

IRAS 22568+6141: a new bipolar planetary nebula

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Abstract. When carrying out a survey of IRAS sources with infrared colours similar to those of planetary nebulae, IRAS 22568+6141 was found to be a new young planetary nebula. It shows an extension of 8" and a bipolar structure. From its optical low resolution spectrum we have derived a high extinction $E_{B-V} = 2.37$, an electronic temperature of $T_e = 11\,500\text{ K}$ and an electronic density of $N_e = 2 \cdot 10^4\text{ cm}^{-3}$. Making use of the Shklovskii modified method and considering an infrared excess $\langle \text{IRE} \rangle = 37$, we have estimated a distance of 6 kpc. This value is consistent with the H α radial velocity $V_{\text{LRS}} = -80\text{ km s}^{-1}$ derived from the high resolution spectrum. An expansion velocity of 70 km s^{-1} is found for the nebula, which combined with the adopted distance gives a kinematical age of 1800 years. From the IRAS data a total dust + gas envelope mass of $0.4 M_{\odot}$ is inferred. This implies that a mass loss rate phase of $\dot{M} \geq 10^{-5} M_{\odot} \text{ yr}^{-1}$ has been necessary to form the nebula. The exciting star has an effective temperature of $T_{\text{eff}} = 24\,000\text{ K}$. The elemental abundances values, its position in the HR diagram, the infrared characteristics and its kinematical age indicate that this is a young planetary nebula with a $1 M_{\odot}$ progenitor.

Key words: planetary nebulae: IRAS 22568+6141 – proto-planetary nebulae – infrared: sources

1. Introduction

Planetary nebulae (hereafter, PNe) are known to be very strong emitters in the far infrared for more than 20 yr (Gillet 1967). During the last decade, with the advent of the IRAS first systematic survey of the sky at 12, 25, 60, and 100 μm , this fact was confirmed. Most of the known PNe were detected at least in the IRAS 25 and 60 μm bands and included in the Point Source Catalogue (PSC) as compact infrared sources (Preite-Martinez 1989, and references therein). Only the more diffuse extended PNe were not detected by the IRAS satellite. In fact, a well defined region of the two colour diagram F_{12}/F_{25} vs. F_{25}/F_{60} contains more than 90% of the PNe detected by IRAS (Pottasch et al. 1988) and there is only a small overlap in this zone of the diagram with some HII regions and Seyfert galaxies, the normal stars being completely separate from PNe. The only important overlap is with the so called OH/IR stars, which are heavily obscured stars surrounded by optically thick and oxygen rich circumstellar envelopes which completely obscure the light coming from the central star. These objects show OH maser emission coming from

their envelopes and are only visible in the infrared. It seems well established that they are transition objects between red giant stars and young and compact PNe (see e.g. Iben & Renzini 1983; Habing et al. 1989). When the stars reach the end of the AGB (asymptotic giant branch) phase, a “superwind” (Renzini 1981) begins and extremely high mass loss rates (sometimes more than $10^{-5} M_{\odot} \text{ yr}^{-1}$) produce the formation of thick circumstellar envelopes at temperatures typically of 150–250 K where dust grains are formed, very similar to the slightly lower dust temperatures found in young and compact PNe (Pottasch et al. 1988; Kwok 1989). This fact can be explained if we consider that a new PN is formed when the high mass loss rate ceases, and the envelope is detached. Afterwards, the temperature decreases as the envelope expands in the interstellar medium and the central star emerges again, hot enough to ionize the surrounding material.

All these things together make the far-infrared radiation very useful when searching for new PNe and objects in the transition phase from AGB stars to PNe. At present we are carrying out an observational programme to search for these objects, making use of the IRAS Point Source Catalogue. From this catalogue we have selected about 1000 sources, most of them unidentified, with the required infrared colours (Manchado et al. 1989). The selection criteria are explained in Pottasch et al. (1988) and we are using not only optical observations but also near-infrared (Manchado et al. 1988; García-Lario et al. 1990) and radio measurements (Zijlstra et al. 1989; Ratag et al. 1990). As a part of the results obtained with this search we have found IRAS 22568+6141 to be a new young bipolar PN. This source had not been previously identified in the literature, but it was also included in a list of possible new IRAS PNe compiled by Preite-Martinez (1988) as PM 1-339. It shows an extremely faint optical counterpart, only visible in the Palomar red print, with stellar appearance. In the following, we will describe the observations we made, followed by a detailed analysis of the data, as well as some comments and conclusions about the nature and evolutionary stage of IRAS 22568+6141.

2. Observations and results

2.1. Direct imaging

Figure 1 shows the H α , Z, Glass R and V CCD images of IRAS 22568+6141 obtained at the 1 m Jacobus Kapteyn Telescope (JKT)¹ in July 1990. In Fig. 2 we have plotted a contour map of

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¹ The JKT, WHT and INT telescopes are operated by the Royal Greenwich Observatory at the Spanish Observatorio del Roque de los Muchachos at La Palma (Spain).

