Διαστημικό Περιβάλλον

Space Enviroment

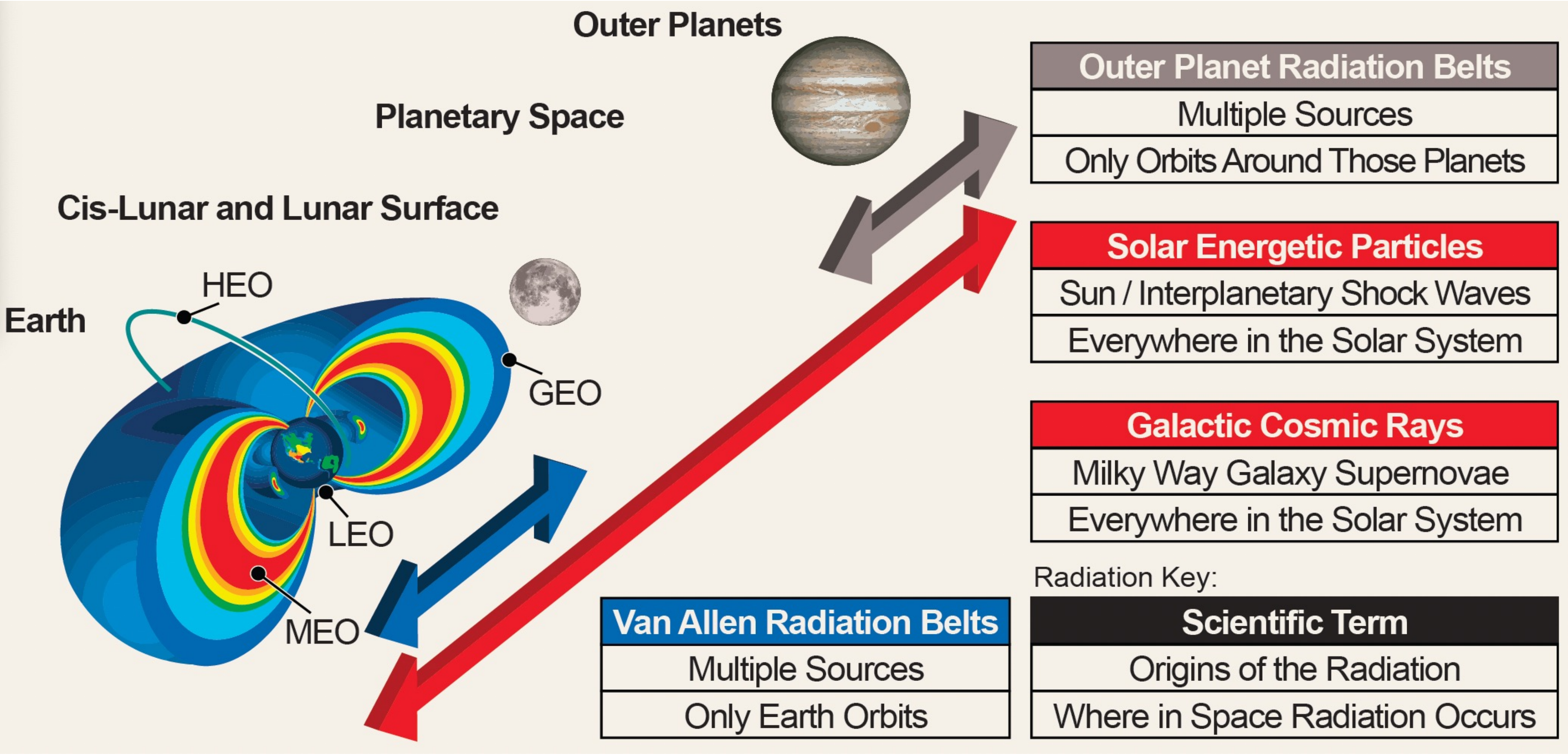
Space Environment
Lecture 6

Hazards of Space Environment Weather

Ανάγκη κατανόησης
επιτήρησης
πρόγνωσης
του Διαστημικού Περιβάλλοντος

Space Particle Radiation

Where does it originate?
Where does it occur?



Space Domain Awareness: The "Why"

Space Hazard
"A Harsh Environment"

The space environment is hostile and hazardous

- Electronics upset
- Materials age
- Radio waves degrade

The space environment affects the dynamic behavior of anthropogenic space objects

The environment needs to be understood and managed

Space Hazards
"The Safety of Flight"

There are many anthropogenic space objects—many dead, some not

- Paths only approximately known
- Space is more crowded today

Anthropogenic space objects are hazardous to each other

- The probability is low, but the consequences are very high!

Traffic management of space congestion needs to assure safe operations, security, and sustainability

Space Threats
"The Adversary"

Space is contested by adversaries today

- The required methods to address the threat are new
- The methods cross many phenomenologies and disciplines
- As long as we do not fully understand and measure the space domain, there will be places to hide and an ability for us to be deceived!!!

The threat is real, and growing

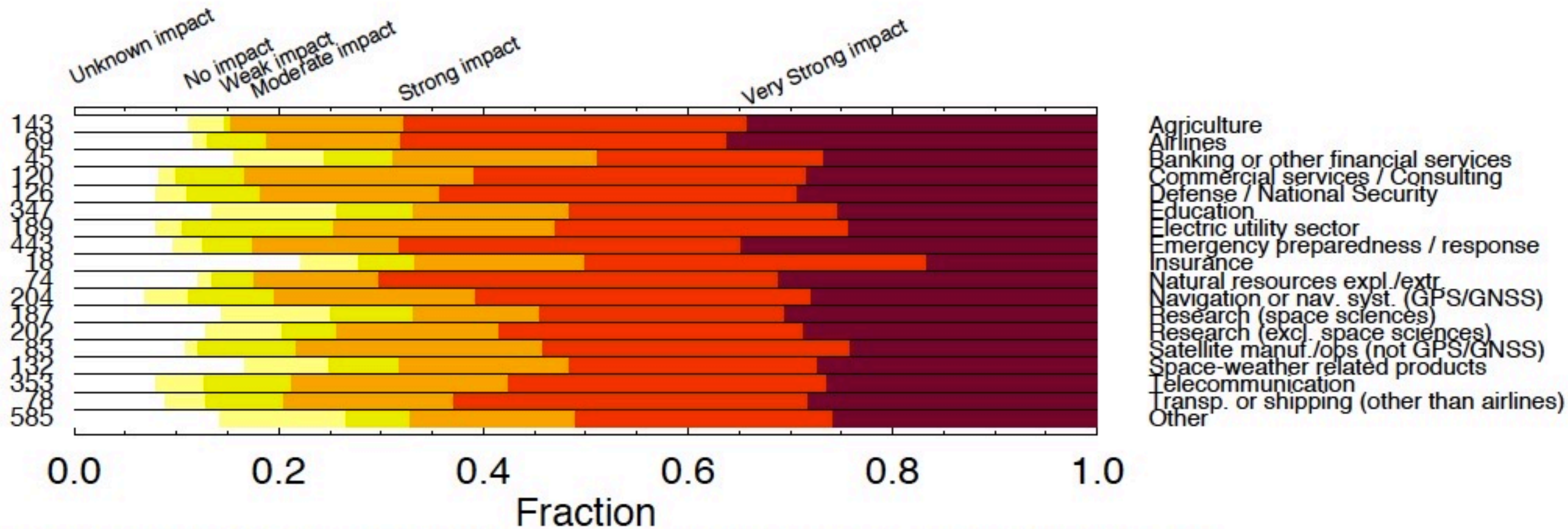
- We must be able to attribute cause of behavior: intentional vs unintentional

The threat must be detected, understood, and addressed

To Know it, you MUST Measure it; to Understand it, you MUST Predict it!

Why do we care?

Because space weather includes
unavoidable hazards leading to **significant potential risks**



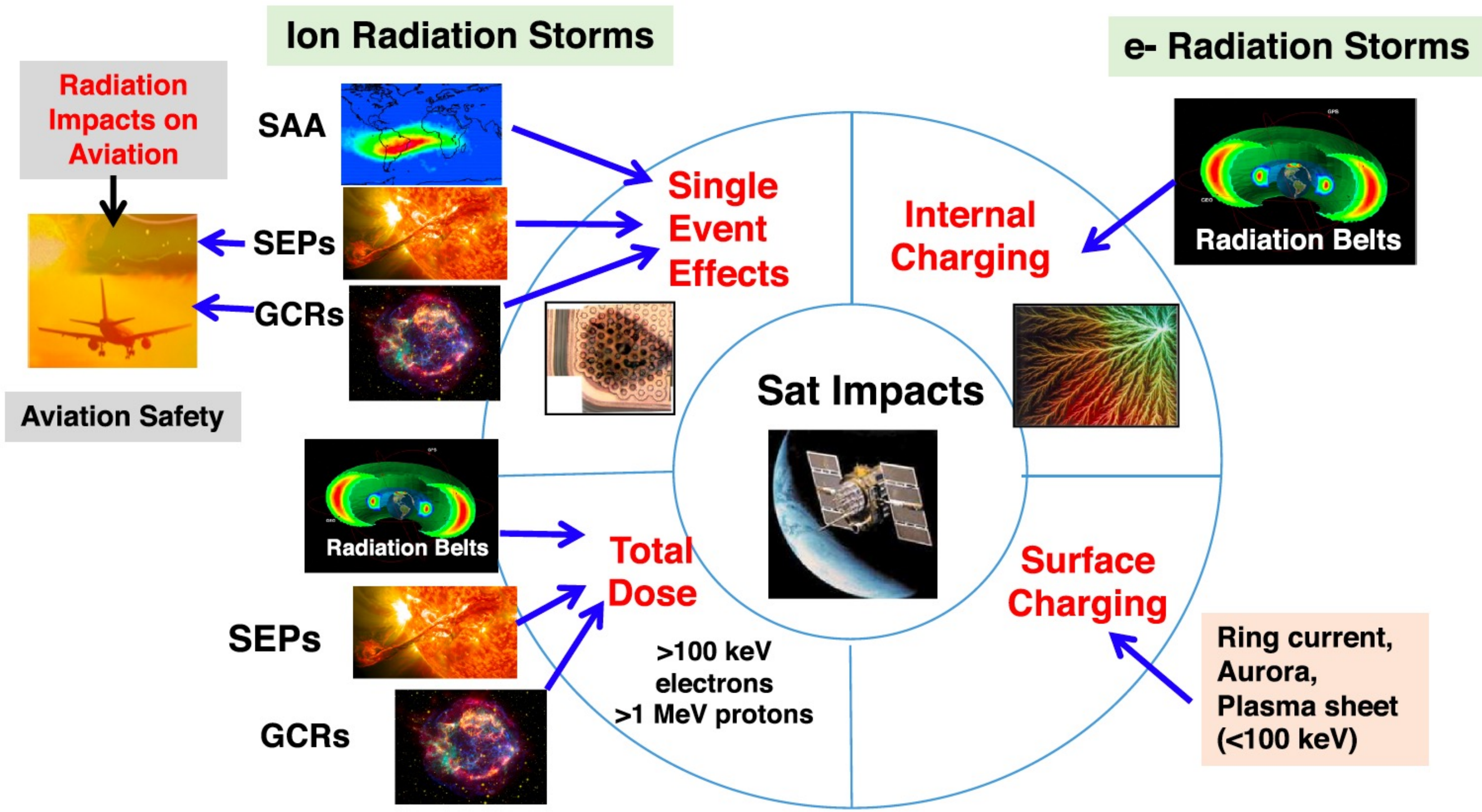
Expected impacts of an extreme GMD event if no action taken (compl.)

Most users anticipate moderate to **very strong** consequences of intense geomagnetic disturbances

Schrijver and Rabanal, 2013, Space Weather Journal doi:10.1002/swe.20092

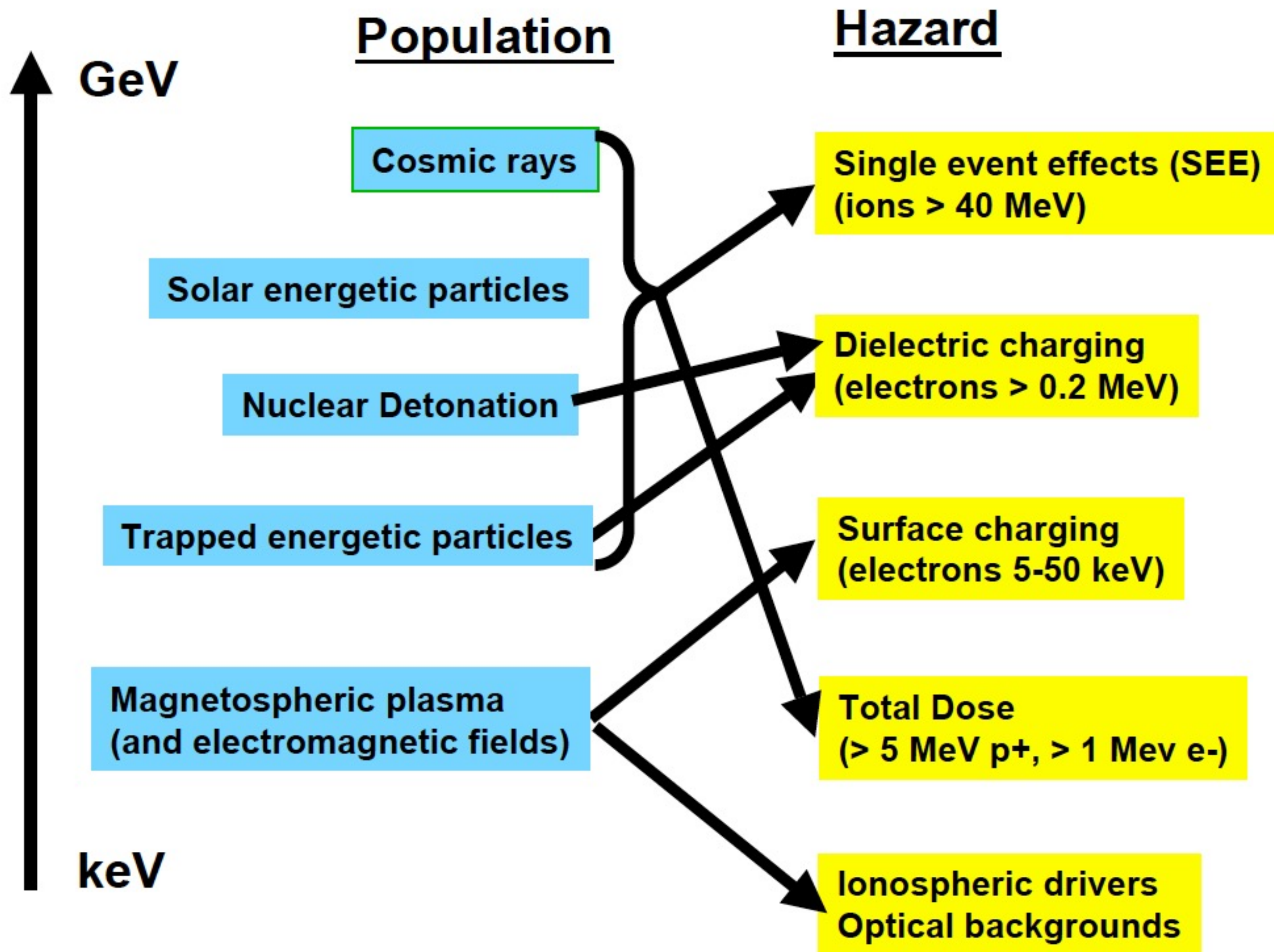
The Unavoidable Hazards

10.1029/2018SW002042



Mission Concept/Planning/Design Mission Launch
Mission Operations Anomaly Resolution

Figure 2. Space radiation and plasma impacts and their sources.


