論文の内容の要旨

論文題目 Mid-Infrared Studies of Cold Dust Distribution in Bipolar Planetary Nebulae

(中間赤外線による双極状惑星状星雲 低温ダスト分布の研究)

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Mass loss process in the final evolutional stage of low mass stars is quite important to understand not only the cycle of matters in the Universe but also their stellar evolution. Classically it is believed to expand isotopically and form spherical symmetric shells. However bipolar planetary nebulae cannot be explained by the classical, isotropic mass loss. One possible explanation proposed is that pair expanding bubbles is made by the interaction between fast wind and a dense circumstellar torus in the equatorial plane (GISW model). The GISW model naturally explains the origin of the bipolar lobes, but it does not address the origin of the equatorial disk or torus at all.

To investigate the equatorial disk or torus in detail, longer mid-infrared observations with sufficient spatial resolution are absolutely essential. We have carried out mid-infrared observations of three bipolar Planetary Nebulae, NGC6302, Mz3, Hb5. These are very famous planetary nebulae and very bright objects at the mid-infrared wavelengths.

A new mid-infrared camera MAX38 developed by ourselves has been used for this study. It was attached on the miniTAO 1.0 meter telescope at the summit of Co.Chajnantor, which is the highest astronomical site in the world. Thanks to high altitude of 5,640m and dry weather condition, we can access the 30 micron wavelength range from the ground.

Mid-infrared images of the Planetary Nebulae at 18, 25, 31, and 37 micron have been successfully obtained. These are the first spatially resolved images of the Planetary Nebulae at the wavelengths longer than 30 micron. The images of NGC6302 show the extended structure, and the detailed characteristics are varied with the wavelengths. The peak is located at eastside of the center at 18.7 micron, at almost center at 31.7 micron, and at western-south side at 37.2 micron. This may be explained by the extinction effect of the dense dusty torus. The mid-infrared images of Mz3 consist of three components, a central bright core and filamentary extended structures in the north and the south. These structures are quite similar to the bipolar planetary nebulae seen in the visible image. On the contrary, the images of Hb5 seems very compact and not to be extended at shorter than 25 micron. These are the first images of Hb5 at the mid-infrared wavelength range with a spatial resolution higher than 8 arcsecond.

It is a surprising result that the unexpected bright 30 micron source has been detected at the center of the nebulae. It suggests cold dust component exists close to the central star. The mass of the cold dust component has been estimated with the simple model. The estimated dust masses of NGC6302, Mz3, and Hb5 are 2.5×10^{-2}, 2.2×10^{-3}, and 1.0×10^{-3} $M_{\odot}$, respectively. These are 1 - 100 times larger than the dust mass estimated in previous studies. The morphological structure of the cold dust component has been estimated based on the ratio of the luminosity of the central star and the cold dust. It suggests that there are geometrical thick tori with the opening angle of 50, 20, and 26 degree for NGC6302, Mz3, and Hb5 on the equatorial plane respectively.

In addition, the tori seem to be very compact even in the 30 micron images. This may be interpreted with two possibilities. One is the optical thickness. In this case, inner warm region which mainly absorbs the stellar radiation should be completely obscured by the outer cold torus, because there are no warm components in the spectral energy distribution. This requires that the outer torus is optically thick even at the shorter side of mid-infrared wavelengths. Furthermore the inner region needs to have almost the same opening angle as the outer torus. The other possibility is dust grain growth in the torus. Since larger dust grains have relatively low emissivity, the thermally balanced temperature is lower than the smaller dust if they receive the same input radiation.

These results give the constraints on the structure of the dusty torus and provide important information to understand the strong mass loss on the equatorial plane.

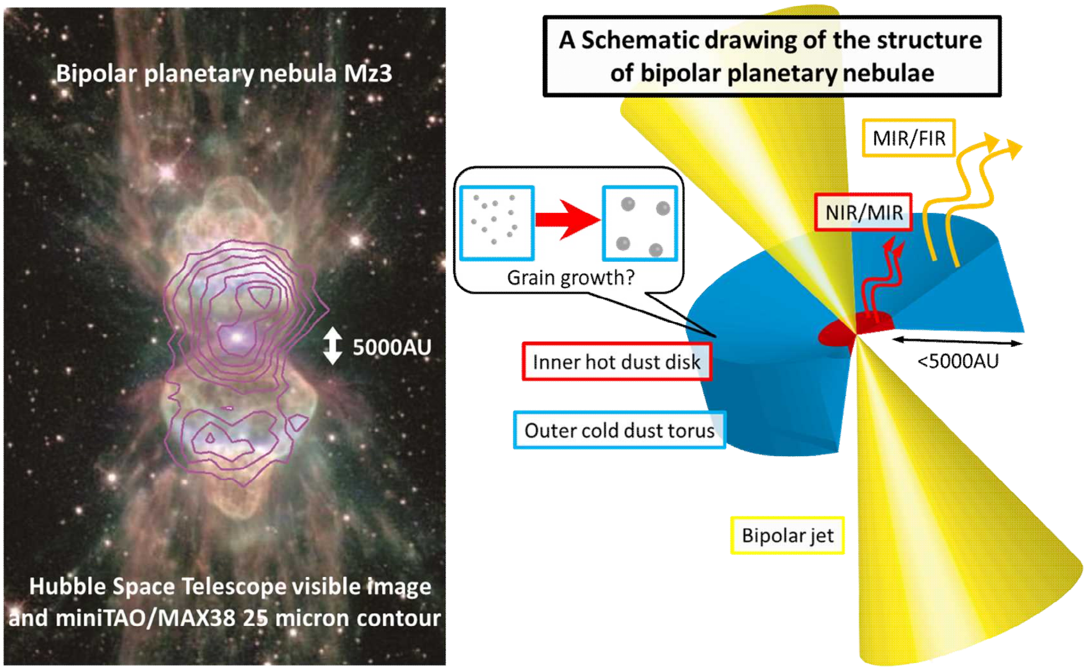

Figure 1.1: Contour map of our image of bipolar PN Mz3 at 25 micron overlying the image at visible obtained of Hubble Space Telescope in a left panel. A schematic drawing of the central region structure of bipolar planetary nebulae is shown in a right panel.