GRAN SASSO
SCIENCE INSTITUTE

*SCHOOL OF ADVANCED STUDIES*

# The NUSES project

**Ivan De Mitri**

7th GSSI Science Fair
L'Aquila, March 2, 2021

www.gssi.it

RIFERIMENTO: NUSES

Data: 07-12-2018
Ediz. D Pag.: 1/38

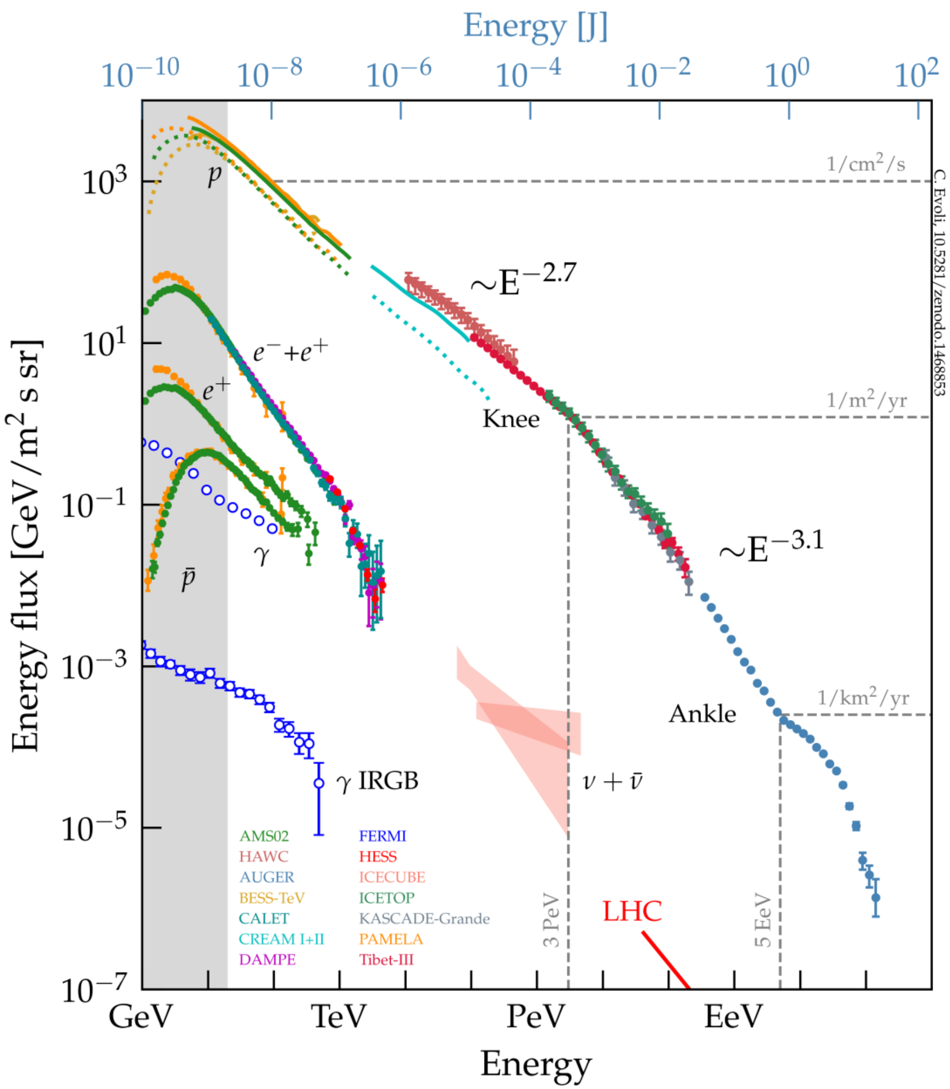
# NUSES

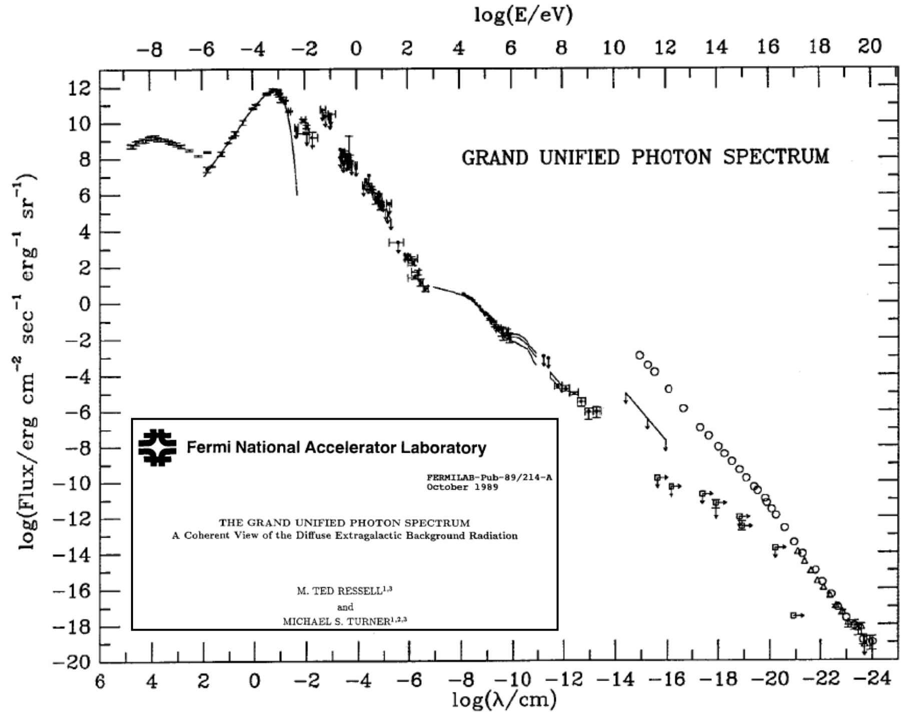
A pathfinder for studying astrophysical neutrinos and electromagnetic signals of seismic origin from space

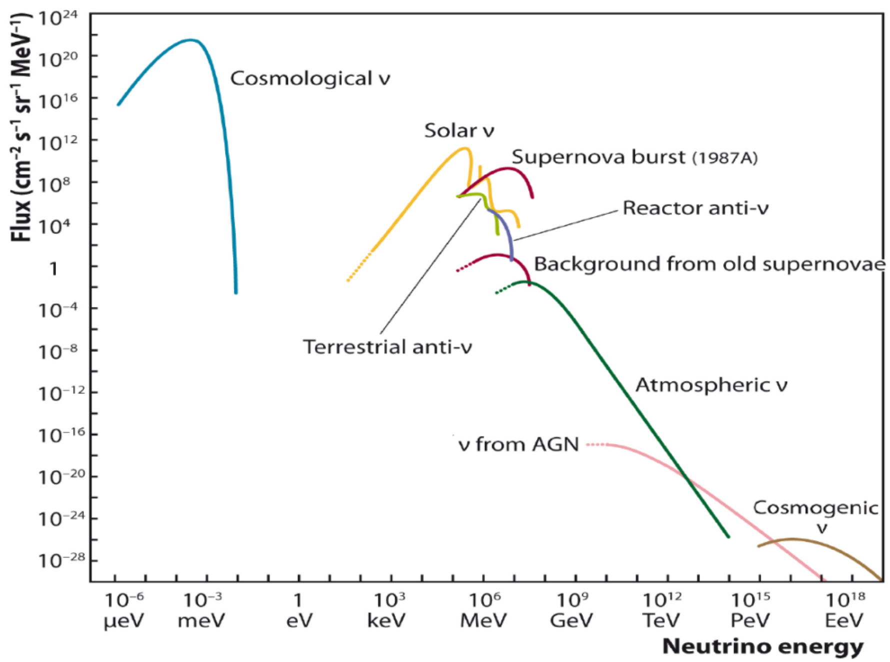
Ziré

Terzina

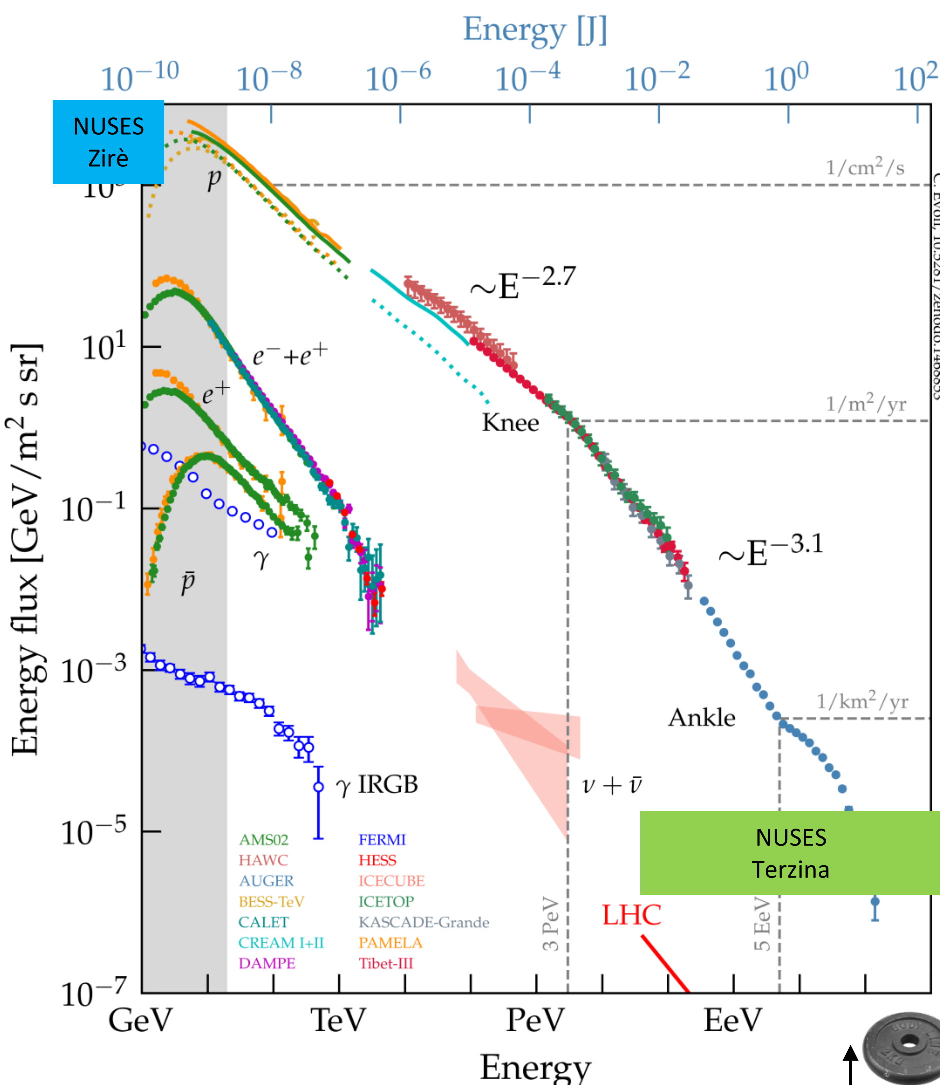
# Our landscapes(s)

