# *LISA Charging Research in Perugia and Plans for Virgo*

Workshop on Charging Issues in
Experimental Gravity
Massachusetts Institute of Technology
Cambridge
July 26-27, 2008

*Helios Vocca*
*INFN sez. di Perugia*
*(N.i.P.S. Laboratory)*

N.i.P.S Laboratory
Noise in Physical Systems

# *The Environment:*

The charging process is mainly due to:

- Primary Cosmic Rays (p = 90%, He = 8%, Heavy Nuclei = 1%, $e^-$ = 1%)
- Solar energetic particles (SEPs)

# *Primary cosmic rays*

## *interpolation function*

$$F(E) = A(E + B)^{-\alpha} E^{\beta}$$

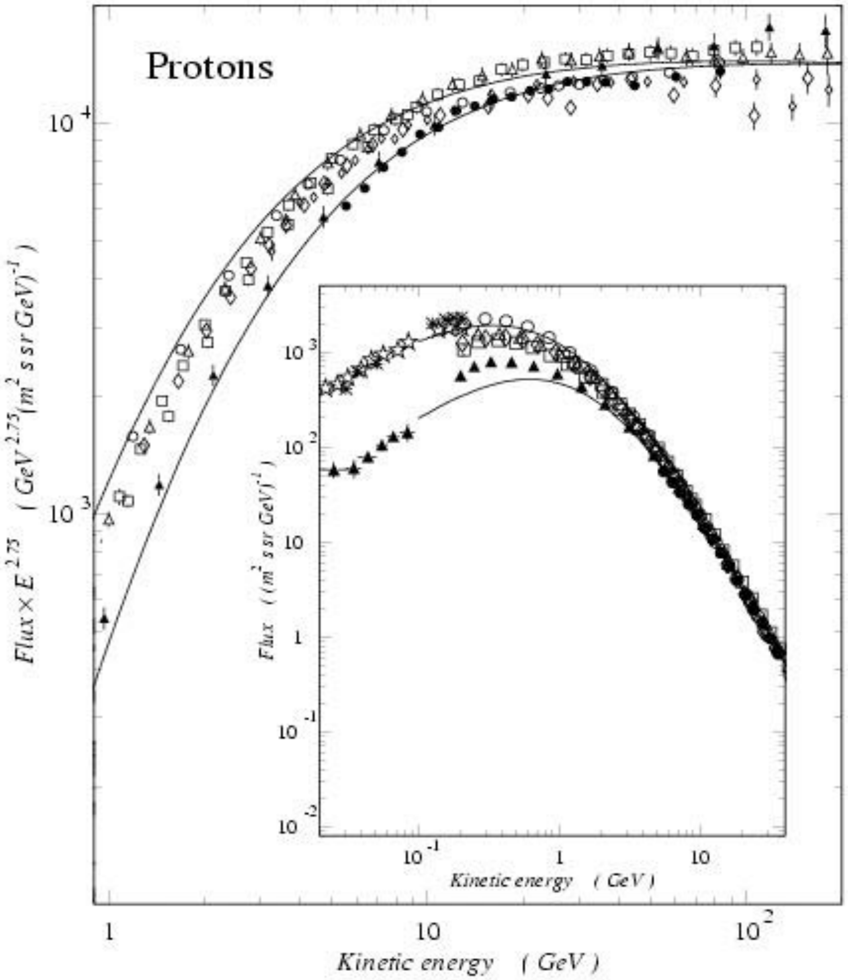
Where E is the energy in GeV/n and:

Solar minimum

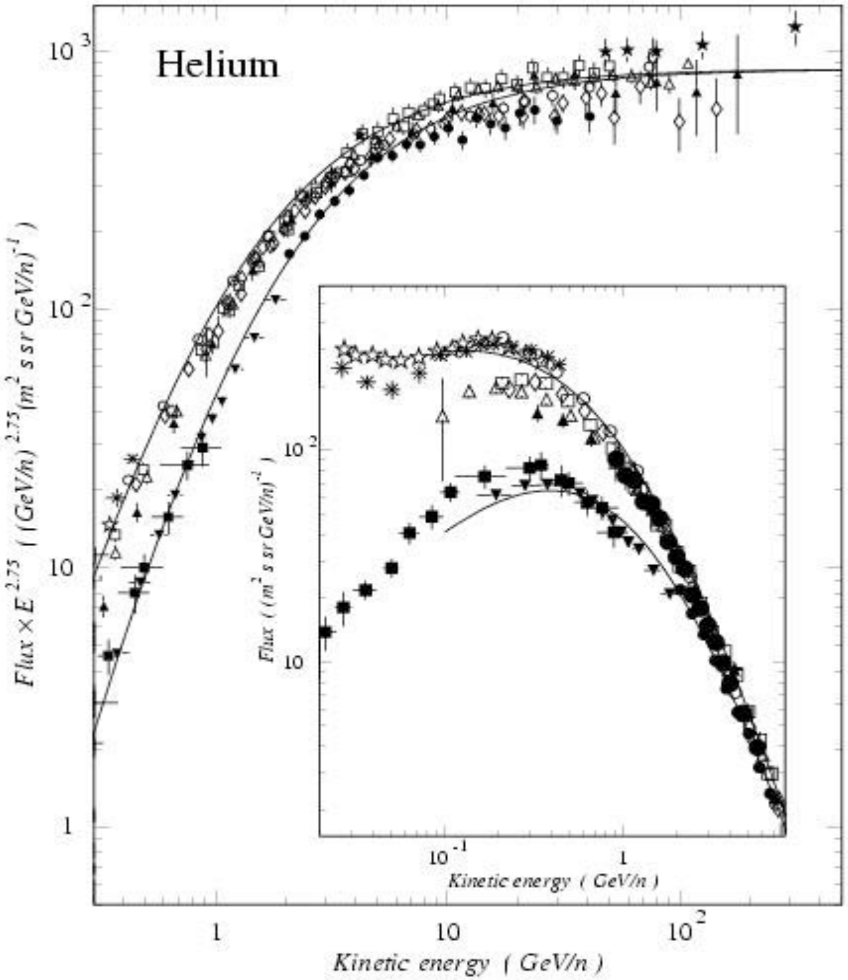
| | A | B | α | β |
|---|---|---|---|---|
| p | 18000 | 1.09 | 3.66 | 0.87 |
| He | 850 | 0.99 | 3.10 | 0.35 |
| C | 23 | 0.95 | 3.00 | 0.29 |
| O | 21 | 0.95 | 3.00 | 0.32 |

Solar maximum

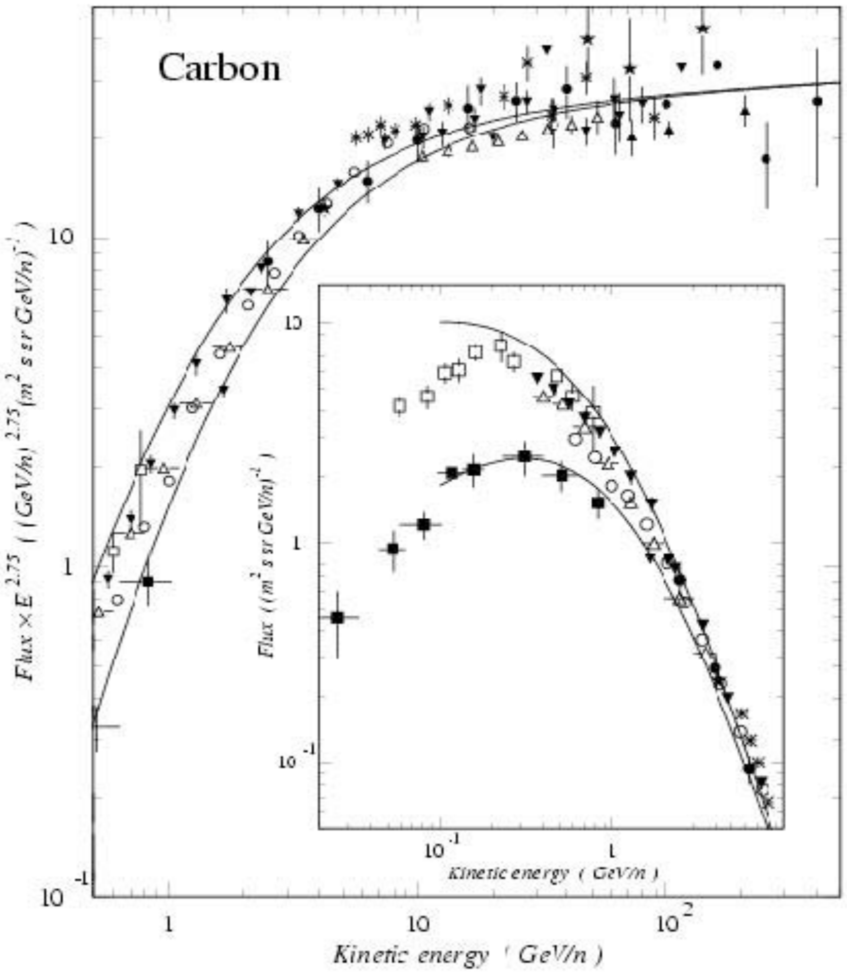
| | A | B | α | β |
|---|---|---|---|---|
| p | 18000 | 1.55 | 3.90 | 1.11 |
| He | 850 | 1.25 | 3.60 | 0.85 |
| C | 23 | 1.22 | 3.40 | 0.69 |
| O | 21 | 1.22 | 3.40 | 0.72 |

