Photometric Study of Transition Objects Which Lie Between the Asymptotic Giant Branch (AGB) and Planetary Nebulae (PNe)

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Abstract

Post-Asymptotic Giant Branch (post-AGB) stars are generally believed to be on their way to the planetary nebula stage. However, there has been a question about the evolutionary path for the low-mass ones. We investigate the evolution of 31 very likely and possible post-AGB candidates selected from the Torun catalogue of Galactic post-AGB sources. The sources in the sample belong to the IRAS selected sources (IRASsel), High Galactic latitude supergiants (hglsg), High Galactic latitude B-type supergiants (hglB) and Bright stars with infrared (IR) excess (IRexc) classifications in the catalogue and are found to lie between AGB and planetary nebulae (PNe). Out of the 31 selected sources, 26 were studied. We compared the IRAS color-color plots of these sources with that of van der Veen & Habing and Szczerba and found that the 26 sources are possibly post-AGB stars. Their temperature and dynamical time plots showed that 11 objects in our sample have their shells completely detached. One object was found to be on the evolutionary track of $M_{core} = 0.55 M_\Theta$ and may likely evolve to a white dwarf, by-passing the PN stage.

Keywords: AGB and Post-AGB, catalogues, color-magnitude diagrams, evolution, photometric

1. Introduction

The evolution of the late type stars from Asymptotic Giant Branch (AGB) to Planetary Nebula (PN) has been studied by Van der Veen and Habing (1988) using the [12]-[25] versus [25]-[60] color-color diagram. Their color-color diagram was divided into regions, each corresponding to different stellar evolutionary stage. Regions I through IIIb (see Figure 5b in Van der Veen & Habing 1988) contain the stars evolving from O-rich Miras to OH/IR stars. Region IV mainly consists of transition objects, and region V consists of planetary nebulae. From their study of transitional objects from AGB to PN, using a sample of 42 IRAS sources, Veen et al. (1989) classified the sources into five categories based on the Spectral Energy Distribution (SED) shape from optical to far-infrared wavelength. The authors concluded that the SED category did not indicate the stellar evolutionary stage and could not show an evolutionary path in the near-infrared and the IRAS color-color diagrams. Thus the analysis of the SED of post-AGB stars needs a combination of the optical and near-infrared photometry, in addition to the IRAS data. In order to understand the nature of the SED in the shorter wavelength, optical and near-infrared photometry has been performed for some of the post-AGB stars. For instance, Manchado et al. (1989), García-Larío et al. (1990, 1997) carried out JHK photometric survey of several IRAS sources with colors like Planetary Nebulae (PNe). Also, Hrivnak et al. (1989) studied the SEDs of eight post-AGB candidates based on BVRIJHK photometry. They showed that multi-color photometry, in combination with spectral types of the IRAS sources, enables one to estimate the parameters of the stars and their circumstellar dust envelopes.

Fuji et al. (2002) showed that the SED of post-AGB stars is double peaked. One peak is at far-infrared wavelengths due to the cold dust-shell (100–200 K) and the other peak is at shorter wave- lengths (optical or near-infrared) from the obscured central star.

The Torun Catalogue of Galactic post-AGB and related objects (Szczerba, 2007, hereafter TC objects) has offered a new opportunity for studying the AGB - PN evolution in infrared color−color diagrams. Hence, the main purpose of this work is to ascertain if these transition objects can be classified as post-AGB stars and to verify if the evolutionary track and color-color distribution of these selected objects are consistent with those

obtained in previous studies (e.g. Van der Veen & Habing, 1988; Fuji et al., 2002; Szczerba et al., 2007), using the IRAS color-color diagram. Though the analysis of the SED of post-AGB stars requires a combination of the optical and near-infrared photometry in addition to the IRAS data, in this work we analyzed the evolution of post-AGB stars using 2MASS data.

