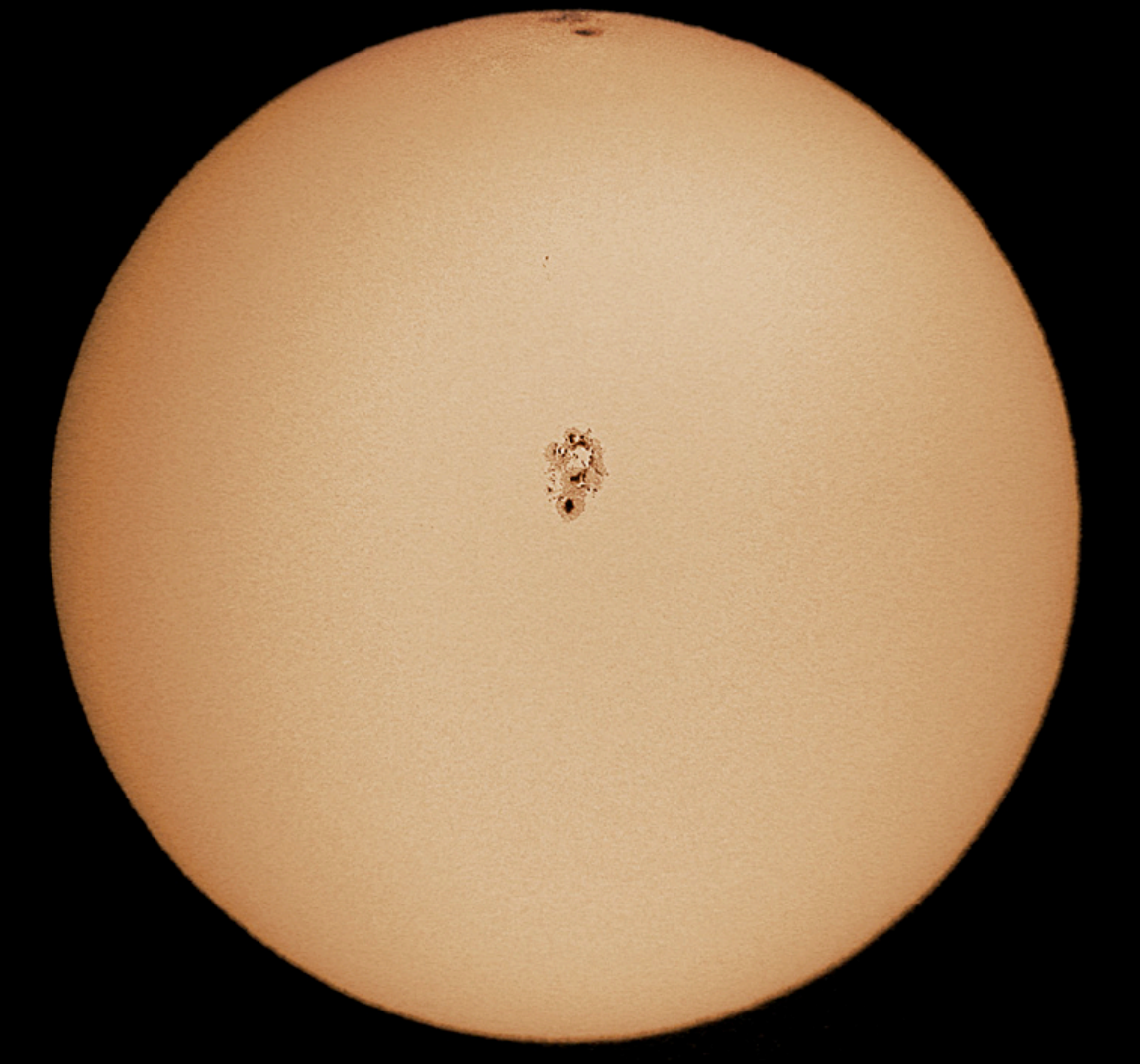
The Sun



Our Star

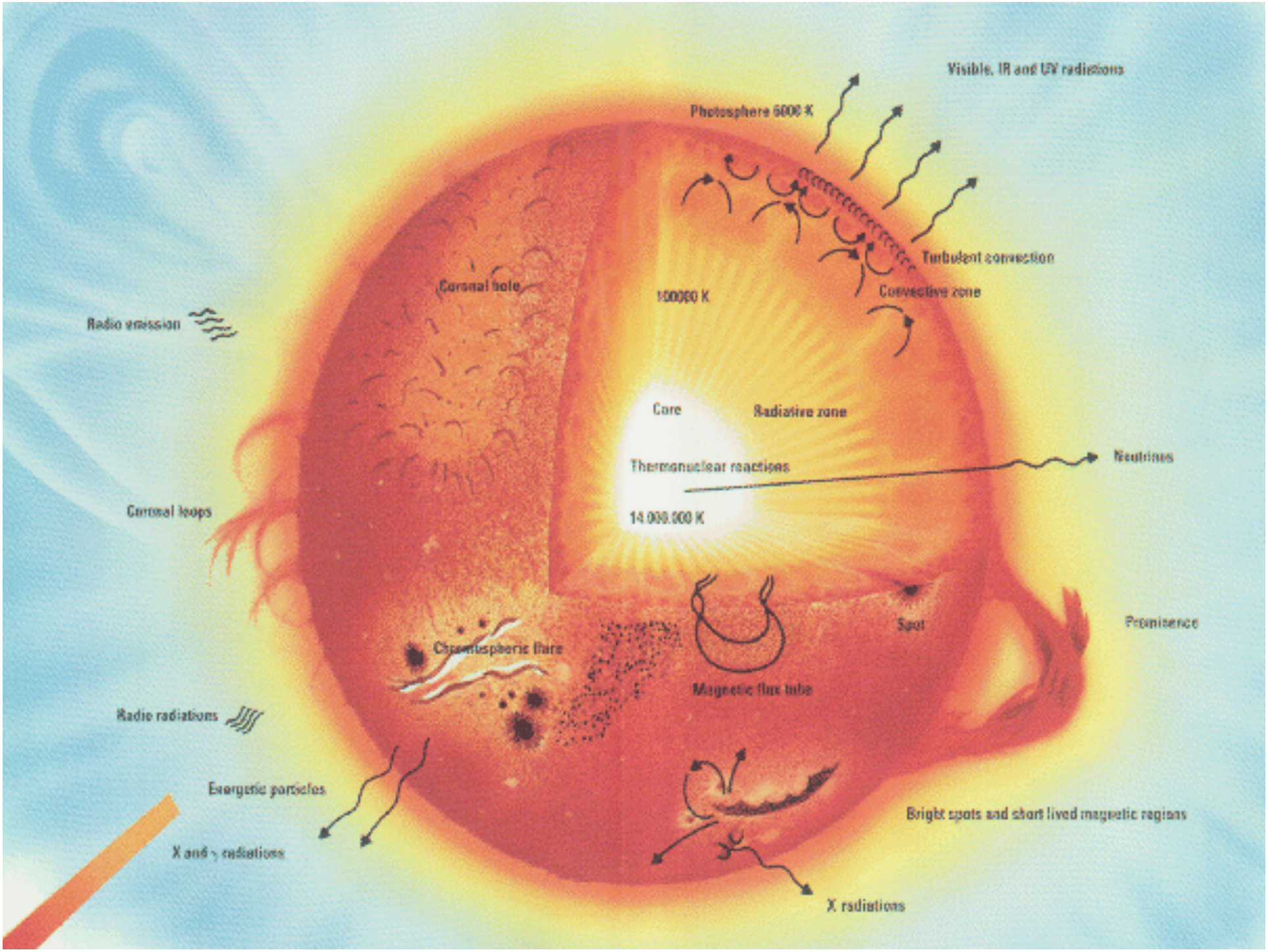
On 1 September 1859, a small white light flare erupted on the Solar surface

17 hours later

- Magnetometers recorded a large disturbance
- Aurorae were seen in the Carribean,
- Telegraphs went haywire

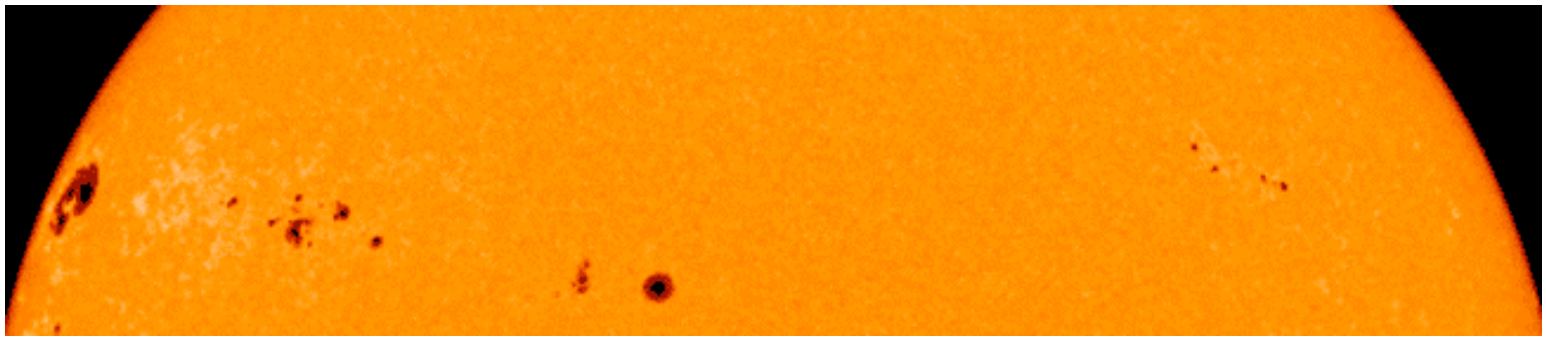
What we know about the Sun

- **Angular Diameter** θ = 32 arcmin (from observations)
- **Solar Constant** f = 1.4 *x* 10^6 erg/sec/cm^2 (from observations)
- **Distance** d = 1.5 *x* 10^8 km (1 AU).
  (from Kepler's Third Law and the trigonometric parallax of Venus)
- **Luminosity** L = 4 *x* 10^{33} erg/s.
  (from the inverse-square law: $L = 4\pi\ d^2\ f$)
- **Radius** R = 7 *x* 10^5 km. (from geometry: $R = \theta\ d$)
- **Mass** M = 2 *x* 10^{33} gm. (from Newton's version of Kepler's Third Law, $M = (4\pi^2/G)\ d^3/P^2$)
- **Temperature** T = 5800 K. (from the black body law: $L = 4\pi R^2\ \sigma\ T^4$)
- **Composition** about 74% Hydrogen, 24% Helium, and 2% everything else (by mass). (from spectroscopy)


