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# The Planetary Nebula Image Catalogue (PNIC)

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**Summary.** The “Planetary Nebula Image Catalogue” (PNIC) containing more than 720 CCD images of more than 620 different planetary nebulae (“PNe”) is now available in the WWW at [www.astro.washington.edu/balick/PNIC](http://www.astro.washington.edu/balick/PNIC). Images have been culled from many sources, including the published journals, various public web sites and archives, and occasionally directly from authors. Each image contains appropriate attribution, references (if available in 2006), names, equatorial and galactic coordinates, filters, and other information embedded in the JPEG files that contain the image. Whenever possible the images are presented as two or three-color overlays. The catalog is organized both in alphabetical order of common name and by galactic coordinates using the SIMBAD convention. A downloadable, sortable spreadsheet of morphological information for each target is linked to the web site. The highlights of the morphological study are presented. Additional HST images of PNe and protoPNe will soon be added to the catalogue.

**Key words:** planetary nebulae image catalog

## 1 Catalogues of Images of Planetary Nebulae

Catalogues of planetary nebulae (“PNe”) have been of invaluable assistance in studying their attributes, correlating their properties, planning observations, and simply organizing vast amounts of empirical information collected over many years [6] (along with six updates published intermittently) was the first major compilation, followed more recently by [1] and [3]. These and many other useful catalogues are available on line from VizieR.

Catalogues of high-quality images of PNe and protoPNe are a different matter. Many excellent images have appeared in the literature over the past decade. Several very useful but limited imaging surveys appeared in the 1990s (e.g., [7], [4] & [2]) using narrowband filters and high-fidelity detectors. These typically included 50 to 100 targets each. Meanwhile many papers appear annually containing images of one or two objects at a time. I have endeavored to assemble a catalogue where the images of any well-observed PN can be easily retrieved.

At this point in time I have downloaded over 720 images of images of more than 620 different PNe available from catalogues available on line, from various public archives and web pages, and occasionally from private sources (with permission). The images in this collection are presented with a more-or-less uniform format with common and standard PNG names, accurate positions, image tagging information, attribution, references and sources, and other useful information. Where possible I show the logarithm of the intensity so that faint outer structures will appear and their relationship to the core will be clear. The entire compilation is called the “Planetary Nebula Image Catalogue”, or “PNIC”. The collection is posted at

[www.astro.washington.edu/balick/PNIC](http://www.astro.washington.edu/balick/PNIC).

(Ultimately the catalogue will be moved to a new web site maintained by the CDS.) Links to the images are listed both by their most common name and by their standard "PNG", or galactic coordinates. The PNG coordinates are especially useful for cross referencing the objects most other catalogues such as SIMBAD. The image of any object can be readily located using the “find” command in all modern web browsers.

In many cases PNe have intricate, high-surface-brightness inner structures as well as large, faint halos. Wide-field images of the same object are posted if one image isn't adequate for displaying all of these features. These images can be identified from the inclusion of “halo” or “wide” in their names. HST images are also included when it is easy to do so. Many Hubble Space Telescope (“HST”) images are included. These contain “hst” in their image names.

I have taken the opportunity to dedicate this catalogue to Donald E. Osterbrock (1924-2007) who was a pioneer in the study of PNe and their kinematics starting in the 1950s until becoming the Director of the Lick Observatory. Osterbrock was my mentor at the start of my career and a wonderful colleague for the past 33 years.

## 2 Morphological Classification of Planetary Nebulae

Once ~700 images were added I undertook a new morphological classification study. This has turned out to be particularly productive owing to the size of the sample. Characteristics that may once has seemed singular in frequency have often turned up in several objects in this sample, and some better ways of defining patterns of shapes have emerged. Therefore, I have slightly expanded the basic morphological classes that have been in common use (round, elliptical, and bipolar). I tried not to be guided by modern theoretical ideas of the evolution of PNe; however, there is no way to entirely purge such bias given my long involvement in this field.

The revised classification scheme is described next. For the sake of maintaining continuity and minimizing confusion, the new scheme builds on standard schemes in common use. However, two previous categories, “elliptical” and “bipolar”, has been extended and modified so that the new morphology scheme is more orderly and comprehensive than its predecessor.

