IRRADIATION PRODUCTION OF ^{26}Al AND THE CANONICAL VALUE OF $^{26}Al/^{27}Al$? S. Sahijpal and G. Gupta, Department of Physics, Panjab University, Chandigarh, 160014 India (sandeep@pu.ac.in).

Introduction Origin of short-lived nuclides (SLRs), specifically ^{26}Al in the early solar system (ESS) has been argued to be due to either fresh stellar nucleosynthesis prior to the formation of the solar system [1,2] or by irradiation during intense magnetic flaring in ESS [3]. The possibility of intense flaring in ESS is supported by astronomical observations of young stellar objects (YSOs) [4]. Since, both stellar [5] and irradiation [6] sources were presumably involved in synthesizing SLRs, it is essential to establish their contributions. Among the proposed irradiation scenarios in the ESS, the X-wind scenario explores the feasibility of thermal processing of protoCAIs along with their irradiation [3]. Based on this scenario, a comprehensive numerical code for the thermal processing and irradiation of protoCAIs has been recently developed [7]. The main objective for developing a numerical code is to infer the spread in the irradiation yields of SLRs. These yields are compared with the observed abundances of SLRs in various pristine meteoritic phases to verify the feasibility of the irradiation scenario. Thus, the X-wind irradiation scenario should explain the observed spread in the canonical value of $^{26}Al/^{27}Al$ [8].

Numerical simulations: In the present work, we have developed a numerical code for the first time to infer the irradiation yields of SLRs, ^{7,10}Be, ^{26}Al, ^{36}Cl, ^{41}Ca and ^{53}Mn for an ensemble of protoCAIs that was thermally evolved over a grain-size distribution in the reconnection ring during the decades long X-wind cycle [3]. We make an assessment of the irradiation contribution of ^{26}Al to the ESS.

Simulations were performed within the framework of the various proposed physico-chemical processes [3]. In the previous work, the dependence of the coronal plasma viscous drag on the grain size distribution of protoCAIs was studied by performing simulations with three distinct core-size distributions, viz., 32 μm–20 mm, 125 μm–16 mm and 500 μm–13 mm [7]. These distributions were dominated by the protoCAIs with the refractory core sizes (D_c, henceforth), 32 μm, 125 μm and 500 μm, respectively. The latter two distributions were found to result in a substantial accumulation of protoCAIs in the reconnection ring and could account for the bulk inventories of SLRs in ESS [7]. This imposed a stringent constraint on the average rock surface density, $\Sigma_r \geq 1.6$ g cm^{-3} for the accumulation of protoCAIs. One of the major shortcomings of this previous work was the inability to dynamically evolve the protoCAIs core-size distribution over their proposed decades long thermal processing [7]. We have now developed a numerical code with a dynamically evolving refractory core-size distribution. Within a simulation, at a specific time during the X-wind cycle, the grain size distribution is dominated by the size of the typical refractory core (D_c) that condense subsequent to the superflares with Lx ~10^{31-32} egs. s^{-1} for Lp/Lx (proton luminosity/X-ray luminosity) ~0.3 [7]. This in turn depends upon the prevailing value of Σ_r at that specific time [3,7]. With the increase in Σ_r, the D_c steadily increases during an X-wind cycle. We have now developed a code where we can simulate the increase in D_c with Σ_r over the X-wind cycle lasting over decades. This would enable us to decipher the exact nature of the proposed X-wind irradiation scenario, and in general any other plausible variances of the irradiation model.

An ensemble of protoCAIs with refractory cores in a size range (118 μm–1.06 cm) was thermally evolved over the decades long X-wind cycle [3]. Compared to the previous work [7], the newly refined grain size distribution now consists of fourteen distinct refractory cores with the radii ratio of $2^{1/2}$ between the two successive core sizes. This is an improvement over an earlier division of the distribution into eight distinct core sizes. The simulations were initiated with D_c=118 μm as the dominant refractory core that condense subsequent to the superflares with Lx ~10^{31-32} egs. s^{-1} for Lp/Lx ~0.3. With the accumulation of irradiated protoCAIs mass in the reconnection ring along with the associated increase in Σ_r, the D_c was steadily increased according to three assumed distinct trends (fig. 1) in a stepwise manner from 118 μm to ~2 mm over a time-span of 1-3 decades of the X-wind irradiation cycle. These representative set of simulations helps in deducing the dependence of the irradiation yields of SLRs not only on the evolutionary trend of the core-size distribution but also on the time-span of a single X-wind cycle. Several additional refinements have been also made in the simulations. The 0.25 R_x wide reconnection ring has been now divided into twenty concentric annular zones compared to the previous division of the ring into five concentric annular zones [7]. Several additional nuclear reactions have been included for the production of SLRs. These include $^{35}Cl(^{3}He,x)^{36}Cl$, $^{34}S(^{3}He,x)^{36}Cl$, $^{39}K(^{3}He,x)^{36}Cl$ and $^{16}O(^{3}He,x)^{7}Be$.

