THE OXYGEN ISOTOPIC COMPOSITION OF THE SOLAR SYSTEM IN A GALACTIC CONTEXT: NEW RESULTS FOR CO IN YOUNG STELLAR OBJECTS AND IMPLICATIONS FOR THE BIRTH ENVIRONMENT OF THE SOLAR SYSTEM. E. D. Young[1,2] , M. Gounelle[3], R. L. Smith[1] , M. R. Morris[4], and K. M. Pontoppidan[5], [1]Department of Earth and Space Sciences, University of California Los Angeles (UCLA), Los Angeles, CA 90095, USA, [2]Institute of Geophysics and Planetary Physics, UCLA (eyoung@ess.ucla.edu), [3]Laboratoire d'Étude de la Matière Extraterrestre, Muséum National d'Histoire Naturelle, 57 rue Cuvier, CP52, 75005 Paris, France, [4]Department of Physics and Astronomy, UCLA, [5]Hubble Fellow, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA

Introduction: The $^{18}O/^{17}O$ composition of the solar system has long been thought to be peculiar with respect to typical Galactic values [1-3]. Recently, the Galactic molecular cloud CO isotopologue ratios have been revisited [4-6]. Results suggest a revision to the mean $^{18}O/^{17}O$ from 3.5 +/– 0.3 [7] to 4.1 +/– 0.1 [5]. Here we present updated ratios among $C^{16}O$, $C^{17}O$ and $C^{18}O$ from young stellar objects and compare these with the revised molecular cloud data and the oxygen isotopic composition of the solar system. This new analysis suggests that the solar system is indeed unusual in its oxygen isotopic composition compared with much of the Galaxy today, requiring that either our understanding of Galactic chemical evolution of oxygen in the Galaxy requires revision or that the solar system was born in an environment polluted from previous generations of star formation.

Molecular Cloud Data: Figure 1 shows radio emission data for CO oxygen isotopologues in molecular clouds across the Galaxy. Both the older data [7] and the revised data [5] are shown. The latter differ from the former primarily by inclusion of more rotational transitions and a model for optical depth effects. Also shown is the $^{18}O/^{17}O$ for the solar system. It is clear from Figure 1 that the solar ratio of the rare oxygen isotopes is inconsistent with the vast majority of Galactic values. The newer data also suggest a hint of a trend towards greater ^{17}O relative to ^{18}O in the Galactic center and an excess of ^{18}O relative to ^{17}O in the outer-most Galaxy. Although ^{17}O and ^{18}O are both secondary nuclides, and so one expects the two to grow in abundance relative to ^{16}O by similar rates, ^{18}O is a product of He burning in higher-mass stars while ^{17}O is the product of CNO hydrogen burning in lower mass stars. There is therefore the possibility for an evolution in $^{18}O/^{17}O$ in some regions of the Galaxy. However, in regions where the Sun may have formed (within a few kpc of R_{GC} = 8 kpc), it is clear that the solar $^{18}O/^{17}O$ is unusually high.

YSO Data: We have begun a survey of oxygen isotope ratios in CO in young stellar objects (YSOs). The purpose in this context is to establish the magnitude and scale of oxygen isotope variability in young stellar systems for comparison with the solar system.

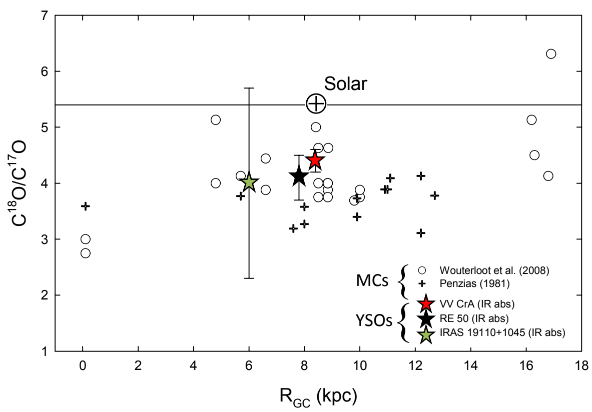

Figure 1. Plot of $C^{18}O/C^{17}O$ vs. distance from the Galactic center (R_{GC}) for previously published molecular cloud data, young stellar objects, and the solar system.

The molecular cloud data represent integrations of pc distance scales while the YSO data represent regions of only a few hundreds of AU. What is more, the YSO data are obtained by infrared absorption and so represent an entirely independent means of measuring the relative abundances of $C^{16}O$, $C^{17}O$ and $C^{18}O$. This is important because it has been suggested that the disparity in $^{18}O/^{17}O$ between molecular cloud data and solar values could be an artifact of systematic errors between the two data sets [3].

Our survey now includes CO oxygen isotopologue data for three young stellar objects, including a new datum for the object Reipurth 50 (RE 50). RE 50 is an embedded YSO in the Orion star-forming cloud 470 pc from the Sun. It is an FU Ori type object in stage I. The data collection and analysis for RE 50 and VV CrA, a stage II T-Tauri disk, are described by Smith et al. [8]. The data were collected using CRIRES on the Very Large Telescope (VLT) at ESO's Paranal Observatory by KMP. We also include here our preliminary analysis of Keck II NIRSPEC data for the YSO IRAS 19110+1045 [9].

