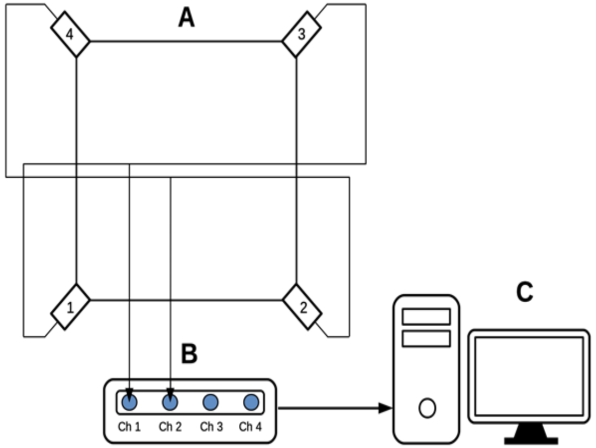
Cosmic Ray Monitoring with the Belgrade Muon Station and the gLOWCOST Network

Nikola Veselinović on behalf of gLOWCOST network and Belgrade muon station at Institute of Physics Belgrade

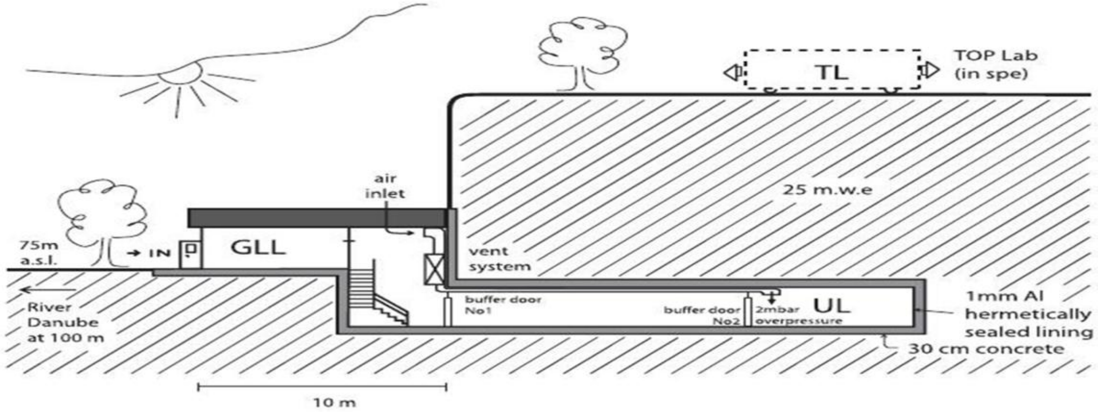
Muographers 2026

Belgrade muon station

Belgrade muon station is a part of Low level laboratory for nuclear physics at the Institute of Physics, Belgrade, Serbia. It is divided into two parts: Ground level (GLL) and Underground (UL) level, dug in 12m of loess (25 m.w.e.). The experimental setup consists of two identical sets of detectors (1m^2) and read out electronics which enables correlation of the events, both prompt and arbitrarily delayed with the time resolution of 10 ns.



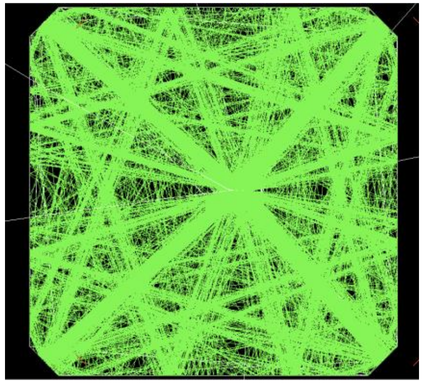
Muon flux = 170±6m^{-2} s^{-1}.

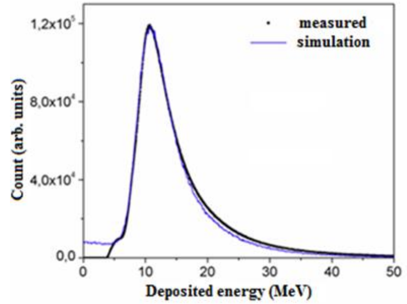


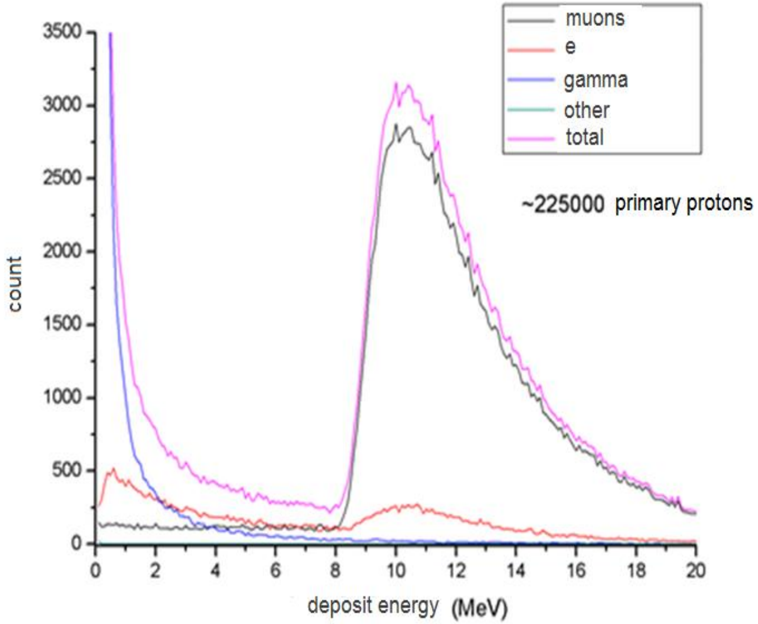
Belgrade muon station

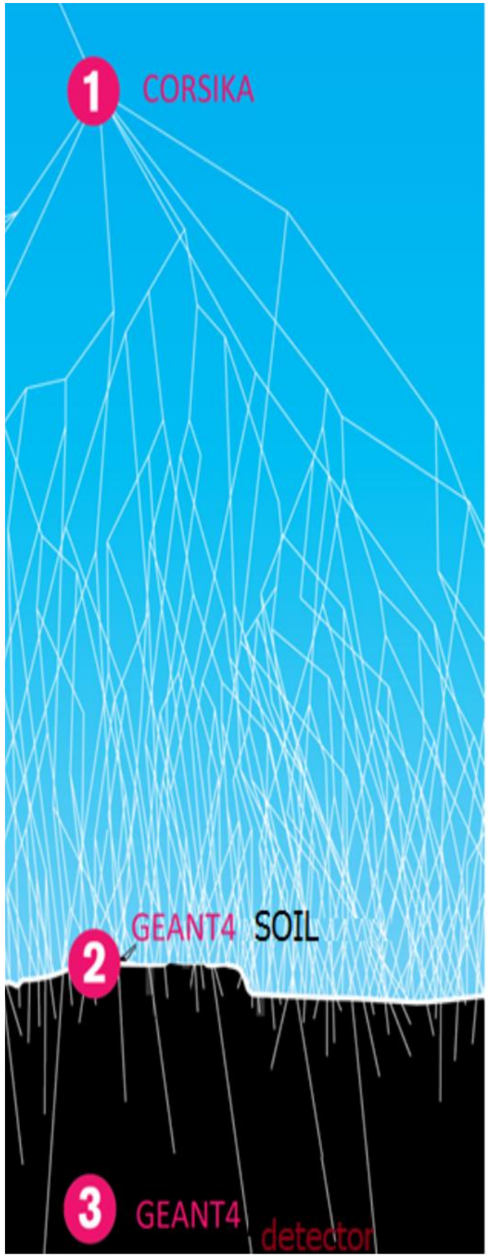
Cosmic rays (CR) propagation through atmosphere for our site were simulated using CORSIKA simulation package.

