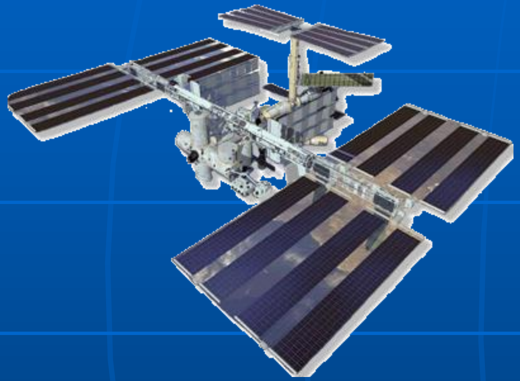
Magnetospheric Particles and Earth

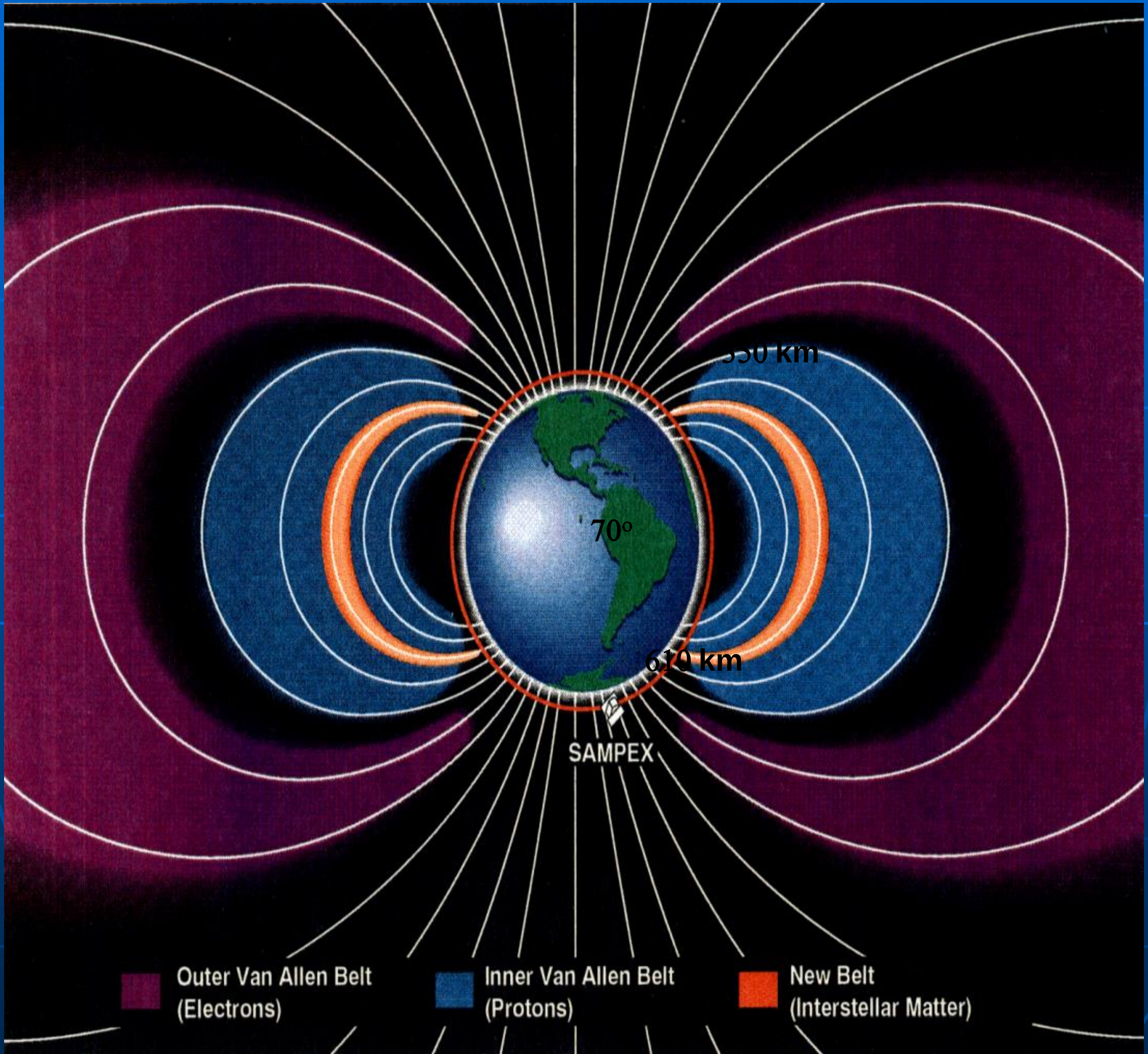


Piergiorgio Picozza
INFN and University of Rome Tor Vergata

12th AGILE Science Workshop
"Astro-Earth: Astrophysics and High-energy Terrestrial Phenomena"
ASI Headquarters
May 8-9, 2014

The History

Van Allen Belts

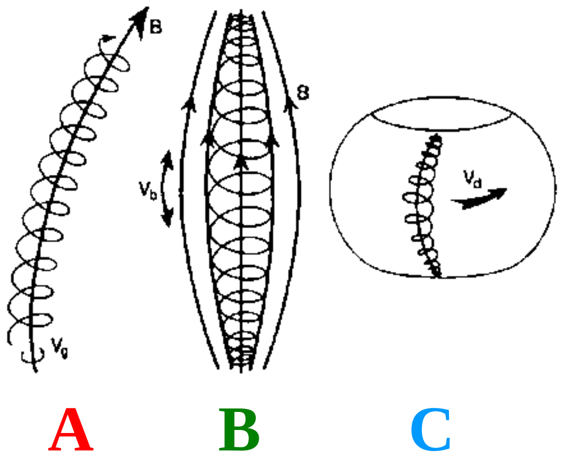


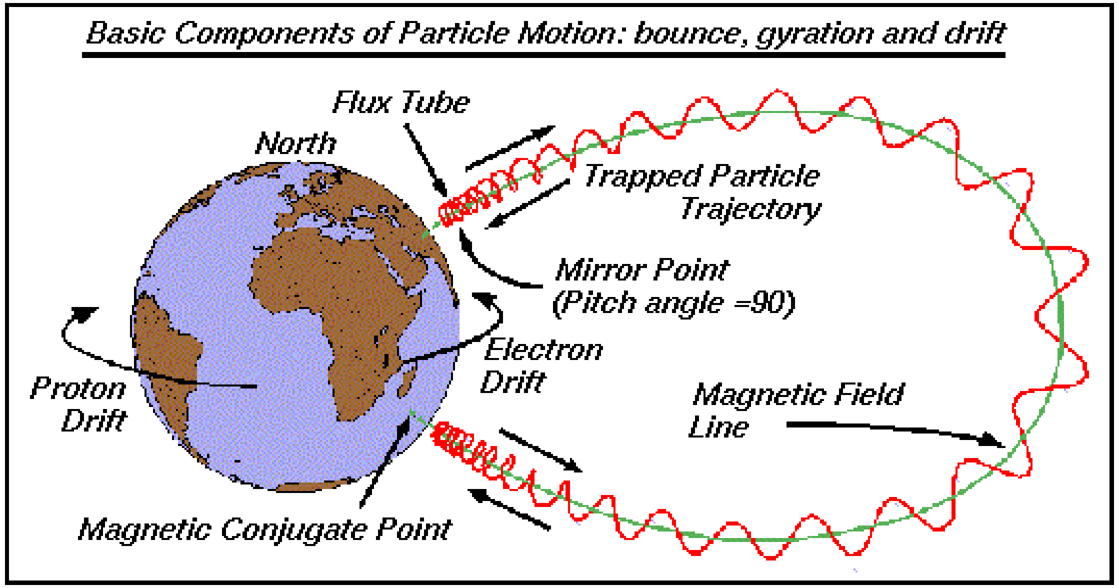
Van Allen radiation belts

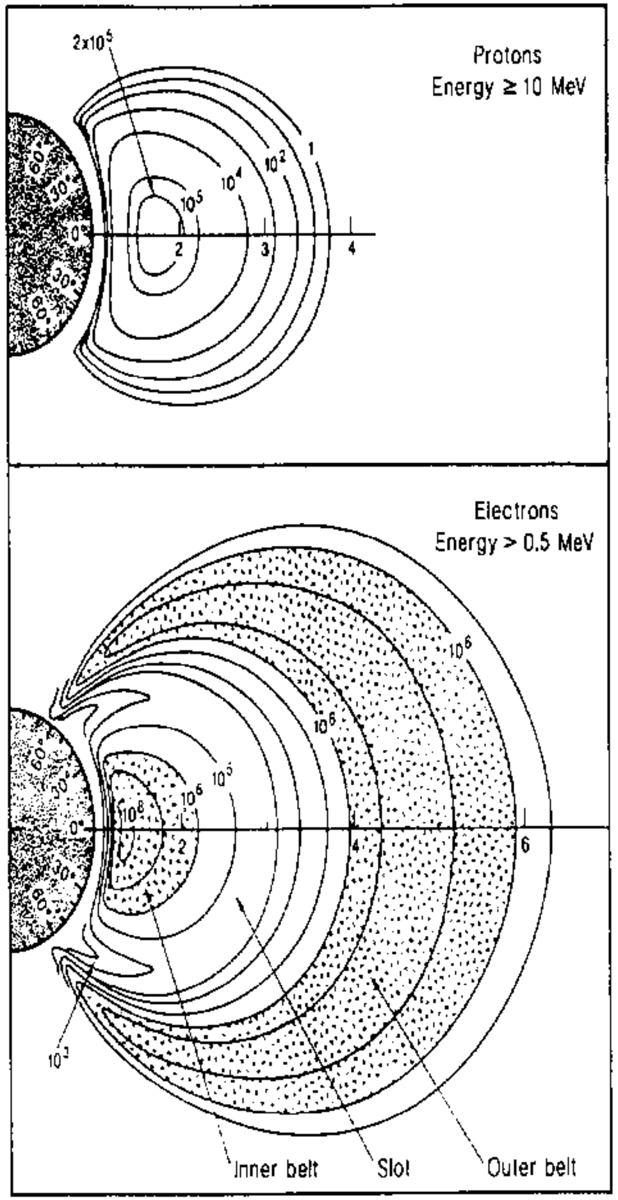
A. Gyro

B. Bounching

C. Longitudinal drift







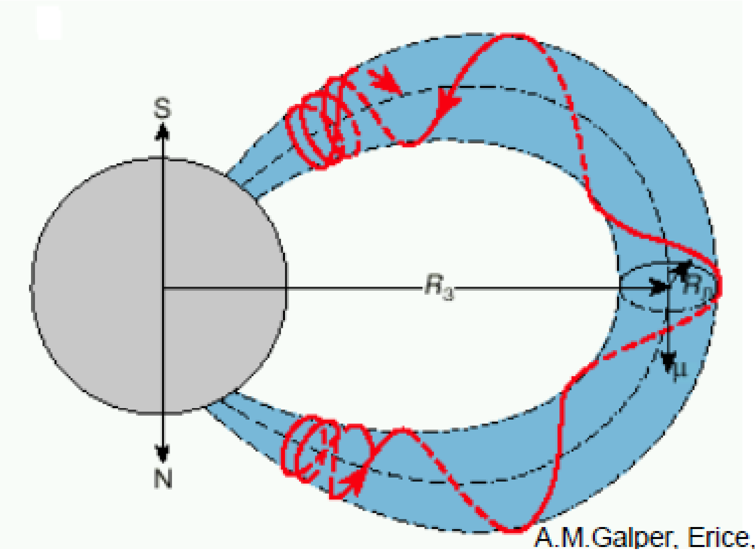
Coordinate systems

Geographical coordinates:

Latitude (ϕ)

Longitude (λ)

Altitude (h)



McIlwain coordinates: L, B

$L=r_{eq}/r_{Earth}$;

B – geomagnetic field induction;

Geomagnetic coordiantes:

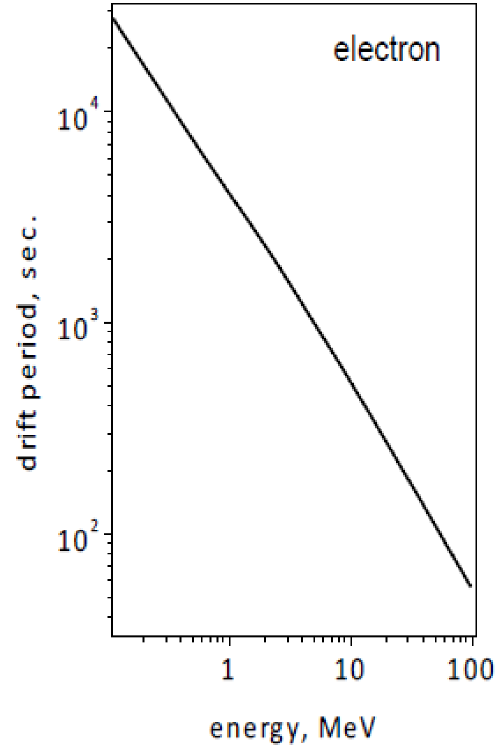
Longitude (λ)

