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ATCA^{*} observations of the very young Planetary Nebula SAO 244567

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ABSTRACT

The radio emission from the youngest known Planetary nebula, SAO 244567, has been mapped at 1384, 2368, 4800, 8640, 16832 and 18752 MHz by using the Australian Telescope Compact Array (ATCA). These observations constitute the first detailed radio study of this very interesting object, as they allow us to obtain the overall radio morphology of the source and to compute, for the first time, the radio spectrum up to millimetre range. Radio emission is consistent with free-free from a wind-like shell, which is also the region where most of the [OIII] comes from as revealed by HST images. Physical parameters of the radio nebula and of the central star were derived, all consistent with SAO 244567 being a very young Planetary Nebula still embedded in the dusty remnant of the AGB phase. The optically thin radio flux density appear to decrease when compared to data from the literature. Even very appealing, the variability of the radio emission, probably related to the evolution of the central object, needs further investigations.

Key words: stars: AGB and Post-AGB –Planetary Nebulae:general —radio continuum:stars

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1 INTRODUCTION

The fate of a star with a main sequence mass in the range from 1 to 8 solar mass is well established: it goes through the asymptotic Giant Branch (AGB) phase, then into the Planetary Nebula phase (PN hereafter) and eventually it will finish its evolution as a White Dwarf. However, the details of these evolutionary phases, such as the formation and the early evolution of PNe is far to be completely understood. It is not clear, for example, which kind of mechanism changes the more or less regular and symmetric circumstellar envelopes (CSEs) around PNe progenitors (AGB stars) into the quite complex morphologies observed in young and more evolved PNe.

New clues on the process of PNe formation can be provided by the analysis of the physical characteristics of objects in the short phase between the end of the AGB and the onset of the ionization in the nebula. For this purpose, many authors have tried to identify very young PNe or proto Planetary Nebula (PPNe) but this has revealed to be quite difficult as this evolutionary phase is very rapid and because the central object is often heavily obscured by the thick circumstellar envelope formed during the AGB phase.

Among post-AGB objects, SAO 244567 appears to be unique, as it is evolved so rapidly that strong spectral and total luminosity changes were followed in a human life time scale. Parthasarathy & Pottash (1989) classified SAO 244567 as a post-AGB star on the basis of its high galactic latitude and because of its far-infrared (IRAS) colours similar to those of known PNe. Very soon it was realized that, in few decades, its optical and ultraviolet spectra have developed characteristics typical of the presence of a nebula making SAO 244567 one of the youngest PN never discovered (Parthasarathy et al. 1993).

In particular, its optical spectrum has evolved quite rapidly: reported by Henize (1976) with only H_α in emission, more recently, it has shown strong forbidden nebular emission lines, which are consistent with a young PN (Parthasarathy et al. 1995). These results confirm that SAO 244567 has turned into a PN within the last 20 years and makes the source a perfect target for studying the early structure and evolution of Planetary Nebulae.

SAO 244567 has been observed in 1996 with WFPC2 on board of the Hubble Space Telescope (Bobrowsky et al. 1998). These observations pointed out that most of the nebular emission originates from a ring/ellipse, whose major axes extends for $\sim 1.6''$, and the presence of low density collimated outflows. The authors interpreted the ring structure as the remnant of the mass-loss during the AGB phase, while the low-density bipolar structures as results

Table 1. Summary of results: flux densities are determined by fitting of visibility curves.

<i>Frequency</i> MHz	<i>Flux</i> mJy	<i>rms</i> mJy	<i>phase cal Flux</i> mJy
<i>Epoch 2000</i>			
4800	57.6 ± 1.7	0.3	4500 ± 50
8640	52.0 ± 1.6	0.4	3400 ± 50
<i>Epoch 2002</i>			
1384	36.6 ± 1.1	0.2	
2368	46.9 ± 1.8	1.2	
4800	48.8 ± 1.5	0.2	5234 ± 20
8640	46.6 ± 1.4	0.2	4271 ± 20
16832	43.8 ± 2.0	0.3	
18752	42.8 ± 2.0	0.3	

from fast-wind experienced by the star during the post-AGB phase. The existence of a companion star, detected at 0.4 arcsec from the central star, indicates that the ring/eclipse is probably a circumbinary envelope and that binarity may play an important role in the shaping of PNe. These images are one of the best examples where nebular structures, that appear to collimate fast outflows, are evident.

As typical for very young Planetary Nebulae (YPN), SAO 244567 shows a strong infrared excess and it is associated to the IRAS source IRAS 17119 – 5926. Measured non-corrected IRAS fluxes are 0.65, 15.50, 8.20 and 3.52 Jy at 12, 25, 60 and 100 μ m respectively.

In spite of the numerous optical studies of this interesting object, very little is still known on its radio properties. Parthasarathy et al. (1993) briefly reported on ATCA 6 and 3 cm observations obtained in 1991. The measured flux densities are 63.3 ± 1.8 mJy and 51 ± 12 mJy at 6 and 3 cm respectively.

In this paper we present new ATCA observations of SAO 2444567 aimed to determine the radio properties of the nebula associated to this very young PN.

2 OBSERVATIONS

We carried out radio observations of SAO 244567 in March 2000 and August 2002. In both epoch the target was observed with the Australia Telescope Compact Array (ATCA) at Narrabri. The ATCA consists of six 22-m antenna, five of which lie along a three kilometer railway track, oriented east-west, and the other antenna lies on a similar railway track three kilometers away thus providing a 6 km maximum baseline lengths.

As each ATCA antenna is equipped with dual-frequency systems, it is possible to observe simultaneously at two different frequency bands.

