AN INTRODUCTION TO SPACE WEATHER

2016 SWC Seminar Series

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Special thanks: Dr. Antti Pulkkinen, NASA/GSFC

Space weather research & forecasting at CUA

The newly opened CUA Space Weather Center (SWC) is a fully functional research and real-time analyses center dedicated to scientific investigations and forecasting of extreme space weather events – violent physical processes around the Earth driven by storms on the Sun.

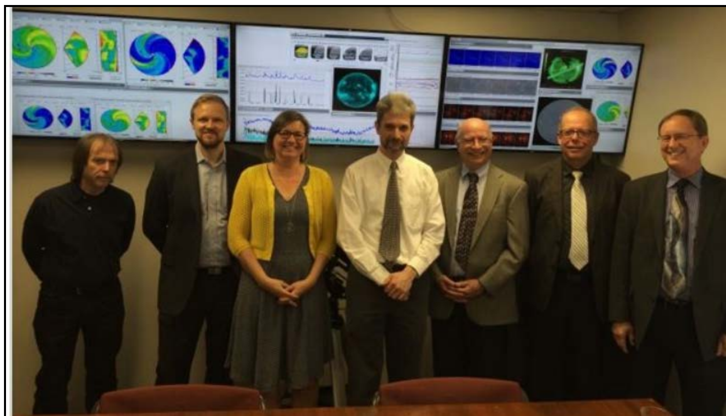
Space weather events present a growing hazard to human technologies and society by disrupting satellite communications and navigation systems, damaging power grids, exposing astronauts to a harsh radiation environment, and causing an array of other detrimental effects in space and on the ground. Understanding the physics of such events has become a priority of NASA science programs which welcome contributions from educational institutions. Space weather has gained recent high-level attention, leading to the release of the space weather action plan by the Office of Science and Technology Policy at The White House.

SWC will enable scientific investigations of extreme space weather events associated with major solar flares, large coronal mass ejections, solar energetic particle events, and intense geomagnetic perturbations and their ionospheric footprints. Data-driven simulations and an advanced statistical analysis of past events will be used to produce student-generated experimental space weather forecasts which will be posted online and disseminated throughout the space weather research community.

http://spaceweathercenter.cua.edu

2016 SWC SEMINARS

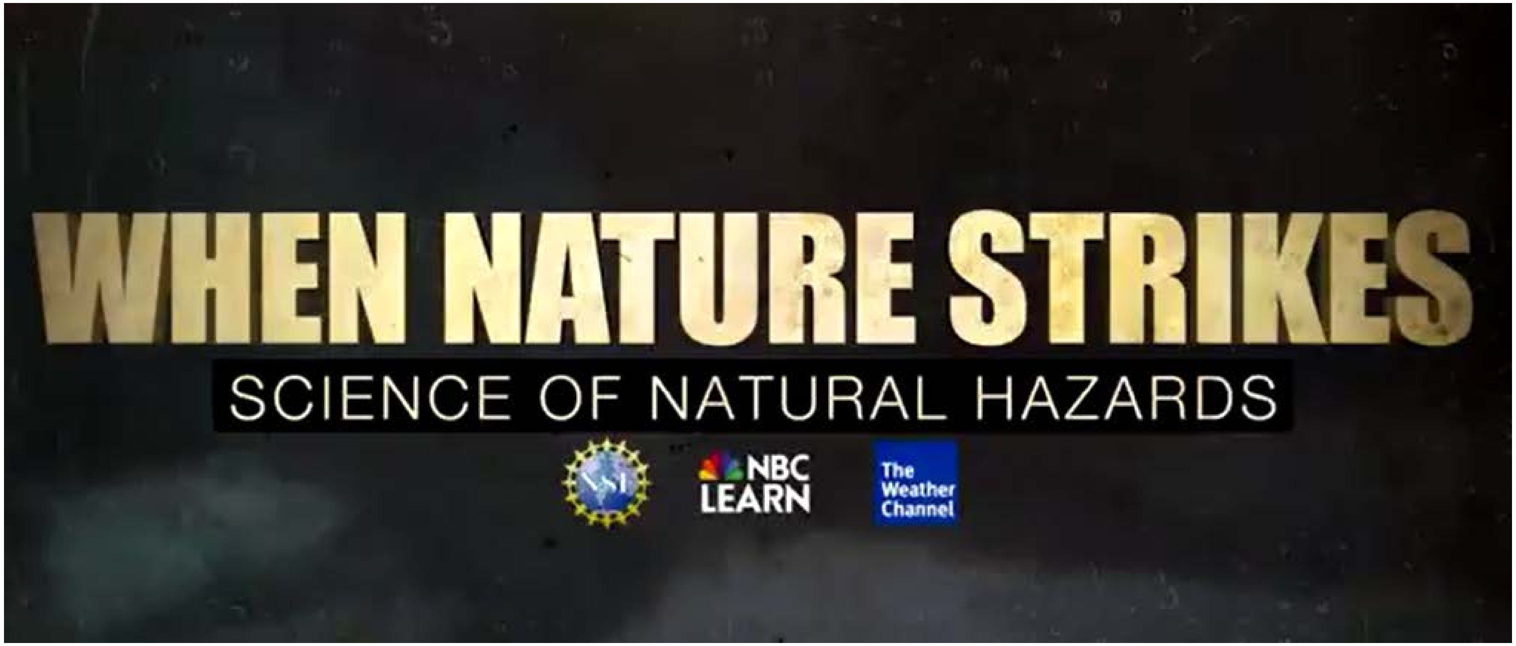
The Space Weather Center launches a series of educational seminar talks focused on scientific, engineering, and sociological aspects of cutting-edge space weather research.



At the opening ceremony, from left to right:

Steve Kraemer, Head of the Physics Dept., CUA
Antti Pulkkinen, Research Astrophysicist, NASA Goddard
Claudia Bornholdt, Acting Dean, School of Arts & Sciences, CUA
Vadim Uritsky, Head of the Space Weather Center, Physics Dept., CUA
Robert Robinson, Director of Institute for Astrophysics & Computational Sciences, CUA
Michael Hesse, Director of Heliophysics Science Division, NASA Goddard
Robert McCoy, Director of Geopyiscal Institute, U of Alaska Fairbanks

Space weather as a natural hazard



NSF VIDEO: When Nature Strikes - Space Weather (5:46)

www.whitehouse.gov

NATIONAL SPACE WEATHER STRATEGY

PRODUCT OF THE

National Science and Technology Council

October 2015

Space Weather Operations, Research, and Mitigation Task Force

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Department of Commerce, National Oceanic and Atmospheric Administration
Department of Homeland Security
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United States Postal Service

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White House Military Office

What is Space Weather?

"Space weather refers to 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 health.

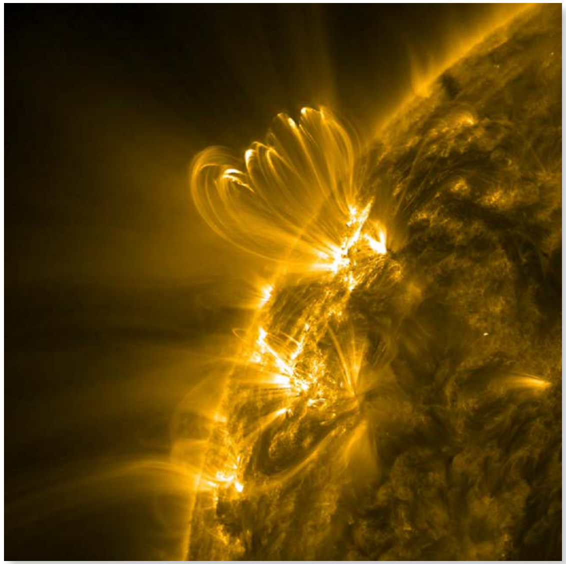
Adverse conditions in the space environment can cause disruption of satellite operations, communications, navigation, and electric power distribution grids, leading to a variety of socio-economic losses."

