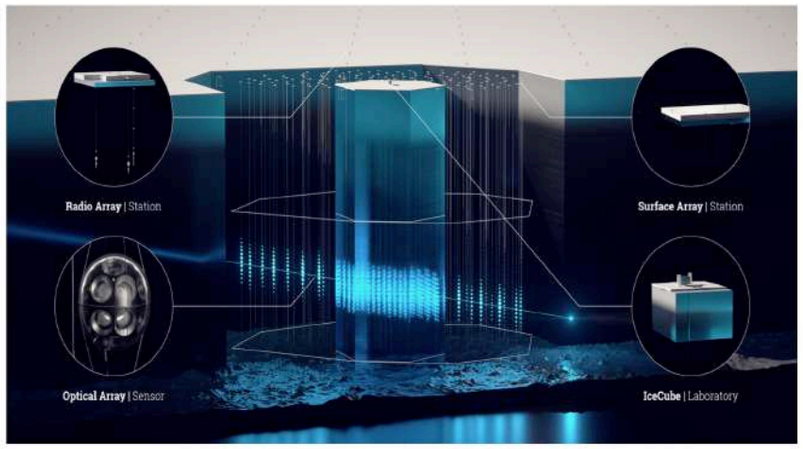
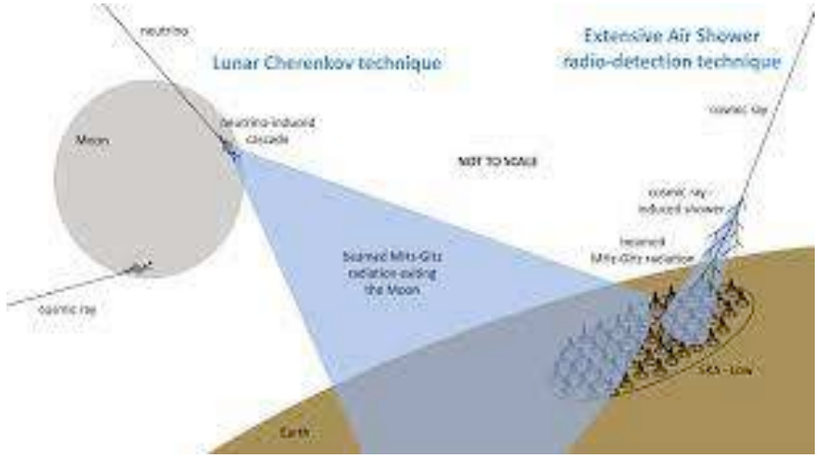
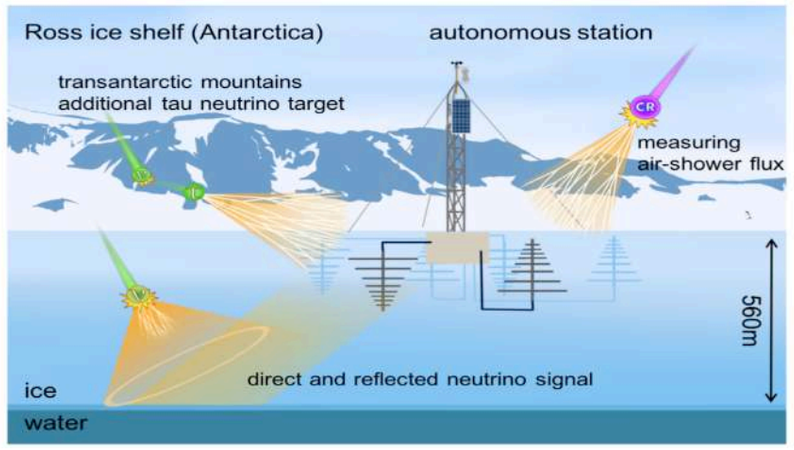
Production of VHE neutrinos from GRB Afterglows
and
Setting up a Radio Array in India to Detect VHE neutrinos







Debanjan Bose
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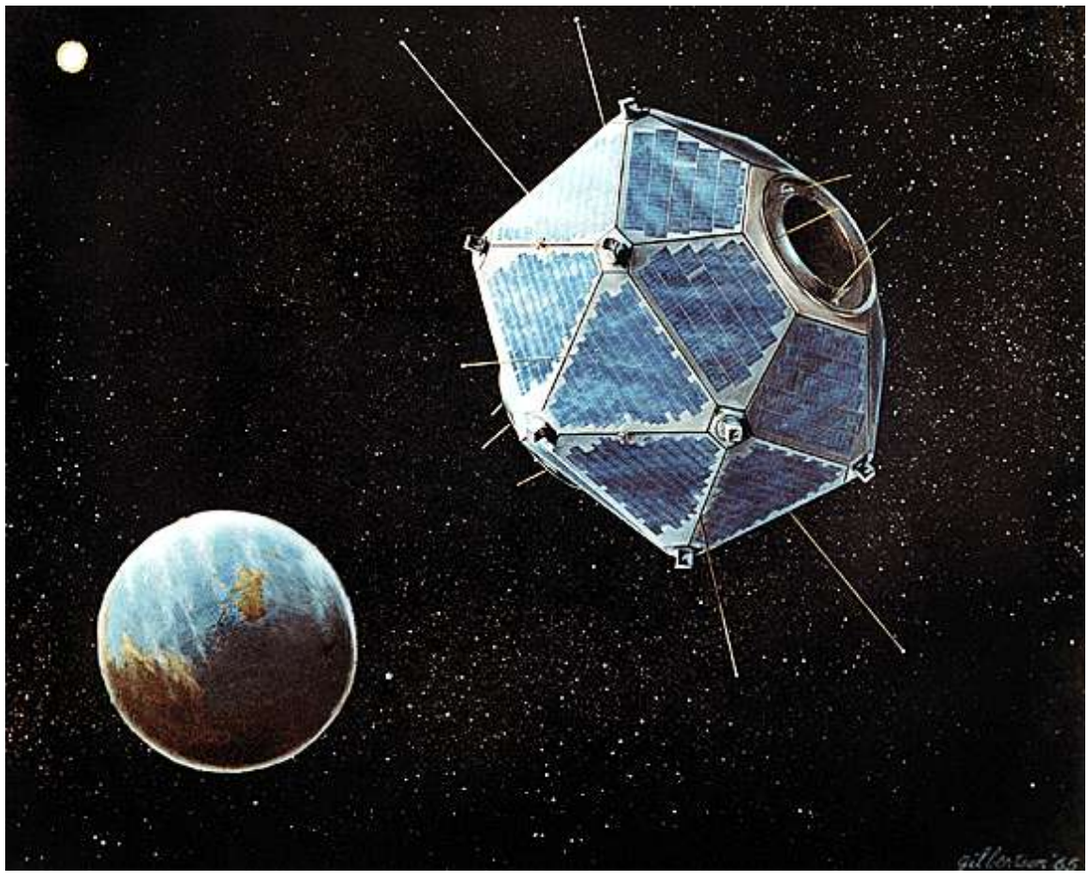
Gamma Ray Burst (GRB)

- GRBs are sudden, intense and non-repetitive flashes of gamma-rays
- They are the most luminous, most energetic events in the Universe, outshines everything else
- They lasts only for few seconds and release 10^{54} ergs; comparable to SN, comparable to optical light emission by Sun over the lifetime
- Non-thermal emission

Serendipitous Discovery of GRBs



Vela Satellite

First detected by Vela military satellite in 1967

Vela had omni-directional gamma-ray detectors onboard to monitor Nuclear explosions in space (in violation of Nuclear Test Ban Treaty) .. launched in pair for triangulation (determine position with high accuracy) .. but it can only tell direction not how far!!

Soon it started detecting gamma-rays coming from space. Announcement made on 1973.

Serendipitous Discovery of GRBs

THE ASTROPHYSICAL JOURNAL, 182:L85–L88, 1973 June 1

OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
Received 1973 March 16; revised 1973 April 2

ABSTRACT

Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to ~30 s, and time-integrated flux densities from $\sim 10^{-5}$ ergs cm^{-2} to $\sim 2 \times 10^{-4}$ ergs cm^{-2} in the energy range given. Significant time structure within bursts was observed. Directional information eliminates the Earth and Sun as sources.

Compton Gamma Ray Observatory

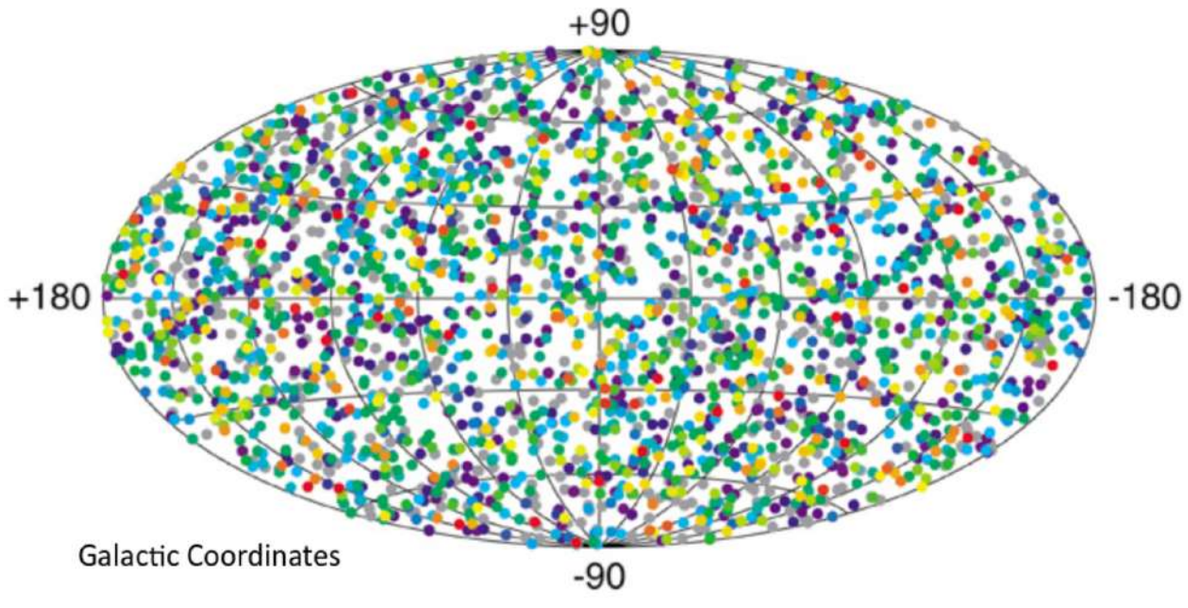
1991-2000

For long time GRBs remain mystery

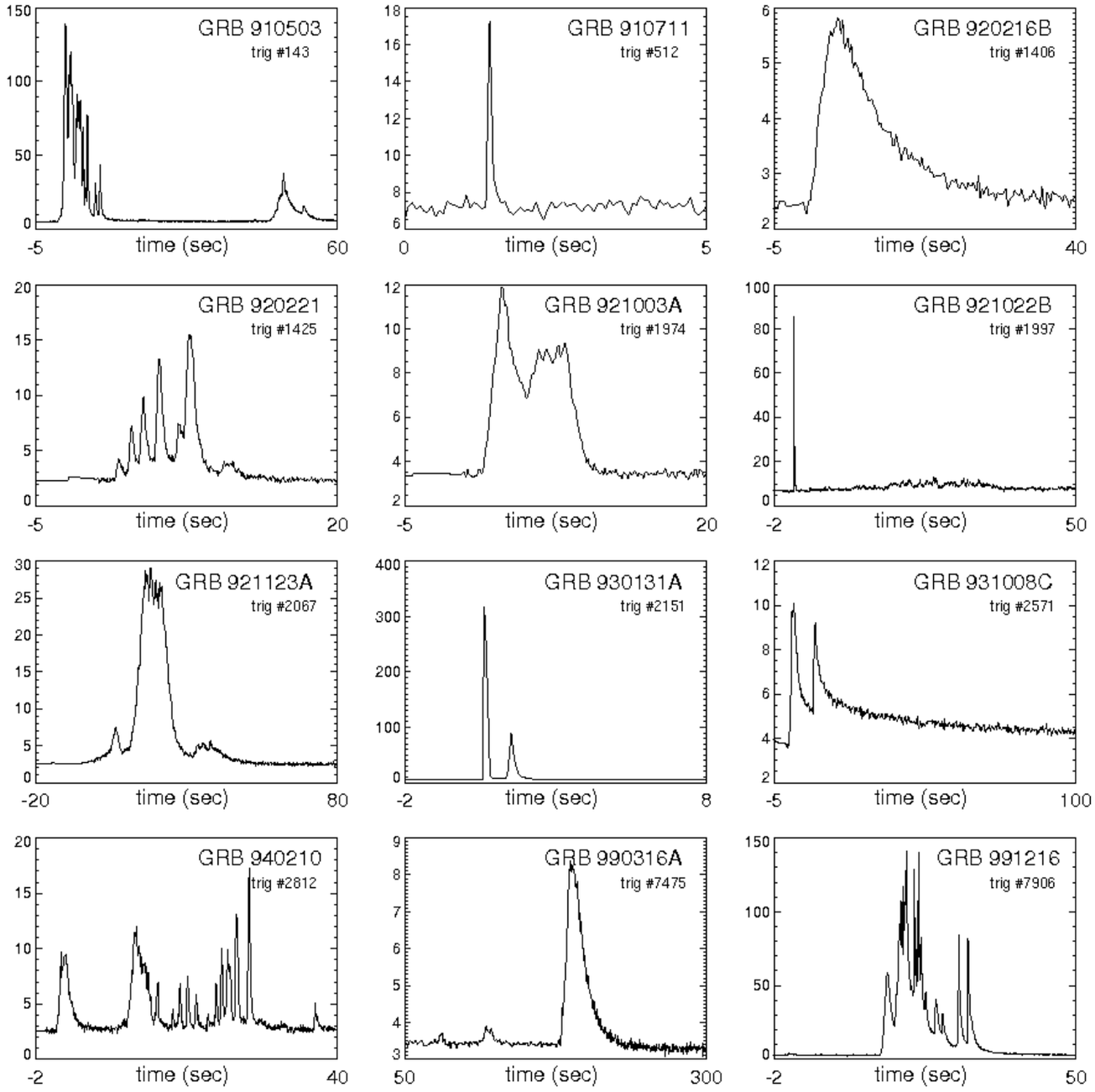
Burst And Transient Source Experiment on Board CGRO changed this picture completely