Population
Hazard
GeV
keV
Cosmic rays
Solar energetic particles
Nuclear Detonation
Trapped energetic particles
Magnetospheric plasma
(and electromagnetic fields)
Single event effects (SEE)
(ions > 40 MeV)
Dielectric charging
(electrons > 0.2 MeV)
Surface charging
(electrons 5-50 keV)
Total Dose
(> 5 MeV p+, > 1 Mev e-)
Ionospheric drivers
Optical backgrounds

Hazards and risks

Risk = Hazard x Vulnerability

Hazards and risks

Risk = Hazard x Vulnerability

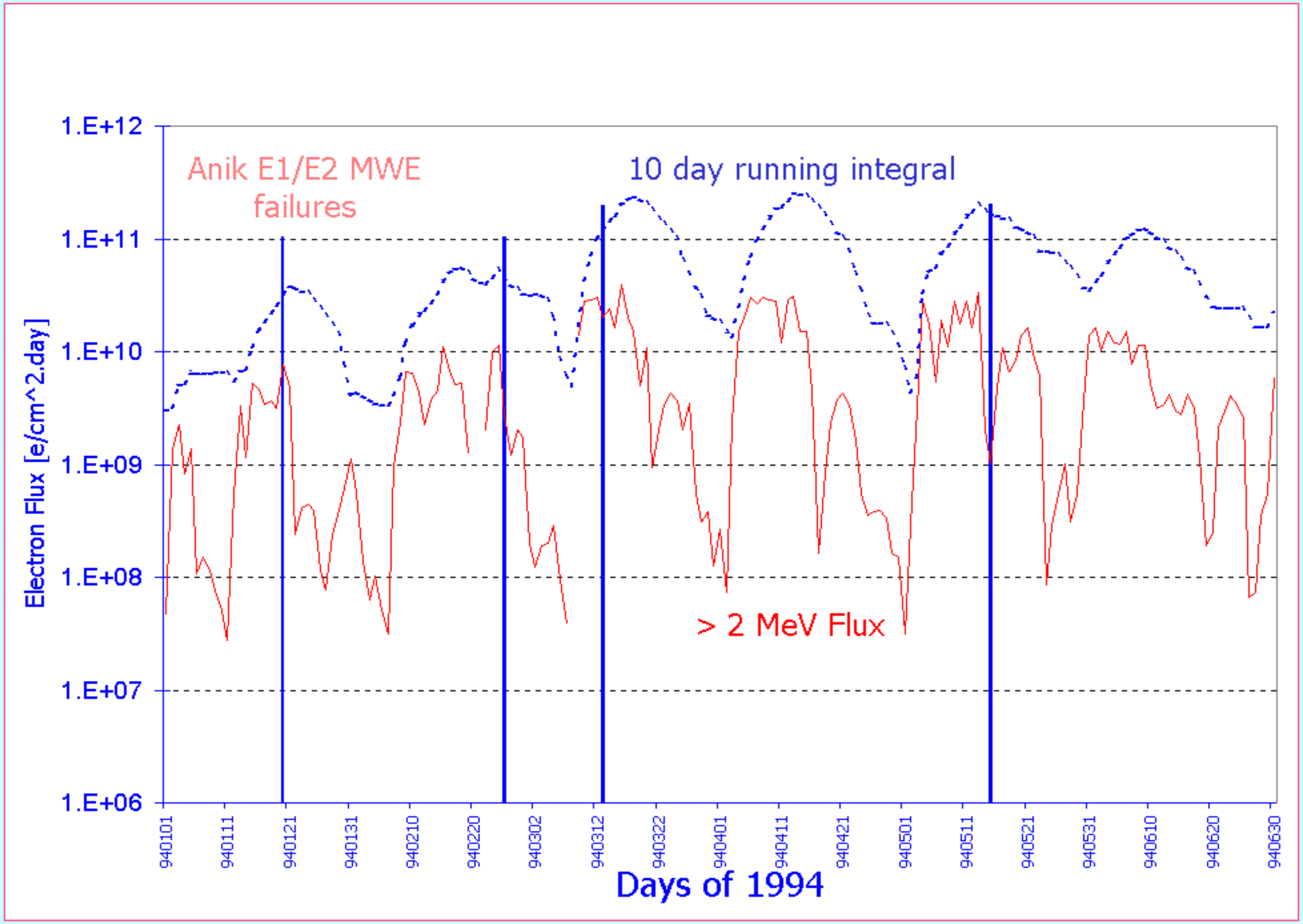
Minimize risk through:

- Reduction of vulnerability (only conditionally feasible)
- Timely and accurate forecast of hazard, enabling protective measures

Achieving Immunity to Space Weather Effects

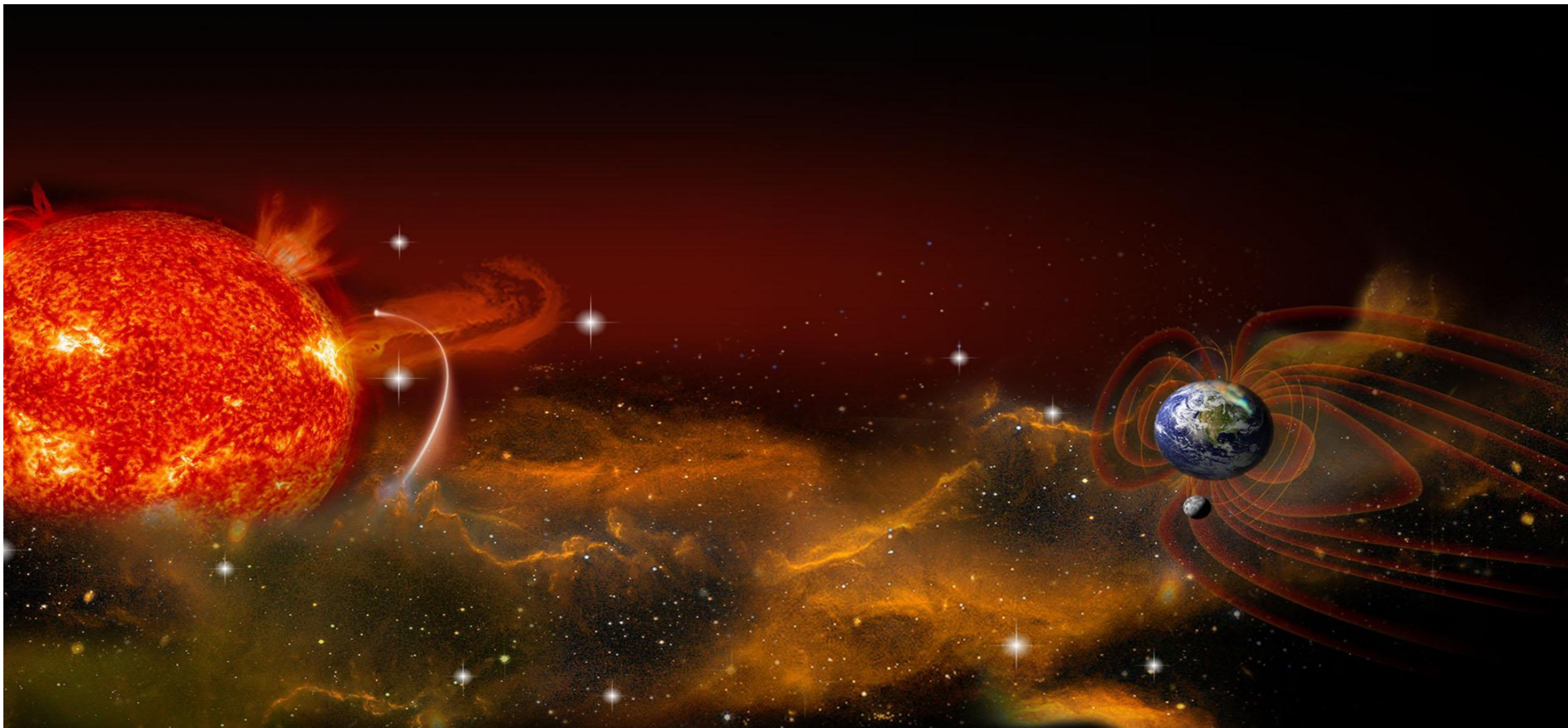
- Sort out anomalies (probably) due to weather
- Correlate to space environment "signatures"
- Determine anomaly mechanism(s)
- Incorporate "signature" into design criteria
- Eliminate susceptibility by design
- Develop design standards - new industry practices
- Audit new designs for weather immunity
- Verify by test and inspection

Correlation to > 2 MeV electron flux



J. Evans, Telesat Canada

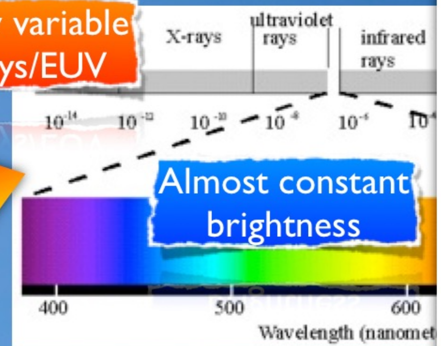
Ως **Διαστημικό Καιρό** ορίζουμε τις μεταβολές στο πλάσμα, το μαγνητικό πεδίο και την ηλεκτρομαγνητική ακτινοβολία στο διάστημα, που **μπορούν να επηρεάσουν την αξιοπιστία, λειτουργία και βιωσιμότητα διαστημικών και επίγειων τεχνολογικών συστημάτων, αλλά και την ανθρώπινη υγεία.**



What the Sun sends our way

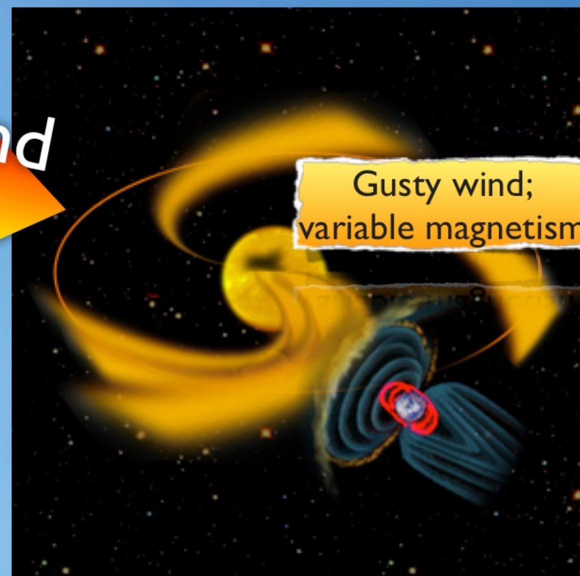
Light (X-ray to radio)

Highly variable X-rays/EUV



Almost constant brightness

Magnetized wind



Gusty wind; variable magnetism

Particle radiation

Highly variable particle streams

Examples of space weather phenomena:

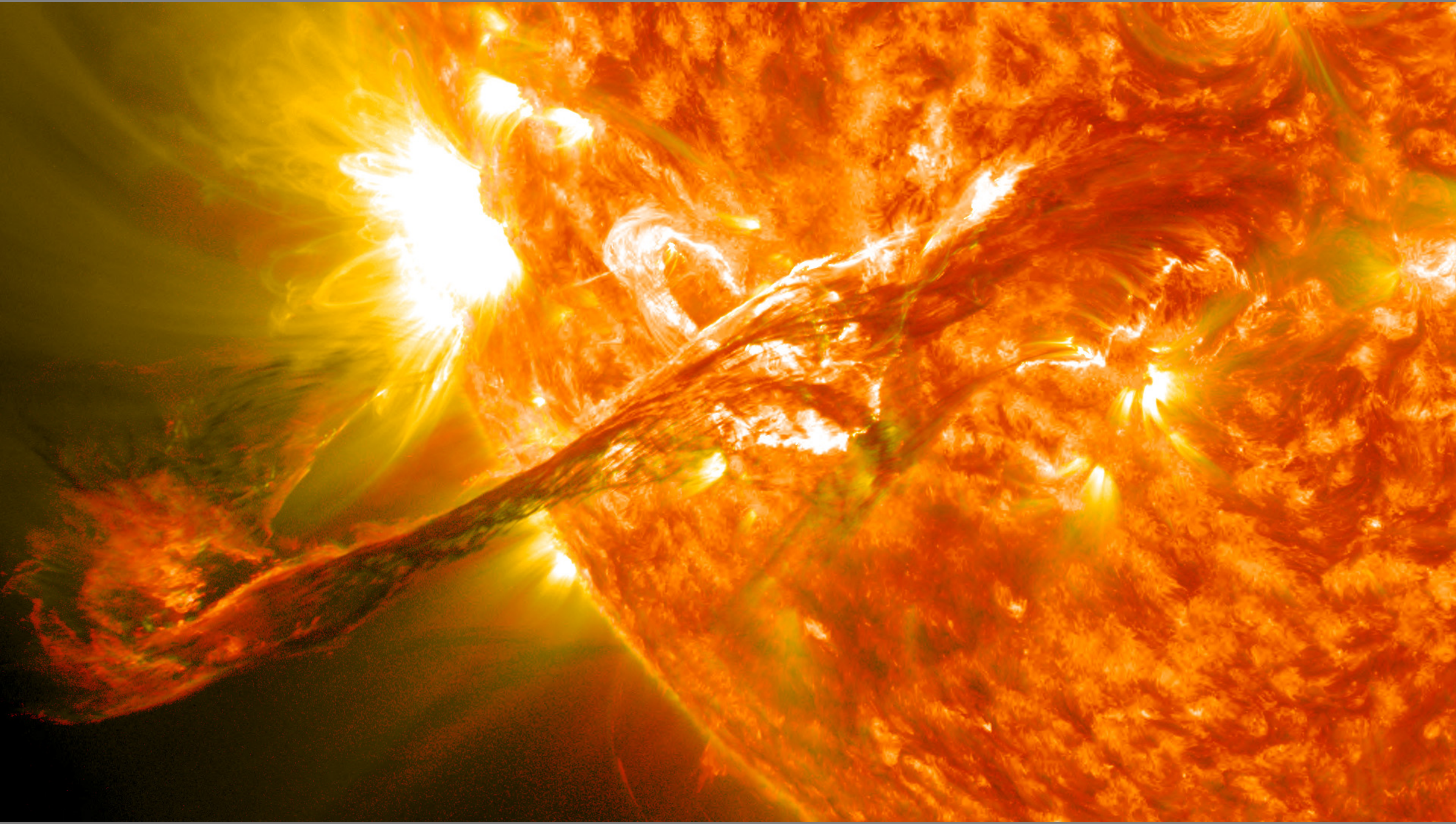
Geomagnetic storms: couple into power grids, cause ionospheric disturbances affecting satellite-based navigation. Aurorae

Radiation storms: hazard to astronaut health and satellite function; affects high-latitude radio comm.; position errors on navigation.

