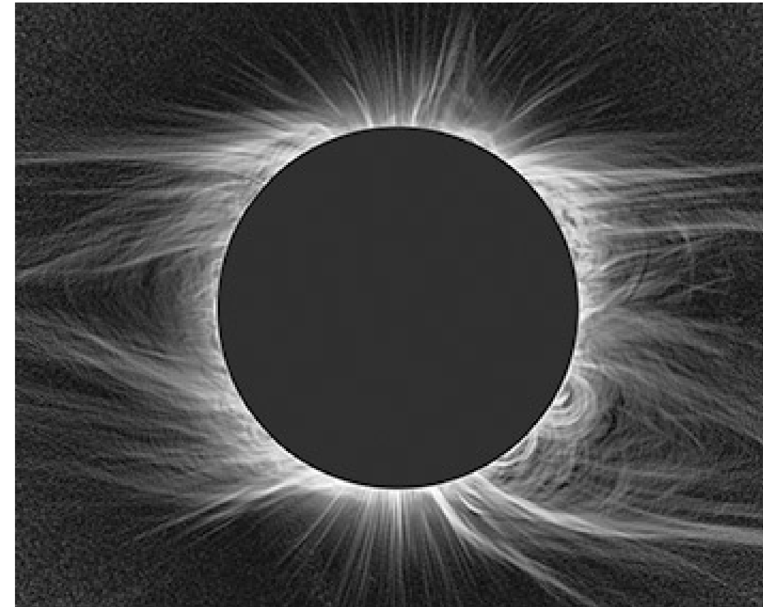
- This is an image of solar corona during the eclipse.
- Why does it look this way, what do we see here?
- Can we see the corona without an eclipse.

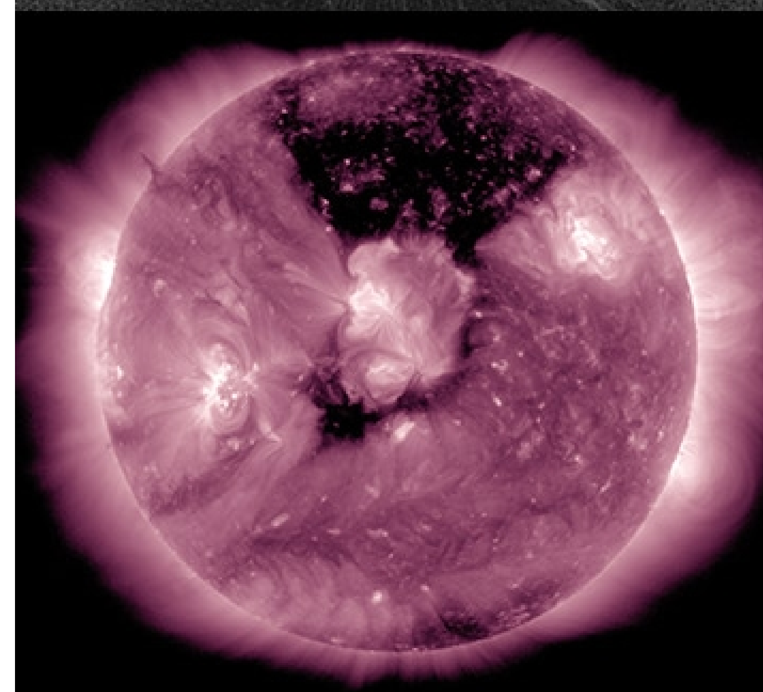


Mazouk et al. 2006

Solar Corona

- Here are two complementary views.
- Upper is white light, during the eclipse.
- Lower is UV light, as seen by Solar Dynamics Observatory (SDO), a telescope observing the whole Sun every day, mounted on a satellite.
- What are the differences in these pictures, what is the physics behind?



