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^{7}Li solar axions: preliminary results and feasibility studies

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Preliminary results and feasibility studies on a search for ^{7}Li solar axion have been carried out. Data collected during 722 h with a LiF powder of 243 g – inserted in a 408 cm^3 low background HP Ge detector (GSOR) at the Gran Sasso National Laboratories (LNGS) of I.N.F.N. – has allowed to set limit on the ^{7}Li solar axion mass of 13.9 keV, better than the previously available one. Improved results would be achieved with a LiF(W) crystal with very low radioactive contamination in U and Th isotopes.

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The existence of axion particle was proposed in order to solve the so-called problem of CP violation in strong interactions (see [1, 2] and references wherein). Sun could be an intensive source of axions. Energy spectrum of Solar axions would consists of the continuous part generated via the Primakoff effect, and quasi-monochromatic lines related with deexcitation of excited levels of nuclides present in Sun through magnetic nuclear transitions. These levels can be thermally excited because of high temperature in the solar core, or can be populated in nuclear reactions. In a deexcitation process, axions could be emitted instead of γ quanta with some probability which is related to their mass.

M1 transitions from the first excited level of ^{7}Li ($E_{exc} = 477.6$ keV) in solar core could be source of quasi-monochromatic axions [3]. This ^{7}Li* level is populated in pp chain of nuclear reactions in Sun when ^{7}Be nucleus, produced through the ^{3}He + $\alpha \rightarrow {}^7$Be + γ reaction, decays to ^{7}Li occupying with 10.5% probability the 477.6 keV level. Coming to Earth, these axions can be resonantly captured by ^{7}Li nuclei. In the subsequent deexcitation process, γ's of 477.6 keV will be emitted (electron conversion coefficient is very low: 7.3×10^{-7} [4]), and, therefore, the possible presence of such axions can be singled out by the presence of the characteristic peak in the energy distribution of a suitable detector placed close to or containing the ^{7}Li sample. The total number of resonant axion absorption processes in a ^{7}Li sample, containing N_7 number of ^{7}Li nuclei, has been calculated [3, 5] by taking into account the current Solar Standard Model as:

$$R = N_7 \times t \times 1.74 \times 10^{-45} \times \left(\frac{m_a}{1\ \text{eV}}\right)^4; \tag{1}$$

here t is the time of measurements (in seconds). In case no evidence is found for the peak searched for, an upper limit on m_a can be set straightforward.

The first experimental work, searching for the ^{7}Li solar axions, gave the limit: $m_a < 32$ keV [3]. Later it was improved to the value of 16 keV [5]. The limits from ^{7}Li are higher than those obtained considering ^{83}Kr ($m_a < 5.5$ keV [6]) and ^{57}Fe ($m_a < 216$ eV [7]). Nevertheless, they are important since if the hadronic axion mass is higher than excitation energy of ^{83}Kr ($E_{exc} = 9.4$ keV) or ^{57}Fe ($E_{exc} = 14.4$ keV), axions just will not be produced in the ^{83}Kr* and ^{57}Fe* transitions. In addition, the ^{7}Li limits are related with the pp chain, the main source of the solar energy, while the ^{57}Fe and ^{83}Kr bounds are subjected to some uncertainties in determination of the iron and krypton abundances in the solar core.

With the aim to preliminarily investigate the ^{7}Li solar axions, measurements on some LiF samples were carried out by using two low background HP Ge detectors in underground conditions (3600 m w.e.) at the Gran Sasso National Laboratories of I.N.F.N.: GSOR (408 cm^3) and GEBER (244 cm^3). Three LiF samples were used in the measurements: i) two LiF powders of different production of 243 g and 47 g, measured in GSOR detector during 722 h and 914 h respectively); ii) a LiF(W) crystal of 224 g, measured with the GEBER detector during 633 h. Details about these measurement and results are reported in ref. [8].

As regard the first samples measurements, comparison of the measured LiF spectrum with the GSOR background shows that the samples are heavily polluted by isotopes from ^{232}Th and ^{238}U chains. As example, Fig. 1 (top) shows the energy distributions measured with and without (background) the 243 g LiF sample for the whole energy range, while Fig. 1 (bottom) shows for the same sample the energy range around the 477.6 keV peak searched for.

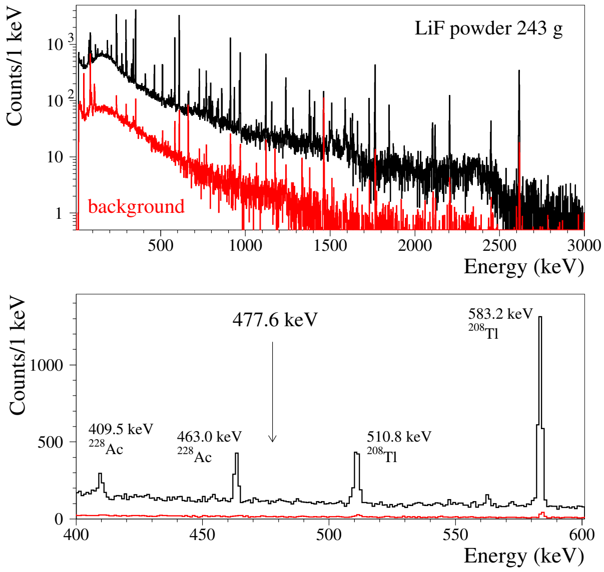

Figure 1: Top: energy distributions measured with the 243 g LiF sample in LNGS HP Ge GSOR detector during 722 h in comparison with the background measured during 1571 h (normalized here to 722 h). Bottom: energy distribution around 477.6 keV.