US National Space Weather Program

The physics of space weather

The physics of space weather is *plasma physics.*

> "*Plasma is quasi-neutral ionized gas containing enough free charges to make collective electromagnetic effects important for its physical behavior*"



EUV image of solar corona (credit: NASA SDO)

Image of auroras at visible wavelengths (credit: spaceweather.com)

The Sun, the space weather driver

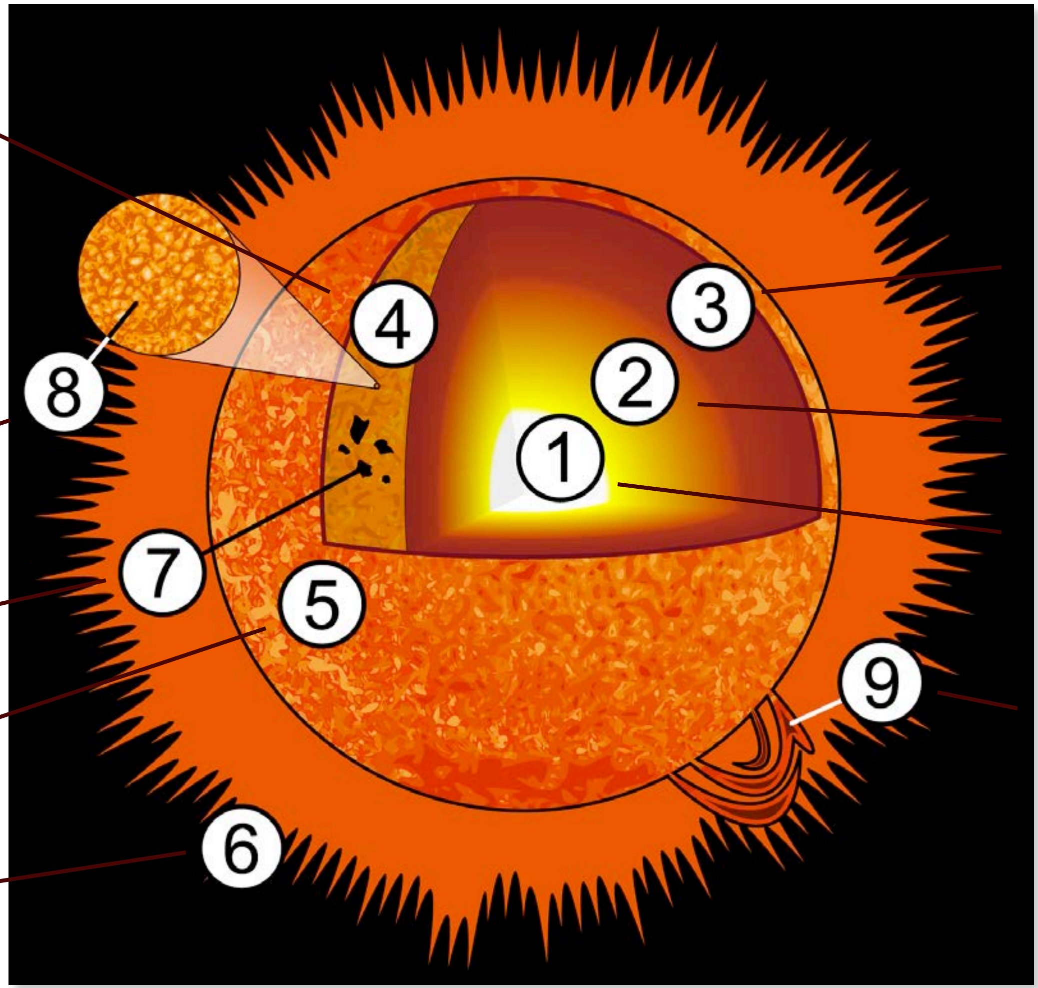
Photosphere at 4300 K (top)

Granulation

Sunspots

Chromosphere at 25000 K (top)

Corona at $\approx 10^6$ K



Convection zone at 6600 K (top)

Radiation zone at $5 \bullet 10^5$ K (top)

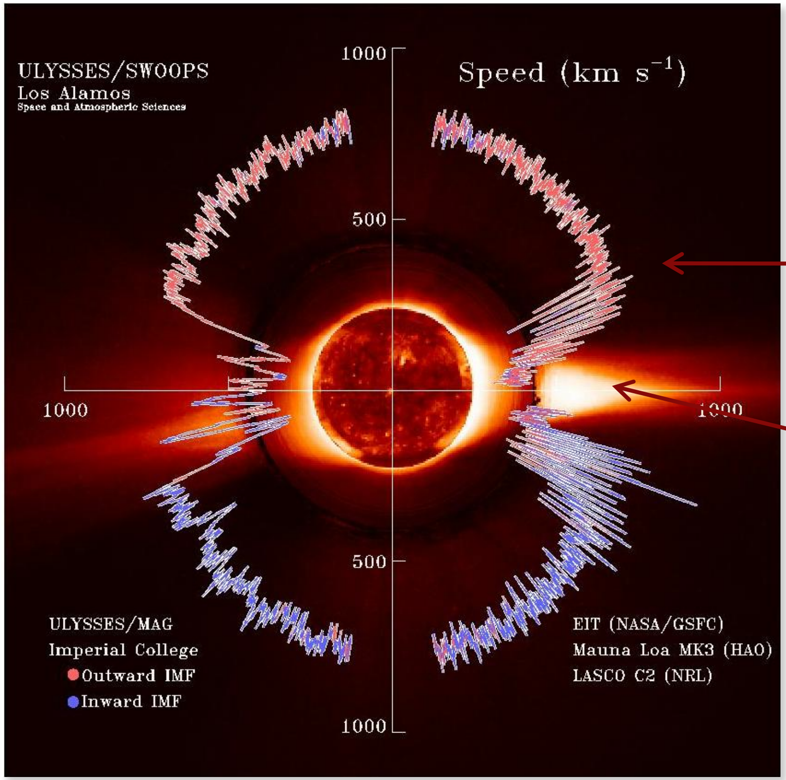
Core (Hydrogen into Helium) at $1.5 \bullet 10^7$ K

Prominence at about 5000-10000 K

Credit: Wikipedia/sun

The heliosphere

Solar atmospheric mass, momentum and energy are being carried away by *solar wind*.



