SPASH ASTRONOMY
CHAPTER 15: THE NATURE OF THE NEAREST STAR
OVERHEAD LECTURE NOTES

1. State three generalities about our Sun:
1). Light from its surface reaches us in only eight minutes. (8 L.M. away)
2). It is a million-kilometer ball of hydrogen and helium at the center of our solar system.
3). It is just another star, and the stars are suns.
4). Solar rotation averages 25.4 days relative to the stars (27.3 days relative to the Earth, since the Earth's orbital motion is in the same direction as the solar rotation and must be added in).
5). As in Jupiter's atmosphere, the equatorial region rotates faster (25 days) than the polar regions (33 days) – proof that the Sun has a gaseous, not solid, surface.

2. What is a spectroheliograph and what can it tell us about the Sun?
Normal photographic films are sensitive to many wavelengths. However, spectroheliographs can restrict the wavelength range and spread light into different colors, from which one color alone is selected to form an image.
When hydrogen is in certain states of temperature and pressure, it emits an especially useful red color – the well-known hydrogen alpha line.

3. What is the composition of the Sun?
The sun is about 76% hydrogen and 22% helium by mass – roughly the same H/He proportions as the giant planets atmospheres. The heavy elements common in the Earth comprise only 2% of the Sun by mass.
STORY: In 1868 both French astronomer Pierre Janssen and English astronomer Norman Lockyer independently found solar spectral lines corresponding to an unknown element. This element, named helium (from the Greek helios, "sun"), was the first to be discovered in space instead of on the Earth (where it was not observed until 1891).

4. What makes the Sun shine?
Remember that all light generally comes from electrons returning to lower energy levels after being exciting to higher ones, but in this case light comes from the nuclear fusion reactions near the Sun's center.

5. I know it looks like a lot of material but it is important. Complete the table one the next page. Think of what you are doing. Most of you only thought three or four states of matter existed in the universe. Now how many states of matter are there really?

THE SEVEN STATES OF MATTER IN THE UNIVERSE

pproximate emperature cale	Velocity of Typical Atoms and Molecules	State of Matter	Typical Location	Typical Radiation Emitted
0 billion K	almost c	NUCLEAR FRAGMENTS collide hard enough to shatter	Accretion disk near a black hole	Gamma Rays & X-ray light
0 billion K	500 km/s	BARE NUCLEI nuclei collide and fuse (fusion)	Core of a star	X-ray & Ultraviolet light
000 K	10 km/s	IONIZED GAS (electrons knocked free)	Atmosphere of a star or Lightning	Visible light
00 K	1 km/s	GAS (separate atoms)	Atmosphere of a planet	Infrared light
00 K	½ km/s	LIQUID (Some atoms linked in chains)	Water	Far Infrared light
E6 K	almost 0 m/s	SOLID (atoms linked in lattice)	ROCK	Radio wave light
E11 K	0 m/s	(BEC) Bose/Einstein condensate	atoms coalesce into a single blob	transmission light

