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Letter to the Editor

Proper motion of the central star of the Planetary Nebula Sh 2–68

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Abstract. We report on the discovery of the proper motion of the central star (CS) of the Planetary Nebula (PN) Sh 2–68 (PN G030.6+06.2). Sh 2–68 is a PN interacting with the interstellar medium (ISM), which impedes and finally stops the expansion of the nebula itself while the galactic motion of the CS leads to it moving out of the geometric center of the PN. Our observation is a direct confirmation of this process and combined with imaging data suggests that the ISM's magnetic field plays an important role in shaping and destroying evolved PNe. The proper motion of 53.2 ± 5.5 mas yr^{-1} is the largest value for a PN found from ground based observations.

Key words. proper motion – Planetary Nebula – central star

1. Introduction

A major effort to determine proper motions (PM) of Planetary Nebulae (PNe) was undertaken in the seventies by Cudworth, who published measurements from photographic plates for 51 objects (Cudworth 1974). He found a PM of 37 mas yr^{-1} for NGC 7293, a value confirmed by Harrington et al. (1980). According to SIMBAD, NGC 7293 is still the PN with the largest PM found by ground based observations. Recently, high quality proper motion and parallax measurements have been obtained for a few PNe by the astrometric satellite observatory *Hipparcos* (Perryman et al. 1997). However, most PN central stars (CSs) are too faint to be detected by *Hipparcos* and the presence of bright nebular emission further limited the number of targets available. The largest well measured PM in the *Hipparcos* PN sample is 62.8 ± 2.0 mas yr^{-1} for the CS of A 35 (Acker et al. 1998), a nebula known to interact with the interstellar medium (ISM).

Over recent years, interaction of planetary nebulae with the surrounding ISM has been recognized as a very important process in the late stages of PN evolution. Once considered a curiosity only seen in a few odd examples, like A 35 (Jacoby 1981; Hollis et al. 1996), recent survey work (Tweedy & Kwitter 1996; Xilouris et al. 1996; Kerber et al. 2000; Rauch et al. 2000) has shown that it is commonly found in old PNe.

The theoretical groundwork for the understanding of the interaction process has been laid by Borkowski et al. (1990) and Soker et al. (1991) and we refer to their work for details. Here we only briefly summarize the major points: PNe are moving with respect to the ambient ISM. For a young PN the density of the nebula is larger than in the surrounding ISM by orders of magnitude, therefore the nebula is expanding freely. When a PN ages the density decreases; at some point the ISM pressure upstream will become comparable to the pressure in the PN shell and the gas in the shell will be compressed resulting in an asymmetric brightness distribution, while the shape is still largely spherical. Over time, the density drops further and finally the expansion of the PN is significantly slowed upstream, first leading to a deformation of the nebula and later to its disruption. During this process the CS, which is not affected by the slowing, will move out of the geometrical center of the PN, subsequently abandoning its nebula, as observed in Sh 2–174 (Tweedy & Napiwotzki 1994). The final result of this evolution will be a white dwarf stripped off its nebula, which mixes with the ISM.

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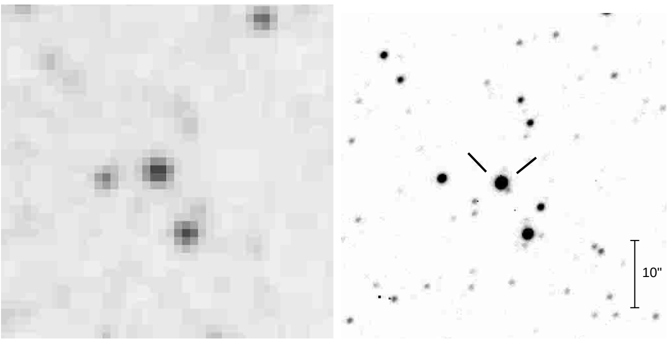

Fig. 1. Images of the field of the CS of Sh 2–68 obtained in 1954 from a photographic plate (103aE) of the POSS I (left) compared to a CCD image (R filter) obtained in June 2001 from the 2.5 m du Pont telescope of the Las Campanas Observatory (right). The displacement of the CS (marked) between the two epochs is evident.

