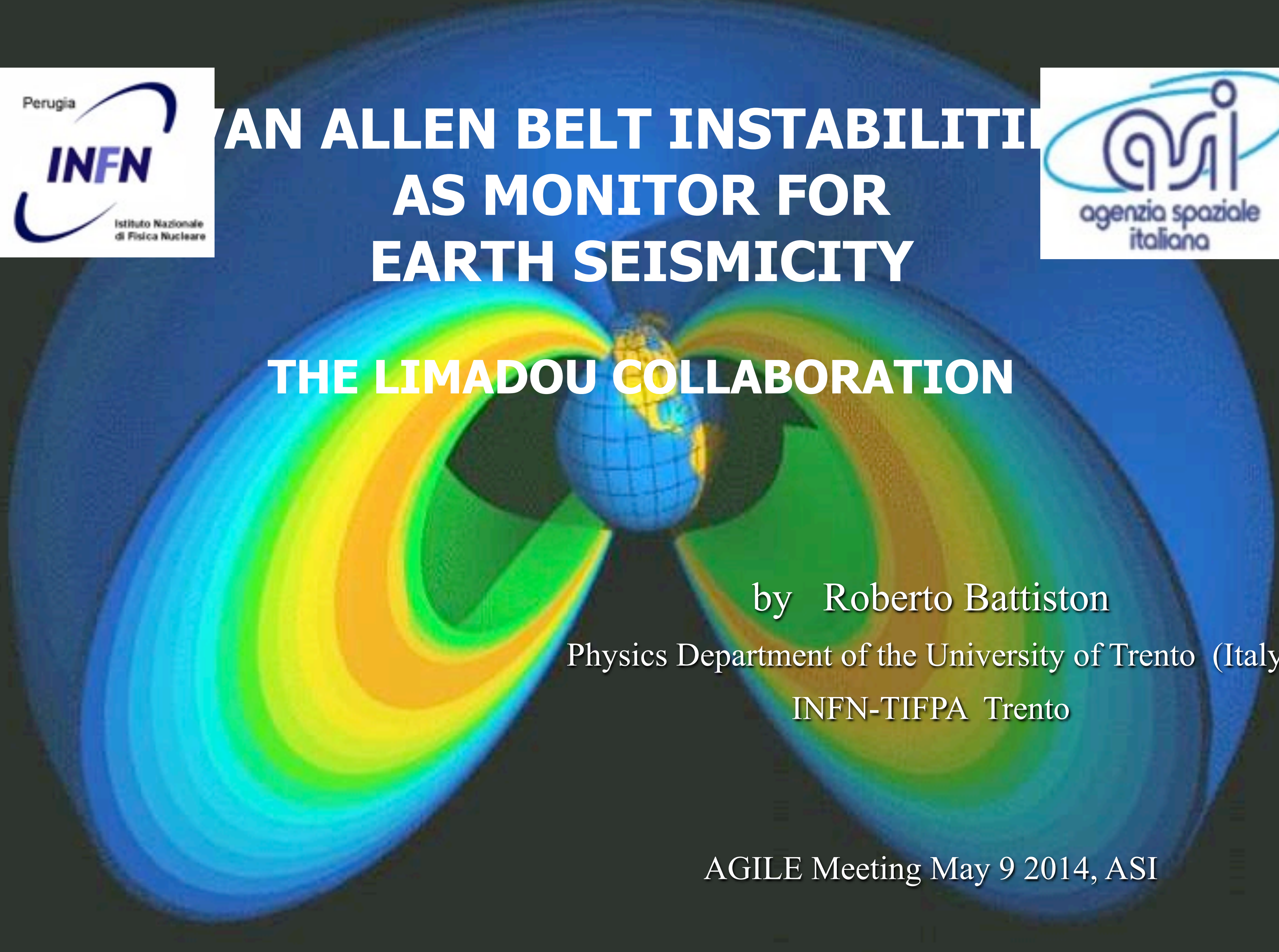


VAN ALLEN BELT INSTABILITI
AS MONITOR FOR
EARTH SEISMICITY

THE LIMADOU COLLABORATION

by Roberto Battiston

Physics Department of the University of Trento (Italy)

INFN-TIFPA Trento

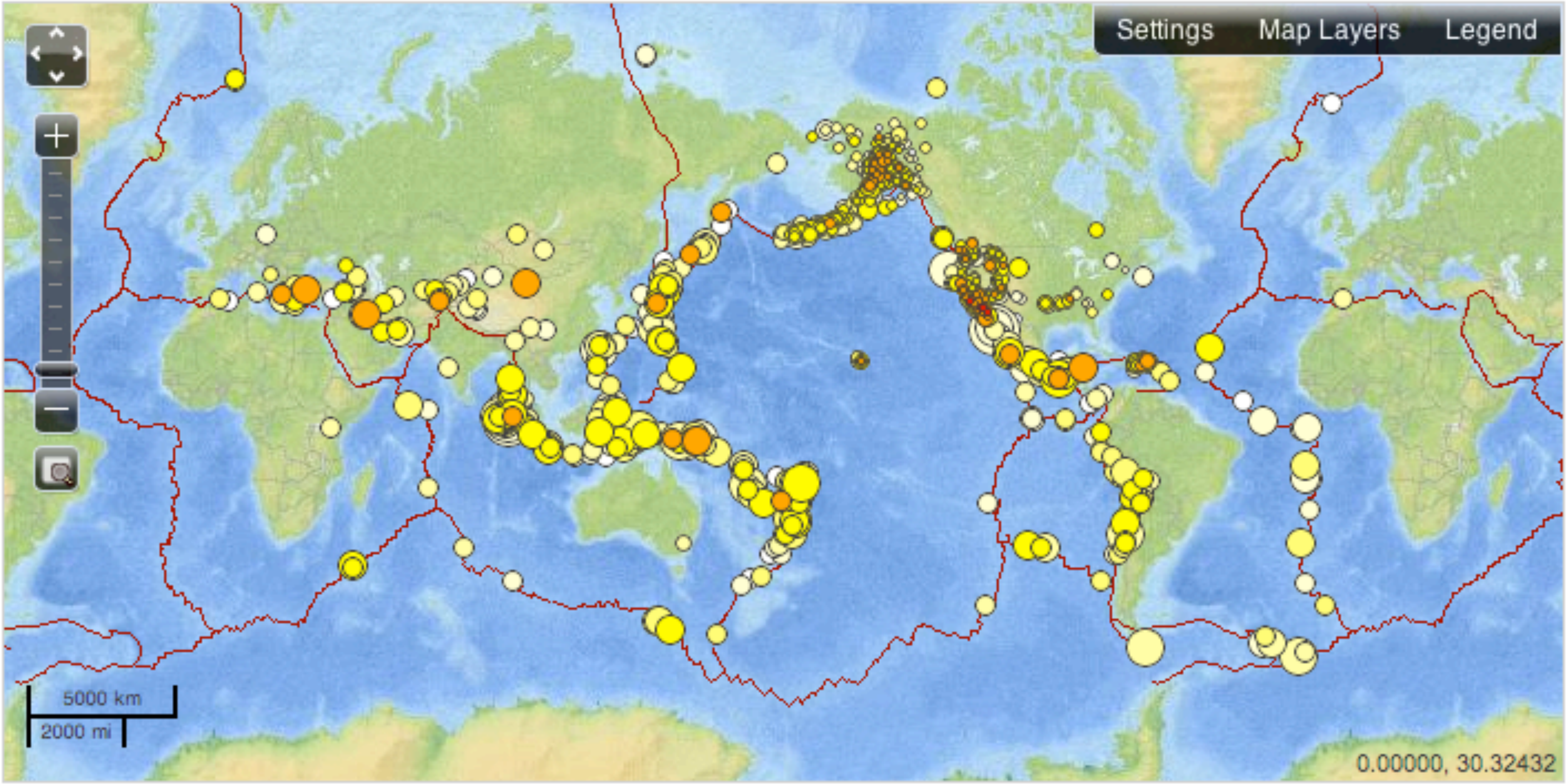
AGILE Meeting May 9 2014, ASI

Layout of the talk

1- Introduction
2- Modeling Litosphere-Magnetosphere Connection
3- NOAA data correlation analysis results
4- SEPS code and simulation results
5- The Limadou-CSES project
6- Conclusions

1-Introduction

Earthquakes are a very complex phenomenon, with a long preparation

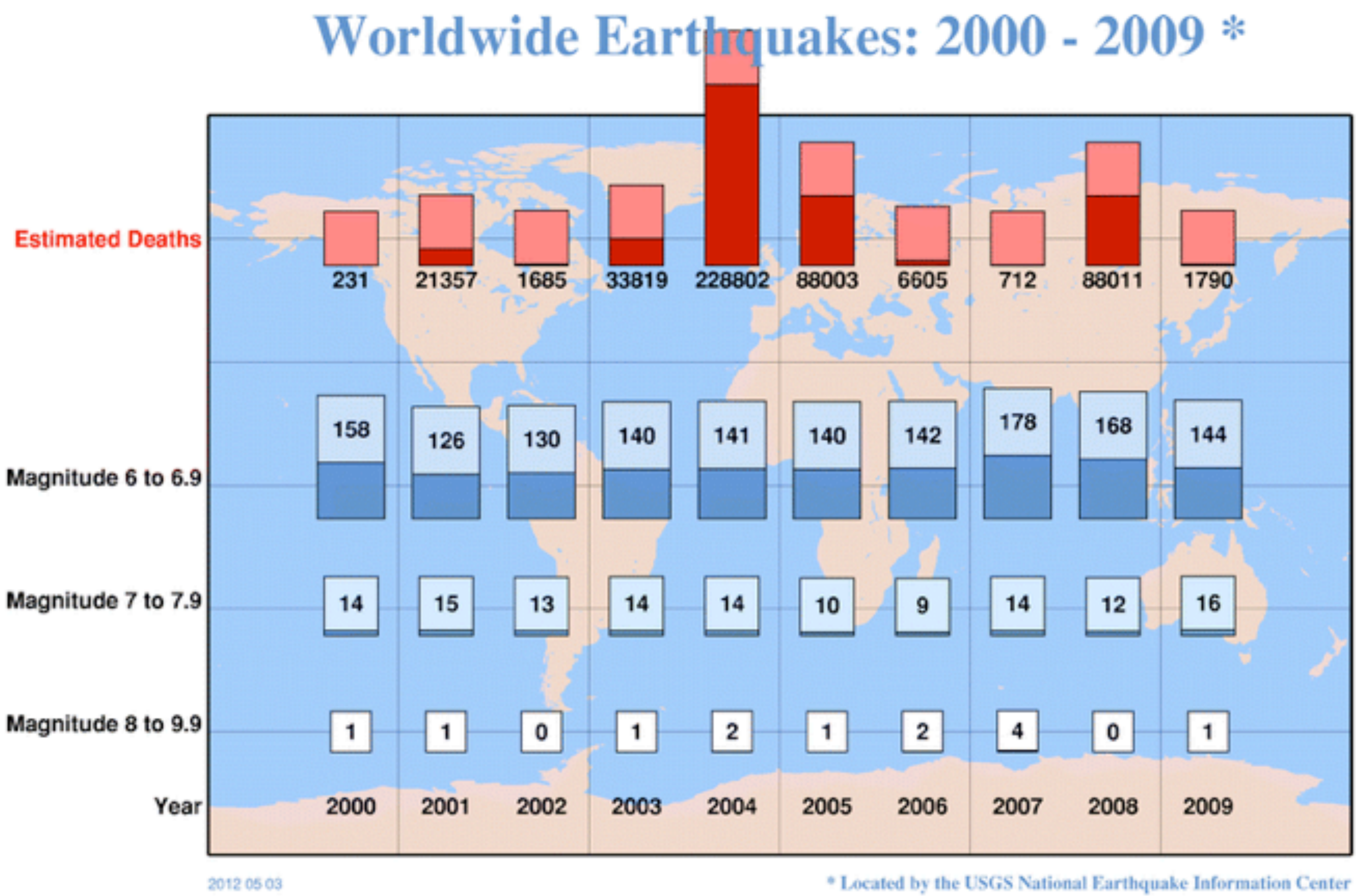


The Distribution Map of Seismic Belts

On each day there are about two Earthquakes with Magnitude M> 5
Every two day there is a M>6 Earthquake

However due to the their very low rate, ground based, short

Loss of lives is likely the most damaging consequence of a

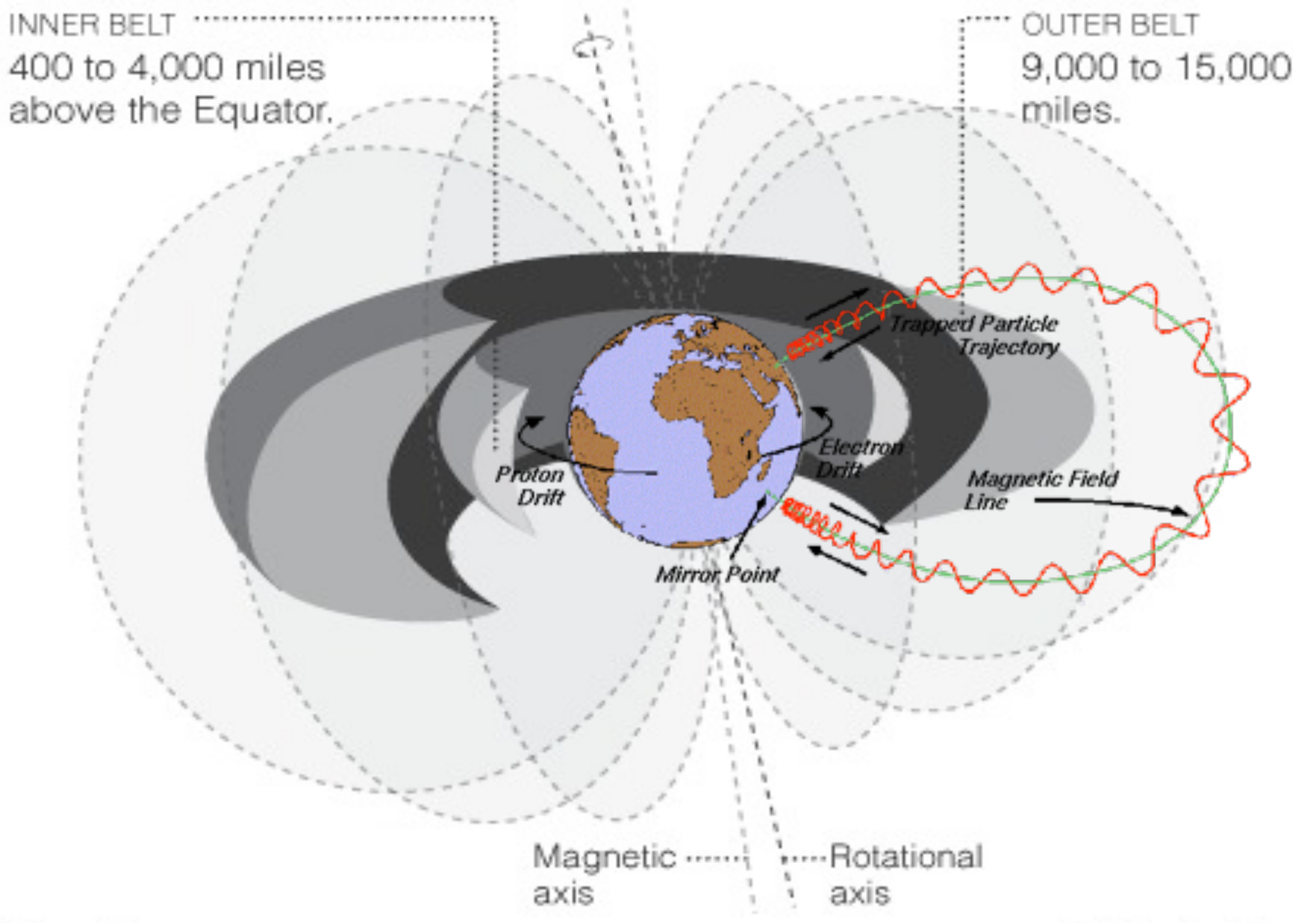


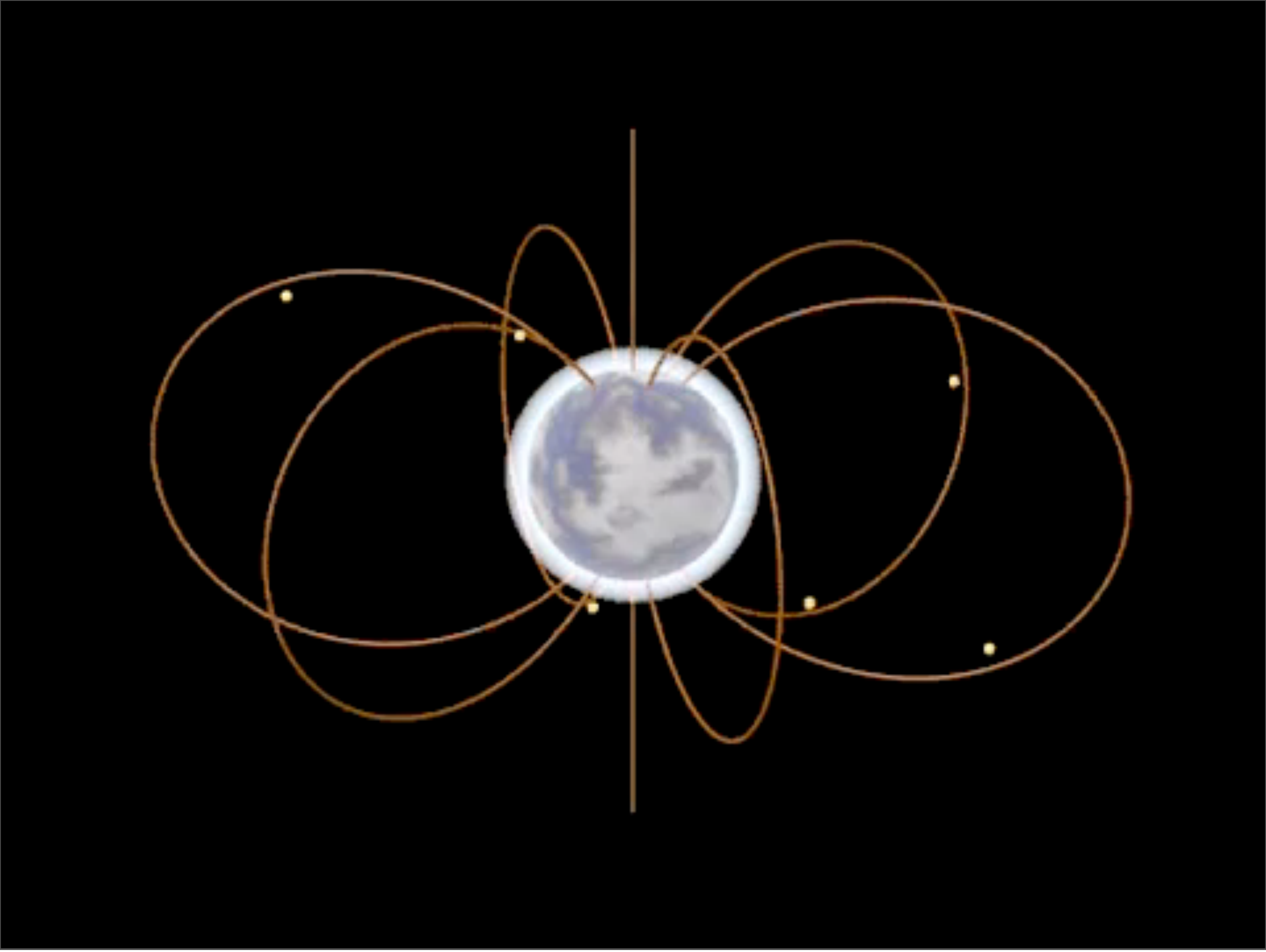
On each day there are about two Earthquakes with M> 5
Every two day there is a M>6 Earthquake

