The Sun

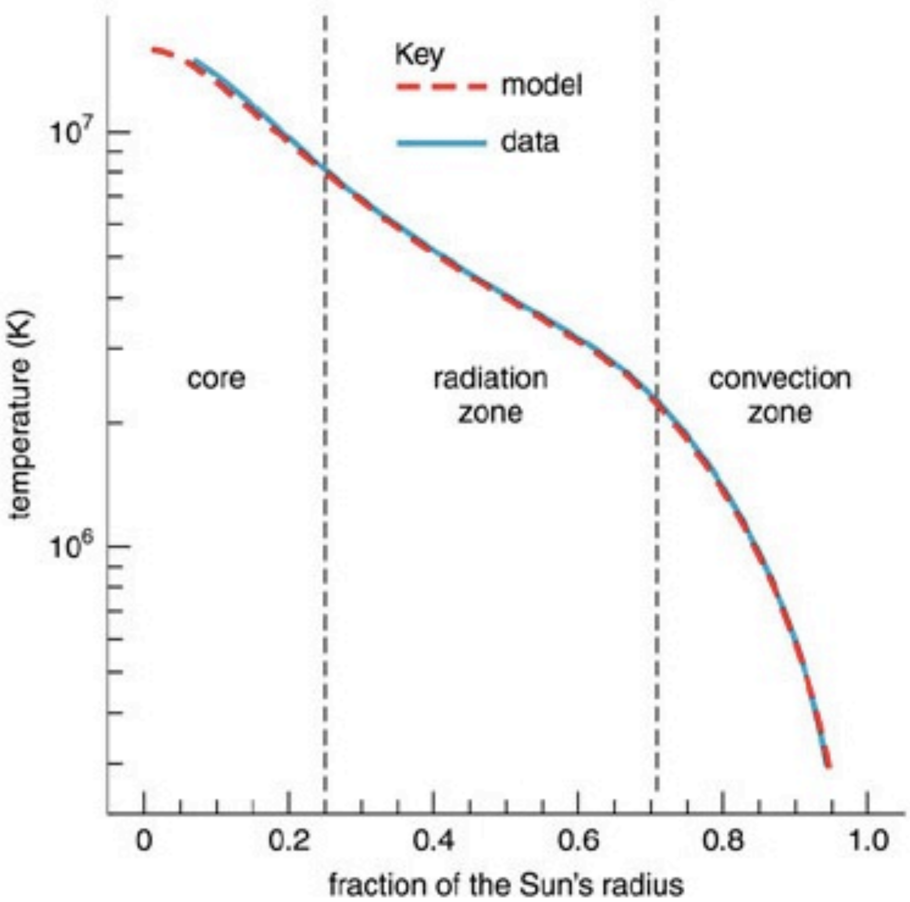
Table 15.1 Basic Properties of the Sun

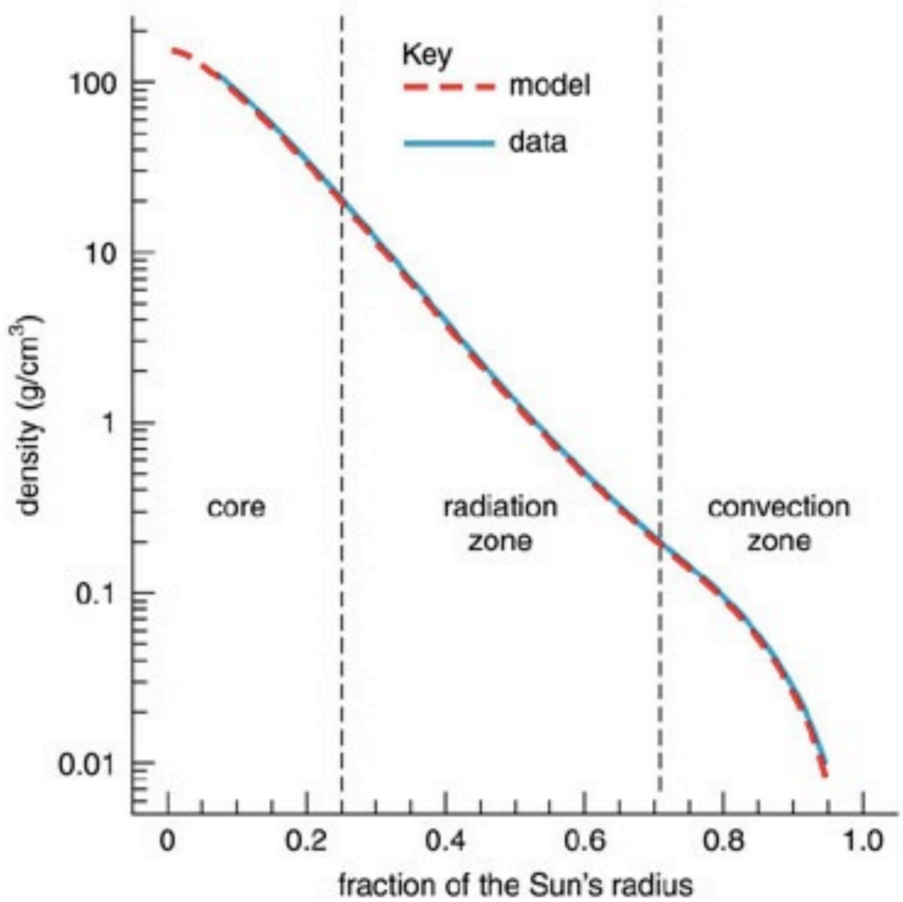
Radius (R_{Sun})	696,000 km (about 109 times the radius of Earth)
Mass (M_{Sun})	2×10^{30} kg (about 300,000 times the mass of Earth)
Luminosity (L_{Sun})	3.8×10^{26} watts
Composition (by percentage of mass)	70% hydrogen, 28% helium, 2% heavier elements
Rotation rate	27 days (equator) to 31 days (poles)
Surface temperature	5,800 K (average); 4,000 K (sunspots)
Core temperature	15 million K

Solar Structure

- Core
- Radiative zone
- Convective zone
- Atmosphere
  - Photosphere
  - Chromosphere
  - Corona
- Solar wind (mass loss)

Conditions Inside the Sun

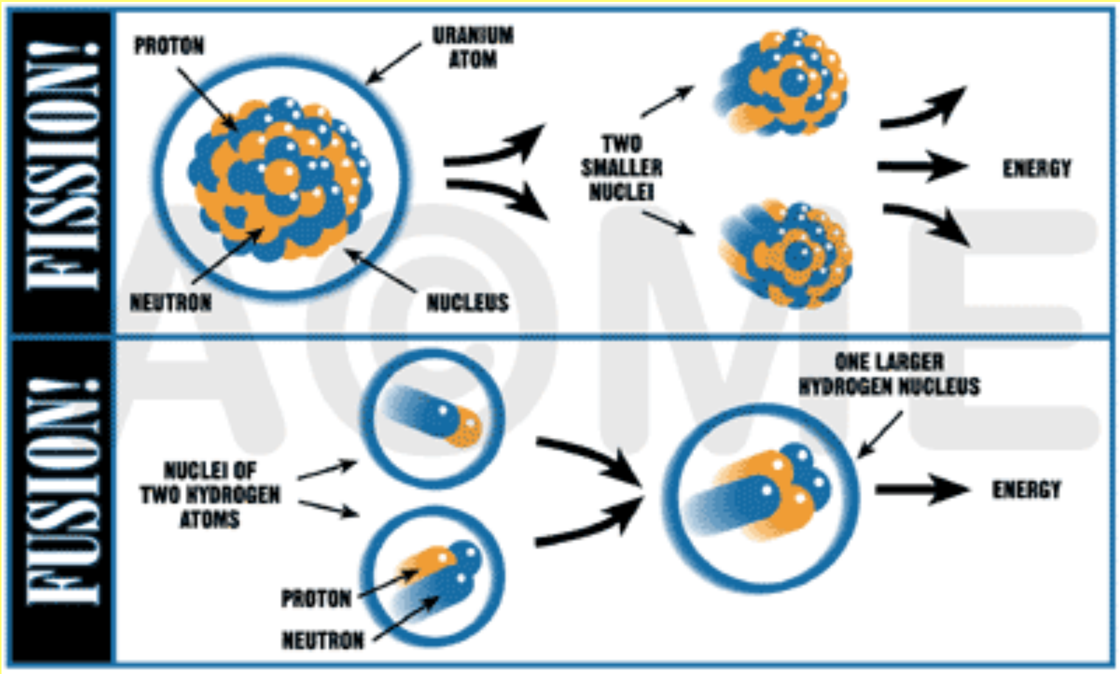




Solar Power

Sun's glow fueled by *Nuclear Fusion*

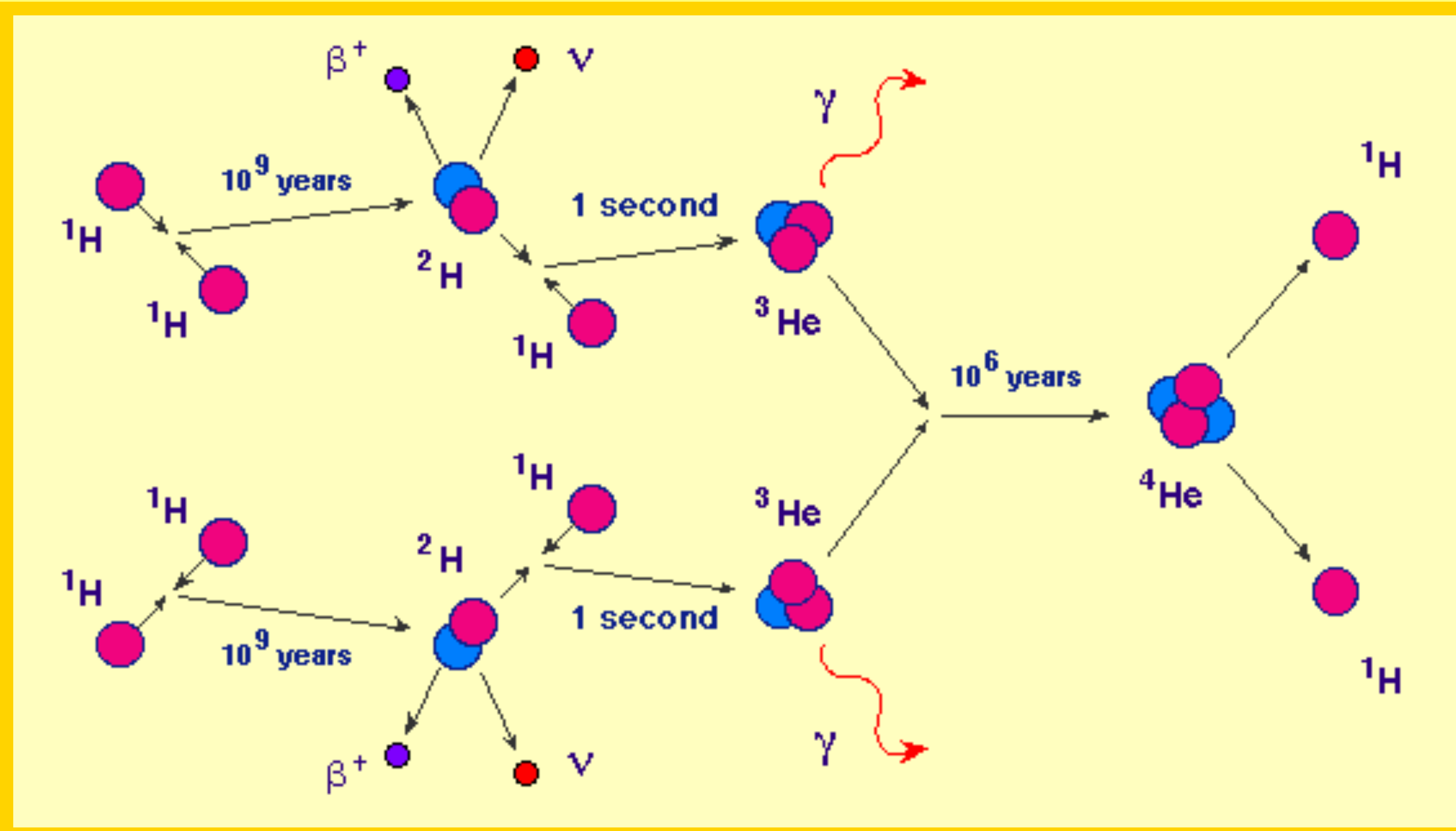
- **Fusion** is a process by which lighter atoms undergo "collisions" that spawn heavier atoms and a release of energy for radiation
- **Fission**, on the other hand, is when a heavy atom "breaks up" to yield a lighter atom plus energy



