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# Circumstellar CO in OH/IR stars close to the Galactic Centre

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**Abstract.** A pilot project is carried out to measure circumstellar CO emission from three OH/IR stars close to the GC using the Nobeyama Millimeter Array at 115 GHz and the Sub-Millimeter Array at 230 GHz. An interferometer is necessary as a ‘spatial filter’ in this region of space because of the confusion with interstellar CO emission. The intention is to find out whether it is possible to later conduct a large-scale survey for mass-loss rates using, for example, ALMA. Thus an important parameter would be added to our understanding of the evolution of the Galactic Bulge. Sources have been detected towards two of the stars with ‘correct’ positions and radial velocities. However, for one of the stars the line profile is not what one expects for expanding circumstellar envelopes. This surprising result is discussed and our plans for future observations are presented.

## 1. Introduction

The most rapid stellar mass loss occurs at the so called red-giant (RGB) and asymptotic-giant branches (AGB). Due to the high stellar density and rapid star formation, the Galactic Bulge contains large numbers of RGB and AGB stars. It is important to measure the mass loss rates of these stars in order to get a picture of the recirculation of matter and metal enrichment in this region of the Milky Way.

The most accurate method of estimating the stellar mass-loss rates is based on the CO rotational spectral lines. The first attempt to detect such circumstellar lines in the vicinity of the Galactic Centre (GC) was made by Mauersberger et al. [1] using the 30-m radio telescope in Spain. They detected the $J = 1 - 0$ and $2 - 1$ CO lines from the proto-planetary nebula (PPN) OH0.9+1.3 which has a high radial velocity ($\sim$ 100 km s$^{-1}$) making it likely to be physically close to the GC. They proposed also to look for CO emission from OH/IR stars, since such stars are believed to be the progenitors of PPNe. Winnberg et al. [2] used the same telescope to observe several OH/IR stars close to the GC but detected CO emission only from one star: OH0.3–0.2. This star has a very high radial velocity (–341 km s$^{-1}$). Observations of all the other candidate stars failed because of confusion with the interstellar background emission.

The present project employs a different observing technique in an attempt to detect the *circum*stellar CO emission in the midst of *inter*stellar CO emission. A radio interferometer with suitable baselines could resolve out the interstellar background but leave the circumstellar emission as unresolved point sources. This use of an interferometer could be called a ‘spatial filter’.

In order to find out the optimal baseline lengths and the most favorable CO lines we started a pilot experiment. We chose three OH/IR stars close to the position of the GC with strong IR fluxes and with low-to-moderate radial velocities. In 2003 – 2004 we used the Nobeyama Millimeter Array (NMA) at 115 GHz (CO, $J = 1 - 0$) and in 2005 we used the Sub-Millimeter Array (SMA; Mauna Kea, Hawaii) at 230 GHz ($J = 2 - 1$).

This paper presents the main results of these two data sets and outlines our plans for future observations.

Ultimately we hope that our project will lead to larger systematic surveys of mass loss rates for late-type stars in the Galactic Bulge using sub-millimetre arrays on the southern hemisphere such as the Atacama Large Millimeter Array (ALMA).

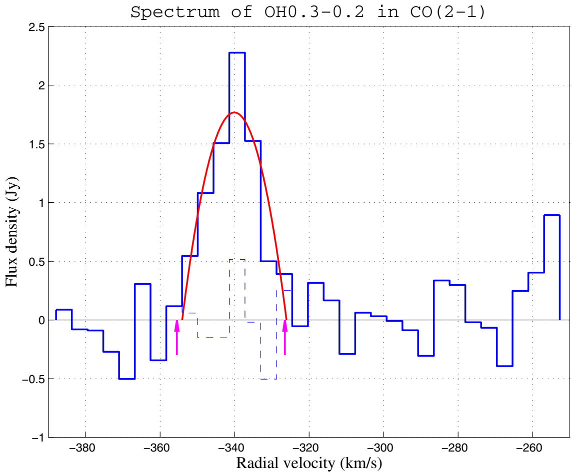

**Figure 1.** Blue solid line: observed spectrum; red solid line: fitted parabola; blue dashed line: observed spectrum minus parabola; arrows: velocities of OH components

