HST Surveys of the LMC
Planetary Nebulae

Dick Shaw

National Optical Astronomy Observatory

With thanks to the MCPN Research Team:

Letizia Stanghellini  Chris Blades  Diane Karlaka
Eva Villaver  Stacy Palen  Stacy Palen
Bruce Balick  Max Mutchler  Mike Dopita
Objective

- Observe large sample of PNe that minimizes:
  - Distance uncertainties
  - Selection bias (from I.S. extinction)
- Understand broad nebular morphological types
- Understand connections of morphology to:
  - Formation & state of nebular evolution
  - Evolution of CS & connection to nebular evolution
  - Population type of progenitor
  - Nebular chemical enrichment
- Gain insight into the role of the host galaxy on PN population
  - Chemical abundances
  - Star Formation History
Observing Program

- **Selected LMC & SMC**
  - Population of hundreds of PNe, most spectroscopically confirmed
  - Nearby

- **Obtained images & spectra using STIS on HST**
  - Angular resolution of ~0.1” yields physical resolution of ~0.03 pc
  - SNAPSHOT mode means many targets and short exposures

- **Broad-band images:**
  - Nebular morphology (Flux > ~10^{-15} erg/cm²/s)
  - CS detected in ~60% of targets (V>25)

- **Medium-dispersion slit-less spectroscopy:**
  - Simultaneous morphology in: Hβ, Hα, He I, [O III], [O I], [N II], [S II]
  - Interstellar extinction & excitation class
# MCPN Imaging Surveys with HST

<table>
<thead>
<tr>
<th>Program</th>
<th>Investigators</th>
<th>Description</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>8271/LMC</td>
<td>Stanghellini, Shaw, Balick, Blades</td>
<td>SNAP: STIS Broad-band imaging &amp; med. resolution slitless spectroscopy</td>
<td>29</td>
</tr>
<tr>
<td>8702/LMC</td>
<td>Shaw, Stanghellini, Balick, Blades</td>
<td>SNAP: WFPC2 Stromgren-y imaging</td>
<td>13</td>
</tr>
<tr>
<td>8663/SMC</td>
<td>Stanghellini, Shaw, Balick, Blades, Jacoby, De Marco</td>
<td>SNAP: STIS Broad-band imaging &amp; med. Resolution slitless spectroscopy</td>
<td>27</td>
</tr>
<tr>
<td>9077/LMC</td>
<td>Shaw, Stanghellini, Balick, Blades</td>
<td>SNAP: STIS Broad-band imaging &amp; med. Resolution slitless spectroscopy</td>
<td>51</td>
</tr>
<tr>
<td>9120</td>
<td>Stanghellini, Shaw, Balick, Blades</td>
<td>GO: UV slitless spectroscopy</td>
<td>12</td>
</tr>
<tr>
<td>10251/SMC</td>
<td>Shaw, Stanghellini, Villaver</td>
<td>SNAP: STIS Broad-band imaging &amp; med. Resolution slitless spectroscopy</td>
<td>TBD (53)</td>
</tr>
<tr>
<td>10259/SMC</td>
<td>Stanghellini, Shaw, Villaver, Balick</td>
<td>GO: UV slitless spectroscopy</td>
<td>13</td>
</tr>
</tbody>
</table>
Completeness (or lack thereof...)

- Surveys of PNe in the MCs are notoriously incomplete (c.f. talk by Jacoby)
  - This will change as next-generation surveys are completed & published
- Expect faint PNe to vastly outnumber bright targets
  - Even allowing for ionization & abundance effects
- Limits on HST/SNAP dwell time
  - The brighter targets were preferentially selected for HST programs
- New SNAP program could more than double this SMC sample
Morphology and Abundances

Abundance indicators correlate strongly with nebular morphology, as in the Galaxy. Asymmetric PNe, relative to symmetric, tend to be:

- Enriched in N/O, depleted in C/O, showing post-MS processing consistent with more massive progenitors
- Enriched in Ne, Ar, S, which are not altered significantly during AGB evolution, showing progenitor population is chemically enriched
- Greater fraction of asymmetric PNe found in LMC, relative to SMC

[L. Stanghellini will discuss these results in more detail]

Implications for PN formation mechanism(s)

- Is asymmetry caused *primarily* by interaction of the CS with a close binary companion?
  - Dependence of duplicity on PN mass?
  - Dependence of duplicity on host galaxy?
Morphology vs. Host Galaxy

- Broad morphological types are:
  - Round (R)
  - Elliptical (E)
  - Bi-polar (B)
  - Bi-polar core (BC), found within R or E types
  - Quadrupolar (Q)
  - Point-symmetric (P)

Asymmetric distribution:

<table>
<thead>
<tr>
<th>Morphology Type</th>
<th>Galaxy</th>
<th>LMC</th>
<th>SMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round (R)</td>
<td>26%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elliptical (E)</td>
<td>47%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bi-polar (B)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bi-polar core (BC)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadrupolar (Q)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point-symmetric (P)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Emission-Line Surface Brightness

- Decline in SB $\sim R^{-1/3}$
- Similar power-law decline in $\mathrm{H\alpha}$, $\mathrm{[N\ II]}$, $\mathrm{[O\ I]}$
- Some segregation of morphological types:
  - R more common at small radius
  - Fewer BC at large radius
  - E at all radii
- Trajectory of individual nebulae depends on co-evolution of CS + expanding nebula: see paper by Villaver
Extinction vs. Size & Morphology

- The amount of extinction appears *not* to depend upon
  - Nebular size
  - Morphological type
- Extinction appears uniform in selected high-c nebulae on spatial scales of ~0.05 pc
- Implications:
  - Extinction largely external
  - No obvious connection between c and CS mass
Morphology & CS Properties

- Although the available data are scarce, no obvious correlations of CS properties (mass, evolutionary state) with morphology of the host PN have emerged.
  - Small sample sizes: 16 LMC and 14 SMC with well determined masses
  - CS masses are typical of Galactic values, but distribution may be different?
  - More data pending analysis, which will increase CS sample by X2
- E. Villaver will discuss these results in much more detail
Summary

A major HST observing program to obtain images & slit-less spectroscopy of MCPNe has yielded major insights into the evolution of PNe and their central stars.

- There is some evidence of morphological evolution with age
- There is strong evidence that progenitor chemistry affects the ultimate PN morphology
- There is strong evidence that more massive CSPNs tend to produce asymmetric nebulae

Future Work:

- Obtain additional data on SMC PNe: luminosity-limited sample
- Compare the nebular & stellar “evolutionary clocks” to understand the AGB->PN transition time
- Use the PN population as a tool to understand the early epoch of star formation of the host galaxy