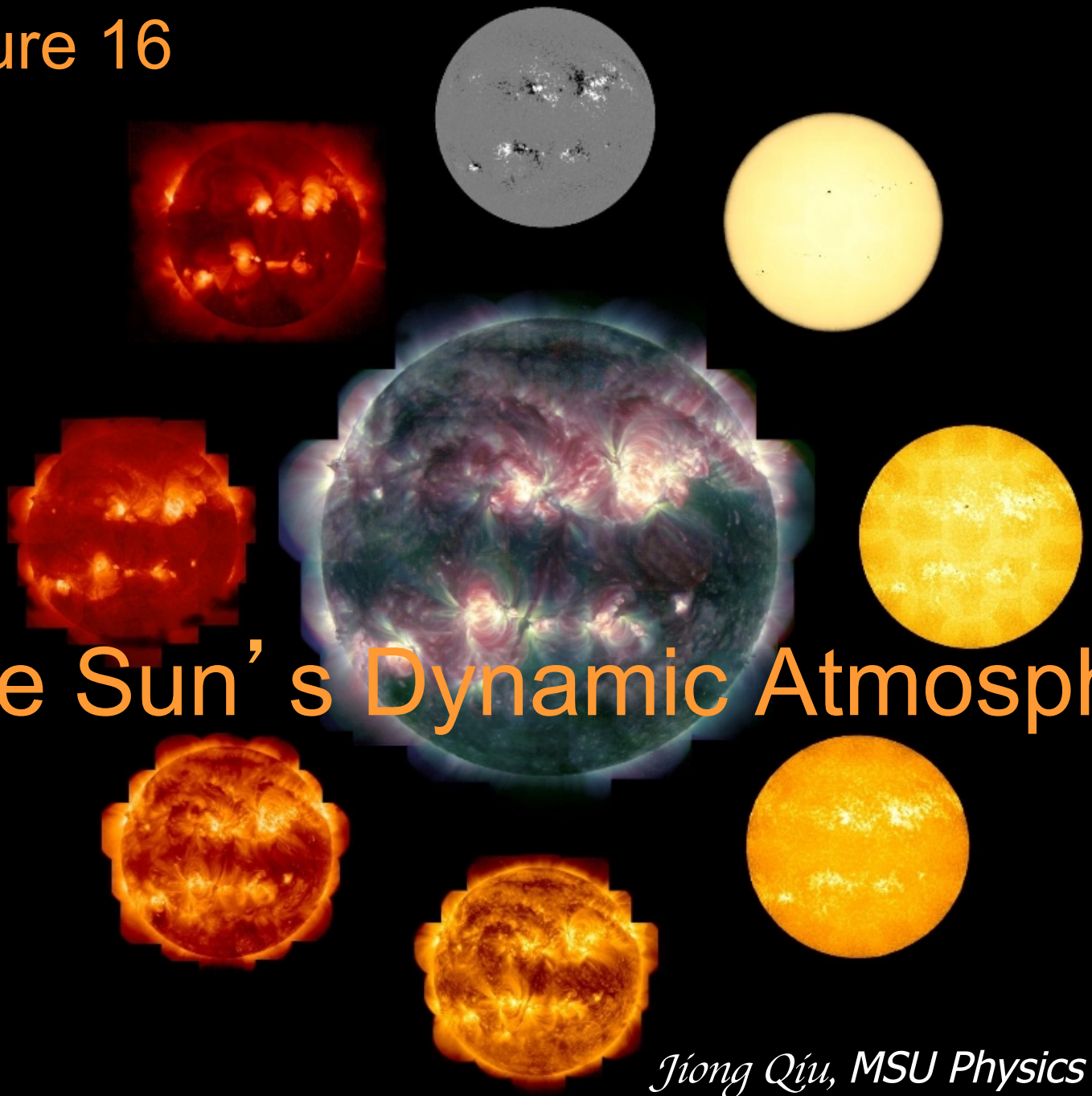
Lecture 16



The Sun's Dynamic Atmosphere

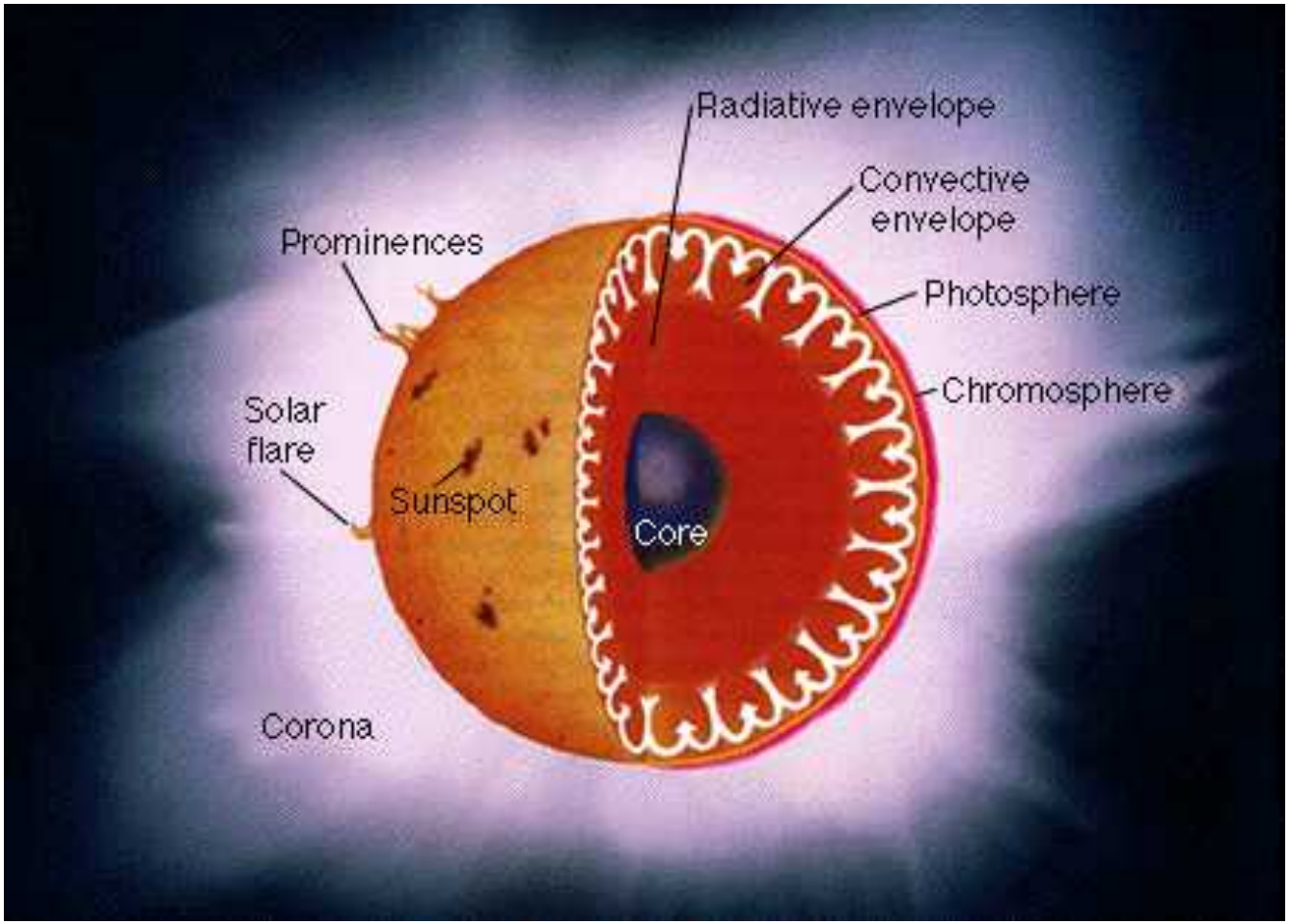
Jiong Qiu, MSU Physics Department

Guiding Questions

1. What is the temperature and density structure of the Sun's atmosphere? Does the atmosphere cool off farther away from the Sun's center?
2. What intrinsic properties of the Sun are reflected in the photospheric observations of limb darkening and granulation?
3. What are major observational signatures in the dynamic chromosphere?
4. What might cause the heating of the upper atmosphere? Can Sound waves heat the upper atmosphere of the Sun?
5. Where does the solar wind come from?

15.1 Introduction

The Sun's atmosphere is composed of three major layers, the photosphere, chromosphere, and corona.



Structure of the Sun

The different layers have different temperatures, densities, and distinctive features, and are observed at different wavelengths.

15.2 Photosphere

The photosphere is the thin (~500 km) bottom layer in the Sun's atmosphere, where the atmosphere is **optically thin,** so that photons make their way out and travel unimpeded.

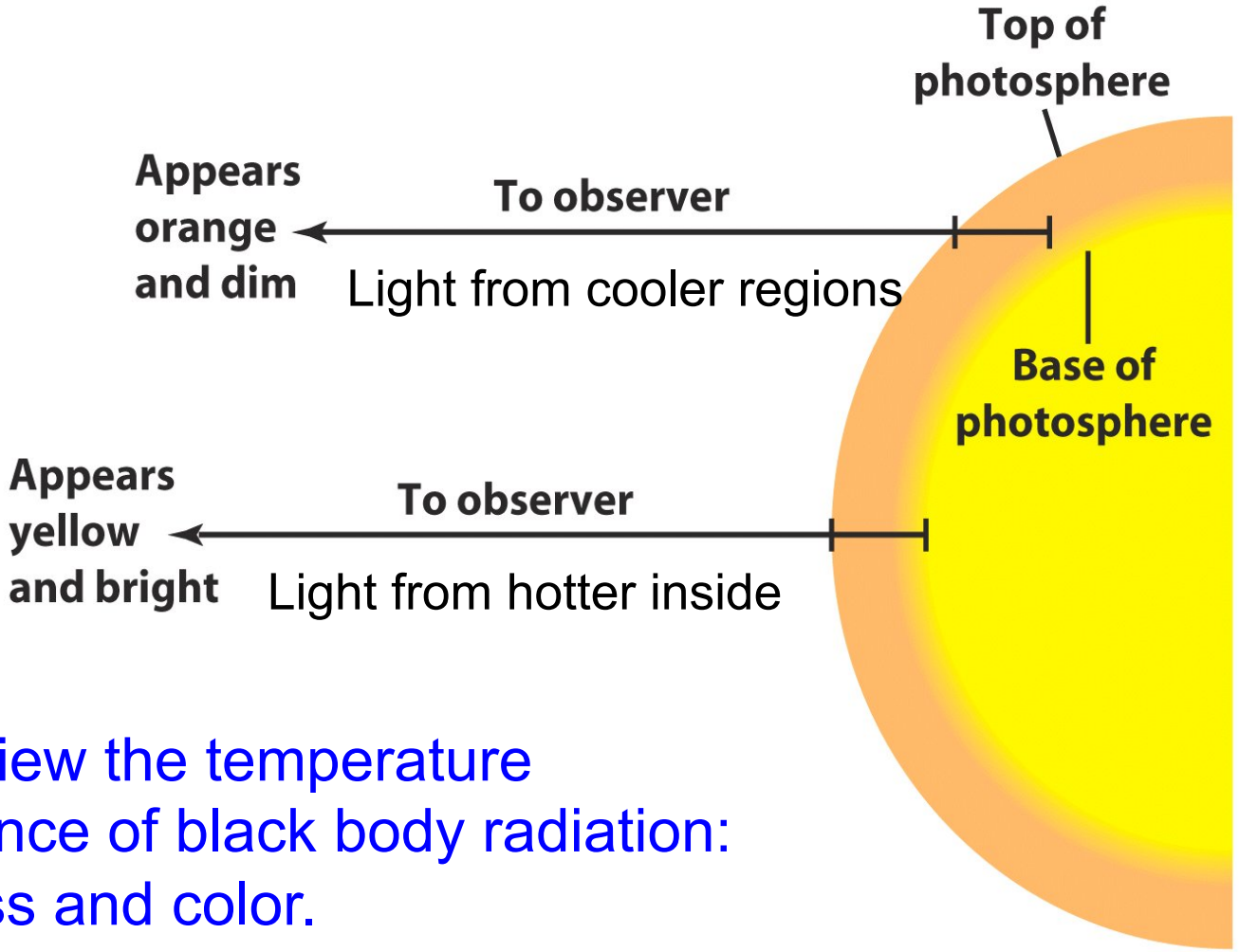
Ex.1: the **mean free path** of photons in the photosphere and the radiative zone.