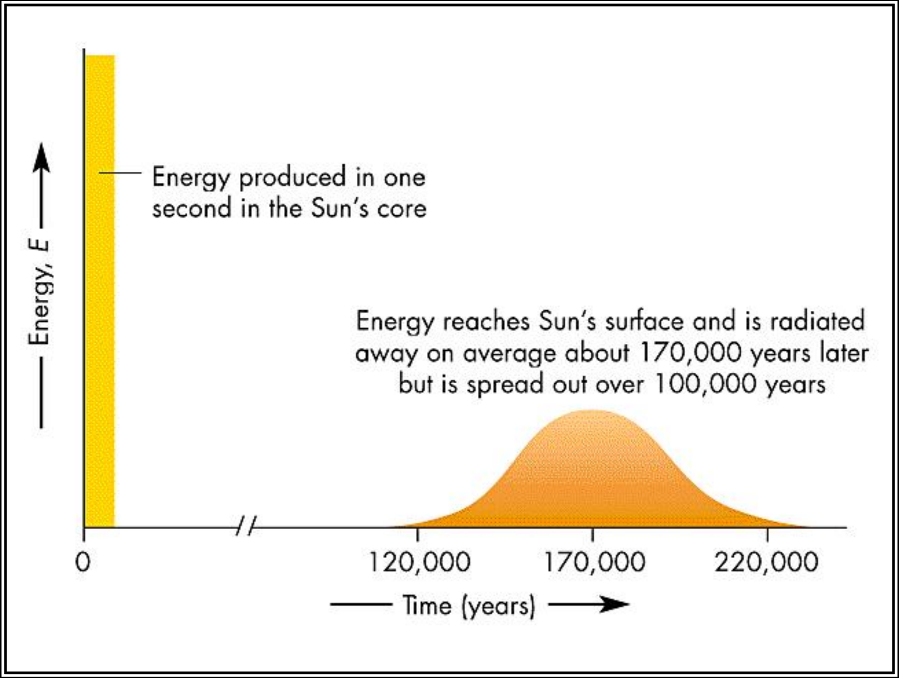
Proton-Proton Chain

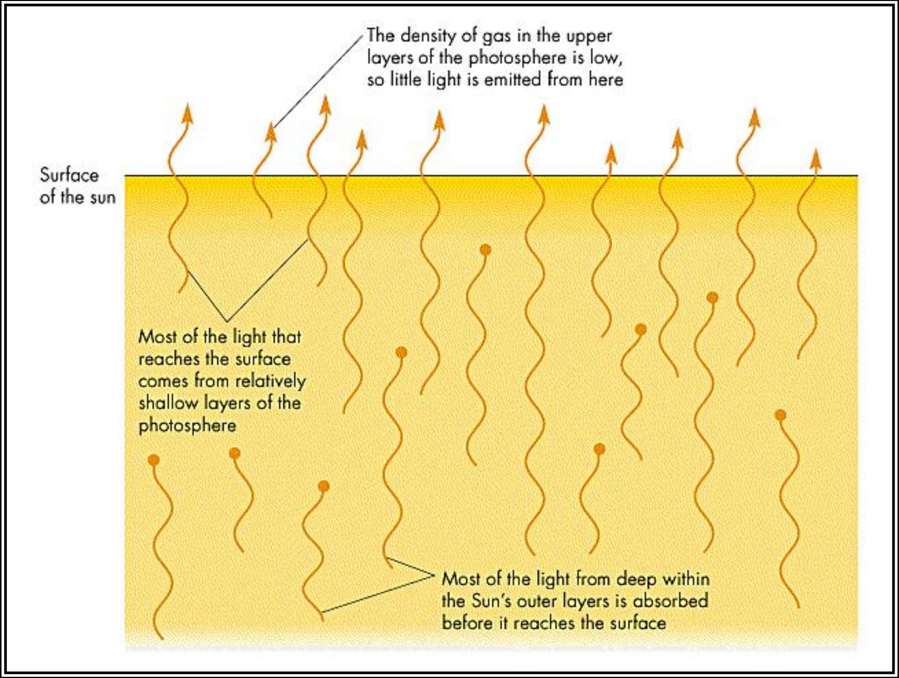
- p-p chain converts 4 ^{1}H into 1 ^{4}He
  (so 4 bare protons combine to make a helium nucleus with 2p's and 2n's)
- Also get photons and neutrinos in this process
- Neutrinos are (nearly) massless particles traveling near light speeds and interacting only weakly with matter

The Chain



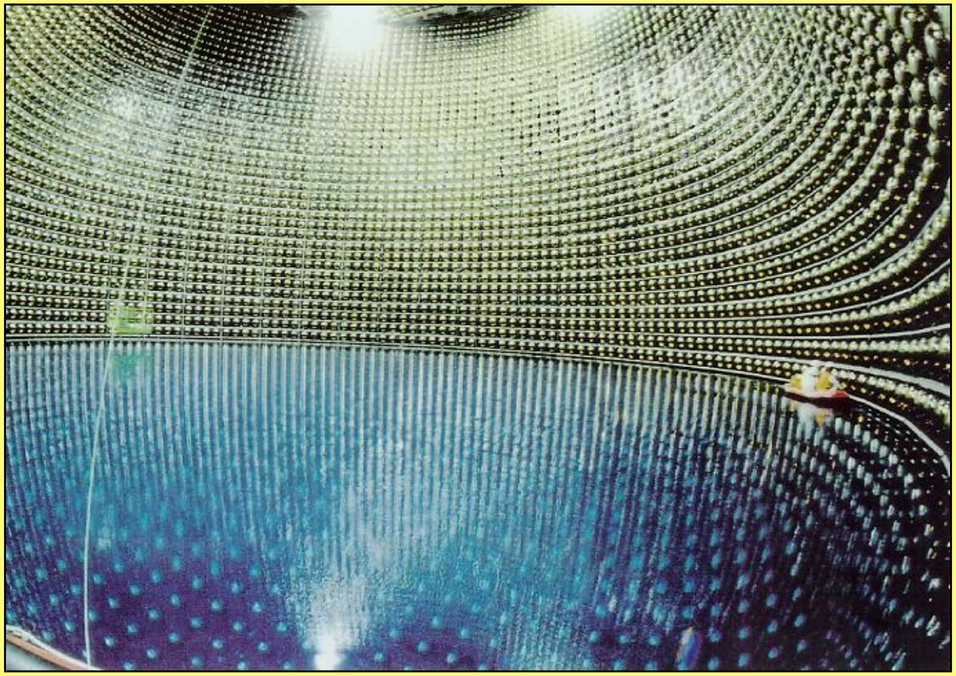
Emergence of Light from the Core





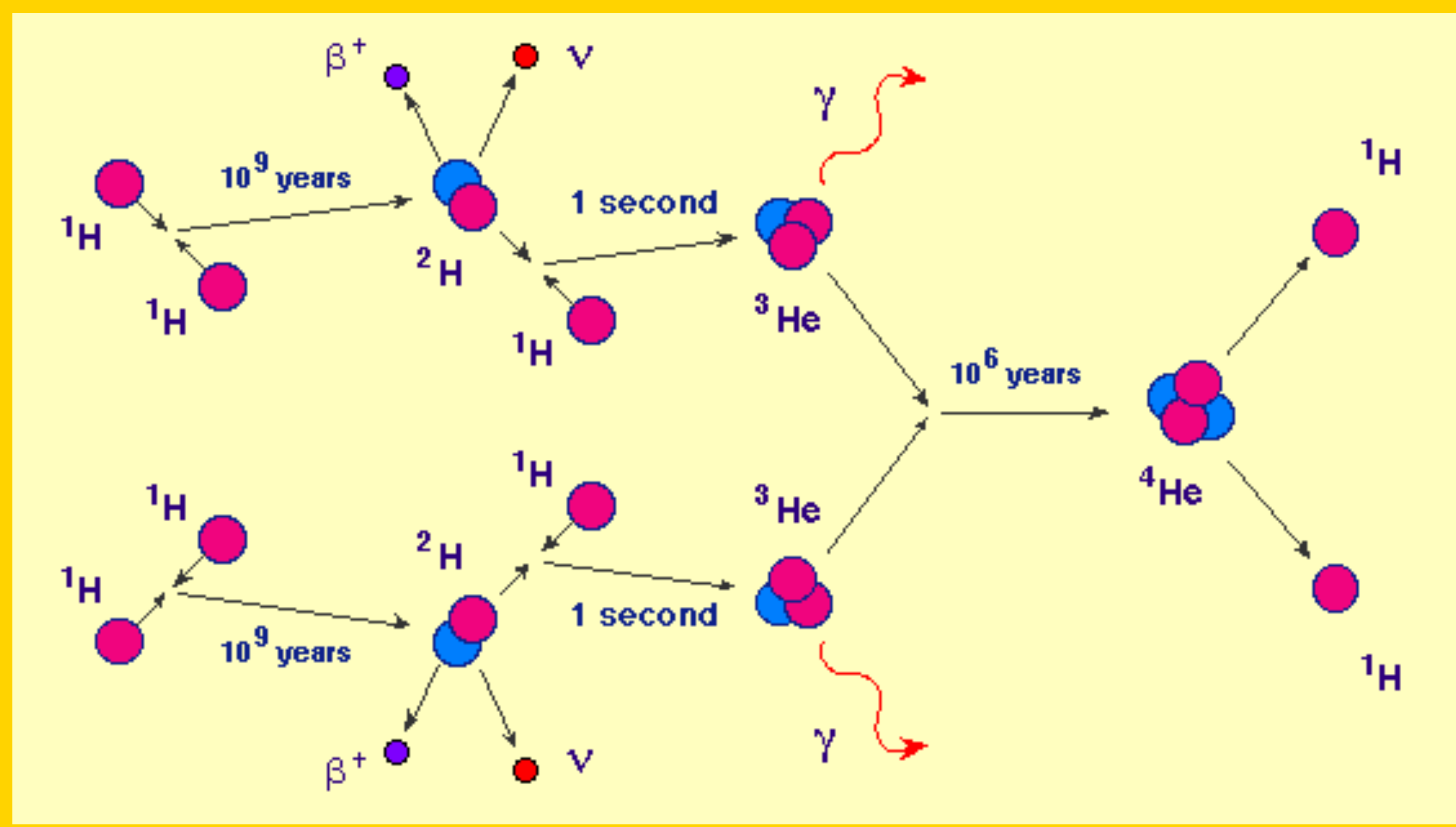
Solar Neutrinos

- Neutrinos are elementary particles moving near light speed, but which interact only weakly with matter.
- They are important because they can come from nuclear reactions to emerge directly from the core of the Sun.
- Raymond Davis arranged for the first neutrino experiment. He discovered a "neutrino problem", but this has now been resolved.



A modern neutrino experiment, Super-Kamiokande run by Japan

The Chain

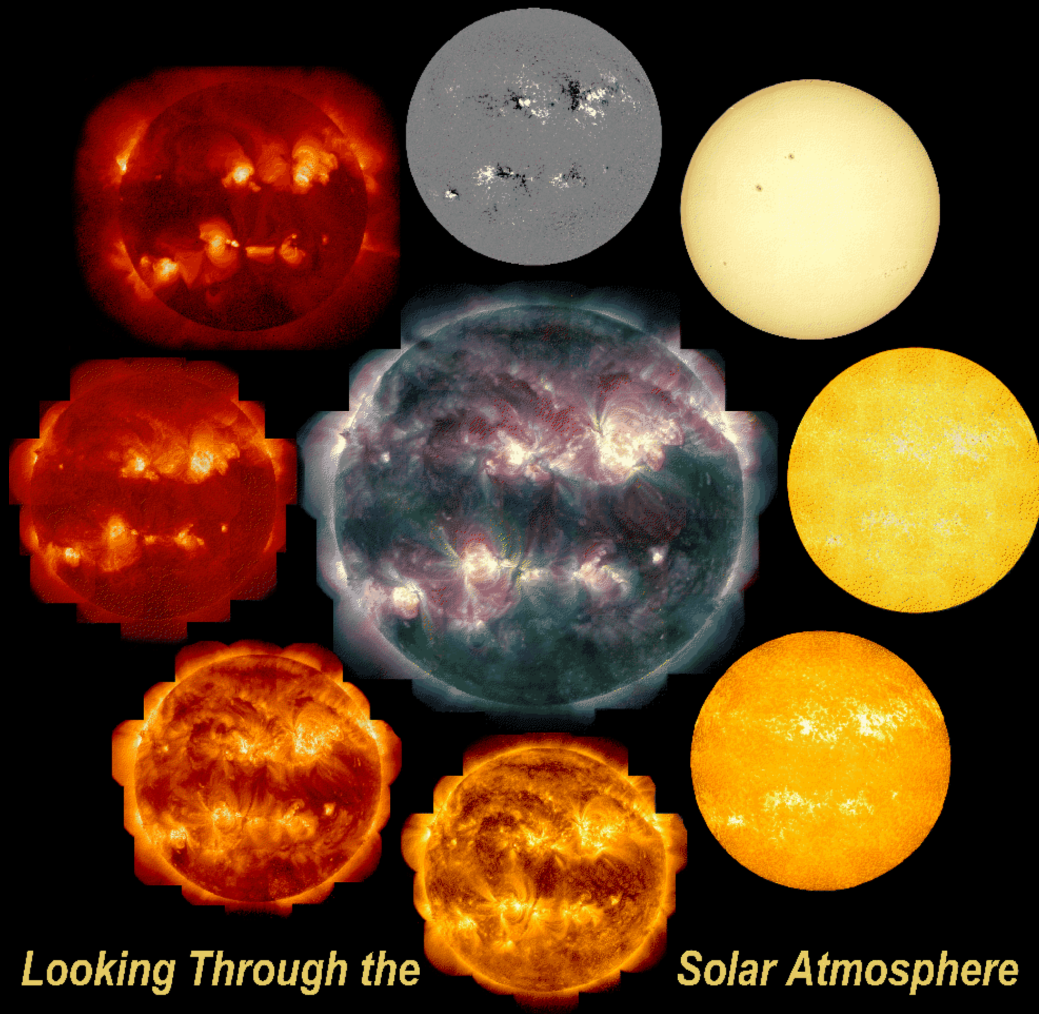


β+
ν
γ
1H
10 9 years
2H
1 second
3He
1H
1H
1H
10 6 years
4He
1H
1H
1H
1H
2H
3He
1H
10 9 years
1 second
β+
ν
γ
1H