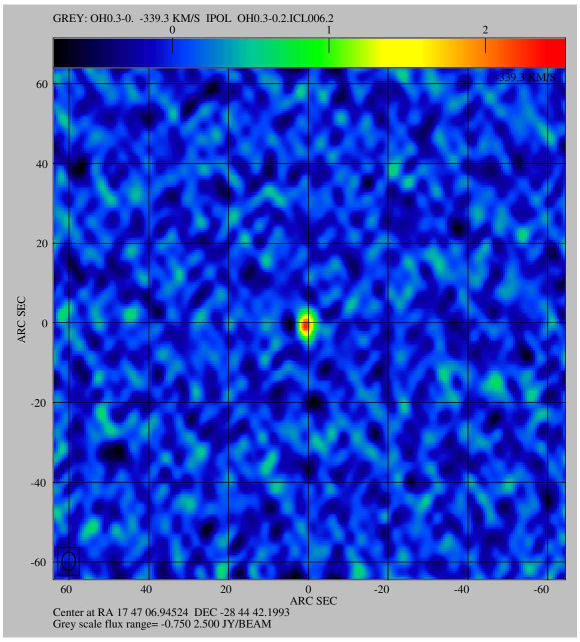

**Figure 2.** Map of OH0.3–0.2 at the 230-GHz CO line maximum. The zero point is at the position of the OH source [3] that has an uncertainty of about 1″.

## 2. Observations

The first observations in this project were done with the 6-element array (NMA) at Nobeyama Radio Observatory, Japan, in November 2003 and January 2004 at 115 GHz (CO 1 − 0). Three OH/IR stars were selected for observations on the basis of strong IR fluxes: OH359.117–0.169, OH359.762+0.120 and OH359.971–0.119. A clear signal was obtained from OH359.971–0.119. The position and radial velocity of the CO line agreed with the corresponding data of the 1612-MHz OH line. However, the line width was too narrow for an unresolved circumstellar CO source.

In June 2005 the same three stars plus the star OH0.3–0.2 were observed using the 8-element array (SMA) on Mauna Kea, Hawaii, at 230 GHz (CO 2 – 1). The spectrometer was configured to give a resolution of 3.25 MHz corresponding to 4.2 $\mathrm{km\,s^{-1}}$. The test star OH0.3–0.2 was detected and showing properties in accordance with the single-dish data (Figures 1 and 2).

Typical resolutions were $4'' \times 7''$ with the NMA and $3'' \times 4''$ with the SMA.

## 3. Data reduction

The *uv* data were investigated for the presence of spatially extended emission by plotting the visibility flux density as a function of projected baseline length. Based on such plots it was decided to exclude baselines shorter than 32.5 m for OH359.762+0.120 and shorter than 39 m for OH359.971–0.119 in order to avoid, as far as reasonable, contamination by residuals of interstellar emission. For OH359.117–0.169 no evidence for significant interstellar emission was found. Unfortunately, no circumstellar emission was found either for this star. No interstellar emission, of course, was found in the IF band of the test source OH0.3–0.2 due to its high radial velocity (–341 $\mathrm{km\,s^{-1}}$).

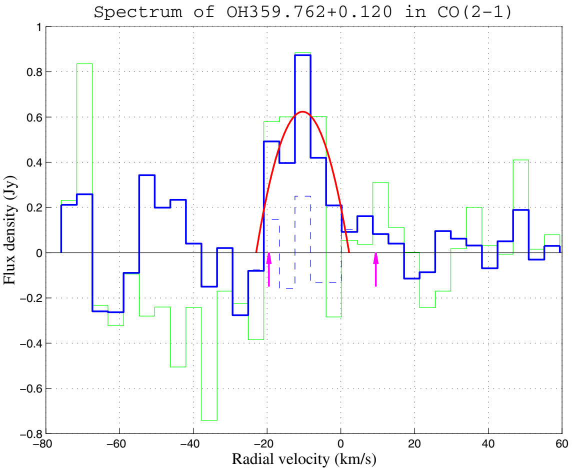

**Figure 3.** Blue solid line, blue dashed line, red solid line and arrows: as in Figure 1. Green solid line: observed spectrum with all projected baseline lengths included.

