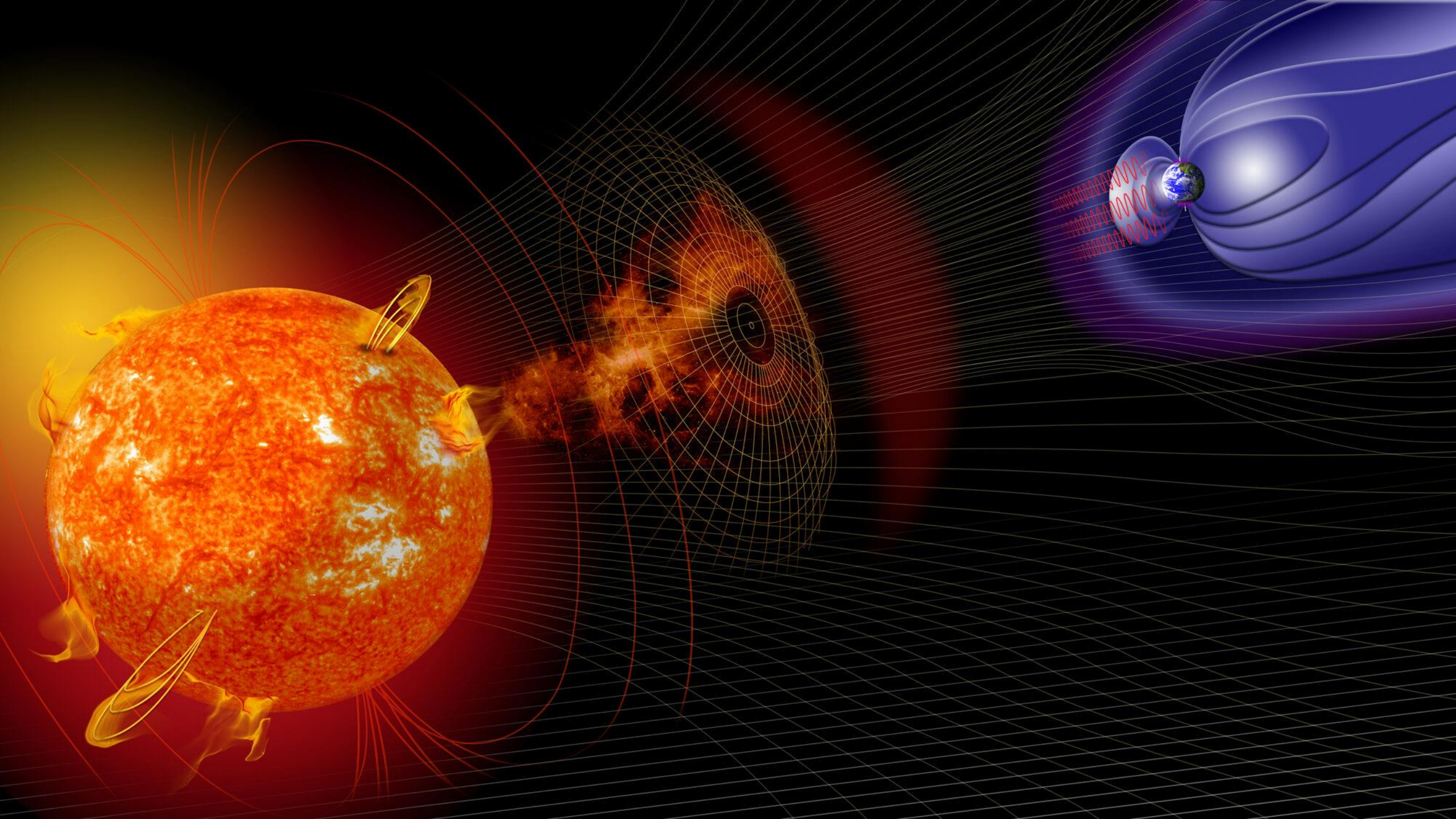
SELENE

Space Weather Effect at different altitude LEvels measured by a Newtron and muon Detectors network

Davide Grandi

On behalf of
INFN Milano Bicocca group

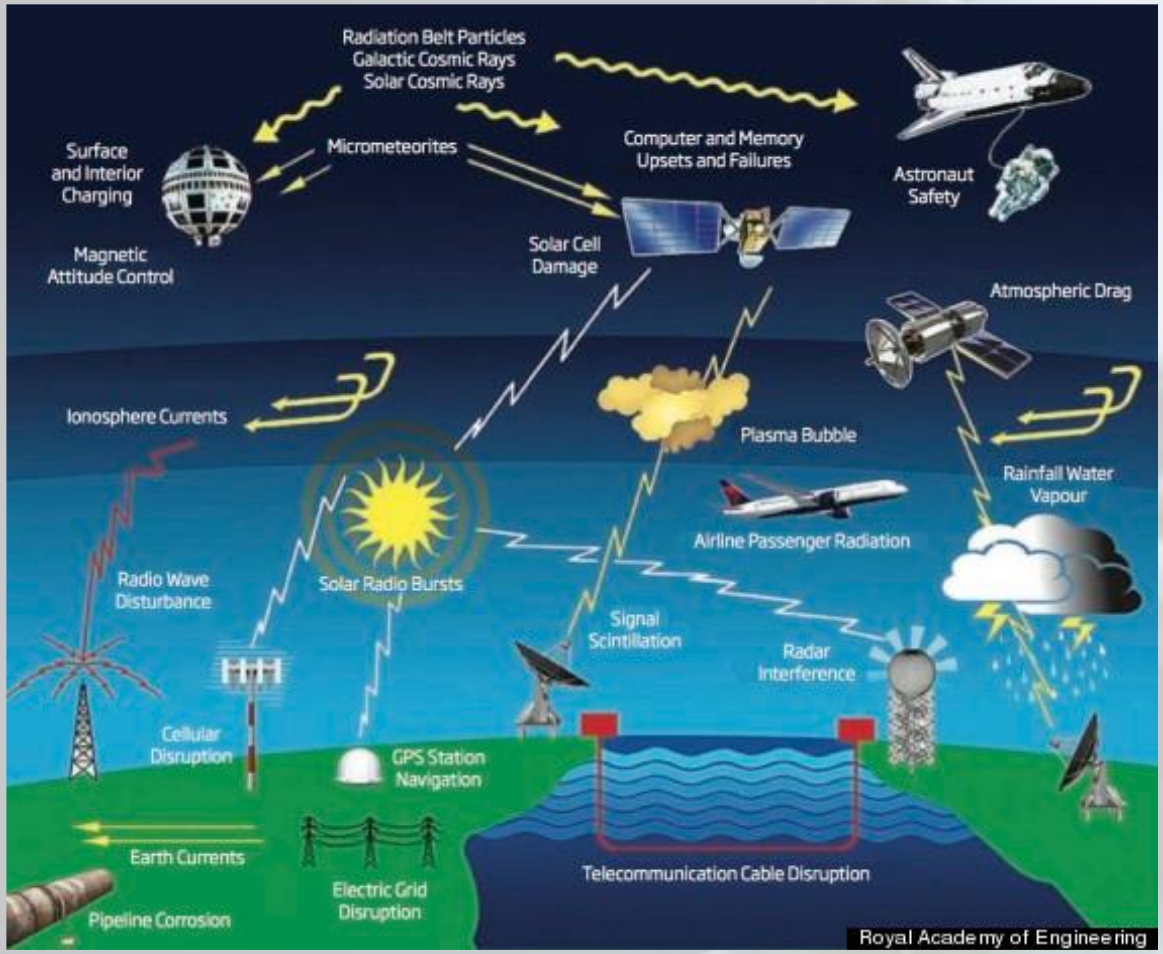
INFN CV Meeting

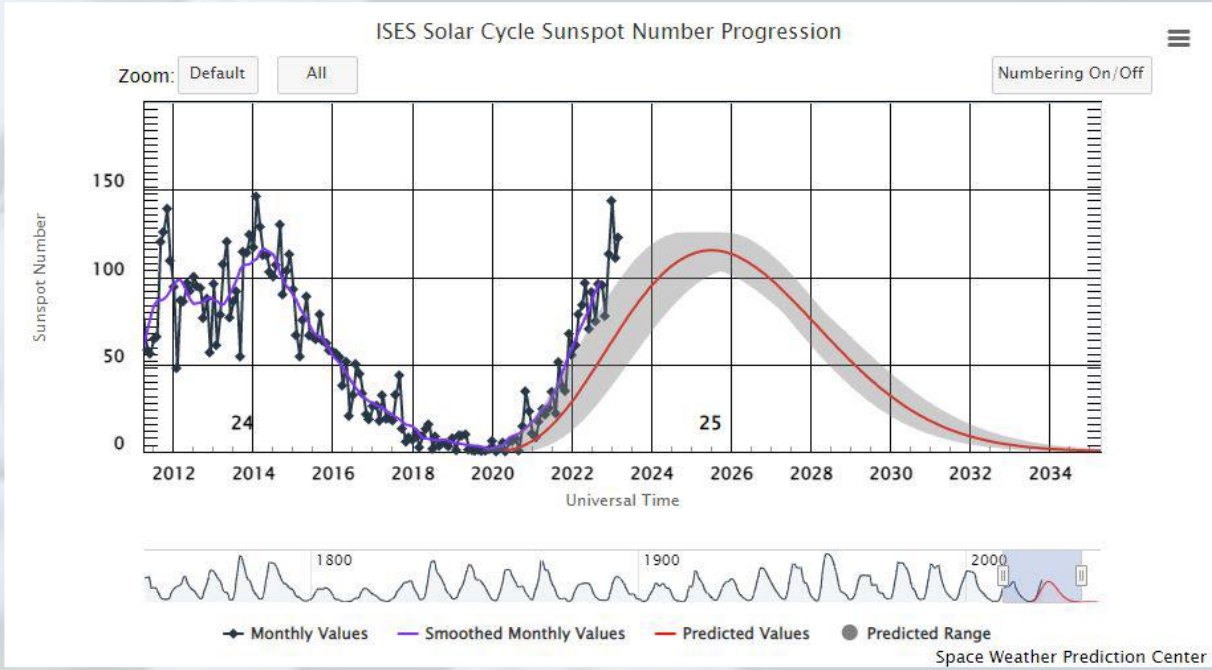


Summary

- Space Weather and Cosmic Rays
- Solar Events
- Neutron Monitors
- Cosmic Muons
- Other experiments
- Science goals
- Timeline
- INFN sites involved
- Our “possible” network

