Molecular emission from the shocked bipolar outflow in OH 231.8+4.2

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Abstract. We present high-resolution observations of several molecular lines in OH 231.8+4.2 taken with the IRAM interferometer. All molecules are distributed in a narrow region along the symmetry axis, and flow outwards following a velocity gradient similar to that found in CO. The HCO\textsuperscript{+} emission is found to be very clumpy and strongly enhanced in the shock-accelerated lobes, indicating that the formation of this molecule is probably dominated by shock induced reactions. SO is present in the axial outflow as well as in an expanding equatorial disk. The SiO maser emission seems to arise from the innermost parts of such a disk. We also report the first detection of NS in circumstellar envelopes.

1. Introduction

OH 231.8+4.2 (hereafter OH 231.8) is a remarkable bipolar nebula located \(\sim\)1500 pc away (Kastner et al. 1992, Bowers & Morris 1984) that surrounds a cold (M 9 III) Mira star (Cohen 1981; Kastner et al. 1998). The optical nebula consists of two extended lobes, oriented at position angle \(\sim\)21\textdegree\ and inclined with respect to the plane of the sky about 36\textdegree\ (Kastner et al. 1992). The gas in the lobes is expanding at high velocity from the nebula center and its optical emission-line spectrum indicates that it has been excited by shocks (Cohen et al. 1985; Sánchez Contreras et al. 1999). The molecular envelope of OH 231.8 is very cold (\(T_{\text{kin}}\sim\)10 K) and massive (\(\sim\)1\(M_{\odot}\)). This envelope is expanding at low velocity (\(\sim\)10–15 km s\(^{-1}\)) near the equator, while at higher latitudes a strong axial expansion appears. In contrast to the atomic material, the molecular gas is highly restricted to the symmetry axis of the nebula (see Alcolea et al. in this volume). The pronounced axial symmetry and the large velocities reached by the gas in OH 231.8 are usually attributed to the impact of a recent, highly collimated wind on the old AGB envelope.

A large variety of molecules has been detected in OH 231.8 (e.g. Morris et al. 1987), which is classified as an O-rich source due to its H\(_2\)O, OH and SiO maser emission. Maps of certain molecules have suggested that an active chemistry, probably induced by shocks, takes place in OH 231.8 (Sánchez Contreras et al. 1997; Jackson & Nguyen-Q-Rieu 1988).
2. Observations and results

We have obtained high-resolution maps of the HCO\(^+\) \((J=1-0)\), SO \((J=2-1)\), H\(^{13}\)CN \((J=1-0)\), SiO \((v=1, J=2-1)\), and NS \((^2\Pi_{1/2}, J=5/2-3/2, \text{parity-e})\) lines in OH 231.8. Observations were performed using the IRAM interferometer (Plateau de Bure, France) during the winters of 96-97 and 97-98, and in February 99. The highest spatial and spectral resolution obtained are \(\sim 3''\) and \(\sim 0.3 \text{ km s}^{-1}\), respectively. The spatial origin of our maps coincides with the position of the maser, that is located at R.A. = 07\(^{h}\)42\(^{m}\)16\(^{s}\).93, Dec. = -14\(^{\circ}\)42\(^{\prime}\)50\(^{\prime\prime}\).2 (J2000).

2.1. HCO\(^+\)

In Fig. 1 we present the interferometric maps of the HCO\(^+\) \((1-0)\) line for different velocity channels. The emission is distributed in a narrow region along the symmetry axis of the nebula. Such a region has a total size of about \((1 \times 7) \times 10^{17} \text{ cm}\), and seems to be a hollow cylinder near the equator. The present high-resolution maps show that the HCO\(^+\) emission is notably clumpy. We confirm the axial velocity gradient (Fig. 2, top-left box) found in previous low-resolution observations. This gradient is almost constant along the axis and similar to that found for \(^{12}\)CO and other molecules (see below and Sánchez Contreras et al. 1997). The position-velocity (p-v) diagram along the nebula equator (Fig. 2, top-right box) roughly corresponds to an expanding, hollow cylinder or ring. It is remarkable that the most intense HCO\(^+\) emission arises from regions moving at high velocities. In fact, there is a local minimum in the emission of the low-velocity
expanding component (between 10–55 km s\(^{-1}\)) near the center, where the rest of the observed molecules reach the maximum intensity (see SO data in Fig. 2 and CO in Alcolea et al. this volume). The observed spatial and spectral distributions of HCO\(^+\) suggest that this molecule is efficiently formed in the accelerated gas by shock-induced reactions.

