The GaGLEs of Winter 2012

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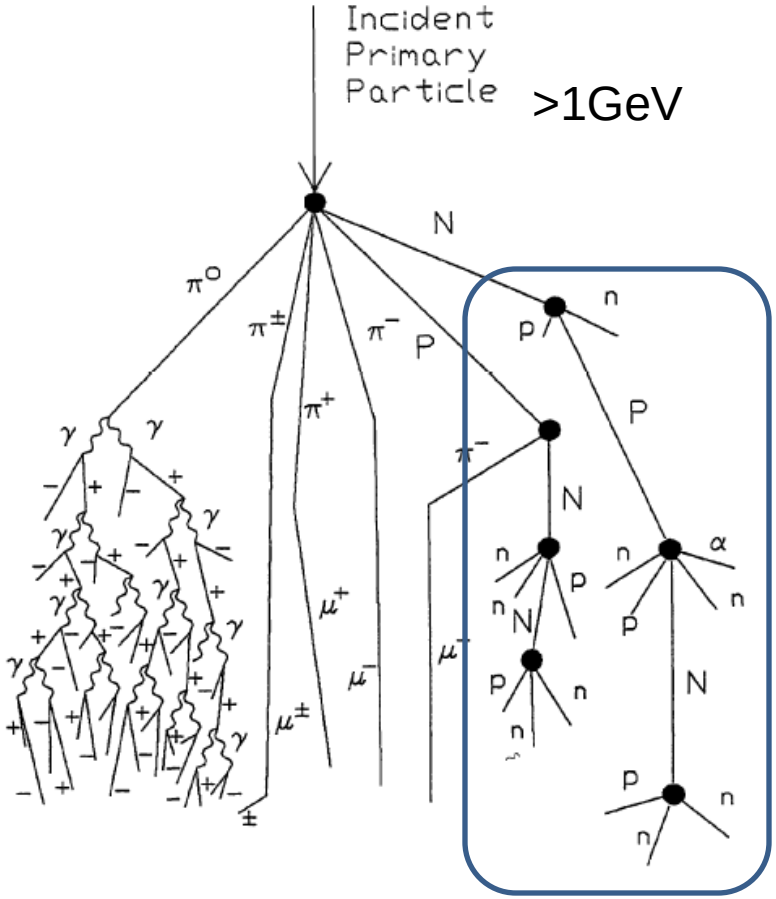
What is a GaGLE? (pronounced gag'-gle)

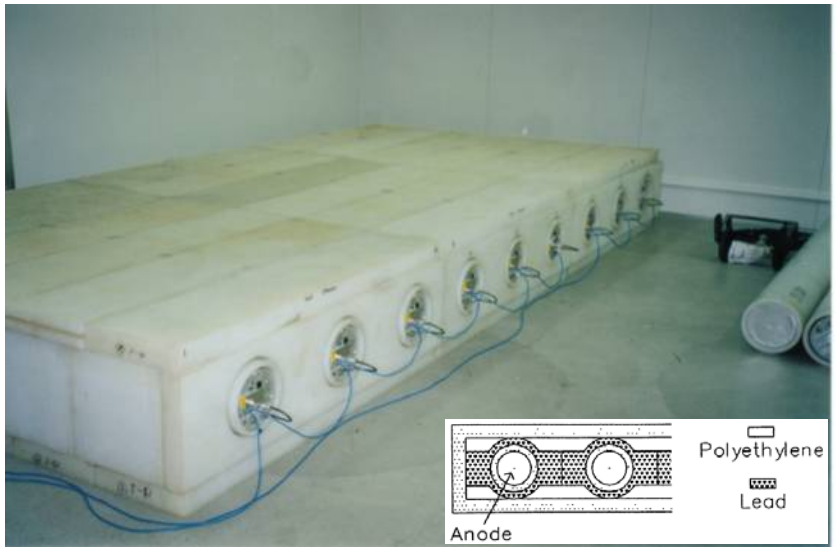
GaGLE = Galactic GLE

GLE = Ground Level Enhancement

- *Usually the term "GLE" implies a flux of relativistic solar particles that is sufficiently intense to be detected by ground-based detectors of atmospheric showers.*
- *It implies an enhancement above the (usual) flux of Galactic cosmic ray (GCRs)*
- *Rigidity cutoffs: To reach Earth, the particles must be above both the atmospheric cutoff (~1 GV) and the geomagnetic cutoff (0-17 GV).*

Neutron Monitor (NM)





