DETECTION OF RARE CO ISOTOPOLOGUES IN PROTOSTELLAR DISKS: AN INFRARED INVESTIGATION OF MOLECULAR SELF SHIELDING.
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Introduction: Here we report an astronomical approach toward investigating molecular self shielding by CO on the surfaces of circumstellar disks. We have detected the fundamental vibrational band of four stable CO isotopologues, including the rare species, $C^{17}O$, in the protostellar object IRAS 19110+1045 with NIRSPEC on the Keck II Telescope. We also report detection of at least 3 of the more abundant CO isotopologues in the solar-type young stellar object, RNO 91, using first-run, high-resolution data obtained with the European Southern Observatory's (ESO) CRIRES spectrograph on the Very Large Telescope (VLT).

Molecular self shielding by CO: The mass-independent variation of oxygen abundances, $^{18}O/^{16}O$ and $^{17}O/^{16}O$, is a pronounced and intriguing feature among rocky bodies in the solar system. One plausible explanation for this phenomenon is self shielding by $C^{16}O$ against photodestruction by far-UV from the central star. Known to be important in the interstellar medium [1,2], molecular self shielding refers to the blocking of photodissociating wavelengths of light by optically thick molecular species. CO absorbs far ultraviolet (FUV) wavelengths in proportion to column densities of the constituent oxygen isotopologues, $^{12}C^{16}O$, $C^{17}O$ and $C^{18}O$. Because interstellar $^{16}O/^{18}O$ and $^{16}O/^{17}O$ ratios are ~ 500 and ~ 2600, respectively, $^{12}C^{16}O$ will be more optically thick and thus photodissociate at a lesser rate (i.e. "self shield" to a greater degree) than $C^{17}O$ and $C^{18}O$ [3].

Our goal is to use infrared spectroscopy to search for $C^{16}O/C^{18}O$ and $C^{16}O/C^{17}O$ excesses in protostellar disks around young stellar objects (YSOs) — environments believed to be similar to the early solar nebula — to test the plausibility of the self shielding phenomenon as a cause for oxygen isotope anomalies. This study will test the viability of the Lyons & Young [4] model for isotope-specific CO photodissociation in disk surface layers (Figure 1). This model predicts that the surfaces of circumstellar disks around YSOs should exhibit high $C^{16}O/(C^{18}O,C^{17}O)$ relative to the surrounding interstellar environment.

Motivation: A recent study reported detection of a high $C^{16}O/C^{18}O$ ratio (800 +/– 500) in the disk surrounding HL Tau, based on high-resolution measurements of IR absorption by gas in the outer disk at ~ 100 K [5]. This offers tantalizing evidence that CO self shielding of stellar UV may be a feature of the chemical evolution of disks, and provides motivation for further study.

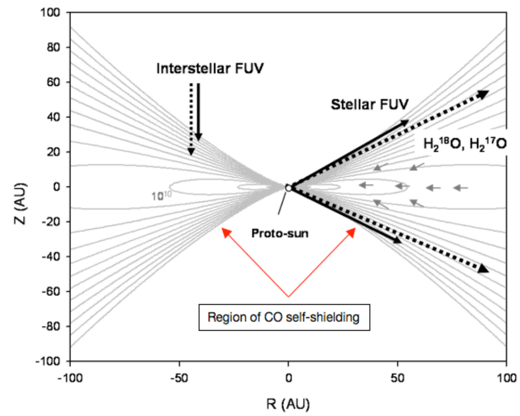

Figure 1. Contour map of a circumstellar disk viewed edge-on, as described for the accretion disk surrounding DM Tau [6]. FUV originates from a central star or interstellar sources. Contours are hydrogen number density, increasing inward at decade increments. Dashed lines are optically thin FUV wavelengths that dissociate $C^{18}O$ and $C^{17}O$ [4].

Methods, results & discussion:

IRAS 19110+1045: We analyzed spectra of the CO 4.7 μm fundamental band in the protostellar object IRAS 19110+1045. These data were collected with the NIRSPEC spectrograph at Keck II Telescope in a 15 minute integration by Geoff Blake's research group at the California Institute of Technology. Spectral resolution is $R = \Delta\lambda/\lambda = 25{,}000$ (~12 km/s). Of particular interest is the detection of $C^{17}O$, appreciable signals of which have not been detected in the near IR. Column densities were obtained using the equivalent widths for optically thin species $C^{18}O$ and $C^{17}O$. A rotational excitation plot was used to estimate the temperatures for these molecules (Figure 2). The ^{13}CO and $C^{17}O$ lines are best fit with a two-temperature model. The apparent break in slope for these species could be due to a temperature gradient in the disk or, in the case of

^{13}CO, a large optical depth (τ). We cannot rule out a temperature gradient from these data.

