Binary central stars of planetary nebulae

Brent Miszalski
SALT Postdoctoral Fellow
Overview

- A little background
- The contribution of close binaries so far
- In search of intermediate period binaries
- Projects with VVV and VPHAS+
Planetary Nebulae (simple definition)

- “A PN is a star that ejects some material while evolving from the red giant to the white dwarf stage” (Lutz 1993)

- “An ionised shell ejected at the end of the AGB phase, either by a single star, or as part of a common-envelope ejection” (Frew 2008)
Abell 39
George Jacoby
(NOAO/WIYN)

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Planetary Nebulae
Planetary Nebula IC 4406
Planetary Nebula NGC 2818
Hubble Heritage Gallery Planetary Nebulae
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How are PNe shaped?

- A protracted debate with no apparent consensus


- Interacting stellar winds (ISW) can explain some

  - Assumes density contrast (e.g. dusty torus)

- Rapid rotation and Magnetic fields?

  - Models can work but require strong fields that aren’t detected and don’t last long enough

- An often fiery debate...
Can we ignore magnetic fields in studies of PN formation, shaping and interaction with the ISM?

Noam Soker 2005

Department of Physics, Technion—Israel Institute of Technology, Haifa 32000, Israel; soker@physics.technion.ac.il

ABSTRACT

Yes. ¹

1. Introduction

In a quest for better understanding the shaping mechanism of planetary nebulae (PNs) I published many papers in the past (e.g., Soker 2004a) all of which came to the same conclusion: For the formation of non-spherical PNs a companion is required, whether stellar or substellar. This results from the basic assumption that angular momentum is a conserved physics quantity. As trivial as this may sound, some published models for the shaping of PNs seem to have ignored this basic physical law. Most recently I discussed this in a paper that was accepted by astro-ph (Soker 2005b), but was rejected by MNRAS and the ApJ. Both referees (a third referee in ApJ can be ignored for a non-scientific report) were either
BINARIES

- Are the `natural’ solution to the problem
- Predicted by theory (e.g. common-envelope evolution)
  - However, observational evidence has been `weak’
- Jets and collimated outflows
  - Accretion disks in close binaries (Soker & Livio 1994)
  - Common-envelope dynamo (Nordhaus+ 2006, 2007)
- Explains strong density contrast between equatorial (orbital) plane and polar direction
- Pre-requisite for dust disk formation? (e.g. Van Winckel+ 2009)
Main Sequence binary

Giant + MS
(symbiotic star)

Roche Lobe Overflow

formation and outflow of the 1st Common Envelope

WD + Giant
(symbiotic star; possibly existence of jets)

Roche Lobe Overflow

formation and outflow of the 2nd Common Envelope
as observed presently

WD + WD
(Double Degenerate binary)

SN Ia? or single WD

P. Podsiadlowski (?)
The NEBULA is the actual common-envelope (CE)

Age < $10^4$ yrs guarantees freshness of the binary

No significant angular momentum loss after termination of CE phase => pristine periods

Period distribution used in parameterised models of CE

Homogeneous sample of post-AGB post-CE binaries useful to better understand CE (De Marco+ 2011)

Progenitors of Cataclysmic Variables ($10^7$-$10^8$ yr before)
Show me the binaries
Asymmetric PN Conferences: APN1 APN2 APN3 APN4 APN5

- Bond+ 1978; Grauer & Bond 1983; Bond 1985
- Grauer+ 1987; Bond & Grauer 1987; Bond & Livio 1990
- Mendez & Niemela 1981; Drilling 1985
- Liebert+ 1995; Lutz+ 1998; Tovmassian+ 2004
- Hillwig 2004; Frew 2009; Hajduk+ 2010
- Miszalski+ 2008, 2009a, 2009b
- Miszalski+ 2010a, this work
Abell 63 (UU Sge)
The first close binary

- Bond (1976)
- Photographic plates showed 14.7-16.0 mag variation
- White dwarf eclipsed by M4V every 0.46 days
- Strong irradiation effect

Pollacco & Bell 1997
The first close binary Abell 63 (UU Sge) was studied by Bond (1976) using photographic plates which showed a magnitude variation of 14.7-16.0. The white dwarf component was eclipsed by an M4V companion every 0.46 days, indicating strong irradiation effects. Additional analysis was performed by Pollacco & Bell in 1993 and 1997.
Abell 63 (UU Sge)

The first close binary

Photographic plates showed 14.7-16.0 mag variation

White dwarf eclipsed by M4V every 0.46 days

Strong irradiation effect

primary eclipse

secondary eclipse

Wawrzyn+ 09

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The first close binary Abell 63 (UU Sge) was studied by Bond (1976) who showed 14.7-16.0 mag variation. White dwarf eclipsed by M4V every 0.46 days. Strong irradiation effect. Pollacco & Bell (1993) analyzed primary and secondary eclipse data. Wawrzyn et al. 1993 provided additional analysis of the system.
How to find them?

