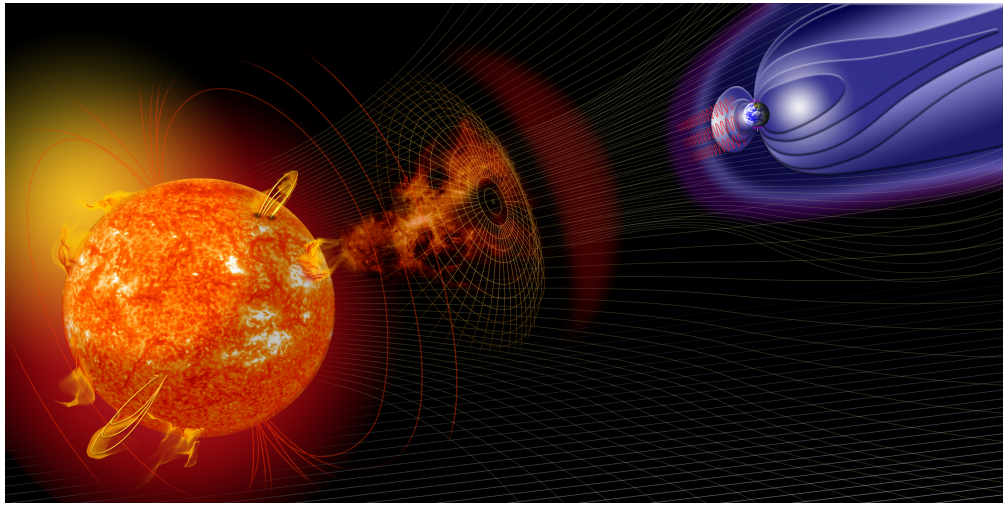
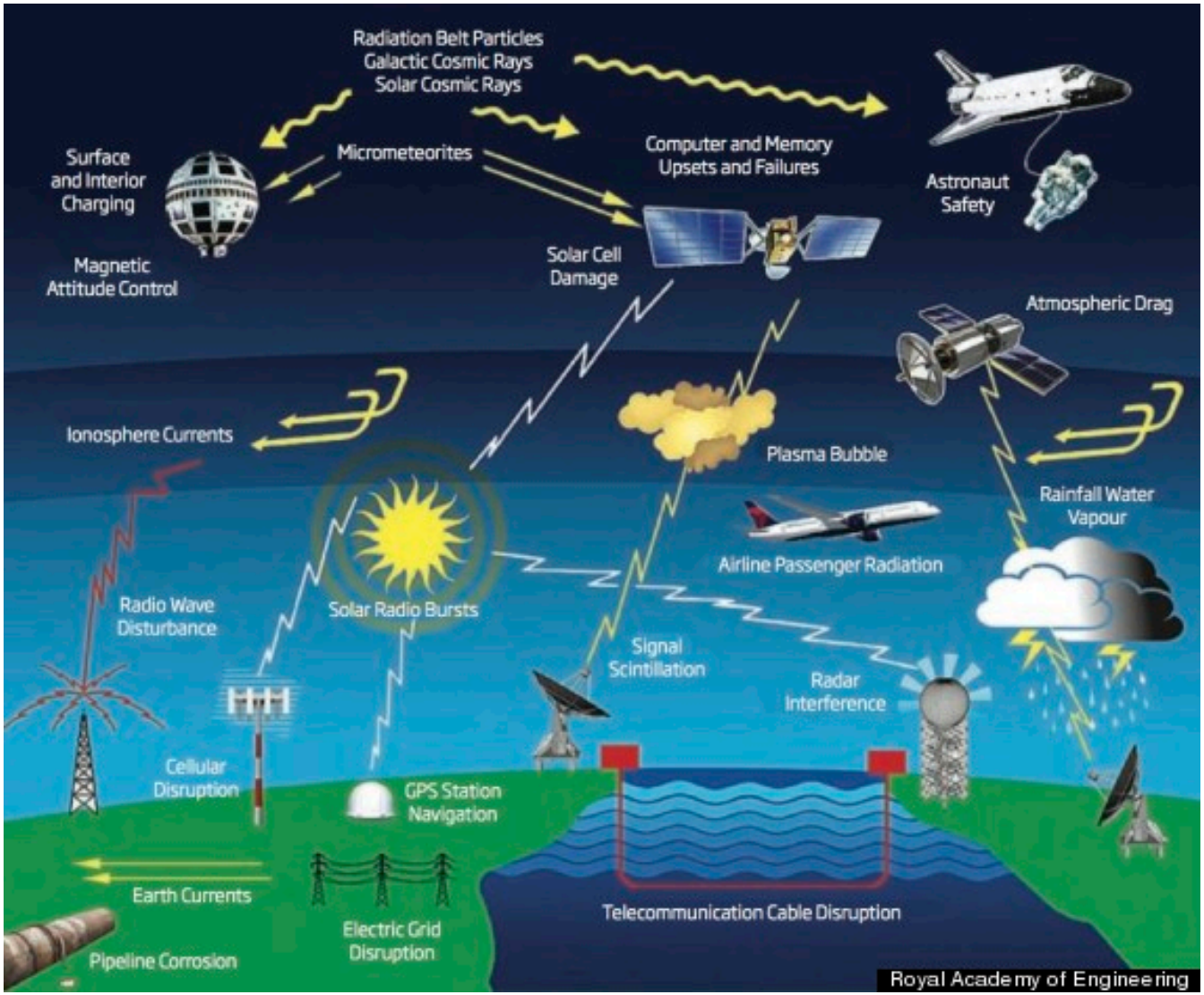
Lecture 18 – Space Weather

- Topics in todays lecture:
  - What is space weather?
  - What causes space weather?
  - What are the technological impacts of space weather?
  - What can we do to protect against space weather?



