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THE FILAMENTARY NEBULA S 188

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RESUMEN

El espectro de la nebulosa S 188 cuya forma es similar a la creciente de luna, permite identificar a esta nebulosa como una nebulosa planetaria (NP) del Tipo I en la clasificación de Peimbert. El trabajo recientemente realizado por medio de la interferometría de Fabry-Pérot nos ha permitido determinar el movimiento del conjunto de esta nebulosa. La distancia cinemática de este objeto resulta ser mayor que la que se puede estimar a partir de la calibración de Cudworth; esto refuerza la idea de que las NPs del Tipo I de Peimbert eyectan masas mayores que las NPs típicas. Discutimos además, el por qué esta nebulosa no tiene una forma esférica.

ABSTRACT

The crescent shaped nebula S 188 is identified as a planetary nebula (PN) of Peimbert's Type I on the basis of its observed nebular spectrum. New FP interferometric work allows to determine the systemic motion of this nebula.

The derived kinematical distance exceeds Cudworth's distance estimate supporting the idea that Peimbert's Type I PNs have larger ejected masses than typical PNs. A discussion about the origin of its non-spherical shape is also given.

Key words: **FP INTERFEROMETRY – INTERSTELLAR MATTER – PLANETARY NEBULA**

I. INTRODUCTION

The nebula S 188 (Sharpless 1953) appears in optical wavelengths as a crescent shaped filamentary nebula of angular dimensions of 8 × 4 arcmin. It has been photographed by Gaze and Shain (1965) who reported an Hα brightness of about 11 mag/sq arcmin for this nebula. The spectroscopic work performed by many authors (Parker 1964; Lozinskaya and Esipov 1971; Johnson 1975; Kwitter 1979) reveals an extremely high [N II]/Hα line-ratio which is thought to be due to an overabundance of nitrogen (Kwitter 1979). This nebula has been mapped in the radio wavelengths by Israel and Felli (1976) who find a very weak source ($S_{1415\ MHz} = 0.06 \pm 0.03$ fu) associated with the optical filaments. Another similar source without any optical counterpart appears also in their map. These two sources together seem to form an elliptical shell of angular dimensions of about 10 × 8 arcmin. Whether the last source is spurious or not is difficult to ascertain, since the weak shell emission is contaminated by the sidelobes of two strong point sources located in the neighborhood. The emission of these point sources was confused in the past with the nebular emission and, thus, pointed to a non-thermal nature. However, the very weakness of S 188 in the radio, along with the relatively bright optical appearance, is a strong argument against the non-thermal nature of S 188 and consequently to the supernova origin of this nebula.

Table 1 reproduces the unreddened line-intensities of two filaments of this nebula (filaments 1S-24 and 1E-KP in Kwitter's (1979) work, here marked by A and B respectively in the [N II] photograph shown in Figure 1 (Plate). This spectrophotometric work has been performed with both the Intensified Image Dissector Scanner (IIDS) attached to the KPNO 2.1 m reflector (filament B) and the Cassegrain Robinson-Wampler Image Tube Scanner (ITS) attached to the Lick Observatory 0.6 m reflector (filament A). Further details about the equipment, observations, data reductions and spectroscopic data of other filaments of S 188 can be found in Kwitter's thesis (1979). Table 2 reports the abundances derived from these data, under the assumption that the nebula is photoion-

TABLE 1[a]

UNREDDENED LINE-INTENSITIES OF TWO FILAMENTS OF S 188, NORMALIZED TO I(Hβ) = 100

Wavelength (A)	Ion	Filament A	Filament B
3726	[O II]	491	...
3729	...	820	...
3869	[Ne III]	157	...
3889	...	42::	...
3968	[Ne III]	53.2	...
4068	[S II]	41.7:	...
4101	H I	27	...
4340	H I	42	...
4363	[O III]	2.1::	...
4713	He I	13.1::	...
4959	[O III]	77:	81.3
5007			215
5755	[N II]	13.0	...
5876	He I	12.7	11.1:
6548	[N II]	350	324
6563	H I	285	280
6584	[N II]	1107	973
6717	[S II]	...	186
6731			161

a. From Table 4-3 of Kwitter (1979).

ized. These abundances are similar to typical abundances of Peimbert Type I planetary nebulae (PN), where the large overabundances of He and N result from CNO enrichment of the stellar envelope prior to shell ejection (Peimbert 1981). Indeed, the exciting star of this nebula seems to be a faint (V $\gtrsim$ 16 mag) blue star located off-center of the optical filaments (Lozinskaya 1970; Kwitter 1979). A featureless low dispersion spectrum of this star reveals a blue continuum.

