

Physics 681: Solar Physics and Instrumentation – Lecture 24

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Chromosphere, Corona, and Solar Wind

- Empirical Facts
 - The Chromosphere
 - The Transition Region
 - The Corona
 - The Wind
- Consequences of High Temperatures
- The Magnetic Field in the Outer Atmosphere
- The Energy Balance
- Explosive Events

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Empirical Facts

- ❑ Magnetic field is the main source of almost all the structure and variability of the Sun's outer layers
- ❑ Solar eclipse: chromosphere = "colored sphere"
- ❑ "Flash" or emission spectrum
- ❑ Mottles and spicules: supergranular network, local enhancements of the magnetic field, height: 5,000 km, width: 500 km, temperature: 10^4 K, density: 3×10^{-10} kg/m³, upward velocity: up to 25 km/s, lifetime: 5-10 minutes, macrospicules
- ❑ Ballistic models are insufficient to explain mass transport to observed height
- ❑ Total mass in spicules exceeds the solar wind mass flux by two orders of magnitude
- ❑ Outward increasing temperature of the chromosphere
- ❑ Emission reversal in the cores of strong resonances lines (Ca II H and K)



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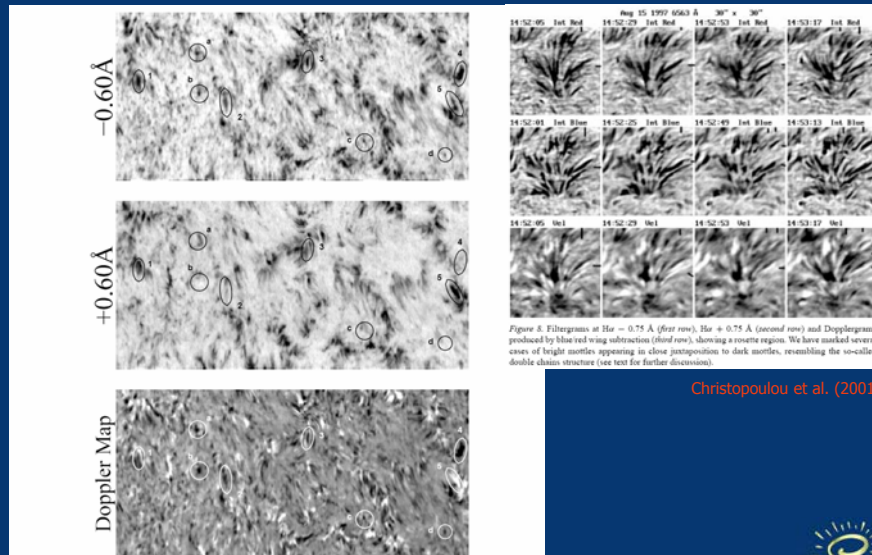


FIG. 1.— Examples of spectrograms constructed at the wavelengths of $\pm 0.6\text{\AA}$ and a Doppler subtraction map of these wavelengths. Some of identified spicule events are marked by circles with annotations of a, b, and so on and some of dark mottles by ellipses with numeric annotations. Dark features in the Doppler map represent bluehilled ones and bright features, redhilled ones. The field of view of each image is $11'' \times 14''$.

Lee et al. (2000)

Christopoulou et al. (2001)



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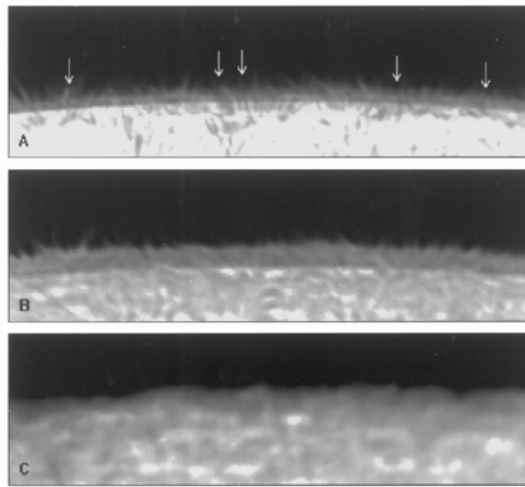


FIG. 1.—(a) Off-band chromospheric image. Several arrows mark the locations of dark and bright spicules crossing the limb. The spicule is brighter than the sky, but normally is in absorption against the disk, even near the extreme limb. (b) Centerline image at the same position angle but a few hours later showing the inner limb due to sidebands of the Zeiss (L.yot) filter. (c) Limb image on a different date with a pure filter (Rakujic filter), with the inner limb barely detectable from the morphology.

