SOFIA/EXES 13 Micron High Spectral Resolution Observations of Orion IRc2

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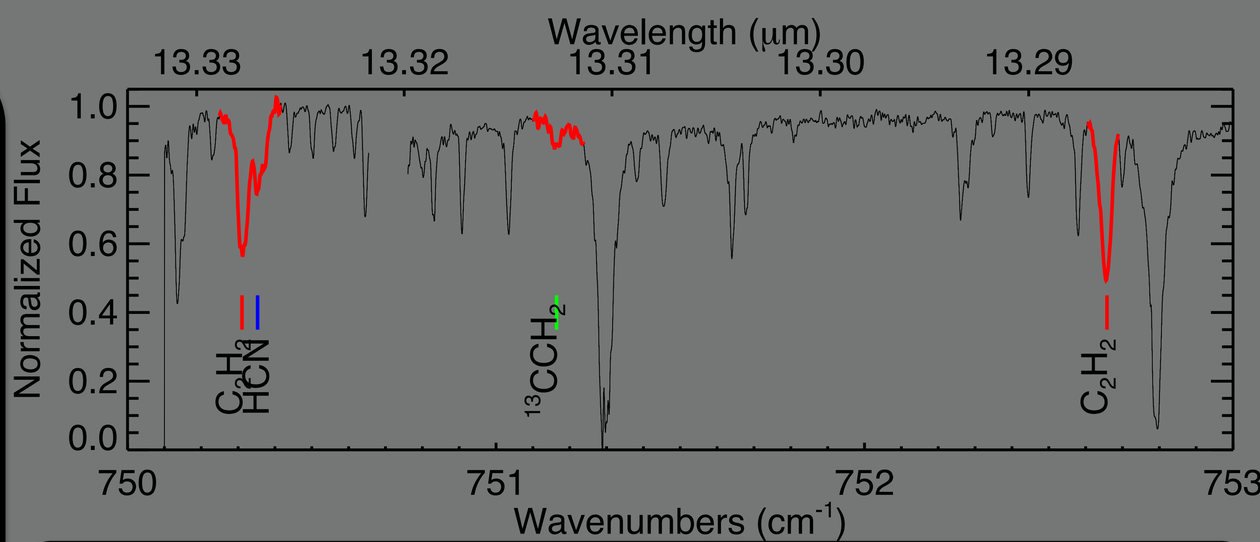
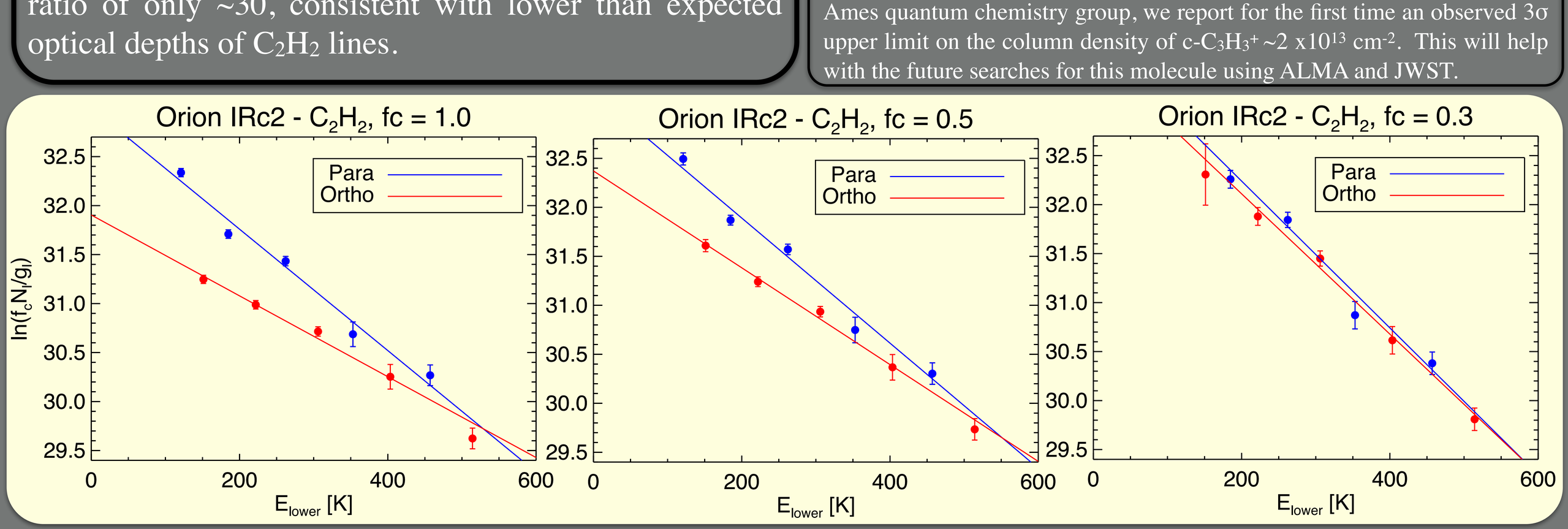
We present results from high resolution EXES spectra of Orion IRc2. Ten ro-vibrational transitions of C_2H_2 were detected - 5 each in the ortho and para states. Their rotational diagrams are shown below for covering fractions (f_C) of 1.0, 0.5 and 0.3. The line fits become increasingly poor below f_C = 0.5, as illustrated by f_C = 0.3. We find that the ortho and para ladders trace different temperatures even at f_C = 0.5, suggesting that this difference is real and not an optical depth effect. This difference could not be measured from previous ground based instruments. Additionally, we obtain a robust measurement of the ortho to para ratio and find that its unusually low, ~0.6 compared to the standard values of 3. Such a low ratio might indicate a different formation path for C_2H_2 that in turn may have significant impact on the formation of other molecules in the ISM since C_2H_2 is considered to be the most common precursor in the formation of bigger hydrocarbons, ring molecules and PAHs in the interstellar medium.

