THE GALACTIC CHEMICAL EVOLUTION OF SILICON: A SURVEY OF INTERSTELLAR SILICON ISOTOPE ABUNDANCES. N. N. Monson[1], M. R. Morris[2] and E. D. Young[1], [1]Department of Earth, Planetary, and Space Sciences, UCLA (nn.monson@ucla.edu; eyoung@ess.ucla.edu), [2]Department of Physics and Astronomy, UCLA (morris@astro.ucla.edu).

Introduction: Stable isotope ratios provide important, long lasting tracers of the environment in which the Solar System formed, and to this end isotopic abundance ratios of accessible Solar System materials are routinely measured to extreme degrees of precision. However, with few observational constraints on the isotopic nature of the Galaxy, our place within this greater Galactic context is not known. We ask the question: was our Solar System formed from typical material and by typical processes, or, was it formed in some atypical environment and/or by unusual processes? In other words, *are we normal*?

While interstellar oxygen isotopes have been studied extensively [5] the same is not true of the other light-element systems having three stable isotopes; ^{24,25,26}Mg and ^{28,29,30}Si. Magnesium does not lend itself to widespread interstellar observations, however silicon can be observed in molecular clouds at millimeter and submillimeter wavelengths. The silicon isotope system is largely analogous to that of oxygen, and galactic chemical evolution (henceforth GCE) necessitates that both systems evolve via the same mechanisms. This makes silicon a potentially valuable benchmark for examining the methodology used to measure Galactic oxygen isotope ratios.

Presolar silicon carbide grains found in meteorites are thought to have condensed out of the winds of ancient AGB stars and therefore be representative of the interstellar medium (henceforth ISM) as it existed when those stars formed >> 5 Ga. The disparate rates of nucleosynthesis between the primary nuclide ^{28}Si and secondary nuclides ^{29}Si and ^{30}Si leads to two predictions; that the primary to secondary isotope abundance ratio will rise *linearly* with time, and that the abundance ratio of secondary isotopes will remain *constant*. Thus, to first order, GCE would dictate that Solar [^{28}Si]/[^{29}Si] and [^{28}Si]/[^{30}Si] ratios, being representative of the ISM when the sun formed (i.e. 4.5 Ga), be smaller than the [^{28}Si]/[^{29}Si] and [^{28}Si]/[^{30}Si] ratios found in presolar SiC grains, *but this is not observed.* This deviation from the simple GCE prediction is not well understood [1], and several hypotheses have been put forth to explain it, including an incomplete understanding of the influence of winds from AGB stars on the isotope ratios in the interstellar medium [2], and pollution of the stellar birth environment by a nearby Type-II supernova [3, 4].

The questions raised by the abundance trend of presolar SiC grains can be put into a Galactic context and perhaps resolved if the present Galactic isotope ratios are determined as a function of Galactocentric radius (a rough proxy for time), as ratios of stable isotopes in the Solar system can be placed in a Galactic context only if the effects of time can be accounted for. In effect, GCE must be considered in any comparison between the Solar system and either the interstellar medium or any extrasolar planetary systems. Here we address this issue by reporting on the first new radio astronomy measurements of silicon isotope ratios across the Salaxy in nearly 30 years.

The Case for Silicon: A number of silicon species, including SiC, SiS, SiCN, SiNC and SiH_4, all have at least one detection in a circumstellar envelope around an AGB star, but local nucleosynthesis and hence the potential for sample bias, makes these unsuitable proxies for the average interstellar abundances. This is not true for silicon monoxide, which is the most commonly observed silicon species in the ISM and is thought to dominate the gaseous silicon budget [6]. Despite SiO being an oxide, no knowledge of oxygen isotope ratios within sources is required to extract silicon isotope ratios from observations. For these reasons, SiO is well suited for probing isotopic GCE, as the chance that observational measurements are not representative of the bulk silicon composition is minimized.

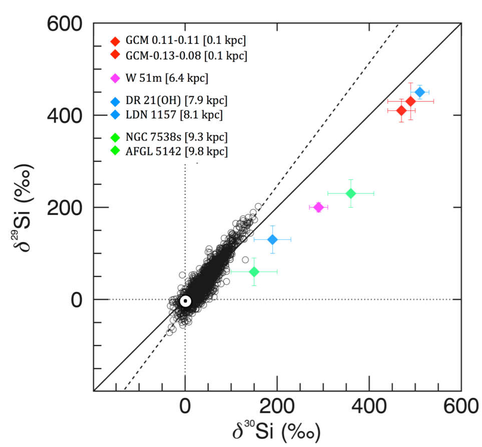

Figure 1: Uncorrected silicon isotope abundance ratio data for the seven sources observed as part of this survey. Mainstream SiC grain data are shown for reference (open circles). The solid line is the slope unity line predicted by GCE, and the dotted line is a regression through the presolar SiC grains.