Fabry-Pérot (FP) interferometry has been performed on this nebula by Georgelin *et al.* (1973) and by Lozinskaya (1970).

A summary of the nebular parameters derived from optical and radio observations is given in Table 3. In this work, we have obtained narrow-band interference filter photographs in the light of Hα, [S II], [N II] and [O III] and have performed additional FP interferometry. These kinematical results agree with the FP interferometry of Lozinskaya (1970) as to the value derived for the expansion velocity of some of the filaments. More important, our results improve the determination of the systemic motion and consequently discriminate between the different values reported for this quantity (Lozinskaya 1970; Georgelin *et al.* 1973).

TABLE 2

TOTAL ABUNDANCES (12 + log X/H) OF FILAMENTS A AND B OF S 188

O	N	N_e	S	H_e	i_{cf}(N, S)	$i_{cf}(N_e)$	i_{cf}(He)
8.95	8.50	9.31	7.04	11.14	1.14	8.30	152

The first five entries from Table 4-6 of Kwitter (1979).
The last three entries from Table 3-3 of Kwitter (1979).

II. OBSERVATIONS AND REDUCTIONS

The observations were carried out with a focal reducer attached mainly to the Cassegrain focus of the 1 meter reflector of the Observatorio Astrónomico de Tonantzintla. Additional photographs were taken with the 2.1 meter reflector of the Observatorio Astronómico Nacional at San Pedro Mártir. We obtained four narrow-band interference filter photographs in the light of Hα, [S II] (λλ6717 A), [O III] (λλ4949-5007 A) and [N II] (λλ6584 A) which are reproduced in Figures 1 and 2 (Plates).

Table 4 gives the characteristics of these photographs. We have also obtained three Hα-FP interferograms by means of an étalon with free spectral range of 190 km s^{-1}. Special care was taken in placing the FP rings perpendicular to the filaments in order to avoid the inhomogeneous brightness effect. The measurements of the interferograms were performed on the "Vibrating Mirror Comparator" of the Marseille Observatory. A description of the measurements and reductions can be found in Rosado *et al.* (1982).

III. KINEMATICAL DATA

The three FP interferograms that we have obtained, cover the whole set of filaments of S 188. Figure 3 (Plate) reproduces one of them. From these interferograms we obtained the radial velocity field of S 188. Some of these points have their FP profiles split. Figure 4 (Plate) shows these splittings super-imposed to our [N II] photograph in order to see their positions within the nebula. In a simple expansion motion, these splittings are correlated with the expansion velocity, assumed to be constant. In that case, the difference in the velocities of the split rings increases when the point approaches the center. In the particular case of S 188, this does not seem to be true: we find low velocity splittings near the assumed center. We did not find any explanation for this under the assumption of constant expansion velocity. However, the high velocity splittings (which are associated with tenuous filaments as revealed in the [N II] photograph) seem to be distributed in agreement with what we expect for a single expansion motion despite the fact that the optical shape of S 188 looks rather like an ellipsoid. These high velocity splittings imply an expansion velocity of 44±10 km s^{-1}. Thus, we can say that at least some filaments of S 188 expand with roughly this velocity. This agrees, within the uncertainties, with Lozinskaya's

TABLE 3

PHYSICAL PARAMETERS OF S 188 DERIVED FROM OPTICAL OR RADIO DATA

Optical dimensions:	8 × 4 sq. arcmin	Notes: 1
Electron density of the filaments:	200 cm^{-3}	2
r.m.s. electron density: (assuming a distance of 1 kpc)	17 cm^{-3}	3
Electron temperature of the filaments:	8900 – 9000° K	2
Observed Hα surface brightness:*	11 $mag/(')^2$	1
1415 MHz flux density of the radio source with optical counterpart:	60±30 mf u	3
Visual extinction:	0.85 mag	2

* Not corrected for reddening nor for the [N II] anomalous emission.
1. From Gaze and Shain 1965.
2. From Kwitter 1979.
3. From Israel and Felli 1976.