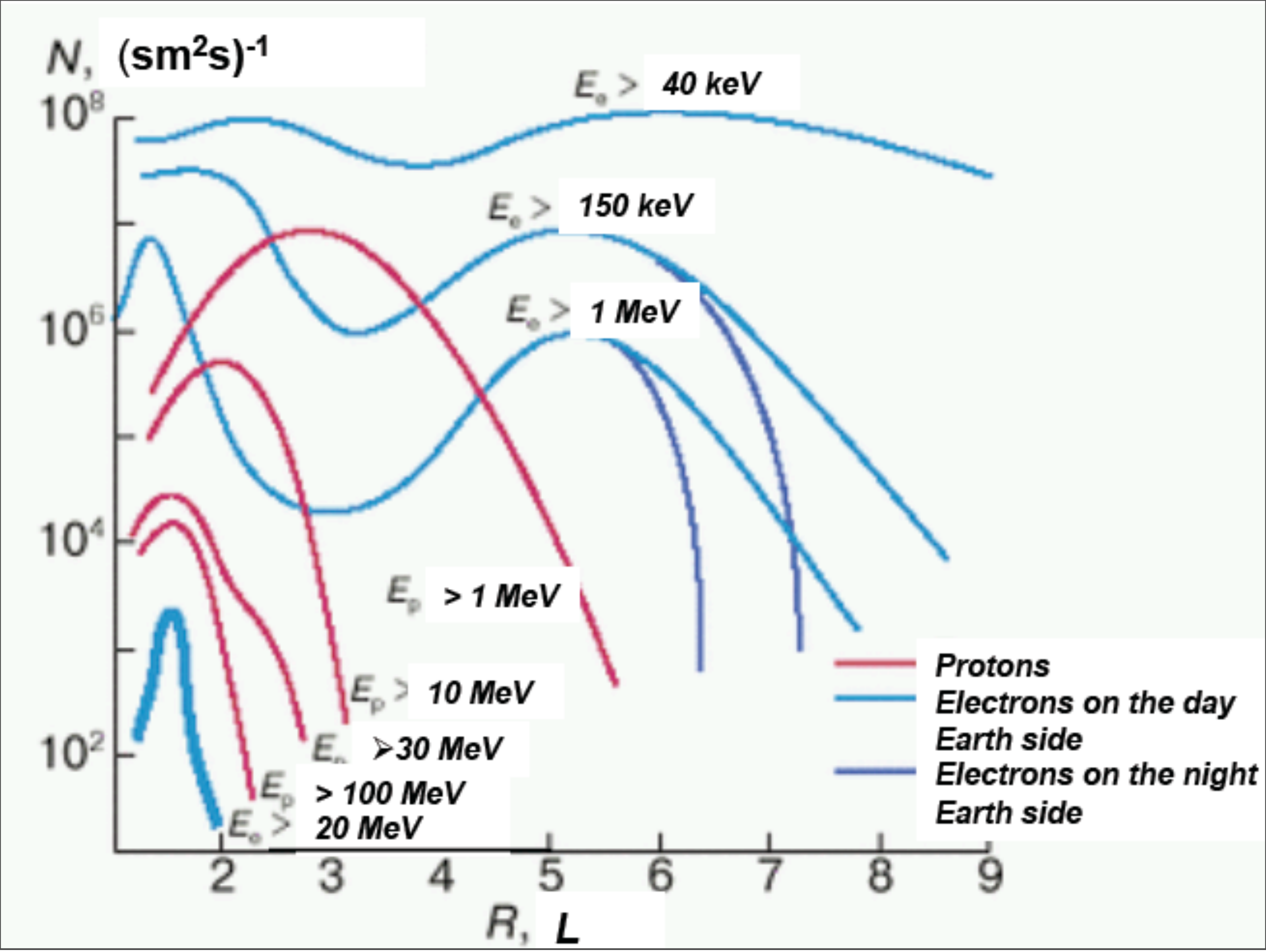
2- Modeling of the Litosphere-Magentosphere Connection

Van Allen Belts

In 1958, Dr. James A. Van Allen, an American astrophysicist, discovered two belts of charged particles circling the planet, trapped by the Earth's magnetic field.






N, (sm²s)⁻¹
10⁸
10⁶
10⁴
10²
Eₑ > 40 keV
Eₑ > 150 keV
Eₑ > 1 MeV
Eₚ > 1 MeV
Eₚ > 10 MeV
Eₚ ≻30 MeV
Eₚ > 100 MeV
Eₑ > 20 MeV
Protons
Electrons on the day Earth side
Electrons on the night Earth side
2 3 4 5 6 7 8 9
R, L

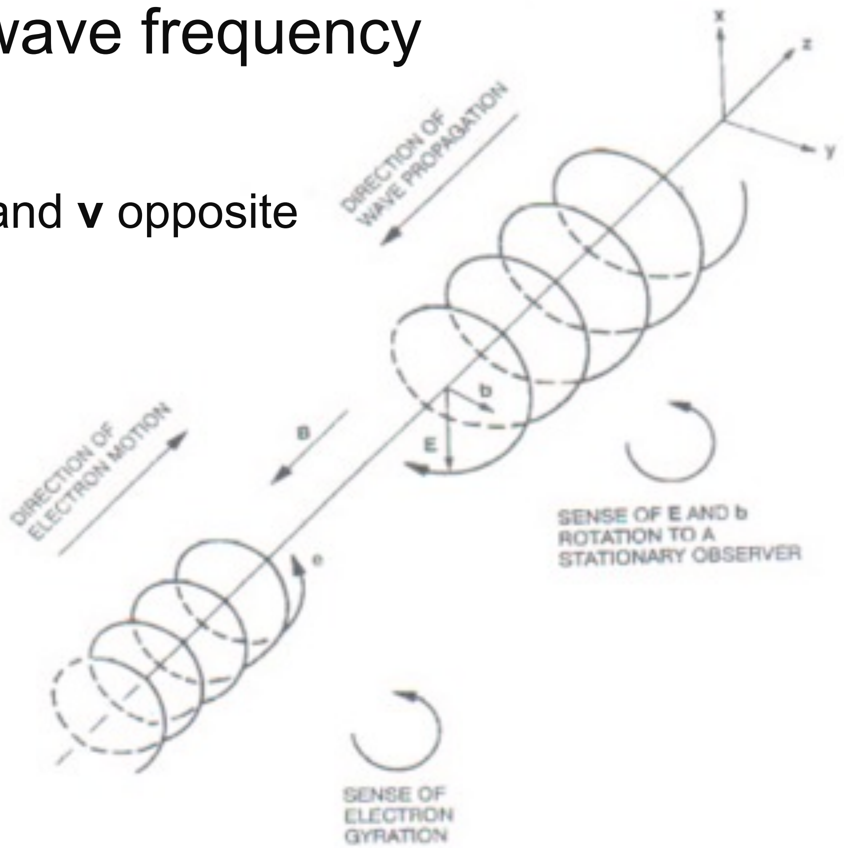
Wave-particle interaction

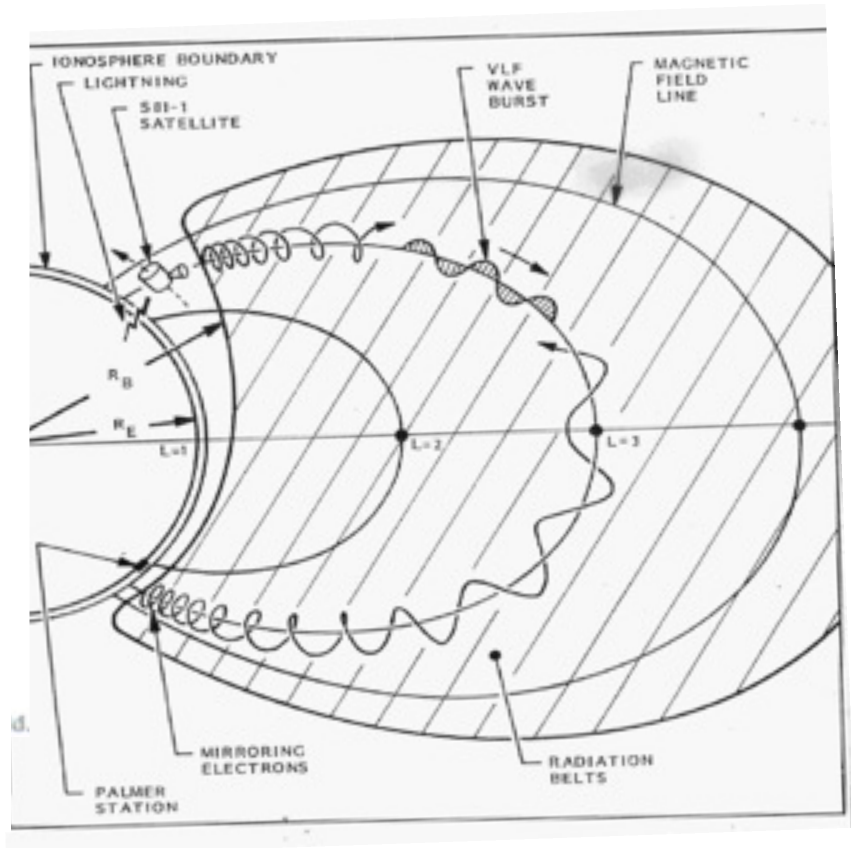
Cyclotron resonance - Whistler mode

Doppler-shifted wave frequency

Cumulative deflection from many interaction with VLF (3-30 kHz period 10-45 s) circularly polarized waves would force electrons into the loss cone i.e pitch angle diffusion

k and **v** opposite





Process efficiency measured with VLF transmitters, viable but low (Imhof,82)

Wave-particle interaction

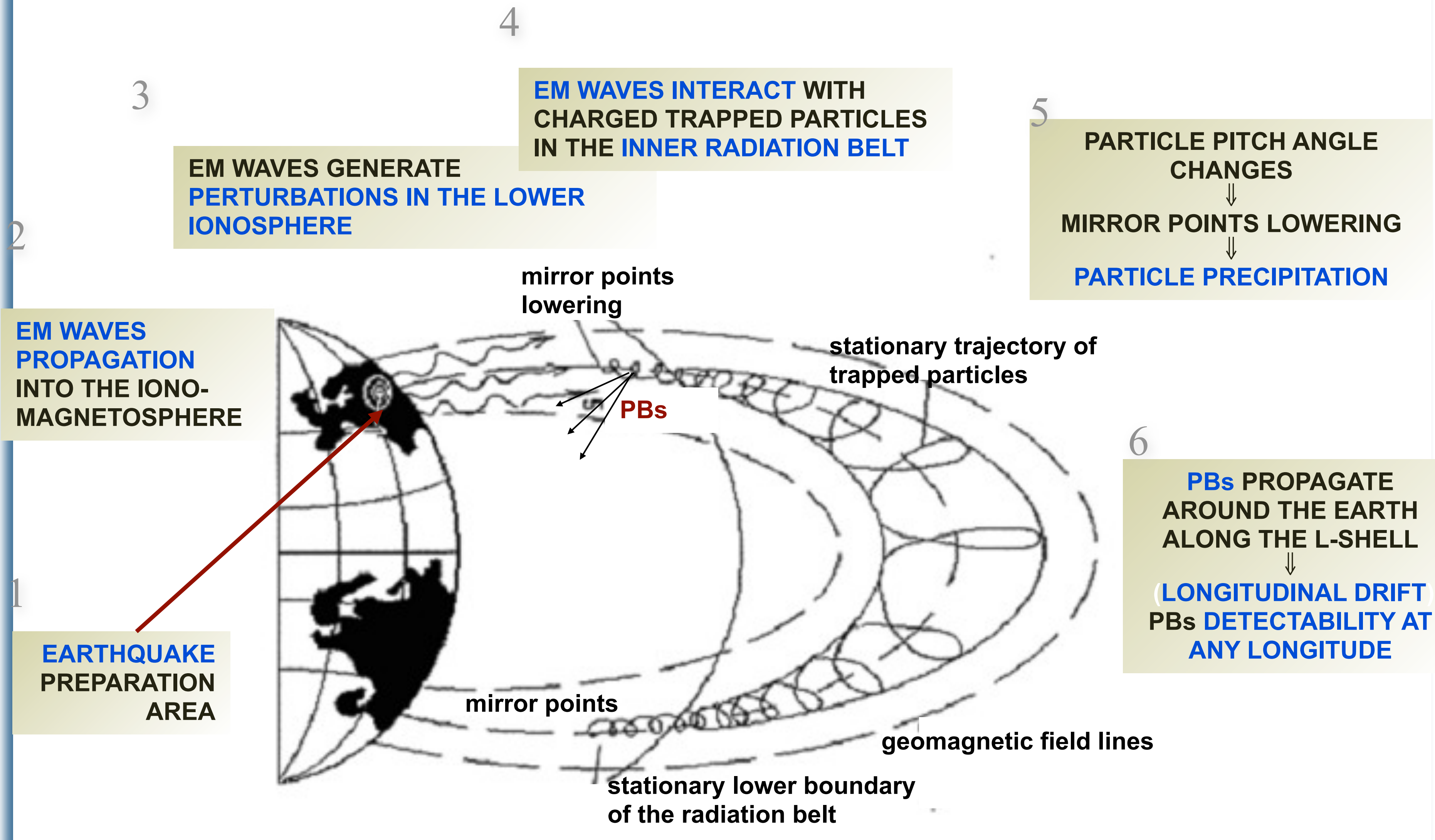
Bounce resonance - Alfven mode

Magnetosonic micropulsation or electrostatic ULF waves (< 3Hz period 300 s) can interact resonantly with particles during their bouncing motion