2.2. SO

The SO emission occupies a narrow region (∼10\(^{17}\) cm) extending ∼3.5 10\(^{17}\) cm along the symmetry axis of the nebula. The total line width is ∼100 km s\(^{-1}\), indicating that SO is present in the accelerated lobes of OH 231.8. In Fig. 2 (bottom-left box) we can see that SO follows the general velocity gradient along the symmetry axis of the nebula. We have also found SO emission in an expanding disk surrounding the central star. The presence of such a disk is indicated by the inversion of the slope of the velocity gradient at the nebula center (Fig. 2, bottom-left box). The characteristic radius and the expansion velocity of the equatorial disk are ∼2 10\(^{16}\) cm and ∼7 km s\(^{-1}\), respectively. These values lead to a kinematical age for the disk of ∼1000 yr, very similar to that found for the bipolar molecular flow. No sign of rotation has been found in the disk (Fig. 2). Differences between the SO abundances in the disk and the outflow are negligible.

2.3. The SiO maser

In Fig. 3 we show the SiO (\(v=1, J=2–1\)) maser spectra in six different epochs. Three main spectral components can be distinguished at (LSR) velocities ∼26, ∼33 (the systemic velocity), and ∼40 km s\(^{-1}\). Each of these features is formed
of (at least) 3 components, indicating the complex and, probably, clumpy distribution of the gas in the vicinity of the central star. We estimate from our mapping that the size of the maser emitting region is $\lesssim 3 \times 10^{15}$ cm. The fact that the three main spectral features are also found in the SO line (Fig. 2) suggests that the maser emission arises from the innermost regions of the expanding disk seen in the SO maps. Our data would indicate a negligible velocity gradient between the inner and outer parts of such a disk. The relative intensity between the different spectral components as well as the total flux of the SiO line is found to strongly vary with time (Fig. 3). We have found a relative minimum of the SiO flux $\sim 60$ days before the n-IR minimum (Kastner et al. 1992). Assuming that maser pumping is radiative, this phase lag would correspond to a distance of $\sim 10^{17}$ cm between the maser (very close to the star) and the nebular dust reflecting the n-IR starlight. This value is in agreement with the measured distance from the center to the region with maximum n-IR emission.

### 2.4 NS and H$^{13}$CN

We report the first detection of nitrogen sulfide ($^2\Pi_{1/2}, J=5/2-3/2$, parity-e) in circumstellar envelopes. The NS emission is found in a compact central region and, tentatively, in the outflow. The total flux of the line (integrated over all the hyperfine components) is relatively high, $\sim 15$ Jy km s$^{-1}$.

We have found the H$^{13}$CN ($J=1-0$) emission to be distributed along the molecular outflow sharing the general velocity gradient. From the H$^{12}$CN/H$^{13}$CN ($J=1-0$) intensity ratio (H$^{12}$CN data from Sánchez Contreras et al. 1997) we deduce an isotopic $^{12}$C/$^{13}$C ratio of $\sim 5-10$.

The large variety and abundance of N- and S-bearing molecules in OH 231.8 is a clear sign of an active chemistry probably induced by shocks. Shocks would initiate (endothermic) reactions that trigger the N and S chemistry (Lada, Oppenheimer & Hartquist 1978), and could also extract additional S from the surface of dust grains (Jackson & Nguyen-Q-Rieu 1988).

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