Low Energy Cosmic Rays Detections and Application at Space Weather War Room

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and

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What are cosmic rays?

- Energetic particles or γ-rays from space
- Discovered by Hess in 1912 (Nobel Prize in 1936)
- Ordinary matter accelerated to high energies
    - p, ^{4}He, ^{12}C, ^{16}O, heavy nuclei and γ, e^+, e^-, μ, ν, …
- Key sources of cosmic rays for Earth's radiation environment:
    - From solar storms (solar energetic particles)
    - From supernova explosions inside the Milky-Way Galaxy (Galactic cosmic rays)
    - From intense events/objects GRB, AGN outside the Galaxy (Extra Galactic cosmic rays)
- Key cause of biological mutation

Space Weather and Earth's Aurora

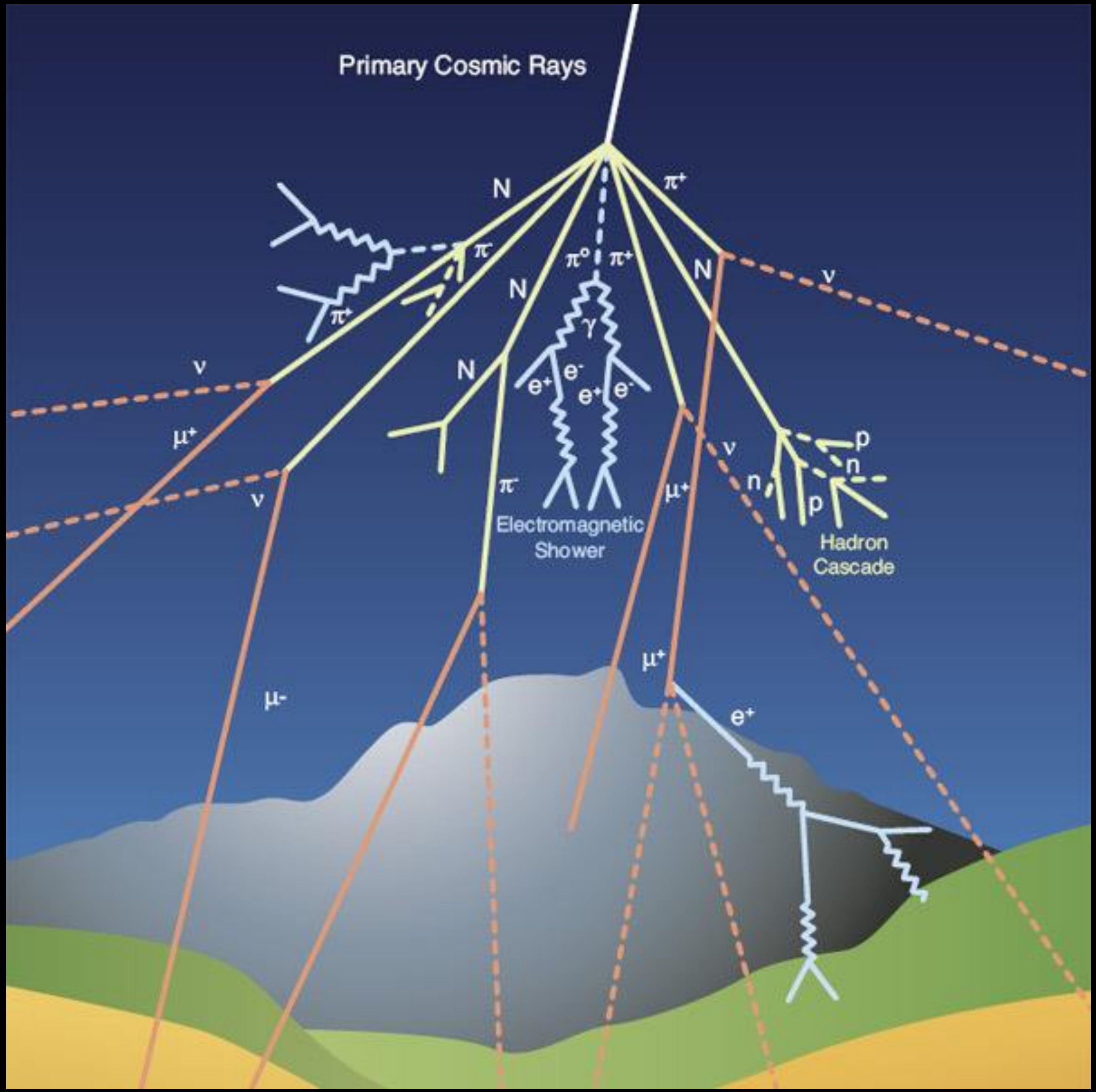
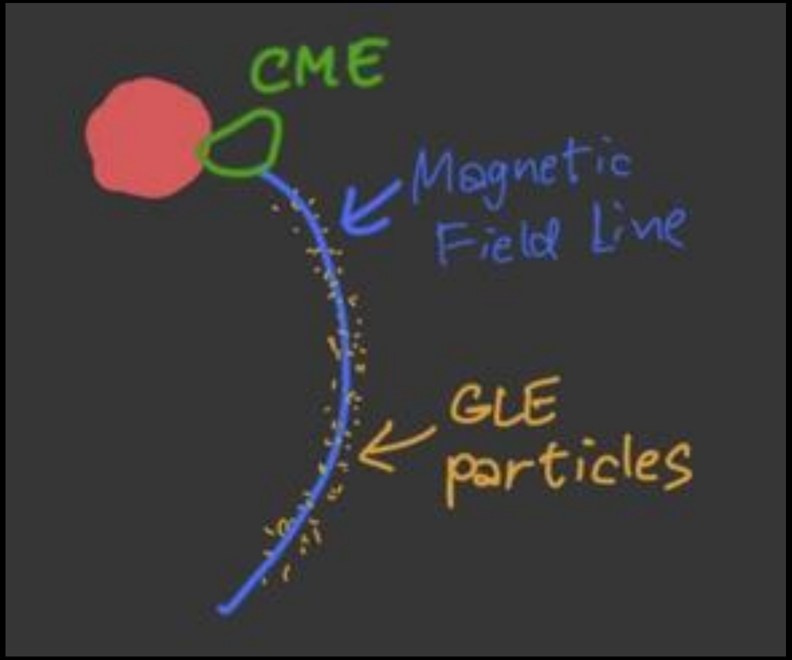


Image Credit: Cosmic rays_ particles from outer space _ CERN.html

Coronal Mass Ejection Effects at Earth

Prompt Effect:

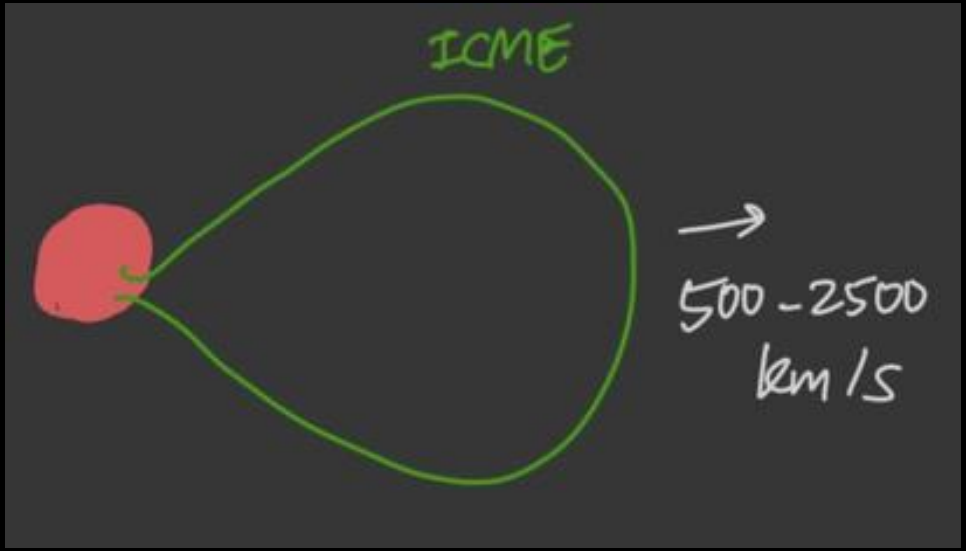
Energetic Particles (GLE)



- Energetic particles (~ 1 GeV) accelerated near Sun
- Occurs 5-20 min after CME lift-off
- Charged particles follow magnetic field line Particles arrive at Earth 10-30 minutes later, <u>if Earth is near the right magnetic field line</u>

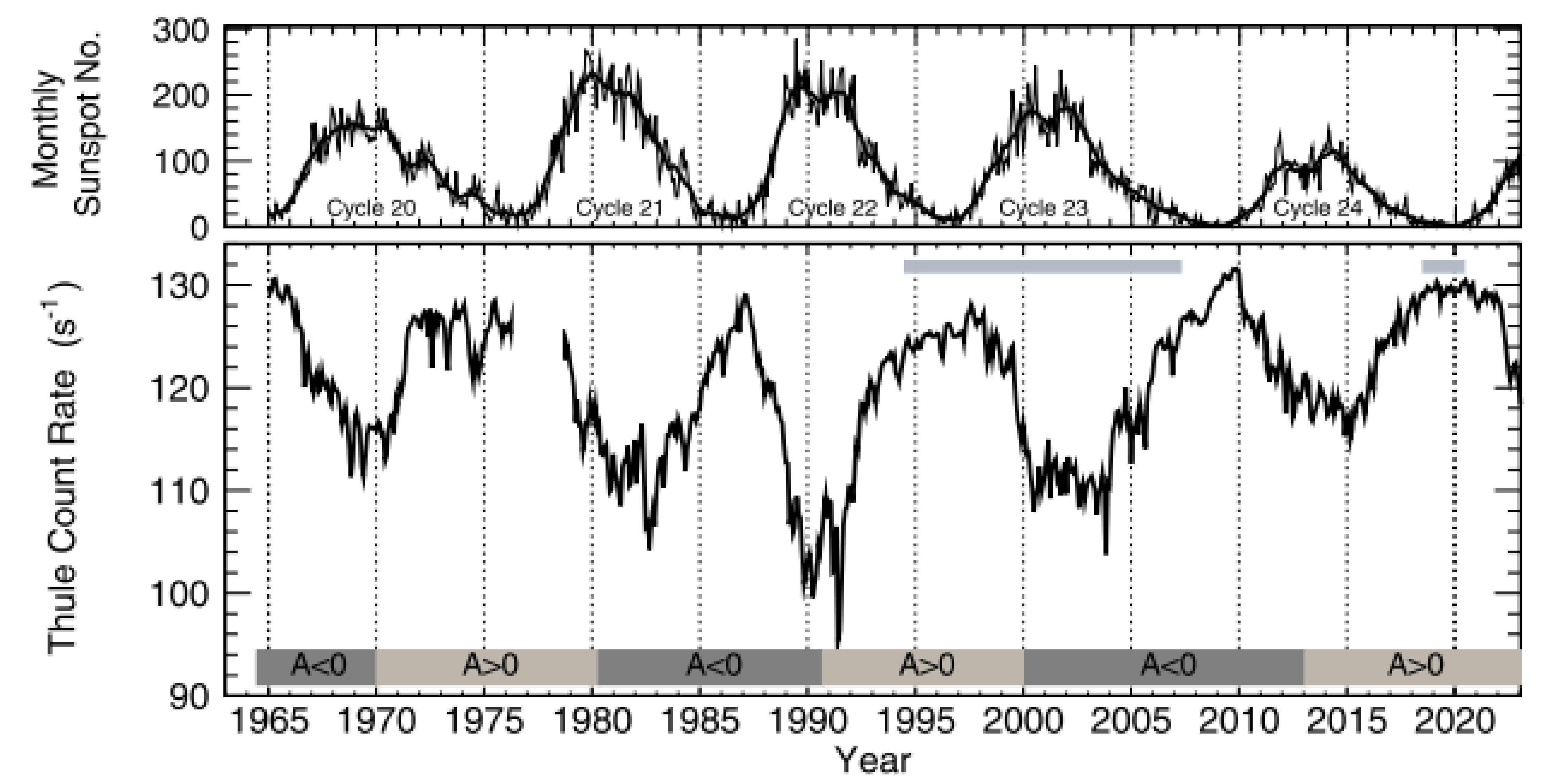
Delayed Effect:

Geomagnetic Disturbance



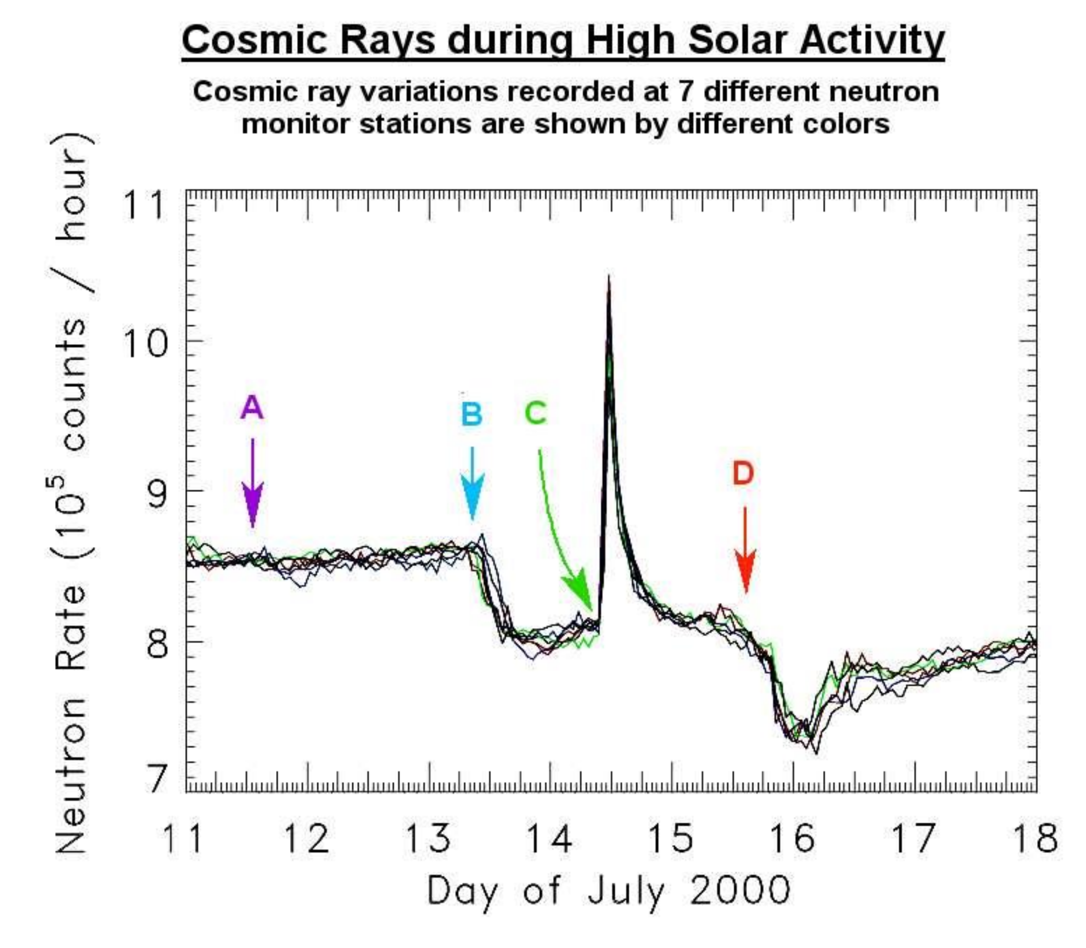
- *Interplanetary* CME arrives at 1 AU 18 hours to 4 days later
- Impact of the ICME plasma with Earth's magnetic field causes a geomagnetic disturbance
- The ICME suppresses Galactic cosmic rays, an effect called a *Forbush decrease*

Solar Modulation



Poopakun et al. 2023

Cosmic rays during high solar activity



A. First coronal mass ejection (CME) at Sun.

B. First CME arrives at Earth. Cosmic rays decrease suddenly – a “Forbush decrease.”

C. Second CME at Sun. This one accelerates high energy particles that reach Earth minutes later. The sudden increase recorded by the neutron monitor is a “ground level enhancement.”

