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SPECTROPOLARIMETRY OF THE BIPOLAR PLANETARY NEBULA M2-9

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RESUMEN

Investigamos la naturaleza de N2, una de las condensaciones más brillantes, observada en los lóbulos de M2-9, una nebulosa proto-planetaria. Estas condensaciones han mostrado un cambio notable en sus posiciones Este-Oeste durante los pasados 40 años y su origen todavía no está bien entendido. Usamos la técnica de espectro-polarimetría óptica para separar la combinación de espectros reflejados y emitidos localmente, presentes en los lóbulos de M2-9, con el fin de derivar las condiciones locales físicas en la condensación N2 y en la nebulosa adyacente.

ABSTRACT

We investigate the nature of one of the brightness enhancements or knots, N2, observed in the lobes of M2-9, a proto-planetary nebula. These knots have exhibited a remarkable change in their E-W positions over the past 40 years and their origin is still not well understood. We use the technique of optical spectropolarimetry to separate the combination of reflected and locally emitted spectra present in the lobes of M2-9 in order to derive the local physical conditions in the knot N2 and adjacent nebula.

Key words: **PLANETARY NEBULAE: INDIVIDUAL (M2-9) — TECHNIQUES: POLARIMETRIC**

1. INTRODUCTION

M2-9 has been classified as a bipolar or butterfly proto-planetary nebula, an object undergoing the transition between the last stages of red giant evolution and the development of a planetary nebula. The nebula consists of symmetric bipolar lobes which extend 20" north and south of a bright, centrally condensed nucleus. These lobes contain brightness enhancements or knots which have shown large changes in their E-W positions on the timescale of decades. Allen & Swings (1972) discovered that between 1952 and 1971 the knots traveled from the western edge of M2-9 to the opposite side of the nebula implying a proper motion of 5" in 25 years. Van den Bergh (1974) studied M2-9 in 1973 and found that while the large scale positions of knots were the same as in 1971, there were noticeable small scale changes in the knots themselves. He suggested that the lobes of M2-9 are photoionized by beams of UV radiation produced by a hot central object that move across the face of the nebula. Based on this idea, Goodrich (1991a) proposed that as these beams of radiation moved from west to east across the nebula, they would leave behind an observable trail of recombining gas. Ions with short recombination times would only be present in or very near the knot, i.e., the location of current photoionization, while ions with long recombination times would be present throughout the recombination tail. He used longslit spectroscopy to observationally explore the feasibility of this idea. He employed an E-W slit cutting across nebula at the level of the knot N2 and found that the ionization state of the gas decreased off the knot and that overall the line ratios qualitatively agreed with the model of a recombination tail. However, [SII]$\lambda\lambda$6717,31 and [NII]$\lambda\lambda$ 6548,83, which have very short recombination times, were present across the entire nebular cut. Goodrich noted a possible problem with the interpretation of his spectroscopy in that previous polarimetry of M2-9 (e.g. Schmidt & Cohen 1981) revealed that the lobes are highly polarized. Goodrich suggested that the recombination tail spectrum that he observed might be contaminated by reflected light. We use the technique of spectropolarimetry to separate the reflected and locally produced spectra thereby eliminating this problem for our data. We then derive the physical parameters relevant to N2 and the adjacent nebula in order to test the validity of Goodrich's recombination tail model.

2. SPECTROPOLARIMETRY: DISENTANGLING FACT AND FICTION

The observed spectra of M2-9 are actually a complicated superposition of reflected and locally emitted radiation. These hybrid spectra do not accurately describe the local conditions of the lobes and knot. Spectropolarimetry, the combination of polarimetry and spectroscopy, allows the accurate determination of the polarization as a function of wavelength. With this information it is possible to separate the locally emitted and scattered radiation present in the lobes of M2-9. The observations were obtained with the McDonald Observatory 2.7 m telescope and spectropolarimeter (Goodrich 1991b) in June 1991. The detector was an 800 x 800 TI CCD with 15mm pixels binned 1 x 2 (dispersion x spatial) providing a spatial scale of 1.27 arcsec pixel^{-1}. All spectra have a resolution of 3.4 Å pixel^{-1} and were taken using a slit width of 2" and a slit length of 35". We placed our slit in the same position as Goodrich (1991a) so that it contained the N2 knot and the adjacent nebula at the same N-S level. We then divided this cut across the nebula into 5 adjacent sections each 2.54" in extent. The first position contains the knot, N2, while four off-knot positions sample the recombination tail proposed by Goodrich. Following the method outlined in Trammell et al. (1993), we have separated the total flux into its two components, the scattered and unscattered fluxes. Figures 1 and 2 show the resulting spectra for the knot N2 and the off-knot position 4.