The selected samples contain very likely post-AGB objects and possible post-AGB objects from the IRASsel, hglsg, hflB and IRexc classifications in the TC to study how these objects are distributed in the IRAS color-color diagrams. We also determined the temperature and dynamical ages of the selected sources in order to understand their evolutionary track. The scheme of this paper is divided as follows: in Sect. 2 we present an overview of the database used in this work; in Sect. 3 color-color diagrams are discussed; Sect. 4 contains a discussion about the stellar temperature and dynamic time relationship; and in Sect. 5 we present our conclusions.

2. Description of the Database

The TC (http://www.ncac.torun.pl/postagb) objects were compiled with the purpose of including objects discovered with the ongoing AKARI infrared sky survey, which has a much greater sensitivity than IRAS. This catalogue is organized into 3 sub-catalogues: very likely post-AGB objects, possible post-AGB objects and disqualified post-AGB objects. The category of very likely post-AGB objects is made up of several classes and gives the available optical and infrared photometry, infrared spectroscopy and spectral types, and links to finding charts and bibliography. The coolest post-AGB objects included in the catalogue have spectral types not later than K, while the hottest have effective temperatures below 25,000 K. The catalogue considered as disqualified post-AGB objects those that have central stars classified as M- or as cool AGB carbon stars. Also luminosity class V objects as well as objects that have been classified as PNe (especially those appearing in the Strasbourg-ESO Catalogue of Galactic Planetary Nebulae (Szczerba et al., 2007) were considered as disqualified. Two sources IRAS 00509+6623 and IRAS 06518-1041 were taken from IRAS point source catalogue. The nature and spectral class of the two sources have not been identified in the observation done by Suarez et al. (2006), though IRAS 06518-1041 was identified as a PN.

The objects used in this study were selected from the classes of very likely post-AGB and possible post-AGB objects. They include:

i. IRAS selected (IRASsel) sources; selected on the basis of their IRAS colors which were found to be between those of AGB stars and Planetary Nebulae (Szcerba et al., 2007);

ii. High Galactic latitude supergiants (hglsg); selected on the assumption that they are low-mass stars in their final stages of evolution and their spectral types are found to be K, G, F and A (Szcerba et al., 2007);

iii. High Galactic latitude B-Type supergiants (hglB); selected on the basis of their location at high Galactic latitudes ($|b| > 15^o$) (Szcerba et al., 2007).

3. Data

3.1 Photometric Data

To determine the position of the objects in the color-color diagram, we used the Photometric data we collected from VIZIER, SIMBAD databases (http://vizier.u-strasbg.fr/viz-bi/Vizier, http://simbad.u-strasbg.fr/simbad/).

We calculated the Bolometric Corrections (BC) using NED calculator (http://nedwww.ipac.caltech.edu/forms/calculator.html). The list of the objects together with their photometric data and IRAS fluxes are given in Table 1. Figures 1 and 2 show J - H versus H - K and J - K versus K - [25] diagrams for the selected objects. The IRAS flux at 25μm was converted to magnitude using [25] = -2.5log (F25/6.73) (e.g. Szczerba, 2007).

