CENTRE DE SUPERCOMPUTACIÓ DE CATALUNYA

CESCA

UNIVERSITAT DE BARCELONA

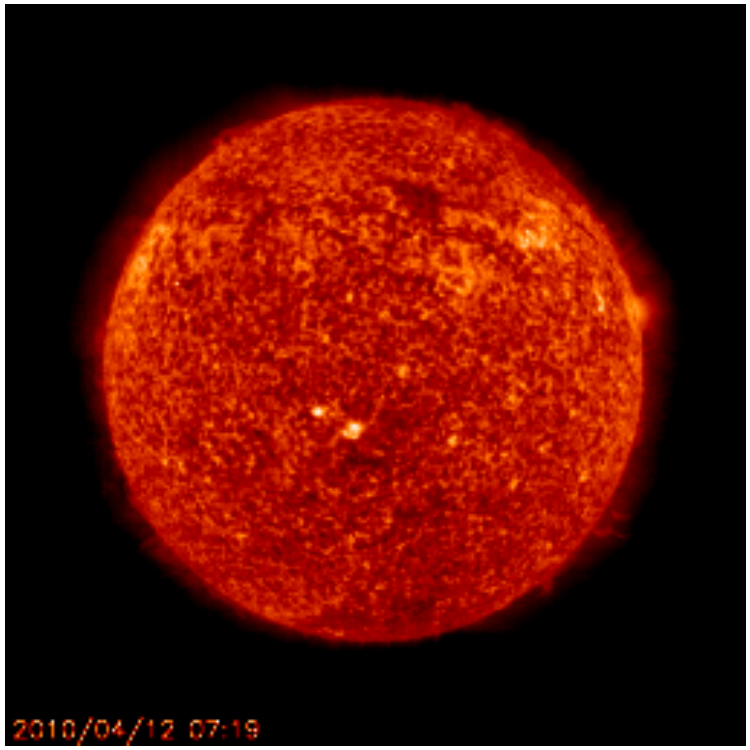
Modeling Solar Energetic Particle (SEP) events by using magnetohydrodynamic simulations

Technical work:

D. Tur, A. Gil and I. Bárcena

Scientific work:

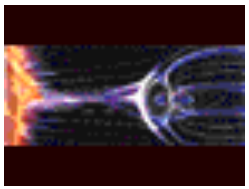
R. Rodríguez-Gasén, A. Aran, B. Sanahuja, D. Lario, C. Jacobs and S. Poedts



Outline

1. Space Weather
2. Earth effects
3. Simulations
4. Technical details
5. Conclusions

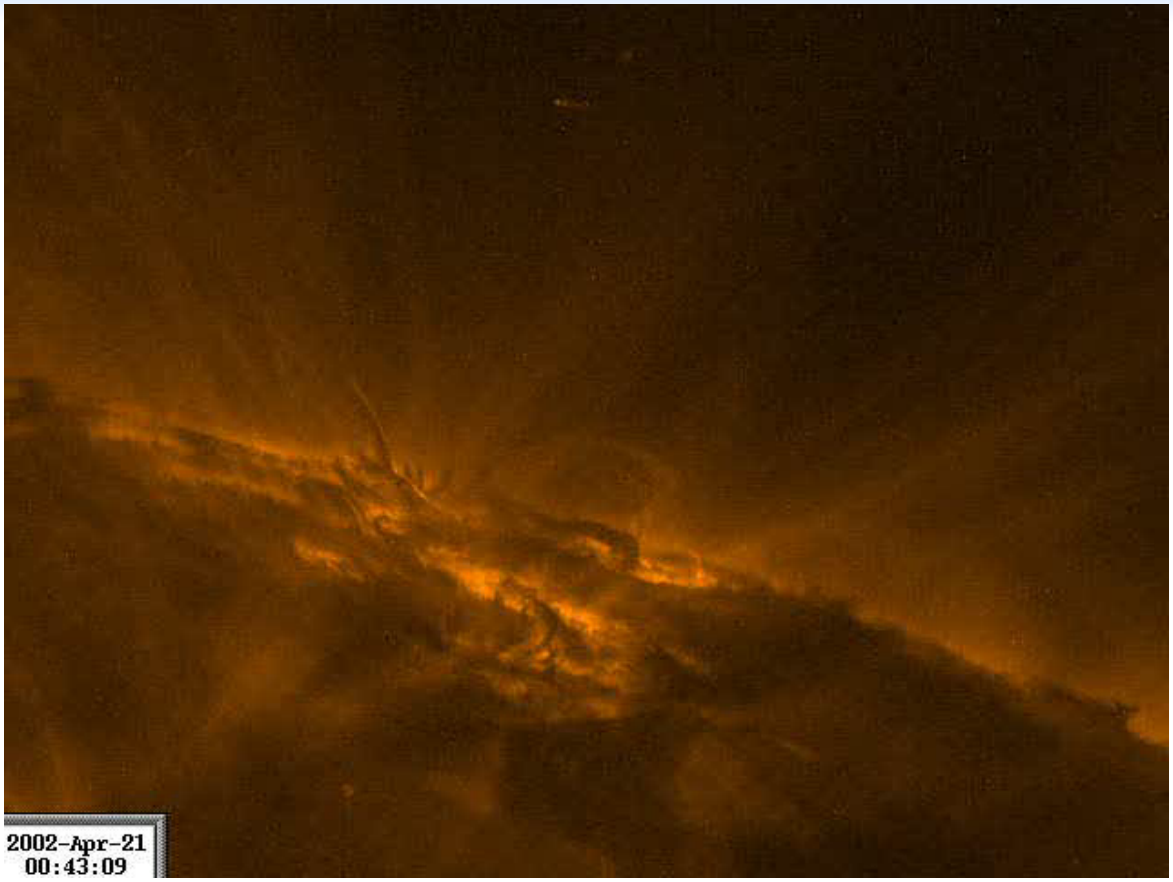
Space Weather



US National Space Weather definitions:

