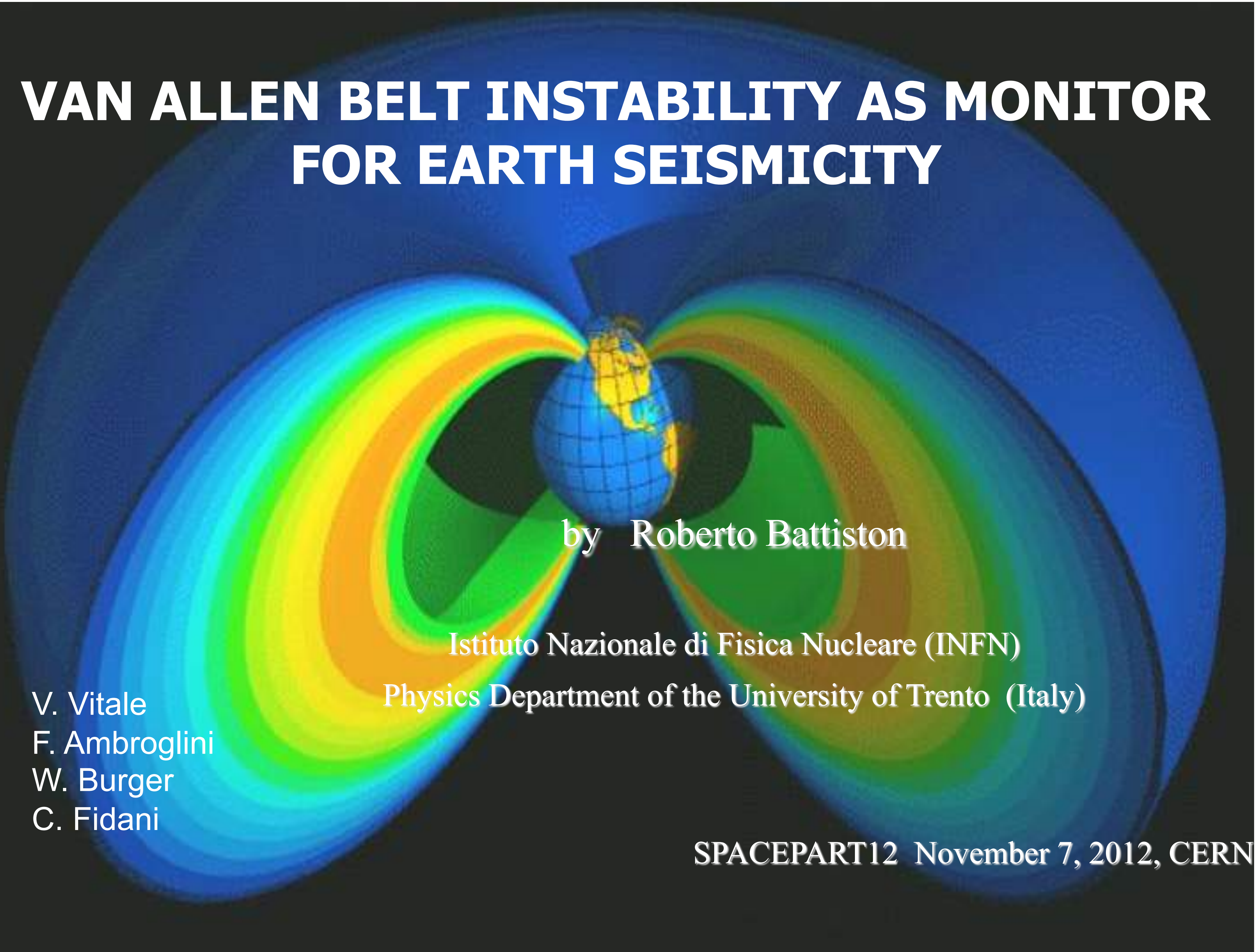
# VAN ALLEN BELT INSTABILITY AS MONITOR FOR EARTH SEISMICITY




by Roberto Battiston

Istituto Nazionale di Fisica Nucleare (INFN)

Physics Department of the University of Trento (Italy)

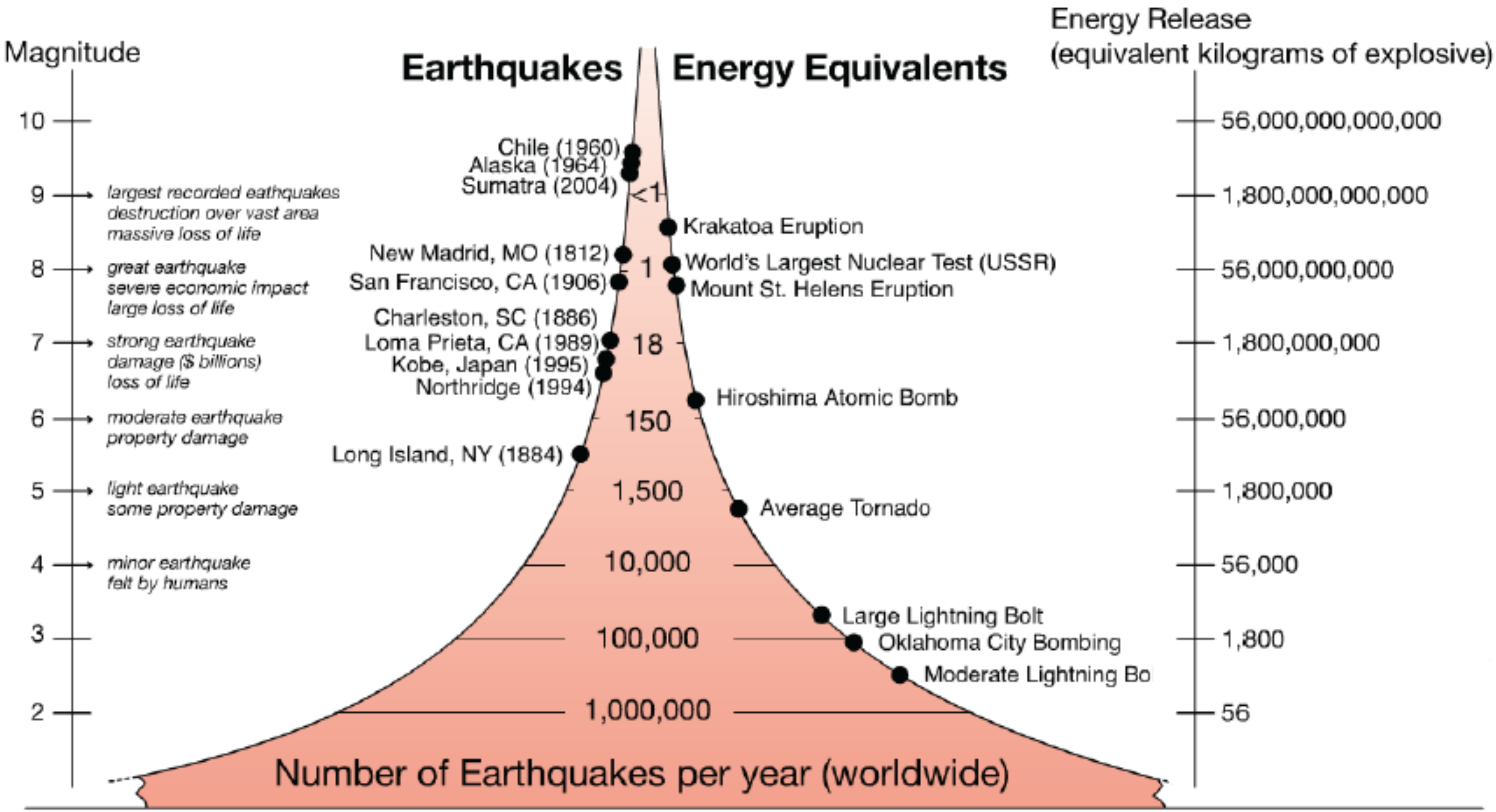
V. Vitale
F. Ambroglini
W. Burger
C. Fidani

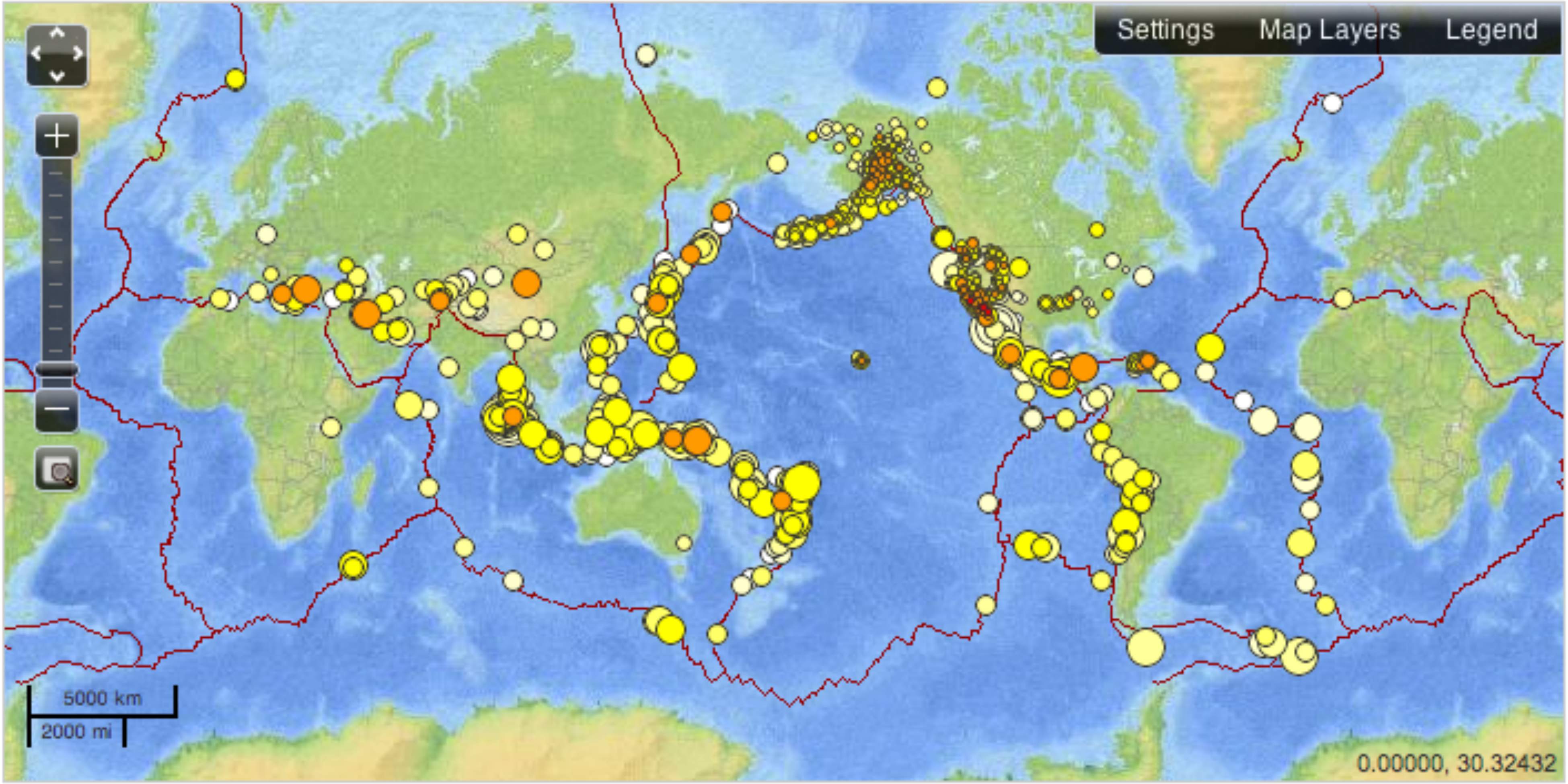

SPACEPART12 November 7, 2012, CERN

# Introduction

Earthquakes are a very complex phenomenon, with a long preparation phase and involving measurable changes of physical parameters over huge surfaces together with large energy releases.

# Energy Scale of Earthquakes






# The Distribution Map of Seismic Belts

On each day there are about two Earthquakes with Magnitude  M> 5

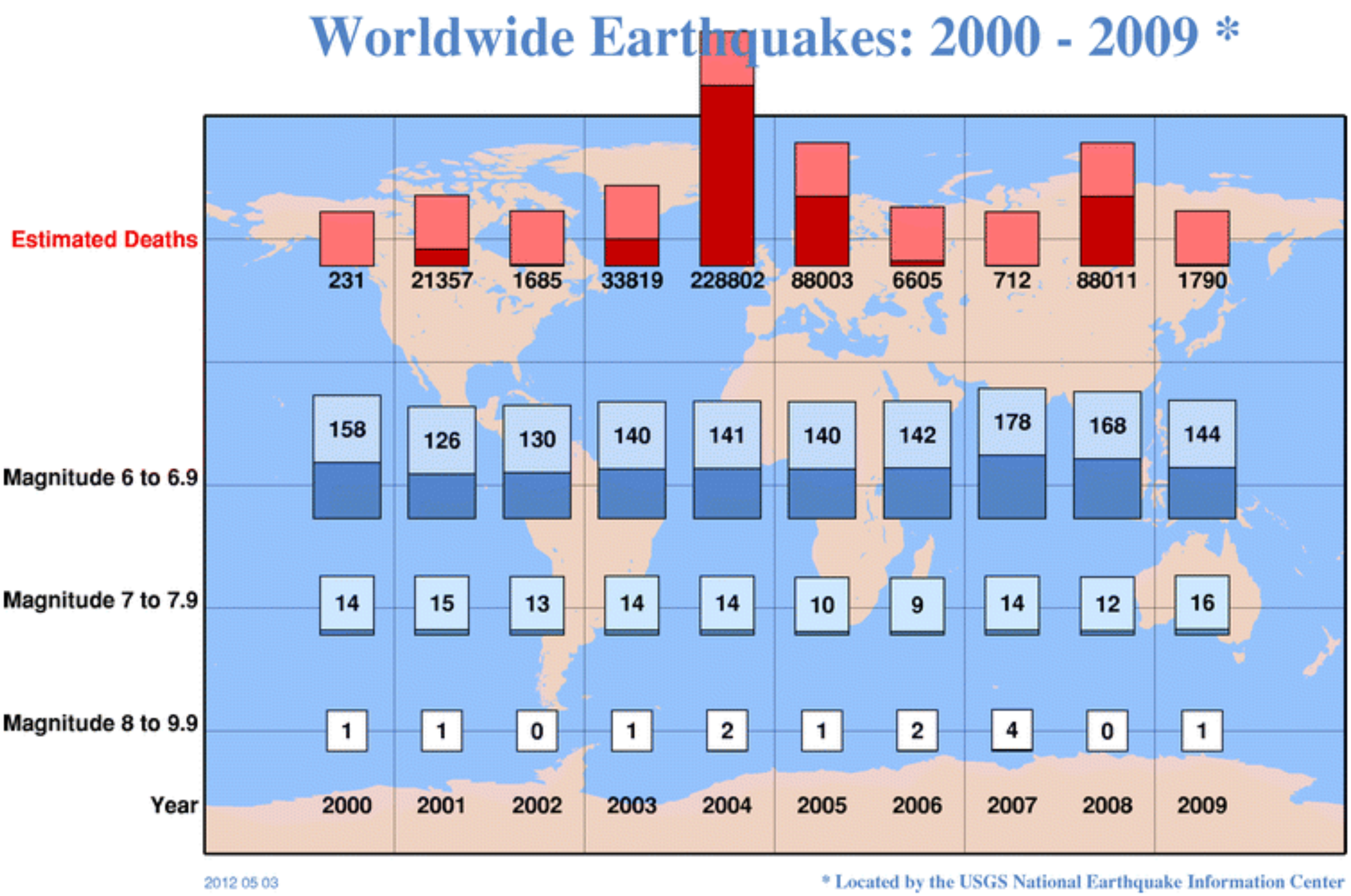
Every two day there is a M>6  Earthquake

However due to the their very low rate, ground based, short term Earthquakes forecast efforts have been so far unsuccessful

Loss of lives is likely the most damaging consequence of a large Earthquakes

but

Earthquakes do not kill, crumbling buildings do !




