PROJECT APEIRO

Cosmic Ray Flux Measurement and Analysis Experiment

Design and Development Report

Abstract: Project Apeiro is a student-led experiment to develop a cosmic ray flux profile as a function of altitude over central part of the Indian subcontinent. The measurement will be performed using a cosmic radiation detecting payload onboard a high-altitude balloon. The payload will be developed to withstand extreme near-space conditions and will continuously collect data during the flight. The data hence collected will be useful for developing a scientific model of the cosmic ray flux profile which will be helpful for determining exposure dosage for various space expeditions and commercial aviation crews.

www.project-apeiro.com

COSMIC RADIATIONS

Cosmic rays are high energy charged particles, originating in outer space, that travel at nearly the speed of light and strike the Earth from all directions. Most cosmic rays are the nuclei of atoms, ranging from the lightest to the heaviest elements in the periodic table. Cosmic rays also include high energy electrons, positrons, and other subatomic particles.

Cosmic rays were discovered in 1912 by Victor Hess, when he found that an electroscope discharged more rapidly as he ascended in a balloon. He attributed this to a source of radiation entering the atmosphere from above, and in 1936 was awarded the Nobel prize for his discovery.

In the past 100 years, since the discovery of cosmic rays, a lot of research has been done to determine their origin and their interaction with the earth's atmosphere. The most basic way to understand these cosmic rays is that they are high energy charged particles from the space.

Cosmic rays include:

- Galactic Cosmic Rays — coming from outside the solar system
- Anomalous Cosmic Rays — coming from the interstellar space at the edge of the heliopause
- Solar Energetic Particles — associated with solar flares and other energetic solar events

Cosmic rays, upon entering earth's atmosphere interact with nuclei in the air to produce new particles. This interaction repeats several times to produce a secondary cosmic ray air shower. Figure 1 illustrates this process. Project Apeiro aims to measure the flux of the secondary cosmic ray air shower.

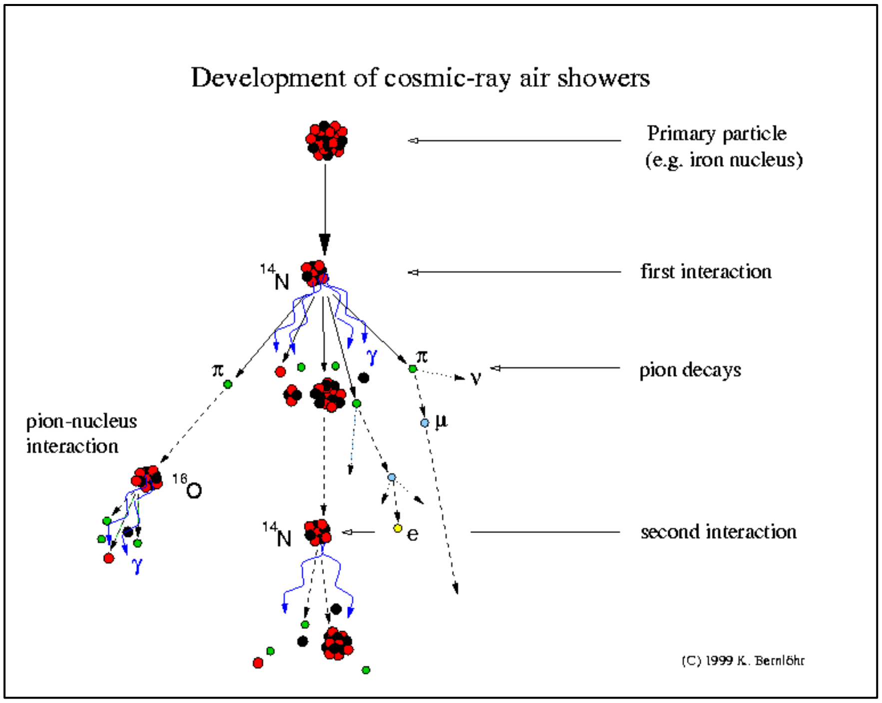


Figure 1: Development of cosmic ray shower.
Source: Max Planck Institute for Nuclear Physics

DETECTION OF COSMIC RAYS

The high energy cosmic ray particles are detected using a combination of a plastic scintillator and photomultiplier tube.

A scintillator is a material which exhibits luminescence when excited by an ionizing radiation. This luminescence is detected by a photomultiplier tube, which is a photosensitive device used for detecting very weak light pulses.