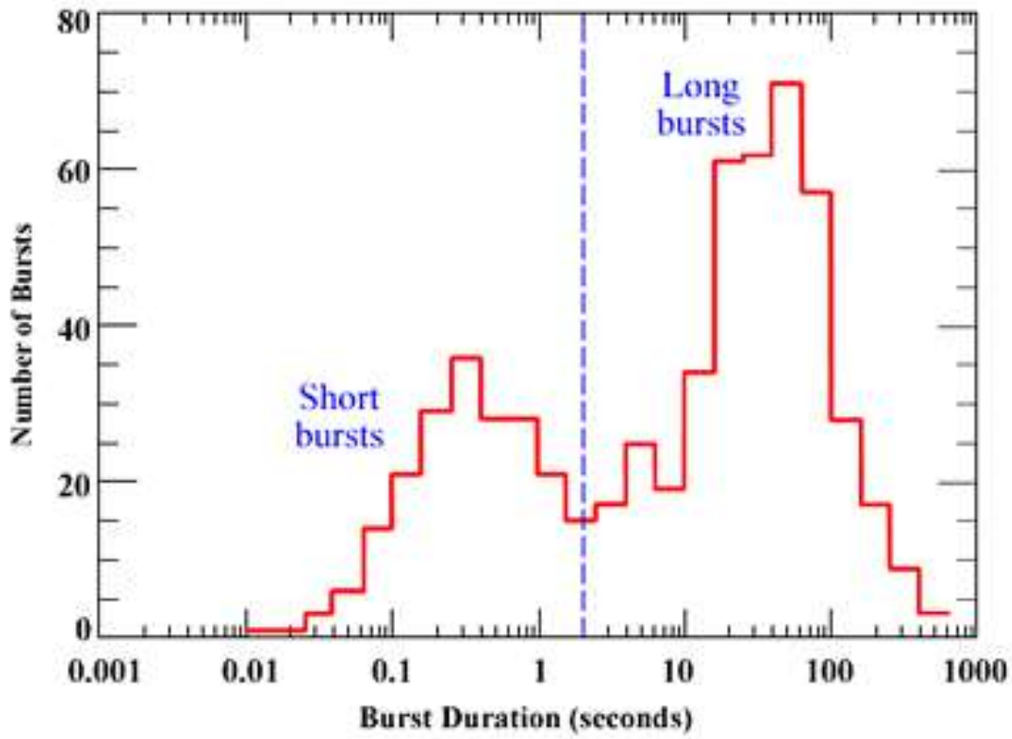
BATSE detected 1 GRB/day within field of view (1/3 rd Sky)

BATSE detected almost 3000 GRBs distributed isotropically : thus they are cosmological



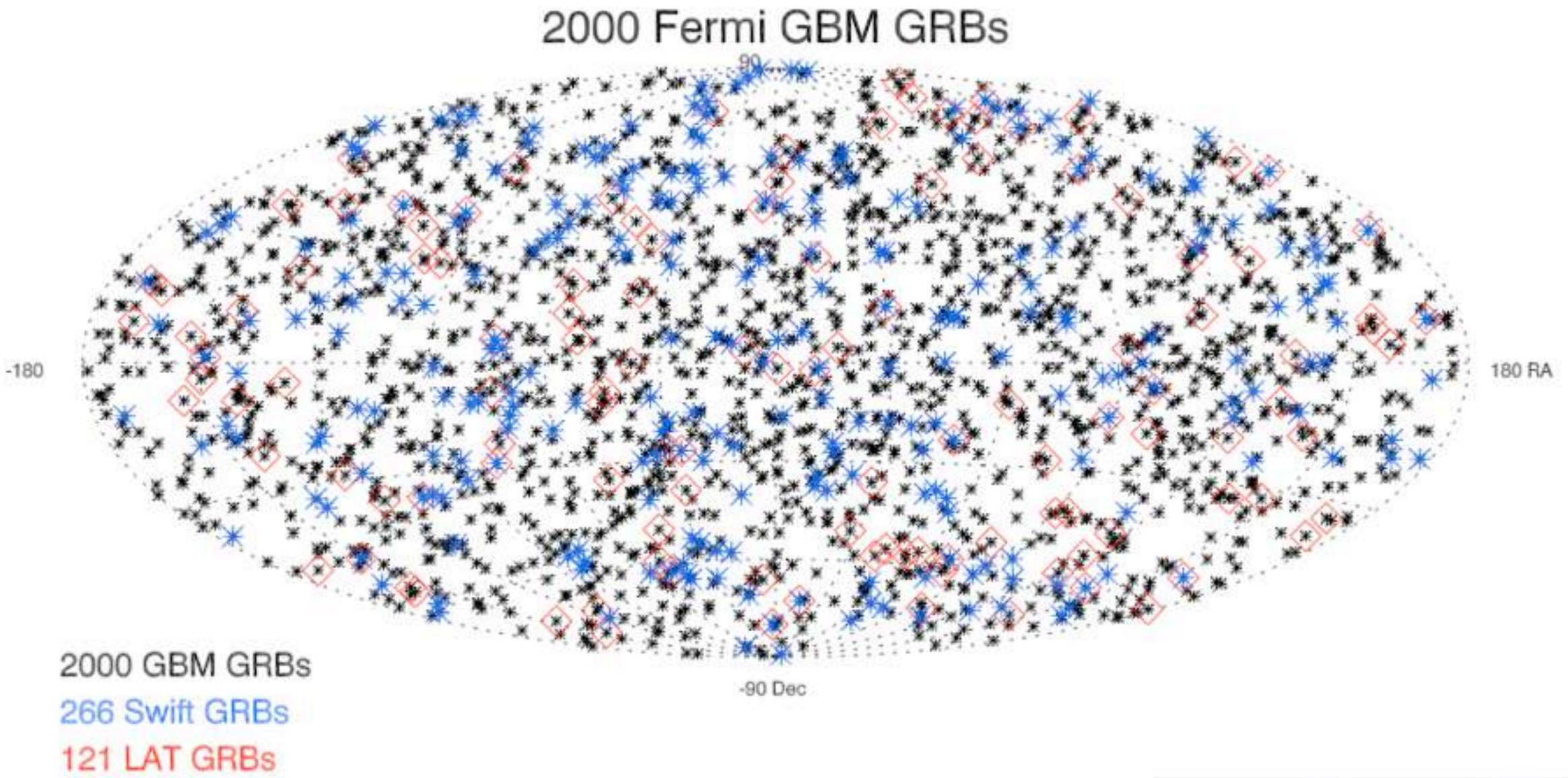
Variability of GRBs



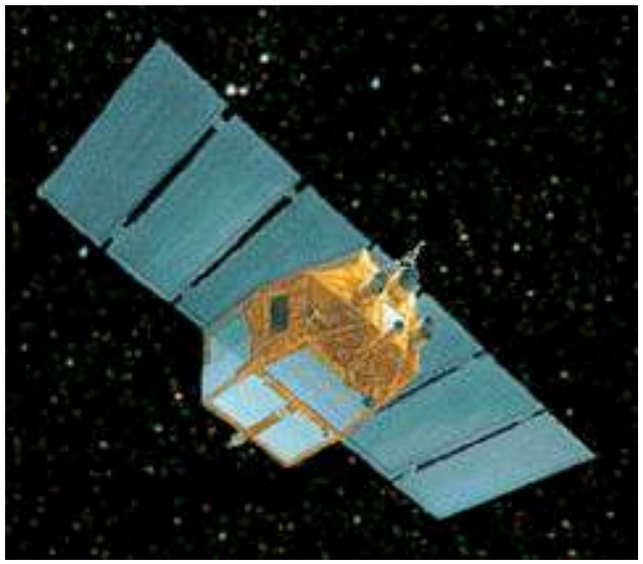


Rapid Variability and short timescales implies compact region and relativistic motion

