THE NATURE OF THE MASSIVE STAR THAT COULD HAVE INJECTED ^{26}AL IN THE EARLY SOLAR SYSTEM. S. Sahijpal and G. Gupta, Department of Physics, Panjab University, Chandigarh, 160014, India (sandeep@pu.ac.in)

Introduction: We make an assessment of the irradiation contributions of the now extinct ^{26}Al and other short-lived nuclides (SLRs) to the early solar system (ESS) within the X-wind irradiation formulation. Furthermore, we explore the nature of the massive star that probably synthesized the bulk inventory of the ^{26}Al.

Numerical simulations: Based on the numerical code of the irradiation of protoCAIs in the magnetic reconnection ring within the X-wind irradiation formulation [1] along with the recent refinements [2], we present the results of the various simulations with a wide range of parameters (fig. 1). Within the framework of the numerous physico-chemical processes operating in the reconnection ring over the repeated x-wind cycles and the wide range of parameters it would be difficult to obtain the canonical value of ^{26}Al/^{27}Al along with the yields of other SLRs in a self consistent manner. In case the gradual flares dominated the early solar system as in the case of modern sun, we anticipate ~1% X-wind irradiation contribution to the initial ^{26}Al to match the requisite amount of ^{10}Be. A massive star probably contributed the bulk [2,3]. We now make an attempt to understand the environment associated with the formation of the massive star and the solar system.

The astrophysical settings: Stars are mostly formed in embedded stellar clusters [4-6]. Whether a cluster of low-mass stars alone (e.g., the Taurus-Auriga complex) or a cluster of low-mass and massive stars together (OB associations, e.g., the Trapezium cluster) is formed depends primarily upon the cluster mass [5]. In a broad sense, two distinct astrophysical settings can be envisaged that can lead to the contribution of SLRs by a massive star to the ESS: **Case A)** the massive star and the solar system were formed in the same cluster [e.g., 6], **Case B)** the two were formed either in the different regions of the molecular cloud or in distinct stellar clusters, e.g., the Scorpius-Centaurus complex [7].

Case A: There need not be any casual relationship between the formation of the massive star and the formation of the solar system in this scenario. Apart from the hypothesis that the ionizing front and winds from the massive star can trigger low-mass star formation, an alternative hypothesis also requires discussion. It is quite likely that within a cluster the formation of low-mass stars occur spontaneously as a result of local density fluctuations in the self gravitationally contracting pre-cluster cores [5,7]. Subsequently, the massive stars are formed at the cluster core by either rapid accretion scenario or stellar mergers during the embedded dense phase [5,8,9]. The ionizing fronts and the winds of the newly formed massive stars terminate the local star formation. This star formation scenario explains the empirical relationship between the mass of the most massive star within a cluster and the estimated stellar cluster mass by forming stars in an ordered fashion, starting with the lowest-mass stars [5]. Within this star formation scenario the formation of the massive star might have occurred a little latter after the initiation of the formation of the solar system. The massive star will eventually undergo core collapse supernova (SN) and eject SLRs into the proto-planetary disc [10]. Several issues regarding this scenario need to be addressed. These are;

1) The mass of the most massive O star within the cluster. This massive star would be the earliest to evolve, explode and eject SLRs. The mass of the stellar cluster would probably determine the mass of this massive star [5]. A single massive star (M_{ZAMS} >30 $M_\odot$;$Z_\odot$) or a primary massive star (M_{ZAMS} >15 $M_\odot$;$Z_\odot$) within a close interacting binary system goes through Wolf-Rayet stage followed by SNIb/c [11-13]. One of these stars could be a potential source of SLRs [3]. For example, the most massive stellar system in the Trapezium cluster, the θ^1 Orionis C is presumably a close interacting binary with an estimated stellar masses of ~34 & ~15 $M_\odot$ [14]. This would probably go through WR+SNIb/c stages. Apart from this, in general, a single massive star >40 $M_\odot$ explodes within an interval of 3-5 Myr after its formation compared to ≥ 7 Myr required by the ≤ 25 $M_\odot$ single stars to explode as SNII. Since in the case of proto-planetary disc scenario [10] the ejection of SLRs should occur early prior to significant evolution of the disc, the massive stars (>40 $M_\odot$) would be favorable.

2) The probability of the massive star against its dynamical ejection from the cluster as a runaway star prior to SN [15,16]. The dynamical ejection of O stars seems to be quite predominant. During the last ~1 Myr the Trapazium cluster could have suffered significant losses in terms of even more massive stars than presently observed and could be presently in a state of further decay [17]. In order to be a source of SLRs, the massive star has to survive the runaway status. In this regard, the Upper Scorpius OB association probably represents an ideal case of an evolved cluster [17] with an age of ~5 Myr and a spatial spread of ~25 pc [7,18]. The progenitor of the pulsar PSR J1932+1059, with an estimated mass of 40-60 $M_\odot$ [17] could have injected SLRs during SN into the proto-planetary discs of the cluster stars within a short period of ~3.5 Myr. This could be a more realistic analog for the solar system,

along with our assumed formation sequence of the low- and massive stars within the cluster.