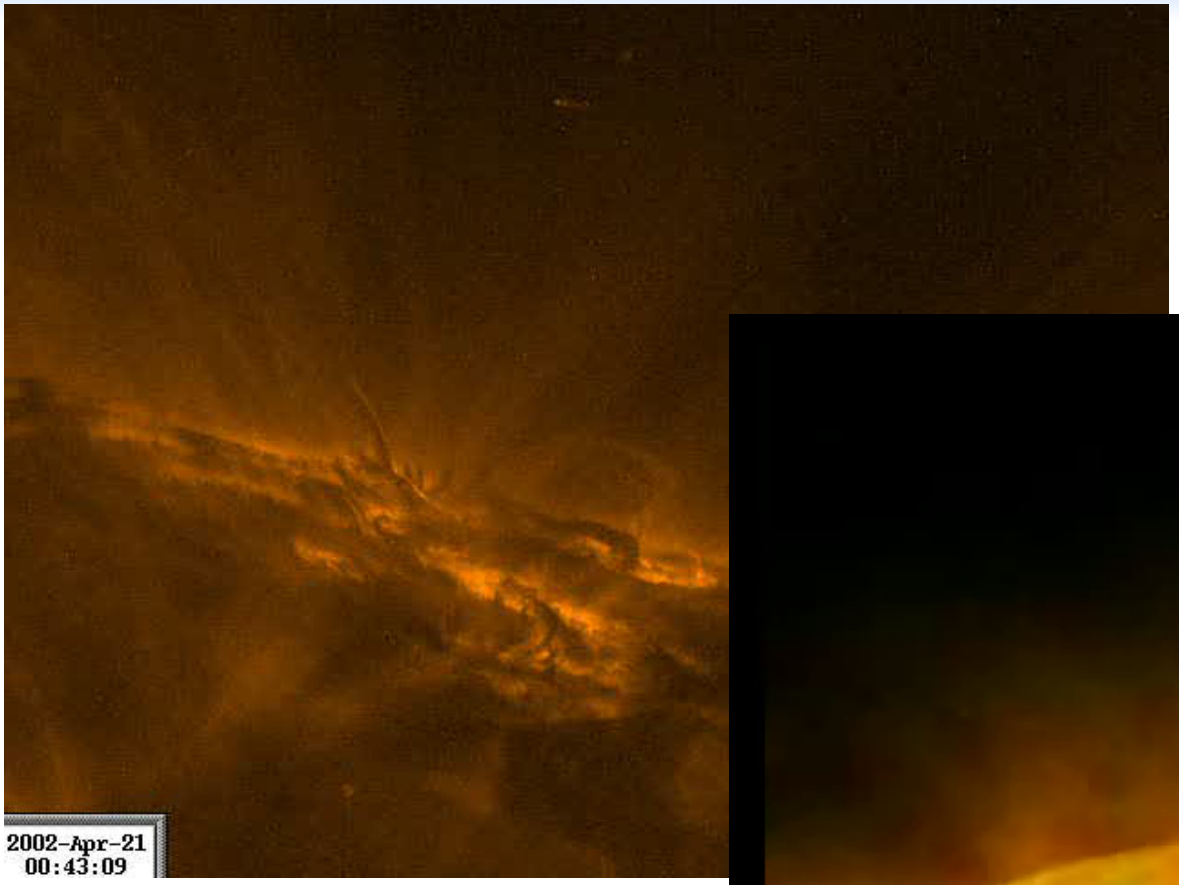
“conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and an endanger human life or health”

