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G247.8+4.9, a nitrogen-dominated nebula at the outskirts of Puppis

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Abstract. Spectra of the emission-line nebula G247.8+4.9 are presented in which an outstandingly high intensity of the lines [N II]λ6548,6583 Å relative to Hα is observed. From the spectra we obtain E(B–V)$\simeq 0.7$ mag; with this value we deduce a lower limit for the distance of 6 kpc. The nebula appears to be located inside a cavity in the IRAS 60 and 100 μm maps. This cavity could be a wind blown bubble formed by the progenitor star of the object. The most likely physical interpretation of the nebula is a supernova remnant, although other possibilities are discussed too.

Key words: ISM: supernova remnants – ISM: individual objects: G247.8+4.9

1. Introduction

The nebula G247.8+4.9 was discovered during a systematic search for galaxies in the zone of avoidance carried out at the University of Innsbruck on POSS I plates. For this search the plates were visually scanned by use of a microscope at 16× magnification, because at low galactic latitudes this method is the most efficient way to distinguish small galaxies from stars and diffuse objects (e.g. Weinberger 1980, Seeberger et al. 1996, Lercher et al. 1996, Saurer et al. 1997). The object G247.8+4.9 was presented by Weinberger (1995) as a possible new supernova remnant (SNR) on the basis of its morphology. The nebula is a quite faint incomplete ellipse with a major axis of about 5′. About 3′ south of the center of the nebula there is an extended radio source (PMN J0821-2758) of 82 mJy at 4850 MHz that probably coincides with a source at 408 MHz (Griffith et al. 1994). Weinberger et al. (1998) report from Griffith & Wright (1993) a radio source at α= 8$^{\rm h}$21$^{\rm m}$12.2$^{\rm s}$, δ= $-27°58'29''$ of about 78 mJy at 4850 MHz. No IRAS or ROSAT counterparts were found. Weinberger et al. (1998) obtained optical spectra from which they estimated a radial velocity of about 50 km s^{-1} and a distance of about 5 kpc. In this paper, we will provide new data on this peculiar nebula.

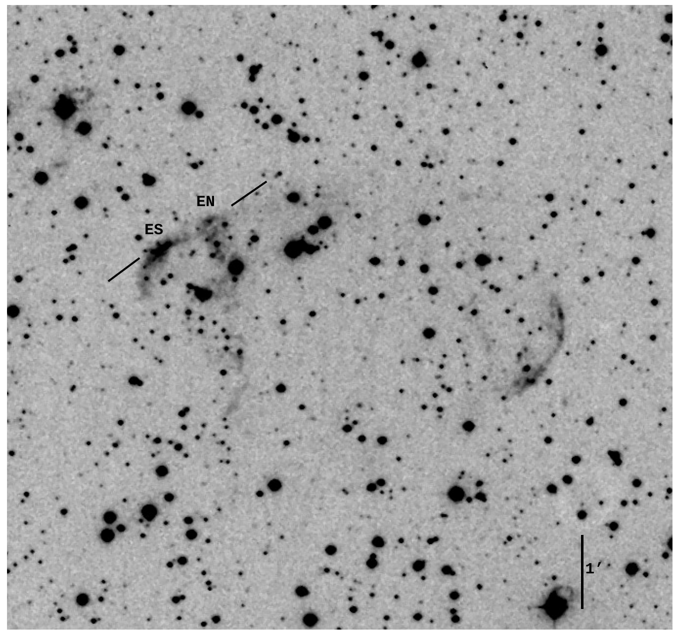

Fig. 1. Broad band Hα image of G247.8+4.9. The position of the two blobs East North (EN) and East South (ES) is marked and the position of the slit is given by the two lines. North is up, East is left.

