The Sun

What makes the Sun Unique?

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Some Answers

- Sun is the closest star
- Only star with well-resolved atmosphere
  - electromagnetic radiation
  - particle detection
- Only star with well-observed interior
  - helioseismology
  - neutrinos
- Only star of importance for life on Earth

Characteristics of the Sun

Basic Facts

Solar radius	695,990 km	109 Earth radii
Solar mass	$1.989 \cdot 10^{30}$ kg	333,000 Earth masses
Solar luminosity	$3.846 \cdot 10^{33}$ erg/s	
Surface temperature	5770 K	
Surface density	$2.07 \cdot 10^{-7}$ g/cm^3	$1.6 \cdot 10^{-4}$ Air density
Surface composition	70% H, 28% He,	
	2% CNO by mass	
Central temperature	15,600,000 K	
Central density	150 g/cm^3	8 times Gold density
Central composition	35% H, 63% He,	
	2% CNO by mass	
Solar age	$4.57 \cdot 10^9$ yr	

solarscience.msfc.nasa.gov/

Distance

- Kepler's 3rd Law:

$$\frac{a^3}{T^2} = \frac{G m_\odot}{4\pi^2}\left(1 + \frac{m}{m_\odot}\right)$$

- ratios of semi-major axes a_i between two bodies

$$\left(\frac{a_1}{a_2}\right)^3 = \left(\frac{T_1}{T_2}\right)^2 \frac{1 + m_1/m_\odot}{1 + m_2/m_\odot}$$

- if one distance known, can derive the others
- m_i from mutual disturbance of objects orbiting the Sun
- direct radar distance measuerement to planets and asteroids
- A = 149597870$\pm$2 km (1 Astronomical Unit, AU)
- 1 arcsec $\approx$ 725 km on solar surface

Mass

- Kepler's 3rd Law:

$$\frac{a^3}{T^2} = \frac{Gm_\odot}{4\pi^2}\left(1 + \frac{m}{m_\odot}\right)$$

- can only determine product $Gm_\odot$
- gravitational constant G is not very well known
- resulting solar mass: $(1.9889 \pm 0.0003) \cdot 10^{30}$ kg
- mass loss: $5 \cdot 10^9$ kg/s

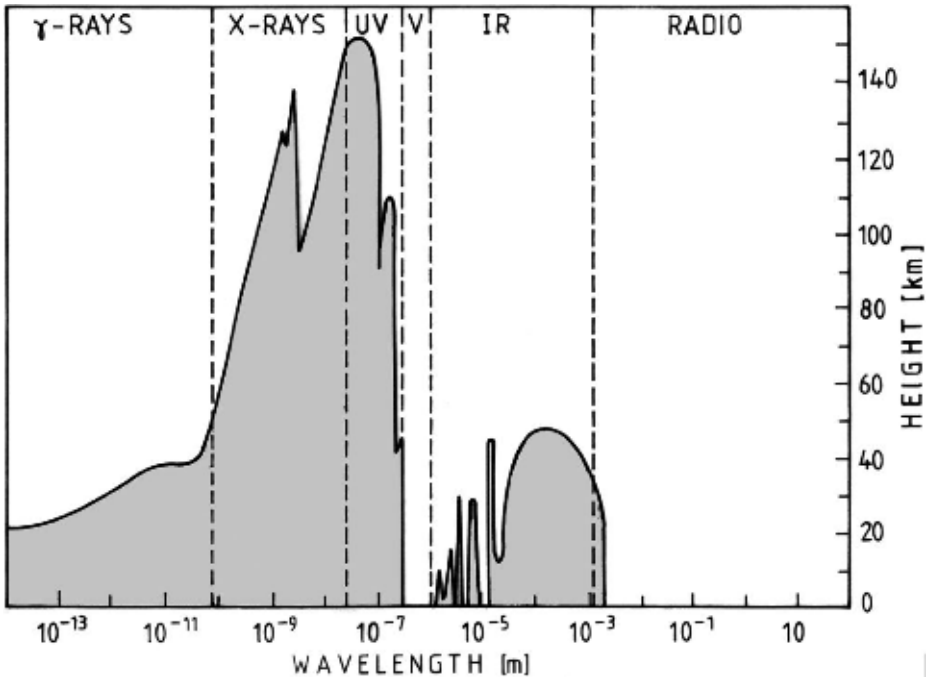
Radius

- use distance from observer and apparent angular diameter
- drift measurements with fixed telescope and measuring time from limb to limb
- but where is the solar limb?
- substantial differences between different measurements
- radius depends on wavelength
- resulting solar radius: $(6.960 \pm 0.001) \cdot 10^8$ m at 550 nm
- resulting mean density: 1.408 g/cm^3
- resultig gravitational acceleration: 274 m/s^2