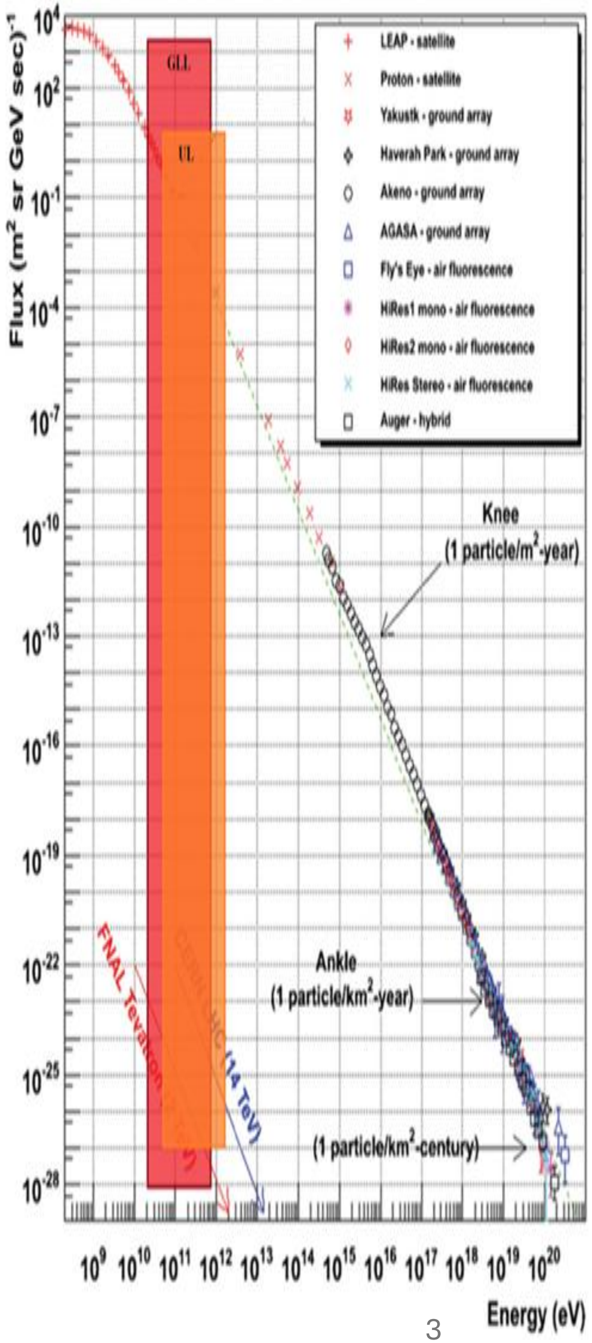
Geant4 was used to simulates the interaction of particles with soil and detector system. Response function for our detector system was determined and ranges of energy of primary CR for detected muons are found









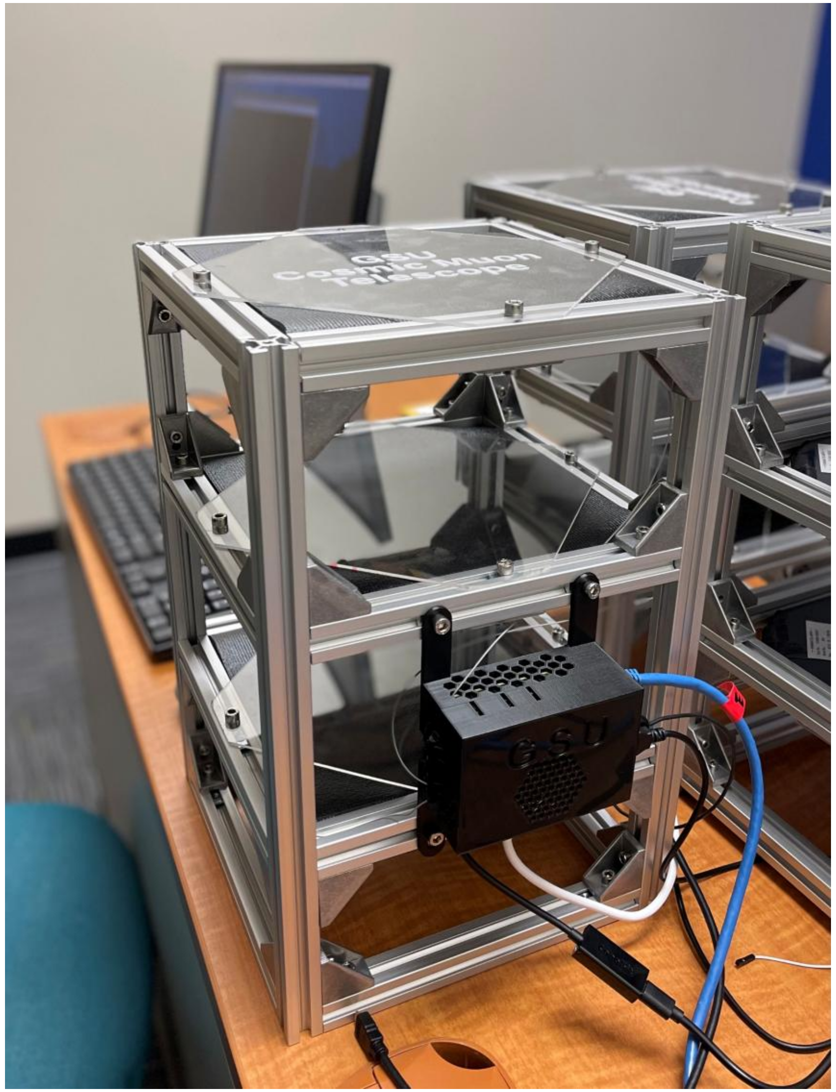


gLOWCOST network

Portable muon particle detector has been developed by the Nuclear Physics Group at Georgia State University, Atlanta, USA ***(PI Xiaochun He)***

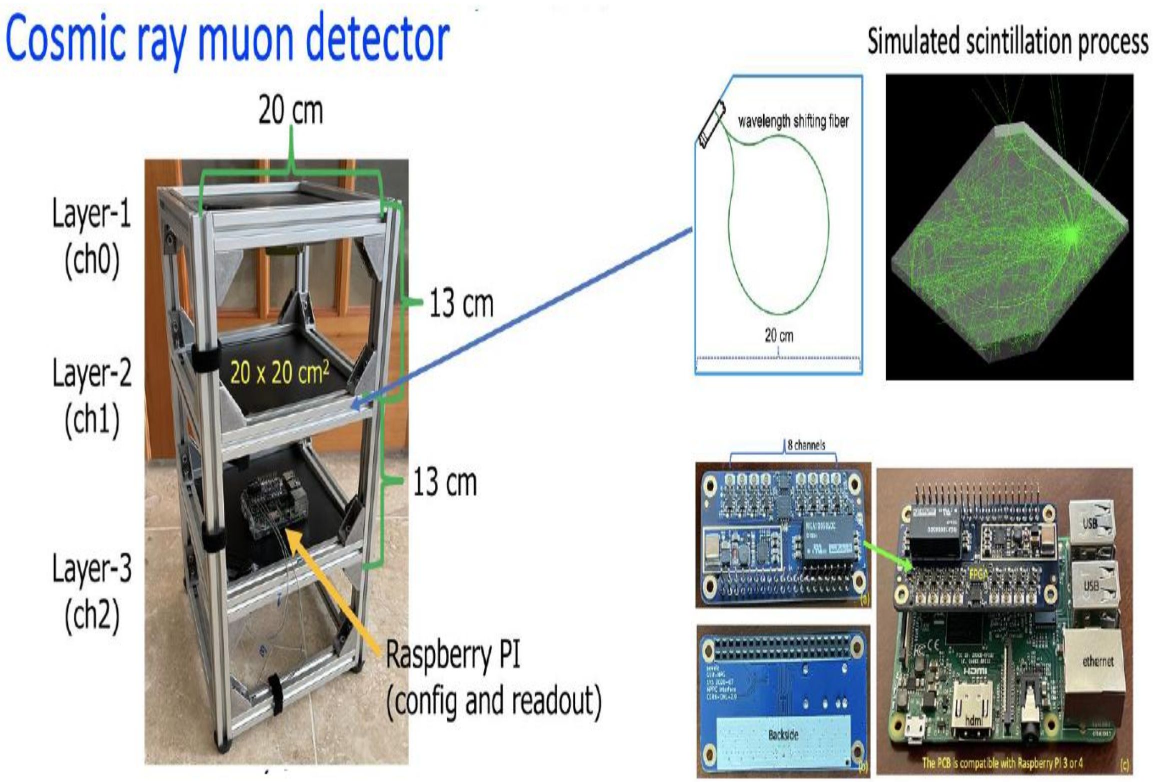
Desktop CR muon detector design consists of three layers of 20cm x 20cm x 1cm scintillator tiles 13 cm apart, with readout electronics.