Johannesson and Zirin (1996)



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- Monotonically increasing absorption \Rightarrow increasingly deeper layers of the atmosphere \Rightarrow as long as temperature decrease, the line become darker (line wings) \Rightarrow at $\lambda_0 \pm 0.25 \text{ \AA}$ absorptions becomes so strong such that we see layers above the temperature minimum \Rightarrow absorption still increases, however, the source function follows the Planck function \Rightarrow emission reversal! \Rightarrow line core (non-LTE, the source function is smaller than the Planck function)
- Ca II emission: plages (active regions) and chromospheric network (supergranulation) \Rightarrow close relation to magnetic field
- Stellar activity: stellar cycle and rotation modulation
- Chromosphere = layer between temperature minimum and $T = 25,000 \text{ K}$, height about 2,000 km (spicule height 5,000 km)
- Transition layer located between chromosphere ($\approx 10,000 \text{ K}$) and corona ($\approx 1,000,000 \text{ K}$), extreme spatial inhomogeneity, sharp transition in temperature
- Emission lines in the UV spectrum
- Chromospheric network fades away in higher layers of the transition region \Rightarrow field fans out and becomes more homogeneous



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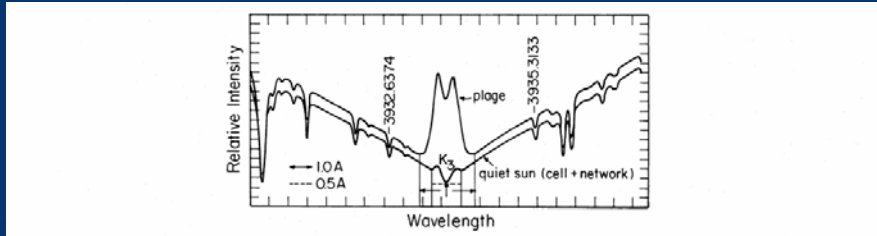


FIG. 1.—Comparison of quiet-Sun and plage Ca II K line profiles. The definition of the K_5 relative intensity and $K0.5$ and $K1.0$ bandwidths are indicated (after White and Livingston 1978).

Skumanich et al. (1984)

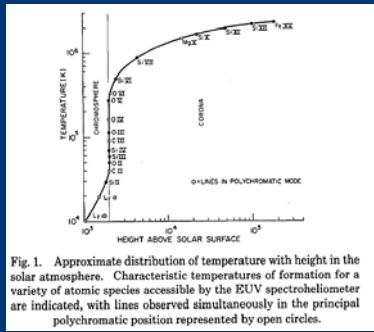


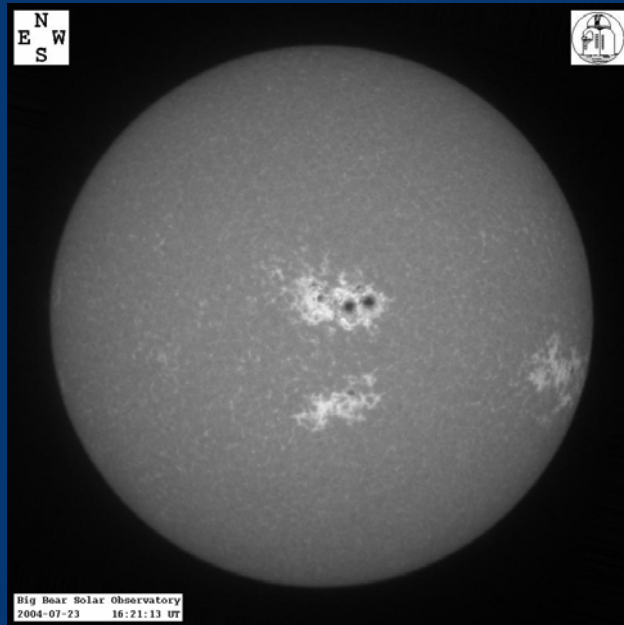
Fig. 1. Approximate distribution of temperature with height in the solar atmosphere. Characteristic temperatures of formation for a variety of atomic species accessible by the EUV spectroheliometer are indicated, with lines observed simultaneously in the principal polychromatic mode represented by open circles.