2. Observations

Our spectra were obtained in April 1996 with the 2.5m du Pont Telescope at Las Campanas Observatory. The telescope was equipped with the modular spectrograph, a 600 lines mm^{-1} grating and a 1024×1024 Tektronic CCD with a pixel size of 0.24 μm giving a dispersion of 2 Å pixel^{-1}. The slit was centered at α(2000)= 8$^{\rm h}$21$^{\rm m}$28$^{\rm s}$, δ(2000)= $-27°54'42''$ with a position angle of $\sim 140°$; the slit position is marked in Fig. 1. We took two exposures of 1800 s each. They were reduced with IRAF software using bias, dome flats and helium hollow cathode comparison spectra. During the night we also observed a spectral standard star from the list of Hamuy et al. (1992) from which we derive the response curve. To achieve the absolute flux calibration of the raw spectra we divided them by the response curve and corrected for the airmass. The subtraction of the bright sky lines (e.g. at 6300 Å) left some residuals in the spectra, so we could not reliably detect emission from the object at these positions. In the two dimensional spectra two main blobs

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are clearly recognizable (East North and East South in Fig. 1), but fainter emission is present along the entire slit. This faint emission has been investigated because in the 'sky' spectra we detected lines that are usually not present in the sky spectrum as: [N II]λ6583 Å and [S II]$\lambda\lambda$6716, 6731 Å. We have extracted the spectrum of this emission near the edge of the slit, because the line ratios (Hα/[N II] and Hα/[S II]) are different from that of G247.8+4.9. We conclude that it might originate from interstellar material present in the foreground or in the background of the nebula and is not related to the nebula itself. Due to this complex emission, it would be highly advisable to take a clean sky spectrum at an offset position, for later spectral investigations.

In February 1998, in spare time of other programs, we obtained one 1800 s image (Fig. 1) of the nebula with the 1m Swope telescope at Las Campanas Observatory: the CCD was a TEK 5, and the scale 0.69 arcsec pix $^{-1}$. We used a broad ($\Delta\lambda = 100$ Å) Hα filter, (i.e. including [N II]λ6548,6583 Å). A reduction with bias and dome flats employing the MIDAS package, was carried out. Because automatic cleaning of cosmic rays could be dangerous with emission line objects we detected and eliminated cosmics with the program IMEDIT of IRAF. Residual bad pixels were then removed by applying a median filter to the image.

3. Results

No complete pattern of symmetry is apparent in G247.8+4.9 (Fig. 1). Knots of different brightness are present in all the nebula's structures. The brightest part of the nebula is a blob in an arc–like structure in the East, named East South in Fig. 1. Opposite this, with respect to the center of the nebula, there is another fainter arc in the West. The two arcs have extensions of about 58″ and 73″ respectively. These two arcs define the ends of the major axis of an ellipse of $\simeq 5'$ and PA$\sim 75°$. At the northern end of the eastern arc a diffuse emission (EN in Fig. 1) is visible; it leads throughout the nebula and forms a short tail to the South with an overall extension of about 2′. The brightness of this filament dims from North to South. These features constitute the main parts of the nebula, but although the S/N is quite low it is possible to identify other emission structures barely detectable above the background. In the North, as a prolongation of the eastern arc, there is diffuse emission that extends to the western arc. These emissions in the northern part seem to break up the ellipse and appear to have opened it to the exterior. At about 44″ east of the West arc a faint arc-like structure of $\sim 57''$ length is present.

In Table 1 the measured fluxes and the intensities of the lines are given. The interstellar extinction was calculated using the average relative reddening curve of Osterbrock (1989) and the Balmer decrement. As intrinsic ratio for East North we assume Hα/Hβ=2.85, but for East South we use Hα/Hβ=3, a value that is consistent with a large range of shock models. The line ratio of East South gives E(B–V)<0; this meaningless value led us to perform a careful inspection of the spectra. This revealed a cosmic ray hit at the position of Hβ, so that we could not rely on the flux of this line; therefore, Hβ of East South was scaled according to the observed flux ratio Hα/Hβ of East North . The line strengths computed according to this assumption are listed in the columns F^a(λ) and I^a(λ) of Table 1. The resulting E(B–V) is 0.72 mag for East North and 0.68 mag for East South . These values of E(B–V) are almost twice that inferred by Weinberger et al. (1998): this increases the maximum possible distance of the object. The extinction distance was derived using the reddening diagrams of Neckel & Klare (1980). In their field they do not get a clear relation for A_V versus distance, however they found A_V <1 mag out to 6 kpc: as our values are larger, we can consider this distance a lower limit; however, we cannot entirely rule out a small local dust cloud at the position of the nebula – but nothing is seen, e.g., in IRAS. The electron density was calculated from the line ratio of [S II]$\lambda\lambda$6716,6731 Å with the task TEMDEN of the NEBULAR package of IRAF: it is about 500 cm^{-3} for East North while East South is in the low density limit, less than 200 cm^{-3}. The usual criterion to find out the presence of shock is the ratio Hα/[S II]<2.5 (Fesen at al. 1985): We found ratios of $\sim$3 and $\sim$1 for East North and East South , respectively, so we state the presence of a shock only for East South , also see Fig. 3.