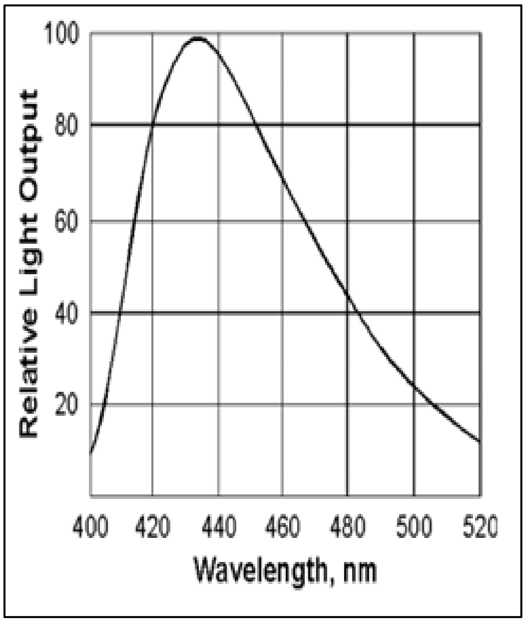
Choice of Scintillator

EJ-208 from Eljen Technologies is chosen for scintillation. This is a general-purpose scintillator and possesses the longest wavelength emission for commonly available blue scintillators. Since high-precision machining of the scintillator is not possible, a scintillator which works well in larger sizes is chosen. This also gives uniform light collection for wide-area photomultiplier tubes. Figure 2 is a graph of the relative light output vs wavelength. The rise time of the scintillator is 1ns which is satisfactory for this experiment.

Choice of Photomultiplier Tube

R6233 from Hamamatsu is chosen for this purpose. A photomultiplier tube is chosen so that it's sensitivity is highest at the wavelength where the relative light output of the scintillator is highest to obtain maximum efficiency. Figure 3 illustrates the sensitivity vs wavelength graph. R6233 exhibits a response time of 9.5ns which is higher than the rise time of the scintillator but still satisfying the experiment's conditions. It operates at 1kV DC with 0.1mA current. This is an essential factor for an airborne payload since high voltage is required to be generated using a special circuit and is also prone to risks. Hence, lesser operating voltage is preferred.

A very important factor while deciding the scintillator and photomultiplier tubes is the cost and availability. Hence, other advanced detection techniques such as SiPMs are not used in this experiment.



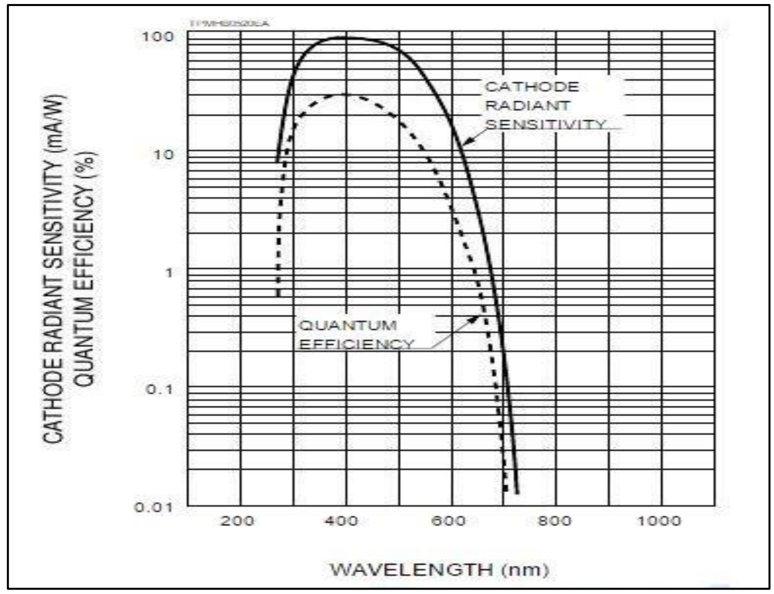


Figure 3

Figure 2

The scintillator and photomultiplier tube are coupled together using an optical glue. They are then wrapped with black paper such that there is no light intrusion. This assembly is placed inside an aluminum casing in order to protect against EMI/EMC.

