MOLECULAR COMPLEXITY IN ENVELOPES OF EVOLVED OXYGEN RICH STARS: IK TAURI AND OH231.8+4.2

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ABSTRACT

During the late phases of low-intermediate mass (0.1 – 8 $M_{\odot}$) stars, a significant mass loss is produced creating a gas and dust envelope surrounding the central star. Due to the physical conditions in the envelope, gas is primarily molecular, placing these objects as efficient molecular factories that will enrich the interstellar medium. Observation and study of molecular emission allows deriving physical and chemical properties of these envelopes. As far as today, Oxygen rich objects are not so well studied as their Carbon counterparts, because Carbon chemistry is much more active than Oxygen chemistry. Importance of this work is that the Oxygen rich envelopes are not completely characterized yet.

We present preliminary results from our on-going milimiter wavelength survey with the EMIR receivers of the IRAM 30 meters radiotelescope towards the envelopes of two evolved Oxygen rich objects: IK Tauri and OH231.8+4.2. We detect a wealth of lines ranging from few mK to K (with rms ranging from 1 to 3 mK in best cases). Both objects present significant differences in their molecular emission features due to contrast of evolutionary stage and physical properties and both show evidences of different chemical formation processes. Some of the molecules identified are CO, SiO, H_2O, NS, HCO^+, SO, SO_2, SH_2, OCS, HCN, HNC, CN, HC_3N, CS, H_2CO, HNCO, HNCS, SiS, N_2H^+ and a number of isotopologues (bearing ^{13}C, ^{33}S, ^{34}S, ^{17}O, ^{18}O, ^{28}Si, ^{29}Si, ^{30}Si and ^{15}N atoms). Some of the molecules identified represent first detections in Oxygen rich AGB stars.

We expect to get a better understanding of the chemistry and structure of these objects, in particular how interaction between AGB (Asymptotic Giant Branch) envelopes and post-AGB winds influences chemistry producing a reformation of molecules through shocked gas reactions.

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IK TAURI (fig.1)

- IK Tauri is an Oxygen rich AGB star with spectral type M8.1-M11.2. It is located at a distance of ~ 250 pc. IK Tauri is surrounded by a spherical molecular envelope which expands at ~ 18 km/s.

- Estimated AGB mass loss rate from CO J=1-0 line is 2.4×10^{-6} - 3×10^{-5} $M_{\odot}$/year.

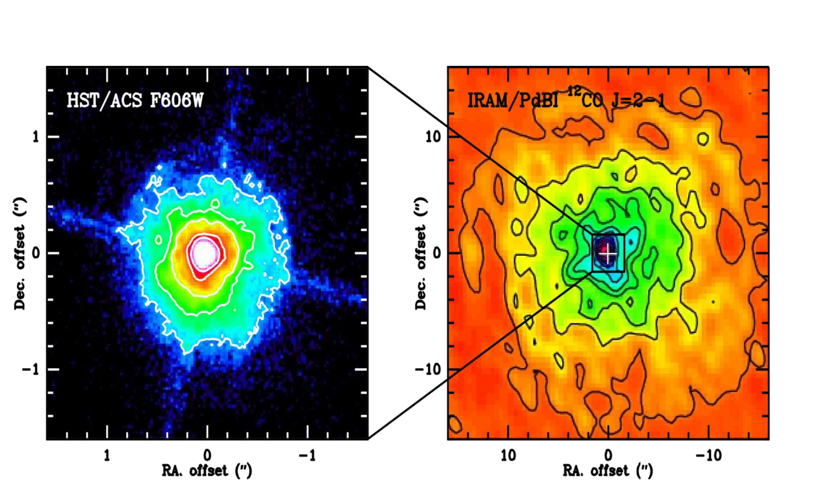


Figure 1: Left, HST image. **Right**, CO J=2-1 emission with the IRAM Plateau de Bure Interferometer. (Castro-Carrizo et al. 2010).