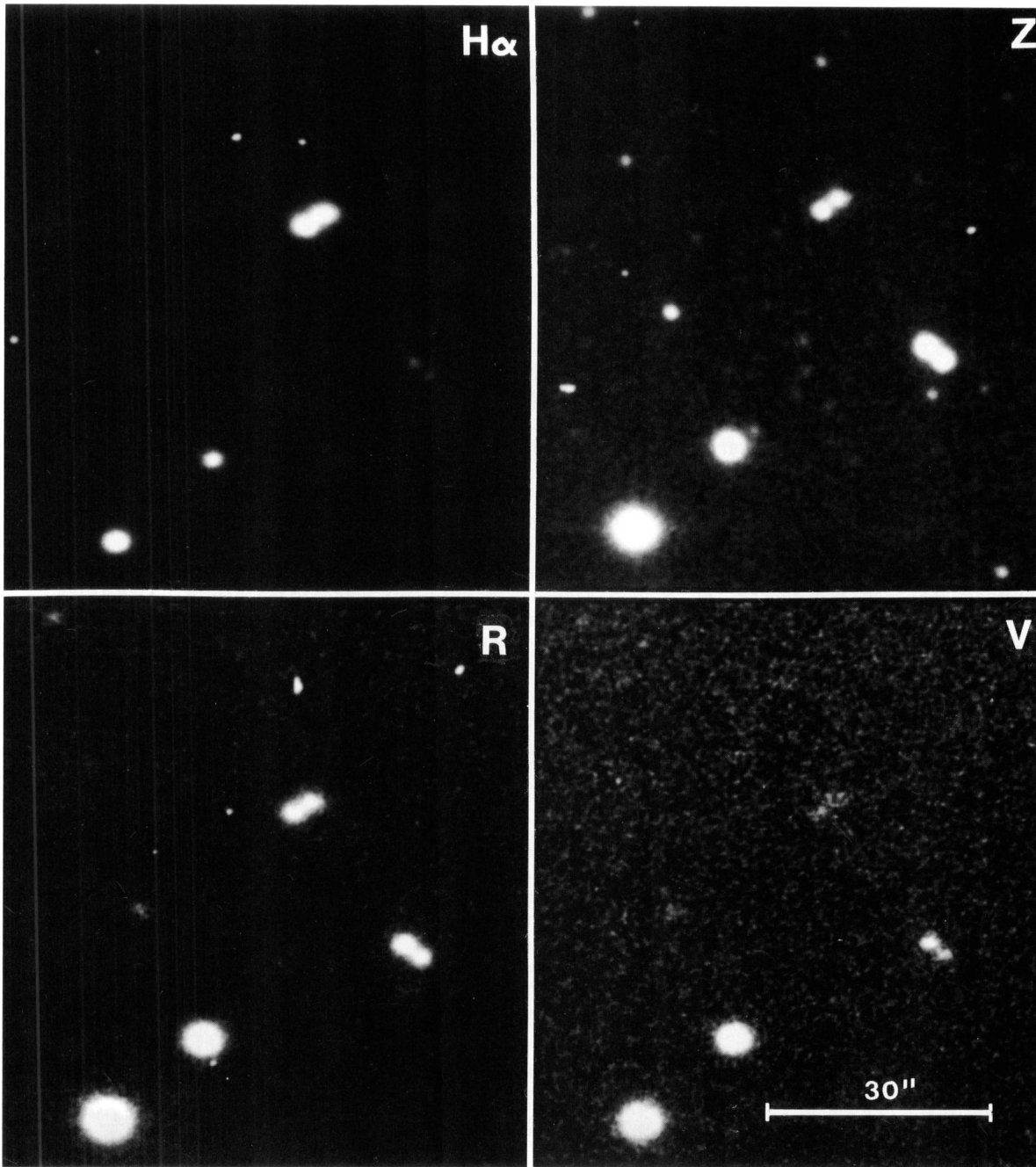


Fig. 1. H α , Z, R and V CCD images of IRAS 22568 + 6141 obtained at the 1 m JKT telescope. North is up and east at the left

IRAS 22568 + 6141 in the light of H α , where the bipolar structure of the nebula is clearly seen. We used a GEC CCD (590×400 pixels) as detector with a scale of $0''.30 \text{ pixel}^{-1}$. The structure consists of two spherical lobes of nebular appearance, each one with a diameter around $4''$, with the south-east lobe brighter than the north-west one. Its location on the sky coincides within the errors with the original IRAS coordinates quoted in the PSC (see Table 1). The estimated errors in the IRAS position are about $15''$ in both R.A. and DEC., while the optical position corresponds to the WHT coordinates, whose accuracy is better than $3''$. From the comparison of the brightness in the different filters, it looks extremely red. The V and R photometric magnitudes have been

derived from these CCD images using standard STARLINK software and they are quoted in Table 1.

2.2. Optical spectroscopy

Low resolution spectroscopy was conducted in July 1988, using the 4.2 m William Herschel Telescope (WHT)¹ with a slit $3'$ long and $1''.5$ wide with a position angle of 140° with respect to the N-S direction, following the bipolar axis of the nebula as viewed in the TV guiding camera of the WHT. The spectrum was obtained using the Faint Object Spectrograph, FOSII (Allington-Smith et al. 1988), attached to the $f/11$ Cassegrain focus. FOSII is a cross-

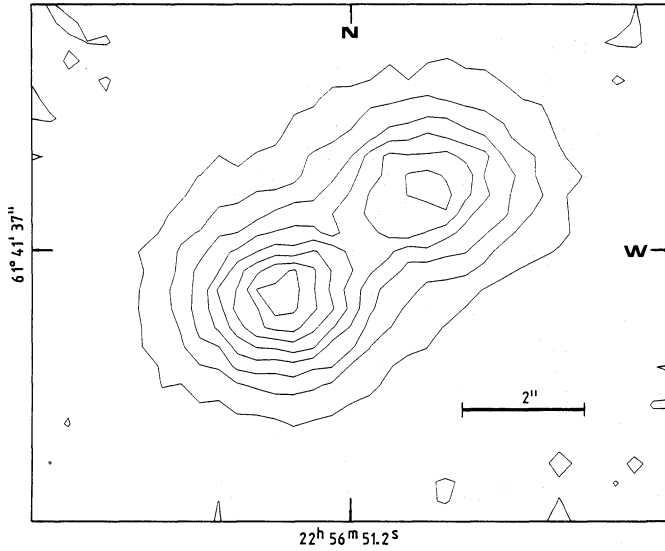


Fig. 2. Contour map of IRAS 22568 + 6141 in the light of H α , derived from the CCD image taken at the 1 m JKT telescope. The scale for the contour levels is linear

Table 1

IRAS position (1950.0)	$\alpha = 22\ 56\ 51.6$ $\delta = +61\ 41\ 39$
Position found (1950.0)	$\alpha = 22\ 56\ 51.2$ $\delta = +61\ 41\ 37$
F_{12} (Jy)	1.85 ± 0.09
F_{25} (Jy)	17.1 ± 0.85
F_{60} (Jy)	20.1 ± 2.8
F_{100} (Jy)	≤ 45
T_d (12/25) (K)	122 ± 2
T_d (25/60) (K)	90 ± 5
$F(\text{IR})$ ($10^{-14} \text{ W m}^{-2}$)	300 ± 10
$\langle \text{IRE} \rangle$	37 ± 5
R (mag)	16.7 ± 0.3
V (mag)	≥ 18.8

