Circumstellar dust shells of hot post-AGB stars

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Abstract. Using a radiative transfer code (DUSTY) parameters of the circumstellar dust shells of 15 hot post-AGB stars have been derived. Combining the optical, near and far-infrared (ISO, IRAS) data of the stars, we have reconstructed their spectral energy distributions (SEDs) and estimated the dust temperatures, mass loss rates, angular radii of the inner boundary of the dust envelopes and the distances to these stars. The mass loss rates ($10^{-6} - 10^{-5} M_\odot \text{yr}^{-1}$) are intermediate between stars at the tip of the AGB and the PN phase. We have also studied the ISO spectra of 7 of these stars. Amorphous and crystalline silicate features were observed in IRAS14331-6435 (Hen3-1013), IRAS18062+2410 (SAO85766) and IRAS22023+5249 (LSIII +5224) indicating oxygen-rich circumstellar dust shells. The presence of unidentified infrared (UIR) band at 7.7 $\mu$m, SiC emission at 11.5 $\mu$m and the "26" and "main 30" features in the ISO spectrum of IRAS17311-4924 (Hen3-1428) suggest that the central star may be carbon-rich. The ISO spectrum of IRAS 17423-1755 (Hen3-1475) shows a broad absorption feature at 3.1 $\mu$m due to C$_2$H$_2$ and/or HCN which is usually detected in the circumstellar shells of carbon-rich stars.

Key words. Stars: AGB and post-AGB — Stars: early-type — Stars: evolution — Stars: circumstellar matter — Infrared: stars

1. Introduction

In the evolution of low and intermediate mass stars ($0.8 - 8 M_\odot$), the post-asymptotic giant branch (post-AGB) or protoplanetary nebula (PPN) phase is a transition stage from the tip of the AGB to the planetary nebula (PN) stage (Kwok, 1993). The hot post-AGB stars form an evolutionary link between the cooler G,F,A supergiant post-AGB stars (Parthasarathy & Pottasch, 1986) and the hotter O-B central stars of PNe (Parthasarathy, 1993a).

Analysis of the UV(IUE) spectra of hot post-AGB stars (Gauba & Parthasarathy, 2003), revealed that in many cases, the hot (OB) central stars of PNe are partially obscured by circumstellar dust shells. Stars on the AGB and beyond are characterised by severe mass loss ($10^{-8} - 10^{-3} M_\odot \text{yr}^{-1}$) which results in the formation of circumstellar envelopes. The physical mechanisms responsible for the intensive mass loss from AGB stars are not well understood although the most promising mechanism to date involves radiation pressure on the dust grains (Tielens, 1983). While AGB stars appear to have spherically symmetric dust outflows (eg. Habing & Blommaert, 1993), PN tend to have axially symmetric inner regions and spherical outer halos (eg. Schwarz et al., 1992). In order to understand the mass loss mechanisms, wind velocities and time scales responsible for the evolution of PNe, we need to study the circumstellar environment of the stage intermediate between the AGB and the PN phase, i.e. the post-AGB/PPN phase. Circumstellar dust shells of some cooler post-AGB stars (eg. Hoogzaad et al., 2002; Hony et al., 2003) and PNe (eg. Siebenmorgen et al., 1994) have been modelled to derive the dust composition, mass loss rates and dynamical ages.

As a consequence of dredge-up of byproducts of helium burning to the surface of stars on the AGB, the oxygen-rich atmospheres of some of these stars may be transformed into carbon-rich atmospheres (see eg. Iben & Renzini, 1983). This change of chemistry would also be reflected in the composition of the dust grains formed in the circumstellar envelopes of AGB and post-AGB stars. With the resolution and wavelength coverage of the ISO mission (Kessler et al., 1996) the detection of prominent gas and solid state features specific to oxygen-rich and carbon-rich chemistries became possible. Amorphous and crystalline silicate features and crystalline water have been reported in the ISO spectra of some AGB and post-AGB stars and the nebulae surrounding [WC] central stars of PNe (see eg. Waters & Molster, 1999; Hoogzaad et al., 2002). Hrivnak et al. (2000) detected the "21$\mu$m" and "30$\mu$m"
emission bands at 3.3, 6.2, 7.7 and 11.3µ in the ISO spectra of a sample of carbon-rich PNNe.

Bogdanov (2000, 2002, 2003) modelled the complete spectral energy distribution (SED) of three hot post-AGB stars, IRAS18062+2410 (SAO85766), IRAS19590-1249 (LSIV-12 111) and IRAS20462+3416 (LSII+34 26) using radiative transfer codes and derived their mass loss rates, inner radii of the dust envelopes, optical depth of the envelopes and the distances to these stars. We need to study a bigger sample of such stars to understand the evolution of the infrared spectrum as the stars evolve from the cooler post-AGB phase to the hot central phases of PNe. In this paper, we have used the radiative transfer code, DUSTY (Ivezić et al., 1999) to model the circumstellar dust shells of 15 hot post-AGB stars. Additionally, 7 stars from our list were found to have ISO spectra. We also report the analysis of the ISO spectra of these stars.

2. Target Selection

The hot post-AGB stars for this study (Table 1) were selected from the papers of Parthasarathy & Pottasch 1989, Parthasarathy, 1993b and Parthasarathy et al., 2000a. High and low resolution optical spectra have confirmed the post-AGB nature of several of these stars, eg. IRAS17119-5926 (Hen3-1357; Parthasarathy et al., 1993c, 1995; Bobrowsky et al., 1998), IRAS18062+2410 (SAO 85766; Parthasarathy et al., 2000b; Mooney et al., 2002; Ryans et al., 2003), IRAS19590-1249 (LSIV-12 111; McCausland et al., 1992; Conlon et al., 1993a, 1993b; Mooney et al., 2002; Ryans et al., 2003) and IRAS20462+3416 (LSII+34 26; Parthasarathy, 1993a; García-Lario et al., 1997a). The UV(IUE) spectra of some hot post-AGB stars listed in Table 1 showed violet shifted P-Cygni profiles of CIV and NV indicating stellar wind and post-AGB mass loss (Gauba & Parthasarathy, 2003).

3. ISO observations

The ISO data archive was searched for spectra of the hot post-AGB stars listed in Table 1. Six of the fifteen sources were found to have only SWS (Short Wavelength Spectrometer) spectra while one source, IRAS 17423-1755 (Hen3-1475) had both SWS and LWS (Long Wavelength Spectrometer) spectra. Log of the observations is given in Table 2. ISO SWS spectra have a wavelength coverage from 2.38 – 45.2µ. The LWS spectra extend from 43 – 197µ.

Our objects were observed in the low resolution (AOT 01) mode of the SWS instrument (de Graauw et al., 1996). A spectrum scanned with SWS contains 12 subspectra, that each consist of two scans, one in the direction of decreasing wavelength (‘up’ scan) and the other in the direction of increasing wavelength (‘down’ scan). There are small regions of overlap in the wavelength between the sub-spectra. Each sub-spectrum is recorded by 12 independent detectors.

The LWS observations were carried out in LWS01 mode, covering the full spectral range at a resolution (λ/Δλ) of ~ 200. The characteristics of the ISO LWS instrument are described in Clegg et al. (1996) and the calibration of the instrument is described in Swinyard et al. (1996).