Table 1. IRAS fluxes, and Photometric data of the selected objects

Source	l	B	Fnu12	Fnu25	Fnu60	Fnu100	J	H	K
00509+6623	123.199	3.800	3.12	8.25	3.27	4.59	13.95	12.18	10.63
01005+7910	123.568	16.591	3.90	24.20	10.10	2.42	10.00	8.35	6.77
04296+3429	166.237	-9.048	12.70	45.90	15.40	9.22	9.58	8.70	8.21
05113+1347	188.857	-14.294	3.78	15.30	5.53	1.67	14.02	12.95	12.33
05341+0852	196.189	-12.141	4.51	9.85	3.96	8.01	14.82	13.63	11.82
05381+1012	195.524	-10.607	0.85	2.93	1.39	9.44	12.40	11.52	10.76
06518-1041	222.841	-4.273	0.53	2.71	2.34	9.52	12.61	10.75	9.61
06530-0213	215.437	-0.135	6.11	27.41	15.05	4.10	5.37	5.00	4.73
07018-5013	219.610	11.840	7.48	3.15	4.14	-	9.00	8.14	7.30
07331+0021	217.802	9.948	15.32	68.11	18.51	3.68	15.22	14.04	13.56
07506-0345	223.610	11.838	0.50	1.18	0.71	1.21	11.67	9.59	7.59
07577-2806	245.570	0.830	0.60	2.87	1.49	9.42	9.02	8.42	8.17
08057-3417	351.700	-1.041	1.36	3.47	0.74	11.48	11.45	10.29	9.66
17436+5003	77.133	30.870	6.12	183.50	151.70	48.67	7.23	6.97	6.86
18062+2410	50.675	19.789	3.98	19.62	2.90	1.00	10.99	10.94	10.79
18313-1738	15.322	-4.268	9.41	7.28	1.00	68.70	7.81	7.49	7.25
18485+0642	38.910	3.178	3.58	21.90	25.30	61.10	10.01	9.41	9.11
18514+0019	33.568	-0.384	4.95	23.40	17.30	152.00	8.72	8.36	8.14
19024+0044	35.208	-2.653	2.86	48.80	42.50	15.70	12.20	11.95	11.65
19114+0002	35.620	-4.956	31.33	648.30	515.90	168.10	8.02	7.10	6.58
19480+2504	61.845	-0.565	20.80	67.90	43.20	26.70	9.65	8.91	8.51
19500-1709	23.984	-21.036	27.82	165.00	73.40	18.18	12.72	11.80	11.28
19590-1249	29.180	-21.264	0.29	10.26	6.45	1.77	10.28	9.36	8.58
20000+3239	69.679	1.760	15.00	71.00	30.00	43.10	7.01	6.88	6.73
20028+3910	75.492	4.174	41.80	211.00	143.00	46.50	5.82	5.32	4.94
20136+1309	54.841	-11.968	4.30	9.69	2.09	1.18	14.06	13.34	12.72
20461+3853	80.191	-2.816	2.10	11.30	4.80	4.46	11.74	11.07	10.82
20462+3416	76.601	-5.747	0.27	13.70	12.10	5.93	10.54	10.45	10.33
20572+4919	89.443	2.394	4.39	11.00	9.70	36.40	8.92	8.34	8.13
22036+5306	99.633	-1.835	8.43	46.30	107.00	50.70	6.10	5.98	5.92
22223+4327	96.754	-11.559	2.12	37.10	22.40	9.54	11.36	11.33	11.23

3.2 Stellar Temperature and Dynamical Time of the Sample Objects

To determine the dynamical time, we applied the Stefan-Boltzmann law for stellar luminosity;

$$L = 4\pi R^2 \sigma T^4 \tag{1}$$

where L is the Luminosity, R is the stellar radius, T is the stellar temperature and σ (= 5.67×10^{-8} Wm^2K^{-4}) is the Boltzmann constant. We used this relation to determine the stellar radius. Following Fuji et al. (2002), we assumed that the central star is a blackbody source with a temperature T_{star} and luminosity L = 8000 L_{Θ}. To estimate stellar temperature of the objects we used the (B-V)–Temperature relation from literature (e.g. Flower, 1995). Thus, the dynamical time t_{dyn} is derived from the relation (Fuji et al., 2002).

$$t_{dyn} = \frac{R_{in}}{V_{exp}} \tag{2}$$

where V_{exp} the expansion velocity is assumed to be 15 kms^{-1} and R_{in} is the inner radius of the dust shell. The values of R_{in} were determined from the relation,

$$R_{in} = 4.062 \times 10^3 R \tag{3}$$

This relation is derived from (Fuji et al., 2002)

$$T_{dust}(r) = \left(\frac{R_{star}}{2r}\right)^{2/5} \tag{4}$$

T_{dust} is the dust temperature at the inner boundary of the dust shell and r = R_{in}. The value 4.062×10^3 is the determined mean value of $\frac{1}{2}\left(\frac{T}{T_{dust}}\right)^{5/2}$.