- Periodic photometric variability (most < 1 day)
  - Most common and successful method (e.g. I-band)

- Spectroscopy
  - Periodic radial velocity variability (~100-200 km/s)
  - Radial velocity shifts of irradiated emission lines
  - Composite spectra

- Photometry
  - Near-infrared or mid-infrared excess
A grand challenge, <2850 PNe known!

Known     (various) ETHOS   Miszalski+ in prep

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PLAnetary Nebula Binaries

PLAN-B is a collaboration to look for binaries in the central stars of planetary nebulae, their progenitors and progeny. We are testing the hypothesis is that binarity is a dominant mechanism to form and shape planetary nebulae, an assertion that is backed by theory. With these pages we coordinate our projects.

Click for more information about the PN binary problem
Community portal: the PLAN-BBlog

The Team

Agnes Acker (Observatoire de Strasbourg, France)
Jana Bilikova (University of Illinois, USA)
Brent Miszalski (Macquarie, Obs. de Strasbourg, FR)
Max Moe (University of Colorado, USA)
Ulisse Munari (Osservatorio d' Asiago, Italy)
Geoff Clayton (Louisiana State University, USA)
Romano Corradi (Isaac Newton Group, Spain)
Orsola De Marco (Macquarie Univ, AUS - coordinator)
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Noam Soker (Technion, Israel)
Peter Sorensen (Nordic Optical Telescope, Spain)
Gagik Tovmasian (UNAM, Mexico)
Hans van Winckel (K.U. Leuven, Belgium)
Albert Zijlstra (University of Manchester, UK)

Publications

www.wiyn.org/planb/

Team Members: LOGIN HERE
Asymmetric PN Conferences: APN1 ↓ APN2 ↓ APN3 ↓ APN4 ↓ APN5 ↓

- Bond+ 1978; Grauer & Bond 1983; Bond 1985
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Microlensing surveys allow variability studies on a massive scale.

Cadence often high enough to detect short periods.

Fainter MASH-I/II PNe more suitable.
Microlensing surveys allow variability studies on a massive scale.

- Cadence often high enough to detect short periods.
- Fainter MASH-I/II PNe more suitable.

**M2-19** - first canonical bipolar with period < 1 day.
OGLE-III Bulge fields

I~20 mag

AAT 2dF/AAOmega  VLT FLAMES

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The OGLE Sample
Miszalski+ 2009a
Close binary fraction: 17±5%

60% are MASH-I/MASH-II PNe
The OGLE Sample
Miszalski+ 2009a
Close binary fraction: $17\pm5\%$

CSPN status: confirmed, likely, non-confirmed

60% are MASH-I/MASH-II PNe
Period distribution too short for common-envelope models (agrees with more evolved WDMS binaries!)

see Rebassa-Mansergas+ 2008
Davis et al. 2010
Morphological Traits of Post-CE PNe

- Needed to identify new binaries and understand what morphological features ARE SHAPED by binaries
- No clear trends in pre-OGLE sample (Bond & Livio 1990)
- Traits deduced from OGLE sample (Miszalski et al. 2009b)
  - Bipolar PNe
  - Low-ionisation filaments (particularly in rings)
  - Jets and collimated outflows (!!)

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General shapes of 30 Post-CE PNe

Miszalski+ 2009b

- Irregular: 16%
- Multiple-Shell: 13%
- Possible Bipolar: 10%
- Likely Bipolar: 35%
- Canonical Bipolar: 26%

∼60% bipolar fraction is plausible
Rings

One ring to rule them all, one ring to find them,
One ring to bring them all and in the darkness bind them.
AND IN THE DARKNESS BIND THEM: EQUATORIAL RINGS, B[e] SUPERGIANTS, AND THE WAISTS OF BIPOLAR NEBULAE

NATHAN SMITH, 2,3,4,5 JOHN BALLY, 3,5 AND JOSH WALAWENDER 3,5,6

Received 2007 February 13; accepted 2007 March 30

One ring to rule them all, one ring to find them,
One ring to bring them all and in the darkness bind them.
SN1987A

**The Necklace**

$D_{\text{ring}} \approx 1.7'' \times 1.2'' (!)$

$D_{\text{ring}} \approx 10''$

Corradi, Sabin, Miszalski+2011

**IPHAS DISCOVERY**

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NGC 1514

OPTICAL (SSS)

MID-INFRARED (WISE)

Wide binary (Kohoutek 1967)  Ressler et al. 2010
Jets
Strong indicator!
Jets
Strong indicator!
close binaries found since OGLE

+ more
in preparation

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How did we find them?