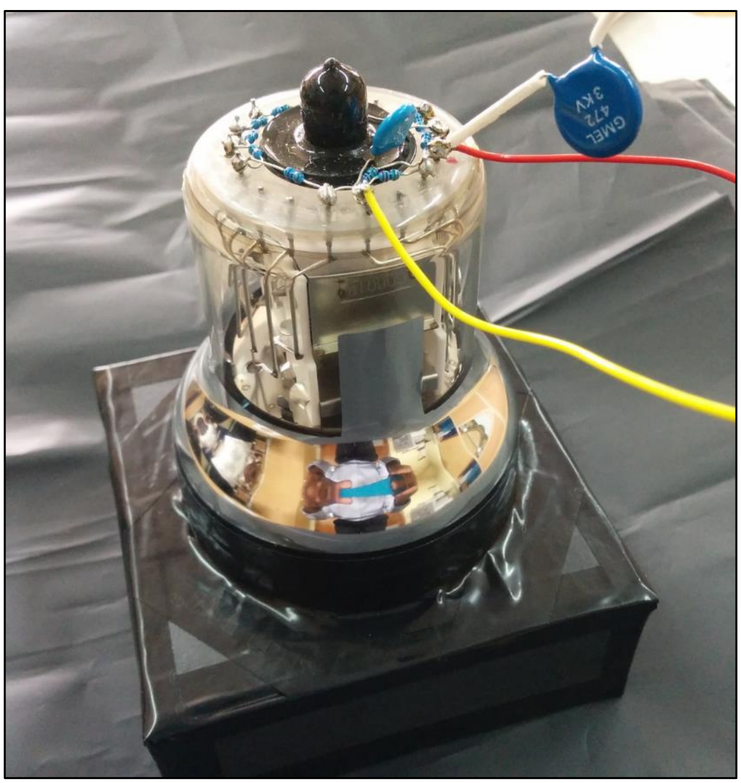


Figure 4: PMT coupled with scintillator

Figure 5

Trigger generation

The trigger for cosmic ray particle detection is generated by using coincidence logic on multiple detector outputs.

It is assumed that the cosmic ray particles are along the normal to the earth's surface. Three detector modules are arranged vertically over each other, such that, any particle which is along the normal passes through all the detector modules and hence is classified as a cosmic ray particle and therefore generates a trigger. All other pulses in the detectors are eliminated as noise. Figure 6 illustrates the arrangement.

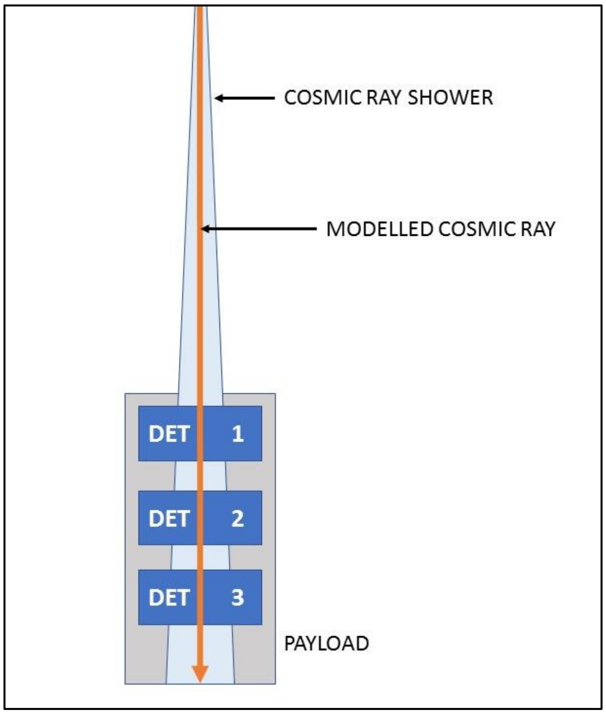


Figure 6

This arrangement effectively eliminates most of the noise and unnecessary components from the signal.

In reality, the cosmic ray shower is not exactly along the normal, hence the actual arrangement provides a margin of about 10 degrees of deviation from the normal for the cosmic ray particles. Figure 7 illustrates arrangement during a calibration test.