The current network consists of 22 detectors spanning across 17 unique observing sites.



gLOWCOST network

A minimum site requirement is a small desk, power and network connection. Sensitive to ambient temperature!



Workflow

Silicone photomultiplier generating an analog pulse from scintillation from charged particle encounters in scintillator tiles

↓

Analog signal amplification

↓

FPGA- Peak detection & coincident count logic operation

↓

Raspberry Pi- Coincident count detection, data logging and data transfer to GSU servers

For temperature compensation		Coincident Counts			
1st Layer raw counts	Dark counts	Layer 1&2	Layer 1&3	Layer 2&3	Date & Time stamp
1463,	1511,	144,	73,	139,	Wed Jun 26 14:27:56 2024
1395,	1417,	141,	72,	130,	Wed Jun 26 14:28:56 2024
1366,	1466,	161,	93,	163,	Wed Jun 26 14:29:56 2024
1403,	1408,	154,	82,	166,	Wed Jun 26 14:30:56 2024
1407,	1431,	166,	90,	179,	Wed Jun 26 14:31:56 2024
1424,	1438,	163,	77,	158,	Wed Jun 26 14:32:56 2024

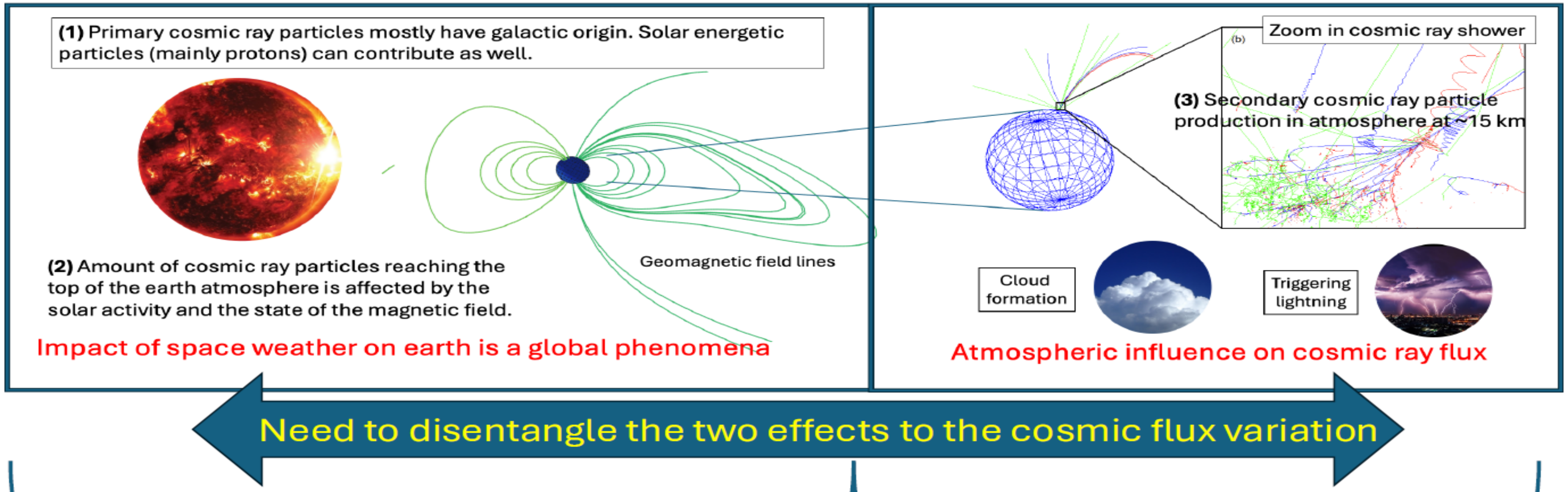
Data Logging Format

CR flux variation

Muon detectors are sensitive to higher primary cosmic ray (CR) energies than neutron monitors (NMs) and can complement the existing global NM network.

They are also sensitive to atmospheric parameters, primarily temperature at various atmospheric levels and pressure.

Variation in cosmic ray flux at ground level reflects the effects of the space and terrestrial weather



Space weather monitoring

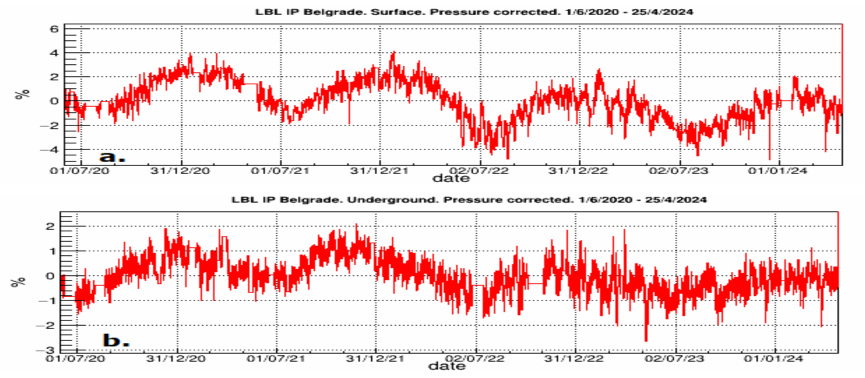
Terrestrial weather monitoring

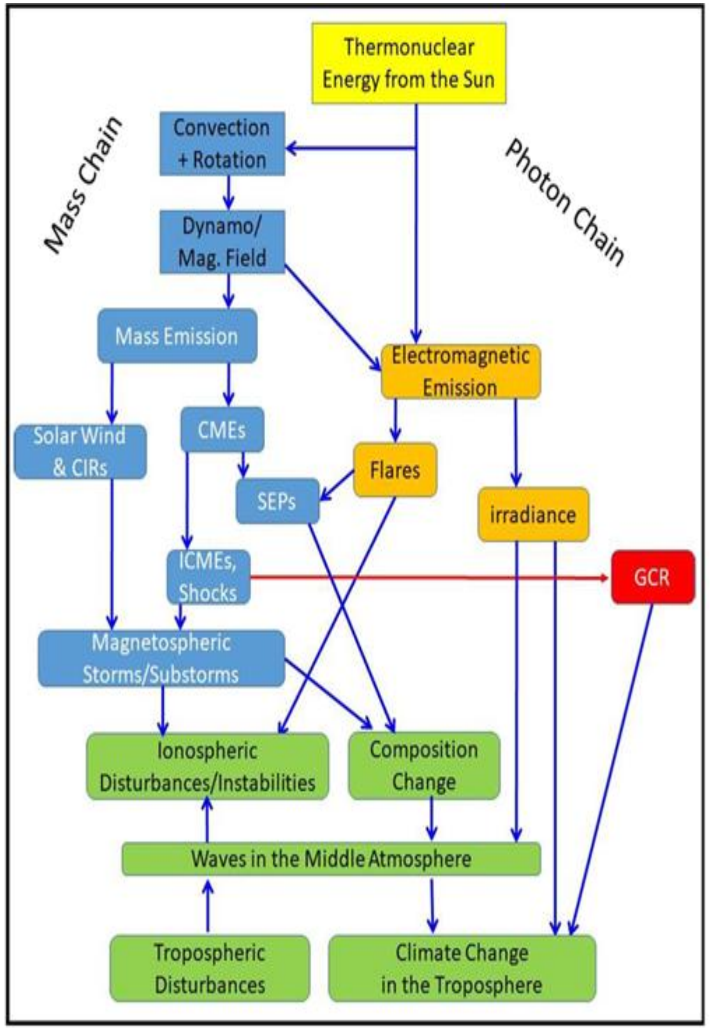
Monitoring solar activity

Transient event and periodic variation in CR flux is **caused mostly by solar activity and heliospheric disturbances** (coronal mass ejection).