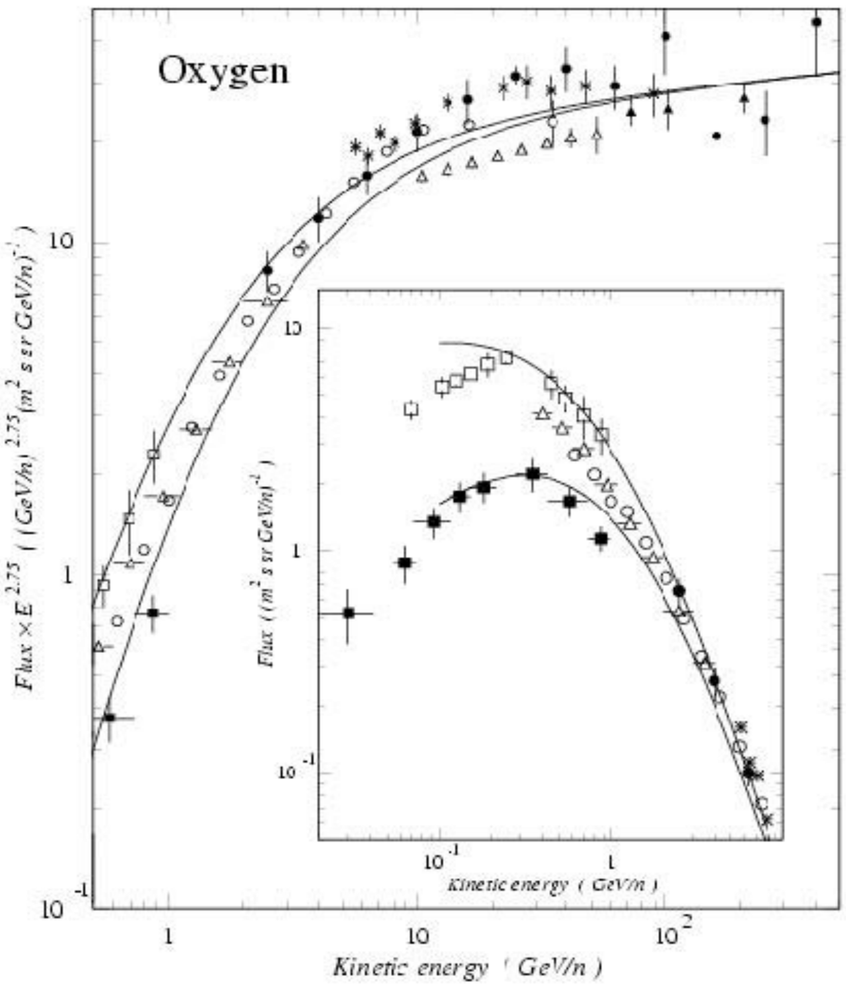


Protons
$10^4$
$10^3$
$Flux \times E^{2.75}$ ( $GeV^{2.75}(m^2\ s\ sr\ GeV)^{-1}$ )
1
10
$10^2$
Kinetic energy ( GeV )
$10^3$
$10^2$
10
1
$10^{-1}$
$10^{-2}$
Flux ( $(m^2\ s\ sr\ GeV)^{-1}$ )
$10^{-1}$
1
10
Kinetic energy ( GeV )



Helium
10 3
10 2
10
1
Flux × E 2.75 ( (GeV/n) 2.75 (m 2 s sr GeV/n) -1 )
1
10
10 2
Kinetic energy ( GeV/n )
Flux ( (m 2 s sr GeV/n) -1 )
10 2
10
10 -1
1
Kinetic energy ( GeV/n )


Carbon
Flux × E^2.75 ( (GeV/n)^2.75 (m^2 s sr GeV/n)^-1 )
Kinetic energy ( GeV/n )
Flux ( (m^2 s sr GeV/n)^-1 )
Kinetic energy ( GeV/n )


Oxygen
Flux × E^2.75 ( (GeV/n)^2.75 (m^2 s sr GeV/n)^-1 )
Kinetic energy ( GeV/n )
Flux ( (m^2 s sr GeV/n)^-1 )
Kinetic energy ( GeV/n )

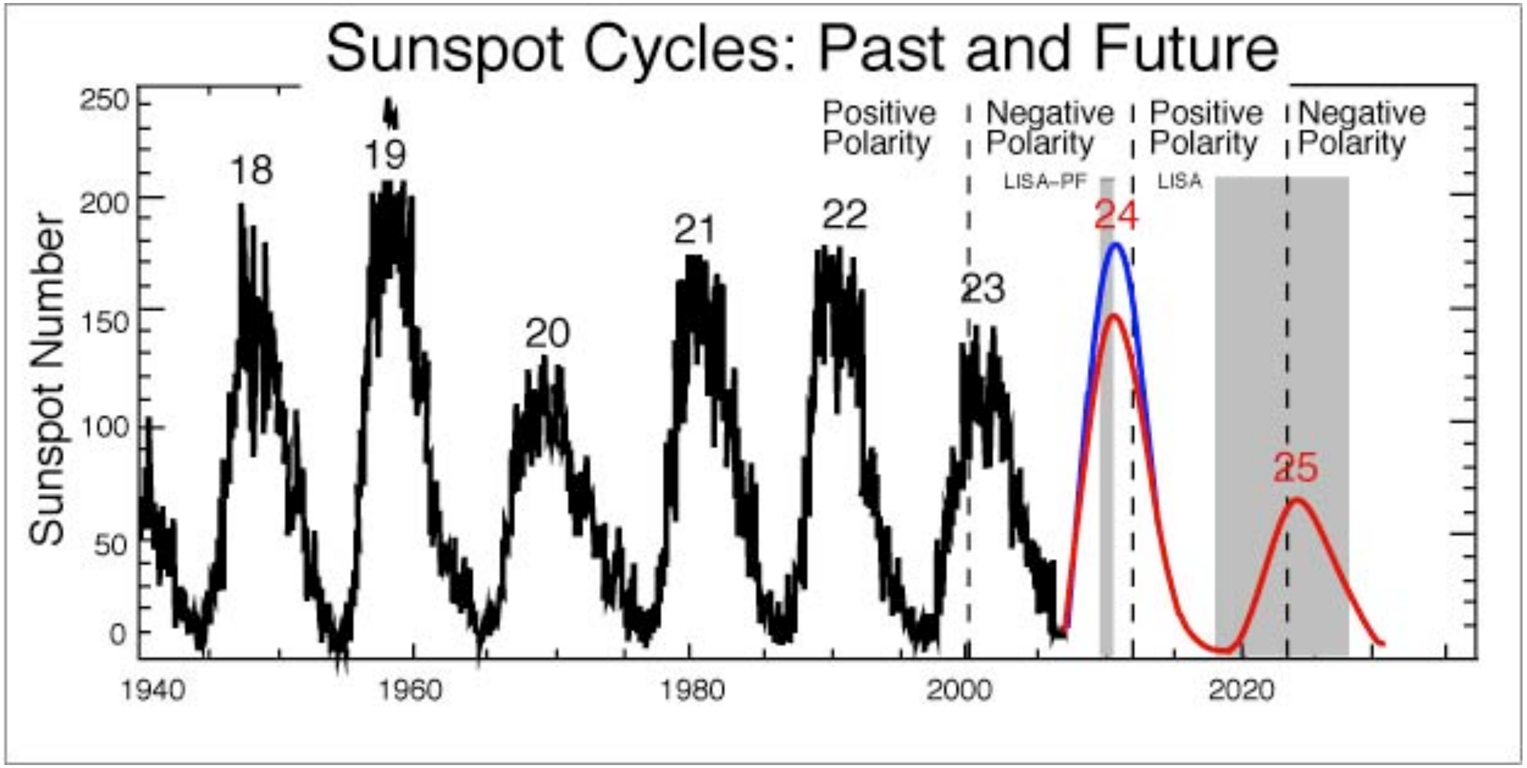
# *Solar flares*

The long waiting time distribution for solar flares is given by the formula:

$$P(\Delta t) \approx \lambda_0^{1-\delta} \Delta t^{-\delta}$$

Where $2 \leq \delta \leq 3$, $\Delta t \geq \lambda_0^{-1}$ and $\lambda_0 \approx 0.15\ \mathrm{hr}^{-1}$