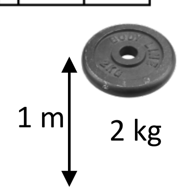


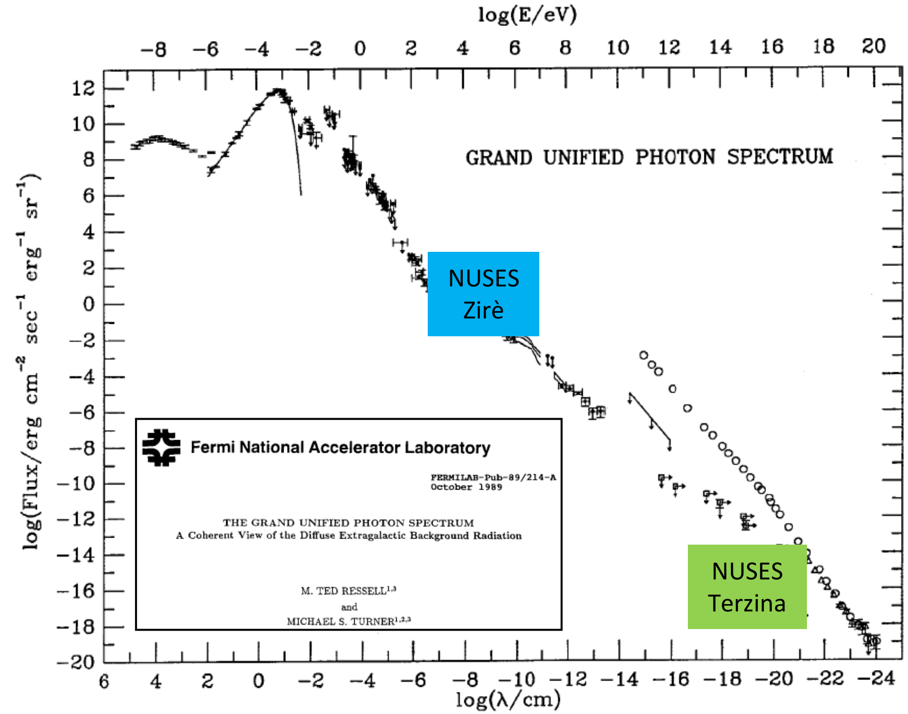



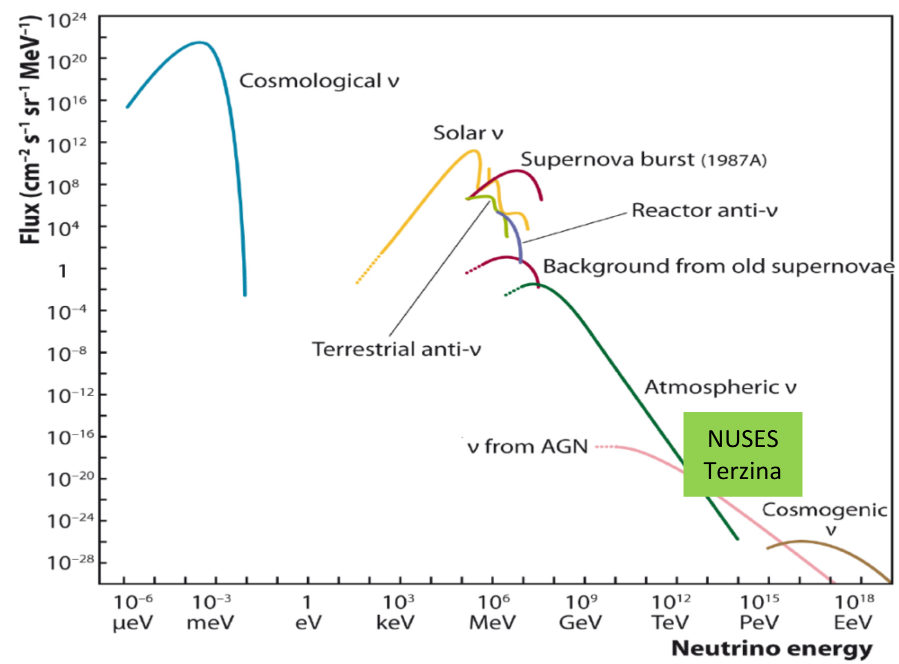



# Technology Pathfinder and First Possible Measurements



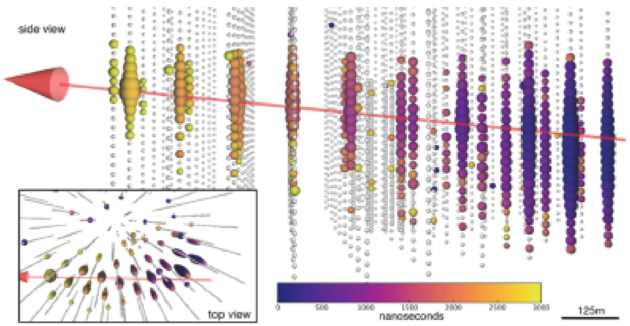



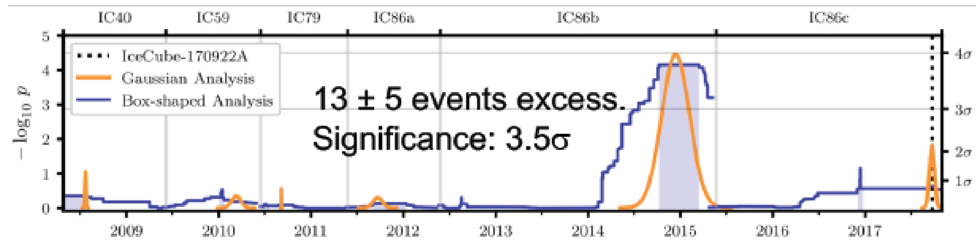



# Neutrinos from the AGN blazar TXS 0506+056

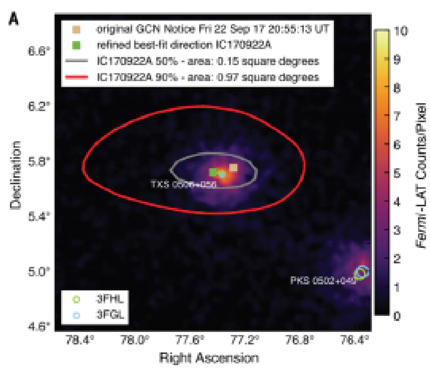
**Sept. 22, 2017:**
A neutrino in coincidence with a blazar flare




**2014-2015:** A (orphan) neutrino flare found from the same object in historical data




Science 361 (2018) no. 6398, eaat2890

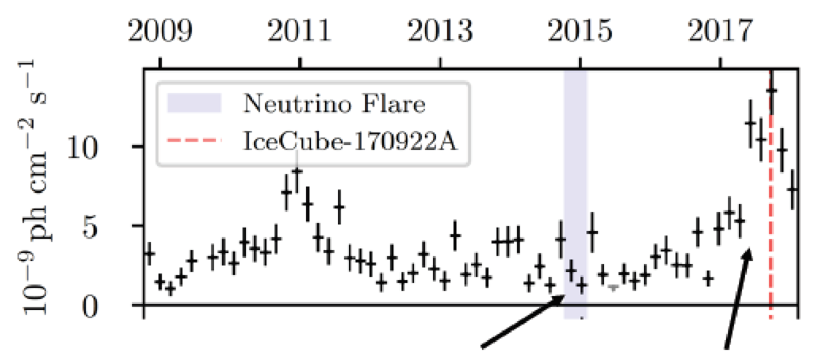



Observed by Fermi-*LAT* and MAGIC

Significance for correlation: 3σ

Science 361 (2018) no. 6398, eaat1378

Fermi-*LAT* data; Padovani et al, MNRAS 480 (2018) 192

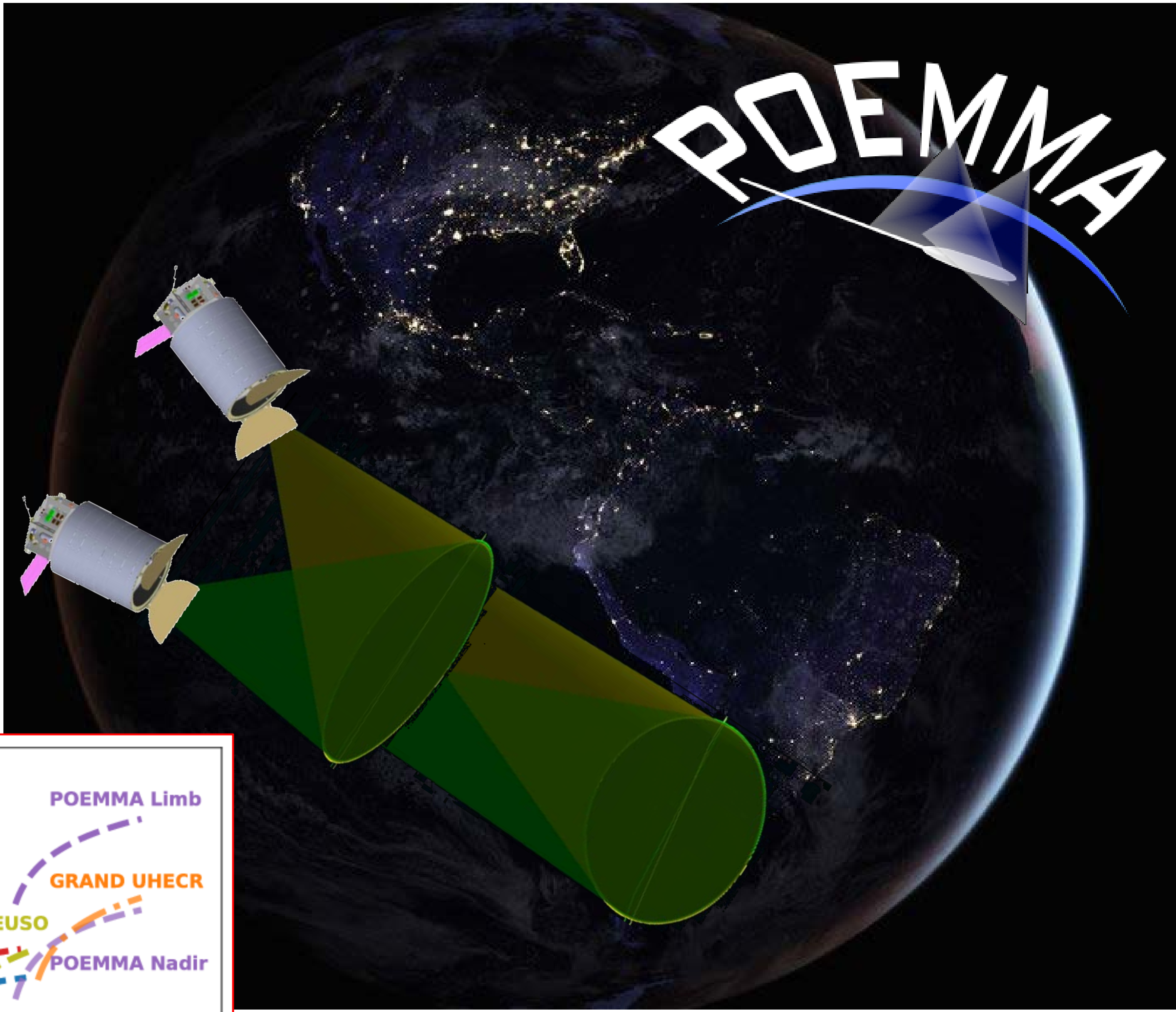


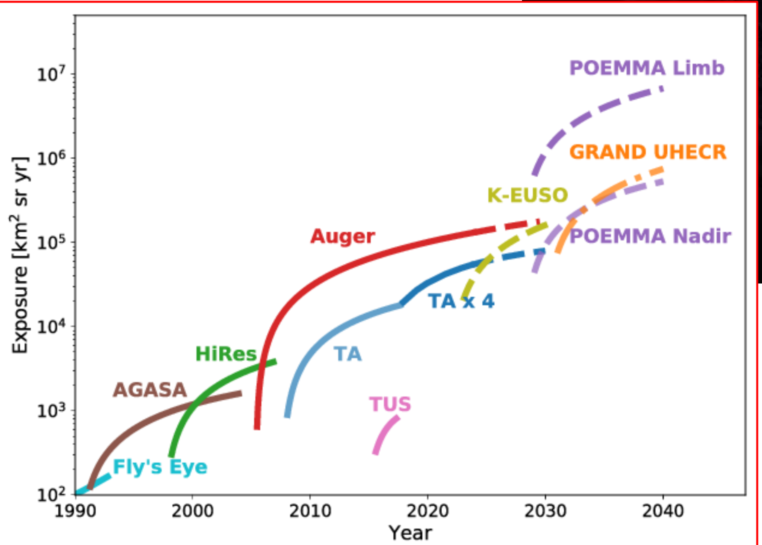

At 2014-15 neutrino flare

The 2017 flare

# Probe of Extreme Multi Messenger Astrophysics

- ✓ Ultra High Energy Cosmic Rays.
- ✓ Astrophysical Neutrinos.
- ✓ International collaboration (lead by U. Chicago) main participants: USA, Italy, Germany, France, Denmark, Japan.
- ✓ Selected by NASA as probe study for the next decade class B missions.