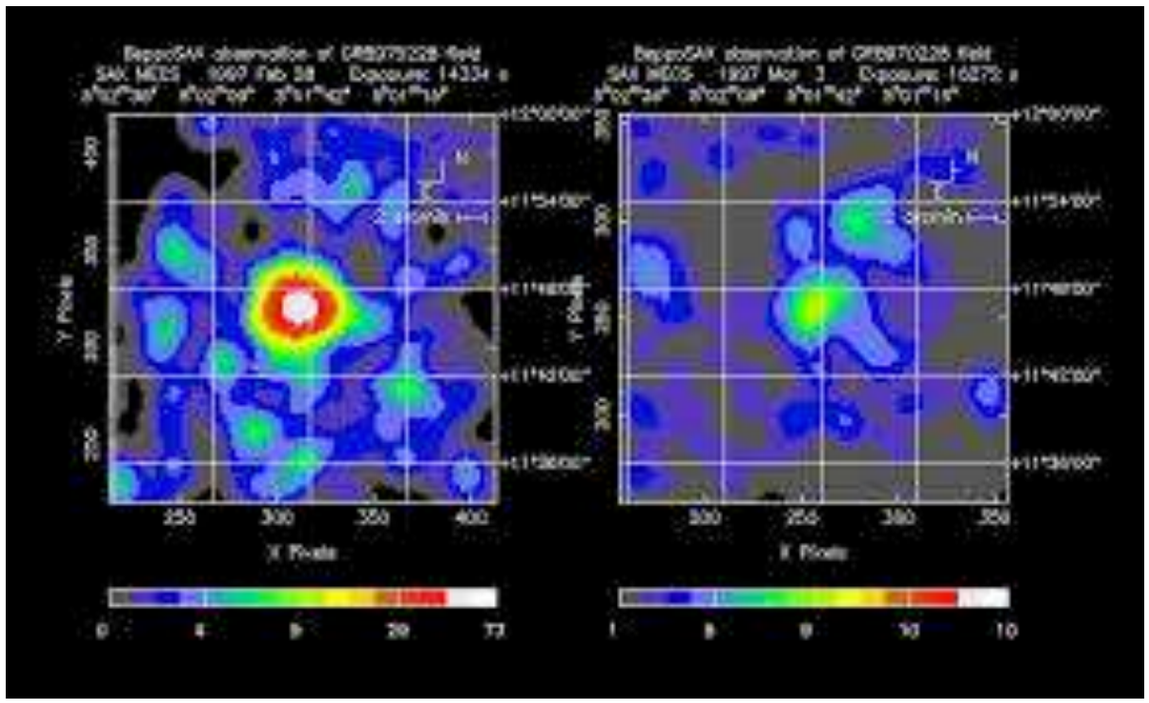
GRBs Detected by Fermi Satellite



Afterglow of GRBs



Bepposax Satellite

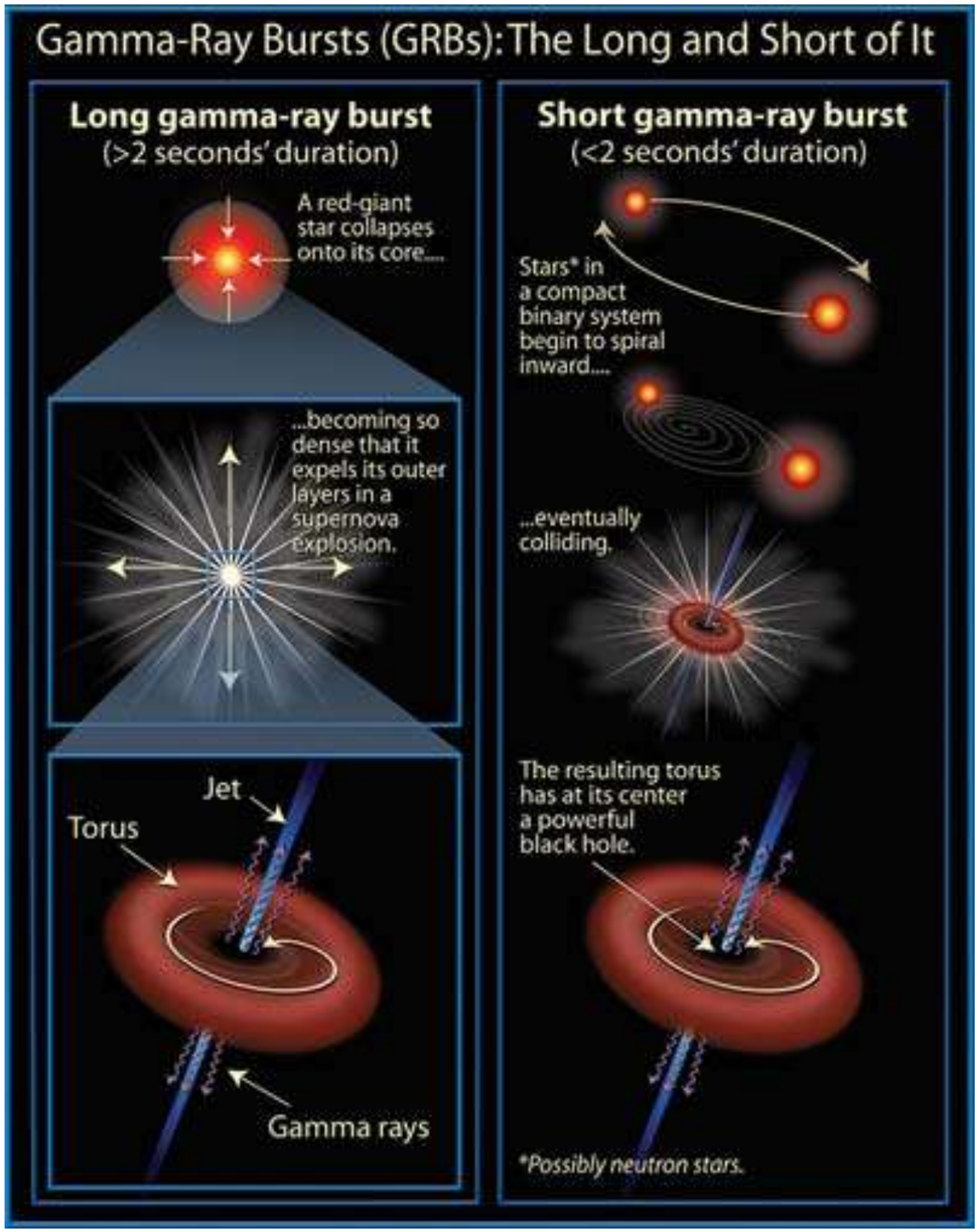


Upto 30 years after discovery only "prompt" emissions were detected from GRBs. Thus Location of these objects and nature of compact objects not known

Observation of afterglow changed that scenario

Measurement of redshift, identification of host galaxies, confirmation that these are cosmological phenomena

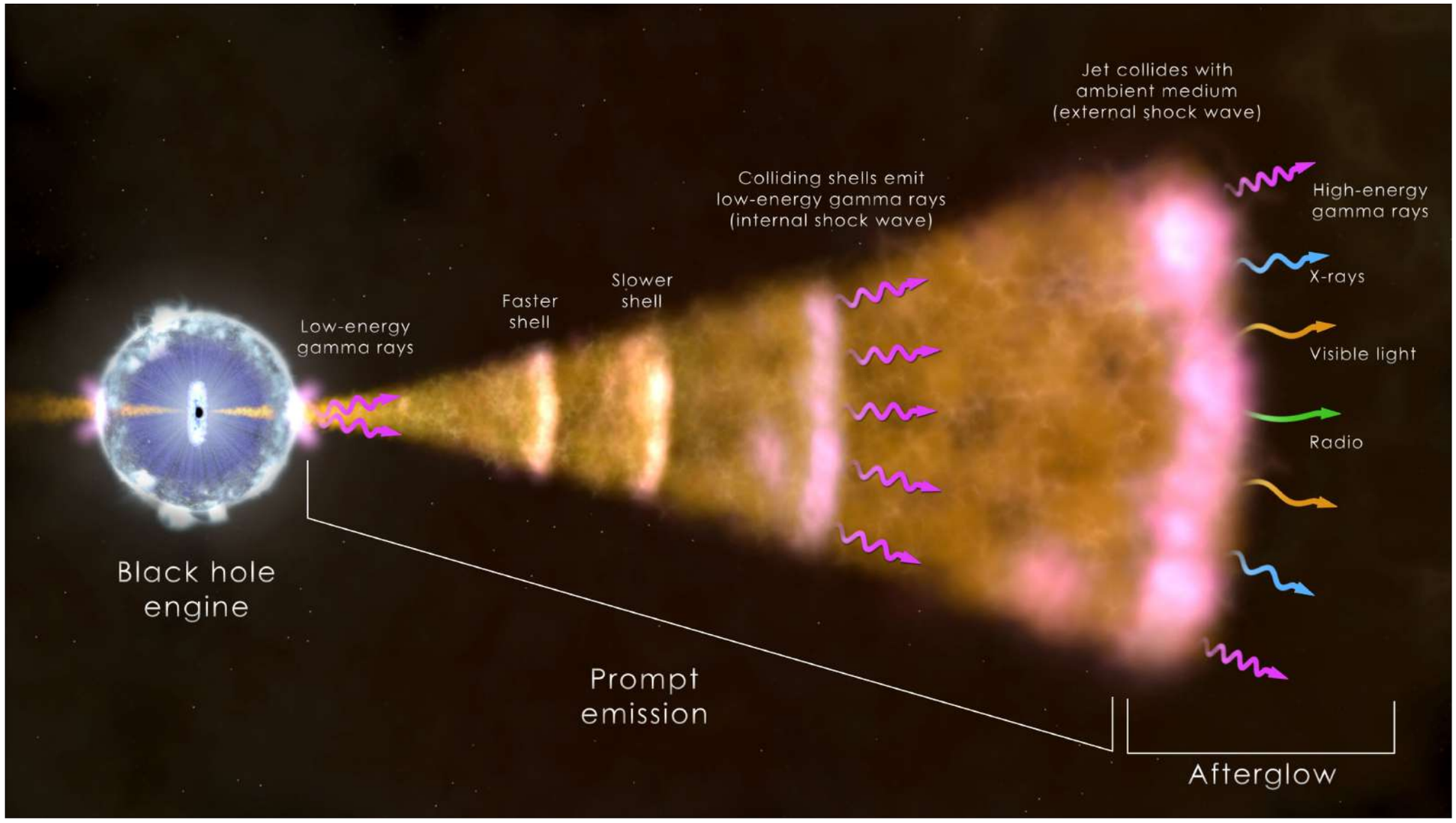
Long & Short GRBs



Long GRBs - core of massive star collapse [Evidence - absorption due to Fe in x-ray continuum spectrum.. associated with SN] .. galaxy merger.. massive young stars die early .. millions of years

Short GRBs - Merger of NS-NS, NS-BH [Never associated with SN; found in elliptical galaxies- compact binaries most abundant] .. takes billions of years to merge

Fireball Mechanism



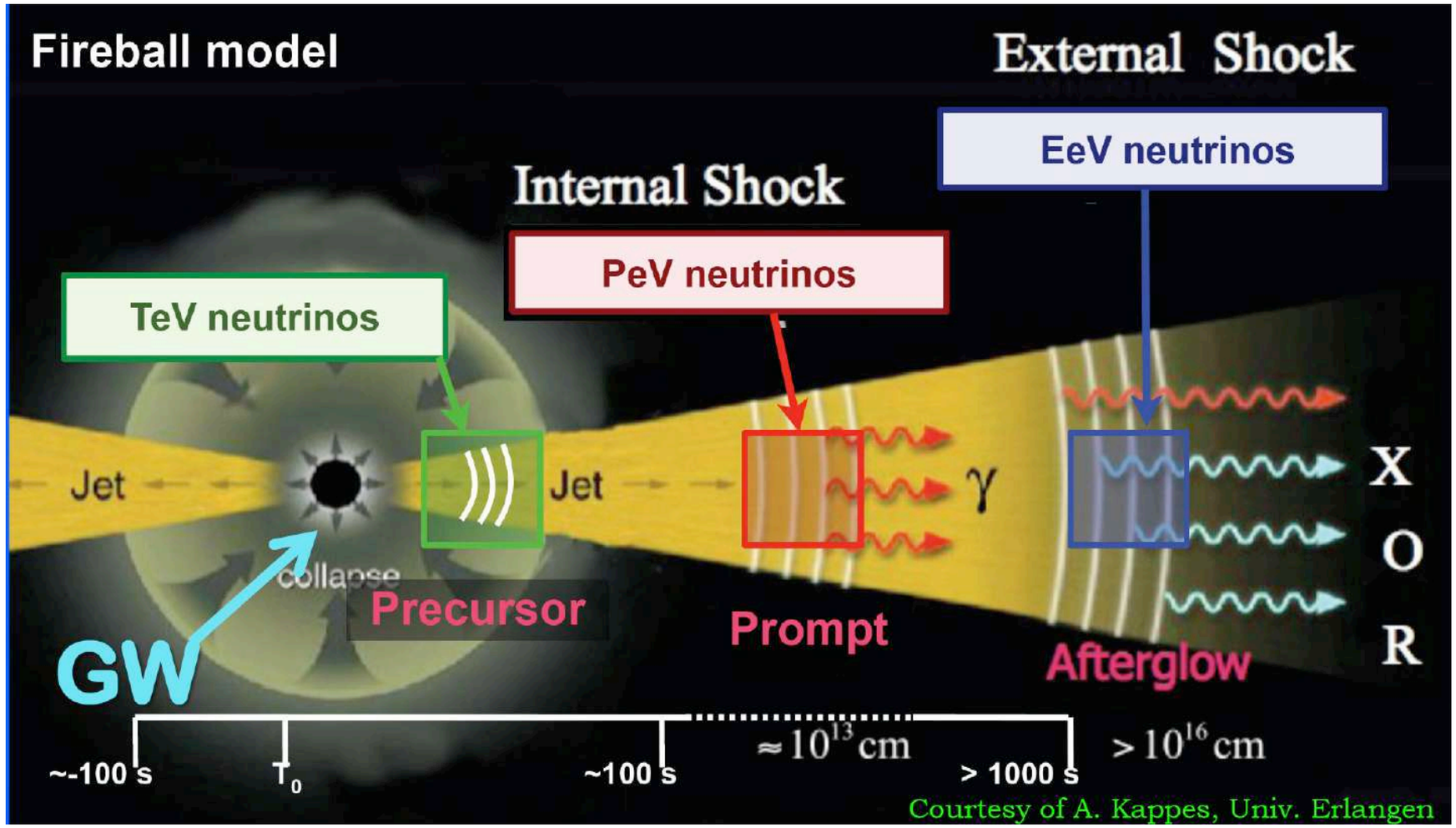
The enormous energy release in a such a short time from very compact region produces tremendous luminosity which overwhelms gravity.