On each day there are about two Earthquakes with Magnitude  M> 5

Every two day there is a M>6  Earthquake

# Space is a privileged point of observation

Worldwide on each day there are
2 Earthquakes with M >5
every two days there is
1 Earthquake with M > 6

Large observational statistics can be accumulated and studied

# 2) Earthquake-Particle Precipitation Correlations

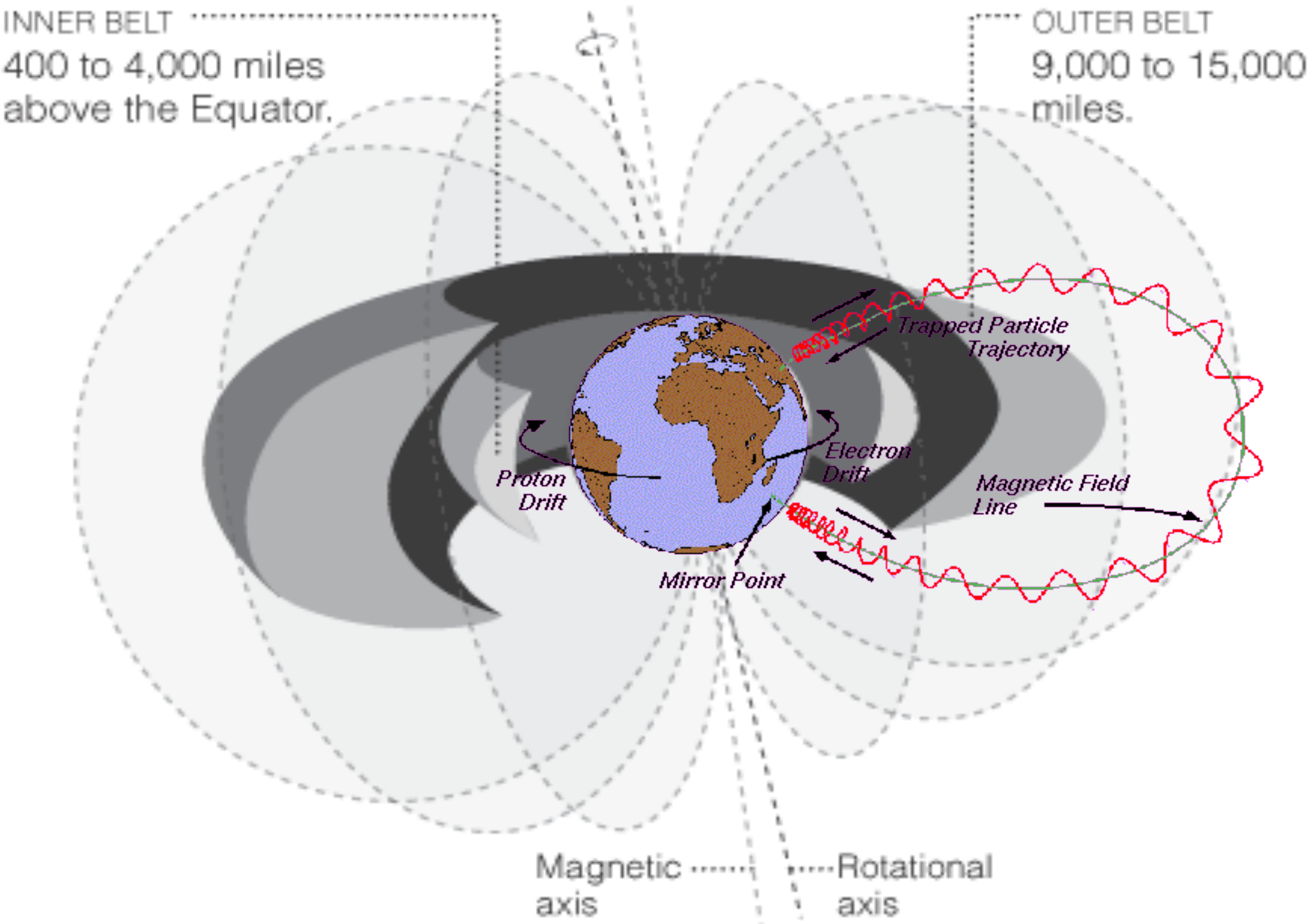
## a) NOAA data analysis

R. B. , V. Vitale 2012

# Analysis of Earthquake-Particle Precipitation Correlations using NOAA-15,16,17 and 18 data (more than 14 years of data)

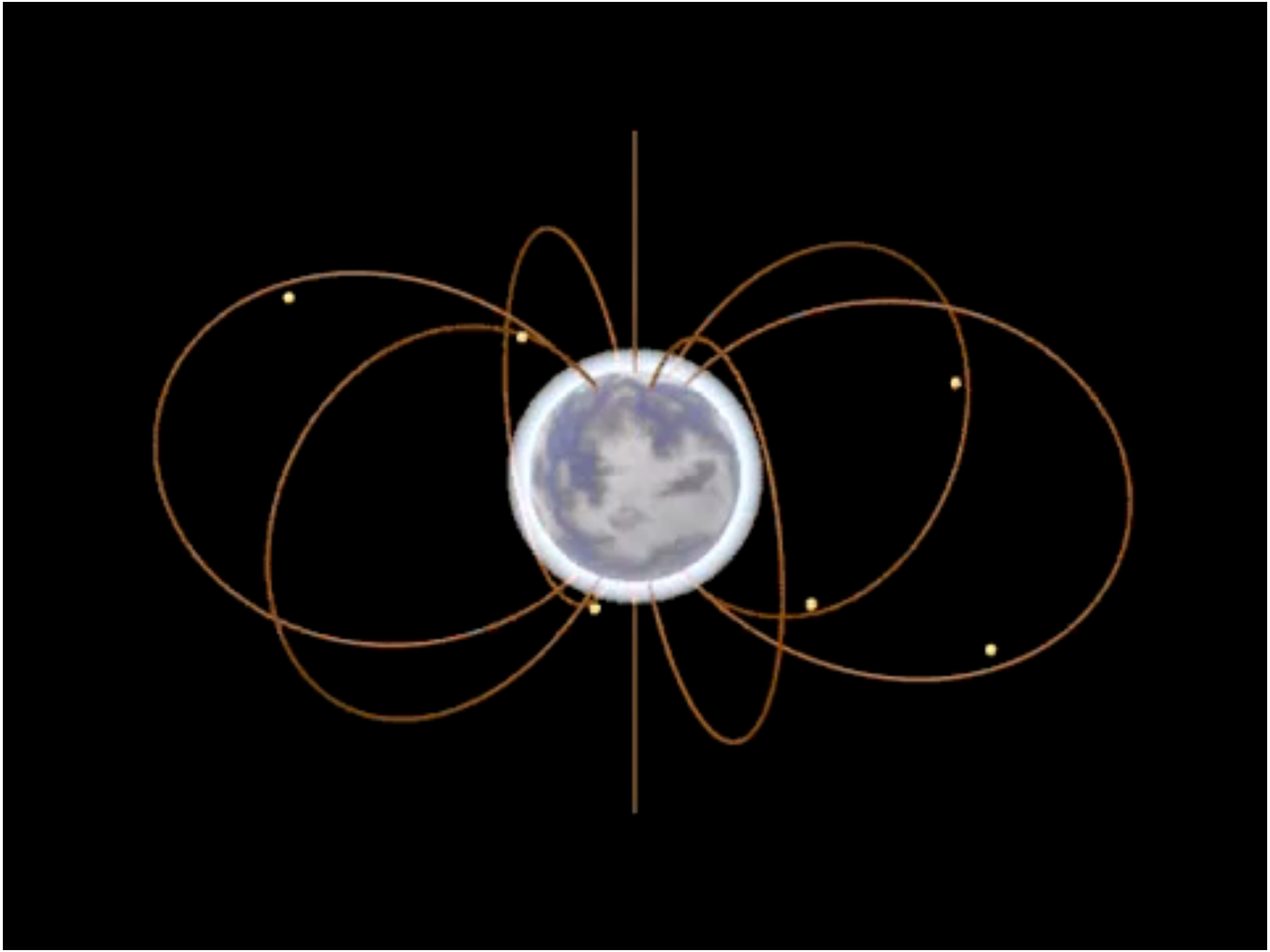
# Van Allen Belts

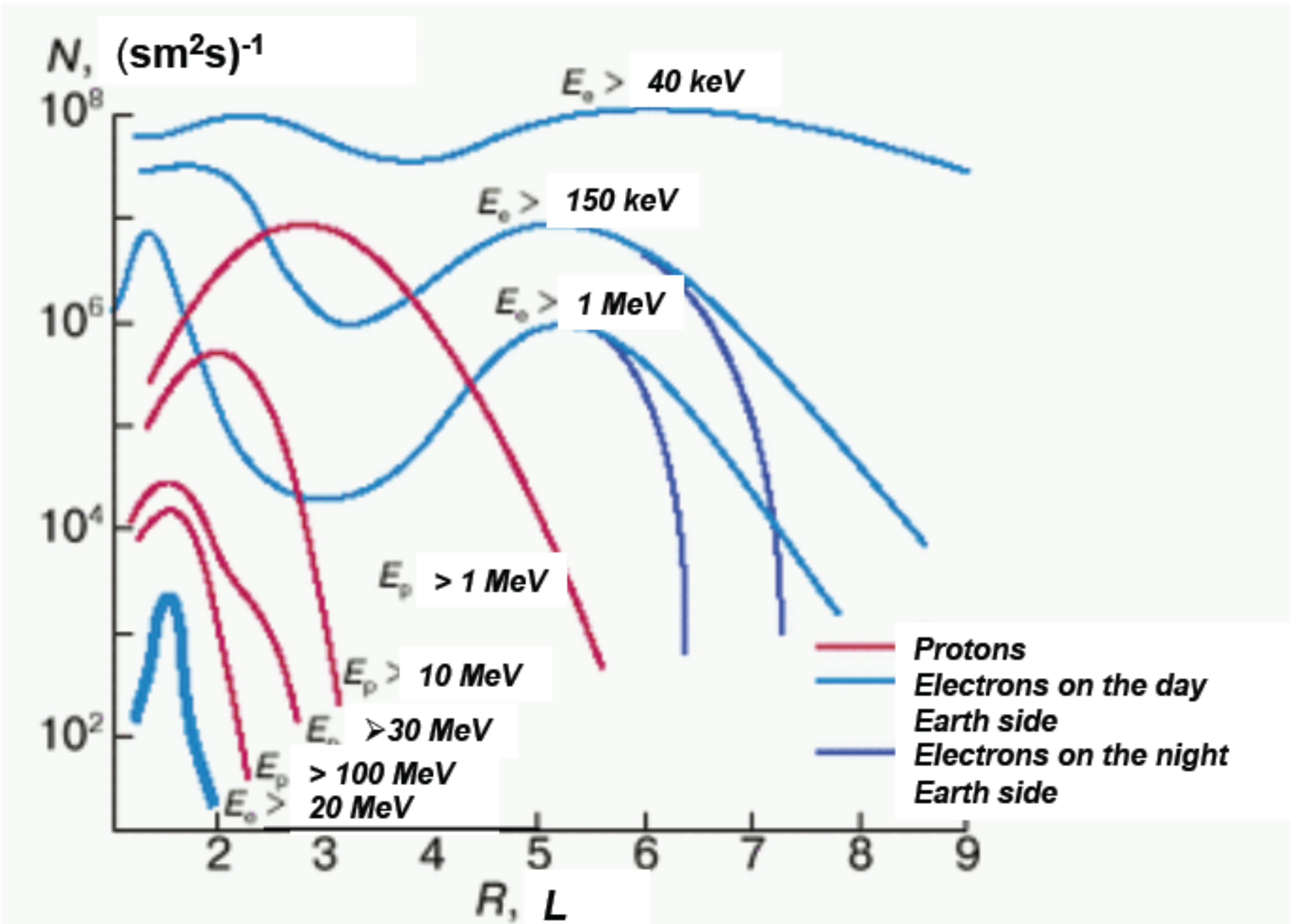
In 1958, Dr. James A. Van Allen, an American astrophysicist, discovered two belts of charged particles circling the planet, trapped by the Earth's magnetic field.




Source: Nasa

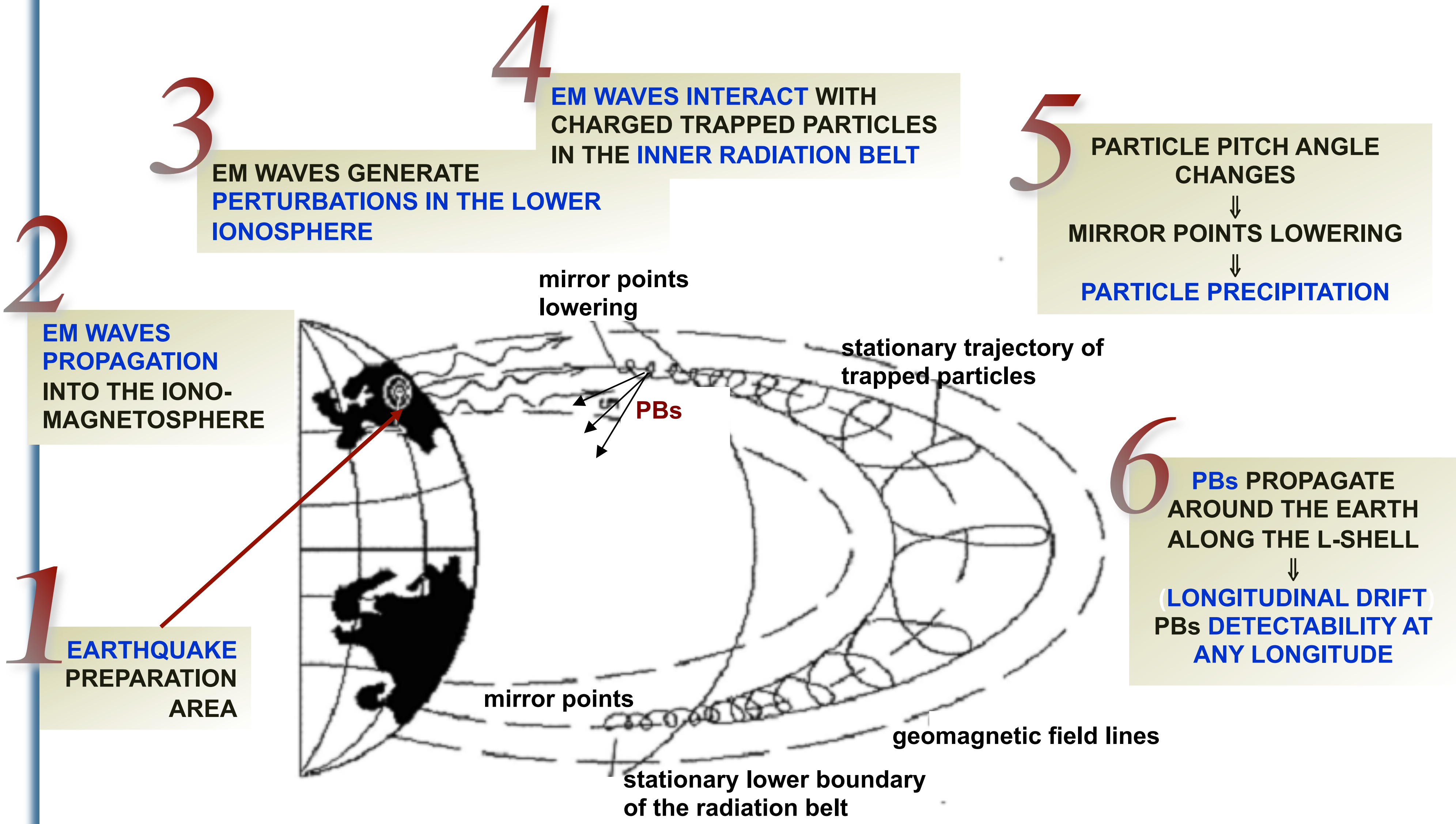
The New York Times





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
2 3 4 5 6 7 8 9
R, L
Protons
Electrons on the day Earth side
Electrons on the night Earth side