All peaks in the LiF samples were identified. They belong to usual contaminants: nuclides from U/Th chains, ^{40}K, ^{60}Co, ^{137}Cs. The 47 g sample shows 2–3 times lower U/Th contamination than the first one and only limits on ^{40}K, ^{60}Co, ^{137}Cs and ^{207}Bi were obtained.

The LiF(W) crystal was produced by the Czochralski method in the Institute for Scintillation Materials (Kharkiv, Ukraine) and doped by W at level of 0.04% to improve its scintillation properties. It is very pure and the energy distribution measured with the sample practically coincides with the background. Only limits for radioactive pollutions were derived.

Summary of samples and crystal activities is given in Table 1.

Table 1: Radioactive contaminations in the LiF samples. Limits are given at 90% C.L.

Chain	Nuclide	Activity, Bq/kg		
		LiF powder 1 243 g	LiF powder 2 47 g	LiF(W) crystal 224 g
^{232}Th	^{228}Ac	0.48(1)	0.17(1)	<0.02
	^{208}Tl	0.11(1)	0.04(1)	<0.02
^{238}U	^{214}Pb	0.58(1)	0.31(1)	<0.02
	^{214}Bi	0.55(1)	0.28(1)	<0.02
	^{40}K	0.064(16)	<0.110	<0.066
	^{60}Co	<0.001	<0.001	<0.002
	^{137}Cs	<0.001	<0.001	<0.003
	^{207}Bi	<0.005	<0.003	<0.005

In the spectrum collected with the LiF powder sample of 243 g during 722 h peak at energy of 478 keV is absent (see Fig. 1 bottom), and only limit on its area with some confidence level can be set. These limits have been derived by considering different statistical approaches [8]. With the so-called "one sigma approach", the more cautious limit on the S value has been obtained as 39 at 90% C.L.. The corresponding limit on the axion mass results

$$m_a < 13.9 \text{ keV at } 90\% \text{ C.L.}$$

Data collected with the other LiF sample and with the LiF(W) crystal were processed in a similar way. However, obtained m_a limits were slightly worse: $m_a < 15.3-15.5$ keV. This is related with lower mass of the second sample measured with the GSOR detector, or with lower efficiency of the GEBER detector used to measure the crystal.

The obtained value of 13.9 keV is better than the best previous limit of 16.0 keV obtained for the ^{7}Li solar axion mass in the experiment of ref. [5]. While this improvement is modest, nevertheless it is important because it closes the existing window of possible axion masses between the previous limit of 16.0 keV and the 14.4 keV energy of the next potential source of quasi-monochromatic solar axions from ^{57}Fe.

In order to estimate the experimental sensitivity reachable in a future experiment the possible background sources – able to populate the excited level of ^{7}Li with $E_{exc} = 477.6$ keV – have been considered. For details see ref. [8]. The conclusion of these estimations is that the only background processes potentially important – assuming absence of a suitable neutron shield – are: i) possible pollution of the LiF sample by ^{10}B (because of reaction $n + {}^{10}\text{B} \rightarrow {}^{7}\text{Li}^{*} + \alpha$); ii) excitation of the 478 keV level of ^{7}Li by α and ^{3}H particles from reaction $n + {}^{6}\text{Li} \rightarrow {}^{3}\text{H} + \alpha$.

As regards future measurements, considering that the measured background rate in the energy interval of 475 – 480 keV in the Ge detectors (0.285 counts/h for the GEBER 244 cm^{3} detector and 0.105 counts/h for the GSOR 408 cm^{3} detector) and the expected efficiencies, a sensitivity on ^{7}Li solar axion mass of $\simeq$8 keV can be obtained with the GSOR detector (which has lower background and higher efficiency) collecting data for 6 months with a bigger and pure LiF(W) crystal (which is available).

Finally, it is worth noting that LiF(W) and LiI(Eu) scintillation crystals could be also used to search for the ^{7}Li solar axions; this would also allow to build a large scale experiment. Measurements to investigate radiopurity of two LiI(Eu) scintillators are in progress.

References

[1] G.G. Raffelt, J. Phys. A 40 (2007) 6607; G.G. Raffelt, *Stars as Laboratories for Fundamental Physics*, University Chicago Press, 1996.

[2] A. Ljubicic, Rad. Phys. Chem. 74 (2005) 443.

[3] M. Krcmar et al., Phys. Rev. D 64 (2001) 115016.

[4] D.R. Tilley et al., Nucl. Phys. A 708 (2002) 3.

[5] A.V. Derbin et al., JETP Lett. 81 (2005) 365.

[6] K. Jakovcic et al., Rad. Phys. Chem. 71 (2004) 793.

[7] T. Namba, Phys. Lett. B 645 (2007) 398.

[8] P. Belli et al., Nucl. Phys. A 806 (2008) 388.

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