Space Weather: An Introduction

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With support of Alain Hilgers
and contributions from a great many others

Outline

- Introduction
- The Space Weather "System"
- Effects of Space Weather
- Space Weather Services:
  - Measurement Needs
  - Data and Models
- Outlook

What is Space Weather?

"*conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health*"

[US National Space Weather Programme]

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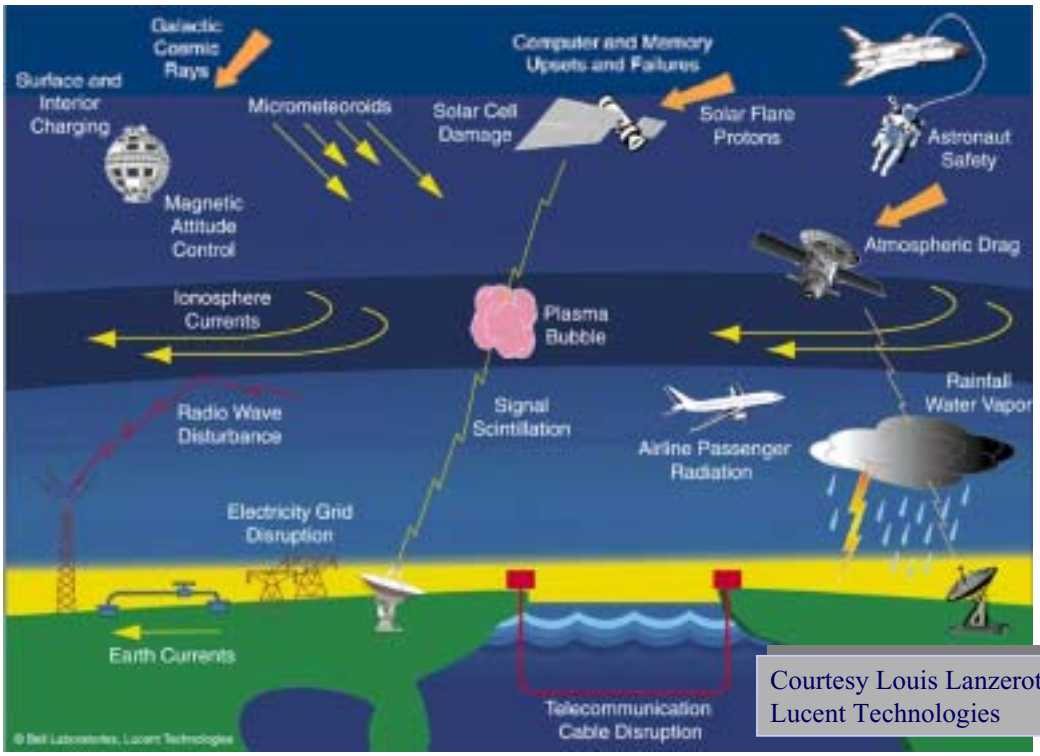
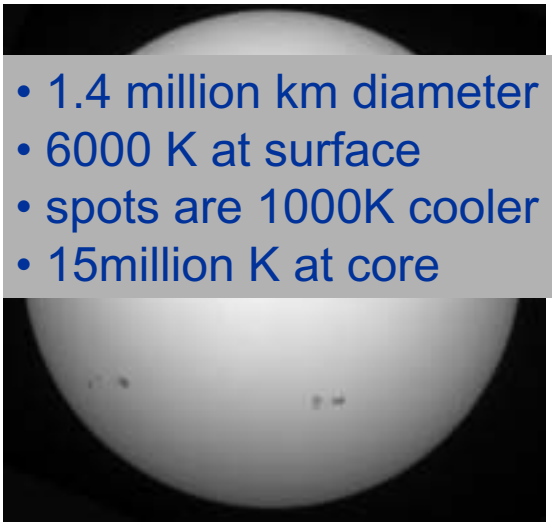
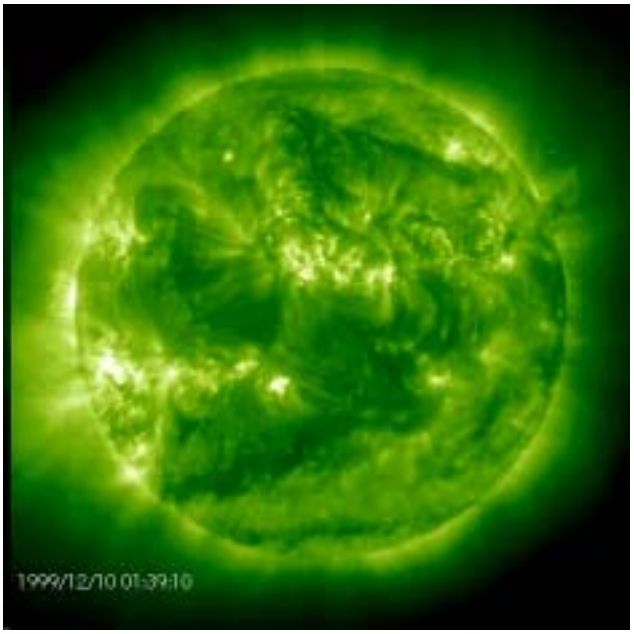


Courtesy Louis Lanzerotti, Lucent Technologies

The Space Weather "System"

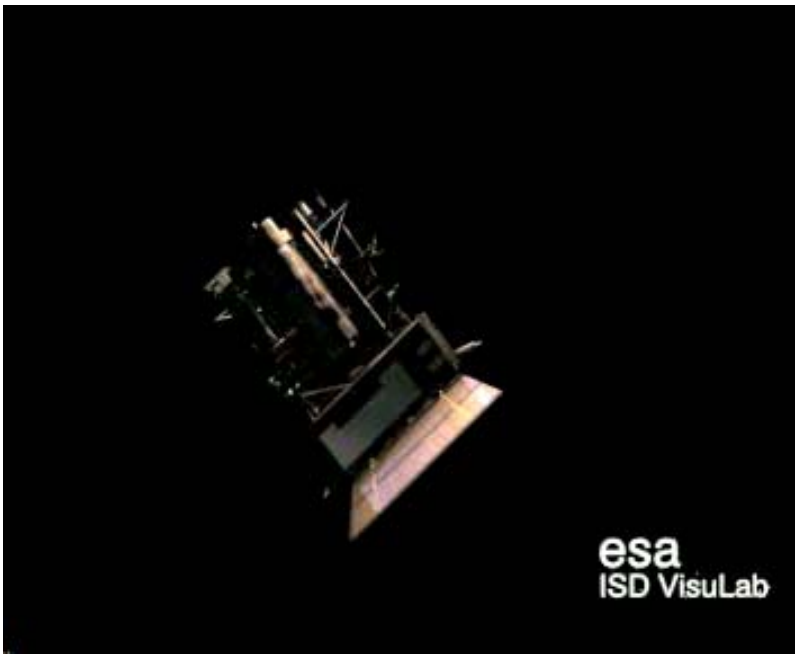
The Sun



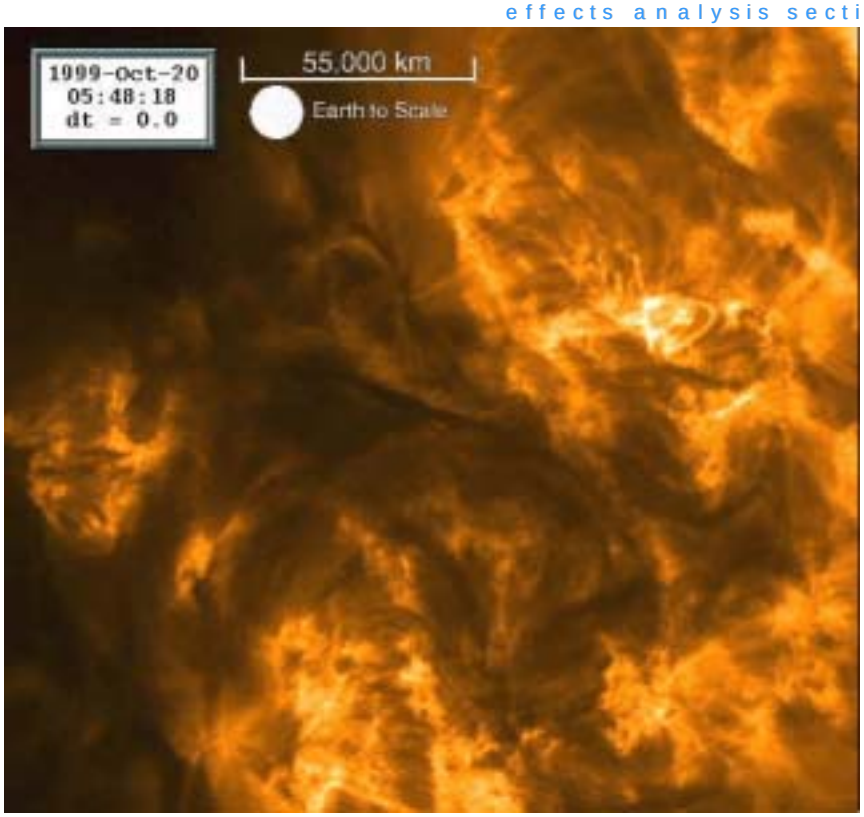


SOHO EIT Telescope

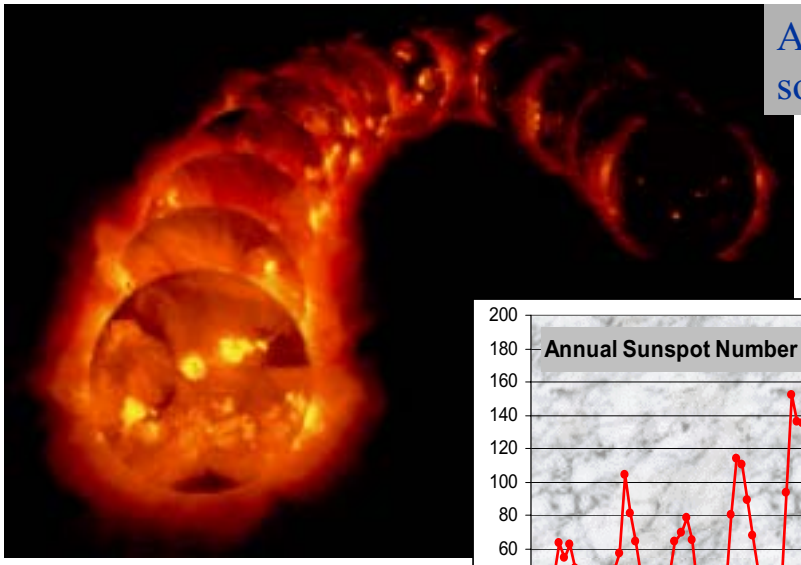
SOHO – A cooperative project between ESA and NASA



