Astronomy 150:
Killer Skies

This Class (Lecture 16):
Killer Sun

Next Class:
Supernova

HW5 due on Sunday!

Music: *It Overtakes Me*– The Flaming Lips

Night Obs

- Dates:
  - Monday, Sept. 21st ✔
  - Tuesday, Sept. 22nd ✗
  - Wednesday, Sept. 23rd ✗
  - Thursday, Sept. 24th ✗
  - Monday, Sept. 28th ✗
  - Tuesday, Sept. 29th ✔
  - Wednesday, Sept. 30th ✔
  - Thursday, Oct. 1st ✗
  - Monday, Oct 5th ✔
  - Tuesday, Oct 6th ✗
  - Wednesday, Oct 7th
  - Thursday, Oct 8th

Go to assignment page on class website for more info.

You **MUST** download worksheet before you go.

Can be cloudy, so check webpage before you go.

Question

Did you go to the Observatory yet?

a) Yes, it was okay.
b) Yes, it was cool!
c) Yes, it was the highlight of my life so far!
d) Yes, but it was boring.
e) No, but I will do so as soon as I can, I promise. I had other things I had to do, but I really, really want to go and I will make it a **top** priority in my life!

Computer Lab: 15% of Grade!

- Computer labs to look for real killer asteroids.
- Dates:
  - Monday Sept 28th ✔
  - Monday, Oct 5th ✔
  - Monday, Oct 12th
- Places:
  - Nevada Labs
  - Oregon Labs
- Limited space each day, so you ***MUST*** have a reservation for that day and that lab!
- See Assignments webpage for more info and to sign up!
- Lectures are cancelled for those dates.

Question

Did you go to the Computer Lab yet?

a) Yes, it was very cool! I saw an NEA!
b) Yes, it was okay.
c) Yes, but it sucked.
d) No, I am going on Oct 12th.

Outline

- The Active Sun
- Sunspots and the magnetic Sun
- The perfect space storm

But, I Know You're Thinking

But Solar Evolution is so far in the future, is there anyway that the Sun can kill us today?

Yes!

Top 10 Ways Astronomy Can Kill you or your Descendents

1. Impacts!
   Splat.. Boom… Watch out for space rocks!
2. Solar Evolution.
   MS to Red Giant to White Dwarf.
3. Coronal Mass Ejections
   Cold winter days..

Imagine

- It's winter. It's cold.
- The Sun is unusually active, and you hear NASA is worried about something called Space Weather.
- A huge batch of new sunspots on the Sun's equator are seen..
- A huge coronal mass ejection from the Sun comes screaming toward the Earth.

Approximate size of earth for

Imagine

- All of our satellites are knocked out.
- Electrical transmission lines overload and melt, causing wildfires.
- Half the planet is without power.
- Thousands die the first night…
- Then, more sunspots…
- And you can't remember what Leslie mentioned about CMEs….

Approximate size of earth for

Top 10 Ways Astronomy Can Kill you or your Descendents

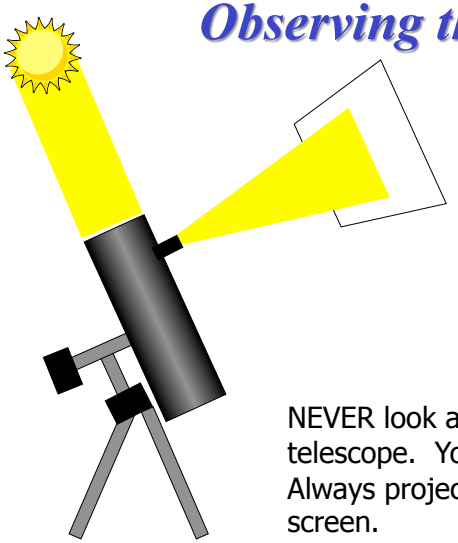
2. Coronal Mass Ejections, CMEs !

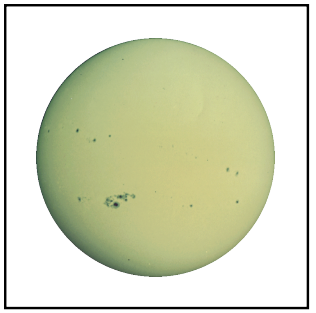
The Sun is a star! The Sun seems the same every day, but it isn't. It changes. The Sun is a huge vast might furiously seething cauldron of mass and energy! The Sun can get mean!

I mean rock impacts may never happen, and Solar Evolution is so far away, but CMEs can kill.