4. Analysis

In this section we describe the analysis of the ISO spectra and the modelling of the SEDs of the hot post-AGB stars.

4.1. ISO Data Analysis

Offline processed ISO SWS01 (OLP version 10.1) and LWS01 (OLP version 10) data were retrieved from the ISO data archive. These were further processed using ISAP (ISO Spectroscopic Analysis Package) version 2.1.

4.1.1. SWS

The data analysis using ISAP consisted of extensive bad data removal primarily to minimize the effect of cosmic ray hits. All detectors were compared to identify possible features. For each sub-band, the flux level of the 12 detectors were shifted and brought to a mean value. They were then averaged, using median clipping to discard points that lay more than 2.5σ from the median flux. The spectra were averaged typically to a resolution of 400, 500, 800 and 1500 for SWS01 data taken with speed 1, 2, 3 and 4 respectively (Table 2). Appropriate scaling factors were applied to the averaged spectra of each subband to form a continuous spectrum from 2.38 – 45.2µ. The data of subband 3E (27.5–29.0 µ) are generally noisy and unreliable (see eg. Hrivnak et al., 2000, Hony et al., 2002). Figs. 1a, b, c and 2a show the SWS spectra of the hot post-AGB stars. The SWS data of IRAS14331-6435 (Hen3-1013), IRAS18062+2410 (SAO 85766) and IRAS22023+5249 (LSIII +5224) below 7µ, IRAS22023+5249 (LSIII +5224) below 12.5µ were noisy and have been excluded.

This is also evident from the low IRAS 12µ flux (< 5 Jy) of these stars. Identification of the infrared spectral features is based on Waters & Molster (1999), Cox (1993), Hrivnak et al. (2000), Volk et al. (2002), Cernicharo et al. (1999) and Jørgensen et al. (2000).

4.1.2. LWS

Reduction of the LWS observation of IRAS17423-1755 (Hen3-1475) consisted of extensive bad data removal using ISAP rebinning on a fixed resolution grid of λ/Δλ = 250. Appropriate scaling factors were applied to the data from different LWS detectors to form a continuous spectrum (Fig. 2c). The LWS spectrum of IRAS17423-1755 (Hen3-1475) appears featureless. The LWS spectrum of IRAS17423-1755 (Hen3-1475) consisted of extensive bad data removal using ISAP rebinning on a fixed resolution grid of λ/Δλ = 250. Appropriate scaling factors were applied to the data from different LWS detectors to form a continuous spectrum (Fig. 2c). The LWS spectrum of IRAS17423-1755 (Hen3-1475) appears featureless. The LWS spectrum of IRAS17423-1755 (Hen3-1475) consisted of extensive bad data removal using ISAP rebinning on a fixed resolution grid of λ/Δλ = 250. Appropriate scaling factors were applied to the data from different LWS detectors to form a continuous spectrum (Fig. 2c).
4.1.3. Joining the SWS and LWS spectra

Although the spectral shape is very reliable, the absolute flux calibration uncertainty is 30% for the SWS at 45µ (Schaeidt et al., 1996) and 10–15% for the LWS at 45µ (Swinyard et al., 1998). The SWS and LWS spectra of IRAS17423-1755 (Hen3-1475) were scaled according to their fluxes in the overlap region. The difference between the flux levels of LWS and SWS in the overlap region was smaller than 30% which is acceptable within the limits of the combined error bars. The combined SWS-LWS spectra of IRAS17423-1755 (Hen3-1475) was used in Fig. 3.

4.2. Spectral energy distributions (SEDs)

To re-construct the spectral energy distributions (SEDs) of the objects, we combined the ISO data with available U,B,V,R,I,J,H,K,L′ and M magnitudes of the stars from literature (Table 3a). We also searched the 2MASS (2Micron All Sky Survey) Catalog within 15′ of each object for their JHK magnitudes and the Midcourse Space Experiment (MSX) catalog within 3′ of each object. The 2MASS data was included only when it was found to be free from confusion flags. MSX fluxes were found only for IRAS17460-3114 (SAO 209306; Table 3b). Infrared data (8.7, 10, 11.4, 12.6 and 19.5µ) on IRAS18062+2410 (SAO 85766; Table 3c) was obtained from Lawrence et al. (1990).

4.2.1. Central star temperatures

The temperatures of the central stars (Table 4) are mainly from Gauba & Parthasarathy (2003). For IRAS12584-4837 (Hen3-847) and IRAS17423-1755 (Hen3-1475), we estimated the central star temperatures based on their spectral types. For the PN, IRAS22495+5134 (LSIII +5142) was carried out by Mooney & Stasińska, 1994). Gauba & Parthasarathy (2003) found that the UV(IUE) spectrum of IRAS22023+5249 was scaled according to the spectral type B2I. LTE analysis of the high resolution optical spectra of IRAS17423-1755 was used in Fig. 3. The temperatures of the central stars (Table 4) are mainly from Parthasarathy et al. (1992a). The intrinsic B−V values, (B−V)obs, for the objects, we combined the ISO data with available U,B,V,R,I,J,H,K,L′ and M magnitudes of the stars from literature (Table 3a). We also searched the 2MASS (2Micron All Sky Survey) Catalog within 15′ of each object for their JHK magnitudes and the Midcourse Space Experiment (MSX) catalog within 3′ of each object. The 2MASS data was included only when it was found to be free from confusion flags. MSX fluxes were found only for IRAS17460-3114 (SAO 209306; Table 3b). Infrared data (8.7, 10, 11.4, 12.6 and 19.5µ) on IRAS18062+2410 (SAO 85766; Table 3c) was obtained from Lawrence et al. (1990).

4.2.2. Reddening

The interstellar extinction (E(B−V)I.S.) in the direction of the stars were estimated using the Diffuse Infrared Background Experiment (DIRBE)/IRAS dust maps (Schlegel et al., 1998; Table 4). The optical spectral types of the stars are mainly from Parthasarathy et al. (1992a). The intrinsic B−V values, (B−V)obs, for the objects, we combined the ISO data with available U,B,V,R,I,J,H,K,L′ and M magnitudes of the stars from literature (Table 3a). We also searched the 2MASS (2Micron All Sky Survey) Catalog within 15′ of each object for their JHK magnitudes and the Midcourse Space Experiment (MSX) catalog within 3′ of each object. The 2MASS data was included only when it was found to be free from confusion flags. MSX fluxes were found only for IRAS17460-3114 (SAO 209306; Table 3b). Infrared data (8.7, 10, 11.4, 12.6 and 19.5µ) on IRAS18062+2410 (SAO 85766; Table 3c) was obtained from Lawrence et al. (1990).