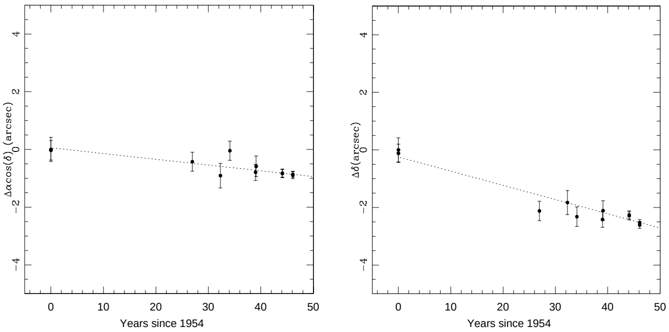

Fig. 2. Proper motion fit in right ascention (left) and declination (right) to the coordinates listed in Table 1. Note that the 1954 epoch has two fully consistent measurements obtained from two independent plates.

In a recent survey Kerber et al. (2000) have found that in about 50% of interacting PNe the CS is no longer located in the geometric center of the PN. This is a direct manifestation of the galactic orbital motion of the CS after the interaction process has decoupled the motion of the nebula and its CS. Such PNe are prime targets for PM searches, as motion of the CS evidently exists, although it may be still difficult to measure it given the time scales of PN evolution.

2. Observations and data reduction

During a recent observing run one of us noticed that the position of the CS of Sh 2–68 on the frame was slightly offset from its position on the POSS I based finding chart, even to the unaided eye (see Fig. 1). To obtain a precise measurement of the CS proper motion, we made use of digitized Schmidt plates of the Palomar Observatory Sky Survey (POSS I & II) and of the SERC, which are used as input for the generation of the Guide Star Catalogue-II (McLean et al. 2001). From the GSC-II plate database, we selected a total of seven scans, distributed over six epochs and spanning a time interval of about 39 years. The plate material is summarized in Table 1, where we list the observing epochs, the computed object coordinates and errors, the source, the plate ID, the passbands, the central wavelengths and widths, the measured magnitudes of the target and errors. The CS coordinates have been derived from the astrometric solution of each plate, which has been computed by the GSC-II plate processing pipeline using as a reference the positions of ≈1000 stars identified from the TYCHO catalogue (Høg et al. 1997). In all cases, the CS was located close to the plate center, which made it possible to achieve the highest astrometric accuracy. The photometry of the CS in the plate passbands was computed according to the GSC-II photometric pipeline, which is calibrated using the Guide Star Photometric Catalogue 2 (GSPC2), a sequence of secondary photometric standards in the Landolt system (Bucciarelli et al. 2001). The magnitudes of the CS are in good agreement with the literature values (Forbes 1989). To complement the time coverage provided by the photographic plates, we have used two broad Hα images of the field obtained on 29.7.1998 at Calar Alto's 1.23 m telescope (scale = 0.5″/pix) from our survey of interacting PNe and B (180 s) and R (90 s) band images (scale = 0.26″/pix) from the recent observing run at Las Campanas Observatory (June 2001). The astrometry of the CCD images has been calibrated using as a reference the positions of 40 to 70 GSC-II stars in the field. The transformation from pixel to sky coordinates was then computed using the program ASTROM (Wallace 1992). The resulting coordinates are given in Table 1 together with the total errors of the position determination. We note that all the coordinates listed in Table 1 are homogeneous, being computed in the same reference frame.

3. Results and discussion

Through a straight absolute astrometry approach, we have measured the proper motion of the CS by comparing its coordinates at the different epochs. A linear fit to the coordinates listed in Table 1 yielded a PM of -19.9 ± 5.6 mas yr^{-1} in right ascension and of -49.3 ± 5.5 mas yr^{-1} in declination (see Fig. 2). As is evident from the distribution of our measurements (Table 1), the CS coordinates at the first epoch (1954.42) weight the most on the PM determination. However, we note that these coordinates have been independently confirmed from the astrometry computed on two different plates (XE630 and XO630 in Table 1). Thus, the values are robust and the resulting PM is reliable. The measured PM corresponds to a total displacement in the plane of the sky of 53.2 ± 5.5 mas yr^{-1}, with a position angle (PA) of $202 \pm 6°$. Note that the errors are comparable to *Hipparcos* results (Acker et al. 1998) due to the much longer baseline in time. The direction of the PM is indicated in Fig. 3. The position angle of the PM is somewhat surprising as the theory of interaction with the interstellar medium, as described above, predicts that the CS will be moving towards the arc-shaped brightness enhancement in the nebular shell, see e.g. Tweedy & Kwitter (1996). This expectation is also voiced by Xilouris et al. (1996) "Though the

Table 1. Summary of observations of the CS of Sh 2–68.