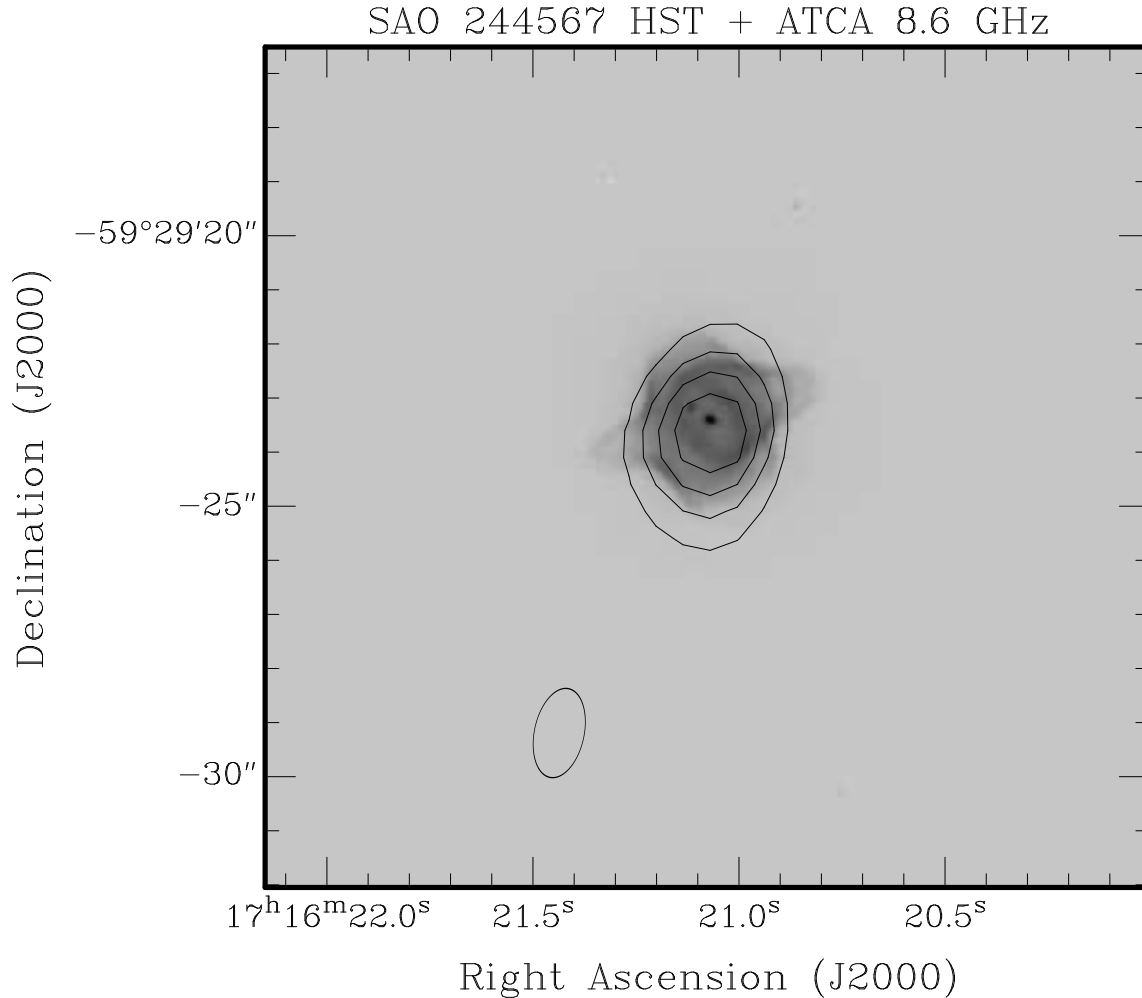


Figure 1. The radio map of SAO 244567 obtained with the ATCA at 8.4 GHz (contour levels) superimposed with the HST image in H_{α} (Bobrowsky et al. 1998). The synthetic beam is shown in the lower left corner.

2.1 The 2000 data

In the first epoch, March 2000, the observations were simultaneously performed at 6 (4800 MHz) and 3 cm (8640 MHz), with a 128 MHz bandwidth divided in 32 spectral channels, with an integration time of 30 sec. The observations were carried out in the 6D configuration, which, with a full synthesis, usually provides a typical beam size (θ_{syn}) of about $2''$ at 6 cm.

The flux scale was fixed by daily observations of the primary flux calibrator 1934 – 638, whose assumed flux densities are 5.83 and 2.84 Jy at 4800 and 8640 MHz respectively. In order to achieve a good phase calibration, the phase calibrator 1718 – 649, which is 5.5 degree away from SAO 244567, was observed at the beginning and at the end of each source observations.

At this epoch the source was observed in the context of a survey program aimed to detect radio emission from a sample of post-AGB stars. Therefore, for a good compromise between UV coverage and total integration time, the observations were performed in snap-mode, which consists of short on source runs carried out at different hour angles. A typical observation of our target consisted of 7/8 cuts, each of 15 minutes long. In the case of SAO 244567 we observed the source with 14 cuts, for a total of 3.5 hours. The observations were, however, obtained in different days starting from March 19 to March 22.

Due to serious hardware problems at one of the antennas, the observations suffered of a degradation of the available angular resolution, resulting in a beam of $7.6'' \times 2.7''$ at 6 cm definitively worst than the angular resolution achievable with the 6D configuration.

2.2 The 2002 data

We have successively re-observed the source this time with a proper full tracking for better UV coverage. The observations were carried out on August 24 and August 29, 2002. In both dates the array was in 6C configuration. On August 24 we observe simultaneously at 16832 and 18752 MHz, with a 128 MHz bandwidth divided in 32 spectral channels, using an integration time of 30 sec. At that time only 3 antenna were equipped with mm backends. High frequency observations are strongly affected by atmospheric phase fluctuations. To minimize this effect, we quickly switched between target and phase calibrator, with typical duty cycle of 6 min (four min on target and 2 min on phase calibrator) for a total of on source time of 7 hours. Reference pointing on our phase calibrator (1718 – 649) was also performed every hour of observing time. Flux scale was fixed by several observations of 1924 – 638 and the flux of 1718 – 649 was boot-strapped using only those scan of primary calibrator performed at the same elevation as 1718 – 649.

