SIMPLE MODEL OF CHROMIUM ISOTOPIC ABUNDANCE EVOLUTION IN INTERSTELLAR DUST.

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Introduction: Chromium isotopic anomalies in primitive Solar System samples have been of considerable interest for decades (e.g., [1,2]). The anomalies arise from incomplete homogenization of the carriers of these isotopes into the early Solar nebula. Although the carriers of the chromium isotopes have not been fully characterized, the importance of chromium anomalies extends to questions regarding the planetary-scale evolution of the Solar System (e.g., [3,4]).

In this brief paper, I present a simple model of the evolution of the abundances of chromium isotopes in the evolution of the Galaxy. The goal is to gain insight into the nature of the carriers of the chromium isotopes into the Solar nebula and their relative contributions to the final Solar isotopic abundances.

Chemical Evolution: I use the Clemson Inhomogeneous Chemical Evolution (ICE) code [5] to follow the isotopic evolution of a number of reservoirs representing interstellar dust and gas in the evolution of the Galaxy. In particular in the model, the Galaxy comprises a metal-poor halo, gas, molecular clouds, interstellar-processed dust ("old dust"), and dust reservoirs for ejecta from low-mass stars, core-collapse (SNII) supernovae, and thermonuclear (SNIa) supernovae. The model uses yields from Woosley and Weaver [6] for core-collapse supernovae and from W7 [7] for thermonuclear supernova. In the model, low-mass stars simply return their starting composition. In addition, I add a rare class of thermonuclear supernovae with scaled up production of ^{54}Cr. Rare, low-entropy nucleosynthesis events are known to be responsible for significant production of neutron-rich, iron-group nuclei such as ^{48}Ca, ^{50}Ti, and ^{54}Cr [8]. While the dominant site for such nucleosynthesis may not be thermonuclear supernovae, but rather some other site (such as electron-capture supernovae [9]), rare, Chandrasekhar-mass thermonuclear supernovae are plausible [10] and are convenient to include in the model. The yield of ^{54}Cr in the rare thermonuclear supernovae is set to ensure the abundance of this isotope reaches its Solar value at 8 Gyr (the time when the Sun forms in the model).

The model allows for build up of the Galaxy's mass by infall from the metal-poor halo. Stars form from the gas and dust present. As stars die, they eject their mass into one of the relevant reservoirs. For example, ejecta from massive stars (core-collapse supernovae) go into the SNII dust reservoir. All dust species and gas get incorporated into molecular clouds on a timescale of 100 Myr, and stars form from in the molecular clouds on an appropriate timescale to give a Galactic gas mass comparable to what is seen in the current Galaxy. Chromium atoms are assumed to return from molecular clouds plated on old dust, and dust outside of molecular clouds is sputtered into gas on a timescale of 200 Myr.

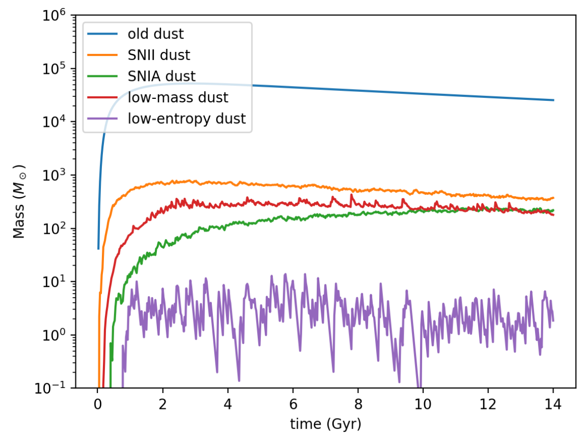

Figure. 1: The mass in various dust reservoirs in the model as a function of time.

Dust Masses: Figure 1 shows the evolution of mass in the different dust reservoirs. Most of the dust is in "old dust", that is, ejected dust that has been subsequently processed in the ISM. The mass of the "low-entropy dust", the dust from the rare thermonuclear supernova, varies dramatically. Since the events are rare, the time intervals between events is long enough to allow significant destruction before the next event. Interestingly, the mass of most dust components falls with time except that for the SNIa dust. In the model, these events occur as white dwarf stars accrete mass and then explode. It takes time for white dwarf stars to form, so the number of such events can rise with time late in the Galaxy's history. In contrast, production of stars and their subsequent deaths tend to follow the gas mass. Since this is declining with time the ejected mass does as well.

Isotopic Evolution: Figure 2 shows the evolution of the mass fractions of the isotopes of chromium in the dust from core-collapse supernovae. The mass fraction of ^{52}Cr is fairly constant in time because this species is predominantly primary in its nucleosynthesis (that is, the production does not depend on pre-existing species). The other species show growth in their mass fractions with time indicating at least some secondary nature (production depends on the presence of pre-existing species in the star).