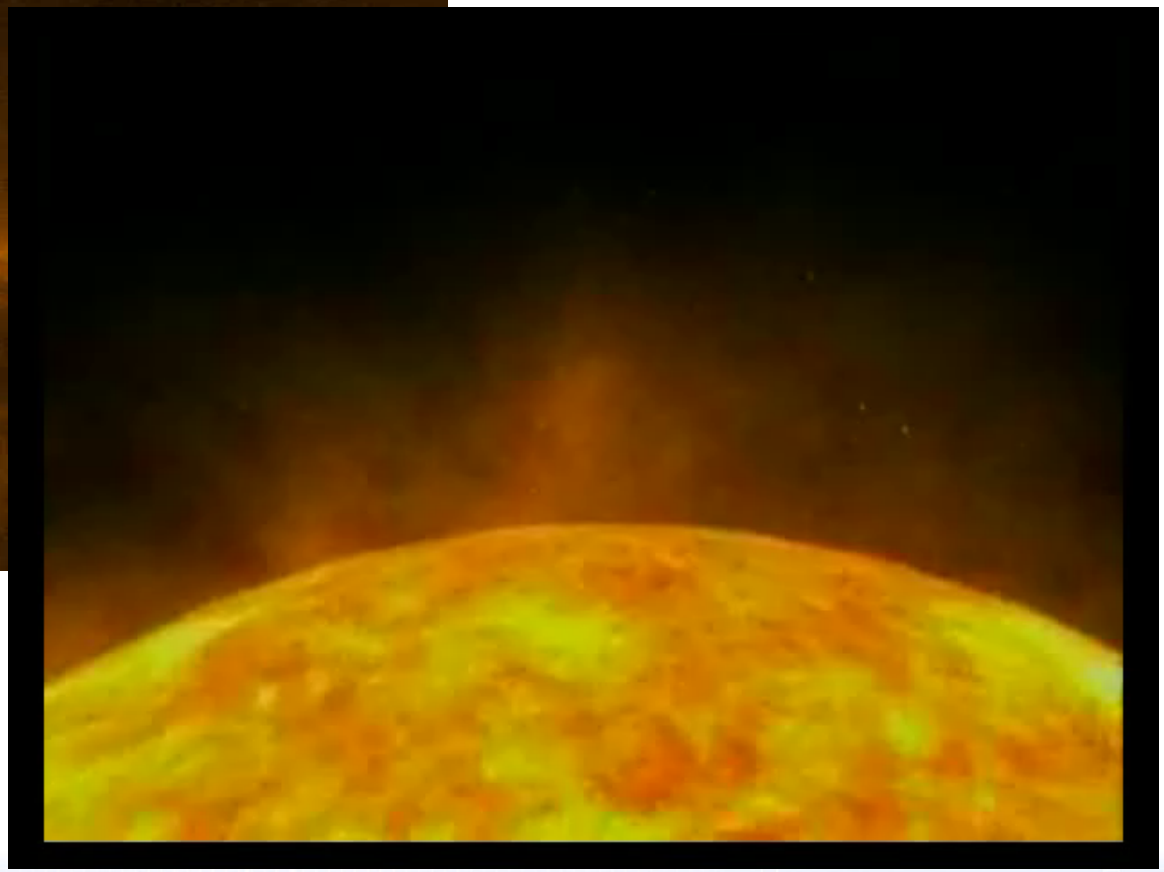
Space Weather



- ✓ Sun is very active!

