"Portare la scienza nel cuore dei giovani"

"Bringing science into young people hearts"

(A. Zichichi)

INTERNATIONAL COSMIC DAY

2024 EDITION

Data analysis of the working group of the "Liceo Scientifico G.B. Scorza" based in Cosenza.

SCORZA
LICEO SCIENTIFICO STATALE

Extreme Energy Events
Science inside Schools

Who are we?

This analysis was produced by the students of “Liceo Scientifico G.B. Scorza”, a high school based in Cosenza. We have been part of the EEE project since 2012. This project offers a wide range of opportunities to Italian students, enabling them to experience how researchers work.

COSE-01 *[Event Display]*	dom 05 novembre	20:35	COSE-01-2023-11-05-00024.bin

The project uses MRPC telescopes to detect muons through gasses in their chambers, which get ionized when collisions with charged particles occur. Recently these gasses were changed into more ecological ones. Lately we received and installed them in our MRPC. This enabled us to start the muon detection once again. That wouldn’t have been possible without the guidance of prof. Franco Mollo.

Who are we?

Our school has been very active in the scientific field throughout the years. In March 2023 a group of about 30 students visited the CERN in Geneva. It was the second time our school had been there: the first visit occurred when a delegation of our students, led by our teacher Prof. Franco Mollo, built our detector there. And since last year our school has been starting a collaboration with the Monte Scuro air base.

What are Cosmic Rays?

Cosmic Rays are highly energetic particles and atomic nuclei, generated by *Extreme Energy Events*. They travel almost at the speed of light and are constantly striking Earth from all directions.

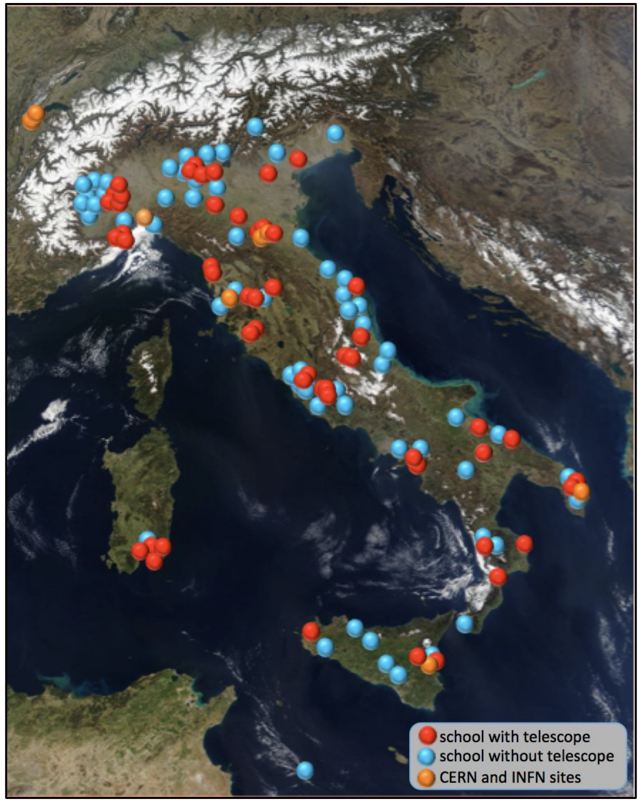
There are two types of Cosmic Rays:

- **Primary Cosmic Rays** originate from the events mentioned above (high energy galactic events, such as quasars, supernovas, etc…).
- **Secondary Cosmic Rays** originate after Primary CR collision with the Earth's atmosphere. They are mainly composed by:
  - At 30% by a **soft component**, like **Electrons**, **Photons** and minimally by **Protons**, **Kaons** and **Nuclei.**
  - At 70% by a **hard component**, called **Muons.**

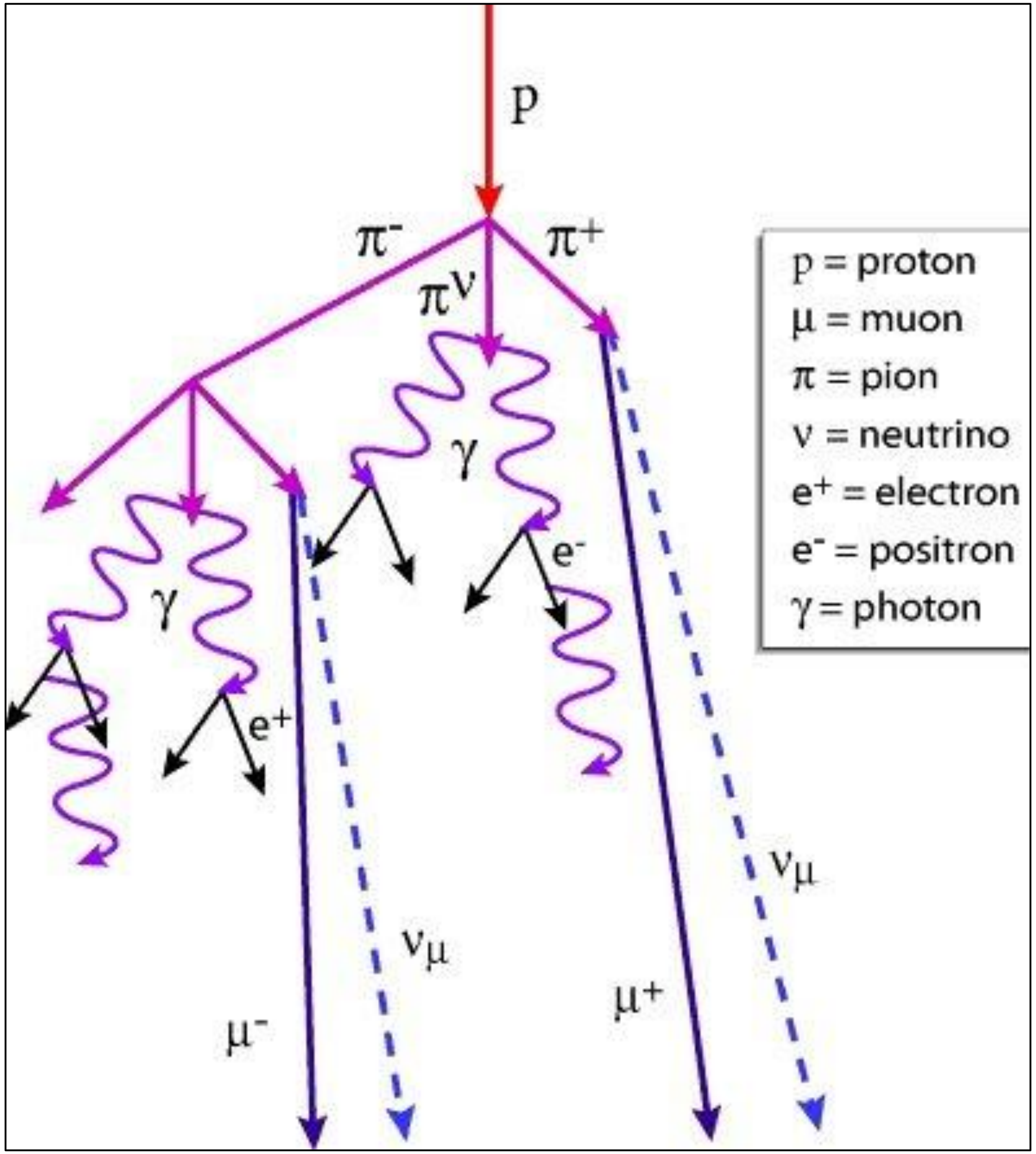
Muons have great penetrating properties and thus make up most of the secondary cosmic rays' composition at the sea level. These properties also make them easy to detect even indoors.

What are Extensive Air Showers (EAS)?

The decay of Primary Cosmic Rays forms *Extensive Air Showers* (**EAS**). Studying Secondary Cosmic Rays that belong to the same shower, is useful to determine the direction of the primary cosmic ray from which they took their origin.



To study these phenomena, the **EEE project** has installed different telescopes on a national scale. Some of them are in the same city, and they are the most useful ones to detect the showers. In order to do so, scientists study the coincidences of events detected in these telescopes that aren't too distant from one another. The revealed events, in fact, belong to the same shower.



How were the RC data used in this analysis produced?

1. **MRPC (Multigap Resistive Plate Chamber)**
   The EEE telescope consists of three sensitive planes of MRPC detectors (160 × 82 cm^2). The passage of a charged particle through each plane is detected via an electrical signal induced on the reading strips. The strips are 160 cm long, 25 mm wide, with a 34 mm center-to-center pitch. The crossing point along the strip is determined by recording the arrival times at both ends of the strip where the signal is generated.

   The MRPC detector structure is made up of six 350 μm thick gaps filled with gas, interspersed with planes of resistive material.

OUR MRPC Detector

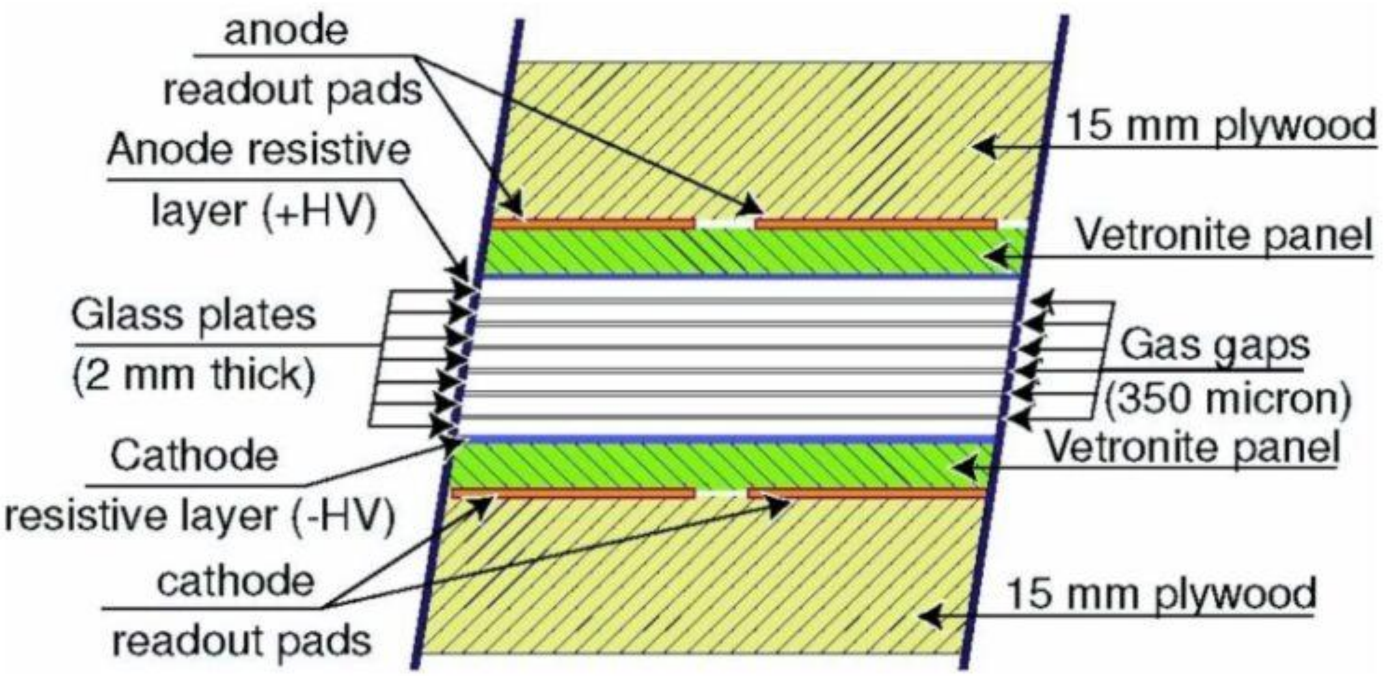
How were the RC data used in this analysis produced?

One of the most diffused class of particle detectors is filled with gas. Basically, they're made out of one (or more) gas volumes, where an electric field is applied.

Among the first and most popular detectors used for the detection of charged particles;

They exploit the ionization produced by the passage of a charged particle in a gas.

But, above all, the beating heart of the detector is none other than the **gaseous mixture**.



A visual section of one MRPC chamber

The actual gaseous mixture used is formed by:

- **$C_3H_4F_4$ze**, which GWP = 4 (in spite of GWP_{C2H2F4} = 1430);
- **He**,which GWP < 1 (in spite of GWP_{SF6} = 23900)

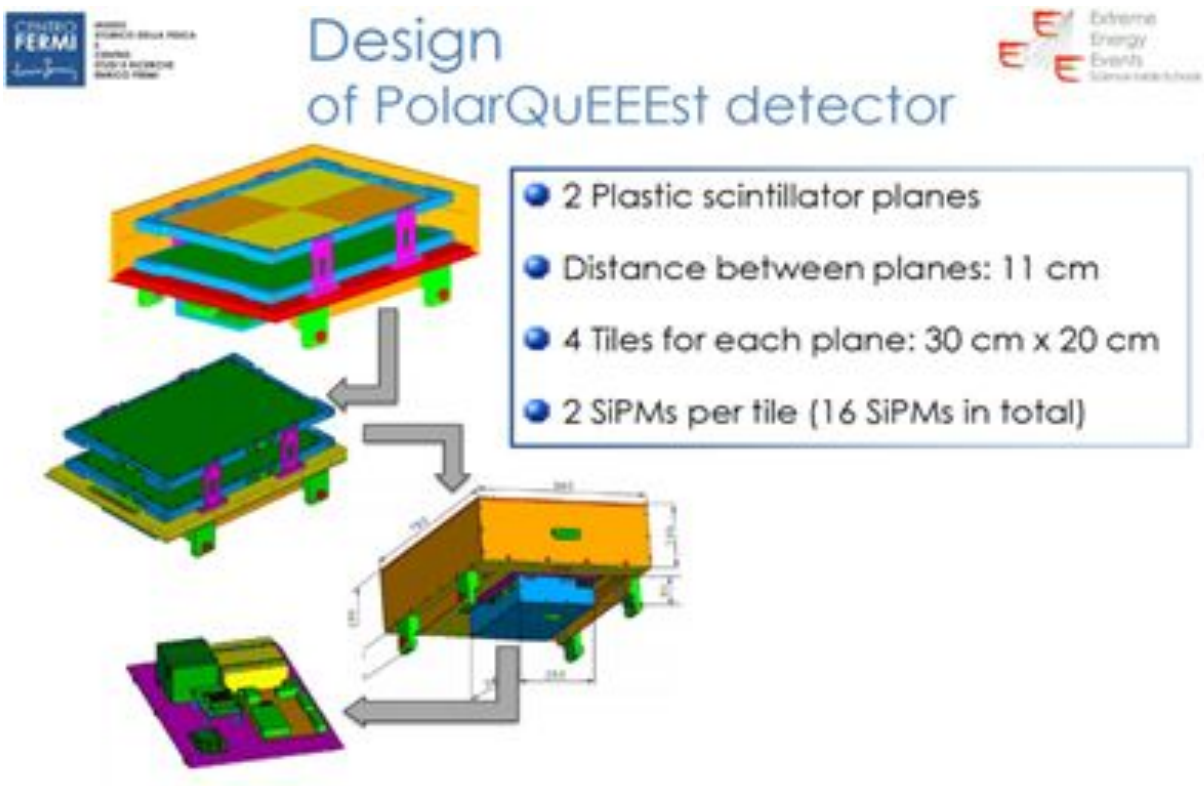
(GWP = Global Warming Power)

How were the RC data used in this analysis produced?

