Neutron monitors as a traditional tool to study cosmic ray variability

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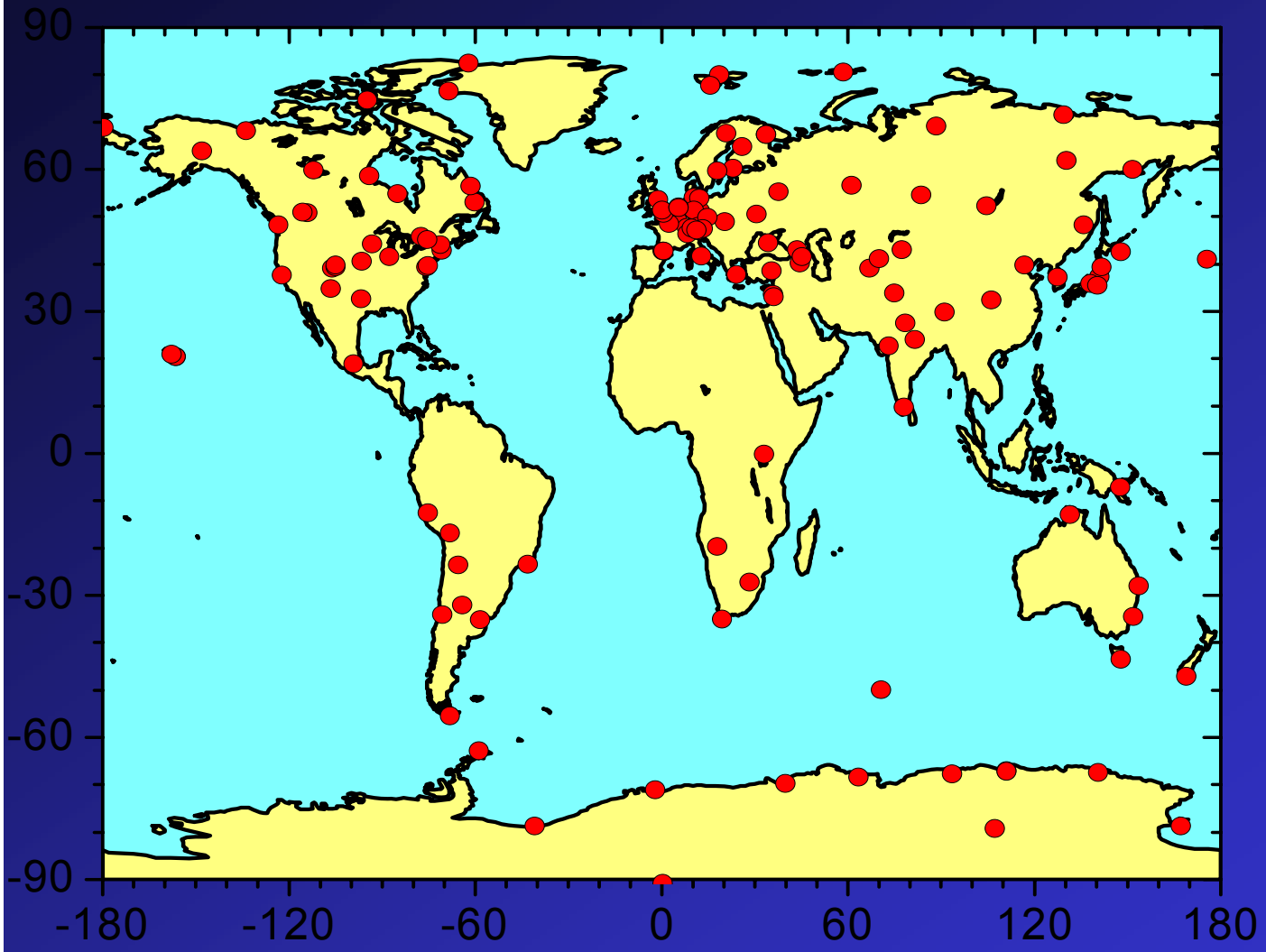
What is a NM?

NM network



In operation since 1951 (IGY), in full extend since 1960's (NM64).

The NM network:
overall ~130 stations;
currently ~50;
30+ long-term running;
from poles to the equator

NM network

- Advantages:
  - » Standard device;
  - » 7-d, 24-h routine monitoring of cosmic rays; online since 2000;
  - » Stable operation (no notable aging or degradation) → homogenous series;
  - » Response is known;
  - » Global distribution;
  - » Low cost (distributed among different countries/institutions), easy maintenance;
- Disadvantages
  - » Energy integrated device – cannot measure the energy spectrum directly.

Can NM be substituted by space-borne missions?

- Large CR-dedicated missions (PAMELA, AMS-02):
  - » study of individual event (not count rates), off-line analysis;
  - » Low, inclined orbit → difficult to reconstruct spectra in the LE part;
  - » Only a fraction of time can be used to study SEP events.
  - » limited life-time;
  - → primary interest in HE, ”exoctic” CR (anti-matter, dark matter, composition), HE astrophysics;

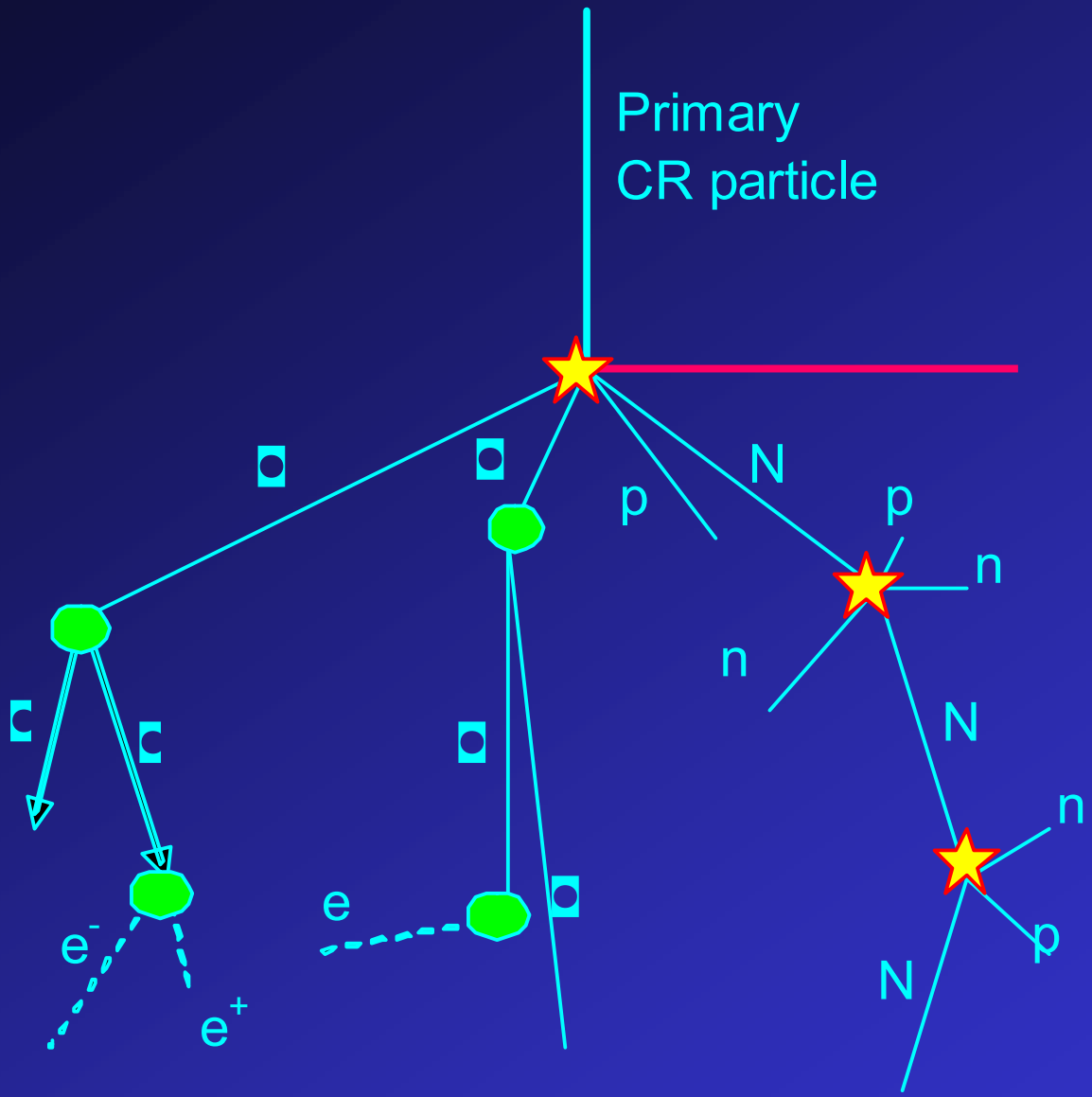
- Low energy space-borne detectors (e.g., SOHO, ACE, GOES):
  - » low energy, cannot give an estimate for the atmospheric penetration;
  - → primary interest in solar transients, interplanetary medium, space weather;

Can NM be substituted by space-borne missions?

- NM network:
  - » continuous monitoring, real time analysis;
  - » short-term forecasts/nowcasts and warnings;
  - » practical use (aircraft dosimetry, background for radiation environment monitoring);

  → primary interest in heliospheric physics, strong/severe solar transients, terrestrial effects, space climate.

