PHYS 7810 : Physics of the solar atmosphere

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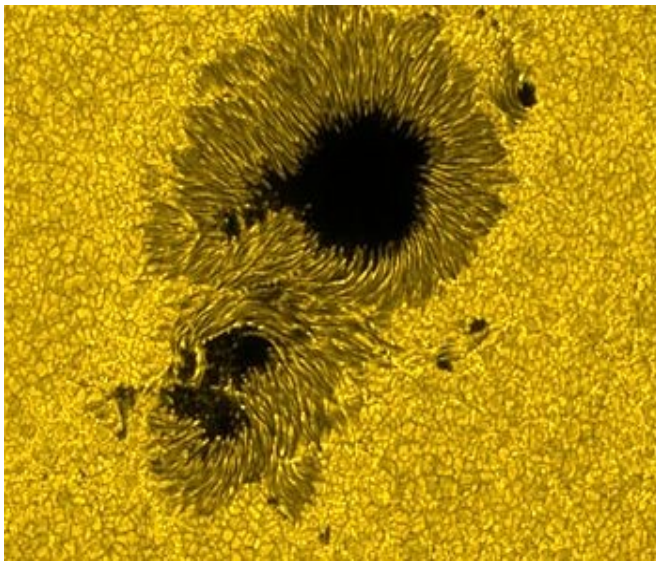
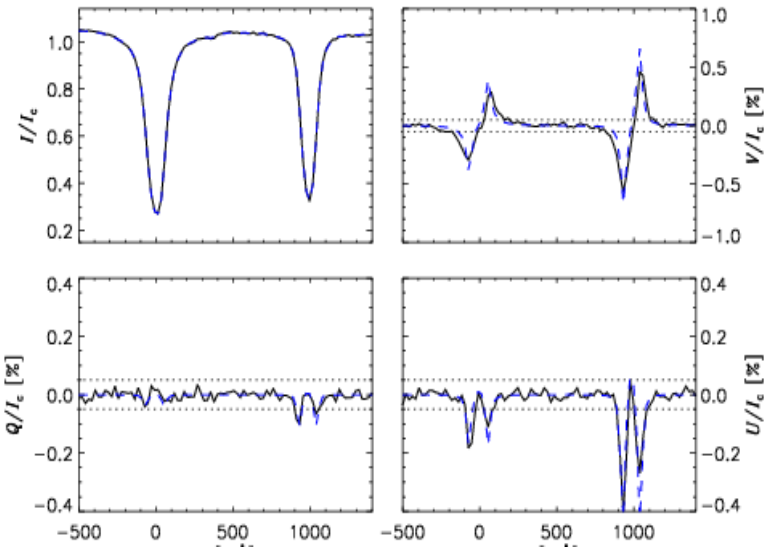
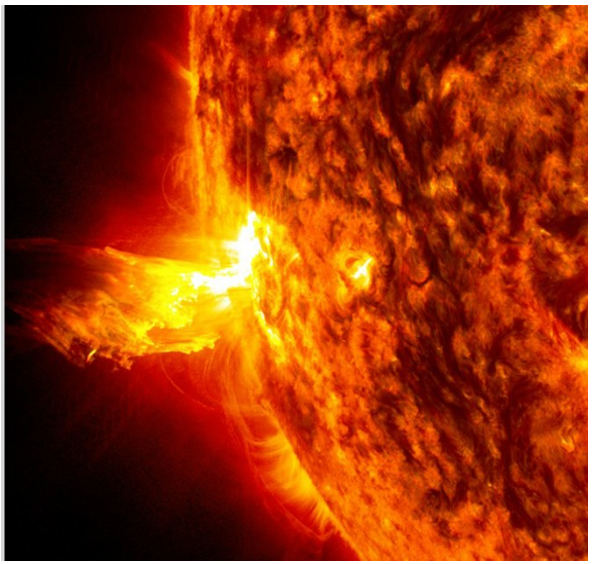
Lecturers: Matthias Rempel, Ivan Milic, Xudong Sun

rempel(at)ucar.edu; ivan.milic(at)colorado.edu; xudongs(at).hawaii.edu

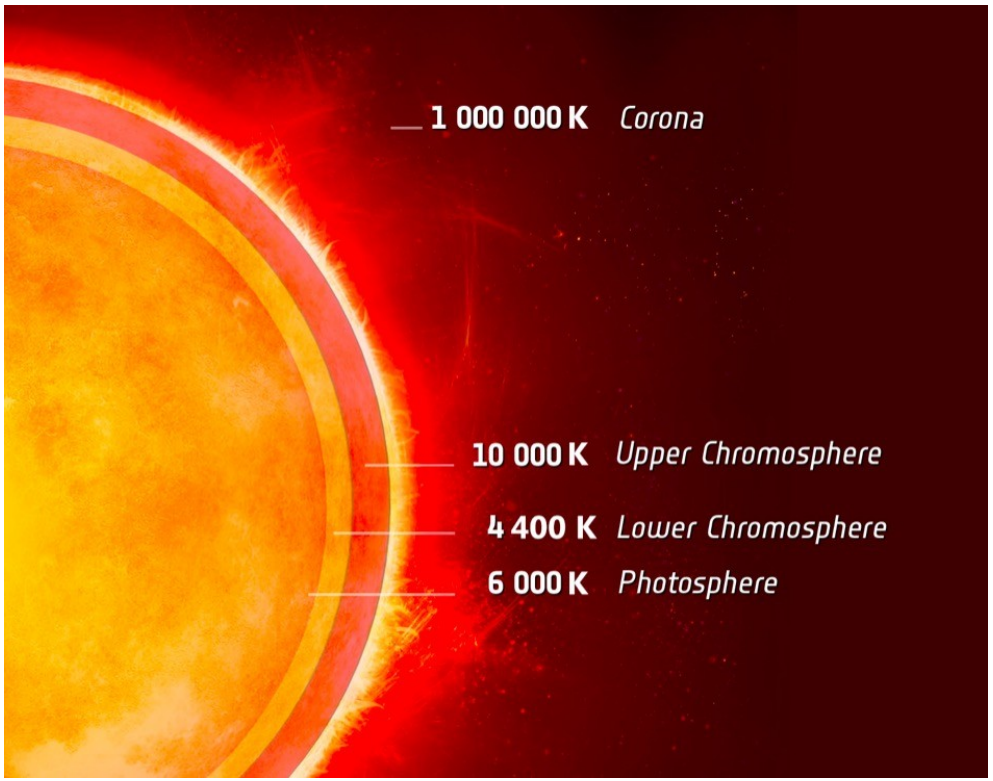






Why the solar **atmosphere**?

