MODELS OF THE CHEMICAL EVOLUTION OF CALCIUM, TITANIUM, AND CHROMIUM ISOTOPES AND THEIR PRESOLAR CARRIERS

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Introduction: The isotopes of the light iron-group elements calcium, titanium, and chromium have long played an important role in cosmochemistry. Primitive samples such as hibonite grains and FUN CAIs show roughly correlated anomalies in the neutron-rich isotopes of these elements (e.g. [1-8]). Bulk meteorites also show anomalies in the isotopes of these elements (e.g., [9]). These anomalies have long indicated the incomplete homogenization of carrier components in the early Solar System.

Because of the significance of isotopic anomalies in calcium, titanium, and chromium for understanding processes in the early proto-planetary disk [9,10,11], it is useful to consider the Galactic chemical evolution of these elements, their isotopes, and their possible carriers into the Solar cloud. In this work I present some models of such evolution.

Methods: To follow the chemical evolution of calcium, titanium, and chromium, I use the open-source code toolset ICE (inhomogeneous chemical evolution) developed over the last several years [12]. The code models multiple zones of the interstellar medium and attaches a full nuclear reaction network to each zone. I evolve the Solar annulus over the lifetime of the Galaxy from initial infall of metal-poor gas to the time of the Sun's birth. I divide up the annulus into multiple zones and allow mass to mix between those zones on a timescale of 10^7 years. I use a density-dependent star-formation rate and a Kroupa initial mass function to distribute new stars in zones throughout the Solar annulus [13]. I use yields from massive stars [14], thermonuclear supernovae [15], and low-mass stars to account for the enrichment of the interstellar medium by stellar debris. I use schematic yields for the low-mass stars derived from a combination of stellar models and expected s-process production from AGB phases. I include yields from rare stellar explosions that are responsible for the most neutron-rich stable isotopes of each element. These events are not fully identified, but are likely electron-capture supernovae [16] or complete thermonuclear explosions of dense C/O white dwarf stars [17] or partial thermonuclear explosions of O/Ne white dwarf stars [18]. For simplicity, I treat these events as single-degenerate thermonuclear explosions of C/O white dwarf stars but explore possible variations due to other scenarios.

To follow the evolution of the isotope carriers, I allow the stars to eject their isotopes into distinct dust reservoirs representing the interstellar dust. Dust cycles into and out of molecular clouds on a timescale of 100 million years, and dust is destroyed in the hot phases of the interstellar medium by sputtering and shattering on a timescale of 200 million years. Free atoms can re-condense onto "old dust" in molecular clouds. Dust is also incorporated into forming stars.

Results: At the time of the Sun's birth, I record the masses of the various isotopes in each dust reservoir. Each reservoir contributes to multiple isotopes, which indicates that several isotopes can be carried by multiple carriers. Nevertheless, for some isotopes, particularly the most neutron-rich species, a single dust reservoir is the dominant carrier. A database of stellar yields used in the model along with the results of the present calculations is available at https://sourceforge.net/u/mbradle/wiki/Research/. From the results of the calculation, interested users may estimate isotopic anomalies that would result from varying mixtures of the dust reservoirs.

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