<u>Solar Atmosphere</u>

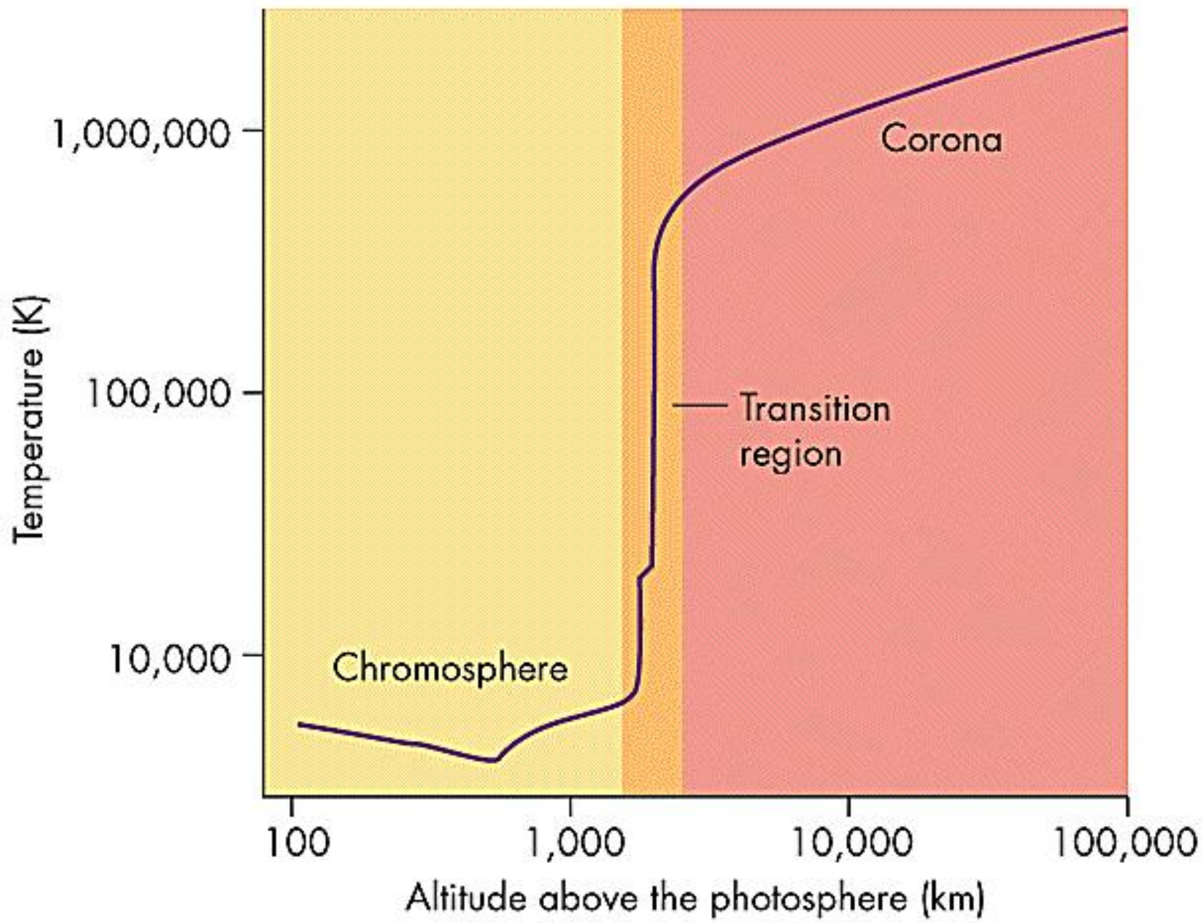
- Photosphere: the layer that we "see" in visible light
- Chromosphere: tenuous, somewhat hotter layer above photosphere
- Corona: extended region of million degree gas above chromosphere extending into space and the solar wind

Perspectives of the Sun



A Solar Eclipse

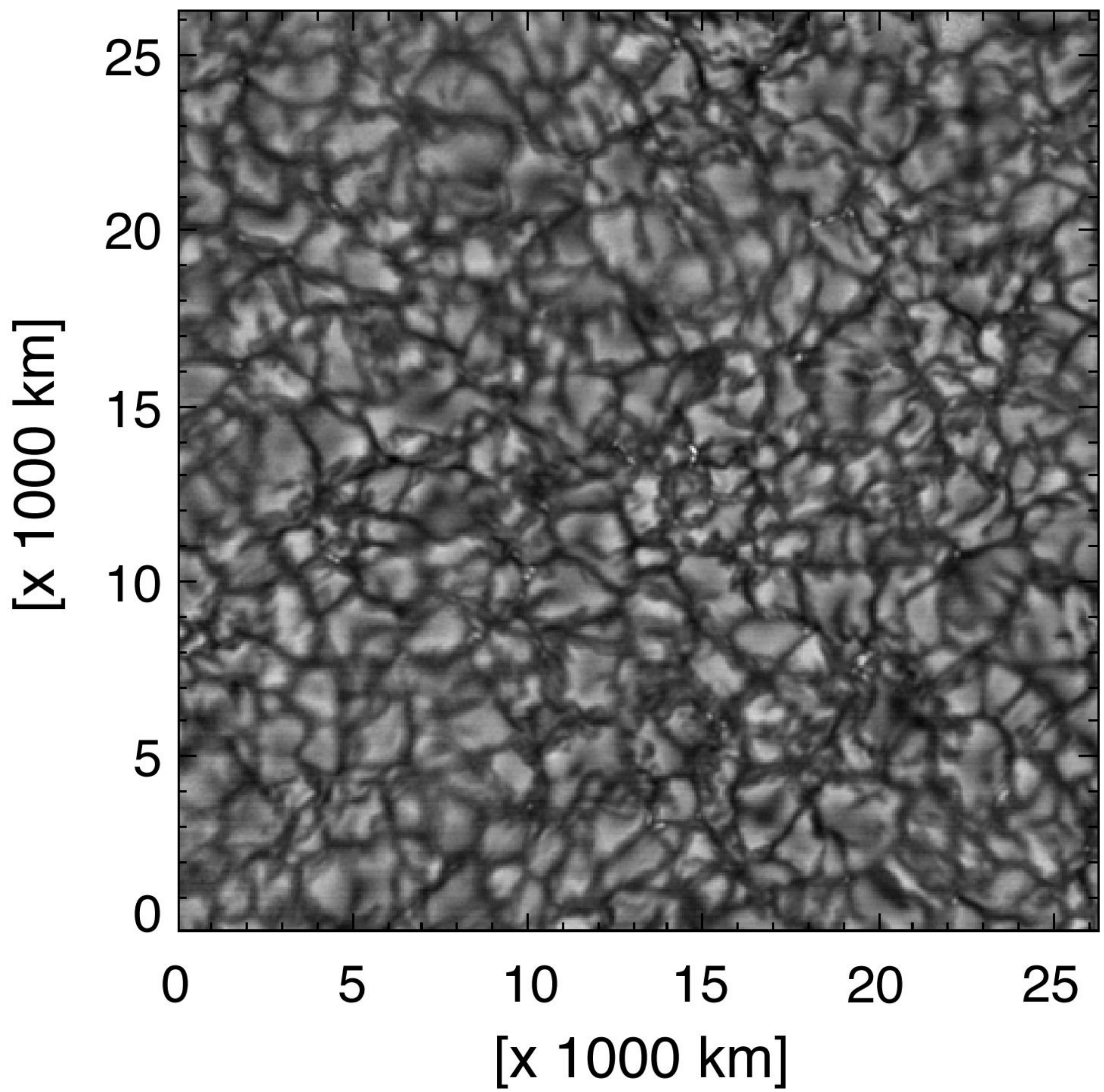
The Transition Region

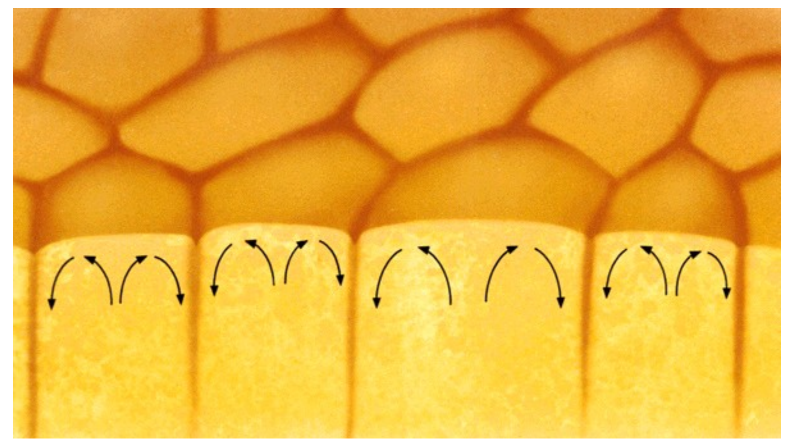


Solar Activity

- Sunspots – cool blemishes that come and go on an 11 year cycle
  - During cycle, spots initially appear at high latitudes and thereafter at progressively lower lats.
- Prominences – extended columns of gas that trace out magnetic loops (can rise to 50,000 km above photosphere)
- Flares – explosive and energetic events involving hot gas of up to 40 million K

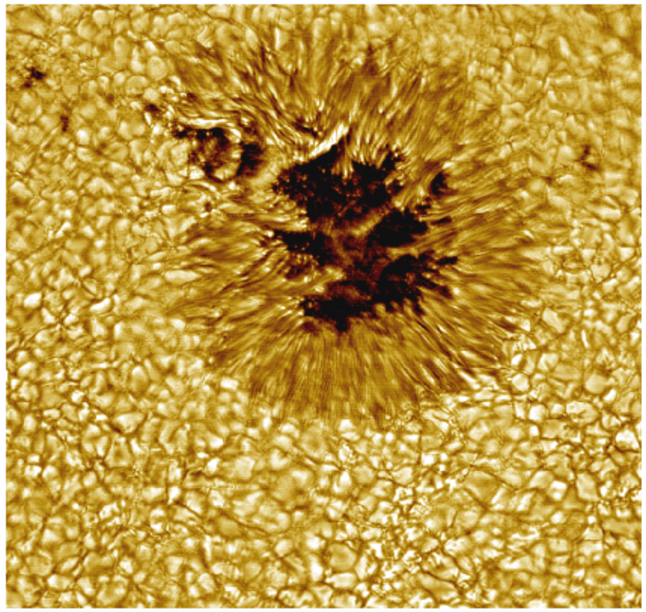
Solar Granulation - Convective Cells





Sunspots

NSO/Sac Peak Hosts High Resolution Solar Physics Workshop 9/28-10/2, 1998

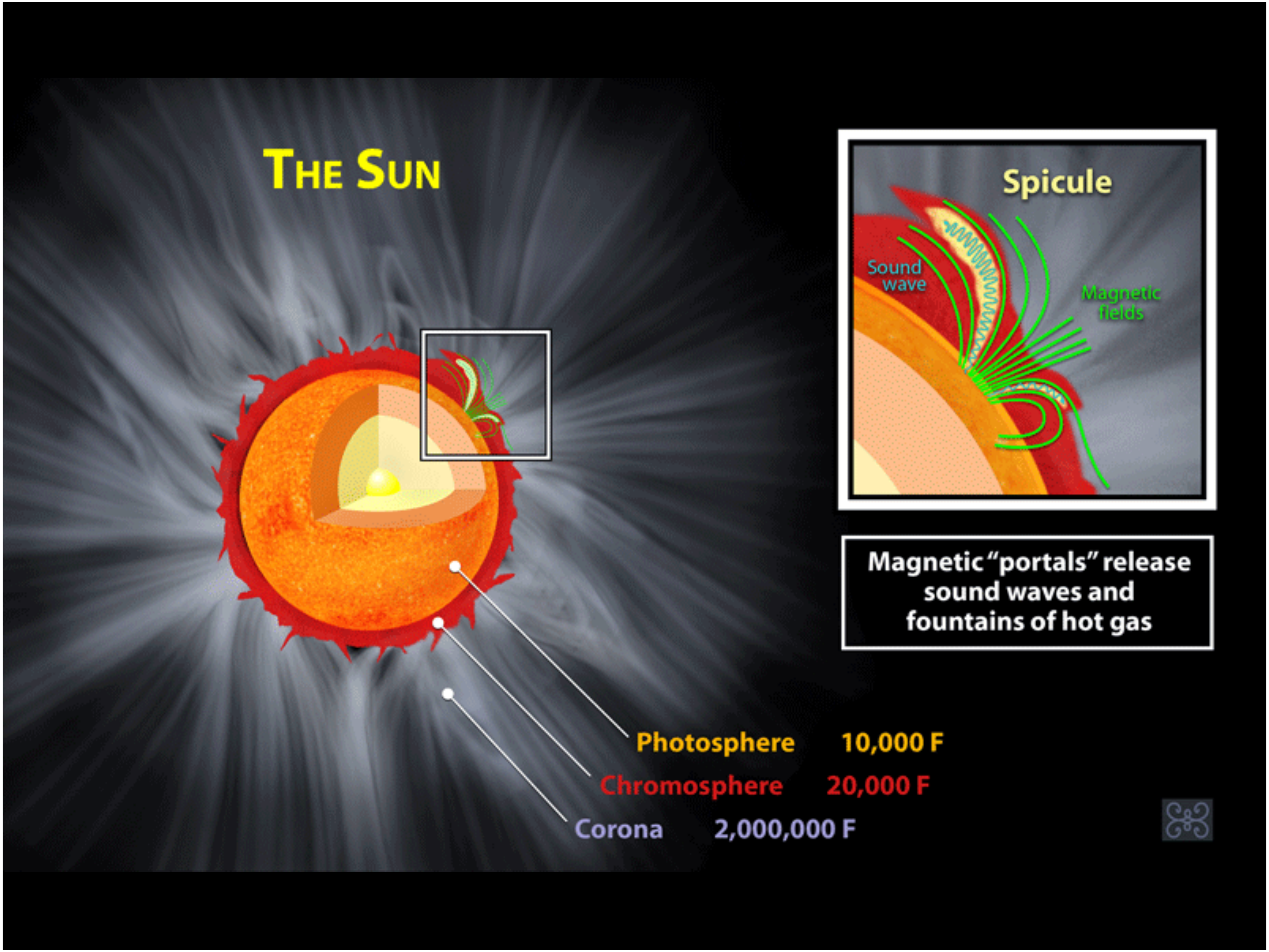


This sunspot from the NSO Sacramento Peak Vacuum Tower Telescope, showing features on the scale of about 100 km, is representative of the images and results to be presented September 28 - October 2, 1998, at the 19th National Solar Observatory / Sacramento Peak Workshop on "High Resolution Solar Physics: Theory, Observations, and Techniques." The workshop is dedicated to Dr. Richard B. Dunn and the Vacuum Tower Telescope will be renamed in his honor during the workshop.

