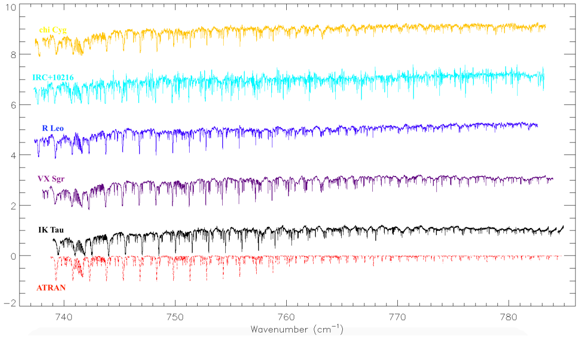
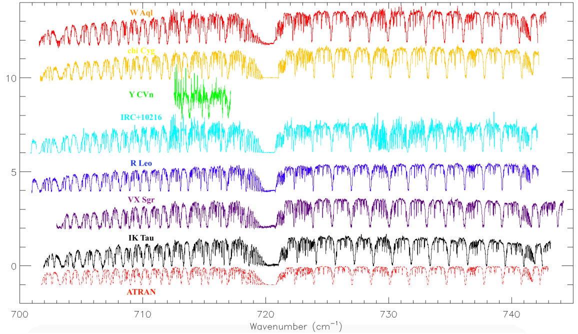
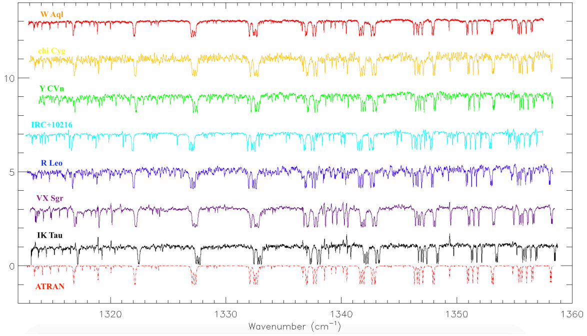
Early Results from SOFIA/EXES High Resolution Spectroscopic Observations of Circumstellar Envelopes of AGB Stars

Edward J. Montiel[1] (emontiel@sofia.usra.edu), J. P. Fonfría[2], M. J. Richter[3], C. N. DeWitt[1], J. Cernicharo[2]

1: SOFIA-USRA; 2: CSIC-IFF; 3: UC Davis



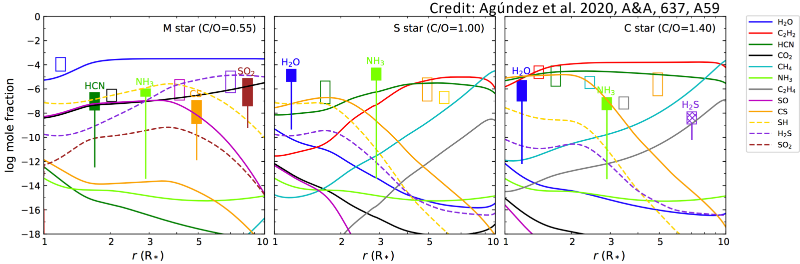




Motivation/Background

We present early results from our project to investigate if there is a relationship between the mass-loss rates of AGB stars and the chemistry within the circumstellar envelopes that this process creates. We have obtained high spectral resolution (R > 60,000) observations with the Echelon Cross Echelle Spectrograph (EXES) aboard SOFIA of a small sample of C, M, and S-type AGB stars. The mass-loss rate of this sample ranges from 10^{-7} to 10^{-5} solar masses per year. We have focused on two spectral regions (7.5 & 13—14 µm) that allow us to study several molecules that are either exceedingly difficult to observe from the ground or have no permanent dipole moment.

Credit: Agúndez et al. 2020, A&A, 637, A59



Molecular abundances between the photosphere and r = 10R* depending on the C/O ratio. The curves are from the results of models. Observational estimates are represented as rectangles. Empty rectangles indicate good agreement between model and observations at any radius of the modeled region, filled rectangles severe disagreement, and dashed rectangles the intermediate case.