http://www.youtube.com/watch?v=Pfkz-uMkafY

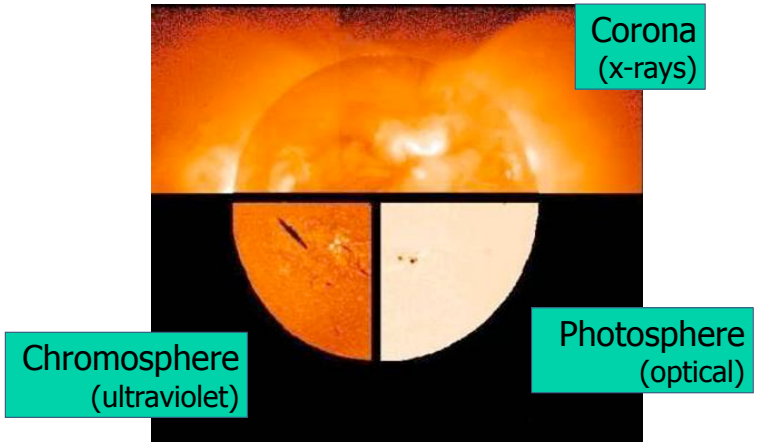
Observing the Sun



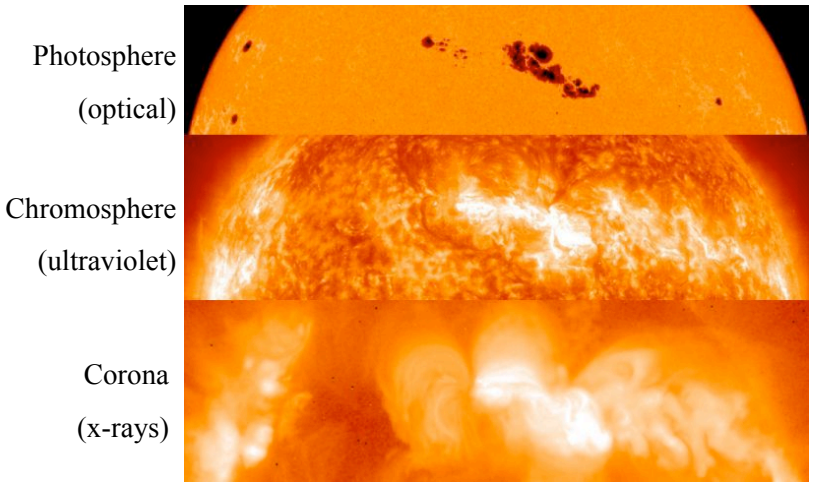


NEVER look at the Sun through a telescope. You will damage your eyes! Always project the Sun's image onto a screen.

The Outer Layers of the Sun



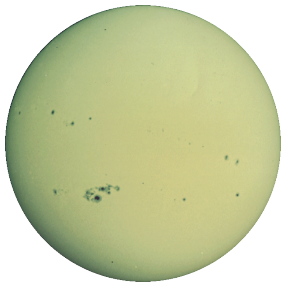
The Various Layers



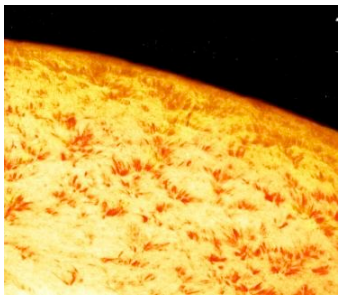
http://antwrp.gsfc.nasa.gov/apod/ap010419.html

The Photosphere

- Apparent "surface" of the Sun
  - Ionized atoms make the gas highly opaque
- Most of the Sun's light we see comes from the photosphere
- Temperature, about 5800 K
  - Hotter as you go deeper into the Sun



The Chromosphere



- Very sparse layer of gas above the photosphere
- Hot – Over 10,000 K
- Produces very little radiation – too sparse
- Only seen during eclipse or with special instruments
- Helium was first discovered in the chromosphere
- Heated by magnetic and acoustic energy

The Corona

- Sun's outer atmosphere
- Visible only by blocking light from photosphere
- Heated by magnetic and acoustic energy
- Temperatures about 2 million K
- Hot enough to produce X-rays!

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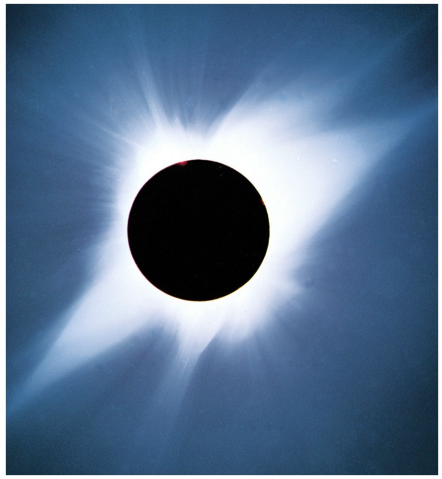


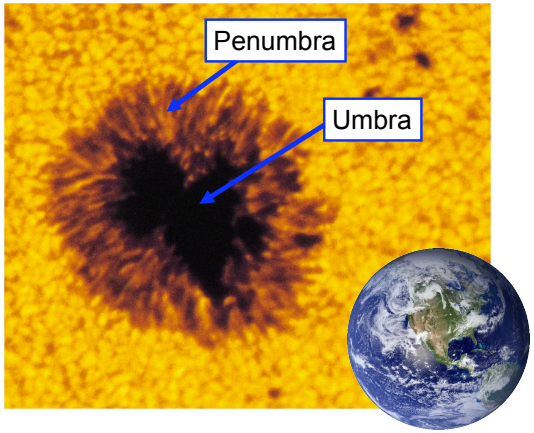
Question

Which of the following is not a layer of the Sun?

a) Stratosphere
b) Corona
c) Chromosphere
d) Photosphere
e) Core

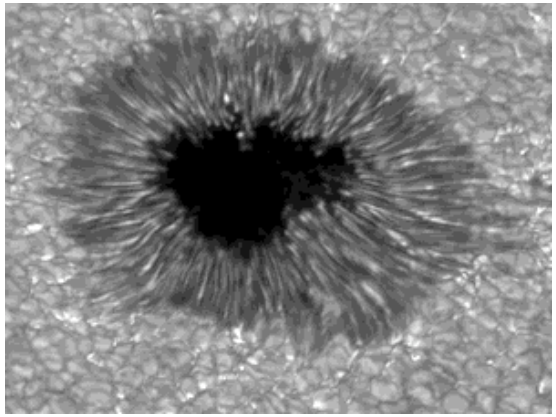
Why are Sunspots Dark?