4.2.3. Modelling the circumstellar dust shells with DUSTY code

The use of the radiative transfer code, DUSTY (Ivezić et al., 1999) for modelling the circumstellar dust shells of hot post-AGB stars was described in Gauba et al. (2003). DUSTY uses six different grain types: 'warm' (Sil-Ow) and 'cold' (Sil-Oc) silicates from Ossenkopf et al. (1992), silicates and graphites (Sil-Dl and grf-DL) from Draine and Lee (1984), amorphous carbon (amC-Hn) from Hanner (1988) and SiC (SiC-Pg) from Pégourié (1988). The central stars were assumed to be point sources at the centers of the spherical density distributions. The SEDs of the central stars were assumed to be Planckian. The standard Mathis, Rumpl, Nordsieck (MRN) (Mathis et al., 1977) power-law was used for the grain size (n(a)) distributions, i.e. n(a) ∝ a−q for a min ≤ a ≤ a max with q=3.5, a (min)=0.005µ and a (max)=0.25µ. For each object, the dust temperature (T d) on the inner shell boundary and the optical depth (τ) at 0.55µ (V-band) were varied. We assumed an inverse square law (a−2) for the spherical density distribution. The shell was assumed to extend to 1000 times its inner radius. We adopted the fits for which the sum of squares of the deviations between the observed and theoretical spectral types of the stars, were taken from Schmidt-Kaler (1982). We adopted (B−V)0=−0.20 for IRAS12584-4837 (Hen3-847) and IRAS17423-1755 (Hen3-1475) corresponding to T eff=20000K. For IRAS22023+5249 (LSIII +5224), we used (B−V)0=−0.16 corresponding to B2I spectral type and for the PN, IRAS22495+5134 (LSIII +5142), we adopted (B−V)0=−0.30 corresponding to T eff=35000K. Using the observed and intrinsic B−V values we derived the total (interstellar plus circumstellar) extinction, E(B−V)total =E(B−V)obs −(B−V)0 towards these stars. Comparing E(B−V)total and E(B−V)I,S., it is evident that there is considerable circumstellar extinction in most cases. Gauba & Parthasarathy (2003) found that the circumstellar extinction law in the UV (from ~ 1300Å to 3200Å ) varies linearly as λ−1 in the case of IRAS13266-5551 (CPD-55 5588), IRAS14331-6435 (Hen3-1013), IRAS16206-5956 (SAO 243756), IRAS17311-4924 (Hen3-1428), IRAS18023-3409 (LSS 4634), IRAS18062+2410 (SAO 85766), IRAS18371-3159 (LSE 63), IRAS22023+5249 (LSIII +5224) and IRAS22495+5134 (LSIII +5142).

Since little is known about circumstellar extinction laws, we corrected the observed optical and near infrared magnitudes of the stars for the total extinction (E(B−V)total) using the standard extinction laws by Rieke & Lebofsky (1985). In particular, Rieke & Lebofsky (1985) assume R V=3.1, where, R V=A V/(B−V). Although this is true for interstellar extinction, it may not be strictly true for circumstellar extinction obeying a λ−1 law in the UV. In particular, R V may be different from 3.1 in the case of circumstellar extinction.
lists the adopted input parameters. Fig. 3 shows the spectral energy distribution of the stars. DUSTY does not allow simultaneous modelling of warm and cold dust shells. Hence, the cold dust in the case of IRAS12584-4837 (Hen3-847) and IRAS17423-1755 (Hen3-1475) had to be modelled and treated independent of the warm dust around these stars.

Having fixed Td and τ, we then used the gas-dynamical mode of the DUSTY code to derive the inner radii, r1(cm) where the dust temperatures (Td) are specified and the mass-loss rates (Ṁ). The radius scales in proportion to L1/2 where L is the luminosity and the code output value corresponds to L=10^4L⊙. The mass-loss rate scales in proportion to L3/4(rgdρs)1/2 where, the gas-to-dust mass ratio, rgd=200 and the dust grain density, ρs=3 g cm^-3. The hot post-AGB stars discussed in this paper have a range of core-masses (Gauba & Parthasarathy, 2003). Pottasch (1992) pointed out that the white dwarf distribution is sharply peaked with a mean mass between 0.56 and 0.58 M⊙ and central stars of PNe have core-masses which show a peak at approximately 0.6M⊙. We carried out calculations for our hot post-AGB stars with core masses of 0.565M⊙ and 0.605M⊙ corresponding to luminosities of 4500L⊙ (Schönberner, 1983) and 6300L⊙ (Blöcker, 1995) respectively. Distances (d) to the stars were derived using r1 and the ratio of the observed and modelled fluxes at 0.55μ. θ (=r1/d) is the angular radii of the inner boundary of the cold circumstellar dust envelopes.

Tables 5a and b list the respective values for T_d, r1, d, θ and M. All calculations were carried out using the best fit parameters for the cold circumstellar dust shells.

4.3. Notes on individual objects

The hot post-AGB stars in this paper, except IRAS19590-1249 (LSIV-12 111), have been described in Gauba et al. (2003) and Gauba & Parthasarathy (2003). Here, we describe, the ISO spectra and dust shell characteristics of some of these objects.

#IRAS 12584-4837 (Hen3-847)

It was found to be variable in the optical (Kazarovets et al., 2000; de Winter et al., 2001). The Hipparcos magnitudes at maximum and minimum are 10^4.52 and 10^6.70 respectively. Comparison of the J,H,K magnitudes of the star from Fouque et al. (1992) and the 2MASS catalog indicate infrared variability as well. The SED of this shows the presence of both warm and cold circumstellar dust. We have modelled the warm dust based on the data of Fouque et al. (1992) (775K) and the 2MASS catalog (700K). The presence of warm circumstellar dust may indicate ongoing post-AGB mass loss. The use of amorphous carbon grains to model the warm dust and silicate grains for the cold dust, indicates that during its evolution along the AGB, the central star may have evolved from an oxygen-rich to a carbon-rich star.

The ISO SWS spectrum reveals the presence of amorphous (10.8μ) and crystalline silicates and/or water (33.6μ, 40.4μ, 43.1μ) in the circumstellar environment of this star. Crystalline silicates have been detected in the dust shells around evolved oxygen-rich stars (see eg. Waters et al., 1996, Waters & Molster, 1999). Waters et al. (1996) found that these emission features are more prominent for objects with cooler dust shells (T < 300K). Emission from crystalline water has been reported in the 40–70μ spectrum of the Frosty Leo nebula and other cool oxygen-rich envelopes (Omont et al., 1990).

#IRAS 16206-5956 (SAO 243756)

The ISO spectrum of this star is noisy and no features could be identified. The continuum from 12.5μ to 45.2μ was used in addition to the IRAS fluxes to better constrain the model fit to the SED.

#IRAS 17311-4924 (Hen3-1428)

The broad "30 μ emission feature" was detected in several AGB stars and PN sources (Forrest et al., 1981; Cox, 1993). More recently it was also detected in carbon-rich PPNs possessing the 21μ emission feature (Omont et al., 1995). Hony et al. (2002) detected this feature in the ISO SWS spectrum of IRAS 17311-4924 (Hen3-1428) and a large sample of carbon-rich AGB stars (C-stars), post-AGB stars and PNe. Substructure in the 30μ feature was recognised by Szczerba et al. (1999). In the spectra of several PPNs and carbon stars, it was resolved into two components (Hrivnak et al., 2000; Volk et al., 2000, 2002), the "26 μ" and "main 30 μ" feature (Fig. 1b). Goebel & Moseley (1985) first suggested that the feature is due to magnesium sulfide (MgS). Hony et al. (2002) too identified MgS as the carrier of the "26 μ" and "main 30 μ" emission features. However, the 30μ band is never seen in oxygen-rich sources (Forrest et al., 1979). Since the feature is seen only in carbon-rich objects, the suggestion that its carrier is a carbonaceous material continues to be appealing (Volk et al., 2002). We modelled the SED of IRAS 17311-4924 (Hen3-1428) using graphite and silicon carbide (SiC). However, we could not obtain a fit in the 30μ emission region (from ~ 20 – 30 μ).