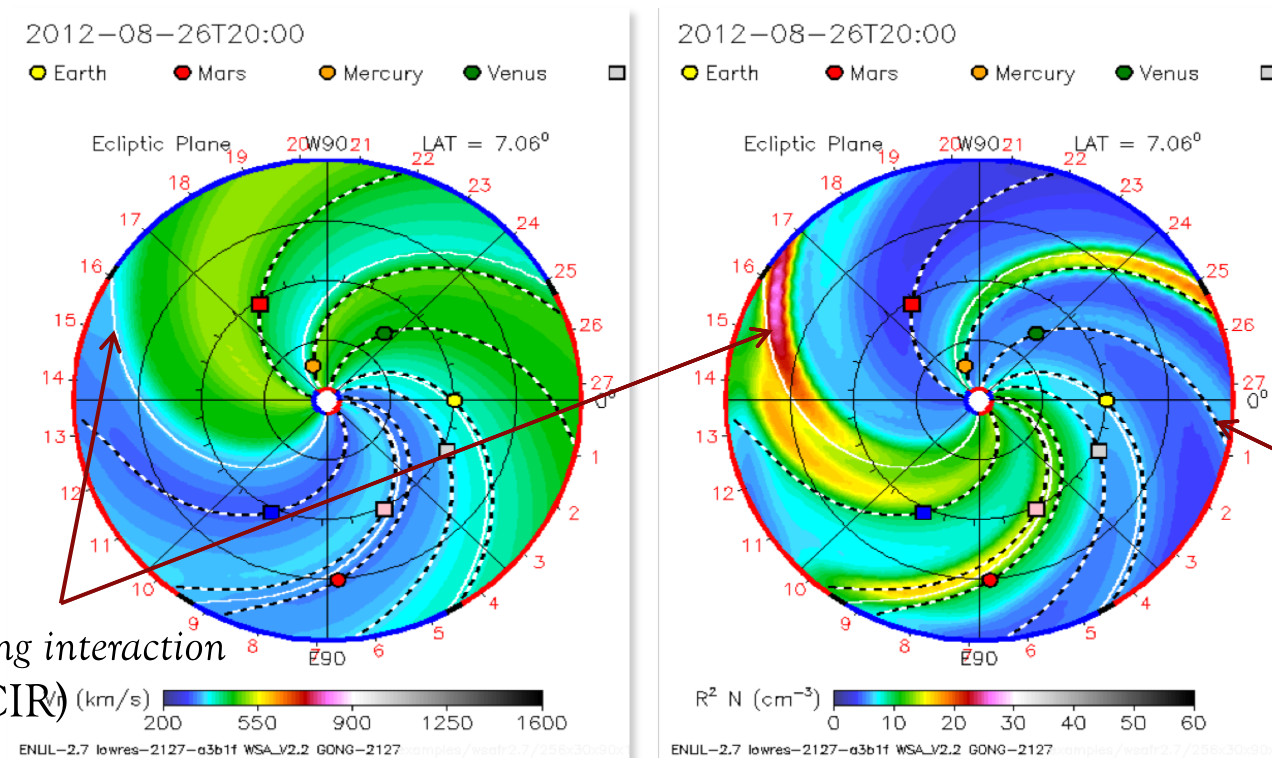
NASA/ESA Ulysses spacecraft data from 1.3-5.3 AU (credit: NASA/ESA)

Fast wind from coronal hole(s)

Denser low speed wind from lower latitudes

The solar wind

Solar wind is *magnetized* – *interplanetary magnetic field* (IMF). Flow generates *Parker spiral*. Also, interaction between slow and fast wind very important.



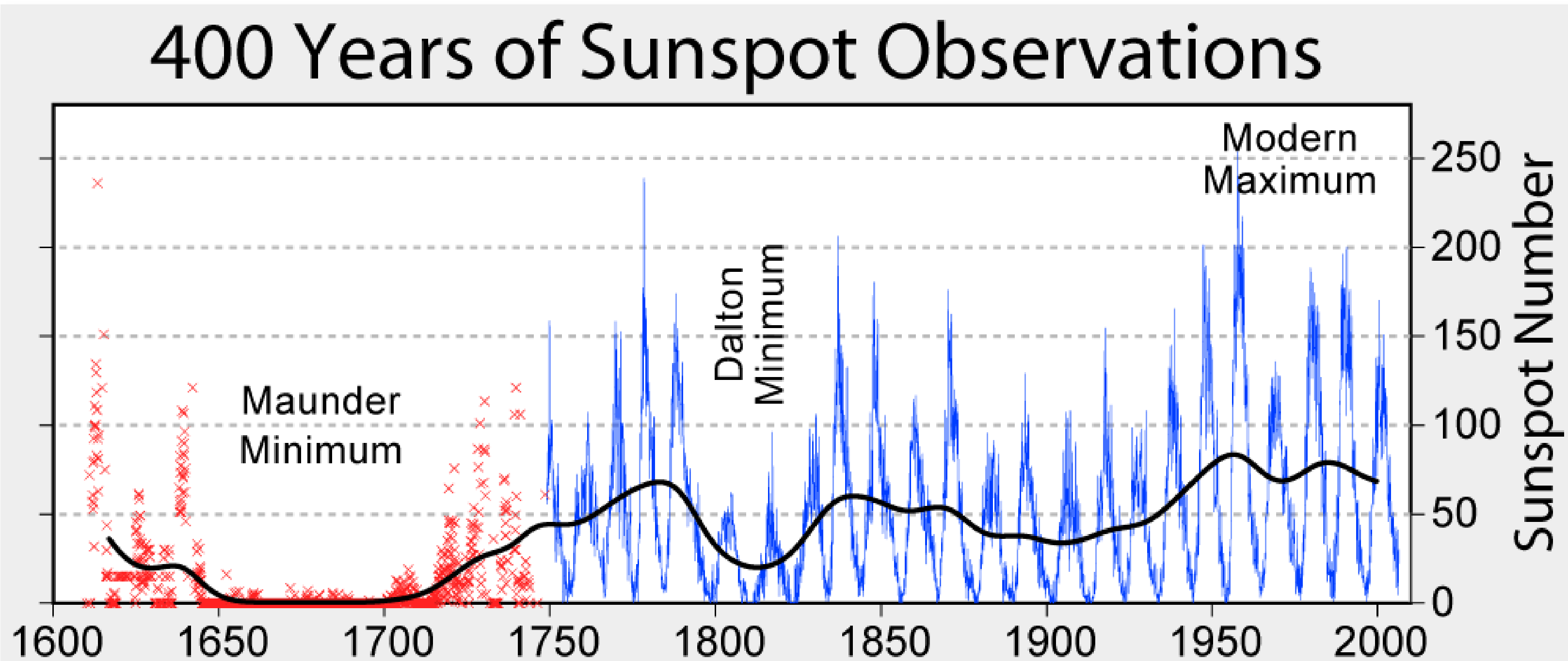
WSA-Enlil prediction of the solar wind conditions (credit: iSWA)

Corotating interaction region (CIR)

Spiral (IMF field-line)

The solar cycle

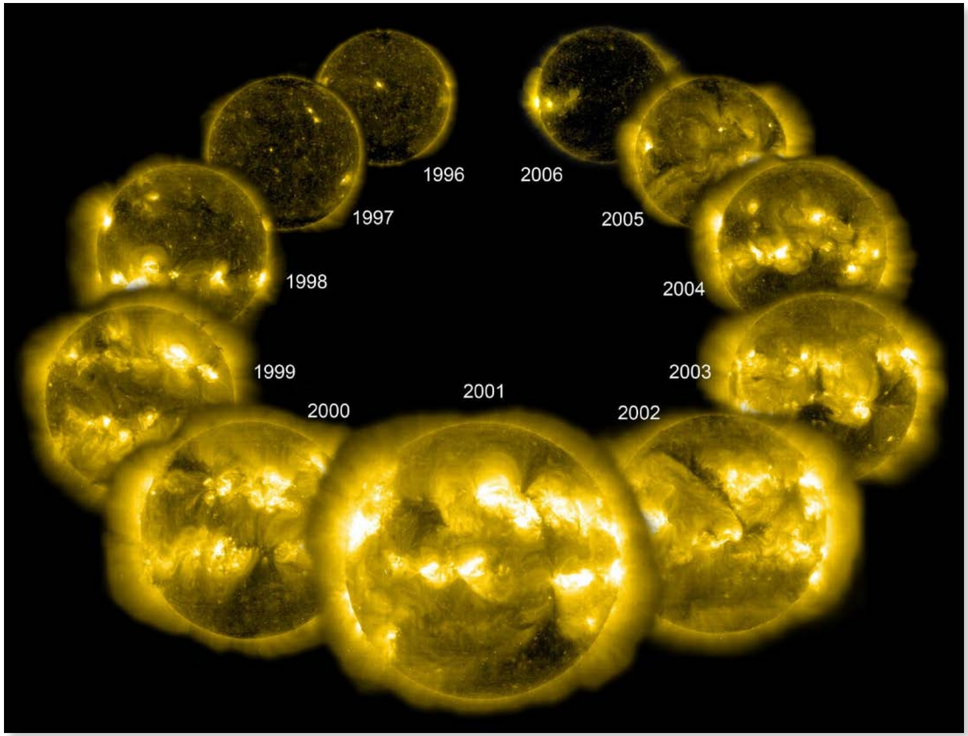
Credit: Wikipedia/Solar_cycle



Increasing sunspot number indicates more complex global solar magnetic field structure → eruptions more likely

Solar activity and complexity

As the global solar magnetic field structure gets more complicated also plasma configurations in the solar corona gain *complexity*.

