The CME-index for short-term estimation of Ap geomagnetic index based on the new ICME list

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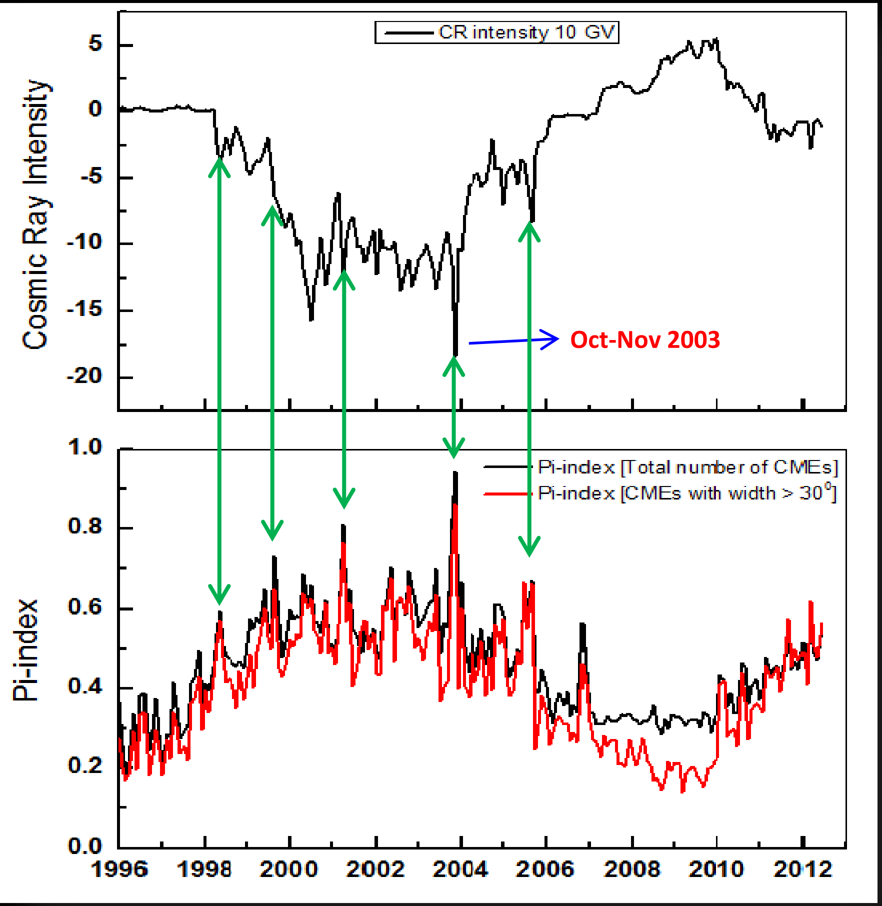
Overview

1. Anti-correlation between CMEs and Cosmic rays
2. The role of the CME-index on the Long-term Cosmic-ray Modulation
3. CME-index and the geomagnetic index Ap
4. Previous model of Ap estimation from CME-index
5. The new ICMEs list
6. An improvement of the CME-index using magnetic fields
7. Athens Space Weather Forecasting Center

CME-index and Cosmic-Rays



Anti-correlation between CMEs and Cosmic-Ray intensity

r = -0.84 with 0 months time-lag

This index follows the relation:

$$P_i = \alpha \cdot \frac{Nc}{Nc_{max}} + \beta \cdot \frac{Vp}{Vp_{max}}$$

$$\alpha + \beta = 1$$

$$\alpha, \beta > 0$$

Nc: The monthly number of CMEs,
Nc_{max}: The maximum Nc for the examined period
Vp: The average linear speed of the CMEs per month,
Vp_{max}: The maximum Vp for the examined period