Space Weather

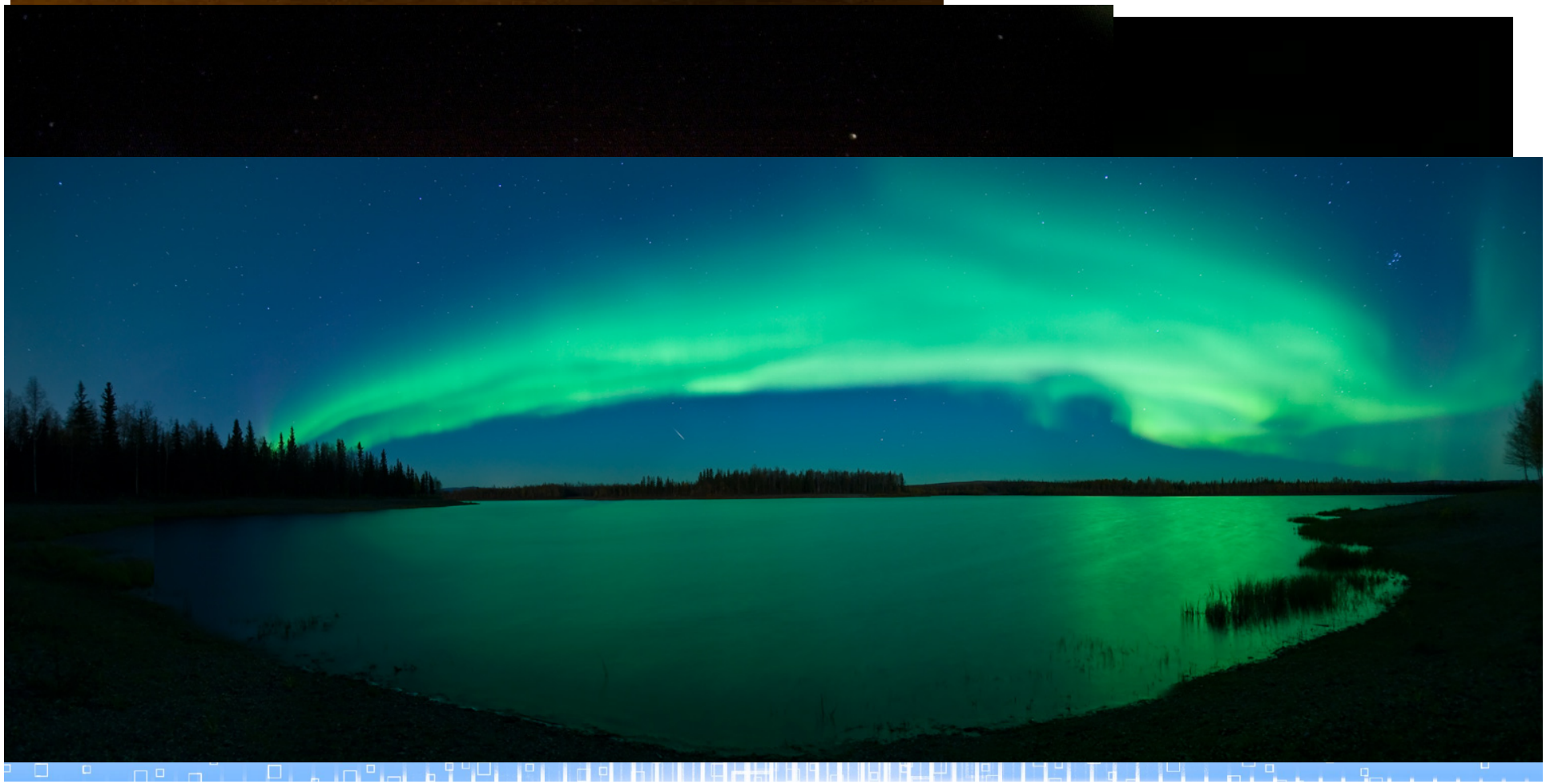




- ✓ Sun is very active!
- ✓ and this affects the Earth

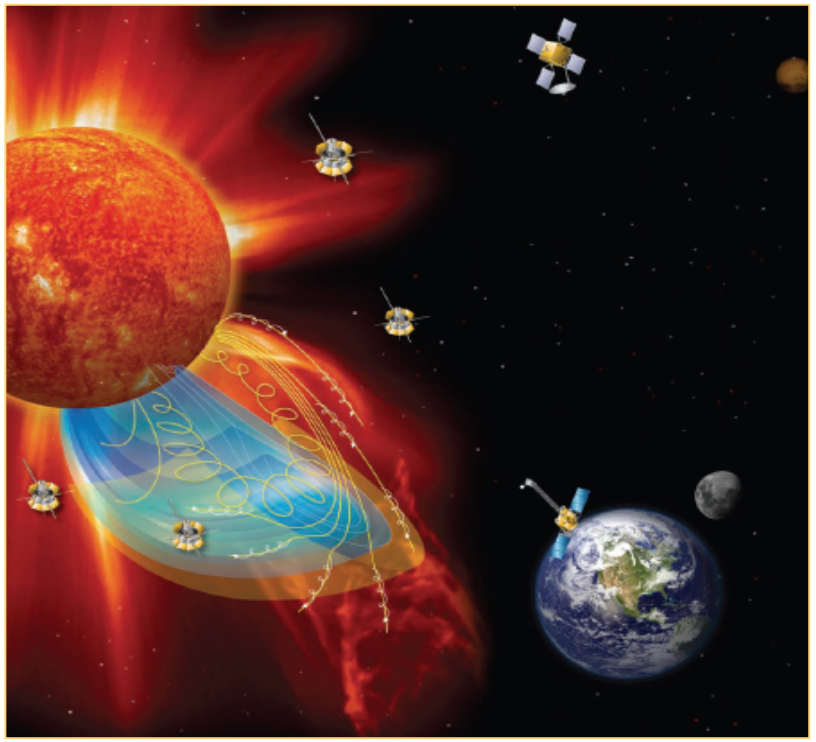
Space Weather

- ✓ Sun is very active!
- ✓ and this affects the Earth
- ✓ e.g. Aurorae



Earth effects

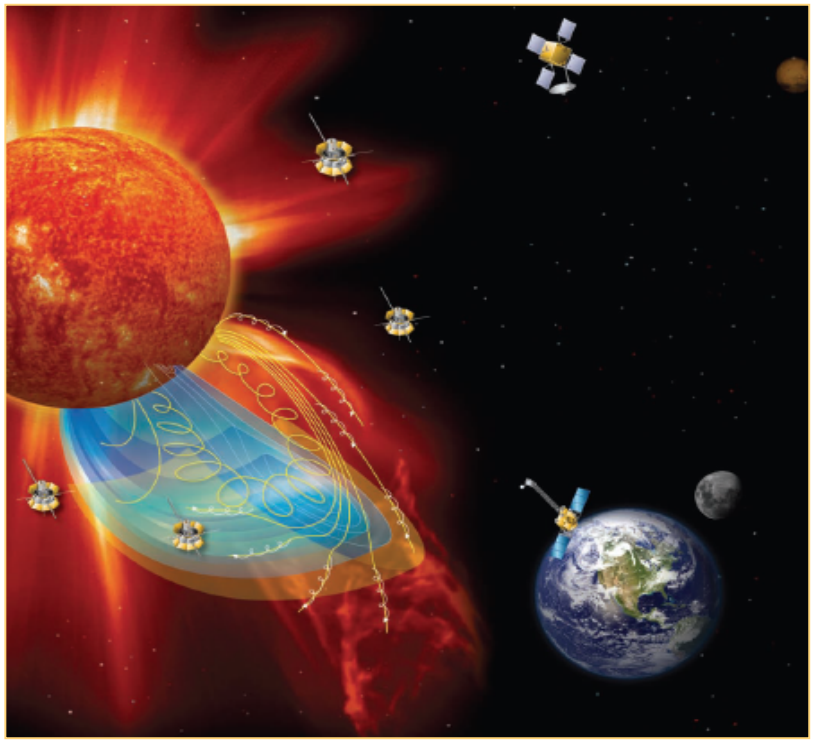
But not just beautiful Earth effects:



Earth effects

But not just beautiful Earth effects:

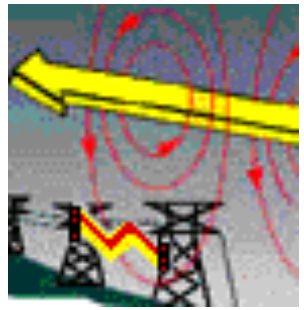
- ✓ Electronics
- ✓ Space flight
- ✓ Aviation
- ✓ Telecommunications
- ✓ Electric Power Transmission
- ✓ Oil and gas industry
- ✓ Railways



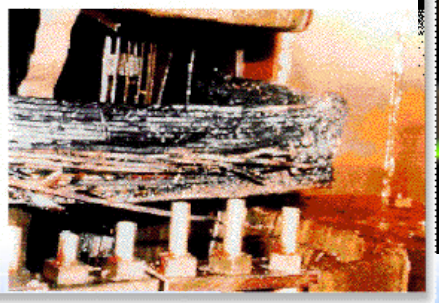
Earth effects

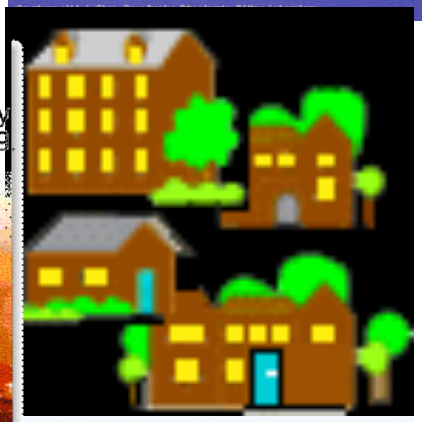
Impact of space weather effects on technological systems

