Due to COVID-19 pandemic we have online lecture:

Today greater dependence on internet than ever before

These tools are keeping us safe from coronavirus

Imagine living without internet and electricity?

That is what solar storm can do!

BBC Click:

https://www.youtube.com/watch?v=azDU2SXBISM&t=290s

Hindi: >16 Lakh views

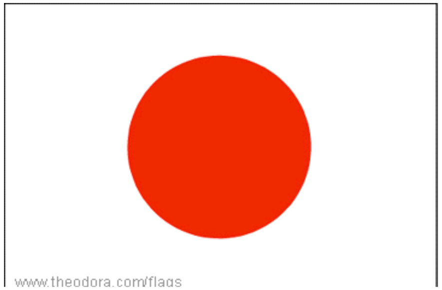
https://youtu.be/bZXyef1vJdM Telugu

https://youtu.be/BZcGCBnsR80 Tamil

Solar storms and their impact on the Earth studied through muons by the GRAPES-3

Sunil K. Gupta

9 September 2020 IIT Indore



1. Tata Institute of Fundamental Research, Mumbai, India
2. Osaka City University, Osaka, Japan
3. Aichi Institute of Technology, Aichi, Japan
4. J.C. Bose Institute, Kolkata, India
5. Indian Institute of Science & Edu. Res. Pune, India
6. Chubu University, Kasugai, Aichi, Japan
7. Hiroshima City University, Hiroshima, Japan
8. Aligarh Muslim University, Aligarh, India
9. Indian Institute of Technology, Kanpur, India
10. Dibrugarh University, Dibrugrh, India
11. Vishwakarma Inst. of Information Tech. Pune, India
12. Nagoya University, Nagoyai, Japan
13. Indian Institute of Technology, Indore, India
14. Utkal University, Bhubaneshwar, India
15. Indian Institute of Technology, Jodhpur, India

Longest India-Japan scientific collaboration 1992-Present

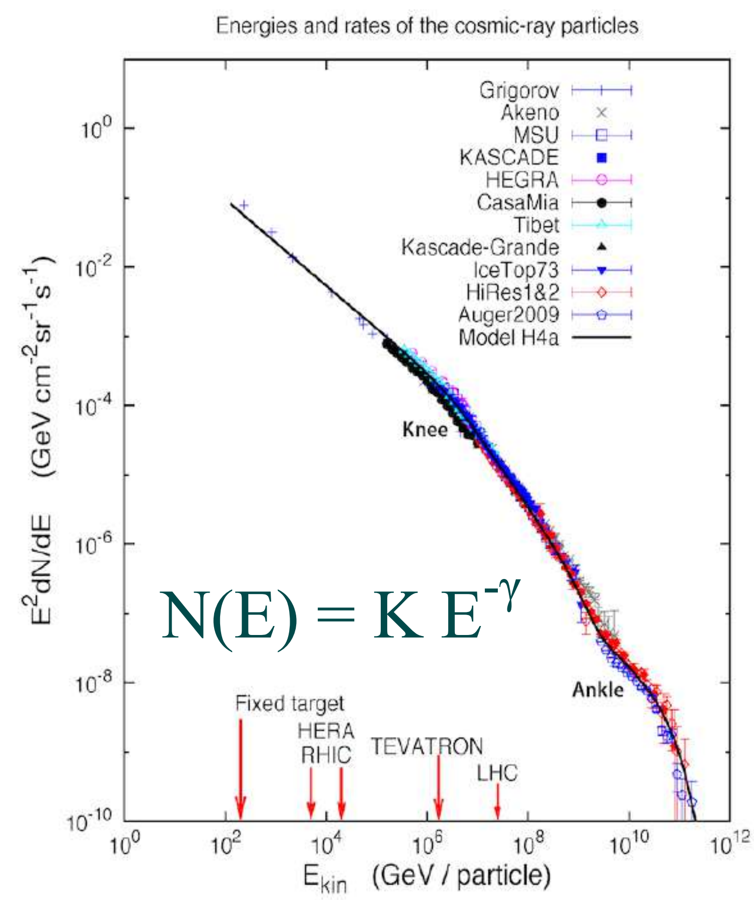
S.K. Gupta, S.R. Dugad, B. Hariharan, P.K. Mohanty, P.K. Nayak, P. Jagadeesan, A. Jain, S.D. Morris, P.S. Rakshe K. Ramesh, B.S. Rao, L.V. Reddy, Y. Hayashi, S. Kawakami, H. Kojima, S.K. Ghosh, S. Raha, P Subramanian, A. Oshima, S. Shibata, K. Tanaka, S. Ahmad, P.K. Jain, U.D. Goswami, C.S. Garde, Y. Muraki, R. Sahoo, S. Mahapatra,, R. Moharana

Plastic Scintillator (2000)
Proportional Counters (8000)
Signal processing (8000)
DAQ systems > 20
Computer Clusters (1500)

GRAPES-3 Experiment on Google Map

Sunil K. Gupta
gupta@grapes.tifr.res.in

1. Why study cosmic rays?
2. Benefits to society?
3. GRAPES-3 experiment
4. Solar storms
5. Thunderstorms?



Top

100 $g.cm^{-2}$

200

300

400

500

600

700

Ooty 800

900

Mumbai 1000

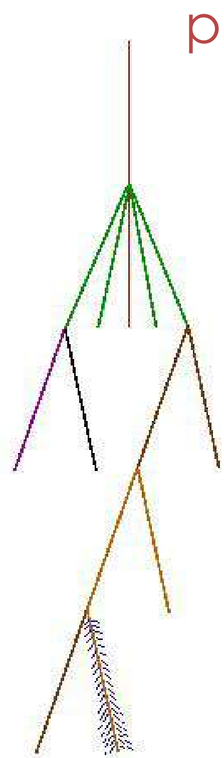
$$p + p \rightarrow p + p + \pi^{+} + \pi^{-} + \pi^{0}$$

$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu} \quad 20\times10^{-9}\ s$$

$$\pi^{0} \rightarrow \gamma + \gamma \quad 10^{-16}\ s$$

$$\gamma \rightarrow e^{+} + e^{-}$$

$$e^{-} \rightarrow e^{-} + \gamma$$



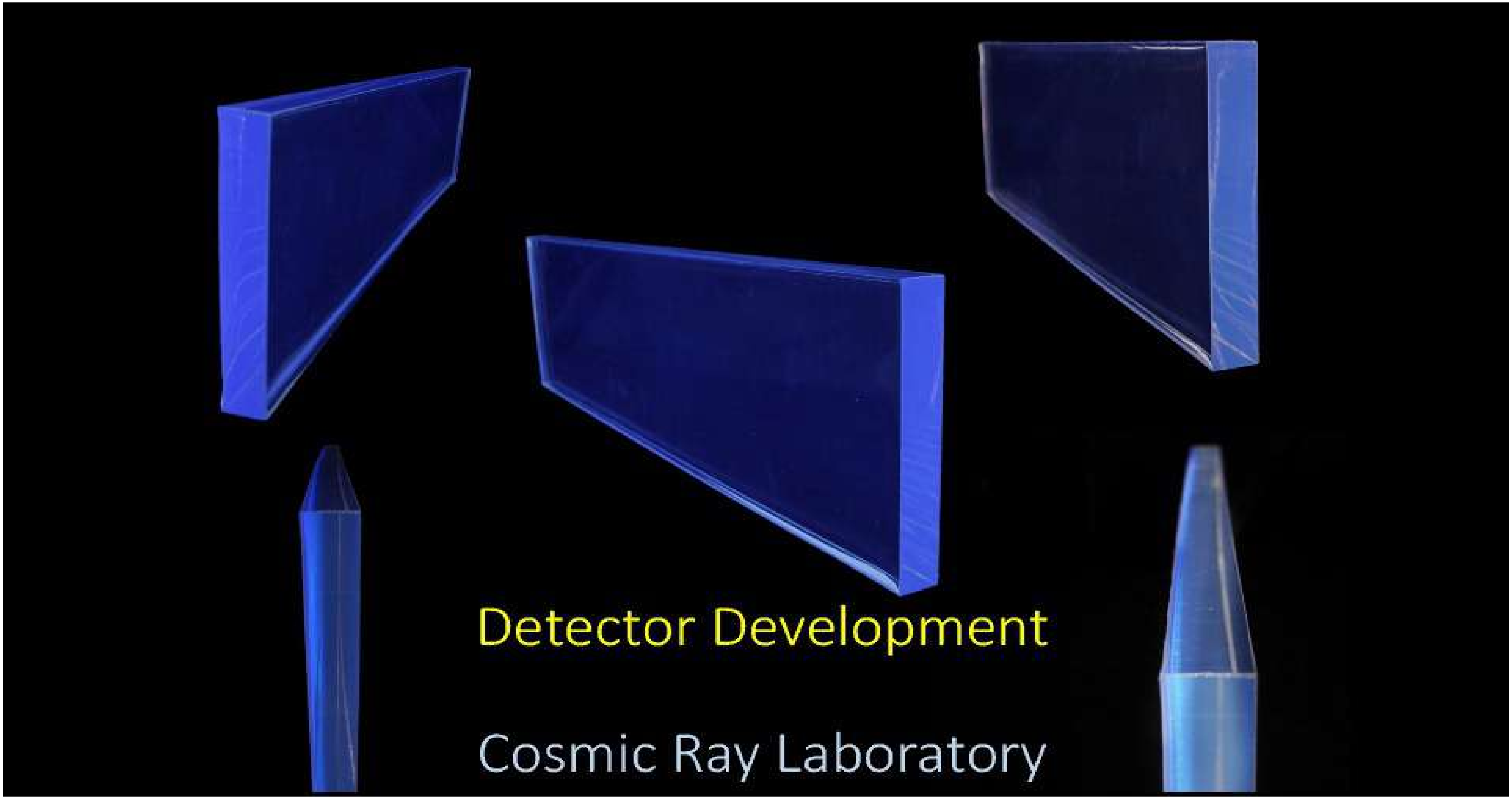
Cosmic Ray Shower:

1. Electrons, Positrons & Gamma rays
   (E-M component, 90 %)
2. Muon (μ^{+}, μ^{-}) Penetrating Component (8%)
3. Pions, Kaons, Hadron Component (1%)
4. Neutrinos usually go undetected

For E = 10^{14} eV at mountains (Ooty)
20000 particles spread over ~1000 m^2

https://www.nature.com/articles/nature24647

Fabrication of plastic scintillator detectors at Cosmic Ray Laboratory, Ooty



Plastic Scintillator development:

Decay Time= 1.6 ns Light Output = 85% Bicron (54% anthracene)

Timing 25% faster Atten. Length $\lambda = 100$cm Cost ~fraction of Bicron

Max Size 100cmX100cm Total > 2000

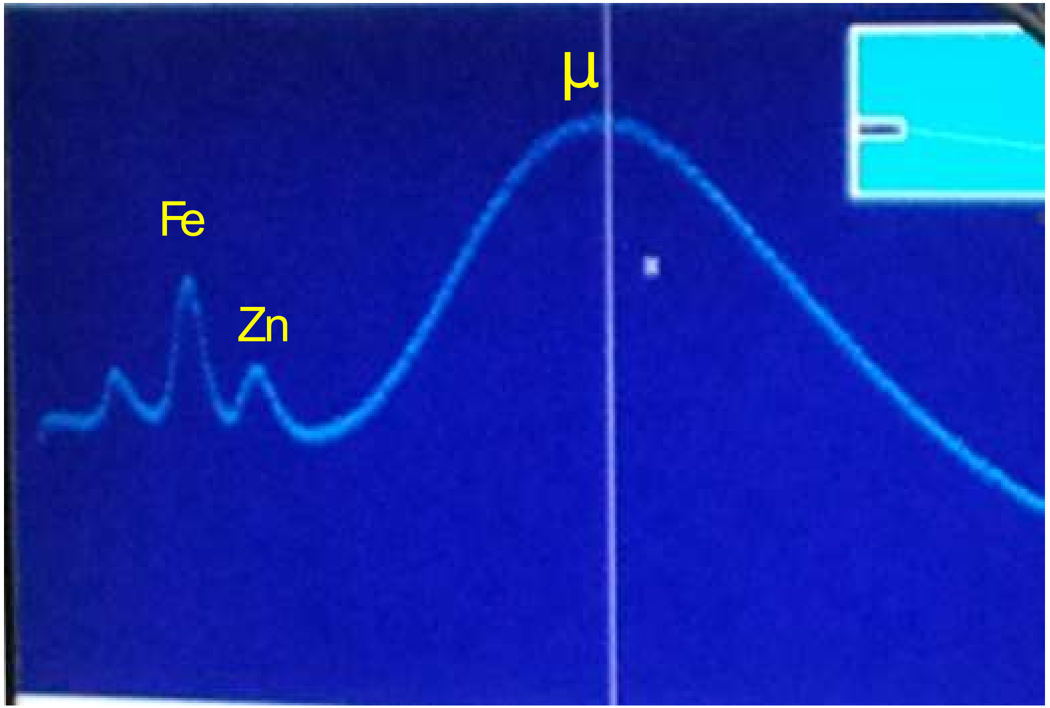
CERN, Osaka, IUAC Delhi, Bose, VECC, DEI Agra, BARC, ECIL, Utkal, BITS(H), IOP, ...

Proportional Counter (PRC) Fabrication

http://www.bbc.com/news/world-asia-india-39100109

3803 PRCs fabricated 101% of required 3776 PRCs in March 2018

http://www.bbc.com/news/world-asia-india-39100109




3 May 2018


14 October 2019

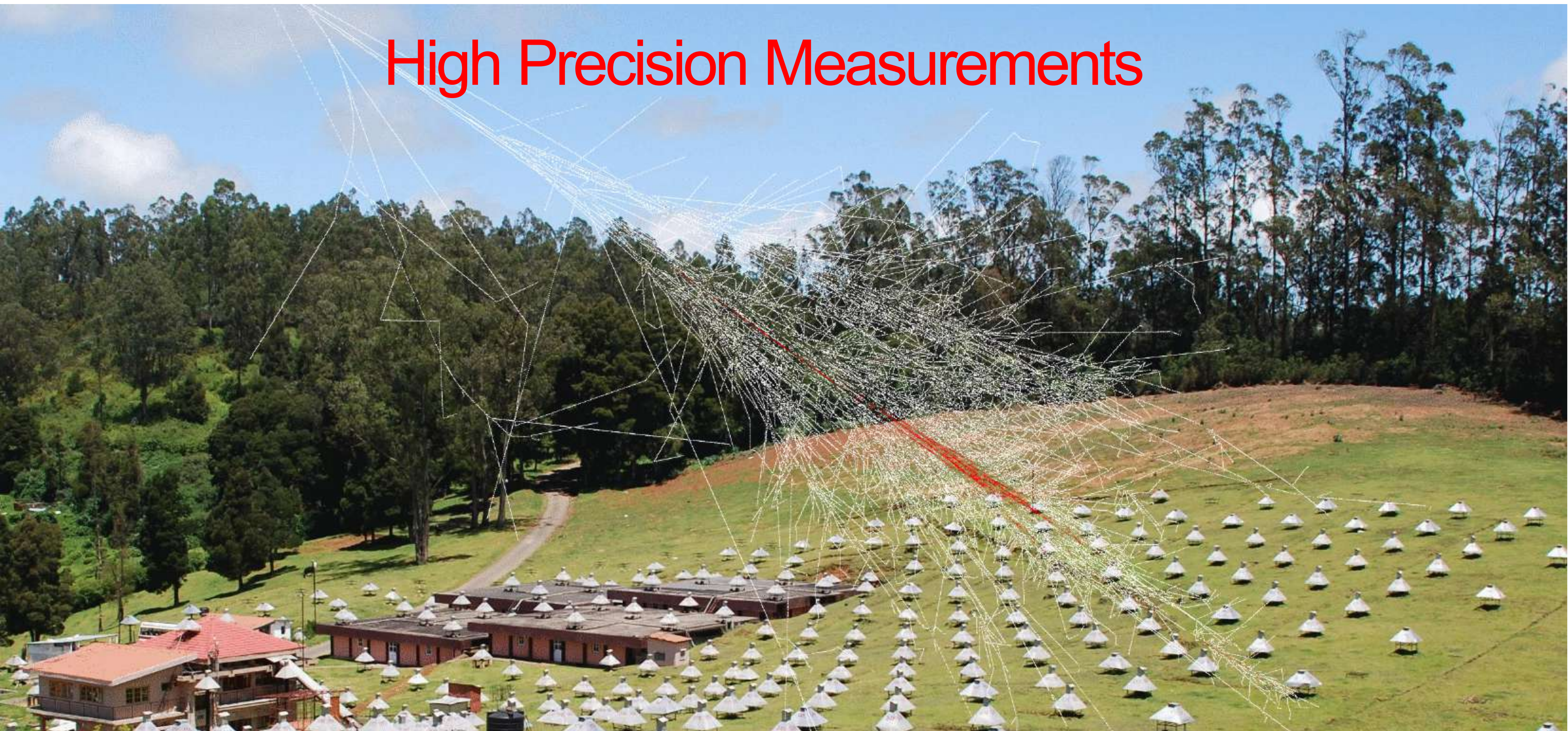
400 Plastic Scintillator detectors (1 m^2 area)

560 m^2 muon telescope (E_μ=1 GeV) (11.4N, 76.7E)