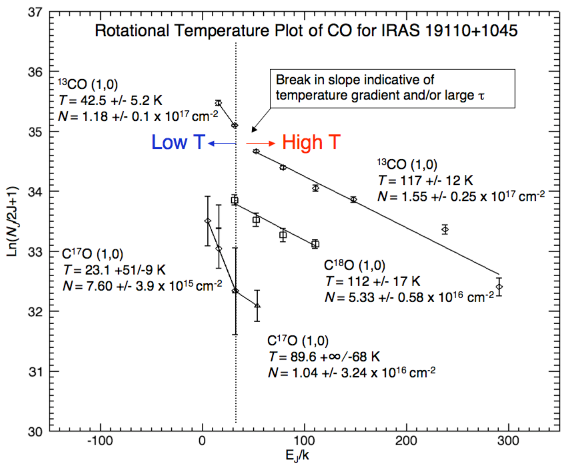

Figure 2. Rotational plot for presumed optically-thin CO isotopologues. Each point represents a separate absorption line from the fundamental ro-vibrational band. One-sigma error bars are from the continuum fit [7].

A curve of growth analysis was used to obtain column densities for optically thick species, ^{13}CO and $^{12}C^{16}O$, and final abundance ratios (Figure 3).

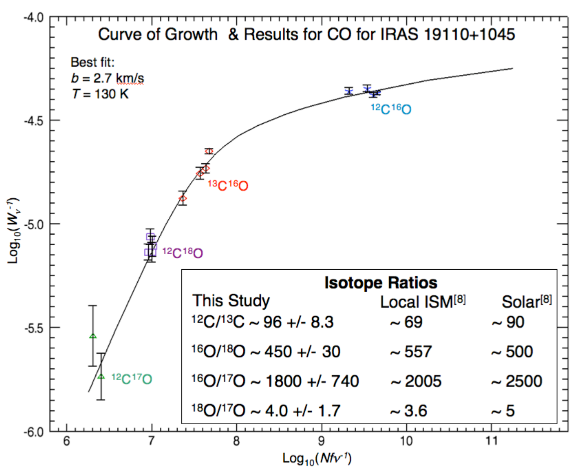

Figure 3. Curve of growth for IRAS 19110+1045. Isotope ratios, determined from inferred column densities, are shown for this study in comparison with local ISM and solar abundances. Errors are 1 se [7].

We found a best-fit temperature of ~130 K and isotope ratios consistent with solar/ISM compositions, albeit with large errors: $^{12}C/^{13}C \sim 96 \pm 8.3$ (1 se), $^{16}O/^{18}O \sim 450 \pm 30$, $^{16}O/^{17}O \sim 1800 \pm 740$, $^{18}O/^{17}O \sim 4.0 \pm 1.7$. No evidence for molecular self shielding by CO (an effect expected to be possibly as large as tens of percent) was found for this object.

RNO 91: We have recently begun analyzing very high-resolution ($R = \Delta\lambda/\lambda = 100{,}000$) spectra for the young stellar object, RNO 91. These first-run data were collected by Pontoppidan and collaborators using the CRIRES spectrograph on the Very Large Telescope (VLT) at Paranal Observatory. The superior resolving capability of the CRIRES spectrograph allows us to resolve the CO absorption lines, which should ultimately enable us to use their profiles for accurate isotope ratio determinations.

Preliminary results include unequivocal detection of $^{12}C^{16}O$, ^{13}CO and $C^{18}O$ ($C^{17}O$ is not yet detected at a significant level). Emission features were also visible. We found a slight trend toward increased line broadening for the less abundant isotopologues: average FWHM = 5.1, 5.4 and 5.8 (km/s) for $^{12}C^{16}O$, ^{13}CO and $C^{18}O$, respectively, suggesting that a multi-component disk model may be needed to explain these data.

Conclusions and future work: Our analysis of IRAS 19110+1045 indicates that all four CO isotopologues are detectable in the infrared ro-vibration lines. No evidence for CO self shielding was found for this object. However, because observations to date have been made with relatively short integration times, we are confident that CO self shielding at disk surfaces is a testable hypothesis using deeper integrations. We anticipate more conclusive results using high-resolution data sets and forthcoming collection runs tailored to our project goals.

References: [1] Bally J. & Langer W. D. (1982) *ApJ 255*, 143-148. [2] Sheffer Y. et al. (2002) *ApJ* 574, L171-L174. [3] van Dishoeck E. & Black J. H. (1988) *ApJ 334*, 771-802. [4] Lyons J. R. & Young E. D. (2005) *Nature 435*, 317-320. [5] Brittain S. D. et al (2005) *ApJ 626*, 283-291. [6] Aikawa Y. & Herbst E. (2001) *A&A 371*, 1107-1117. [7] Smith et al. (2007) *LPS XXXVIII,* Abstract #2293. [8] Wilson T. L. (1999) *Rep. Prog. Phys. 62,* 143-185.