Solar event onset detection on board LISA-PF

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Abstract

LISA (Laser Interferometer Space Antenna) and its precursor mission, LISA-PF will carry particle monitors for noise diagnostics. We show that these instruments will allow us to study the dynamics of solar particles above a few tens of MeV(/n) associated with both weak and strong solar events.

The LISA missions

LISA is the first interferometric device devoted to the detection of gravitational waves in space in the frequency range 10^{-4} - 10^{-1} Hz. It consists of three spacecraft placed 5×10^6 km apart at the corners of an equilateral triangle. The formation center of mass lies on the ecliptic. Each spacecraft hosts two inertial sensors. The heart of the inertial sensors are cubic gold-platinum test masses. The test masses constitute the interferometer mirrors. Their position is detected with gold plated electrodes. Energetic solar and cosmic rays charging the test masses are one of the most important sources of noise for the experiment (Araújo et al., 2005; Grimani et al., 2004; Grimani et al., 2005). Ultraviolet light beams will be used to discharge the proof masses (Tombolato, 2008 and references therein).

LISA will likely fly around 2018. The maximum mission duration is expected to be 10 years.

LISA-PF consists of one satellite hosting two test masses to be sent into orbit around L1 at the end of 2012. LISA-PF target sensitivity is one order of magnitude smaller than LISA (Bortoluzzi et al., 2005). Data will be gathered for six months.

Radiaton Monitors on board LISA-PF

Radiation detectors monitoring cosmic-ray and energetic solar particle fluxes will be placed on board LISA-PF and LISA missions. Their design was finalized for LISA-PF only (Cañizares et al., 2009). Two silicon wafers of 1.4 x 1.05 cm^2 area will be located in a telescopic arrangement at a distance of 2 cm. The geometrical factor of each silicon layer for an isotropic incidence is 9 cm^2 sr and for coincidence events is about one tenth of this. The silicon telescopes are placed inside a copper box of 6.4 mm thickness in order to limit the energy of protons and helium nuclei traversing these detectors to a few tens of $MeV(/n)$ (see figure 1). This energy cutoff is similar to the minimum energy needed for the most abundant components of cosmic rays to penetrate the test masses [100 $MeV(/n)$]. No electron monitoring is allowed for on LISA-PF.

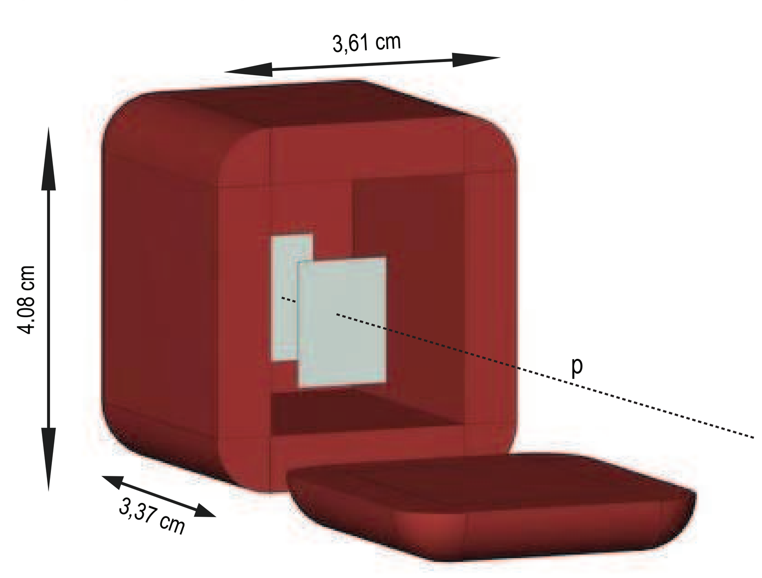

Figure 1: LISA-PF radiation monitor set-up. Silicon wafers are sketched inside the shielding copper box. An incident proton trajectory is shown. Other details are reported in the text.

Solar activity and solar polarity at the time of LISA-PF

Predictions of a solar cycle include both amplitude and timing. Timing depends on the characteristics of the solar minimum. Due to the unusually long lasting solar minimum we presently expect the next maximum to occur in 2013. The presently available projections for the solar cycle 24 are reported in fig. 2 (Hathaway, 2009a; 2009b). We point out that the same work reported here was carried out in the past on the basis of the solar cycle 24 projections available in 2008 according to Hathaway and Dikpati, 2006 (see fig. 2 for comparison). An extensive review of the solar cycle 24 projections is reported in Posnell, 2008. Unfortunately, the majority of these predictions result far from the trend shown by the first phase of the solar cycle 24. In particular, out of 54 predictions, 4 only indicated a solar maximum to occur beyond 2012.