3) In order to avoid perturbations to the evolving planetary system it would be essential for the solar system, formed within a cluster, to avoid close encounters with the companion stars [18]. The cluster should disperse prior to the major planetary formation, otherwise highly eccentric planetary orbits would result.

Case B: This is a conventional scenario involving the triggered formation of the solar system by a distant massive star. Due to the various isotopic and dynamical constraints, the massive star contributing ^{26}Al to the presolar cloud should be <10 pc away [3]. This would place the SN right within the evolved stellar cluster as in the case of Upper Scorpius. The chances of a SN to trigger star formation within these shorter distances would be less than the chances of a SN injecting SLRs into an already existing proto-planetary disc as the former scenario could lead to the disruption of the presolar cloud rather than its gravitational collapse. The distant SN >10 pc can contribute ^{60}Fe without ^{26}Al along with triggering the gravitational collapse [3].

Conclusions: The bulk of the ^{26}Al in ESS was probably synthesized by a massive star. Further, we have explored the feasibility of the initiation of the formation of the solar system followed closely by the formation of the massive star with in a single stellar cluster. As the cluster dynamical evolves and the massive star eventually explodes, the SLRs are injected into the proto-planetary disc. The cluster is eventually dispersed prior to the major planetary formation.

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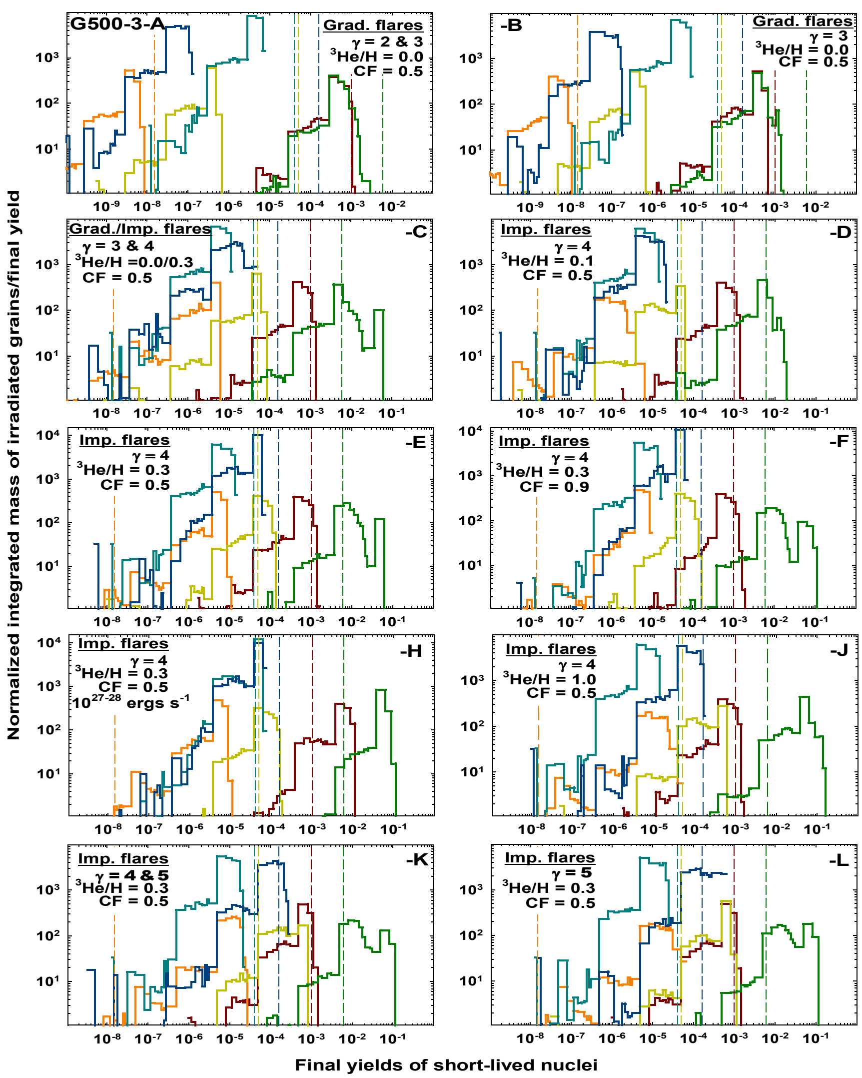

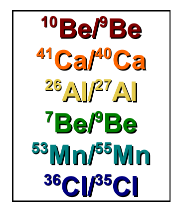

Figure 1. The normalized differential mass spectra of the final yields of the short-lived nuclides for the core-mantle ensemble of grains at the end of various simulations [1,2]. ***Grad**ual flares*: ^{4}He/^{1}H = 0.01; ***Imp**ulsive flares*: ^{4}He/^{1}H = 0.1. The energy spectra: dN α E $^{-\gamma}$dE. The dashed vertical lines represent the various empirical estimates of the SLRs.

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