PRODUCTION OF Iron-60 IN A SELF-ENRICHING MOLECULAR CLOUD. M. J. Bojazi[1] and B. S. Meyer, [1]Department of Physics and Astronomy, Clemson University, Clemson, SC, 29634-0978, USA.

Introduction: The presence of short-lived radioactivities in the early Solar nebula has been inferred from excesses of their daughter isotopes embedded within primitive meteorites found and analyzed via various physical and chemical means over the last 50 years. The challenge is to reconcile the abundances of these short-lived radioactivities, as inferred from meteorites, to those as predicted from ongoing, continuous Galactic nucleosynthesis and then to use that information to infer the circumstances of the Solar System's birth. The abundances of several of the short-lived species are too large compared to expectations from continuous Galactic nucleosynthesis (e.g., [1]). One thus appeals to a recent injection of fresh stellar matter into the proto-solar cloud or enhanced stellar activity around the time of the Sun's birth to account for the abundance of several short-lived species, such as ^{26}Al and ^{41}Ca.

The abundance of radioactive ^{60}Fe (average lifetime of approximately 3.78 million years) presents a particular challenge because multiple sources provide a range of inferred values of the early Solar System abundance of this radioactive species. A value of ~2×10^{-8} for the initial ^{60}Fe/^{56}Fe is that inferred from chondrules [5] while a value of ~3×10^{-7} is closer to that inferred from SIMs measurements [6,7]. In this brief paper, we consider the role of the mass concetration on the production of ^{60}Fe in a model of star formation in a molecular cloud.

Massive Star Production of ^{60}Fe: Iron-60 is produced in AGB stars or the AGB stage of stellar evolution during helium-intershell burning, as well as in massive stars during hydrostatic and explosive helium-shell and carbon-shell burning, via neutron captures on unstable ^{59}Fe nuclei in the s-process and n-process. Minimal production also occurs via the s-process during hydrostatic helium-core burning, the freshly-synthesized nuclei expelled to the ISM in the winds of Wolf-Rayet stars or the Wolf-Rayet stage of stellar evolution.

Inhomogeneous Chemical Evolution Model: To consider the abundance of ^{53}Mn in a self-enriching molecular cloud, we use the ICE (Inhomogeneous Chemical Evolution) code we have developed on top of the multi-zone component of NucNet Tools [2]. The multi-zone code includes a nuclear reaction network and an arbitrary number of zones distinguished by three labels. A zone is a collection of abundances of species in the reaction network and an arbitrary number of user-defined mutable properties. At each time step, the multi-zone code sets up links between zones. Once the links between the zones are constructed, the code builds the network matrix and then simultaneously solves the abundance changes dues to nuclear reactions and mixing.

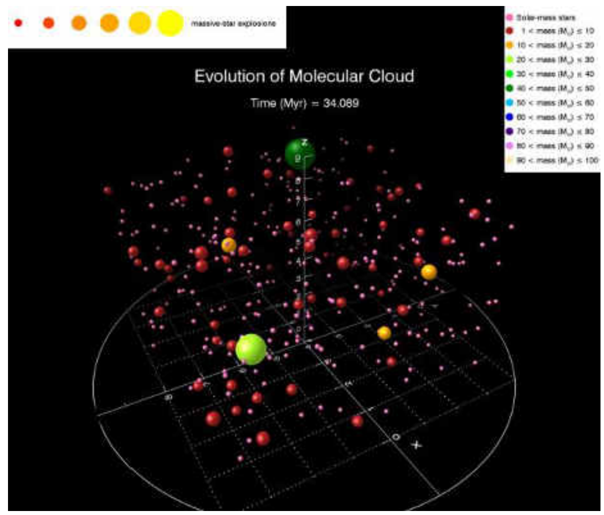

Figure 1

To build the version of ICE for these calculations, we constructed an 8x8x8 cubic molecular cloud containing a total of 512 zones. Zones are sub cubes within the larger cube, and these sub cubes are labelled by indices (x,y,z) which give the three cartesian spatial coordinates. At each time step, ICE computes the number of stars formed in the cloud during the time step from a Poisson random distribution generator using an average star formation timescale of 1000 years. For each star that forms, we use a random number to determine the stellar mass from an initial mass function [3] and three random numbers to choose the sub cube in which to place the star. Following in the spirit of the work by Fatuzzo and Adams [8], we also consider a Bonnor-Ebert [9][10] "spherical" cloud in which the mass of each zone and stellar location probability are proportional to the density of the cloud. The fall-off in density is prescribed by the value of *n*. Fig. 1 shows a frame from the molecular cloud evolution for n = 0.

We record the star and its starting composition (the composition of the cloud from which it forms at the formation time). We also compute, from the stellar mass, the time the star will die (its lifetime). We keep track of the stars in a priority queue such that the star at the top of the queue is the first to die and eject its matter. We evolve the cloud and update abundances (with the appropriate decay rates and a mixing timescale between zones of 10^6 years), as needed, and move on to the next time step of duration. When a star explodes, we mix the ejecta from that star into its local sub cube and pop the exploding star from the priority queue. In the present calculation, we evolve the cloud over a time of 100 million years. The cloud initially had Solar abundances [4] and was devoid of any short-lived radioactivities.