- 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

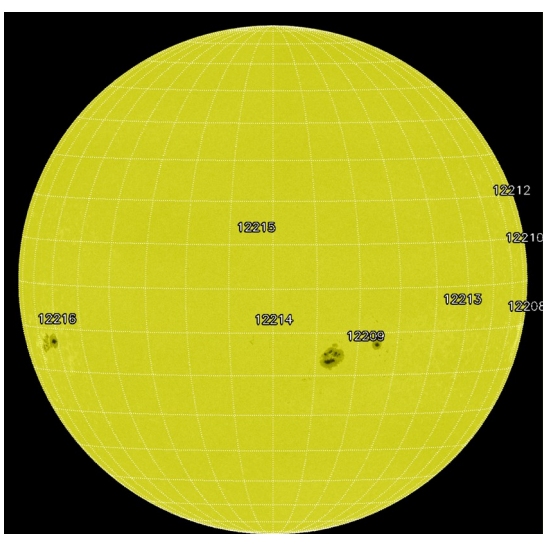


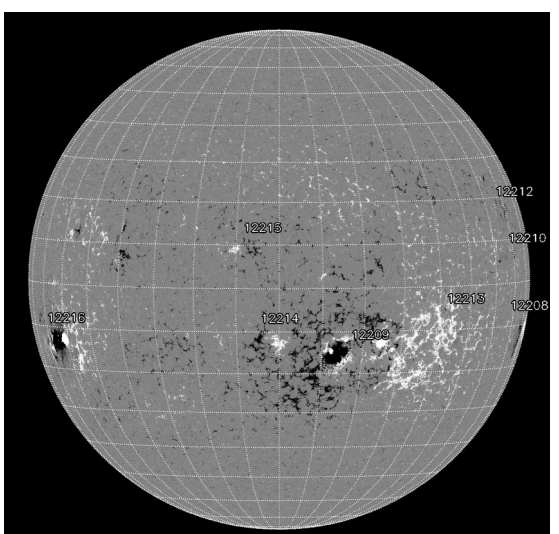
Credits: ESA

The Sun is pervaded with the magnetic field

- Range of strengths, scales and shapes.
- We can’t measure it directly (velocities/temperatures/densities neither)
- We want to model and diagnose these processes. And to teach you how to do it! :)

