Cosmic-ray observations on board the LISA missions

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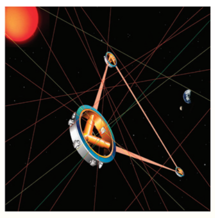

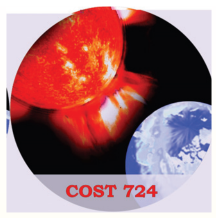

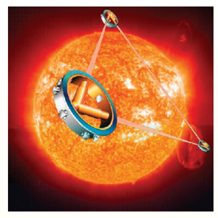

Abstract

Galactic and solar cosmic rays with energies larger than 100 MeV/n penetrate and charge the test masses of the LISA missions. It has been shown that solar gradual events and galactic cosmic-ray short time fluctuations generate signals that exceed the LISA noise budget. Silicon particle detectors will be placed on board the LISA spacecraft to monitor the overall particle flux incident on the test masses. These instruments will allow us to study spatial and temporal characteristics of solar energetic particles (SEP) associated with evolving coronal mass ejections and galactic cosmic-ray (GCR) variations and fluctuations. In this work we report about galactic and interplanetary cosmic rays. In particular, we focus on solar activity level and Global Solar Magnetic Field (GSMF) polarity affecting the LISA test-mass charging. The simulation work has been carried out with the Fluka Monte Carlo program.

Introduction

LISA is the first space based interferometer devoted to the detection of gravitational waves in the range 10^{-4} - 10^{-1} Hz. Galactic and solar cosmic rays with energies larger than 100 MeV(/n) penetrate and charge the LISA-PF and LISA free-floating test masses[1,2,3]. Spurious forces occur between the test masses and the surrounding electrodes mimicking gravitational wave signals[4,5]. It has been recognized as necessary[6] to monitor the overall particle fluxes incident on the test masses. Silicon detectors will be placed on board the LISA-PF and LISA satellites to this purpose. These telescopes offer the unique chance to map SEP fluxes at small steps in longitude and galactic cosmic-ray variations and fluctuations[7,8,9,10]. These topics are of major interest to solar and cosmic-ray physics.

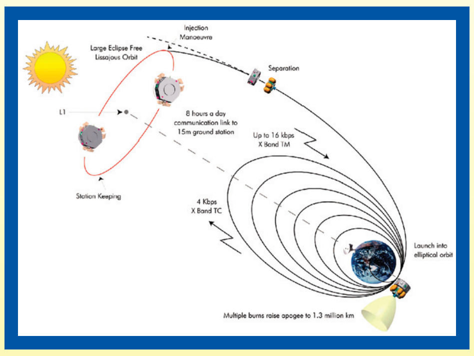

Fig. 1 LISA-PF orbit

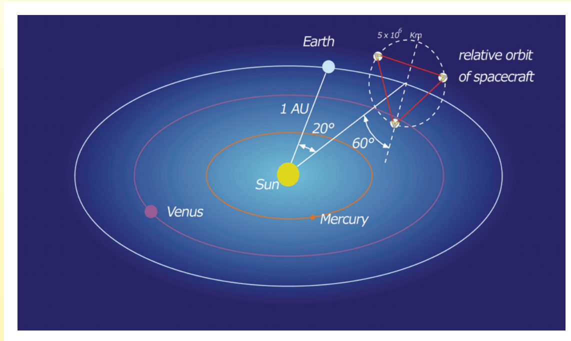

Fig. 2 LISA orbit

Mission Characteristics

In fig. 1 and fig. 2 we have reported the LISA-PF and LISA orbits[11,12], respectively. The S/C are traversed by galactic and energetic solar cosmic rays. In fig. 3 we report the expected solar activity level and GSMF polarity during the LISA missions. Particles with energies larger than 100 MeV(/n) pass 10 g/cm^2 of material and penetrate the test masses. An extensive work of simulation has been carried out in order to evaluate the test-mass acceleration noise and spurious signals due to charging. However, solar related events occur randomly; short-term GCR fluctuations cannot be predicted as well. In order to monitor the most abundant components of energetic particle fluxes (protons and helium nuclei) incident on the test masses in real time radiation monitors will be placed on board. They consist of two layers of silicon detectors of 1.05 x 1.4 cm^2 area, 300 micron thickness placed at 2 cm from each other. The GF is 9 cm^2 sr for particle isotropic incidence on each silicon layer, while is 0.87 cm^2 sr for isotropic incidence of particles traversing both detectors. The silicon layers are surrounded by 6 g/cm^2 of titanium. This amount of material is used because of experiment weight limitation and in order to better detect the transit of small-medium solar events. In fig. 4 the set-up of the detector is shown.