The photosphere is seen in visible light continuum (so-called white light). Observable features on the photosphere include:

- **Limb darkening:** from the disk center to the limb, the brightness fades.
- **Sun spots:** dark areas of magnetic field concentration in low-mid latitudes.
- **Granulation:** convection cells appearing as light patches divided by dark boundaries.

Q: does the full moon exhibit limb darkening?

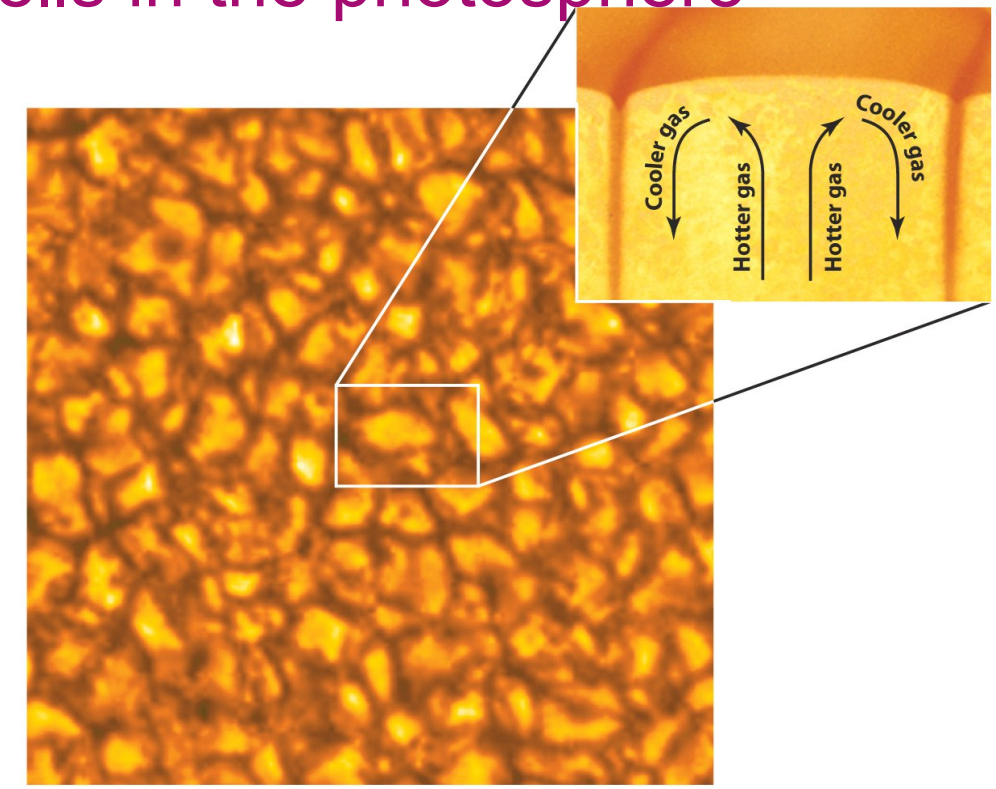
Limb Darkening: limb darkening phenomenon indicates that temperature decreases with altitude in the photosphere. Modeling the limb darkening profile tells us the structure of the stellar atmosphere.

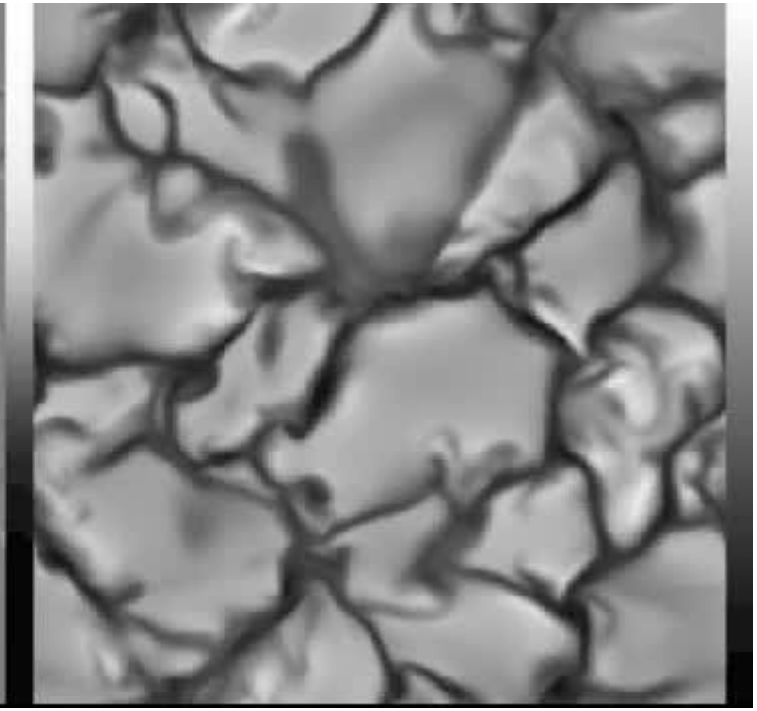


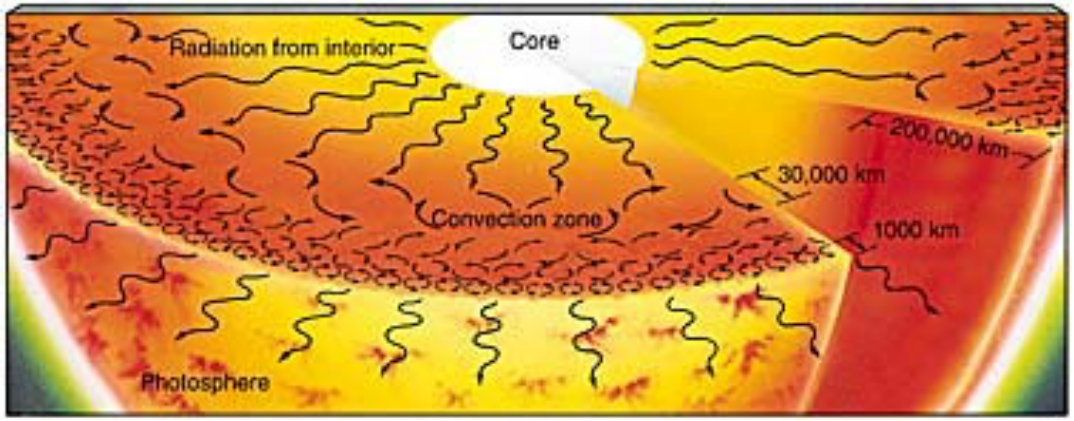
Ex.2: review the temperature dependence of black body radiation: brightness and color.

Granules are convection cells in the photosphere

From below the surface upward, granulation starts from **supergranules**, breaking to **mesogranules**, and then **granules** on the surface.

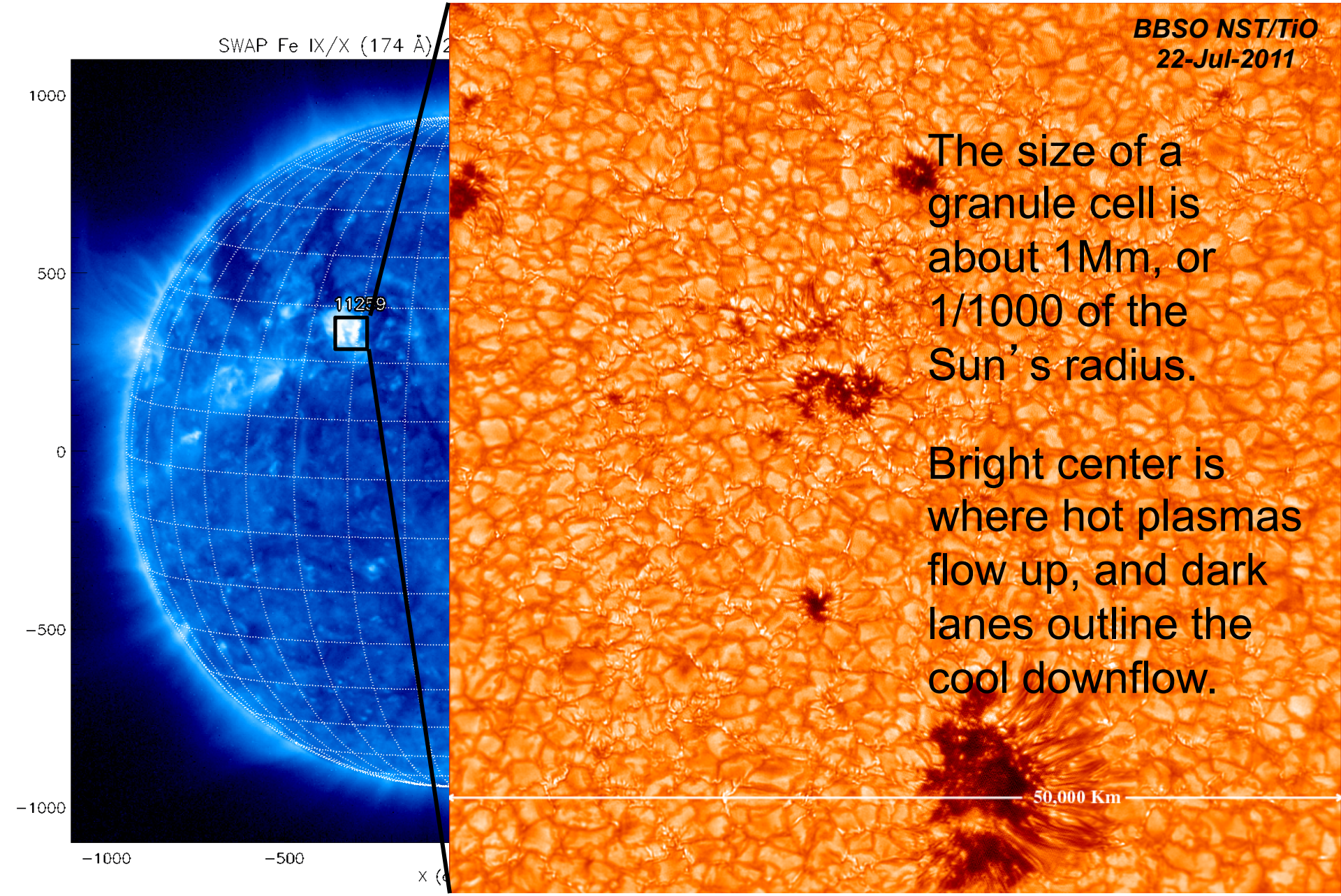






Numerical simulation of solar convection.