Visible, IR and UV radiations
Photosphere 6000 K
Turbulent convection
Convective zone
Coronal hole
100000 K
Radio emission
Core
Radiative zone
Thermonuclear reactiones
Neutrinos
Coronal loops
14 000 000 K
Spot
Prominence
Chromospheric flare
Magnetic flux tube
Radio radiations
Energetic particles
Bright spots and short lived magnetic regions
X and γ radiations
X radiations

The Solar Surface

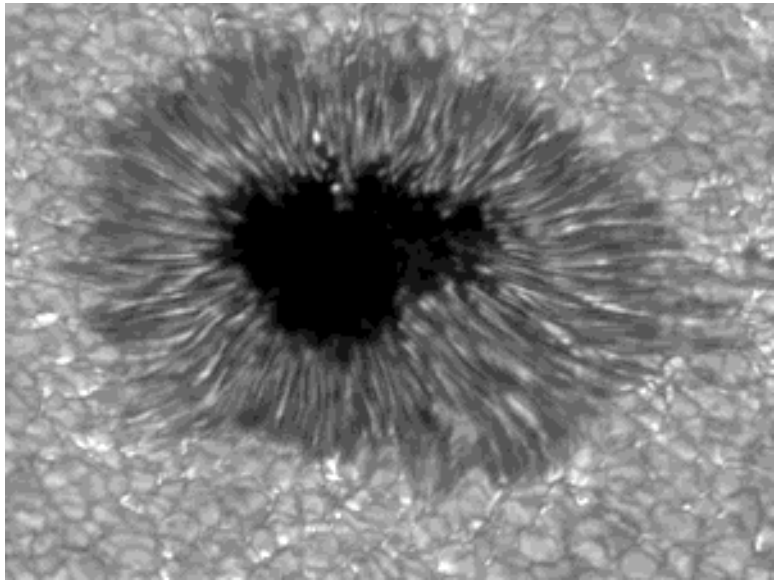
The **photosphere**. The visible light disk.



Galileo observed sunspots (earlier noted by Chinese observers)

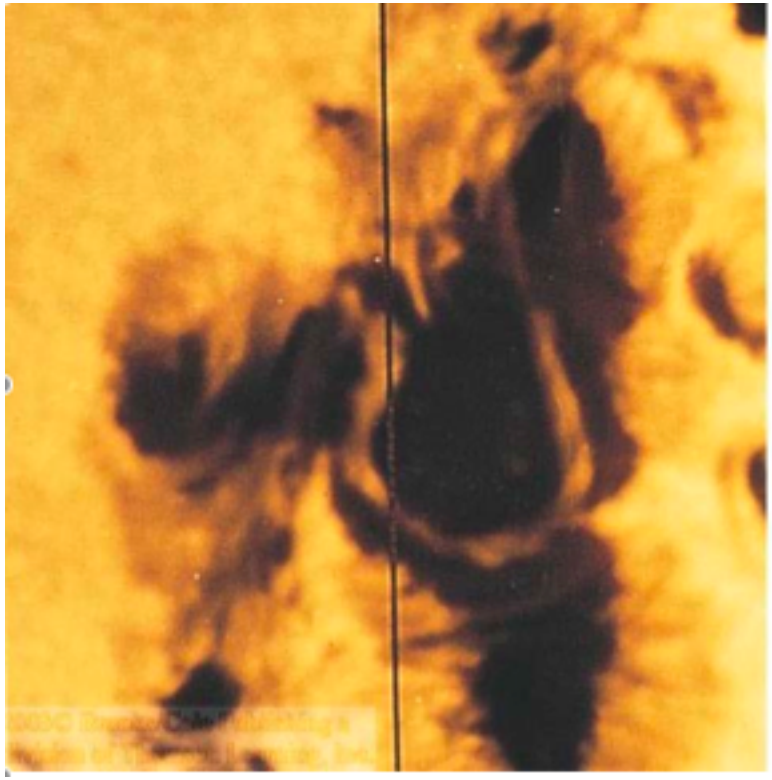
- Sunspots are regions of intense magnetic fields
- Sunspots appear dark because they are cooler than the photosphere
- A large sunspot is brighter than the full moon.

