The morphology and kinematics of planetary nebulae: a tribute to Hugo Schwarz

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Summary. This opening talk is dedicated to the memory of our friend and colleague Hugo Schwarz, who tragically died a few months before "Asymmetrical Planetary Nebulae IV" was held, and to whom the conference is dedicated. Hugo has been a pioneer first, and a very active researcher later, in the study of the morphological and dynamical properties of planetary nebulae and nebulae around symbiotic stars. I present here a short review of Hugo's most significant scientific contribution in these fields, during the journey through science and life that we have done together.

Key words: planetary nebulae: morphology and kinematics

I first met Hugo on February 1991 in Santiago de Chile, when I arrived for a 2-yr studentship of the European Southern Observatory (ESO). In the ESO guesthouse, I found a letter stating: "I am Hugo Schwarz, and will be your supervisor in Chile. I will pick you up at 5 p.m. and will go to a scientific meeting with astronomers of the Tololo Observatory". Being young and somewhat shy, I dressed with my most elegant shirt and well ironed trousers, and waited for Dr. Schwarz to come. At the expected time, I heard a loud noise coming from outside the guesthouse, and a long-hair man, dressing a Harley-Davidson leather jacket and riding a noisy motorbike, was waiting for me. "Bad choice of trousers", I thought, "but certainly a very interesting beginning". And it was indeed the start of a relation lasting many years during which Hugo and I have been working together, as my supervisor first (who caught me into the fascinating world of planetary nebulae), as a collaborator later, and always as a fantastic friend.

1 The ESO catalogue of images of planetary nebulae

My first task as Hugo's student was to help him to complete the ESO atlas of CCD narrow-band images of planetary nebulae [13]. It was in those years, mainly thanks to the advent of the CCD detectors in telescopes with excellent

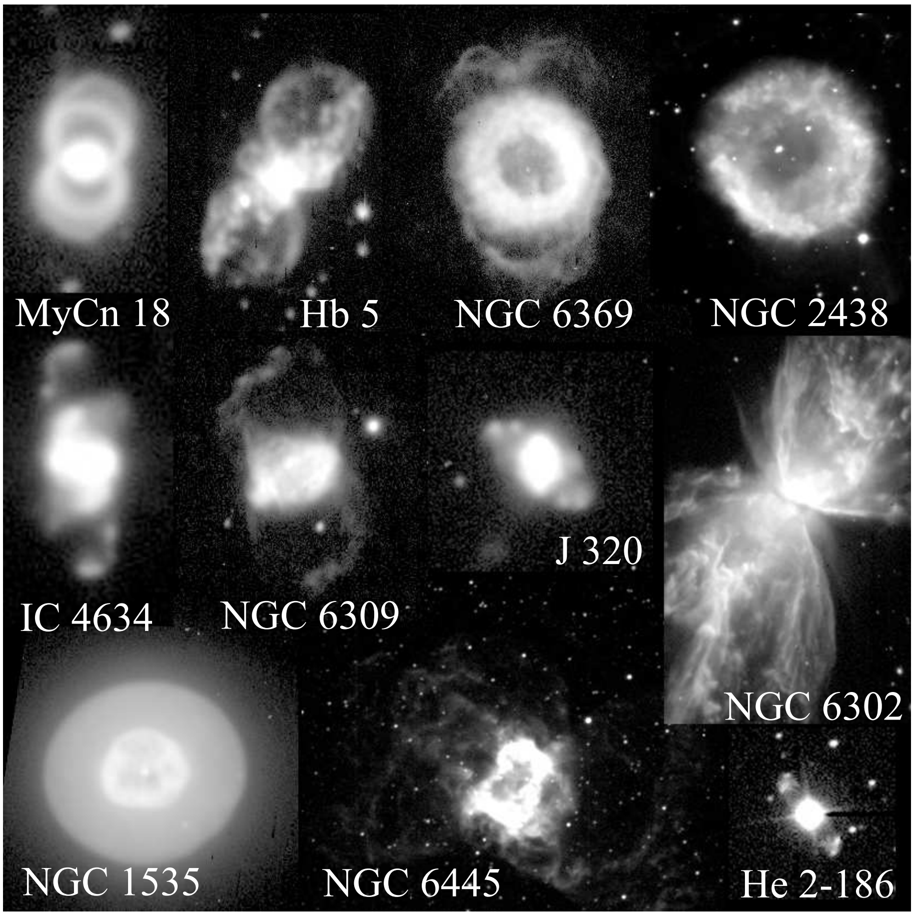

Fig. 1. Selected images from the Hugo Schwarz's atlas of planetary nebulae [13]

image quality, that the extraordinary variety of shapes of planetary nebulae (PNe) was fully revealed. Besides other CCD surveys (e.g. [9] [2] [1]), our ESO atlas [13] contributed to the development of the concept that the PNe shaping is a complex process which contains valuable and unexpected information about the physics of mass loss in evolved stars.

