

Time dependent GCR intensity with Neutron Monitor, PAMELA and AMS02 measurements

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Complete Oulu data (1964-04-01 - 2021-11-15). Monthly averages. Average CR: 6198.29

40
5
0
-5
-10
-15
-20

1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019 2021

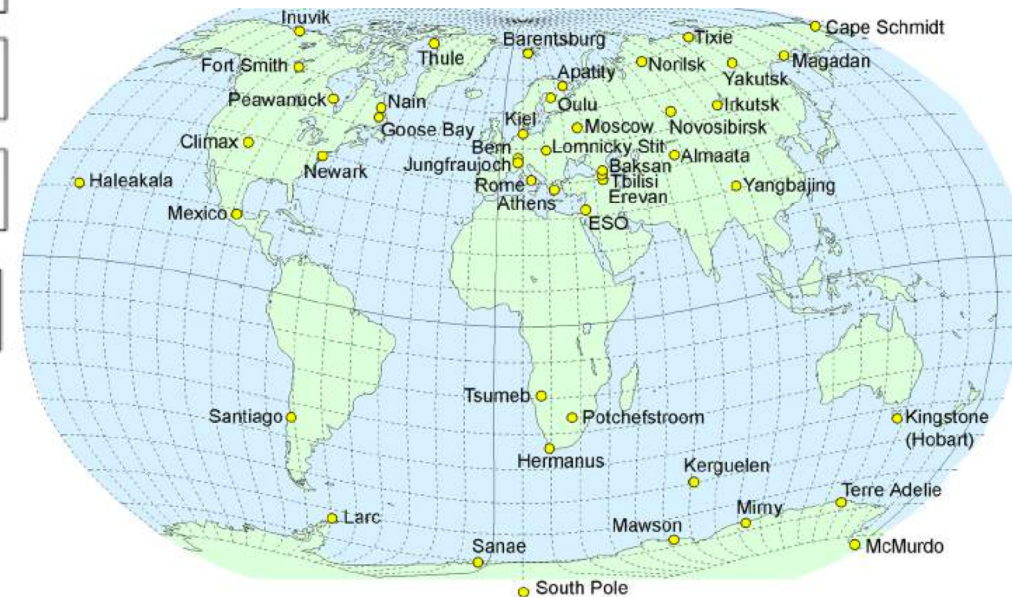
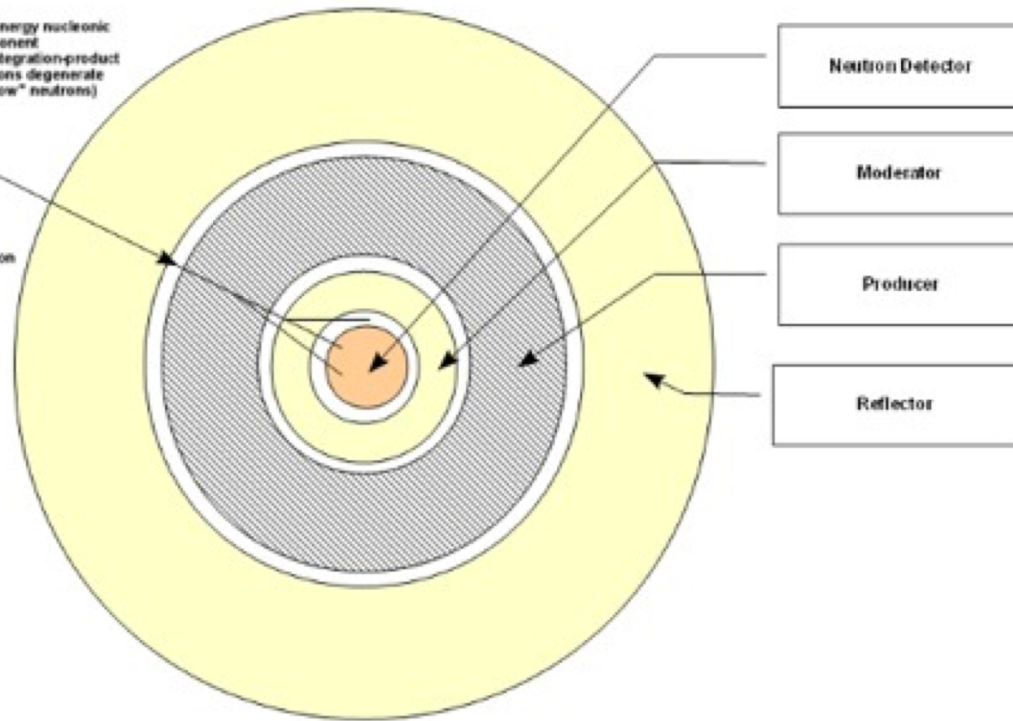
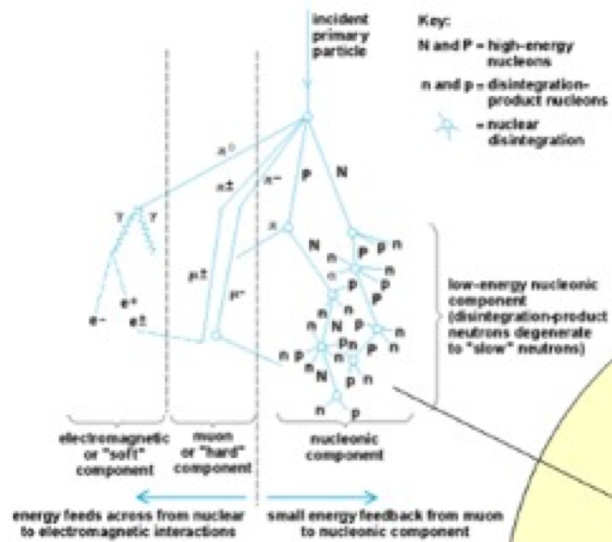
years

The diagram shows an incident primary particle entering from the top, initiating a cascade of nuclear interactions. The cascade is divided into three main components by vertical dashed lines:

- Electromagnetic or "soft" component:** This region on the left shows the production of electron-positron pairs (e^- , e^+) and photons (γ) from π^0 and π^\pm decays.
- Muon or "hard" component:** This middle region shows the production of muons (μ^\pm) from π^\pm decays.
- Nucleonic component:** This region on the right shows a dense cascade of nucleons (N) and disintegration-product nucleons (n and p).

Key features and feedback loops:

- Key:**
 - N and P = high-energy nucleons
 - n and p = disintegration-product nucleons
 - \star = nuclear disintegration
- Energy Flow:**
 - A blue arrow at the bottom indicates "energy feeds across from nuclear to electromagnetic interactions".
 - A red arrow at the bottom indicates "small energy feedback from muon to nucleonic component".
- Low-energy nucleonic component:** A bracketed region on the right notes that "disintegration-product neutrons degenerate to 'slow' neutrons".



