OBSERVATIONS OF HIGH ^{12}CO/^{13}CO TOWARD PROTOSTARS AND IMPLICATIONS FOR THE ORIGIN OF THE ^{12}C/^{13}C RATIO IN THE SOLAR SYSTEM. Rachel L. Smith[1], Klaus M. Pontoppidan[2], Edward D. Young[1,3], and Mark R. Morris[4], [1]Department of Earth and Space Sciences, University of California Los Angeles (UCLA) (rsmith@ess.ucla.edu), [2]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA (pontoppi@gps.caltech.edu), [3]Institute of Geophysics and Planetary Physics, UCLA (eyoung@ess.ucla.edu), [4]Division of Astronomy and Astrophysics, Department of Physics and Astronomy, UCLA (morris@astro.ucla.edu)

Introduction: The ^{12}C/^{13}C abundance ratio of the solar system has been estimated to be $\sim$ 89 [1, 2, 3] from bulk solar system materials. This value is consistent with recent solar photospheric CO spectral measurements (86.8 ± 3.8 [4]). Solar system values of carbon isotope ratios are consistently higher than ^{12}C/^{13}C for the local interstellar medium (ISM): i.e., 69 ± 6 [3]; 62 ± 4 [5]; 68 ± 15 [6]. This apparent discrepancy between the solar system and ISM has been attributed to Galactic enrichment of ^{13}C relative to ^{12}C over the lifetime of the solar system (e.g. [6], [7]); such Galactic Chemical Evolution (GCE) models assume that the current solar system ^{12}C/^{13}C ratio reflects the local ISM ~ 4.6 Gyr ago.

Toward establishing an astronomical context for the chemical evolution of the solar system, we have derived new CO isotopologue abundance ratios for local protostellar objects and one cloud source in the ρ Ophiuchus (ρ Oph) star-forming cloud. We find significantly higher ^{12}CO/^{13}CO abundance ratios, $\sim 110 - 160$, compared to ISM values. Our data may be revealing an evolutionary trend from diffuse cloud to young stellar object (YSO). This effect would imply that the solar system does not necessarily represent the ISM. If so, then this would impact current GCE models.

Observations: We present new observations for the YSOs IRS 63 and IRS 43 in ρ Oph, and the extincted YSO IRS 51, which traces chemistry of the foreground ρ Oph ridge. The 4.7 μm fundamental $(v = 1-0)$ and 2.3 μm overtone $(v = 2-0)$ CO rovibrational infrared absorption bands were obtained with the Cryogenic Infrared Echelle Spectrograph (CRIRES) on the Very Large Telescope (VLT) in Chile at very high resolution ($\lambda/\Delta\lambda \approx 95\,000$). Representative fundamental bands for the embedded YSO IRS 43 and extincted object IRS 51 are shown in Figure 1.

Derivation of column densities and isotope ratios: Total column densities for the observable CO isotopologues (^{12}C^{16}O, ^{13}C^{16}O, ^{12}C^{18}O and ^{12}C^{17}O) were calculated by summing the measured column densities of observed rotational states and assuming a Boltzmann distribution for the remaining states at the best-fit temperature derived from the observed lines. Given the high spectral resolution of CRIRES ($\sim$ 3 km s^{-1}), we were able to infer the optical depths and intrinsic line broadening parameters from the line profiles; these parameters were used along with molecular constants to derive precise column densities and isotope ratios. This method is described by Smith et al. [8].

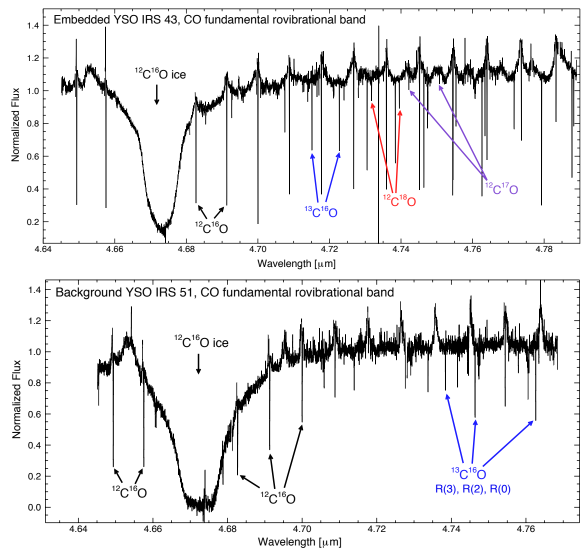

Figure 1: Infrared spectra of the CO fundamental rovibrational bands toward two protostars in ρ Ophiuchus, showing the forest of narrow CO absorption lines. Representative lines and deep CO ice features characteristic of cold envelope/cloud material are marked. Only a few of the most abundant CO gas-phase molecules, ^{12}CO and ^{13}CO, are observed in IRS 51, which traces the gas in the dense foreground cloud.

Results and discussion: Rotational plots for our ρ Oph sources are shown in Figure 2, illustrating the sub-level column densities, $N_J/(2J+1)$ versus the energy of the state J compared to the best-fit linear trend expected for a single-temperature gas. The excitation temperature (T) of the gas is determined from the negative reciprocal of the slopes of their respective best-fit lines. Single- or two- temperature fits best capture the distribution of the data. The plots show a general trend of warmer gas lines for sources with a more dissipated envelope (IRS 63) versus those dominated by cold foreground material (IRS 51). Ratios of carbon and oxygen isotope abundances that are significantly different from the ISM are noted on the plots, where the ISM ratios for the oxygen isotopes are taken to be ^{16}O/^{18}O = 557 ± 30 and ^{16}O/^{17}O = 2005 ± 155 [3].