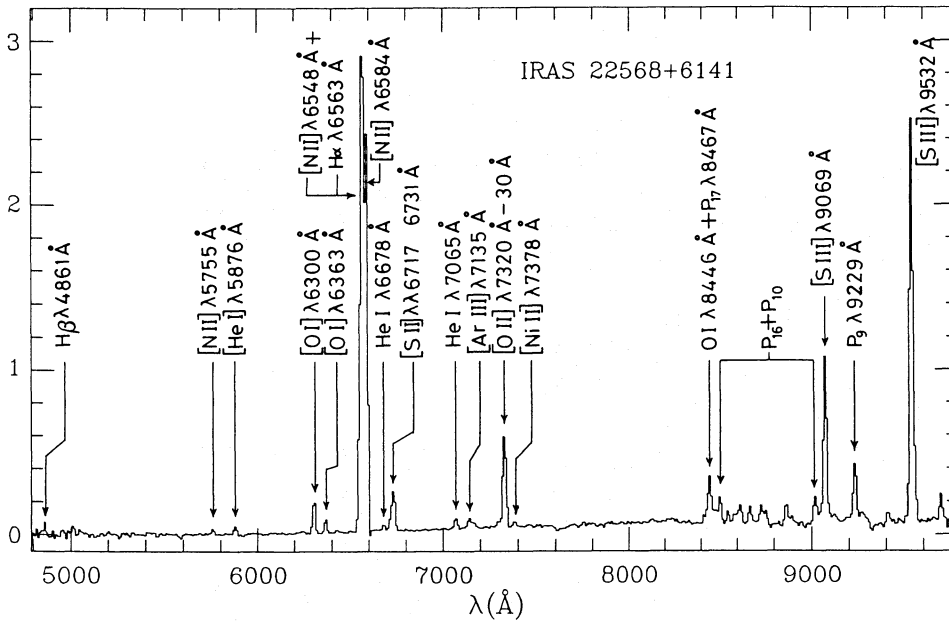


Fig. 3. Low resolution spectrum of IRAS 22568 + 6141 taken at the 4.2 m WHT telescope

dispersed spectrograph with a blue-coated GEC CCD as detector. The spectral range covers from 4700 Å to 9800 Å and from 3400 Å to 4900 Å, with spectral resolutions of 16.3 Å and 8 Å, in the first and the second order, respectively. The spatial scale is 0.8 pixel^{-1} . Preliminary FOSII data reduction was carried out at La Palma with the on-line data reduction package available in the WHT VAX 8300 (software written by J. Allington-Smith). Firstly, correction for geometrical distortion is done using the stored geometrical correction coefficients. Afterwards, extraction of the spectra, including subtraction of the background is carried out. Wavelength calibration was done using the standard coefficients. Flux calibration and subsequent analysis was done at the IAC's VAX 8350, using the Starlink Software Collection.

The low resolution spectrum is shown in Fig. 3. For this plot we have added the spatial increments corresponding to both lobes as they did not show any significant difference and includes only the first order of the spectrum because the second order (blue component) does not show any other line but H β in emission, probably because of the high extinction (see Sect. 3.1). No [O III] lines at 4959 and 5007 Å are seen, and the presence of emission lines of He I and O I, as well as the absence of higher ionization states indicates the low excitation nature of IRAS 22568 + 6141. Although very faint, we must note here the presence of an underlying continuum which can be explained as reflected light, coming from the central star, by the surrounding dust. These line intensities are presented in Table 2 referred to H β = 100.

Table 2. Line intensity ratios for IRAS 22568 + 6141

Line	$f(\lambda)$	$I(\text{H}\beta=100)$	$I^a(\text{H}\beta=100)$
4861 H β	0.00	100 $\pm$ 10	100 $\pm$ 10
5755 N II	-0.13	41 $\pm$ 4	8.0 $\pm$ 0.8
5876 He I	-0.23	74 $\pm$ 7	11.9 $\pm$ 1.2
6300 [O I]	-0.30	294 $\pm$ 15	27.3 $\pm$ 1.3
6363 [O I]	-0.31	123 $\pm$ 6	10.5 $\pm$ 0.5
6548 [N II]	-0.34	1140 $\pm$ 20	78 $\pm$ 2
6563 H α	-0.34	4475 $\pm$ 80	304 $\pm$ 6
6584 [N II]	-0.34	3475 $\pm$ 75	235 $\pm$ 5
6678 He I	-0.35	50 $\pm$ 7	3.1 $\pm$ 0.4
6717 [S II]	-0.36	165 $\pm$ 15	9.5 $\pm$ 0.9
6731 [S II]	-0.36	331 $\pm$ 25	19.1 $\pm$ 1.5
7065 He I	-0.40	110 $\pm$ 10	4.6 $\pm$ 0.4
7137 [Ar III]	-0.41	170 $\pm$ 25	6.6 $\pm$ 1.0
7320, 30 [O II]	-0.43	1085 $\pm$ 75	36 $\pm$ 3
7378 [Ni II]	-0.49	60 $\pm$ 15	1.9 $\pm$ 0.5
8446 [O I]	-0.56	500 $\pm$ 50	6.2 $\pm$ 0.6
9015 P ₁₀	-0.62	260 $\pm$ 40	1.9 $\pm$ 0.3
9069 [S III]	-0.64	1650 $\pm$ 150	10.3 $\pm$ 1.0
9229 P ₉	-0.64	640 $\pm$ 80	4.0 $\pm$ 0.6
9535 [S III], 9540 P ₈	-0.65	4400 $\pm$ 300	25.5 $\pm$ 1.8
$F(\text{H}\beta)$ (erg cm ⁻² s ⁻¹)		1.16 10 ⁻¹⁵	2.35 10 ⁻¹²

^a Corrected of extinction

Figure 4 shows a higher resolution spectrum of IRAS 22568 + 6141 in the range from 6200 to 6800 Å obtained using the 2.5 m Isaac Newton Telescope (INT) ¹ with the slit again following the bipolar axis. At the INT we used the Intermediate Dispersion Spectrograph IDS (La Palma Observer's Guide, 1988) on the *f*/15 Cassegrain focus, with the 235 mm camera and the IPCS as detector. The IPCS was used in the configuration of 2040 spectral channels by 120 spatial increments, with pixel sizes of 50 µm in the spatial direction and 15 µm in the spectral direction. Using the 1200 g mm⁻¹ grating in the first order the dispersion of 35 Å gave an effective spectral resolution of 0.9 Å, while each spatial

increment corresponds to 1".5. Data reduction was carried out at the IAC's MV 20000 computer using the standard software package PANDORA; these data were wavelength calibrated, sky subtracted and extinction corrected in two dimensions. Wavelength resolution is better than 0.13 Å (6 km s⁻¹ at H α).

2.3. CO observations

IRAS 22568 + 6141 was observed in the *J*=2→1 line of CO during February 1989 using the 12 m NRAO antenna at Kitt Peak. ² The measured beam size was 30" while the rms pointing error was of 5". We used a 2 MHz filter corresponding to a velocity resolution of 2.6 km s⁻¹ and employed the usual ambient chopper technique to remove atmospheric attenuation and telescope losses; this procedure yields a temperature scale denoted T_A^* , subsequently transformed into T_R^* via the forward spillover function n_{fss} (Kutner & Ulich 1981), $T_R^* = T_A^*/n_{\text{fss}}$, where n_{fss} is taken to be 0.75.

