Aalto University
School of Electrical
Engineering

ELEC-E9550 - Magnetism and applications

Magnetic Storm effects on Earth

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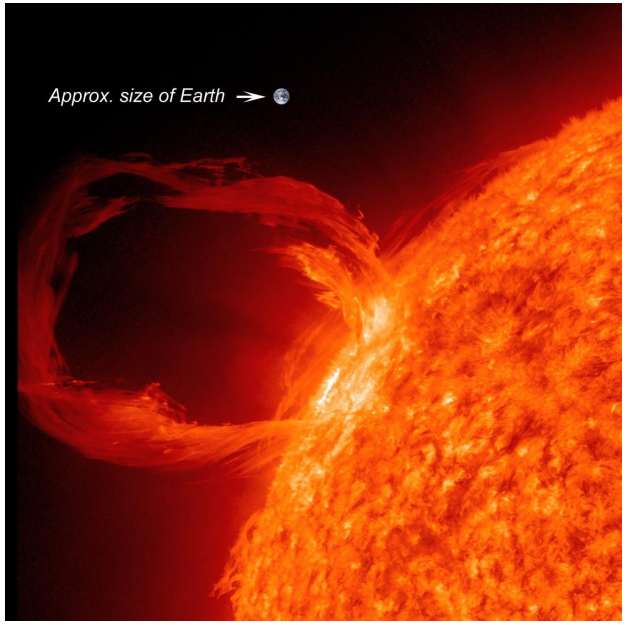
Solar Storm background

- Solar storms are radio, particle and magnetic eruptions of the Sun affecting the near-Earth space

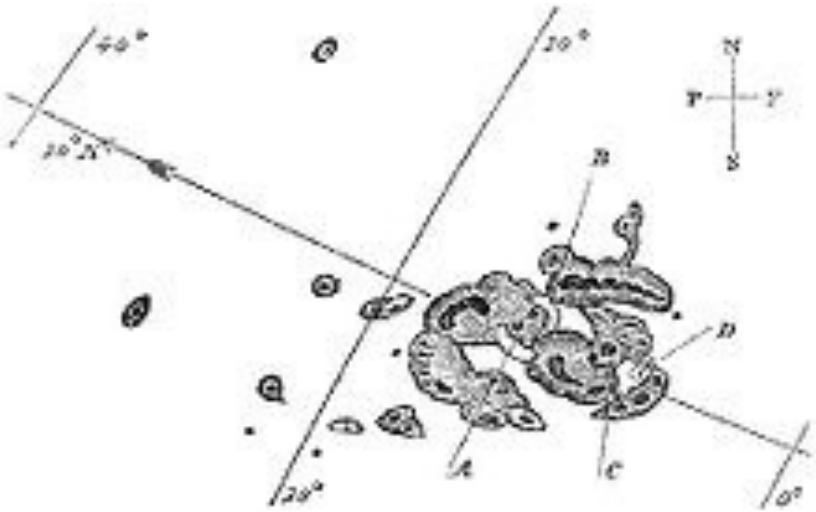
- Solar storms affect mainly systems outside of the Earth's magnetosphere, such as satellites, but also infrastructure on the ground. These infrastructures include gas pipelines, electric grids and oil drilling

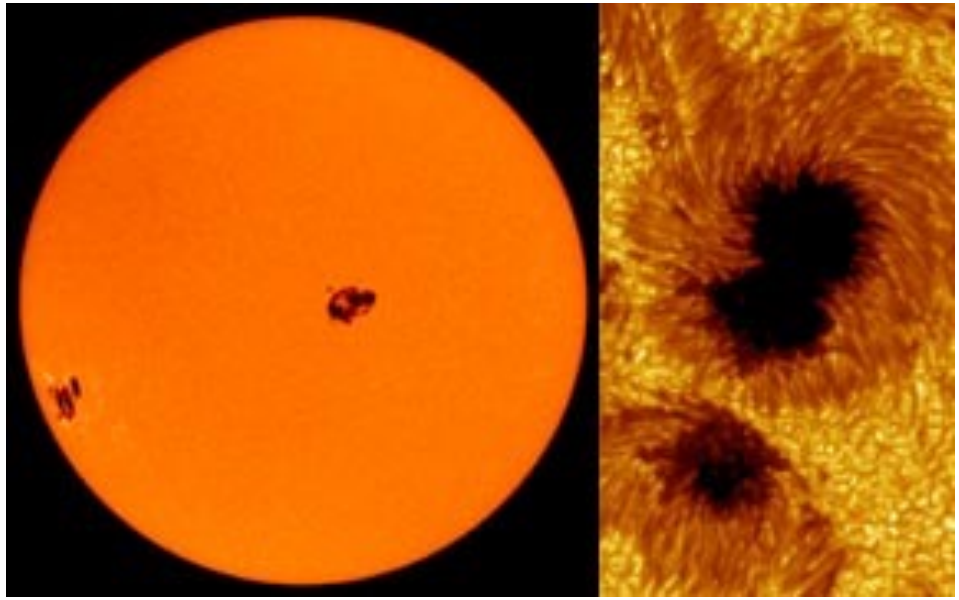
- Solar storm damage can be mitigated by several different means, such as closing of satellites, protection of electric grids and rerouting of flights



The largest known solar storm

- Carrington superstorm on 29.8.1859
- Caused by a huge flare eruption on the Solar surface
- Caused disruption on the telegraph infrastructure, fires on the lines itself and aurora near the equator