TABLE 4

CHARACTERISTICS OF THE NARROW-BAND INTERFERENCE FILTER PHOTOGRAPHS

Plate Number	Date	Filter characteristics λ_0(A)	$\Delta\lambda$(A)	Telescope	Exposure (min)	Emulsion
SN 87	November 25, 1980	6563	10	1 m	25	103aG
SN 94	November 25, 1980	6719.2	16.3	1 m	60	103aG
SN 239	October 22, 1981	5018.2	9.7	2.1 m	30	103aG
SN 259	October 22, 1981	6584	10	2.1 m	10	103aG

(1970) value of 35±2 km s^{-1}, which has been found by fitting a least squares straight line to both the high and low velocity splittings. The error she reports seems to be too low given the dispersion in her data. On the other hand, from the radial velocity field, we can obtain the motion of the nebula as a whole (systemic motion). A histogram of the radial velocities shows a single maximum in the velocity range −10 to −29 km s^{-1}. This implies that the filaments are moving with a single systemic motion within this velocity range.

More accurately, the systemic motion could be determined by taking a mean over the values of the radial velocities of points located at the outer boundary of the nebula. From such points we obtain V_c = −23±4 km s^{-1} (relative to the LSR). This value agrees quite well with Lozinskaya's value of −26±10 km s^{-1}, also obtained from FP interferometry (Lozinskaya 1970). It disagrees, however, with both Lozinskaya's spectroscopic value of −43±15 km s^{-1} (Lozinskaya 1970) and with the value reported by Georgelin *et al.* (1973) of −14.5±2 km s^{-1}. We think that our value represents an improvement because we have corrected the expansion motion by taking only points located at the outer bounday of S 188. In a simple expansion motion, these points do not make any contribution to the radial velocity component of the expansion velocity and thus, their measured velocity corresponds to the radial component of the systemic motion.

IV. IMPLICATIONS OF THE KINEMATICAL DATA UNDER THE HYPOTHESIS THAT S 188 IS A PN

a) *The Distance to S 188*

Distances to optically thin PN can be obtained in several ways (all of them highly uncertain). In the case of S 188, we have already discussed (Section I) that this nebula is most likely a PN of Peimbert's Type I. So that, in this particular case, we can obtain its statistical distance from Cudworth's correction (Cudworth 1974) to O'Dell's (1962) distance scale of optically thin PN: $d = 108\ \phi^{-3/5}\ I(H\beta)^{-1/5}$ pc, where ϕ is the mean angular radius in arcsec and I(Hβ) is the unreddened Hβ flux in cgs units. Taking $\phi = 210$ arcsec, an extinction of $A_V = 0.85$ mag (Kwitter 1979) and the estimated Hα flux given by Gaze and Shain (1965), corrected from the higher contribution of the [N II] (λλ6548-6584 A) lines, we obtain a distance to S 188 of about 0.74 kpc within a factor of two.

On the other hand, if S 188 is a Peimbert Type I PN, its deviation from circular motion cannot be very large and consequently we can obtain its kinematical distance from the knowledge of its systemic velocity. With a systemic velocity of -23 ± 4 km s^{-1}, we find a kinematical distance of $d = 1.6 \pm 0.27$ kpc. There could be some objection to this kinematical distance because S 188 is in the direction of the Perseus Arm where deviations from circular motions amount to about 5 km s^{-1}.

However, S 188 is located much closer to us than the Perseus Arm, in what is considered to be the Local Arm. The regions defining this Local Arm have quite different kinematical properties compared to those located at the Perseus Arm; they do not seem to deviate from circular motions (Georgelin *et al.* 1973). Thus, the kinematic distance seems to be reliable, and is larger than Cudworth's statistical distance. Consequently, we will take into account both of them in what follows.

b) *Velocity of Ejection and Age in the Spherically Symmetric Approximation*

Let us assume that the shell was formed by ejection of material from the progenitor of the PN nucleus (PNN). The ejected mass, m_o, begins to expand into the interstellar matter (ISM). Due to the pressure of the ISM and the fact (discussed in Isaacman 1979) that this mass immediately cools down, the ISM is rapidly accreted. Consequently, the motion of the ejected gas is governed by the equations of mass accretion and momentum conservation, which yield a time dependence for the radius and velocity of the type:

$$r + \frac{1}{4}\frac{r^4}{R_0^3} = V_e t \qquad (1)$$

$$V + V\frac{r^3}{R_0^3} = V_e \; , \qquad (2)$$

where

$$R_o \equiv \left(\frac{3\,m_o}{4\pi\rho_o}\right)^{1/3}$$

is the radius at which the ejected mass equals the mass swept up from the ISM of density ρ_o; V_e is the initial velocity of ejection and t is the age of the nebula. Equations (1) and (2) form a system of equations for the unknown V_e and t, for fixed values of v, r and R_o.