2. POLA Detector

The POLA telescopes are designed with lightweight structures, each weighing less than 50 kg and consuming less than 15 W of power, making them ideal for extreme conditions. The telescopes consist of two parallel planes, spaced 11 cm apart. Each plane is made up of four rectangular plates, each measuring 300 × 200 mm². These plates feature cuts at opposite corners, where two Silicon PhotoMultipliers (SiPMs) are housed.

The plates are coated with a material that is transparent to particle passage while being reflective to electromagnetic radiation. This coating helps guide the photons produced by the scintillation process toward the SiPM windows. The SiPMs then convert the photons into electrical signals, which are processed into LVDS format by a Front-End board for further analysis.



Representation of a pola detector

PolarQuEEEst

This type of analysis is also done in Ny Alesund, a city in the Svalbard Islands, through the detectors POLA-01, POLA-03 and POLA-04. They were installed there in 2019. This location is particularly strategic because, due to the Earth's magnetic field, there are a lot more cosmic rays at the North Pole, than at lower latitudes.

Beforehand, though, **POLA-01** and **POLA-03**, had taken part in a scientific experiment: the **Polar Quest Experiment**.

Its objectives were many, but the most relevant ones were the study of cosmic rays' rate variation depending on the latitude of the revelation, and the celebration of the Italia Airship tragedy.

PolarQuEEEst 2018

It was 1928 when Umberto Nobile, with his crew of researchers, made it to the North Pole and explored it with the Italia Airship. Unfortunately, it wrecked during its scouting of the location, determining the death of the whole crew except for 8 survivors, including **Umberto Nobile** himself. The Polar Quest mission was carried out by a team of international scientists on board the Nanuq vessel in 2018, from July to September. The cosmic ray detector POLA-01 was on that ship, whereas **POLA-02** and **POLA-03** were located in ground sites (*Oslo* and *Turin*).

POLARQUEST

POLARQUEEEST 2019

Then, from December 2018 to April 2019, POLA-01 was involved in another Polar Quest mission, which put it on the road, and made it travel across Italy, Germany and CERN. During its journey, the team also visited our school "Liceo Scientifico G.B. Scorza", in Cosenza.

It was an immense honour for our students to be able to conduct an experiment with POLA-01, coordinating it with the MRPC detector in our laboratory: they allowed us to study the rate of cosmic rays at different floors of the building.

PolarQuEEEst 2019

Finally **POLA -01**, **POLA-03** and **POLA-04** reached *Ny Alesund* in May 2019, and were installed in locations a bit distant from one another:

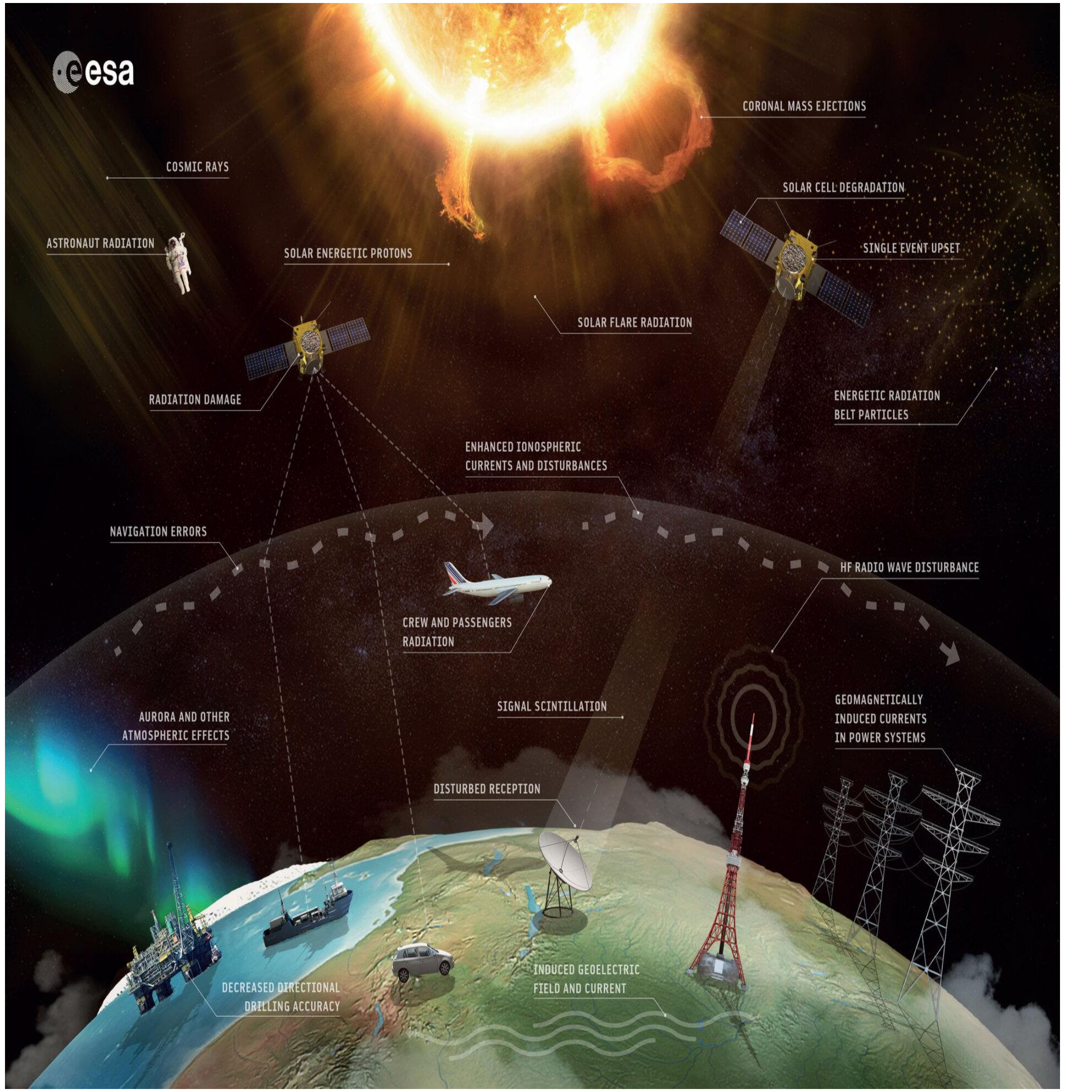
- **POLA-01** is currently in the Amundsen-Nobile Climate Change Tower;
- **POLA-03** is in "Dirigibile Italia" Station, named after the 1928 tragic mission;
- **POLA-04** is placed in the Gruvebadet atmospheric laboratory.

THEORETICAL NOTES

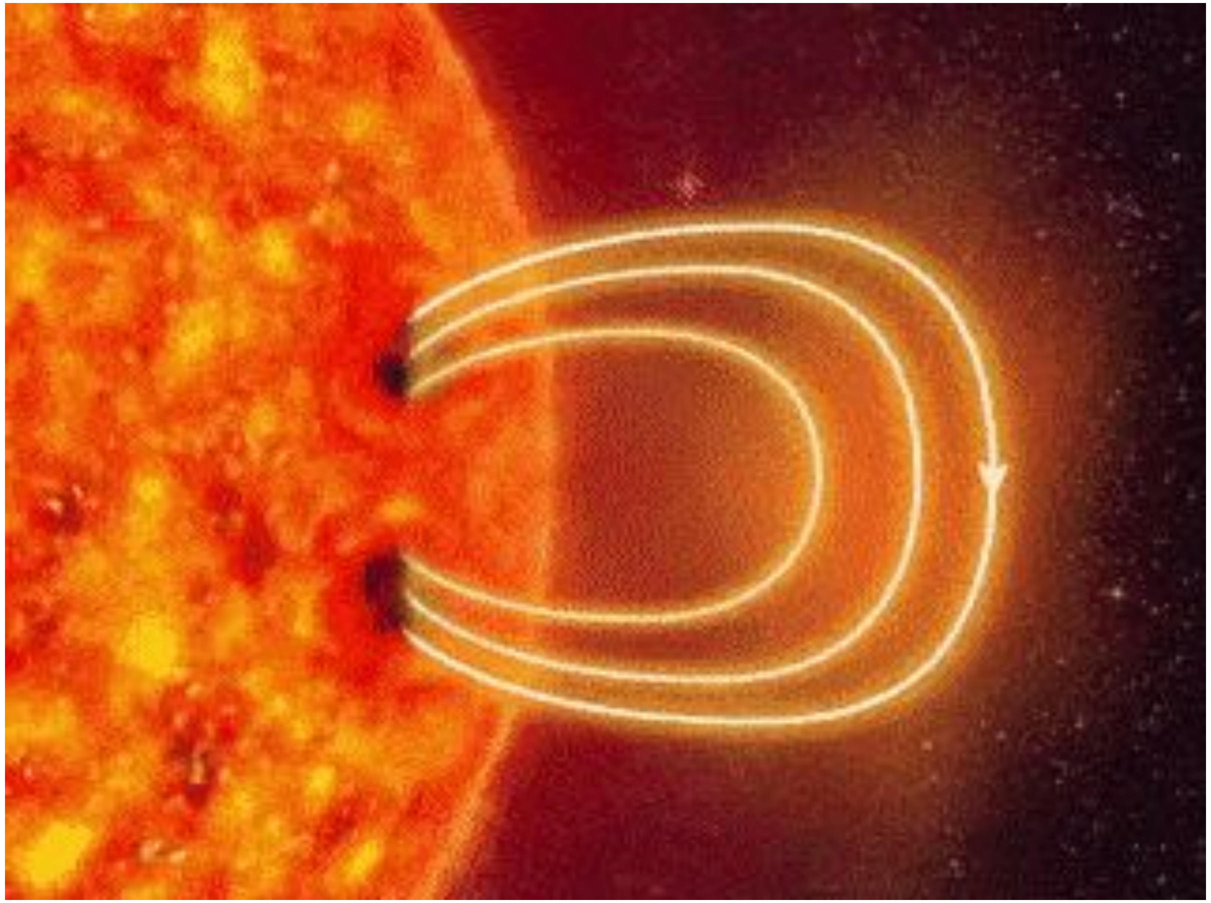
A brief introduction to the contents and theoretical notes used in the study and analysis procedures

The importance of the Space Weather

- Space Weather (SW) conditions are of extreme importance in modern technology and life.
- They are related to the Sun’s activity which can influence the performance and reliability of a variety of space-born and ground-based technological systems **(Koons et al., 1999)**.
- SW exhibits a climatology which varies over timescales ranging from days to the 11-years solar cycle **(Lockwood et al., 2012)**.



Infographics on the Space Weather effects on human life by ESA ESA/Science Office, CC BY-SA 3.0 IGO



Infographics on the formation of a Coronal Mass Ejections and the consequences on the Heart Magnetic Field

- A chain of physical processes occurring the Sun and in the space around us.
- Coronal Mass Ejections (CMEs) and intense solar Flares produced from the Sun’s surface can be dangerous for human technologies.
- CMEs can propagate through interplanetary space and hit the Earth.
- The most hazardous SW threat is represented by the high-energy Solar Energetic Particles (SEPs), which are emitted at the Sun during solar eruptions and penetrate the Earth's environment.

Classification of Geomagnetic storms

- **Geomagnetic storms** are mostly classified by the geomagnetic index Dst, which quantifies the perturbation of the magnetic field due to the ring current around the Earth. Dst is the decrease in the field and is usually negative.

-50 nT < Dst < -30 nT	**small** storm
-100 nT < Dst < -50 nT	**moderate** storm
Dst < -100 nT	**strong** storm

- The most reliable predictor of Dst is found to be the product VB_s, where V is the solar wind speed and B_s is the southward component of the interplanetary magnetic field. VB_s is the electric field in dawn-dusk (y) direction.

- **Gonzales and Tsurutani (1987)** proposed that to have a strong storm one should have in the solar wind $B_s > 10$ nT and duration of the southward B $\Delta t > 3$ hours, with a corresponding electric field $E_y = VB_s > 5$ mV/m.

CMEs effects on Secondary Cosmic Rays

The effect of solar phenomena on the observed flux of cosmic rays in the Earth manifests itself not only in the periodic behaviour of sunspots, but also in aperiodic events, during which abrupt changes in the intensity of cosmic rays can be observed. One type of such events is the so-called **Forbush variations** (or *Forbush Effect*).

What is Forbush Effect?

Forbush Variations are **temporary decreases** in the flux of galactic cosmic rays (GCR) detectable on Earth, first observed by Scott Forbush in the 1930s. These fluctuations occur during high-energy solar events, such as coronal mass ejections (CME) or solar flares, which release dense plasma and intense magnetic fields into interplanetary space.

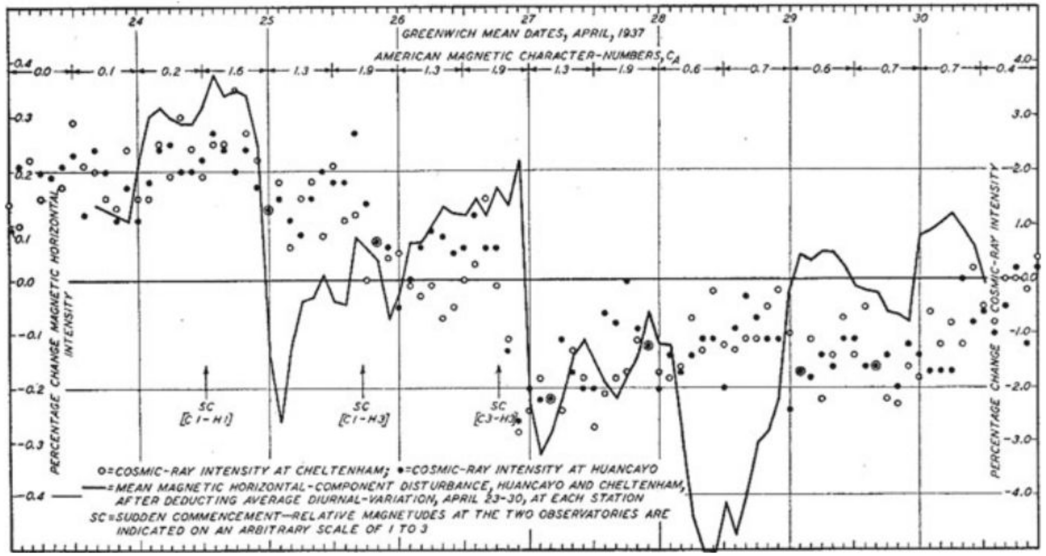


Fig. 12.6 Trend of the intensity of cosmic radiation measured continuously at two distant survey stations (Cheltenham in USA and Huancayo in Peru, data indicated by empty and solid symbols respectively), compared with the trend of the horizontal component of the Earth's magnetic field (solid line). Figure reproduced by S. E. Forbush, *On the Effects in Cosmic-Ray Intensity Observed During the Recent Magnetic Storm*, Physical Review **51**(1937)1108. Copyright (1937) American Physical Society, License RNP/22/JUL/055430