Solar storm on 18.11.1882

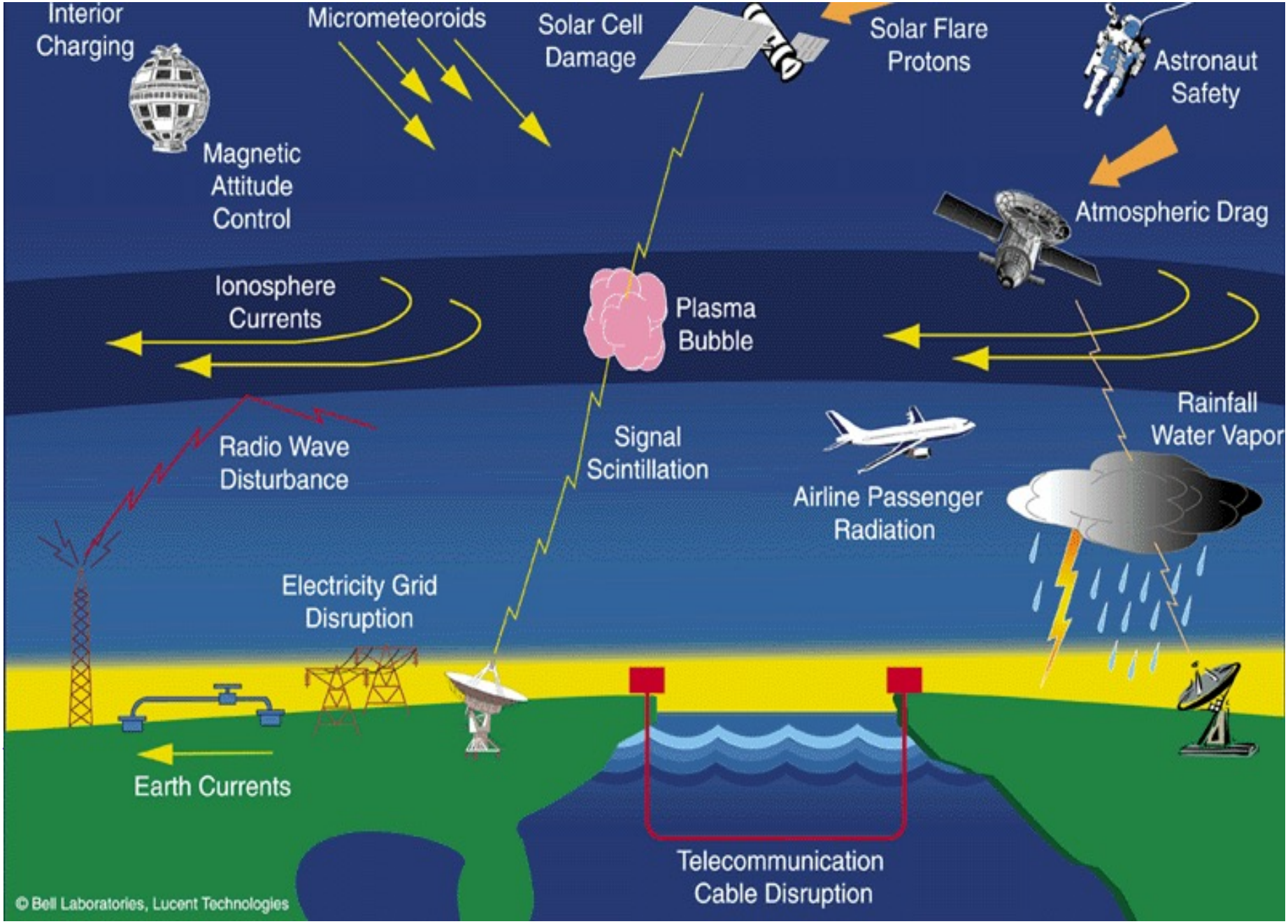
A STORM OF ELECTRICITY

TELEGRAPH WIRES USELESS FOR SEVERAL HOURS.

ONE OF THE MOST SEVERE DISTURBANCES FOR MANY YEARS, EXTENDING EVEN TO EUROPE—TELEPHONE WIRES ALSO OBSTRUCTED—BUSINESS DELAYED A GOOD PART OF THE DAY.