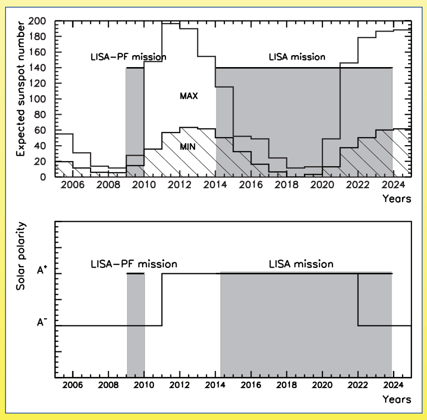

Fig. 3 Expected solar modulation and GSMF polarity during the LISA mission

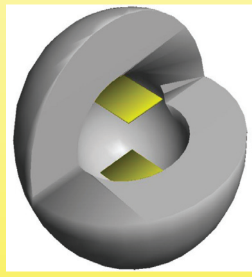

Fig. 4 Radiation monitor set-up

Energetic interplanetary particles charging the LISA test-masses

The particle energy cut-off of 100 MeV(\n) for test-mass charging is related to protons, heavy ions and nuclei while it does not apply to highly penetrating particles such as electrons that can reach and charge the test masses above a few MeV. In fig. 5 we have reported the primary cosmic-ray protons and nuclei producing a charging of at least 1% of protons at both solar minimum (continuous lines) and maximum (dashed lines)[13]. Long-term GCR variations are due to solar activity (11-year period) and GSMF polarity (22-year period) while GCR fluctuations are due to interplanetary phenomena. The role of galactic and solar protons, helium and heavy particles in charging the test masses have been studied in 1-2-3 at solar minimum and maximum. Solar, jovian, primary and secondary galactic electrons populate the interplanetary medium as well. In figures 6 and 7 we have reported the electron spectrum during a negative (A<0) and positive (A>0) solar polarity epoch, respectively (thick continuous lines). A comparison is made with measurements and calculations at the interstellar medium (thick dot-dashed and thin continuous line). It is very interesting to notice as data gathered far from Earth (large diamonds) during a negative polarity period agree very well with the Ferreira[14] estimate. All references are reported in 15. The trend is different during a positive polarity epoch (see fig. 7). In Table 1 we have reported the test-mass net and effective charging due to interplanetary electrons with respect to protons (%p). In fig. 8 we show electron fluxes associated to two strong events of solar origin (dotted line September 7th 1973 flare and dot-dashed line November 3rd 1973 flare). A comparison is made with interplanetary electrons. The test mass charging due to solar electrons is reported in Table 2 (%p). It can be observed that galactic nuclei[2] and inteplanetary electrons account for about 20% of the test mass charging with respect to protons while solar electrons play a minor role. In fig. 9 we have reported the maximum variation expected at solar minumum for protons and helium nuclei during a negative polarity epoch (dashed lines). The expected difference in charging the LISA test masses is 20%.