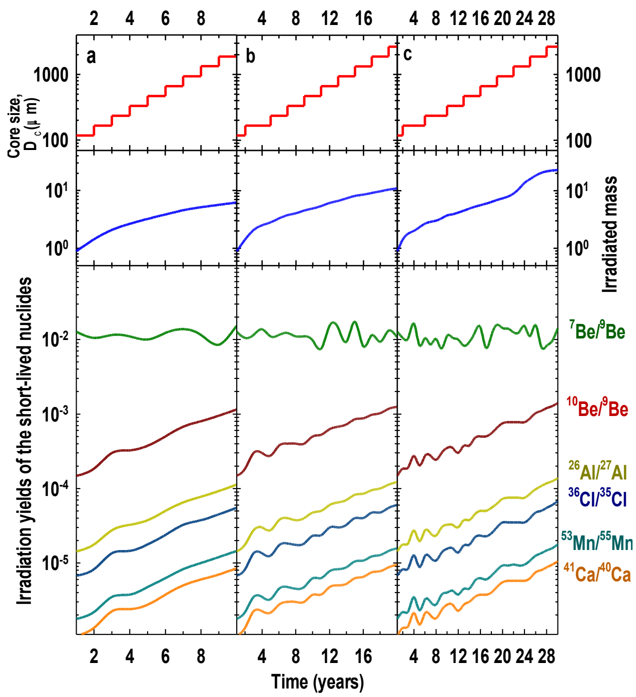

Fig. 1. The bottom panels represent the temporal evolution of the average irradiation yields of the short-lived nuclides over the X-wind cycle corresponding to three distinct evolutionary trends of the core-size distribution over 1-3 decades. The top panels represent the assumed stepwise increase in the dominant refractory core size (D_c) over the X-wind cycle, with the middle panels representing the normalized increase in the irradiated protoCAIs mass in the reconnection ring. Impulsive flares were triggered in the simulations with ^{3}He/proton =0.3, ^{4}He/proton =0.1, Lp/Lx (proton luminosity/X-ray luminosity) =0.3, and the energy spectra, dN/dE ∝ E^{-4} [7].

Results: The results obtained from a set of simulations with distinct parameters and trends in the evolution of protoCAIs core size distribution are presented in fig. 1. Irradiation yields of SLRs, except ^{7}Be, gradually increase over time with the evolution of the core-size distribution. This is inherently expected from the irradiation of an evolving ensemble of protoCAIs over an X-wind cycle lasting over decades due to the accumulation of protoCAIs in the reconnection ring. This aspect has never been appropriately considered in the original proposed scenario [3]. Further, the three distinct choices for the evolution of core-size distribution infer distinct yields of SLRs for an identical X-wind irradiation time-span. These findings impose stringent constraints on the irradiation scenario, and in general any other plausible variances of the model to be the major source of at least ^{26}Al. It would be difficult to eventually produce the confined observed spread [8] in canonical value of ^{26}Al/^{27}Al (fig. 2) in ESS as a result of numerous repeated X-wind cycles until unless each of this cycle repeats with an identical time-span and with identical nature of physico-chemical processes. In addition, the hypothetical superflares with Lx >10^{32} egs. s^{-1} that could vaporize all protoCAIs and homogenize the irradiated yields of SLRs have never been observed [4].

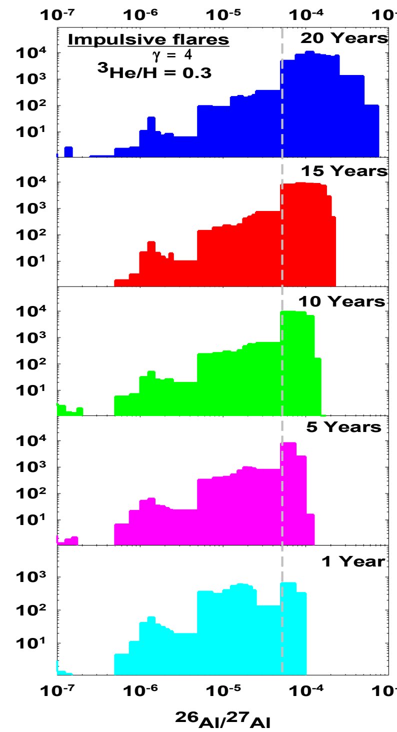

Fig. 2. Time evolution of the normalized differential spectra of the irradiation yields of ^{26}Al/^{27}Al during a single X-wind irradiation cycle corresponding to the simulation results presented in fig. 1b. Dashed line represents the canonical value of ^{26}Al/^{27}Al [8].

Conclusions: In case the gradual flares dominated the early solar system as in the case of modern sun, we anticipate ≤10 % X-wind irradiation contribution to the initial ^{26}Al. The bulk ^{26}Al was probably of stellar origin [2]. Comprehensive analyses of the plausible stellar sources suggest that a massive star probably contributed ^{26}Al along with ^{60}Fe to the early solar system [2,9]. This scenario would involve injection of SLRs into either the presolar cloud or proto-planetary disc [9]. In contrast to the X-wind irradiation scenario this stellar scenario would inherently produce a canonical value of ^{26}Al/^{27}Al on account of rapid mixing in the ESS.

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Acknowledgments: This work is supported by PLANEX grant.