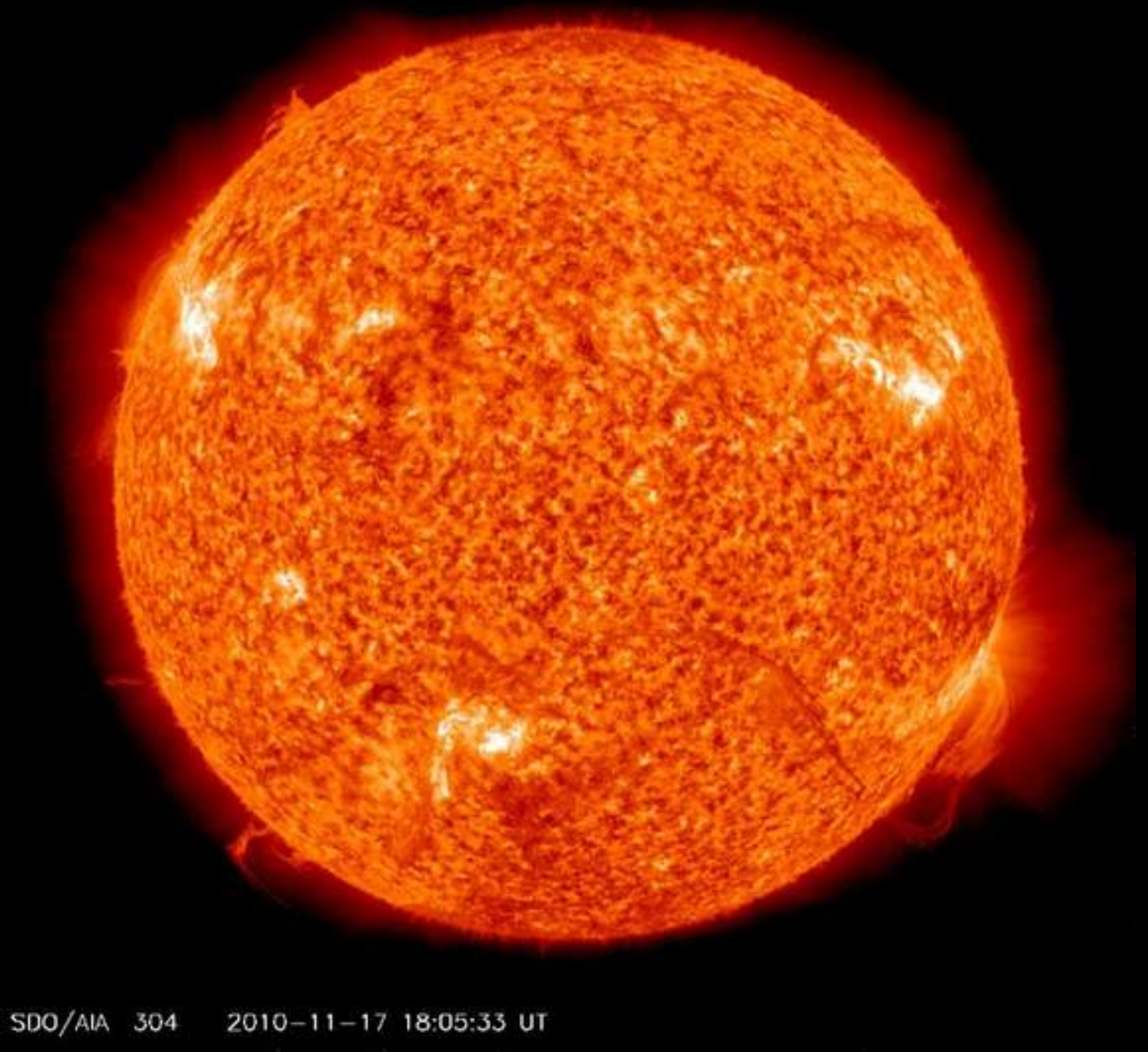
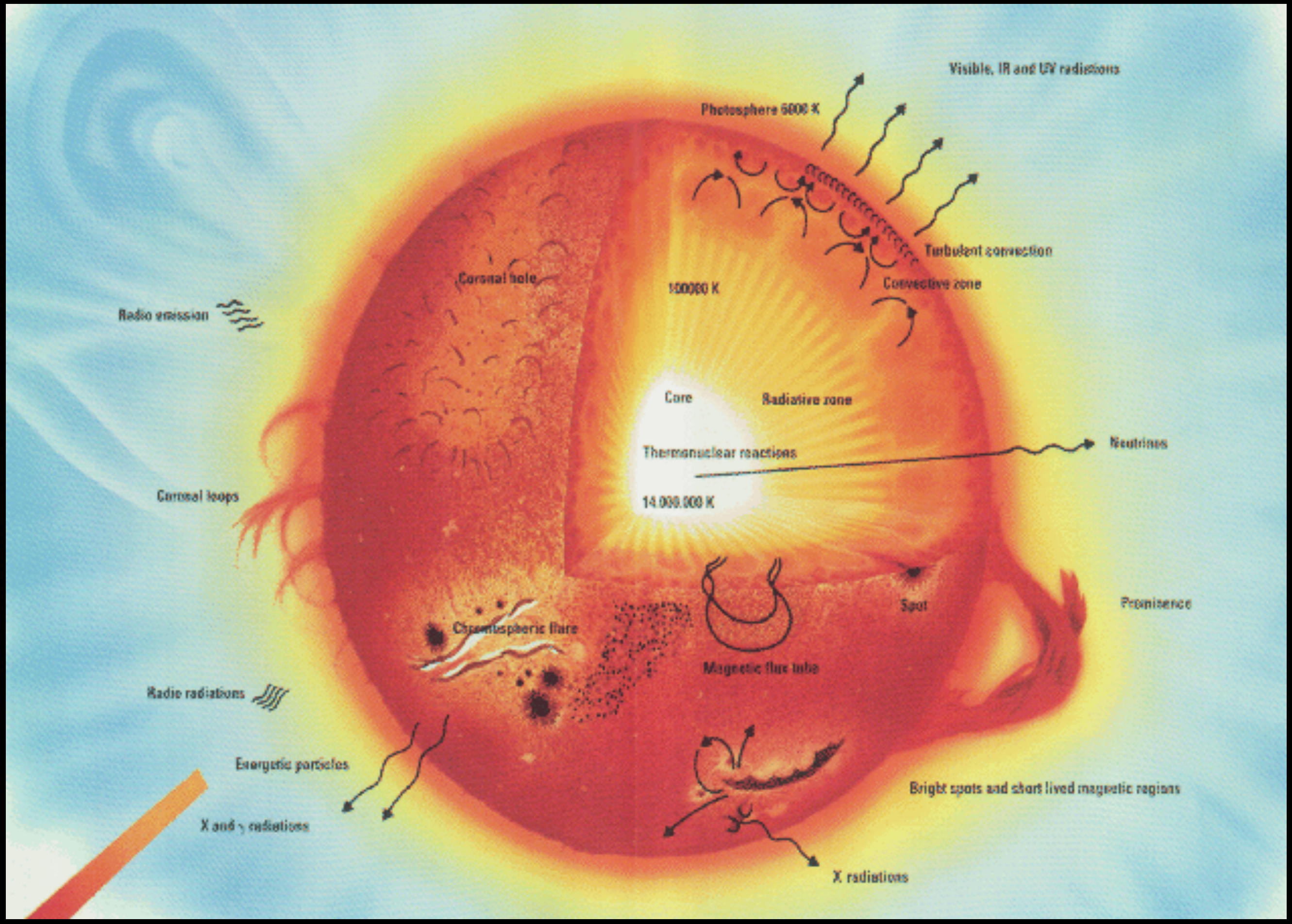


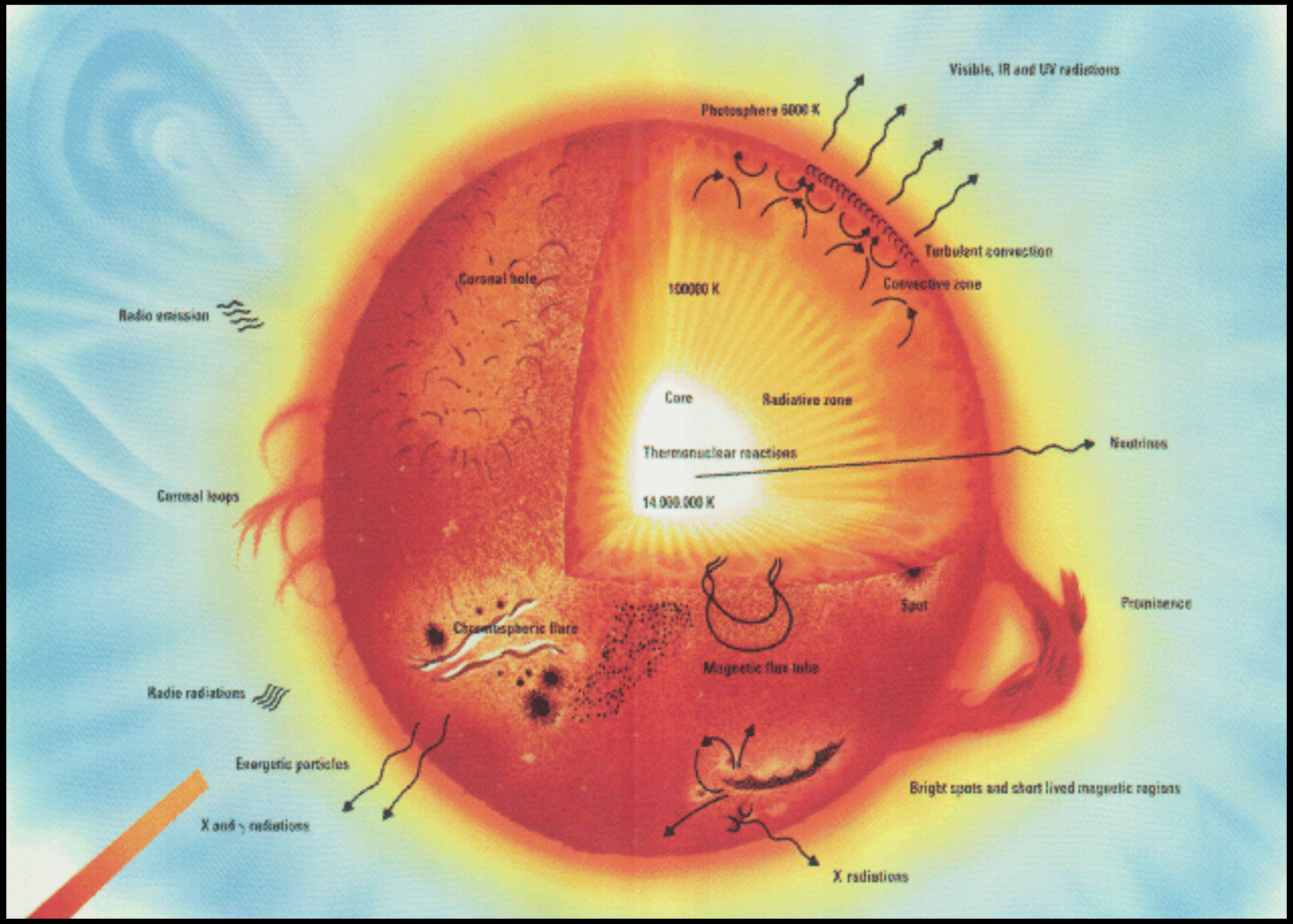
The Sun is a self-luminous ball of gas held together by its own gravity and powered by thermonuclear fusion in its core. Our Sun is a typical star among the various stars in the Galaxy, average in mass, size and temperature. It is a ``dwarf'' star with a radius of 109 Earth radii and a mass of 3.3x10^5 Earth masses.