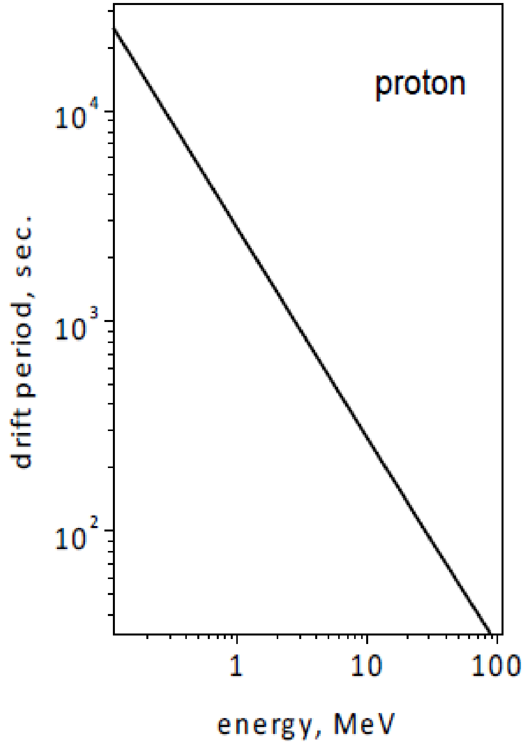
$L=1/\cos^2(\phi_m)$

ϕ_m – geomagnetic latitude

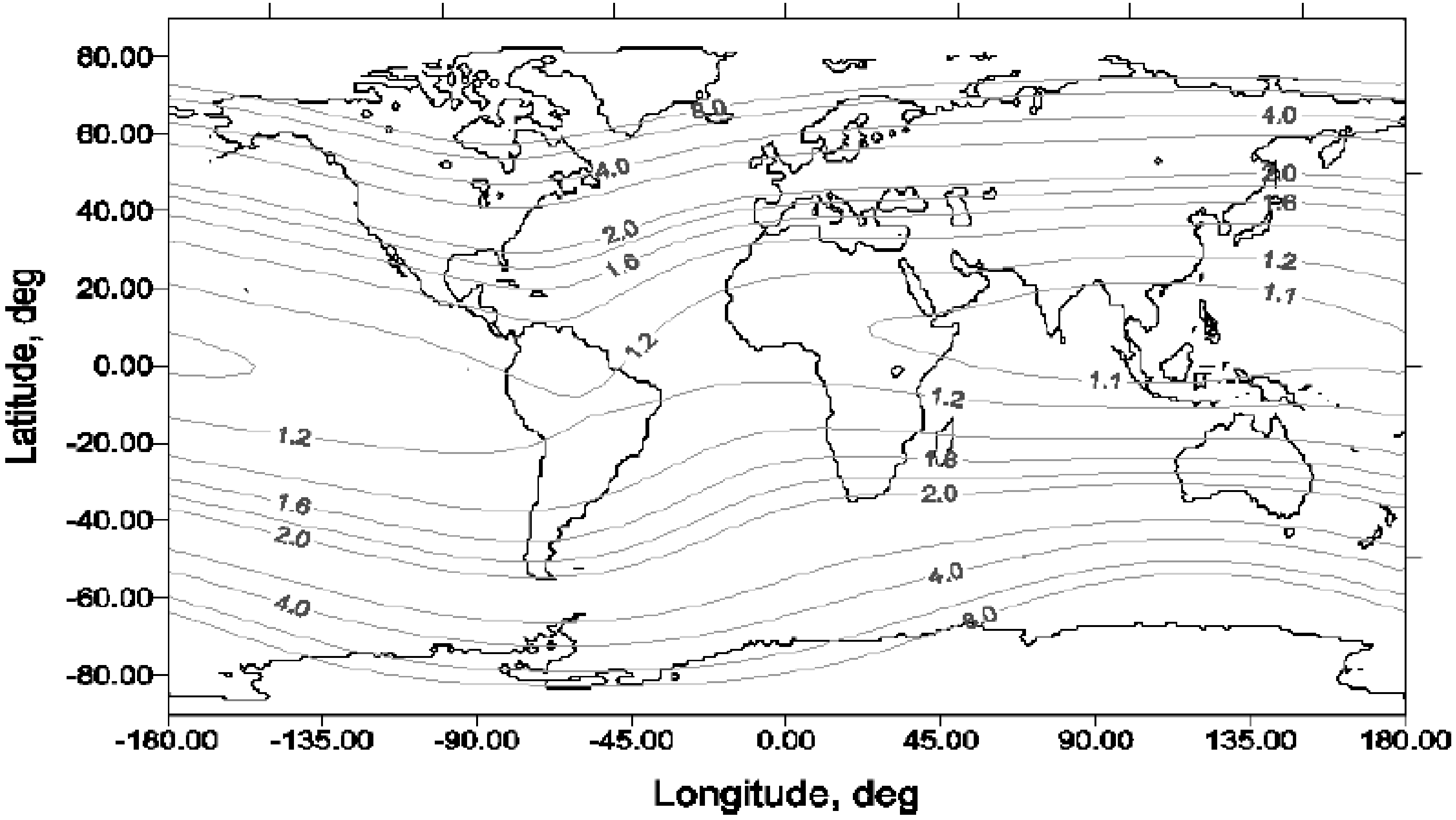
$r_{eq=} r_{Earth}+h$

Periods of longitudinal drift of electrons and protons in radiation belt (for L=1.2)





Connection between latitude and L-coordinate for low-altitude orbits (400 – 600 km)

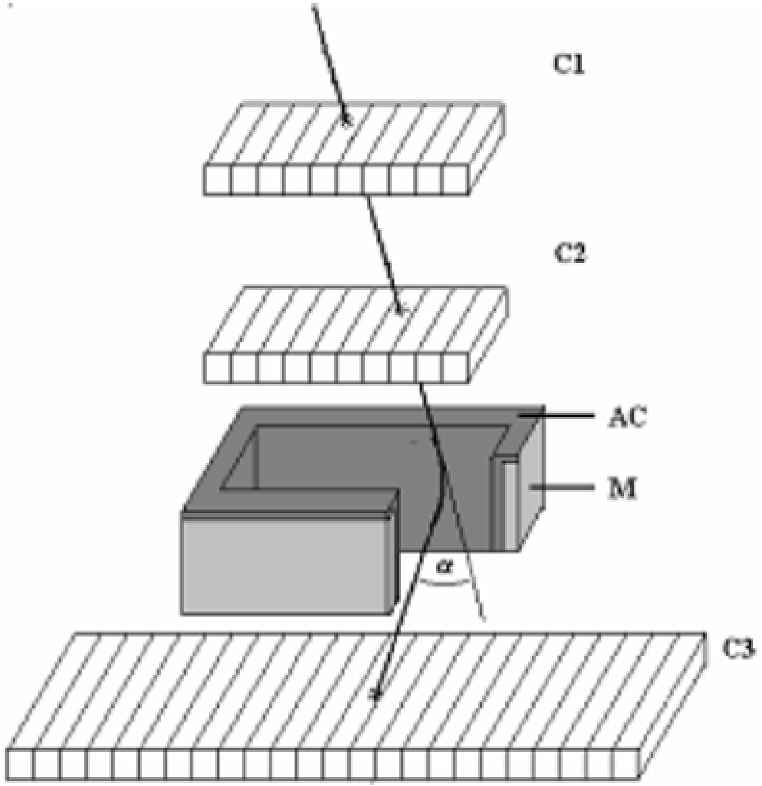


Early Space Missions

Electron and Proton flux variations below the radiation belts

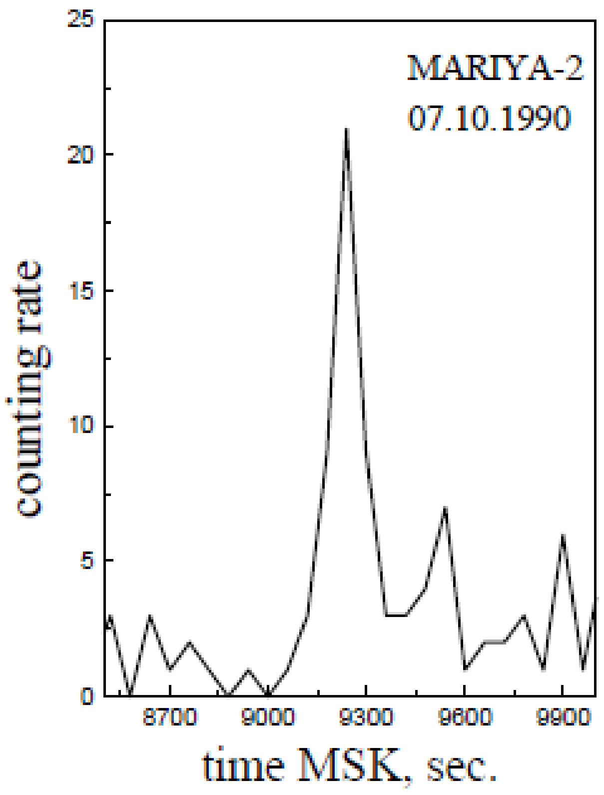
- Electron   Intercosmos Bulgaria-1300 and Meteor 3
- Mariya   Salyut 7
- Mariya-2   MIR
- Gamma 1   GAMMA Astrophysical Station
- Meteor 3A
- Oreol 3

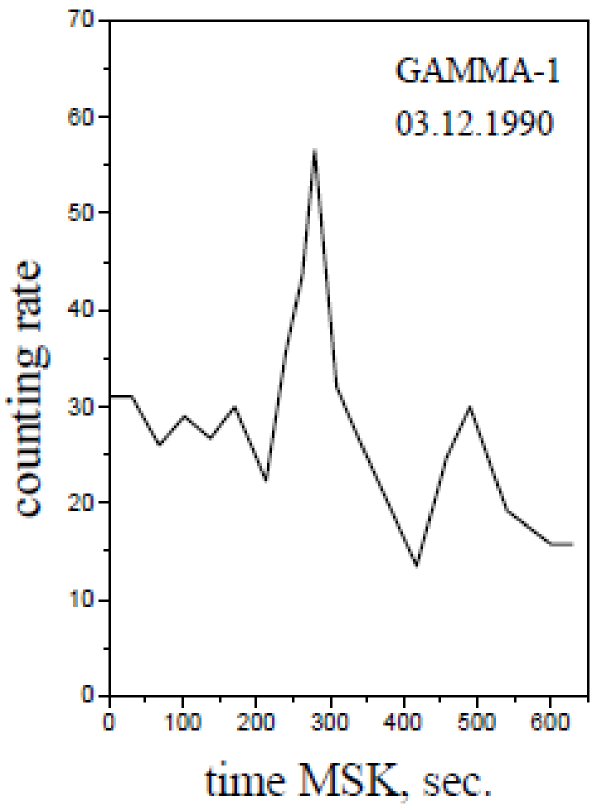
Magnetic time of flight spectrometer Mariya (Mariya-2)

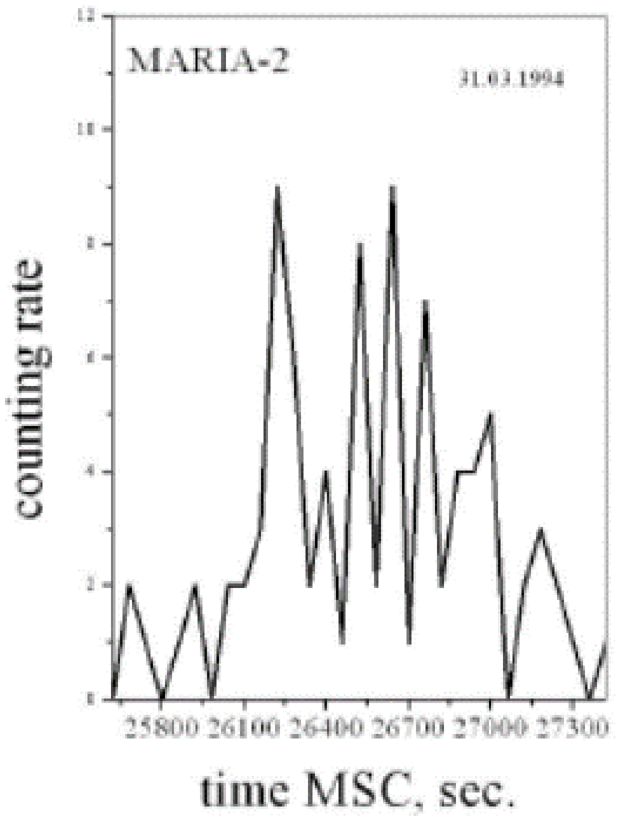


Spectrometer registers charged particles (20-200 MeV) separately: electrons, positrons, protons, antiprotons et. al., measures their energy and incident angles. Instrument consists of plastic scintillation hodoscope, permanent magnet and time of flight system.