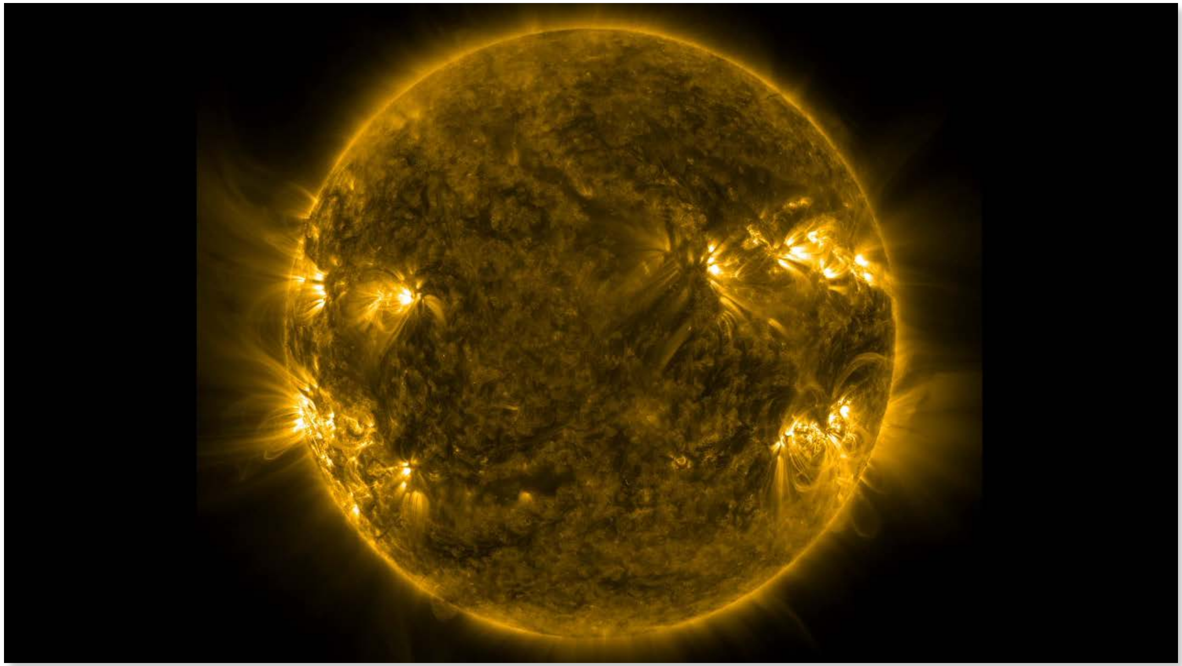


SOHO EIT 284 Angstrom images (2 million degree plasma)

Credit: NASA/ESA

Solar flares

Solar flares lasting, depending on the signature of interest, 1-60 min are the largest eruptions in the solar system. Energy of the order of 10^{25} J can be released by flares (annual world energy consumption $\approx 10^{20}$ J).



SDO AIA 171 Angstrom (1 million degree plasma)

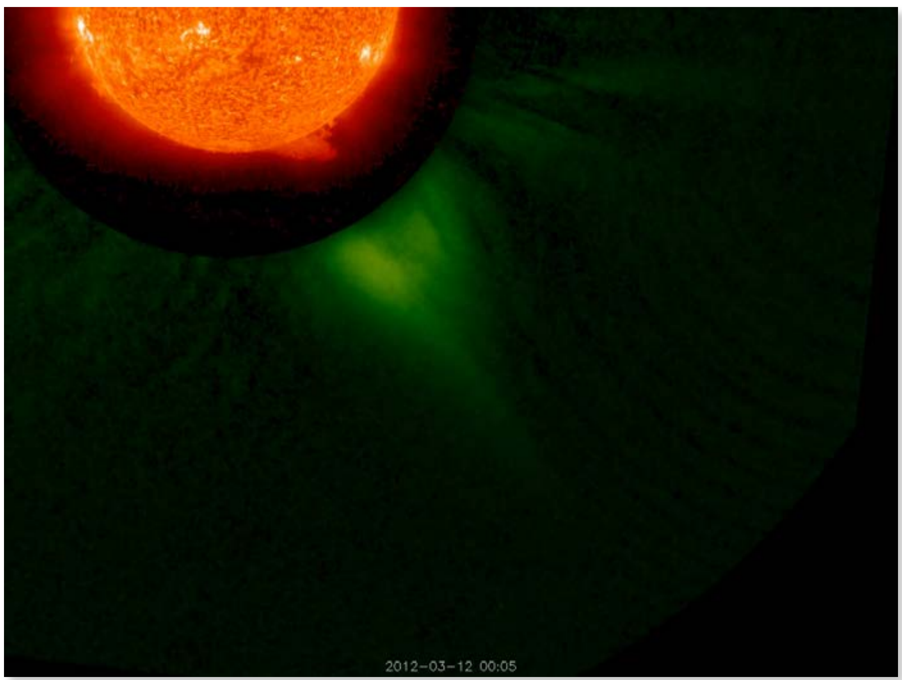
Credit: NASA GSFC SVS

Effects of solar flares

- In solar flares, a free magnetic energy is converted into heat, non-thermal particle acceleration and electromagnetic radiation.
- Solar flares generate, for example, X-ray, Extreme Ultraviolet (EUV) and radio emissions, and solar energetic particles (SEPs).
- All of the above effects have significant space weather consequences.

Coronal mass ejections (CMEs)

Many large flares are associated with *coronal mass ejections* (CMEs) releasing billions of tons of solar corona material at speeds of 200-3000 km/s. Total kinetic energy of CMEs can be of the order of 10^{25} J.



STEREO B 304 Angstrom EUV and white light coronagraph March 12, 2102

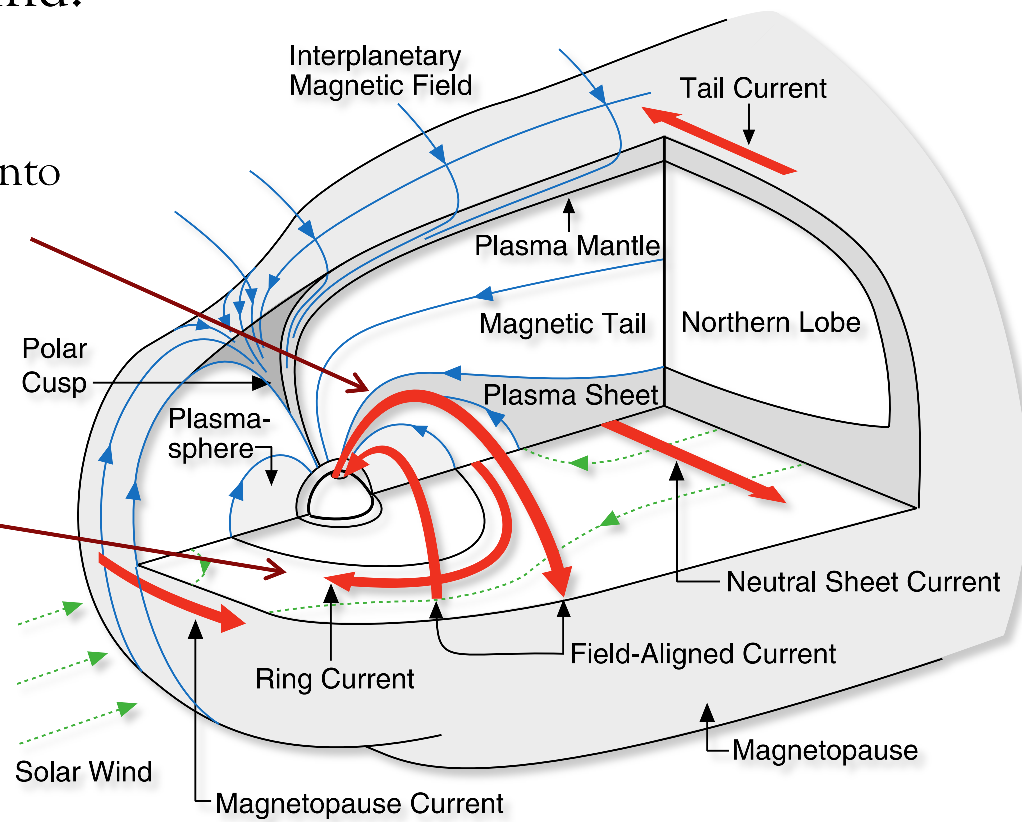
Credit: NASA

Earth's magnetosphere

Various magnetospheric electric current systems get powered by the solar wind.