high resolution observation of solar granules (convective cells)

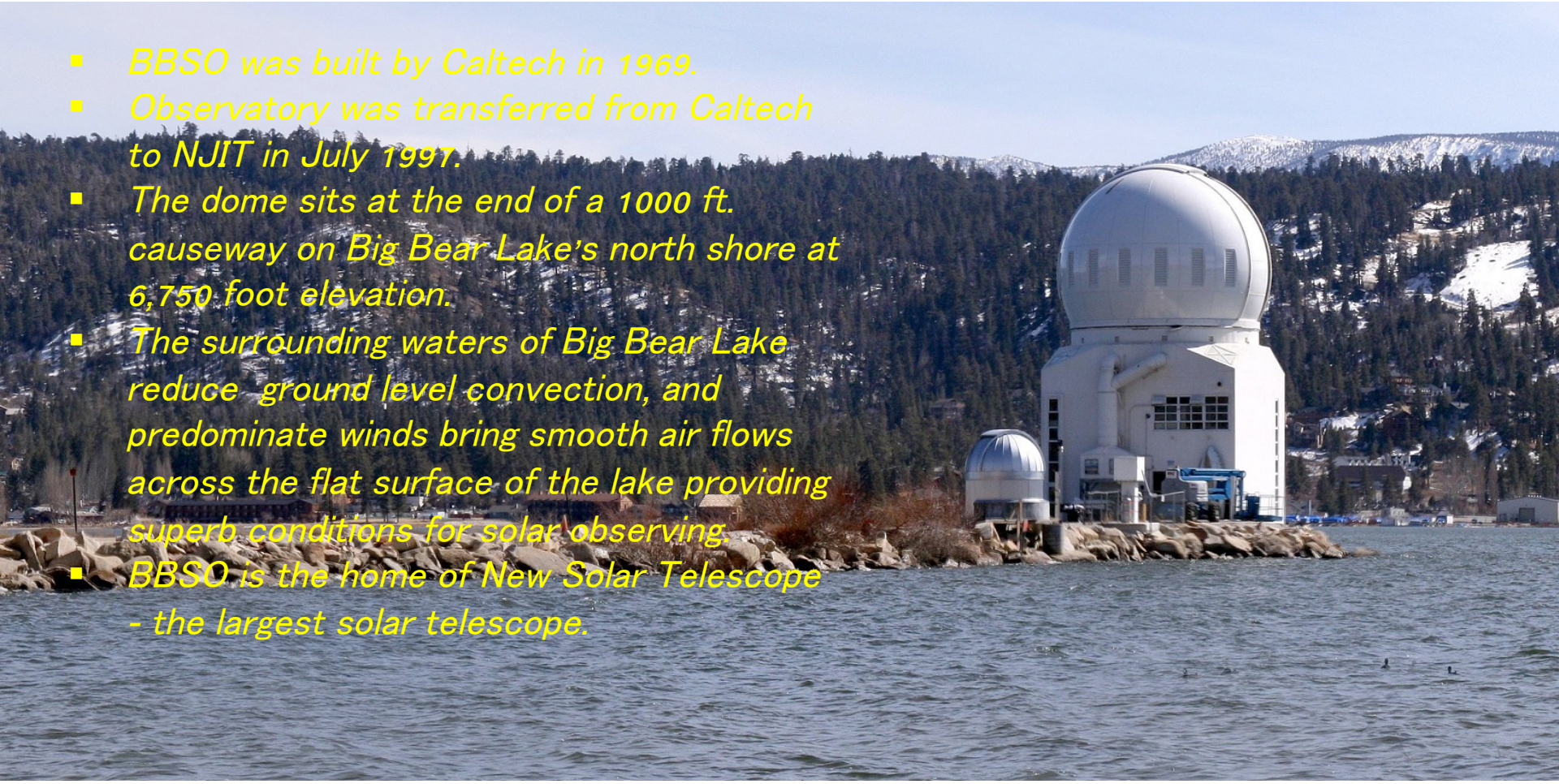


The size of a granule cell is about 1Mm, or 1/1000 of the Sun's radius.

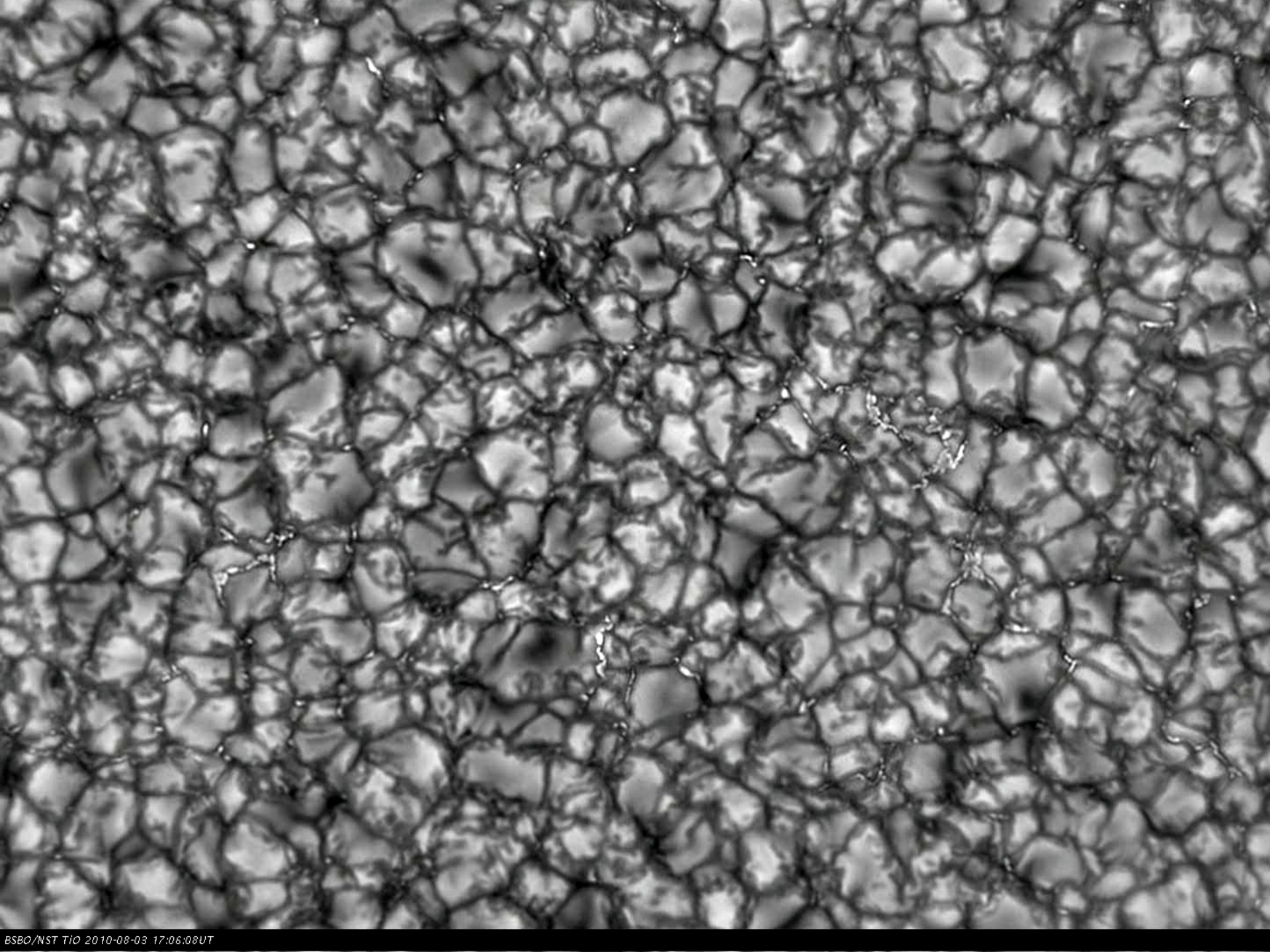
Bright center is where hot plasmas flow up, and dark lanes outline the cool downflow.

NST and its Science Instruments:
Commissioning, Upgrades and Future

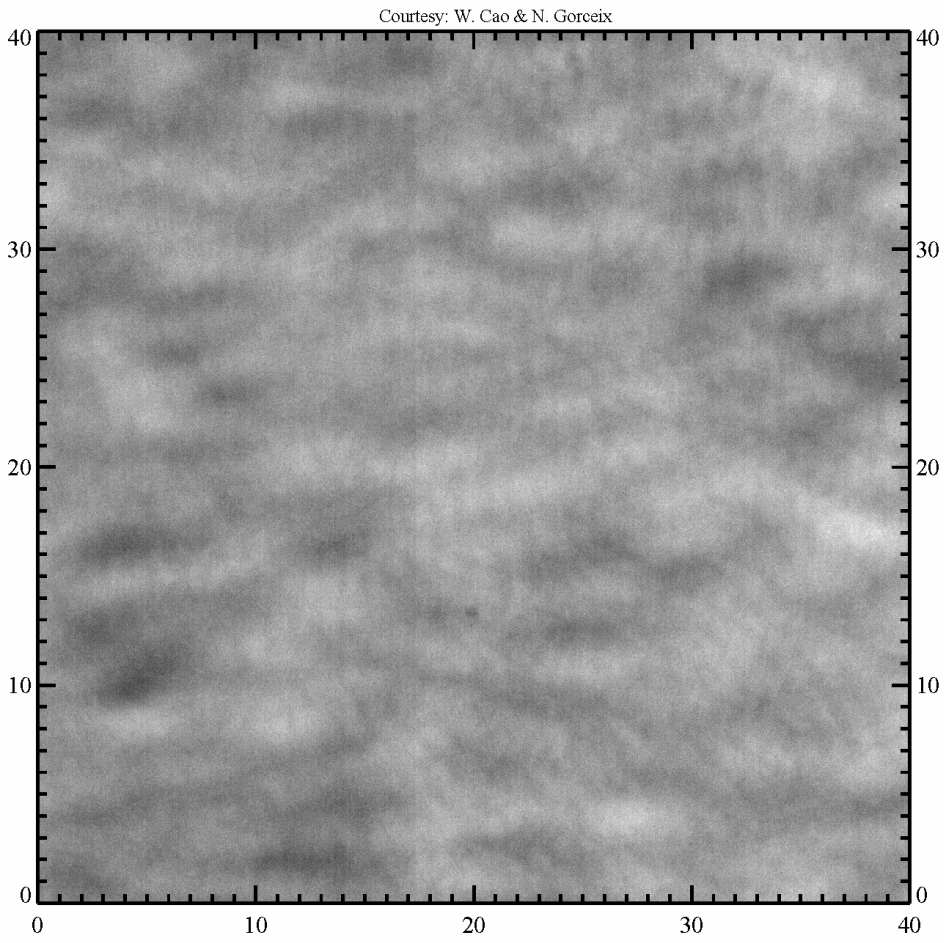
Wenda Cao & NST Team



- *BBSO was built by Caltech in 1969.*
- *Observatory was transferred from Caltech to NJIT in July 1997.*
- *The dome sits at the end of a 1000 ft. causeway on Big Bear Lake's north shore at 6,750 foot elevation.*
- *The surrounding waters of Big Bear Lake reduce ground level convection, and predominate winds bring smooth air flows across the flat surface of the lake providing superb conditions for solar observing.*
- *BBSO is the home of New Solar Telescope - the largest solar telescope.*


BSBO/NST TiO 2010-08-03 17:06:08UT

Atmosphere turbulence compromises telescope's resolution.



