20-22 February 2025
Warsaw University of Technology
Rektorska 4
Warsaw, Poland

PAiP-2025 conference
Particle Astrophysics
in Poland

Solar modulation of galactic cosmic rays-recent updates

Agnieszka Gil

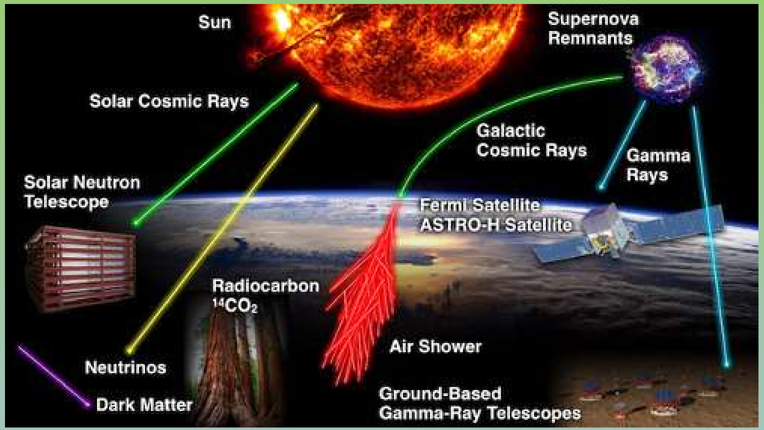
21.02.2025

Uniwersytet
w Siedlcach

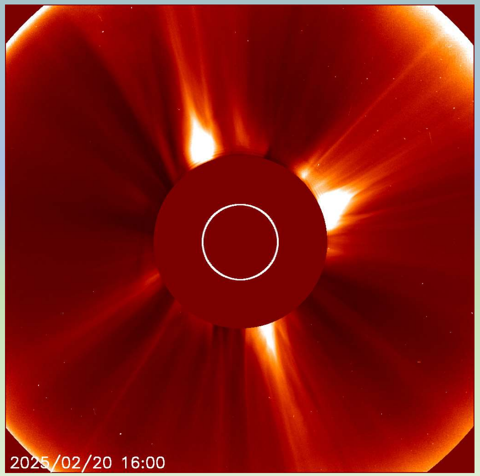
CBK PAN

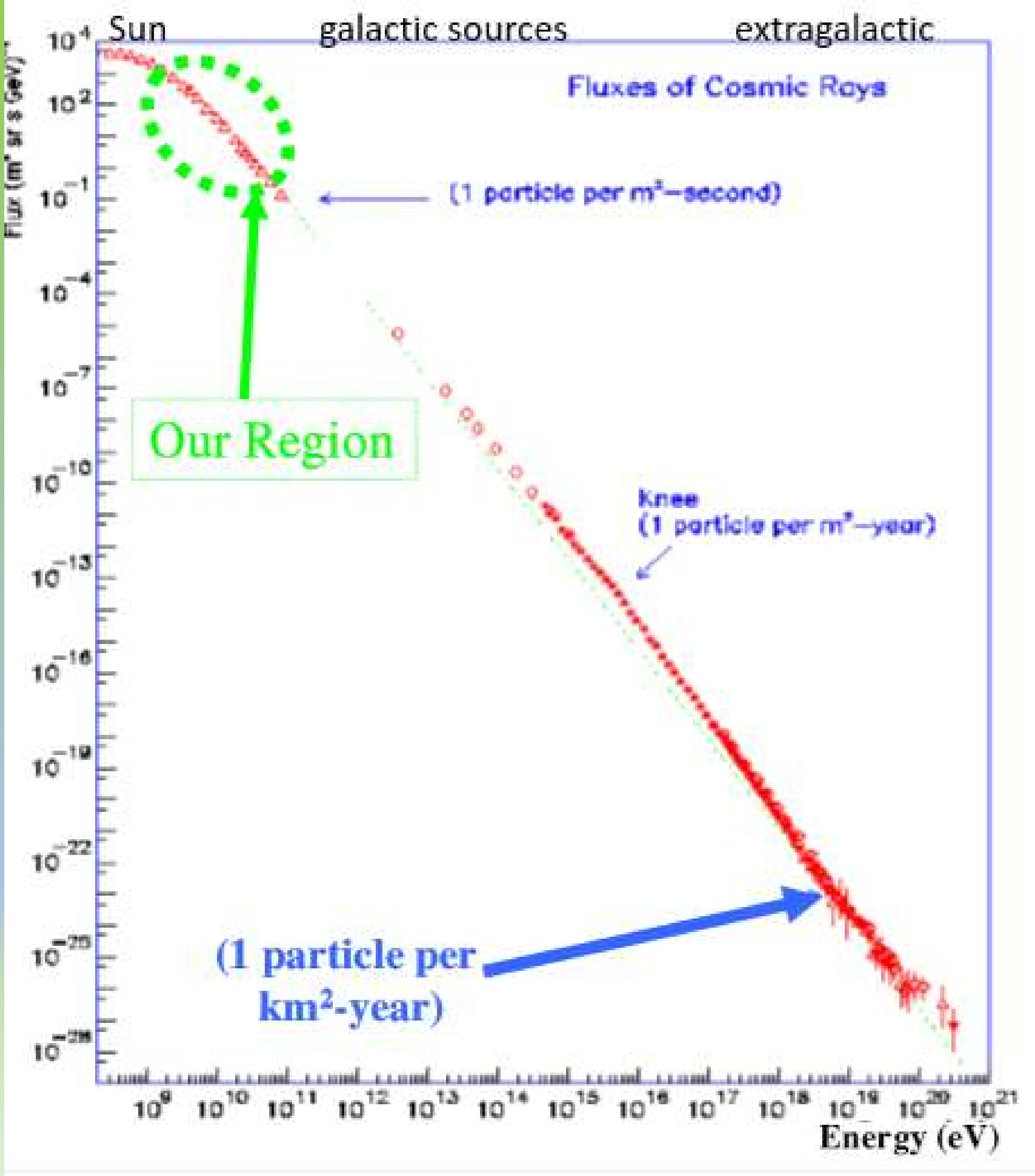
Abstract

The cosmic rays stream reaching Earth is of extragalactic origin, some come from the center of our Galaxy, while the source of cosmic rays of the lowest energies is Sun. A common way to register galactic cosmic ray (GCR) and its variability are measurements made by a global network of ground neutron monitors (NMs), operating continuously since 1951. They measure secondary cosmic rays: the nucleonic component of the atmospheric cascade initiated by primary cosmic rays. NMs show fluctuations in the original cosmic ray intensity. These variations occur as a result of a solar changeability and reflect the level of solar activity. The basic periodicity observed by neutron monitors is the 11-year cycle, which is a reflection of the Schwebe cycle, characterized by consecutive periods of amplified solar activity of about 11 years. There is a high anti-correlation between the number of sunspots that perfectly illustrate the level of solar activity and the GCR changeability. The next cycle is the 22-year Hale cycle, related to the reversal of the Sun’s magnetic field polarity. There are observed also shorter periodicities: connected to solar rotation, as well as transients appearing in solar behavior. There will be discussed recent updates of long-, mid- and short-term modulation of GCR, based on the neutron monitors observations, as well as mathematical modeling of GCR transport.

