AL-26 AND BE-10 IN EFREMOVKA AND ACFER CAIS: CONSTRAINTS ON THE ORIGIN OF SHORT-LIVED RADIONUCLIDES. G. Srinivasan[1], Marc Chaussidon [2], and A. Bischoff [3]. [1]Dept. of Geology, University of Toronto, Toronto, ON M5S 3B1 (srini@geology.utoronto.ca) [2]CRPG-CNRA, BP 20 54501 Vandoeuvre-les-Nancy, France (chocho@crpg.cnrs-nancy.fr). [3]Institut für Planetologie, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany.

Introduction: Primitive meteorite constituents like Ca,Al-rich Inclusions (CAIs) and chondrules contain fossil records of several now-extinct short-lived nuclides with half-lifes varying from a hundred thousand years to a few tens of millions of years. Some of these nuclides with short half-lifes, such as ^{41}Ca, ^{26}Al, ^{60}Fe, and ^{53}Mn are products of stellar nucleosynthesis injected into the protosolar cloud before or during its collapse (e.g., [1,2]) or they could be products of interactions of energetic particles with gas and dust in the solar nebula (e.g., [3]). The recent discovery of now-extinct ^{10}Be in CAIs [4-7] has strengthened the proposal that energetic particles are a source of some or the entire inventory of short-lived radionuclides, because ^{10}Be is not a product of stellar nucleosynthesis [3]. Beryllium-10 with a half-life ($T_{1/2}$) ~1.5 Myr is unique among the short-lived radionuclides in that it is formed only by spallation reactions and not by nucleosynthesis (e.g., in a supernova). The production of Be-10 within the solar nebula was challenged recently by Desch et al. [8] based on calculations that Be-10 concentrations observed in CAIs could be achieved by magnetic trapping of GCRs in the molecular cloud parental to the solar nebula. Because of their respective uncertainties, the calculations of solar particle irradiation and GCR trapping cannot discern how much each of these mechanisms contributed to the inventory of Be-10 and in turn how much the former contributed to the inventory of other short-lived radionuclides. It is now quite certain from X-ray observation of low mass stars in pre T-Tauri and T-Tauri phases that they are a source of intense flux of energetic particles [9]. Recent X-ray observations in the Orion nebular cluster of ~43 YSOs with ages from <0.3 to ~ 10Ma and masses ranging from 0.7 to 1.4M (solar masses) demonstrate that essentially all solar type stars experience greatly enhanced X-Ray luminosity [10]. Scaling of such enhanced activities leads to estimates of solar cosmic ray flux $>10^5$ times the modern flux of the Sun. From the astronomical observations it seems inevitable that our Sun may/would have passed through such a phase. The question then is: Did constituents of primitive meteorites experience such an environment and what record can they provide ? One way out of this conundrum is perhaps to examine for multiple isotopic signatures in the earliest formed and most primitive and pristine CAIs.

Samples: We have selected a set of 22 CAIs from CH chondrite Acfer 182 and 3 CAIs from CV3 chondrite Efremovka for Be-10, Al-26 and Ca-41 studies using the large geometry Cameca ims1270. We report the results from 3 Acfer CAIs and 2 Efremovka CAIs. Acfer 182 contains CAIs which unlike CAIs from CV chondrites are small but contain abundant refractory grossite. We have chosen all the CAIs previously analyzed by Weber et al. [11] and identified 3 previously unanalyzed CAIs. One Acfer 182 CAI Pl1267-Hib1 (Fig 1a) with a chondrule-like shape has laths of hibonite rimmed by olivine and spinel at the periphery. The egg-shaped Acfer 182 PL 1266-B2 (Fig1b) has a core of melilite and blocky hibonite crystals. Efremovka CAIs E65 and E66 were also analyzed. E65 is a type B1 CAI previously analyzed for Al-26, Ca-41 and Be-10 [12-15]. The Mg isotopic studies were carried out in static multi-collector mode using Faraday Cups with a primary ion beam of ~50nA and ^{24}Mg ion signal ranging from 10^7-10^8 cps. Boron isotopes were measured using earlier techniques [7].