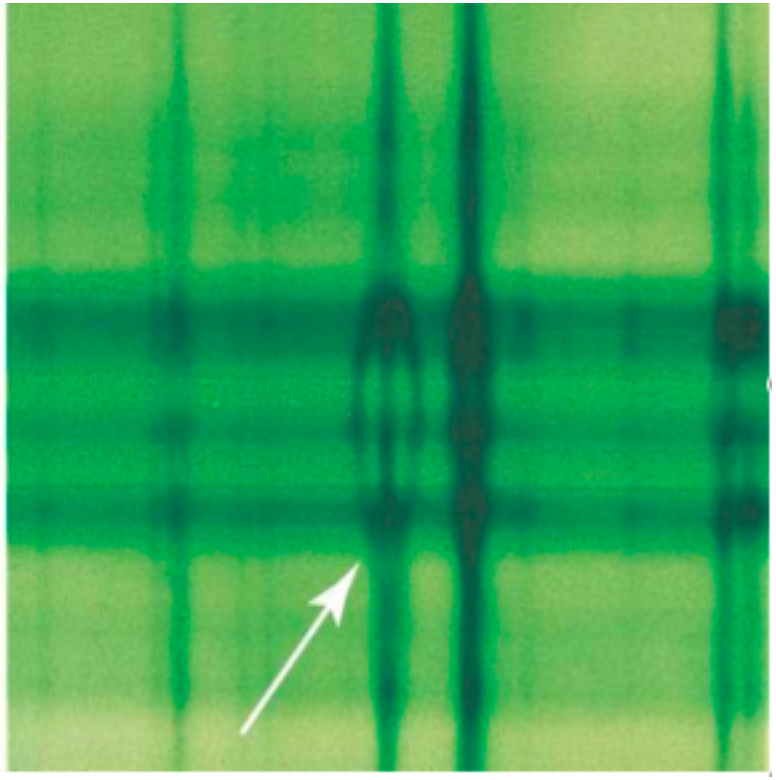
Solar Granulation



Real time: 20 minutes

Photospheric Magnetic Fields



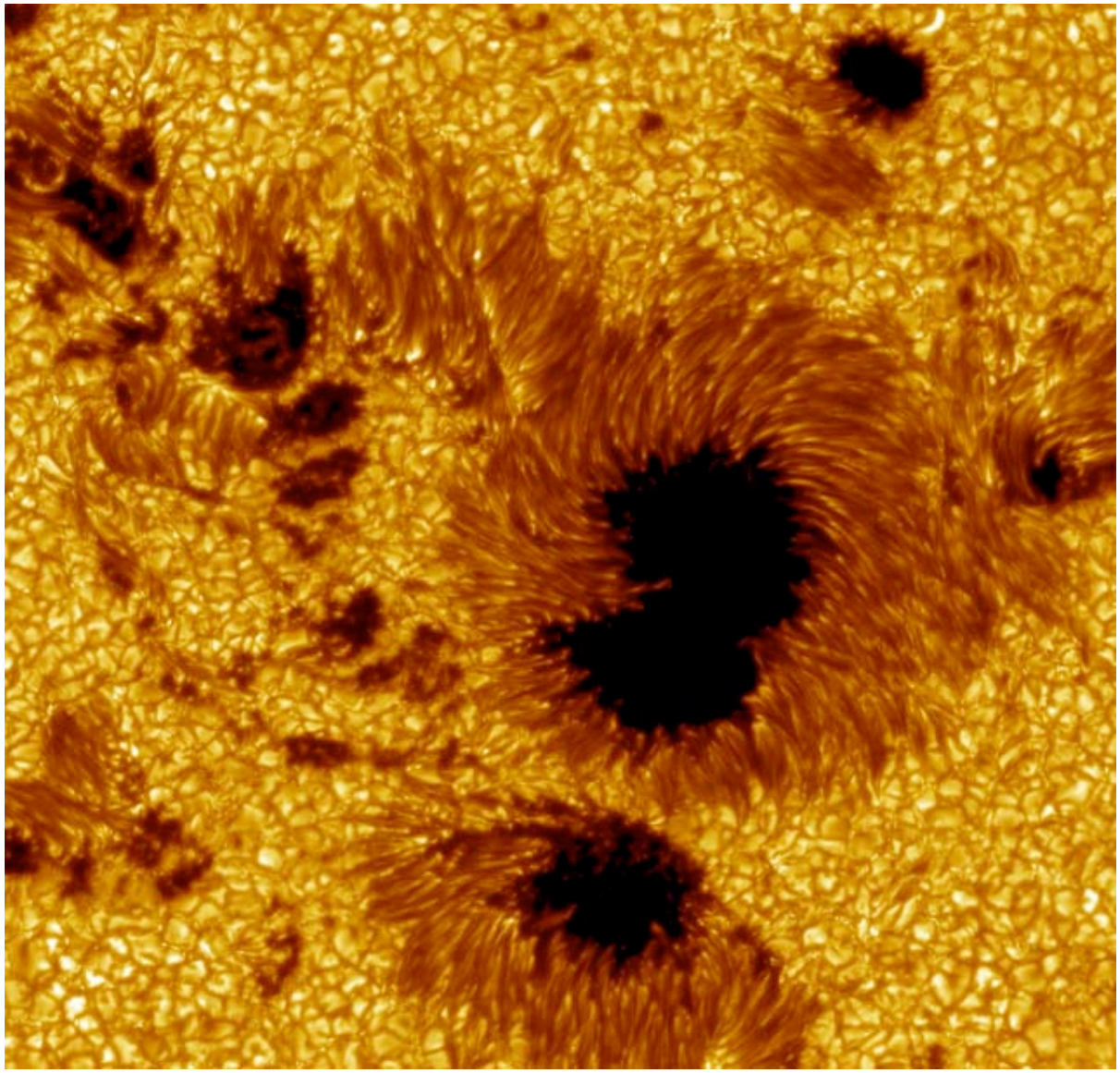


Zeeman Effect

Sunspots

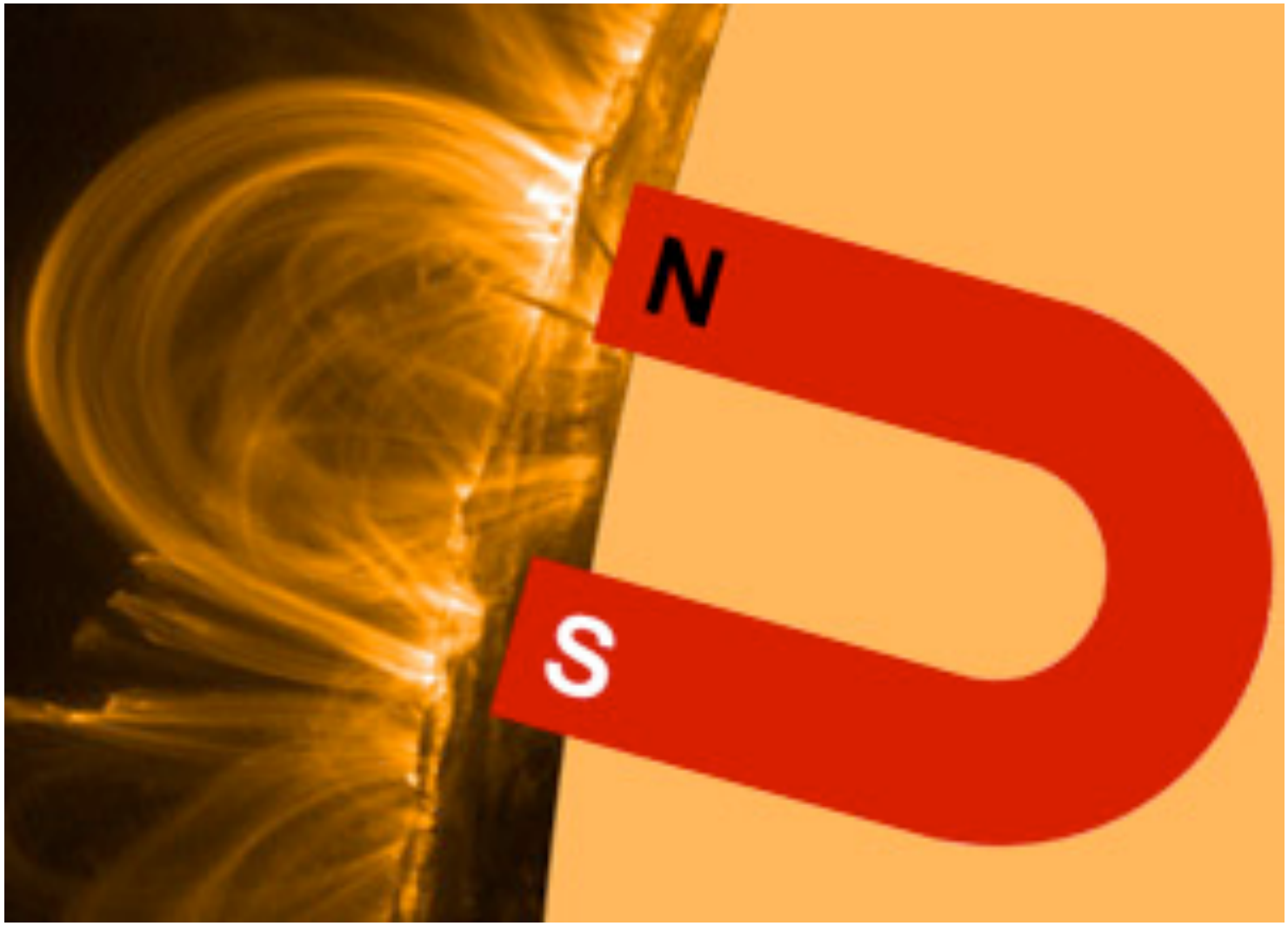
Pressure balance:
Gas pressure +
magnetic pressure
in spot
=
gas pressure
outside spot