Credits: TRACE

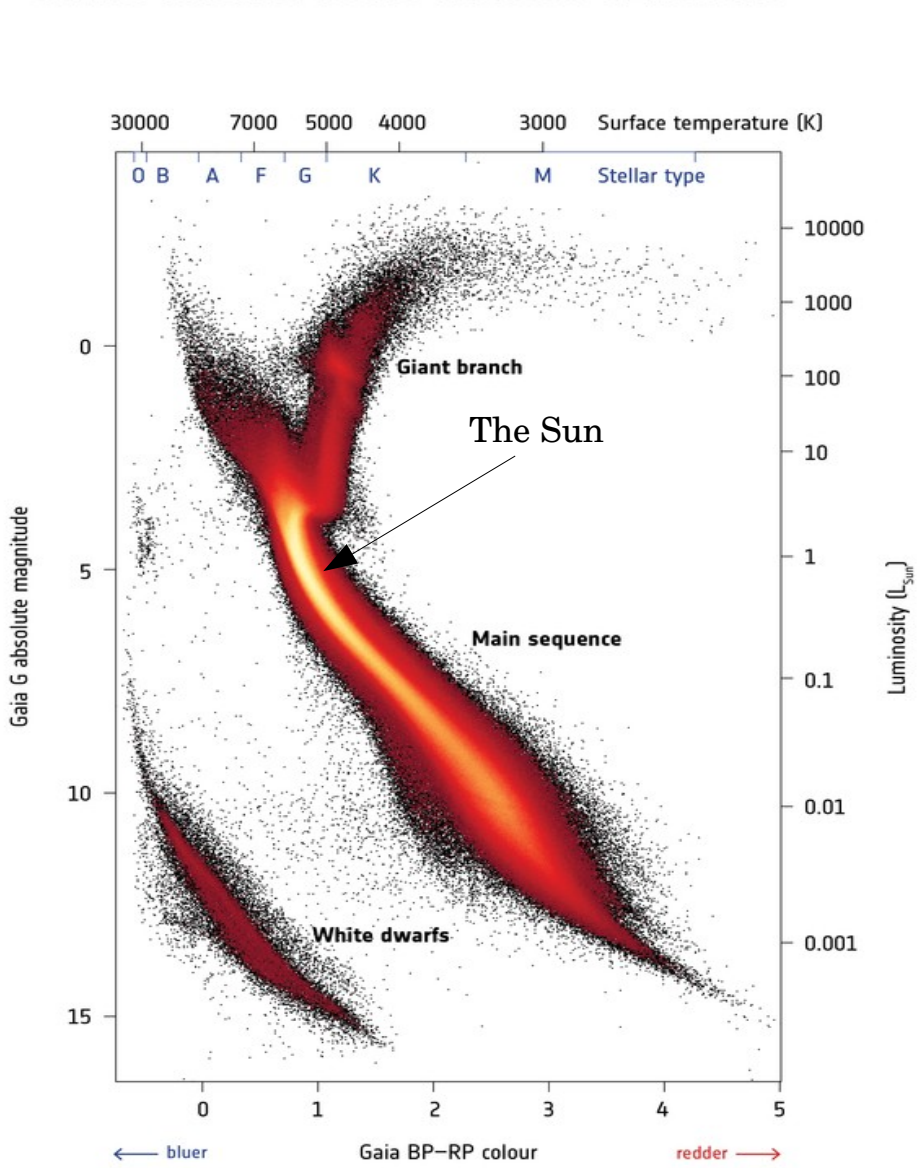




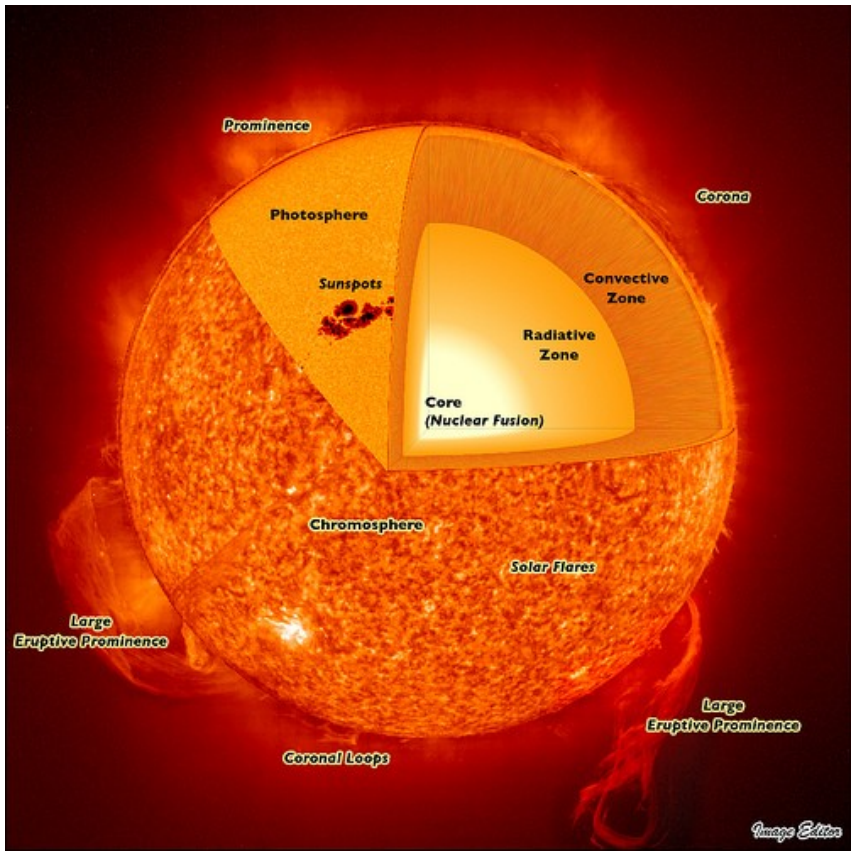
Credits: SDO

Astrophysical context

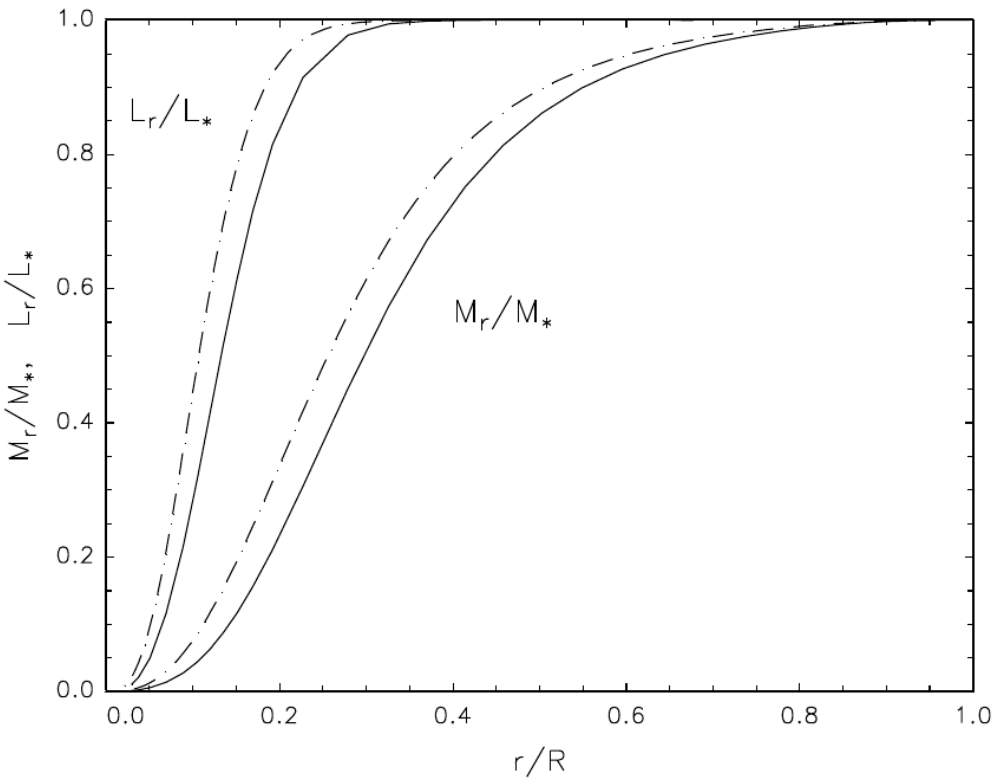
- A G2 V ‘yellow dwarf’
- Magnitude and color index (CI) depend on the atmospheric properties
- These depend on the effective temperature, which depends on the stellar properties (mass and composition, recall Vogt-Russel theorem)
- *Refresher:* ‘Stellar Interiors’ by Hansen, Kawaler, Trimble; ‘The Observation and Analysis of Stellar Atmospheres’, Gray



Canonical 1D picture of the solar interior:

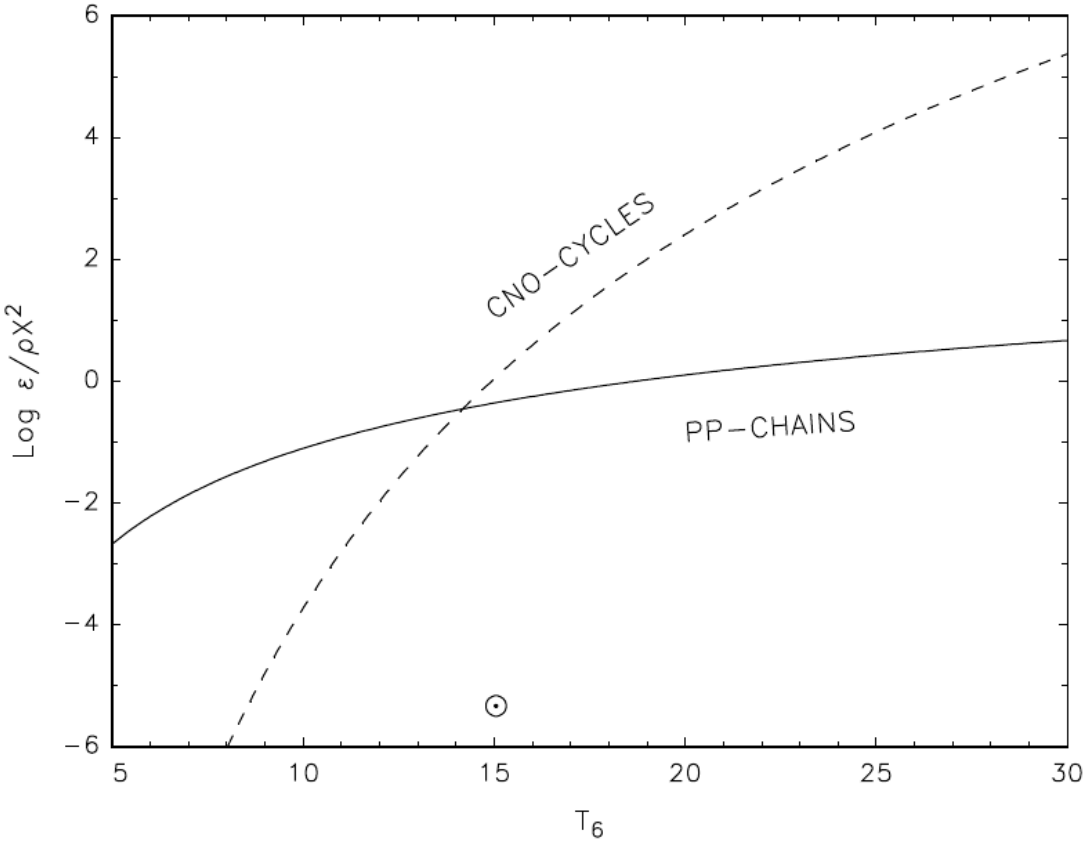


You have seen this a million times, right?



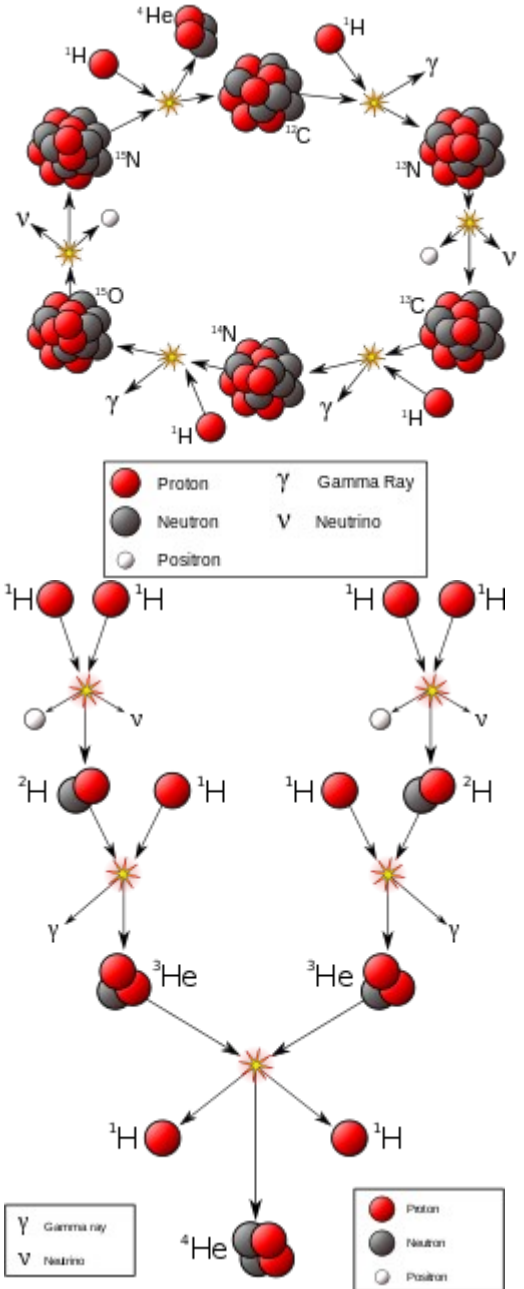
From “Stellar Interiors” , chapter 9

Energy sources: pp chain and CNO cycle



From “Stellar Interiors” , chapter 6

So, temperature in the core + composition → Luminosity



Radiative zone

"In an intuitive picture of diffusion, one usually conceives of a slow leakage from a reservoir of large capacity by means of a seeping action. These ideas apply in the radiative diffusion limit as well."

— Dimitri Mihalas in Stellar Atmospheres (1978)

OK, this plus a little math and I suppose we're done.