CMEs effects on Secondary Cosmic Rays

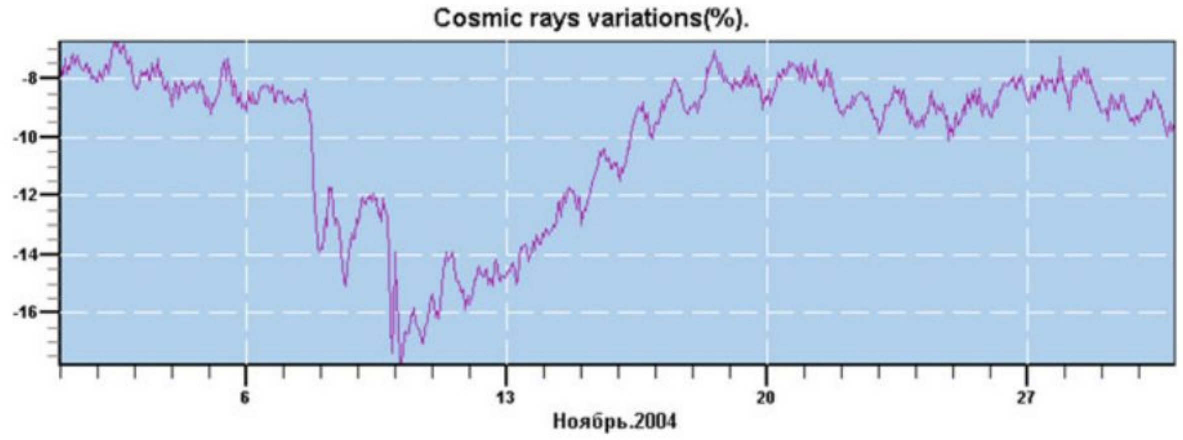


Fig. 12.7 Percentage change in cosmic ray flux, measured by the Moscow Neutron Monitor Station [IZMIRAN], during November 2004

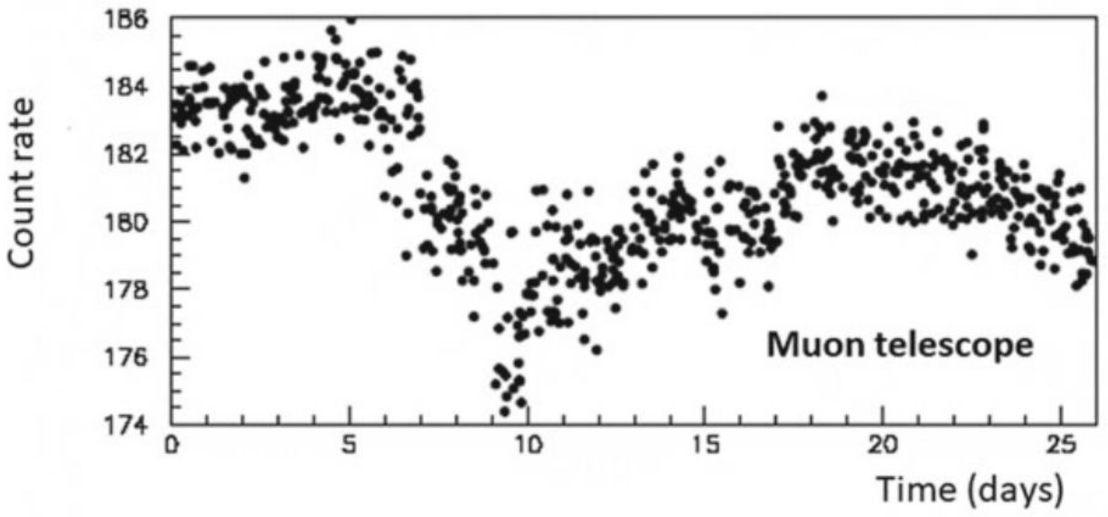


Fig. 12.9 Comparison between the intensity measured by a neutron monitor station located in Moscow and a muon detector operating in Adelaide (Australia), during the month of November 2004 [LaRocca2005]

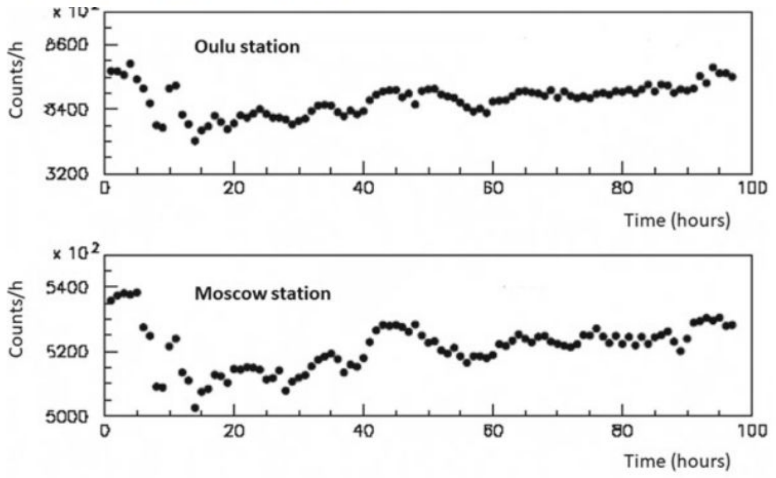


Fig. 12.8 Comparison between the intensity measured by two different neutron monitor stations, located in Moscow and Oulu (Finland) for a few days, starting on November 9, 2004 [LaRocca2005]

Astrophysical Implications

Forbush variations are critical for:

1. Studying the structure and intensity of magnetic fields associated with CMEs.
2. Understanding the solar modulation of cosmic radiation.
3. Analyzing interactions between the Sun and the heliosphere, which have implications for space and terrestrial technologies (e.g., GPS and satellite communications).

Scientific Characteristics

Amplitude of variation
Forbush variations can reduce cosmic ray intensity by up to 20–30%, depending on the power of the solar event and its interaction with Earth.

Duration
The decrease can occur over hours while the return to normal levels may take several days.

Solar wind propagation
The plasma emitted by the Sun travels through interplanetary space at typical speeds ranging from 300 to 800 km/s, affecting the flux of cosmic rays interacting with the Earth's magnetosphere.

Physical Causes

CMEs carry twisted magnetic fields and dense plasma that act as a barrier, deflecting or blocking incoming cosmic rays.

The effect is more pronounced at the poles, where the Earth's magnetic field is less effective in shielding the atmosphere.

Variation Models

Forbush variations are commonly measured using:

- **Neutron monitors:** Devices sensitive to secondary neutron production triggered by cosmic rays in Earth's atmosphere.
- **Muon telescopes:** Instruments that track muons produced by cosmic ray collisions with atmospheric nuclei.

EUHFORIA: a 3D-MHD numerical code for understanding CMEs propagation

- EUHFORIA is a full 3D-MHD data-driven model used to represent the background solar wind and CME propagation in the heliosphere up to 2 AU
(Pomoell J. and Poedts S.,2018).

- EUHFORIA's spatial domain is divided into two regions:

  A) The coronal domain (up to 0.1 AU);

  B) The heliospheric domain (from 0.1 AU to 2 AU).

- In order to modelize a CME event in EUHFORIA, two different methods are used:
  - **Cone CME model**, which describes CMEs as uniform spherical plasma-bubbles;
  - **Linear force-free spheromak CME model**, which model CMEs as flux-rope structures.

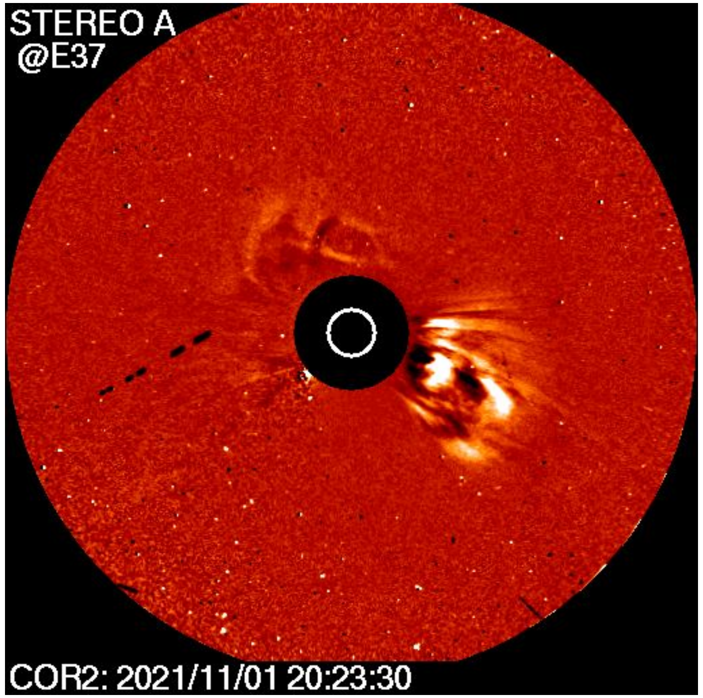
Numerical Results

Analysis of the 03/11/2021 event with EUHFORIA simulations

DEFINITION

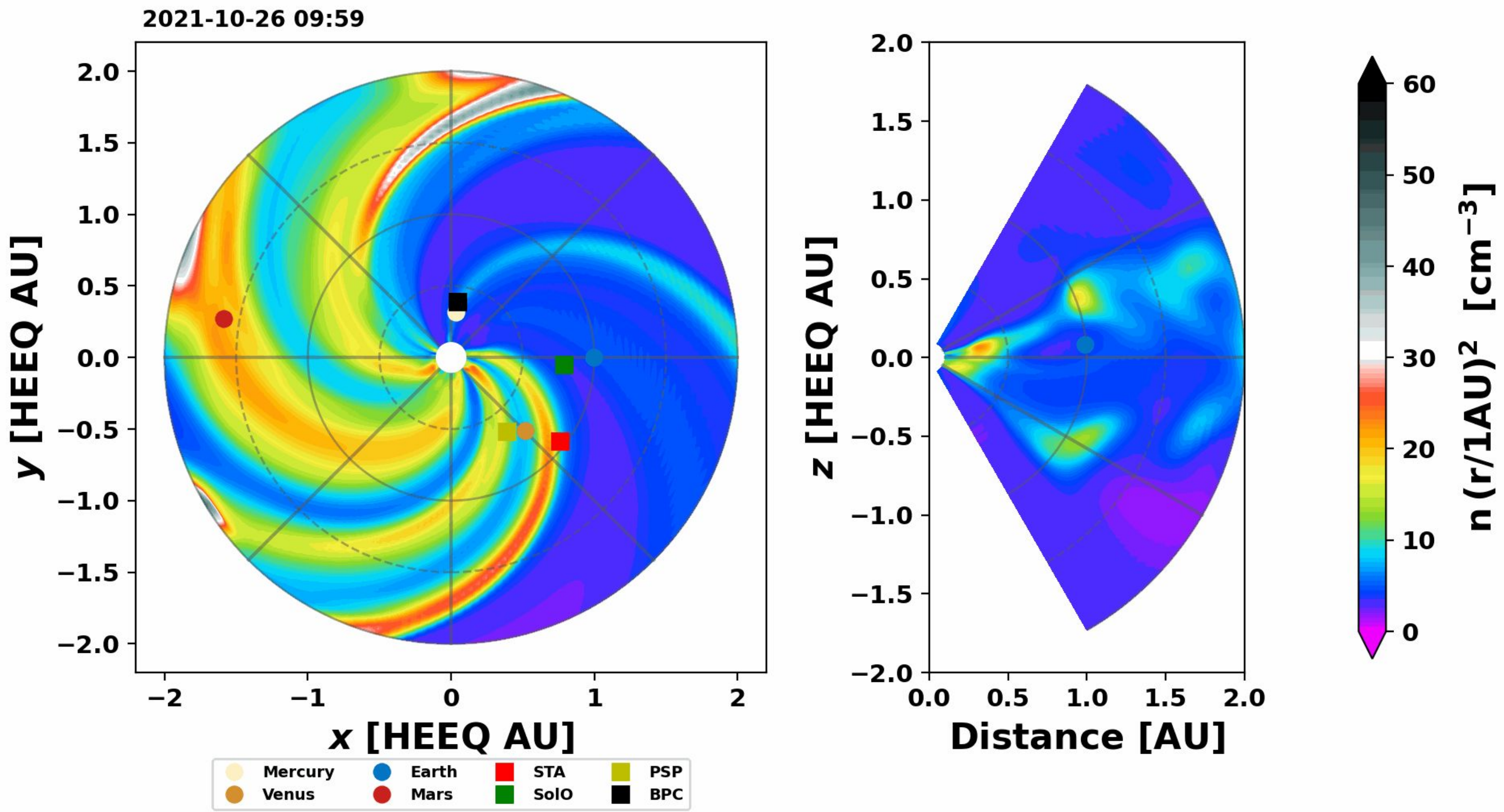
Halo CME: A CME directed in a geoeffective manner, that is, in the direction of the Earth, which appears as a diffuse halo with almost spherical symmetry around the emission area. They are called Full Halo when the symmetry is almost spherical, Partial Halo when it deviates even by several degrees from an ideal sphere.

Observed phenomenon



(Prete G. et al., 2024)

Simulated phenomenon



THE ANALYSIS

Now let's analyze the data provided by the Fermi Center, in parallel with those obtained by the STEREO (A & B) and SOHO telescopes, to look for experimental evidence of the FORBUSH effect (and understand if it is more powerful in Italy or at the Poles)

Data Analysis: Step by Step

Step 1: Data Preparation

1. Download the data:

- Choose the dataset to analyze (from available .csv or .root files).
- Make a copy of the chosen file and append "_orig" to its name.

2. Open the file:

- Open the file in Excel. If the data is not divided into columns, use Data -> Text to Columns.

3. Convert #BinStart to a readable date:

- Add a column next to #BinStart and name it "Date";
- Use the formula: =(A2/86400)+DATE(2007,1,1);
- Format the column as a date (e.g., dd/mm/yy);
- Extend the formula to the entire column.

Step 2: Correction for Barometric Effects

1. Create a new tab:

- Click the "+" button to create a new worksheet and rename it to "BarometricCorr".

2. Analyze pressure data:

- In the original worksheet, identify the minimum and maximum pressure values (from the Pressure column).

3. Build a pressure-rate average table:

4. Create a graph and exponential fit:

- Plot a scatter plot with pressure on the x-axis and average rate on the y-axis.
- Add an exponential trendline to obtain the barometric coefficient.

5. Correct the rate in the instruction and add the s calculation to a new column in the original worksheet and extend the formula.

Step 3: Correction for Barometric Effects

1. Create a new worksheet:

- Define 2-hour time intervals based on #BinStart and calculate the midpoint of each interval.

2. Calculate the average rate per interval:

- Use the formula AVERAGEIFS to compute the average rate within the time bounds of each interval:

AVERAGEIFS(Rate_Column, Time_Column, ">Lower_Bound", Time_Column, "<Upper_Bound")

3. Plot the average rate:

- Create a plot of the average rate versus time (using the interval midpoints).

Step 0: Space Weather Analysis

1. Download all files:

- Download all files related to data produced by **STEREO A**;
- Download all files related to data produced by **SOHO**; Download all files related to data produced by **STEREO A**;
- Download all the frames of the image produced by **STEREO A**, and create a gif.