≈ 1 MA current into the ionosphere

Charged (10-200 keV) particles carrying the ring current partly overlap with the radiation belts



Credit: Russell, C. (IEEE Trans. on Plasma Science, 2000)

Upper atmosphere

Earth's ionized upper atmosphere (80-1000 km altitude) reacts for example to solar flare-related X-rays, EUV, SEP events and magnetospheric activity.

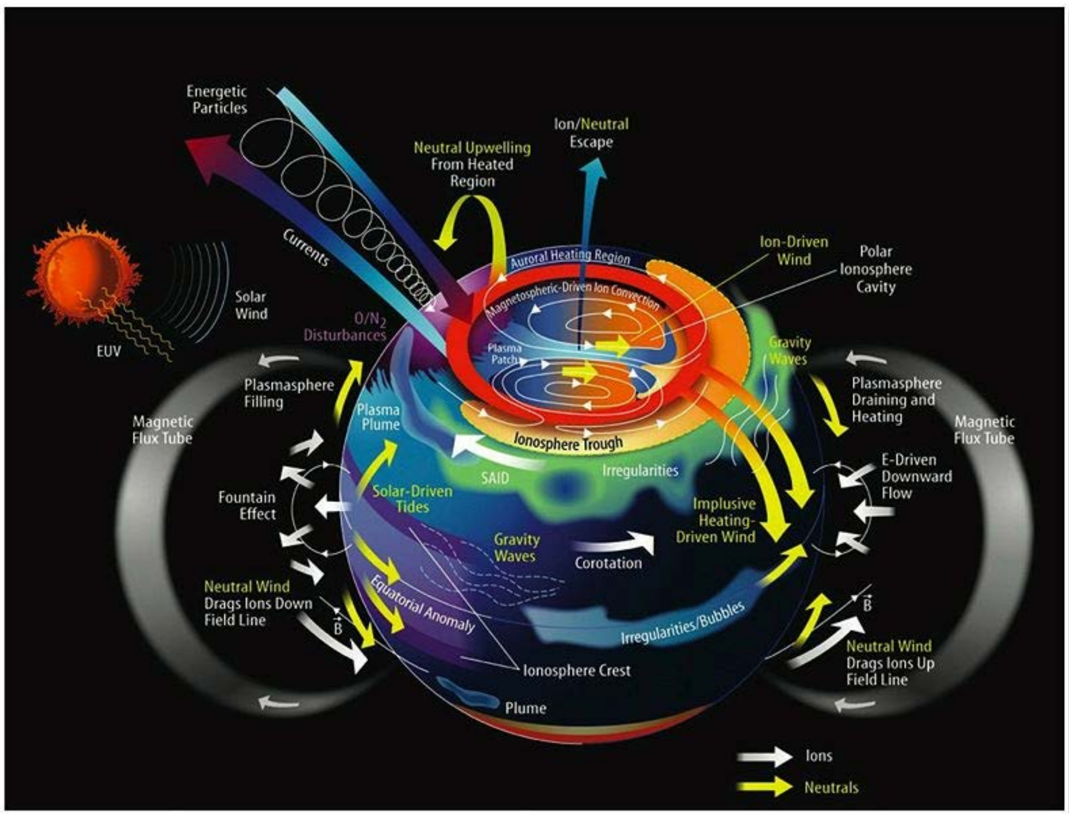
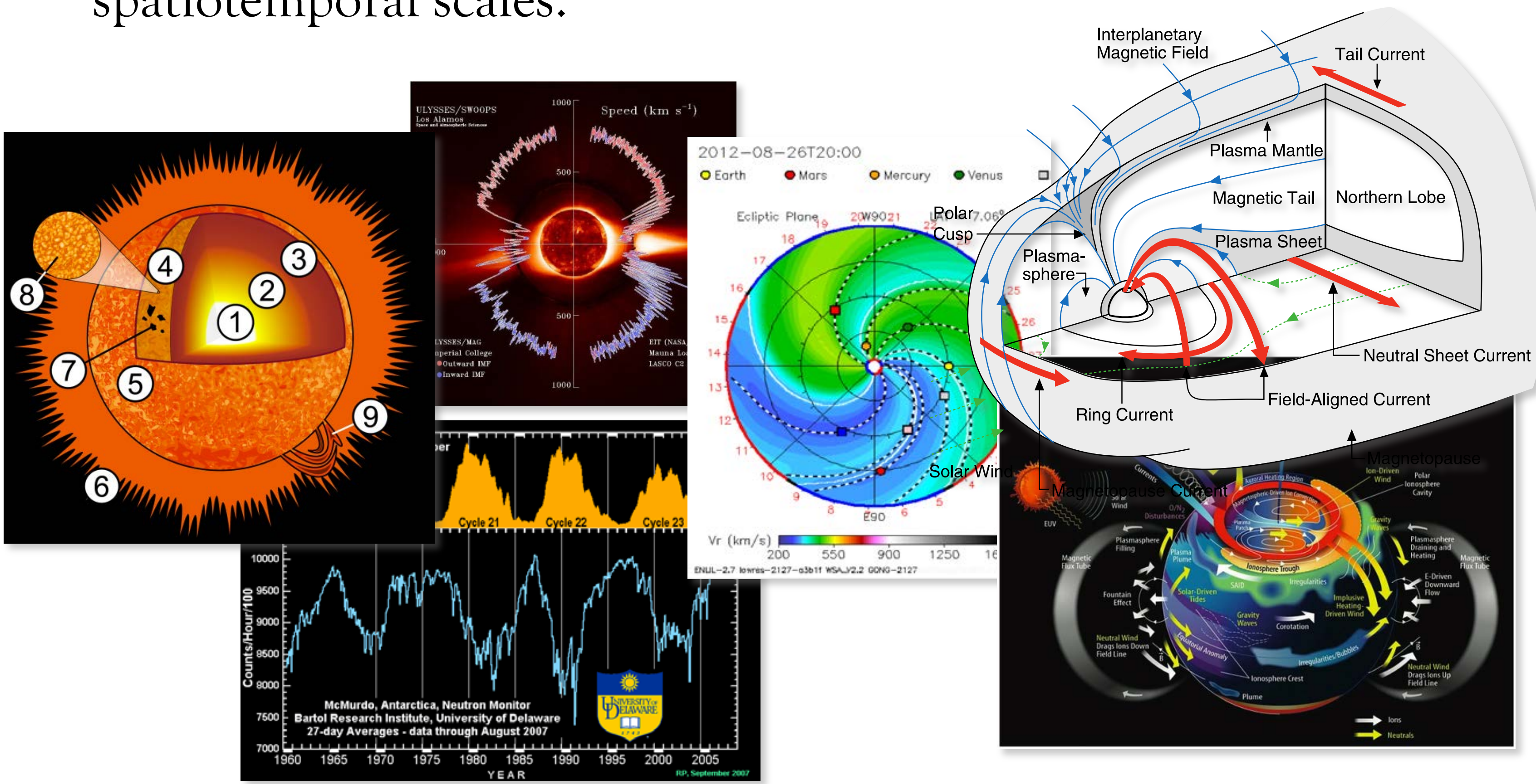


Illustration of upper atmospheric dynamics (quite simple, no?)