On August 29, the observations were carried out at 4800/8640 MHz and at 1384/2368 MHz. The observations were performed following the same procedure as on August 24, using 1718 – 649 as phase calibrator, with a typical on source scan of 15 minutes. However, only 30% of the total on source time of 10 hours was spent observing at the lowest frequencies. The flux scale was fixed relatively to 1934 – 638 whose flux is assumed to be 14.94, 11.59, 5.83 and 2.84 Jy at 1384, 2368, 4800 and 8640 MHz.

3 RESULTS

The data from both epochs were reduced with the MIRIAD package, following the standard reduction steps. Visibilities were weighted by applying the robust weighting (robust parameter=0.5). This method allows to obtain the same sensitivity as with natural weight but with a much better beam shape. Finally the obtained maps were cleaned down to few times the theoretical noise, estimated to be of the order of 0.1–0.2 mJy.

The map with best combination of resolution and sensitivity is that obtained at 8640 MHz in 2002. The radio map (Fig. 1) reveals a slightly extended structure, whose overall size ($\sim 1.7''$) compares quite well with that observed in H α (Bobrowsky et al. 1998). However, the limited ATCA angular resolution prevented us to point out any fine detail of the radio structure.

Total flux density and the angular dimension can be usually estimated directly from the obtained map, by a 2D Gaussian fit of the radio source. However, because an interferometer will spatially filter out structures larger than the resolution corresponding to the minimum antenna spacing, the evaluation of flux density by Gaussian fit becomes less precise for partially resolved sources. This effect will be more evident at higher frequencies. In this case it is advisable to derive flux densities directly from UV data, by fitting the visibilities at zero baseline. When the sources are angularly small, different methods to derive the flux density, i.e. from the map or from the fit of visibility data, provide consistent flux values to within a few %. In our case, differences between total fluxes as measured from the map and from fit at zero baseline are of the order of 0.1 percent up to 4800 MHz, but become more important at 18750 MHz where it goes up to $\sim 17\%$. For this reason, in the following analysis we will consider the flux density derived from visibility fits. Results are summarized in Table I, where the observing frequency, the measured flux density, with its associated σ and the rms of the visibility fit are reported. An error in the flux calibration can result in a systematic error in flux of the observed source. Therefore the σ associated to the flux density estimation is derived from:

$$\sigma = \sqrt{(rms)^2 + (\sigma_{cal}S)^2}$$

where rms is the error associated to the fit, σ_{cal} is the error associated to the absolute flux density scale, which is accurate to within few (3–5) percents and S is the derived flux density. In order to successively compare results from different epochs, for frequencies with multi-

Table 2. Parameters of different models for the radio nebula around SAO 244567.

Parameter	Value
Model 1 (Wind Shell)	
Density	$n(R_{\text{int}}) = 2.5 \times 10^4 \text{ cm}^{-3}$, $n \propto R^{-2}$
Shell internal radius R_{int}	0.75 arcsec
Shell external radius R_{ext}	1.5 arcsec
Shell Temperature	9600 K
Model 2 (Shallow Shell)	
Density	$n = 1.45 \times 10^4 \text{ cm}^{-3}$
Shell internal radius	0.65 arcsec
Shell external radius	1.3 arcsec
Shell Temperature	10000 K
Model 3 (Sphere)	
Density	$n = 1.23 \times 10^4 \text{ cm}^{-3}$
Sphere size	1.4 arcsec
Sphere Temperature	10000 K

epoch data we also report, in the last column of Table I, the flux density of the phase calibrator (1718 – 649).

We note that the flux density at 4800 and 8640 MHz appears to decrease from 1991 (Parthasarathy et al. 1993) to 2002 (this paper). This decrement appears to be real and not related to a variation in the absolute flux scale as the flux density of the phase calibrator changes between the last two epochs but with a different trend, and it is actually increasing maintaining the same spectral index. In the following analysis only the multi-frequency epoch 2 data set will be used.

4 THE NEBULA

4.1 The Radio Morphology

Some information on source morphology can be derived from the analysis of the visibility data, i.e. the fringe amplitude as function of the interferometer spacing. Since the ATCA is a linear interferometer, each of the different 15 minutes on source scans (cuts) will give a maximum resolution in one direction and the corresponding visibility will be function of the source morphology in that direction. Different visibility corresponding to different cuts look quite similar and this indicates that the overall morphology of the radio source is symmetric with respect to a central point. The small elongation in the S-W direction, probably reflects the UV coverage, and therefore the synthetic beam with which the visibility data are convolved and it is not intrinsic to the source.

We have modelled the visibilities of the entire observing run, averaged over 15 minutes, assuming 3 different symmetric morphology for the radio source, i.e.: 1) a shallow shell, 0.75'' thick, with a density decreasing with distance from the central star ($n \propto \frac{1}{r^2}$); 2) a constant density shallow shell, 0.65'' thick; 3) a constant density sphere, with a radius of 1.4''.

The best-fit parameters of the 3 models are summarized in Table II and results, relative to visibilities observed at 8640 MHz, are shown in Fig. 2. In the first panel the expected visibility from a stellar wind is shown (dotted line) for comparison. From this analysis we may conclude that the source morphology is consistent with both a shallow shell (with constant or with $\propto \frac{1}{r^2}$ density) and with a constant density sphere.