- Dark spots on the Sun.
- Slightly cooler than their surroundings: 4000 K vs. 5800 K
- Since brightness depends on temperature like the 4th power, they are only 30% dimmer.



Sunspots

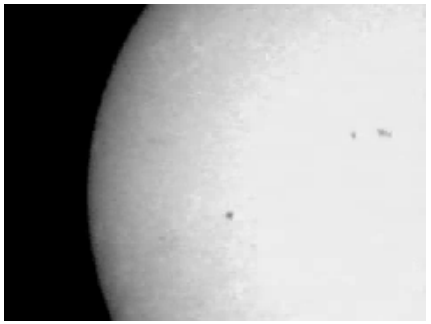
- Usually last a few days to few weeks, sometimes months.
- Sunspots change over time
  - Grow, shrink, merge, rotate



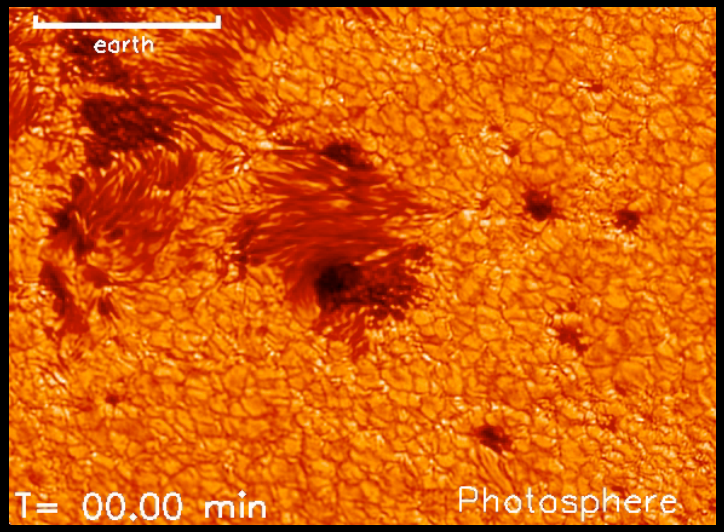
http://antwrp.gsfc.nasa.gov/apod/ap000223.html

Sunspot Motion

- Sunspots' motion reveals the Sun's rotation!
- The Sun spins about once every 25 days at the equator
- At the poles, it spins once every 30 days
- Called **differential rotation**

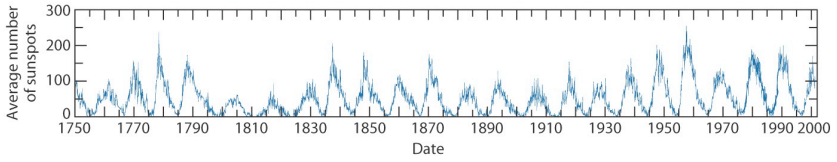


Sunspots



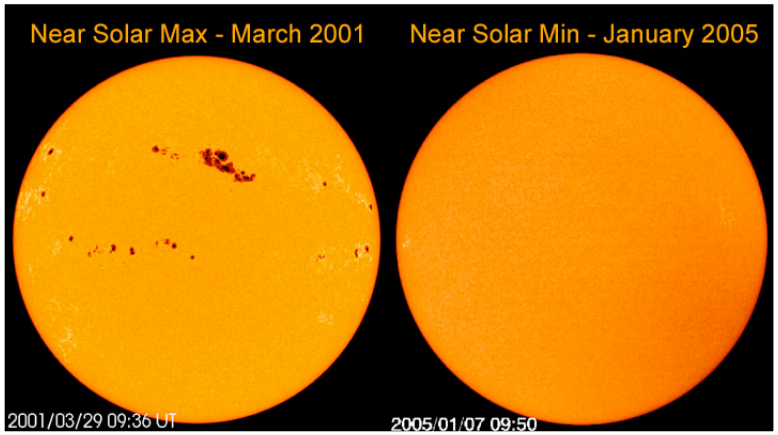
http://www.astro.physik.uni-goettingen.de/~bruno/APOD/apod.html

Sunspot Cycles



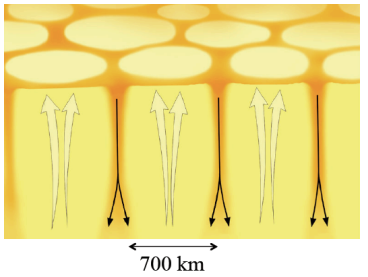
- Start near 30°N/S, migrate toward equator
- More numerous every 11 years (**solar maximum**)
- 2008/2009 the least number of sunspots since 1950s
- Next maximum is May 2013 with expected below average count

