Space Weather

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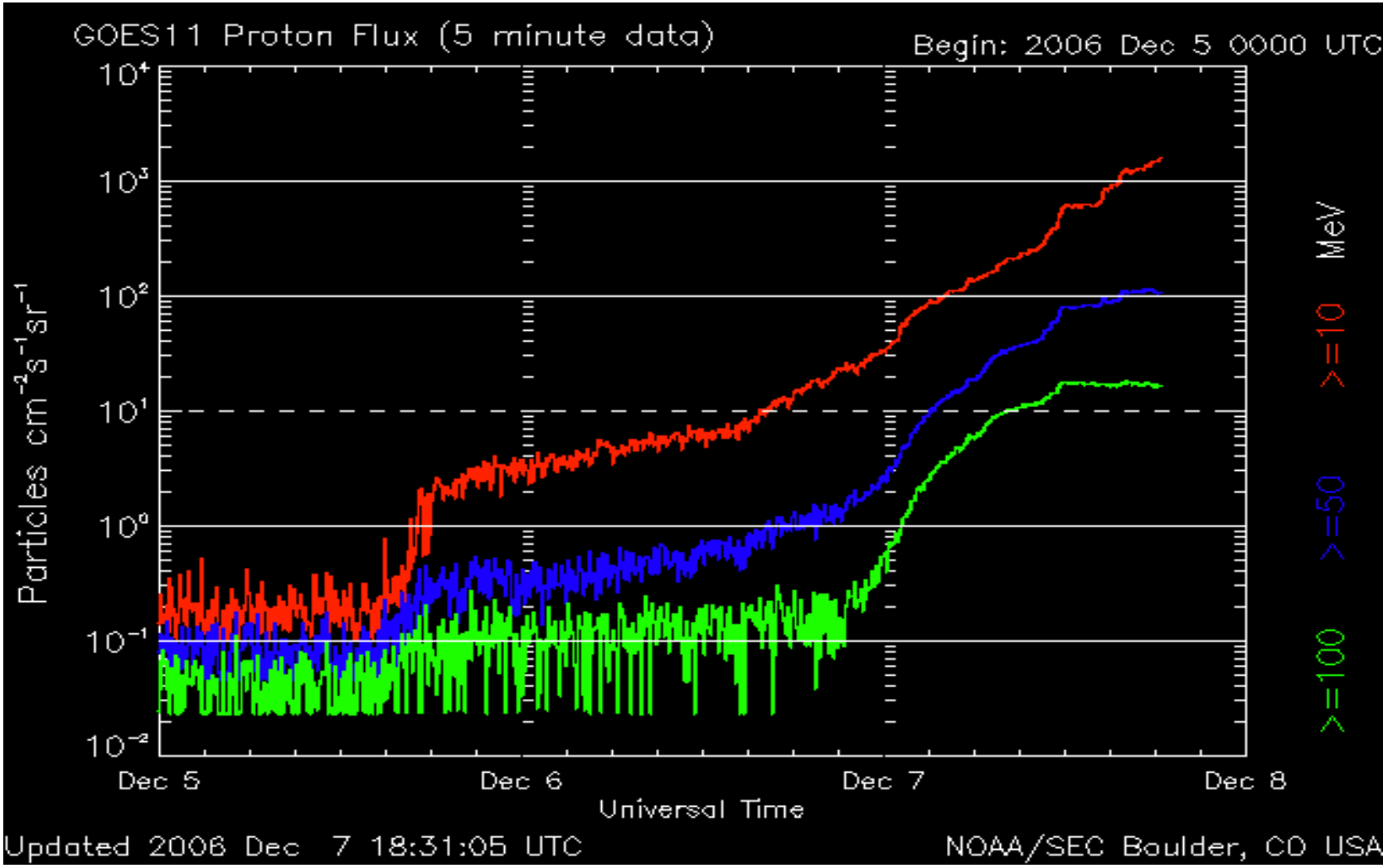
Definition of Space Weather

- **Space weather** is the concept of changing environmental conditions in near-Earth space or the space from the Sun's atmosphere to the Earth's atmosphere.
- Space weather is the description of changes in the ambient plasma, magnetic fields, radiation, and other matter in space. Much of space weather is driven by energy carried through interplanetary space by the solar wind from regions near the surface of the Sun and the Sun's atmosphere (chromosphere and corona)

