Chemical Abundances of Compact Planetary Nebulae

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Galactic PNe

• > 3000 PNe known
• Found mostly near Galactic plane, with the greatest concentration near the Galactic center
• Chemical analyses exist for ~10% of them
  – Only ~10 % of those are compact PNe
Characteristics of compact PNe

• < 4"
  – Spectral apertures include most nebular light

• Marginally resolved from the ground
  – Images from HST

• Mostly young & close, a few distant and large
  – Study onset of morphology
Compact PNe Survey

- Spitzer spectra: dust properties (Stanghellini et al. 2012)
- HST images: morphology and central star masses
- Need high quality optical spectra!
  - Most have only confirmatory spectra
HST Images

PN G 000.8-07.6  
PN G 014.0-05.5  
PN G 026.5-03.0  
PN G 275.3-04.7  
PN G 286.0-06.5  
PN G 289.8+07.7
Compact PNe Survey

• Processed elements and nucleosynthesis
  – SMC PNe:

![Graph](Shaw et al. 2010)

Circles: Round
Asterisks: Elliptical
Squares: Bipolar
Half-filled squares: Bipolar-core
Circled cross: SMC HII region

(Shaw et al. 2010)
Compact PNe Survey

- Processed elements and nucleosynthesis
  - LMC PNe:

  ![Graph showing log N/O vs. log O/H + 12 with different markers for SMC and LMC PNe and symbols for symmetric and non-symmetric PNe.]

(Shaw et al. in prep.)
Compact PNe Survey

• Unprocessed elements and metallicity
  – Oxygen, neon, sulfur and argon
  – Oxygen and neon gradients are steepening with time indicating by Type I, II, and III PNe (Stanghellini & Haywood 2010)
Compact PNe Survey

- PN gas vs. dust chemistry
  - Spitzer dust types: carbon-rich, oxygen-rich, mixed-chemistry, featureless
  - PNe with mixed-chemistry dust tend to be more massive, higher He and N (Garcia-Hernandez & Gorny 2014)
Compact PNe Survey

• PN abundances vs. Morphology and central star masses
  – About $\frac{1}{3}$ of compact PNe have HST images
  – Asymmetric PNe are more nitrogen-rich, indicating more massive progenitors
Observations

- Goodman high throughput Spectrograph
- $-11.2 < \log F(H\beta) < -13.0$
- 600 $l/mm$ gratings (R ~ 1500)
  - Acquisition images in H-alpha
- 3650-6310 Å and 4700-7370 Å
  - provides overlap for accurate red/blue flux calibration
  - may obtain near-IR spectra for some targets
- Data collected so far: 44 objects
  - 2012 - 2015
Optical Spectra

PN G 263.0-05.5

PN G 275.3-04.7
From spectra to abundances

• Measure line intensity
  – Integrate the area

• Correct for extinction
  – Intrinsic $I(\text{H}\alpha)/I(\text{H}\beta)$ ratios

• Determine gas density and temperature

• Calculate abundances
Determine $N_e$ and $T_e$

- $N_e$
  - [S II] $I(6731)/I(6716)$
  - [S II] $I(4069)/I(4076)$
  - [Ar IV] $I(4740)/I(4711)$
  - [Ne III] $I(15.6\mu)/I(36.0\mu)$
  - [Cl III] $I(5538)/I(5518)$
- $T_e$
  - [N II] $I(5755)/I(6548), I(5755)/I(6584), I(5755)/(I(56548)+I(6584))$
  - [O III] $I(4363)/I(5007), I(4363)/(I(5007)+I(4959))$
  - [Ne III] $I(3868)/I(15.6\mu), (I(3869)+I(3968))/I(15.6\mu)$
  - [S II] $(I(4069)+I(4076))/(I(6716)+I(6731))$
  - [S III] $I(6312)/I(18.7\mu)$
  - [Ar III] $I(5192)/I(7136), I(7136)/I(9.0\mu)$
Finding Temperature and Density
Finding Temperature and Density
Calculate abundances

- Ionic abundances
  - Low-ionization zone: singly-ionized species except He\(^+\)
  - Med-ionization zone

- Elemental Abundances
  - He: direct sum of He\(^+\) (5876) and He\(^{+2}\) (4686)
  - O: direct sum of O\(^+\) (3727), O\(^{+2}\) (4959, 5007) and O\(^{+3}\) (25.9\(\mu\))
  - N: ICF from Kingsburgh & Barlow (1994)
First Results

Solid circles: CRD
Open circle: ORD
Asterisk: MCD
Triangles: SMC PNe
First Results

Solid circles: CRD
Open circle: ORD
Asterisk: MCD
Triangles: SMC PNe
PN G285.4+01.5

HST [O III] image

SOAR Hα image
Future work

• Finish current data with abundance calculation, including Ne, S and Ar, and compute the uncertainties
• Finish collecting data for bright southern objects – SOAR
• Collect data for bright northern objects – Mayall
• Telescope(s) for fainter objects
Summary

• ~150 compact PNe with IR spectra, ~ ⅓ of them with HST images
• We are in the process of collecting optical spectra for all of them
• Allow for a more complete and robust abundance analysis
• Relate to other studies of well known and extended PNe