Sunspot Cycles

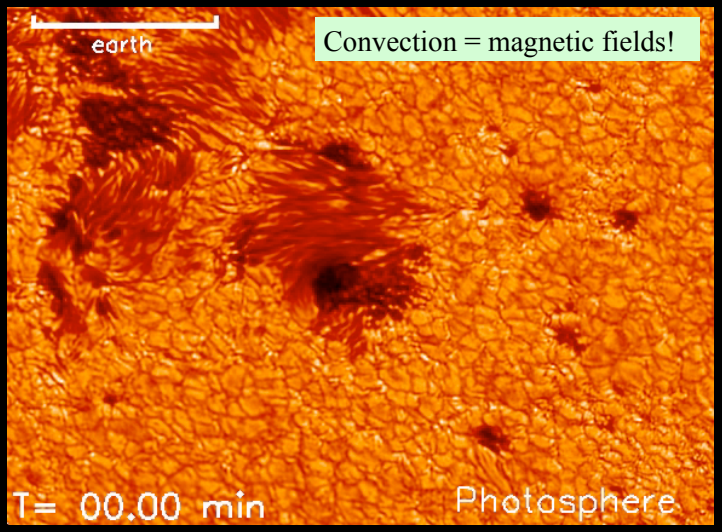


The Solar Surface: Boiling Soup

- The Solar surface is a cauldron of bubbling and noise.
- In the Sun's upper layers, hot gas rises to the surface, cools, and falls back into the Sun
- This **convection** is primary means of transporting energy to the surface.



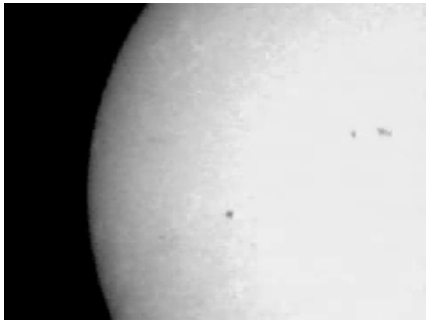
Sunspots



http://www.astro.physik.uni-goettingen.de/~bruno/APOD/apod.html

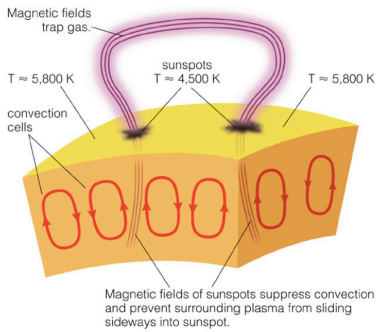
The Magnetic Cycle

- Sun's magnetic field comes from its surface
- Convection and differential rotation twist and wrap magnetic field lines
- When field lines get too twisted, they pop through the surface
  - Makes sunspots!



What Causes Sunspots?

- Magnetic field "loops" popping through the photosphere
- Powerful magnetic activity shuts down convection
  - 5,000 times stronger than the Earth's field
- Gas cools off (4000 K)
- Appears darker than the rest of the photosphere

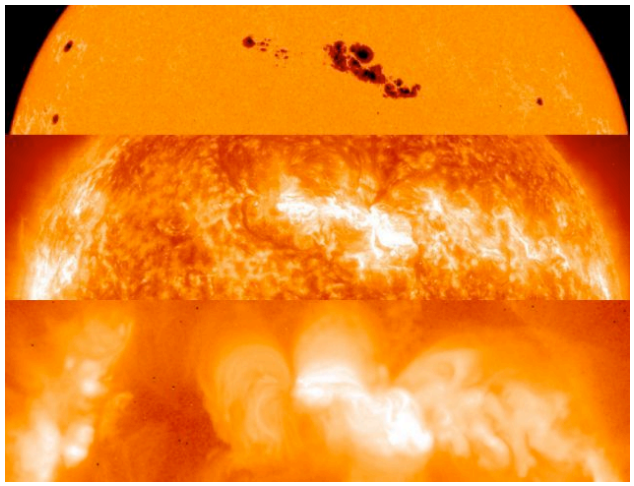


Sunspots and the Outer Layers

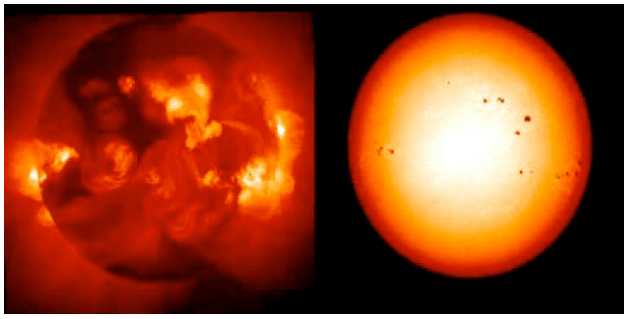
Photosphere (optical)

Chromosphere (ultraviolet)

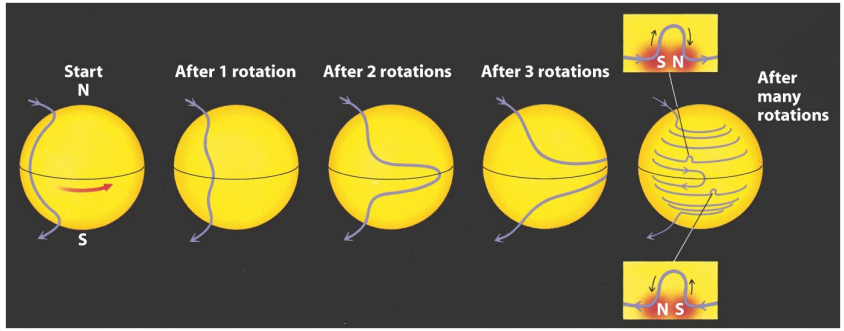
Corona (x-rays)