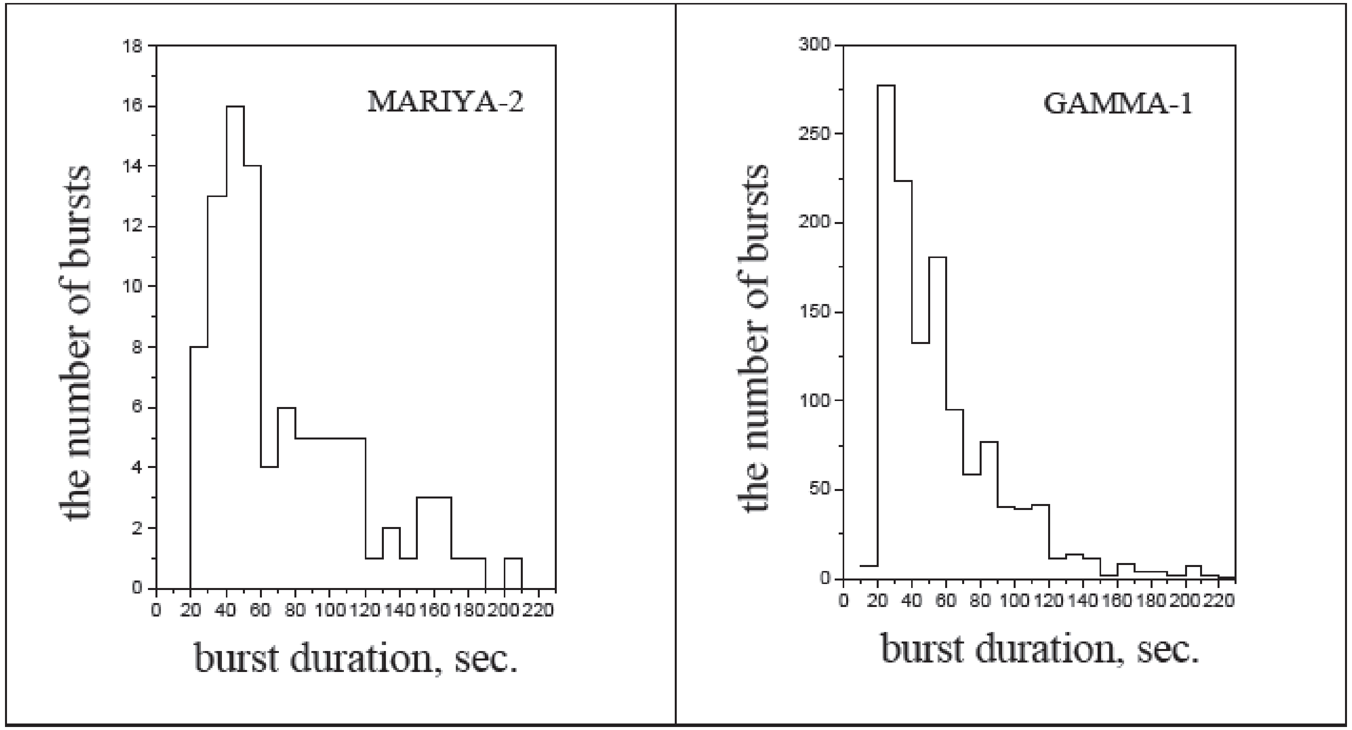
Single and Multiple Electron Bursts



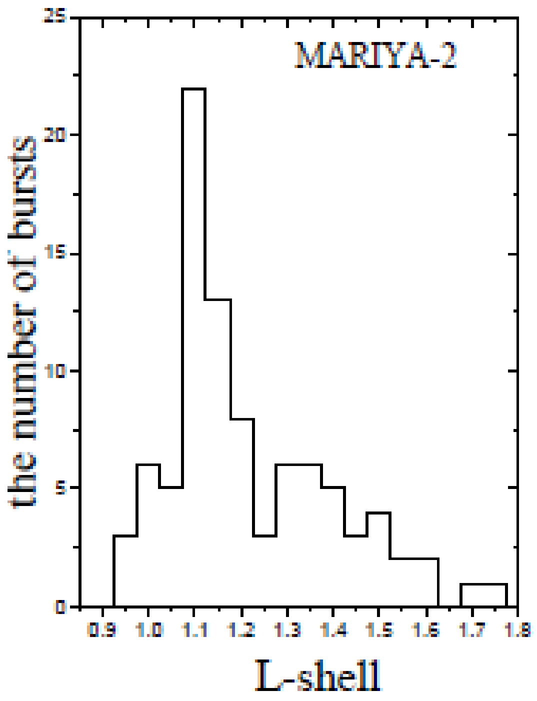


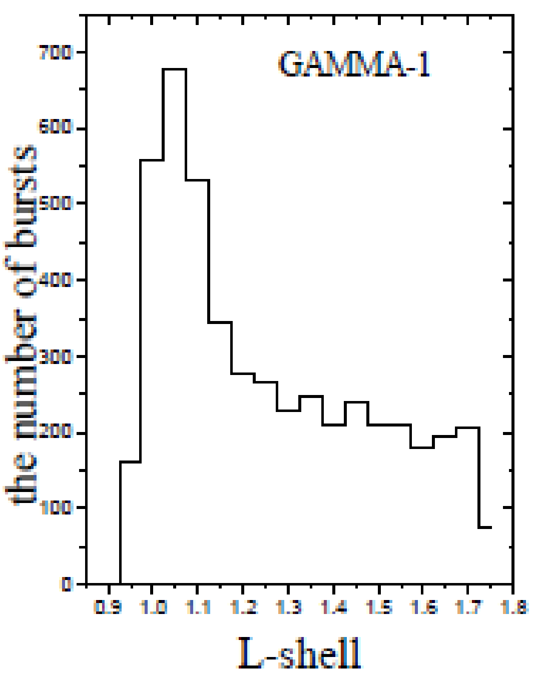


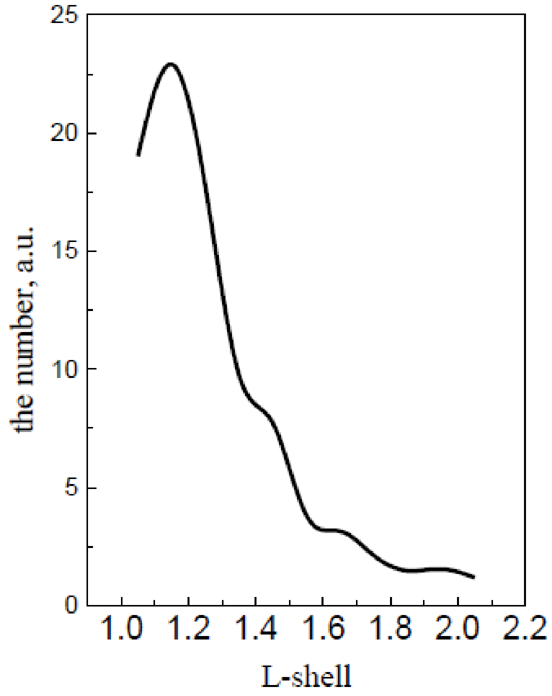
Duration distributions for high-energy electrons bursts (experimental data)



L-distribution for earthquakes







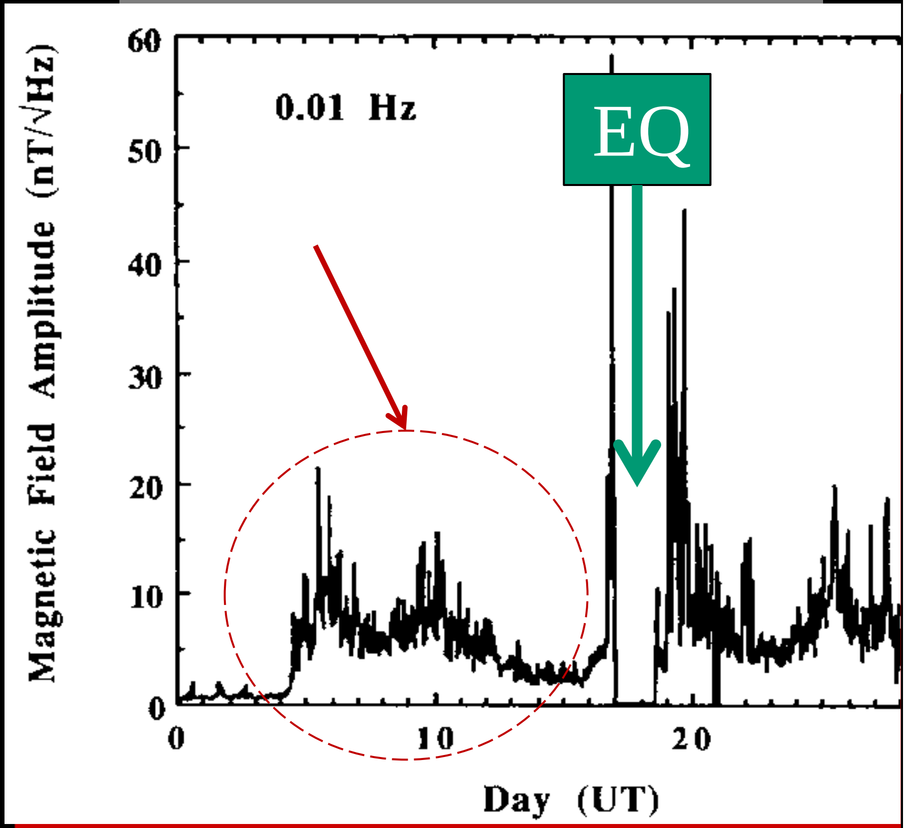
earthquake distibution

Ionospheric-magnetosferic perturbation

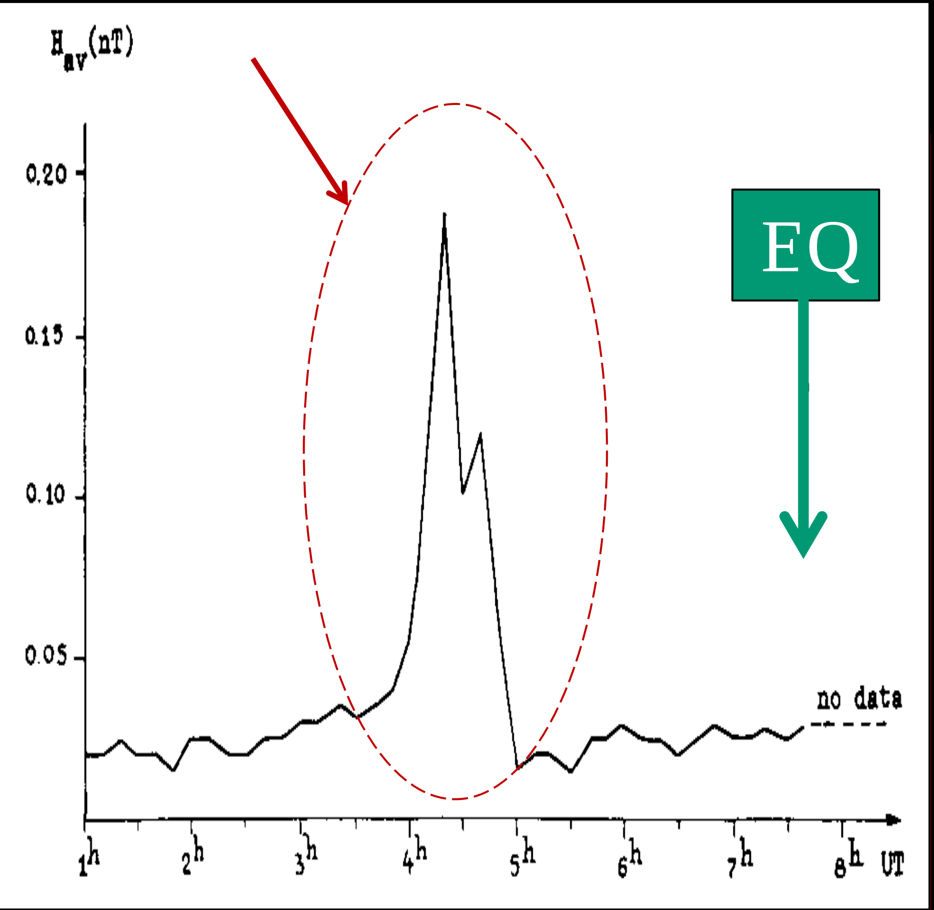
EME
- Natural emissions (earthquakes and volcanic eruptions)
- Anthropogenic emissions (PLHR, VLF & HF transmitters)

ULF EME wave-trapped particle interaction?