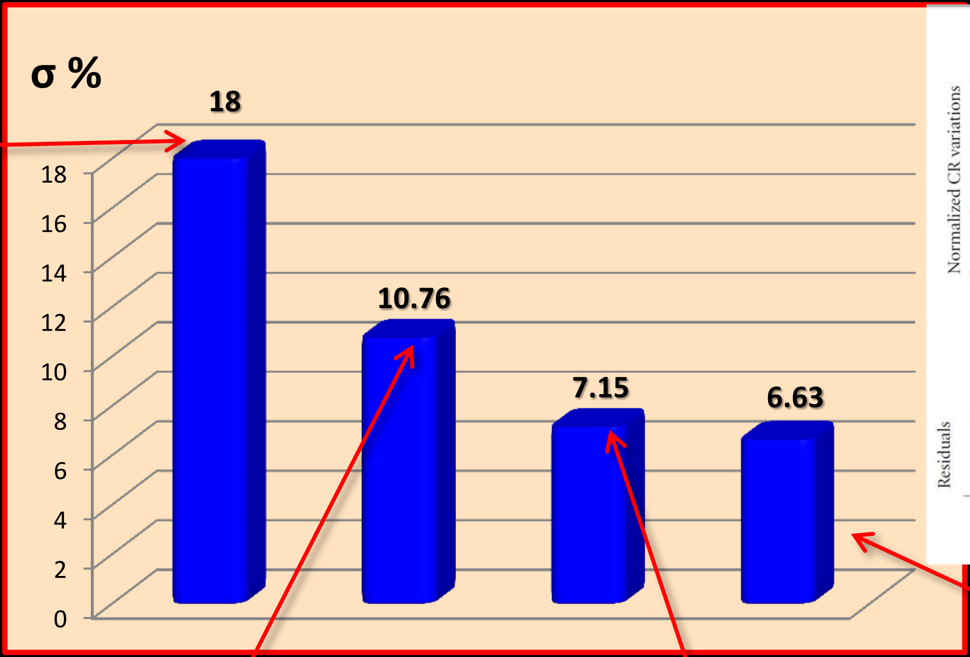
(Paouris, 2013)
(Mavromichalaki and Paouris, 2012)

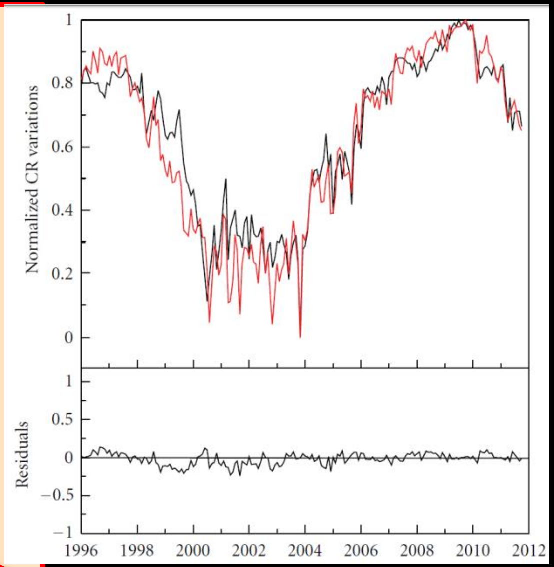
CME-index and Long-term Modulation

$$I = f\left(Rz, Nf, Ap\right)$$

(Xanthakis et al., 1981)
(Mavromichalaki et al. 2005)

- A proxy which applied with success in Long-term Modulation of Galactic Cosmic-Rays





$$I = f\left(Rz, Nc, Ap, HCS\right)$$

(Mavromichalaki, Paouris and Karalidi, 2007)

$$I = f\left(Rz, P_i, IMF, HCS\right)$$

(Paouris et al., 2012)

$$I = f\left(Rz, P_i^*, IMF, HCS\right)$$

(Mavromichalaki and Paouris, 2013)