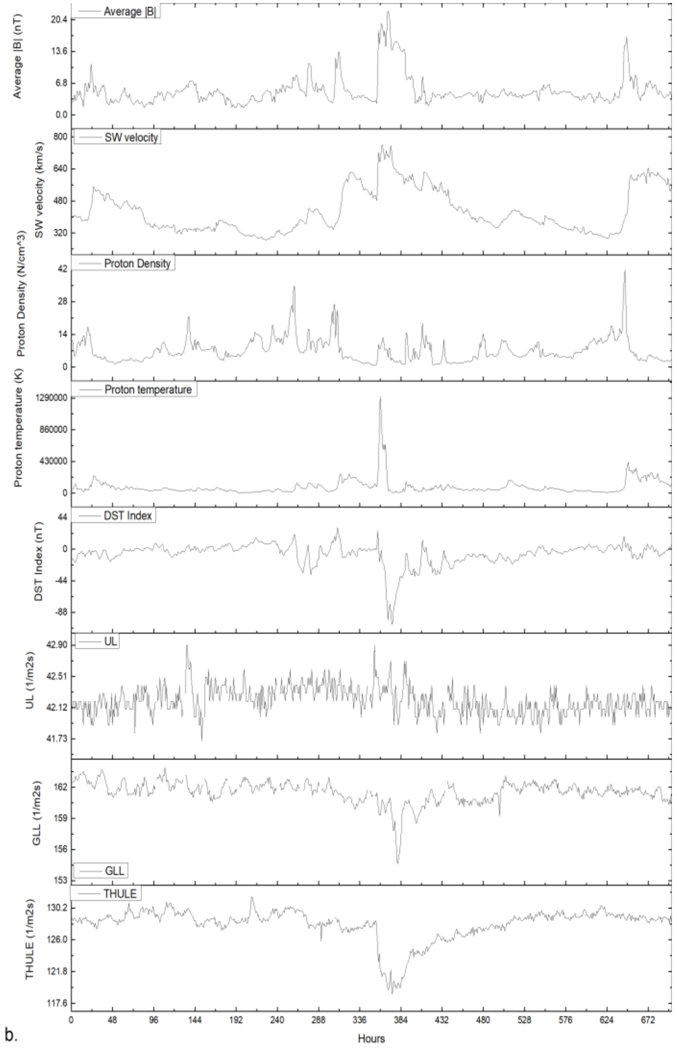
By registering flux originated from primary cosmic rays with muon monitors complement other ground detector (neutron monitors) and satellite data.

A global cosmic ray (CR) detector network can function as a giant spectrometer (due to different rigidity cut-offs) and also study CR anisotropy.





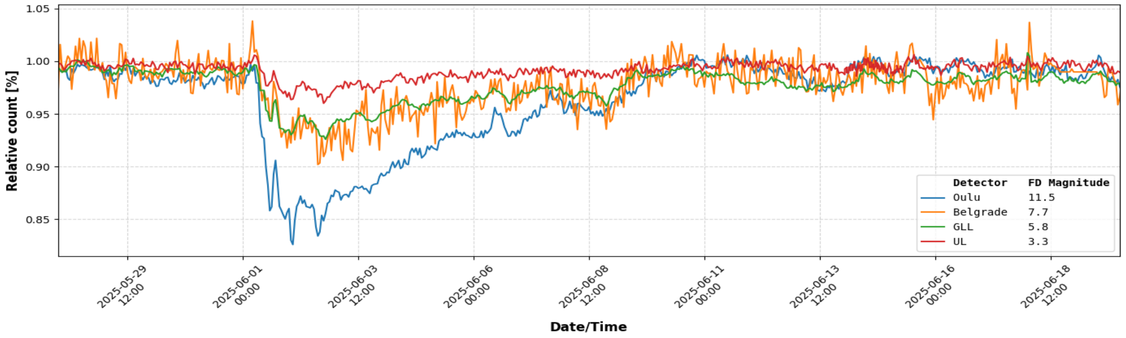
Nat Gopalswamy, NASA Goddard Space Flight Center, UN/ISWI workshop 2023 June 26-30

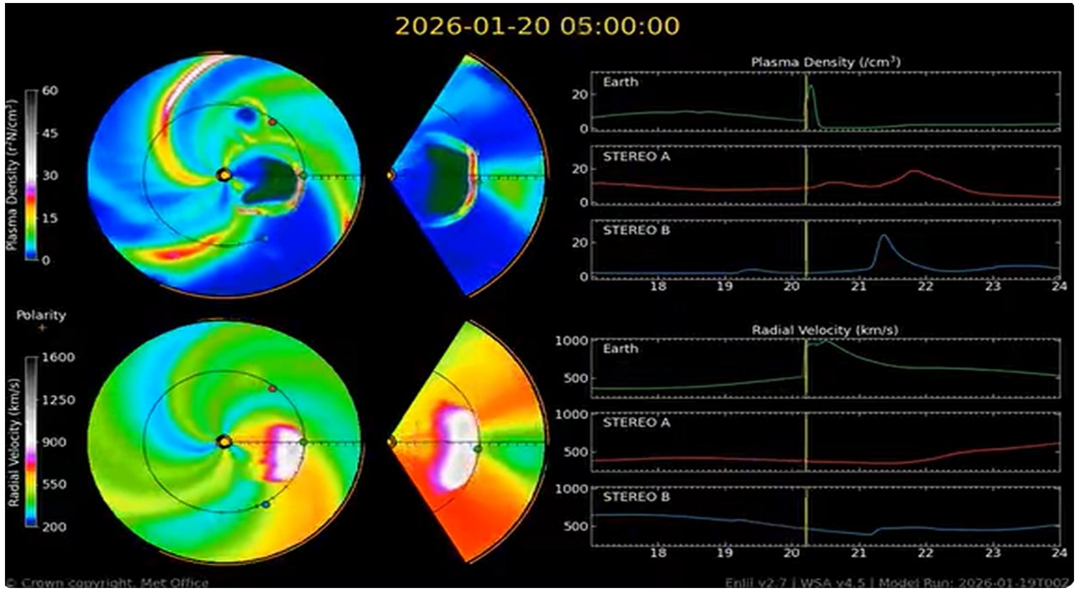


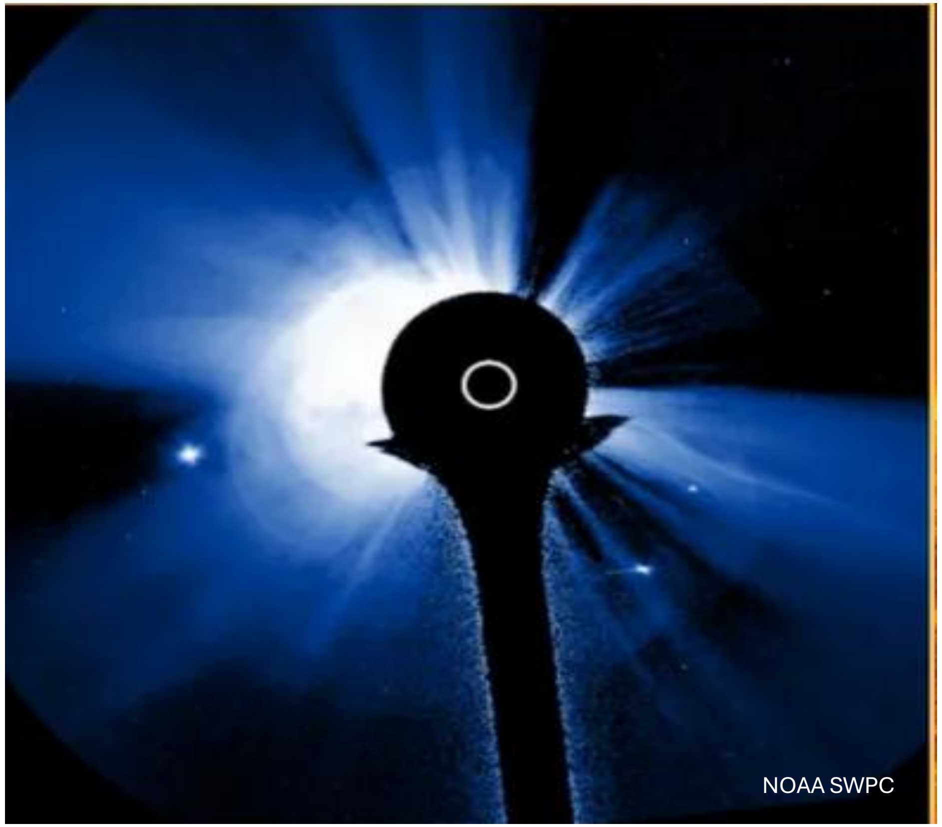
b.

