Transient weakening of geomagnetic field probed by GRAPES-3

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for GRAPES-3 collaboration

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GRAPES-3 Muon Telescope (Ooty, India, 11.4°N, 76.7°E, Rc = 17 GV)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modules</td>
<td>16 (35 m² each)</td>
</tr>
<tr>
<td>Directions</td>
<td>13 x 13 (169)</td>
</tr>
<tr>
<td>Sky coverage</td>
<td>Up to 60° zenith</td>
</tr>
<tr>
<td>Total Area</td>
<td>560 m²</td>
</tr>
<tr>
<td>Muon Rate</td>
<td>$5 \times 10^4$/sec</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.1% / minute</td>
</tr>
</tbody>
</table>

Each module: 58 x 4 PRCs
PRC dimension: 6 m x 10 cm x 10 cm
GRAPES-3 muon rate during 13 June – 05 July 2015

Burst

Forbush Decrease (FD)
WIND spacecraft measurements (at L1 point) showed three coronal mass ejections (CMEs) struck Earth during 21 - 22 June 2015 within 24 hours.

Third CME at 18:40 UT on 22 June triggered a G4 class geomagnetic storm with a maximum DST change of -200 nT at 05:00 UT on 23 June.
Burst association with IMF

During the 2 hour burst $10^6$ excess muons detected over $3 \times 10^8$.

**Important point to note**

$B_z$ to be delayed 32 minute relative to muon to get maximum correlation.

30 minute propagation delay of solar wind from L1 to bow-shock nose + additional 32 minute delay.

$B_z = -40\text{nT}$

$54\sigma$

94% correlation
Burst in 9 directions

Two important observations

1. Smaller amplitude in south and west directions - not consistent with rigidity dependence.

2. Simultaneous (+/- 4 min)

Must be local origin. Very close to Earth.
Simulation of Cutoff rigidity variation

Model field = GMF + IMF

$10^9$ cosmic ray proton events simulated using back-tracing trajectories in the model field.
89% correlation between data and simulation

Important to note

IMF to be enhanced 17 times to match the amplitude.

\[-40\text{nT} \times 17 = -680\text{nT}\]
210° deflection of near cutoff rigidity cosmic ray particles from day side enabling detection by GRAPES-3 on night side.

Alma-Ata neutron monitor (76.5° E) recorded an increase in rate coincident with GRAPES-3.
COORDINATING EFFORTS TO PREPARE THE NATION FOR SPACE WEATHER EVENTS

By the authority vested in me as President by the Constitution and the laws of the United States of America, and to prepare the Nation for space weather events, it is hereby ordered as follows:

Section 1. Policy. Space weather events, in the form of solar flares, solar energetic particles, and geomagnetic disturbances, occur regularly, some with measurable effects on critical infrastructure systems and technologies, such as the Global Positioning System (GPS), satellite operations and communication, aviation, and the electrical power grid. Extreme space weather events -- those that could significantly degrade critical infrastructure -- could disable large portions of the electrical power grid, resulting in cascading failures that would affect key services such as water supply, healthcare, and transportation. Space weather has the potential to simultaneously affect and disrupt health and safety across entire continents. Successfully preparing for space weather events is an all-of-nation endeavor that requires partnerships across governments, emergency managers, academia, the media, the insurance industry, non-profits, and the private sector.
Transient weakening of Earth’s magnetic shield probed by a cosmic ray burst

P.K. Mohanty et al., 20 October 2016.

1089 reports in 119 countries in 37 languages

American Physical Society
Physics World
Science
Nature
BBC
World Steel association

Almetric rating:
#14 out of 16035 PRL outputs
Summary

• A strong direct correlation between muon burst and IMF reported.

• Simulation results showed a 2-hour weakening of Earth’s magnetic field by 680nT.

• Burst well explained by a simple cutoff rigidity model.

• 32 minute delay of the burst relative to IMF is a key issue. Slow down of plasma in the magnetosphere could be an possible explanation. Requires further investigation.

• The delay could be very important for space weather warnings.

• 17-years of existing high statistics GRAPES-3 data would be very useful to learn further on this phenomena.
Thank you!
Backup slides
GRAPES-3 Experiment (Ooty, India, 11.4°N, 76.7°E)

400 Plastic Scintillator detectors (1 m² area)
560 m² muon telescope based on 3712 Proportional Counters

Muon measurement
- Sync with EAS trigger (10^{13} – 10^{16} eV)
  - CR composition and gamma-hadron separation
- Single muon trigger (> 10 GeV)
  - Solar and atmospheric studies
Diurnal

0.128% hPa⁻¹

1 m air column = 5σ
$0.3^\circ C = 5\sigma$

Annual (2005-2010)

$0.169\% K^{-1}$
Cosmic Ray Rate for 16 modules (2006)

99.99%
Muon burst on 22 June 2015 midnight

After Pressure Correction

Mean Rate = 2888.3
RMS = 27.3

Mean Rate = 2810.0
RMS = 25.3

Mean Rate = 3003.9
RMS = 27.7

Mean Rate = 2833.3
RMS = 26.9
Geomagnetic cutoff rigidity for GRAPES-3

14 GV in West to 32 GV in East

P.K. Mohanty, Ph.D. thesis
Background removal by FFT
16 module detections

13σ
URAGAN observation
Here’s how the world could end—and what we can do about it

By Julia Rosen  Jul. 14, 2016, 2:00 PM

Threat one: Solar storms
CMEs don’t harm human beings directly, and their effects can be spectacular. By funneling charged particles into Earth’s magnetic field, they can trigger geomagnetic storms that ignite dazzling auroral displays. But those storms can also induce dangerous electrical currents in long-distance power lines. The currents last only a few minutes, but they can take out electrical grids by destroying high-voltage transformers—particularly at high latitudes, where Earth’s magnetic field lines converge as they arc toward the surface.

Threat two: Cosmic collisions
For another menace from the sky—an impact by a large asteroid or comet—there is no way to limit the damage. The only way for humanity to protect itself, researchers say, is to prevent the collision altogether.

Threat three: Supervolcanoes
The most inexorable threat to our modern civilization, however, is homegrown—and it strikes much more often than big cosmic impacts do. Every 100,000 years or so, somewhere on Earth, a caldera up to 50 kilometers in diameter collapses and violently expels heaps of accumulated magma. The resulting supervolcano is both unstoppable and ferociously destructive. One such monster, the massive eruption of Mount Toba in Indonesia 74,000 years ago, may have wiped out most humans on Earth, causing a genetic bottleneck still apparent in our DNA—although the idea is controversial.