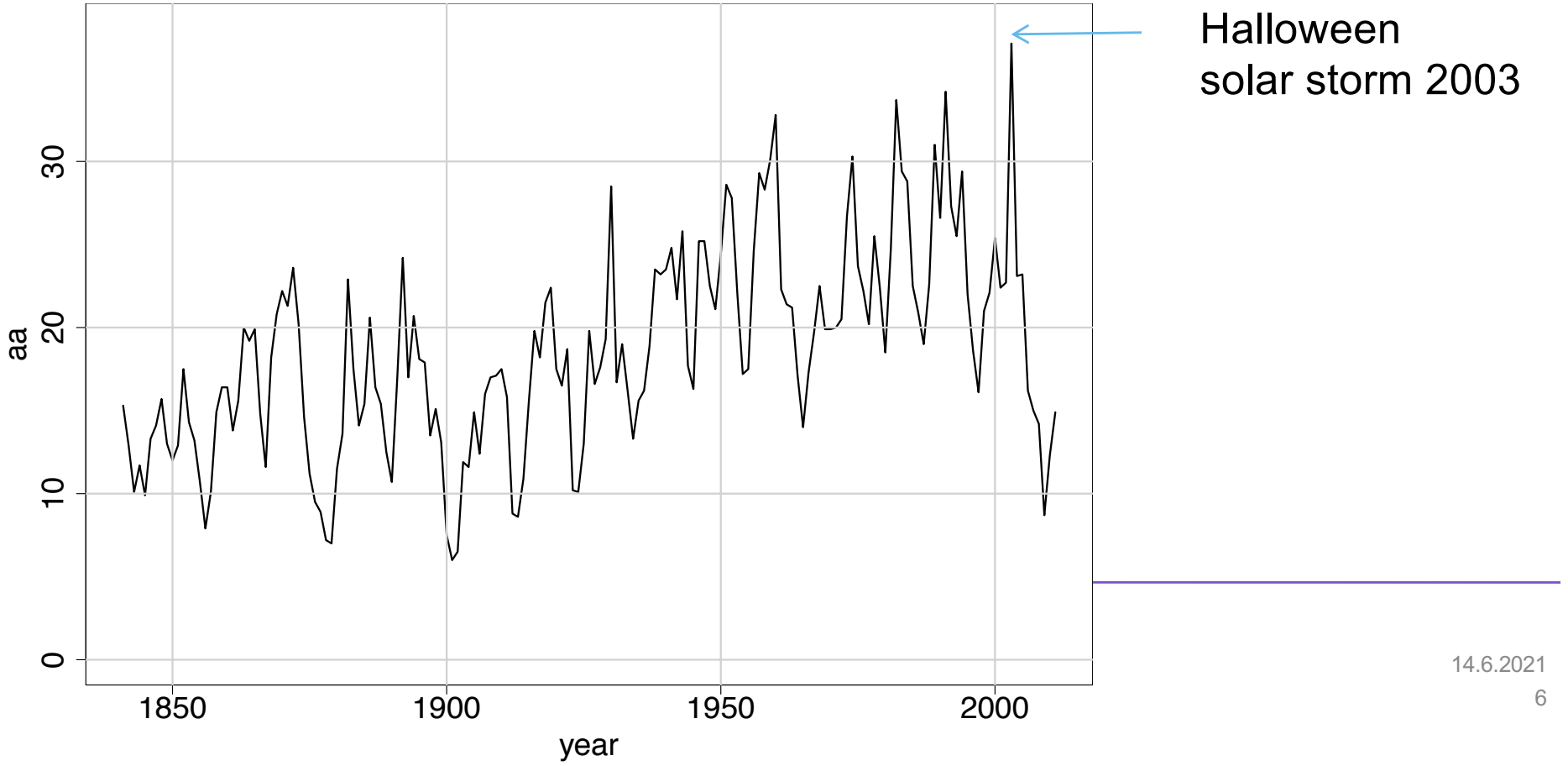
Yesterday's storm was accompanied by a more serious electrical disturbance than has been known for years. It very seriously affected the workings of the telegraph lines both on the land and in the sea, and for three hours—from 9 A. M. until noon—telegraph business east of the Mississippi and north of Washington was at a stand-still.

Solar storm effects



“Once in a 100 years” solar storm

- Halloween storm on 19.10.2003 – 7.11.2003
- Storm period duration roughly 3 weeks
- Largest geomagnetic disturbances recorded by the aa index (1840-)



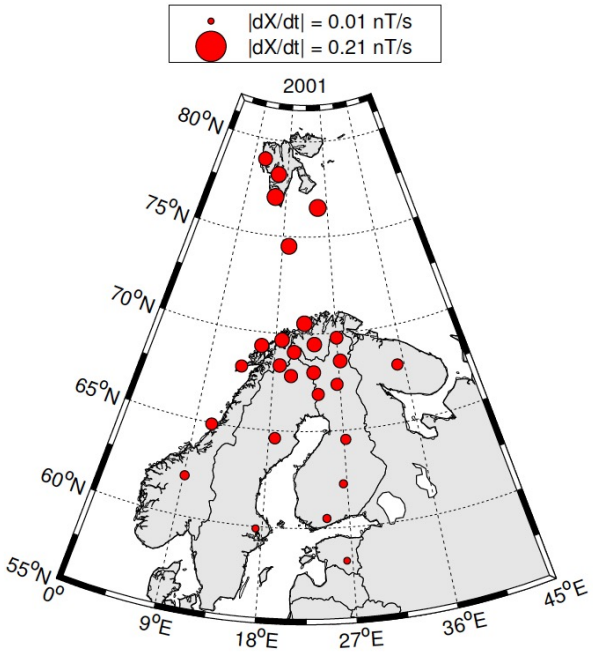
Halloween storm effects

- Economic and infrastructural effects
- Numerous societal impacts on communication, navigation, energy and food and water supply

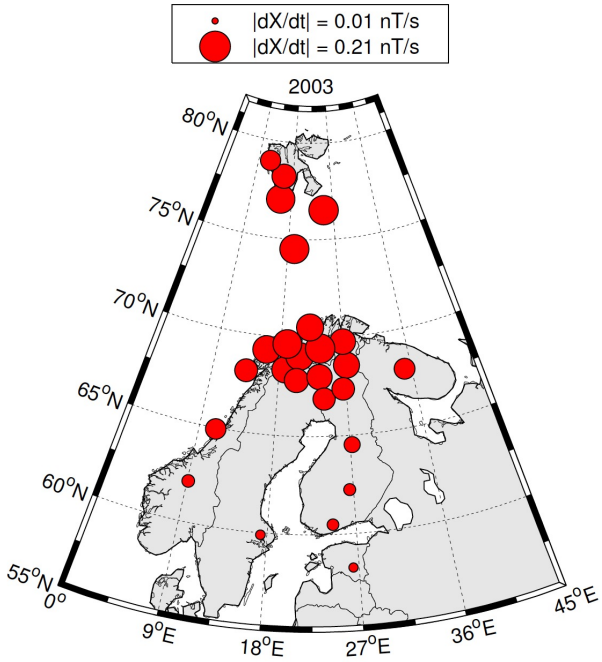
- One destroyed satellite and 30 large satellite anomalies
- Re-routing of flights on polar regions
- Electric black-out in Malmö and 15 destroyed transformers in South-Africa
- Disruption of oil drilling in the Barents Sea
- Navigational errors and solar panel disruptions
- Elevator and fire alarm malfunctions, phone infrastructure disruptions