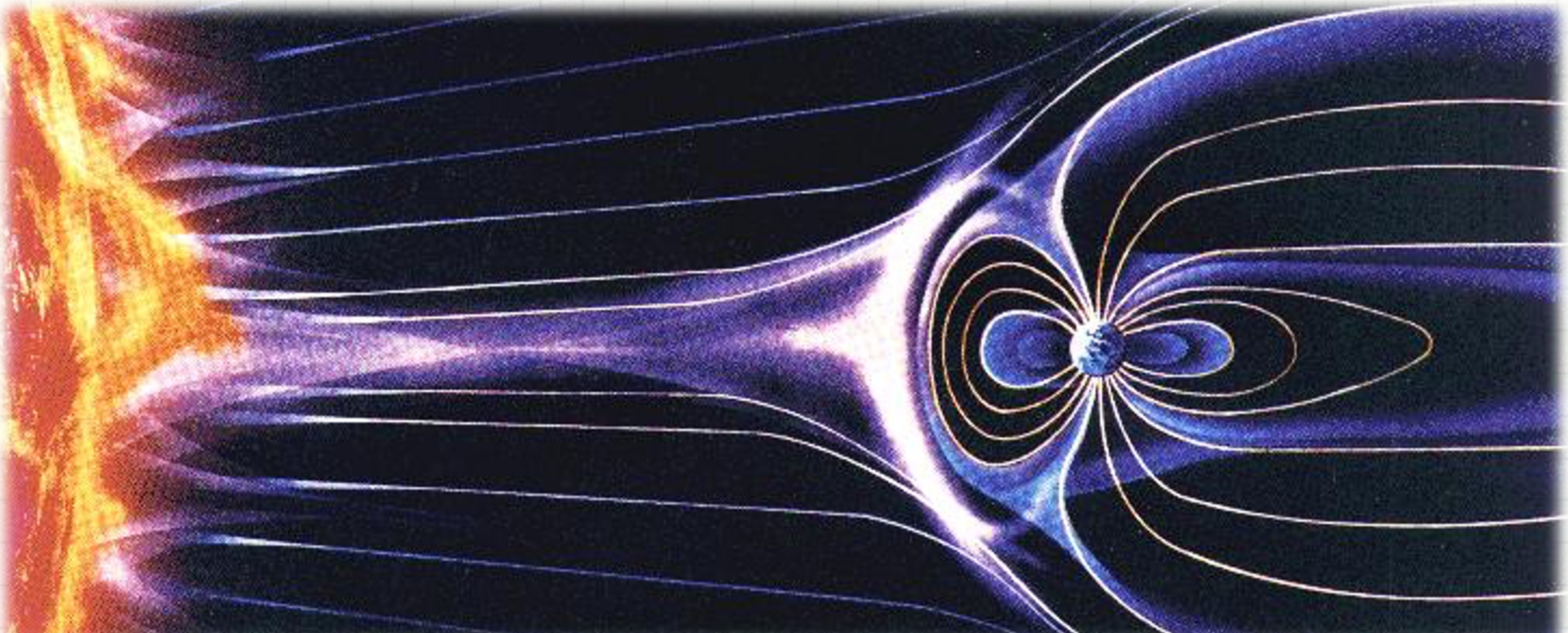
Radio blackouts. Satellite drag affecting orbits and re-entry.

SDO flares and CMEs

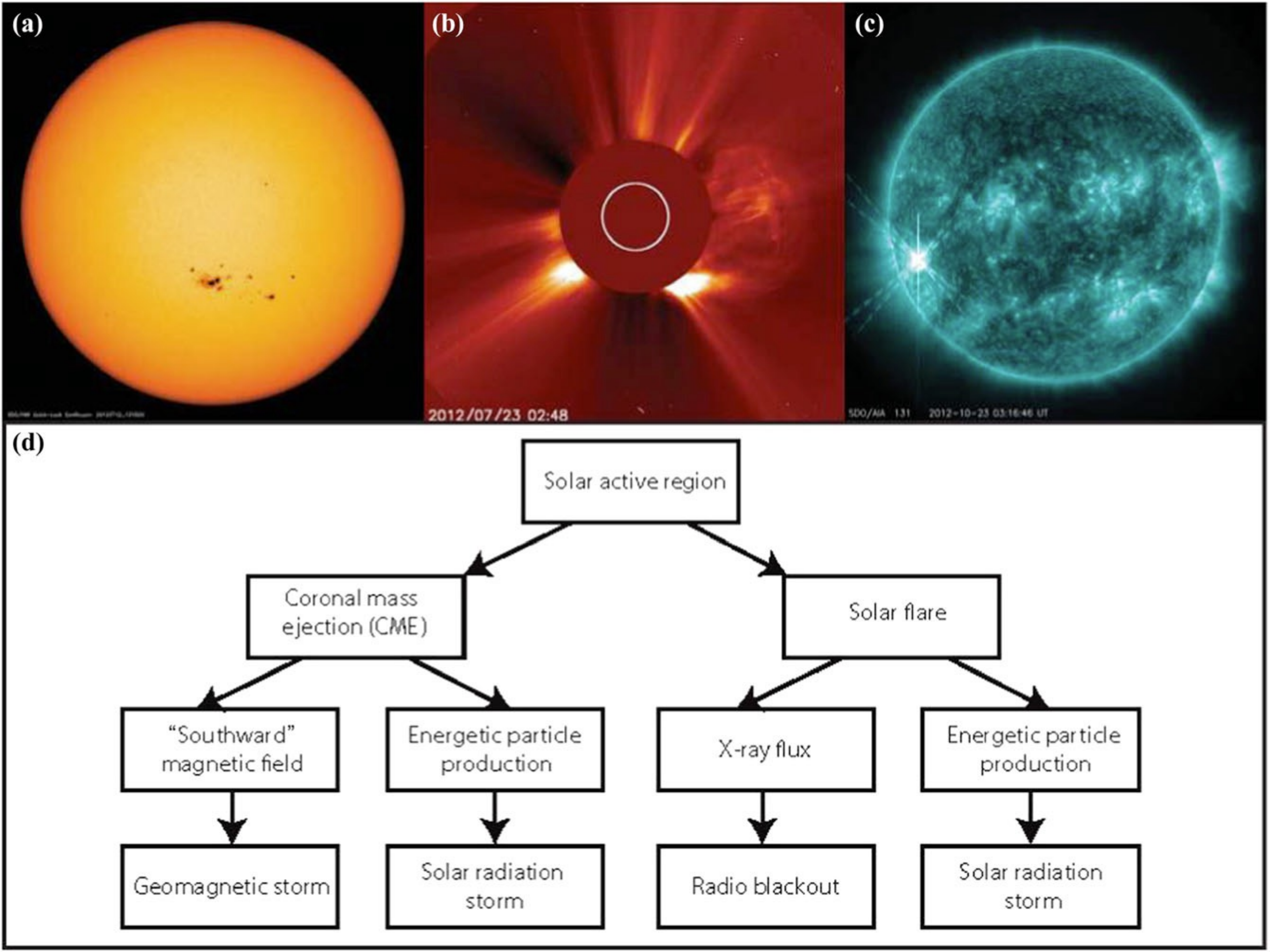
https://youtu.be/GrnGi-q6iWc?si=6C5AzN4vqDYS-Dj9



Space weather includes all conditions and events on the Sun, in the solar wind, in near-Earth space and in our upper atmosphere that can affect space-borne and ground-based technological systems and, through these, human life and endeavor



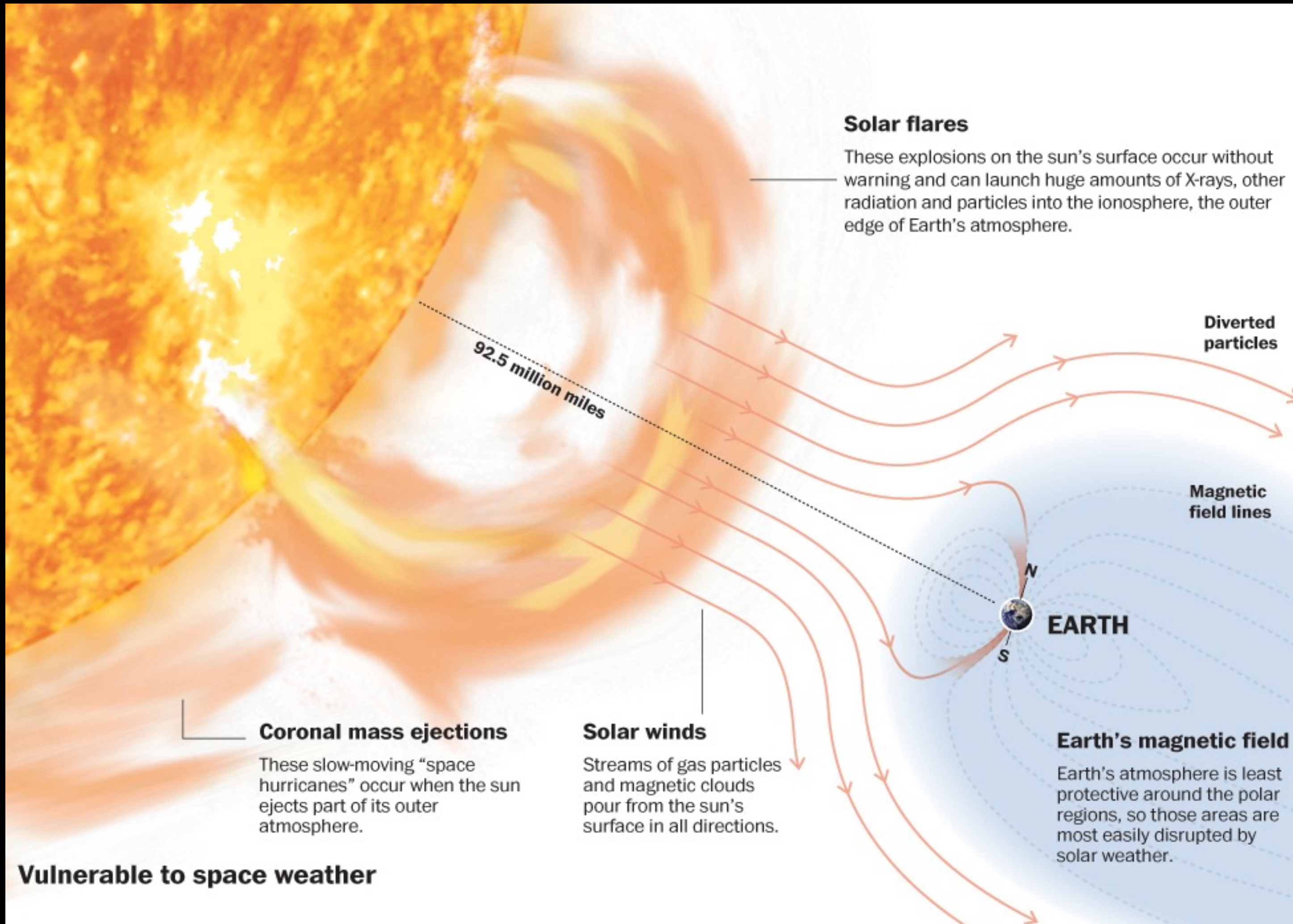
Space weather is the physical and phenomenological state of natural space environments. The associated discipline aims, through observation, monitoring, analysis and modelling, at understanding and predicting the state of the Sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them, and also at forecasting and nowcasting the potential impacts on biological and technological systems.


(a)
(b)
2012/07/23 02:48
(c)
SDO/AIA 131 2012-10-23 03:16:46 UT
(d)
Solar active region
Coronal mass ejection (CME)
Solar flare
"Southward" magnetic field
Energetic particle production
X-ray flux
Energetic particle production
Geomagnetic storm
Solar radiation storm
Radio blackout
Solar radiation storm

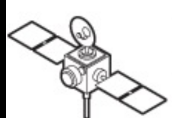
WHY STUDY SPACE ENVIRONMENTS & EFFECTS?

- Spacecraft anomalies
  - 1/3 of all spacecraft anomalies related to the environment

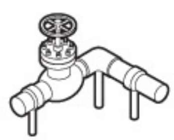
- Spacecraft failures
  - 1/4 of all spacecraft failures related to the environment



Vulnerable to space weather



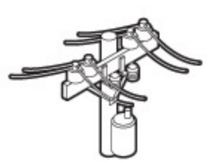
Satellites and GPS devices
Radiation storms can befuddle satellites, delaying or garbling radio waves and mucking up sensitive electronic controls.



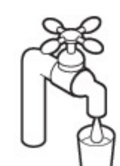
Oil pipelines
Aboveground pipelines can conduct stray currents and become corroded. Alaska's lines are vulnerable because they're so near the North Pole.

Aircraft communications
Transmissions that depend on low-frequency radio waves become unreliable, especially near the North Pole.

International space station
No humans are closer — therefore more vulnerable — to space radiation than residents of the space station.

