VLBA H_2O and SiO maser observations in the pPN OH 231.8+4

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Summary. We report high-resolution observations of H_2O, $6_{1,6}$–$5_{2,3}$ and ^{28}SiO v=2, J=1-0 maser emissions obtained with the Very Long Baseline Array in the well known bipolar protoplanetary nebulae OH 231.8+4.2 (see [6]). Phase referencing technique was used to recover the absolute position of both emissions and high quality maps were produced. We detected two groups of water vapor emission oriented nearly north-south and separated by about 60 milli-arcseconds (80 AU). SiO masers are tentatively found to be placed between the two H_2O maser emitting regions, probably indicating the position of the Mira component of the system.

Key words: Maser, stars: AGB and post-AGB, radio lines: stars

1 Introduction

OH 231.8+4.2 (hereafter OH 231.8) is a well studied pre-planetary nebula (pPN). The central source is a binary system formed by an M9-10 III Mira variable (i.e. an AGB star) and a A0 main sequence companion, as revealed by optical spectroscopy [12]. The remarkable bipolar nebula shows all the signs of post-AGB evolution: fast bipolar outflows with velocities ∼200–400 km s^{-1}, shock-excited gas and shock-induced chemistry. The distance to this source, ∼ 1500 pc, and the inclination of the bipolar axis with respect to the plane of the sky, ∼ 36°, are well known, in particular thanks to measurements of phase lags between the variability of the radiation coming from the two lobes and of the light polarization in them (see [2, 9, 13]). The presence of a late-type star in the core of a bipolar post-AGB nebula like OH 231.8 is very unusual since the central stars of pPNe are typically hotter, with spectral types from B to K.

Due to the late spectral type ($T_{\rm eff}$ ∼ 2500 K) of its AGB central star, OH 231.8 still shows intense SiO masers, contrarily to what happens in the majority of pPNe. NRAO[4] Very Long Baseline Array (VLBA) observations of ^{28}SiO masers in OH 231.8, carried out at 7 mm (v=2, J=1–0) in April 2000, revealed for the first time the structure and kinematics of the close stellar environment in a pPN [11]. The SiO maser emission arises from several compact, bright spots forming a structure elongated in the direction perpendicular to the symmetry axis of the nebula. Such a distribution is consistent with an equatorial torus with a radius of $\sim$6 AU around the central star. A complex velocity gradient was found along the torus, which suggests rotation and infall of material towards the star. Such a distribution is remarkably different from that typically found in maps of AGB stars, where the masers form a roughly spherical ring-like chain of spots resulting from tangential maser amplification in a thin, spherical shell [5, 4].

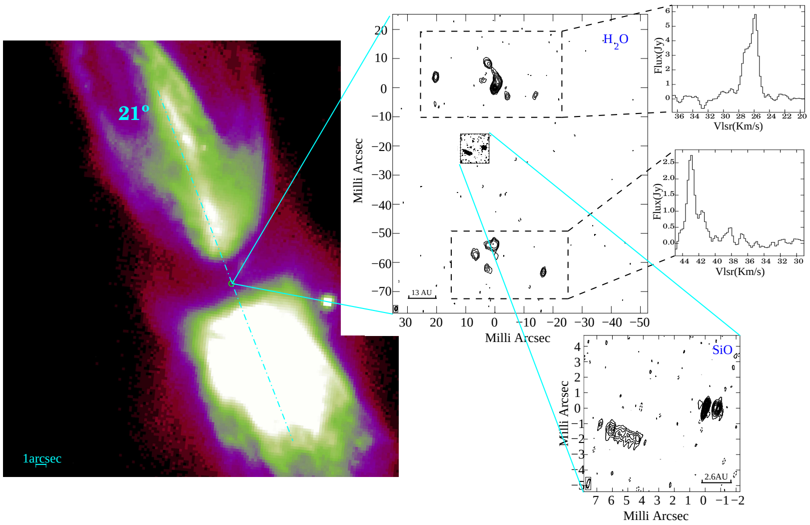

Fig. 1. Total intensity map of the H_2O maser, compared with the *HST* image of the nebula (taken with the WFPC2, filter F791W); accurate astrometry has been performed for the HST image and maser maps. The small square map indicates the absolute position of the SiO maser, and the SiO map reproduces the SiO data by [11]. Top right panels show the composed profile of H_2O maser for the two main regions.