Solar cycle effects

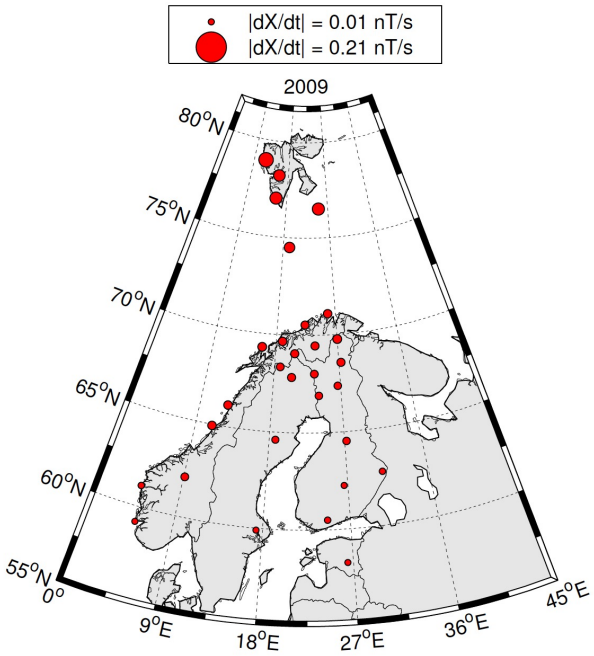
Solar maximum



Declining phase



Solar minimum



→ The largest effects on high latitudes 2-3 years afther the sunspot maximum

Effects on the electric grid

Examples of energy distribution disruption:

- Large blackout in New Jersery Canada 1980
- Blackout in New Zealand 2001
- First recorded solar storm caused electric blackout in the Nordic Countries in Malmö at 30.10.2003, 50000 people affected for a duration of 20-50 minutes

Taulukko L2.1. Magneettikentän muutosnopeuden arvoja Ruotsin sähköverkosta.

Ajankohta	Maksimi dB/dt (nT/s)
13-14.7.1982	44.8
8-9.2.1986	19.0
13-14.3.1989	11.6
6-7.5.2000	7.2
15-16.7.2000	6.6

Taulukossa L2.2 on esitetty vertailun vuoksi mitattuja GIC-arvoja Japanista, Hokkaidon saarelta Memanbetsusta (kaukana revontuliovaaleilta) aikavälillä joulukuu 2005 ja maaliskuu 2008.

New Jersey blackout 1989

Electric supply cut of for 9 hours on 13.3.1989

- Lost power supply of 21 500 MW
- Economic impact 13,2 million Canadian dollars (10 million euros) [UK Royal Academy of Engineering 2013]

Blackout affected 6 million people

Effects spread in 5 minutes

Effects on transformers

- 8-9.11.1998, New England, large temperatures where measured in the Seabrook transformer, which led to a halt in electric power supply
- Induced currents and effects caused by them melted the transformers metallic parts, and it had to be replaced
- Depending on the supplier, the build time for a high voltage transformer can be 12-15 months

- Cost for protection of transformer grid: New England & Maine region electric grid transformer protection would cost 300 000 dollars per transformer, in total 4,2 million dollars

Effects on natural gas pipelines

Solar storm caused power spikes and power fluctuations cause degradation of surfaces and pipeline breaking

Taulukko L2.3. Suomen maakaasuputkiverkkoon indusoituneita GIC-virtoja Mäntsälän mittausasemalta.

Ajankohta	maksimi virta
29.10.2003	57,0 A
30.10.2003	48.8 A
9.11.2004	42.8 A
7.11.2004	34.8 A
24.11.2001	32.0 A
6.11.2001	31.6 A
31.10.2003	30.3 A

Nuclear power safety

- Solar storm effects on nuclear safety: disruptions on power supply, disruptions on satellite based communication and information supply

- Transformer heating and fibrations (power spikes and power fluctuations

- Safety precautions during large solar storms: reduction of output or controlled shutdown

- Two known cases: Salem 1989 and New Hampshire 2012

Salem nuclear power plant 1989

-Example 1:

March 1989 disruption at Salem nuclear power plant in New Jersey USA, caused by transformer destruction by solar storm

New Hampshire nuclear power plant 2012

-Example 2:

15-16.7.2012 plant output reduced due to impending solar storm

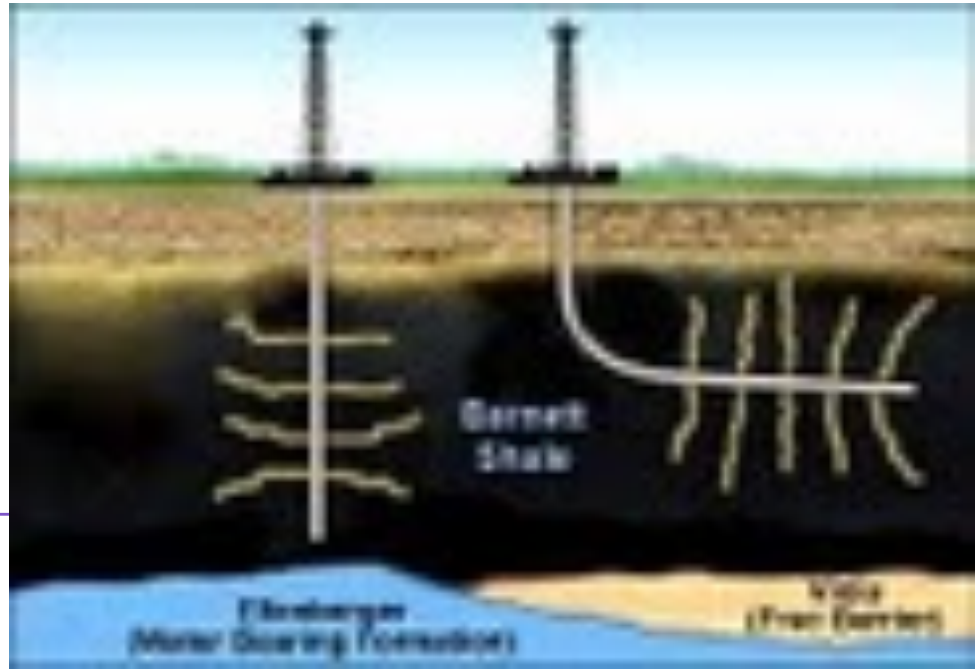
“Excess heat from induced currents in transmission lines would permanently damage approximately 350 extra high voltage transformers. The replacement lead time for extra high voltage transformers is approximately 1-22 years. As a result, about two-thirds of nuclear power plants and their associated spent fuel pools would likely be without commercial grid power for a period of 1-2 years.” Referenssi: NRC & NERC

Effects on oil drilling

-Directional drilling during oil prospecting is based upon the Earth magnetic field. This is highly unstable during a large solar storm

-Nordic magnetometers are utilized for oil drilling in the Barents Sea, North Sea and the Arctic Ocean

-Precautionary measures include corrections for directional drilling and pausing of activity. A single Lost day of oil drilling could equal 1,4 million dollars worth of financial loss

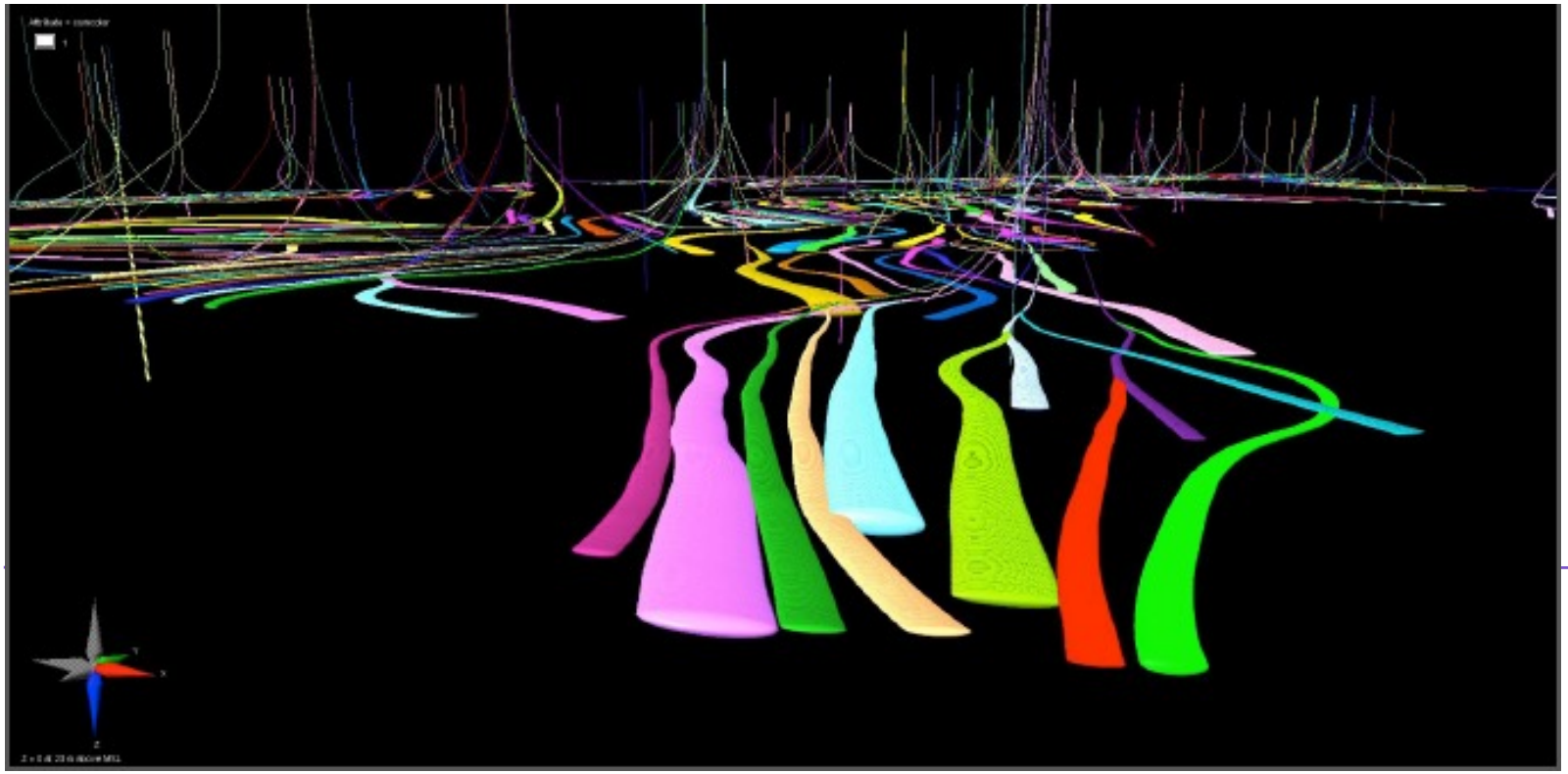


Economic loss, oil drilling

- Solar storm effects on directional drilling are increased during difficult circumstances, such as horizontal drilling and dense drilling networks