The Sun's lifetime is about 10 billion years, meaning that after this time the hydrogen in its core will be depleted. The most outstanding characteristic of the Sun is the fact that it emits huge quantities of electro-magnetic radiation of all wavelengths. The total output of the Sun is 3.99x1033 ergs/sec.



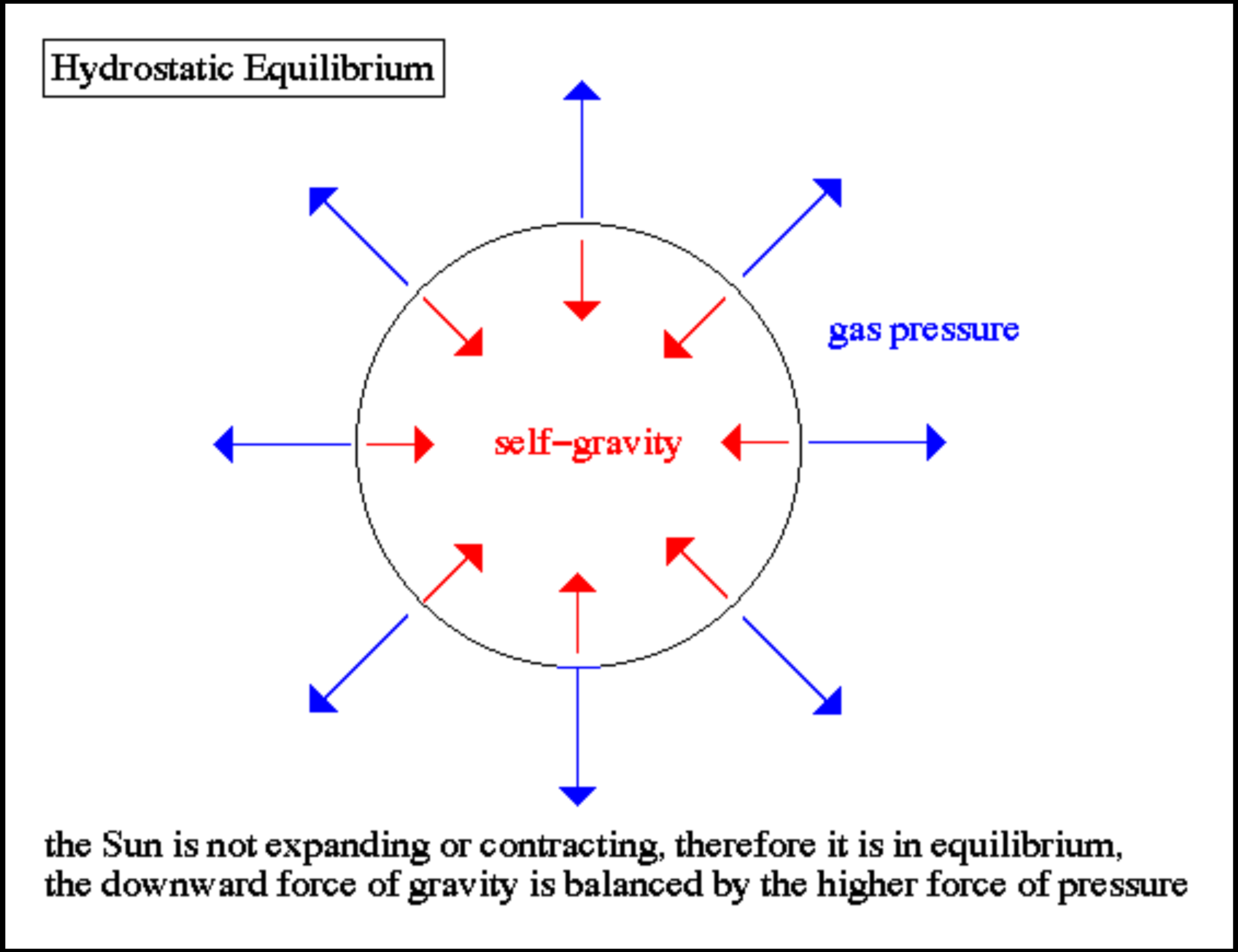
The Sun is divided into six regions based on the physical characteristics of these regions. The boundaries are not sharp.

1) fusion core - region of energy generation
2) radiation shell - the region where energy transport is by radiation flow
3) convection shell - the region where energy transport is by convection cells
4) photosphere - the surface where photons are emitted
5) chromosphere - the atmosphere of the Sun
6) corona - the superhot region where the solar wind originates

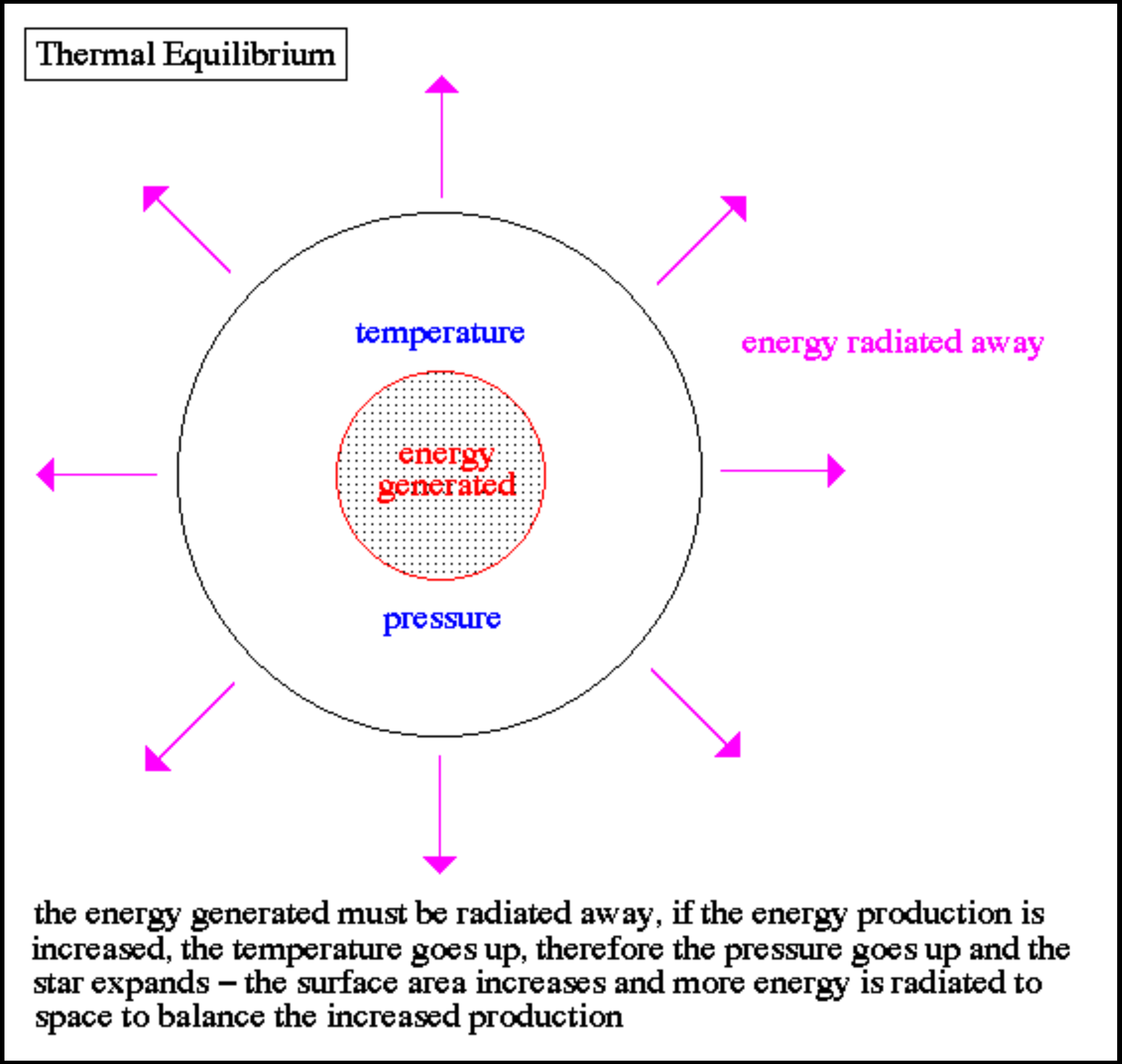


The structure of the Sun is determined by 5 relations or physical concepts:

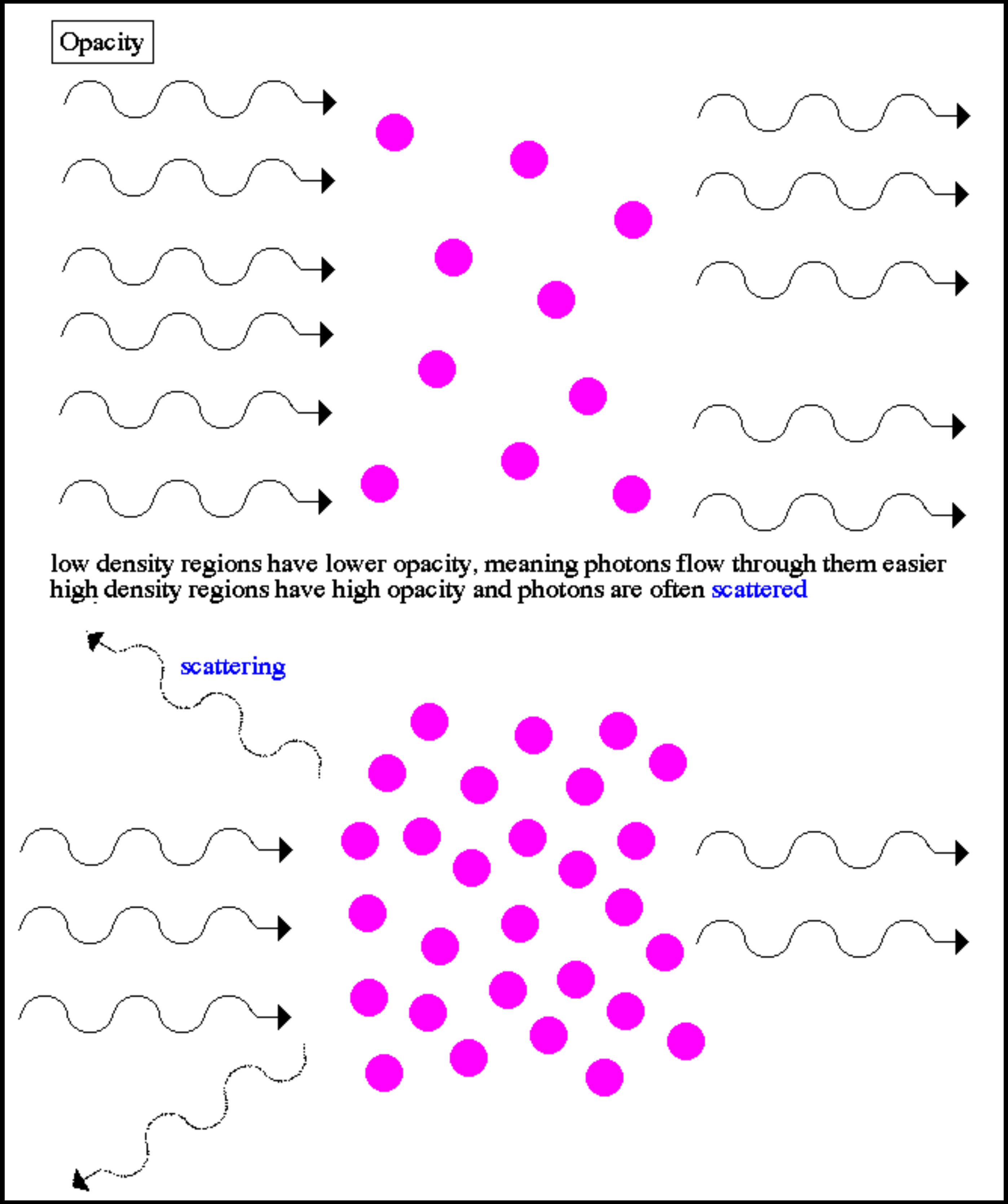
1) hydrostatic equilibrium - the fact that pressure balances the self-gravity



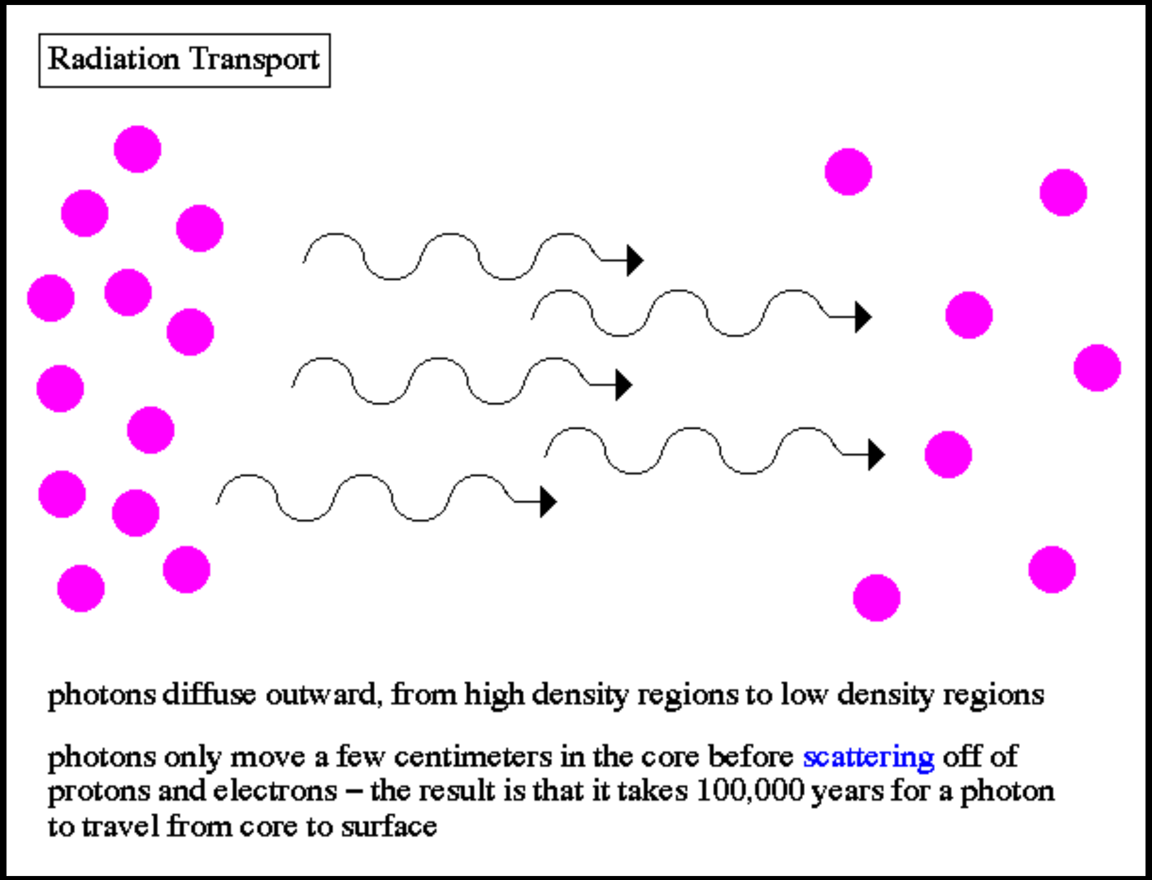
2) thermal equilibrium - the amount of energy generated equals the amount radiated away

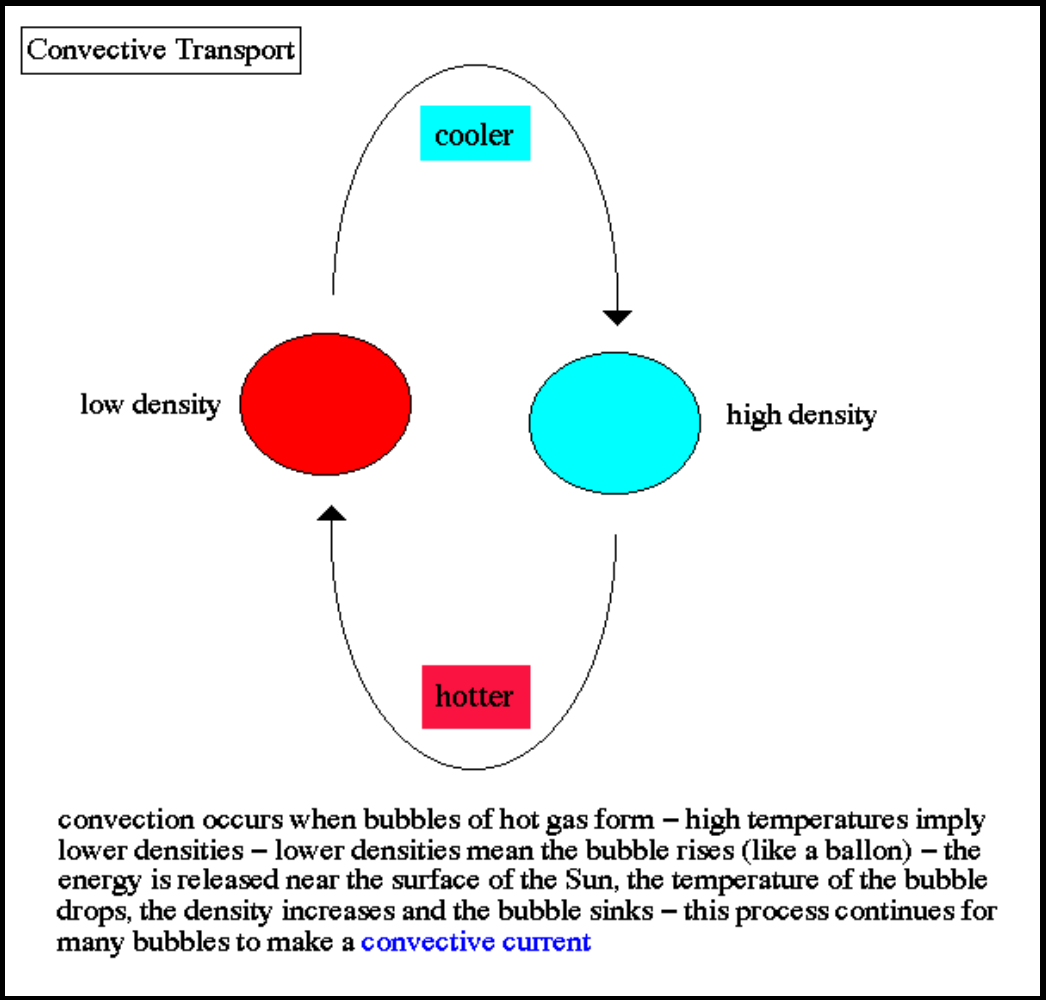


3) opacity - the resistance of the solar envelope to the flow of photons (how fast the energy is released)