# *Rate of occurrence of solar flares*




D. Hathaway and Dikpati M. http://science.nasa.gov/headlines/y2006/10may_lagrange.htm

# *Solar Energetic Particles (SEPs)*

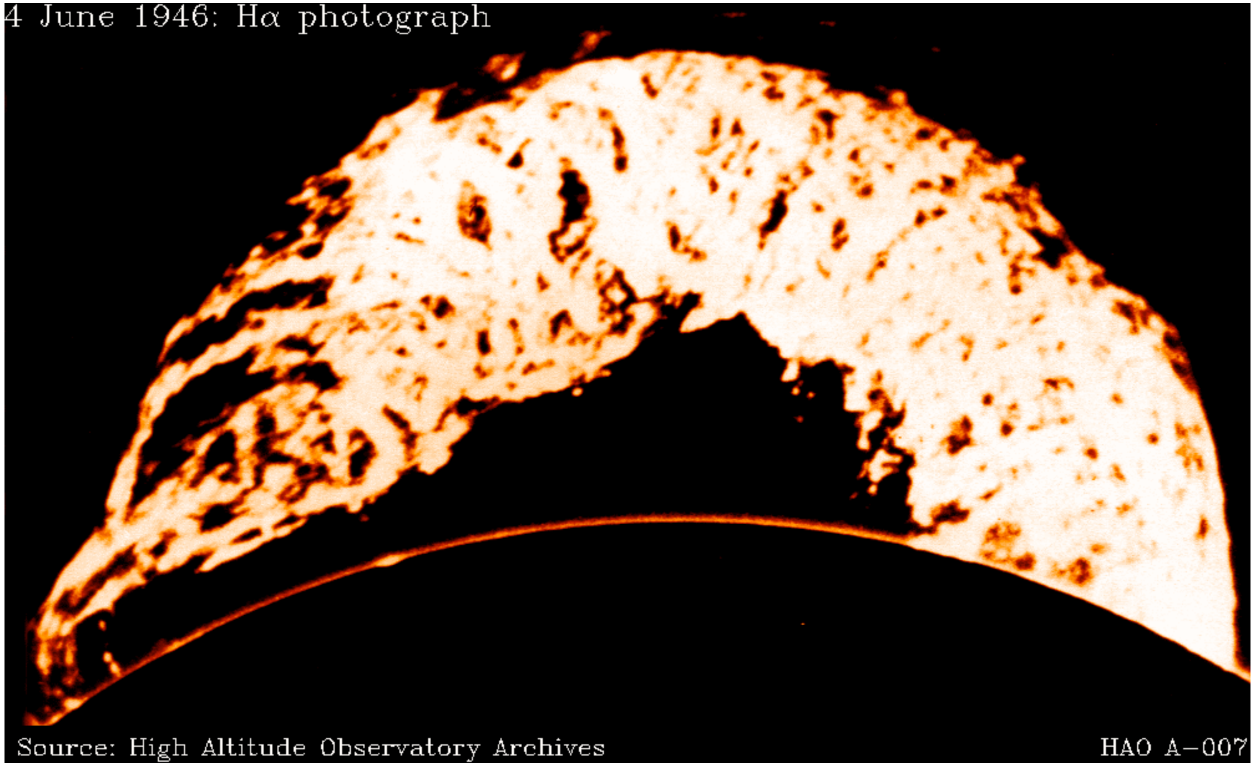
SEPs are particles above 1 MeV emitted by the Sun.
They are mainly divided in two types of events: **Impulsive** and **Gradual**

| | **Impulsive** | **Gradual** |
|---|---|---|
| **Particles** | *Electron-rich* | *Proton-rich* |
| **3He/4He** | *~1* | *~0.0005* |
| **Fe/O** | *~1* | *~0.1* |
| **H/He** | *~10* | *~100* |
| **QFe** | *~20* | *~14* |
| **Duration** | *Hours* | *Days* |
| **Longitude Cone** | *<30 deg* | *~180 deg* |
| **Radio Type** | *III, V (II)* | *II, IV* |
| **X-rays** | *Impulsive* | *Gradual* |
| **Coronagraph** | - | *CME (96%)* |
| **Solar Wind** | - | *IP Shock* |
| **Events/year** | *~1000* | *~10* |

Reames, D V 1996, Energetic Particles from Solar Flares and Coronal Mass Ejections, in High Energy Solar Physics, Eds. R Ramaty, N Mandzhavidze, X-M Hua, *AIP Conf. Proc. 374, p35*.

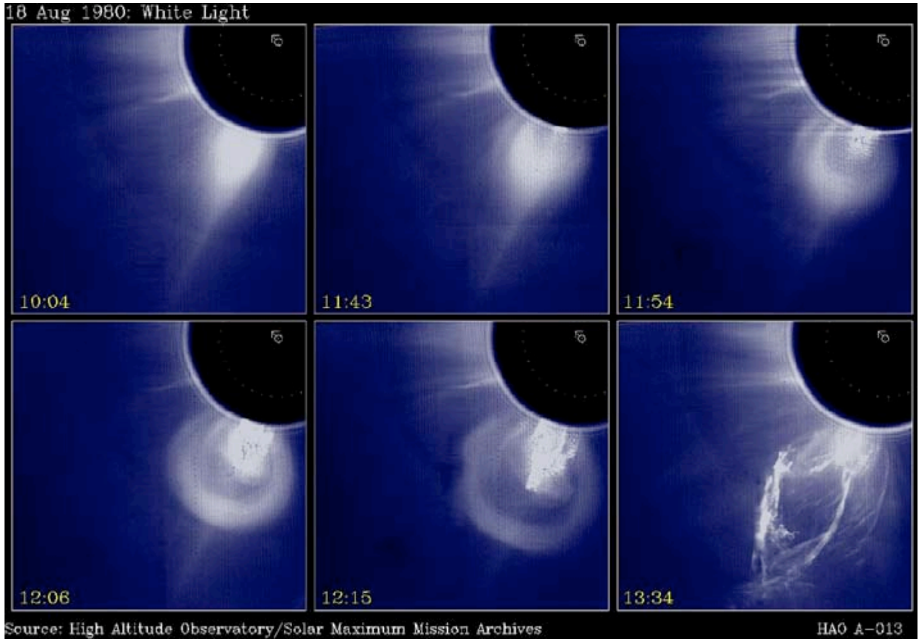
# *Gradual Events*

SEPs in gradual events are accelerated at a shock driven by a coronal mass ejection (CME) moving through the corona into the interplanetary medium.




CME-driven shocks produce most of the large particle events at 1 AU and can accelerate protons up to 20 GeV.

In large events the shock has been directly observed by spacecraft near 1 AU that are separated in longitude by 160°.

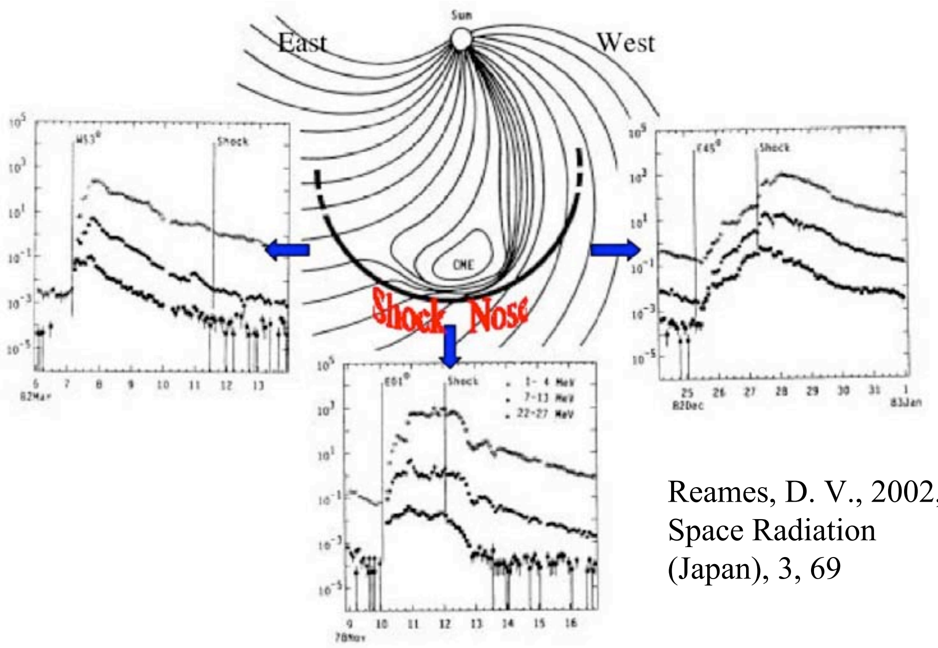



# *CME propagation*

The high fluence active sun period is of 7 years, from 2 years before the solar maximum year to 4 years after.

