Space Weather and its Societal Impacts

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NASA / ADNET

Heliophysics Summer School
June 1, 2012

Space Weather - Origins

Impacts – Radio Communication
- Submarine Cables
- Computer Systems
- Satellite Systems
- Cellular and Mobile Phones
- GPS Systems
- Electric Power Grids
- Aviation and Passengers

Space Weather Forecasting

- Solar Flares
- Coronal Mass Ejections
- The Sunspot Cycle

Modeling the Societal Impacts

- Satellite Systems
- Electric Power Grid
- Commerce

Worst Case Preparedness is now in-Vogue

Basic Physics of the Sun-Wind-Earth System

The Sun

Volume 1, Chapter 7, 12

Earth's Magnetosphere

Volume 1, Chapters 10, 11

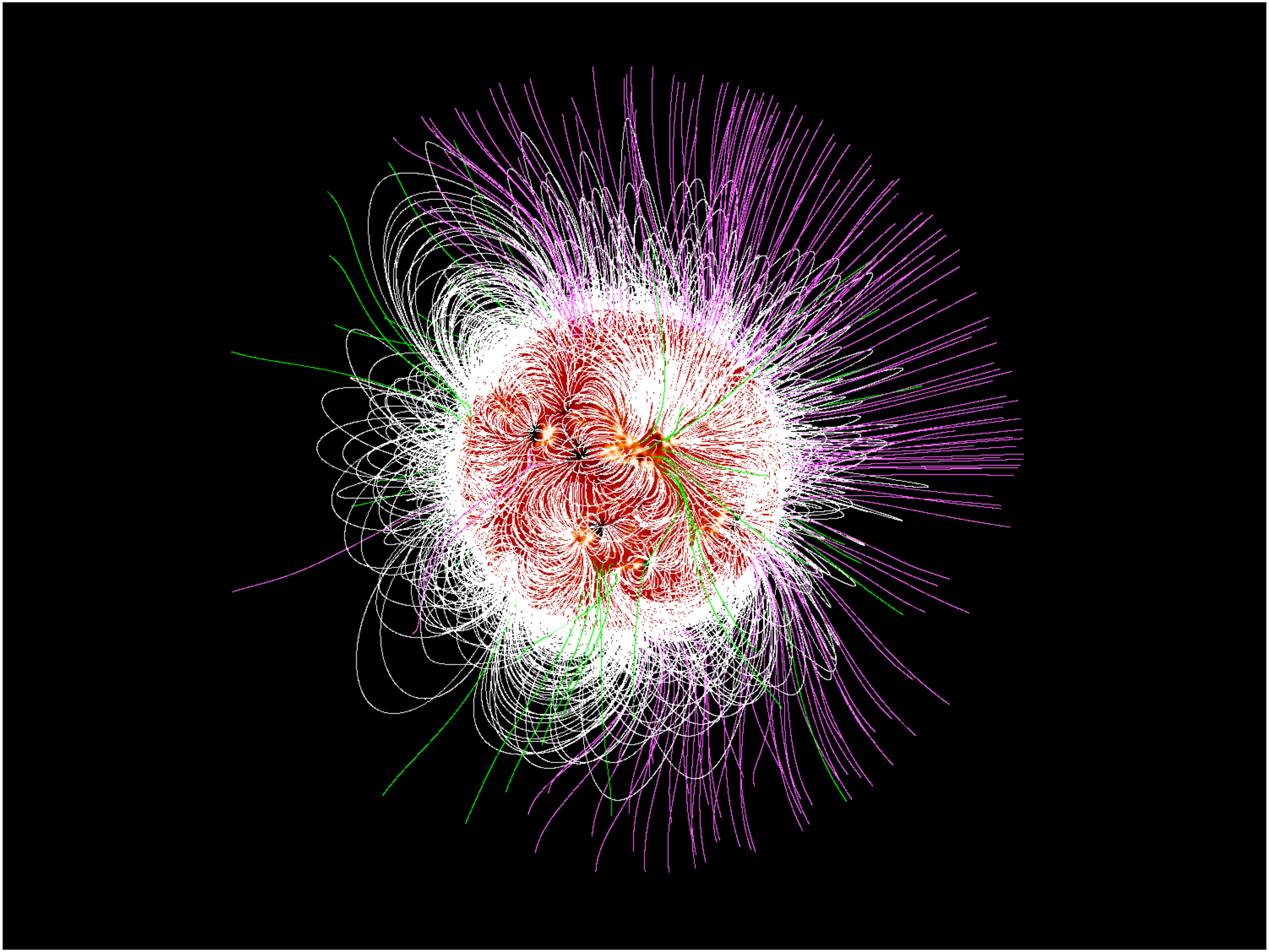
Radiation Belts

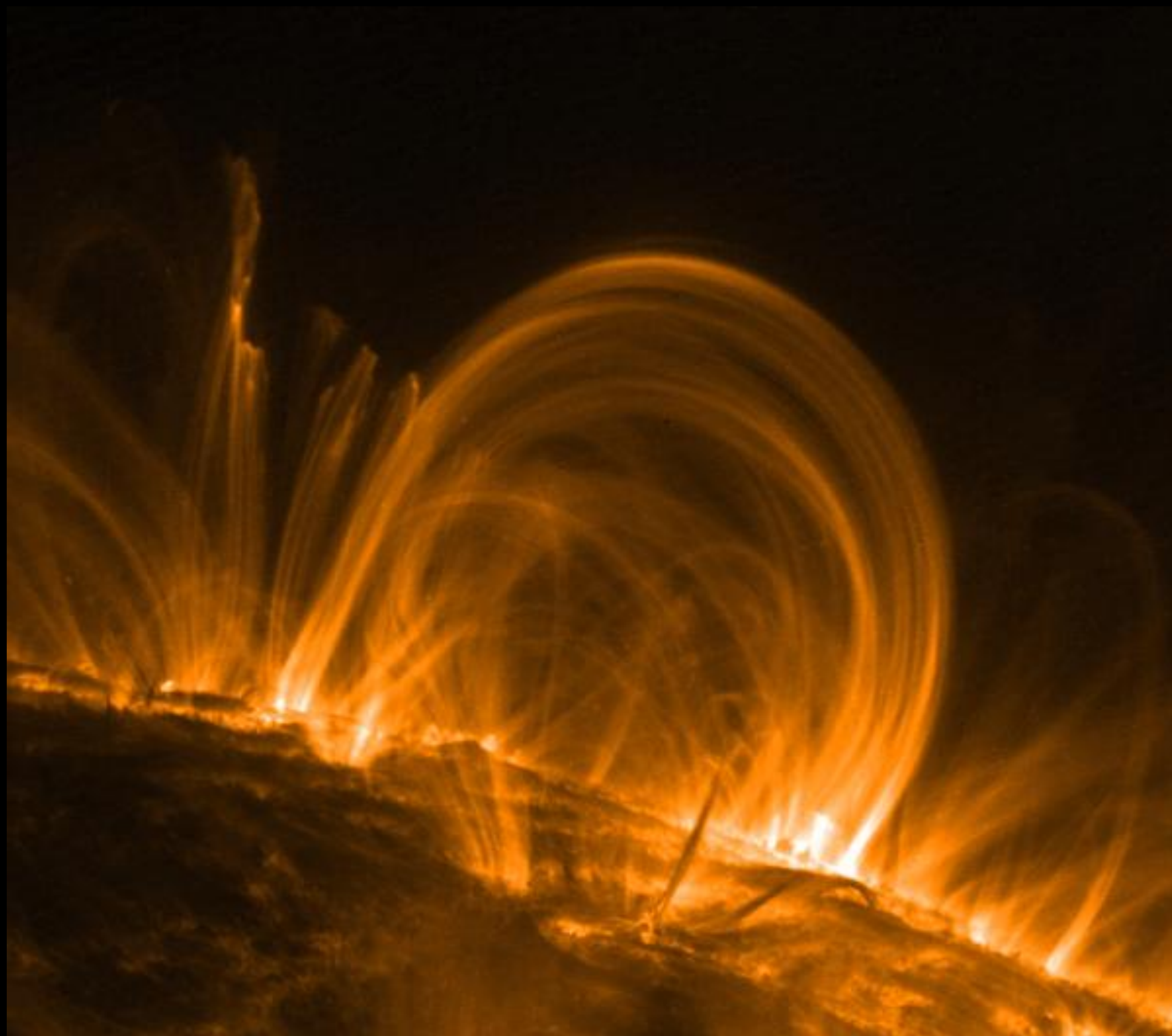
Volume 2, Chapter 11

The Ionosphere

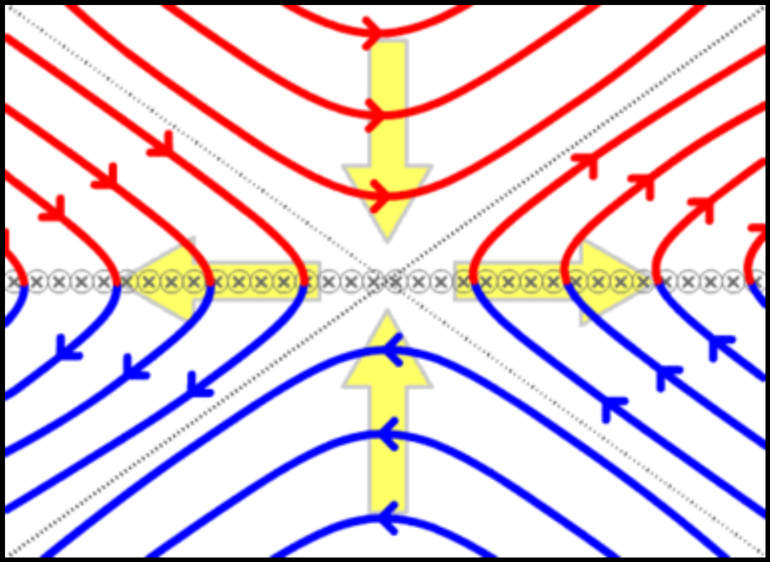
Volume 1, Chapter 12

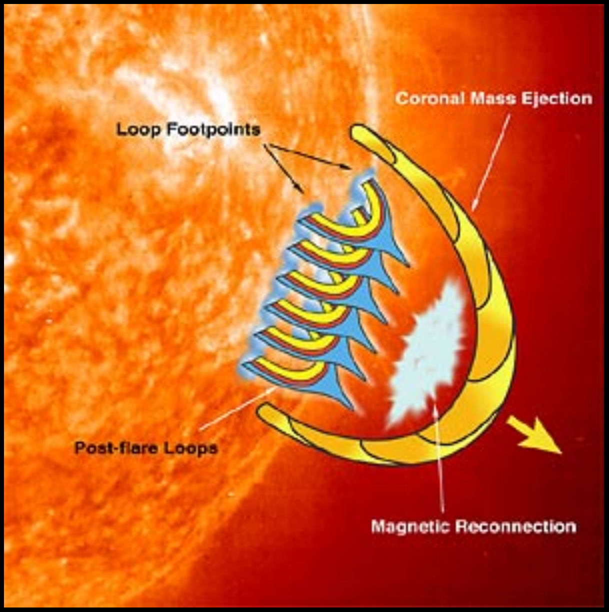
Volume 3, Chapter 13



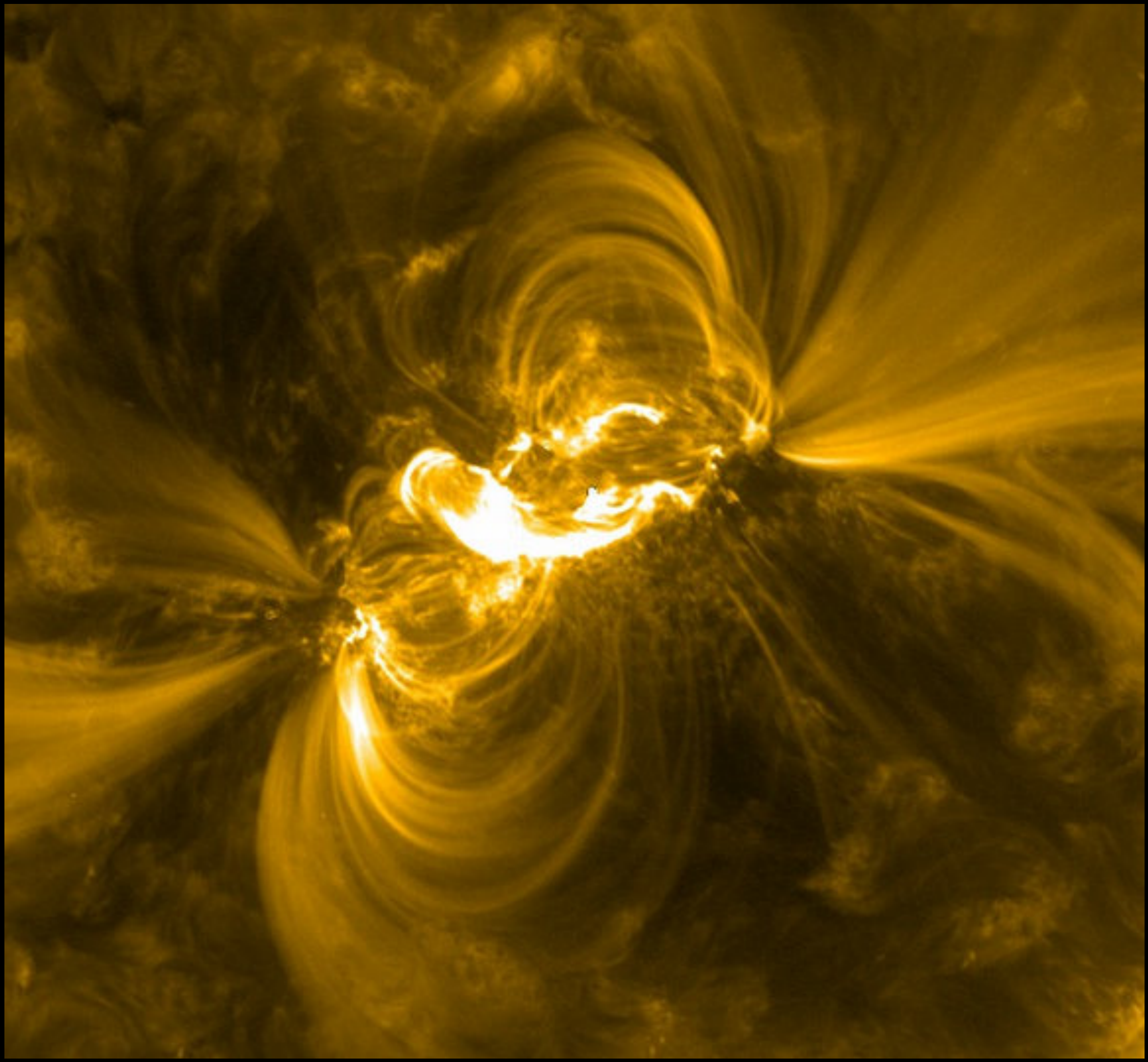


Magnetic Reconnection

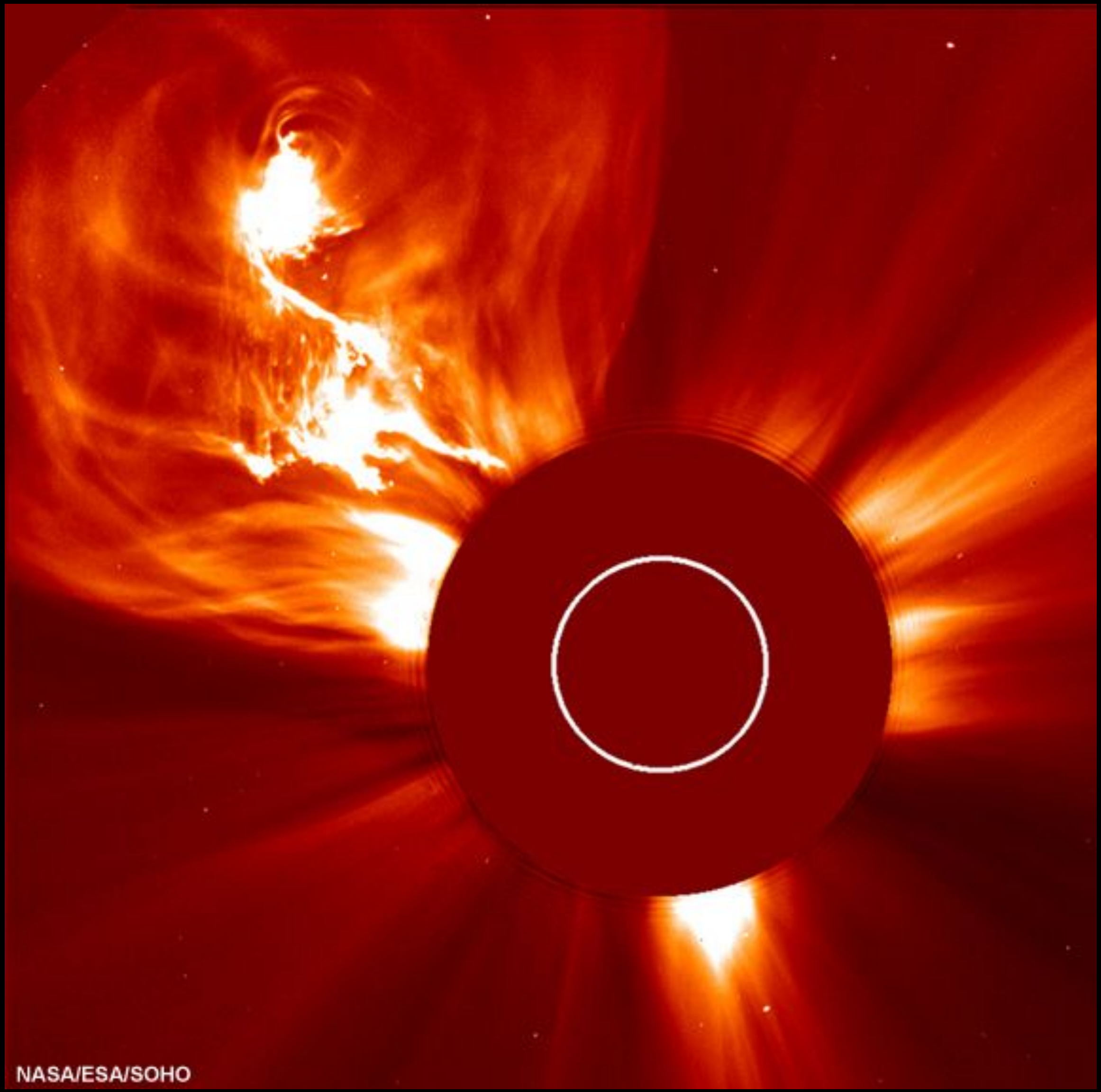




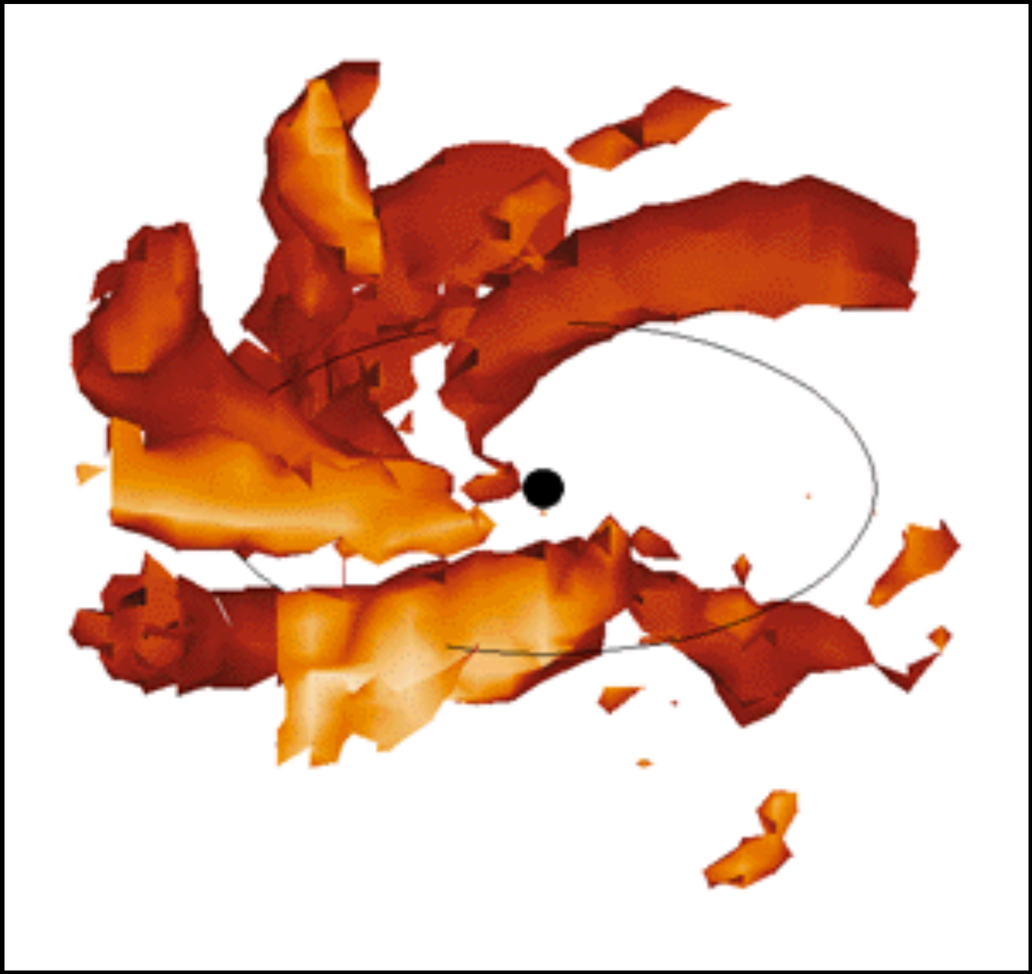
Solar Flares



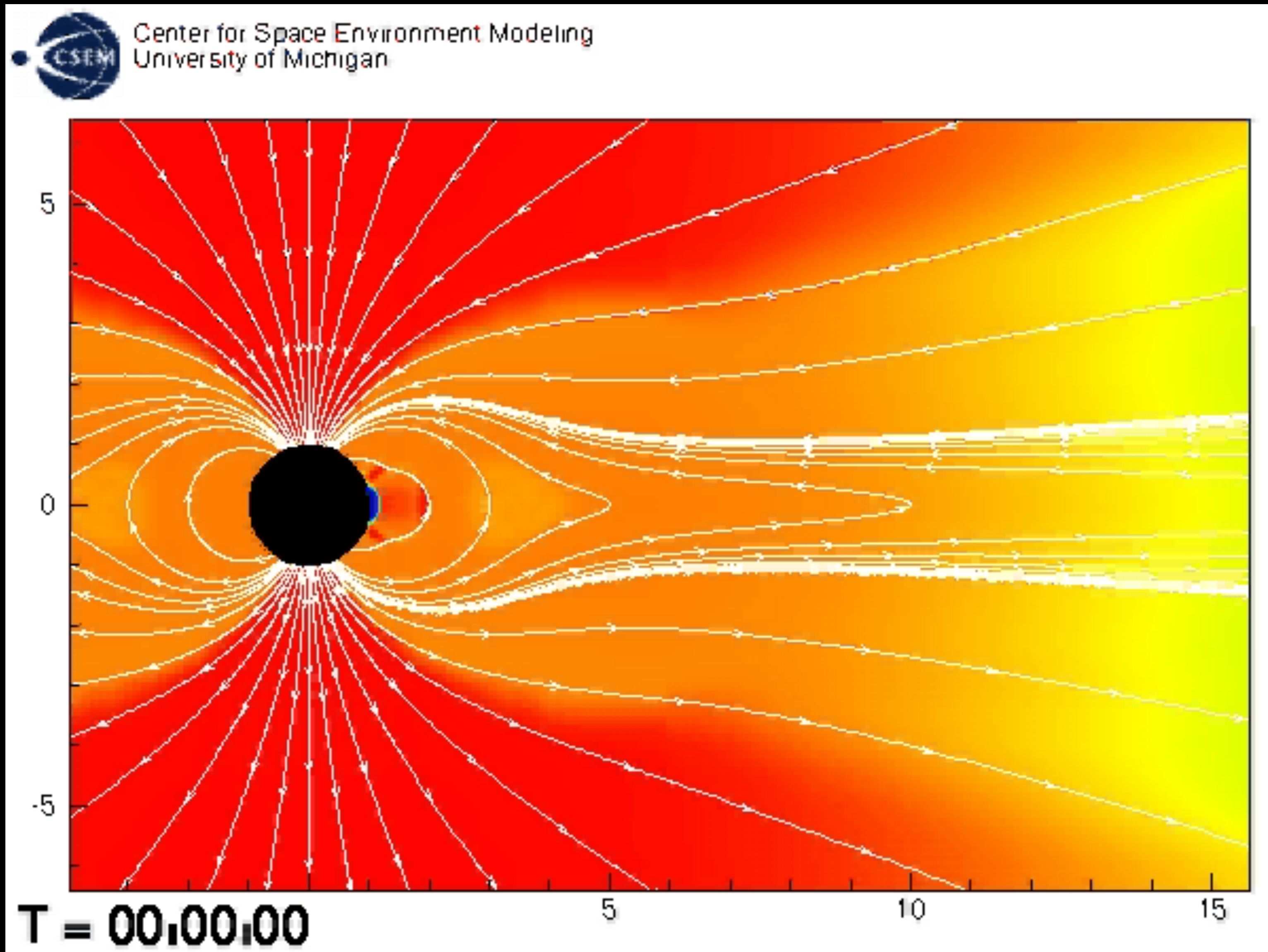
Courtesy – SDO



Courtesy - SOHO



Courtesy – B. Jackson (UCLA)



Courtesy – Darren De Zeeuw (CSEM)

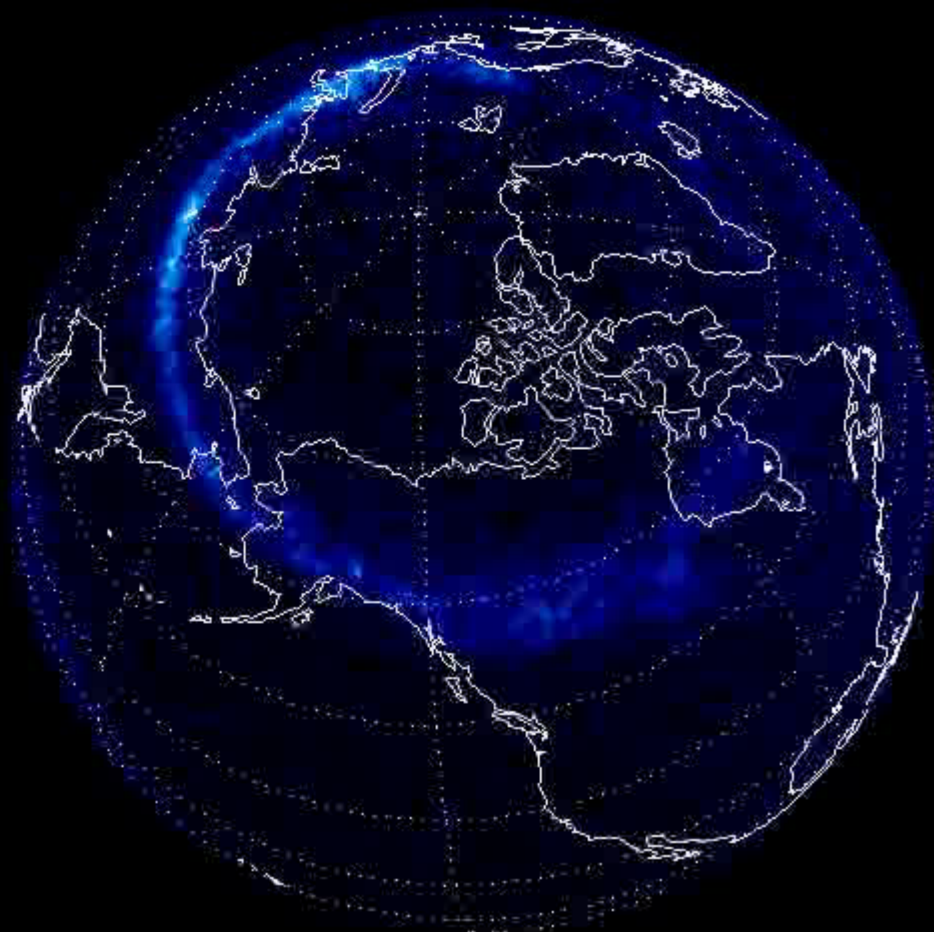


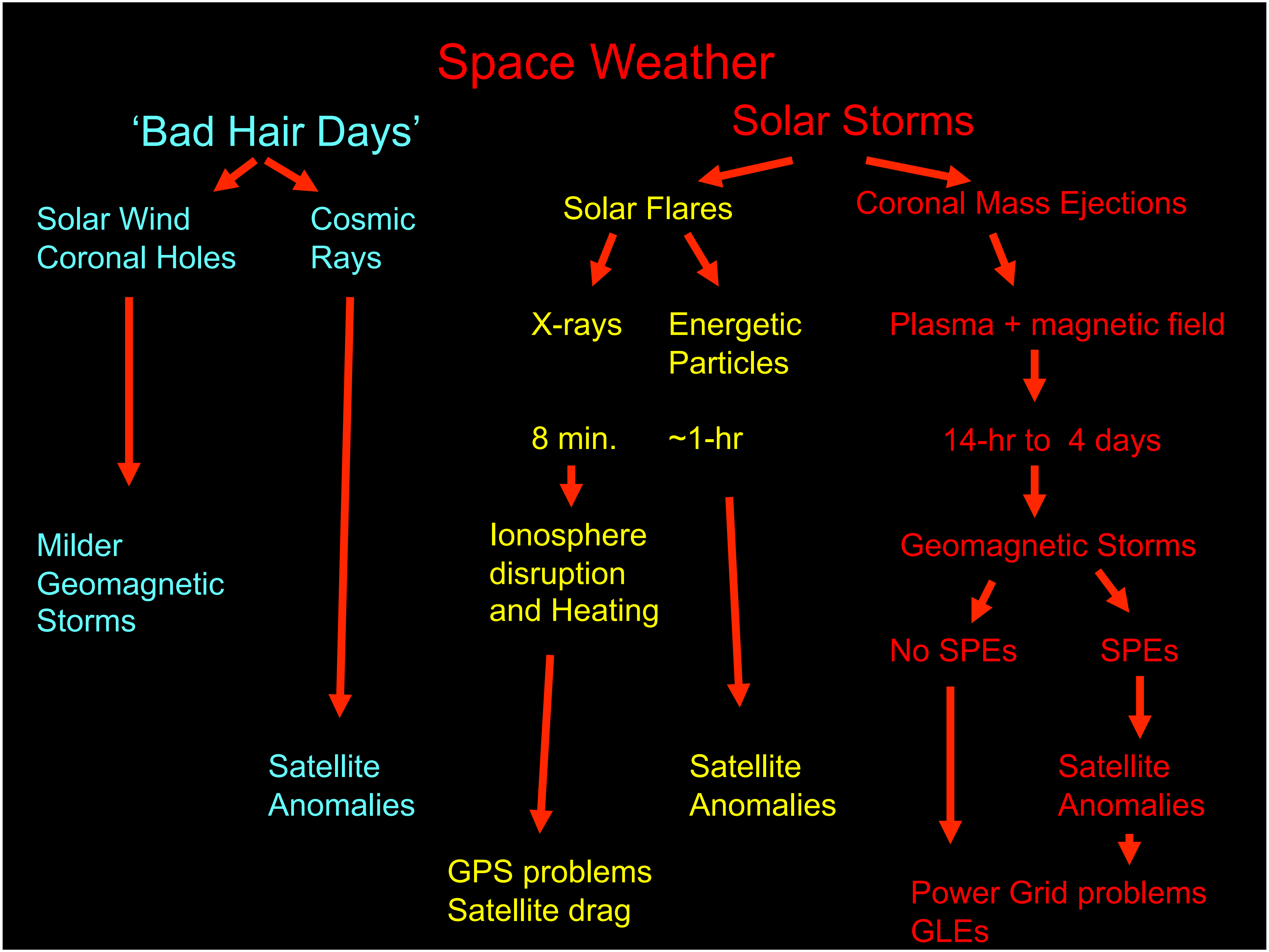
IMAGE-FUV-SI12, 2000-07-15-13:30:06

Courtesy - IMAGE

Atlantic Communications Broken By Largest Solar Flare in Years

Coast Guard officials in New York said that the flare had already knocked out maritime communications in the Atlantic for an hour and 45 minutes this morning.