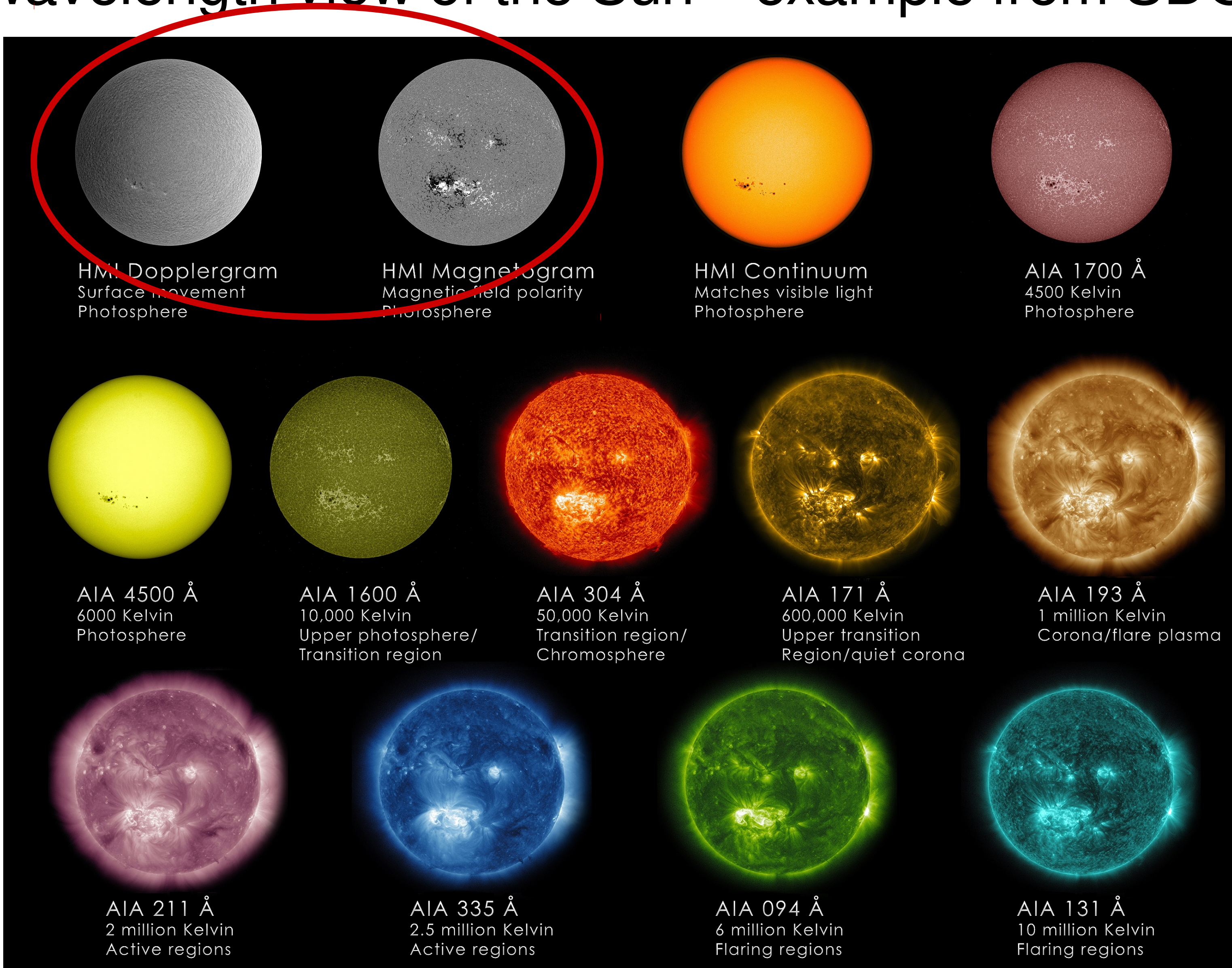


Multi-wavelength view of the Sun

- The main premise of all these examples was: We need to analyze the light spectrally, the images are not enough.
- Sun looks different at different wavelengths because different regions and **different processes** create / influence the radiation.
- **Example:** Why do we look different when viewed in visible and IR light?