# Schematic representation in a meridian plane of the trapped particle trajectories

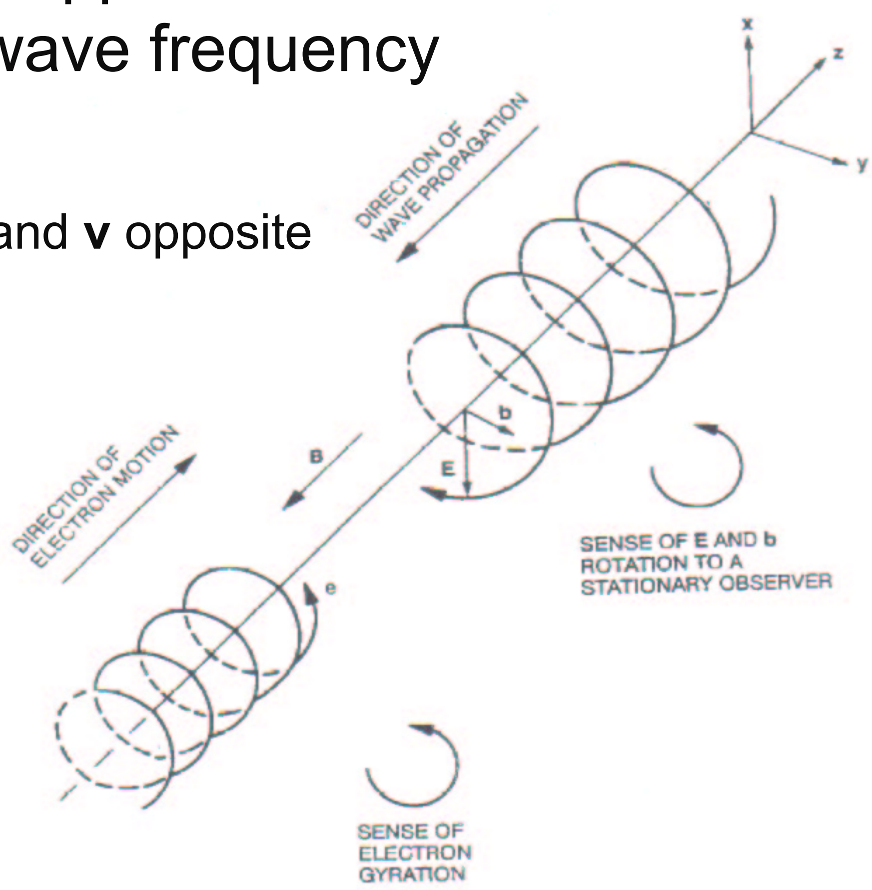


# Wave-particle interaction

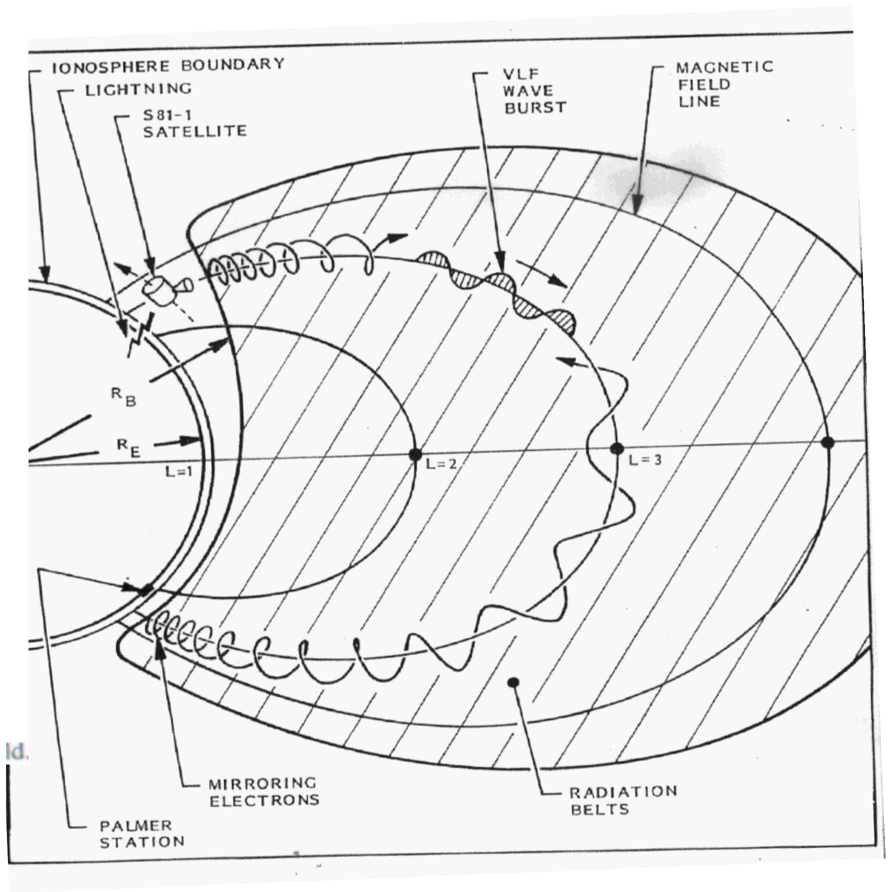
Cyclotron resonance - Whistler mode

Doppler-shifted wave frequency

**k** and **v** opposite




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




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

# Wave-particle interaction

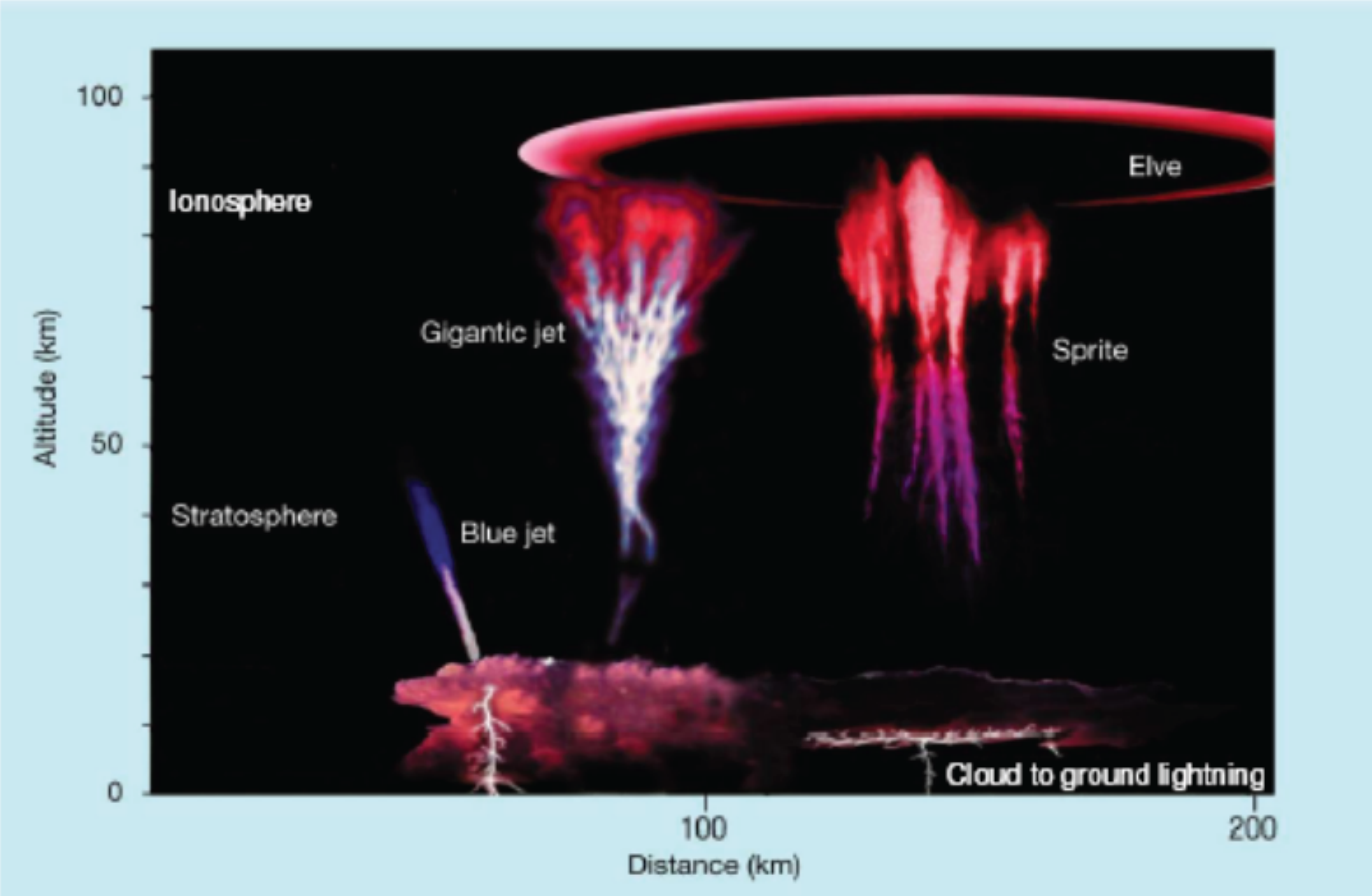
Bounce resonance - Alfven mode

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* $\Delta\alpha_{bounce}=10°$

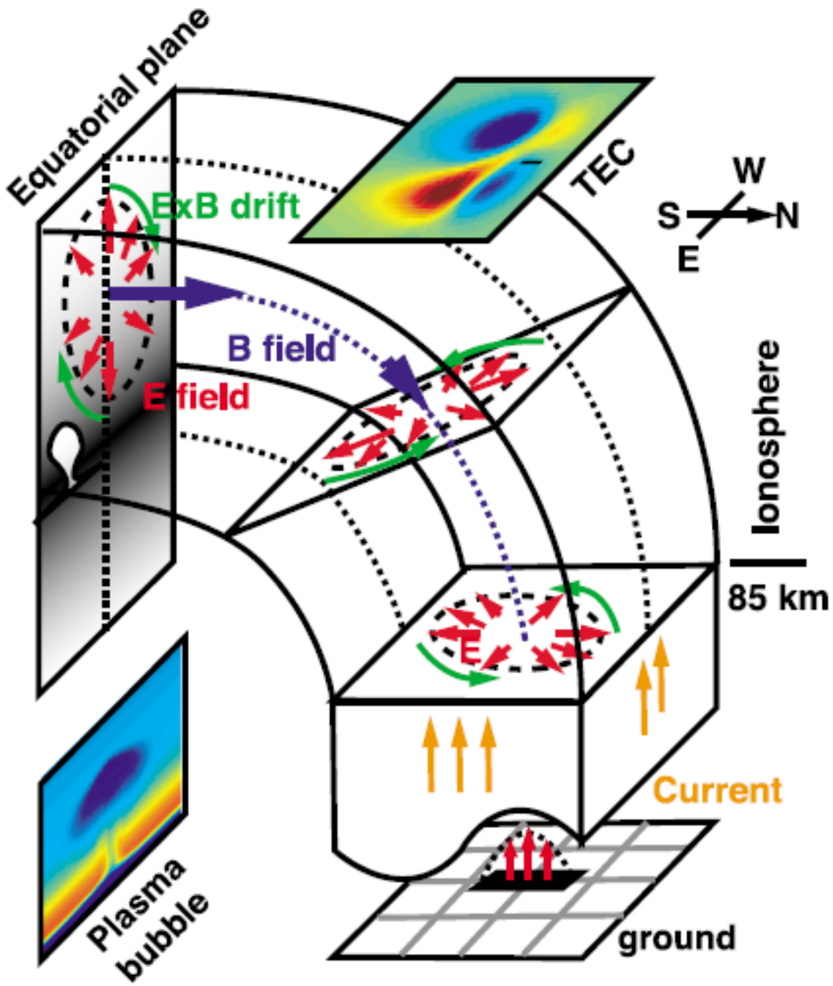
Process efficiency viable between ULF waves and protons of E>10 MeV and electrons of E>1 MeV (Aleshina 92)

# High-altitude electric discharges




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

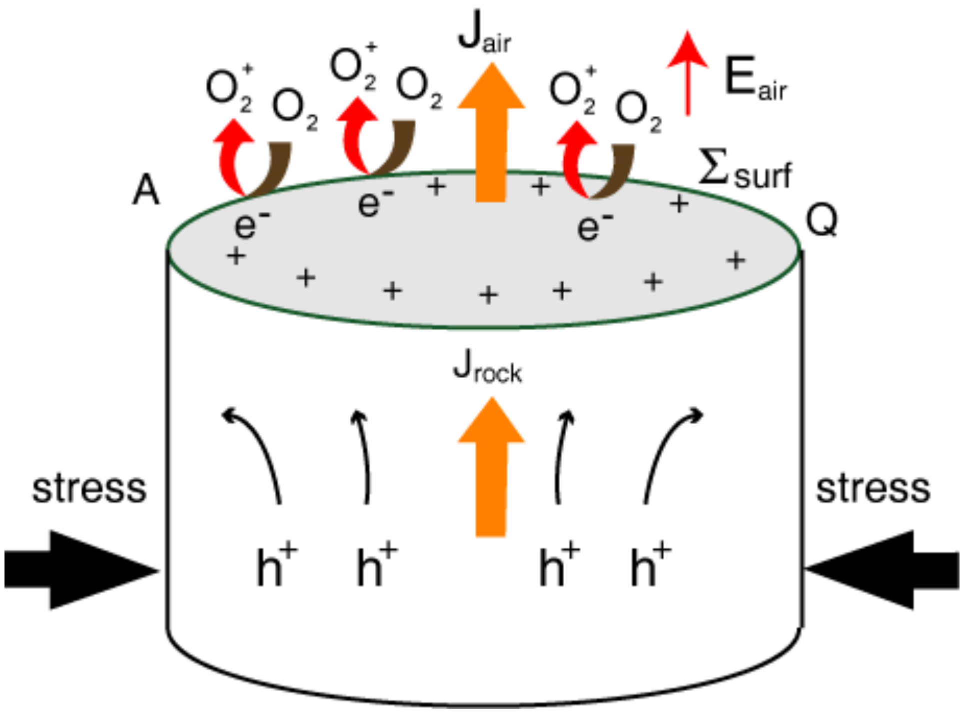
# Electric coupling between the ionosphere and surface charges