4.2 The physical properties

Information on several parameters of a radio source can be derived by analyzing its radio spectrum, in particular when the transition region between optically thick and optically thin regime can be pointed out. The analysis of visibility data indicates a symmetric morphology, consistent with both a constant density sphere and a wind or constant density shell. Very little studies on modelling of free-free radio spectrum of PNe have been conducted, mostly because of the very few multi-frequency spectra available in the literature. Among them, Aaquist & Kwok (1991), by analyzing a sample of compact (young) PNe, noted a trend of increasing value of spectral index α ($\text{flux} \propto \nu^\alpha$), evaluated in the optically thick part of the spectrum, as the turnover frequency (ν_c) decreases. This was interpreted as evidence, in the very early stages of nebula evolution, for most of the free-free emission coming from the AGB progenitor's wind, with typical $\alpha = 0.6$. Taylor et al. (1987) modelled the radio continuum of 18 compact PNe with a shell model, with a radially dependent density. Observed radio spectra are well represented by a wind-shell, supporting the idea that free-free originates from a region formed with a constant stellar mass-loss during the precedent red giant phase.

These precedent results together with the fact that SAO 244567 is a very young PN, will lead us to assume for SAO 244567 a wind-shell morphology. Model 1 well reproduces the observed visibilities at each frequency (Fig. 3). The foreseen radio spectrum, superimposed to the observed data, is shown in Fig. 4. with a turnover frequency, i.e. the frequency at which the nebula becomes transparent, between 2368 and 4800 MHz. The model will allow us to get an estimate of the total ionized mass contained in nebular shell. In the hypothesis

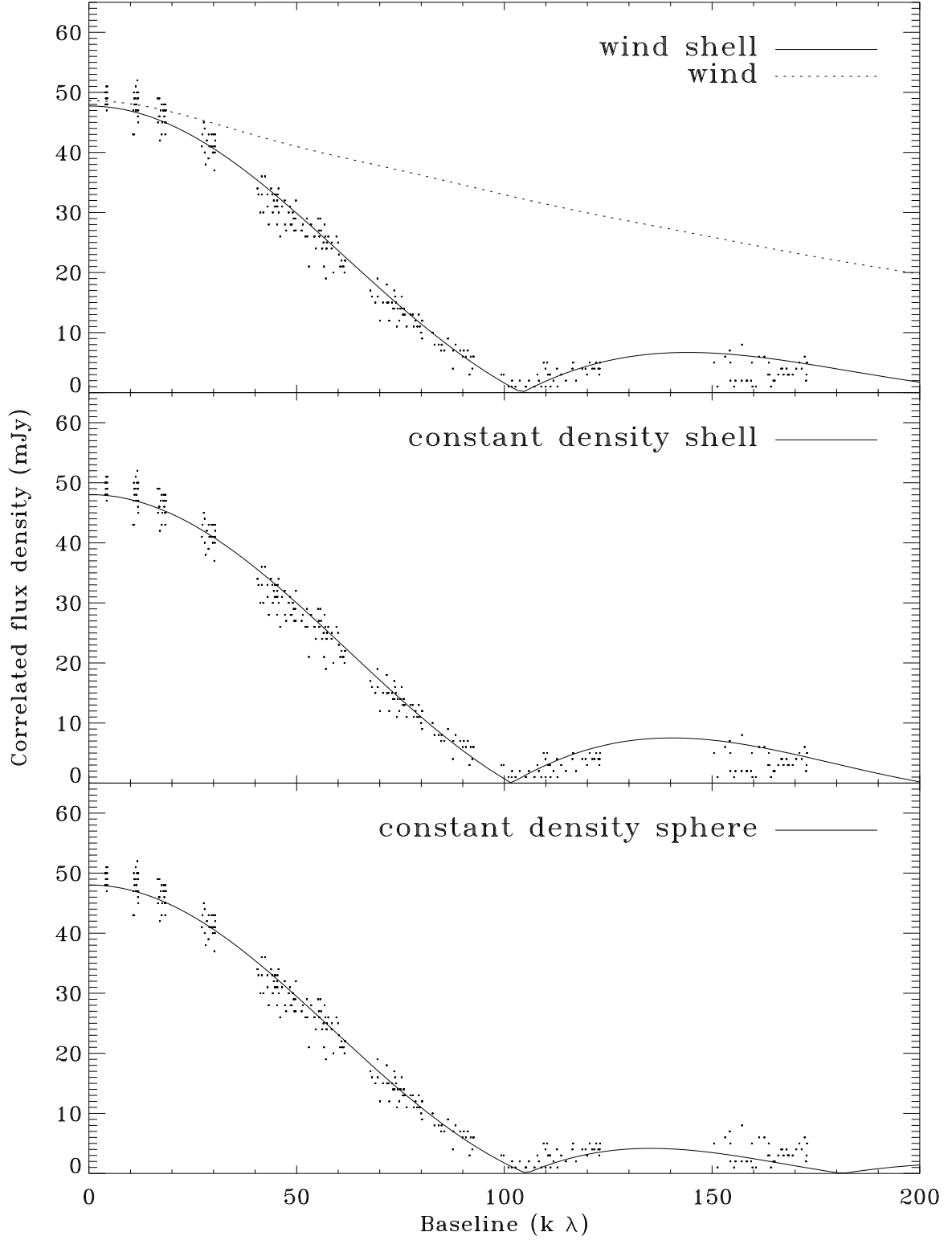


Figure 2. Comparison between different modelling of the radio source. Both a shallow shell (with density $\propto \frac{1}{r^2}$ or constant) and a constant density sphere are consistent with the observed visibilities. A stellar wind extending to infinity is shown as example.