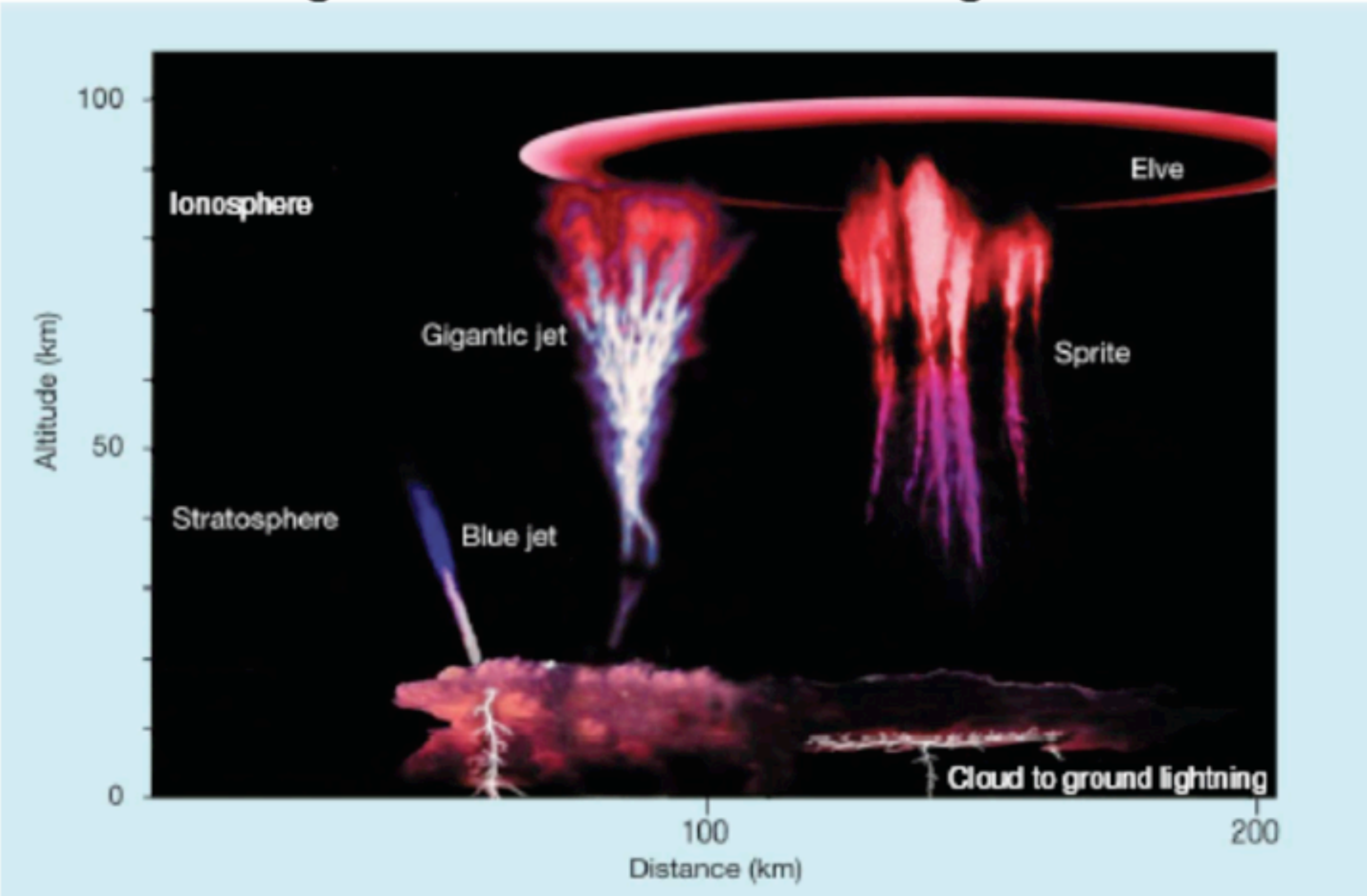
drifting $d\lambda/dt = 5 deg/s$ interacting with an ULF wave of field $E = 10^{-1}$ V/m with typical extent of interaction region in longitude $\Delta\lambda = 12°$ and in latitude $\delta\varphi = 5°$ change in pitch angle $\Delta\alpha_{bounce} = 10°$

Process efficiency viable between ULF waves and protons of E>10 MeV and electrons of E>1 MeV (Aleshina 92)

Schematic representation in a meridian plane of the trapped particle trajectories

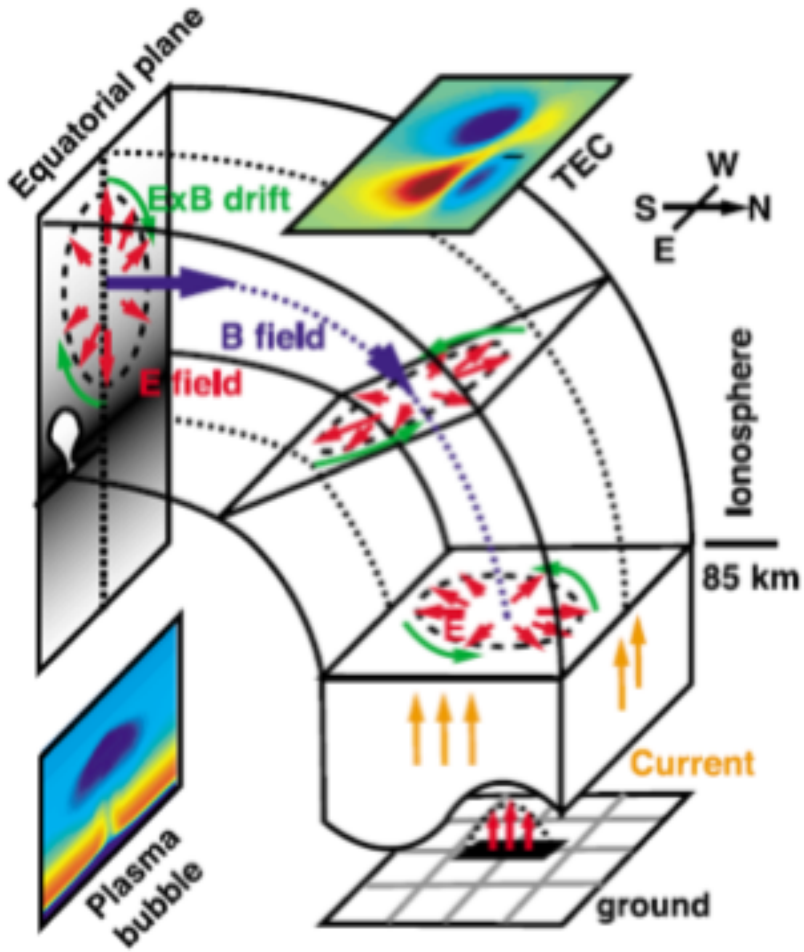


High-altitude electric discharges



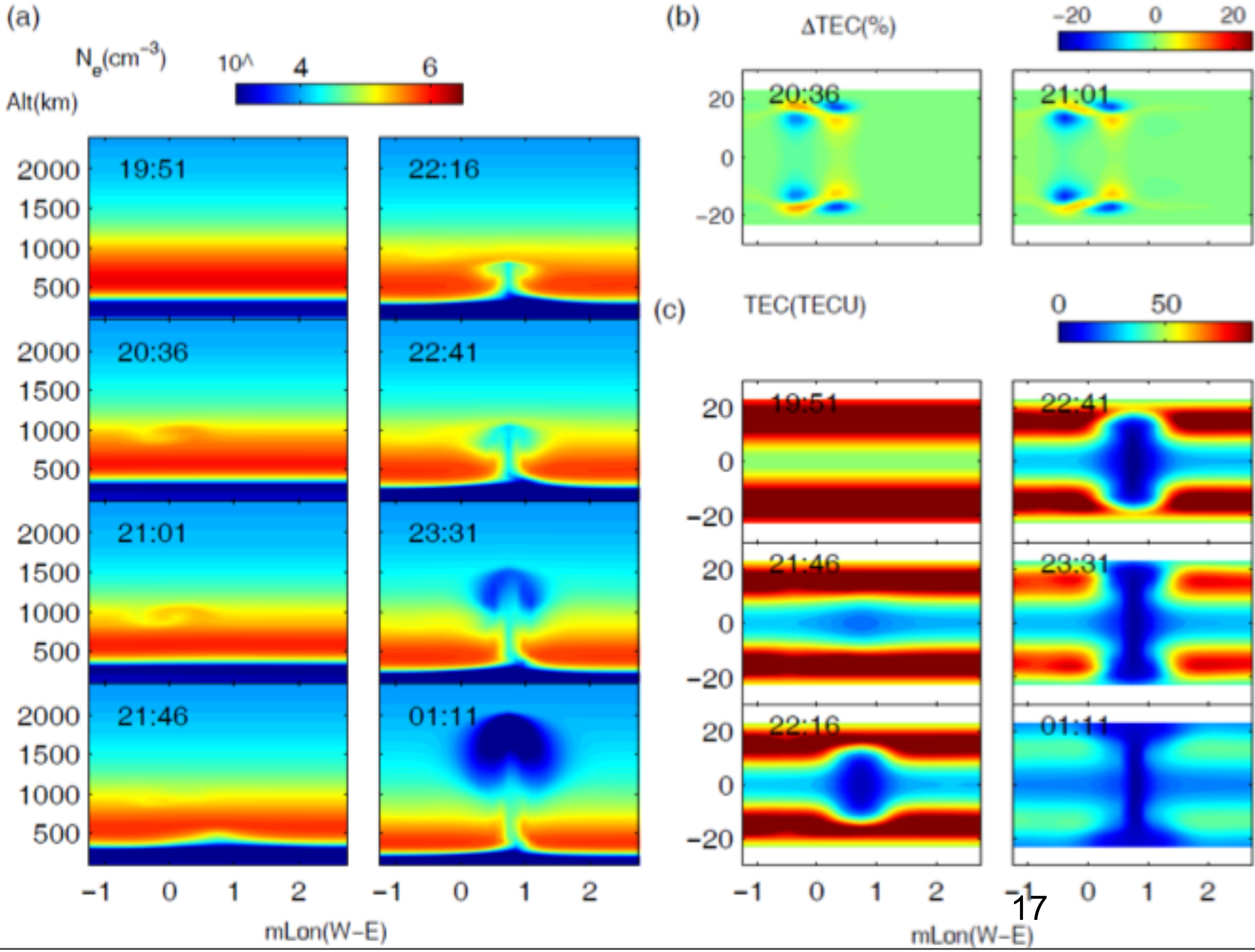
[Lyons et al., BAMS, 84, 445, 2003; Pasko, Nature, 423, 927, 2003]

Electric coupling between the ionosphere and surface charges



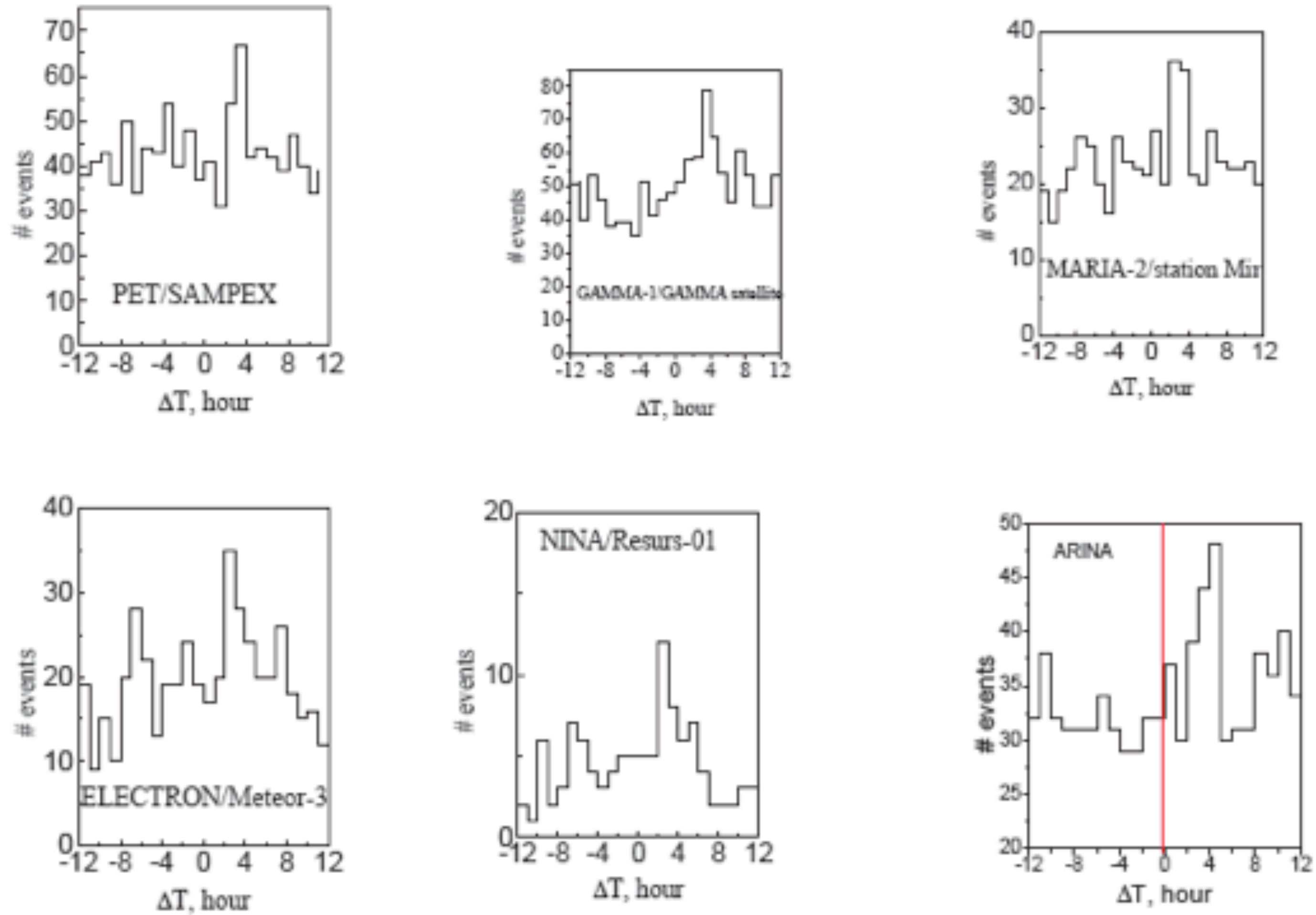
C. L. Kuo, J. D. Huba, G. Joyce, L. C. Lee, J. Geophys. Res., 116, A10317, 2011.

Nighttime case ($J_{rock} = 0.2\mu Am^{-2}$)



Correlations have been reported by different space experiments

INTERKOSMOS-BULGARIA-1300, METEOR-03, MIR, GAMMA, RESOURCE 01, RESOURCE DSK, SAMPEX, NOAA



S.V.Aleksandrin, A.M.Galper, S.V.Koldashov et al. Annales Geophysical, 2003, 21, 597.

ARINA 卫星实验 ARINA satellite experiment

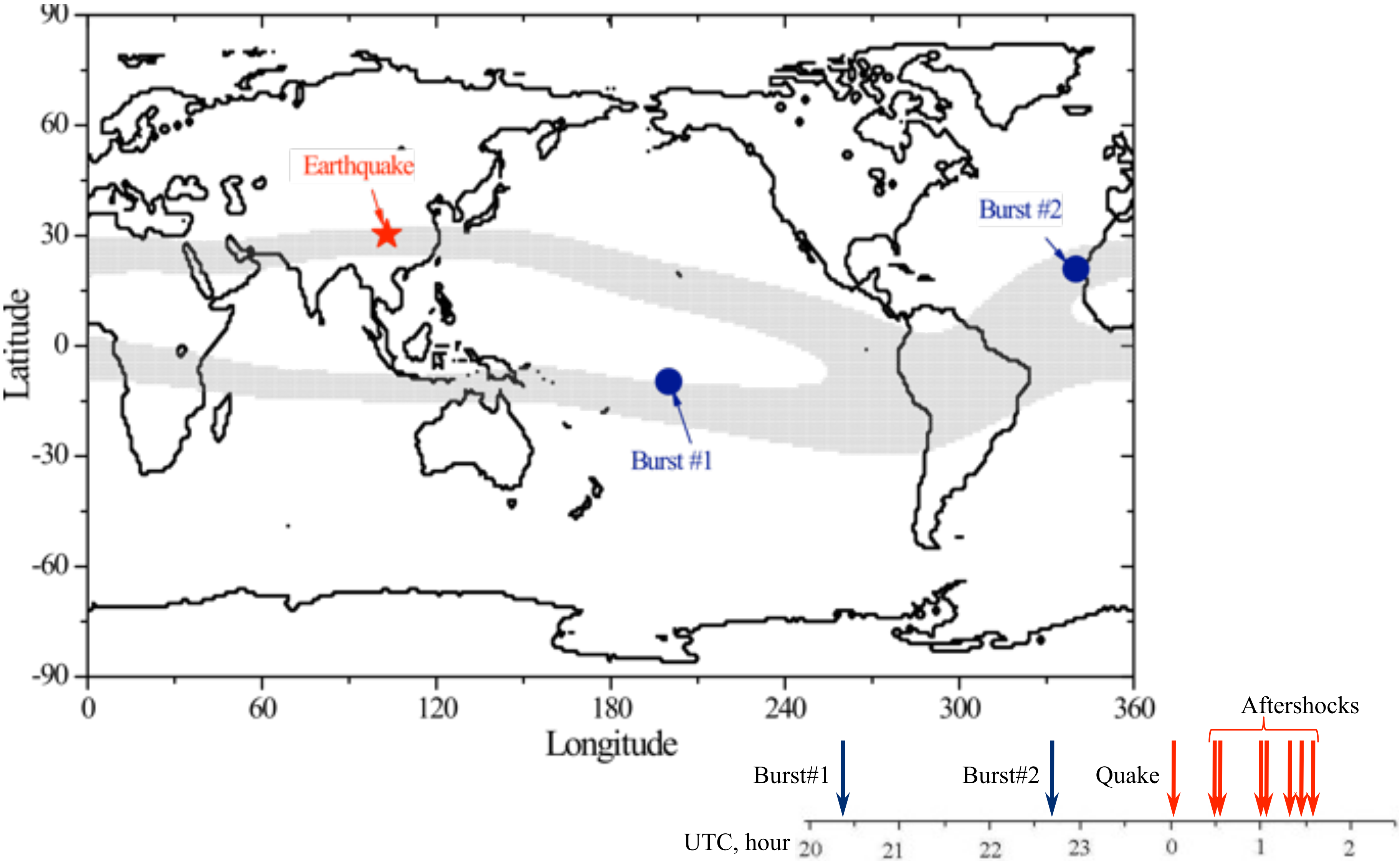
对高能量电子爆发的观测-地震前兆 Observation of high energy electron bursts – earthquakes precursors