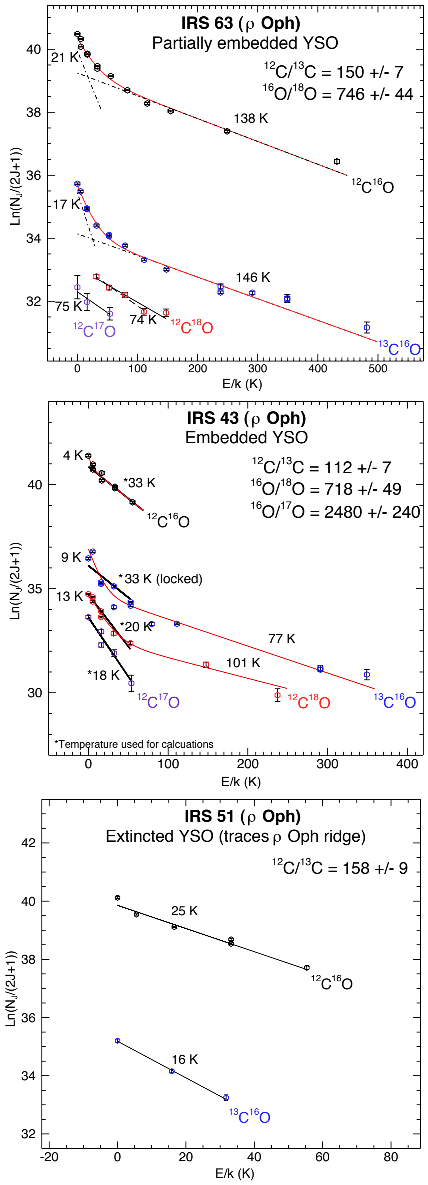

Figure 2: Rotational plots for the ρ Oph sources in this study: the two YSOs, IRS 63 and IRS 43, and YSO IRS 51, which traces cloud chemistry in the foreground ρ Oph ridge. Error bars are 1σ. E_J is the energy of the J^{th} rotational state, and k is the Boltzmann constant.

Initial analyses for the new sources show high $^{12}C/^{13}C$ abundance ratios: 150 ± 7 for IRS 63; 112 ± 7 for IRS 43; and 158 ± 9 for the foreground cloud (IRS 51). Figure 3 shows these data along with ratios from our earlier report for the VV CrA disk (100 ± 10) and embedded YSO RE 50 (110 ± 7) [8]. Measurements of high $^{12}C/^{13}C$ in diffuse regions of the ρ Oph cloud attributed to CO photochemistry [9, 10] are shown. It is clear that all of our YSOs and cloud source, IRS 51, have significantly higher $^{12}C/^{13}C$ ratios as compared to the reported ratio for ρ Oph (65±6.3 [11]). Ratios of

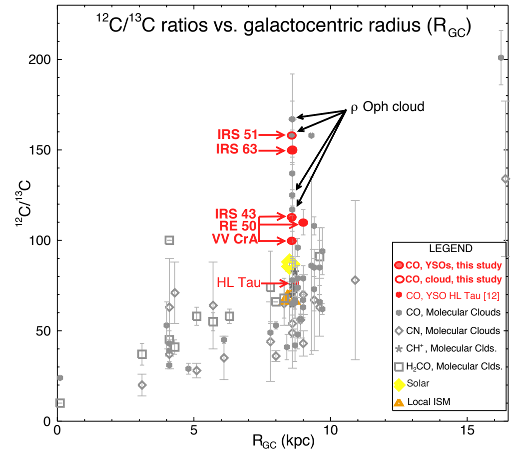

Figure 3: Compilation of published $^{12}C/^{13}C$ ratios for carbon-bearing molecules versus R_{GC} (kpc). Our YSO data show $^{12}C/^{13}C$ ratios that are significantly higher than recent values for the ISM $(68 \pm 15$ [6]), as derived from different molecules. The solar value, 86.8 ± 3.8 [4], is noted. The black arrows indicate high $^{12}C/^{13}C$ measured in diffuse regions of ρ Oph [9, 10].

oxygen isotopes are shown in Figure 2. We find mass-independent fractionation signatures in oxygen at the $\sim 20-30\%$ level in YSO IRS 43, which is consistent with evidence for CO self-shielding reported for the VV CrA disk [8]. The high $^{16}O/^{18}O$ found for IRS 63 may be attributed to CO photochemistry. We also suggest that CO self-shielding may at least partially explain the high $^{12}C/^{13}C$ in our YSO data, with potential inheritance of a photochemical signature in dense clouds from an earlier diffuse phase. Our results cannot be explained by GCE models, or apparently by kinetic or equilibrium chemistry.

Conclusions: Our ongoing observational study of local protostellar objects thus far reveals high $^{12}C/^{13}C$ abundance ratios for the YSOs and one cloud source compared to the ISM. Our results indicate that YSOs may be isotopically different from their parent clouds. If this effect is real, current GCE models for explaining the discrepancy in stable carbon isotopes between the solar system and local ISM may need to be revisited.

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