### 2.1 Core Morphology: The Primary Morphology Designator

The cornerstone of the new scheme builds on the geometric properties of PNe that the shortest image that uncovers nebulosity will reveal. This philosophy will help to

assure that classifications will be universal (but see the caveats below). In practice, PNe reveal a continuity of shapes. Therefore, as in past schemes, there are no sharply defined boundaries to separate the classes since this would be artificial. Each PN in the catalogue is assigned to one and only one of the primary designators.

**Round.** PNe in this class have cores that show a round boundary with an elongation less than about 10%.

**Closed Elliptical.** This is the analogue of the more classical designation of “Elliptical”. However, it differs in one respect: the outline of the core must be closed; i.e., without any large gaps. Most PNe presently known to have extended x-ray emission are members of this morphology class. The x rays lie within the boundaries of the closed core.

**Open Elliptical.** With a large sample it has become clear that many PNe have cores that are basically elliptical along their minor axes, but they exhibit openings at opposite ends of the core along the major axis. Another useful term for this class is “barrel”, as exemplified by a standard wood wine storage container with rounded sides. Lobes often extrude from the openings of the barrel, some of them long and well formed, and others stubby in appearance. Some PNe with pairs of lobes previously designated as “bipolar” are assigned to this class. A good example is NGC 6886.

**Pinched Waist.** This is a rough analogue of the classical “extreme bipolar” shape. In this case a pair of lobes usually extends from each end of a small bright hourglass-shaped core. However, in short exposures, it is the tapered, or “hourglass-shaped” waist which appears since the lobes have much lower surface brightnesses.

If a PN has multiple sets of lobes it usually has pinched waist as well. Mz3, Hen 2-104, and Hen 3-320 are examples of PNe with two sets of lobes with pinched waists lying long a common symmetry axis. M 1-37, M 2-46, NGC 2440, and Hen 2-47 are outstanding examples of PNe with several pairs of lobes lying along multiple symmetry axes and a pinched waist. (However, NGC 7026, 7027, and IC 4634 show multiple pairs of lobes that emanate from an open elliptical core.)

**Disk.** This is a new primary morphological class. Some PNe show have a core consisting of a bright ring or disk with a large gap between the edge of the core and the central star. Often lobes extend along the ring’s symmetry axis, such as Hen 2-47, K 3-28, Mz1, and NGC 6309. A few PNe, such as Hen 2-120, Hf 4, and SuWt 3, exhibit only a disk or torus with no traces of any other structures. These PNe could not be accommodated in previous morphological classes.

Two additional classes must be added for the sake of completeness: **Poorly resolved** PNe are too small to be classifiable with reasonable certainty. **Complex** PNe are just that: they are too messy or too amorphous to be classified using the classification criteria adopted.

**Caveats.** Two limitations in classifying the bright cores of PNe must be emphasized. One is that better spatial resolution often reveals structures in the core that are simply not obvious otherwise. For example, many new HST images have forced morphology changes during the course of assembling this catalogue. Also, the shapes of the cores may depend on the emission line used for the classification. Many PNe look startlingly different in [NII], on the one hand, and H $\alpha$  and [OIII], on the other. I have made every effort to classify PNe in H $\alpha$  or, when it isn’t available, an emission line arising in the largest or most representative volume of the core.

### 3 Additional Morphological Features

As noted above, each PN is assigned a core classification based the shape of the core (or more precisely, the shape of its outline). However, deep exposures reveal an array of additional shapes and larger features. This mandates the use of extra, or “secondary” descriptors. Any PN may have none, one, or more than one of these secondary structural descriptors added to its primary morphological class. The secondary descriptors fall into three broad groups, “overall symmetry”, “extended features”, and “small-scale structures”.

