Physics Letters B 720 (2013) 116–119

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Search for correlations between solar flares and decay rate of radioactive nuclei

E. Bellotti [a], C. Broggini [b,*], G. Di Carlo [c], M. Laubenstein [c], R. Menegazzo [b]

[a] Università degli Studi di Milano Bicocca and Istituto Nazionale di Fisica Nucleare, Sezione di Milano, Milano, Italy
[b] Istituto Nazionale di Fisica Nucleare, Sezione di Padova, Padova, Italy
[c] Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Gran Sasso, Assergi (AQ), Italy

ARTICLE INFO

Article history:
Received 7 December 2012
Received in revised form 16 January 2013
Accepted 2 February 2013
Available online 6 February 2013
Editor: L. Rolandi

Keywords:
Radioactivity
Solar flare
Gran Sasso

ABSTRACT

The decay rate of three different radioactive sources (^{40}K, ^{137}Cs and ^{nat}Th) has been measured with NaI and Ge detectors. Data have been analyzed to search for possible variations in coincidence with the two strongest solar flares of the years 2011 and 2012. No significant deviations from standard expectation have been observed, with a few 10^{-4} sensitivity. As a consequence, we could not find any effect like that recently reported by Jenkins and Fischbach: a few per mil decrease in the decay rate of ^{54}Mn during solar flares in December 2006.

1. Introduction

In the past years, a correlation between the Sun and the decay rate of radioactive isotopes has been proposed. In particular, two effects have been considered: the annual modulation due to the seasonal variation of the Earth–Sun distance [1] and the decrease of the decay rate during a solar flare [2]. In this Letter we are interested in the latter phenomenon.

Briefly, solar flares are explosions on the surface of the Sun near sunspots. They are powered by the release of magnetic energy stored in the corona, up to one hundredth of the solar luminosity, and they affect all layers of solar atmosphere, from the photosphere to the corona. On the Sun this amount of energy is released within a few minutes to tens of minutes. In this interval the plasma is heated to tens of millions of degrees with a strong X-ray emission and electron and proton acceleration (up to several tens and hundreds of MeV, respectively).

In particular, the 2006 flares from December 2nd 2006 to January 1st 2007 gave rise to X-ray fluxes which, measured on the Geostationary Operational Environmental Satellites (GOES), were of a few times 10^{-4} W/m^2 at the peak (see Fig. 1 of Ref. [2] for details). At that time the activity of a ∼1 μCi source of ^{54}Mn was being measured by Jenkins and Fischbach [2] with a 2×2 inch NaI crystal detecting the 835 keV γ-ray emitted after the electron capture decay. A significant dip (up to $4 \cdot 10^{-3}$, $\sim 7\ \sigma$ effect), in the count rate, averaged on a time interval of 4 hours, has been observed in coincidence with the solar flares. On the other hand, a different experiment with a $\sim 10^{-3}$ sensitivity, carried out by Parkhomov [3], did not observe any deviation in the activity of ^{60}Co, ^{90}Sr–Y and ^{239}Pu sources in coincidence with the same flare.

After a few years of quiet Sun, solar activity is now increasing, as shown both by the increase of the steady X-ray flux as well as of X-flares and of other typical solar phenomena. As a matter of fact, we are approaching the maximum of the 11 year solar cycle which is predicted to take place in Fall 2013. In our analysis we focus on the two most intense flares of the last years, namely those that occurred on August 2011 and March 2012: X6.9 on August 9th 2011 @ 08:08 UTC and X5.4 on March 7th 2012 @ 00:24 UTC [4].

Solar flares are classified according to the power of the X-ray flux peak near the Earth as measured by the GOES-15 geostationary satellite: X identifies the class of the most powerful ones, with a power at the peak larger than 10^{-4} W/m^2 (within the X-class there is then a linear scale). The two flares were well defined in time (a few minutes) and they illuminated the entire Earth. Their intensities are comparable, or even larger, than those observed in December 2006. During the 2011 flare the activity of the ^{137}Cs and ^{nat}Th sources were being measured with a Ge and with a NaI detector, respectively. On the other hand, during the 2012 flare the ^{137}Cs and ^{40}K sources were being studied with the same Ge detector and with a different NaI detector, as described in the next section. These different nuclides gives the possibility to search for

* Corresponding author.
E-mail address: broggini@pd.infn.it (C. Broggini).

0370-2693/$ – see front matter
http://dx.doi.org/10.1016/j.physletb.2013.02.002

Table 1
Experimental set-ups active at the time of large solar flares. The ^{137}Cs and ^{nat}Th measurements are running underground while the ^{40}K set-up is installed in the external laboratory at Gran Sasso.

Flare time	Peak intensity	Source	Detector	Observed decay type	Mean counting rate	Integration time
August 9th 2011 08:08 UTC March 7th 2012 00:24 UTC	X6.9 X5.4	^{137}Cs	HPGe	β^-	680 Hz	1 hour
August 9th 2011 08:08 UTC	X6.9	^{nat}Th	NaI	$\alpha + \beta^-$ decay chain	3300 Hz	24 hours
March 7th 2012 00:24 UTC	X5.4	^{40}K	NaI	EC	790 Hz	1 hour

possible effects correlated with solar flares in three different decay processes: alpha, beta and electron capture.