Monitoring solar activity

The **sudden decrease** of galactic CR, followed by a **gradual recovery** to the previous intensity (lasting for hours or days) is called **Forbush decrease** (FD).







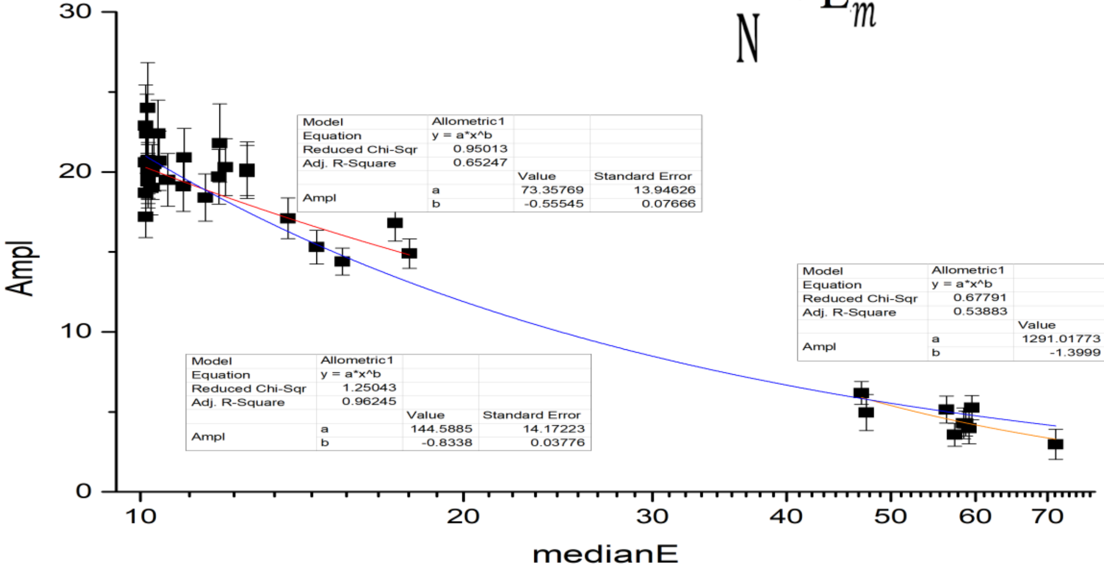
January 2026 was defined by historically intense solar activity, most notably peaking with the strongest solar radiation storm to hit Earth since 2003. This massive outburst featured X-class flares, severe geomagnetic storms, and mid-latitude auroras.

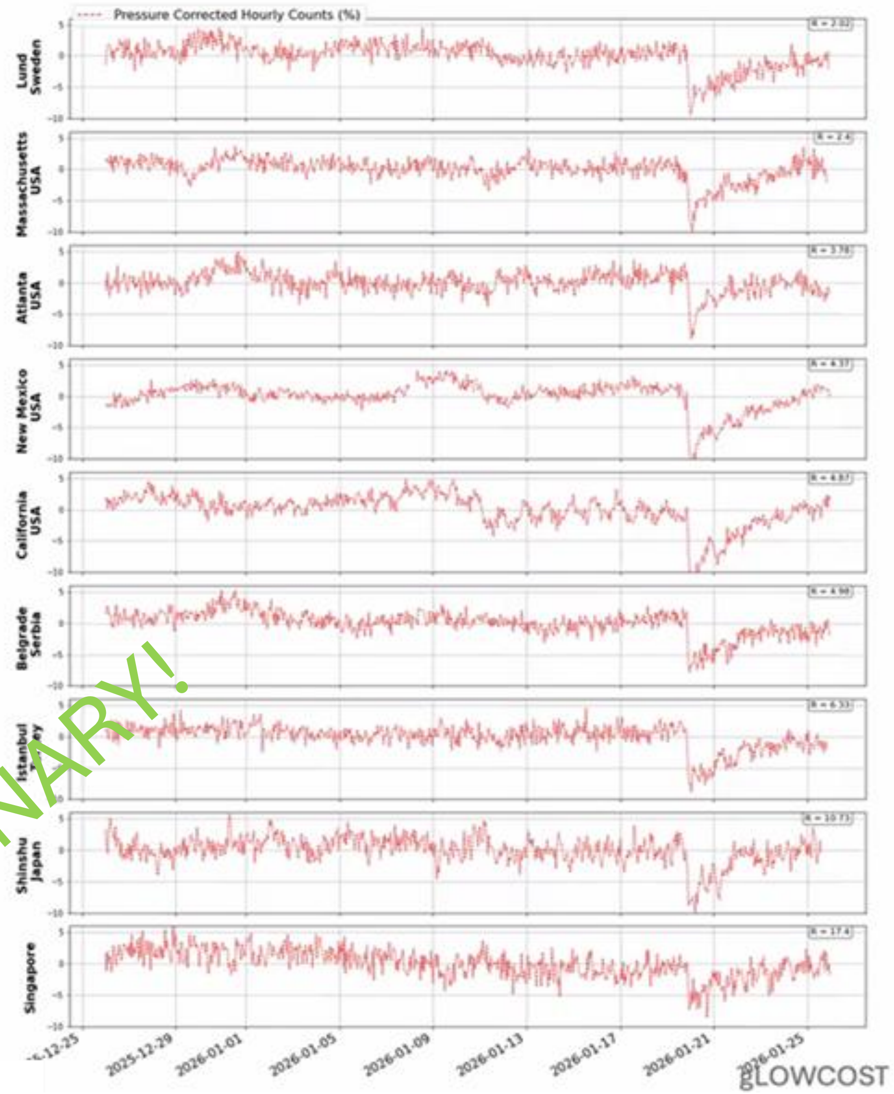
Monitoring solar activity

The **magnitude** of a Forbush decrease is strongly median **energy-dependent** and generally follows a power-law form, where the spectral exponent γ typically ranges from 0.4 to 1.2.

We analyzed the energy dependence of the FD magnitude observed on **20. January 2026**. using multiple neutron monitors (NMs) and gLOWCOST stations.

$$\frac{\Delta N}{N} \sim E_m^{-\gamma}$$





Atmospheric corrections

As secondary cosmic-ray muons propagate through the atmosphere, their flux at ground level is influenced by **variations in atmospheric parameters**. Correcting for these effects is essential to improve the sensitivity of ground-based muon detectors.