Atmosphere as a detector

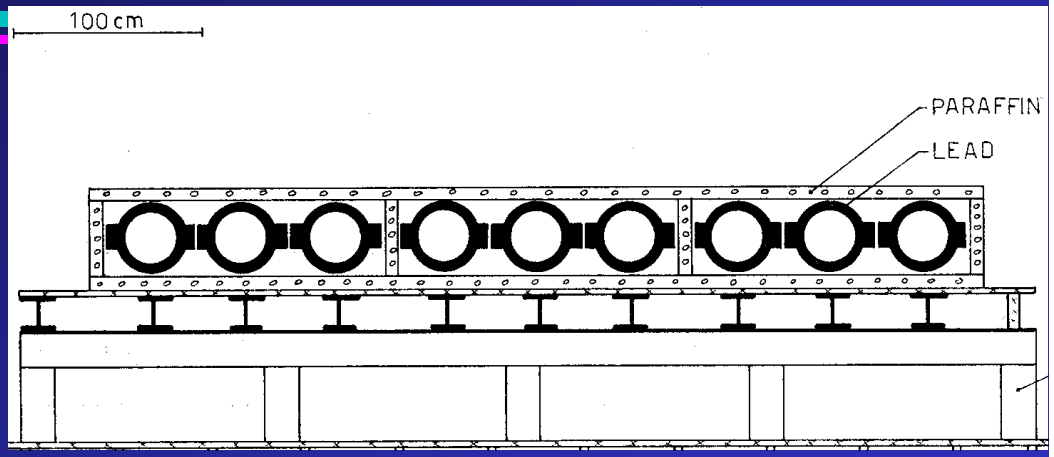


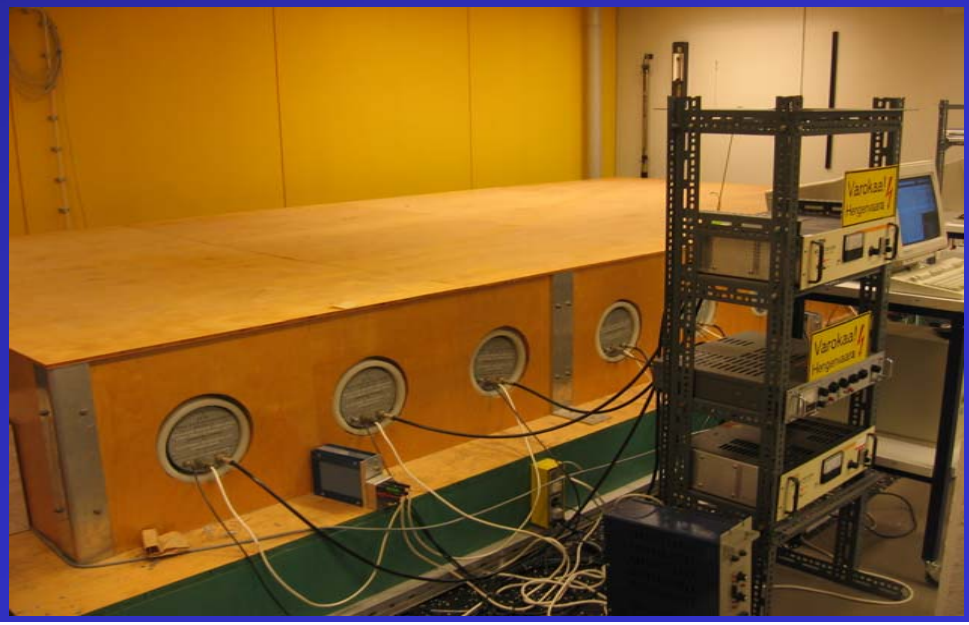
Neutron monitor

- Reflector (paraffin / polyethylene) absorbs slow n's but transparent for higher energy n and p.
- Producer (lead) multiplies neutrons (~10 slow n's per one fast).
- Moderator (paraffin) thermalizes neutrons.
- Proportional counter (3 kV) filled with BF_3

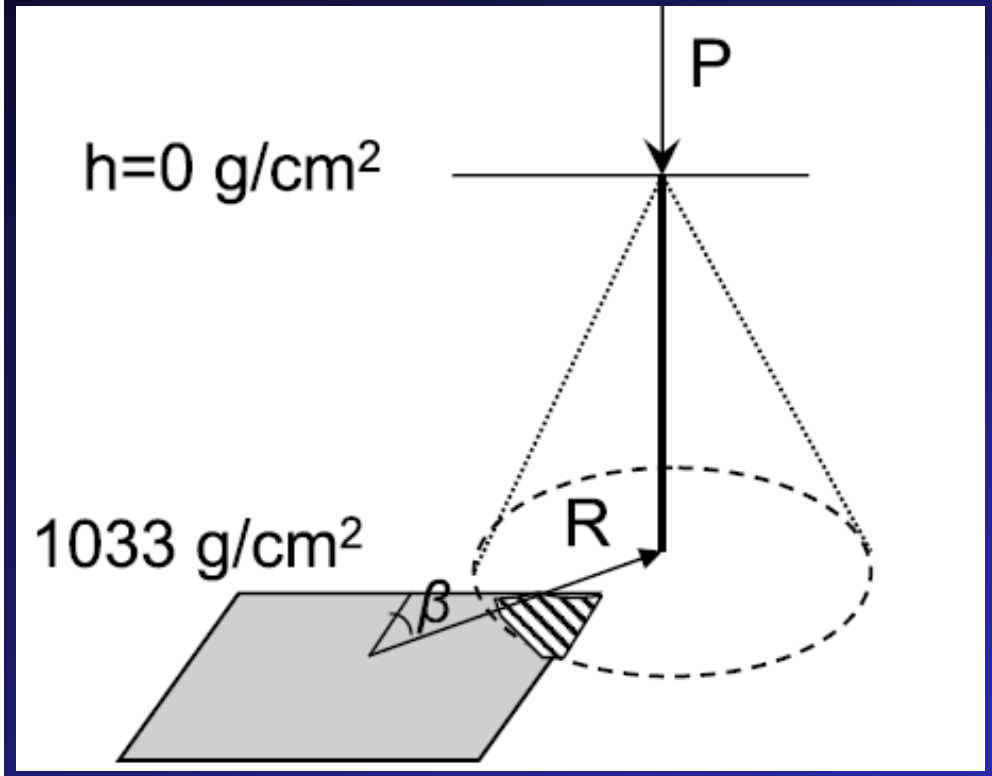
$$^{10}B + n \rightarrow {}^{7}Li + \alpha$$

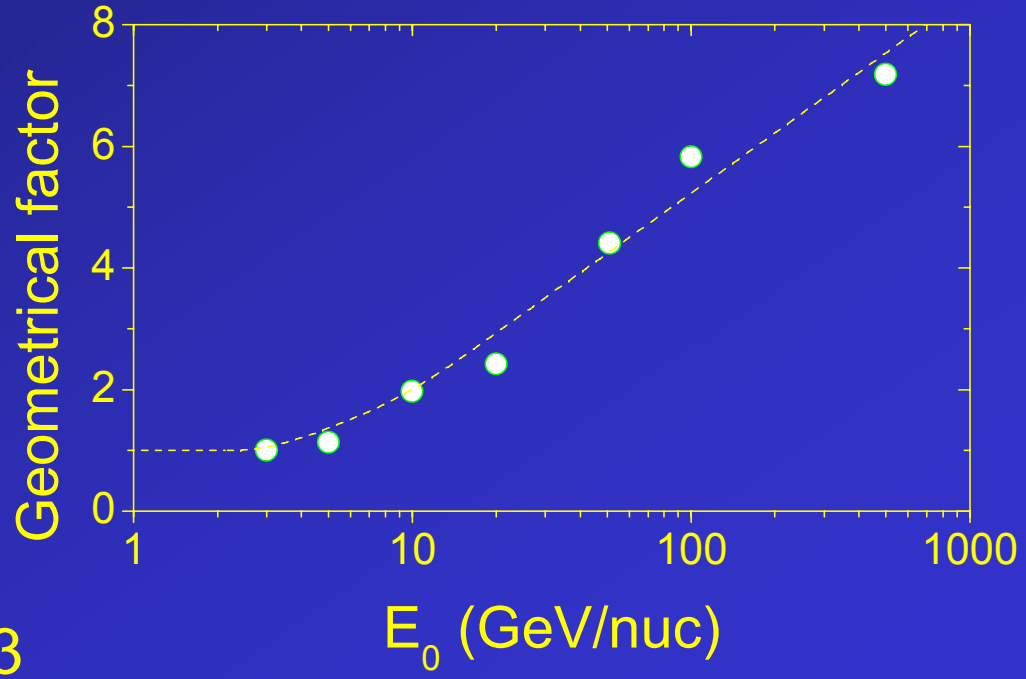
- Fast helium and *Li* strip electrons from neutral atoms in the tube, leading to a charge avalanche in the tube.





