LICEO SCIENTIFICO STATALE
"Arcangelo Scacchi"

Extreme Energy Events
Science inside Schools

Observation of the May 2024 Forbush decrease by the EEE Telescopes

Simone Ragno
Maria Lucrezia Sabatelli
Chiara Mazziotta
Sofia Ciriaco

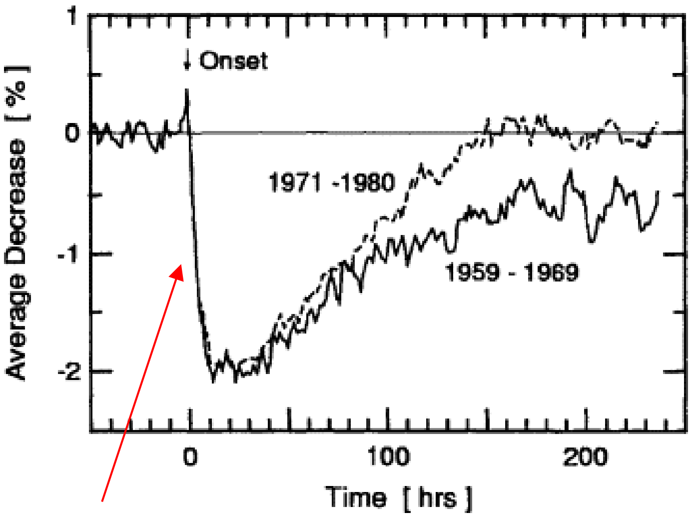
DESY.

What is a Forbush Decrease?

Forbush Decrease (FD) [1] is an important transient variation of the cosmic ray flux observed at Earth characterized by a rapid decrease (in a few hours) of the cosmic-ray flux.

The phenomenon is characterized by a recovery to the original value in a time scale of the order of a few days and with a nearly exponential shape.

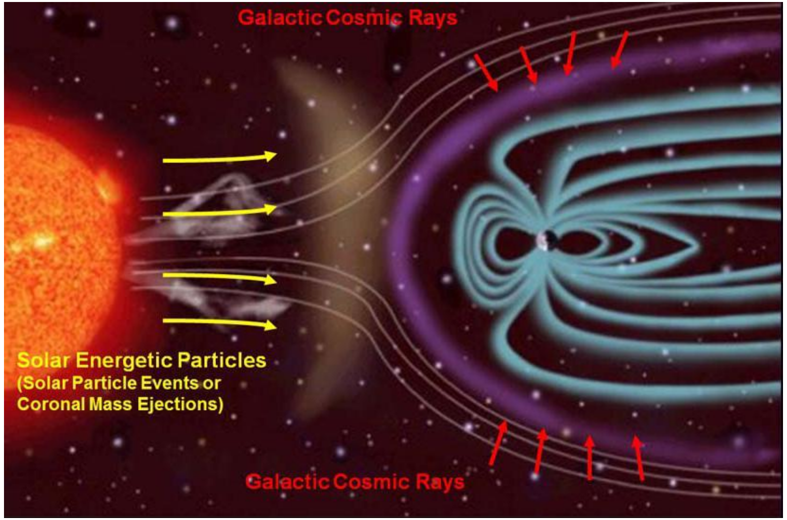
Coronal Mass Ejections (CMEs) shocks and Interaction Regions have proven to be able to produce FDs (Belov et al., 2001; Blanco et al., 2013).



Plot of "averaged" Forbush decreases as observed with the neutron monitor at Hermanus (South Africa)

Why does the FD happen?

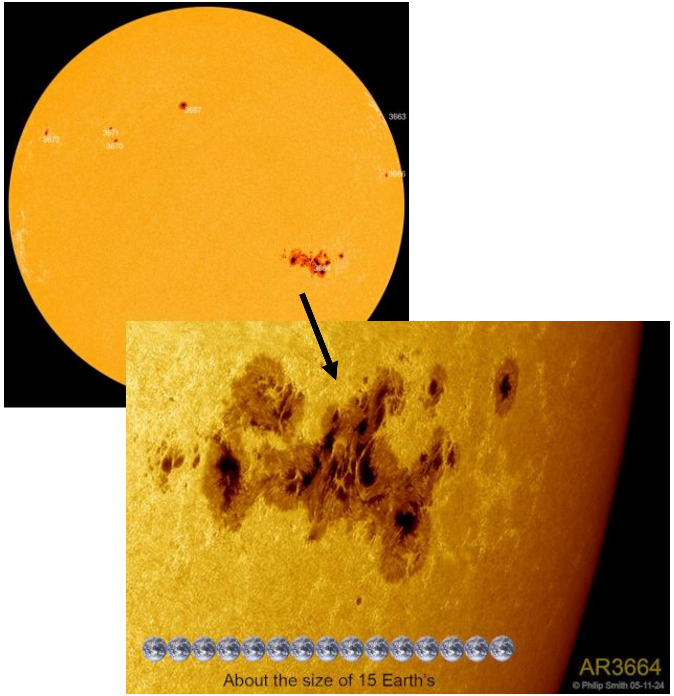
Cosmic rays are mainly fully ionized atomic nuclei, although most of them (more than 90%) are protons. During a Coronal Mass Ejection (CME), plasma mass is expelled in the space.



Given the fact that the plasma mass is ionized, a magnetic field is produced thanks to the charge of plasma. Once the magnetic field, caused by the ejection of the plasma mass, reached the Earth magnetic field deflects the ionized cosmic rays due to the Lorentz force. The consequence of this phenomenon is the decrease of the measurement of the ionized cosmic rays in our observation.