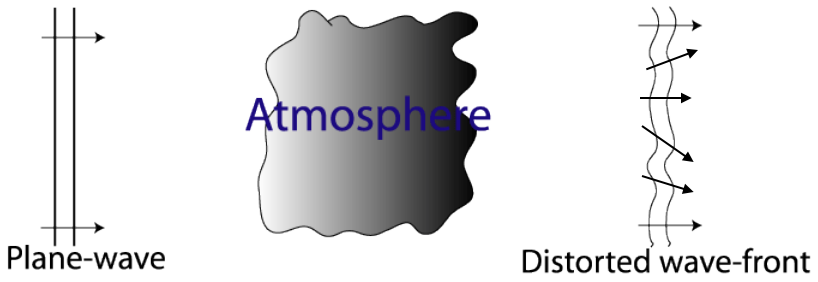
Ex 2. Is it possible to perceive solar granulations with a backyard 8 inches telescope?

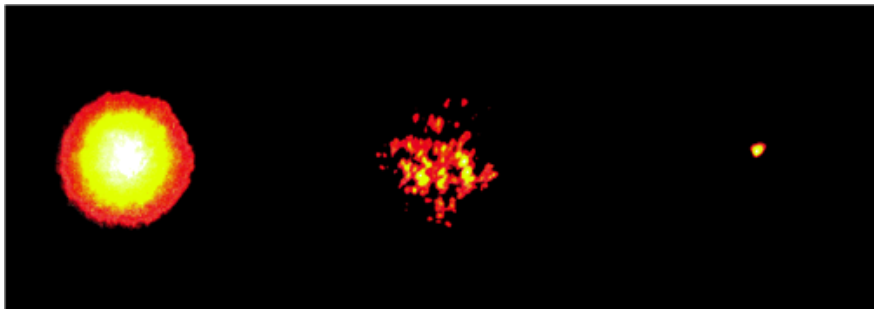
Ex 3. What is the diffraction-limited resolution of a 1.6 m aperture at 500 nm?

$$\theta'' = 0.25\frac{\lambda(\mu m)}{D(m)}$$

$$= 0.25\frac{0.5\mu m}{1.6m} \approx 0.078''$$

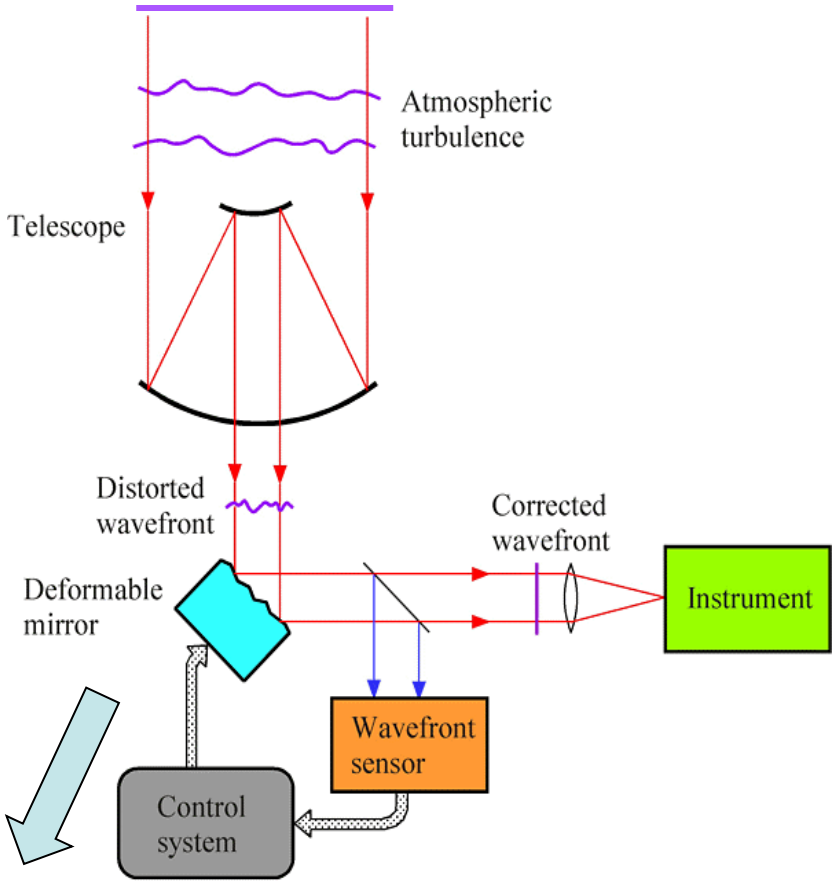
Adaptive Optics technique applied to correct atmosphere turbulence

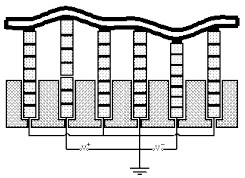




Atmosphere turbulence blurs the image of a point source.