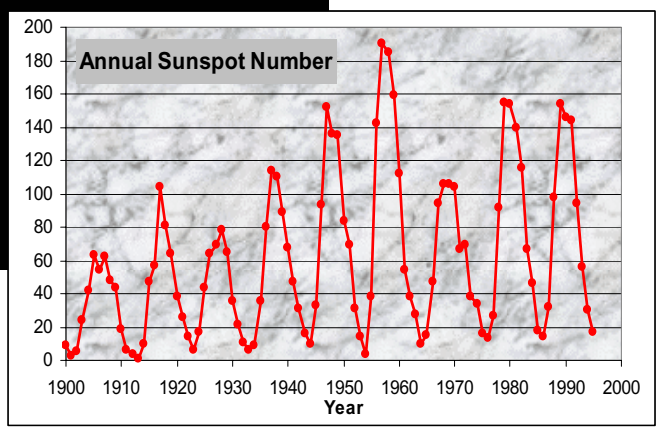
Trace mission



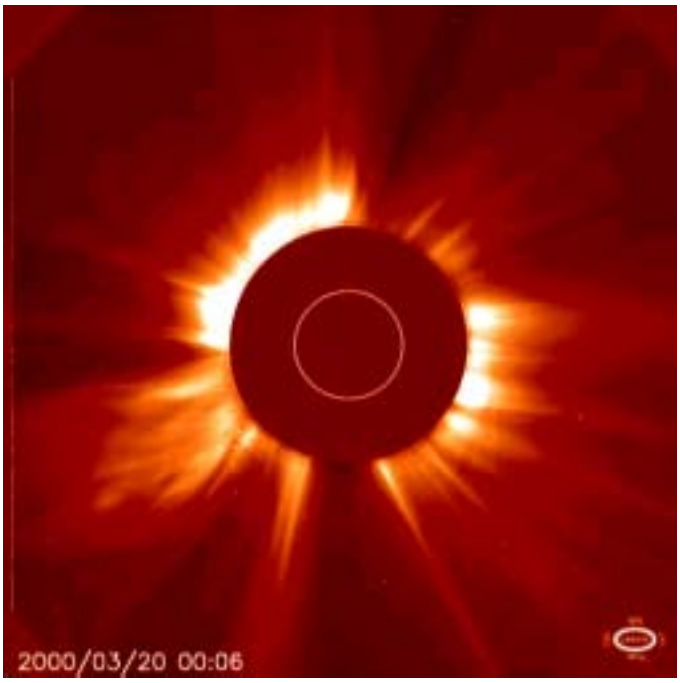
The Changing Sun



An 11-year cycle of solar activity



A Plasma Cloud is Generated



SOHO Coronagraph

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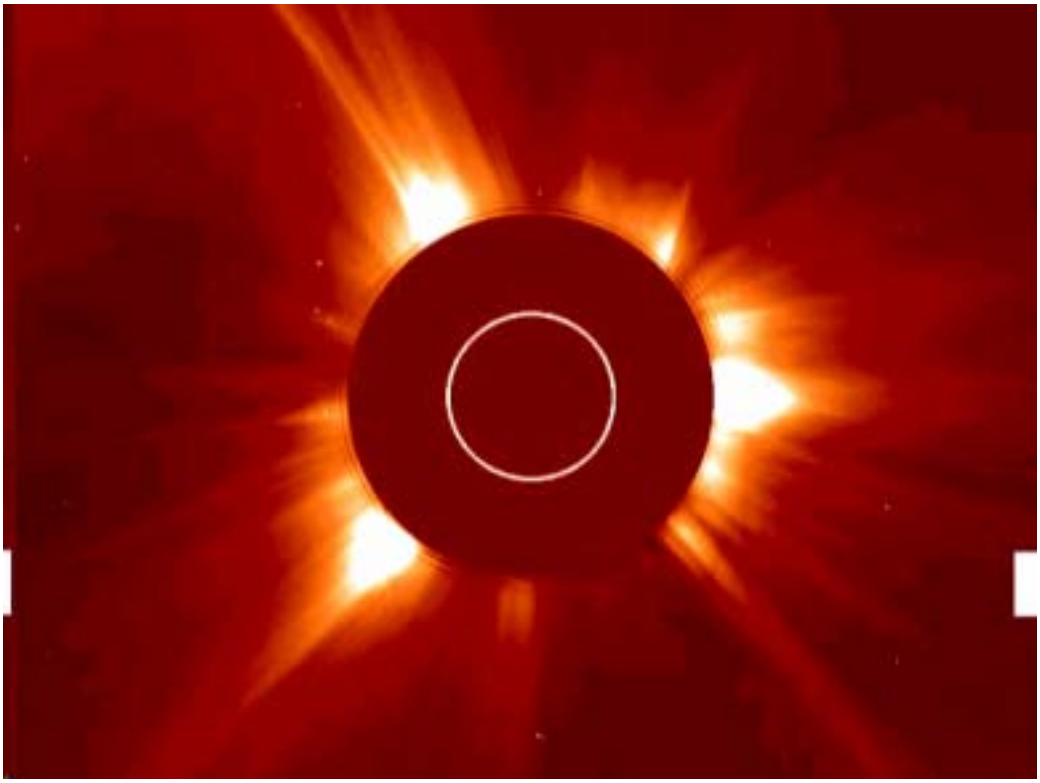
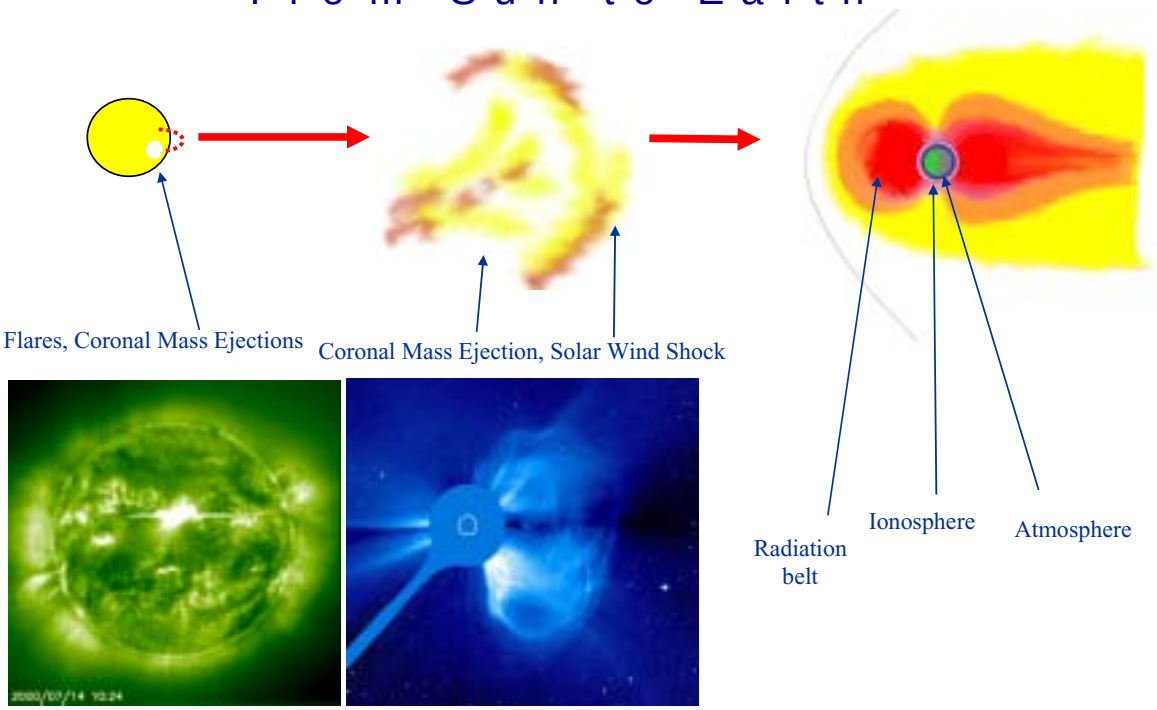
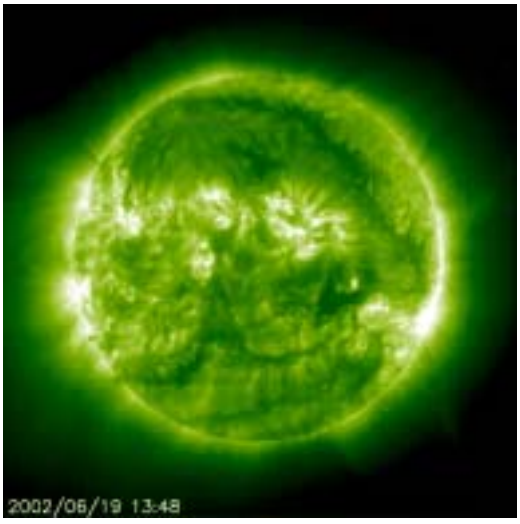
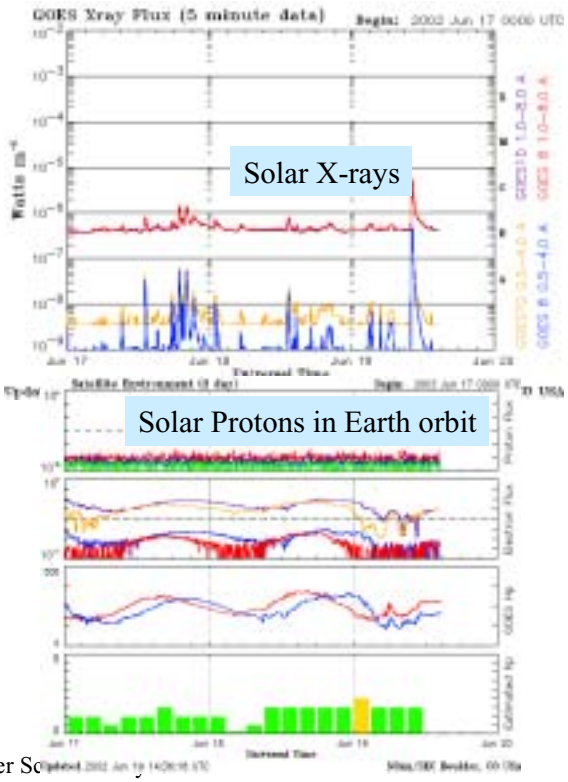