- Horizontal drilling requires turns of even 90 degrees during drilling

- Equipment loss due to erroneous drilling can cost up to hundreds of thousands of dollars



Effects on satellites

- Low Earth Orbit satellties are especially vulnerable to solar storm effects. Earth atmosphere changes due to increased particle content can cause alterations on the satellite orbit and even lower the orbit of the satellite, causing it to deorbit

- Satellites affected by orbital changes include GOCE, ENVISAT and Hubble Space Telescope

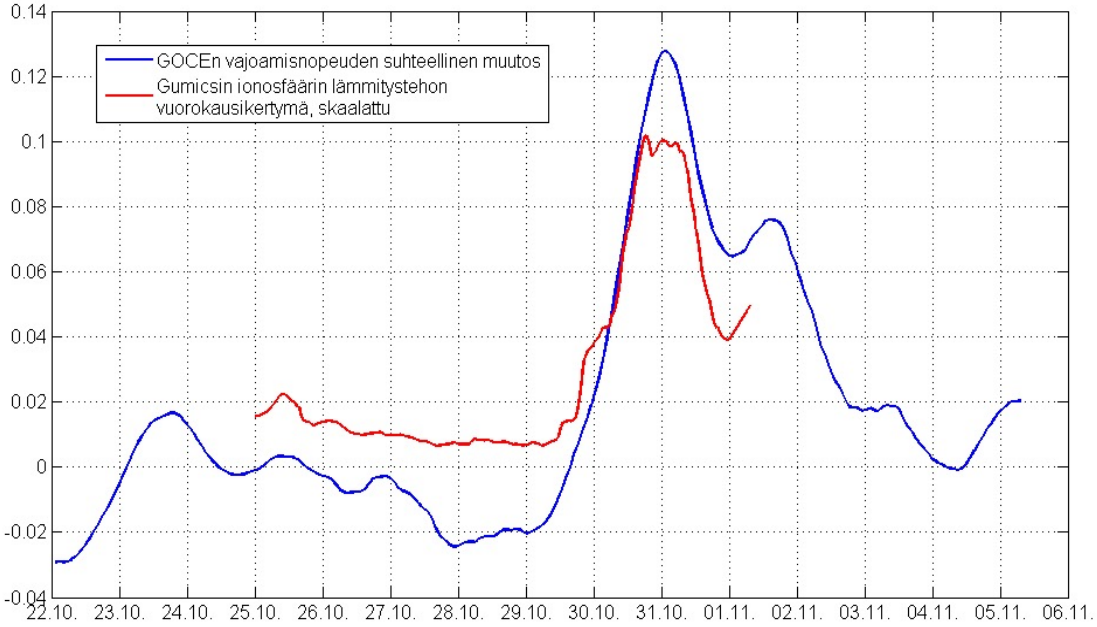
GOCE remote sensing satellite

- GOCE had an orbit of 250 km

- Satellite ended operations on 21.10.2012. Roughly one year after closure of operations the satellite fell to the Earth atmosphere

- The fall was accelerated by 12% due to space weather effects

12% →



Destroyed satellites

-The Halloween storm casualty list:

-ADEOS-2 climate change satellite, estimated build cost 640 million dollars

-Mars Odysseus for study of Martian radiation environment

-ACE satellite LEMS instruments for solar wind protons

Other anomalies

-August 1972: telecommunication satellite blackouts and satellite solar panel degradation

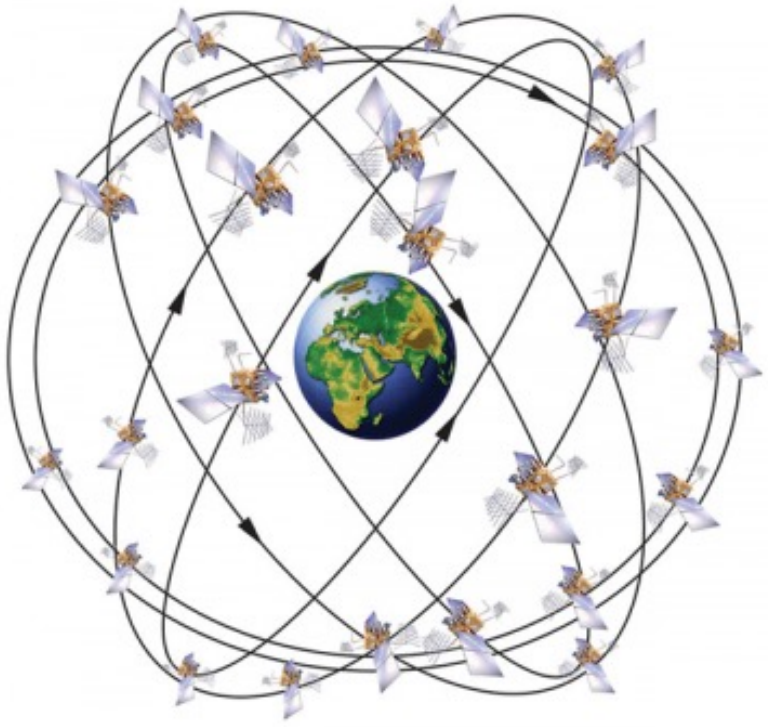
-13-14.3.1989: communication loss on over 1000 satellites for roughly a week