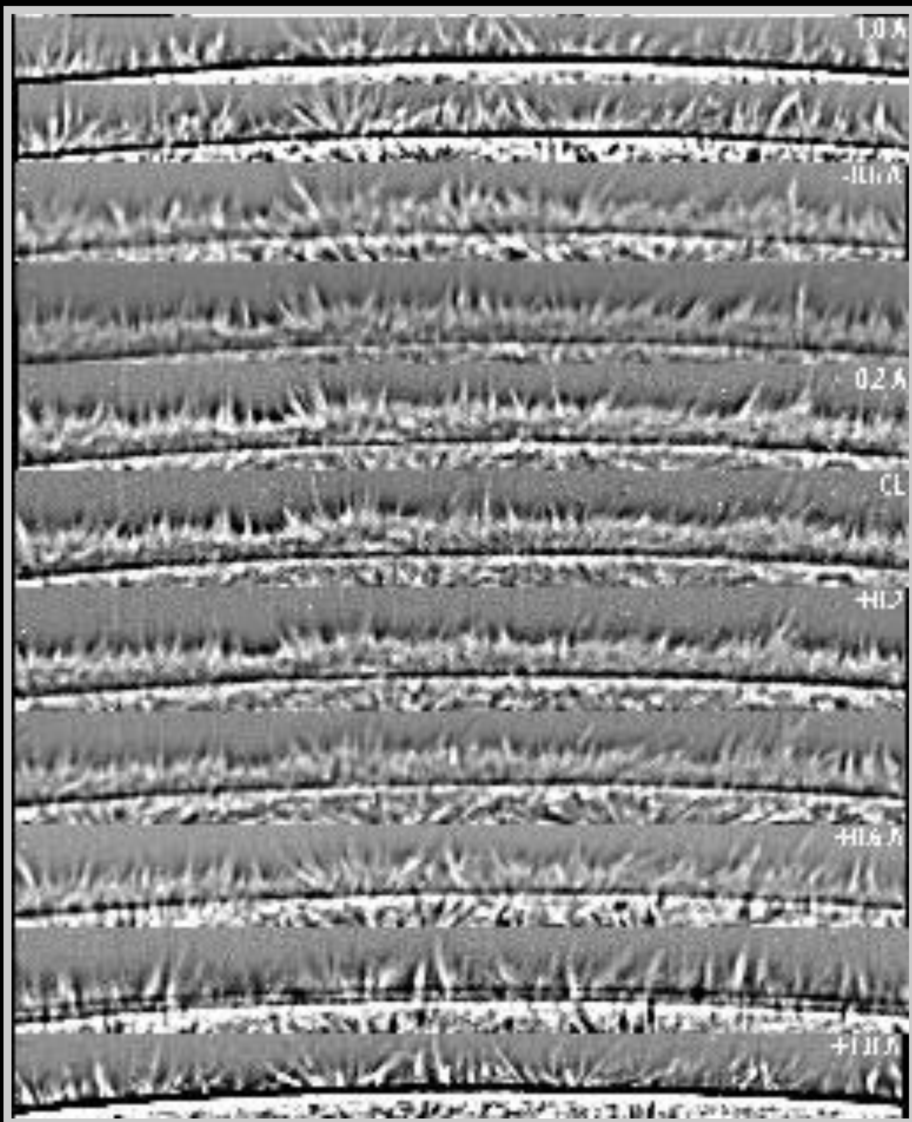
Attention Editors: A high-resolution version of this image can be obtained over the Internet via http://www.noao.edu/

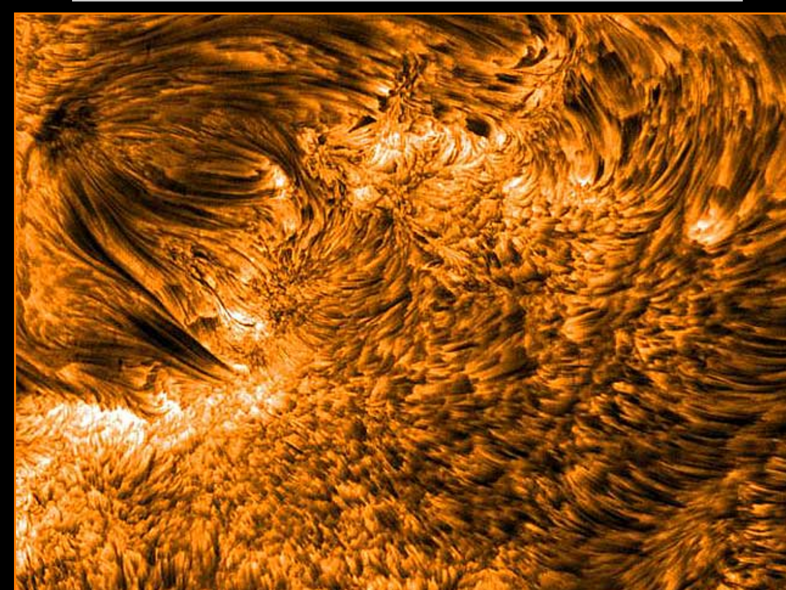
The National Optical Astronomy Observatories are operated for the National Science Foundation by the Association of Universities for Research in Astronomy.

NSF

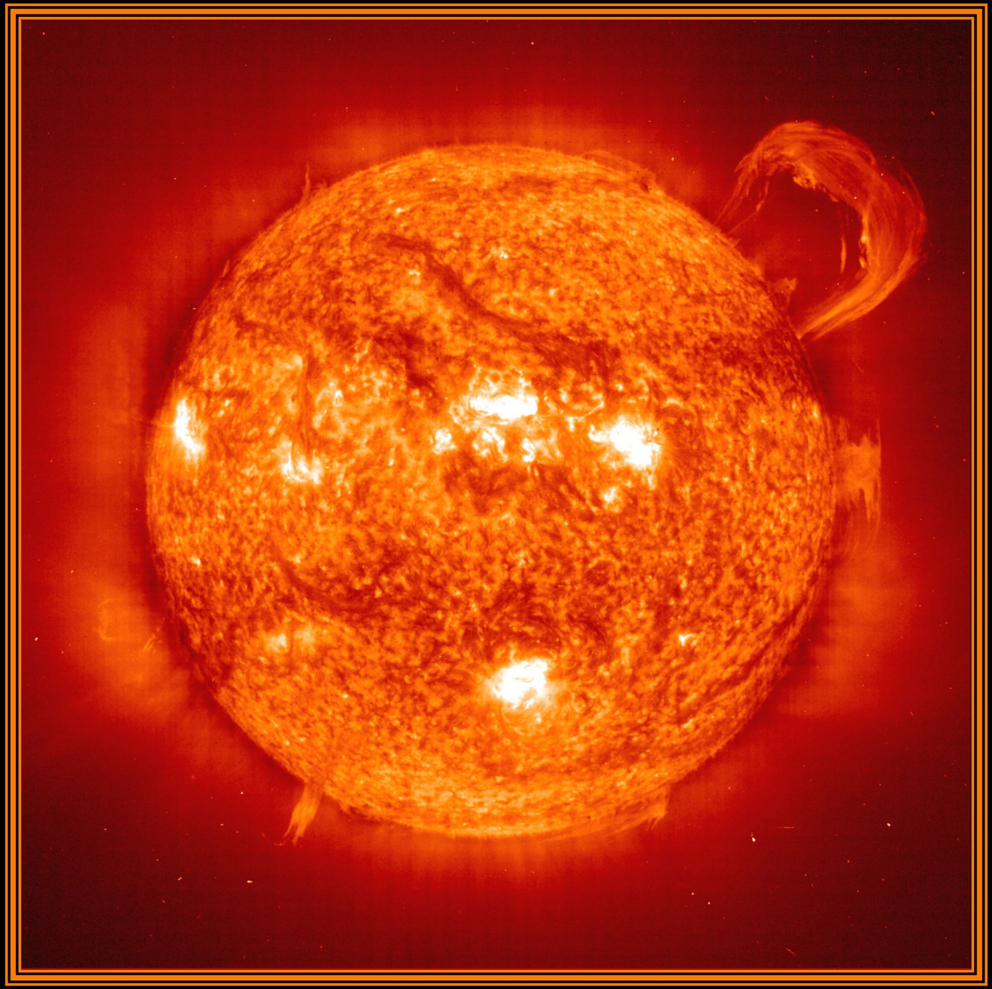

THE SUN
Spicule
Sound wave
Magnetic fields
Magnetic "portals" release sound waves and fountains of hot gas
Photosphere 10,000 F
Chromosphere 20,000 F
Corona 2,000,000 F