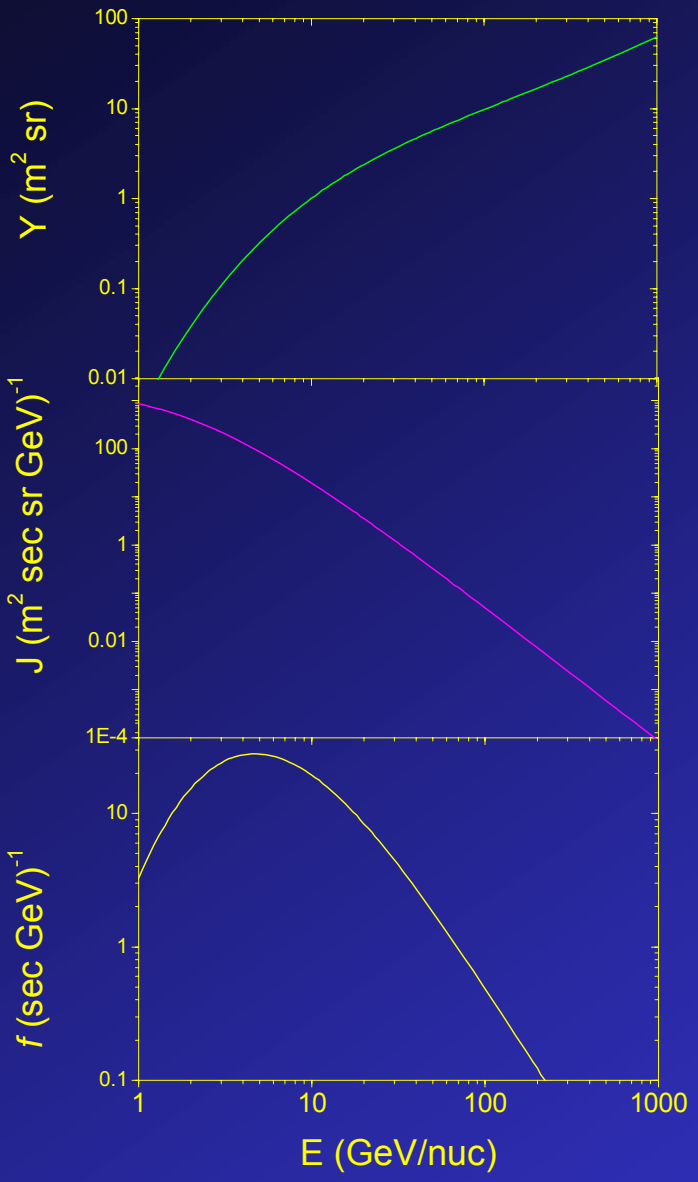
Geometrical factor





Mishev, Usoskin, Kovaltsov, 2013

Yield function

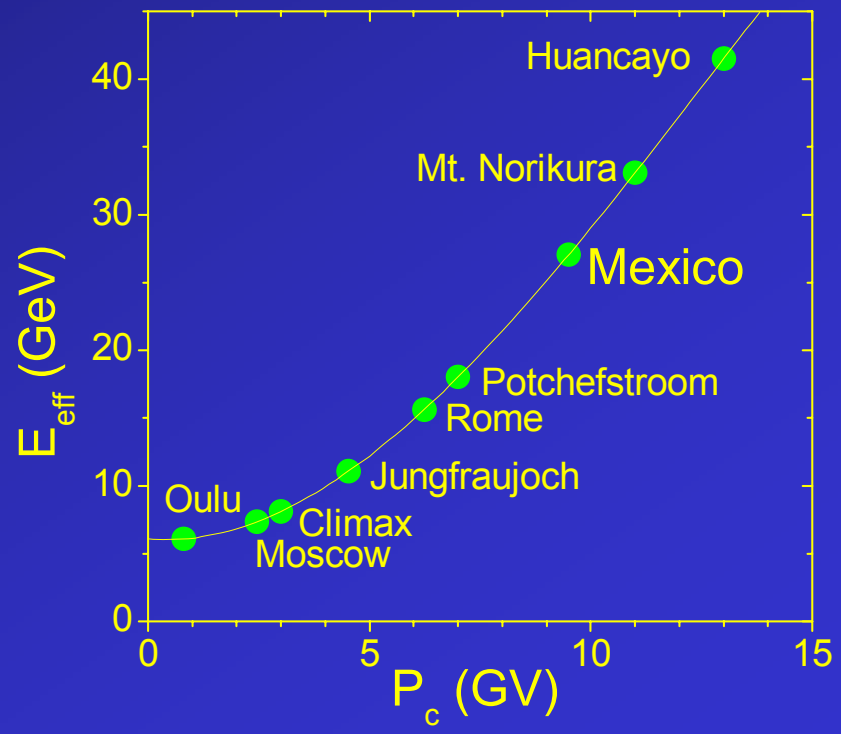


$$N(h,t) = \sum \int_{Pc}^{\infty} Y(E,h) \times J(E,t) \times dE$$

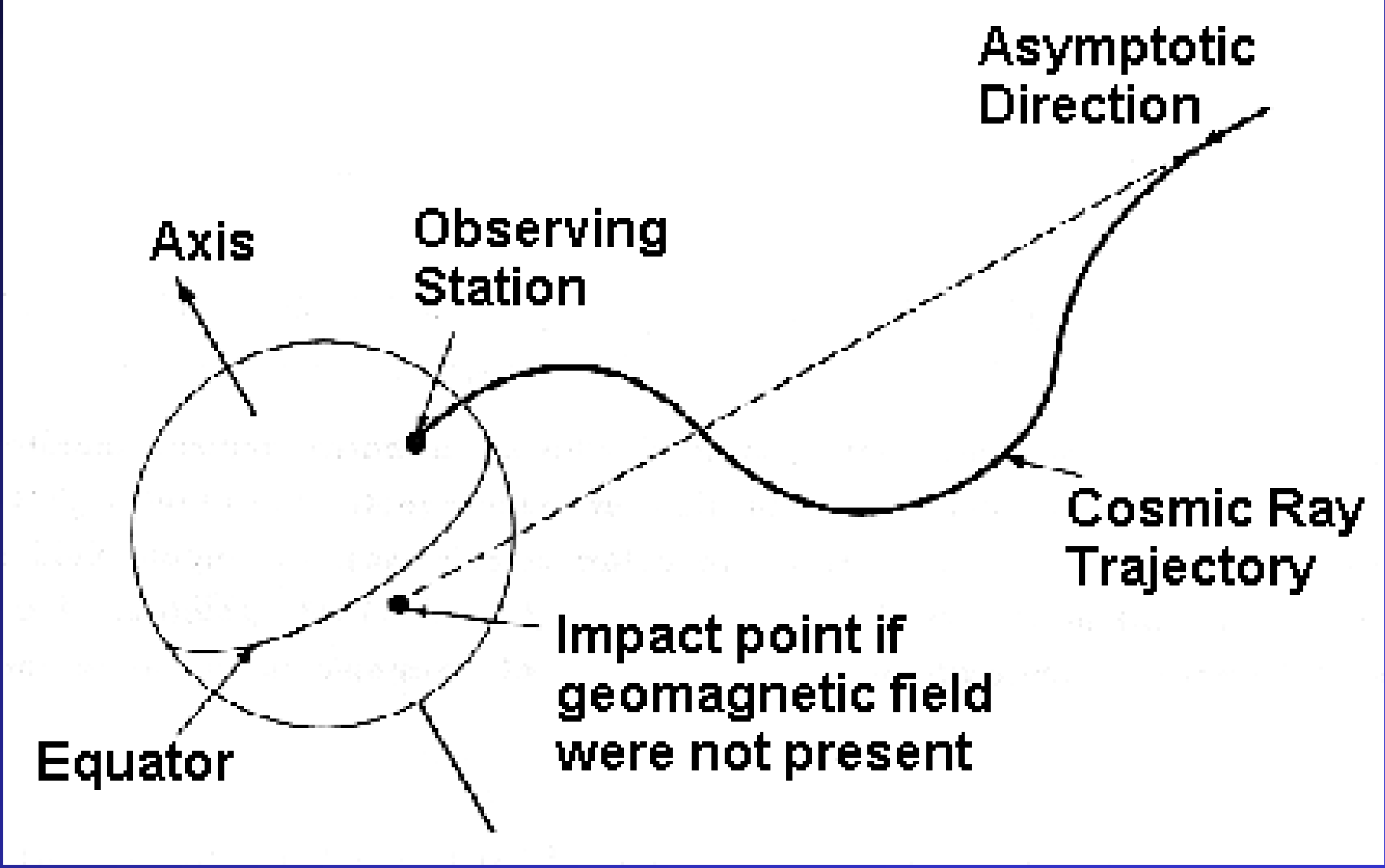
Sea-level polar NM:

E_{eff}=6 GeV

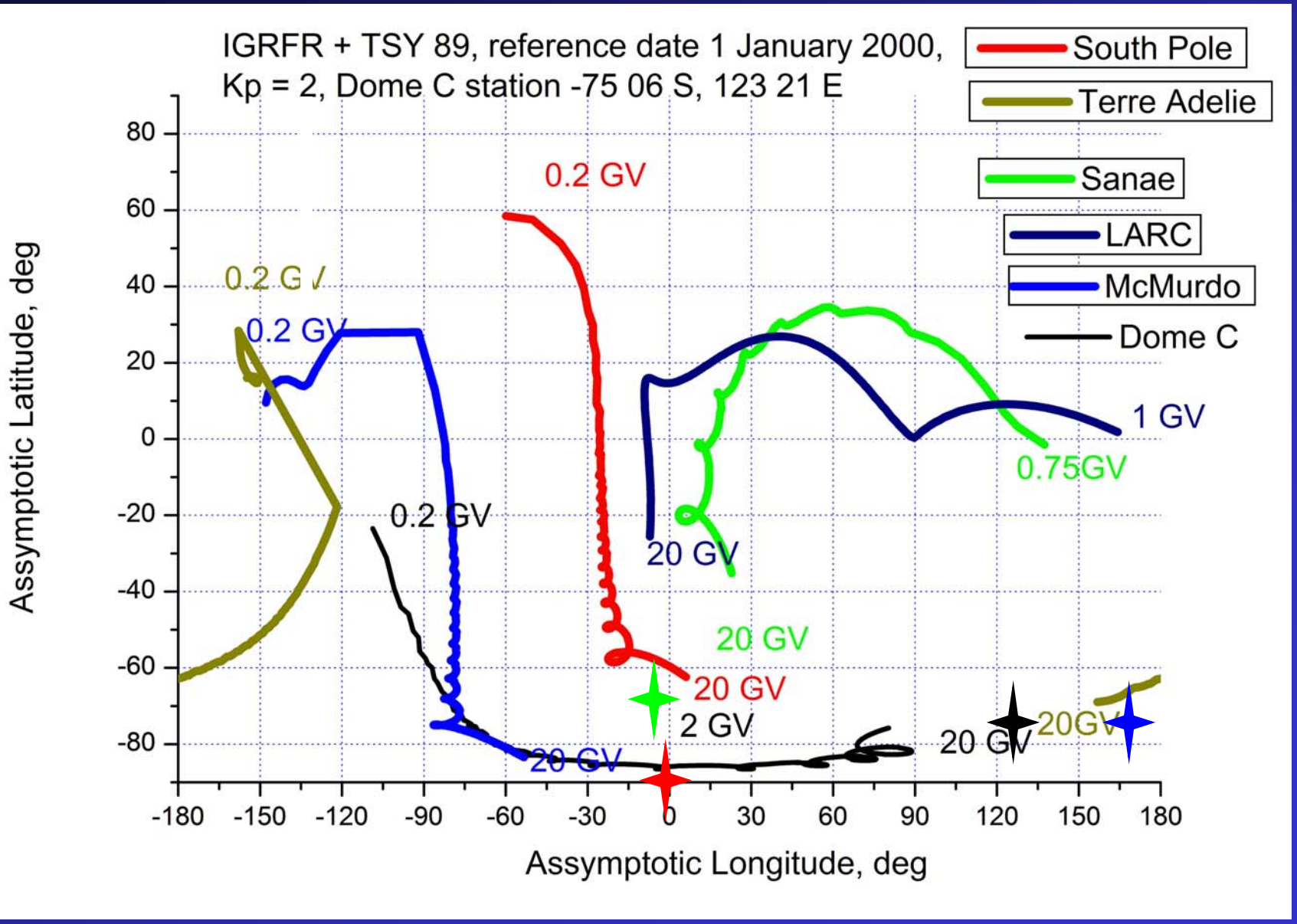
E_{med}=14 GeV



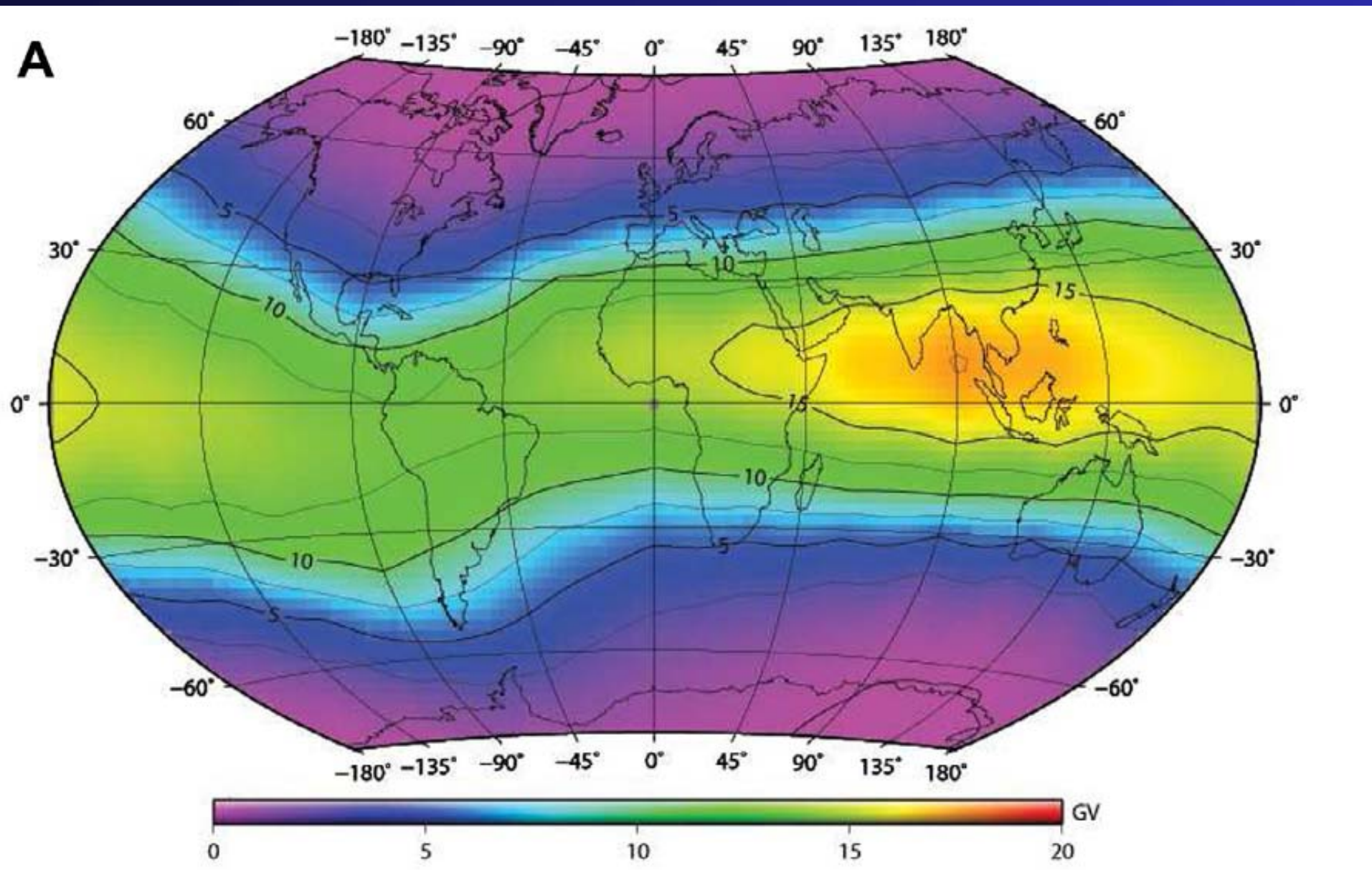
Asymptotic direction



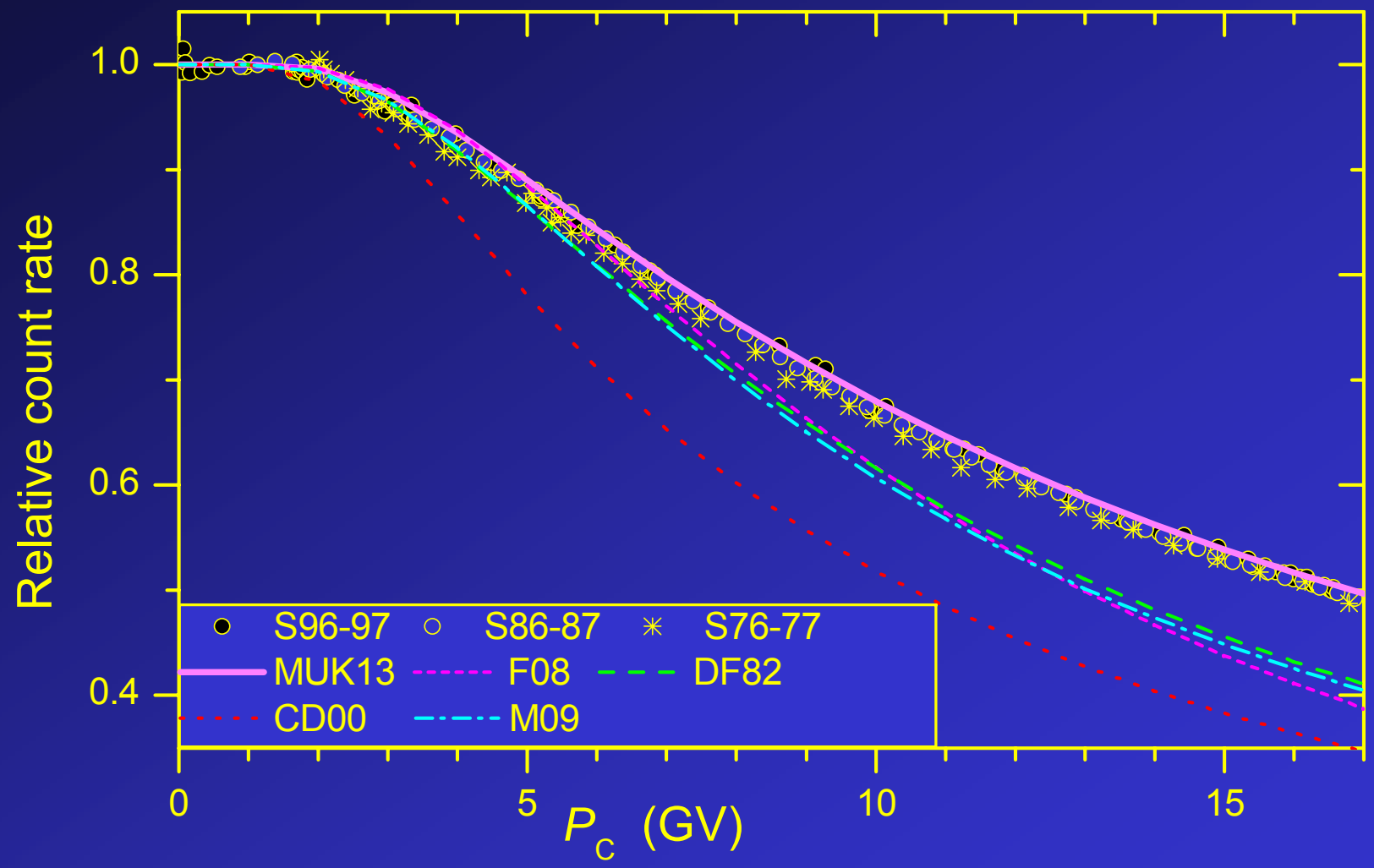
Asymptotic directions for 2000



Geomagnetic cutoff rigidity

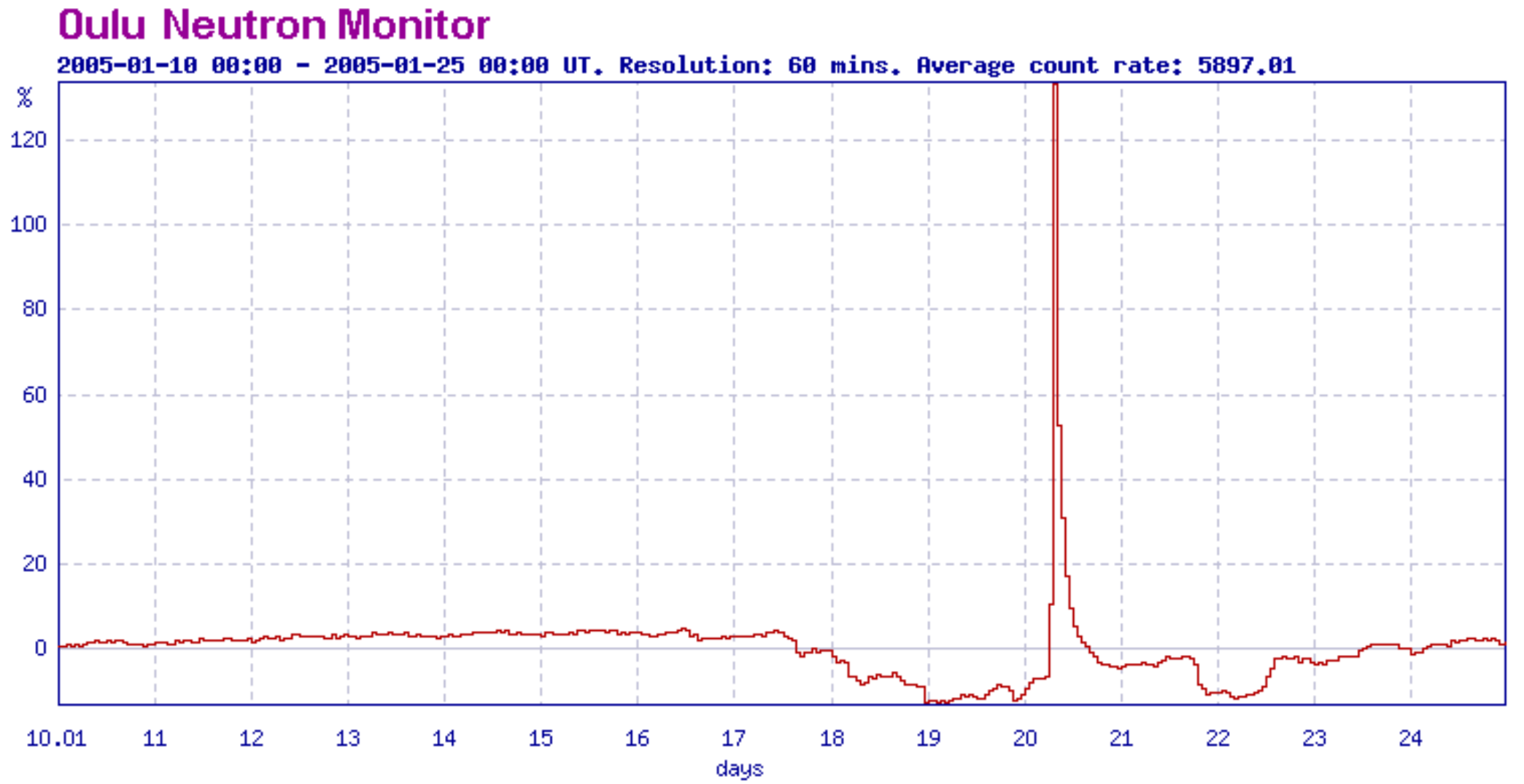