Space Weather Effects



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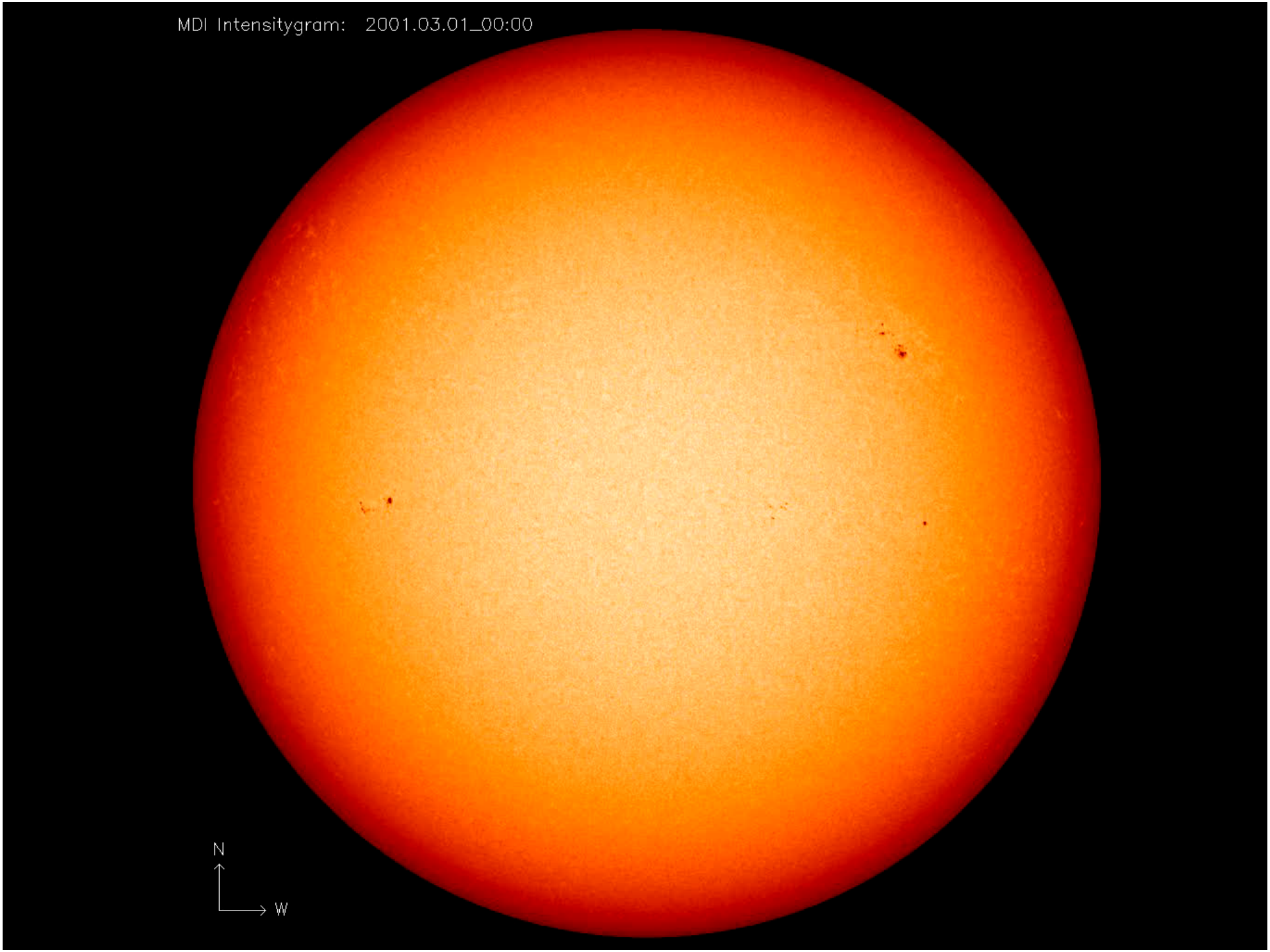
MDI Intensitygram: 2001.03.01_00:00
N
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