BF_3 type

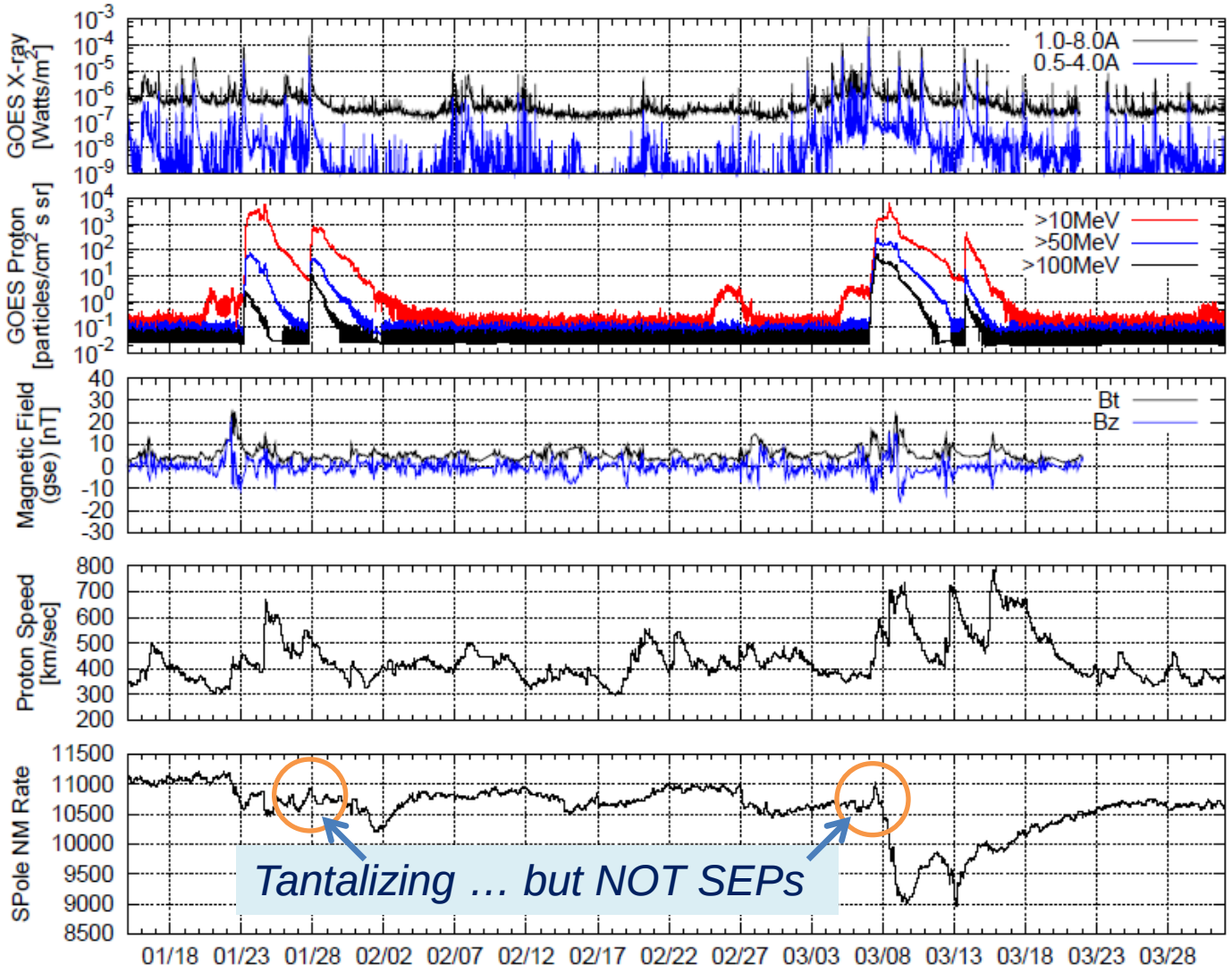
$$^{10}\mathrm{B} + \mathrm{n} \rightarrow \alpha + {}^{7}\mathrm{Li}$$

^{3}He type

$$^{3}\mathrm{He} + \mathrm{n} \rightarrow \mathrm{p} + {}^{3}\mathrm{H}$$

Ground-based detection of secondary neutrons from collisions of primary comic rays with air.

