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Unravelling the 'Helix' nebula

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Summary. It is proposed that the complex structures observed in some planetary nebulae may, in part, be due to the focusing action of a binary companion to the star losing mass. Helix-like structures can arise due to orbital precession of the pair under the action of mass loss induced torques. The 'Helix' nebula is presented as a possible example even though duplicity in this object has not yet been observed.

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1 Introduction

Several planetary nebulae, most notably the nearby 'Helix' nebula (NGC 7293), show highly organized curvilinear structure. Most previous explanations have emphasized the importance of magnetic fields in creating and maintaining such structures in the ejected gas (e.g. Gurzadian 1962; Münch 1968; Woyk 1968). However, theoretical difficulties (Menzel 1968) and the apparent lack of non-thermal emission (Higgs 1973) prompt us to offer an alternative explanation. We investigate here the effect of a comparatively distant binary companion on the ejecta. Such a companion may gravitationally focus a significant fraction of the slowly moving gas, thereby generating ring-shaped and other curved structure in the final nebula envelope. Furthermore, ejection-induced precession of the orbit can explain the observed isophotal (Carranza, Courtes & Louise 1968) and velocity appearance of NGC 7293 (Taylor 1977) and of NGC 6543 (Münch 1968).

A large fraction of all stars appear to have at least one companion (Abt & Levy 1976) and it seems reasonable to suppose that this applies also to planetaries. Indeed, several central stars in planetary nebulae are observed to have visual companions (Cudworth 1973; Kohoutek & Laustsen 1977) while in others, such as NGC 1514 (Kohoutek & Hekela 1967; Greenstein 1972) and NGC 2346 (Kohoutek & Senkbeil 1973), possible duplicity is inferred from spectroscopic observations.

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2 The effect of a binary companion

We assume that a planetary nebula is formed by the ejection of $\sim 1M_\odot$ of material from a
evolved 1–2$M_\odot$ star at a velocity of $20\,v_{20}$km/s. The mass loss-rate $\dot{M} = 10^{-3}\dot{M}_{-3}M_\odot$/yr. binary companion (also of $1M_\odot$) orbits this star in 10^3P_3yr at a distance, a, c $1.8\times10^{15}P_3^{2/3}$cm. This companion has an accretion radius, $R_A = 2GMv^{-2}$, given by (see, e.g the review of accretion processes by Spiegel 1970)

$$R_A = 6.7\times10^{13}v_{20}^{-2}\ \text{cm}.$$

Matter ejected within an impact parameter $s\sim\sqrt{R_Aa} = 3.5\times10^{14}P_3^{1/3}v_{20}^{-1}$ cm of the cor panion is gravitationally deflected into a parallel (or tighter) beam (Fig. 1). Thus, if the ejec tion is spherically symmetric a fraction

$$f \simeq \frac{\pi s^2}{4\pi a^2} = \frac{R_A}{4a} = 9.2\times10^{-3}P_3^{-2/3}v_{20}^{-2}$$

is focused. The matter in the focused beam has a higher density than the remainder of th ejecta and may therefore be thermally unstable (see, e.g. Hunter 1973). The cooling tim scale, t_{cool}, in the ejecta is $\sim 30\dot{M}_{-3}^{-1}v_{20}r_{15}^2$yr due to atom–dust collisions alone and is le than the flow time-scale near the companion at radii $r = 10^{15}r_{15}$cm, $t_{\text{flow}}\sim 16\,v_{20}^{-1}\,r_{15}$yr, $\dot{M}_{-3}^{-1}v_{20}^2r_{15}\lesssim 0.5$. The density contrast in the accretion wake may thus be enhanced by factor of 10 or more if the cooled wake is contained in pressure equilibrium at temperatur $\lesssim 10^2$K by the remainder of the ejecta at $\gtrsim 10^3$K. The exact temperatures depend upo the radiation transfer etc. in the outflow.

The wake material flows away from the binary orbit in a spiral of pitch $d\simeq 6$ $10^{16}v_{20}P_3$cm. The details of the velocity changes encountered by the wake material cau its outward velocity to be somewhat less than the original ejection velocity. The spiral wak then acts as an obstacle to which fresh outflowing material is added. The density contra persists out to large radii provided that the wake cools and is maintained in pressure equil brium by uncooled nebula. We note that *any* mechanism for the large-scale density enhanc ments must involve some form of confinement. Ionization of the nebula by the central st at later times may cause further compression by the passage of a supersonic ionization fron

The effects of a binary companion on a planetary nebula may be most noticeable if bot a and v are small. The radiation emissivity is, however, approximately proportional to tl density squared. Even slight density inhomogeneities may then produce a marked contra in the appearance of planetary nebulae.