Ground-based preseismic EME observations



Loma Prieta earthquake, October 18, 1989, M=7.1



Spitak earthquake, December 7, 1988, M = 6.9

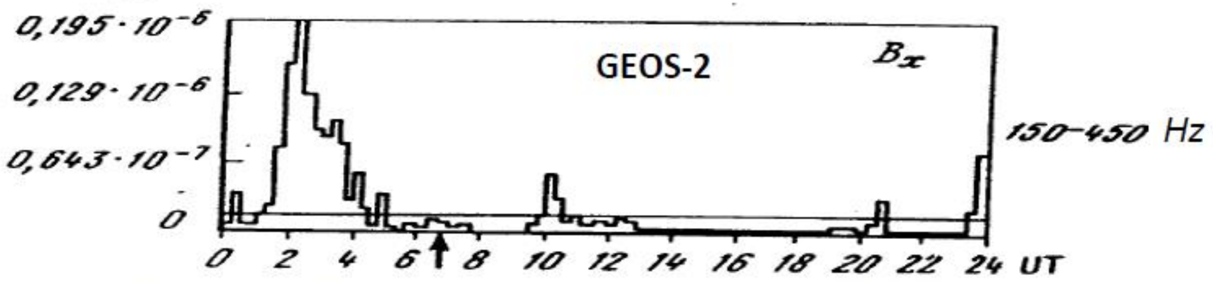
ULF and LF seismic origin electromagnetic noises.

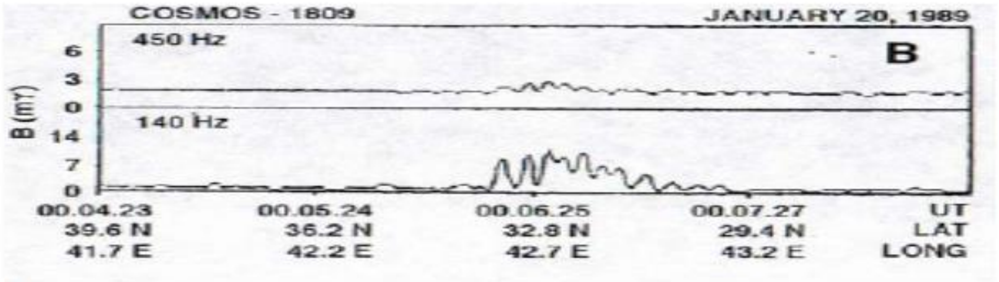
1. Observation of ULF emission on the surface of the Earth (1989, Lomo-Prieto, M=7.9). 3 hours before earthquake (0.05 – 0.2 Hz).

Fraser-Smith A.C., Bernard A., Mc. Gill P.R. Geophys. Res. Letts, 1990, 17/9, 1465.

2. Observation in the space:

V.A.Liperovsky, O.A.Pochotelov. Ionosphere precursors of the earthquakes. Moscow, Nauka, 1992, 204.





20.01.1989: Particle burst was registered in two hours and ten minutes before earthquake

Wave – particles interaction mechanism

Schematic representation in a meridian plane of the trapped particle trajectories

1

EARTHQUAKE PREPARATION AREA

2

EM WAVES PROPAGATION INTO THE IONO-MAGNETOSPHERE

3

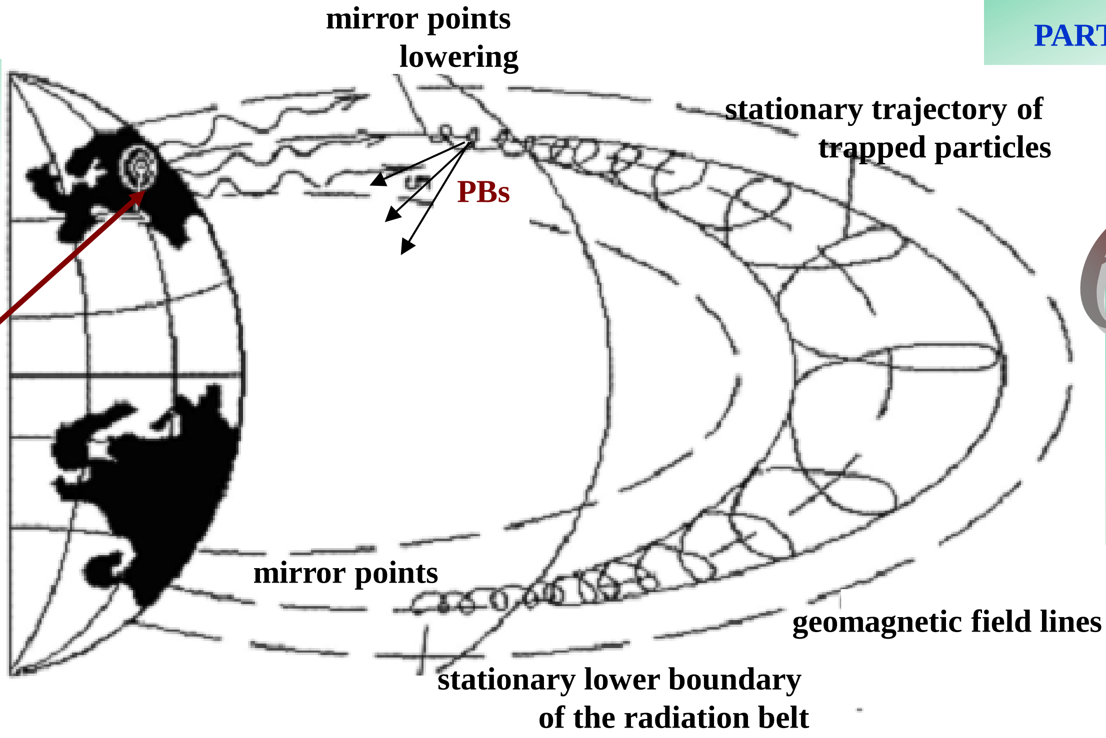
EM WAVES GENERATE PERTURBATIONS IN THE LOWER IONOSPHERE

4

EM WAVES INTERACT WITH CHARGED TRAPPED PARTICLES IN THE INNER RADIATION BELT

5

PARTICLE PITCH ANGLE CHANGES
⇓
MIRROR POINTS LOWERING
⇓
PARTICLE PRECIPITATION



6

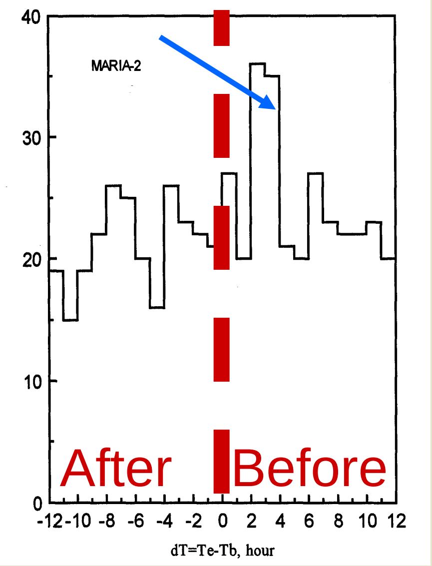
PBs PROPAGATE AROUND THE EARTH ALONG THE L-SHELL
⇓
(LONGITUDINAL DRIFT) PBs DETECTABILITY AT ANY LONGITUDE

$$\Delta L = (L_{EQ} - L_{PB}) \leq 0.1$$

$$H_{mirror} \approx 300 \text{ km}$$

$$\Delta T = T_{EQ} - T_{PB}$$

Correlations between EQ & ps: $\Delta T_{EQ\text{-}PB}$ distributions

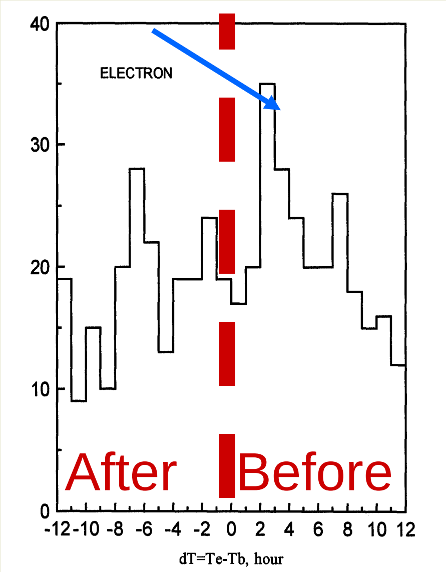


MIR mission
1985-2000

Altitude: 400 km

Inclination: 51°

E_e: 20 ÷ 200 MeV
E_p: 20 ÷ 200 MeV

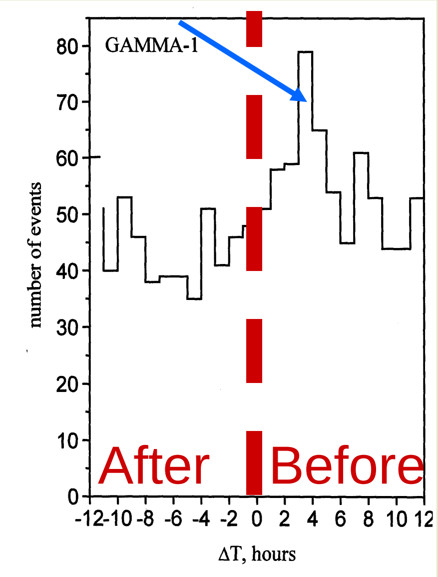


METEOR-3 mission
1985-1986

Altitude: 1250 km

Inclination: 82°

E_e: ≤ 30 MeV



GAMMA-1 mission
1990-1992

Altitude: 350km

Inclination: 51°

E_e: > 50 MeV

o

SAMPEX-PET Mission

Orbit altitude:	520÷670 km
Orbit inclination:	82°
PET Pointing modes:	ORR; MORR; 1 RPM (see text)

PET channel Level-2 data used for this study

Particles	Energy (MeV)	Geometric factor ($cm^2 sr$)	Channel
Protons	28÷60	1.5	PHI
Protons	19÷28	1.65	PLE
Electrons	2÷6	1.65	ELO
Electrons	4÷15	1.5	EHI
Electrons	4÷30	-	EWG
Protons	> 60	0.4	RNG
Electrons	> 15		
Protons	> 85	0.25	PEN
Electrons	> 30		

SAMPEX Pointing Modes

SAMPEX/PET has operated with three different pointing programs:

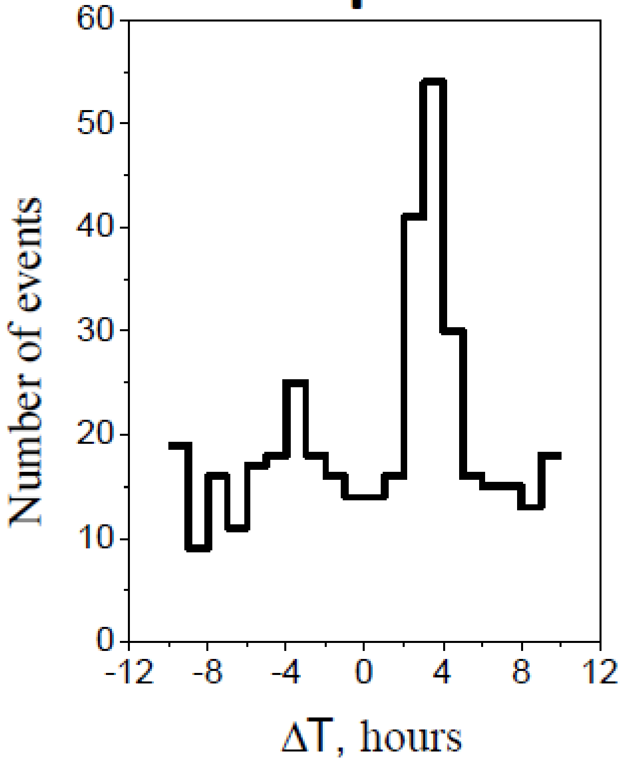
- **ORR** (original **O**rbit **R**ate **R**otation)
- **MORR** (**M**odified **O**rbit **R**ate **R**otation)
- **1 RPM** (**1 R**otation **P**er **M**inute)

✓During the ORR pointing mode the **PET yaw axis is substantially radial to the Earth**. So, PET may detect particles with pitch angle in a wide range and, in particular, also in the **loss cone** (precipitating particles) or near to it.

✓On the contrary, in the MORR mode the detector yaw axis is fundamentally **perpendicular to the geomagnetic field lines**, since it was implemented mainly to study particles with pitch angle near 90° (**trapped particles**). Measurements for α_{PET} values far from 90° are performed in periods during which PET yaw axis is parallel to the geomagnetic field (B), when B > 0.3 G, and perpendicular to it, when B < 0.3 G.

✓Finally, in the 1 RPM mode the α_{PET} distribution is flat since **the PET yaw axis, rotating continuously at 1 RPM**, allows the particle detection at **any pitch angle value**.

