The Chemistry of Young Stellar Objects at Low Metallicity
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Our program probes the chemistry of YSO envelopes in the low metallicity environments of the LMC and SMC. Oliveira et al. (2009, 2011) find that CO and CO ices are more abundant with respect to H2O ice in the LMC than in the Galaxy. Since both ice species are enhanced consistently, it is unlikely this results from increased CO2 production as previously suggested. Instead it may result from a reduced H2O column density in the LMC YSO envelopes, a consequence of stronger UV radiation and reduced dust-to-gas ratio at lower metallicity. Oliveira et al. (2011) also show that while H2O and CO ices are detected, CO ice is not detected in the SMC YSOs; we also observe a reduction in CO2 column density. This suggests that low gas-phase CO density and higher dust temperature in the SMC inhibit CO freeze-out and CO2 survival. The SMC objects are part of a larger sample of 34 YSOs identified spectroscopically. With an ongoing Herschel spectroscopy program we will study the gas-phase abundance of H2O, CO, OH, atomic O and C, to constrain the cooling budget at low metallicity.

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The figure above shows the ice column densities for the MC sample (from Oliveira et al. 2011; Shimonishi et al. 2010) and the massive YSO Galactic sample (Gerakines et al. 1999; Gibb et al. 2004) for H2O, CO2, and CO.

- The ternary diagram shows that the ice properties in the SMC, LMC and the Galaxy are distinct.
- In the LMC, CO2 and CO ices are more abundant with respect to H2O ice than in the Galaxy:
  - LMC: N(CO2)/N(H2O) ~ 0.32, N(CO)/N(H2O) ~ 0.27
  - Galaxy: N(CO2)/N(H2O) ~ 0.20, N(CO)/N(H2O) ~ 0.17
- The fraction of polar (H2O-rich) CO2 ice is reduced in the LMC (Oliveira et al. 2009).

- N(CO)/N(CO2) ~ 0.8 both in the LMC and the Galaxy, implying CO2 and CO enhancements are related, i.e. the two species vary in a concerted way.
- In the LMC, either CO2 and CO are overabundant, or water is depleted.
- CO2 ice abundance can be enhanced by thermal processing in warmer YSO envelopes; since CO is very volatile this cannot explain the CO enhancement. Instead water ice may be depleted in the LMC.
- Both CO2 and CO ices are depleted in the SMC, in particular no CO ice is detected.
- The dust temperature in the SMC is higher than in the LMC (van Loon et al. 2010a,b), preventing significant CO freeze-out.

The figure above shows the ice column densities to investigate abundance ratios.

The sample of 7 Magellanic YSOs includes 3 LMC (Oliveira et al. 2009) and 4 SMC sources (Oliveira et al. 2011). The L- and M-band spectra were obtained with ISAAC at the ESO/VLT. The Spitzer-IRS spectra were obtained as part of the SAGE-Spec Spitzer Legacy Program of the LMC (Kemper et al. 2010) and GTO program #50240 on the SMC (P.I. G.C. Sloan).

The optical depth spectra are shown below. H2O, CO2, and CO ices are detected towards LMC YSOs. No CO ice is detected towards the SMC objects. We measure ice column densities to investigate abundance ratios.

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The figure above shows a schematic representation of the column densities of the three ices (for a given H2 column, not to scale) compared between the Galaxy, LMC, and SMC.

- The reduced metallicity of the MCs results in a lower dust-gas ratio; combined with harsher UV-field this leads to enhanced photo-desorption of water and reduced freeze-out in the outer H2 envelope.
- The “snowline” for water moves inwards in the YSO envelope, reducing the column density of water ice, consistent with LMC observations.
- Gas-phase CO requires high density to accrete onto the icy grains. In the LMC CO freeze-out still occurs and CO2 ice forms both in CO-rich and H2O-rich mixtures.
- In the SMC, significant CO freeze-out does not seem to occur due to higher dust temperature.

References:
Kemper F. et al. 2010, PASP 122, 683
van Loon J.Th. et al. 2010a, AJ 139, 68
van Loon J.Th. et al. 2010b, AJ 139, 1553