- ✓ Examples of space weather-related system failures
  - ✓ 24.3.1940: first report on power system failure
  - ✓ 13.3.1989: Quebec without electric power



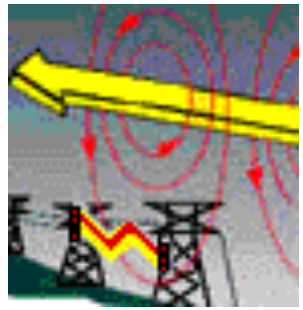
PJM Public Service
Step Up Transformer
Severe internal damage caused by the space storm of 13 March, 1989





Earth effects

Impact of space weather effects on technological systems



- ✓ Examples of space weather-related system failures
  - ✓ 24.3.1940: first report on power system failure
  - ✓ 13.3.1989: Quebec without electric power

- ✓ Satellite failures
  - ✓ 11.1.1997: loss of Telstar 401
  - ✓ 18.5.1998: loss of Galaxy-4

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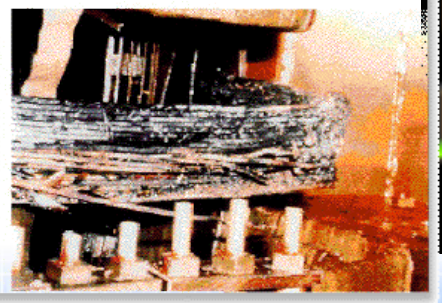
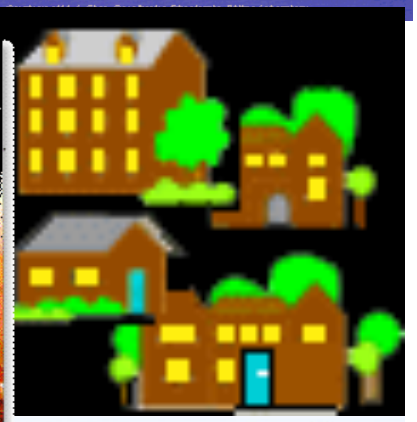
Severe internal damage caused by the space storm of 13 March, 1989





Earth effects

- Atmospheric drag of satellites
- Solar energetic particle (SEP) events is an hazard

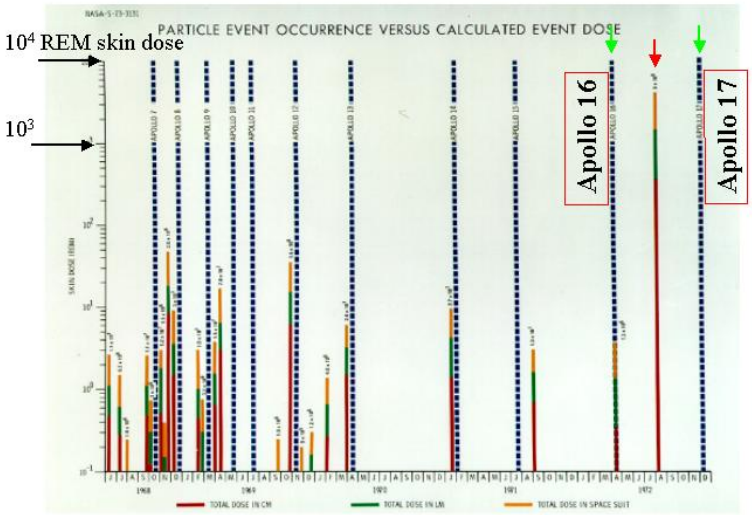
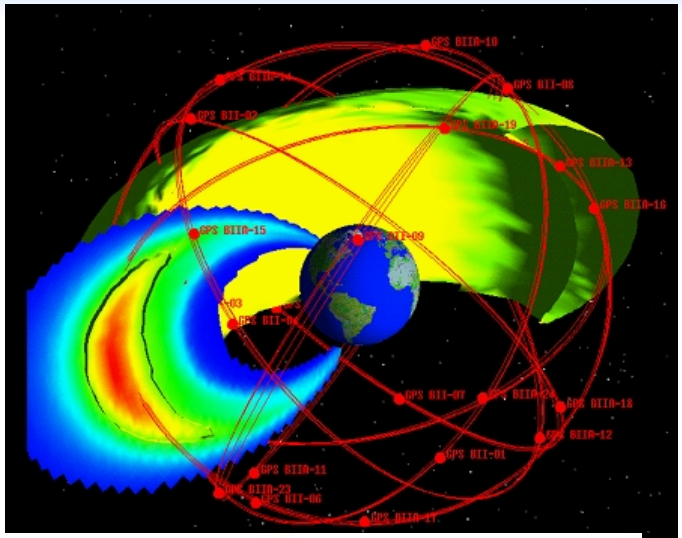
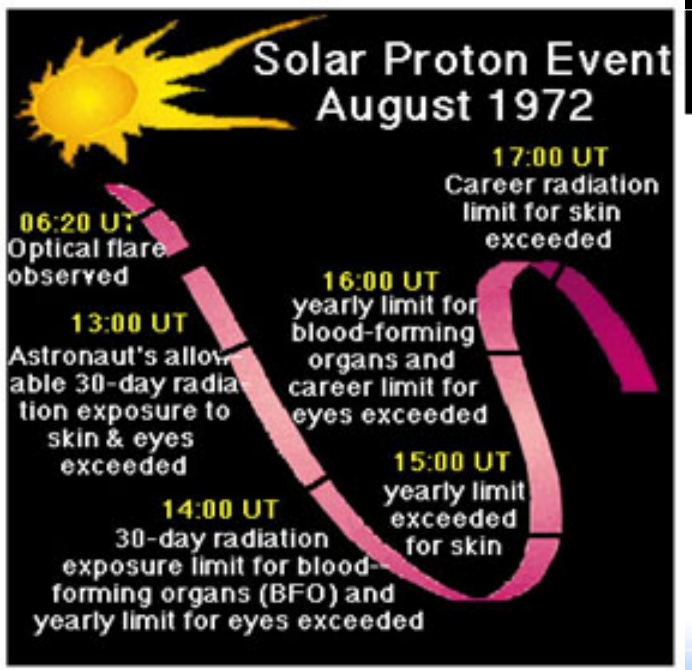


Figure 10. Solar proton events during the Apollo Program.