SEP events in 2012

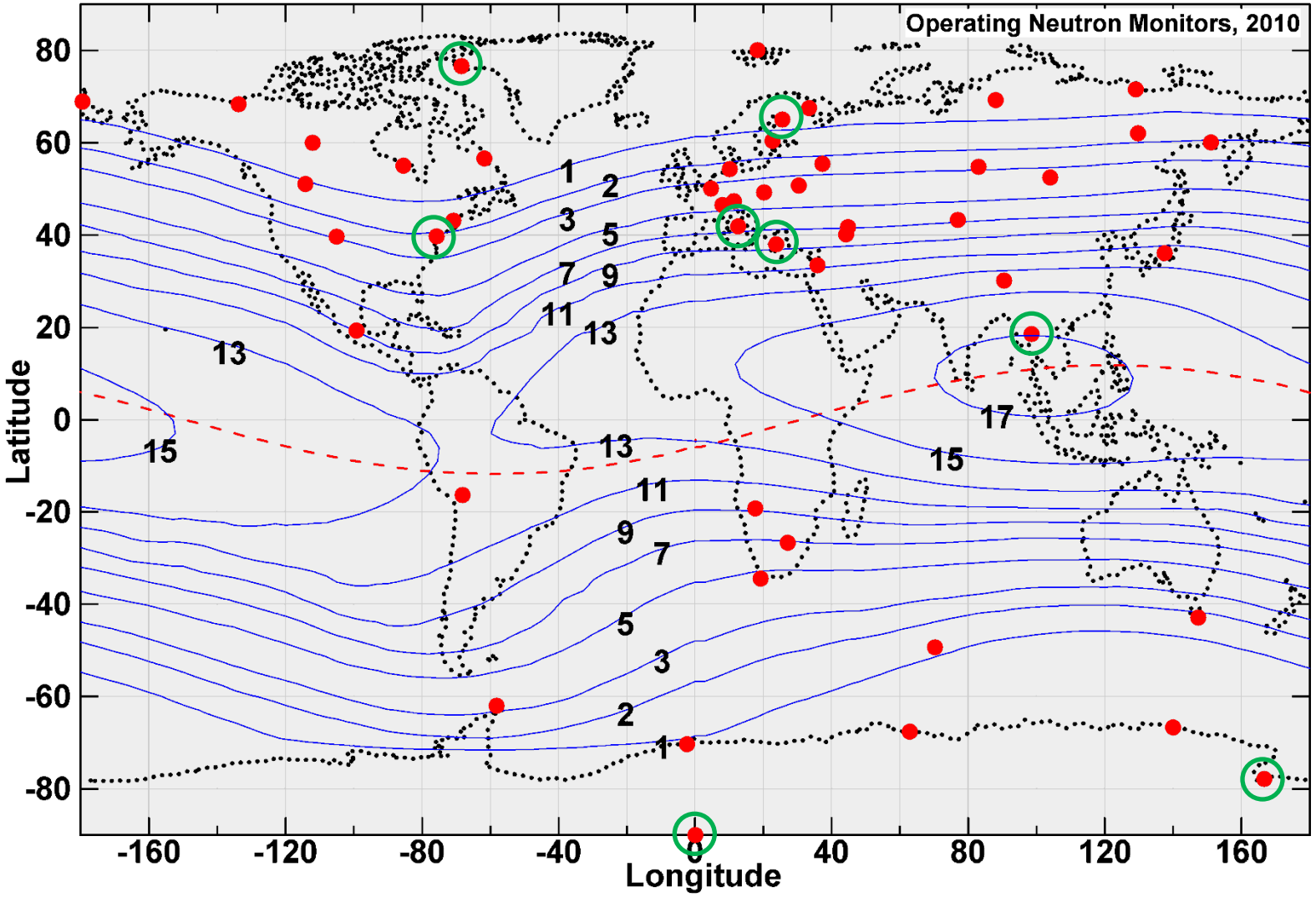


Major >10 MeV SEP events since 2001

Year	Date	Time	Flux	GLE
2001	Nov 4	17:05	31,700	○
2003	Oct 28	12:15	29,500	○
2001	Nov 22	23:20	18,900	
2001	Sep 24	12:15	12,900	
2012	Mar 7	5:10	6,530	
2012	Jan 23	5:30	6,310	
~~2005~~	~~Jan 16~~	~~2:10~~	~~5,040~~	
~~2005~~	~~May 14~~	~~5:25~~	~~3,140~~	
2002	Apr 21	2:25	2,520	
2001	Oct 1	11:45	2,360	
2004	Jul 25	18:55	2,086	
2006	Dec 6	15:55	1,980	
2005	Sep 8	2:15	1,880	
2005	Jan 20		1,860	○
2003	Nov 2	11:05	1,570	○
2001	Apr 2	23:40	1,110	
2001	Apr 15	14:10	951	○
2002	May 22	17:75	820	
2012	Jan 27	19:05	796	
2001	Dec 26	6:05	779	○
~~2006~~	~~Dec 13~~	~~3:10~~	~~698~~	○
2004	Nov 7	19:10	495	
2001	Aug 16	1:35	493	
2012	Mar 13	18:30	469	
2003	Oct 26	18:25	466	
~~2002~~	~~Nov 9~~	~~19:20~~	~~404~~	
2001	Apr 10	8:50	355	
2003	Nov 4	22:25	353	
2005	Aug 22	20:40	330	
2001	Apr 18	3:15	321	○
2002	Aug 24	1:40	317	○
2004	Sep 13	21:05	273	
2012	May 17	2:10	255	○
2002	Jul 16	17:50	234	
~~2002~~	~~Sep 7~~	~~4:40~~	~~208~~	
2005	Jul 14	2:45	134	
2003	May 28	23:35	121	
2001	Dec 30	2:45	108	

- These are Ground Level Enhancements … but enhancements in Galactic cosmic rays, not solar energetic particles …
- … hence the term GaGLE.
- To better understand GaGLEs, consider data for different geomagnetic cutoff rigidities.

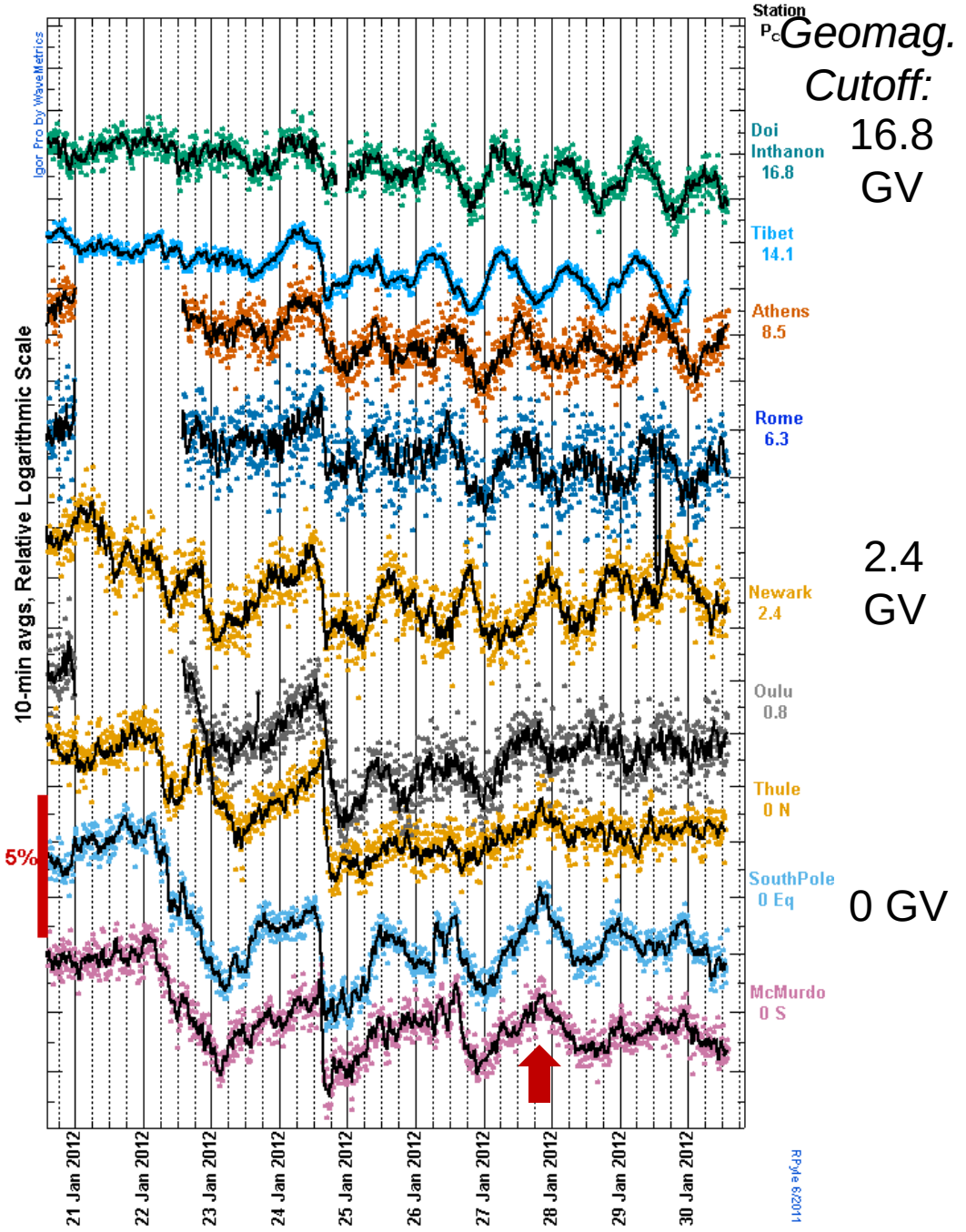
Locations of neutron monitors and their cutoff rigidities in GV