Reeves et al. (1977)



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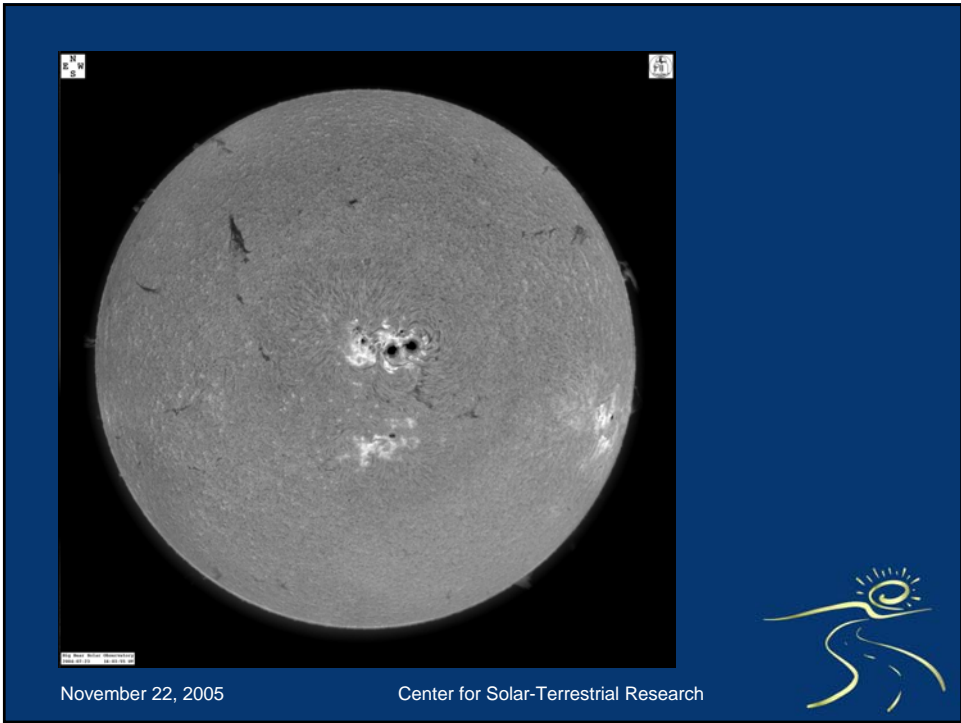
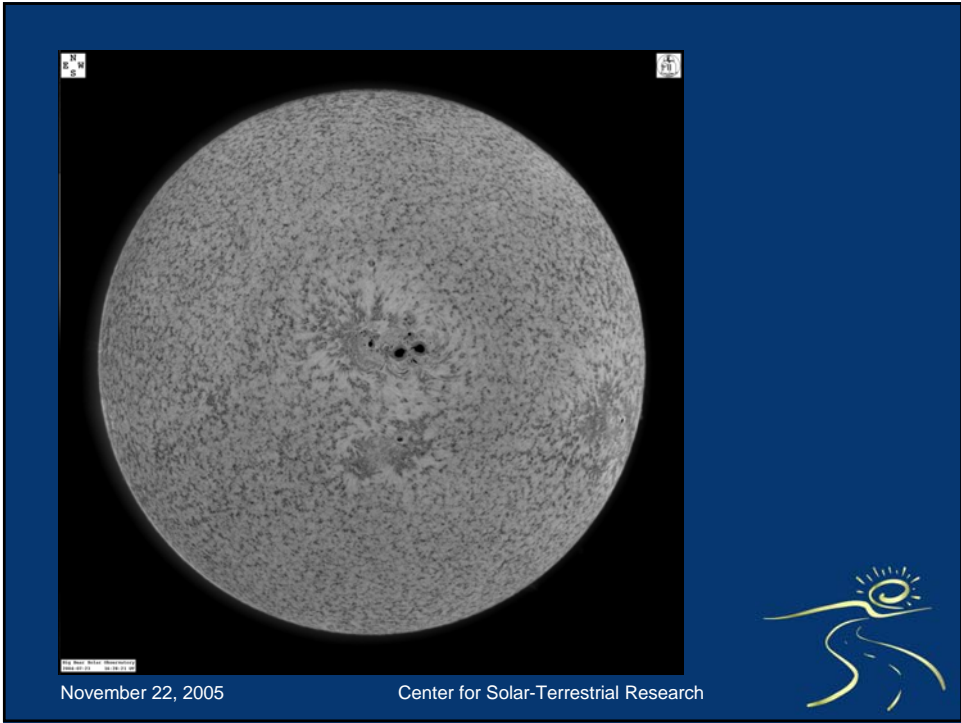
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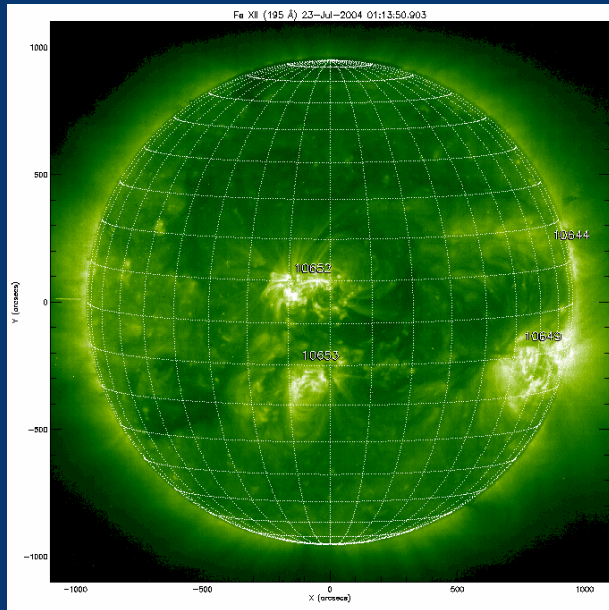