The effect of FD is evident for the neutrons we can observe on the Earth. As a matter of fact, even though these particles were not influenced by the Lorentz force, because they are not ionized, they would have been reduced given that the majority of neutrons we measured originated from the protons decay in our atmosphere.

The solar flares of May 10, 2024



Giant sunspot AR3664 has a 'beta-gamma-delta' magnetic field that harbors energy for X-class solar flares

- The biggest geomagnetic storm in almost 20 years.
- It has reached category G5 , an extreme event.
- The first of six CMEs (coronal mass ejection) hurled toward Earth by giant sunspot AR3664 hit our planet's magnetic field at 16:45 UT [2].
- Solar wind speed: 725.1 km/sec
- density: 8.82 protons/cm^3

The barometric effect

The barometric effect is a consequence of the mass absorption of muons in the Earth's atmosphere. In fact the atmosphere acts as an absorber for the muons and an increase of barometric pressure above the detector causes a greater absorption and thus a lower detection rate. For small pressure variations dp, the observed rate variation dR can be expressed in differential form as follows [3,4]:

$$\frac{dR}{dp} = \beta R$$

where the proportionality coefficient β is known as the barometric coefficient.

In finite form, the formula used to correct the observed rate R_{oss} as a function of the observed pressure p_{oss} given by:

$$R_{cor} = R_{oss} + \beta\overline{R}(P_{oss} - \overline{P})$$

where R_{cor} is the corrected rate, $\overline{R}$ is the average measured rate over the observation period, and $\overline{P}$ is the average atmospheric pressure measured over the same period.

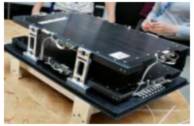
The coefficient β was obtained by dividing the slope of the regression line by $\overline{R}$

- Another important factor which influences the coefficient β is the geomagnetic latitude. Because of the Earth’s magnetic field, the average energy of the secondary particles decreases with increasing latitude and therefore the atmosphere absorbs a larger number of particles. This means that the barometric coefficient increases going from the equator to higher latitudes.

- The coefficient β also depends on the direction of incidence of the detected particles. Indeed the average energy of the secondary particles becomes larger as the zenithal angle is increased because the layer of atmosphere traversed is greater for particles coming from more oblique directions.

- The barometric coefficient is finally influenced by the thickness of the shield surrounding the detector.If a detector is located inside a building, the cosmic rays had inevitably to traverse some “natural” shield thicknesses (like the roof, the surrounding walls and so on) before reaching the detector. The value of β rapidly decreases with increasing shield thickness.

Table: The main parameters of detectors employed in the investigation



	POLA-01	VICE-01	BOLO-02	OULU
Latitude	78°55’ 16’’ N	45°33’ 29’’ N	44°29’ 04’’ N	65°03’ 15’’ N
Longitude	11° 51’ 45’’ E	11°32’ 04’’ E	11°22’ 21’’ E	25°28’ 05’’ E
Altitude	44 m asl	42 m asl	60 m asl	28 m asl
Average rate during period of investigation	31.3 Hz	45.6 Hz	14.6 Hz	95,8 Hz (5750 counts/min)
Type of detector	muon telescope : 2 planes of plastic scintillators readout by SiPMs	muon telescope: Multigap Resistive Plate Chambers (MRPC)	muon telescope: Multigap Resistive Plate Chambers (MRPC)	neutron station

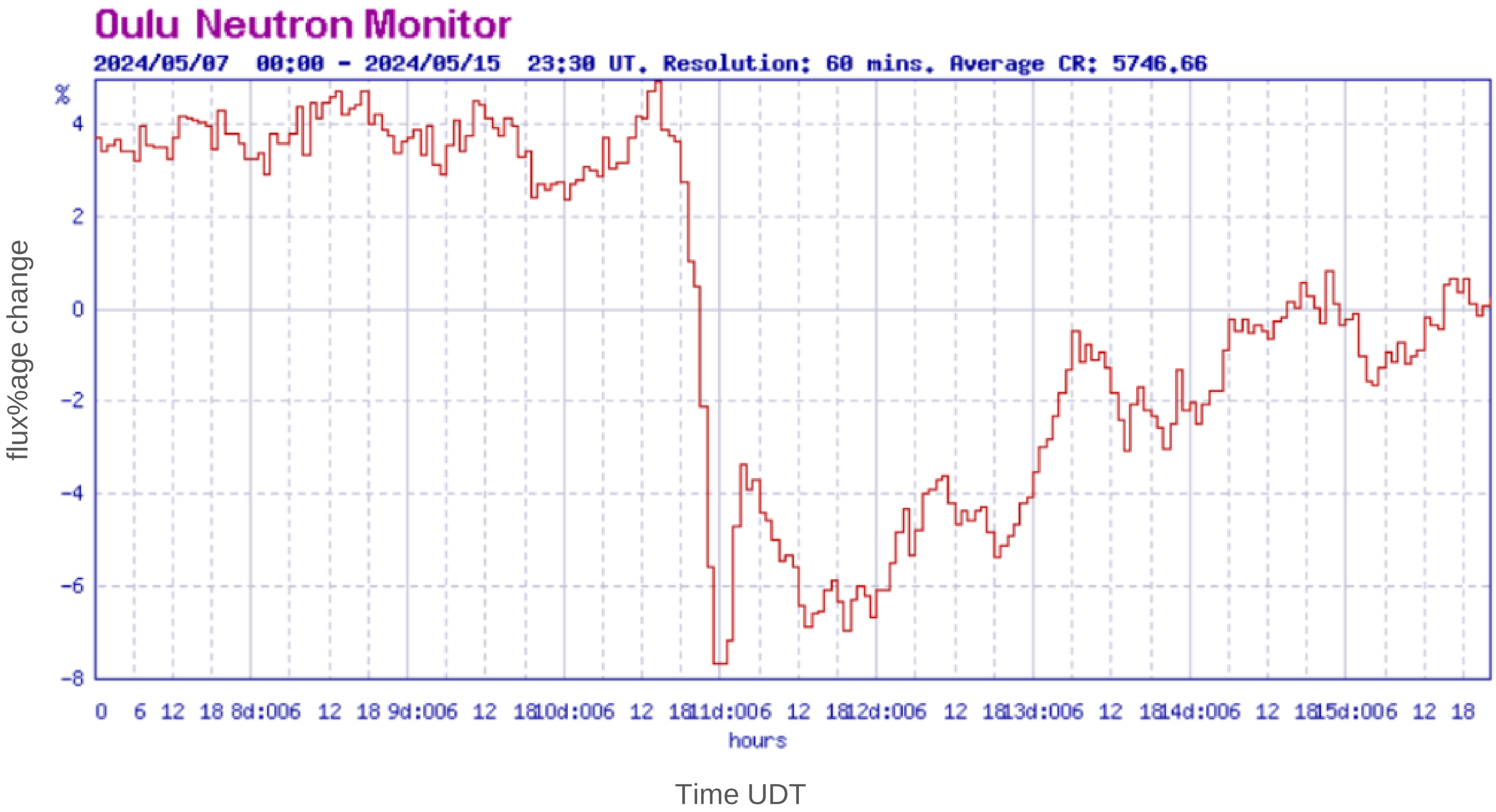
Experimental setup and working conditions