2 Observations

Using the VLBA, we performed milliarcsecond resolution observations of the H_2O $6_{1,6}$–$5_{2,3}$ and SiO v=1 and v=2, J=1–0 maser emission in the pPN OH 231.8. The

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H_2O and SiO observations were obtained on 24th November 2002 and on 3rd July 2003, respectively. The data were recorded in dual circular polarization with a velocity resolution (i.e. channel width) of $\sim$0.2 km s^{-1} and a total velocity coverage of about 110 km s^{-1}. To be able to measure the relative position of the H_2O and SiO maser spots/clumps, part of the observations were made using the phase referencing technique. To ensure the detection of our source, we alternate standard line observations with observations in phase referencing, each observing block lasting 40 minutes. The coordinates are then absolute positions referred to the quasar J0730–11. The data reduction followed the standard scheme for spectral line calibration data in the Astronomical Image Processing System (AIPS). The amplitude was calibrated using the template spectra method. To improve the phase calibration solutions, we extensively mapped all the calibrators, and their brightness distributions were introduced and taken into account in the calibration process.

3 Results and discussion

The H_2O maser integrated flux map is shown in the Figure 1. The restored clean beam has a full width at half maximum of about $\sim$ 1.5 x 0.75 mas, and is oriented with a position angle of PA $= -5°$. Maser emission have been searched on a large area of up to 900 mas. Maps have been cleaned down to a noise level of 15 mJy/beam at 3 σ. H_2O maser emission arises in two groups of compact spots separated by $\sim$60 mas (80 AU) along the north-south direction, i.e. roughly along the nebular symmetry axis(note that we also found an isolated maser spot at few tenths of mas to the west, at Δ R.A. -59 mas y Δ Dec. -55 mas); a clear velocity gradient is observed indicating an expansive kinematics in this region (Fig. 1). Our SiO observations indicate that the SiO masers arise from a region placed approximately in the middle of both H_2O maser-emitting areas, probably pinpointing the location of the central Mira component of the central stellar system. In an earlier work [11], the SiO masers were found to be distributed in a torus- like equatorial structure (Fig. 1).

The size of the total emitting region in OH 231.8, $\sim 10^{15}$ cm, is consistent with that in standard red giants. The deprojected expansion velocity of the spots, $\sim$10-15 km/s (for an inclination of the nebular axis of i$\sim$ 36° - [13], is in good agreement with the usual velocities found in AGB stars (e.g. [10, 14]). The total velocity dispersion in OH 231, $\sim$20 km/s, however, is larger than those found in the majority of H_2O profiles from AGB stars (see [7, 8, 3, 1]). Therefore, from the point of view of the pumping conditions and kinematics, the H_2O emission in our object comes from a region that we can assume to be typical of water masers in AGB stars. No special phenomena (shocks, photo induced chemistry, ...) are then required to explain our observations, just the usual physical and chemical conditions in the envelope of a O-rich AGB star.