We observed the source at three positions: the centre (the nominal PSC position) and offsets of 40" to the north and south, with the reference position separated by 30' in azimuth. No emission was detected at any position with $T_R^* \geq 0.1$ K and $V_{\text{LSR}} = -80 \pm 50$ km s⁻¹ (this is the V_{LSR} derived from the high resolution spectrum, as we will see below) and there is only a strong emission/absorption feature around $V_{\text{LSR}} = -8$ km s⁻¹ which is due to incomplete subtraction of the background emission, as IRAS 22568 + 6141 is located in a zone rich in molecular complexes, with the nearby outflow source Cep A (see e.g. Plambeck et al. 1983) as the most prominent member, with the same V_{LSR} than this feature.

3. Optical analysis

3.1. Spectral analysis and physical properties

From the low resolution spectrum we derived a high extinction $E_{B-V} = 2.37$. The visual extinction has been estimated from the

² The National Radio Astronomy Observatory is operated by Associated Universities Inc. under contract with the National Science Foundation.

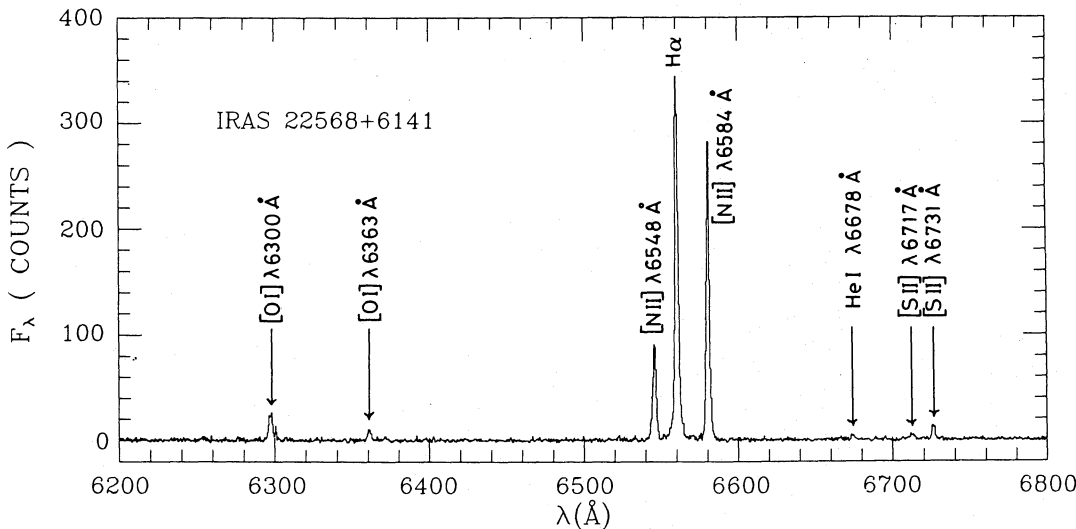


Fig. 4. High resolution spectrum of IRAS 22568 + 6141 taken at the 2.5 m INT telescope

ratio between $H\alpha$ and $H\beta$ adopting case B recombination (and $T_e = 10^4$ K) using the standard reddening law by Whitford (1958). This gives a value for $A_v \sim 7.4$ mag. The $H\beta$ flux has been derived from the blue component of the spectrum where this line shows a higher signal to noise ratio. The use of the ratios between the Paschen and Balmer lines leads to slightly higher values. However, we have adopted the extinction derived from the Balmer lines because the determination of the Paschen lines fluxes in our spectrum is more uncertain. We present in Table 2 the intensities of the emission lines observed in IRAS 22568 + 6141 before and after the correction due to extinction. In this Table we have only included those lines which are not severely affected by blends (this is the case of many of the Paschen lines), except O I at $\lambda 8446$, which is blended with P_{17} ($\lambda 8467$). In fact, the expected flux for P_{17} assuming recombination (case B), which, as we will see below, is valid for the Paschen lines, gives a contribution of less than 15% to the total flux measured. The presence of this oxygen line is remarkable because it cannot be explained in terms of pure recombination. In that case, we should also detect the stronger O I $\lambda 7774$ line, which is not visible at all in the spectrum. There are two other possible mechanisms of formation for this line (Mc Gregor et al. 1984). One of them is direct excitation by radiation coming from the central star, but then we should have detected other O I emission lines at $\lambda 7002$ and $\lambda 7254$. The other one seems more reasonable: the upper levels of O I are excited because of the coincidence in wavelength between the transitions $Ly\beta$ $\lambda 1025.72$ and O I $\lambda 1025.76$. After this excitation, several emission lines are produced at $\lambda 11287$ ($3p^3P \rightarrow 3d^3D$), $\lambda 8446$ ($3s^3S \rightarrow 3p^3P$), and $\lambda 1302$ ($2p^3P \rightarrow 3s^3S$). To check this hypothesis we should need to measure these lines which are not included in the observed spectral range. Until this can be confirmed we must accept the Lyman- β fluorescence as the most plausible origin for this line.

Another peculiar feature in IRAS 22568 + 6141 is the presence of an emission line at $\lambda 7378$ Å which we have identified as [Ni II]. If this is true, we should also find another [Ni II] line at $\lambda 7412$ Å, which is not present in the spectrum. However, this line should emit only 10% of the flux we observe for the main line, which is at the noise level in this region. This fact, together with the poor resolution of the spectrum, makes it impossible to confirm its nature. This [Ni II] $\lambda 7378$ line has also been detected in Seyfert galaxies and H-H objects with a stronger intensity than expected in gaseous nebulae, and cannot be explained in terms of enhancement of Ni abundance, although nobody has found any alternative mechanism to explain the strong intensities detected (Henry & Fesen 1988).

Concerning the Paschen lines of hydrogen between 8447 Å (P_{17}) and 9229 Å (P_8), all them have been detected in our spectrum, but the measurement of their fluxes is difficult as some of them appear partially blended with other lines, like P_{17} with O I $\lambda 8446$, as we have referred above, or are extremely faint. In these cases we did not include them in Table 2. Bearing all this in mind we have tried to study the ratios between these lines and $H\beta$ considering recombination (case B) comparing the measured values with those expected from the theory. The observed values are systematically higher than expected. However, these ratios are extremely sensitive to the extinction. This could indicate, either that the extinction has not been correctly calculated (a small difference in the adopted value produces large changes in the corrected fluxes at these wavelengths) or that the average extinction law is peculiar in this region of the sky or is no longer valid in the wavelength range near 1 μ m. The alternative we used to check if recombination (case B) is consistent with the measured fluxes is the use of the internal ratios between the different Paschen lines. In