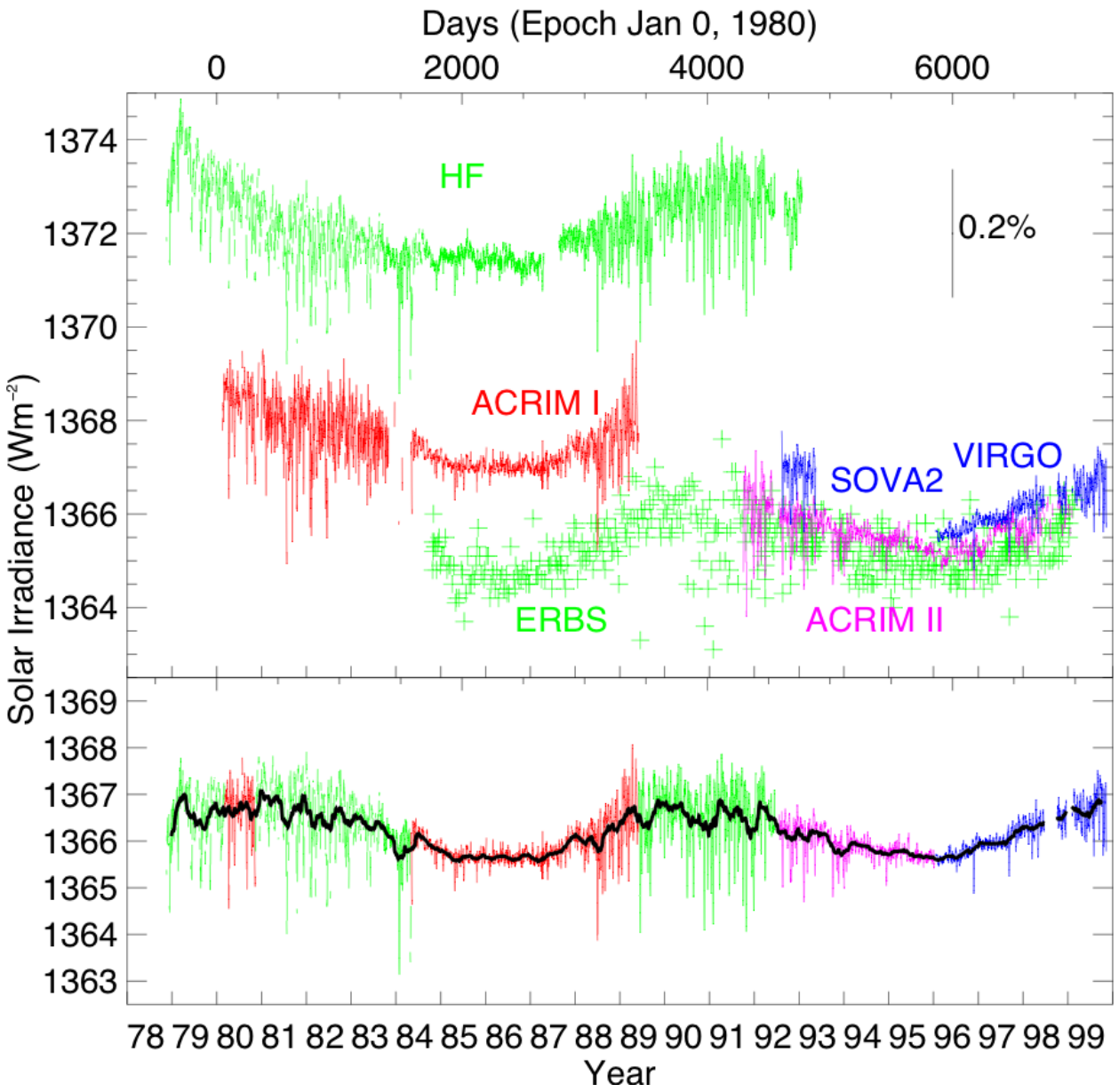
Luminosity

- defined as total photon energy output per unit time
- at Earth we measure the total solar *irradiance* (TSI)
- and the solar constant: 1367 W/m^2
- must be measured in space because of atmospheric absorption
- relation between luminosity and irradiance not necessarily fixed

Absorption in Earth's Atmosphere



Total Solar Irradiance

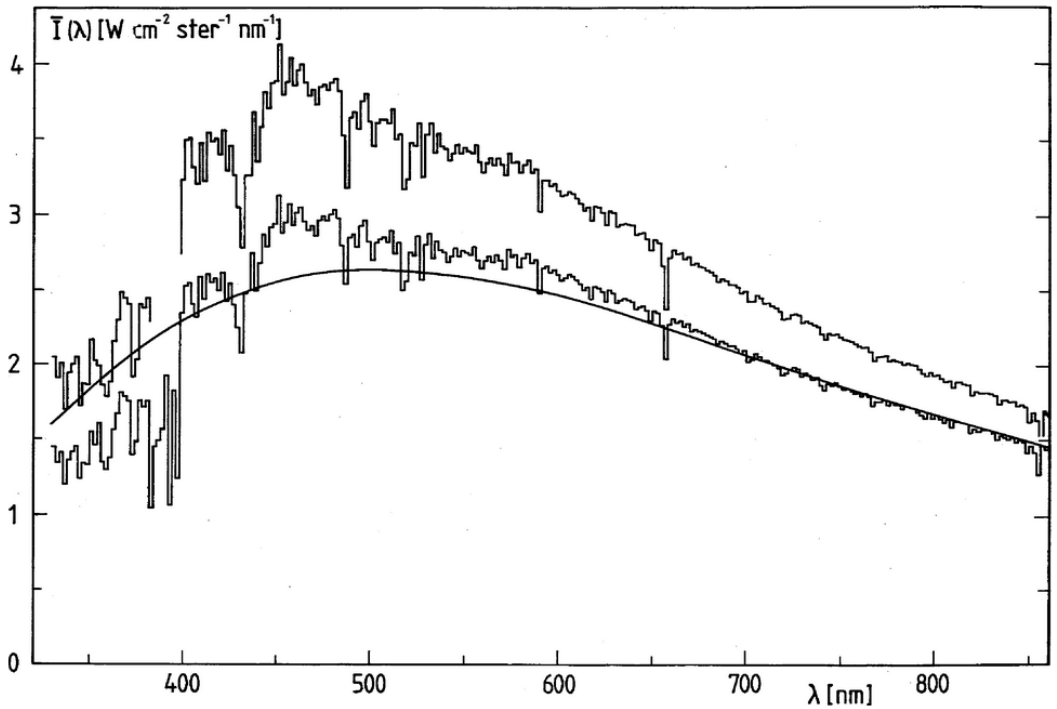


Spectral Energy Distribution (SED)