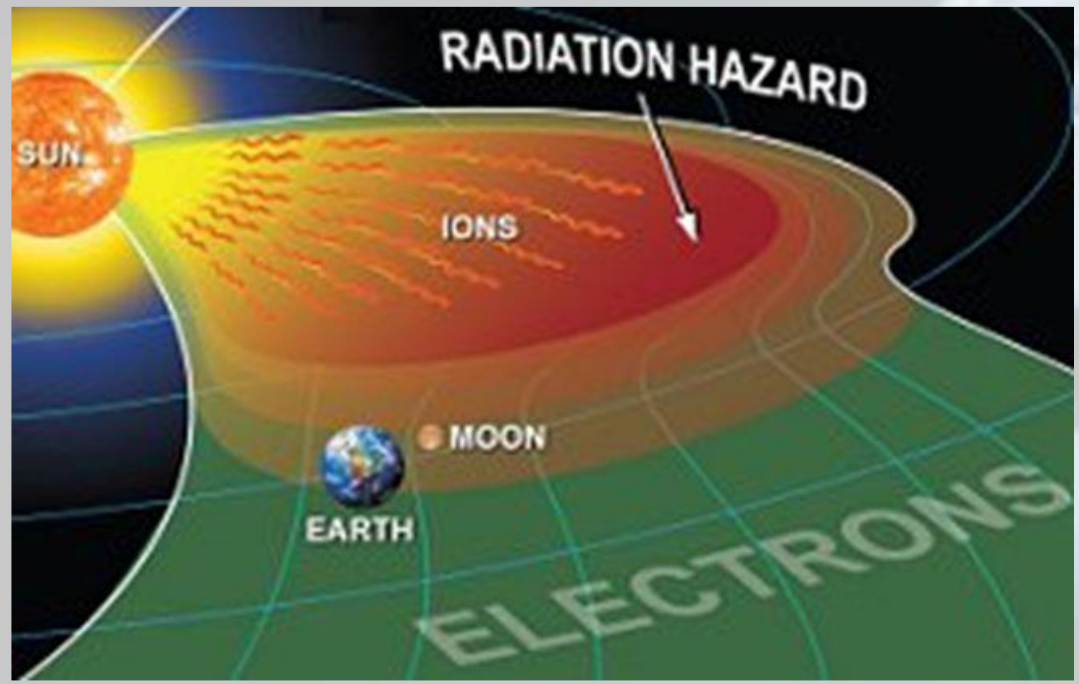
Space Weather and Cosmic Rays



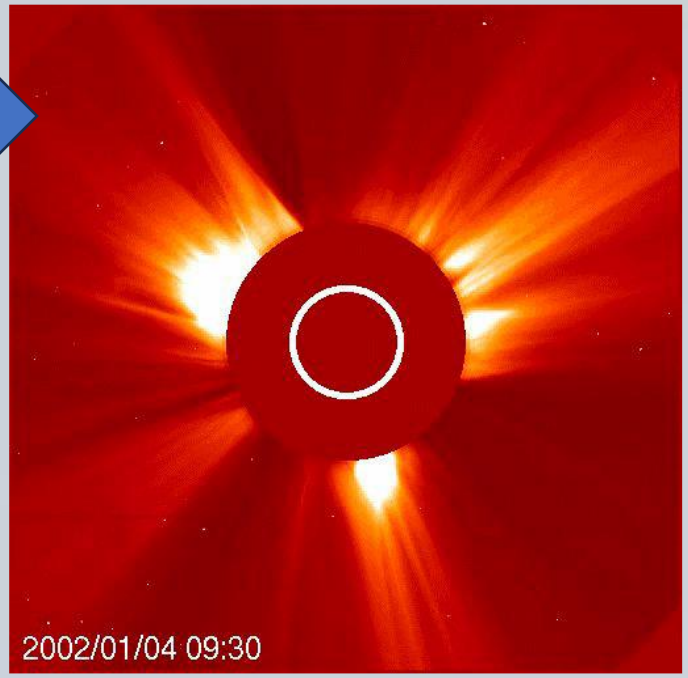


Current solar cycle 25 is ramping up; currently on the high side of the forecast margin of error

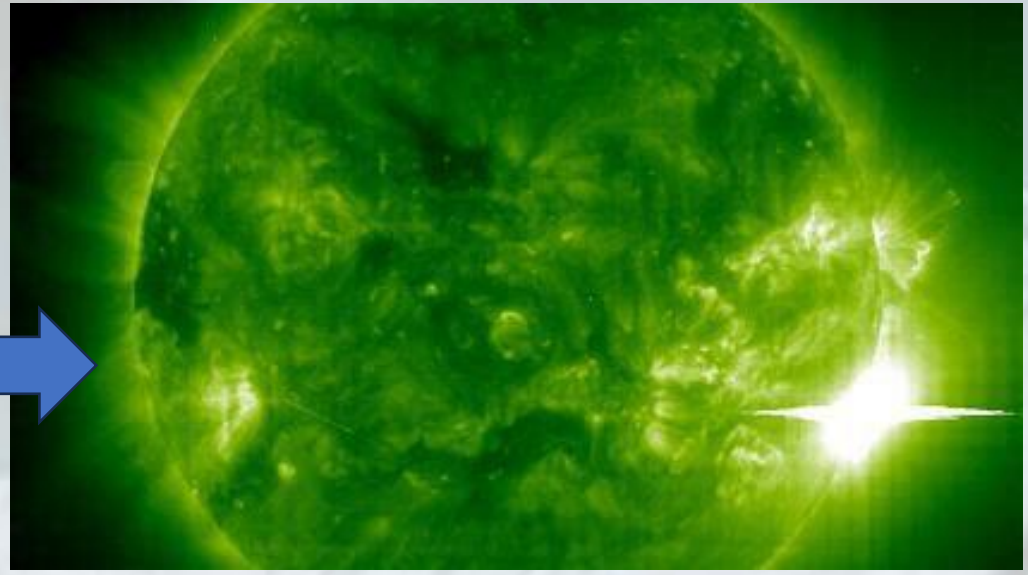
Solar events



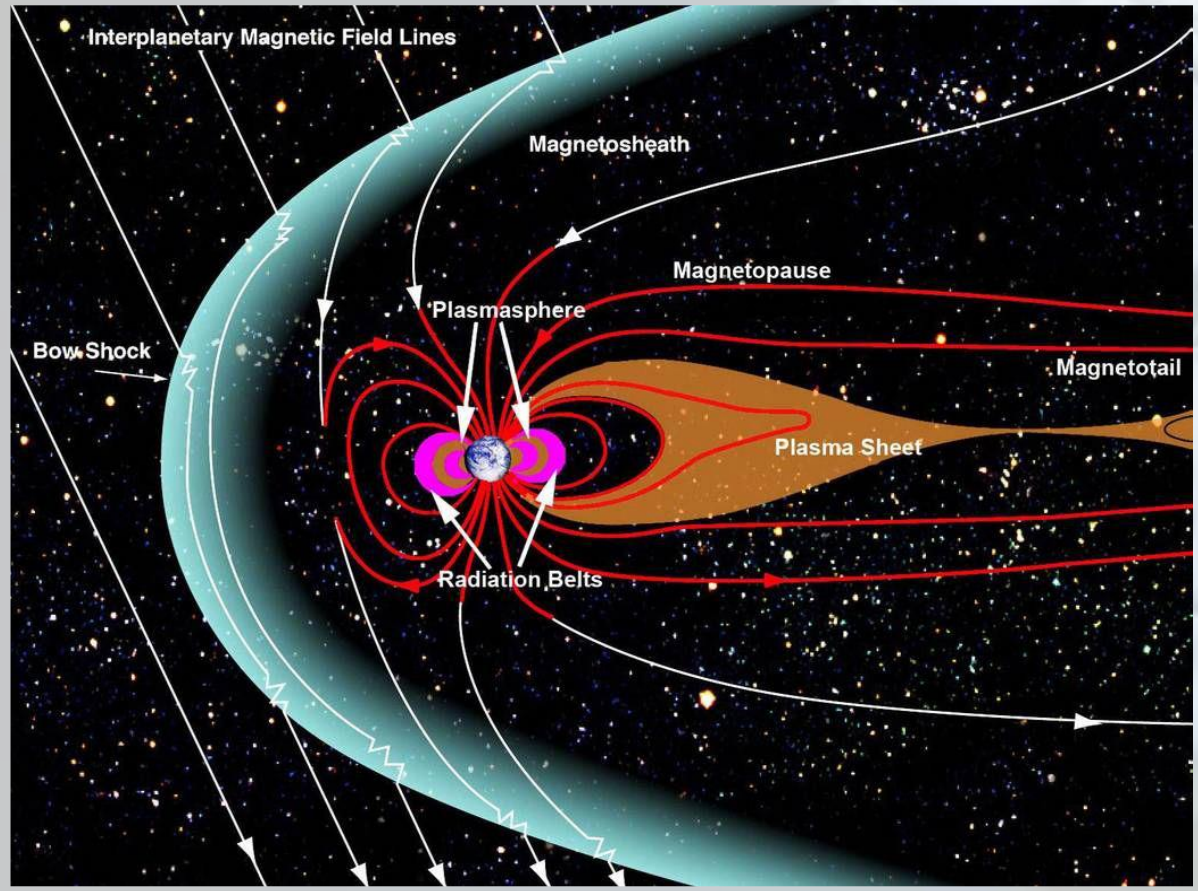
Coronal Mass Ejection (CME): Tremendous expulsions of solar material from or through the solar corona, carrying embedded magnetic fields. Their impact to our magnetosphere can cause major changes resulting in **Geomagnetic Storms**

