PLANETARY NEBULAE AND ALMA

Patrick Huggins, New York University
PNe: Overview

- Reminders
  - evolution: AGB stars – proto-PNe – PNe – white dwarfs
  - properties

- Problems and challenges
  - current observational limitations – scientific challenges

- Focus areas
  - large scale structure – microstructure – chemistry
Post-AGB star evolution

- Fast evolution time scale 100 – 1000 yr

Visible, photo-ionized PNe
Proto-PNe

White dwarf cooling tracks
Core mass

Blocker 1995
Photo-Ionized Nebulae
PN: Properties

- **Hot**  
  central star hot > 30,000 K  
  ionized gas hot ~ 10,000 K

- **Diffuse**  
  densities $10 - 10^5$ /cm$^3$  
  ionized mass up to ~1 M$_\odot$

- **Transient**  
  $v_{\text{exp}} \sim 20$ km/s  
  radius < 1 pc  
  lifetime $10^4$ yr

- Many PNe show a **neutral** component
  - molecules: CO, H$_2$, plus other species  CN, HNC, …
  - neutral atoms H I, C I, O I, …
CO 2-1

mm cont.
NGC 7027

80” x 80”

MERLIN-VLA Bains et al. 03

H$_2$ 2.1 µ CFHT Cox et al. 02

CO 1-0 BIMA Fong et al. 04
Helix Nebula

CO 2-1 CSO Young et al. 99

$H_2$ ISO 5-8.5 µ Cox et al. 98

$H_2$ 2.1 µ Speck et al. 02

$H_2$ IRAC 3-8 µ Hora et al. 06
Neutral gas strongly influences nebula shape

Strong evolution effects

Strong population effects

Neutral gas is important for shaping PNe and relates their origins in mass-loss on the AGB
PNe: Current Problems and Challenges

- **Current limitations**: need better data to define the phenomena
  - nearby archetypes
  - flux measurements
  - x10 big advance

- **Scientific challenges**
  - Origin of large scale structure? jets and tori …..
  - Origin of microstructure? globules, ansae, …
  - Role of magnetic fields? much debated !!
  - Molecule survival and chemistry? partly
  - Which stars become PNe? only binaries !!!?

<table>
<thead>
<tr>
<th>PN</th>
<th>age (yr)</th>
<th>dist. (pc)</th>
<th>$\theta_{\text{ion}}$ (”)</th>
<th>$\theta_{\text{G.C.}}$ (”)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFGL 618</td>
<td>100</td>
<td>900</td>
<td>0.3</td>
<td>0.03</td>
</tr>
<tr>
<td>NGC 7027</td>
<td>1,000</td>
<td>700</td>
<td>10</td>
<td>0.9</td>
</tr>
<tr>
<td>Helix</td>
<td>10,000</td>
<td>200</td>
<td>600*</td>
<td>15</td>
</tr>
</tbody>
</table>

* still need <1”

All these issues are connected with the neutral component

**Important** for PN studies as a whole
Most PNe asymmetric
- equatorial enhancements
- bi-polar or point symmetries

Variations
- evolved PNe – washed out
- young PNe – more prominent
  - very common (Sahai & Trauger 98)

Cause
- ejection of neutral tori and jets
NGC 7027

$H_2$ 2.1$\mu$
Cox et al. 02

Chandra
Kastner 01

HST
Bond 96

BD +30°3639

CO 2-1

mm cont.

12” x 12”
IRAM
Bachiller et al. 00
Current theoretical view – uncertain
- widespread view of role of binaries
- consensus on magnetic field collimation
- physical models ?? disk of companion, disk of primary, magnetic wind from star

Jets and related ejecta – Much to do at high resolution
- characterize properties jets, tori, disks in young PNe, proto-PNe and AGB stars

- prospects good – at GC: 500 yr old ejection torus v = 10 km/s 0.13”
  jet v = 100 km/s 1.3”

Role of magnetic field
- current observations are promising
  - first kG fields measured in central stars (Jordan et al. 05)
  - strong fields in AGB maser spots extend to proto/young PNe (K 3-35 Miranda 01)
  - mm dust polarization AFGL 2688, NGC 7027 (JCMT, Greaves 02)
- high resolution critical to resolve structure
PNe: Microstructure

- Globules
  - Helix prime example
  - nearest with molecules

- Optical properties
  - heads 1 – 2” plus tails
  - photo-ionized surfaces

- What are globules?

- What are their origins?

HST O’Dell 96
• Globules are neutral blobs
  • masses (CO, dust) $\sim 10^{-5} M_\odot$
  • mini PDRs on front facing star
  • CO linewidth $\sim 0.5$ km/s
  • entire envelope in $10^4$ globules
  • molecules in head and tails
• Recent evolution: photo-evaporation
Globules: Beyond the Helix

- Globules are common
  - seen in other nearby PNe
    - Ring, Dumbbell
  - probably in all evolved PNe with mols.
- Ring observations
  - narrow line widths
  - evolution from filaments?

HST Dumbbell O'Dell et al. 02

Ring IRAM CO Josselin et al. 07
Globules: Outlook

- Globules: current theoretical view uncertain
  - heads: formed in stellar atmosphere (Dyson et al. 89, 06)
    - instability of shell (e.g., Capriotti 75)
  - tails – wind swept? from formation? shadows?

- Needs:
  - nearby systems:
    - < 0.1” spatio-kinematic images of globules and tails
    - proper motions (Helix: 0.1” in 5 yr)
    - hydro simulations waiting to be tested
  - more distant systems to study early development

- Expect solution of the origin & tail problems
PDRs & Chemistry

- PDR work & chemistry are at an early stage

- Physical conditions and chemistry reflect rapid evolutionary time scale
  - dense/dark envelopes, tori, (long lived?) disks
  - molecular shocks via jets – not much work on this
  - dense/intense PDRs
  - globule and tail environments

- Rich chemistry in proto-PNe
  - case of CRL 618 (Cernicharo et al.)
  - enhancements of cyano-polyyene chains poly-acetylene chains ....
  - explained by build up of uv field

- Classic PNe: lines weaker/sparser

![Figure 1](image-url)
- Classic PN species: radicals and ions
  
  $\text{CO} \quad \text{CN} \quad \text{CH} \quad \text{OH} \quad \text{HCN} \quad \text{HNC}$
  
  $\text{CCH} \quad \text{HCO}^+ \quad \text{CO}^+ \quad \text{N}_2\text{H}^+ \quad \text{CH}^+ \quad \text{C}_3\text{H}_2$
  
  $\text{CS} \quad \text{H}_2\text{CO}$
  
  plus $\text{H}_2$ and neutral atoms incl. $\text{C I}$

- Strongest source is NGC 7027

![Graph](image)
Cox et al. 02

Observations: ion radical enhancements

PDR ~ 0.5" wide unresolved

C-rich PDR models Hasagawa & Kwok 00
- similar ion/radical enhancement young – old!
- clump models only partly successful (e.g. Redman et al. 03)
- BUT structure completely unresolved

For PDRs & Chemistry of PNe young & old

The need is to resolve the structure and we need high resolution to do this
Final Remarks

- The prospects for PNe are excellent

- We can expect important advances on:
  - origin and evolution of the large scale structure
  - origin and evolution of the microstructure
  - changes in the physics and chemistry

- These will be major contributions to the study of PNe