Spicules

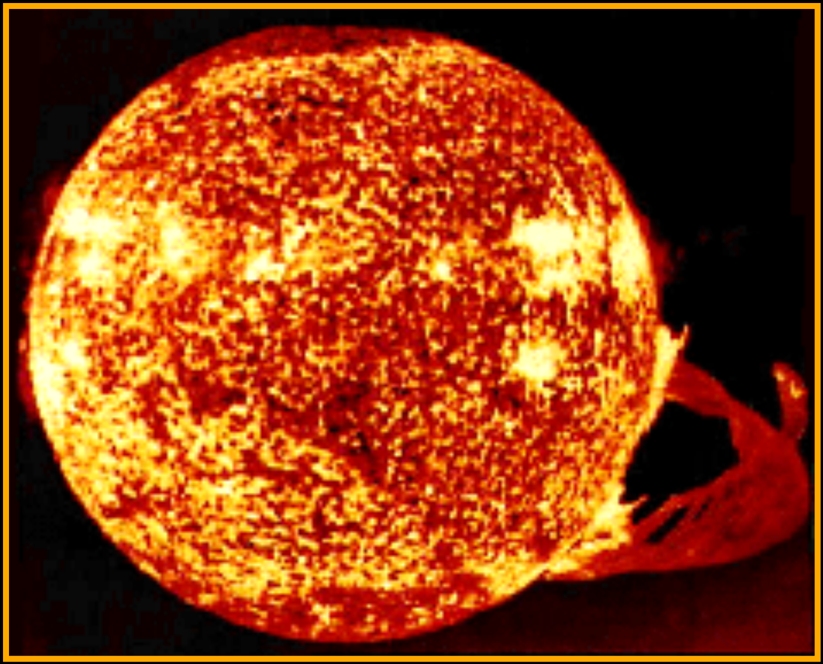


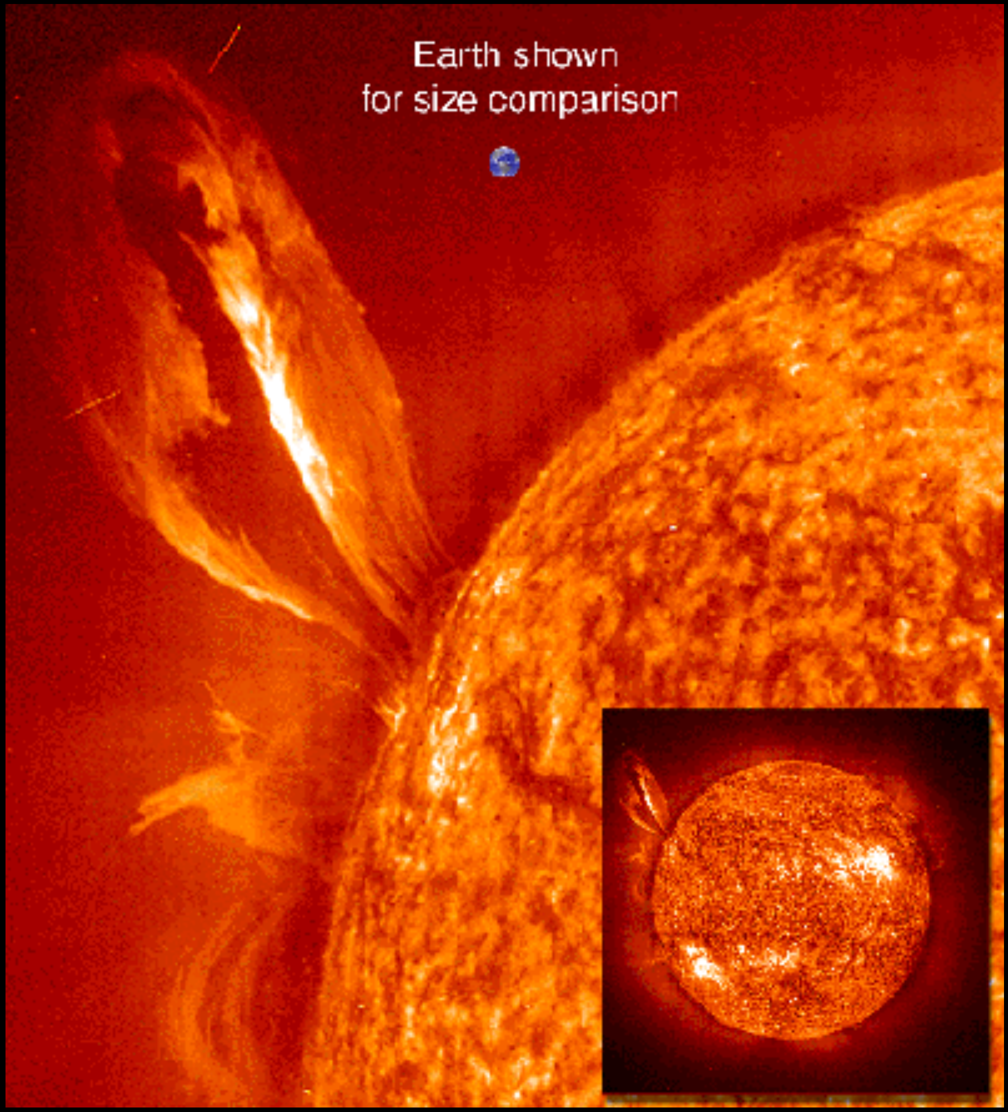


The Active Sun

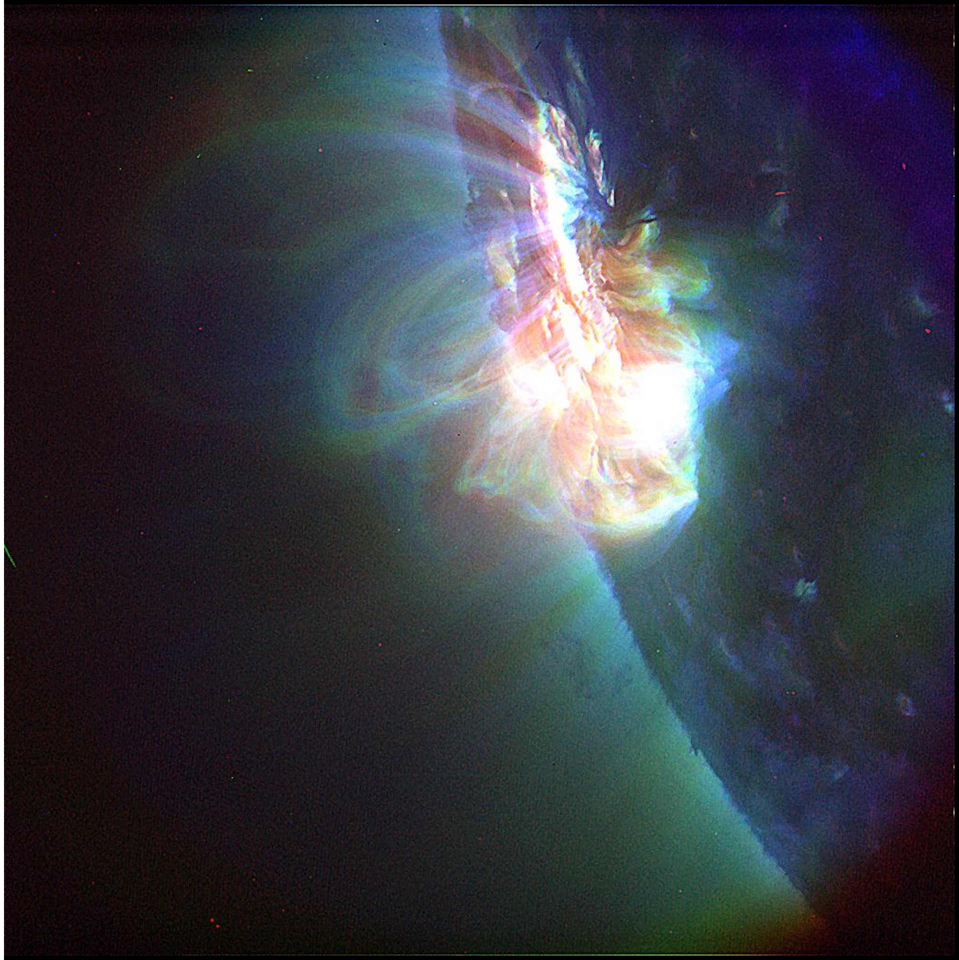


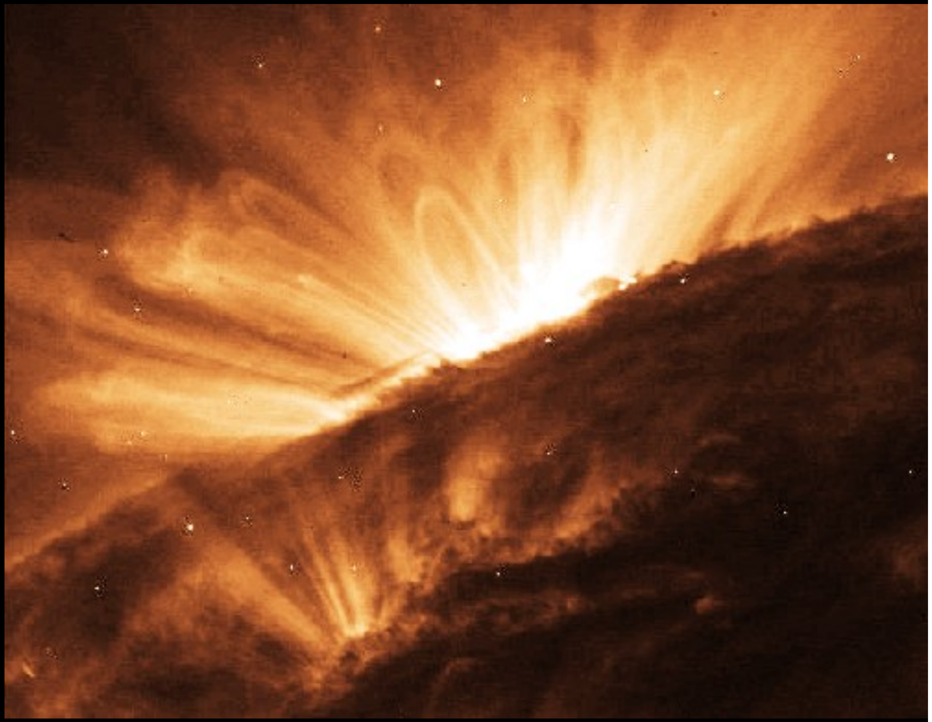
Prominences



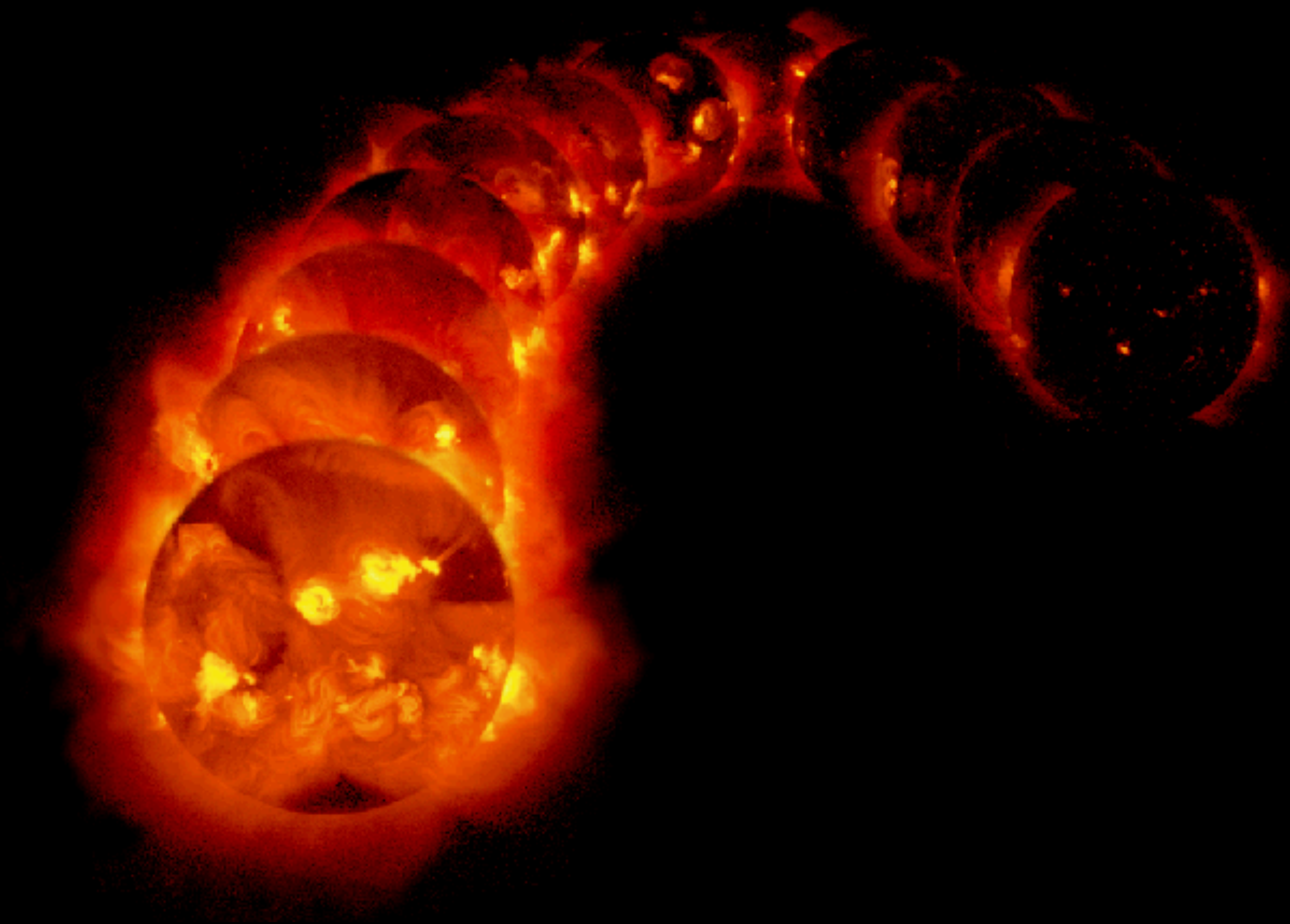


Magnetic Loops at the Sun



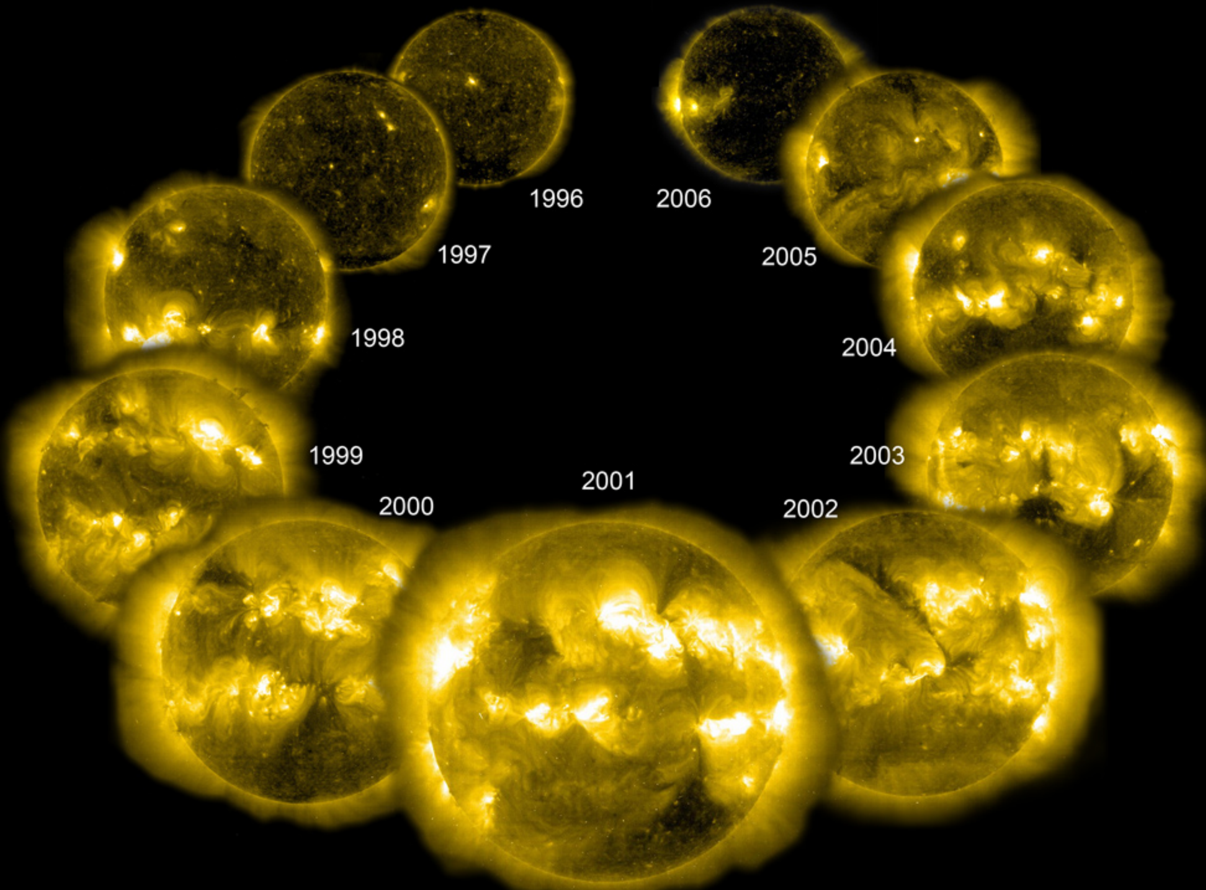