2. The set-ups

Table 1 summarizes the information on the experimental set-ups we are running to search for modulations in the decay rates of different radioactive sources (period from few days to one year). In particular, in this Letter we only consider an interval of ± 10 days around the time of the 2 solar flares in order to search for any significant deviation (positive or negative) in the decay rate correlated with the flares. The choice of this time window is quite arbitrary, since there is no model, to our knowledge, that correlates the flare intensity with the activity of a radioactive source. On the other hand, we note that, according to data shown in Fig. 2 of [2], the alleged influence of the flare on the source activity lasts for a few days around the occurrence of the flare.

2.1. Potassium source

A 3×3 inch NaI crystal is surrounded by about 16 kg of potassium bicarbonate powder. The set-up, installed above ground, is shielded by at least 10 cm of lead. The total count rate in the 17–3400 keV energy window is about 800 Hz, to be compared to the background of less than 3 Hz when the source is removed. The energy spectrum is dominated by the full energy peak at 1461 keV energy due to the electron-capture decay of ^{40}K to ^{40}Ar. The peak position and the energy resolution ($\simeq 90$ keV at 1461 keV) are fairly constant over months.

2.2. Cesium source

The activity of a 3 kBq ^{137}Cs source is being measured since June 2011. The set-up is installed in the low background facility STELLA (SubTErranean Low Level Assay) located in the underground laboratories of Laboratori Nazionali del Gran Sasso (LNGS). The detector is a p-type high purity germanium (96% efficiency) with the source firmly fixed to its copper end-cap and it is surrounded by at least 5 cm of copper followed by 25 cm of lead to suppress the laboratory gamma-ray background. Finally, shielding and detector are housed in a polymethylmetacrilate box flushed with nitrogen at slight overpressure and which is working as an anti-radon shield. The total count rate above the 7 keV threshold is of 680 Hz. The intrinsic background, i.e. shielded detector without Cs source, has been measured during a period of 70 days: thanks to the underground environment and to the detector shielding, it is very low, down to about 40 counts/hour above the threshold (0.01 Hz). The spectrum is dominated by the 661.6 keV line due to the isomeric transition of ^{137m}Ba from the beta decay of ^{137}Cs.

Details of the experiment and the results obtained in the first 210 days of running to search for an annual modulation of the ^{137}Cs decay constant are given in [5]. Briefly, a limit of $8.5 \cdot 10^{-5}$ at 95% C.L. is set on the maximum allowed amplitude independently of the phase.

2.3. Thorium source

The activity of a sample of natural thorium is measured with a 3×3 inch NaI crystal installed underground in the same laboratory as the germanium experiment with the ^{137}Cs source. The sample is an optical lens, made by special glass heavily doped with thorium oxide. Note that this technique, used for improving the optical properties of glass, was quite common until the seventies. The lens is placed close to the crystal housing and both the lens and the NaI detector are shielded with at least 15 cm of lead. The total count rate above the threshold of 10 keV is of about 3200 Hz (gammas from ^{228}Ac, ^{212}Bi, ^{212}Pb, ^{208}Tl), with a background of 2.3 Hz (due to ^{40}K, thorium and uranium chains and lead X-rays). The energy spectrum is acquired once a day, with a corrected dead time of 2.63%. Even if the chain is not at the equilibrium, the total count rate increases by only $1.7 \cdot 10^{-4}$ over a time period of 1 month.

3. Results

We consider separately the two largest solar flares occurred in the data taking period, i.e. X6.9 August 9th 2011 and X5.4 March 7th 2012 [4]. For each of them only two of the set-ups given in Table 1 were running. As a matter of fact, the ^{nat}Th set-up went out of order in February 2012, due to a failure in the DAQ system, whereas the ^{40}K set-up started taking data in November 2011. On the contrary, the ^{137}Cs set-up is continuously running since June 2011.

Fig. 1 shows the data collected in a 20 day window centered on the August 9th 2011 flare (the day is given in terms of the Modified Julian Date). The X-ray peak flux is plotted in linear scale and given in W/m^2, in the 0.1–0.8 nm band measured by the GOES-15 satellite [4]. Inside the two bands are plotted the residuals of the normalized count rate of the ^{nat}Th and ^{137}Cs sources (i.e. the difference between the measured and expected count rate divided by the measured one), averaged over a period of 1 day.

The error bars are purely statistical. Systematic errors are negligible as compared to the statistical ones during a data taking period of a few days only. For the ^{nat}Th data a linear trend (5.7 ppm/day), due to the recovering of the secular equilibrium, is subtracted, while the ^{137}Cs data are corrected for the exponential decay of the source, using the nominal mean life value of 43.38 y. This latter correction amounts to 63 ppm/day.

From the data we can conclude that the ^{137}Cs source does not show any significant dip or excess in correspondence with the X-ray main peak. On the other hand, the ^{nat}Th source shows a questionable dip in the count rate, starting 1.5 days before the X-flare. However, the dip is well compatible with a statistical fluctuation. As a matter of fact, fluctuations of the same order of magnitude can be seen at different times during the data taking, uncorrelated with X-ray flux peaks. In any case, the existence in our data of an effect as large as the one reported in [2], of the order of a few per mil per day and lasting several days, can be excluded. The maximum effect compatible with our data is smaller than $3 \cdot 10^{-4}$ per