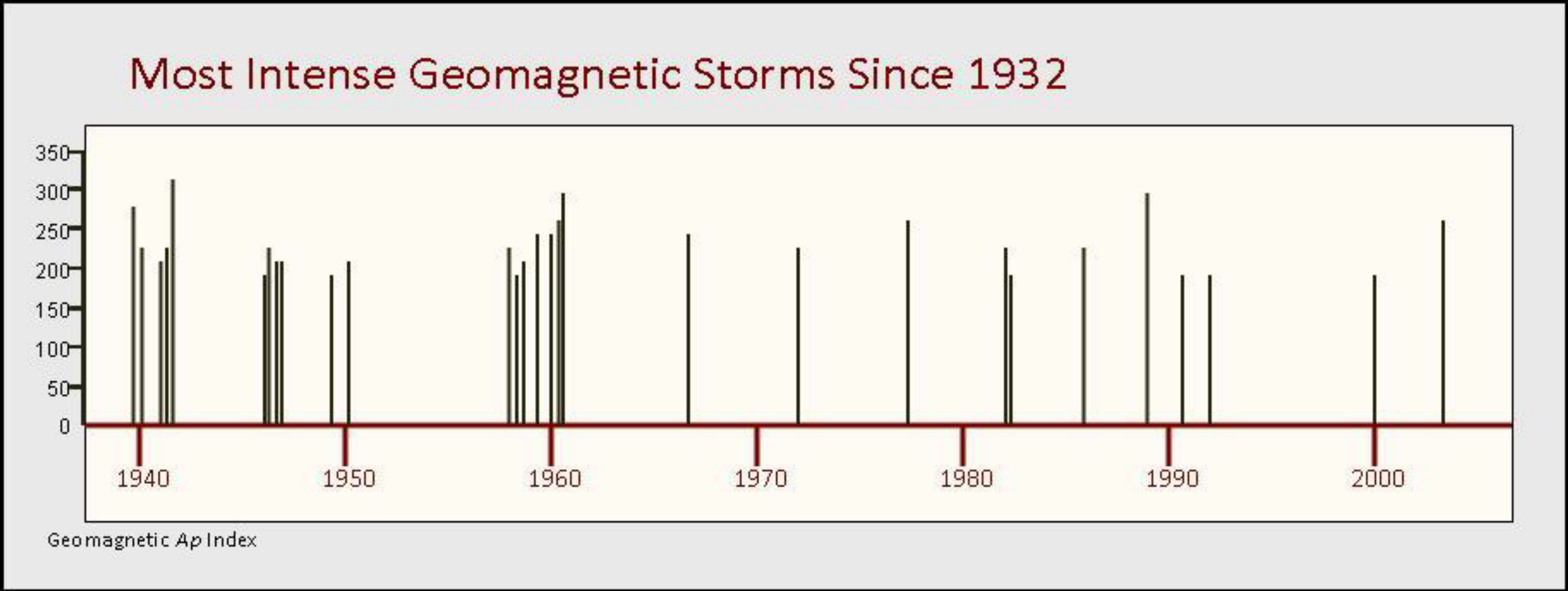
New York Times…April 29, 1978


Space Weather
'Bad Hair Days'
Solar Storms
Solar Wind
Coronal Holes
Cosmic
Rays
Solar Flares
Coronal Mass Ejections
X-rays
Energetic
Particles
Plasma + magnetic field
8 min.
~1-hr
14-hr to 4 days
Milder
Geomagnetic
Storms
Ionosphere
disruption
and Heating
Geomagnetic Storms
No SPEs
SPEs
Satellite
Anomalies
Satellite
Anomalies
Satellite
Anomalies
GPS problems
Satellite drag
Power Grid problems
GLEs

The Most Severe Geomagnetic Storms

March 13, 1989	Cycle 22	-589 nT = Dst
July 15, 1959	Cycle 19	-429
November 20, 2003	Cycle 23	-465
February 11, 1958	Cycle 19	-426
May 25, 1967	Cycle 20	-387
March 31, 2001	Cycle 23	-387
October 29, 2003	Cycle 23	-363
November 13, 1960	Cycle 19	-339
February 8, 1986	Cycle 22	-307
July 15, 2000	Cycle 23	-301
November 6, 2001	Cycle 23	-292
April 7, 2000	Cycle 23	-288
July 8, 1958	Cycle 19	-286
May 4, 1998	Cycle 23	-205
August 4, 1972	Cycle 20	-125

The Most Severe Geomagnetic Storms (Ap Index)



The Most Severe X-class Flares

1	04/11/03	Cycle 23	X45
2	02/04/01	Cycle 23	X20.0
2	16/08/89	Cycle 22	X20.0
3	28/10/03	Cycle 23	X17.2
4	07/09/05	Cycle 23	X17
5	06/03/89	Cycle 22	X15.0
5	11/07/78	Cycle 21	X15.0
6	15/04/01	Cycle 23	X14.4
7	24/04/84	Cycle 22	X13.0
7	19/10/89	Cycle 22	X13.0
8	15/12/82	Cycle 21	X12.9
9	06/06/82	Cycle 21	X12.0
9	01/06/91	Cycle 22	X12.0
9	04/06/91	Cycle 22	X12.0
9	06/06/91	Cycle 22	X12.0
9	11/06/91	Cycle 22	X12.0
9	15/06/91	Cycle 22	X12.0
10	17/12/82	Cycle 21	X10.1
10	20/05/84	Cycle 21	X10.1

Cycle 21=5
Cycle 22=9
Cycle 23=5

Total Cycle 23
122 X-class

14,500 total
(C,M,X)

Recent Cycle 24

3/6/2012 X5.4
8/10/2011 X6.9

The Most Severe Solar Proton Events

3/23/1991	Cycle 22	43,000 pFU
10/19/1989	Cycle 22	40,000
11/4/2001	Cycle 23	31,700
10/28/2003	Cycle 23	29,500
7/14/2000	Cycle 23	24,000
11/22/2001	Cycle 23	18,900
11/8/2000	Cycle 23	14,800
9/24/2001	Cycle 23	12,900
2/20/1994	Cycle 22	10,000
8/12/1989	Cycle 22	9,200
1/23/2012	Cycle 24	6,300
1/16/2005	Cycle 23	5,000
3/9/1992	Cycle 22	4,600

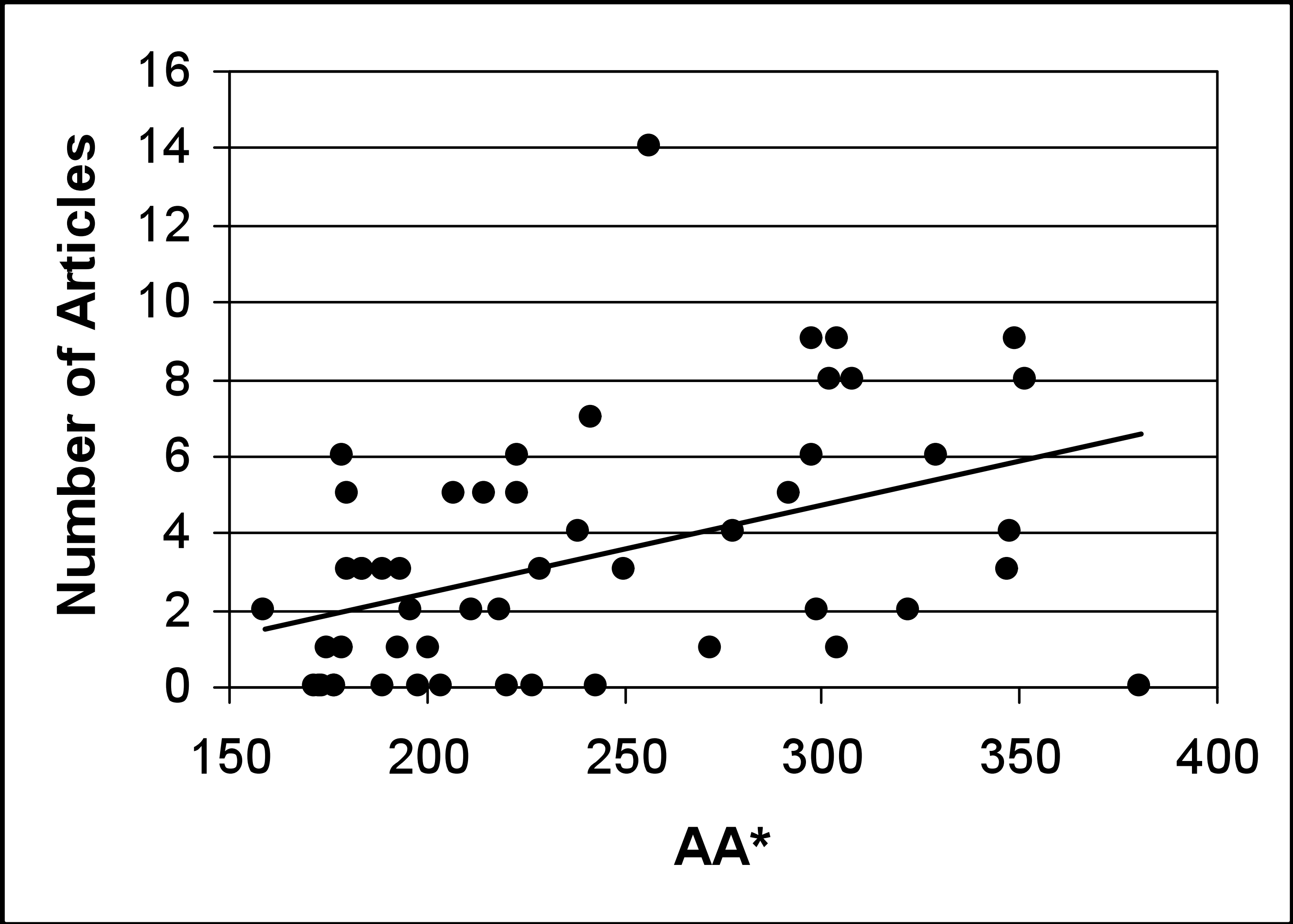
Worst-case storm events

Year	**1859**	1921	1941	1960	2003
Date	**Aug-Sept**	May 5	July 5	Nov. 13	Oct 29
Duration	**8 days**	7 days	1 day	1 day	3 days
Sunspot phase	**-1 year**	+4 years	+4 years	+3 years	+3 years
Transit Time	**17.6 hrs**	< 24 hrs	< 72 hrs	< 48 hrs	20.3 hrs
SPE (P/cm2)	**18.8**	1.0	0	9.0	3.3
AA*	**> 500**	257	277	352	298
Sunspot size (millionthsHemi)	**1600**	805	2101	5286	2808
Technological Impacts	**Telegraph**	Telegraph Wireless	Telegraph Telephone Radio	Radio	Radio Satellites Pwr Grid

Human and Technology Impacts

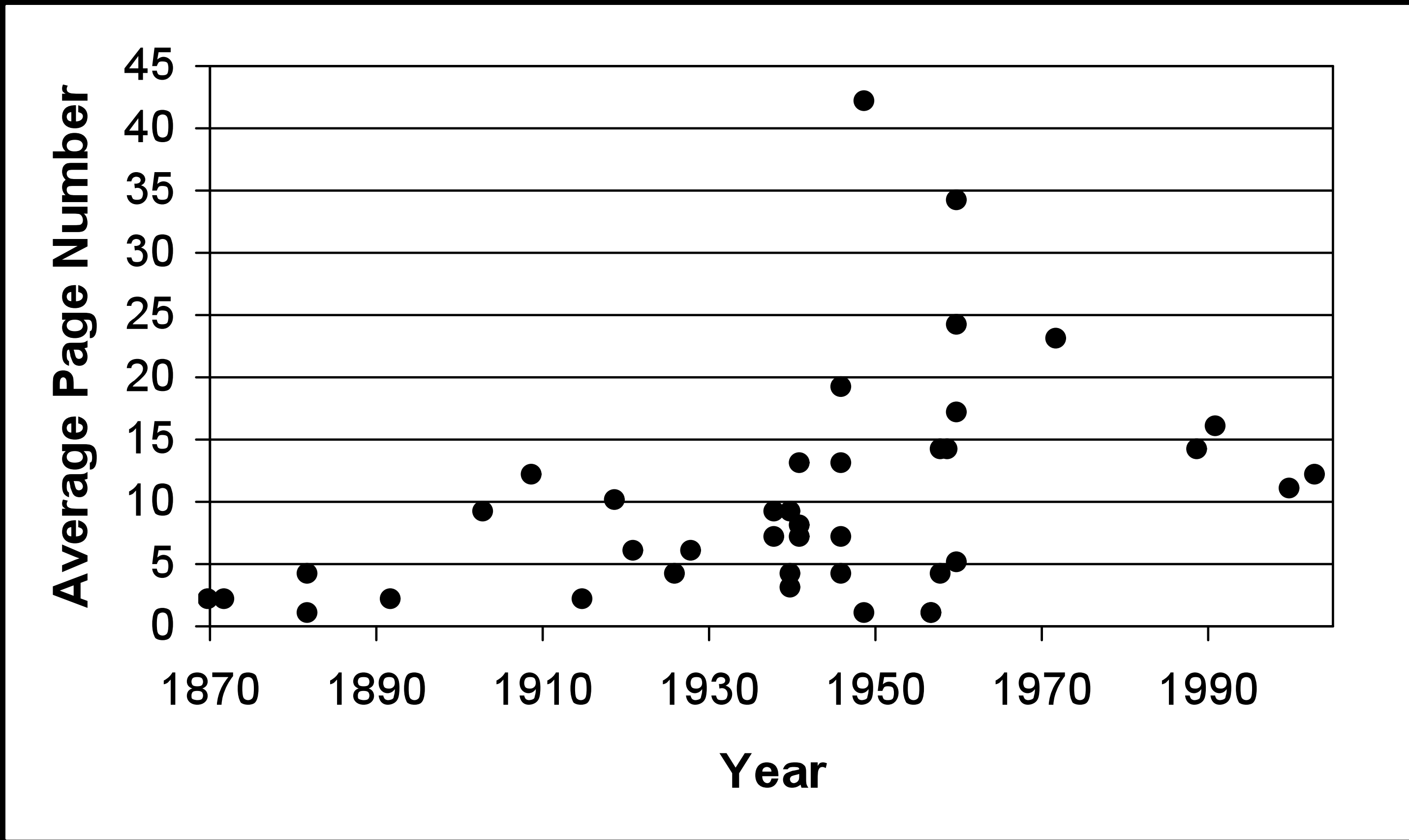
1830, 1837, 1839, 1859, 1870, 1892, 1921, 1926, 1927, 1938, 1940, 1958, 1960, 1981	Perceptions of cities on fire, fire department calls
1851, 1852, 1858, 1859, 1870, 1872, 1877, 1882, 1894, 1921, 1926, 1938, 1940	Telegraph outages
1919, 1921, 1930, 1938, 1940, 1941, 1946, 1958, 1960, 1972	Radio or TV interference
1832, 1837, 1859, 1882, 1926, 1938, 1960, 1989	Severe psychic anxiety, mass panic, 'Doomsday'
1903, 1918, 1989, 1991, 2003	Electrical system failures or disruptions
1835, 1837, 1859, 1872, 1946	Compass and navigation problems
1859, 1882, 1921, 1940	Fires and equipment damage.
1859, 1860, 1882, 1903, 1909, 1921, 1940, 1958	Electrical shocks and high-voltage conditions
1972, 1989, 1998, 2000, 2003	Satellite failures and upsets
1972, 1989, 2000, 2003	Excessive astronaut radiation dosages
1938, 1940, 1946, 1989	Air Travel issues
1915, 1918, 1926, 1940, 1941, 1943, 1950, 1957, 1958, 1989	Military communications problems
2003	GPS positioning errors

Newspaper Reportage



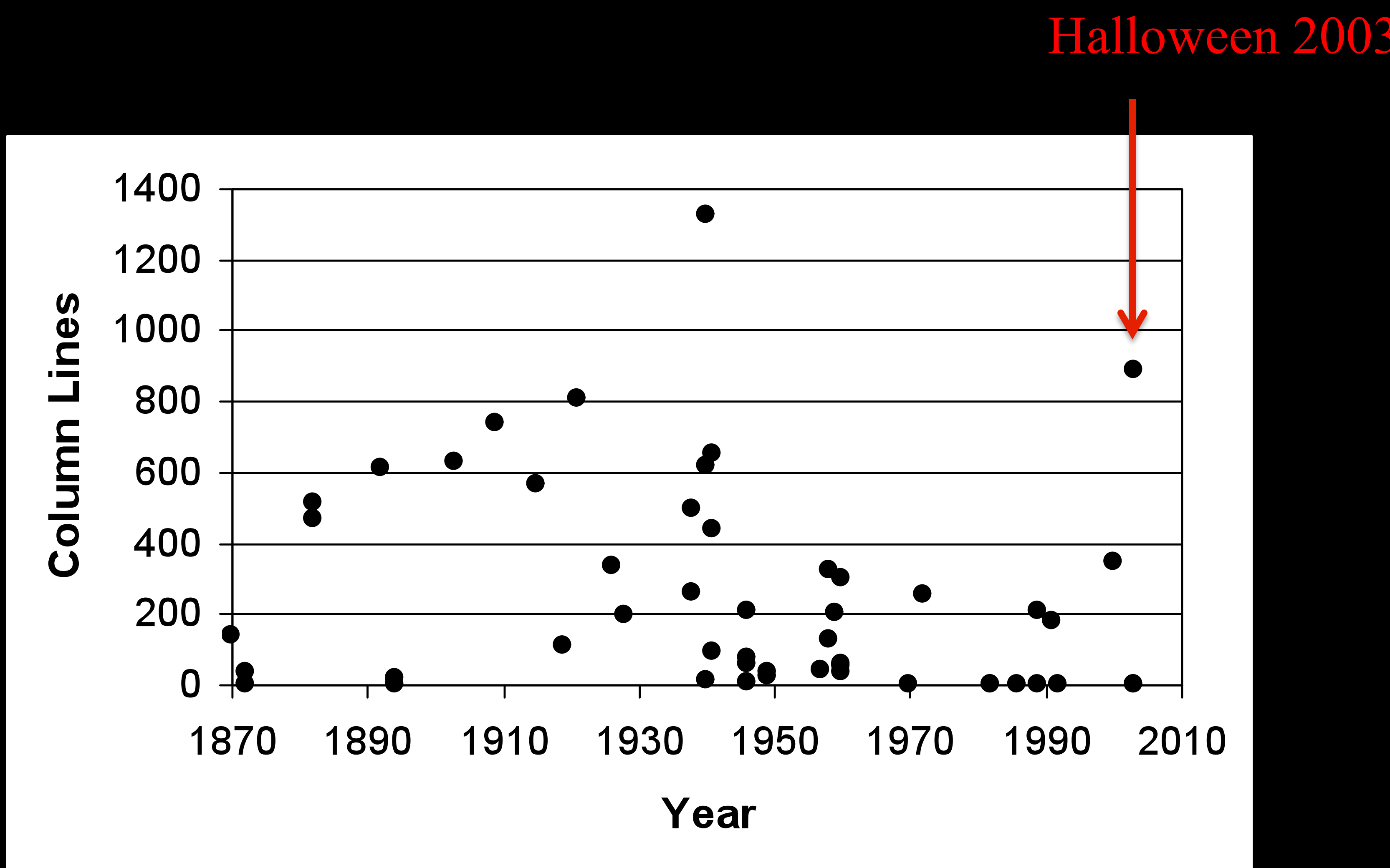
The most intense storms usually get reported

Newspaper Reportage



Since ca 1945, the location in the paper has dramatically shifted

Newspaper Reportage



…and the news stories are significantly shorter.

Radio Communication

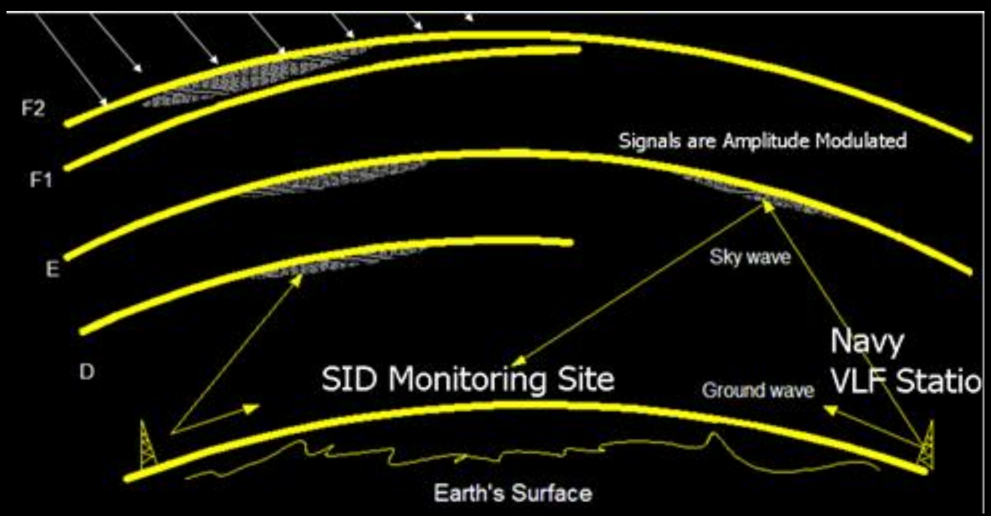
MAGNETIC STORMS BOMBARD RADIO

Sun Spots Blamed for Blasts of Static That Rip European Waves on the Way to America for Rebroadcasting

New York Times….. March 2, 1930

Radio Communication

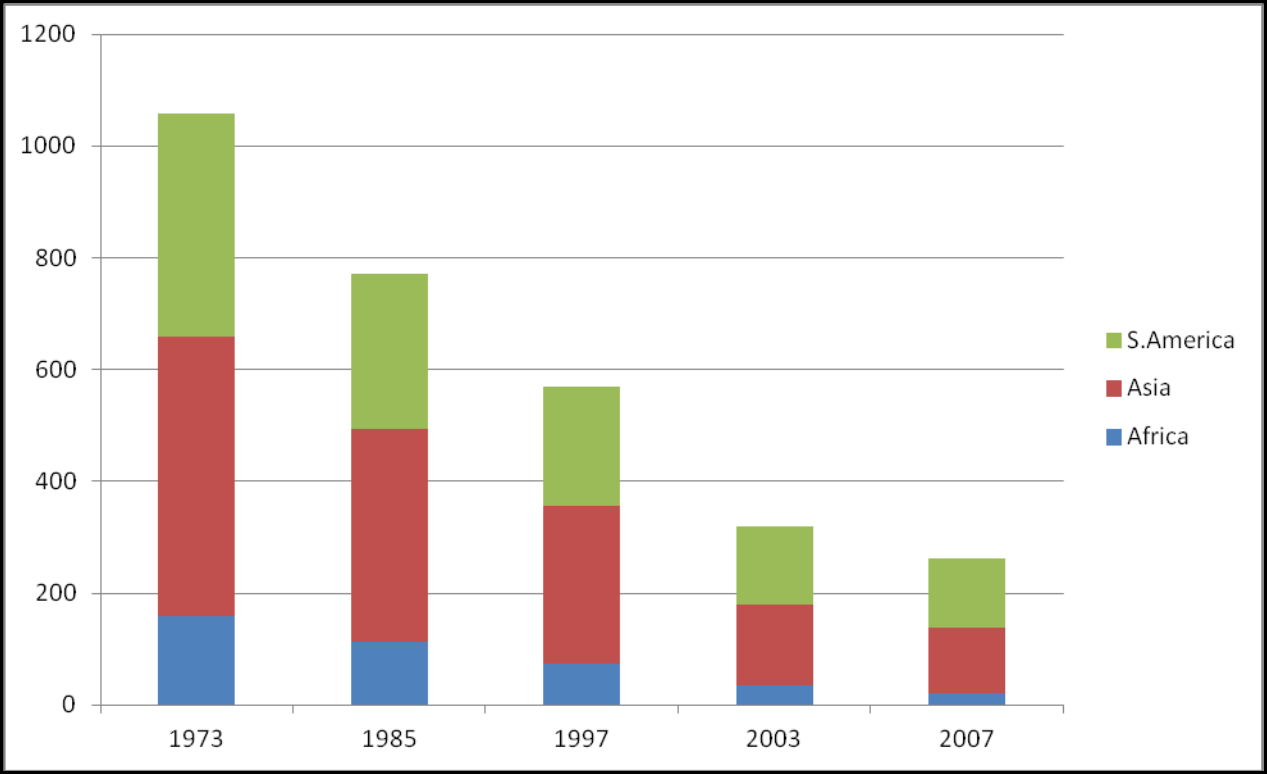
Space Weather Impact – SW fadeouts



Ionization in D-Region increases SW signal absorption

Radio Communication

Who cares? ---- Dramatic decline in short-wave stations and usage, worldwide



Radio Communication

Ham Operators Save the Day!!!!

Wireless on msnbc.com

Ham radio operators to the rescue after Katrina

Amateur radio networks help victims of the hurricane

Jump to discuss
Loading comments...

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By Gary Krakow
Columnist

The Christian Science Monitor

Ham radio operators tune in hurricane help

By Barbara W. Carlson, Contributor to The Christian Science Monitor / September 15, 2005

NEWINGTON, CONN.

Richard Webb, an amateur radio operator, was asleep on his air mattress at University Hospital in New Orleans during the aftermath of hurricane Katrina when he was awakened at 5 a.m. by a hospital administrator.

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Ham operations work when phones, Web won't

• *Weekend event explains how older technology works when other systems fail*

By Naomi Klouda
Homer Tribune

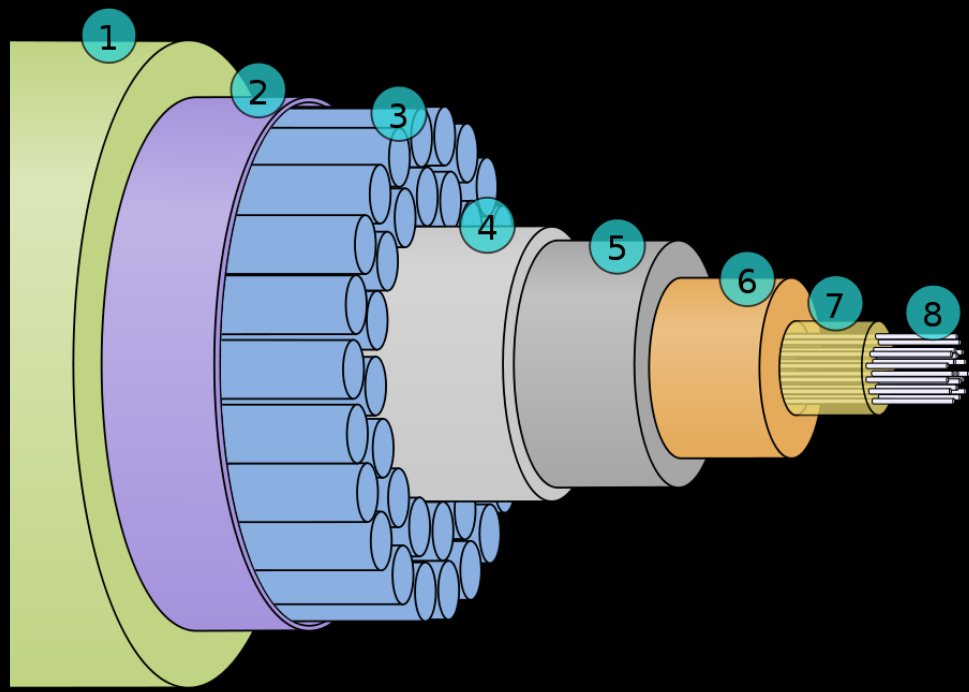
When Hurricane Katrina struck, phone lines went down, cell towers toppled and Internet connections were nonexistent. But the ham operators kept going.

This band of men who make earnest practice keeping their citizen's band radio tuned, were able to communicate with the outside world.