**Overall Symmetry.** The overall symmetry of PNe is preponderately axisymmetric. In relatively rare cases the overall symmetry may be **multisymmetric** or “**S**” or **point symmetric**. A special case of considerable interest is **orthogonal symmetry**. Multisymmetric PNe appear to have two or multiple sets of lobes, each lying along a different symmetry axis. PNe with “S” symmetry have similar structures on diametrically opposite sides of the nucleus. The orthogonal class refers to axisymmetric nebulae which has an additional, often much fainter and amorphous feature which is extended along their minor axes so that the ensemble resembles a “+”.

**Extended Features.** Deep exposures often reveal faint, relatively smooth, well-defined structures extending well beyond the nebular core. **Shells** are the most common of these. Shells surround open or closed elliptical cores and invariably share their symmetry. Their surfaces are amorphous, their brightness falls approximately linearly with radius, and they are bounded by sharp outer edges. Shells are never seen in pinched-waist or disk-like cores.

**Lobes** are generally oval in shape if they are closed, or else their walls project onto the sky with “V” shapes if they are open. **Halos** surround some cores and their shells. They have lower surface brightnesses than cores and shells, and more turn up as images go deeper. Halos are invariably round in projection on the sky and edge-brightened, this suggesting that they are thin spherical bubbles. Like shells, halos are often amorphous; however, halos occasionally exhibit knotty leading edges. Halos are often single, but they can also be found in large sets of a dozen or more concentric rings—such as those in NGC 6543—or sets of round ring segments as seen in CRL 2688 and NGC 7027. A special subclass of round halos resemble **bow-waves** that encapsulate the core and all its associated structures. These are always limb-brightened, especially at the apex of the bow.

**Small-scale structures.** Small **knots** and **filaments** are fairly common in the cores and surroundings of elliptical and pinched-waist PNe. It is not uncommon for knots to come in one or more pairs, each with its symmetry axis in a different orientation. For example, NGC 5189 and 5307 have three distinct pairs of knots on equal and opposite sides of the central star. The knots often have a lower ionization state than the gas that surrounds them; for example the knots may appear bright in  $N^+$  and  $O^+$  lines whereas lines of  $O^{++}$  dominate the emission from their surroundings.

Other types of regular and sometimes striking arrangements of small-scale features are possible. There are three or possibly four PNe when a series of low-ionization knots resembles a **necklace** along the boundary of the core. Of these, NGC 6751 is the best example. Often the knots resemble short **spikes**. In a few cases, such as Pe 1-17 and NGC 2452, the spikes come in one or more symmetric pairs, but more often the spikes are located irregularly near the perimeter of the core. NGC 2392 has dozens of such low-ionization spikes in the shell extending

from its core. There are many examples of PNe whose cores contain **filamentary** features, sometimes flocculent (NGC 5882 and 6818) and sometimes tangled (NGC 1501). Thin **jets** are rarely seen in PNe, and when they are, they connect to the tips of an elliptical core rather than directly to the nucleus. NGC 7009 and 7354 have such jets.

## 4 Statistical Frequency of Features

Statistics of the frequency of various morphological features are of interest. But examining the selection bias is of paramount importance before the statistics can make much sense. Most previous studies have been based on surveys using excellent detectors, but whose sample selection can easily introduce many biases. For example, cameras used for imaging have a limited field of view, so there is a tendency to select objects that will fit onto a frame. Samples are almost always biased towards objects of high flux or surface brightness, or those of low or high ionization, or those visible from a particular observatory in a few nights of time, or combinations of these selection criteria. Thus PNe with very large, low-surface-brightnesses and those that are distant, faint, or hidden by galactic dust are surely under-represented in almost all samples.

In the present case, the  $\sim 620$  objects are drawn from various surveys and papers or one or a few objects, so the selection bias is the sum of many others. Moreover, a distance-selected sample is impractical since distance uncertainties are very large. For all of these reasons I am unable to gauge the extent of selection bias in determining the statistical frequency of various structures. The frequency statistics are reported without further comment.

