MULTIPLE EPISODES OF SUPERFLARES FROM OUR NASCENT SUN: EVIDENCES FROM A CANONICAL CAI IN VIGARANO. R. K. Mishra[1] K. K. Marhas[2] and M. Chaussidon[3], [1]Independent researcher, Vill: Dhawalpura, Po: Kaitha, District Bhagalpur, Bihar 813211 India (riteshkumarmishra@gmail.com), [2]Planetary Sciences Division, Physical Research Laboratory, Navrangpura, Ahmedabad, Gujarat, 380009 India, [3]Université de Paris, Institut de Physique du Globe de Paris (IPGP) 1 rue Jussieu 75238 Paris Cedex 05 France.

Introduction: The birth and early evolution of the Sun is one of the major drivers of the physical, chemical, isotopic, evolution and processes in the proto-planetary disk. The intensity and frequency of flares from the nascent Sun remain under constrained from the existing records of their potential products in meteorites [1]. Calcium, aluminum, -rich inclusions (CAIs) within chondrites are considered to be the first forming solar system solids. Short-lived now-extinct radionuclides (SLNs) are important relative time keepers of the events and processes during the origin and early evolution of the Solar system. To identify early episodes of flares, their chronology and causality on the early evolution of the Solar system, lithium-beryllium-boron (Li-Be-B) isotope systematics were studied in a CAI from Vigarano (CV~3.1-3.4).

Meteorite and CAI: Petrography and Mineralogy: Vigarano (CV~3.1-3.4) is one of the least altered meteorites that has been extensively studied. Vigarano CAI 1 is a large (~4.6 mm×3.6 mm), irregular shaped inclusion (Fig. 1). It is classified as type B CAI and has been studied for ^{26}Al-^{26}Mg isotope systematics [2]. It consists of predominantly large blocky melilites that host subordinate euhedral, subhedral spinels ranging in size from 5 to 200 µm, that are clustered within the central region of radius of ~1000 µm. Plagioclase, pyroxene, perovskite, and other secondary, altered phases typically found in CV CAIs are absent. A Wark-Lovering (WL) rim of variable width 200-350 µm that consists of a few layered sequences of mineral phases of varying width (50-250 µm) faithfully palisades the outer margin except for chipping off at the edges with sharp bend. The melilite composition decreases rapidly in aluminum content from Åk 9 to Åk 25-30 mol% within 200-300 µm from the edges of CAIs. The inner region is quite uniform in composition (Åk 35mol%). Abundance of lithium (0.4-37 ppb), beryllium (70-970 ppb), vary quite significantly up to a few orders of magnitude, in the inner region that broadly follow the trend that can be explained from closed system crystallization of these elements in melilite. Boron abundance in the melilite also vary quite significantly from 0.13-16.9 ppm. Lithium-beryllium-boron isotopic study uniquely combines decay of ^{7}Be to ^{7}Li ($t_{½}$ = 53.12±0.07 days) [3] and ^{10}Be to ^{10}B (1.389±0.3 Ma) [4]. Owing to very short half-life of ^{7}Be and very high diffusivity of Li in melilite, obtaining meaningful records for this particular radioactive decay isotope systematics has been challenging. Furthermore, all CAIs have complex evolutionary history of experiencing multiple high temperature evaporation, condensation, heating events, in addition to parent body metamorphism that further complexifies the search for primitive early Solar system records.

Analytical Method: Li-Be-B in situ isotope measurements in melilites within the interior regions and in the Wark-Lovering rim were made using secondary ion mass spectrometer ims 1270 at Centre de Recherches Pétrographiques et Géochimiques CRPG-CNRS, Nancy France. A primary ~25 nA O^- beam, focused to spot size of ~20×25 µm, on a sample kept at 10 kV, for a total impact energy of ~23 kV was used to obtain secondary positively charged ions of isotopes of Li, Be, B. A typical analytical measurement involved measuring ion intensities at mass 5.8, ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B, ^{11}B for 3, 3, 2, 3, 10, and 5 seconds, respectively. The data were obtained in two sessions over a period of 3 months. The sums of counts obtained over 50-150 cycles were used to calculate ratios.

Results and Discussion: Vigarano has a cosmic ray exposure age of ~5.6 Ma. The measured lithium isotopic ratios (^{7}Li/^{6}Li) corrected for cosmogenic Li range from 11.8-18.3 (δ^{7}Li up to 530‰). ^{10}B/^{11}B isotopic ratio range from 0.2445-0.2627 (δ^{10}B up to ~60‰). Error weighted linear regression of the data (^{7}Li/^{6}Li vs ^{9}Be/^{6}Li and ^{10}B/^{11}B vs ^{9}Be/^{10}B) were calculated using isoplot 4. A linearly correlated relationship, can result from (i) in situ decay of radionuclides ^{7}Be, and ^{10}Be (ii) mixing between two different reservoirs of chondritic lithium or boron and of another component obtained under plausible physical, chemical conditions either from (a) cosmogenically produced Li (Fig. 2), or (b) implanted Solar wind, or (c) diffusion related mixing. However, the lack of spatial correlation within the CAI in the observed abundances of Li-Be-B and their corresponding isotopic ratios, and the absence of expected suitable end-members, makes plausible that the observed excesses in ^{7}Li/^{6}Li result from the in-situ decay of ^{7}Be. Thus, the observed correlation between ^{7}Li/^{6}Li and ^{9}Be/^{6}Li could be suggestive of in-situ decay of ^{7}Be corresponding to an initial ^{7}Be/^{9}Be ratio of (4.3±3.5)×10^{-3} (2σ; Fig. 2a) and an intercept δ^{7}Li of (0.9±10.8)‰. The ^{7}Be/^{9}Be abundance in Vigarano CAI