Sample (see Doppler corrected spectra left)

3 Oxygen AGB stars (O-rich | C/O < 1| M-type):

- IK Tauri: MLR = 2.0 x 10^{-5} solar masses yr^{-1}| v_{LSR} = 36.0 km s^{-1} | v_{Exp} = 19.0 km s^{-1}
- VX Sagittarii: MLR = 5.5 x 10^{-6} solar masses yr^{-1}| v_{LSR} = 6.5 km s^{-1} | v_{Exp} = 24.0 km s^{-1}
- R Leonis: MLR = 1.0 x 10^{-7} solar masses yr^{-1}| v_{LSR} = -1.0 km s^{-1} | v_{Exp} = 6.0 km s^{-1}

2 S-type AGB stars (C/O ≅ 1):

- W Aquilae: MLR = 2.7x 10^{-6} solar masses yr^{-1}| v_{LSR} = -25.0 km s^{-1} | v_{Exp} = 17.2 km s^{-1}
- Chi Cygni: MLR = 6.0 x 10^{-7} solar masses yr^{-1}| v_{LSR} = 10.5 km s^{-1} | v_{Exp} = 8.5 km s^{-1}

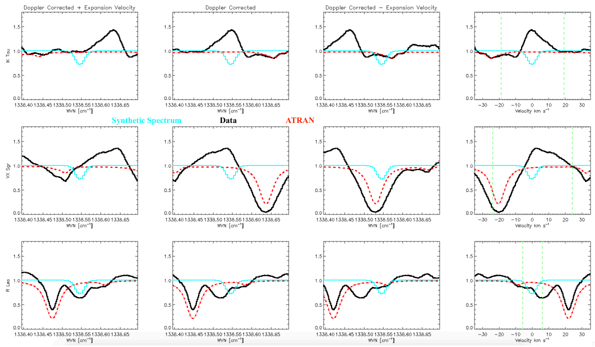
3 Carbon AGB stars (C-rich | C/O > 1 | C-type):

- IRC+10216: MLR = 2.7 x 10^{-5} solar masses yr^{-1}| v_{LSR} = -26.5 km s^{-1} | v_{Exp} = 14.5 km s^{-1}
- V Hydrae: MLR = 2.0 x 10^{-6} solar masses yr^{-1}| v_{LSR} = -17.0 km s^{-1} | v_{Exp} = 15.0 km s^{-1} (pending)
- Y Canum Venaticorum: MLR = 1.5 x 10^{-7} solar masses yr^{-1}| v_{LSR} = 21.0 km s^{-1} | v_{Exp} = 8.0 km s^{-1}

Molecules (& Isotopologues) Identified

H_2O, CO_2, SO_2, C_2H_2, HCN, CS, SiS

H_2O in O-rich AGB Stars (Montiel et al, in prep)

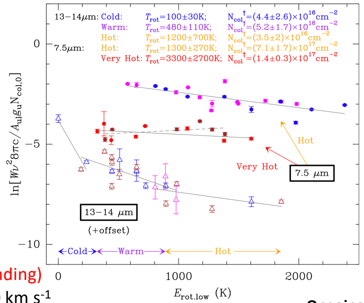


We have identified many transitions of H_2O in both spectral ranges. The 7.5 µm range (see snapshot above) contains the v_2 fundamental band and associated hot bands. The velocity space plot on the right is of just the Doppler corrected panel. Dashed vertical green lights are at +/- the expansion velocity of the envelope. The features appear mostly in emission/P Cygni profiles in IK Tau & VX Sgr. The H_2O features in R Leo show absorption at +/- the expansion velocity, which point to presence of detecting in-falling material. Evidence for in-falling material has also been seen in ALMA observation of R Leo (Fonfría et al 2019, A&A, 622, L14).

Individual Star Results

CO2 in R Leo -- Fonfría et al (2020, A&A, 643, L15)

HCN in Y CVn -- Fonfría et al (in review. see below)



Ro-vibrational diagram of absorption components of the infrared HCN lines at 7.5 and 13—14 µm (with an offset for improved visibility). Four populations with various rotational temperatures derived from the fitted solid straight lines can be distinguish (cold, warm, hot, and very hot).

Ongoing Work

We are continuing with our analysis of Oxygen—based, Carbon—based, and other molecules (such as Sulfur bearing species). Interested in working with the data? Contact me at emontiel@sofia.usra.edu