中国的芦山地震 The Lushan earthquake in Chine

2013-04-20 0:02:47 Lat=30°; Long=130°; M=6.6 L=1.17

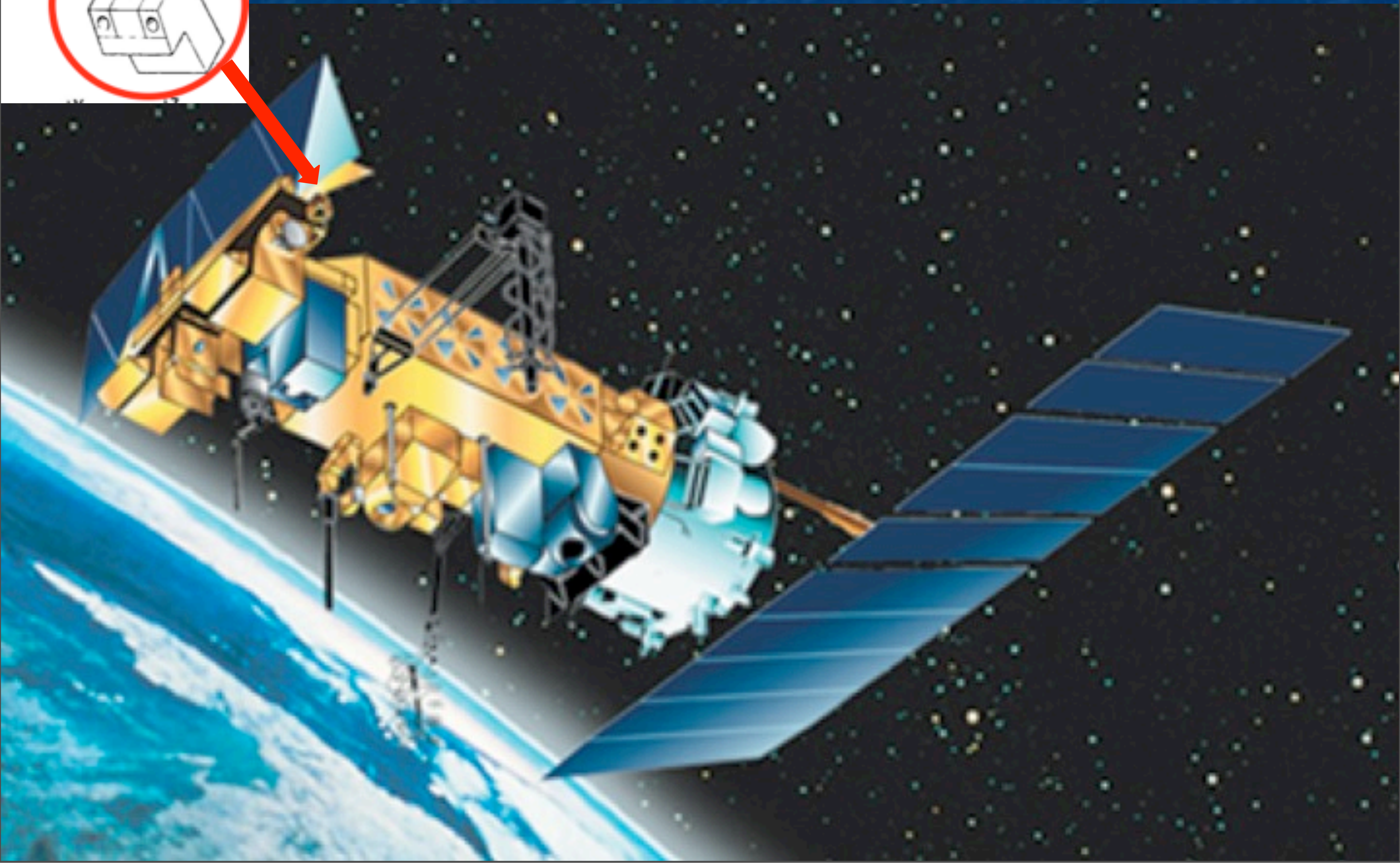
Burst #1 2013-04-19 20:25:02 Lat=-10°; Long=200°; L=1.1 (4.2δ)

Burst #2 2013-04-19 22:45:52 Lat=21°; Long=340°; L=1.16 (3.5δ)

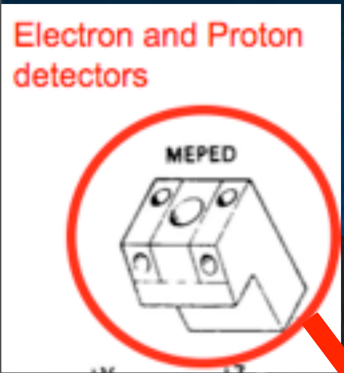


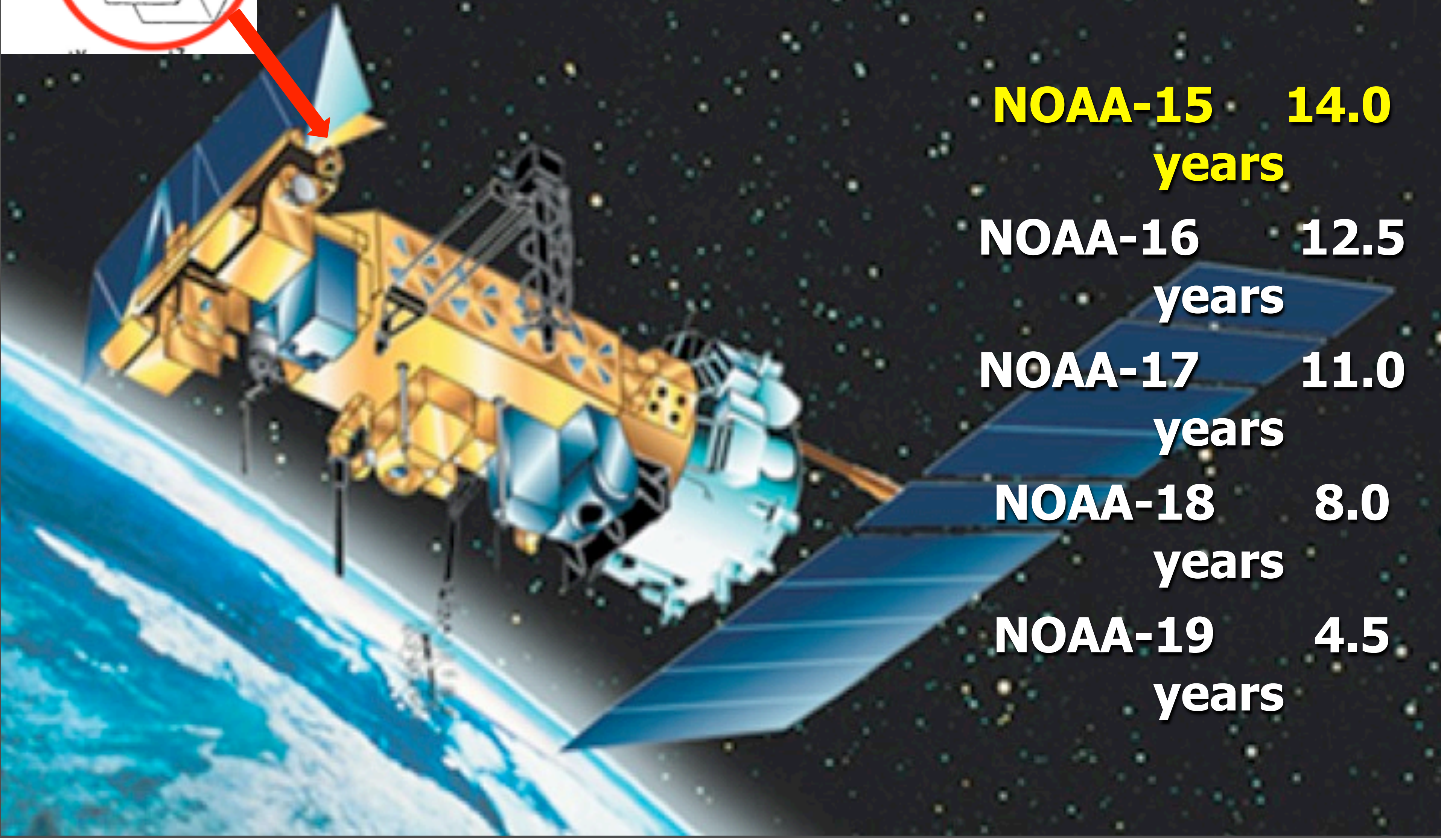
3- NOAA data analysis

NOAA Satellites



NOAA Satellites





NOAA-15 14.0 years

NOAA-16 12.5 years

NOAA-17 11.0 years

NOAA-18 8.0 years

NOAA-19 4.5 years

Particle Bursts

Particle Bursts are significant fluctuation in the counting rate

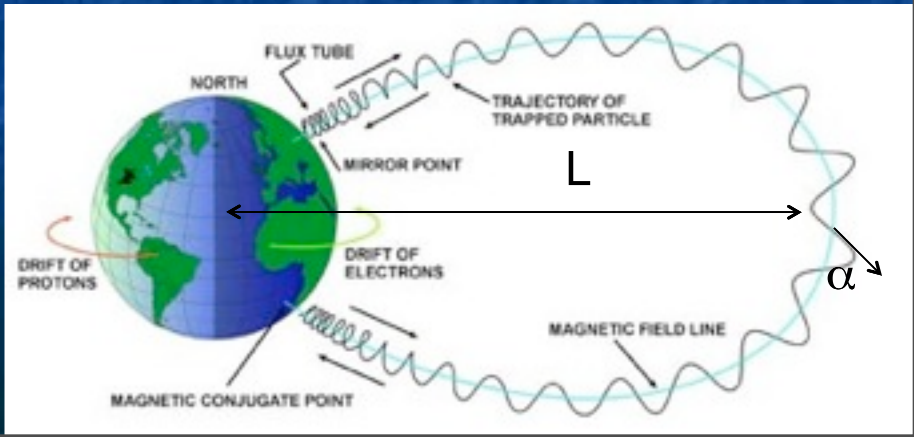
"significant" can be quantified by studying the counting rate statistics (7 σ)

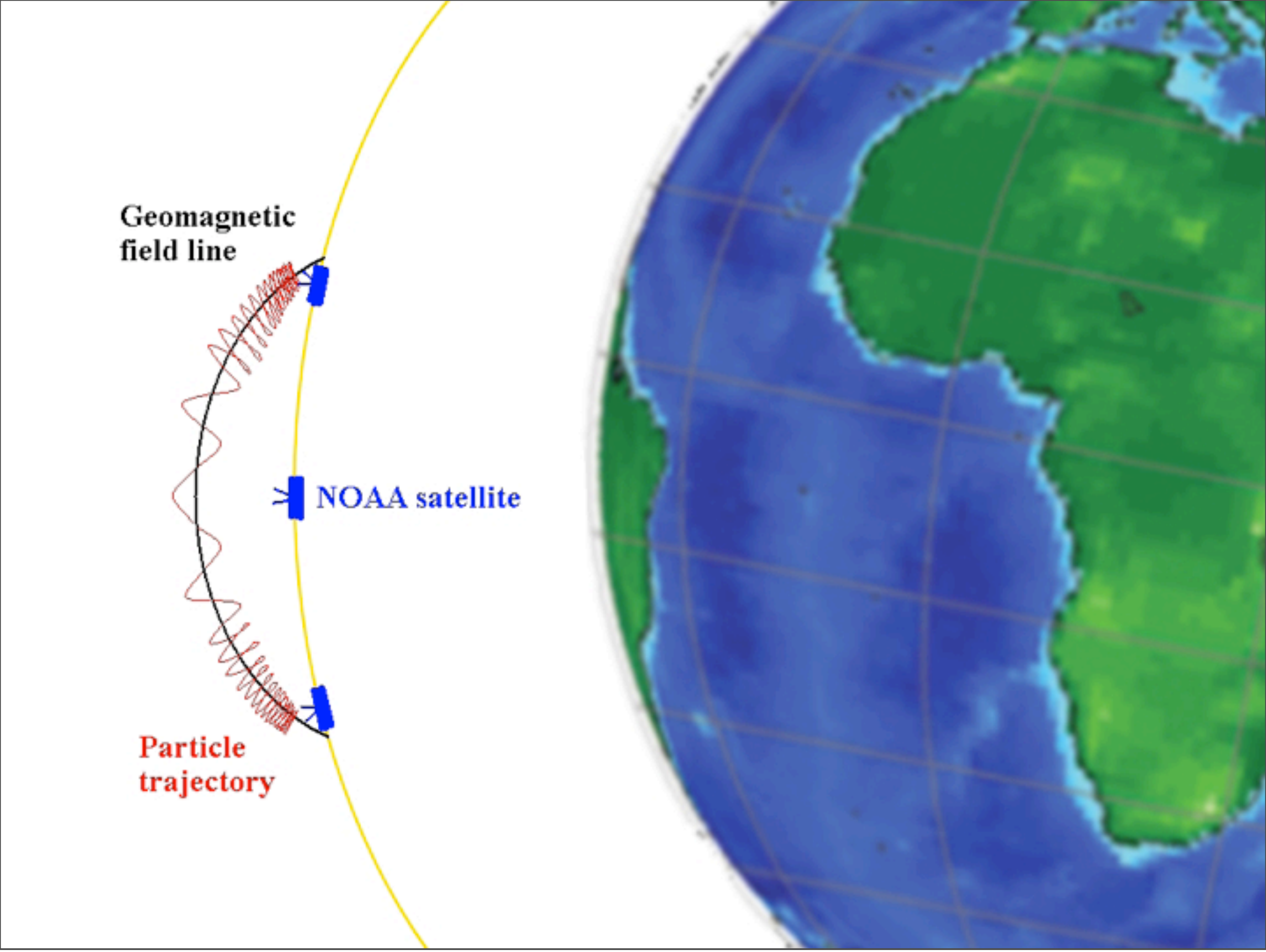
As the particle motion is strongly variable along the satellite orbit we choose to study the counting rate statistics in the invariant space (L,α,B)

L : L-shell

α: Pitch angle

B : Geomagnetic field




Geomagnetic
field line
NOAA satellite
Particle
trajectory

Examples of Particle Bursts

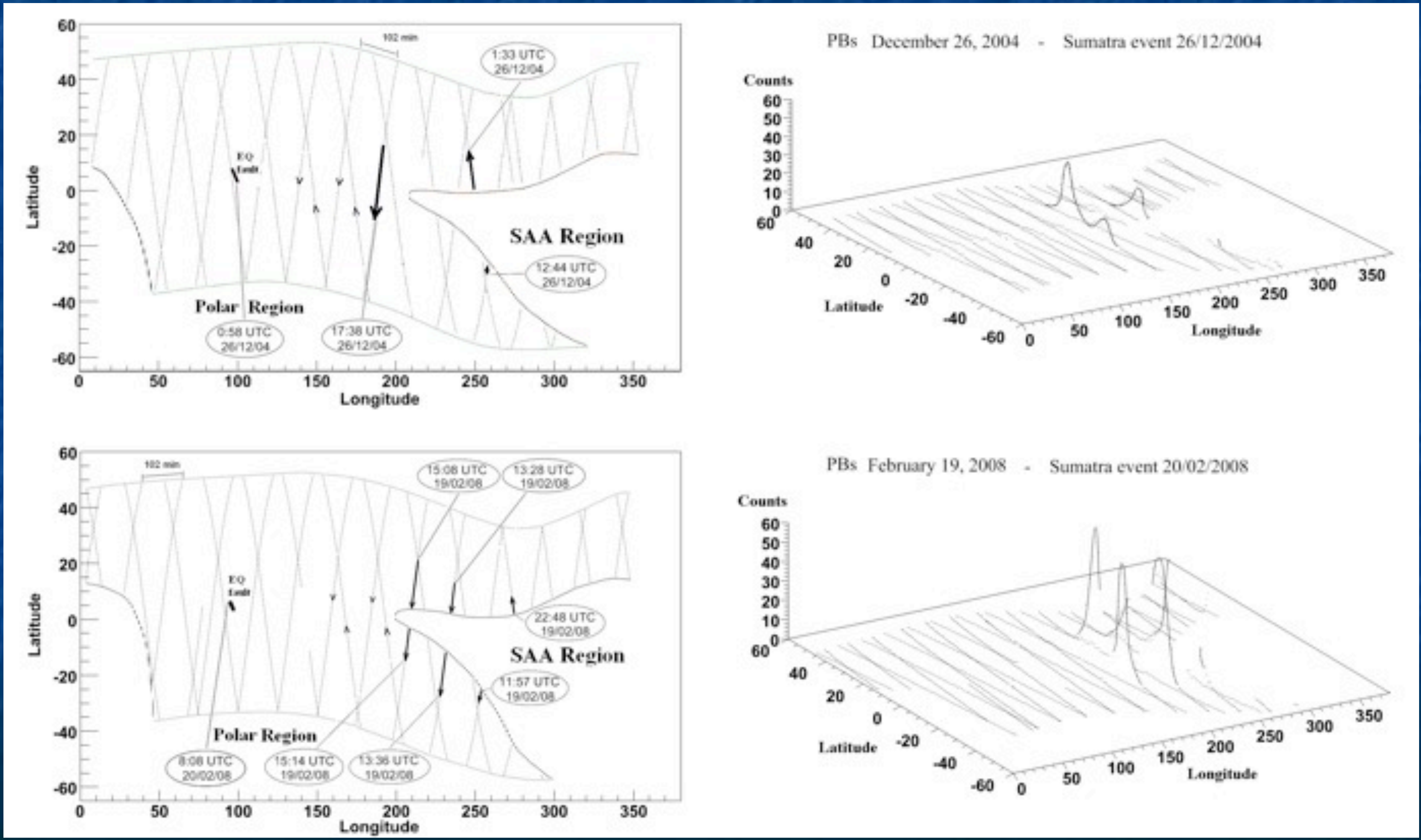
(C. Fidani and R.B., NHESS, 8, 1277-1291,2008)