Rigidity is *pc/q,* determines particle trajectory in magnetic field

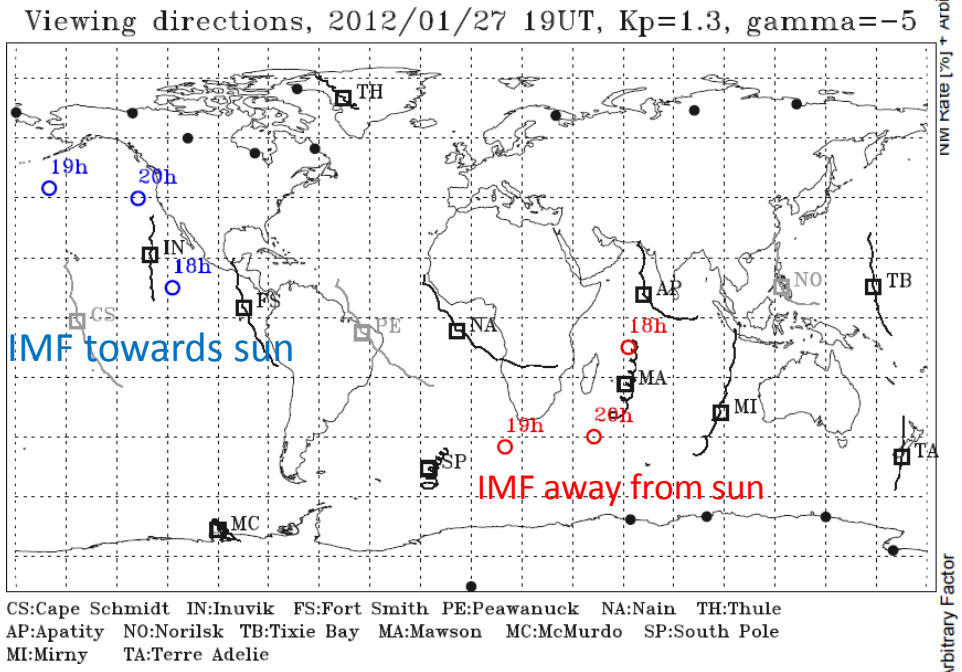
Selected real-time neutron monitor rates on Jan. 27, 2012

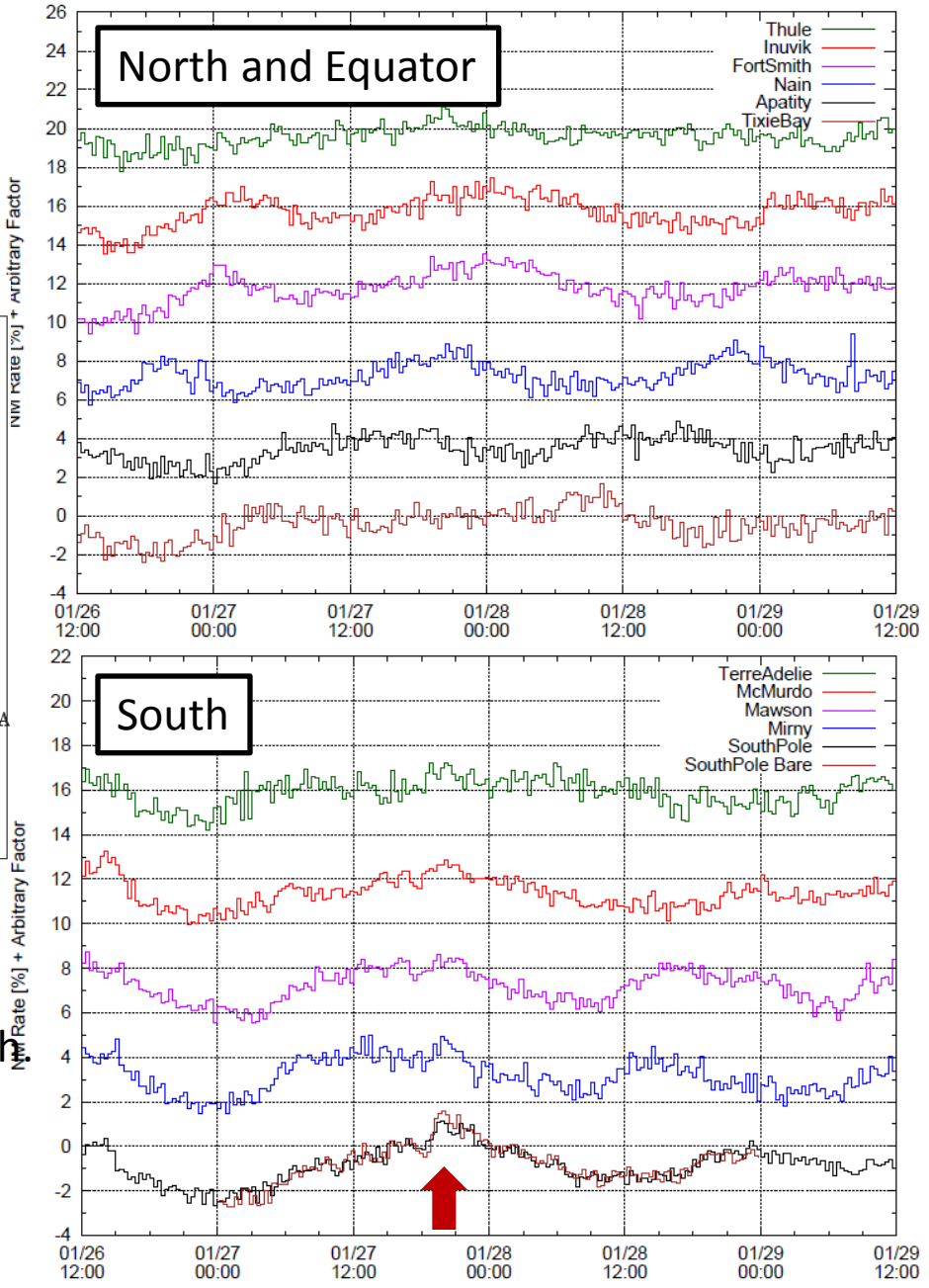
The GaGLE is mainly seen at low cutoff rigidity (red arrow). By coincidence, there was also a strong solar storm during that time period. While the GaGLE could be confused with a standard GLE (due to solar particles), the rise time is much slower than for solar particles.