- The minimal energy a primary must have in order to produce secondary particles able to reach the Earth in that location plays an important role in determining the absolute value of the observed Forbush decrease

- Monitoring of Forbush decreases is usually done through neutron monitor stations, since most of the intensity variation is associated to low energy particles, whereas GeV muons are sensitive to more energetic primaries [6]. (This means that such effects are more difficult to see with muon detectors, especially if they have small counting rates)

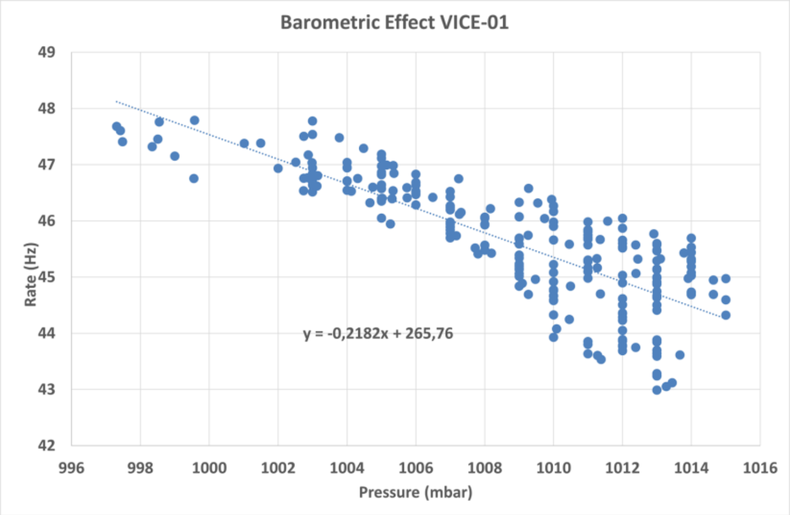
- A correlation analysis between neutron counting rates from neutron monitor stations and the muon rate from three muon telescopes was carried out, following a Forbush decrease on May 10th, 2024.

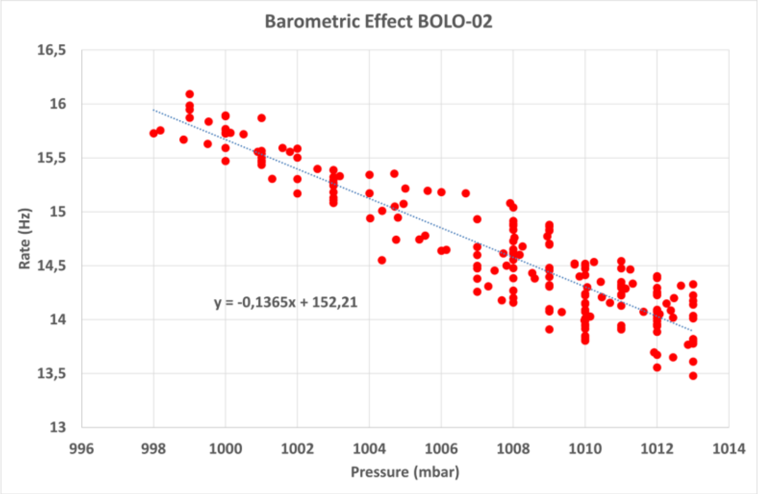
Time variation of the measured neutron flux at the Oulu neutron station from 7 to 16 May 2024 [7]