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

# A Coupling Model

## Earthquake Region

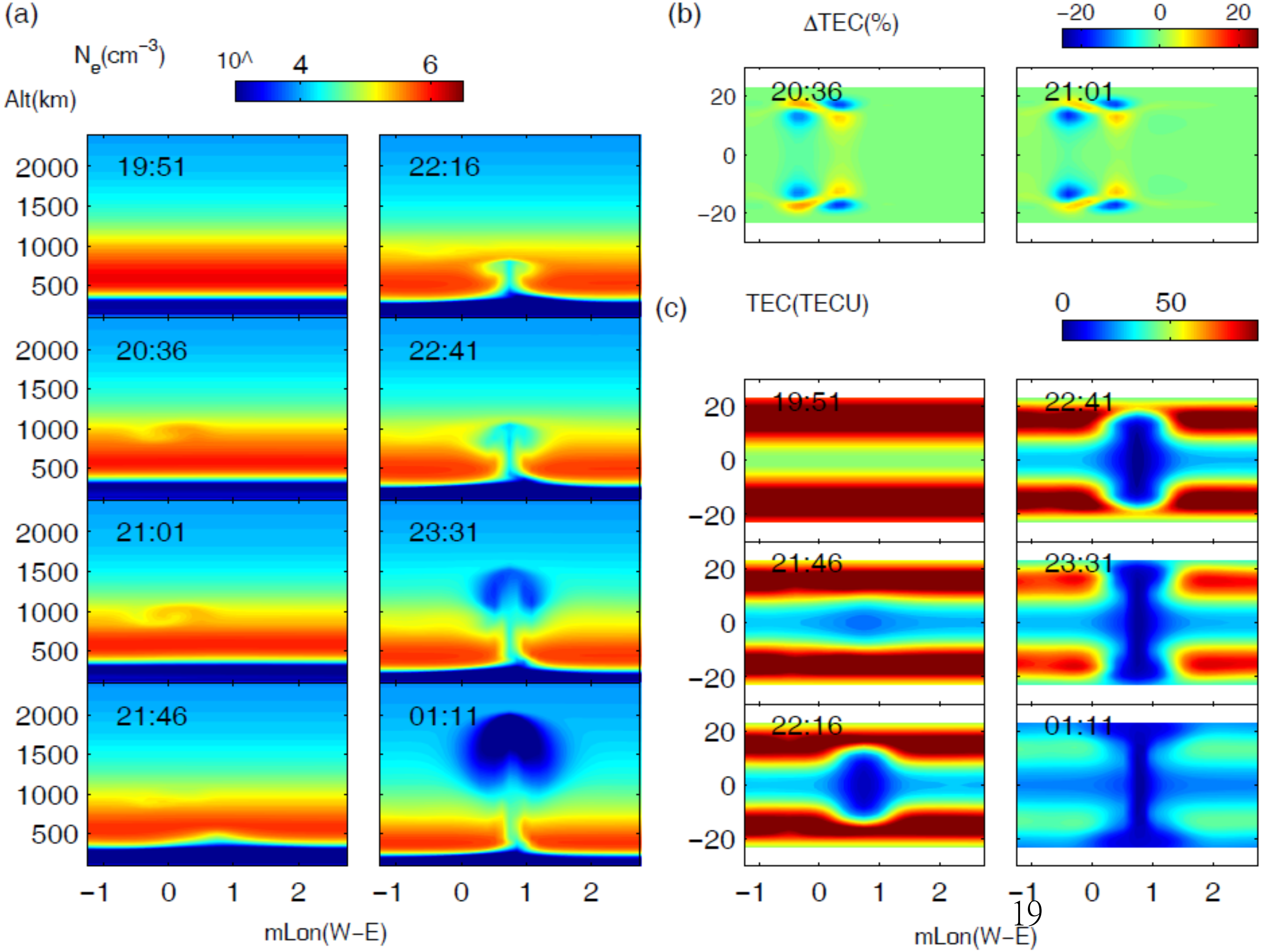



The surface charge density $\Sigma_{surf}$ and total charge amount $Q$ are accumulated by positive charges from the rock surface and $O_2^+$ ions in the air. The upward electric field $\boldsymbol{E}_{air}$ associated with the positive surface charges will drive the upward current $J_{air}$.

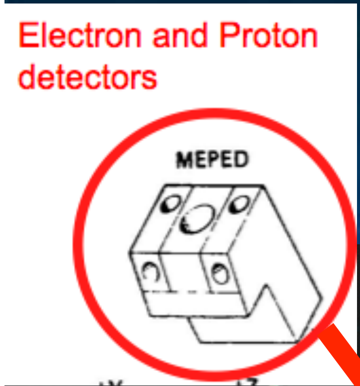
$$\boldsymbol{E}_{air} = \left(\Sigma_{surf} / \varepsilon_0\right)\hat{\boldsymbol{z}} \qquad \boldsymbol{J}_{air} = \sigma_{air}\boldsymbol{E}_{air}$$

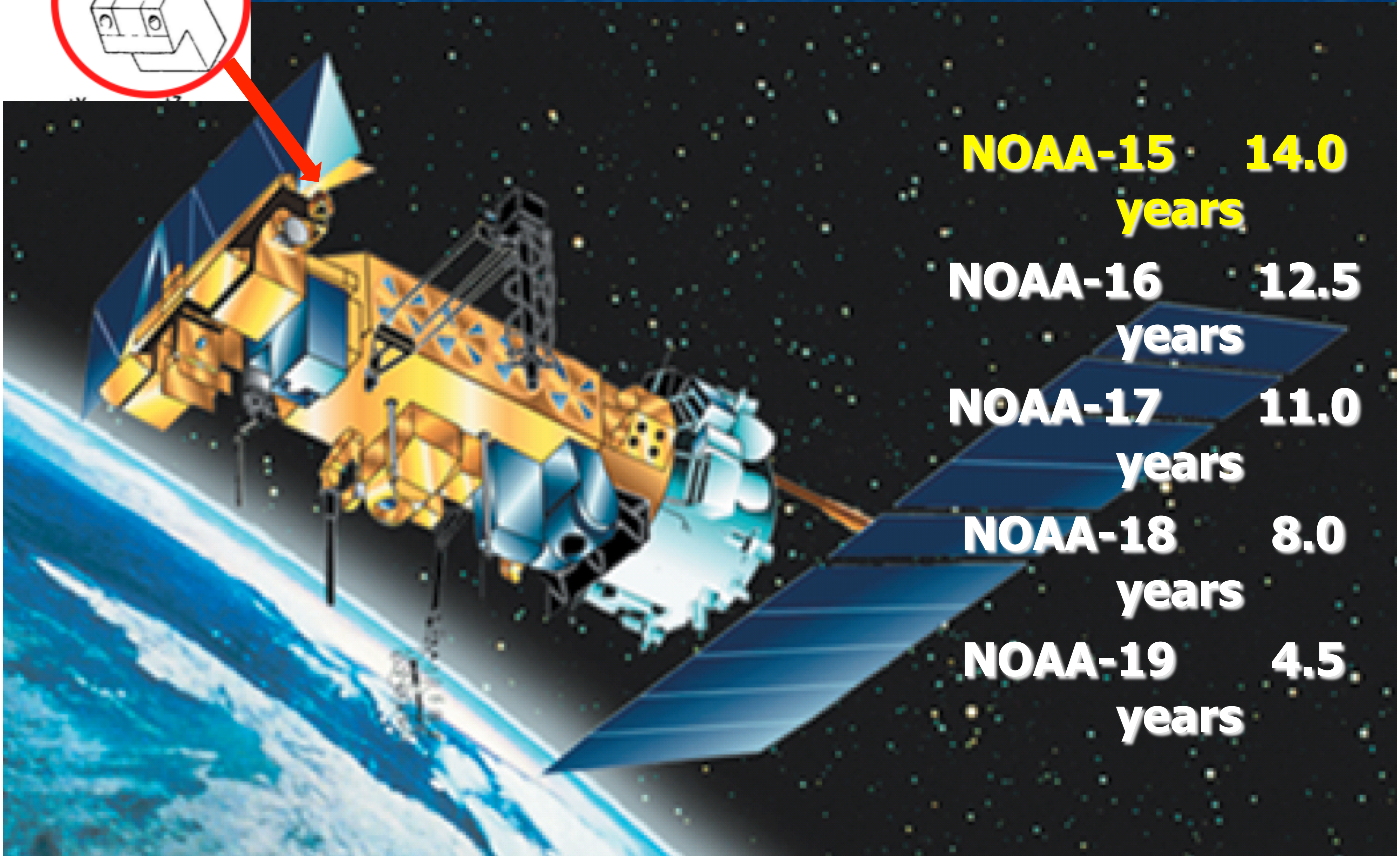
**C. L. Kuo, J. D. Huba, G. Joyce, L. C. Lee, J. Geophys. Res., 116, A10317, 2011.**

# Nighttime case ($J_{rock}$= 0.2μAm$^{-2}$)



# NOAA Satellites



NOAA-15 14.0 years

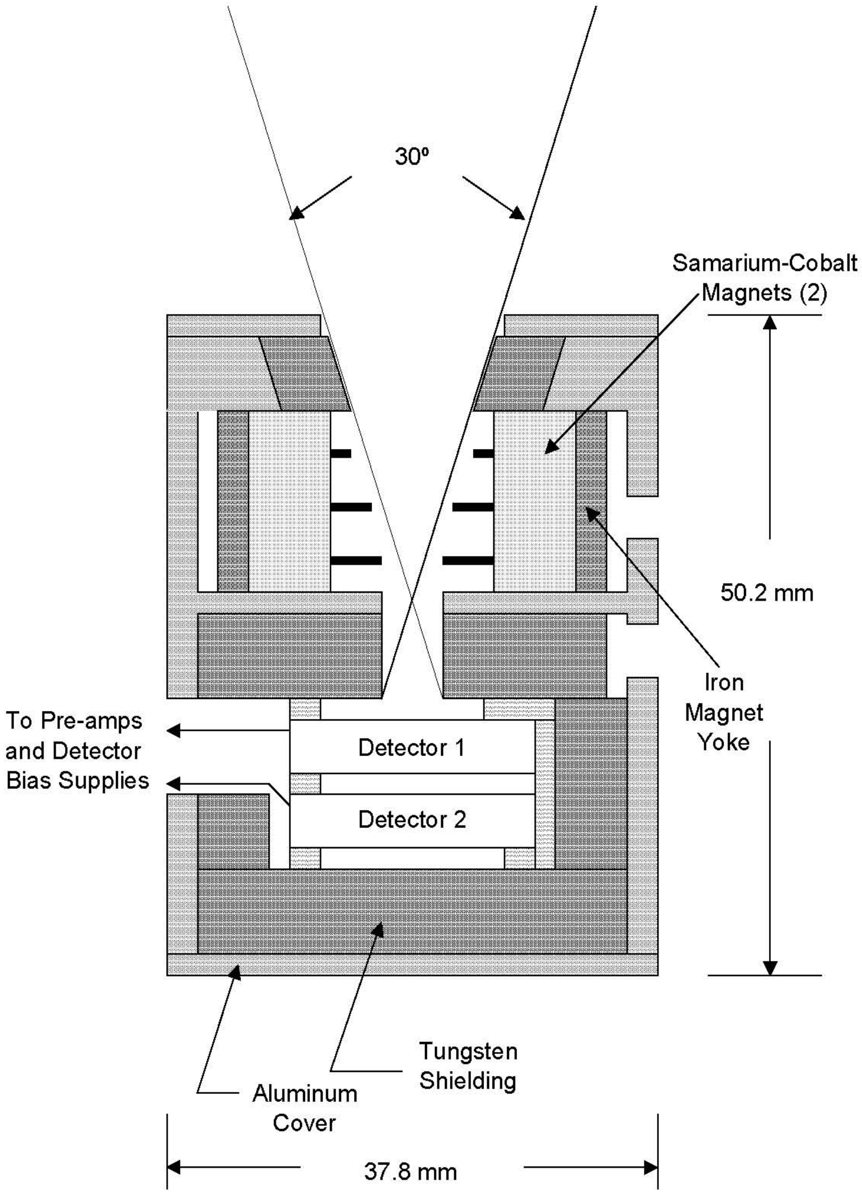
NOAA-16 12.5 years

NOAA-17 11.0 years

NOAA-18 8.0 years

NOAA-19 4.5 years

# POES MEPED




- Telescope at 0deg oriented with central axis 9deg from direction –X in (-X,-Z) plane
- Telescope at 90deg rotated 9deg from +Y direction in the YZ plane
- At geomagnetic latitude > 30deg is it 0deg telescopes see particles in the loss cone while with 90deg telescope trapped ones
- 30deg Collimator
- Aluminum and tungsten foil avoid electrons with energies <6MeV e/o protons <90 MeV to cross the detector

# DETECTORS PARAMETERS

| detectors channels | energy range keV | contaminants |
|---|---|---|
| e1 | 30-2500 | 210-2700keV protons |
| e2 | 100-2500 | 280-2700keV protons |
| e3 | 300-2500 | 440-2700keV protons |
| p1 | 30-80 | |
| p2 | 80-240 | |
| p3 | 240-800 | |
| p4 | 800-2500 | |
| p5 | 2500-6900 | |
| p6 | >6900 | >700keV electrons |
| $p6_{omni}$ | >16000 | >800keV electrons |
| $p7_{omni}$ | >36000 | |

Table 2: MEPED Telescopes Parameters. Electron detectors have energy channels identifier starting with *e*, protons detector with *p*. In the second columns the channel energy range is reported and in the third one the known contaminants. Data are taken from [14] and [16].

[14] Evans, D.S and M.S. Greer, (2000) Polar Orbiting Environmental Satellite Space Environment Monitor-2: Instrument Descriptions and Archive Data Documentation, NOAA Technical Memorandum OAR SEC-93, Boulder, CO.