Results: In CAI E66 hibonite, melilite, and spinel were analyzed for Mg isotopic composition and in E65 melilite, spinel, and anorthite were analyzed. The E66 isochron is extremely well defined with an initial $^{26}Al/^{27}Al$ = $(5.49+0.16/-0.12)\times10^{-5}$ ($2\sigma_m$) obtained on the basis of correcting all the phases for ionization efficiency of BCG glass. In E65 some of the analyzed plagioclases are disturbed [e.g., 15]. The melilite-spinel ^{26}Al abundance is within errors similar to E66. The initial Al-26 abundance for Acfer CAI PL1266-B1 is higher, $^{26}Al/^{27}Al = (1.11\pm0.49)\times10^{-5}$, and for Acfer CAI PL1267-Hib1 is lower, and $^{26}Al/^{27}Al = (4.5\pm3.6)\times10^{-6}$ ($2\sigma_m$), which overlap in their uncertainties. The Efremovka CAIs E66 and E65 have $^{10}Be/^{9}Be = (1.24 +0.71/-0.90)\times10^{-3}$ and $^{10}Be/^{9}Be = (1.24\pm0.27)\times10^{-3}$ ($2\sigma_m$), respectively. These are the highest values observed for ^{10}Be abundance in the solar system. The Acfer CAIs (PL1266-B2 and PL1267-Hib1) have lower $^{10}Be/^{9}Be = (6.9\pm1.6)\times10^{-4}$ compared to E65 and E66. The very high precision in-situ analyses of Mg isotopes has given opportunity to resolve Mg-26 excess which previously may not have been possible with the low counting statistics measurements using the small geometry ion probe.

Discussions: 1. The Efremovka CAIs have high Al-26 and high Be-10 abundance. 2. The Acfer CAIs have lower Al-26 (factor of 5 to 10) and Be-10 (factor of two) abundance than E66 and E65 respectively. 3. The values for E65 (Al-26) are differ from previously reported data [12]. 4. The Be-10 abundance for E65 is consistent with previously reported data [14]. 5. Unlike the previously analyzed Acfer 182 CAIs [11] which showed no excess ^{26}Mg and lack of Al-26, the two analyzed CAIs have resolvable excess in Mg-26 and Al-26 abundance which is a factor of 5 to an order of magnitude less than the canonical value.

To interpret the data chronologically we assume uniform distribution of Al-26 and Be-10 in the solar nebula with the highest observed values of $^{26}Al/^{27}Al = 6\times10^{-5}$ [16]. If the lower abundance of Al-26 is attributed to time then E66 formed 0.18 mys after CAIs with supra-canonical values [16]. Using this time difference we infer the initial solar system abundance of $^{10}Be/^{9}Be = 1.34\times10^{-3}$. Acfer CAIs based upon Al-26 abundance formed nearly 1.7 and 2.6 mys later. However, on the basis of Be-10 data they formed 1.43 mys later. The time inferences based upon these two radionuclides do not converge. One possibility is that Be-10 and Al-26 were decoupled in their source and the former produced by solar irradiation could vary in time and space. The lower Al-26 abundance in one Acfer-182 CAI is due to later resetting of Mg isotopes.

An alternative scenario is that Al-26 abundance in Acfer CAIs is a signature of the steady state abundance of Al-26 in the local interstellar medium [17,18] and the lower Be-10 is the GCR produced Be-10 complement trapped in the protosolar cloud [8]. The observed high value of Be-10 in E65, E66 can be accounted by addition of SCR produced Be-10. The high value of Al-26 abundance in E66 and E65 is due to addition of Al-26 produced locally or injected from stellar source(s). Therefore, in this scenario Acfer CAIs formed earlier than Efremovka CAIs. If this interpretation is correct the Acfer CAIs should not have any Ca-41, since this isotope has an extremely low half-life. Preliminary results from one Acfer 182 CAI from the suite analyzed earlier [11] did not have Ca-41 [19]. Short-lived radionuclide inventory cannot be explained due to energetic particle production or nucleosynthetic contributions by treating them as mutually scenarios. If we consider the separation of protosolar nebula from the interstellar medium and its subsequent evolution, then oldest CAIs will trap the steady state abundance of short-lived radionuclides of the ISM and the component of GCR contribution. The relatively younger CAIs will incorporate nucleosynthetic contribution (single or multiple) if stellar input into the protosolar nebula followed much later after separation, and SCR (irregular and extreme intensity and/or steady and high intensity) produced products. In this set of experiments we have provided a clue to decouple the magnitude of some of these contributions; however, there is no obvious way of proving this scenario