$B_s \sim 2kG$
$T_s \sim 4500K$

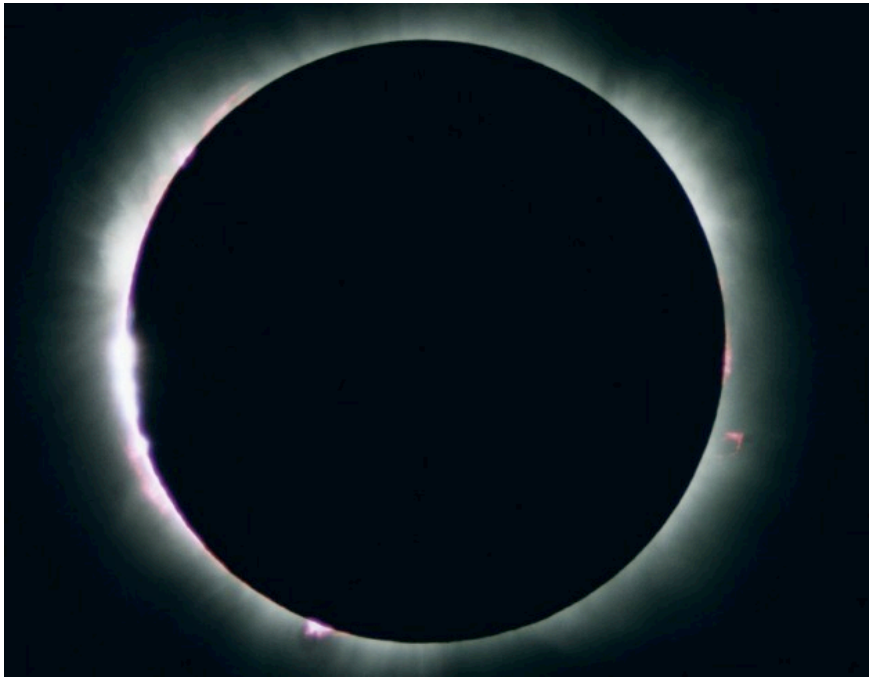


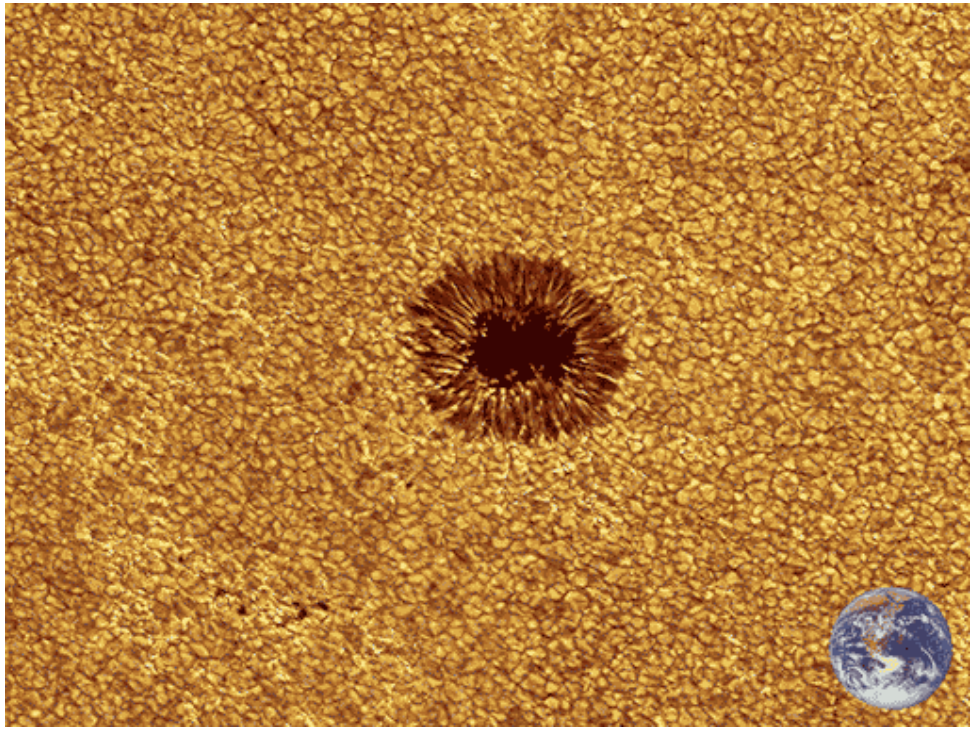
Magnetic Flux Loops

- Magnetic energy density: $B^2/8\pi$

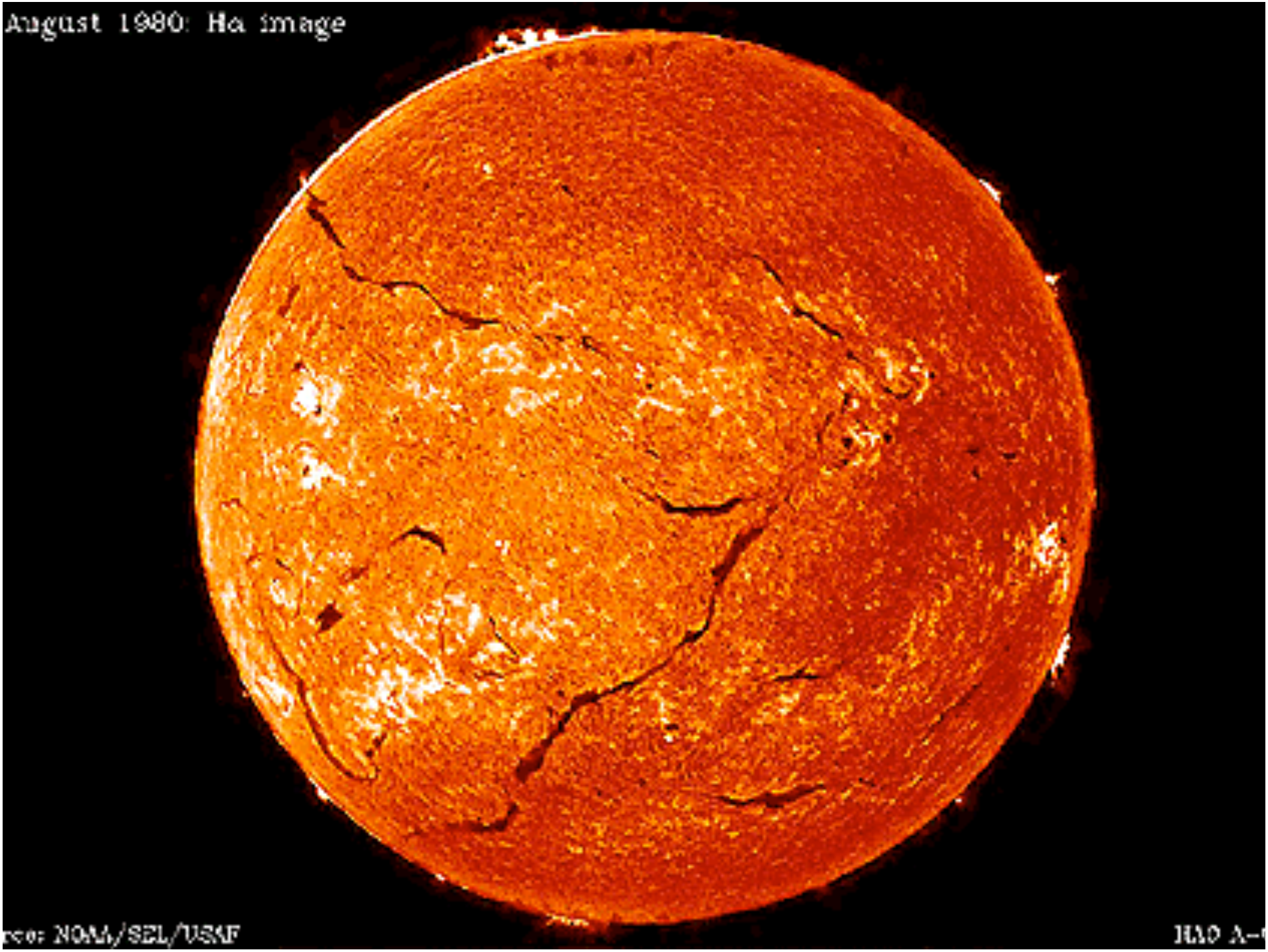


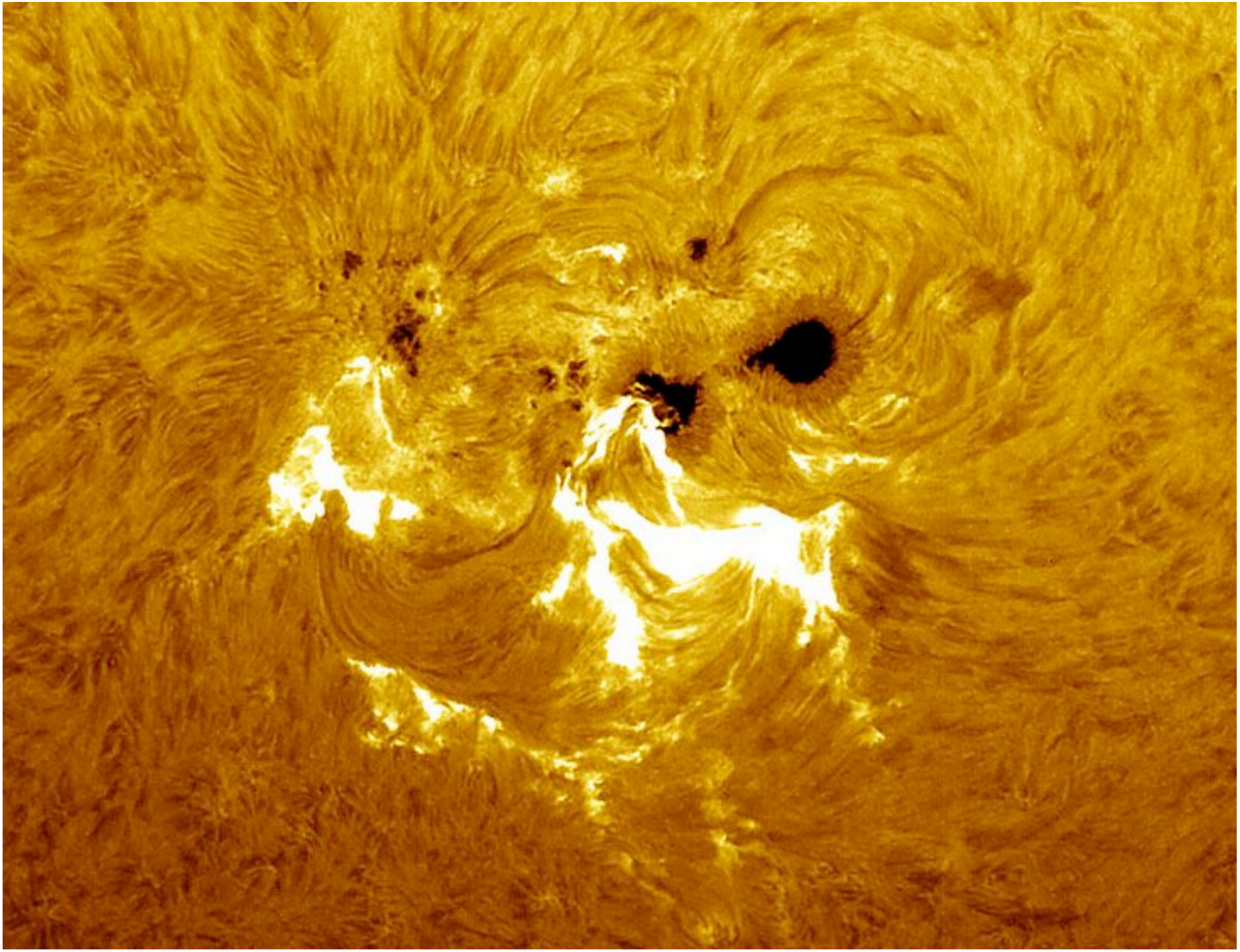
The Chromosphere





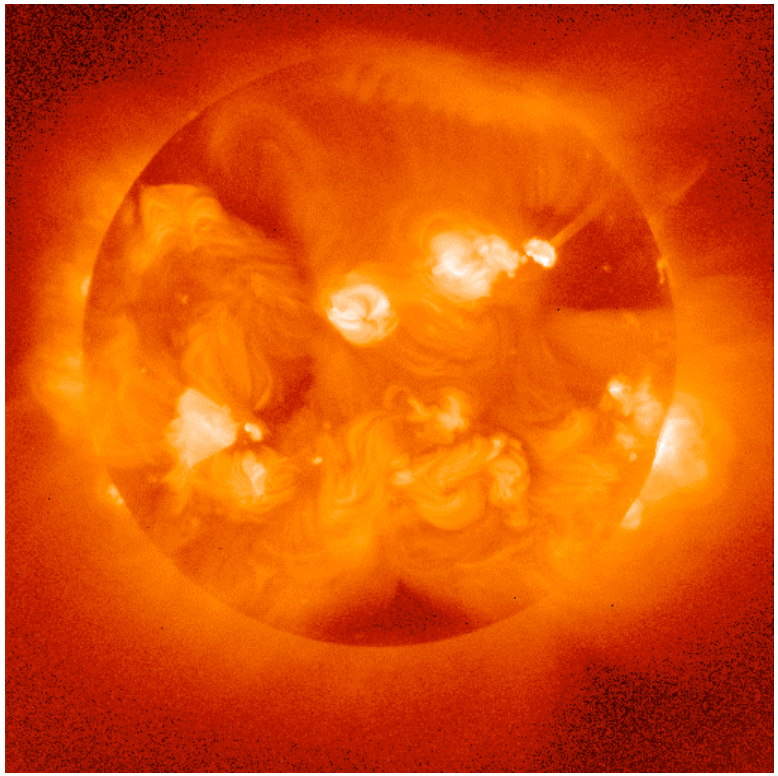
- First noticed in total solar eclipses.
- Name from the red color (from an emission line of Hydrogen)
- Hot (8000-20,000K) gas heated by magnetic fields.
- Bright regions known as *plage*.