Table 1. Relative line intensities

		East North		East South		
Ident	λ(Å)	F(λ)	I(λ)	F(λ)	F^a(λ)	I^a(λ)
Hβ	4861	100:	100:	100:	100	100:
[N I]	5200	75	59			
[N II]	5755			76	206	122
[N II]	6548	557	231	1013	2739	1202
Hα	6563	689	285	254	687	300
[N II]	6583	1451	597	3192	8638	3750
[S II]	6716	118	47	414	406	170
[S II]	6731	115	45	293	275	115

[a] related the ratio Hα/Hβ of East North

To infer a limit on the velocity (v_s) of this observed shock we note that the lack of the [O III]λ 5007 Å line points (according to the shock model of Hartigan et al. 1987) to a $v_s < 60$ km s^{-1}.

4. The nature of G247.8+4.9 nebula

The G247.8+4.9 nebula is peculiar as can clearly be deduced from its spectrum: [N II]/Hα $\sim$3 for East North and $\sim$16 for East South (see Fig. 2). This high line ratio cannot be achieved in a medium of usual interstellar composition by different shock velocity - see e.g. shock models (Cox & Raymond 1985, Hartigan et al. 1994); hence, it could be an indication of a peculiar composition in the material of the nebula, i.e. enhancements in the abundance of nitrogen. The nebula therefore has probably formed from material that was processed via the CNO-cycle and was subsequently ejected from a star: this gives a clue regarding the history of the progenitor of G247.8+4.9, it had to be evolved to produce the nitrogen. To give a quantitative description of this enhancement we estimated the ionic abundance of

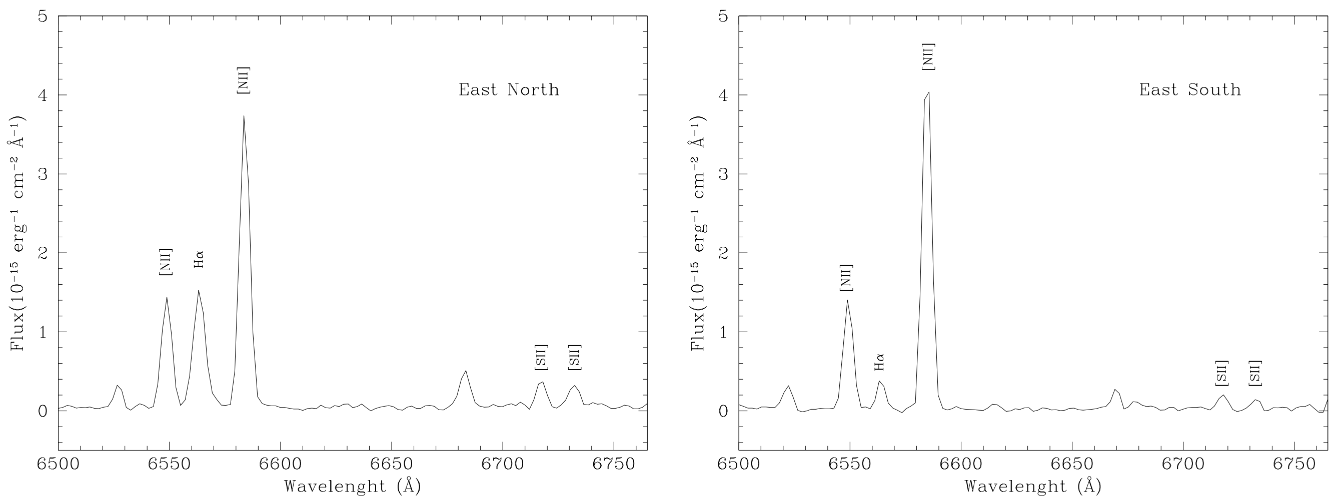

Fig. 2. The red part of the spectra of East North and East South illustrating the peculiar [N II] emission.