If we assume a spherical shell of linear radius of 0.8 pc (for Cudworth's distance, d_{CW}) or 1.9 pc (for the kinematical distance, d_{kin}), and we take $v \cong -40$ km s^{-1} for the expansion velocity as obtained in Section III, there remains to determine R_o. This quantity can be found from the measured radio flux (Israel and Felli 1976), and from the spectroscopic electron density (Kwitter 1979) which together with the estimated distances give the values of the total mass of the shell ($m_{sh} = \alpha^{1/2}\, M_\odot\, m_{sh}$ (rms); where $\alpha = (17/200)^2$ is the filling factor) of 0.04/(m_{sh} (rms) = 0.5 $M_\odot$) and 0.2 $M_\odot$ (m_{sh} (rms) = 2.3 $M_\odot$) for Cudworth's and kinematical distances, respectively. In obtaining this, we have assumed that the shell is formed by high density clumps ($n_e \sim 200$ cm^{-3}, as deduced from the [S II] line-ratio) with a small filling factor ($\sim (17/200)^2$) in order to explain the n_e(rms) value derived from the radio observations. Presumably these clumps are formed by material ejected from the envelope of the PN progenitor and by the swept-up ambient medium. In order to obtain the mass of the ejected gas we have to make some assumptions about the ambient interstellar matter (ISM): we assumed that the density of the ambient ISM has a Gaussian distribution in Z (Falgarone and Lequeux 1973) so that we could obtain the value of ρ_0 given the position of S 188 below the Galactic Plane. We obtain that $\rho_0 = 2.9 \times 10^{-25}$ or 2.7×10^{-25} gr cm^{-3} and consequently, the swept-up mass, $m_{su} = 0.01$ or 0.12 $M_\odot$ depending whether the distance is Cudworth's or kinematical. Thus, the derived ejected mass, m_o, is 0.03 $M_\odot$ (m_o(rms) $\cong$ 0.35 $M_\odot$) if the nebula is at Cudworth's distance or 0.08 $M_\odot$(m_o(rms) $\cong$ 0.94 $M_\odot$) if it is at the kinematical distance. Furthermore, depending on the adopted distance, we find for R_o either 1.18 or 1.68 pc. Solving equations (1) and (2) we finally obtain:

$$V_e = \begin{cases} 52 \text{ km s}^{-1} & \text{CW} \\ 98 \text{ km s}^{-1} & \text{KIN} \end{cases}$$

$$t = \begin{cases} 1.0 \times 10^4 \text{ yr} & \text{CW} \\ 2.6 \times 10^4 \text{ yr} & \text{KIN} \end{cases}$$

where CW and KIN mean that we have computed the value by adopting Cudworth's or kinematical distances.

There are some problems with this simple approach: the presumed PNN is located appreciably off-center of the approximate circle defined by the shell. Besides, the optical shape, and more markedly the radio shape, deviate from spherical symmetry. In fact, if the radio shape of S 188 is reliable, the asymmetry becomes more pronounced (see Figure 2 of Israel and Felli 1976).