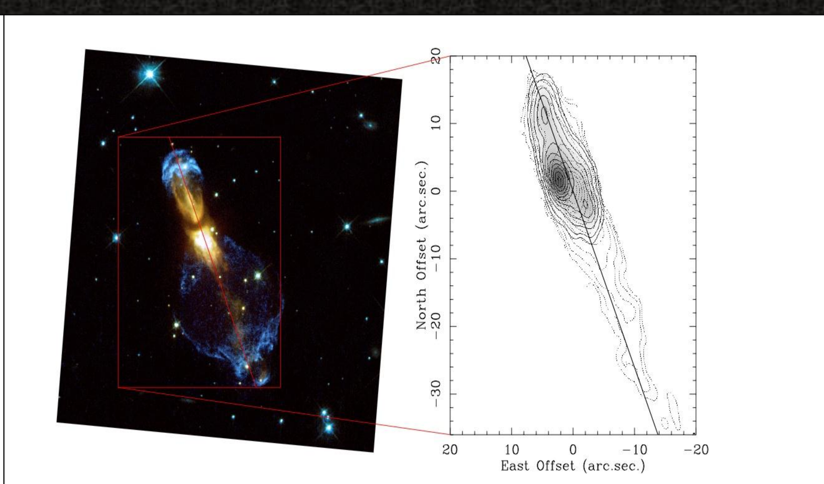


Figure 2: Left, false color image from HST. Reflection nebula (R-band yellow) and Hα emission from shocks (blue). **Right**, CO J=2-1 map (contours) and HCO^+ J=1-0 (grey scale) taken with the IRAM Plateau de Bure Interferometer.

OH231.8 + 4.2 (fig.2)

- OH231.8+4.2 is a bipolar nebula surrounding a Mira Oxygen rich star Qx Pup with spectral type M9III and a A0V companion (Sánchez Contreras et al. 2004). It is located at a distance of ~ 1500 pc. OH231 is surrounded by a bipolar molecular envelope with a total mass of ~1$M_{\odot}$ and an average kinetic temperature of ~20K (Sánchez Contreras et al. 1997) . The molecular gas is outflowing along the nebular axis and reaches expansion velocities of up to ~400 km/s at the tip of the lobes.

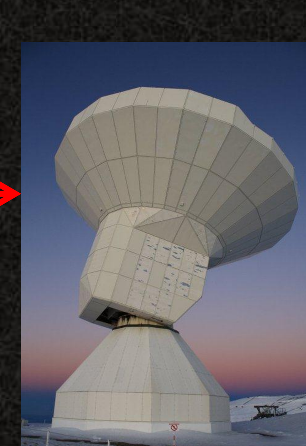
- The fast, bipolar molecular flows are believed to result from the impact of collimated, fast winds (jets) on the spherical and slowly expanding circumstellar envelope (CSE) formed in the previous AGB phase.

- Estimated AGB mass loss rate is ≥ 10^{-4} $M_{\odot}$/year.

OBSERVATIONS

Our on-going milimeter survey of both sources is being done with the IRAM 30 meters antenna, located in Pico Veleta, Granada. Observations to date have been done in several campaigns during 2009, 2010 and 2011. We're using state-of-the-art EMIR receivers (Carter et al. 2012) connecting four different backends with different capabilities. We focus the analysis on the spectra obtained with one of these backends: WILMA (2 MHz resolution).

Observational results can be seen at figure 3.