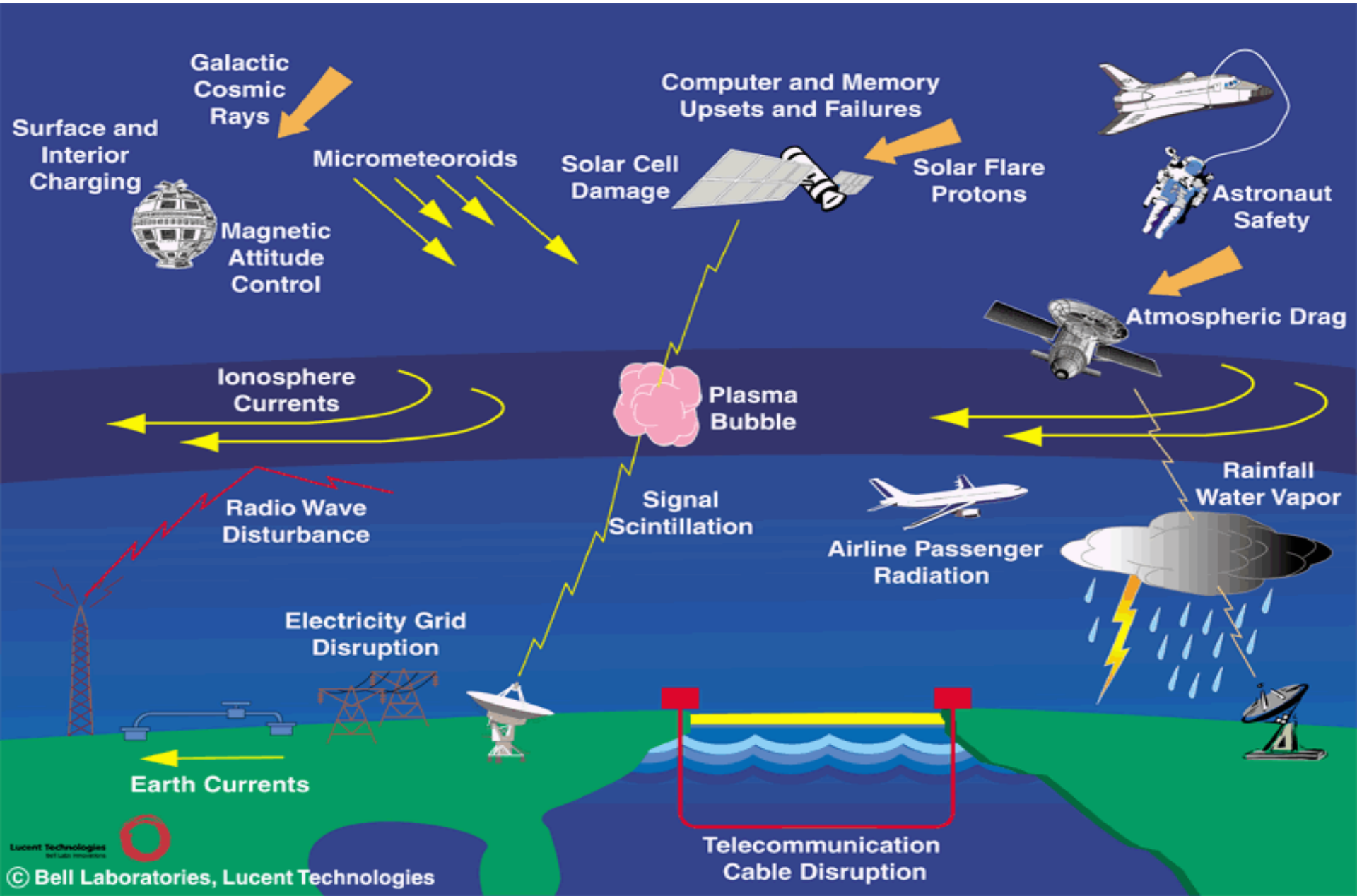
Geomagnetic Storm

- A geomagnetic storm is a temporary disturbance of the Earth's magnetosphere.
- Associated with solar coronal mass ejections, coronal holes, or solar flares, a geomagnetic storm is caused by a solar wind shock wave which typically strikes the Earth's magnetic field 24 to 36 hours after the event.
- The increase in the solar wind pressure initially compresses the magnetosphere and the solar wind's magnetic field interacts with the Earth’s magnetic field and transfers an increased energy into the magnetosphere