Telephones, cell phones, Internet, trunk lines, satellite phones – they all have to go through many "vulnerable choke points" and need electric power to operate, said

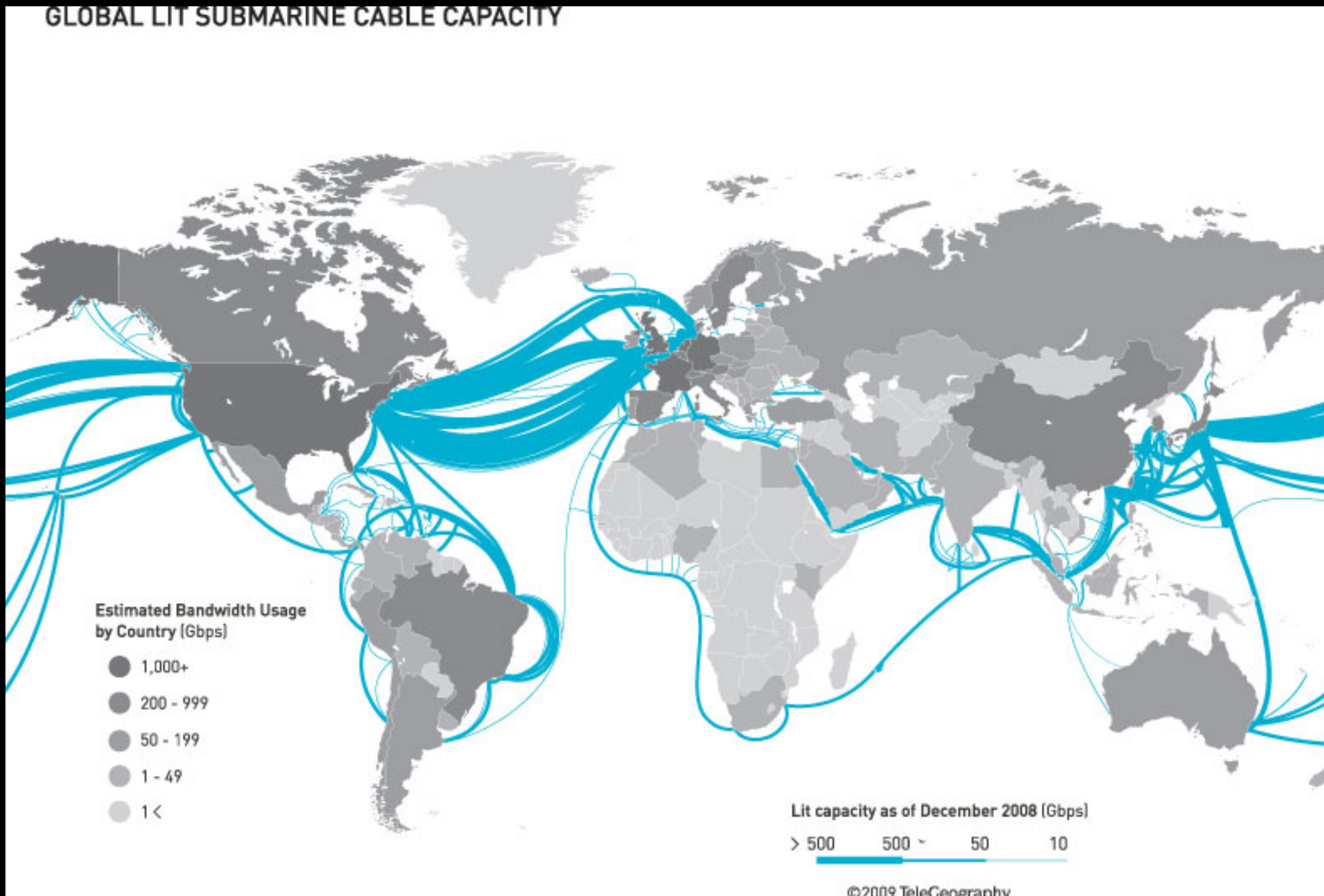
HOMER TRIBUNE/Naomi Klouda - Ham radio operators George VanLone, Dale Hershberger, Ed Beck and Kris Kerce make contact for the refuge.

Submarine Cables – Fiber and copper



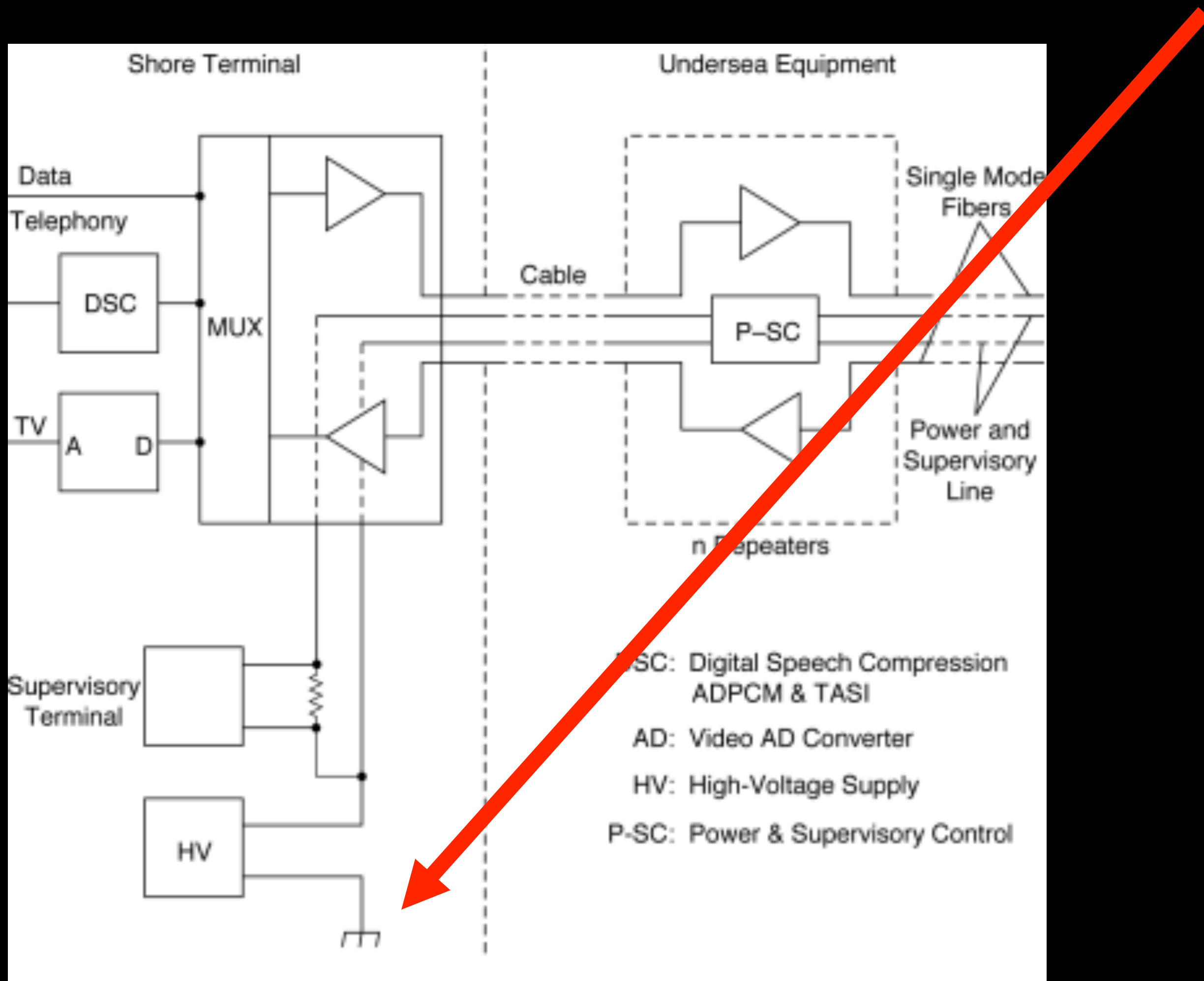
Repeaters and amplifiers every 10 km.

Submarine Cables



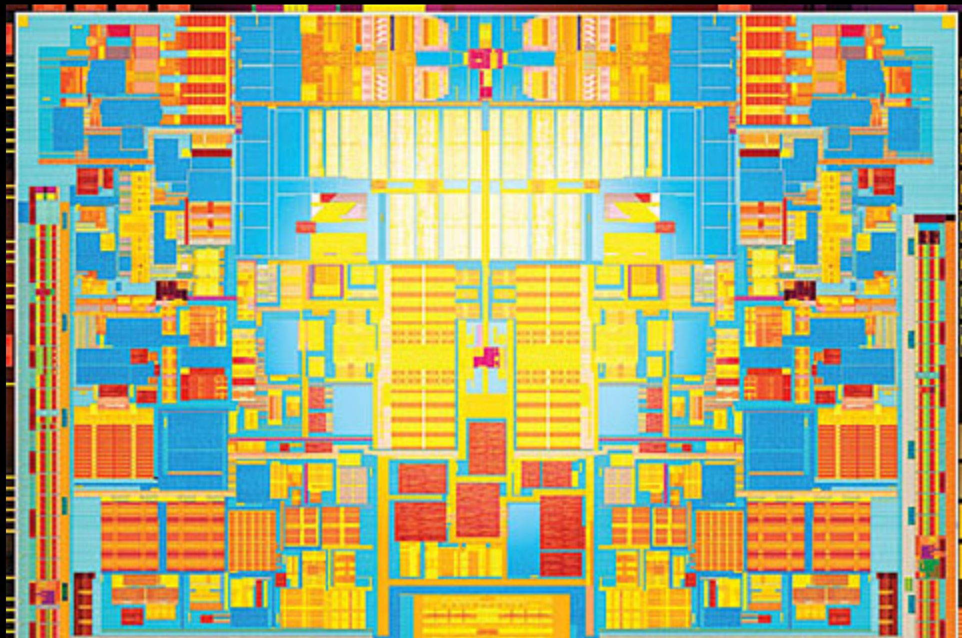
Submarine Cables

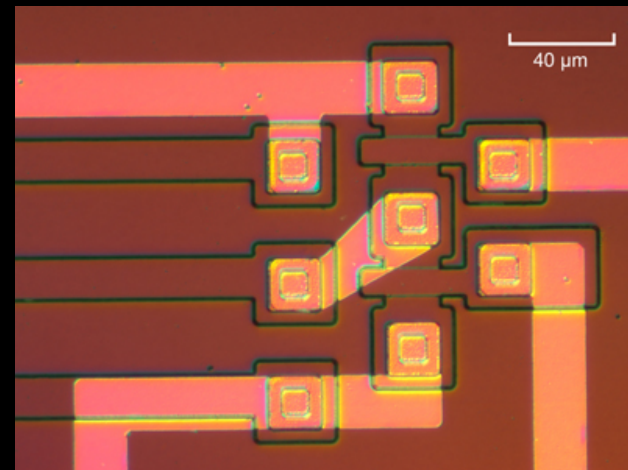
Like telegraph systems, cable HV supplies are grounded

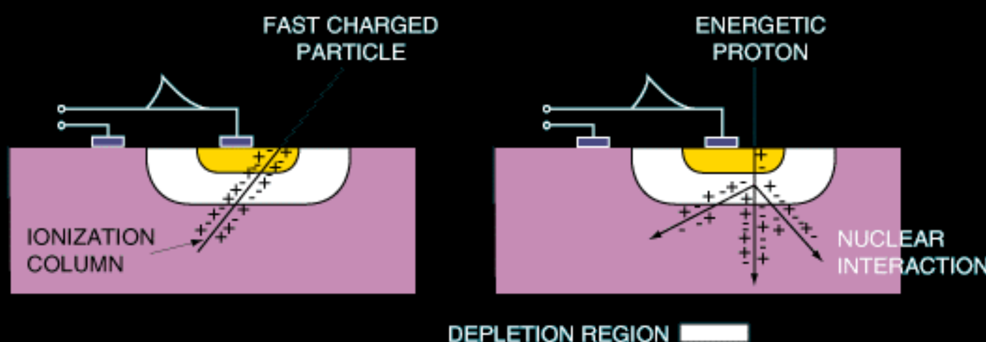


GICs enter system, cause ‘repeater’ malfunctions

Computer Systems







Excess charge causes gate state change

Computer Systems

Single Event Effects – SEEs

Single Event Upsets - SEU

- state change in binary gate '0 to 1'
- reset by power cycling or re-boot

Single Event Latch Up - SEL

- Permanent state change
- May not be resetable

Single Event Transient – SET

- Excess charge travels through circuit
- May dissipate w/o intervention

Mitigation

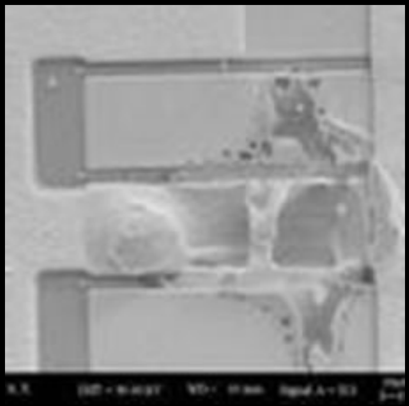
Error Detection and Correction (EDAC)

Parity bits - soft ware correction

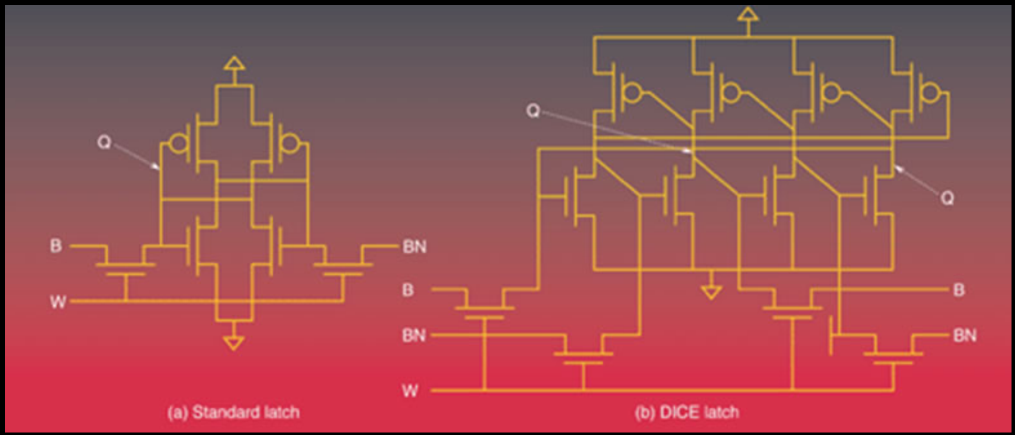
Watchdog timer – normal operation resets timer.
- if timer runs out, hard reset

Redundancy - polling before action among
independent microprocessors

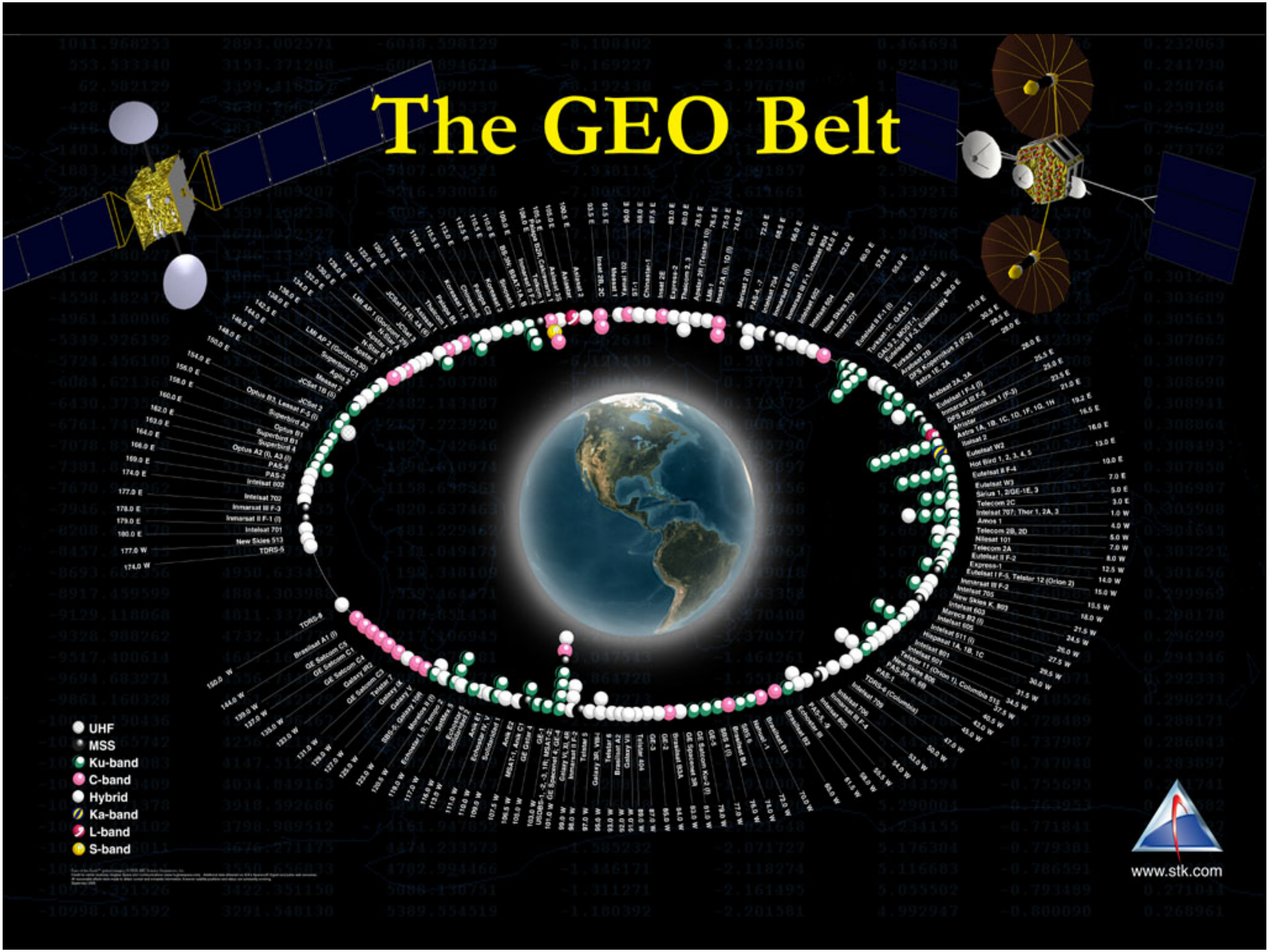
Radiation-Hardening is expensive



Catastrophic 'latch-up' due to heavy ion impact
Figure provided by Aerospace Corporation
http://www.aero.org/



A six-transistor latch, commonly used as the storage element in a static memory circuit, is shown alongside a design-hardened 12-transistor variant. (Courtesy Aerospace Corp)

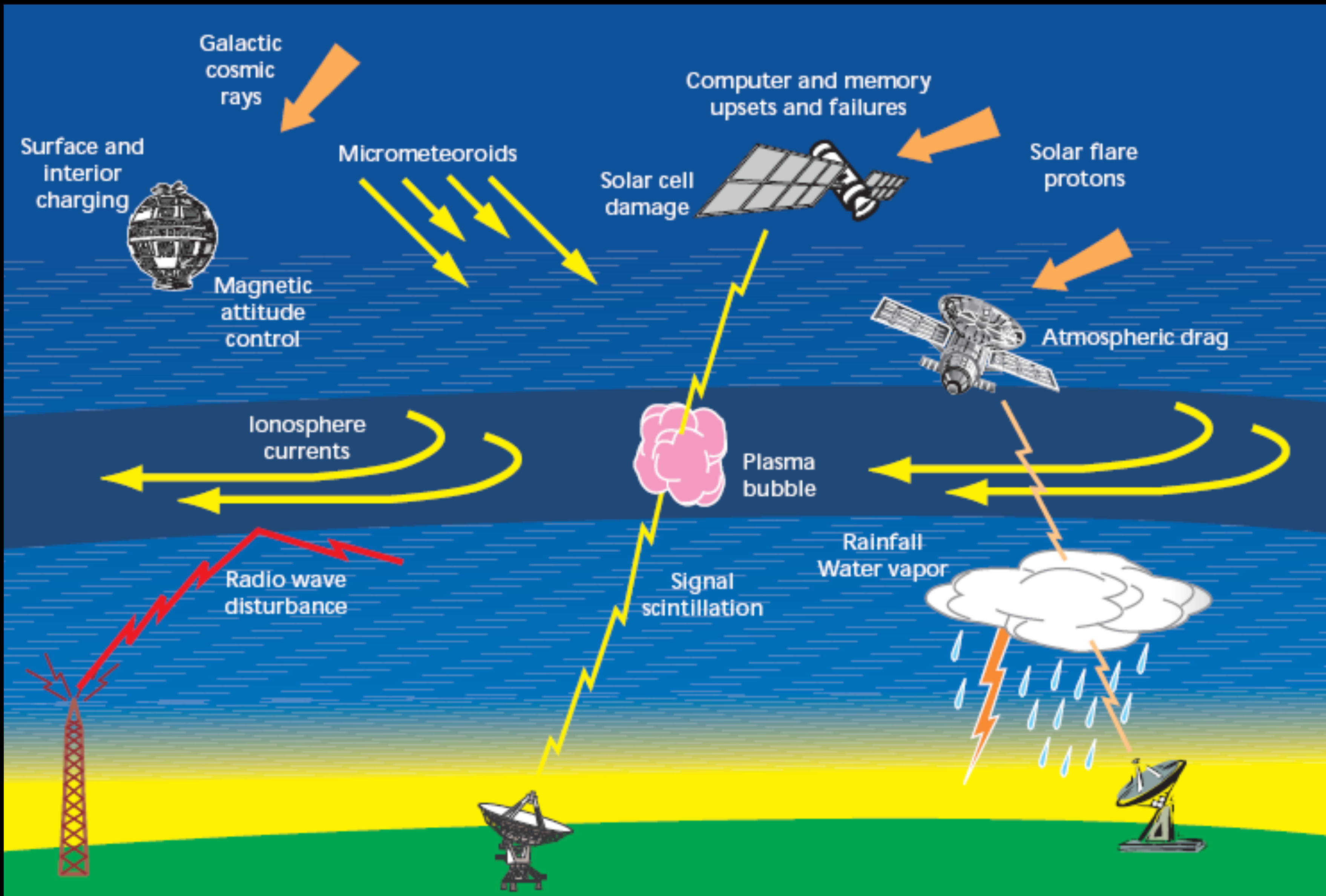

The GEO Belt
UHF
MSS
Ku-band
C-band
Hybrid
Ka-band
L-band
S-band
www.stk.com

The Economic Real Estate

Location	Commercial	Military	Research	Total
LEO	273	94	70	437
MEO	19	101	12	132
GEO	308	51	8	367
Totals:	600	245	91	936

- Total Satellite Fleet (ca Dec, 2004)………… ~ 936
- Total hardware + launch cost………………. ~ $ 230 billion
- GEO Transponder Capacity…………………. ~ 6,800
- GEO industry annual revenue………………. $ 87 billion
- LEO + MEO satellite annual revenue……... $ 10 billion
- Satellite Industry annual revenue………….. $ 225 billion

Satellite Impacts



23^{rd} Cycle Satellite Outages (1997-2004)

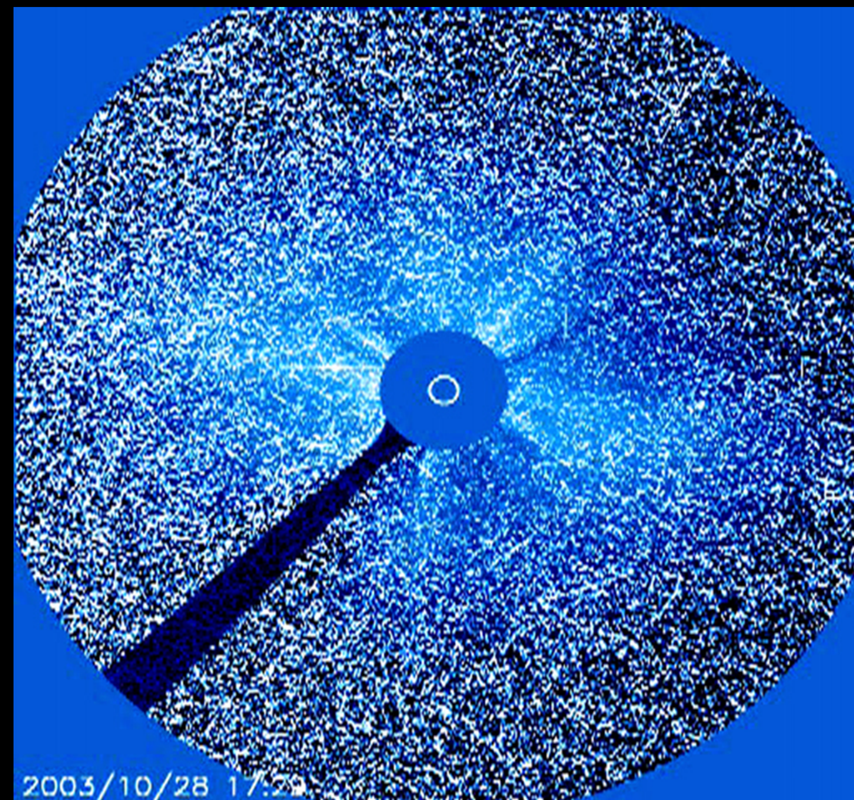
Telstar 401	$ 250 million
Tempo-2	$ 150 million
Adeos	$ 474 million
PAS-6	$ 150 million
Equator-S	$ 12 million
ASCA	$ 100 million
Midori-II	$ 640 million

Total = $1.8 billion to $2.95 billion

Physical Effects of Space Environment

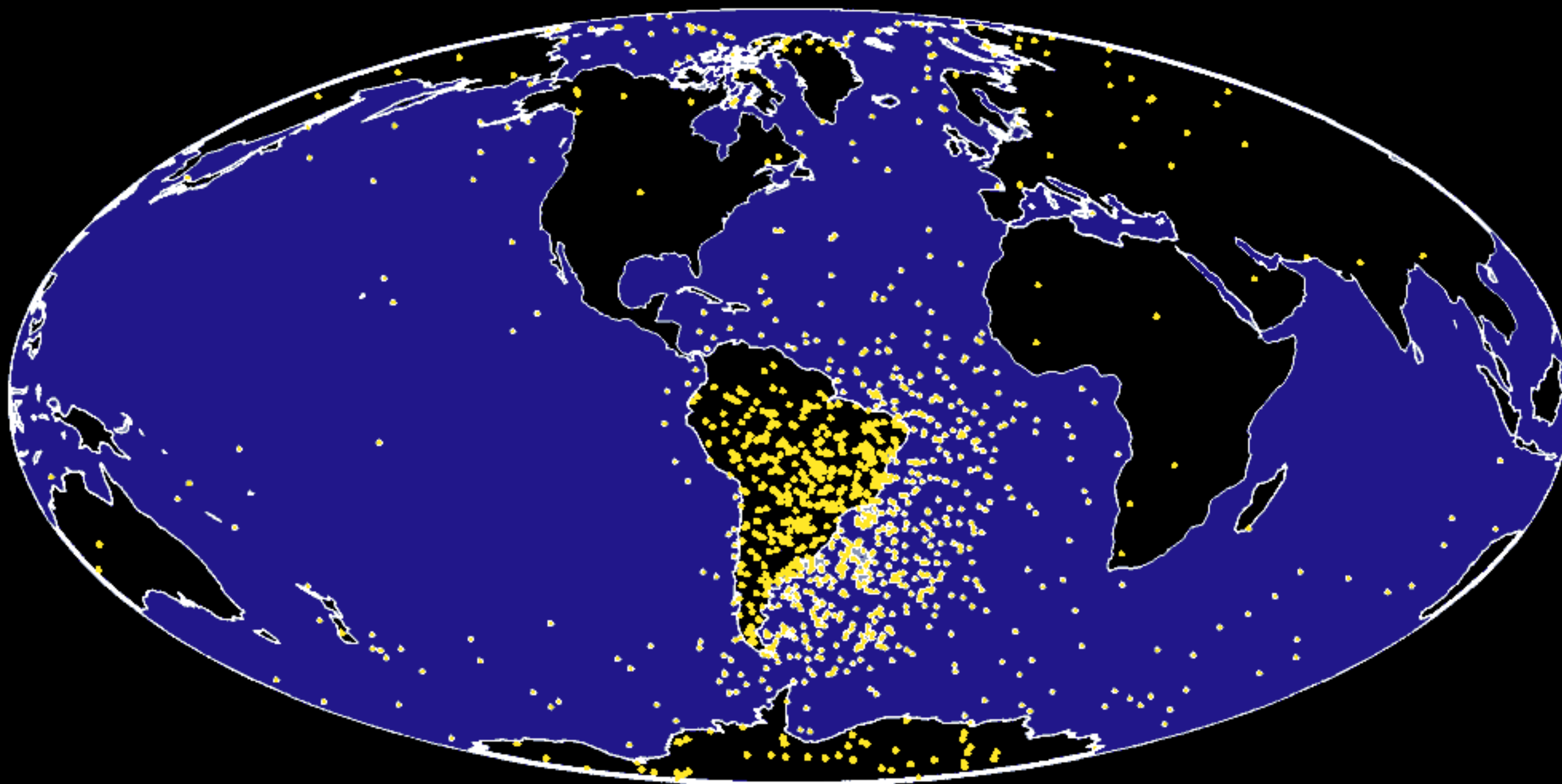
- **Low energy electrons - surface charging (ESD)**
- **High energy electrons - internal charging (IESD)**
- **Solar flare protons - solar array degradation**
- **Ionizing dose - electronics, materials aging**
- **Non-ionizing dose - CCD's, optical couplers**
- **Heavy ions/cosmic rays - single event effects**
- **Ultraviolet - cover glass darkening, surface degradation**

MMT Observatory 1-hour dark frame with GCR tracks



Exposed imaging CCD on SOHO during SPE event after CME

UOSAT-2 Memory Upsets



ESA/ESTEC The Netherlands

NOAA/NGDC Boulder

Particle fluences are large but satellite anomalies are rare

GCR fluence through satellite………….. 10^{12} particles / year

Single Event Upsets………………………10^{6} events / year

Anomalies…………………………………. 1 – 10 / year

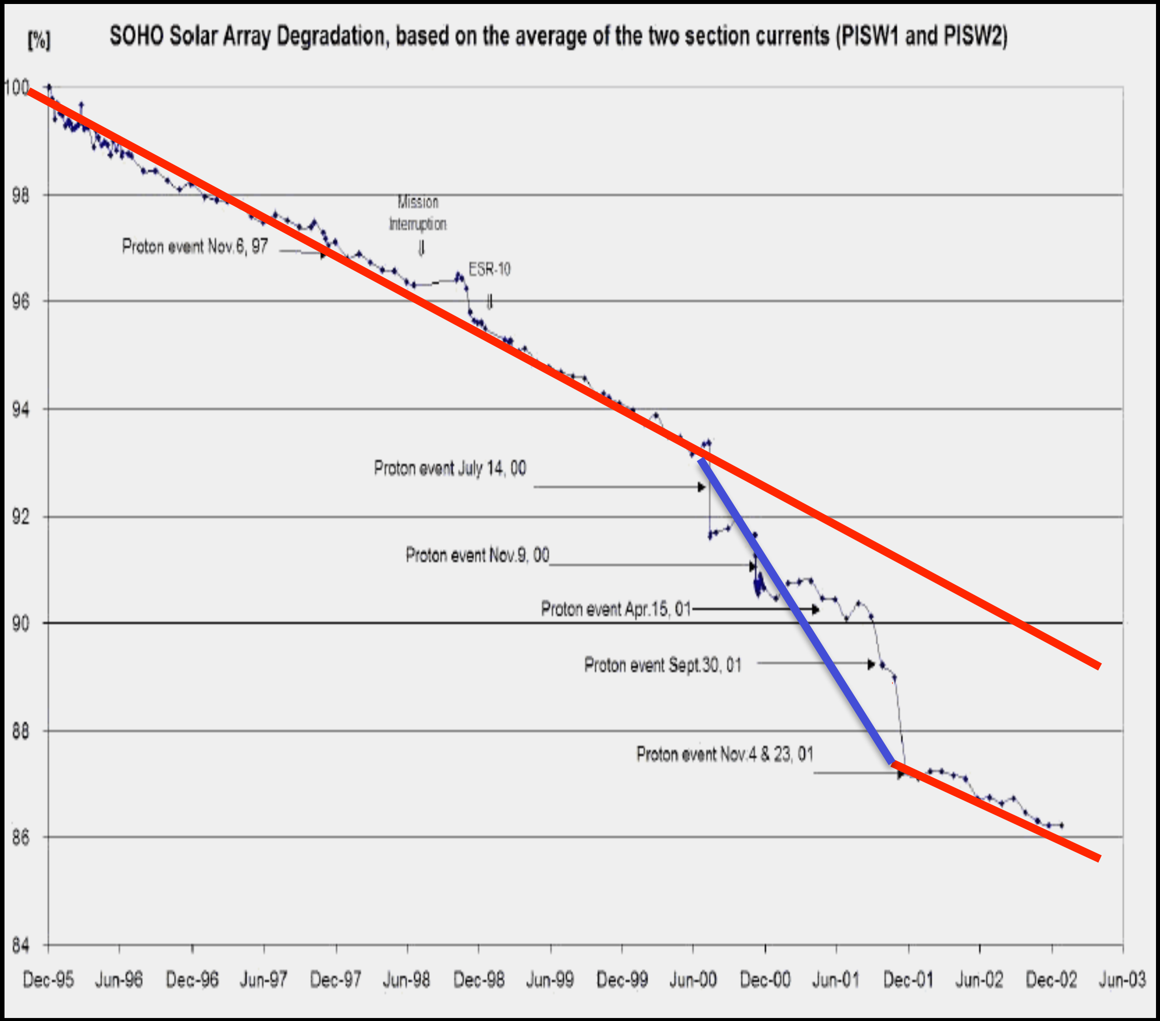
Mean Time to Failure…………………….. 250 years

Satellites are reliable 364 days of year, but to get 100% on that last day can be cost-prohibitive.