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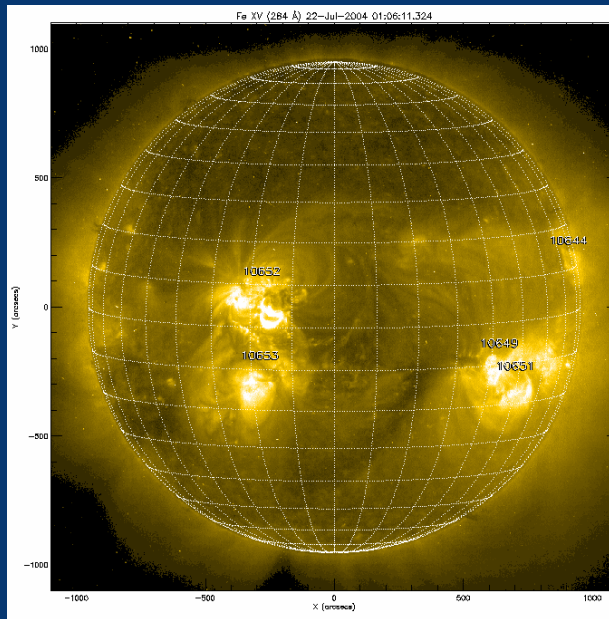






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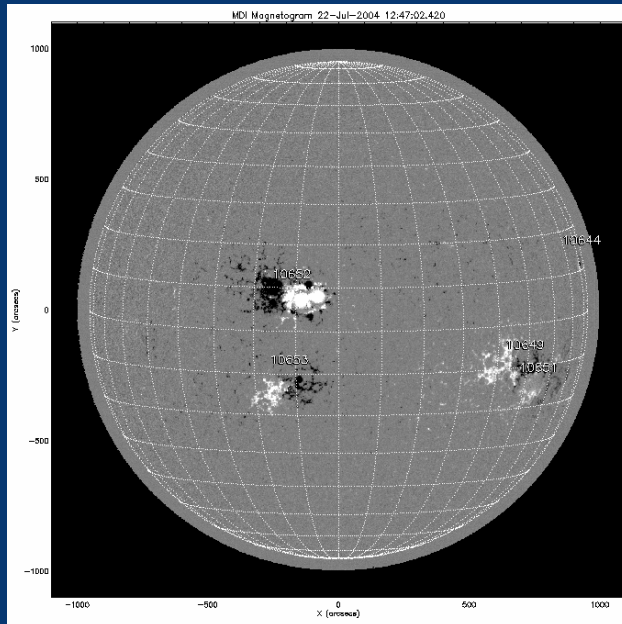
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