**Basic Core Morphology.** The relative frequencies of round, closed elliptical, open elliptical, pinched waist, and disk cores in PNe are 13% (81 objects), 27% (168 objects), 22% (136 objects), 6% (40 objects), and 7% (45 objects), respectively. Of the remaining 148 PNe, 11% have complex or amorphous structures, and 13% are poorly resolved. (N.B.: New HST observations invariably change the classification of objects that are poorly resolved from the ground.) [5] find that the frequency of round, elliptical, and bipolar nebulae are 22%, 58%, and 17%, respectively, of all classifiable PNe in their complete sample. If I adopt their designation and exclude poorly resolved and amorphous PNe, as they did, then the corresponding values based on the PNIC images are 17%, 65%, and 19%, respectively. The disagreement is minor. Small differences in the class definitions along with subjective selection choices in marginal are partially to blame for the discrepancy.

In the remaining discussions I shall exclude all poorly resolved, amorphous and complex PNe from the sample.

**Overall Core Symmetry.** The frequencies of multisymmetric, point symmetric, and orthogonal symmetries are 10% (47 objects), 7% (32), and 6% (29), respectively. In their study, [4] find 3% of PNe are quadrupolar (analogous to my “multisymmetric” class) and that 4% have point symmetry.

**Extended Features.** The frequencies of PNe with lobes, shells, round halos, and halos with bow-wave outer boundaries are 35% (165 objects), 26% (121), 10% (45), and 3% (13), respectively. The fraction of PNe with lobes in this study is far higher than in previous ones. This is partly the result of the increasing numbers of images

taken with very sensitive detectors that enable faint, extended structures to be separated from sky background and detector readout noise. Some of the difference is the result of systematically displaying the images logarithmically, which often reveals lobes that are difficult to see otherwise. This will be discussed more fully in an upcoming publication.

**Small-scale structures.** The frequencies of PNe with symmetric arrangements of knots is 13% (61 objects). In most cases the knots come in symmetric pairs called “ansae”, or in pairs of confined groups of closely spaced knots. In other cases the knots are distributed throughout the core or in the shells adjacent to the cores.

Spikes are found in 4% of the sample (19 objects). The cores and shells of 12% (57) of the sample have knotty edges. Another 4% (19 objects) show [N II] emission surrounding their cores and shells, suggesting that they may be fully ionization bounded (IC 418 is an example). If this is correct then much or most of the stellar photons that can ionize hydrogen escape into the halos or beyond of 96% of the all PNe.

Finally, 16% (77 objects) of the sample has filaments or flocculent structure in the core or shell. An inspection of the associated images suggests that in about half of the cases, the filaments are much like disorganized wrinkles or sinewy filaments of dusty, low ionization gas on the surface of a dense core-shell interface. Rings seem to be “imprinted” on the edges of the lobes of pinched-waist nebula are seen in MyCn18, Hubble 12, Hen 2-104, possibly Hubble 5, and a handful of other objects.

## 5 Conclusions

I have assembled images of 620 PNe of widely varying quality from published surveys, papers, and public web sites with a public interface at

[www.astro.washington.edu/balick/PNIC](http://www.astro.washington.edu/balick/PNIC)

The catalogue serves as a valuable reference for observers and for theoretical studies of structural features and a useful complement to lists of positions, spectroscopic data, and other information of PNe found in existing catalogues. The entries have been assigned morphology designations that indicate their most common features.

With a sample as large as this one we can realistically distinguish between structural anomalies and common features, and to define new classes accordingly. We have separated the classical designation “elliptical” into open and closed categories, depending on whether the elliptical boundaries of the core exhibit symmetric protrusions or openings along the ellipses’ major axis. A few objects previously called “bipolar” but without bulbous waists are now reclassified as “open ellipses with lobe pairs”. Other former bipolars have cores with pinched waists. We prefer the term “pinched waist” for these objects in order to differentiate them from the others with elliptical cores. We have added a new core morphology class, “disk”, to identify PNe whose cores are really disk-like (with or without additional lobes). This and other new classes will be described in a forthcoming paper.

Three undergraduate students at U.W. and I are in the final stages of adding additional images to PNIC from the HST archives. We have systematically downloaded every image of a PN from the HST archives as of late 2006 that we could identify from keywords in this database. All of those images in which the nebulae

are larger than  $\approx 0.''1$  will be included. There are approximately 100 images of PNe and 50 images of protoPNe in this sample.

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