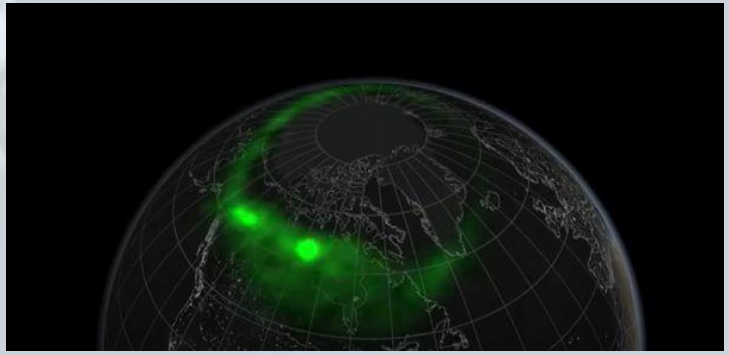


Solar Flares: great, sudden bursts of electromagnetic energy that can immediately impact the sunlit side of Earth from minutes to hours. More intense flares can ionize the lower ionosphere (D-layer) and cause HF **Radio Blackouts**



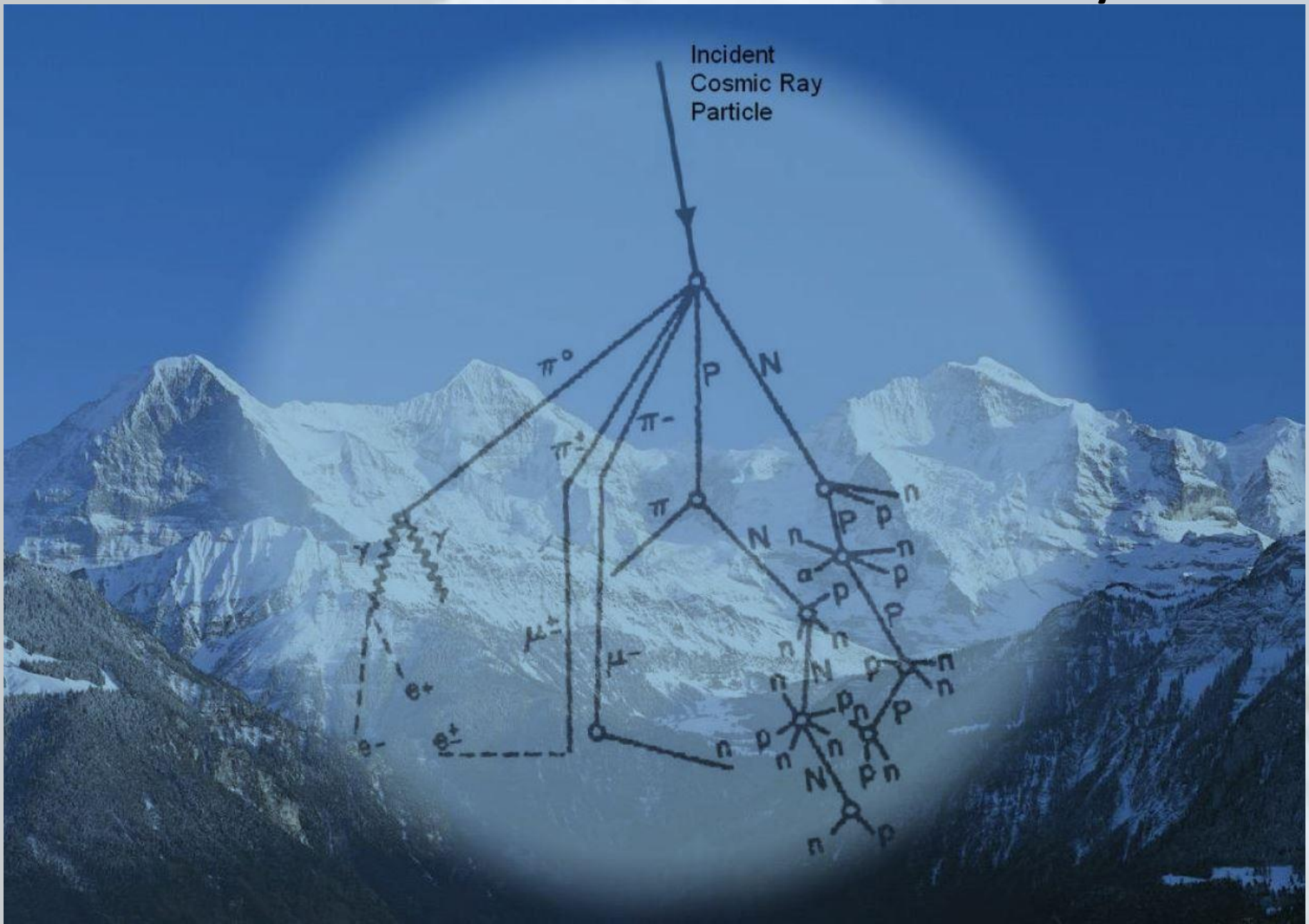
Geomagnetic Field



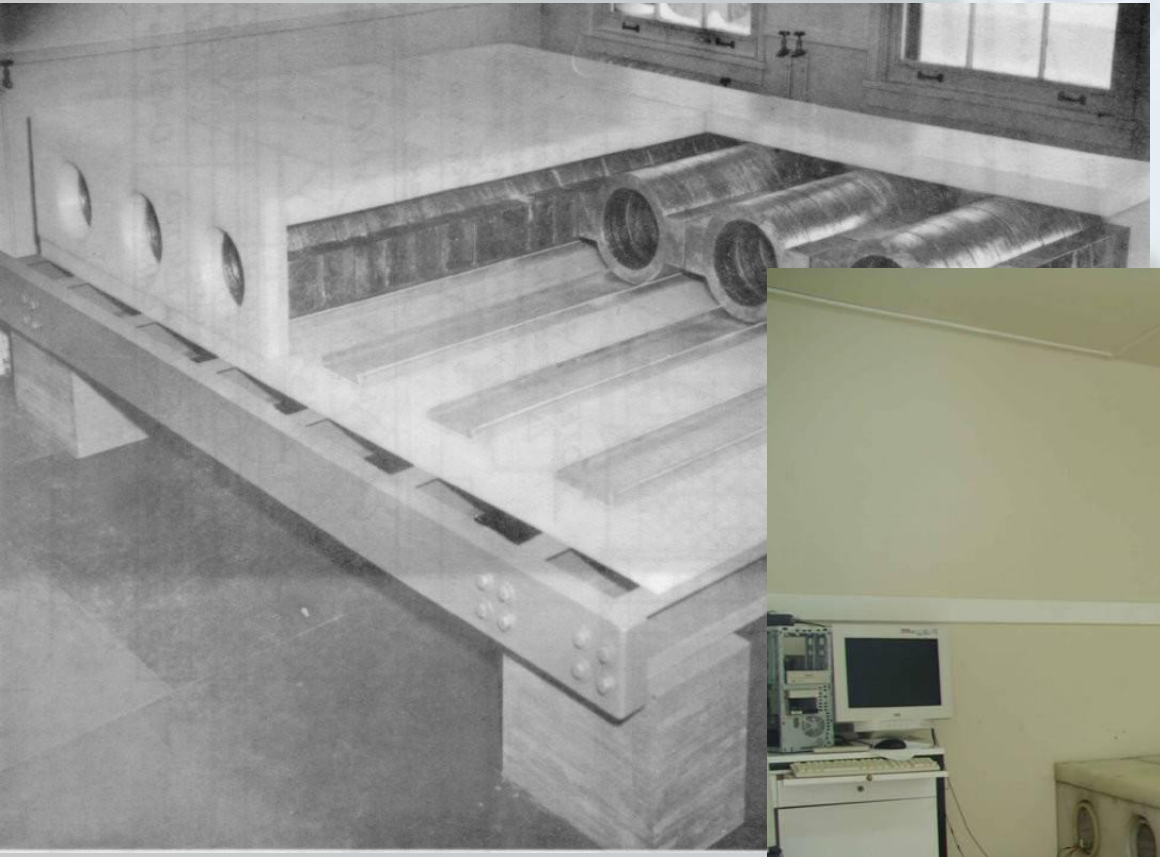


GEOMAGNETIC STORM:
can lead to outer atmospheric changes that can cause satellite drag, collision avoidance issues; ionospheric electron density changes that may impact SATCOM, GNSS; DC current buildup on power grid; and more