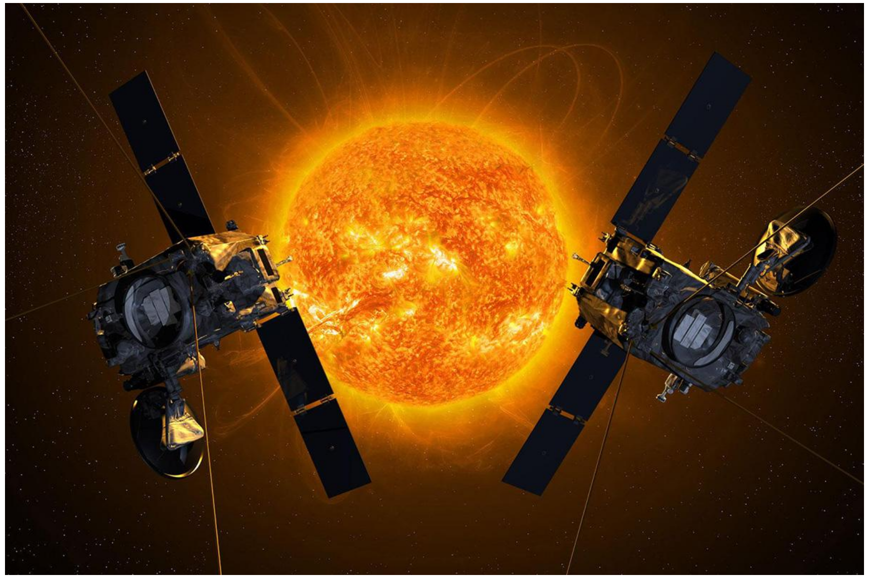
2. Interpreting the data:

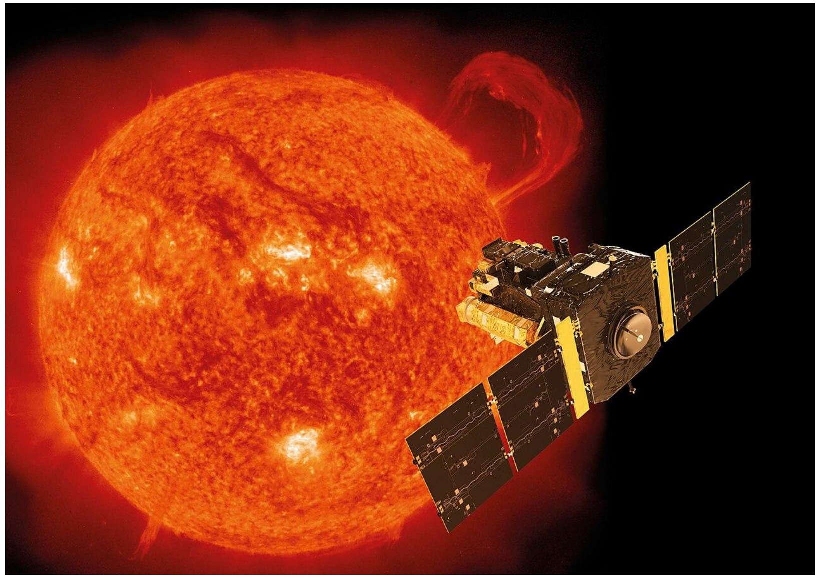
- Assuming that the plasma moves in **URM**, calculate (*assuming it is a material point*) how long it takes to travel **1 AU**;
- Extrapolate the power of CMEs and set it in a range to determine their classification (nT).

This part of the analysis focuses on identifying the correlation between a given SW phenomenon and the Forbush effect on CRs.

CMEs Event Analysis

Satellites that produced the SW data





STEREO (A & B)

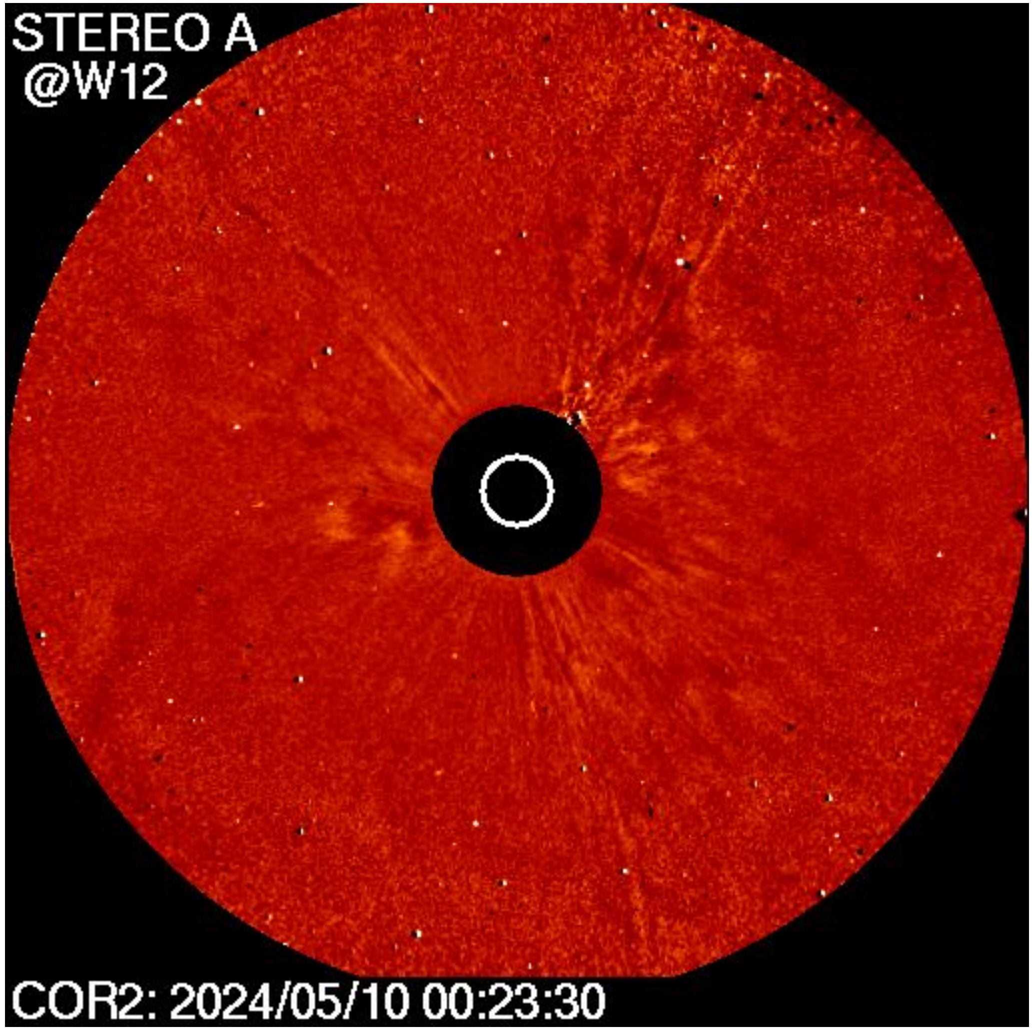
consists of a space-based observatory, **STEREO-A**, orbiting the Sun just inside of 1 AU - slowly catching up with Earth as it orbits about the Sun. This viewpoint away from the Earth-Sun line allows scientists to see the structure and evolution of solar storms as they blast from the Sun and move out through space.

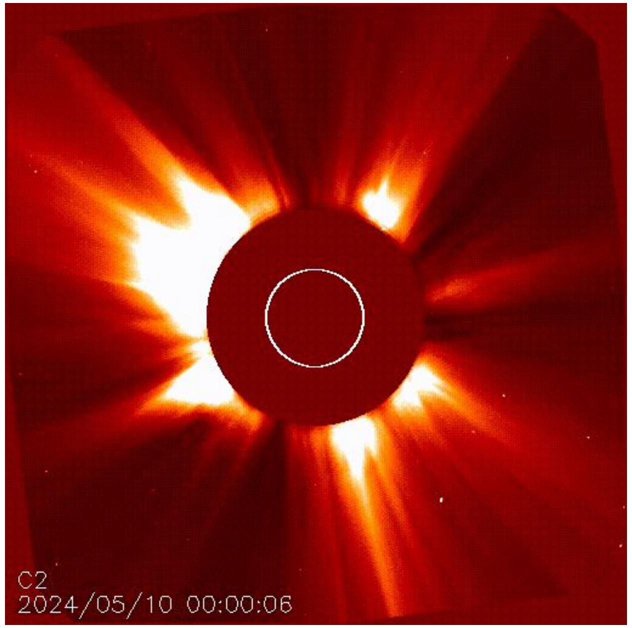
SOHO

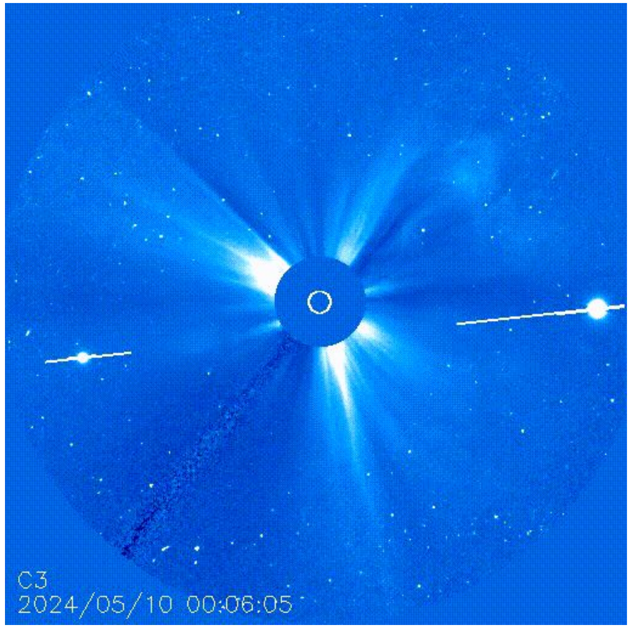
the joint NASA-ESA Solar and Heliospheric Observatory mission (SOHO), was designed to study the Sun inside out. Though its mission was scheduled to run until only 1998, it has continued collecting data, adding to scientists' understanding of our closest star, and making many new discoveries, including more than 5,000 comets.

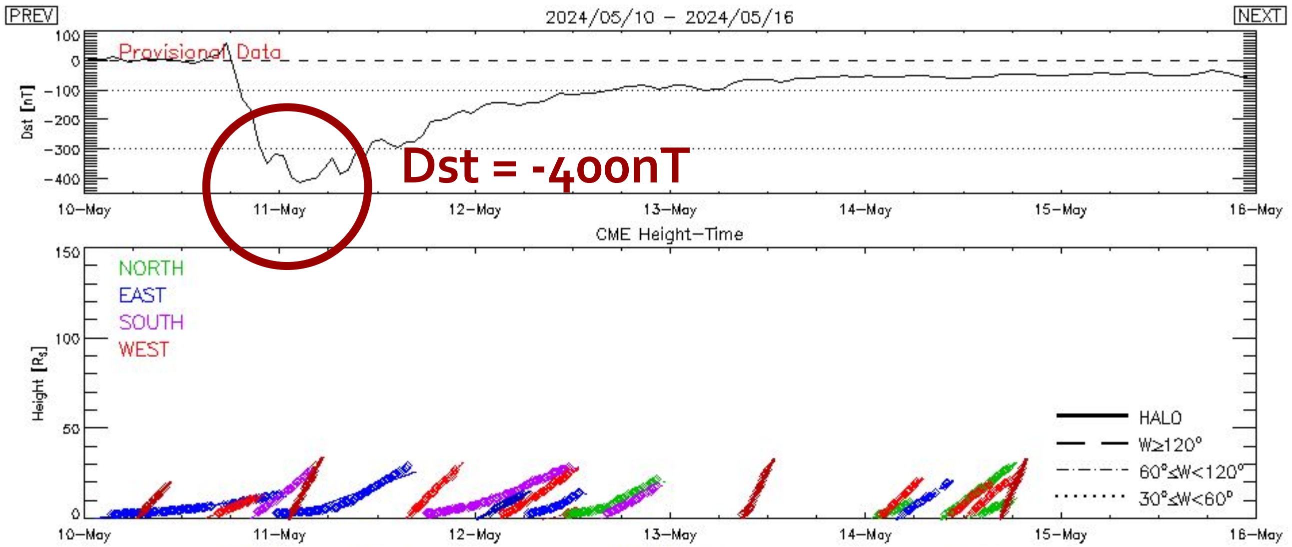
CMEs Event Analysis

10/04/2024 HALO EVENT (Satellites DATA)