From Sun to Earth

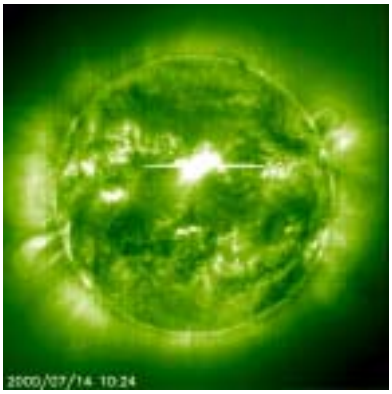


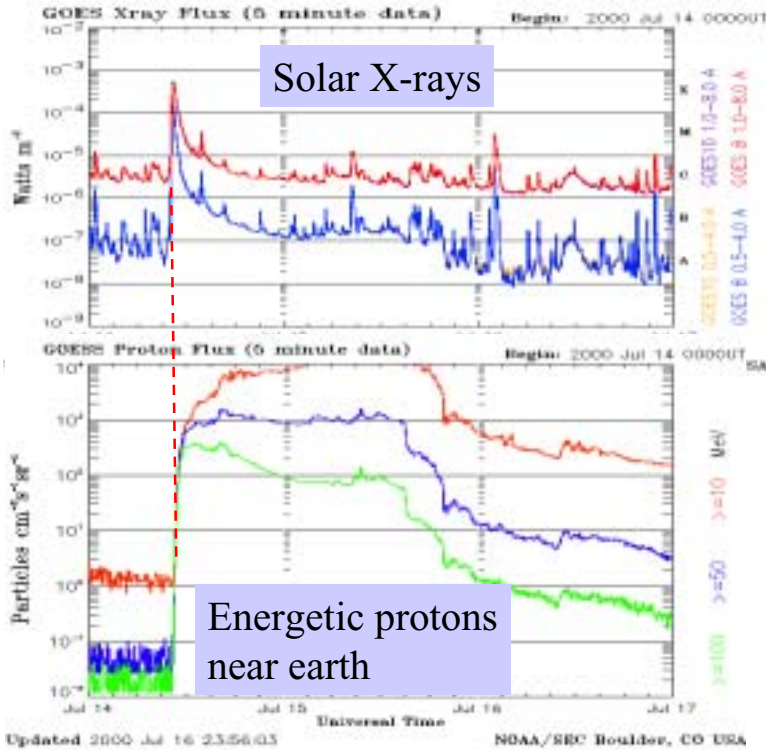
A quiet period

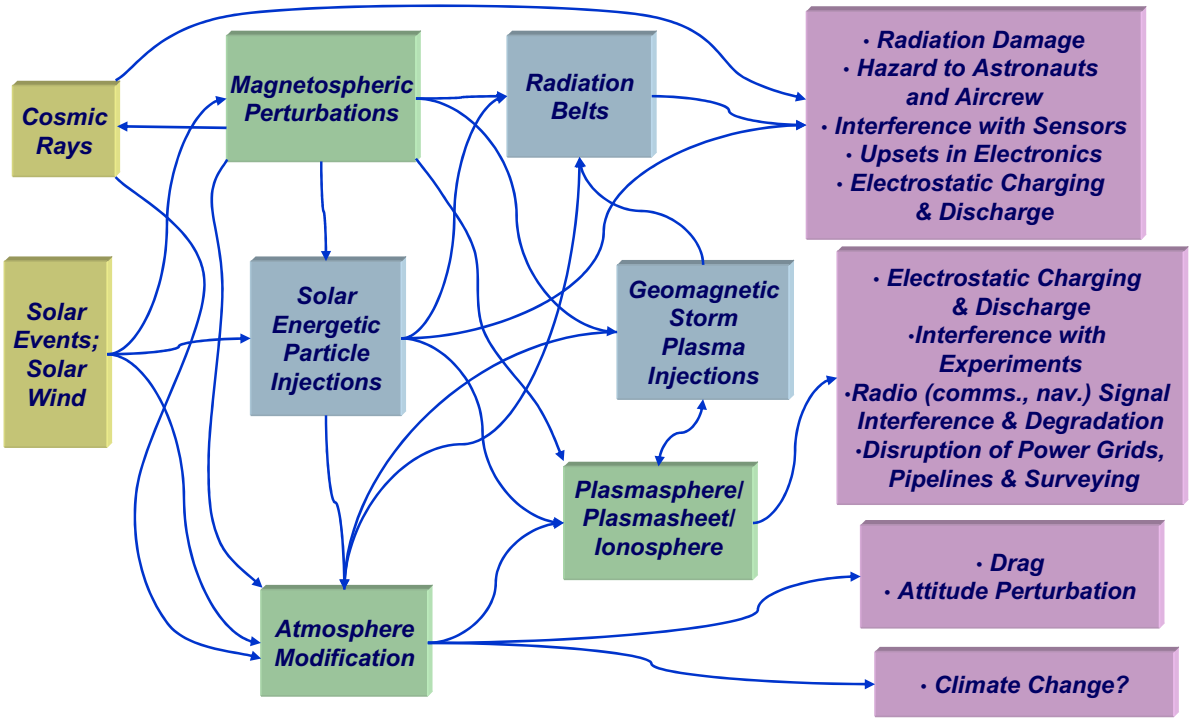




Bastille Day 2000







Effects of Space Weather

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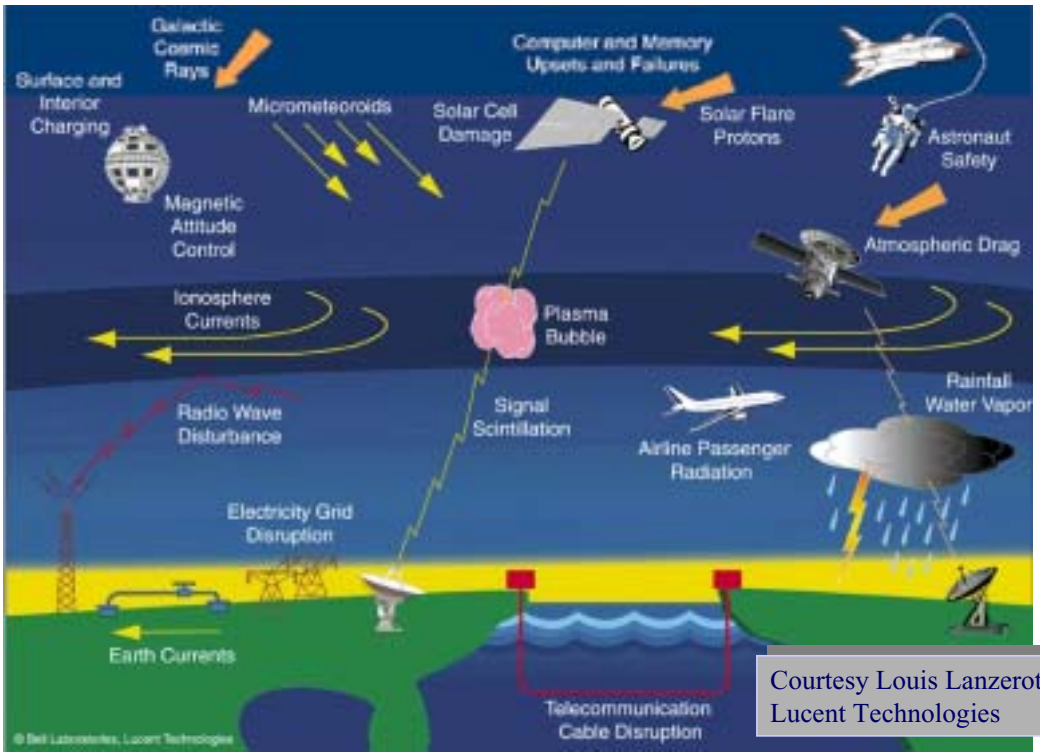
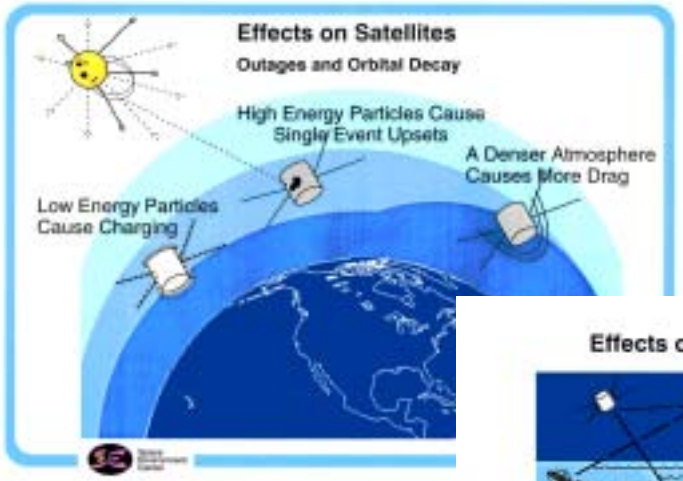
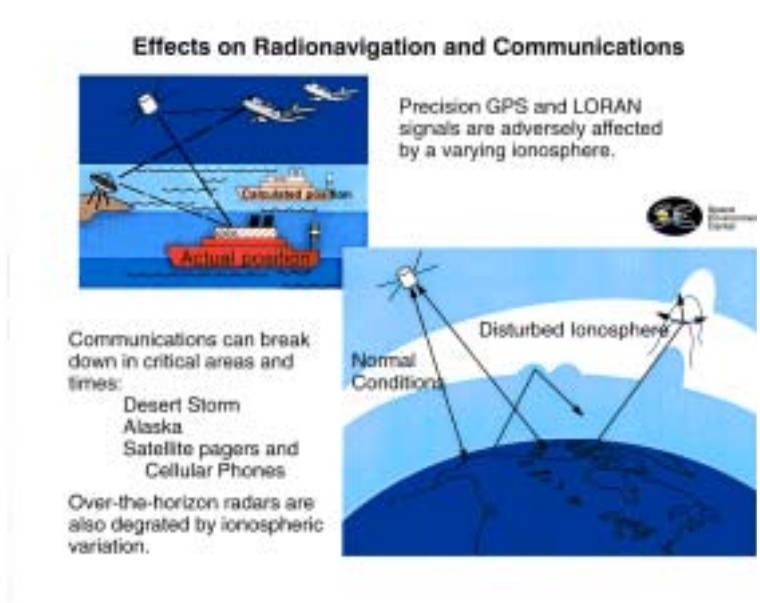