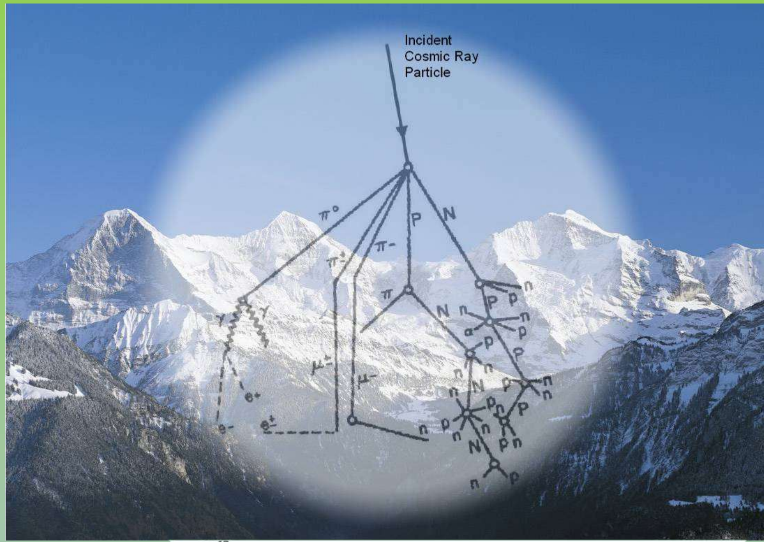


www.isee.nagoya-u.ac.jp

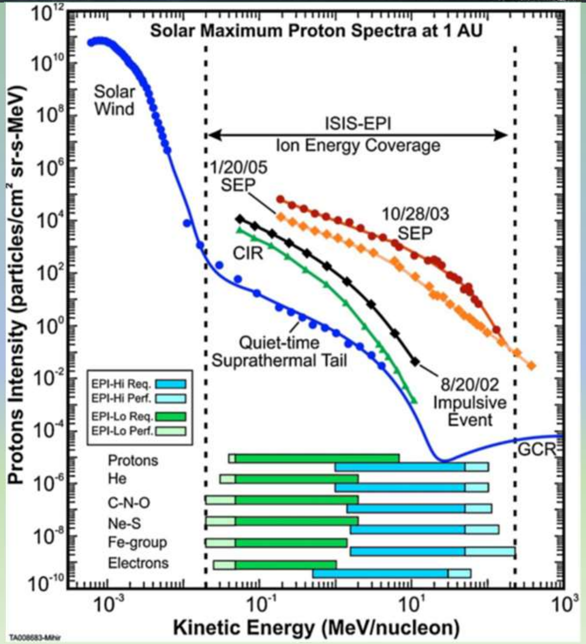




CERN courier, 1999

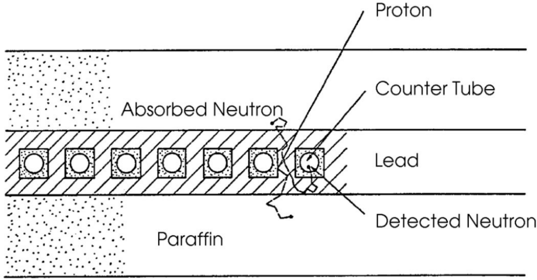


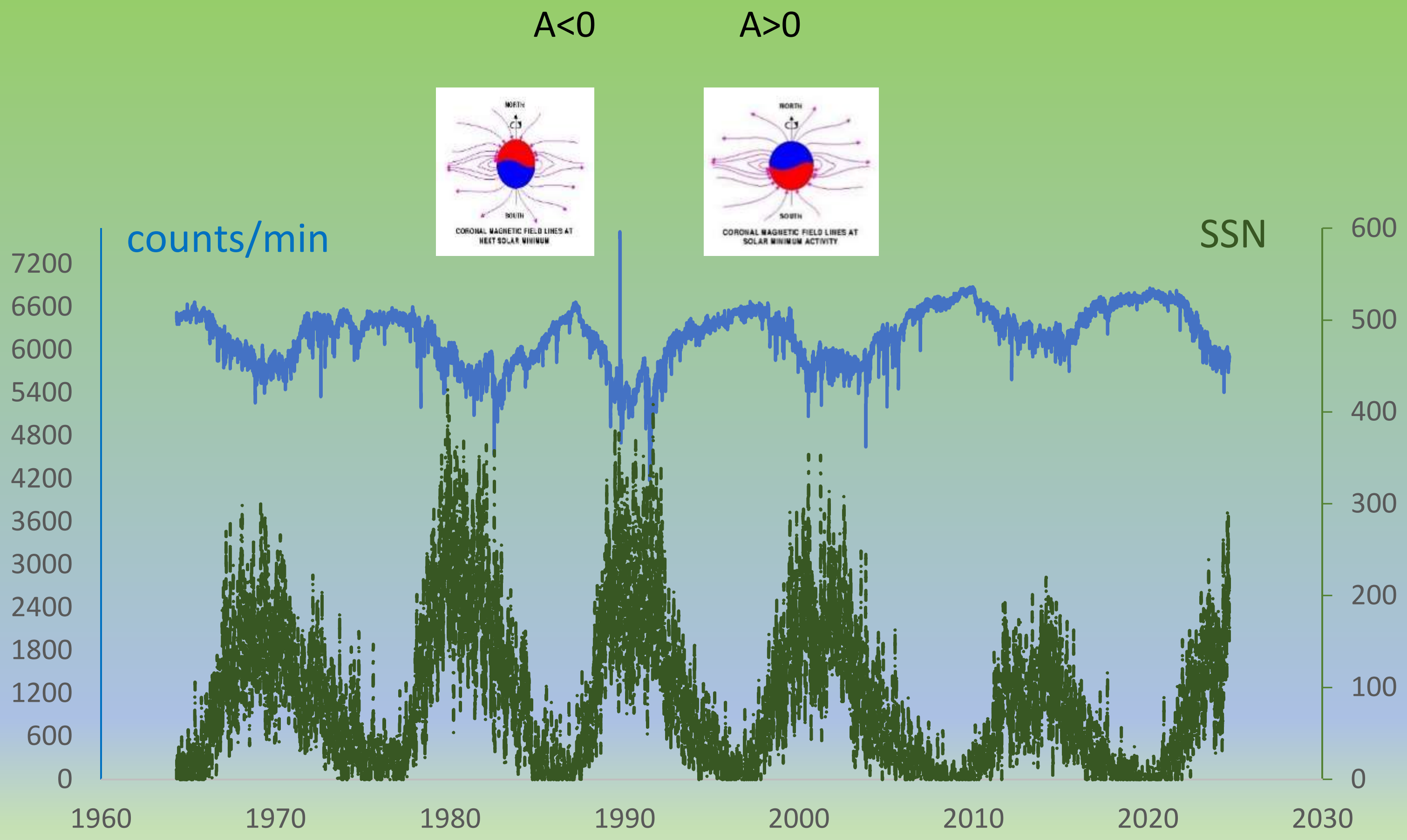
www.nmdb.eu



Cohen et al., 2023

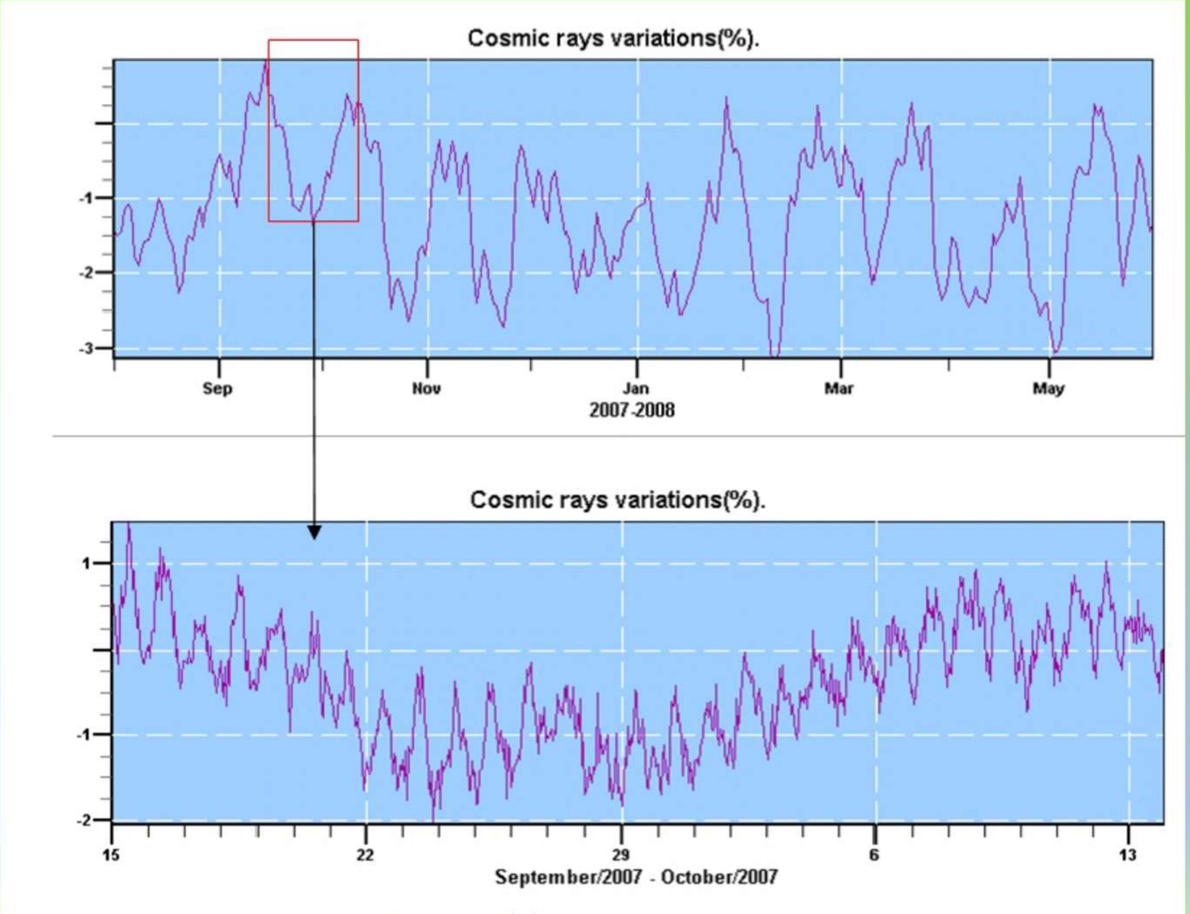
http://www.nmdb.eu/





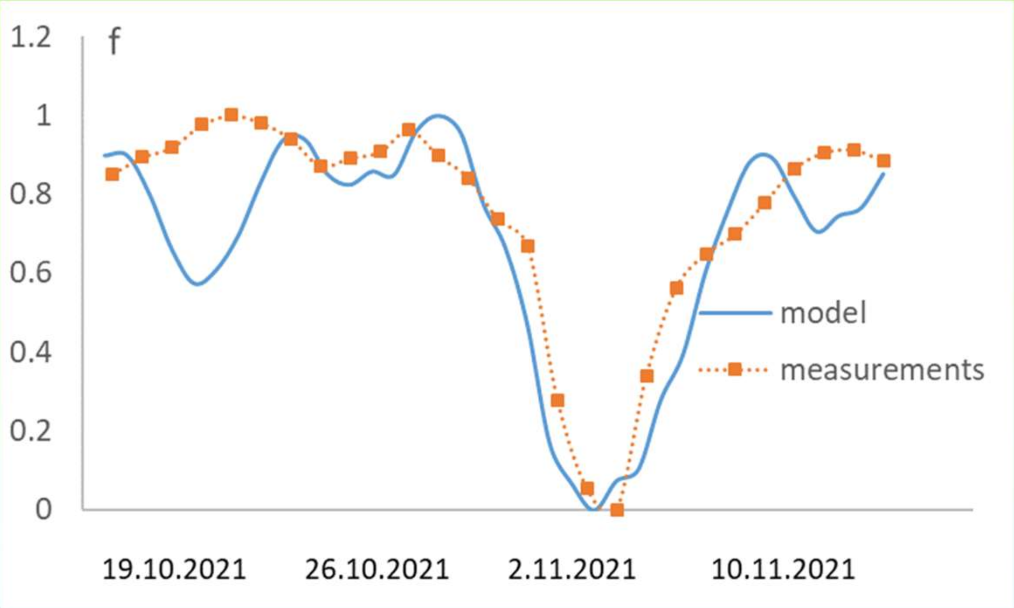
Oulu NM data from cosmicrays.oulu.fi and **SSN** from OMNIWeb (1964-2024)

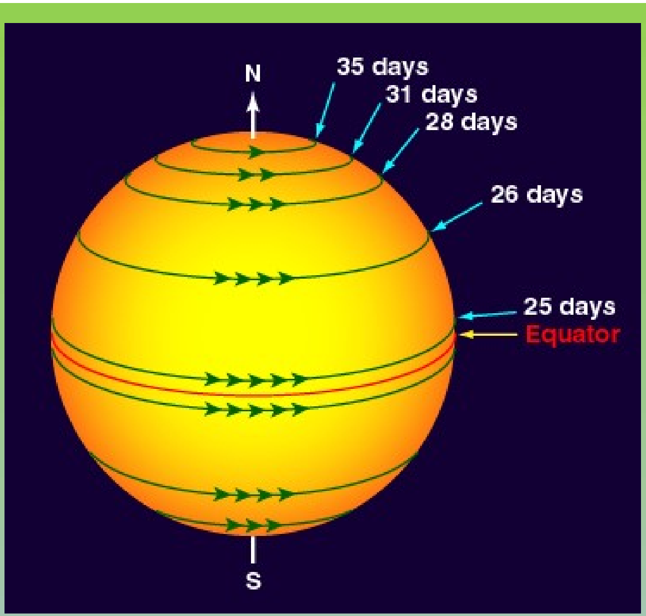
Cosmic ray variations: 11, 22-years, 27-days, solar anisotropy



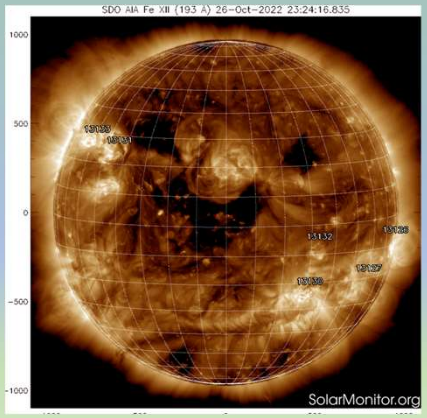
http : //cr0.izmiran.rssi.ru

www.astro.washington.edu





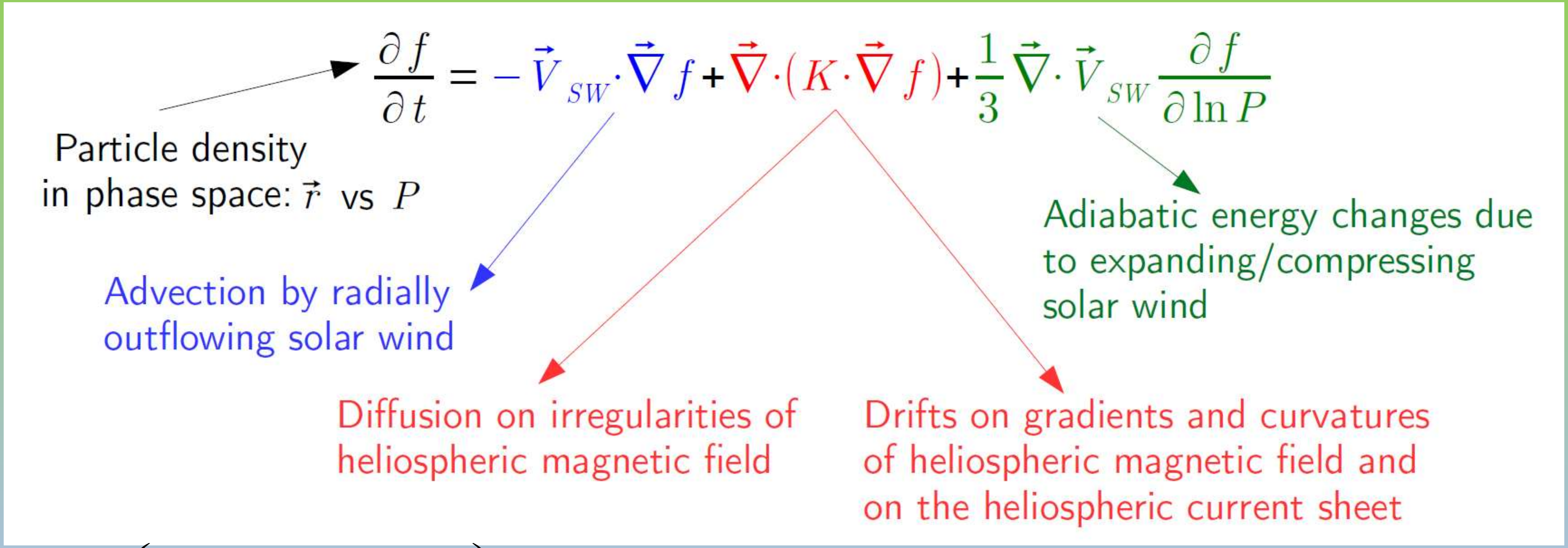
star.bris.ac.uk



https://solarmonitor.org/