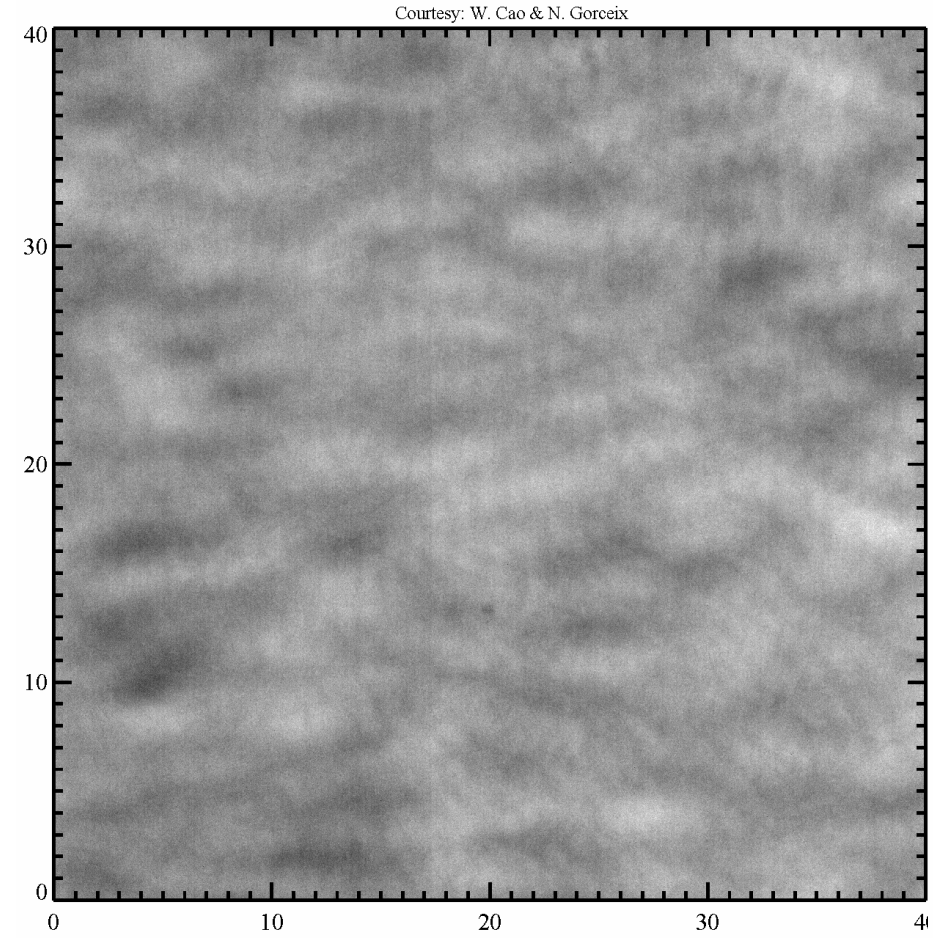
Courtesy W. Cao

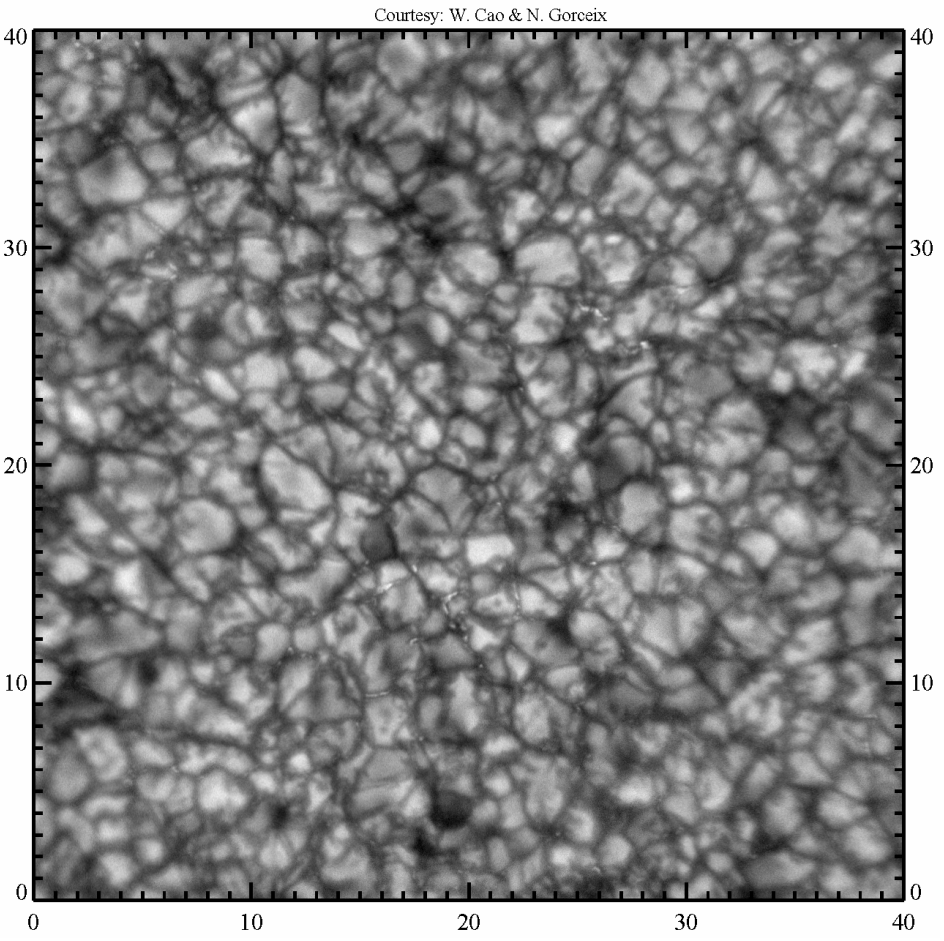




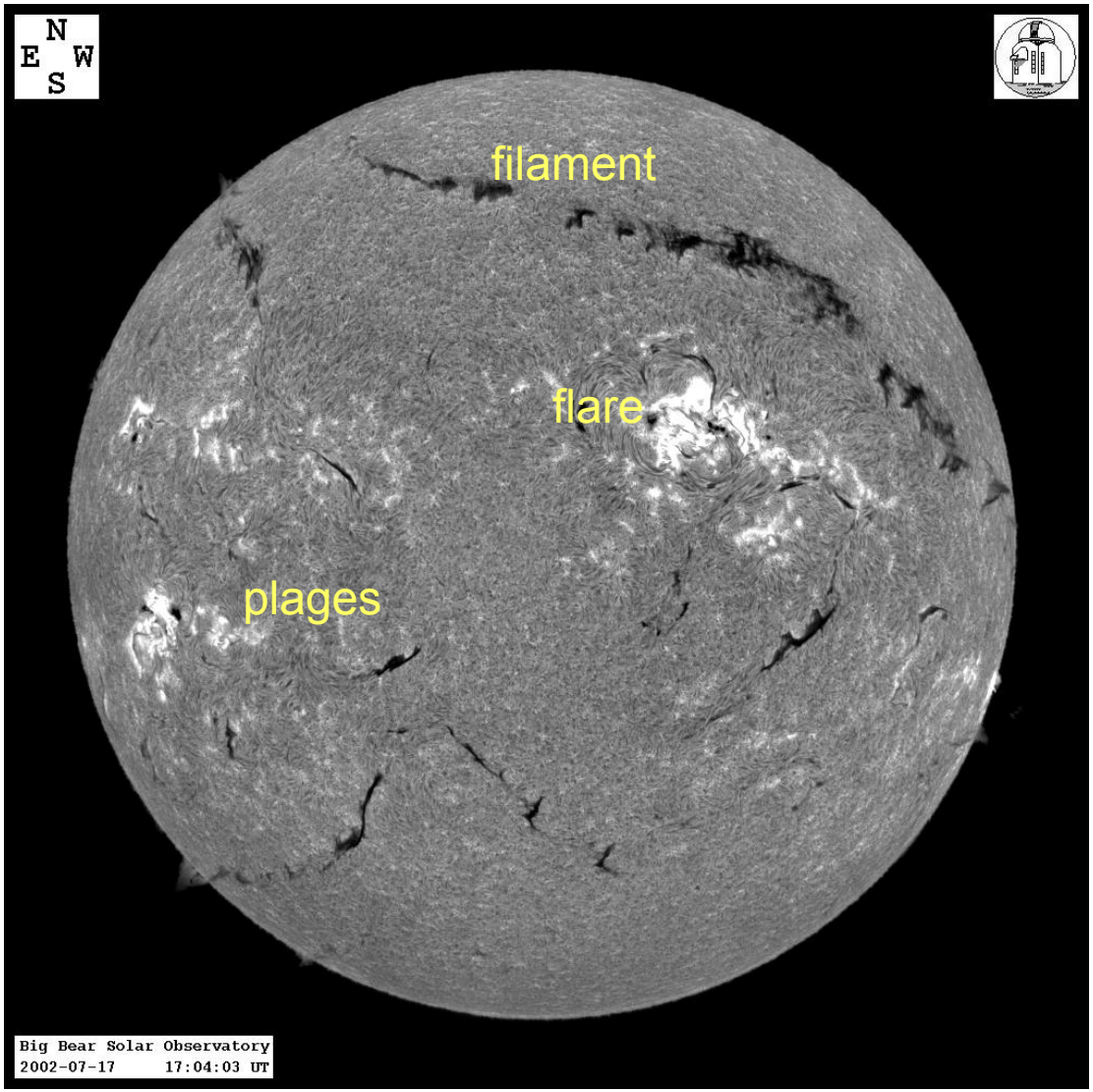
AO system corrects the distorted wave front with deformable mirror.

Adaptive Optics technique applied to correct atmosphere turbulence



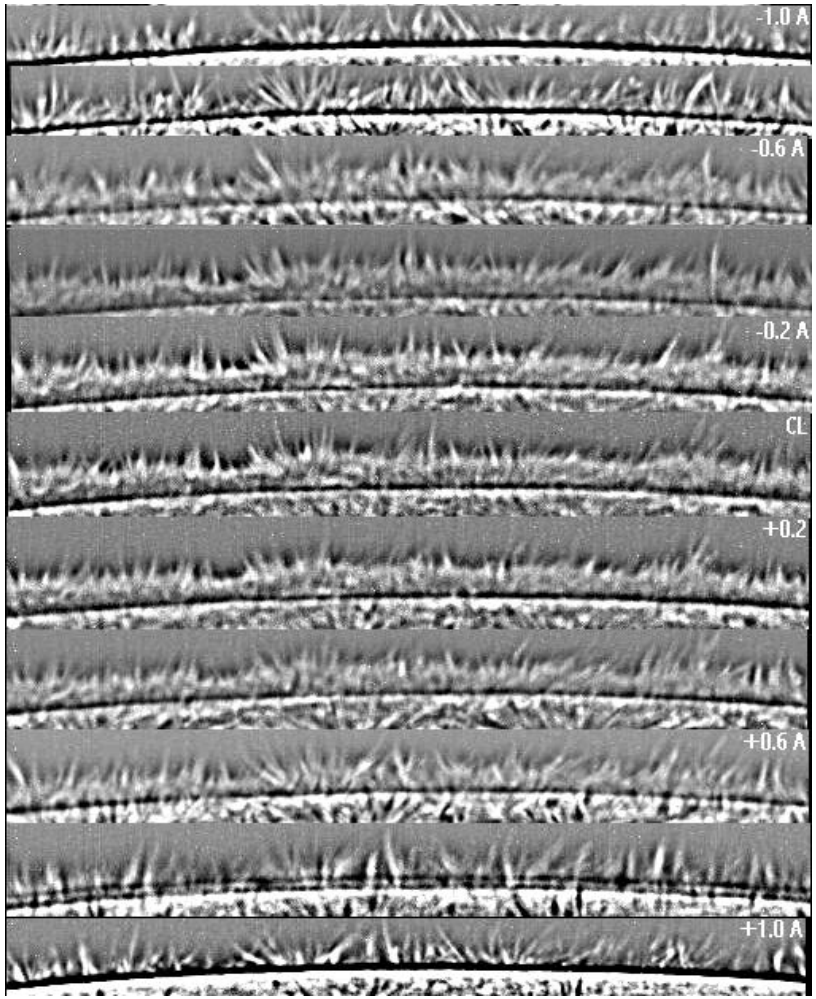


15.3 Chromosphere (the color sphere)



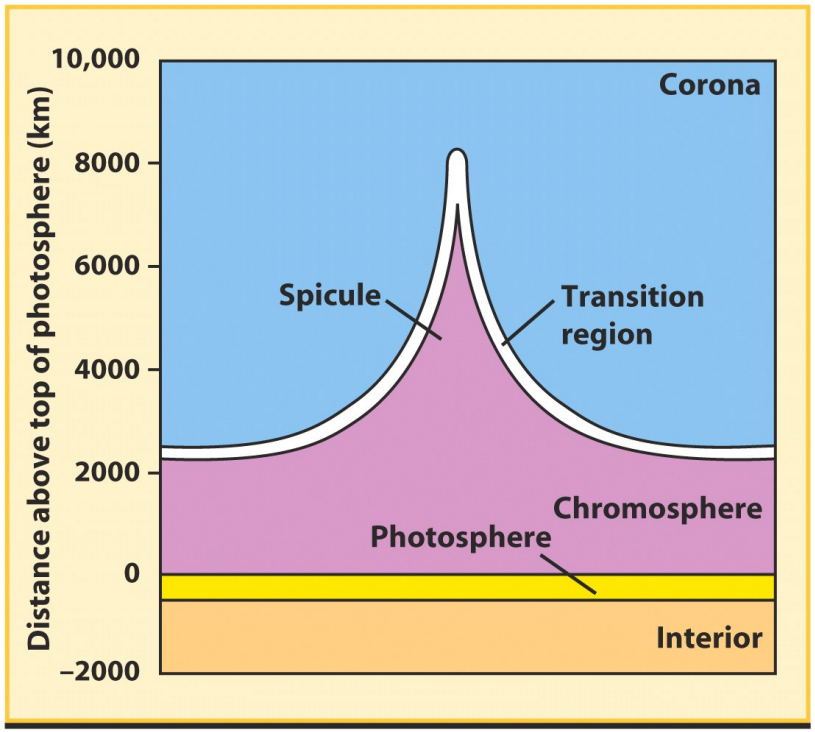
- The chromosphere spans for a few Mm above the photosphere with **lower density** and **higher temperature** (?), with many hydrogen, helium, and metal lines.
- Chromosphere is very dynamic.
- Observable features include: **spicules, filaments, plages, flares.**

Image of the Sun's chromosphere at H-alpha line



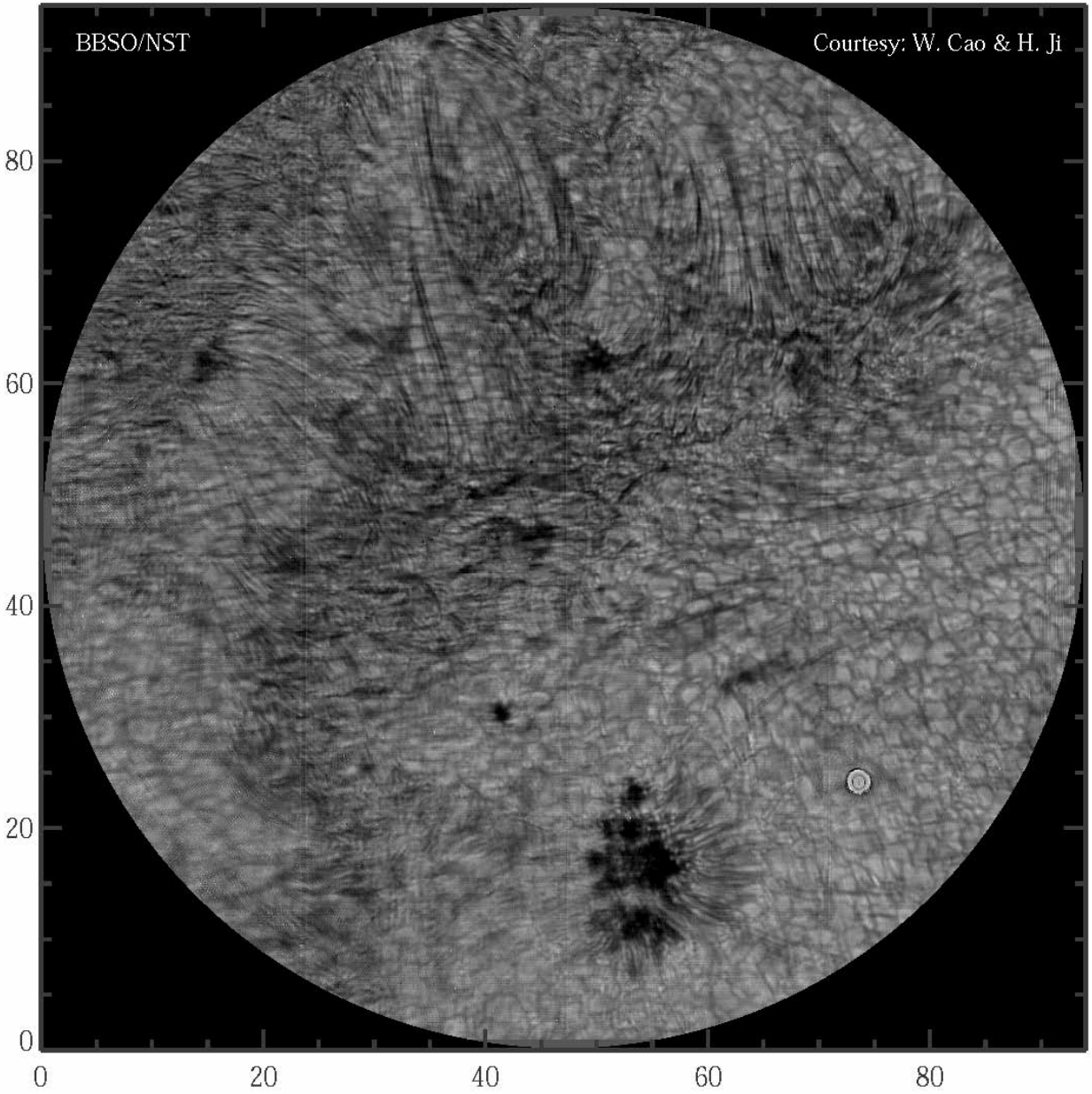
Spicules extend upward from the photosphere into the chromosphere along the boundaries of supergranules. They may provide mass and energy flux upward.