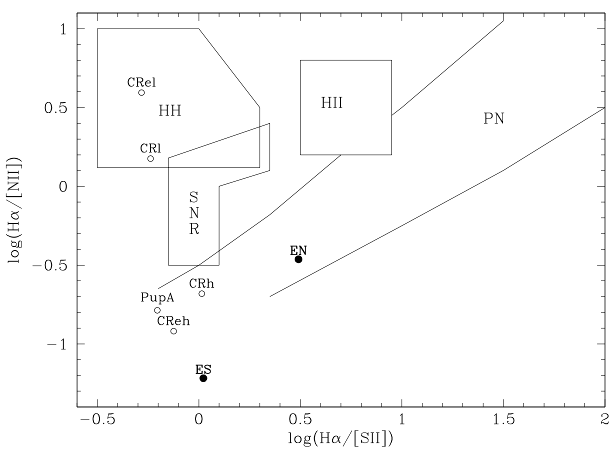

Fig. 3. Diagnostic diagram for East North (EN) and East South (ES). We include also Puppis A (Sutherland & Dopita 1995) and position of the Crab Nebula (MacAlpine et al., 1996) with different line ratio: extreme low-N (CRel), low-N (CRl), high-N (CRh), extreme high-N (CReh).

N^+ with the task ABUND of IRAF. In our spectrum there are not enough lines to calculate the electron temperature and density in the zones of different ionization stages, therefore we assumed a constant electron temperature and density inside East North and East South . As only nitrogen lines are usable we restrict ourselves to the abundance of this element, moreover we cannot get the total N abundance because it is not possible to reliably evaluate the ionization correction factor. For East North we assumed $T_e = 10^4$K and used the electron density calculated from the [S II] doublet ratio $N_e = 500$ cm^{-3}, for East South we have from [N II]$\lambda\lambda$5755,6548,6583 Å lines $T_e = 15680$K and assume $N_e = 100$ cm^{-3}. The ionic abundance (expressed as $12 + \log(N^+/H^+)$) is 8.05 for East North and 8.39 for East South . This is considerably larger than the value of 7.02 reported for the Orion Nebula (Shaver et al. 1983).

The morphology of G247.8+4.9 resembles that of the SNR W50 that could be connected to SS433 (for references see Weinberger et al. 1998). W50 has a ratio [N II]/Hα $\sim$4 (Kirshner & Chevalier, 1980) which, although lower than G247.8+4.9, is already a rather high ratio for SNRs. The central source SS433 has a peculiar spectrum that shows Hα in emission. To investigate this coincidence Weinberger et al. (1998) have taken spectra of four stars roughly in the center of G247.8+4.9. We have further explored this possibility by looking for stars with Hα emission using the red-infrared comparison technique (Sabbadin 1986). This method is based on the consideration that, in galactic fields, stars tend to be brighter in the infrared than in the red, due to differential interstellar absorption. In contrast, Hα emission line objects are brighter in the red than in the infrared. We have performed the red-infrared comparison on the plate of the Palomar Near Infrared Photographic Survey of the Galactic Plane for all the stars we see inside the nebula, but none show the characteristic of Hα emission.

Also from a morphological point of view a wind blown bubble around a Wolf-Rayet (WR) star or an OB association cannot be excluded. An object that shows a relatively intense [N II]/Hα ratio is NGC 6888, a nebula around a WN star, that has [N II]/Hα $\sim$3 (Kwitter 1981). To pursue this possibility we calculated the expected brightness of such a star and compared it to the brightest star present in the field. The magnitude of this star is measured on the ESO J film for which Hörtnagl et al. (1992) calculated a relation between m_j and the diameter of the stars. The brightest star in the field of the nebula has $m_j \simeq 15$ mag. A WN star has $<M_V> \sim -6$, with the observed E(B–V), assuming a distance of 6 kpc and using the relation of King at al. (1981) between m_V, m_B and m_j we expect a WN star of $m_j \simeq$ 10 mag. Such a star would obviously be the most prominent in the field - but none exists there. Therefore the interpretation as a wind blown bubble around a WR does not seem to apply.