Sunspots and the Outer Layers

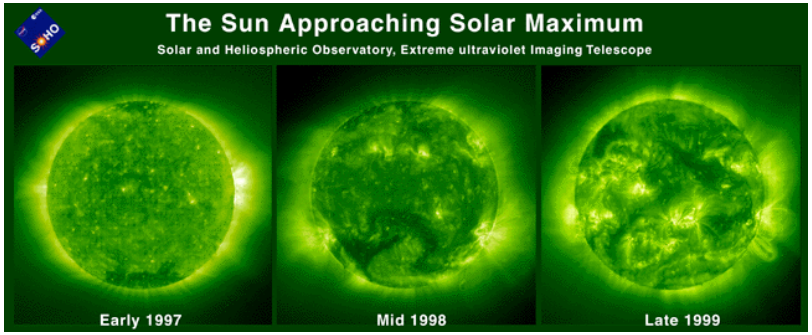


The Magnetic Cycle= Solar Cycle

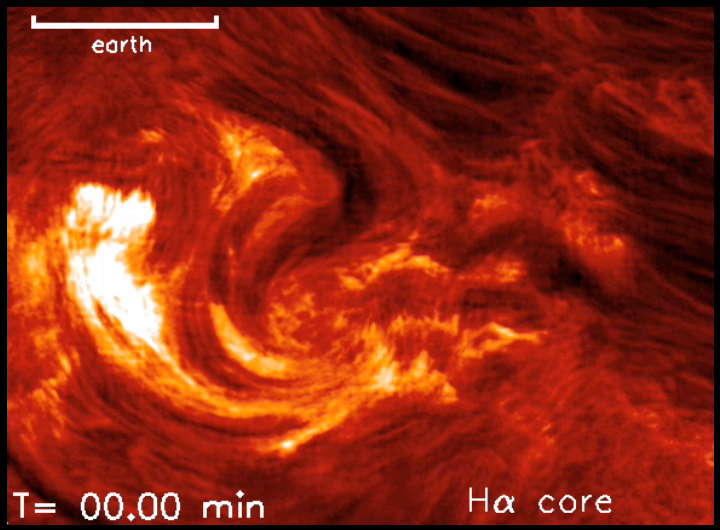


- Every 11 years, the field breaks apart and reorders itself
  - North and south magnetic poles flip!

Magnetic Activity on the Sun



Sunspot and Magnetic Fields



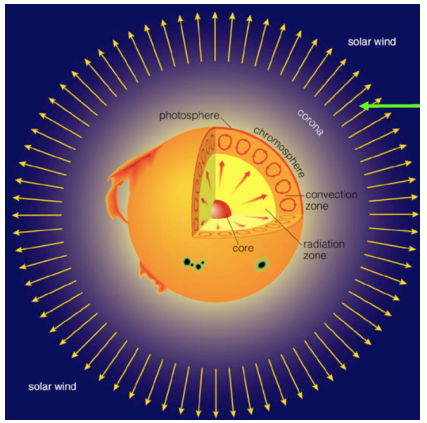
Question

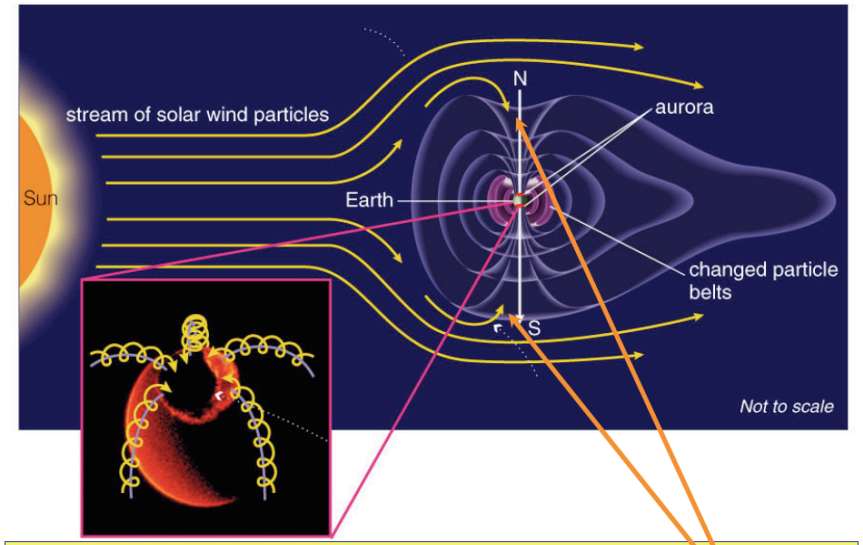
What causes Sunspots?

a) It is a natural feature of a young Sun. It should clean up as it ages.
b) Magnetic fields.
c) Thermonuclear explosions.
d) Granulation
e) Heavy rock music.