This outward pressure flings out matter, which gets heated up into a fireball made of electrons, positrons, gamma-rays, protons, neutrons

GRB Neutrino Connection

Long GRBs - core of massive star collapse- Core collapse SN produce huge number of MeV neutrinos

proton - neutron inelastic collision (at much lower radii compare to where shocks occur) can produce GeV neutrinos



- **Photonuclear** $p\gamma \to \Delta^+ \to n\pi^+ / p\pi^0$
- **Nucleon-nucleon** $pp/pn \to \pi^\pm / K^\pm$

ν production channels $\pi^+ / K^+ \to \mu^+ \nu_\mu \to e^+ \nu_e \bar{\nu}_\mu \nu_\mu$

Recent IceCube ATEL

[Previous I Next]

IceCube-250309A - IceCube observation of a high-energy neutrino candidate track-like event coincident with GRB 250309B

ATel #17070; *Anna Franckowiak (Ruhr-University Bochum), Lu Lu (University of Wisconsin Madison), Giacomo Sommani (Ruhr-University Bochum), Tianlu Yuan (University of Wisconsin-Madison), Angela Zegarelli (Ruhr-University Bochum), Justin Vandenbroucke (University of Wisconsin-Madison), Marcos Santander (University of Alabama)*
*on **9 Mar 2025; 14:18 UT***
Credential Certification: Anna Franckowiak (anna.franckowiak@desy.de)

On 2025-03-09 at 07:36:04.75 UT IceCube detected a track-like event with a high probability of being of astrophysical origin. The event was selected by the ICECUBE_Astrotrack_GOLD alert stream. This alert has an estimated false alarm rate of 0.18 events per year due to atmospheric backgrounds. The IceCube detector was in a normal operating state at the time of detection.

After the initial automated alert (https://gcn.gsfc.nasa.gov/notices_amon_g_b/140626_1288692.amon), more sophisticated reconstruction algorithms have been applied offline, with the direction refined to:

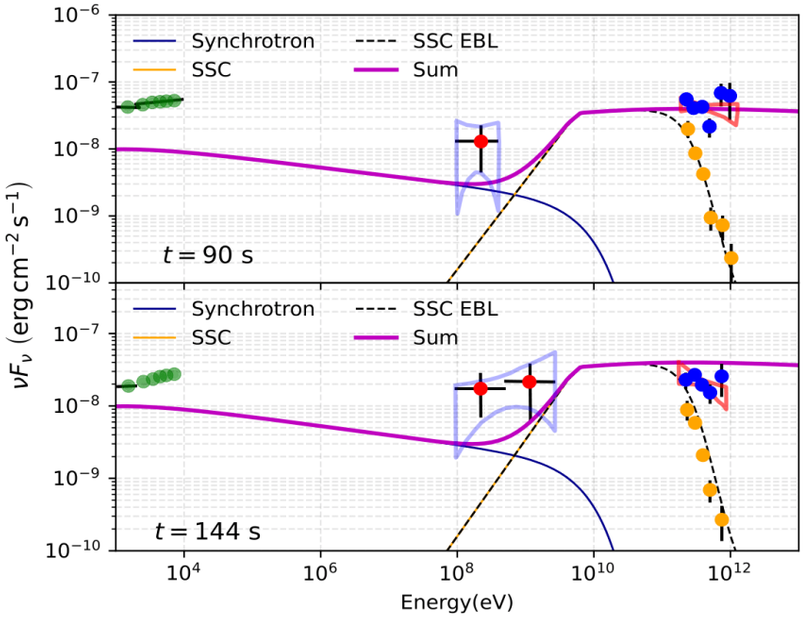
Date: 2025-03-09
Time: 07:36:04.75 UT
RA: 211.07 (+0.31 -0.30 deg 90% PSF containment) J2000
Dec: -10.73 (+0.26 -0.30 deg 90% PSF containment) J2000

The inferred neutrino energy of this alert is ~4 PeV, making it the fourth-highest energy known detection by IceCube over the past decade.

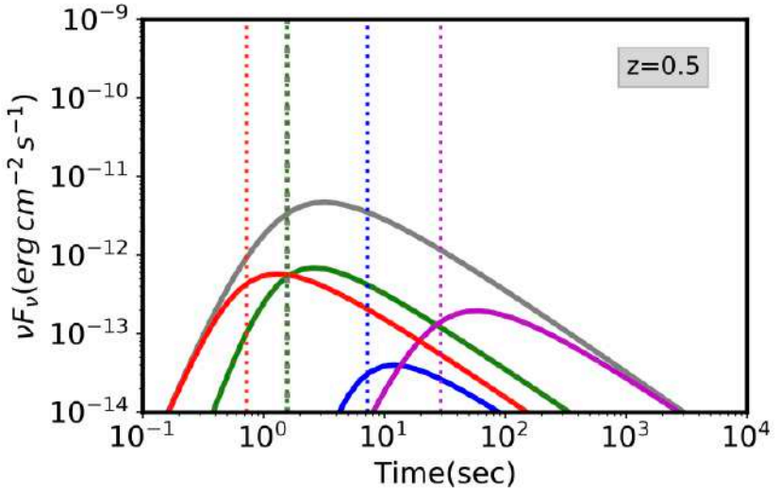
Modelling of Long GRB Afterglow at VHE regime and Detection Prospect with Cherenkov Telescope Array

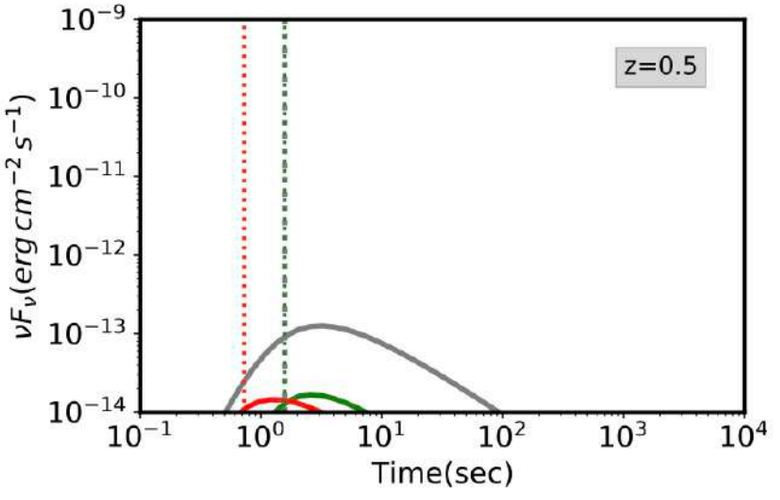
Tanima Mondal

PMRF, IIT Kgp



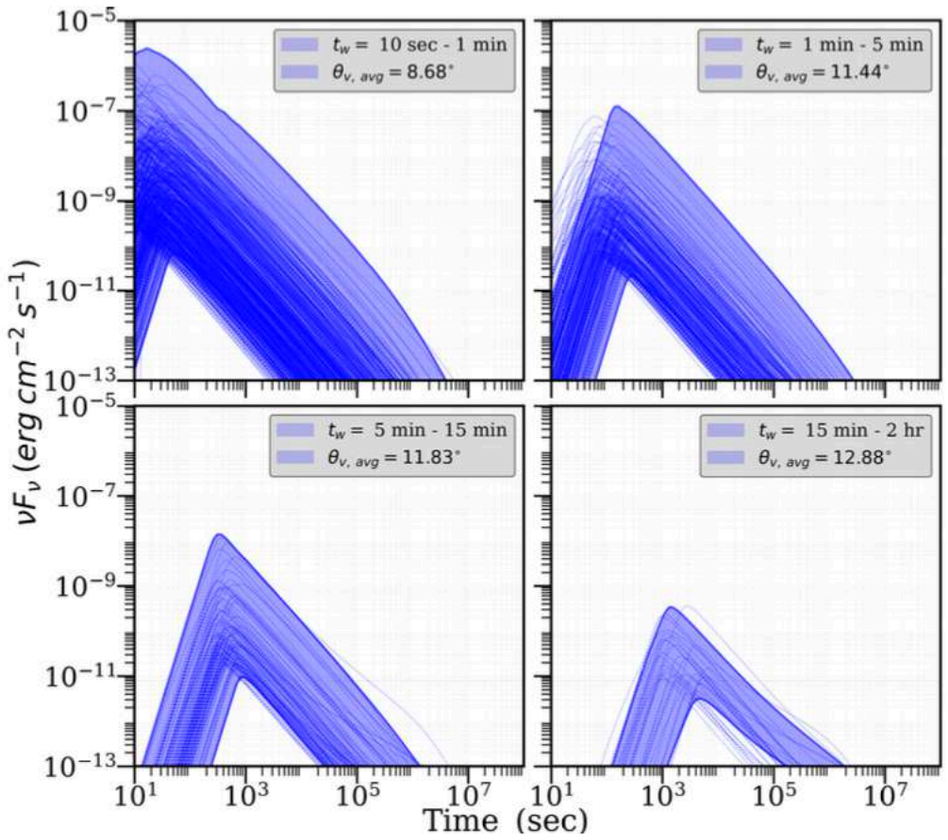
Without EBL **With EBL**

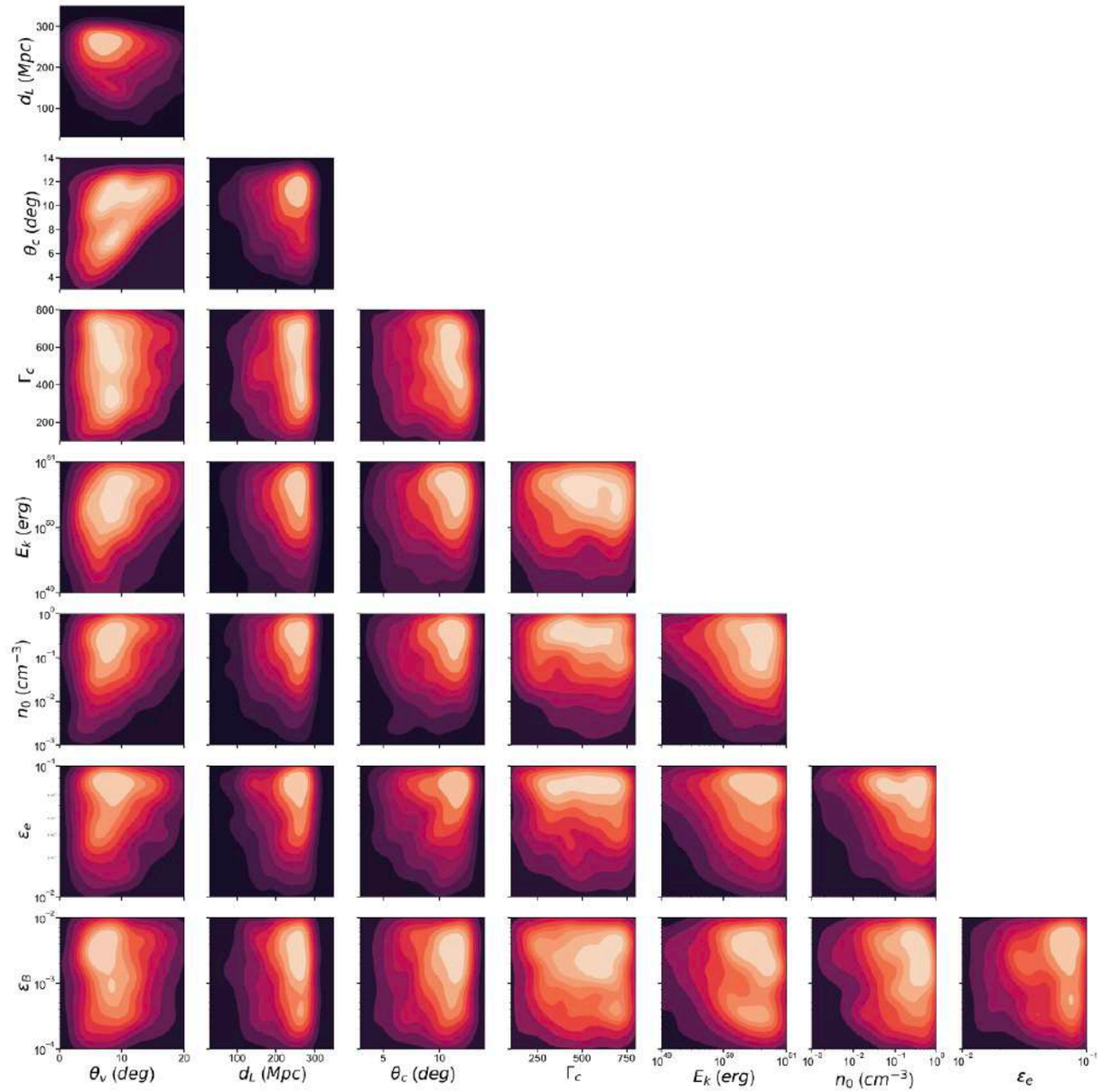




T. Mondal et al, MNRAS 522, 5690-5700 (2023)

Joint Detection Prospects of Binary Neutron Star Mergers using CTA and Gravitational-Wave Detectors





- Higher values of E_k, n_0, ε_e, θ_c enhances likelihood of CTA (joint) detection.
- Smaller θ_v/θ_c favourable for joint detection.