The 11.5μ band (Fig. 1b) is attributed to SiC (Treffers & Cohen, 1984) and has been detected in carbon-rich evolved objects (see eg., Cernicharo et al., 1989). Cox(1993) pointed out that all AGB stars where a 30μ emission band is present show the 11.5μ emission feature (Fig. 1b). Goebel & Moseley (1985) attributed the 11.5μ feature (Fig. 1b). Goebel & Moseley (1985) first suggested that the feature is due to magnesium sulfide (MgS). Hony et al. (2002) too identified MgS as the carrier of the 11.5μ band (V Cyg, S Cep and Y CVn). Using the DUSTY model, we obtained a good fit to the SIC emission.

We also detected the 7.7 μ UIR feature in the ISO spectrum of this object. UIR features are commonly attributed to polycrystalline hydrocarbons (PAHs) and have been detected in other carbon-rich protoplanetary nebulae (see eg. Beintema et al., 1996; Hrivnak et al., 2000).
Gauba et al. (2003) modelled the SED of this star using DUSTY. They found a warm dust component at 1500K in addition to the cold-dust at 100K indicating ongoing post-AGB mass-loss. Plotting the ISO spectrum of the star (2.38µ - 171 µ) along with the photometric data from Gauba et al (2003), near-IR data from García-Lario et al. (1997b) and IRAS fluxes and using the DUSTY code, we detected a second warm dust component at 1000K.

The broad absorption feature at 3.1µ seen in the ISO spectrum is due to C2H2 and/or HCN (Ridgway et al., 1978; Cernicharo et al., 1999; Jørgensen et al., 2000). This feature is observed in carbon stars (Merrill & Stein, 1976; Noguchi et al., 1977; Groenewegen et al., 1994). The far-IR flux distribution of the star was modelled with amorphous carbon and silicon carbide confirming the carbon rich nature of the circumstellar dust shell. The LWS spectrum appears featureless.

#IRAS 18062+2410 (SAO 85766)
High resolution optical spectra (Parthasarathy et al., 2000b; Mooney et al., 2002; Ryans et al., 2003) indicated the underabundance of carbon in this star. The ISO spectrum shows strong emission due to amorphous silicates at 10.8µ and 17.6µ in conformity with an oxygen-rich chemistry (i.e. C/O < 1) for the central star.

The J,H,K magnitudes from García-Lario et al. (1997b) and the 2MASS catalog indicate that the star is variable in the near-infrared. Optical variations of the star were detected by Arkhipova et al. (1999). The K,L,M fluxes by Lawrence et al. (1990) lie above the modelled SED (Fig. 3). In particular the K-band flux of Lawrence et al. (1990) lies above the K-band flux estimated by García-Lario et al. (1997b). If the K,L,M fluxes of the star by Lawrence et al. (1990) were not overestimated, the observed mismatch may be due to the variable nature of this object. Gauba & Parthasarathy (2003) reported variable circumstellar extinction which in addition to stellar pulsations may be due to a dusty torus in motion around the hot central star.

Bogdanov (2000) modelled the SED of this star using a different radiative transfer code. They derived T_d=410K. This value is much higher than the dust temperature (T_d=230K) derived by us from the model fit. Bogdanov (2000) had used the K,L,M fluxes by Lawrence et al. (1990) only. Besides they did not use the ISO spectrum of the star to constrain the SED. We believe that we have a better estimate of the physical parameters of the star especially since our model gives a very good fit to the IRAS fluxes and ISO spectrum of the star.

#IRAS 18379-1707 (LSS 5112)
The star was found to be variable in the near-infrared based on the J,H,K magnitudes from García-Lario et al. (1997b) and the 2MASS catalog.

#IRAS 19590-1249 (LSIV-12 111)
It was classified from low dispersion spectroscopy by Kilkenny & Pauls (1990) as having a spectral type around B0. Based on an analysis of its high resolution optical spectra, McCausland et al. (1992) and Conlon et al. (1993a, b) showed that the star has an extensive dust envelope. Furthermore, the ISO spectrum of this PN is noisy and spectral features could not be identified. The angular radii (θ) derived using the DUSTY code (Tables 5a and b) are in good agreement with the angular diameter of 4″ reported by Tylenda & Stasińska (1994) and Acker et al. (1992) respectively. From the Hipparcos and Tycho Catalogues (ESA 1997), the PN has a parallax of 0.42 mas. This implies a distance of 2.38 kpc. Assuming a core mass (M_core) of 0.605 M☉, we derived a distance of 2.17 kpc to the PN.

5. Discussion and Conclusions
We have modelled the circumstellar dust shells of 15 hot post-AGB stars using the radiative transfer code, DUSTY and derived their dust temperatures, distances to the stars, mass loss rates and angular radii of the inner boundary of the dust envelopes (Tables 5a and b). These stars have detached dust shells (as is evident from the SEDs, Fig. 3), OB-giant or supergiant spectra and cold dust between 100−315K, satisfying the observational properties of PPNs as defined by Kwok (1993, 2001). In addition to the cold dust, warm dust was detected in the case of IRAS12584-4837 (Hen3-847) and IRAS17460-3114 (SAO 209306) suggesting that the central stars in these two cases may have undergone a recent change from an oxygen-rich to a carbon-rich chemistry. Such hot post-AGB stars may have undergone a recent change from an oxygen-rich to a carbon-rich chemistry.
may evolve into the [WC] central stars of PNe. Recently, Waters et al. (1998) detected carbon-rich PAH features in the near-infrared and crystalline silicates in the far-infrared ISO spectra of two PNe with [WC] central stars, BD+30 3639 and He2-113.