Particles Emitted in Magnetic Storms



Effects of Space Weather

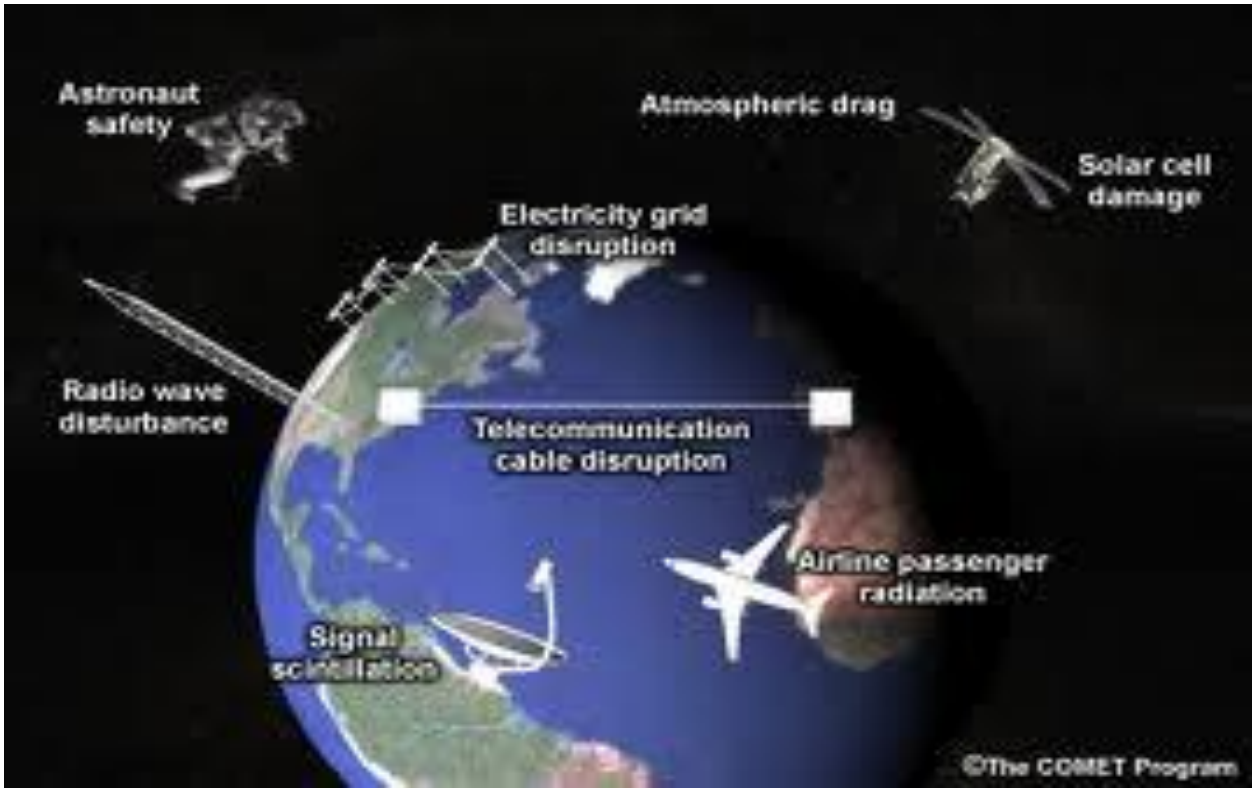


Effect of Space Weather in Ground Systems

- Disruption of GPS and other spacecraft signals
- Disruption of long-distance radio signals
- Effect of radiation on humans at and near ground level
- Ground Induced Current: electrical transmission, pipelines
- Effect of space weather on terrestrial weather