Figure 7: Actual arrangement of detectors during a calibration run

DATA ACQUISITION

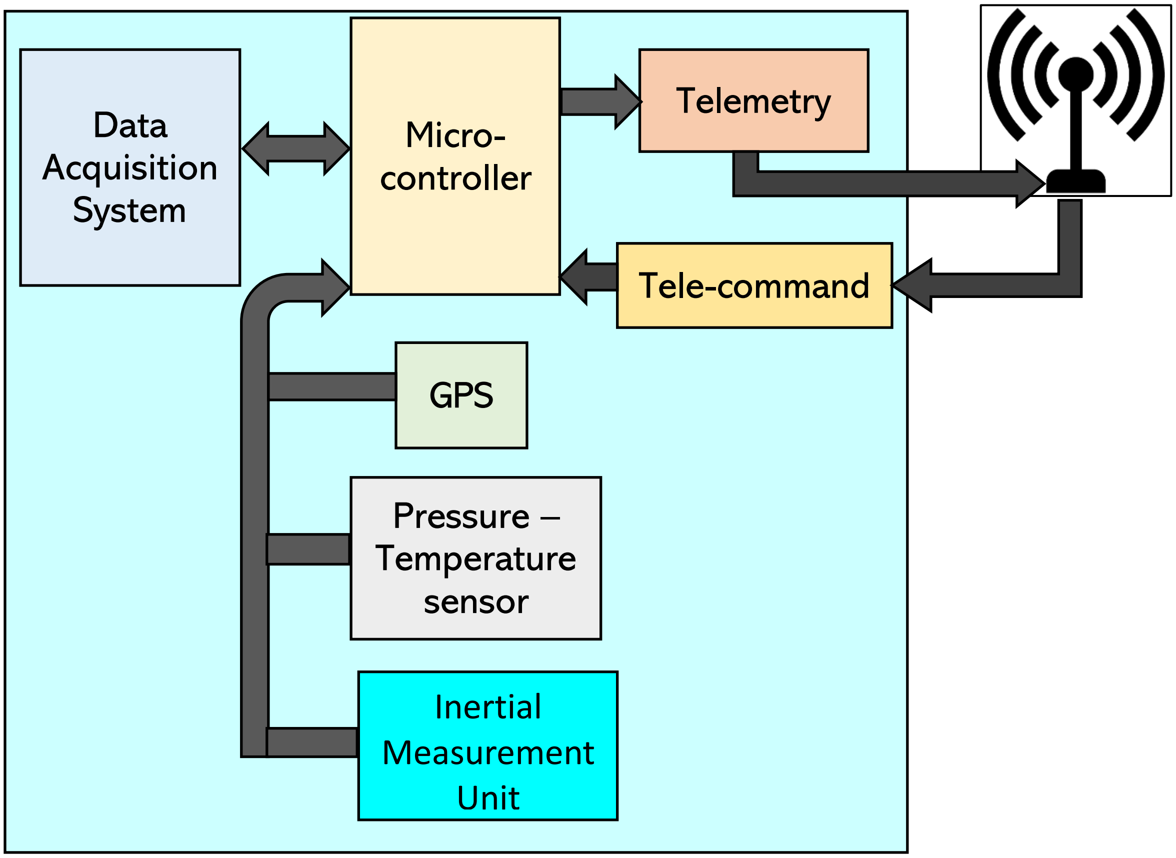


Figure 8: Block diagram illustration of the payload

Separate data is collected from each photomultiplier tube, henceforth referred to as PMT. The data is then processed to obtain the cosmic ray flux measurement.

The PMTs generate a negative analog pulse corresponding to every light pulse detection. The amplitude and time duration of this pulse varies according to the intensity and time duration of the light pulse generated by the scintillator which depends upon the energy and the type of particle detected. Since this experiment is not concerned about the energy spectrum or any specific type of cosmic ray particles, no significance is assigned to the amplitude and time duration of pulses. Figure 8 is a block diagram of the data flow which explained further.