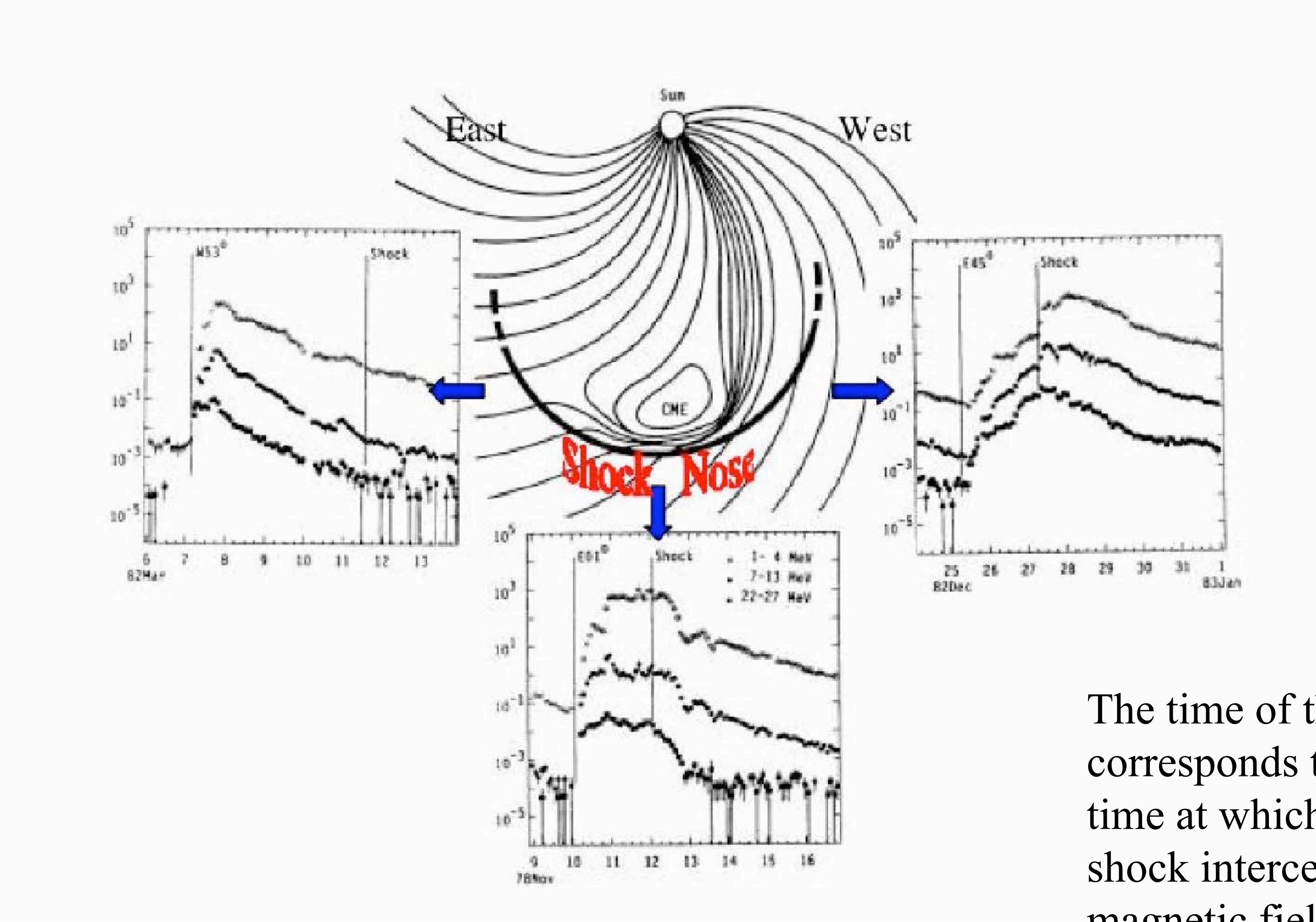
The propagation time (between event and appearance of protons at the spacecraft) is a strong function of the longitude of the solar event.

Events originating in the western hemisphere of the Sun are more likely to produce SEPs able to reach the Earth with respect to those in the eastern hemisphere.




Reames, D. V., 2002, Space Radiation (Japan), 3, 69

# *CME observed at different longitudes*




The time of the onset corresponds to the time at which the shock intercepts the magnetic field lines to the spacecraft.

Reames, D. V., 2002, Space Radiation (Japan), 3, 69

# *LISA spacecraft characteristics*

- Distance from the Sun

  $0.9933 \div 1.0133$ AU
- Latitude off the ecliptic

  $0.7^{o} \div 1.0^{o}$
- Longitude difference with respect to Earth

  $19^{o} \div 21^{o}$

# ***SEPs on LISA***

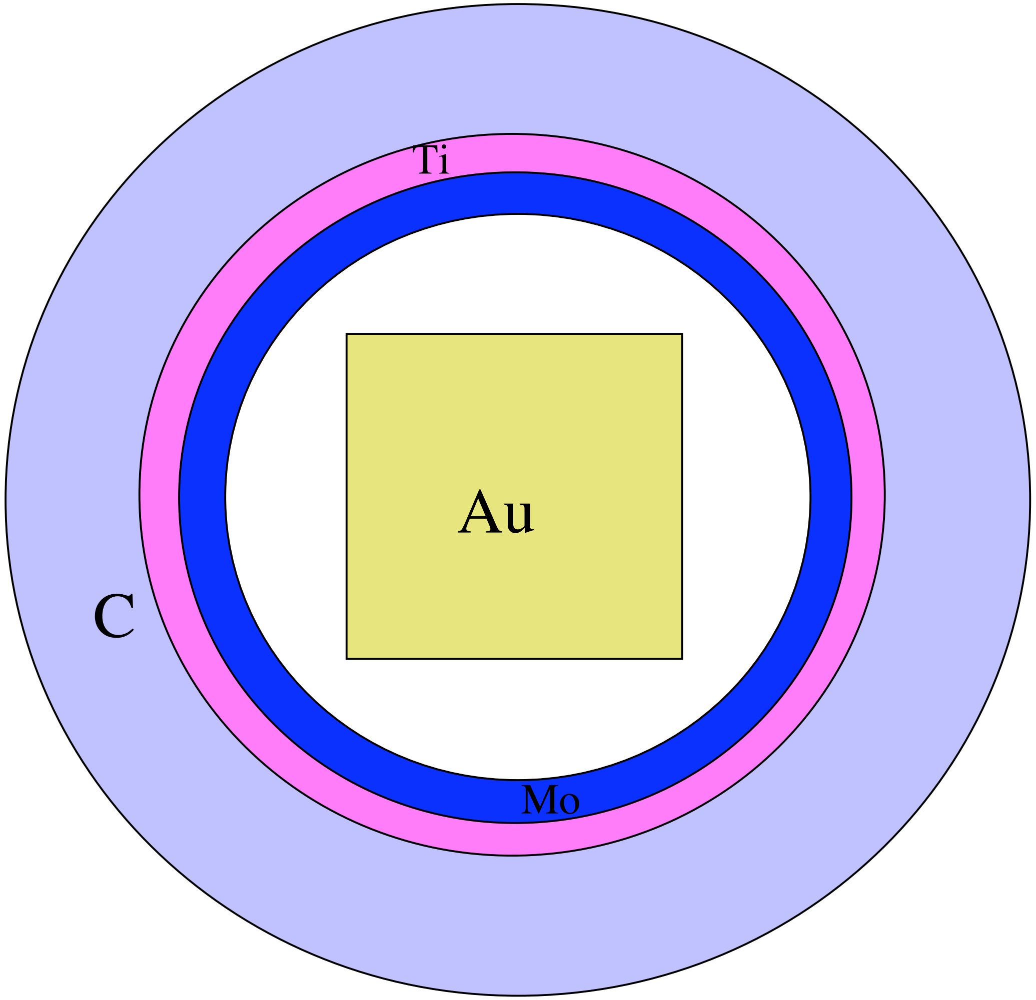
- The *shock nose* of a typical gradual event takes about two days to reach  Earth or LISA, and about one hour to go through the three LISA detectors

- Gradual event characteristics cause series of signals of frequency below a few units $10^{-4}$ Hz