NM data: where to get? and stability

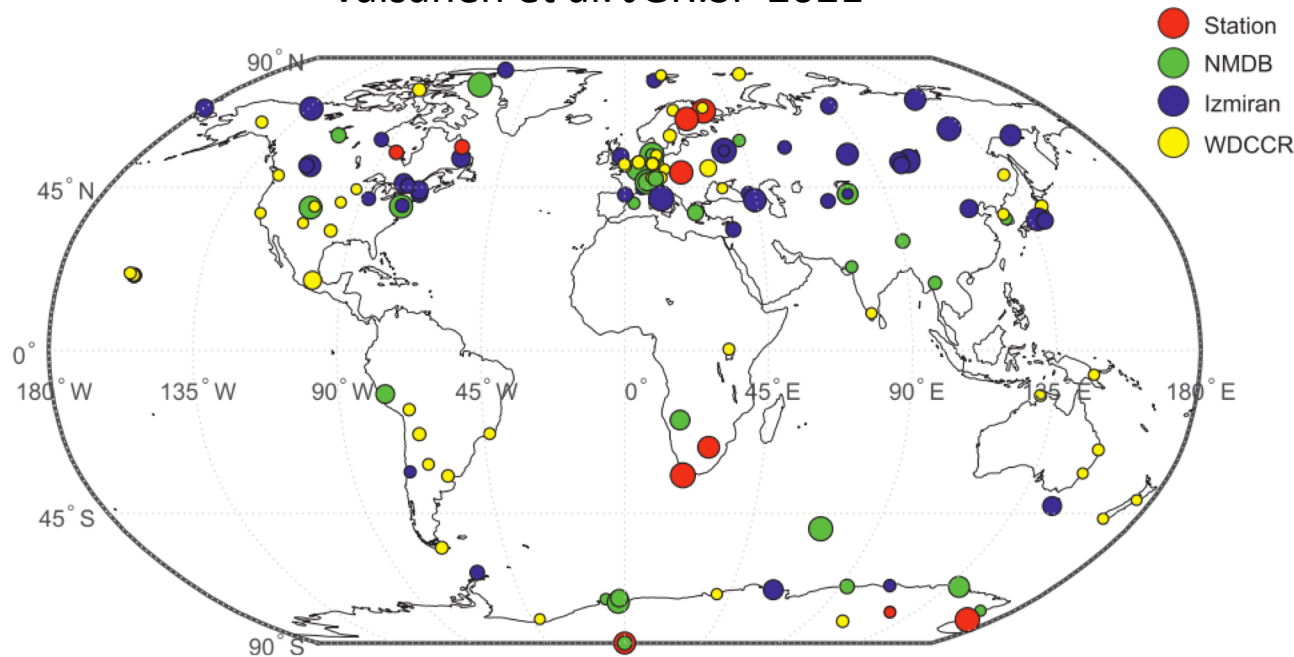
NMDB: <http://www02.nmdb.eu/nest>

WDC: <https://cidas.isee.nagoya-u.ac.jp/WDCCR/readme.html>

IZMIRAN: <http://cr0.izmiran.ru/common>

Dedicated NM databases

Väisänen et al. JGR:SP 2021



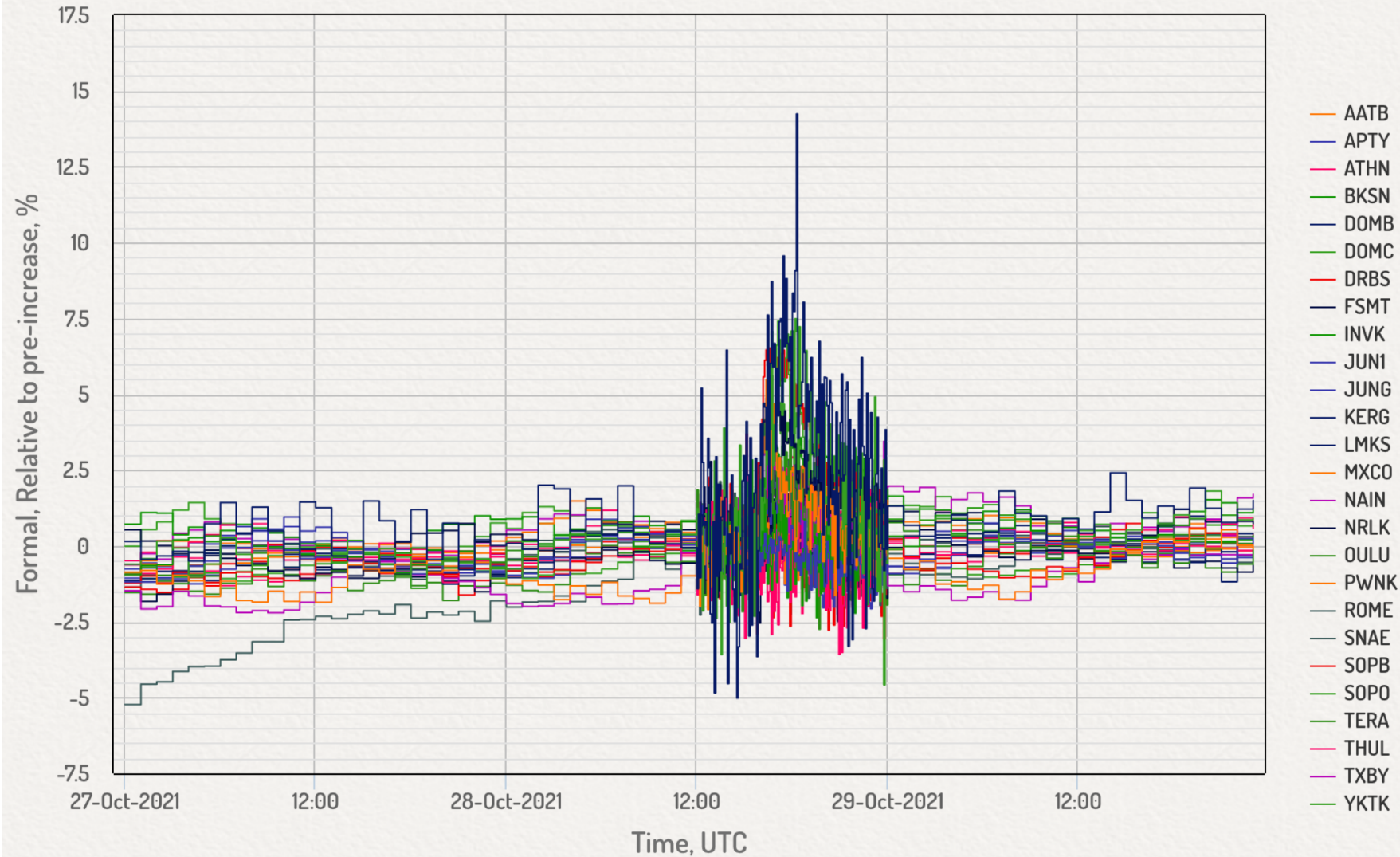
Direct measurements of CR databases:
<https://tools.ssdsc.asi.it/CosmicRays/>
<https://lpsc.in2p3.fr/crdb/>

