HUGE ASPHERICAL DUST STRUCTURES AROUND THE PLANETARY NEBULAE NGC 6826

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Abstract: By systematically searching regions around planetary nebulae (PNe) for signs of interactions of their precursors' wind with ambient matter we found a number of huge IRAS dust structures. Some of them may be chance projections, but a few appear to be real, like those around NGC 6826 and NGC 2899. In the case of NGC 6826 we noticed a giant (~ 2^o) bipolar dust emission, whose axis is along the proper motion of the central star. The PN itself is offset in the direction of motion both as to the center of this ~30 pc large dust structure and to the center of a similarly large new H_α nebula. Here the formation of dust structure probably has commenced in the asymptotic giant branch (AGB) phase. Hence, the general opinion of spherically symmetric mass flow in the AGB phase might need some revision.

Key words: Planetary Nebula; Interstellar dust; Interstellar medium; Infrared.

INTRODUCTION

The Infra Red Astronomical Satellite (IRAS) mission was a major advance for astronomy. Almost the entire sky was covered in four passbands (12, 25, 60, and 100 μm). The all-sky maps turned out to be useful in many respects, e.g. by demonstrating that dust structures are ubiquitous and come in all kinds of shapes and sizes. Curiously enough - although the IRAS mission took place two decades ago - the maps are still not exhausted of their riches, as we could demonstrate very recently by the discovery of the first jets (size ~ 9^o each) found in the far infrared (Weinberger & Armsdorfer 2004). These fossil jets were discovered as a byproduct during our systematic search for dust structures around PNe: the latter structures around PNe can be ancient and can originate from interactions of the wind of the precursors of PNe, the AGB stars, with ambient (interstellar) matter (ISM).

AGB stars represent the final stages of stars with low or intermediate main sequence mass (1 de M de 8 M⊙). During the AGB phase, which lasts some 10^6 yr, stars shed matter at high rate, up to 10^{-4} M⊙ yr^{-1}. The PN community usually assumes that in this phase the mass loss is practically spherically symmetric, but in the short transition period between the AGB and PN stages, these objects drastically modify their spatio-kinematic structure (e.g. Sahai et al. 2003). Obviously, high-speed, jet-like flows play an important role in this transformation (Sahai & Trauger 1998).

Due to the lack of sufficient resolution it is difficult to reveal details of how, in a geometrical sense, the wind from AGB stars is blown. To check this, one may search for still existing signs of this wind material, which has been expelled with typically 5—20 km s^{-1}. In the course of time, this material will interact with ambient (interstellar) matter, but still might preserve the main patterns of outflow. If one would like to venture into the period, say, 1 x 10^6 yr prior to the PN phase (i.e. deep into the AGB phase), then by assuming a constant velocity of 15 km s^{-1}, this (partly swept-up) material will be ~ 15 pc distant from the PN. At D = 1 kpc, this corresponds to an angular distance of ~ 1^o. Hence, large fields around PNe must be examined. We have carried out such a search around many PNe on IRAS maps and demonstrate that material blown by AGB stars (and mixed with ISM) can indeed be detected, offering surprising results how the spatial mass shed of AGB stars took place.

THE SEARCH

We are not the first who use IRAS maps for a systematical search for dust structures around evolved stars. For example, Gillett et al. (1986) found a large fossil shell around R CrB, and Hawkins (1990) an analogous object around W Hya. Young et al. (1993) reported the detection of numerous infrared shells around red giant stars and young PNe; they found e.g. 4 large shells with a diameter of > 4 pc. However, we appear to be the first who systematically searched for dust structures around many 'normal' PNe by examining very large regions around them.