6. How many Hydrogen atoms does it really take to fuse into one normal Helium atom?

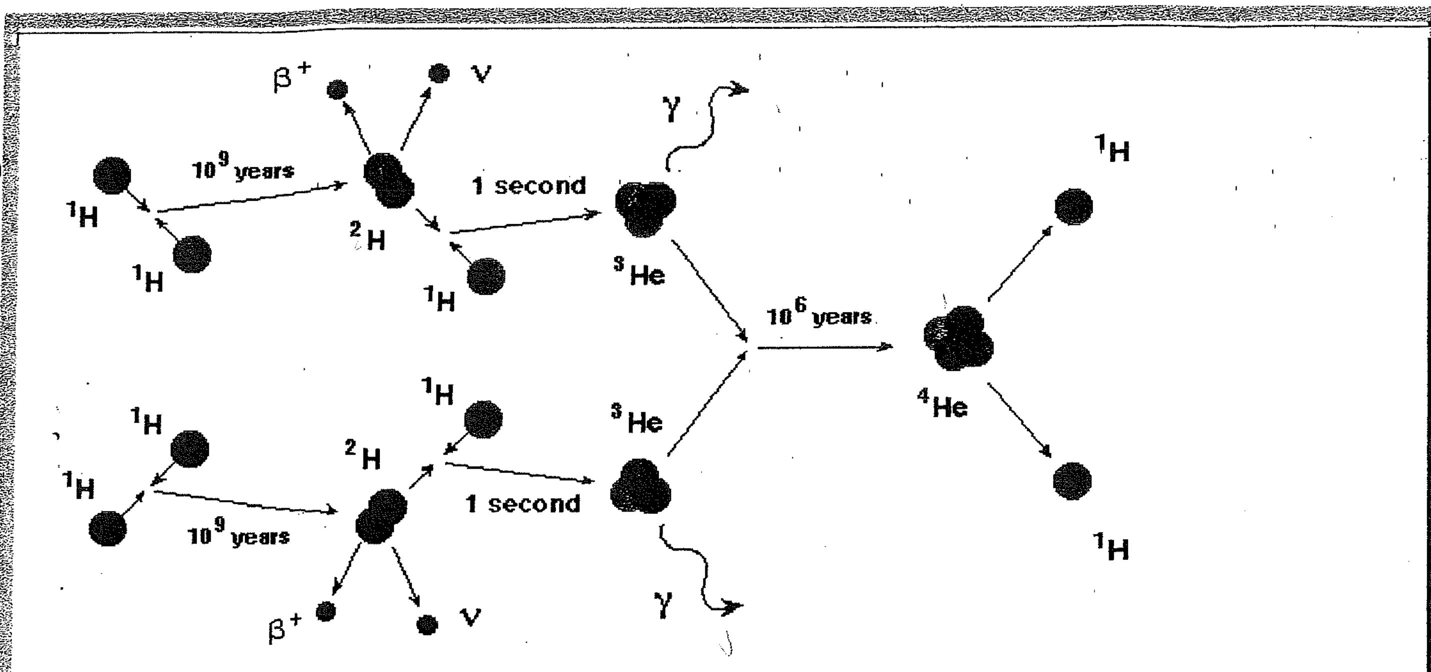
Step 1 $^{1}H + ^{1}H$ results in ^{2}H + positron (e^{+}) + neutrino (v)

Note ^{2}H is deuterium or heavy hydrogen with twice the mass of ordinary hydrogen with one proton and two neutrons in the nucleus and a Positron is the antiparticle of the electron. Positrons have the same mass but positive charge. Note also a neutrino is a ghostly particle, with no charge and with vanishingly small mass (many physicist believe it has no mass (all energy) like a photon.

Step 2 $^{2}H + ^{1}H$ results in ^{3}He + photon

Step 3 $^{3}He + ^{3}He$ results in $^{4}He + ^{1}H + ^{1}H$ + photon

Note: ^{4}He is the normal form of helium. Also note in the chart below the time it takes for each reaction to occur. This is important as it slows to make the Sun last longer.



Main branch of the proton-proton chain.

7. So where does all the energy come from in the above reaction?
In the Sun's fusion sequence, about 0.007 kg of matter is converted into energy for each kilogram of hydrogen processed. This liberates 4×10^{26} J/s inside the Sun, and the Sun radiates this much every second to maintain equilibrium. During the fusion, a small amount of mass (m) is converted to an amount of energy (E), according to Einstein's famous equation $E = mc^2$.

-Every second, the Sun converts 4 million tons of hydrogen into energy and radiates it into space.
- Recent calculations say the Sun won't run out of hydrogen for about 4 billion years.

8. What is the temperature, pressure, and density of the Sun's core?
- Sun's center temperature reaches about 15 million Kelvins.
- The gas pressure at the Sun's core is about 250 billion times the Earth's at sea level.
- Sun's core density 158.000 kg/m^3 which is 158 times denser than water and about 20 times denser than iron. One cubic inch of this core gas would weigh nearly 6 lbs.
- The core of the Sun occupies about the inner quarter of the Sun's radius. This 1/64th of the Sun's volume contains about half the solar mass and generates 88% of the solar energy.

9. How does the energy get from the core to the surface of the Sun?

- Throughout most of the Sun's volume, this energy moves primarily by radiation.
- Very little moves by conduction. In the outer part the Sun uses convection.

0. What is the solar neutrino puzzle?

nstruments that detect neutrinos detect fewer neutrinos than solar theorists predict.
ide note: Considering that about 10 trillion neutrinos pass through your body every econd and that neutrinos interact so weakly that vast detectors must be assembled to atch the rare interactions between a neutrino and an atomic nucleus and that the etectors must be placed deep underground to shield them from contaminating signals ue to cosmic ray particles from interstellar space, I'm not surprised that this problem xists.