1 is ~4× higher compared to the Efremovka CAI (E40) and similar to Allende CAI 3529-41 [1, 3]. The inferred abundance of $(1.4\pm1.2)\times10^{-2}$ for $^{10}Be/^{9}Be$ (Fig. 2b) would be amongst the highest observed ($(4\text{-}100)\times10^{-4}$) so far [5-14] but the ^{10}Be isochron is not well behaved. A small range of $^{9}Be/^{11}B$ combined with thermal disturbance and mixing of boron within the CAI may have resulted in the significant scatter in the data, thus causing large uncertainty in the inferred isochron. A narrow range in $^{10}Be/^{9}Be$ abundance of $(4\text{-}8)\times10^{-3}$ has been observed in type B CAIs in CV chondrites.

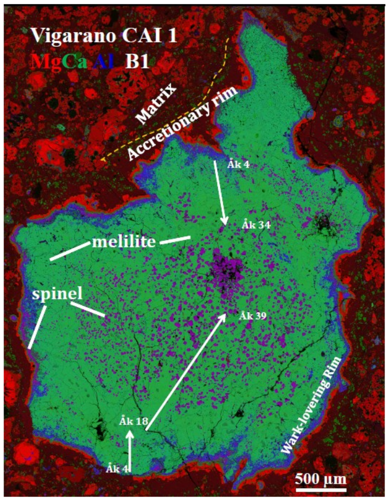

Fig. 1 (A) Mg-Ca-Al (RGB) mosaic map of Vigarano CAI#1. ^{26}Al-^{26}Mg isotopic system in Vigarano CAI 1 gave $^{26}Al/^{27}Al$ abundance of $(4.89\pm0.38)\times10^{-5}$ implying its formation at (0.07±0.08) Ma, early in the history of the accretion disk [2].

The short half-life of ^{7}Be essentially delimits the production of ^{7}Be, and by genetic association of ^{10}Be, to spallation reaction induced by solar energetic particles on the solids and gas in the proto-planetary disk [1,5-7, 10]. The other alternative scenarios of production of ^{10}Be [15,16] and ^{7}Be [17] though physically possible have insignificant contribution to the inventory. A model theoretical calculation similar to previously reported [1] can simultaneously explain high abundance of $^{7}Be/^{9}Be$ and $^{10}Be/^{9}Be$ produced during an intense irradiation event. Our spallation calculations show that an X-ray intensity of the flare corresponding to L_x ~5×10^{32} erg/sec irradiating the gas and precursor solids for about a year can coherently explain the observed ^{7}Be and ^{10}Be abundances with the limiting constraint coming from the short half-life of ^{7}Be. Since the inferred abundance of $^{7}Be/^{9}Be$ and $^{10}Be/^{9}Be$ in Vigarano CAI 1 are higher by a factor of 4 and 10 respectively than those in Efremovka CAI 40, the present set of model calculations (within their uncertainty) can also explain the observations in E40. The observed high abundance of ^{7}Be in Vigarano CAI 1 taken together with Efremovka CAI 40 that formed about 0.4 Ma later explicitly imply at least two (multiple) epochs of super flare events from the nascent Sun.

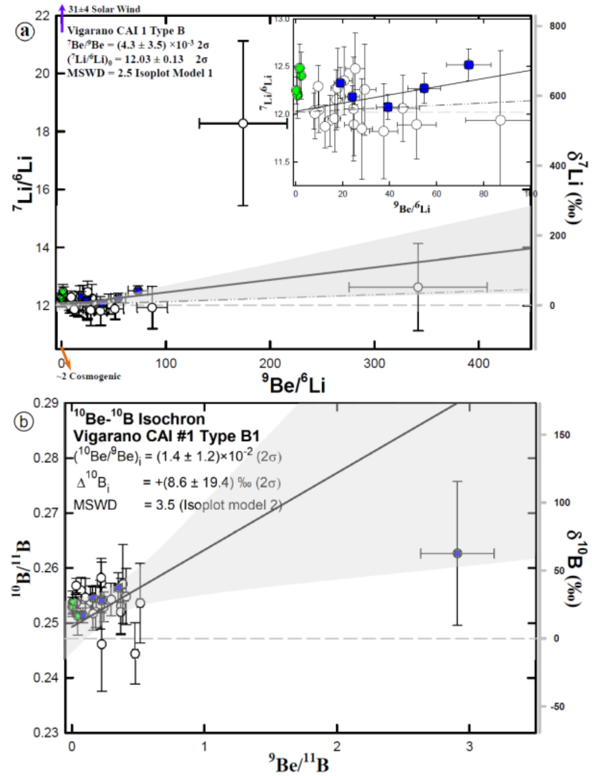

Fig. 2 Isochron plots of (a) $^{7}Be/^{9}Be$ (b) $^{10}Be/^{9}Be$ for Vigarano CAI 1. All indicated errors are 2σ. The open circle and filled green rhombus show analyses of melilite in the central region and in WL-rim respectively during the first session while the filled blue squares are analyses with higher precision of melilite in the central region made during the 2nd session. Note the small errors in the second session that anchor the isochrons.

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