We used *SkyView* server (http://www.skyview.com) and searched regions with image sizes of 2^o, 5^o, 10^o and 15^o, centered on about 400 PNe at 12, 25, 60, and 100 μm, respectively (Weinberger & Aryal 2003). The ~ 400 PNe represent about 1/4 of the registered Galactic PNe population and comprise all NGC, IC and Abell

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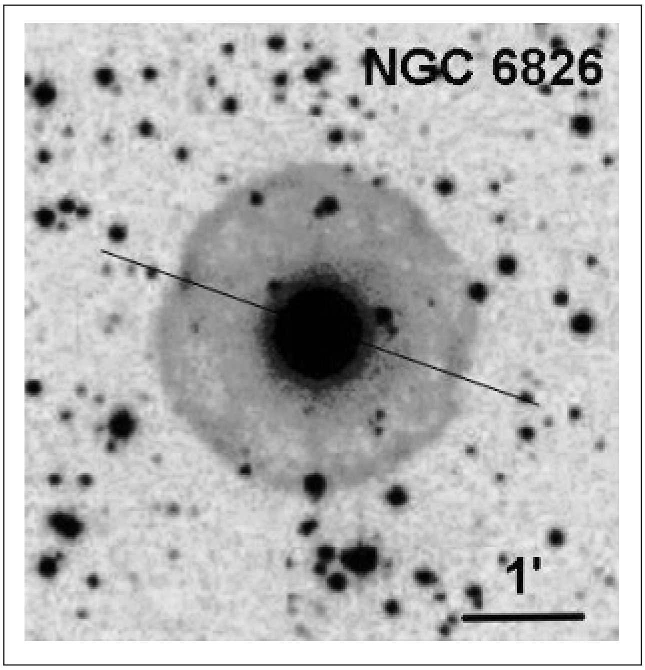

Fig. 1: An optical image of NGC 6826 (POSS II R). A mild deviation from circular symmetry at p.a. 255° ± 10° can be seen. The arrow represents the direction of the proper motion of the central star.

planetaries as well as additional extended PNe from several other compilations. The use of '*Stern Special*' as colour table and of '*Histogram Equalization*' as brightness scaling turned out to be the most favourable way to detect faint structures.

BASIC DATA

NGC 6826 (PN G083.5+12.7; R.A. = $19^h44^m48^s$, Dec. = $+50^o31'30''$ (J2000)) is a well studied PN (Fig. 1). It is classified as Type I multiple shell PN or 'faint halo PN'. The large round halo is $>10^3$ less bright than the main nebula, has a distinct outer rim, and is 2-3 times more massive than the main nebula (Middlemass et al. 1989). The halo's temperature (~ 13 kK) is higher than that of the inner nebula (Middlemass et al.1989) and its expansion velocity (6 km s^{-1}) is small (Hippelein et al. 1985). The central star (CS) is bright (V = 10.1), not very hot (~ 46 kK), has log($L/L_\odot$) = 3.88 and a mass-loss rate of 5.2 x 10^{-8} $M_\odot$ yr^{-1} (Perinotto et al. 1989). The proper motion of the CS is towards S-W (~ -11.0, -9.7 *mas* yr^{-1}), i.e. along potion angle (PA) ~ 230^o (Hog et al. 1998). The distance of NGC 6826 is uncertain - most reliable estimates cluster at distances slightly above 1 kpc. We adopt D = 1.1 kpc.

THE FAR INFRARED

NGC 6826 was found to be located between two broad long arcs (length ~ 90' each) that are best visible at 60 and 100 μm (Fig. 2a). Figure 2b shows a 60 μm IRAS contour map (using the Groningen IRAS server). The western arc clearly stands out, while the eastern one is affected by extended emission. One notices that, i) the western arc is clearly connected to the PN, ii) there is a bridge-like connection between both arcs, iii) the bridge extends approximately along the p.m. of the CS, iv) the PN is located on this bridge, v) both arcs can be outlined