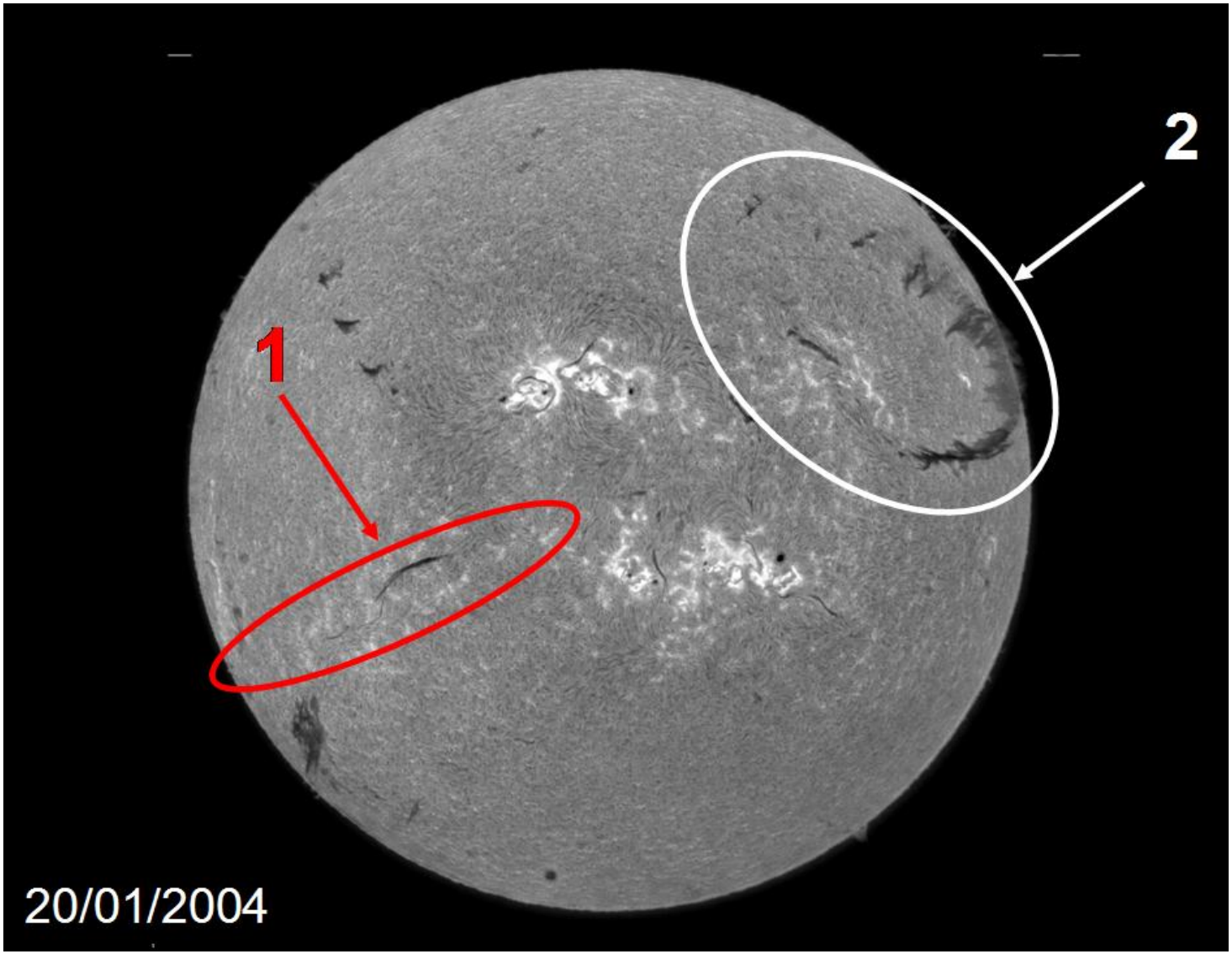
Ex.4: what drives spicules?



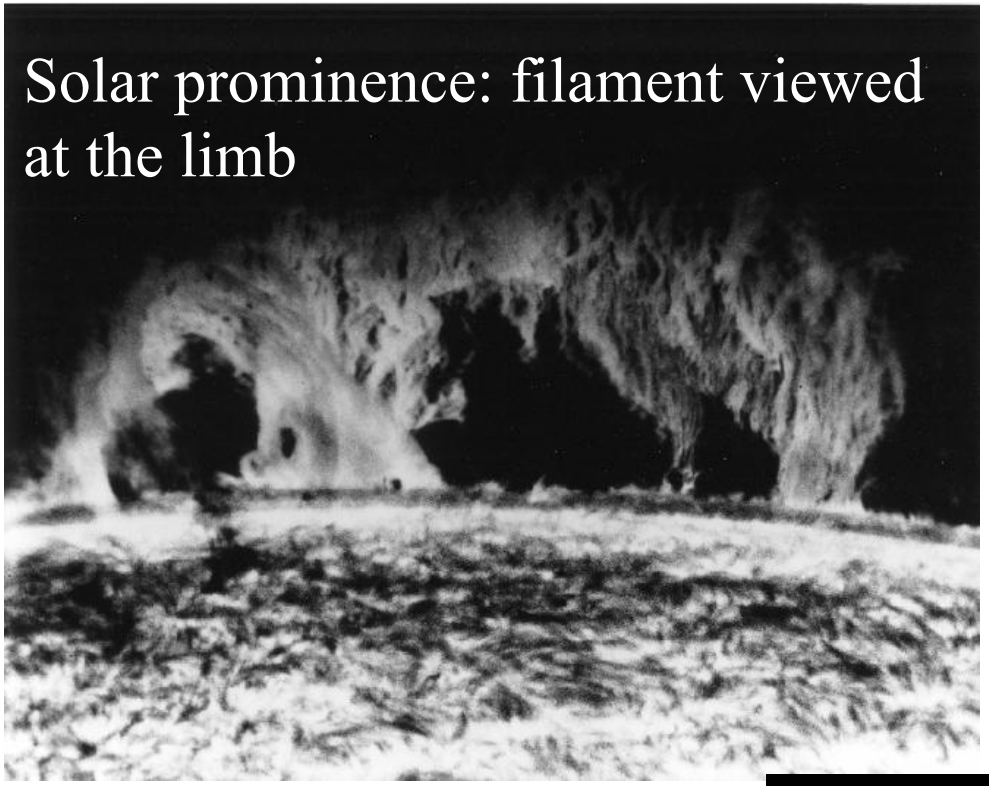
Q: when spicules are observed at the Sun's disk, how do we know that they are gases with a rising motion?

- *2011 July 22*
- *NOAA 11259*
- *BBSO 1.6 m NST with AO correction*
- *He I 10830 Å images processed with speckle reconstruction (Wöger & von der Lühe 2008)*
- *Blue wing: - 0.25 Å*
- *Lyot filter bandwidth 0.5 Å*
- *Field of view: 94”*
- *Cadence: 15 seconds*
- *Accuracy of the images co-alignment between TiO, HeI and AIA/SDO better than 0.5”*



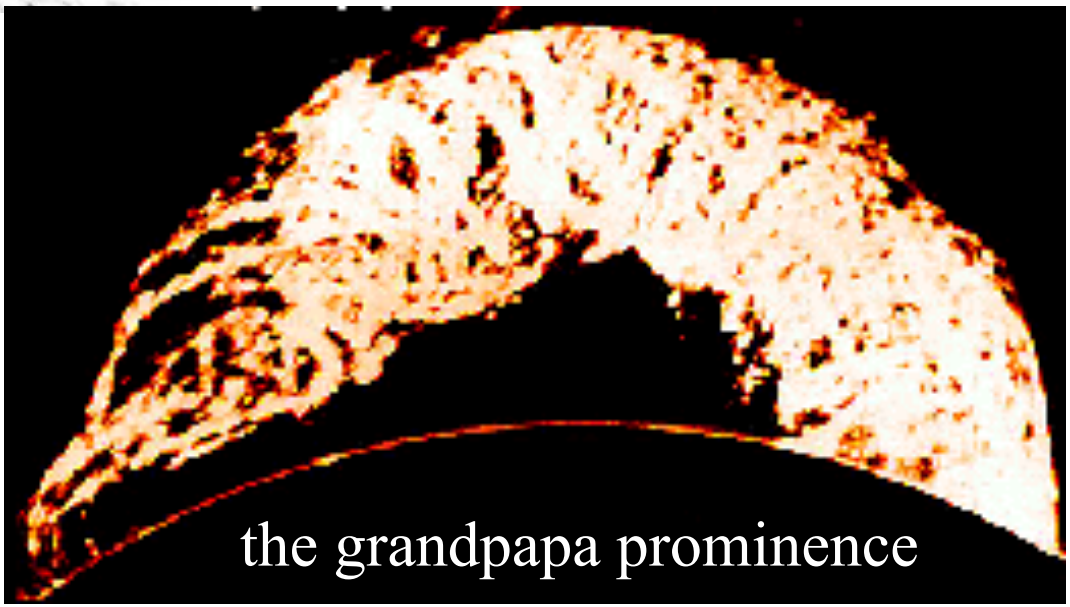


Filaments are cool dense plasmas hung in the air.