Courtesy Louis Lanzerotti, Lucent Technologies

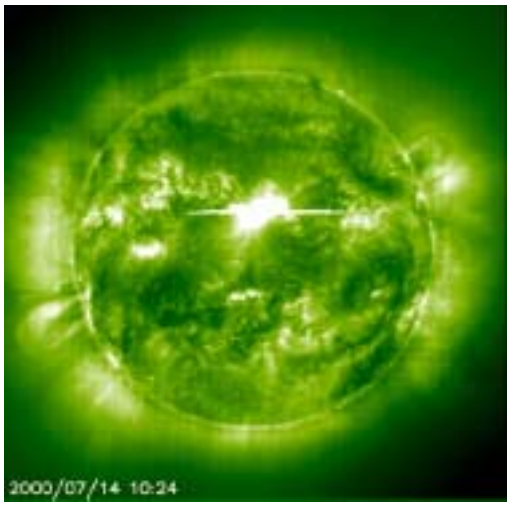
Effects

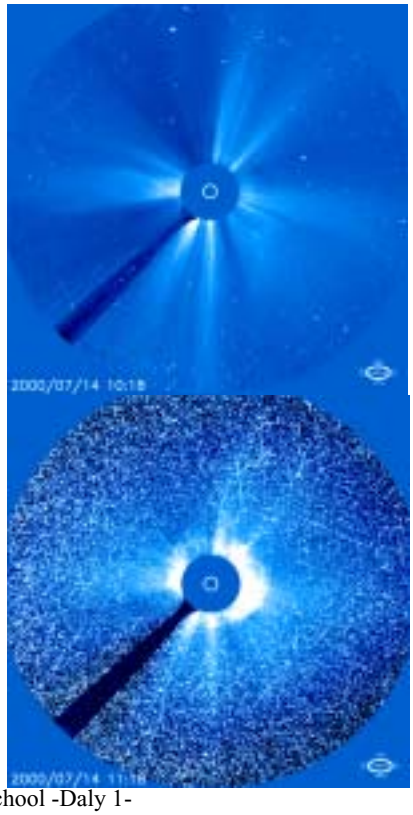
- Satellites affected by radiation, plasma, atmosphere, particulates;
- Astronauts - ISS, future exploration missions;
- Radiation hazards to air crew and avionics;
- Ground power outages from currents induced in lines;
- Disruption to communications relying on the ionosphere;
- Disruption of navigation satellite signals (GPS - Galileo);
- Prospecting;
- Climate;
- see **www.esa.int/spaceweather**



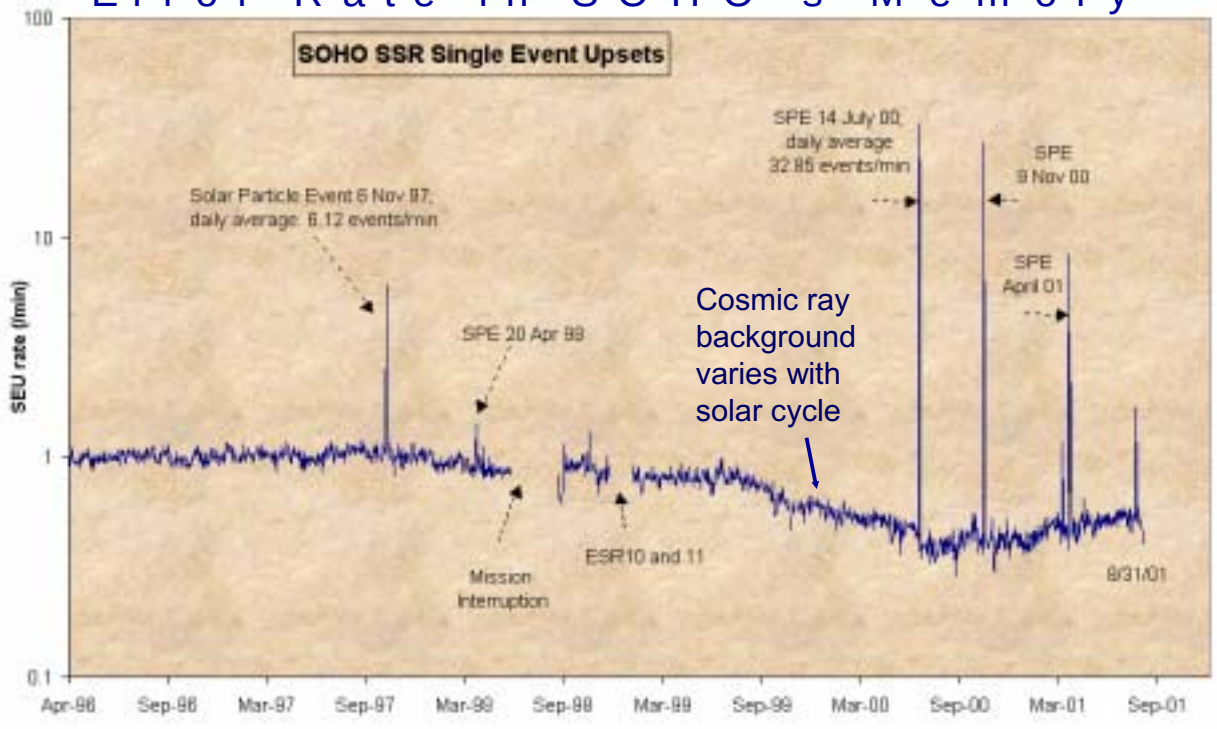


SOHO Image "snowing" on 14 July 2000

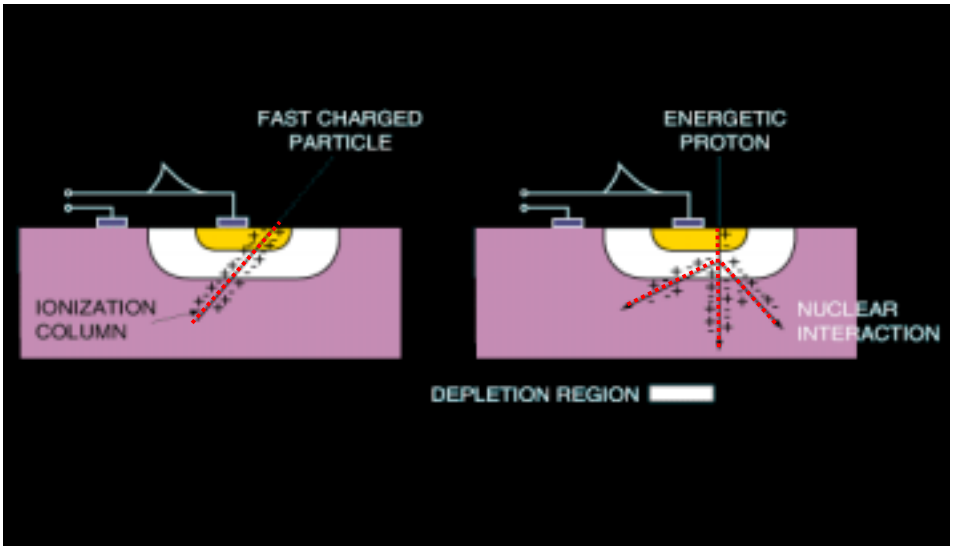




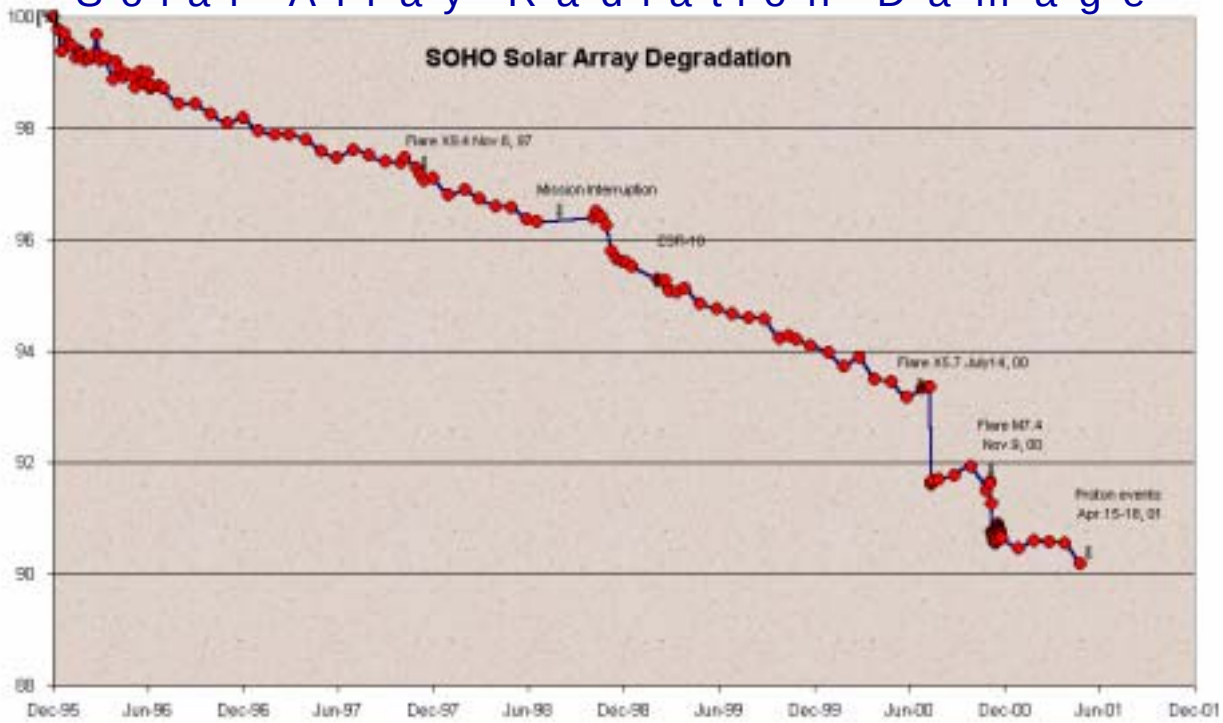
Error Rate in SOHO's Memory



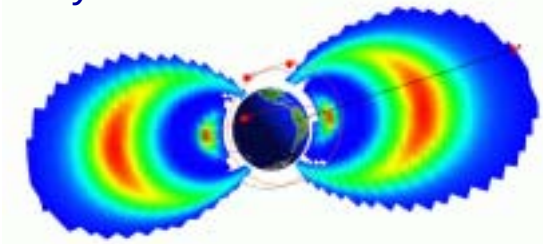
"Single Event Upset"