# POEMMA: the detector

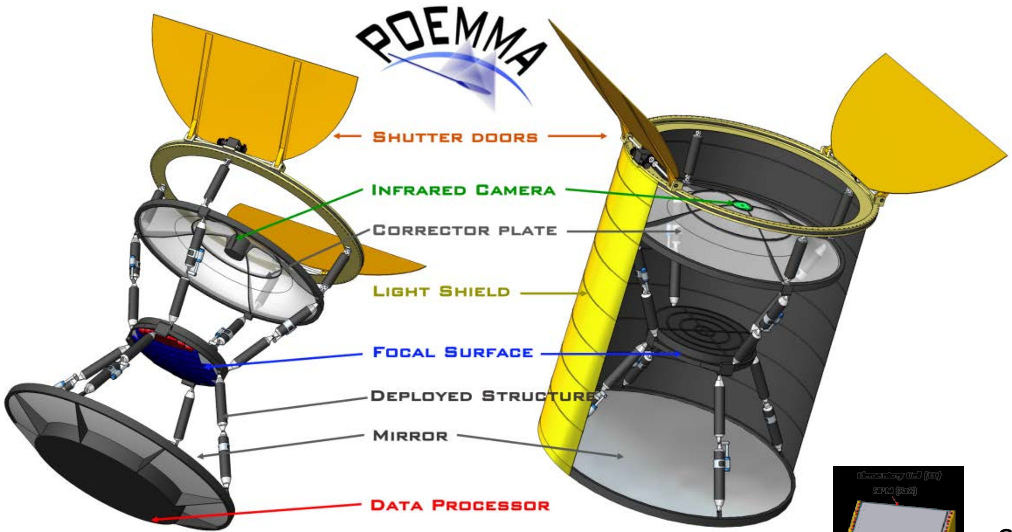
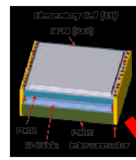


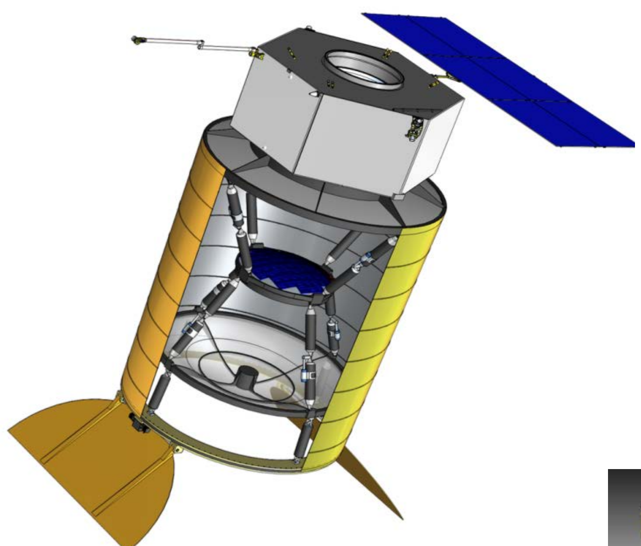

TABLE I: POEMMA Specifications:

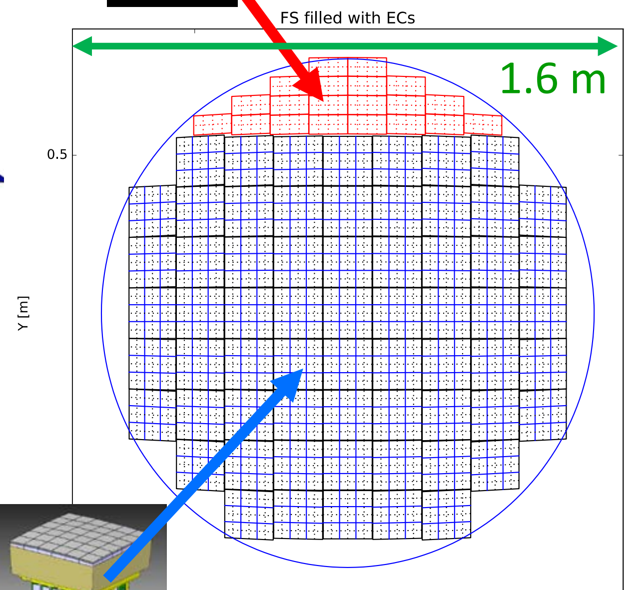
| Photometer | Components | | Spacecraft | |
|---|---|---|---|---|
| Optics | Schmidt | 45° full FoV | Slew rate | 90° in 8 min |
| | Primary Mirror | 4 m diam. | Pointing Res. | 0.1° |
| | Corrector Lens | 3.3 m diam. | Pointing Know. | 0.01° |
| | Focal Surface | 1.6 m diam. | Clock synch. | 10 nsec |
| | Pixel Size | $3 \times 3$ mm$^2$ | Data Storage | 7 days |
| | Pixel FoV | 0.084° | Communication | S-band |
| PFC | MAPMT (1$\mu$s) | 126,720 pixels | Wet Mass | 3,450 kg |
| PCC | SiPM (20 ns) | 15,360 pixels | Power (w/cont) | 550 W |
| Photometer | (One) | | Mission | (2 Observatories) |
| | Mass | 1,550 kg | Lifetime | 3 year (5 year goal) |
| | Power (w/cont) | 700 W | Orbit | 525 km, 28.5° Inc |
| | Data | < 1 GB/day | Orbit Period | 95 min |
| | | | Observatory Sep. | ~25 - 1000+ km |

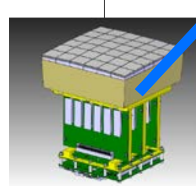
Each Observatory = Photometer + Spacecraft; POEMMA Mission = 2 Observatories



Silicon Photo Multiplier (10 ns)





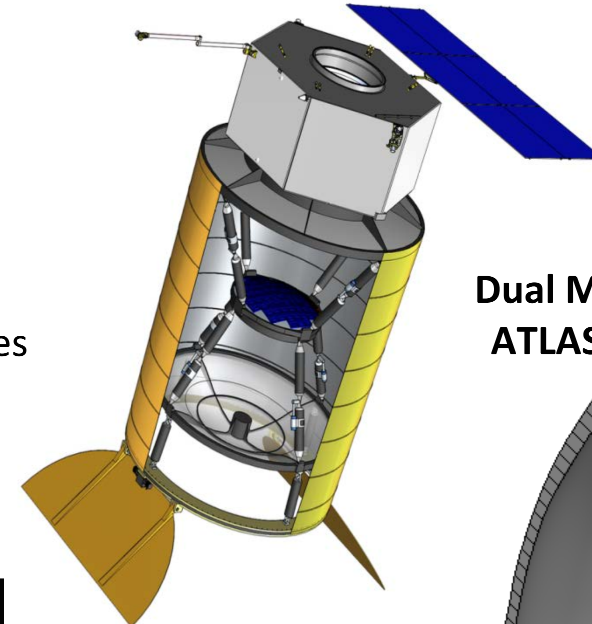



Multi anode Photo Multiplier (1 µs)

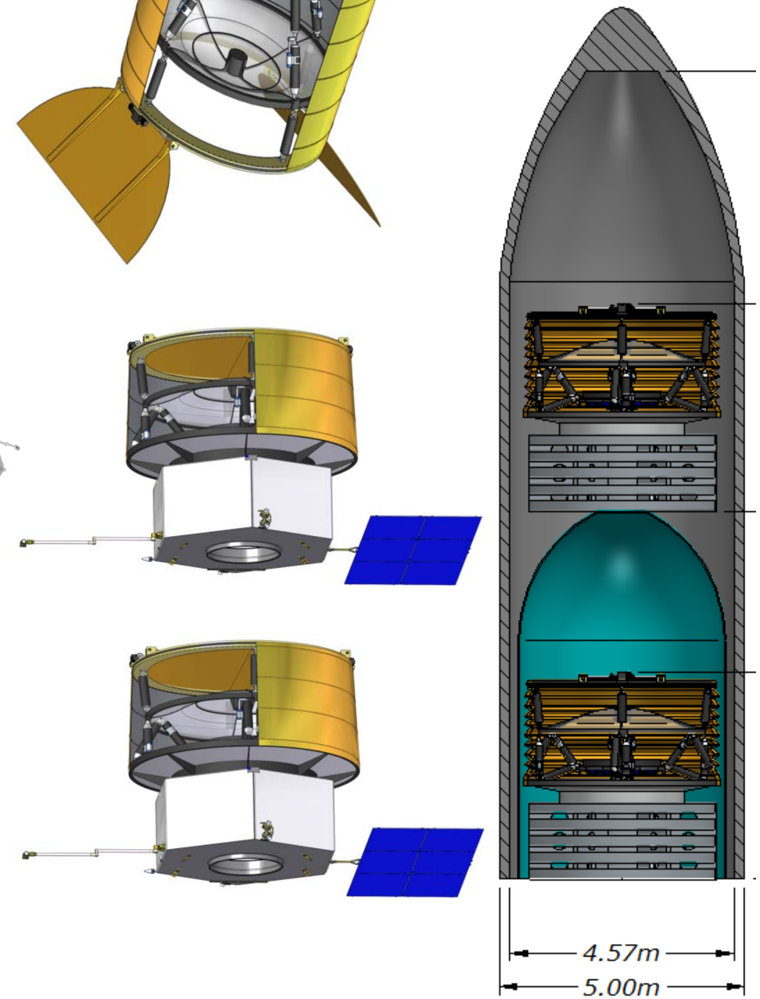
- ✓ hybrid focal surface
- ✓ SiPM – Cherenkov visible light detection.
- ✓ MaPM – Fluorescence UV light detection.
- ✓ 20 SiPMm (150k pixels)
- ✓ 64 Photo Detector Modules = 147k pixels (1 PDM = 36 MaPM 2,3k pixels)

# POEMMA: mission

- ✓ hybrid Class B Mission
- ✓ 3-year Prime Mission, 5-year Mission Goal
- ✓ LEO 525 km, 28.5° inclination
- ✓ From 300 km to 25 km separation among satellites
- ✓ Phase A start 10/2023 (NASA HQ guidance)
- ✓ Launch 11/2029 (MDL forecast)