From "Stellar Interiors" , chapter 4

Diffusion of the energy through the star:

$$\mathcal{F}(r) = -\frac{4ac}{3}\frac{1}{\kappa\rho}T^3\frac{dT}{dr} = -\frac{c}{3\kappa\rho}\frac{d(aT^4)}{dr}$$

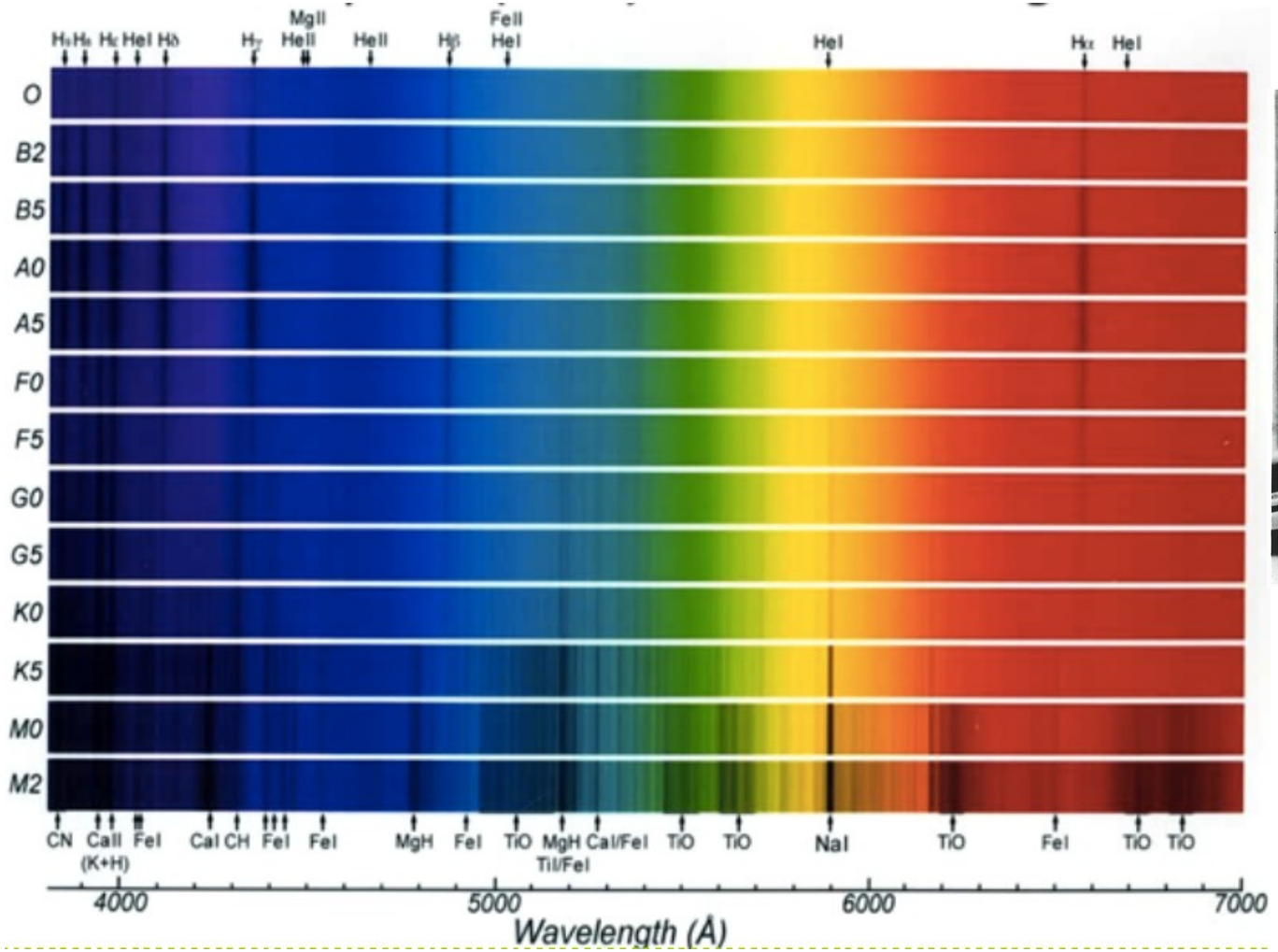
This works well deep inside. You might recall an alternative version:

$$\nabla \equiv \frac{d\,\ln T}{d\,\ln P} = -\frac{r^2 P}{G\mathcal{M}_r\rho}\frac{1}{T}\frac{dT}{dr}\ .$$

In the outer regions, convection is more efficient, so we have convective zone, which extends up to the atmosphere.

But, that is a story for an another occasion...

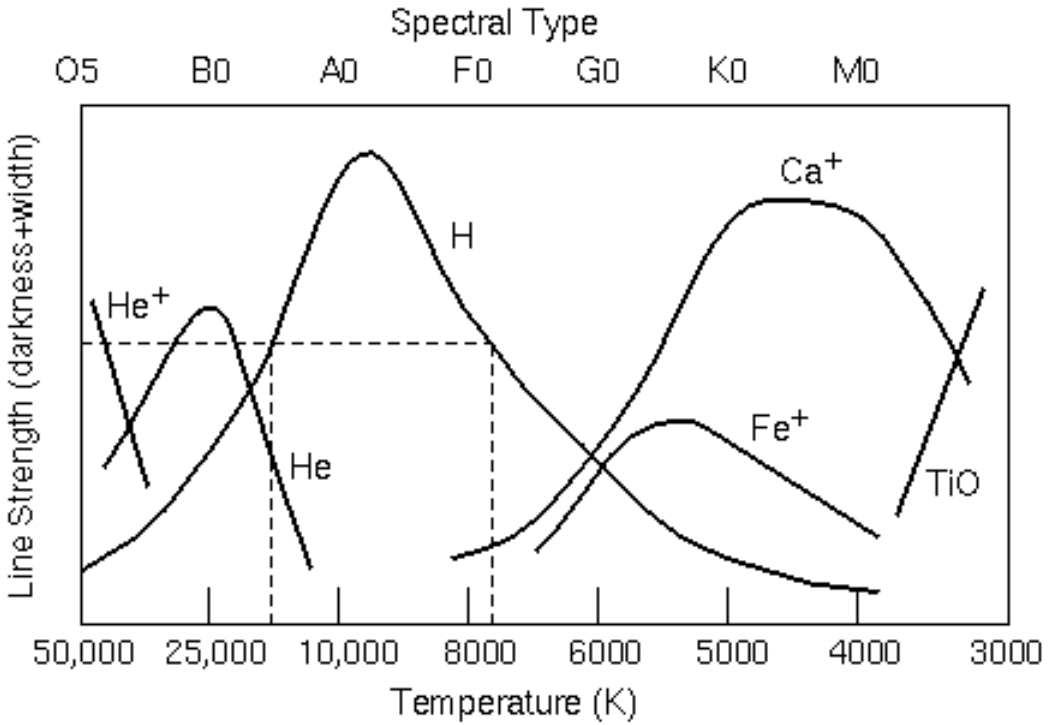
Finally, the atmosphere, where the spectrum is formed:



Annie Jump Cannon,
Harvard classification.