Correction on pressure

β barometric coefficient

Correction on temperature- Muons are more affected

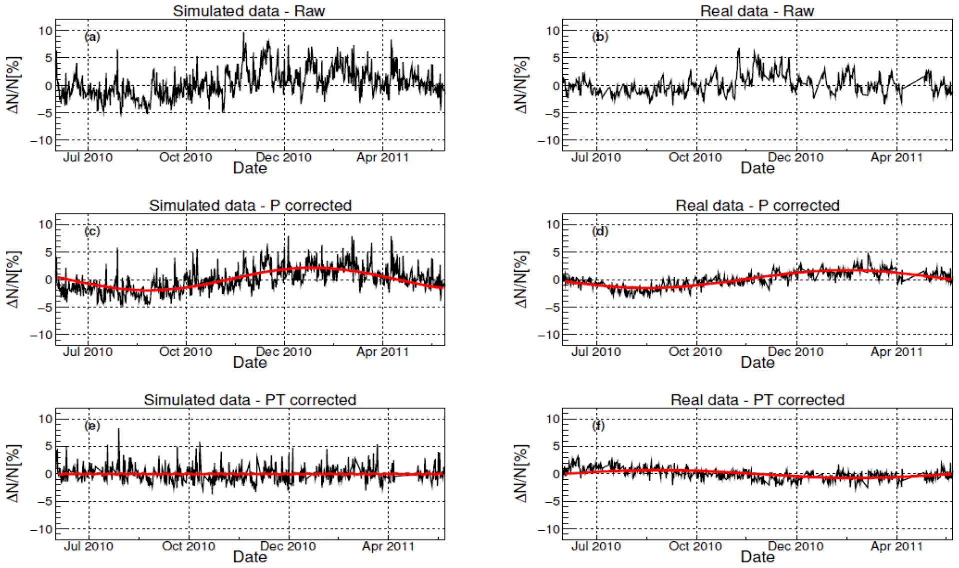
Negative temp. effect

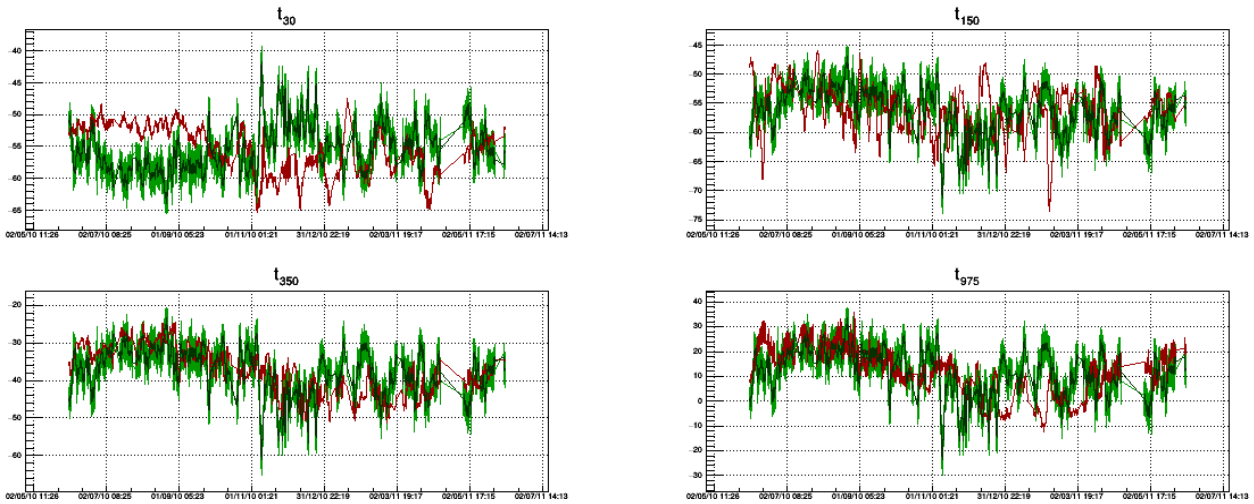
Positive temp. effect

We developed a **new method** for modelling of meteorological effects which utilize PCA and machine learning. We simulated muon flux at Earth's surface under varying atmospheric conditions using the CORSIKA Monte Carlo code.

Goal is to use this new methods to get clear data for studying space weather but also to use cosmic rays (CR) as **thermometer** for high altitude layers of atmosphere and atmospheric tomography.

$$\frac{\Delta I}{I} = \beta \Delta p + \int \alpha(h) \Delta T(h) dh$$





Cosmic Ray Measurement

- gLOWCOST network at ground
- Radiation measurement in flight
- Cosmic ray CubeSat