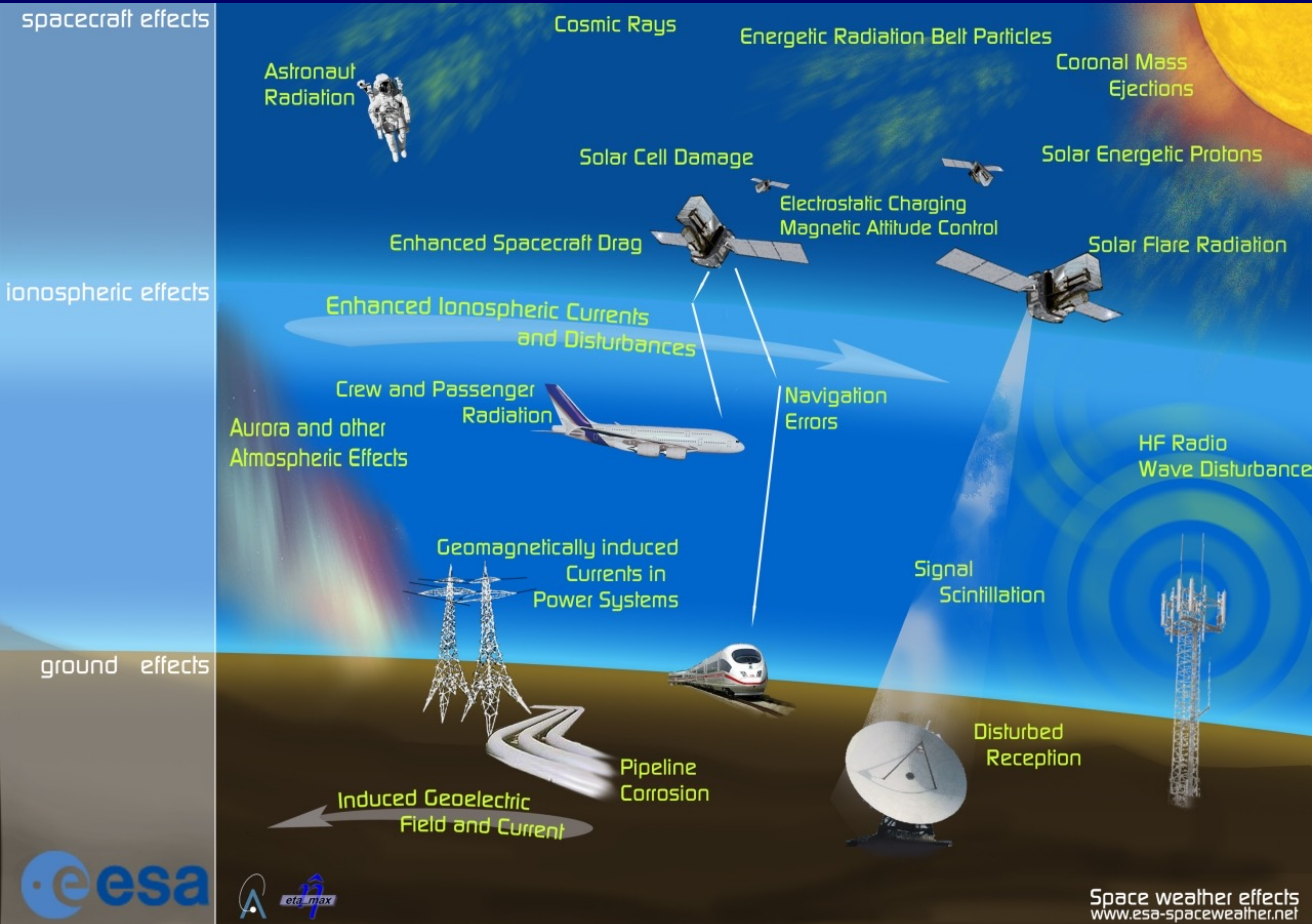


Power grid
Power lines can conduct currents that develop in the ionosphere. The grid is so interconnected that a few blown transformers can cripple a large area.

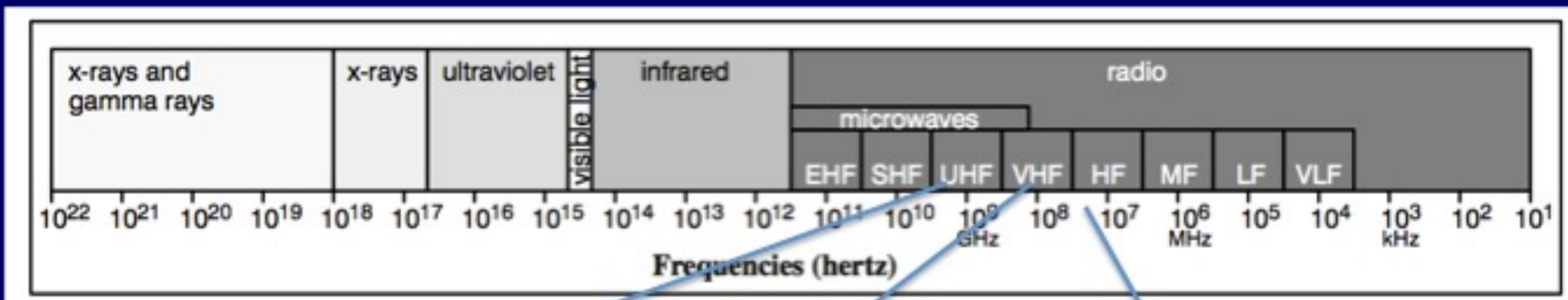


Water supply
Because water processing and distribution depend so heavily on electricity, a major loss of power would affect water delivery within days.

Sun and Earth are shown to approximate scale, but distance is not to scale.


spacecraft effects
ionospheric effects
ground effects
Cosmic Rays
Energetic Radiation Belt Particles
Coronal Mass Ejections
Astronaut Radiation
Solar Cell Damage
Solar Energetic Protons
Electrostatic Charging
Magnetic Attitude Control
Enhanced Spacecraft Drag
Solar Flare Radiation
Enhanced Ionospheric Currents and Disturbances
Crew and Passenger Radiation
Aurora and other Atmospheric Effects
Navigation Errors
HF Radio Wave Disturbance
Geomagnetically induced Currents in Power Systems
Signal Scintillation
Disturbed Reception
Pipeline Corrosion
Induced Geoelectric Field and Current
esa
eta_max
Space weather effects
www.esa-spaceweather.net

Types of space weather events affecting nav and com



UHF – GPS

- Energetic protons/ particles – via SEEs - affecting GPS satellites components
- Geomagnetic storms/ ionospheric storm - cause scintillations

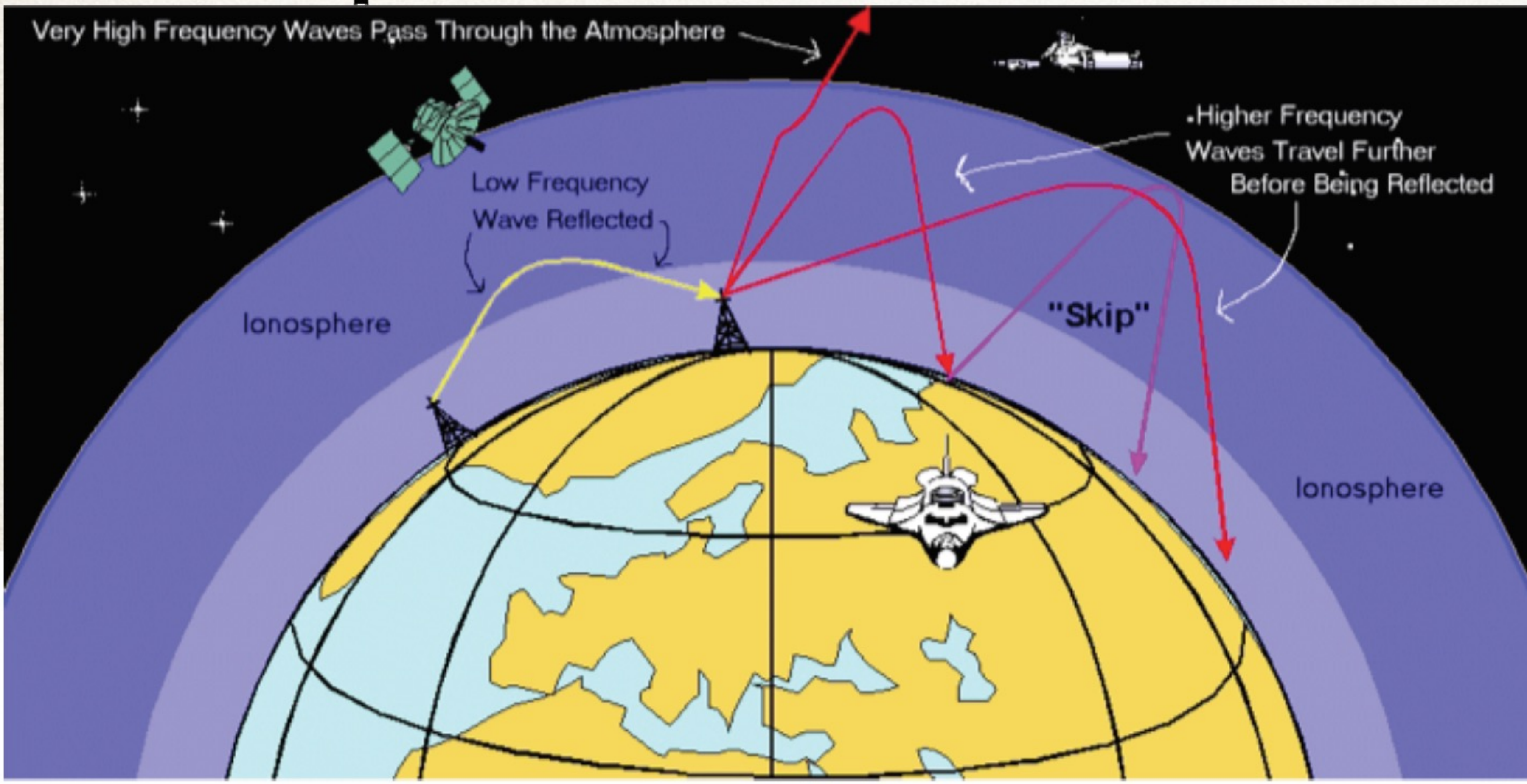
VHF:

- Energetic protons - PCA
- Geomagnetic storms
- Solar radio emission associated with flare/CME

HF:

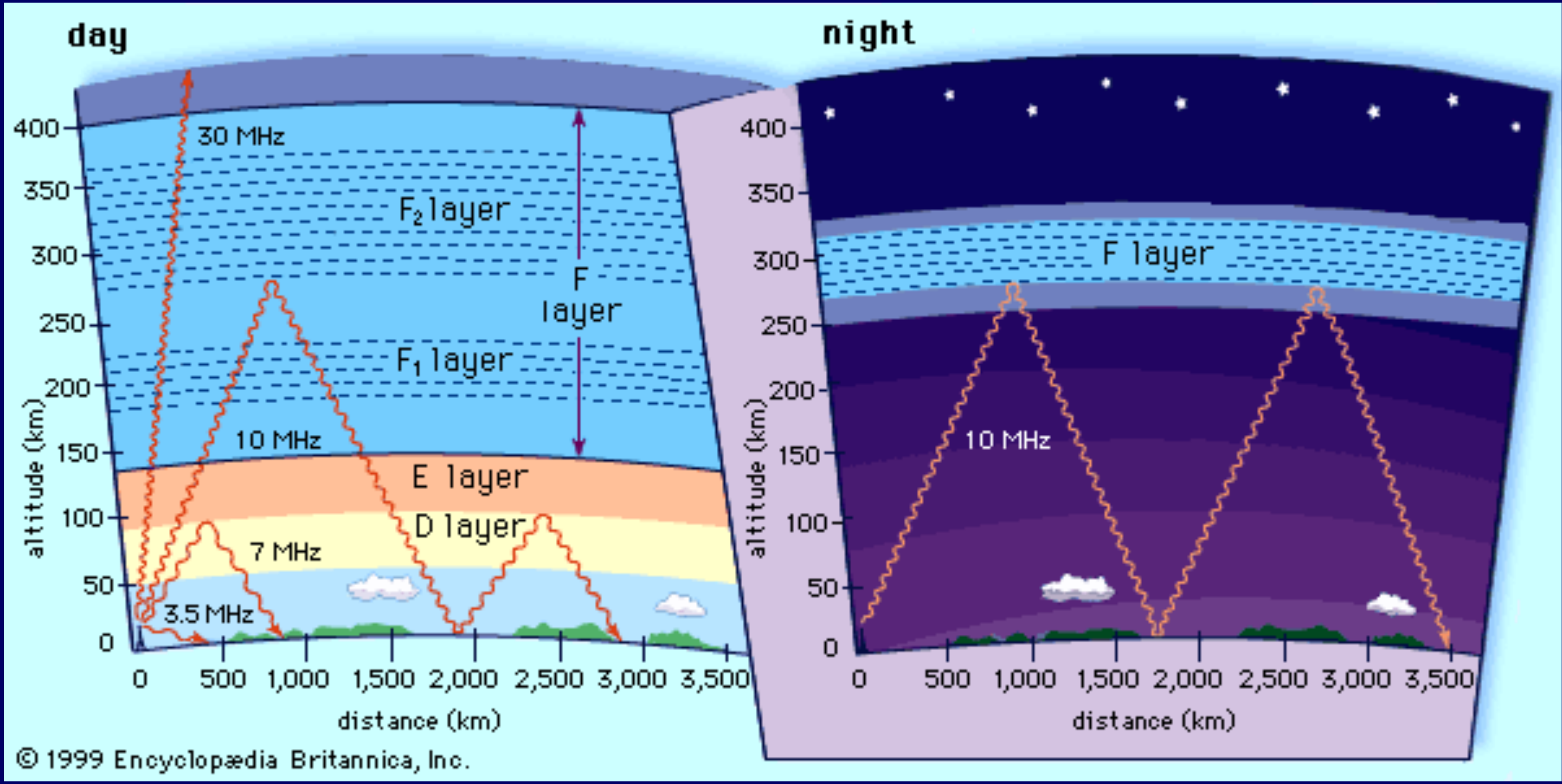
- Solar flares/x-ray
- Energetic protons - PCA
- Geomagnetic activities

Ionospheric cutoff at ~10 MHz:



Συχνότητα ταλάντωσης πλάσματος

$$f_p = 9 * \sqrt{n}\, Hz$$


day
night
400
350
300
250
200
150
100
50
0
altitude (km)
30 MHz
F₂ layer
F
layer
F₁ layer
10 MHz
E layer
D layer
7 MHz
3.5 MHz
0 500 1,000 1,500 2,000 2,500 3,000 3,500
distance (km)
F layer
10 MHz

Secure and safe space environment

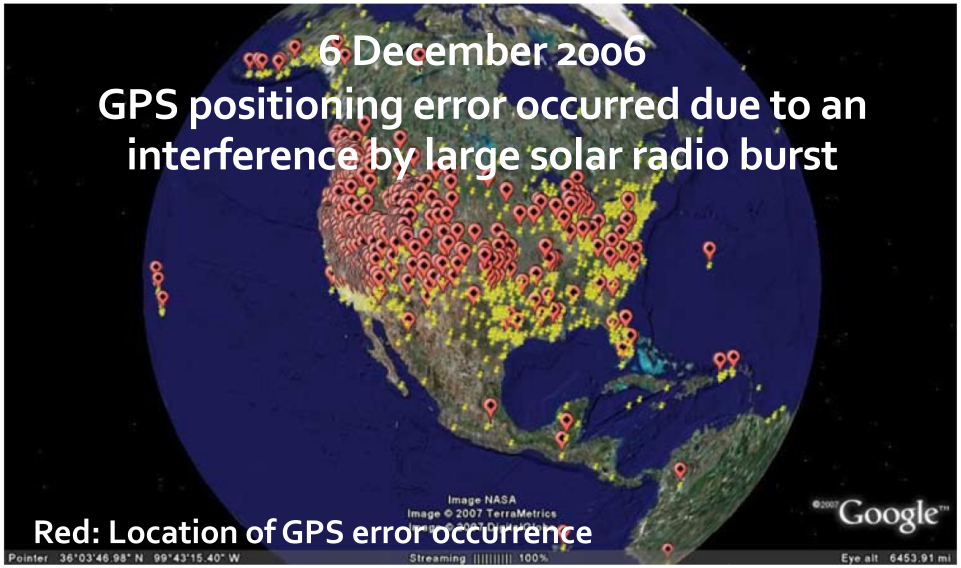
Space capacities are strategically important to civil, commercial, security and defence-related policy objectives. Europe needs to ensure its freedom of action and autonomy. It needs to have access to space and be able to use it safely.