# *Fluka particle transport*

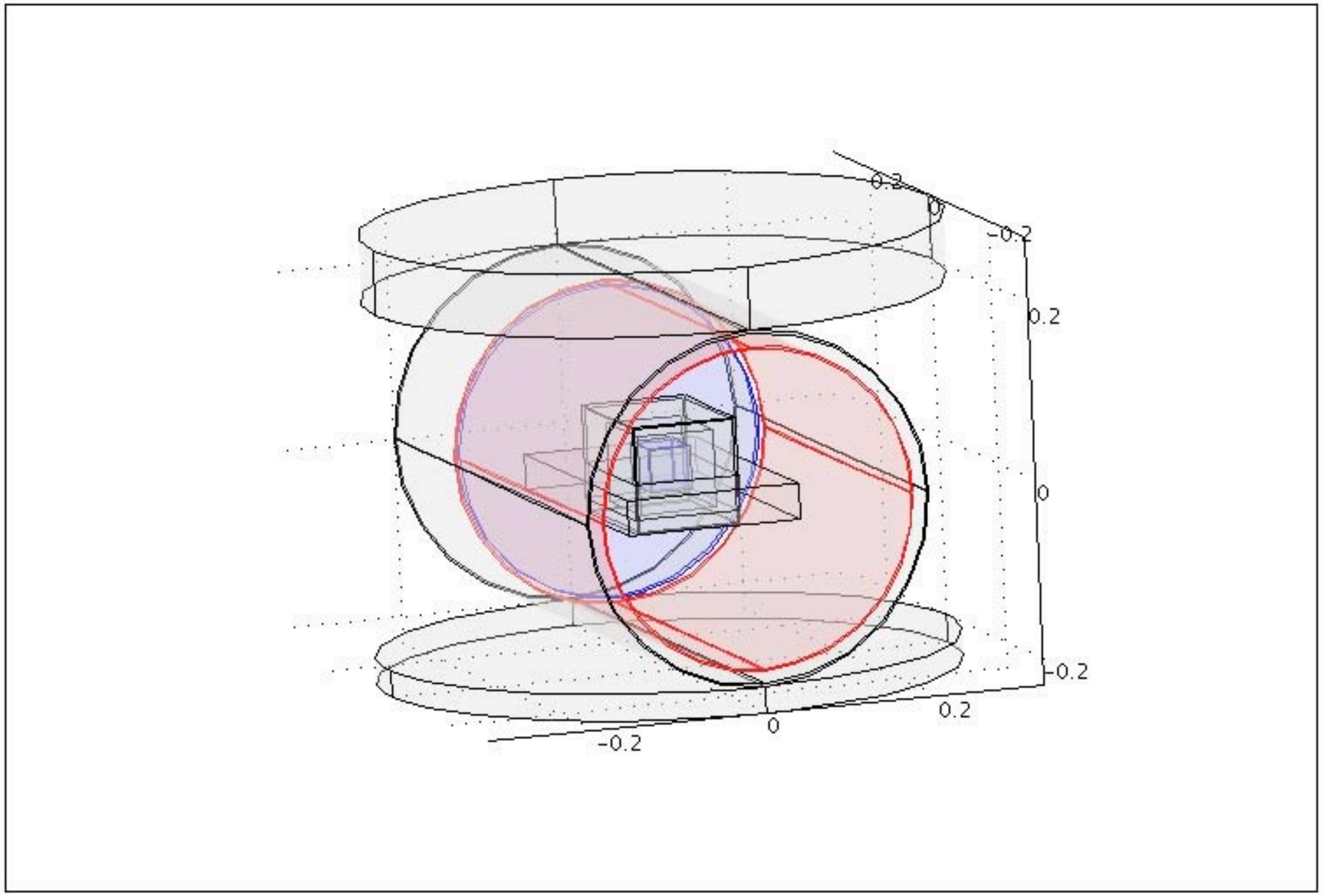
| | Secondary particles | Primary particles |
|---|---|---|
| **Charged hadrons** | *1 KeV ÷ 20 TeV* | *100 KeV ÷ 20 TeV* |
| **Neutrons** | *Thermal ÷ 20 TeV* | *Thermal ÷ 20 TeV* |
| **Muons** | *1 KeV ÷ 1 PeV* | *100 KeV ÷ 1 PeV* |
| **Electrons (low-Z)**<br>**(high-Z)** | *1 KeV ÷ 1 PeV*<br>*1 KeV ÷ 1 PeV* | *70 KeV ÷ 1 PeV*<br>*150 KeV ÷ 100 TeV* |
| **Photons** | *1 KeV ÷ 1 PeV* | *7 KeV ÷ 1 PeV* |

# *First simulation scheme*




- Shape: cube
- Side: 4.6 cm
- Material: gold
- Thickness : 88.9 $g/cm^2$

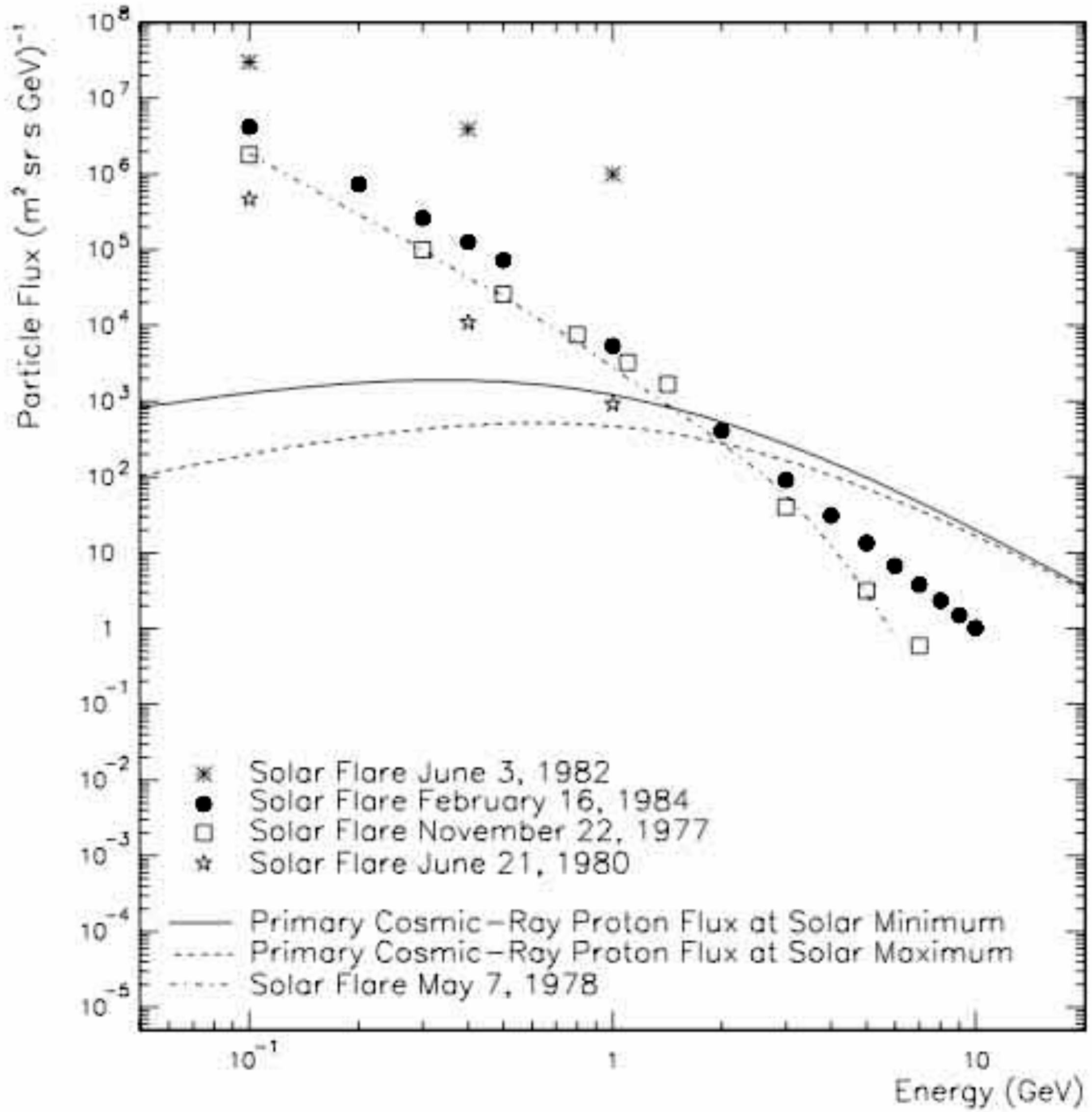
# *Upgraded simulation scheme*



# ***Preliminary Notes***

- Approximately 8 $g/cm^2$ of matter surround the LISA proof masses
- No incident particles below 80 MeV/n have been considered