NM Latitude survey

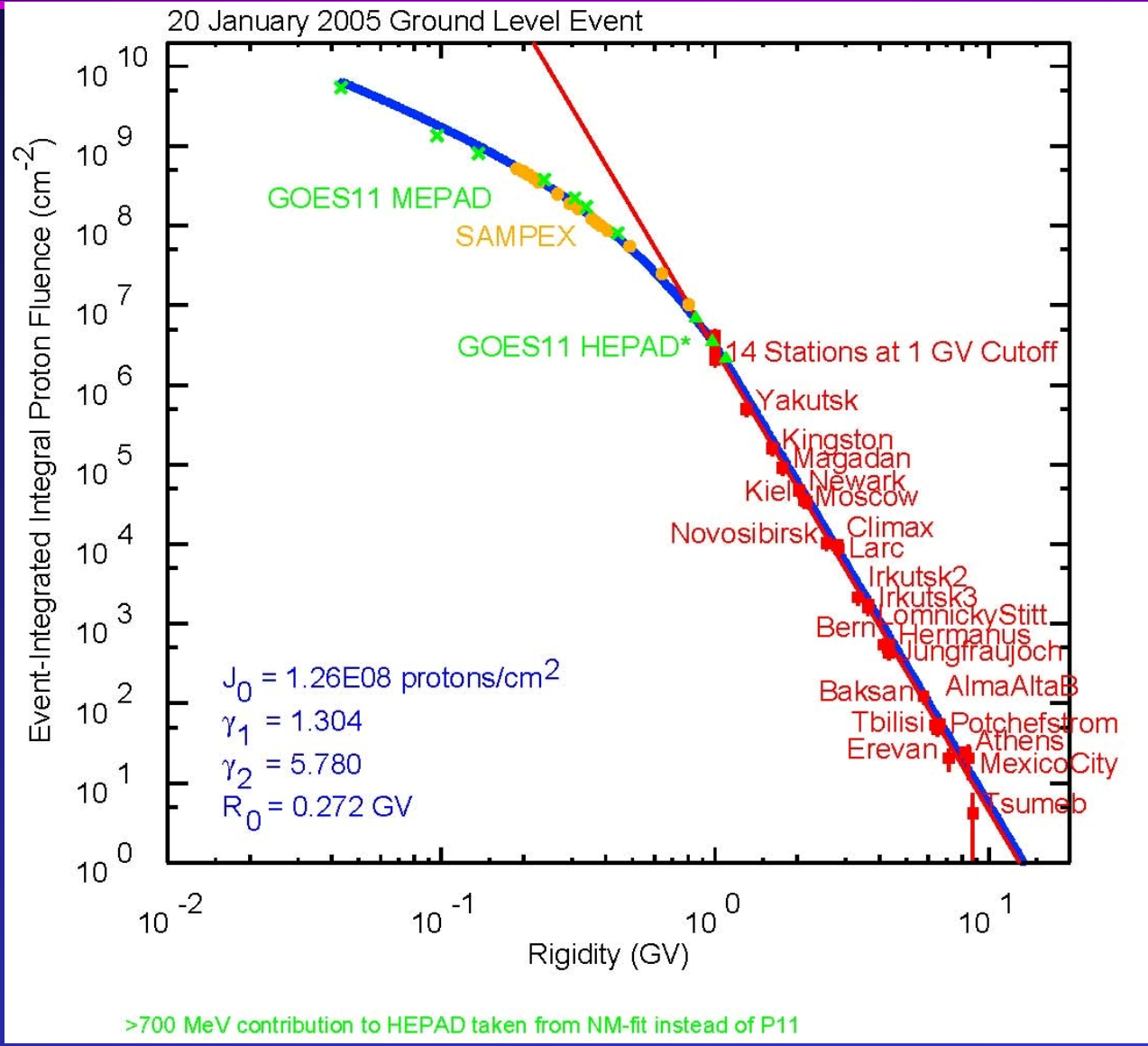


Ground level enhancements (GLE)

GLE 69, 20-01-2005

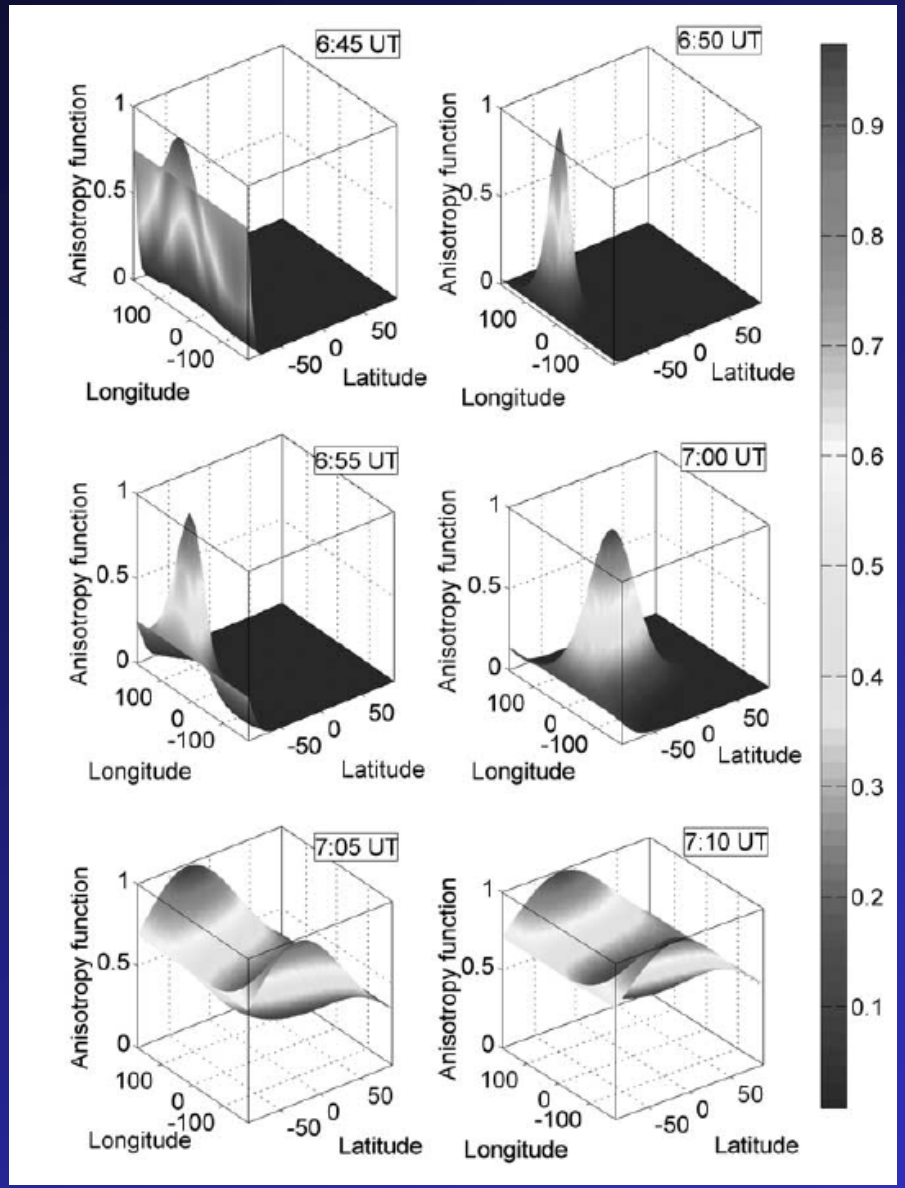


SEP spectrum

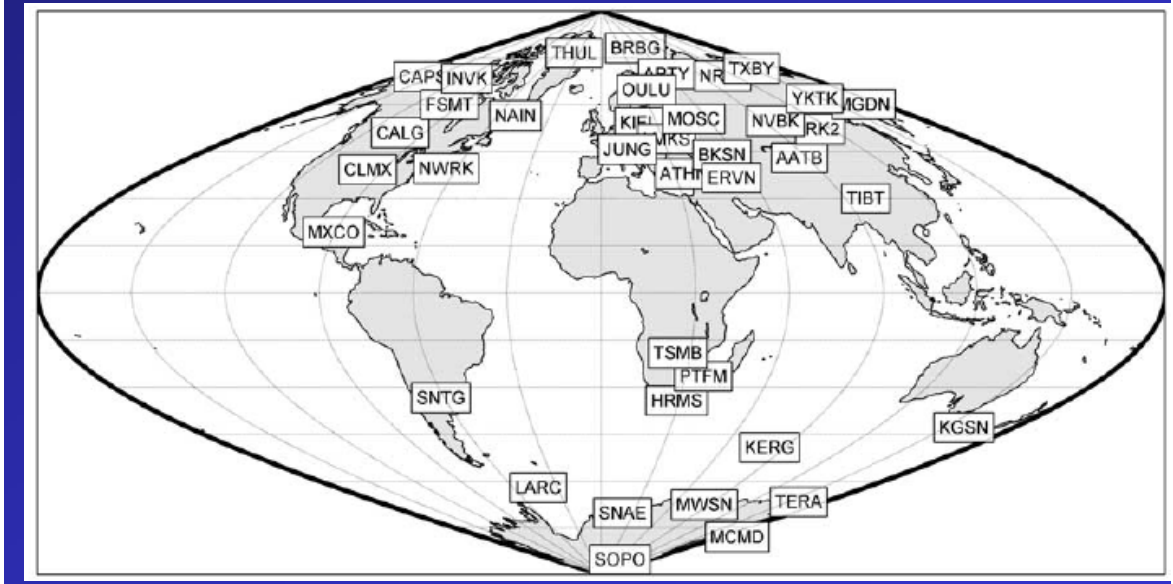


Fitting of the Band-shaped energy spectrum for 20-Jan-2005 (A. Tylka)