Satellite Anomalies at GEO
A Few Examples

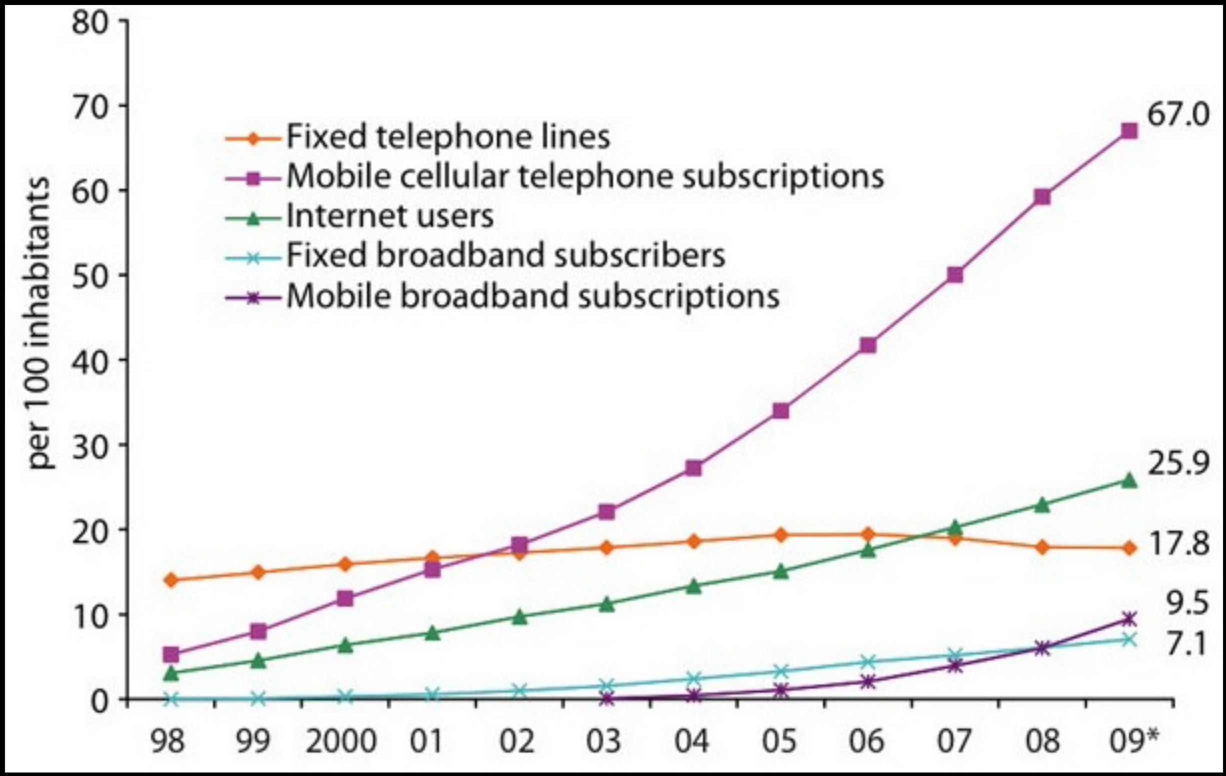
Telstar-401	13 January 1997	Satellite Failure
GALAXY-VII	13 June 1998	Satellite Control Processor
BRAZILSAT	9 April 2000	Transponder Amplifier
SOLIDARIDAD-I	27 Aug 2000	Satellite Control Processor
ECHOSTAR-IV	31 Oct 2000	Transponders lost
INSAT-2B	4 Nov 2000	Service outage
GALAXY-VII*	22 Nov 2000	Satellite Control Processor
ECHOSTAR-VI	April 2001	Service outage
GALAXY-IIIR	21 April 2001	Satellite Control Processor
TELSTAR-6	22 April 2001	Satellite Control Processor

Relatively Harmless Problem with Power Loss



2% per year
decline from GCRs
6% from SPEs

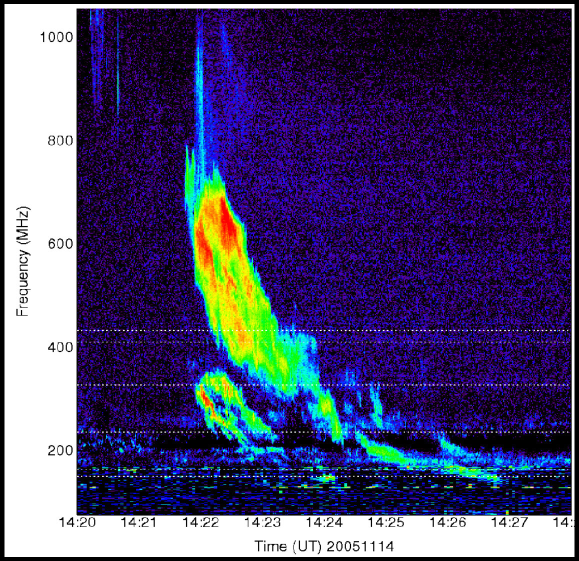
Cellular and Mobile Phones



By 2010 67% of human population have cell phones

Cellular and Mobile Phones

Space Weather Vulnerability

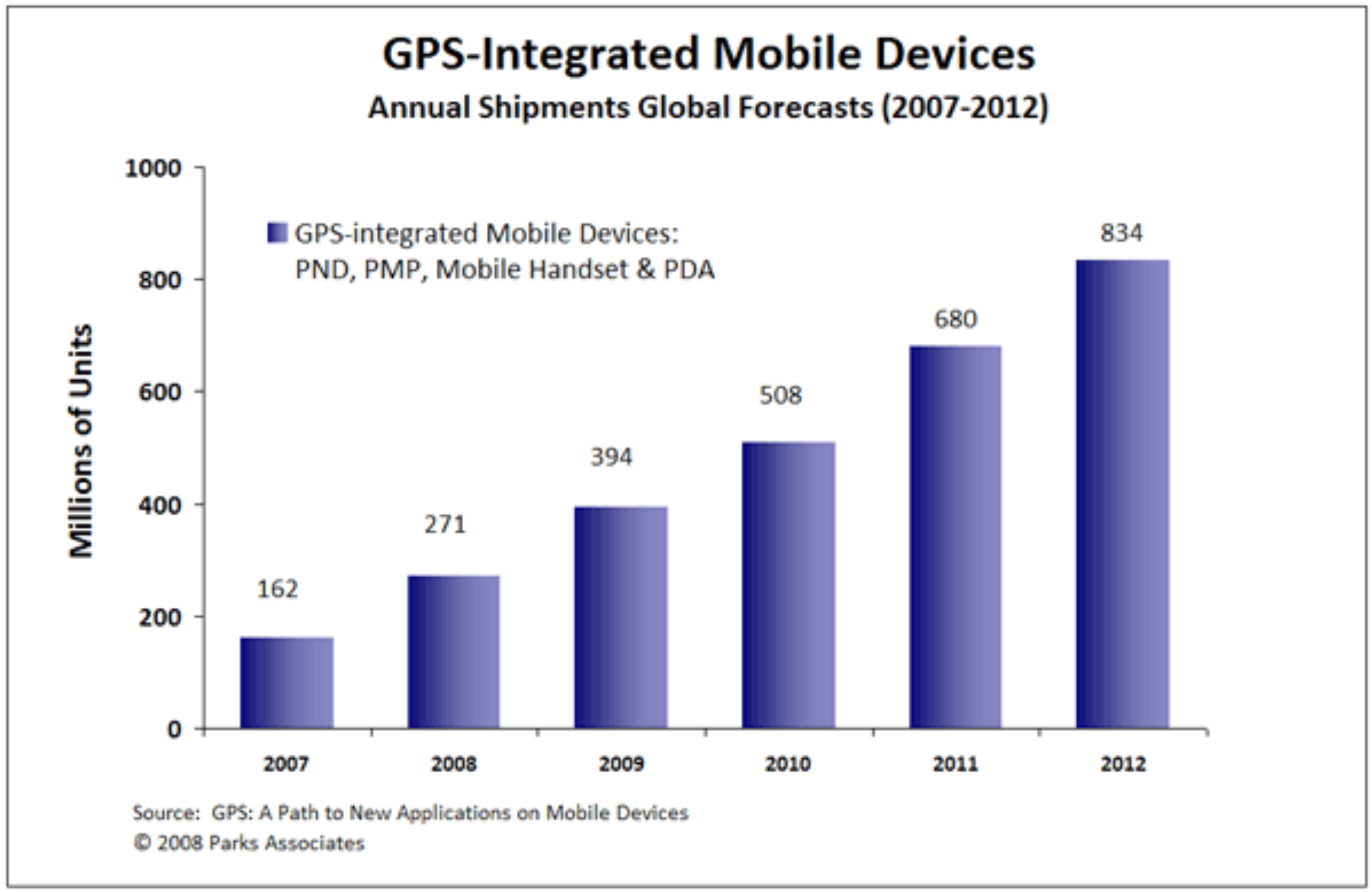


A high-frequency Type II burst observed on 2005 November 14 (NRAO)

Dropped-call rate 1 every 3 days during solar max.

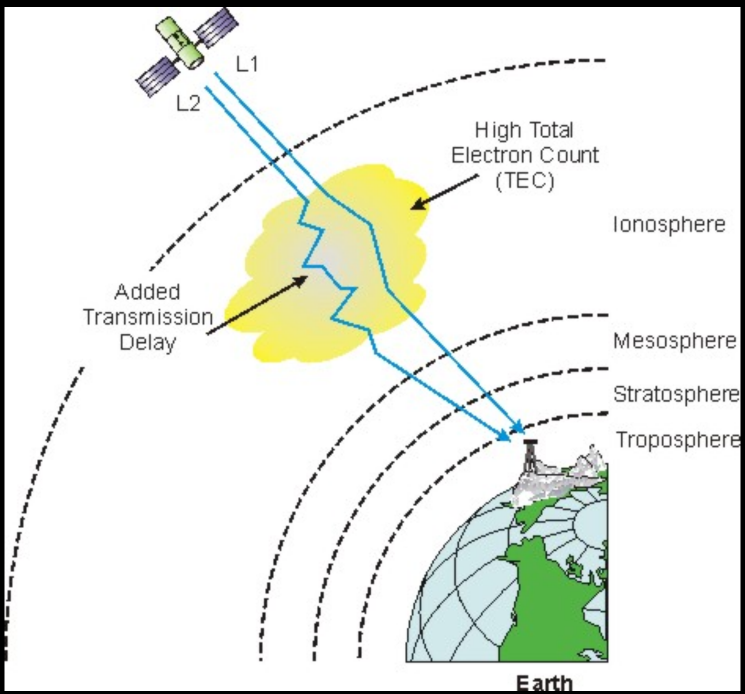
Lanzerotti, et al, 2005 ‘Noise in wireless systems from solar radio bursts’

GPS Systems

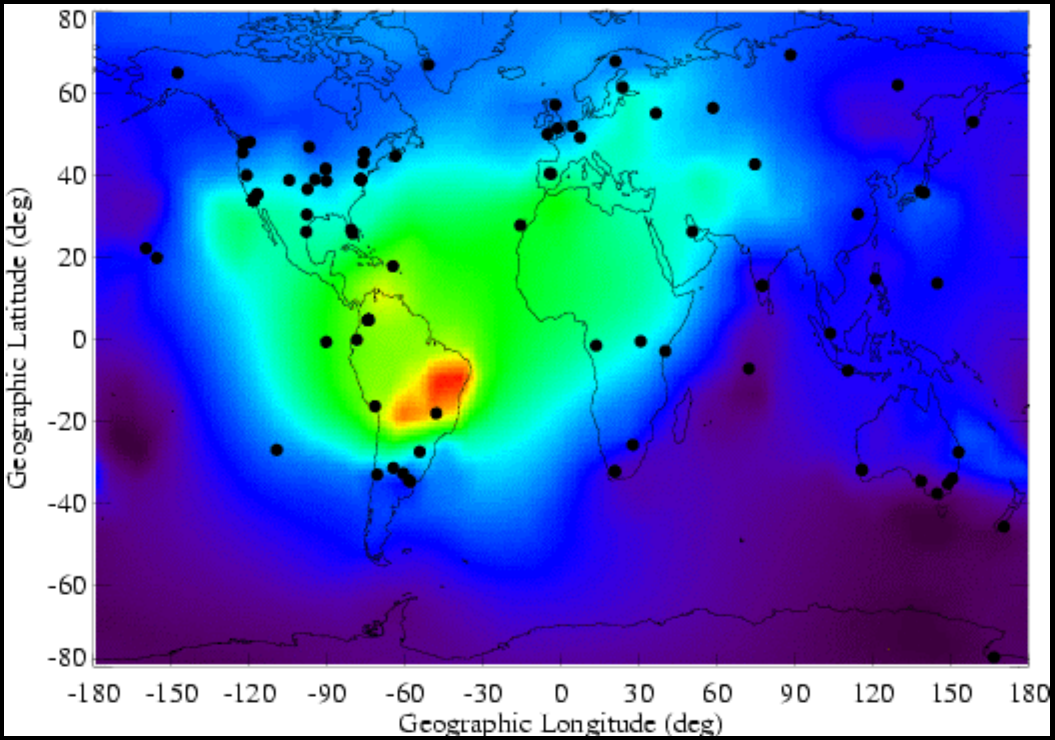


GPS-Integrated Mobile Devices
Annual Shipments Global Forecasts (2007-2012)
GPS-integrated Mobile Devices:
PND, PMP, Mobile Handset & PDA
Millions of Units
1000
800
600
400
200
0
162
271
394
508
680
834
2007
2008
2009
2010
2011
2012
Source: GPS: A Path to New Applications on Mobile Devices
© 2008 Parks Associates

GPS Systems



Propagation through ionosphere

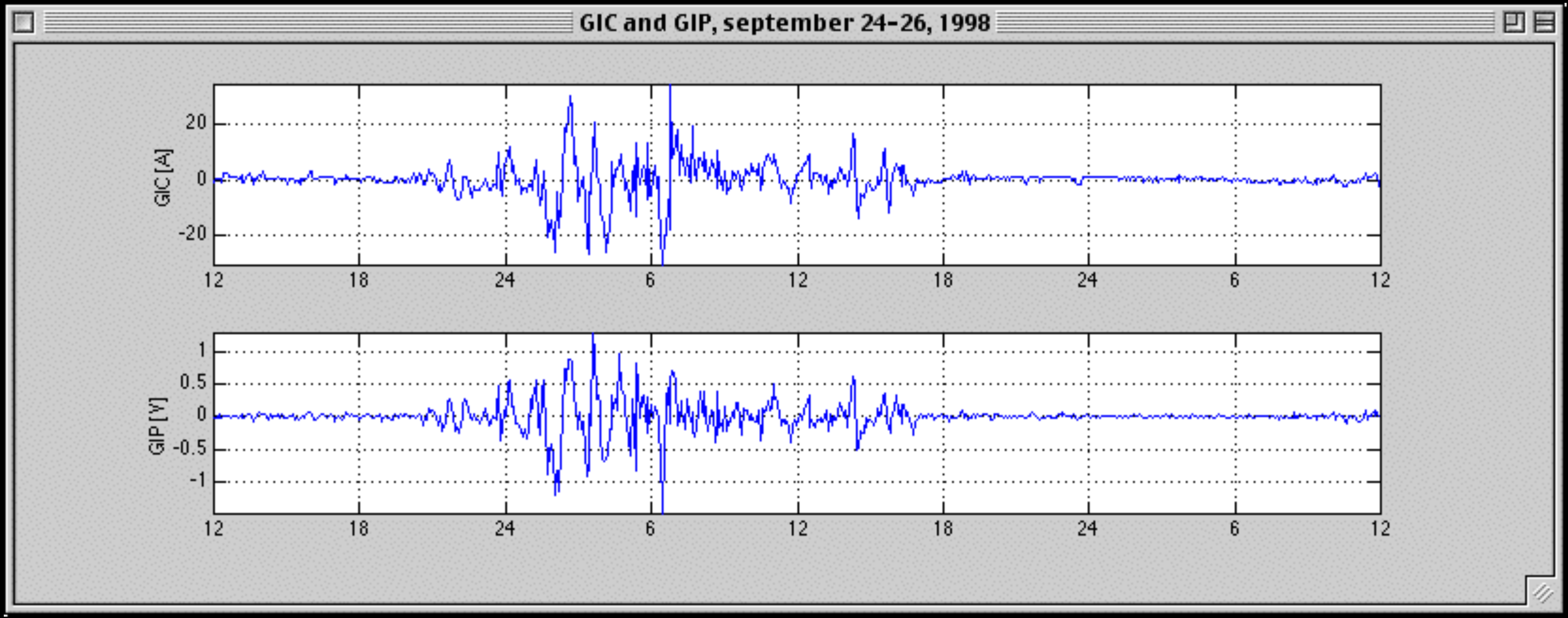


$$1.0 \text{ TECU} = 10^{16} \text{ e/m}^2$$

5 TECU = 1 meter GPS pos. error

Electric Power Grids - GICs

Impacts – Geomagnetically-Induced Currents
David Boteler (Helio III, June 6)



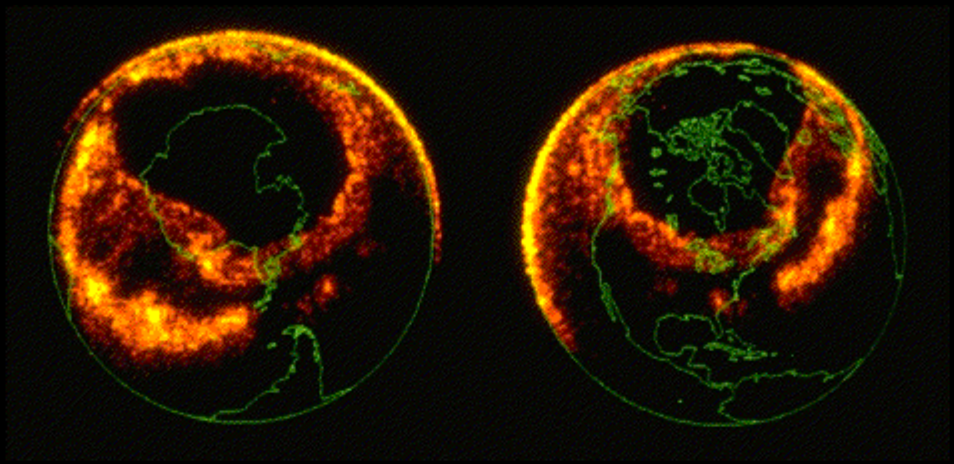
Top = GIC in 400 kV transformer ground – southern Sweden
Bottom – GIC in natural gas pipeline – southern Sweden

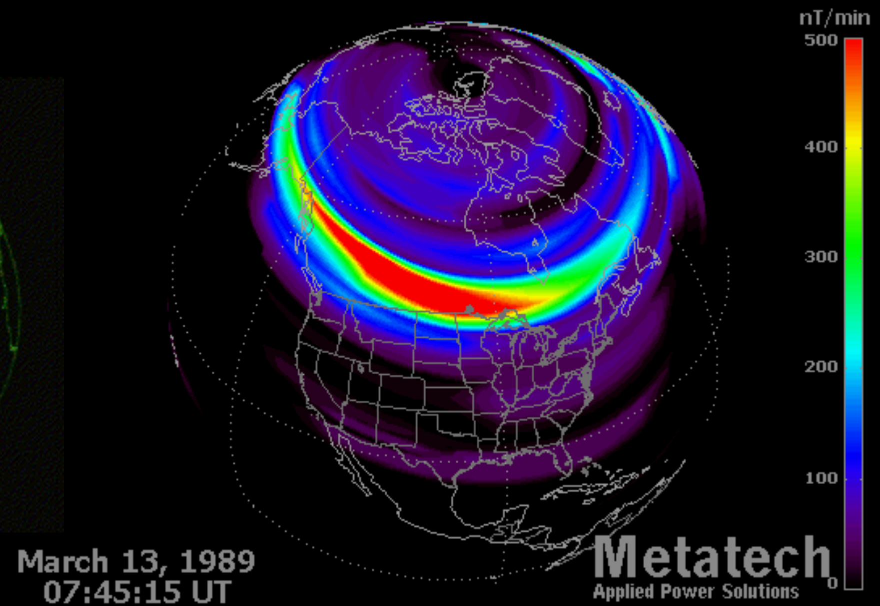
Courtesy – Lund Space Weather Center (www.lund.irf.se)