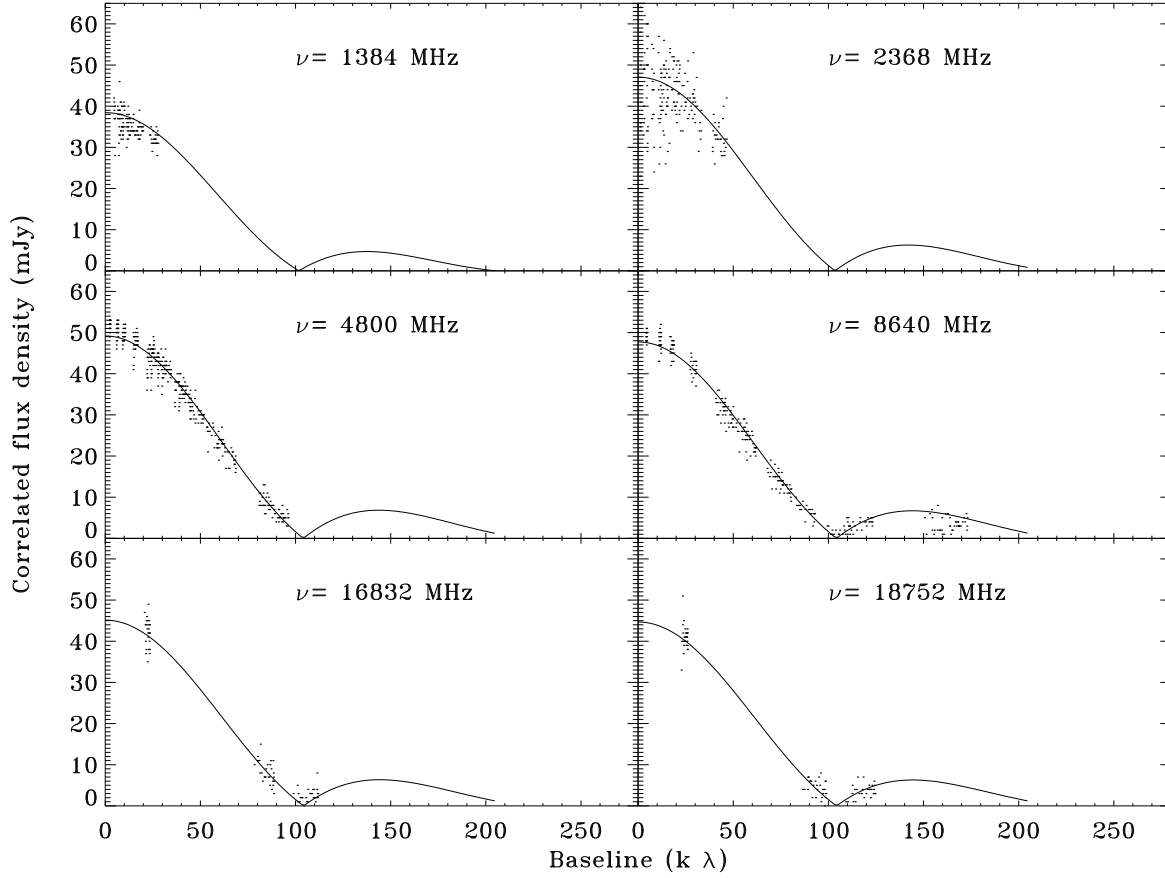


Figure 3. The modelling of visibilities at various frequencies. Fits are obtained assuming a shallow shell, with decreasing density ($\propto r^{-2}$), with $T = 9600$ K and $n = 2.5 \times 10^4 \text{ cm}^{-3}$ at the inner radius

of a pure hydrogen nebula at 5.6 Kpc (Parthasarathy et al. 1993), we derive a total ionized mass of $\sim 0.065 M_{\odot}$. This value depends on the value of volume filling factor of the nebula, which has been assumed to be 1. A similar value was derived by Parthasarathy et al. (1993), while Bobrowsky (1994) derived a value of $0.2 M_{\odot}$ from the H_{β} flux.

In the spectral region where the source is optically thin we can use the observed radio flux density plus the angular size to derive the mean emission measure as follows (Terzian & Dickey 1973):

$$\langle EM \rangle = \frac{\int_{\Omega} EM d\Omega}{\Omega} = \frac{5.3 \times 10^5 F_{8.4 \text{ GHz}}}{\theta^2} = 1.1 \times 10^7$$

where $F_{8.4 \text{ GHz}}$ is the measured radio flux density, in mJy, at 8.4 GHz, and θ , in arcsec, the angular dimension of the radio emitting region as derived from the model. The mean emission measure is expressed, as usual, in $\text{cm}^{-6} \text{ pc}$.

Young PNe should have emission measures of the order of $10^6 - 10^8 \text{ cm}^{-6} \text{ pc}$ (Terzian & Dickey 1973; Kwok et al. 1981).