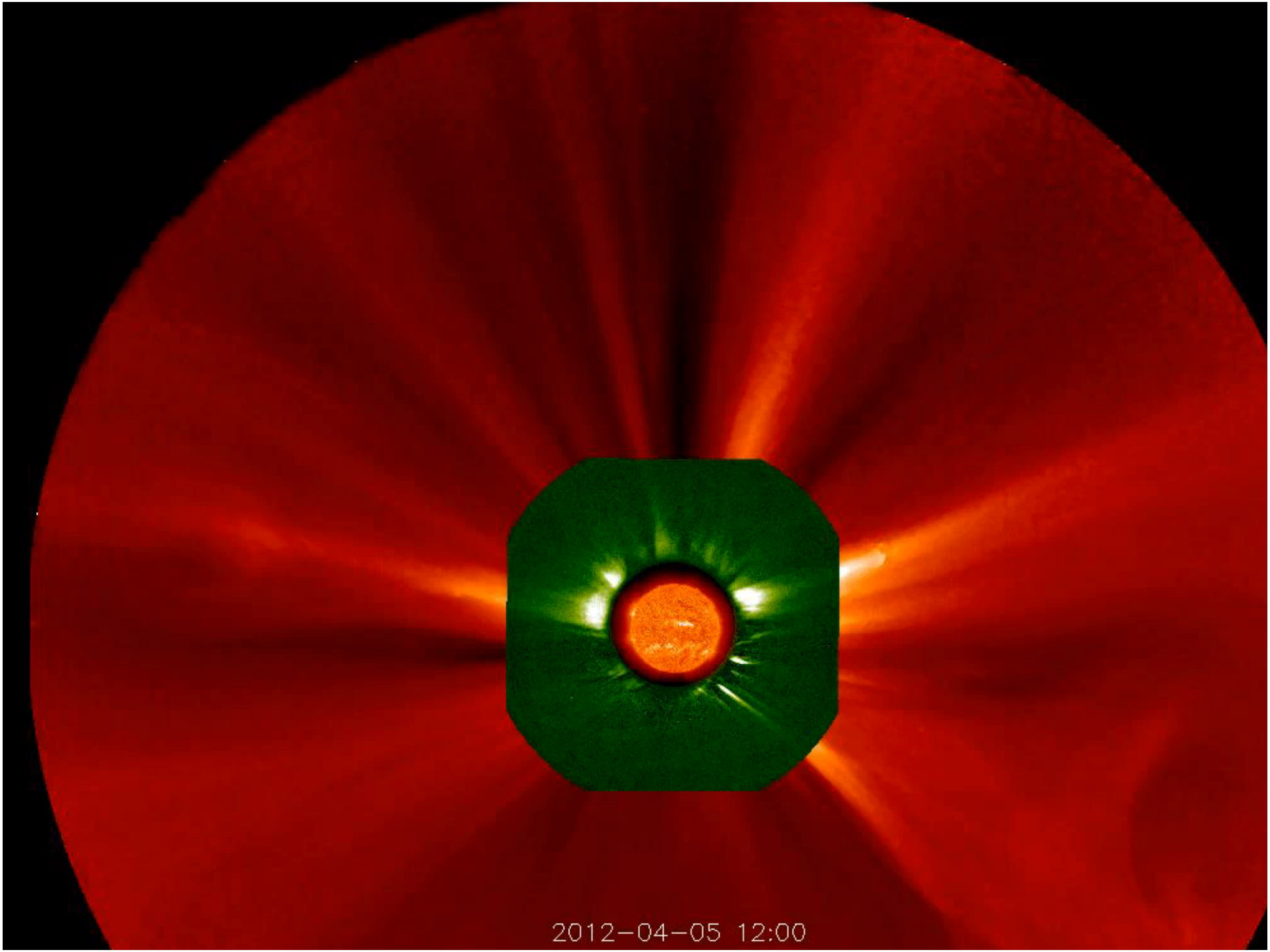
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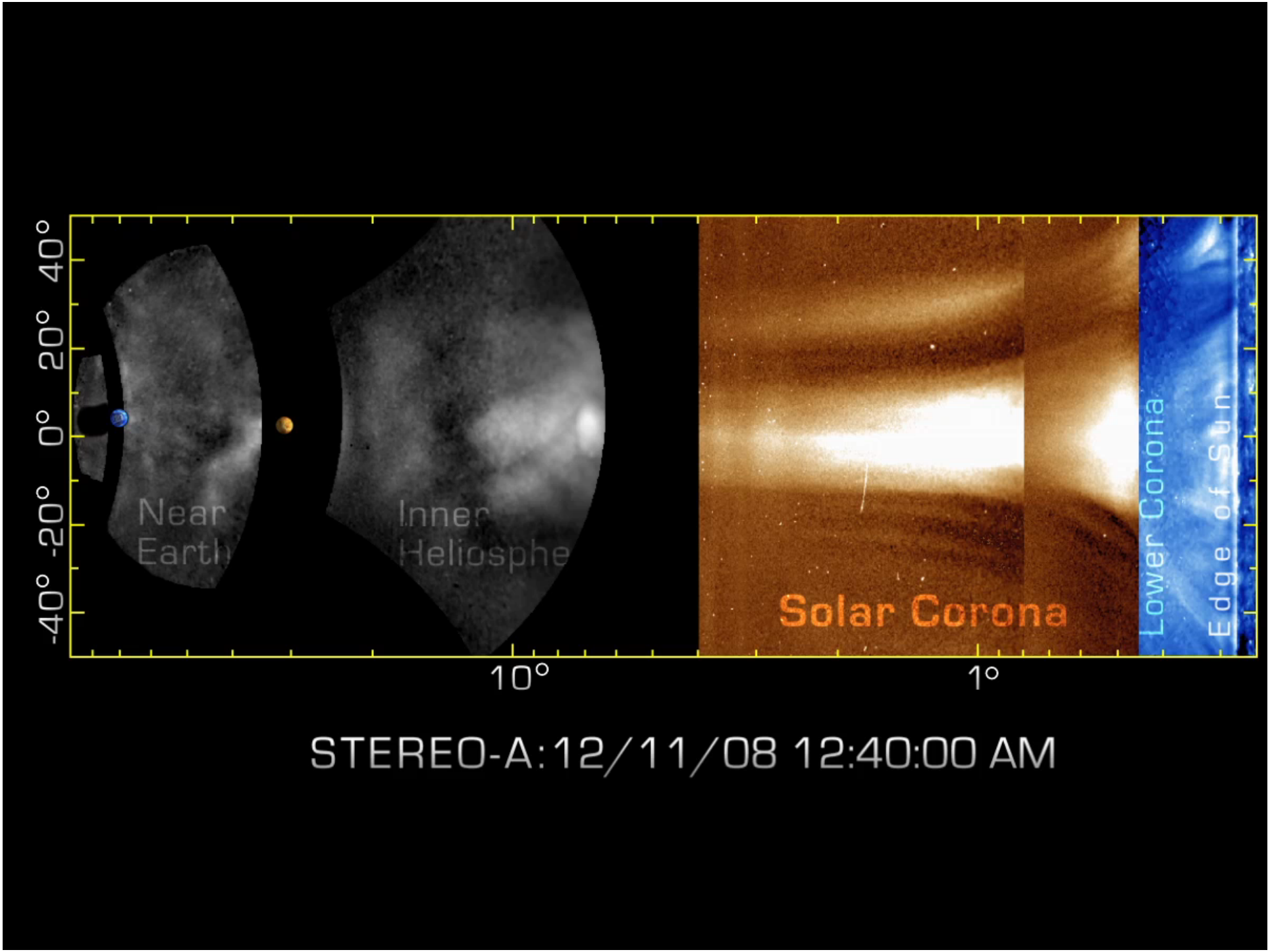
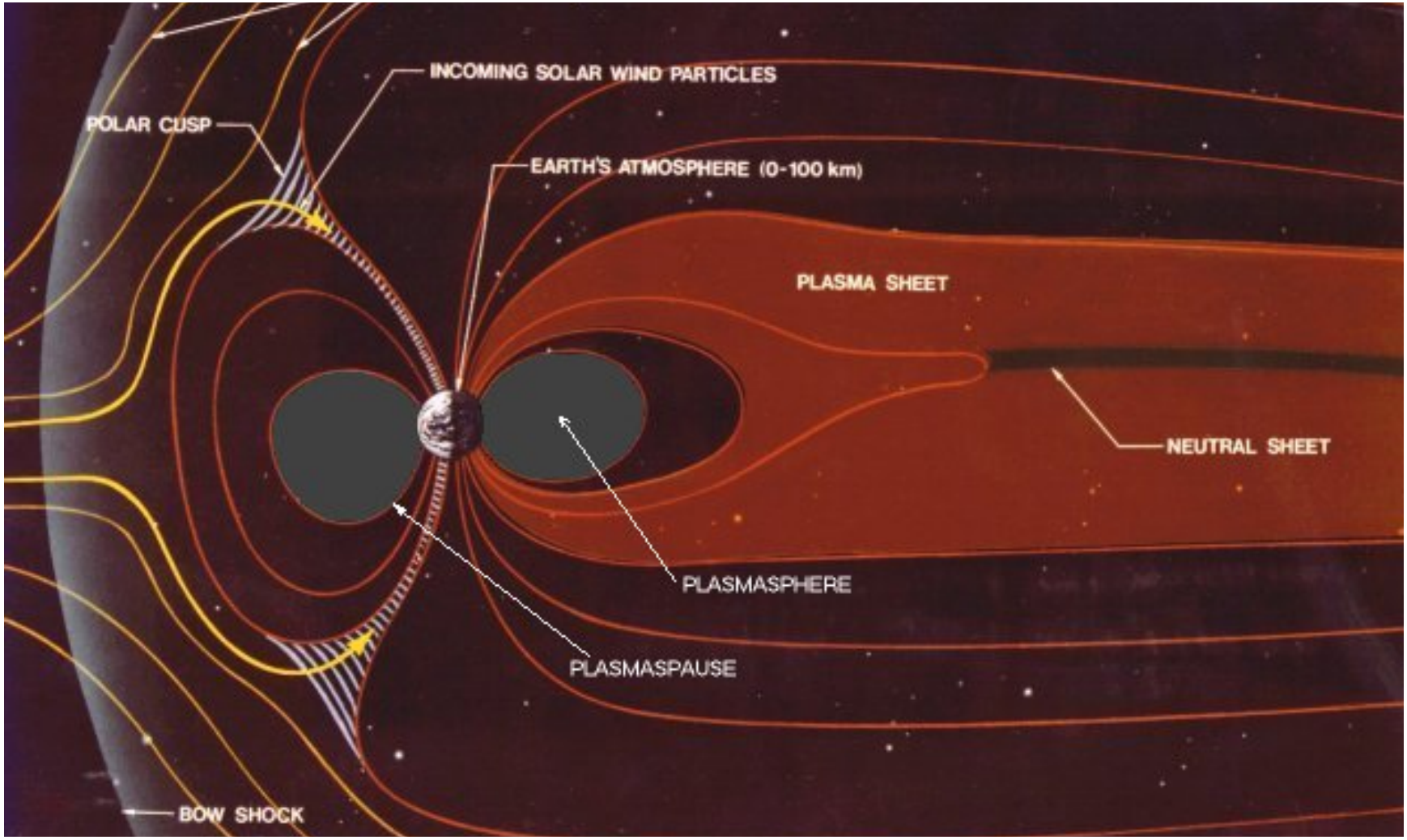