SEP physics using NM data

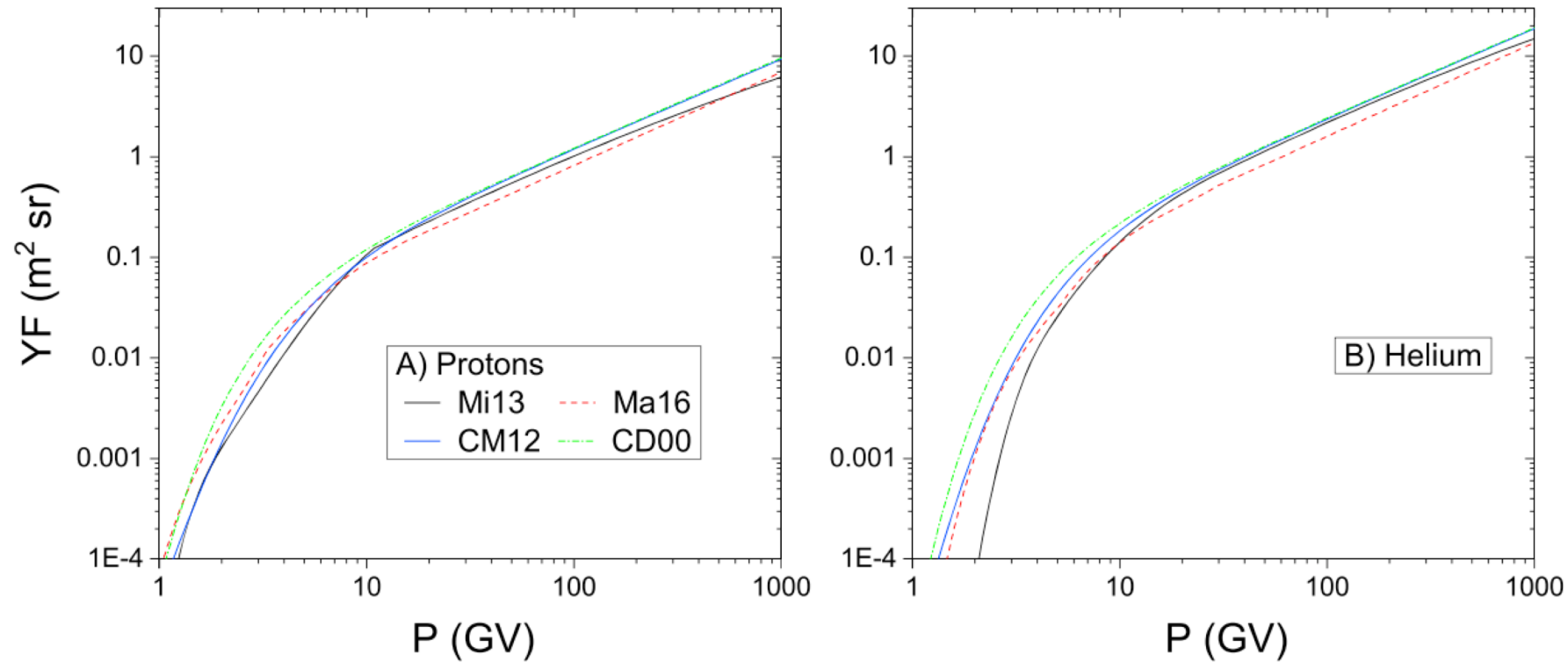
<http://gle.oulu.fi/#/>

GLE #73 — 2021-10-28

<https://gle.oulu.fi>



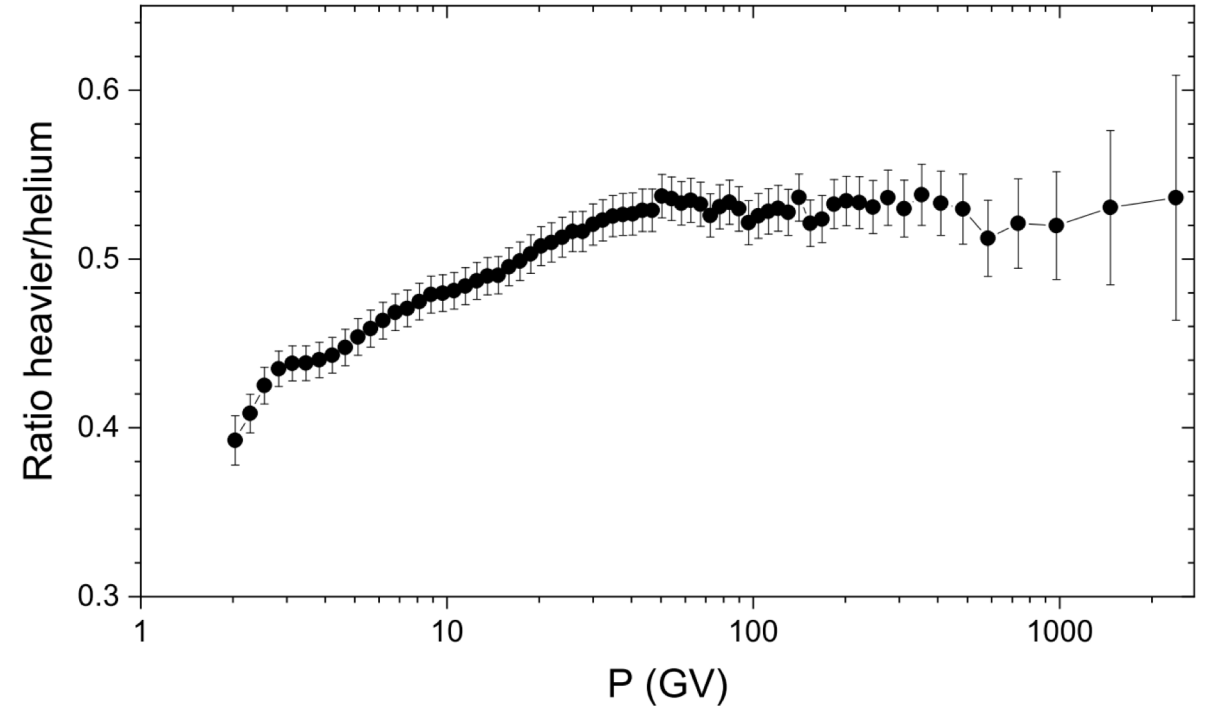
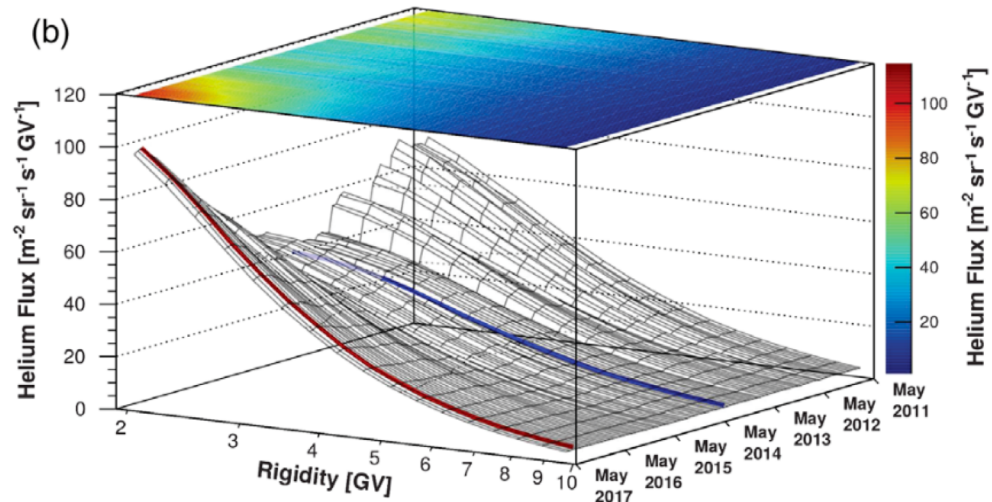
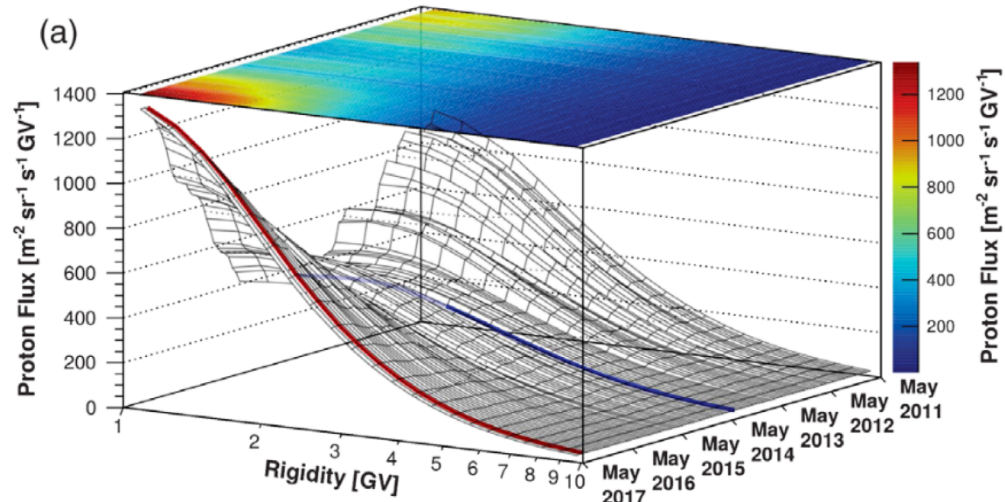
NM yield functions



$$N(t, h) = \frac{1}{K} \sum_i \int_{P_c}^{\infty} J_i(P, t) \cdot Y_i(P, h) \cdot dP$$

NMs are energy-integrating detectors

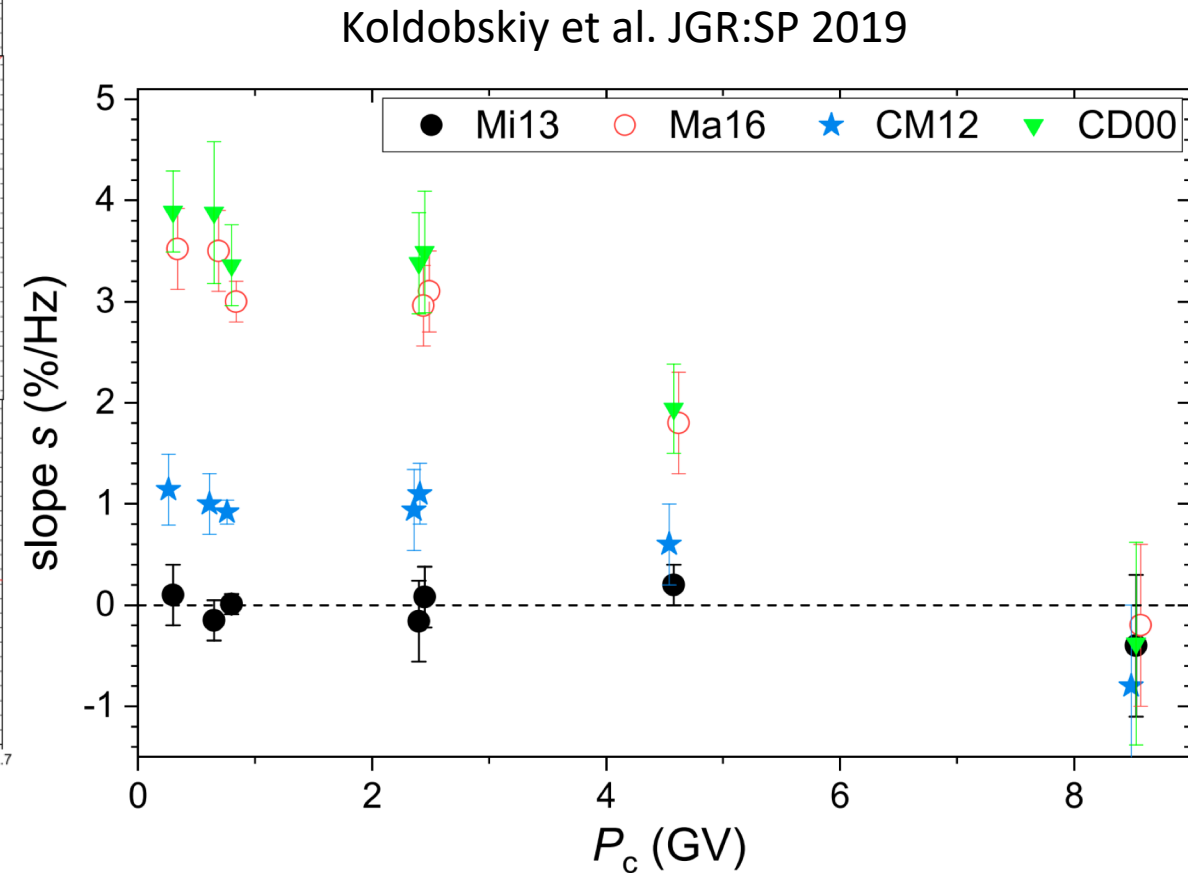
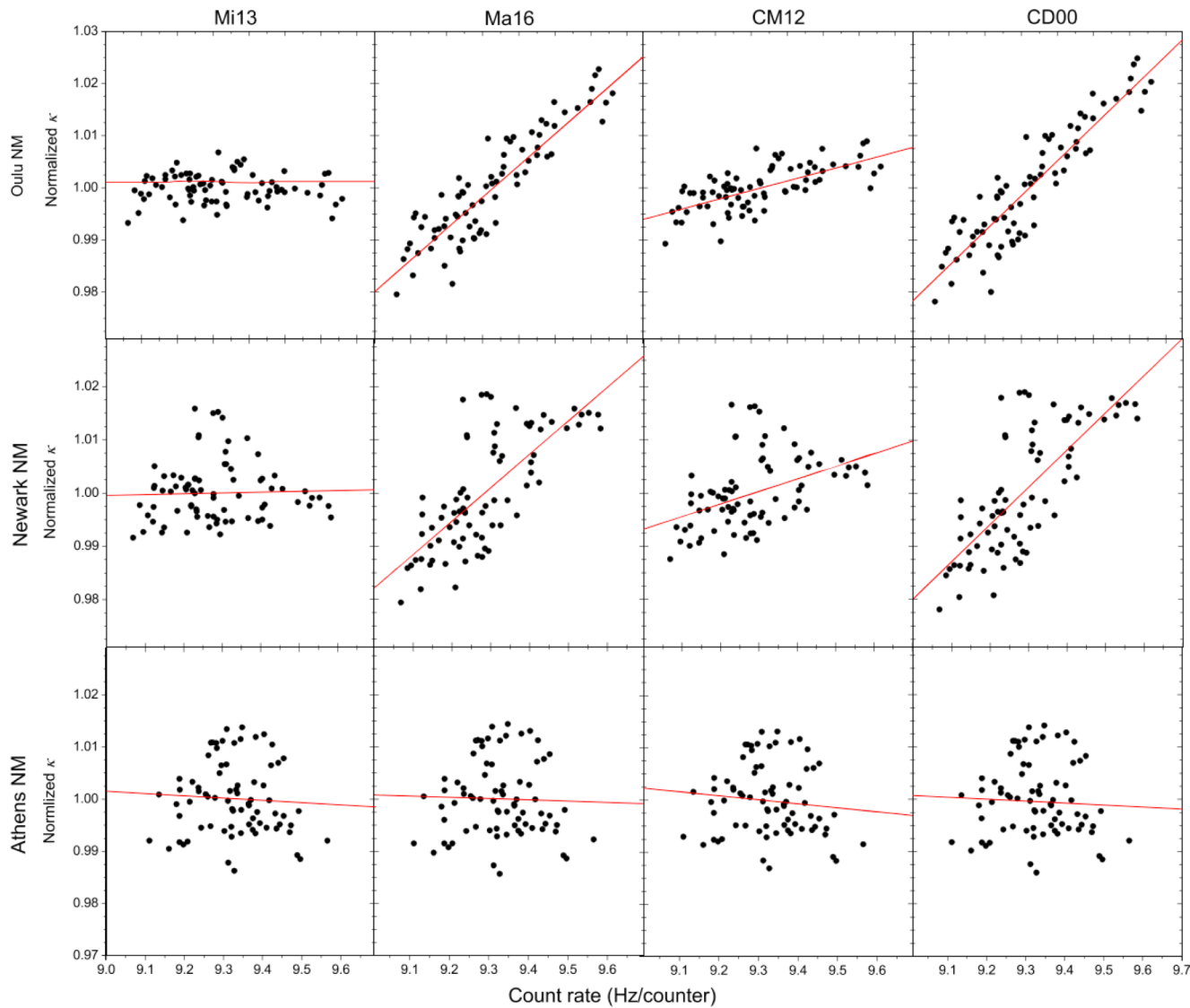
Neutron monitor and AMS-02 data