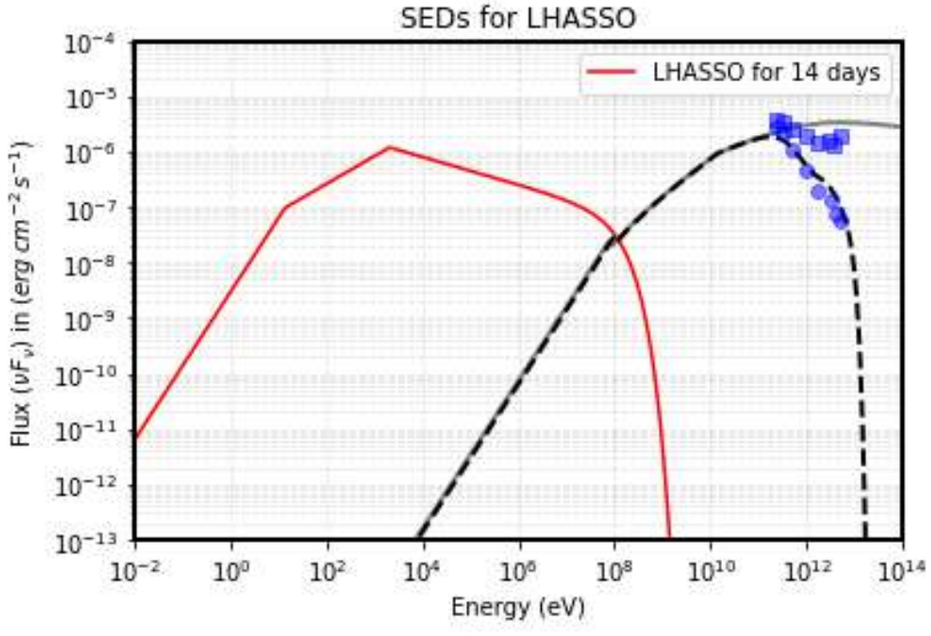
Joint detection event rate is 0.003 to 0.5 per year

T. Mondal et al, Accepted in ApJ [arXiv: 2409.07916]

LHASSO GRB

GRB 221009A ***(z=0.4245):*** (LHASSO collaboration 2022)

- ➔ The brightest GRB ever detected at redshift z=0.151.
- ➔ More than 64,000 photons > 0.2 TeV were detected within the first 3000 seconds.



LGRBs — VHE afterglow flux can be explained SSC radiation mechanism, however during the afterglow of the blast waves, there is p γ interaction takes place, **through which we can also explain the origin of sub-TeV photons.**

Photo hadronic model — interaction between high energy proton (CR) + high-energy synchrotron photons (afterglow)

Interaction done through photo-meson processes via resonance, producing pions and kaons that decay into neutrinos:

$$p\gamma \rightarrow \Delta^{+} \rightarrow n\pi^{+}\ or\ p\pi^{0}$$

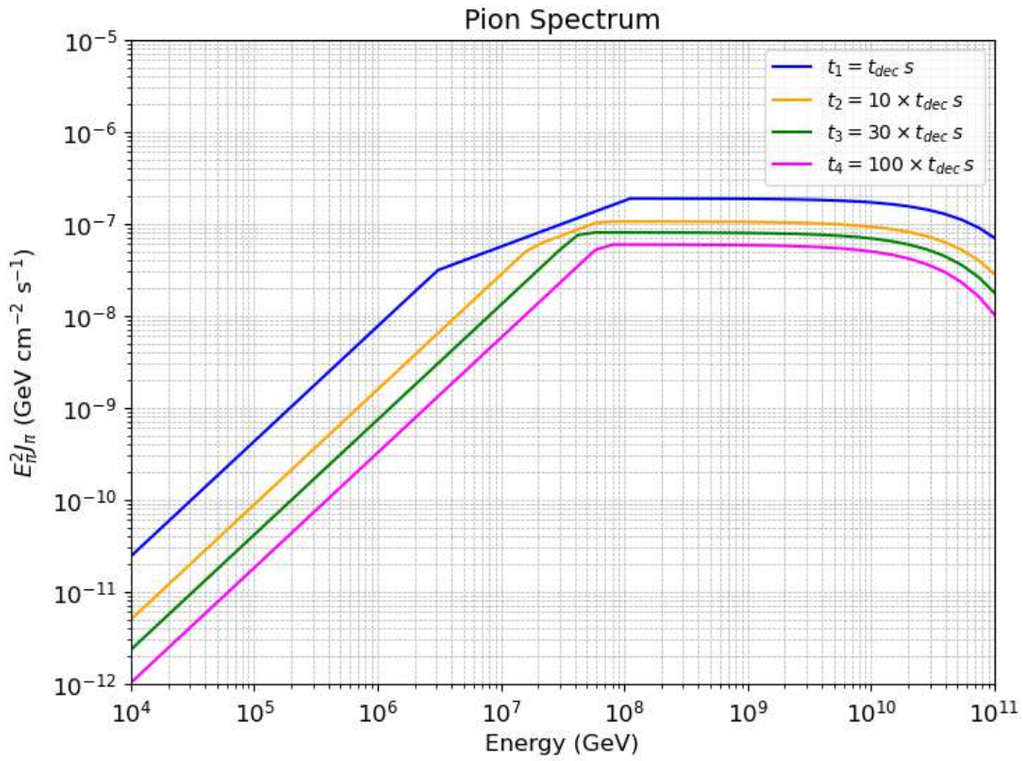
$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu} \rightarrow e^{+} + \nu_{e} + \nu_{\mu} + \bar{\nu_{\mu}} \quad \text{(Neutrino emission)}$$

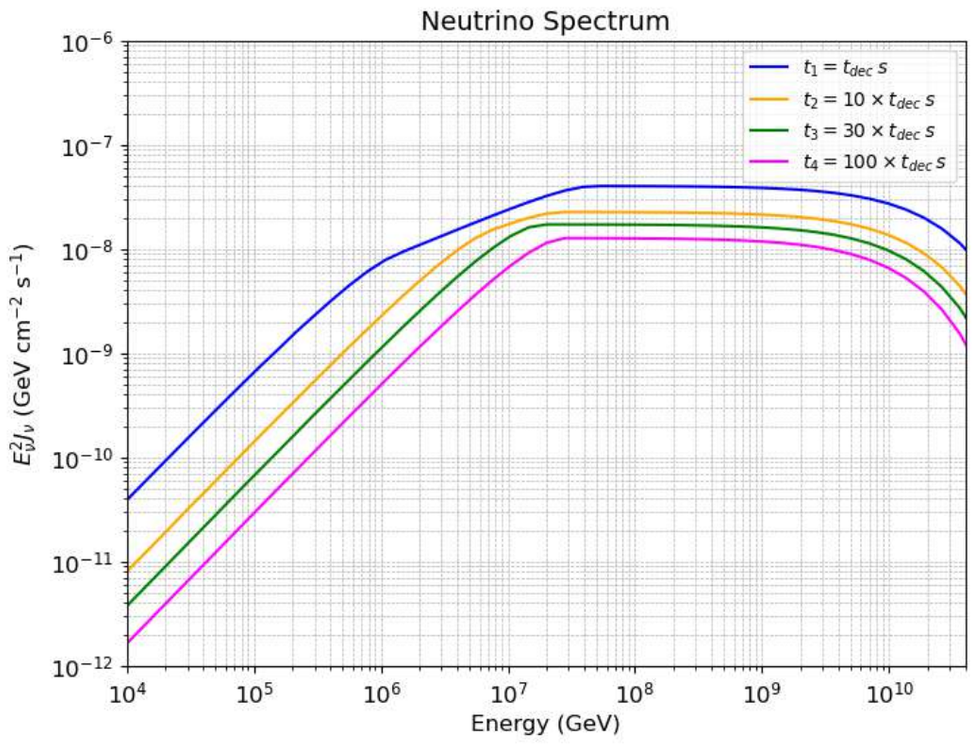
$$\pi^{0} \rightarrow \gamma + \gamma \quad \text{(Gamma-ray emission)}$$

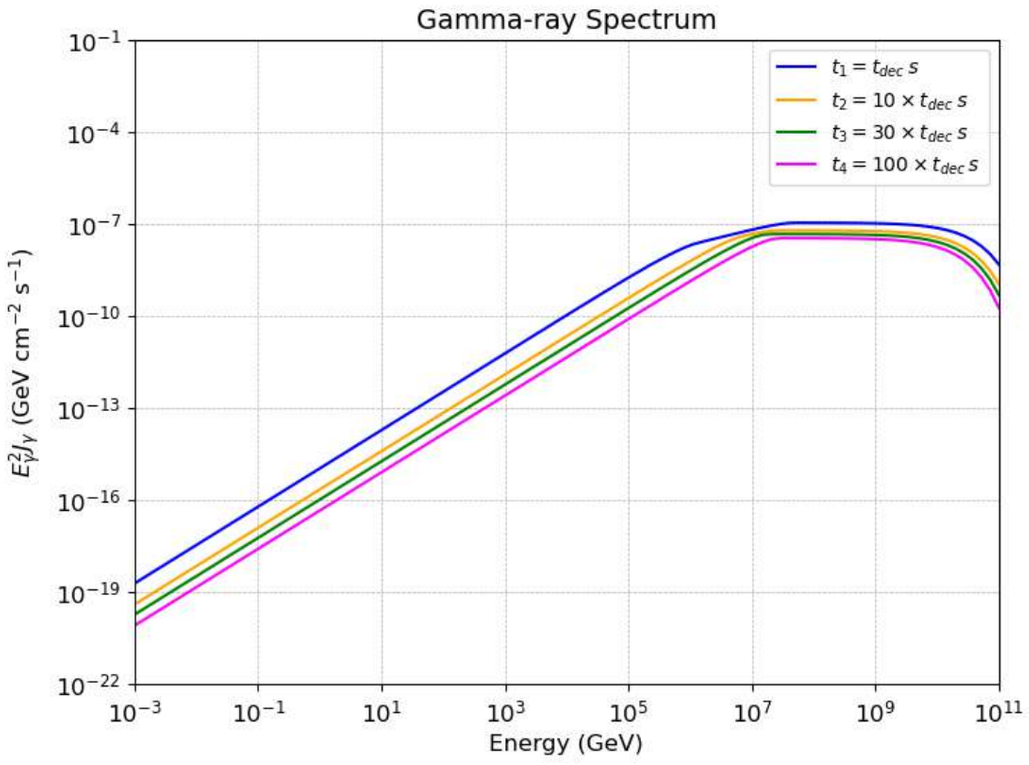
Synchrotron and SSC Radiation: Dominates the emission in the optical, X-ray, and gamma-ray bands.

pγ interactions extend the emission spectrum, contributing additional neutrino flux, especially at **PeV to EeV** energies for afterglows.