Preliminary analysis of $^{13}CCH_2$ gives an isotopic $^{12}C/^{13}C$ ratio of only ~30, consistent with lower than expected optical depths of C_2H_2 lines.



Observations: A 13 μm spectrum of Orion IRc2 covering 0.4 μm with a resolution of 5 km/s was obtained as part of our Cycle-3 SOFIA/EXES proposal. A portion of this spectrum is presented above. In about 500s of integration time, we detected 10 R-branch C_2H_2 lines (v_4, J = 9– 8 to 18–17), along with $^{13}CCH_2$ and HCN lines with high S/N. Compared to previously published observations of C_2H_2 from the ground (e.g., Evans et al. 1991), which did not have continuous coverage and had larger uncertainties produced by atmospheric corrections, our data were clearly able to separate ortho and para ladders and provide robust measurements of their column densities and the ortho-to-para ratio. Moreover, a clean measurement of the C_2H_2 line profiles showed a systematic difference in the line width between the ortho and para species.

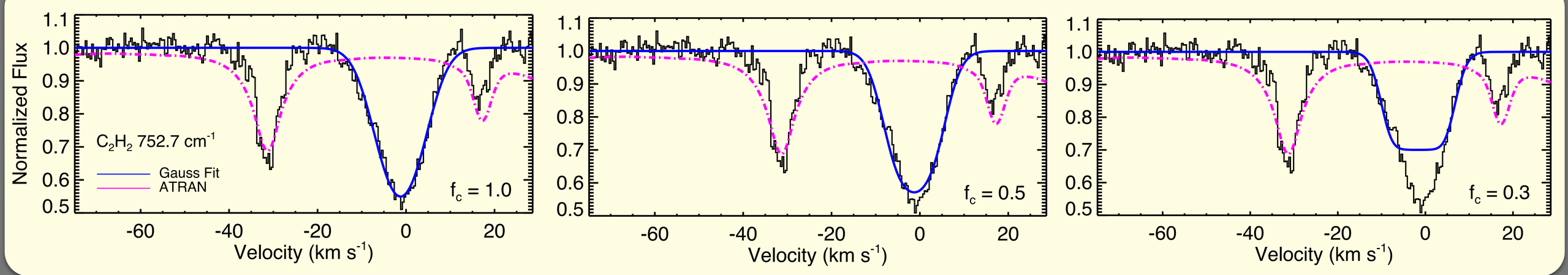
Upper Limit on $C_3H_3^+$: This project began as a search for c-$C_3H_3^+$, the most important precursor in the formation of c-C_3H_2 - an interstellar organic ring molecule widespread in the ISM. There has been interest in detecting c-$C_3H_3^+$ in astrophysical environments for more than 25 years. Using these EXES observations along with *ab initio* calculations from the Ames quantum chemistry group, we report for the first time an observed 3σ upper limit on the column density of c-$C_3H_3^+$ ~2 x10^{13} cm^{-2}. This will help with the future searches for this molecule using ALMA and JWST.



[T_{ex}]$_{Para}$ = 161.4 ± 7.3 K
N_{Para} = (4.0 ± 0.2) x 10^{16} cm^{-2}
[T_{ex}]$_{Ortho}$ = 242.3 ± 15.2 K
N_{Para} = (2.3 ± 0.2) x 10^{16} cm^{-2}
O/P = 0.57 ± 0.05

[T_{ex}]$_{Para}$ = 156.6 ± 8.0 K
N_{Para} = (4.5 ± 0.4) x 10^{16} cm^{-2}
[T_{ex}]$_{Ortho}$ = 202.4 ± 12.3 K
N_{Para} = (2.9 ± 0.2) x 10^{16} cm^{-2}
O/P = 0.63 ± 0.07

[T_{ex}]$_{Para}$ = 133.4 ± 8.8 K
N_{Para} = (6.6 ± 1.0) x 10^{16} cm^{-2}
[T_{ex}]$_{Ortho}$ = 139.6 ± 9.0 K
N_{Para} = (5.7 ± 0.9) x 10^{16} cm^{-2}
O/P = 0.87 ± 0.19



Future Work: We are currently working on the HCN analysis. The preliminary analysis gives T_{ex} = 145 K and N(HCN) = 8 x 10^{16} cm^{-2}. It is interesting that the excitation temperature derived from HCN is consistent with only para C_2H_2. We are working with Eric Herbst and Kinsuk Acharyya to compare our observations with their most current gas-grain chemical models, which estimate the abundances of molecules as a function of time and physical conditions (e.g., Acharyya et al. 2015, He et al. 2016). For IRc2, the chemical simulations are run in a warm up mode, in which the temperature increases as the source of the infrared radiation turns on and heats up (e.g.,Garrod & Herbst 2006). They will help us investigate various scenarios that can produce low ortho to para ratios and provide a physical explanation for differences in ortho and para physical conditions.