The ESO atlas consisted of [OIII] and $H\alpha + [NII]$ images of 255 PNe obtained during the commissioning of the ESO 3.5m New Technology Telescope (NTT). Many of them were of sub-arcsec seeing quality, which allowed us not only to reveal the overall morphology of the nebulae, but also to highlight the presence of small-scale or faint structures [5] which provide additional clues to understand the mass loss phenomenon in all its aspects. A few examples of images from the ESO atlas are shown in Figure 1. Note that, 15 years later, this is still the largest available collection of CCD images of PNe.

The richness of information contained in these morphological surveys called for both detailed studies of the individual objects and for statistical studies of the global properties of the nebulae and their progenitor stars.

2 Bipolar PNe and the similar nebulae around symbiotic stars

We started by studying one of the most remarkable morphological classes, the bipolar PNe. Besides an intrinsic curiosity on how these extreme shapes form, there was Hugo's strong interest in binary stars, and in particular symbiotic binaries and their link with PNe. In 1989, Hugo had in fact discovered the magnificent nebula around the symbiotic star Hen 2-104, that he named as "the Southern Crab" [11]. Morphologically, the Southern Crab (Fig. 2) is

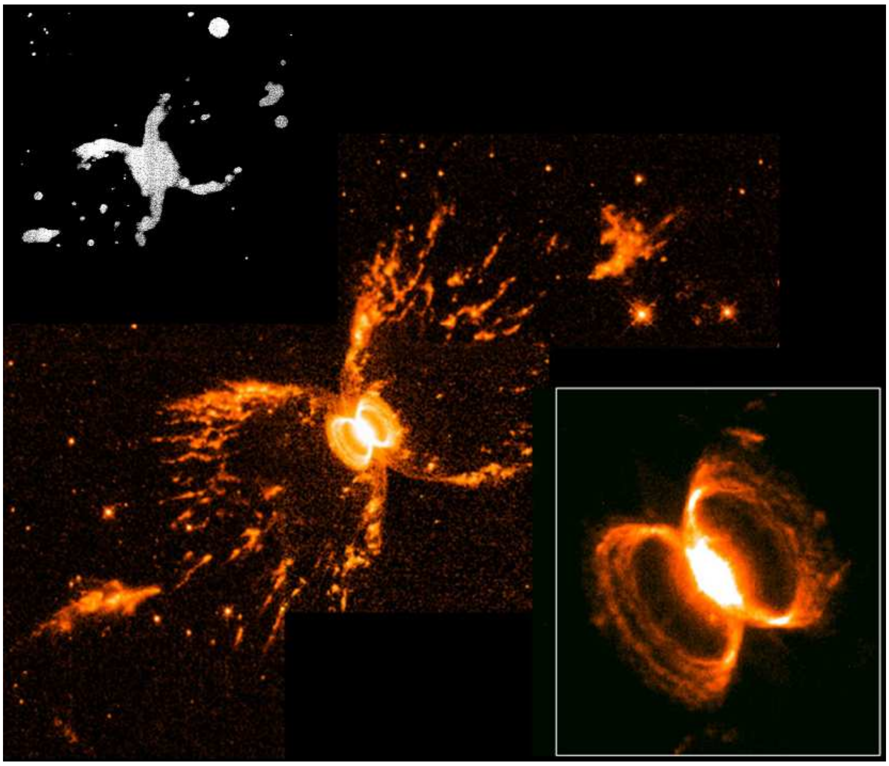

Fig. 2. The Southern Crab (Hen 2-104). On upper left corner, Hugo's 1989 discovery image [11]. Below, our 1999 HST [NII] image [7].

very similar to several (supposedly) genuine PNe with bipolar shape, like e.g.