http://neutronm.bartol.udel.edu/~pyle/Spectral.png

NM rate in polar stations (at low cutoff rigidity)

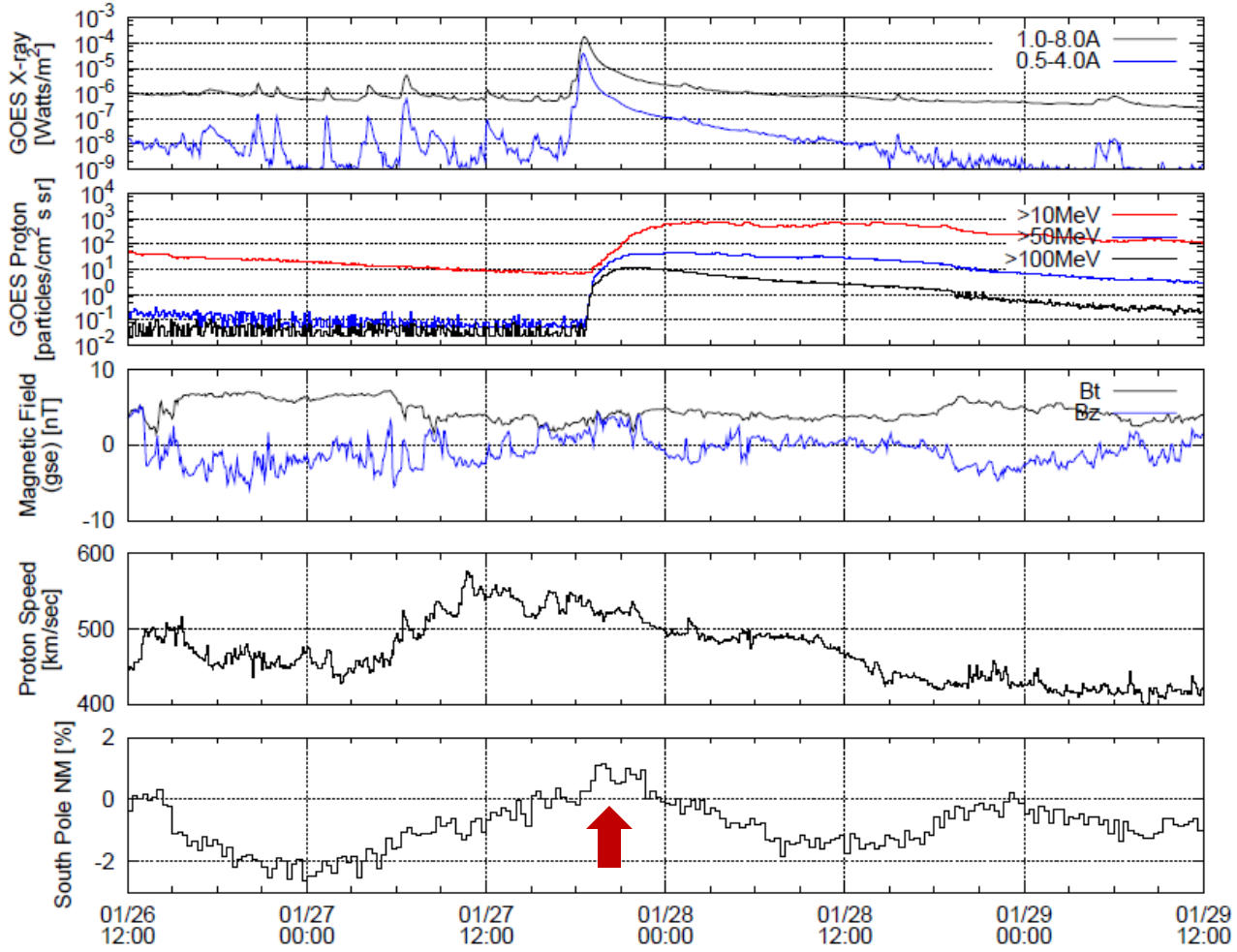




Enhances are seen in the stations looking South.
This is the direction of IMF away from the Sun.

This GaGLE could also be interpreted as an enhanced diurnal anisotropy.

January 27 SEP event: The GaGLE (enhanced GCR flux) was coincident in time, but had a much slower rise. Such GCR variations can pose a challenge to detection and measurement of the SEP flux in a GLE.