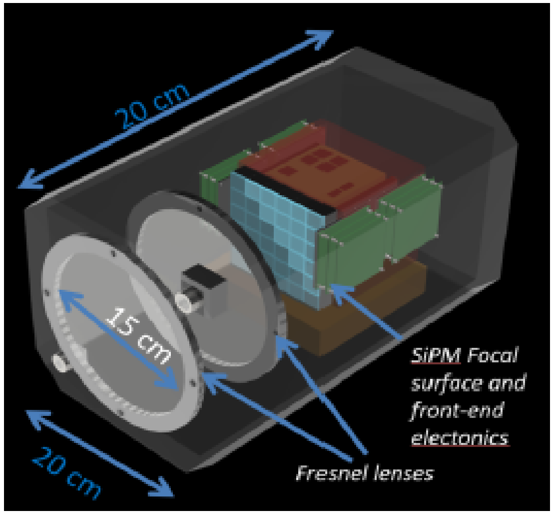


**Dual Manifest ATLAS V LPF**

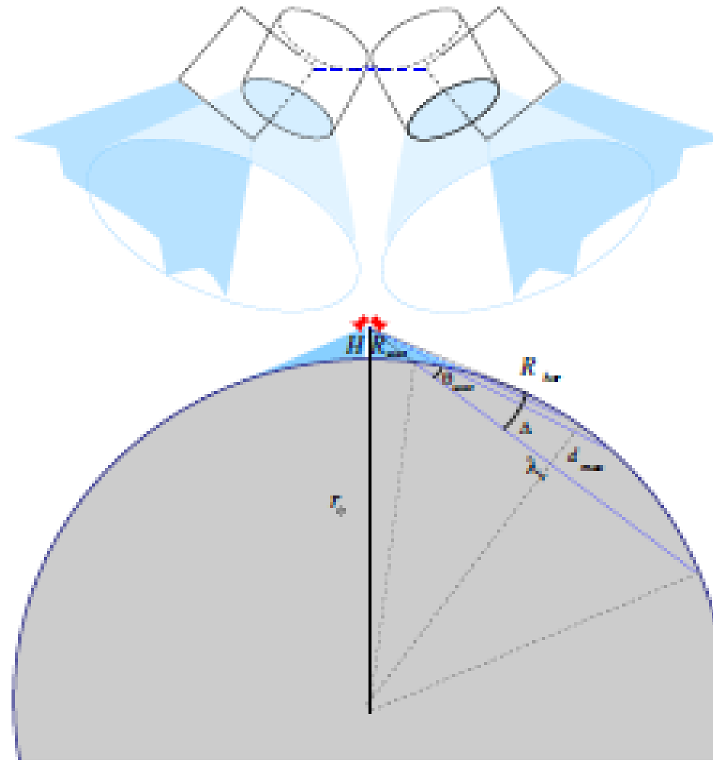


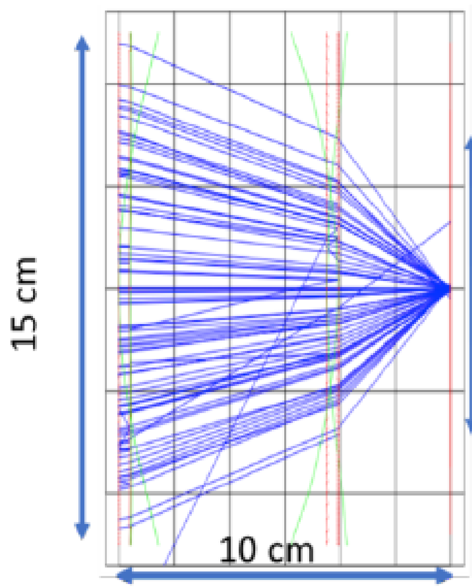
# NUSES: Terzina

Characterization of the background in the observation of astrophysical neutrinos (E>1 PeV) by means of IACT from space.

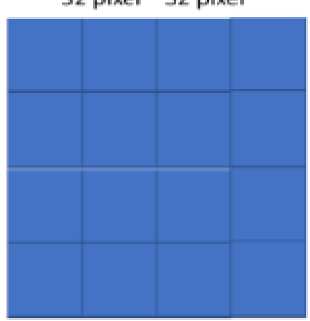



- First design: 150 mm Fresnel optics. The optic project is still under discussion in order to align the Terzina design with EUSO-SPB2;
- SiPM focal surface.





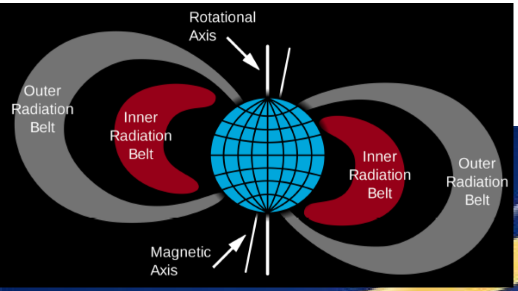

First Fresnel lens Second Fresnel lens

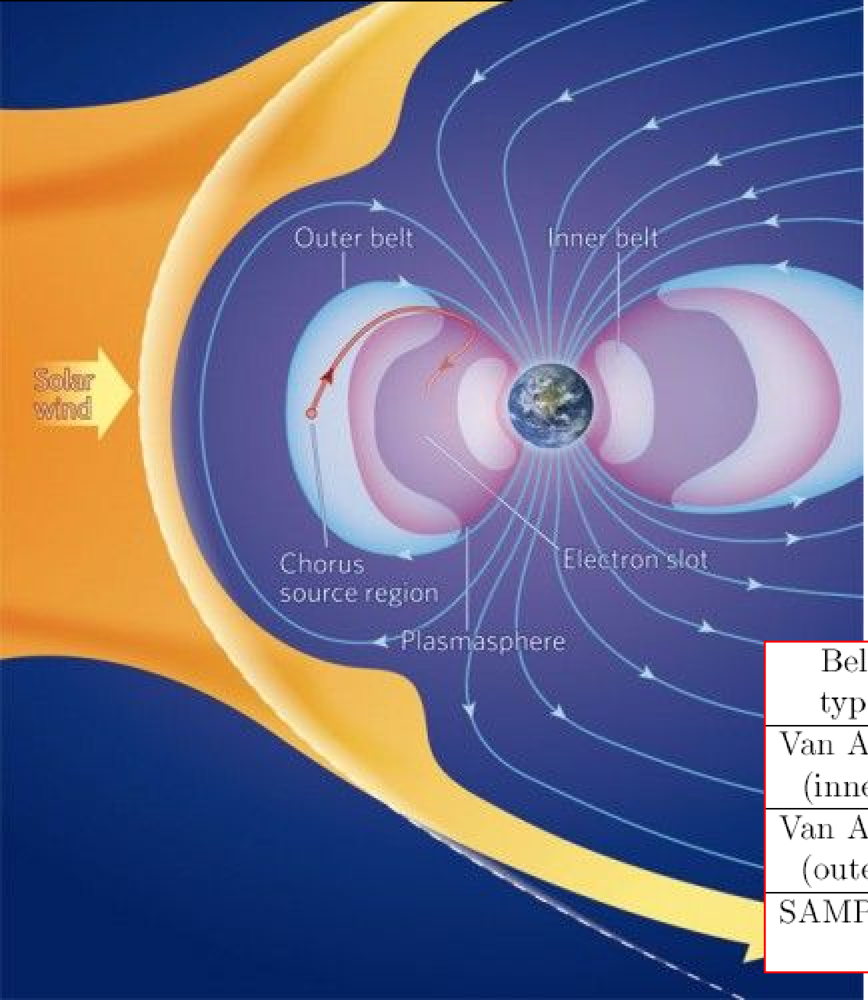


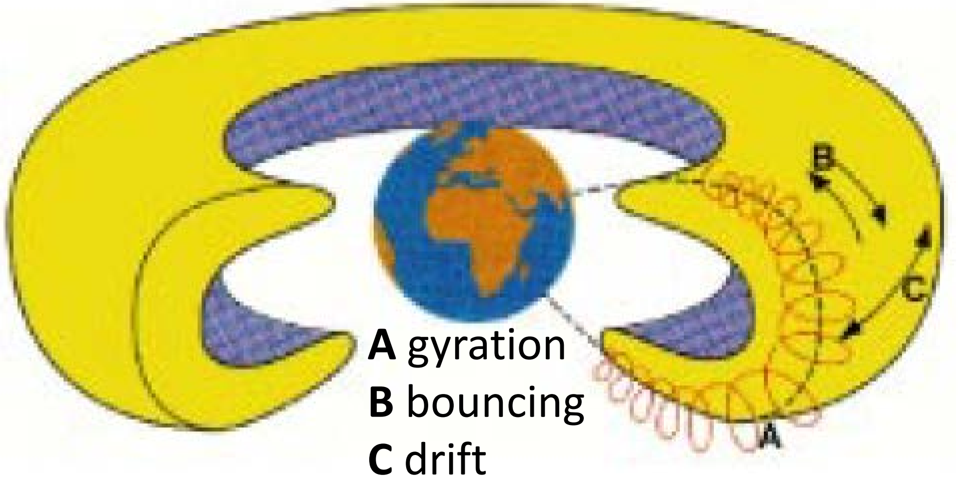

SiPM
Focal Surface

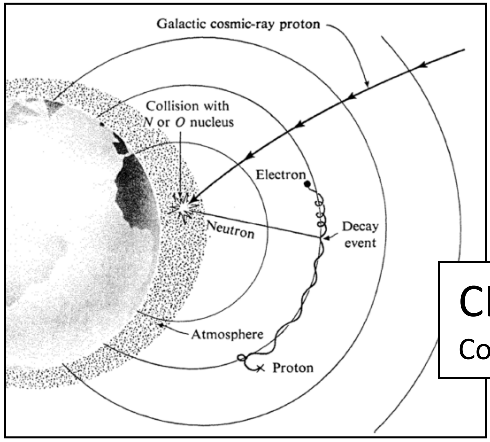
- Needed the same intensity per pixel expected in future large area IACT in space (POEMMA).
- Test of new technologies for Astroparticles studies in space.

# (Van Allen) radiation belts



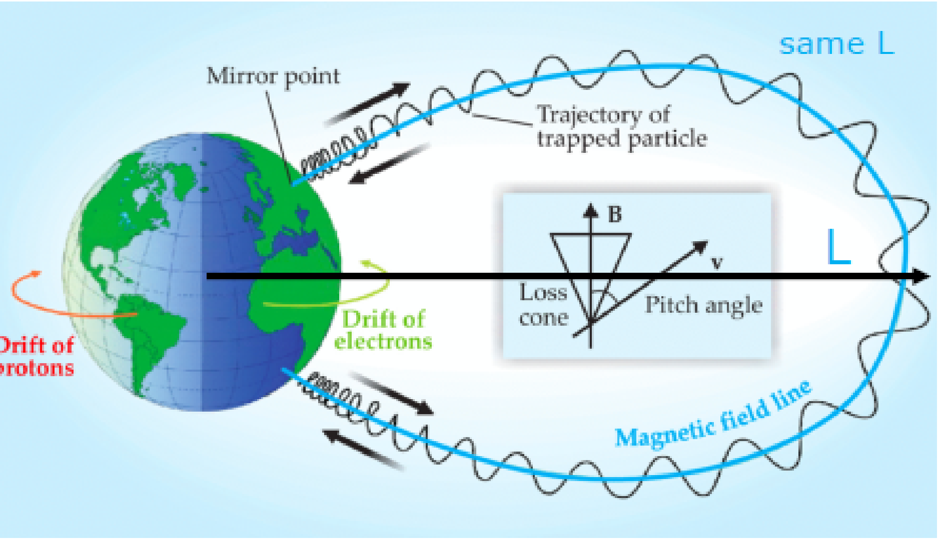



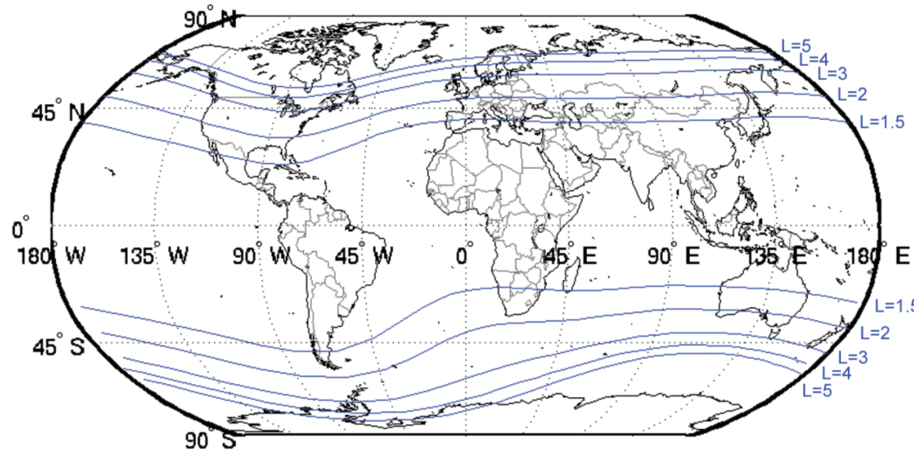




**CRAND**
Cosmic Ray Albedo Neutron Decay

| Belt type | Composition | Rigidity [MeV/n] | Filling mechanisms | L | Residence time [d] |
|---|---|---|---|---|---|
| Van Allen (inner) | $p$<br>$e^-$ | $0.1 - 100$<br>$0.01 - 1$ | $n \to pe^- \overline{\nu}_e$,<br>external belts | $< 2.5$ | $10 - 1000$ |
| Van Allen (outer) | $e^-$<br>$p$ | $1 - 10$<br>$0.1 - 1$ | solar wind | $> 2.5$ | $1 - 10$ |
| SAMPEX | $N^{+x}, O^{+x}$,<br>$Ne^{+x}$ | 10<br>$10 - 100$ | Anomalous CR | 2 | $10 - 100$ |