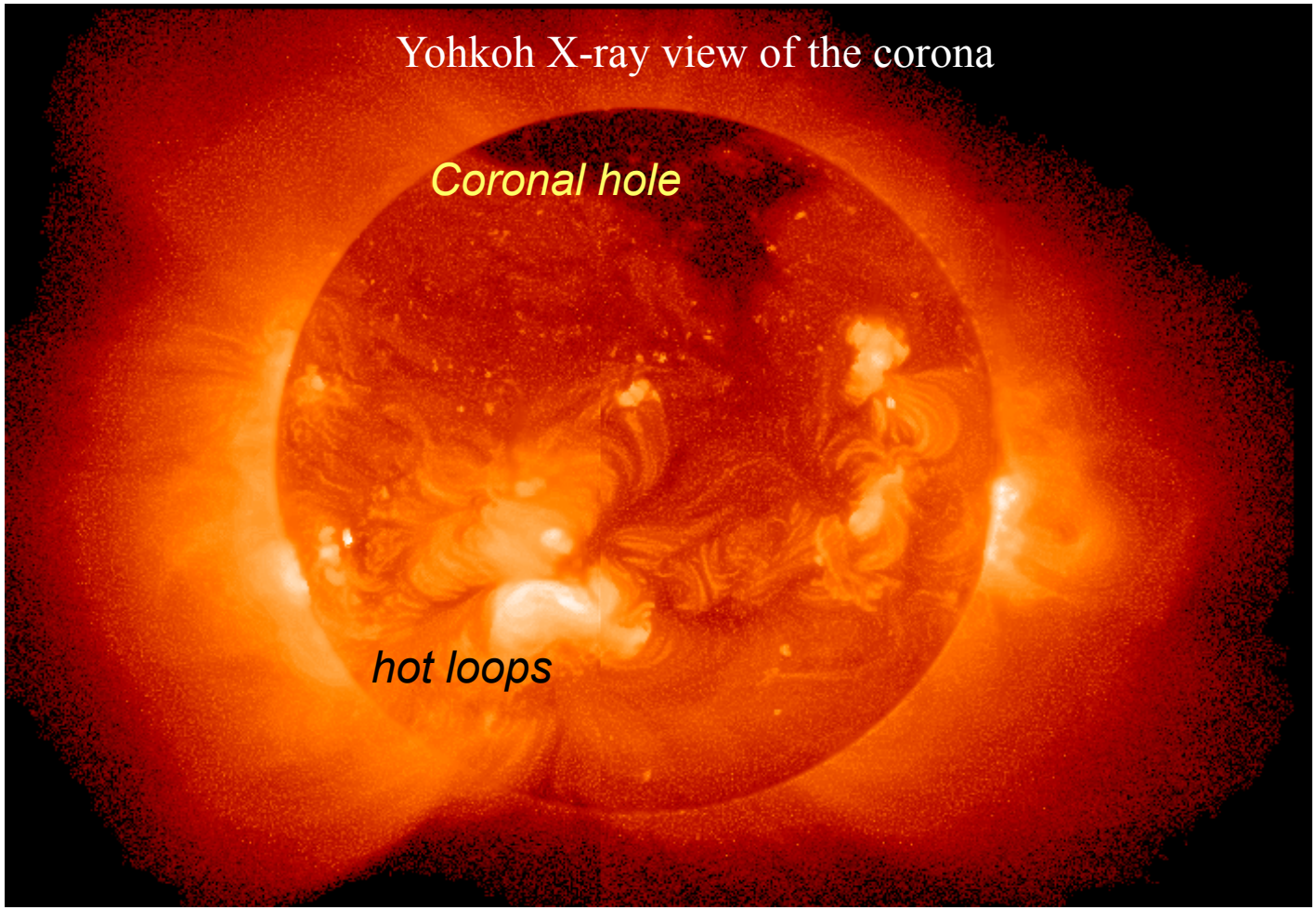


Dark filaments seen on the disk become bright **prominences** at the limb against dark background.

Filaments are supported by magnetic fields. They have very complicated structures, indicative of magnetic structure.

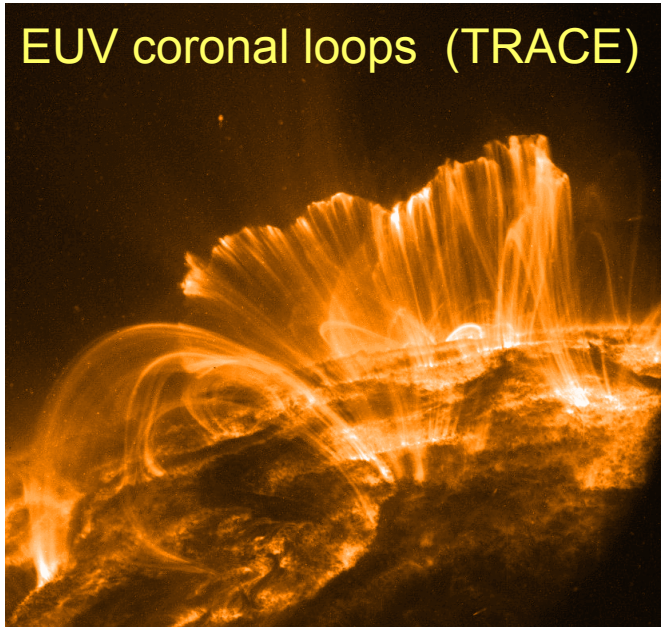


15.4 Corona

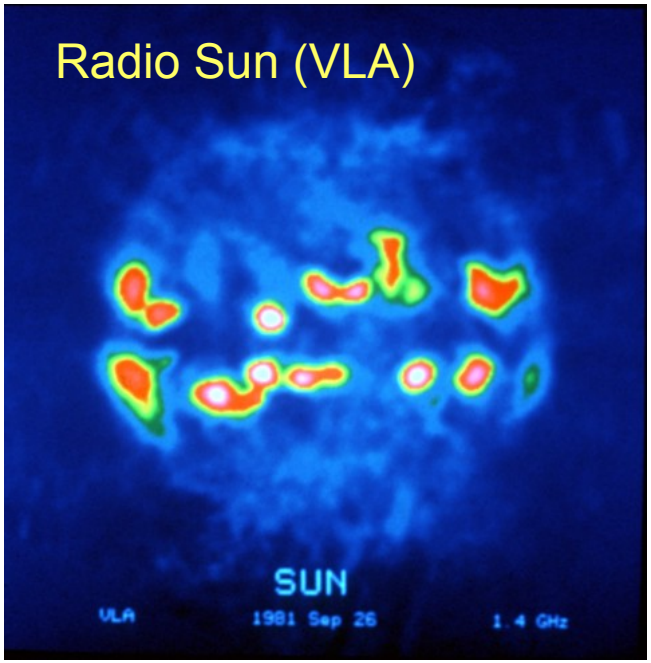


The corona is very hot (2 million K degree), sparse, and extensive. There are hot **coronal loops** and **coronal holes**. **Solar winds** originate from the corona.

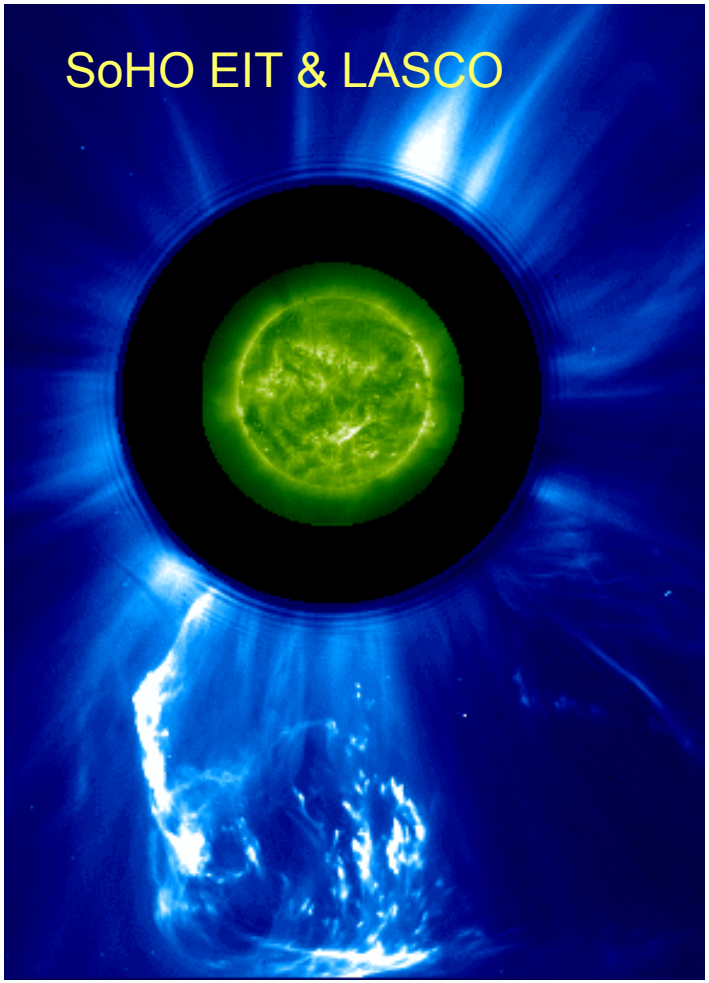
The corona is seen in radio, ultraviolet, and X-ray observations.



hot plasmas confined in **magnetic loops** observed in extreme ultraviolet emission lines.



hot plasma in **active region** corona emitting in radio wavelength.



Coronal mass ejections are observed with a coronagraph nearly once a day.