Credits: NOAO/AURA/NSF

Why do the spectra vary - Temperature!

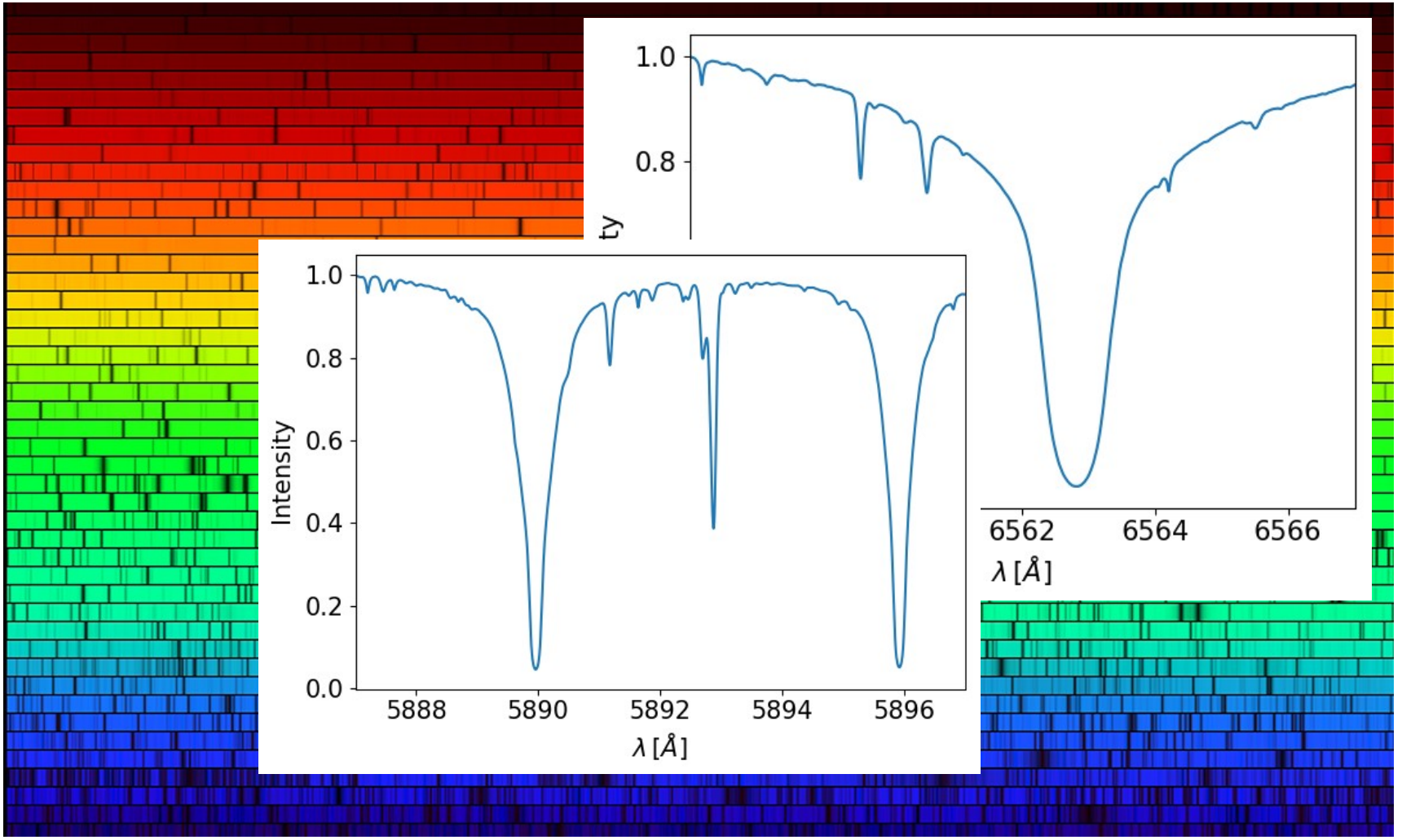


Cross-referencing different line strengths narrows the possible temperature range. A given strength for the Hydrogen line could mean two possible temperatures (hot or warm). If Helium line is present, then the choice is the hot temperature. If the ionized Calcium line is present (and Helium not present), then the choice is the warm temperature.

Cecilia Payne Gaposchkin, applying Saha equation.

"... the most brilliant PhD thesis ever written in astronomy... " (said by Otto Struve)