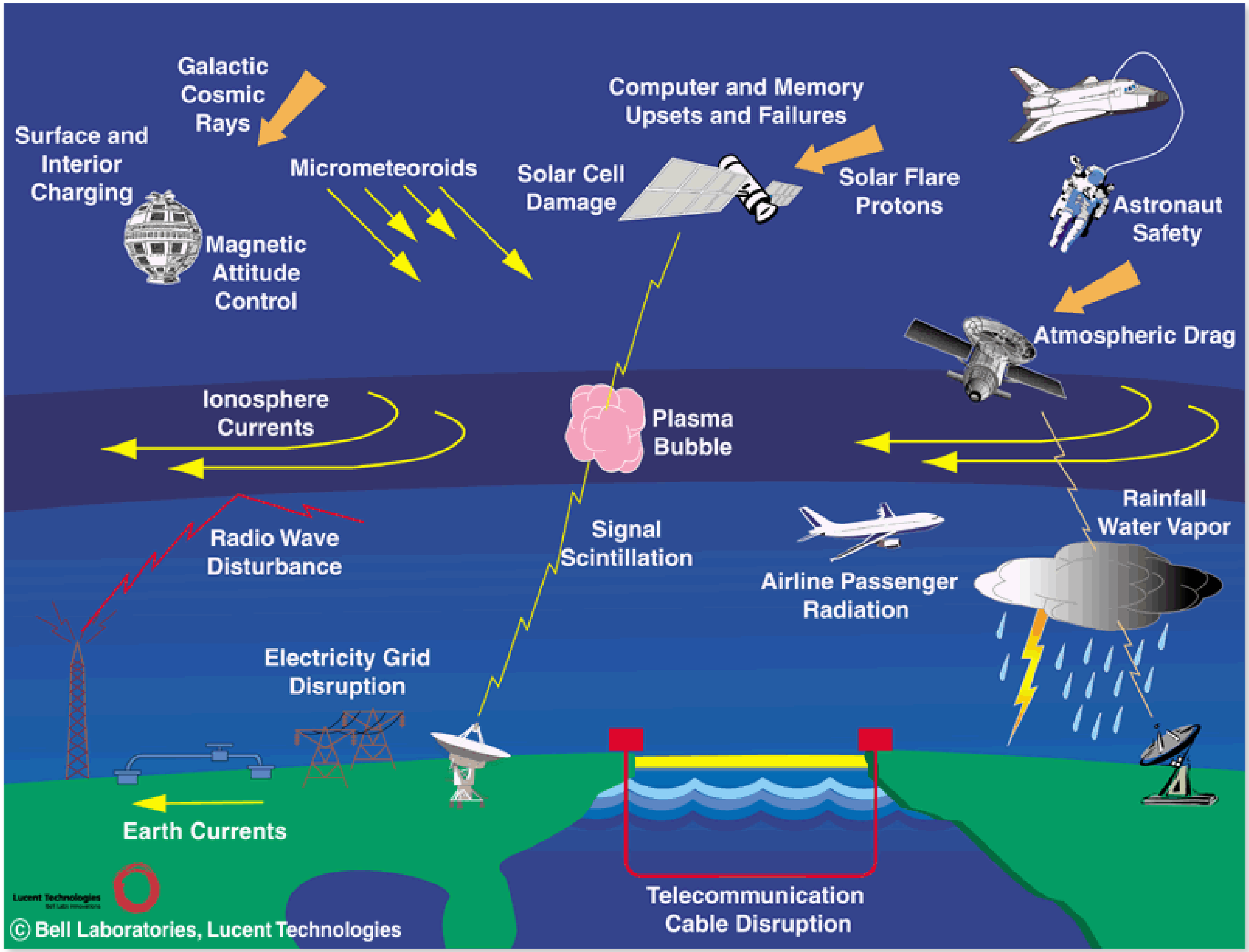
Credit: J. Grobowsky/NASA

The couples space weather system

So we see that space weather really is a vast chain of complex interacting systems covering wide ranges of physics and spatiotemporal scales.



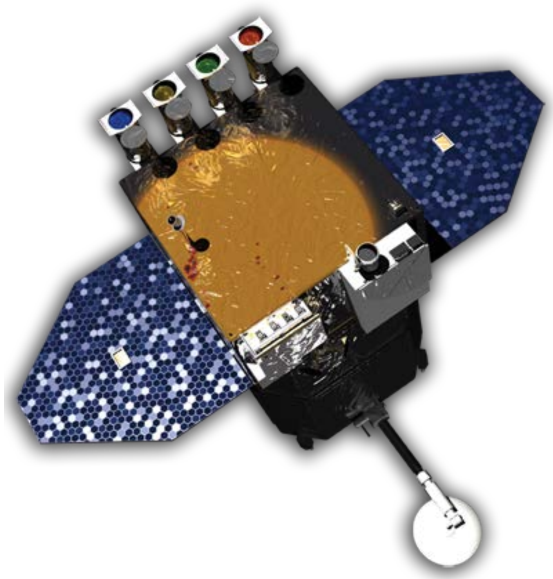
The space weather impacts



credit: L. Lanzerotti/Bell Labs

Spacecraft damage and loss

Spacecraft can be impacted in a number of different ways depending on the orbit of the vehicle.

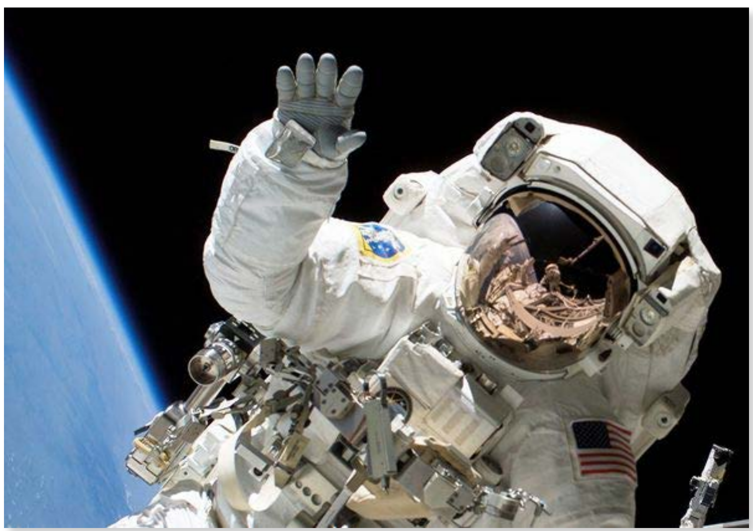


Solar Dynamics Observatory (credit: NASA)

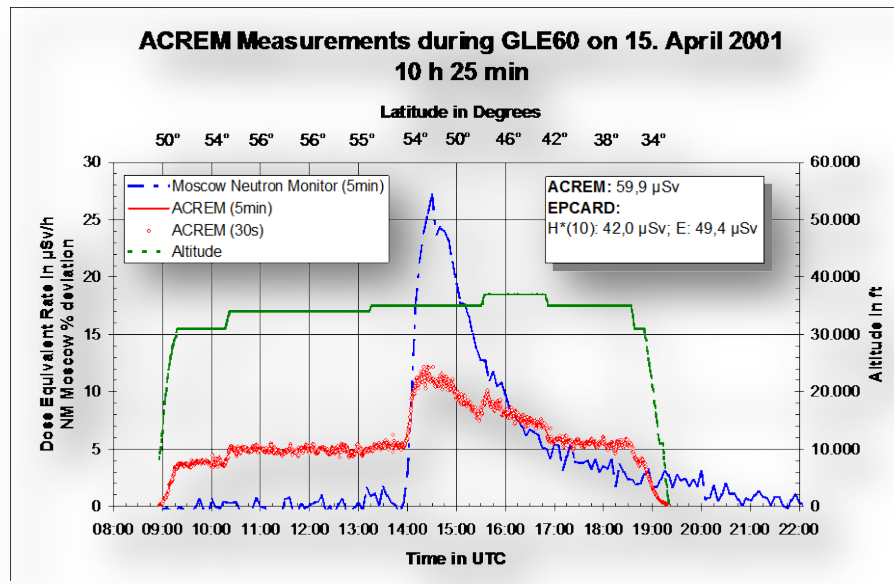
- Surface (auroral and ring current electrons) and deep internal charging (radiation belt electrons).
- Single event upsets (GCRs [galactic cosmic rays] , SEPs, inner radiation belt protons).
- Drag effects (upper atmospheric expansion).
- Total dose effect (cumulative radiation in any environment).
- Effects on the attitude control systems (magnetic field fluctuations and SEPs).