3712 Proportional Counters (6m x 0.1m x 0.1m)

E = 10^{14} eV ~20000 particles over ~1000 m^2

High Precision Measurements



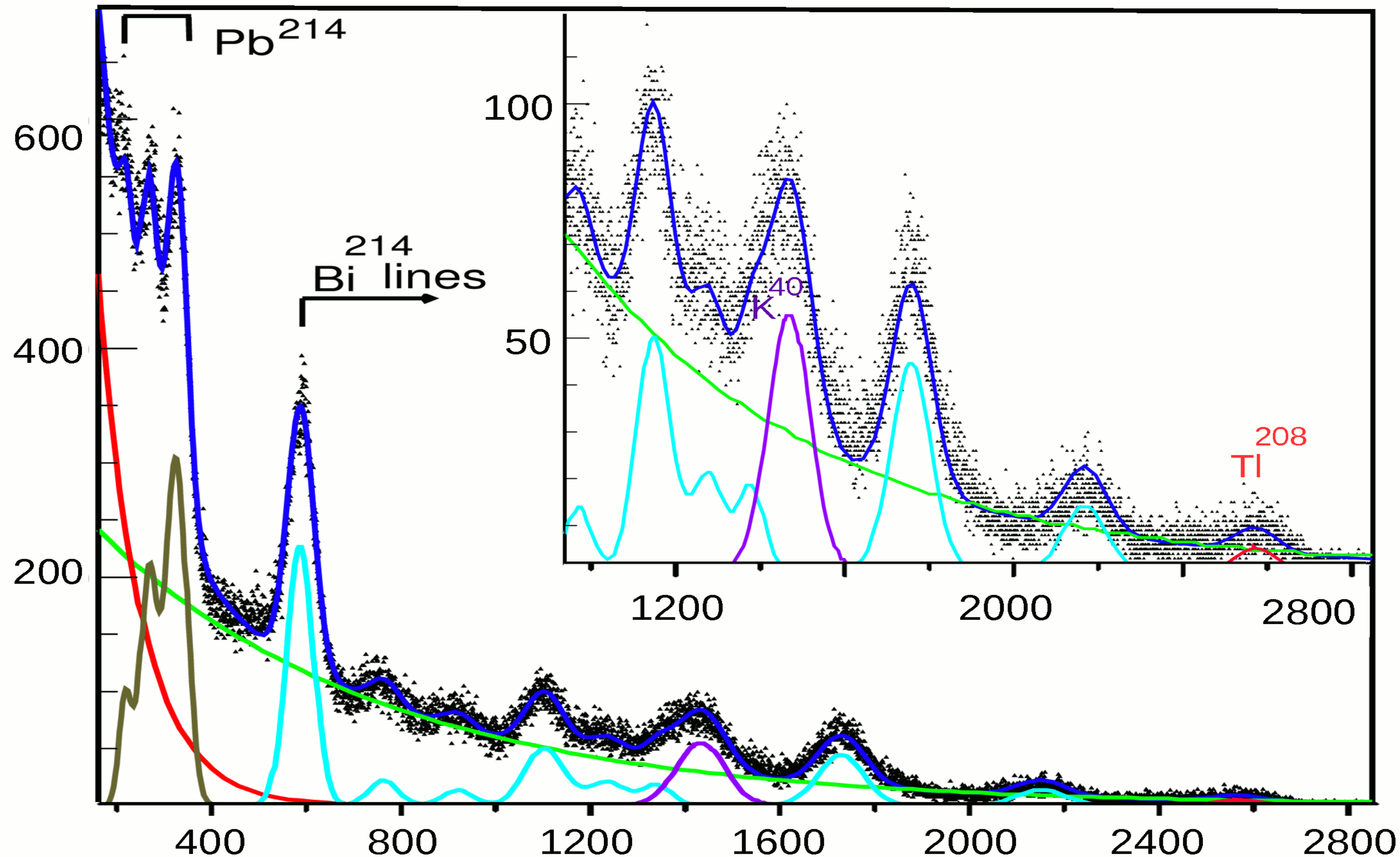
Ph.D Thesis: (1) M. Sasano (2) H. Tanaka (3) T. Nonaka (4) A. Oshima (5) M. Minamino (6) P.K. Mohanty (7) K.P. Arunbabu (8) A. Chandra (9) V. Jhansi (10) M. Zuberi (11) B. Hariharan

Current Ph.D : (12) F. Varsi, IITK (13) D. Pattanaik, UU (14) G.S. Pradhan, IITI (15) M. Chakraborty, TIFR (16) J. Soni, IITK, (17) B. Pant, IITJ (18) R. Scaria, IITI …..

	α		β		β		α		α		α	
$_{92}U^{238}$	----->	$_{90}Th^{234}$	----->	$_{91}Pa^{234}$	----->	$_{92}U^{234}$	----->	$_{90}Th^{230}$	----->	$_{88}Ra^{226}$	----->	$_{86}Rn^{222}$
$T_{1/2}$	$4.5x10^{9}$ Y		24.1 d		70.2 s $T_{1/2}$		$2.5x10^{5}$ Y		$7.5x10^{4}$ Y		1600 Y	

	α		α		β,γ		β,γ	
$_{86}Rn^{222}$	----->	$_{84}Po^{218}$	----->	$_{82}Pb^{214}$	----->	$_{83}Bi^{214}$	----->	$_{84}Po^{214}$
$T_{1/2}$	3.82 d		3.1 d		26.8 min		19.9 min	

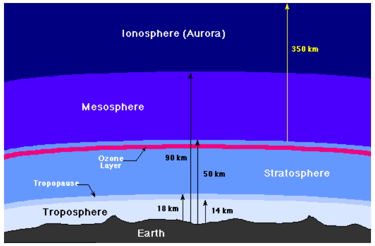
ppm 1 in 1,000,000
ppb 1 in 1,000,000,000
1 in 100,000,000,000,000,000,000
STORY OF THE EARTH



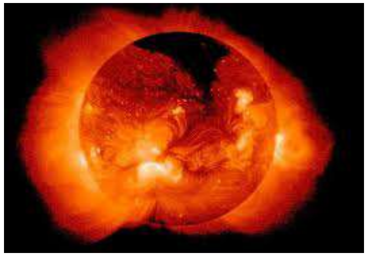
Objective: Universe at high energies

Acceleration, propagation of high energy particles,
Extreme conditions may require new physics ...

1. Acceleration in atmospheric electric field
   Energy ~1 GeV   Scale ~10^{6}-10^{7} cm



2. Solar flares, Coronal Mass Ejections
   Energy ~10 GeV   Scale ~10^{11}-10^{13} cm



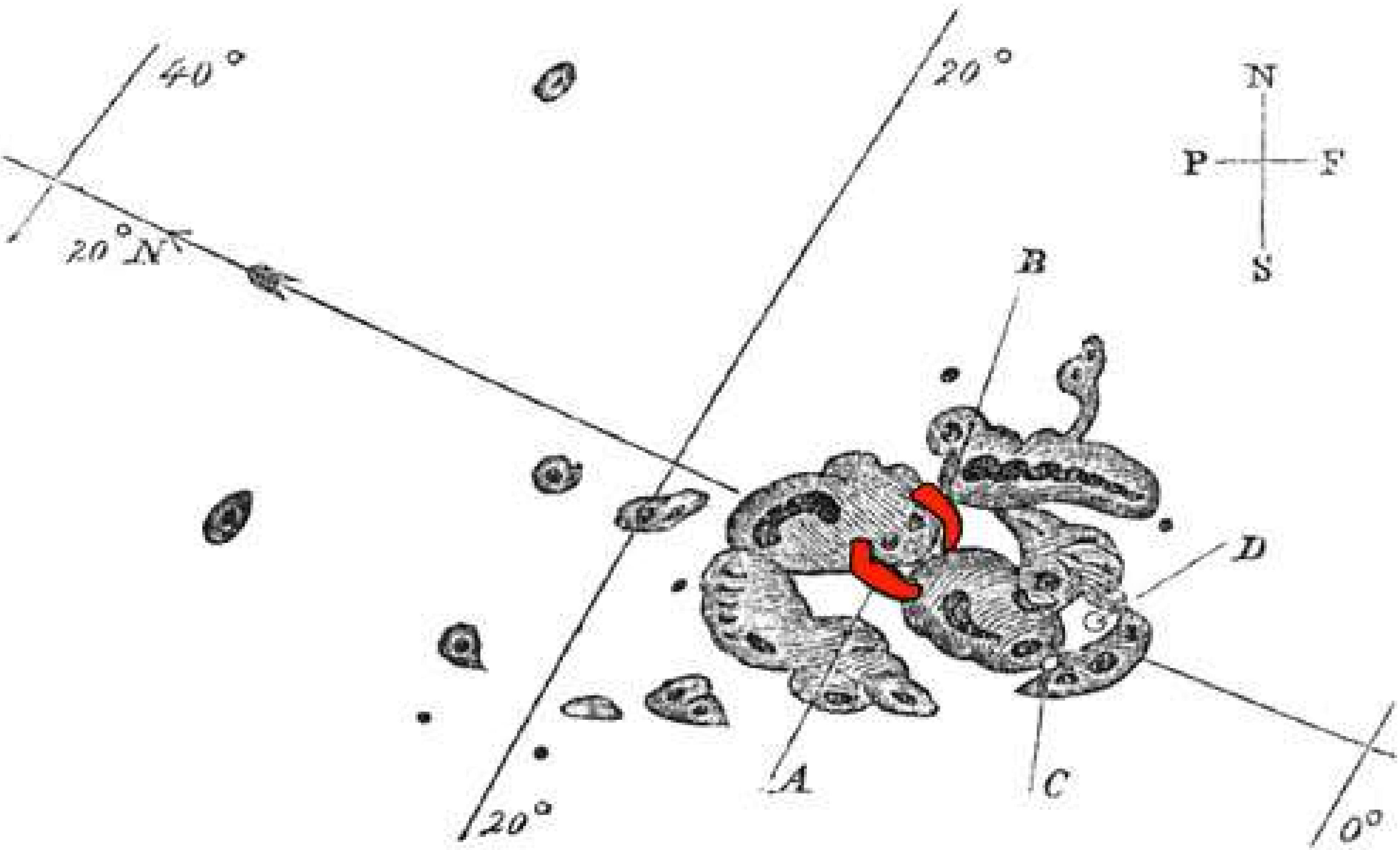
3. Galactic Cosmic Rays at "Knee"
   Energy ~1 PeV   Scale ~10^{21}-10^{23} cm

4. Diffuse multi-TeV **γ**-rays
   Energy ~100 EeV   Scale ~10^{24}-10^{26} cm


GRAPES-3 has most sensitive muon telescope
Total area = 560 m2


Inside view of
muon telescope

28 August 1859 two bright regions “A” and “B” in a sunspot seen by Carrington. On 1 September 1859 biggest solar storm reached Earth at 2400 km/s, aurorae seen at low latitudes, DST=-1600 nT, disrupted telegraph lines in Europe and USA.



http://www.sciencemag.org/news/2016/07/here-s-how-world-could-end-and-what-we-can-do-about-it

Here's how the world could end—and what we can do about it

sciencemag.org/news/2016/07/here-s-how-world-could-end-and-what-we-can-do-about-it

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

08/07/2016

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.

whitehouse.gov/the-press-office/2016/10/13/executive-order-coordinating-efforts-prepare-nation-space-weather-events

EXECUTIVE ORDER

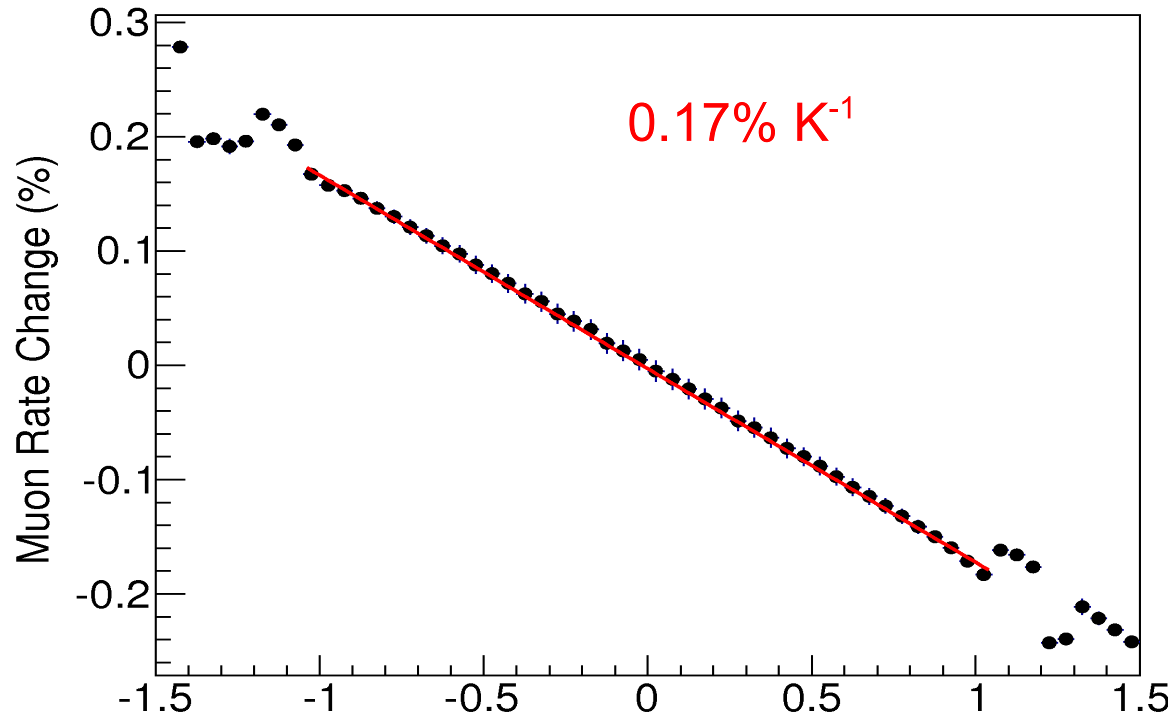
COORDINATING EFFORTS TO PREPARE THE NATION FOR SPACE WEATHER EVENTS

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:

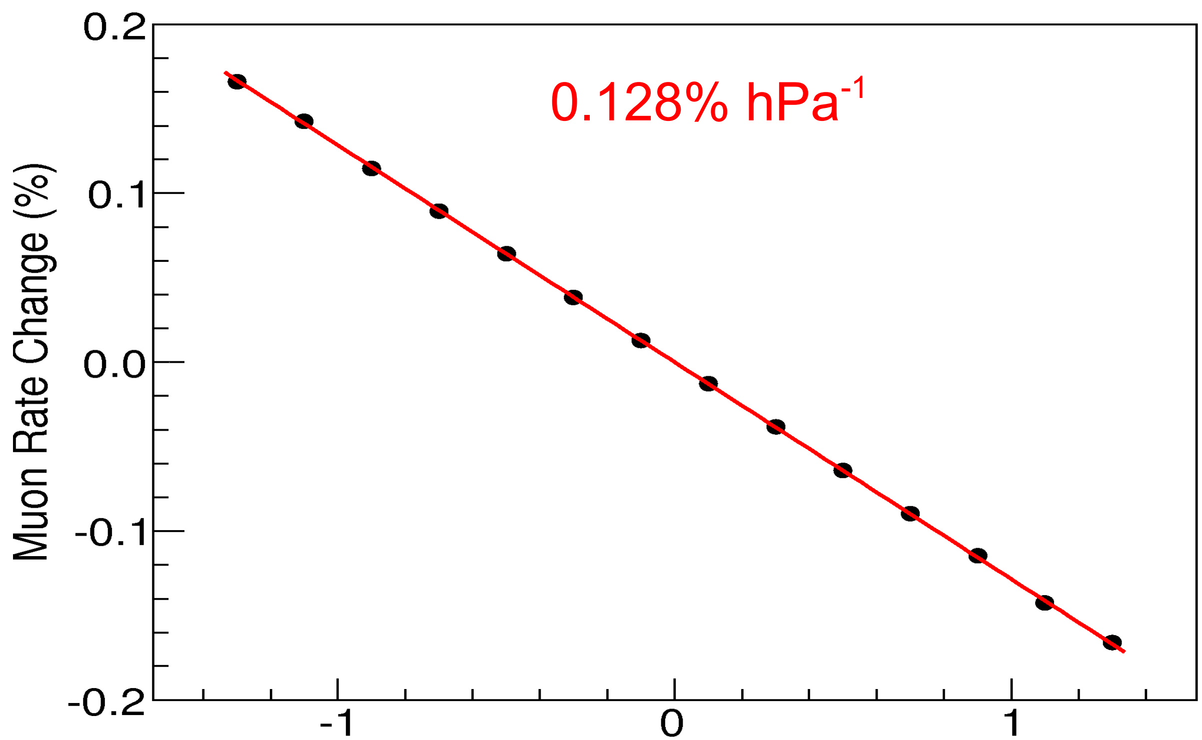
Section 1. Policy. Space weather events, in the form of solar flares, solar energetic particles, and geomagnetic disturbances, occur regularly, some with measurable effects on critical infrastructure systems and technologies, such as the Global Positioning System (GPS), satellite operations and communication, 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.

