MOLECULAR COMPLEX 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 – 4 M_☉) 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 millimeter wavelength survey with the EMBR receivers of the IRAM 30 meters radiotelescope towards the envelopes of two evolved Oxygen rich objects: IK Tau and OH231.8+4.2. We detect a wealth of lines ranging from few mK to T (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, SO, H2O, CS, HCN, HCO+, HCO, SO, SH, OCS, HCN, CN, HNC, CS, HC3N, HCO+, HNC, HCS, SiS, N2H+, and a number of isotopologs (bearing ¹⁰C, ¹⁴N, ³²S, ²³⁰Th, ¹⁸O, ³⁴S, ³²Si, ³¹Si) and a strong indication of CO+ and O2+. The abundance of SiS and CN is the highest ever identified in an Oxygen rich AGB star.

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

REFERENCES & BIBLIOGRAPHY

IK TAURI (fig.1)

- IK Tau is an Oxygen rich AGB star with spectral type M3 I-M3 II. It is located at a distance of ~ 250 pc. IK Tau is surrounded by a bipolar molecular envelope which expands ~ 150 kpc.
- Estimated AGB mass loss rate from CO J=2-0 line to be 2.4×10⁻⁶ M_☉/yr.

Figure 1: Left: HST image, Right, CO J=2-0 emission with the IRAM Plateau de Bure Interferometer (Contreras et al. 2006). Figure 2: Left: Hα line from HST, Right, CO J=2-0 emission with the IRAM Plateau de Bure Interferometer (Contreras et al. 2006)

DIAGRAM OF VELOCITY SPACE FOR OH231.8+4.2

- OH231.8+4.2 is a bipolar nebula surrounding a Mira Oxygen rich star Qs Pup with spectral type M3III and a 20% companions (Cernicharo 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 ~1M_☉ and an average kinetic temperature of ~20K (Cernicharo et al. 1997). The molecular gas is outflowing along the nebula axis and reaches expansion velocities of up to ~400 km/s at the top 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 > 10⁻⁶ M_☉/yr.

Figure 3: Left: infrared image for both components, Left, B408u image for both components. Right, Identification sample in both sources, IK Tau in black and (OH231) in red.

OBSERVATIONS

Our on-going millimeter survey of both sources is being done with the IRAM Plateau de Bure antenna. Observations to date have been done in several campaigns during 2009, 2010 and 2011. We are using state-of-the-art EMBR receivers (Contreras et al. 2004). This allows us to compare different sources with different capabilities. We focus the analysis on the spectra obtained with one of them, the IRAM Plateau de Bure Interferometer (MAEX).

Observational results can be seen at figure 3.

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 note that molecular line identification was 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 bandwidth).

Figure 4: Different population diagrams for CS towards IK Tau top-left and OH231 (bottom-left) and SO towards IK Tau top-right and OH231 (bottom-right).

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 unless rotation temperature
- Medium responsible of the emission is homogeneous

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 “CO” in this case, which is 2100 (referred to Hz).

Abundances for some molecules in both sources

- Molecular CO, CH3OH, H2S, and OCS, are formed in the inner regions of the envelopes of the two objects IKT and OH231.
- The CH3OH abundance is larger in OH231 than in IKT.
- Tauri, OH231, and the two objects are relatively abundant while in OH231 are very low. The same can be observed for SO molecules.
- For CH3OH, we found a density drastically affected by shocks, we observe the presence of abundant molecular species as HCO+ and CH3OH typical of the envelope. With SO, SO+ abundances towards OH231 are higher, and these two molecules are probably formed through reactions among sulfur and OH sulfilling coming from H2 photodissociation. Non-gas containing molecules are also more abundant in OH231 probably indicating an extra source of energy (UV vs excitation of shocks).
- Internal tests of IKT are expanding at low velocities creating a non-dispersive chemistry. On the other hand OH231 displays UV photodissociation shock driven chemistry and in general non-equilibrium processes are playing a key role in its evolution and structure.

PRELIMINARY RESULTS

We have found significant differences between these two objects. For IK Tauri, we detect emission of N2H+ and H2O, and 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 hence NaCl and H2O are primarily formed at the innermost parts of the CSE. We interpret similarly the abundances found for CO and N2H+ both objects, in the inner part of the molecular envelopes are relatively abundant while in OH231 are very low. The same can be observed for SO molecules.

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FUTURE PERSPECTIVE

Improving analysis in our first goal. We are 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 constrain chemical abundances in different regions of the envelopes (e.g. radial abundance profiles) and also physical structure of the envelope. We will study in detail different chemical states comparing observations with chemical models.

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