Experimental results and data analysis

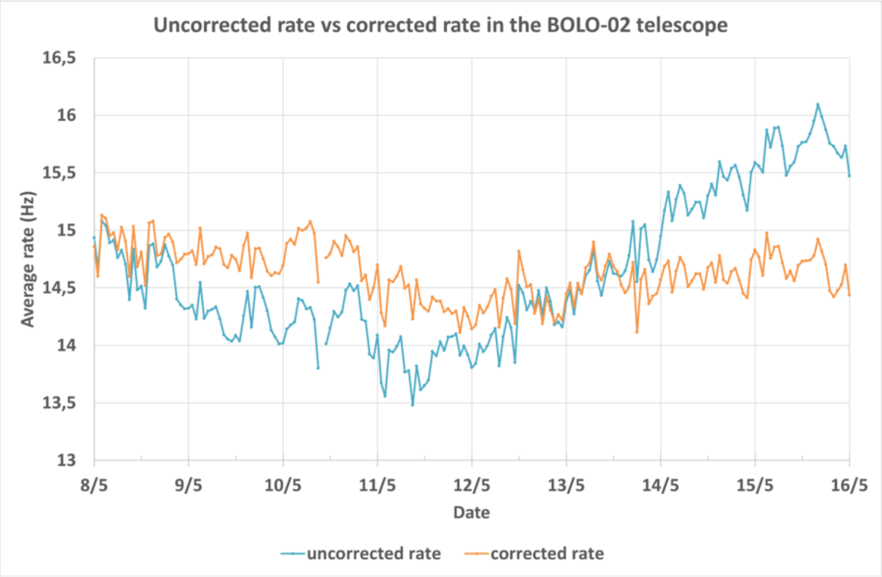
- The value of β obtained for the EEE telescope BOLO -02, located 60 meters above sea level, is −(0.94 ± 0.11)%/mbar.
- For comparison, the value measured for the EEE telescope VICE-01, which is at 42 meters asl, is −(0.48 ± 0.02)%/mbar.
- No barometric correction was investigated for POLA-01 due to the fact that pressure was flat during the Forbush



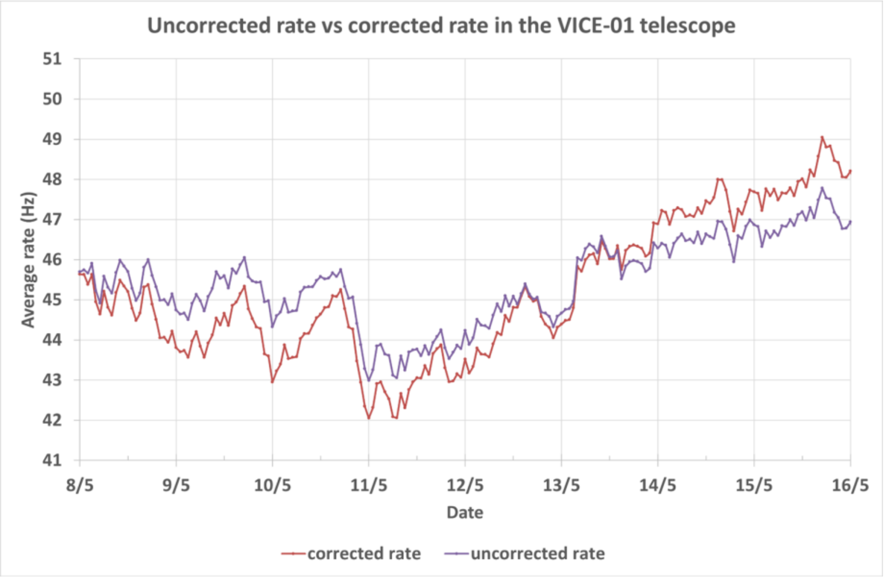


Atmospheric pressure/ rate correlogram from May 7, 2024, to May 16, 2024.
From the slope of the regression line, the value of the barometric coefficient is obtained.

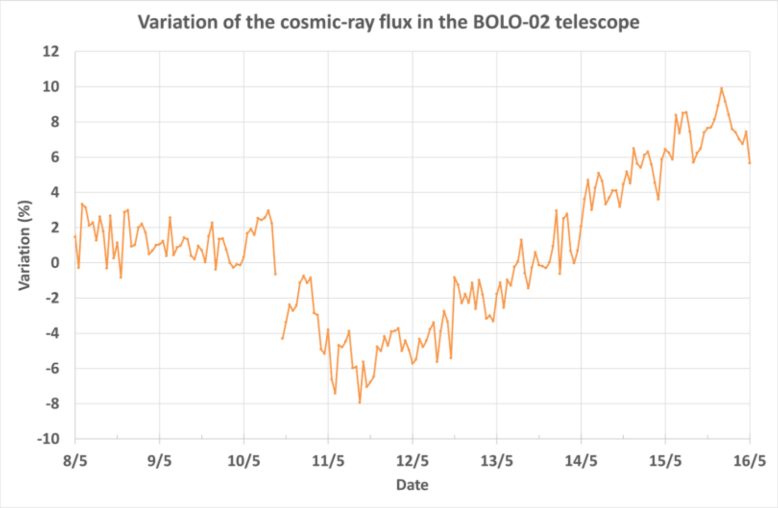
BOLO-02 average rate as a function of time