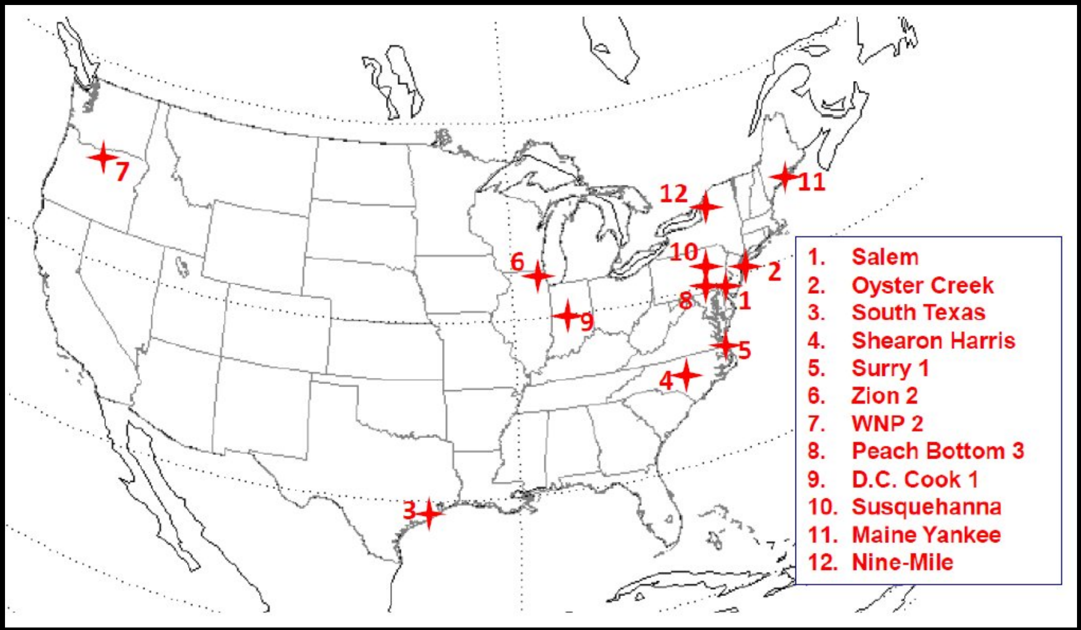
Electric Power Grids

Transformer damage

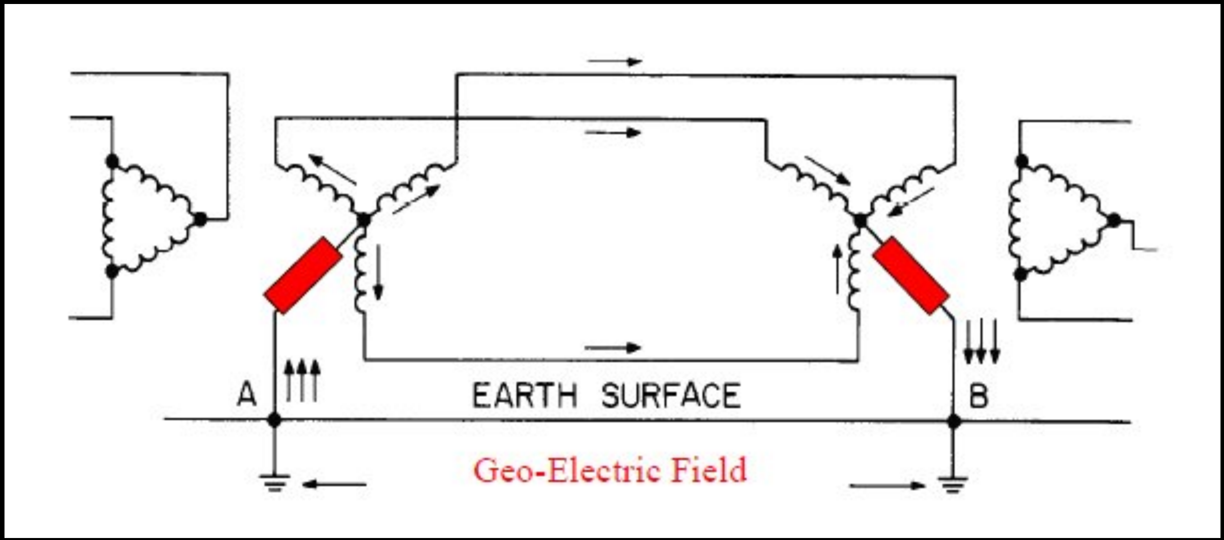
1989 Quebec Blackout







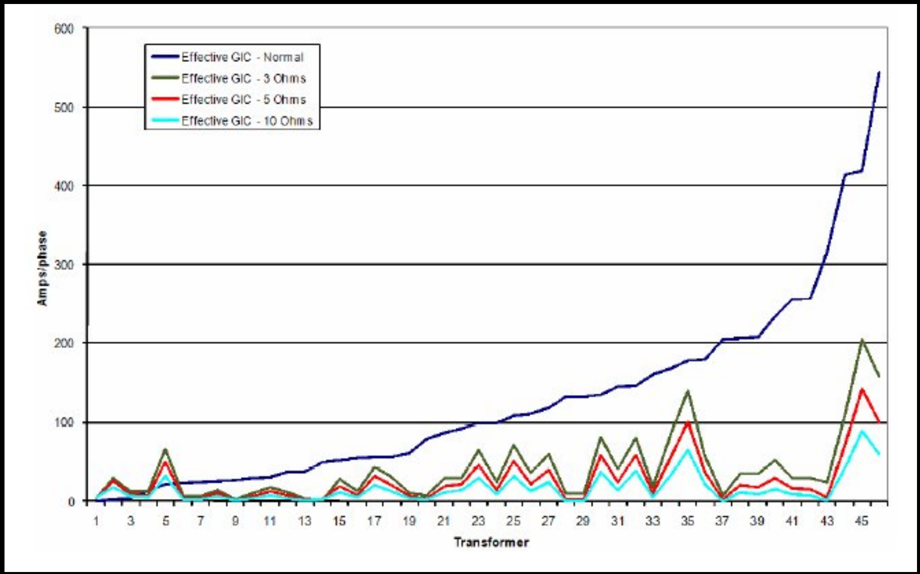
Mitigation



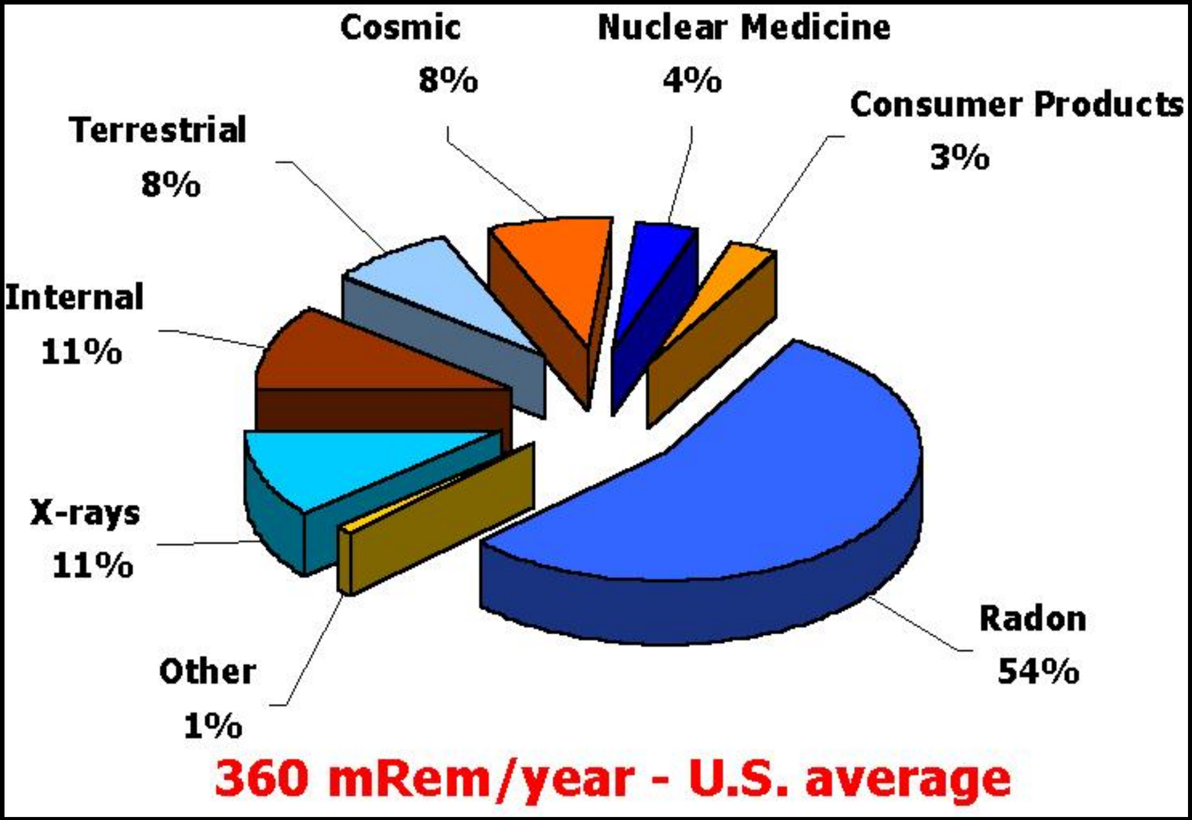
Adding resistors to ground lines

$500 million

Total amperes to US grid using various resistor values



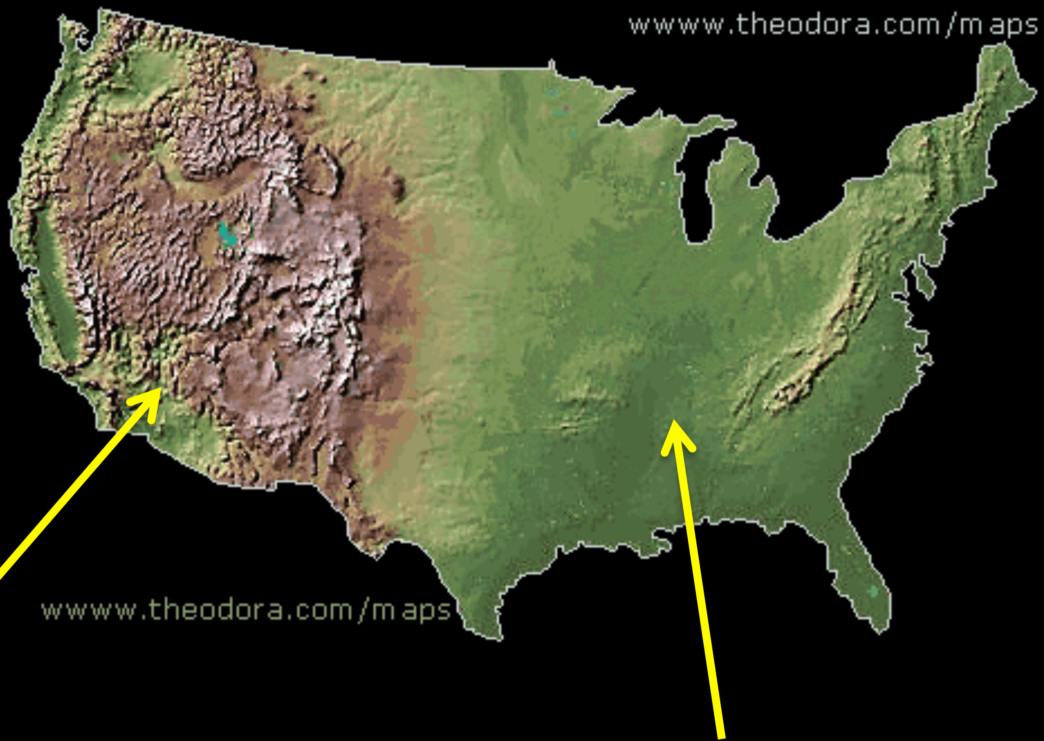
Sources of Radiation



The normal total dose rate is 0.41 microSv/hr

Cosmic Rays

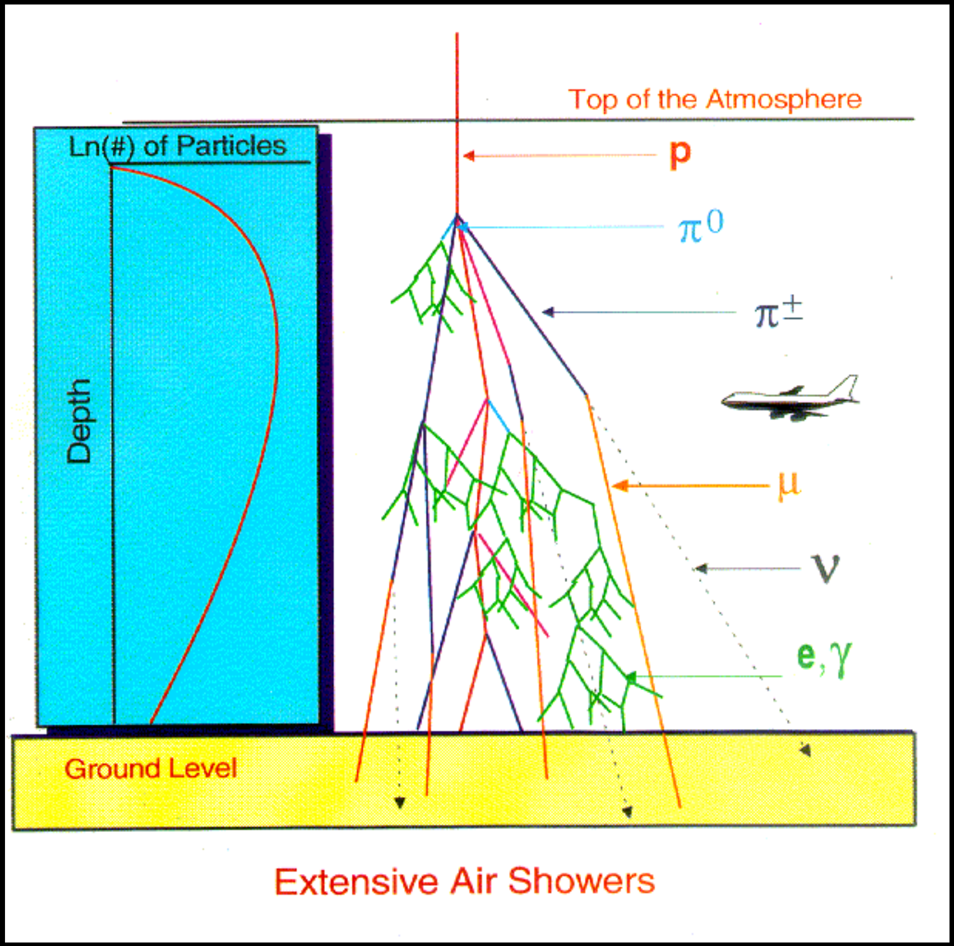
Cosmic Ray background varies with elevation

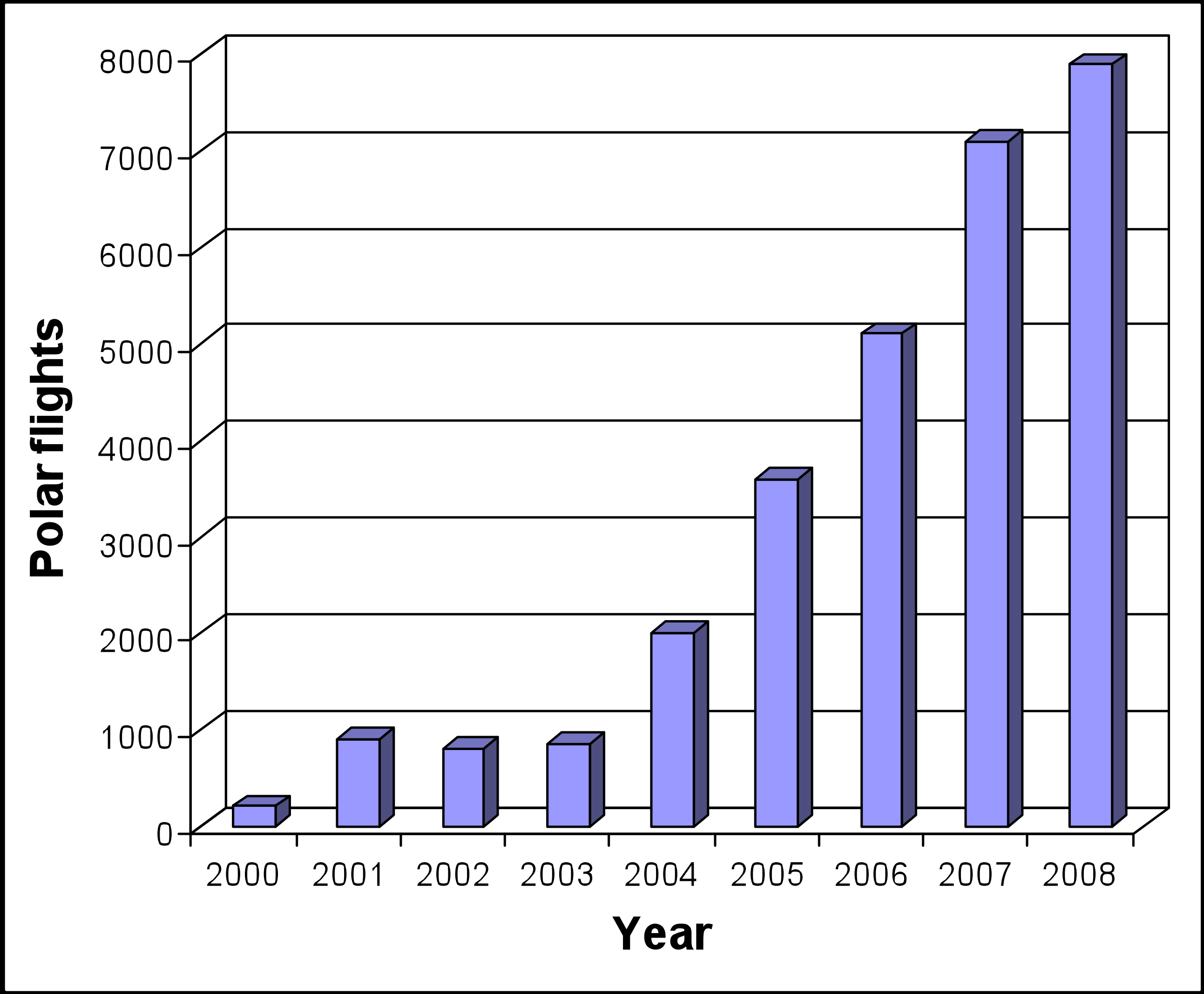


High = 0.1 microSieverts/hr   Low = 0.03 microSieverts/hr

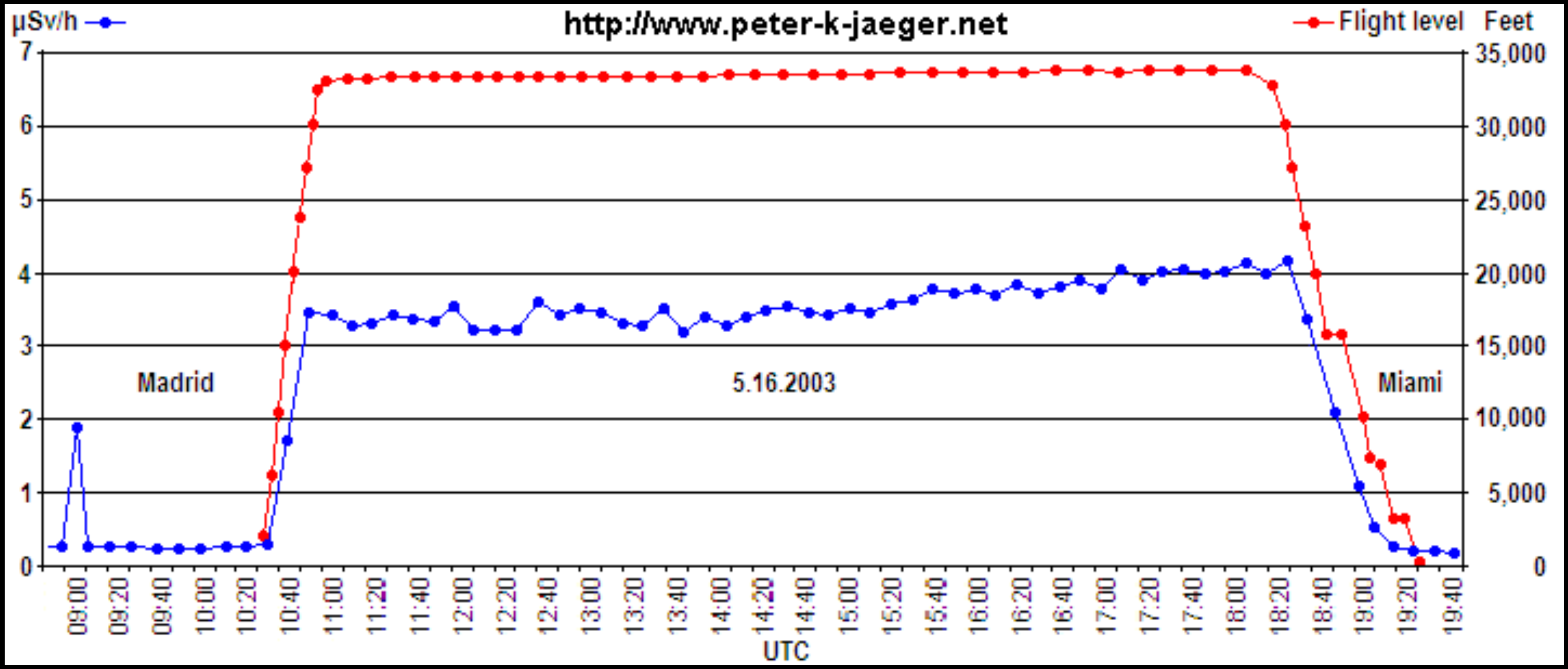
The normal Total dose rate is 0.41 microSv/hr

Air Travel – Cosmic Rays





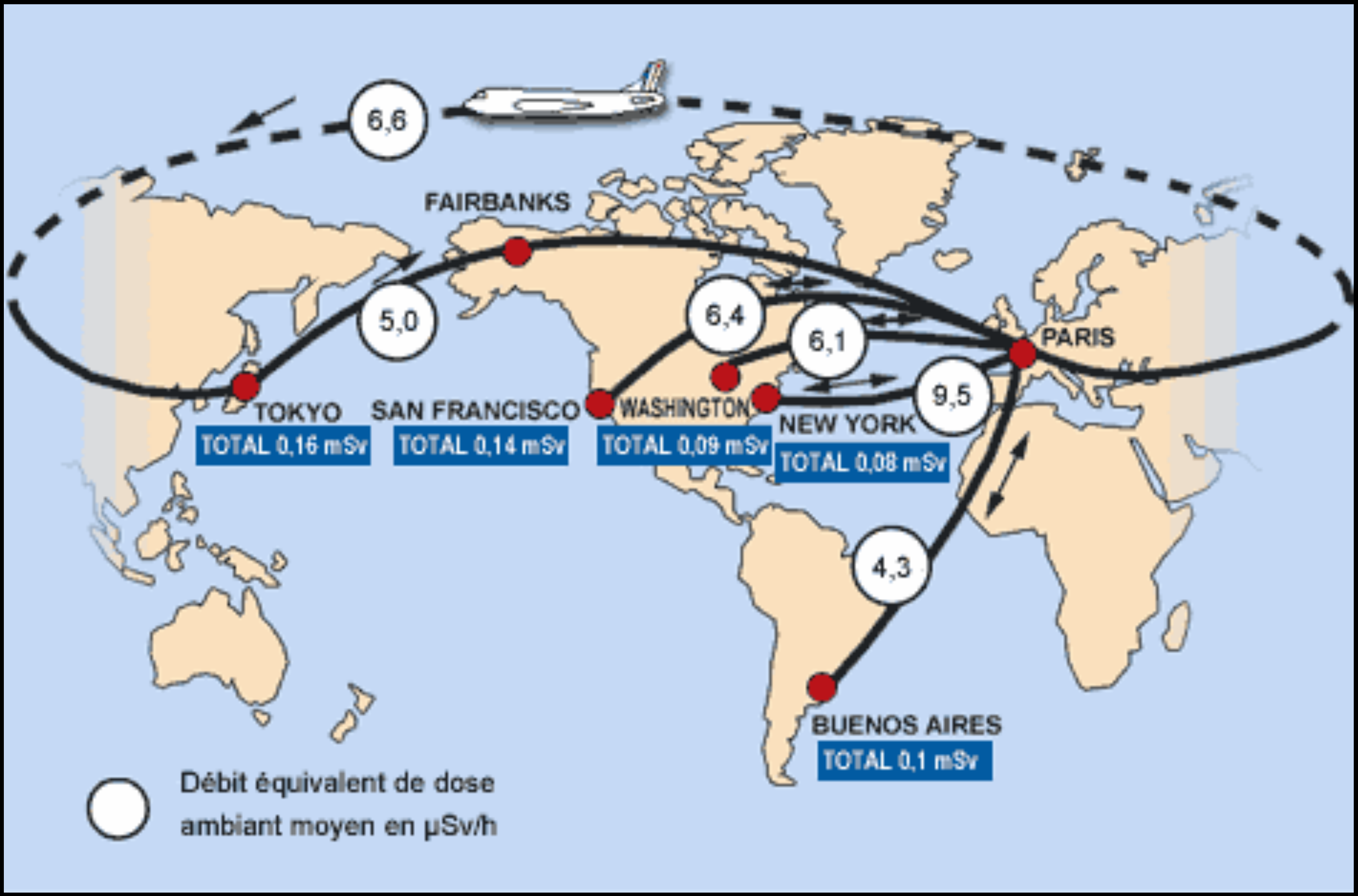
Passengers flying polar routes



Amateur Scientist Peter Jaeger (2003) in a flight from Madrid to Miami.
This is a non-Polar flight. Typical = 7 microSieverts/hr

On the ground, the normal dose rate is 0.41 microSv/hr.

For a few hours you get 20 times normal dose rate

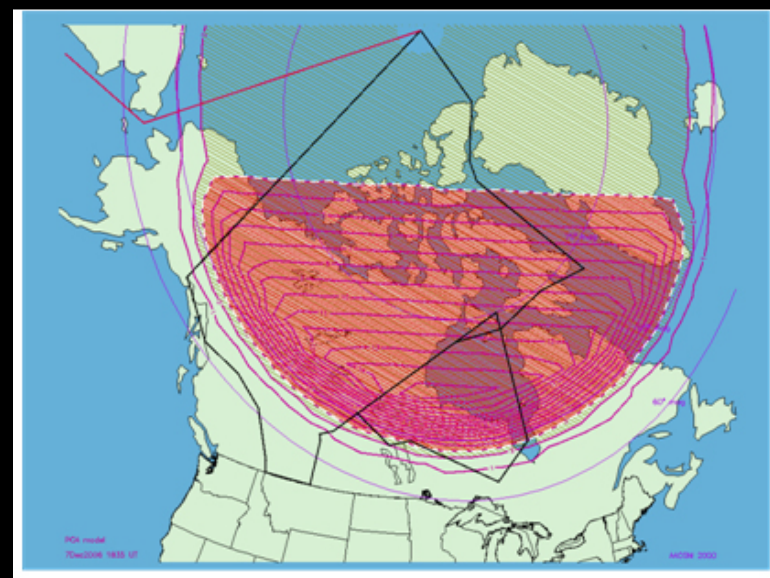


900 hrs x 7 microSv/hr = 6.3 milliSv

Annual= 3.6 milliSv

Polar Cap Absorption and HF Comunication blackouts

Image Credit: M. A. Shea, Geophysics Directorate, Philips Laboratory



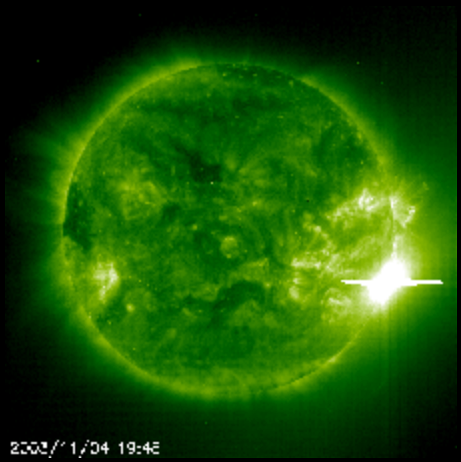
Courtesy: SpaceWeather.org

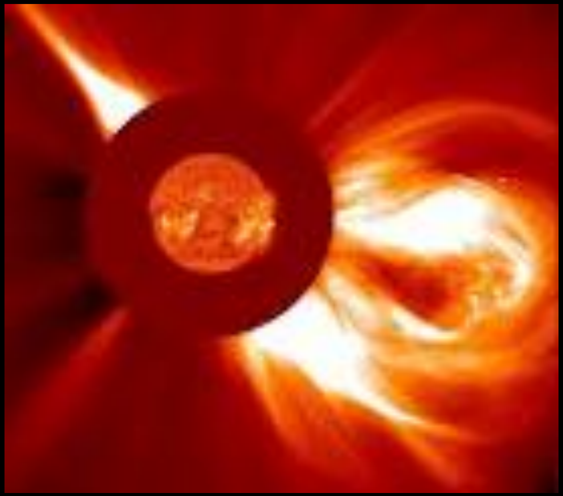
Space Weather Forecasting and Modeling

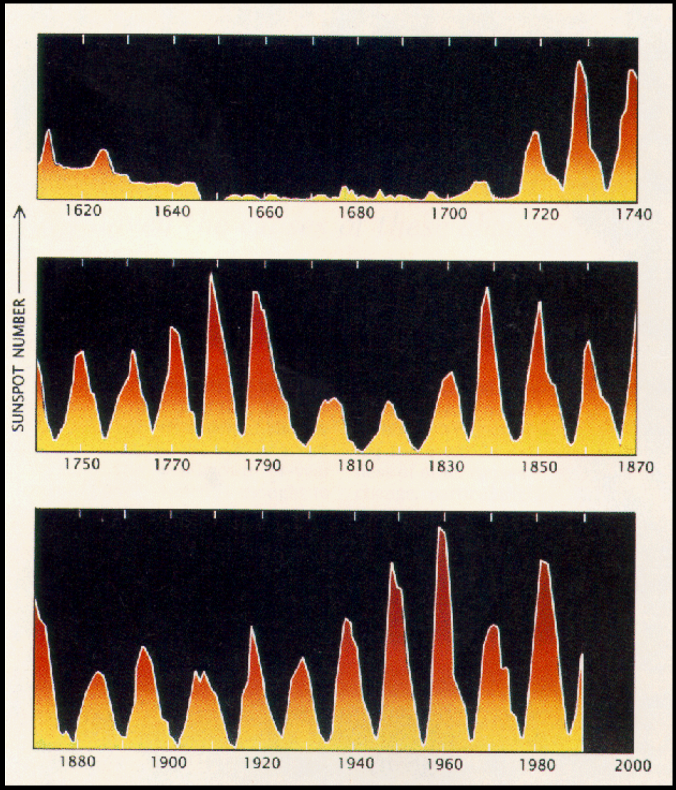
Solar Flares

Coronal Mass Ejections

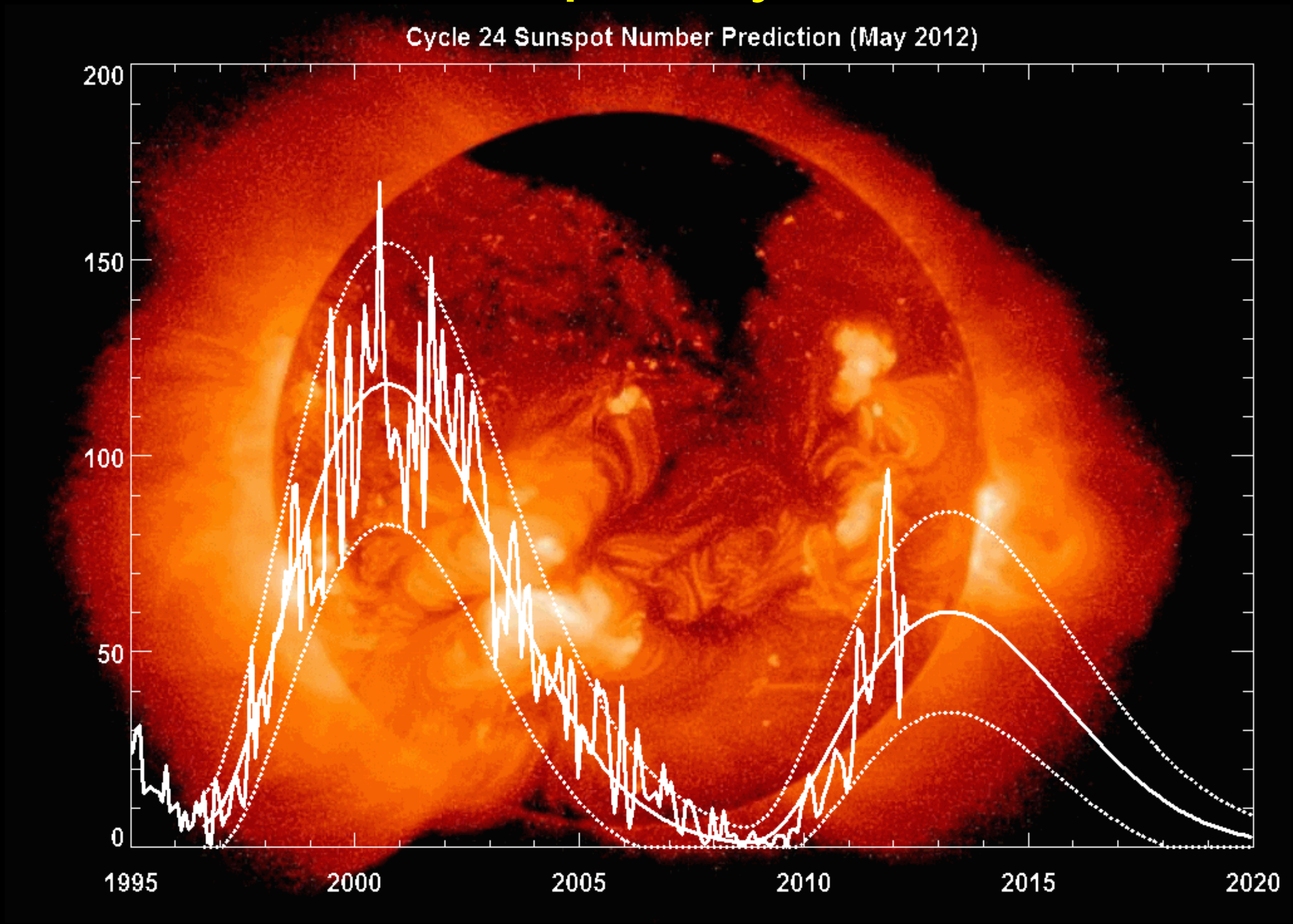
The Sunspot Cycle





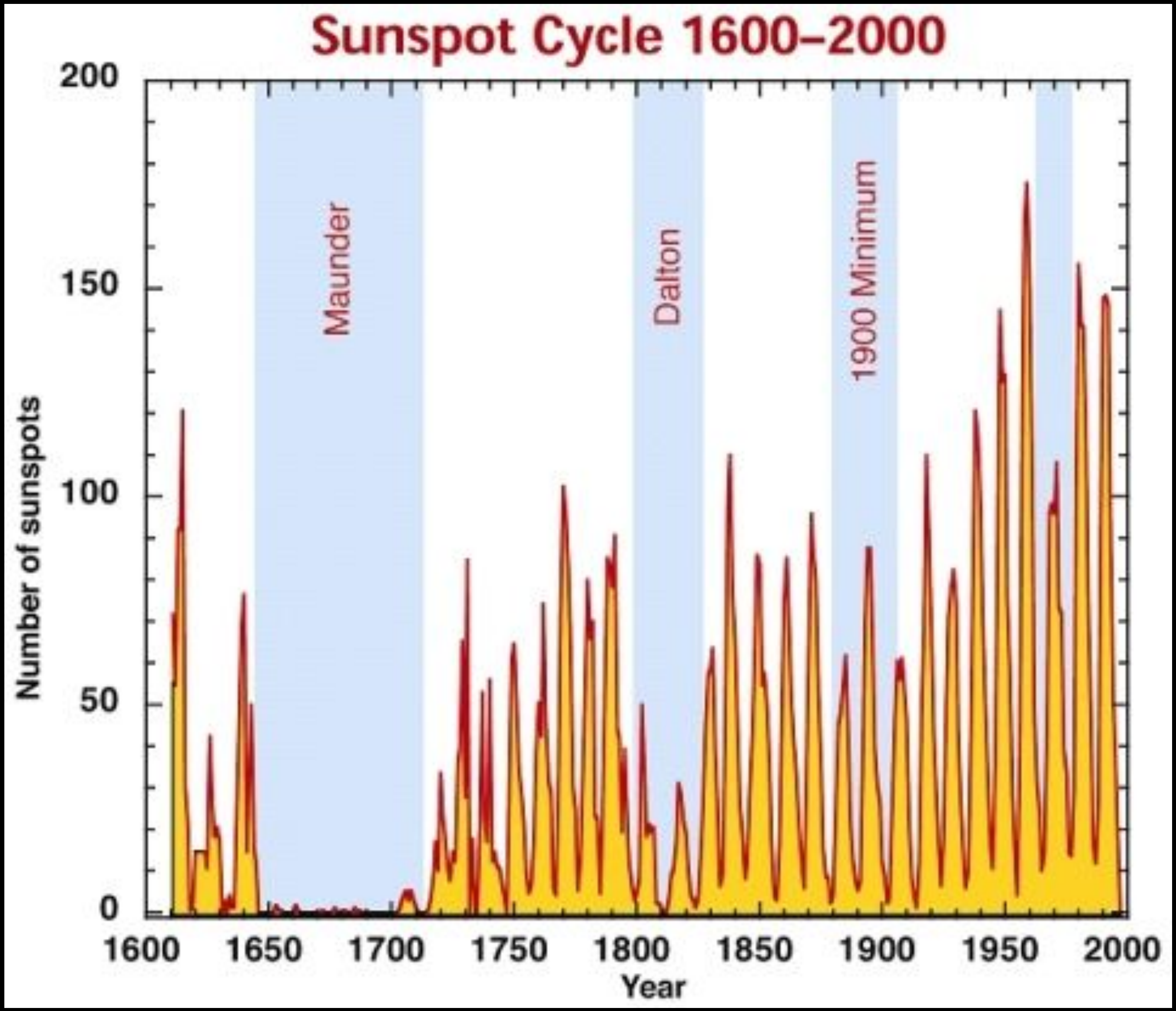


Sunspot Cycle



Hathaway/NASA/MSFC

Sunspots


Sunspot Cycle 1600–2000
Number of sunspots
0
50
100
150
200
Maunder
Dalton
1900 Minimum
1600
1650
1700
1750
1800
1850
1900
1950
2000
Year