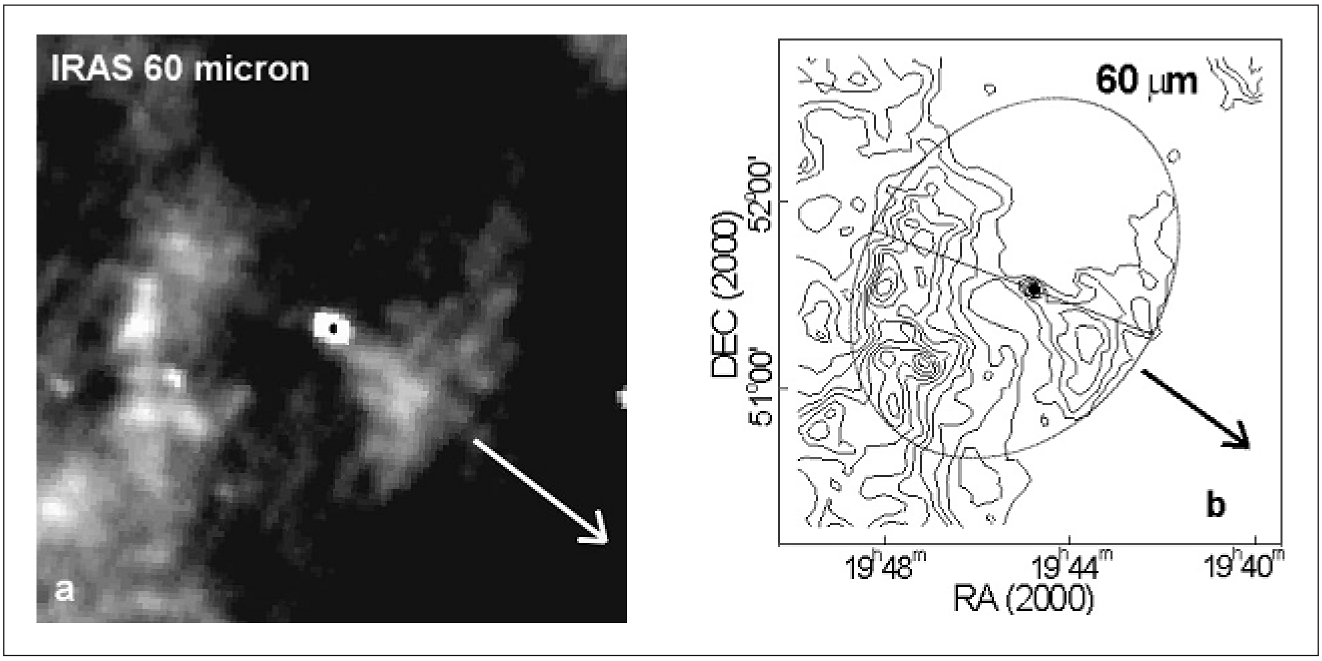

Fig. 2: (a) A 2.5° x 2.5° IRAS image at 60 μm around NGC 6826 (central dot), showing two large broad IR arcs W and E of the PN. (b) A 60 μm contour map of Fig. 2a. Contours are separated by 0.75 (in MJy/sr) with the lowest contour at 8.95 MJy/sr. The ellipse circumscribes both arcs and the line joins the mid point of the western arc, the PN and the eastern arc. The direction of the p.m. of the central star of NGC 6826 is represented by an arrow in the lower right corner.