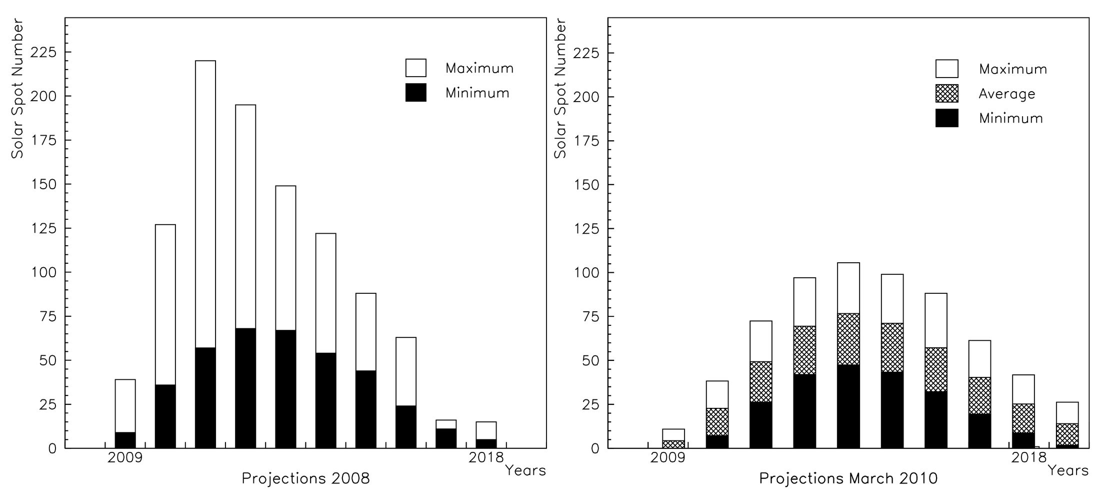

Figure 2: Predictions of the annual average sunspot number for the solar cycle 24: 2008 and updated projections are compared.

Galactic cosmic-ray proton and helium energy spectra at the time of LISA-PF

Assuming that LISA-PF will be launched in April 2012 and that about 3 months will be needed to reach its final orbit in L1, data will be taken during the second half of 2012. Very close to the next solar maximum (see fig. 2) and possibly during the same negative polarity epoch we are presently experiencing.

At the moment, the expected number of minimum, average and maximum annual averaged solar spots in 2012 are 42.03, 69.53 and 97.03, respectively. Very similar to 2003 (40.18, 67.18, 94.18 respectively; Hathaway, 2009b). The estimated solar modulation parameter in 2003 was 959 MV/c (Hathaway 2009b). We use this same value here within the model by Gleeson and Axford (1968) to estimate the input fluxes during a positive polarity epoch (continuous lines in fig. 3, for protons (left panel) and helium nuclei (right panel)). The particle flux interpolation at the interstellar medium was gathered from Shikaze et al. (2006).

The input fluxes during a negative polarity epoch were estimated according to Grimani et al., 2007 for near-solar-maximum conditions (dashed lines in fig. 3 both panels). The - to + polarity change is plausibly expected in 2013. Since at solar maximum the solar polarity is expected to play a minor role in modulating positive particle fluxes, we consider our estimates a lower limit at the time of LISA-PF.

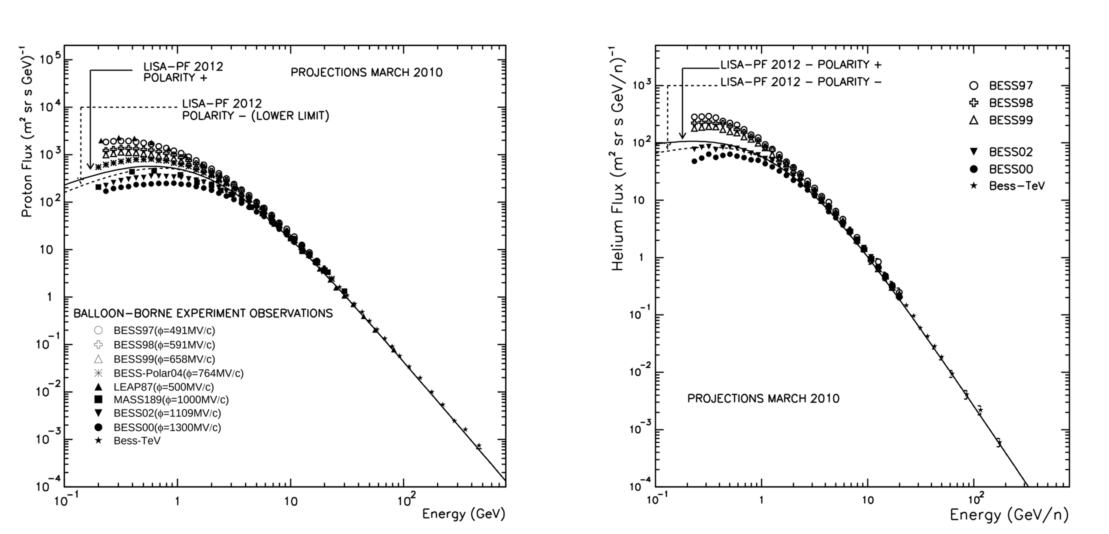

Figure 3: Estimated galactic cosmic-ray proton and helium energy spectra during LISA-PF (2012).

