TEMPORAL VARIABILITY IN CARBON MONOXIDE ABUNDANCES IN YOUNG STELLAR OBJECTS AND IMPLICATIONS FOR THE EARLY SOLAR SYSTEM.

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Introduction: Observations of young stellar objects (YSOs) provide a unique window into protoplanetary chemistry. In particular, high-resolution near-infrared observations of carbon monoxide (CO) gas toward YSOs and evaluation of carbon and oxygen isotopes have yielded valuable insights into protoplanetary processes with implications for the early solar nebula [1-7]. While each spectral observation is a snapshot in a several-million-years timescale, YSOs have interestingly been observed to vary in several important parameters over timescales of months to a few years. For example, observations of late-stage solar-type disks reveal up to 50% variability in infrared (IR) fluxes, possibly due to the stellar companions or magnetic fields [8], and 70% of Class I and II YSOs studied in Orion show IR variability in amplitude, possibly due to gas extinction or warps in disk geometry [9]. Significant light-curve variations have further been found in YSOs of the Lynds 1688 region, attributed to possible structural changes in the inner disk [10], and IR photometric variability in nearly 100 YSOs in Cygnus observed over a few years could be due to changes in disk dynamics [11]. Here we present our intial variability analysis of gas-phase CO observations toward a range of solar-type and massive YSOs, with separations in observations of each YSO target ranging from months to a few years. This study is centered on exploring how key molecular reservoirs may vary in the very short-term in evolving systems, and how these variations may differ between solar-type and massive YSOs.

Observations and Methods: Our data set includes CO rovibrational bands observed with Keck-NIRSPEC in high-resolution mode (R~25,000, ~12 km/s) for three massive, luminous YSOs each observed 2 to 3 years apart, and six low-mass, solar-type YSOs observed with VLT-CRIRES at very high resolution (R~95,000, ~3.2 km/s), from a few months to 1 year apart. Fundamental (υ=1−0, 4.7 μm) bands were obtained for all targets, probing optically thin $^{13}C^{16}O$, $^{12}C^{18}O$ and $^{12}C^{17}O$ isotopologue lines. First-overtone (υ=2−0, 2.3 μm) spectra, probing optically thin $^{12}C^{16}O$, were obtained for two of the massive YSOs, enabling $^{12}C/^{13}C$ comparisons between epochs. Column densities were measured using equivalent widths and a curve-of-growth analysis (NIRSPEC data), or Gaussian fits to measure the optical depths and line widths directly from the line profiles (CRIRES data). Total molecular column denstities and gas temperatures were computed using a Boltzmann distribution in a rotational analysis for each data set.

Results: Initial findings for the massive YSOs show that in the span of two years, total $^{12}C^{16}O$ and $^{13}C^{16}O$ column densities increased by as much as ~17% and ~33% respectively, while gas temperatures changed by ~10%. Column densities for $^{12}C^{18}O$ varied by ~8%, and [^{12}CO]/[^{13}CO] varied by ~12%. An example of significant spectral variability is shown in **Fig. 1** for massive YSO, W3IRS5. We find that low-mass YSOs thus far show less variability in CO column densities, with $^{13}C^{16}O$ and $^{12}C^{18}O$ changing by only ~3% in observations separated by 1 year, gas temperatures varying by 15% or less, and [$^{13}C^{16}O$]/[$^{12}C^{18}O$] remaining constant.

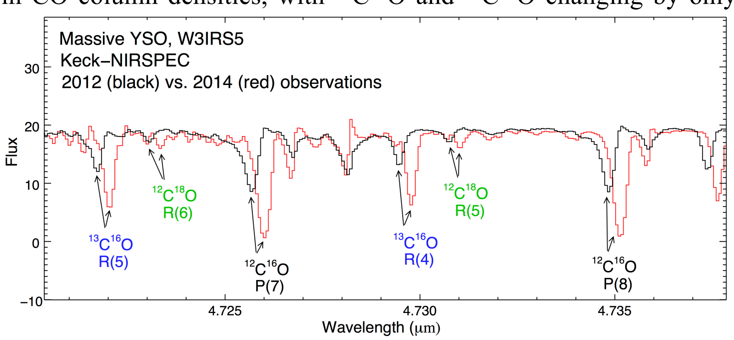

Figure 1. Portion of the 4.7 μm spectra obtained with Keck-NIRSPEC for YSO, W3IRS5, clearly showing the variability in line depths between 2012 and 2014. CO isotopologue lines are marked.

Conclusions: Our initial results suggest that massive YSOs may be more prone to column density variability as compared to low-mass YSOs, which may be due to their significant wind and/or radiation field variations. Low-mass YSOs could be less prone to significant molecular abundance changes even with short-term IR flux or disk variations. This ongoing exploration of molecular variability in a range of YSO environments is relevant to the formation of planetary systems in high radiation fields, and to solar system models that explore molecular reservoirs parameterized with disk physics and nebular processes. We aim to supplement our data with near-future observations at the Infrared Telescope Facilty and/or Keck telescopes.

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