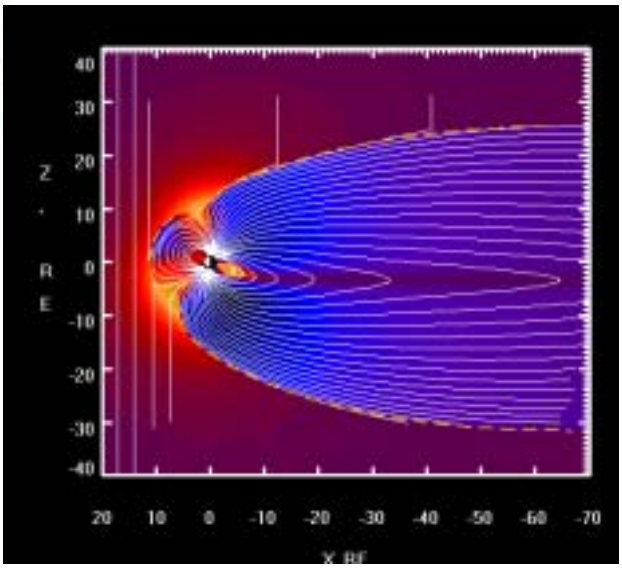


Solar Array Radiation Damage



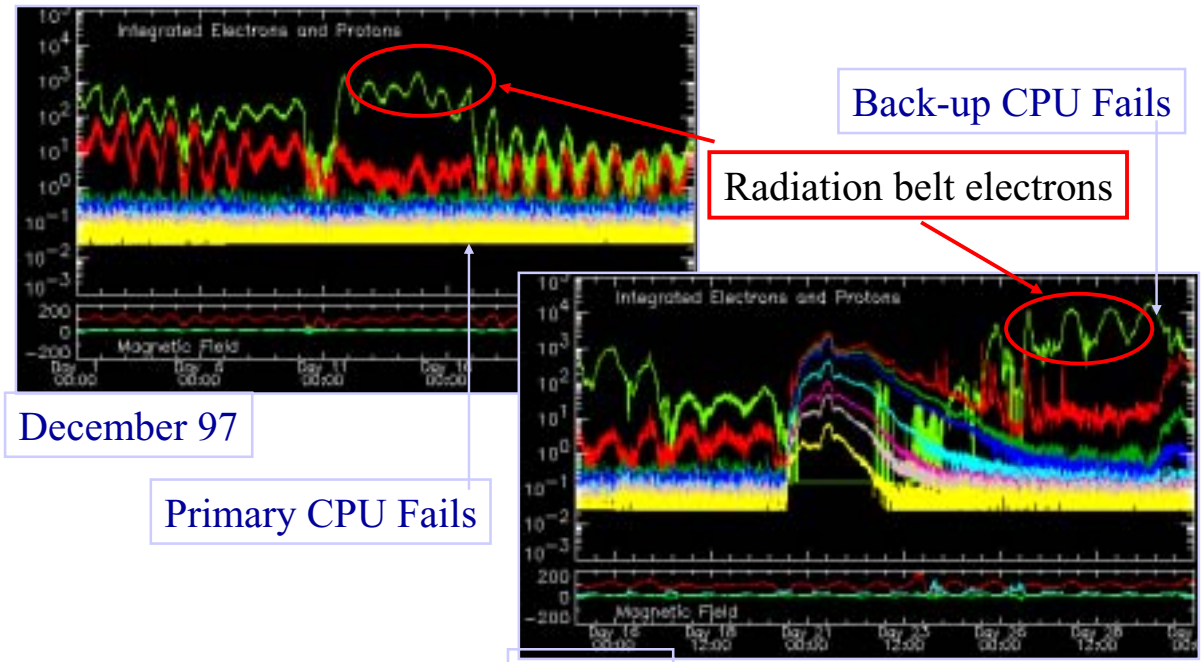
Inside the Magnetosphere: Dynamic Radiation Belts





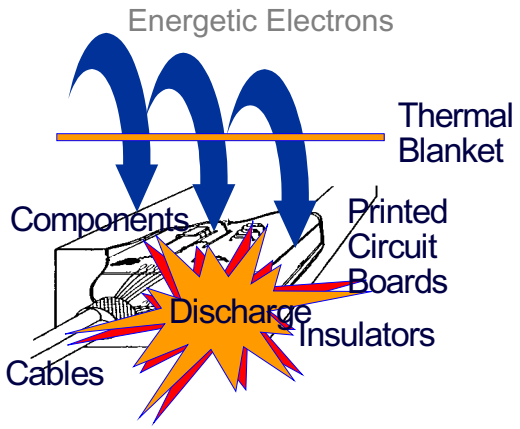
- Storms replenish and clear out the outer (electron) belt;
- 27-day recurrence of episodes points to influence of coronal holes, high speed streams and boundaries
- Outer belt is stronger after solar maximum;

A satellite failure: *Equator-S*



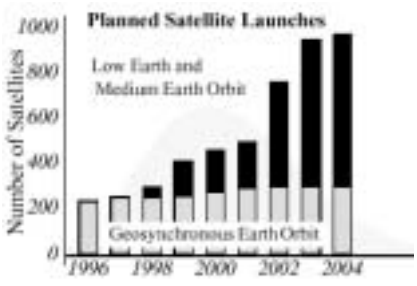
Spacecraft Charging

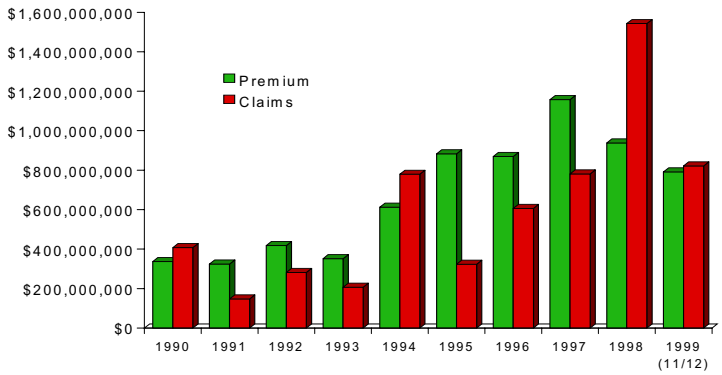
Many satellites experience "anomalies" which usually do not lead to satellite loss



Assets in Space - Satellite Insurance

- Total value of more than 600 satellites currently in orbit is about $50-100 billion
  - 235 of these are insured (value: $20 billion)
- Growing market: 1500 space payloads are expected to be launched the next 10 years
  - potential insured value $80 billion





This charts shows total claims, not only space weather related

Estimated $500 million in damages due to space weather last 4 years

Source: USAU

Manned Space Missions

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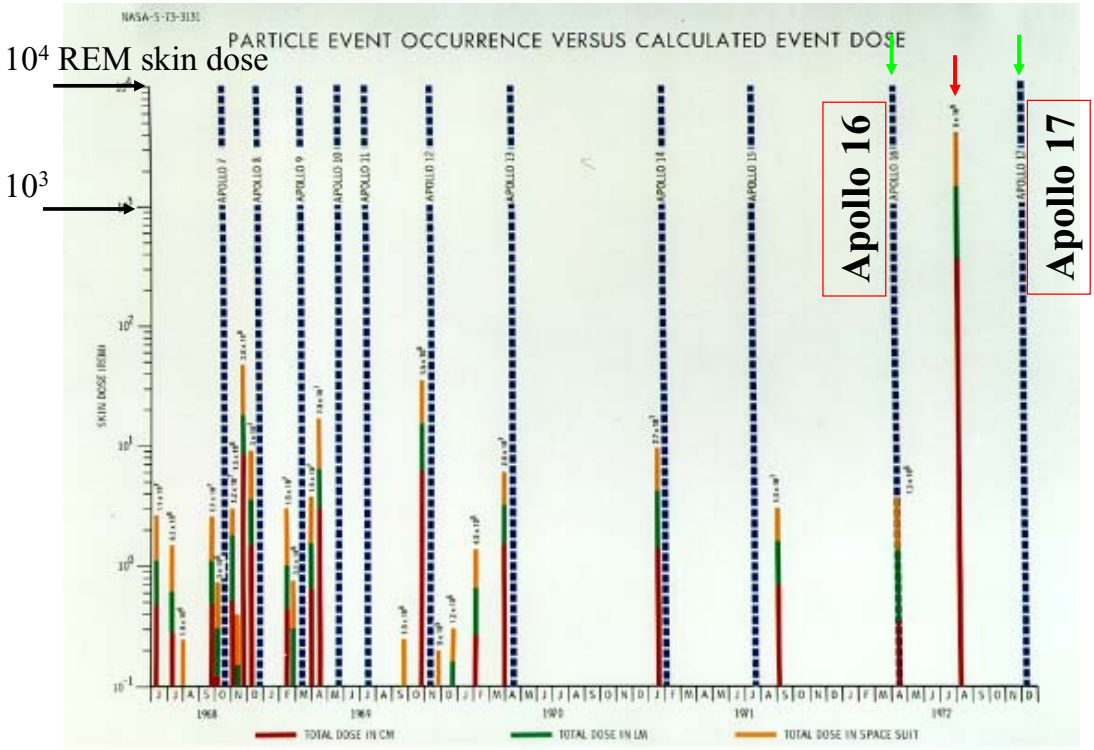
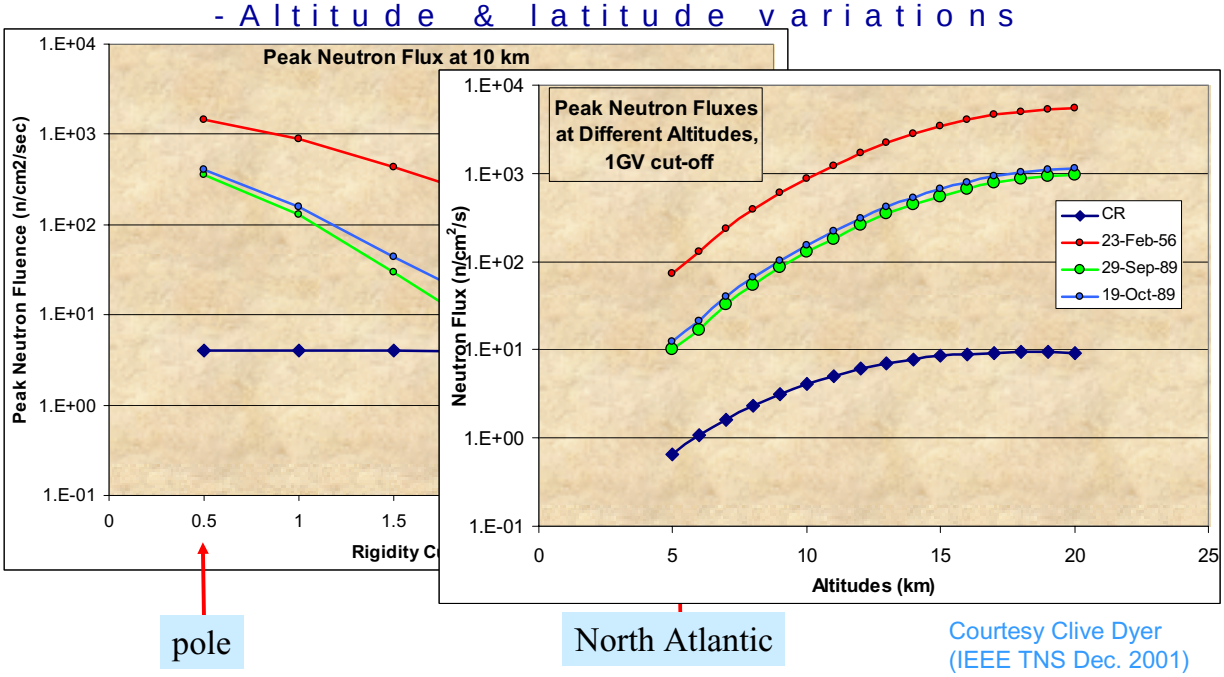