SEPs are produced at the shock front of CME-driven interplanetary shocks, expanding from the sun

Simulations: Shock-and-particle model

- Developed by STP/SWG of the Universitat de Barcelona

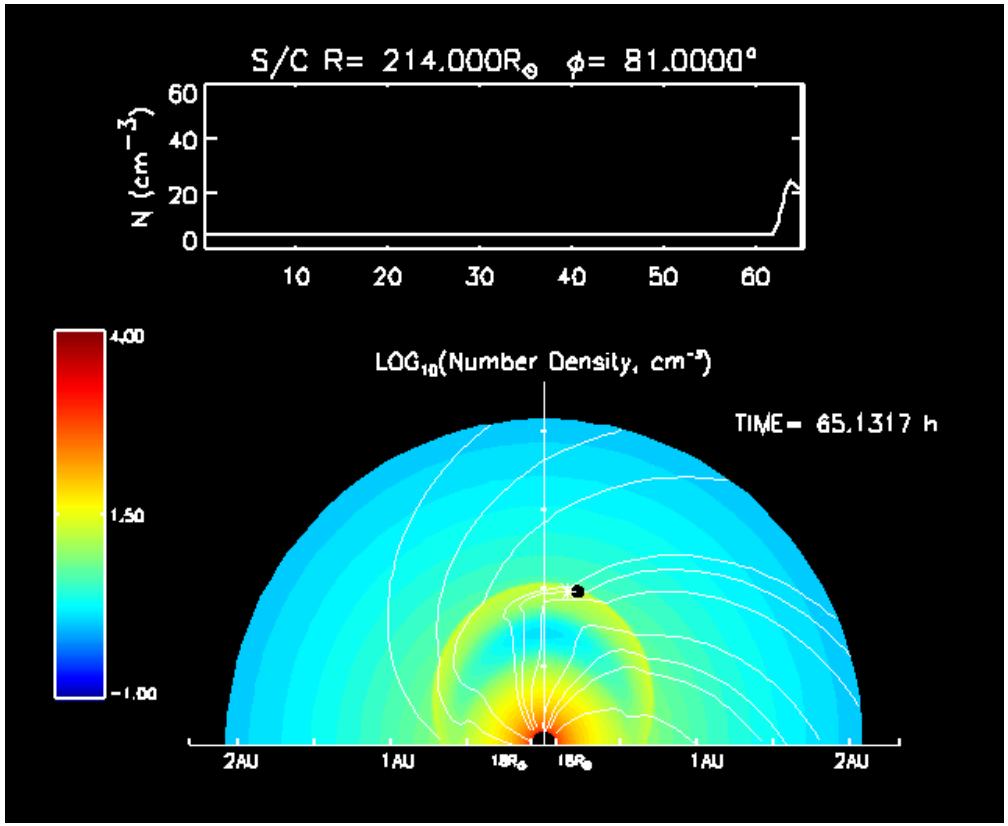
- To model SEP events requires a compound model, able to simulate both, the expansion of the interplanetary shock and the propagation of shock-accelerated particles along the interplanetary magnetic field, up to the observer's location:

Thus:

2D or 3D magnetohydrodynamic (MHD) model for shock propagation

+

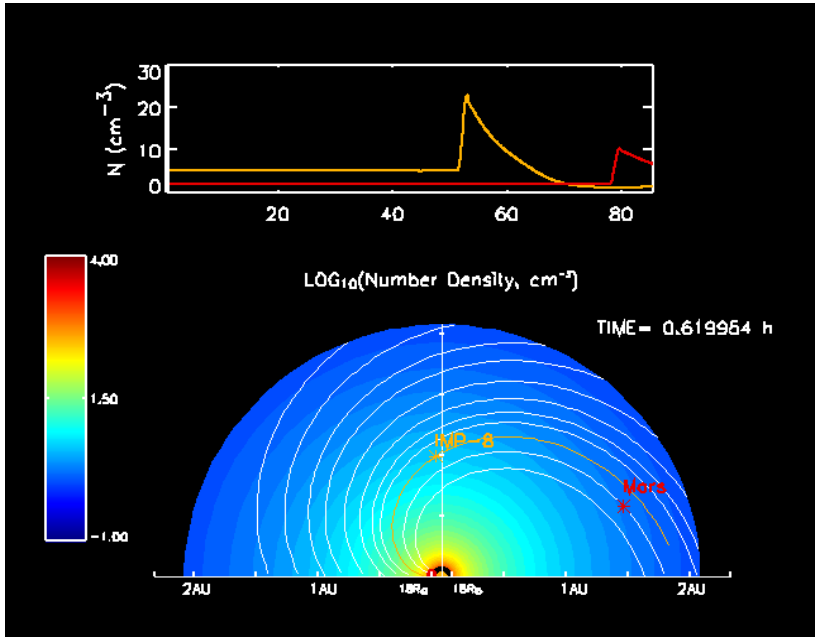
Interplanetary particle transport model



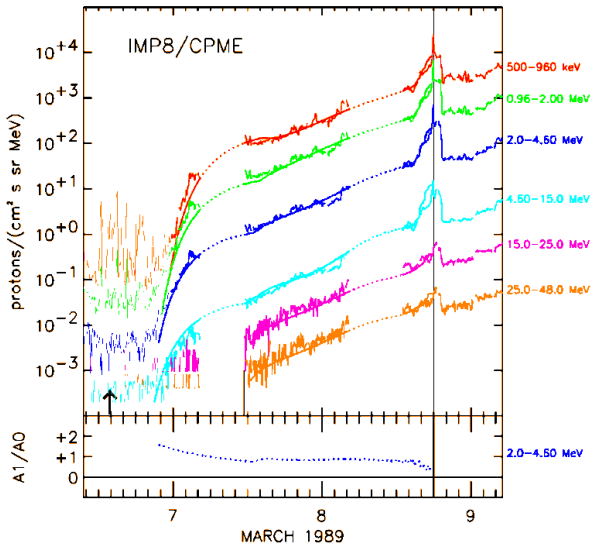
Simulations and results (I)

