SHORT-LIVED RADIONUCLIDES AND THE EVOLUTION OF THE MILKY WAY GALAXY. T. Kaur and S. Sahijpal, Department of Physics, Panjab University, Chandigarh. 160014, India. (sandeep@pu.ac.in)

Introduction: The presence of the short-lived nuclides (SLRs), ^{26}Al, ^{36}Cl, ^{41}Ca, ^{53}Mn and ^{60}Fe, in the early solar system has been extensively used to understand the nature and the chronology of the various astrophysical and planetary processes related with the origin and the early evolution of the solar system [e.g., 1-9]. The SLRs contribution in the early solar system is generally attributed to a localized environment associated with evolved star(s) [1-9]. The *homogeneous* galactic chemical evolution is ruled out as a significant contributor of SLRs to the early solar system [10,11]. However, the birth of the solar system as a natural consequence of the evolution of stellar cluster(s) during the evolution of the Milky Way galaxy has been studied [11]. The recent chemodynamical evolution model provides an account of the heterogenous chemical evolution of SLRs in the galaxy [9]. Here, we present *homogeneous* GCE model (*hom*-GCE) for the SLRs based on our recent galactic chemical evolution (GCE) model for the entire galaxy [12] that employs updated prescriptions for the formation of the galaxy [see e.g., 13]. Further, we present *heterogeneous* GCE model (*het*-GCE) that integrates the features of our high spatial resolution (~0.5-2 kpc^2) evolution of galaxy [14] with our recent GCE model [12]. We attempt to understand the formation of solar system in a stellar association in context with the evolution of the galaxy.

Numerical approach: The galaxy is assumed to have formed ~13.7 Gyr. (Giga years) ago, whereas, the solar system formed ~4.5 Gyr. ago in our GCE models with a temporal resolution of one million years (Myr.). We adopted the *Model H* from our recent work on GCE in the case of *hom*-GCE model [12] to deduce the GCE of the relevant SLRs. The GCE model is based on the three infall accretion scenario for the formation of the galaxy [13] that successfully reproduces majority of the observed features of our galaxy [12]. We avoid the simulation details here. In the *hom*-GCE model, the entire galaxy is divided into concentric annular rings of width 2 kpc each. The solar neighborhood is defined at a galactocentric distance of 8-10 kpc. Subsequent to the evolution of the stars after their mass and metallicity dependent life-spans, the stellar nucleosynthetic yields are instantly homogenized over the individual annular rings. Homogenization provides an averaged isotopic abundance evolution [10,11].

The heterogeneous GCE models (*het*-GCE) circumvents the rigorous assumption regarding the large scale homogenization of the nucleosynthetic yields by locally homogenizing [14]. These models assume the homogenization of yields from evolving stellar associations/cluster(s) over an assumed region of ~0.5-2 kpc^2, thereby, maintaining heterogeneities over a larger galactic area [14]. We integrated the features of our heterogeneous evolutionary model [14] with our recent GCE model [12] for the solar annular ring. We ran two simulations with the division of the ring into 50 (***Case A***) and 200 (***Case B***) spatial grids. This corresponds to spatial grid areas of ~2.2 and ~0.5 kpc^2, respectively. The grids are individually evolved in terms of star formation and evolution from evolving stellar associations/cluster(s). The nucleosynthetic yields of the massive stars (>11 $M_\odot$) are homogenized within the individual grid, thereby, producing localized homogeneity, along with the heterogeneities over a larger spatial scale. Compared to the *hom*-GCE model, the SLR yields of the low-mass (AGB) stars and supernova SN Ia are not included in the *het*-GCE models. Massive stars contributions dominate in these high spatial resolution models due to the localized mixing.

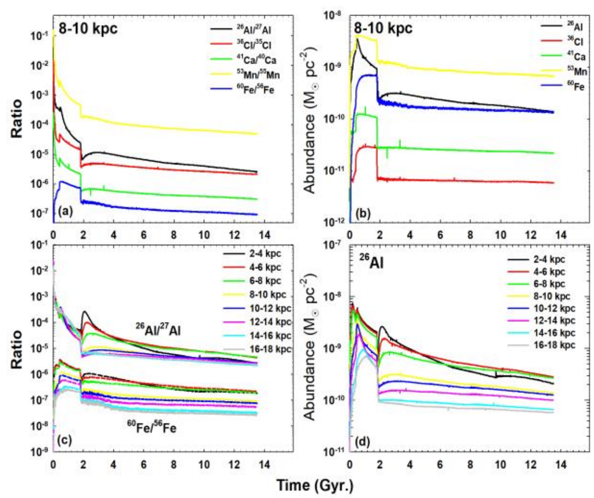

Fig 1. The deduced GCE of the SLRs for the *hom*-GCE model in terms of, a) the ratios of SLRs with respect to their most abundant stable isotope, and b) the abundance of SLRs within the solar annular ring at 8-10 kpc. c, d) The GCE of ^{26}Al and ^{60}Fe across the entire galaxy. Solar system formation occurred at ~9.2 Gyr.