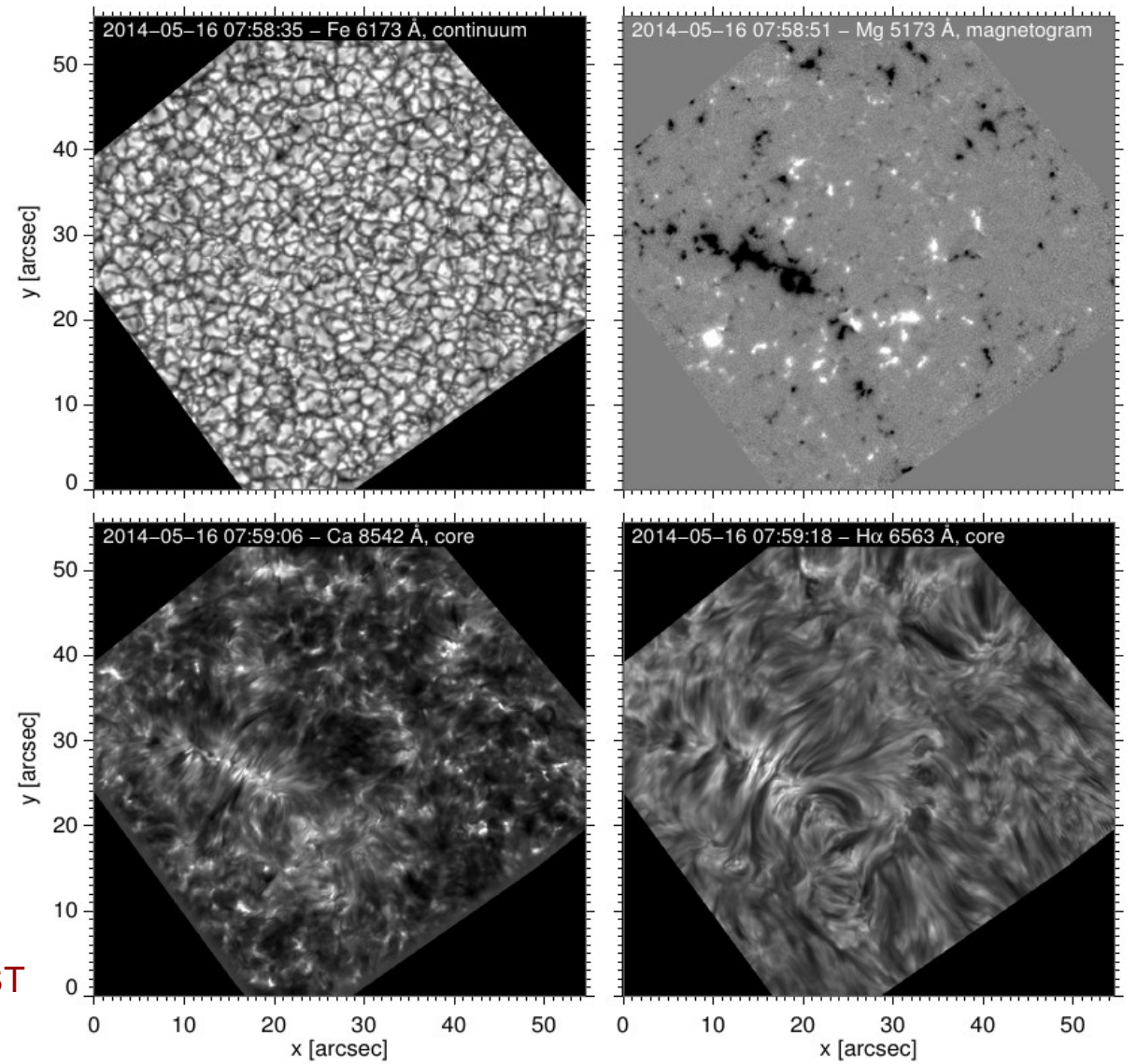
We can, by looking at the solar spectrum:



N.A.Sharp, NOAO/NSO/Kitt Peak FTS/AURA/NSF

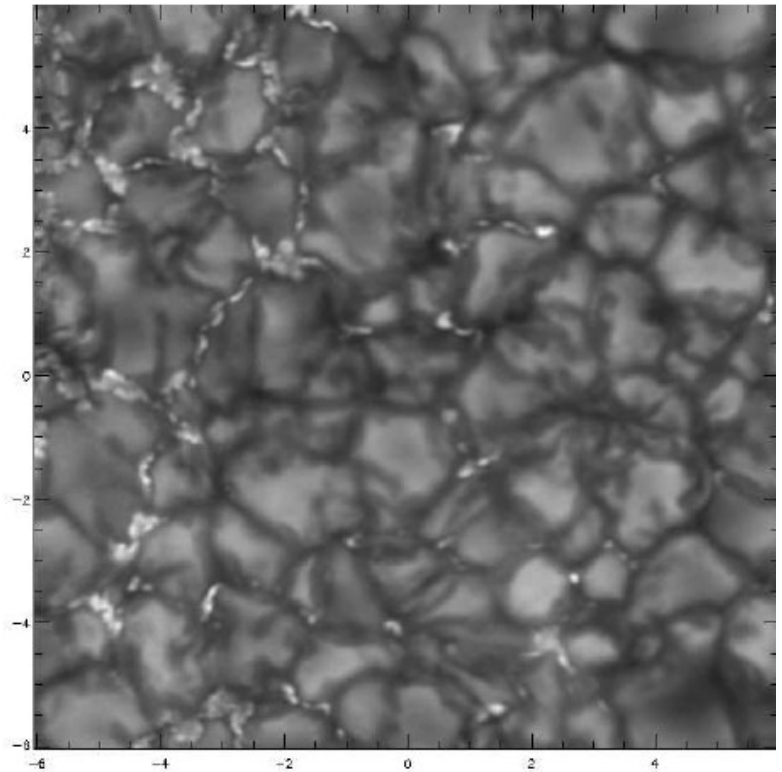
Multi-wavelength look at the atmosphere:

- It looks significantly different!
- Different wavelengths → different heights, different physics
- In astronomy in general different wavelengths → different objects, different physics