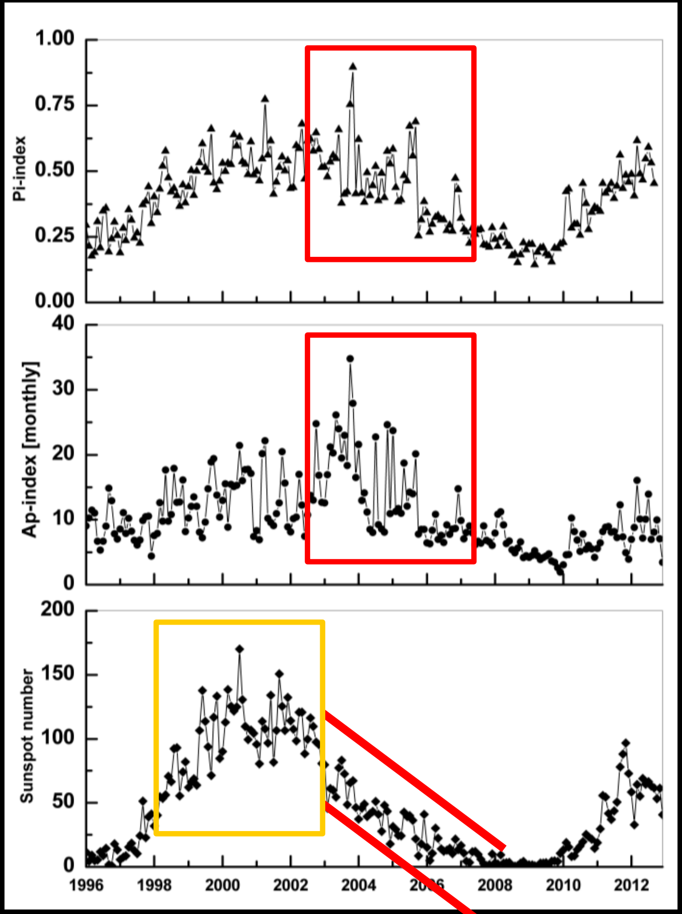
CME-index and Ap index

Correlation Analysis:

Ap-index - Rz	
Pearson cc	**0.47**
Spearman cc	0.57

Ap-index - P_i-index	
Pearson cc	**0.68**
Spearman cc	0.67

P_i-index - Rz	
Pearson cc	0.76
Spearman cc	0.85



Sunspot number:
No information for extreme events!

CME-index:
Based on the extreme events!
"This index is strongly connected to extreme events and not only to the overall solar activity as the sunspot number does"

(Paouris, 2013)

Ap estimation from Pi-index – Previous Model

Determination of the best model function:

$$Ap = Ap_o + A \cdot e^{R_o \cdot P_i}$$

Ap calculated values

Pi: CME-index values

$$P_i = \frac{Vp}{Vp_{max}} + \frac{w}{w_{max}}$$

Ap_o = -226.5

A = 211.9

R_o = 0.43638

Results

18 events were studied

- Examined period: 1996-2012
- Ap (daily value) > 100
- **8 events with σ < 10%**

Event	Ap_{calc}	Ap_{obs}	%
2003/05/29	239	236	1
2001/11/06	295	300	2
2003/10/30	390	400	3
2004/11/10	288	300	4
2001/11/24	248	236	5
2000/08/12	166	179	7
2003/10/31	325	300	8
2003/11/20	275	300	8
2003/08/18	135	154	13

(Paouris et al., 2013)

$(Ap_{calc} - Ap_{obs})/Ap_{obs}$ (%)	
< 10 %	8
< 20 %	1
< 30 %	2
< 40 %	3
> 40 %	4

Improvement: Introduction of the **magnetic field** and the **transit velocity** of the CME in the Pi-index

ICMEs lists

Previous Lists:
- Mitsakou and Moussas, 2014
- Richardson and Cane, 2010
- Zhang et al., 2007
- Jien et al., 2006

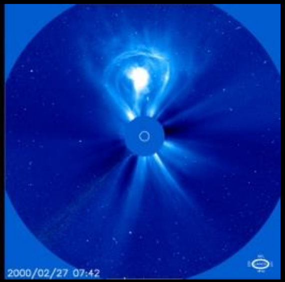
Details/CME:

- Start/End times of sheath and ICME
- Start/End times of sheath and ICME, V_I, V_{max}, $V_{transit}$, B, MC, Dst, SOHO/LASCO association
- Start/End times of shock and ICME, V_I, width, Dst, flare association SOHO/LASCO association
- Start/End times of shock and ICME, V_{min}, V_{max}, B_{max}, Comments

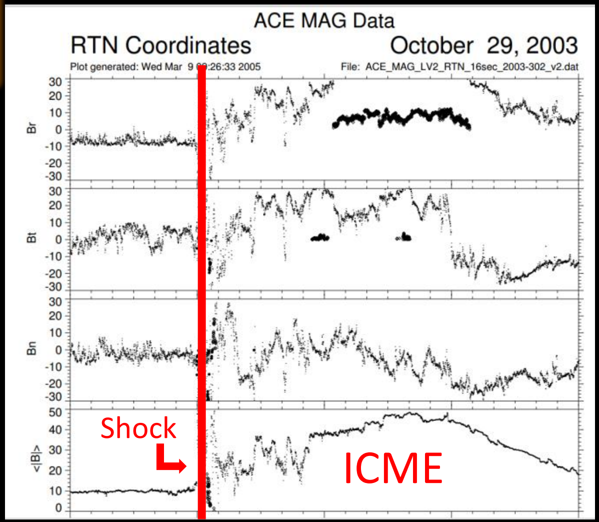
Each one has important information but these are separated works → **ONE list with as many as possible information per CME**