- *energy flux* at solar surface $F(\lambda)$ assuming spherical symmetry

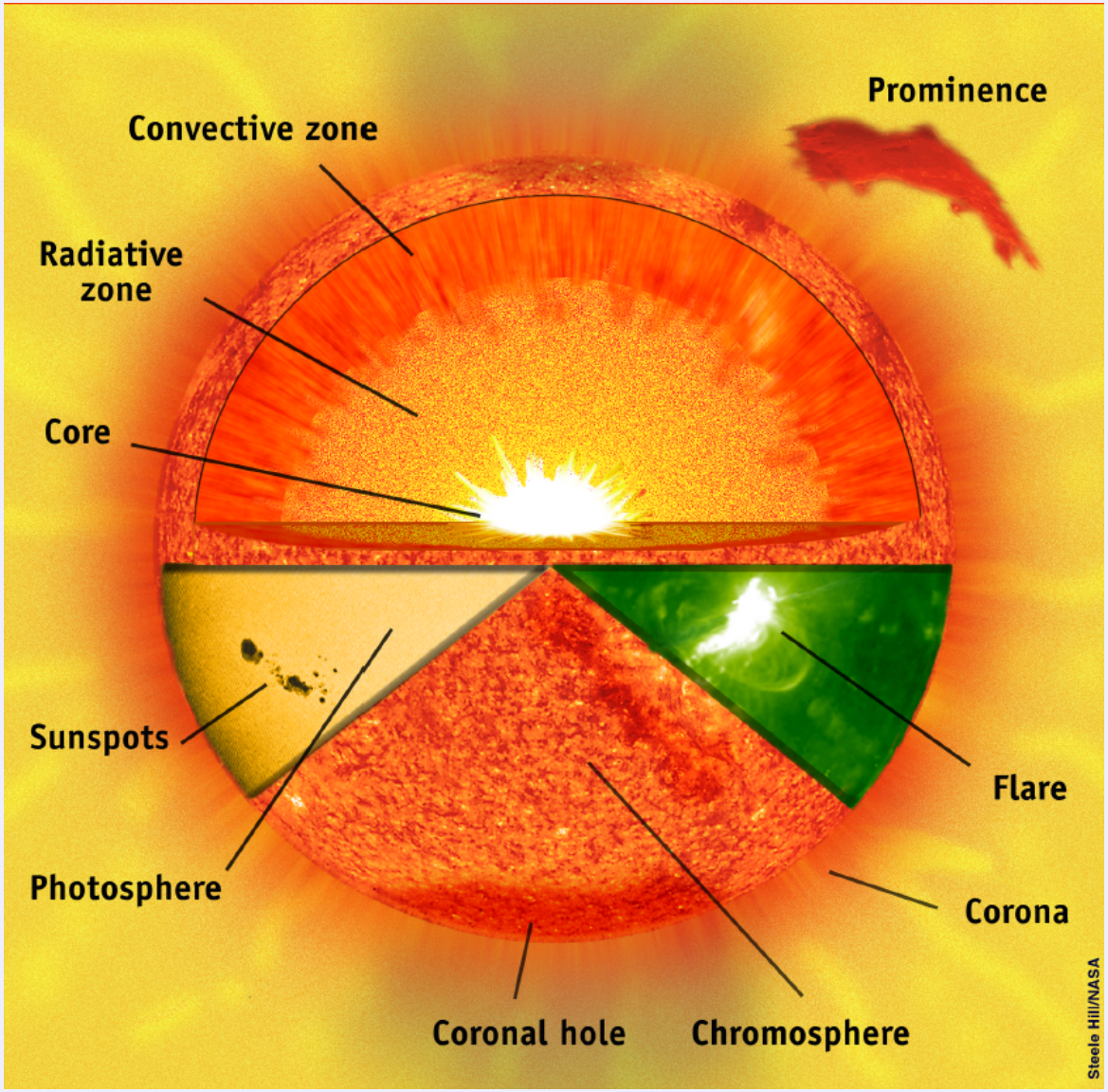
$$r_\odot^2 F(\lambda) = A^2 S(\lambda)$$

- *intensity*: emitted energy per unit area, time, wavelength interval, and solid angle $I(\theta, \lambda)$
- *theta*: angular distance away from surface normal