Definition:

anomalous short-term and sharp increases in high energy particle counting rates

Examples of Particle Bursts

(C. Fidani and R.B., NHESS, 8, 1277-1291,2008)



5,4 σ correlation observed using NOAA data

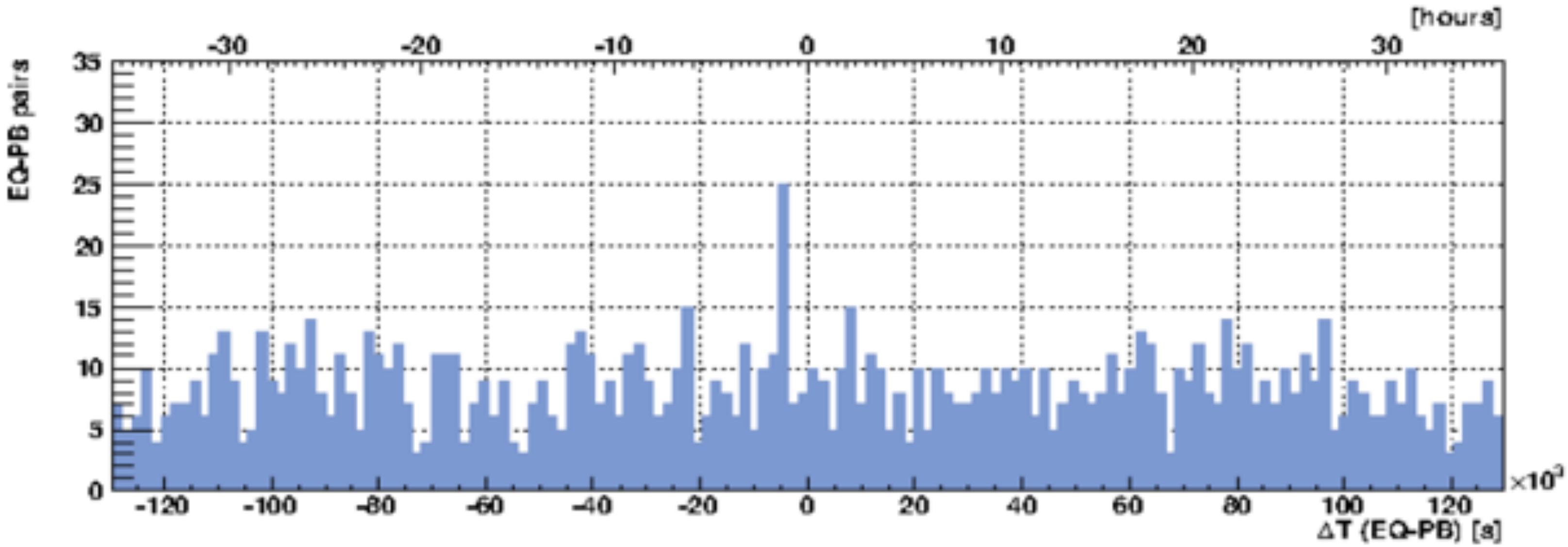
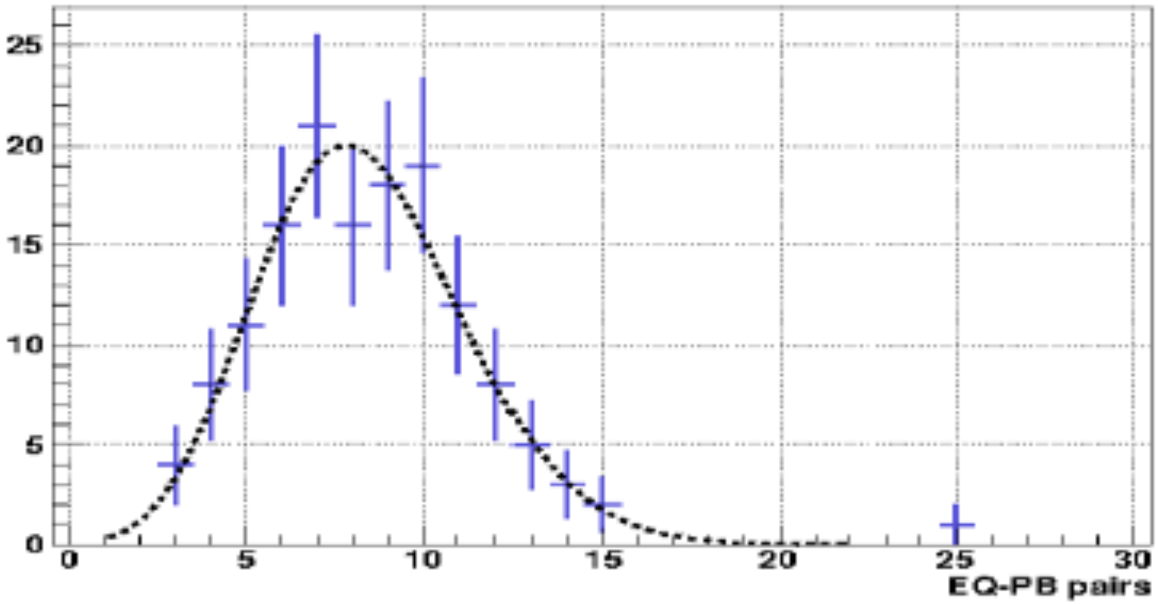


Figure 3: The Time Difference Distribution. Here the time delays between the seismic events and the selected particle bursts are ploted. EQ-PB pairs are taken within a time window of ±1.5 days. This distribution is uniform within the statistical errors but with an excess at -1.25±0.25 hours.



R. Battiston, V. Vitale,
NPB **243**, p. 249-257 (2013)

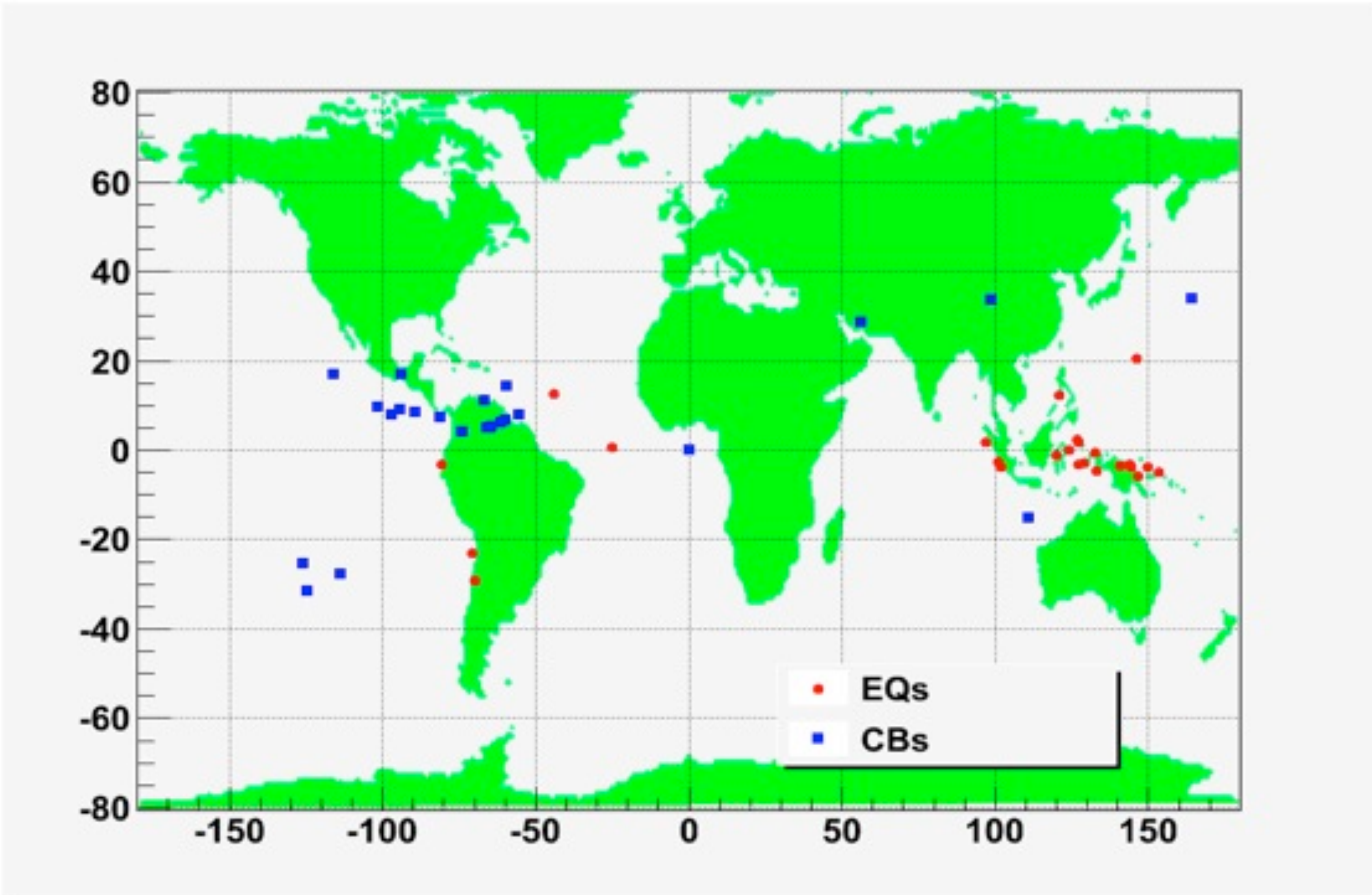
SINGLE SATELLITES RESULTS

Satellite	C	μ	$(C-\mu)/\sqrt{\mu}$
15	7	3.25±0.19	2.08
16	7	2.00±0.16	3.53
17	7	2.21±0.13	3.23
18	4	0.98±0.12	3.05

Table 5: Contributions of each satellite to the found excess. Here are reported identification number of the satellite in use, the number of counts in -1.25 hours bin (C), the mean value of in the Δt distribution (μ) and significance of the counts in the -1.25 hours bin $(S-M)/\sqrt{\mu}$.

- All the data samples (satellites) contribute to the excess

GEOGRAPHIC LOCATIONS



Geographic locations of Eqs and CBs in the 1.25 hours correlation bin

Result for NOAA analysis

We established a 1,25 hours correlation between electron Particle Bursts and Earthquakes.
For the low energies covered by the NOAA detectors (E ~ 300 keV), a 5,4 sigma correlation is observed, concentrated on a small region near the South Atlantic Anomaly.

The correlation appears when integrating 14 years of NOAA 15, 16, 17 and 18 data, and involve 25 Earthquakes with M>5.

Space Earthquake Perturbation Simulation (SEPS)

Filippo Ambroglini - INFN
Roberto Battiston - University of Trento & TIFPA
William J. Burger - University of Perugia & INFN
Vincenzo Vitale - INFN
Yu Zhang - China Earthquake Administration & INFN

EGU General Assembly 2014
Wien 27/04 – 02/05

SEPS

- We want to apply the High Energy Particle physics methodology and instrumentation to study earthquake precursor behavior.
- We perform perform a particle by particle analysis.
- Develop a simulation code that can help to understand the interaction mechanism among the Earthquake and trapped electron.
- We want to have a better understanding of the results obtained in the past with time correlation analysis between earthquake and particle burst.

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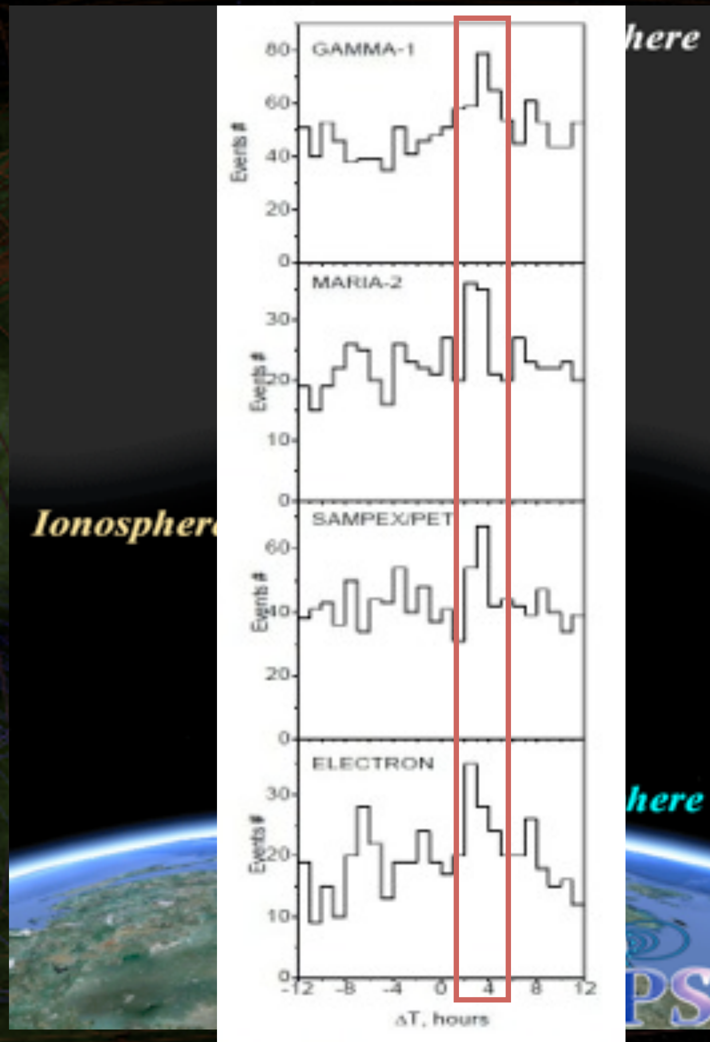
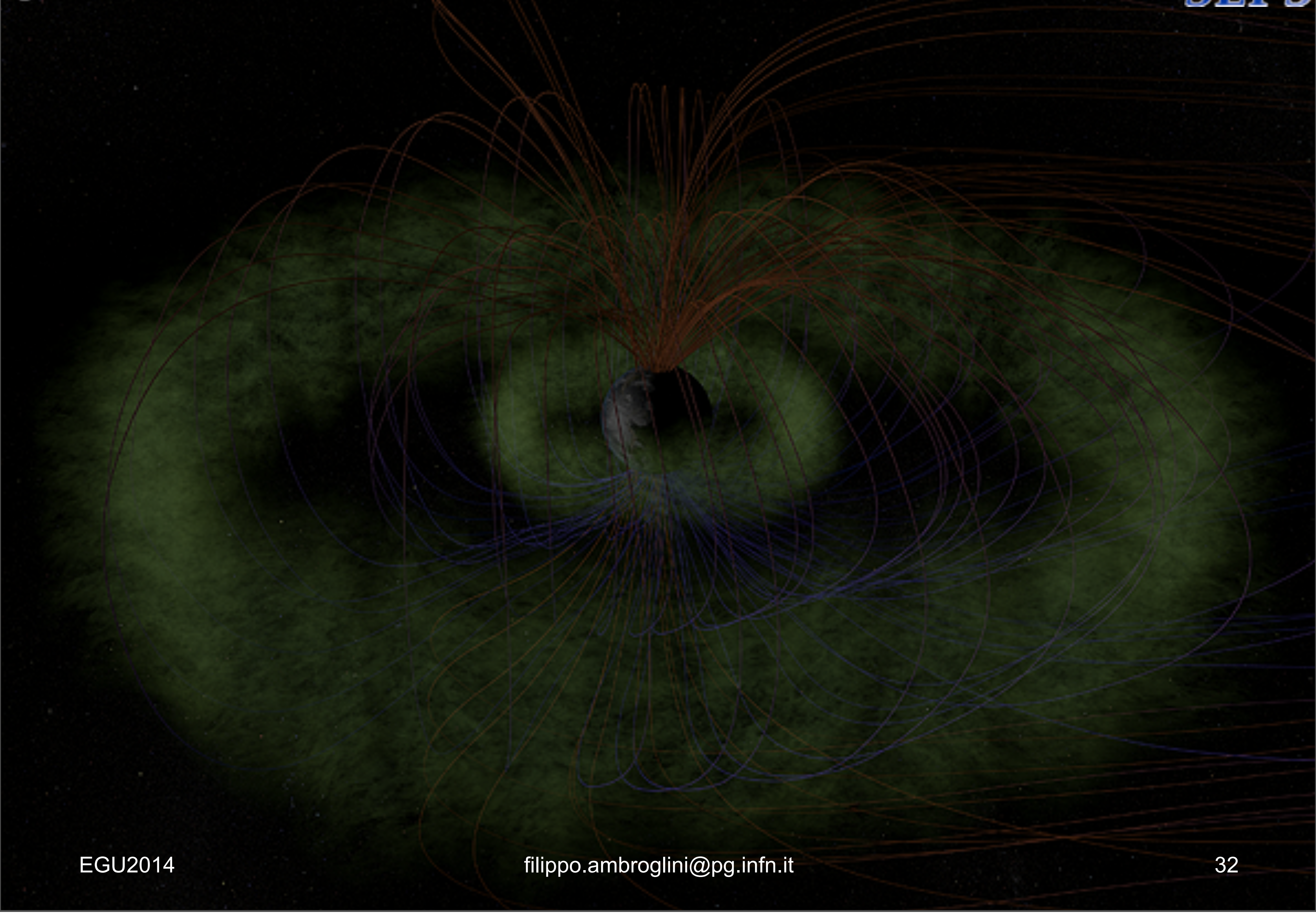
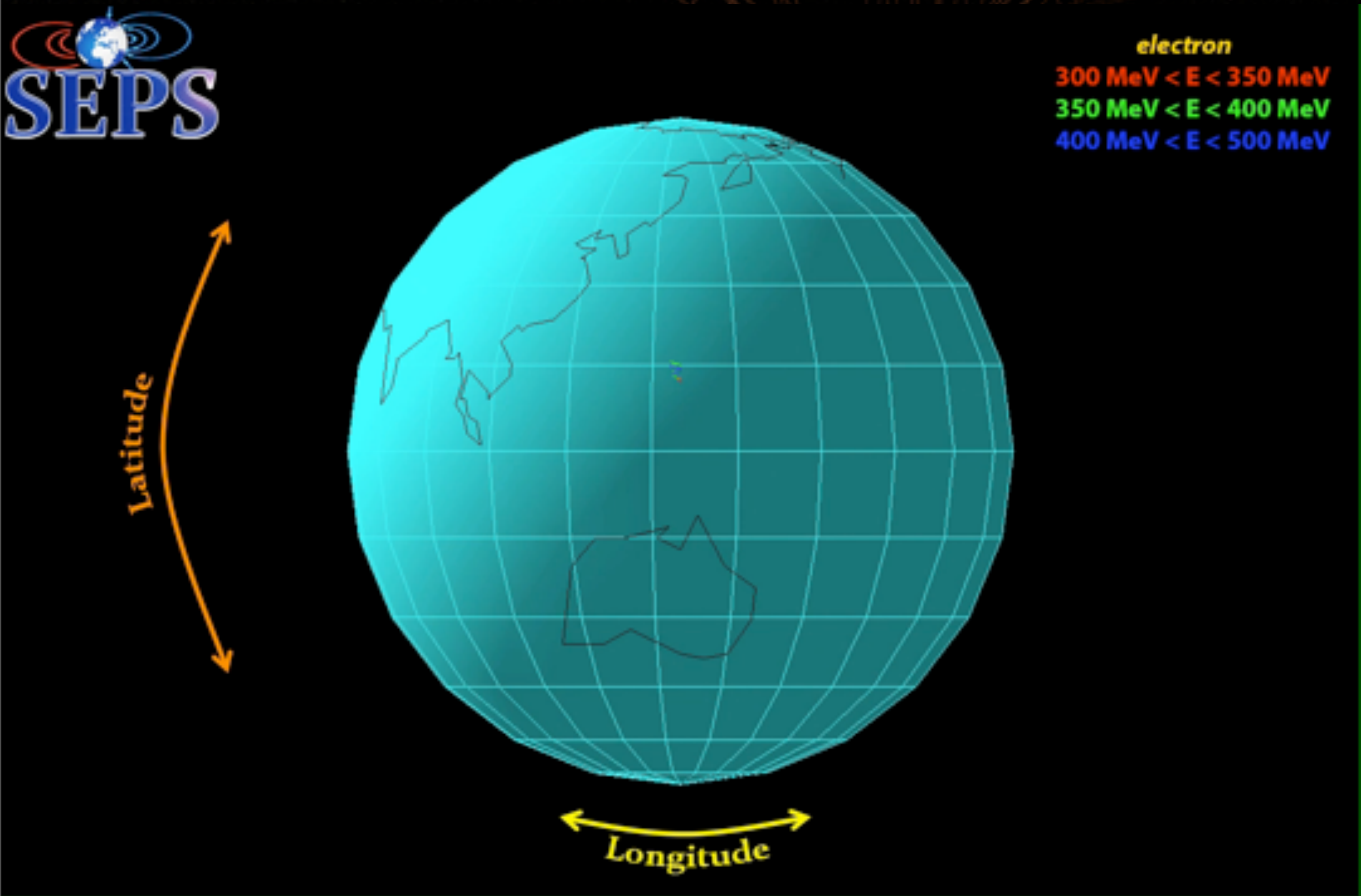