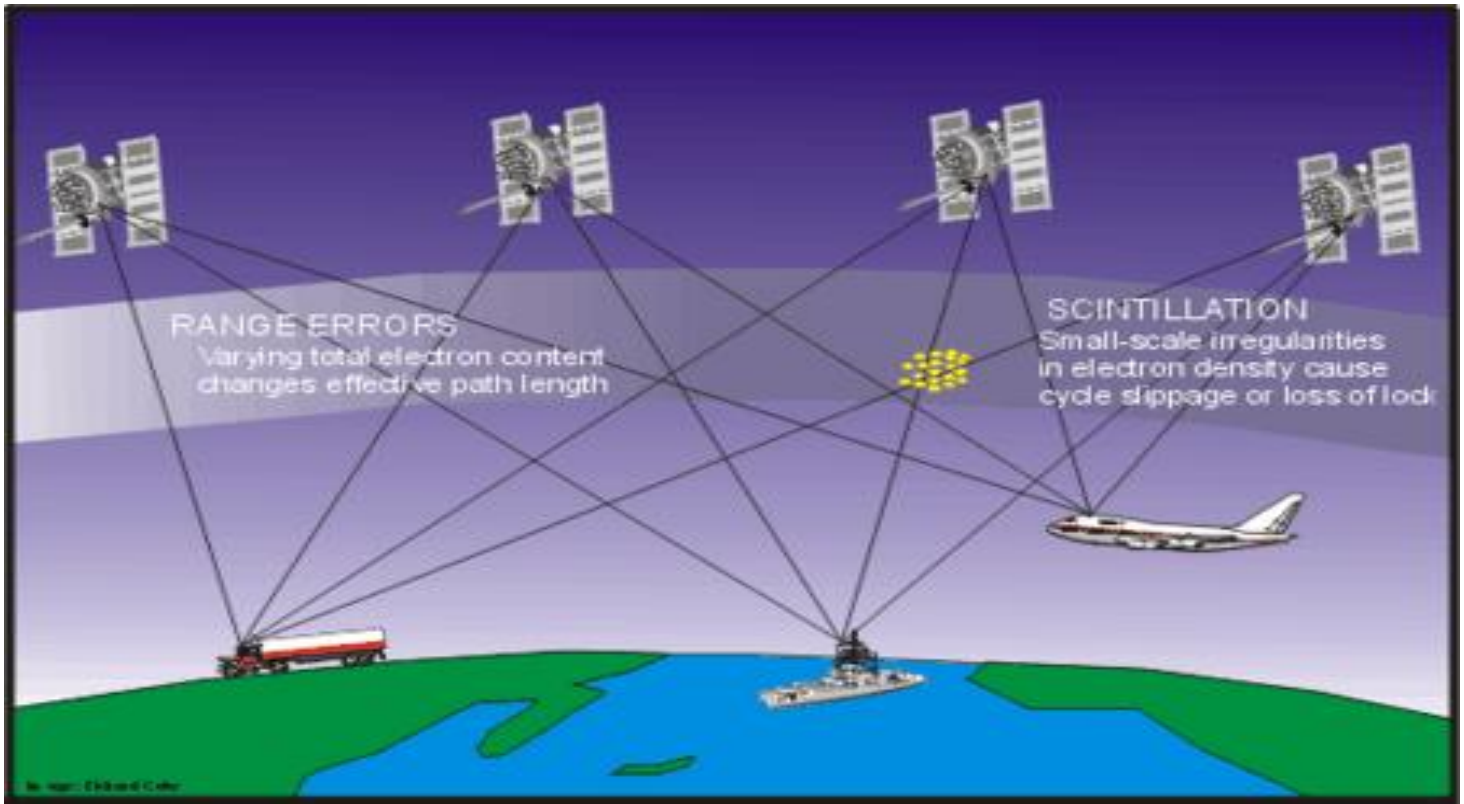
Effect of Space Weather in Space Systems

- Spacecraft anomalies
- Spacecraft orbit changes
- Effect of radiation on humans in space



Navigational Effects

- Ships at sea require good navigation signals to stay on route.
- Navigation errors can lead to wasted fuel, groundings and spilled cargo.
- Plane navigation will also be effected.