- upper: central intensity
- lower: average intensity

Solar Structure and Terminology



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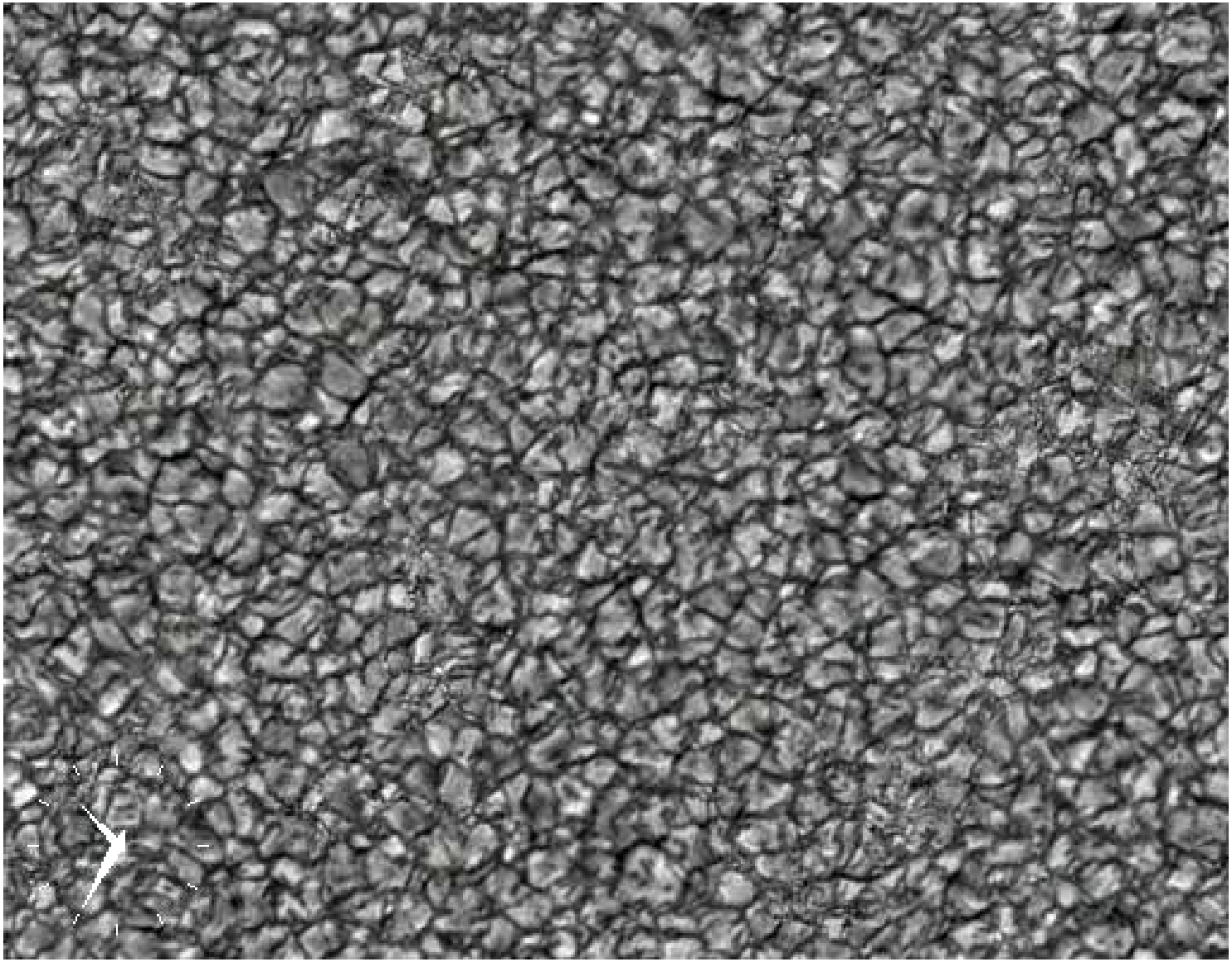
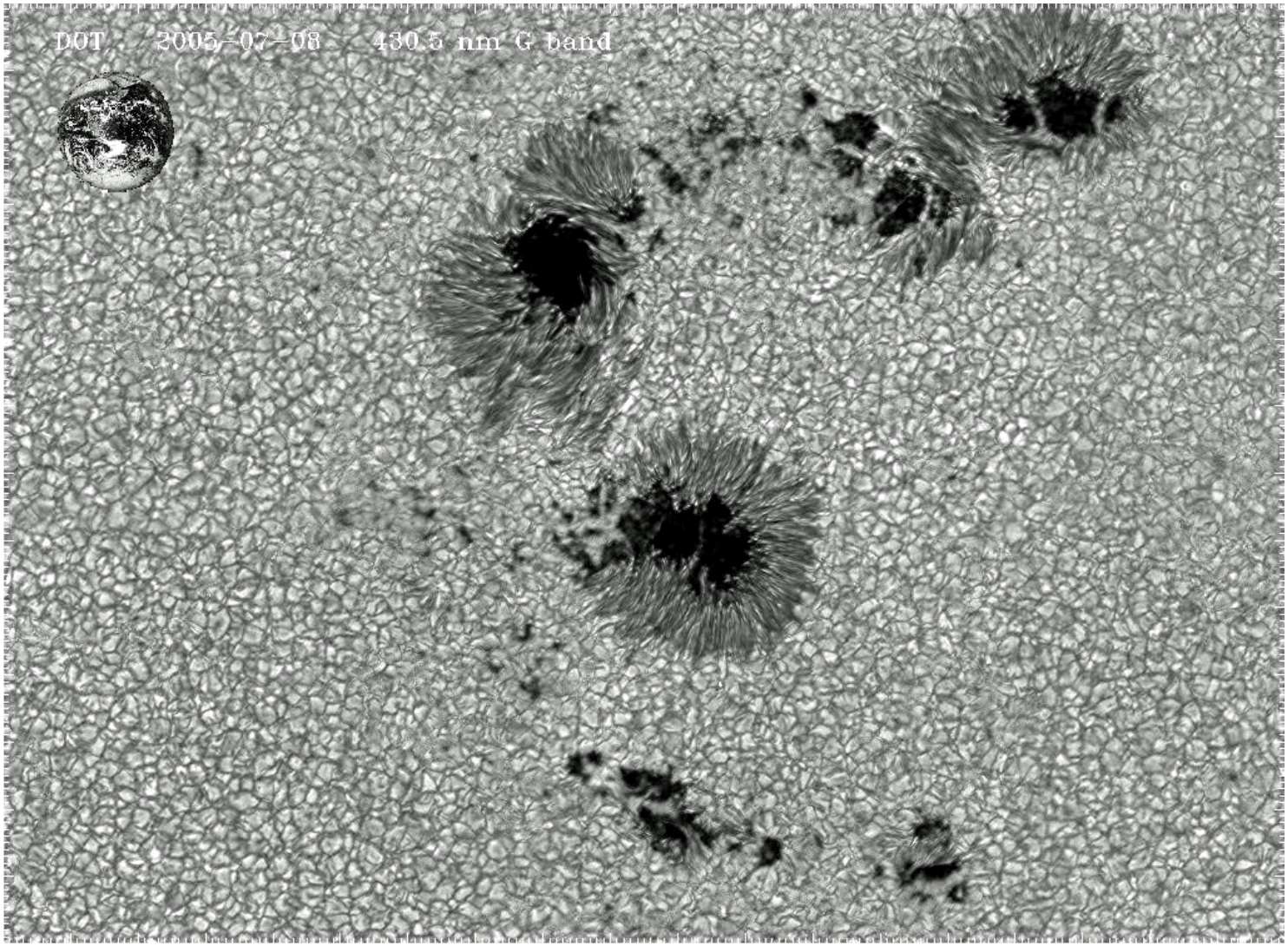
The Photosphere