Fig. 2. ΔT distribution histograms for particle bursts and earthquakes obtained in GAMMA-1, MARIA-2, PET and ELECTRON experiments ($M > 4$, $|\Delta L| < 0.1$).

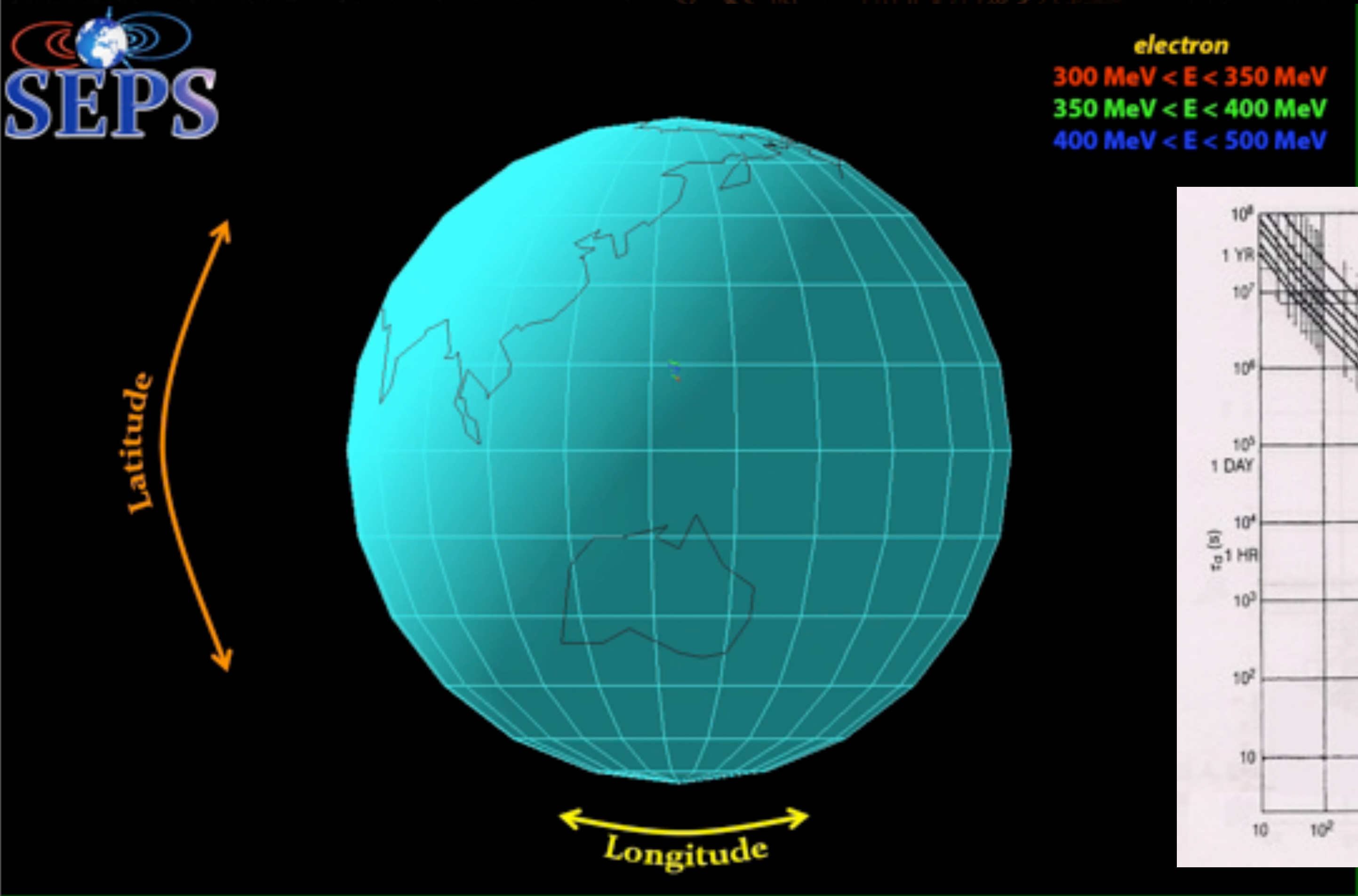
SEPS: Results

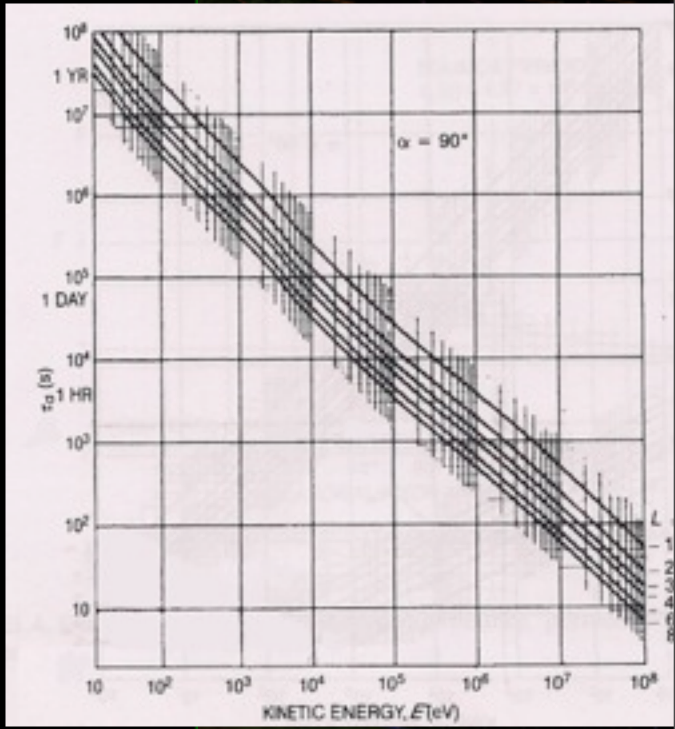


SEPS: Results

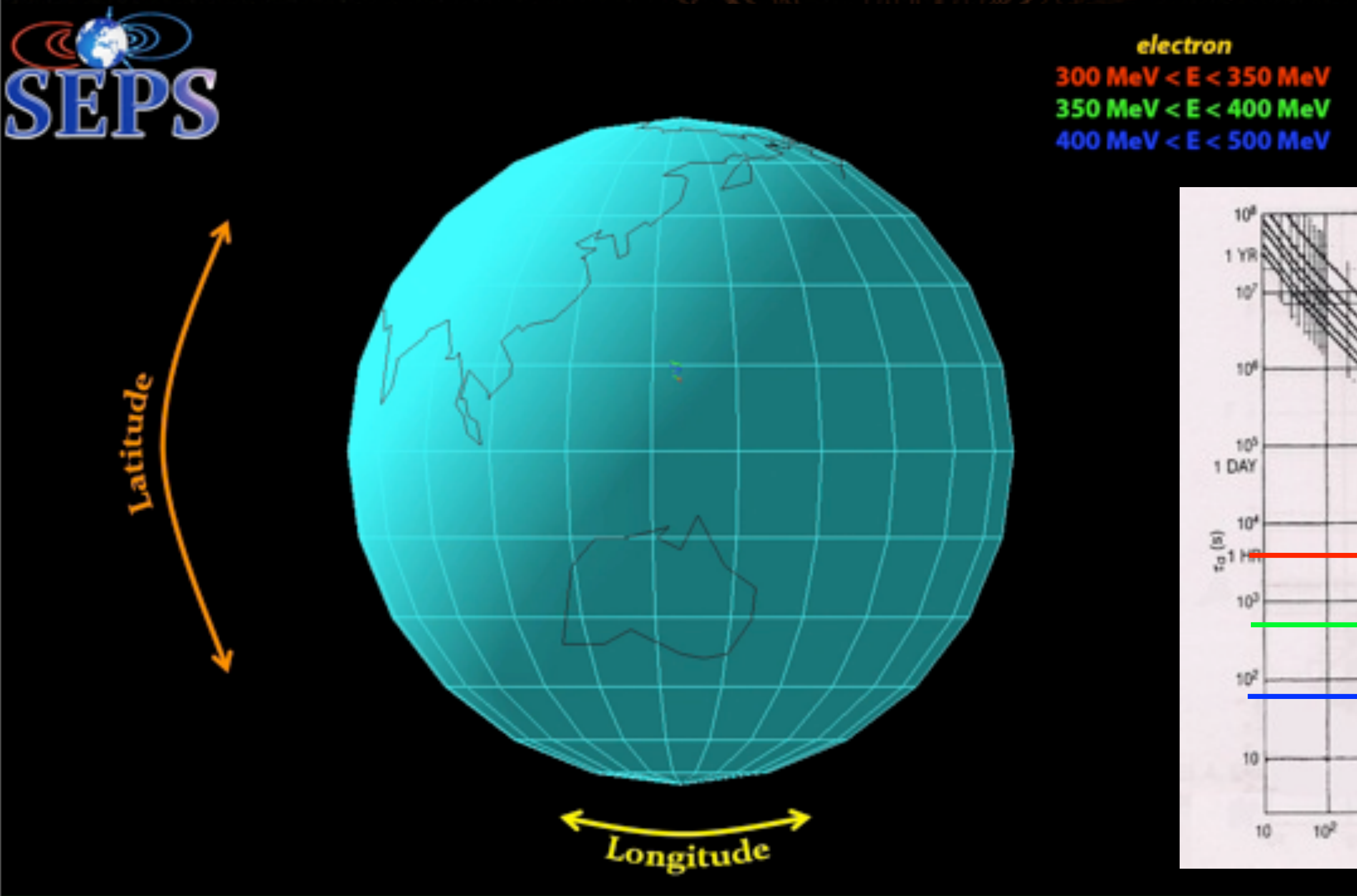


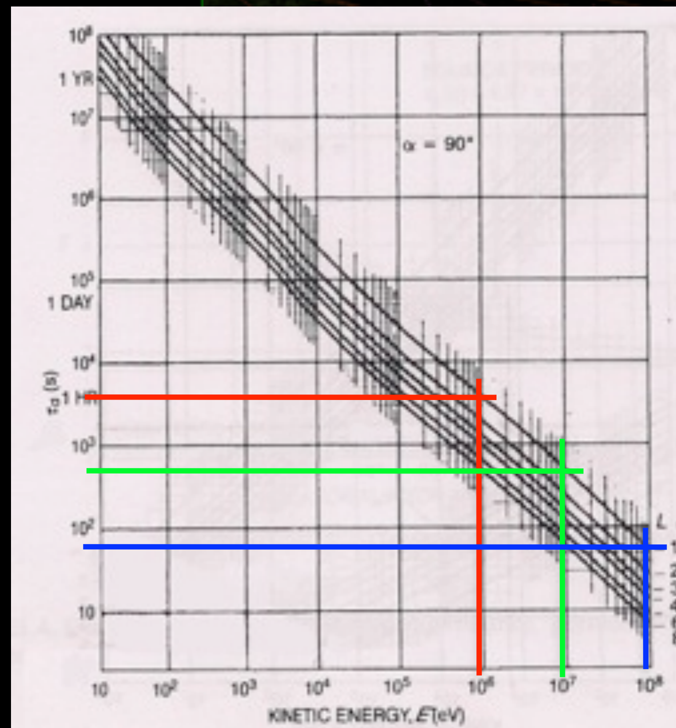
SEPS: Results



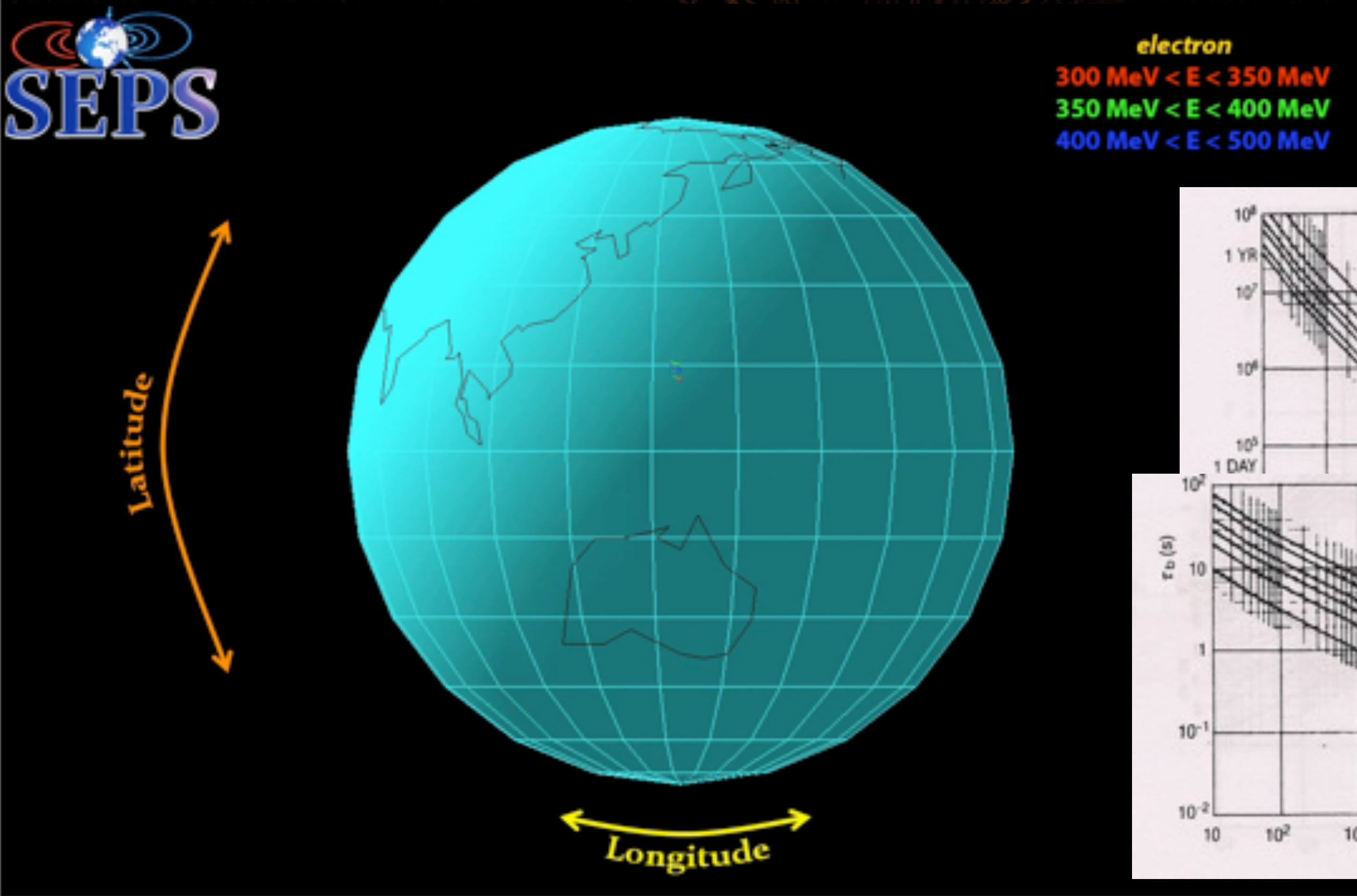


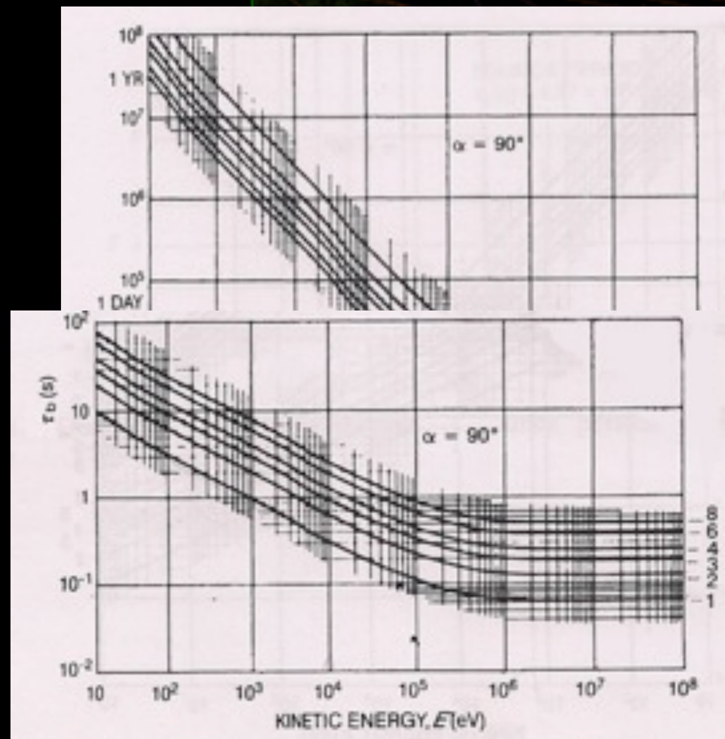
SEPS: Results



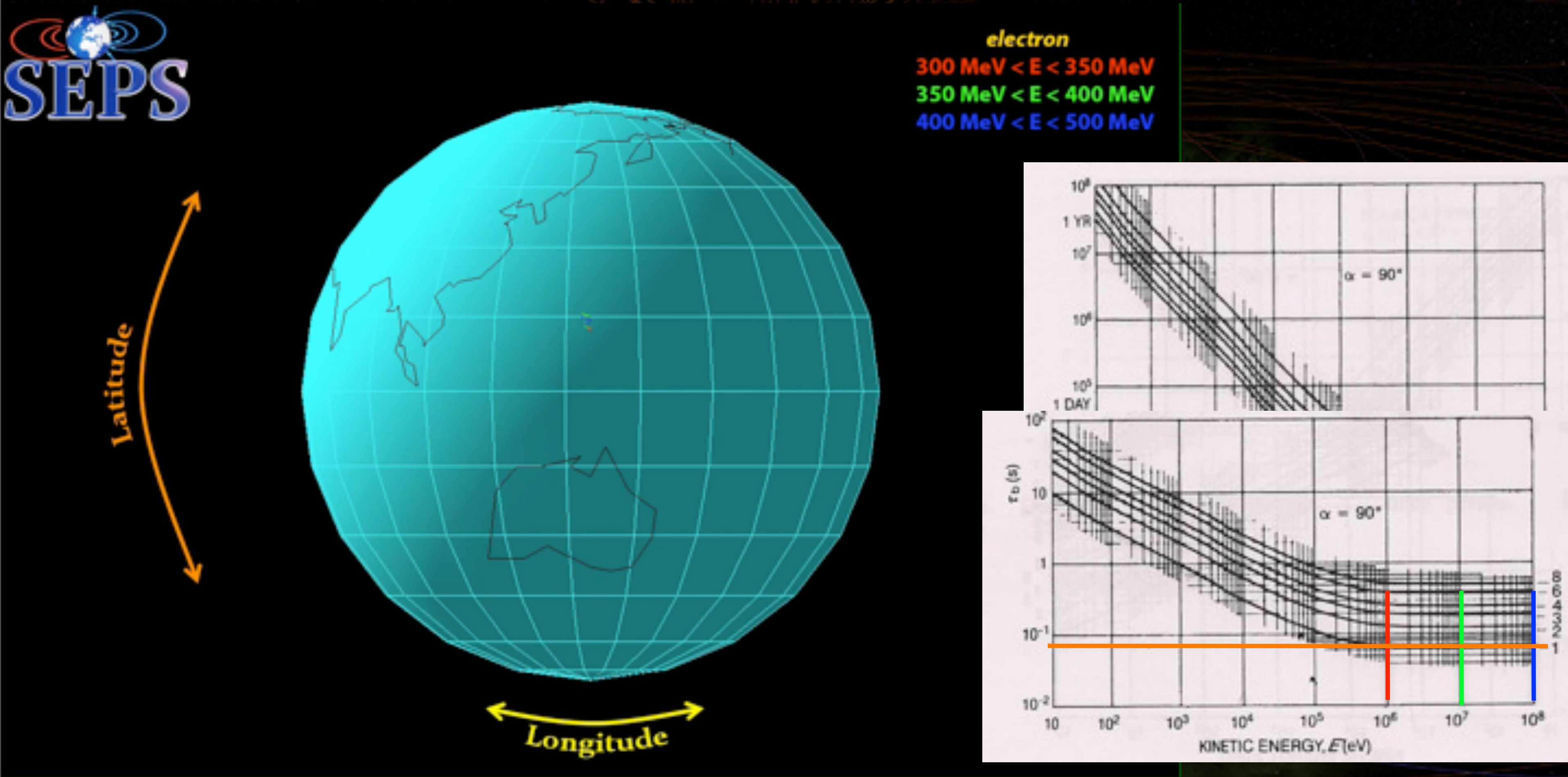


SEPS: Results





SEPS: Results



SEPS used to verify one of the SAMPEX

ELSEVIER

Journal of Atmospheric and Solar-Terrestrial Physics 67 (2005) 1448–1462

Journal of ATMOSPHERIC AND SOLAR-TERRESTRIAL PHYSICS

www.elsevier.com/locate/jastp

Correlations between earthquakes and anomalous particle bursts from SAMPEX/PET satellite observations

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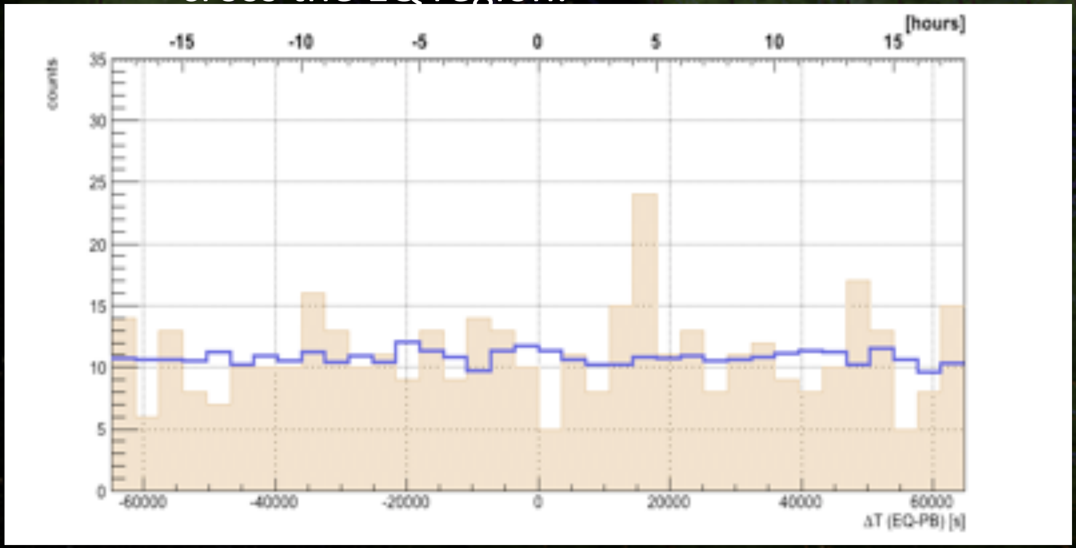
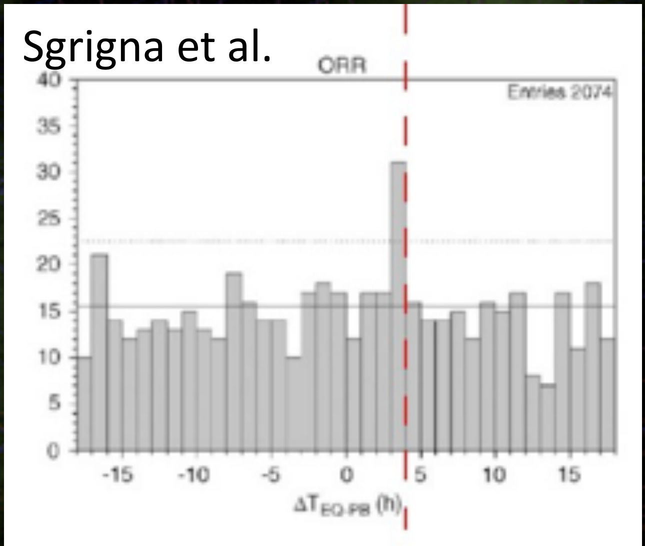