It is not clear how many of the previously analyzed CAIs from Acfer 182 [11] and Murchison hibonites (e.g., [20]) whose Mg isotope data were interpreted as absence of Al-26 could have low but measurable Al-26 abundance. The "decoupling" observed between Al-26 and Be-10 may be really a case of low Al-26 (an order of magnitude less than canonical value) and lower Be-10, similar to our observations in Acfer 182. Work is in progress to address these questions.

References: [1] Wasserburg G.J. et al. (2006) *ApJ* **424** 412. [2] Meyer B.S. and Clayton D.D. (2000) Sp. Sci Rev. **92** 133-152. [3] Gounelle M. et al. (2001) *ApJ* **548** 1051-1070 [4] McKeegan K. et al. (2000) *Science* **289** 1334-1337. [5] Sugiura et al. (2001) *Meteorit. Planet. Sci.* **36** 1397-1408. . [6] MacPherson G.J. et al. (2003) *Geochim Cosmochim Acta* **67** 3165-3179. [7] Chaussidon M. et al. (2006) *Geochim Cosmochim Acta* **70** 224-245. [8] Desch S.J. et al. (2004) ApJ **602** 528-542. [9] Feigelson E.D. and Montmerle T. (1999) *Annu. Rev. Astron. Astrophys.* **37** 363-408. [10] Feigelson et al. (2002) *Ap J* **572** 335-349. [11] Weber D. et al. (1995) *Geochim. Cosmochim. Acta* 59 803-823. [12] Goswami J.N. et al. (1994) *Geochim. Cosmochim. Acta* [13] Srinivasan G. et al. (1994) *Ap J* 431 L67-L69. [14] Srinivasan G. (2001) *MAPS* **36** A195. [15] Srinivasan G. et al. (2000) *MAPS* **35** A152. [16] Young et al. (2005) *Science* **308** 223–227. [17] Clayton D.D. and Leising M.D. (1987) *Phys. Reports* **144** 1-50. [18] Prantozos N. and Diehl R. (1996) *Phys. Reports* **267** 1-69. [19] Srinivasan G. and Bischoff A. (2001) *MAPS* **36** A196 [20] Marhas et al. (2002) *Science* **298** 2182-2185.

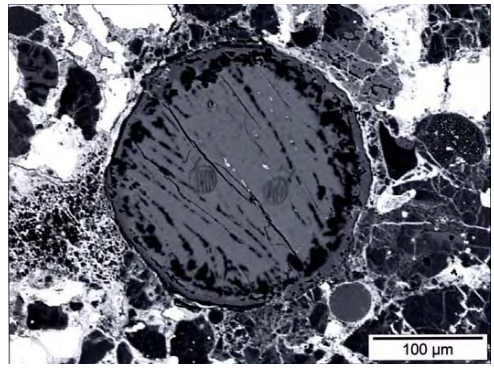

Fig 1a: BSE Image of Acfer182 Pl1267-Hib1

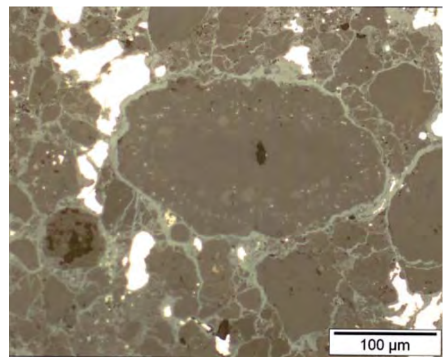

Fig 1b: BSE Image of Acfer182 CAI Pl1266-B2