Growing threats are emerging in space: from space debris to cyber threats, the impact of space weather and Near-Earth Objects (NEOs). Europe must draw on its assets and use space capacities to meet the security and safety needs of the Member States and the EU.

Commonly occurring space weather events have the potential to impact the performance of critical space and ground infrastructure, disrupting operations and communications in multiple sectors of society.

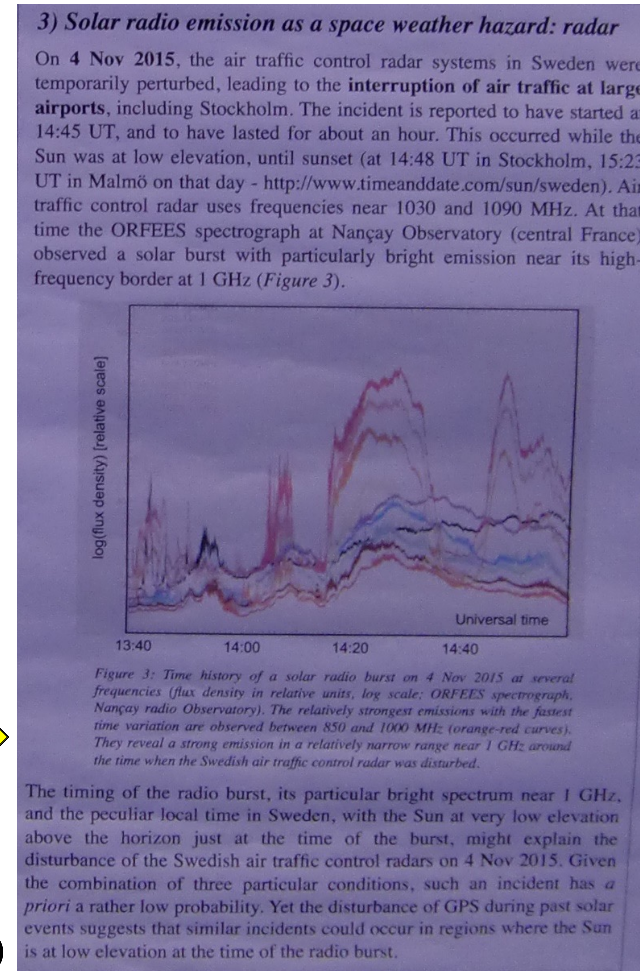
Extreme events could have devastating societal and economic consequences with potential costs for disruptions and damages estimated in tens or even hundreds of billions of Euros.

Monitoring GHz solar radio bursts



(Cerruti+ 2008)

Interruption of air traffic at airport due to disturbance of traffic control radar system by solar radio bursts (2015/11/4 @ Stockholm)



3) Solar radio emission as a space weather hazard: radar

On **4 Nov 2015**, the air traffic control radar systems in Sweden were temporarily perturbed, leading to the **interruption of air traffic at large airports**, including Stockholm. The incident is reported to have started at 14:45 UT, and to have lasted for about an hour. This occurred while the Sun was at low elevation, until sunset (at 14:48 UT in Stockholm, 15:23 UT in Malmö on that day - http://www.timeanddate.com/sun/sweden). Air traffic control radar uses frequencies near 1030 and 1090 MHz. At that time the ORFEES spectrograph at Nançay Observatory (central France) observed a solar burst with particularly bright emission near its high-frequency border at 1 GHz (*Figure 3*).

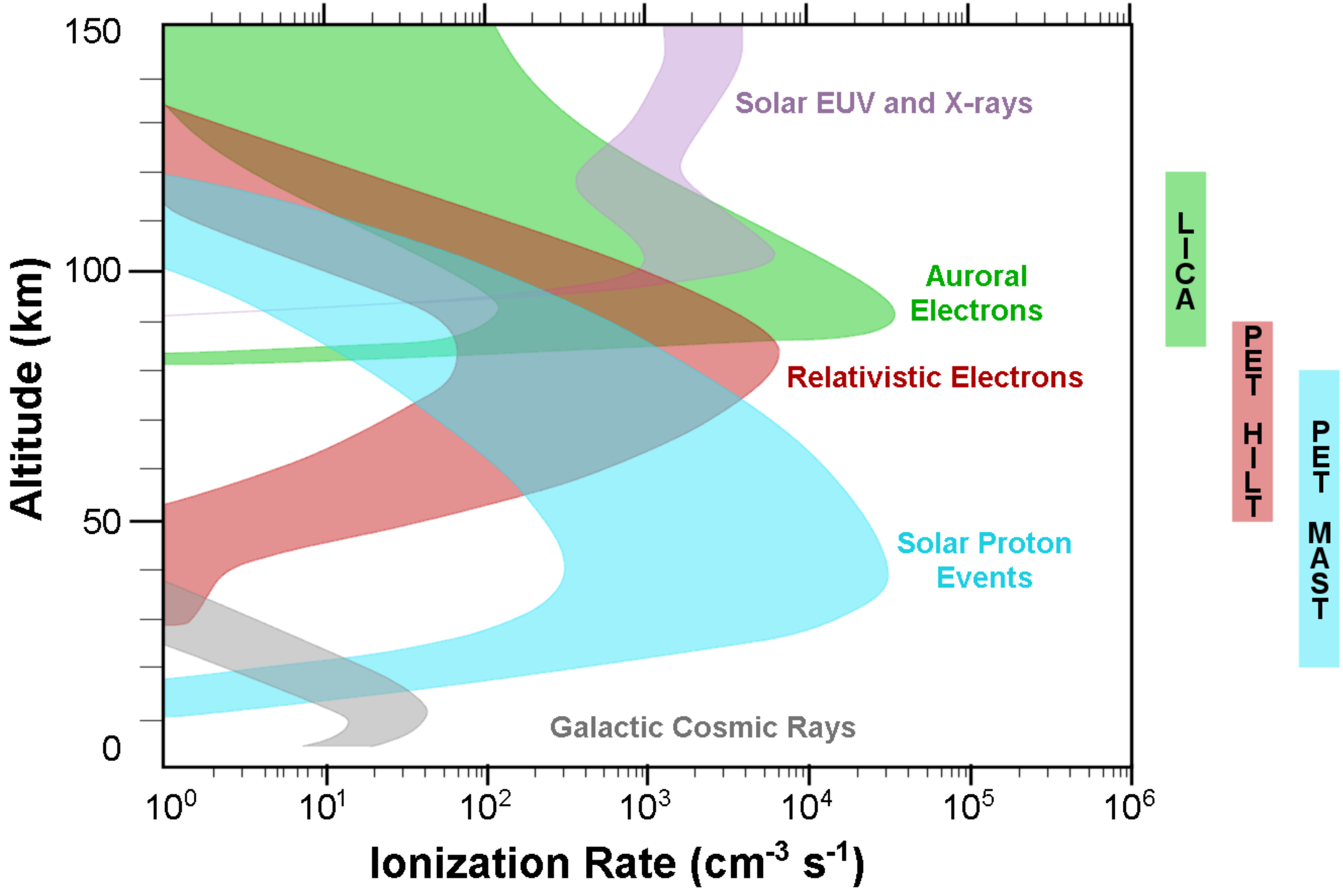
Figure 3: Time history of a solar radio burst on 4 Nov 2015 at several frequencies (flux density in relative units, log scale; ORFEES spectrograph, Nançay radio Observatory). The relatively strongest emissions with the fastest time variation are observed between 850 and 1000 MHz (orange-red curves). They reveal a strong emission in a relatively narrow range near 1 GHz around the time when the Swedish air traffic control radar was disturbed.

The timing of the radio burst, its particular bright spectrum near 1 GHz, and the peculiar local time in Sweden, with the Sun at very low elevation above the horizon just at the time of the burst, might explain the disturbance of the Swedish air traffic control radars on 4 Nov 2015. Given the combination of three particular conditions, such an incident has *a priori* a rather low probability. Yet the disturbance of GPS during past solar events suggests that similar incidents could occur in regions where the Sun is at low elevation at the time of the radio burst.

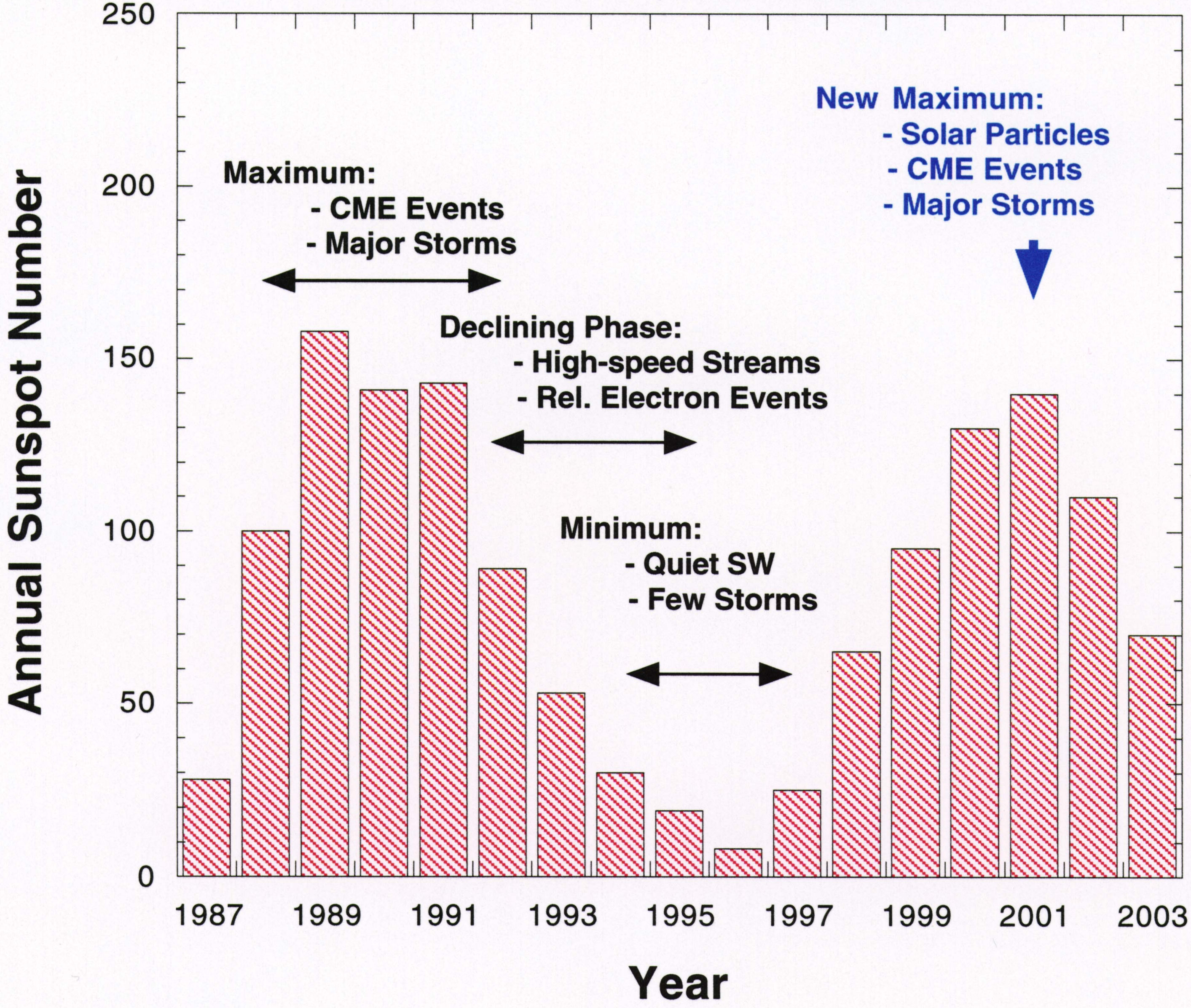
(Klein+ 2015)

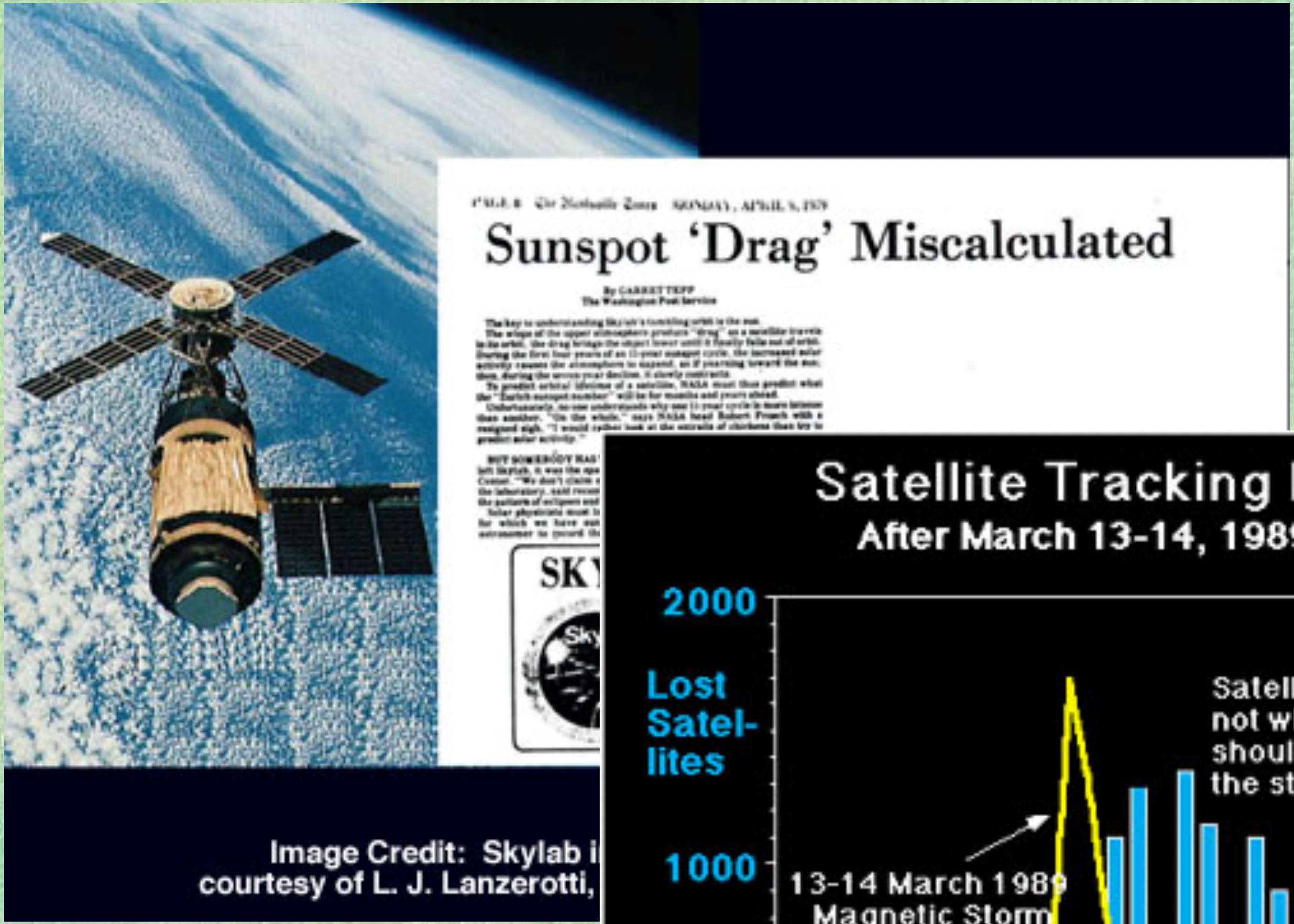
Cerruti, A. P. +, Space Weather, 6, S10D07, 2008
Klein, K.-L. +, European Space Weather Week 12, Poster Presentation, 2015