[16] C.J. Rodger et al, 2010 Journal of Geophysical Research, 115, A04202

# Particle Bursts

Particle Bursts are significant fluctuation in the counting rate

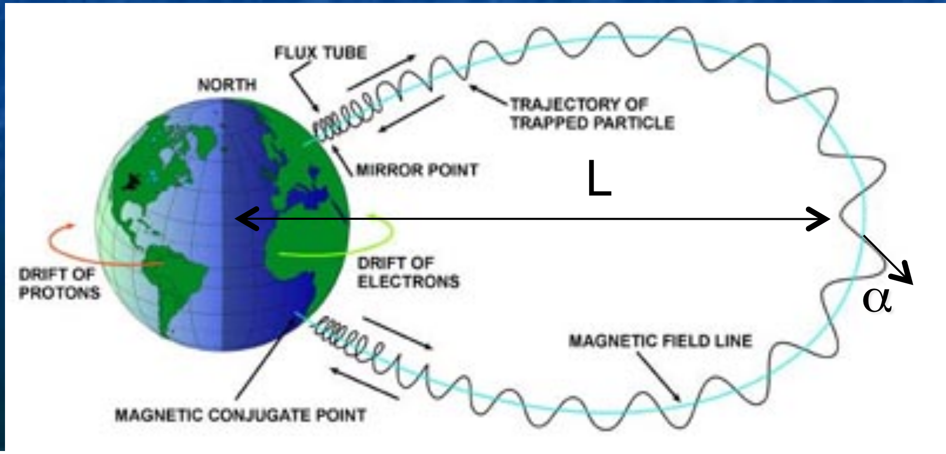
"significant" can be quantified by studying the counting rate statistics ( 7 $\sigma$ )

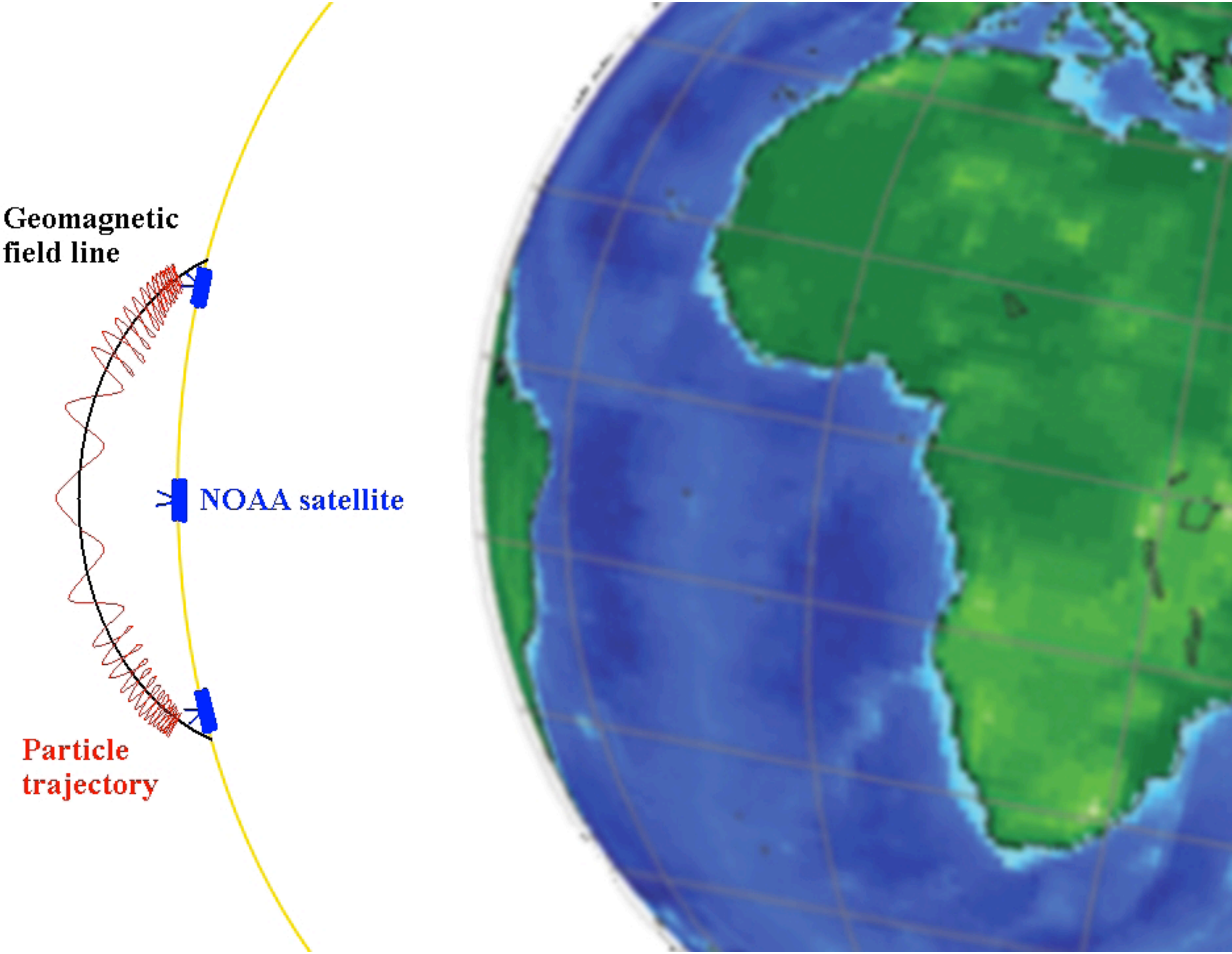
As the particle motion is strongly variable along the satellite orbit we choose to study the counting rate statistics in the invariant space (L,$\alpha$,B)

L : L-shell

$\alpha$: Pitch angle

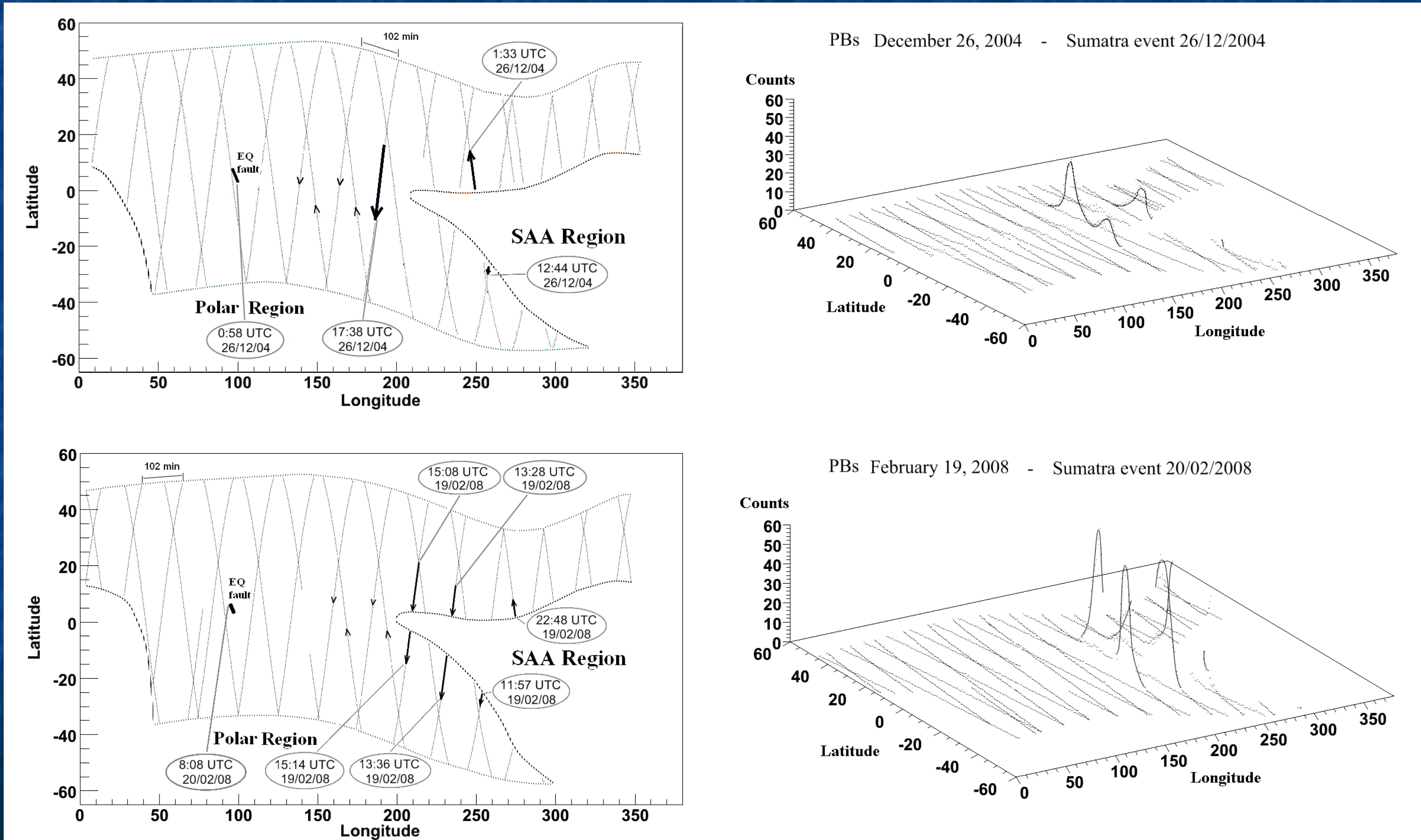
B : Geomagnetic field




Geomagnetic
field line
NOAA satellite
Particle
trajectory

# Examples of Particle Bursts

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



# Search for correlations with Earthquakes by first eliminating spurious effects

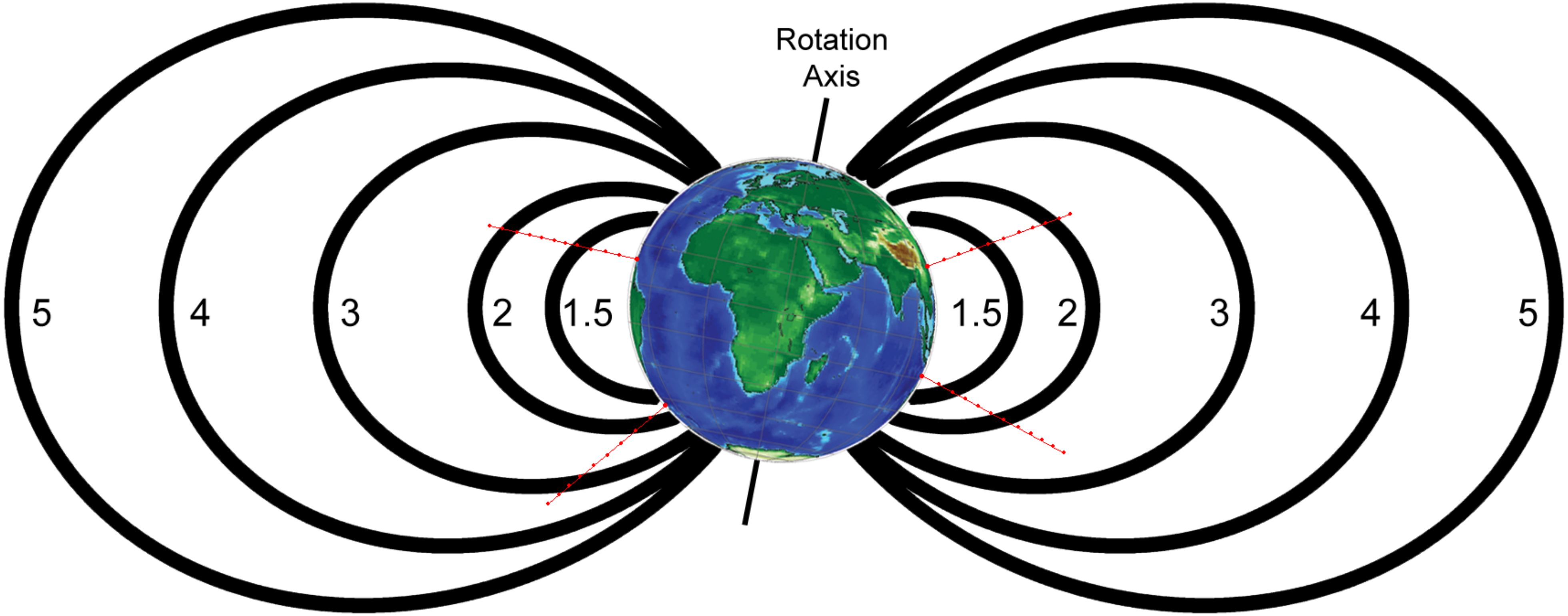
1) Solar influence (SID)

2) Earthquake clustering

3) SAA masking

4) Particle Burst merging

# Correlation with the earthquakes




$L_{Earthquake}$ : L-shell where earthquake interact with the Particle Burst

**Fora a given a projection altitude** we considered only the Earthquakes with :

$|L_{Earthquake} - L_{ParticleBurst}| < 0.1$

(Aleksandrin et al., 2003; Sgrigna et al. 2005)

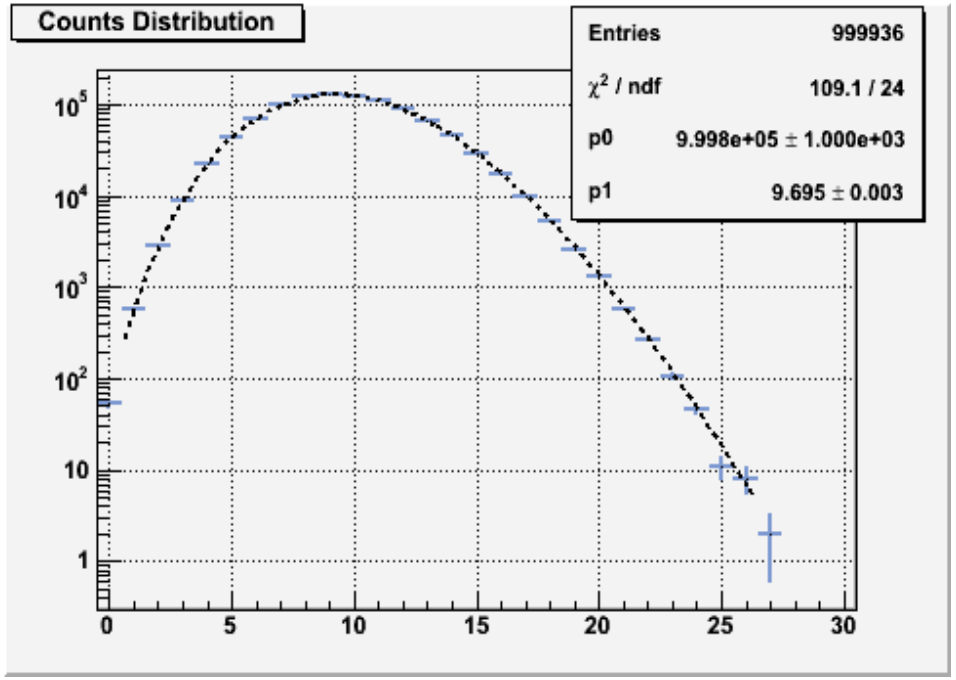
# SINGLE SATELLITES RESULTS

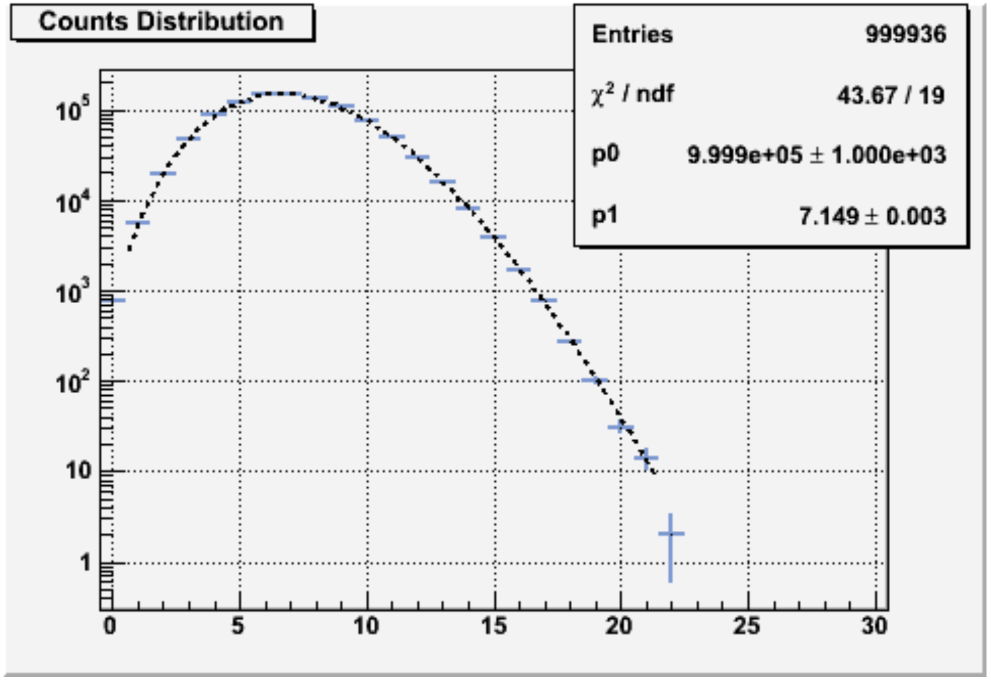
| Satellite | C | $\mu$ | (C-$\mu$)/ $\sqrt{\mu}$ |
|---|---|---|---|
| 15 | 7 | 3.25±0.19 | 2.08 |
| 16 | 7 | 2.00±0.16 | 3.53 |
| 17 | 7 | 2.21±0.13 | 3.23 |
| 18 | 4 | 0.98±0.12 | 3.05 |

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 ($\mu$) and significance of the counts in the -1.25 hours bin (S-M)/ $\sqrt{\mu}$.