Solar Wind

- Some of the gas in the Sun's corona is moving fast enough to escape the Sun's gravity
- Accelerated by the Sun's magnetic field
- Flows out into the solar system
- Made of charged particles





Most solar wind particles are deflected by Earth's magnetic field, but some enter at the poles

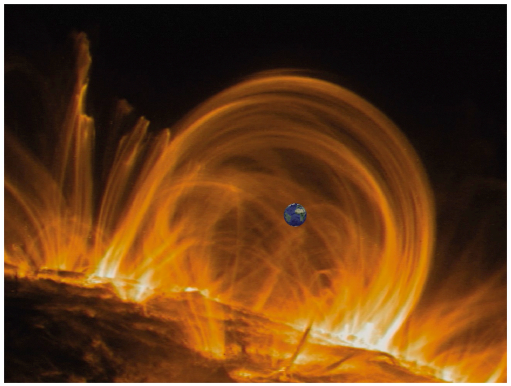
Auroras (Northern/Southern Lights)

http://www.youtube.com/watch?v=icugqEEOgkg

Energetic particles from the solar wind cause *auroras*

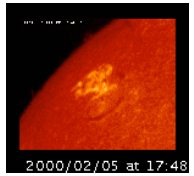
Prominences

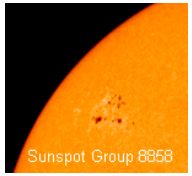
- Ropes of gas trapped in magnetic loops
- Almost always associated with sunspots
- Gas can reach temperatures of 50,000 K!

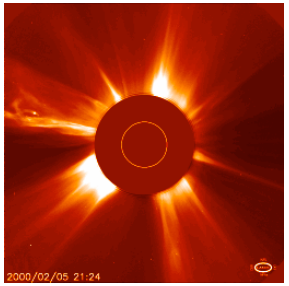


Solar Flares

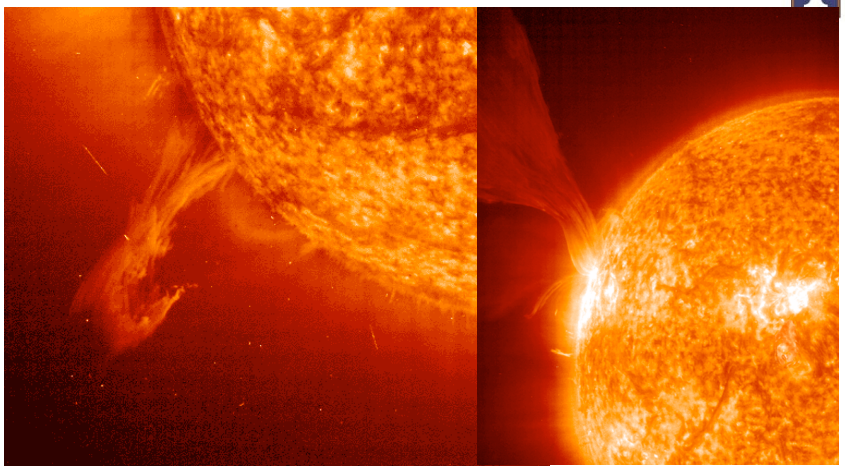
- Explosive releases of magnetic energy above sunspot groups
- Occur when magnetic loops get tangled
- A "short-circuit" of the magnetic field
- Think of it as cutting a coiled up spring.. It releases energy all at once.







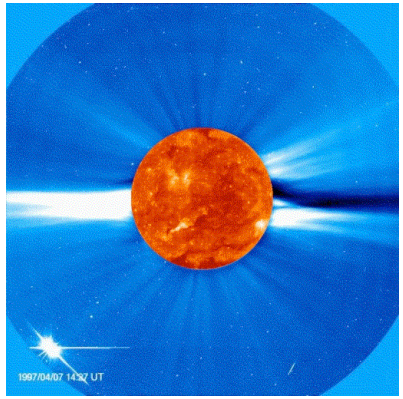
Flares



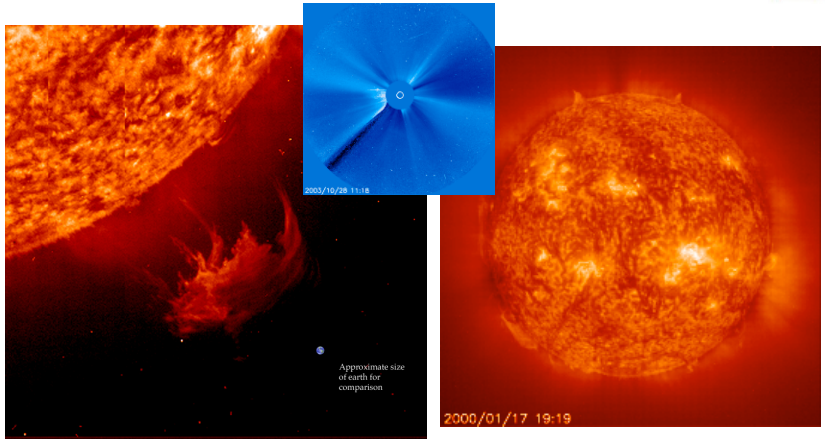
Magnetic activity causes *solar flares that* send bursts of X-rays and charged particles into space from a sunspot group.