At ground

In Air

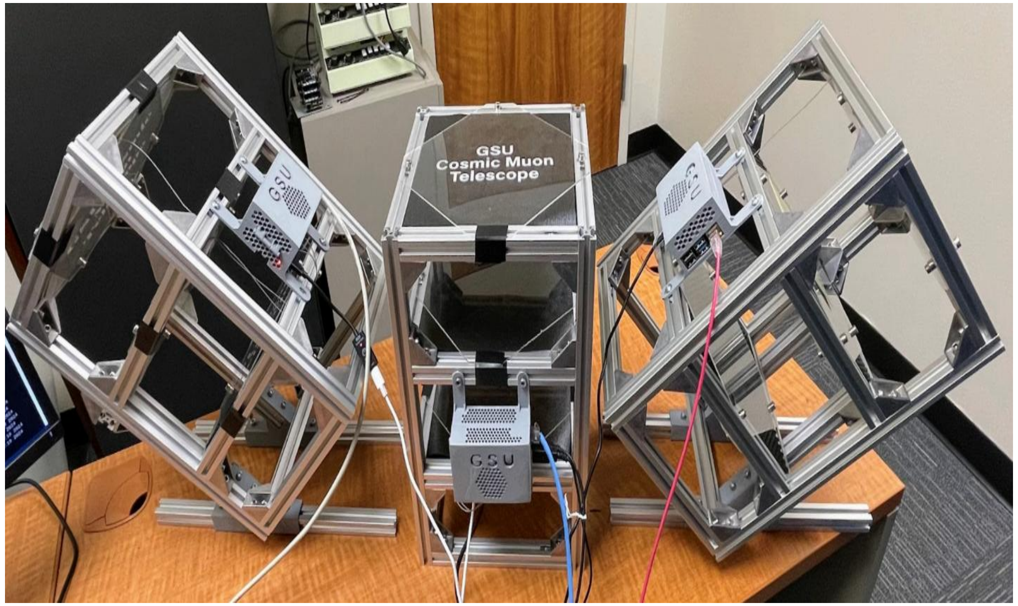
In Space

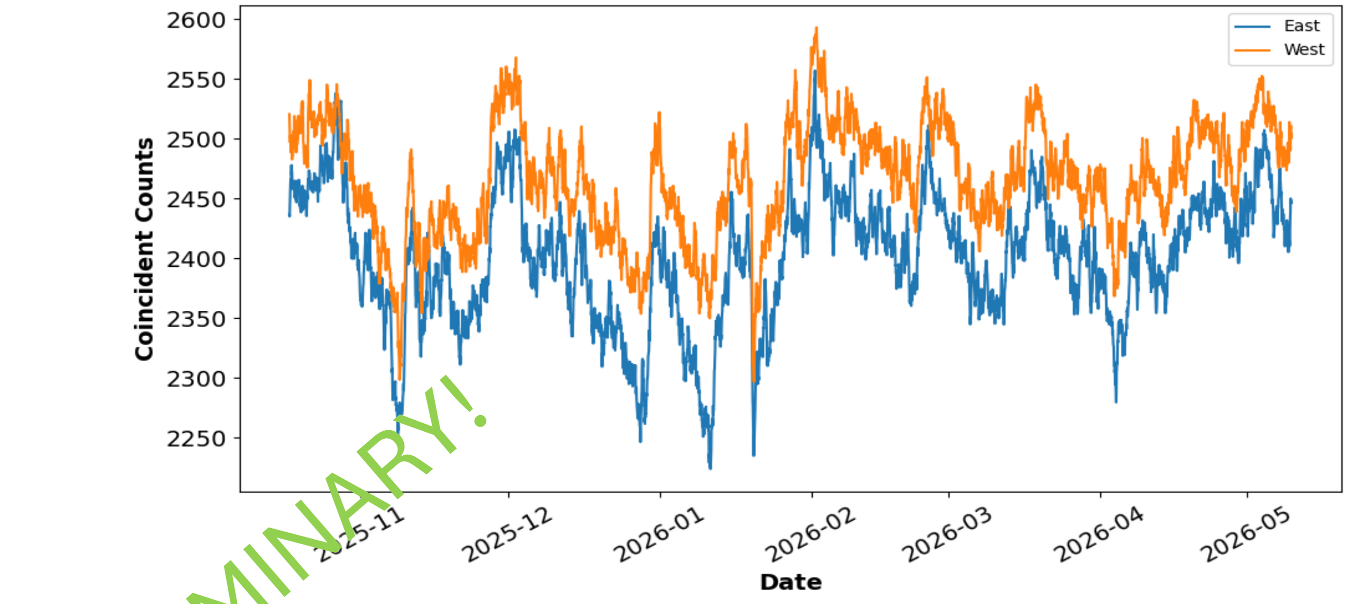
gLOWCOST Cosmic Ray Detector Network

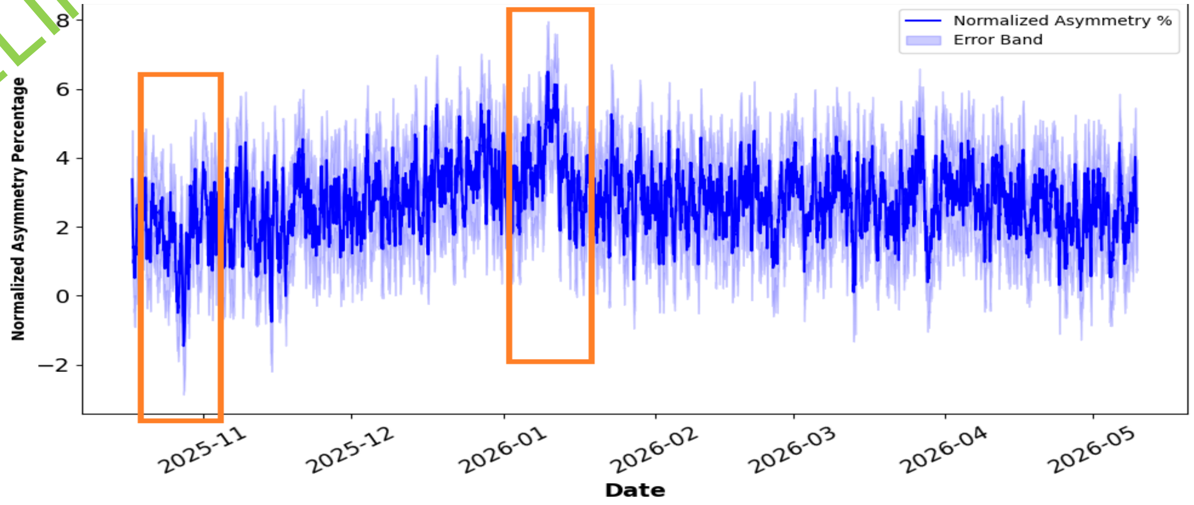
gLOWCOST Preliminary results: East-West anisotropy

The geomagnetic field causes an east-west asymmetry in cosmic rays because it deflects positively charged particles more strongly from the west, resulting in a higher flux from the east.

Cosmic ray measurements can provide an independent method to validate and complement data from magnetometers and satellites but also for atmospheric studies!





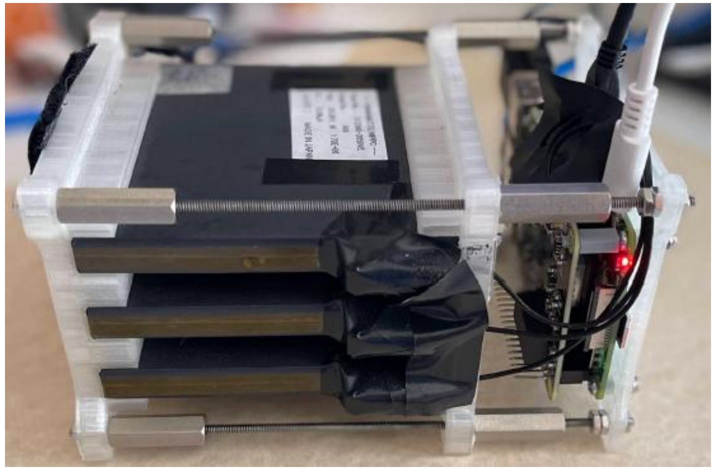


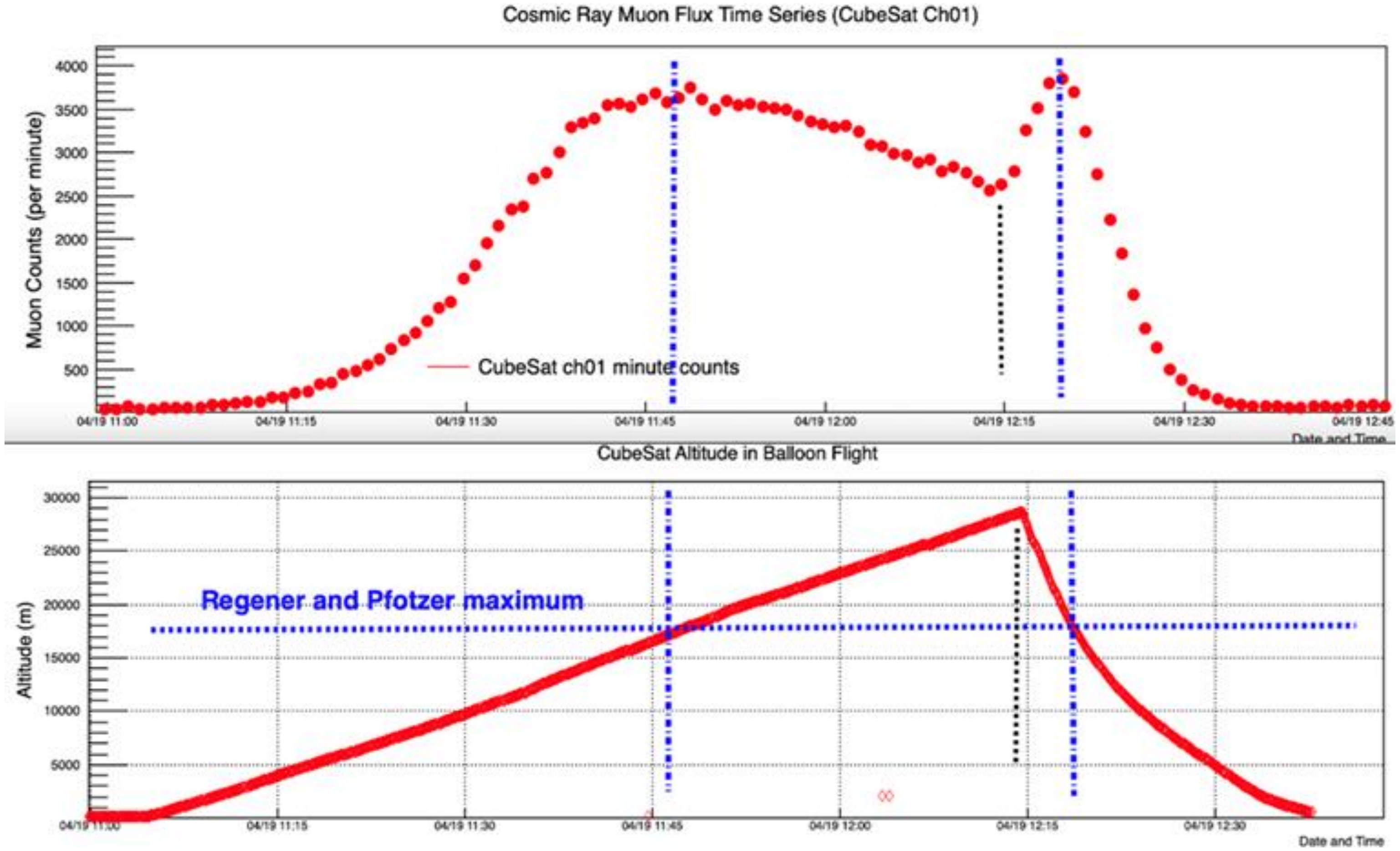
gLOWCOST Preliminary results: Balloon measurements

Smaller prototype of detectors has been developed.