-40° -20° 0° 20° 40°
Near Earth
Inner Heliosphe
Solar Corona
Lower Corona
Edge of Sun
10°
1°
STEREO-A:12/11/08 12:40:00 AM

Earth's Magnetosphere



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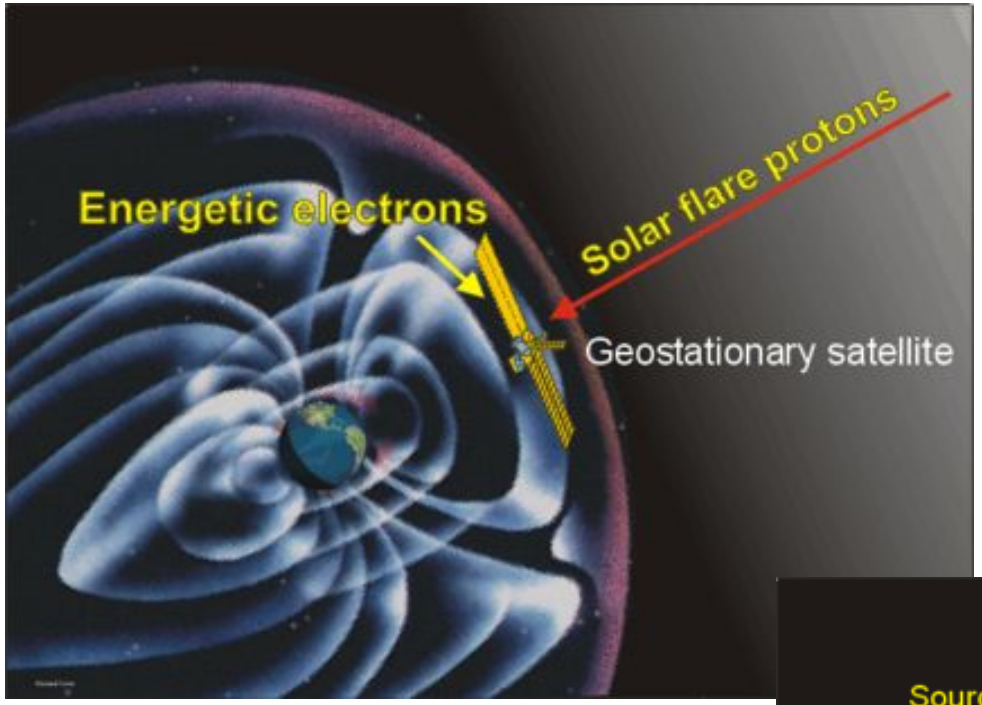
Space Weather and Satellites

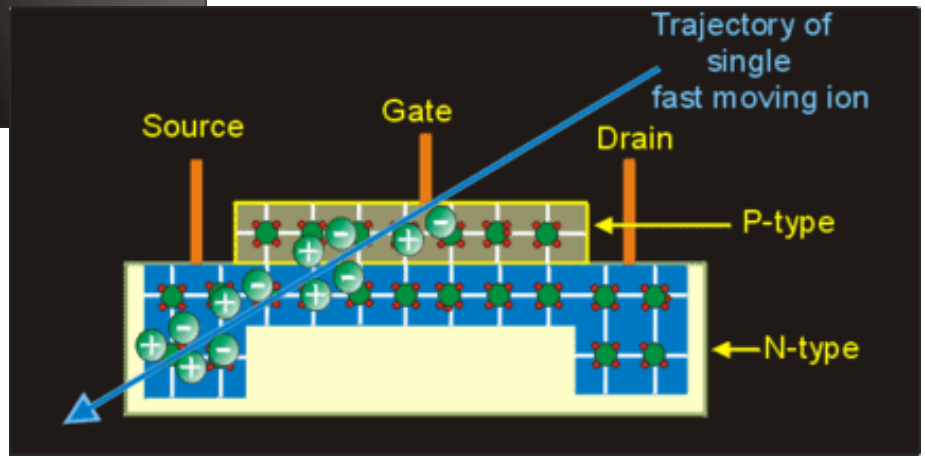


Surface charging

Internal charging

Electronic damage

Satellite drag



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Satellite Failures due to Space Weather

- Anomalies due to spacecraft surface and internal charging
  - Marecs, ECS, Meteosat, TELE-X, etc
- Latch-up induced failures
  - ESR-1, PRARE, Equator-S, etc
- SEU in circuits
  - Anik 1 & 2, etc.
- Solar Array problems/degradation
  - Tempo, PanAm, ECS, etc.
- Galaxy IV (1998)
  - Silenced 80% of pagers in North America