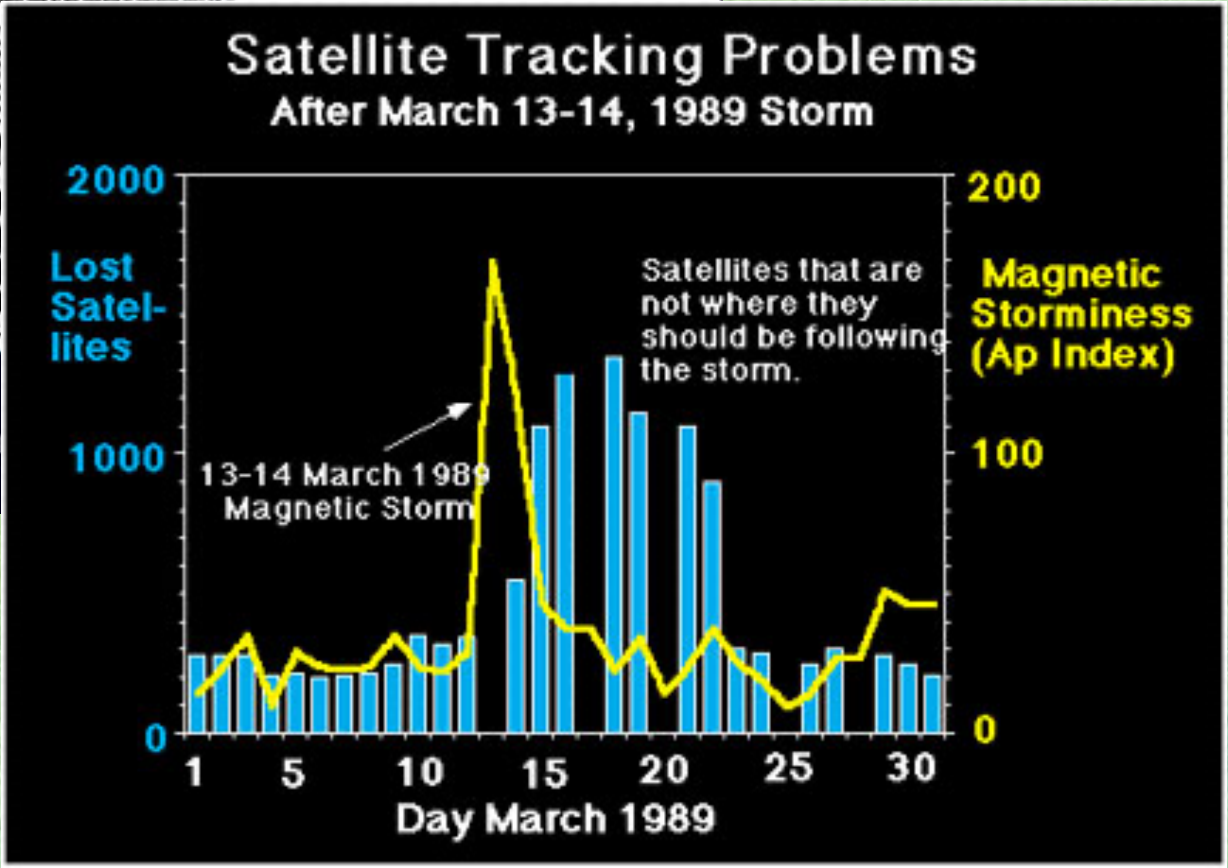
Atmospheric Penetration

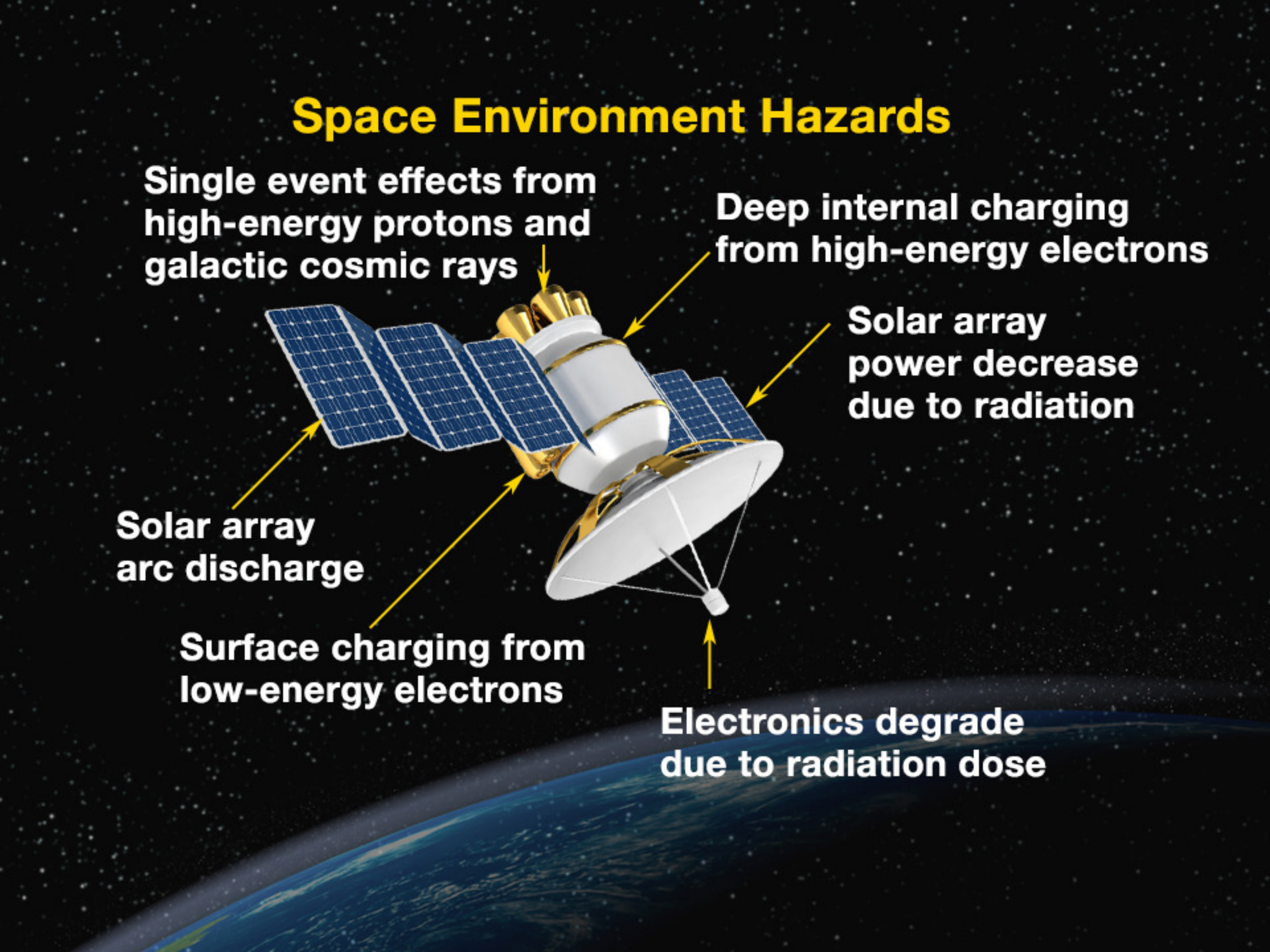


The Solar Cycle and Space Weather

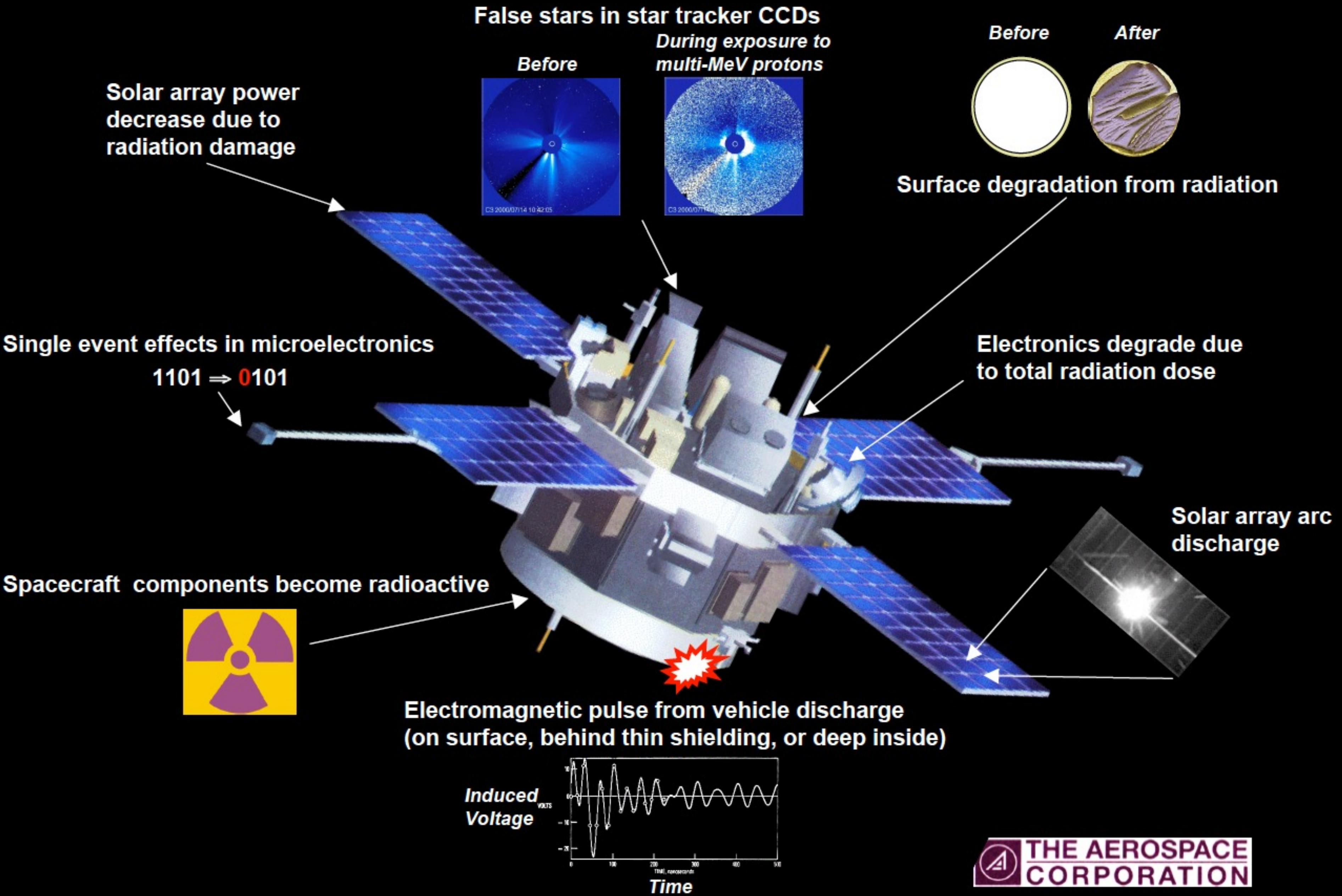



Sunspot 'Drag' Miscalculated
Image Credit: Skylab i
courtesy of L. J. Lanzerotti,


Satellite Tracking Problems
After March 13-14, 1989 Storm
Lost Satel-lites
2000
1000
0
Magnetic Storminess (Ap Index)
200
100
0
Satellites that are not where they should be following the storm.
13-14 March 1989 Magnetic Storm
1
5
10
15
20
25
30
Day March 1989


Space Environment Hazards
Single event effects from high-energy protons and galactic cosmic rays
Deep internal charging from high-energy electrons
Solar array power decrease due to radiation
Solar array arc discharge
Surface charging from low-energy electrons
Electronics degrade due to radiation dose

Major Space Environment Hazards

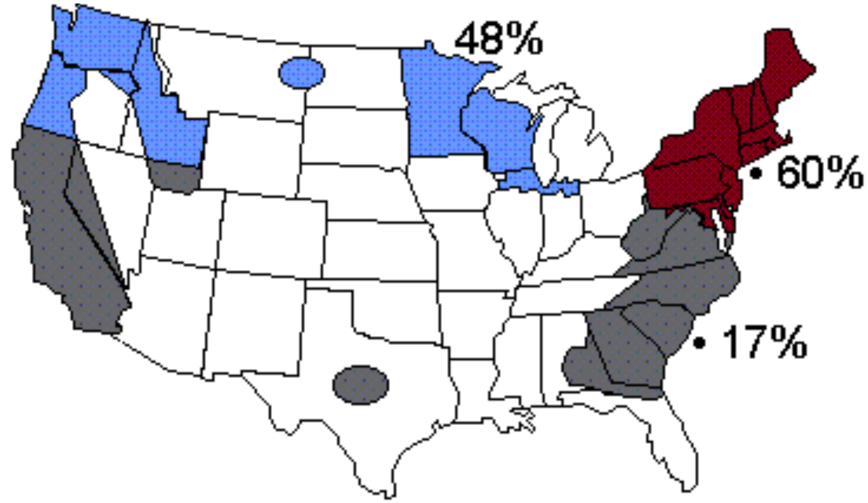


Space weather events

• 20.1. 1994	Damaged	Canadian Anik-1&2	communication
• 26.3. 1996	Damaged	Canadian Anik-1&2	communication
• 11.1. 1997	Lost	Telstar 401	communication
• 2-4.5. 1998	Lost	Equator-S Galaxy-4	scientific communication
• 6.-7.4. 2000	Degraded (solar panels aged in one day as much as usually during one year)	SOHO	scientific
• 10.11.2000	Degraded (solar panels lose 2% of power)	Cluster	scientific