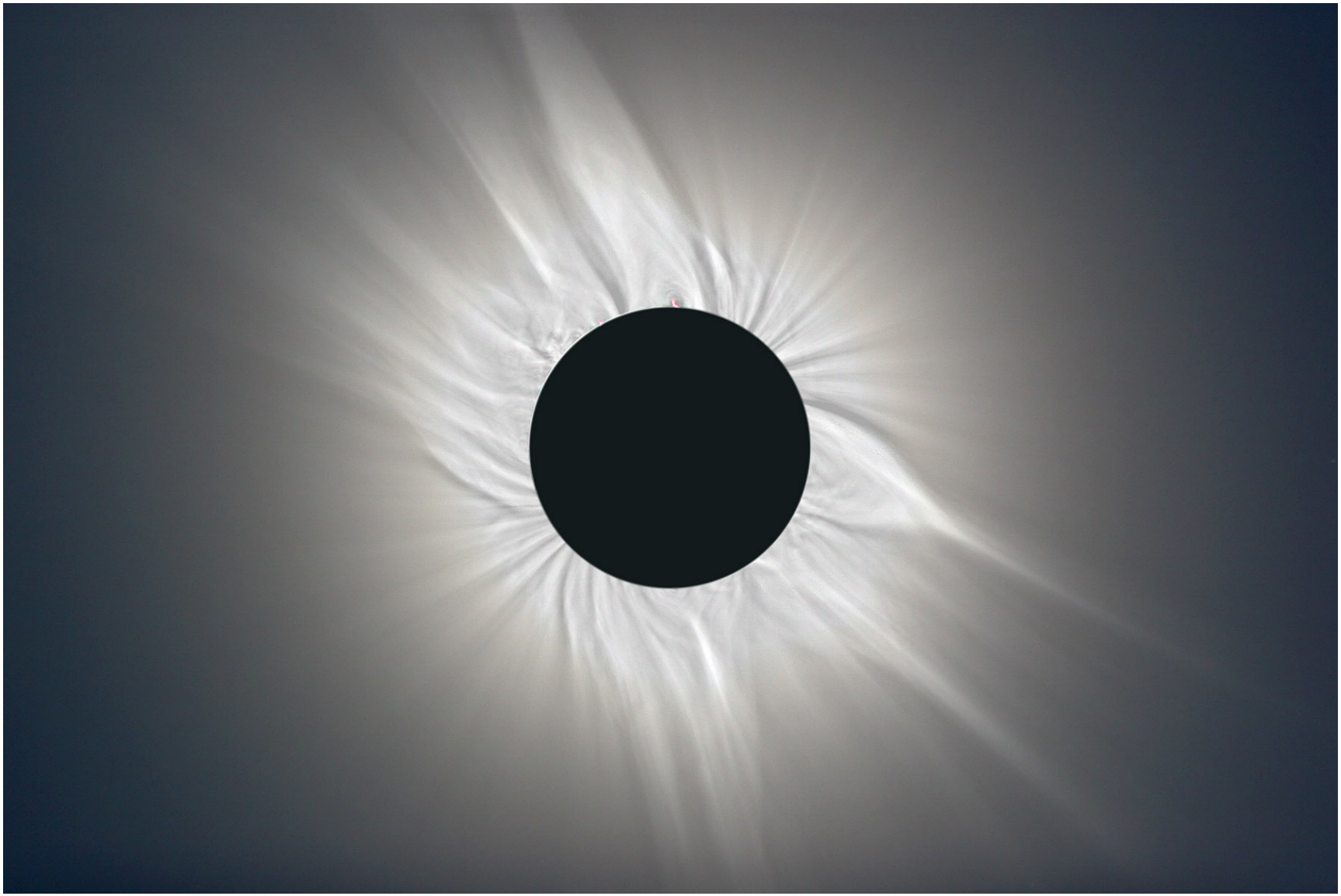
dotdb.phys.uu.nl/DOT/Data/2003_05_02

The Chromosphere



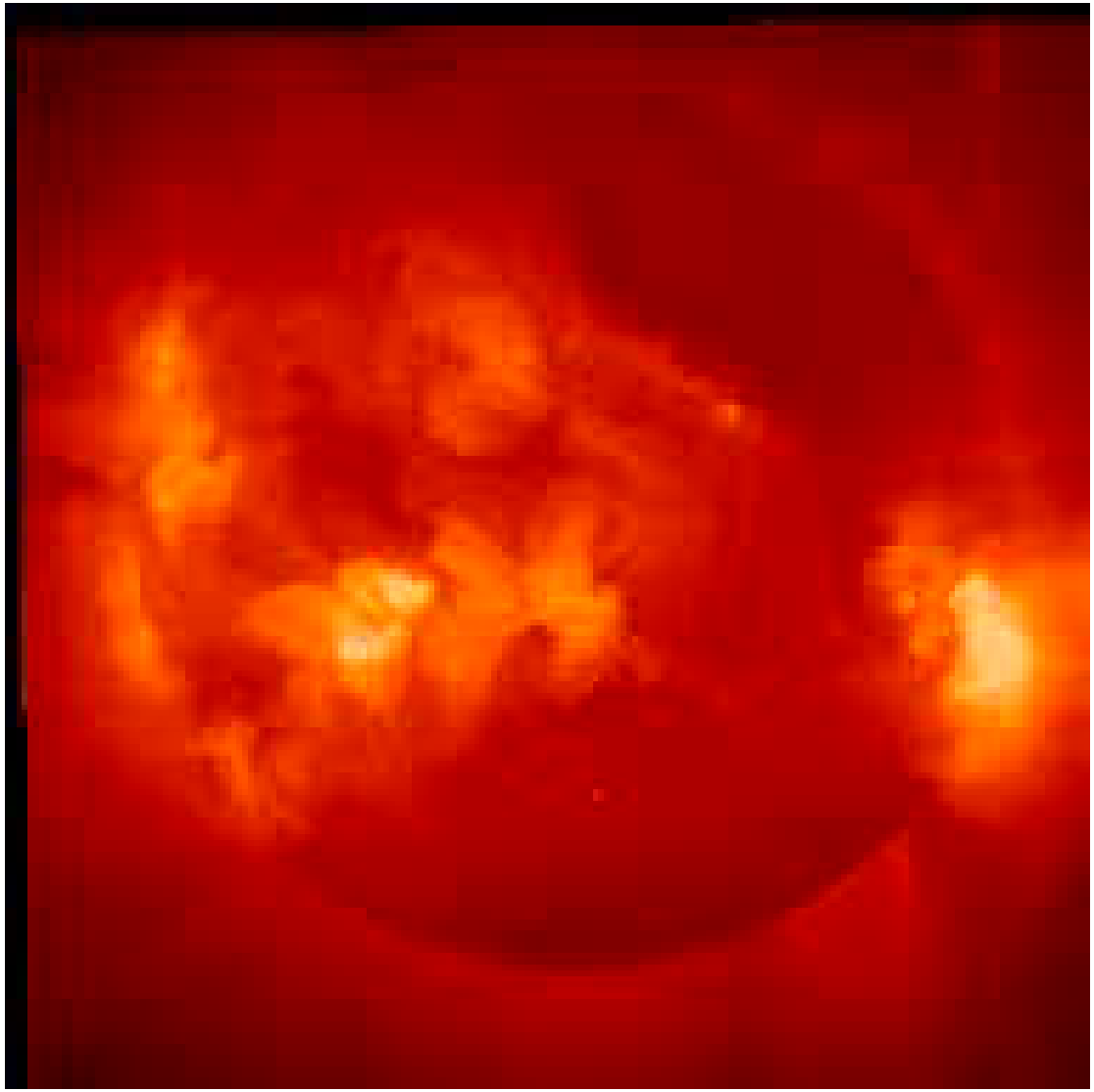
dot.astro.uu.nl/DOT_specials.html