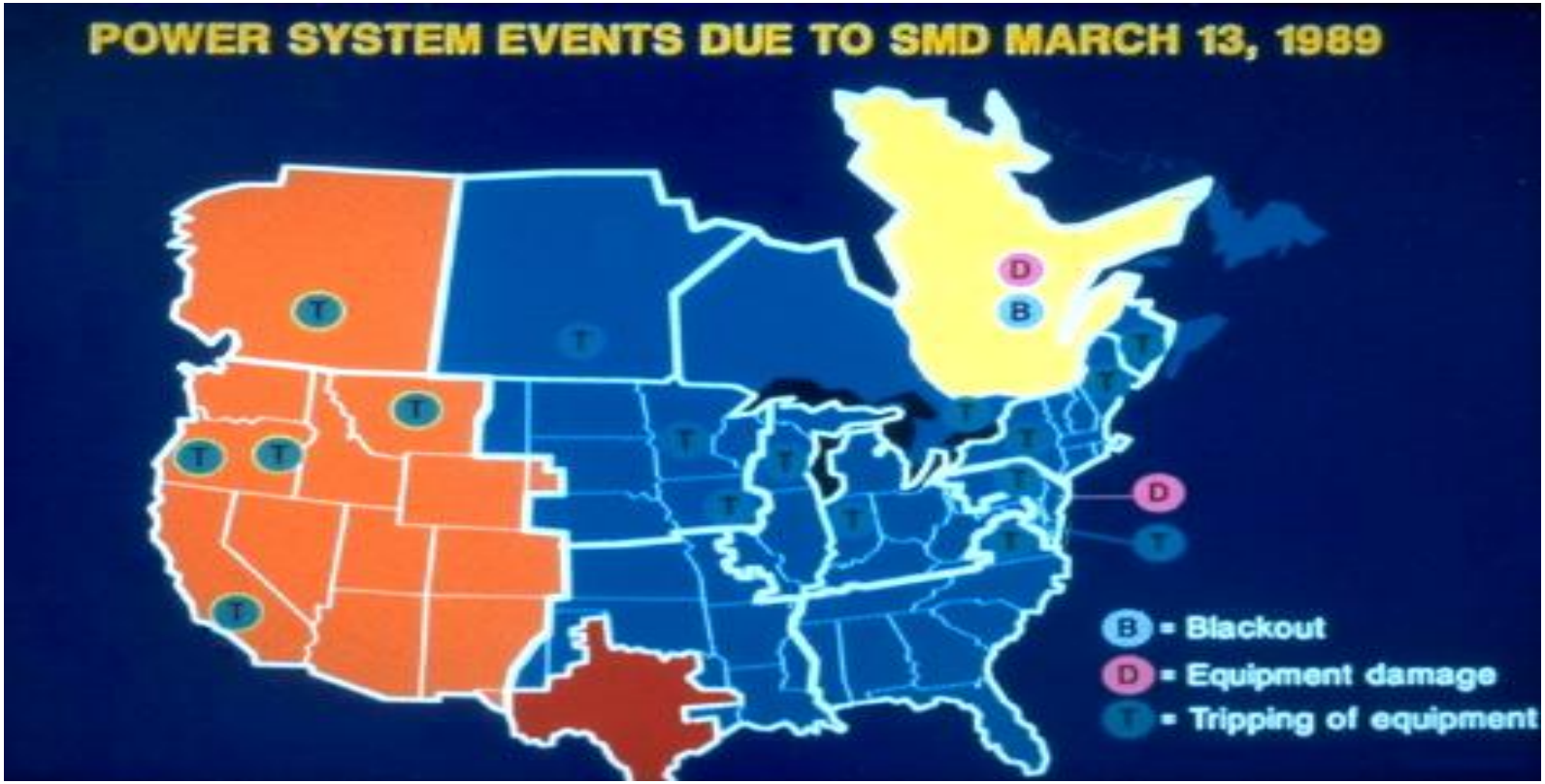


Radio Signals Effects

- Radio signals can get lost and absorbed, bounce and miss the receivers.
- Especially communication over the poles will be problematic.

Electric Power Effects

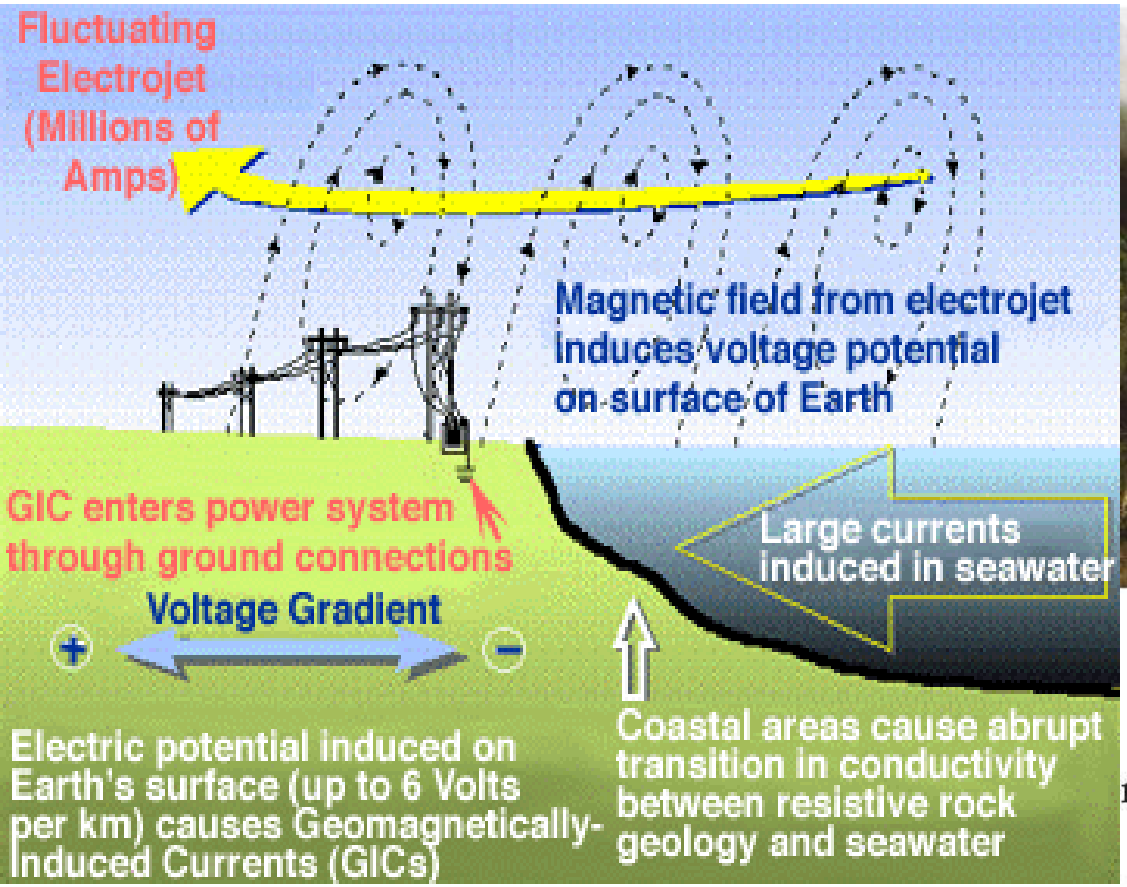
- Transformers can be damaged by geomagnetic storms
- Blackouts can be widespread.