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

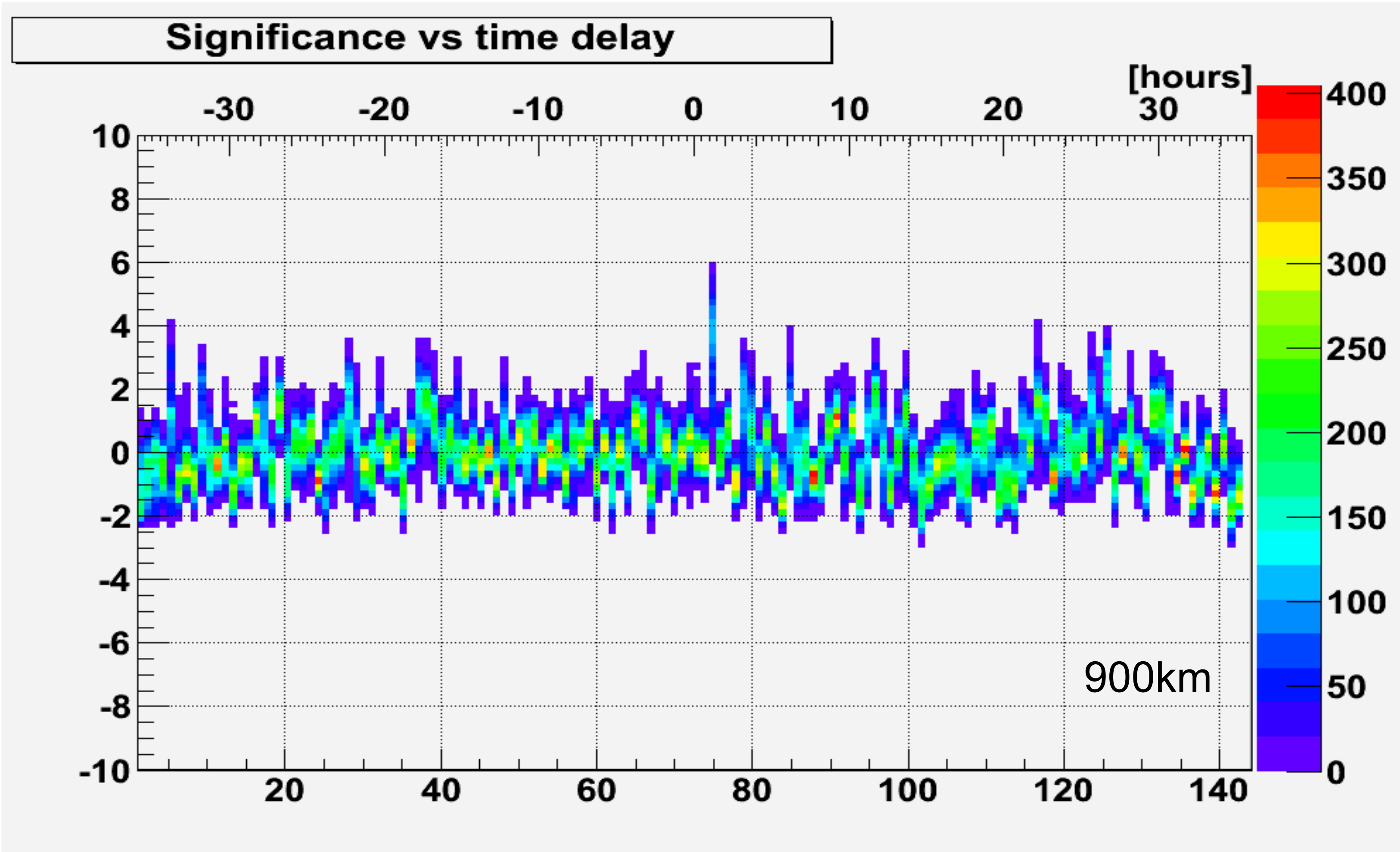
# Statistical significance




- Can random samples of EQs generate the found excess ?
- The analysis was repeated 2 X 6944 times with simulated EQs
- For each repetition approx 18k Earthquakes are simulated
- For test 1 only the time of EQs is simulated randomly within the relevant time range
- For test 2 time latitude and longitude are simulated
- Test 1 (2) reaches a maximum of 27(22) counts, eq a 5.5 s.d. event, in 1 million trials
- No systematic deviation from the expected Poisson statistics is found

# Stability analysis

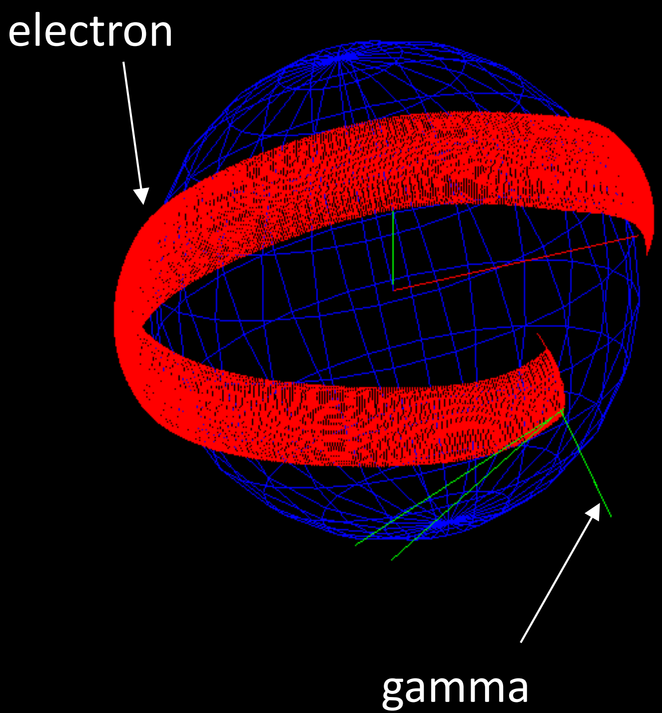



- Significances reached in each delay channel, with the 1715 analysis repetition, with P5=900km. Channel 75 @ t = -1.25 hours

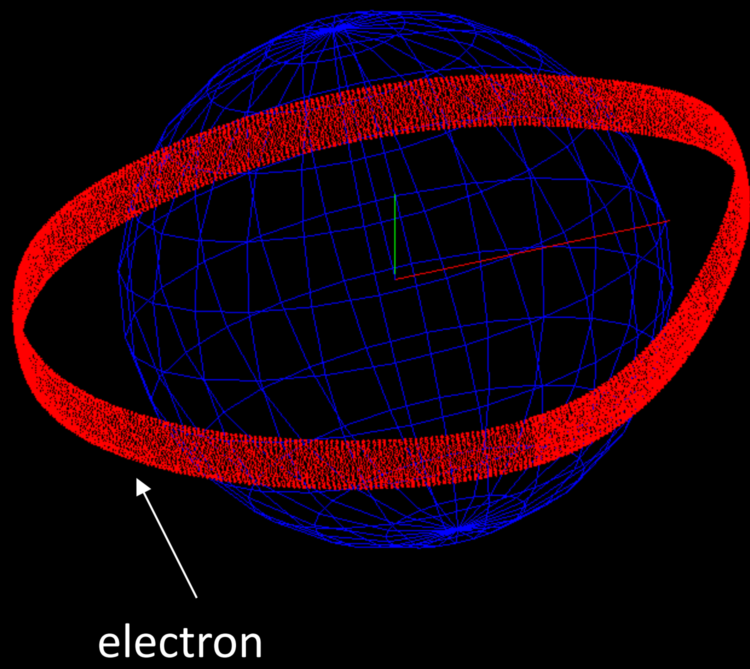
# SPES: PLANETOCOSMICS

Example of particle propagation with IGRF magnetic field and NRLMSISE00 atmosphere model

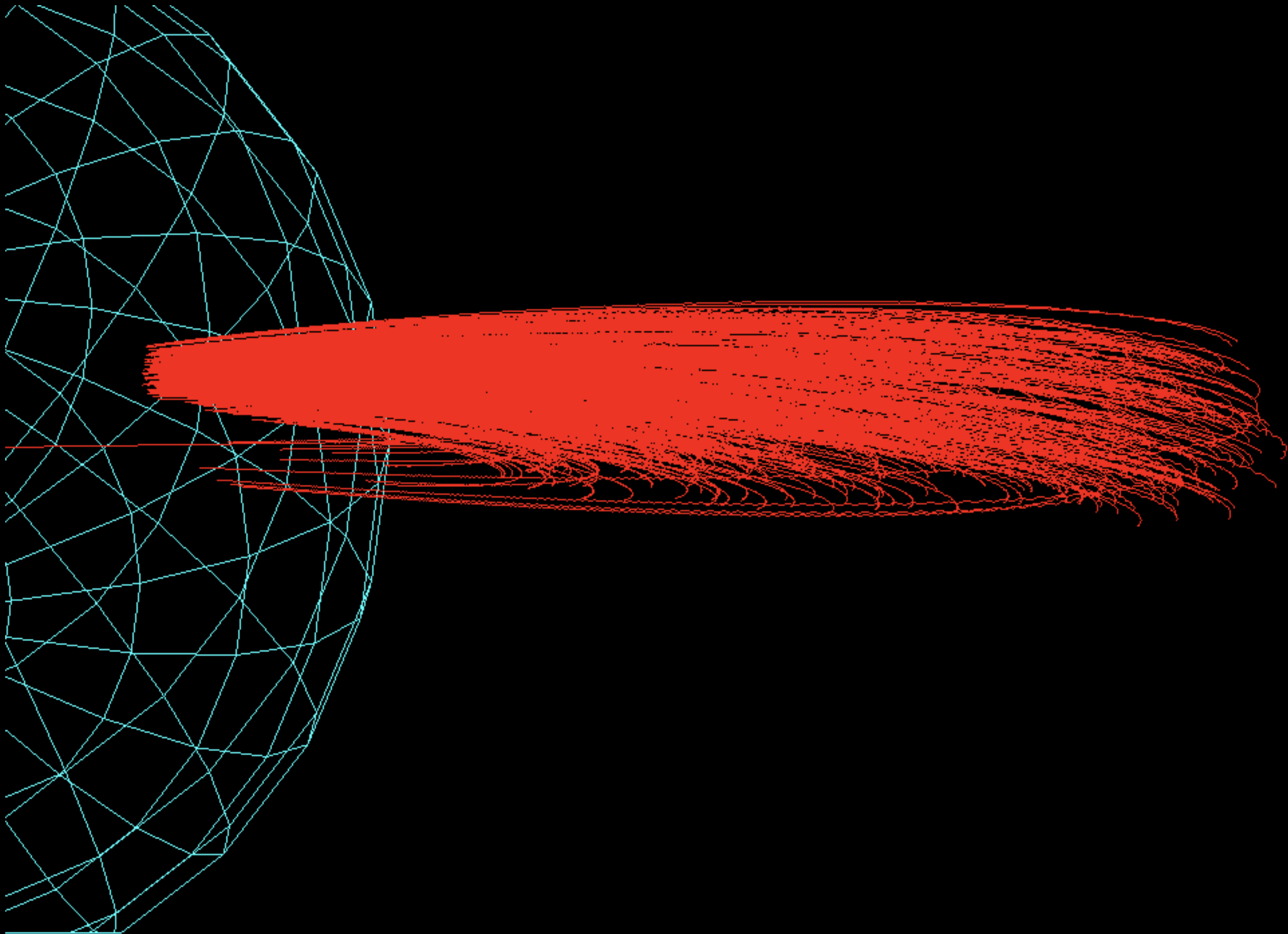
e- 100 MeV Lat 0° Long 0° Altitude 500 km




e- 100 MeV Lat 0° Long 0° Altitude 2000 km



# SPES events



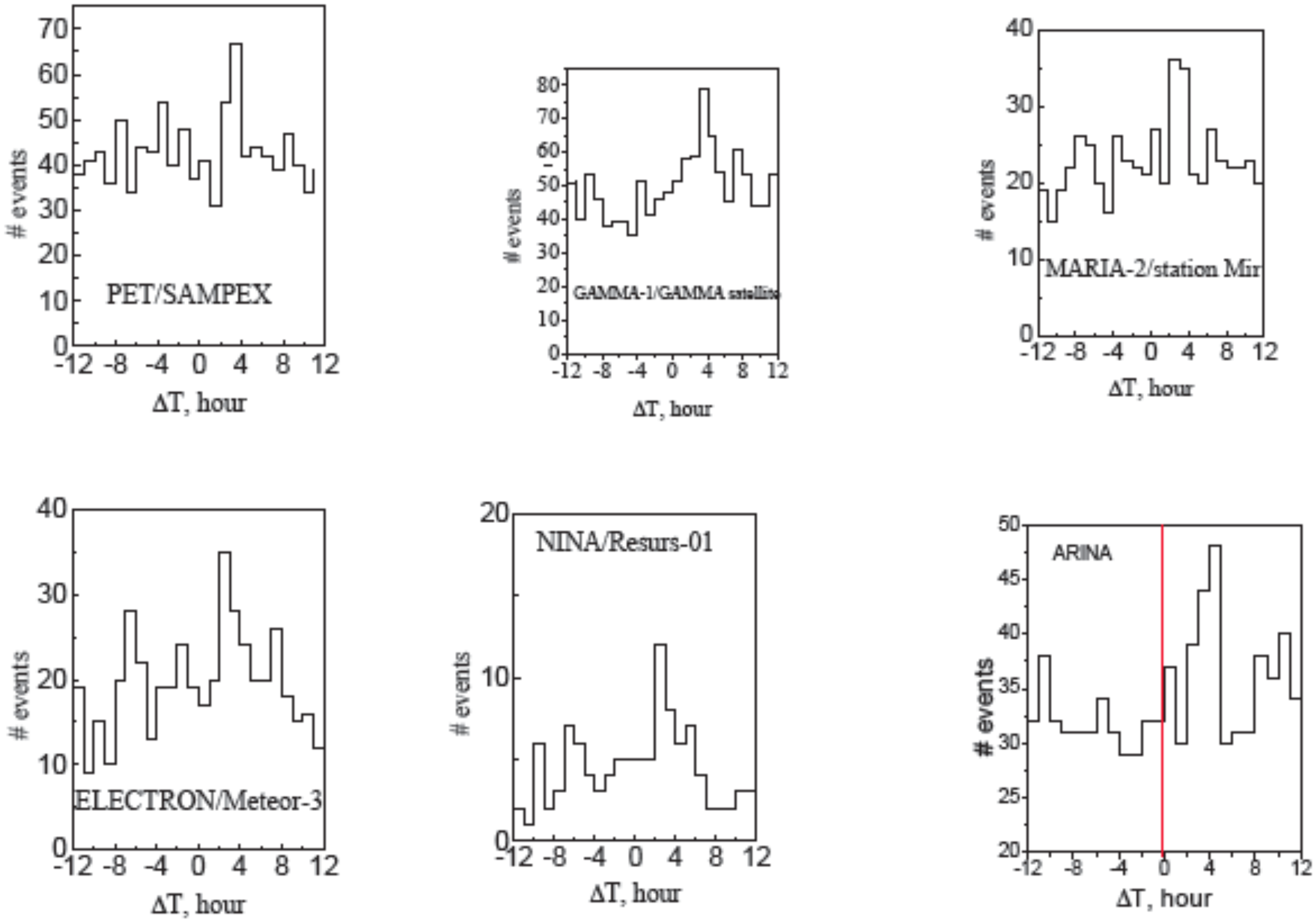
# Result for NOAA analysis

We established a 1,25 hours correlation (precursor) between electron Particle Bursts and Earthquakes. For the low energies covered by the NOAA detectors (E ~ 300 keV), a 5,7 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.