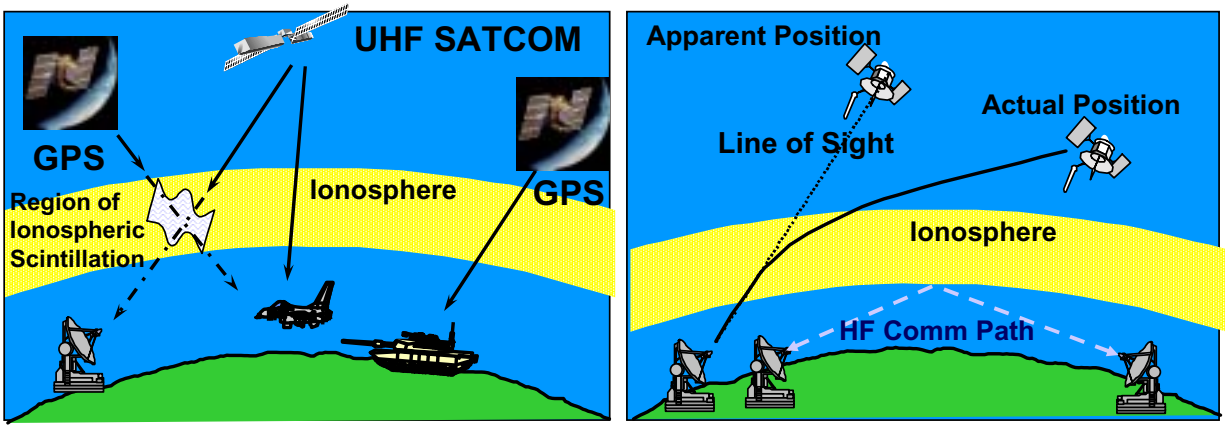
Figure 10. Solar proton events during the Apollo Program.

Radiation Enhancements in the Atmosphere -Altitude & latitude variations



Courtesy Clive Dyer
(IEEE TNS Dec. 2001)

Communications and Navigation



US DoD presentation on Space Weather

Quebec Power Outage 1989 caused by a "super" geomagnetic storm

Damage to transformers

Damage to a transformer at a power plant Delaware, New Jersey i march 1989.

Price: 10 M$

Repair can take up to 1 year.

In this particular case they were lucky to find a used one from a shut down plant. Took only 6 weeks to restore

(Some estimate that total impact of such an event in US in future could reach 3-6B$)

Sweden: simultaneous power loss in six 130 kV power distribution lines

Chicago: Five transformers in the Chicago area failed due to elevated geomagnetic activity in April 94

Not a New Problem!

In a telegraph system in 1849:

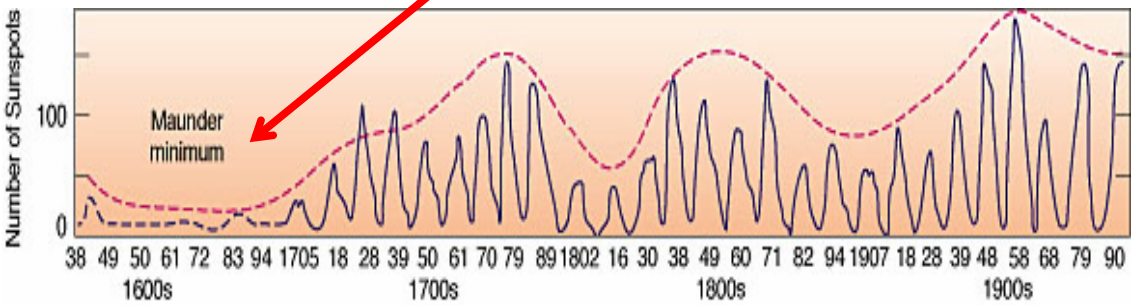
W.H. Barlow,
"**On spontaneous electrical currents observed in the wires of the electric telegraph**", *Phil. Trans. R. Soc.*, 61, 1849:

"The observations described… were undertaken in consequence of certain spontaneous deflections having been noticed in the needles of the electric telegraph on the Midland Railway, the erection of which was carried out under my superintendence as the Company's engineer."

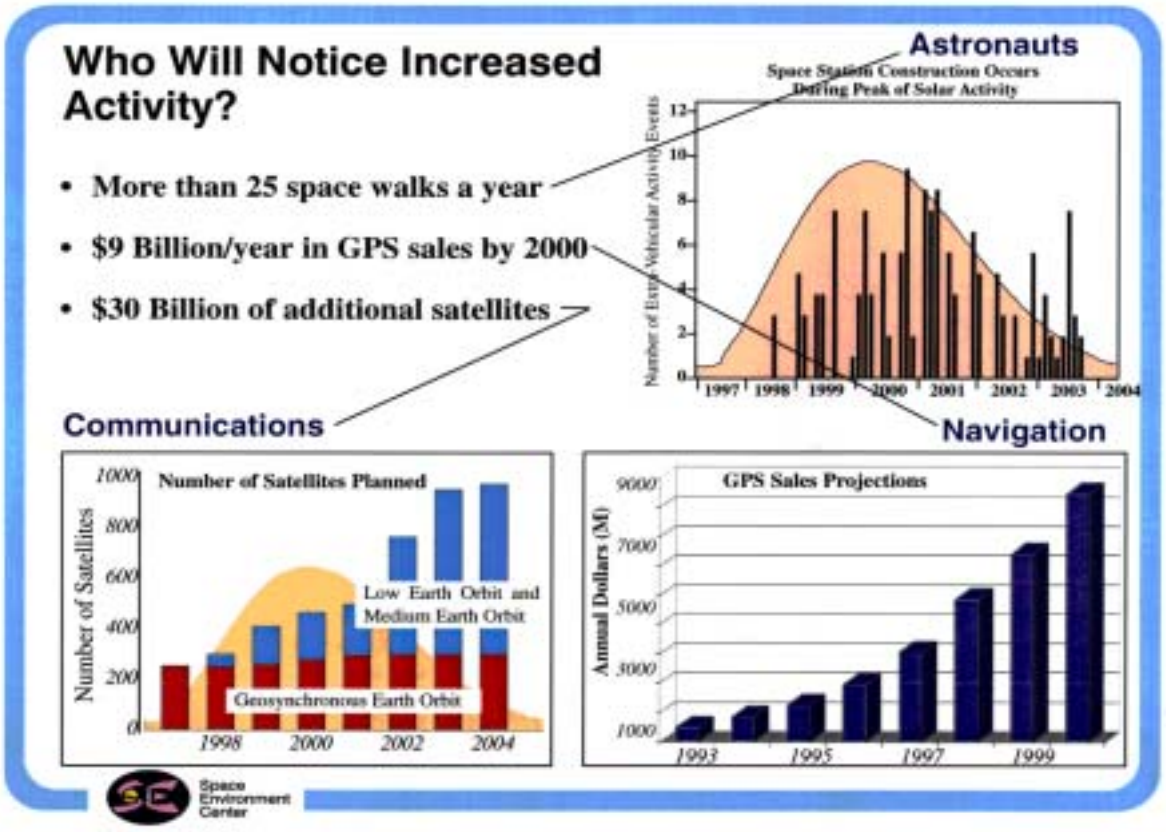
"… in every case which has come under my observation, the telegraph needles have been deflected whenever aurora has been visible"

Climate Changes?

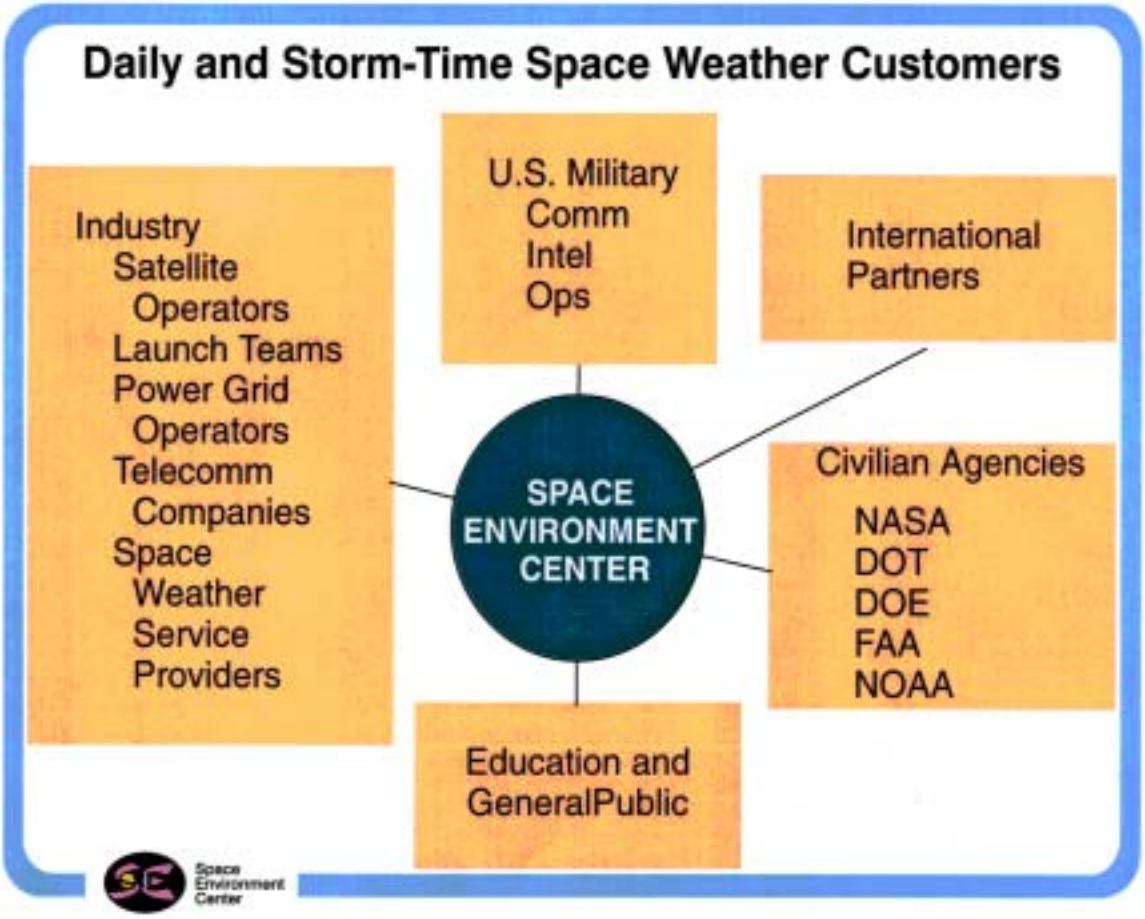
Probably the most recent example of large social disruption of cosmic origin is the 70 year-long European Mini-Ice Age during the "Maunder minimum" of 1645-1715.