Credit: P. Brekke

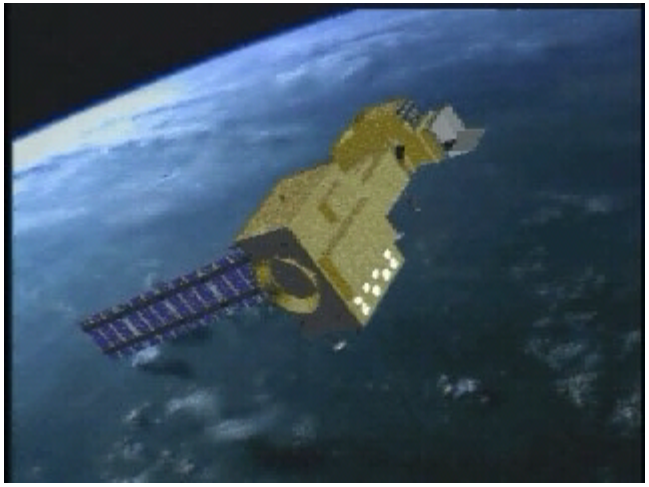
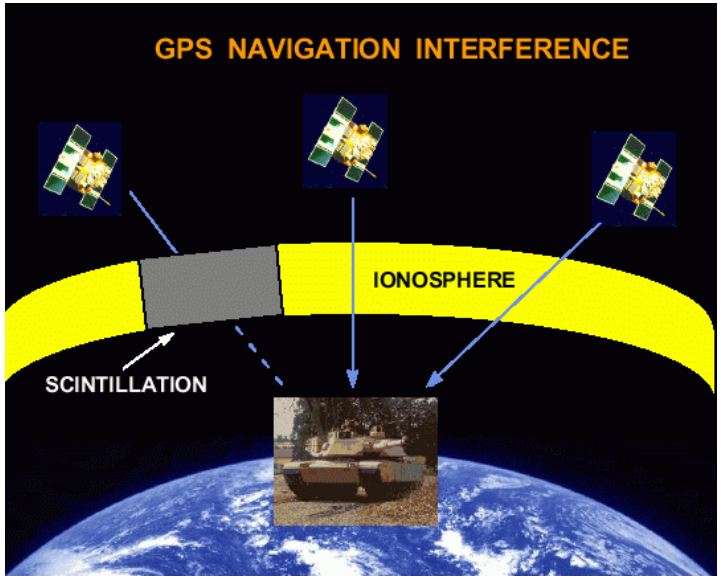
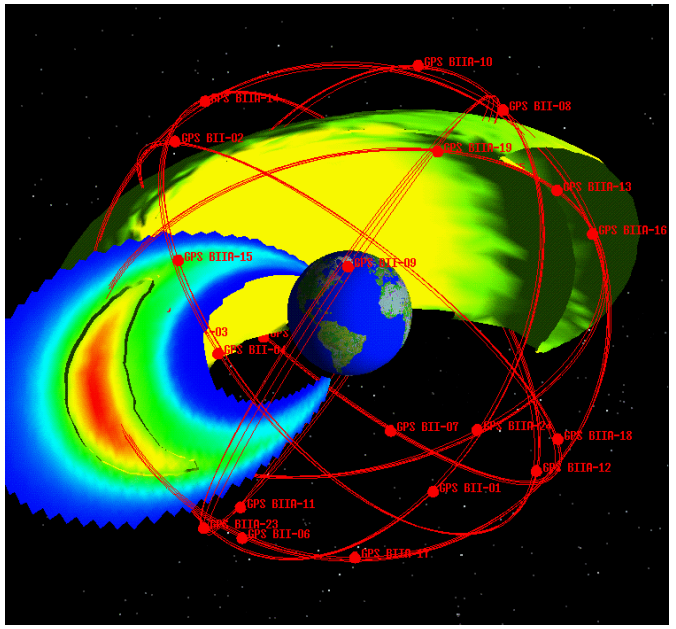


Figure courtesy of The Solar Data Analysis Center

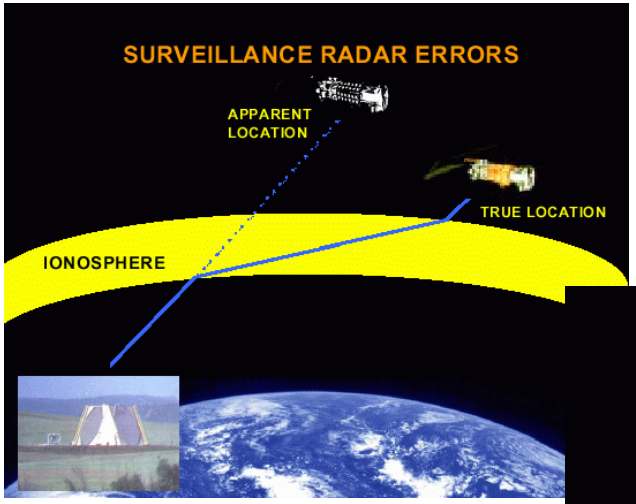
Navigation systems - GPS

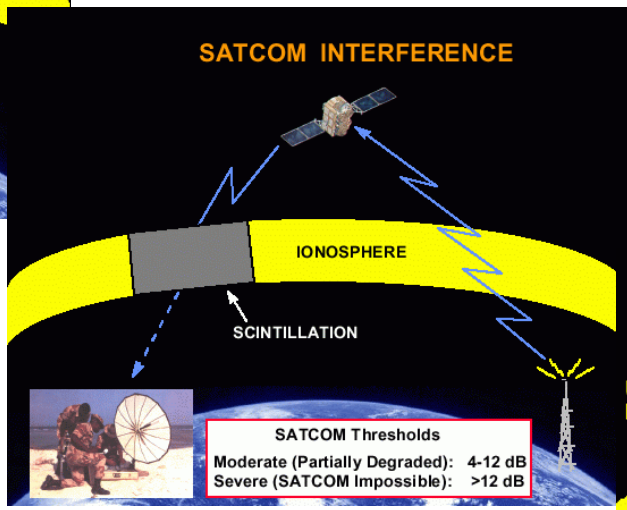
- Ionosphere between satellites and the user becomes irregular => signal may “scintillate” and prove difficult to track.
- Positioning errors of up to 100 m