MyCn 18 in Fig. 1. The NTT telescope, with its long slit spectrograph and superb image quality, offered us the opportunity to study the kinematical properties of a number of (symbiotic and non-symbiotic) bipolar nebulae (see e.g. [3] [7]), and pursue the idea that the physical processes acting in interacting binaries are the main way (and the only one?) to produce markedly bipolar outflows.

The main result was to highlight the simplicity of the kinematic pattern of this class of nebulae: most of them show a self-similar expansion pattern, produced by apparently "ballistic" motions of the gas particles which are well described by an "Hubble law" (expansion velocity proportional to the distance from the central star). This is an important clue on the origin of the nebulae, because such an expansion pattern indicates that the nebular shaping must be done in a short lapse of time compared to the nebula lifetime, which in turn points to "explosive" or "erupting" events at the origin of these nebulae. This is naturally explained in the case of symbiotic stars by the nova-like explosions (slow novae) that this class of objects suffer as a consequence of mass accretion on their white dwarfs, and by analogy points to the presence of interacting binary stars in all markedly bipolar PNe.

Simultaneously, we continued our search for extended nebulae around symbiotic stars, increasing the total number of known system to a dozen of objects [6] (very few were known before). The vast majority of them contain a Mira variable (i.e. a star with a strong mass loss) as the cool component. With this increased sample, it became clear the one-to-one relation between binarity and collimation of the mass outflow in these systems.

2.1 A special gem: M 2-9

Hugo was fascinated (and so am I) by M 2-9, the *butterfly nebula*. Its "dentist mirrors" and "rotating lighthouse" are unique among bipolar nebulae. The former are produced by high-velocity dusty blobs at the tip of the faint outer lobes of the nebula (Fig. 3, deep image at the top), which reflect the light from the bright central star and nebular core. The combination of dust reflection and the relative motions of the core, blobs, and observer, makes them to appear red-shifted *on both sides of the nebula*, as explained in [15].

Fig. 3 (sequence at bottom) illustrates the rotating pattern within the inner lobes of M 2-9. Hugo started its imaging monitoring on 1987, and more recently we have taken advantage of the image quality of the 2.6m Nordic Optical Telescope at La Palma, of which Hugo was the *Astronomer in Charge* from 1995 to 2000. The lighthouse is produced by a beam of ionizing radiation **or** of fast particles rotating with a period of about one hundred years, hitting the walls of the inner bulbs of the nebula (Fig 4, left panel), and exciting the gas. As O^{++} recombines within a matter of a few months at the typical densities of the bulbs, its emission is at any epoch a very good tracer of the position of the exciting beam (green emission in the sequence at the bottom of Fig. 3). On the contrary, H^{+} and N^{+}, with their longer recombination times,