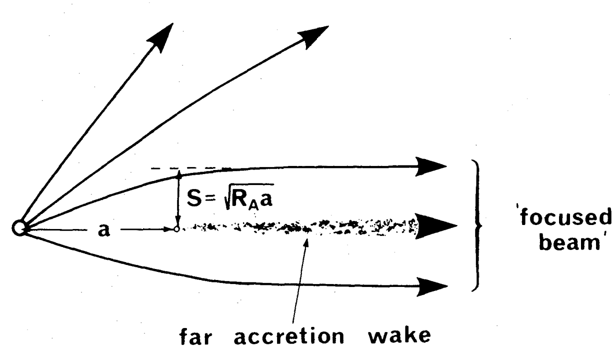

Figure 1. A sketch of the focusing action of the companion on the wind of the primary. The axis orbital motion lies in the plane of the paper.

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The ejection process may occur over a few thousand years, and the spiral may thus have but a few turns. During this period, however, any asymmetry in the ejection itself may create a significant torque on the ejecting binary, causing it to precess. Indeed it is conceivable that a low-mass binary companion may become unbound in this process. An estimate for the couple is $\Gamma_1 \simeq (a/2)\,\delta \dot{M} v$ where δ is the fractional asymmetry normal to the orbital plane and $\dot{M}$ is the mass loss-rate ($\dot{M} = 10^{22}\dot{M}_{22}$ gm/s); i.e. $\Gamma_1 \simeq 2 \times 10^{43}\,\delta v_{20} \dot{M}_{22} P_3^{2/3}$ cgs. To produce a rate of precession of $\sim 0.1(2\pi/P_{\rm orb})$ requires a couple of $\Gamma_2 \simeq 7 \times 10^{41} P_3^{-2/3}$ cgs. Thus, with typical values of the parameters, an asymmetry of $\delta \sim 10$ per cent (or even less) can produce a significant precession of the orbit.

3 Application to NGC 7293 and other nebulae

Taylor (1977) has interpreted his velocity map of NGC 7293 in terms of an expanding 'extended' helix with fair success. His corresponding match of the isophotes appears to be quite good (see also Carranza *et al.* 1968). We note here, however, that a precessed orbit (Fig. 2) traced on to an otherwise expanding, quasi-spherical, shell also gives a reasonable qualitative fit to the data. The outer ring is identified as the first orbit. This has been partially destroyed in the north-west corner by higher velocity material, ejected whilst the second, inner, ring, produced in the course of a $\sim 60°$ precession was formed. Note that the binary separation is $\lesssim 1$ per cent of the radius of the nebula. The position of the observed central star is thus likely to appear coincident with the centre of the nebula and with the centre of the radial filaments (Vorontsov-Velyaminov 1968).

A precessed orbit also forms a plausible explanation for NGC 6543, suggested to be an expanding helix by Münch (1968, in which a good image in [O III] is available). The linear structure in the Dumbbell Nebula (NGC 6853) lies along the position angle of the central visual binary (separation ~1400 AU). We suggest that the pronounced curvilinear structures within the shells of many other planetary nebulae, e.g. NGC 3587 (the Owl Nebula), NGC 5189 (the Ring Nebula), NGC 7009 (the Saturn Nebula) and Shapley 1, may again be due to, as yet unseen, binary companions. Much of this structure appears to have a distinct starting point which lies *inside* the general ring shape of the nebula. This would be a relatively unlikely occurrence if the structures were based on extended helices.

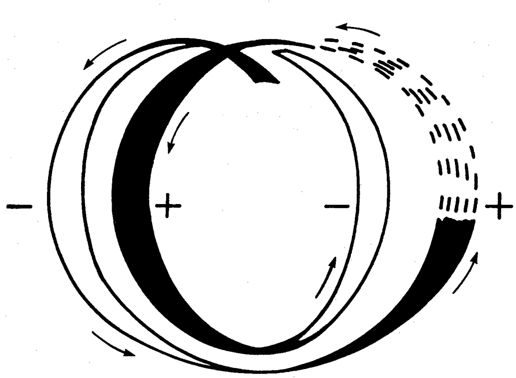

Figure 2. A highly schematic representation of the 'Helix' nebula NGC 7293. The structure (drawn as a band for clarity) is considered due to a precessed orbit, traced on an expanding spherical shell. The inner surfaces are shaded and a gap is left at the bottom for clarity. The sense of evolution of the helix is indicated by the arrows. The trend of Taylor's (1977) velocity data are indicated: minus for material approaching the observer, plus for receding material. Compare this diagram with the neutral oxygen photograph of Warner & Rubin (1975).

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We note that some of the structure obtained in nova shells may be due to the underlying binary system. Shocks formed near the companion star (Fabian & Pringle 1977) may cause a redistribution of matter just above and below the orbital plane.

4 Conclusions

Duplicity among the active stars of planetary nebulae may account for some of the nebula structures observed. In particular, the Helix nebula may not actually be a helix, but rather a precessed ring traced on an expanding, quasi-spherical shell. We urge that observations be made of the central star in this and similar objects to determine whether wide binaries are in fact present. Further detailed velocity maps will also be of importance.

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