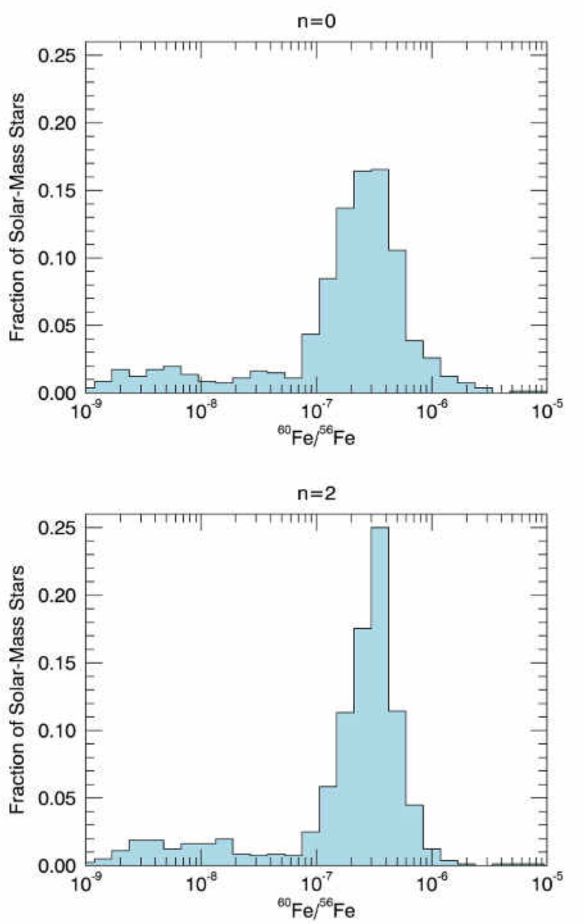

Figure 2

Results and Discussion: Fig. 2 shows the $^{60}Fe/^{56}Fe$ abundance ratios for Sun-like stars with initial masses between 0.95 and 1.05 Solar masses in our calculation for values of 0 and 2 for *n*. The spread in the $^{60}Fe/^{56}Fe$ abundance ratios decreases and the peak near 3.5x10-7 becomes more pronounced as the value of *n* increases. The population of stars is much more concentrated near the center of the molecular cloud and so the matter (comprised of radioactive species and other isotopes) there cannot diffuse much. The matter is also quickly locked up into stars before having much time to decay, thereby increasing the number of stars with that $^{60}Fe/^{56}Fe$ abundance ratio near 3.5×10^{-7}.

In Fig. 3, after ~20 million years have passed in the evolution of our cloud, Solar-mass stars are born with the $^{60}Fe/^{56}Fe$ abundance ratio near 3.5×10^{-7}. The cloud eventually achieves steady-state as massive stars die and explode while new stars are born, the radioactive matter of the supernova ejecta mixing into the cloud matter while radioactive matter of the cloud decays away. These initial results appear conclusive of the higher initial $^{60}Fe/^{56}Fe$ abundance as inferred from SIMs measurements.

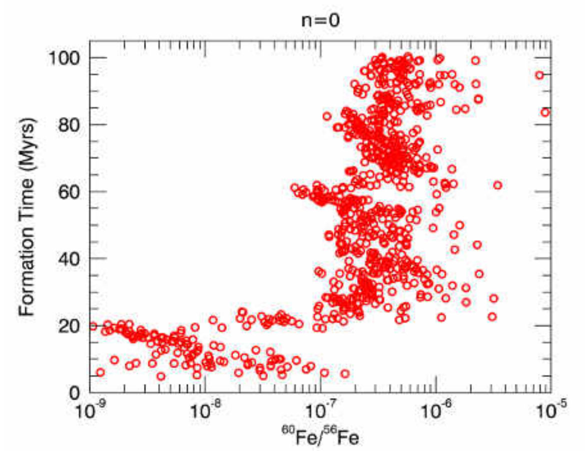

Figure 2

References:

[1] Huss G. et al. (2009) *GCA, 73,* 4922. [2] See http://sourceforge.net/p/nucnet-tools. [3] Kroupa P. (2002) *Science, 292,* 82-91. [4] Anders E. and Grevesse N. (1989) *GCA, 53,* 197-214. [5] Tang H. and Dauphas N. (2014) *EPSL, 359-360,* 248-263. [6] Tachibana S. and Huss G. R. (2003) *Astrophys. J. Lett., 588,* L41-L44. [7] Mishra R. K. et al. (2010) *Astrophys. J. Lett., 714,* L217-L222. [8] Fatuzzo, M. and Adams, F.C. (2015) *Astrophys. J., 813,* 55-63. [9] Bonnor, W. (1956) *MNRAS*, 116, 351. [10] Ebert, R. (1955) *Z. Astrophys*, 37, 217.