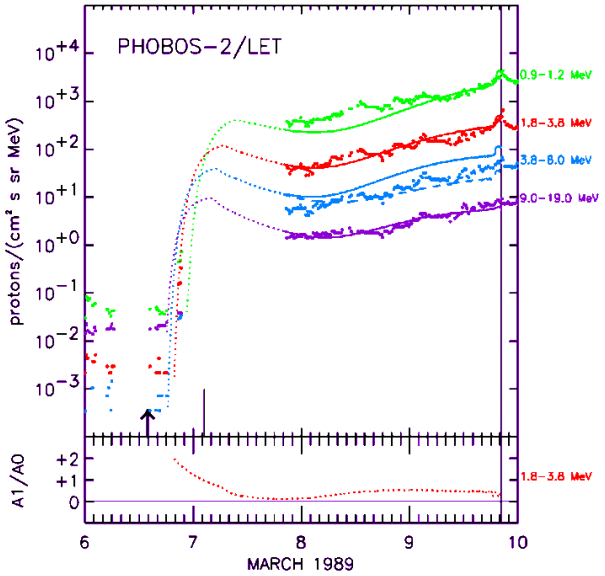
2D Modeling: 6 March 1989 SEP event

Aran et al., Astronomy & Astrophysics, (2007)



- Supercomputing facilities
  CESCA





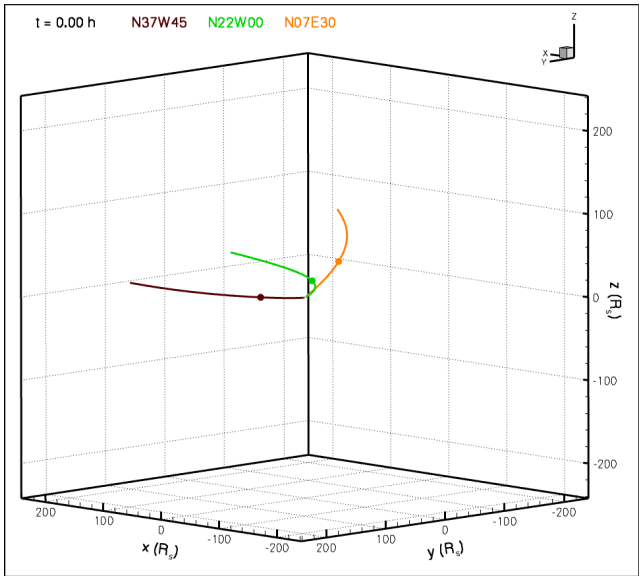
Simulation of the SEP event observed by IMP8 at Earth (top) and by Phobos-2 at Mars (bottom)

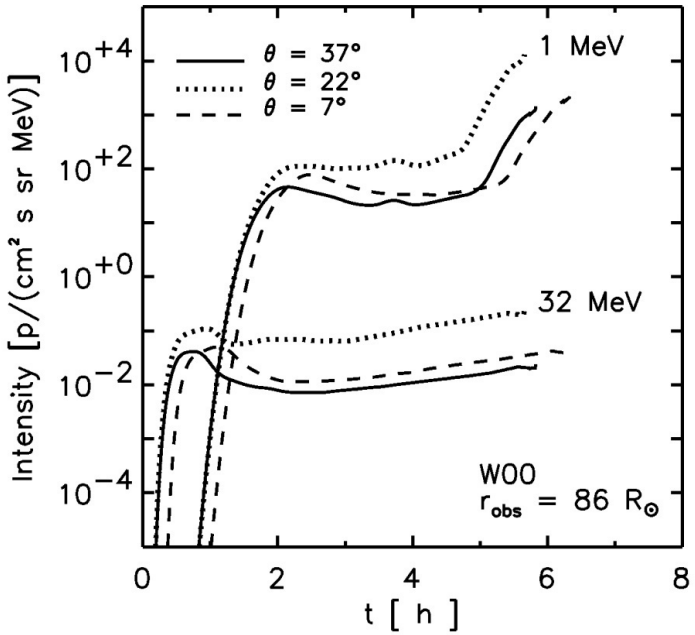
(UB-NOAA-APL/Jhons Hopkins collaboration)

Simulations and results (II)

2. 3D Modeling*

(UB, CPA/KU Leuven collaboration)





***Rodríguez-Gasén, R. Et al., AdvSR, doi: 10.1016/j.asr.2010.03.021, in press, 2010.**

- Supercomputing facilities:

  - CESCA/Altix
  - KU Leuven/VIC cluster
  - BSC/MareNostrum

Changes in peak intensities up to 1 order of magnitude due to the latitude

Technical details

- **CESCA: Centre de Supercomputació de Catalunya;**
  SGI-Altix 3700, 128 CPUs

Ex: 30 R_s, 32 CPUs, 10 000 HC
30 R_s, 128 CPUs, 9 000 HC
1 AU, 64 CPUs, 110 000 HC