Pipeline Effects

- Pipelines can corrode due to geomagnetic storms. This corrosion can cause loss and damage

Pipeline Corrosion



Pipelines are made of conducting material. Intense electric currents flow in the atmosphere during space weather events, causing fluctuating magnetic fields. These magnetic field fluctuations induce currents in the Earth's surface. In regions with large concentrations of igneous rocks, these currents find the path of least resistance - the pipelines, causing corrosion.

History of Space Weather

Some Major Solar Storms

9/2/1859 - Strongest solar storm recorded, with aurora worldwide and telegraph disruptions

5/13/1921 - Storm shuts down NY City transit system with induced ground currents

3/25/1940 - Easter Sunday storm halts U.S. long distance phone service for hours, radio and wire services disrupted

2/10/1958 - Radio blackout caused by one of the 10 strongest storms

3/13/1989 - Quebec power grid collapses for nine hours

10/29/2003 - "Halloween" storms cause numerous satellite problems and produce the strongest X-ray flare ever recorded

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Milestones of Solar Exploration

1610

Galileo Galilei is among the first to study the Sun & sunspots with a telescope

1859

First solar flare observed and sketched by Richard Carrington

1908

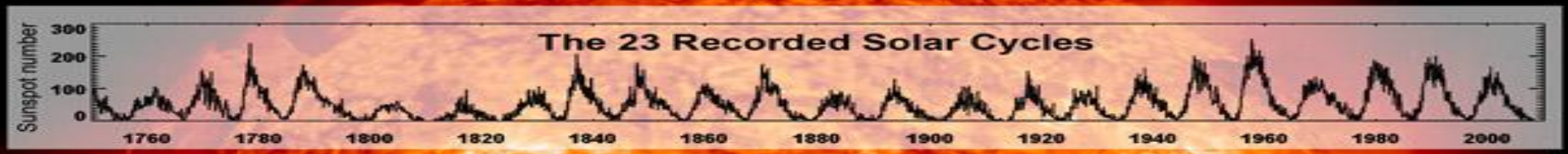
George Ellery Hale discovers magnetic fields in sunspots -- a key to under-standing solar activity