ΔT distribution of events (particle bursts and earthquakes). $\Delta T = T_{earthq} - T_{burst}$. Experimental data of PET/SAMPEX



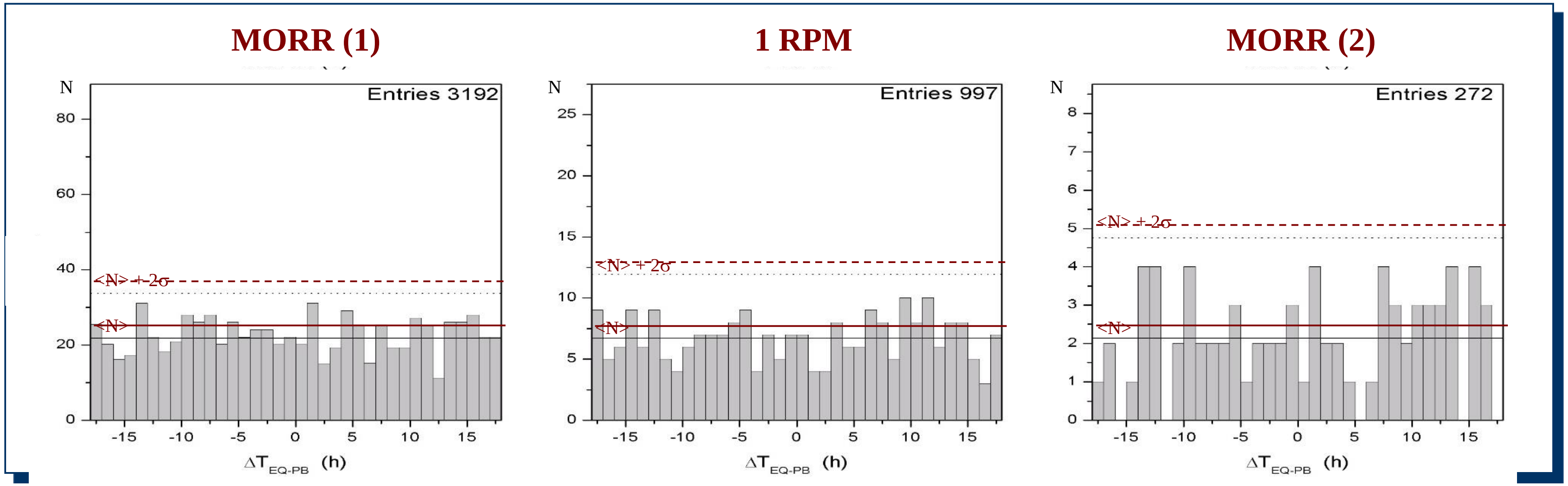
Event selection:

1) $|\Delta L| < 0.05$

2) Magnitude of earthquakes M>5.0

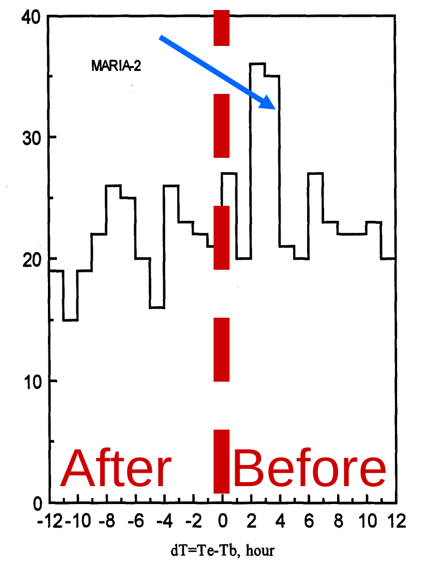
S.V.Aleksandrin, A.M.Galper, S.V.Koldashov et al. Annales Geophysical, 2003, 21, 597.

Dependence of the $\Delta T_{EQ\text{-}PB}$ correlation on the PET yaw axis orientation



- ✓ **No correlation** is obtained (that is, no relevant peak is observed) with PBEHI data collected in the other **MORR(1)**, **1RPM**, and **MORR(2)** pointing periods
- ✓ **No correlation** is obtained in the 4 pointing mode periods with **PBELO** data.

Correlations between EQ & ps: $\Delta T_{EQ\text{-}PB}$ distributions



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1985-2000

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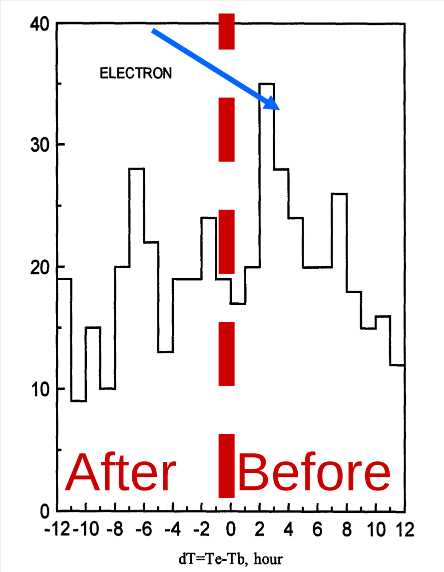
Inclination: 51°

E_e: 20 ÷ 200 MeV
E_p: 20 ÷ 200 MeV



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Altitude: 1250 km

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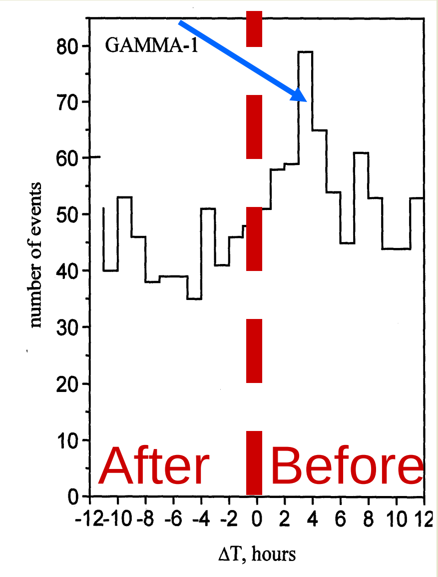
E_e: ≤ 30 MeV



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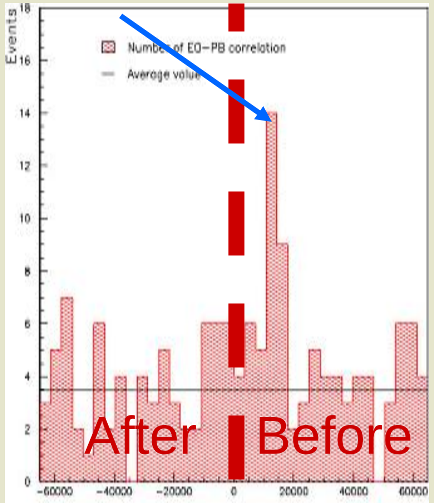
1990-1992

Altitude: 350km

Inclination: 51°

E_e: > 50 MeV



ORR
(Orbit Rate Rotation;
July 1992 - May 1994)

SAMPEX/PET
Mission 1992-1999

Altitude: 520÷740km

Inclination: 82°

4 ≤ E_e ≤ 15 MeV

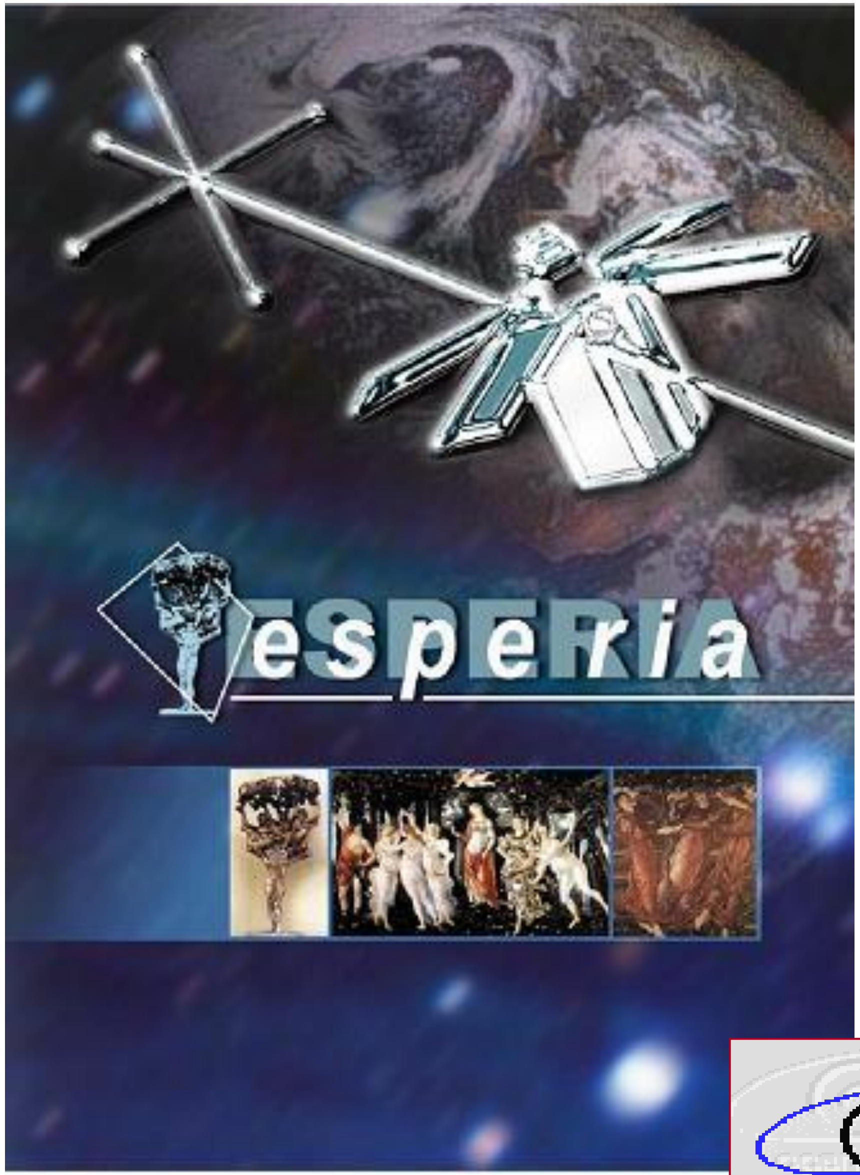
Phase A Report
Italian Space Agency Program for Small Scientific Missions
July 2001

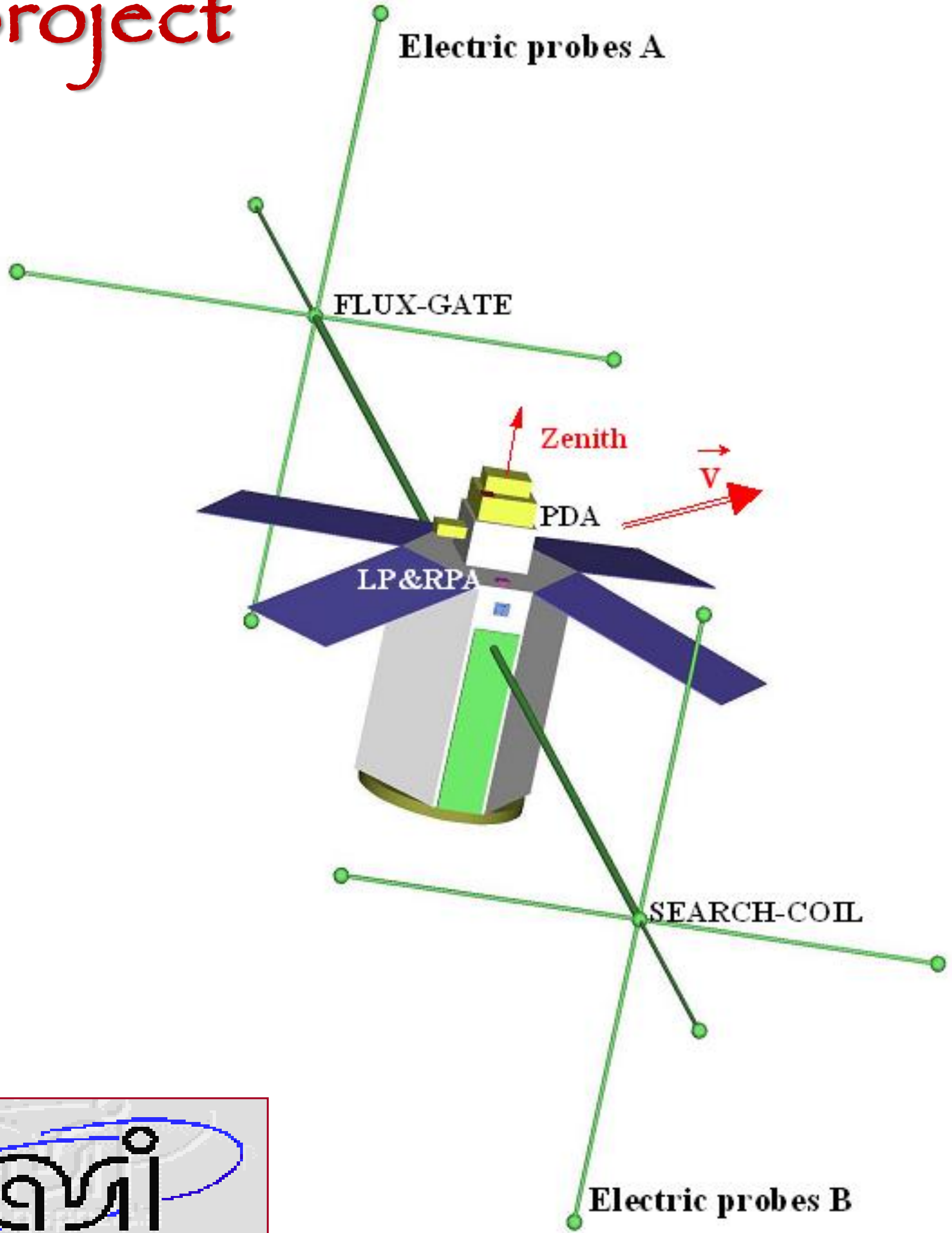
ESPERIA

Earthquake investigation by **S**atellite and **P**hysics of the **E**nvironment **R**elated to the **I**onosphere and **A**tmosphere