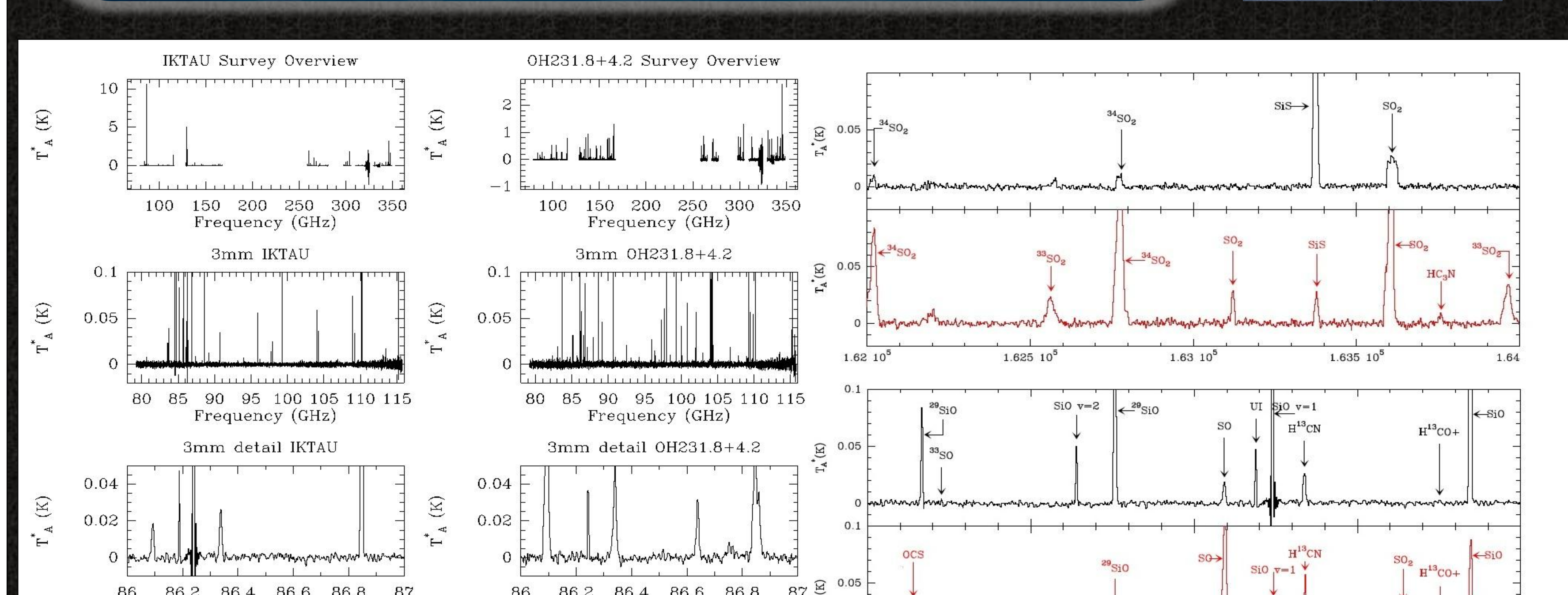


Figure 3: **Left,** survey overview for both sources and details of 3mm band; **Right,** identification sample in both sources, IK Tauri in **black** and OH231.8+4.2 in red

Frequency (MHz)

LINE IDENTIFICATION

Due to the physical properties of the envelopes, transitions found correspond to rotationally and vibrationally excited lines, with low excitation temperatures ~30K.

Identification is done with MADEX (Cernicharo 2012) , CDMS and JPL catalogues. We should emphasize that molecular line identification is not simple owing to the wealth of molecules and transitions to take into account (e.g. can be found about 8 potential candidates around just one MHz of bandwith).

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ANALYSIS: LTE CALCULATIONS

First approximation to solve the excitation problem is to consider LTE (Local Thermodynamic Equilibrium) conditions and make use of the population diagrams (Goldsmith et al. 1999). This approximation is valid only if:

- Molecular emission is in the Rayleigh-Jeans limit
- Lines are optically thin
- All rotational levels are in thermodynamical equilibrium with the same temperature
- Background temperature is negligible versus rotational temperature
- Medium responsible of the emission is homogeneus

Population diagrams allow to determine a first order rotational (pseudo-kinetic) temperature of the envelope and also column densities. With column densities we can obtain abundances fitting and comparing with a well determined molecular abundance: ^{13}CO in this case, which is 2×10^{-5} (refered to H_2).