Coronal Mass Ejections

- Huge bubbles of gas ejected from the Sun
- Often associated with flares and/or prominences
- 2 trillion tons of ionized gas hurled into the solar system
- 2-3 day at solar maximum (1 per week normally)

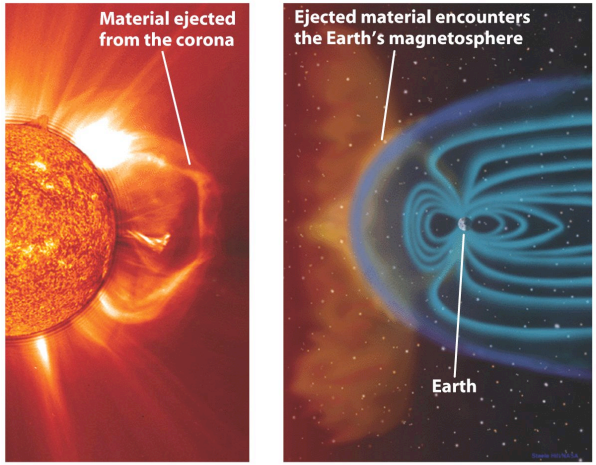


Coronal Mass Ejection: CME



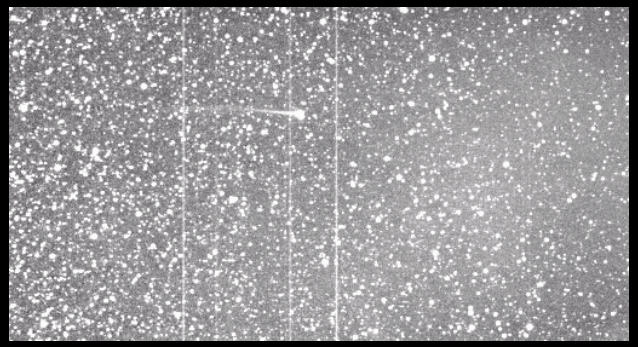
A coronal mass ejection is a much larger eruption (at once) than a solar flare. CMEs eject immense amounts of gas.

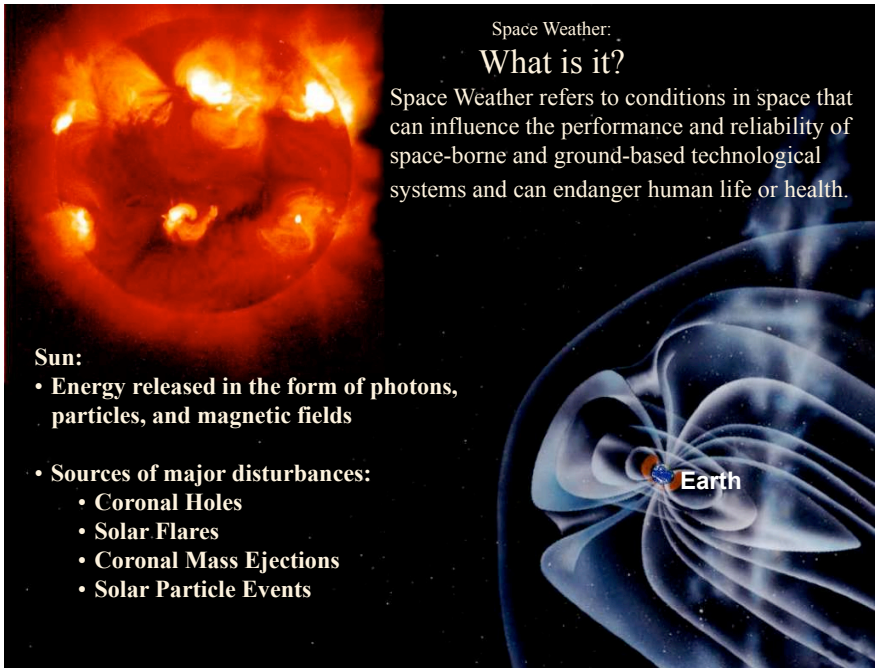
CMEs



(a) A coronal mass ejection (b) Two to four days later

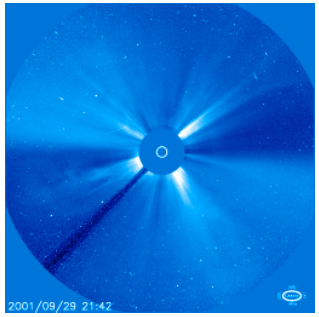
A CME Ripping Off Comet Encke's Tail





1859: The Perfect Space Storm

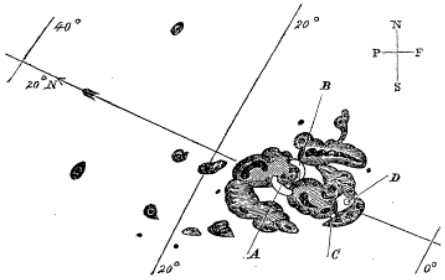
- Most CMEs don't hit the Earth.
- To hit, CME must be from the Sun's equator and in proper orbital phase.
- The bigger the more of an effect
- And, the magnetic field of the event can make a larger impact on the Earth.



Pulkowa, October, 1859.

Description of a Singular Appearance seen in the Sun on September 1, 1859. By R. C. Carrington, Esq.

While engaged in the forenoon of Thursday, Sept. 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. The image of the sun's disk was, as usual with me, projected on to a plate of glass coated with distemper of a pale straw colour, and at a distance and under a power which presented a picture of about 11 inches diameter. I had secured diagrams of all the groups and detached spots, and was engaged at the time in counting from a 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 general remark), two patches of intensely bright and white light broke out, in the positions indicated in the appended diagram by the letters A and B, and of the forms of the spaces left white. My



first impression was that by some chance a ray of light had penetrated a hole in the screen attached to the object-glass, by

Monthly Notices of the Royal Astronomical Society, Volume 20, November 11, 1859

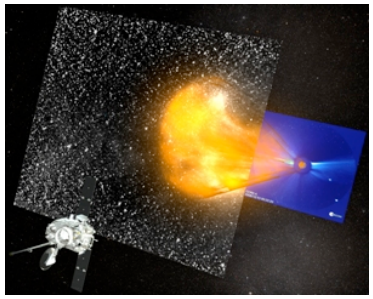
The great magnetic storm hit 18 hours later, traveling at 2300 km/s!

