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HIGH RESOLUTION OBSERVATIONS OF CO IN PLANETARY NEBULAE

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ABSTRACT In order to examine the structure and kinematics of the molecular gas around planetary nebulae, we have made aperture synthesis observations of $^{12}CO(J=1\text{-}0)$ emission in three planetary nebulae, IRAS 21282+5050, CRL 618 and M 1-7, using Nobeyama Millimeter Array.

INTRODUCTION

Recent CO surveys showed that a number of PNe have CO molecular gas which is thought to be ejected from their progenitor stars in the AGB phase or in the transition phase to PN (e.g., Huggins & Healy 1989). The investigation of the distribution and the velocity structure of the molecular gas around planetary nebulae (PNe) or around proto-planetary nebulae (PPNe) gives us clues in understanding the mass-loss mechanisms in the evolved stars and the subsequent formation and evolution of PNe. Single dish CO mapping observations have been carried out for several PNe (e. g. Bachiller et al., 1989 a,b; Cox et al., 1991; Forveille & Huggins, 1991; Sahai, Wooten & Clegg, 1990,1991). These single dish observations are limited to relatively large PNe because of their angular resolution size (> 15"). Hence, interferometric observation with higher angular resolution has an important role to study rather compact or young nebulae in order to investigate the early phase of planetary nebula evolution.

OBSERVATIONS

We have observed ^{12}CO J=1-0 emission at 115.271 GHz using Nobeyama Millimeter Array (NMA) at Nobeyama Radio Observatory. The observations were made with two or three configurations of five 10 m antennas. We obtained the angular resolutions of 3".2 x 3".1, 3".6 x 3".5 and 4."3 x 3".8 in IRAS 21282+5050, CRL 618 and M 1-7, respectively. The antennas were equipped with SIS receivers, providing a system temperature (SSB) of about 600 K at 115 GHz. The backend was a 1024 channel digital FFT spectrocorrelator. We used a bandwidth of 320 MHz, which gave a total velocity coverage of 833 km s^{-1} and a velocity resolution of 0.81 km s^{-1}. We have observed a point-like continuum source 10 minutes per

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every 30 minutes in order to calibrate the amplitude and phase of obtained data. Continuum maps have made using the line-free visibility channels.

RESULTS

In CRL 618, the CO emission has a size of about 15" x 12" and concentrates to the center of the continuum emission (Fig.1). CO emission extends the north-west to south-east direction at the lower contours. But at the higher contours, it elongates to the east-west direction and has a weak extension which extend to south at the western part of emission. In the velocity channel maps (Fig. 2), the emissions have only one peak and change complexly their feature at each velocities. No systematic trend with velocity can be seen in these maps. We can say that the approximate structure of CO gas in CRL 618 may be spherical. It is considered that the ionized cavity in the molecular gas can not be resolved because of its small size. Though it is in lower S/N ratio, CO emission shows 'horn'-like feature which extend toward the south-east in the blue-shifted velocity in Fig. 2. This horn may reveal a part of CO gas which is affected by a blue component of bipolar flow. We could detect a red high velocity wing of CO(1-0) emission marginally but could not a blue wing. This is partly caused by the absorption of the continuum emission by the high velocity outflow gas. Total flux density of the continuum emission at 115GHz is 1.48 Jy. We may consider all of 1.48Jy comes from a free-free emission of the ionized gas. Our value consist with the cylindrical isothermal ionized gas model with power-law density distribution (Martín-Pintado et al. 1988).

The integrated CO map in M1-7 shows that the CO emission elongates toward a position angle of 60° (perpendicular to the optical major axis) and has a size of about 10" x 20" (Fig. 3). Two emission peaks are shown in both sides of the nebular center. Position-velocity diagrams clearly show the toroidal structure around the minor axis of the optical image and show good correlation with the velocity field of ionized gas derived by Sabbadin et al. (1984). The CO structure of M 1-7 is very similar with that of NGC 2346 (Bachiller et al. 1989). It is suggested that M1-7 is in the earlier evolutionary stage than NGC 2346 and that the ionized gas in M1-7 will develop faster toward the pole of the CO toroid than toward the equatorial direction and then become a bipolar nebula like NGC 2346.

In the case of IRAS 21282, CO emission is elongated to north and south and has a size of about 12" x 17". The emission peaks are seen at north and south sides of the field center on the central-velocity maps (Figure 4, the central velocity of CO line profile is about 18 km s^{-1} in V_{LSR}). The extension of CO emission in channel maps decreases with velocities away from the central velocity and its center in the channel map reveals no systematic displacement. The position-velocity map at the position angle of 0° shows an asymmetric round structure surrounding the star position. We conclude that CO gas forms an expanding toroid whose axis lies along the east-west direction and is normal to the line of sight. Both from the ratio of the size of CO gas to that of ionized gas and from the intensity ratio of [OIII] λ5007 to Hβ, we conclude that IRAS21282+5050 is in earlier evolutionary stage of planetary nebula than NGC 7027 and NGC 2346. The detailed discussions are given in Shibata et al. (1989).

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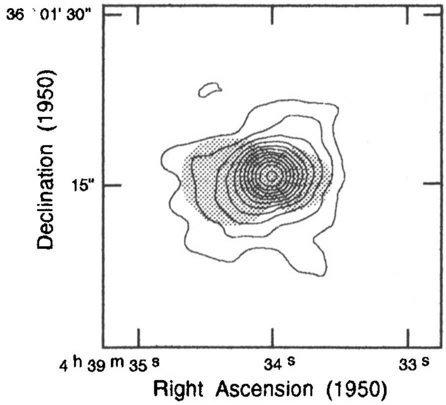

Fig. 1 Integrated intensity map of the 12CO J=1-0 line in CRL 618. The visible bipolar lobes are presented by a hatched region.