August 1980: Hα image
NOAA/SEL/USAF

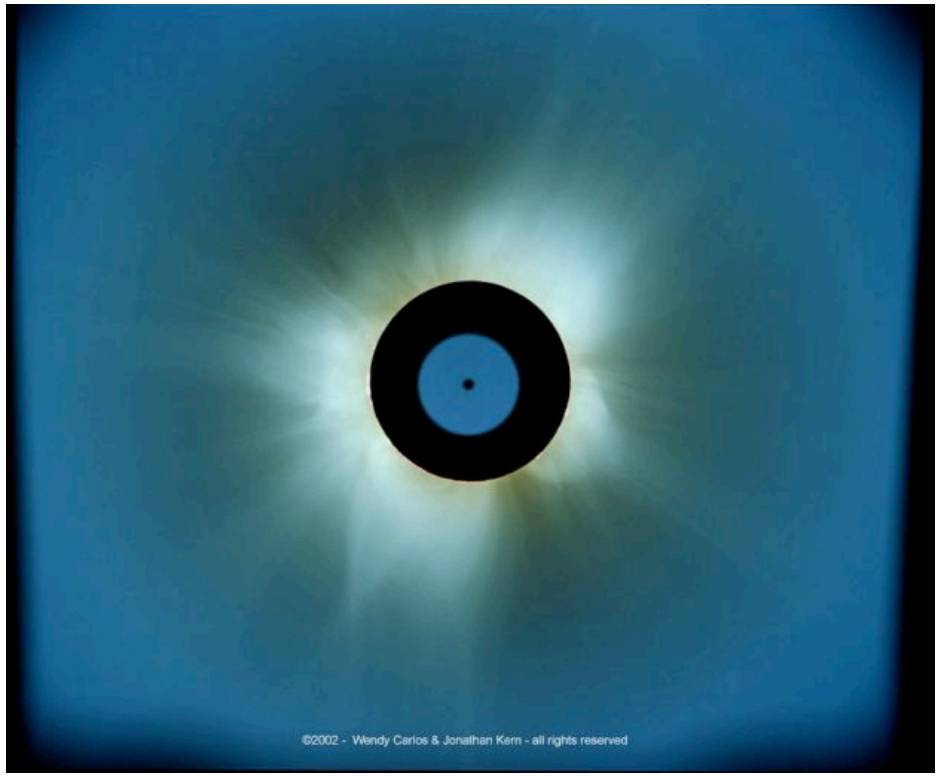


The Corona

The diffuse outer atmospheres of the Sun.



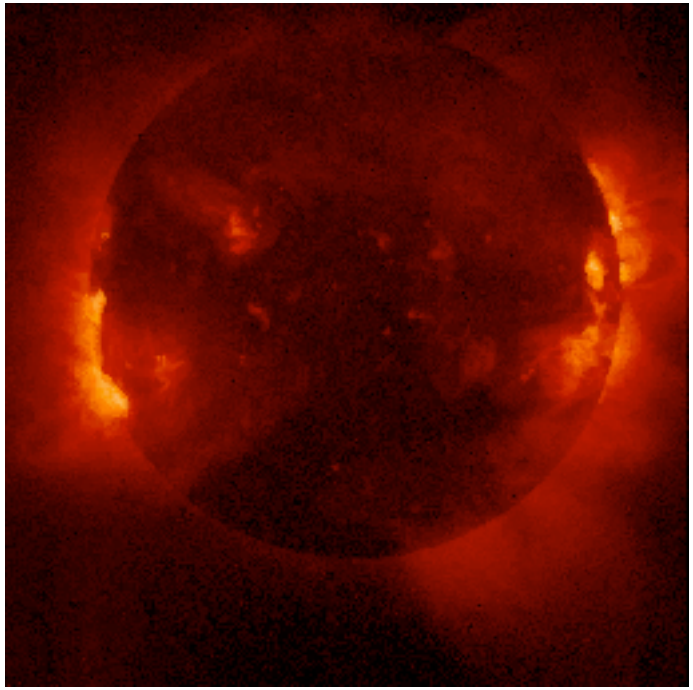
The X-ray corona



The white-light corona

Also, the K corona - sunlight scattered from interplanetary dust

The Corona



Description of a Singular Appearance seen in the Sun on September 1, 1859.
by Richard C. Carrington,
Monthly Notices of the Royal Astronomical Society, vol. 20, 13-15, 1860

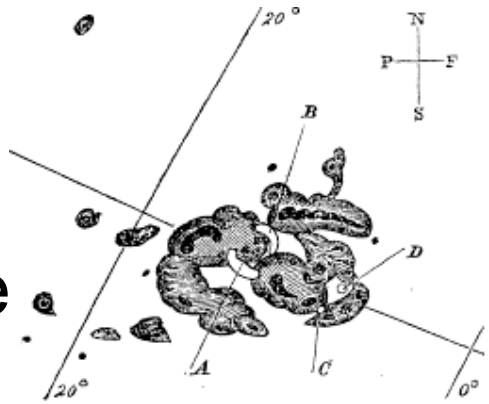
While engaged in the forenoon of Thursday, September 1, in taking my customary observation of the forms and positions of the solar spots, an appearance was witnessed which I believe to be exceedingly rare. …
I had secured diagrams of all the groups and detached spots, and was engaged at the time in counting from the chronometer and recording the contacts of the spots with the cross-wires used in the observation, when within the area of the great north group (the size of which had previously excited great remark), two patches of intensely bright and white light broke out, in the positions indicated in fig. 1 ...

My first impression was that by some chance a ray of light had penetrated a hole in the screen attached to the object glass, for the brilliancy was fully equal to that of direct sun-light; but by at once interrupting the current observation, and causing the image to move ...

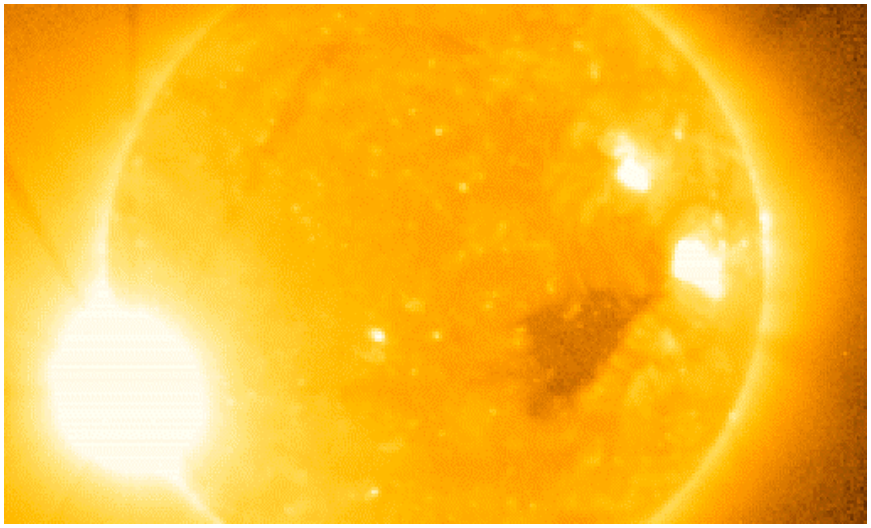
I saw I was an unprepared witness of a very different affair. I therefore noted down the time by the chronometer, and seeing the outburst to be very rapidly on the increase, and being somewhat flurried by the surprise, I hastily ran to call some one to witness the exhibition with me, and on returning within 60 seconds, was mortified to find that it was already much changed and enfeebled. Very shortly afterwards the last trace was gone. In this lapse of 5 minutes, the two patches of light traversed a space of about 35,000 miles.

The 1 Sept 1859 Flare

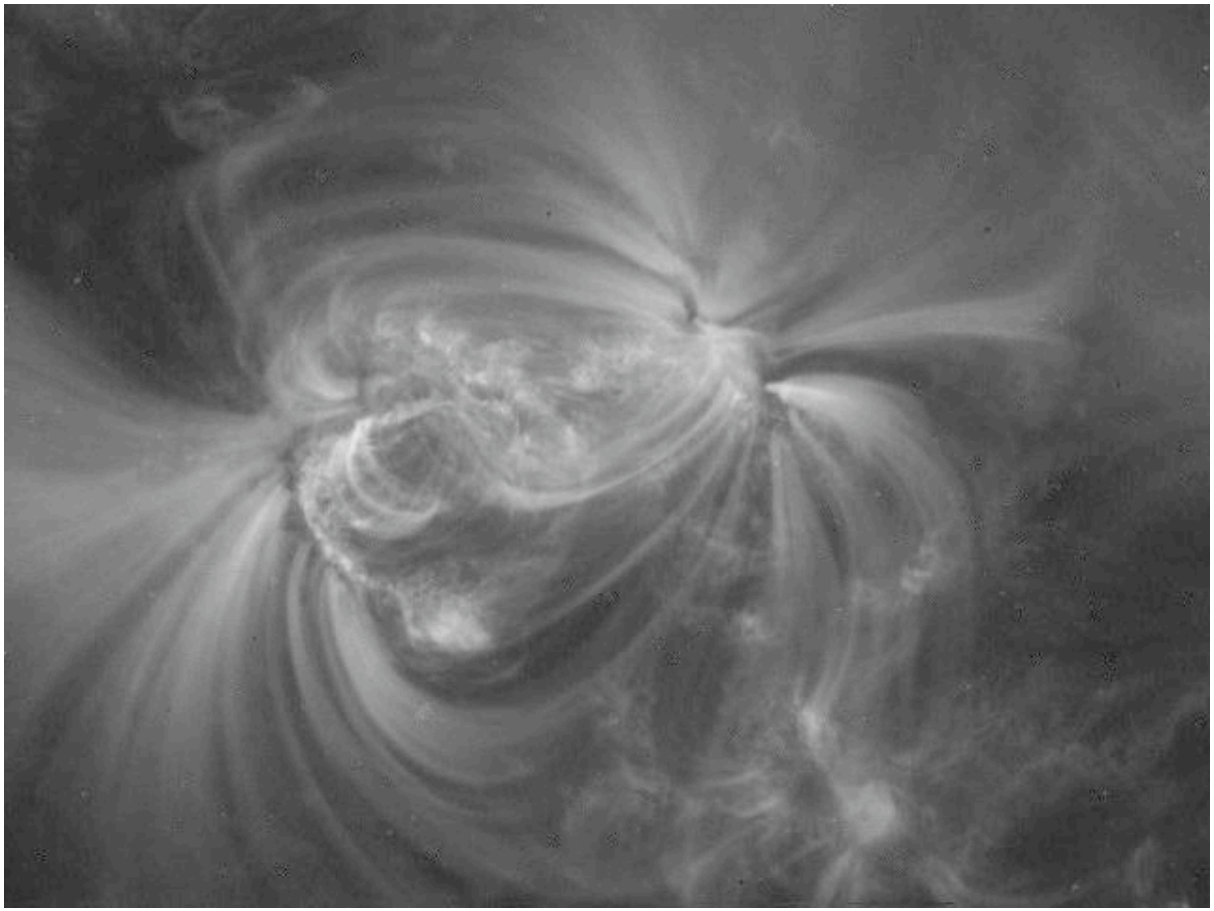
- 9/1: Carrington observed white-light flare
- 9/2: Brilliant auroras seen
  (as far south as the Caribbean)
- Telegraphs functioned w/o batte
- Telegraph operators shocked