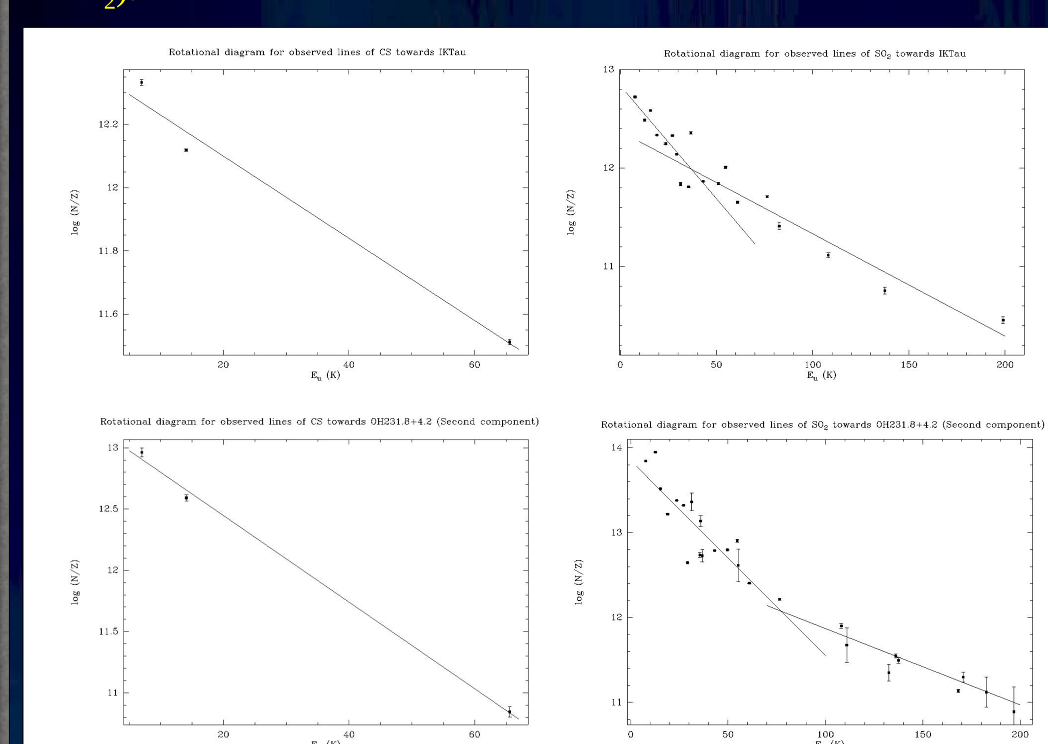

Figure 4: Four different population diagrams for CS towards IK Tau (top left) and OH231 (bottom left) and SO_2 towards IK Tau (top right) and OH231 (bottom right).

Abundances for some molecules in both sources

Molecule	IK Tauri	OH231.8+4.2
^{13}CO	2.0E-05	2.0E-05
SO	3.3E-07	8.1E-07
SO_2	3.5E-07	1.6E-06
SiO	2.4E-07	6.3E-09
CS	2.7E-08	8.8E-08
HNC	5.3E-09	1.1E-08
HCN	6.7E-08	4.4E-08
HCO^+	2.7E-09	9.4E-09
HNCO	< 1.3E-09	5.3E-08
HNCS	< 9.3E-09	1.3E-08
HC_3N	< 1.1E-09	3.8E-09