Physics-based Modeling

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \quad (1)$$

$$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J}_f \quad (2)$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \cdot \mathbf{D} = \rho_f$$

Maxwell's Equations

$$\frac{\partial \rho_n}{\partial t} = -\nabla \cdot (\rho_n \boldsymbol{v}_n), \quad (1)$$

$$\frac{\partial \rho_i}{\partial t} = -\nabla \cdot (\rho_i \boldsymbol{v}_i), \quad (2)$$

$$\rho_n \frac{\partial \boldsymbol{v}_n}{\partial t} = -\rho_n(\boldsymbol{v}_n \cdot \nabla)\boldsymbol{v}_n - \nabla P_n - \gamma_{\mathrm{AD}} \rho_i \rho_n (\boldsymbol{v}_n - \boldsymbol{v}_i), \quad (3)$$

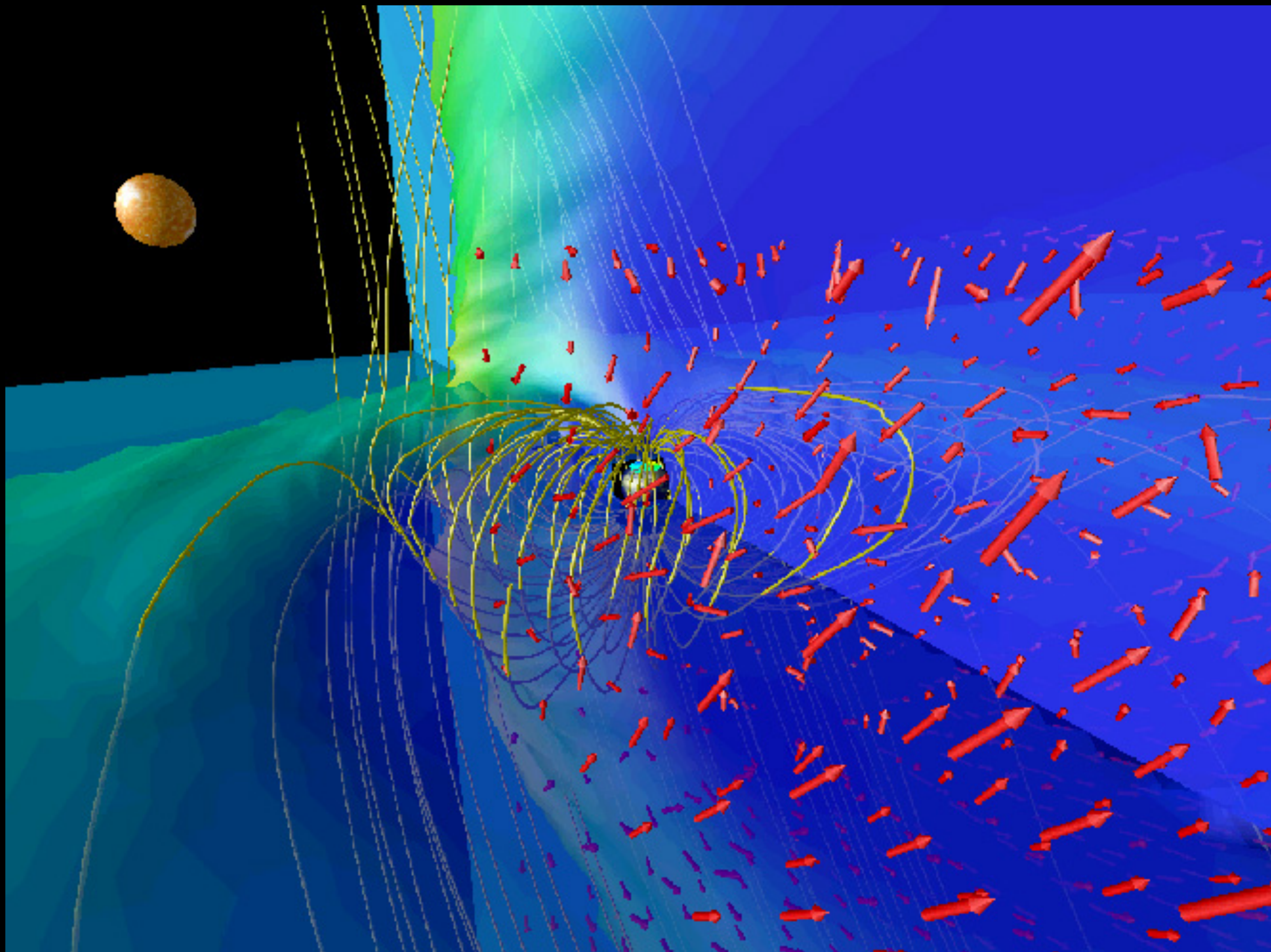
$$\rho_i \frac{\partial \boldsymbol{v}_i}{\partial t} = -\rho_i(\boldsymbol{v}_i \cdot \nabla)\boldsymbol{v}_i - \nabla P_i - \gamma_{\mathrm{AD}} \rho_i \rho_n (\boldsymbol{v}_i - \boldsymbol{v}_n) + \frac{1}{4\pi}(\nabla \times \boldsymbol{B}) \times \boldsymbol{B}, \quad (4)$$

$$\frac{\partial \boldsymbol{B}}{\partial t} = \nabla \times (\boldsymbol{v}_i \times \boldsymbol{B}), \quad (5)$$

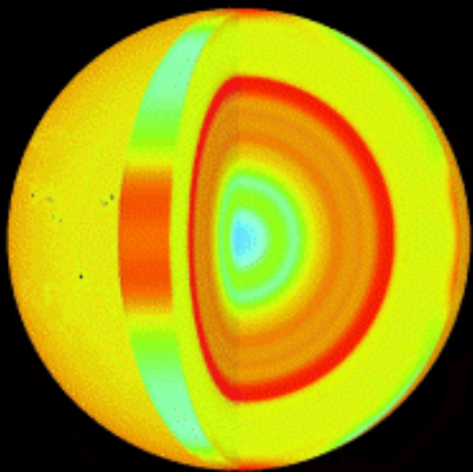
$$\nabla \cdot \boldsymbol{B} = 0, \quad (6)$$

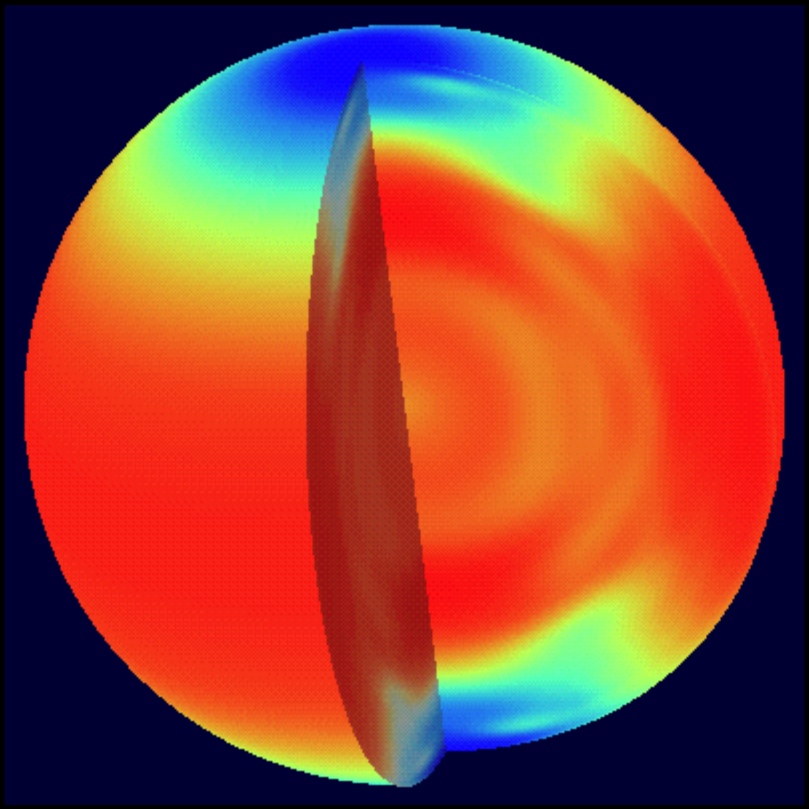
Magnetohydrodynamics Equations:
Conservation of mass, energy, momentum for neutrals and ions