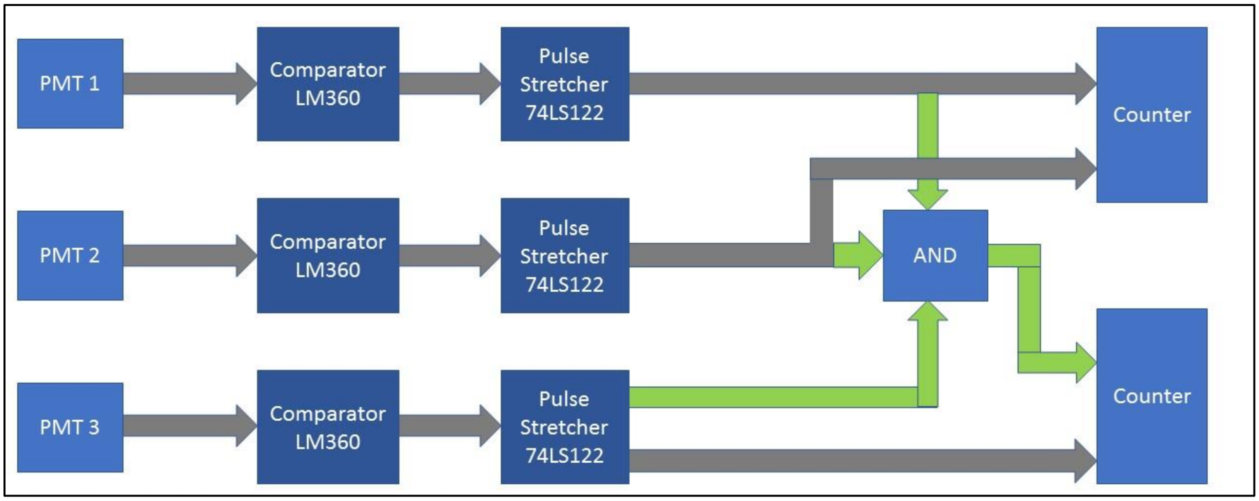


Figure 9: Block diagram for data flow

The negative going analog pulse generated by the PMTs cannot be easily processed, it is converted into a standard TTL form. This is achieved by using the LM360 Comparator IC by Texas Instruments. It is a high-speed IC which allows negative threshold values. The threshold can be manually selected depending upon experimental requirements decided after calibration tests.

The pulses produced by every PMT for each detection vary in time duration which depends upon several factors such as the type of particle detected, marginal errors in the construction, etc. The non-uniform pulses can create issues with the counters. Hence, all the pulses are extended in time domain to a uniform value for all. This is achieved by using a monostable multivibrator IC, 74LS122J. This process also eliminates double-detection caused by an undershooting pulse.

The data from all three detector modules, after aforementioned processing, is loaded into the counters.

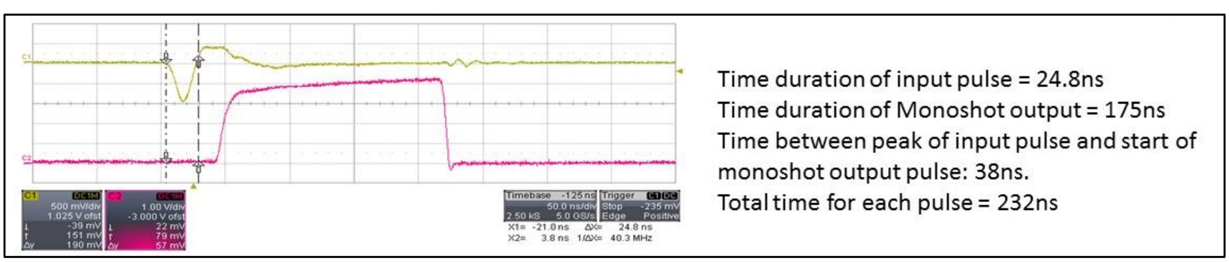


Figure 10: The yellow pulse corresponds to output from PMT. The pink pulse corresponds to the output from the monostable multivibrator (monoshot)

To perform the coincidence logic, processed data from all three detector modules is passed via a high speed AND gate. This ensures that a pulse is recorded only when there is a simultaneous pulse in all three detectors. This value is also loaded into the counter. The counters are interfaced with a microcontroller.

The microcontroller used for this experiment is Texas Instruments' MSP430F5438. It is very robust and has various low power consumption modes and allows for quick-debugging and error handling.

Various parameters are monitored to develop correlations for further study and test the health of the payload.

The Garmin 18x LVC GPS module is used to obtain high precision GPS data along with the timing signal. The temperature and pressure are monitored using BMP180. Altitude can be calculated using data from the pressure readings as well as from the GPS module.

The MPU-9250 module is used as the Inertial Measurement Unit (IMU). The payload, during its balloon flight, may swing and deviate from the vertical arrangement of the detectors. The data from the IMU is essential for the experiment since it signifies the angle of inclination of the payload from the vertical and hence helps to validate the experimental data.

On board EEPROM memory is used to store the data. Spansion s25fl216k is used for this purpose.

POWER SUPPLY

Two power supply systems are required by the experiment: High voltage power supply and Dual polarity low voltage power supply. Onboard lithium polymer batteries supply power to all systems.

High Voltage Power Supply

The PMTs operate at a voltage of 1000 V regulated DC demanding a current of 0.1mA. The supply is provided using the 12AVR1000 voltage multiplier module by PICO electronics. The supply is designed to be highly regulated since unregulated power supply produces noise in the output of the PMTs.