1. What do solar seismologist do, what have they discovered thus far, and where do they o their work?
olar seismologist study solar oscillations. The oscillations are seen as volumes of gas near he Sun's surface that rise and fall with a particular frequency.
'he most well-studied oscillation has a 5-minute period (found in 1960), during which ortions of the Sun's surface move up and down by 10 km.
ong-period oscillations offer the prospect of mapping out conditions near the core.
'o get their data they probably now use SOHO (explained below) or the established esearch station at the South Pole, so they can take advantage of the long summer days for ontinuous observations; and they have established a set of observers with similar istruments at observatories around the world, allowing 24 hour coverage of the Sun.

The Solar and Heliospheric Observatory (SOHO)

OHO was launched on December 2, 1995. The SOHO spacecraft was built in urope by an industry team led by Matra, and instruments were provided by uropean and American scientists. There are nine European Principal

Investigators (PI's) and three American ones. Large engineering teams and more than 200 co-investigators from many institutions supported the PI's in the development of the instruments and in the preparation of their operations and data analysis. NASA was responsible for the launch and is now responsible for mission operations. Large radio dishes around the world which form NASA's Deep Space Network are used to track the spacecraft beyond the Earth's orbit. Mission control is based at Goddard Space Flight Center in Maryland.

12. If the Sun is a giant ball of gas, why does it appear to have a sharply defined surface?

The answer involves the opacity of the gas – its ability to obscure light passing through it. Gas in the photosphere has many negative hydrogen ions (extra electron) which obstruct light and cause high opacity. They produce an opaque layer beyond which we cannot see.

13. What is a granule in the Sun's photosphere?
The convective motions that bring mass and energy from the interior disturb the photospheric surface. These disturbances cause granules (Figure 15-6 page 297) which is a convection cell 1000 to 2000 km across, rising from the subphotospheric layers. Each granule rises at a speed of 2 to 3 km/s and lasts for a few minutes. Slightly darker regions between granules mark areas where cooled gas descends again into the Sun.

14. List at least two facts about the solar atmosphere.

1). The chromosphere (which means "color layer") is a pink-glowing region of gas just above the photosphere. Its light is mainly the red hydrogen alpha emission line. E.G.Gibson (1973) described it as "froth on top of the turbulent and relatively dense photosphere."
2). The chromosphere is a thin layer about 2500 km thick. In its upper regions the temperature exceeds 10,000 K.
3). Above the chromosphere is the rarefied, hot gas of the corona. Gas in the corona reaches amazing temperatures of 2 million kelvins, due to magnetic effects and shock waves from the violent convective motion in the photosphere and chromosphere.
4). During solar eclipses the chromosphere can be seen as a thin ring of small, intense red flames, and the corona is visible to the naked eye as a pearly, glowing gas around the Sun. In 1930 French astronomer Bernard Lyot built an instrument called the coronograph, which artificially eclipses the Sun and allows the intriguing gases of the corona and chromosphere to be studied at will. We should check this out!

5. What are sunspots?

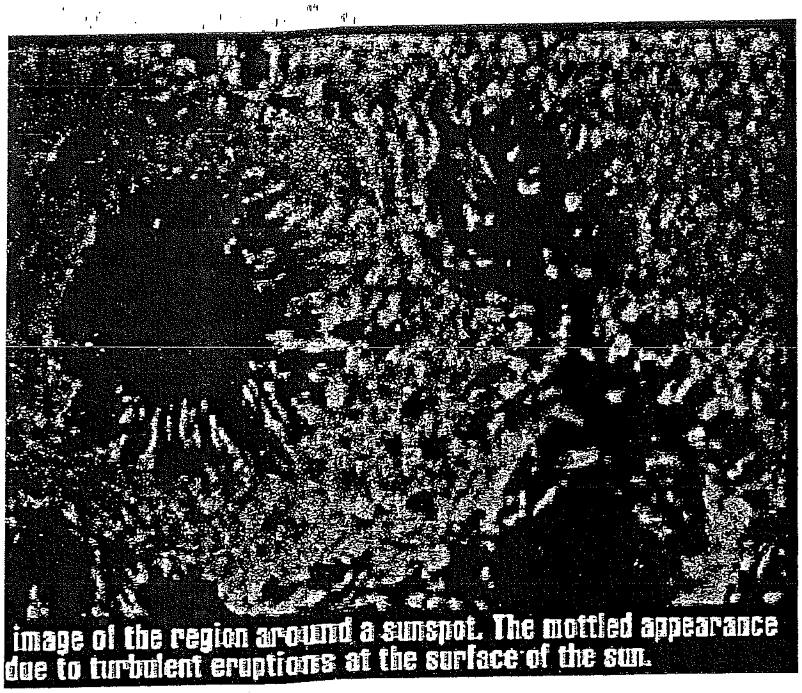


image of the region around a sunspot. The mottled appearance due to turbulent eruptions at the surface of the sun.