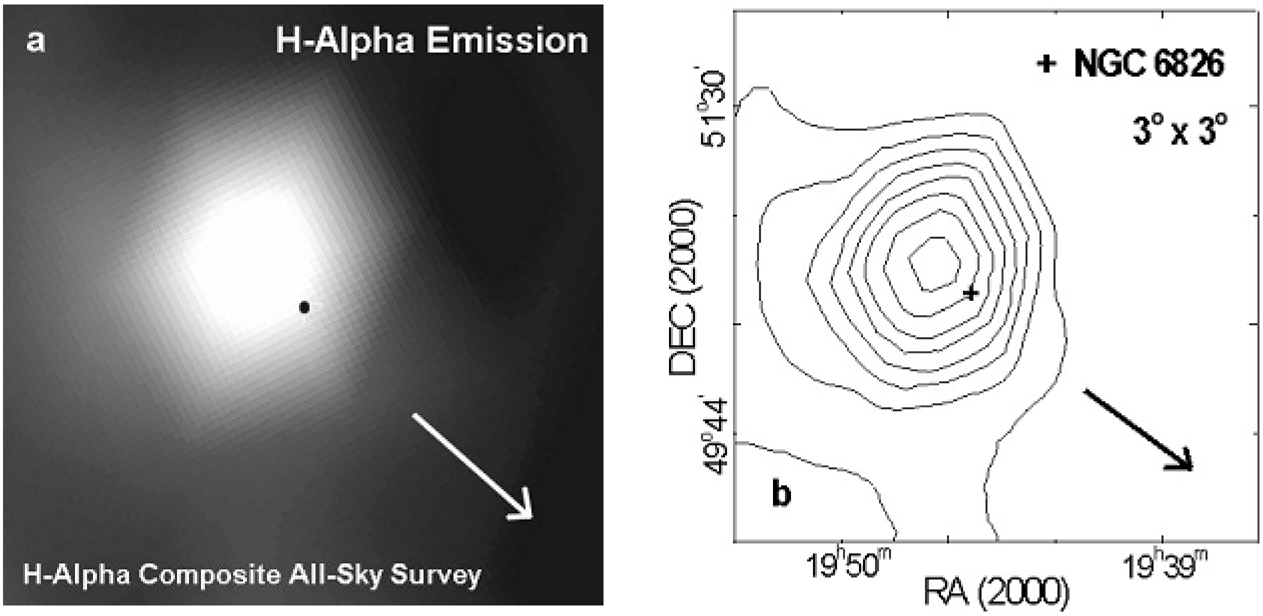

Fig. 3: (a) A 3° x 3° image showing an H_α emission nebula, extracted from the H_α Composite All-Sky Survey. (b) A contour map of the H_α emission from Fig. 3a. The contours span 6 to 18 MJy/sr, separated by 1.5 MJy/sr. The black dot represents NGC 6826. The direction of the p.m. of the central star of NGC 6826 is represented by an arrow.

by an ellipse, and vi) the PN is offset towards the western arc, roughly along its proper motion.

H_α EMISSION

Using *SkyView* we searched for counterparts of the above infrared bipolar structure at other wavelengths. None were found except one: we detected a giant roundish H_α nebula (in the "*H_α Composite All-Sky Survey*") whose centre almost coincides with the centre of the ellipse outlining the arcs (Fig. 3a). Its radial velocity (~ 11 km s^{-1}) is roughly comparable to the radial velocity of the PN (-6.2 km s^{-1}). In a contour map one can see a slight compression towards the west (Fig. 3b). We suggest that this huge H_α blob might be ISM ionized by the CS and its offset towards the north-east is the result of interaction with ambient matter. Using the Stromgren formula we estimated the density of the blob and found ~ 0.1 cm^{-3} - a reasonable ISM density for *z* = 240 pc above the Galactic plane.

DISCUSSION

The line in Fig. 2b (nearly representing the minor axis of the ellipse) amounts to a physical length of about 30 pc (at *D* = 1.1 kpc). This is the by far largest structure ever seen around a PN or around a precursor of a PN. The characteristics of this structure (bipolarity) as well as the other data mentioned above strongly suggest that the two huge infrared arcs are no chance superpositions but are linked to the PN (or its prior stages). By the way note that a slight deviation from circular symmetry along west-south-west and east-north-east can even be traced in the halo of the PN (Fig. 1), further supporting that the PN runs into ambient matter (matter from the 'bridge'?).

We used formulae (1) and (51) given by Weaver et al. (1977) to estimate the evolution time. By assuming a constant expansion velocity of 15 km s^{-1} and a mass-loss rate of 10^{-7} M⊙ yr^{-1} (reasonable for a stage prior to the onset of the superwind phase) the ejection started 9 x 10^5 years ago, i.e., in the AGB phase. In other words, an aspherical, probably bipolar, mass loss has commenced in the AGB phase of a object which almost 1 million years later became the PN NGC 6826 (Weinberger & Aryal 2004).