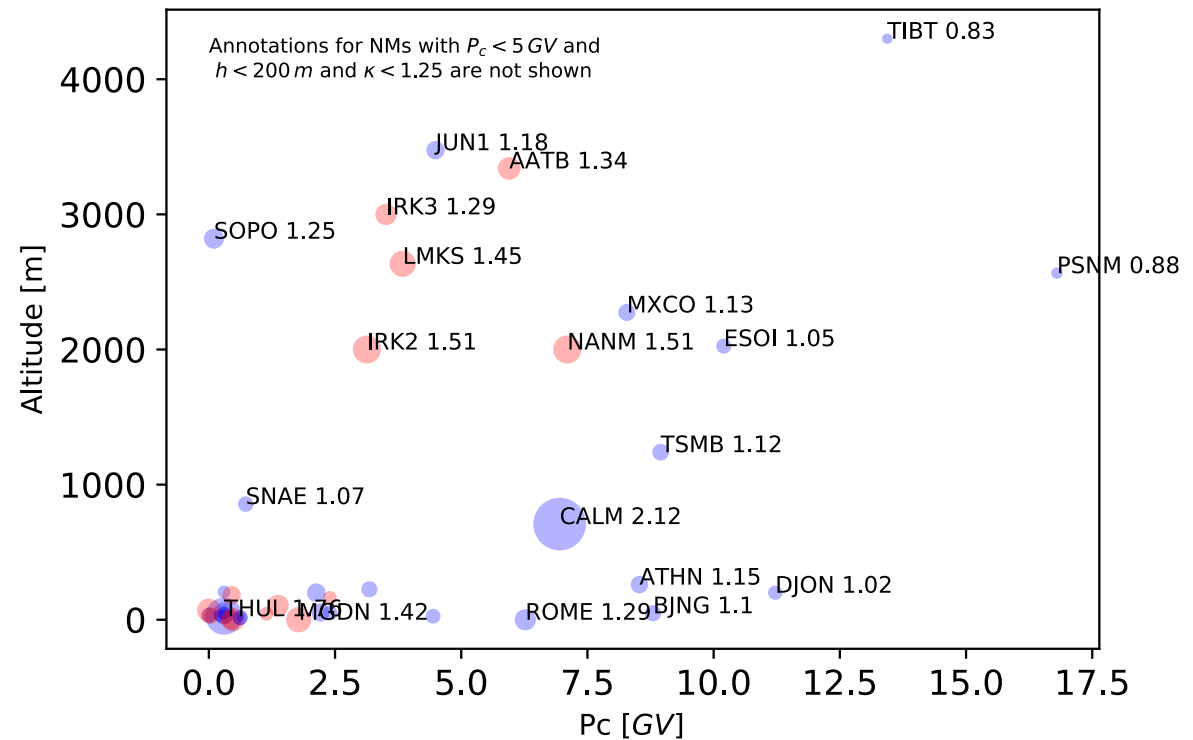
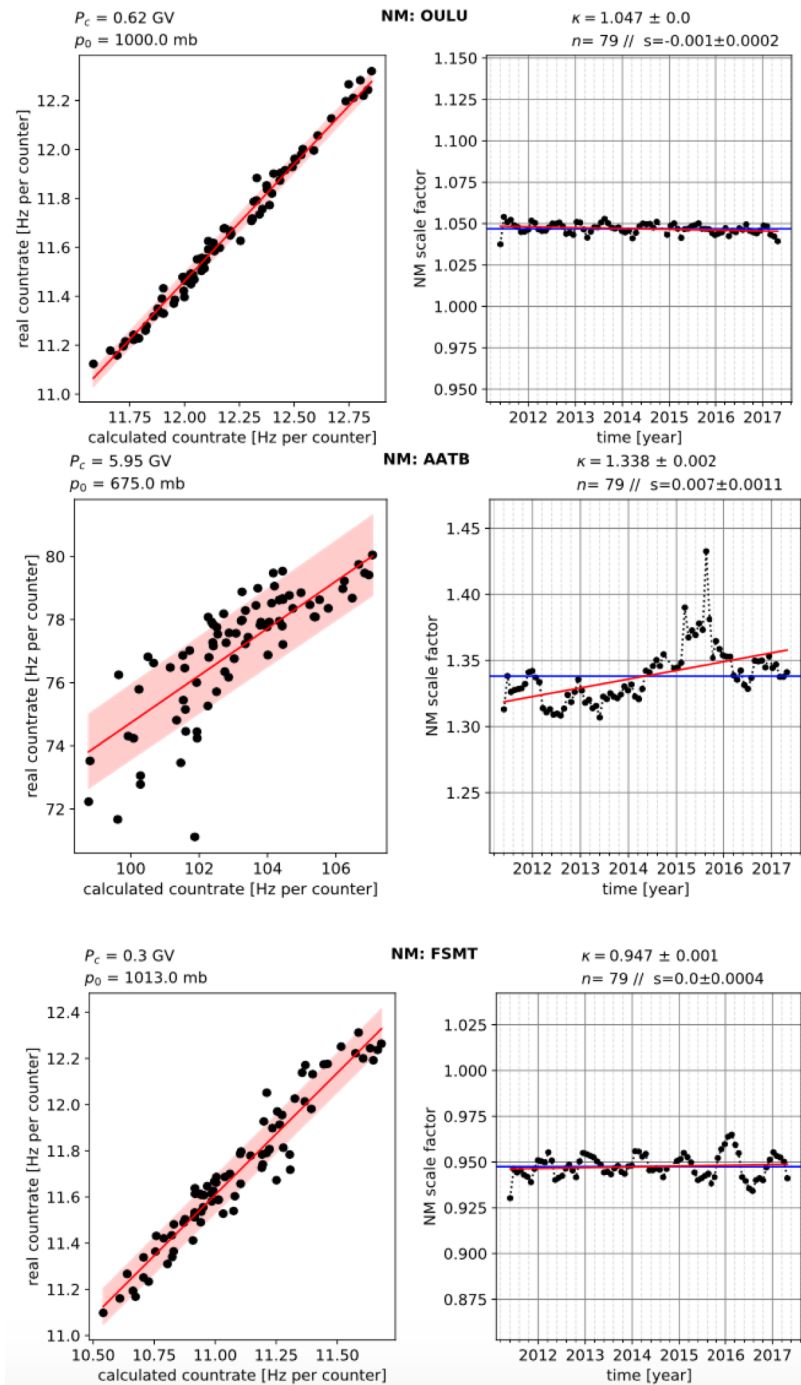
Neutron monitor count rate:

$$N(t, h) = \frac{1}{K} \sum_i \int_{P_c}^{\infty} J_i(P, t) \cdot Y_i(P, h) \cdot dP$$