Terminology:
Solar flare → coronal mass ejection → solar storm → geomagnetic storm {Space weather}

0.06 ℃ = 1σ



20 cm air column = 1σ



GRAPES-3 is unique instrument, being a sensitive,

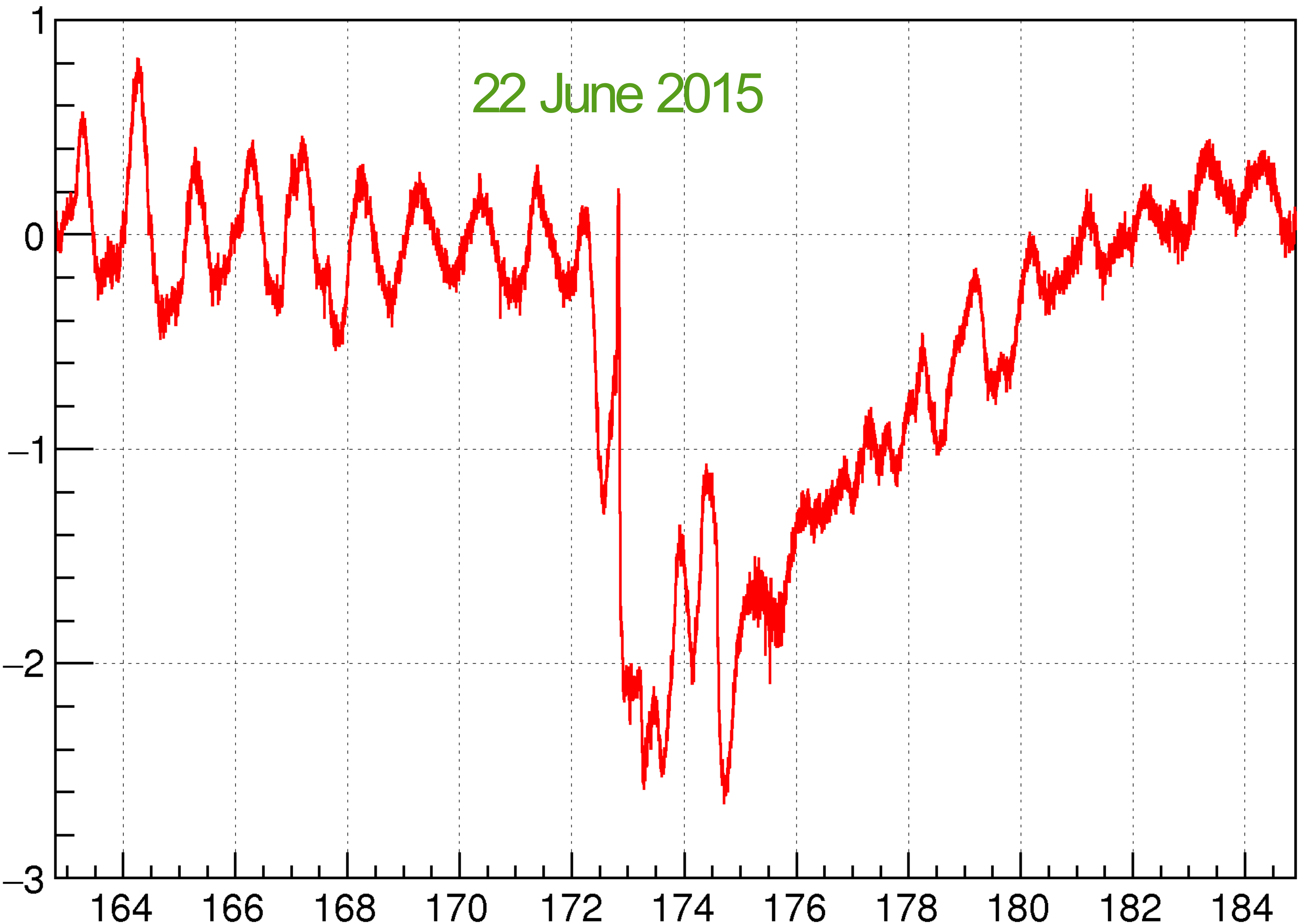
1. Barometer (20 cm air column or 1/2000 blood pressure change)

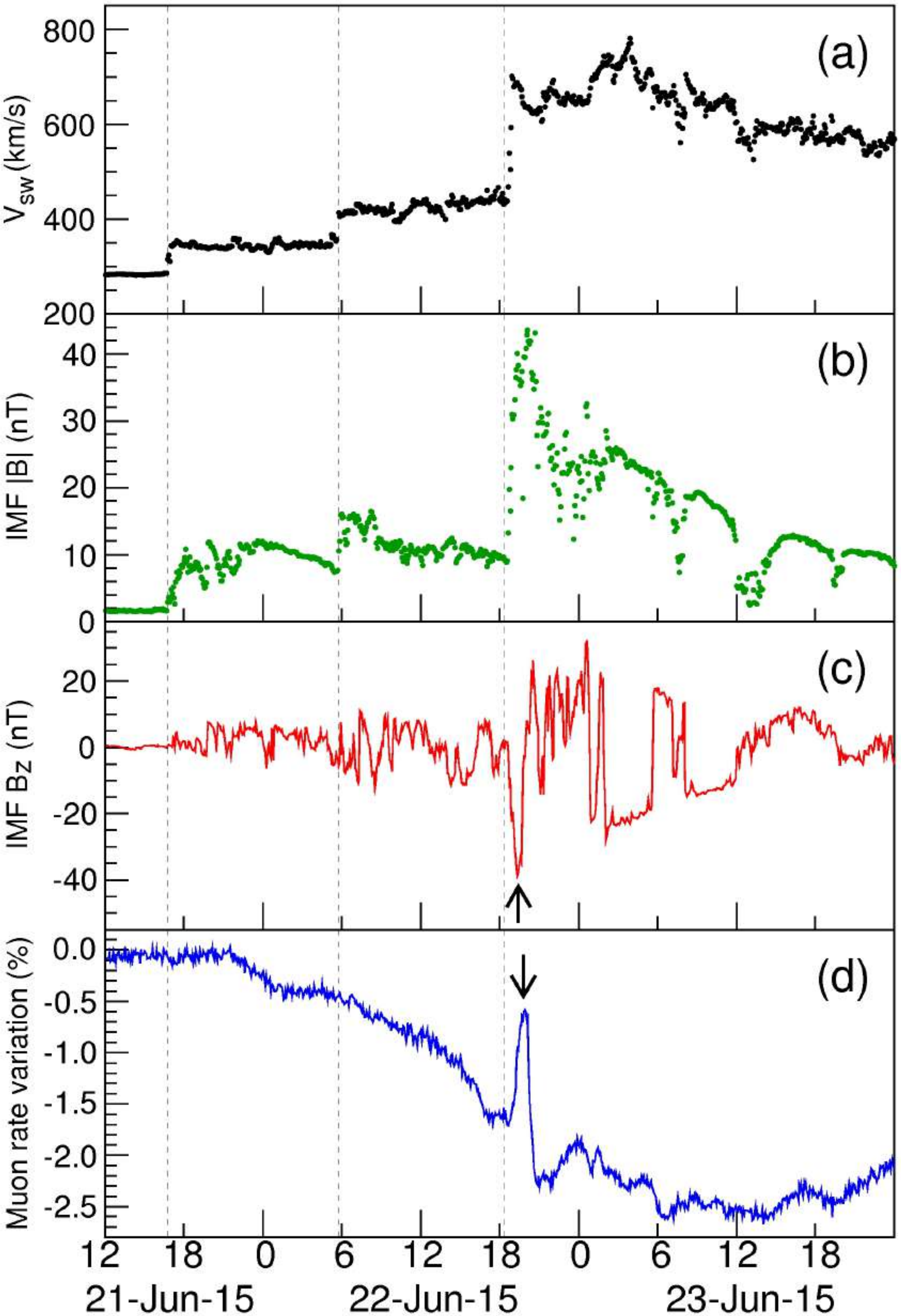
2. Thermometer (0.06^{o} C)

3. Interplanetary magnetometer (0.1 nT = 10^{-6} Geomagnetic field)

4. Atmospheric Voltmeter (GV electric potential)

5. Atmospheric ammeter (1 f A; precision=1 A A or 10^{-18} A)


22 June 2015
1
0
−1
−2
−3
164
166
168
170
172
174
176
178
180
182
184

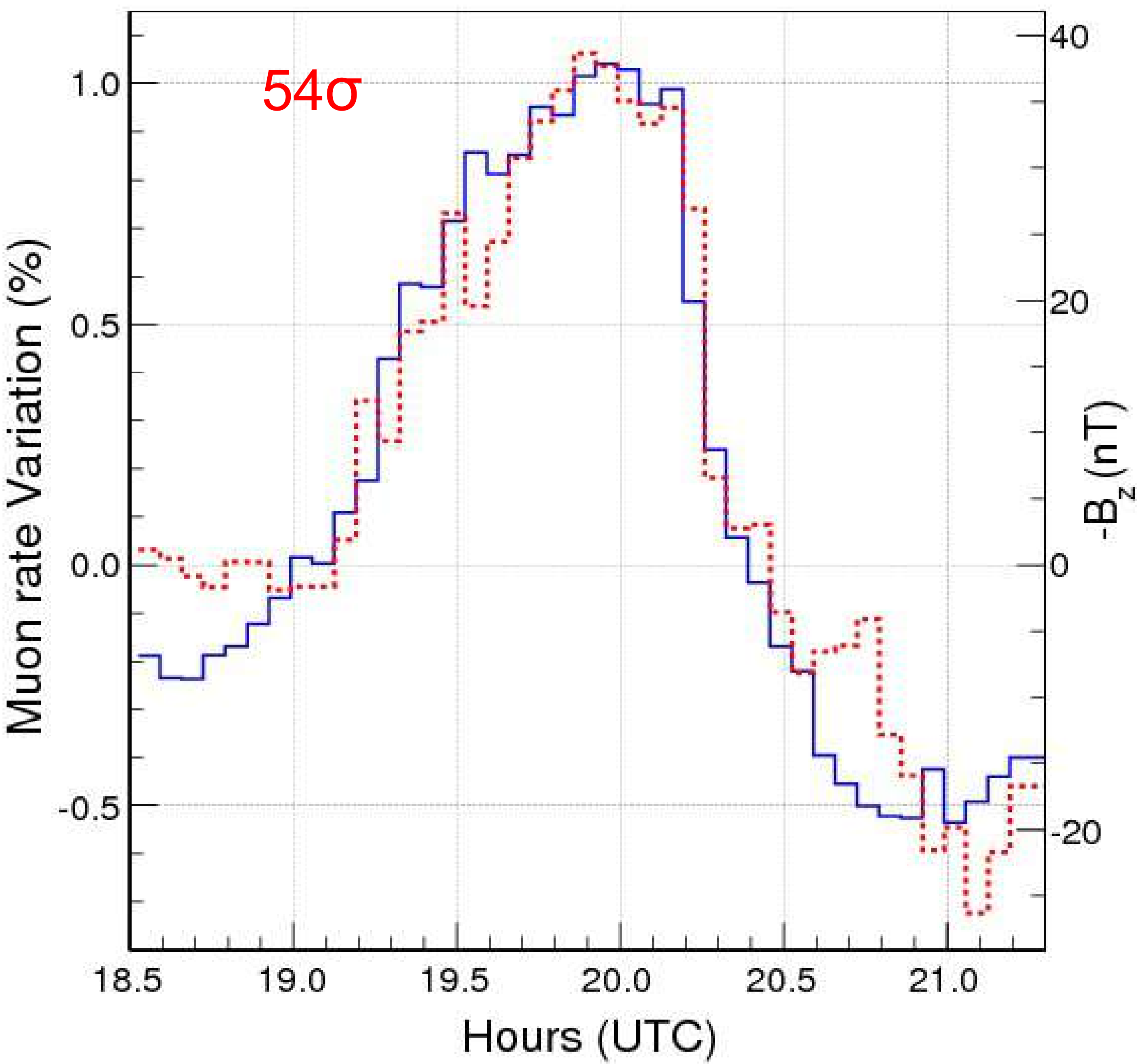


Massive Solar storm
of 22 June 2015

Mass=10^{10} tonne
Energy=10^{33} erg
Solar power= $4x10^{33}$ erg/s

Initial Speed= 1400 km/s
Speed at L1=700 km/s

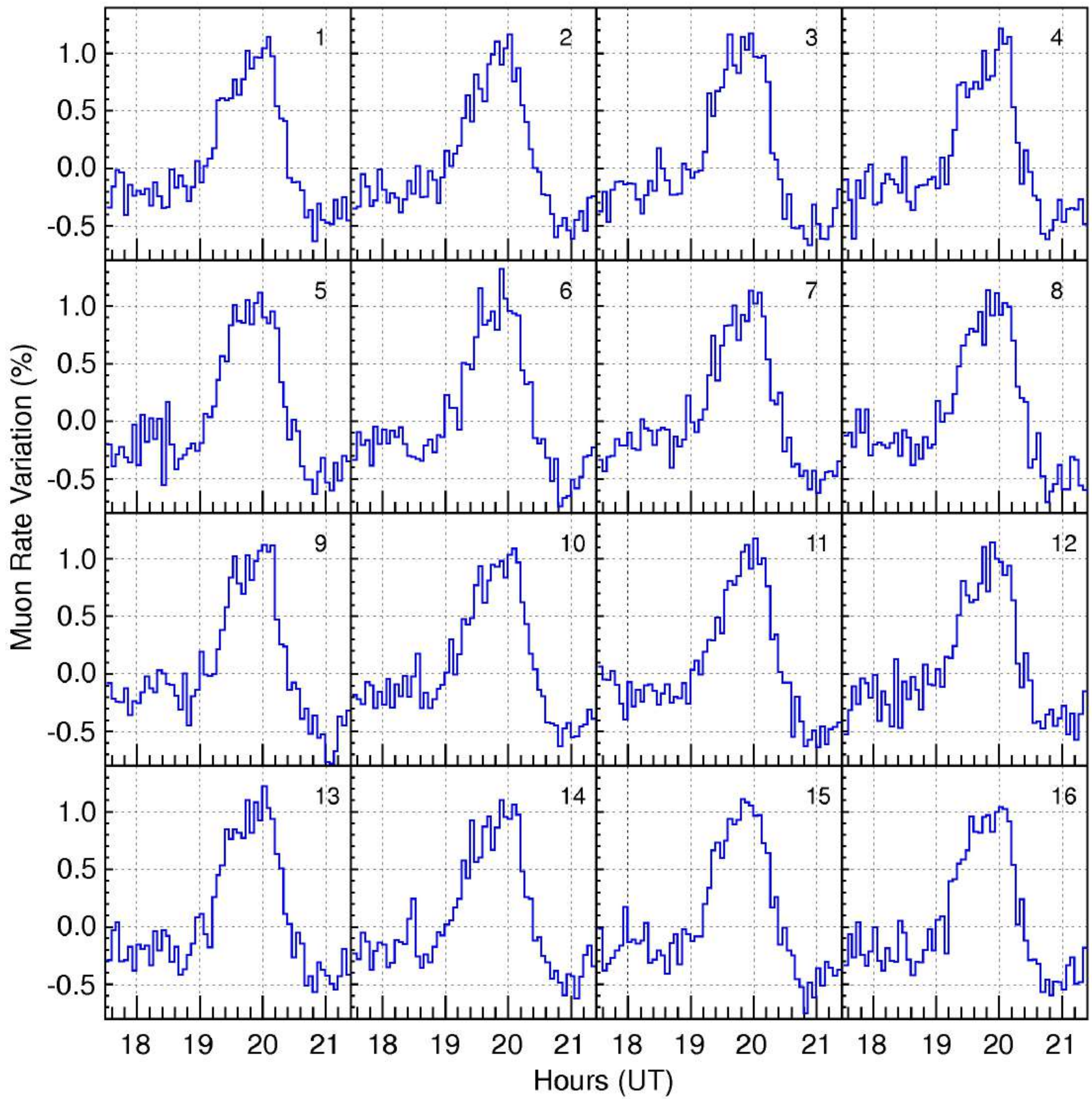
Solar Storm on 22 June 2015 Ooty, midnight



CME characteristics
for 22 June 2015 event

Mass=10^{10} tonne
Energy=10^{33} erg
Solar power= 4×10^{33} erg/s

Initial Speed= 1400 km/s
Speed at L1=700 km/s

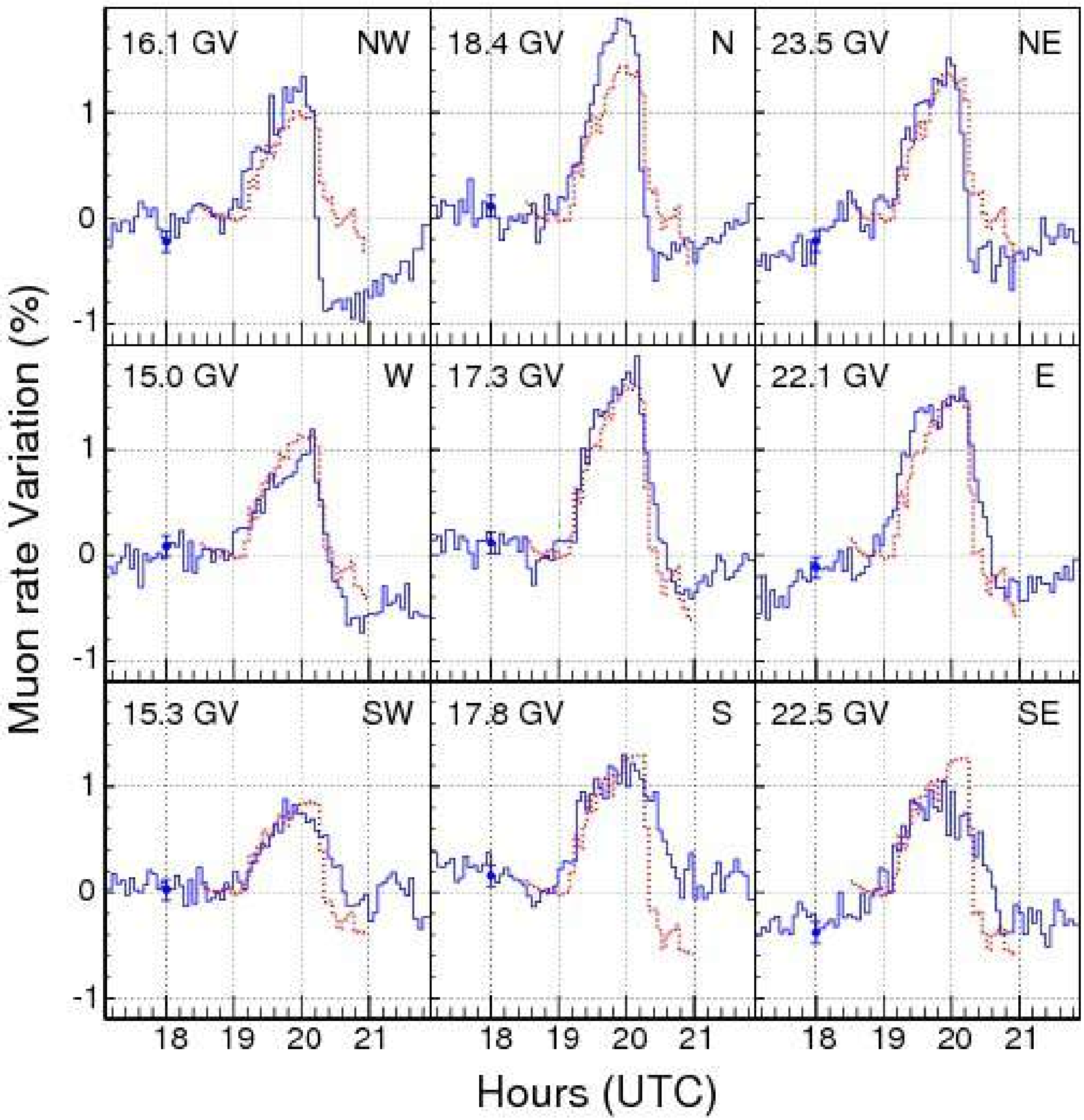


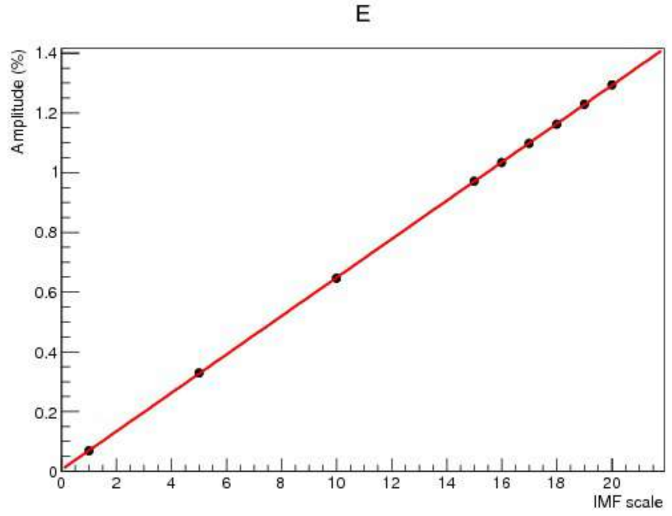
Muon Rate Variation (%)
Hours (UT)
1.0
0.5
0.0
-0.5
18
19
20
21
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