# (Van Allen) radiation belts




**L**: distance (in $R_E$) of the field line passing through the observation point, measured on the equatorial plane.

**B**: magnetic field intensity at the observation point.

*(L,B): McIlwain coordinates*

**pitch-angle α**: for each trajectory, the (v,B) angle at the Equator (back-tracing).

(**B**,**α**)→ $\mathbf{B_m}$ (field at the mirror point)
($\mathbf{L_m}$, $\mathbf{B_m}$): drift shell, invariant

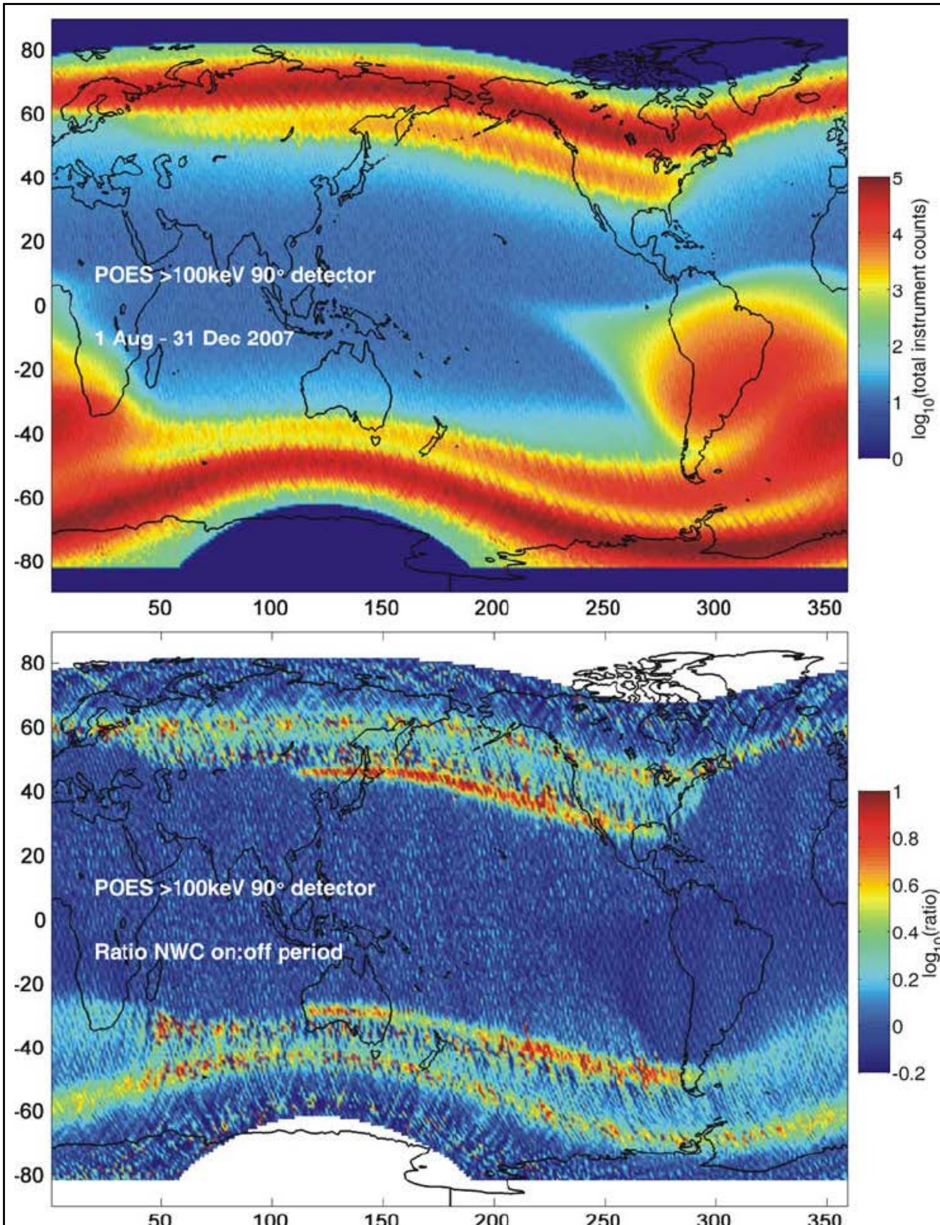
**Inner Van Allen belt:**
electrons and protons O(100 keV) – O(100 MeV)
(enhanced proton flux on the South Atlantic Anomaly)

**Outer Van Allen belt**: mostly electrons

Any electromagnetic perturbation determines sizeable effects on particle trajectories in Van Allen belts:

- from the Earth (VLF/ULF emitters, seismic activity…)
- from the outer space (solar activity)

# Artificially induced radiation belt particle precipitation




**Man made Very Low Frequency (VLF) transmissions**
U.S. Navy transmitter
NWC , North West Cape , Australia
19.8 kHz, 1MW radiated power

JOURNAL OF GEOPHYSICAL RESEARCH

## Satellite Observations of Electrons Artificially Injected into the Geomagnetic Field*


JAMES A. VAN ALLEN, CARL E. MCILWAIN, AND GEORGE H. LUDWIG

*Department of Physics*
*State University of Iowa*
*Iowa City, Iowa*



*Abstract*—Our four radiation detectors in satellite 1958ε (Explorer IV) easily and promptly observed the geomagnetically trapped electrons resulting from the three high-altitude nuclear detonations Argus I, II, and III in August–September 1958. An account of over 160 satellite passes through the three Argus "shells" of artificially injected electrons is given herein, and a preliminary appraisal of the geophysical significance of these experiments is offered.


TABLE 2

DATA ON BURSTS

| | Argus I | Argus II | Argus III |
|---|---|---|---|
| Nominal yield | 1 to 2 kilotons | 1 to 2 kilotons | 1 to 2 kilotons |
| Approximate time of burst | August 27, 1958, 0230 U.T. | August 30, 1958, 0320 U.T. | September 6, 1958, 2210 U.T. |
| Approximate geographic coordinates | 38° S, 12° W | 50° S, 8° W | 50° S, 10° W |

Nominal altitude of all bursts ~480 km.

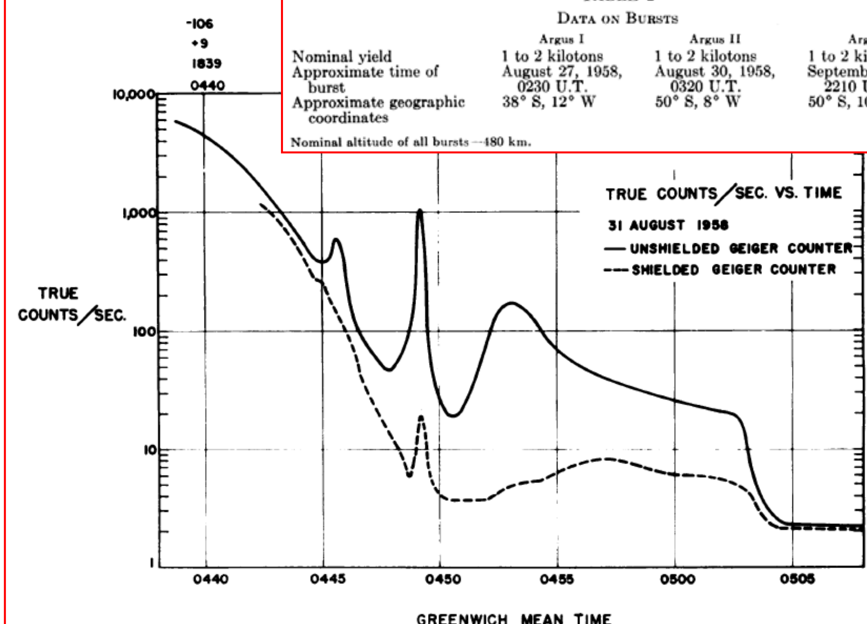



Fig. 8.—A plot of radiation observations on August 31, 1958 showing the decaying Argus I peak (at 0446 U.T.) and the fresh Argus II peak (at 0449 U.T.).

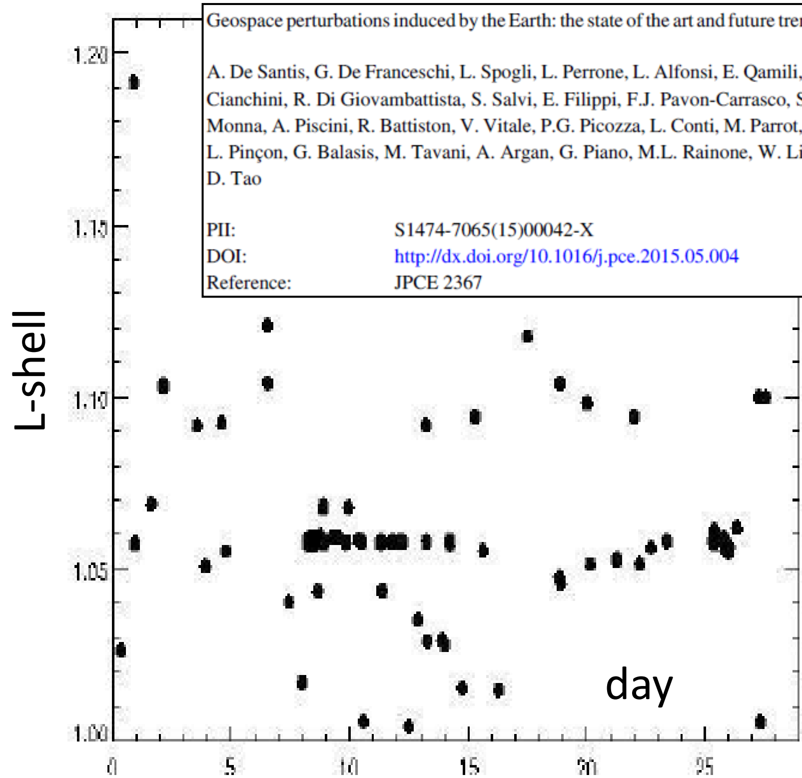
## Earthquakes (L-time) map

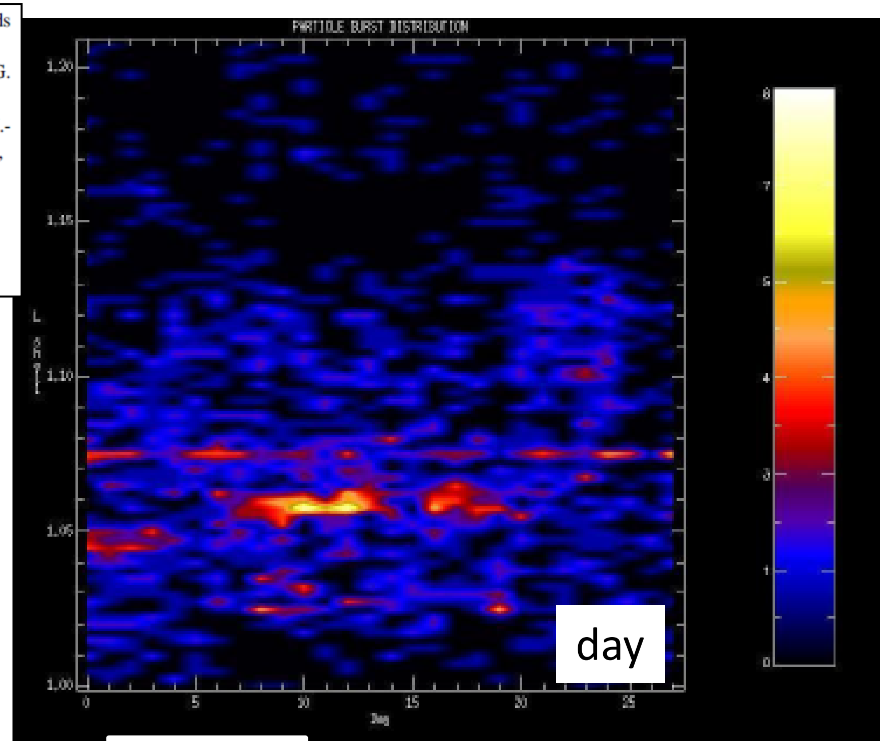
## Normalized particle burst (AGILE data)