Credits: NASA/JPL-Caltech/ R.Hurt (SSC)

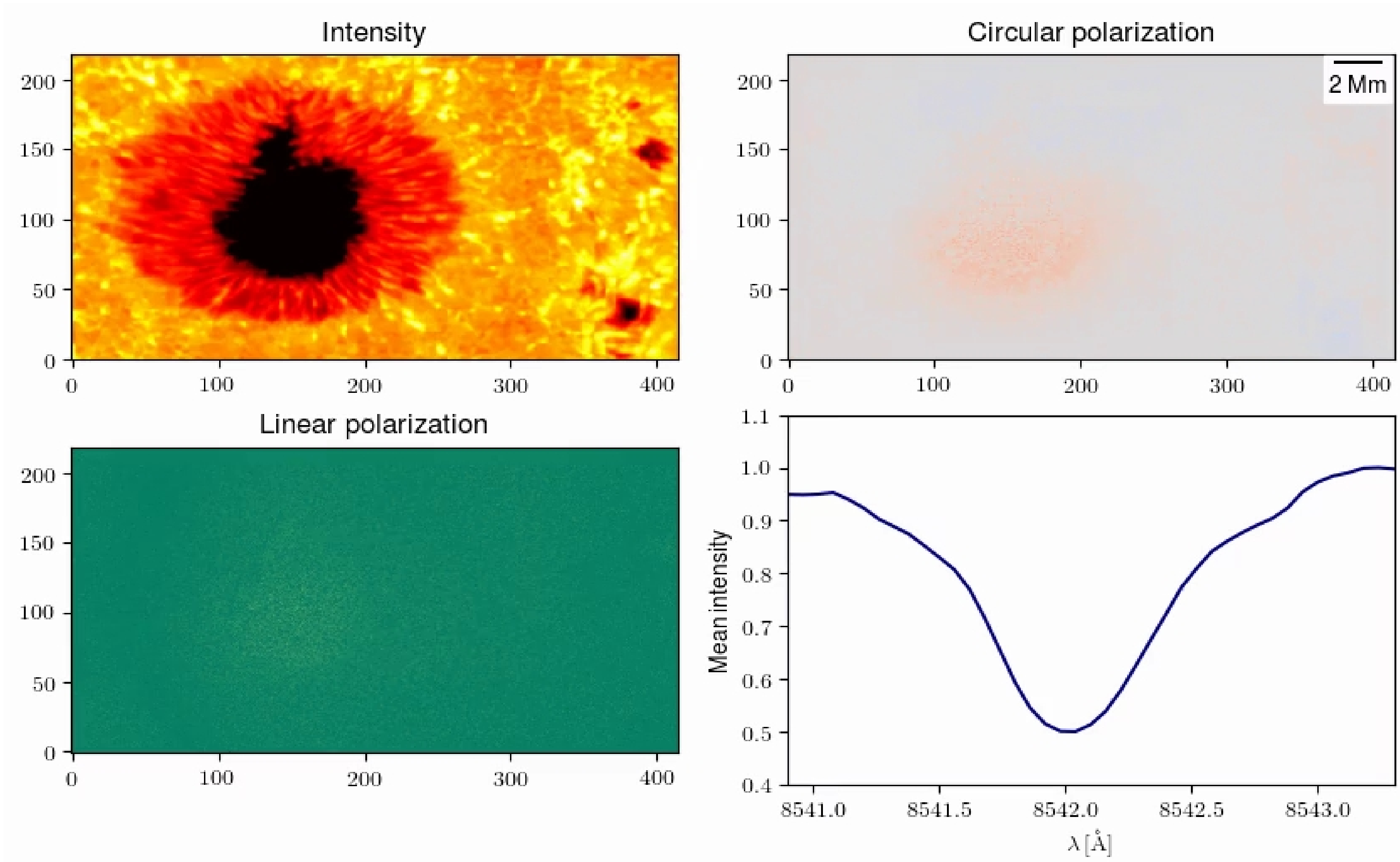
Multi-wavelength view of the Sun – example from SDO