Vittorio Sgrigna Piergiorgio Picozza Livio Conti

ESPERIA project





agenzia spaziale italiana

LAZIO

LOW
ALTITUDE
ZONE
IONIZATION
OBSERVATORY

&

ENEIDE mission

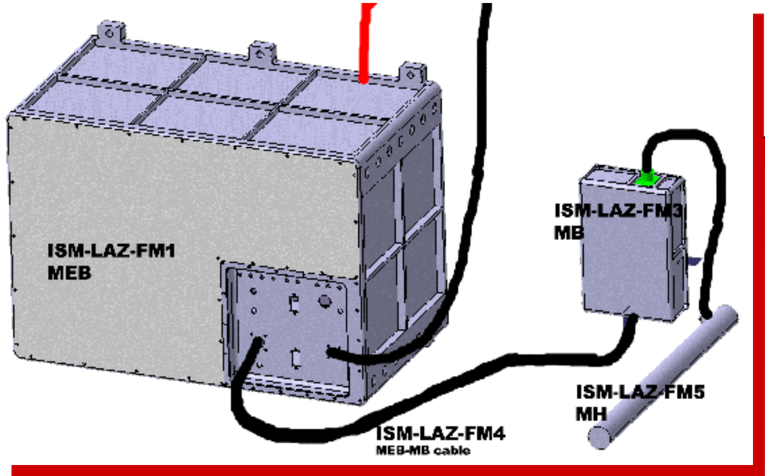
15-25 April 2005

Roberto
Vittori

esa

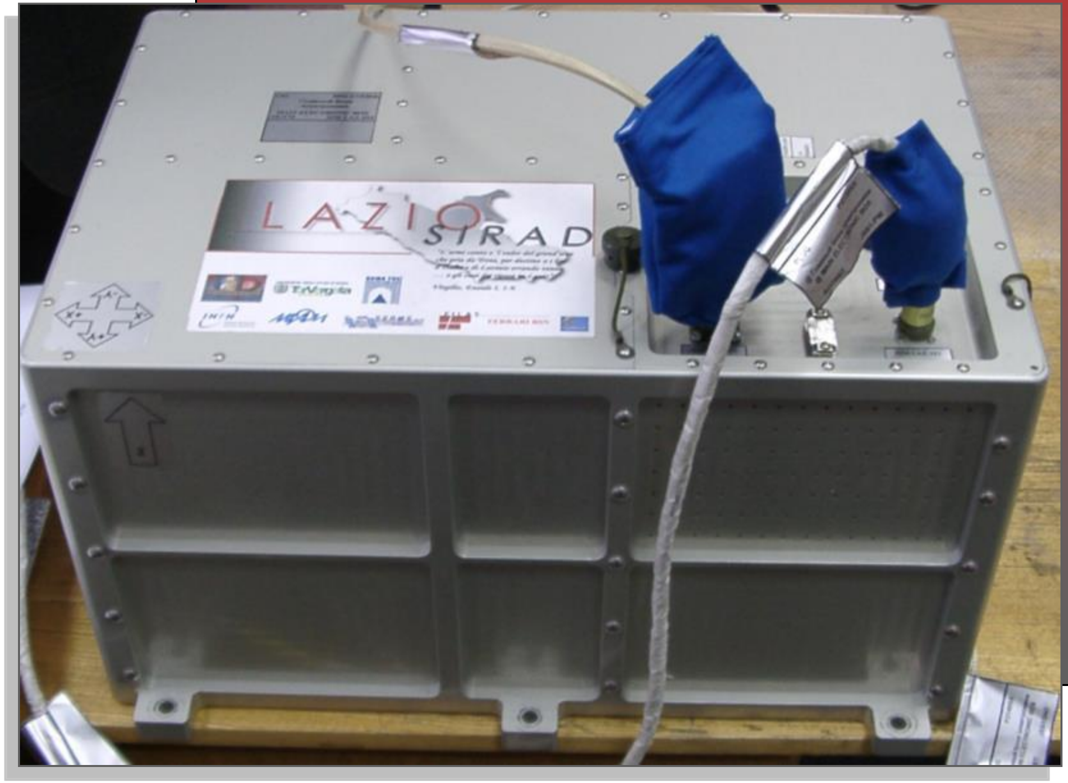
EGLE

Esperia
Geo-magnetometer
for a **L**ow-frequency
wave **E**xperiment


ISM-LAZ-FM1
MEB
ISM-LAZ-FM3
MB
ISM-LAZ-FM5
MH
ISM-LAZ-FM4
MEB-MB cable

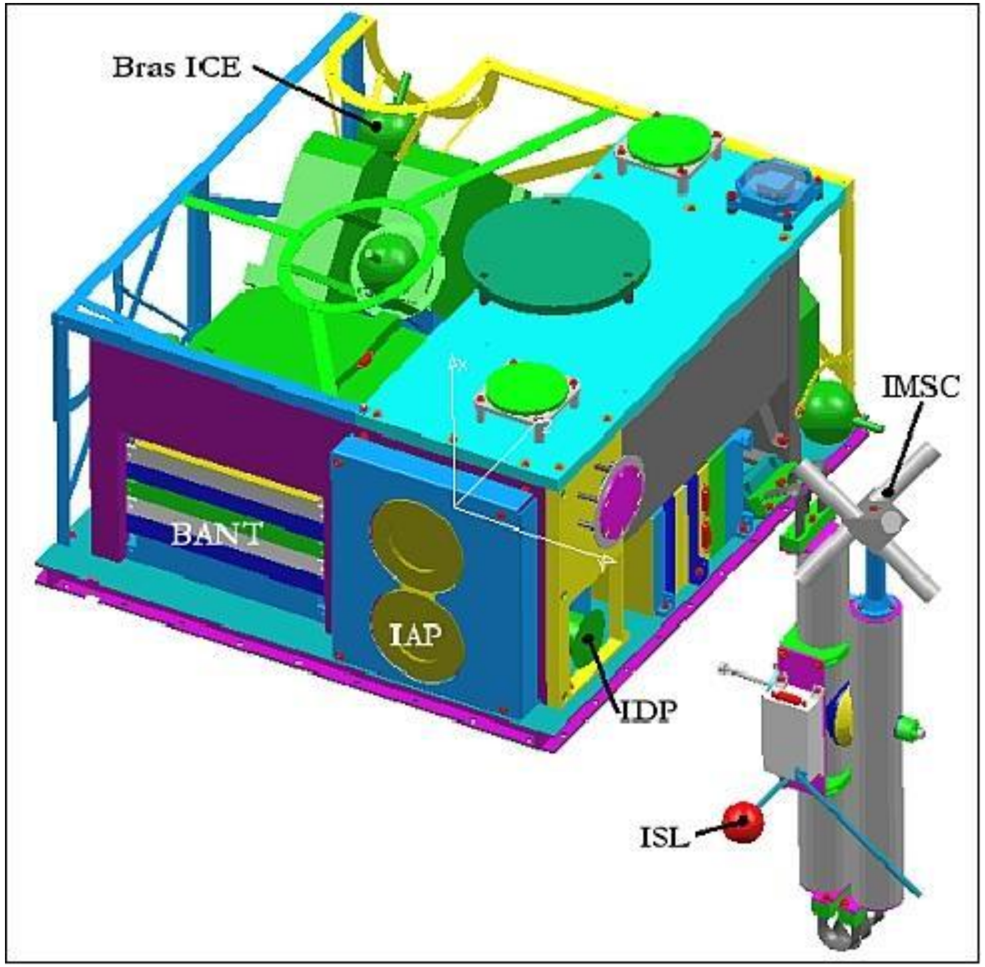
LAZIO & EGLE


EGLE


LAZIO
SIRAD

DEMETER   Talk M. Parrot

29/06/2004 – 9/12/2010

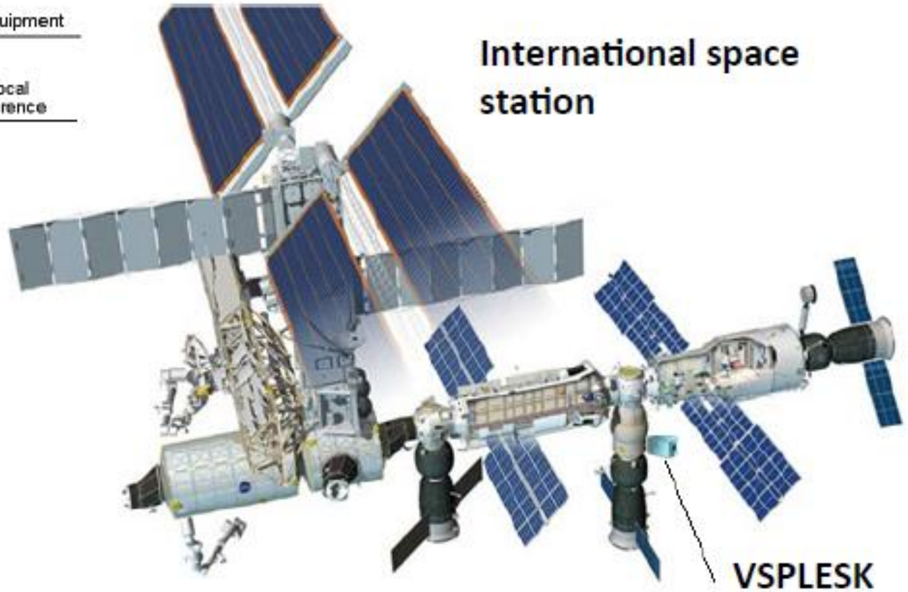


The Resurs DK1 and VSPLESK ERA AGILE?

ARINA (Resurs-DK1 satellite, inclination 71°, altitude 350-600 km, from 2006)
VSPLESK (ISS, inclination 51,6°, altitude 300-350 km, from 2006)

Resurs DK1 satellite

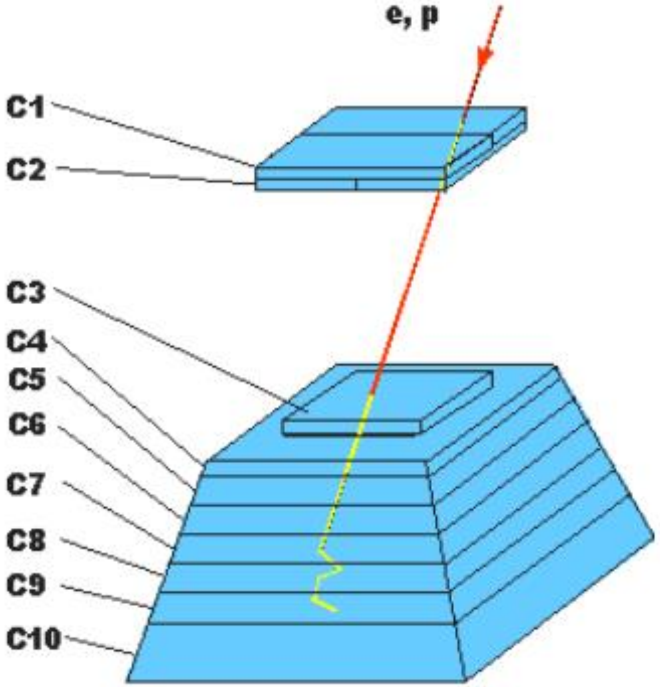
International space station



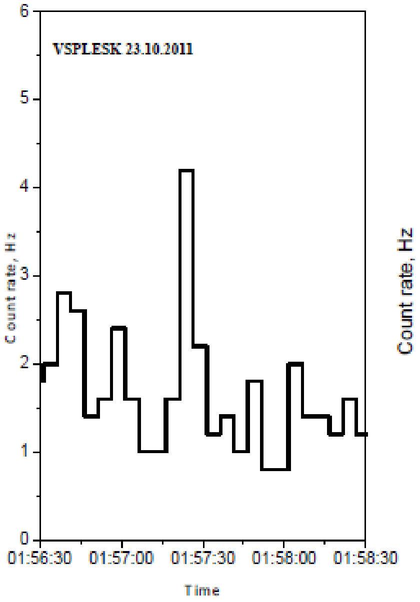
ARINA instrument

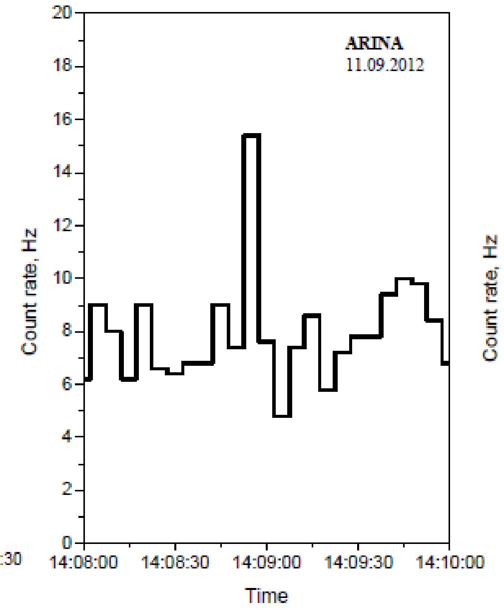
On the basis of multilayer scintillation detector.
Acceptance of ARINA 10-50 times higher than acceptance of instruments, used in earlier experiments for similar studies.