Neutron monitor yield function verification

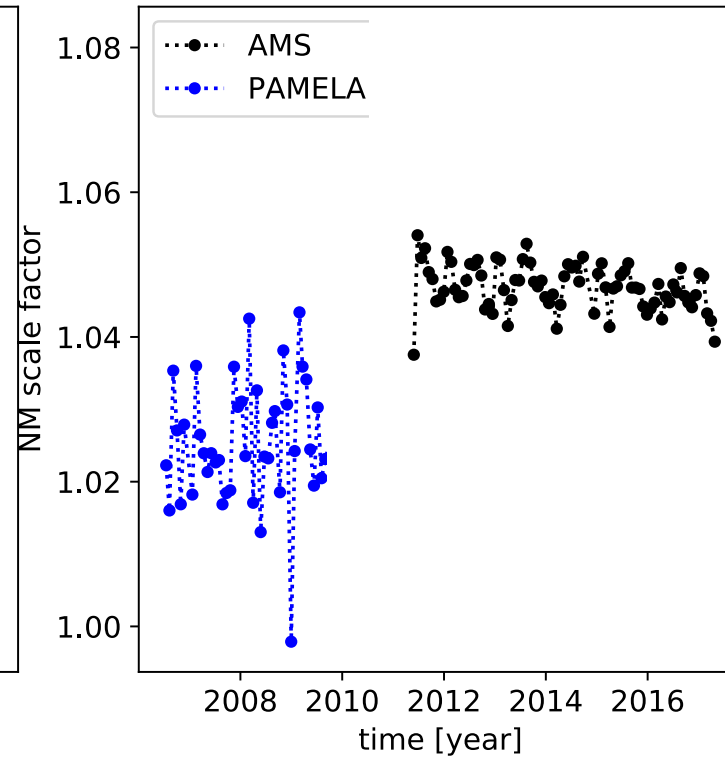
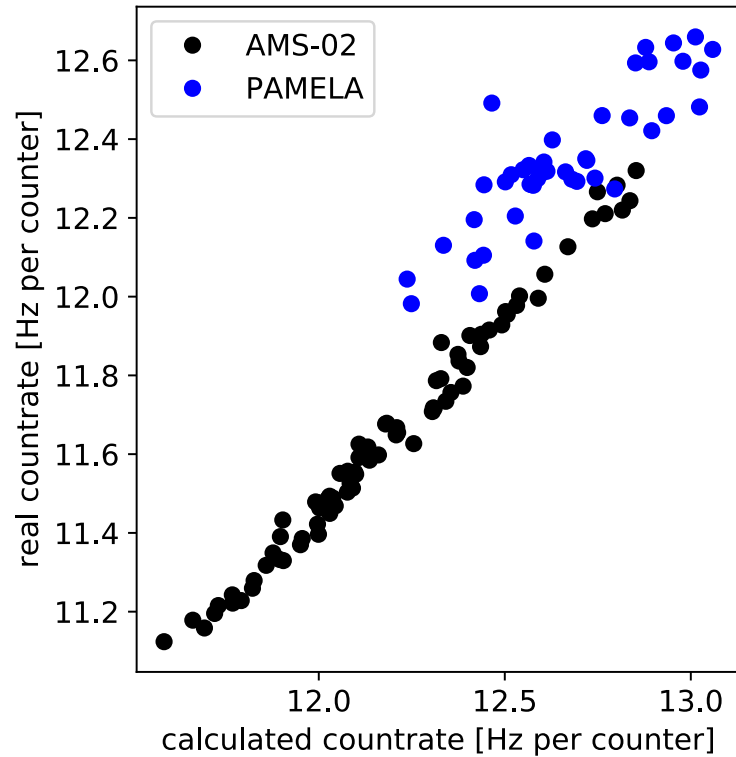


AMS-02 allowed to check the stability of neutron monitors and to compute the scale factors for NM operating in 2006—2017.



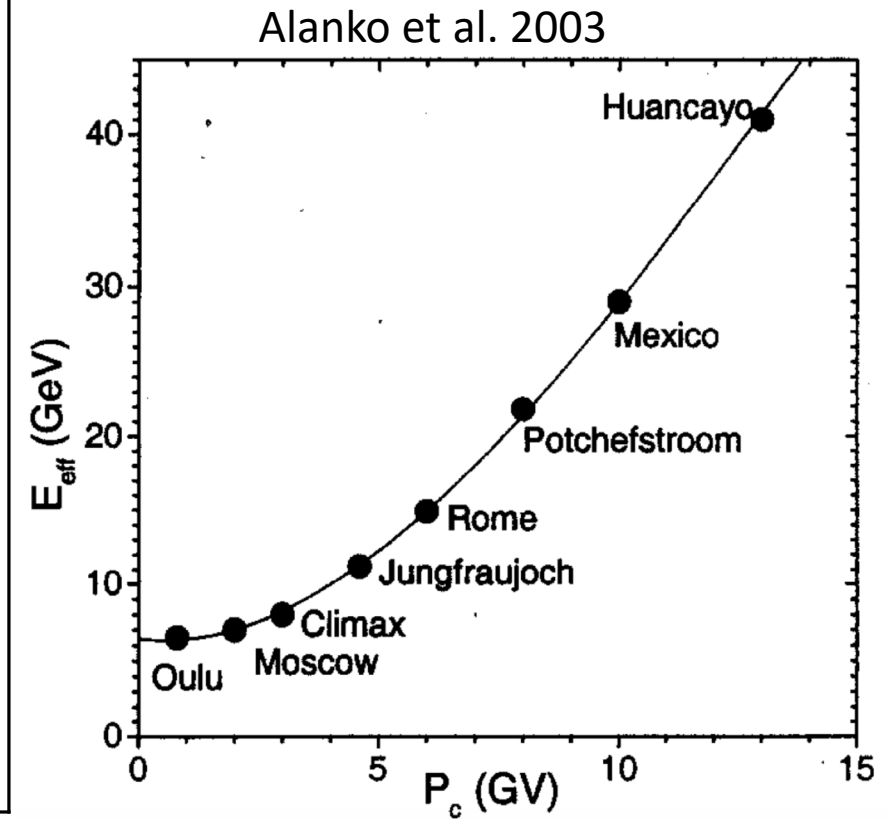
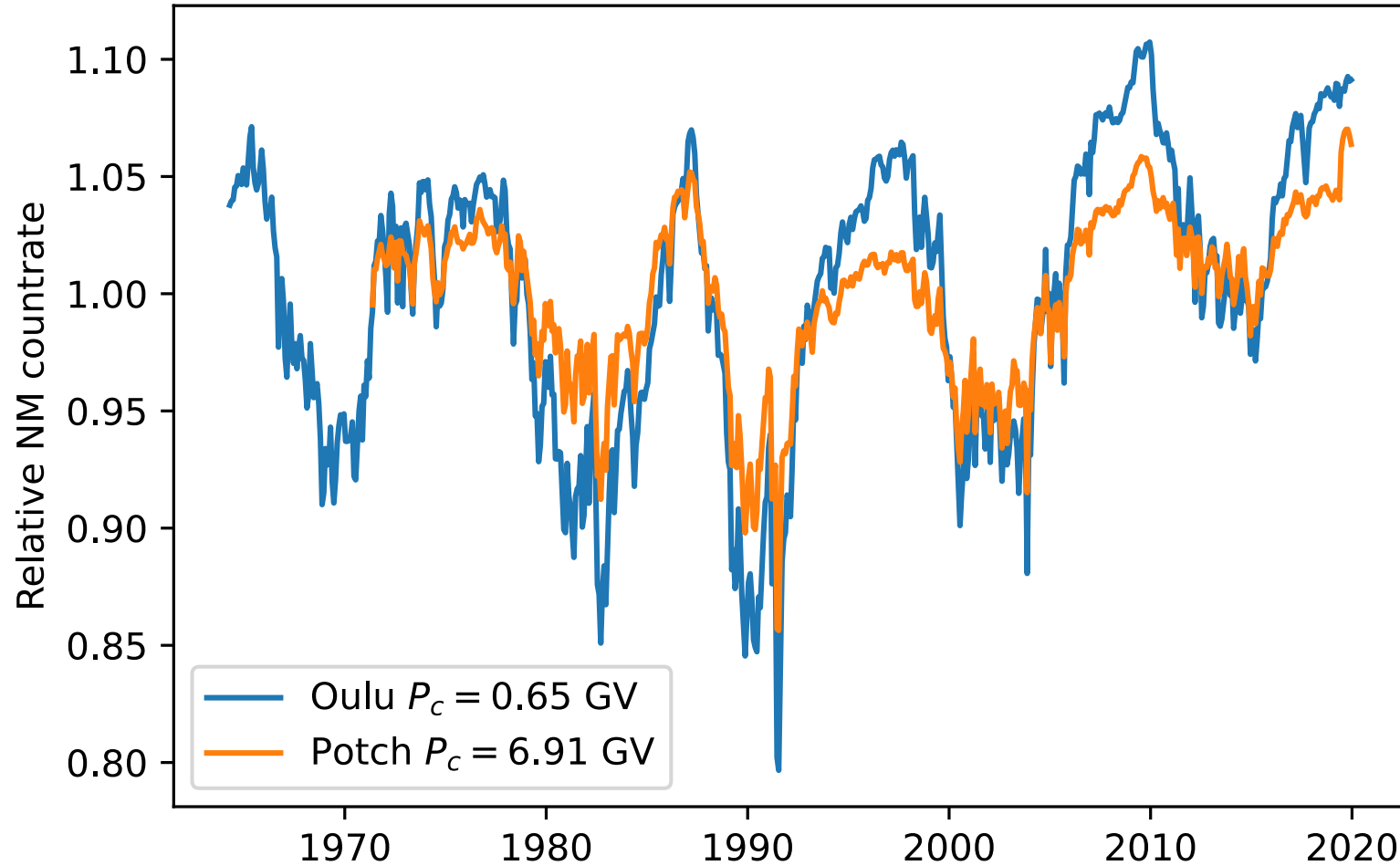
PAMELA vs AMS-02 calibration with NM