The new ICME list

CME → LASCO/SOHO → Earth directed



***in situ* observations from ACE**



New List with 48 parameters for each CME/ICME:

Start time of the disturbance/discontinuity, Start/End time of the ICME, background conditions (before the arrival of the ICME), Shock/MC existence, Vinitial, Vicme/max, Vdist/max, Vtransit, Binitial, Bicme/max, Bdist/max, Bz_dist/icme/min, plasma parameters (plasma β, Tp, Np, alpha ratio), Dst min and time, Ap max and time, SOHO/LASCO CME association date/time and angular width, solar flare association C,M,X-class, peak time, AR region with coordinates, Comments about the event

The new CME-index

ICME

- Magnetic field - **|B|**
- Transit Velocity - $\mathbf{V_{tr}}$
- Angular width - **w**

$$P_i = \frac{B_I}{B_{I(\max)}} + \frac{V_{tr}}{V_{tr(\max)}} + \frac{w}{w_{\max}}$$

$$0 < P_i \leq 3$$

Pi = 3 (maximum value) for "Halloween event"
29 October 2003 with:
B_{ICME} = 31.72 nT, $V_{transit}$ = 2235 km/s and w=360° (halo)

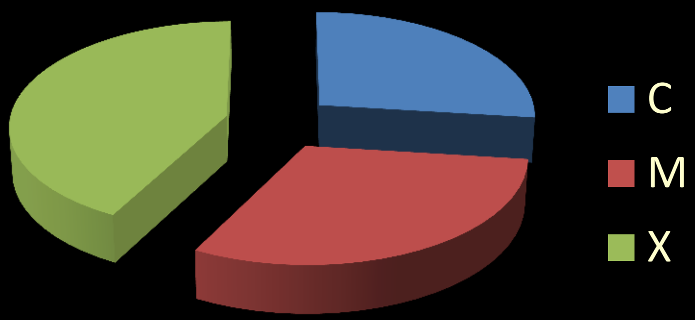
Data collection

- Geomagnetic storms with 100 < Ap_{max} < 400
- Examined period (1996 – 2012) number of events = 26

Dataset:

1. Ap geomagnetic index – maximum value,
2. ICMEs characteristics (magnetic field, transit velocity, angular width)
3. CME-Flare association

Analysis of Events



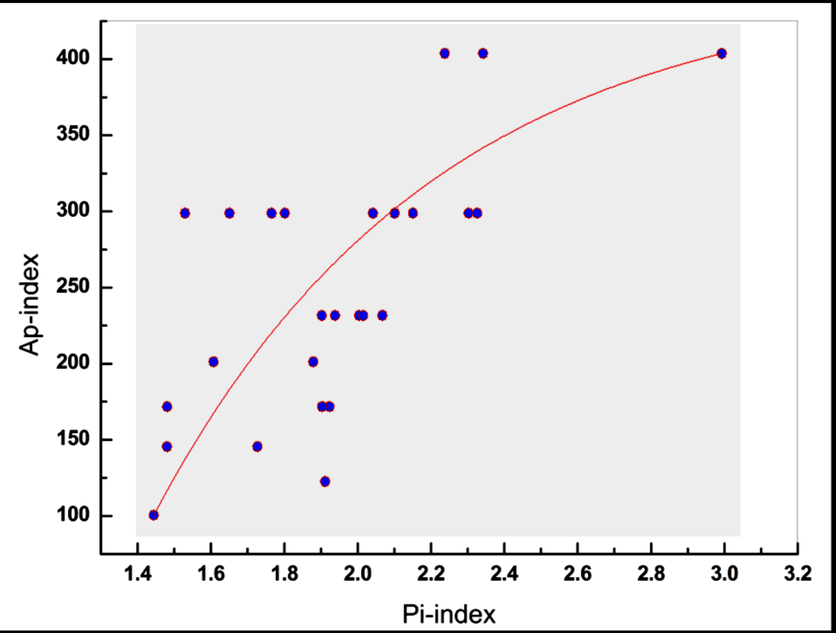
Events and Flare association	Events	MC	%
C – class	7	4	27
M – class	8	7	31
X – class	11	8	42

All of the ICMEs which caused geomagnetic storms are associated with a solar flare

