

Natural Disasters

Lecture 35

Topic 4: Solar Storms

Text Source Today:

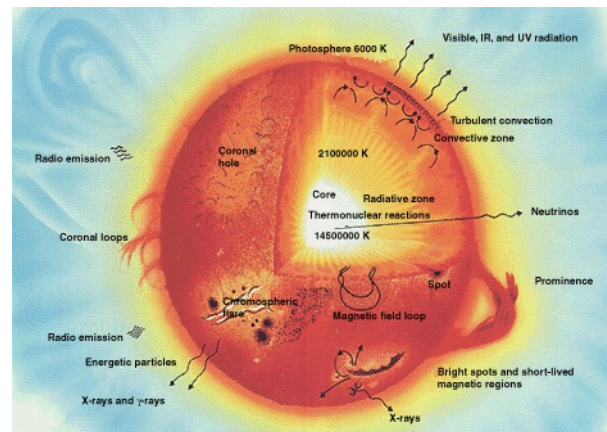
None.

Topic 4: Solar Storms

- **Our Sun:** a “**yellow star**” at the center of our solar system
- Mean distance of 150 million km (93 million miles; **1 AU**) from Earth; mean diameter ~1.4 million km (~865,000 miles); **> 1 million** Earth's could fit inside the Sun

- Sunlight reaches Earth in about **8 minutes, 19 seconds**

♦ Sun's mass consists of **~72% hydrogen**, **~26% helium** and **< 2%** other elements



- Internal structure of Sun determined by pressure waves, called “**sunquakes**”; **helioseismology**

● Layers of the Sun:

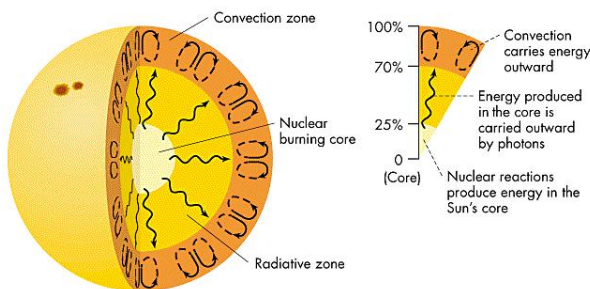
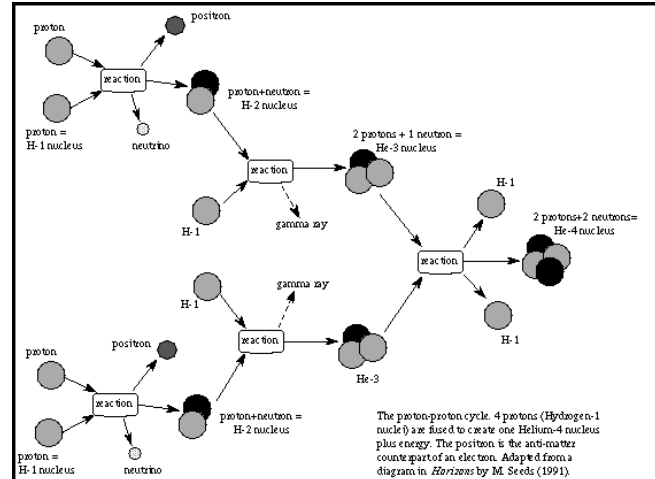
Layer	Thickness (km) and/or Feature			Temperature (°C)	Visible Features
Heliosphere	contains solar wind and extends past Pluto to the Heliopause (100 AU)				
Corona	creates the solar wind			1-2 million	solar eclipse
Chromosphere	2000 ; prominences/spicules			6000(bot)-20,000(top)	eclipse flash
Photosphere	200 ; visible surface of Sun			6000	granulation
Layer	Solar Radii	Heat Transfer	Density (g/cm ³)	Temperature (°C)	Features
Convection Zone	70% to surface	convection	0.2	Top: 6000 Bot: 2 million	creates solar granulation
Radiative Zone	25% to 70%	radiation	Top: 0.2 Bot: 20	Top: 2 million Bot: 7 million	generates magnetic field
Plasma Core	0% to 25%	nuclear fusion	150	>15 million Source of Intense Heat	$E = mc^2$ $H \rightarrow He$

♦ **Nuclear fusion in the core, p-p (proton-proton) chain**, is where all the Sun's heat is produced as **protons (hydrogen nuclei)** are fused into **helium** nuclei. Every second, about 3.7×10^{38} protons (out of a total of about 8.9×10^{56} free protons)

are converted to helium. The energy released amounts to the equivalent of 9.15×10^{10} megatons of TNT per second!