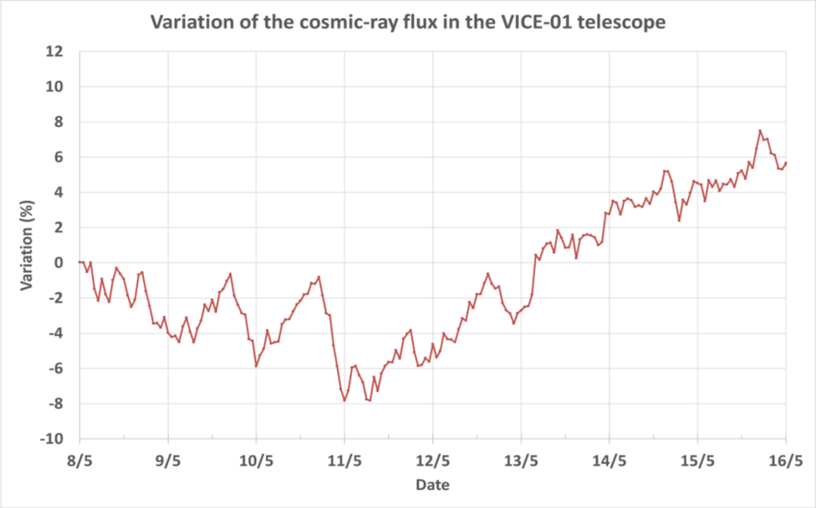


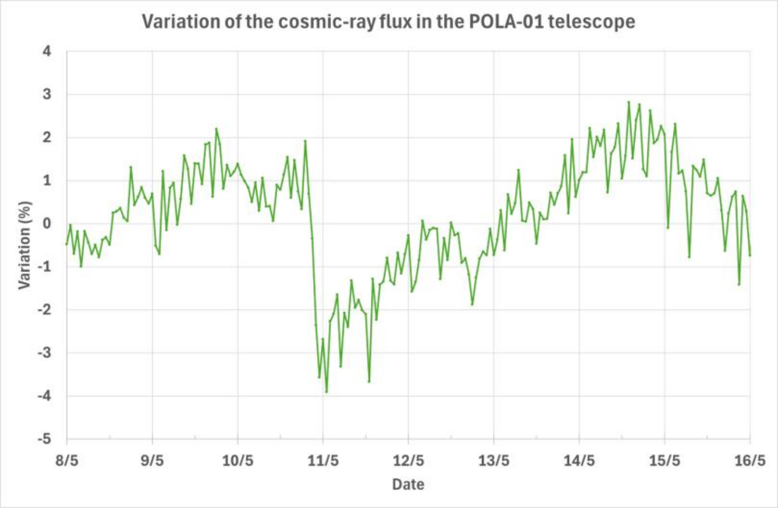
VICE-01 average rate as a function of time [5]

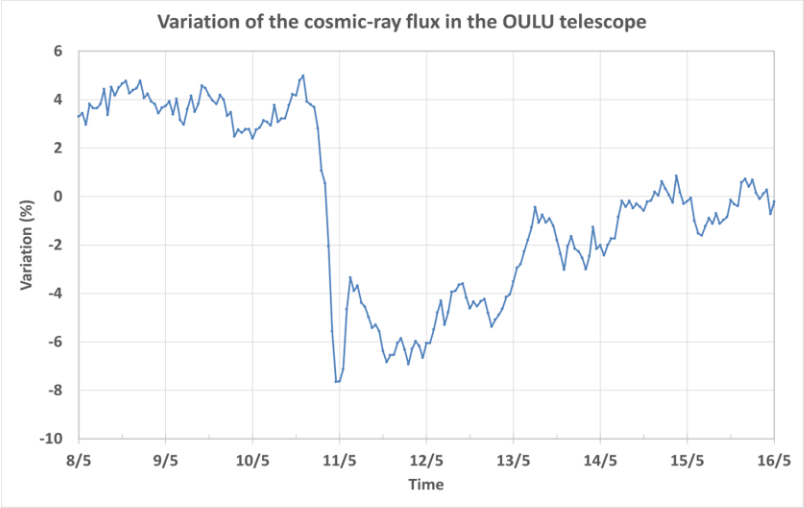


The count rate (averaged over a one-hour period) in the telescope was corrected for the barometric effect and plotted as a function of the time, for the period May 7 to 16 .To compare data from the different stations, they were normalized to the average value of the count rate and the percentage variations with respect to such reference level are plotted.