-April 2012: Contact lost to Galaxy-15 communication satellite for a week, roughly 100 million dollar loss due to disrupted business

Effects on satellite telecommunication

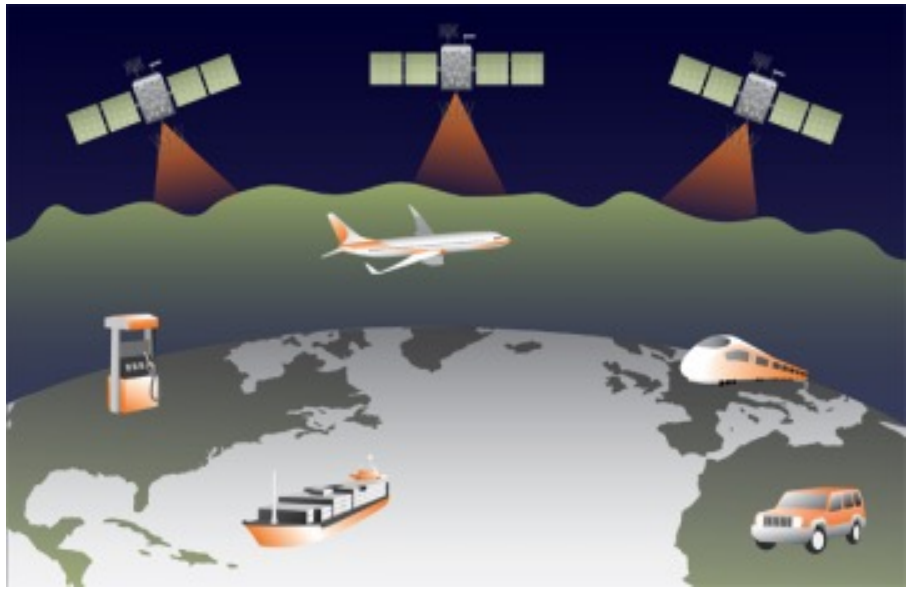
- GPS satellites are on a higher orbit, thus they are not affected by changes in the atmosphere

- However other effects apply, causing positioning errors to grow to tens of meters



Air traffic effects

- Navigational errors on ships, aircraft and ground based transports
- X-ray and UV from flare eruptions disrupt GPS signals
- Due to increase in high energy particle flux, polar flights are rerouted



Effects on humans

- Spacecraft and space station human occupants also affected by increased high energy particle flux. One of the first verified cases during Apollo landing in August 1972

- Terrestrial polar flights have increased risk of cancer

Effects on other ground based infrastructures

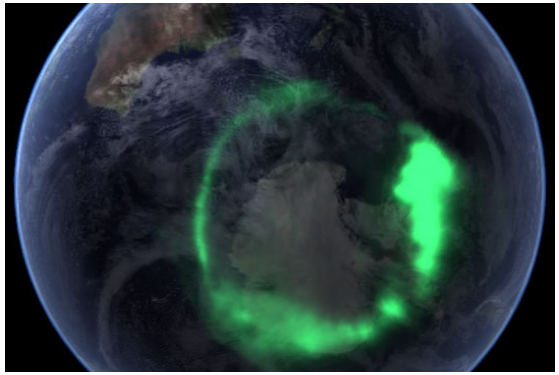
- Toronto Stock Exchange closed for 3 hours in August 1989 due to solar storm effects on hard drives

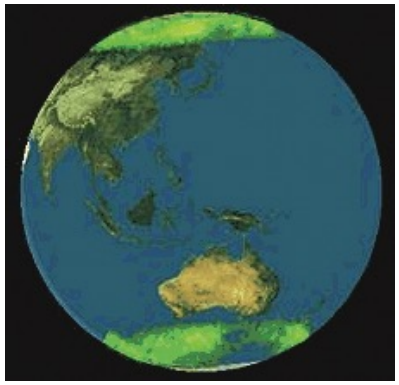
- Indirect effects on water supply, energy supply and safety. Energy supply effects more pronounced during winter, while food and water effects during the summer

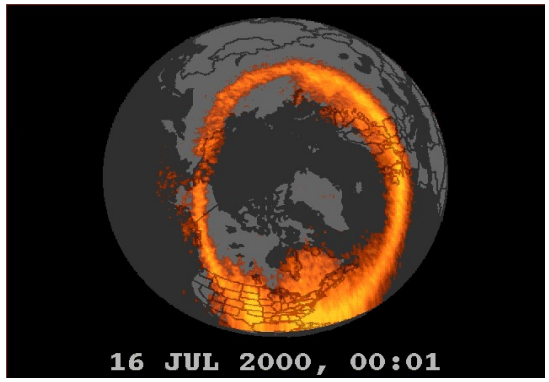
Large scale impacts: Near nuclear war in 1967