Observational evidence (eg. Chu et al., 1991) suggests that three winds are involved in stripping the outer envelope of the AGB star on its way to becoming a PN (Marten et al., 1993; Frank, 1994): the spherically symmetric AGB wind (eg. Habing & Blommaert, 1993) when the star loses mass at rates of $10^{-7} - 10^{-8}$M$_{\odot}$yr$^{-1}$ with a wind velocity of $\sim 10$ kms$^{-1}$; the superwind phase when the mass loss is thought to increase dramatically at the end of the AGB, up to $10^{-5} - 10^{-6}$M$_{\odot}$yr$^{-1}$, still with a wind velocity of $\sim 10$ kms$^{-1}$; once the superwind exhausts most of the AGB star's envelope, a fast wind with mass loss rate of $10^{-6}$M$_{\odot}$yr$^{-1}$ and a wind velocity of $\sim 1000$ kms$^{-1}$ develops at some point during the PPN phase. Velocities of 1000 kms$^{-1}$ and mass loss rates of $\sim 10^{-8}$M$_{\odot}$yr$^{-1}$ have been observed in the central stars of PNe (eg. Gauba et al., 2001). For our hot post-AGB stars, we derived mass loss rates of $10^{-5} - 10^{-6}$M$_{\odot}$yr$^{-1}$. The mass loss rate ($M$) scale with the gas-to-dust mass ratio ($r_{gd}$). We have adopted $r_{gd} = 200$. For carbon-rich AGB and post-AGB stars values between 200 and 250 are often used (eg. Jura, 1986; Meixner et al., 1997). For the cool (F3lb) post-AGB star, HD161796 (Parthasarathy & Pottasch, 1986) with an oxygen-rich circumstellar environment, Hoogzaad et al. (2002) estimated with an oxygen-rich circumstellar environment, Hoogzaad et al. (2002) estimated $r_{gd} = 270$. Furthermore, our models assume that the dust density distribution falls off as $\gamma^{-2}$ in the entire circumstellar dust shell. Such an assumption would break down in the case of episodic mass loss (Olofsson et al., 1990). Episodic mass loss may have been responsible for the rapid evolution (30 - 40 years) of IRAS17119-5926 (Hen3-1357) and IRAS18062+2410 (SAO85766) from B-type post-AGB supergiants to young PNe (Parthasarathy et al., 1993c, 1995; Bobrowsky et al., 1998, Parthasarathy et al., 2000b).

The proper motions ($\mu$) of the stars from the Tycho-2 Catalogue (Hog et al., 2000) have been listed in Tables 5a and b. Using the derived distances ($d$) in conjunction with the proper motions we estimated the component of the stellar space velocities of the targets tangent to the line of sight ($V_T$). For IRAS17203-1534, IRAS18062+2410 (SAO85766) and IRAS18371-3159 (LSE63), the large $V_T$ values (Tables 5a and b) imply very high space velocities ($V_a = (V_a^2 + V_T^2)^{1/2}$; where $V_a$ is the radial velocity of a star), close to the escape velocity from the Galaxy of 290 kms$^{-1}$ near the Sun. Mooney et al. (2002) estimated a distance of 8.1 kpc to IRAS18062+2410 (SAO85766) which is much greater than our estimate of $\sim 5$ kpc. Such a large distance, if correct, would imply a still higher space velocity. We believe our distance estimates are closer to the actual values for these stars. However, the assumption of spherical density distributions in our models, may be an over simplification for some of these objects. Eg. IRAS17423-1755 (Hen3-1475) has IRAS colors moderately may have a disk instead of a spherical outflow (see eg. Jura, 2003, Fisher et al., 2003). The predicted angular sizes of the inner radii of the dust shells (Tables 5a and b) suggests that these objects should be easily resolvable in the mid-IR images with large ground based telescopes. Imaging of these objects in the IR would serve to test the basic assumptions such as those of spherical symmetry for our models.

In Table 6 we have compared the observed and predicted (V-J) values for these stars ($\Delta(V-J) = (V-J)_{predicted} - (V-J)_{obs}$) where, $(V-J)_{predicted} = (V-J)_o + A_V - A_J$. The intrinsic (V-J) colors ($(V-J)_o$), for the spectral types of the stars are from Ducati et al. (2001). For stars with emission lines in their optical spectra, IRAS12584-4837 (Hen3-847), IRAS17423-1755 (Hen3-1475), IRAS22023+5249 (LSIII+5224) and for the PN, IRAS22495+5134 (LSIII+5142), $(V-J)_o$ could not be assumed. In the case of IRAS14331-6435 (Hen3-1013), IRAS17203-1534, IRAS18062+2410 (SAO85766) and IRAS18379-1707 (LSII512), we find significant differences between the values of $(V-J)_{predicted}$ and $(V-J)_{obs}$. On first sight, this would then raise a suspicion about the adopted E(B-V)$_{total}$ values. However, we would like to point out that the V and J magnitudes of these stars have not been recorded simultaneously. Many of these stars are variable as evidenced from the J,H,K data on IRAS12584-4837 (Hen3-847), IRAS18062+2410 (SAO85766) and IRAS18379-1707 (LSII512). The V and J magnitudes may have been recorded at different epochs of the variability cycle and hence it may not be suitable to compare $(V-J)_{predicted}$ and $(V-J)_{obs}$.

We also studied the ISO spectra of 7 hot post-AGB stars, IRAS14331-6435 (Hen3-1013), IRAS16206-5956 (SAO243756), IRAS17311-4924 (Hen3-1428), IRAS17423-1755 (Hen3-1475), IRAS18062+2410 (SAO85766), IRAS22023+5249 (LSIII+5224) and IRAS22495+5134 (LSIII+5142). A weak amorphous silicate feature (10.8$\mu$m) along with crystalline silicate features was found in the dust shells of IRAS14331-6435 (Hen3-1013) and IRAS22023+5249 (LSIII+5224). The 17.6$\mu$m amorphous silicate feature was missing in these two stars. The post-AGB star IRAS18062+2410 (SAO85766) did not show evidence for the presence of crystalline silicates but strong amorphous silicate features at 10.8$\mu$m and 17.6$\mu$m were detected. Volk & Kwok (1989) predict that at dust temperatures of typically a few 100K for post-AGB stars, the spectrum should increase from 8 to 23$\mu$m and the 10.8$\mu$m and 17.6$\mu$m silicate features should cease to be observable. This appears to be consistent with the observed spectral features and the dust temperatures of 230K, 130K and 120K for IRAS18062+2410 (SAO85766), IRAS14331-6435 (Hen3-1013) and IRAS22023+5249 (LSIII+5224) respectively from our model fits. The presence of silicate features in these stars indicates the O-rich nature of the central stars. The formation of crystalline silicates in the circumstellar shells of post-AGB stars is still not well understood (see eg., Waters et al., 1996). In
30 µm" features and 11.5 µm SiC emission in IRAS17311-4924 (Hen3-1428), are typical of circumstellar dust shells around carbon-rich post-AGB stars. However, the 21 µm emission feature detected in several carbon-rich PPN (Hrivnak et al., 2000) was notably absent in the ISO spectrum of IRAS17311-4924 (Hen3-1428). Volk et al. (2002) pointed out that although all sources with the 21 µm emission feature also display the "26 µm" and "main 30 µm" features, the converse is not true. The hot post-AGB star, IRAS01005+7910 (Klochkova et al., 2002) which showed the "26" and "main 30 µm" emission also did not show the 21 µm emission feature (Hrivnak et al., 2000). It may be that the dust grains responsible for the 21 µm emission are destroyed as the central star evolves hotter temperatures. The broad absorption feature at 3.1 µm in IRAS17423-1755 (Hen3-1475) attributed to C2H2 and/or HCN indicates that the central star may be carbon-rich.