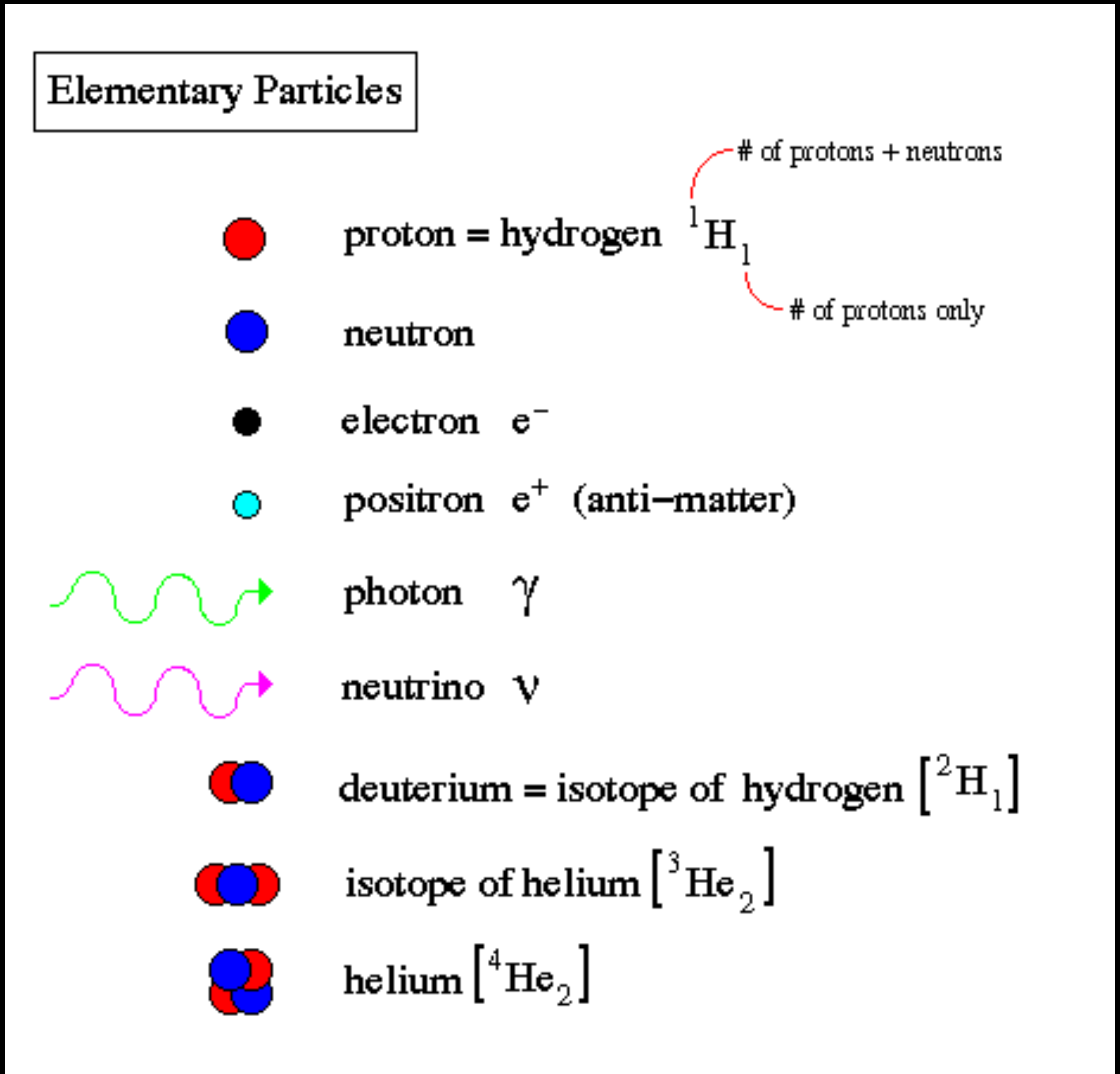


4) energy transport - how energy is transported from the core to the photosphere (convection or radiation



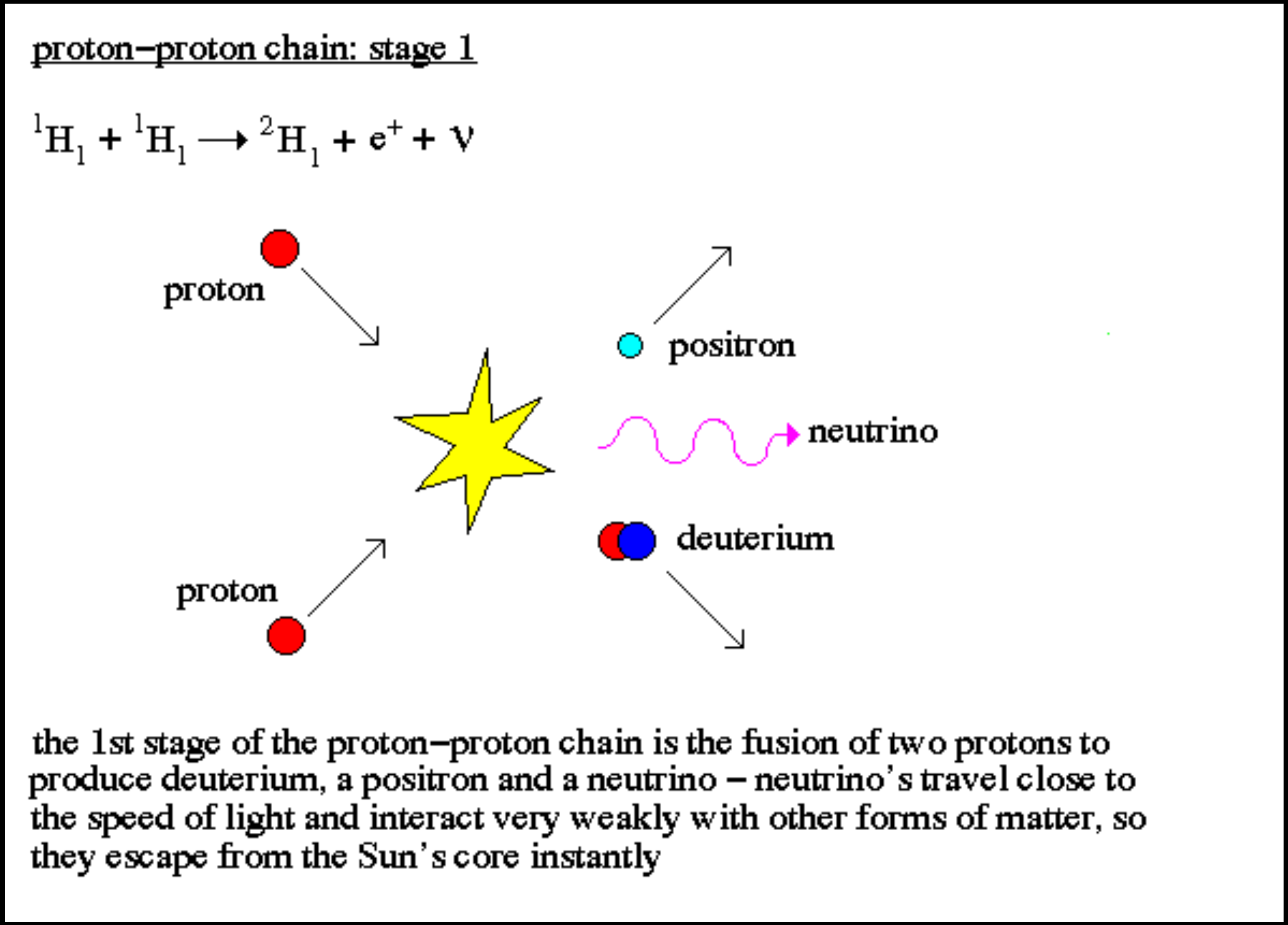


5) energy production - in the case of stars, energy is produced by thermonuclear fusion (see below)



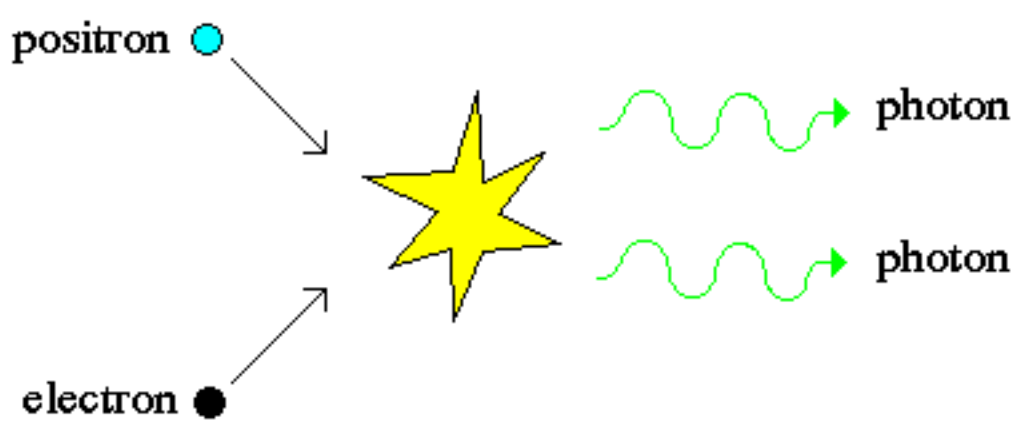
Nuclear reactions involve many elementary particles that make up all of matter (this is called the Standard Model). The primary output from nuclear reactions are photons in the form of gamma-rays, but a large number of other particles are important as well.

This fusion reaction in the Sun is called the proton-proton chain (the same process that powers H-bombs). It has the following four stages:



proton–proton chain: stage 2

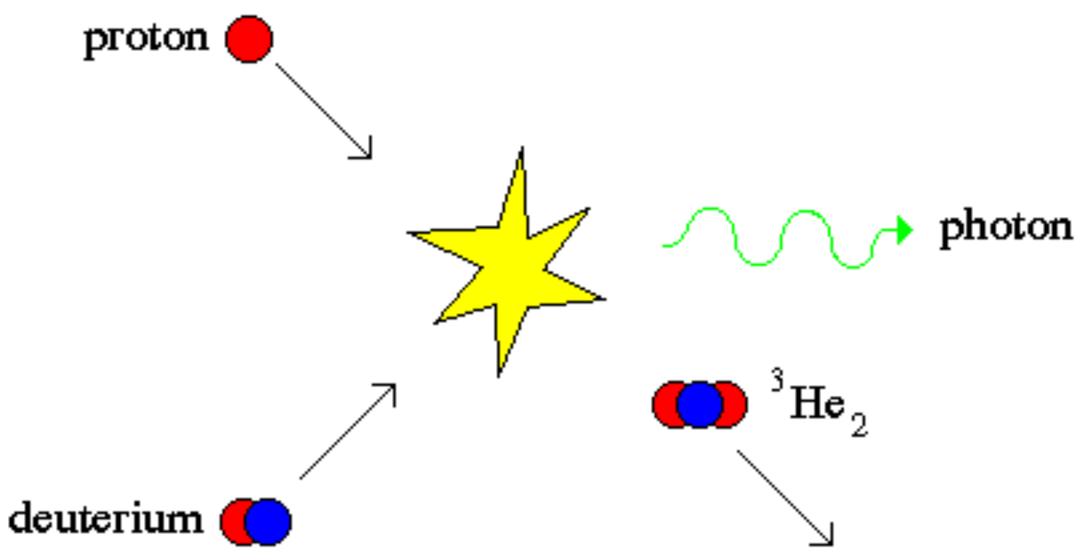
$$e^{+} + e^{-} \longrightarrow \gamma + \gamma$$



the 2nd second stage of the proton–proton chain is the destruction of the positron from the 1st stage by a collision with an electron – when matter and anti–matter collide they annihilate each other to produce two photons (gamma–rays) – the gamma–rays are the 1st amounts of energy produced by the proton–proton chain

proton–proton chain: stage 3

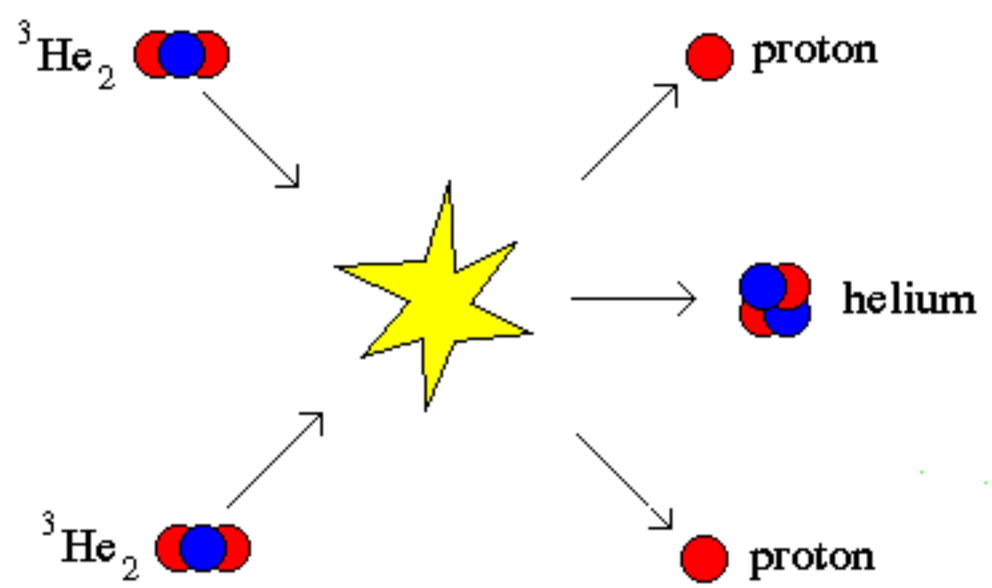
$$^{2}H_{1} + {}^{1}H_{1} \longrightarrow {}^{3}He_{2} + \gamma$$



the 3rd stage to the proton chain used the deuterium from stage 1 and another proton to produce tritium (an isotope of helium) and energy in the form of another gamma–ray – isotopes are protons and neutrons combined to produce a nucleus, but usually missing a proton or neutron needed to make a complete element – isotopes tend to decay in short times