As already noted by Weinberger at al. (1998) the morphology of G247.8+4.9 does not resemble a planetary nebula: practically all PNe that show high [N II]/Hα ratios are bipolar, thus if our nebula was a PN we would expect a bipolar morphology. The PN with probably the highest [N II]/Hα ratio is PNG

321.6+02.2 with [N II]/Hα=12 (Corradi et al. 1997). The central stars of bipolar PNe are among the hottest PNe nuclei (Corradi & Schwarz 1995), hence high excitation features are usually pronounced. On the contrast they are not at all present in our spectrum. Furthermore the brightest parts in bipolar PNe are normally at the ends of the minor axis, whereas in our case the bright rims are at the end of the major axis of the ellipse. As a final point we note that G247.8+4.9 has a height above the galactic plane z>500 pc (assuming d> 6 kpc): this value is considerably greater than the scale height of bipolar PNe of 130 pc (Corradi & Schwarz 1995). On the basis of all this evidence we rule out the identification with a PN.

Comparison with other SNRs has already been mentioned in the context of W50, but other SNRs may be even more relevant in terms of the observed [N II]/Hα emission ratio, e.g. the Crab Nebula and Puppis A. The [N II]/Hα ratio measured in the Crab spans an interval of $\sim$8 and 0.3 (MacAlpine at al. 1996). The highest value of the ratio is reached in Pup A where [N II]/Hα $\sim$20 in some filaments (Danzinger 1983). It is useful to compare (Fig. 3) the line ratio of these two SNRs and G247.8+4.9 with the help of the Hα/[N II] versus Hα/[S II] diagnostic diagram (García Lario et al. 1991). All the points lie outside the region of SNRs due to their unusual [N II] lines strength; this is reasonable because the diagram is built up on the basis of the average properties of the different classes of objects. The Hα/[S II] in East North indicates that no shock is present, but East South shows the most extreme [N II]/Hα ratio ($\sim$ 16), because the spectrum of Pup A used here has an average value of [N II]/Hα $\sim$ 6 only. With the exception of East North, all these data points would be shifted inside (or very near to) the SNR zone, if the nitrogen lines were of "normal" strength. This peculiar line ratio, in the Crab and in Pup A, is attributed to a higher abundance of nitrogen, and can be present in young or moderate age SNRs, before the stellar ejecta is diluted in the interstellar medium. The linear dimension of the major axis of our nebula is 8.7 pc (at d = 6 kpc) in accord with the size of a moderate age SNR. Unfortunately the lack of other lines in the spectra of our nebula do not allow an abundance analysis and a more detailed comparison with the emission of SNRs. We should however underline that in the above mentioned SNRs too the line ratio between different filaments is drastic, for example some filaments are brightest in [N II] lines and others in [O II]. This general effect combined with the faintness of our object can explain the limited emission observed.

Although G247.8+4.9 has no IRAS counterpart, it is worth noting that an interesting feature that is present in the IRAS 60 and 100μm bands. Around the nebula there is a "cavity" in these two bands with extensions of about 30′. In Fig. 4 we show the 100μm emission, where the cavity is more clearly visible, in a region of 2°. The position of our object is delineated by the rectangular box. The inner boundary of the shell has an intensity level of 10.7 MJy sr^{-1}. Outside this region the emission is higher, and at the boundary of the field (except in the South) and in the North-West we have an emission lower than 10.7 MJy sr^{-1}. To form such a homogeneous region with low 100μm emission we need a mechanism that destroys and/or pushes away the dust.