Technical details

• CESCA: Centre de Supercomputació de Catalunya;
SGI-Altix 3700, 128 CPUs

Ex: 30 R_s, 32 CPUs, 10 000 HC
30 R_s, 128 CPUs, 9 000 HC
1 AU, 64 CPUs, 110 000 HC

• VIC: Cluster of the Katholieke Universiteit Leuven, Belgium; AMD Opteron Cluster, about 900 CPUs

Ex: 30 R_s, 128 CPUs, 9 500 HC
1 AU, 440 CPUs, 105 600 HC

• MARENOSTRUM: BSC Supercomputing Center;
RES (Red Española de Supercomputación);
IBM Power PC 970MP, 10 240 CPUs

Ex: 30 R_s, 256 CPUs, 12 100 HC
30 R_s, 384 CPUs, 14 100 HC
30 R_s, 512 CPUs, 14 400 HC

• 30 R_s: ~ 35 500 iterations; 1AU: ~ 300 000 iterations

Conclusions

✓2D: Good results obtained and a collaboration with ESA is being started to improve the model

✓3D: Differences in peak Int. up to 1 order of magnitude due to latitude

Conclusions

✓2D: Good results obtained and a collaboration with ESA is being started to improve the model

✓3D: Differences in peak Int. up to 1 order of magnitude due to latitude

✓Big scientific challenges require:

- ✓ Science: Development and improvement of theory & algorithms
- ✓ Technology: Fast computers, performance analysis, code improvement…

Supercomputing Centers help researchers to do science!

✓Space weather is just starting … much more work to do

Thanks for your attention!

Technical work:
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Scientific work:
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C. Jacobs[5,6] and S. Poedts[5,6]

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[3] Researchand Scientific Support Department of European Space Agency, ESTEC, Noordwijk, The Neteherlands

[4] Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, USA.

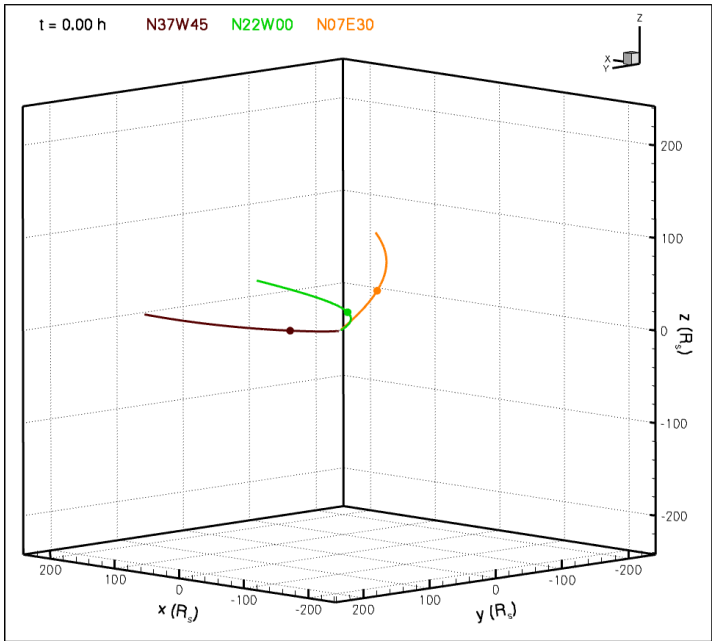
[5] Centrum voor Plasma-Astrofysica, K.U. Leuven, Leuven, Belgium

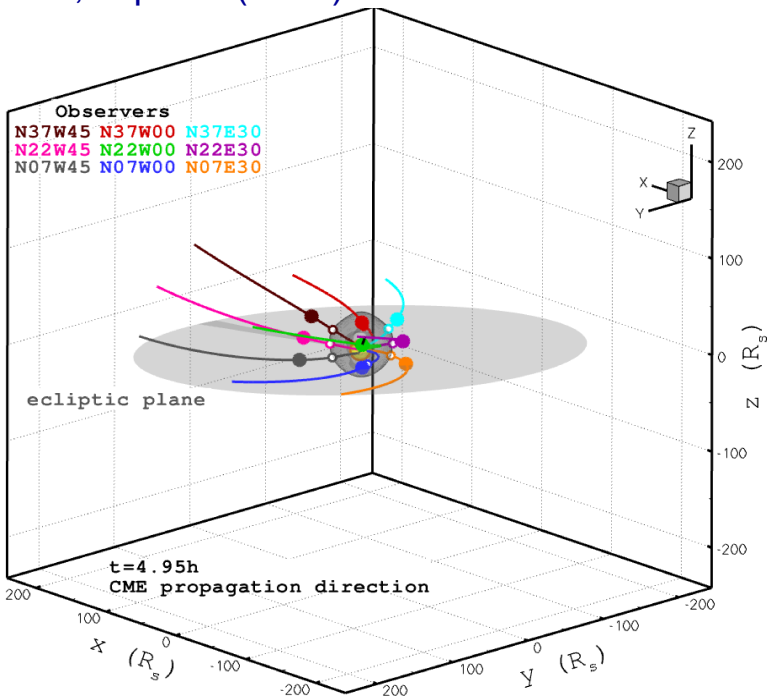
[6] Leuven Mathematical Modelling Centre, K.U.Leuven, Leuven, Belgium

Simulations and results (II)

3D Modeling: altitude and radial heliocentric dependence

R. Rodríguez-Gasén et al., Advances in Space Research, in press (2010)





- Supercomputing facilities:
  CESCA/Altix
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  BSC/MareNostrum

(UB-CPA/K.U. Leuven collaboration)

- Snapshot of 3D MHD shock modeling. Location of nine observers at ~86 solar radii, the corresponding cobpoints and the connecting interplanetary magnetic field lines