The Corona seen during a Solar Eclipse



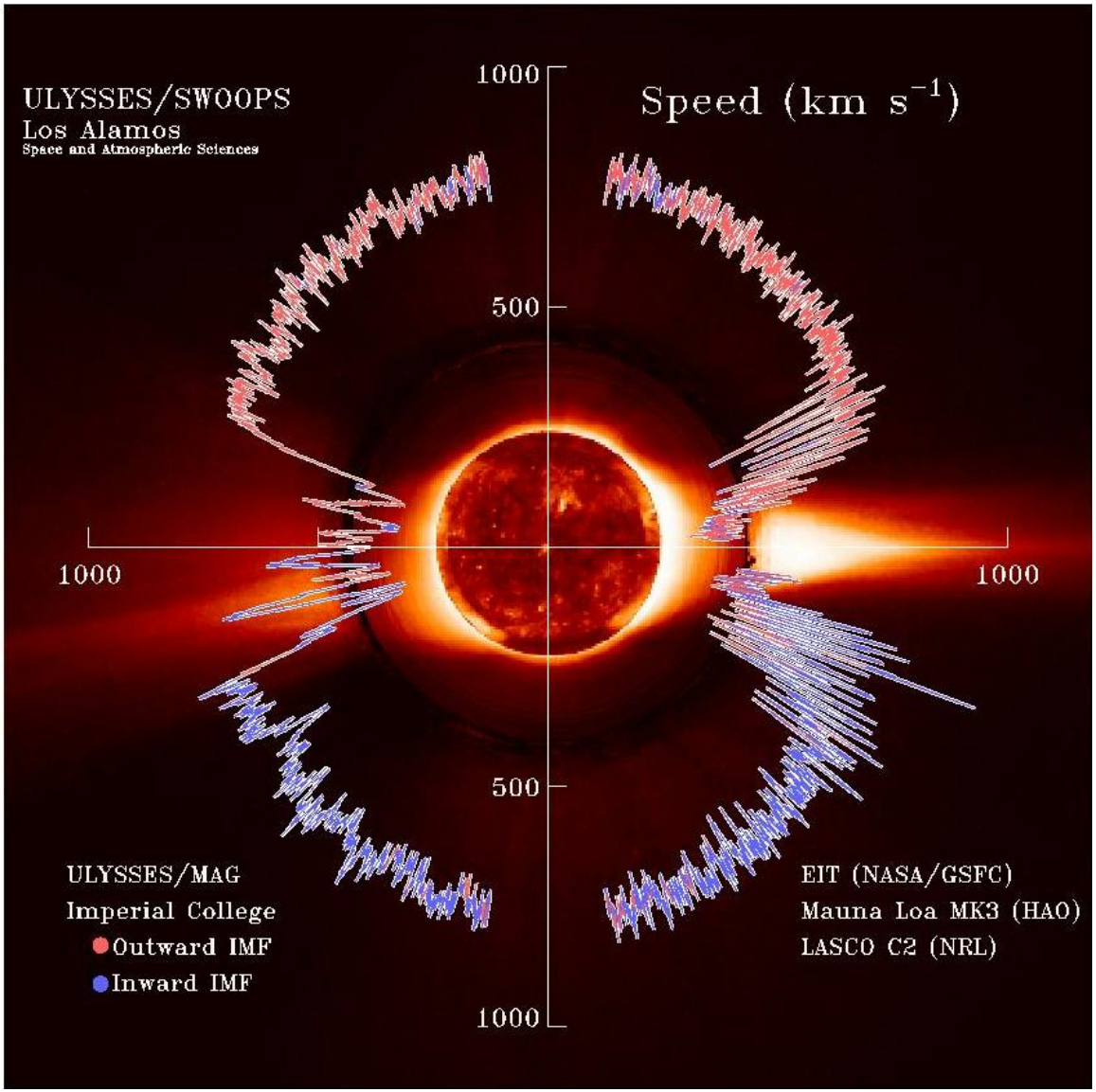
antwrp.gsfc.nasa.gov/apod/ap060407.html

The Corona in 1992 seen in X-Rays from the Yohkho Satellite