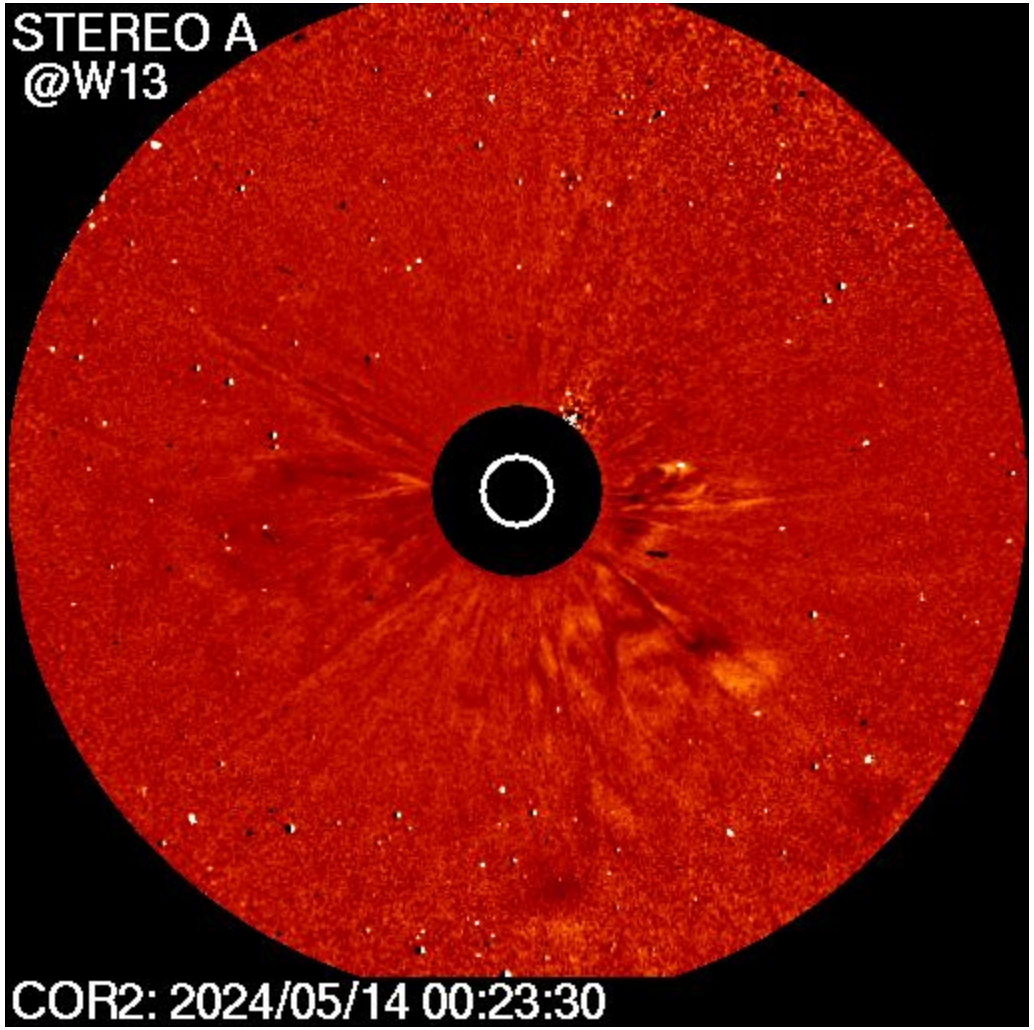


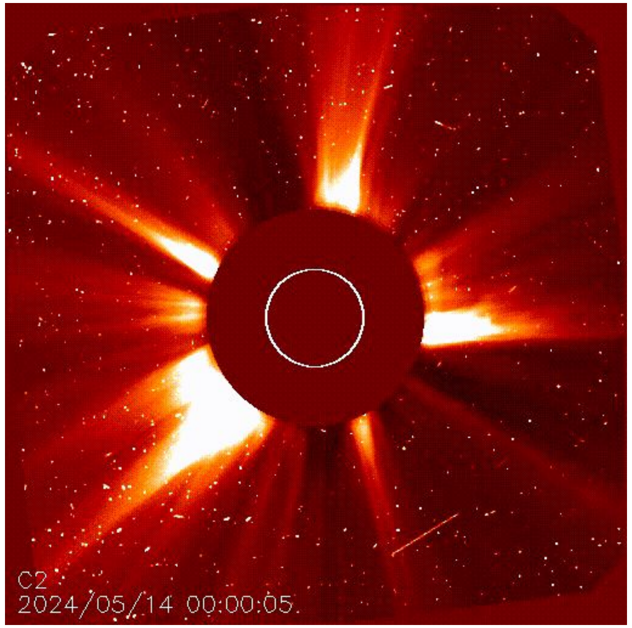


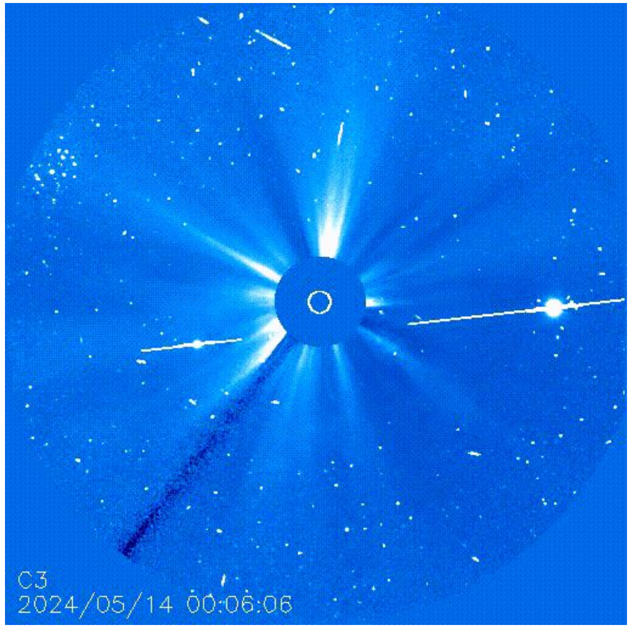


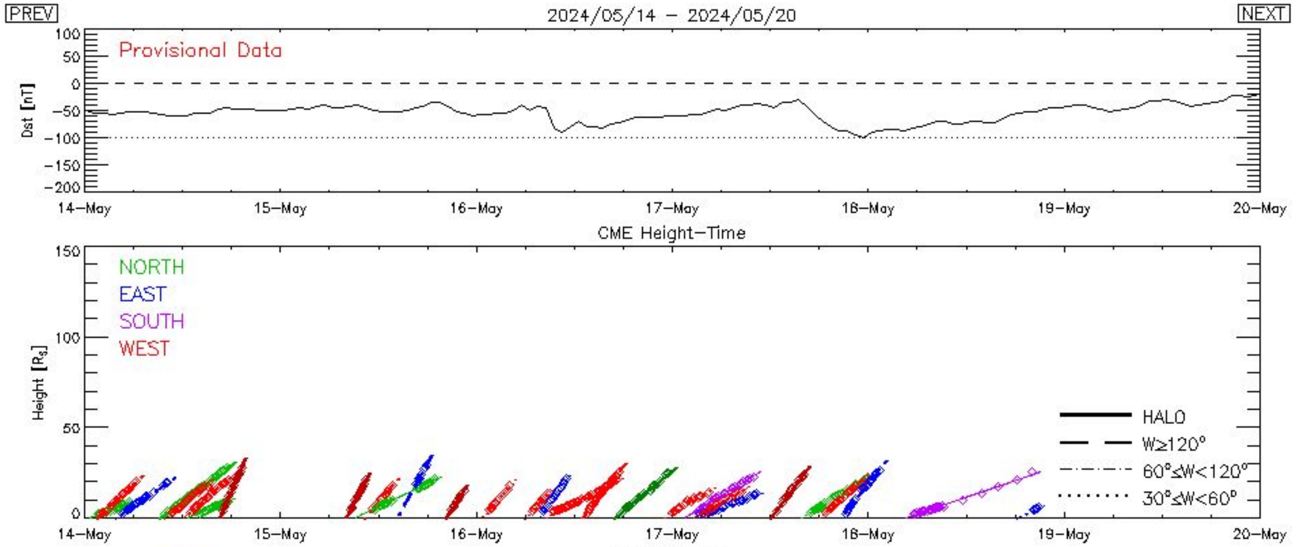
CMEs Event Analysis

14/04/2024 HALO EVENT (Satellites DATA)

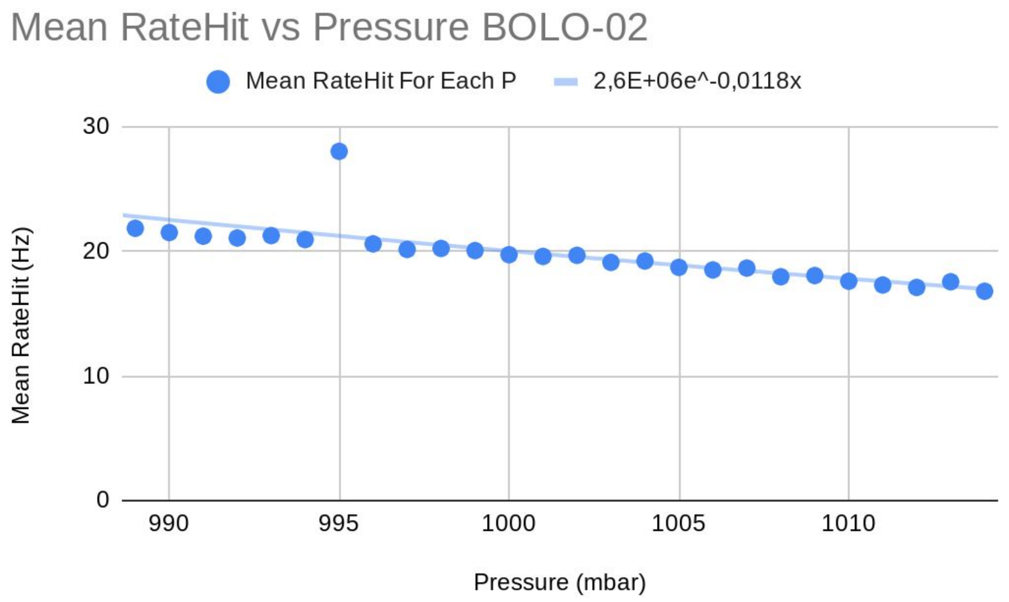


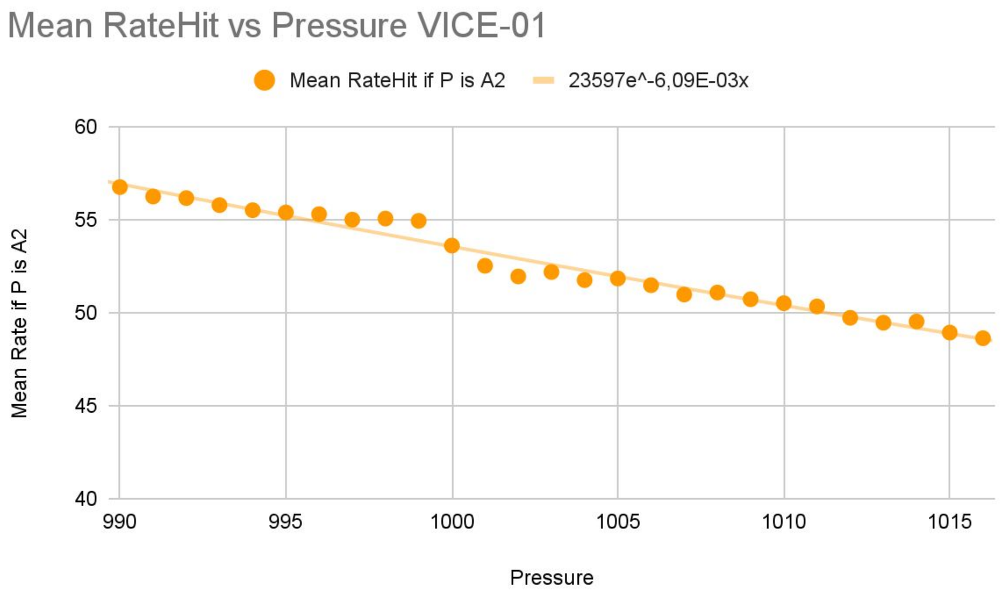


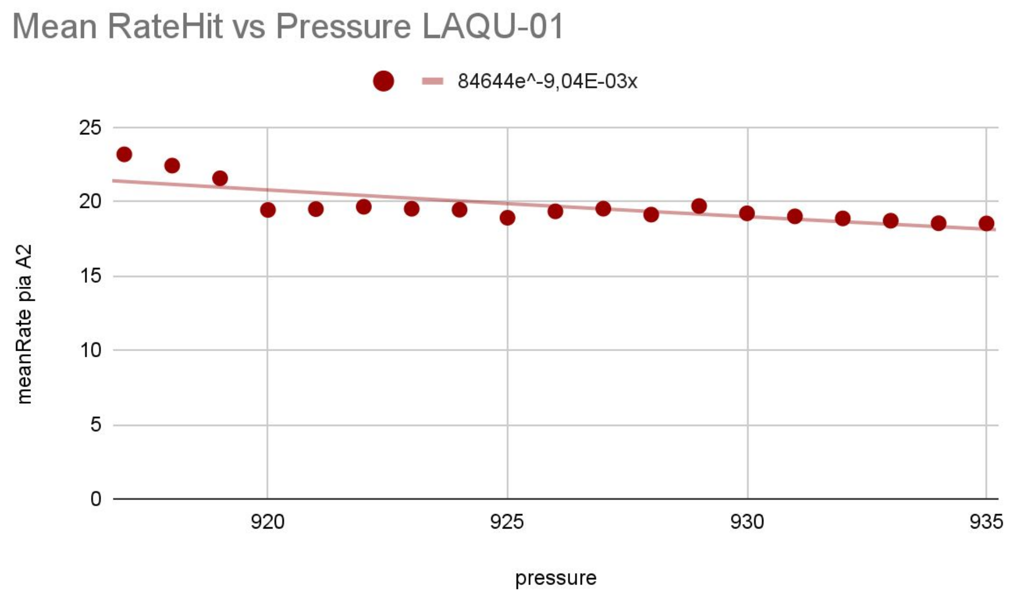




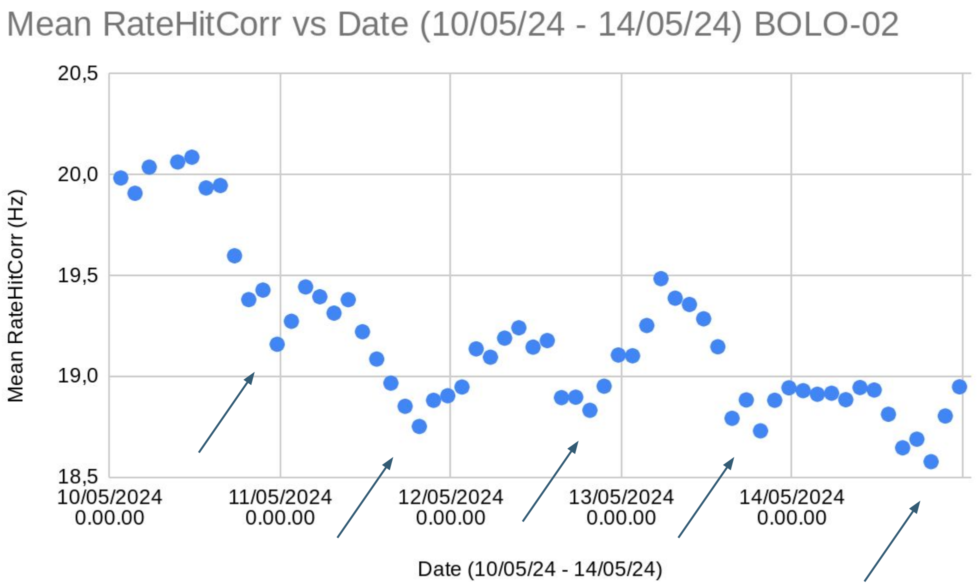
Step 3: Correction for Barometric Effects

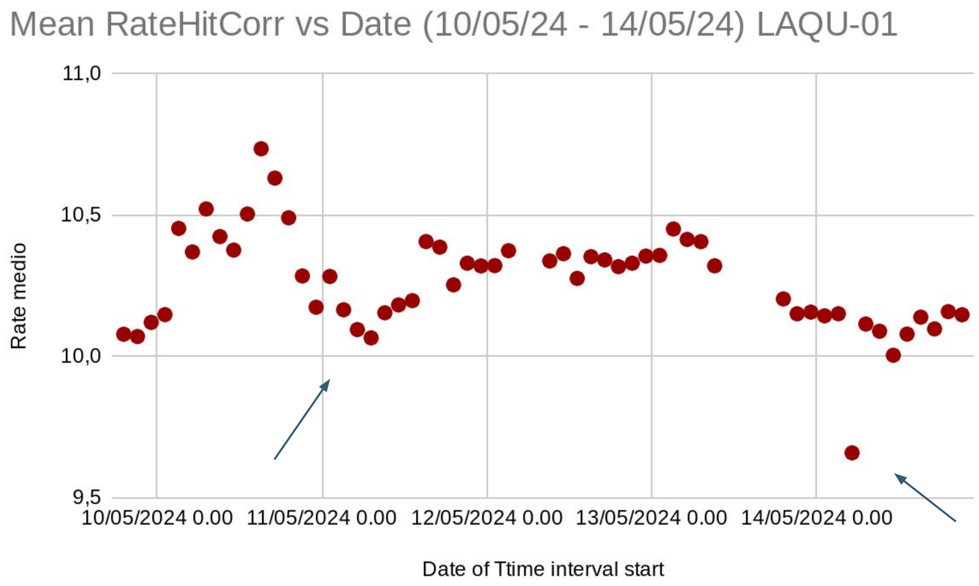


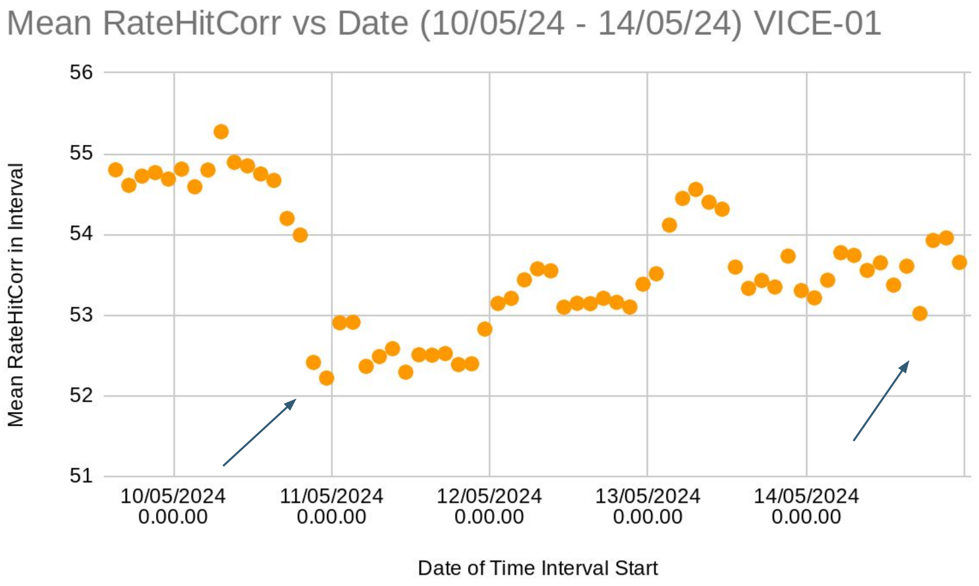




FORBUSH effect evidence (on MRPC)