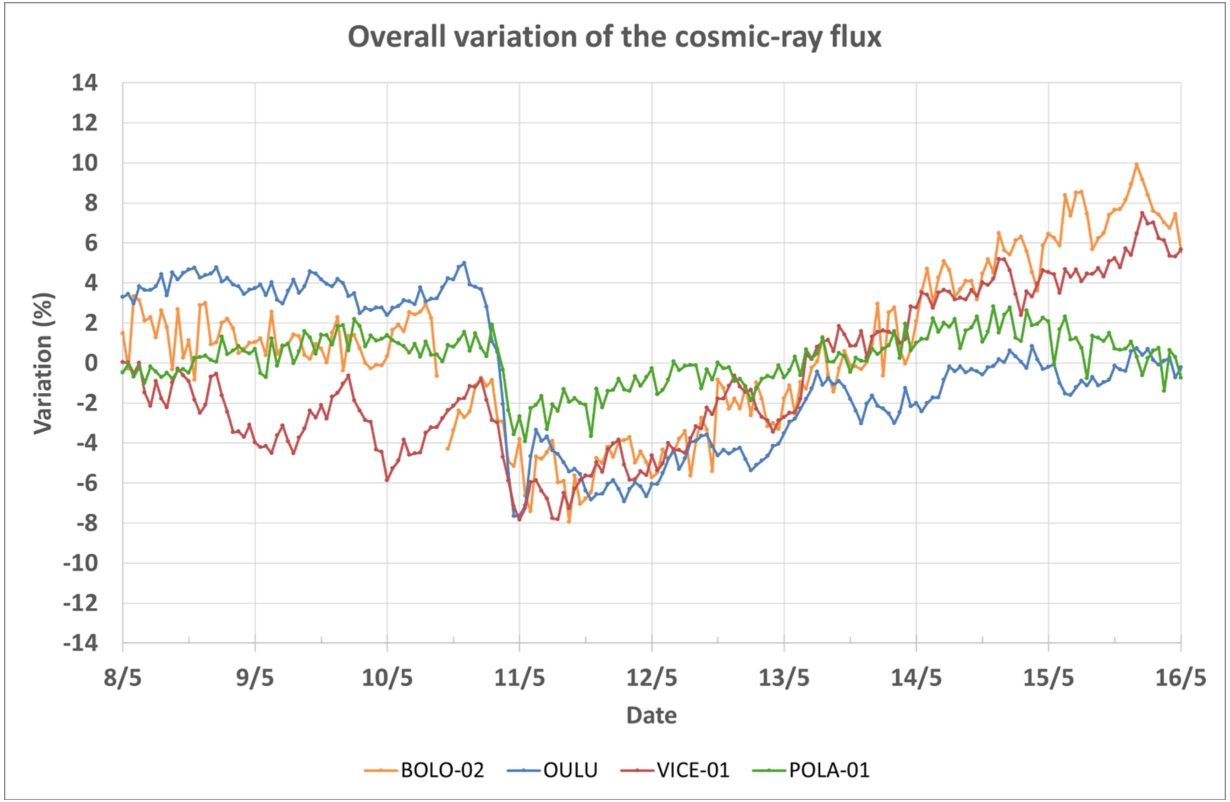

Variation of the cosmic-ray flux in the BOLO-02 telescope
Variation (%)
Date
8/5
9/5
10/5
11/5
12/5
13/5
14/5
15/5
16/5


Variation of the cosmic-ray flux in the VICE-01 telescope
Variation (%)
Date
8/5
9/5
10/5
11/5
12/5
13/5
14/5
15/5
16/5

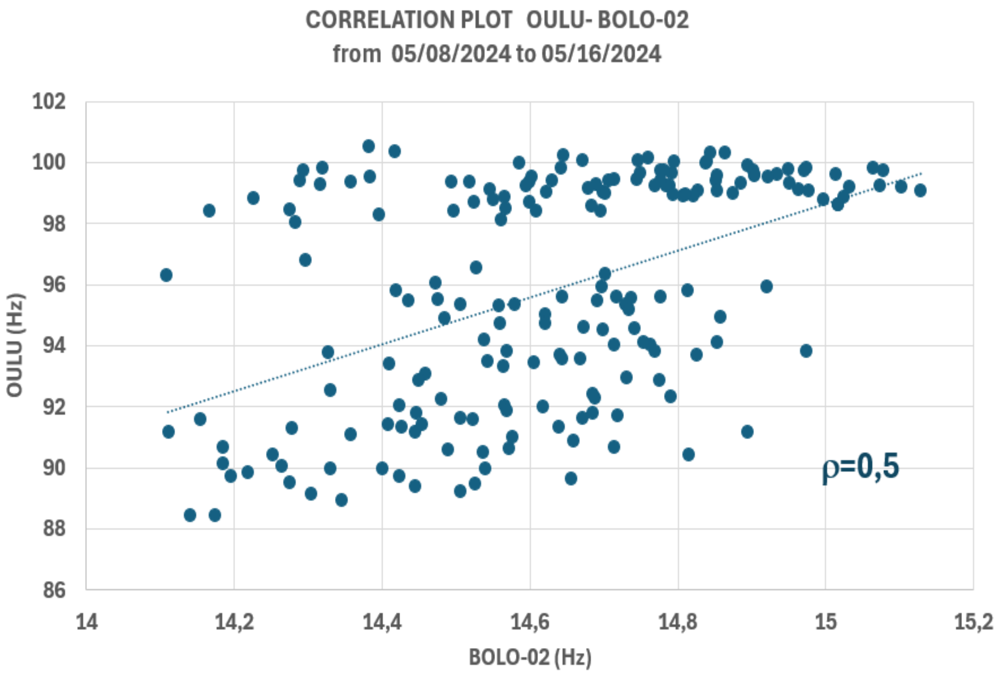

Variation of the cosmic-ray flux in the POLA-01 telescope
Variation (%)
Date
8/5
9/5
10/5
11/5
12/5
13/5
14/5
15/5
16/5

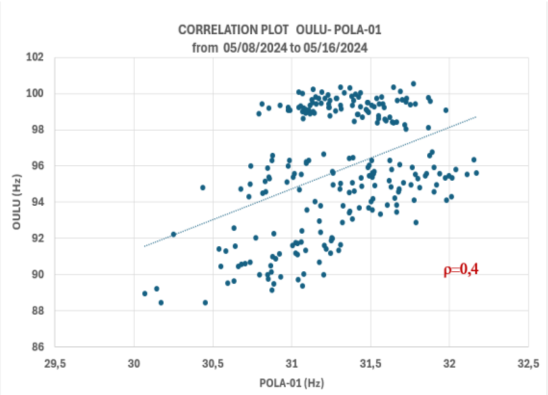

Variation of the cosmic-ray flux in the OULU telescope
Variation (%)
Time
8/5
9/5
10/5
11/5
12/5
13/5
14/5
15/5
16/5

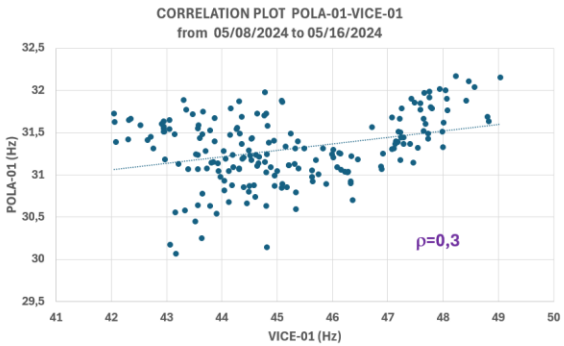
Time variation of the measured cosmic-ray flux in the three EEE telescopes, corrected for atmospheric pressure variation. In the same plot the corresponding neutron flux, as measured by the Oulu neutron station is also shown.