13σ

-Bz=680 nT

28 minutes

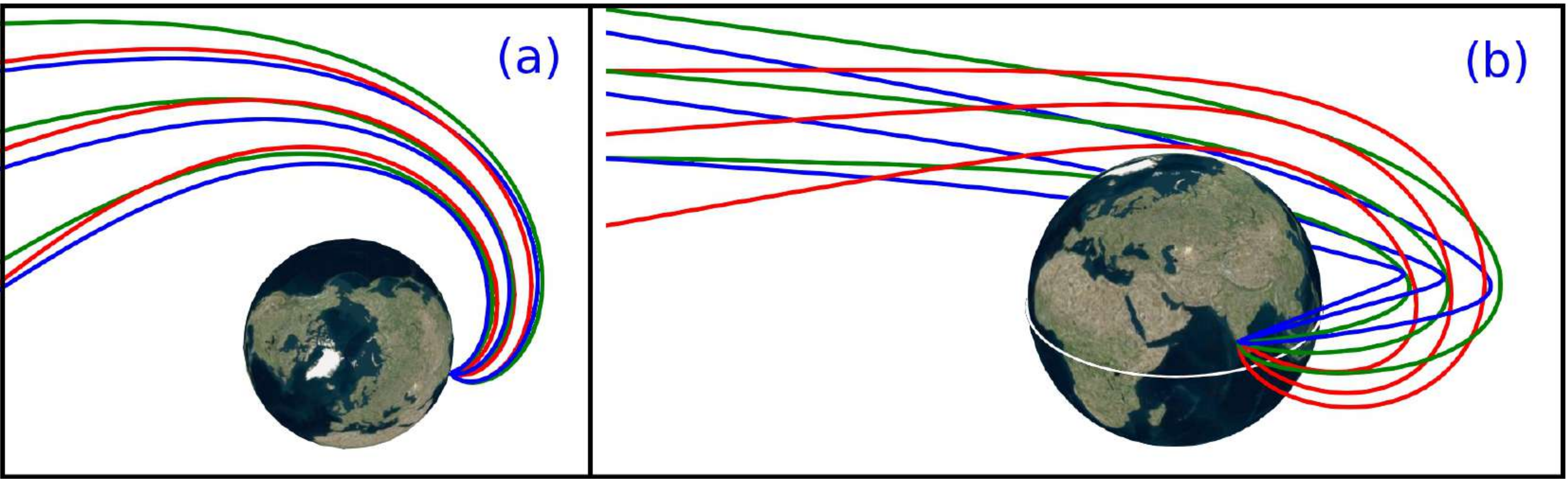




0.7 GeV

0.6 GeV

0.5 GeV



NW N NE W V E SW S SE

Transient Weakening of Earth's Magnetic Shield Probed by a Cosmic Ray Burst

P. K. Mohanty, K. P. Arunbabu, T. Aziz, S. R. Dugad, S. K. Gupta,*
B. Hariharan, P. Jagadeesan, A. Jain, S. D. Morris, and B. S. Rao
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Faculty of Engineering, Aichi Institute of Technology, Toyota City, Aichi 470-0392, Japan†
(Received 16 June 2016; published 20 October 2016)

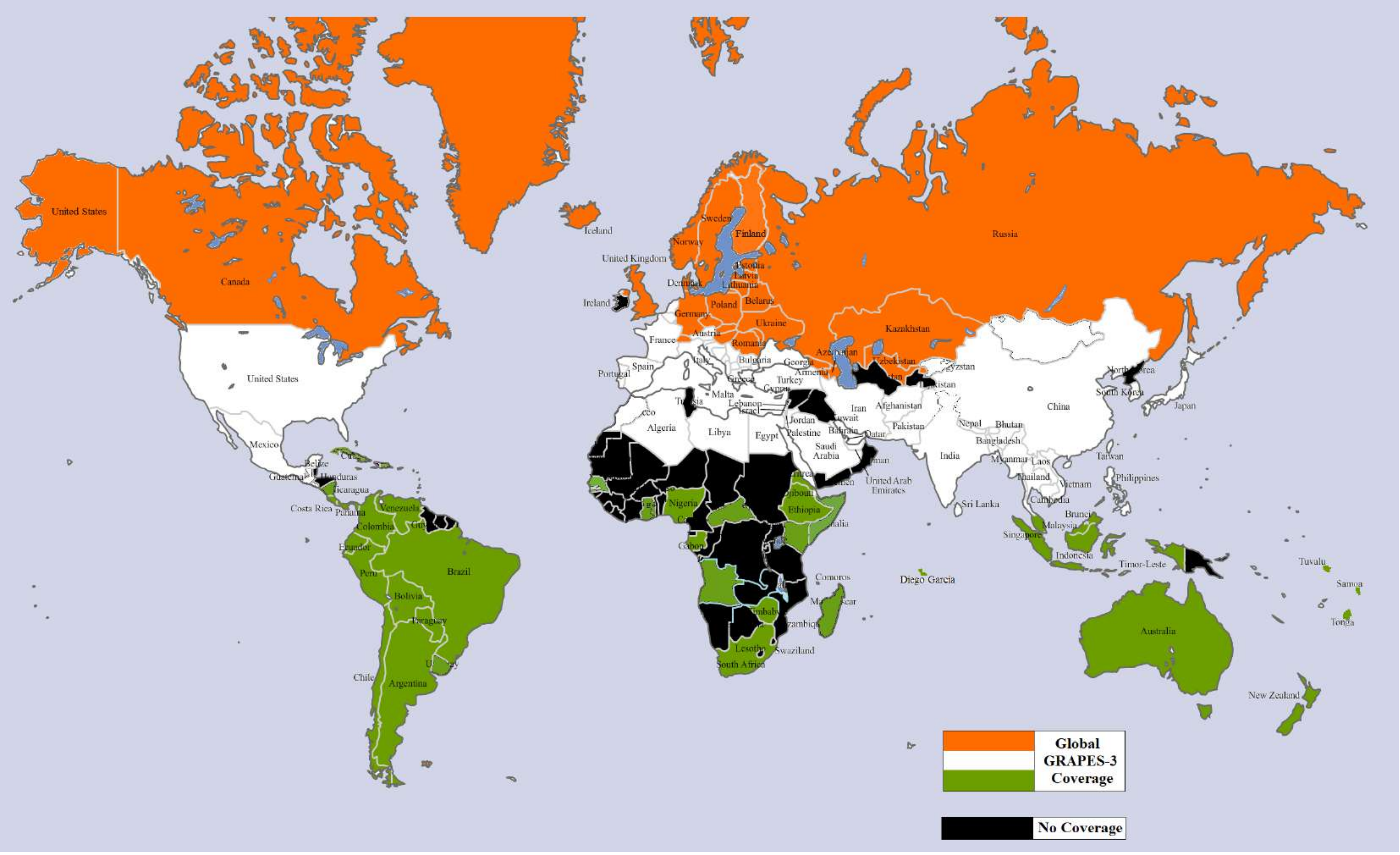
The GRAPES-3 tracking muon telescope in Ooty, India measures muon intensity at high cutoff rigidities (15–24 GV) along nine independent directions covering 2.3 sr. The arrival of a coronal mass ejection on 22 June 2015 18:40 UT had triggered a severe G4-class geomagnetic storm (storm). Starting 19:00 UT, the GRAPES-3 muon telescope recorded a 2 h high-energy (~20 GeV) burst of galactic cosmic rays (GCRs) that was strongly correlated with a 40 nT surge in the interplanetary magnetic field (IMF). Simulations have shown that a large (17×) compression of the IMF to 680 nT, followed by reconnection with the geomagnetic field (GMF) leading to lower cutoff rigidities could generate this burst. Here, 680 nT represents a short-term change in GMF around Earth, averaged over 7 times its volume. The GCRs, due to lowering of cutoff rigidities, were deflected from Earth's day side by ~210° in longitude, offering a natural explanation of its night-time detection by the GRAPES-3. The simultaneous occurrence of the burst in all nine directions suggests its origin close to Earth. It also indicates a transient weakening of Earth's magnetic shield, and may hold clues for a better understanding of future superstorms that could cripple modern technological infrastructure on Earth, and endanger the lives of the astronauts in space.

DOI: 10.1103/PhysRevLett.117.171101

Worldwide coverage in 119 Countries, 24 YouTube Videos

1093 Reports in 37 Languages

https://www.youtube.com/watch?v=IYFt40J12go&t=98s

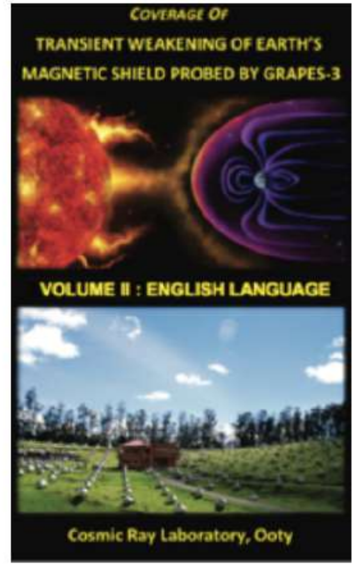


grapes-3.tifr.res.in/discovery.html

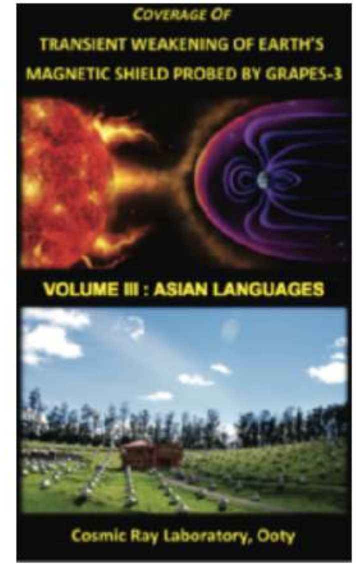
119 Countries, 1093 Reports, 37 Languages

Vol-1

Vol-2



Vol-3

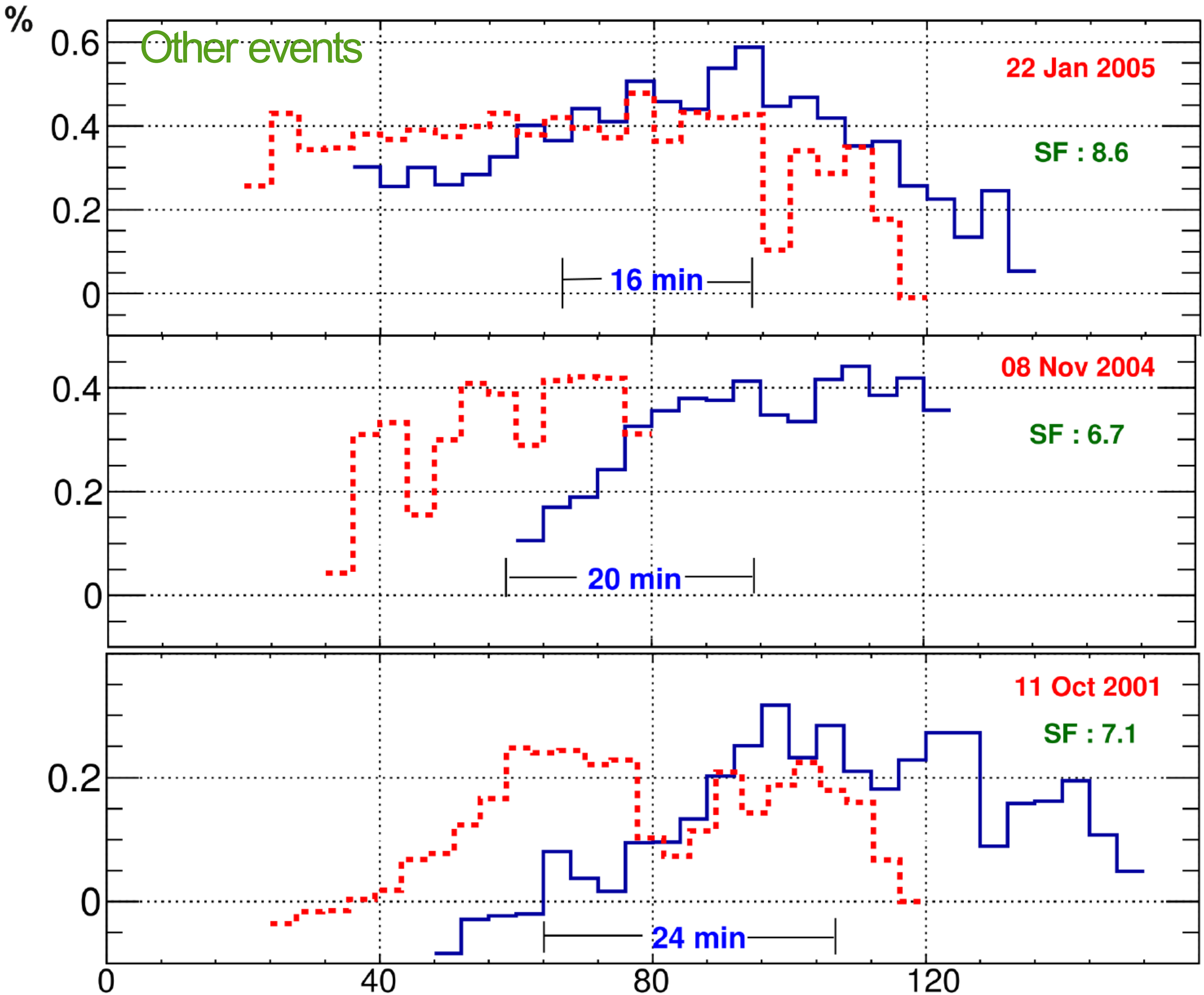


Vol-4

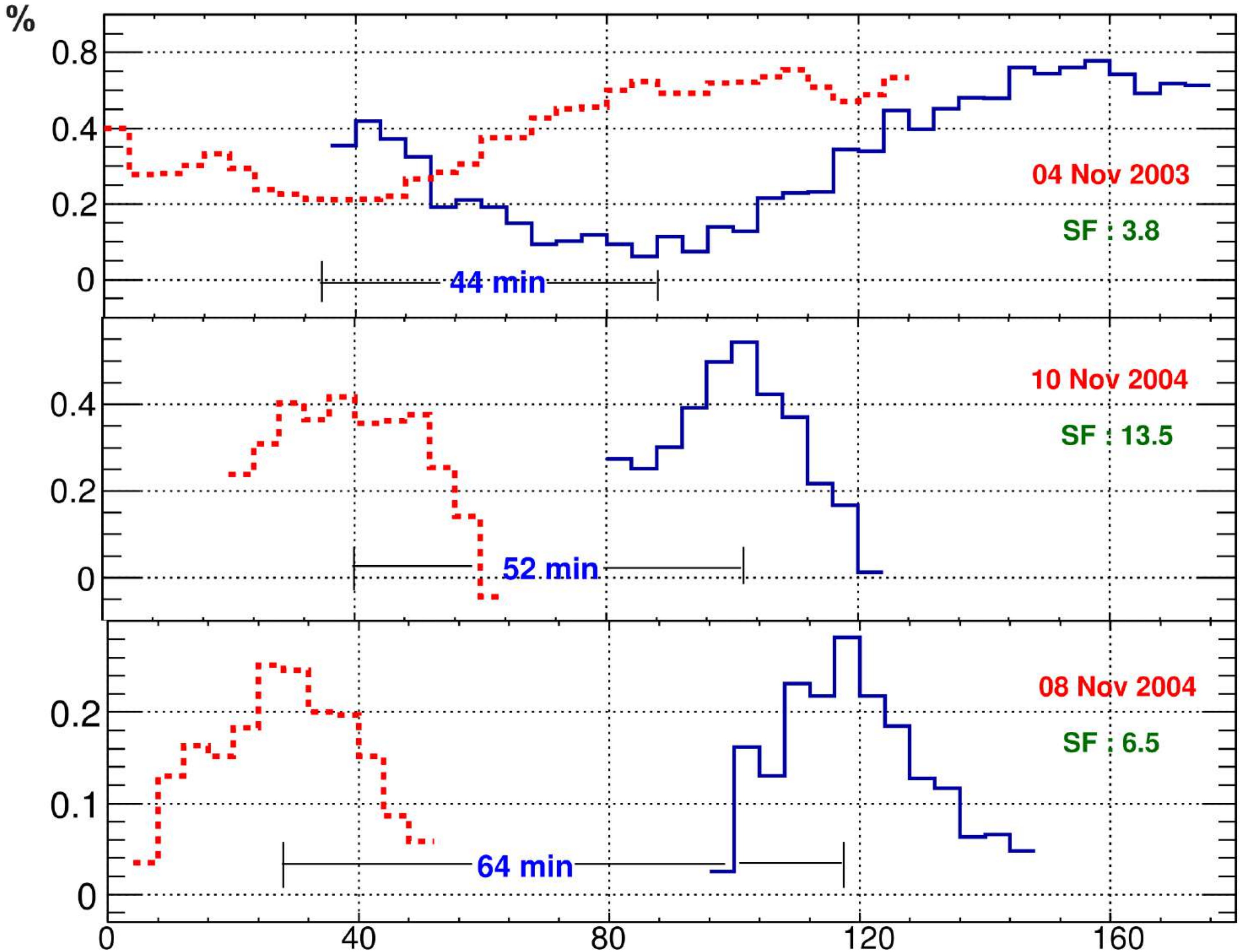
Vol-5

Vol-6

Video



%
Other events
22 Jan 2005
SF : 8.6
16 min
08 Nov 2004
SF : 6.7
20 min
11 Oct 2001
SF : 7.1
24 min
0.6
0.4
0.2
0
0
40
80
120