MC – Events: 73%
The storm is associated with an interacting ICME with magnetic cloud

The most intense solar flare was a **X17.2** which associated with the "Halloween event"

Ap index estimation



Pi: CME-index values

$$Ap = A_0 + A \cdot e^{R_o \cdot P_i}$$

Ap calculated values

A_o = 11704.2

A = -11784.2

R_o = -0.01386

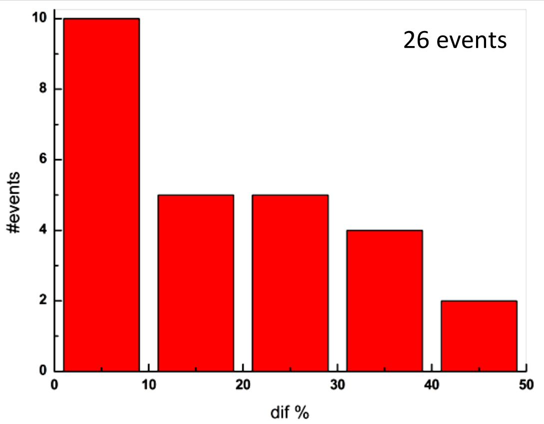
Results

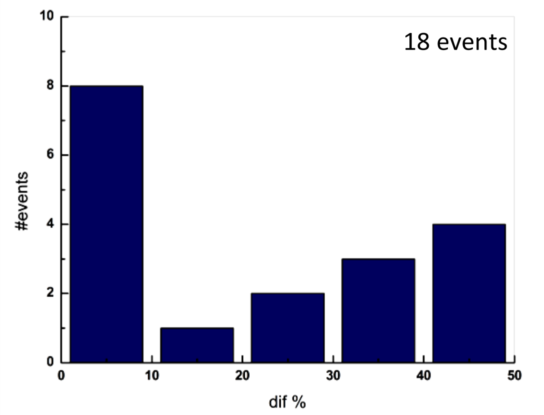
(Paouris et al., 2013)

Event	Ap_{calc}	Ap_{obs}	%
2003/10/29 18:00-21:00	400	400	0
2006/12/15 00:00-03:00	232	236	1.5
2003/11/20 15:00-21:00	294	300	1.9
2001/04/11 21:00-24:00	243	236	2.9
2001/03/31 03:00-09:00	291	300	3.1
2001/03/31 21:00-24:00	159	154	3.2
2005/05/15 06:00-09:00	245	236	3.7
2000/09/17 21:00-24:00	227	236	3.9
2001/11/24 06:00-09:00	253	236	7.2
1999/09/22 21:00-24:00	223	207	7.7

Variation $(Ap_{calc} - Ap_{obs})/Ap_{obs}$ (%)	
< 10 %	**10**
< 20 %	**5**
< 30 %	**5**
< 40 %	**4**
> 40 %	**2**

Variation $(Ap_{calc} - Ap_{obs})/Ap_{obs}$ (%)	
< 10 %	8
< 20 %	1
< 30 %	2
< 40 %	3
> 40 %	4

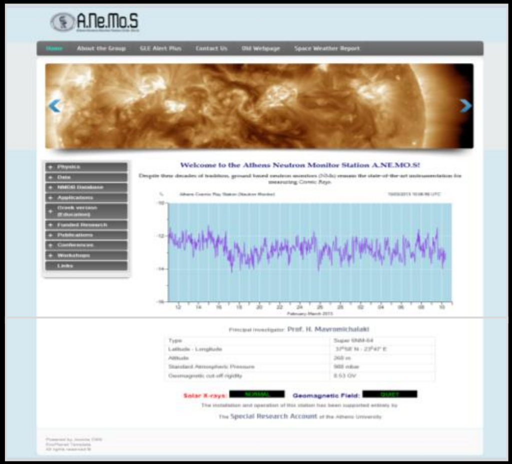




A.Ne.Mo.S Applications

- Athens Space Weather Forecasting Center
- Barometric coef.
- GLE Alert Plus – ESA SSA Project

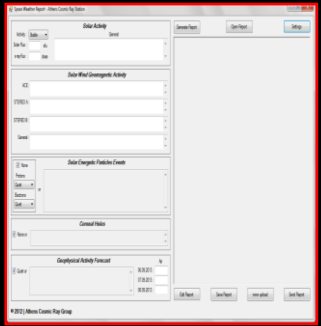
(http://cosray.phys.uoa.gr)