Radiation hazard for humans

Energetic charged particle radiation is a hazard for humans in space and at airline altitudes. Especially less predictable SEPs are a concern.



Credit: NASA



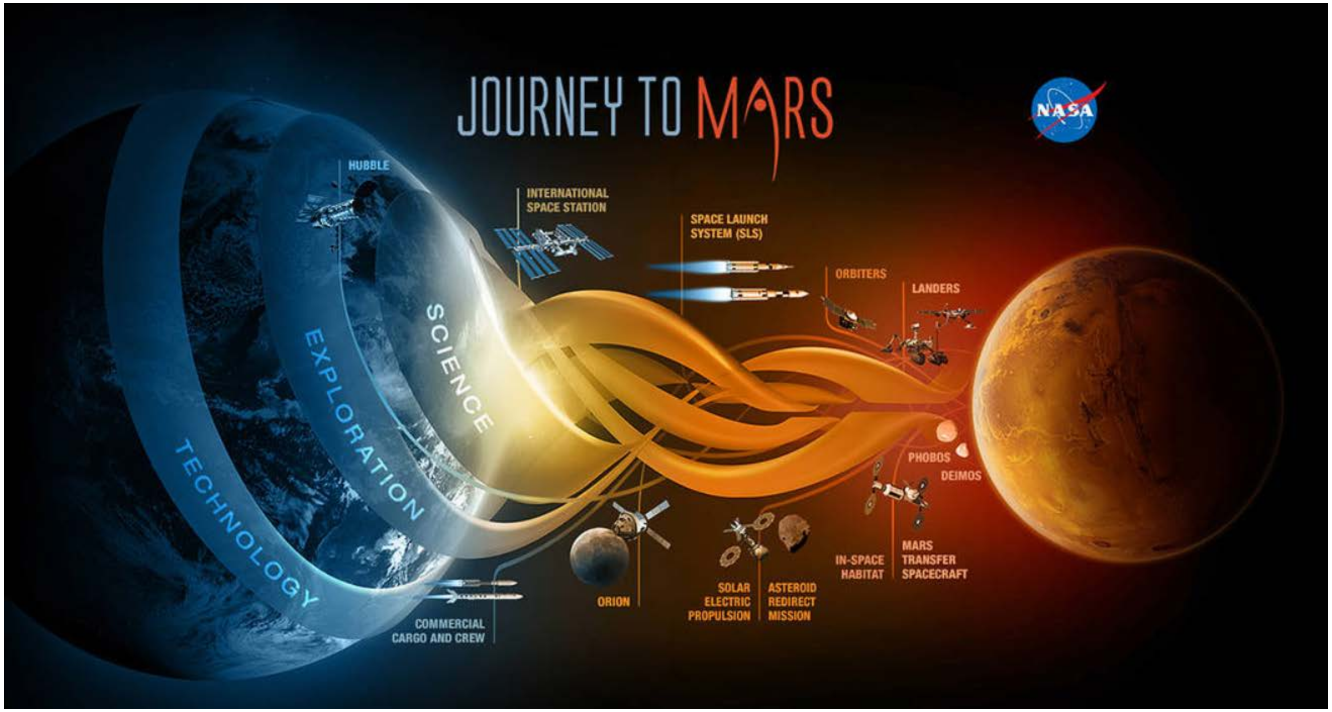
Dose observations from a commercial flight (Credit: Bartlett et al., 2002)

Energetic ions in space

- Energetic charged particle radiation in space and at high altitudes poses a problem for biological systems such as humans.
- The key problem is *ionizing radiation* – radiation (typically > 10 MeV ions) with sufficient energy to ionize atoms and molecules along the path of penetration.
- Primary sources for energetic ions contributing to possible problems include galactic cosmic rays, SEPs and inner radiation belt.

Space weather and interplanetary travel

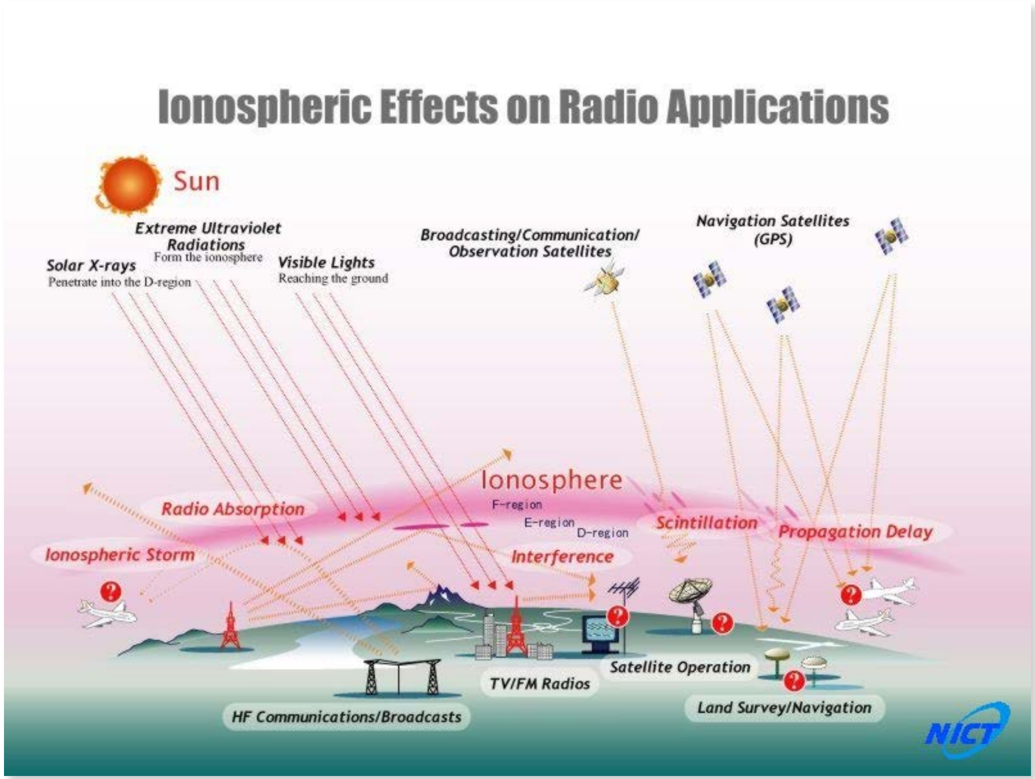
At low Earth orbits (LEO), manned missions mostly safe. For **interplanetary** missions while galactic cosmic rays also pose a problem the risk may be manageable. Major SEP events pose a serious problem.



SPACE.COM VIDEO: The Human Challenges of Mars: Radiation **(1:14)**

Interference with radio signals

Signals using ionosphere or "just" passing through ionosphere are affected by space weather.



Credit: NICT

- Global navigation satellite systems such as GPS (e.g., EUV, X-rays, SEPs, magnetospheric activity)
- High-frequency (HF) radio communications (e.g., EUV, X-rays, SEPs, magnetospheric activity)
- Other GHz range comms such as cell phones (solar radio noise)

Induction effects on the ground

Geomagnetic field fluctuations drive geomagnetically induced currents (GIC) that can be a hazard to long conductor systems on the ground.