# *Proton fluxes*

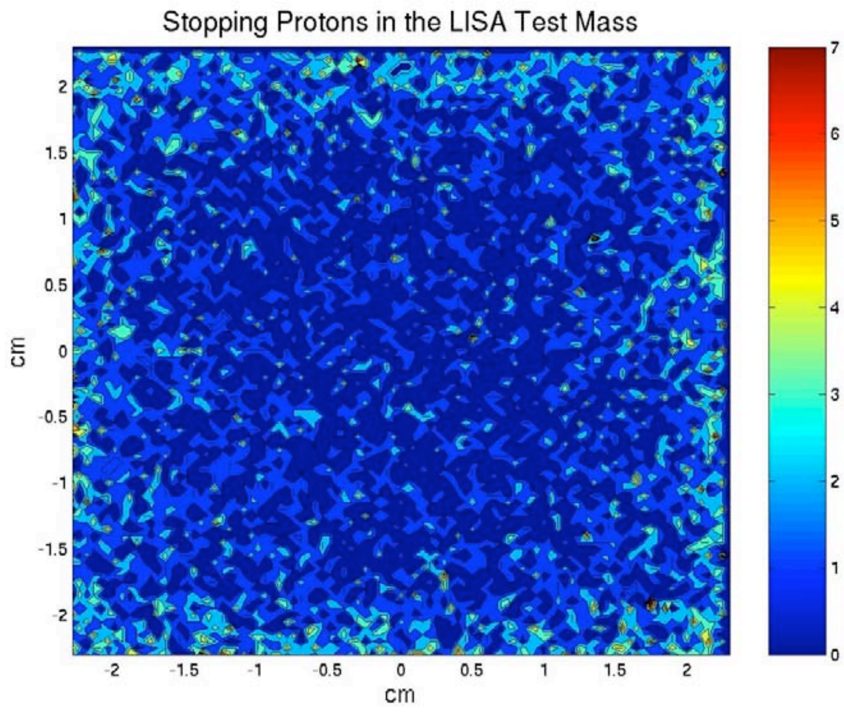


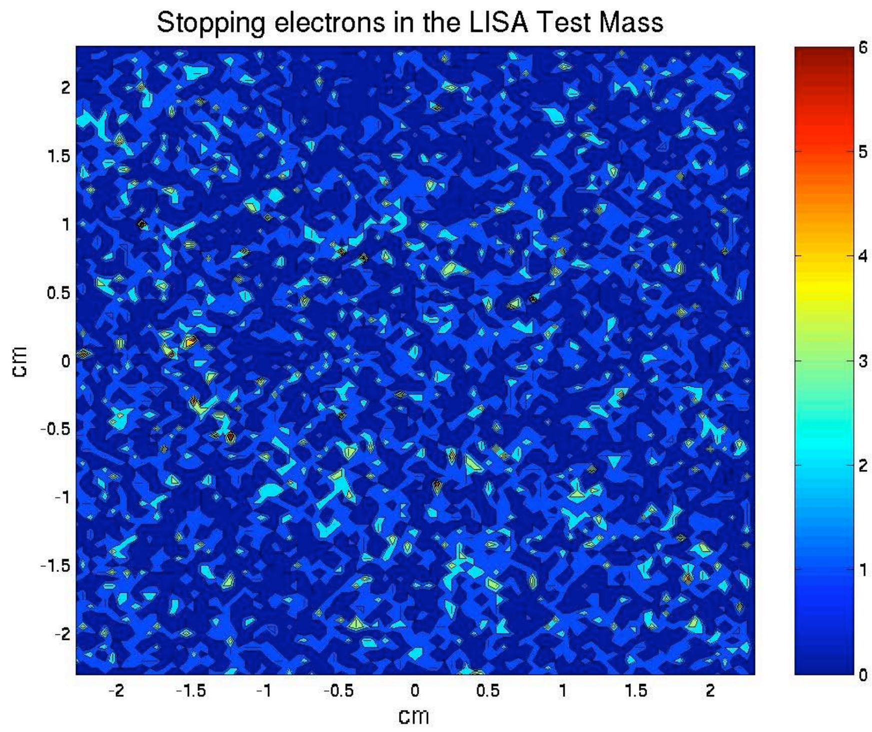
# *Proton results:*

| Source | Charge rate ($e^+/s$) | Effective charge rate ($e/s$) |
|---|---|---|
| **GCR at solar maximum** | *15* | *110* |
| **GCR at solar minimum** | *40* | *150* |
| **Gradual Event 1** | *180* | *200* |
| **Gradual Event 2** | *2100* | *2150* |
| **Gradual Event 3** | *3500* | *3600* |
| **Gradual Event 4** | *4400* | *4400* |
| **Gradual Event 5** | *4600* | *4600* |
| **Solar Flare peak flux** | *10700* | *10700* |

variability is below 10%

# *Spatial distribution:*



# LISA acceleration noise spectral density

$$S^{1/2}(\omega) = 0.8 \times 10^{-15} \frac{m}{s^2\sqrt{Hz}} \left(\frac{4mm}{gap}\right)\left(\frac{V_{dc}}{10mV}\right)\left(\frac{\lambda_{eff}}{300s^{-1}}\right)^{1/2}\left(\frac{0.1mHz}{f}\right)$$

Required acceleration noise limit
for random charge:

*$9.4 \cdot 10^{-16}$ ($m\ s^{-2}\ Hz^{-1/2}$)*
*[total: $3 \cdot 10^{-15}$]*

*($10^{-4} \div 10^{-1}$ Hz)*

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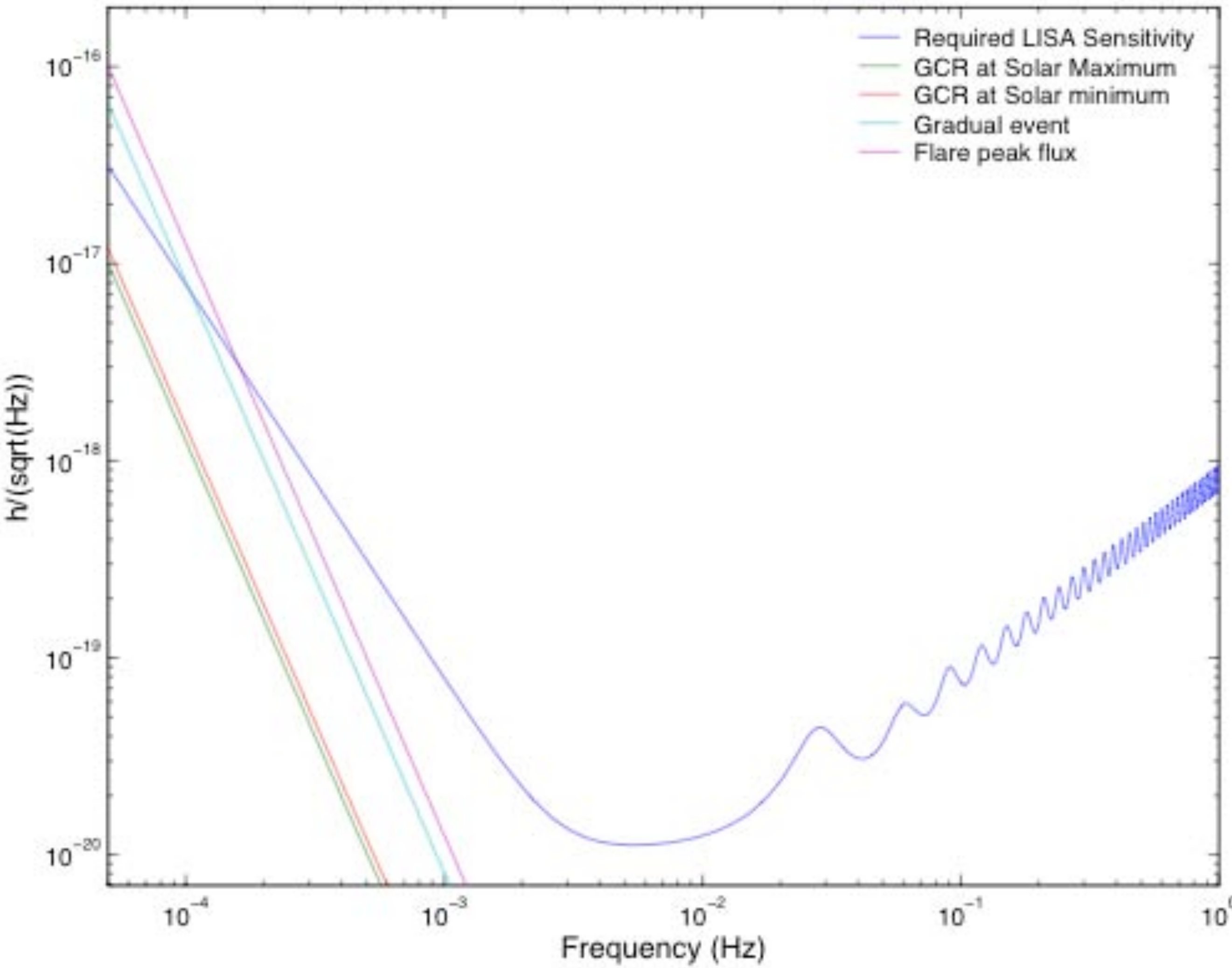
# LISA acceleration noise spectral density

| Source | Effective charge rate (*e/s*) | Acceleration noise spectral density @ 0.1mHz ($m\ s^{-2}\ Hz^{-1/2}$) |
|---|---|---|
| **GCR at solar maximum** | *110* | $0.48 \cdot 10^{-15}$ |
| **GCR at solar minimum** | *150* | $0.57 \cdot 10^{-15}$ |
| **Gradual Event 1** | *200* | $0.66 \cdot 10^{-15}$ |
| **Gradual Event 2** | *2150* | $2.1 \cdot 10^{-15}$ |
| **Gradual Event 3** | *3600* | $2.7 \cdot 10^{-15}$ |
| **Gradual Event 4** | *4400* | $3.1 \cdot 10^{-15}$ |
| **Gradual Event 5** | *4600* | $3.1 \cdot 10^{-15}$ |
| **Solar Flare peak flux** | *10700* | $4.8 \cdot 10^{-15}$ |

# *LISA sensitivity*

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# *Test-mass charging process:*
## *(In collaboration with the group of Fi-Ub)*

✓ net and effective charge rate on the test masses due to galactic and solar cosmic rays have been estimated

✓ It has been found (using the Fluka Monte Carlo program) that galactic cosmic rays do not constitute a limitation to the experiment sensitivity, while THIS IS NOT THE CASE for SEPs associated to solar gradual events.

✷ Particle monitors will be located on board the LISA PF spacecraft to detect real time overall cosmic-ray incident flux above 100 MeV in order to discriminate SEPs from galactic cosmic rays.