Cosmic Shower and Secondary CRs



Neutron Monitors



Neutron Monitors

NMDB users

- NMDB Alerts, fluctuations, GLE, solar neutrons, dosimetry...
- Dosimetry for airplane personel at Air France, DLR, Globalog
- Space Weather Alerts at NOAA
- Integrated Space Weather Analysis at CCMC (NASA/GSFC)
- Cosmic Rays and Climate
- Cosmic Ray – cloud connections
- Cosmic Rays and the geomagnetic field
- Soil moisture measurements (US, AUS, UFZ Leipzig, UK)
- Department of Homeland Security / NUSTL
- Space Weather Forecaster at USAF

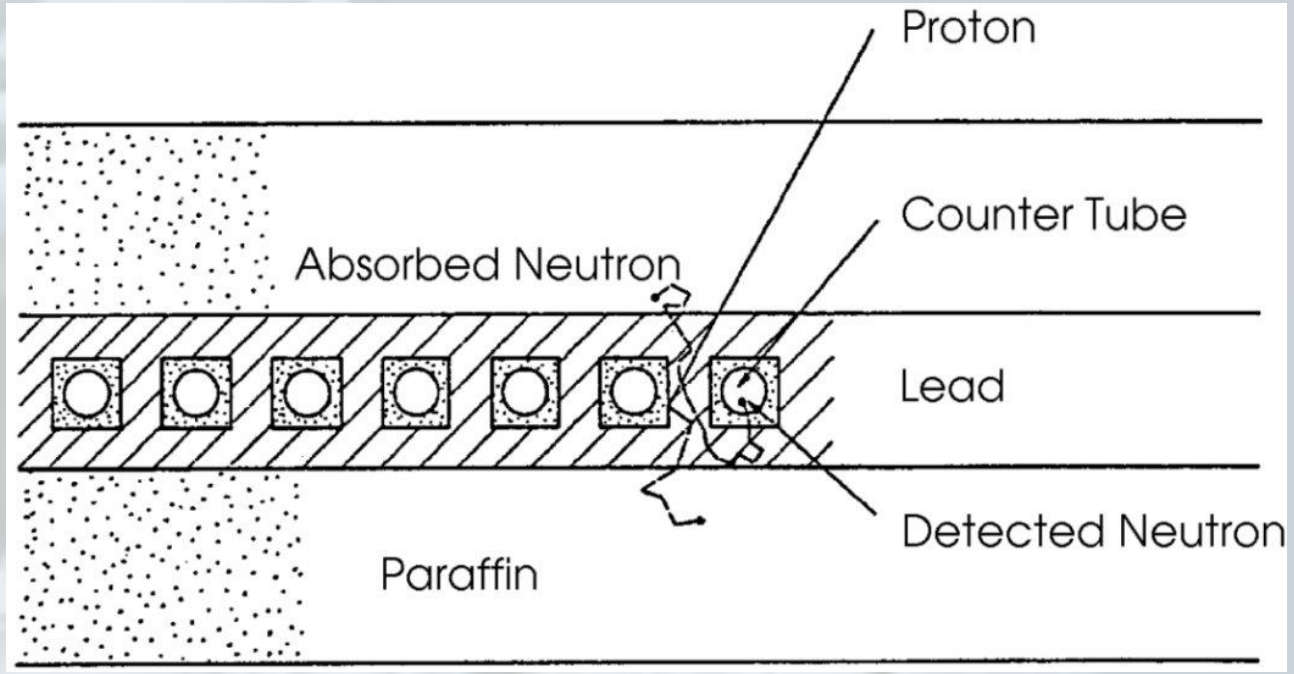
https://www.nmdb.eu/

$$^{10}B_5 + n \rightarrow {}^{7}Li_3 + {}^{4}He_2$$

NM “old” system

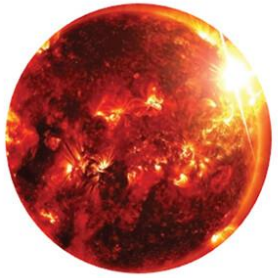
$$^{3}He_2 + n \rightarrow {}^{3}H_1 + \text{proton}$$

NM “new” (1990) system

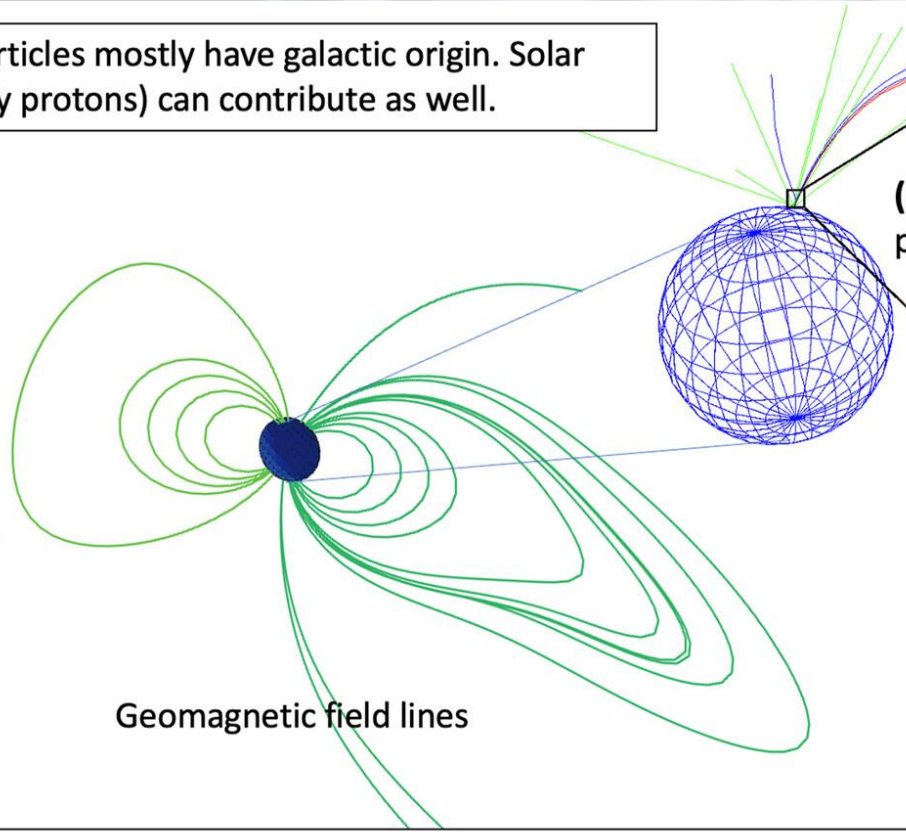


Cosmic Muons

(1) Primary cosmic ray particles mostly have galactic origin. Solar energetic particles (mainly protons) can contribute as well.



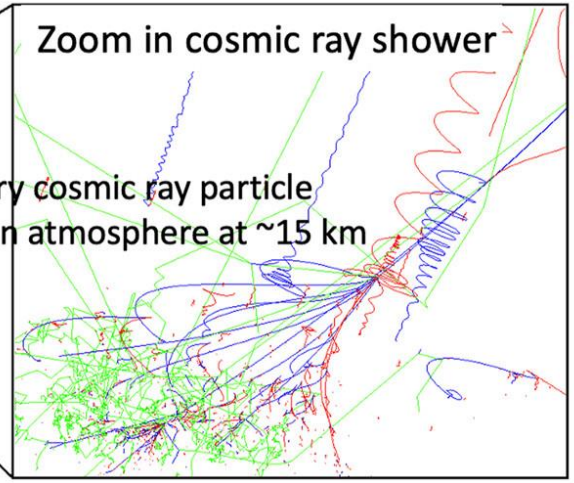
(2) Amount of cosmic ray particles reaching the top of the earth atmosphere is affected by the solar activity and the state of the magnetic field.