The YSO data are shown in Figure 1. These results are consistent with the molecular cloud radio emission data in showing that typical Galactic $^{18}O/^{17}O$ is near 4 (the $C^{18}O/C^{17}O$ values are 4.1 +/– 0.4 for VV CrA, 4.4 +/–0.2 for RE 50, and 4.0 +/−1.7 for IRAS 19110+1045). The implication is that the solar system is indeed unusual, and that the difference between solar $^{18}O/^{17}O$ and typical Galactic $^{18}O/^{17}O$ cannot be attributed to heterogeneity in oxygen isotope ratios on the scale of individual stars. A systematic error in the molecular cloud data is also now excluded.

Discussion: One possible explanation for the unusually high $^{18}O/^{17}O$ of the solar system might be the 4.6 Gyr age difference between the solar system and the present-day Galaxy. Galactic chemical evolution (GCE) has the potential to lead to a change in $^{18}O/^{17}O$ over time. This explanation defies conventional wisdom since it is thought that the principal control on the evolution of oxygen isotopes in the Galaxy is the increase in the abundance of the secondary nuclides ^{17}O and ^{18}O relative to the primary nuclide ^{16}O, suggesting that $^{18}O/^{17}O$ is ~ constant with time. However, ^{17}O is made in low mass stars and ^{18}O in larger mass stars, and it is conceivable that we do not yet understand the consequences of these different sources for the GCE of oxygen isotopes.

An explanation that does not violate the conventional wisdom regarding the GCE of oxygen isotopes is that the solar system formed from material polluted by a previous generation of star formation. This scenario is illustrated in Figure 2. Here we show an estimate for the local interstellar medium (ISM) 4.6 Gyr before present based on an age of 13.6 Gyr for the Galaxy, the relationship % Δage ~ % $\Delta[^{18}O/^{16}O]$ (e.g., D. Clayton, pers. comm.), and an $^{18}O/^{17}O$ consistent with the molecular cloud and YSO data. From this starting composition we show two mixing curves in the three-isotope space in Figure 2. One is towards ejecta from a type II supernova (SN II) that derives from a 15 $M_{\odot}$ progenitor [10]. The other is towards ejecta from a SN II from a 10 $M_{\odot}$ progenitor. The curves suggest that pollution from low-mass SNe II progenitors mixed with local ISM oxygen 4.6 Gyr before present could explain the solar system oxygen $^{18}O/^{17}O$. The implied amount of oxygen added to the ISM by SNe II eject is on the order of 10% (Figure 2). Because the [O/H] of the SNe II eject is greater than solar by ~ 10x [10], this implies a total pollutant fraction of ~ 1 % . Previous generations of star formation are implicated as the pollutant because the progenitor ~10 $M_{\odot}$ stars evolve for > 20 Myr prior to explosion, exceeding the lifetimes of young stellar objects like the nascent solar system.

Pollution of the proto-solar cloud by SNe II oxygen has collateral consequences for the abundances of other stable nuclides. Supernova pollution would add carbon with high $^{12}C/^{13}C$. The solar system is indeed high in $^{12}C/^{13}C$ compared with the local ISM [1]. An excess in ^{28}Si relative to ^{29}Si and ^{30}Si in the solar system is also expected and may also be present [11].

Conclusion: These YSO data imply that the $^{18}O/^{17}O$ of 5.2 for the solar system is indeed peculiar. We suggest that the most plausible explanation for this disparity in oxygen isotope ratios is pollution of the proto-solar cloud by SNe II from generations of star formation that predate that of the Sun.

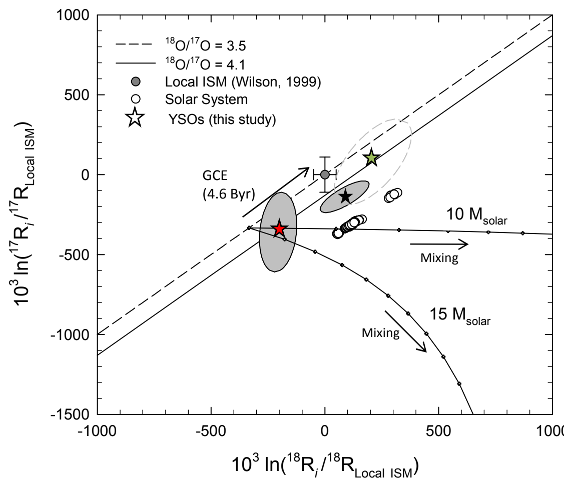

Figure 2. Three-isotope ratio plot showing the 95% confidence ellipses for YSOs VV CrA and RE 50 and the YSO IRAS 19110+1045 datum (errors in the IRAS 19110+1045 datum are not formalized). Dots on ISM-SNe II mixing curves represent intervals of 10% addition of SNe II O.

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