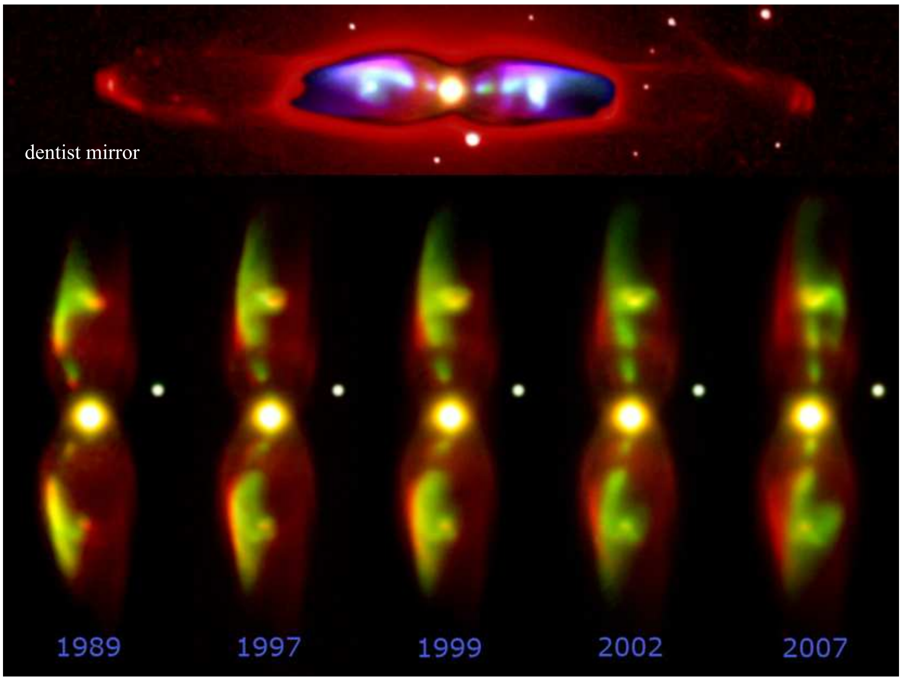

Fig. 3. Top: a deep Hα+[NII] image of M2 9 showing the outermost lobes with their high-velocity dusty blobs (the "dentist mirrors"). **Bottom**: the evolution of the rotating pattern of M 2–9 as observed in the last ten years from the 2.6m Nordic Optical Telescope on La Palma. Red is Hα+[NII] emission, green is [OIII]500.7 nm. A gif animation of the sequence of images can be found at *http://www.iac.es/project/apn4/media/images/m29_video.gif*

leave a visible and long-standing trail that can be recognized as enhanced red emission in Fig. 3. Whether the beam is produced by particles (a jet) or photons is still a controversial issue. However, if we assume that the beam itself is not bended, there is a clear delay in exciting positions in the bulbs at the same longitude but at different latitudes; the delay is estimated to be of ~2 years between the brightness enhancements N1 and N2, and between S1 and S2 (Fig. 4, right). This would correspond to a traveling speed of more than 5000 km s^{-1} (Corradi et al., in preparation), indicating that the source of the excitation might indeed be a high-velocity jet, as originally proposed by [8], and not a light beam.

3 Morphology tracing galactic populations of PNe

An other important point that needed to be addressed with the large image database of PNe that became available in the 90's, was to understand if mor-

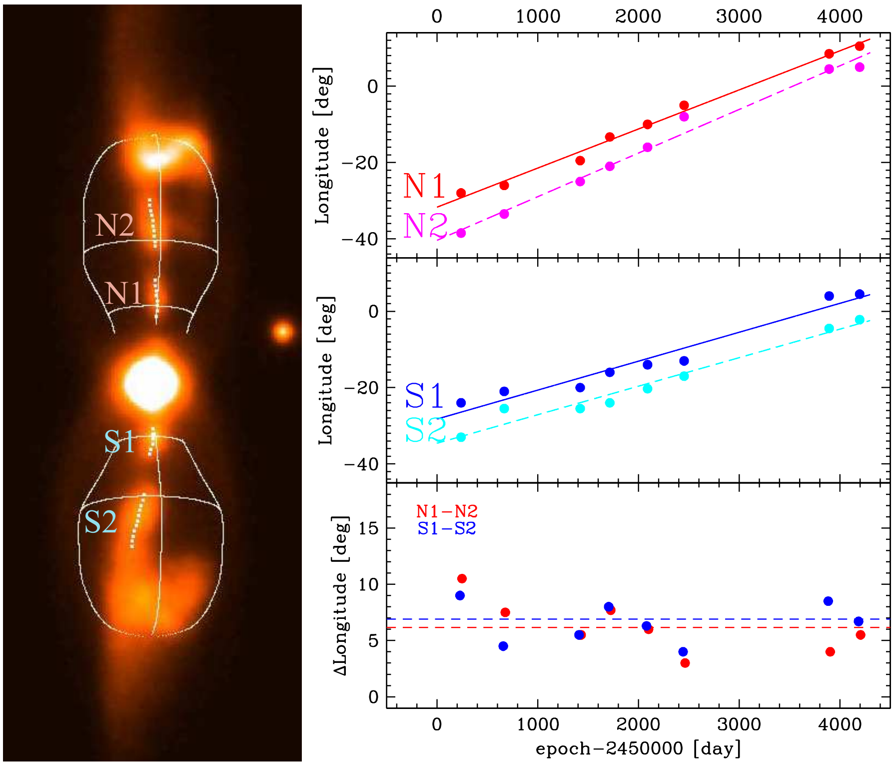

Fig. 4. Left: the 2006 [OIII] image of M 2-9. Superimposed to the image is the outline of the inner bulbs, as well as a representative longitude line which helps to highlight the bending of the rotating pattern. **Right**: the longitude measured by Gaussian fitting along the horizontal axis for the emission at N1, N2, S1 and S2 at the different epochs (upper graphs). In the bottom graph, the longitude difference is plotted, which can be interpreted as due to a delay in the excitation because of the traveling time of the exciting beam to go from N1 to N2, and from S1 and S2.

