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Research Note

Discovery of a Large, High-excitation Planetary Nebula at $l = 136°$, $b = +5°$

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Summary. The discovery of a new planetary nebula from [O III] interference-filter imagery is reported. The nebula, 136 + 5°.1, is 15′ in diameter and asymmetric in appearance. Spectrophotometry of the central regions indicate it is of excitation class of 8–10. A single bright condensation within the nebula exhibits emission lines of much lower ionization with [S II] λλ 6717, 6731 line intensities indicating an electron density of about 350 ± 150 cm^{-3}. High resolution [O III] imagery of this planetary nebula is also presented.

Key words: new planetary nebula

I. Introduction

The emission-line survey of the galactic plane by Parker et al. (1979; PGK) has proven valuable in detecting faint nebulosities that exhibit strong [O III] λ 5007 relative to their Hα, [N II], and [S II] emissions. The [O III] images in this survey have revealed the optical structures of the supernova remnants G 65.3 + 5.7 (Gull et al., 1977), G 126.2 + 1.6 (Blair et al., 1980), and CTA 1 (Fesen et al., 1981) as well as several new ring nebulae around Wolf-Rayet stars (Heckathorn et al., 1982). Here we report the discovery of an asymmetric nebulosity which is bright in [O III] emission and is centered at $\alpha = 02^h59^m35^s$ and $\delta = +64°44'$ (1950). Although 15′ in diameter, this nebula escaped previous attention, probably due to its very faint appearance on the Palomar Sky Survey (PSS). It is not catalogued as a planetary nebula (Perek and Kohoutek, 1967: Kohoutek, 1977; Weinberger, 1977), H II region (Sharpless, 1959; Marsalkova, 1974) or supernova remnant (Clark and Caswell, 1976; van den Bergh, 1978). No known O star (Goy, 1973; Garmany et al., 1982), Wolf-Rayet star (van der Hucht et al., 1981), variable star (Ochsenbein et al., 1981), Be star (Wackerling, 1970), or white dwarf (McCook and Sion, 1977) is known within the boundaries of this nebula. Radio surveys have also not detected a source at this position (Gower et al., 1967; Fanti et al., 1974; Caswell, 1976).

In this paper we present spectrophotometry and deep [O III] images from which we conclude that this object is a very large, old, high excitation planetary nebula. We designate this new planetary nebula 136 + 5°.1 following the system of Perek and Kohoutek (1967).

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II. Observations

a) Imagery

The nebula was discovered on the [O III] plate of the PGK survey for the field $l = 135°.5$ and $b = +5°$ (see Fig. 1). It is also faintly visible on their Hα + [N II] λ 6570 plate, but not detectable on their [S II] λ 6730 or Hβ plates. The PGK survey was obtained using a special wide-angle telescope consisting of narrow-passband interference filters mounted in front of a 300 mm *f*/2.8 Nikkor lens coupled to a two-stage Carnegie Image Tube intensifier (CIT). The [O III] filter had a peak transmission of 60% at 5010 Å and a bandpass of 28 Å (FWHM). Angular resolution was about one-half arc min. Additional properties of the survey are given in PGK.

We obtained follow-up, high-angular resolution [O III] images of this nebula in October 1981 with the No. 1 −0.9 m telescope at Kitt Peak and the same CIT used by PGK. The resolution of this camera-telescope system was nearly seeing-limited at about 2″ with a field diameter of 17′. The [O III] filter used by us had a peak transmission of 73% at 5009 Å and a bandpass of 22 Å (FWHM). The intensifier output was recorded on IIIa-J plates hypersensitized by baking in forming-gas. Exposure times varied from 60 to 90 min. Complete coverage of the object required three plates, which have been used to create the mosaic shown in Fig. 2.

b) Spectrophotometry

Spectrophotometry of the nebula's diffuse central [O III] region and of a conspicuously bright, eastern condensation visible in Fig. 2, was obtained using the No. 1 −0.9 m telescope with the Intensified Reticon Scanner (IRS). This instrument has a dual reticon array which samples through two east-west apertures that are centered 60″ apart. The brightest central region was measured twice, first with 22″ diameter apertures covering the range 3700–5100 Å with 8 Å (FWHM) resolution, and later with a 14″ × 36″ rectangular aperture covering 3700–7000 Å with 13 Å (FWHM) resolution. Sky measurements were taken at positions well outside the nebula. For both measurements of the central region, the spectra through the two apertures were very similar and were added together to increase the signal-to-noise.