Summary

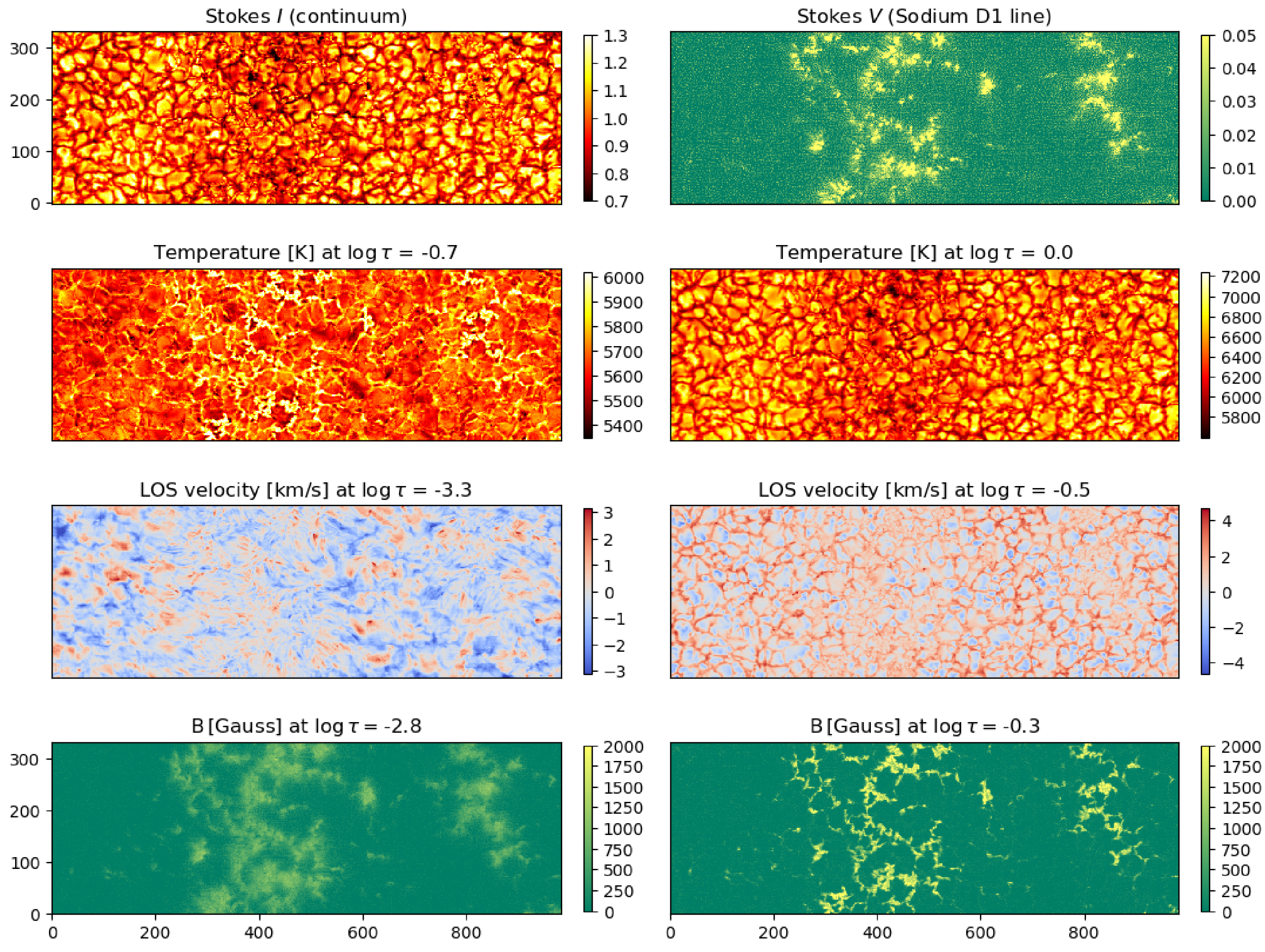
- Different wavelengths probe different regions and different processes
- To understand the physics behind and use this, we need to know what influences the light on its way through the atmosphere (absorption/emission/scattering).
- Besides the intensity of the light, we will also use the **polarization.**
- We also need to have the observations in the first place.
- This course will focus on these two aspects: **gathering the data** and **interpreting the data.**
- We will try to use simple models and to discuss more complicated ones.
- If you happen to like this, you can learn more by attending **DKIST workshops.**