The distribution of the H_2O masers in OH 231 is different from the circular distribution typically found in AGB stars. The fact that the SiO maser emission comes from a region in the middle of the H_2O spot areas confirms that the latter are placed at both sides of the star, along the symmetry axis of the nebula. The distribution of the H_2O and SiO masers suggests that the equatorial regions of the inner circumstellar envelope of OH 231.8 have been strongly modified. In particular, an equatorial density enhancement, e.g. induced by the presence of the companion, could have quenched and intensified the H_2O and SiO masers respectively in these

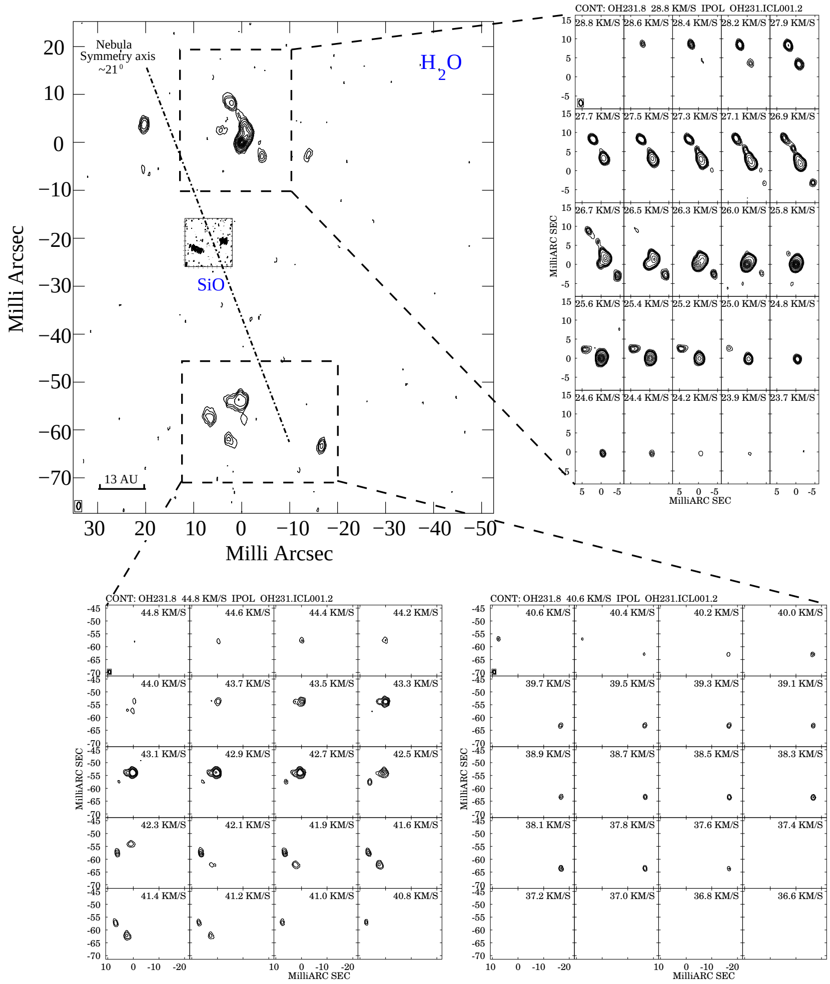

Fig. 2. Integrated and channel velocity H_2O map.

equatorial regions. But we cannot rule out that the H_2O maser spots of OH 231.8 are placed at the base of a bipolar outflow, whose very fast, extended components are detected in scattered light and CO line emission. In this case, the H_2O masers would trace the base of a relatively slow bipolar outflow and would be expected to be centered around the compact companion of the binary system, which is most likely to power the jets in this case [12], and not around the mass-losing star, i.e. the Mira, as we observe.

To summarize, in view of their spatial distribution and kinematics, the H_2O maser spots in OH 231.8 seem to be the result of a pumping process very similar to that at work in AGB circumstellar envelopes, and under similar physical and chemical conditions. However they take place in an envelope that has been seriously altered, probably due to the presence of a companion, in such a way that only (unshocked) polar regions of the envelope keep favorable conditions for H_2O maser pumping. The fact that the SiO maser region is much smaller than the H_2O region and perpendicular to its distribution probably indicates that gravitational/tidal forces due to the companion strongly affect these inner circumstellar shells, supporting our conclusion on their effects on the H_2O emitting region.

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