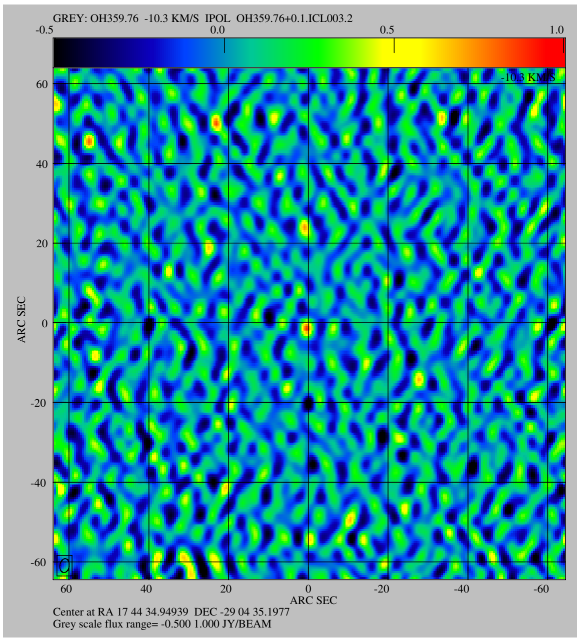

**Figure 4.** Map of OH359.762+0.120 at the 230-GHz CO line maximum. The zero point is at the position of the OH source [4] that has an uncertainty of about $1''$.

Maps were made with $256 \times 256$ pixels of size $0.5''$ with natural weighting. They were cleaned using the standard Högbom/Clark algorithm taking account of the noise fluctuations and the dynamic range of the beam pattern. If a compact source was seen in one of the channels within the OH velocity span at a position close to the phase centre (the position of the OH source) a two-dimensional elliptical Gaussian fit was made of this source and a spectrum was made at the pixel closest to this position.

## 4. Results

In the SMA maps of OH359.762+0.120 and OH359.971–0.119 there are sources close to the phase centres (Figures 4 and 6). The deviations are well within the limits expected on the grounds of OH position errors, CO phase calibration errors and signal-to-noise ratios, i.e. within $1'' - 2''$. In addition the CO lines have frequencies corresponding to radial velocities (LSR) inside the OH velocity ranges. Finally, the detection of OH0.3–0.2 serves as a guarantee of the fact that the instrument worked correctly.

OH359.762+0.120 was detected with a rather poor S/N. Therefore there are quite large errors associated with the elements of the fitted parabola (Figure 3). Within these errors the mean radial velocity of the line and the line width are compatible with the systemic velocity of the star and its envelope expansion velocity as measured from the OH line profile. The impression of skewness of the line is probably not significant. Notice that the exclusion of short baselines did not improve the detection of the line significantly. It merely improved the spectral baseline.

OH359.971–0.119 was detected with moderate to good S/N. However, the CO line is narrow and close to the 'red-shifted' OH line component, i.e. the backside of the envelope (Figure 5). A similar line was observed with the NMA at 115 GHz. Notice that the line profile obtained when all the *uv* data are included (green line) shows a much stronger and broader 'red-shifted' line and even a 'blue-shifted' counterpart. The 'hole' in between these two line components is probably caused by an unresolved 'dip' in the interstellar background.