Parker : "We know from observations of a few sun-like stars that one of them lost 0.4% of its luminosity in only a few years. If the Sun did that, it could quickly reproduce the cold conditions of 300 years ago..."



Daily and Storm-Time Space Weather Customers



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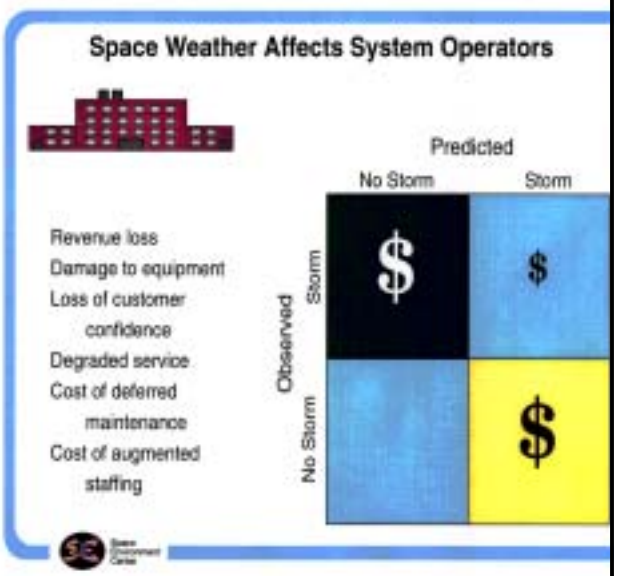


Future...

- More sensitive technologies in space (hundreds of satellites will beco thousands)
- More use of space as part of the social infrastructure (e.g. navigation, observation, communications, defence)
- More aircraft issues
- New groups affected (prospecting, …)
- Growing user community with a growing set of user requirements…

Space Weather Services

- Measurement Needs
- Data and Models

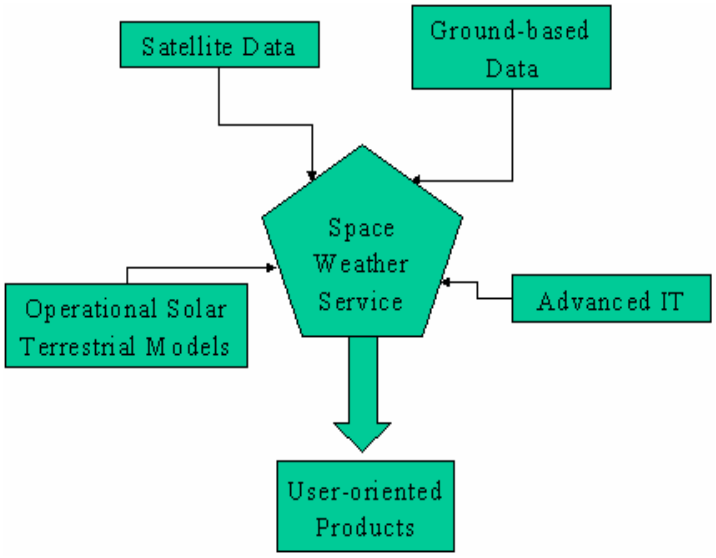
Background

- Effects are an increasing problem;
- Service providers provide supporting to users;
- Space Science provides:
  - Data and expertise to help protect systems affected *(the spacecraft that provide warnings are often science missions);*
  - Foundations of improved ability to understand & predict (ESA, NASA and others are working on important space physics research and applications developments);
- There are movements towards dedicated "Space Weather Services"

What is a Space Weather Service?

- *provides end-users in the affected sectors with tailored products to avoid or reduce space weather hazards through design or operation.*

- Data & services which can be provided are already proving valuable in certain sectors (e.g. power grids, communication, defence, spacecraft)
- A space weather service federates ground and space based measurement of the solar-terrestrial environment, not to perform science, but to derive products.
- A service includes advanced data processing and information technologies to exploit data and execute simulations of the space weather systems.



Example of an Operational Service: Shuttle Operations

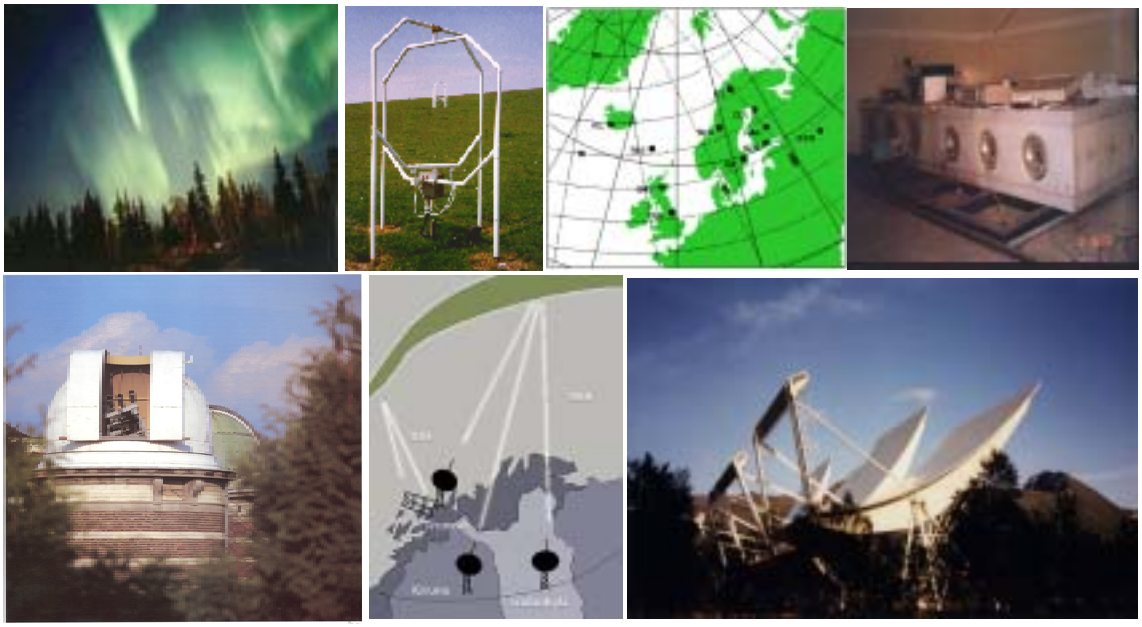
Engineers and Users' Requirements:

1. Extracting accurate specifications from a good statistical basis.
2. Forecasting the long term space environment conditions for spacecraft design.
3. A posteriori determination of the condition of the space environment that prevailed at dates requiring in depth analysis or data quality label (e.g. date of spacecraft anomaly or date of scientific data collection).
4. Evaluating in real-time whether the space environment conditions are compatible with planned operations or are requiring specific actions.
5. Forecasting the short to medium term space environment conditions for operation planning.

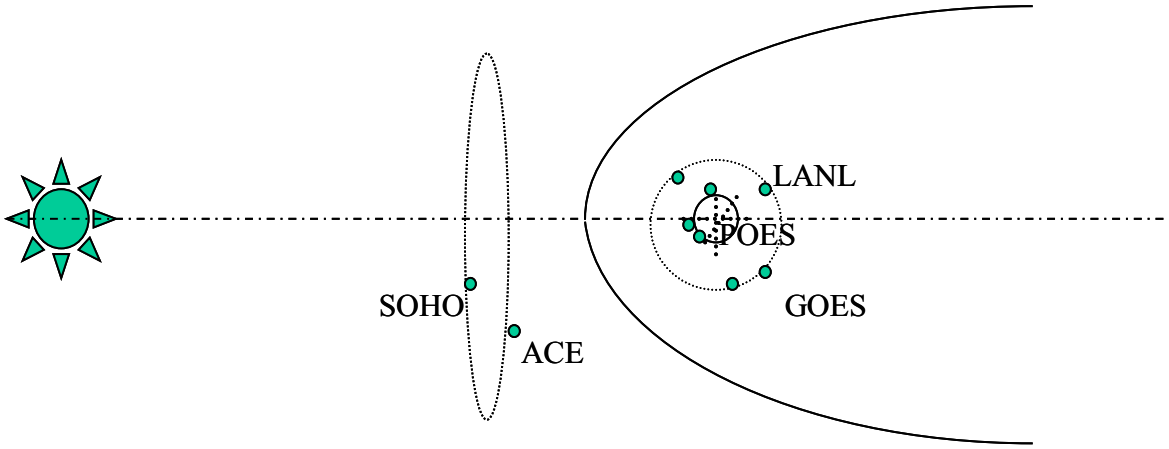
Data and Models

- Space weather covers a wide spatial range, so sources of data are wide-ranging:
  - Ground-based
  - Space-based

Ground-based sources of near real time data



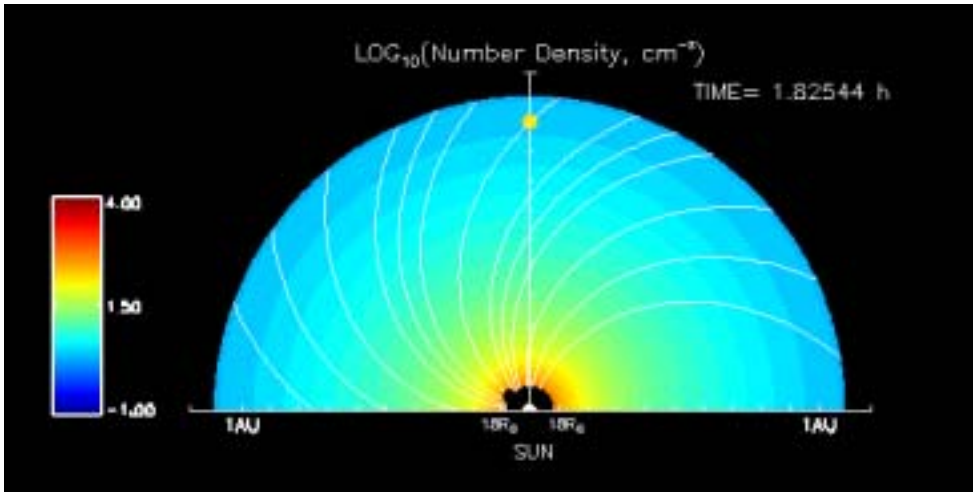
Space-based Sources of Near-Real Time Data