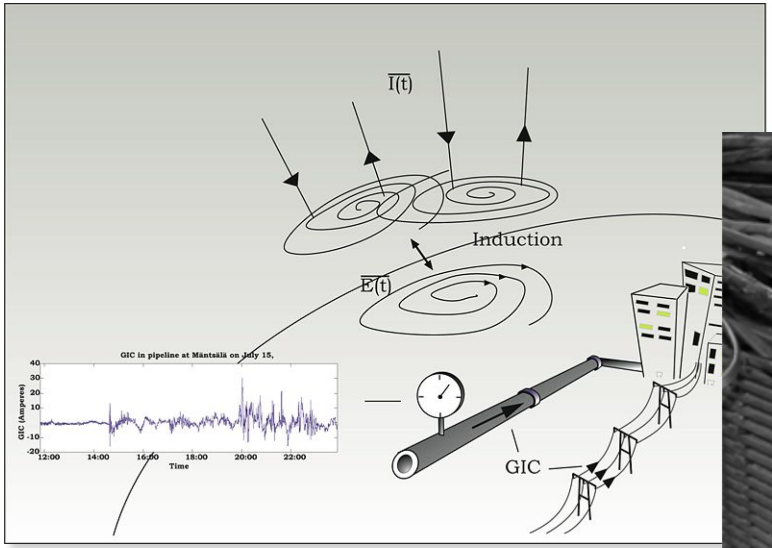


Illustration of mechanism for generating GIC

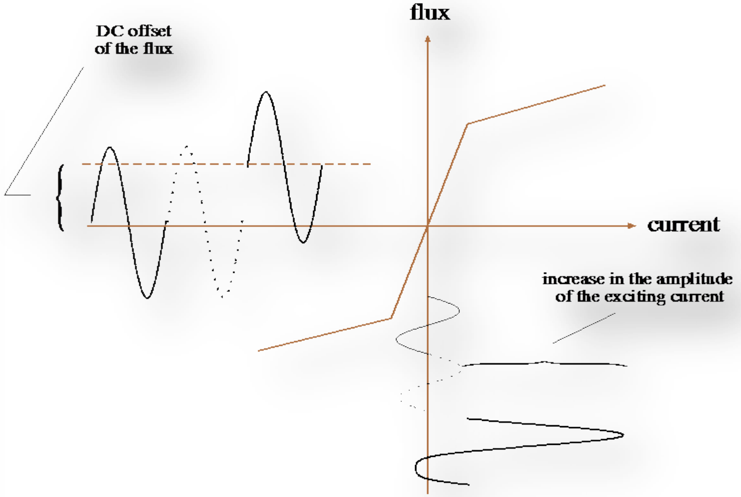
Transformer damage in South Africa

Credit: Gaunt and Coetzee (2007)

Space weather impacts power grids

- GIC has been shown to cause various problems but most of the recent focus due to potential magnitude of the impact has been on the power grids.
- The basis of the problem is the half-cycle saturation of high-voltage power transformers.

High-voltage power transformers (credit: Mitsubishi Electric)



Principle of half-cycle saturation

Coping with GICs

- Hardware-based GIC mitigation includes
  - Blocking the quasi-DC current flow using capacitors on transmission lines and transformer neutrals.
  - Transformer design reducing GIC sensitivity.
- Storm warning and monitoring-based GIC mitigation techniques include
  - Postponing maintenance of critical lines.
  - Avoiding switching the state of the system.
  - Dispatching reserve power.

Probability of catastrophic events

Self-organized criticality in X-ray flares of gamma-ray-burst afterglows

F. Y. Wang & Z. G. Dai

Nature Physics **9**, 465–467 (2013) | doi:10.1038/nphys2670
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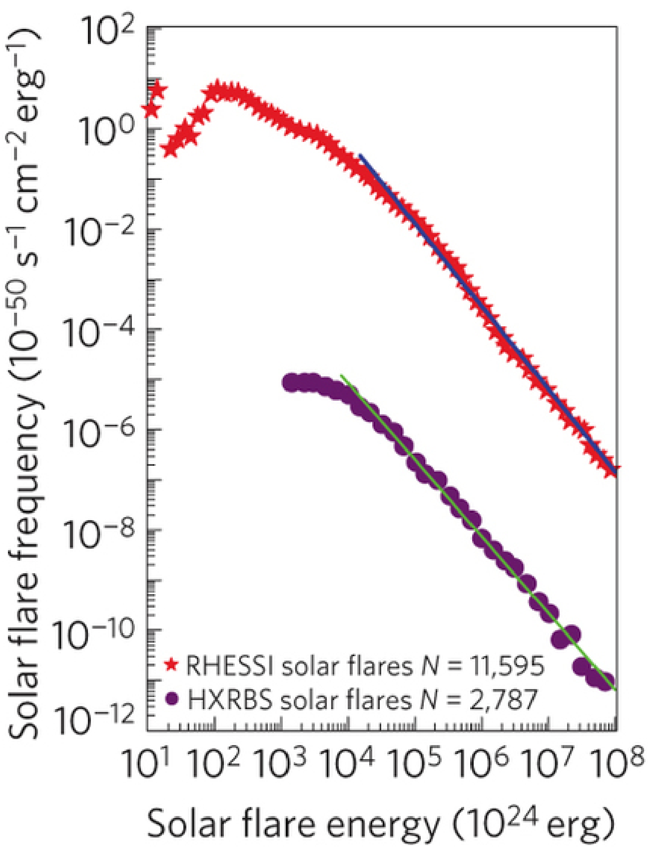
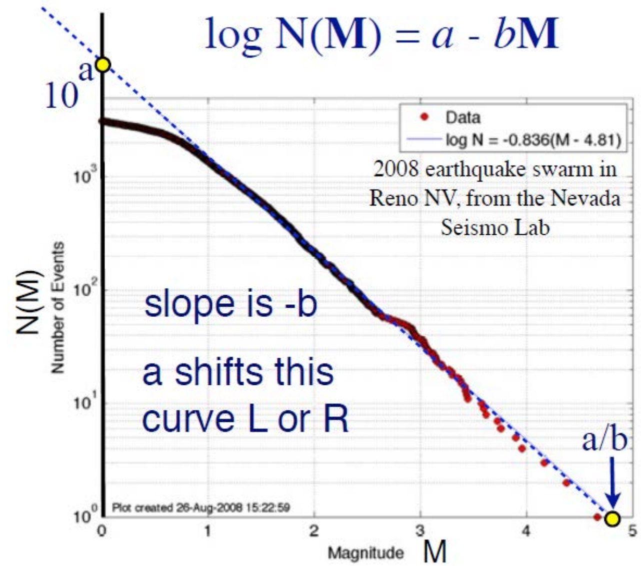


Compare with: Gutenberg–Richter law for earthquake magnitudes



Huge events WILL occur.

A new Carrington event?

THE MOVIE TRAILER: The FIGHT to SURVIVE Begins NOW (1:55)

NEXT SWC seminars

Schedule of talks

October 25, 1016 (Tuesday):	**AN INTRODUCTION TO SPACE WEATHER**
November 01, 2016 (Tuesday):	**THE SCIENCE OF SOLAR HURRICANES**
November 16, 2016 (Wednesday):	**FORECASTING EXTREME SPACE WEATHER**
November 30, 2016: (Wednesday):	**SPACE HAZARDS AND THE HUMAN SOCIETY**

Location: Rm 106, Hannan Hall **Time**: 7:00pm

Practical experience

Students with sufficient backgrounds in physics and math will be offered a unique **hands-on experience with space weather forecasting tools** available at the SWC through its collaboration with the Community Coordinated Modelling Center at NASA Goddard Space Flight Center.

Contact information: **Dr. Vadim Uritsky**, 206 Hannan Hall, uritsky@cua.edu

THANK YOU !