The asymmetry and the off-center position of the PNN can be due either to the motion of the central star relative to the ISM or to the existence of large scale density inhomogeneities (such as density gradients). We have investigated the possibility of a density gradient along the Z-direction in the Galaxy but we have discarded this assumption because the radio major axis direction is almost parallel to the Galactic Plane. Furthermore, these effects are relevant to density gradients of the same characteristic length as the radius of the nebula. On the other hand, relatively dense clouds may be responsible of a density gradient in at least two ways: by density distributions in the cloud material itself in which case the ambient medium must be of high density or by an increase in the density of the intercloud medium (ICM) towards the cloud; in the latter case the medium would be less dense. The large overabundances of N and He implied by the spectroscopic data point towards a low density ambient medium. In fact, in order to explain the high N enrichment of the shell in the case where the ambient medium is quite dense (and consequently, the ejected material has swept-up large amounts of ambient mass), the star must have a high initial mass ($M \sim 60\ M_{\odot}$) and it has to eject a great deal of material from deep layers of its envelope (which have the desired abundance in N) towards the end of its MS phase. If, at the very limit, we assume that this material could be lost in the form of winds, then, the mass-loss must be at a rate of about $10^{-6} - 10^{-5}$ $M_{\odot}$/yr or even higher, and this must continue until now in order to explain the existence of the SSSW driven bubble, in this case identified with S 188. No such massive, windy star is found inside S 188. The blue star we proposed as the exciting star has a spectrum, probably of the type of a white dwarf and from the knowledge of mass loss in these stars it seems quite difficult to explain such a strong wind. Thus, the density gradient is better explained by the existence of a density variation in the low density medium immediately outside the cloud (probably with an exponential density law) rather than by the high density medium of the cloud.

Weak CO emission ($T_A \sim 0\overset{\circ}{.}7$ K and with two peaks at $v_{LSR} = -16$ and -22 km s^{-1}) has been found in a position offset by 11 arcmin from the optical filaments in the SE direction (Israel 1980). It is quite possible that this weak cloud has nothing to do with S 188 though one of the velocity components is nearly equal to the systemic velocity of this nebula. In fact, the uncertainties in the kinematic distance of this nebula ($\sim$ 270 pc) are much larger than typical cloud dimensions ($\sim$ 10 pc). Furthermore, the CO emission spreads over a wide range of radial velocities ($\Delta V_r \cong 10$ km s^{-1}) so that we are not able to know, at present, if there are several components located at different distances or a single cloud with turbulent motions in which case the kinematical distance of the cloud would be rather uncertain. The offset position of the cloud is inconclusive until we know the real distance of this cloud and its dimensions. A higher sensitivity survey of this region is required in order to ascertain if the cloud is indeed interacting with the nebula. As a speculation, at a kinematic distance of 1.6 kpc, the mentioned offset position corresponds to a linear separation of 5 pc so that, if the cloud is located at this distance and if it is a relatively small cloud (of about 5 pc in diameter) then the low density ICM, having a density gradient; may be responsible for the non-spherical shape of this nebula due to the interaction of the stellar ejecta with this density-varying IC medium (Dyson 1977; Kompaneets 1960).

V. DISCUSSION

The kinematical data we have obtained agree with Lozinskaya's (1970) results and allow us to discriminate a value of the systemic velocity among the values already reported. These data, together with the new spectroscopic data (reported here and in Kwitter 1979) allow us to understand better the nature of S 188: a) this object is quite probably a PN of Peimbert's Type I (Peimbert 1981). b) Some of the optical filaments are found to be expanding at about 40 km s^{-1}, as Losinskaya has already shown (Lozinskaya 1970). c) The kinematic distance derived from the results of this work places S 188 farther away than the location predicted by Cudworth's distance scale.

The non-spherical shape of the nebula and the off-center position of the presumed PNN can be explained either by the motion of the PNN relative to the ambient medium or by the existence of a density gradient in the ambient medium. In the latter case, the disagreement between kinematical and Cudworth's distances could be interpreted as evidence of a larger rms mass of ionized hydrogen (m_{sh} (rms) = 2.3 $M_{\odot}$, instead of the assumed value of 0.5 $M_{\odot}$), as found in Section IV. This would imply that Peimbert's Type I PN's have larger ejected masses than typical PN's and consequently this would be an indirect evidence that the progenitor of Peimbert's Type I PN's are more massive stars.

At present, the observations are insufficient in order to discriminate between the two possible origins of the non-spherical shape already mentioned. The observed overabundances point towards a low density ambient medium. If the non-spherical shape is due to the existence of a density gradient in the ambient medium, this could be the intercloud medium located near a molecular cloud of higher density rather than the medium of the molecular cloud itself. This ICM has presumably a variation in density distribution. The observation of weak CO emission at 11 arcmin off-set from the direction of the optical filaments must be pursued further, at higher sensitivity, in order to ascertain if this weak CO cloud is associated with S 188, and in addition to know the dimensions and the density of the cloud. Without these required data we can only speculate about the possible influence (if any) of this cloud on the filaments.

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