Geomagnetic field lines

Zoom in cosmic ray shower

(3) Secondary cosmic ray particle production in atmosphere at ~15 km

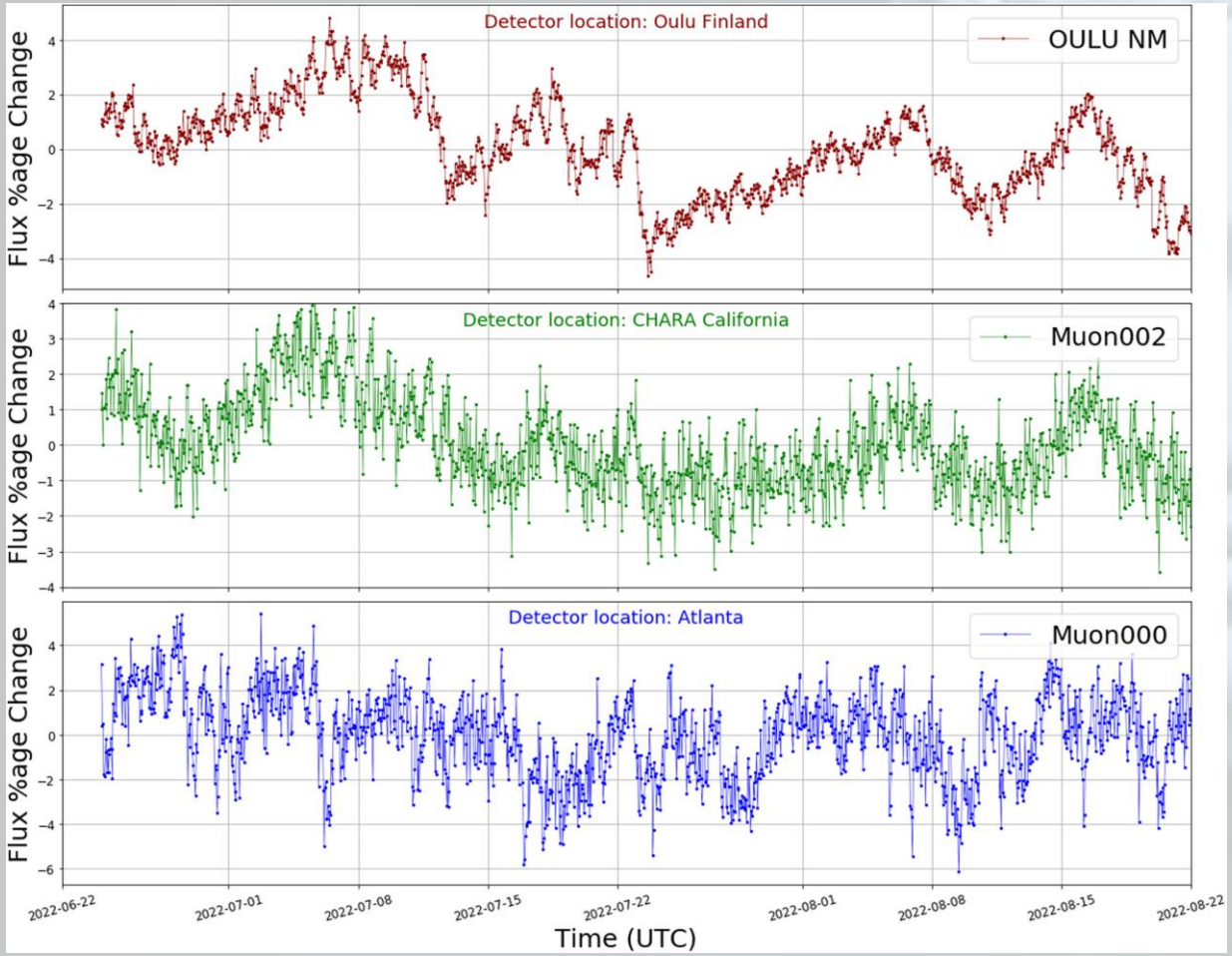


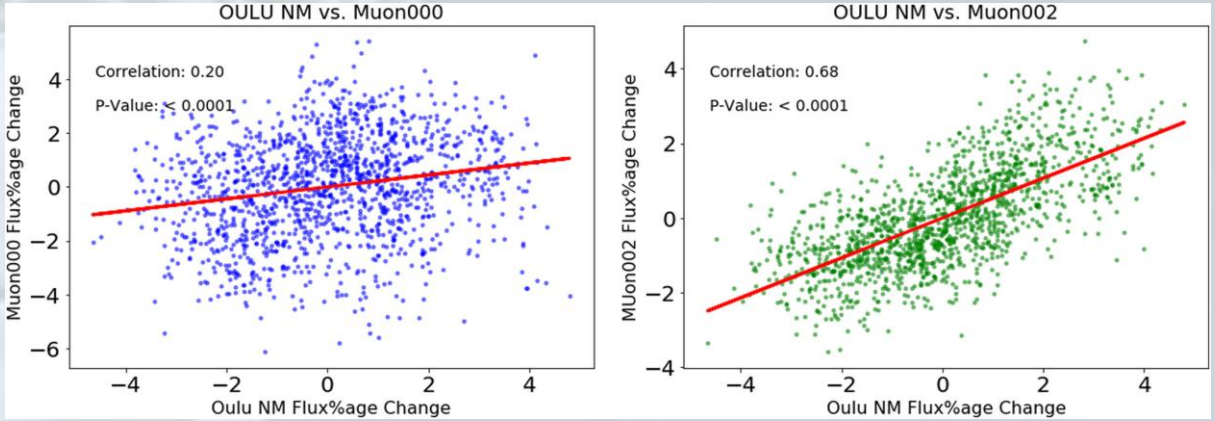
These ionizing particles are regarded as health hazards for flight crew.

(4) Most particles reaching to the surface of earth are muon particles together with a few percent of neutrons. Measuring muon flux variation around the world allows us to monito the state of space weather and atmospheric properties in real-time, and to explore the associated applications of using cosmic rays (cloud formation, lightning, etc.)

https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023JA031943

Cosmic Muons





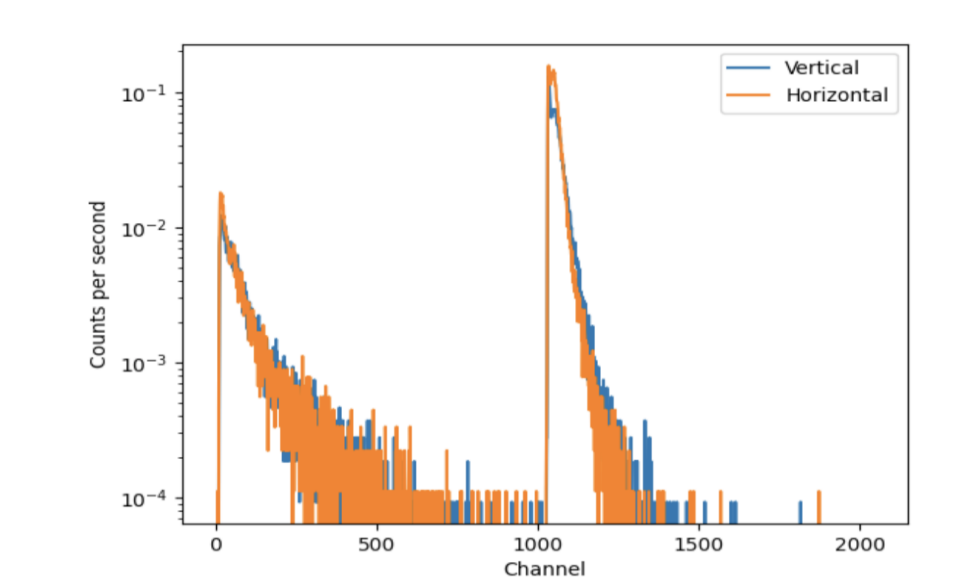
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023JA031943

Selene - the Muon Cosmic Hunter

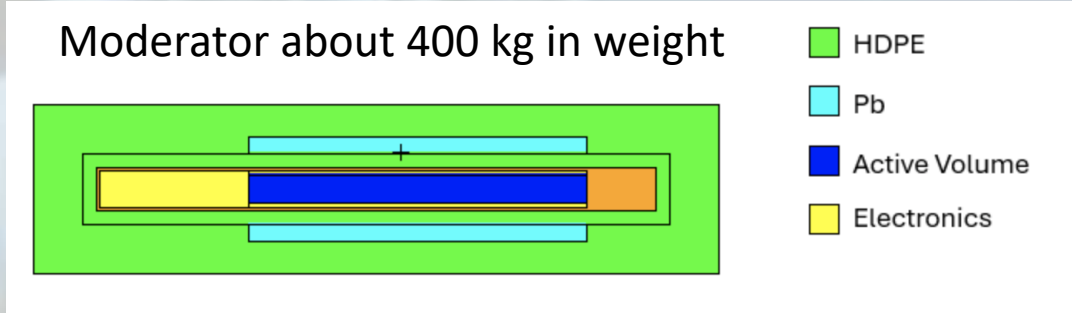
«our» Neutron Monitor

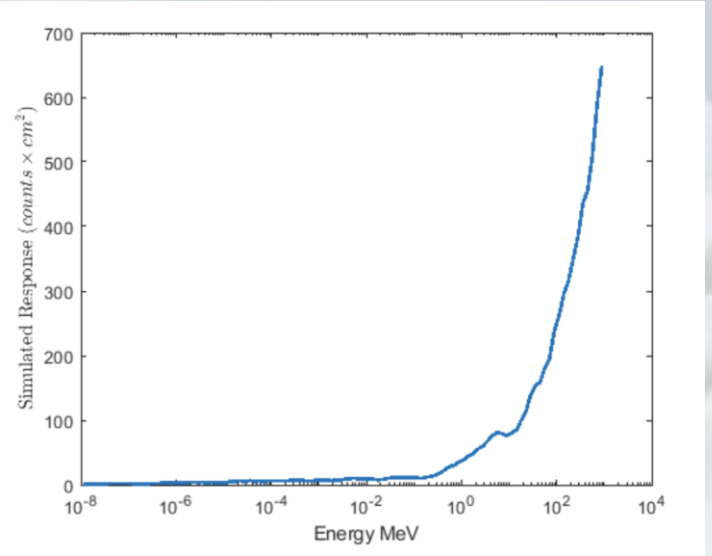
with added capability of measuring the muon flux

Rod of acrylic light-pipe coated with ZnS(Ag) scintillator mixed with B-10 to make it sensitive to thermal neutrons. The detector is also sensitive to muons scintillating in the acrylic rod



Example of the PSD output. The channels in the range 0-1000 represent the pulse high spectrum for the neutron signal. The channels in the range 1001-2000 represent the pulse high spectrum for the muon signal. The neutron signal is independent of the detector position. The muon signal is, as expected, lower for the vertical position.