epoch	α [hh mm ss.s]	δ [dd ′ ″]	$\Delta\alpha$ [″]	$\Delta\delta$ [″]	Source	Plate	Passband	Wavelength (Å)	Mag
1954.42	18 24 58.497	+00 51 38.47	0.42	0.42	POSS I	XE630	103aE	6500 (800)	16.24 (0.2)
1954.42	18 24 58.495	+00 51 38.35	0.34	0.32	POSS I	XO630	103aO	4300 (2000)	16.32 (0.3)
1981.34	18 24 58.468	+00 51 36.35	0.33	0.34	SERC	S878	IIIaJ+GG395	4635 (1081)	16.64 (0.2)
1986.65	18 24 58.435	+00 51 36.64	0.43	0.42	SERC	ER878	IIIaF+OG590	6445 (720)	16.29 (0.3)
1988.52	18 24 58.494	+00 51 36.15	0.33	0.34	POSS II	XJ878	IIIaJ+GG395	4635 (1081)	16.5 (0.3)
1993.36	18 24 58.443	+00 51 36.05	0.28	0.27	POSS II	XI878	IV-N+RG9	8060 (1103)	15.87 (0.34)
1993.53	18 24 58.457	+00 51 36.36	0.36	0.34	POSS II	XP878	IIIaF+RG610	6538 (581)	16.12 (0.3)
1998.58	18 24 58.440	+00 51 36.18	0.14	0.14	CAHA	CCD	Hα	6560 (100)	–
2001.45	18 24 58.436	+00 51 35.86	0.12	0.12	LCO	CCD	B	4600 (1700)	–
2001.45	18 24 58.438	+00 51 35.94	0.11	0.11	LCO	CCD	R	6600 (2500)	–

proper motion of the central star has yet to be measured, it is expected to be moving towards the south-east arc".

In the case of Sh 2–68 this brightness enhancement is located East of the CS, therefore the observed direction of motion is roughly perpendicular to the expected one.

One explanation would be to assume that the moving star is not the CS of Sh 2–68. This is unlikely as the star has been found to be a rare kind of pre-white dwarf, a so-called hybrid PG 1159 star of which only four examples are known (Napiwotzki 1991). At a temperature of about 100 000 K it must have formed a planetary nebula in its recent evolutionary past. The Hα image (their Fig. 1) by Xilouris et al. (1996) gives an important additional piece of information. They found a cometary halo extending for about 14$'$.5 to the north, that is in line with the stellar motion. The expansion velocity of the nebula shows very low values of 5 to 10 km s^{-1} in different ionic species (Hippelein & Weinberger 1990), which indicates a significant deceleration from the initial expansion, typical for highly evolved PNe. Similarily the radial velocity (local standard of rest) is low at 11 ± 3 km s^{-1} (Fich et al. 1990).

We conclude that the moving star is indeed the central star of a PN, which is falling apart due to interaction with the ISM while the CS is leaving the nebula behind. There is one prominent example for a CS abandoning its nebula: Sh 2–174 (Tweedy & Napiwotzki 1994).

Combining all the information available, the past of Sh 2–68 may look like this: Assuming constant velocity of the star, the CS and its nebula were located at the tip of the cometary halo about 16 500 years ago. This is a lower limit as the material which now forms the halo was probably stripped with a relative velocity of a few km s^{-1} so it initially retained a significant fraction of the star's proper motion and was slowed down over time, and of course the halo may extend further to the north than currently known. Therefore we estimate the PN was formed more than 30 000 years ago. Soker & Dgani (1997) (hereafter SD) (their Fig. 1) show that such stripping of nebular material is likely to occur over a wide range of PN/ISM parameters for PNe moving at a moderate velocity (>40 km s^{-1}) close to the Galactic plane in the

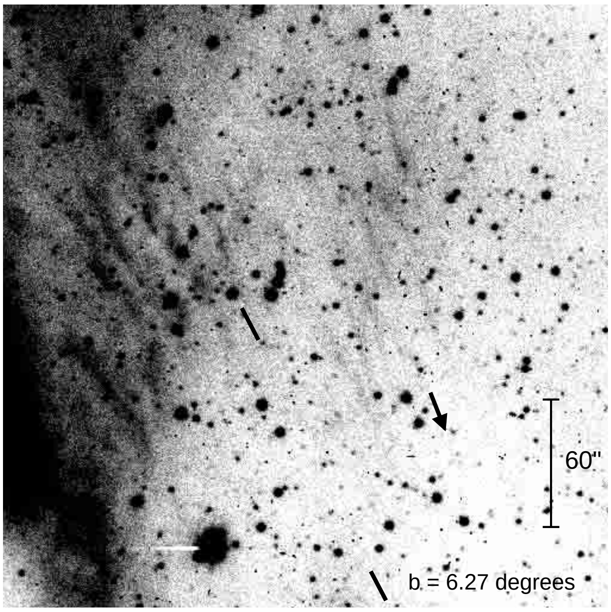

Fig. 3. Hα image (1.23 m, Calar Alto) showing the filamentary structure within the nebula indicating possible Rayleigh-Taylor instability. The arrow indicates the direction of motion of the CS. The lines denote galactic latitude 6°.27.