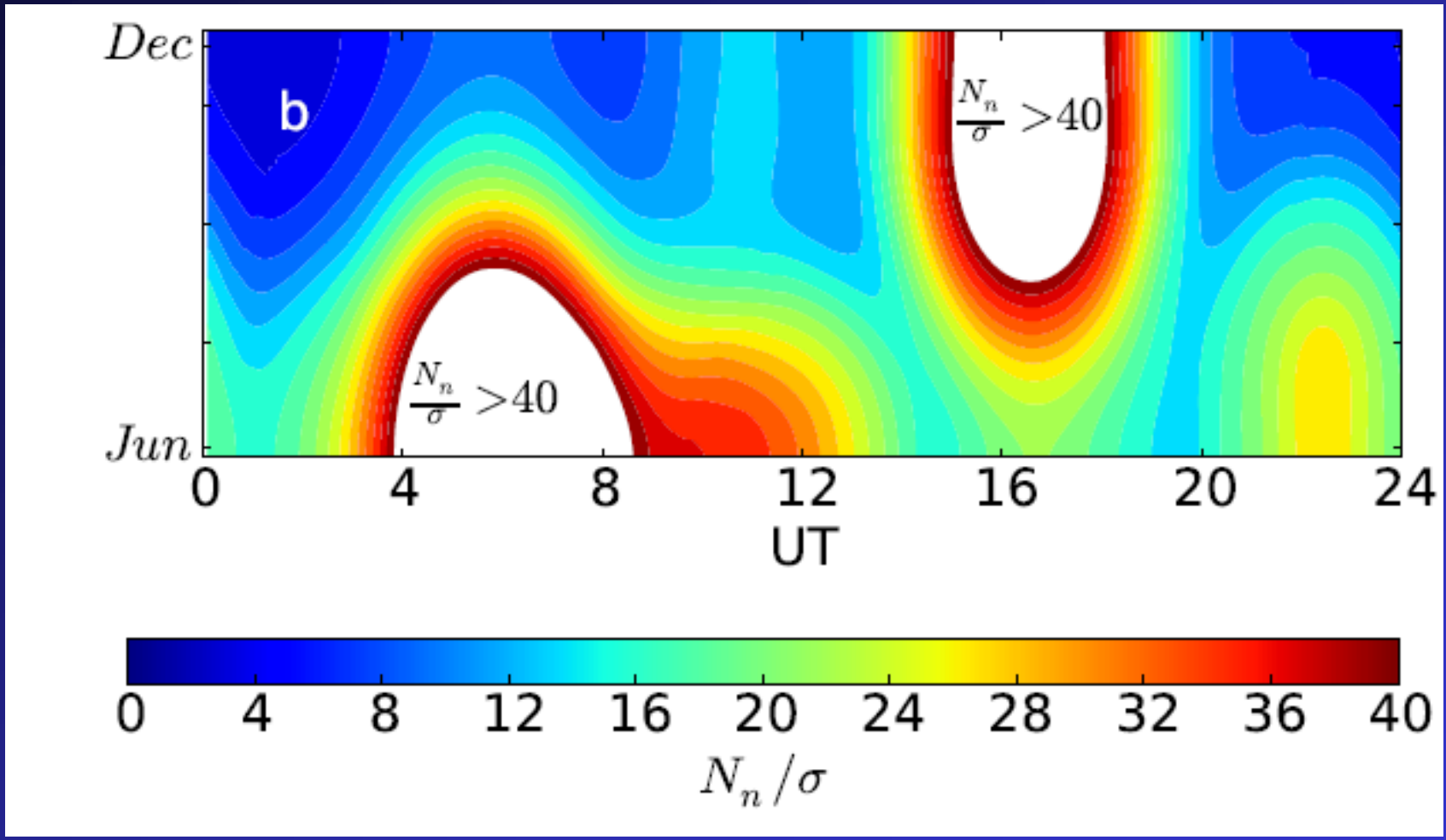
GLE study



anisotropy function of SEP during the GLE of 20-Jan-2005 (Plainaki et al, JGR, 2007)