A sunspot is a magnetically disturbed region that is cooler than its surroundings. A sunspot looks dark only because its gases, at 4000-4500 K, radiate less than the surrounding gas at about 5700 K. "A sunspot is a dark part of the sun's surface that is cooler than the surrounding area. It turns out it is cooler because of a strong magnetic field there that inhibits the transport of heat via convective motion in the sun. The magnetic field is formed below the sun's surface, and extends out into the sun's corona."

6. Why do they call it a 22 year solar cycle when the sun actually flips its ıagnetic poles every 11 years?

he sun has the maximum amount of sunspots every 11 years because the Sun otates faster at its equator than near its poles. The reason it is called a 22 year ycle is that if the North magnetic pole is on top then 11 years later it flips to the ottom and the South magnetic pole is on top and then 11 years later it flips ack the same way it was 22 years earlier.

7. What makes up the solar wind?

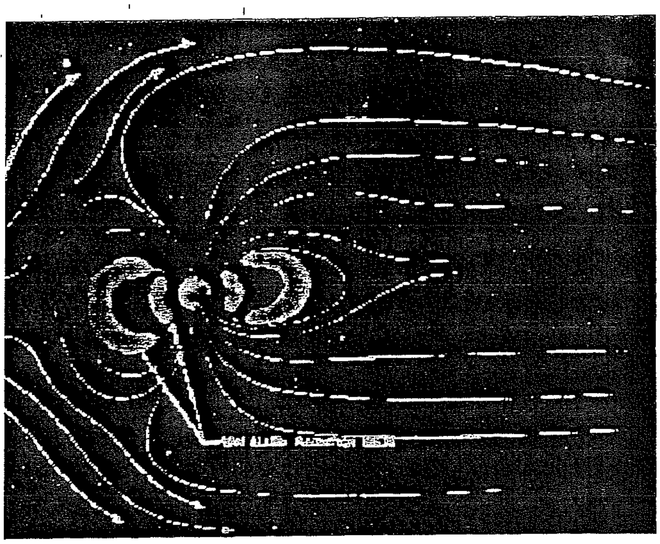
he solar wind streams off of the Sun in all directions at speeds of about 400 m/s (about 1 million miles per hour). The source of the solar wind is the Sun's ıot <u>corona</u>. The temperature of the corona is so high that the Sun's gravity annot hold on to it.

Solar Wind Variations

he solar wind is not uniform. Although it is always directed away from the Sun, t changes speed and carries with it <u>magnetic clouds</u>, <u>interacting regions</u> where ıigh speed wind catches up with slow speed wind, and <u>composition variations</u>. he solar wind speed is high (800 km/s) over <u>coronal holes</u> and low (300 km/s) ver <u>streamers</u>. These high and low speed streams interact with each other and lternately pass by the Earth as the Sun rotates. These wind speed variations buffet the Earth's magnetic field and can produce storms in the Earth's magnetosphere.

Note is the solar wind anywhere near the speed of light? Solar radiation itself exerts an outward force on small dust particles. This effect, which is greater on small particles, is called radiation pressure. Together these are the forces that blow comet tails away from the Sun.

18. What are the Van Allen belts and when were they discovered?



The Earth's Van Allen Belts consists of highly energetic ionized particles trapped in the Earth's geomagnetic fields. On the sunward side of the Earth, the geomagnetic fields are compressed by the Solar Wind while on the opposite side of the Earth, the geomagnetic fields extend to three Earth Radii. As a result, the geomagnetic field form an elongated cavity, known as the Chapman-Ferraro Cavity, around the Earth. Within this cavity, reside the Van Allen Radiation Belts. These radiation belts are composed of electrons with thousand eV energies, and protons with million eV energies.

The particles in the belts are not directly injected by the Solar Wind. Magnetic fields of a magnitude of 0.3 gauss prevent the Solar Wind from directly entering the radiation belts. Most of the particles result from neutron Albedo. Neutron Albedo is the process where Solar Flare particles interact.