Solar Cycle in X-rays



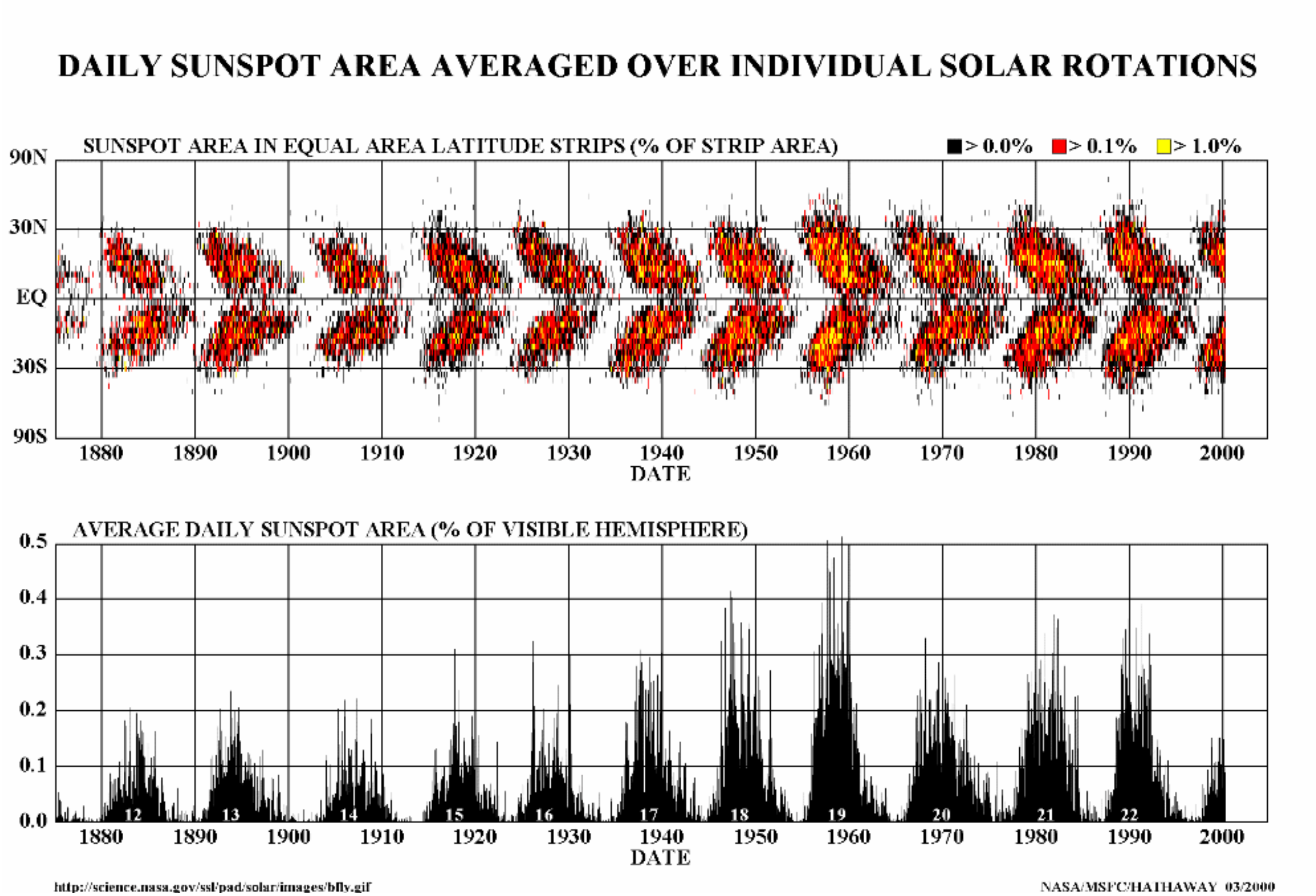
X-ray emission from the solar corona, taken every 120 days, from 1991 (left) to 1995 (going right)

Solar Cycle in the UV

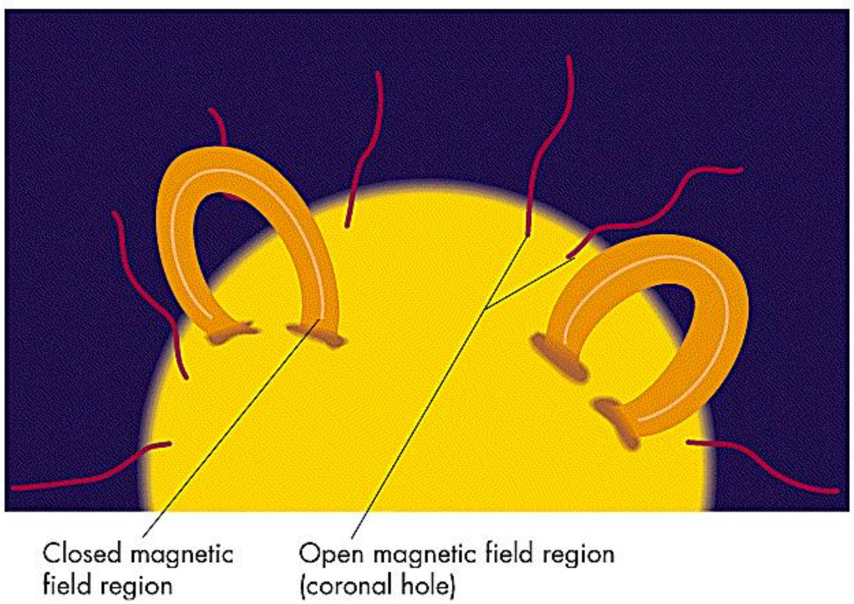


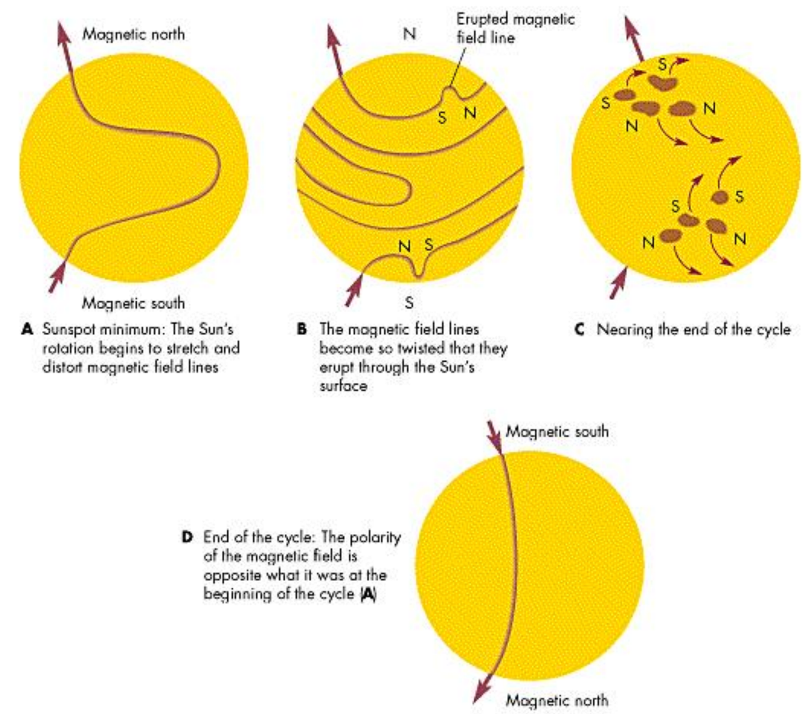
Images of the Sun in Extreme UV radiation