1971-74

OSO-7, Skylab are first space-craft to study solar storms

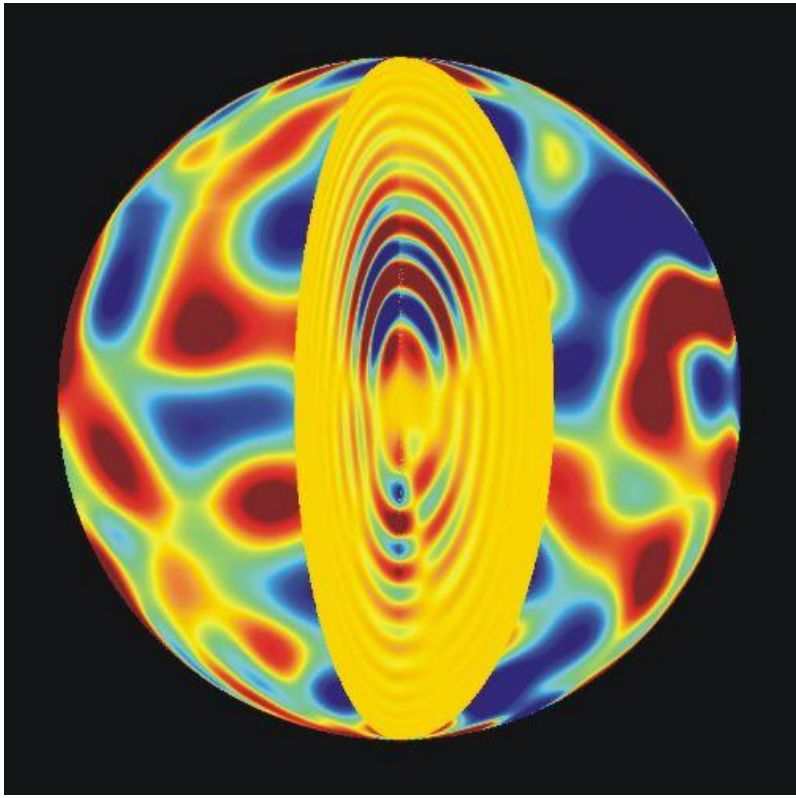
1995

The Solar & Heliospheric Observatory (SOHO) begins sophisticated solar study mission



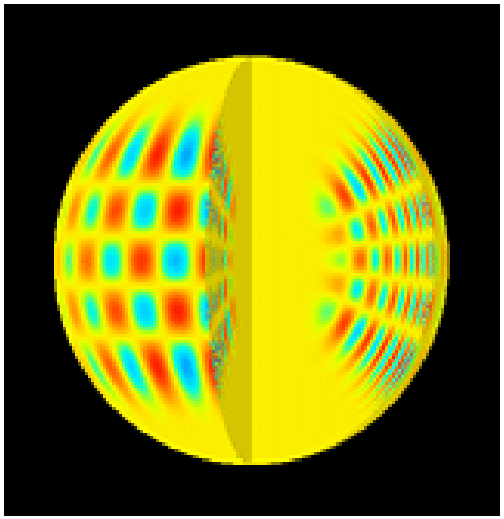
Helioseismology

- The science studying wave oscillations in the Sun is called *helioseismology.*
- For the Sun, no one source generates solar "seismic" waves. The sources of agitation causing the solar waves that we observe are processes in the larger convective region. Because there is no one source, we can treat the sources as a continuum, so the ringing Sun is like a bell struck continually with many tiny sand grains.
- On the Sun's surface, the waves appear as up and down oscillations of the gases, observed as Doppler shifts of spectrum lines. If one assumes that a typical visible solar spectrum line has a wavelength of about 600 nanometers and a width of about 10 picometers, then a velocity of 1 meter per second shifts the line about 0.002 picometers
- In helioseismology, individual oscillation modes have amplitudes of no more than about 0.1 meters per second.



Oscillation Modes of the Sun

- The three different kinds of **waves** that helioseismologists measure or look for are: **acoustic**, **gravity**, and **surface gravity waves**.
- These three waves generate **p modes**, **g modes**, and **f modes**, respectively, as resonant modes of oscillation because the Sun acts as a resonant cavity.
- The spectrum of the detected oscillations arises from modes with periods ranging from about 1.5 minutes to about 20 minutes and with horizontal wavelengths of between less then a few thousand kilometers to the length of the solar globe

