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Search for variability in the kinematics of the ionized circumstellar region of M2–9

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In our previous study of M2–9 we found that the radial velocities of the forbidden lines of the ionized species in the nuclear spectra show a negative gradient which correlates with density, electron temperature and electron pressure. The size of the ionized region is relatively small and the travel time with the observed velocities is of order of decades. In an attempt to reveal the nature of the unusual velocity gradient, we present second epoch observational spectral data of the nucleus of M2–9.

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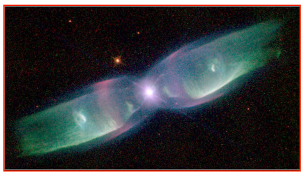


Abstract

In our previous study of M2-9 we found that the radial velocities of the forbidden lines of ionized species in the nuclear spectra show a negative gradient which correlates with density, electron temperature and electron pressure (Torres-Peimbert et al. 2010). The size of the ionized region is relatively small and the travel time with the observed velocities if of order of decades. In an attempt to reveal the nature of the unusual velocity gradient, we present second epoch obseravational spectral data of the nucleus of M2-9.

Observations

The observations were performed at the 2.1-m telescope of the Observatorio Astronómico Nacional in San Pedro Mártir with the REOSC echelle spectrograph. We have secured long exposures centered on the star. The spatial scale along the slit is 0.99"/pixel, while the velocity resolution is of 10 km/sec/pixel. In each case we have extracted individual spectra along the slit with extraction windows 10 pixels wide. The data analyzed were obtained in 12/08/2003 and compared to those secured in 25/04/1996 with the same instrument.

M2-9

M2-9 is an very interesting proto-planetary nebulae of extreme bipolar morphology with dusty lobes and a very complex nuclear spectrum.

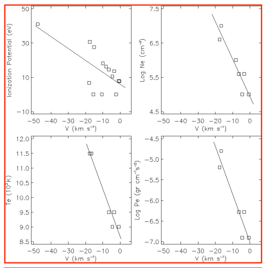
Nuclear Spectrum

It shows nebular lines in emission over a weak continuum. No absorption lines have been observed, therefore the determination of its stellar spectral type is very uncertain. It has been proposed that the nucleus is composed of a binary system: a hot component that ionizes the O++ gas and a B5 star that contributes to its visible luminosity (Calvet & Cohen 1978). Also Schwarz et al. (1997) suggest that a compact but hot component must be present where the hot component ionizes the high excitation emission lines, while the B5 (or cooler) star provides part of the luminosity.

The forbidden emission lines in the core present negative velocities (including [O III] that has a complex profile). That is, we are only observing the approaching side of the core, and presumably there is obscuring material that does not allow us to see the receding part.

From the [S II] and [N II] narrow filter HST observations it is found that in these ions the region has an extended morphology in the equatorial direction. It is here proposed that this extended region is the one that emits with these peculiar characteristics.

The upper limit to the size of the ionized region is that of the [S II] emission region in the HST image (~1.5arcsec in diameter) which to a distance of 650 pc corresponds to 490 AU in radius. We can estimate that the more internal emission zones (for example [O III]) are located at about 170~AU from the exciting star. If these assumptions are valid, the extended emitting zone located in the direction of the equator is composed of expanding material.



Behavior of physical conditions relative to the observed radial velocity in M~2-9. On the upper left panel the velocity dependence on ionization potential is shown for those forbidden species where more than one line was measured. On the lower left panel, the electron temperature is presented; on the upper right panel, the electron density; and on the lower right panel, the electron pressure. The velocities are given relative to the systemic velocity. Solid lines indicate best linear fit to the data.

Circumstellar torus

We have proposed that the optical emission lines are produced in an inner extension of the molecular torus located very close to the star, which extends to large enough distances to pinch the waist of the lobes.

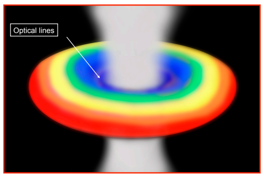
In our scheme the optical emission lines are produced in the inner regions of the torus that is surrounding the central star. The high ionization species are located in the innermost region where the gas is being shocked by the fast wind, and the less ionized species in the external part. The expansion rate of the neutral species is consistent with the low velocity of the CO torus.

This scenario corresponds to a very extended torus where the inner region is producing the optical emission lines and the radio continuum emission (Kwok et al. 1985), followed by a warm H_2 component (Smith et al. 2005), that merges into a CO torus (Zweigle et al. 1997), altogether forming a warm dusty torus at 260 K (Smith & Gehrz 2005).

In principle, this scenario is in agreement to the wind interaction models (Mellema 1993; Franco et al. 1990) at very close distance to the central star, and compatible with the radio continuum spectral index that agrees with mass loss from the central star.

The size of the circumstellar structure is so small and the characteristic times are relatively short (for a structure 490 AU radius the crossing time from the central star outwards at a velocity of 30 km sec^{-1} is of 80 years, and at the same velocity the distance from the inner border to the outer edge of the ionized region can be reached in 53 years).

Furthermore, we suggest that the cores of the group of pinched waist planetary nebulae should be studied spectroscopically to find out if the emission line kinematics extends to all of them, and if that is the case, to monitor their behavior in time.



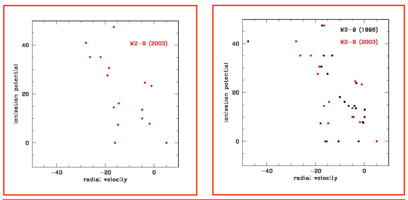
Cartoon of the circumstellar torus.

Possible variations in time

Thus it was considered of interest to monitor the kinematic behavior of the emission lines, for any possible changes in timescales of decades. Furthermore, we suggest that the group of pinched waist planetary nebulae should be investigated to find out if this behavior extends to all of them.

Conclusions

With our present data of 7 years interval no significant variations in kinematics were found. We will continue to monitor this object to try to ascertain whether it presents any changes in kinematical behavior.



Comparison of kinematic behavior of circumstellar optical emission lines of epoch 1996 and 2003. Wtihin our uncertainties we do not find any significant difference in behavior.

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