D. Second CME arrives at Earth. Cosmic rays decrease again. This CME produces the largest geomagnetic storm in 10 years. Aurora observed as far south as Georgia.

Effects of Space Weather on Human Activities

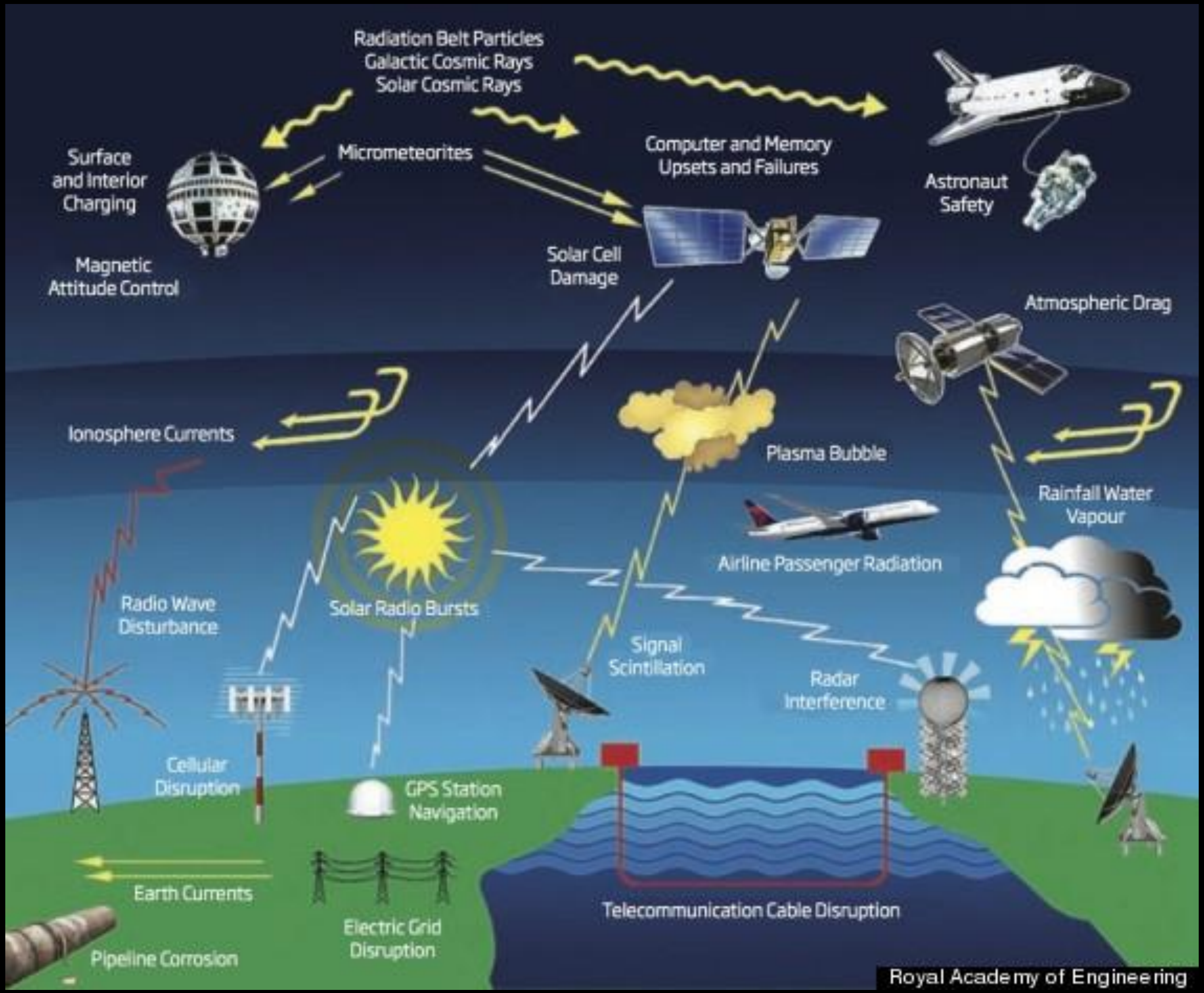


Image credit: https://www.sansa.org.za/2014/10/24/world-economy-and-society/

Observation of Cosmic Rays with Ground-Based Detectors

- Neutron Monitor
- Muon telescope
- IceTop

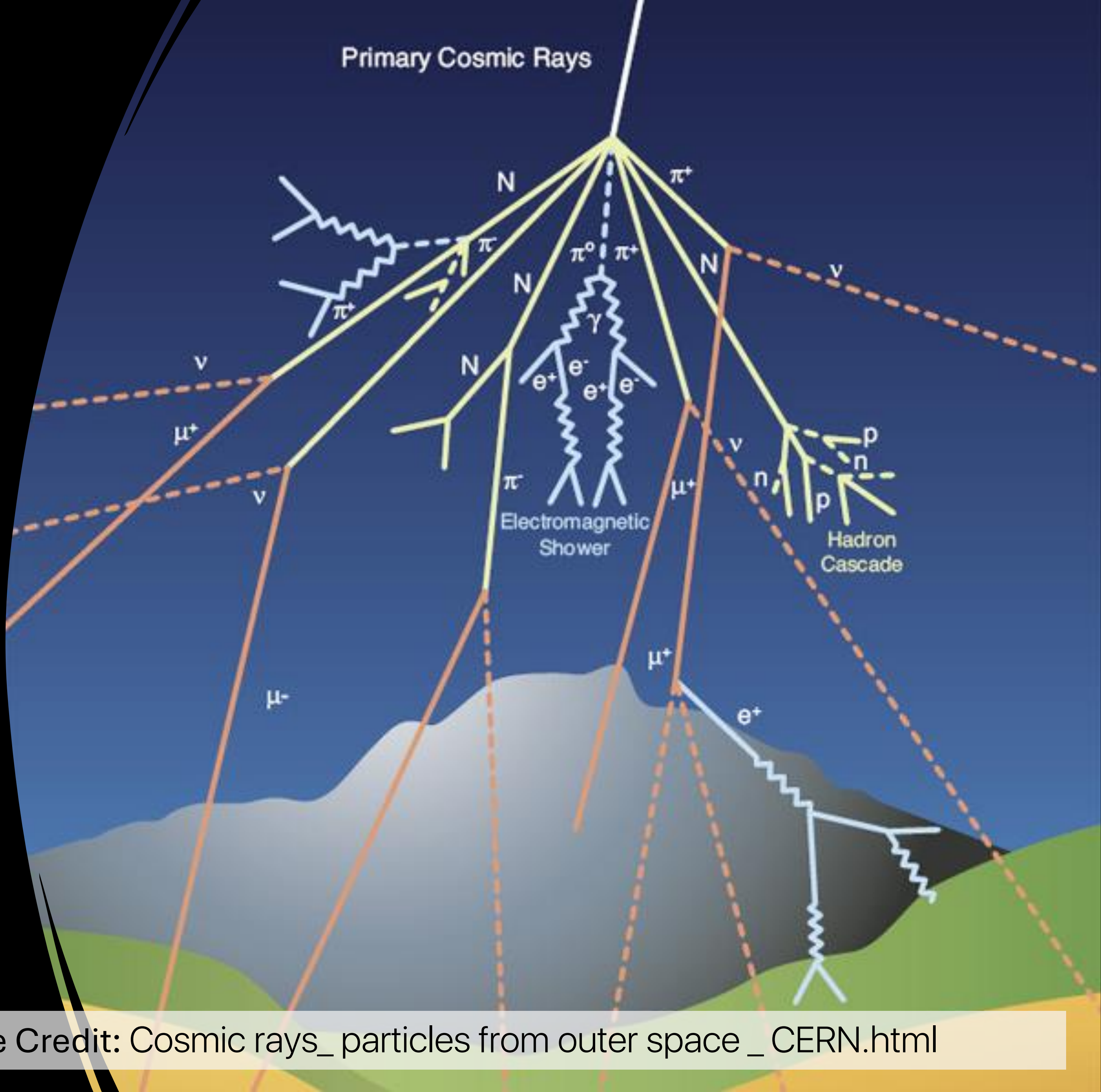
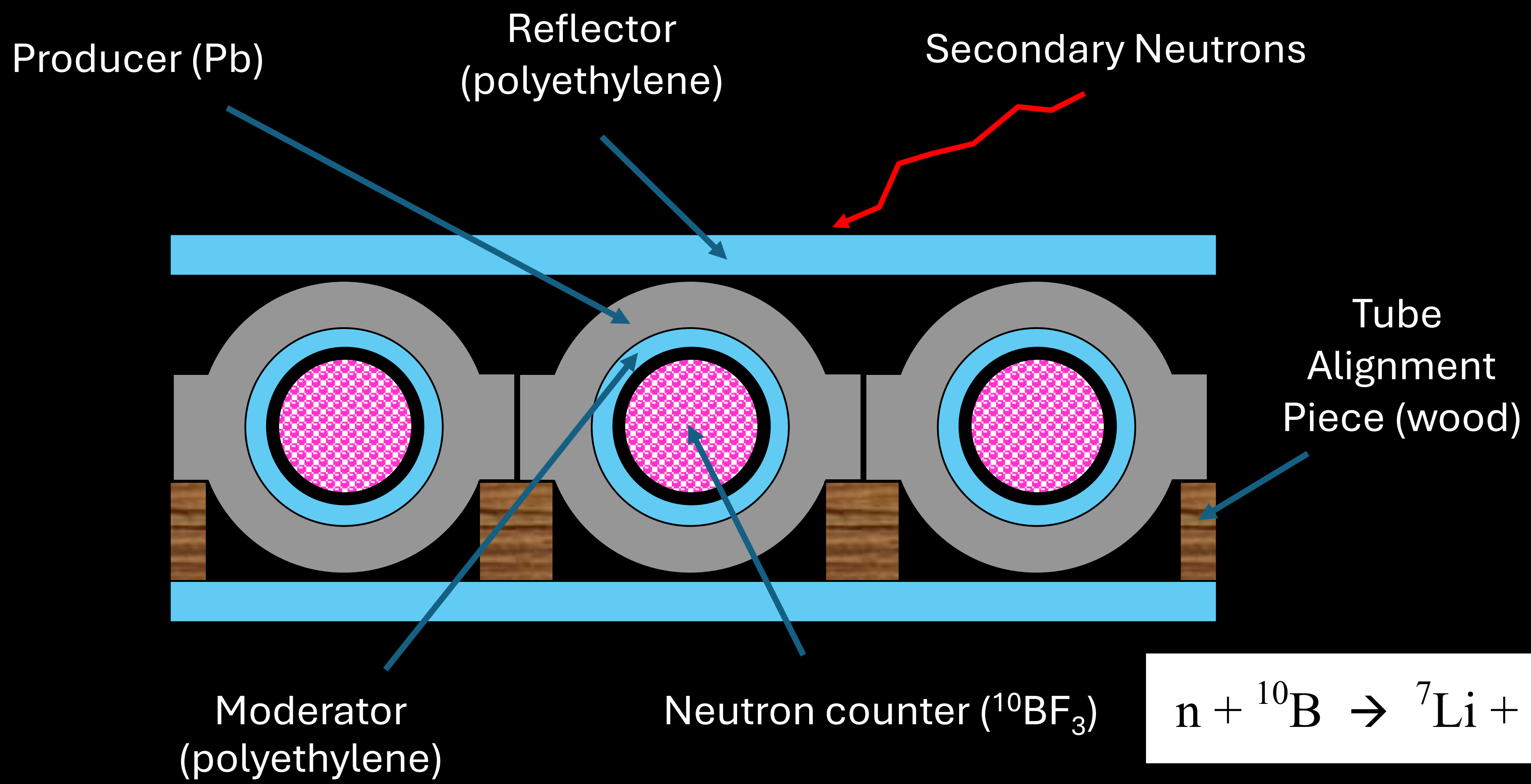