Gil et al. 2023: Modeling results of the recurrent GCR modulation by CIR, comparison of the experimental data (the GCR counts by Oulu NM) with modeling results (relative density) with taken into account heliolongitudinal asymmetry of HMF strength and SW velocity during solar rotation 19.10-14.11.2021

Parker transport equation (Parker, 1965)



$$\frac{\partial f}{\partial t} = -\vec{V}_{SW}\cdot\vec{\nabla} f + \vec{\nabla}\cdot(K\cdot\vec{\nabla} f) + \frac{1}{3}\vec{\nabla}\cdot\vec{V}_{SW}\frac{\partial f}{\partial \ln P}$$

Particle density in phase space: $\vec{r}$ vs P

Advection by radially outflowing solar wind

Diffusion on irregularities of heliospheric magnetic field

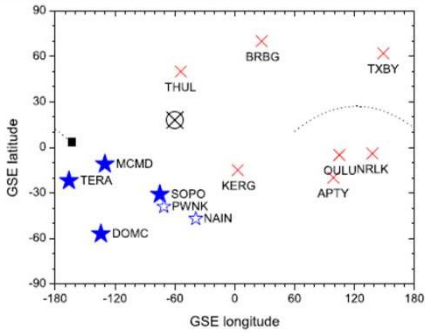
Drifts on gradients and curvatures of heliospheric magnetic field and on the heliospheric current sheet