The detector consists of three layers of 9.5cm x 9.5cm x 1cm scintillators with wavelength shifting fiber glued in a groove on the scintillator.

Prototype is used on several balloon flights to measure how CR flux depends on altitude (CR are discovered in a similar experiments at the beginning of 20th century).

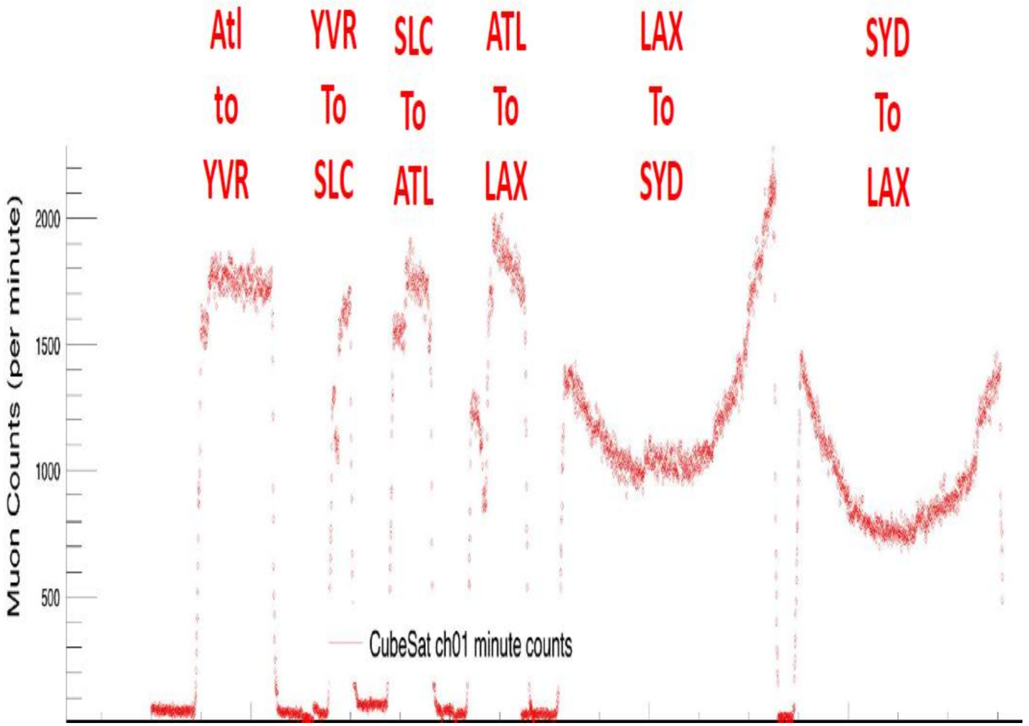




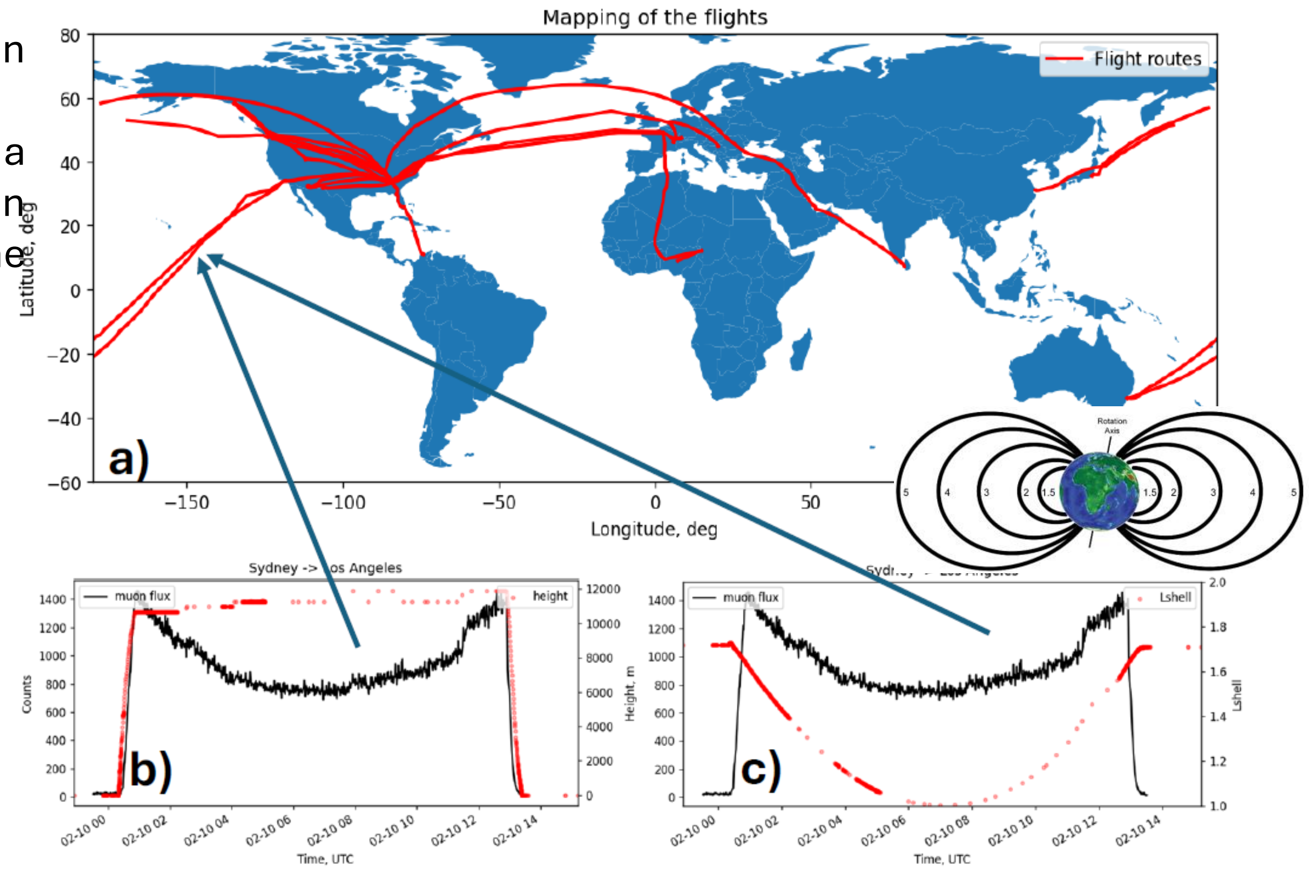
CR flux measured during balloon flight

gLOWCOST Preliminary results: Muons measurements in flights

Prototype is also used to measure the cosmic ray radiation dosage on commercial flights around the world.
For measurements on flights, the detector is powered by a phone battery charger and is put inside a box both for protection and easy carry. Once on the plane, the box is seated under the seat.



CR flux during several airplane flights



Flight from Sydney, Australia to Los Angeles, USA. The flight altitude (panel b) and the L-shell (panel c) are shown in red. The muon flux shows a U-shaped pattern, indicating that the flight has crossed the geomagnetic equator.

Summary and further goals

- The variation in muon flux is strongly influenced by atmospheric parameters such as pressure and temperature and is also sensitive to space weather phenomena
- Expanding the current gLOWCOST detector network of portable low cost muon detectors will allow for a more robust collection of data across different environmental and geophysical conditions using the same hardware.
- Versatile and scalable detector and detector network can be use as an outreach project but also as a spectroscope the size of the Earth.
- Focus for expanding network in the future will be on:

1. Developing comprehensive models to quantify the atmospheric dependence of muon flux and working towards constructing a predictive forecasting system.

2. Investigating the impact of space weather events on muon flux with the aim of building a reliable model to forecast these variations.

3. Exploring the influence of geomagnetic changes on muon flux and integrating this understanding into broader environmental models.

4. Applications in muography (collaborators at UPEA in Bolivia is interested in using detectors to explore an ancient Tiwanaku ruin,...)

We are looking for many more institutions to join this effort!

Thank you for your attention!

https://cosmic.ipb.ac.rs/

https://cosmic.gsu.edu/

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