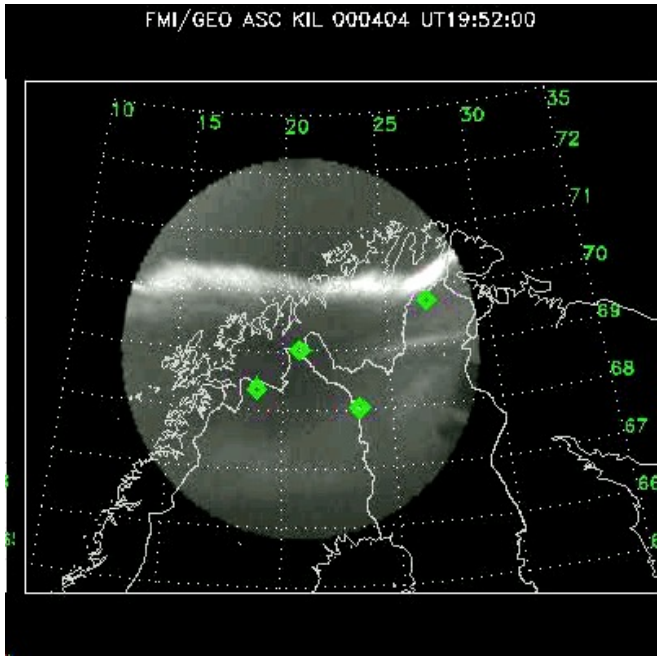
- Large scale disruption of US radar and communication → Soviet jamming?
- In reality caused by large solar eruption
- Situation somewhat unclear → catastrophic escalation possible

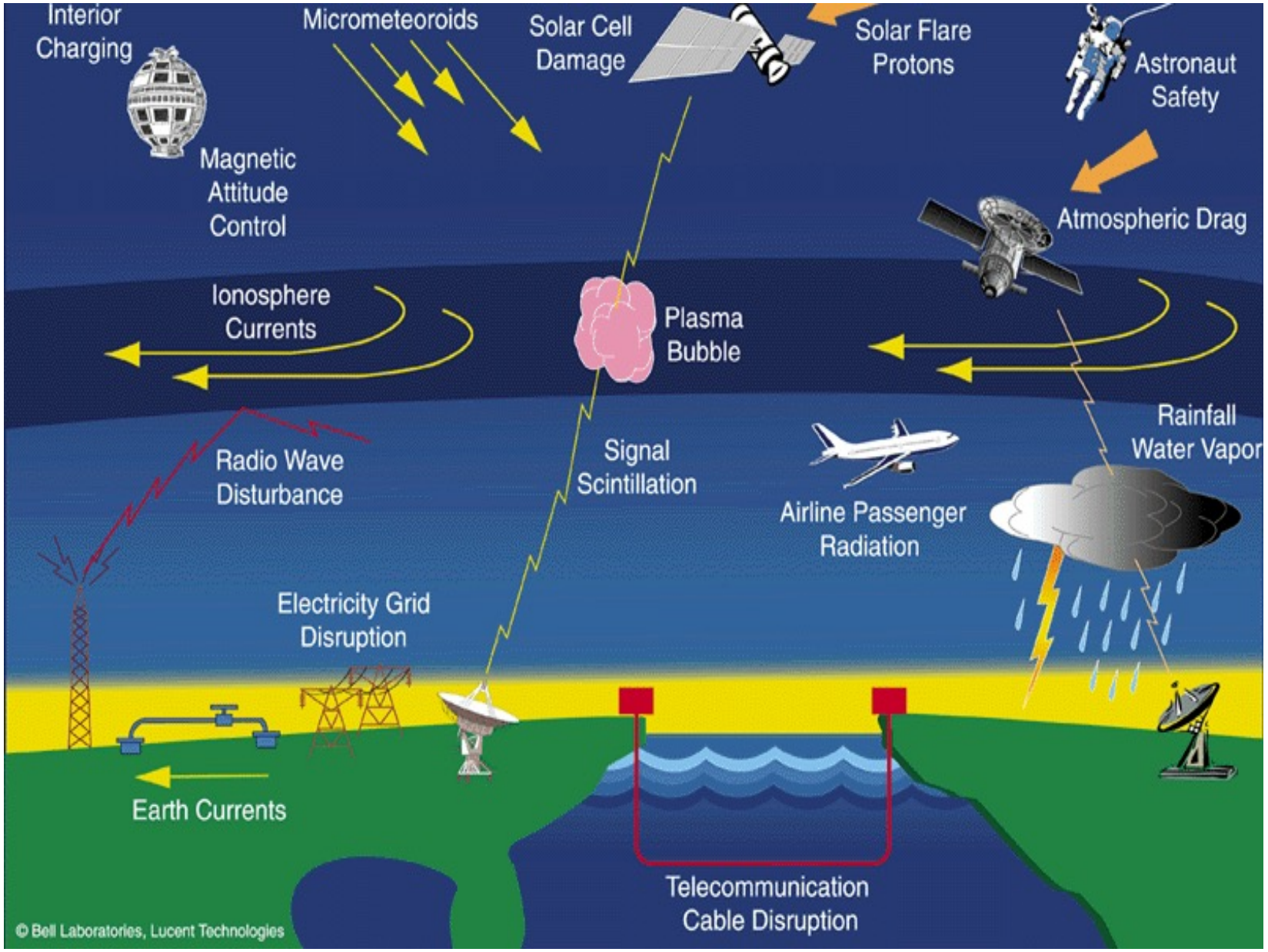
Auroral tourism










Interior Charging
Micrometeoroids
Solar Cell Damage
Solar Flare Protons
Astronaut Safety
Magnetic Attitude Control
Atmospheric Drag
Ionosphere Currents
Plasma Bubble
Rainfall Water Vapor
Radio Wave Disturbance
Signal Scintillation
Airline Passenger Radiation
Electricity Grid Disruption
Earth Currents
Telecommunication Cable Disruption
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