The data for the emission knot was obtained using 14″ circular apertures and covered the spectral range 4500–7500 Å with 13 Å (FWHM) resolution. We attempted to obtain the emission from only the knot by subtracting from its spectrum the spectrum of the nebula taken 60″ east and west of the knot.

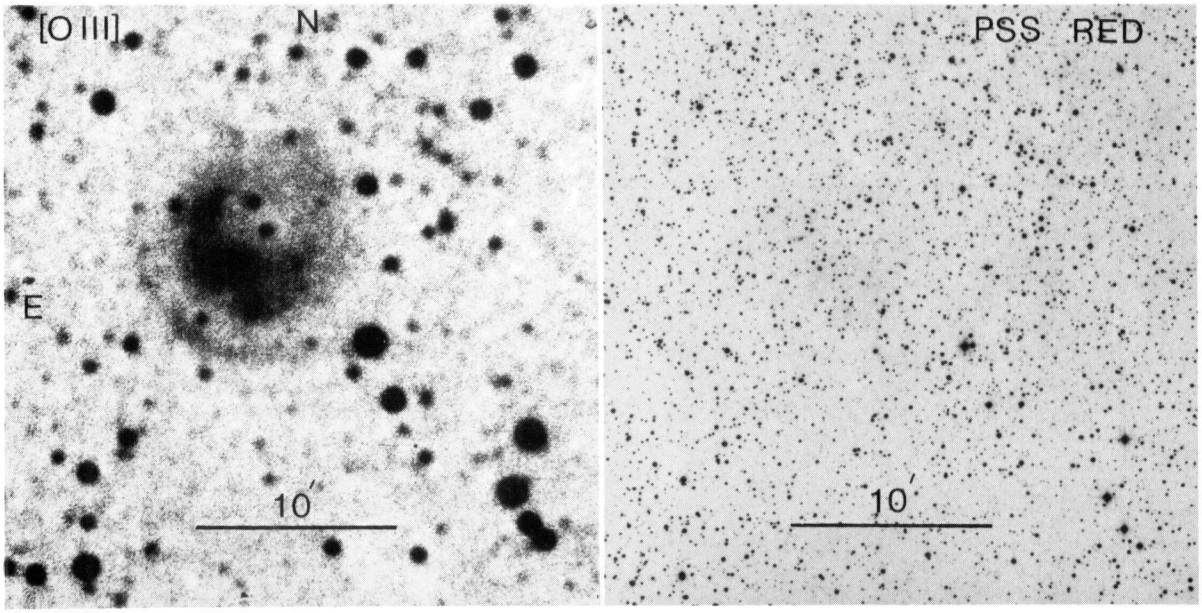

Fig. 1. Comparison of 136+5°1 on the [O III] λ 5007 plate from the PGK Survey to the Palomar Sky Survey red print. The nebula is very bright in [O III] emission but is barely detectable on the PSS red print which is primarily sensitive to Hα+[N II]