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Fig. 1a. The ISO SWS spectrum of IRAS14331-6435 (Hen3-1013) shows emission due to amorphous (10.8µ) and crystalline silicates and/or H$_2$O (33.6µ, 40.4µ, 43.1µ) (see eg. Waters & Molster, 1999). ISO spectrum of IRAS16206-5956 (SAO 243756) is noisy and only the continuum is seen here.
Fig. 1b. The ISO SWS spectrum of IRAS17311-4924 (Hen3-1428) shows emission due to the UIR band at 7.7\(\mu\), SiC (11.5\(\mu\)) and the "30\(\mu\) feature" (see eg. Hrivnak et al., 2000; Volk et al., 2002). IRAS18062+2410 (SAO 85766) shows emission due to amorphous silicates at 10.8\(\mu\) and 17.6\(\mu\) (see eg. Waters & Molster, 1999).
Fig. 1c. The ISO SWS spectrum of IRAS22023+5249 (LSIII +5224) shows emission due to amorphous (10.8μ) and crystalline (33.6μ) silicates (see eg. Waters & Molster, 1999). ISO SWS spectrum of IRAS22495+5134 (LSIII +5142) is noisy and only the continuum is seen here.
Fig. 2. ISO SWS (2.4µ – 44.4µ) and LWS (43µ – 171µ) spectra of IRAS17423-1755 (Hen3-1475) are presented in Figs. 2a and 2c respectively. The SWS spectrum shows a broad absorption feature at 3.1µ due to C$_2$H$_2$ and/or HCN (see eg. Cernicharo et al. 1999; Jørgensen et al., 2000). This broad absorption feature is seen clearly in Fig. 2b showing the SWS spectrum of the star from 2.4µ – 10µ only. The LWS spectrum of the star (Fig. 2c) appears featureless.
Table 1. Hot post-AGB stars

| Star No. | IRAS   | Name       | Optical Sp. Type | 12µ  | 25µ  | 60µ  | 100µ |
|----------|--------|------------|------------------|------|------|------|------|
| 1.       | 12584-4837 | Hen3-847 | Be               | 304.60 | +13.95 | 36.07 | 48.75 | 13.04 | 3.31 |
| 2.       | 13266-5551 | -55 5588  | B1Ibe            | 308.30 | +6.36  | 0.76  | 35.90 | 35.43 | 11.66 |
| 3.       | 14331-6435 | Hen3-1013 | B3Ie             | 313.89 | -4.20  | 4.04  | 108.70 | 70.71 | 20.61 |
| 4.       | 16206-5956 | SAO 243756 | A0Ia^2          | 326.77 | -7.49  | 0.36  | 11.04 | 12.30 | 4.83 |
| 5.       | 17203-1534 |           | B1IIIpe          | 8.55  | +11.49 | 0.32  | 10.70 | 6.88  | 3.37 |
| 6.       | 17311-4924 | Hen3-1428 | B1Ie             | 341.41 | -9.04  | 18.34 | 150.70 | 58.74 | 17.78 |
| 7.       | 17423-1755 | Hen3-1475 | Be               | 9.36  | +5.78  | 7.05  | 28.31 | 63.68 | 33.43 |
| 8.       | 17460-3114 | SAO 209306 | O8III            | 358.42 | -1.88  | 6.26  | 20.82 | 12.20 | 220.40L |
| 9.       | 18023-3409 | LSS 4634  | B2IIIe           | 357.61 | -6.31  | 0.26  | 2.94  | 1.82  | 25.64L |
| 10.      | 18062+2410 | SAO 85766 | B1I^3            | 50.67  | +19.79 | 3.98  | 19.62 | 2.90  | 1.00L |
| 11.      | 18371-3159 | LSE 63    | B1Iabe           | 2.92  | -11.82 | 0.25  | 6.31  | 5.16  | 1.95 |
| 12.      | 18379-1707 | LSS 5112  | B1IIIpe          | 16.50  | -5.42  | 1.67  | 23.76 | 7.12  | 3.66L |
| 13.      | 19590-1249 | LSIV-12 111 | B1Ibe           | 29.18  | -21.26 | 0.29  | 10.26 | 6.45  | 1.77 |
| 14.      | 22023+5249 | LSIII +5224 | B^3             | 99.30  | -1.96  | 1.02  | 24.69 | 14.52 | 3.93L |
| 15.      | 22495+5134 | LSIII +5142 | PN^5            | 104.84 | -6.77 | 0.54  | 12.37 | 7.18  | 3.12 |

A colon : indicates moderate quality IRAS flux, L is for an upper limit.

The spectral types are from Parthasarathy et al. (2000a) except 1Kazarovets et al. (2000); 2Schild et al. (1983); 3Parthasarathy et al. (2000b); 4Simbad database; 5Acker et al. (1992)

Table 2. Log of ISO observations

| IRAS   | Name    | Date of Obs. | Duration of Obs.(s) | TDT^a | Mode^b | Speed^c |
|--------|---------|--------------|---------------------|-------|--------|---------|
| 14331-6435 | Hen3-1013 | 14 July 1997 | 3454 | 60600607 | SWS01 | 3 |
| 16206-5956 | SAO 243756 | 6 Sept. 1996 | 6538 | 29401311 | SWS01 | 4 |
| 17311-4924 | Hen3-1428 | 28 Feb. 1996 | 1834 | 10300636 | SWS01 | 2 |
| 17423-1755 | Hen3-1475 | 17 March 1997 | 1140 | 48700267 | SWS01 | 1 |
| 18023-3409 | LSS 4634 | 17 March 1997 | 1140 | 48700168 | LW01 | – |
| 18062+2410 | SAO 85766 | 18 Feb. 1997 | 1140 | 46000275 | SWS01 | 1 |
| 22023+5249 | LSIII +5224 | 5 Jan. 1997 | 1140 | 41600993 | SWS01 | 1 |
| 22495+5134 | LSIII +5142 | 5 Jan. 1997 | 1140 | 41601295 | SWS01 | 1 |

^aTDT number uniquely identifies each ISO observation. ^bSWS observing mode used (see de Graauw et al., 1996). ^cSpeed corresponds to the scan speed of observation.
**Table 3a. Photometric data on hot post-AGB stars**

| IRAS          | U mag | B mag | V mag | R mag | I mag | J mag | H mag | K mag | L mag | L' mag | M mag |
|---------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 12584-4837    | 10.65a| 10.58a|       |       |       | 9.99b | 9.14b | 7.49b |       | 4.53b | 3.59b |
| 13266-5551    | 10.33c| 10.99c| 10.68c|       |       | 9.96d | 9.84d | 9.70d |       |       |       |
| 14331-6435    | 11.11c| 11.48c| 10.90c|       |       | 9.35d | 9.03d | 8.72d |       |       |       |
| 16206-5956    | 9.87c | 10.07c| 9.76c |       |       | 9.00e | 8.87e | 8.71e |       |       |       |
| 17203-1534    |       | 12.37a| 12.02a| 11.75g| 10.18b| 10.18b| 9.42b | 7.80b | 4.53b | 3.59b |
| 17311-4924    | 10.52f|       | 10.68f| 9.74d | 9.54d | 9.19d |       |       |       |       |       |
| 17423-1755    | 13.57g| 13.3h | 12.64d|       |       | 9.61d | 8.32d | 6.80d |       |       |       |
| 17460-3114    | 7.45c | 8.17c | 7.94c | 11.75g| 10.91b|       |       |       |       |       |       |
| 18023-3409    | 11.70c| 12.01c| 11.55c|       |       |       |       |       |       |       |       |
| 18062+2410    | 10.86c| 11.59c| 11.54c|       | 11.22d| 10.97d| 10.84d| 10.21f| 9.61f |       | 7.30f |
| 18371-3159    | 12.09c|       | 11.98c| 11.36d|       |       |       |       |       |       |       |
| 18379-1707    | 11.94c| 12.38c| 11.93c|       |       |       |       |       |       |       |       |
| 19590-1249    | 10.75c| 11.41k| 11.32k| 10.76d| 10.55d| 10.33d|       |       |       |       |       |
| 22023+5249    | 13.21c| 12.52a|       |       |       |       |       |       |       |       |       |
| 22495+5134    | 12.00c| 11.78a|       |       |       |       |       |       |       |       |       |