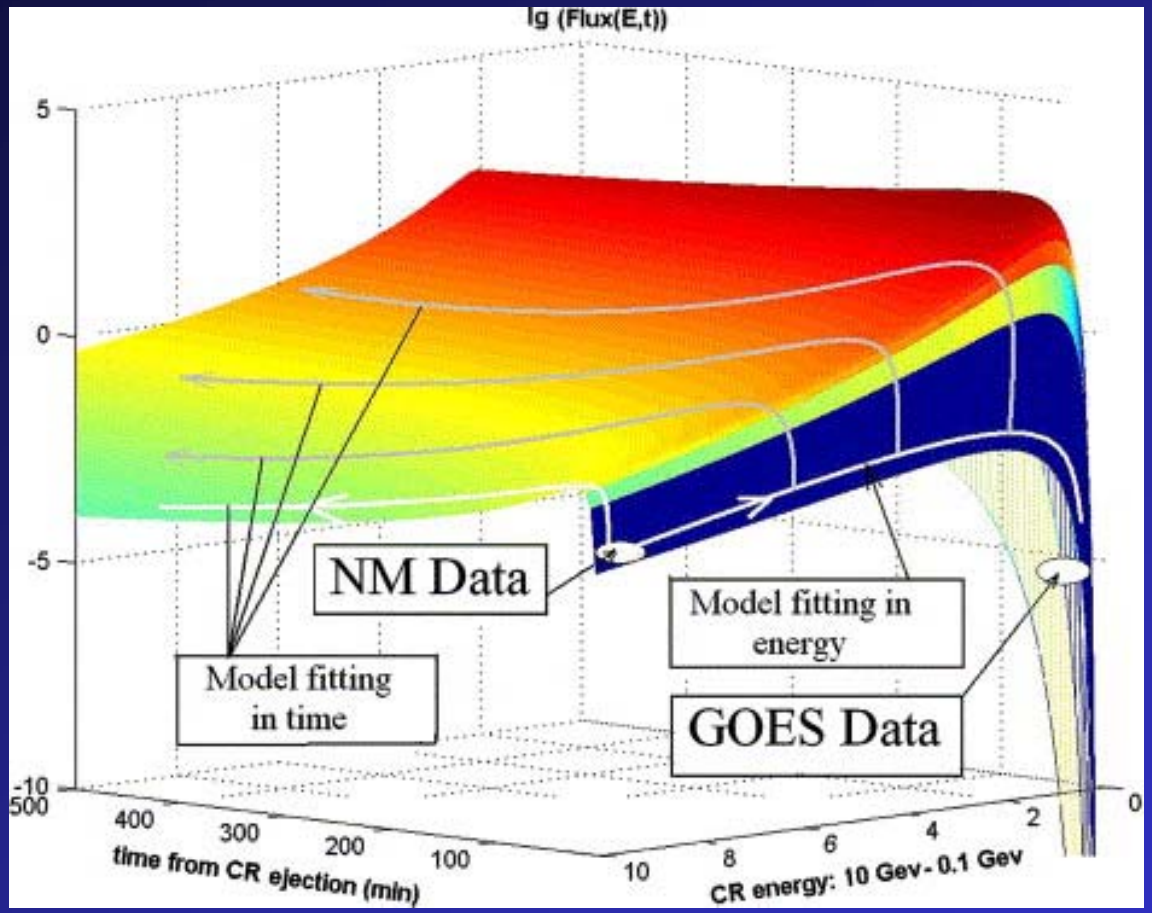


NM network and solar neutrons



Sensitivity of NM network to solar neutrons in σ for the event of May 1990

Space weather forecasts

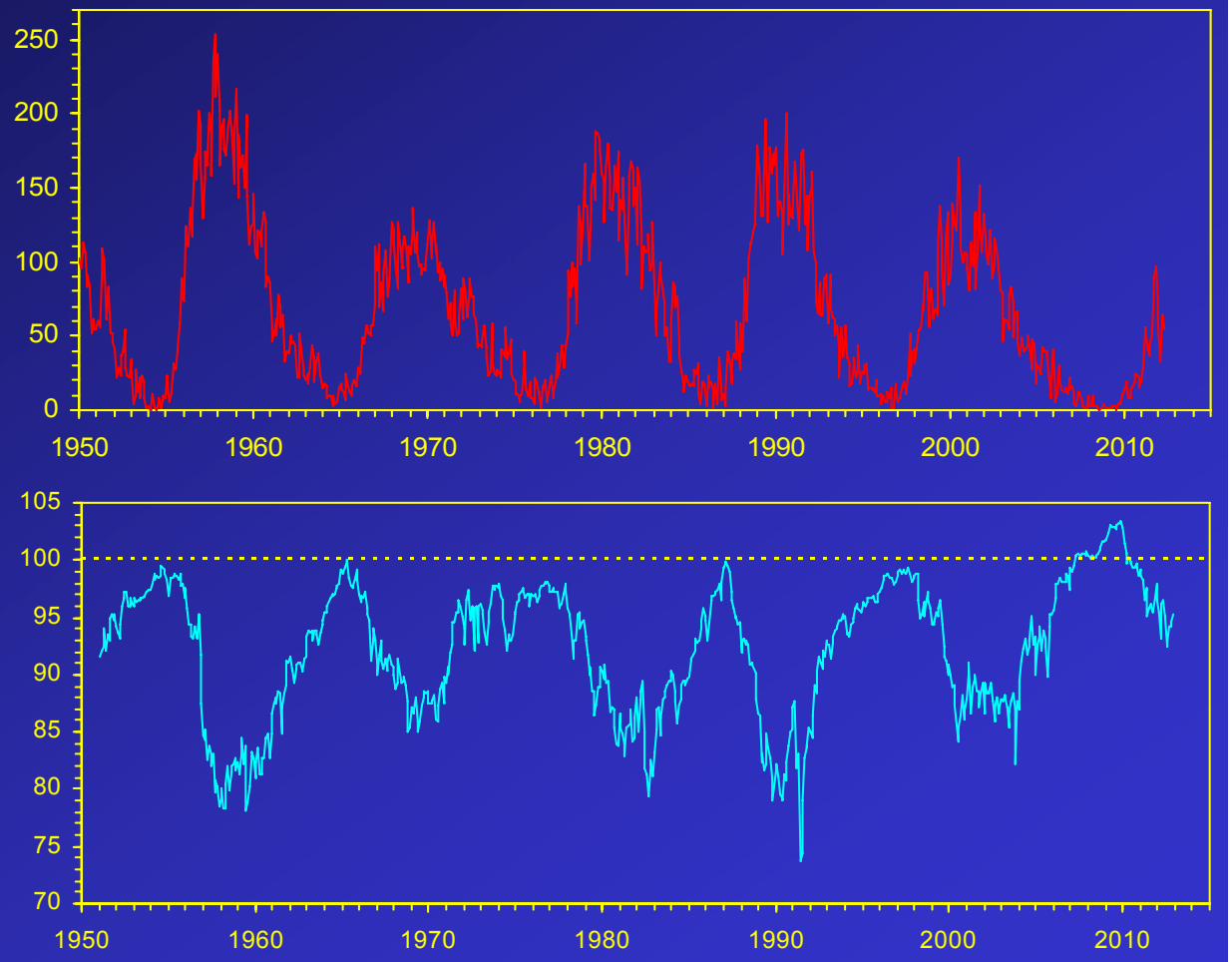


Dorman et al., 2005

Long-term CR variability

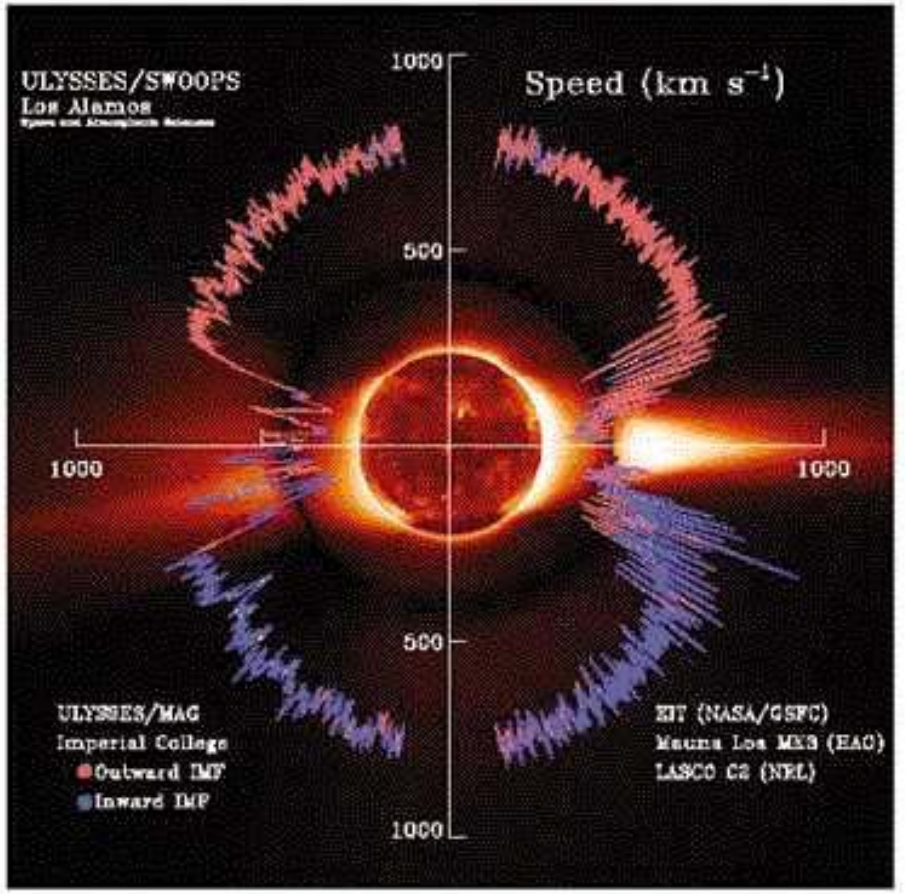
CR variations

- 11-year cycle is modulated by solar activity
- 22-year cycle is determined by charge-dependent drift effects
- short-term fluctuations.
- Centennial variability?



Heliospheric data

- Most of direct data exist for the ecliptic plane:
  - » IMF → can be approximated assuming the regular Parker's field;
  - » Solar wind → little variability over the solar cycle;
- Latitudinal scans (ULYSSES):
  - » latitudinal variability of the solar wind;
- Solar observations:
  - » HCS tilt angle; CMEs;
- Distant missions:
  - » Discovery of the termination shock;



McComas, D.J., et al., Geophys. Res. Lett., 25, 1-4, 1998

Quality and quantity of data decrease backwards in time.

Force-field approximation

Under some simplifying assumptions, the force-field (FF) approximation of CR transport equation is:

$$\frac{\partial f}{\partial r} + \frac{VP}{3\kappa} \cdot \frac{\partial f}{\partial P} = 0$$

Solution: $P = P_{LIS} - \Phi$

$$j_{1\mathrm{AU}}(T) = j_{LIS}(T + \Phi)\frac{P^2}{(P+\phi)^2}$$

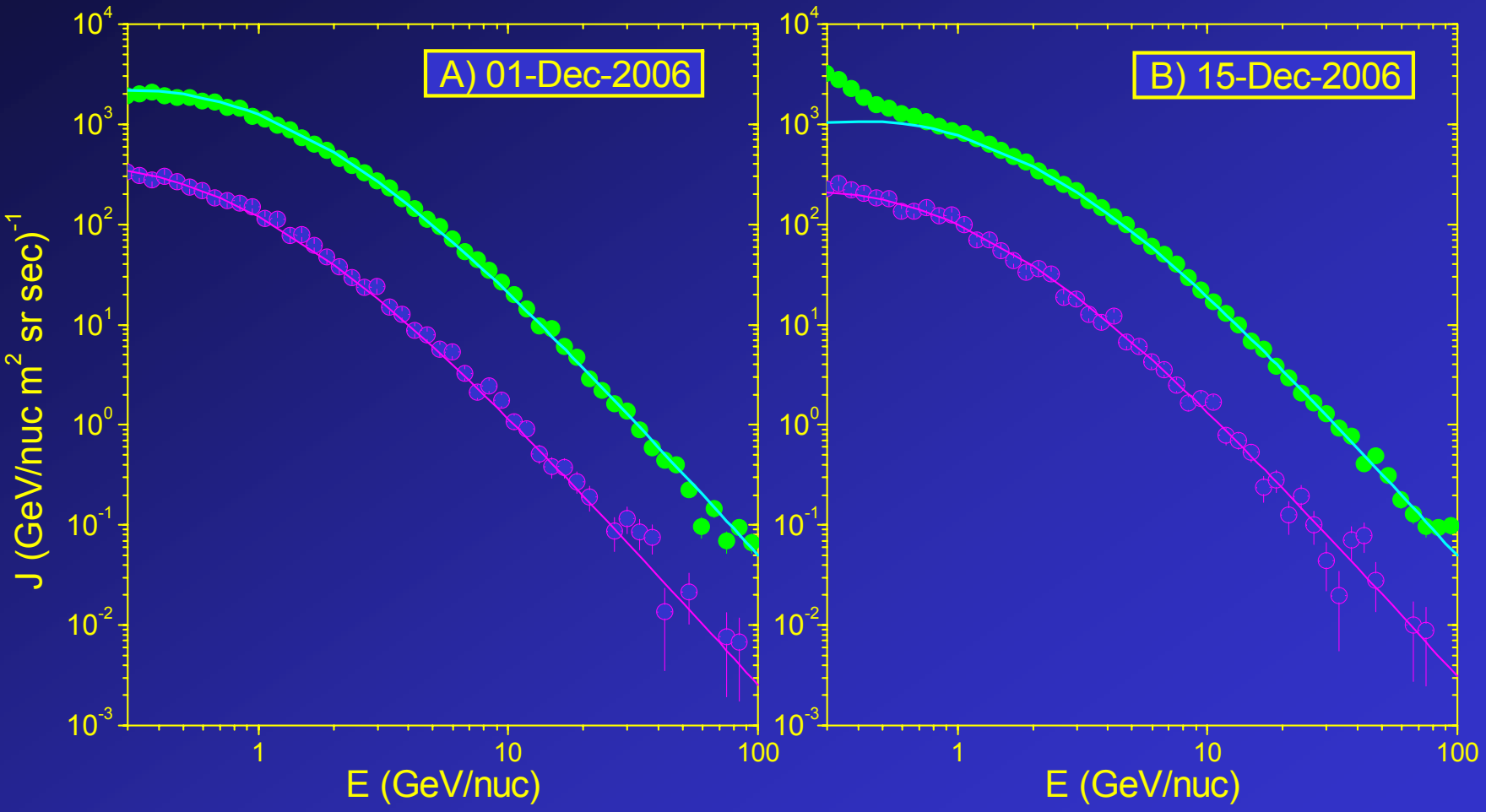
where $j = P^2 f$ and

$$\Phi = \frac{eZ}{A}\phi$$

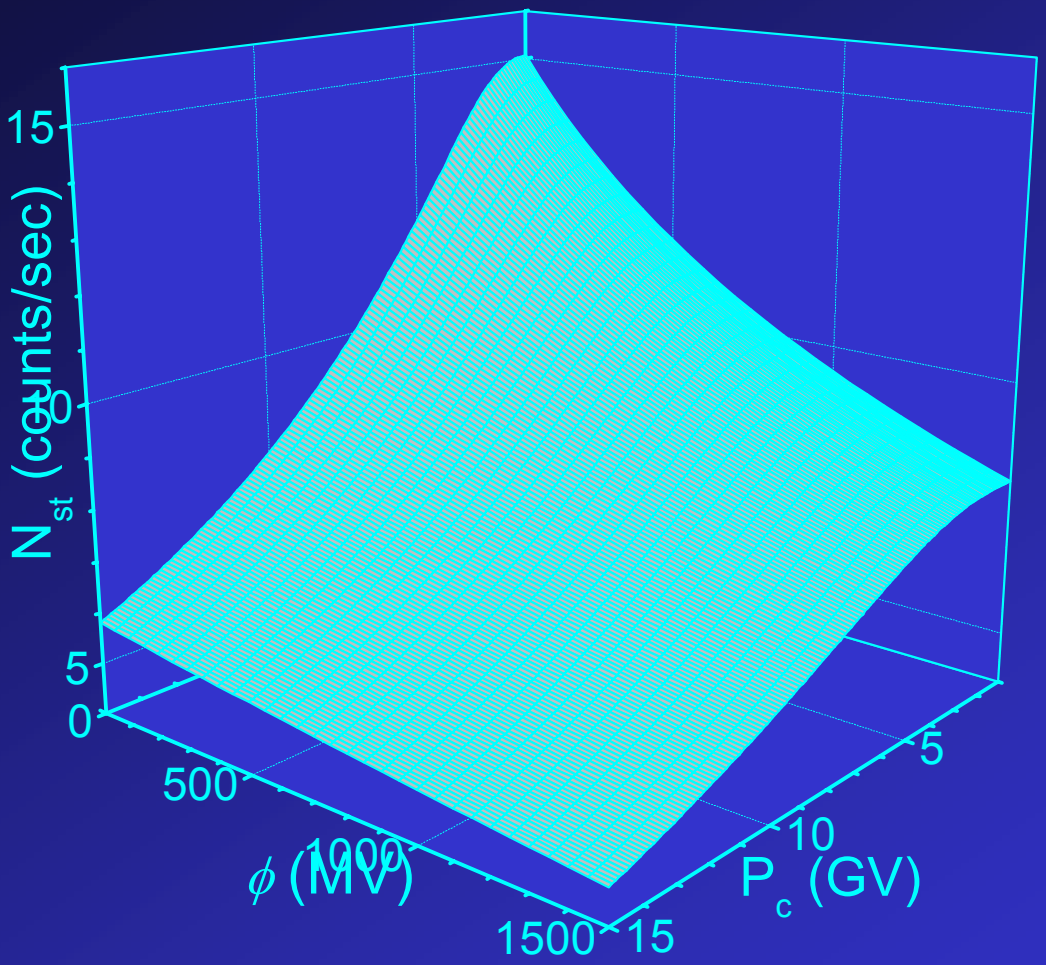
is the modulation strength (in MV)