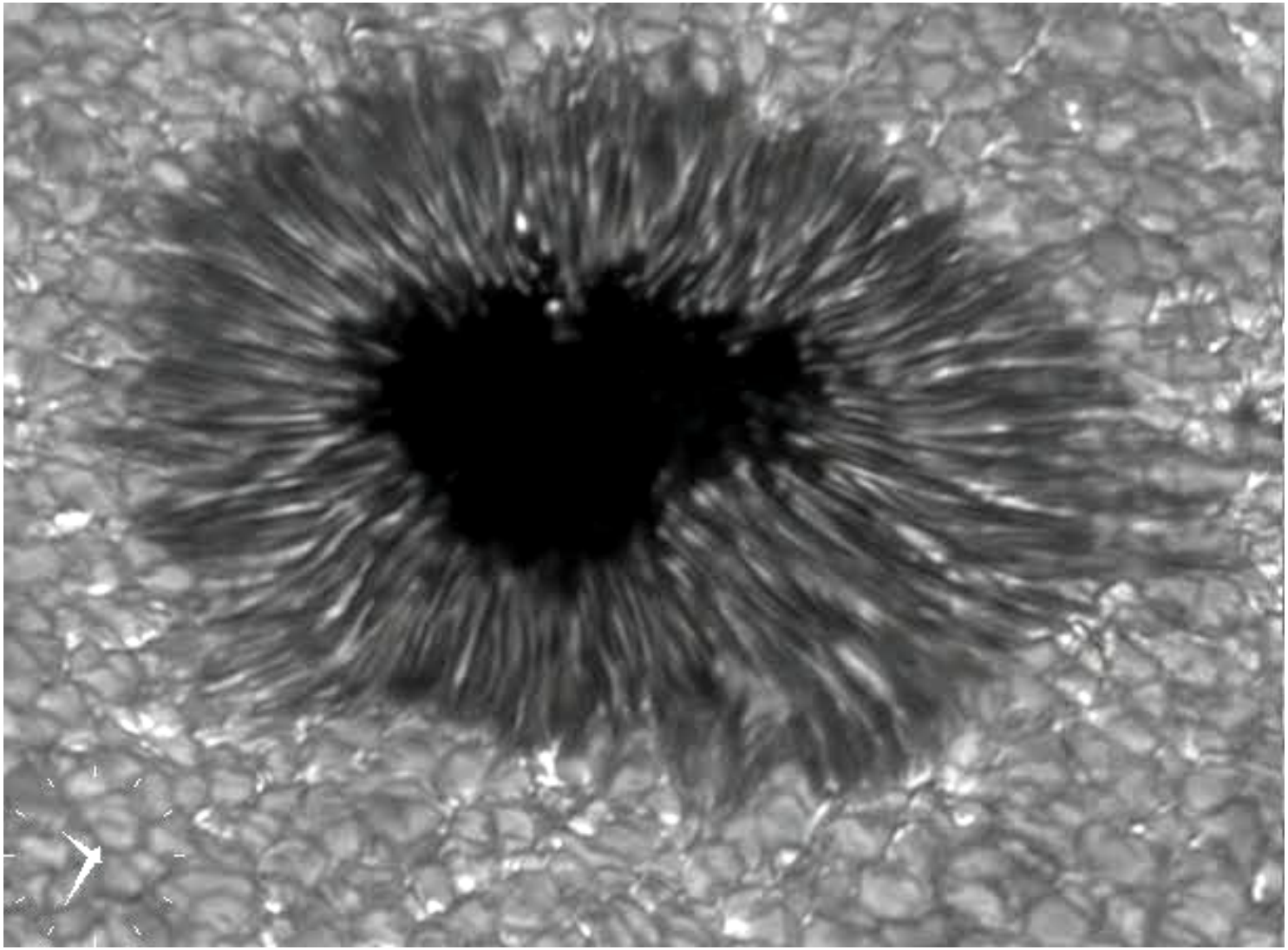
www.windows.ucar.edu/cgi-bin/tour_def/sun/atmosphere/corona.html

The Solar Wind



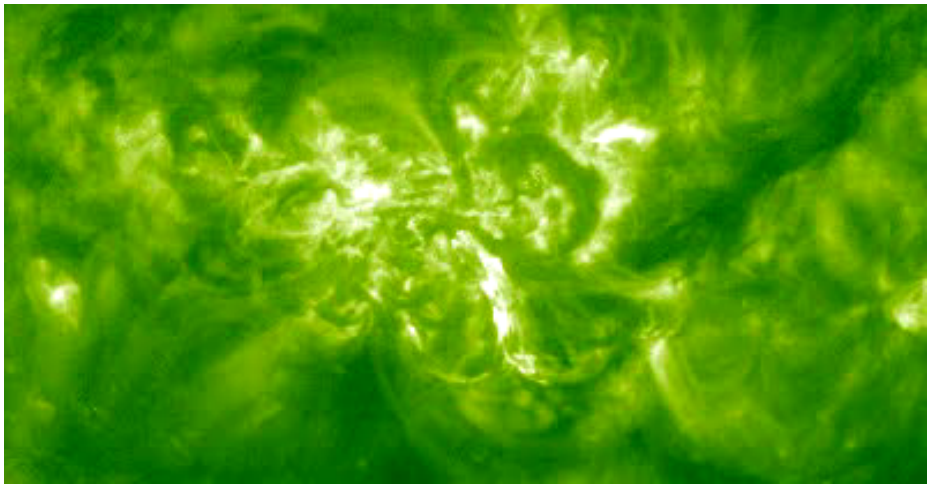
solarscience.msfc.nasa.gov/SolarWind.shtml