Simulated response function in counts per unit of neutron fluence Expected a sensitivity per Kg of moderator about 1.5 times higher than existing NM

Selene WP

- ***WP1 IMPLEMENTAZIONE SISTEMI DI RIVELAZIONE E DAQ***
  - ***Creazione rete rivelatori a basso costo***
  - ***calibrazione e test dei rivelatori e efficienze di misura***
  - ***costruzione della rete e installazione rivelatori***
  - ***accessibilità dati online***
- ***WP2 Ottimizzazione dei sistemi***
  - ***Caen***
- ***WP3 SIMULAZIONI MONTE CARLO***
  - *Dipendenza dello spettro dei muoni a terra dall'energia del primario*
- ***WP4 TEST SISTEMI DI MISURA***
- ***WP5: Development of a Modular and Transportable Neutron Monitor with capability of measuring the muon flux***
- ***WP6 MISURE E ANALISI DATI***
  - ***Distribuzione angolare muoni in corrispondenza di eventi solari***
  - ***Confronto con misure esistenti (CRC/NM)***
- ***WP7 - Monitoring the Neutron Spectrum and Cosmic Ray induced Dose in the South Atlantic Anomaly and Testa Grigia Laboratory***

Our “possible” network

Our “possible” network

- ***Finland***
  - ***Oulu NM site - Muon Cosmic Hunter – Low Rigidity cutoff (0.8 GV) - Comparison with NM data***
- ***Slovakia***
  - ***Kosice/Lomnicky Stit NM site - Muon Cosmic Hunter – Mid Rigidity Cutoff (4 GV) - Altitude study***
- ***Australia***
  - ***Melbourne - Monash University - Muon Cosmic Hunter – Mid Rigidity Cutoff (4.2 GV) - Correlation study***
- ***Italy***
  - ***Milano Bicocca - Muon Cosmic Hunter + Neutron Detector - Correlation study***
  - ***Testa Grigia Laboratory - Muon Cosmic Hunter - Altitude and Correlation study***
- ***Bolivia***
  - ***Muon Cosmic Hunter - NM site – Comparison with NM data - Altitude and SAA study***
- ***Dubai***
  - ***High Rigidity Cutoff (14,9 GV) - Detector Calibration and Correlation Study***
- ***Antarctica***
  - ***Low Rigidity Cutoff - Muon Cosmic Hunter***
- ***Maldive***
  - ***High Rigidity Cutoff (16,9 GV)- Detector Calibration and Correlation Study***

INFN SITES INVOLVED

- *Milano Bicocca - 1,7 FTE*
- *Milano Celoria - 2,05 FTE*
- *Cagliari - 1 FTE*
- *Napoli - 1,1 FTE*
- *Torino - 2,2 FTE*
- *Trieste - 1 FTE*
- *LNF - 1 FTE*

RICHIESTE MIB 2025

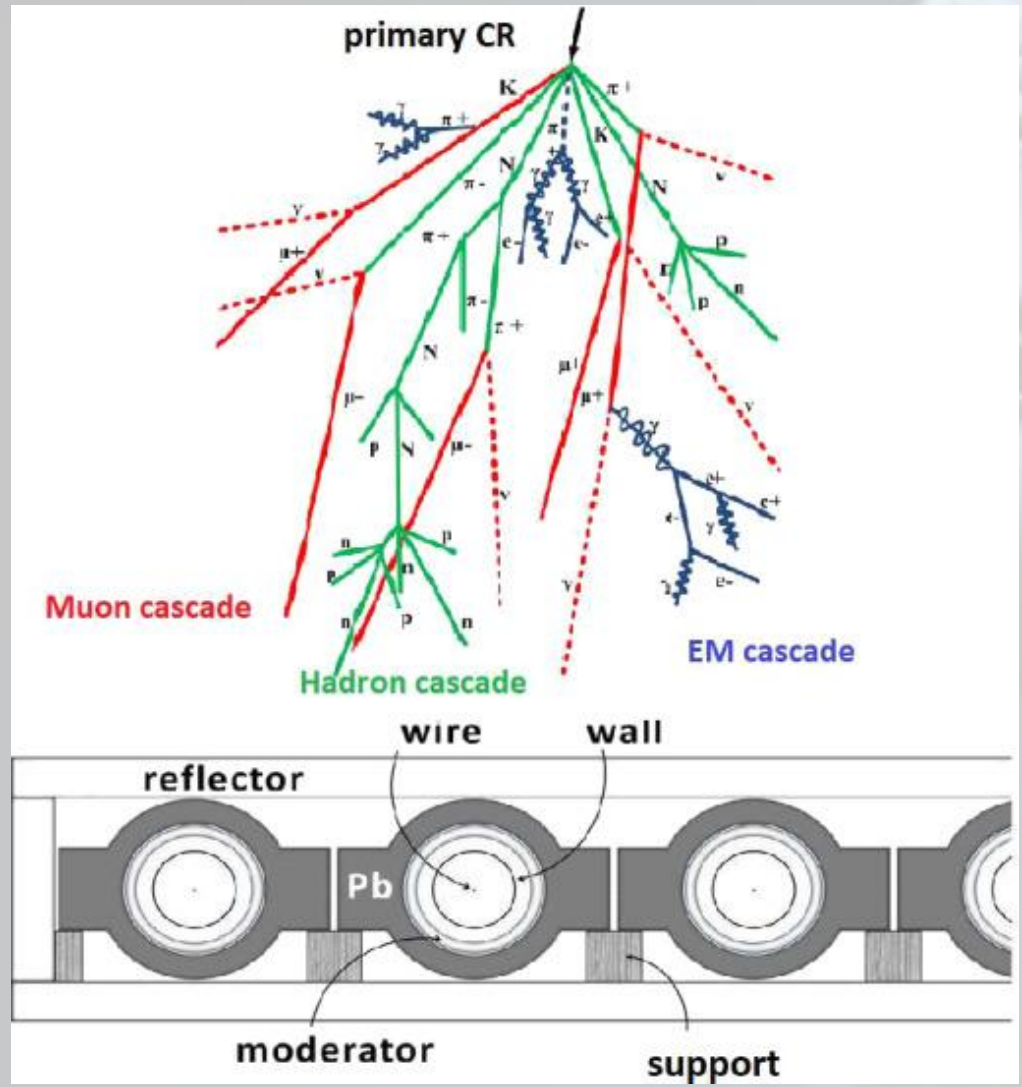
- *Missioni* *15K*
- *Materiale Consumo* *10K*
- *Inventariabile* *30K (7 Cosmic Hunter)*
- *Trasporto* *5K (spedizioni 7 Cosmic Hunter)*

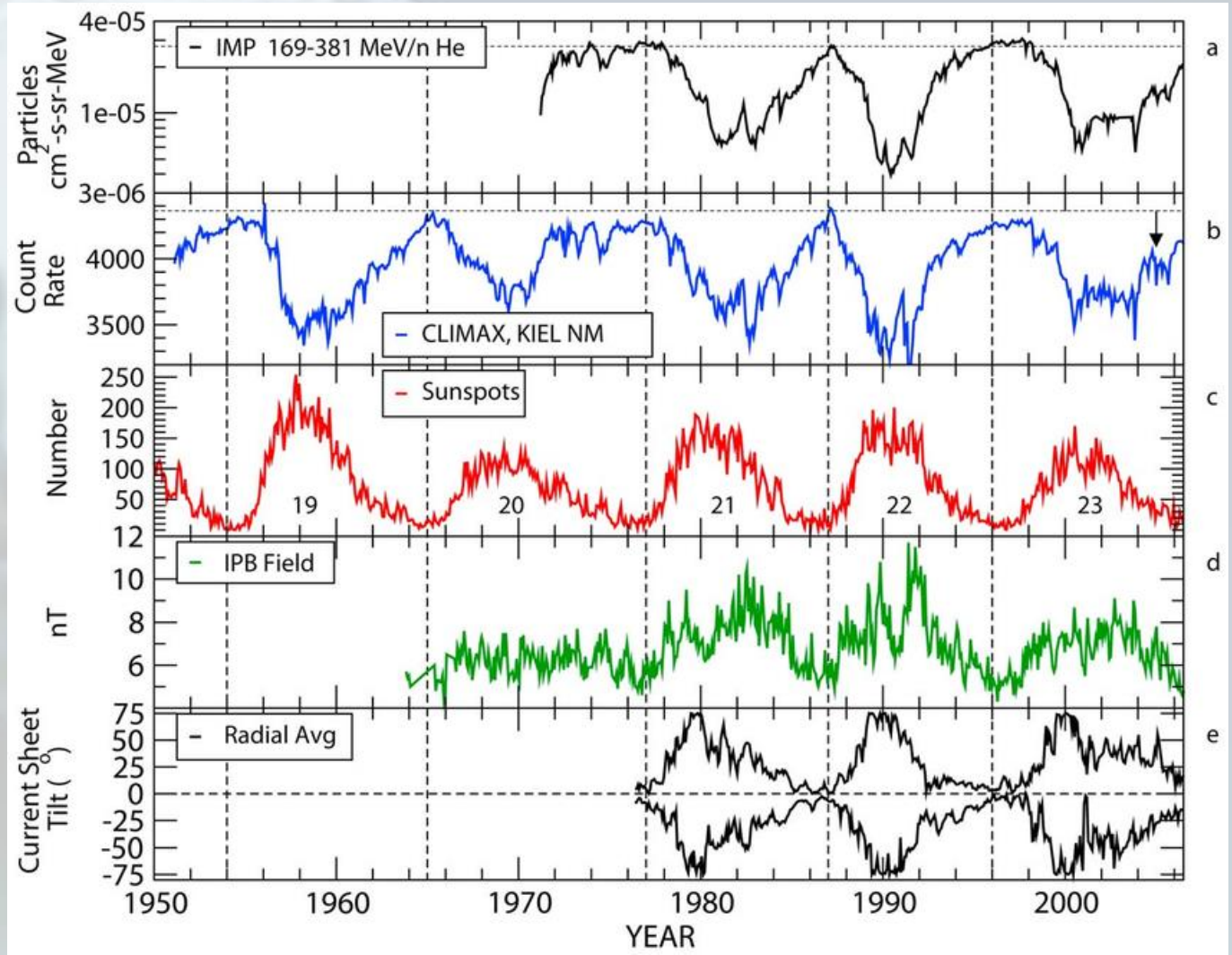
MILESTONES 2025 (2026)