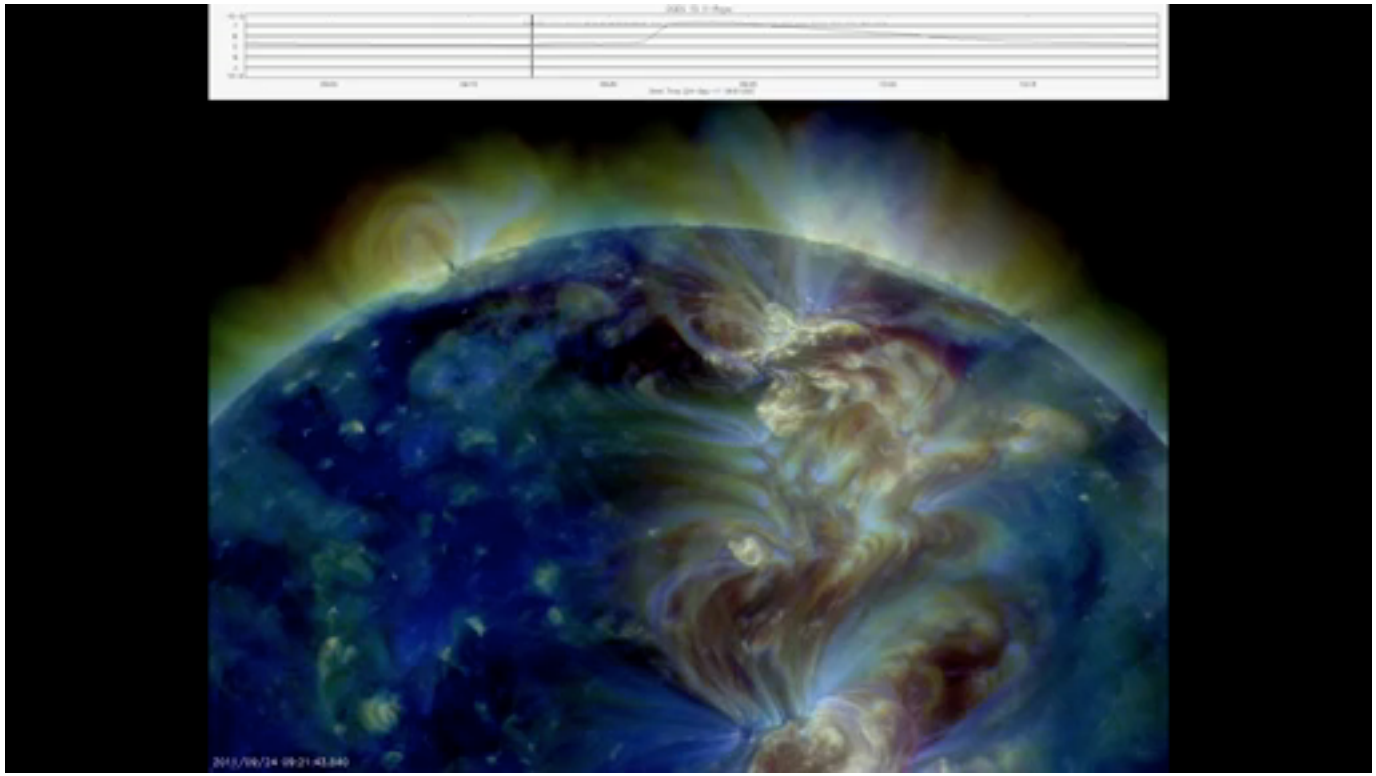
- First solar flare recorded
- Strongest in ~500 years



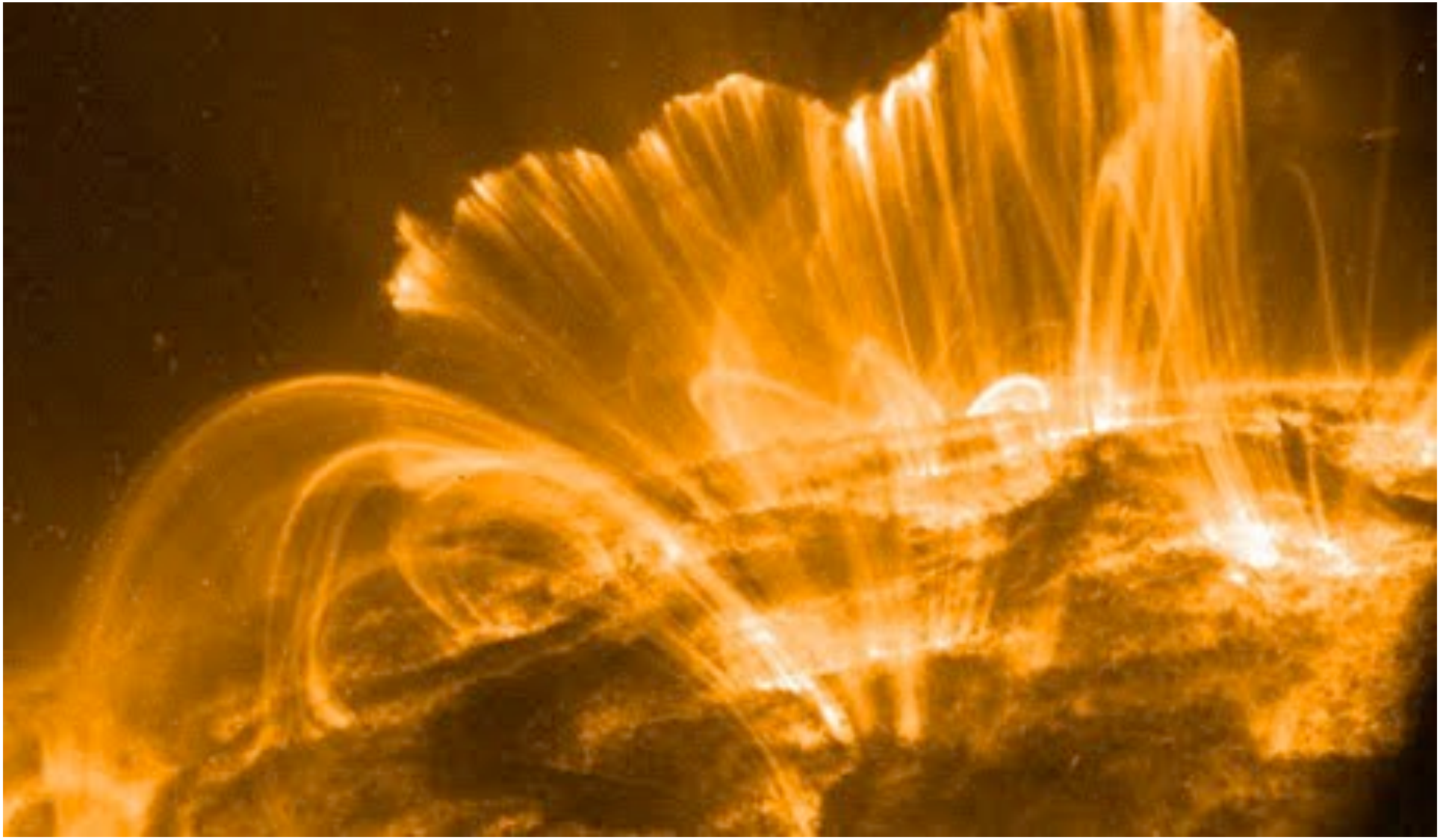
Flares



SDO X1.4 flare



The Magnetic Carpet



Classification of Solar Flares

Class	Intensity (W/m^2)	Luminosity ($L_\odot$, 100 sec)
B	10^{-7}	10^{-8}
C	10^{-6}	10^{-7}
M	10^{-5}	10^{-6}
X	10^{-4}	10^{-5}

Solar Flare Statistics

$dN/dW \propto W^{-1.7}$

- Largest flare recorded:
- Peak luminosity ~ 2×10^{29} erg/s
- Total energy ~ 3×10^{31} erg

Extrapolating from one X14 flare/yr:

- 10^{32} erg every 50 years
- 10^{35} erg every 10^{6} years
- 10^{38} erg flare once in 10^{12} years

Effects of large solar flares

- Most of the radiation is in X- and γ-rays.
- Ionizing radiation is absorbed in Earth's atmosphere
- X- and γ-rays can ionize metal in spacecraft and cause electrical shorts
- X- and γ-rays can kill unprotected astronauts
- UV radiation can destroy ozone

How Big Can Solar Flares Get?