Image Credit: Cosmic rays_ particles from outer space _ CERN.html

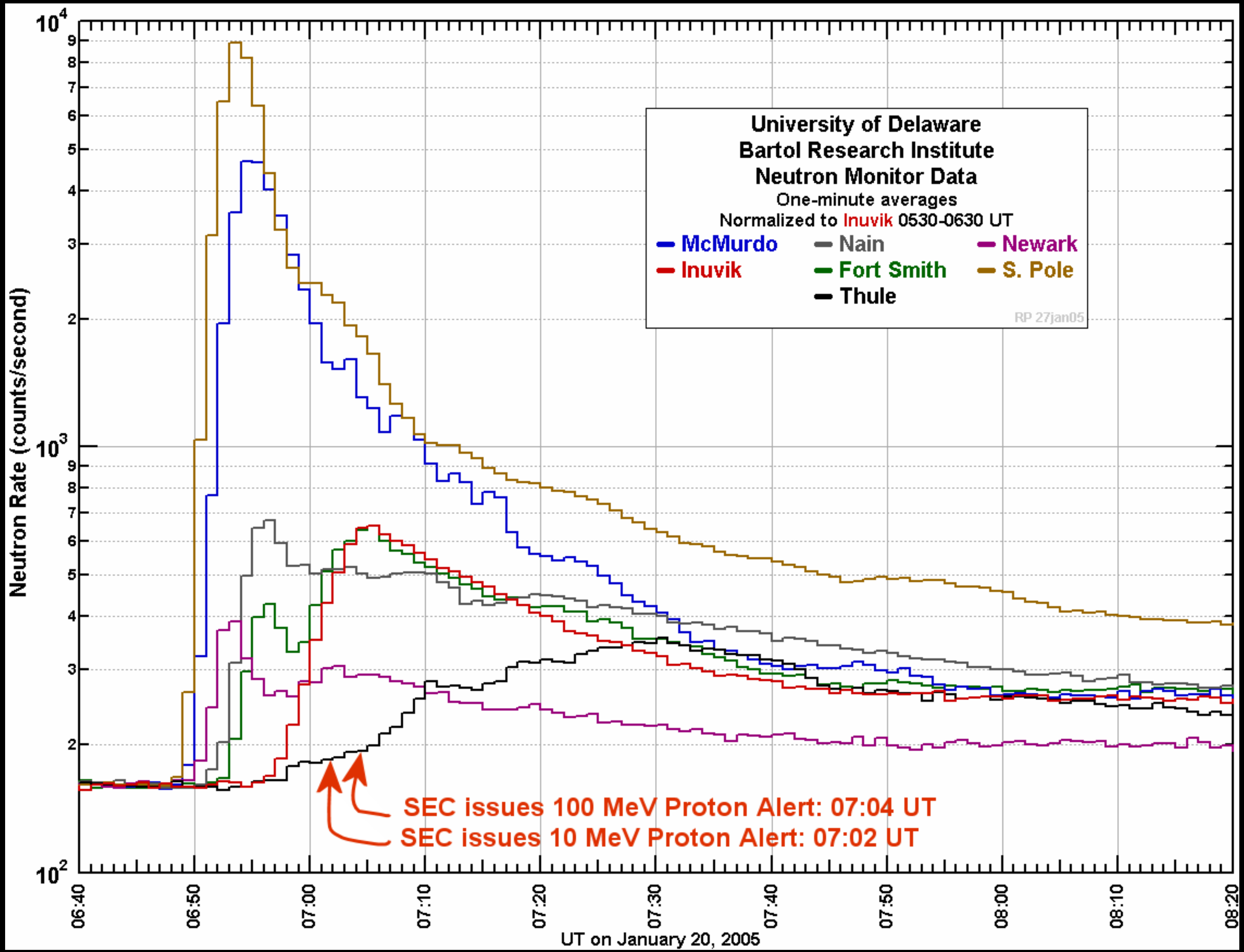
Collaborators

Neutron Monitor



$$n + {}^{10}B \rightarrow {}^{7}Li + {}^{4}He$$

Neutron Monitors Can Provide the Earliest Alert of a Solar Energetic Particle Event



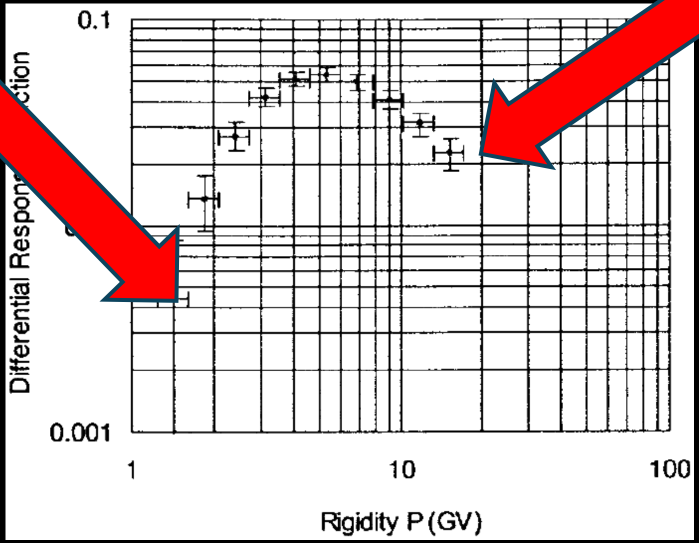
- In the January 20, 2005 GLE, the earliest neutron monitor onset preceded the earliest Proton Alert issued by the Space Environment Center **by 14 minutes.**

GLE Alert system (on progress)

- A GLE Alert is issued when 3 stations from polar regions (plus South Pole) record a 4% increase in 3-min averaged data.
- With 4 stations, false alarm rate is near zero.
- GLE Alert precedes SEC Proton Alert by ~ 10-30 min.

Earth as a Giant Magnetic Spectrometer:
A High-Altitude Array Spanning a Range of Cutoffs

- Low-Cutoff (or No Cutoff) Monitor at High Latitude, e.g., Pole or Summit
- Above: South Pole Monitor at Sunset, 2002.



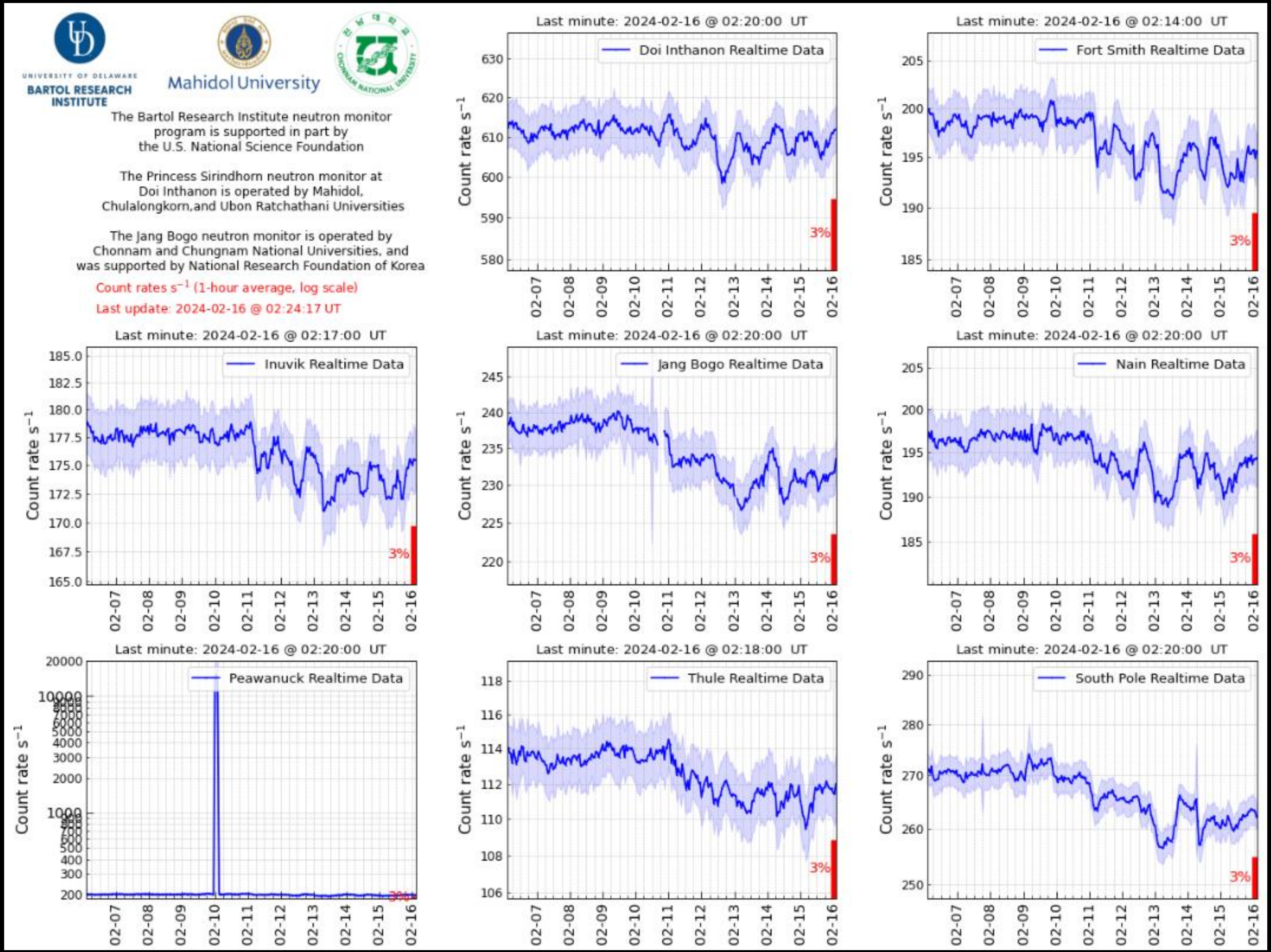
- High-Cutoff (17 GV) Monitor in Thailand
- Above: Princess Sirindhorn Neutron Monitor. Dedicated January, 2008

Realtime data of cosmic rays

- https://neutronm.bartol.udel.edu/~pyle/EightPanel_10days.png

Solar Influences Data analysis Center - RWC Belgium
Royal Observatory of Belgium

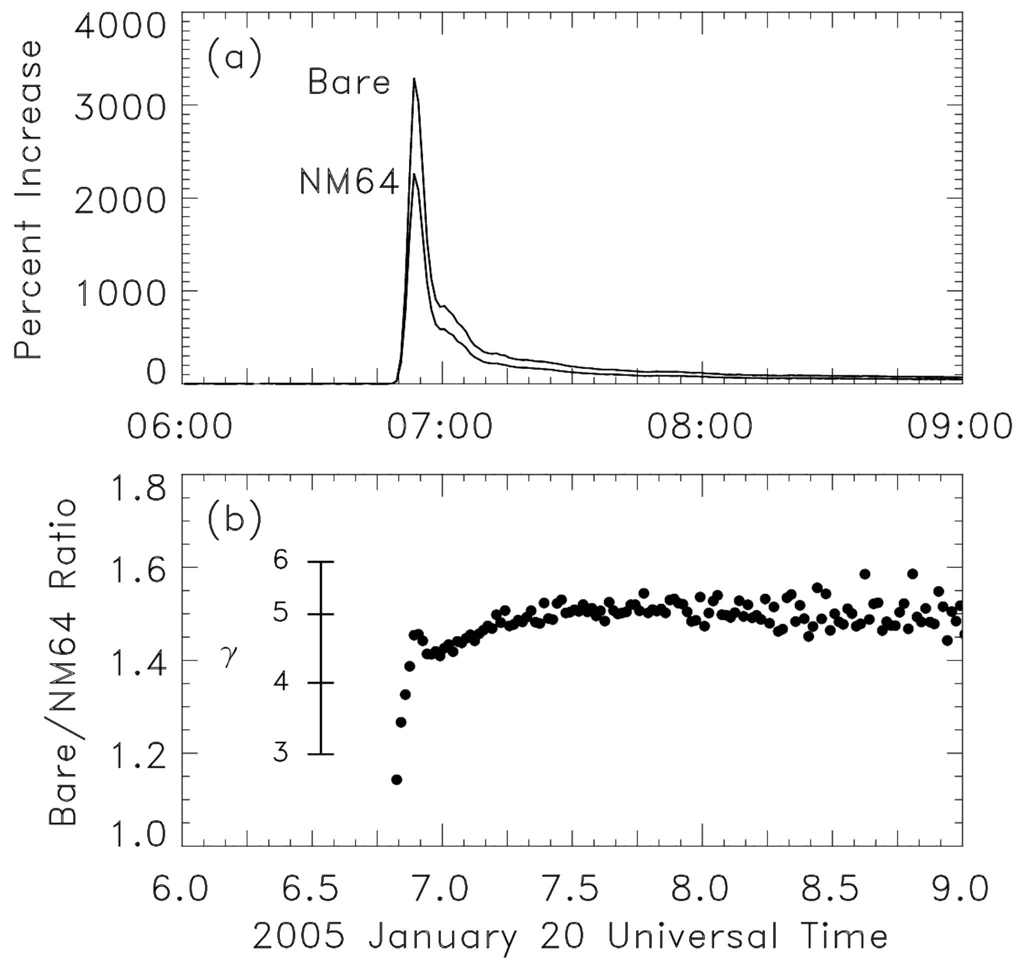
Website http://www.sidc.be.



Prediction of SEP Energy Spectrum

- Polar Bare Method
- Yield function from Latitude Survey (Unleaded/Leaded)
- Leader fraction

Polar Bare Method



Bieber et al. 2013

South Pole station has both a standard neutron monitor (NM64) and a monitor lacking the usual lead shielding (Bare). The Polar Bare responds to lower particle energy on average. Comparison of the Bare to NM64 ratio provides information on the particle spectrum.

- This event displays a beautiful dispersive onset (lower panel), as the faster particles arrive first.
- Later, the rigidity spectrum softens to $\sim P^{-5}$ (where P is rigidity), which is fairly typical for GLE.

LATITUDE SURVEY

Current Collaborations:

South Korea (KOPRI):

- Survey year 2023-2024
- Survey year 2024-2025
- Survey year 2025-2026

There is a possibility of changes occurring.

University of Hawaii: Haleakala summit

Chinese Icebreaker Xue Long

survey years:

- 2018-2019
- 2019-2020

GCR spectrum

Yield function

Integral Response Function

$$N(P_c, h, t) = \int_{P_c}^{P_L} J_i(P,t) Y_i(P,h) dP$$

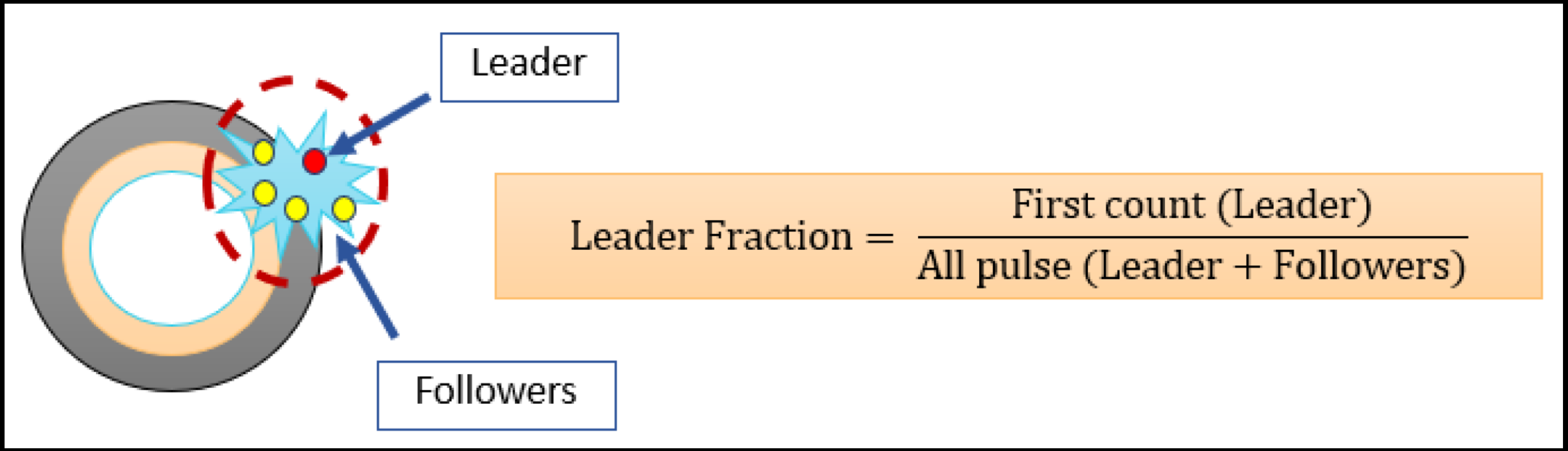
Differential Response Function

$$DRF(P) = -\left[\frac{dN}{dP}\right]_p = \sum_i J_i(P,t) Y_i(P,h)$$

Leader fraction

Leader Fraction or Inverse Multiplicity

- *A way to track spectral variation with time*
- *We use special electronics from U. Delaware, USA to record histograms of neutron time delays*
- *We extract the "leader fraction" as proxy of spectral index*
- *This fraction divides out many station-specific systematics*