Table 3. Physical parameters and abundances for IRAS 22568 + 6141

$E(B - V)$	2.37
N_e (cm $^{-3}$)	$2 \cdot 10^4$
T_e (K)	11 500
T_{eff} (central star) (K)	24 000
$N(O^+ (7320))/N(H)$	$26.3 \cdot 10^{-5}$
$N(O^0 (6300))/N(H)$	$4.0 \cdot 10^{-5}$
$N(O^0 (6363))/N(H)$	$4.7 \cdot 10^{-5}$
$N(N^+ (6548 + 6584))/N(H)$	$4.35 \cdot 10^{-5}$
$N(S^+ (6717 + 6731))/N(H)$	$0.23 \cdot 10^{-5}$
$N(S^{2+} (9069))/N(H)$	$0.11 \cdot 10^{-5}$
$N(Ar^{2+} (7137))/N(H)$	$0.16 \cdot 10^{-5}$
$N(He^+ (6678))/N(H)$	0.08
$N(O)/N(H)$	$30.5 \cdot 10^{-5}$
$N(N)/N(H)$	$5.0 \cdot 10^{-5}$
$N(S)/N(H)$	$0.34 \cdot 10^{-5}$
$N(Ar)/N(H)$	$0.24 \cdot 10^{-5}$
$N(He)/N(H)$	≥ 0.08
$N(N)/N(O)$	0.165

this case, the observed data and the theory are consistent within the errors.

The electronic density N_e has been estimated from the ratio $[S II] \lambda 6717/[S II] \lambda 6731$ in the high resolution spectrum, obtaining a value of $N_e \sim 3 \cdot 10^4$ cm $^{-3}$ for the east lobe and $N_e \sim 4 \cdot 10^3$ cm $^{-3}$ for the west one, thus indicating high densities in both lobes, but the discrepant values are consistent within the errors; so, a mean value of $N_e = 2 \cdot 10^4$ cm $^{-3}$ has been adopted for the calculation of the ionic and elemental abundances.

The electronic temperature has been derived from the ratio $[N II] \lambda 5755/[N II] (\lambda 6548 + \lambda 6584)$ in our spectrum, obtaining a value of $T_e = 11\,500 \pm 500$ K, where the associated error has been taken considering the dependence of the temperature with the density and the range of values for N_e above determined.

3.2. Ionic and elemental abundances

Using a programme to solve the equations of statistical equilibrium for a ten level atom written by Preite-Martinez (1986) and the compilation of atomic coefficients by Mendoza (1983), we have calculated the ionic abundances, which are presented in Table 3 together with other relevant physical parameters. Elemental abundances were calculated assuming simple ionization correction factors (Torres-Peimbert & Peimbert 1977) and are also shown in Table 3. Errors are estimated to be about 20% in both the ionic and elemental abundances.

A special attention deserves the calculation of the helium abundance. The ionic abundance of He^+ can be determined from the recombination lines at $\lambda 5876$ and $\lambda 6678$, which are less affected by collisional and self-absorption effects than other helium lines. Taking into account the possibility for these lines to be affected by collisional effects as the density is considerably high, and following Ferland (1986), we found that the $He I$ line at $\lambda 5876$ is significantly affected (about 25%) by collisions, while the effect on the $\lambda 6678$ $He I$ line is neglectable (less than 1%). On the other hand, self absorption tends to increase the intensity of the $He I$ $\lambda 7065$ line. This effect can be studied from the ratio $He I \lambda 7065/He I \lambda 4471$. Unfortunately, the extinction is so high that we did not detect the $\lambda 4471$ line, but we have proved that $He I \lambda 6678$ is

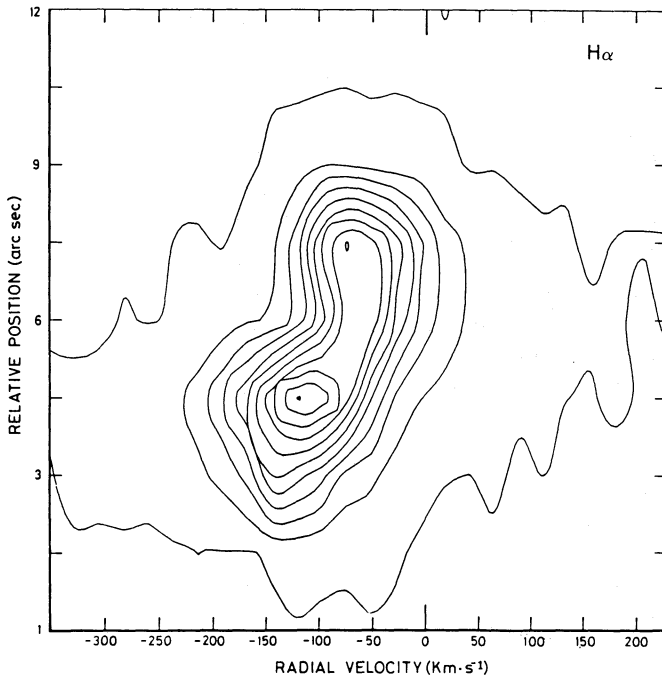


Fig. 5a. Contour map of velocities vs. position for the $H\alpha$ line. The slit was orientated following the bipolar axis

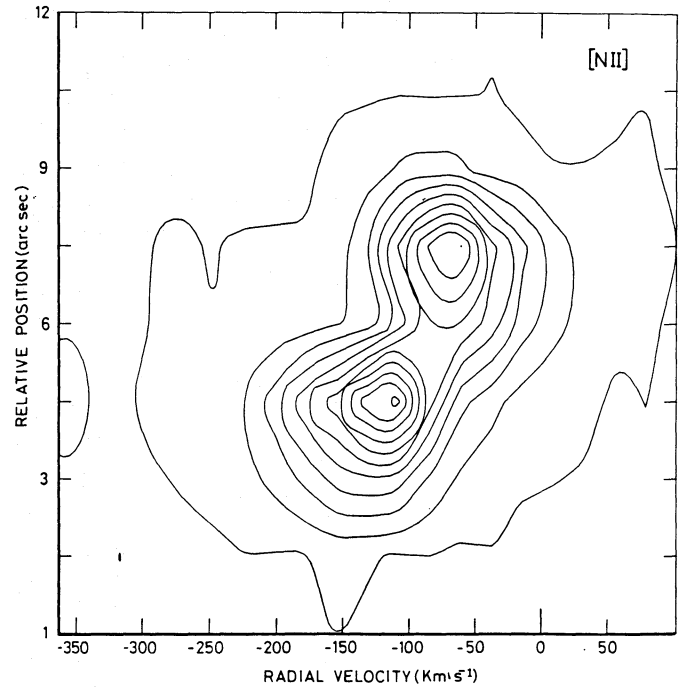


Fig. 5b. Same as Fig. 4a for the $[N II] \lambda 6584$ line

not affected by collisions; so, we can use the ratio $He I \lambda 7065/He I \lambda 6678$ as an indicator. The theoretical value for pure recombination is 0.4 (Pottasch 1984). In our case, we found a value of 1.5, thus indicating that the $He I \lambda 7065$ line is probably enhanced by self-absorption, and thus, will not be used in our calculations.