Schaefer et al (2000, ApJ 529, 1026) report 9 **superflares** in solar-like stars

- Luminosities > 10^{33} ergs, to 10^{38} ergs
- 10^{36} erg flare destroys 80% of ozone layer
- 10^{38} erg flare melts ice caps

Extrapolated superflare rate ~ 1/millenium

But Wait - There's More

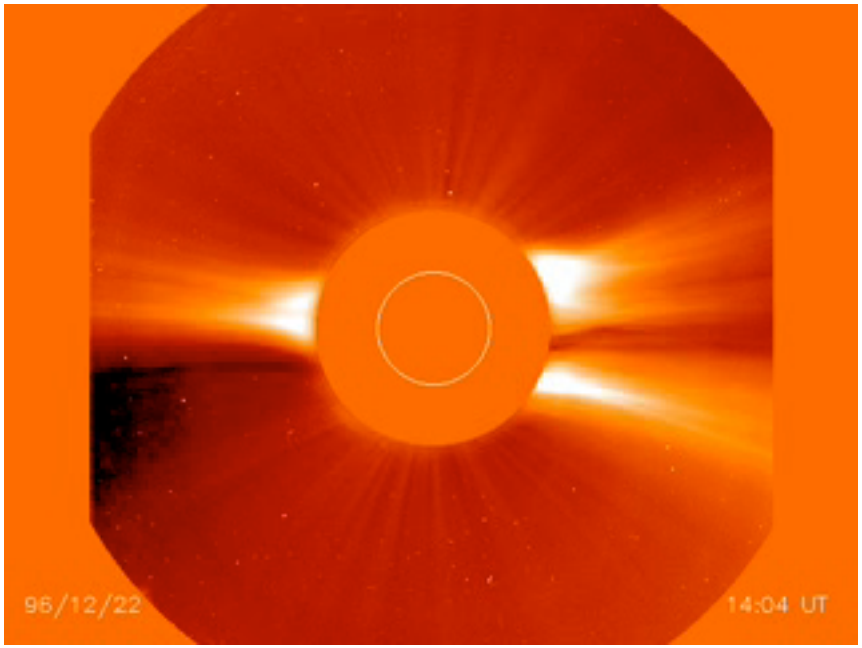
Solar Flares often generate

Coronal Mass Ejections,

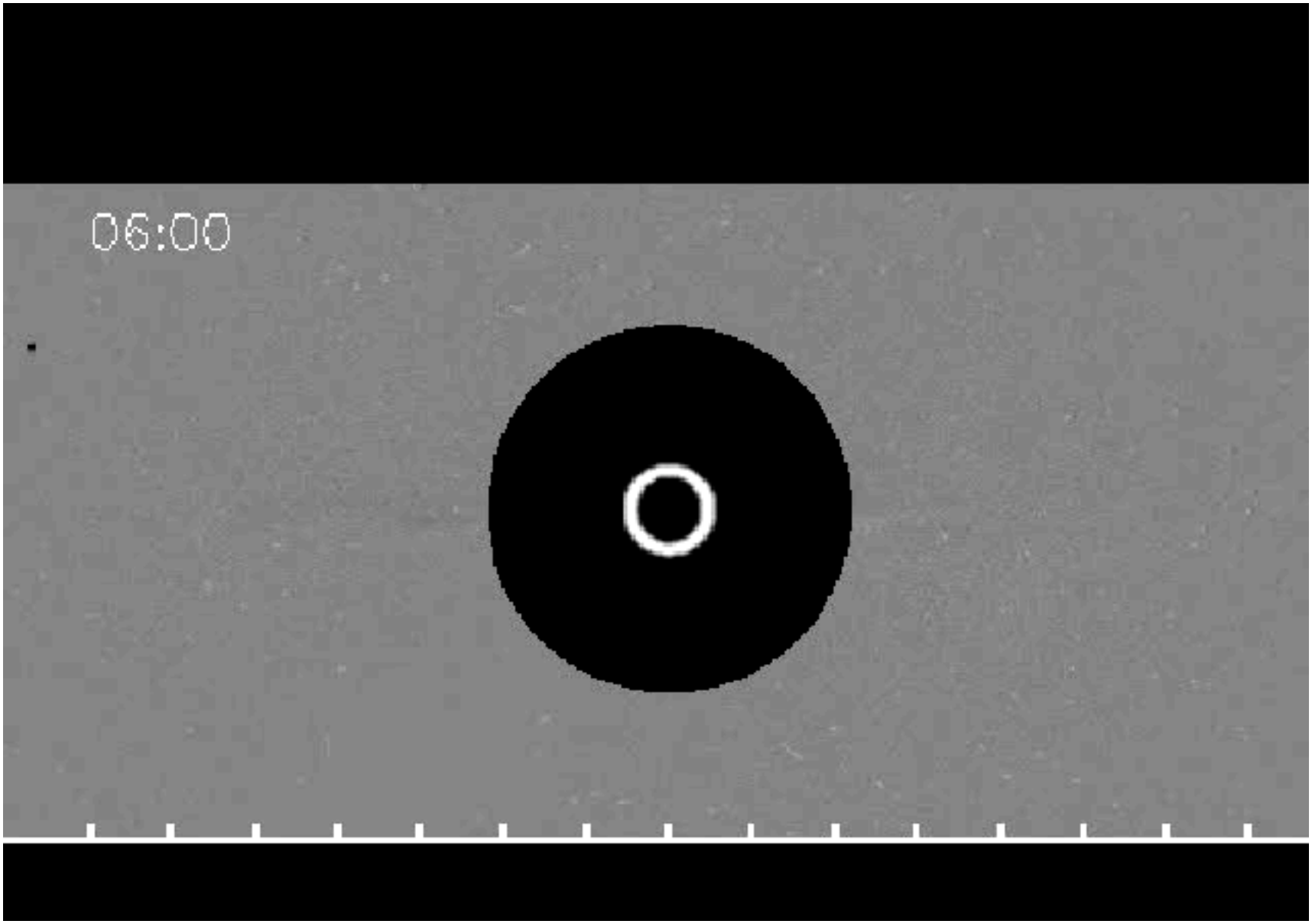
outflows of charged particles.