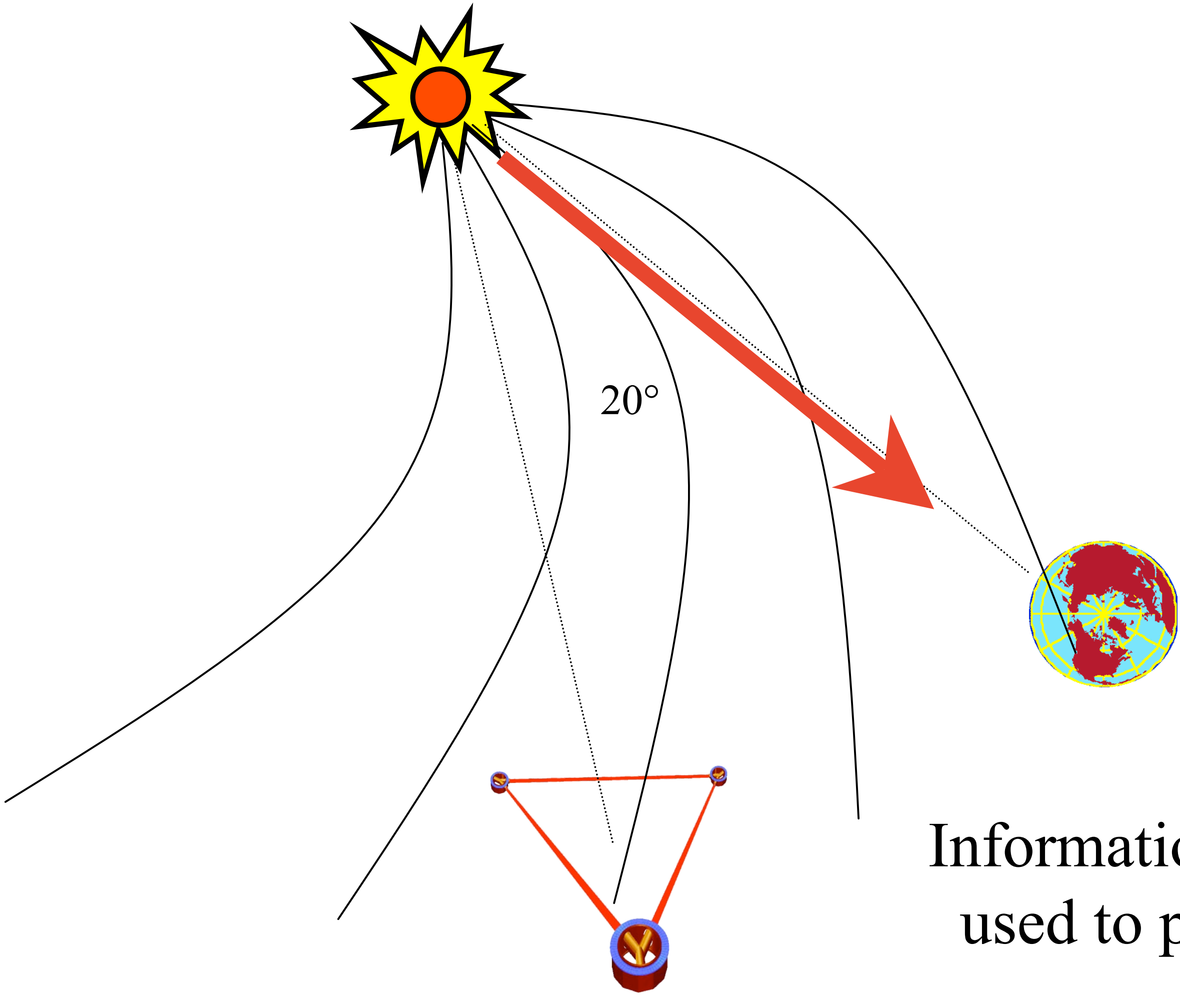
✷ On Lisa the particle telescopes will allow to study the dynamics of CMEs at different steps in longitude.

# *The study of CME dynamics is mandatory for:*

- Stat. & non-stat. noise source for LISA
- Solar physics modelization
- Space Weather forecasting

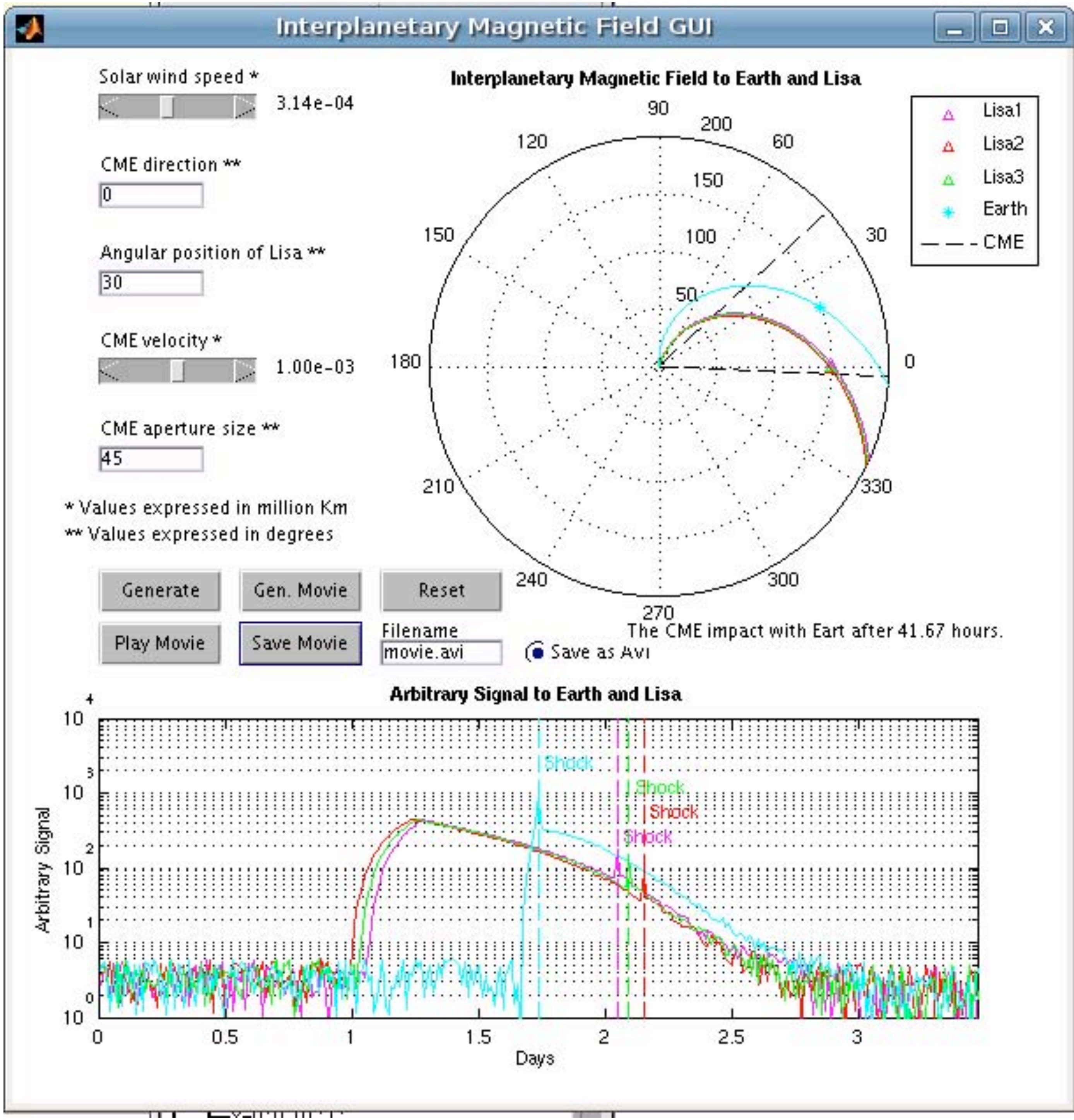
From this June we have been funded by the Italian Space Agency (ASI)