Once corrected for collisional excitations, the ionic abundances of He^+ derived from the helium lines at $\lambda 5876$ and $\lambda 6678$ are coincident within the errors ($N(He^+)/N(H) = 0.08$). However, this value must be considered only as a lower limit, as the calculation of the total helium elemental abundance must also include the correction factor due to neutral helium which is expected to be present in the nebula, considering the low excitation characteristics seen in the spectrum, but cannot be obtained directly from the observations. We have used the formula given by Peimbert & Torres-Peimbert (1977) to try to correct for this effect. From this expression we obtain that 75% of the helium in the nebula should be in the form of He^0 . This yields an extremely high value for the helium abundance of $N(He)/N(H) \sim 0.30$ which seems to be non realistic and could be an overestimation, probably due to the uncertainties involved in the determination of this ionization correction factor.

3.3. Kinematic properties

From the high resolution spectrum, shown in Fig. 4, we have computed a radial velocity of $V_{LRS} = -80 \text{ km s}^{-1}$. Assuming that the nebula belongs to the disk (the galactic coordinates are $l = 110.1$, $b = +1.9$) we can estimate a kinematic distance between 6 and 9 kpc if we suppose the object follows the rotation curve of the Galaxy (Pottasch 1984), although PNe are known to show large deviations from circular velocities. In Figs. 5a and 5b we present the contour maps of velocities for the $H\alpha$ and $[N II]$ lines. They have been obtained from the spatial analysis of the line profile observed in this high resolution spectrum. Both show a very similar appearance and reveal the bipolar structure of the

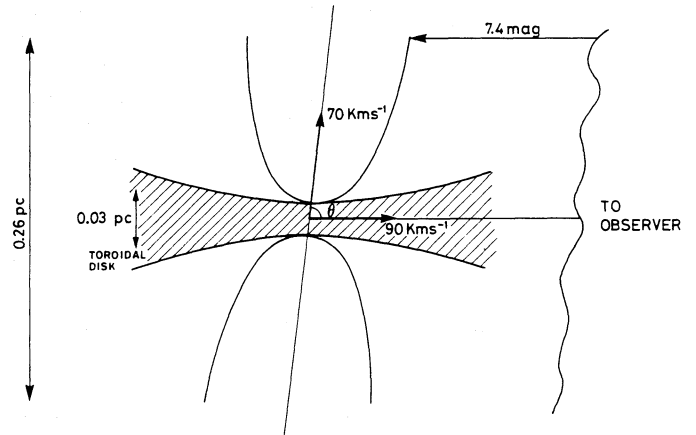


Fig. 6. Proposed model for IRAS 22568 + 6141

nebula, although the dark central zone can not be resolved. From both maps we obtain the same difference of $60-70 \text{ km s}^{-1}$ between the peaks of each lobe. A simple model has been plotted in Fig. 6 which can explain all the kinematic properties observed in the high resolution spectrum. From the adopted geometry we have derived an expansion velocity of $V_{exp} = 70 \pm 15 \text{ km s}^{-1}$. For this model we have assumed that the predominant emission arises from the edges of the outflow region. However, we did not find splitting in the lines; therefore, it is possible that the outflowing gas is filling the whole volume of the lobes. In this case, this expansion velocity should be considered as a lower limit. These very high expansion velocities have also been observed in other young PNe with similar bipolar outflows like 19W32 (López 1987), Mz-3 (López & Meaburn 1983), M2-9 (Walsh 1981) or NGC 6302 (Meaburn & Walsh 1980), and could be explained as the result of the strong collimation produced by the disk of dust which is suspected to be

the responsible for the formation of the bipolar structure, accelerating the material which is being ejected through the lobes.

4. Infrared results

In Table 1 we present the far infrared non colour-corrected IRAS PSC flux densities of IRAS 22568+6141. The associated errors are given by the parameter RELUNC quoted in the PSC (see IRAS Explanatory Supplement, 1985). We also show the corresponding dust colour temperatures derived by fitting modified blackbodies ($\epsilon \propto \lambda^{-1}$ was assumed for the grains) to the IRAS points. These values are typical of PNe and dissimilar to those shown by giant or compact H II regions (Antonopoulou & Pottasch 1987; Churchwell 1990). Furthermore, its location in the [100]–[25] vs [60]–[25] diagram also separates IRAS 22568+6141 from the locus occupied by H II regions.

An important parameter relating dust and gas properties in an ionized region, the infrared excess $\langle \text{IRE} \rangle$ can be estimated from the integral H β and far infrared luminosities by comparing the observed far infrared flux with the far infrared flux expected if all the Lyman- α photons produced in the nebula were responsible of the heating of the dust (Pottasch 1984). In large and old nebulae the mean values found coincide with what should be expected from this mechanism of heating, but in young and compact PNe there are strong infrared excesses which cannot be explained only as the result of heating by the absorption of Lyman- α photons. In these cases direct radiation coming from the central star seems to be the most plausible source of this extra-heating (Preite-Martinez 1989). The strong infrared excess found for IRAS 22568+6141 of $\langle \text{IRE} \rangle = 37$ therefore suggests a relatively early evolutionary status for IRAS 22568+6141 as a PN. We must note here that, with this value for the $\langle \text{IRE} \rangle$, one should expect a considerable radio continuum flux for the object of $S(5 \text{ GHz}) = 8 \text{ mJy}$. However, no radio measurements have been attempted yet for this source.

Making use of the Shklovskii modified method (Pottasch 1984), we can obtain an estimation for the distance to IRAS 22568+6141, from the relation between distance, far infrared flux and infrared excess (see e.g. Preite-Martinez 1988, for a detailed description of this procedure), of $D = 6 \text{ kpc}$, in good agreement with the kinematic value deduced above. We will adopt this value in the following.

The infrared luminosity of the source, on the other hand, can be estimated integrating the IRAS fluxes and extrapolating them from $60 \mu\text{m}$ to $\lambda = \infty$ following Myers et al. (1987), obtaining

$$L = 9.35 \cdot 10^{-5} D^2 (\text{pc}) (L_{\odot}) \quad (1)$$

or $L = 3300 L_{\odot}$ at $D = 6 \text{ kpc}$ in agreement with the typical values found in objects in the transition phase from post-AGB stars and PNe (Habing et al. 1989). This is indeed a lower limit to the total luminosity of the source, because we are neglecting the contribution from wavelengths shorter than $12 \mu\text{m}$ although it will approach closely the actual luminosity if the bulk of ultraviolet and optical photons are reprocessed by dust grains, which, considering the faintness of the object in the visible, seems to be a plausible hypothesis. With all this in mind we estimate an uncertainty of a factor of 2 in the quoted value for the total luminosity.