Hadronic Mechanism - Neutrinos



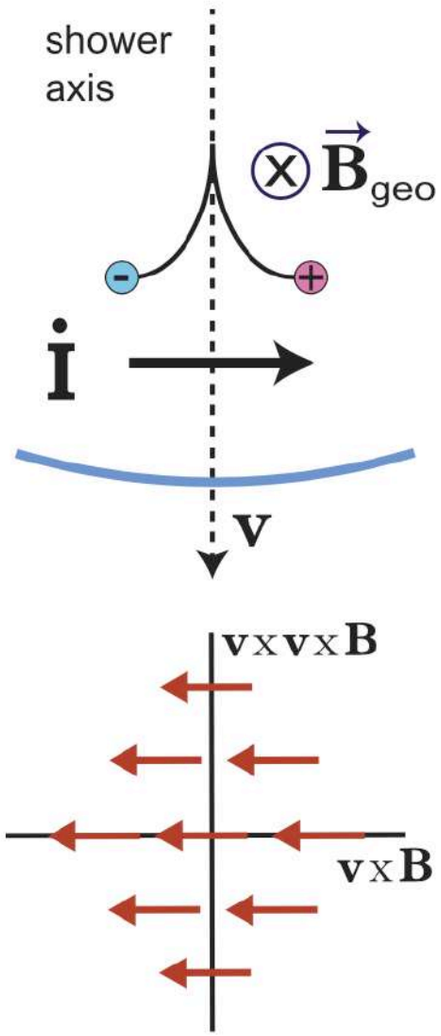




Detection of neutrinos on Ground Above PeV Energies : Radio Waves

Abundant target material - long attenuation length
Cost effective instrumentation of large volume with sparse radio detectors

Geomagnetic Radio Emission

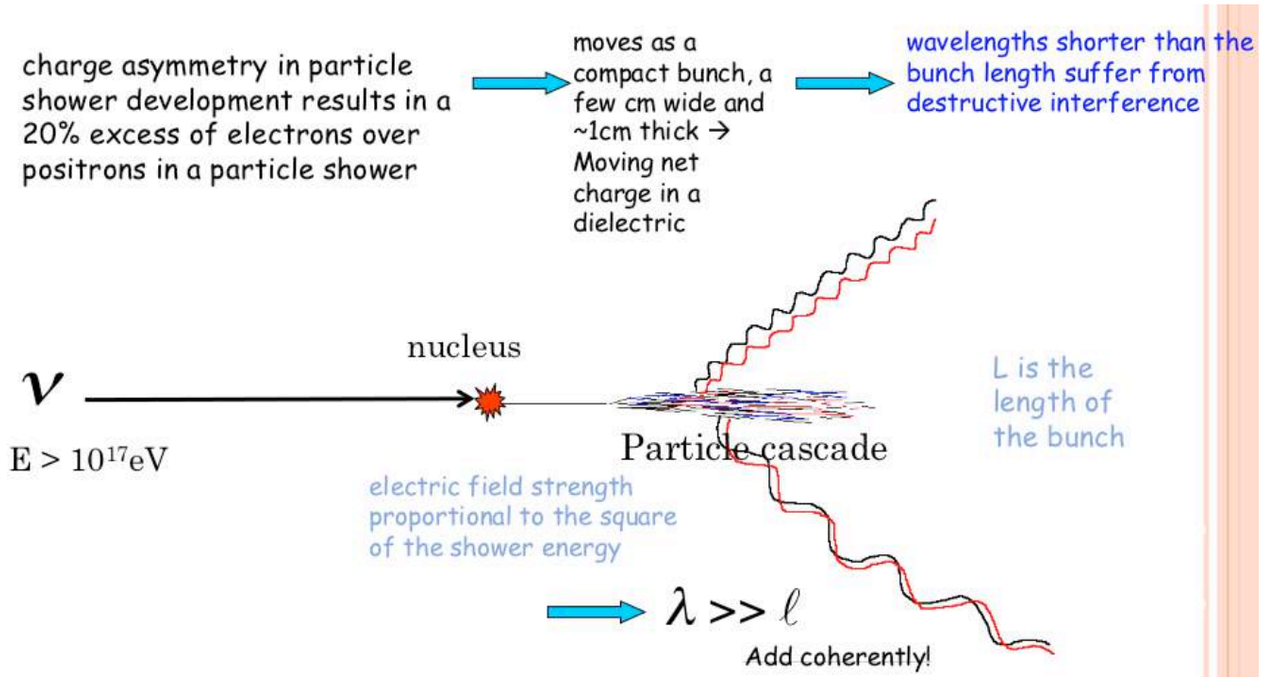


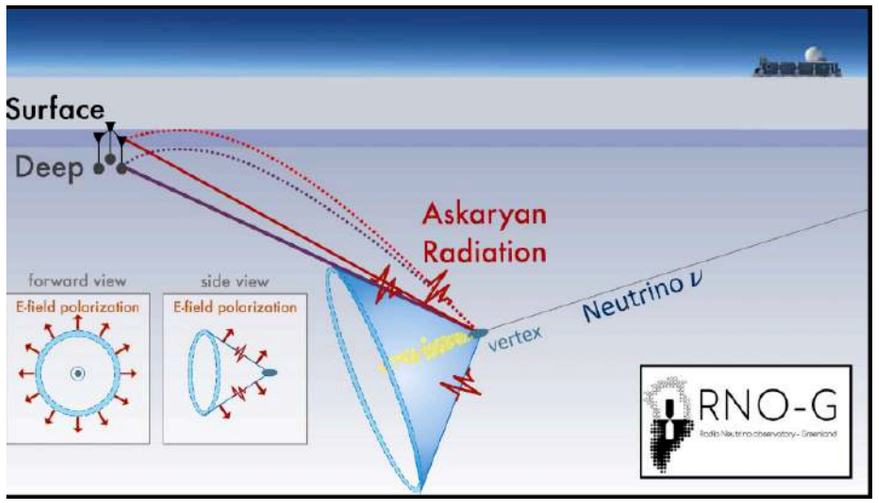
Geomagnetic emission

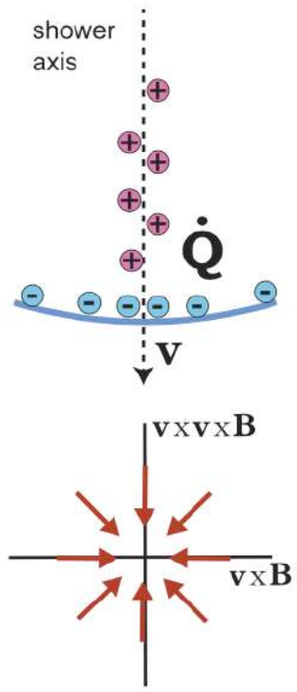
- Lorentz force of the geomagnetic field deflects electrons and positrons in opposite dir. - induces time varying transverse drift current as number changes with shower development
- Emission proportional to strength of local B and angle between B and shower axis
- Radiated energy proportional to duration of emission or longitudinal length of the shower
- In the air longitudinal extension ~ large so strongest
- In the dense media extension small thus negligible
- Less than 100 MHz

Askaryan Radio Emission

- Askaryan radio emission is caused by time varying excess negative charge in the shower
- Charge excess primarily due to Compton scattering also positron annihilation
- If the $\lambda > l$ (lateral spread of the shower) - wavelengths will add coherently
- Emitted power $P \propto N^2$
- Cherenkov like radiation, strongest at Cherenkov angle
- More than 100 MHz

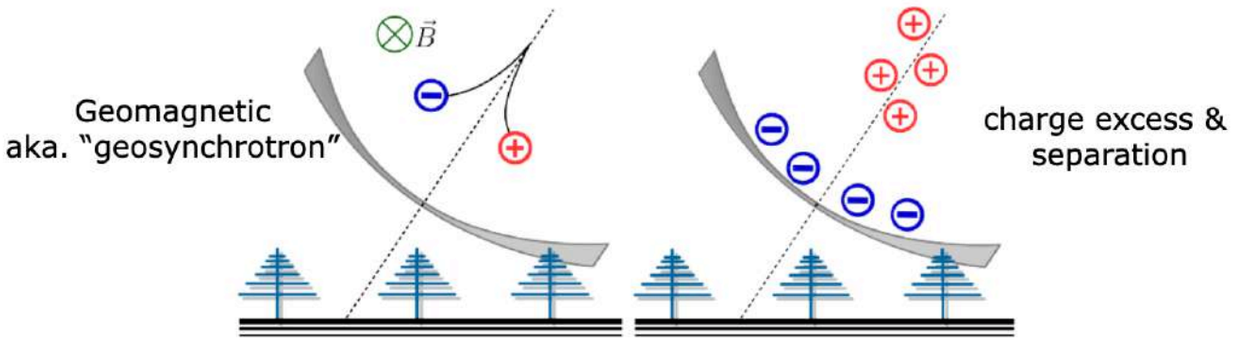


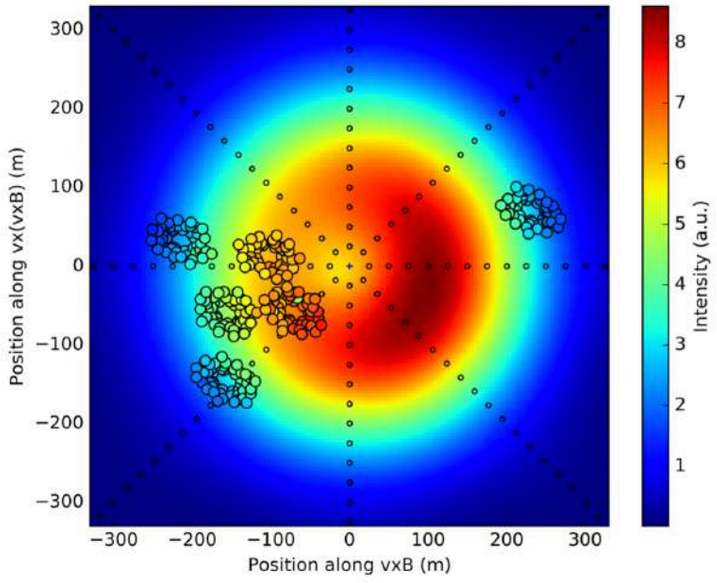




Askaryan emission

UHECR Detection

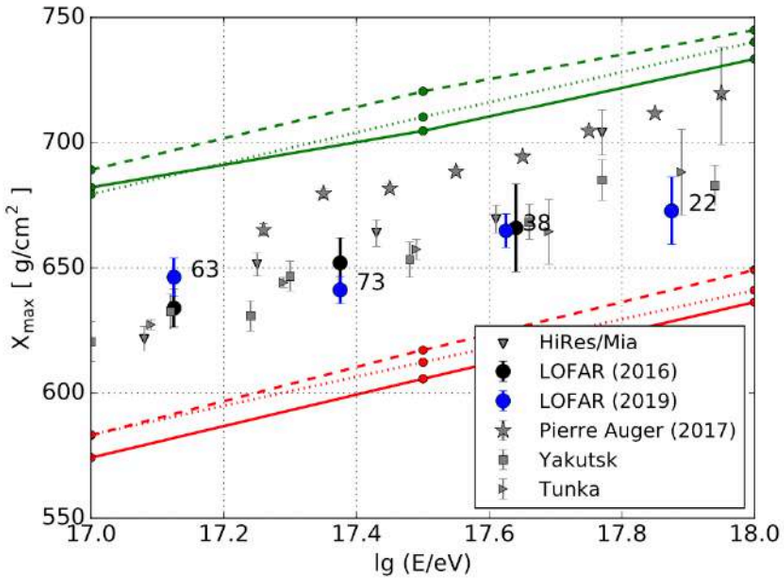


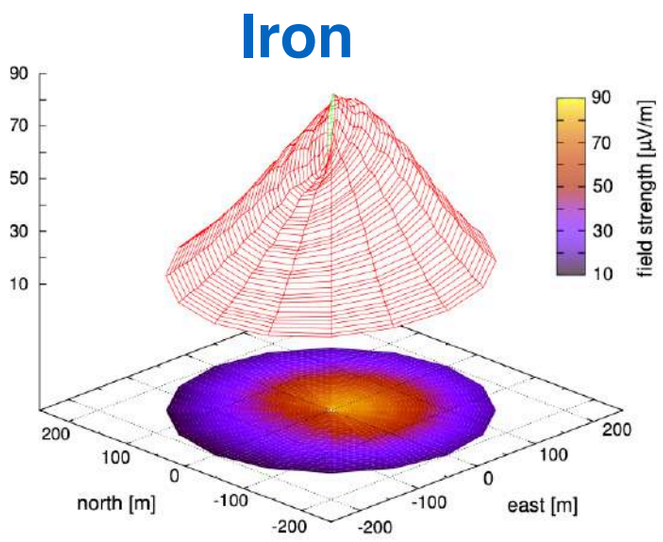


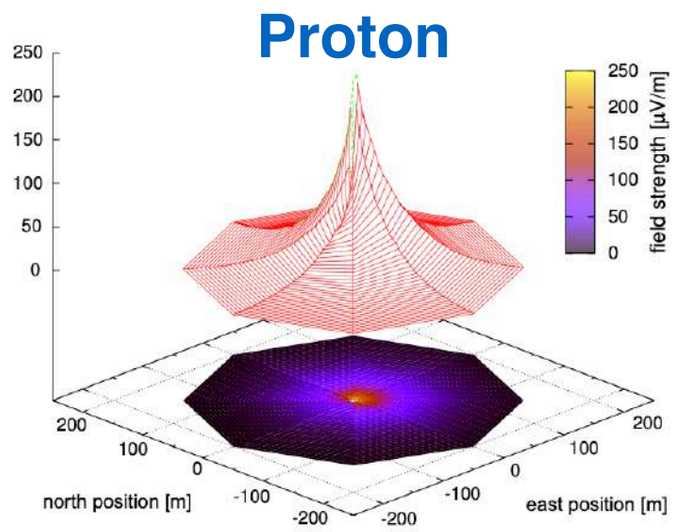
- UHECRs produce particle showers in atmosphere
- Shower front is ~2-3 m thick ~ wavelength at 100 MHz
- $e^{\pm}$ emit synchrotron in geomagnetic field
- Emission from all $e^{\pm}$ (N_e) add up coherently
- Radio power grows quadratically with N_e