Photometry is from:  
aHog et al.(2000);  
bFouque et al.(1992);  
cReed(1998);  
dGarcía-Lario et al.(1997b);  
e2MASS;  
fKozok (1985);  
gGauba et al. (2003);  
hMonet et al. (1998);  
iArkhipova et al. (1999);  
jLawrence et al.(1990);  
kArkhipova et al. (2002),  
lConlon et al. (1993a)

**Table 3b. MSX data**

| IRAS         | MSX Fluxes (Jansky) |             |             |             |             |             |
|--------------|---------------------|-------------|-------------|-------------|-------------|-------------|
|              | Band A 8.28µ       | Band C 12.13µ | Band D 14.65µ | Band E 21.34µ |
| 17460-3114   | 4.0095              | 5.2726      | 6.9896      | 20.730      |

**Table 3c. Infrared data on IRAS18062+2410 (SAO85766)**

| IRAS         | IR data in magnitudes |
|--------------|-----------------------|
|              | 8.7µ                  | 10µ         | 11.4µ       | 12.6µ       | 19.5µ       |
| 18062+2410   | 4.29                  | 2.17        | 2.22        | 2.31        | −0.25       |
Table 4. Input physical parameters for DUSTY and the adopted reddening values

| IRAS          | dust type | E(B−V) | E(B−V) | T_{eff} (K) | grain types † | optical depth (τ) at 0.55μm | T_d (K) |
|---------------|-----------|--------|--------|-------------|---------------|-----------------------------|---------|
| 12584-4837    | warm      | 0.27   | 0.18   | 20000       | amC-Hn        | 0.26                        | 775     |
|               | warm      | 0.27   | 0.18   | 20000       | amC-Hn        | 0.29                        | 700     |
|               | cold      | 0.27   | 0.18   | 20000       | Sil-DL & SiC  | 0.29                        | 200     |
| 13266-5551    | cold      | 0.51   | 0.53   | 20800       | grf-DL        | 0.12                        | 160     |
| 14331-6435    | cold      | 0.71   | –      | 16200       | Sil-Ow        | 0.50                        | 130     |
| 16206-5956    | cold      | 0.29   | 0.22   | 11200       | grf-DL & amC-Hn| 0.16                       | 170     |
| 17203-1534    | cold      | 0.61   | 0.44   | 19000       | Sil-Ow        | 0.15                        | 117     |
| 17311-4924    | cold      | 0.66   | 0.22   | 20300       | grf-DL & SiC-Pg| 0.22                       | 250     |
| 17423-1755    | warm      | 0.86   | 0.67   | 20000       | amC-Hn        | 0.16                        | 1500    |
|               | warm      | 0.86   | 0.67   | 20000       | amC-Hn        | 0.32                        | 1000    |
|               | cold      | 0.86   | 0.67   | 20000       | SiC-Pg        | 0.35                        | 100     |
| 17460-3114    | cold      | 0.54   | –      | 35000       | Sil-DL & grf-DL| 0.0005                     | 315     |
| 18023-3409    | cold      | 0.70   | 0.44   | 20000       | grf-DL        | 0.015                       | 220     |
| 18062+2410    | cold      | 0.24   | 0.11   | 20750       | Sil-Oc & Sil-DL| 0.32                       | 230     |
| 18371-3159    | cold      | 0.30   | 0.15   | 20800       | grf-DL        | 0.13                        | 180     |
| 18379-1707    | cold      | 0.71   | –      | 19000       | Sil-DL        | 0.13                        | 140     |
| 19590-1249    | cold      | 0.29   | 0.20   | 20500       | Sil-Ow & Sil-DL| 0.08                       | 120     |
| 22023+5249    | cold      | 0.85   | –      | 18500       | Sil-Oc & Sil-DL| 0.29                       | 120     |
| 22495+5134    | cold      | 0.52   | 0.36   | 35000       | Sil-DL        | 0.011                       | 125     |

†The grain types used for modelling the SEDs are 'warm' (Sil-Ow) and 'cold' (Sil-Oc) silicates from Ossenkopf et al. (1992), silicates and graphites (Sil-Dl and grf-DL) from Draine and Lee (1984), amorphous carbon (amC-Hn) from Hanner (1988) and SiC (SiC-Pg) from Pégourié (1988). ‡IRAS12584-4837 (Hen3-847), IRAS18062+2410 (SAO85766) and IRAS18379-1707 (LSS5112) are variable in J, H, K bands (see Table 3a). Hence, two separate models satisfied the warm dust component in IRAS12584-4837 (Hen3-847). Model 1 conforms to the J, H, K data from Fouque et al. (1992). Model 2 conforms to the J, H, K data from the 2MASS catalog.

Table 5a. Derived stellar and dust envelope parameters for M_\odot=0.565M_⊙

| IRAS          | r1 (cm)    | d (kpc) | θ (′′) | M/\odot yr^{-1} | \mu mas yr^{-1} | V_T km s^{-1} |
|---------------|------------|---------|--------|-----------------|----------------|--------------|
| 12584-4837    | 2.03X10^{16}| 2.85    | 0.47   | 1.34X10^{-3}    | 9.96           | 134.89       |
| 13266-5551    | 3.92X10^{16}| 2.05    | 1.28   | 8.08X10^{-6}    | 8.22           | 79.92        |
| 14331-6435    | 5.10X10^{16}| 2.10    | 1.62   | 3.27X10^{-5}    | 6.75           | 66.66        |
| 16206-5956    | 2.91X10^{16}| 3.24    | 0.60   | 7.14X10^{-6}    | 3.96           | 60.55        |
| 17203-1534    | 5.25X10^{16}| 3.70    | 0.95   | 1.35X10^{-5}    | 9.90           | 173.80       |
| 17311-4924    | 1.72X10^{16}| 1.66    | 0.70   | 8.24X10^{-6}    | 4.75           | 37.52        |
| 17423-1755    | 2.98X10^{16}| 3.15    | 6.39   | 5.30X10^{-5}    | 3.90           | 5.55         |
| 17460-3114    | 9.93X10^{15}| 0.30    | 2.19   | 1.86X10^{-7}    | 3.90           | 5.55         |
| 18023-3409    | 3.12X10^{16}| 2.46    | 0.58   | 1.25X10^{-6}    | 13.93          | 161.04       |
| 18062+2410    | 9.13X10^{15}| 4.48    | 0.14   | 1.03X10^{-5}    | 12.59          | 271.26       |
| 18371-3159    | 3.14X10^{16}| 5.04    | 0.41   | 7.69X10^{-6}    | 7.94           | 188.18       |
| 18379-1707    | 3.00X10^{16}| 3.10    | 0.64   | 1.12X10^{-5}    | 4.96           | 78.37        |
| 19590-1249    | 4.80X10^{16}| 3.93    | 0.82   | 9.89X10^{-6}    | 7.56           | 143.34       |
| 22023+5249    | 4.62X10^{16}| 3.33    | 0.93   | 2.09X10^{-5}    | 4.96           | 78.37        |
| 22495+5134    | 5.59X10^{16}| 1.83    | 2.04   | 3.05X10^{-6}    | 2.97           | 25.60        |
Table 5b. Derived stellar and dust envelope parameters for $M_c = 0.605M_\odot$