# 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.

These detectors, however, were not optimized for Earthquakes monitoring, had limited sensitivity and were not able to exploit all the informations available to determine the Earthquakes geographical position

# An optimized Particle Spectrometer for Earthquake precursors localization

R. B., W. Burger, et. Al. NIM A, 617, 467, 2009

Viewing angle : zenith

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

Single particle detection → backtrackng for E.Q. localization

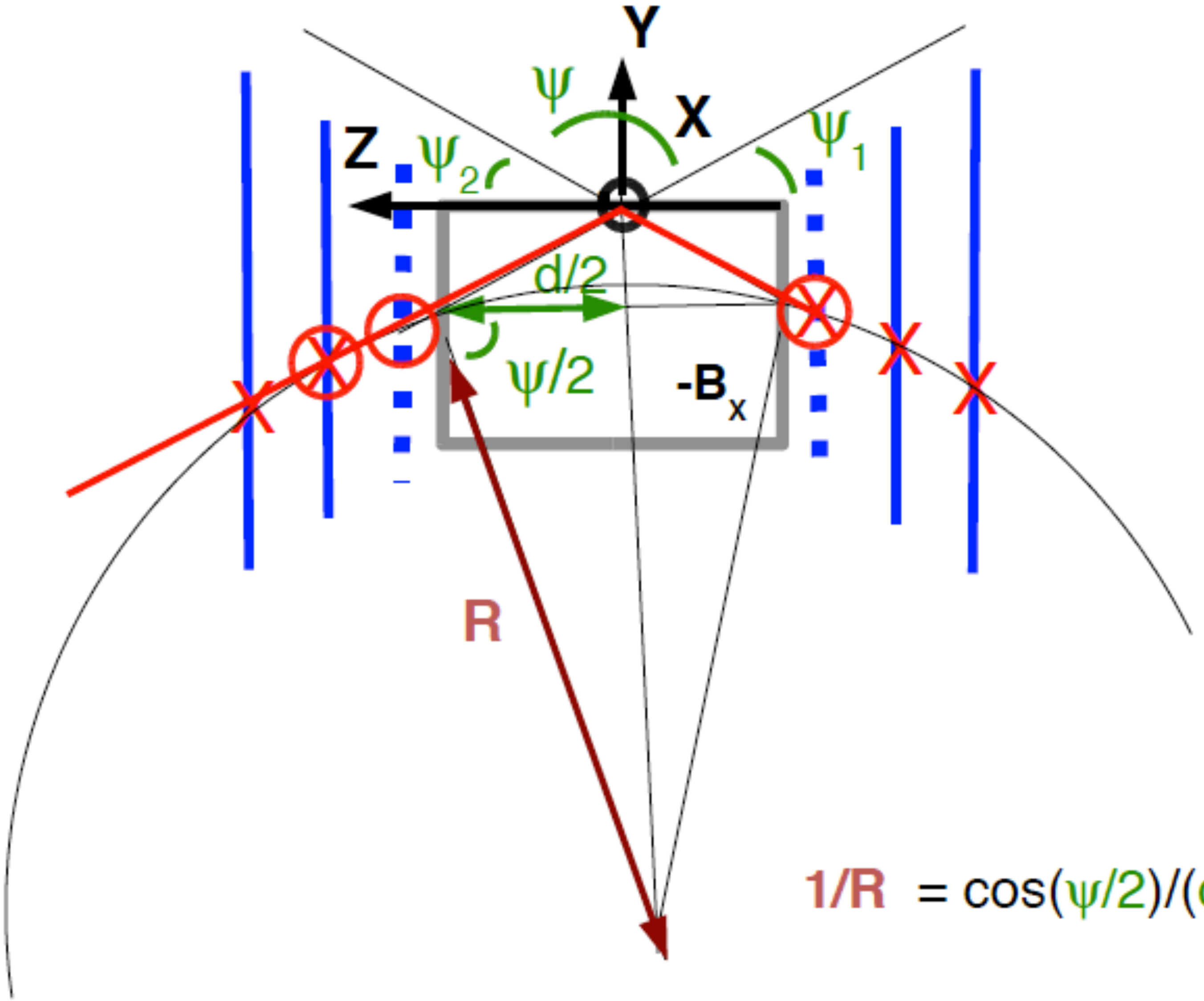
Pitch angle resolution : < 10 degree;

Acceptance, Energy resolution: the best possible

# Energy vs Localization dependance of precipitating particles based on existing experience

NOAA: 0.3 MeV Correlation strongly orbit dependent;

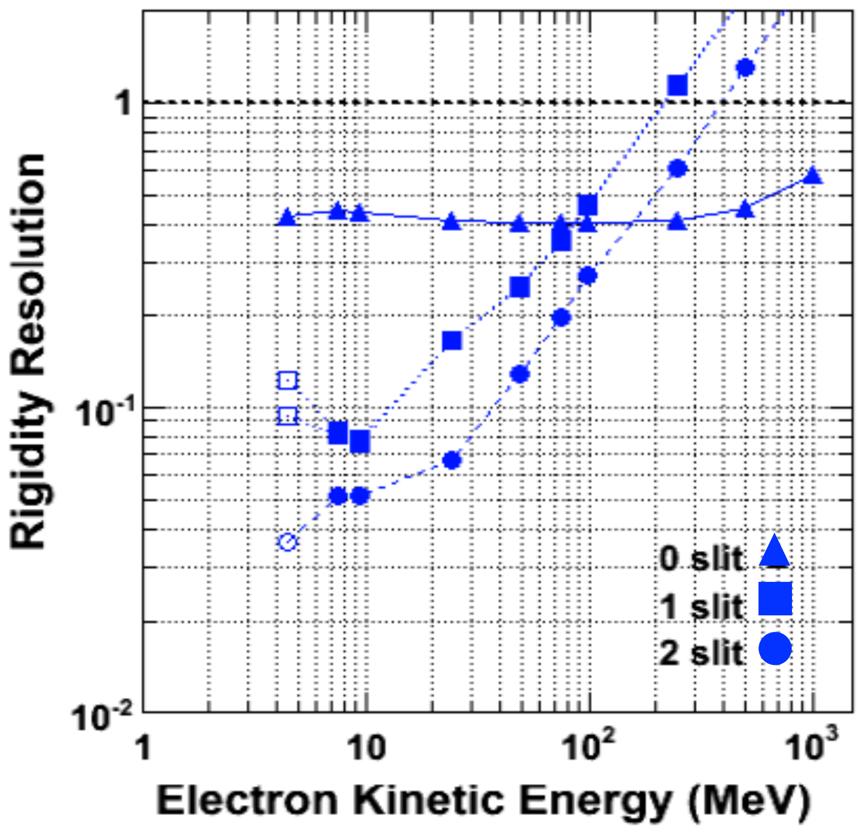
SAMPEX: 4-20 MeV Correlation slightly orbit dependent;

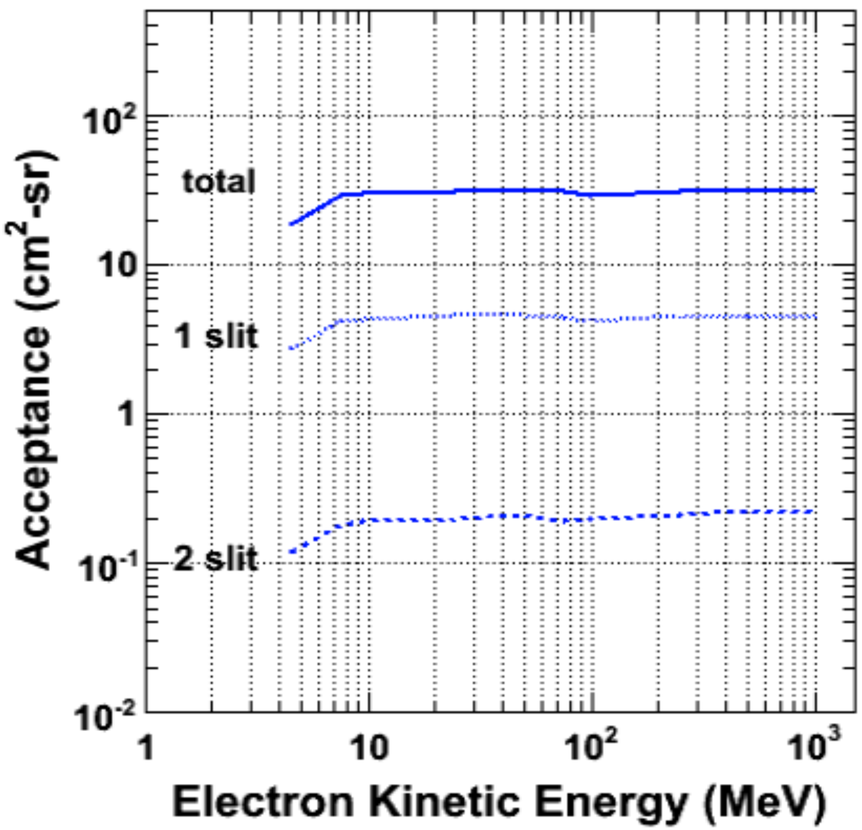



1/R = cos(ψ/2)/(d/2)

