GALACTIC CHEMICAL EVOLUTION AND THE OXYGEN-ISOTOPE COMPOSITION OF THE SOLAR SYSTEM. L. R. Nittler[1] and E. Gaidos[2], [1]Dept. Of Terrestrial Magnetism, Carnegie Institution of Washington, Washington DC, 20015 (lnittler@ciw.edu), [2]Dept. of Geology and Geophysics, University of Hawaii at Manoa, Honolulu, HI 96822.

Introduction: The Sun formed some 9 Gyr after the Big Bang and its elemental and isotopic composition is a product of billions of years of Galactic evolution. The theory of Galactic Chemical Evolution (GCE) attempts to explain the changing elemental composition of the Galaxy with time and place due to succeeding generations of stars ejecting newly-synthesized elements into the interstellar medium (ISM). Oxygen is of profound importance for cosmochemistry due to its abundant presence in both gas and solid phases in the ISM and solar nebula. Moreover, the O-isotopic ratios ($^{17}O/^{16}O$ and $^{18}O/^{16}O$) are heterogeneously distributed in the Solar System, with Earth, Moon, Mars, asteroids, and cometary dust systematically depleted in the major isotope ^{16}O, relative to the Sun (as measured by the solar wind [1]) by several %. Currently, the most popular explanation for this difference is that it was caused by widespread photochemical self shielding by CO in the solar nebula, fractionating an originally isotopically homogeneous reservoir [2]. Alternatively, it has been suggested that the O-isotope systematic in the Solar System may reflect an original difference in the isotopic composition of gas and solids in the protosolar cloud, most likely due to GCE processes [3, 4]. In addition, the present-day ISM is observed to have a significantly lower $^{18}O/^{17}O$ ratio than the Sun. This has been taken as evidence for a local enrichment of the protosolar cloud by supernova ejecta [5]. This work discusses current understanding of O-isotope GCE and its implications for the starting composition of gas and solids in the Solar System.

GCE of O Isotopes: As stars evolve and contribute newly-synthesized nuclei to the ISM, the overall *metallicity* (fraction of elements heavier than He) of the Galaxy increases. However, because different isotopes are made by different nuclear processes in different types of stars (which may evolve over very different timescales), isotopic and elemental ratios also vary with metallicity. In terms of O isotopes, GCE theory distinguishes between *primary* ^{16}O, which could be made in a star of initially pure H and He and *secondary* ^{17}O and ^{18}O, which require preexisting C, N and/or O in order to be made. Simple analytical GCE models [3] predict that the ratio of a secondary to a primary nucleus (e.g., $^{17}O/^{16}O$) should increase linearly with metallicity and a ratio of two secondaries (e.g. $^{18}O/^{17}O$) should remain constant.

This analysis is based on the assumption that the evolutionary timescales of the stellar sources can be ignored, a reasonable approximation if the considered species are only synthesized in massive stars which evolve rapidly on Galactic timescales. For example, in the numerical GCE calculation of [6], all 3 O isotopes were assumed to be synthesized in massive stars and the model predicted O-isotopic evolution that closely follows the simple secondary/primary expectations outlined above. However, subsequent refinement of nuclear reaction rates has shown that ^{17}O is not efficiently made in massive stars and must largely come from low-mass AGB stars and/or novae. Both source evolve on relatively long timescales, indicating that ^{17}O is in some sense "more secondary" than ^{18}O and the $^{17}O/^{18}O$ should increase as the Galaxy evolves. For example, the GCE model of [7] included AGB production of ^{17}O and predicted a strong increase in the $^{17}O/^{18}O$ ratio in the Galaxy since solar birth. However, a more recent calculation incorporating the most current AGB and supernova yields [8] found that the $^{17}O/^{18}O$ ratio becomes approximately constant by the time the solar neighborhood has reached half solar metallicity, in agreement with the simple GCE expectations. Clearly, the impact of AGB stars on O-isotope GCE is unsettled.

The situation is even less clear for novae. Novae are nuclear explosions on white dwarf (WD) stars accreting material from binary companions. The high-temperature H-burning that accompanies the explosion is predicted to produce copious ^{17}O. Because they require both the evolution of the parent star to the WD stage and ~2 Gyr of WD cooling to ensure a strong nova outburst, novae are expected to contribute to GCE much later than AGB stars. To our knowledge, there is only one study addressing the role of novae in the GCE of O isotopes [9]. Comparison of this model's predictions for GCE in which ^{17}O is solely produced by novae with other GCE predictions for supernova-derived ^{18}O [e.g., 6] demonstrates that the $^{17}O/^{18}O$ ratio of the ISM could easily have evolved quite dramatically in the last 4.6 Gyr, if novae are indeed significant ^{17}O producers.