Muangha et al. 2023

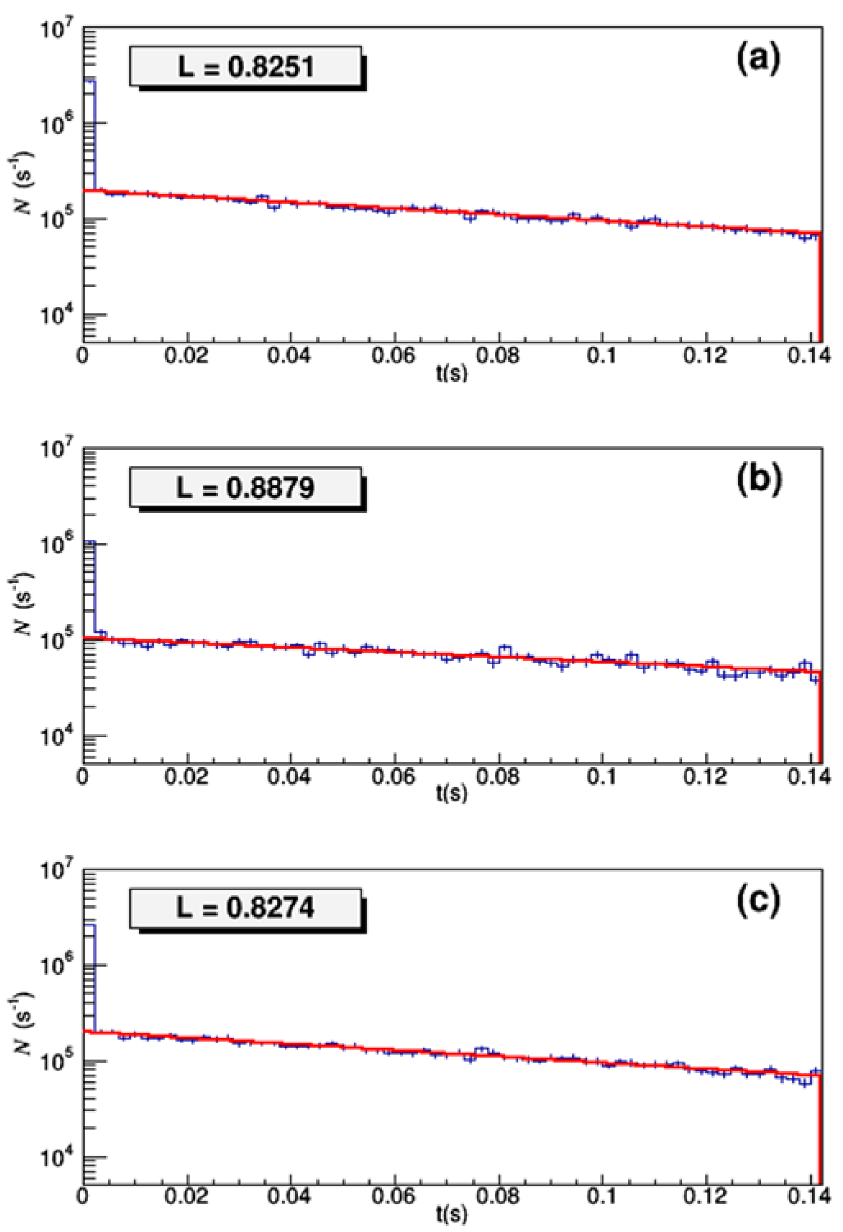
Leader fraction

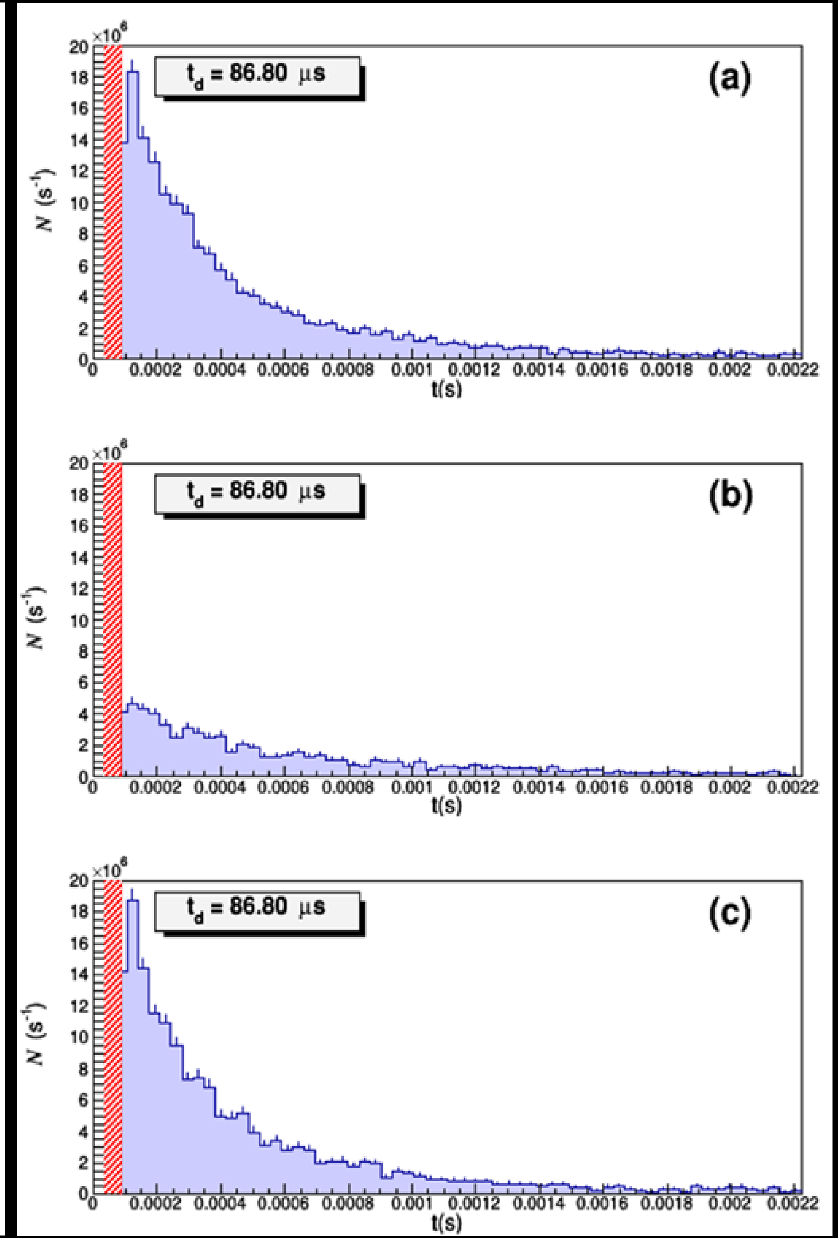
Mobile Neutron Monitor

- *1-hr Histogram data*
- *Deadtime = 86.80 μs*

$$L = \frac{\int_{t_d}^{\infty} A_0 e^{-\alpha t}\, dt}{\int_{t_d}^{t_o} N(t)\, dt + \int_{t_o}^{\infty} A_0 e^{-\alpha t}\, dt}$$

$$L = \frac{\frac{A_0}{\alpha} e^{-\alpha t_d}}{\sum_{t=t_d}^{t_o} N_t + \frac{A_0}{\alpha} e^{-\alpha t_o}},$$