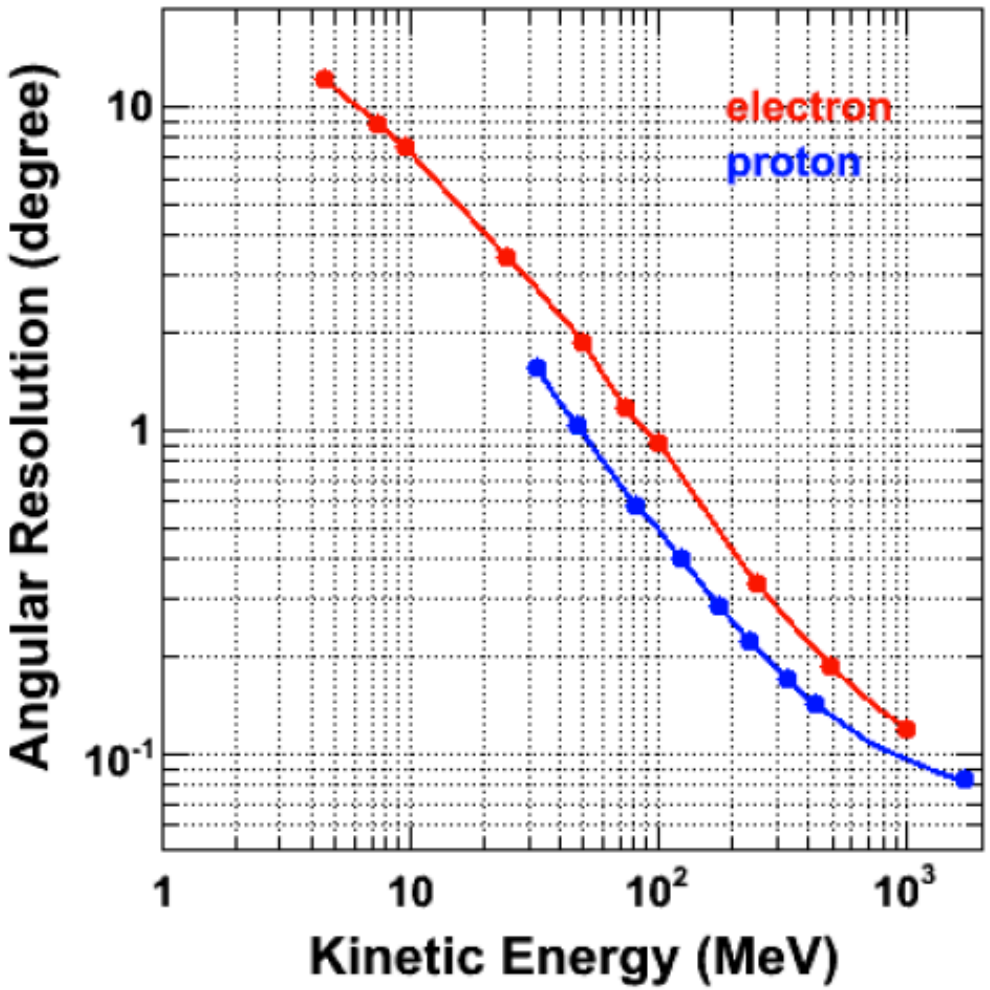
**1 Slit Event 3 point reconstruction**

# Electron Performance
# Resolution and Acceptance



# Angular Resolution



# Low Energy Particle Spectrometer

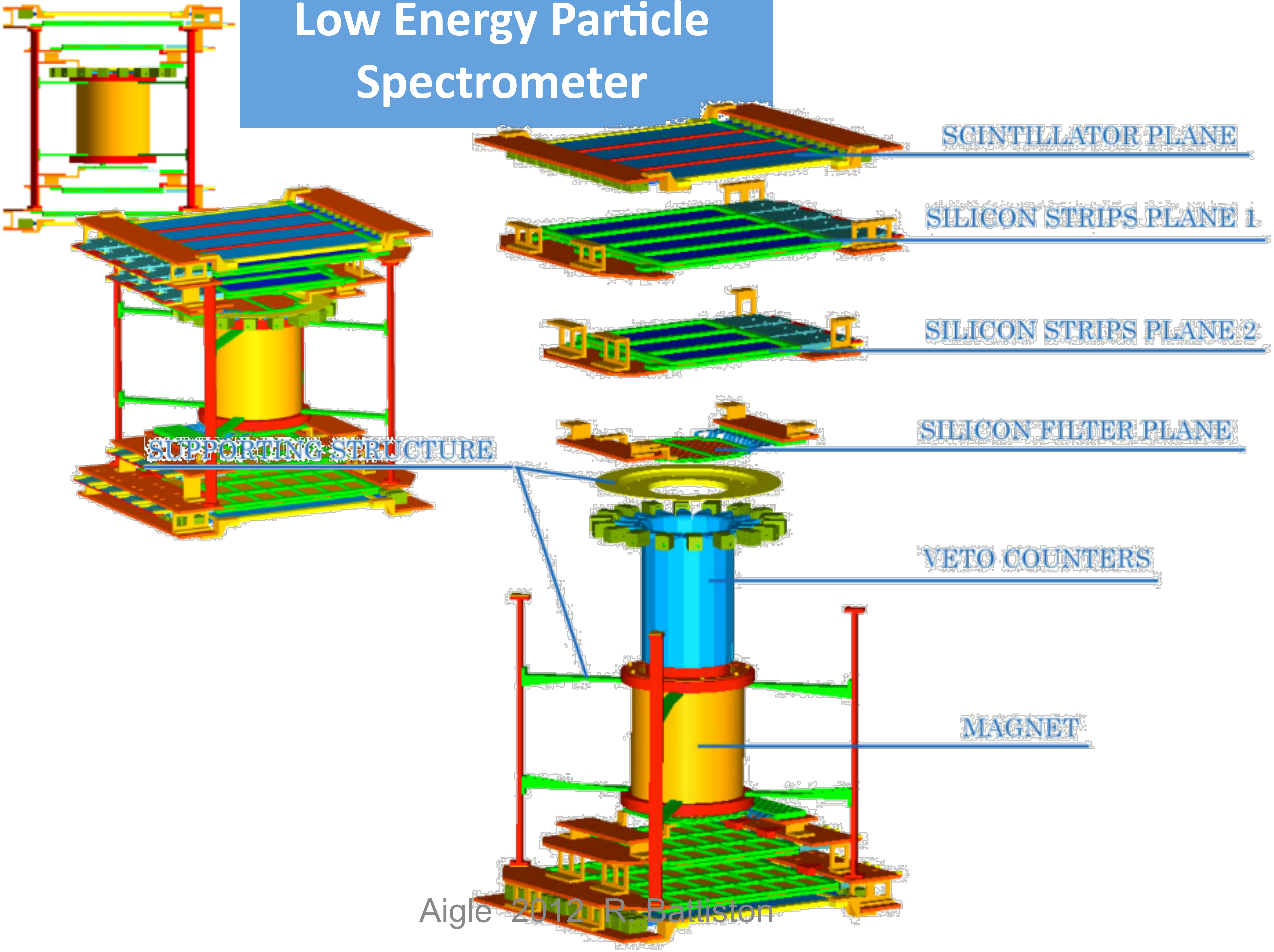
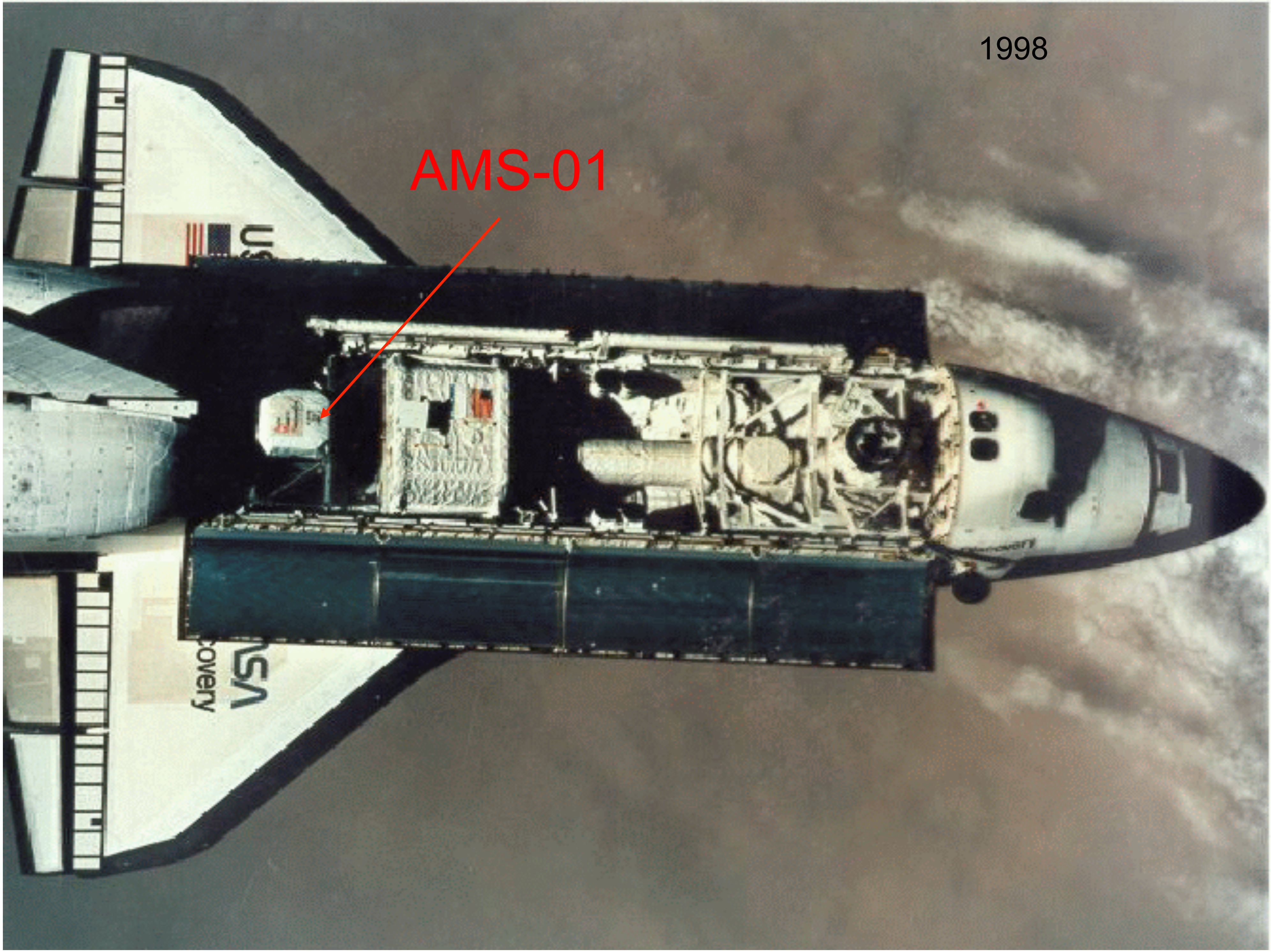


**Table 1:** Performance compared with existing satellite payload particle detectors.

| Detector | Geometric Factor *cm²-sr* | Aperture | Pitch Angle | Energy Range Electron (*MeV*) | Energy Range Proton (*MeV*) |
| --- | --- | --- | --- | --- | --- |
| NOAA MEPED | 0.1 | $30^0$ no angular res. | $0\text{-}90^0$ $90\text{-}0^0$ | 0.03-2.5 | 0.03-6.9 |
| AIGLON (Si) | 4.35 30 | $70^0$ $(\Delta 13.4^0 \;\; \Delta 1.7^0)^2$ | $0\text{-}90^0$ | 5-25[1] | 30-100[1] |

[1]energy range with resolution better ≤ 15%

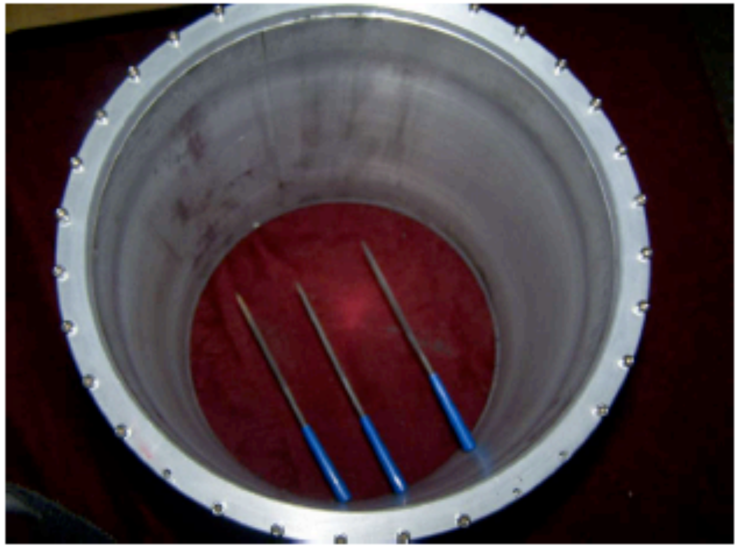
[2] limiting values of the angular resolution at the lowest energies


1998
AMS-01

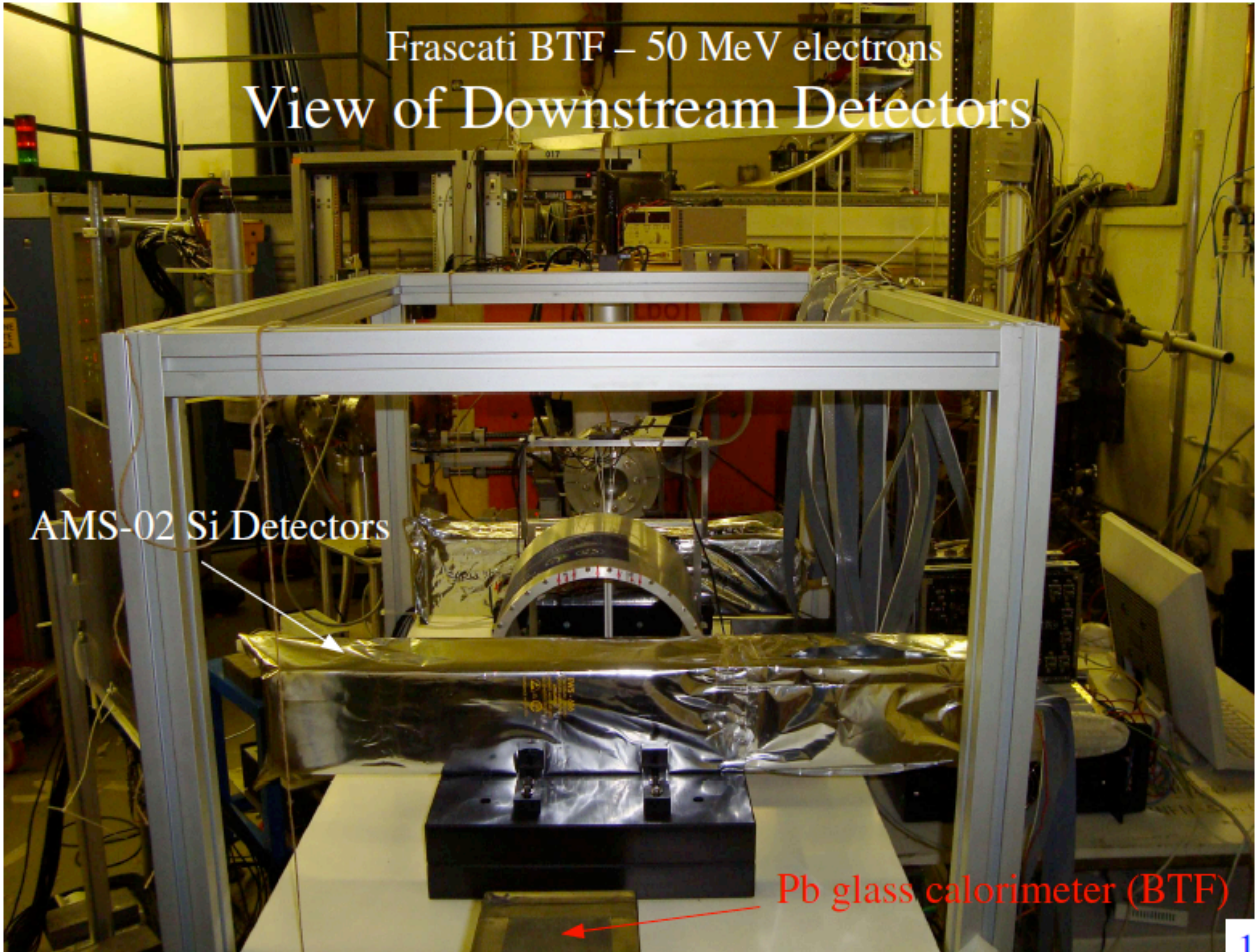

AMS-02
2011

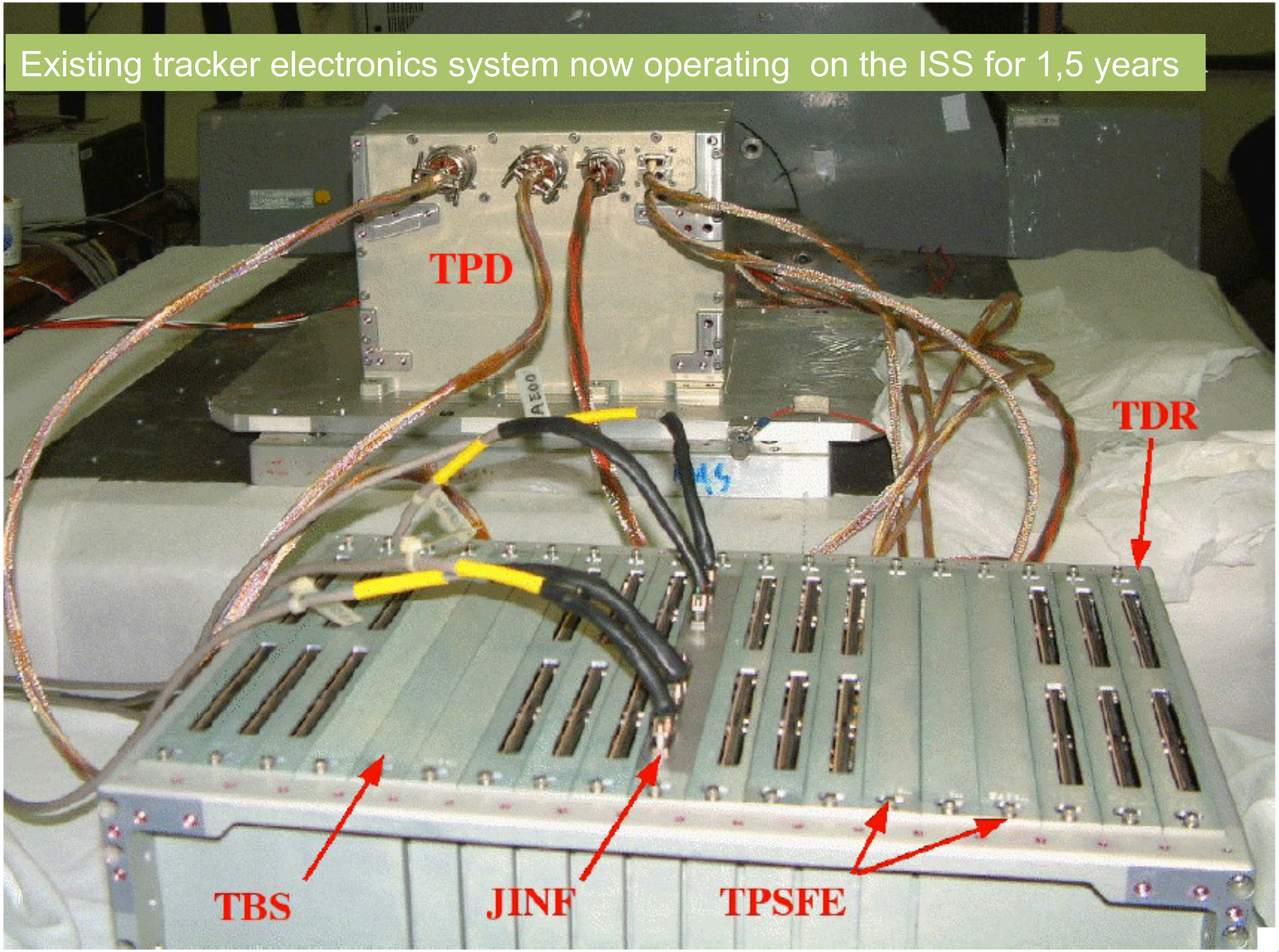
# NdFeB Magnets

Feasibility study magnets



**B = 0.522 kG**
**mass = 10.2 kg**


Frascati BTF – 50 MeV electrons
View of Downstream Detectors
AMS-02 Si Detectors
Pb glass calorimeter (BTF)


Existing tracker electronics system now operating on the ISS for 1,5 years
TPD
TDR
TBS
JINF
TPSFE

# 5) Conclusions

Observations from space support the evidence for detectable precursor phenomena influencing the magnetosphere producing precipitating particle burst taking place 1-3 hours before major earthquakes

In order to localize the position of the precursor effects a low energy cosmic ray detector is required

This design is  derived from the technology used succesfully for the AMS detector on the ISS

Thanks for your attention