Low Voltage Power Supply

The microcontroller operates at 3.3V DC. LM1117 is used to produce this. All other components require a power supply of 5V DC. LM7805 is used to produce this. The comparator ICs require a negative threshold, hence, -5V DC is also required. This is produced using LM7905. All the power supplies are highly regulated to ensure smooth functioning of all components.

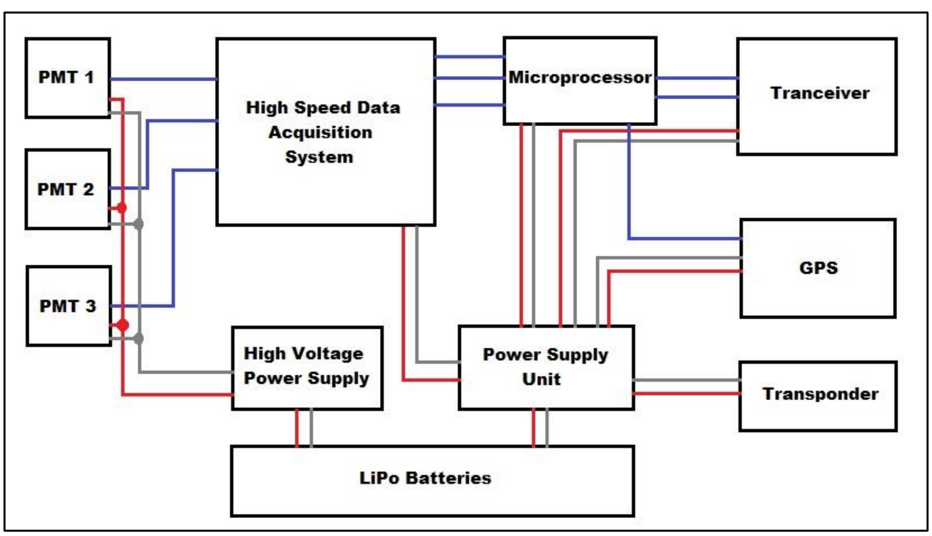


Figure 11: Illustration of the payload's power supply and data flow

STRUCTURAL DESCRIPTION

The chassis housing the experiment is constructed of aluminum and covered with black paint. Following figures illustrate the structure.