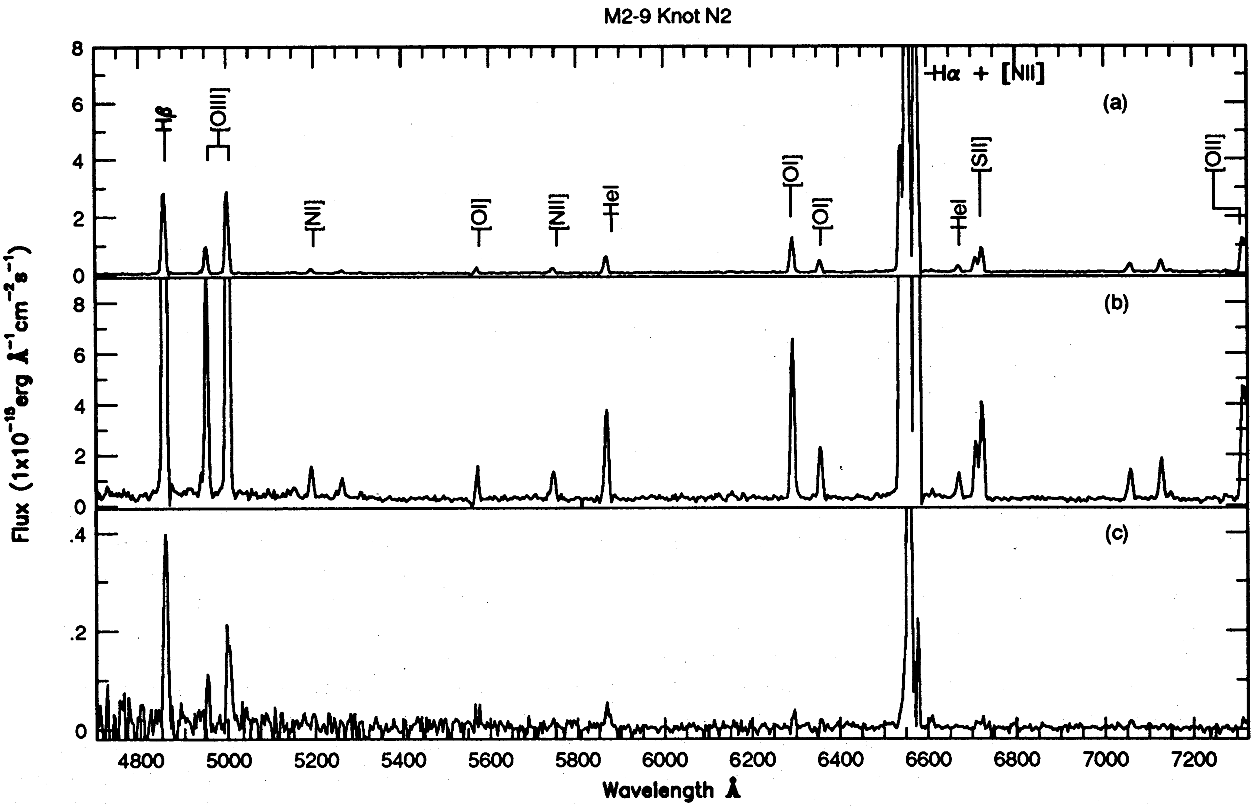

Fig. 1. (a) The total flux spectrum of the N2 knot. (b) The unscattered flux spectrum of N2. (c) The scattered flux spectrum of N2.