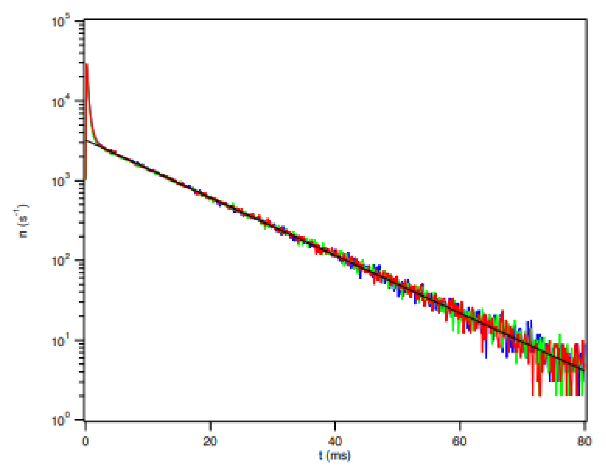


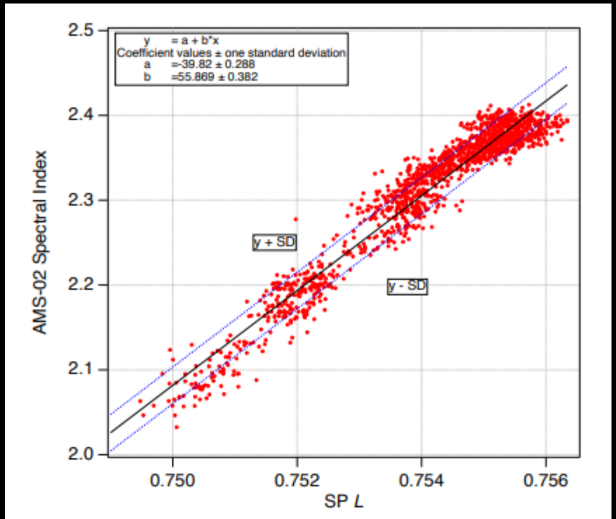


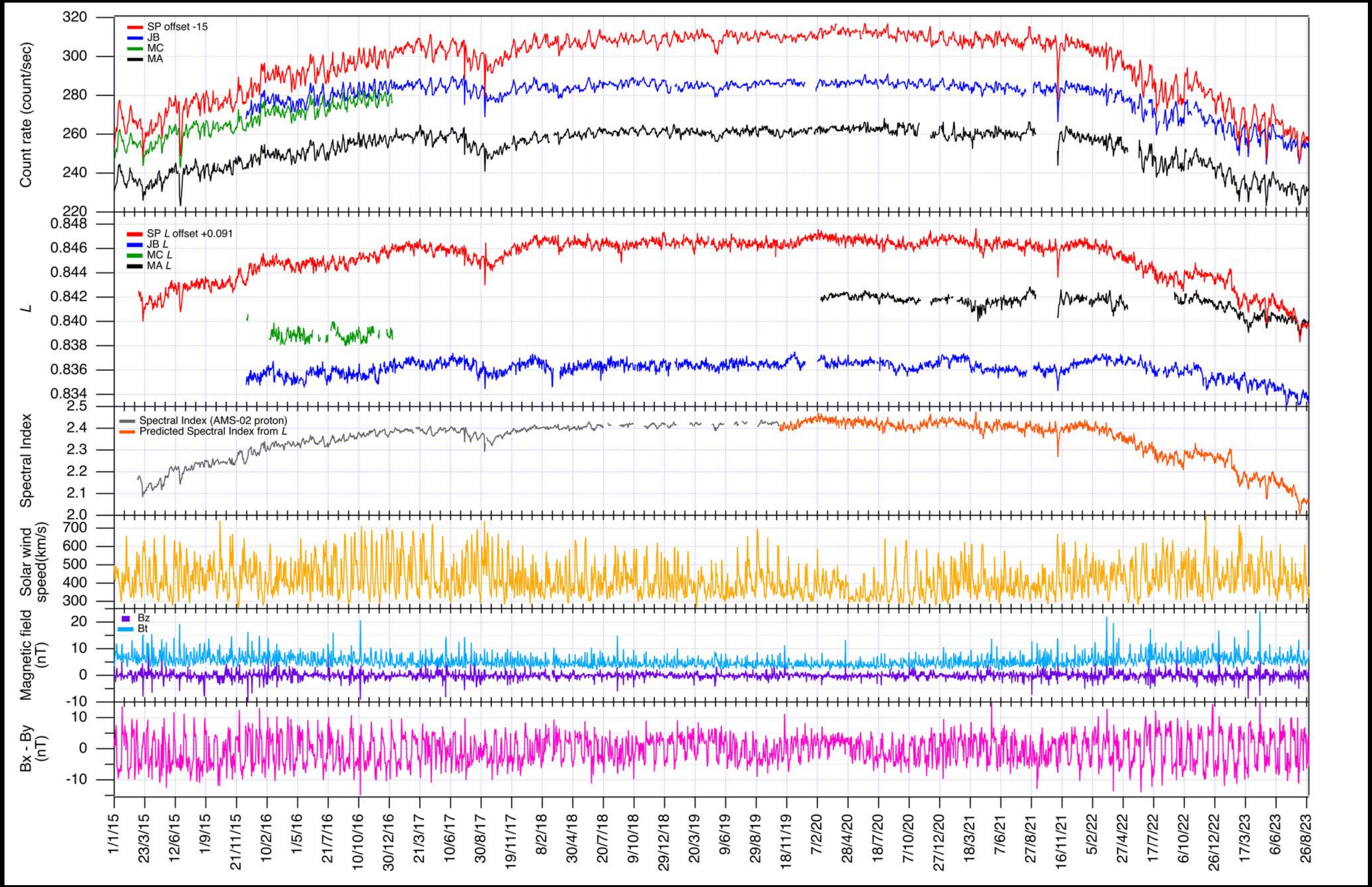
Yakum et al. 2023

Leader fraction

Fixed Neutron Monitor

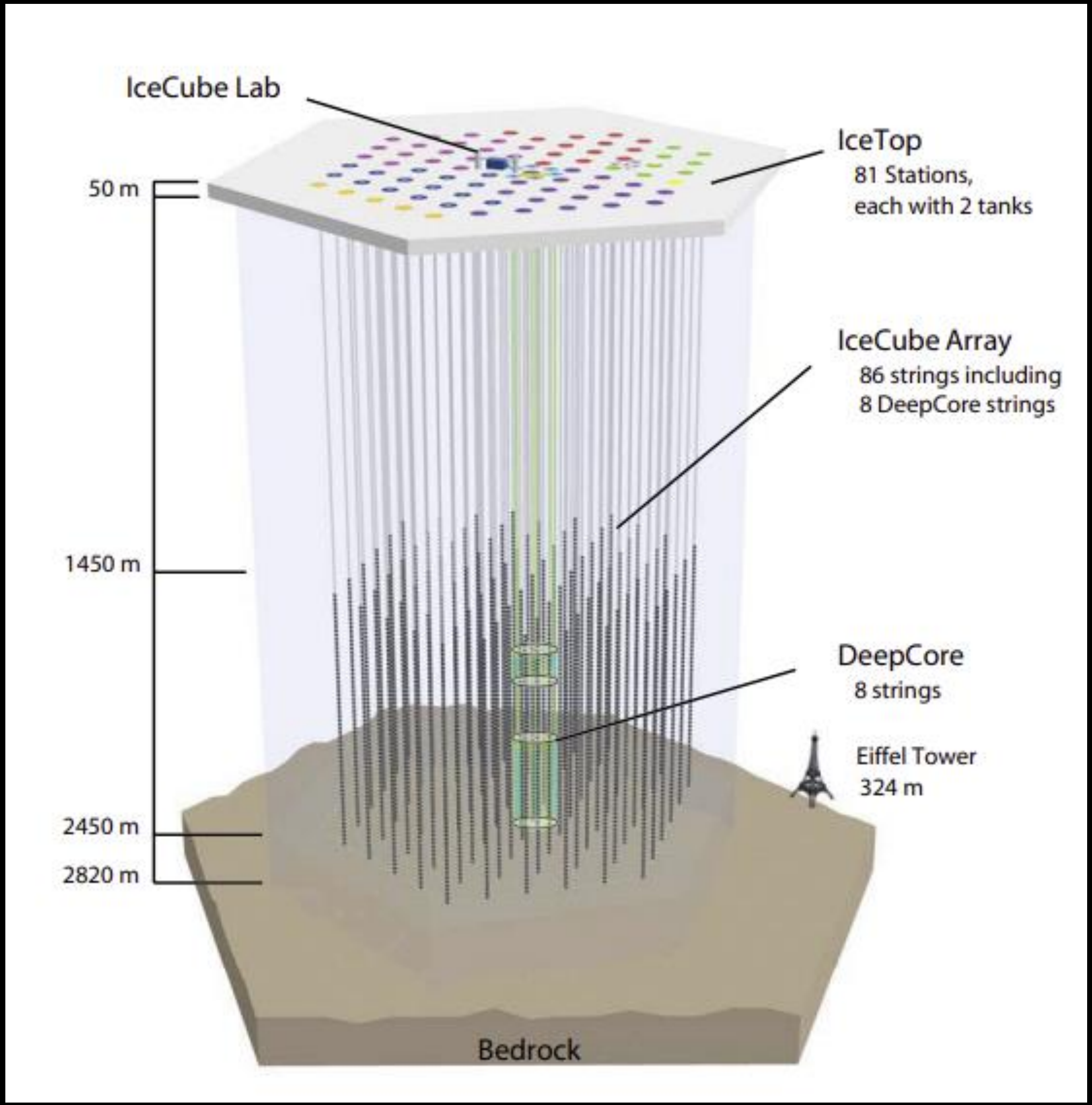


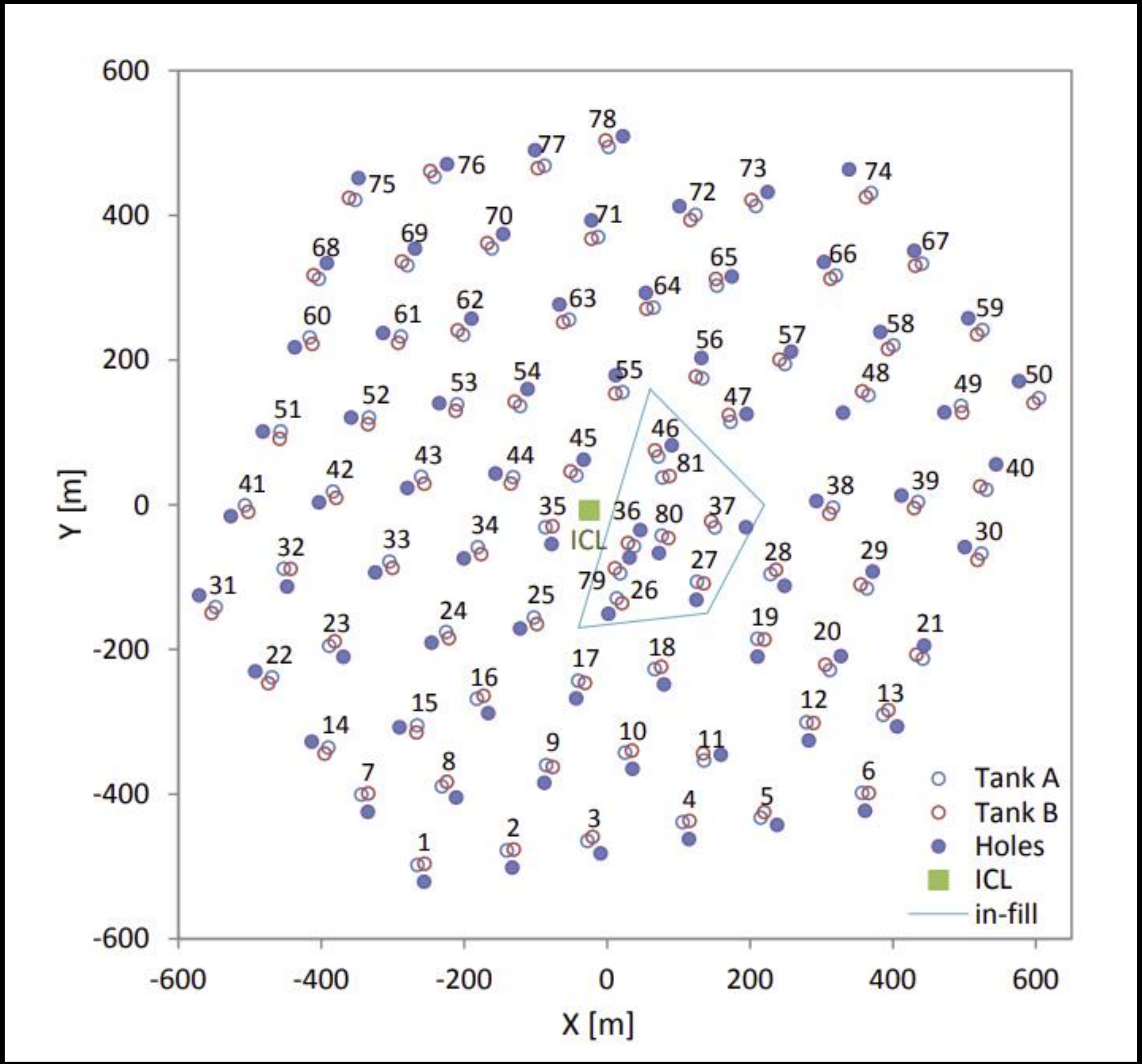




Muangha et al. 2023

IceTop: The surface component of IceCube

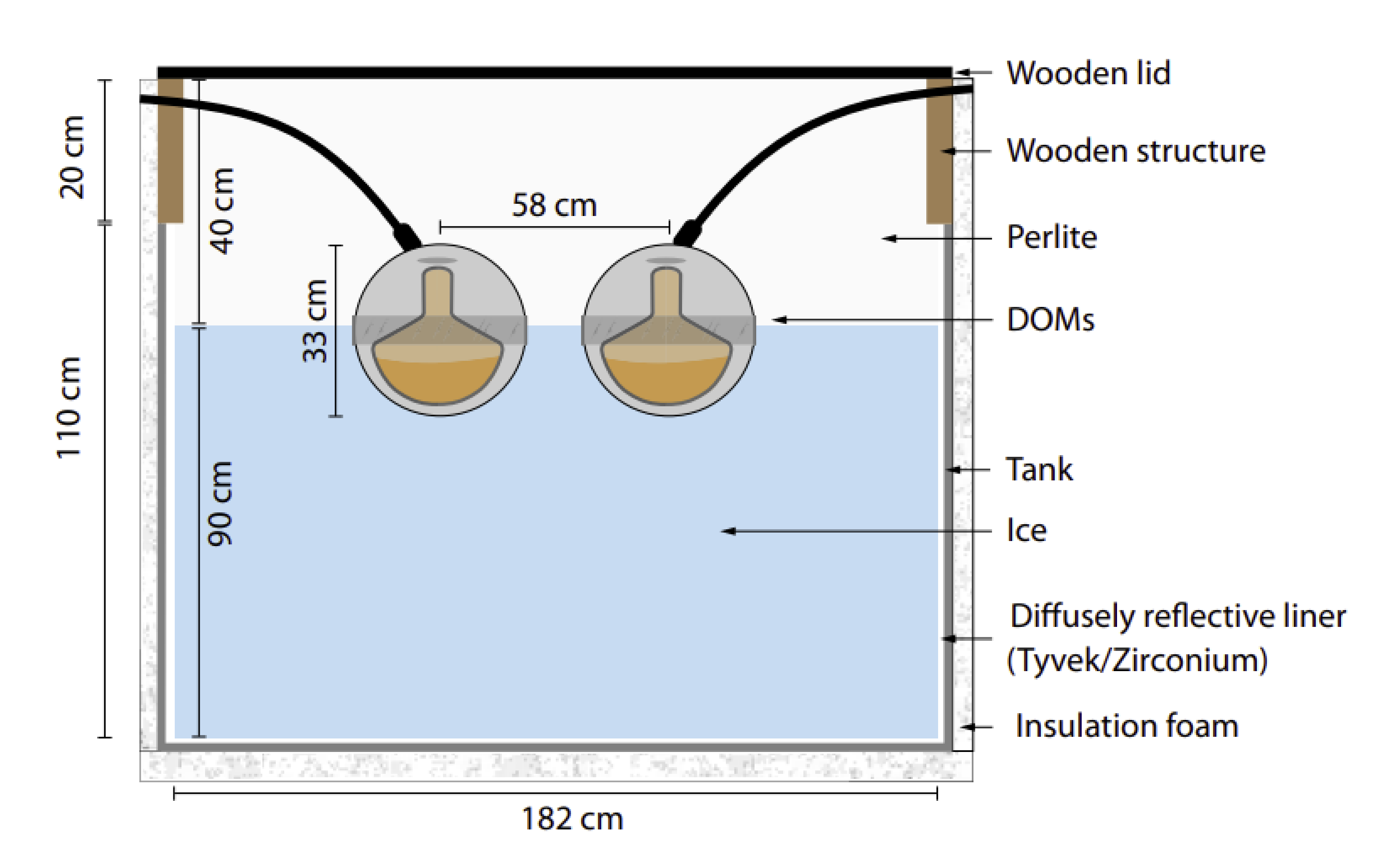




https://doi.org/10.48550/arXiv.1207.6326

A denser in-fill array is formed by the stations 26,27,36,37,46,79,80,81

Tank dimensions in a cross-sectional view

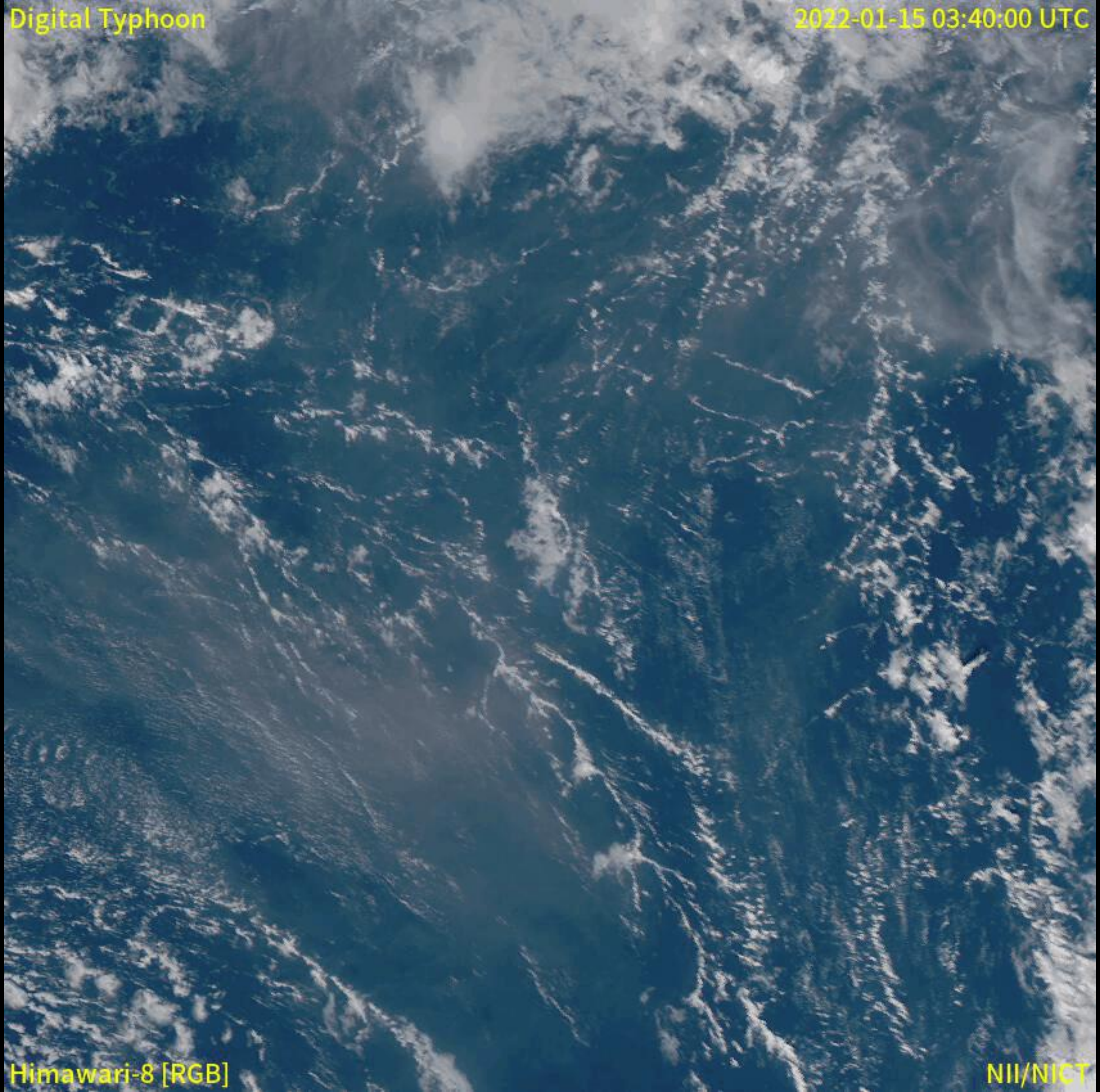


https://doi.org/10.48550/arXiv.1207.6326

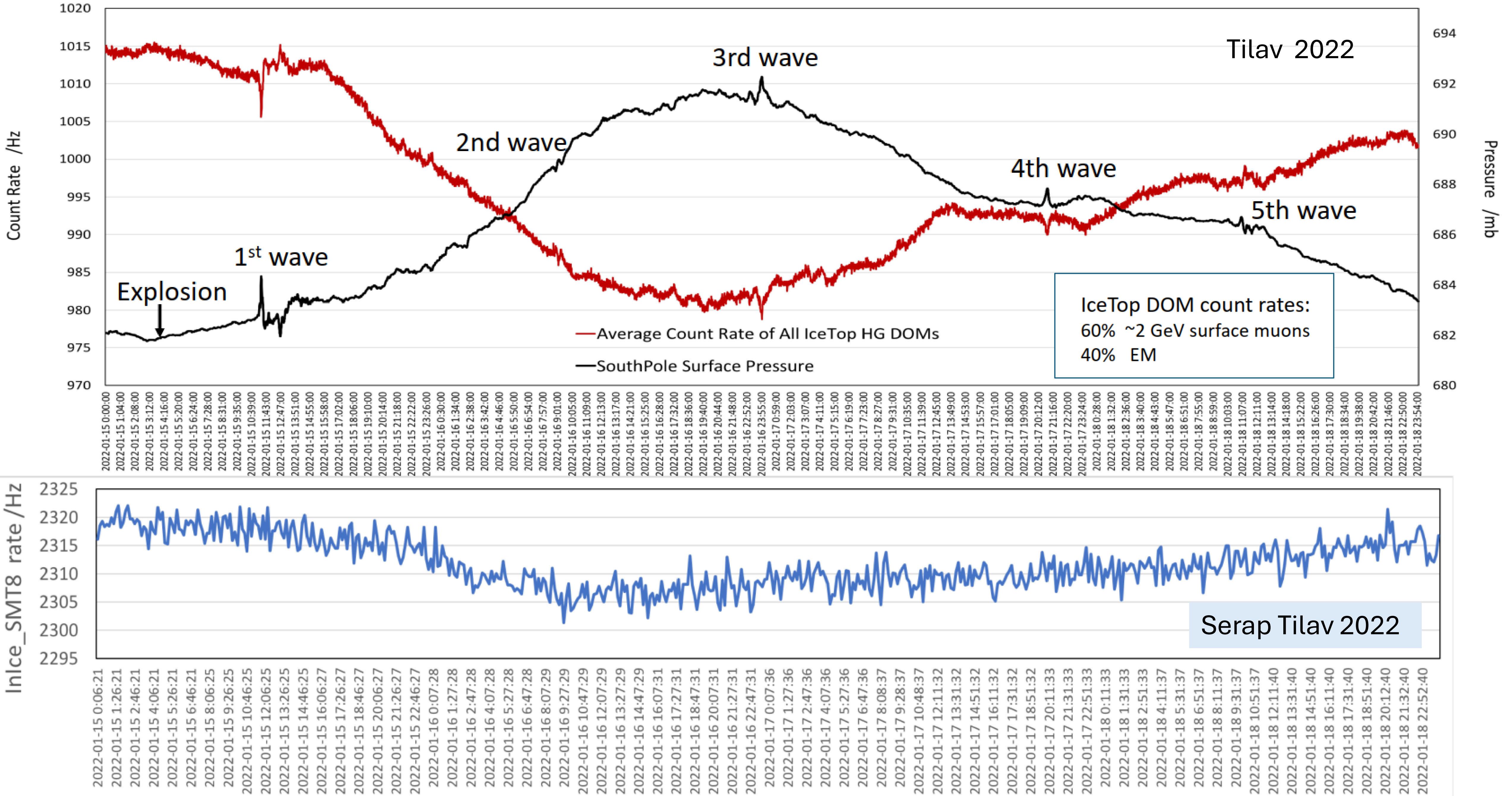
- Tank responds to Cherenkov light from charged particles in tank

2022 Hunga Tonga–Hunga Ha‘apai eruption and tsunami

https://en.wikipedia.org/wiki/2022_Hunga_Tonga%E2%80%93Hunga_Ha%CA%BBapai_eruption_and_tsunami



IceCube muons are not affected by the shockwaves



Role of Neutron Monitor Arrays for Space Weather Forecasting

- Automated GLE Alert System