Table 2 shows the calculated values of the stellar temperature, inner radius and dynamical time of the dust shells of the selected objects.

Table 2. Stellar temperature, inner radius and dynamical time of the dust envelope of the selected objects

Source	B	V	B - V	Temp./K	t_{dyn}/yr
00509+6623	5.769	4.432	1.337	4316	1052
01005+7910	1.02	0.784	0.236	7120	380.4
04296+3429	3.451	2.652	0.799	5400	668.6
05113+1347	1.829	1.405	0.424	6335	483.1
05341+0852	1.197	0.92	0.277	6889	407.0
05381+1012	1.425	1.095	0.33	6655	436.8
06518-1041	4.842	3.72	1.122	4722	877.5
06530-0213	4.702	3.612	1.09	4782	855.3
07018-0513	0.351	0.27	0.081	8721	250.2
07331+0021	0.229	0.176	0.053	9221	222.8
07506-0345	2.73	2.098	0.632	5807	576.8
07577-2806	0.128	0.098	0.03	9611	204.3
08057-3417	0.482	0.371	0.111	8302	277.2
17436+5003	3.114	2.393	0.721	5604	620.1
18062+2410	5.462	4.196	1.266	4440	993.8
18313-1738	4.67	3.588	1.082	4803	847.8
18485+0642	0.886	0.681	0.205	7324	358.9
18514+0019	0.843	0.647	0.196	7401	351.3
19024+0044	7.443	5.718	1.725	3339	1765.0
19114+0002	3.892	2.99	0.902	5195	723.2
19480+2504	0.861	0.662	0.199	7401	351.3
19500-1709	4.361	3.35	1.011	4951	797.3
19590-1249	1.412	1.085	0.327	6655	436.8
20000+3239	4.592	3.528	1.064	4845	833.0
20028+3910	0.747	0.574	0.173	7654	327.8
20136+1309	5.769	4.432	1.337	4316	1052
20461+3853	1.02	0.784	0.236	7120	380.4
20462+3416	3.451	2.652	0.799	5400	668.6
20572+4919	1.829	1.405	0.424	6335	483.1
22036+5306	1.197	0.92	0.277	6889	407.0
22223+4327	1.425	1.095	0.33	6655	436.8

4. Results and Discussion

4.1 Color-Color Diagram

The J-H vs H-K and J-K vs K-[25] plots we obtained were compared with the plots of van der Veen and Habing 1988 and Szczerba et al. (2007). According to Szczerba et al. (2007), objects with H-K < 0.75, J-H <1 and K-[25] > 8 have thin envelopes with clearly visible central stars. From Figures 1 and 2, we identified 10 sources which fall within this category. On the other hand, the object IRAS18313-1738 have H-K > 0.75 and K-[25] < 8 which is an indication that they have no signature of circumstellar envelope (Szczerba, 2007).

Figure 1. H-K vs J-H diagram of the objects

Figure 2. J-K vs K-[25] diagram of the objects

Van der Veen and Habing (1988) and Szczerba et al. (2007) defined the typical region to search for post-AGB stars with colors close to Planetary Nebulae in the color-color diagram as [12]-[25] > 0.75 and [25]-[60] < 1.15. Our plots in Figure 3 show that most of the objects we used for our observation lie within this IRAS color box, with the exception of the objects IRAS07018-5013, IRAS07506-0345, IRAS07577-2806 and IRAS18313-1738. Apart from IRAS18313-1738, which happens to belong to the category of very likely post-AGB objects, the other three objects belong to the possible post-AGB objects. They are well separated from other types of objects. Based on the IRAS color-color diagrams, one can conclude that there is a good chance that an object is a PN, a PPN or a post-AGB star if it is within the box defined by the colors mentioned above, though an occasional HII region, Seyfert galaxy or T-Tau star is not excluded from this range (Pottasch et al., 1988; Preite-Martinez, 1988).