Adiabatic energy changes due to expanding/compressing solar wind

From Corti et al., 2023

$$\kappa_{ij} = \begin{pmatrix} \kappa_{11} & \kappa_{12} & \kappa_{13} \\ \kappa_{21} & \kappa_{22} & \kappa_{23} \\ \kappa_{31} & \kappa_{32} & \kappa_{33} \end{pmatrix}$$

3D anisotropic diffusion tensor (Alania, 1978; 2002)



ACRE-anisotropic cosmic-ray enhancement,
12-19 UT 07.06.2015, 9-14UT 05.11.2023

Gil et al., 2018

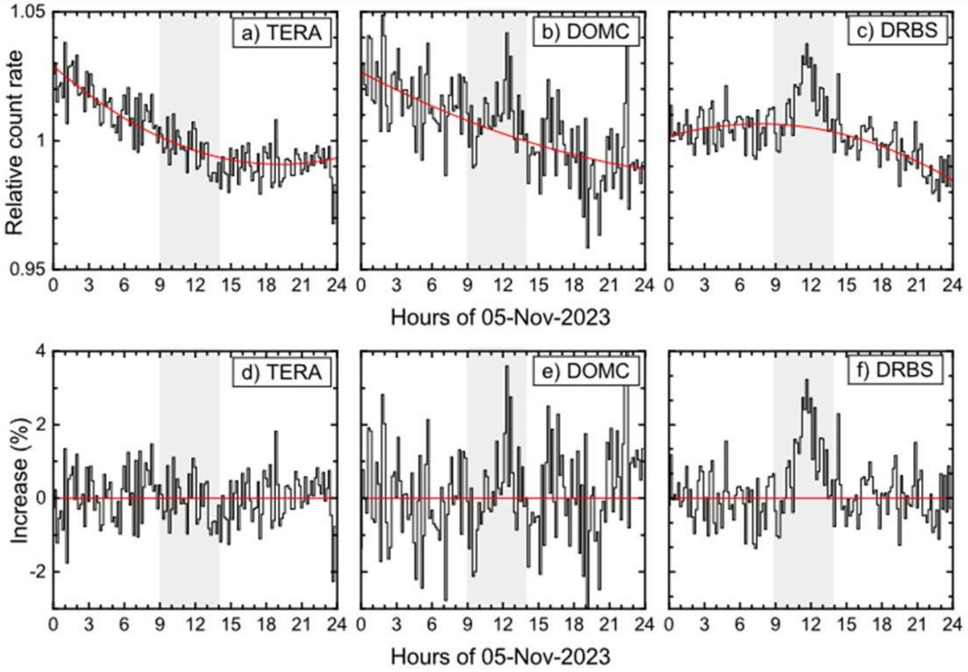
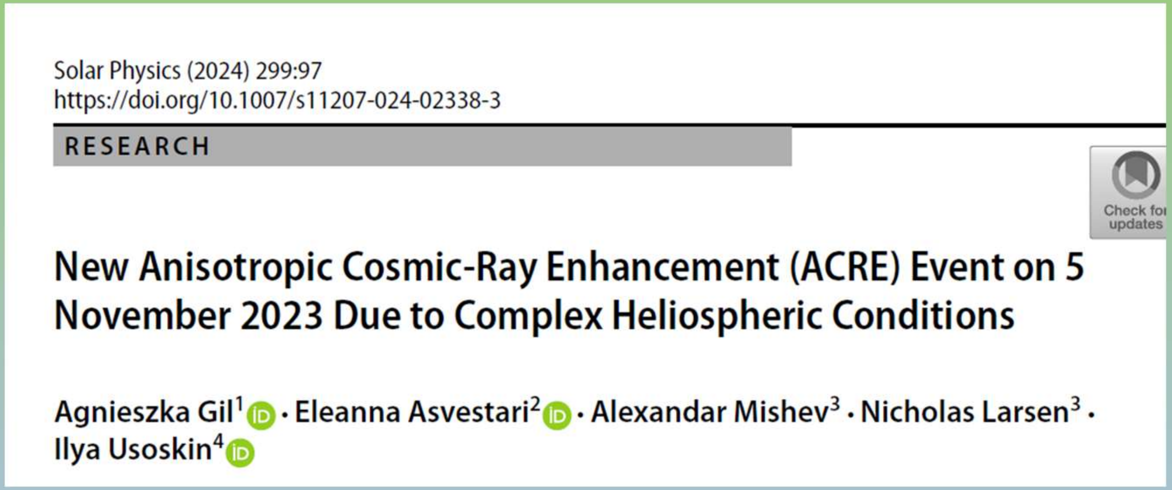


Figure 1. Normalized relative 10-minute averaged count rates of selected neutron monitors during DOY 309 (05 November) 2023. The upper row shows the raw data (black lines) with the fitted background trend (red curves – see text for details). Panels a – c represent typical cases of no event observed (TERA NM), a marginally defined event (DOMC) and a significantly defined event (DRBS). The lower row (panels d – f) depicts the detrended data corresponding to panels a – c. The grey-shaded bars denote the time of the event studied here, viz. 09 – 14 UT.

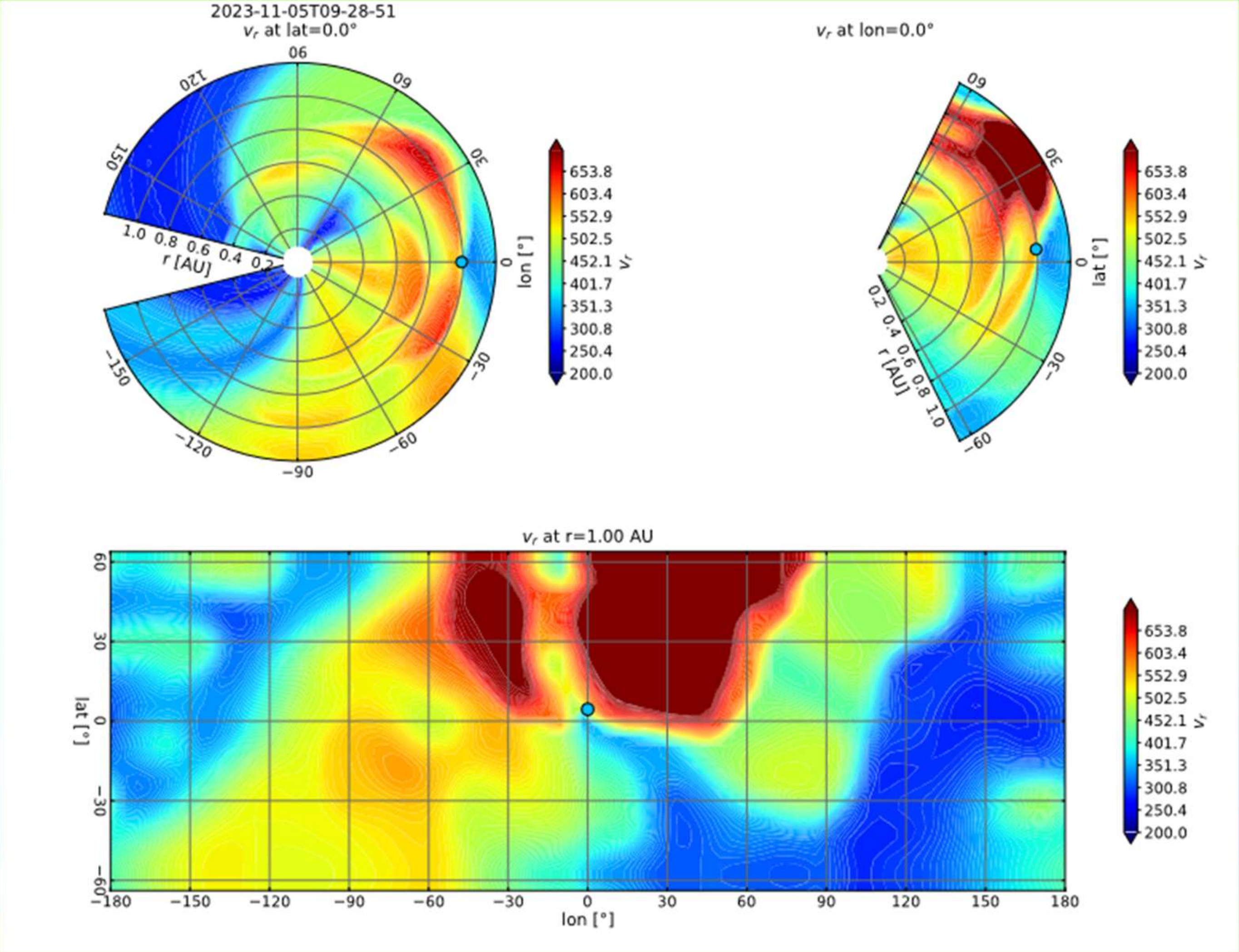


Solar Physics (2024) 299:97
https://doi.org/10.1007/s11207-024-02338-3

RESEARCH

New Anisotropic Cosmic-Ray Enhancement (ACRE) Event on 5 November 2023 Due to Complex Heliospheric Conditions