NM: OULU

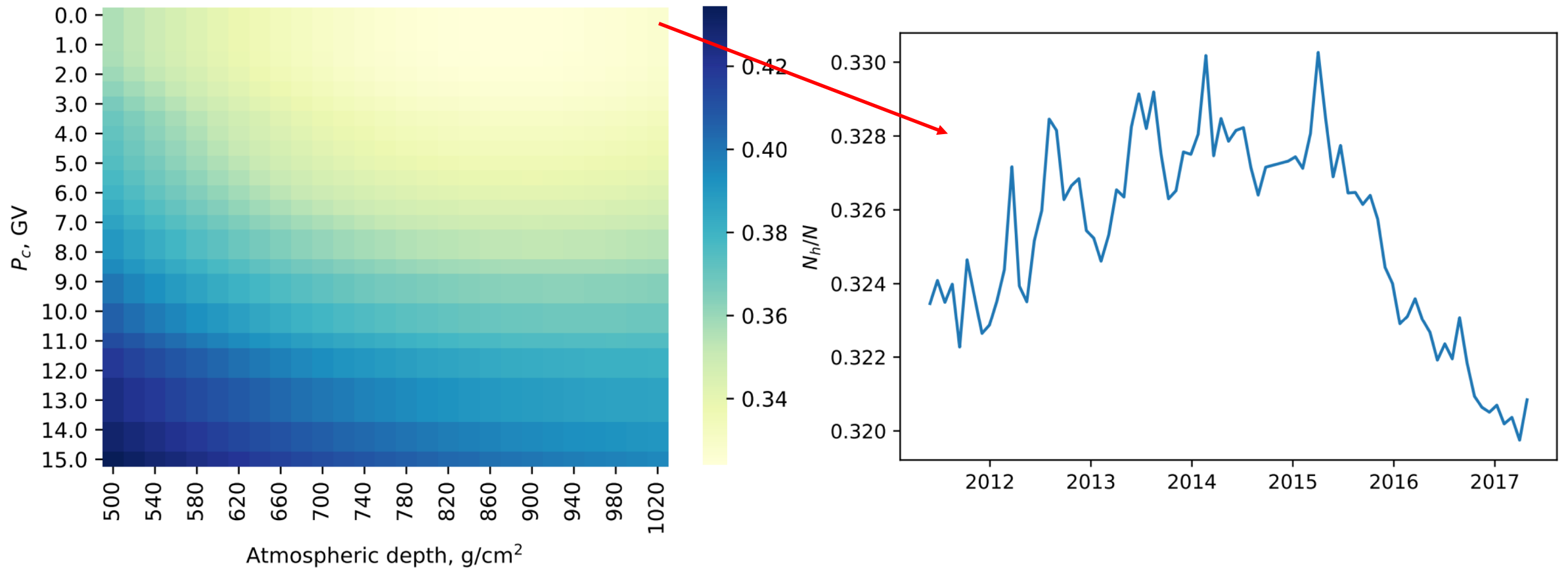


The systematic difference is visible (but not big!) as discussed yesterday. Again we are not able to say which experiment has better data.