- Prediction of SEP Energy Spectrum (Polar Bare Method / Leader Fraction)
- Realtime Specification of Galactic Cosmic Ray Spectrum (High-Altitude Array across a range of cutoff)

Future work plans:

- Automated GLE Alert System from neutron monitor leader fraction
- Automated GLE Alert System by using IceTop Tank data and the Global muon telescope
- Correlation between Galactic Cosmic Ray and TEC data

AURORAL, MAGNETOSPHERIC, AND IONOSPHERIC RESEARCH

AT CHIANG MAI UNIVERSITY

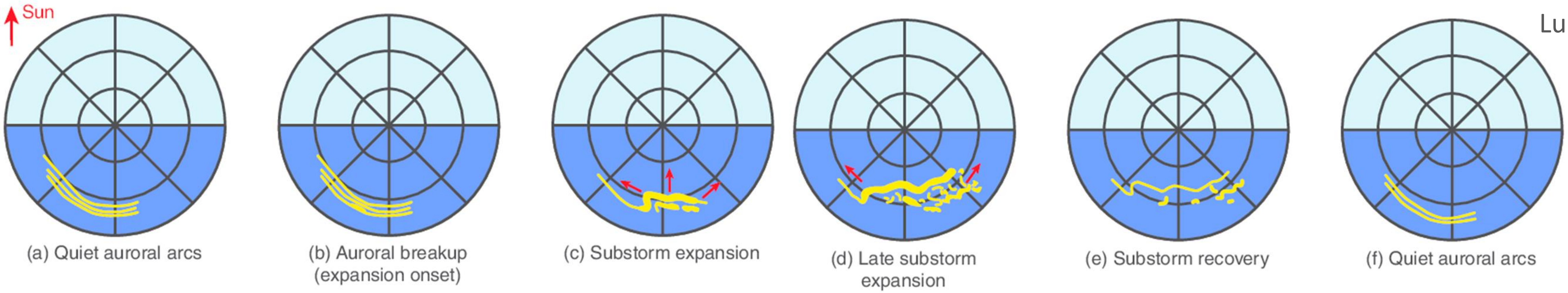
Suwicha Wannawichian

Kanpatom Kasonsuwan

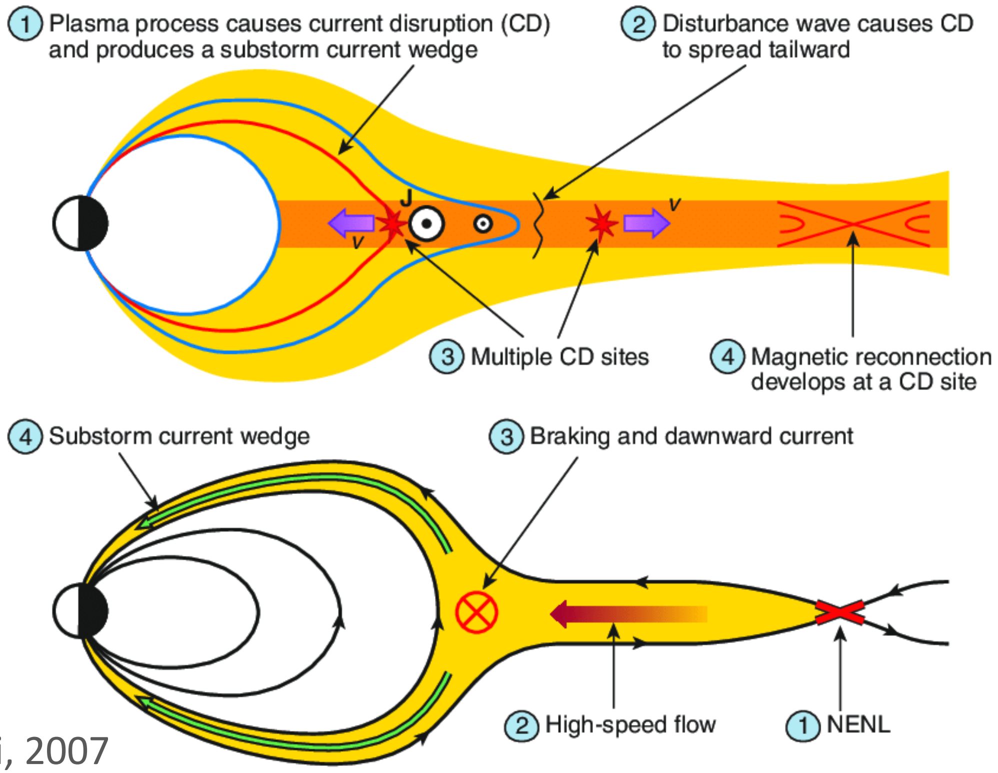
Paparin Jamlongkul

AURORAL SUBSTORM

Lui, 2007



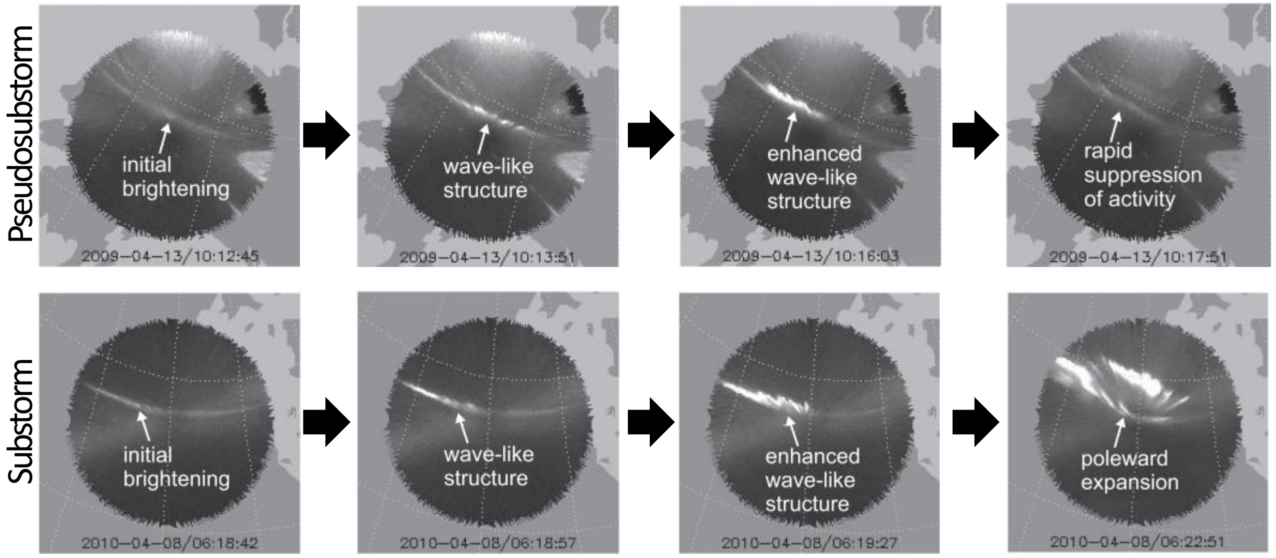
TWO SUBSTORM MODELS



Lui, 2007

SUBSTORMS VS PSEUDOSUBSTORMS

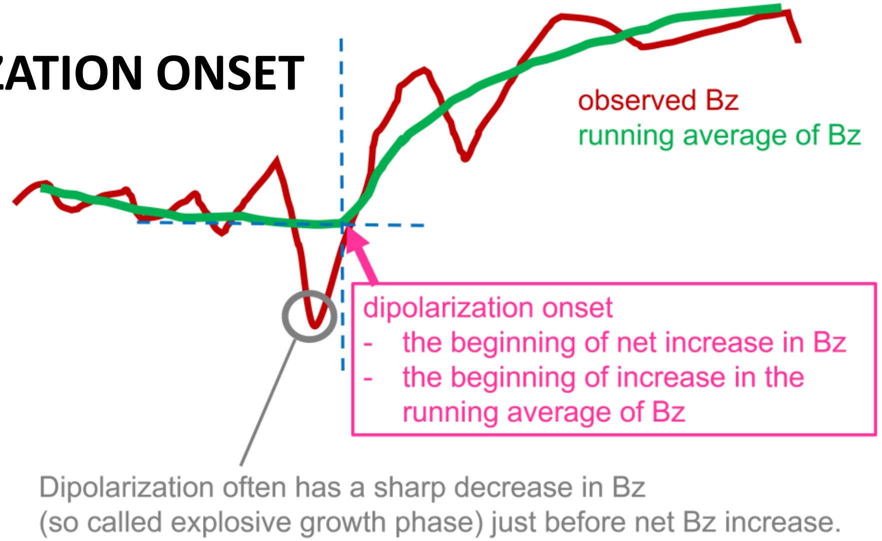
Substorms are characterized by poleward expansion and east-west expansion following the onset. In contrast, poleward expansion does not occur for pseudosubstorms.



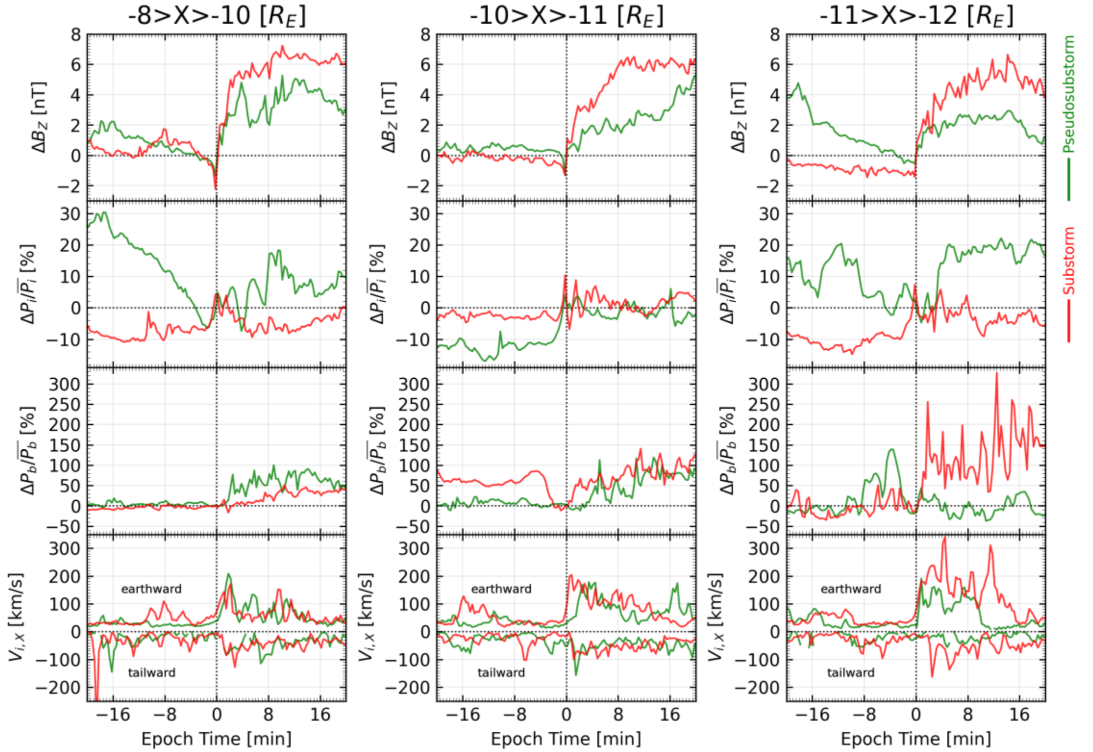
Examples of auroral onset arc development from all-sky images (Fukui et al., 2020).