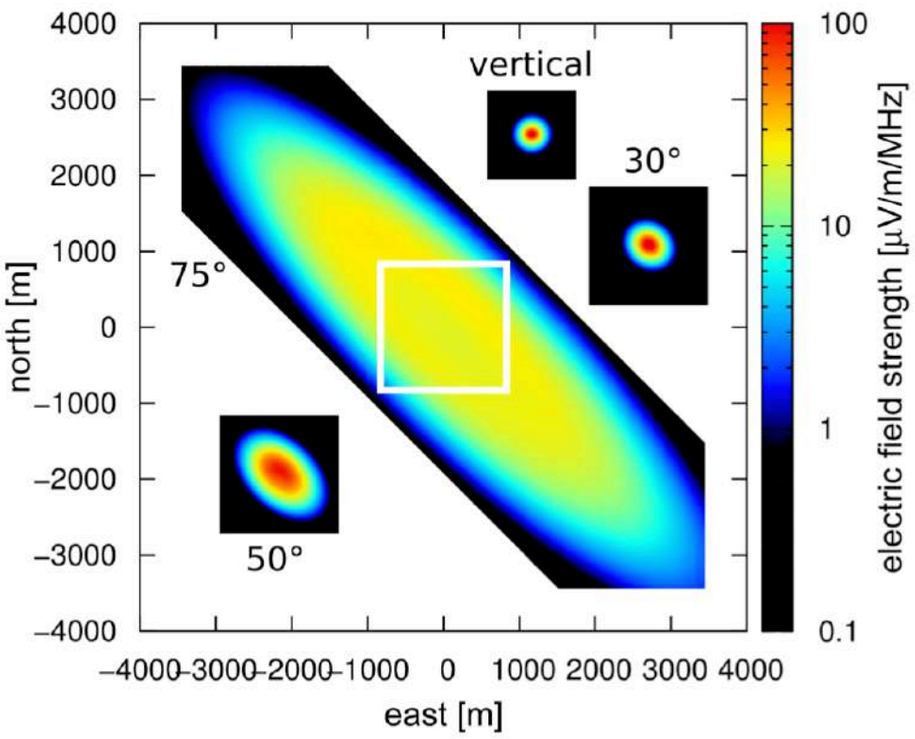
⇒ $E_{total}=N_e*E_e$
⇒ Power $\propto E_e^2 \propto N_e^2$