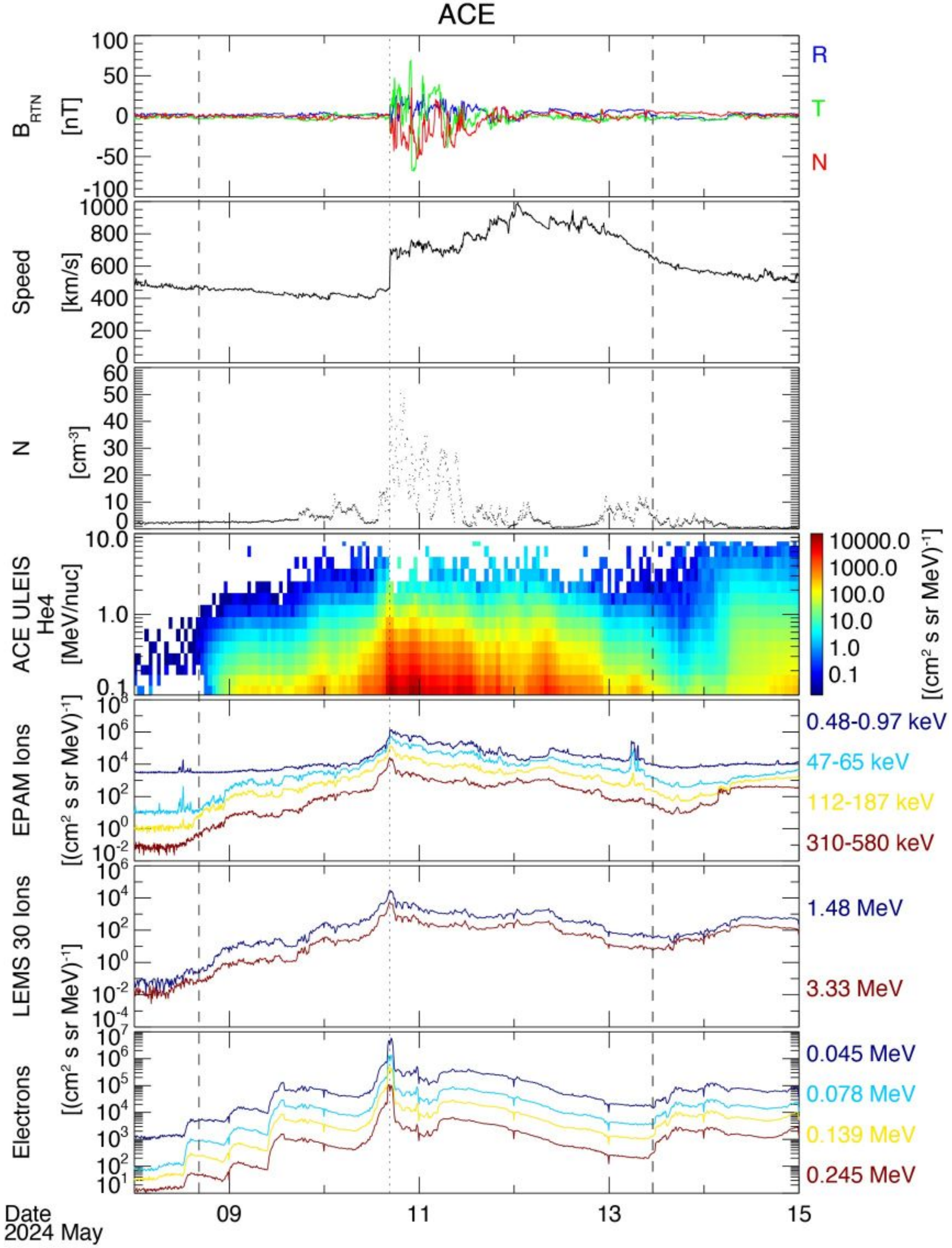
The **range varies very widely**, and this is due to the large solar activity of those days (*not only localized to May 10th*)

Largest SEPs Observed at Upstream at Earth between May 8-15

(George C. Ho et al., 2024) SEPs = Solar Energetic Particle

- May 8th ~12:00 UT associated with M8.6 (S17W11) and ~800 km/s CME
- May 9th ~09:00 UT associated with X2.2 (S20W25) and ~1300 km/s CME
- May 11th ~01:39 UT associated with X5.8 flare (S17W47) and >1300 km/s CME. GLE #74
- May 13th ~09:12 UT associated with several M flares (S22W80s) and >1400 km/s CME

- ESP: May 10th interplanetary shock arrived at L1 ~16:37UT



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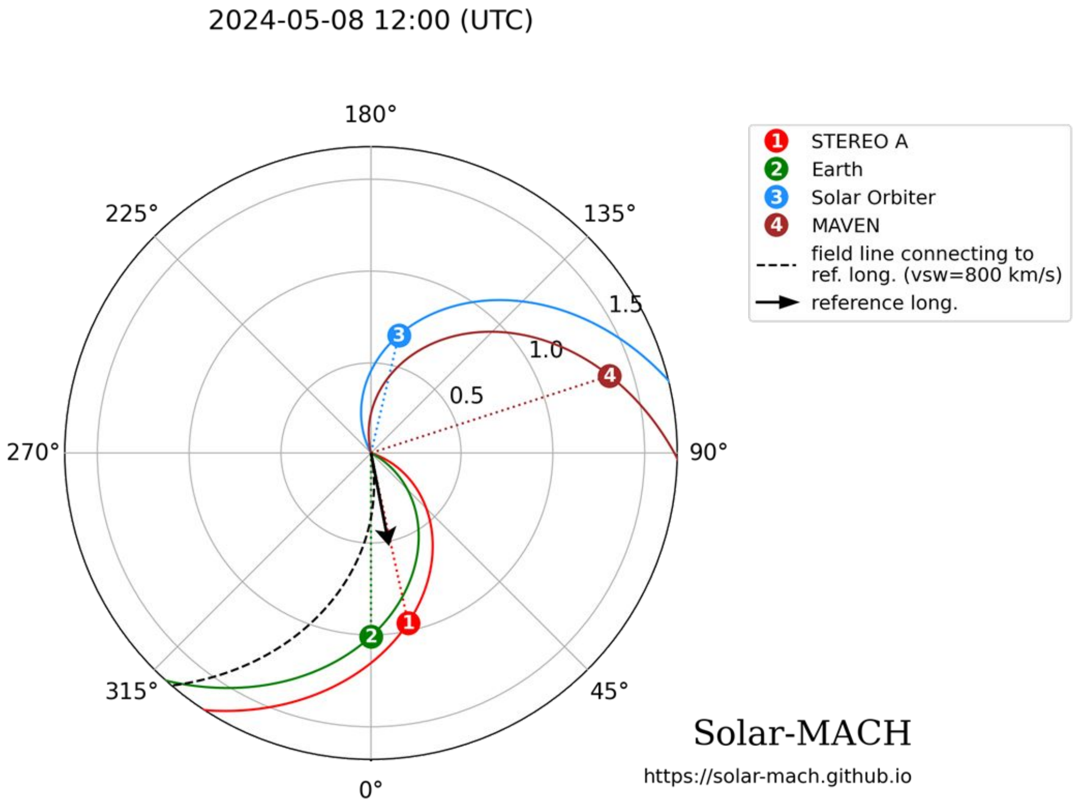

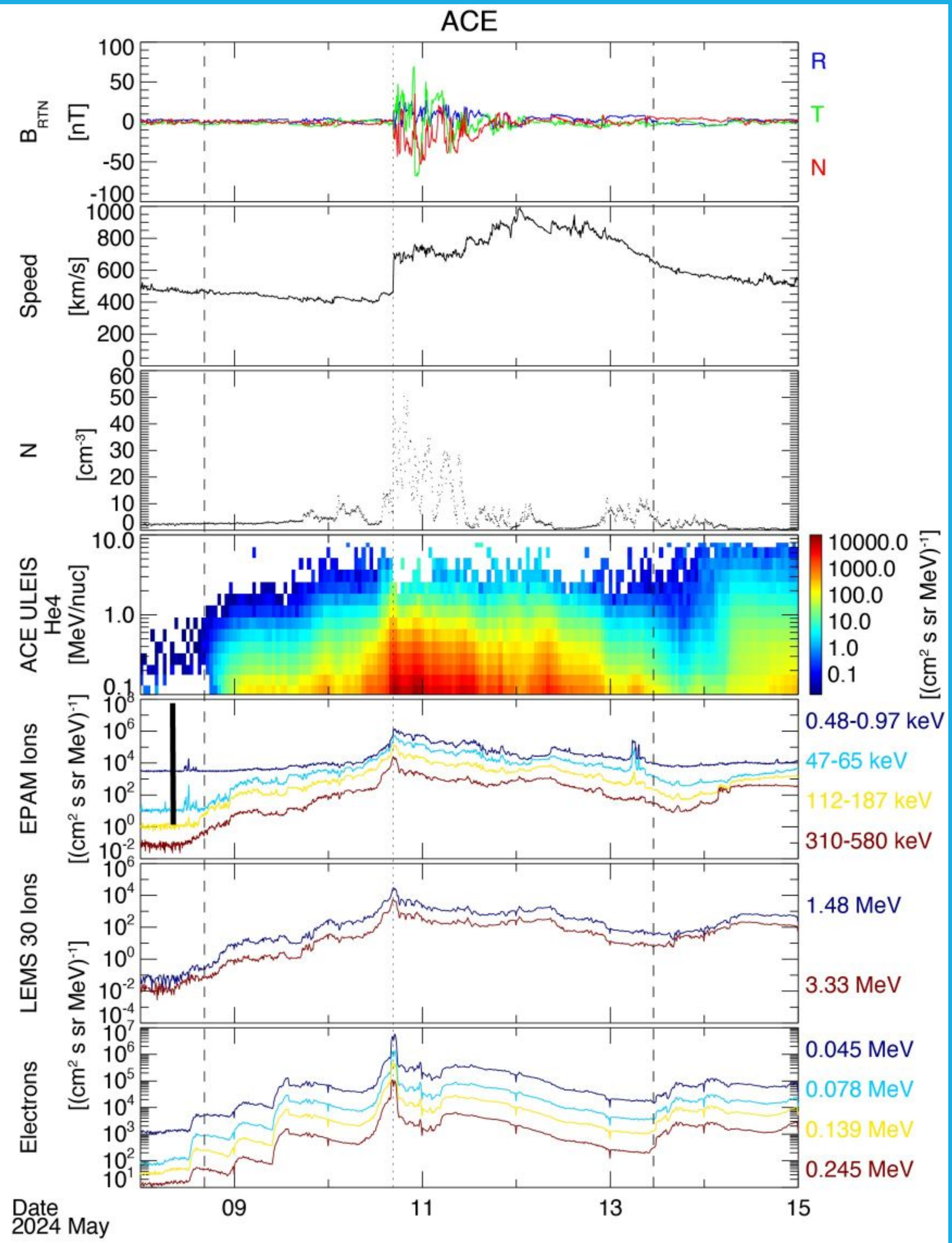

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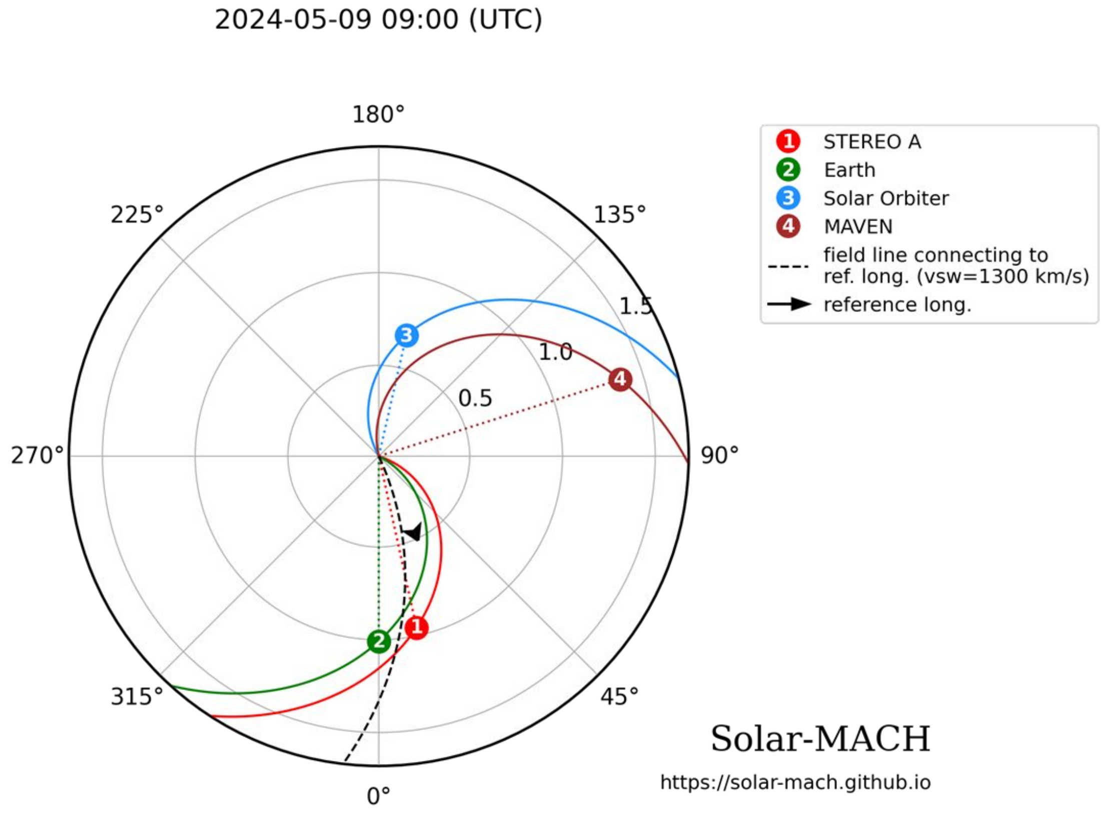
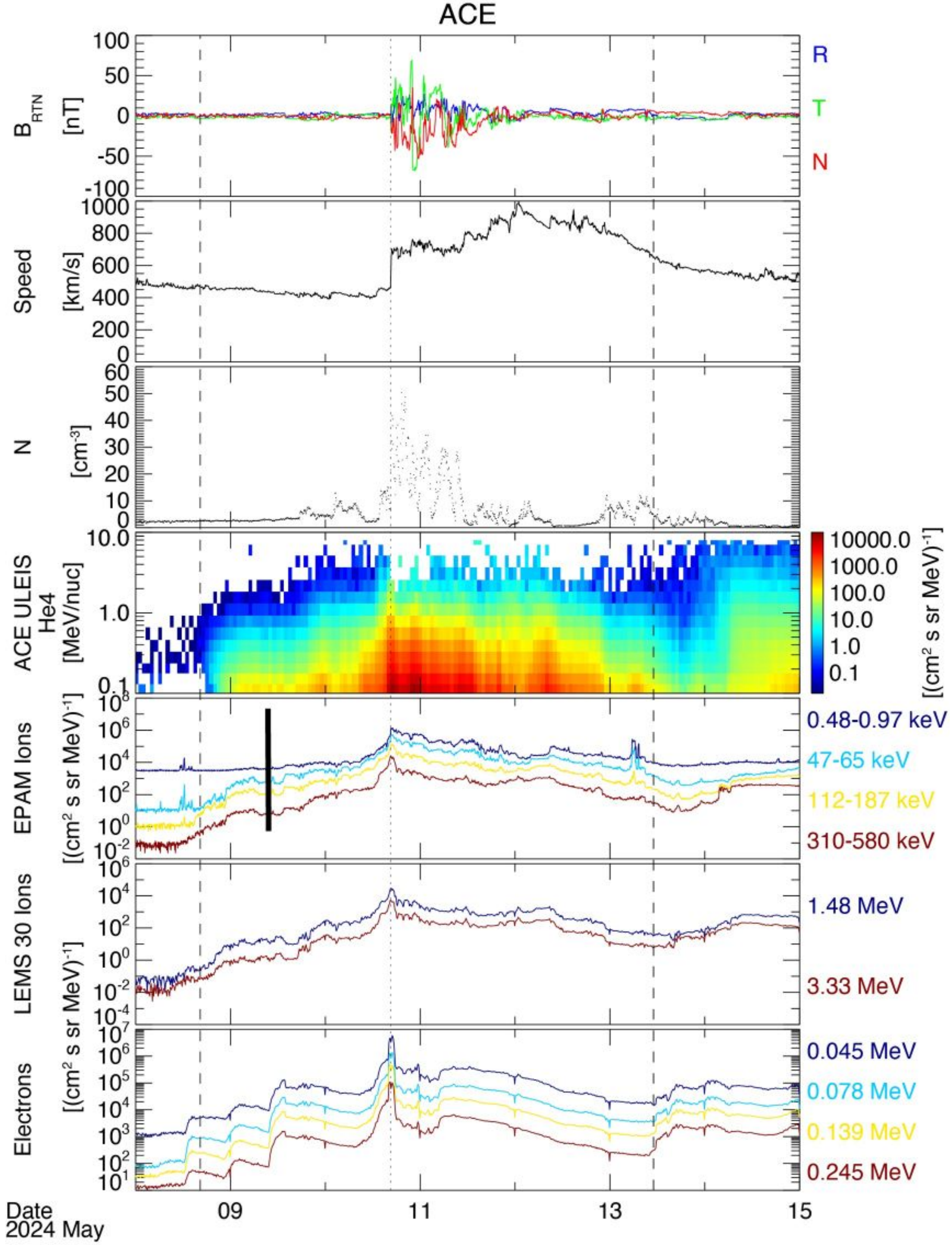
- May 9th ~09:00 UT associated with X2.2 (S20W25) and ~1300 km/s CME