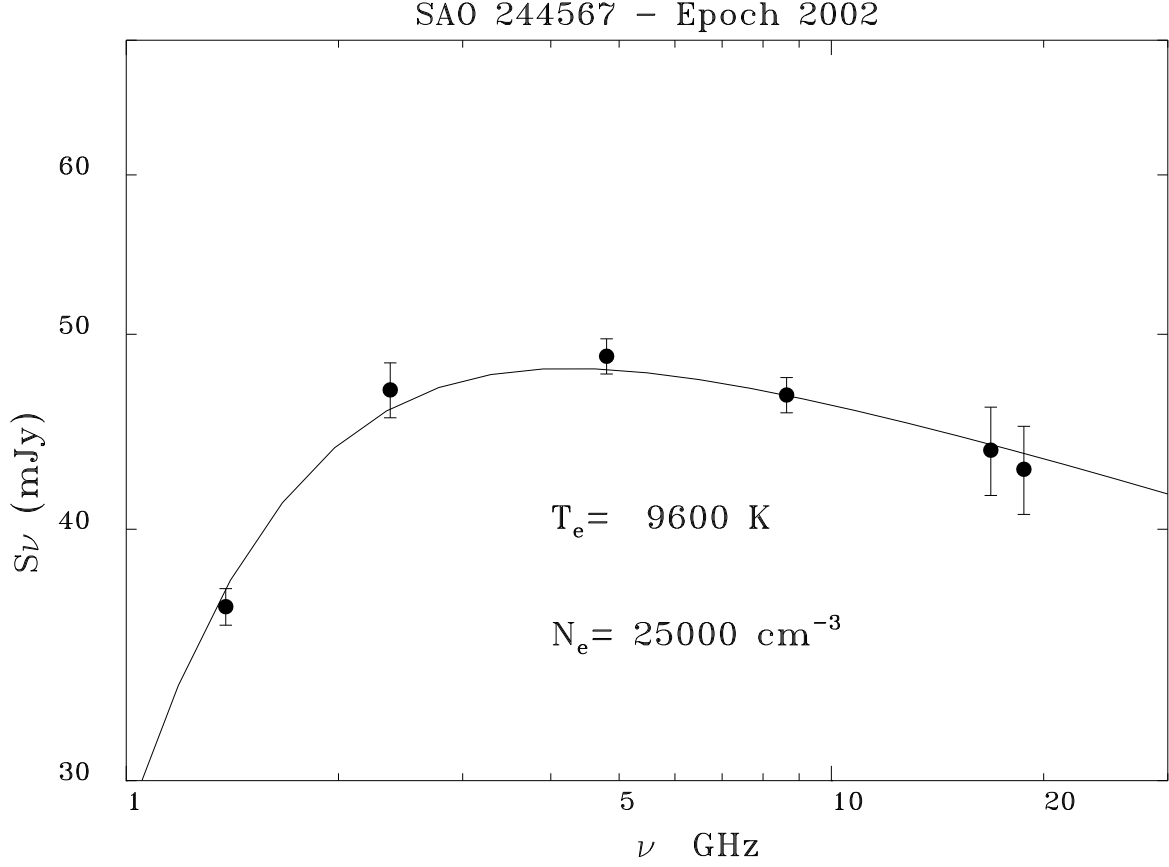


Figure 4. The radio spectrum of SAO 244567 obtained from the fit showed in figure taking as flux density the zero spacing value.

From the radio optically thin flux we can also derive the excitation parameter (U_{exc}) required to account for the measured radio flux:

$$U_{\text{exc}} = 13.3(\nu^{0.1} T^{0.35} D_{\text{Kpc}}^2 F_\nu)^{\frac{1}{3}} \text{ pc cm}^{-2} \quad (1)$$

where F_ν is the optically thin radio flux density, expressed in Jy, at the observing frequency ν (in GHz); T is the nebula temperature, expressed in 10^4 K , and D_{Kpc} is the source distance in Kpc.

As the PN associated to SAO 244567 is very young we can assume that it is ionization bounded; in this case the excitation parameter is directly related to the number of ionizing photons emitted by the central star.

$$L_{\text{uv}} = 1.23 \times 10^{56} \beta U_{\text{exc}}^3 \text{ photons s}^{-1} \quad (2)$$

where β is the hydrogen recombination coefficient summed over all levels above the ground level ($\sim 3 \times 10^{-13} \text{ cm}^3 \text{ s}^{-1}$ for $T \sim 10^4 \text{ K}$) (Spitzer 1978).

From equation (1) and equation (2), assuming a nebular temperature of $T \sim 9600 \text{ K}$ and a distance of 5.6 Kpc, from the radio flux density measured at 4.8 GHz, we derive a number

of ionizing photons of $L_{\text{uv}} \sim 1.5 \times 10^{47} (\text{photons s}^{-1})$.

This corresponds to the flux of Lyman continuum photons of a B0–B0.5 V with an effective temperature of $T_{\text{eff}} \sim (2.8 \pm 0.2) \times 10^4 \text{ K}$ (Panagia 1973).

This value for the effective temperature of the central star is somehow lower than the value of $T_{\text{eff}} \sim 3.7 \times 10^4 \text{ K}$ estimated by Parthasarathy et al. (1993) from the analysis of the UV spectra and corresponding to a O8V star. This may indicate the presence of significant quantity of dust well mixed with the gas in the inner regions of the nebula. Dust, in fact, competes with the gas for the absorption of the ionizing photons and for a given number of ionizing photons emitted by the central star, it will reduce the observed radio flux.

5 THE DUSTY ENVELOPE

One of the most important results from PNe studies based on IRAS data was the realization that, on the average, in young PNe about 40% of the emergent flux is emitted in the far-infrared (Zhang & Kwok 1991). This is due to the presence of an extended dusty envelope, around YPNe, which is the remnant of the precursor’s wind not yet dispersed. In YPNe the spectrum emitted by the dust, between 10 and 100 μm , is usually well described by a single temperature black body curve (Zhang & Kwok 1990; Stasinska & Szcerba 1999). We therefore derive a dust temperature of $T_{\text{dust}} = 137 \pm 2$ by using a least-squared fitting procedure to the IRAS measurements. This procedure provides, as a by-product, the total far-infrared flux (F_{IR}), obtained by integrating, over the IRAS band (25 to 100 μm), the Planck curve that fits the IRAS data.

It is therefore possible to define the far infrared excess (IRE) as the ratio of the observed total far infrared flux (F_{IR}) over the expected total infrared flux. Under the hypothesis that the far infrared flux is due to thermal emission from dusty grains heated by Ly α photons, this ratio is unity. However, in young PNe heating by direct starlight is important and IRE can be much higher than unity. Pottasch (1984) has derived a formula to express the expected total infrared flux in terms of optically thin radio flux density:

$$IRE = 1.07 \frac{F_{\text{IR}}}{F_{8.6 \text{ GHz}}} = 2.8$$

where F_{IR} is expressed in $10^{-14} \text{ W m}^{-2}$, $F_{8.6 \text{ GHz}}$ in mJy, and the high density approximation has been adopted. This value is consistent with the hypothesis that SAO 244567 is a very YPN where the dust plays an important role.