Agnieszka Gil[1] · Eleanna Asvestari[2] · Alexandar Mishev[3] · Nicholas Larsen[3] · Ilya Usoskin[4]



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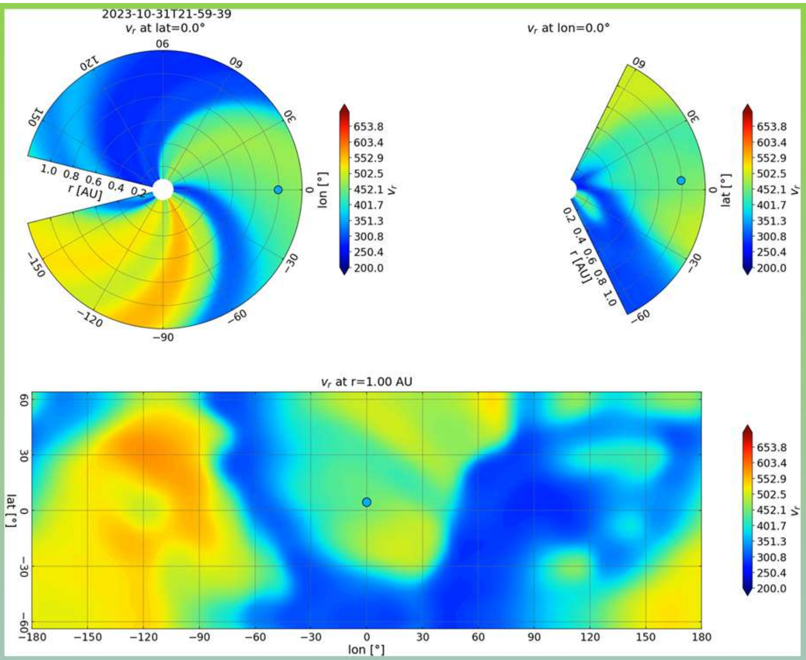


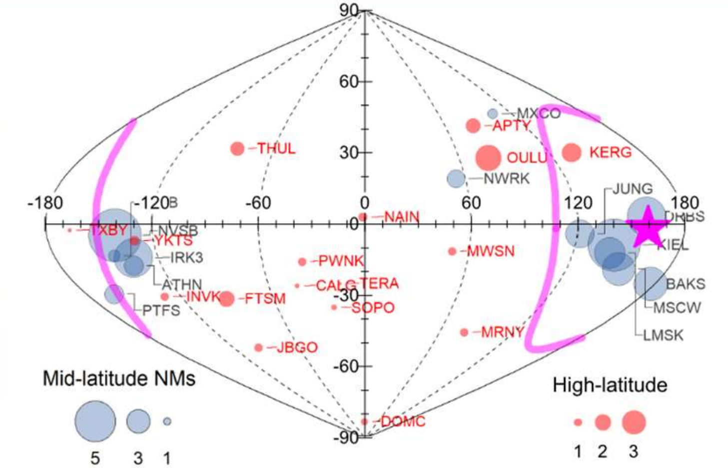
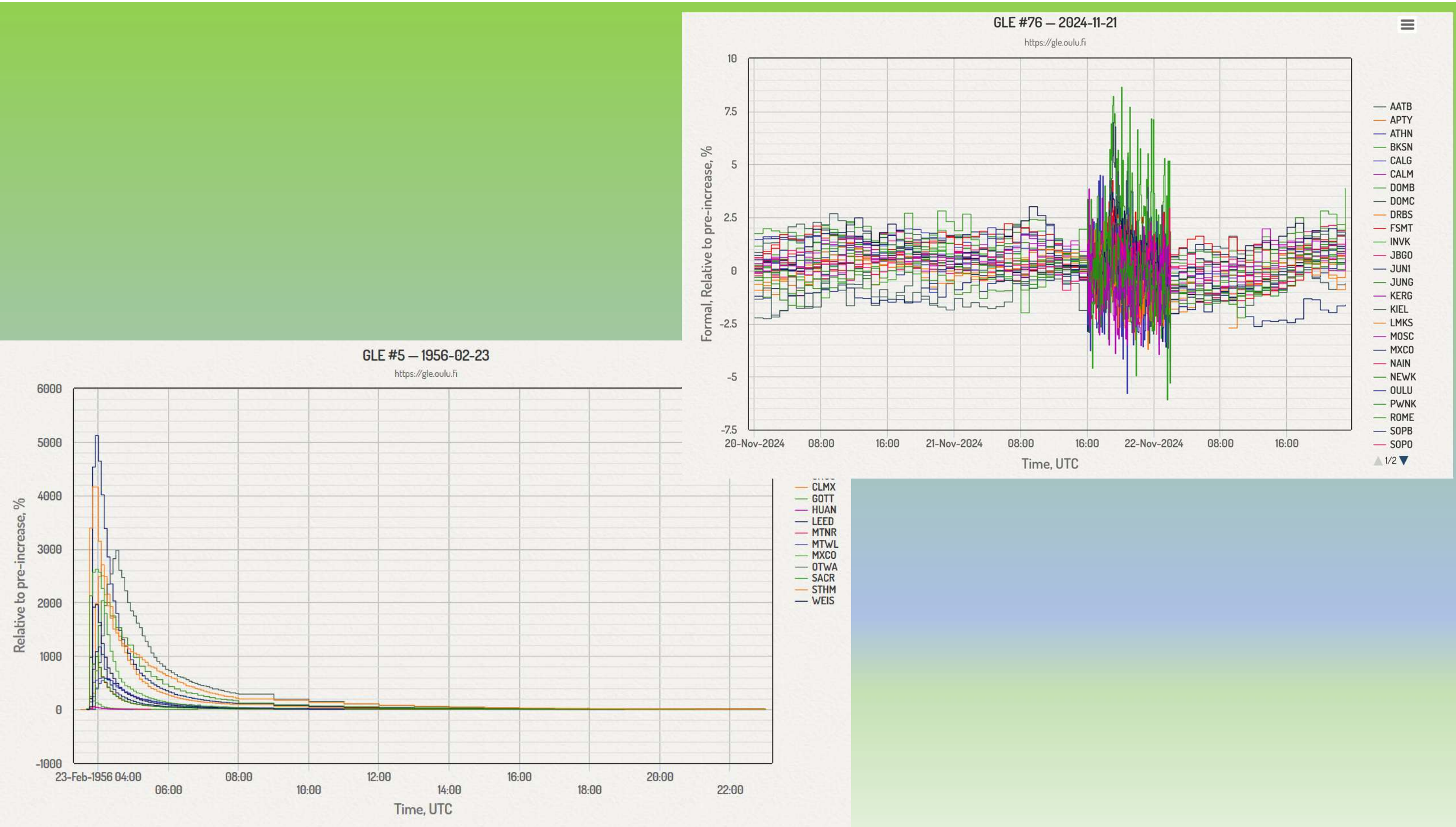
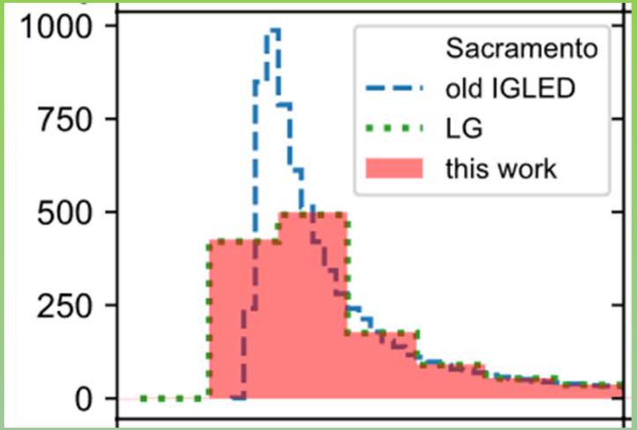


Figure 3. Map (sinusoidal projection, GSE coordinates) of the ACRE responses of the NMs at high ($P_c < 2$ GV, red circles) and mid-latitudes (blue circles). The coordinates of the points correspond to the asymptotic directions of the NM at the rigidity P^*=max(2 GV,P_c). The size of the symbols represents the intensity in %*hr (see Table 1) as indicated in the bottom panel. The magenta star and the thick curve depict the fitted (see Equation 2) anisotropy axis and its 1σ interval, respectively.