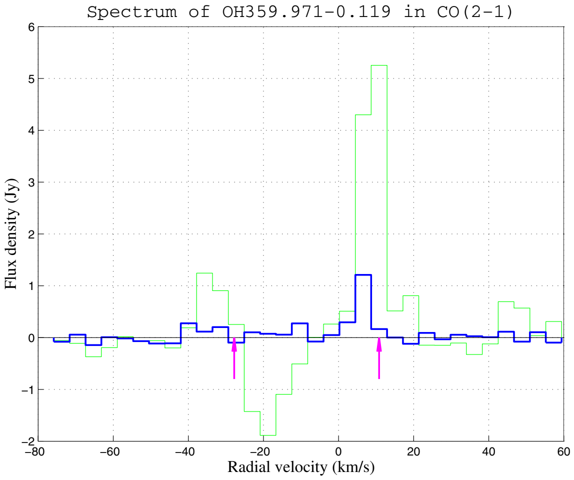

**Figure 5.** Blue solid line, green solid line and arrows: as in Figure 3.

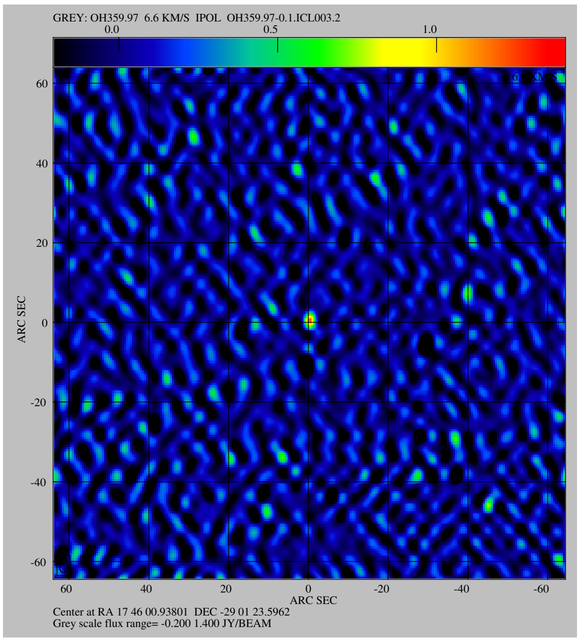

**Figure 6.** Map of OH359.971-0.119 at the 230-GHz CO line maximum, i.e. the strongest channel in the 'blue profile' in Figure 5. The zero point is at the position of the OH source [4] that has an uncertainty of about $1''$.

## 5. Discussion

As to OH359.762+0.120 there is little doubt that the detected CO source is a true circumstellar source. The S/N needs improvement, however.

The CO source associated with OH359.971–0.119 is an enigma so far. The line profile is similar to that expected from a resolved stellar envelope where unresolved sources are left at the front and back sides. For such a picture to be true, the distance needs to be so short that the star would not belong to the Galactic Bulge. For example, assuming that the diameter of the CO envelope is $2 \times 10^{17}$ cm (which might be an overestimate for the $2-1$ transition) and that the angular diameter is $20''$, the distance would be about 700 pc only. The IR properties of this star also are such that it is arguable whether it belongs to the Bulge (cf. [5] and [6]).

Another explanation of the line profile would be that it is the result of strong absorption of interstellar CO in front of the source.

Finally, there is always the (improbable?) explanation that the source is an unresolved remnant of interstellar CO emission that happens to be at the same position and radial velocity as OH359.971–0.119.

## 6. Plans

We have applied for further observations with the SMA. First of all we want to re-observe all the four stars, including OH0.3–0.2, at 345 GHz ($J = 3 - 2$) with the same compact configuration. Secondly we want to observe the stars OH359.762+0.120 and OH359.971–0.119 plus two new stars (OH359.938–0.077 and OH0.319–0.040) that have somewhat higher radial velocities using the SMA in its extended configuration at 230 GHz.

If the sources are interstellar, or circumstellar and extended, we would expect a weak or even undetected 345-GHz line. If they are circumstellar and absorbed (compact or extended) we would expect a less absorbed 345-GHz line. These prospects are based on the facts that the interstellar CO line at 345 GHz is weaker than those at 230 and 115 GHz whereas its circumstellar counterpart is somewhat stronger or at least as strong as the one at 230 GHz. In addition, of course, the SMA resolution is higher at 345 GHz.

The re-observation of OH359.762+0.120 and OH359.971–0.119 at 230 GHz in the extended configuration is motivated by the fact that less data will be wasted by rejection of short baselines. We also want to explore the dependence of radial velocity by observing the stars OH359.938–0.077 and OH0.319–0.040 that have somewhat higher radial velocities (–83.3 and +74.8 $\mathrm{km\,s^{-1}}$, respectively). We expect the interstellar emission to be less of a concern in connection with these stars.

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