Some correlation plots between the counting rate measured by the Oulu neutron monitor and the EEE telescopes, during the period spanning the Forbush decrease.



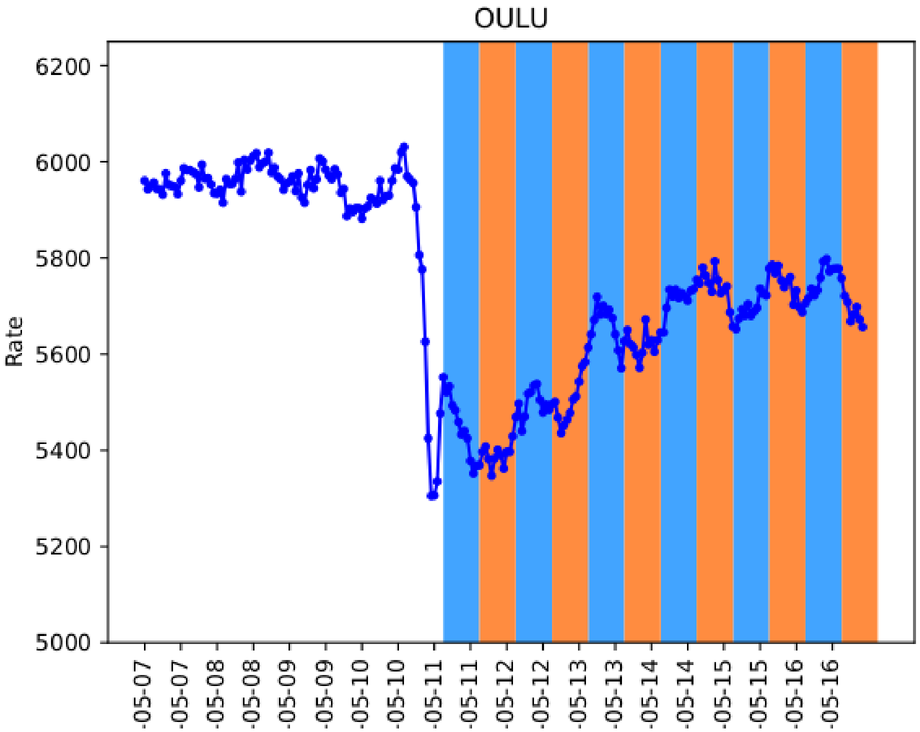




A correlation is observed between the data sets.

ρ stands for Bravais-Pearson coefficient

The OULU plot shows particularly well the day-night effect in the reprise from the Forbush. The blue and orange stripes are 12-hours intervals.



It seems that there is a night/day effect probable due to night/day temperature effect as for the barometric one.
We expect a 24h periodic variation in the function.

We used the lmfit model function in Python to fit a function y=c+a*sin*(kx)-b$e^{-\alpha x}$.

We obtain the following parameter values:

c=5840.23418 +- 38.18049

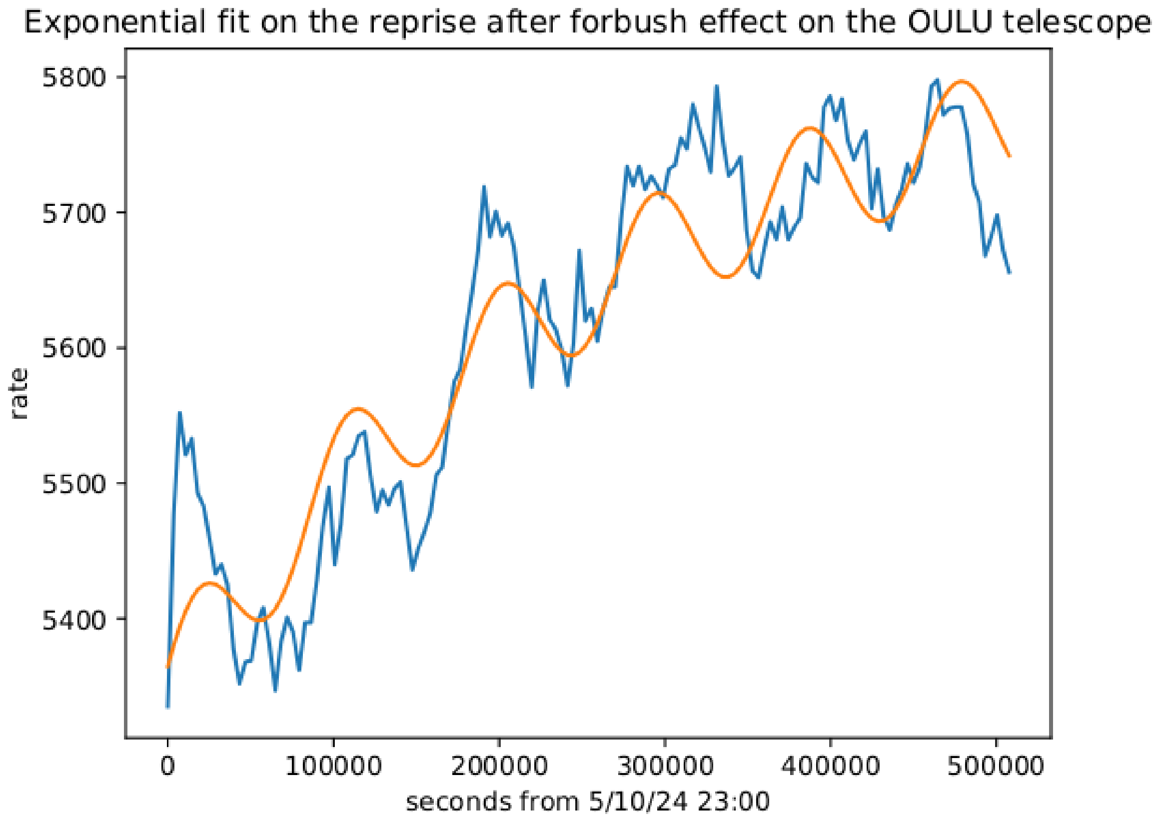
a=43.5242585+-6.37532

b=493.572379+-31.4447

k=6.818×10^{-5} +-9.716×10^{-6}

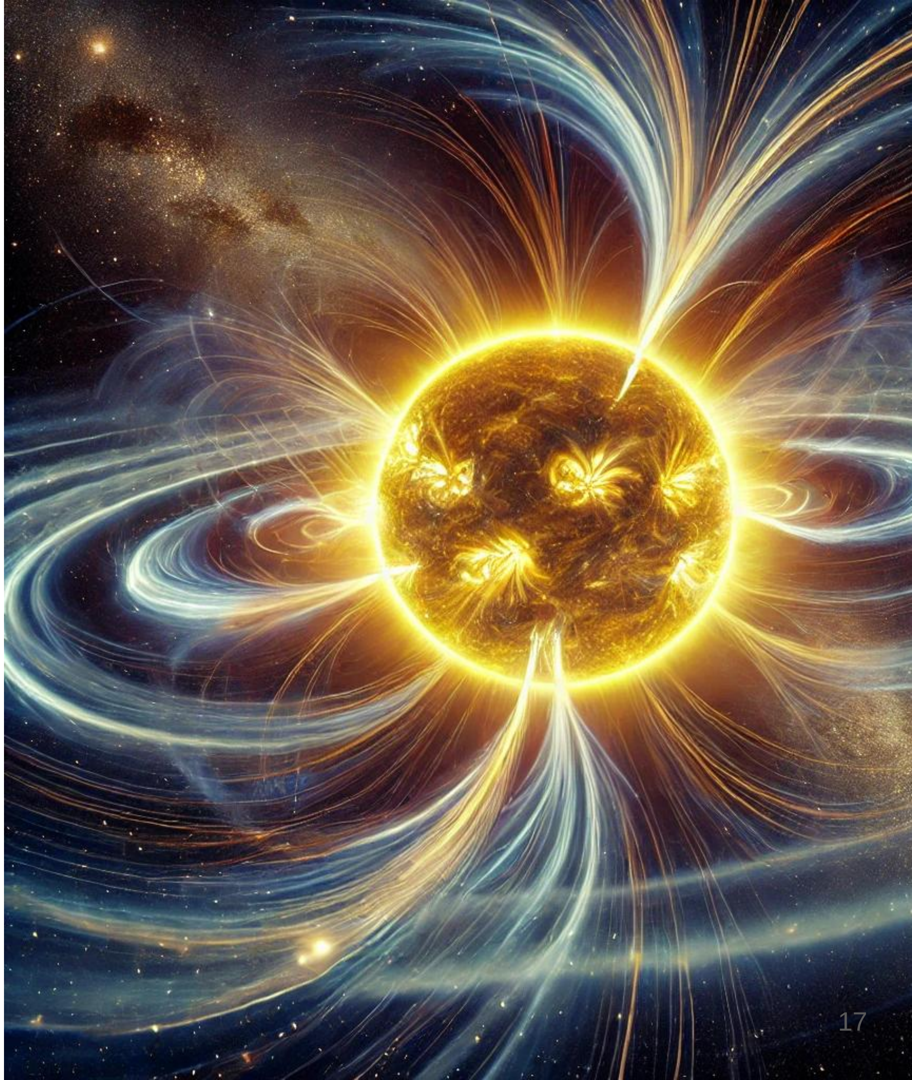
α=3.6322×10^{-6} +-6.2603×10^{-7}

Given $k = \frac{2\pi}{T}$, T is 92300 s, versus the expected value of 86400 s (24h) , with a fractional difference of 6%.



Conclusions

- The Forbush decrease following the largest solar flare in the last years has been observed by two independent MRPC-based muon telescopes of the EEE Project and by a PolarquEEEst detector made of two scintillator planes coupled to Silicon Photo Multipliers (SiPM)
- The data extracted by the telescopes were found to be highly correlated with those measured by neutron monitor station, although this is more sensitive to low-energy primaries, whereas muons detected in the POLA-01 and the two EEE telescopes originate from higher-energy events in the atmosphere.
- The exponential reprise shows a strong day-night effect that can be investigated using a best fit procedure.



References

[1] S.E. Forbush, Phys. Rev. 51, 1108 (1937).

[2] https://www.spaceweather.com/

[3] La Rocca P., Tesi di Laurea Università degli Studi di Catania a.a. 2003/2004.

[4] M.Muscarella et al., Nuovi risultati dell'esperimento EEE al Liceo "A. Scacchi" di Bari, Giornale di Fisica vol.LVI, N.3, Luglio-Settembre 2015.

[5] EEE monitor-DQM, https://iatw.cnaf.infn.it/eee/monitor/

[6] M. Abbrescia et al., Eur.Phys. J.Plus.126:61 (2011)

[7] Oulu Neutron Monitor, http://cosmicrays.oulu.fi