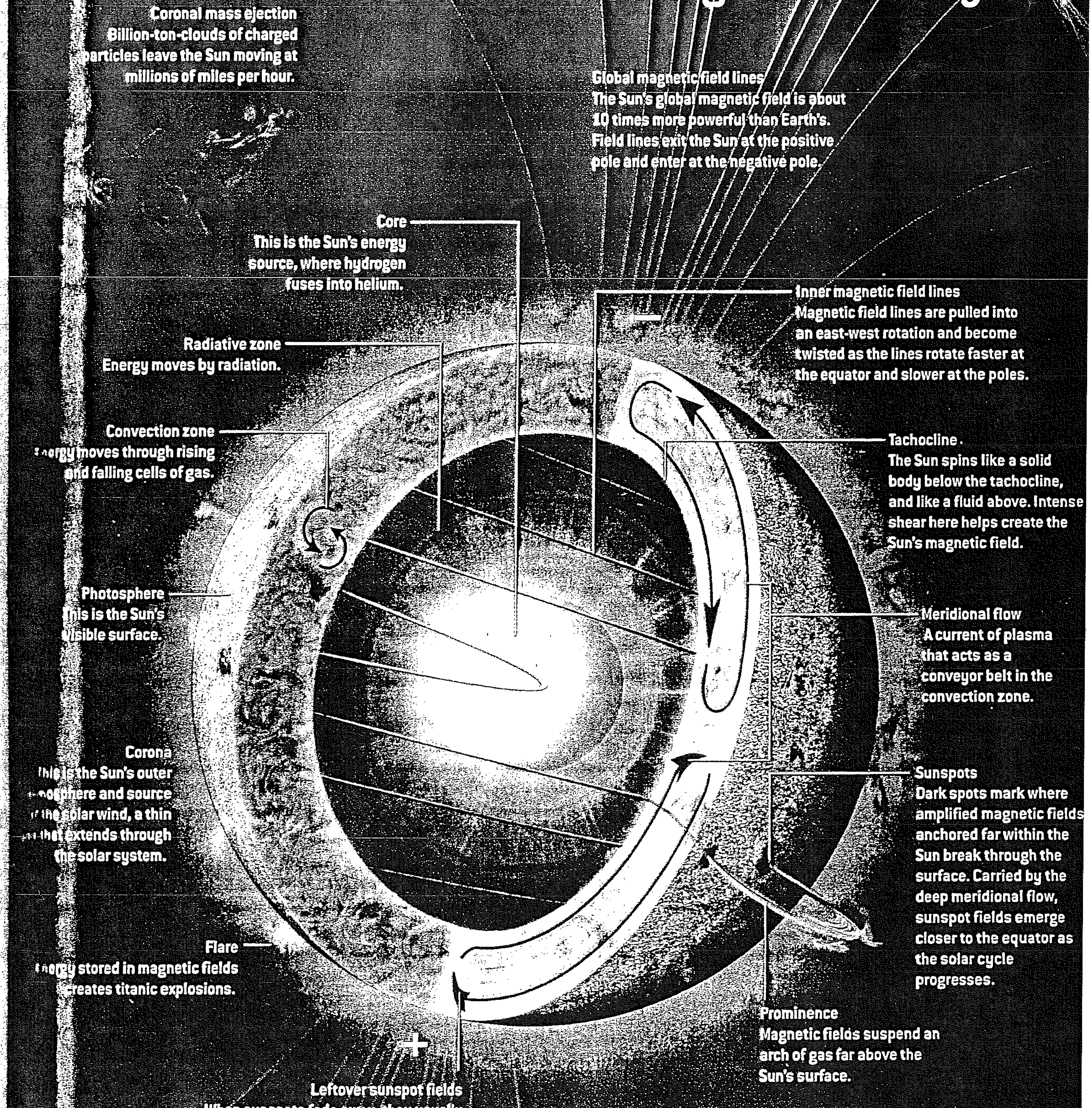
These Van Allen belts of radiation were discovered in 1958 by the first artificial satellites.

19. What causes the northern lights and the southern lights?

Some ions in the solar wind are driven by our magnetic field along the magnetic field lines which are strongest at the poles. These particles crash into the upper atmosphere, excite the gas atoms there, and cause them to glow. This glow can be seen from the ground; it is called the aurora or northern lights. Because these effects are related to mighty solar flares, they are most common around the years of sunspot maximum.

Even on days or nights when there is no aurora, reactions among molecules in the high atmosphere cause a faint glow at various wavelengths. This glow is called airglow.

Peeling the Sun's layers



SOLAR SCIENTISTS' UNDERSTANDING of what makes the Sun tick has improved dramatically over the last decade. This is due in large part to advances in helioseismology, which probes the solar interior using sound waves that ripple throughout the Sun. Near the surface, a meridional flow moves sunspot leftovers toward the Sun's poles. Of opposite polarity to the Sun's global field, these remnant fields accumulate at the poles and force our star's magnetic flip. The same flow pulls the fields deep into the Sun — to the tachocline at the base of the convection zone — where they will be amplified to provide sunspots for the following solar cycle.