| IRAS          | $r_1$ (cm) | d (kpc) | $\theta$ (") | $M_{\text{Ms yr}^{-1}}$ | $\mu_{\text{mas yr}^{-1}}$ | $V_T$ km s$^{-1}$ |
|---------------|------------|---------|----------------|-------------------------|----------------------------|-----------------|
| 12584-4837    | 2.40X10$^{16}$ | 3.37    | 0.47           | 1.73X10$^{-9}$           | 9.96                       | 157.37          |
| 13266-5551    | 4.63X10$^{16}$ | 2.42    | 1.28           | 1.04X10$^{-5}$           | 8.22                       | 95.03           |
| 14331-6435    | 6.03X10$^{16}$ | 2.49    | 1.62           | 4.22X10$^{-5}$           | 6.75                       | 80.00           |
| 16206-5956    | 3.44X10$^{16}$ | 3.83    | 0.60           | 9.22X10$^{-6}$           | 3.96                       | 72.19           |
| 17203-1534    | 6.21X10$^{16}$ | 4.38    | 0.95           | 1.74X10$^{-5}$           | 9.90                       | 204.03          |
| 17311-4924    | 2.03X10$^{16}$ | 1.96    | 0.70           | 1.06X10$^{-5}$           | 4.75                       | 44.15           |
| 17423-1755    | 3.52X10$^{17}$ | 3.72    | 6.39           | 6.84X10$^{-5}$           |                            |                 |
| 17460-3114    | 1.17X10$^{16}$ | 0.36    | 2.19           | 2.40X10$^{-7}$           | 3.99                       | 6.65            |
| 18023-3409    | 2.48X10$^{16}$ | 2.92    | 0.58           | 1.62X10$^{-6}$           | 13.93                      | 194.20          |
| 18062+2410    | 1.08X10$^{16}$ | 5.29    | 0.14           | 1.33X10$^{-5}$           | 12.50                      | 314.09          |
| 18373-3159    | 3.71X10$^{16}$ | 5.95    | 0.41           | 9.93X10$^{-6}$           | 7.94                       | 221.38          |
| 18379-1707    | 3.55X10$^{16}$ | 3.67    | 0.64           | 1.45X10$^{-5}$           |                            |                 |
| 19590-1249    | 5.67X10$^{16}$ | 4.64    | 0.82           | 1.28X10$^{-5}$           | 7.56                       | 170.64          |
| 22023+5249    | 5.46X10$^{16}$ | 3.94    | 0.93           | 2.70X10$^{-5}$           | 4.96                       | 94.04           |
| 22495+5134    | 6.61X10$^{16}$ | 2.17    | 2.04           | 3.94X10$^{-6}$           | 2.97                       | 30.60           |

Table 6. Predicted and observed (V-J) colors

| IRAS          | $A_V = 3.1 \times E(B-V)_{\text{total}}$ | $A_J = 0.28 \times A_V$ | $(V-J)_o$ | $(V-J)_{\text{predicted}}$ | $(V-J)_{\text{obs}}$ | $\Delta (V-J)$ |
|---------------|------------------------------------------|--------------------------|------------|----------------------------|----------------------|---------------|
| 12584-4837    | 0.84                                     | 0.23                     | –          | –                          | 0.59$^a$             | –             |
| 13266-5551    | 1.58                                     | 0.44                     | -0.47      | 0.67                       | 0.72                 | -0.05         |
| 14331-6435    | 2.20                                     | 0.62                     | -0.37      | 1.21                       | 1.55                 | -0.34         |
| 16206-5956    | 0.90                                     | 0.25                     | 0.02       | 0.67                       | –                    | –             |
| 17203-1534    | 1.89                                     | 0.53                     | -0.47      | 0.89                       | 1.07                 | -0.18         |
| 17311-4924    | 2.05                                     | 0.57                     | -0.47      | 1.01                       | 0.94                 | 0.07          |
| 17423-1755    | 2.67                                     | 0.75                     | –          | –                          | 3.03                 | –             |
| 17460-3114    | 1.67                                     | 0.47                     | -0.57      | 0.63                       | 0.62                 | 0.01          |
| 18023-3409    | 2.17                                     | 0.61                     | -0.47      |                            | –                    | –             |
| 18062+2410    | 0.74                                     | 0.21                     | -0.47      | 0.06                       | 0.32$^a$             | -0.26         |
| 18371-3159    | 0.93                                     | 0.26                     | -0.47      | 0.20                       | –                    | –             |
| 18379-1707    | 2.20                                     | 0.62                     | -0.47      | 1.11                       | 1.17$^c$             | -0.06         |
| 19590-1249    | 0.90                                     | 0.25                     | -0.47      | 0.18                       | 0.24                 | -0.06         |
| 22023+5249    | 2.63                                     | 0.74                     | –          | –                          | 1.22                 | –             |
| 22495+5134    | 1.61                                     | 0.45                     | –          | –                          | -0.04                | –             |

Based on J,H,K data from $^a$Fouque et al. (1992); $^b$2MASS and $^c$García-Lario et al. (1997b)
Fig. 3. Spectral energy distributions (SEDs) of the hot post-AGB stars. UBVRI data (asterisk) are plotted alongwith JHK (triangle), MSX (square) and IRAS data (cross). IRAS12584-4837 (Hen3-847), IRAS18062+2410 (SAO85766) and IRAS18379-1707 (LSS5112) are variable in J,H and K bands. The 2MASS, J,H,K data of these three stars is represented by filled diamonds. ISO spectra of the hot post-AGB stars are plotted as solid lines. Dusty model fits are shown by dashed-dotted lines. The model fit corresponding to the 2MASS J,H,K data of IRAS12584-4837 (Hen3-847) is shown by a solid line. We could not obtain a fit to the "30 µm emission feature" in IRAS17311-4924 (Hen3-1428). The IR (8.7, 10, 11.4, 12.6 and 19.5 µm) and K,L,M data of IRAS18062+2410 (SAO85766) by Lawrence et al. (1990) is indicated by diamonds. Notice the mismatch between the K-band flux of Lawrence et al. (1990; diamond) and García-Lario et al. (1997b; triangle) for the star. The L and M-band fluxes also do not lie on the modelled SED of the star (see Sec. 4.3).
Fig. 3. contd....