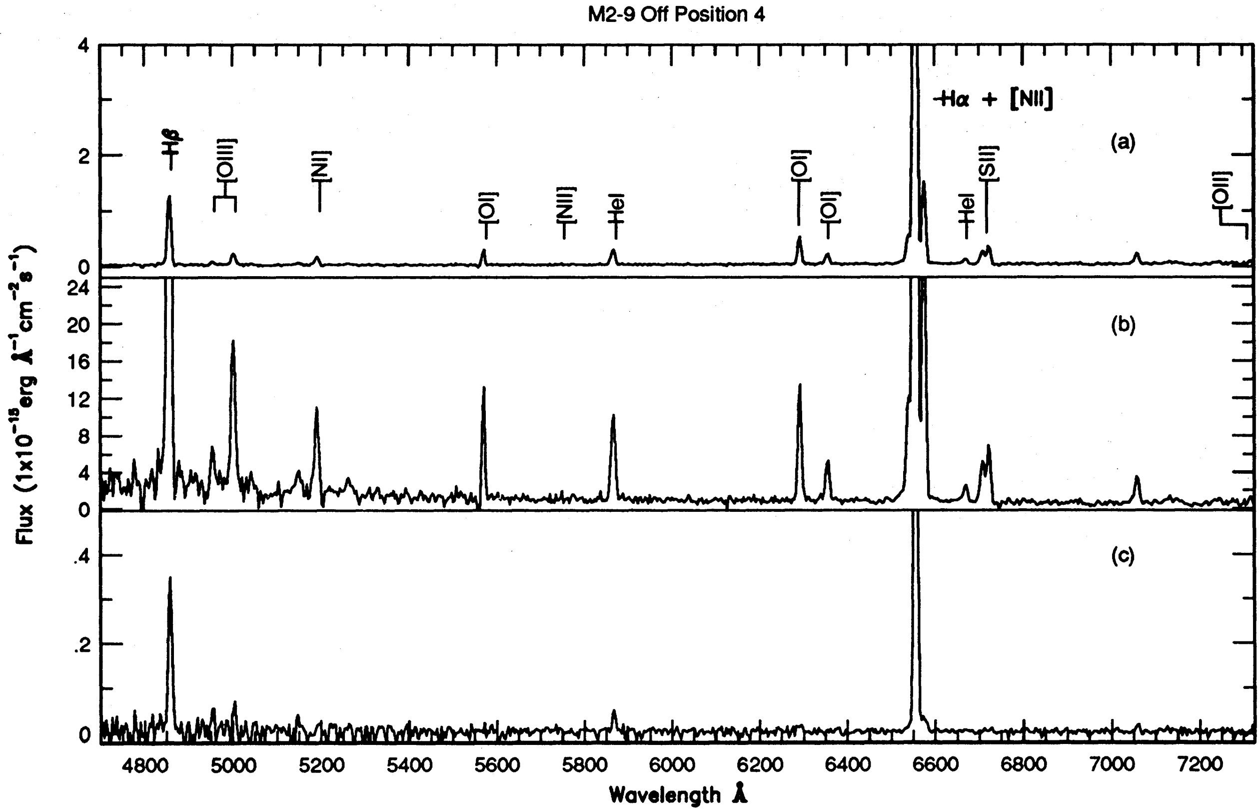

Fig. 2. (a) The total flux spectrum of the off-knot position 4. (b) The unscattered flux spectrum of the off-knot position 4. (c) The scattered flux spectrum of the off-knot position 4.

Table 1 : Electron Temperature vs Position

Position	T_e (K)
N2	9800 ± 1000
off position 1	9800 ± 1000
off position 2	8050 ± 1000
off position 3	≥ 7612
off position 4	≥ 8514

3. RESULTS

Our results do not support Goodrich's recombination tail model. The unscattered spectra (panel b in both Figs. 1 and 2), show that the level of excitation decreases away from the knot, consistent with a recombination tail as proposed by Goodrich. However, we see that [SII] and [NII] are present at position 4, as well [OII] and [OIII], even though all of these ions have very short recombination times. We have now isolated the local emission and can not attribute this discrepancy to contamination of the recombination tail spectrum by a reflected line spectrum. More importantly, for a recombination tail model, one would expect the electron temperature to decrease as the distance from the knot increased. Instead we find that the temperature inferred form the locally emitted [NII]$\lambda\lambda$5755,6548+6583 lines is constant across our entire nebular cut (see Table 1). Therefore, we propose an alternative explanation for the difference in the knot and off-knot spectra. At the position of N2 the nebula is photoionized by a relatively unobscured spectrum produced by the central object. At positions off the knot this same spectrum is attenuated by dust in the inner regions of M2-9, resulting in a lower excitation spectrum at the off-knot positions. We are currently investigating this idea more thoroughly by using the photoionization code CLOUDY (Ferland, 1993) to predict the line ratios as a function of position using attenuated ionizing continua.

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