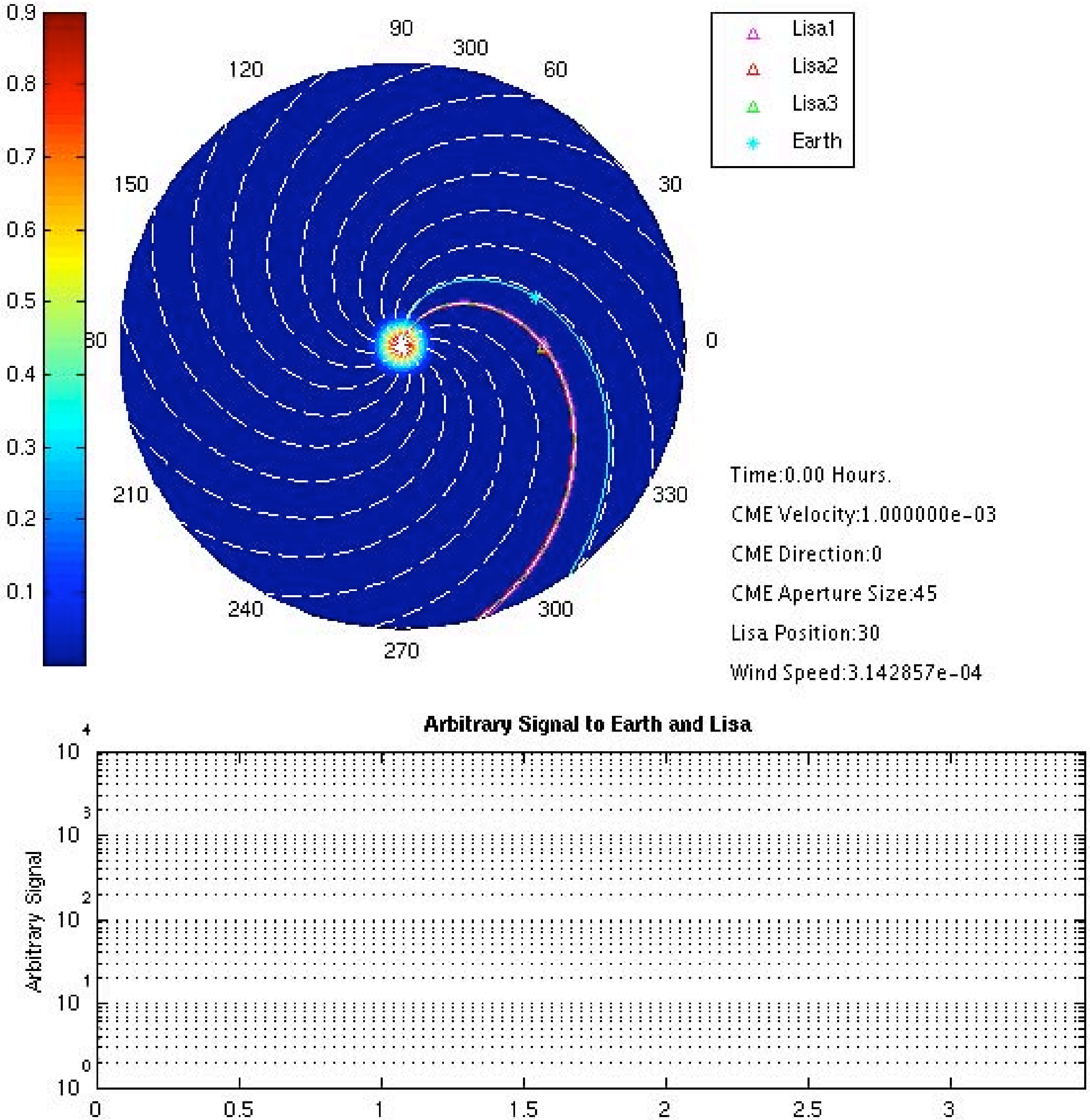
# *Space Weather prediction with LISA*




CMEs investing Earth are detected by the LISA particle monitors before!!!

Informations on LISA could be used to predict SW on Earth.


Interplanetary Magnetic Field GUI
Solar wind speed *
3.14e-04
CME direction **
0
Angular position of Lisa **
30
CME velocity *
1.00e-03
CME aperture size **
45
* Values expressed in million Km
** Values expressed in degrees
Generate
Gen. Movie
Reset
Play Movie
Save Movie
Filename
movie.avi
Save as Avi
Interplanetary Magnetic Field to Earth and Lisa
Lisa1
Lisa2
Lisa3
Earth
CME
The CME impact with Eart after 41.67 hours.
Arbitrary Signal to Earth and Lisa
Shock
Shock
Shock
Shock
Arbitrary Signal
Days


Lisa1
Lisa2
Lisa3
Earth
Time:0.00 Hours.
CME Velocity:1.000000e-03
CME Direction:0
CME Aperture Size:45
Lisa Position:30
Wind Speed:3.142857e-04
Arbitrary Signal to Earth and Lisa
Arbitrary Signal

# *Virgo charge build-up problem*

- For Virgo nothing has been done up to now !!!

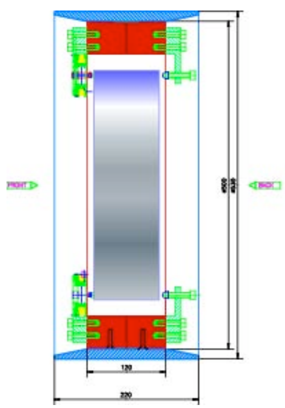
- On the present suspensions the charge has not been measured (it doesn't mean that there is not).

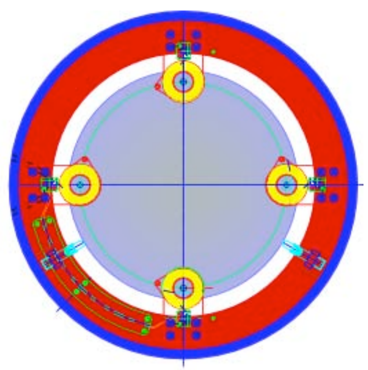
- …

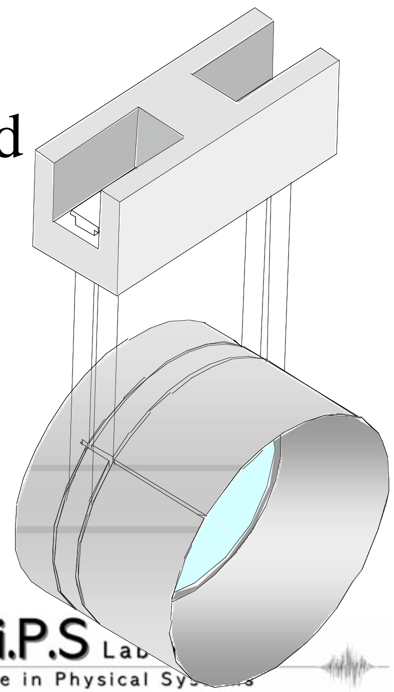
Can we develop something already for Virgo+ ?

# *The point:*

- The build-up of electric charge on interferometer optics has been observed in Geo and Ligo;
- It is well known that a degradation of Q is correlated with the charge on the surface (Coulomb damping);
- Electrical charges stopping inside the mass produce spurious Coulomb forces between the mass itself and surrounding apparata;

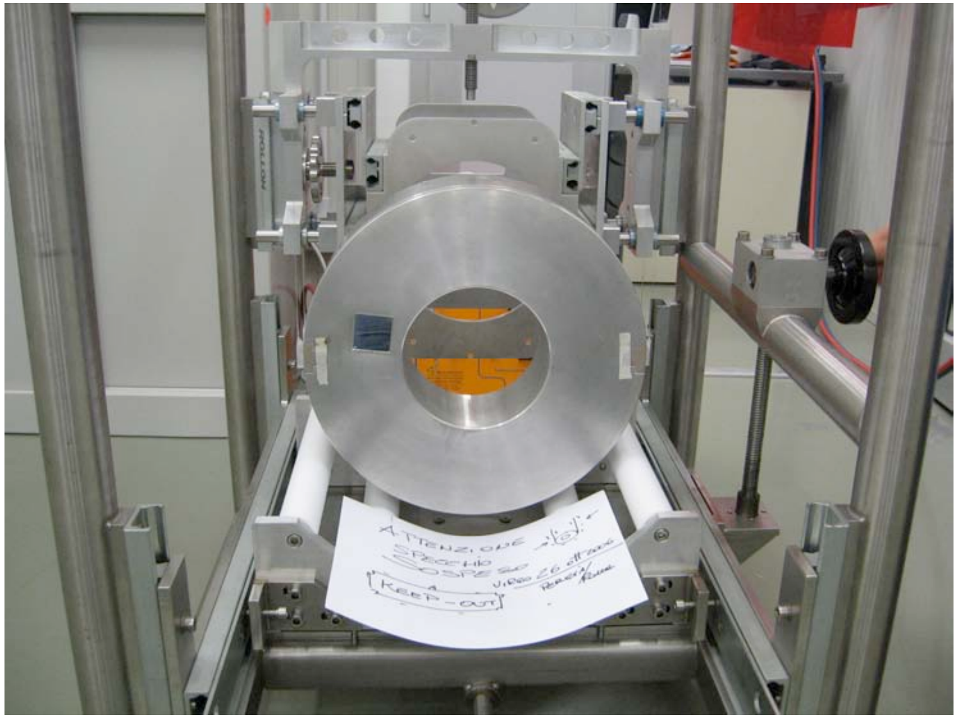






# *Monolithic suspensions:*

In Virgo+ will be installed monolithic suspensions (hopefully!)
In advanced Virgo certainly…



Can dielectric mass and fibers add an extra noise due by the charging process?

# *Advanced Virgo:*

• The electrostatic actuators are under study
  - an estimation of the charge shot-noise is important

• A discharge system has to be developed
  - UV illumination ?
  - Conducting coating (as shown by Glasgow) ?

• An estimation of the electrostatic coupling with the surrounding material is needed (mirror dampers, reference mass…)

A big effort has to be concentrated on the charge!

# *What we plan to do…*

Three main tasks are starting (finally):

1. The use a Monte Carlo program (Fluka or Geant) to evaluate the shot-noise expected by the charging rate;

2. The realization of an experimental apparatus to measure the Q degradation due to the net charge accumulated in Fused Silica samples. The use of a known charge flux could be useful to study the interaction of charged particles with a test mass in a controlled environment.

3. The development of a facility using UV to discharge the optics, with a measurement of the possible effects on various kinds of coatings.

# *Virgo groups:*

- The Perugia group is starting an evaluation on the simulation Monte Carlo program to be used (Fluka and Geant).
  In Perugia there are various facilities to measure the quality factor of Fused Silica samples of different dimensions and shapes.
  In addition there is some experience acquired from the Lisa experiment for UV discharging.

- The Roma2 group has made a good experience on the effects of extensive air showers and electron beams on suspended resonant masses. Various tests on resonators of different materials (aluminium alloy, niobium) have been performed in the Frascati Beam Test Facility.

- The Napoli group is developing the electrostatic actuation. A good interaction is planned…

# The LSC-Virgo collaboration

Time is running…

A good interaction on this item appears to be very usefull.

This workshop is an important starting point.

Let's continue!!!