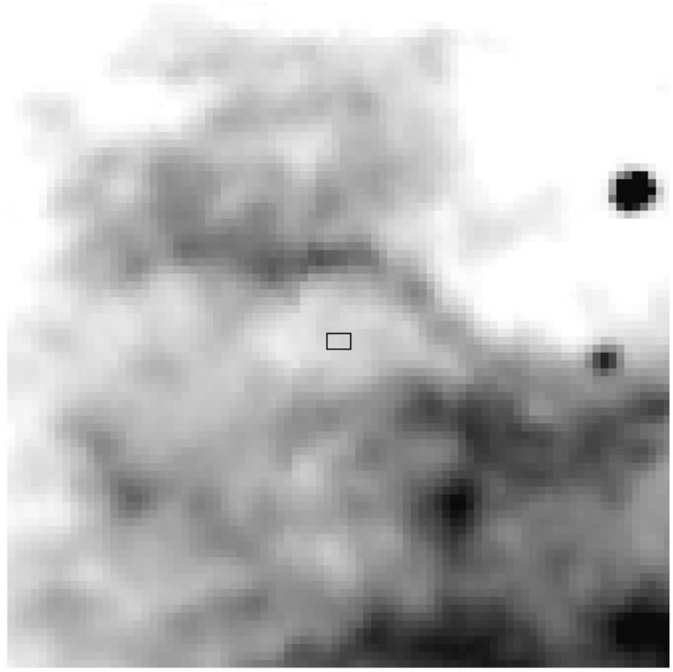

Fig. 4. IRAS data at 100μm. The rectangular box approximates the boundary of the G247.8+4.9 nebula.The field is 2° square. Higher IRAS emissions are black.

In an attempt to explain the characteristics of G247.8+4.9 in a comprehensive manner we consider the framework of the evolution of massive stars, because we think such an object may have been the progenitor of our nebula. A schematic description of the evolution is: O star (main sequence) $\rightarrow$ red supergiant (RSG) and/or luminous blue variable (LBV) $\rightarrow$ WR $\rightarrow$ supernova (SN) (van der Hucht 1992). A peculiar characteristic of massive stars is the mass loss that they experience in every phase of their evolution. We suspect that different parts of our object could be formed in different episodes of mass loss, during the rather brief lifetime of a massive star. First there is the IRAS cavity, the outermost and thereby oldest structure. Marston (1996) found IRAS shells (with diameter from 10 to $\sim$ 300 pc) around several WR star and deduced that they could be formed by an O star during its evolution on the main sequence (2 to 3 million years). Also the shell we observe is consistent with this interpretation because its linear dimension (at d=6 kpc) is 50 pc, a value that is inside the range found observationally by Marston. Additionally García-Segura et al. (1996) while performing hydrodynamic simulation on evolution of circumstellar gas around massive stars, found a value of 36 pc for the main sequence bubble before the SN explosion, the agreement is quite good especially considering that in our situation additional time has passed since the SN explosion and accounting for a different velocity. The second element we consider is the nebula, with its high abundance of nitrogen. The nebula can be interpreted as the result of high mass loss during the RSG or LBV phase; the ejected matter would be material processed via the CNO-cycle, as we already suggested. García-Segura et al. (1996) show that such a nebula will be N-enriched when the star passes either through the RSG or the LBV phase, explaining the origin of the extraordinary amount of nitrogen we observe. The relative abundances of the C, N and O would be different in the two cases, but the spectrum available does not allow us to discriminate between the two possibilities. As in the case of the IRAS hole the dimension of the nebula is compatible with the typical dimensions both observed and calculated by hydrodynamic simulation. This scenario also naturally explains why no progenitor star is visible today as it has exploded as a SN after the evolution through the WR phase. G247.8+4.9 could then be understood as a possible superposition of a SNR and evolved stellar ejecta located within a cavity formed by an O star.

5. Conclusion

The physical nature of G247.8+4.9 is not yet completely clear, but its interpretation as a SNR is, if not certain, least unlikely. Most puzzling is the lack of He lines, because the CNO-cycle would lead to an enhanced helium abundance just as it is observed for nitrogen, and the absence of oxygen lines. Detection of these lines would be most valuable in order to carry out additional useful diagnostics. The similarity of morphology, linear dimensions and line ratios with characteristics of other SNRs corroborates the interpretation as a SNR. We discuss a scenario for its formation which suggests that evidence for all phases of the evolution of an O star - from the main sequence to a supernova remant - is present in this object. Useful studies to supplement our results on this peculiar nebula would be the acquisition of much deeper narrow band images to provide a precise description of the morphology and of the structure in different emission lines and deeper spectra at several positions in the different filaments.

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