1859: The Perfect Space Storm

- Plasma blob ejected from the Sun right at the Earth.
- The blob had extremely high speeds
- The plasma blob's magnetic field were opposite from the Earth's field
- High technology at the time was telegraphs.
  - The charged particles overloaded the system
  - Melted wires, starting wildfires
  - Aurora were seen as far South as Rome and Hawaii

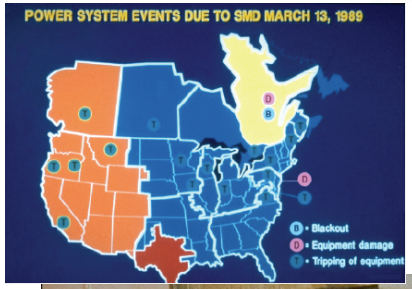
1958: Storm Hard

- Feb 1958 CME observed
- 28 hours later, one of the greatest magnetic storms
- Effects:
  - Toronto area plunged into temporary darkness
  - Western Union experienced serious interruptions on its nine North Atlantic telegraph cables
  - Overseas airlines communications problems



1989: Storm Hard

- March 13, 1989 – a CME knocked out a power transformer in Quebec
- Plunged 6 million customers into darkness!
- Affected power grids across North America



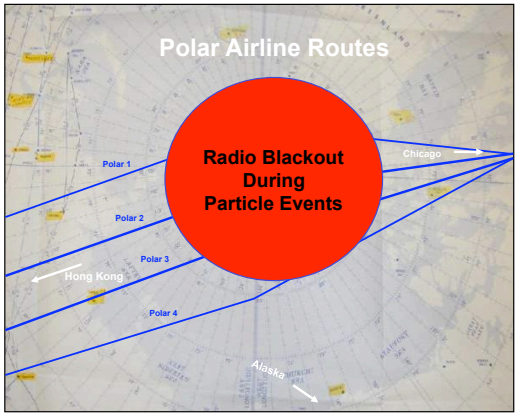
Energetic Particle Effects

High Latitude HF Communications

- Polar airline routes loose ground communications
  - `Alternate routes required
  - Uses more fuel
  - Flight delays

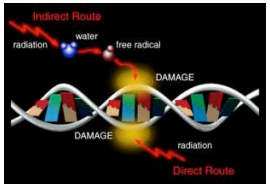
Sample of Flights Affected:

- **10/26/00: Lost of HF prior to 75N, re- route off Polar route with Tokyo fuel stop. 15:00 flight now 20:30**
- **11/10/00: Due to poor HF, ORD to HKG flown non-polar at 47 minute penalty**
- **3/30/01-4/21/01: 25 flights operated on less than optimum polar routes due to HF disturbances resulting in time penalties ranging from 6 to 48 minutes**
- **11/25/00: Polar flight re-route at 75N due to Solar Radiation, needed Tokyo fuel stop**
- **11/26/00: Operated non-polar at 37 minute penalty due to solar radiation**
- **11/27/00: Operated non polar at 32 minute penalty due to solar radiation.**
- **11/28/00: Operated non-polar at 35 minute penalty due to solar radiation**



Energetic Particles Effects

Radiation Hazard



- Health Hazards from Energetic Particles
  - –Humans in space
  - –Space Shuttle, International Space Station, missions to Mars
  - –Crew/Passengers in high-flying jets

Today

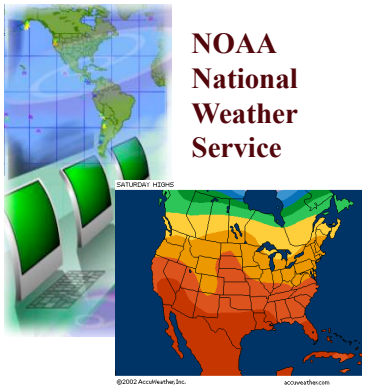
- With the technology today a big solar storm would have a more significant impact
- 1989 a solar storm took out the Hydro-Quebec power grid causing an estimate at hundreds of millions of dollars
- 1994 a solar storm caused several satellites to malfunction and newspaper, radio, and television services to experience problems
- None of these were as powerful as the perfect solar storm of 1859

Today

- Besides being fried by energetic particles, satellites can be dragged down when the atmosphere puffs up after CME event.
  - – We do lose satellites each year from this
- Why are the power transmission lines so vulnerable?
  - – We are near the operational limit, when extra charge is added from fluctuation mag field, they overload, which can melt the transmission lines.
  - – Knock out expensive and hard to replace transformers.

Mitigation:Monitoring

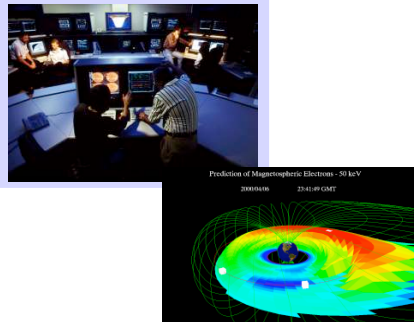
Weather



NOAA National Weather Service

Space Weather

NOAA Space Environment Center



Accuweather

http://www.youtube.com/watch?v=DU4hpsistDk