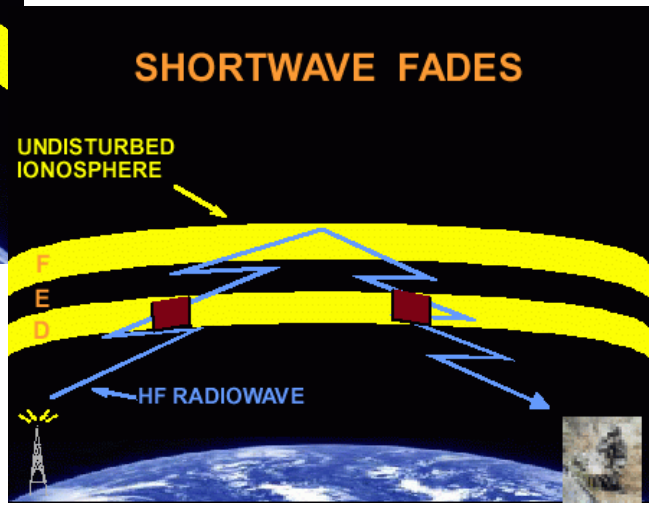




Effects on Military Systems







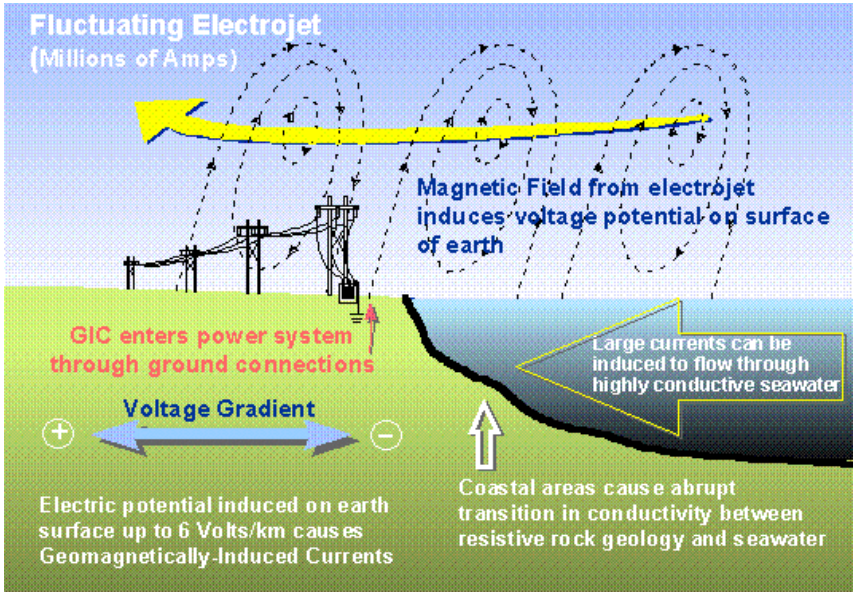
- Tracking errors
- HF satellite communication blackouts

Space weather effects on Humans

- Humans in space
  - Space Shuttle
  - International Space Station
  - Missions to Mars
- Crew/Passengers in high-flying jets
  - Trans-polar routes
  - Passengers may receive radiation doses equivalent to several chest X rays

Geomagnetic Induced Currents

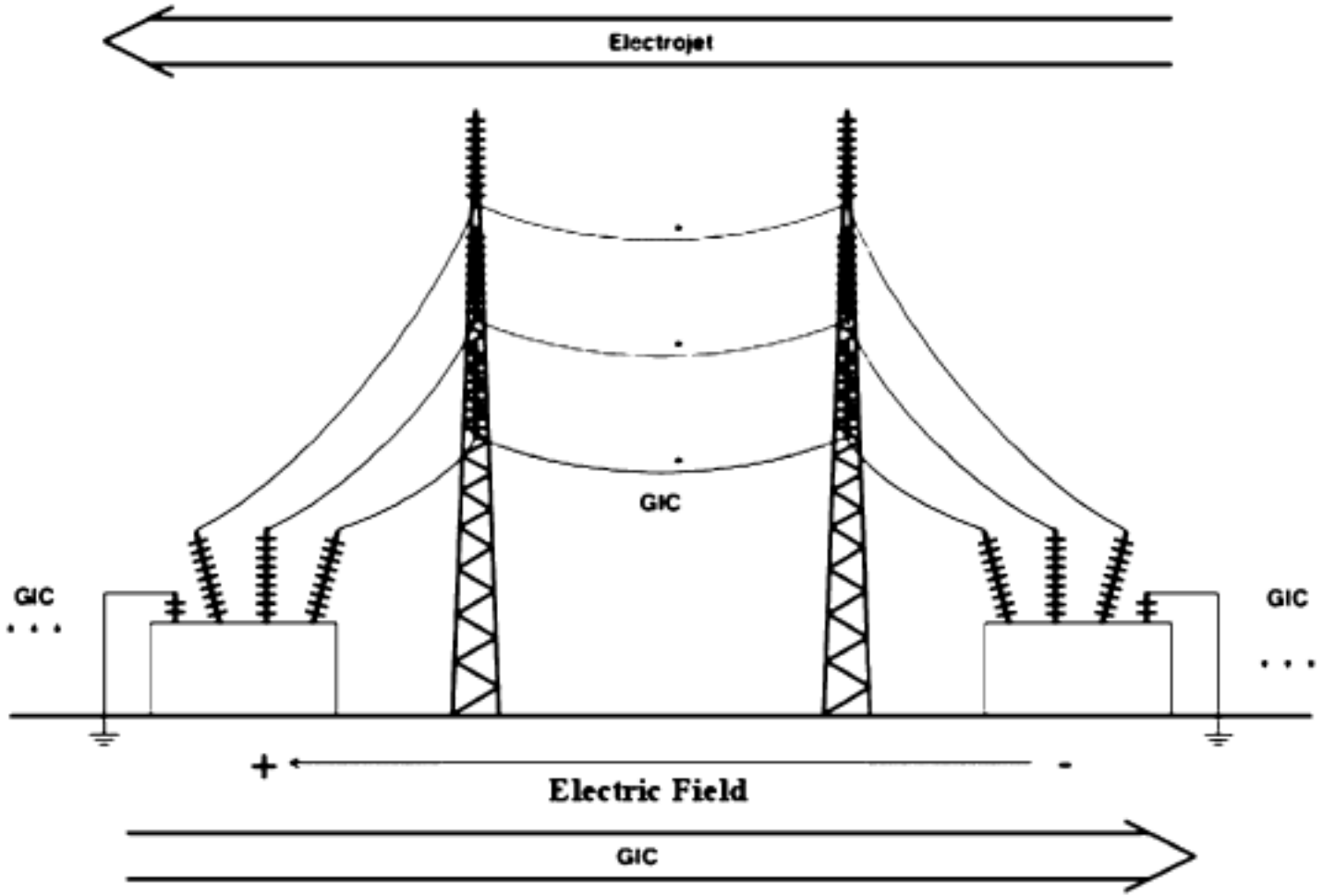
- Currents leak into long conductors:
  - Power grids
  - Oil and gas pipelines
- Train light signals can be affected
-
  - Eg. Multiple documented events in Sweden.