- ~10^{11} kg of material
- V ~ 10^3 km/s

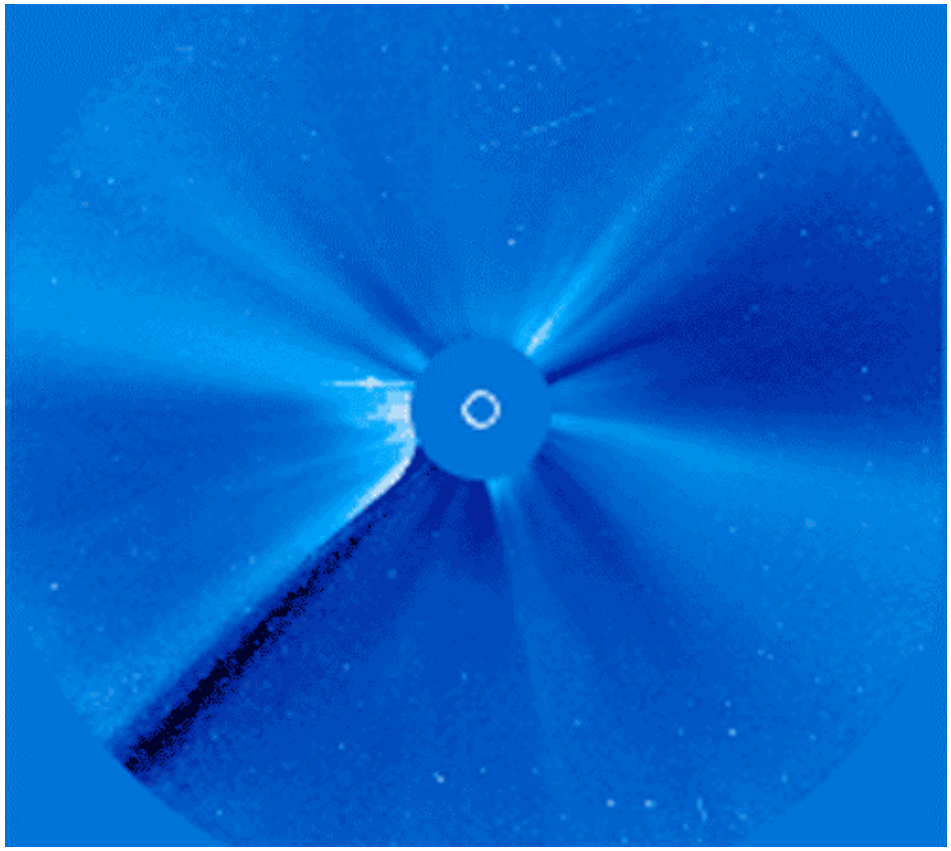
Coronal Mass Ejections



Coronal Mass Ejections



Coronal Mass Ejections

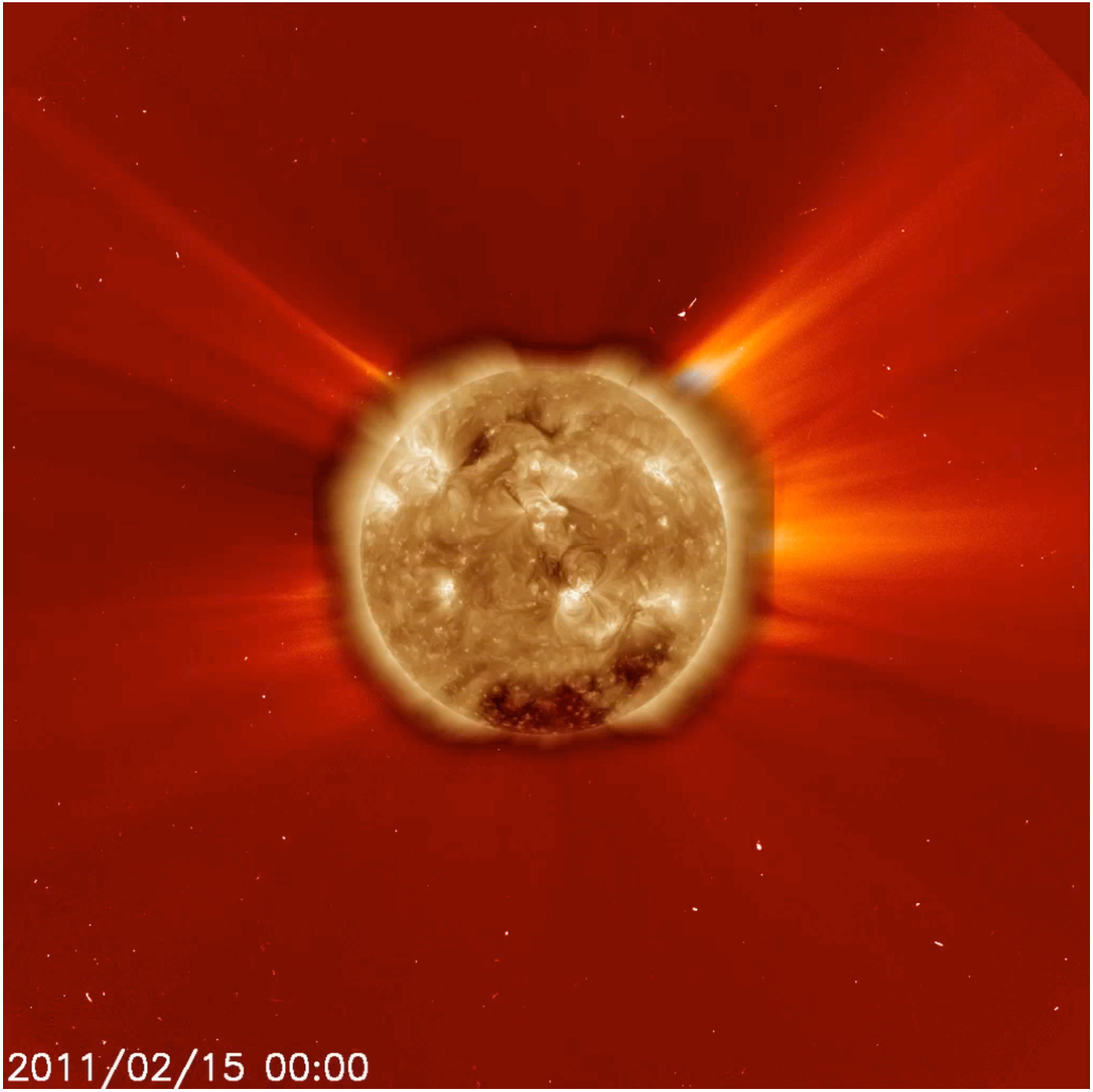


Effects of Coronal Mass Ejections

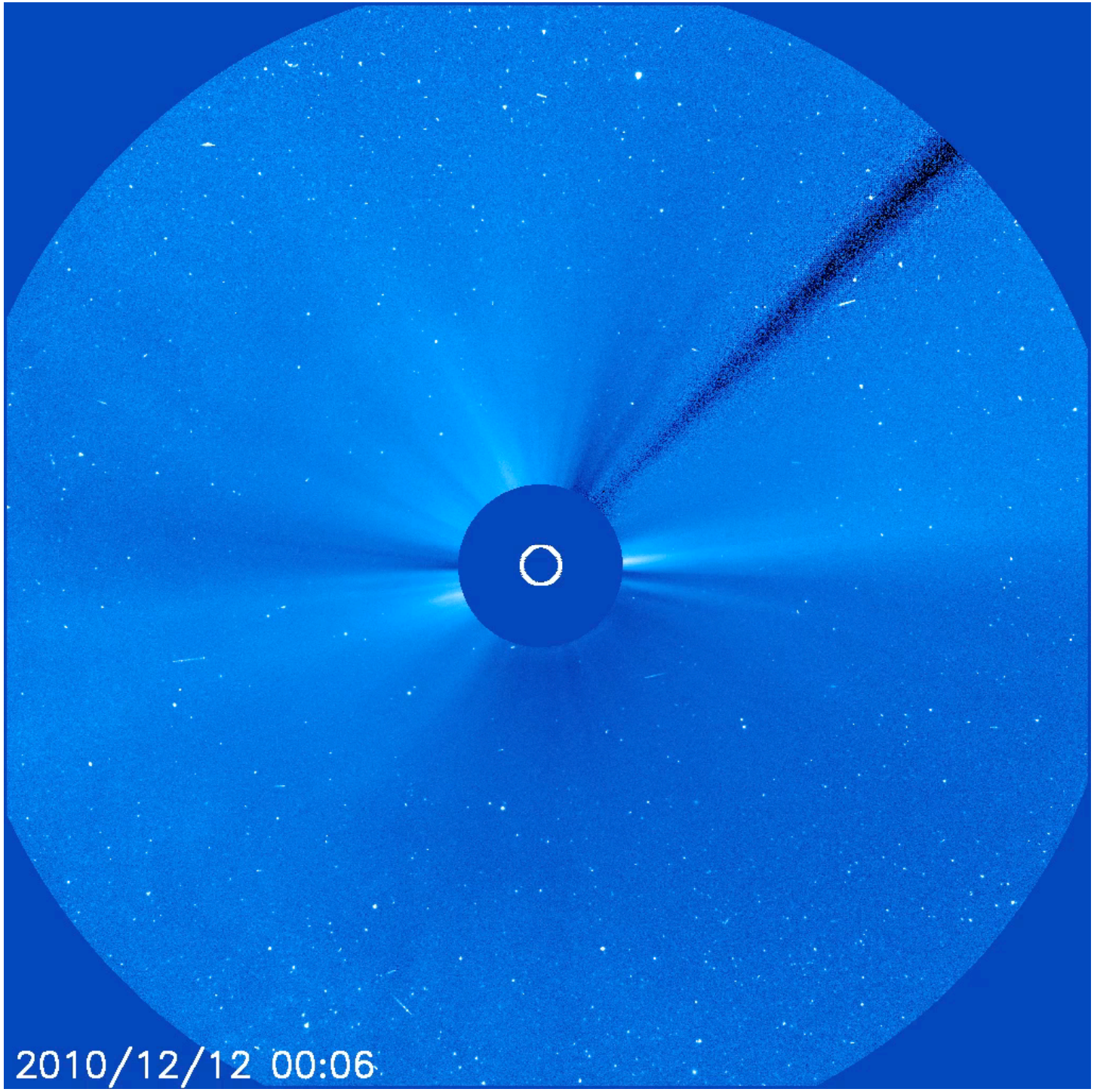
Charged particles disrupt Earth's magnetic field

- Set up voltage gradient
- Can cause current surges
- Can bring down the power grid
- Can burn out transformers
- Disrupts the ionosphere
- Fries satellites

SOHO flare and CME



SOHO CME

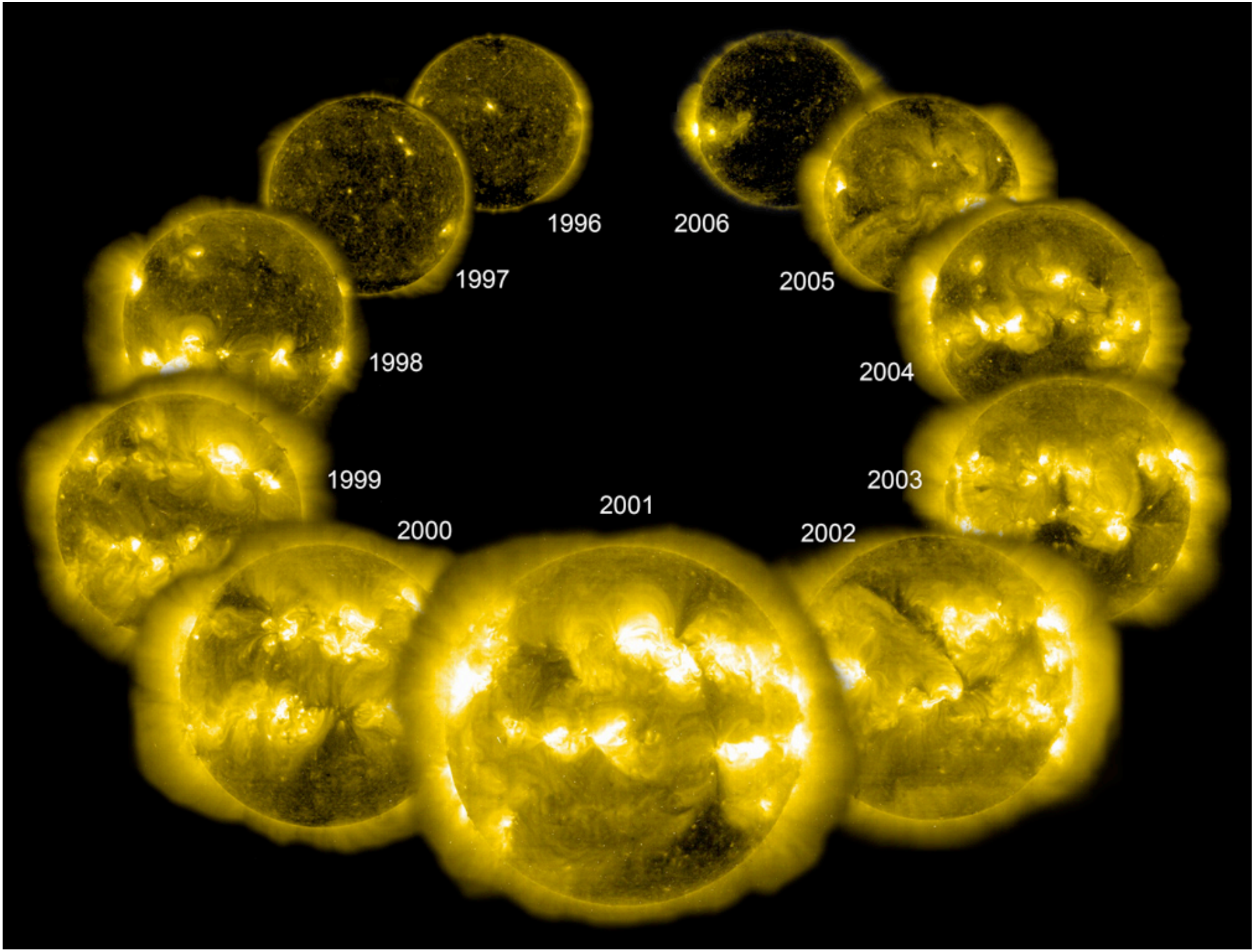


More Pictures and References

- Solar Data Analysis Center (SDAC): http://umbra.nascom.nasa.gov/
  includes links to SOHO, SDO, HINODE, and YOHKOH

Other Solar Missions:

- STEREO: http://www.nasa.gov/mission_pages/stereo/main/index.html
- TRACE: http://trace.lmsal.com/


1996
2006
1997
2005
1998
2004
1999
2003
2001
2000
2002

The Magnetic Cycle

Spot cycle ~11 years
Magnetic cycle ~22 yrs