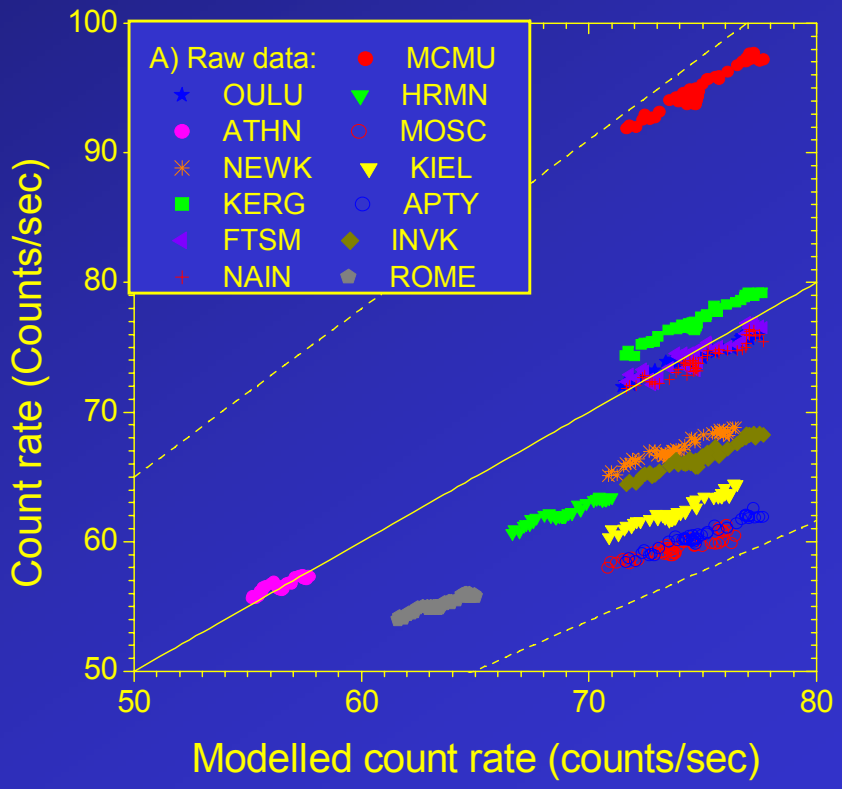
variable parameter and **fixed parameter LIS**

Force-field: fit to PAMELA spectra

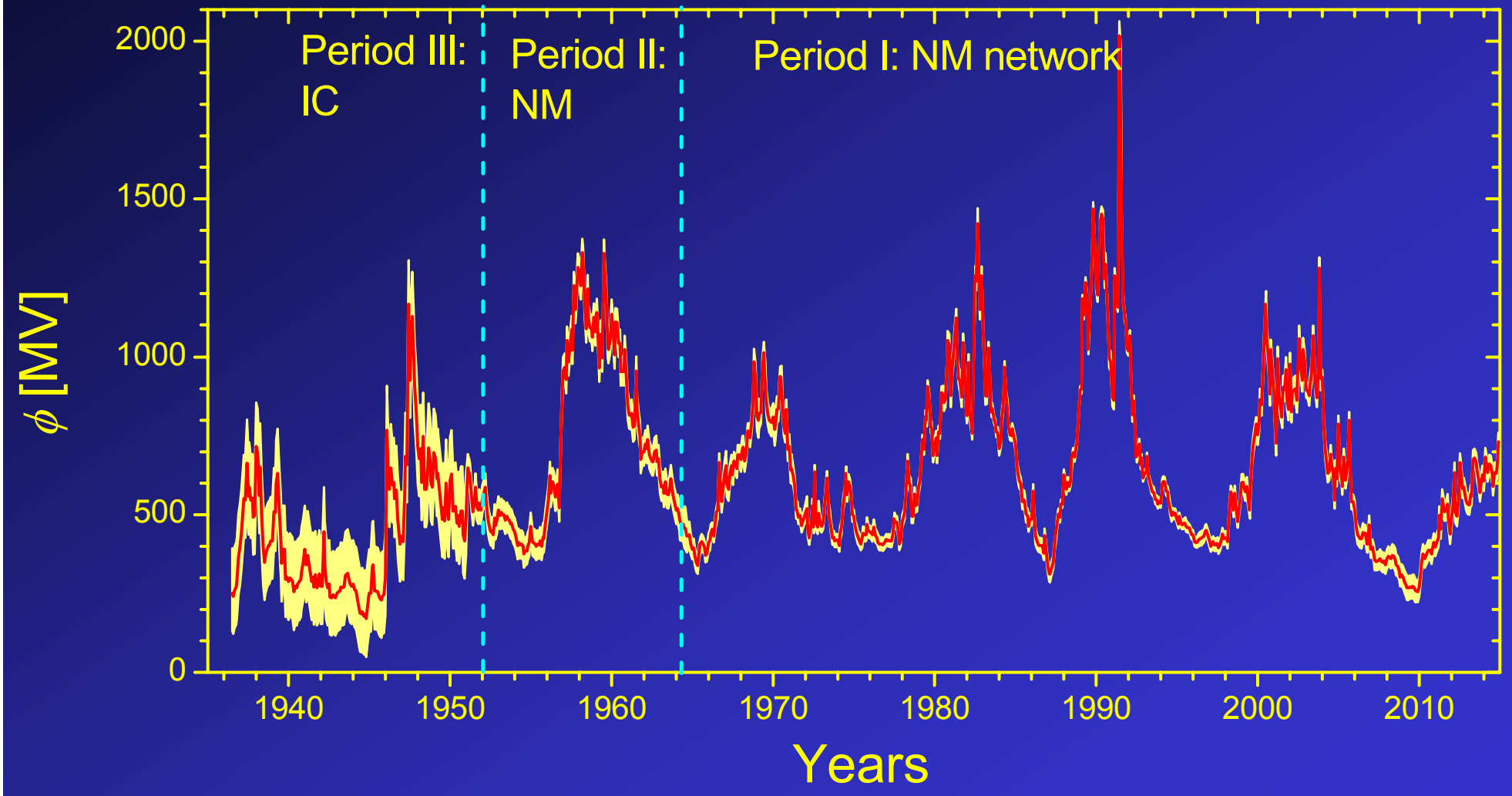


NM response to GCR

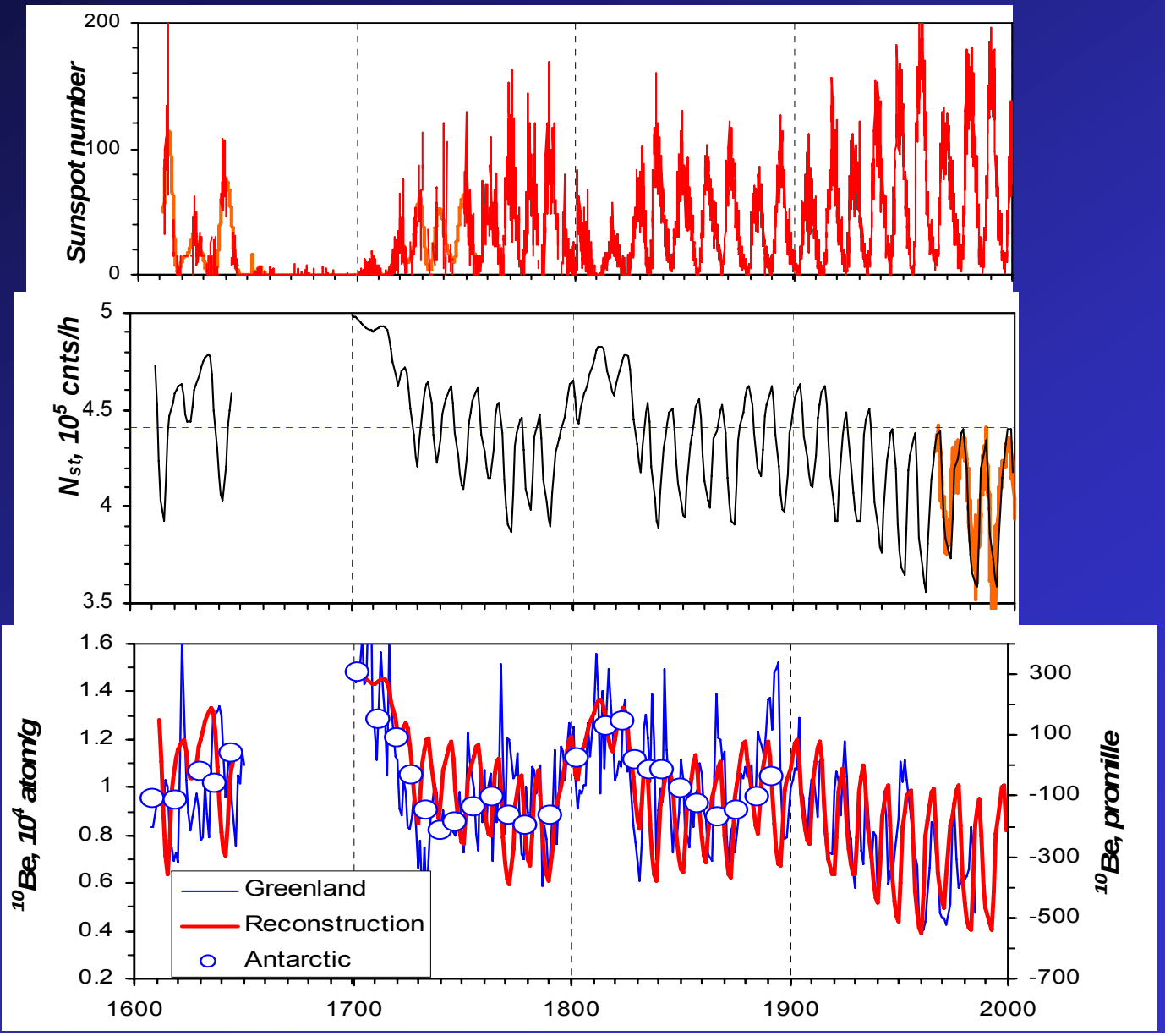




CR modulation reconstruction



Long-term CR


Sunspot number
200
100
0
N_{st}, 10^5 cnts/h
5
4.5
4
3.5
^{10}Be, 10^4 atom/g
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
^{10}Be, promille
300
100
-100
-300
-500
-700
Greenland
Reconstruction
Antarctic
1600
1700
1800
1900
2000

Summary

- Monitoring of CR variability:
  - » Long-term record
  - » Radiation dosimetry;
  - » Space weather (fore(now)casting)
- 3D probing of the heliosphere
- GLE (high energy tail of SEP events)
- Solar neutrons
- Long-term solar variability (solar activity)

THANK YOU !

Space Climate 6 Symposium and School

30 Mar – 07 Apr 2016

Levi, Northern Finland

http://www.spaceclimate.fi/SC6/

Auroral watching guaranteed *

* *Subject to weather conditions*