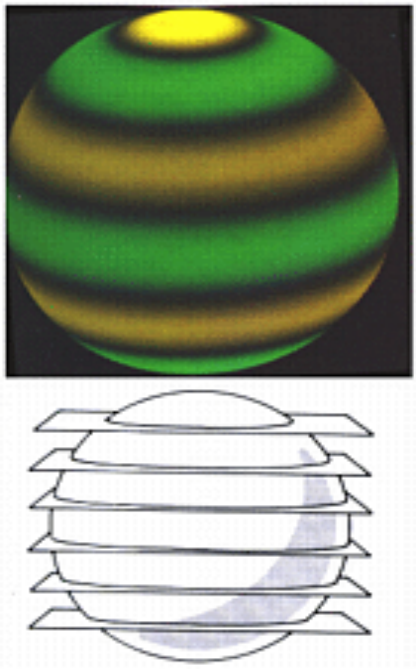


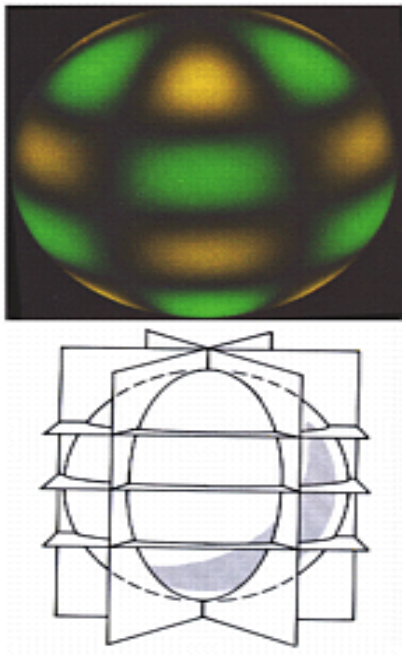
Spherical Harmonics of the Sun

- Oscillation modes use spherical harmonics: *l*, and *m*, and *n* values. The spherical harmonic functions provide the nodes of standing wave patterns. The order *n* is the number of nodes in the radial direction. The harmonic degree, *l*, indicates the number of node lines on the surface, which is the total number of planes slicing through the Sun. The azimuthal number *m*, describes the number of planes slicing through the Sun longitudinally.

Harmonics

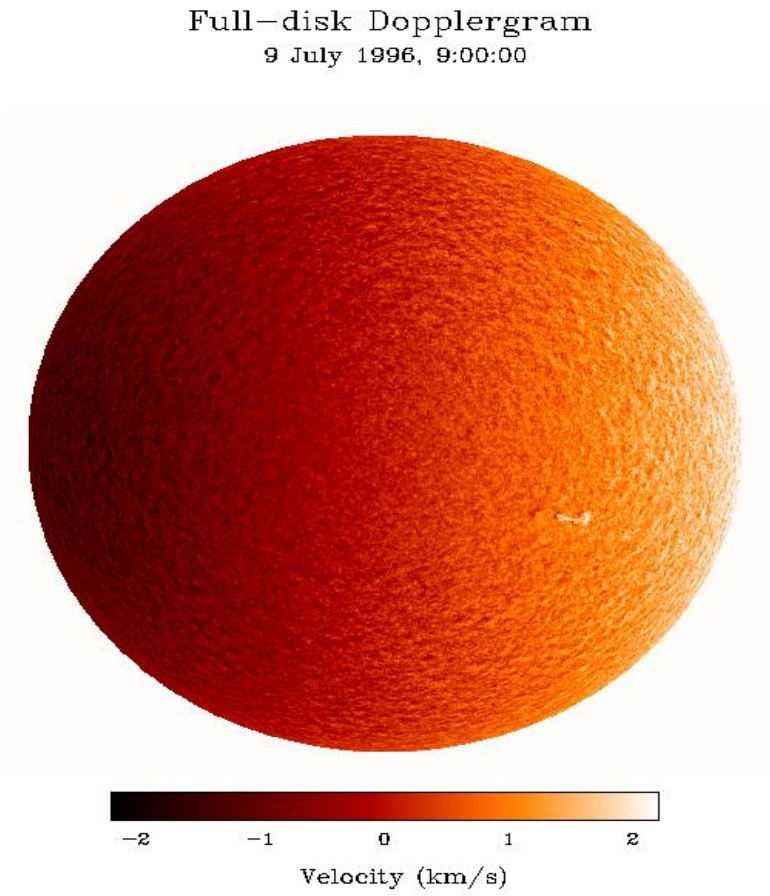
- The figure on the left shows spherical harmonic numbers *l* = 6 and *m* = 0. The dark regions are the nodal boundaries, the green colors denote areas moving radially outward, and yellow colors show those areas moving radially inward.
- The figure on the right shows spherical harmonic numbers *l* = 6 and *m* = 3. The dark regions are the nodal boundaries, the green colors denote areas moving radially outward, and yellow colors show those areas moving radially inward





Oscillation and Velocity

- It is possible to get the velocity picture of the sun by analyzing the transmission of the waves across its surface.



Solar Dynamo

- From the looping shape of fiery solar flares, to the varying intensity of the solar winds, to the mysterious 11-year sunspot cycle, large-scale events on the surface of the Sun are controlled by strong magnetic fields generated deep in its interior.
- This region extends to a layer 38,000 miles thick and centered at a depth of about 135,000 miles below the solar surface. In this region, they have found evidence for two conditions indicative of the dynamo's presence: a high level of turbulence and shear flows caused by changes in rotation rate.