Geospace perturbations induced by the Earth: the state of the art and future trends

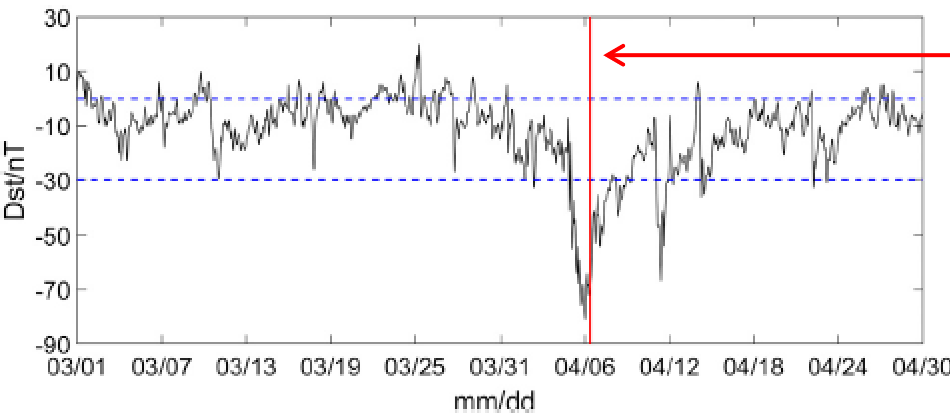
A. De Santis, G. De Franceschi, L. Spogli, L. Perrone, L. Alfonsi, E. Qamili, G. Cianchini, R. Di Giovambattista, S. Salvi, E. Filippi, F.J. Pavon-Carrasco, S. Monna, A. Piscini, R. Battiston, V. Vitale, P.G. Picozza, L. Conti, M. Parrot, J.-L. Pinçon, G. Balasis, M. Tavani, A. Argan, G. Piano, M.L. Rainone, W. Liu, D. Tao

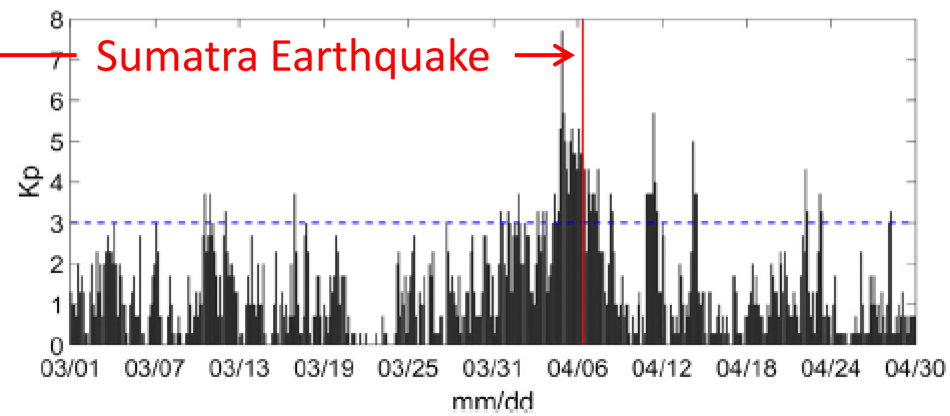
PII: S1474-7065(15)00042-X
DOI: http://dx.doi.org/10.1016/j.pce.2015.05.004
Reference: JPCE 2367




## Geomagnetic field disturbance indexes from March to April 2010 (DEMETER data)



# Electromagnetic perturbations

ANNALS OF GEOPHYSICS, 55, 1, 2012; doi: 10.4401/ag-5356

Special Issue: EARTHQUAKE PRECURSORS

## Extremely low frequency plasma turbulence recorded by the DEMETER satellite in the ionosphere over the Abruzzi region prior to the April 6, 2009, L'Aquila earthquake

Jan Błęcki[1,*], Małgorzata Kościesza[1], Michel Parrot[2], Sergey Savin[3], Roman Wronowski[1]

[1] *Space Research Centre PAS, Warsaw, Poland*

[2] *Laboratoire de Physique et Chimie de l'Environnement et de l'Espace, Université d'Orléans, CNRS, Orléans, France*

[3] *Space Research Institute, Russian Academy of Sciences, Moscow, Russia*

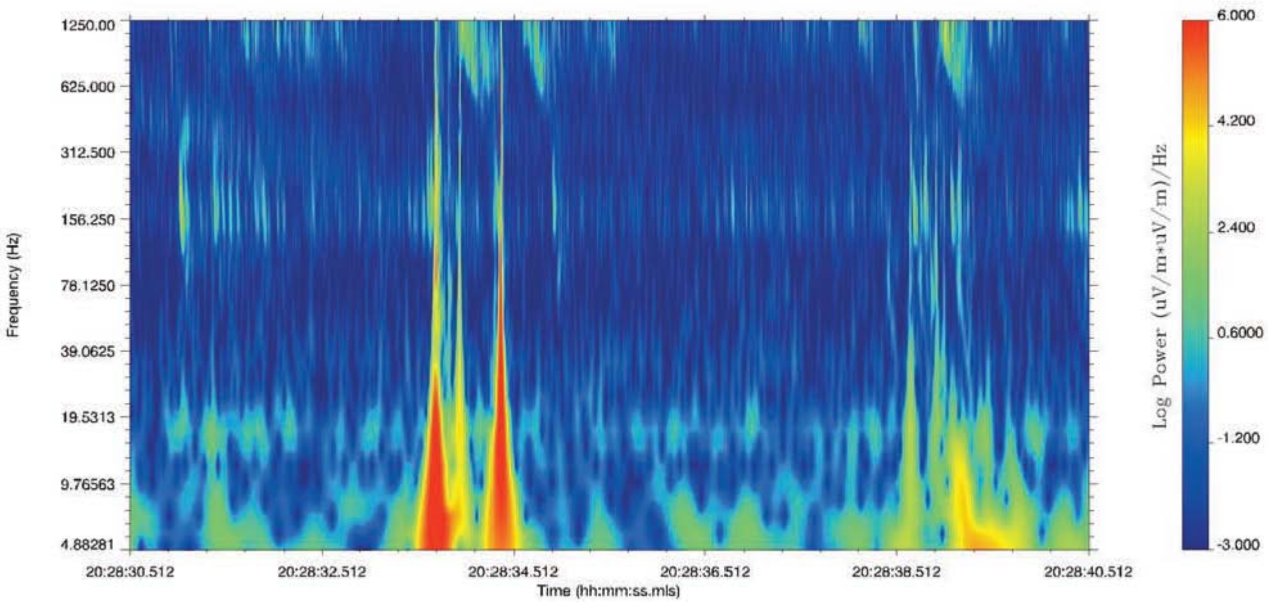



Figure 7a. Wavelet spectrogram of the broad-band emission in the ELF range recorded on April 4, 2009. The distance of the footprint of the satellite to the epicenter was about 280 km. The color scale is as in Figure 2.

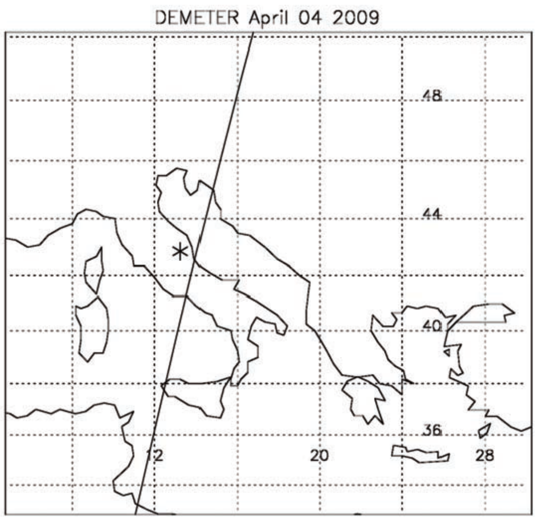



Figure 6. Map showing the epicenter of the April 6 L'Aquila earthquake (*) and the orbit of the DEMETER satellite on April 4, 2009. The point of closest approach from the epicenter was 125 km.

# A possible model for MILC

*"quantitatively explain the experimental observations about 6h before and at the moment of "* (Aug 5, 2018 Indonesia) *"earthquake observation"*

*remote sensing*

MDPI

*Article*

**Magnetospheric–Ionospheric–Lithospheric Coupling Model. 1: Observations during the 5 August 2018 Bayan Earthquake**

**Mirko Piersanti [1,*,†], Massimo Materassi [2,†], Roberto Battiston [3,†], Vincenzo Carbone [4,†], Antonio Cicone [5,†], Giulia D'Angelo [5,†], Piero Diego [5,†] and Pietro Ubertini [5,†]**

1 I.N.F.N.—Department of Physics, University of Rome "Tor Vergata", via della Ricerca Scientifica, 00133 Rome, Italy

2 Institute of Complex Systems, ISC-CNR, via Madonna del Piano 10, Sesto Fiorentino, 50019 Florence, Italy; massimo.materassi@isc.cnr.it

3 University of Trento, TIFPA, Department of Physics, Via Sommarive, Povo, 38123 Trento, Italy; roberto.battiston@unitn.it

4 Physics Department, Universitá della Calabria, Ponte Pietro Bucci, Rende, 87036 Cosenza, Italy; vincenzo.carbone@fis.unical.it