%
0.8
0.4
0.2
0
04 Nov 2003
SF : 3.8
44 min
0.4
0.2
0
10 Nov 2004
SF : 13.5
52 min
0.2
0.1
0
08 Nov 2004
SF : 6.5
64 min
0
40
80
120
160

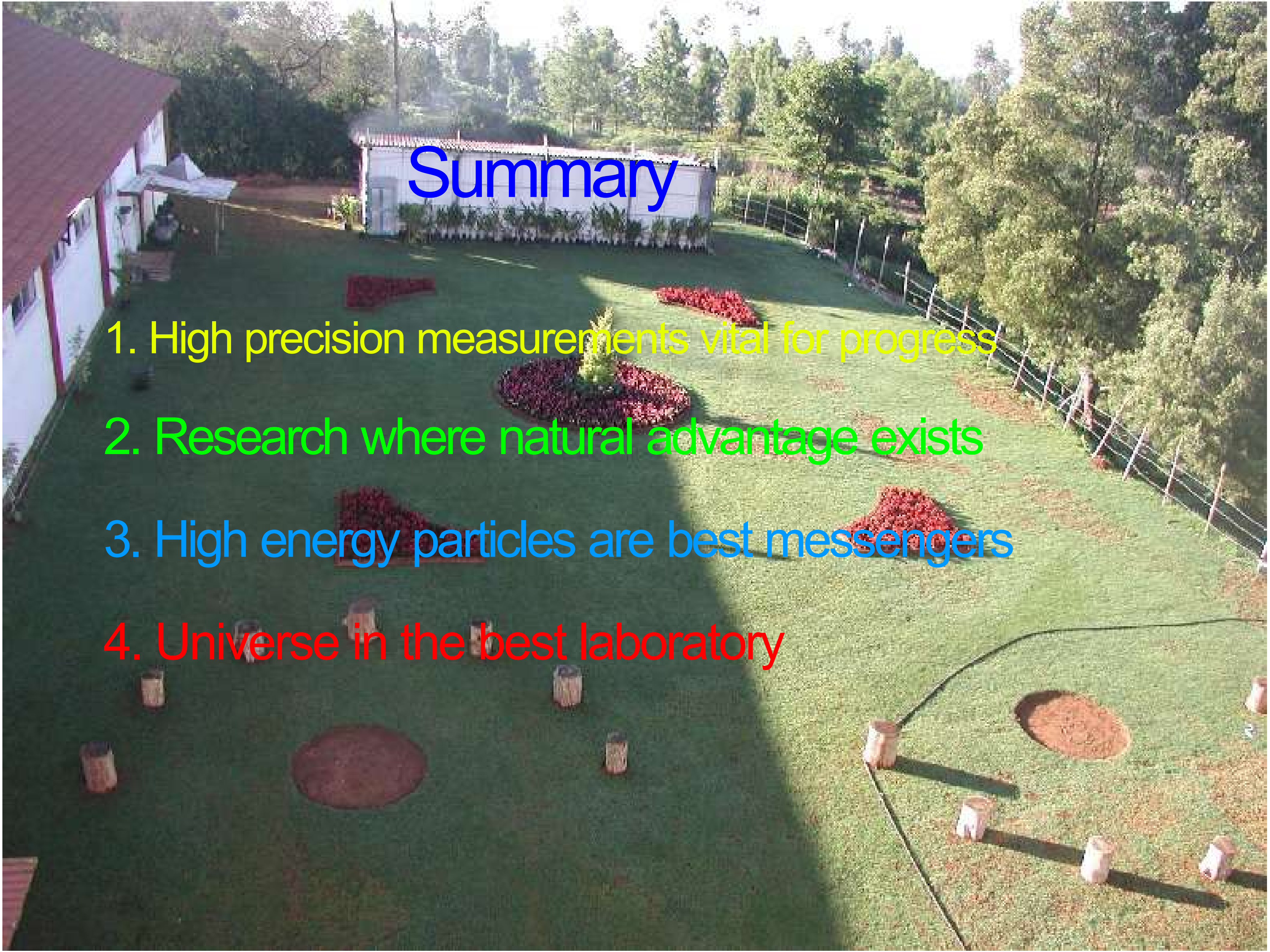
Summary

1. High precision measurements vital for progress

2. Research where natural advantage exists

3. High energy particles are best messengers

4. Universe in the best laboratory



The GRAPES-3 Team

Thanks

Workshop & Winter School on Astroparticle Physics
GRAPES-3, Ooty 17-29 December 2016

http://grapes-3.tifr.res.in

Education: ~400 attended 11 winter schools
~300 B.E./M.Sc students ~80 projects 2010-16
Visitors: ~2500 in 2016 Thanks

HPTDC (Stop Watch)

32-channels

τ=100 ps

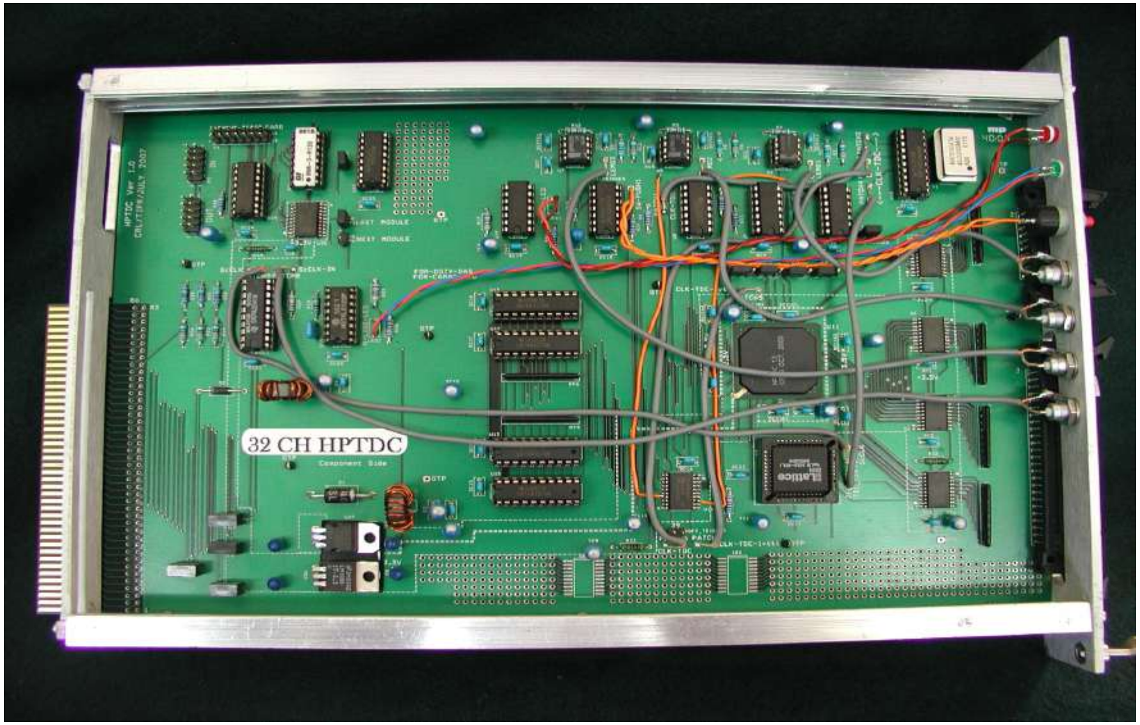
Range: 50 µs

Multi-hit capability

Trigger mode (no delay)

Novel method measuring TDC-Zero

S.K. Gupta et al. Experimental Astronomy
DOI: 10.1007/s10686-012-9320-3(2012)



Long history of India-Japan cosmic ray collaboration

(1) Visit of Prof. S. Miyake to Tata Institute in 1950s

(2) Underground experiments in KGF to study muons

(3) EAS experiments in Ooty with large Cloud Chamber

(4) Detection of first atmospheric neutrinos in 1965

(5) Search for proton decays in KGF in 1980 → neutrino experiments

(6) Inspired p-decay search in Kamiokande → supernova neutrinos

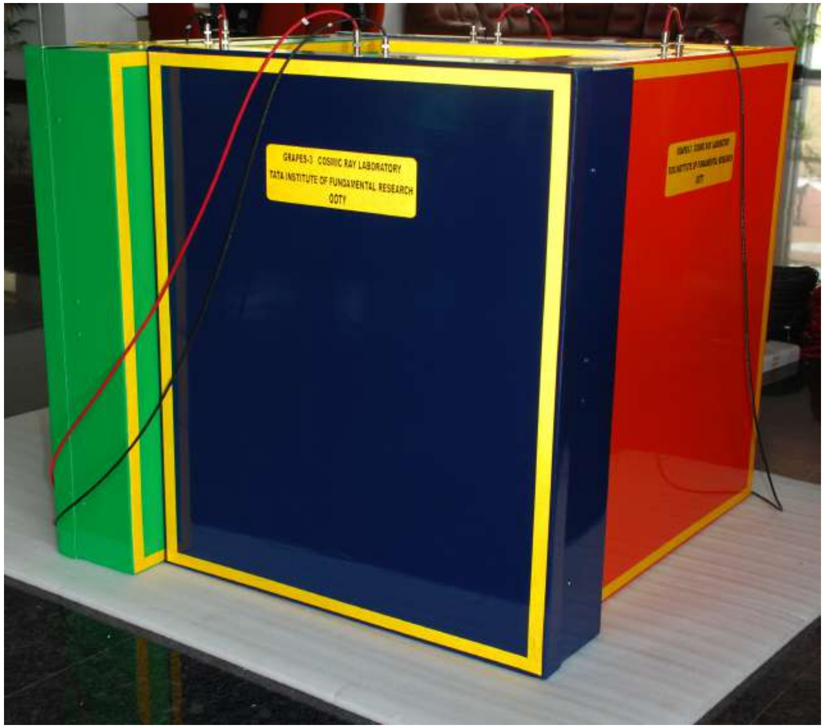
(7) Super-Kamiokande → neutrino oscillations

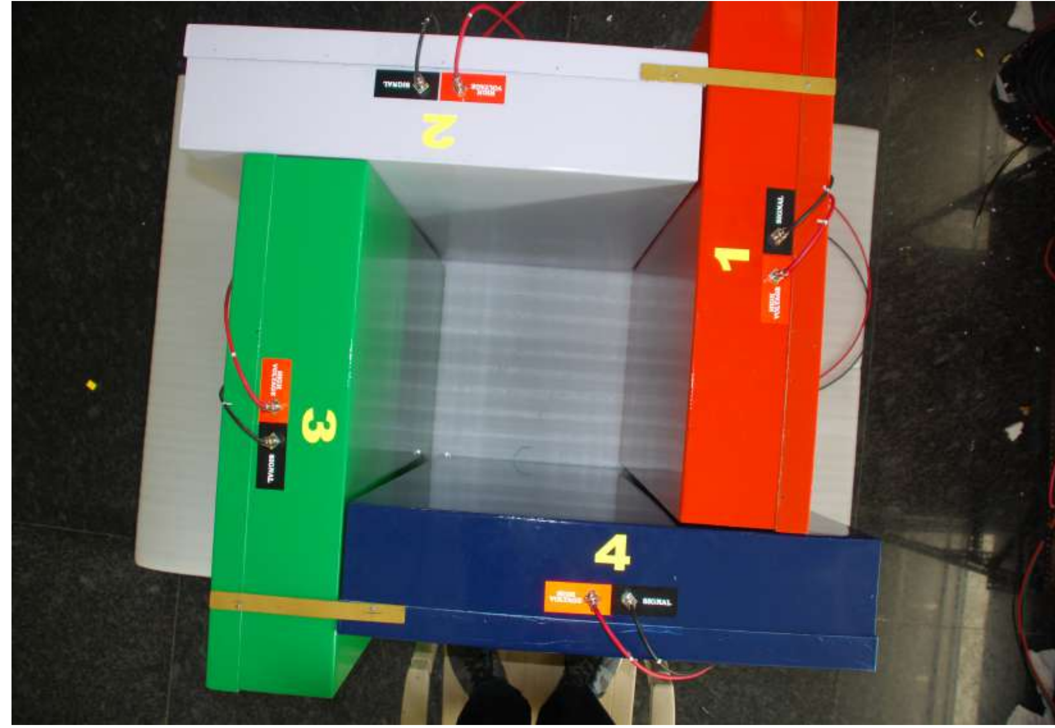
(8) Start of GRAPES-3 in 1993 → Recycled PRCs from KGF

(9) Very many Ph.D from KGF and Ooty, both Japanese Indian

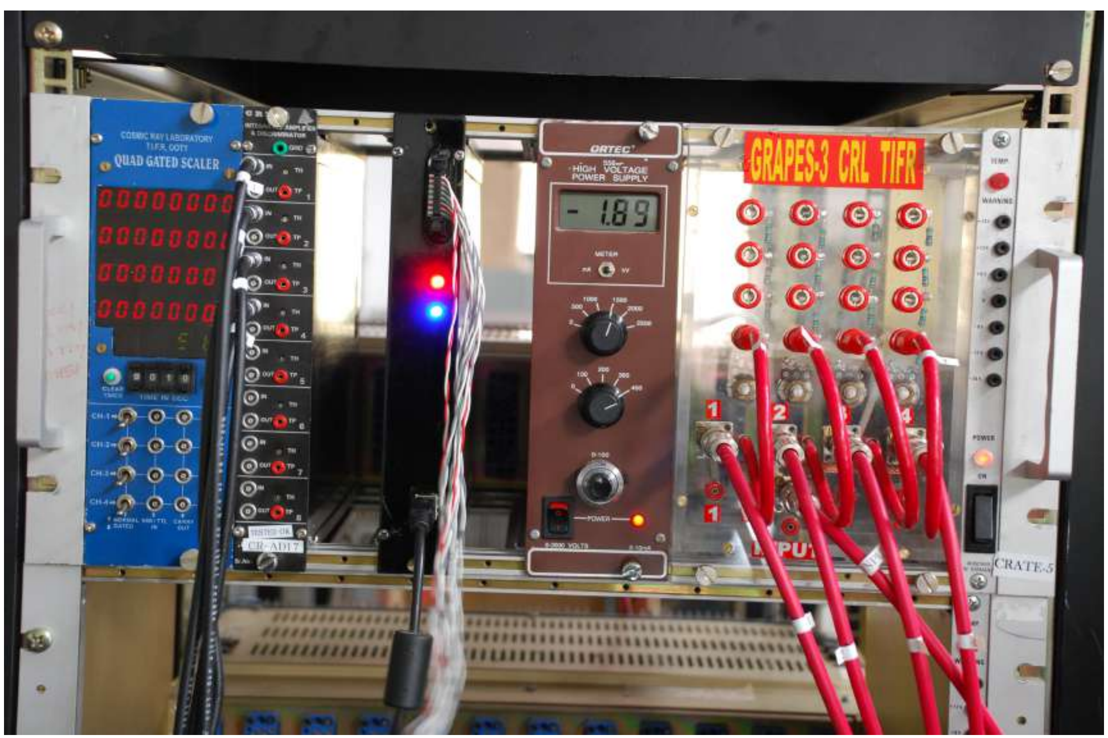
Ramanamurthy, Narasimham, Krishnaswamy, Mondal, Dugad, Mohanty, Arunbabu, Chandra, Zuberi, Jhansi, Hari