Sunspots



dotdb.phys.uu.nl/DOT/Data/1999_09_20

Flares



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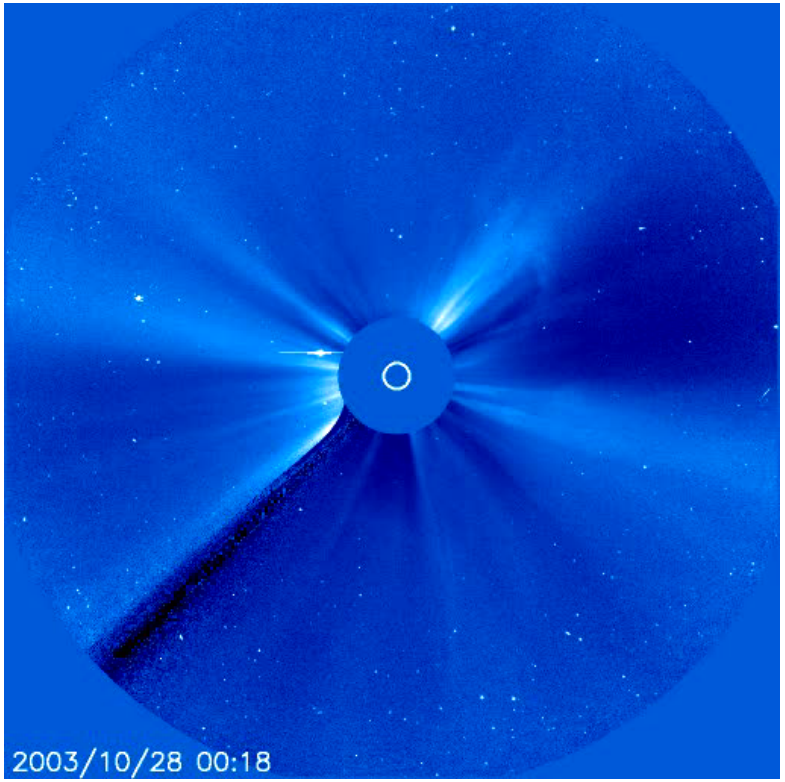
Coronal Mass Ejection



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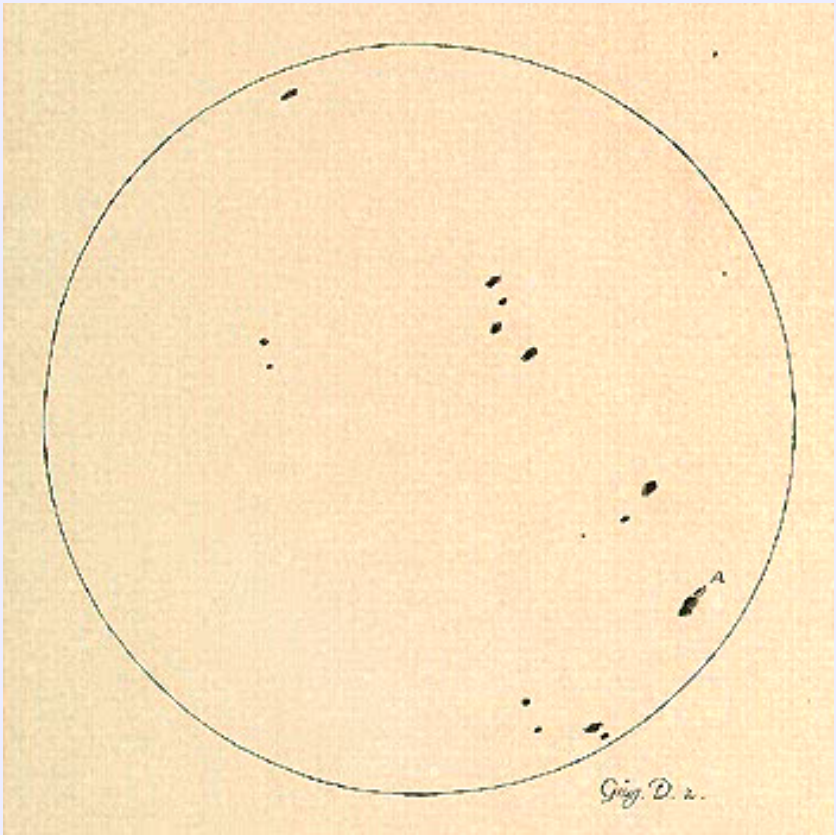
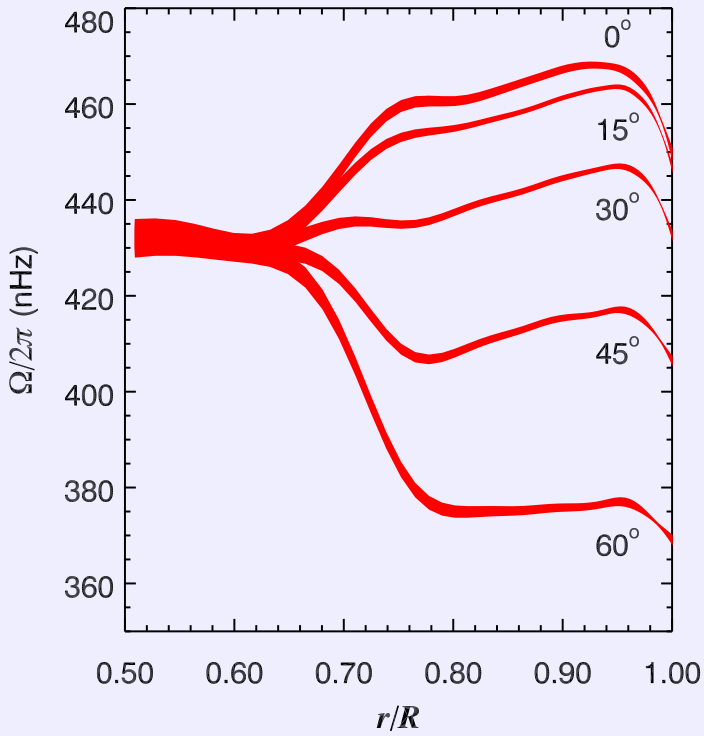
Rotation



galileo.rice.edu/sci/observations/sunspot_drawings.html



soi.stanford.edu/press/GONG_MDI_03-00/

Differential Rotation

- Christoph Scheiner in 1630: slower rotation at higher latitudes
- helioseismology reveals internal solar rotation rate
- only convection zone shows differential rotation

Current Problems in Solar Physics

- **oxygen abundance**: numerical simulations imply metal abundances that are in disagreement with helioseismic frequencies
- **FIP-effect**: photospheric and solar wind abundances are not the same
- **origin of supergranulation**: physical mechanism
- **coronal heating process**: energy source, transport, dissipation mechanisms
- **solar wind accelleration**: physical mechanism
- **nature of flares**: source of magnetic energy, instability, forecasting
- **origin of solar cycle**: physics of the (large-scale) dynamo
- **origin of small-scale fields**: leftovers from sunspot cycle or small-scale dynamo in surface layers