[**4H-1**: 4.03176; **He-4**: 4.002602; **m**= 0.029158 g/mol; **E=mc²**]

1 gram of mass → 21.5 kilotons of TNT; 0.029158 g → 0.63 kt TNT

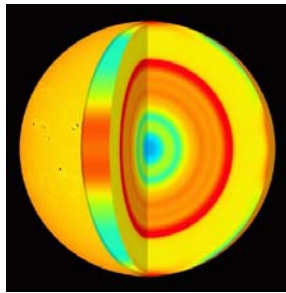


- The high-energy photons (gamma rays) released in the **p-p chain** reaction are absorbed in a few millimeters of solar plasma and re-emitted in a **random** direction. Each gamma ray in the Sun's core is converted into several **million** visible light photons before

escaping into space. It can take from **10,000 to 170,000 years** for a photon to reach the **surface of the Sun**! (It only takes about a **week** to rise through the convection zone.)

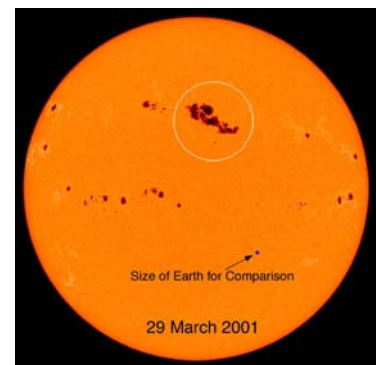
♦♦ The **tachocline** is the sharp transition between the top of the **uniform** rotation of the radiative zone and the **differential rotation** of the convection zone above. The resulting **large shear** at this transition zone is believed to be the source of the Sun's strong **magnetic field (solar dynamo)**.

- The Sun rotates on its axis about once per **month**. The resulting **centrifugal effect** of this **slow** rotation is 18 million times weaker than the surface **gravity** at the equator. The tidal force of the planets is even weaker. This is why the Sun is a near **perfect sphere**.

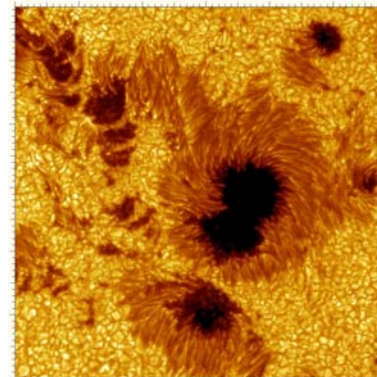
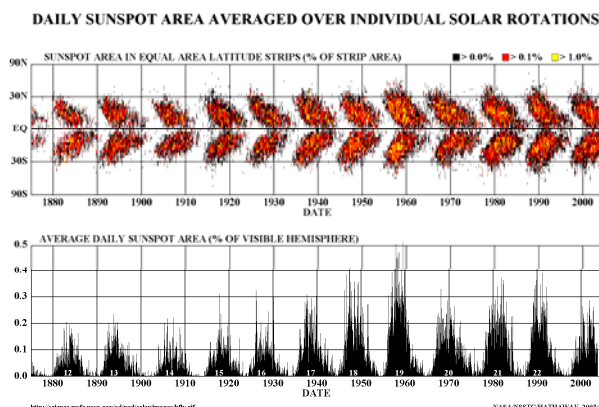


- ♦♦ The Sun actually rotates faster at its **equator** (25 days) than at its **poles** (33.5 days). This differential rotation from equator to the poles results in a twisting of the magnetic lines of force leading to the formation of **sunspots**, **solar prominences**, **solar flares** and **CMEs**.

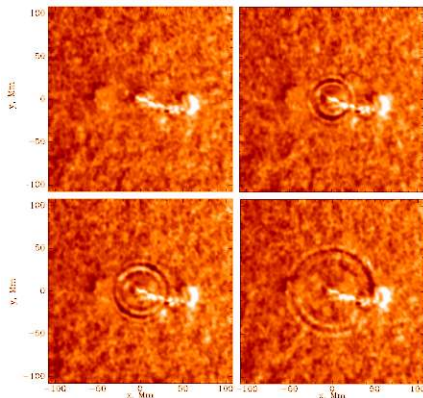
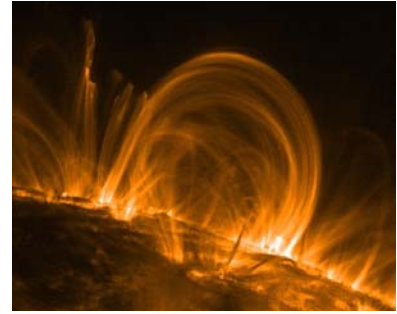
- ♦ **Sunspots** are caused by intense magnetic activity, which inhibits convection, forming areas of **reduced** temperature, $\sim 4000^\circ\text{C}$ (and thus, appear **darker** than surrounding material). Can last only an hour or two, to as long as several months.



- ♦ **Sunspots** operate on an **~ 11 -year cycle** from minimum, to maximum when the Sun experiences a magnetic **pole reversal**. The sunspots first appear in the **higher** latitudes and end up near 10° north and south of the equator at the time of solar maximum. The graph below displays the “**butterfly** diagram.”

