The Sun and Space Weather

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What is Solar Wind?

- Streams of plasma ejected from Sun's corona (outermost region of Sun's atmosphere, as shown here) at 400-800 km/s
- Plasma, or ionized gas, consists mostly of high-energy protons and electrons with small amounts of doubly ionized helium and trace amounts of other heavier ions (animation)

Mariner 2

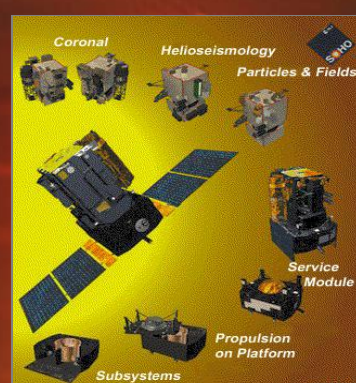
- First spacecraft to study another planet (Venus in 1962)
- First to measure density, velocity, composition, and variation over time of solar winds

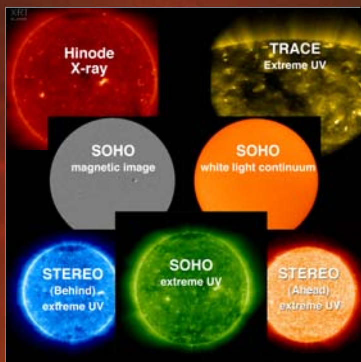
S.O.H.O.
Solar and Heliospheric Observatory

- Orbits at Earth/Sun L1 point (animation)
- Designed to answer 3 fundamental scientific questions about the Sun:
  - What is the structure and dynamics of the solar interior?
  - Why does the solar corona exist and how is it heated to the extremely high temperatures of ~1 million °C?
  - Where is the solar wind produced and how is it accelerated?

S.O.H.O.'s
12 Scientific Instruments

- CDS - coronal diagnostic spectrometer
- CELIAS - charge, element, and isotope analysis system
- COSTEP - comprehensive suprathermal and energetic particle analyzer
- EIT - extreme ultraviolet imaging telescope
- ERNE - energetic and relativistic nuclei and electron experiment
- GOLF - global oscillations at low frequencies
- LASCO - large angle and spectrometric coronagraph
- MDI/SOI - Michelson doppler imager/ solar oscillations investigation
- SUMER - solar ultraviolet measurements of emitted radiation
- SWAN - solar wind anisotropies
- UVCS - ultraviolet coronagraph spectrometer
- VIRGO - variability of solar irradiance and gravity oscillations



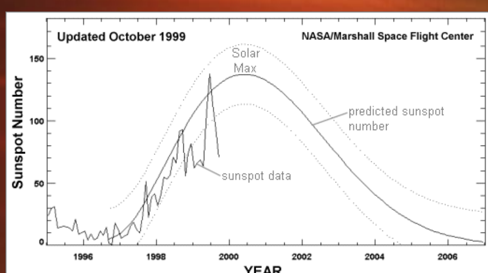


Variations In Solar Wind: Sunspots

- Sunspots are regions in the Sun's photosphere characterized by lower temperatures and strong magnetic fields
- Come in pairs with magnetic field lines emerging from one and diving into another (animation)
- Sunspot numbers increase as Sun reaches the maximum of its 11-year cycle and decrease as it reaches its minimum
- Primary sources of solar wind, solar flares, and coronal mass ejections (CME's)

Variations In Solar Wind

The 11-year Sunspot Cycle



Average Solar Wind Values at Earth Distance

- Velocity ~ 468 km/s
- Density ~ 8.7 protons/cm^3
- Magnetic Field Strength ~ 6.6 nT
- Comparison: Earth's Magnetic Field Strength ~45,000 nT at surface
- Reaches Earth in 24-36 hours

How Does Solar Wind Escape?

- Corona~1 million° C
- This large thermal (kinetic) energy helps particles escape Sun's gravity
- 3x10^-14 solar masses (6x10^16 kg) lost to solar wind every year
- But…

Escape Velocity Mystery

- Thermal energy alone cannot account for measured velocity of escaping solar wind

Supersonic Flow of Solar Wind

- Supersonic flow occurs when solar winds travel faster than the speed of sound
- Models based on thermal energy alone predict a supersonic transition at ~4 solar radii from Sun's photosphere
- Transition appears to occur much earlier: at ~1 solar radii from photosphere
- The cause of this extra acceleration is currently unknown, but thought to involve the Sun's magnetic field (animation)

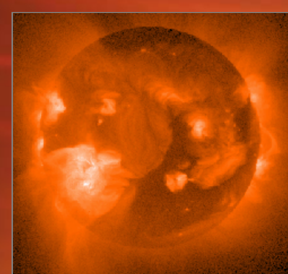
How Can Solar Winds Affect Us?

- Harm astronauts in space
- Damage orbiting spacecraft
- Cause colorful auroras
- Cause surges in power grids resulting in large-scale blackouts

How Can Solar Winds Affect Us?

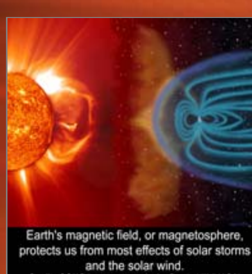
- Solar winds can also cause Earth's upper atmosphere to expand resulting in increased drag felt by low-Earth orbiting satellites
- Hubble Telescope

Question: So What Protects Us From Harmful Solar Winds?



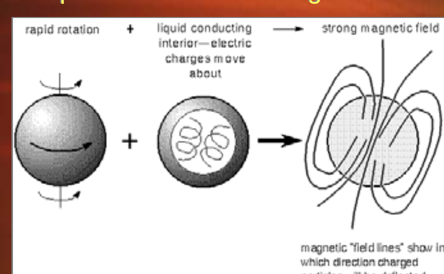
Magnetosphere!

Our Shield from the Sun

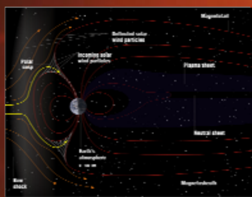


How It Works

Requirements for a magnetic field



Earth's Magnetosphere



- 10-12 Earth radii thick on Sun-facing side depending on solar wind intensity
- Tail stretches to over 200 Earth radii
- Contains mix of electrons and ions from solar wind as well as Earth's ionosphere

Formation of Auroras and Geomagnetic Storms

- Earth's magnetosphere compresses as it is impacted by solar wind
- This causes it to "squish" out, creating an even larger surface area for the solar wind to impact
- Once the force on the magnetosphere reaches a critical point, some magnetic field lines are broken
- Particles are energized as the unbroken field lines "snap" back into place
- These energized particles get magnetically funneled to Earth's polar regions
- The impact of these particles on Earth's atmosphere cause auroras and geomagnetic storms (animation)

Famous Auroras and Geomagnetic Storms

- On March 13, 1989 a severe geomagnetic storm caused the Hydro-Quebec power grid to go down in a matter of seconds
- 6 million people were left without power for 9 hours
- Auroras were seen as far South as Texas

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