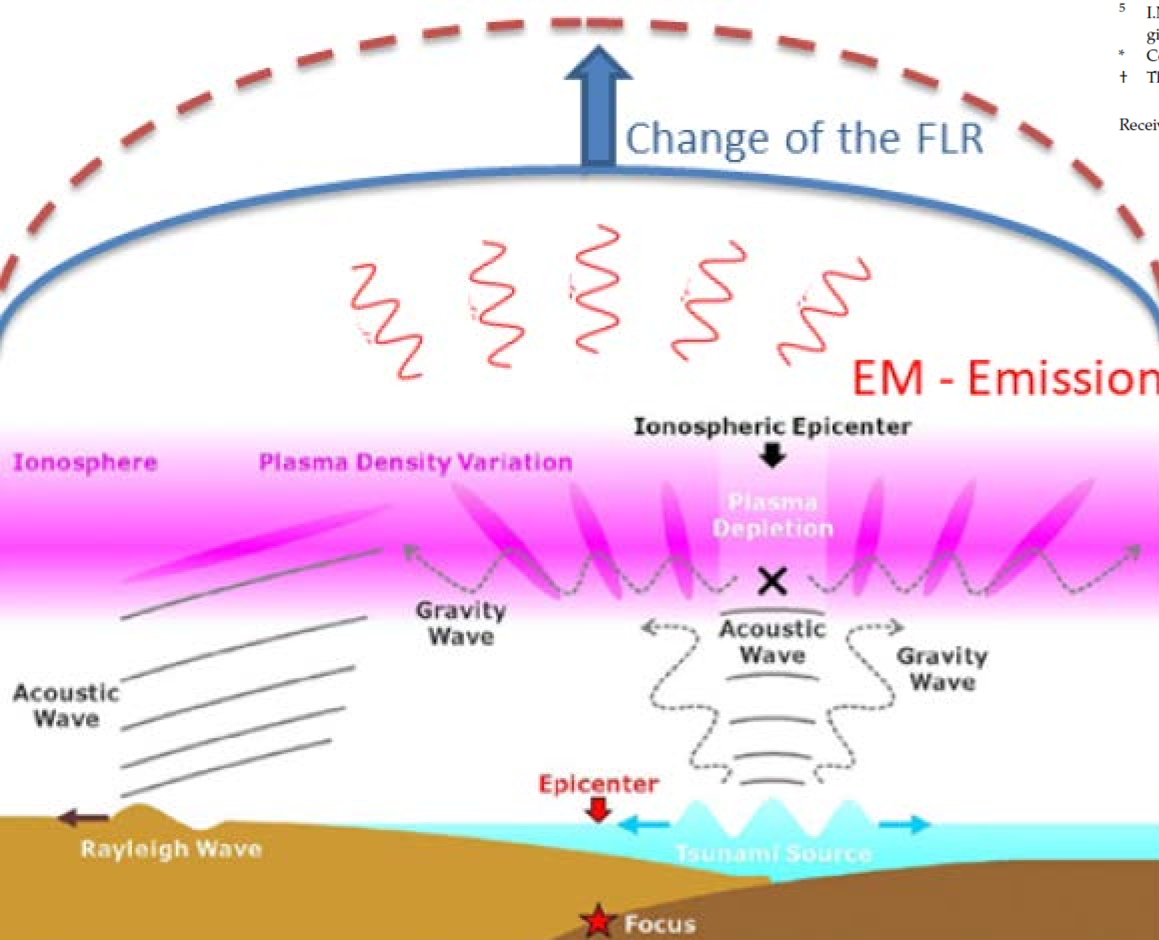
5 I.N.A.F.–I.A.P.S., Via del Fosso del Cavaliere, 00133 Rome, Italy; antonio.cicone@univaq.it (A.C.); giulia.dangelo@inaf.it (G.D.); piero.diego@inaf.it (P.D.); pietro.ubertini@inaf.it (P.U.)

* Correspondence: mirko.piersanti@roma2.infn.it

† These authors contributed equally to this work.

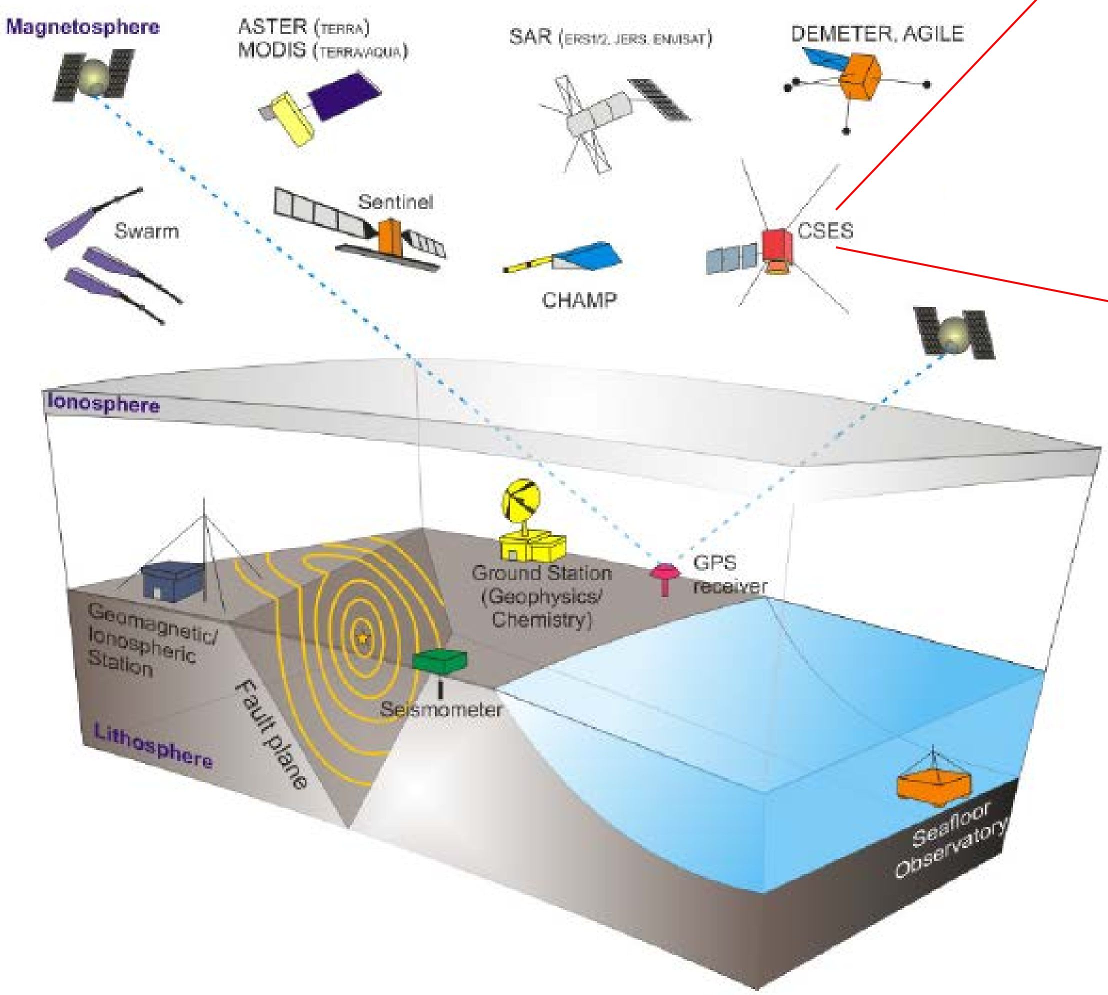
Received: 26 August 2020; Accepted: 3 October 2020; Published: 11 October 2020

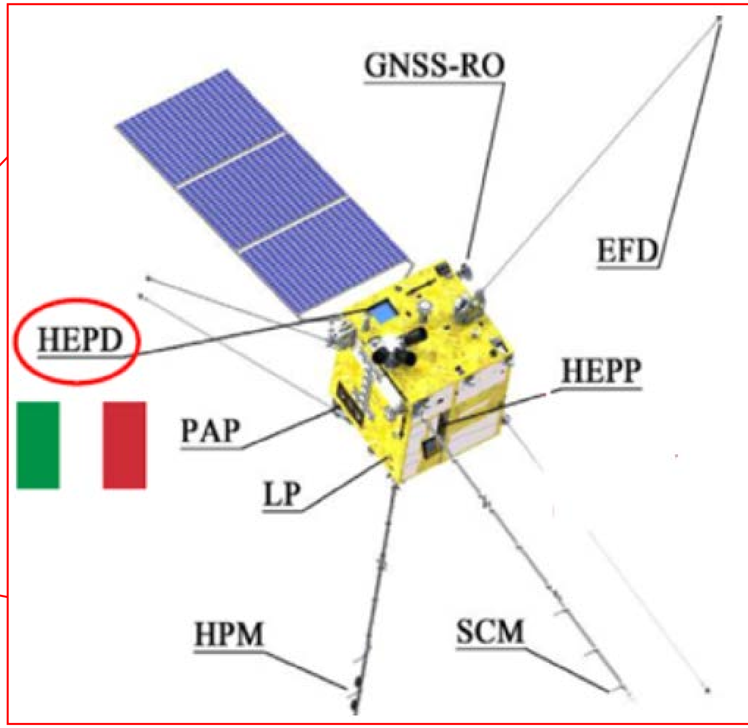
check for updates




- Seismic activity
- Atmospheric Gravity Wave
- Mechanical perturbation of ionospheric plasma density
- Generation of EM waves
- Field Line Resonance (FLR) variations
- .....

# A network of ground and space based instruments



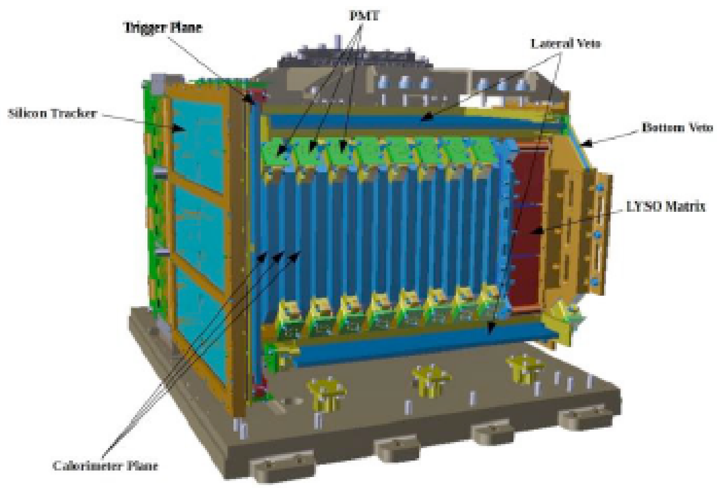




**CSES**
China Seismic Electromagnetic Satellite
LIMADOU → HEPD
(High Energy Particle Detector)

CSES-01 on orbit since February 2018
CSES-02 launch (2022)

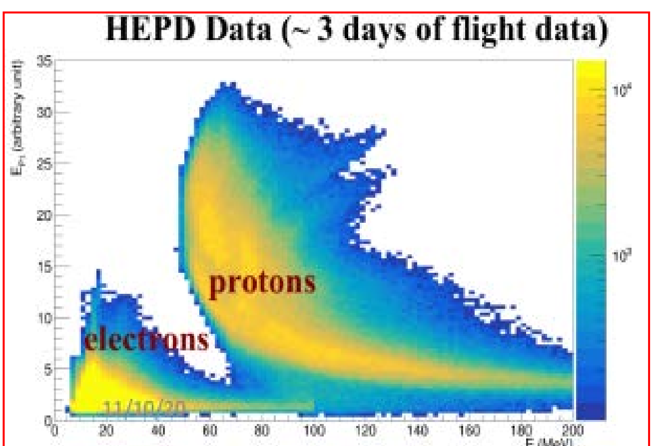
# The HEPD

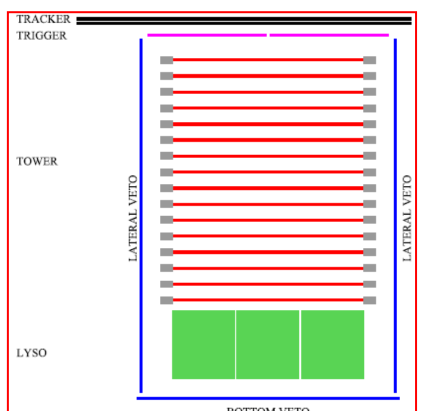
*Visualizzzione CAD di HEPD con i sub-detector in evidenza*



