

# Mid-Infrared Studies of the Cool Dust Distribution in Bipolar Planetary Nebulae

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**Abstract.** To understand mass loss history and mass loss and dust formation history of massive AGB stars, we carried out observations of three bipolar planetary nebulae (BPNe) in 30 micron bands from a ground-based telescope. All of our targets have a compact strong emission source in the mid-infrared (MIR) around the position of the central star of planetary nebula (CSPN). These detected emissions can be originated from cool dust. Our results show that the cool dust component is compactly distributed and much more massive than previous studies indicated. These findings suggest that they experienced a strong mass loss into the equatorial direction in past.

**Keywords.** Bipolar, mass losing star, planetary nebulae, dust

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## 1. Observation and Results

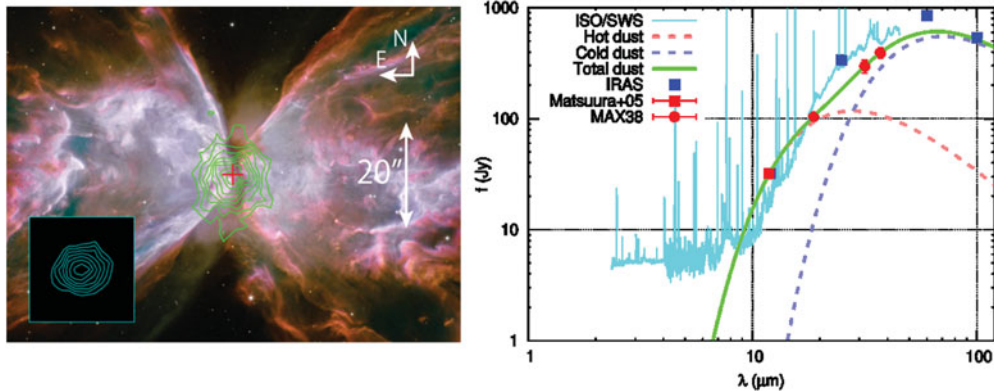
We observed our target BPNe, NGC6302, Mz3, and Hb3, in the 30  $\mu\text{m}$  band from the ground with MAX38 instrument at the miniTAO. MiniTAO is an infrared telescope with a 1 meter primary mirror at the summit of Co. Chajnantor in Atacama Desert, Chile. It is located in the highest astronomical observatory in the world at an altitude of 5,640 m. Thanks to the high altitude and dry weather, Atacama Desert is an extraordinary site especially for MIR observation. MAX38 is an MIR camera for MiniTAO developed by us (Asano *et al.* 2012). It is not only a rare camera covering the 25  $\mu\text{m}$  in the south hemisphere, but also a unique one having a capability of imaging at the 30  $\mu\text{m}$  wavelength range.

These PNe meet two criteria; (1) The declination is less than 30 degree to be accessible from the southern hemisphere, and (2) the MIR flux is bright enough for MAX38, specifically  $> 70$  Jy at 30  $\mu\text{m}$  ( $f_{30}$ ; if previously not observed, estimated by linear-interpolation with the IRAS fluxes at 25 and 60  $\mu\text{m}$ ). Our targets are the brightest PNe in the MIR. Therefore, they are intrinsically luminous, and hence, relatively massive. We selected bright enough PSF and flux reference stars, while three of them (VX Sgr, W Aql, and V1185 Sco) are known as variable stars. According to Schaeidt *et al.* (1996), the ISO fluxes of the reference stars themselves contains calibration errors from 10 to 30%: we adopted the 30%.

Our images are the first images of these PNe obtained in 30  $\mu\text{m}$  in the world. A compact and bright MIR source is seen around the position of the CSPN in all targets. An image of NGC6302 at 31  $\mu\text{m}$  is shown in Fig. 1. We performed gray-body SED fitting

**Table 1.** Results of cool dust component concentrated around CSPN flux, mass, luminosity.

Target	$f_{18}$ [Jy]	$f_{25}$ [Jy]	$f_{31}$ [Jy]	$f_{37}$ [Jy]	$T_{cool}$ [K]	$L_{cool}$ [ $L_{\odot}$ ]	$M_{cool}$ [ $M_{\odot}$ ]	$\dot{M}$ [ $M_{\odot}\text{yr}^{-1}$ ]
NGC6302	100	–	300	390	70	1200	$2.5 \times 10^{-2}$	$0.9 \times 10^{-5}$
Mz 3	45	70	100	–	120	4000	$1.0 \times 10^{-3}$	$1.5 \times 10^{-6}$
Hb 5	55	120	160	–	100	700	$2.2 \times 10^{-3}$	$4.1 \times 10^{-6}$



**Figure 1.** Left: NGC6302 31  $\mu\text{m}$  overlaid image of MAX38 (green contour) on the image of HST visible. PSF image is shown in the small window of left panel. A red cross indicates position of the CSPN. Right: SED of NGC6302. Light blue solid line shows total SED of NGC6302. Green solid line, blue and red dot lines show emission from concentrated dust component.

to estimate the cold dust mass, adopting one or two component dust model with (1) cold dust component at temperature  $T_{cool}$  and (2) hot dust component at temperature  $T_{hot}$ . These results are shown in Table 1. The best fitting model of NGC 6302 is shown in the right panel of Figure 1. Our dust mass estimates revealed that there are much heavier dust around CSPN than previous studies indicated.

The structure of low temperature dust component around CSPN is naturally considered as a compact torus for the following reasons; (1) marginally or not resolved dust component with MAX38 30  $\mu\text{m}$  images indicate a compact structure ( $< 5000$  AU). (2) Bipolar shape of HST images with highly-excited ionized gas suggests a dense equatorial distribution of cold dust. (3) Torus structure of dust explains large covering factor of cold component over CSPN. We also estimated opening angles under the assumptions of optically thick dust torus and no UV absorption in polar directions.

According to Lykou *et al.* (2007), a hot and light dust disk exists around the CSPN. The presence of the cool and geometrically thick dust torus indicates that mass loss took place preferentially in the equatorial direction and that the dust distribution have changed from torus to disk. Assuming well-mixed dust and gas in the torus, the rate of mass loss can be derived from the CO expansion velocity, torus structure, and cold dust mass. Our MIR study in BPNe clearly indicates the existence of massive but compact cold dust torus around the CSPN suggestive of an enhanced mass loss in the past.

## References

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