Updated estimate of the number of solar events during LISA-PF

Nymmik (1999a, 1999b) has found that the SEP (solar energetic particles) fluence distribution follows a power-law trend with an exponential decrease for large fluences. This model applies to solar proton fluences ranging between 10^6 and 10^{11} $protons\ cm^{-2}$ for particle energies above 30 MeV. The Nymmik's model offers the possibility to predict solar events in terms of energy range and of particle peak fluxes instead of fluence only (for a review of other models see Storini et al., 2007; Lantos, 2005 and references therein). We estimated the number of SEP events in individual intervals of fluence during the six months of LISA-PF data taking using Nymmik model. The method is described in detail in Grimani et al., 2009. The expected minimum, average and maximum number of solar events in 2012 is 2.92, 4.83 and 6.73, respectively. Half of these in six months. The number of events expected to occur during the LISA-PF mission per interval of fluence appears in fig. 4. Well below previous expectations.

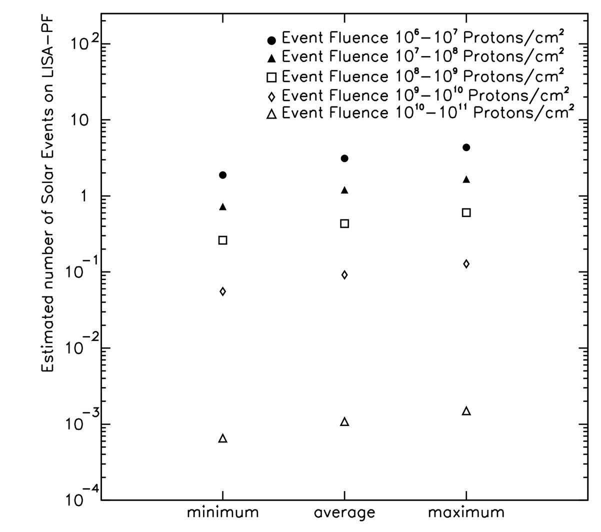

Figure 4: Estimated number of solar events per interval of fluence during the second half of 2012.

This might mean that no events or, at least, no events with fluences equal or larger than 10^7 $protons/cm^2$ might occur at the time of LISA-PF data taking. We point out that 10^7 $protons/cm^2$ is the intensity of events generating a noise larger than the whole LISA noise budget (at the peak).

SEP onset on LISA-PF Radiation Monitors

In order to estimate the performance of the LISA-PF radiation monitors in detecting the dynamics of solar energetic events, we have simulated the event dated May 7th 1978 (Fassò et al., 2005). Unfortunately, a very limited set of differential flux measurements of solar particles are available in the literature. We have found that the overall radiation monitor countrate can be used to detect solar particles. Particle ionization energy losses will be studied as well (see Grimani et al., 2009). In fig. 5 we have reported the countrate in each silicon layer of the radiation monitors at steady state (galactic cosmic rays; red region) and during a May 7th 1978-like event.

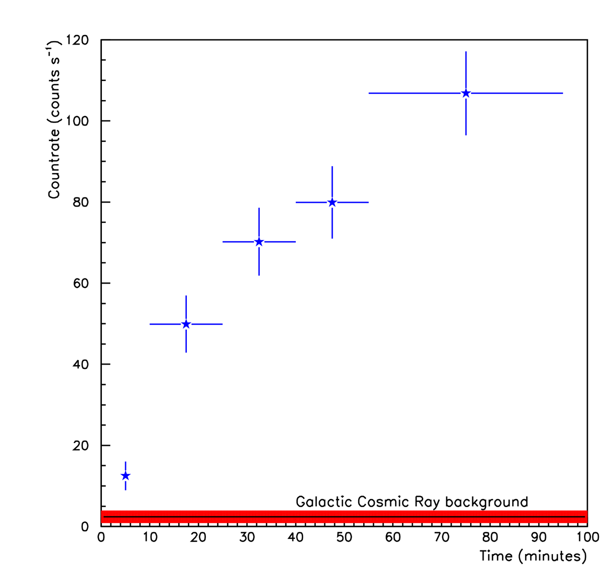

Figure 5: LISA-PF Radiation Monitor countrate at the onset of a solar event of fluence larger than 10^6 $protons/cm^2$. The red band represents the steady-state galactic cosmic ray flux.

Conclusions

The LISA missions will allow for multispacecraft monitoring of the dynamics of solar particles at 1 AU above a few tens of MeV(/n). Precious clues will be provided by the comparison of our data to those of experiments devoted to solar physics in flight during the same period.

Acknowledgements

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