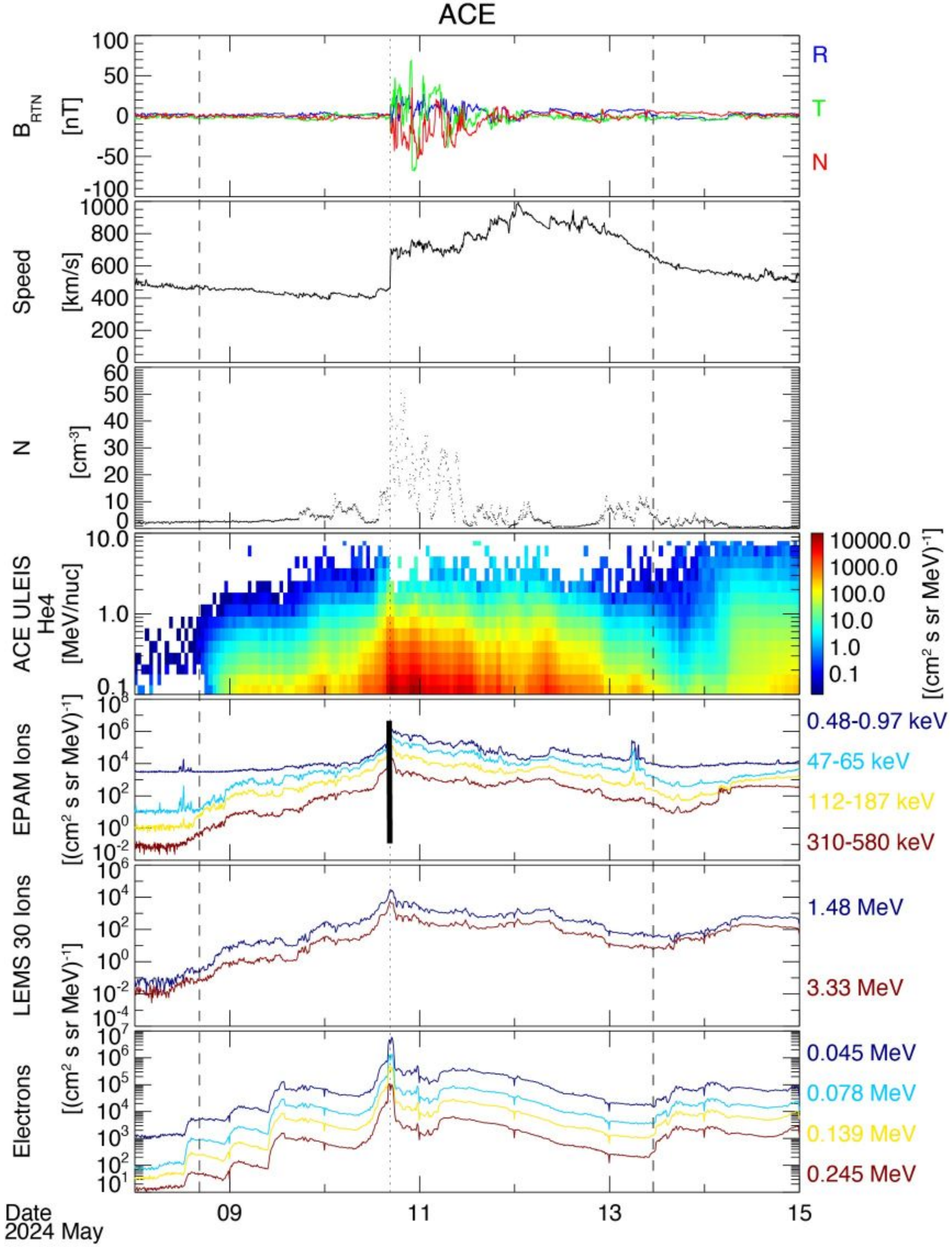




Largest SEPs Observed at Upstream at Earth between May 8-15

(George C. Ho et al., 2024) SEPs = Solar Energetic Particle

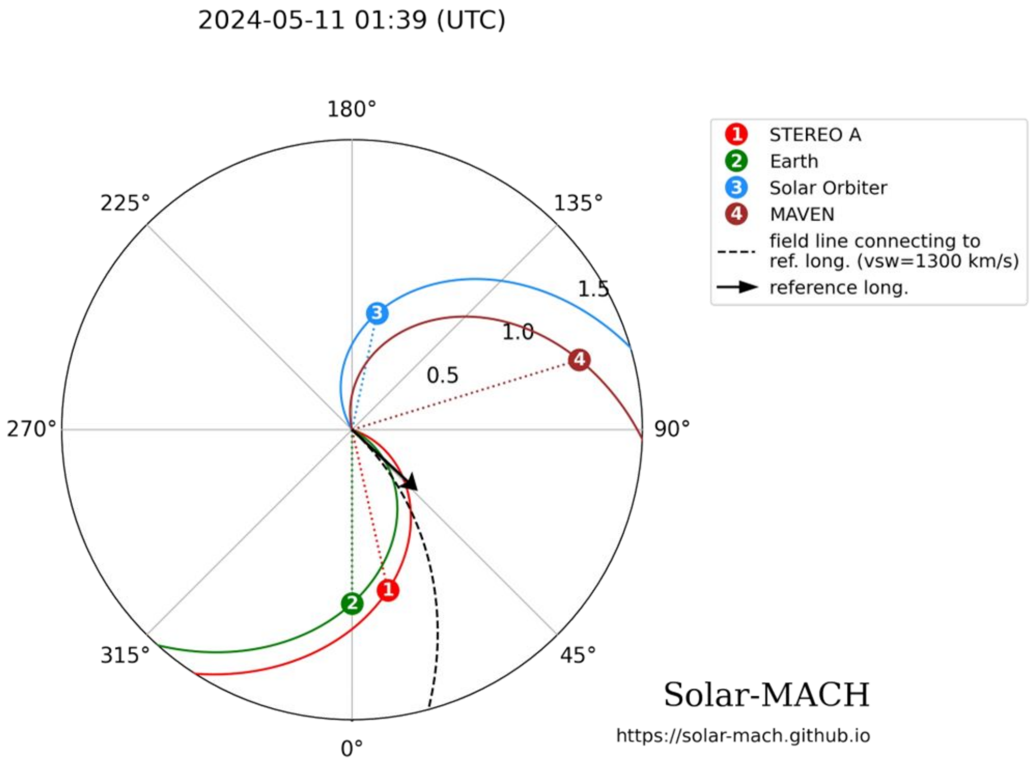
- ESP: May 10th interplanetary shock arrived at L1 ~16:37UT

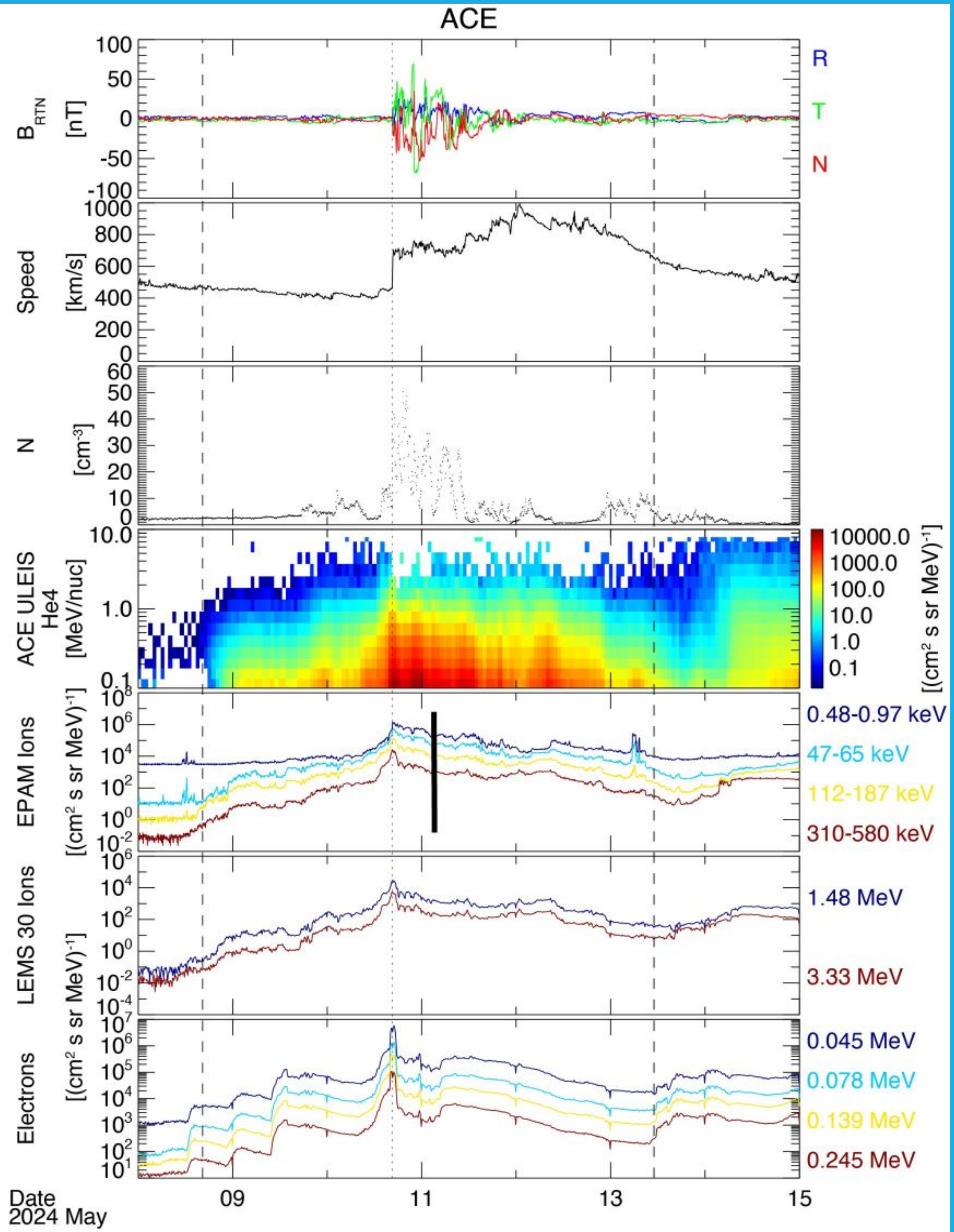


Largest SEPs Observed at Upstream at Earth between May 8-15

(George C. Ho et al., 2024)   SEPs = Solar Energetic Particle

- May 11th ~01:39 UT associated with X5.8 flare (S17W47) and >1300 km/s CME. GLE #74