GLE #76 — 2024-11-21
https://gle.oulu.fi
Formal, Relative to pre-increase, %
10
7.5
5
2.5
0
-2.5
-5
-7.5
20-Nov-2024
08:00
16:00
21-Nov-2024
08:00
16:00
22-Nov-2024
08:00
16:00
Time, UTC
AATB
APTY
ATHN
BKSN
CALG
CALM
DOMB
DOMC
DRBS
FSMT
INVK
JBGO
JUN1
JUNG
KERG
KIEL
LMKS
MOSC
MXCO
NAIN
NEWK
OULU
PWNK
ROME
SOPB
SOPO
1/2
GLE #5 — 1956-02-23
https://gle.oulu.fi
Relative to pre-increase, %
6000
5000
4000
3000
2000
1000
0
-1000
23-Feb-1956 04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time, UTC
CLMX
GOTT
HUAN
LEED
MTNR
MTWL
MXCO
OTWA
SACR
STHM
WEIS

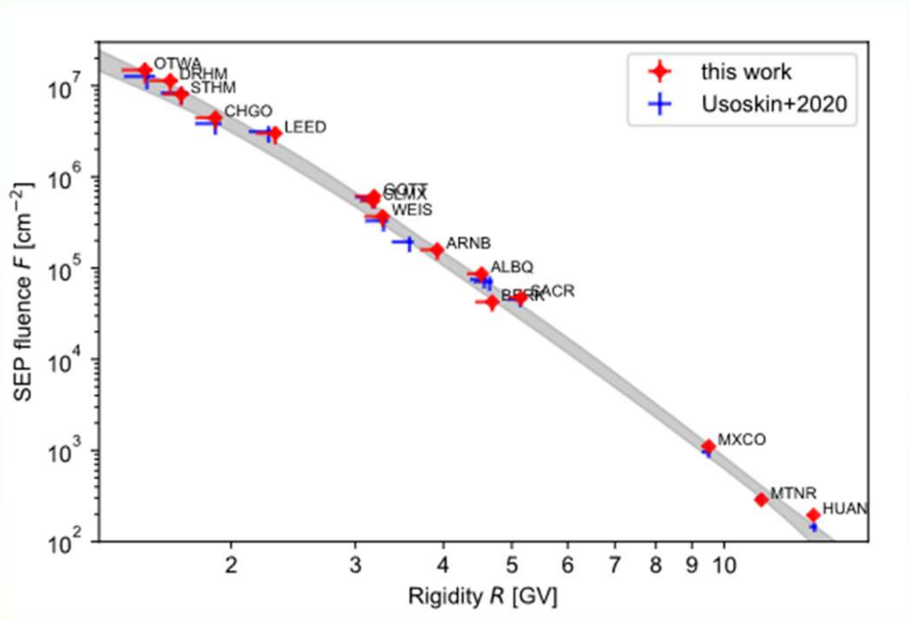


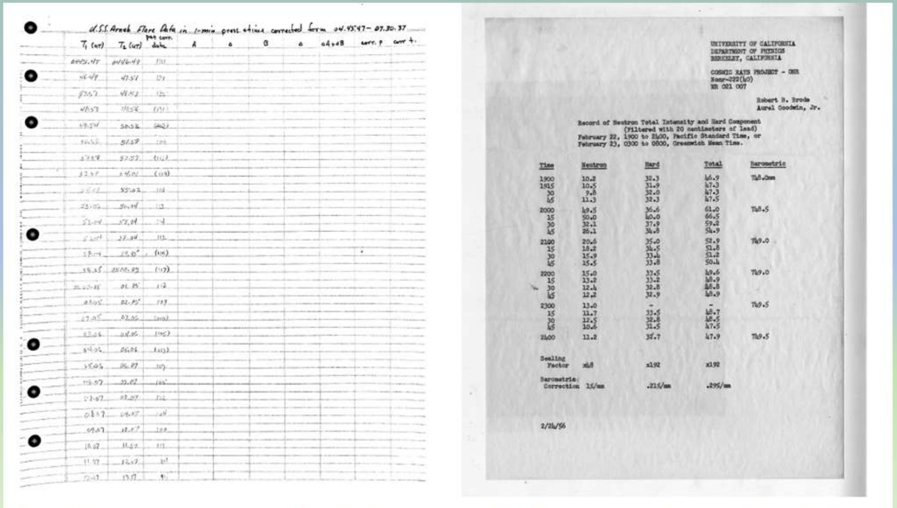

A&A, 684, A46 (2024)
https://doi.org/10.1051/0004-6361/202348699

Astronomy & Astrophysics

Revision of the strongest solar energetic particle event of 23 February 1956 (GLE #5) based on the rediscovered original records

Hisashi Hayakawa[1,2,3,4], Sergey Koldobskiy[5,6], Alexander Mishev[5,6], Stepan Poluianov[5,6], Agnieszka Gil[7,8], Inna Usoskina[6], and Ilya Usoskin[5,6]




U.S.S. Arneb Flare Data in 1-min press. & time corrected form 04.45.47 – 07.30.37

UNIVERSITY OF CALIFORNIA
DEPARTMENT OF PHYSICS
BERKELEY, CALIFORNIA

COSMIC RAYS PROJECT - ONR
Nonr-222(40)
NR 021 007

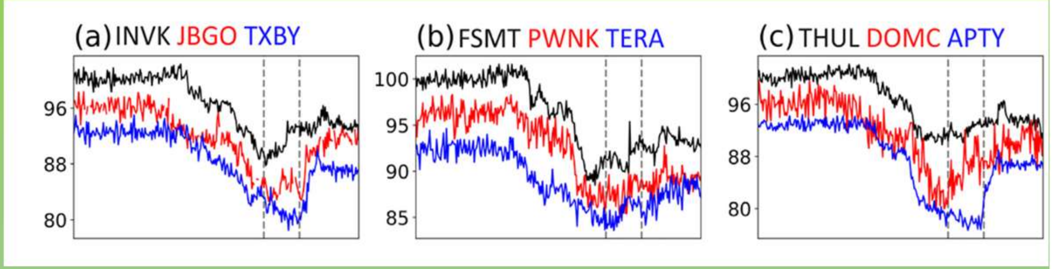
Robert B. Brode
Aurel Goodwin, Jr.

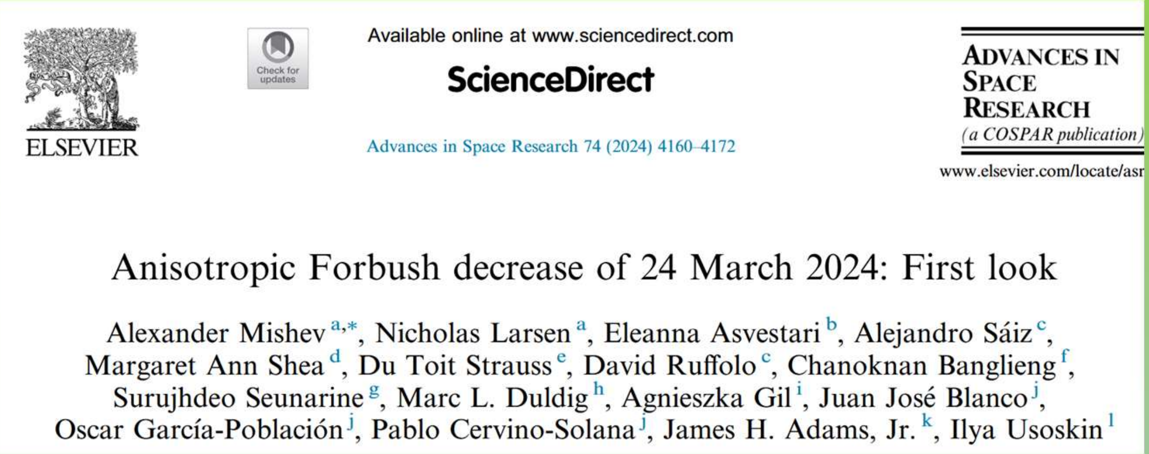
Record of Neutron Total Intensity and Hard Component
(Filtered with 20 centimeters of lead)
February 22, 1900 to 2400, Pacific Standard Time, or
February 23, 0300 to 0800, Greenwich Mean Time.