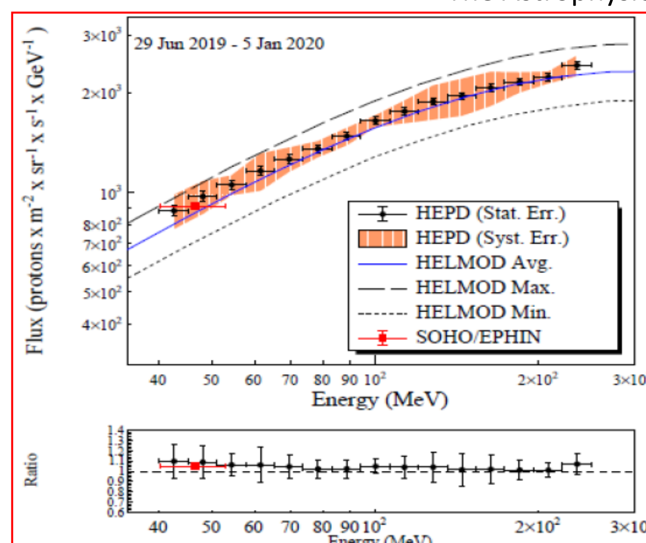

- Sistema di TRACKING (2 piani a microstrip di Silicio) – **direzionalità/energia depositata dalla particella entrante**
- Piano di TRIGGER (6 barre di plastici) - **informazioni sul tempo di arrivo della particella**
- 16 piani di scintillatore plastico (TORRE) - **calorimetro a range per la misura di perdita totale di energia**
- Sistema di VETO (4 piani laterali e uno posto in fondo allo sttrumento) – **informazioni sul contenimento delle particelle entranti, reiezione secondari**
- Matrice di LYSO (9x9 cristalli) – **aumentano il range dinamico per la stima energetica**

**Range:**
**Elettroni: 3 – 100 MeV**
**Protoni: 30 – 250 MeV**
**Nuclei leggeri: centinaia di MeV**



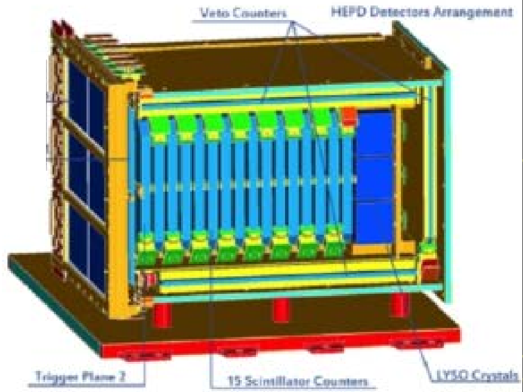



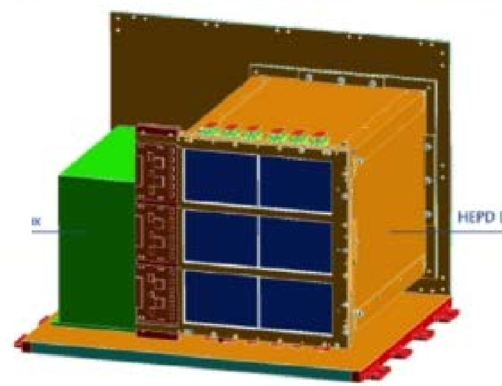

The Astrophysical Journal 901:8 (2020)

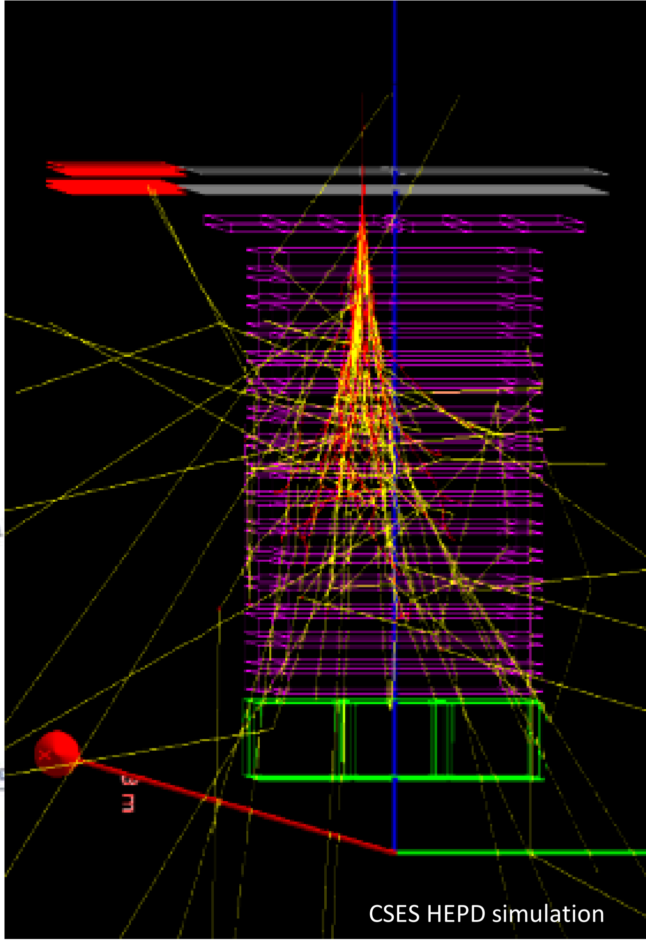


# NUSES: Zirè

| | |
|---|---|
| Mass | 35 kg |
| Volume | 550* 400* 400 mm$^3$ |
| Temperature | −10 +35 °C |
| Power | 30 W |
| Telecommands | CAN2 bus |
| Data Handling | RS422 |






| | |
|---|---|
| Trigger | Scintillatori |
| Calorimeter | Lyso |
| Readout | SiPM and PMT |
| Electrons range | 3 – 100 MeV |
| Proton range | 30 – 200 MeV |
| Angular resolution | <8 deg at 5 MeV |
| Energy resolution | <10% a 5 MeV |
| Trigger rate | $10^7$ p/cm$^2$s sr |

**Start from the HEPD design, then:**

**- Use SiPM instead of standard PMT**

**- Optimize the tracker and test new technologies (e.g. MAPS, Fiber Tracker, …..)**

**- Possible new design for the calorimeter readout……**

**-**

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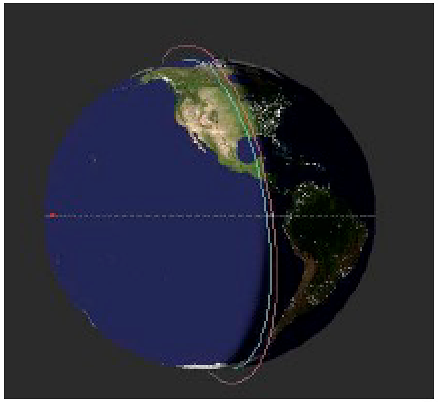
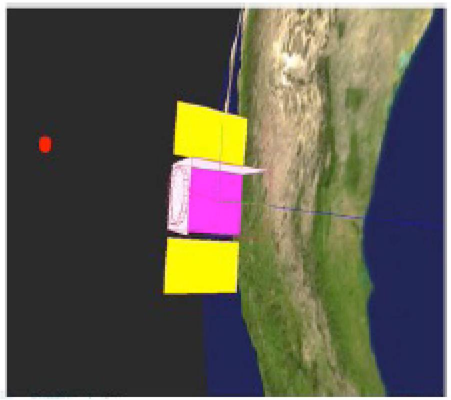
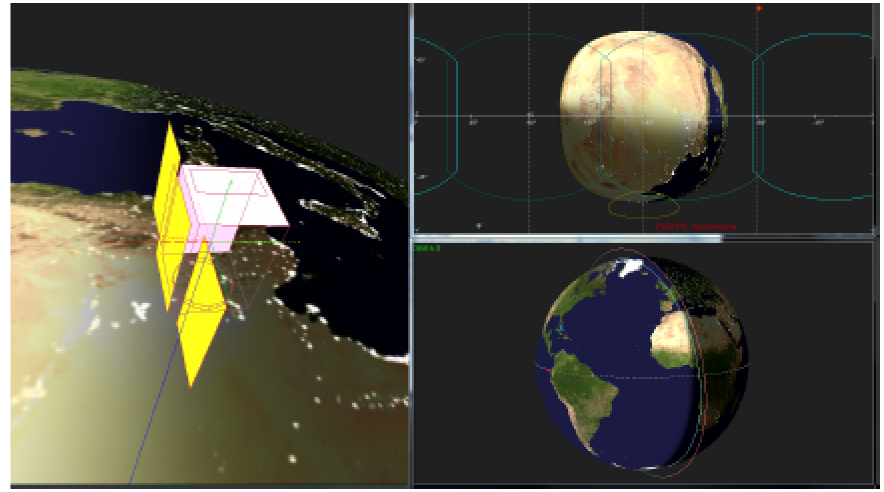
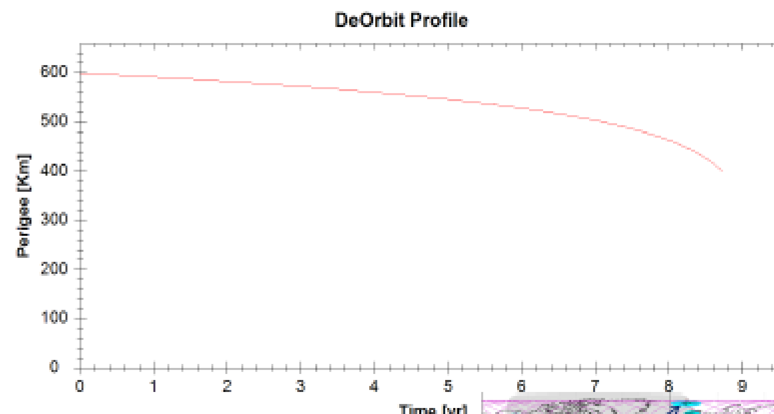
# NUSES: orbit and downlink



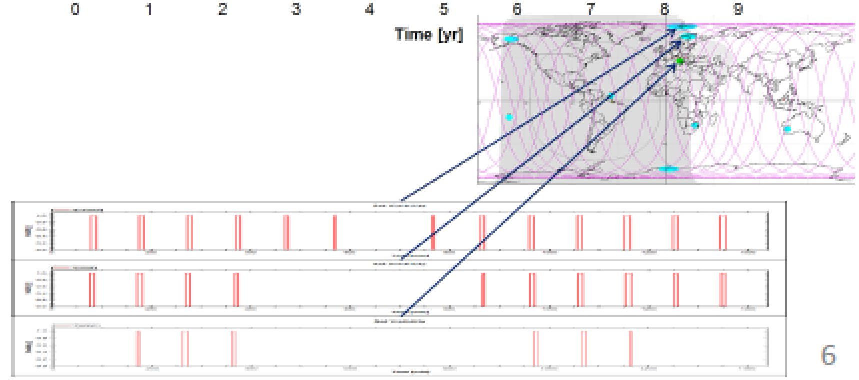







- Low Earth Orbit (LEO) with high inclination, sun-synchronous orbit on the day-night border (mean altitude = 600 Km, inclination = 97.8°, LTAN = 18:00);
- Orbit optimization for neutrino detection, still under discussion because of the interplay between Terzina-Zirè orbit requirements;
- Ballistic mission (no propulsion for orbital control).

| Stazione | N° di contatti al giorno | Durata totale dei contatti al giorno (secondi) | Quantità di dati scaricabile al giorno (Gbyte) |
|---|---|---|---|
| Fucino | 6 | 2500 | 1.25 |
| Svalbard | 14 | 6900 | 3.45 |
| Kiruna | 10 | 5100 | 2.55 |



# NUSES

- **Terzina** - Path-finder of future missions devoted to the detection of high energy astrophysical neutrinos through Imaging Atmospheric Cerenkov Telescopes from space (CHANT satellites, POEMMA mission).

- **Zirè** - Monitor of the variations of particle's flux in the ionosphere and magnetosphere induced by seismic activity. Several hints, coming from past missions, seem to correlate seismic activity with the behavior of the magnetosphere and ionosphere. This is a follow-up activity of the CSES mission.

- **New technologies** - Development of new particles detection technologies based on Silicon Photomultipliers (SiPM) for space missions.

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