Available online 19 September 2005

SEPS: Analysis strategy

- The analysis has been redone based on the data available now and we have obtained a result that is compatible that give as the possibility of accessing on detail the EQ-PB pair list.
  - Forward Tracking analysis: starting propagating forward the electron from the EQ position looking for kinematics that make possible the detection of PB.
  - Backward Tracking analysis: starting propagating the electron backward (positron forward propagation) from the detection point looking if they can cross the EQ region.



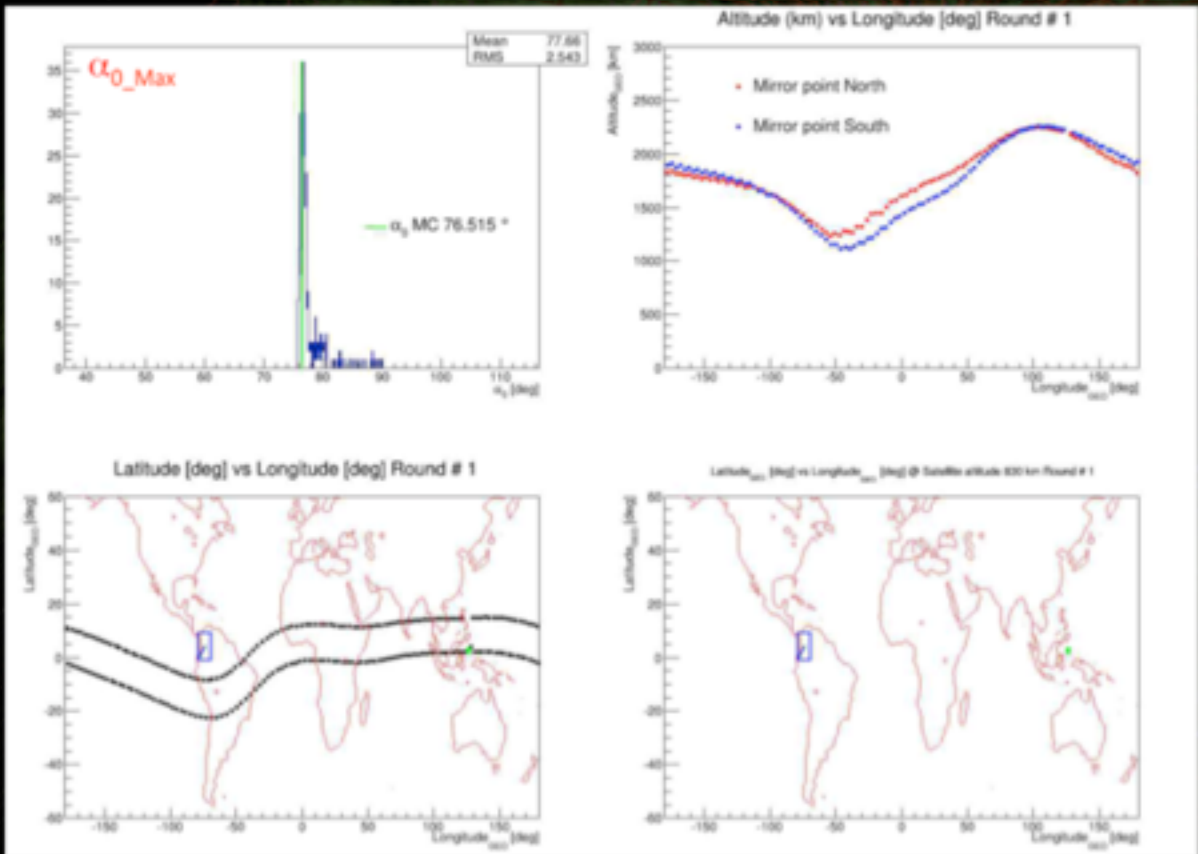


Forward Tracking: Results

α_{0_Max} = 77.66° α_{0_SatMax} = 59.21° α_{0_DBMin} = 52.55° α_{0_SatMin} = 44.29° α_0

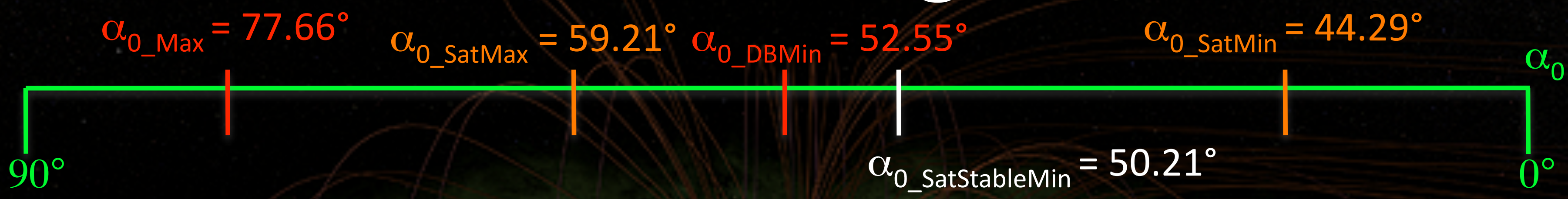
90° 0°

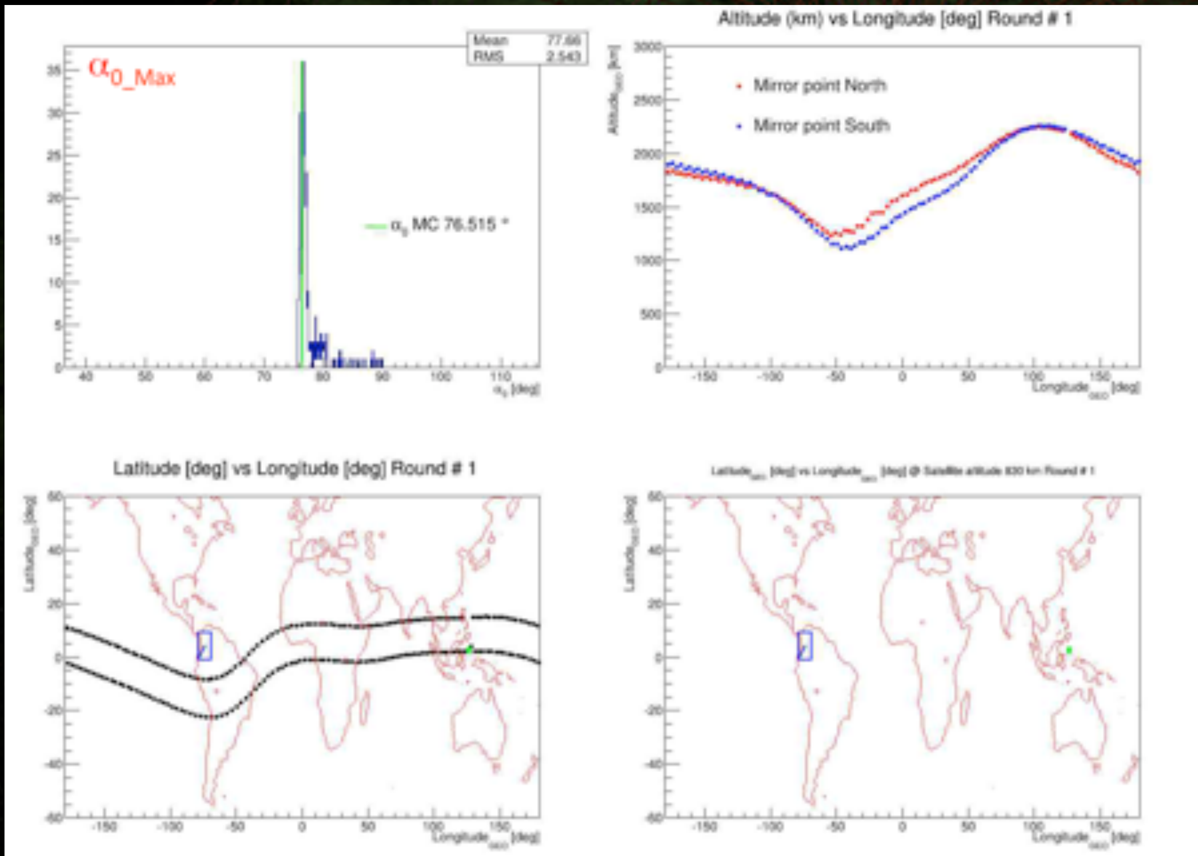
$\alpha_{0\_SatStableMin}$ = 50.21°



The electron flux is visible @ the satellite altitude for some configuration also without perturbation.

