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Molecular Line Survey of CRL618 and Complete Modeling

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Abstract. We present a complete survey and model of the emission from the C-rich protoplanetary nebula CRL 618 at the frequencies accessible with the IRAM-30m telescope (80.25-115.75 GHz, 131.25-179.25 GHz, and 204.25-275.25 GHz) and some results of still on-going observations at the Caltech Submillimeter Observatory (280-360 GHz). Although the number of lines detected is large (several hundreds), the number of chemical species from which they arise is rather small. In fact, lines from cyanopolyynes HC_3N and HC_5N dominate by far the long-wave spectrum of CRL618, with detection of numerous vibrationally excited states and isotopic substituted species. Most of detected species exhibit P-Cygni profiles at the lowest frequencies (3 mm window), and they evolve to pure emission as frequency increases. This fact can only be explained by the behavior of the continuum emission arising from the inner ultracompact HII region and surrounding dust. The data set itself has been used to characterize the continuum emission by averaging all the continuum measurements during the time span of the survey (∼8 years). The physical parameters of the different gas regions have been established by studying the large number of detected cyanopolyynes lines. Using these constraints, the abundances of many other species relative to HC_3N could also be determined and a general model, that reproduce the whole data set at a very detailed level of agreement, could be built.

Keywords. surveys - stars: AGB and post-AGB, stars: individual (CRL618), circumstellar matter, radio lines: stars.

1. Introduction

The motivation to perform the complete millimeter line survey presented here with the IRAM-30m telescope has been to gather the most complete information on the molecular content in one particular stage (protoplanetary nebula, PPNe) of stellar evolution from the Asymptotic Giant Branch (AGB) to Planetary Nebulae (PN), of which CRL618 is the best example. Its chemical richness and its complex morphology are now very well known. Detailed chemical models for this object have been developed (Cernicharo 2004) indicating the influence of the rapid evolution of the central star on the ejected circumstellar material. The formation of relatively complex molecules, such as benzene, detected in the IR spectrum of CRL618 by Cernicharo et al. (2001; first discovery of an aromatic ring outside the Solar System) is also discussed. Physical and chemical variations seem to occur at short -almost human- time scales.

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2. Observations

The now complete observations at the IRAM-30m telescope were performed during 8 winters at the accessible frequencies between 80 and 275 GHz using heterodyne receivers. The CSO telescope observations between 280 and 356 GHz are still on-going. Concerning the cyanopolyynes family ($HC_{2n+1}N$ and isomers), the J_{up} range explored for the different members has been the following: 1 to 4 for HCN and HNC, 9 to 39 for HC_3N, 31 to 133 for HC_5N, and 72 to 85 for HC_7N (not detected beyond J_{up}=85).

For both instruments the frequency resolution used has been around 1 MHz with ∼0.5 GHz wide spectrometers. The observing procedure was the chopping of the secondary mirror at ∼ 1 Hz and ∼90" throw. The pointing was checked every two hours on CRL618 itself (IRAM-30m) or the available planets (CSO). See Pardo et al. (2004) for more details on the observational procedures at the two facilities.

3. Analysis

A radiative transfer model has been developed to study the physical conditions and chemical abundances that explain the whole observed millimeter wave spectrum of CRL618. The precise knowledge of the spectral behavior of the continuum emission (see Pardo et al. 2004) is paramount since it plays a very important role in the observed line profiles (specially in the emission-to-absorption line ratio). The model consists of a gas envelope around a central continuum source, considered spherical with size and effective temperature adjusted to fit the whole IRAM-30m continuum data and assumed to have the same spectral index in the range 280-356 GHz (CSO observations). The description of the gas component allows for different shells with different physical conditions. The geometry is not restricted to be spherical, to agree with the observed morphology, and shells with both radial and azimuthal velocity components can be defined.

Since the observations reveal that different gas regions are traced by different molecular species, we proceed in our analysis in different steps. The first one has been to study those species arising from the inner ∼1.5" slowly expanding envelope, with outflow velocities of ∼10 to 15 km·s^{-1}, turbulence velocities around 3.5 km·s^{-1}, and temperatures in the range 250-275 K. Then, we included both the colder and outer circumstellar gas (necessary to explain the rotational lines in the ground vibrational state of HC_3N, HC_5N, HC_7N, and several other molecules) and the high velocity wind component (seen in the line wings of some abundant species, including v=0 HC_3N). Among the observed features, only H and He recombination lines, arising from the same region of the continuum emission have not been analyzed yet. Tables with the derived physical parameters and chemical abundances will be presented in the poster. The general model for all observed frequencies and species and the comparison with the data will also be discussed.

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