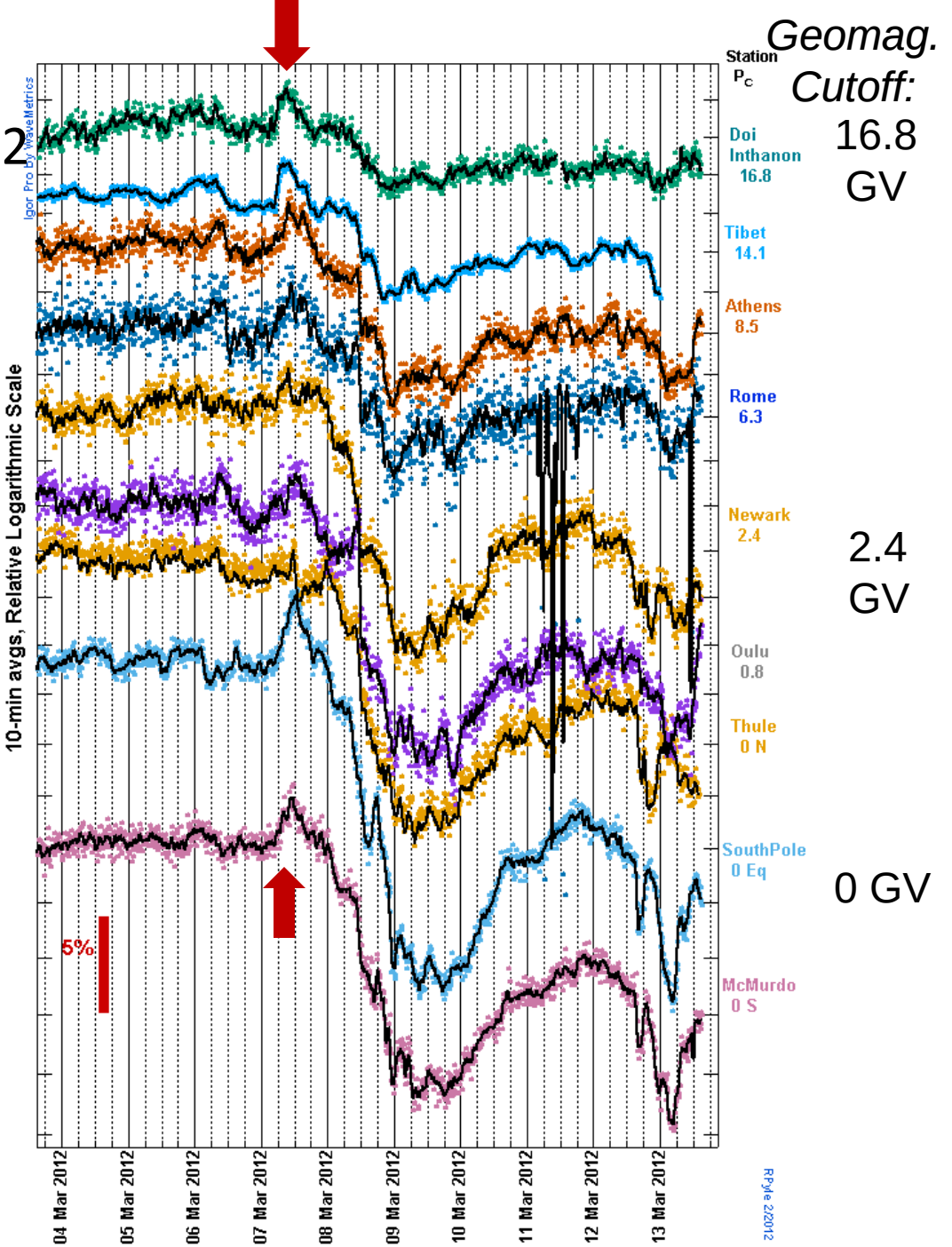


SEP variations at sub-GeV energies

GCR variations (no SEP) in GeV range

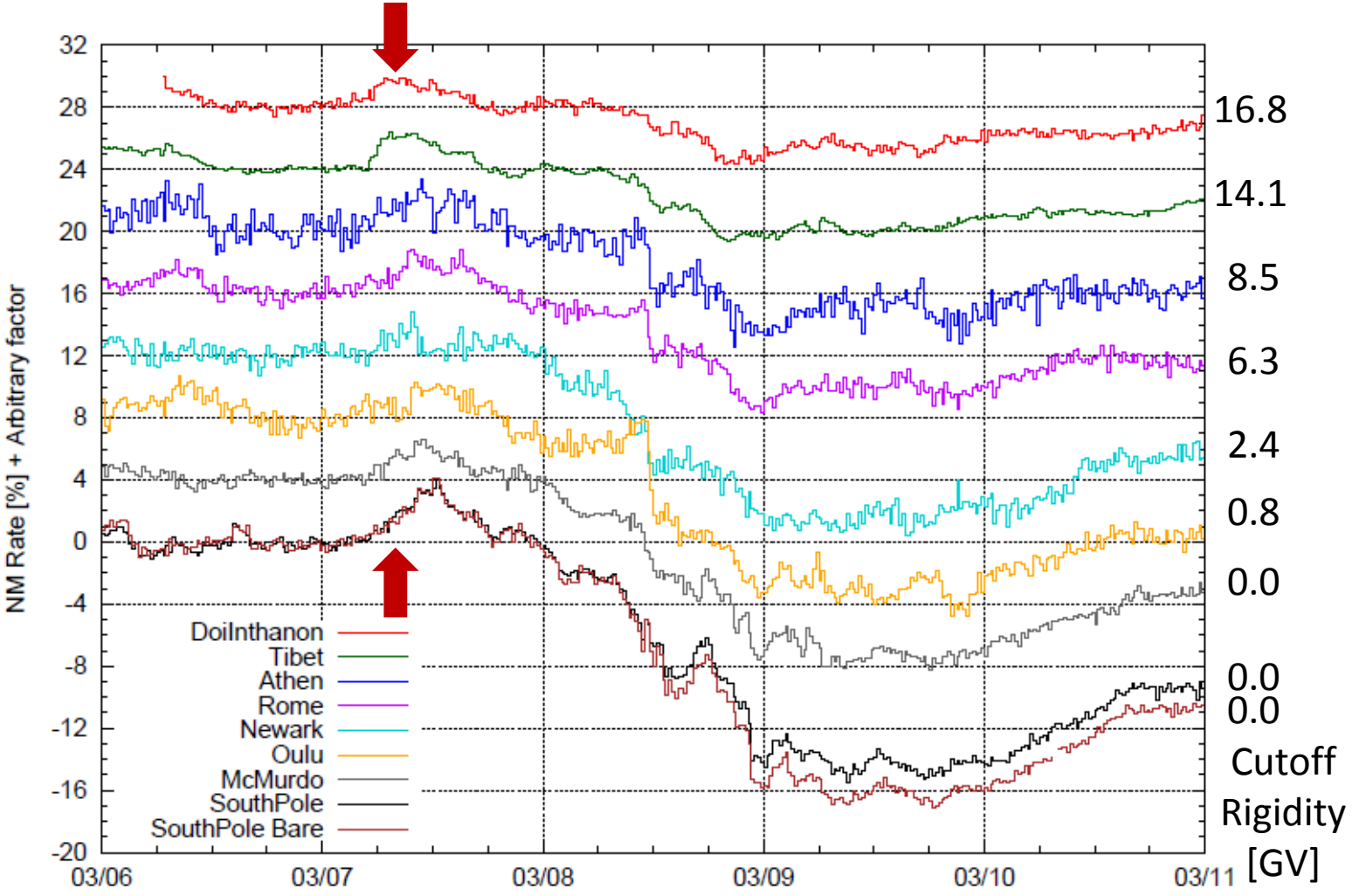
Selected real-time neutron monitor rates on March 7, 2012