- *M1 - Acquisto Cosmic Hunter (CH) 30/06/2025*
- *M2 - Calibrazione e test Montecarlo CH 30/09/2025*
- *M3 - Installazione nei siti principali (Finlandia/Slovacchia...) CH 31/12/2025*
- *M4 - Messa online dei rivelatori CH e realizzazione sito raccolta dati 30/06/2026*
- *M5 - Realizzazione scheda dE/dx scintillatori CH 31/12/2025*
- *M6 - Realizzazione prototipo Neutron Monitor trasportabile (NMT) 30/06/2025*
- *M7 - Calibrazione e test Montecarlo NMT 30/09/2025*
- *M8 - Installazione nei siti principali (Finlandia/Slovacchia..) NMT 31/12/2025*
- *M9 - Messa online dei rivelatori NMT e realizzazione sito raccolta dati 30/06/2026*

Backup Slides

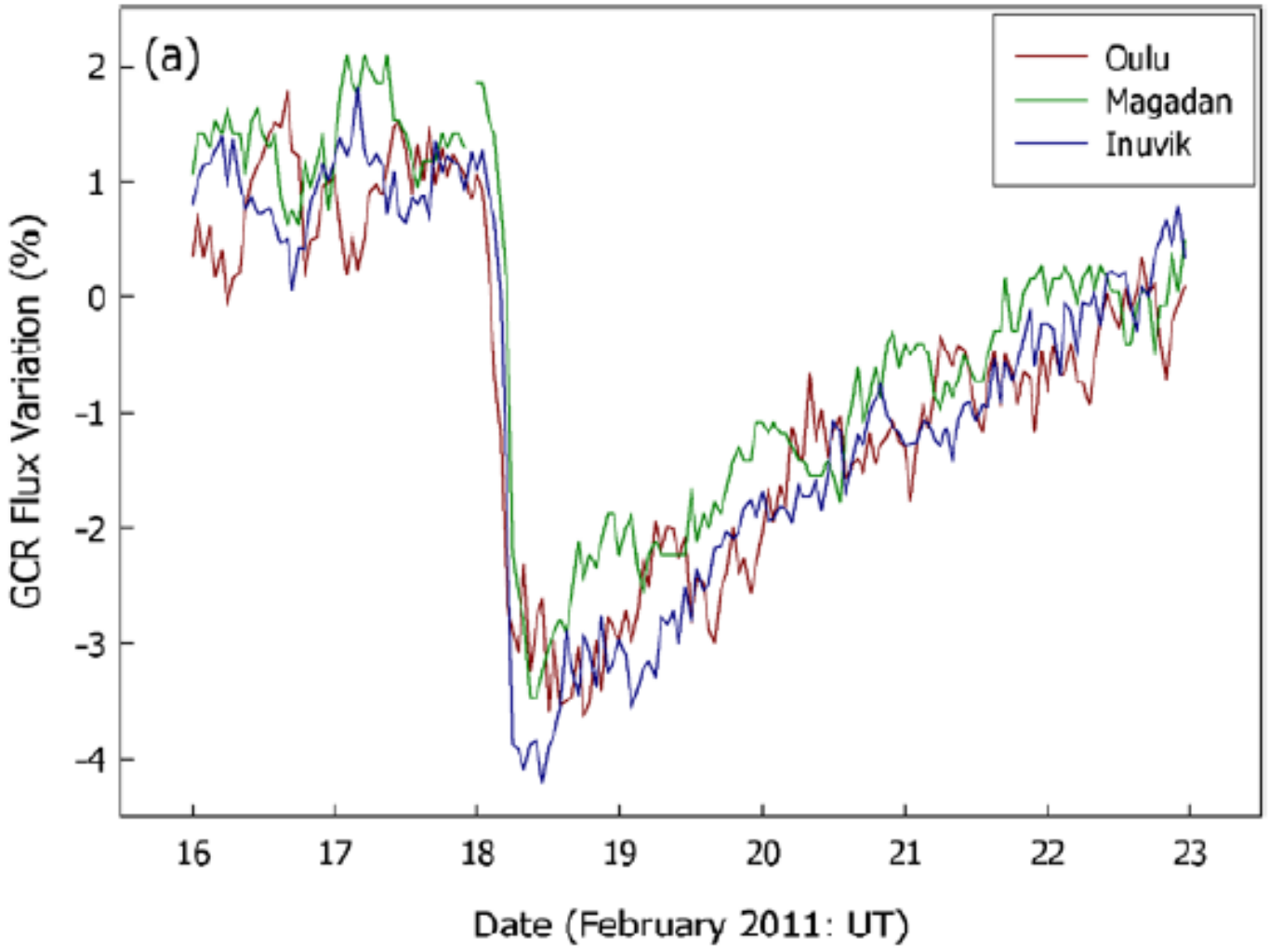