We estimated the mass of the dust and gas in the region outlined by the ellipse in Fig. 2b, based on fluxes of 1.26 Jy at 60 μm and 2.73 Jy at 100 μm, assuming a gas-to-dust ratio of 200, *D* = 1.1 kpc, and using the dust mass relation of Hildebrand (1983). A dust temperature of 26 ± 3 K was obtained using Henning et al. (1990). We determined a total mass of 0.74 ± 0.50 M⊙ for this region. The western structure alone has a mass of 0.34 ± 0.23 M⊙, i.e. about half of the total mass, as expected for a bipolar outflow. We suspect that a part of this matter is swept-up ISM, as suggested by the arc-like shapes.

A comment on the flux density change along the N-E and S-W bridge: in the N-E direction the flux density suddenly drops at a distance of ~ 11' (R.A. = $19^h46^m29^s$, Dec = +50°35'20" (J2000)) from the PN (Fig. 4a). This drop might indicate the possibility of a weakening of the bridge in the north-east because the PN itself is offset in the opposite direction, i.e., along the proper motion. In the S-W bridge, the presence of a rather high flux density could be combined effects of compression shocks due to H_α emission and interaction with the ISM (Fig. 4b).

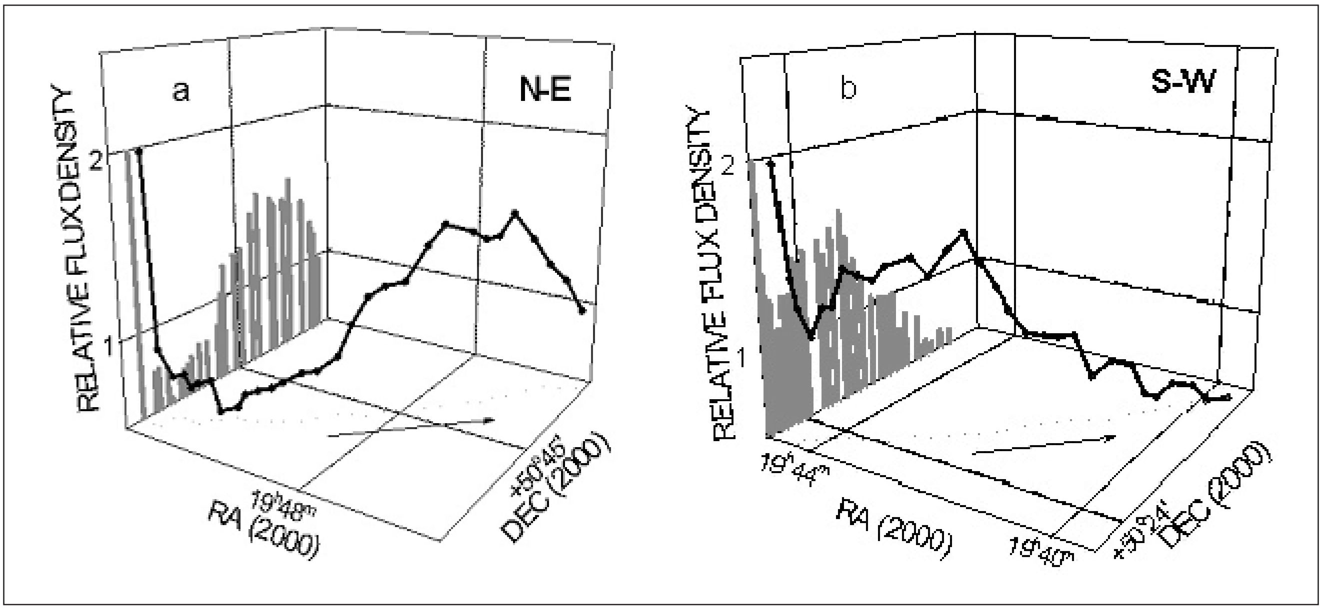

Fig. 4: The change in the 60 µm flux density along (a) N-E and (b) S-W (as evident from Fig. 1b). The bright peak (at extreme left) corresponds to the outer edge of the PN.

To sum up, in the case of NGC 6826, we have good reasons to believe that an aspherical mass loss - in contrast to the common belief of spherical symmetric mass loss - has taken place in the AGB phase of the predecessors of these planetary nebulae. Almost certainly, this is not the sole example of this kind. A discovery of additional examples on IRAS maps will however be hampered by foreground/background dust emission.

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