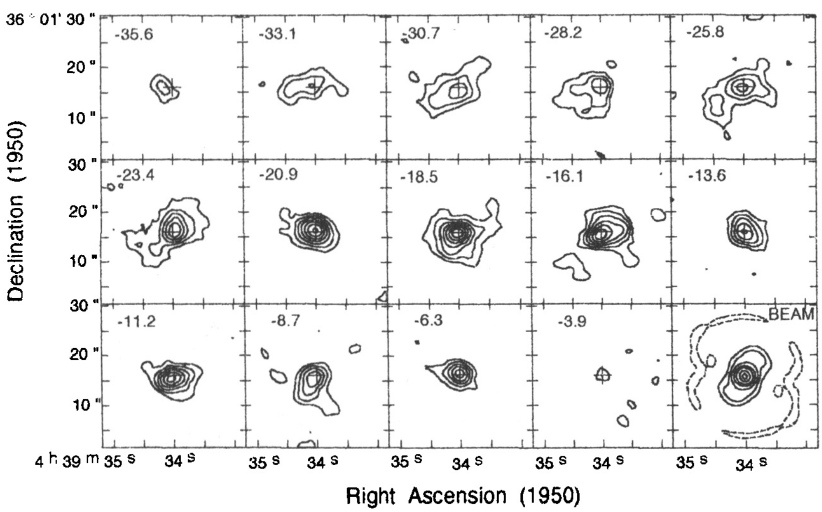

Fig. 2 Velocity channel maps of the ^{12}CO J=1-0 emission in CRL 618. Each map was obtained by 3-channel averaging corresponding to a velocity resolution of 2.4 km s^{-1}. The panels are labeled with the LSR radial velocities. The position of the continuum peak is marked with the cross.

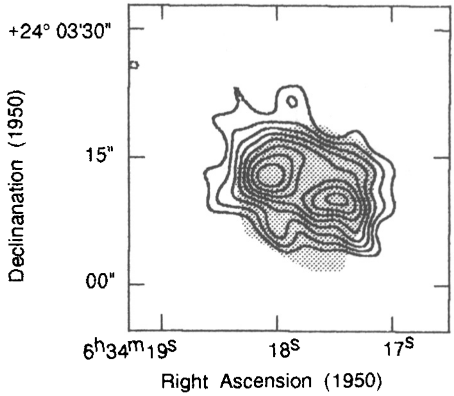

Fig. 3 Integrated intensity map of the ^{12}CO J=1-0 for a velocity range from V_{LSR}= -38 to 15 kms^{-1} in M 1-7. Hatched region presents 5 GHz continuum emission observed with VLA

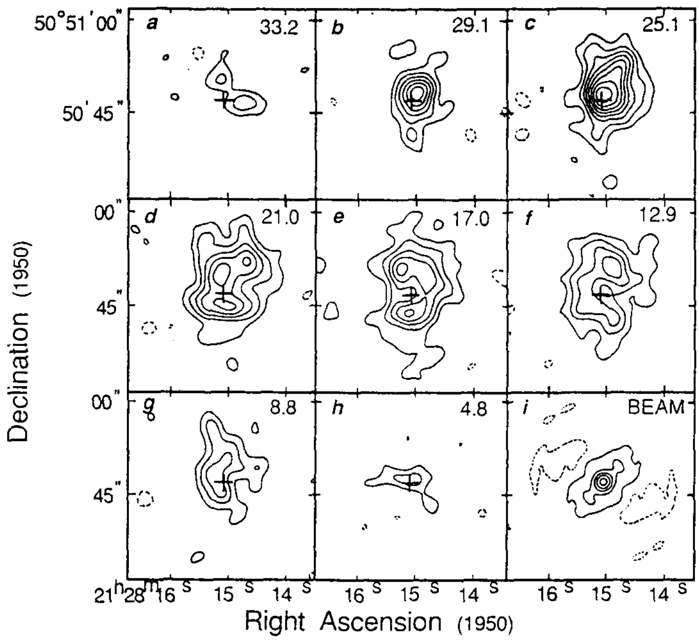

Fig. 4 Velocity channel maps of the ^{12}CO J=1-0 emission in IRAS 21282+5050. Each map was obtained by 5-channel averaging corresponding to a velocity resolution of 4 km s^{-1}. The panels are labeled with the LSR radial velocities. The position of IRAS 21282+5050 is marked with the cross.

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Question

Ishizuki, S. : There may be another idea ; the central gas was ionized after the mass loss and there is no kinematical relation between the central ionized gas and the surrounding molecular gas. Can you deny this idea.

Shibata, K. M. : The comparison between the velocity fields of CO gas and ionized gas (N^+) shows a good correlation in which N^+ gas appears to exist along the inner side of CO toroid or CO cylindrical shell. NGC 2346 shows similar correlation (Bachiller et al. 1989), too. These observational results suggest the existence of the kinematical relation between ionized gas and molecular gas, that is, the surrounding molecular gas obstructs an expansion of ionized gas which is accelerated by a fast wind from the central star and make a complex morphology of visible planetary nebula, and at the same time, the ionized gas pushes the wall of molecular gas. The kinematical relation between the molecular gas and the ionized gas is consistent with the interacting winds model of planetary nebulae formation.

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