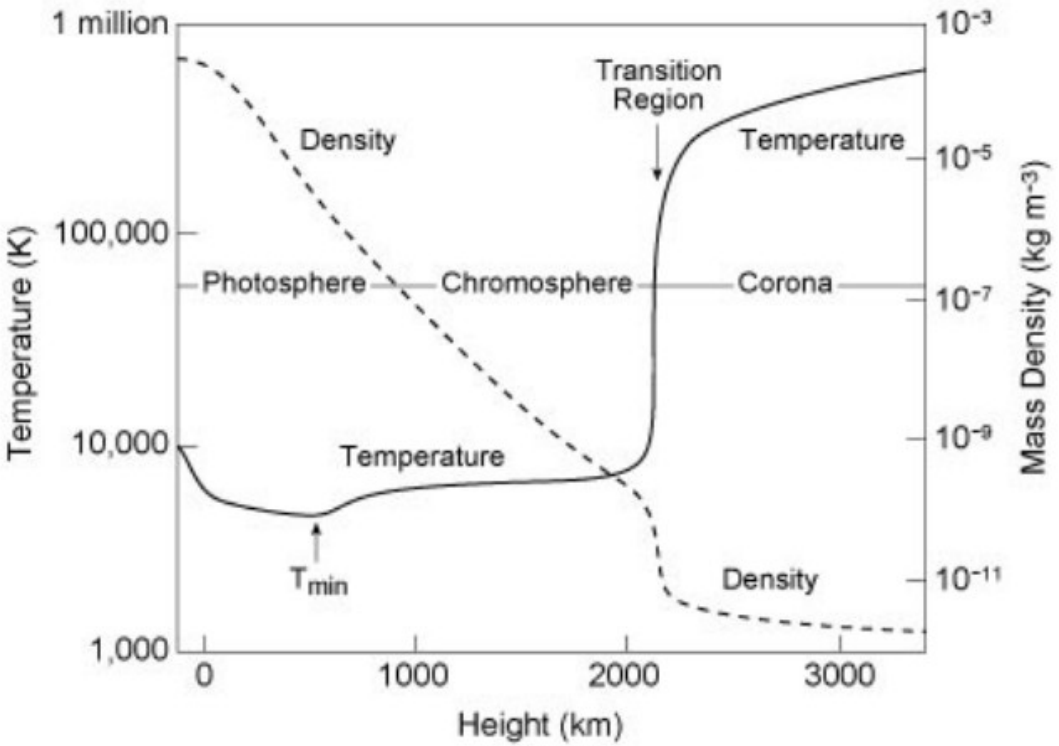


From Gošić et al., 2018, observed at SST

Semi-empirical 1D models of the solar atmosphere

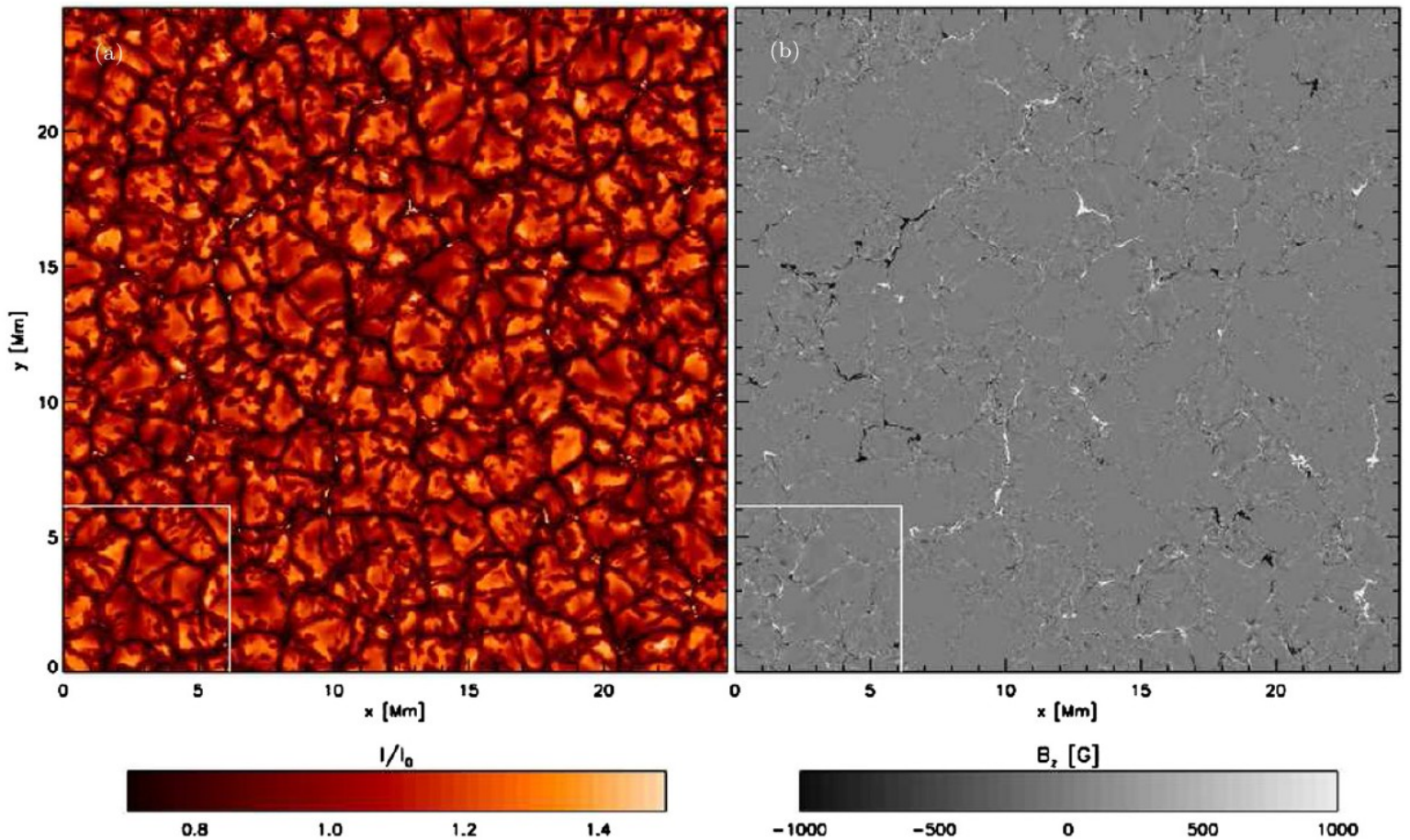


From “Solar Atmosphere” by Hansteen & Carlsson (2009)



Courtesy of Eugene Avrett

3D Radiative MHD models of solar atmosphere (we make an atmosphere *ab initio)*



From Rempel (2014)

So why do we study the solar atmosphere?

- Its structure reflects the inner conditions in the Sun.
- There is plenty of physics happening in (or close to) the atmosphere itself – flux emergence, dynamo, reconnection, flux transport
- It can affect the interior (oscillations)
- It allows us to understand some general principles of stellar physics and understand other stars better.
- Some additional reading:

  ”Solar Atmosphere”, Hansteen & Carlsson 2009

  “Stellar Atmospheres theory: An introduction”, Hubeny

  “Stellar Interiors”, Hansen, Kawaler & Trimble, 2004 (whichever chapter you need)