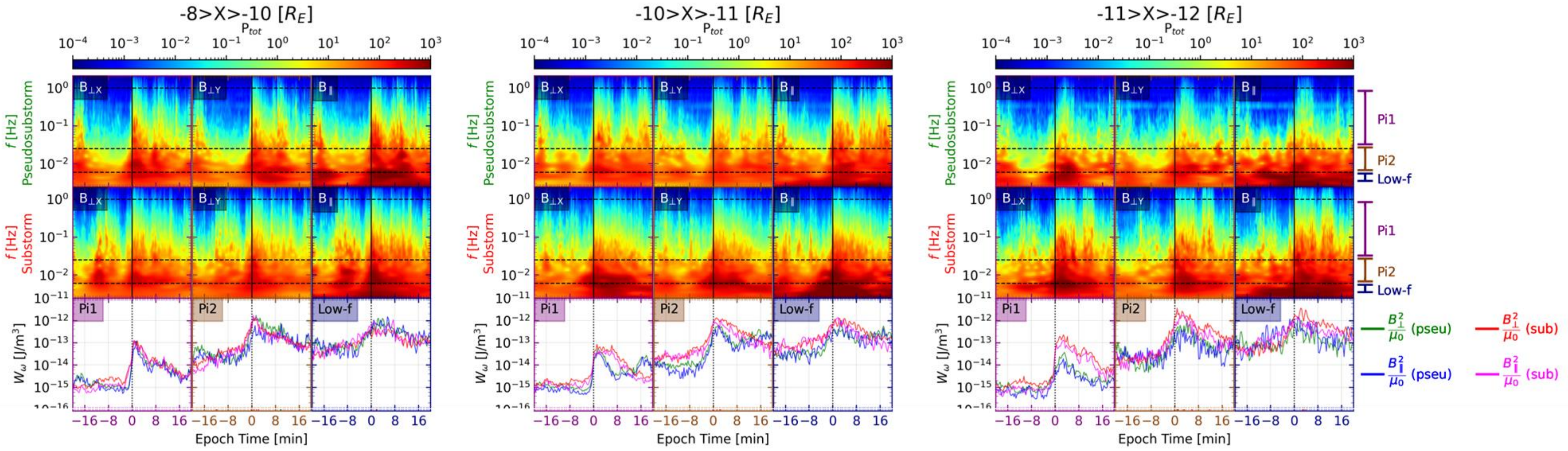
FEATURE OF ULF WAVES ASSOCIATED WITH DIPOLARIZATION BETWEEN SUBSTORMS AND PSEUDOSUBSTORMS IN THE PLASMA SHEET

DIPOLARIZATION ONSET

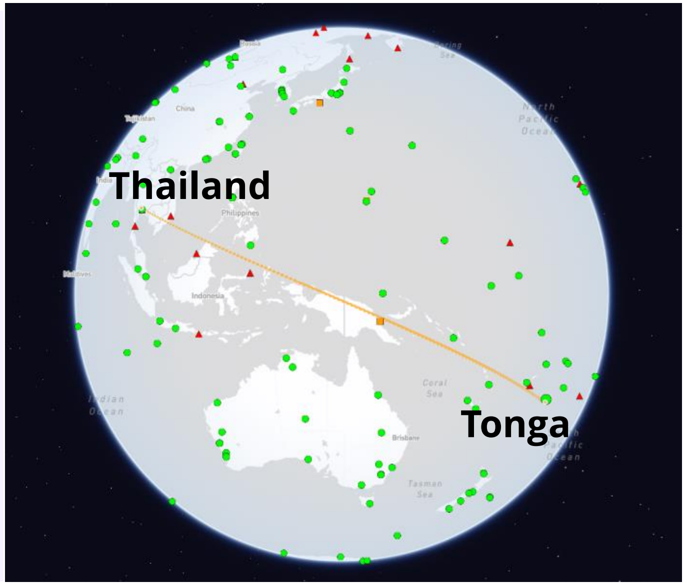


SUPERPOSED EPOCH ANALYSIS DATA





VTEC started to enhance after the eruption time ~9 hr during the recovery phase of the geomagnetic storm.



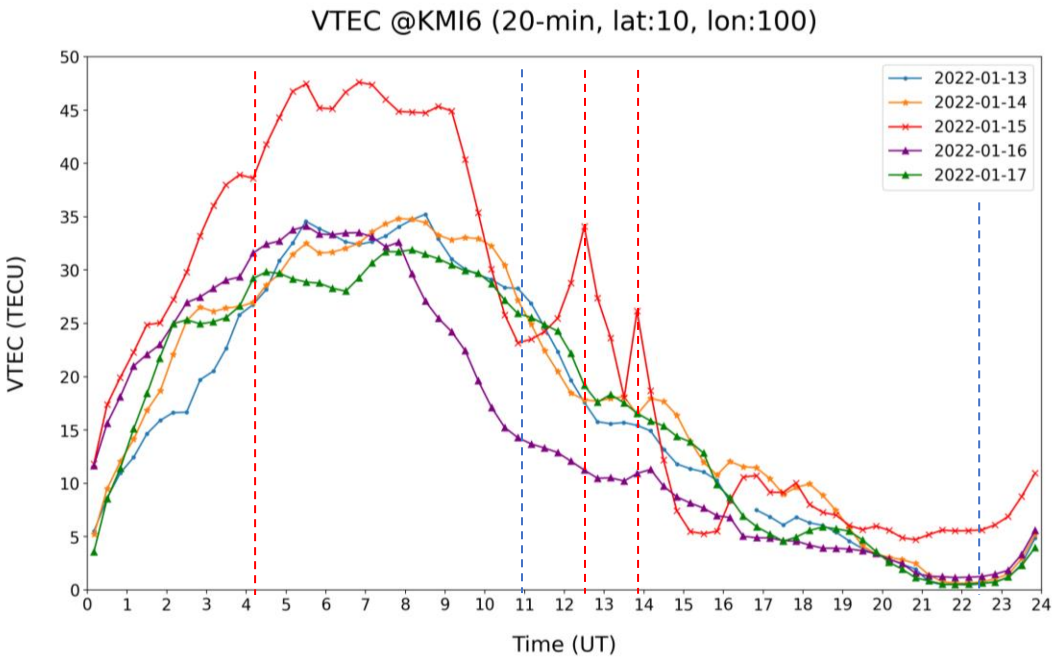
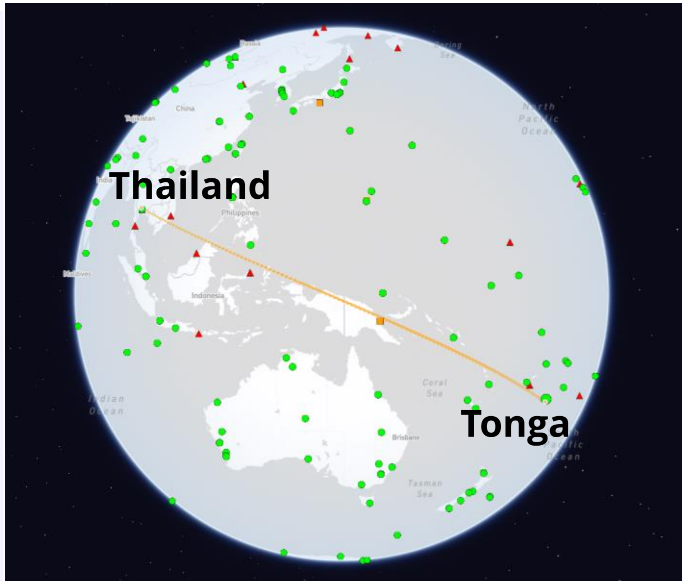


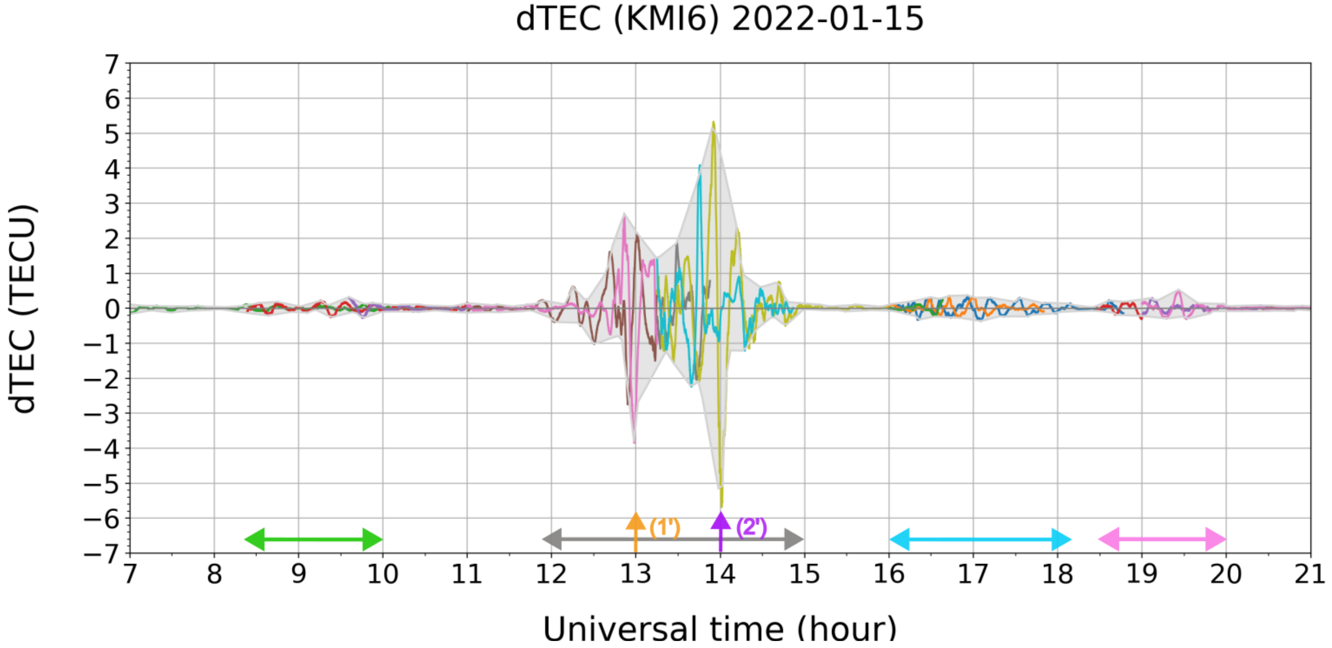
Figure 1. The 20-minute range time variations of mean VTEC from KMI6 station at 10 degrees latitude and 100 degrees longitude, respectively, during January 13th-17th, 2022.

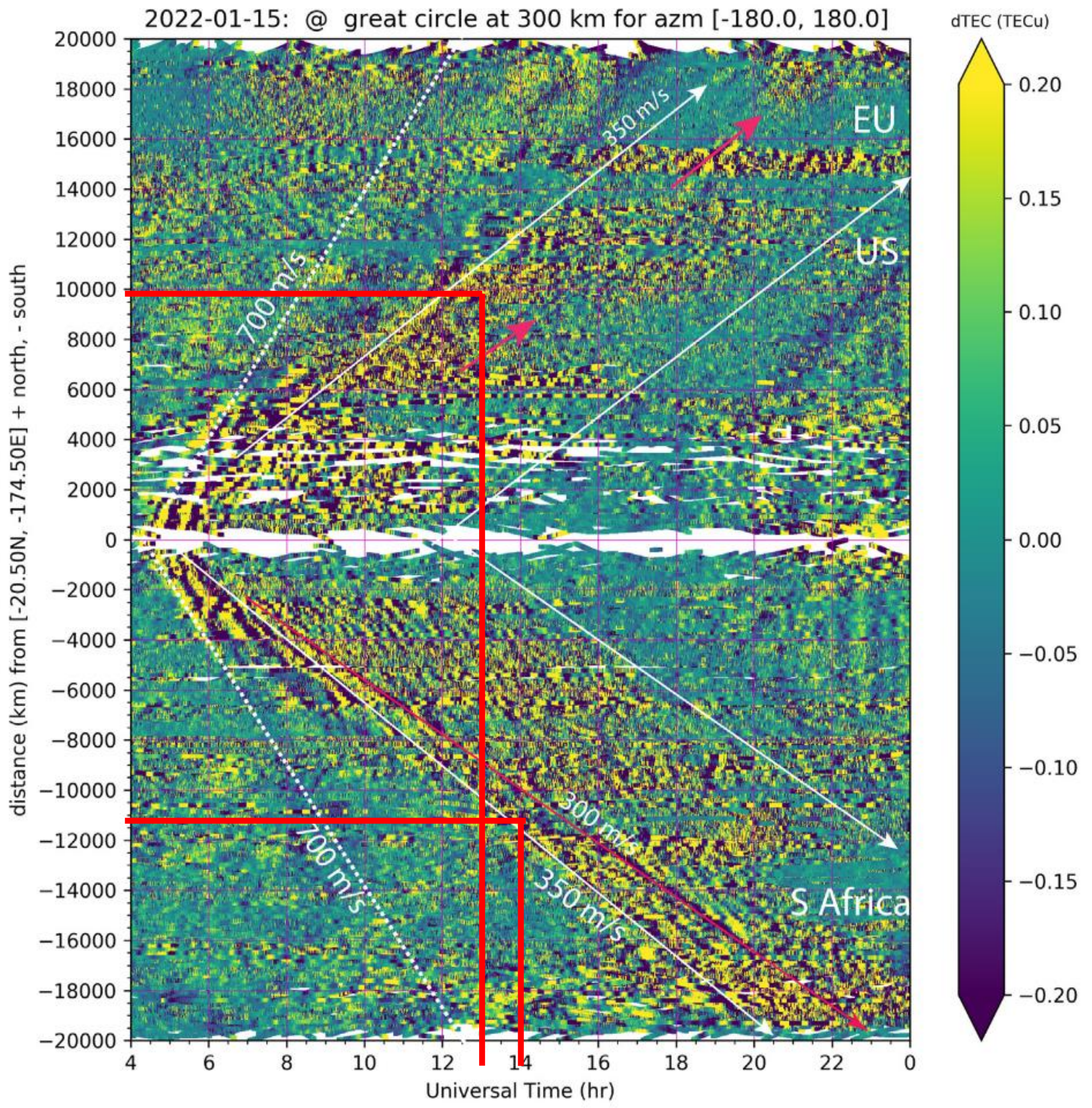
Table 1. Date and time of sub-events from the effects the geomagnetic storm and volcanic eruption

Source	Sub-events	Date and time
External source	Geomagnetic storm (Onset time)	14 Jan, ~11 UT (14 Jan ~18 LT)
External source	Geomagnetic storm time (Minimum SYM-H time)	14 Jan, ~22 UT (15 Jan, ~5 LT)
Internal source	HTHH eruption time	15 Jan, ~4 UT (15 Jan, ~11 LT)
Internal source	1st peak of pertubations after volcanic eruption	15 Jan, ~12:40 UT (15 Jan, ~19:40 LT)
Internal source	2nd peak of perturbations after volcanic eruption	15 Jan, ~13:40 UT (15 Jan, ~20:40 LT)

VTEC started to enhance after the eruption time ~9 hr during the recovery phase of the geomagnetic storm.