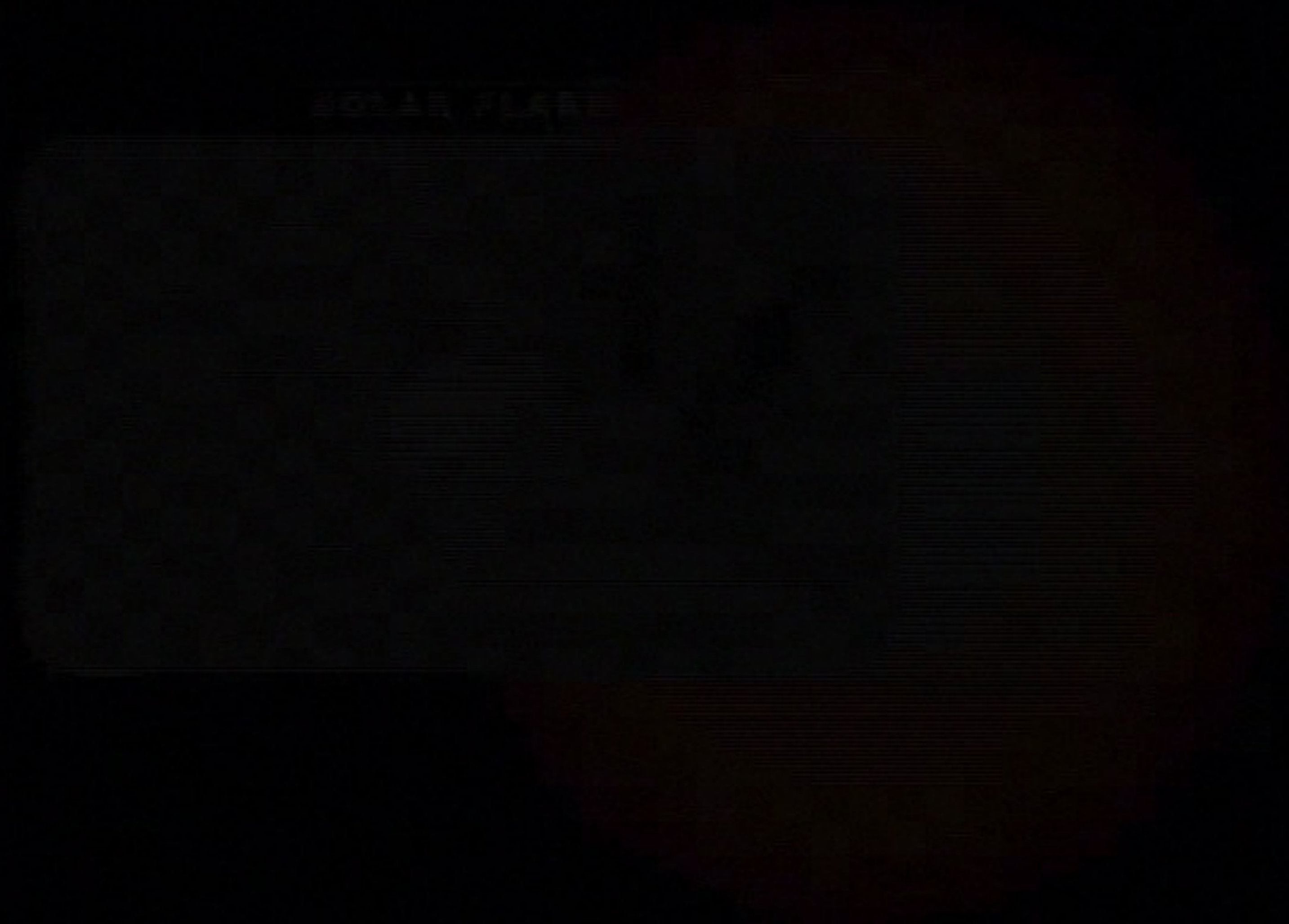
- Incidents on commercial satellites poorly reported

Συγκριτικά ποσοστά βλαβών μετασχηματιστών στις ΗΠΑ



Βλάβη μετασχηματιστή στο πυρηνικό εργοστάσιο του Salem, κοντά στη Βοστώνη, το Μάρτιο του 1989

Καταστροφή πηνίου μετασχηματιστή από ισχυρή διαστημική καταιγίδα


SOLAR FLARE

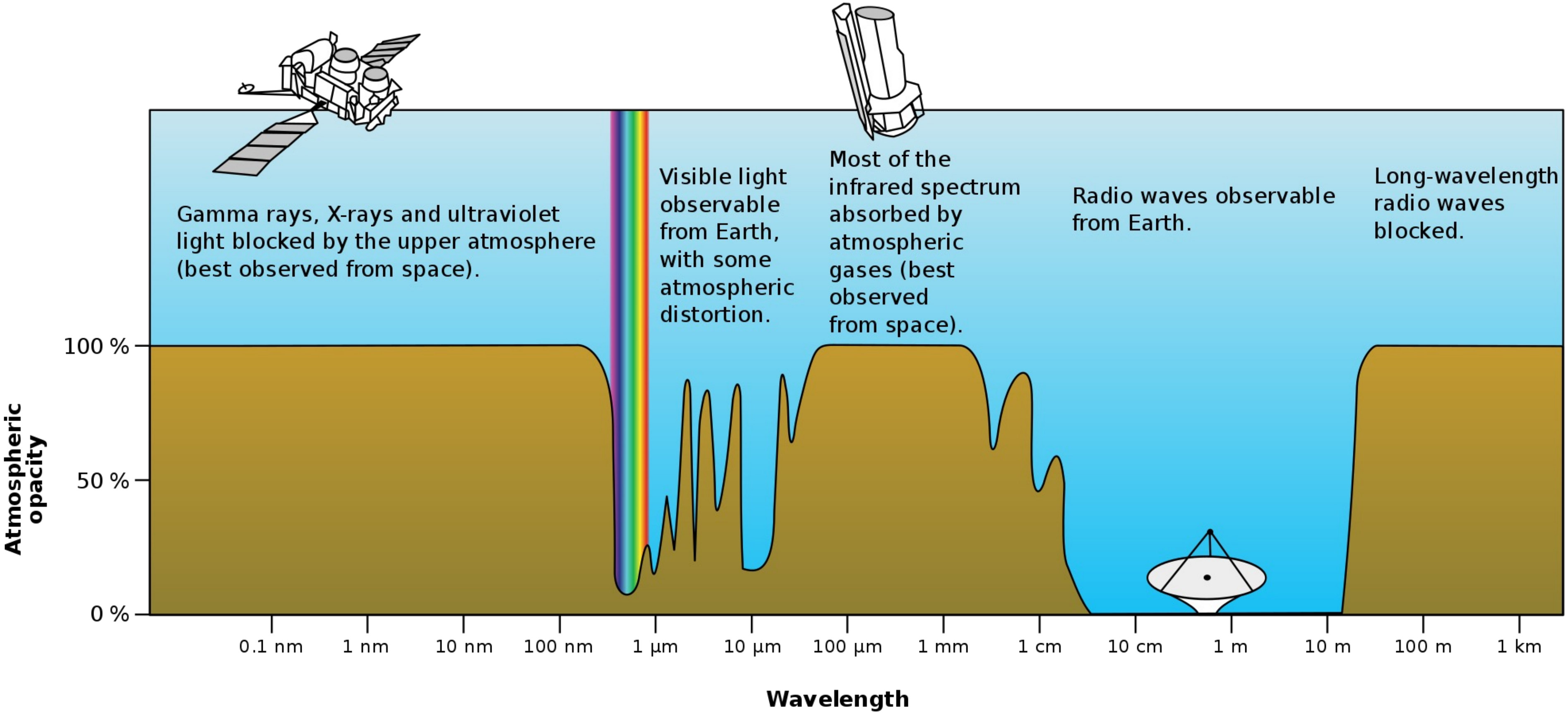
Επίδραση Διαστημικού Καιρού

Space weather effects on the near-Earth space environment (geospace) are due to **dynamic changes in the energy transfer processes from the Sun's photons, particles, and fields**. Domains of geospace that are affected by space weather: the magnetosphere, ionosphere, thermosphere, and even troposphere

Διαστημικό περιβάλλον και επιπτώσεις

Components of the space environment	Effects	System affected	Other problems
Neutrals	Drag Oxidisation Contamination	Orbit control Temperature control Shields	Glow
Photons	Heating Photo-emission Surface ageing Backgr. noise increase Positive voltage	Temperature control Sensors	Contamination
Plasmas	Surface ageing Current closure Surface charging ESDs EM noise	High-voltage systems Temperature control RF systems	Contamination
Particle radiation	Ageing Atom displacements Internal charging ESDs Backgr. noise increase SEEs DNA damage Cell destruction	Temperature control Electronic components Solar cells Star trackers Detector background Living organisms	Genetics, Cancer Death
Meteoroids	Impact Induced neutral and plasma environment	Partial destruction Attitude control Coating erosion	ESDs Contamination
Debris	Impact Induced neutral and plasma environment	Partial destruction Attitude control Coating erosion	ESDs Contamination
Magnetic field	Local change	Magnetic attitude control	

Ατμοσφαιρική αδιαφάνεια



Ταξινόμηση διαστημικής κακοκαιρίας κατά NOAA

Ραδιοκαταιγίδες [flares]
(Radio storms)
Ηλιακές καταιγίδες [flares/CMEs]
(Solar radiation storms)
Γεωμαγνητικές καταιγίδες [CMEs]
(Geomagnetic storms)

Ραδιοκαταιγίδες:

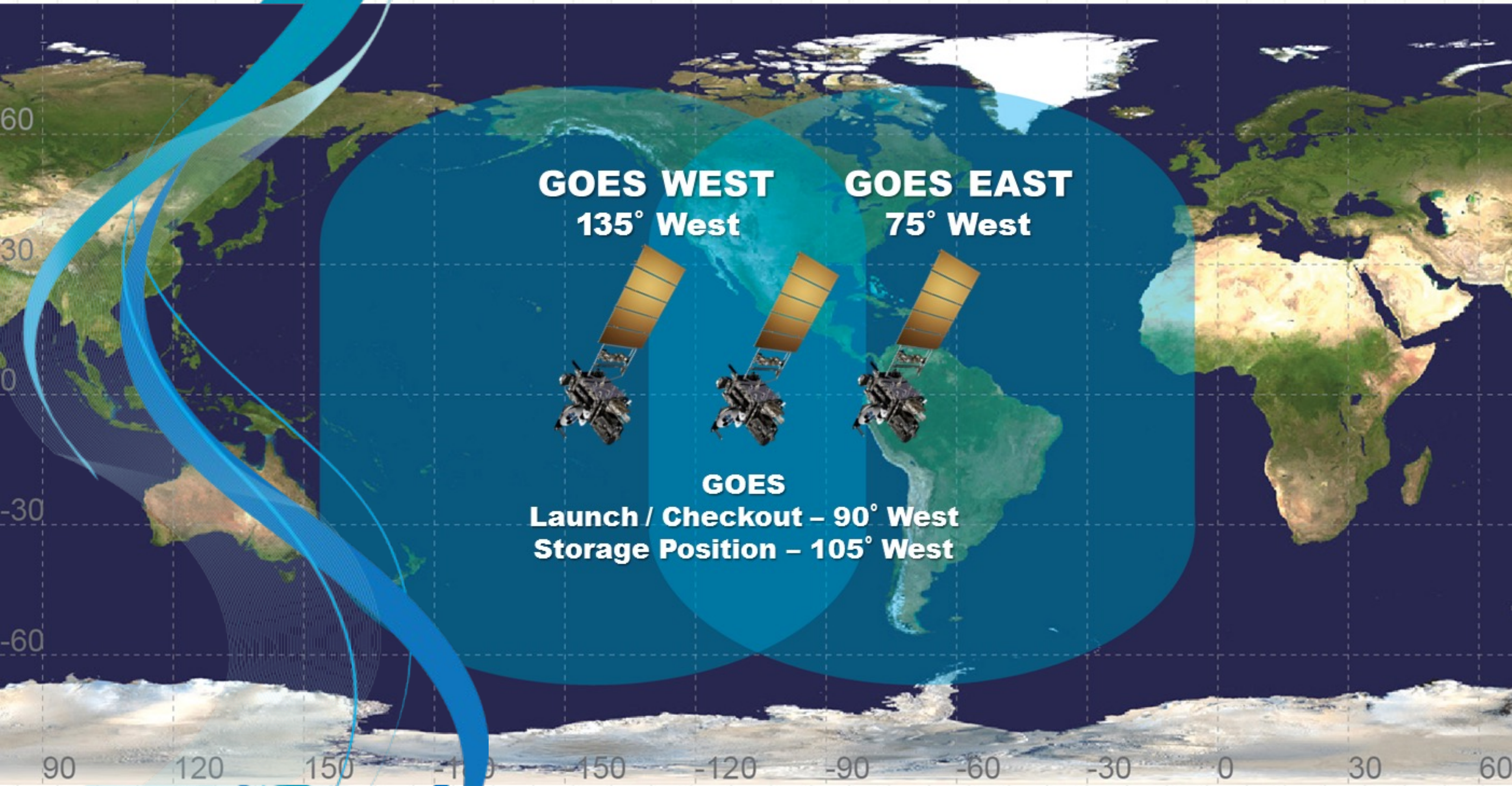
Αφορούν τηλεπικοινωνίες και δορυφορική πλοήγηση