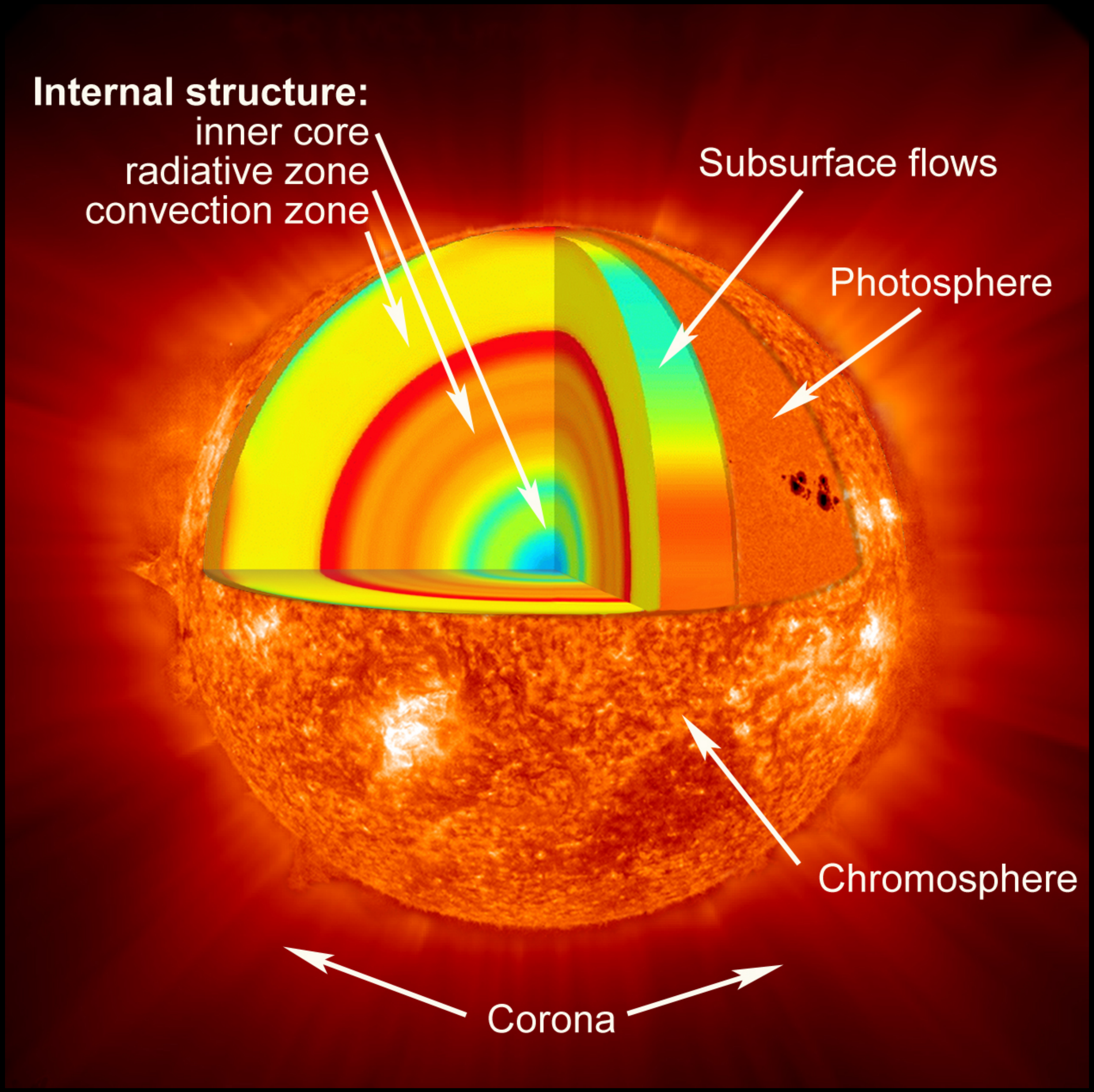
proton–proton chain: stage 4

$$^{3}He_{2} + {}^{3}He_{2} \longrightarrow {}^{4}He_{2} + {}^{1}H_{1} + {}^{1}H_{1}$$



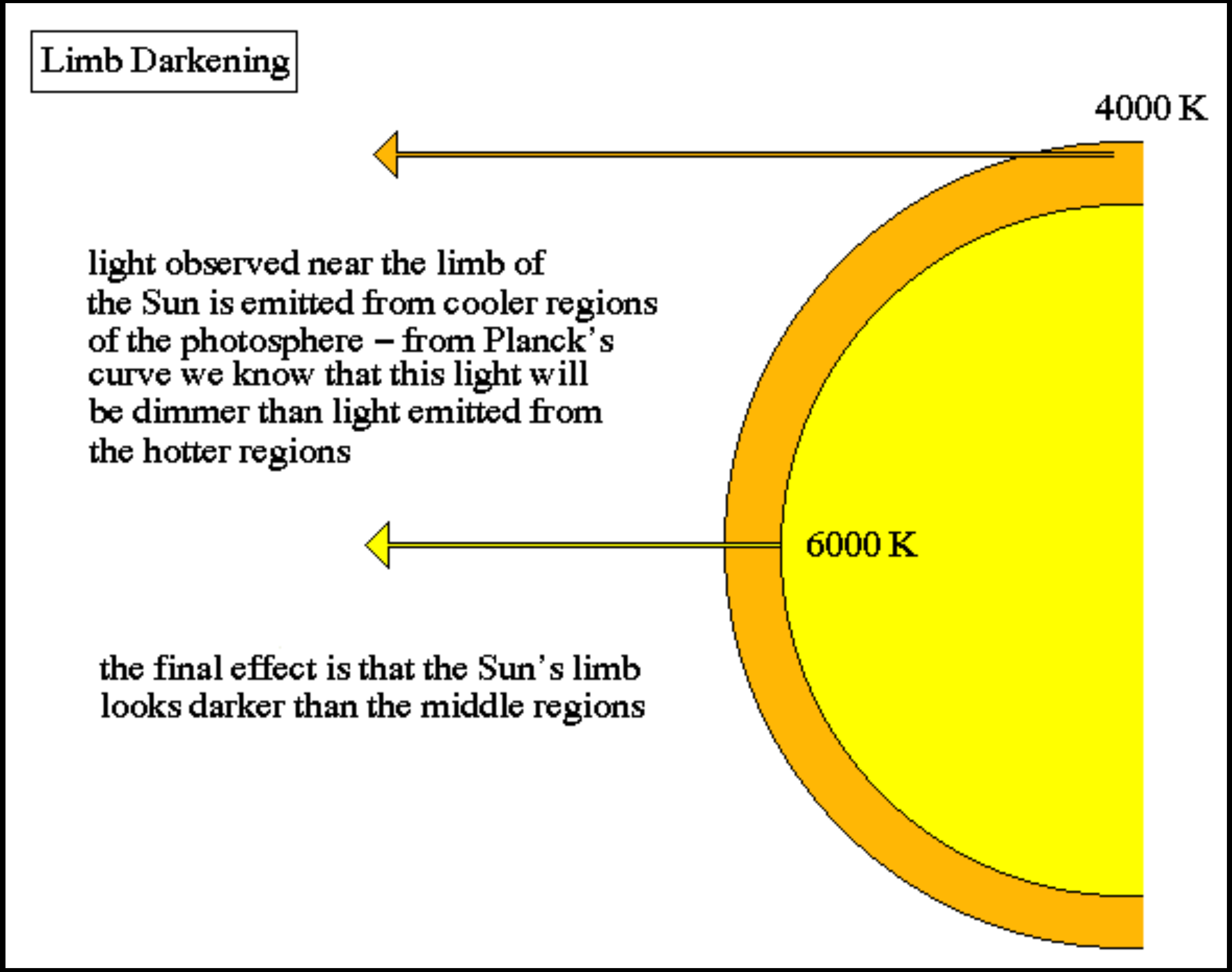
the last stage in the proton–proton chain is to convert two tritium nuclei into a full helium nuclei and release two protons – note that the protons can now go off and start two more stage 1 chains (thus the origin of the words ''chain reaction'') – the endresult of the proton–proton chain is to convert 4 hydrogen nuclei (protons) into 1 helium nuclei with the release of several photons in the form of high–energy gamma–rays