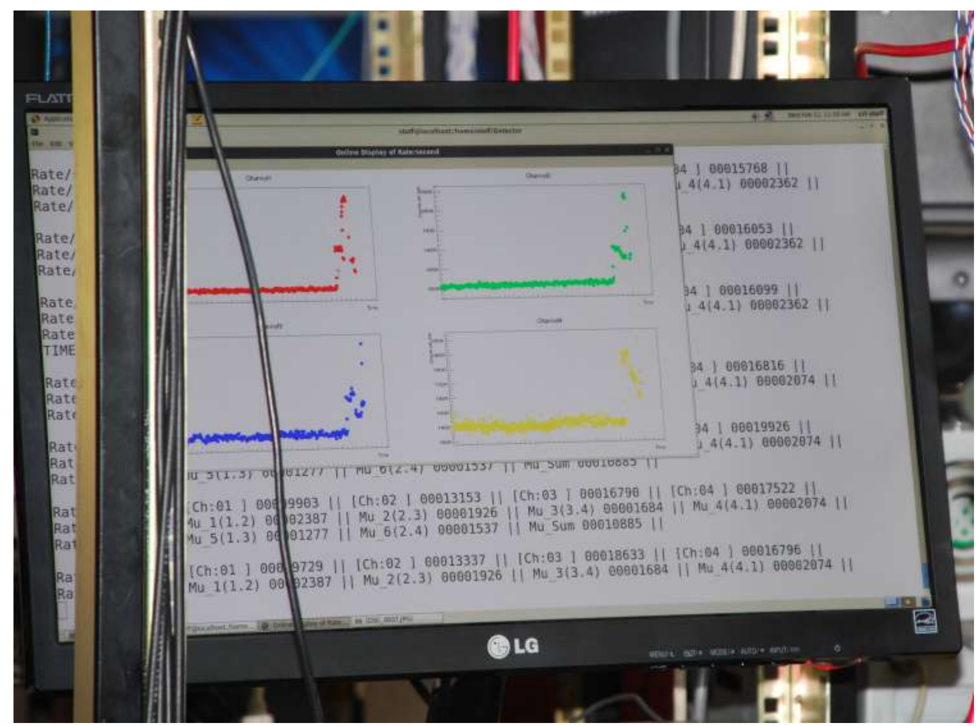
Ito, Kawakami, Hayashi, Tanaka, Nakamura, Uchihori, Sasano, Kojima, Nonaka, Oshima, Minamino





GRAPES-3 Radiation Monitor for RPG BARC





VIIT, Pune and GRAPES-3 joint R&D activity

Hardware project examples:
(1) 64 channel FPGA based scalar with Ethernet
(2) 64 channel pulse-width analysis with USB
(3) Monitoring 1000 channels of HV using Ethernet
(4) Programmable power supply (100 V)
(5) Multiple solar panel power regulation & control

Software project examples:
(6) Web-tools for remote processing of data including dynamic plots
(7) Web-based database management of calibration and other data
(8) Web-based monitoring of experiment
(9) Inventory management of detector components

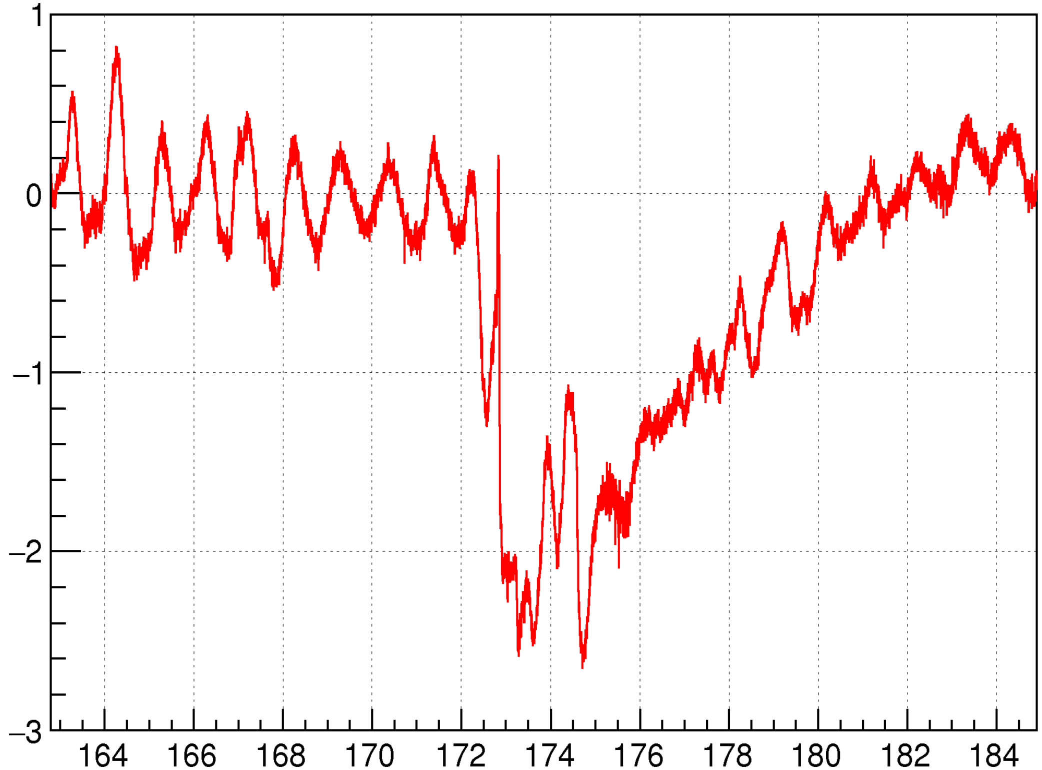
Participation during 2010-2016:

VIIT faculty	10
GRAPES-3 members	10
BE Final students	77
Projects	28
(20 Hardware + 8 Software)	

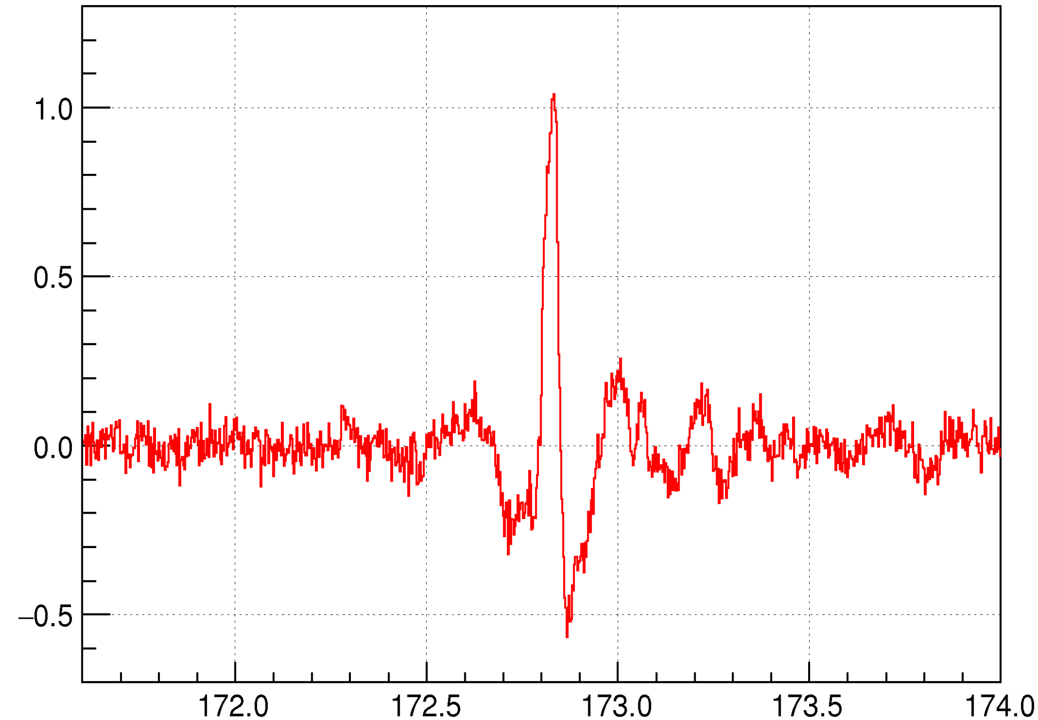
GRAPES-3 projects	= 28 (72%)	Students = 77 (73%)
Rest TIFR projects	= 11 (28%)	Students = 28 (23%)
Total projects	= 39	Students = 105

Cosmic Ray Rate for 16 modules (2006)

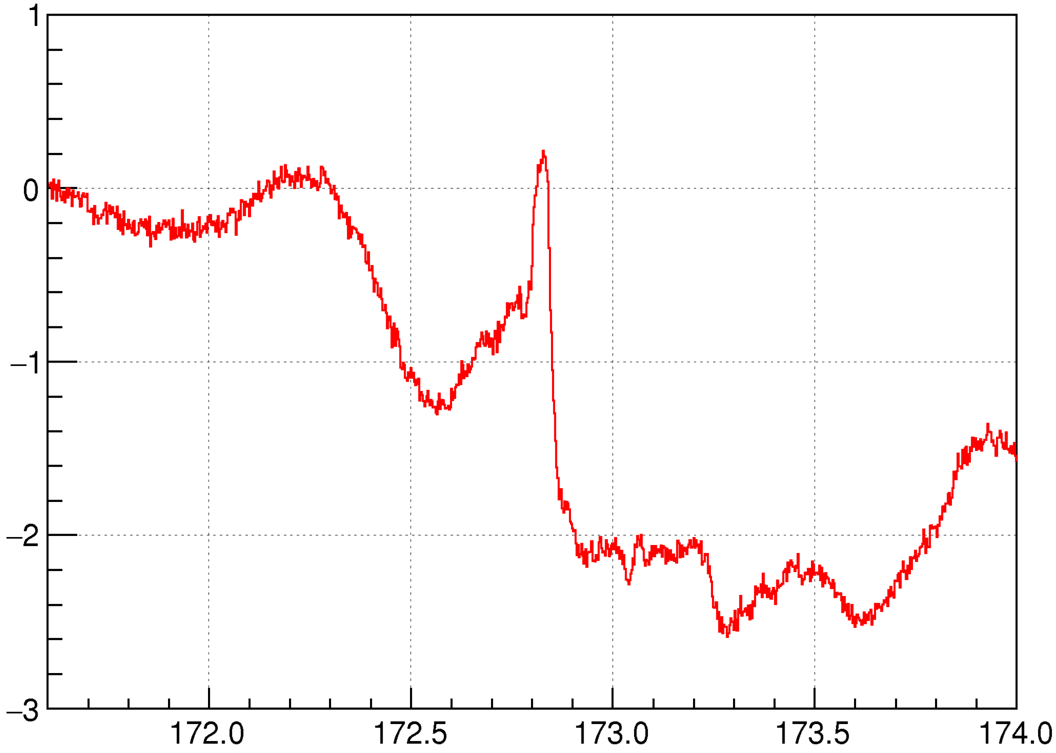
99.99%



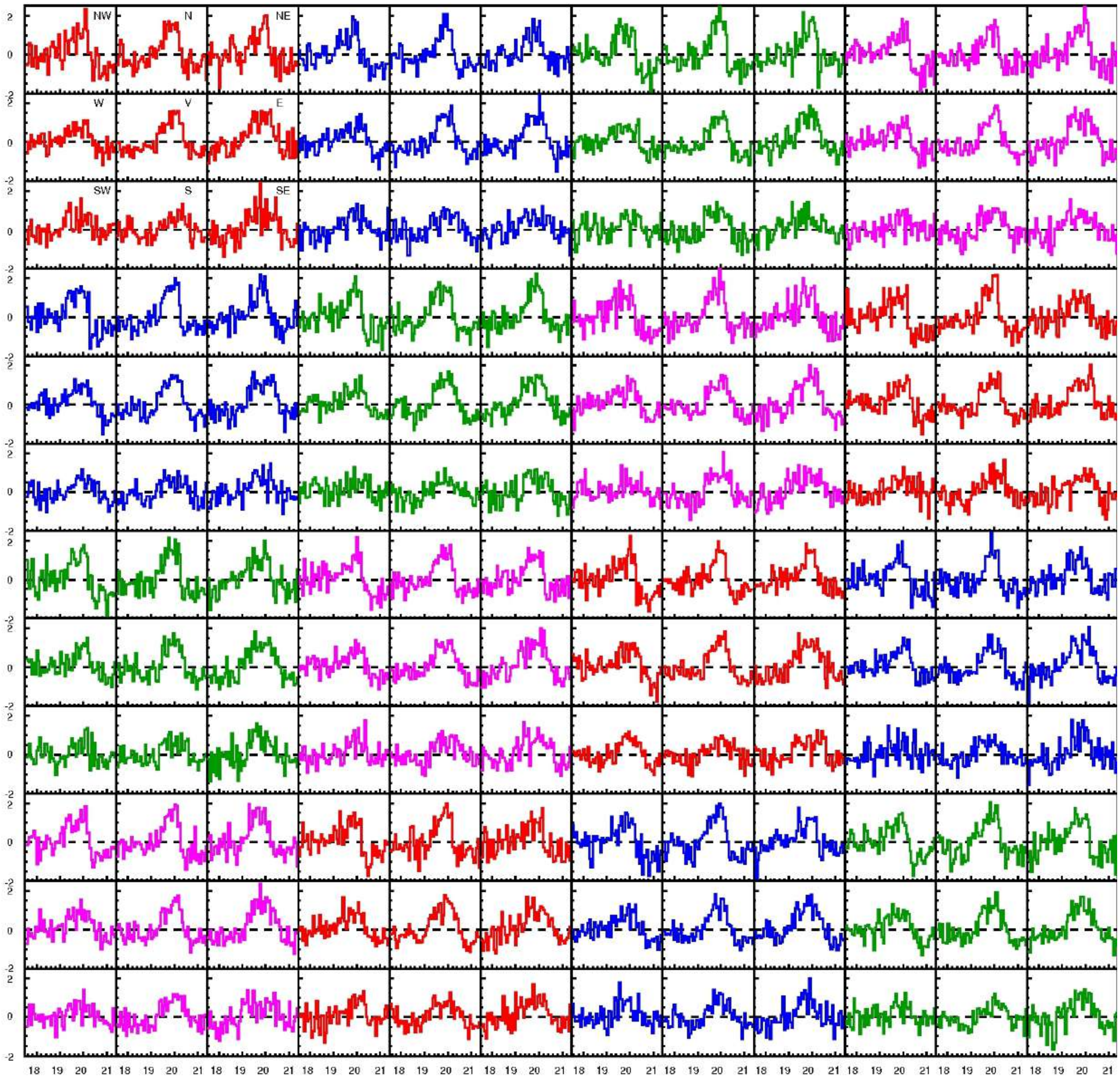
1
0
−1
−2
−3
164
166
168
170
172
174
176
178
180
182
184



1.0
0.5
0.0
−0.5
172.0
172.5
173.0
173.5
174.0



1
0
−1
−2
−3
172.0
172.5
173.0
173.5
174.0



>5σ 42

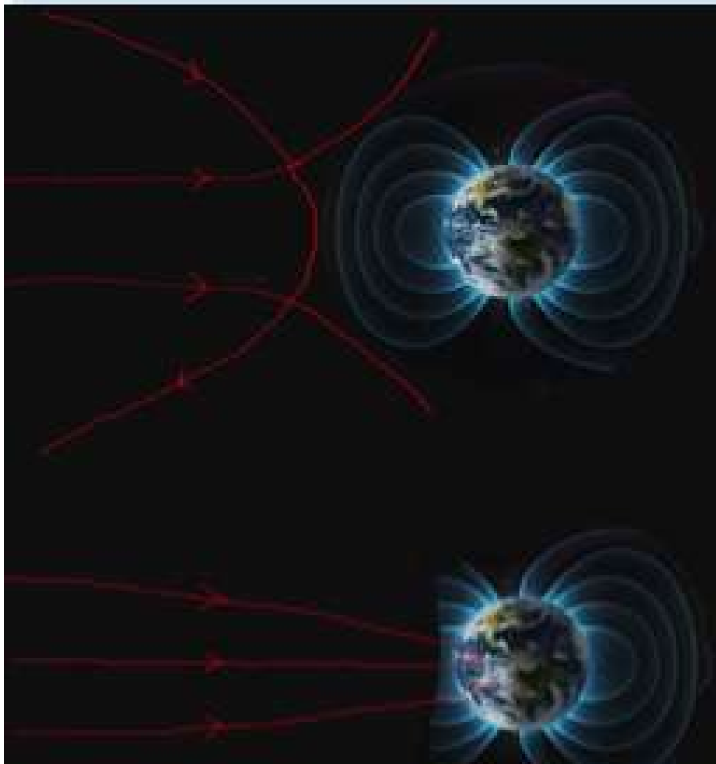
4-5σ 37

3-4σ 40

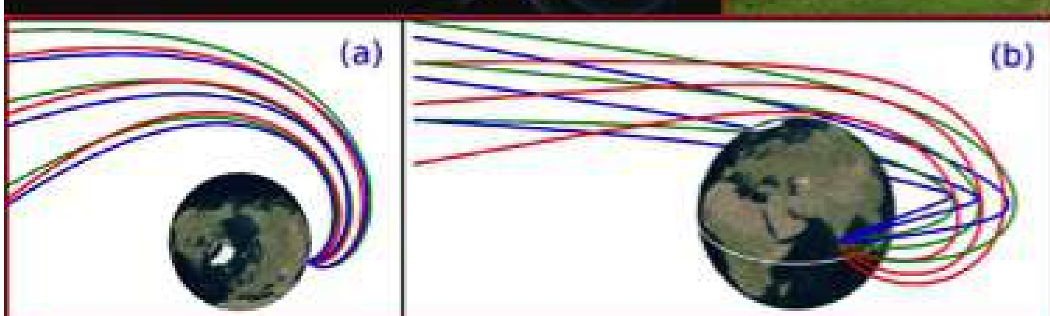
<3σ 25

The Indian Muon Telescope at Ooty discovers Crack in Earth's Magnetic Shield on June 22, 2015 when solar storm struck Earth

Solar super-storms cause dangerous currents in power-lines destroying transformers plunging world into darkness for years.