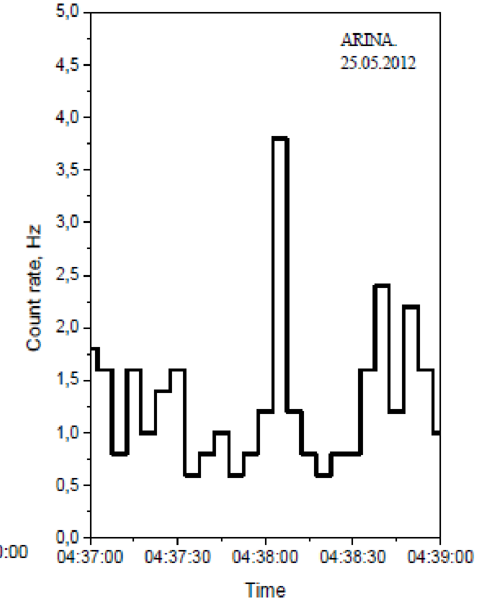
Acceptance		10 sm^2sr
Aperture		±30 degrees
Energy range	protons	30 – 100 MeV
	electrons	3 – 30 MeV
Energy resolution	protons	10%
	electrons	15%
Time resolution		100 ns
Mass		8,6 kg
Power consumption		13,5 W



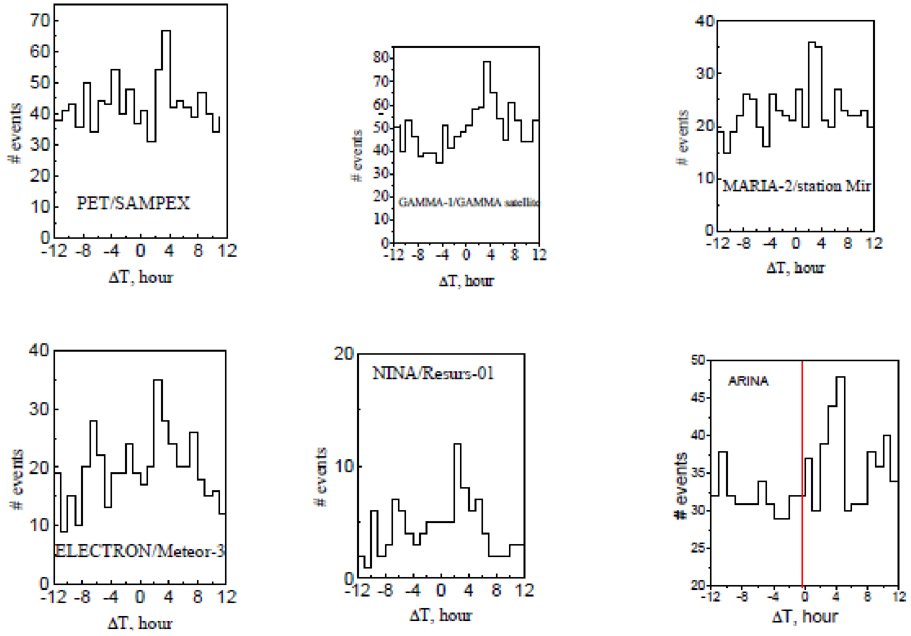
ARINA and VSPLESK experiment. Experimental data examples for particle bursts

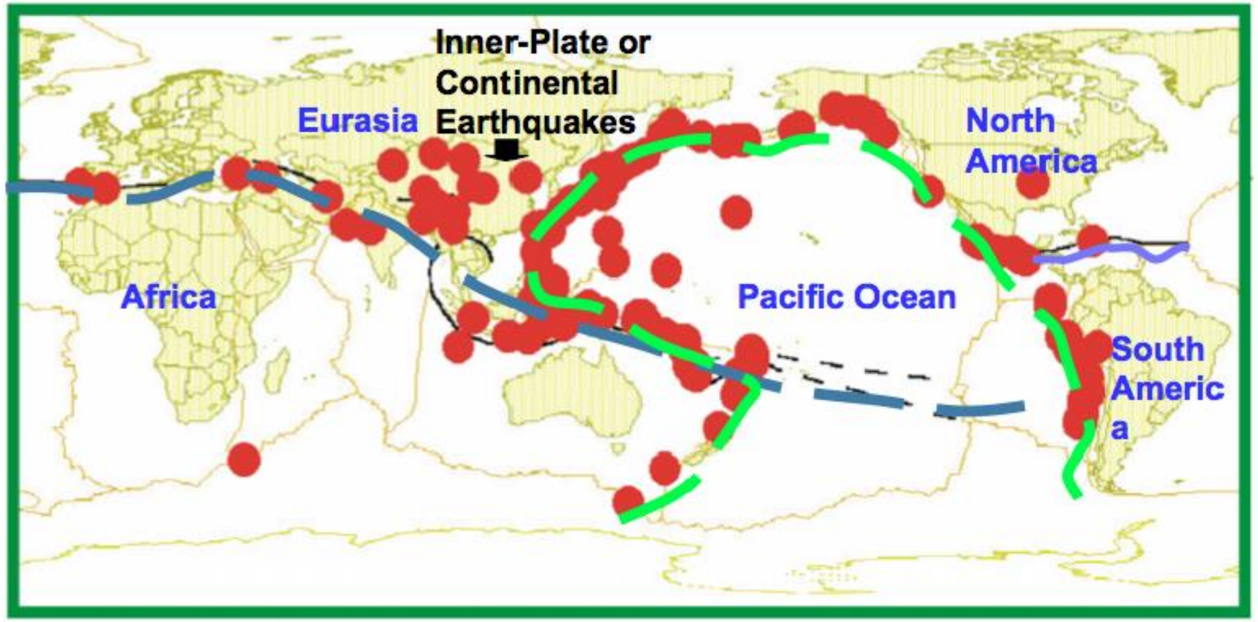






ΔT distributions of events for various satellite experiments. $\Delta T = (T_{equake} - T_{burst})$, $\Delta L < 0.1$, $\Delta L = |L_{equake} - L_{burst}|$



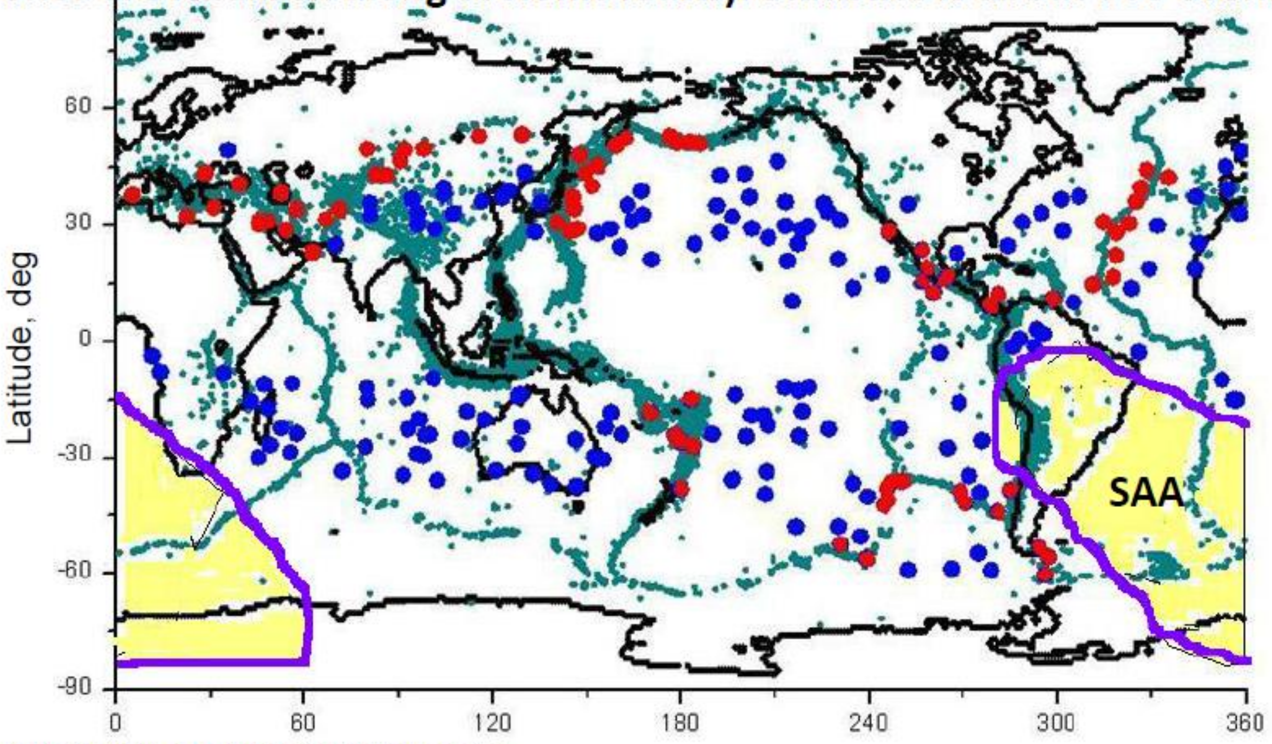


The Distribution Map of Seismic Belts

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

Every two day there is a M>6 Earthquake

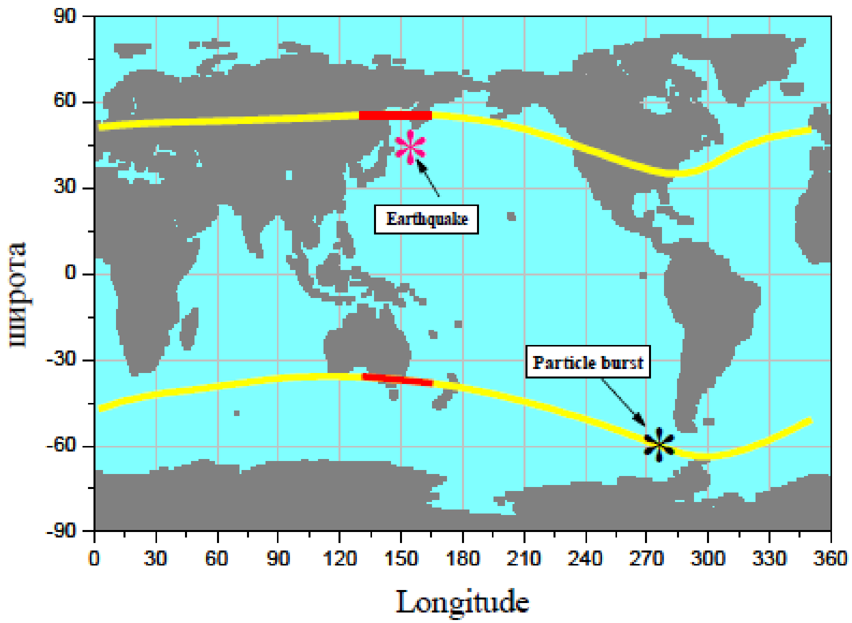
ARINA (2006 – 2011) and VSPLESK (2008 – 2011) experiments. Geographical distribution of high-energy electron bursts. Light green lines – tectonic faults. Blue and red dots – particle bursts (red ones are localized along tectonic faults). Statistics is about 300 events.



S.V.Aleksandrin, A.M.Galper, S.V.Koldashov et al.
Proc. 31 RCRC, Moscow, MSU, 2010, GEO_9.