phology is related to any other distinctive property of the nebulae and their stellar progenitors. As a first step, Hugo proposed a morphological scheme to classify PNe in the ESO atlas [14]. The adopted philosophy was to avoid any *a priory* assumption on the intrinsic 3D shapes of the nebulae and on the physical processes producing them. PNe were therefore divided into five main classes (Fig. 5): elliptical nebulae (*e*, this includes truly spherical ones, which were a minority in the 1992 ESO atlas), bipolar objects (*b*, a somewhat strict definition was adopted, which requires the nebulae to have a narrow waist from which two opposite lobes depart), point-symmetrical ones (*p*), irregular (*i*) nebulae, and unresolved ("stellar"=*st*) objects.

The difference between the stellar populations producing bipolar PNe, which represented 14% of the nebulae in the ESO atlas, and elliptical nebulae

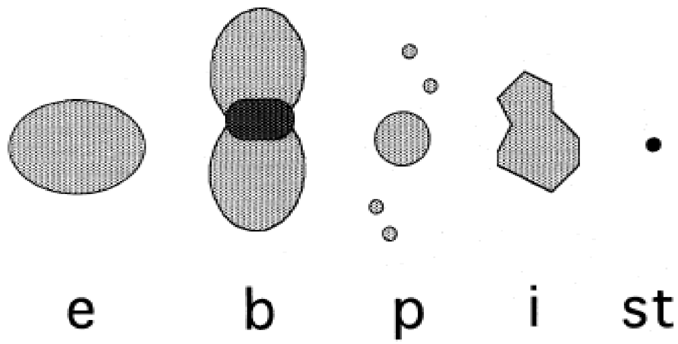

Fig. 5. Hugo's morphological classification of PNe [14].

(64%), became evident as soon as we start correlating the nebular morphologies with their distribution and kinematics in the Galaxy (scale height on the disc and velocity dispersion from the Galaxy rotation curve) [16] [4]. Bipolar PNe were then found to clearly belong to a younger stellar population than elliptical PNe, or in other words to be produced by more massive progenitors. This was further supported by the chemical enrichment in He and N of bipolar PNe (produced by the efficient dredge-up episodes expected in the most massive progenitors), and by their hot central stars (the most massive progenitors move quickly to large temperatures in their post-AGB evolution). These results were later refined by several other studies, but their substance has remained basically unvaried. Some doubts have been recently raised about the fact that bipolar PNe have central stars which are statistically hotter than elliptical PNe; however, the clarity of the result obtained from the sample in [4] calls for further investigation of the issue.

4 Point-symmetry

Another morphological property that attracted Hugo's interest was the point-symmetrical geometry displayed by a number of PNe. This symmetry can show up as the main morphological characteristic of a nebula (e.g. IC 4634, see Fig. 1), or superimposed to an overall bipolar structure (e.g. NGC 6309 and Hb 5, also in Fig. 1). In order to explain it, Hugo's belief was very decided: point-symmetry implies *precession* of the collimating source, most likely an accretion disc in an interacting binary star. He strongly defended this opinion during the lively conference that he organised in La Serena (Chile) on 1992 [12].

5 Other works

Hugo's interests in Astronomy were multiple. He was an expert of stellar polarimetry and of astronomical instrumentation in general, and deeply involved in the defense of astronomical observatories from light pollution (see e.g. [10]).

In our field, like many of us he has always been annoyed by our chronic inability of measuring distance to individual PNe in our own galaxy. For this reason, he started an ambitious programme of 3-D photoionization modeling of PNe using multi-slit or integral-field spectroscopy (see the contribution by H. Monteiro in this conference), demonstrating that the method provides indeed a very good way (albeit quite expensive in terms of observing and modeling time) to determine distances.

In summary, it is impossible to condense, in the little space of this contribution, all the work done by Hugo in Astronomy. But it is also clear that there is no real need to do it, because his ideas are well present in our minds, especially in all of us who had the pleasure to meet Hugo in one occasion or the other. In all conferences that Hugo has attended, he has always contributed a lot to both science and atmosphere. His scientific and public talks, and his private conversations were infused with humor and wonder. We have missed him a lot during APN4, and we will miss him a lot in future.

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