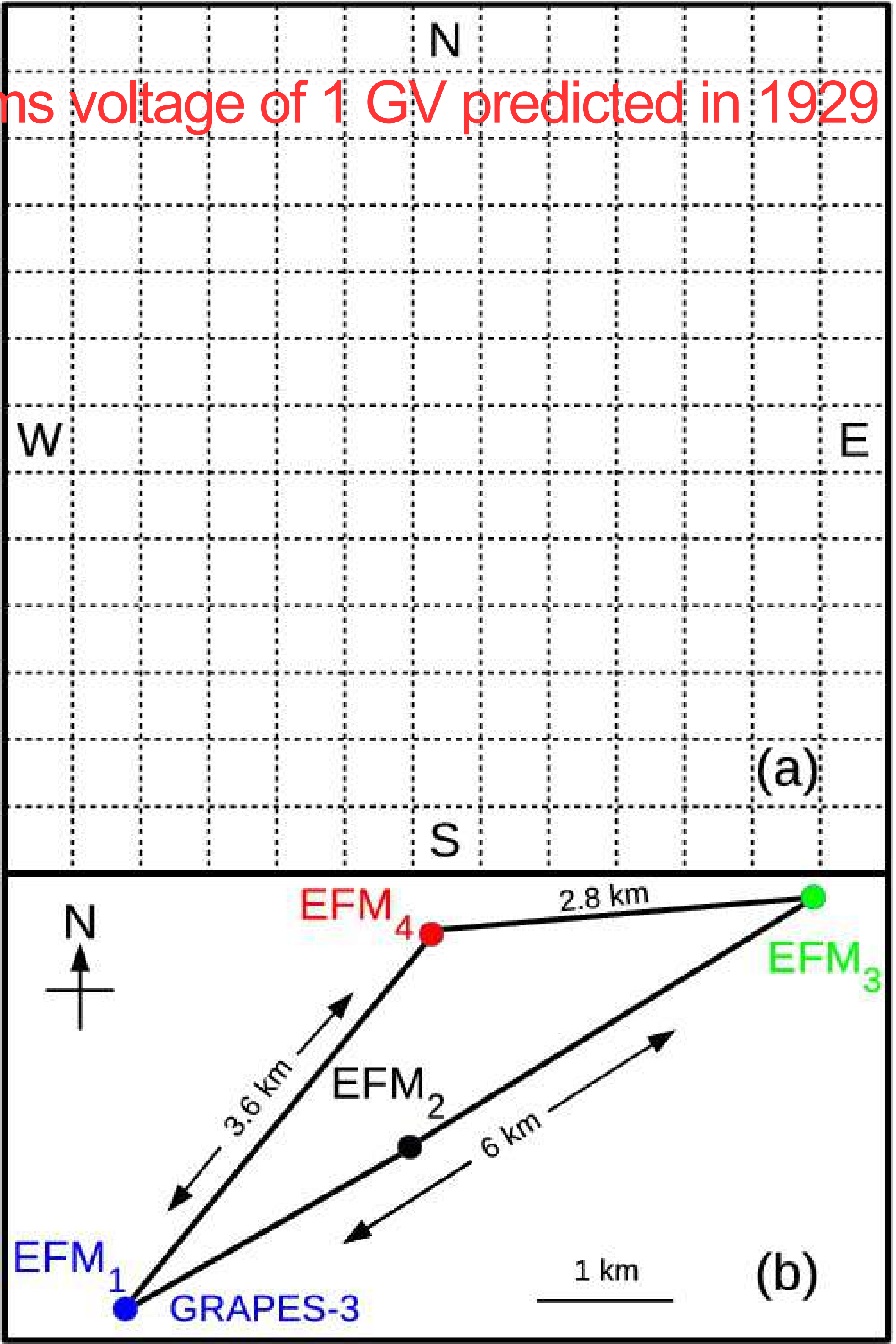
World's Best Muon Telescope

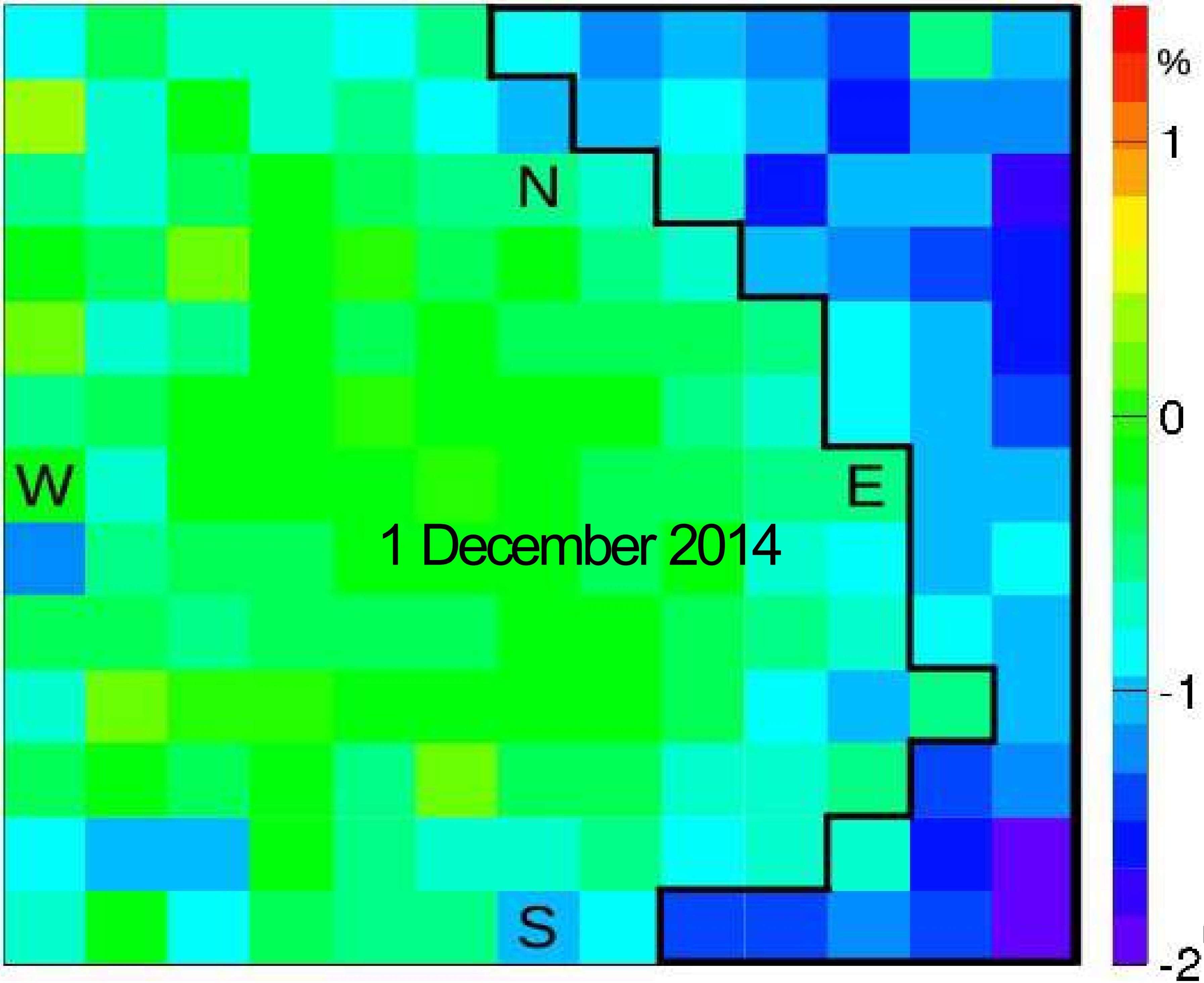


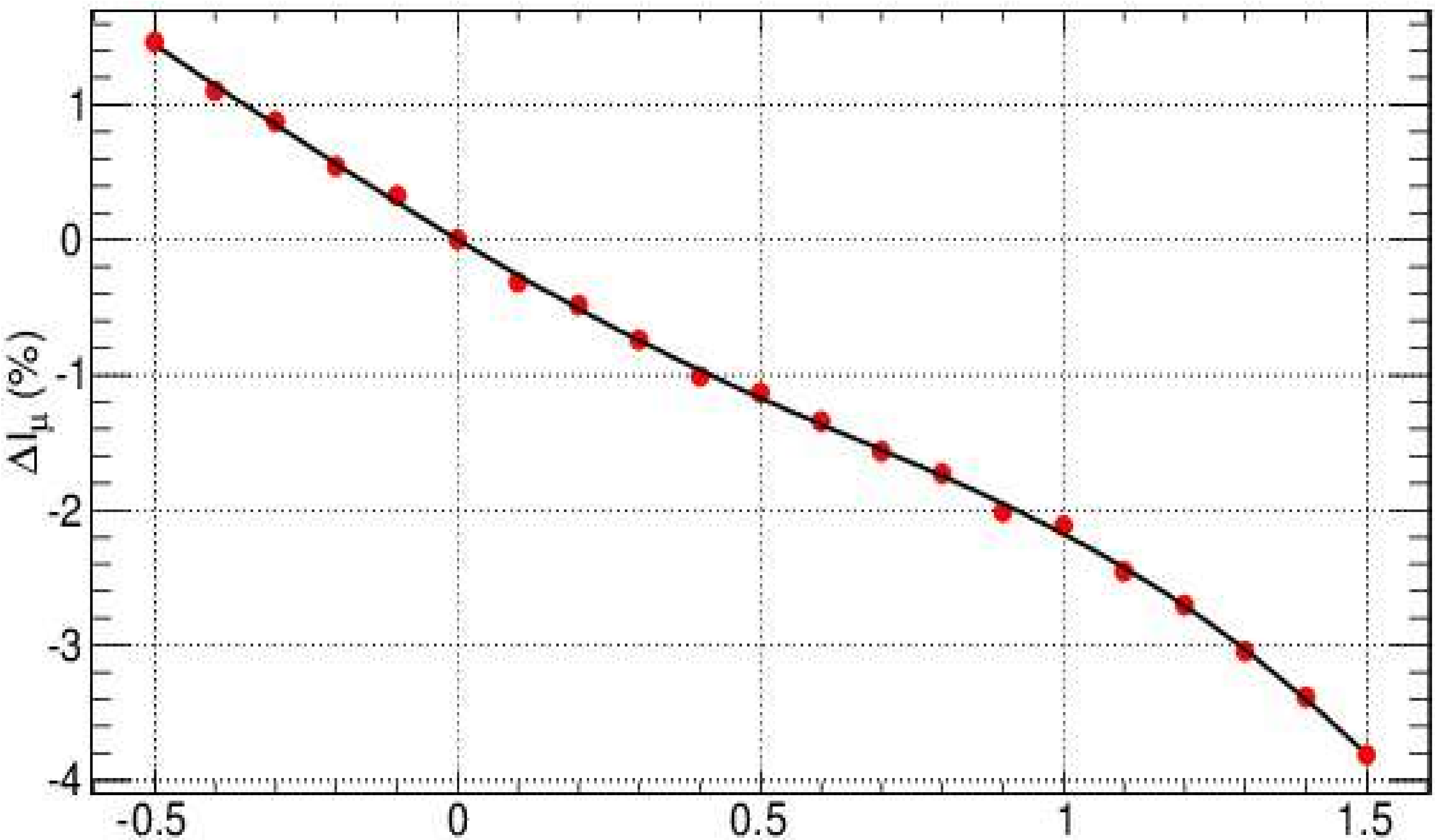
Indian discovery has captured worldwide attention. Over 500 electronic and print media reports in 48 countries in 27 languages (90% of world population)


Pattanaik
2 Two
5 five

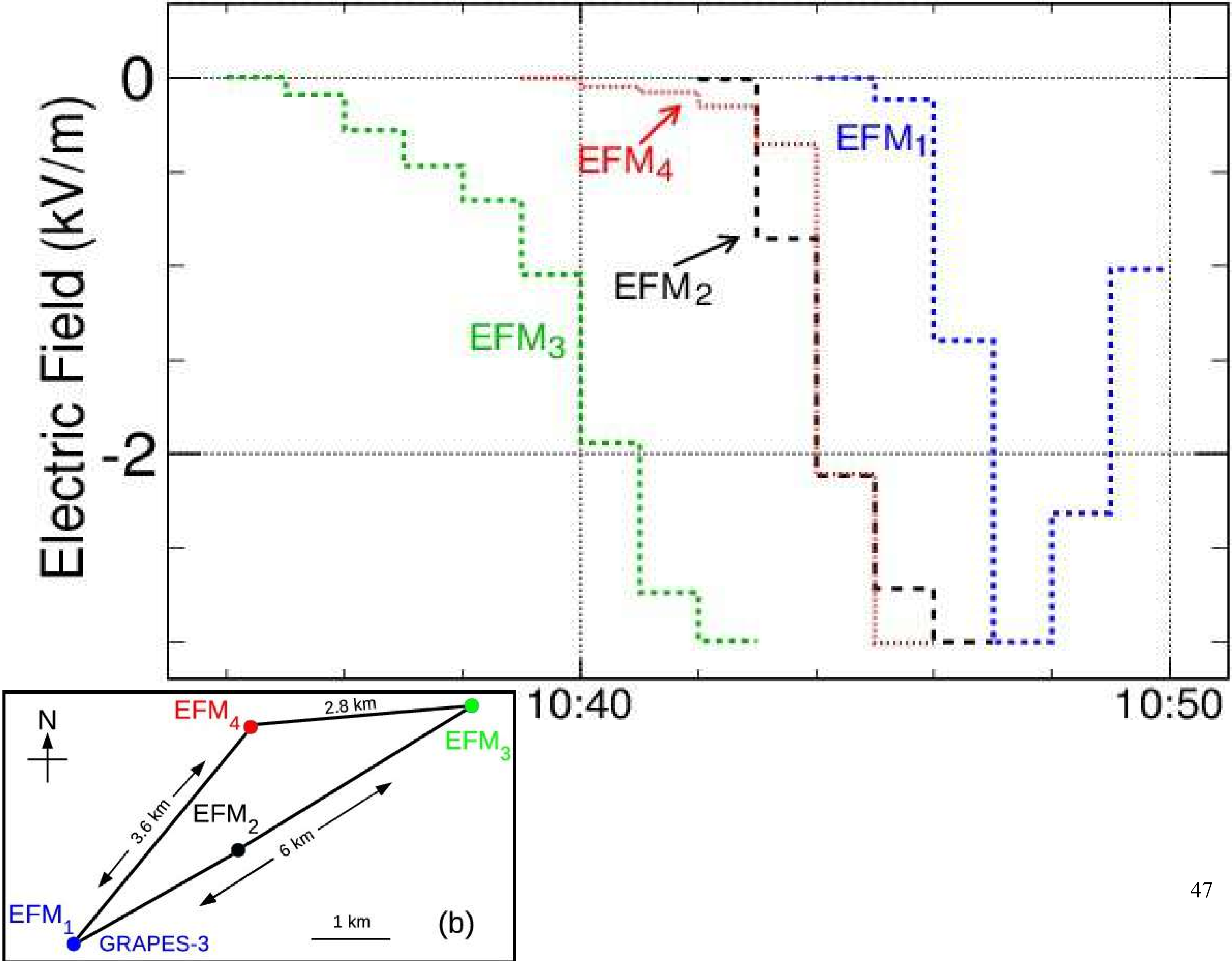
A thunderstorms voltage of 1 GV predicted in 1929 by Wilson (NL)