Time	Neutron	Hard	Total	Barometric
1900	10.2	32.3	46.9	748.0mm
1915	10.5	31.9	47.3	
30	9.8	32.0	47.3	
45	11.3	32.3	47.5	
2000	49.5	36.6	61.0	748.5
15	50.0	40.0	66.5	
30	32.1	37.9	59.2	
45	26.1	34.8	54.9	
2100	20.6	35.0	52.9	749.0
15	18.2	34.5	51.8	
30	15.9	33.4	51.2	
45	15.5	33.8	50.4	
2200	15.0	33.5	49.6	749.0
15	13.2	33.2	48.9	
30	12.4	32.8	48.8	
45	12.2	32.9	48.9	
2300	13.0	-	-	749.5
15	11.7	33.5	48.7	
30	12.5	32.8	48.5	
45	10.6	31.5	47.5	
2400	11.2	34.7	47.9	749.5
Scaling Factor	x48	x192	x192	
Barometric: Correction	1%/mm	.21%/mm	.29%/mm	

2/24/56

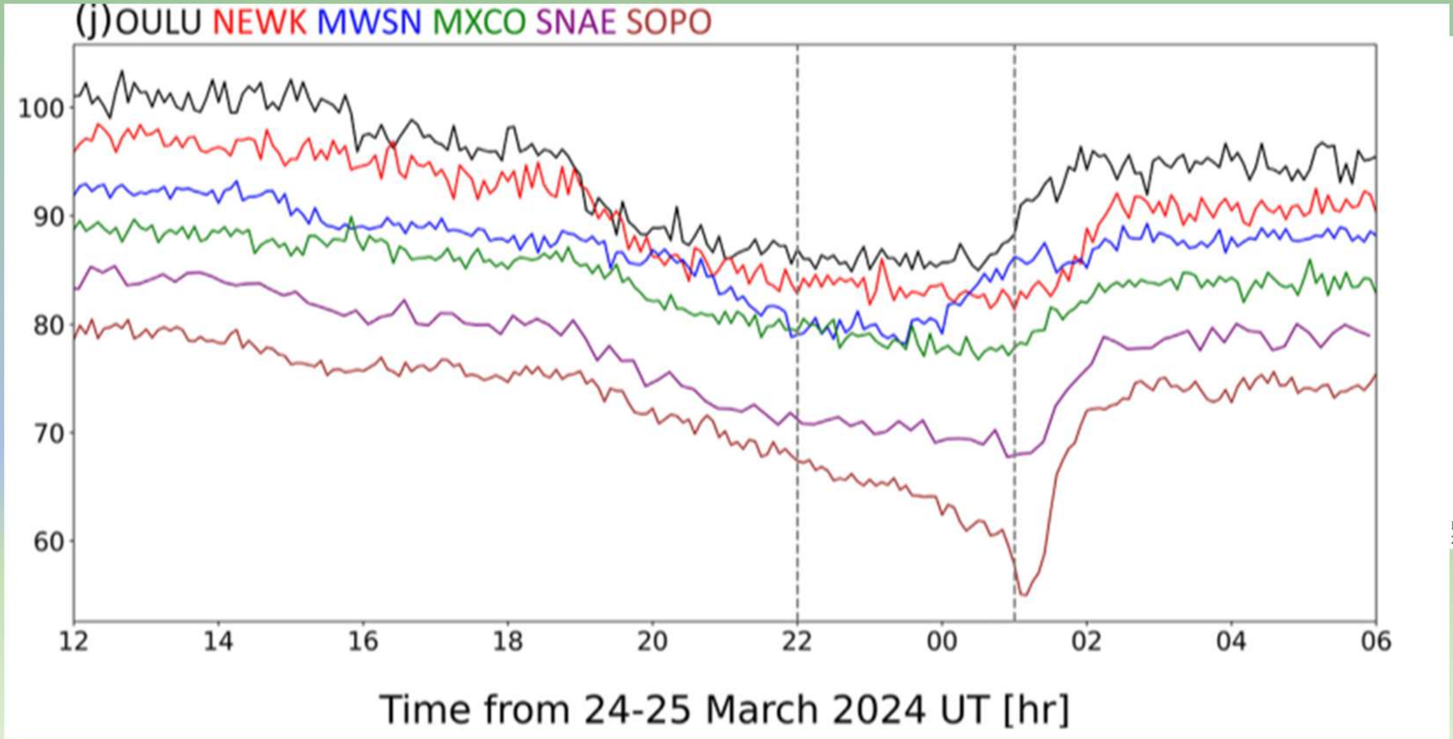
Fig. 1. Example images of archival records for the NM measurements during GLE #5. Left panel shows a summary for NM of the USS Arneb at Wellington Harbour (MS Simpson B218 F1). Right panel shows a report for Berkeley NM (MS Simpson B216 F12). Both are reproduced by courtesy of the Hanna Holborn Gray Special Collections Research Center, University of Chicago Library.




Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 74 (2024) 4160–4172
ADVANCES IN SPACE RESEARCH
(a COSPAR publication)
www.elsevier.com/locate/asr

Anisotropic Forbush decrease of 24 March 2024: First look

Alexander Mishev [a,*], Nicholas Larsen [a], Eleanna Asvestari [b], Alejandro Sáiz [c], Margaret Ann Shea [d], Du Toit Strauss [e], David Ruffolo [c], Chanoknan Banglieng [f], Surujhdeo Seunarine [g], Marc L. Duldig [h], Agnieszka Gil [i], Juan José Blanco [j], Oscar García-Población [j], Pablo Cervino-Solana [j], James H. Adams, Jr. [k], Ilya Usoskin [l]



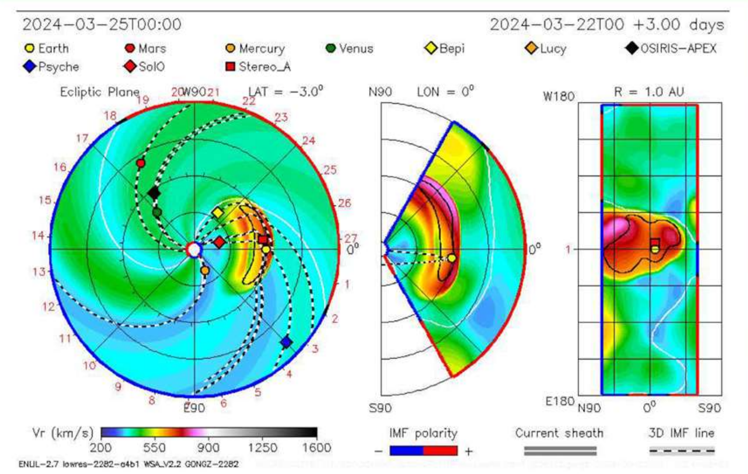
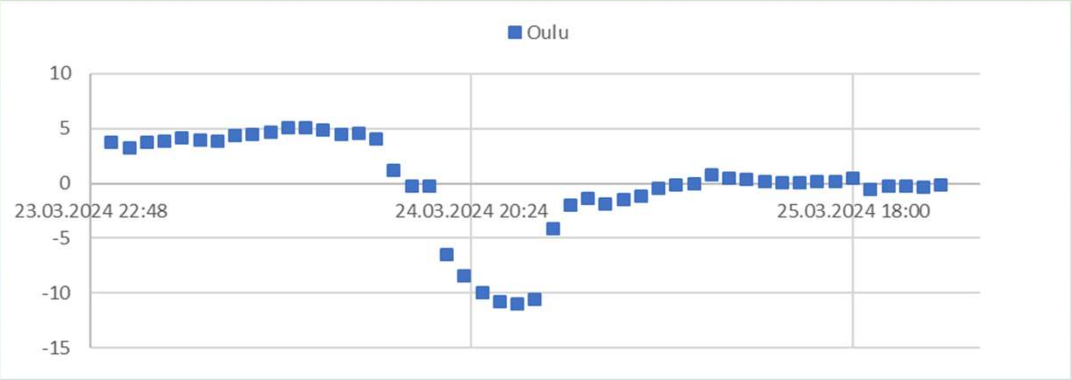
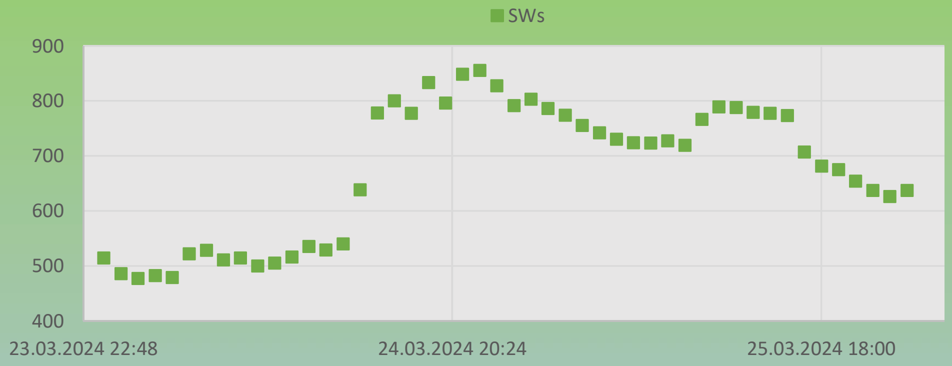


Fig. 6. Radial solar wind velocity contour plots shown in the ecliptic (left panel), meridional (middle panel), and radial (right panel) planes for 25 March 2024 at 00:00 UT (source: https://ccmc.gsfc.nasa.gov/).