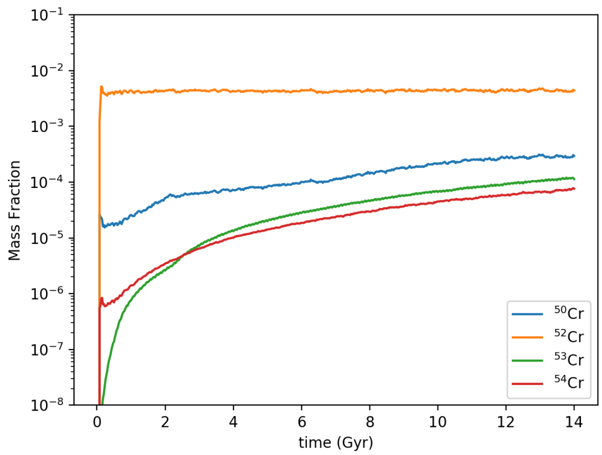

Figure 2: The mass fraction of chromium isotopes in dust from core-collapse supernovae.

Other dust reservoirs show roughly similar behaviors to that in Figure 2 except for the SNIa and low-entropy (rare thermonuclear supernova) reservoirs. Since the stellar events ejecting matter into these reservoirs have constant yields in the model, their chromium isotope mass fractions do not vary with time.

Inferred Carrier Contributions: Figure 3 shows the fractional contribution of the four non-processed reservoirs to the isotopic abundances at the time of the Sun's birth (at 8 Gyr in the model). The contributions are all of the order of a few percent (the remaining contribution is from the processed dust).

From Figure 3, it is clear that multiple carriers contribute to the abundance of each isotope. SNIa supernova dust is the dominant non-processed contributor to ^{50}Cr and ^{52}Cr in the model, though SNII and low-mass stars also contribute. The low-entropy dust is the dominant non-processed contributor to ^{54}Cr, and this isotope is the only one to which this site contributes. Low-mass star dust is the dominant non-processed contributor to ^{53}Cr. The model does fail to reproduce the Solar ^{53}Cr abundance, so there may be a problem with the yields for that isotope. As a consequence, the carrier contribution for ^{53}Cr should be viewed with caution.

Future Work: The model presented here is extemely simple. It considers only five dust reservoirs. There is no chemistry that might fractionate the isotopes within given ejected matter. The dust processing in the interstellar medium is particularly simplistic. All these issues in the model need to be addressed in future work to make the model more realistic. Nevertheless, it is hoped that this model can provide a useful starting guide for connecting chromium isotopic anomalies with possible carriers.

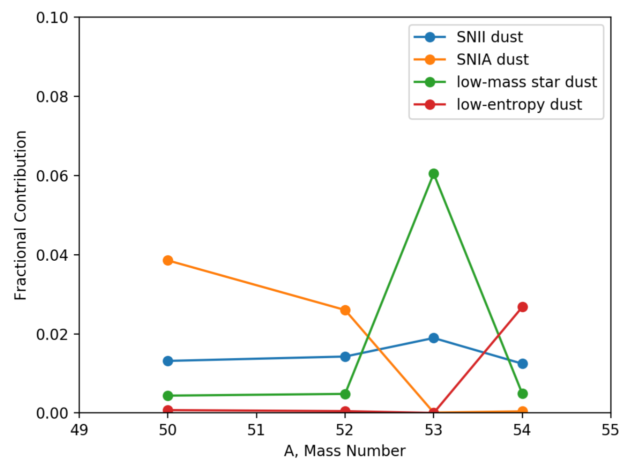

Figure 3: Contribution to the final Solar isotopic abundance from each dust reservoir in the model. The remaining contribution for each isotope is from the ISM-processed dust ("old dust").

References: [1] Birck J. L. and Allegre, C. J. (1984) *Geophys. Res. Lett., 11,* 943-546. [2] Papanastassiou D. A. (1986) *Astrophys. J., 308,* L27-L30. [3] Warren P. H. (2011) *EPSL, 311,* 93-100. [4] Kruijer T. S. et al. (2017) *PNAS, 114,* 6712-6716. [5] Bojazi M. J. and Meyer B. S. (2018) *LPS XLIX,* Abstract 2890. [6] Woosley S. E. and Weaver T. A. (1995) *Astrophys. J. Suppl., 101,* 181-235. [7] Nomoto K., Thielemann F.-K., and Yokoi K. (1984) *Astrophys. J., 286,* 644-658. [8] Meyer B. S., Krishnan T. D., and Clayton D. D. (1996) *Astrophys. J., 462,* 825-838. [9] Wanajo S., Janka H.-T., and Mueller B. (2013) *Astrophys. J., 767,* L26. [10] Woosley S. E. (1997) *Astrophys. J., 476,* 801-810.