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Young planetary nebulae: *Hubble Space Telescope* imaging and a new morphological classification system

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Using *Hubble Space Telescope* images of about 120 young planetary nebulae (PNe), most of which have not previously been published, we have devised a comprehensive morphological classification system for these objects, with minimal prejudice regarding their underlying physical cause. However, in many cases, physical causes are readily suggested by the primary geometry, along with the kinematics that have been measured in some systems. Secondary characteristics in our system such as ansae indicate the impact of a jet upon a slower-moving, prior wind; a waist is the signature of a strong equatorial concentration of matter, whether it be outflowing or in a bound Keplerian disk, and point symmetry indicates a secular trend (presumably precession in the orientation of the central driver of a rapid, collimated outflow). This system generalizes a recently-devised system for pre-planetary nebulae, which are the immediate progenitors of planetary nebulae. Unlike previous classification studies, we have focussed primarily on young PNs rather than all PNs, because the former best show the influences or symmetries imposed on them by the dominant physical processes operating at the first and primary stage of the shaping process. Older PNs develop instabilities, interact with the ambient interstellar medium, and are subject to the passage of photoionization fronts, all of which obscure the underlying symmetries and geometries imposed early on.

Young Planetary Nebulae: HST Imaging and A New Morphological Classification System

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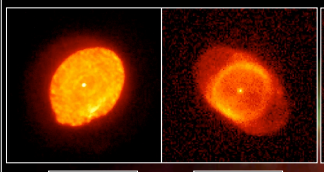
Introduction: Most PPNs - transition objects between the Asymptotic Giant Branch (AGB) and Planetary Nebula (PN) phases of stellar evolution - and PNs are aspherical objects, often with fast outflows (≥ 100 km s^{-1}) directed along one or more axes. Based on images taken with the Hubble Space Telescope (HST), a comprehensive morphological classification scheme was recently developed for Pre-Planetary Nebulae (PPNs) (Sahai et al. 2007), We present here a generalization of our PPN classification scheme for young PNs and we show that this can be done with relatively few modifications and extensions.

About 120 young planetary nebulae were classified using high-resolution HST images (mostly in Hα). The criteria used for classifying these PNe range from primary characteristics defined by the general shapes of their lobe or shell structures, and secondary characteristics defined by smaller structures and geometrical symmetries within these shapes.

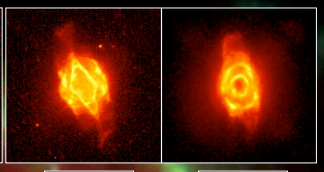
The Classification: Our classification scheme is shown in the center of the poster. Descriptors representing modifications to the PPN classification, are highlighted in red.

Elongated (E)



PK235-01#1 PNG002.8+01.7

Collimated Lobe Pair (L)



PK032-02#1 PK037-06#1

Statistics

Class Code	Number	Percent
B	22	27
M	24	30
E	26	31
I	8	69
R	4	34
L	10	85
S	4	34
ps	52	45

PN Classification Scheme

PRIMARY CLASSIFICATION:
Nebular Shape

B	Bipolar
M	Multipolar
E	Elongated
I	Irregular
R	Round
L	Collimated Lobe Pair
S	Spiral Arm

SECONDARY CHARACTERISTICS

Lobe Shape:

o	lobes open at ends
c	lobes closed at ends

Central Region:

w	central region is (relatively) dark, and shows an obscuring waist
t	central region is bright and has a toroidal structure
bcr	central region is bright and barrel-shaped
bcr(c)	barrel has closed ends
bcr(o)	barrel has open ends
bcr(i)	irregular structure present in barrel interior

Central Star:

*	central star evident in optical images
***(nnn)**	star is offset from center of symmetry of one or more nebular structures, *nnn* is maximum offset in mas

Other Nebular Characteristics:

an	ansae
ml	minor lobes
sk	a skirt-like structure around primary lobes
ib	an inner bubble inside the primary nebular structure
wv	a patterned structure, such as a weave or a mottling
rg	rings projected on lobes
rr	radial rays
pr	one or more pairs of diametrically opposed protrusions on the primary geometrical shape
ir	additional unclassified nebular structure lacking symmetry, not covered by the primary/secondary classifications

Point Symmetry: ↓

ps(m)	due to presence of two or more pairs of diametrically-opposed lobes
ps(an)	due to diametrically-opposed ansae
ps(s)	overall geometric shape of lobes is point-symmetric
ps(t)	waist has point-symmetric structure
ps(bcr)	bcr has point-symmetric structure
ps(ib)	inner bubble has point-symmetric structure

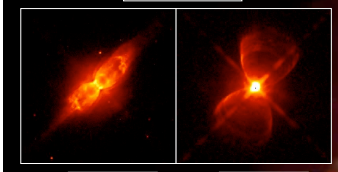
Halo:

h	halo (relatively low-surface brightness diffuse region around primary nebular structure) present
h(e)	halo has elongated shape
h(i)	halo has indeterminate shape
h(a)	halo has centro-symmetric arc-like features
h(sb)	halo shows searchlight-beams
h(d)	halo has a sharp outer edge, or shows a discontinuity in its interior