- **Team:** B. Miszalski, R. Corradi, D. Jones, H. Boffin, M. Santander-Garcia, P. Rodriguez-Gil

- Select PNe that fit Miszalski et al. (2009b) traits for post-CE nebulae

- Time series-photometry and some spectroscopy

- A mix of small (Mercator 1.2m, SAAO 1.9m, INT) and large (VLT, Gemini South, WHT) telescopes

- Identify and develop cutting-edge methods to find new binaries over traditional, less-rapid methods
The Necklace
Corradi, Sabin, Miszalski+ 2011
P=1.16136 days
0.75 mag amplitude!
WD $T_{\text{eff}} > 100$ kK
**Choice of filter**

- Nebula can totally obscure CSPN and render photometry useless.
- I-band often used but is susceptible to [SIII] contamination.
- Stromgren $y$ is a good compromise ($\lambda_0=547$ nm, $W_0=23$ nm).
- Best solution: narrow-band filter slightly off blue nebular lines, e.g. H$\beta$-continuum, [OII]-continuum? (CSPN are hot blue stars).
- Some nebula continuum remains.

OGLE-III I-band
Miszalski+ 2009a

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Example: NGC6309

Halpha on-band

Halpha off-band
<table>
<thead>
<tr>
<th>GMOS spectrum</th>
<th>$\mathbf{RV_{hel}}$ (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nebula</td>
<td>-1</td>
</tr>
<tr>
<td>CIII/NIII (Secondary)</td>
<td>158</td>
</tr>
<tr>
<td>HeII 5412 (Primary)</td>
<td>-50</td>
</tr>
</tbody>
</table>
GMOS spectrum

VLT FORS2 spectra must be a binary!
GMOS images
Miszalski et al. 2011

SAAO CCD
1.9m
Strömgren $y$ 600s exposure

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SAAO 1.9m lightcurve; Strömgren $y$

NGC 6326

$P=0.372$ days

David Jones (ESO Chile); Miszalski et al. 2011
Online database of all Galactic PNe under development

Miszalski
Acker
Parker
Oschenbein

hosted by CDS
Extremely Turquoise Halo Object Survey
Miszalski et al. (in prep)
SuperCOSMOS Science Archive selected PNe!

ETHOS2 (SDSS)

ETHOS3 (NTT)
SSA - SuperCOSMOS Science Archive

LATEST NEWS: A new database of ~200 plates in the single survey field no. 287 has been included in the SSA - for more details click on F287 here or in the navigation bar below left.

The SuperCOSMOS Science archive holds the object catalogue data extracted from scans of photographic Schmidt survey plates.

At around 4 terabytes in size, the database contains nearly 6.4 billion individual object detections which are merged into just under 1.9 billion multi-colour, multi-epoch sources and covers the whole sky in three wavebands (BRI), with one colour (R) represented at two epochs.

Access to the data has previously been made available through the SuperCOSMOS Sky Survey pages. The SSA is based on the same underlying data but it is housed in a relational database (Microsoft SQL Server 2008). This platform allows users more power and control over how they can access the data.

A short description of the SSA database structure and content is given in the Data Overview, for full details see the Schema Browser.

Users wishing to access the data should first read the general introductory notes under Data Access.
jets ~120 km/s
## Jets ejected before main nebula

<table>
<thead>
<tr>
<th>Name</th>
<th>$T_{\text{nebula}}$ (yrs/kpc)</th>
<th>$T_{\text{jets}}$ (yrs/kpc)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abell 63</td>
<td>3500</td>
<td>5200</td>
<td>Mitchell+ 2007</td>
</tr>
<tr>
<td>Necklace</td>
<td>1100</td>
<td>2350</td>
<td>Corradi+2011</td>
</tr>
<tr>
<td>ETHOS 1</td>
<td>900</td>
<td>1750</td>
<td>Miszalski+2011</td>
</tr>
</tbody>
</table>
Jets in PNe

- Probably ejected by temporary (wobbly) accretion disk (during RLOF?)
- Ejection before main nebula
- No evidence *(yet?)* for ongoing accretion in PNe (no flickering)
- General lack of strong collimation, supporting precession
- Jet speeds of 100-300 km/s common
- Excellent signposts to find new binaries!
Intermediate periods?