Gil et al., 2025 in preparation



Solar Physics (2023) 298:28
https://doi.org/10.1007/s11207-023-02120-x

RESEARCH

Analysis of Galactic Cosmic Ray Anisotropy During the Time Period from 1996 to 2020

Witold Wozniak[1] · Krzysztof Iskra[2] · Renata Modzelewska[3] · Marek Siluszyk[2,3]

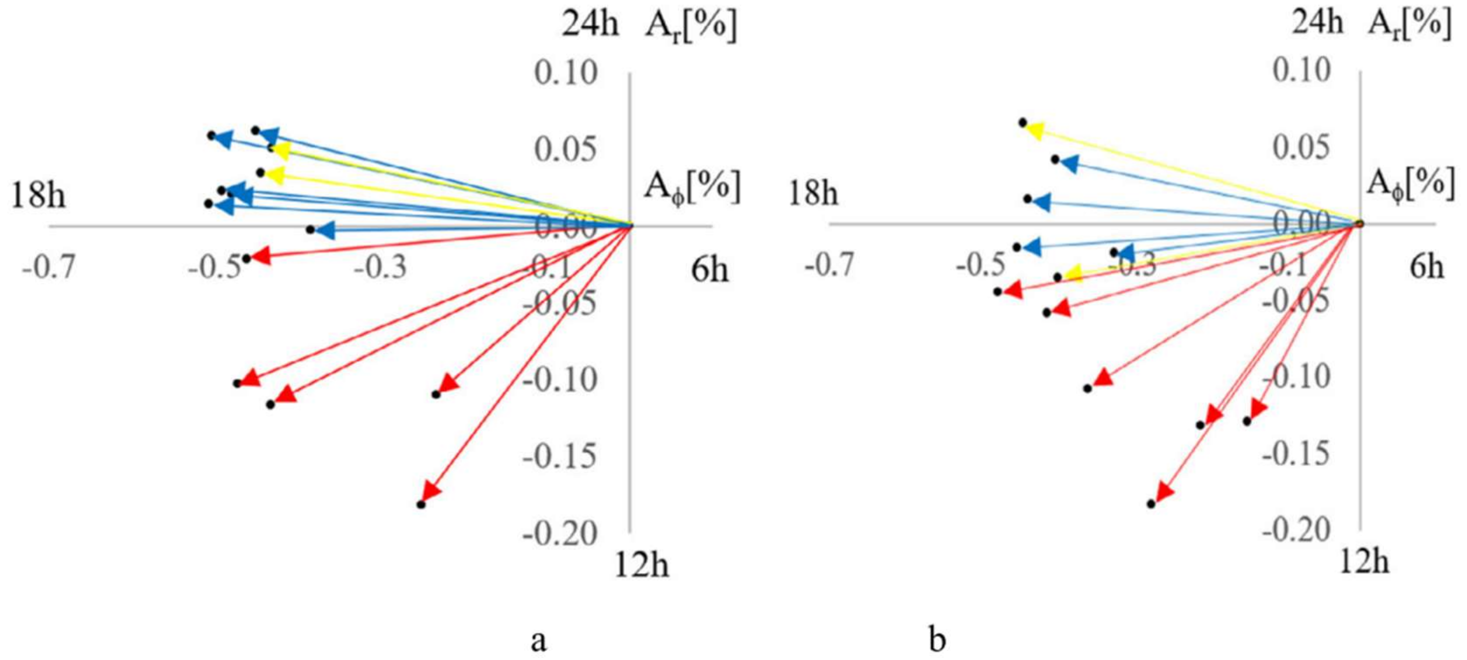


Figure 2 (**a**) Harmonic diagrams of the GCRA from year to year for the periods 1996 – 2008 (the last year of Solar Cycle 22 and Solar Cycle 23), (**b**) the same for 2009 – 2020 (Solar Cycle 24 and the beginning of Solar Cycle 25). Colors determine magnetic polarity: positive periods ($A > 0$) shown in red, negative ($A < 0$) periods in blue, reversal time in yellow.

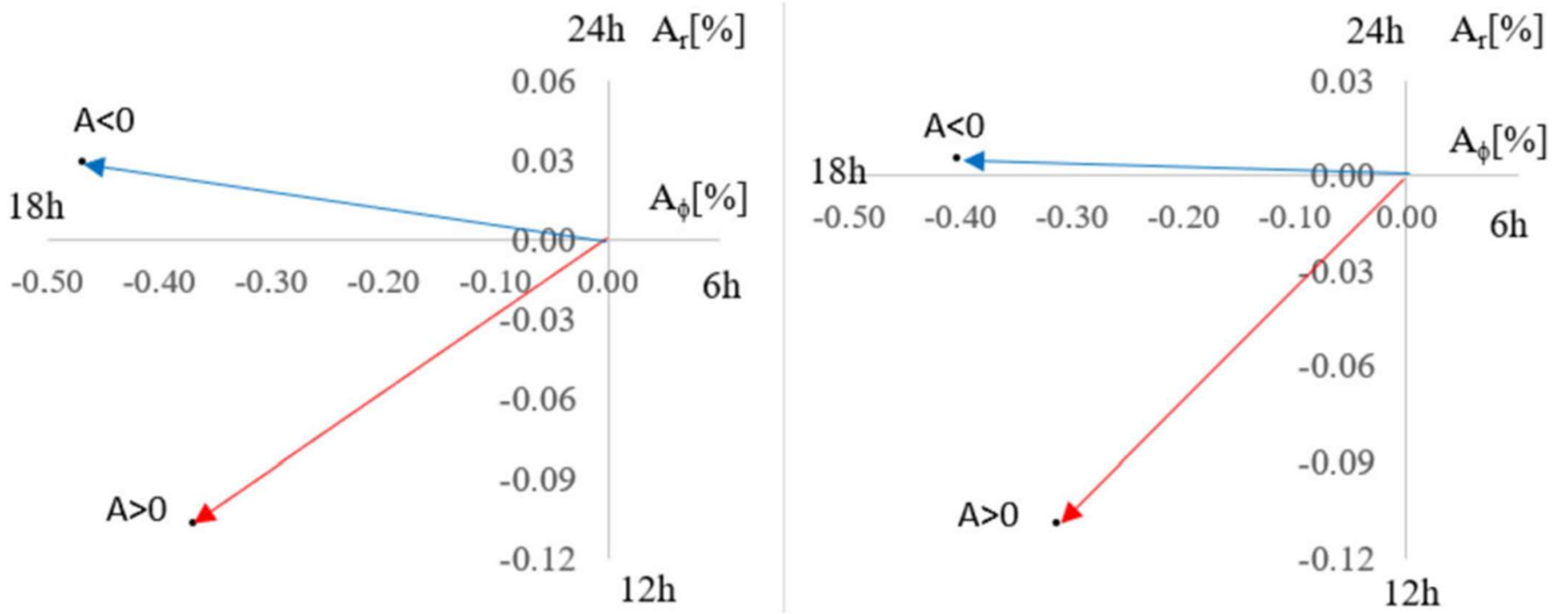


Figure 3 (**a**) Harmonic diagrams of the average GCRA vectors for the period 1996 – 2008 (last year of the Solar Cycle 22 and Solar Cycle 23) with various signs of the HMF, i.e., for 1996 – 2000 when $A > 0$ and 2003 – 2008 when $A < 0$. (**b**) The same for 2009 – 2020 (Solar Cycle 24 and the beginning of the Solar Cycle 25) for 2009 – 2012 when $A < 0$ and 2015 – 2020 when $A > 0$. Colors determine magnetic polarity: positive periods $A > 0$ shown in red, negative ($A < 0$) periods in blue, reversal time in yellow.

Sumary:

Thank you!

Ground observations of the lower part of the GCR spectrum is successfully done by NMs. The main task of NMs is to show changes in the original cosmic ray intensity. These changes occur as a result of a behavior of Sun and reflect the level of solar activity. In this context, the GCR particle flux continuously reaching the Earth is an unique and incessantly available source of information about the state of interplanetary space.

It allows not only to better understand the properties of galactic cosmic rays, but also to discover the properties of the heliosphere and Sun, in various time scales - indirectly.

It also serves in space weather research, e.g. to determine the level of exposure of aircraft crews to ionizing radiation. It can also be used as an element of post-factum analysis of individual episodes of geomagnetic storms, allowing the creation of a broad characteristic of these phenomena.