This GaGLE is quite different. The magnitude of the rise is nearly independent of cutoff rigidity from 0 GV for polar NMs (where NM response is limited by the atmospheric cutoff of ~1 GV) to 16.8 GV at Doi Inthanon, Thailand. That alone precludes a solar spectrum, and the rise time is again slower than for solar particles.



http://neutronm.bartol.udel.edu/~pyle/Spectral.png

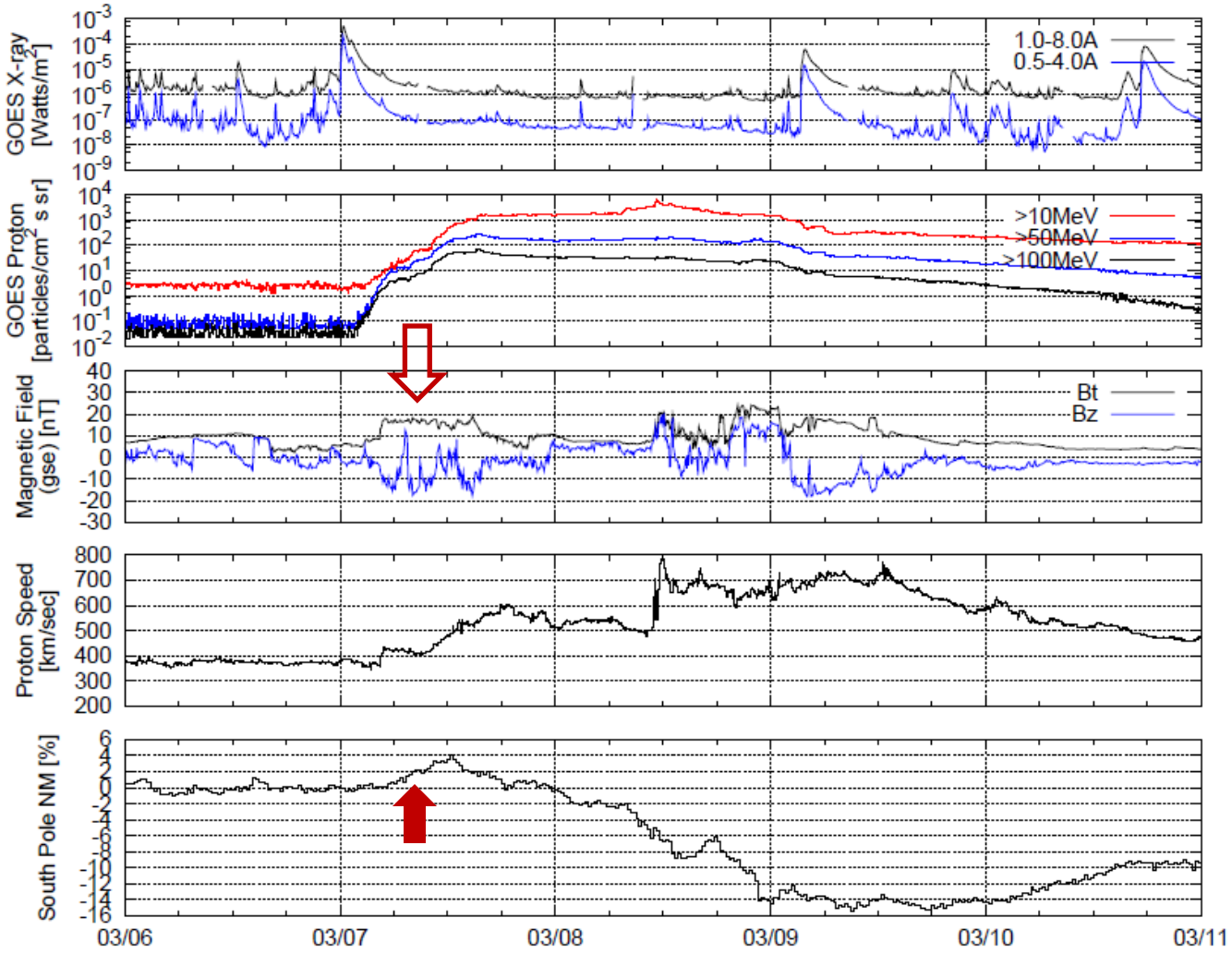
NM rates in different cutoff rigidity stations: The GaGLE time profile has some dependence on rigidity, but is independent of “look direction” -> not just enhanced anisotropy. Amplitude has very weak rigidity dependence.