Butterfly Diagram

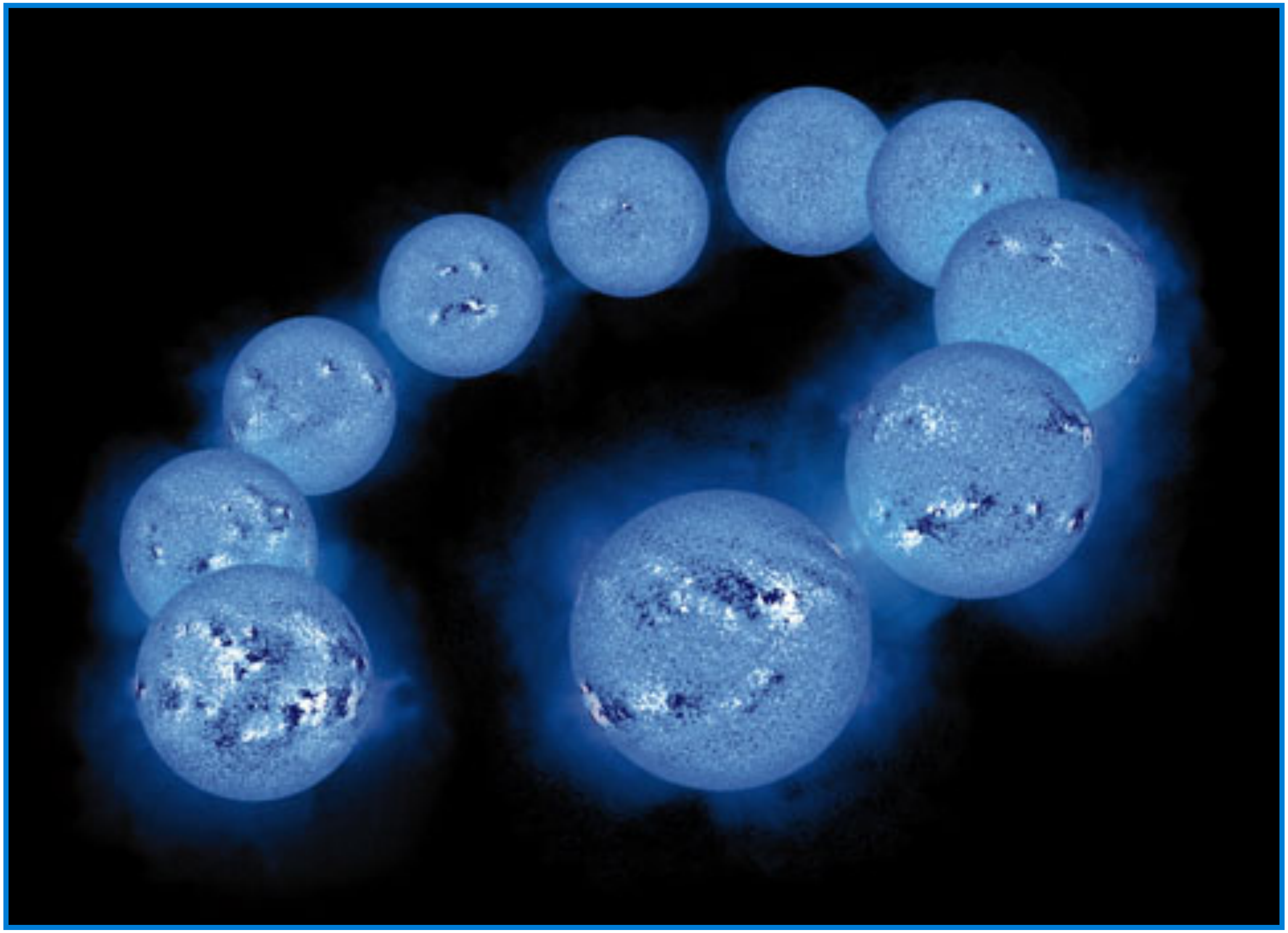


Understanding The Solar Cycle

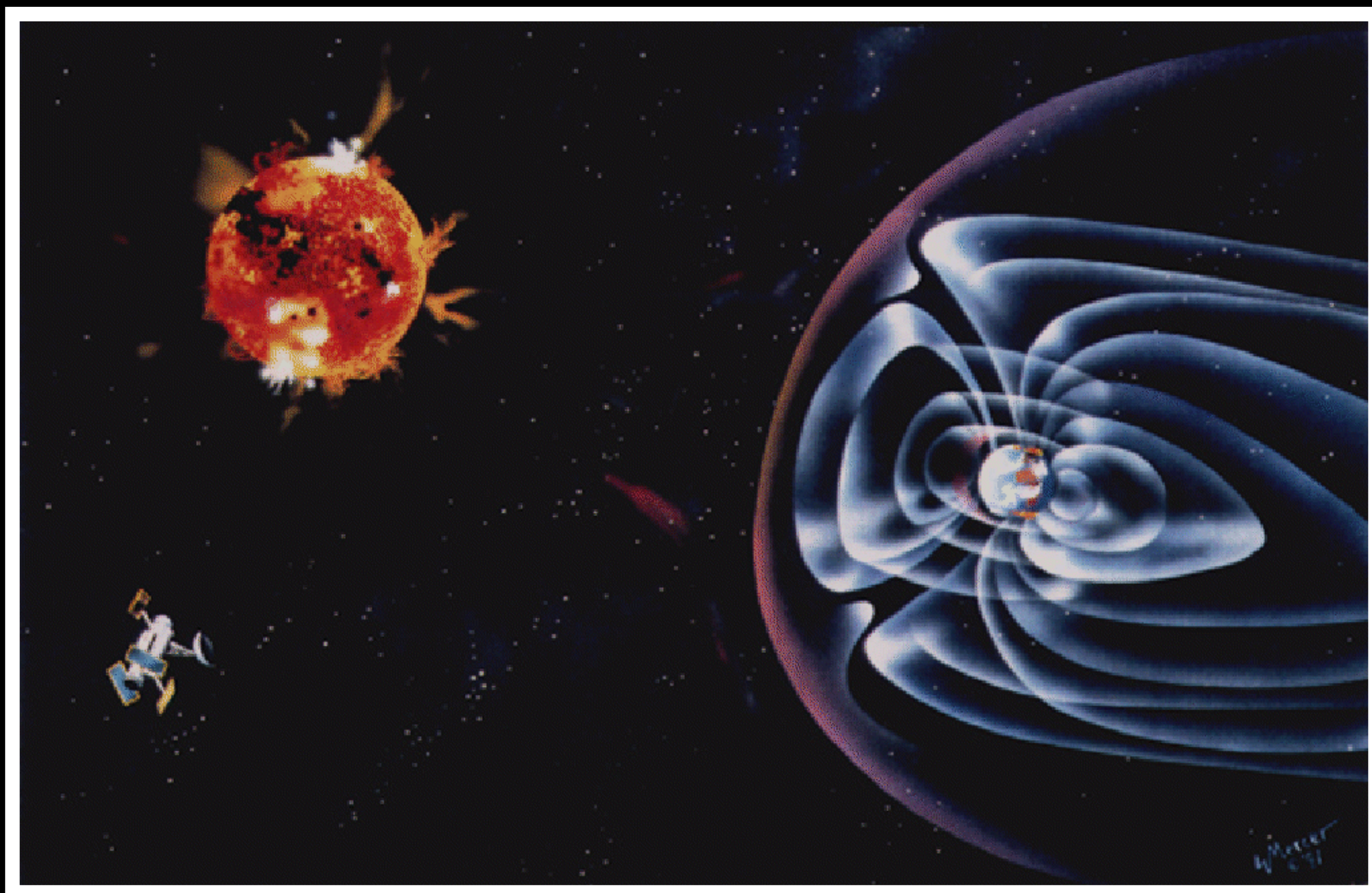


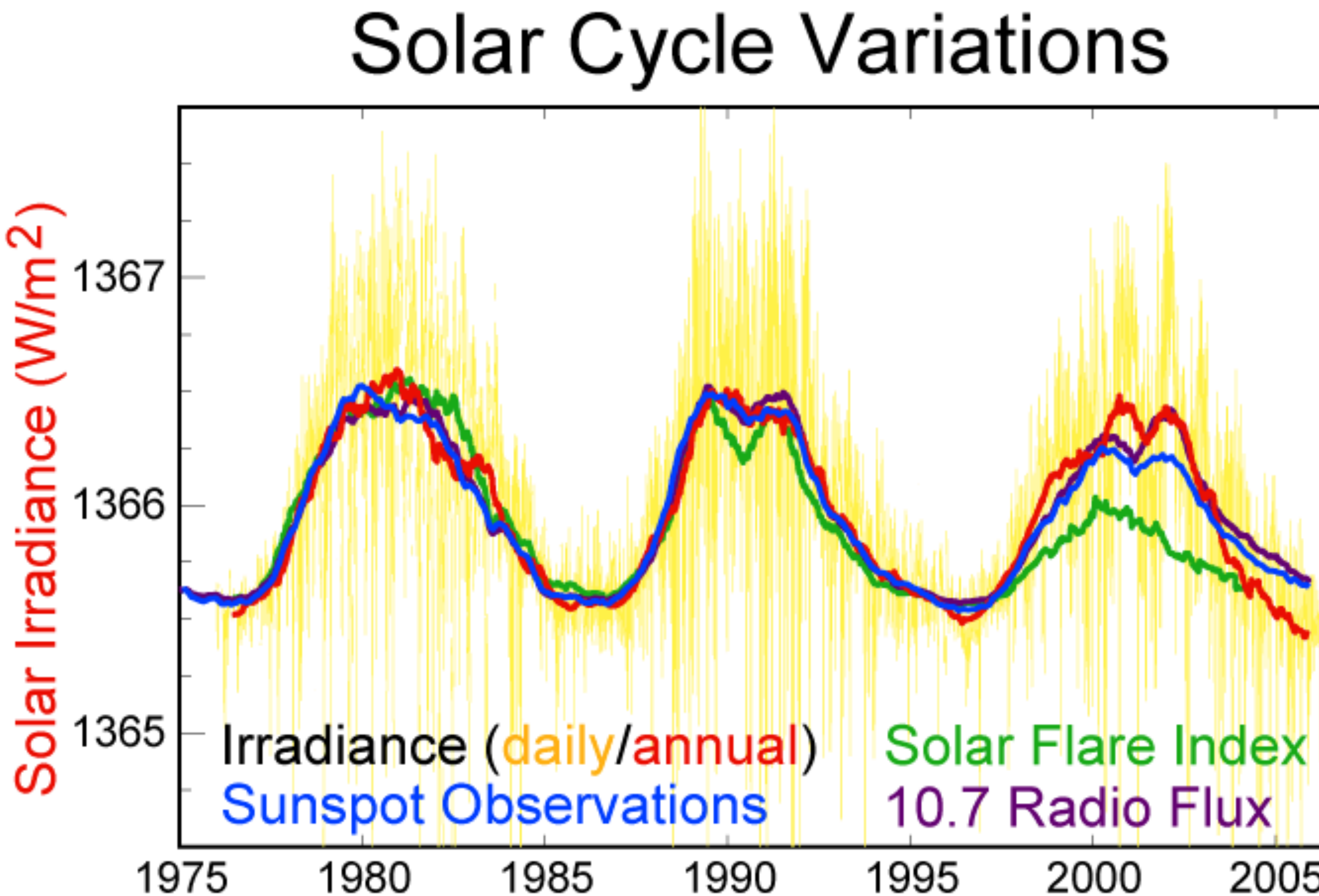


The Solar Cycle in Magnetism

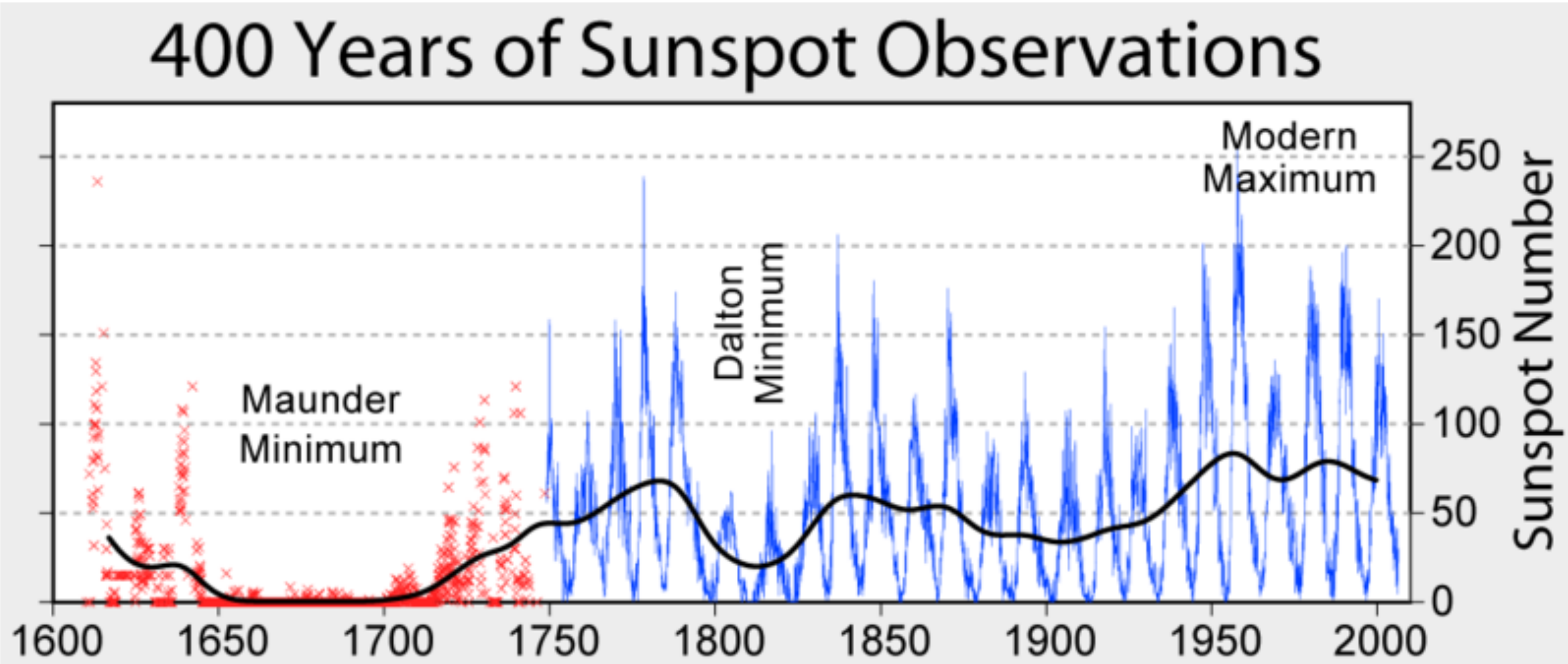


Sun-Earth Connection




Solar Cycle Variations
Solar Irradiance (W/m2)
1367
1366
1365
1975
1980
1985
1990
1995
2000
2005
Irradiance (daily/annual)
Sunspot Observations
Solar Flare Index
10.7 Radio Flux

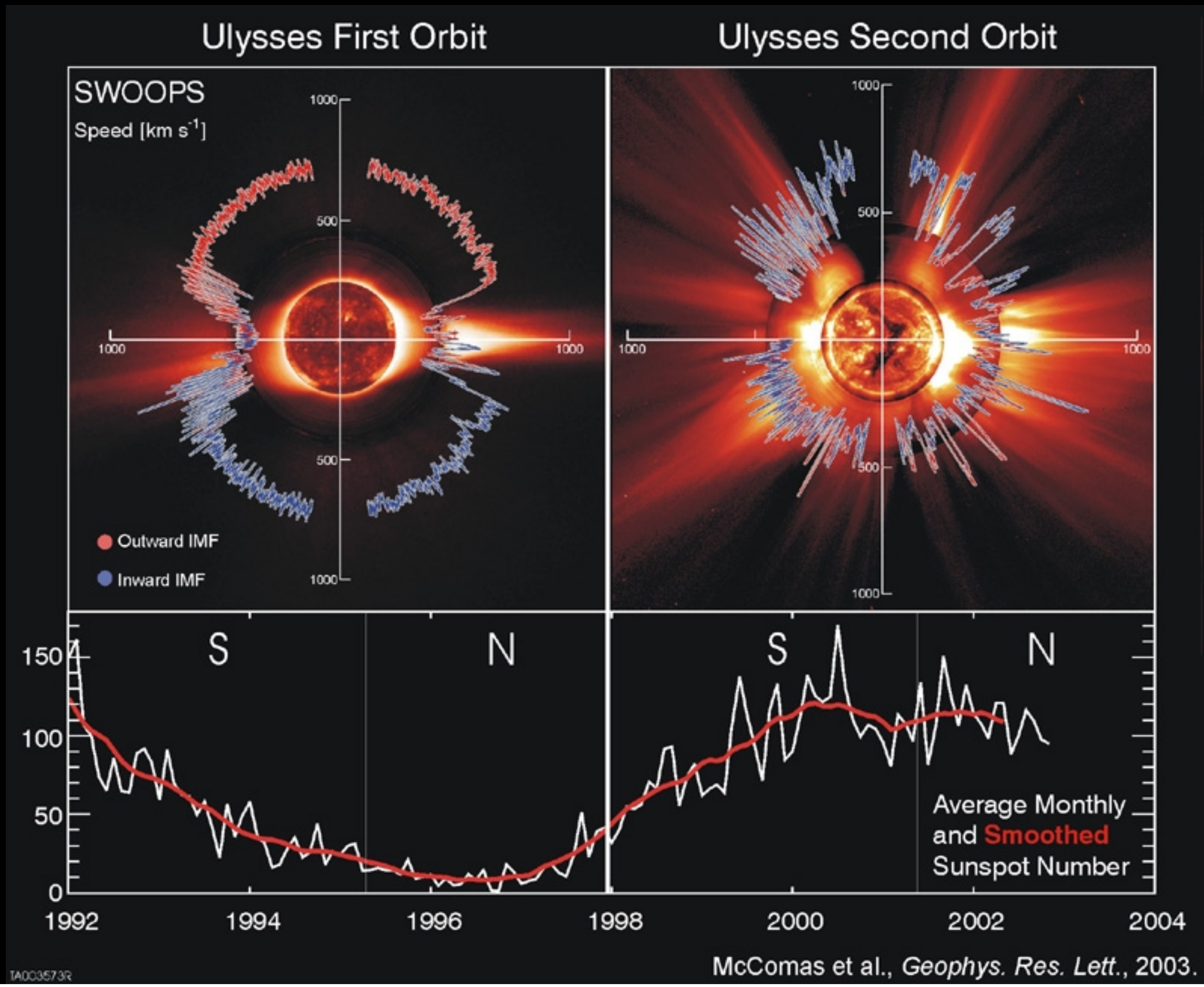
Solar Cycle and the Earth's Climate



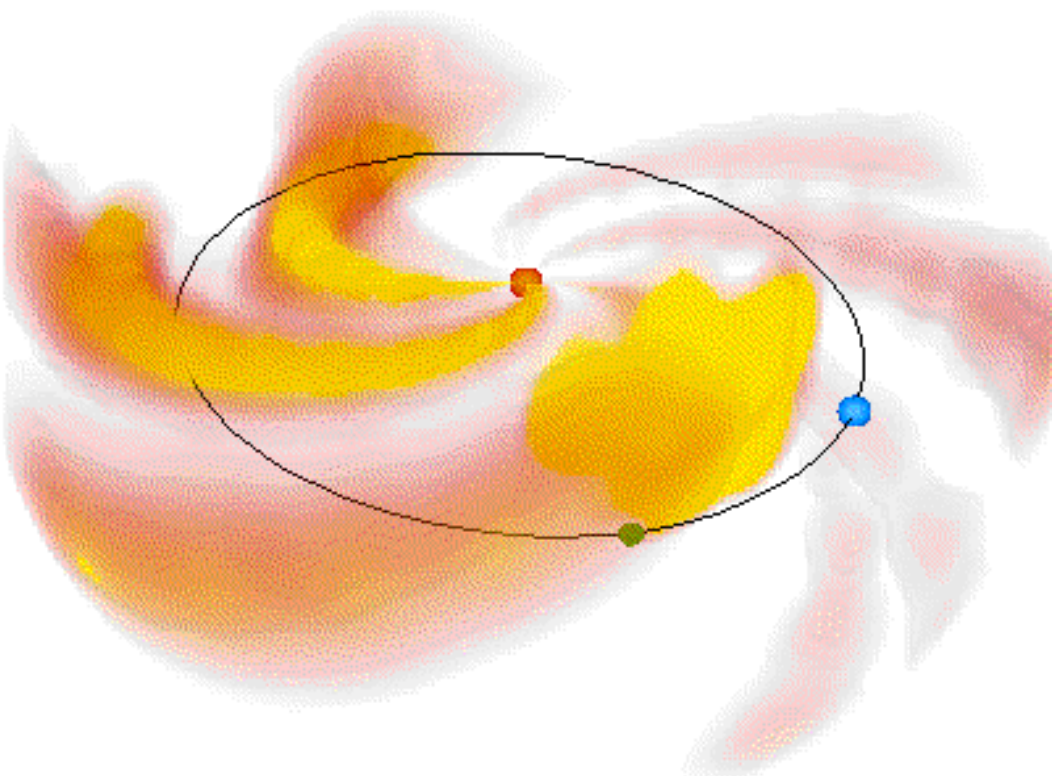
The Solar Wind

- 1951, Biermann discovered solar wind by considering comet tails
- Speed near earth is around 400 km/s with a travel time across 1 AU of ~4 days
- Combination of the wind outflow and the magnetic field have caused a "spin down" of Sun's rotation over time