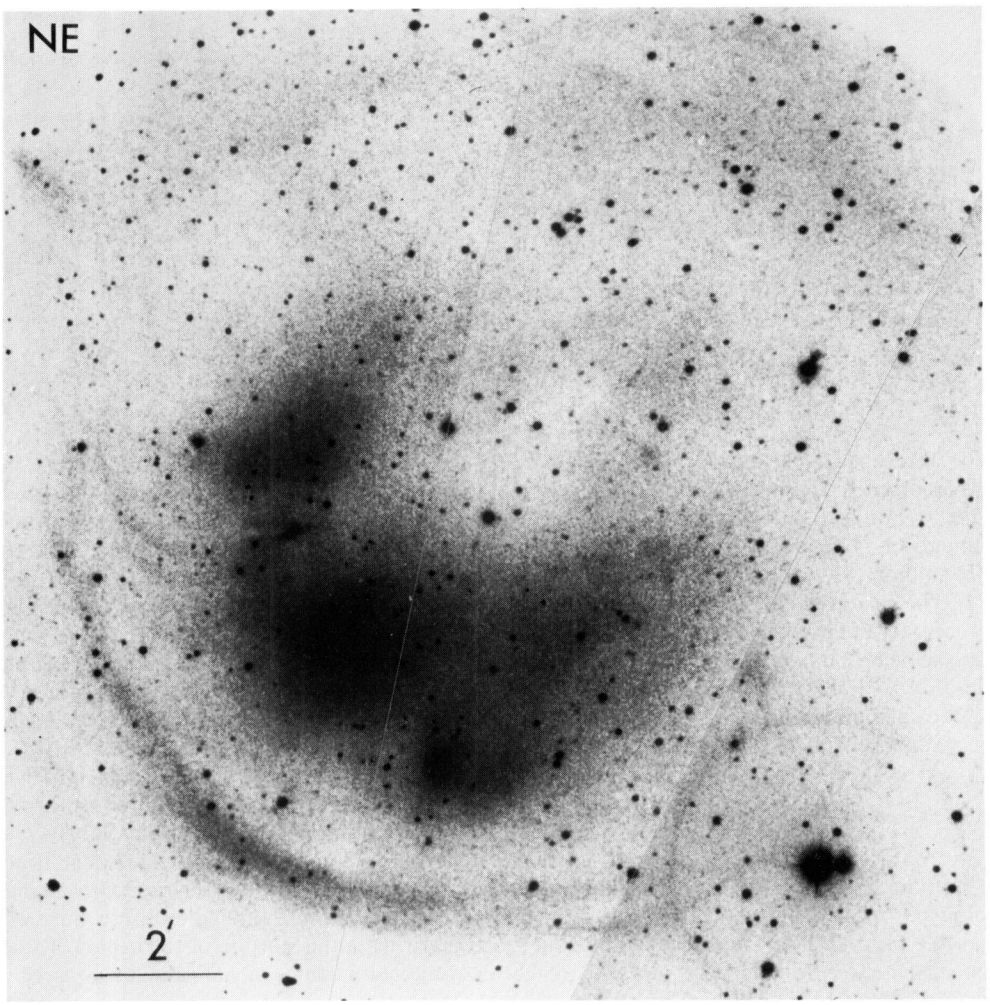

Fig. 2. A mosaic of three high-resolution [O III] plates showing 136+5°1 in detail. Three diffuse emission regions are interior to the outer ring structure, and a bright knot is east of center. Faint diffuse patches of emission to the west and southwest of center are instrumental

Table 1. Relative emission-line intensities ($I_{H\beta}=100$)

		Position 1		Position 2		Knot	
ID	Å	$F(\lambda)$	$I(\lambda)$	$F(\lambda)$	$I(\lambda)$	$F(\lambda)$	$I(\lambda)$
[O II]	3727	<100	<140	< 120	< 170	—	—
Hγ	4340	(65)	(78)	—	—	—	—
He II	4686	110	117	75	80	—	—
Hβ	4861	100	100	100	100	100	100
[O III]	4959	280	270	400	390	160	154
[O III]	5007	770	740	1250	1200	540	510
He I	5876	—	—	—	—	(30)	(22)
[O I]	6300	—	—	—	—	170	110
[O I]	6364	—	—	—	—	(70)	(45)
[N II]	6548	—	—	—	—	330	200
Hα	6563	—	—	435	290	475	290
[N II]	6583	—	—	< 50	< 35	990	630
[S II]	6717	—	—	—	—	165	98
[S II]	6731	—	—	—	—	140	83
$E(B-V)$		a		0.38		0.46	
$F_{H\beta}$ [b]		$1\ 10^{-6}$		$2.5\ 10^{-6}$		$4\ 10^{-5}$	