Thank to the
Tibet NM collaboration to
provide Tibet data

Same amplitude in different cutoff rigidity
Probably galactic cosmic ray variation

March 7 SEP event: The GaGLE was again coincident with solar particles. There was a Forbush decrease after the GaGLE, due to the March 7 CME. The GaGLE seems to be associated the magnetic compression after the preceding CME.



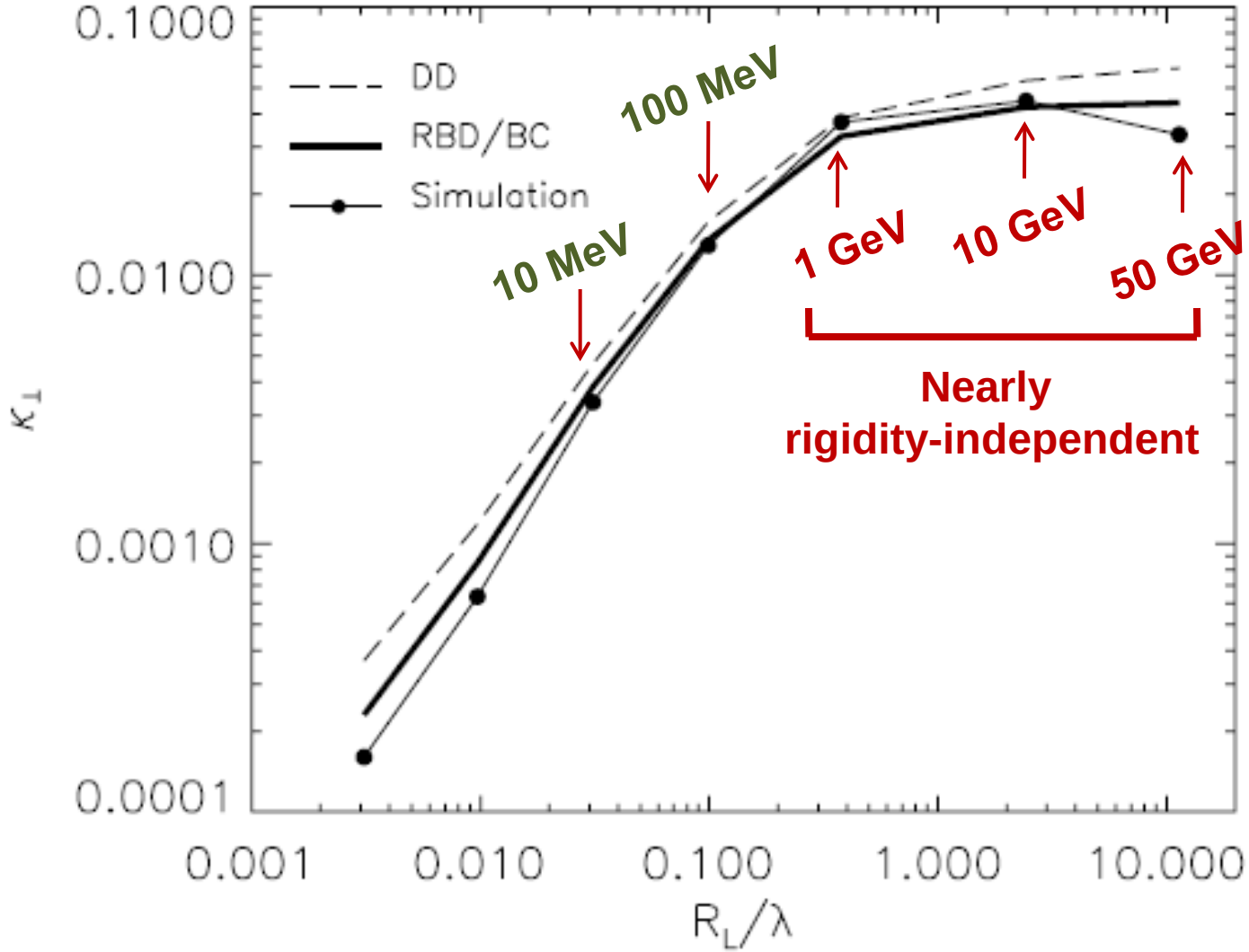
SEP variations at sub-GeV energies

GCR variations (no SEP) in GeV range

How to explain the nearly rigidity-independent GaGLE (GGR enhancement) of March 7, 2012?

- GCR intensity variations are almost always strongly dependent on rigidity.
- Rigidity-dependent variations such as Forbush decreases are typically attributed to the parallel diffusion coefficient $\kappa_{||}$, which depends on rigidity.
- We imagine that the GaGLE may instead depend on $\kappa_{\perp}$, which is nearly independent of rigidity for relativistic particles (see below). The sharp onset of the GaGLE at Doi Inthanon & Tibet (see above) is consistent with a weaker (e.g., perpendicular) diffusion process.

Recent results on perpendicular diffusion of relativistic particles



Modified NLGC theory by Ruffolo et al. ApJ, 747, L34 (2012)

Conclusions

- We identify a type of Ground Level Enhancement in Galactic cosmic rays, not solar energetic particles, hence the term GaGLE.
- There is frequently a time coincidence between a GaGLE and a solar storm because major solar-interplanetary disturbances frequently occur in sequence from the same active region.
- GaGLEs could affect the detection and measurement of relativistic solar particles during standard GLEs.
- We point out the uses of low-latitude (high-cutoff) neutron monitors together with other ground-based detectors for diagnosis of interplanetary conditions, which provides important information for GLE detection and analysis.