To quantify the total mass of the dust we will use the optically thin expression (Hildebrand 1983):

$$M_{\text{dust}} = \frac{F_{60\mu\text{m}} D^2}{\chi B\nu(T_{\text{dust}})}$$

where $F_{60\mu\text{m}}$ is the flux density measured at $60\mu\text{m}$, D is the distance to the source (Kpc), $B\nu(T_{\text{dust}})$ is the value of the BB function of T_{dust} , evaluated at $60\mu\text{m}$ and χ is the mean absorption coefficient for the grains ($\text{cm}^2 \text{g}^{-1}$). This formula provides only an estimation of the total dust mass as a single temperature and an unique size for the grains is assumed. Moreover, while this dust mass determination is independent on the distribution of the grains, it strongly depends on the chemical composition of the grains.

There are still problems in understanding the chemical composition of the dust component in PNe. Usually, in carbon rich PN, dust is mainly composed of carbon-based grains, while in O-rich PN, dust is mainly composed of different forms of silicates. As for SAO 244567 we don't have any information on its chemical composition, we compute the dust mass for two different value of χ , namely $53.45 \text{ cm}^2 \text{g}^{-1}$, which corresponds to circumstellar silicates and $145.32 \text{ cm}^2 \text{g}^{-1}$, which corresponds to graphite (Stasinska & Szcerba 1999). This results in a total mass dust of $2 \times 10^{-4} M_{\odot}$, in case of silicates, and $7.5 \times 10^{-5} M_{\odot}$, in case of graphite. If we assume that dust and gas occupy the same volume, we may derive a dust to gas ratio of 3×10^{-3} and 1.15×10^{-3} for silicates and graphite respectively. These values are in the range for $M_{\text{dust}} / M_{\text{gas}}$ derived for a large sample of PNe (Stasinska & Szcerba 1999).

6 THE VARIABILITY OF RADIO EMISSION

One of the most striking and unexpected characteristic of radio emission from SAO 244567 is its variability. In Fig. 5, we report the flux density at 4800 MHz, as measured by Parthasarathy et al. (1993) and in this paper, indicating a linear decreasing trend of the optically thin flux. The dashed line is the weighted fit to the 4800 MHz data points, which results in a flux decrement of $\sim 1.3 \text{ mJy year}^{-1}$. Assuming that the radio emission from the source will keep this trend a flux density of $\sim 43 \text{ mJy}$ in 2008 is foreseen. In the same figure we also include the 2000 and 2002 8640 MHz data, without considering the quite noisy datum from Parthasarathy et al. (1993).

In the hypothesis that, between March 2000 and August 2002 (ΔT), the ionized mass remains the same (i.e. any effects due to the evolution of the central object are not considered), and the nebula is expanding homologous, we have:

$$M_{\text{Tot}} \propto n_{2000} R_{2000}^3 = n_{2002} R_{2002}^3 \quad (3)$$

Starting from the results for epoch 2002, from equation (3) we obtain constraints for epoch 2000. To reproduce the flux density observed at 4800 and 8640 MHz in epoch 2000, we then used the model, as illustrated in par 4.1, obtaining a reasonable fit that satisfies equation (3), for $T_{\text{eff}} = 9600$ K, as in 2002 fit, with an internal radius of $0.71''$, an external radius of $1.4''$ and a density, at the base of the shell, of $n_{2000} = 2.9 \cdot 10^4 \text{ cm}^{-3}$. To obtain such an expansion we need the nebula to expand in a time ΔT with an average velocity of $\sim 850 \text{ km sec}^{-1}$. We should stress here that a variation of radius of the order of few $0.1''$ would be not detectable with present instrumentation (ATCA).

High expansion velocity have been observed is the ultraviolet lines of some PPNe and YPNe (Gaubert et al. 2001) and are usually related to fast-winds events occurring during the post-AGB phase. For SAO 244567 Parthasarathy et al. (1995) reported, in 1988, an ultraviolet spectrum characterized by strong P-Cyg profiles, indicating the presence of a strong wind with expansion velocities of the order of $\sim 3000 \text{ km sec}^{-1}$. This spectral structures were observed until 1993 and by 1994 they were almost vanished, indicating the end of a rapid mass-loss event. At the same times, Parthasarathy et al. (1993) derived, from high-resolution [OIII] profile, an expansion velocity of the order of $\sim 8 \text{ km sec}^{-1}$, consistent with the fact that the ionized shell, from which most of the [OIII] comes from, is the remnant of mass-loss during the previous AGB phase. Both results are consistent if we assume that UV lines are produced in the low-density polar region, where episodic rapid mass-loss event can occur, while the bulk of the ionized material, and also the radio emission, is localized in the main ring/shell, as indicate by the HST images, which is expanding with typical velocity as expected for a AGB wind. Therefore, we may conclude that an expansion of the main shell can not explain the observed decrement in the radio flux density because the required expansion velocity is too high.

High velocity mass-loss events may, however, contribute to the total ionization of the nebula. This is what is claimed by Sanchez Contreras et al. (2004) to explain the decrease in millimetric, free-free optically thin flux observed in the PPNe CRL 618. According to these authors, in this source there is a substantial contribution of shocks, originating from interaction between the fast post-AGB wind with the CSE environment, to the total ionization. As the fast wind stops, the ionization rely only on the central star radiation field and the optically thin radio emission is, therefore, decreasing. However, this explanation requires

episodic high-velocity mass-loss events to justify the flux increasing reported by the same authors 2 year later (Sanchez Contreras et al. 2004b). A decrease in the optically flux density has been also noted in NGC 7027 (Zijlstra et al. 2007) and it is interpreted as related to the evolution of the central object. NGC 7027 is located just at the tip of the WD cooling track, where its luminosity starts to decrease while its temperature is still increasing. This leads to a decreasing number of ionizing photons. Since the optically thin free-free emission is directly related to the ionizing flux from the central object, this would imply a decreasing optically thin radio flux density.

