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Thermal and Density Structures and Elemental Abundances in the Bipolar PN Mz 3

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1. Introduction

Mz 3 is a young bipolar planetary nebula (PN) with lobes extending over $\sim$ 50 arcsec on the sky. It consists of a bright core, two approximately spherical bipolar lobes and two outer large filamentary bipolar nebulae. The salient features of Mz 3 are more easily studied than other bipolar nebula because of its large angular extent. It is very bright in the far-infrared. There is an extended shell of warm dust surrounding the central star. And the bipolar lobes are filled with hot ionized gas. Cohen et al. (1978) found that Mz 3 is He-rich. Based on the LWS observations of the far-IR fine-structure lines, Liu et al. (2001) derived a high N/O ratio in Mz 3 and identified the bipolar nebula as a Type-I PN.

We have obtained high-resolution, deep optical long-slit spectrum of Mz 3, covering the wavelength range from 3420–7400 Å. Over two hundred emission lines have been detected, many of them are permitted and forbidden transitions from ionized iron. The spectra have been used to study the nebular thermal and density structures and elemental abundances. The bright central emission core, where the prominent [Fe III] emission originates, is found to be of very high density, with physical conditions vastly different from those prevailing in the surrounding low density nebular regions. The presence of this dense significantly affects the derivation of elemental abundances in this nebula.

2. Observation and Data Reduction

The data were obtained with the ESO 1.52 m telescope using the B&C spectrograph. The slit was orientated north-south (PA= 0°), roughly along the nebular major axis, and through the central star. The spectra were reduced using the LONG92 package in MIDAS following the standard procedure. The nebula was divided into two zones which were analyzed separately: a) A core emission region between $r < 4$ arcsec; b) An extended emission region consistent of the two bright inner lobes on either side the central star between $4 < r < 15$ arcsec.

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3. Result and Discussion

The very rich and prominent [Fe III] emission lines detected in the Mz 3 spectrum provide powerful diagnostic tools to determine the physical conditions in the central emitting regions. We find that all the observed [Fe III] diagnostic line ratios yield a temperature of T_e =11 000 K and an electron density of $\log N_e$ = 6.5 (cm^{-3}). The value of density is close the densities where the ratios of these [Fe III] diagnostic lines are most sensitive to density variations, suggesting that the actual densities in the bright central emission core of Mz 3 could be even higher. In contrast, all the other standard nebular forbidden line density- and temperature-diagnostics, all of them have lower critical densities than the [Fe III] lines and are therefore only useful at densities $\lesssim 10^6\,cm^{-3}$, yield consistently lower electron densities, with the resultant values correlated with the critical densities of the diagnostic lines involved. This indicates that the central dense emission core has a highly stratified density structure where forbidden lines of relatively low critical densities are collisionally suppressed in the high-density regions. Given the large uncertainties in the electron temperature and density in the central dense core, no reliable ionic and total element abundances can be determined using the empirical method, except for possibly that of iron, for which we find a value of $\sim$ half the solar abundance.

In contrast, the emission region of the extended bright bipolar lobes of Mz 3 is well represented by a mean electron temperature of 6600 K and an electron density of 6300 cm^{-3}. The element abundances derived for this region, on a logarithmic scale where H = 12, are He = 10.93, C = 8.41, N = 8.37, O = 8.50, Ne = 7.64, S = 7.15, Cl = 5.27 and Ar = 7.14. In all the cases, the abundances are close to the average values deduced for Galactic PNe. In particular, there is no evidence of He enrichment in Mz 3, as claimed in previous studies, and its N/O abundance ratio is only moderately higher than the solar value. In the previous abundance studies of Mz 3, due to the contamination of emission from the dense central core, the average electron temperature in Mz 3 was significantly overestimated, resulting grossly underestimated elemental abundances.

The electron temperature in the central emission core is significantly higher than the value found for the extended bipolar lobes, suggesting that, apart from photoionization, shock waves might also play an active role in heating the central dense region. This is supported by a spatial analysis of our long slit spectrum and is consistent with the evidence from the previous kinematic studies.

A possible model that can account for the observed features of Mz 3 is that the bipolar nebula is a binary system — consisting of a hot white dwarf and a Mira with high N/O abundance ratio (Schmeja & Kimeswenger 2001). The extended lobes were created by mass loss from the current hot white dwarf, where the dense emission core could be produced by mass outflow from the Mira which is accreted by the white dwarf, forming a dense disk surrounding it.

References

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