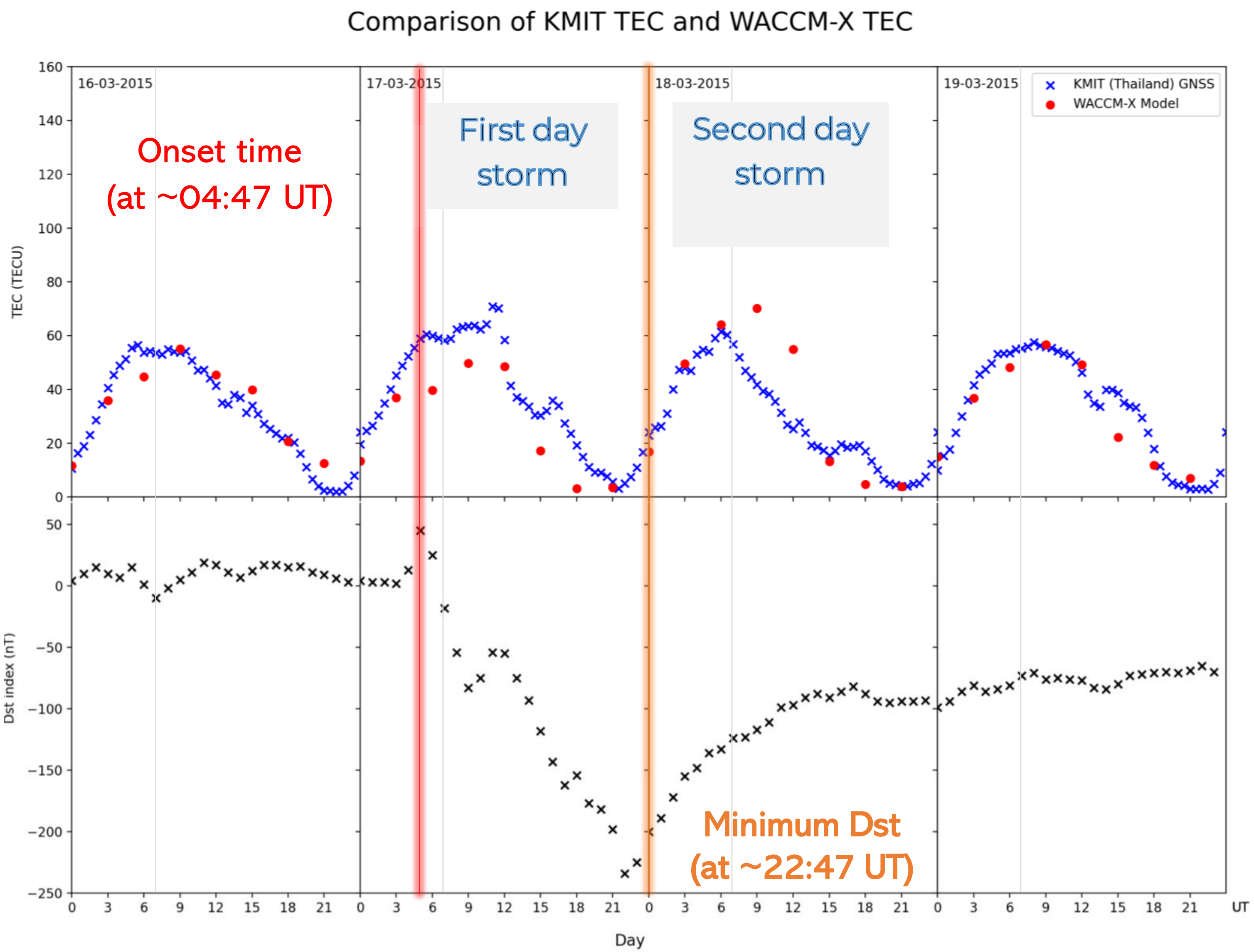




Zhang et al. (2022)

Figure 2. The dTEC represented mixed wave packets from 7 UT to 21 UT where satellite's lines of sights are oriented from Hunga Tonga to Thailand, occurring at various intervals: 8.5-10 UT (green double-head arrow), 12-15 UT (gray double-head arrow), 16-18 UT (sky blue double-head arrow), and 18.5-20 UT (pink double-head arrow). Between 12-15 UT, disturbances intensified around 12 UT, about 9 hours after the HTHH eruption. Fluctuations in dTEC peaked around 13 UT (orange arrow) and again at 14 UT (purple arrow), resembling TID shock waves in comparison with Zhang et al. (2022). Intensity decreased after 15 UT.

St. Patrick's Day on March 17th, 2015: KMIT GNSS TEC vs WACCM-X TEC



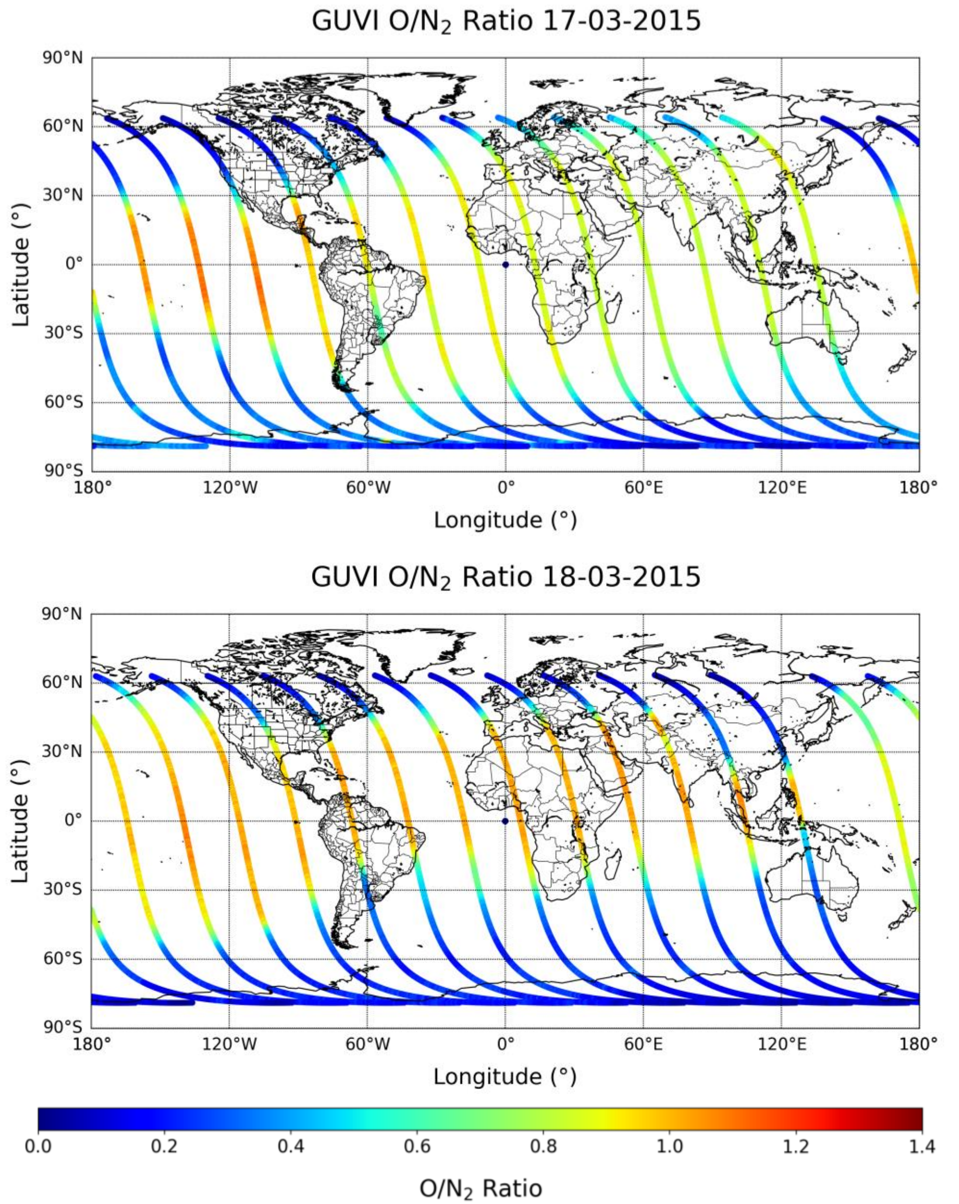


Figure 2. (Left) The time variations of mean VTEC from KMI6 station and WACCM-X model (above) and Dst index (below) during March 16th-19th, 2015. (Right) O/N2 observed by GUVI/TIMED during March 17th (above) and 18th (below), 2015.

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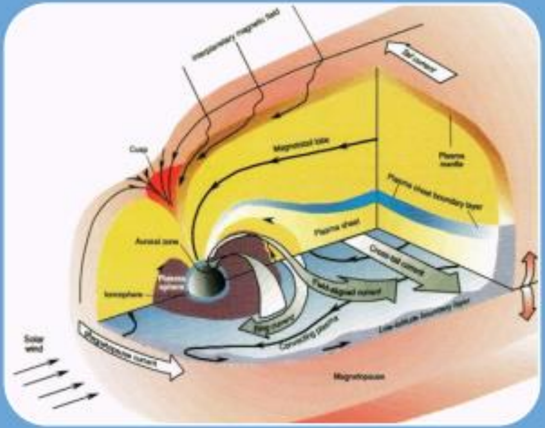
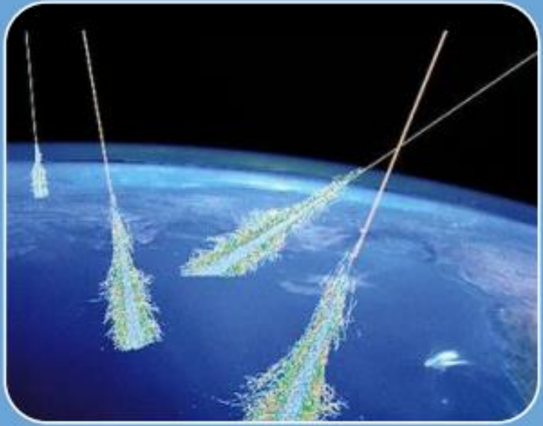




Magnetosphere
- Aurora
- Ionosphere

High energy Astrophysics
- Neutrino Detectors: IceCube and SND@LHC CERN
- Latitude surveys
- Cosmic rays observation network

Astrobiology
- Origin of Life
- Food for Space

Education & Outreach program

Researchers

Science		Education	Engineering
Physics and Materials Science	Biology	Curriculum, Learning and Teaching	Civil Engineering

Siramas Komonjinda

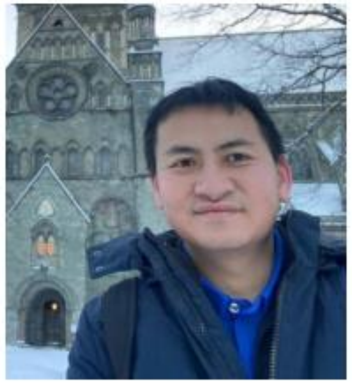
Suwicha Wannawichian

Waraporn Nuntiyakul

Jeeraporn Pekkoh

Kreetha Kaewkong

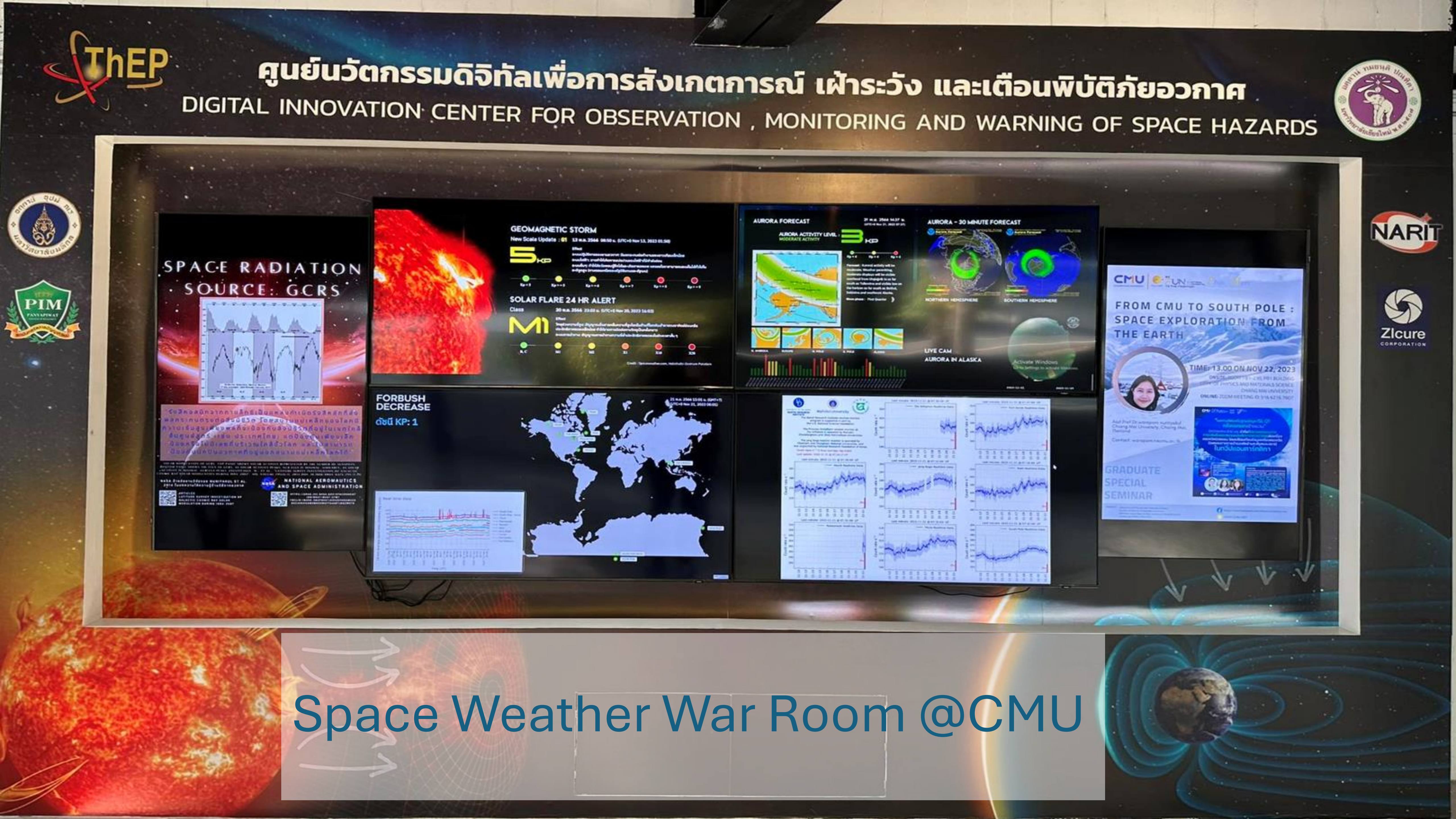
Chana Sinsabvarodom



Post doctoral researcher

Achara Seripienlert

Krittiya Pinyo



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