presence of a significant magnetic field. Such interaction with the ISM will lead to Rayleigh-Taylor (RT) instability which destroys the leading edge of the nebular shell and enables the ISM to gain access to the inner region of the nebula (Dgani & Soker 1998, hereafter DS, their Fig. 1), where it causes characteristic filamentary structure (RT-rolls), see Fig. 3 in DS (1998). Sh 2–216 is an example for which the role of the ISM's magnetic field in shaping the PN has been discussed in some detail (Borkowski et al. 1990; Tweedy et al. 1995; SD). Our Hα image (1800 s) of the inner nebula (Fig. 3) shows similar filamentary structure roughly aligned with the stellar motion. The RT instability also leads to the fragmentation of the leading edge of the nebular shell. Later, the forward motion of the PN slowed down and probably came to a standstill about 2000 years ago, while the CS began to move out of the geometric center of the nebula. Today, the southern and western part of the nebular shell has dispersed into the

ISM with only traces visible in Hα imagery (Xilouris et al. 1996). The eastern section of the shell was slowed down forming the prominent arc. This difference in life time of the different regions of the shell also implies an inhomogeneous distribution of the ambient ISM, with the densest part located to the East (towards the galactic plane). The CS is moving almost along constant galactic latitude, suggesting a rather regular disk orbit. For distances smaller than 1 kpc the height above the galactic plane is well below 200 pc, the limiting value found observationally by DS (1998) for the kind of interaction described above.

The distance to Sh 2–68, like for most galactic PNe, is not well known. Napiwotzki & Schönberner (1991) found 1000 ± 400 pc from analysing the stellar atmosphere. From the equivalent width of the Na D absorption, Napiwotzki & Schönberner (1995) deduced a distance of 560 pc, while the standard Shklovski distance gives about 300 pc. The PM of course is the result of both space velocity and distance. With the distance so poorly determined, we look at the likely velocity range from other studies. The average transerve motion of stars in the solar neightbourhood is 20 to 40 km s^{-1} with basically no stars faster than 130 km s^{-1} (Skuljan et al. 1999). For white dwarfs an average velocity of 67.4 ± 39.5 km s^{-1} has been found by Sang-Gak (1999). For disk PNe, DS (1998) give 60 km s^{-1} as an average. The galactic latitude of 6.2 degrees of Sh 2–68 and its PM do suggest that the CS belongs to the disk population. A velocity of 30 km s^{-1} would place the star at a distance of 120 pc, while the median white dwarf velocity would result in a distance of $\approx$270 pc. PM has been found for very few PNCSs to date, therefore Sh 2–68 may be part of the high velocity tail of PN space motion. Assuming a maximum velocity of 150 km s^{-1} we obtain a maximum distance of 600 pc. Taking into account the velocity suggested by the evidence for RT instability in the morphology of the PN and the various proper motion samples, we assume that the PN is located at a distance of 200 to 500 pc (corresponding to a velocity of 50 to 125 km s^{-1}) and a z of 22 to 54 pc. This corresponds to a diameter of the nebula of 0.35 to 0.87 pc and an extent of 0.84 to 2.11 pc including the halo. The absolute magnitude of the star is 8.9 to 6.9 mag. The resulting parallax will be 2 to 5 mas, which can be directly measured with the Hubble Space Telescope's fine guidance sensors. Once the distance has been reliably determined, a galactic orbit will be deduced and the theory of interaction with the ISM can be put to a much more stringent test. Therefore Sh 2–68 promises to be an important astrophysical test bed for our understanding of stellar evolution and PN–ISM interaction.

4. Conclusions

We have measured the proper motion of the central star of the PN Sh 2–68 to be 53.2 ± 5.5 mas yr^{-1} with a PA $= 202 \pm 6$ degrees. On detailed examination we explain the morphology of the nebula as the possible result of a Rayleigh-Taylor instability which is caused by an interaction of the PN with the interstellar medium. We conclude that the distance is in the range of 200 to 500 pc and suggest to measure the parallax using the HST. With this additional knowledge, Sh 2–68 will be a prime candidate for quantatively testing the theory of PN-ISM interaction.

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