SAO 244567 has shown many spectral changes in the last 20 years. Most notably, the changes in the UV flux level, which suffered a factor 2.83 decrement in 7 years, while the central was gradually becoming hotter (Parthasarathy et al. 1995), implying a total drop of the central star luminosity. This place the central star of SAO 244567 in the same position on the HR diagram as NGC 7027 (Zijlstra et al. 2007), just on the top of the cooling WD track. However, as already pointed out by Parthasarathy et al. (1995); Bobrowsky et al. (1998), such a very fast evolution is very difficult to be explained in the framework of actual post-AGB evolutionary models, that for a core mass object of $\sim 0.056M_{\odot}$ (Parthasarathy et al. 1993), foresee a much slower evolution.

7 SUMMARY

We have presented ATCA multi-epoch, multi-frequency observations of the YPNe SAO 244567, aimed to derive its radio characteristics to complete the picture of this quite intriguing object. The best radio map, for sensitivity and resolution, has been obtained at 86400 MHz (3.6 cm), which reveals a slight extended radio structure. The angular resolution of ATCA does not allow to evidence the fine details of the nebula as shown by HST observations. However, some morphological information have been derived by a model to the observed visibilities data, which are consistent with a wind-like shell whose external radius is in agreement with that of the main structure observed by HST.

The mean emission measure and the infrared excess, as derived by our observations, are consistent with a very young planetary nebula, still embedded in its dusty envelope, remnant of the earlier AGB phase. By comparison between total ionized gas mass, as derived from the radio, and the total dust mass, as derived from the IRAS data, a dust to gas ratio has been derived, by considering two different types of chemistry for the dusty envelope.

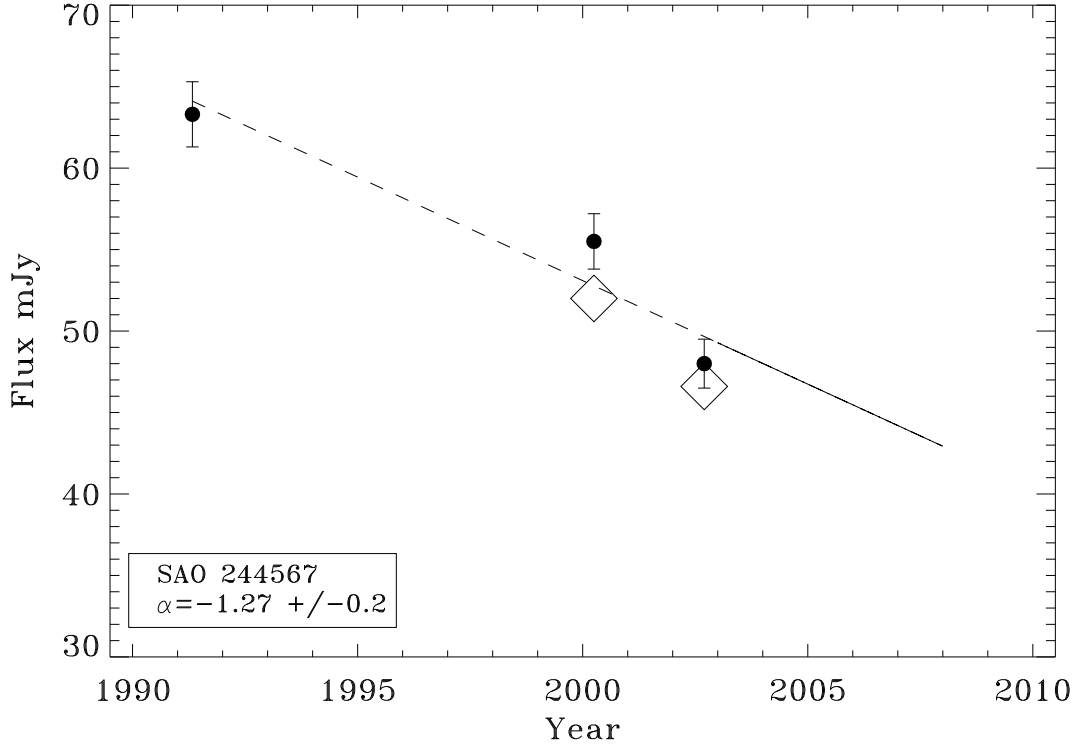


Figure 5. The behaviour of flux density of SAO 244567 as measured at 4800 MHz, filled dots. Data are from Parthasarathy et al. (1993) and this paper. A weighted fit to the data is also shown, which foresees a radio flux density at this frequency of 43 mJy at the beginning of 2008. Measures at 8640 MHz are also plotted, diamonds.

When compared with previous observations, the radio flux appears to vary. In particular, the decrement of the 6 cm flux (from 1991 to 2002), does not agree with an expansion of the main shell but appear to be related to the characteristics of the stellar object, whose fast evolution is difficult to be explained in the framework of the recent models of post-AGB evolution. Further multi-frequency monitoring and mapping with the ATCA fully equipped with millimetre receivers are necessary to confirm such variation with a longer time baseline. Up to now, variation (decrement) of the optically thin radio emission have been observed only in other two objects: the proto-PN CRL 618 and the PN NGC 7027. In both cases, the observed variations have been interpreted in terms of evolution of the central object. The paucity of objects where such variations have been followed makes further radio observations of SAO 244567 very important. as typical timescale of such variations can be used to test current evolutionary models.

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