A.M.Galper, Erice, Italy, 23 October 2012

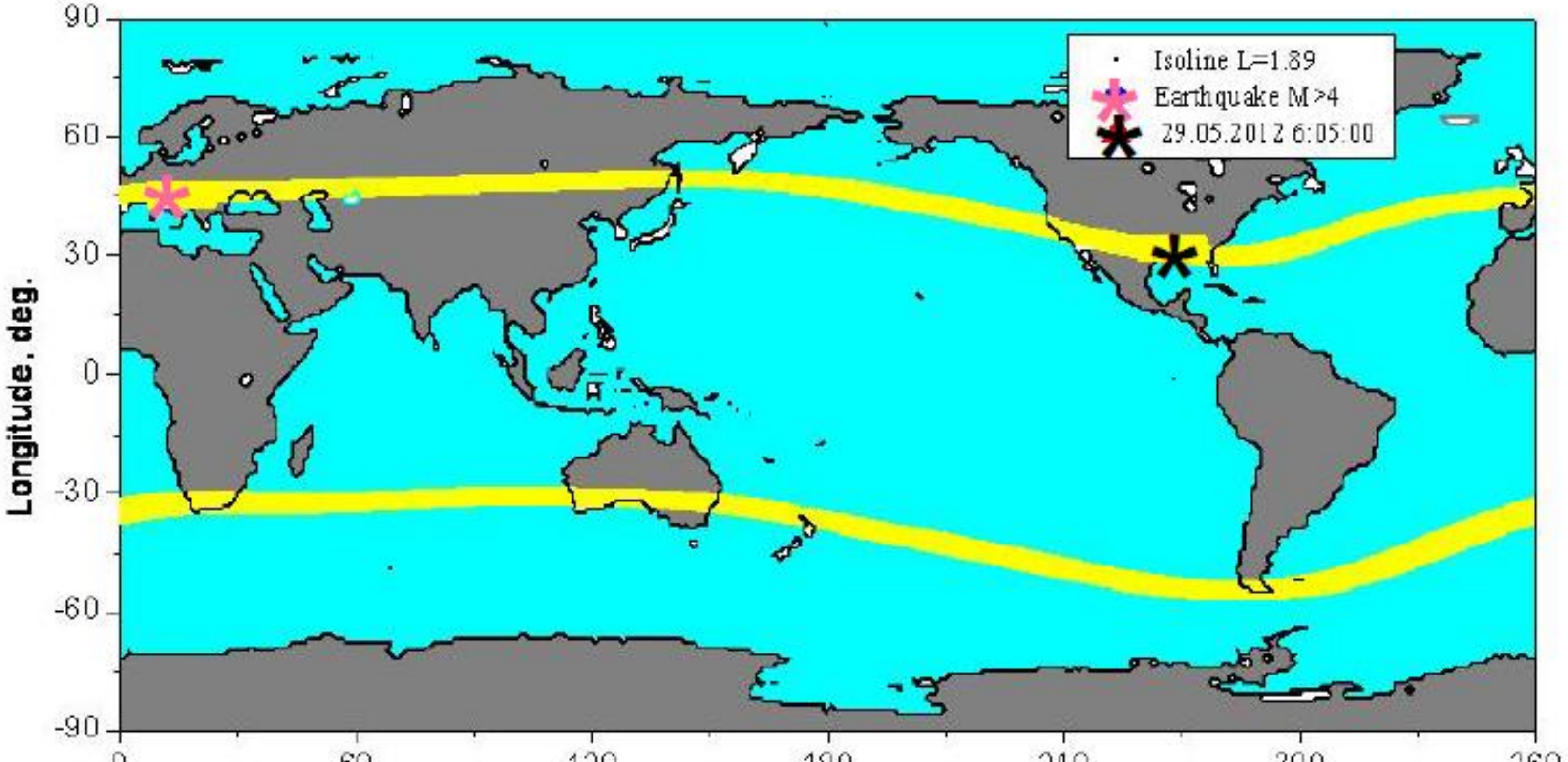
ARINA observation of event 13.06.2006. particle burst (4:20); earthquake M=5.0 (6:30)



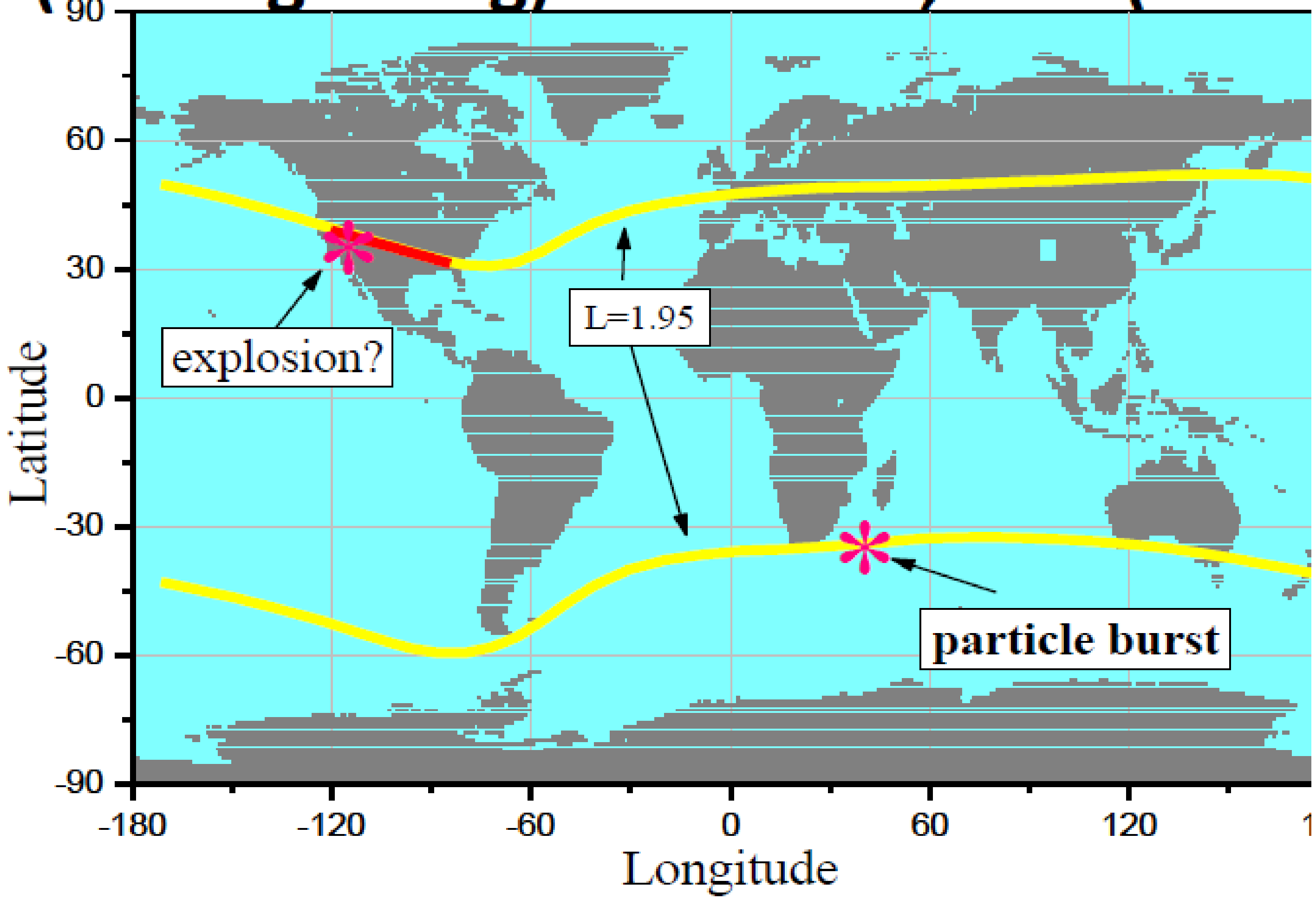
S.V.Aleksandrin, A.V.Bakaldin, A.M.Galper et al. Izvestiya RAN, 2009, 73, 379.

- At this moment, it' s possible to use the following way for using particle bursts for remote diagnostics of local magnetospheric and geophysical events, including seismic. If the spectrometer on the satellite registered a electron burst, it is possible to determine the location (latitude) of the local perturbation of the radiation belts, which should be at the same L-shell that the place of particle burst registration. In case of a seismic disturbance that occurred during the earthquake preparation, it possible to determine the latitude of forthcoming earthquake. If there is a difference in the time of registration between groups of particle bursts with different energies, then by analyzing of the time structure and energy spectra of particles detected during the burst can provide additional constraints on the longitude of the location of possible disturbance source of the radiation belt, that is, longitude of the upcoming earthquake. The figure below illustrates this approach.

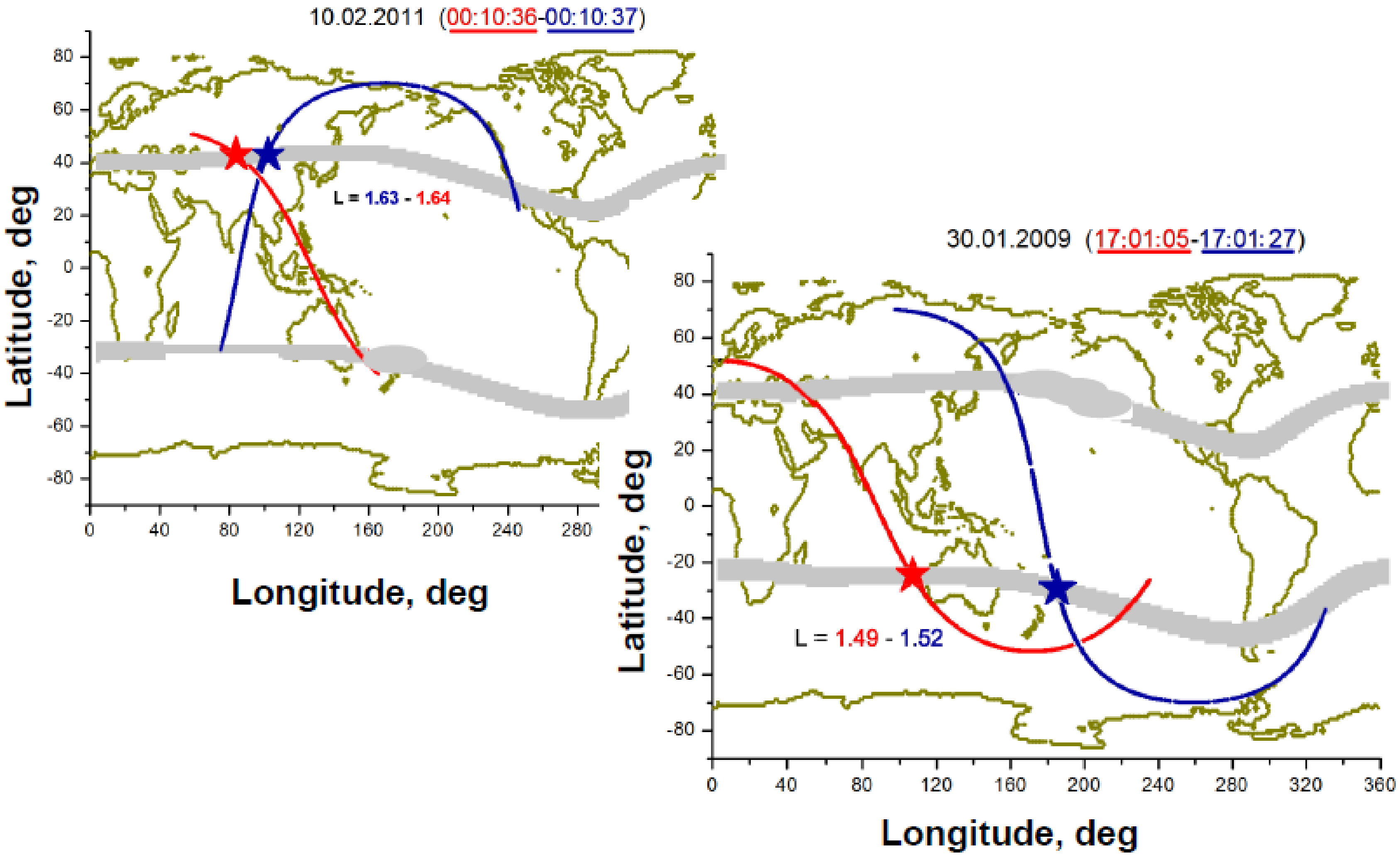
ARINA observation of event 29.05.2012. Particle burst (06:05:00 UTC); earthquakes M from 4.3 to 5.5 (first 08:15:09 UTC)



ARINA observation of event 05.06.2006 particle burst (18:57); chemical explosion (dust lightning) in Nevada, USA (18:53)



Simultaneous observation of electron bursts on ISS (red) and Resurs-DK1 satellite (blue)



Conclusions

- **PBs of precipitating high-energy Van Allen electrons appear to precede statistically by some hours the occurrence of moderate and strong EQs.**

- **No correlation was found between PBs and other non-seismic sources.**

Indication for a deeper investigation of the physical mechanisms under study.

The Next Future

- LIMADOU- CSES

CHINA SEISMO-ELECTROMAGNETIC SATELLITE

- Talk R. Battiston

Thanks!

http://spaceweather.roma2.infn.it