[a] Assumed equal to 0.38
[b] erg s^{-1} cm^{-2} $strad^{-1}$
( ) Indicates significantly more uncertain values

Integration times of 2400 s and 3200 s were made on the central region with 6400 s taken on the bright emission knot. The data were corrected for atmospheric extinction, sky-subtracted, and placed on a linear wavelength scale using comparison lamp scans. Flux calibrations were obtained through observations of white dwarfs with known absolute fluxes (Oke, 1974). The measured line fluxes relative to Hβ are listed in Table 1. The accuracy of the relative line strengths for the brighter lines is estimated to be better than ±25%, while the estimated error for the Hβ flux is ±50%. The line intensities have been corrected for extinction assuming an intrinsic Hα/Hβ ratio of 2.9 and the Whitford reddening law (cf. Miller and Mathews, 1972).

III. Discussion

The visibility of 136+5°.1 on the PGK [O III] survey plate is striking in contrast to its appearance on the Palomar Sky Survey print (see Fig. 1). The nebula appears on the red PSS print as a very faint, diffuse and featureless nebulosity, approximately 8′ in diameter, and is not visible on the blue PSS print. However, the PGK [O III] image shows a bright, asymmetric nebula 9′ in diameter with a thin outer filament to the southeast. With the higher resolution [O III] image shown in Fig. 2, the object's morphology can be seen in detail. The southeastern filamentary arc is well-resolved and appears to form an almost complete, symmetrical ring 15′ in diameter around the inner nebulosity. The ring's faint northern section may appear artificially brighter in Fig. 2, due to image tube background enhancement near the edge of the field-of-view. Three bright, diffuse emission regions can be seen interior to the ring. Two of these regions, the northeastern and the middle, have no noticeable internal structure but the southern region has a denser emission area approximately 1′ in size near its southern edge. Between the northeastern and middle diffuse regions there is a sharp, bright knot about 20″ × 40″ in size. This feature (on which we have obtained spectrophotometry) is visible on the red print, and very faintly on the blue print of the Palomar Sky Survey. On our [O III] image shown in Fig. 2, some faint filaments extend from this knot eastward and connect with the outer ring. Other faint filaments also seem to extend from the middle diffuse emission region toward the outer ring in this portion of the nebula. These filaments might be projected portions of the nebula's outer ring structure.

We believe this object, 136+5°.1, is a previously unknown planetary nebula. Its morphology is similar to that seen in double

shell planetary nebulae (Kaler, 1974), with the ratio of its outer to inner shell diameters about two. The spectrum of its central region resembles those seen in high-excitation planetary nebulae, and is substantially different from those of H II regions or supernova remnants. It exhibits a large $I([O\,III])/I(H\beta)$ ratio of 10–16, a $I(He\,II)/I(H\beta)$ ratio of about 1.0, with weak [S II] λ6725 and [O II] λ3727. H II regions have $I([O\,III])/I(H\beta)$ less than 7 and show no He II emission (Chopinet and Lortet-Zuckerman, 1976). Although supernova remnants often have large [O III]/Hβ ratios, their spectra also have strong [S II], [N II], and [O II] emission which we do not observe in the central regions of 136+5°.1. Our measured ratios of $I([O\,III])/I(H\beta)$ greater than 7 and $I(He\,II)/I(H\beta)$ around 1 indicate that 136+5°.1 is a planetary nebula of excitation class 8–10 (Aller and Liller, 1968).

We have estimated the distance to 136+5°.1, based on our average observed $E(B-V)$ of 0.43 ± 0.07 for the nebula. Using the distance-reddening relations of FitzGerald (1968) and of Lucke (1978), the distance corresponding to $E(B-V)=0.43$ in the direction $l=136$ would be 500–600 pc. At a distance of 500 pc, 136+5°.1 would have a linear radius of 1.1 pc for its outer ring and 0.65 pc for the inner region. While this distance estimate would indicate that 136+5°.1 is one of the largest planetary nebulae, there is reason to believe that reddening is patchy in this direction. Abell 6, a planetary nebula only 40′ southwest of 136+5°.1, has an $E(B-V)$ of approximately 1.0 (Kaler, 1982), which is twice the value expected from its estimated distance of 790 pc (Cahn and Kaler, 1971) using distance-reddening relations. Since 136+5°.1 lies in nearly the same direction, a distance for this nebula determined on the basis of reddening is probably unreliable.