NM cutoff rigidity dependence

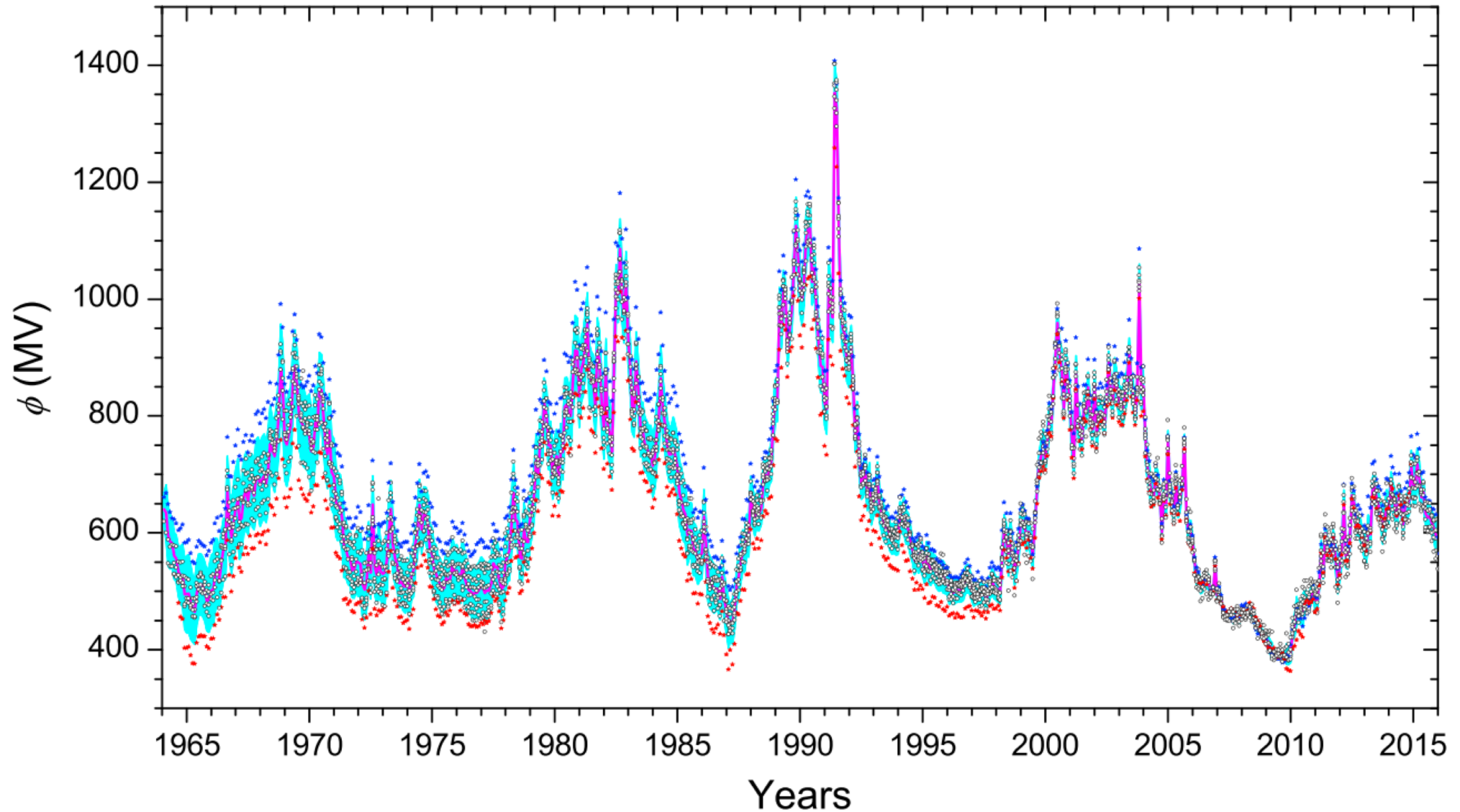


Heavy nuclei in NM response

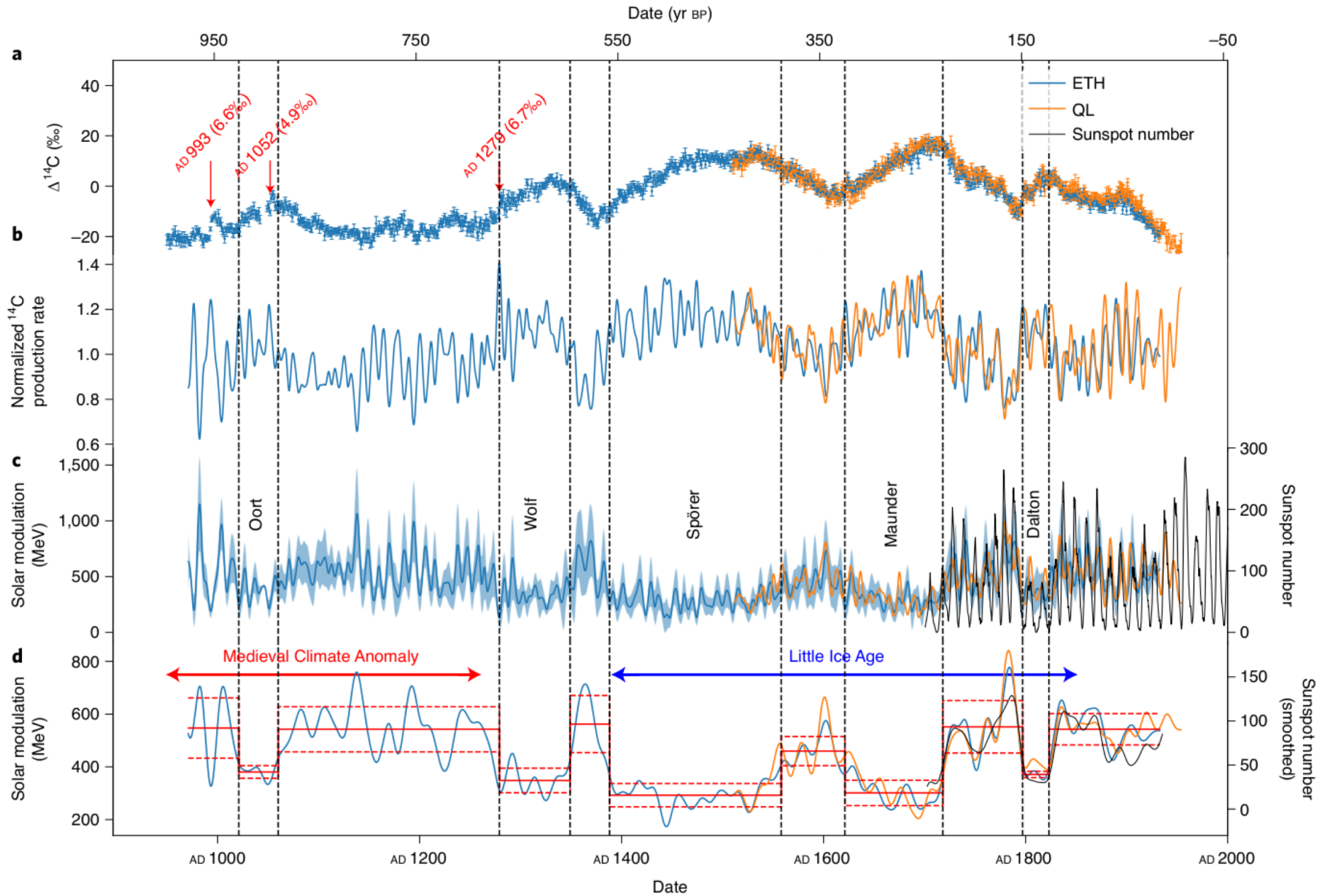


Force-field approximation I

$$J_i(T, \phi) = J_{\text{LIS}_i}(T + \Phi_i) \frac{T(T + 2T_r)}{(T + \Phi_i)(T + \Phi_i + 2T_r)}$$

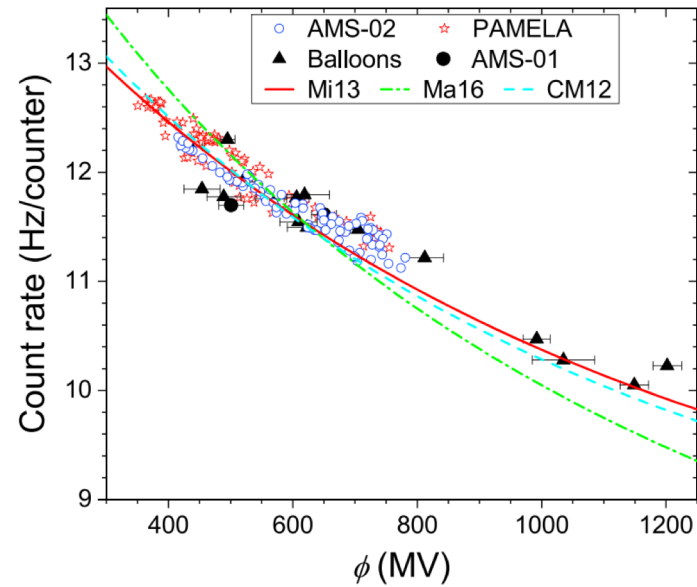


Force-field approximation II

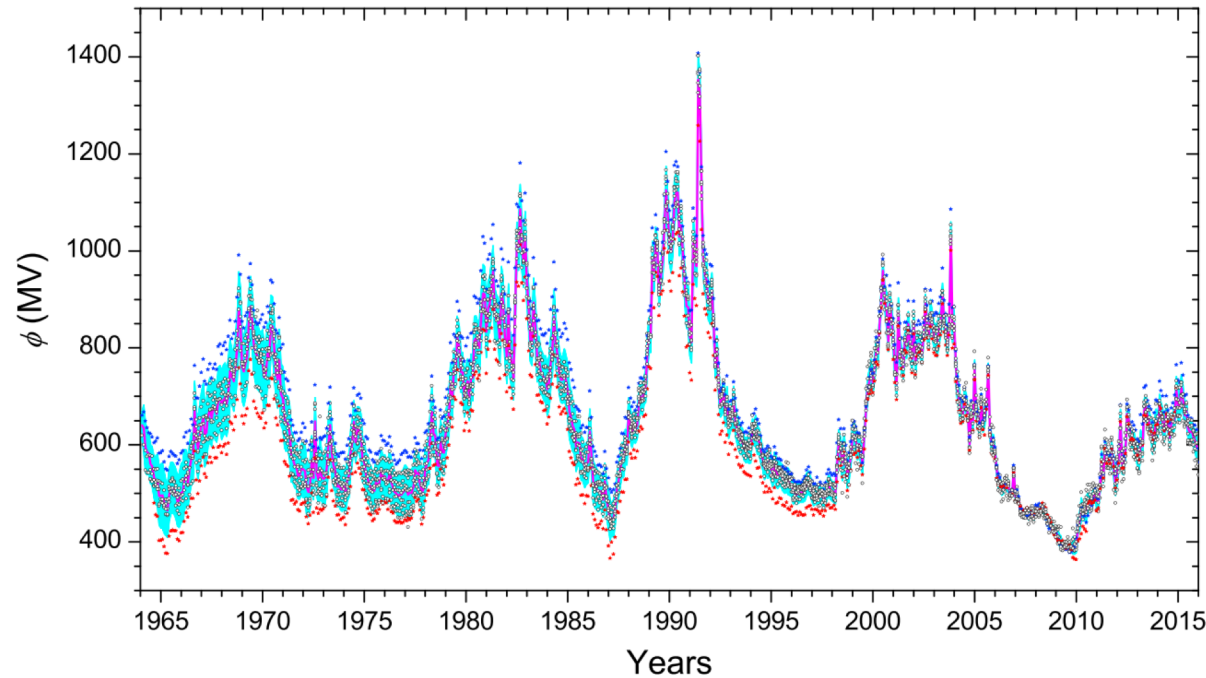


^{14}C
+
 ^{10}Be
 ^{36}Cl

Force-field approximation and NMs



Usoskin et al. JGR:SP 2017



Another reconstructions:
Ghelfi et al. ASR 2017,
Kobelev et al. BRAS 2021

Pros:

Simple, that makes it super useful for practical application and quantification of the solar modulation strength;

Cons:

- Too simple, it is not possible to get an understanding of different solar modulation processes;
- Exact value of solar modulation potential is depended on LIS (can be corrected).
- Erroneous in low energies.

Force-field modifications

Shen et al ApJ 2021

Corti et al. ApJ 2016

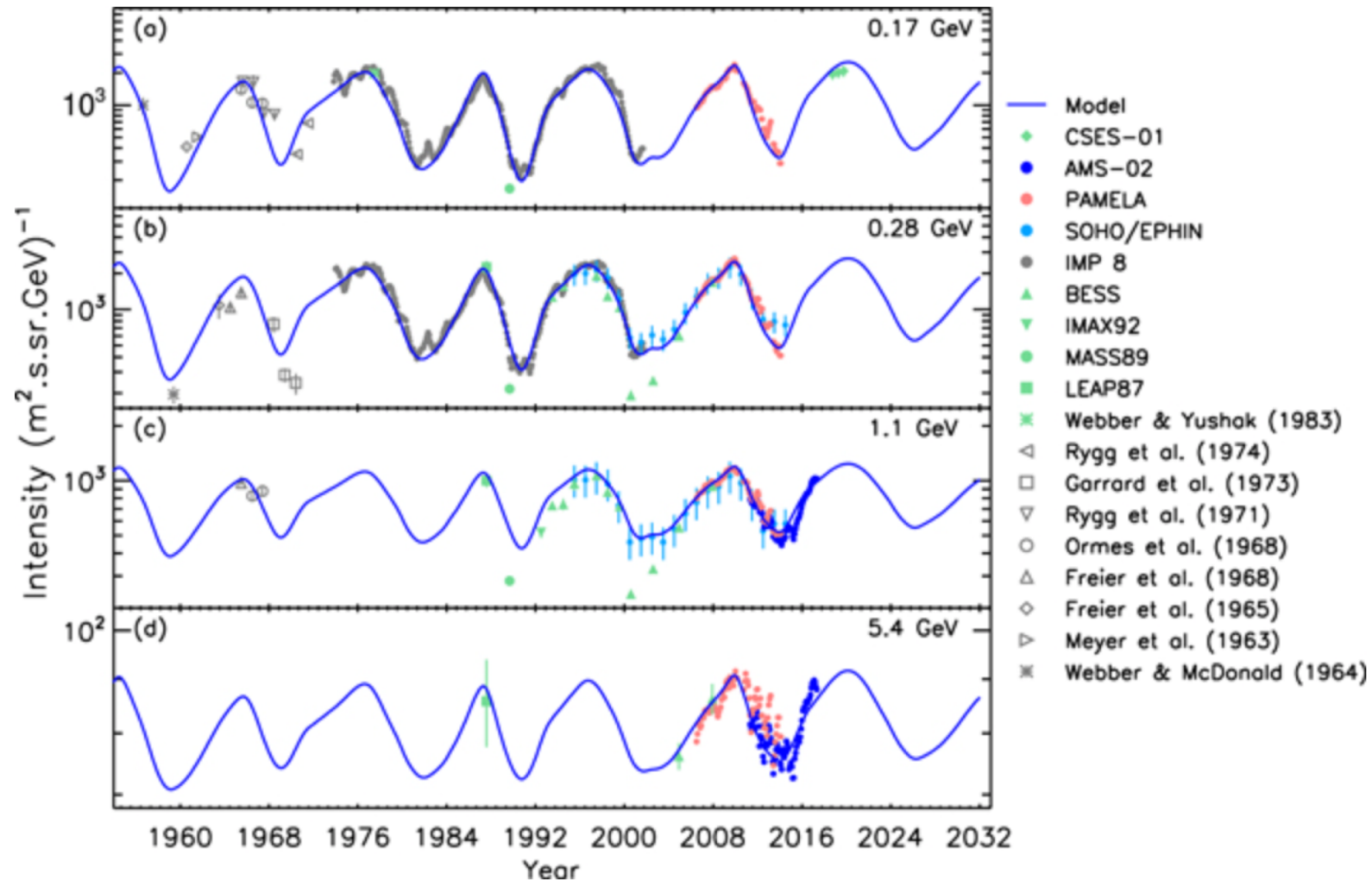
$$\phi(R) = \begin{cases} \phi_L, & R < R_L \\ f(R, \phi_L, \phi_H), & R_L \leq R \leq R_H \\ \phi_H, & R > R_H, \end{cases}$$