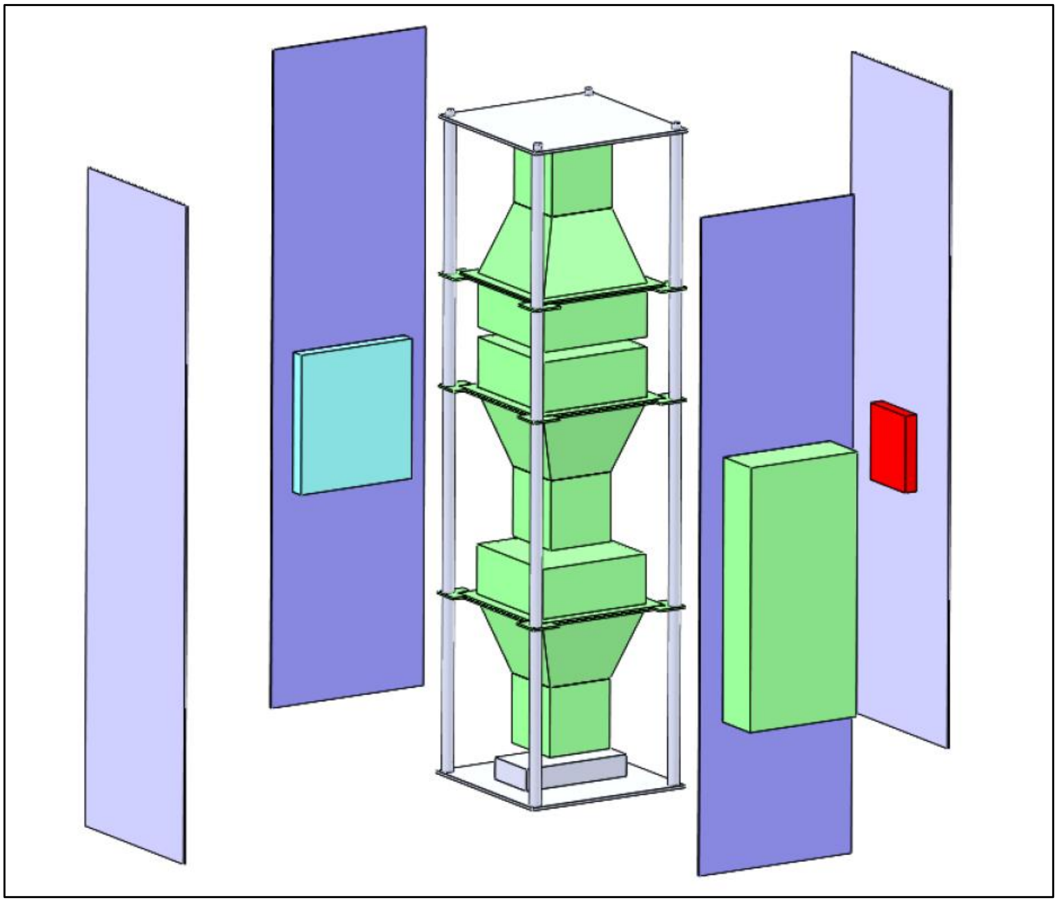


Figure 12: Exploded view of the payload

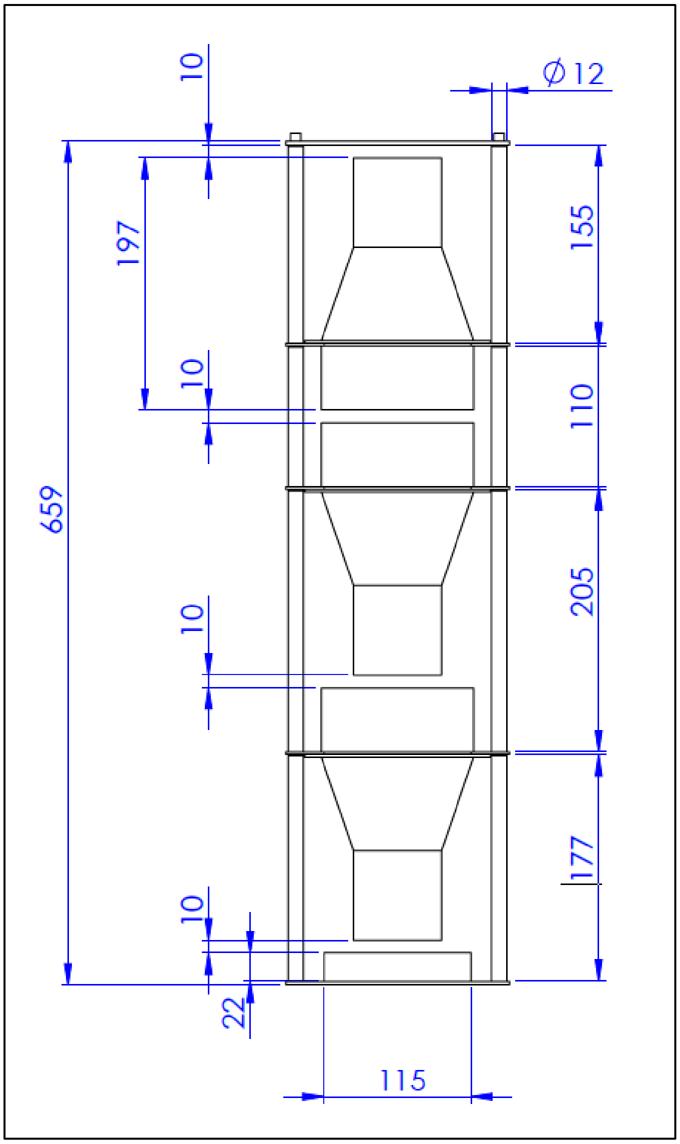


Figure 13: The dimensions of the payload

FLIGHT PLAN

The payload will be launched onboard a high-altitude balloon from TIFR National Balloon Facility at Hyderabad, India.

The balloon will ascend continuously to an altitude of 20kms above sea level where it will float for about 1hr. The balloon will then ascend to a higher altitude and float for another 1hr after which the flight will be terminated. The payload will descend to the ground with the help of a parachute. During the ascent, float and descent phase, the system is continuously acquiring data which will be transmitted to the ground station over the telemetry system. A telecommand system also allows us to control crucial parameters of the flight. Figure 14 illustrates the flight plan.