Close binaries
Miszalski+09
De Marco+08

Post-AGB stars
Van Winckel (2003)

HST resolved
Ciardullo+ 1999

PNe??????????

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Figure 6. The central star of PN binary period distribution (black/burgundy), plotted along with the post-AGB binary period distribution (dark grey/dark orange) and compared with a preliminary prediction by Moe and De Marco (in preparation; light grey/blue).

De Marco, Farihi & Nordhaus 2009
How to find longer period binaries

- Subgiants and giants need more space in their orbit => longer periods
- Huge range in $M_V$ in from -2 to +7 mag!
- Composite spectra can be found
- Giants in most systems can be detected
- Sub-giant or even MS in fainter systems

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MPA1508-6455
ASAS lightcurve => P=12.5 d

Primary Secondary
T~40kK      K giant
log g~4       Mv~ -1
Barium central stars

- Barium stars: peculiar s-process enriched giants with white dwarf companions
- During AGB thermal pulses of primary dredge-up s-process and carbon rich material
- Wind accretion **pollutes** the companion, that then evolves to giant phase
- Left with WD, enriched companion and, if lucky, a planetary nebula from the WD
WeBo 1
(Bond, Pollacco & Webbink+2003)

- K0III: p Ba5; chromospheric emission
- 4.7 day rotation period; sin i ~ 90 km/s
- Only four others: Abell 35, LoTr 1, LoTr 5 and...
Abell 70 (PN G038.1-25.4)

Miszalski, Boffin et al.
MNRAS, submitted

GALEX
All sky survey

GMOS

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Abell 70 (GMOS)
Spectral Energy Distribution

NGC 7293
(scaled to A 70 GALEX)

G8 IV (Pickles)

A 70 GMOS

log $F_{\nu}$ (μJy)

Wavelength (μm)
Chromospheric Emission

Trace along GMOS spectrum spatial axis

Counts

Hα
[N II] 6584
[O III] 5007
Radial velocities

V_{neb}=72.3\pm 2.8 \text{ km/s}

<table>
<thead>
<tr>
<th></th>
<th>MJD</th>
<th>V_{helio} (km/s)</th>
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</thead>
<tbody>
<tr>
<td>GMOS</td>
<td>54944.83</td>
<td>-92.7\pm 1.7</td>
</tr>
<tr>
<td>FORS 2009</td>
<td>55026.40</td>
<td>-66.7\pm 17.9</td>
</tr>
<tr>
<td>FORS 2010A</td>
<td>55364.41</td>
<td>-68.6\pm 7.9</td>
</tr>
<tr>
<td>FORS2010B</td>
<td>55366.4</td>
<td>-69.6\pm 8.0</td>
</tr>
</tbody>
</table>

bad S/N consistent with no orbital motion above 8 km/s
<table>
<thead>
<tr>
<th></th>
<th>Abell 70</th>
<th>Type I</th>
<th>non-Type I</th>
<th>Solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Te(NII) [K]</td>
<td>12400+- 200</td>
<td>11.28</td>
<td>11.05</td>
<td>10.93</td>
</tr>
<tr>
<td>Te(OIII) [K]</td>
<td>13200+- 200</td>
<td>11.11</td>
<td>11.05</td>
<td>10.93</td>
</tr>
<tr>
<td>He</td>
<td>8.68</td>
<td>8.72</td>
<td>8.14</td>
<td>7.78</td>
</tr>
<tr>
<td>N</td>
<td>8.43</td>
<td>8.65</td>
<td>8.69</td>
<td>8.66</td>
</tr>
<tr>
<td>O</td>
<td>0.25</td>
<td>0.07</td>
<td>-0.55</td>
<td>-0.88</td>
</tr>
<tr>
<td>N/O</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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VVV and PNe

- Ks lightcurves!! (as survey progresses)
- Flag Ks variables for small telescope followup
- Nebula morphology
- Central star magnitudes with VPHAS+ => NIR excess to white dwarfs (wider binaries)
- Unusual or individual object followup
H2-17  Hen2-81  Hb6

VVV Ks images

NGC6565  M2-30

PHR1246-6324

PHR1801-2522  Hen2-85

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MPA1729-3513

highly obscured torus

Recent onset of ionisation?

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VPHAS+

- Superior resolution over photographic SuperCOSMOS Halpha Survey
- Limited scope for new PN discoveries (SHS already thoroughly searched for new PN)
- May reveal more SN1987A rings (e.g. Necklace)
- Will provide excellent resource to ID blue central stars => needed to revise binary fraction estimates in conjunction with OGLE-III/IV and VVV results

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