Forward Tracking: Results



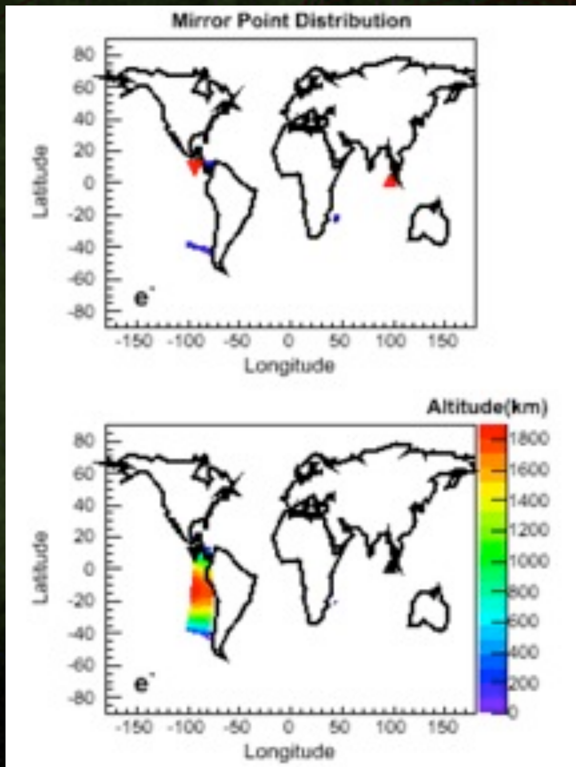


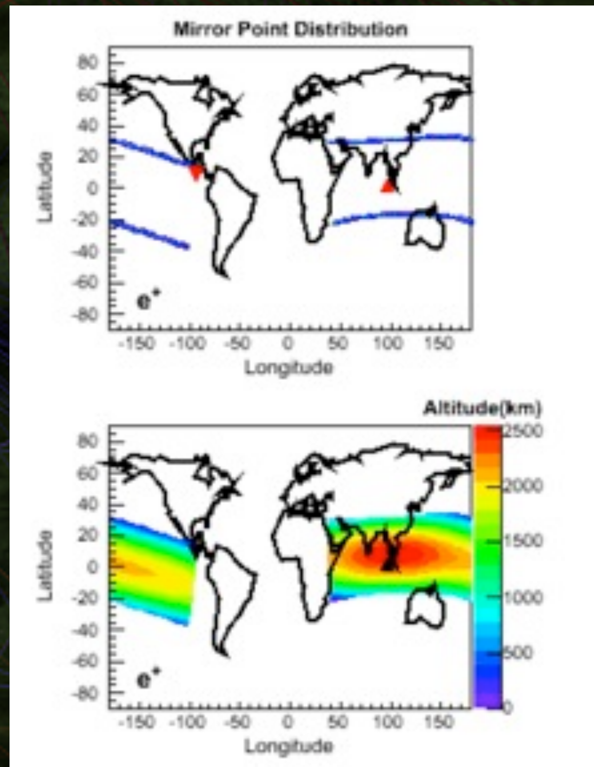
The electron flux is visible @ the satellite altitude for some configuration also without perturbation.

Backward Tracking

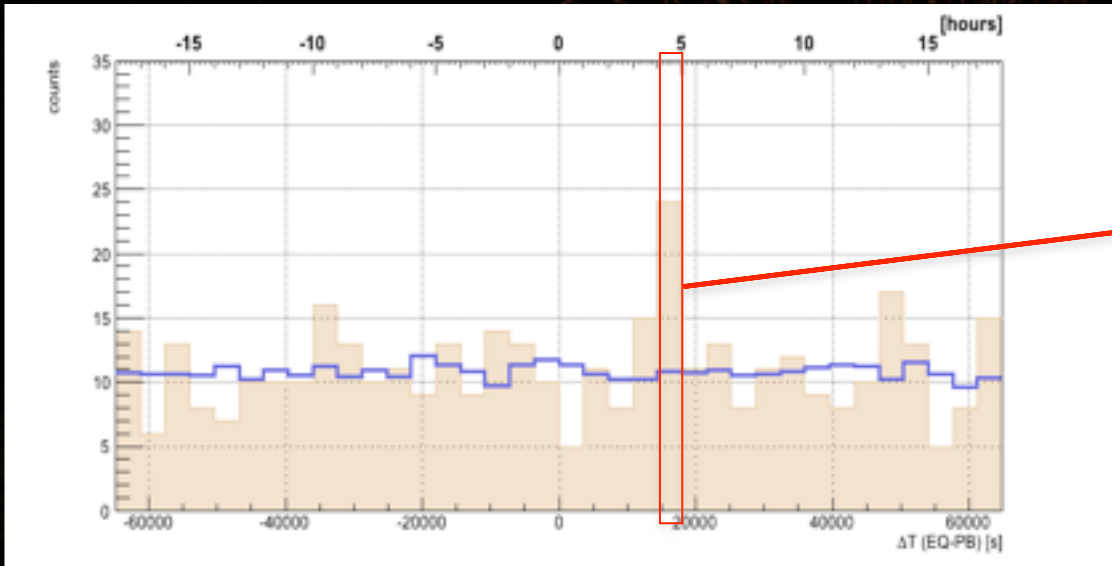
Positron back traced from the observation point (▼) is compatible with the earthquake location (▲).

Neither the positron nor the electron make a complete revolution around the Earth.





SAMPEX Analysis conclusion



This bin contains 24 pairs with an estimated background of 11 pairs then suppose to have 13 good pairs.

	Earthquake Site			Drift	Observation Point		
N.	Alt. (km)	Pitch Angle	L	Bmax (μT)	Alt. (km)	Pitch Angle	L
5	1104	117°	1.17	29.1	600	104°	1.17
6	1511	56°	1.17	27.5	600	88°	1.17
7	2030	46°	1.32	32.3	600	102°	1.32
8	1774	130°	1.33	32.7	600	104°	1.34
10	2125	134°	1.31	27.4	600	81°	1.23
14	9462	13°	2.46	39.4	600	75°	2.56
17	4132	151°	1.61	32.5	600	76°	1.61
18	7539	18°	2.20	34.0	600	88°	2.20
21	3419	32°	1.59	23.7	600	108°	1.61
23	4590	147°	1.78	24.5	600	111°	1.77
24	1570	55°	1.26	29.7	600	88°	1.26

With both Forward and Backward analysis we have found the same results. We have been able to flag as good pairs 11, compatible with the estimated background.

NOAA-POES Analysis verification


Available online at www.sciencedirect.com

ScienceDirect

NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS

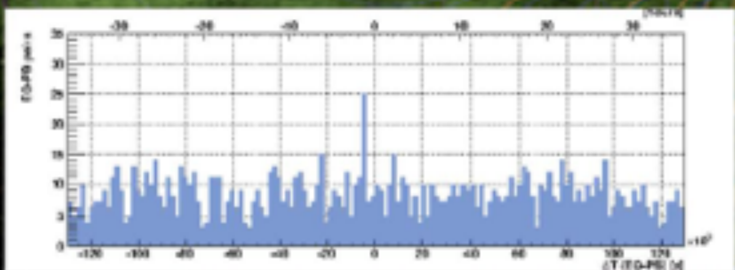
ELSEVIER

First evidence for correlations between electron fluxes measured by NOAA-POES satellites and large seismic events.

Abstract

We present the result for the search of correlations between the precipitation of low energy electrons (E > 0.3 MeV) trapped within the Van Allen Belts and earthquakes with magnitude above 5 Richter scale. We used the electron data measured by the NOAA POES 15,16,17 and 18 satellites collected during a period of 13 years, corresponding to about 18 thousands M>5 earthquakes registered in the NEIC catalog of the U.S. Geological Survey. We defined Particle Burst (PB) the fluctuations of electrons counting rate having a probability < 1% to be a background fluctuation. Within a time window of ± 36 hours, we observe a clear correlation peak at -1.25 ± 0.25 hours. This result is obtained using data driven algorithms independent from specific modelling of the lithosphere-ionosphere coupling and adding the data collected by each POES satellite. The significance of the observed correlation peak is 5.7 s.d. corresponding to a probability of 1.2 10^-8 of being a statistical fluctuation. The observed correlation involves about 1.4 10^-3 of the earthquakes in that period of time. It provides the first statistically convincing evidence for the existence of a detectable coupling mechanism between the lithosphere and the magnetosphere having well defined time characteristics.

Keywords:
Van Allen Belt, particle burst, earthquake



- The same study done in order to verify the SAMPEX results has been done for this analysis.
- Also in this case both approach find a number of good events compatible with the estimated background

5- The Limadou-CSES project

Trento, Tor Vergata, UniNettuno, Bologna, Perugia

An optimized Particle Spectrometer for Earthquake precursors

Viewing angle : zenith

Energy range: <50 MeV (e) , <300 MeV (p)

Single particle detection → backtrackng for E.Q. localization

Pitch angle resolution : < 10 degree;

Acceptance, Energy resolution: the best possible

地震定位发展计划

Earthquake localization scheme

proposed in 2004 by R.Battiston to China Earthquake Administration

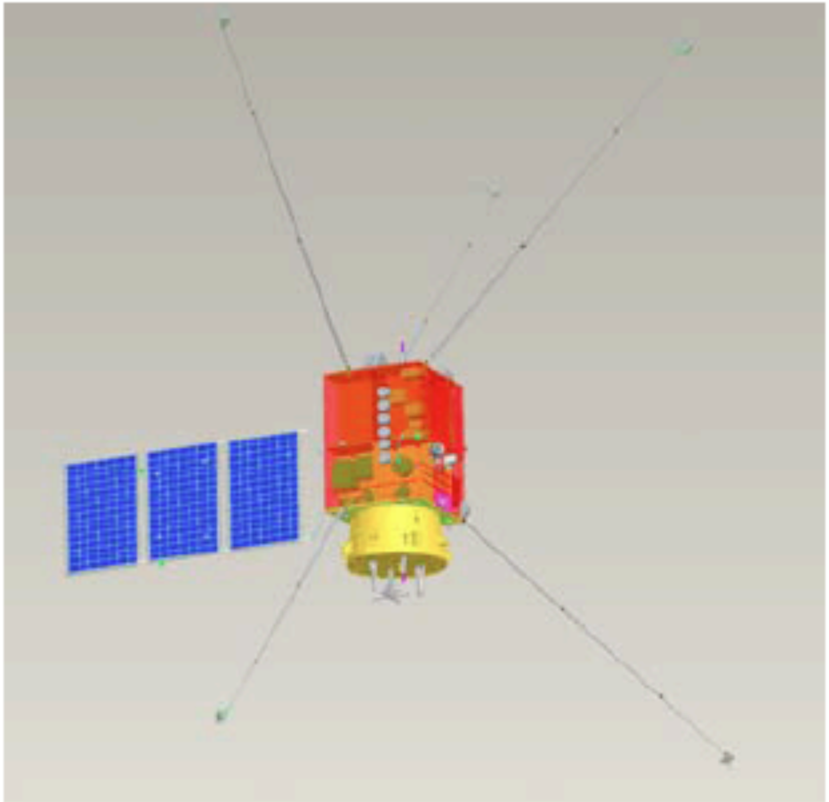
纬度：由对沉淀颗粒爆发的观测位置给地面的投影所提供。

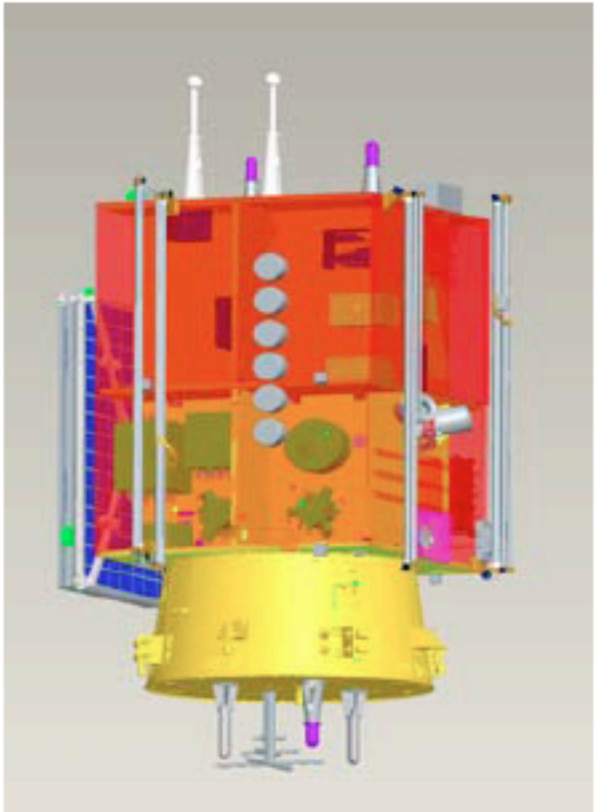
LATITUDE : is provided by the projection to ground of the observed location of the precipitating particle burst

经度：由对沉淀颗粒爆发的观察时间的能源依赖性所提供。

LONGITUDE : is provided by the energy dependence of the time of observation of the precipitating particle burst

CSES : China Seismo Electromagnetic Satellite





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Matteo Ricci

Preliminary Design Review (PDR) passed with DFH January 23, 2014

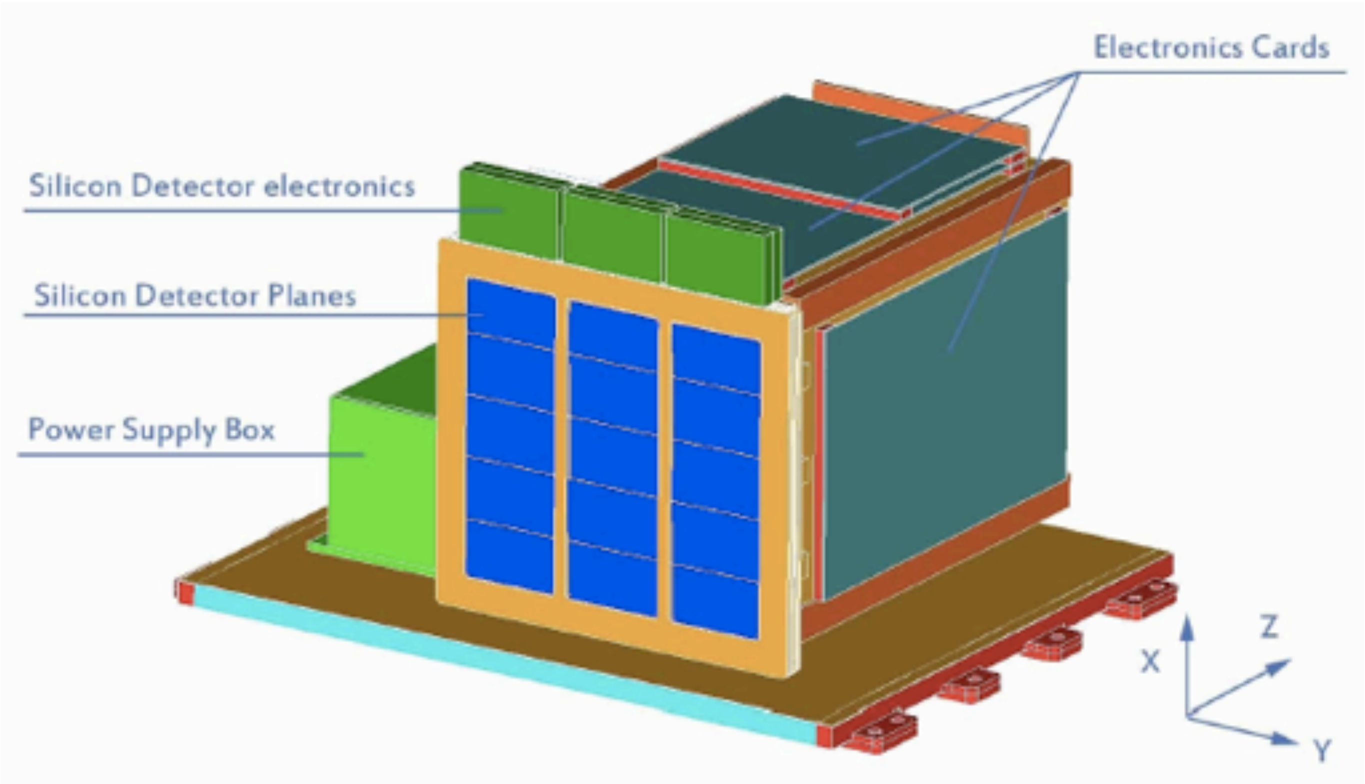

Fig. 4: View of the HEPD electric box and detector.

6) Conclusions

In order to localize the position of

Thanks for your attention