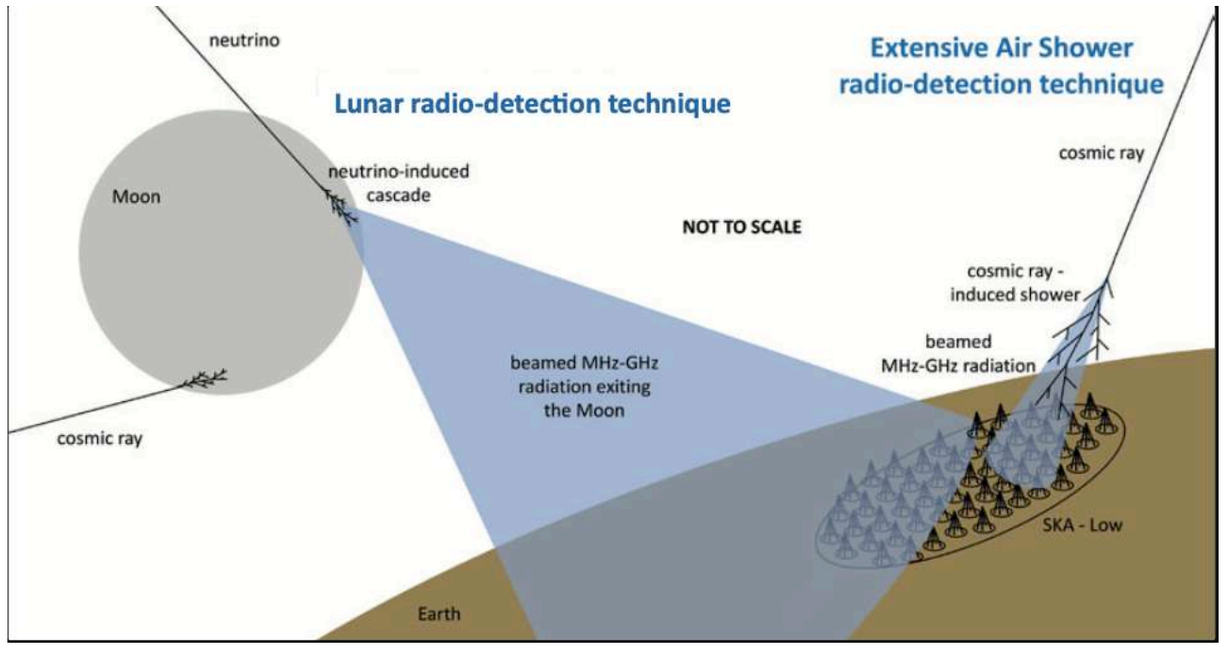
UHECR Detection



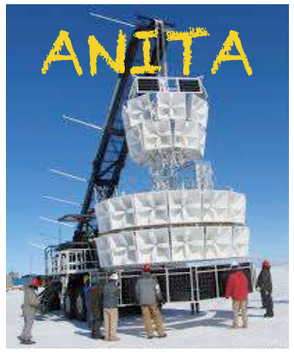


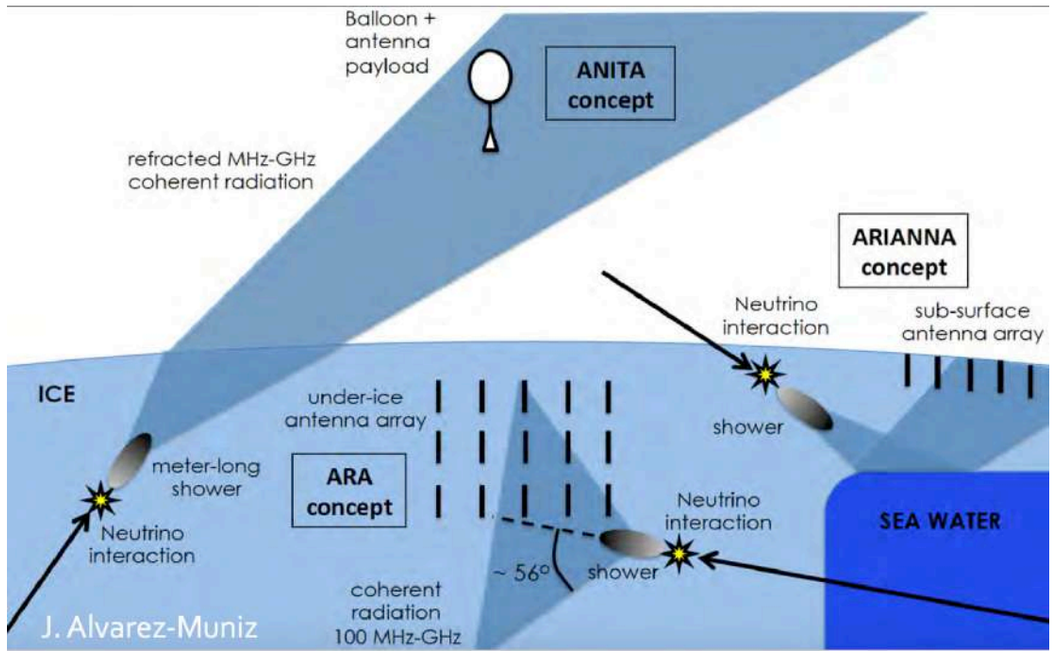


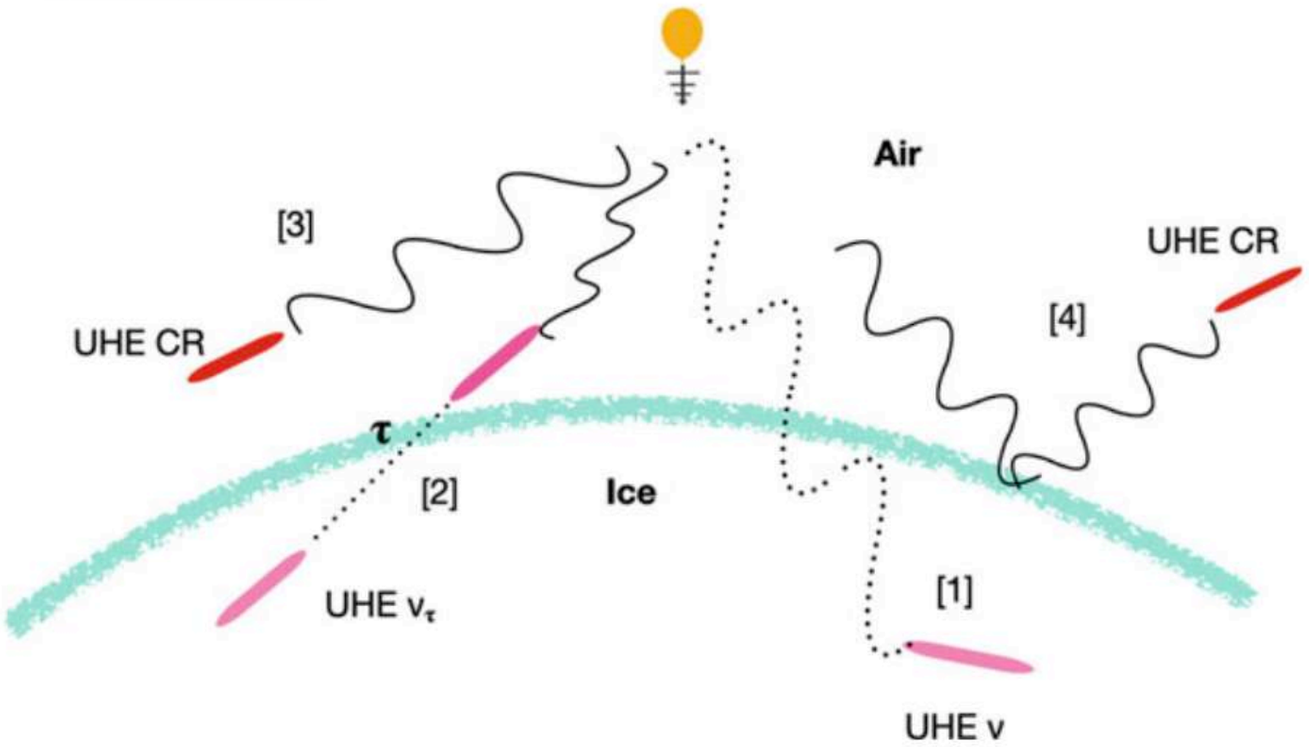




UHE Neutrino Detection

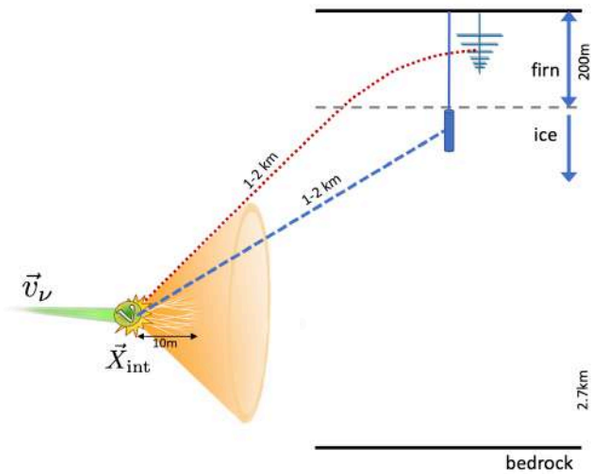


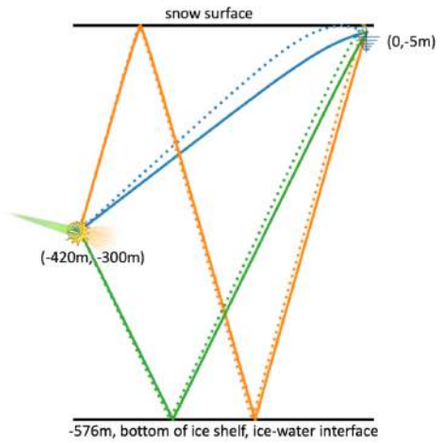


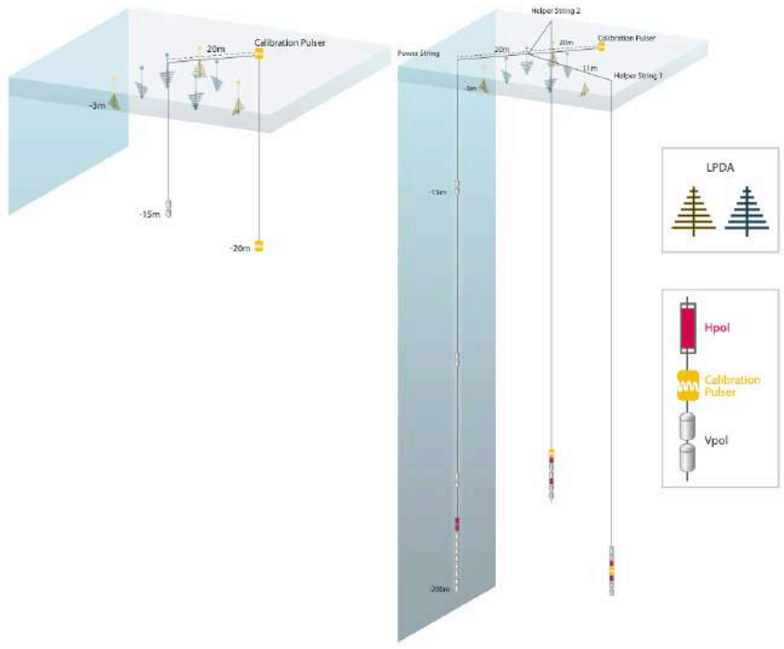


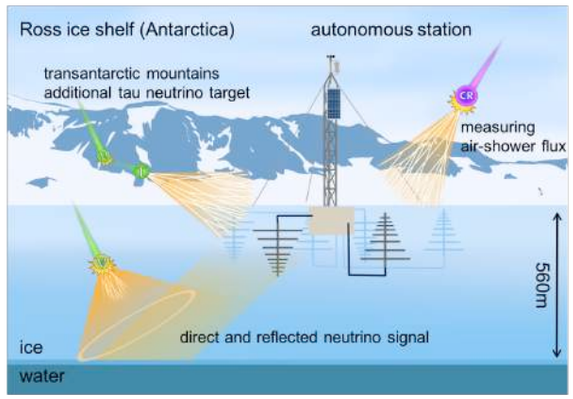
- ANITA scans entire glacial ice at south pole with balloon
- Energy threshold increases if the detector far away from vertex
- Energy threshold for lunar regolith highest

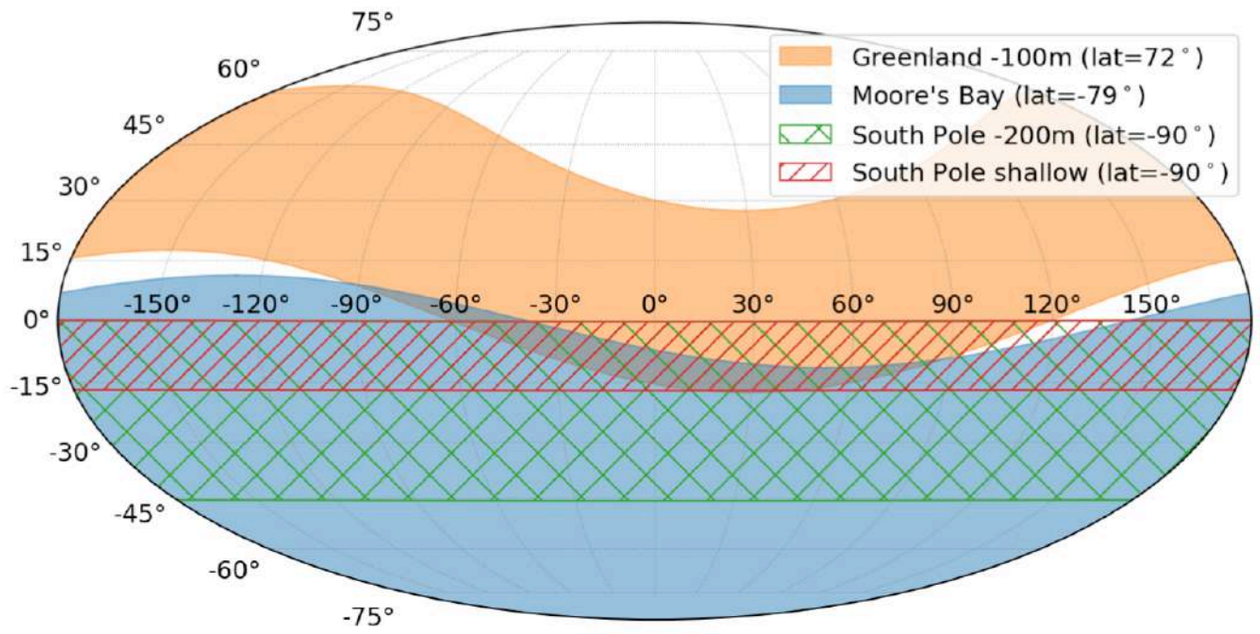
UHE Neutrino Detection



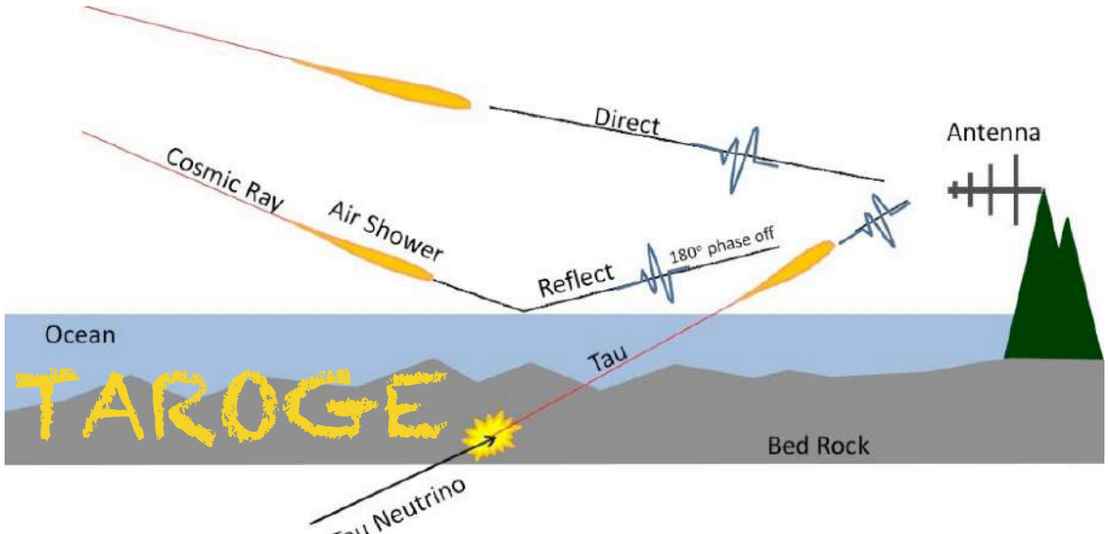


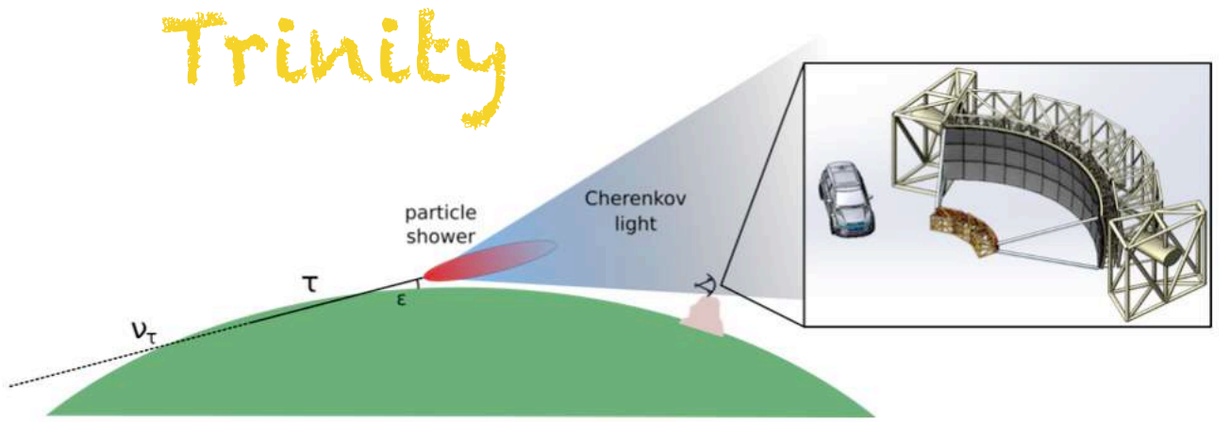


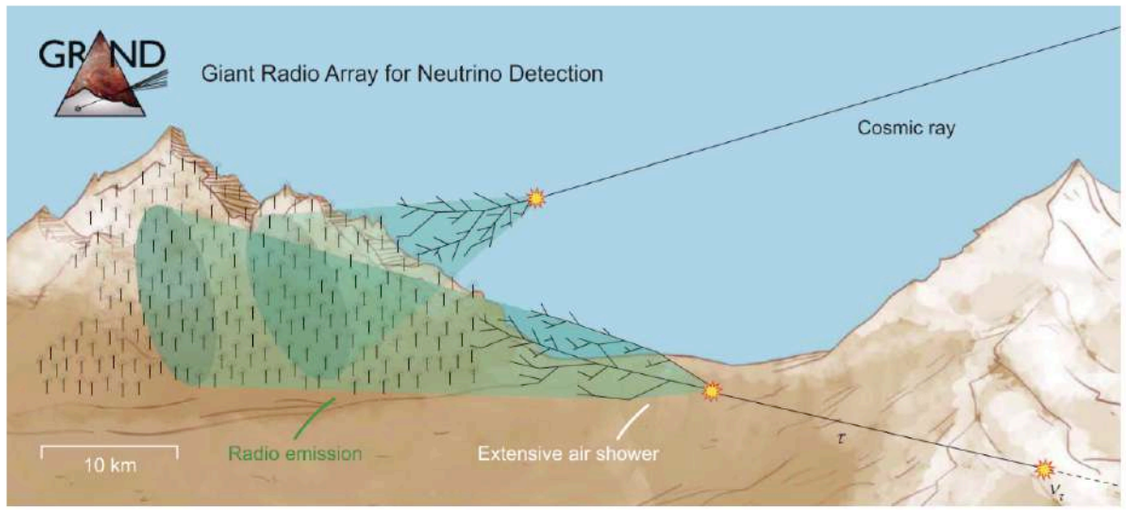


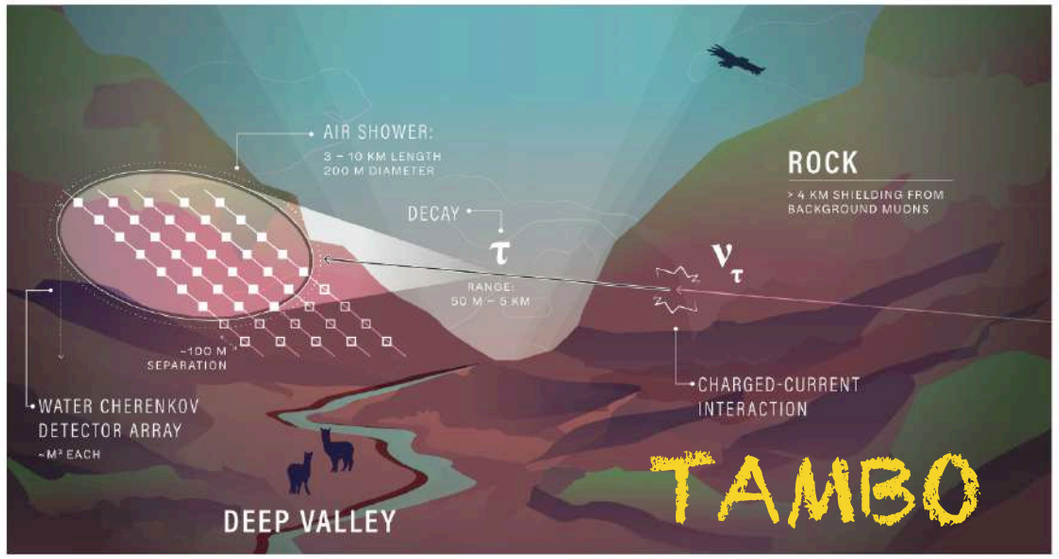


Some More UHECR & UHENU Expts









Thank you !!