Modeling

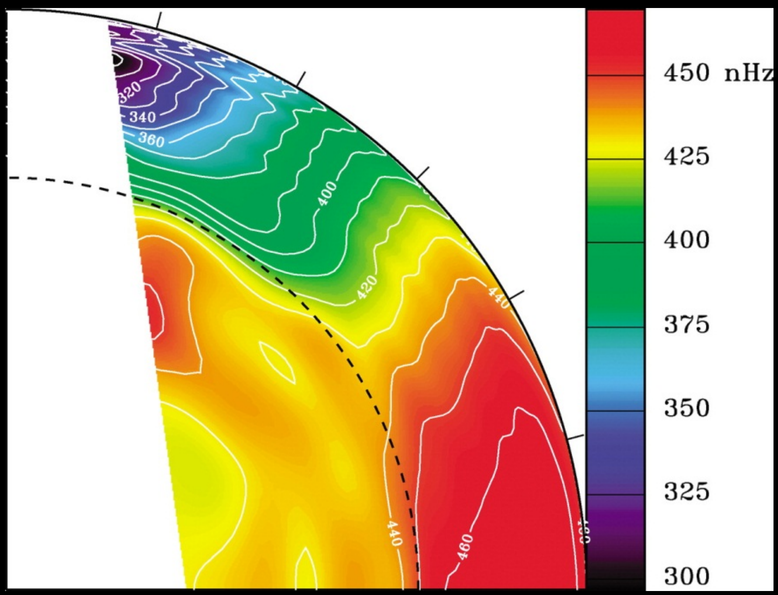


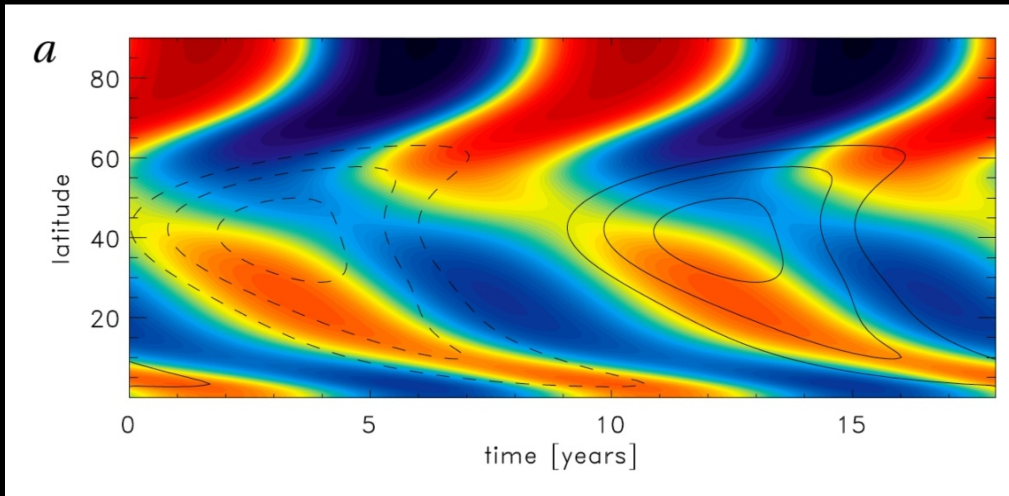
Solar Modeling

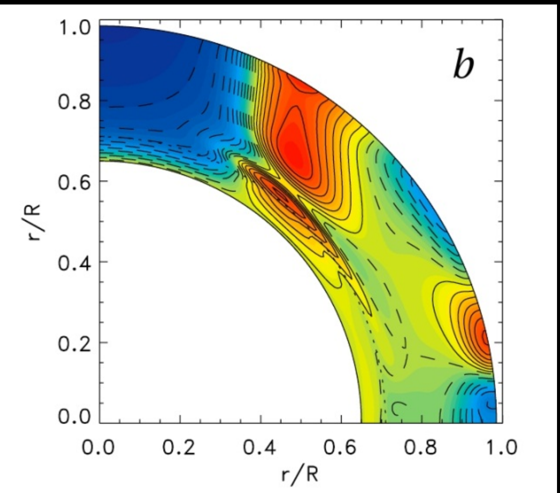




Solar Rotation and Plasma Flows

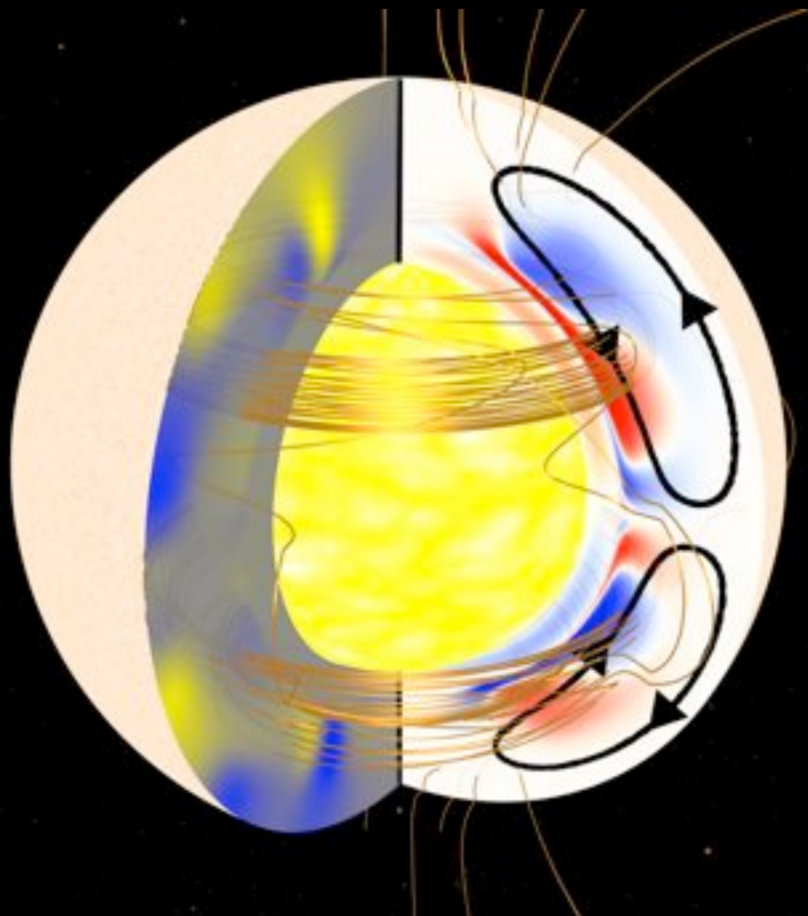




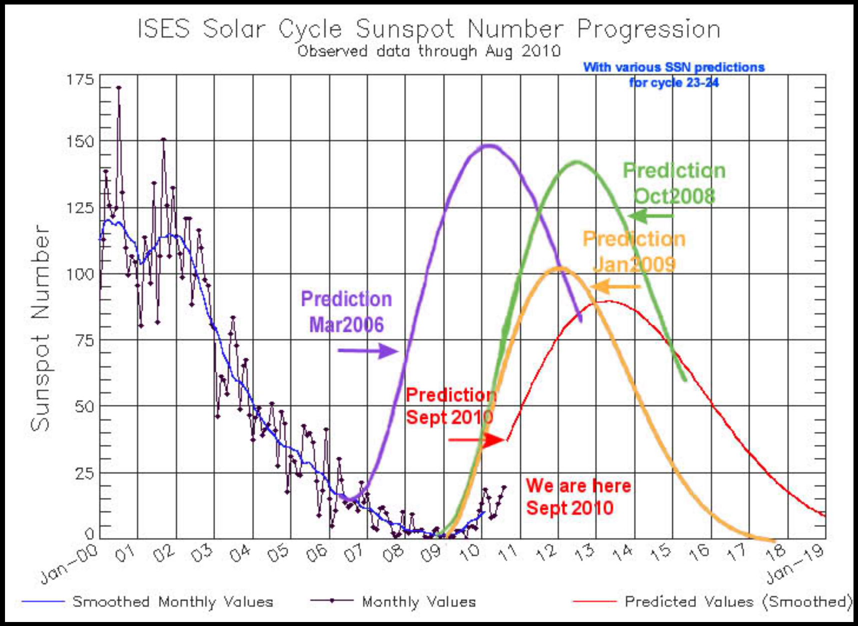


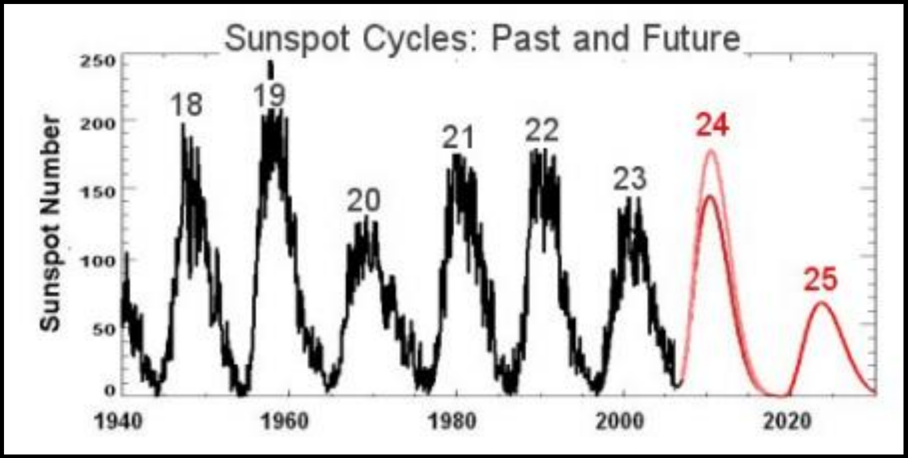
Sunspot Modeling

Sunspot Cycle Modeling

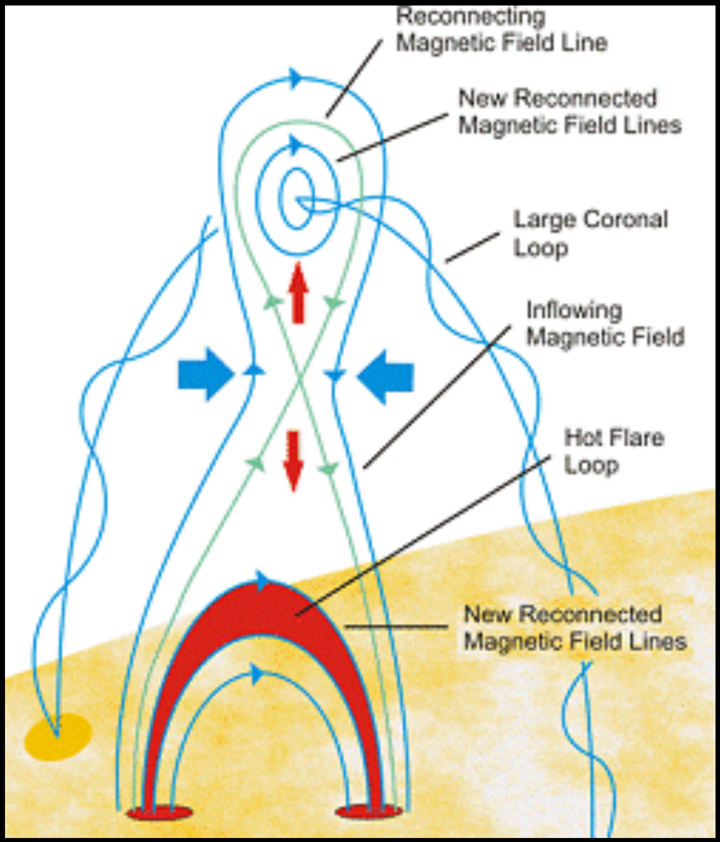


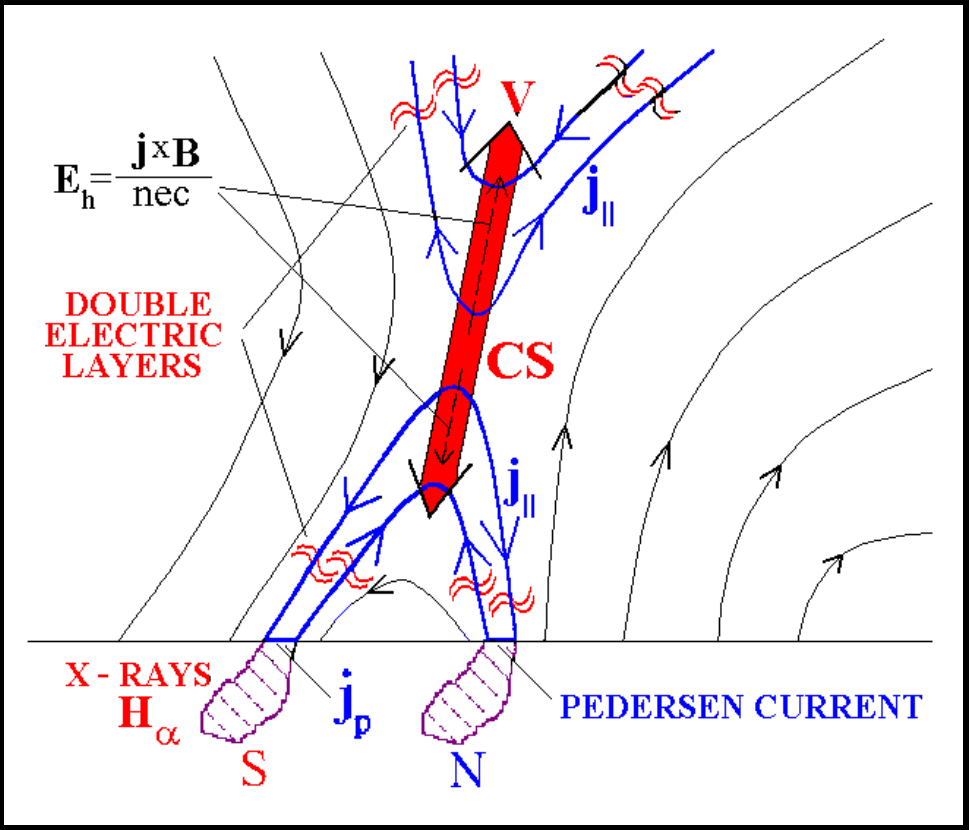
Sunspot Cycle Modeling



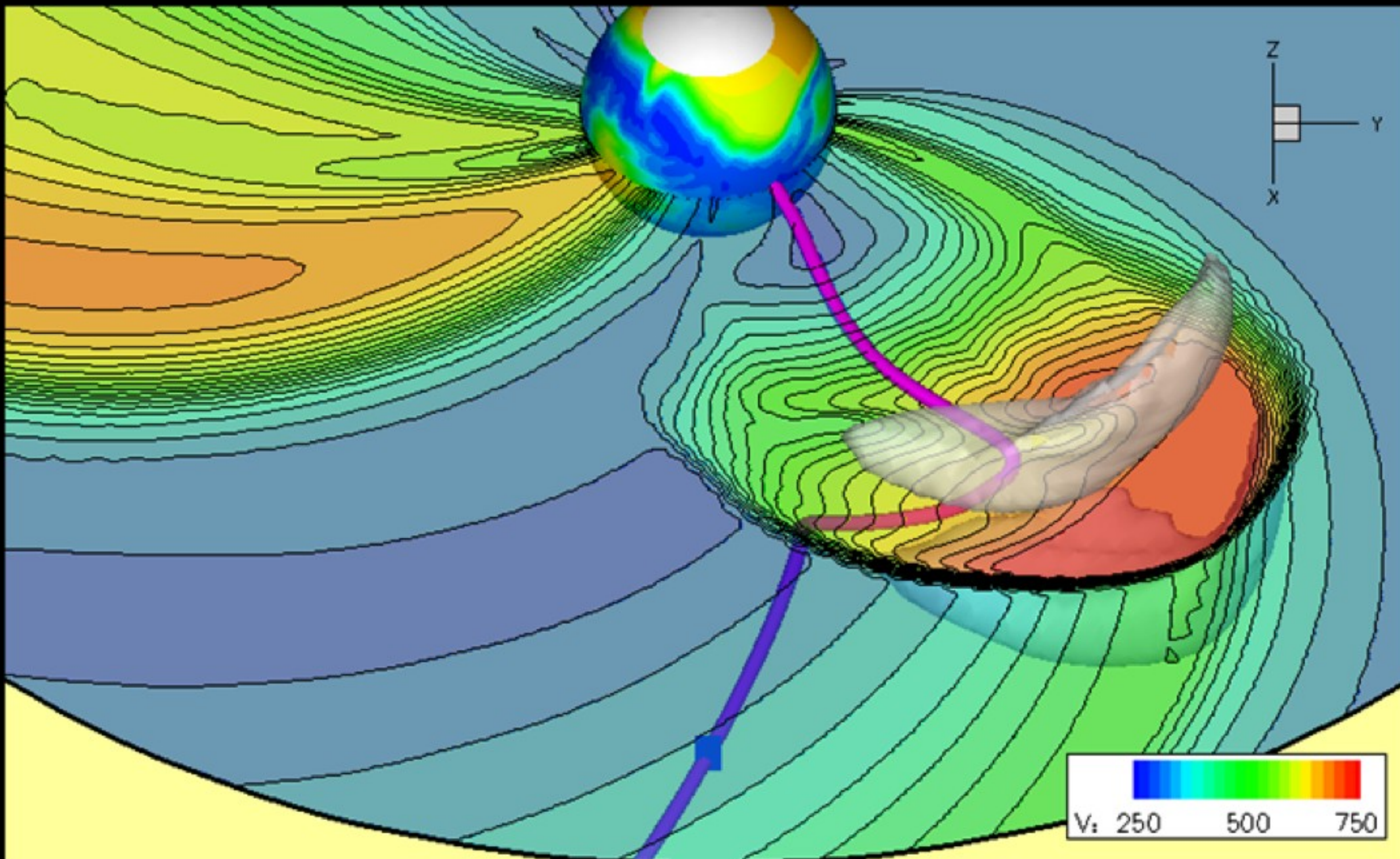


Solar Flare Modeling

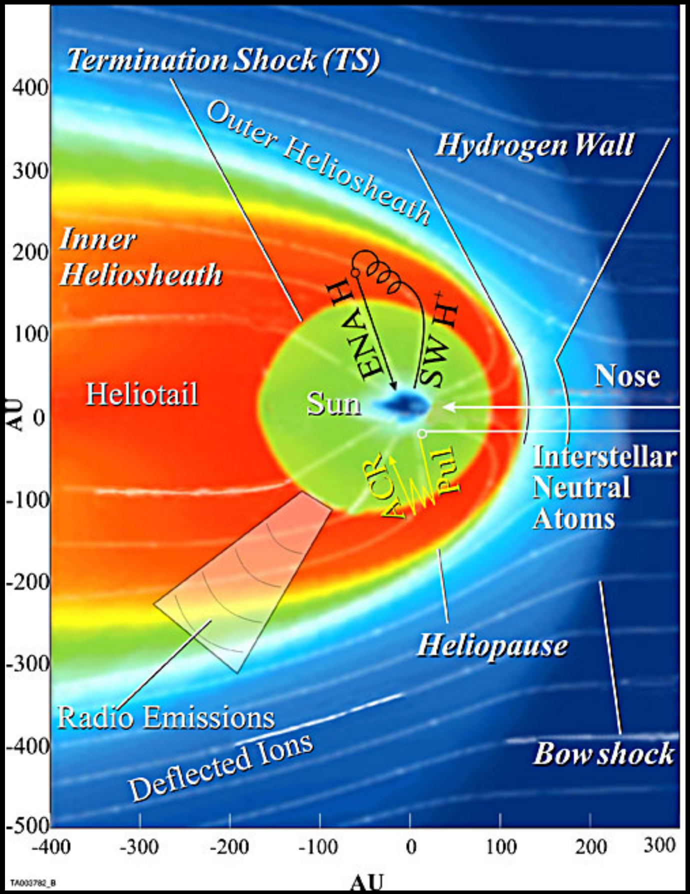


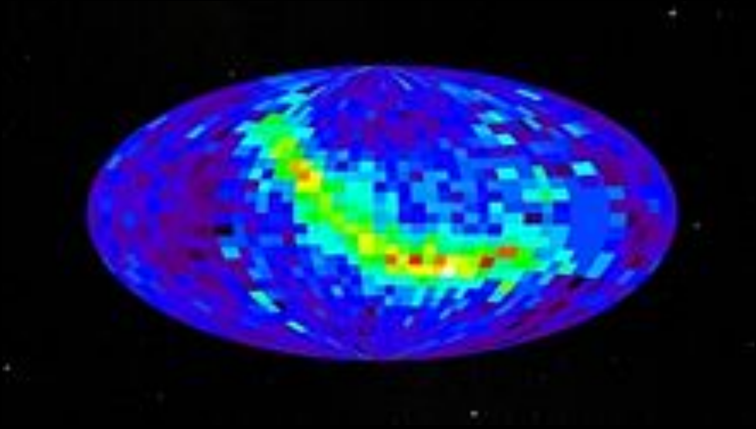


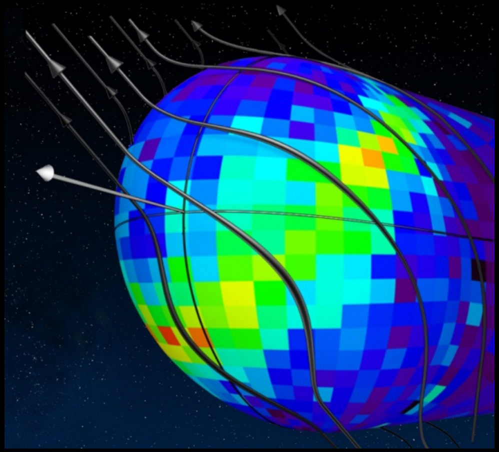
CME Modeling



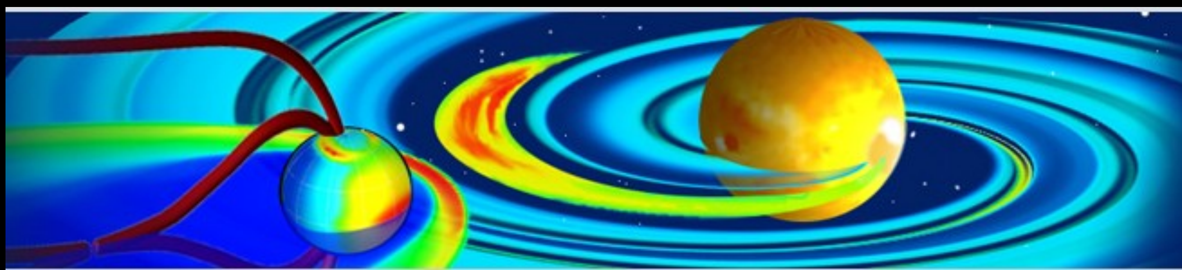
Cosmic Ray Modeling







NASA Community Coordinated Modeling Center



Community Coordinated Modeling Center

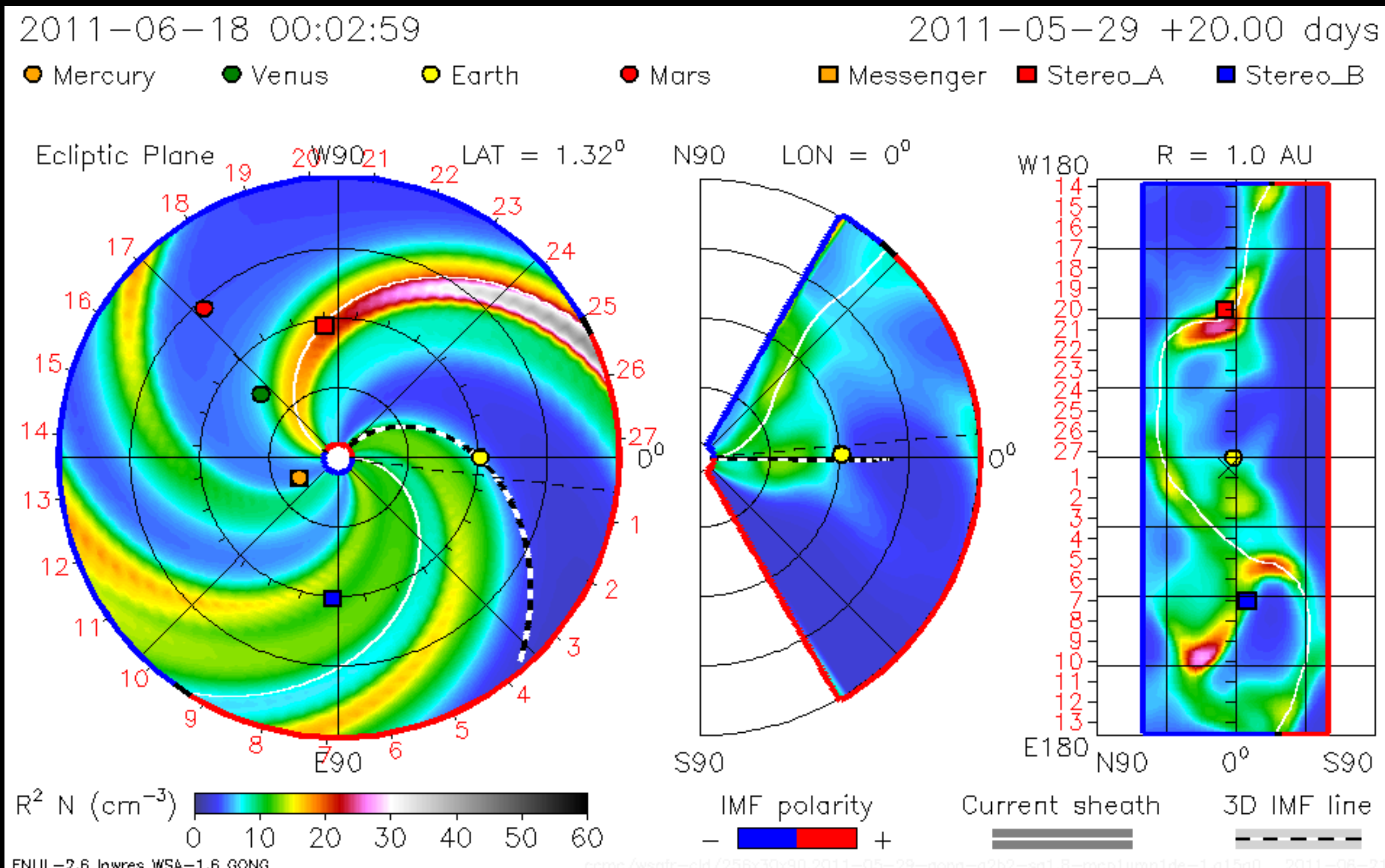
http://ccmc.gsfc.nasa.gov/

Cradle-to-grave

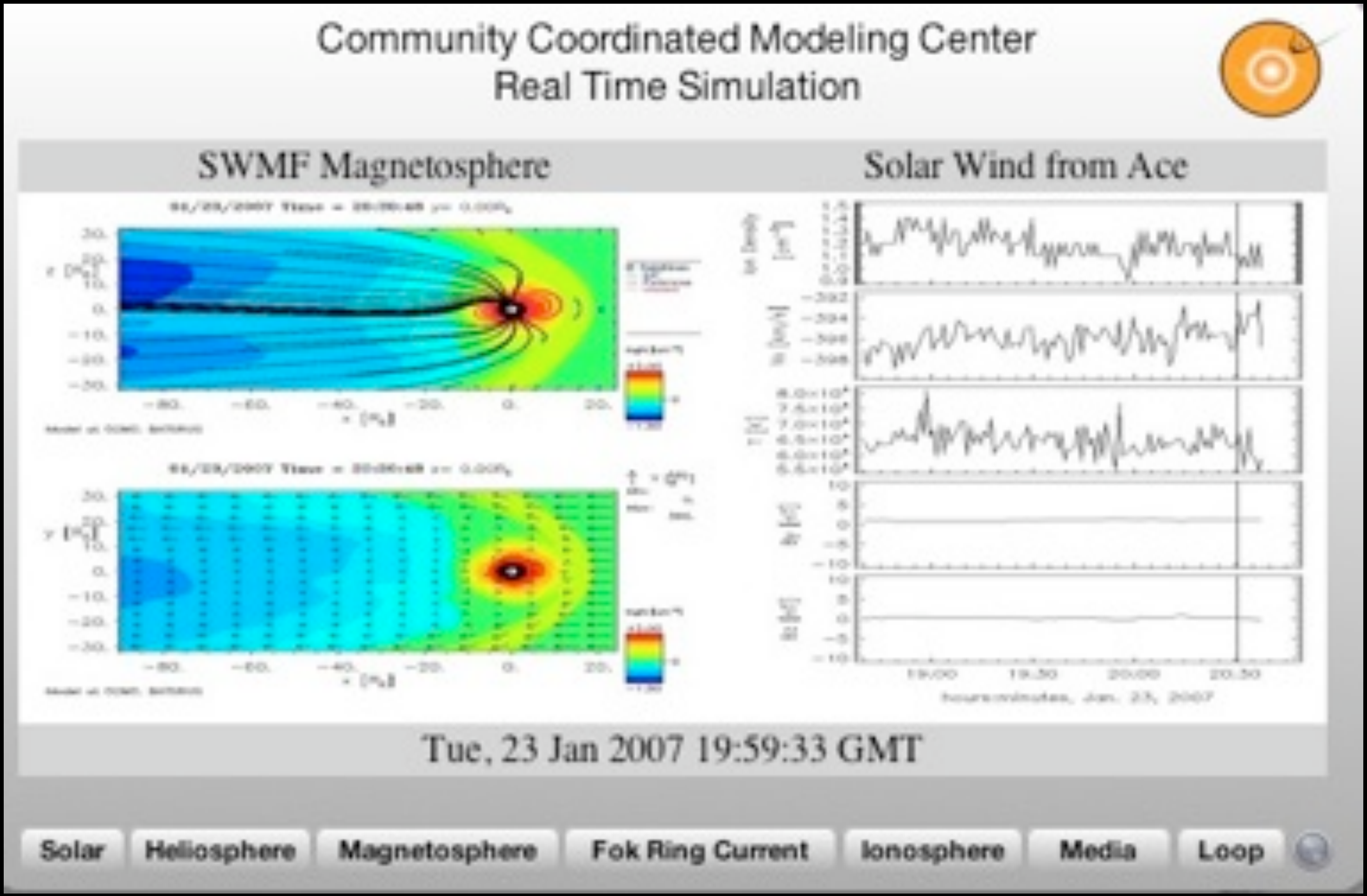
Solar surface
Solar wind
Geospace

- **Integrated Space Weather Analysis System** is a web-based dissemination system for NASA-relevant space weather information.
- **Space Weather Awareness at NASA** space weather information portal.
- **LWS Supported Tools and Methods**
- **Kameleon software**: model output from different models can now be stored uniformly in a common science data format. Users can request the CDF-formatted output for a CCMC run.
- **Movies on Request**: you can now request to generate a movie, images and ASCII data files for each time step of a model run.
- **CCMC Space Weather on Google Earth**: CCMC is now providing space weather-related Google Earth overlays.

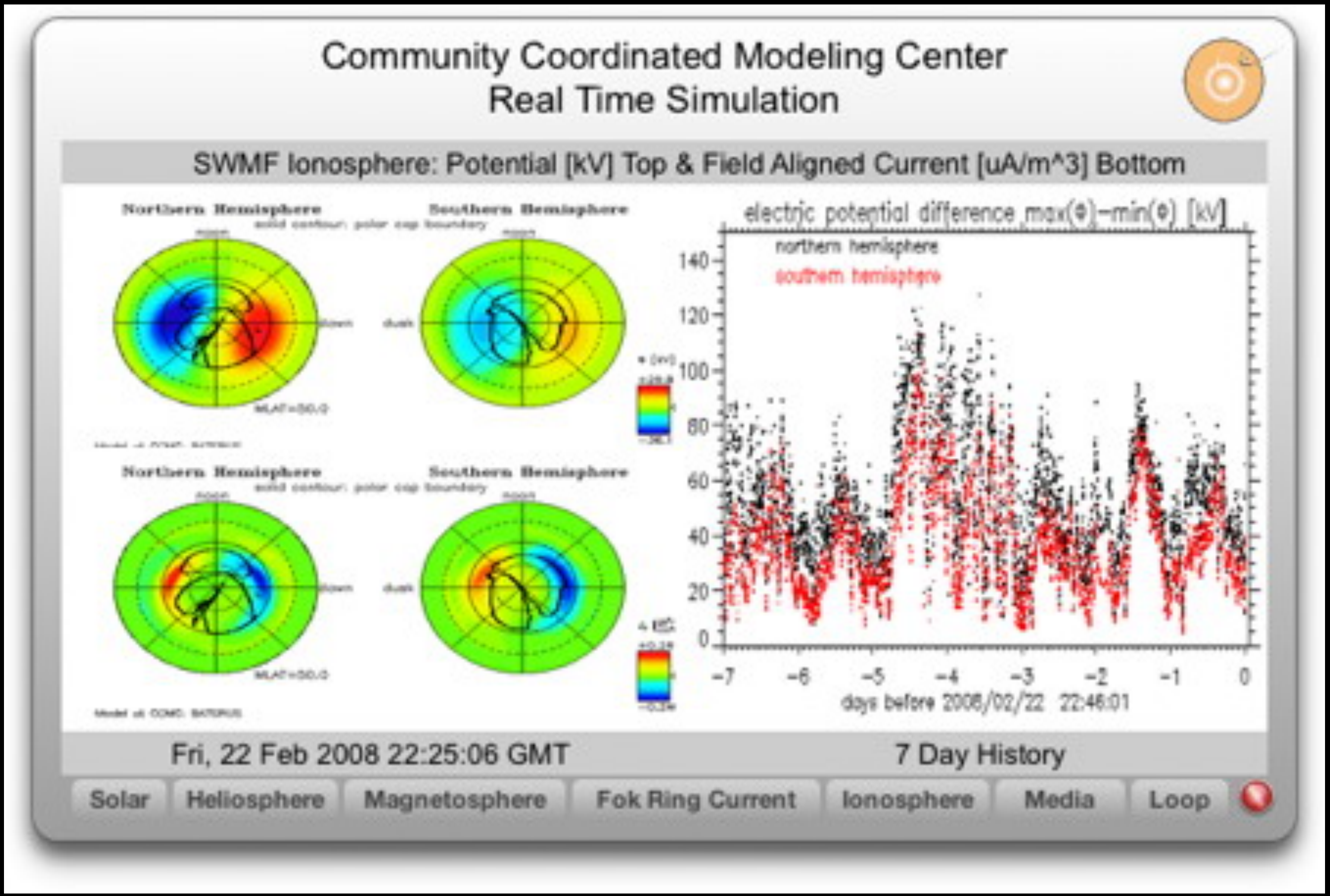
CCMC - Products



CCMC - Products

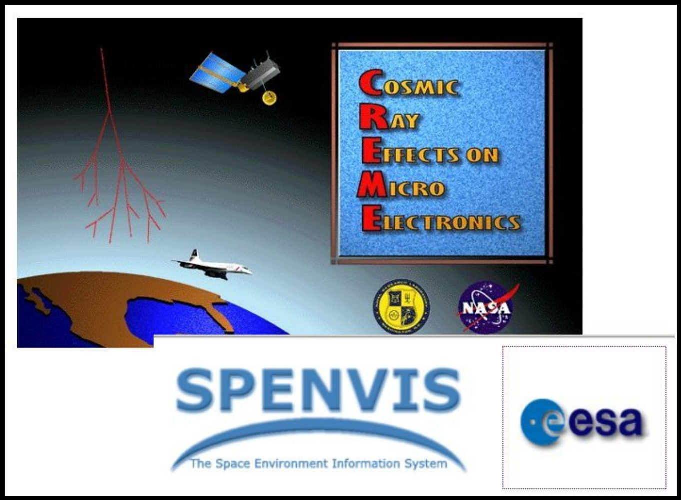


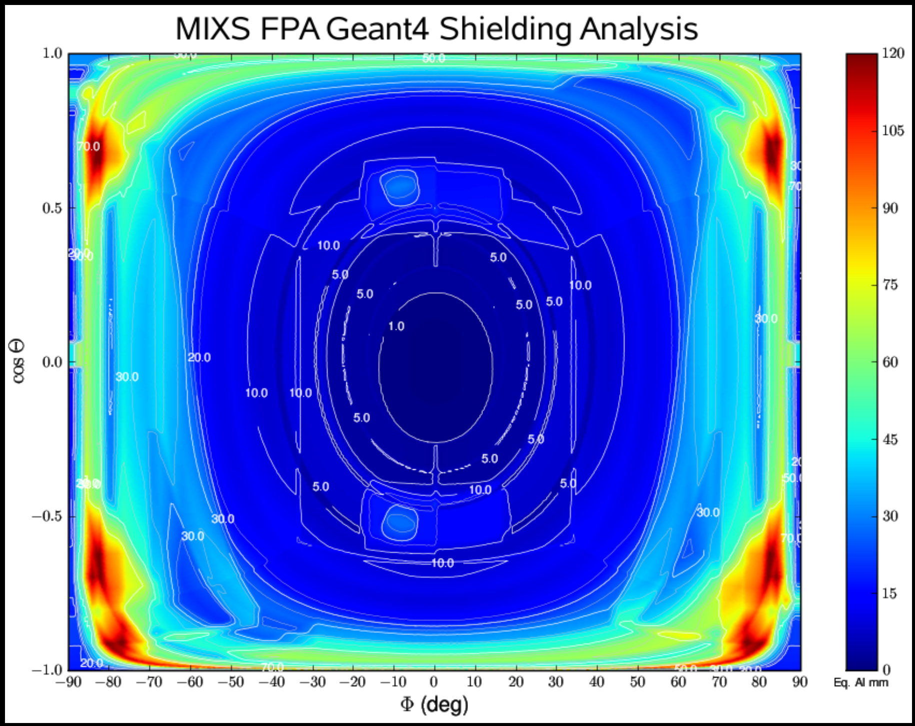
CCMC - Products



Radiation Modeling – SPENVIS

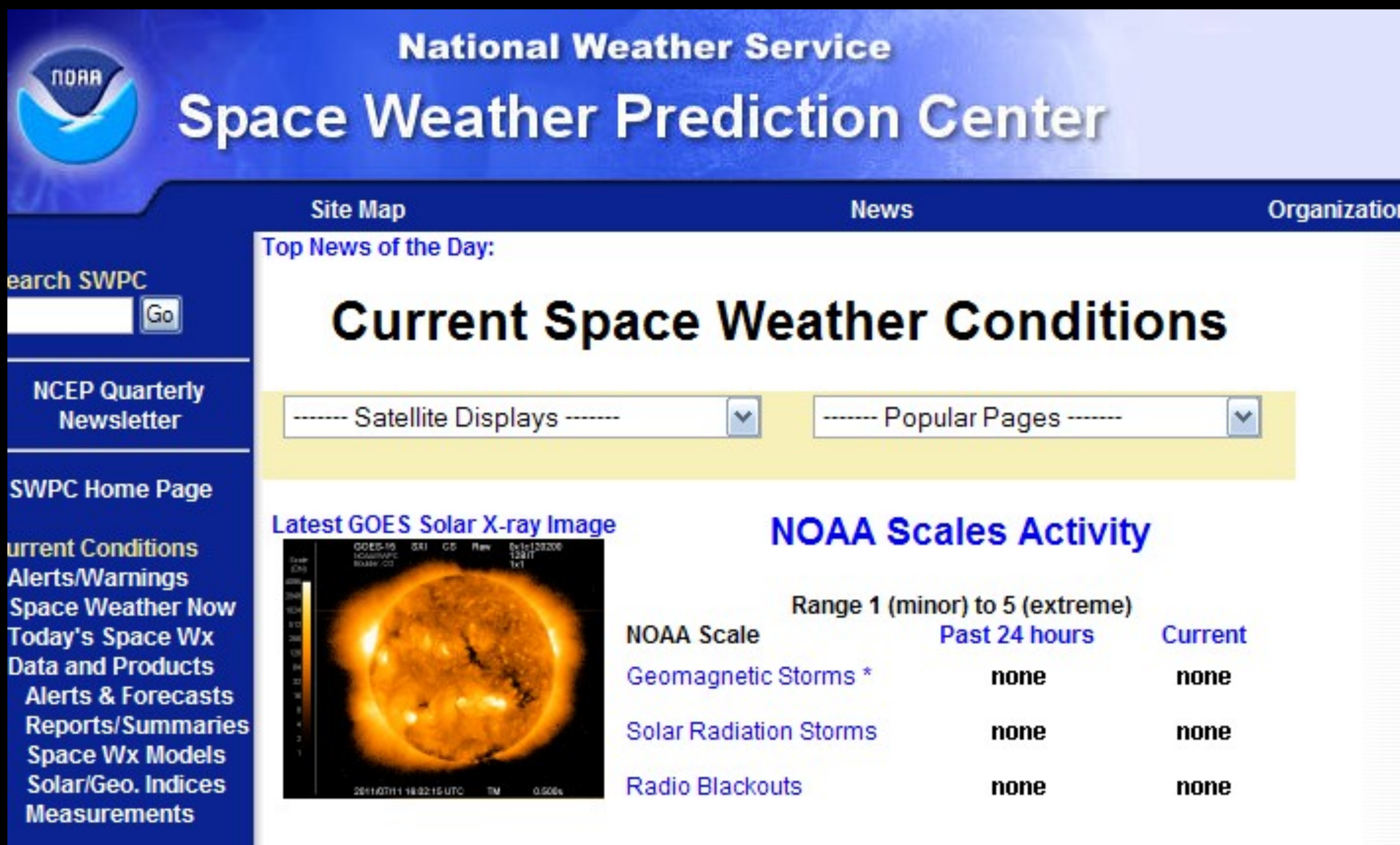
http://www.spenvis.oma.be/





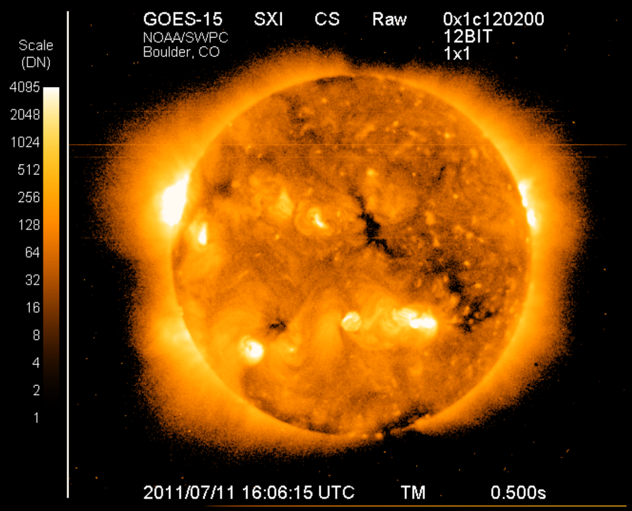
NOAA/SWS Space Weather Prediction Service

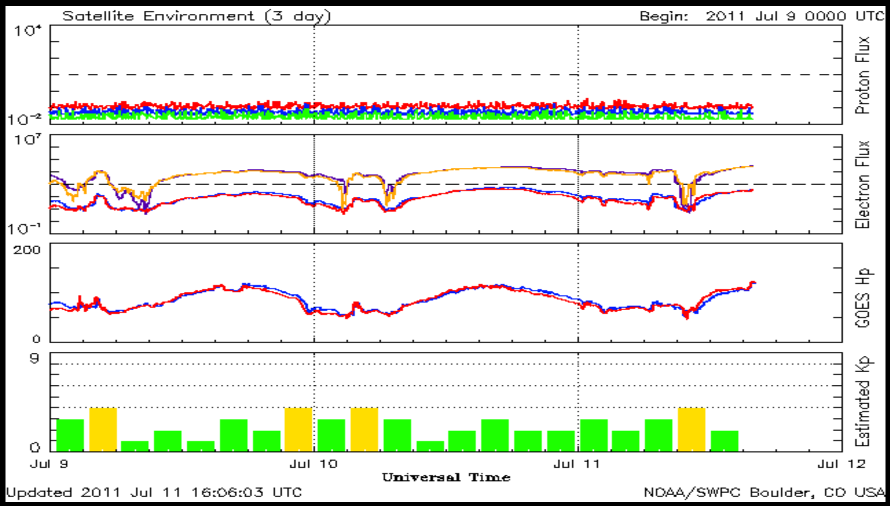
http://www.swpc.noaa.gov/

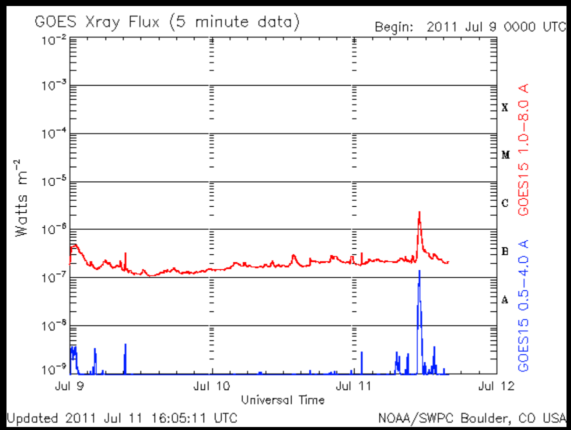


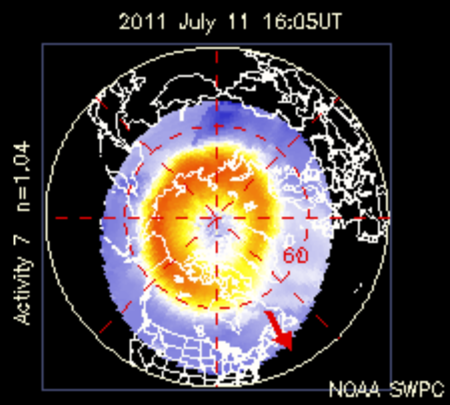
NOAA/SWS Space Weather Prediction Service

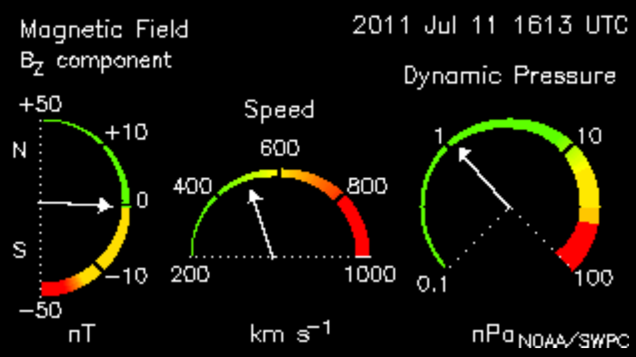
http://www.swpc.noaa.gov/





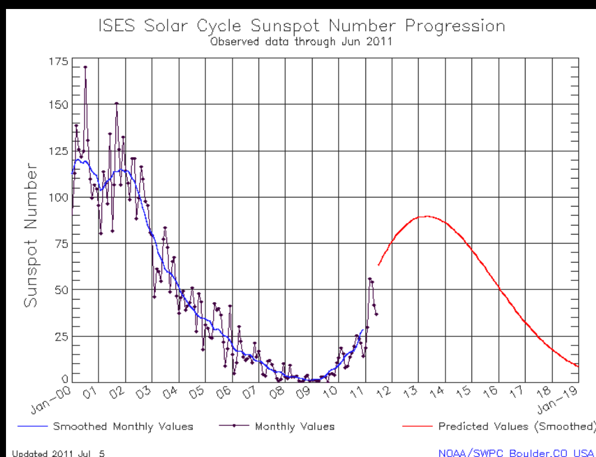






The Sun Today

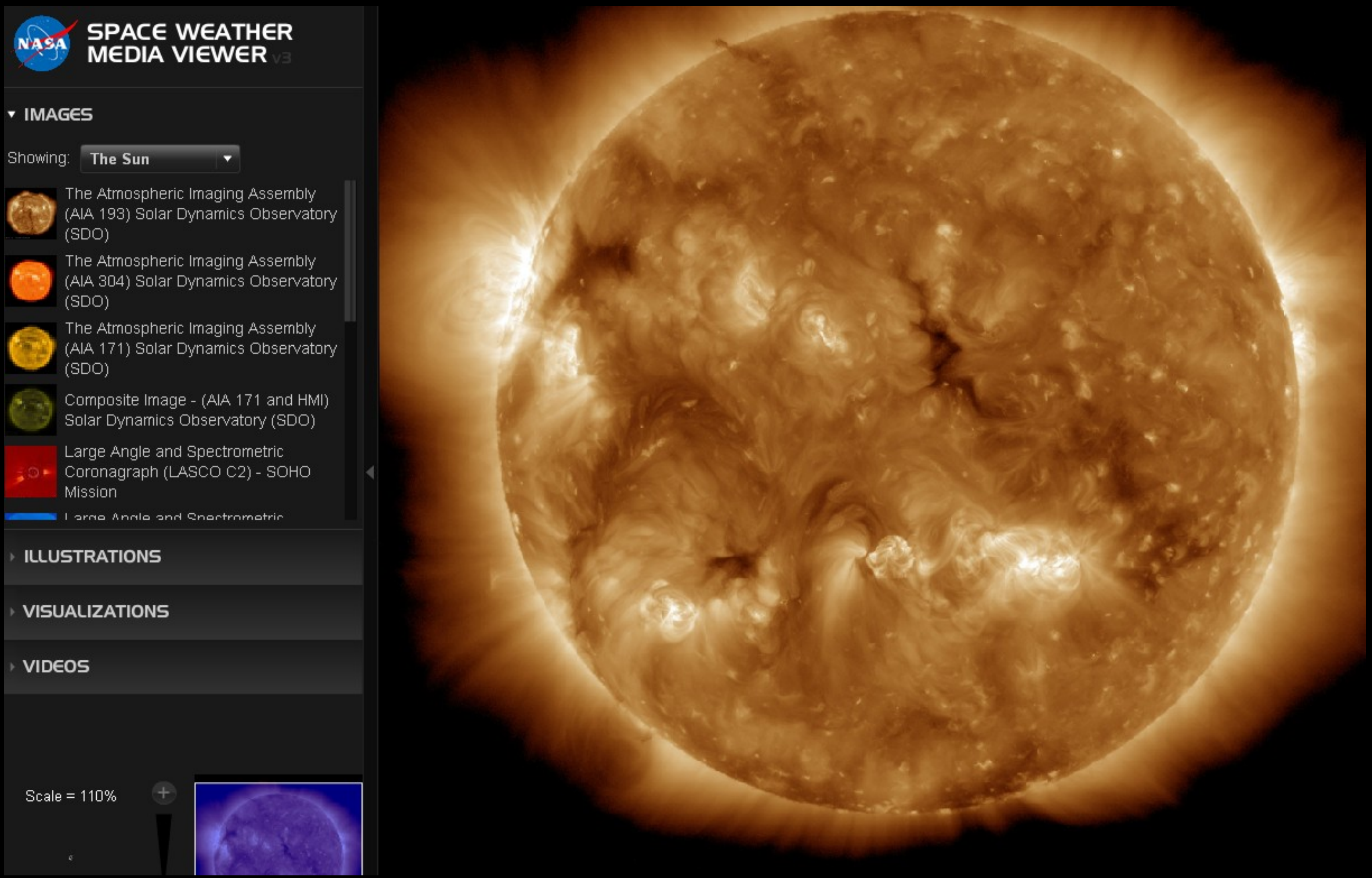
http://www.swpc.noaa.gov/



http://www.swpc.noaa.gov/SolarCycle/

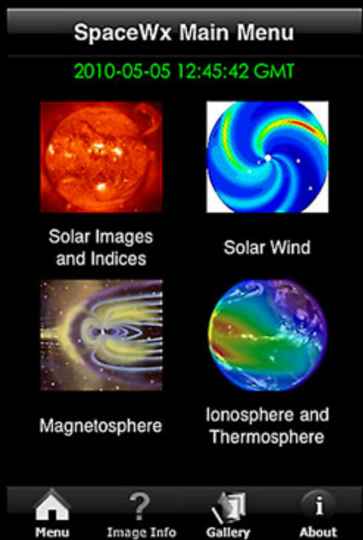
http://sdowww.lmsal.com/

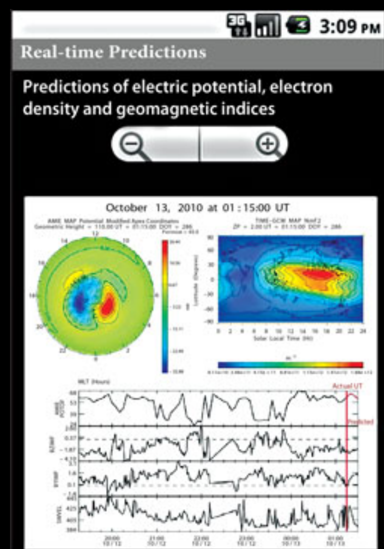
The Sun Today

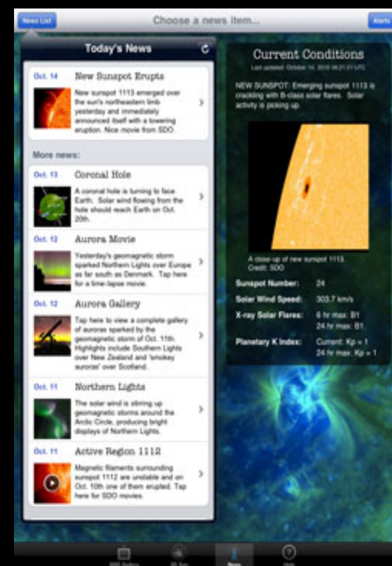


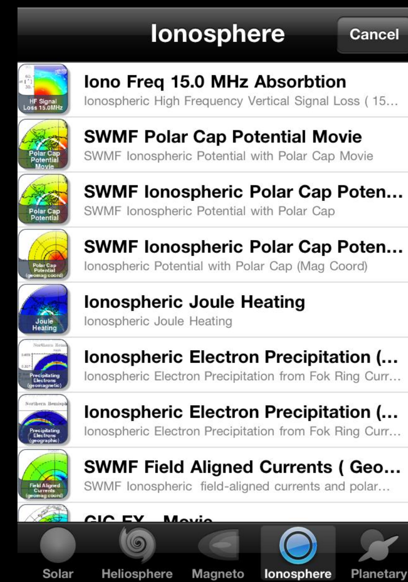
http://sunearth.gsfc.nasa.gov/spaceweather/#

…and yes there's an App for that !!