the dynamic sun in a day

EUV sun by Solar Dynamic Observatory

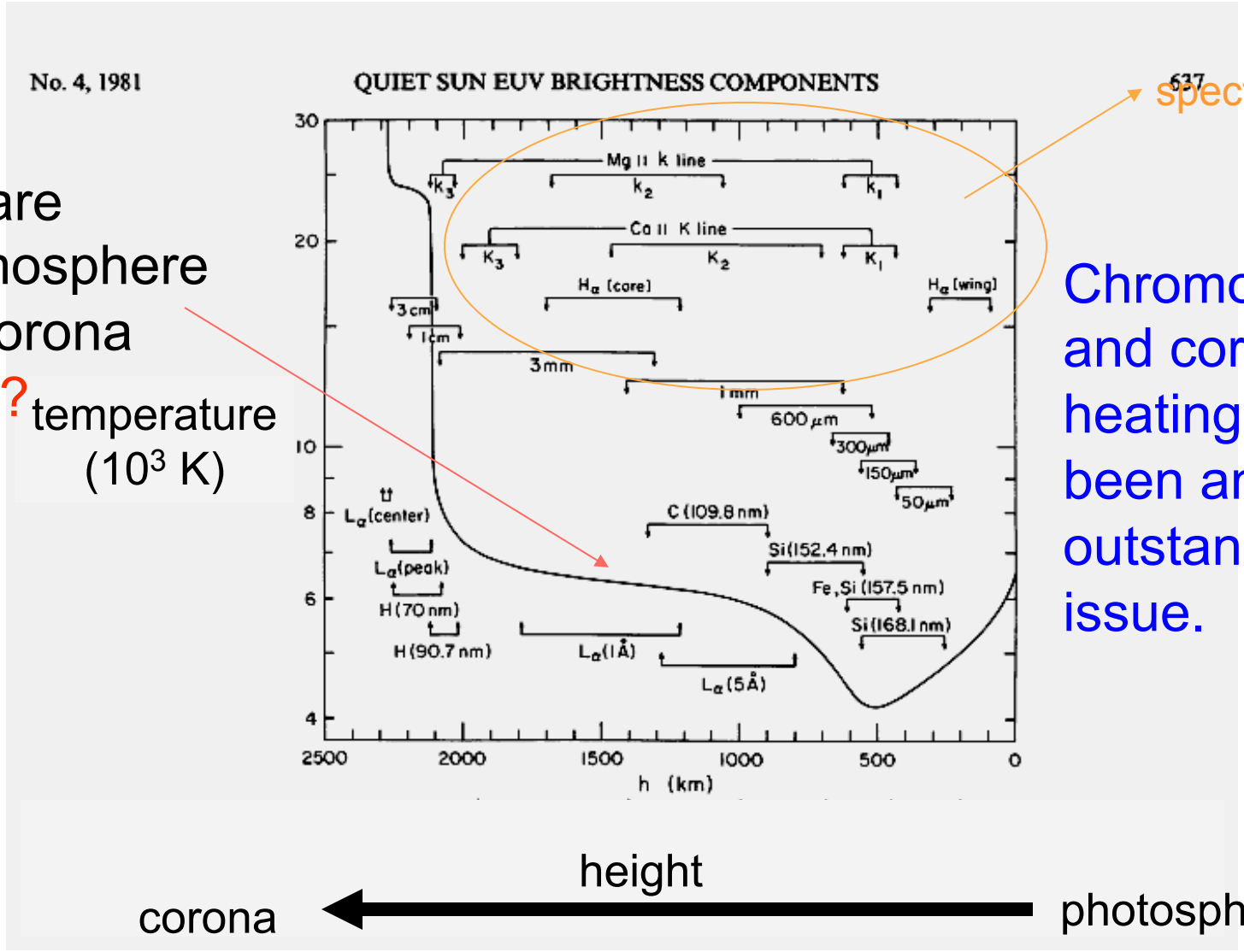
the dynamic sun in a day

EUV sun by Solar Dynamic Observatory

Two surprising facts about the sun's atmosphere

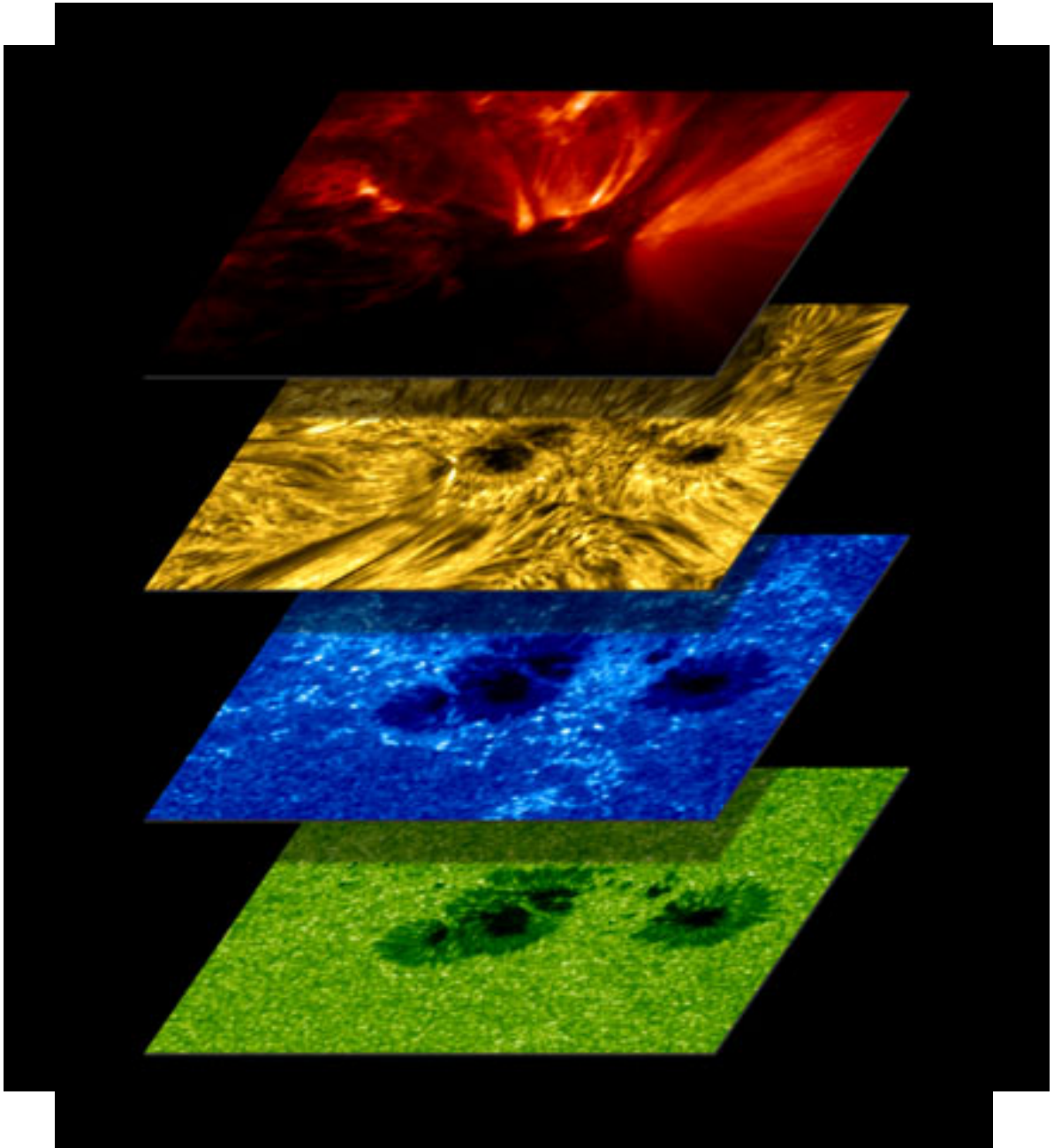
- The temperature of the sun's atmosphere above the photosphere increases with height.
- The atmosphere is very dynamic and inhomogeneous.

Above the photosphere, the temperature **increases** with altitude!

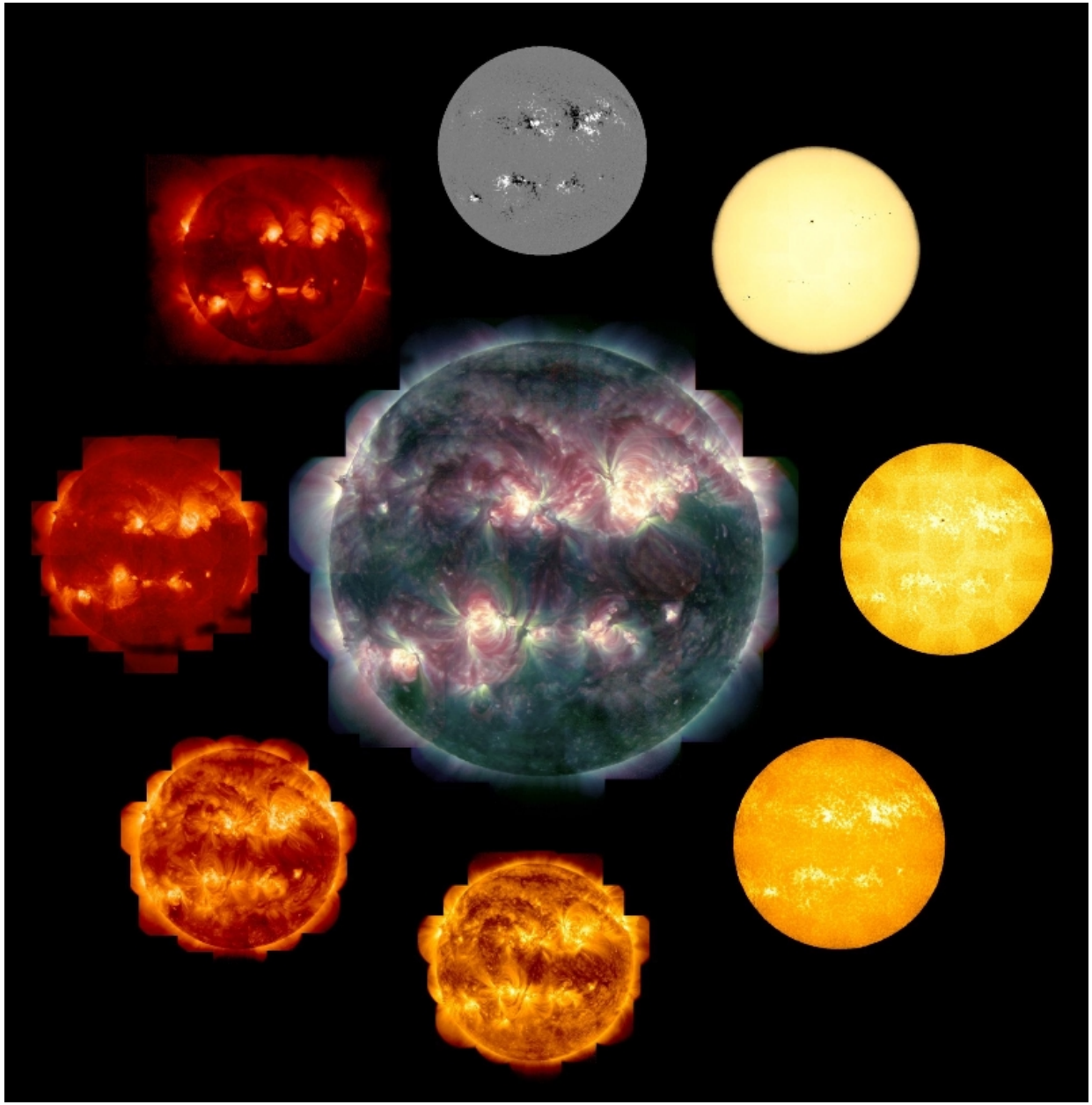


Standard quiet sun atmosphere model constructed from extensive **spectroscopic** observations by Vernazza, Avrett, & Loeser, 1981.

Looking through the Sun's atmosphere



From the photosphere to the chromosphere and then the corona, the temperature rises from 5800 K (seen in visible light) to a few million K degree (seen in X-rays), and the density drops by 8-9 orders of magnitude. The corona extends to interplanetary space.



magnetic field links many features in these images!

Key Words

- chromosphere
- chromosphere heating
- convection
- corona
- corona heating
- coronal hole
- coronal mass ejection
- filament
- granulation
- granule
- limb darkening
- photosphere
- plage
- plasma
- prominence
- spicule
- solar wind
- sunspot
- transition region

summary

- The Sun's atmosphere has a temperature and density stratification. It is composed of **photosphere, chromosphere,** and **corona,** with sharply increasing temperature and decreasing density outwards.
- Major features in the photosphere include **sun spots**, which are areas of strong **magnetic fields**, and **granules**, which are **convection cells** on the solar surface.
- **Limb darkening** of the photosphere indicates the temperature structure of the photosphere.
- The chromosphere is **dynamic,** with mass motion events like **spicules** and **filaments,** and enhanced plasma heating in **plages** and **flares**.
- The corona is the hot, sparse, and extensive part of the outer atmosphere filled with **magnetized plasmas**. The corona is highly structured and dynamic.
- Charged particles from the Sun escape to interplanetary space in **solar winds** and **coronal mass ejections.**

Reference: lecture notes and Chap 16