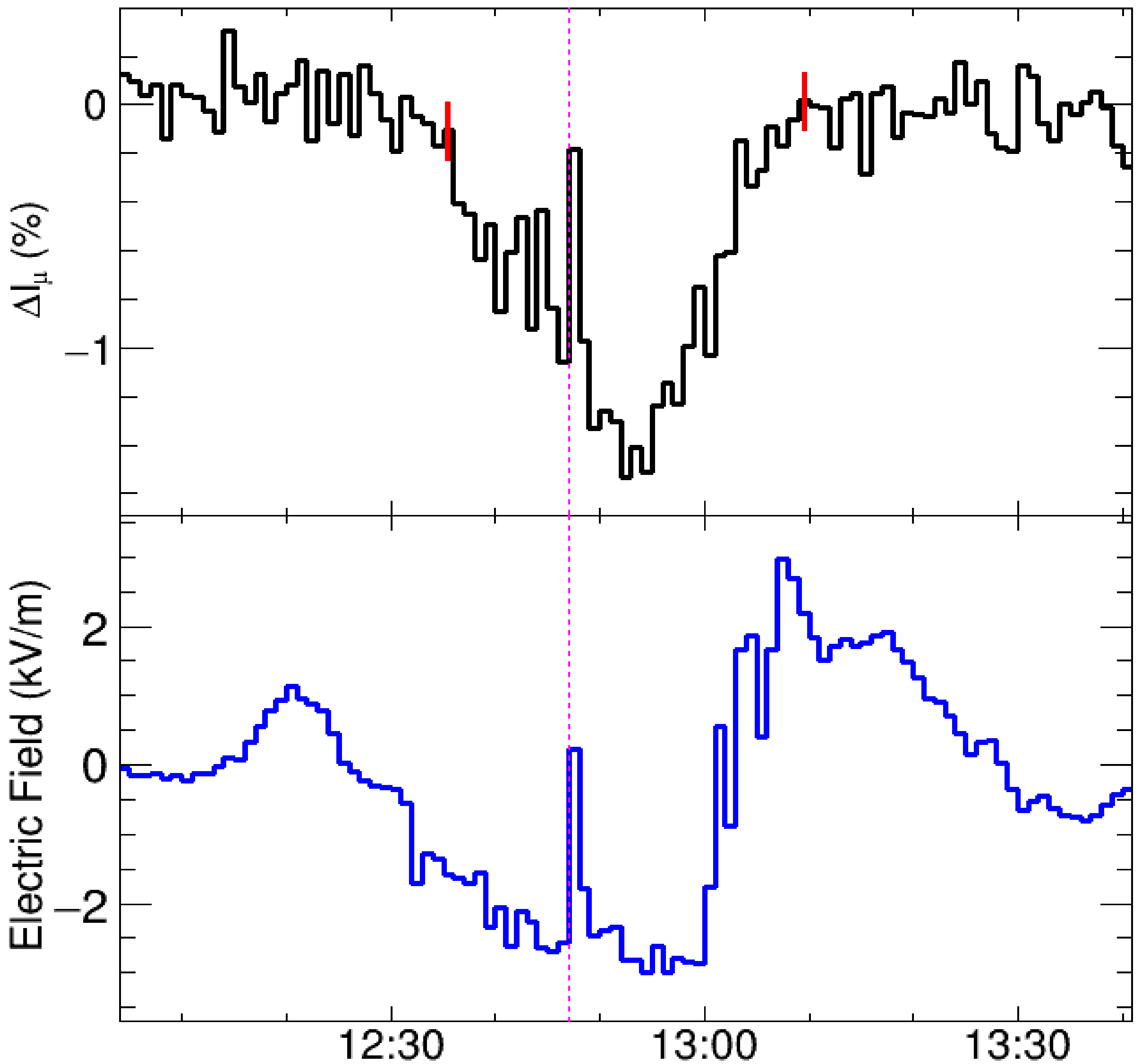

N
W
E
S
1 December 2014
%
1
0
-1
-2

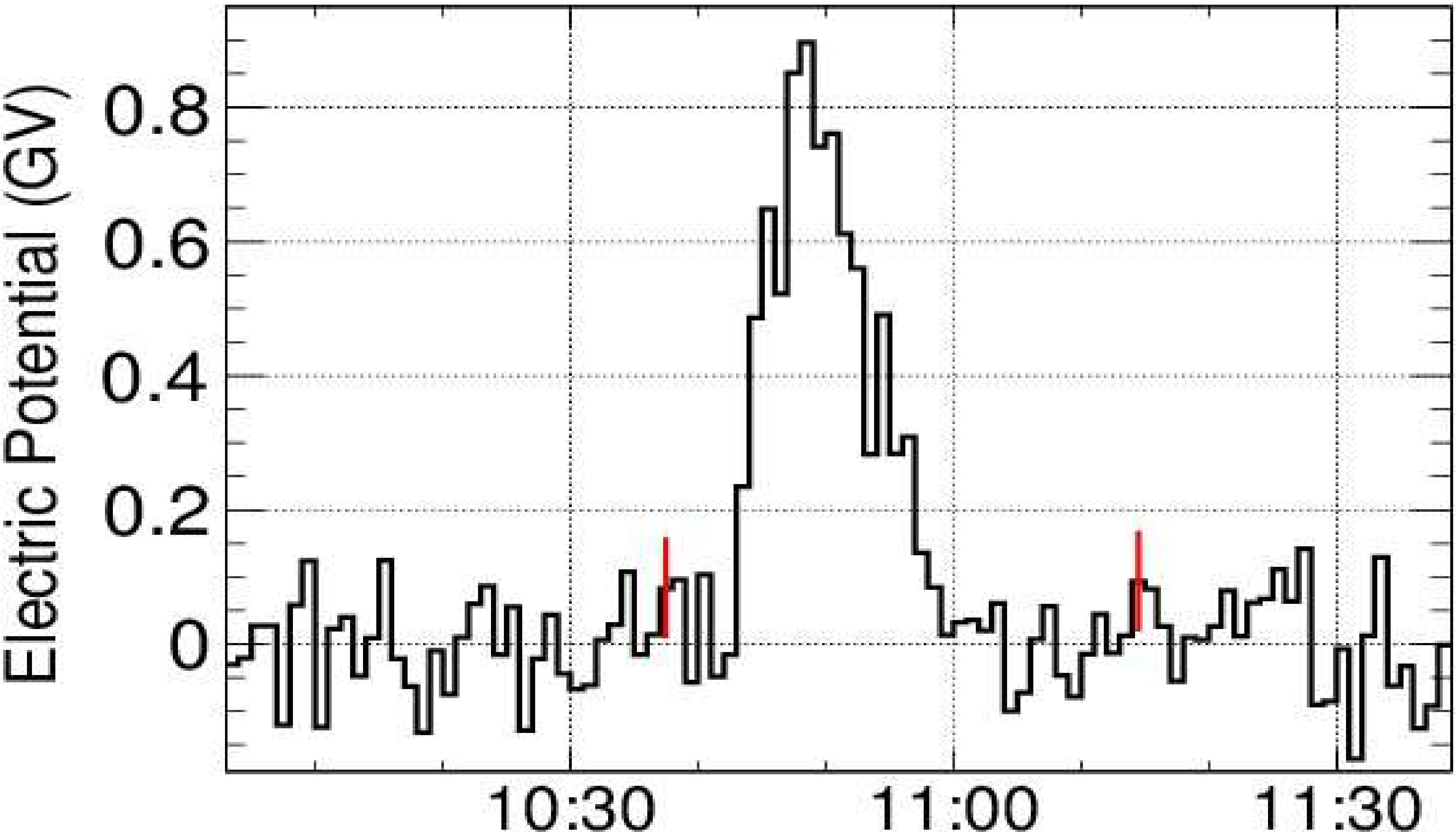


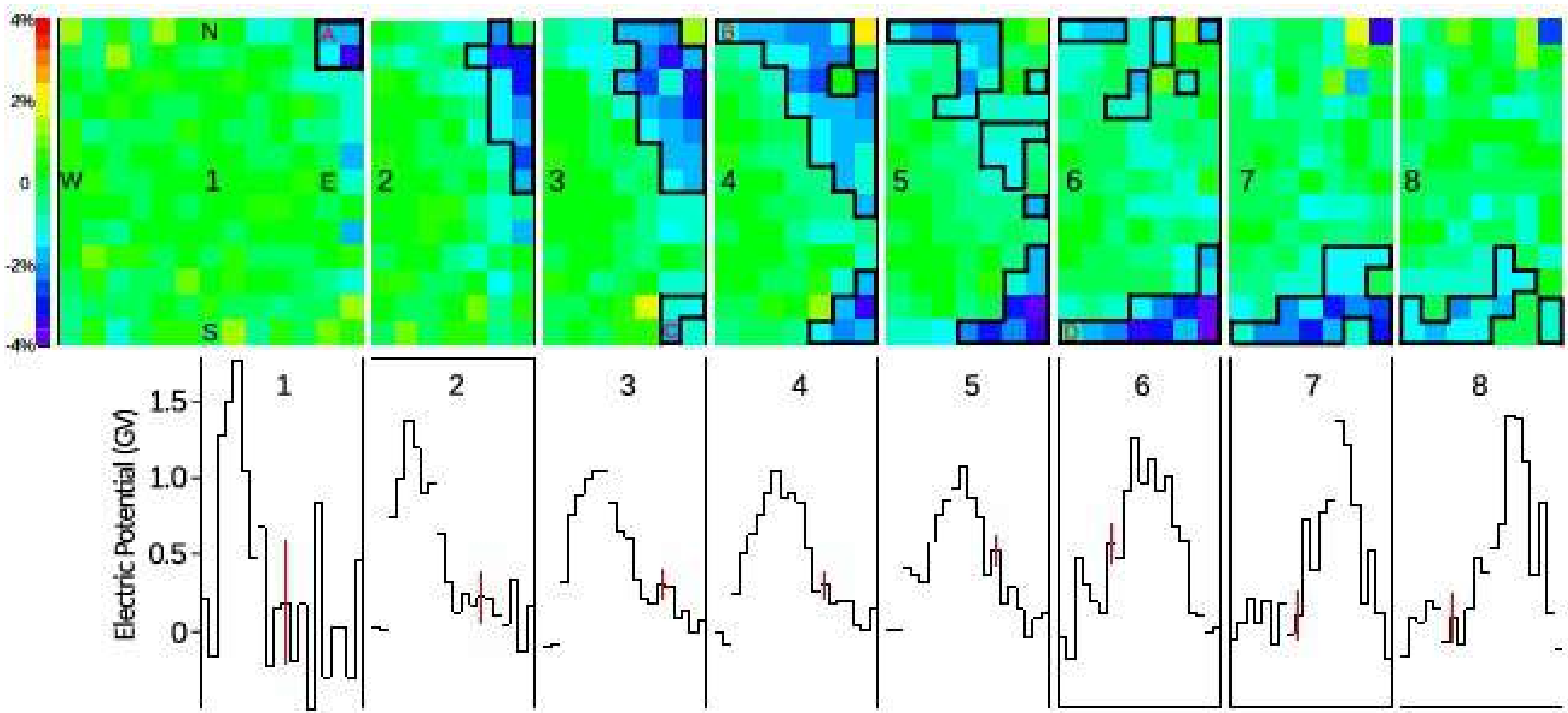
ΔI_μ (%)
1
0
-1
-2
-3
-4
-0.5
0
0.5
1
1.5


Electric Field (kV/m)
0
-2
10:40
10:50
EFM1
EFM2
EFM3
EFM4
N
2.8 km
3.6 km
6 km
1 km
GRAPES-3
(b)

30 September 2015 thunderstorm




Electric Potential (GV)
0.8
0.6
0.4
0.2
0
10:30
11:00
11:30



4%
2%
0
-2%
-4%
N
W
E
S
A
B
C
D
1
2
3
4
5
6
7
8
Electric Potential (GV)
1.5
1.0
0.5
0

Thunderstorm properties measured by GRAPES-3:

(1) A giant capacitor with a voltage of 1.3 GV

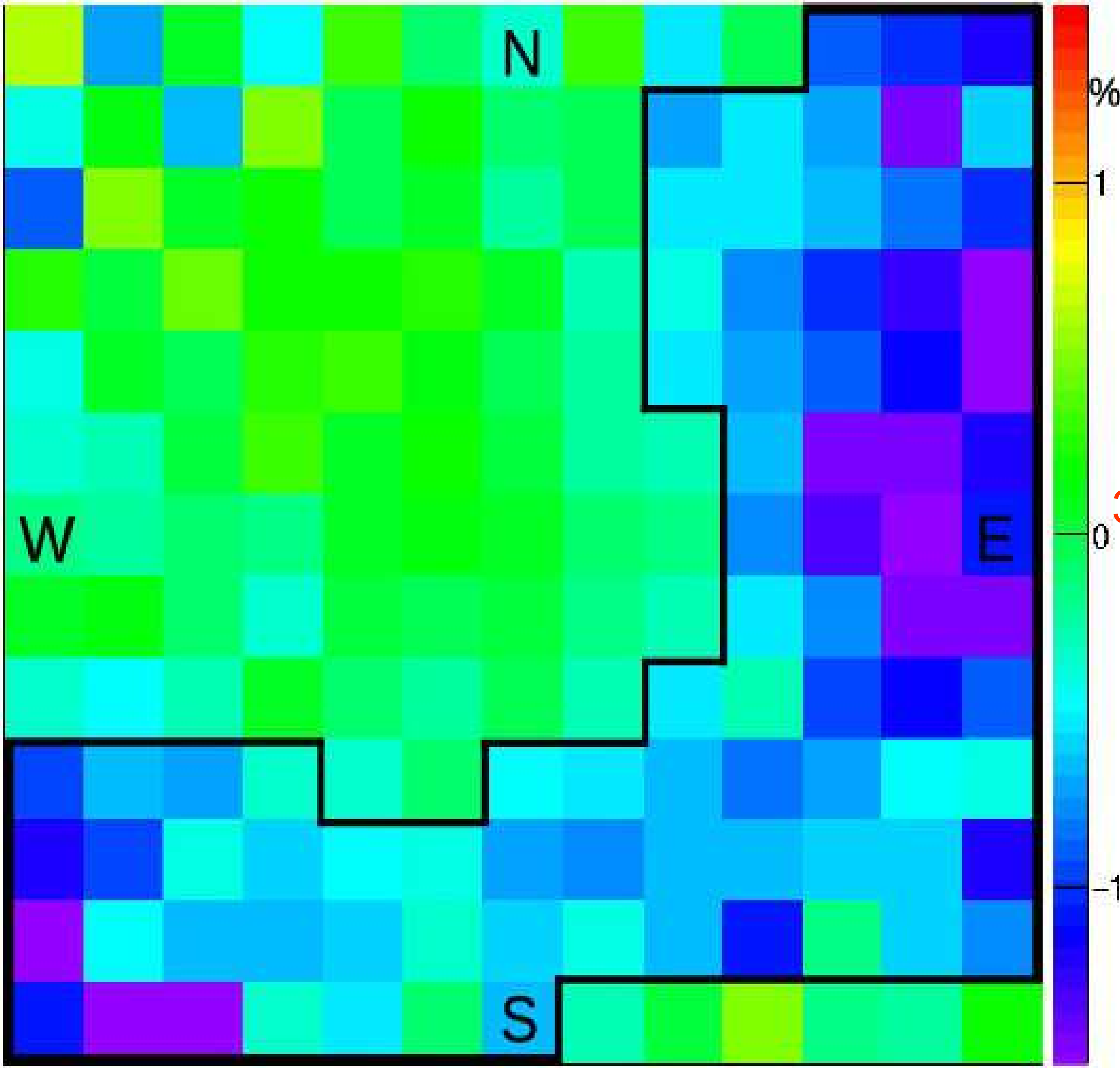
(2) Area = 400 km^2

(3) Speed = 60 km/h

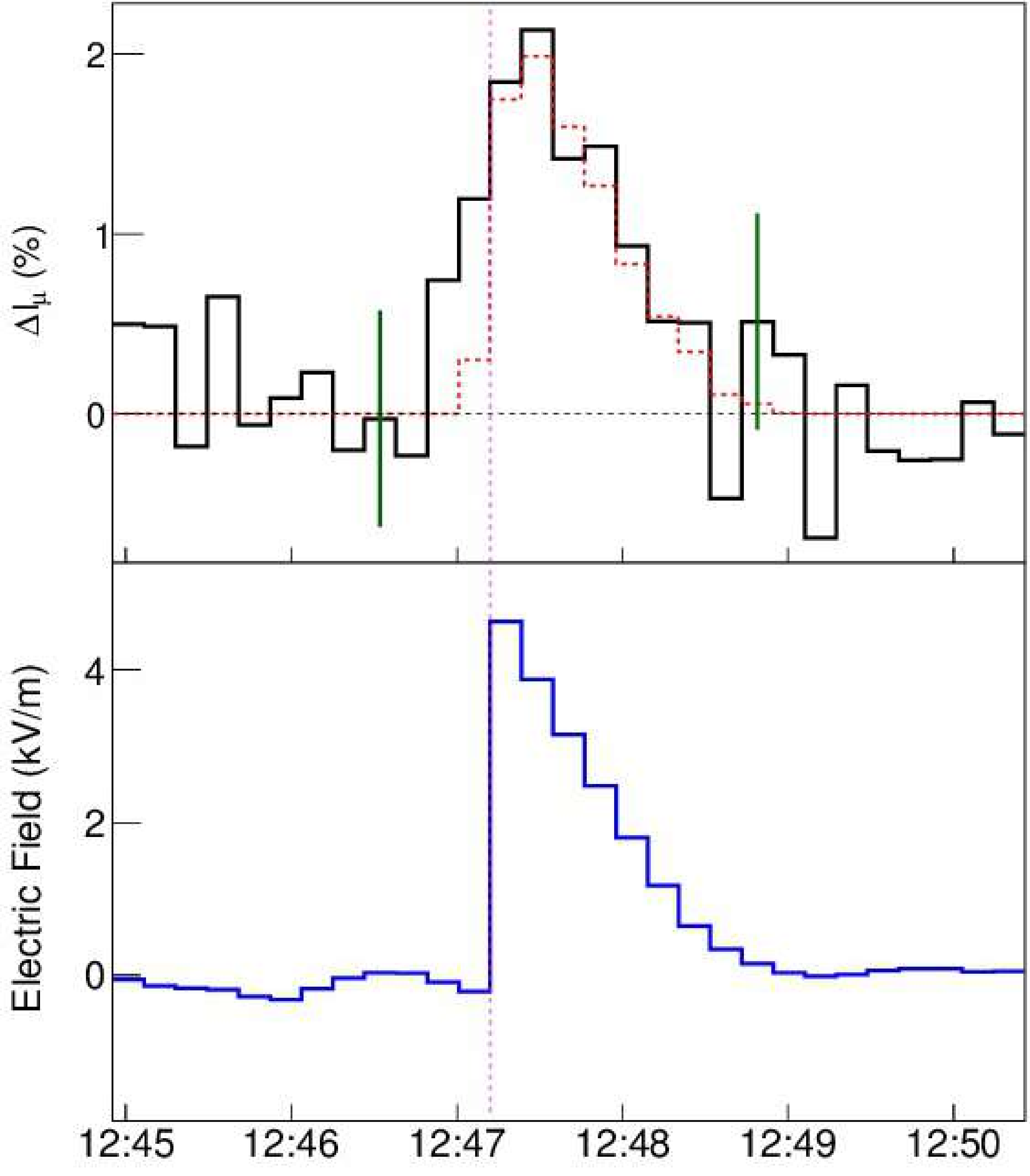
(4) Altitude between 11.4 to 17.4 km above sea level in Jet stream

(5) Energy stored = 720 GJ (power Mumbai for 50 minutes)

(6) Powered by >2 GW thermal power



30 September 2015
Thunderstorm



Charging time = 60 s
Power > 10 GW

Discharging pixels