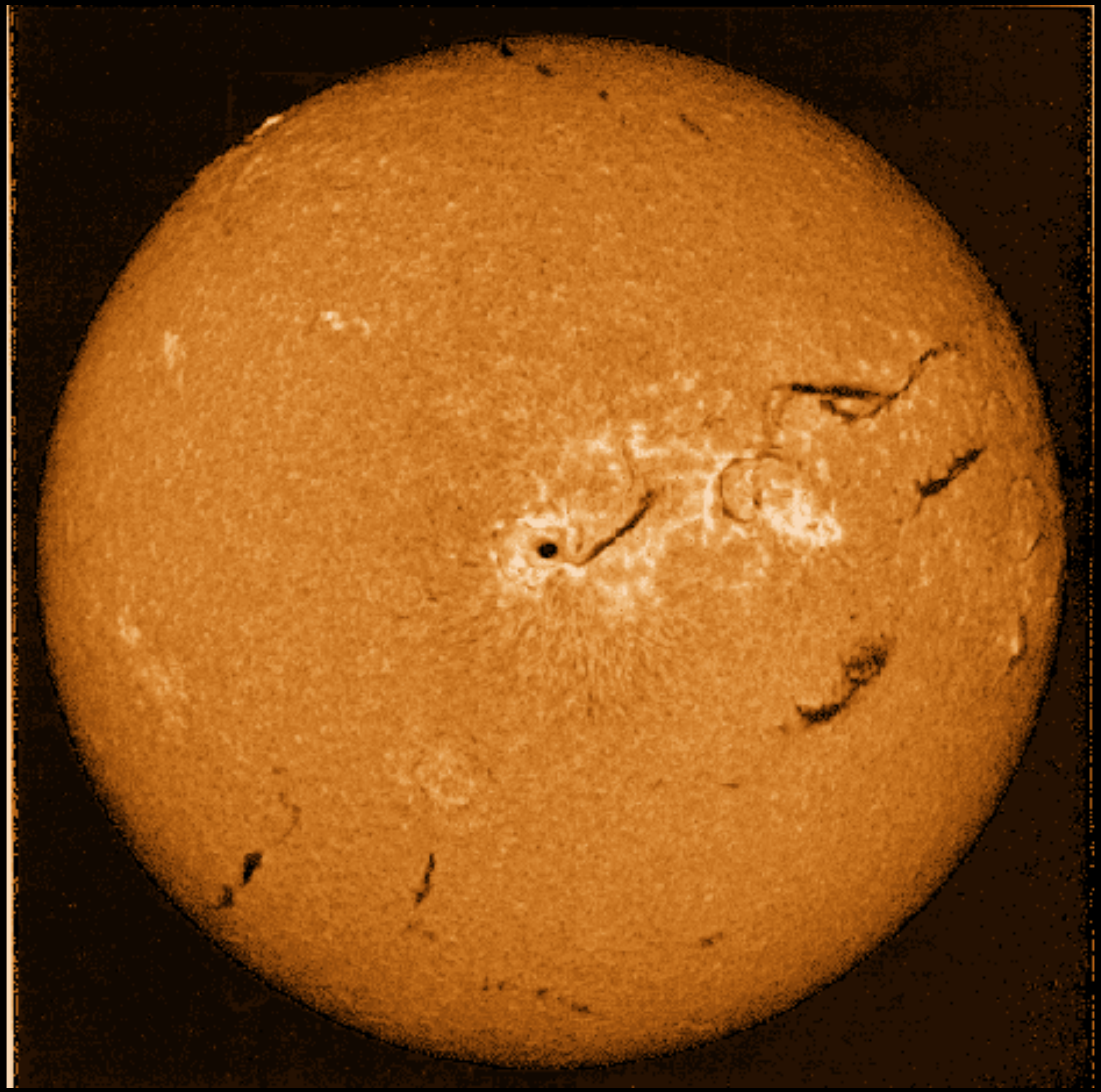
Note also the the mass of $^{4}He_{2}$ is 99.29% the mass of 4 protons, so 0.71% of the mass is ''missing'' – this is the mass used in $E=mc^2$, the famous formula to relate mass and energy for nuclear reactions



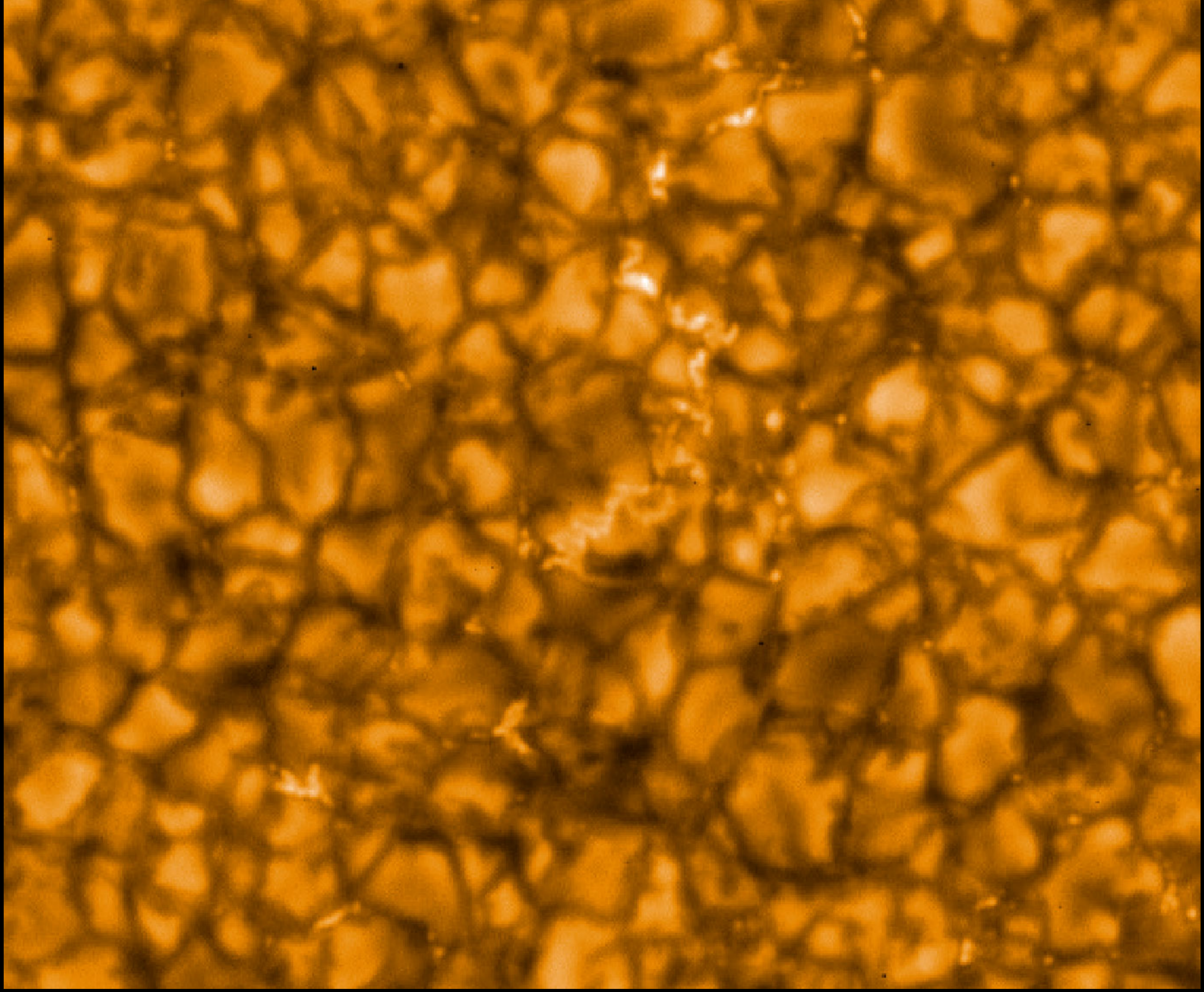
Although direct study of its interior is impossible, insights into the conditions - temperature, composition and motions of gas - within the Sun may be gained by observing oscillating waves, rhythmic inward and outward motions of its visible surface. The study of these solar oscillations is called helioseismology. In many ways, it resembles the study of seismic waves generated by earthquakes to learn about the Earth's interior.

The photosphere is the effective ``surface'' of the Sun since it is the point where the photons break free of scattering and zip into outer space. However, the photosphere is not a thin surface, but rather has a thickness of about 100 km. Within that 100 km, the temperature drops from 6000 K at the bottom to 4000 K at the top. Lower temperature means less luminosity from Planck's curve, so the edge of the Sun's disk is darker than the center, this is called limb darkening.