Space Weather Center	ASTRA	3D Sun	Space Weather
	Android phone	NASA	NASA
iPhone.		iPhone	iPhone

Modeling the Societal Impacts

Satellite Systems

Electric Power Grid

Commerce

Large economic events…

San Francisco Earthquake.......1906…………$ 500 billion

Hurricane Katrina………………2005……..….$ 120 billion

North American Power Grid Blackout……..…$ 30 billion/day
GEO satellite revenue loss……………………..$ >25 billion

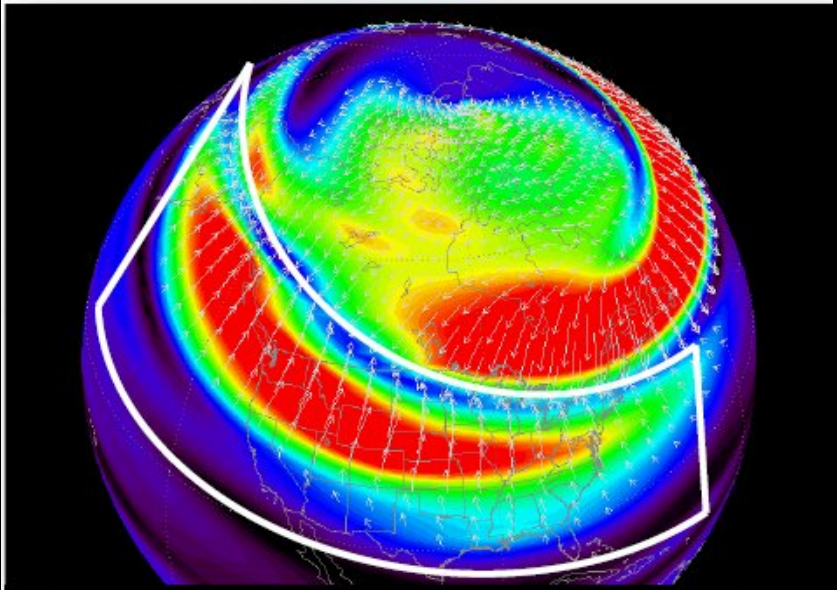
Blackout of East Coast............1965…………$ 10 billion

Mt Lassen Volcanic Eruption…1915………..$ 5 billion

Quebec Blackout………………1989…………$ 2 billion

Typical Large Annual Storm…………………..$ 1 billion

Worst Case Preparedness



Geomagnetic field electrojets, March 1989 storm:
Outline: estimated footprint of 1921 superstorm

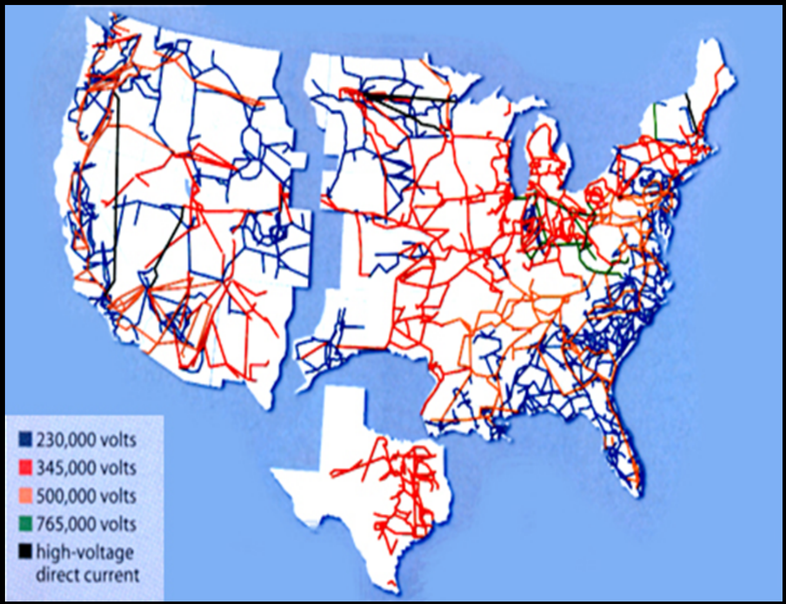
Kappenmann (1997) has an extensive record of modeling the US power grid with increasingly more sophisticated models of the electrodynamics of GICs and exhaustive studies of the North American electric grid network at the component level.

Currently, his efforts use historical geomagnetic storms (e.g. 1921 event) and their impact on the contemporary electric power grid. Among the forecasts are for year-long recovery periods costing

over $1 trillion in GDP.

“Establishing the Economic Impact of Space Weather:
The case of electricity”
Kevin Forbes (Helio III, June 7)

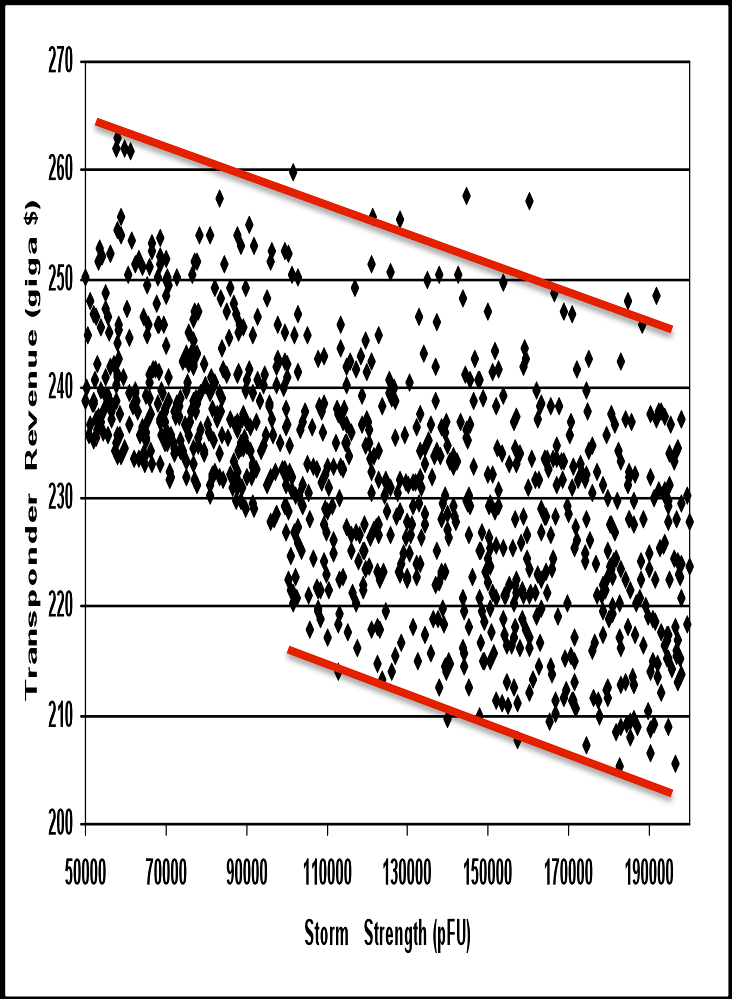
Forbes and St. Cyr (2004)



Space weather disrupts the system that transmits the power from where it is generated to where it is distributed to customers. Between June 1, 2000, through Dec. 31, 2001, solar storms increased the wholesale price of electricity by approximately 3.7 percent or approximately

$500 million over 19 months..

Economic losses to commercial satellites

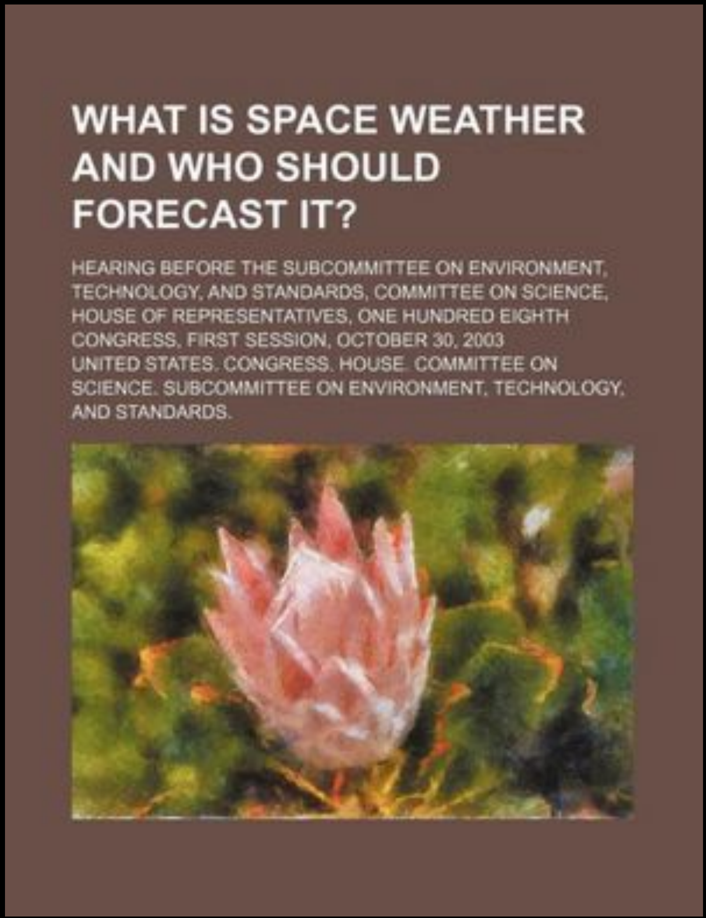


Odenwald and Green (2007)

Monte-Carlo simulation using realistic GEO satellite population and transponder transactions. An 1859-scale 'superstorm' near sunspot maximum

$50 billion in lost revenue and assets.

Worst Case Preparedness Becomes Political

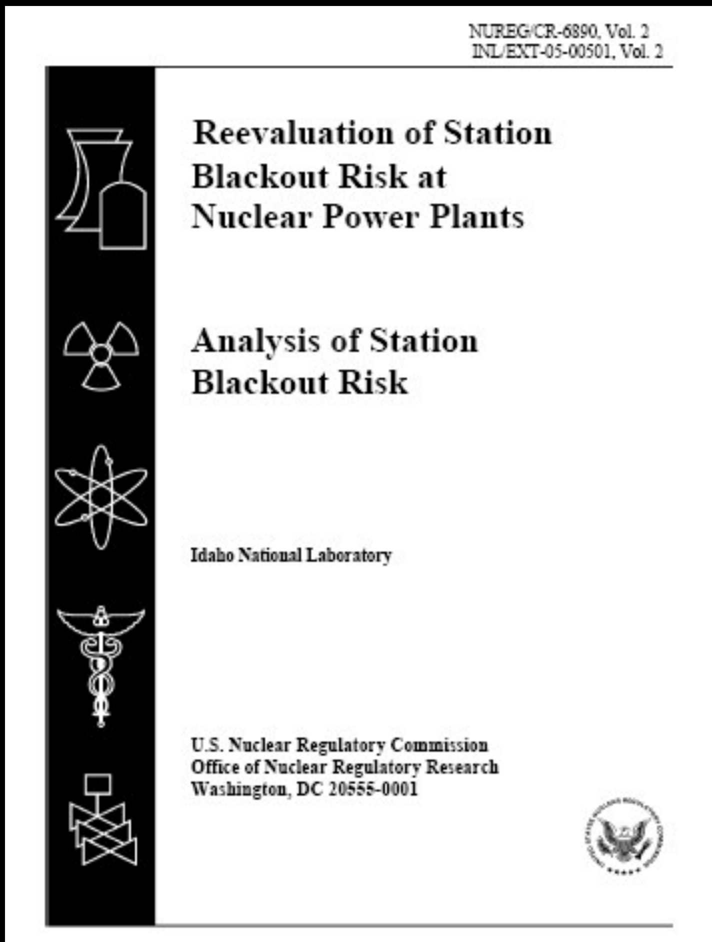


October 2003 – 'What is Space weather and who should forecast it?

Congressional Hearing on Space Weather held before the Subcommittee on Environment, Technology, and Standards, Committee on Science, House of Representatives, One Hundred Eighth Congress, first session, October 30, 2003, (Congress, 2003)

Debate over who should fund SEC

Nuclear Reactor Safety and GICs


NUREG/CR-6890, Vol. 2
INL/EXT-05-00501, Vol. 2

Reevaluation of Station Blackout Risk at Nuclear Power Plants

Analysis of Station Blackout Risk

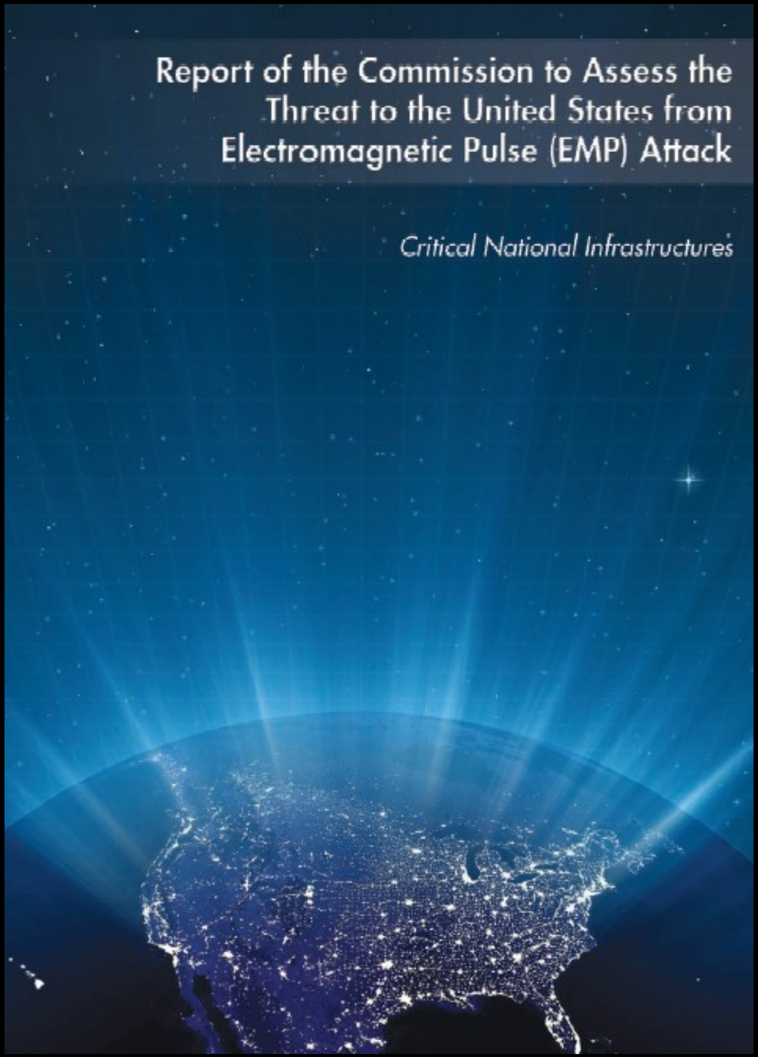
Idaho National Laboratory

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

December 2005, Idaho National Laboratory and NRC published 'Reevaluation of Station Blackout Risk at Nuclear Power Plants--Analysis of Station Blackout Risk.'

The executive summary from this report reads in part: The availability of alternating current (ac) power is essential for safe operations and accident recovery at commercial nuclear power plants. (INL, 2005)

Worst Case Preparedness – National defense



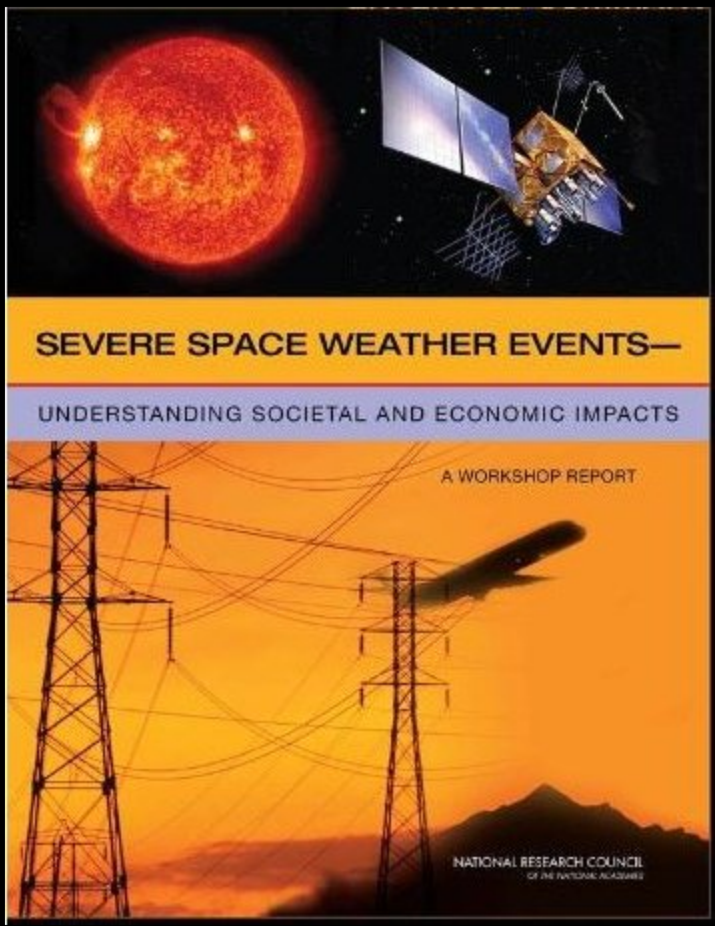
April, 2008: "Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Critical Infrastructures".

The US Congress funded a vulnerability assessment research under the National Defense Authorization Act to evaluate the impact of an electromagnetic pulse (EMP) from a high altitude nuclear detonation by a terrorist event on the nation's critical infrastructure including the electric grid.

The same study also discussed geomagnetically - induced currents. (EMP Commission, 2008)

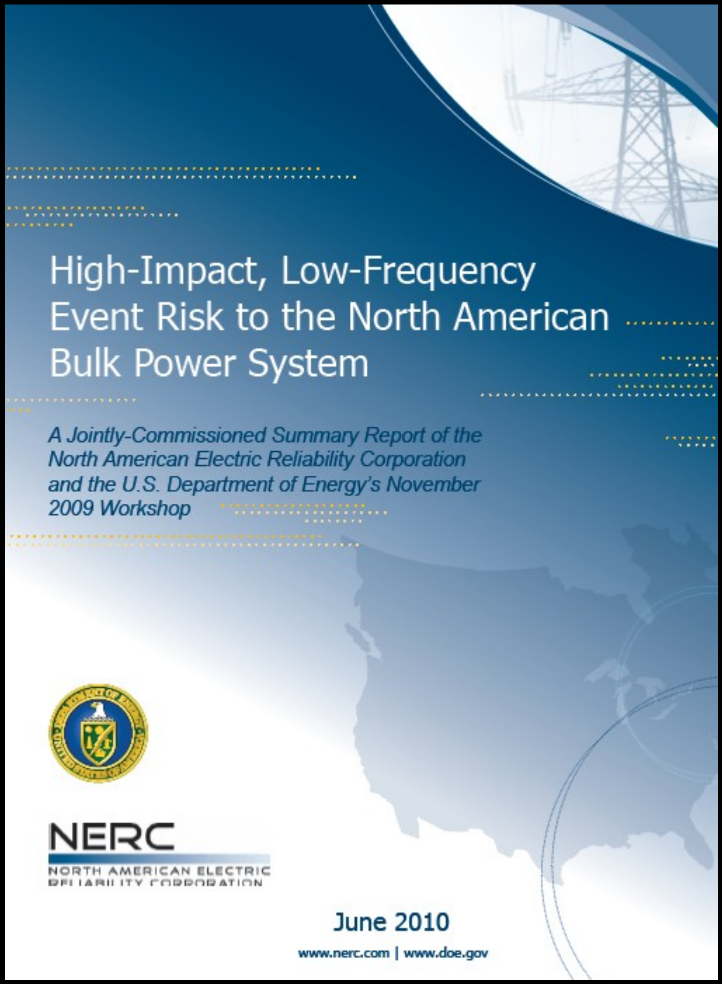
208 pages!

Worst Case Preparedness – Doomsday Scenarios



2008 'Severe Space Weather Events—Understanding Societal and Economic Impacts Workshop Report'.

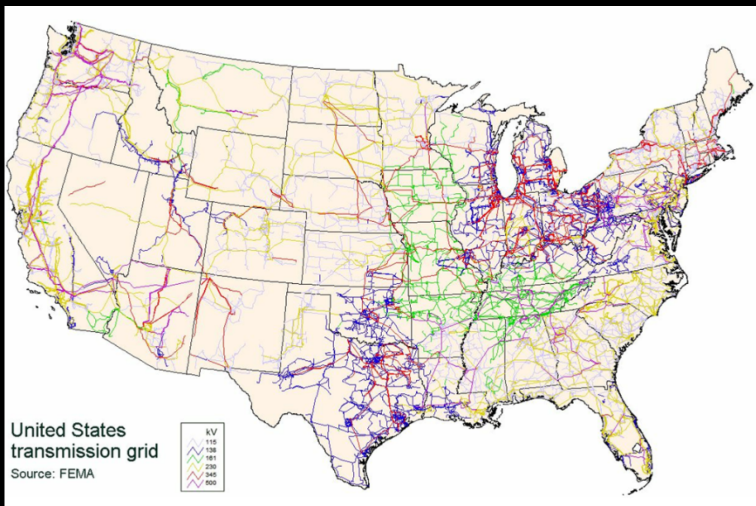
The National Academy of Sciences determined that severe geomagnetic storms have the potential to cause long-duration outages to widespread areas of the North American grid. (NAS, 2008)



June 2010, "High-Impact, Low-Frequency Event Risk to the North American Bulk Power System,"

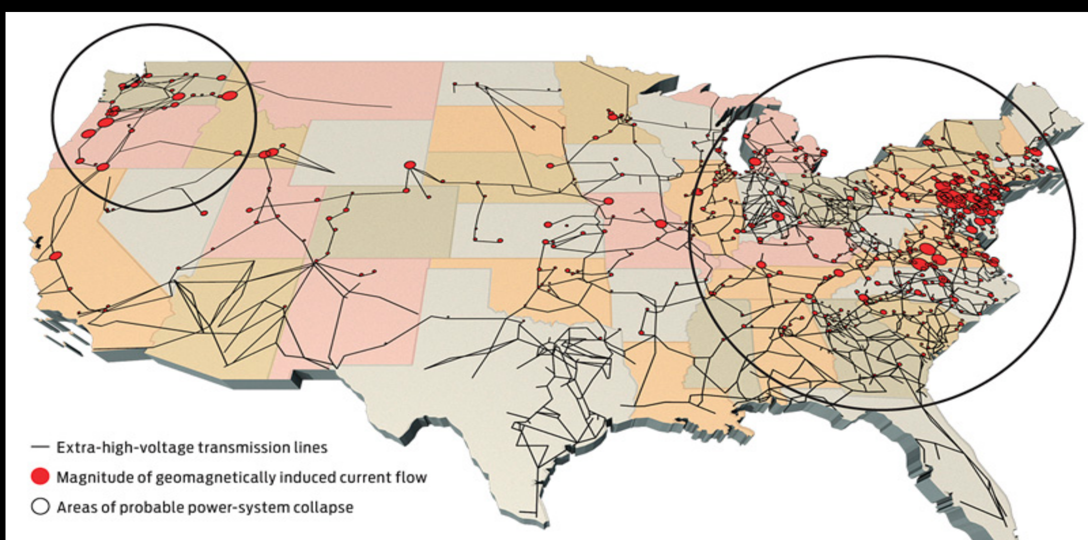
jointly sponsored by NERC and the Department of Energy, NERC now concedes that the North American power grids have significant reliability issues in regard to High-Impact, Low-Frequency events such as severe space weather.

The NERC report explains commercial grid vulnerability to space weather (NERC, 2010)



October 2010, ‘Electromagnetic Pulse: Effects on the U.S. Power Grid’, Oak Ridge National Laboratory - FERC, Department of Energy, Department of Homeland Security.

The commercial power grids in two large areas of the continental United States are vulnerable to severe space weather. The replacement lead time for extra high voltage transformers is approximately 1-2 years. (Oak Ridge Labs, 2010)



Worst Case preparedness is now in-Vogue
…but now the stakes seem higher!!!!

The Telegraph

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Nasa warns solar flares from 'huge space storm' will cause devastation

Exclusive: Britain could face widespread power blackouts and be left without critical communication signals for long periods of time, after the earth is hit by a once-in-a-generation “space storm”, Nasa has warned.

May 30, 2012

Dire warning: U.S. unprepared for massive solar flare storm; could lose power, communications

BY SHERRY MAZZOCCHI
DAILY NEWS WRITER

Thursday, June 24, 2010

According to a new report, the United States is in danger of a massive space... (Daily News Illustration)

It may sound like the premise for the next Michael Bay, big-budget action extravaganza -- but scientists say a storm from space could change life on Earth as we know it.

And the United States is woefully unprepared for such a disaster, according to a new report.

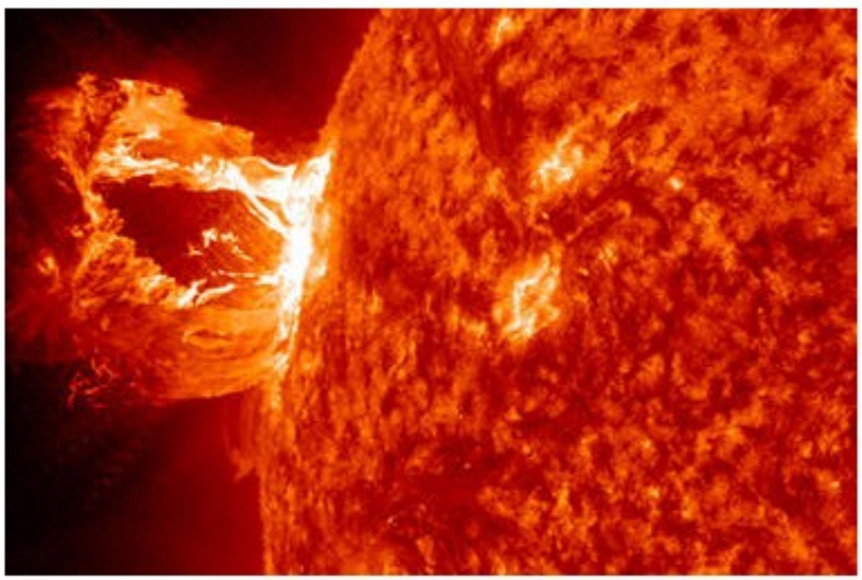
The potential threat, detailed in a National Academy of Sciences, Severe Space Weather Events report, said radiation bombarding the planet from powerful solar flares could result in the loss of power, water and communications on a global scale.

The Christian Science Monitor

How a solar flare could send us back to the Stone Age

A powerful enough solar flare could knock out our power grids, disrupt our GPS satellites, and bring the global economy to a halt, warns a British scientists.

By Amina Khan, *Los Angeles Times* / May 9, 2012



This image provided by NASA shows the sun releasing a M1.7 class flare in April 2012. This image was taken by the Solar Dynamics Observatory. This visually spectacular explosion occurred on the sun's Northeastern limb (left) and was not Earth directed.

NASA/SDO/AIA/AP/File

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