Observations: Observations of the vibrational ground-state, J = 1→0 pure-rotational transition of the three silicon isotopologues of SiO were carried out at the Robert C. Byrd Green Bank Telescope (GBT) between May 2013 and February 2014. Seven sources, DR21(OH), W51m, NGC 7538, AFGL 51242, LDN 1157 GCM -0.13-0.08 and GCM 0.11-0.11 have been observed to date. Extraction of isotope ratios from the raw data was done via a novel vectorized calibration routine and a series of line profile integrations performed by a suite of purpose built IDL and Fortran programs written by the first author.

Discussion: Historically, SiO emission has been assumed to be optically thin due to the modest brightness of the observed lines, but Penzias was quick to demonstrate that SiO thermal emission often contravenes this assumption [8], and the same was found to be true for this survey. But unlike in previous work, modern high-resolution, low-noise receiver systems are sensitive enough to determine variations in $[^{29}SiO]/[^{28}SiO]$ and $[^{30}Si]/[^{28}SiO]$ with accuracy and precision sufficient to address optical depth effects and determine what, if any, silicon isotope gradient exists in the Galaxy.

Optical depth was found to vary from source to source. Emission lines from DR21(OH) and AFGL 5142 show no evidence of optical depth, with an estimated detection limit of $\tau \approx 0.2$. Other sources, including the two Galactic center sources, GCM -0.13-0.08 and GCM 0.11-0.11, show evidence of appreciable optical depth in the main isotope emission line profiles. Using a series of simple radiative transfer codes to generate synthetic spectra, the optical depth at the center of the observed main isotope lines can be shown to be of order unity for both sources. Correcting for the effect of optical depth has a profound effect on silicon isotope ratios. While our uncorrected data show evidence of a spread up and down the slope-one line in Si three-isotope space (Figure 1), anchored by the two Galactic center sources and LDN 1157 at Solar R_{GC}. Correcting for the effects of optical depth removes the spread, clustering the data near the isotopically-heavy end of the mainstream SiC presolar grain trend and effectively destroying the apparent trend with R_{GC} (Figure 2). All seven datum lie well within error of one another with respect to both δ^{29}Si and δ^{30}Si. One could argue for a small, and poorly resolved, gradient remains in both isotopologues near the Solar circle, which coupled with the depressed Galactic center may suggest a trend similar to the [Fe/H] gradient reported in young Cepheids in the thick disk and LBVs in the Galactic core [9,10,11].

These results appear to support the argument that optical depth was responsible for previous evidence of a large Galactocentric silicon isotope gradient [7]. Desptie scant evidence of a gradient, Galactic silicon isotopic abundances do not appear static, and are in a state of temporal flux in so far as the modern Galaxy appears to be isotopically heavy with respect to both the Sun and the preponderance of presolar SiC grains (the latter representing the ISM ≥ 4.6 Ga). However the work is far from complete; our data for δ^{30}Si suffers from poor signal to noise ratios in many sources, and our survey lacks sources in the 2-5 kpc R_{GC} region, a shortcoming that we hope to correct with additional observations scheduled to begin in February of 2015.

There are, however, other phenomena that could be affecting the observed isotopic ratios; weak inversions [12] or an enhanced radiation field within one of the line profiles could is causing divergent excitation of the three isotopologues, and effecting the extracted isotope ratios in a manner largely indistinguishable from optical depth. Efforts to constrain the excitation temperature of all three species are still in progress.

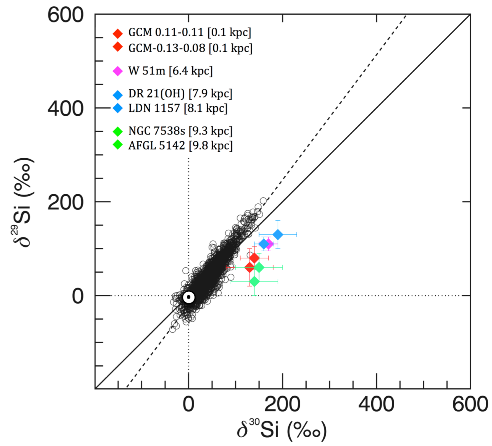

Figure 2: Calculated silicon isotope abundance ratios after correcting for optical depth effects.

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