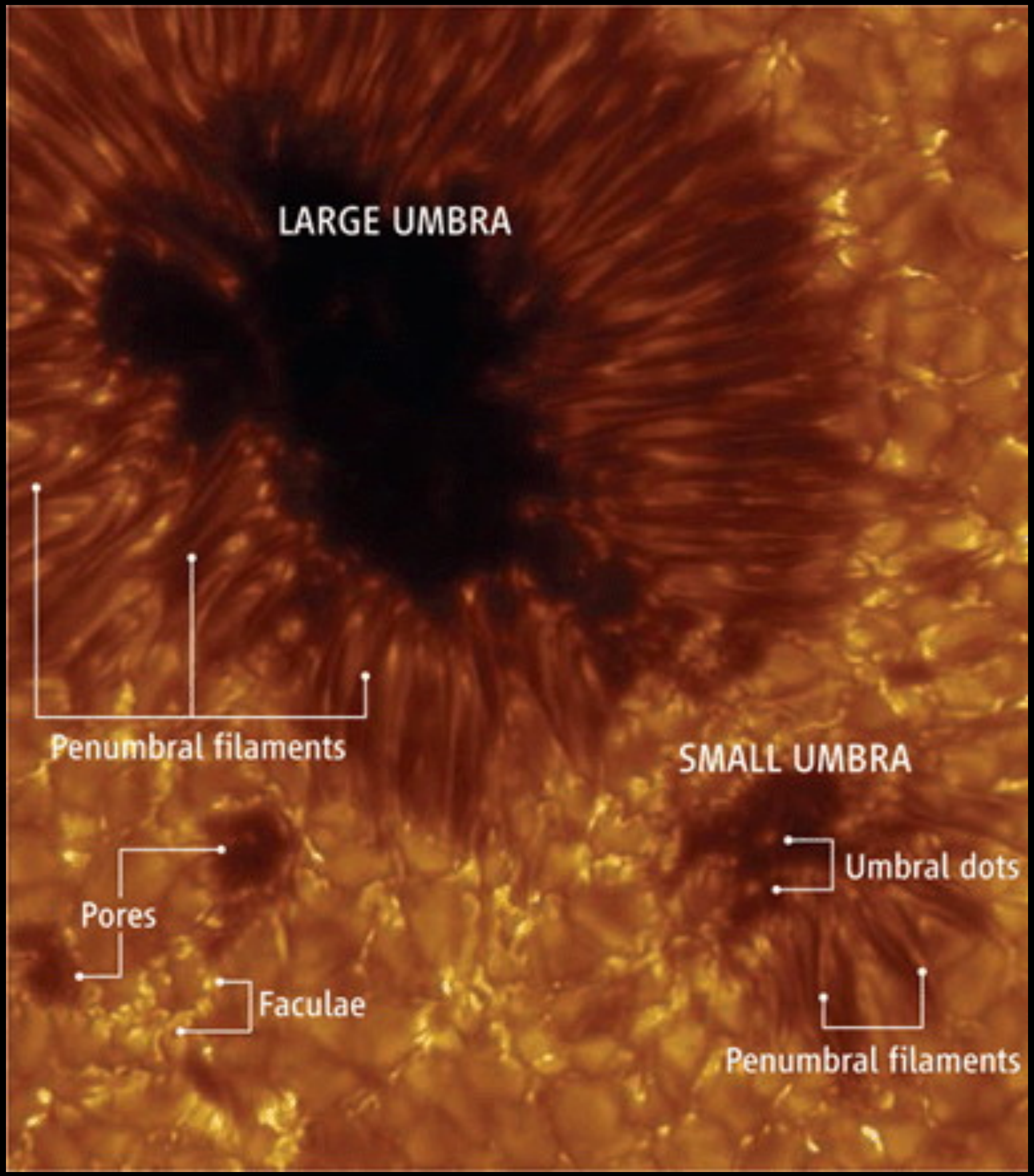




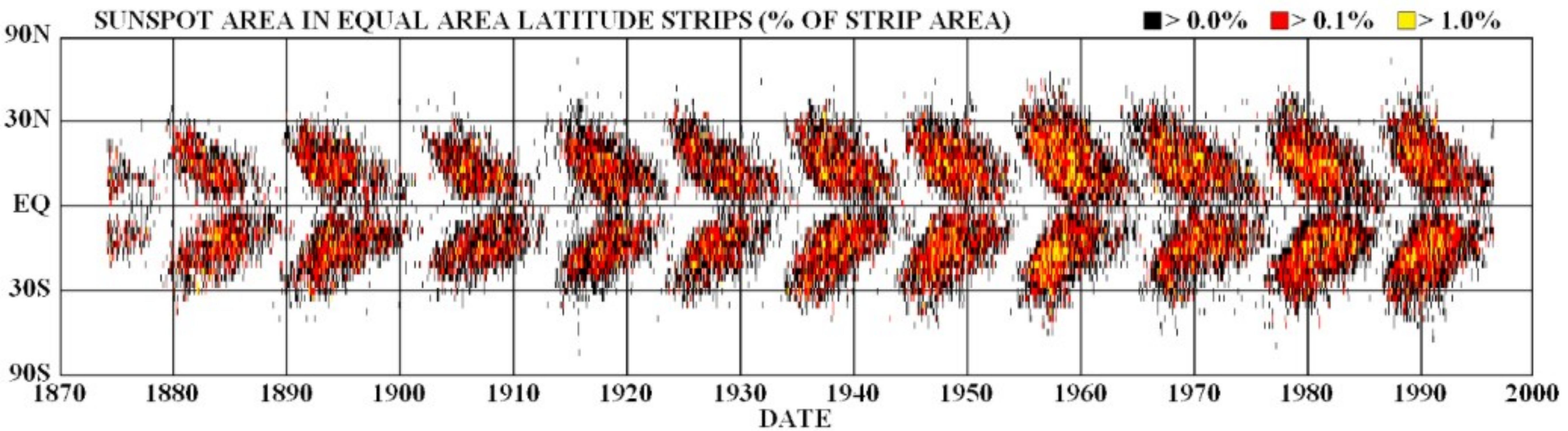
faculae - large, bright regions. Faculae occur where strong magnetic fields greatly reduce the local density of the gas. The low density makes it nearly transparent, so the lower levels of granules are more easily visible. At these deeper layers, the gas is hotter and radiates more strongly, explaining the brightening.

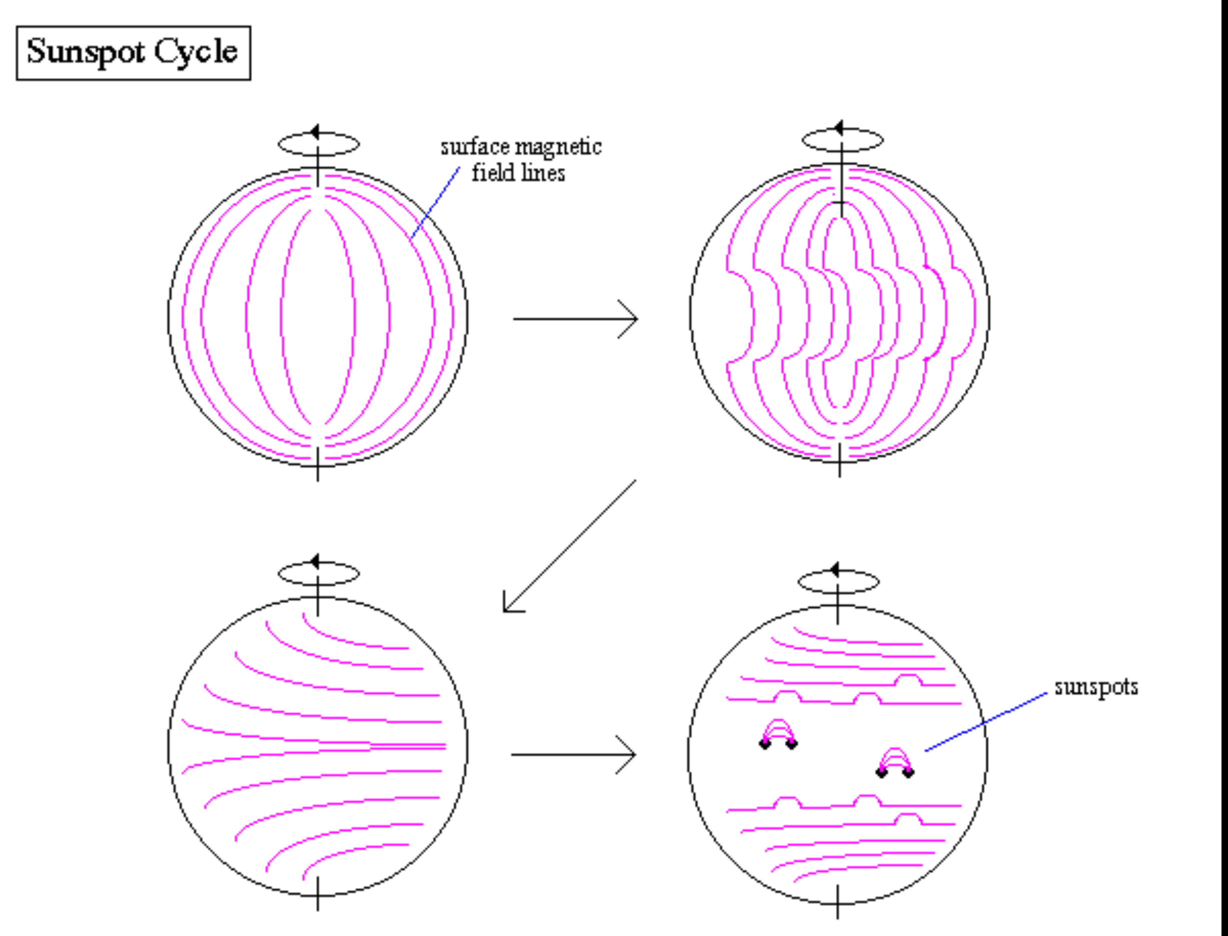


granules - small (1000 km wide), bright regions that change brightest on the order of several minutes = tops of convection cells sunspots - dark regions that travel in pairs (north and south magnetic poles)

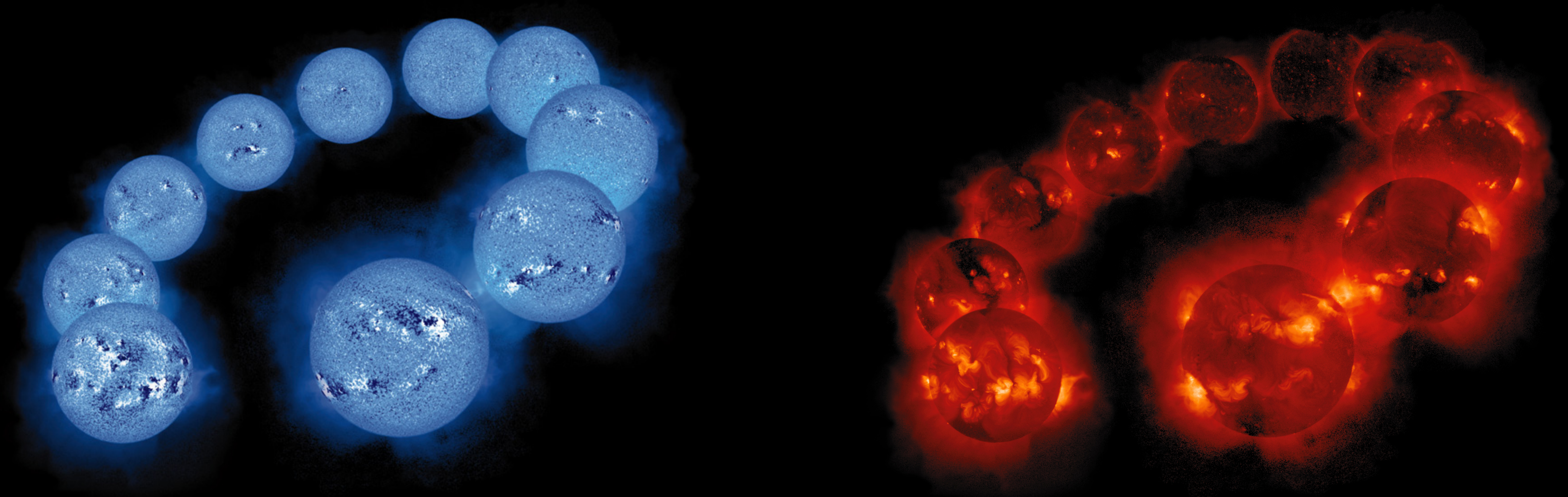


Sunspots pairs are due to magnetic flux tubes on the surface of the Sun. The flux tubes carry energy away causing the surface to be cooler (1800 degrees cooler) than the surrounding material, thus their darker appearance. The sunspots always travel with a north and south pole, oriented along the equator. The number of sunspots per year varies with an 11 year cycle and the peaks are associated with times of high solar activity (many flares and solar storms).