Gieseler et al. JGR:SP 2017

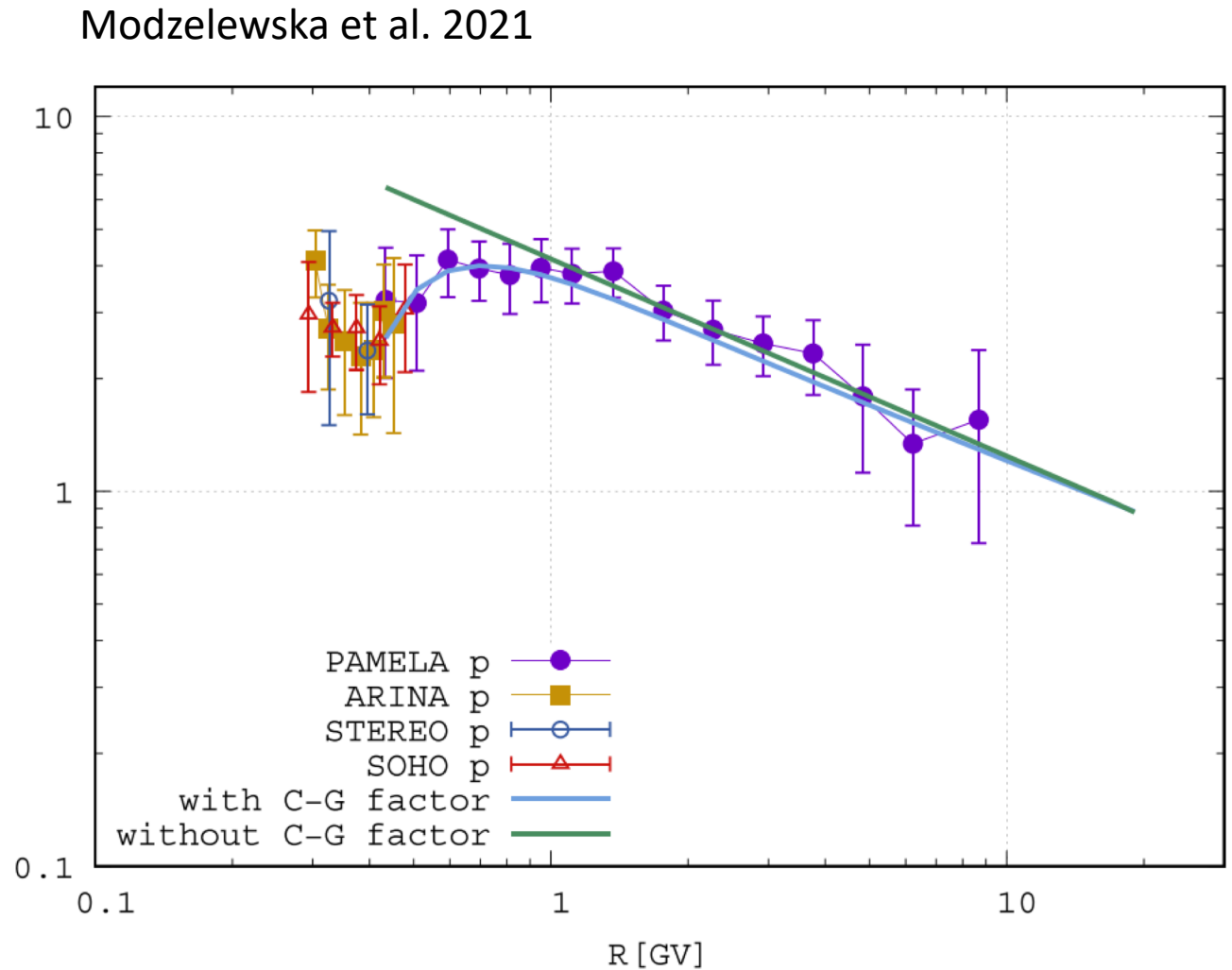
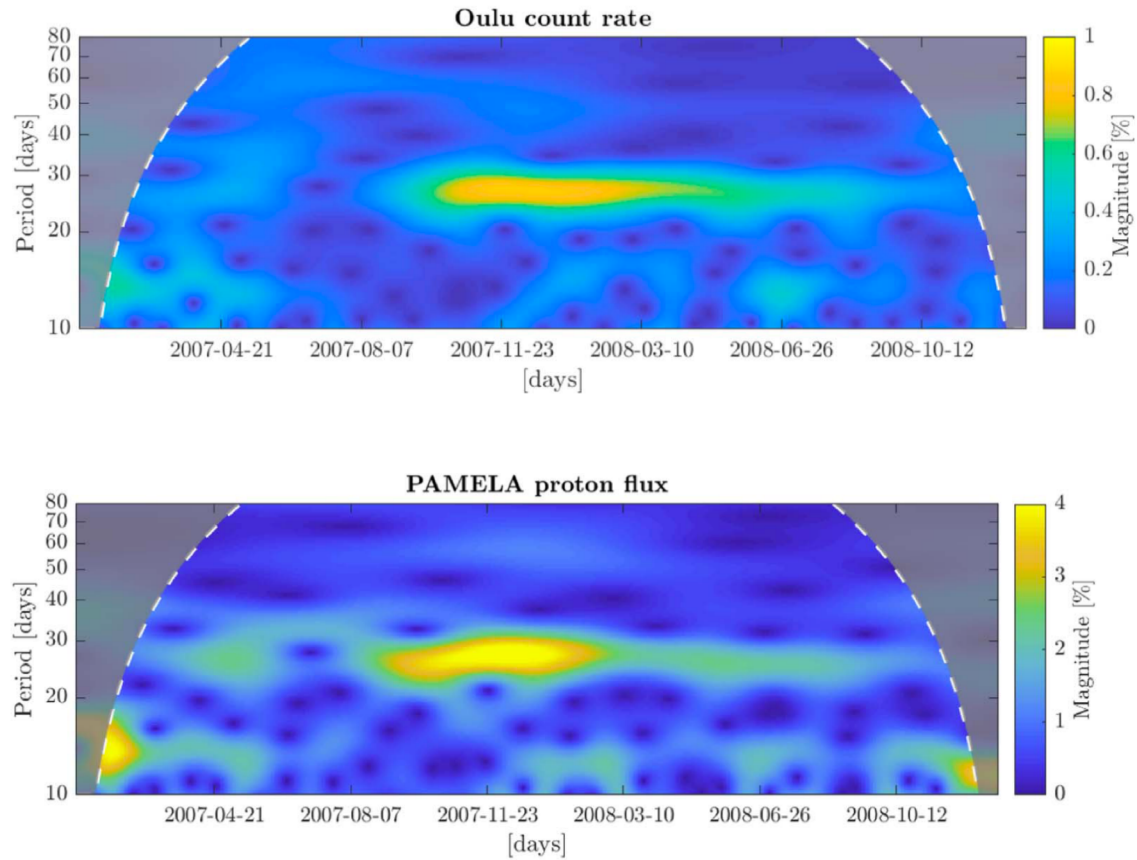
$$\phi(P) = \begin{cases} \frac{\phi_{\text{Uso11}} - \phi_{\text{pp}}}{P_{\text{Uso11}} - P_{\text{pp}}} \cdot (P - P_{\text{pp}}) + \phi_{\text{pp}} & \text{if } P < P_{\text{Uso11}} \\ \phi_{\text{Uso11}} & \text{if } P \geq P_{\text{Uso11}} \end{cases}$$

Shen et al ApJ 2021

$$\phi = \phi_0 \beta^{-1} \left(\frac{E}{E_b} \right)^{\phi_1} \left[1 + \left(\frac{E}{E_{b1}} \right)^{b_1} \right]^{b_2}$$



27-day variations of GCR flux



Conclusions

- Neutron monitors are still very important for study of the long-term solar modulation and SEP physics;
- PAMELA and AMS-02 gave the opportunity to calibrate NM and check their stability;
- Force-field model is of course can not be used for detailed study of detailed “laboratory conditions” but only for measuring the average temperature.