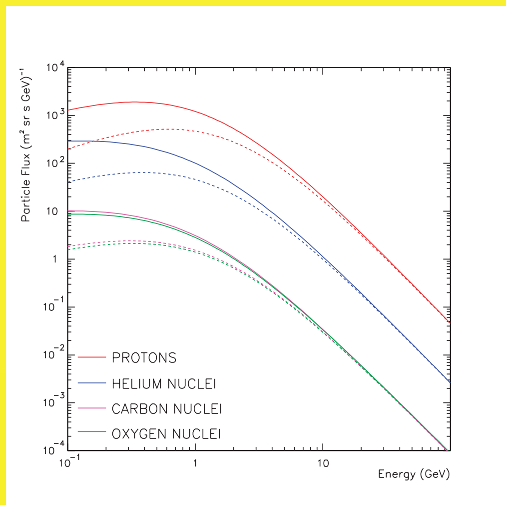

Fig. 5 Primary GCR protons and nuclei

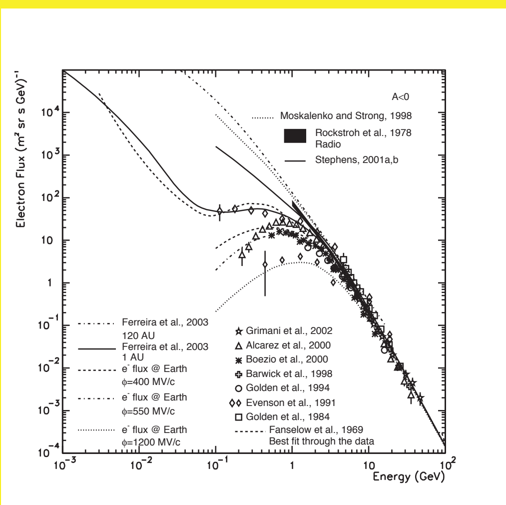

Fig. 6 Interplanetary, interstellar and near-Earth calculated and observed electron fluxes. Interplanetary electrons have been estimated for a negative polarity epoch (thick continuous line).

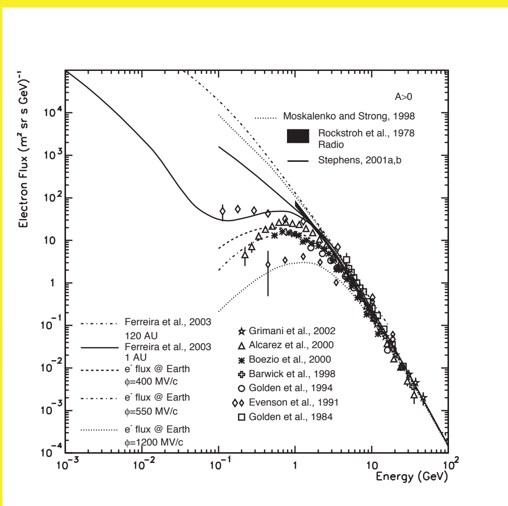

Fig. 7 Same as fig. 6 during a positive polarity epoch.

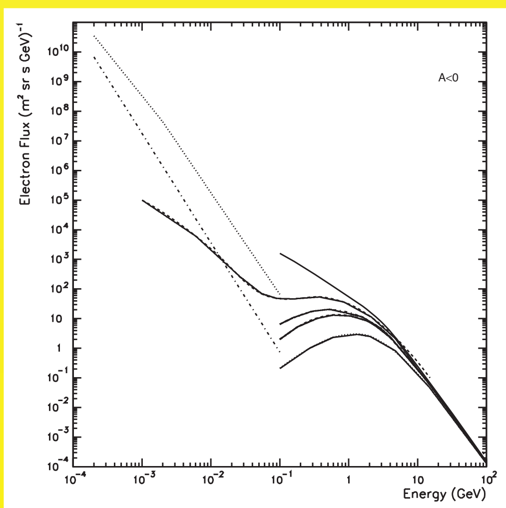

Fig. 8 Solar (dotted line - September 7th 1973 flare; dot-dashed line - November 3rd 1973 flare), interplanetary (continuous thick line) and primary (thin continuous lines) electron fluxes.

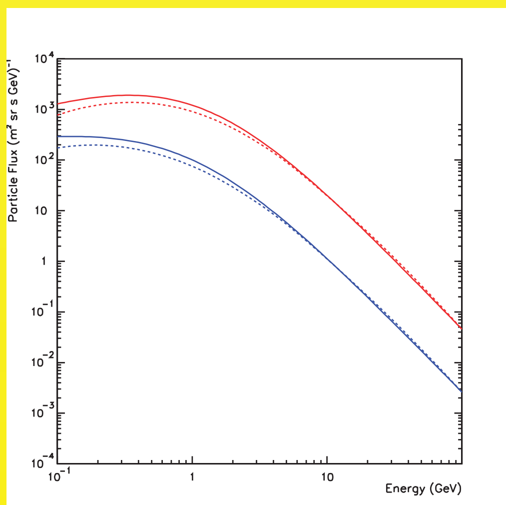

Fig. 9 Primary proton maximum variation during a negative polarity epoch at solar minimum

polarity	Net charge (%p)	Effective charge (%p)
A<0	13%	1.5%
A>0	15%	1.7%

Table 1
Test-mass charging due to interplanetary electrons

Flare	Net charge (%p)	Effective charge (%p)
3/11/1973	< 1%	< 1%
7/09/1973	< 2.7%	< 1%

Table 2
Test-mass charging due to solar electrons

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