It must be emphasized that all GCE models have substantial uncertainties and a model is often considered successful if it reproduces a few basic observational constraints (e.g. the metallicity distribution of low-mass stars in the Galaxy) and matches the solar composition to within a factor of 2. Specific isotope predictions are particularly susceptible to (sometimes enormous) uncertainties in nucleosynthesis yields as witnessed by the factor of >10 decrease in ^{17}O yields from supernovae since 1995. Therefore, one should treat specific quantitative predictions of GCE models with great caution when confronting high-precision data like O-isotopic measurements of materials in the Solar System.

Observational constraints: Radio observations of molecular clouds (MCs) in the Galaxy over the last few decades have supported the basic view of O-isotopic GCE. Namely, there is evidence for gradients of increasing $^{17,18}O/^{16}O$ ratios with decreasing distance from the galactic center, but relatively constant $^{18}O/^{17}O$ ratios throughout the Galaxy [5, 10]. Since overall metallicity increases towards the galactic center, this supports the idea that ^{16}O is primary and $^{17,18}O$ are secondary nuclei. However, recent studies have in fact suggested the presence of a galactic gradient in the $^{18}O/^{17}O$ ratio [11], supporting the above view that this ratio evolves during GCE even at disk metallicities, and one study has questioned the existence of a gradient in $^{18}O/^{16}O$ [12]. Thus, the radio observational constraints on O-isotope GCE are also unsettled.

One important radio observation, that the $^{18}O/^{17}O$ ratio of present-day MCs is ~4, compared to the value of 5.2 of the Sun, has been confirmed by infrared observations of young stellar objects [13]. This difference has been taken as evidence that the O-isotopic composition of the protosolar cloud was strongly modified by injection of material from one or a few supernovae shortly before solar birth [5, 14]. This explanation rests on the assumption that GCE does not modify the $^{18}O/^{17}O$ ratio (i.e., pure secondary/secondary behavior). However, as discussed above, both theory and observations are unsettled on this score and, in particular, if novae are important ^{17}O sources, the difference between solar and ISM $^{18}O/^{17}O$ ratios may be explained as a natural consequence of GCE in the last 4.6 Gyr. Moreover, the O-isotopic distribution of presolar grains is well explained if the Galaxy had $^{18}O/^{17}O$ ratios at least as high as the solar ratio for several billion years prior to solar birth, but not if it had the lower present-day ratio of ~4 [15].

Chemical Memory: More than two decades ago D. D. Clayton introduced the concept of "chemical memory" to suggest the possibility that interstellar dust could have a different isotopic composition on average than the interstellar gas, and that this difference could persist through star formation and influence isotopic variations in solar system materials [3]. Recently, this idea has been revisited as an alternative explanation to photochemistry for explaining O-isotopic systematics in the Solar System [4]. Based on the GCE ideas outline above, chemical memory models have postulated that the isotopic composition of interstellar dust is either ^{16}O-rich [3] or ^{16}O-poor, relative to the gas [4]. The former assumes that the dust is on average older than the gas and hence samples ISM material less enriched in secondary isotopes ("old dust"), whereas the latter assumes that the dust preferentially contains the most recent additions to the ISM ("young dust"). In fact, interstellar dust is believed to be composed partially of isotopically anomalous stellar grains, but dominated by re-equilibrated material formed in the ISM itself. AGB stars dominate the input of dust into the Milky Way disk and thus if the average composition of interstellar dust is controlled by young dust, it would be expected to be enriched in ^{17}O , but not ^{18}O, as observed in the vast majority of AGB stars and presolar O-rich grains [15]. On the other hand, old dust would be largely equilibrated with the gas and have close to the same O-isotopic composition (but perhaps slightly ^{16}O-rich). In any case, quantitatively predicting the composition of interstellar dust requires more sophisticated models than have been considered so far, taking into account, for example, condensation efficiencies in different types of stars, timescales of equilibration in the ISM etc. We note also that the survival of presolar stardust grains in meteorites also implies the survival of other presolar materials with less obvious isotopic anomalies. It is estimated that isotopically normal ISM silicates should be at least 100 times more abundant than AGB silicates at the time of solar birth [16]. Thus, if the Solar O-isotopic composition was indeed strongly modified by a very late injection of supernova material [5], one would expect to find a large population of grains with the typical isotopic composition of the pre-injection protosolar ISM. Such a population would have $^{18}O/^{17}O$ ~4 and a narrow range of $^{17,18}O/^{16}O$ ratios and has not been seen in extensive searches for presolar grains.

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