Sample Classifications

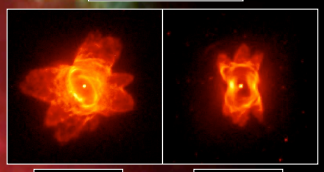
Name	MC
002.8+01.7	E,c,t,*,ps(s)
002-03#3	M,c,t,*,ps(m),h(a)
002-09#1	B,o,t,bcr(o,i),*,ps(s),h
007-04#1	E,*,ib,ps(s),h
051+09#1	B,c,bcr(o),*,ib,ir,ps(s),h
051-03#1	E,bcr,*,ib,ps(s)
082+07#1	M,o,t,ib,ps(m,s,ib),h
111-02#1	B,o,rg,h
130-11#1	I,*?
211-03#1	L,c,bcr(o),*,h
215-24#1	E,c,*,ib,wv,pr,ps(s),h
226-03#1	E,c,*,wv,ps(s),h(e,d)
232-04#1	E,c,t,*,h(e,d)
235-01#1	E,c,*,h,ib,wv
235-03#1	L,c,bcr,*,ps(s,bcr),h
258-00#1	E,c*,ib,wv,pr,ps(s),h
285-02#1	M,c,t,*,ps(t),h(i)
331-01#1	B,o,w,*,ib,rr
352-07#1	B,o,t,an,sk,ib,h(e)
356.8+03.3	S,t,h(i)
356-03#3	L,bcr(c),*,ib?,ps(s,bcr),h
357.2+02.0	R,h
358-00#2	M,c,bcr(c),*,ir,h(i)
032+07#2	S,*
032-02#1	L,bcr(o),an,ib,ps(ib),h(i)
037-06#1	L,c,bcr(c),ib,h

Bipolar (B)



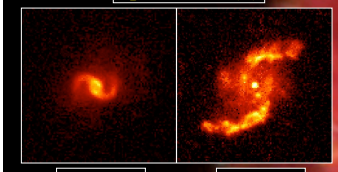
PK352-07#1 PK111-02#1

Multipolar (M)



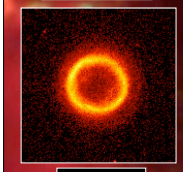
PK285-02#1 PK002-03#3

Spiral Arm (S)



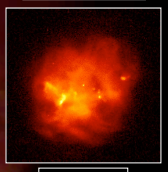
PNG356.8+03.3 PK032+07#2

Round (R)



PNG357.2+02.0

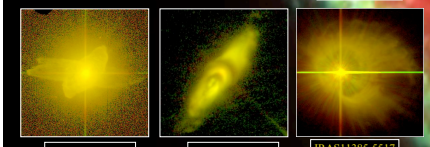
Irregular (I)



PK130-11#1

Pre-Planetary Nebulae

IRAS17150-3224 IRAS19024+0044 IRAS2000+3239

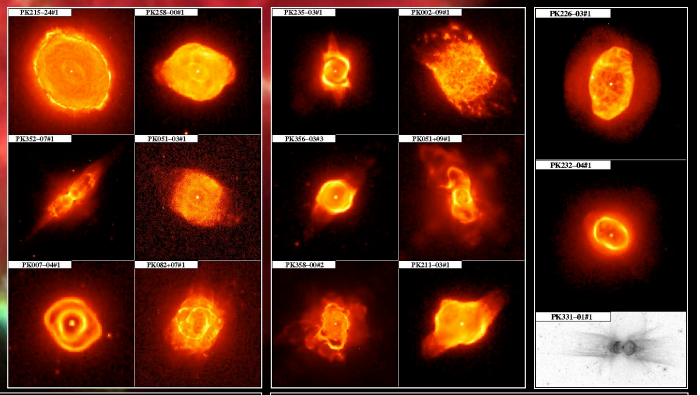


IRAS19475+3119 IRAS22036+5306 IRAS11385-5517

Pre-Planetary Nebulae and Planetary Nebulae

By comparing such images of PPNs with PN images within the poster, one can see that the wide variety of morphologies found in PPNs are qualitatively similar to those found for young PNs, which is to be expected given that the latter represent the immediate evolutionary phase after the PPN phase.

New Secondary Characteristics



SUMMARY

1) We have devised a comprehensive morphological classification system for young PNs, with minimal prejudice regarding their underlying physical causes. (estimates of the expansion ages of our objects show that these are typically 2,000 to 5,000 years, consistent with their classification as young PNs.)
2) Our system shares similarities with, but is broader than, previous ones (e.g., Schwarz, Corradi & Stanghellini 1993, Manchado et al. 1996), encompassing a more diverse array of morphologies, and is also more precise. One of the most notable difference is the recognition in our study that point symmetry can be present in all primary classes (except I) - it is not a separate class as defined in the previous studies.
3) 3 new primary classes (collimated lobe pair, round and spiral) have been added to the original system devised for PPNs, the progenitors of young PNs.
4) The Round class is very rare, (3.4%) confirming expectations from previous studies.
5) Bipolar, Multipolar and Collimated Lobe Pair objects constitute about 56% the sample; Ellipticals are 30%.
6) Point-symmetry (of 7 different classified types), is seen in 45% of the sample.
7) The most important distinction in the secondary classification descriptors for the PPN and PN systems is related to the appearance of the waist region; which is generally dark for PPNs (imaged in scattered light) and generally bright in PNs (imaged in emission lines). This change is largely a result of the continued expansion of the waist region as objects evolve from the PPN to the PN phase.

Modifications and Extensions

The images of PNs shown above demonstrate some of the new descriptors added to our classification scheme. The two left panels show examples of PNs with an "inner bubble" (ib). The two center panels shows PNs with large, typically barrel-shaped, central regions (bcr), which can be closed or open at their ends [bcr(o), bcr(c)]. The rightmost panel shows two PNs (top two) with discontinuities in their halos, h(d); the lowermost PN in this panel is an example of PNs with radial ray structures (rr).

References:

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