Results and Discussion: The results obtained from the *hom*-GCE model are presented in Fig 1. This low spatial resolution model provides the averaged GCE of the SLRs across the entire galaxy. As far as ^{26}Al, the most well studied SLR is concerned, the low-mass (AGB) stars and massive stars contribute almost equally to the steady state GCE abundance.

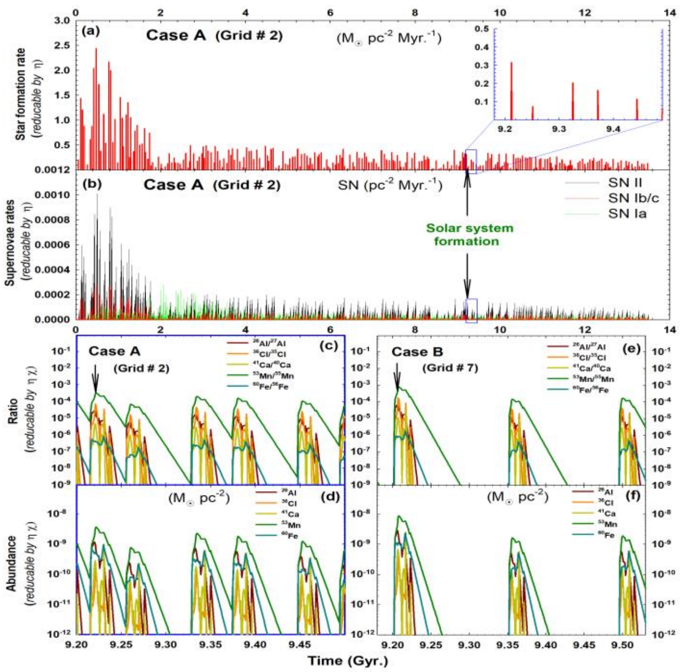

Fig 2. The deduced, a) star formation (*in the form of stellar associations/clusters*) rates, b) supernovae (SN II, SN Ia, SN Ib/c) rates, c) the SLR ratios, and d) the SLRs abundances due to massive stars (>11 M⊙) contributions for the *het*-GCE model (***Case A***) corresponding to the grid #2, with an area of ~2.2 kpc^2. The formation and evolution of at least six distinct stellar associations (see inset fig 1a) around ~9.2 Gyr. can be identified. The frequency of the formation and the mass of the stellar associations are determined according to random number generators in the adopted Monte Carlo approach [14]. An average mass of ~3×10^5 M⊙ is obtained beyond 2 Gyr. The deduced, e) SLR ratios, and d) the SLRs abundances for the *het*-GCE model (***Case B***) corresponding to an area of ~0.5 kpc^2. η and χ are two scalable parameters that are taken to unity in the figure. However, as discussed in text these are variables.

The results obtained from the two distinct *het*-GCE models (***Case A & B***) are presented in Fig 2. On contrary to the *hom*-GCE model, the *het*-GCE models are capable of producing high SLRs yields over localized regions (< 2 kpc^2, preferably < 0.5 kpc^2) during the initial stages of the evolution of stellar associations /clusters. The maxima achieved for SLR in some cases is high enough to explain the canonical value of ^{26}Al/^{27}Al. However, these contributions are directly associated with the evolution of massive stars within localized stellar cluster(s) at a particular instant.

There are two critical aspects related with the production of SLRs, namely, the average mass of the stellar association/clusters and the spatial homogenization scales of SLRs during their lifetimes. The deduced star formation rates (SFR) (Fig 2a) indicate the formation of stellar associations/clusters with an average mass of ~3×10^5 M⊙ beyond 2 Gyr. of galactic evolution. However, this average mass estimate can be up to two orders of magnitude high compared to the observed estimates even though stellar associations with these masses do exit [15,16]. The observed stellar clusters exhibit a power law distribution in mass with an upper limit of ~10^5 M⊙ [15,16]. We introduce a parameter, 'η' (in the range of ~1-100), in order to reduce the average mass of a typical stellar association/cluster. This would require an identical reduction in the star formation rates, and an associated linear reduction in the supernovae rates, the nucleosynthetic yields of SLRs and their deduced ratios compared to those mentioned in the Fig 2. The reduction in the SLRs abundance and their ratios by a factor of 1-100, however, can be appropriately compensated by reducing the spatial extent of homogenization of SLRs within the grids having an area of ~0.5-2 kpc^2. We introduce a parameter, 'χ' (in the range of ~10^0-10^{-2}, ∍ $\eta\chi$ ~1) that would substantially reduce the tangible homogenization area of SLRs within a grid so as to locally reproduce a canonical value of ^{26}Al/^{27}Al within a cluster system. This would essentially confine the SLR contamination region to be right within the vicinity of the massive stars. It should be noted that the parameters, η and χ, are crucial for SLRs. These parameters do not substantially influence the stable nuclides GCE, except for the production of spatial heterogeneities that are homogenized over longer timescales > 10^8 years [14], thereby, maintaining a steady state evolution of metallicity.

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