The mass of the emitting grains has been evaluated in the usual way (Hildebrand 1983), from the $60 \mu\text{m}$ flux and using the colour temperature $T_{25/60} = 90 \text{ K}$

$$M_d = \frac{4a\rho}{3Q(\text{IR})} \frac{D^2 S_v(\text{IR})}{B_v(T_d)} (\text{cgs units}) \quad (2)$$

with a the radius, ρ the density and $Q(\text{IR})$ the assumed emissivity of the dust grains, D the distance to the source, $S_v(\text{IR})$ the measured IRAS flux and $B_v(T_d)$ a blackbody function for grains at temperature T_d . This procedure provides clearly only an estimation for the total mass, since a single temperature and grain size, together with uniform chemical composition are assumed for the grains. However, a reasonable level of agreement with more elaborated models may be obtained through an appropriate choice of the emissivity law and adopted grain temperature (see e.g. Harrington et al. 1988). For $a\rho/Q = 0.013 \text{ g cm}^{-2}$, typical of interstellar standard dust grains (Draine & Lee 1984) we then obtain $M_d = 4.3 \cdot 10^{-3} M_{\odot}$ or a total mass of gas $M_g \sim 0.4 M_{\odot}$ if a standard gas to dust mass ratio of 100 is assumed. This result is consistent with the limit found from our CO measurements (see Sect. 5 below).

The spatial distribution of the far infrared emitting grains and the optical depths are difficult to evaluate for IRAS 22568+6141 given the point source nature of the object in the IRAS beams. However, a crude approach to the problem can be made by assuming that most of the $60 \mu\text{m}$ emitting grains are located at a distance to the central source given by the equilibrium radius (Scoville & Kwan 1976)

$$\frac{r}{(\text{pc})} = 44.55 T_d^{-5/2} \left(\frac{L}{L_{\odot}} \right)^{1/2}, \quad (3)$$

where L is the total luminosity of the exciting star. This yields $r = 0.03 \text{ pc}$ or roughly $1''$ at $D = 6 \text{ kpc}$, indicating that dust grains are located very close to the exciting star, and within the limits of the optical nebula. The optical depth of the emitting grains at $\lambda = 60 \mu\text{m}$ can be now estimated by comparing the observed IRAS flux and that expected from a $1''$ blackbody sphere at the assumed temperature

$$\tau_{(\text{IR})} = -\ln \left(1 - \frac{S_v}{\Omega \times B_v(T_d)} \right) \quad (4)$$

with Ω the solid angle subtended by the source from the observer. We thus find $\tau(60) = 0.02$ and $A_v = 6 \text{ mag}$ if the relation $A_v \sim 300 \tau(60)$ (Draine & Lee 1984) holds in our source. This value is similar to that obtained from the optical data.

Alternatively, one could adduce that a spherical geometry for the circumstellar material around the central star is probably not the best choice for this object, where a bipolar appearance is clearly observed. The location of the dust in PNe is poorly known. Dinerstein & Lester (1984) have found in Abell 30 and NGC 6302 infrared emission from warm dust with a disk-like morphology. For NGC 6302 the disk lies between the optical lobes with its long axis perpendicular to the long axis of the bipolar structure. This is probably collimating the outflow and is responsible of the bipolar structure observed. This is the reason why we have preferred this possibility for the model proposed in Fig. 6. This is also consistent with the non-detection of the exciting star, heavily obscured by the disk of dust. Under these circumstances we can consider a simple disk geometry with thickness ~ 10 times smaller than the radius, from where it can be simply deduced that the maximum visual extinction (i.e., corresponding to a line of sight passing through the equator) reaches a value ~ 13 times larger than that deduced assuming spherical symmetry for the dust envelope. Hence, if this is the case, A_v will approach $\sim 80 \text{ mag}$ in the equatorial plane. Near infrared observations may help testing this hypothesis.

5. Millimeter observations

From the CO data we can make an estimation of the molecular content around the IRAS source using the limit $T_R^* \leq 0.1$ K mentioned in Sect. 2 (see e.g. Phillips et al. 1990). Assuming that the $J=2 \rightarrow 1$ line is optically thin, the lower levels are thermalized, and the kinetic temperatures are reasonably large ($T_K \sim 30$ K, i.e. typical of molecular complexes), then for Lobelevian envelope expansion with a velocity range of $\Delta V \sim 75 \text{ km s}^{-1}$ (similar to the expansion velocity of the optical ionized region) we derive a column density

$$N(\text{CO}) \sim 1.22 \cdot 10^{13} T_R^* T_K \Delta V \leq 2.7 \cdot 10^{15} \text{ cm}^{-2} \quad (5)$$

and a corresponding hydrogen density

$$N(\text{H}_2) \sim \frac{N(\text{CO})}{5 \cdot 10^{-5}} \leq 5.5 \cdot 10^{19} \text{ cm}^{-2} \quad (6)$$

from where a limit to the mass can be estimated

$$M_{\text{H}_2} \sim 10^{-21} \left(\frac{B}{\text{arcmin}} \right)^2 \left(\frac{D}{\text{kpc}} \right)^2 N(\text{H}_2) \leq 0.5 M_{\odot} \quad (7)$$

with B the beam size and $D = 6 \text{ kpc}$ the adopted distance. This upper limit of around half a solar mass for the molecular mass in the envelope obtained from the lack of CO emission is consistent with the dust masses derived from IRAS data and the evolutionary status of IRAS 22568 + 6141, as we will see below.

6. The nature of IRAS 22568 + 6141

In order to discern the ionization mechanism and, furthermore, the nature of the nebula, we have located the $\text{H}\alpha/[\text{N II}]$ and $\text{H}\alpha/[\text{S II}]$ ratios in a diagnostic diagram (Cantó 1981), which is shown in Fig. 7. This diagram helps us to distinguish objects for which photoionization is the mechanism responsible for the emission lines, from regions ionized by shock waves like supernova remnants or H-H objects. At the same time H II regions and PNe are located in different regions of the diagram. From Fig. 7 it is clear that IRAS 22568 + 6141 falls in the region of PNe, completely apart from H II regions or any other kind of object.

In Table 4 we compare the elemental abundances derived in this Paper with the mean values found in the literature for PNe (Natta et al. 1980) and H II regions (Shaver et al. 1983). The oxygen, sulfur and argon abundances of IRAS 22568 + 6141 match very well with what should be expected for normal PNe. The exceptions are the nitrogen abundance, which is slightly below the mean value found for PNe, and the helium abundance, for which there are indications of a possible overabundance. Concerning the nitrogen it is interesting to note here that the N/O ratio is similar to the solar value and very low compared with the usual ratios found in other proto-planetary objects like CRL 618, for which the progenitor mass has been estimated to be $M_i \geq 2.4 M_{\odot}$ considering this parameter. This can be explained if the progenitor star of the nebula was not so massive. However, it is more difficult to explain the apparent helium overabundance, as it would be not expected in low mass PNe.