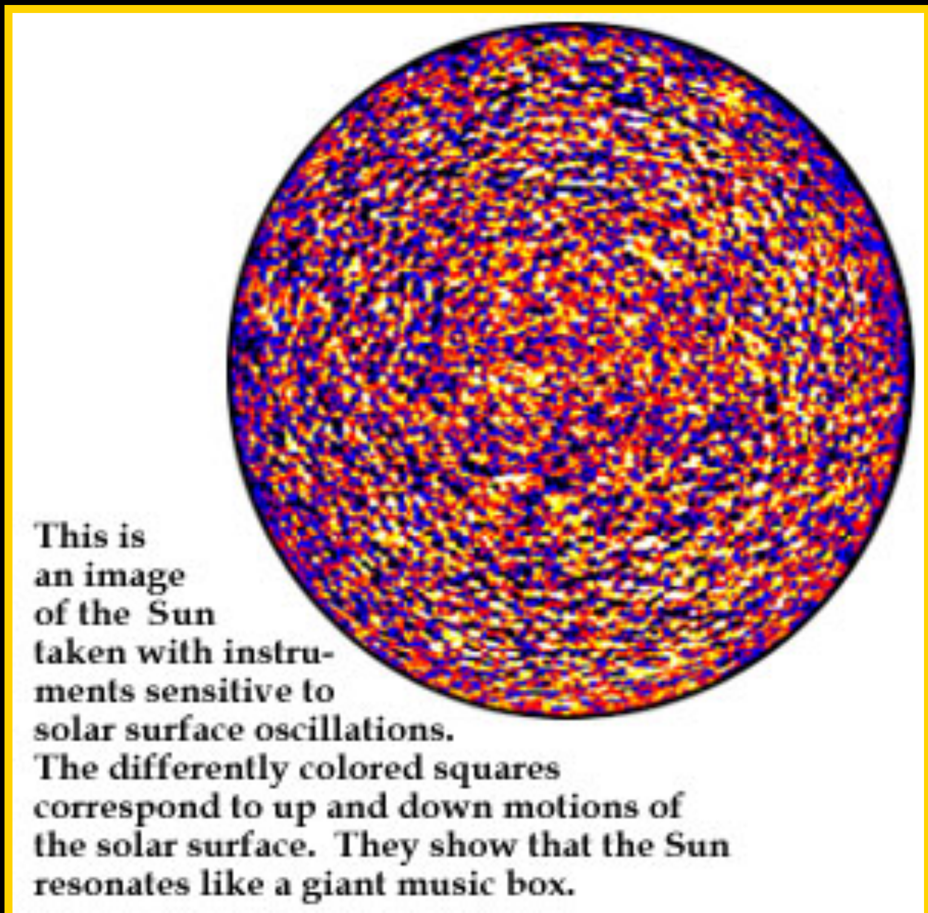
Solar Wind Mass Flux

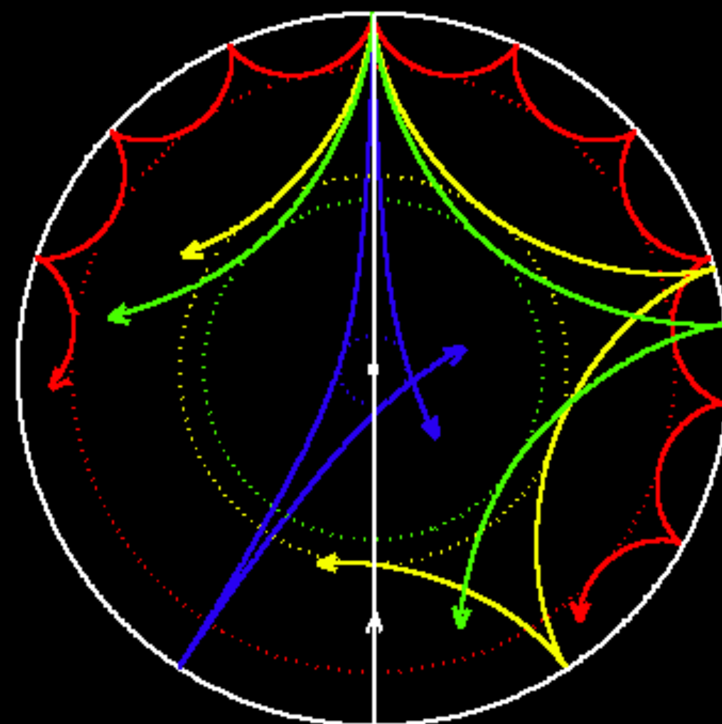


Space Weather

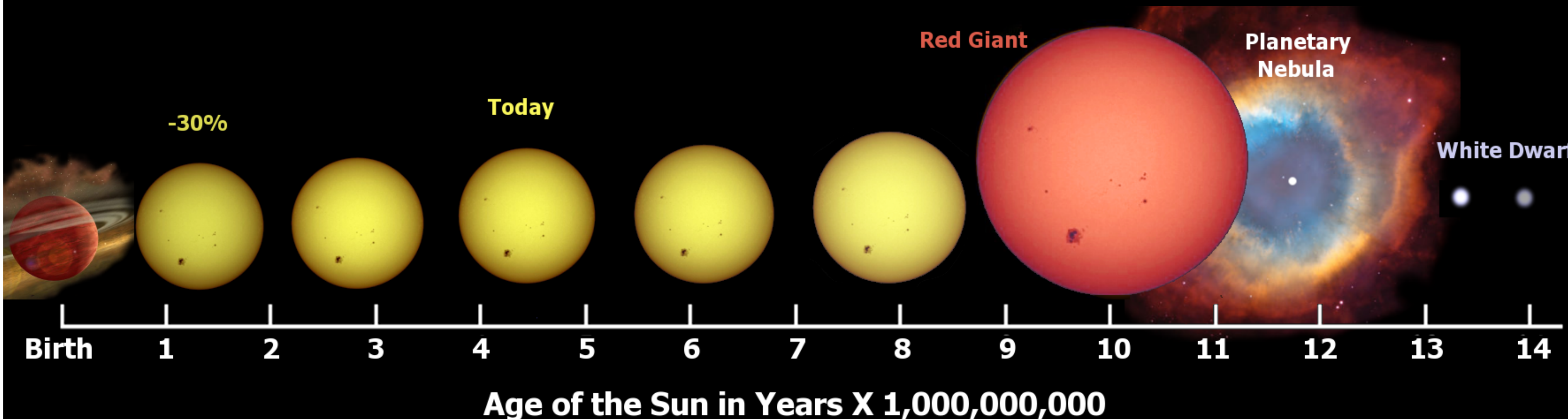


The Resonating Sun

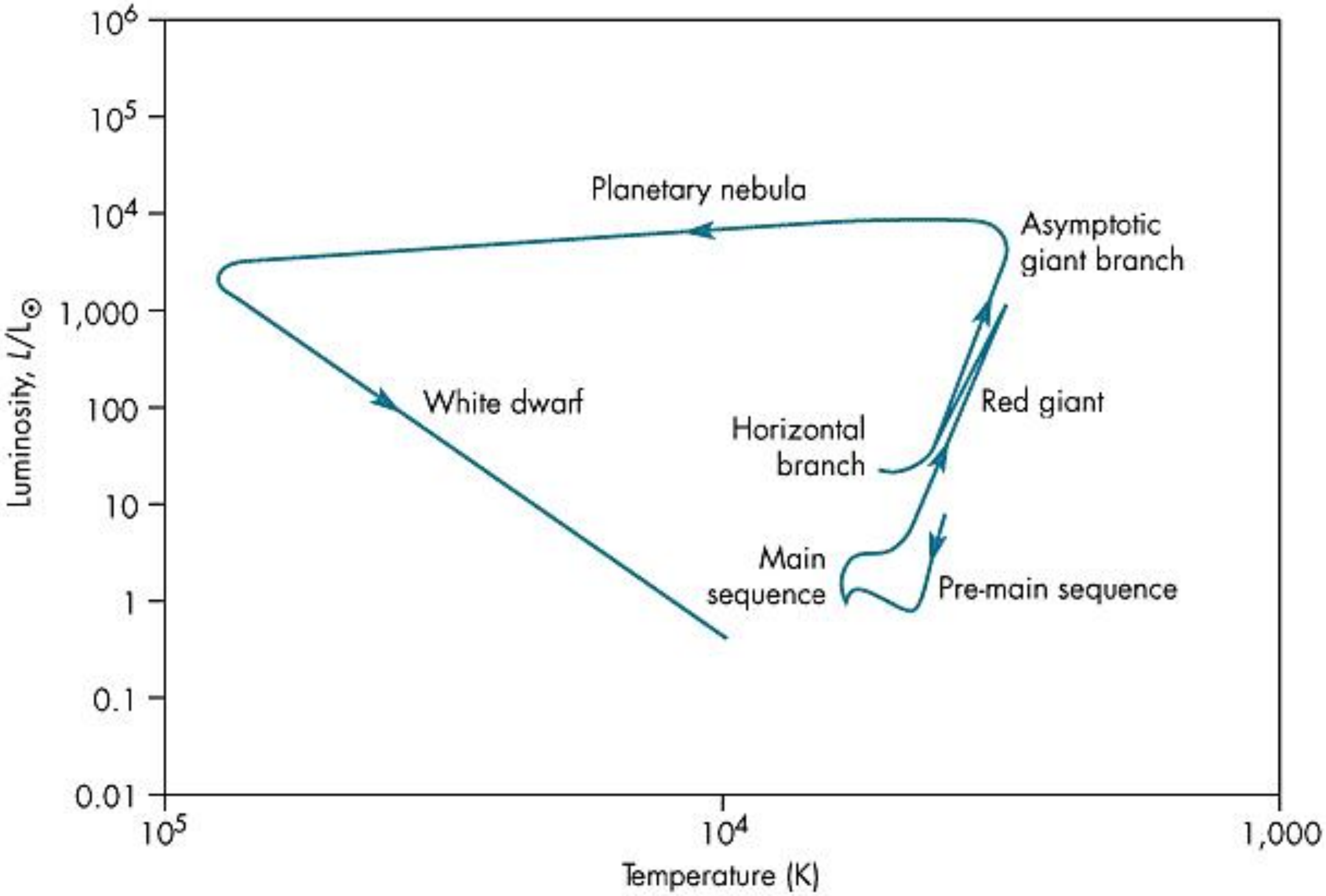




Long-Term Changes in the Sun



The Sun in Time

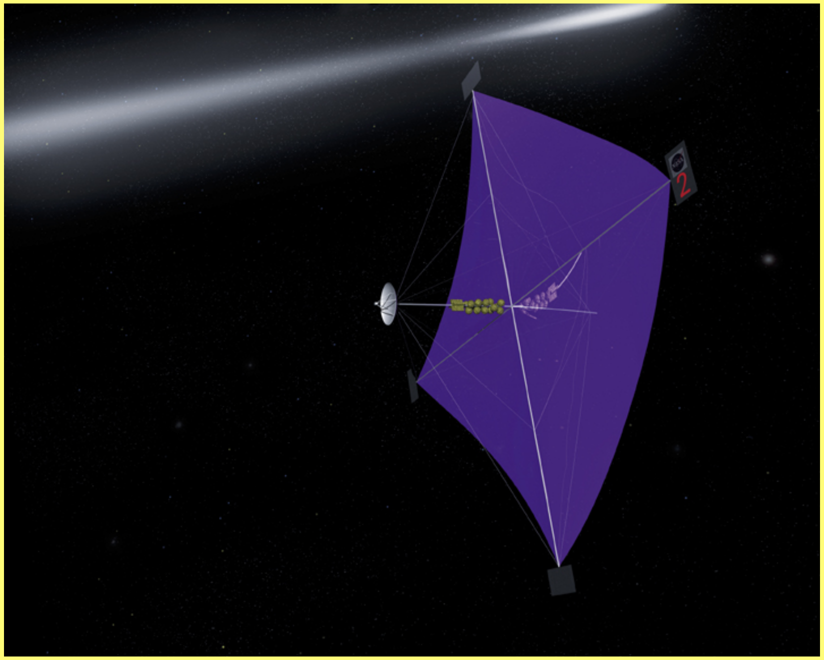


Solar Sailing: Propulsion in the Future?

$$a_{net} = g_{rad} - g_{Sun}$$

$$= (\Gamma - 1)\frac{GM_o}{r^2}$$

$$\Gamma = \left(\frac{L_o}{4\pi GM_o c}\right)\cdot\left(\frac{A_{sail}}{m_{sail}}\right)$$



- To make G > 1 requires a material with (A/m) > 1300 m^2/kg (equivalent to 36m x 36m)
- For 1 kg of sail, and G = 2, F_{net} = 0.006 N