Neutron Monitors and Solar CR



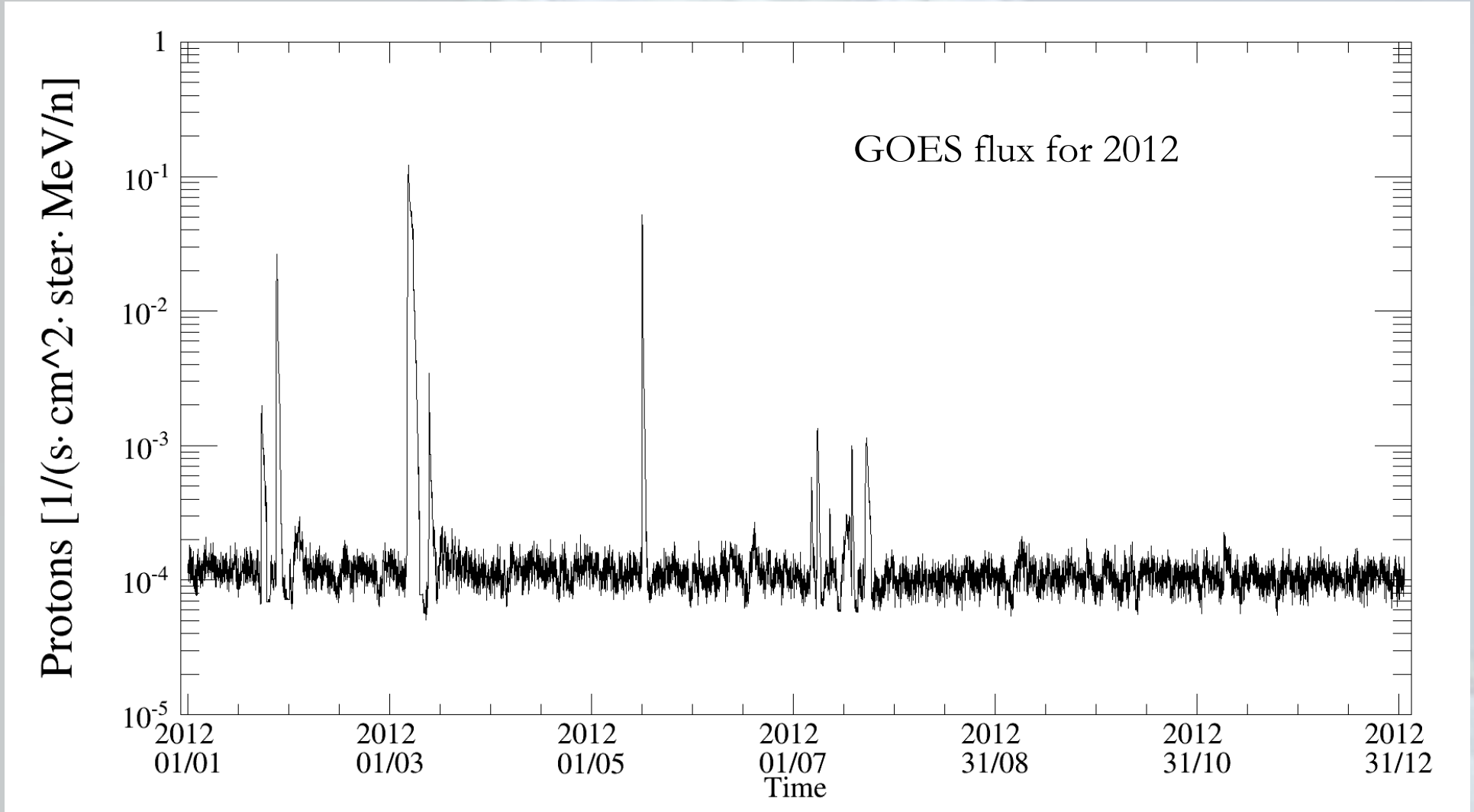


Neutron Monitors and Solar CR

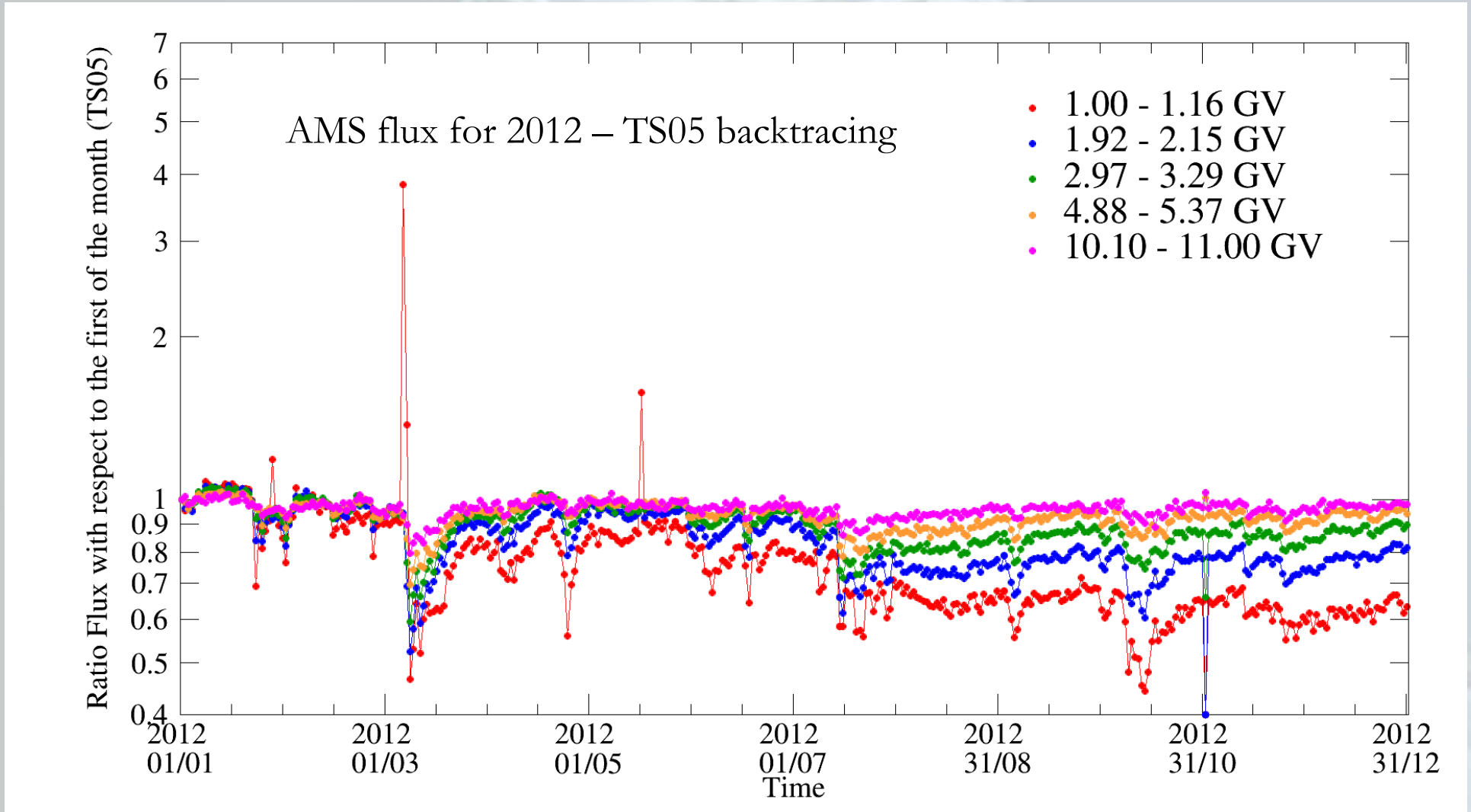
Figure 5 Time variations of GCR flux of an FD event on 18 February 2011 at the Oulu, Magadan, and Inuvik NM stations in (a) UT and (b) LT.



Solar Events

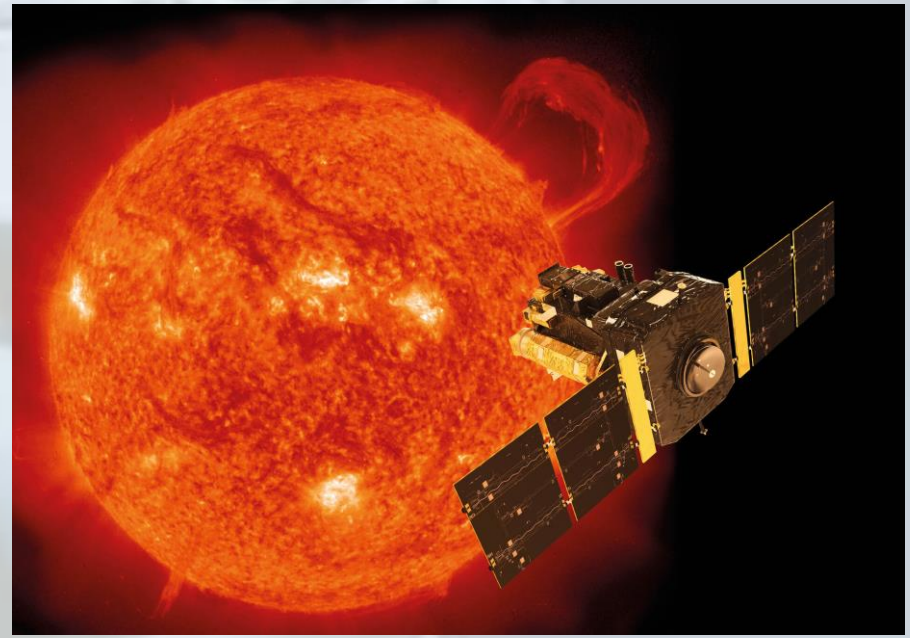


Solar Events



Other Experiments – in space

https://www.goes-r.gov/



https://www.esa.int/Science_Exploration/Space_Science/SOHO/SOHO_overview

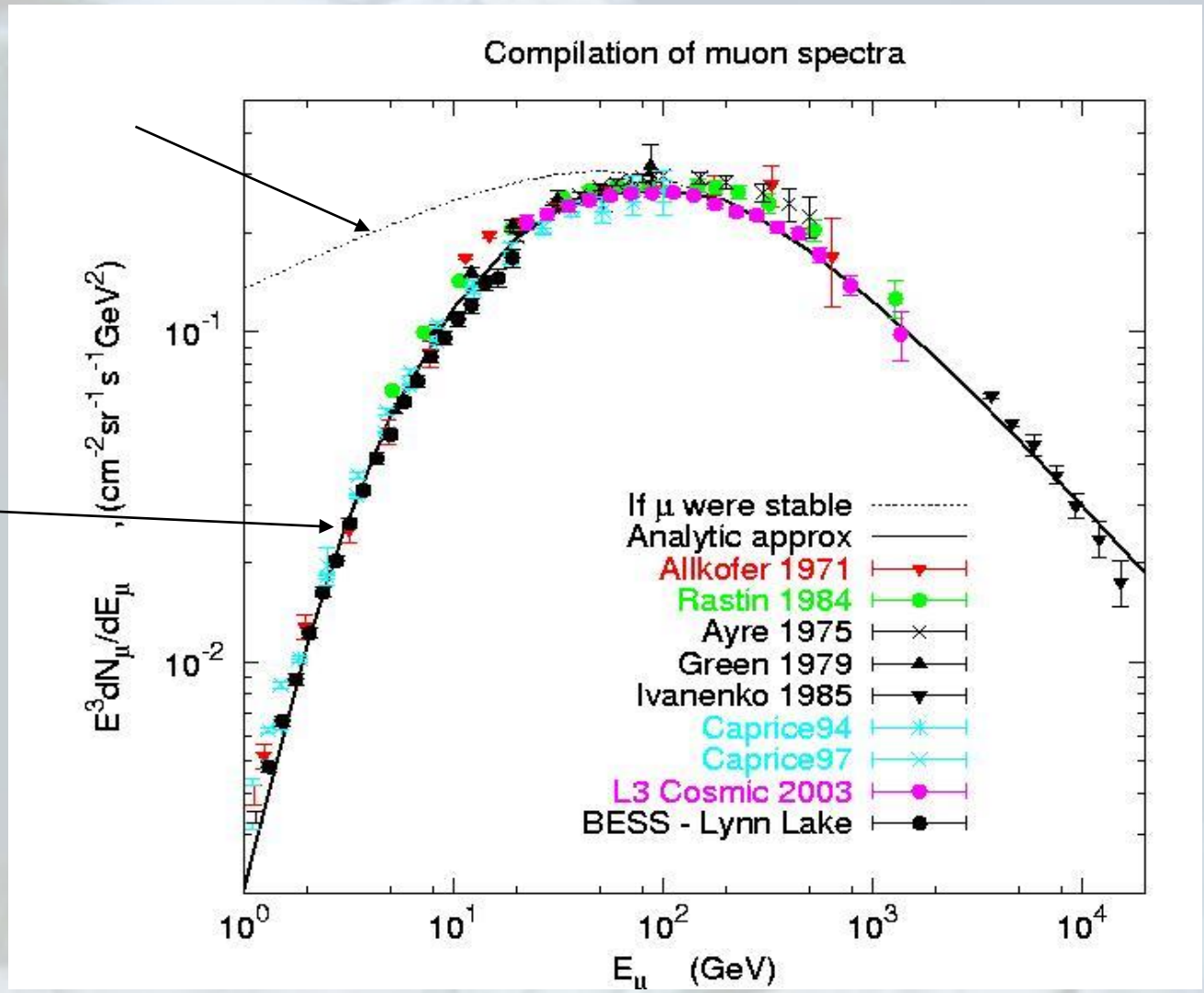
https://www.esa.int/Space_Safety/Monitoring_space_weather2

Atmospheric μ

Account for μ energy loss

Account for μ decay

Analytic approximation works well!



Geomagnetic Field & Aurorae