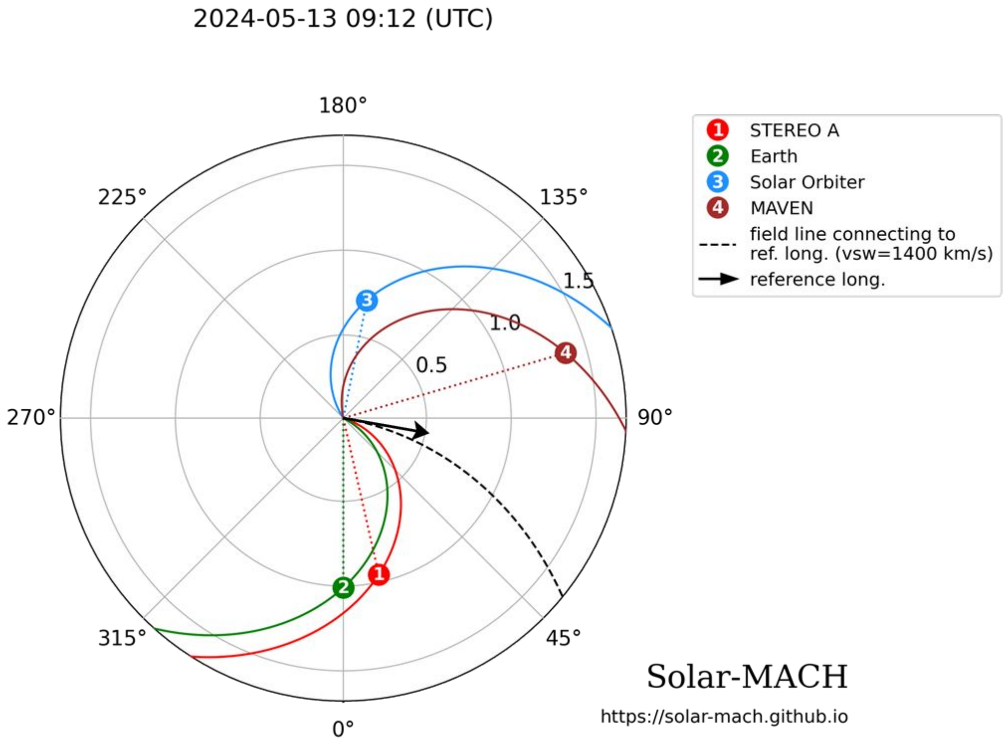


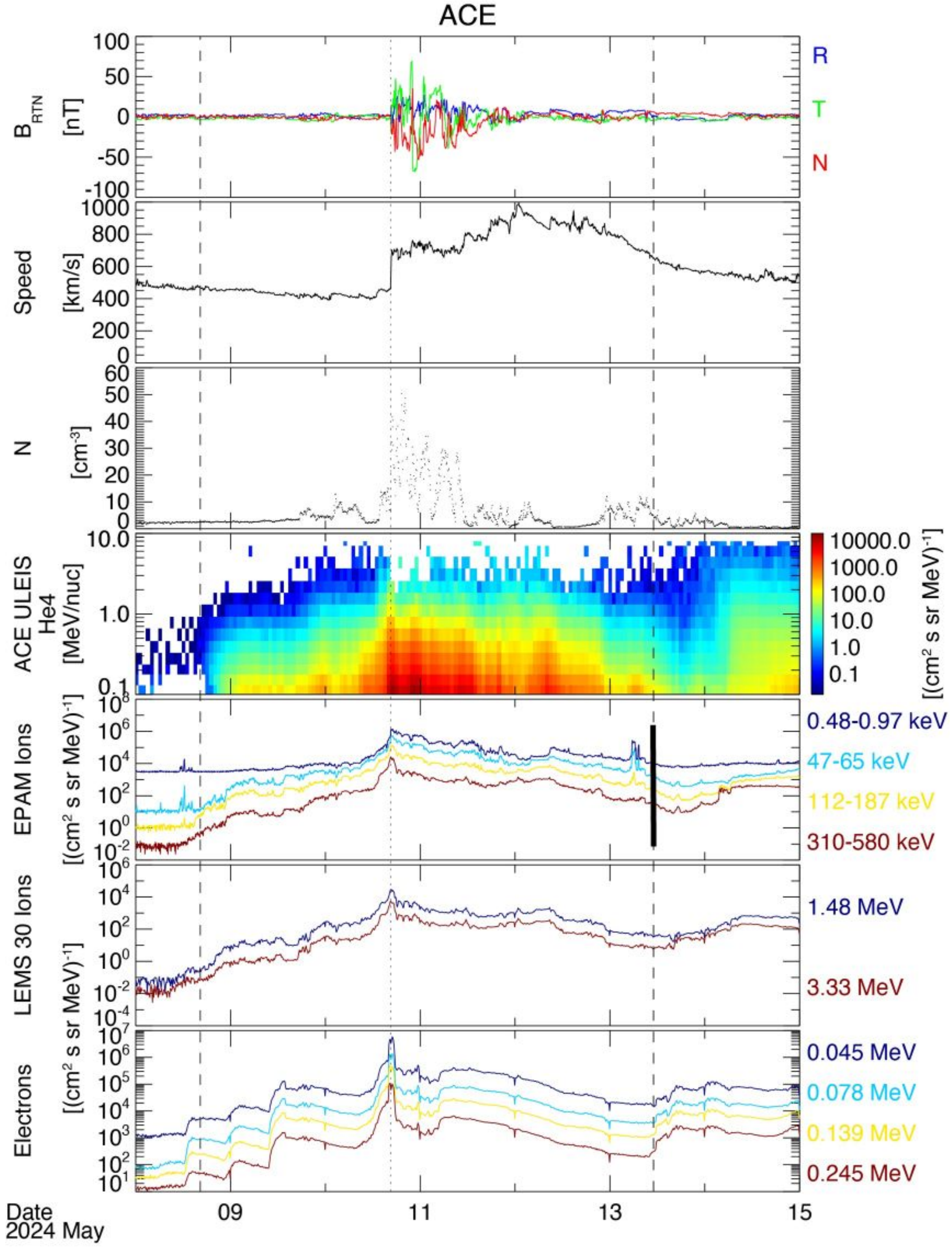


Largest SEPs Observed at Upstream at Earth between May 8-15

(George C. Ho et al., 2024)   SEPs = Solar Energetic Particle

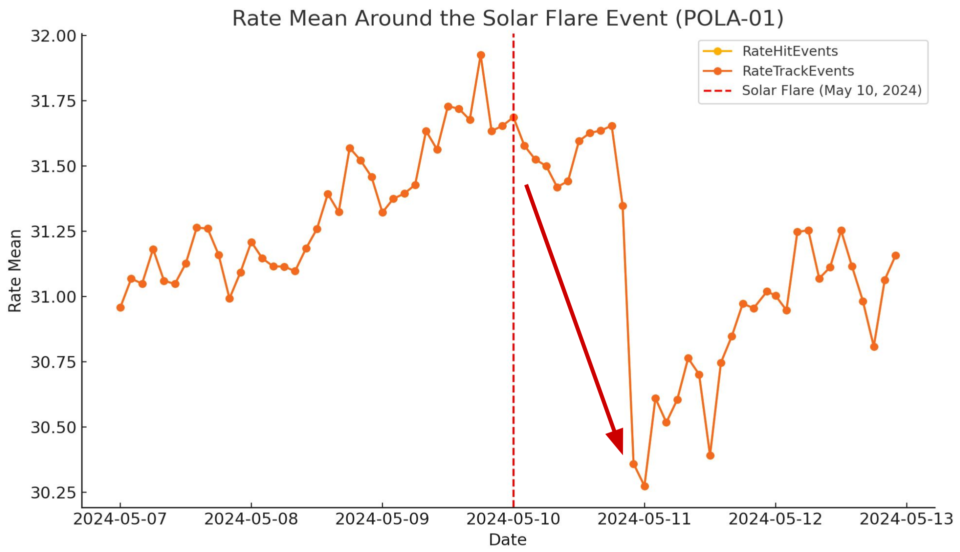
- May 13th ~09:12 UT associated with several M flares (S22W80s) and >1400 km/s CME

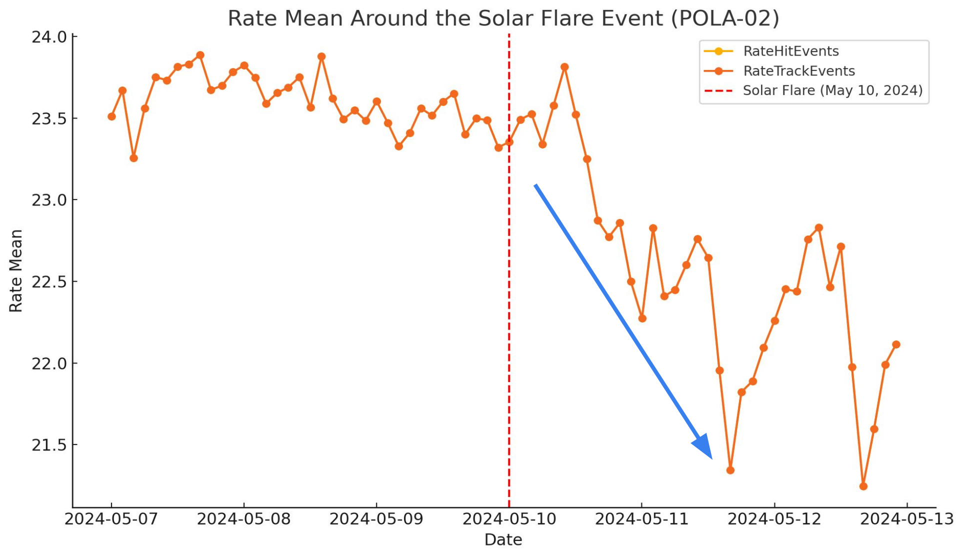


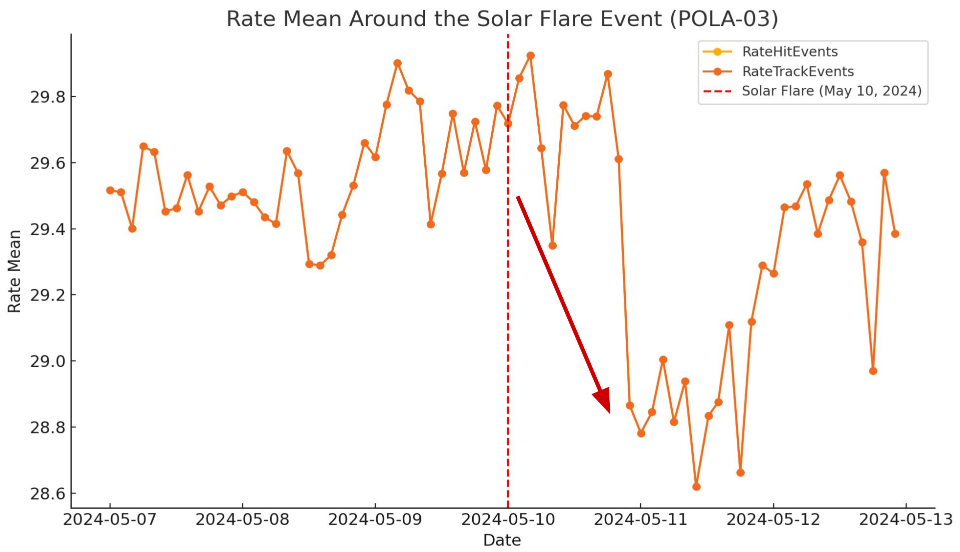


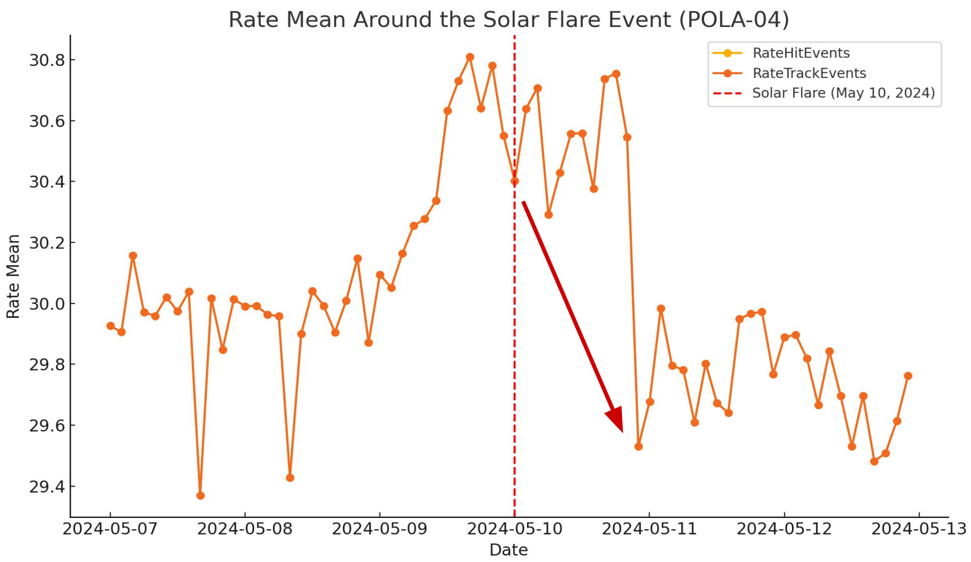
FORBUSH effect after 10.05.2024 HALO (on POLA)

As predicted by theory, the Forbush effect is markedly more evident in all detectors located at the (North) Pole



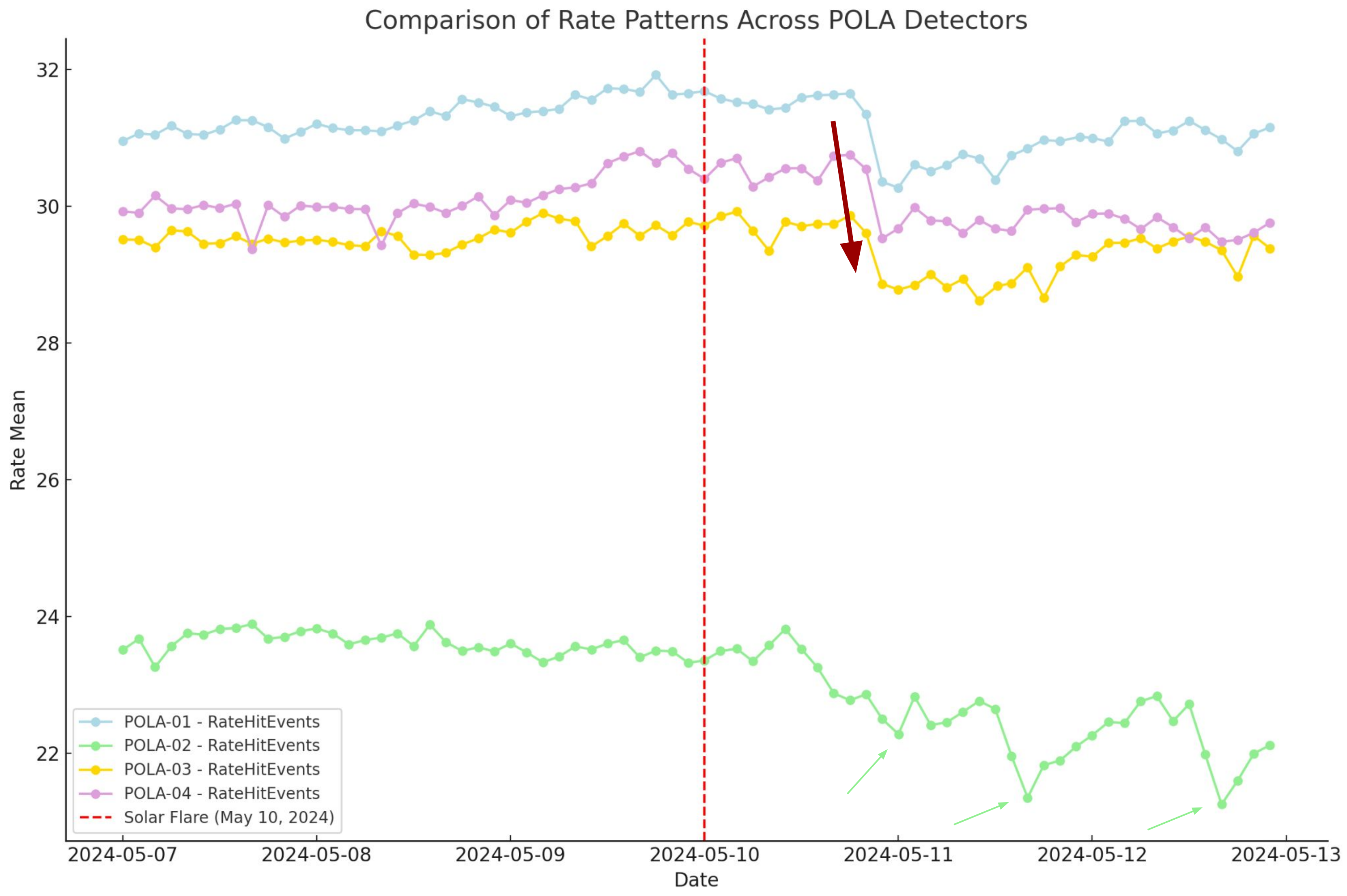






FORBUSH effect after 10.05.2024 HALO (on POLA)

To better observe the performance of the individual POLA detectors, we translate all 4 rate tracks into a single graph



Note no. 1

The Forbush effect, in the *POLA-01*, *POLA-03* and *POLA-04* detectors is evident and can be highlighted in a comparable time span in the three rate tracks graphed

Note no. 2

Despite the geographical distance between the three detectors located at the North Pole and the one in Bologna, the trend of the rate tracks is quite similar.

Conclusions

The analysis led to the following key results:

1. **Forbush Effect and Variations in Cosmic Ray Flux**:
   - The Forbush effect was clearly detected in the recorded data, showing a decrease in cosmic ray intensity following high-energy solar events, particularly Coronal Mass Ejections (CMEs).
   - The effect was more pronounced at the poles, due to the weaker shielding provided by the Earth's magnetic field in these regions, as demonstrated by the measurements from POLA telescopes.
2. **Geographical Comparison**:
   - The variation rates of cosmic rays detected by the POLA telescopes at the North Pole and the MRPC detector in Italy displayed a similar trend despite the geographical distance. However, the variations observed at the poles were of greater magnitude, confirming the sensitivity of these regions to solar disturbances.
3. **Astrophysical Implications**:
   - The results reinforce the importance of cosmic ray measurements in understanding the structure and intensity of magnetic fields associated with CMEs. Furthermore, the data contribute to the study of interactions between the Sun and the heliosphere, with potential impacts on terrestrial and space technologies.
4. **Detector Performance**:
   - The POLA and MRPC telescopes provided consistent and reliable measurements, demonstrating their effectiveness in observing phenomena such as the Forbush effect and other variations in secondary cosmic rays.

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THANKS FOR THE ATTENTION!

We hope you've enjoyed it!

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