From the *energy-balance method* (Pottasch 1984) we find an effective temperature for the central star of $T_{\text{eff}} = 24000 \text{ K}$, by comparing the intensity of the forbidden lines with respect to $\text{H}\beta$. This value must be considered an approximation, as other forbidden lines can be present at other wavelength ranges in the emission line spectrum. On the other hand, the departure from

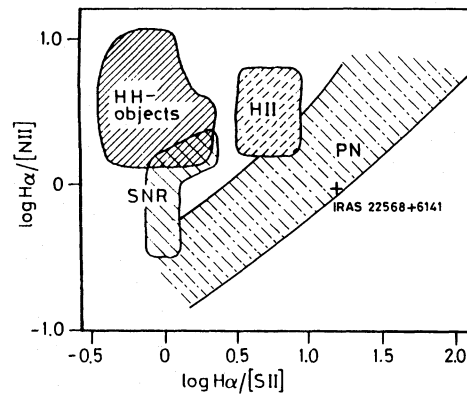


Fig. 7. Diagnostic diagram, (adapted from Cantó 1981), where the positions of different kind of objects are shown as a reference

Table 4

$12 + \log (X/H)$	O	N	S	Ar
IRAS 22568 + 6141	8.48	7.70	6.53	6.38
$\langle \text{PN} \rangle^a$	8.5	7.94	6.72	6.29
$\langle \text{H II regions} \rangle^b$	8.7	7.57	7.06	6.42
Sun	8.87	7.96	7.10	6.57

^a Natta et al. (1980)

^b Shaver et al. (1983)

black body emission in the stellar radiation can also produce some uncertainty in this result. However, this method is much less affected by the presence of dust in the envelope than the *Zanstra method*, which gives only a lower limit for the temperature of the central star when $\langle \text{IRE} \rangle > 1$, as ionizing photons longward of the Lyman limit can also be absorbed by the dust. With the luminosity and the effective temperature we can locate IRAS 22568 + 6141 in the HR diagram. If we compare its location in the diagram with the evolutionary tracks predicted for post-AGB models (Schönberner 1989) we can see the agreement with the position predicted for a $1 M_{\odot}$ progenitor star with an estimated age of 1000–2000 yr after leaving the AGB phase (zero age is assumed at $\log T_{\text{eff}} = 3.7$).

Moreover, for hydrogen-shell burning evolutionary tracks, we can also estimate the core mass using the Paczynski relation (1968)

$$L \sim 6 \cdot 10^4 (M_c/M_{\odot} - 0.5) L_{\odot} \quad (8)$$

from which we derive a value for the core mass of IRAS 22568 + 6141 of $M_c = 0.57 M_{\odot}$. If we consider that the progenitor mass M_i is $M_i = M_c + M_e$ and the results obtained in Sect. 4 from the analysis of the IRAS data we obtain again the value of $M_i = 1 M_{\odot}$, consistent with its position in the HR diagram and the limit for the mass in the envelope found from the CO observations.

On the other hand, from the observed $\text{H}\beta$ flux, once corrected for extinction, and adopting $\epsilon = 1$, we found a value for the ionized mass of only $M_{\text{H II}} \sim 0.02 M_{\odot}$. This would mean that either the envelope is not yet fully ionized and there is still a large amount of neutral material in the envelope or the gas to dust ratio is anomalous in IRAS 22568 + 6141. In the first case, this would mean that the nebula is still ionization bounded and passing through an early stage as a PN.

There is also a good agreement between the age of the nebula derived from its position in the HR diagram and the combination of the optical size of the nebula (0.26 pc at the adopted distance) with the $V_{\text{exp}} = 70 \text{ km s}^{-1}$ derived in Sect. 3. In this case a kinematic age of 1800 yr is found. If the total dust + gas mass in the envelope has been ejected during this short transition phase after the end of the AGB-phase this result implies that IRAS 22568 + 6141 has suffered in the recent past a strong mass loss rate phase of $\dot{M} \sim 10^{-4} - 10^{-5} M_{\odot} \text{ yr}^{-1}$, consistent with the theory of the “superwind” (Renzini 1981), which predicts mass loss rates of this order of magnitude for objects evolving from the AGB-phase to PN.

Moreover, infrared data also support the idea of this object being a PN because of its infrared colours. It is located apart from the region of young stellar objects in the IRAS two-colour diagram and in the region occupied by objects whose strong mass-loss phase has recently stopped and are now moving to higher values of [12]–[25] (see Habing et al. 1989) as a consequence of the dilution of the detached circumstellar shell in the interstellar medium. Variable OH/IR stars in this zone of the diagram show a very high variability index VAR (most of them show $VAR \geq 90\%$ – see IRAS Explanatory Supplement, 1985 –) before they evolve and transform into non-variable OH/IR stars when the pulsation stops. When this occurs this parameter falls indicating the end of the intense mass loss phase. The low variability index quoted in the PSC (only 1%) for IRAS 22568 + 6141 is also indicating that the thermal pulses have definitively stopped and the strong mass loss phase has ceased.

7. Conclusions

We have presented in this Paper a set of optical, infrared and millimeter data on IRAS 22568 + 6141. From these observations we have determined the evolutionary status of this previously unidentified IRAS source. The analysis of the data here presented indicates unambiguously that this is a new young bipolar planetary nebula. The position of IRAS 22568 + 6141 in the HR diagram is typical of a young PN with an age of about 1000–2000 yr and a progenitor mass of $1 M_{\odot}$. Both age and mass are consistent with the values found from kinematic and luminosity considerations. The evolutionary status of this IRAS source as a young PN is also confirmed by its infrared energy distribution and the strong infrared excess found.

However, there is still a lot of work to do on this object. Radio and near infrared measurements should be necessary to complete the analysis of IRAS 22568 + 6141 and test the possible presence of a disk of dust collimating the outflow, as well as a more detailed analysis of the structure of the high velocity outflow, which could also give some light about the problem of the apparent helium overabundance.

IRAS data have become the most important tool to search for new young and compact PNe still heavily obscured by their circumstellar envelopes. This short transition phase is still poorly known and it is very important to enlarge the number of objects in this stage of the stellar evolution. Only a few of them are known at the present, and IRAS 22568 + 6141 is only an example of what can be done with the help of the IRAS data in order to understand the physical processes which lead to the formation of a new PN.

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