Models

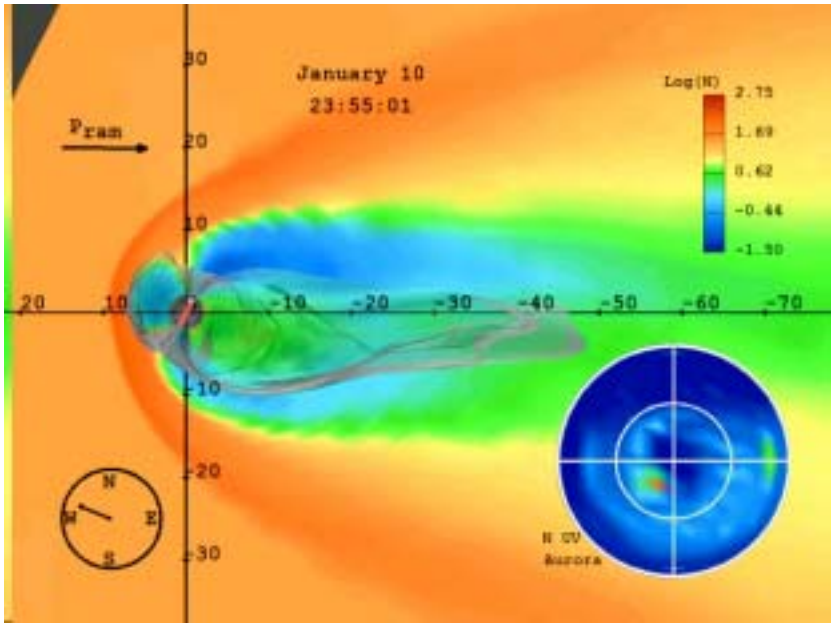
- Solar wind disturbances & ICME propagation
- Magnetospheric dynamics
- Ionospheric dynamics
- Thermospheric
- …

Simulation of Solar Wind Shock Propagation

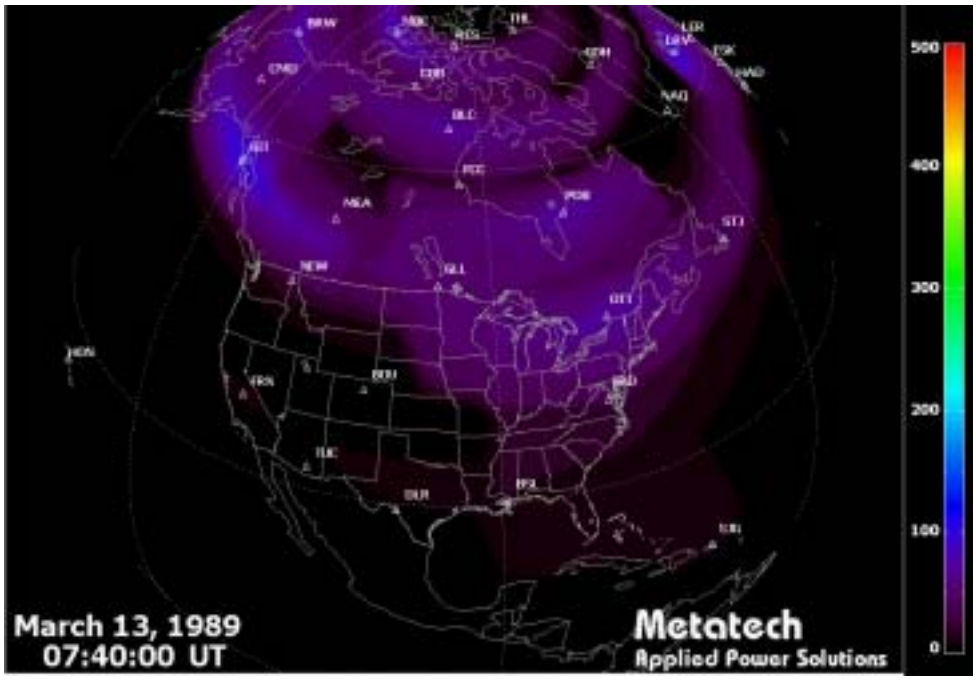


Produced by Angels Aran and Blai Sanahuja of University of Barcelona and David Lario of Johns Hopkins University

Simulation of CME interaction with the magnetosphere

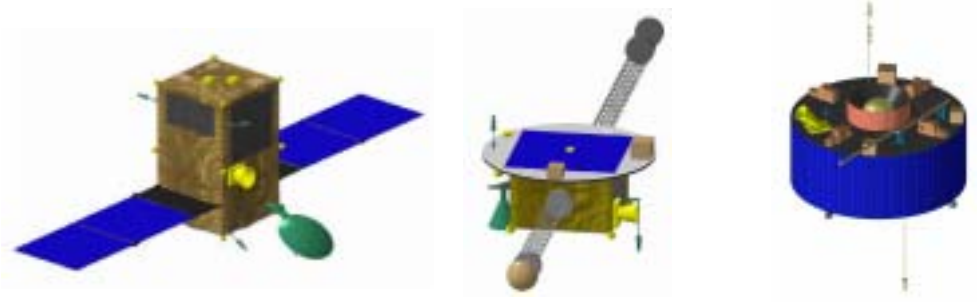


Simulation of Auroral Electrojet



Space Weather Missions

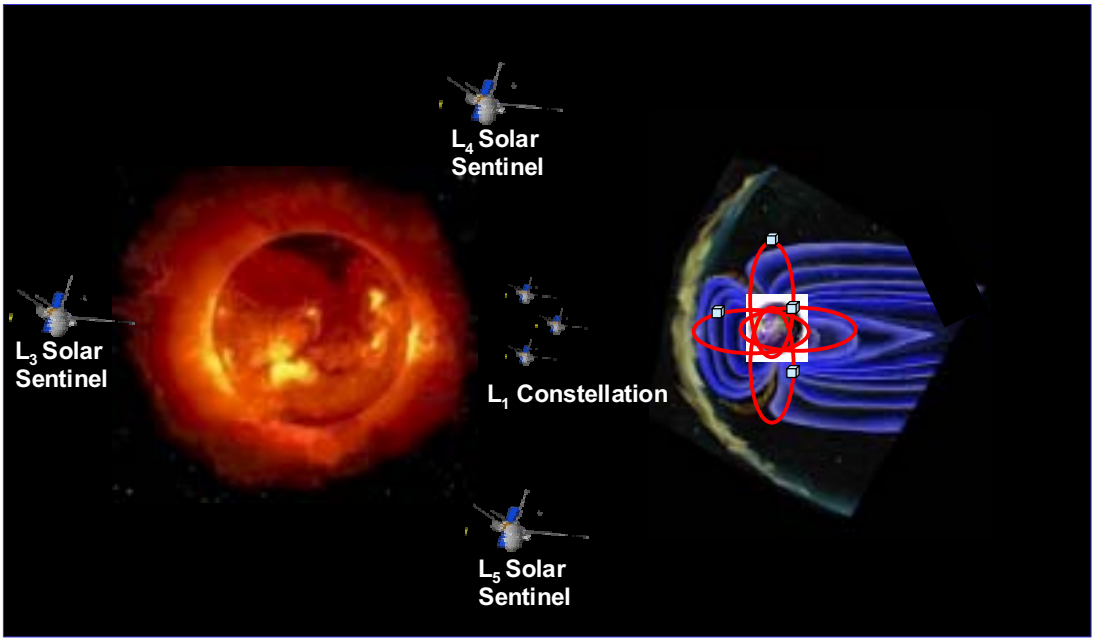
- Mostly scientific in nature
- Some studies have been made of feasibility and requirements for Applications missions



International Context

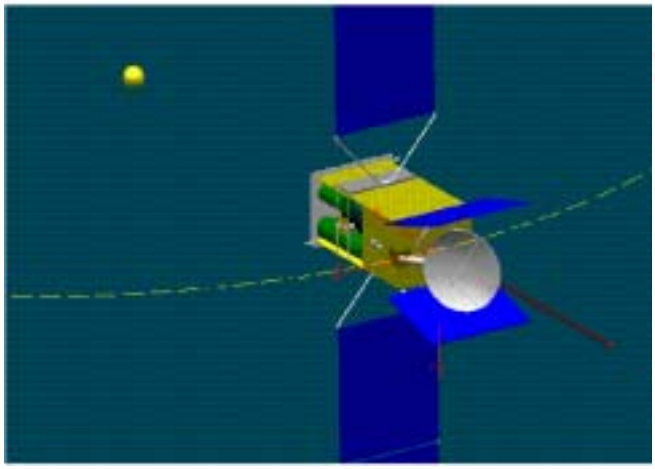
- US:
  - NASA Science: (International) Living with a Star programme and other solar-terrestrial programmes;
  - NOAA Space Environment Centre and Data system
  - NASA Manned Programme
  - Department of Defence
- ESA/Europe
  - Space Science Missions (SOHO, Solar Orbiter, +)
  - National science missions; national technology missions;
  - Space Weather Applications Pilot Project
- Japan:
  - Study of an "L5" mission + others
- Other nations are active
- A coordinated world approach is the natural way forward

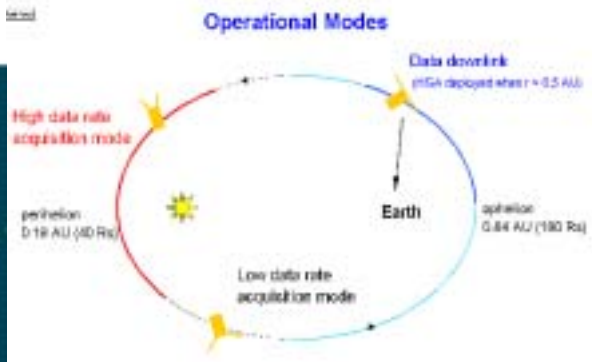
"NASA Living with a Star" Programme



ESA's Solar Orbiter (2010+)

Near-sun studies of the sun and solar wind





European Strengths

- Space Science (solar, S-T) programmes
- Established space environments and effects community (monitors, models, tools,…)
- Ground-based effects (comms/nav, GIC): much activity; some services; recognition of needs;
- Ground based measurements
- Data systems/IT and modelling
- Space Industries
- Many efforts at national and European levels

Conclusions

- Scientific investigation of the solar-terrestrial system continues to be an important venture;
- Increasing sensitivity of technologies and society to space weather requires “services”;
- Your task: design a service (you decide what for)
- Your tools: the lectures + your initiative
- The output: a final presentation