Figure 3. [12]-[25] vs [25]-[60] flux distribution for the observed sources

4.2 Dynamical Time of the Dust Shells

The plot of t_{dyn} against T_{star} is shown in Figure 4. The temperatures we used were derived from literature. Overall, our observational results differ in some aspects with the theoretical post-AGB models (Blocker, 1995; Schonberner, 1983). The result which is shown in Figure 4 differs from the figures shown by van der Veen et al. (1989) and Schonberner and Blocker (1993). One peculiar thing with our work is that stars with low temperatures have larger dynamical ages.

Figure 4. Comparison of the stellar temperature with dynamical time of the dust shell

Our calculations in Table 2 actually showed the stellar radii of the objects are not larger than 1.5×10^{16} cm, the usual radial size of the dust forming region of the AGB stars (Fuji et al., 2002). Figure 4 compares the stellar temperature with the dynamical time of dust shell. The common feature of the theoretical evolutionary tracks of post-AGB stars with different core masses is that the detached shell appears when the stellar temperature goes up to 5000 or 6000 K an indication that the superwind mass-loss phase terminates at these temperatures (Schonberner, 1983; Blocker, 1995). Fourteen of the objects studied are distributed below the 5000 K line. This line represents the line of $M_{core} = 0.546 M_{\Theta}$ (Blocker, 1995). Three out of these fourteen objects (IRAS 20461+3853, IRAS00509+6623 and IRAS04296+3429) have large dynamical ages, though their stellar temperatures are low. These stars may not evolve to PN stage due to their low temperatures, but might evolve to

white dwarfs. Also, IRAS07331+0021, IRAS05113+1347 and IRAS18514+0019, are peculiar M type stars, and IRAS07577-2806 is a possible post-AGB star (Szczerber, 2007) while the remainder are all G type.

In Figure 4, one star exist in the main group, despite its relatively low stellar temperature, the dynamical age of the dust shell is large. It is on the evolutionary track of $M_{core} = 0.546 M_{\Theta}$, suggesting low mass for its parent star. This may indicate that this star might evolve directly to white dwarf by-passing the PNe stage as predicted by Renzizni (1981). Scarcity of PNe in globular clusters supports this hypothesis.

In general, the agreement between the observational results and the theoretical evolutionary tracks is satisfactory. However, the observations appear to fit with a somewhat lower core mass indicating a somewhat lower luminosity than assumed luminosity $L = 8000 L_{\odot}$ used in our calculation.

5. Conclusion

We have studied 31 transition objects (very likely post-AGB and possible post-AGB objects) selected from Torun Catalogue of Galactic post-AGB and related objects. The selected objects belong to the IRASsel source, hglsg, hglB and IRexc classifications in the catalogue. Their IRAS color-color distribution and flux density at the 12, 25, and 60μm wavelength were determined. We obtained estimates of the inner radii of the circumstellar shell, stellar temperature and the dynamical ages of the objects.

The IRAS color-color distribution of our objects showed that most of the objects were found within the IRAS color box defined by [12]-[25] > 0.75 and [25]-[60] < 1.15 as defined by van der Veen and Habing (1988) and Szczerba (2007). The only exceptions are IRAS07018-5013, IRAS07506-0345, IRAS07577-2806 and IRAS18313-1738. Apart from IRAS18313-1738, which happens to belong to the category of very likely post-AGB objects, the other three objects belong to the possible post-AGB objects. We also found that eleven objects have their shells completely detached from the central stars. Comparing with the theoretical evolutionary tracks of the post-AGB stars (Schonberner, 1983), one object can be classified as a slowly evolving post-AGB star which may evolve into white dwarf without experiencing the PNe phase. Thus we can conclude that the 26 sources studied are post-AGB stars. Their temperature and dynamical time plots showed that 11 sources have their shells completely detached. One object was found to be on the evolutionary track of $M_{core} = 0.55 M_{\odot}$ and may likely evolve to a white dwarf, by-passing the PN stage.

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