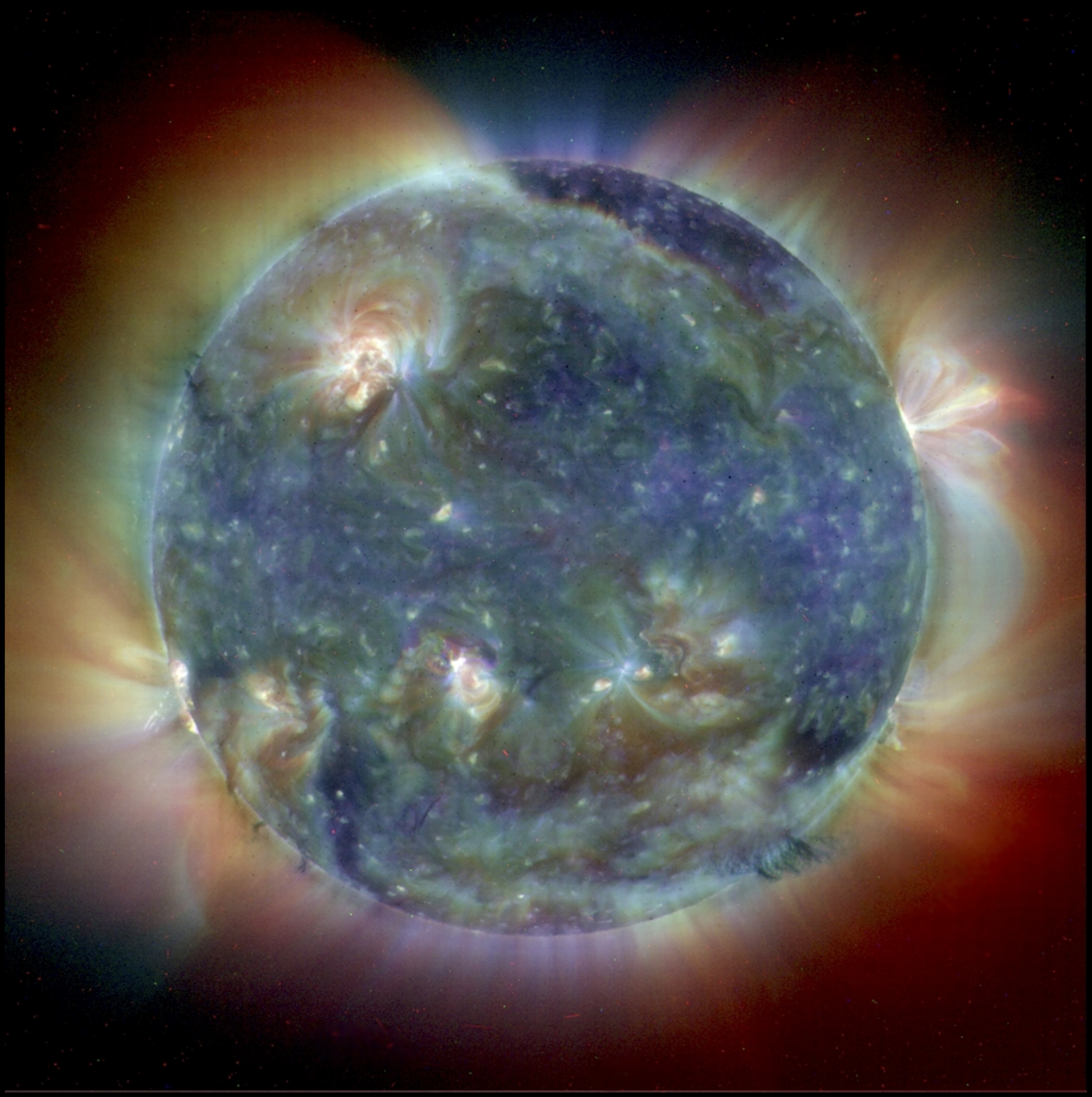




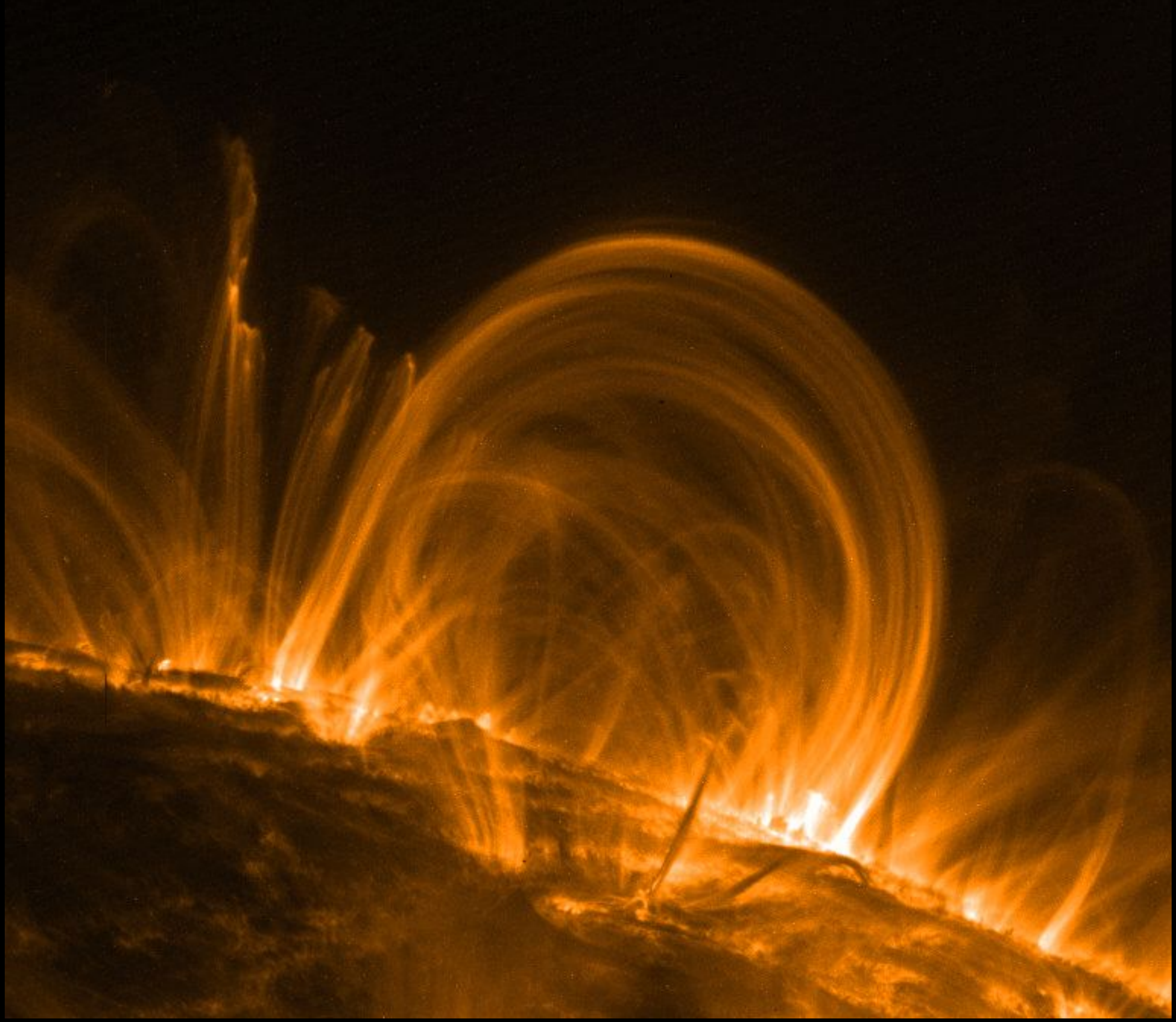
the sunspot cycle takes 11 years, at the start the magnetic field lines are smooth and north/south, as the differential rotation of the Sun wraps the field lines ''kinks'' form and flux tubes pop above the solar surface to produce sunspots



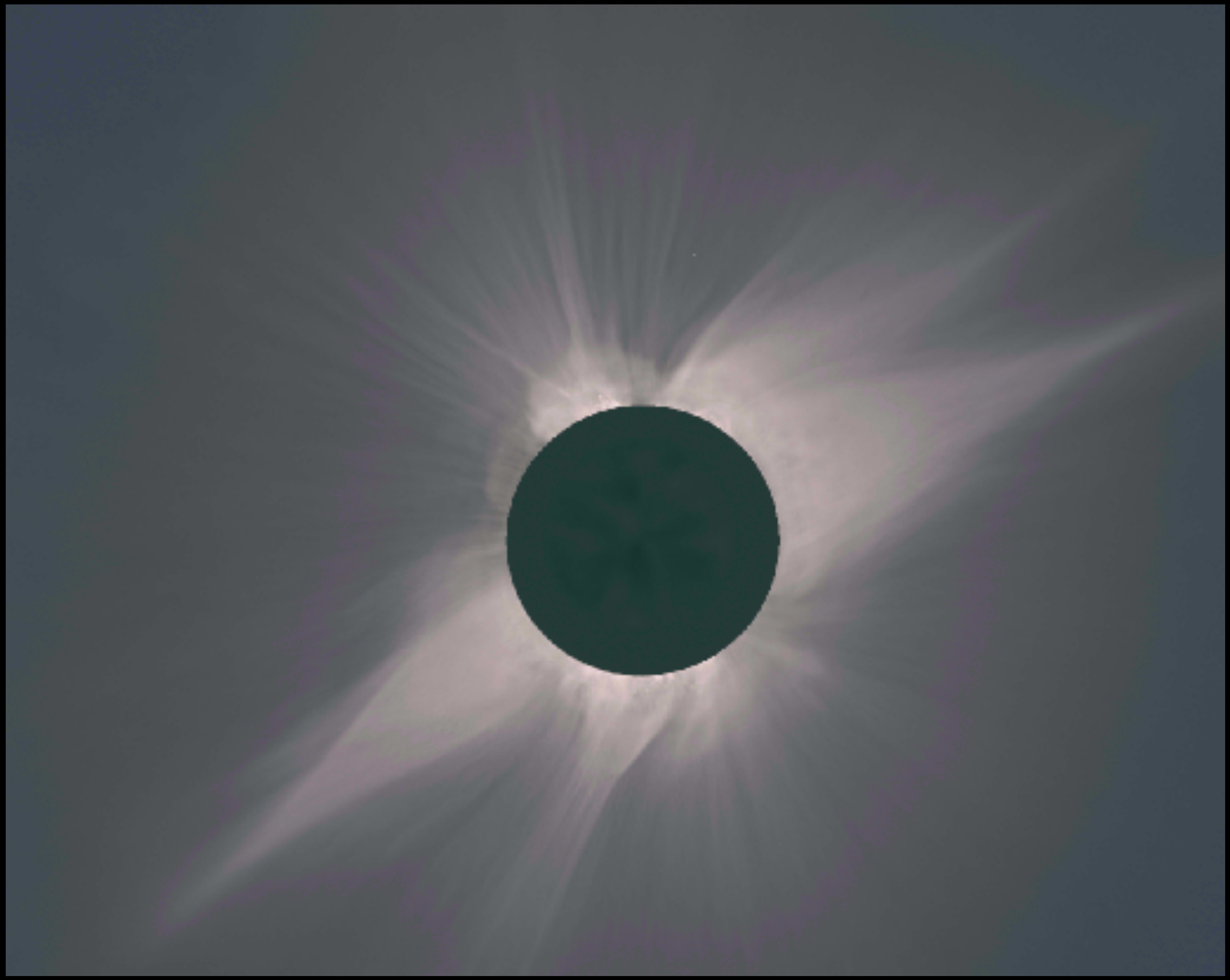
A sequence of snapshots of the changing solar magnetic field (left) and the soft X-ray corona (right) every year from 1991 to 2000 almost an entire solar cycle. Obtained one year apart between one solar maximum (lower right) and the next, they show the evolution of coronal structure due to changes in the magnetic fields at its base.



A solar flare is a sudden intense brightening of a small part of the Sun's chromosphere in the vicinity of a plage or facula and often near a sunspot group. The flare develops in a few minutes and may last several hours. Most of the energy consists of ultraviolet radiation; intense X rays are also emitted, along with cosmic rays and less energetic particles.



Solar flares, arcs and prominences are linked to sunspot activity. Gas is trapped in the flux lines created by the sunspot pairs and lifted off the photosphere into the chromosphere. Over a period of a few hours, the magnetic fields collapse hurling the hot gas outward (much like a breaking rubber band). These event also create a large flux of high energy particles which reach the Earth as magnetic storms and cause a sharp increase aurora activity.



The corona of the Sun is a large, white halo of glowing gas visible during a total eclipse. The corona gas is extremely hot (temperatures on order of a million degrees) and is the source of the solar wind.