Damage to Transformers

- Damage to a transformer in New Jersey in March 1989
  - Cost $10 million and took 6 weeks to restore
- Sweden: simultaneous power loss in six 130 kV power distribution lines
- Chicago: 5 transformers in the Chicago area failed due to elevated geomagnetic activity in April 94
- Recent failures in South Africa and New Zeeland.

Space Weather and Power Systems



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Damage to Transformers

- Stray flux causes localised heating
- Current causes voltage depression
- Harmonics causes other equipment to trip and heating in rotors

Transformer in New Jersey (40N)

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What makes a transformer vulnerable?

- **Location:** Currents likely to enter network at coastal substations
- **Network voltage:** Higher voltage networks offer lower resistance and tend to span greater distances
- **Transformer design:** Modern transformers are more resilient to DC. Single Phase Transformers particularly vulnerable
- **Transformer loading:** Highly loaded transformers have higher starting temperature

Québec Black Out

- March 13, 1989 solar storm
  - Knocked out power across Quebec for more than 9 hours
  - 6 million people effected
- According to the U.S. National Oceanographic and Atmospheric Administration (NOAA):

  "cost more than $30 million, putting the event on par with damage caused by hurricanes and earthquakes"

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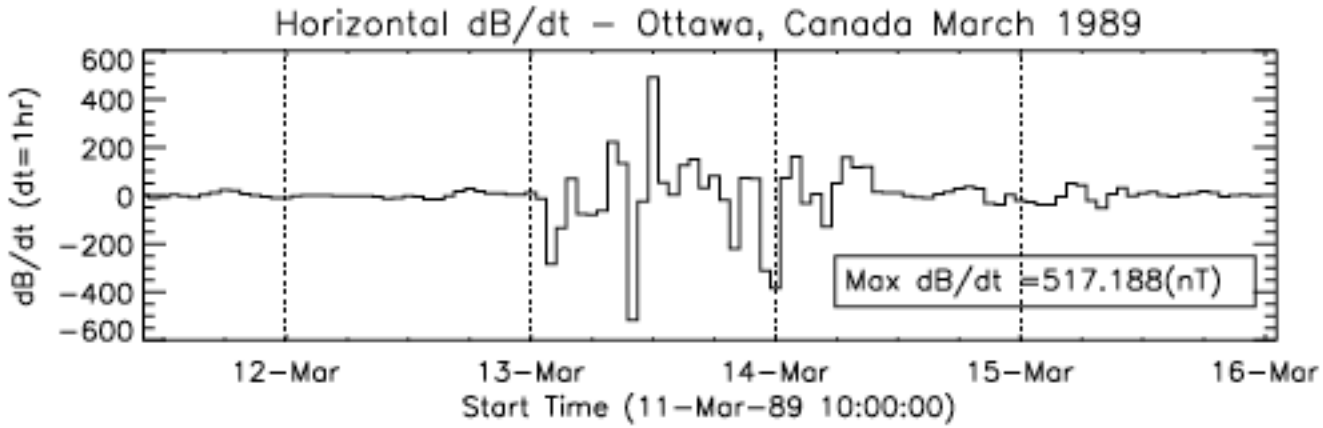
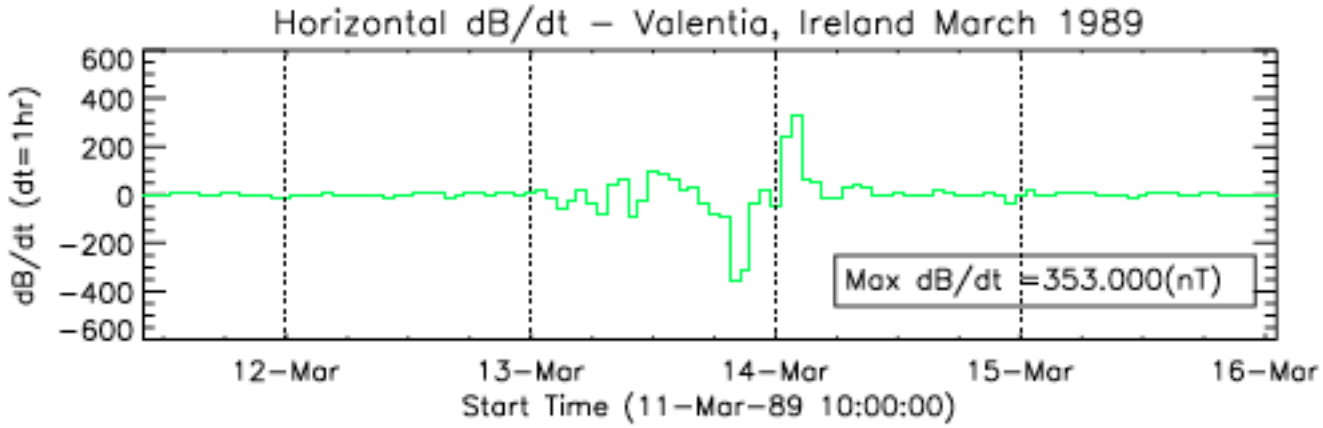
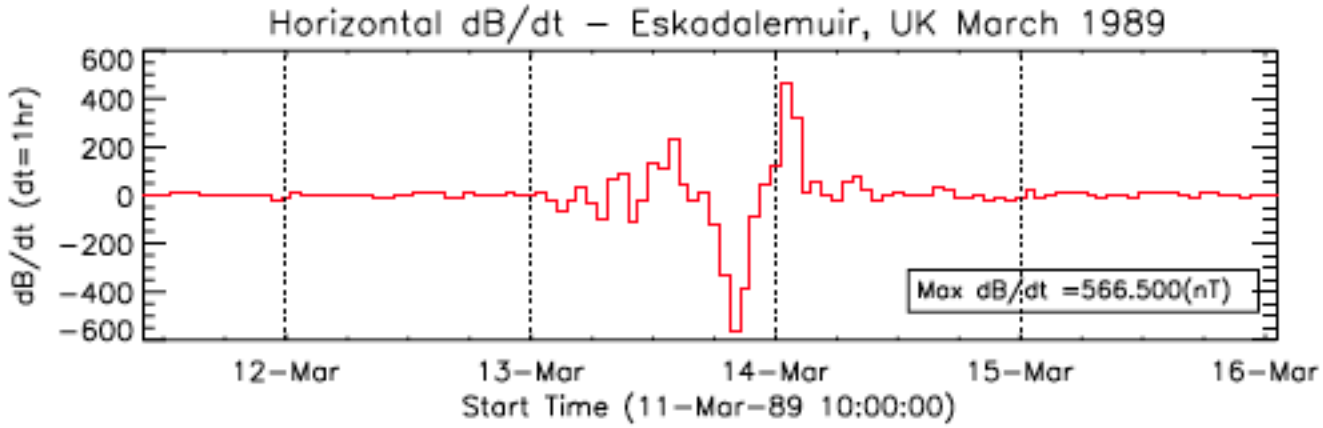