Ελάσσων – Μέτρια – Ισχυρή – Σοβαρή - Ακραία

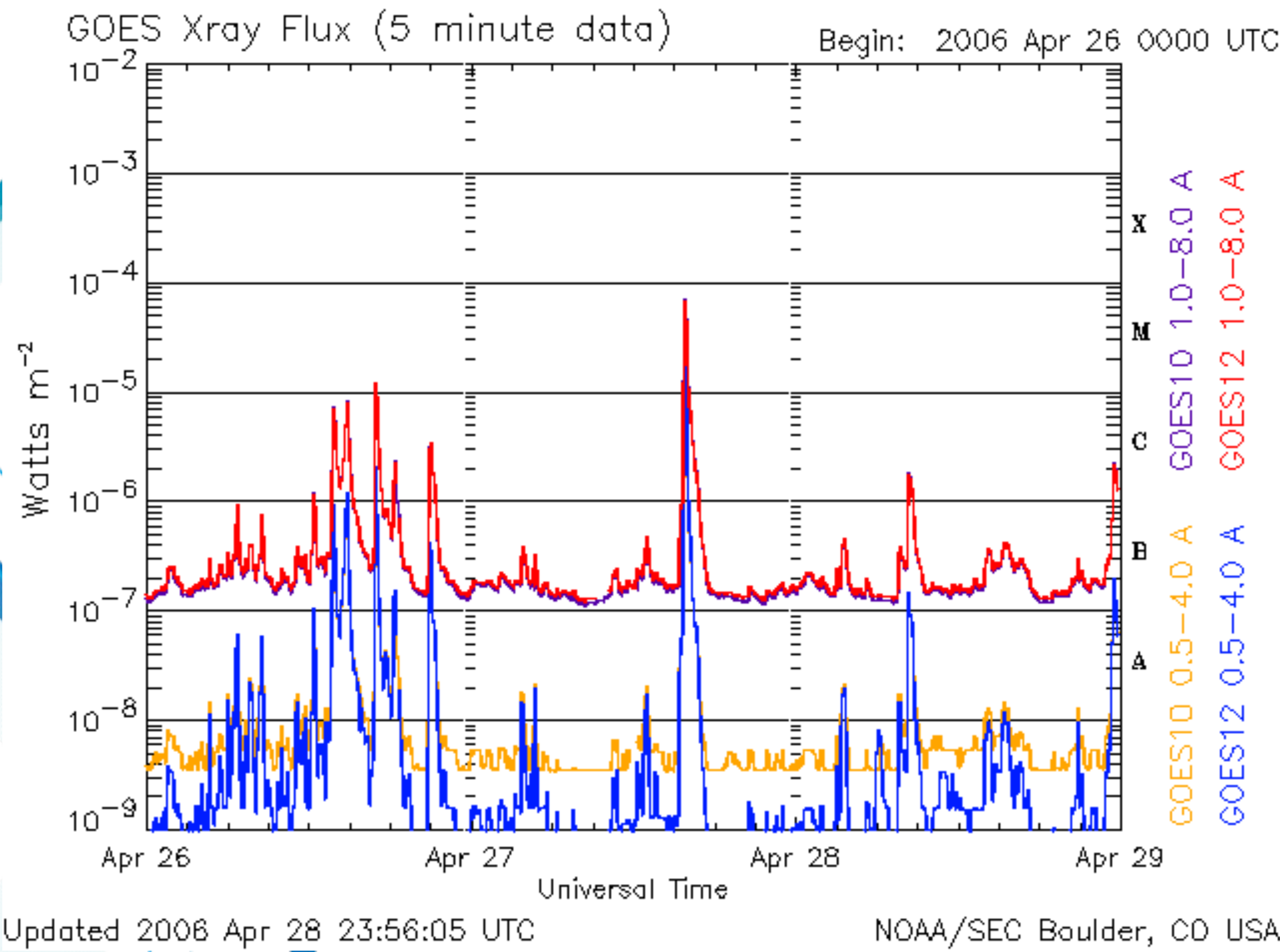
Ακτίνες Χ από GOES:

M1 – M5 – X1 – X10 - X20

GOES

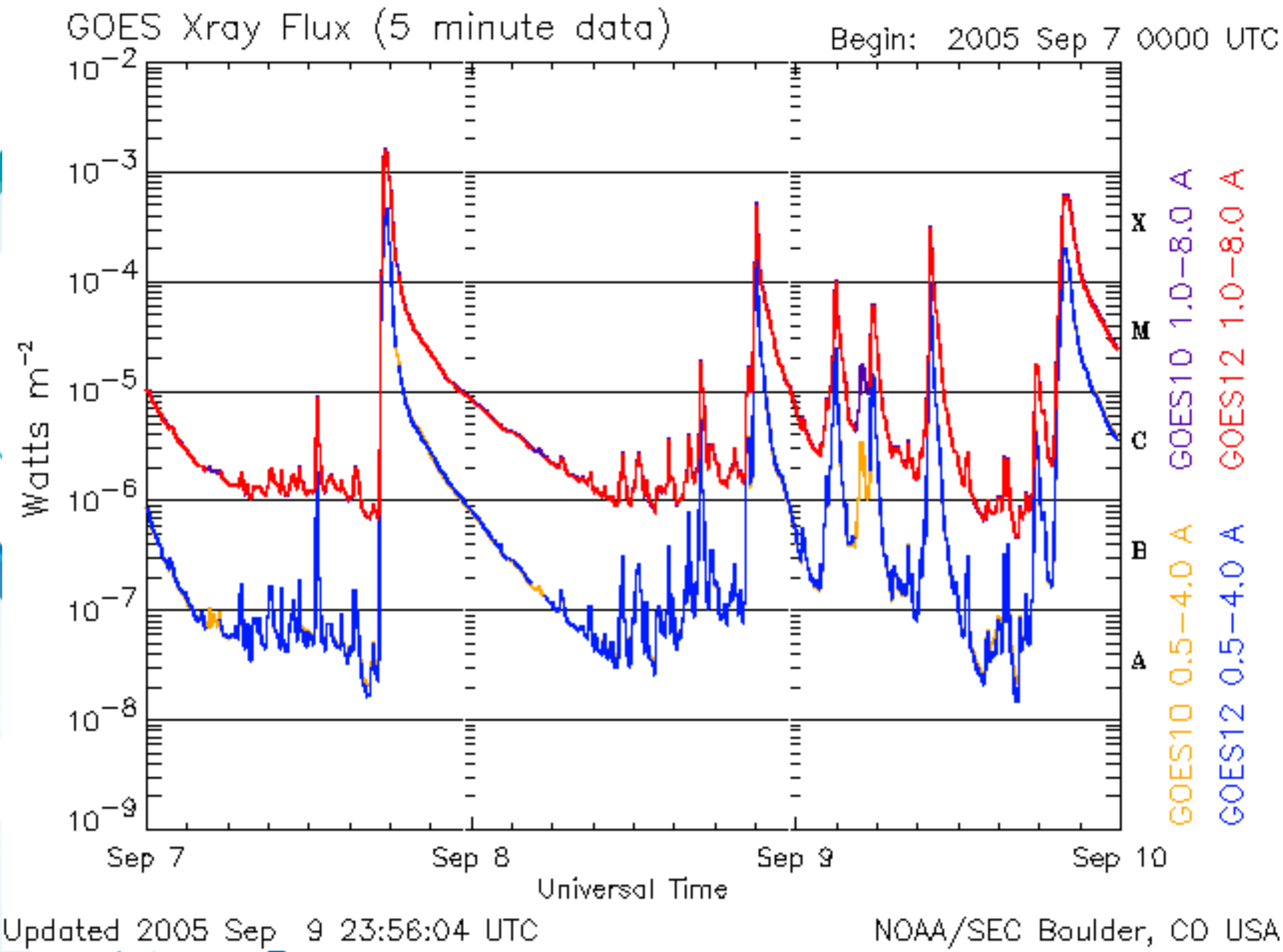

GOES WEST
135° West
GOES EAST
75° West
GOES
Launch / Checkout – 90° West
Storage Position – 105° West
60
30
0
-30
-60
90
120
150
-150
-120
-90
-60
-30
0
30
60

Soft X-Ray Light Curves from GOES (Geostationary Operational Environmental Satellites)



M7 Flare

Soft X-Ray Light Curves from GOES (Geostationary Operational Environmental Satellites)



X17 Flare

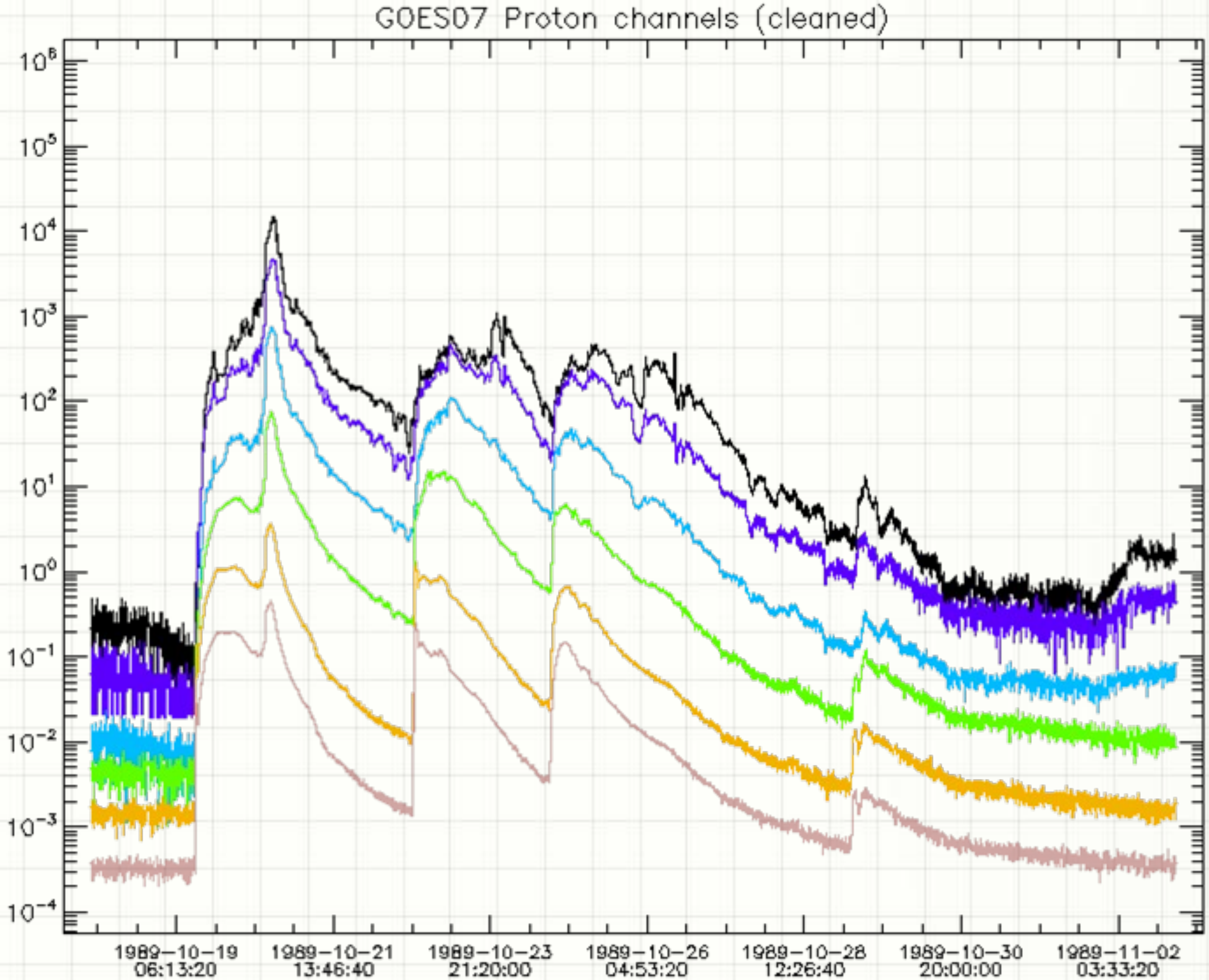
Ηλιακές καταιγίδες:

Αφορούν λειτουργία δορυφόρων και βιολογικές επιπτώσεις

Ελάσσων – Μέτρια – Ισχυρή – – Σοβαρή – Ακραία

Ροή ενεργητικών ιόντων >10 MeV

$10 - 10^2 - 10^3 - 10^4 - 10^5$



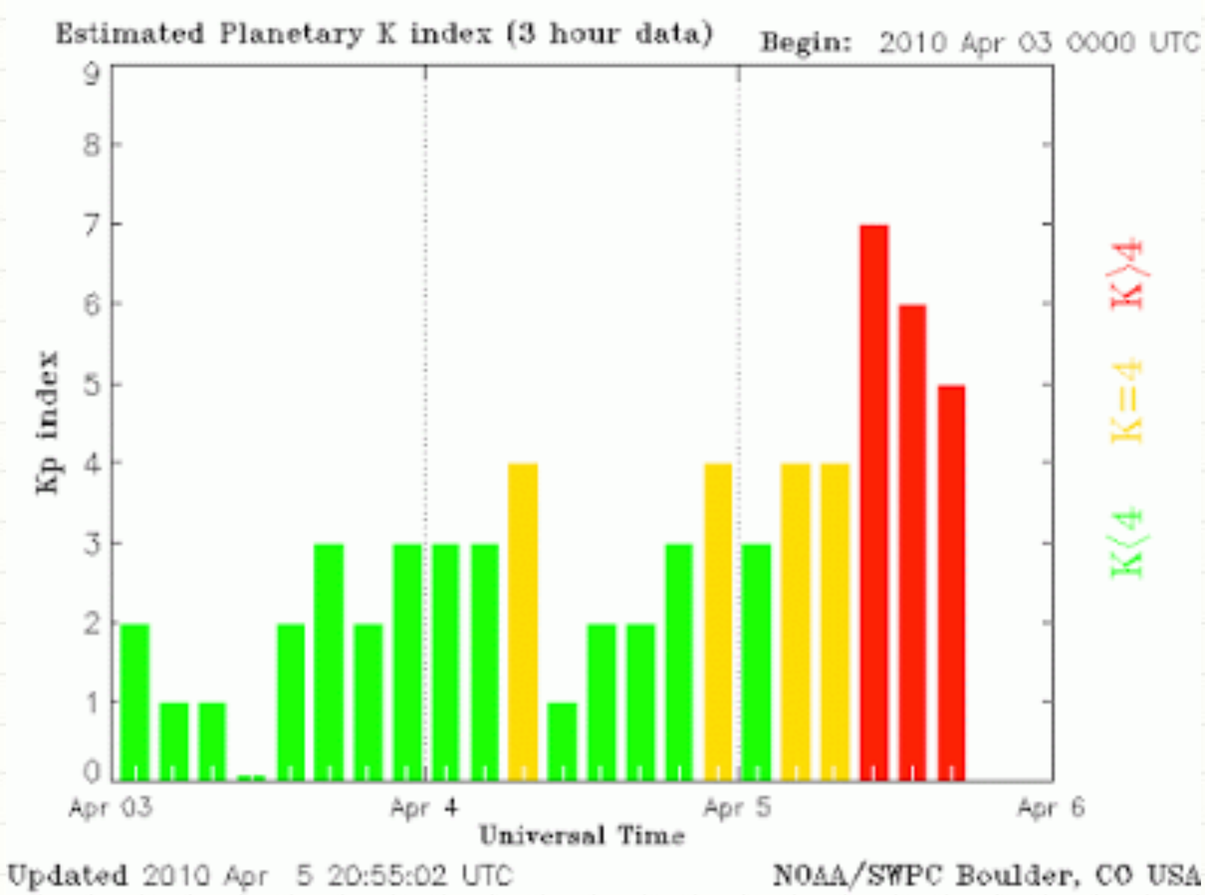
GOES07 Proton channels (cleaned)
10⁶
10⁵
10⁴
10³
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
1989-10-19 06:13:20
1989-10-21 13:46:40
1989-10-23 21:20:00
1989-10-26 04:53:20
1989-10-28 12:26:40
1989-10-30 20:00:00
1989-11-02 03:33:20

Γεωμαγνητικές καταιγίδες:

Αφορούν λειτουργία διαφόρων τεχνολογικών συστημάτων

Ελάσσων – Μέτρια – Ισχυρή – Σοβαρή – Ακραία

Δείκτης Kp: 5, 6, 7, 8, 9



Estimated Planetary K index (3 hour data)
Begin: 2010 Apr 03 0000 UTC
Kp index
0
1
2
3
4
5
6
7
8
9
Apr 03
Apr 4
Apr 5
Apr 6
Universal Time
K<4
K=4
K>4
Updated 2010 Apr 5 20:55:02 UTC
NOAA/SWPC Boulder, CO USA

http://www.swpc.noaa.gov/noaa-scales-explanation