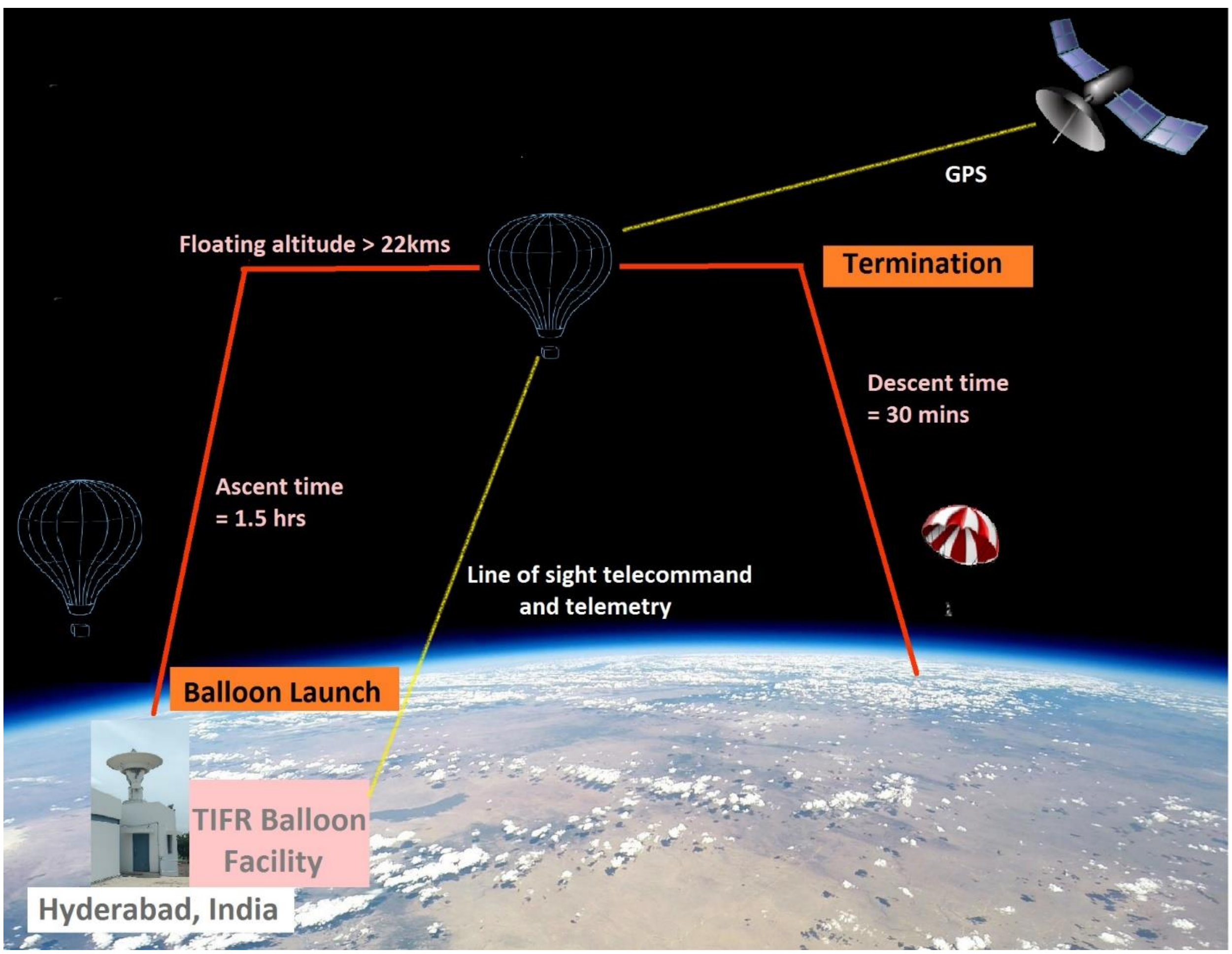


Figure 14: Illustrative flight plan

COLLABORATIONS

- India-based Neutrino Observatory (INO) Group, Tata Institute of Fundamental Research (TIFR), Mumbai, India
  Lead mentor: Dr. B. Satyanarayana, Scientific Officer (H), DHEP, TIFR
  Collaboration for development of the cosmic radiation detector system

- TIFR National Balloon Facility, Hyderabad, India
  Collaboration for the launch and recovery of the payload.

Advice and mentorship from several members of the GRAPES and ASTROSAT groups at TIFR, Mumbai.

TEAM

The project is started and led by undergraduate students of BITS Pilani, Goa Campus, India.

The student team and mentors from TIFR posing with the payload

Sanket Deshpande
sanket@ieee.org

Pankaj Tiple
ps99tiple@gmail.com

Lucky Kapoor
luckykapoor03@gmail.com

Vibhav Joshi
joshivibhav9@gmail.com

Aishwarya Praveen
anshu4321@gmail.com

Srihari Menon
menonsrihari@gmail.com