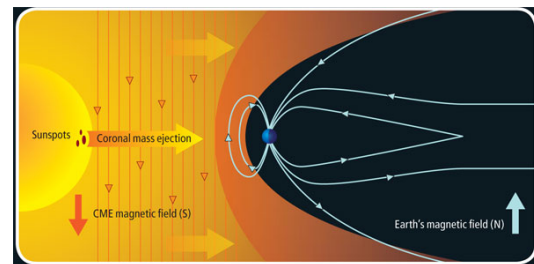
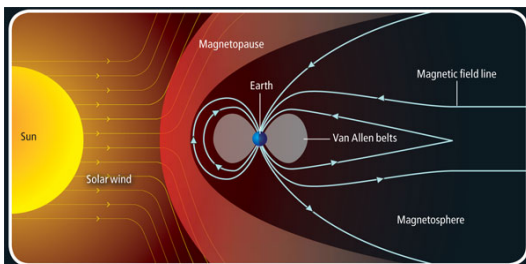
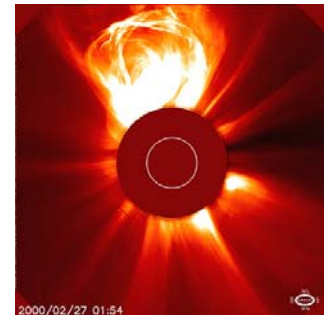


♦♦ **Solar prominences** are arcs of **cooler** gas that erupt from the surface of the Sun, extending hundreds of thousands of miles into space and are held above the Sun's surface by the **strong magnetic field**. They can last for **months**, eventually ejecting their material into space.



♦♦ **Solar flares** which appear very **bright**, are a **super hot** (2-13 million °C) gaseous surface eruption that are ejected thousands of miles into space. Usually found in active regions around **sunspots** and last from **minutes to hours**. Solar flares can cause **“sunquakes”**.

♦♦ **Coronal Mass Ejection (CME):** A massive balloon-shaped eruption of coronal **plasma** material (protons, electrons, and small quantities of heavier elements), which carries the coronal **magnetic field**. Typically reach Earth in **1 to 5 days** after the initial eruption. When the **CME** reaches Earth, it compresses the magnetosphere on the day side and extends the night-side tail. When it **reconnects** on the night-side, it is directed back toward Earth's upper atmosphere, creating the **auroras**.



♦ CMEs and solar flares create **geomagnetic storms**, which can disrupt radio transmissions, cause power outages (blackouts) and can cause damage to satellites (swelling atmosphere) and to electrical transmission lines. A moderate storm is measured at **-100 nT** (**nano-Teslas**) and an extreme one at **-300 nT**. A “worst case scenario” is when the **polarity** of the CME is **opposite (southward)** to the polarity of Earth’s magnetic field.

♦ **Solar Superstorm of 1-2 September 1859:** A massive CME (est. **-1760 nT**) caused the failure of telegraph systems all across Europe and North America. Auroras were seen as far south as Hawaii and the Caribbean! The CME took fewer than 18 hours to reach Earth, the path being “cleared” by a previous CME.

● **Quebec, 13 March 1989:** A CME (**-589 nT**) knocked out power to the entire Canadian province for 9 hours.

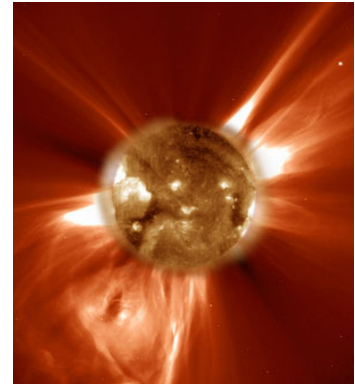
♦♦ A CME induces a **fluctuation** of the power, which overheats the coils in **transformers**, starting fires and in many cases, melting them. This could result in a cascading failure within the power grid. (Attempts to balance rapidly **fluctuating** induced currents in **oil/gas pipelines** greatly increases corrosion rates.)

♦ A super CME could overload the **global power grid** (especially in the U.S, Canada and China) and create a **global blackout** that could take months to a year (or more) to rebuild!

♦ The world today is way more dependent on **electricity** than it ever was back in **1859**. An event similar to **1859** could, in effect, set the **high-tech** countries, including the U.S., back to “**developing country**” status by the World Bank!

Potential Scenario following a Massive CME

- Induced ground currents knock out **300 key transformers** within about **90 seconds**, cutting off power for more than **130 million people**.



- First to go (immediately for those in high-rise buildings) is **drinking water**.

- With no trains, no trucks, no cars (filling stations would not be able to pump gas), **supermarket shelves would go empty very quickly**.

- Back-up generators would **run out of fuel** in fewer than **72 hours**. After that, **hospitals** shut down. No more modern healthcare. And, with the factories shuttered, no more medications.

- Forget **nuclear power**. The stations are programmed to shut down in the event of serious grid problems and are not allowed to restart until the power grid is up and running.

- With no power for **heating, cooling or refrigeration systems**, people could begin to die within days.

♦ In a report funded by NASA and issued by the National Academy of Sciences (NAS): **“It could conceivably be the worst natural disaster possible, a planetary disaster. It is questionable whether the U.S. would ever bounce back.”**

NASA is warning that there’s a 12 percent chance an extreme solar storm will hit Earth in the next decade!