Horizontal dB/dt – Ottawa, Canada March 1989
dB/dt (dt=1hr)
600
400
200
0
−200
−400
−600
Max dB/dt =517.188(nT)
12−Mar
13−Mar
14−Mar
15−Mar
16−Mar
Start Time (11−Mar−89 10:00:00)

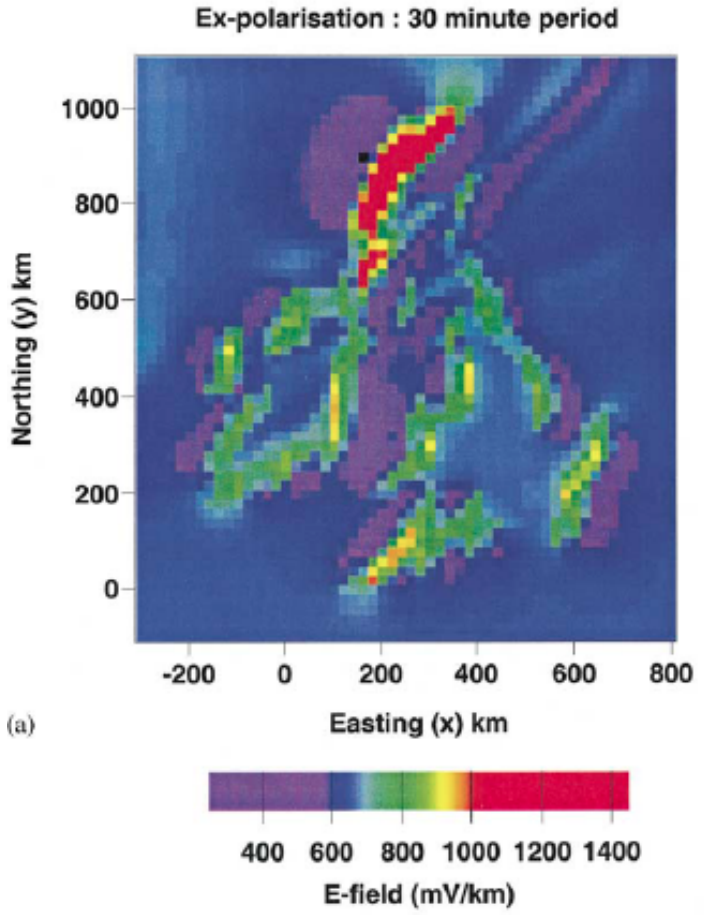

Horizontal dB/dt – Valentia, Ireland March 1989
dB/dt (dt=1hr)
600
400
200
0
−200
−400
−600
Max dB/dt =353.000(nT)
12−Mar
13−Mar
14−Mar
15−Mar
16−Mar
Start Time (11−Mar−89 10:00:00)


Horizontal dB/dt – Eskadalemuir, UK March 1989
dB/dt (dt=1hr)
600
400
200
0
−200
−400
−600
Max dB/dt =566.500(nT)
12−Mar
13−Mar
14−Mar
15−Mar
16−Mar
Start Time (11−Mar−89 10:00:00)

GICs in Britain and Ireland

- Britain and Ireland have distinct resistivity structure and surrounded by shelf-seas.

- Resistivity contrast between seawater and onshore geology, particularly around the Scottish NW produces enhanced electric fields at coastal sites.



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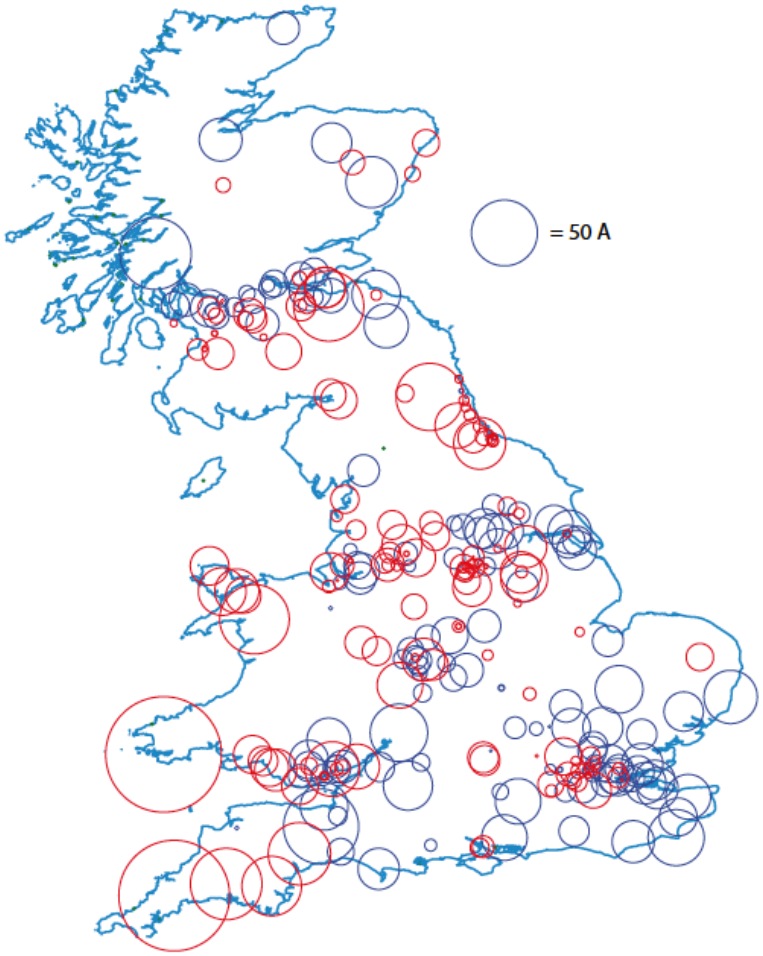
GICs in GB grid in Oct-Nov 2003 storms

- BGS models of current flow through 252 major transformers
- BGS monitored in near realtime magnetic variations
- Continuously updated UK power industry



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Space weather and its impacts

- What is space weather?
  - *Sun's effects on Earth and technology*
- What causes space weather?
  - *Solar storms and solar wind*
- What are the technological impacts of space weather?
  - *GPS, power grids, telecommunications*
- What can we do to protect against space weather?
  - *Research, monitoring, worst-case planning*

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