What data we want – “cubes” like this one

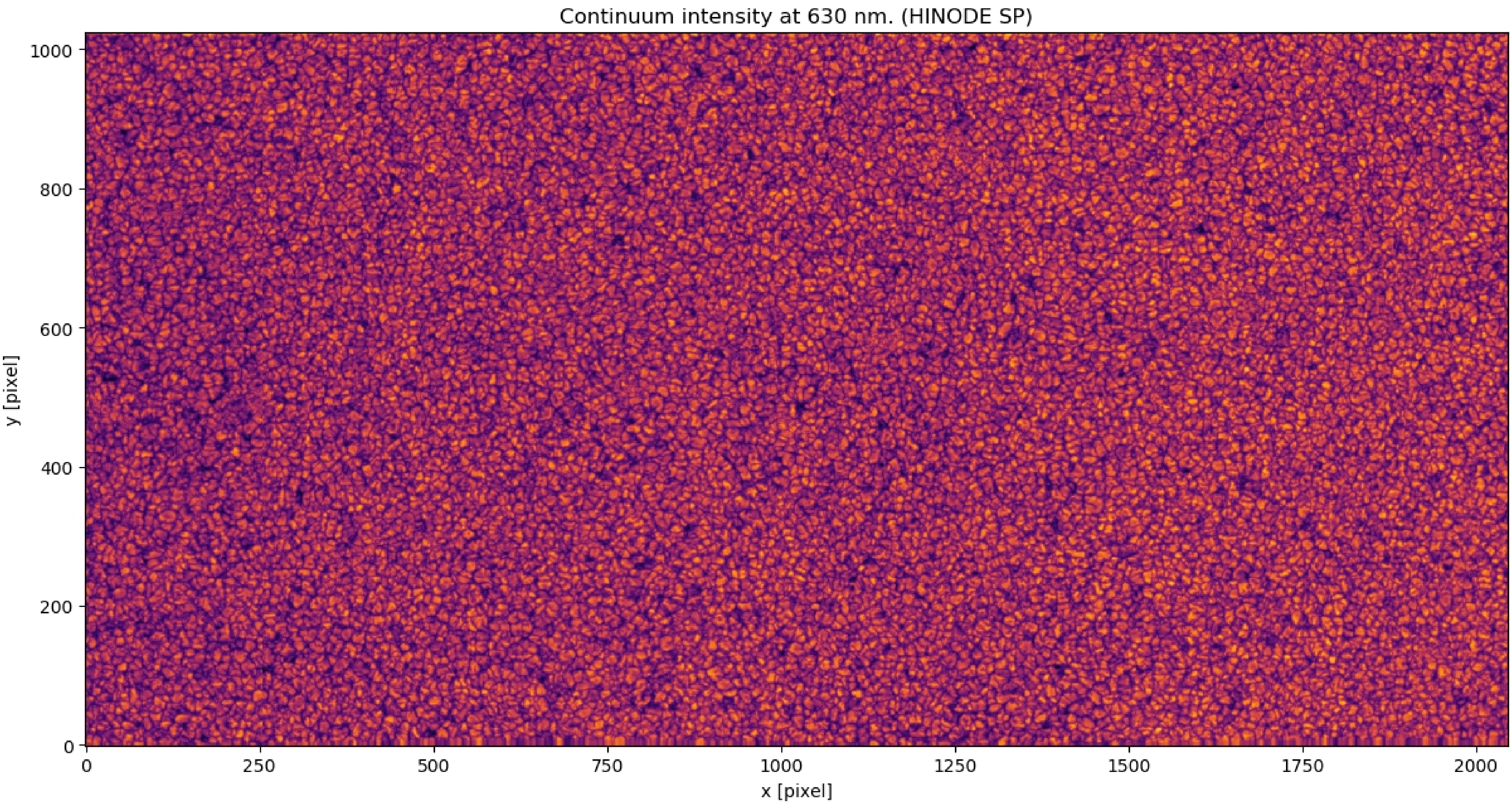


Time → Wavelength; Sunspot observations with IBIS at the NSO/Dunn Solar Telescope.
Courtesy of L. Kleint, K. Reardon, and A. Tritschler

What do we want to obtain – parameter maps like this one



Let’s try the most simple approach we can think of on this:



How would you proceed?

$$I_\lambda = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

- Zeroth level approximation would be to say the atmosphere radiates as a blackbody.
- But how to infer the specific intensity? (We will go deeper in these quantities in the next class).
- Compare intensity at each pixel to the mean quiet Sun intensity and infer temperature that way?
- What are the problems of this approach.
- What about looking at this figure at a different wavelength?

What could you infer from this intensity?