The distance to 136+5°.1 can also be estimated from its Hβ surface brightness using the Shklovsky method. The estimated mean surface brightness, $F(H\beta)=6\ 10^{-12}$, erg cm^{-2} s^{-1}, for the inner region (radius 4′.5) yields a distance of 350–400 pc, the larger estimate being obtained if a filling factor of 0.6 is used. The radius of the nebula's inner region would then be 0.45–0.5 pc with the outer ring 0.75–0.9 pc. However, if the radius of the outer ring is used instead of that of the inner region, the distance determined by the same method is 250–300 pc with the corresponding size of the outer ring of 0.55–0.7 pc. Because distances to double shell planetary nebulae have generally used the radius of the inner region, we adopt the distance estimate of 350–400 pc for consistency.

The properties of large, high excitation planetary nebulae have recently been studied by Kaler (1981). Our new planetary nebula is probably a member of this class, as the selection criteria are 1. a radius greater than 0.2 pc, 2. $I(He\,II)$ λ4686) greater than 0.75 Hβ, and 3. weak or absent [O II] and [N II] lines. Kaler concluded that, in general, these planetary nebulae also show shell or ring-like morphology, over-luminous central stars ($M_v=+1.0$ to $+4.0$), and low Lyman optical depth. 136+5°.1 does appear to have a ring-like morphology as other members of this class, in spite of its asymmetric interior. However, it may not have an over-luminous central star. A centrally located, 15th magnitude star ($\alpha=02^h59^m34^s$, $\delta=64°41'45''$) is a candidate for the nebula's central star based on a short-integration, low-dispersion scan covering 4500–7000 Å. Although the star does not appear blue on the PSS, it does appear brighter on the PGK blue survey plates than on the red plates. At a distance of 400 pc, this star would have an absolute visual magnitude of 6.0 ± 1.0, which would not be considered over-luminous for a central star of a planetary nebula.

The nebula's bright eastern knot has a considerably lower ionization state than seen in the central region of the nebula (see Table 1). Lines of He I, [O I], [S II], and [N II] appear strong, with the [N II] λ6583 line about twice the intensity of Hα. The electron density of the condensation estimated from the [S II] $\lambda\lambda$6717, 6731 ratio is 350 ± 150 cm^{-3}. The density of the main nebula is likely to be much lower than this value due to its higher ionization state and lower surface brightness. These data are consistent with the low ionization condensations modeled by Capriotti (1973), and the condensations observed in some planetary nebulae, such as NGC 6543, NGC 6720 (Aller and Walker, 1970; Czyzak et al., 1968), and NGC 7293 (Warner and Rubin, 1975). For example, the bright knot in the outer shell of NGC 6543 has an electron density estimated from its [O II] lines of approximately 500 cm^{-3} (Czyzak et al., 1968), a value similar to that determined here for the knot in 136+5°.1. However, at a distance of 400 pc, this knot would be about 10^{17} cm, at least an order of magnitude greater than the size predicted by Capriotti due to fragmentation of an H I shell, and larger than observed in other planetary nebulae.

IV. Conclusions

We have discovered a large, high-excitation planetary nebula by means of [O III] interference-filter imagery. This new nebula, 136+5°.1, has an outer ring 15′ in diameter and an inner region which is asymmetric in appearance. Spectrophotometry indicates the nebula is a high-excitation planetary nebula with a large, bright low-ionization condensation. Distance estimates based on the measured reddening of $E(B-V)=0.43$ are probably unreliable due to patchy extinction in this direction. We adopt a distance estimate of 350–400 pc based on its Hβ surface brightness.

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