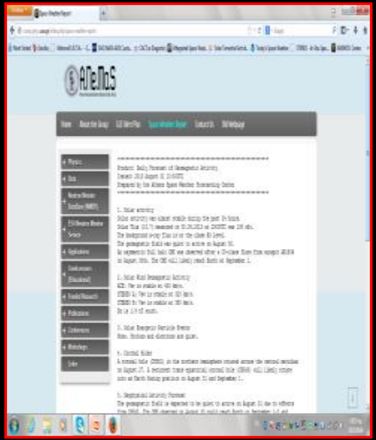


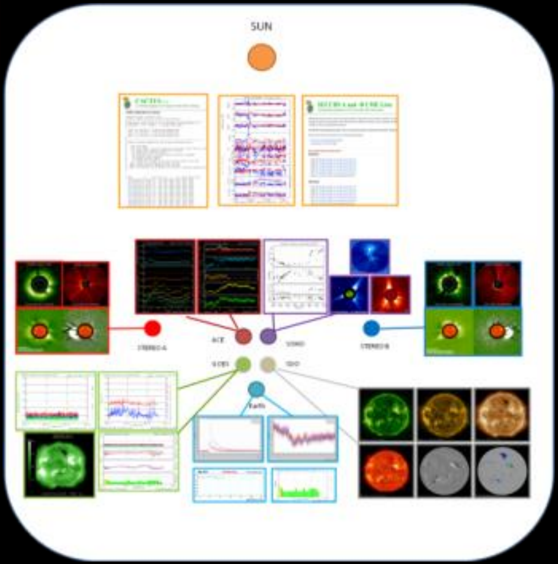
Autoregressive model (AR model)
a) Solar events, CMEs and Coronal holes
b) Magnetic activity 27-days before
c) Phase of solar cycle

Estimation of the Ap index with a set of rules that include a number of known parameters/properties of Ap index, as well as current observations of the Sun and near-Earth space

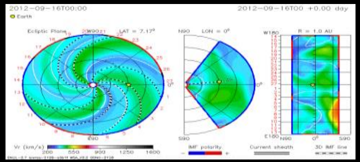
Athens Daily forecast Report







Real time MPEG movies from SOHO SDO PROBA STEREO A and B via **Media Download developed by Athens Cosmic ray group**



WSA –ENLIL CONE model-CME evolution

Conclusions

1. The new ICMEs list with 48 parameters for each event (Start/End times, velocities, magnetic fields B, Bz, plasma parameters, geomagnetic conditions)

2. CME-index defined for the first time from the **magnetic field**, **transit velocity** and **angular width**, with maximum value of Pi=3 for the event of 29/10/2003 which caused the most intense geomagnetic storm of solar cycle 23

3. All of the 26 events are associated with solar flares (27 % C-class, 31% M-class and 42% X-class)

4. The Ap values defined through the new Pi-index values are based on an exponential model with a very good approximation.

In future work:

- This method will be useful for Space Weather studies and it will be applied to the Athens Space Weather Forecasting Center very soon
- This preliminary study will be extended to the events with Ap<100
- Connection of this CME-index with solar flares and their characteristics (type, coordinates on the Sun)

Publication List

- Paouris, E., Mavromichalaki, H., Belov, A., Gushchina, R., Yanke, V.: "Galactic Cosmic Ray Modulation and the Last Solar Minimum", Solar Physics, 280, 255-271, 2012.
- Mavromichalaki, H. and Paouris, E.: "Long-Term Cosmic Ray Variability and the CME-Index", Advances in Astronomy, Article ID 607172, DOI: 10.1155/2012/607172, 2012.
- Paouris, E.: "Ineffectiveness of Narrow CMEs for Cosmic Ray Modulation", Solar Physics, DOI: 10.1007/s11207-012-0166-7, 2013.
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- Richardson, I.G. and Cane, H.V.: "Near-Earth Interplanetary Coronal Mass Ejections During Solar Cycle 23 (1996 – 2009): Catalog and Summary of Properties", Solar Physics, 2010.
- Zhang, J., Richardson, I.G., Webb, D.F. et al.: "Solar and interplanetary sources of major geomagnetic storms (Dst 100 nT) during 1996–2005", Journal of Geophysical Research, vol. 112, 2007.

Thank You !

Athens NM Station

Neutron Detectors