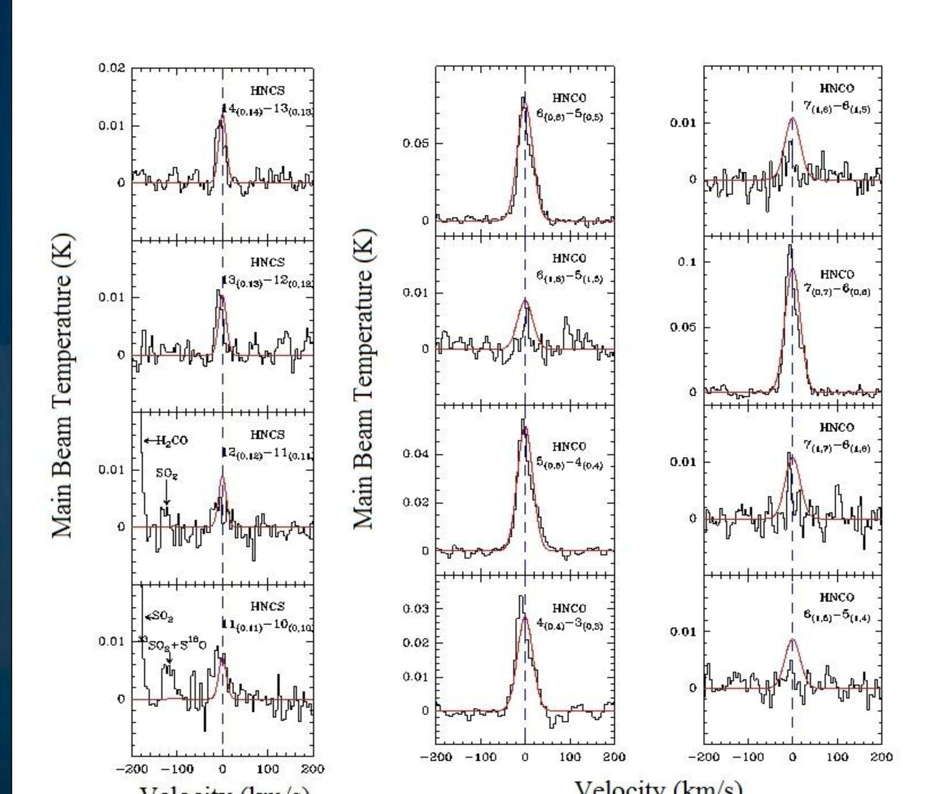

Figure 5: Emission lines corresponding to different transitions of HNCS and HNCO towards OH231. LTE models are presented in red.

For isocyanic acid (HNCO) model best fit is for transitions with K_a=0. K_a=1 transitions show a different profile.

Population diagram of HNCO gives a T_{rot}~~15K and 2.2 x 10^{14} cm^{-2} of column density.

Therefore LTE calculations are just given as an aproximation. We can observe in figure 4, how different excitation temperatures, i.e. different regions of the envelope, are responsible of the emission for different transitions.

K_a=1 transitions may correspond to a higher excitation temperature than 15 K, also these lines are narrower than K_a=0 transitions. On the other hand, wider profile of K_a=0 transitions suggest a blend of two different components.

PRELIMINARY RESULTS

We have found significant differences between these two objects. For IK Tauri, we detect emission of NaCl and H_2O, not present in OH231, this fact should be due to differences in evolutionary stage (AGB vs post-AGB), an indication that AGB envelope of OH231 is being detached cause NaCl and H_2O are primarily formed at the innermost parts of the CSE. We interpret similarly the abundances found for SiS and SiO in both objects, in IK Tauri these two molecules are relatively abundant while in OH231 are very low. The same can be observed for SiO masers.

For OH231, we found a chemistry drastically affected by shocks, we observe the presence of abundant ionized species as HCO^+ and N_2H^+, typical of this scenario. Also SO and SO_2 abundances towards OH231 are higher, and these two molecules are probably formed through reaction between sulfur and OH, sulfur coming from H_2S photodissociation. Nitrogen containing molecules are also more abundant in OH231, probably indicating an extra source of N atoms (UV photodissociation or shocks).

Innermost shells of IK Tauri are expanding at low velocities creating a non-dissociative chemistry. On the other hand OH231 displays that UV photodissociation, shock driven chemistry and in general non-equilibrium processes are playing a key role in its evolution and structure

FUTURE PERSPECTIVE

Improving analysis is our first goal. We're actually working on a multi-shell LVG (Large Velocity Gradient) radiative transfer code based on MADEX which calculates emission output through the molecular envelope modeled as a collection of thin shells with different physical and chemical conditions. This tool will allow us to constraint chemical abundances in different regions of the envelopes (i.e. radial abundance profiles) and also physical structure of the envelope. We will study in detail different chemical routes comparing observations with chemical models.

We need to complete the survey with the IRAM 30m antenna and we hope that it will be finished in late 2012 or early 2013. Also we're expecting Herschel HIFI data for both sources and ALMA data (several proposals are being submitted from our group in Cycle 1 Early Science).