Planetary nebulae and H II of the local group of galaxies

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Topics

1. Deep spectroscopy of bright planetary nebulae and H II regions


Liu X.-W., Optical recombination lines as probes of conditions in planetary nebulae, in IAU Symp. #234, Planetary Nebulae in our Galaxy and Beyond, eds. M. J. Barlow and R. H. Mendez, pp.219-226 (2006)

2. A LAMOST survey of M 31
Deep spectroscopy of emission line nebulae

- Measurements and analyses of lines as faint as $10^{-6} \times \text{H} \beta$ in bright nebulae (CNONe ORLs; CELs from rare elements, e.g. fluorine and s- and r-process elements)

- Mathis & Liu (1999), by comparing the observed [O III] $\lambda 5007/\lambda 4959$ and $\lambda 4931/\lambda 4959$ intensity ratios with theoretical predictions, demonstrate that accurate flux measurements can be achieved over a dynamic range of 10,000

- Progress in observational technology has enabled us to address some of the long-standing problems in nebular astrophysics as well as opened up new windows of opportunities.

WHT optical spectrum of NGC 7027

Synthesis of fluorine in AGBs:
The dichotomy of CELs versus ORLs/Continua

$Liu \ & \ Danziger \ 1993, \ MN, \ 263, \ 256$

$Liu \ et \ al. \ 1995, \ MN, \ 272, \ 369$

\[ T_e(BJ) = 7,200 \text{ K} \]
\[ T_e([O \ III]) = 10,000 \text{ K} \]
\[ adf(O^{++}/H^+) = 4.7 \]
Dichotomy of CELs versus ORLs/Continua

The discrepancies between electron temperatures and ionic abundances deduced from ORLs/continua and from CELs are found to be ubiquitous amongst PNe and H II regions. The effects are bigger for larger, older PNe. For a given PN, the discrepancy increases towards the nebular center.

- If the higher ORL abundances are correct, then we don't understand the nebular thermal structure.
- If the ORL abundances are wrong, we don't even understand the recombinations of hydrogenic ions!

1) \( T_e(\text{ORLs/Cont.}) < T_e(\text{CELS}) \)
2) \( \frac{X_i^+(\text{ORLs})}{H^+} > \frac{X_i^+(\text{CELS})}{H^+} \)

Are the discrepancies caused by temperature fluctuations postulated by Peimbert?
Evidence of a new component of cold, metal-rich plasma

- X/H(CELs) derived from UV, optical or IR lines agree well
- X/H(ORLs) ≈ 10 × X/H(CELs)

The nebula contains another previously unknown component of cold, high-metallicity gas, which is too cool to excite any significant opt/UV CELs and is thus invisible via such lines.

In this model, heavy element ORLs arise mainly from the cold (<1000 K) plasma.

Liu et al. 2000, MN, 312, 585
Photoionization models of NGC 6153

Yuan et al. 2008, in preparation

HST/WFPC2 images

Chemically homogeneous model

Model with H-deficient inclusions (0.125″ × 0.167″)

The model predicts:

\[ T_e([\text{O III}]) = 8800 \text{ K} \gg T_e(\text{H I BIJ}) = 6080 \text{ K} \gg T_e(\text{He I J3421}) = 3300 \text{ K} \gg T_e(\text{O II ORLs}) = 800 \text{ K} \]
## Comparison of plasma diagnostic results

<table>
<thead>
<tr>
<th></th>
<th>adf</th>
<th>$T_e$ ([O III]) (K)</th>
<th>$N_e$ (CELs) (cm$^{-3}$)</th>
<th>$T_e$ (BJ) (K)</th>
<th>$N_e$ (BD) (cm$^{-3}$)</th>
<th>$T_e$ (He I) (K)</th>
<th>$T_e$ (O II) (K)</th>
<th>$N_e$ (O II) (cm$^{-3}$)</th>
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<tbody>
<tr>
<td>NGC 7009</td>
<td>4.7</td>
<td>9980</td>
<td>4260</td>
<td>7200</td>
<td>6300</td>
<td>5040</td>
<td>420</td>
<td>9000</td>
</tr>
<tr>
<td>NGC 6153</td>
<td>9.2</td>
<td>9120</td>
<td>3400</td>
<td>6000</td>
<td>6300</td>
<td>3350</td>
<td>350</td>
<td>9000</td>
</tr>
<tr>
<td>M 1-42</td>
<td>22</td>
<td>9220</td>
<td>1200</td>
<td>4000</td>
<td>5000</td>
<td>2260</td>
<td>&lt;288</td>
<td>6000</td>
</tr>
<tr>
<td>Hf 2-2</td>
<td>71</td>
<td>8820</td>
<td>1000</td>
<td>1000</td>
<td>400</td>
<td>940</td>
<td>630</td>
<td>4800</td>
</tr>
</tbody>
</table>

O II ORLs arise from \(~500\) K plasma!

And as predicted, in general, $T_e$ (O II) < $T_e$ (He I) < $T_e$ (BJ) < $T_e$ ([O III])

(Liu 2003, in IAU Symp. 209; Liu et al. 2006, MN, 368, 1959)

Oxygen in “cold” component $M_{\text{ORL}}(O) = 4.9 \times 10^{-4} M_{\odot}$

$M_{\odot}$

Oxygen in “warm” component $M_{\text{CEL}}(O) = 1.5 \times 10^{-3} M_{\odot}$

$M_{\odot}$

NGC 6153: $4.9 \times 10^{-4} M_{\odot}$

Hf 2-2: $7.4 \times 10^{-5} M_{\odot}$

4.6 \times 10^{-5} M_{\odot}$
Comparison of emission line widths of ORLs and

NGC 7009 (adf ~ 5)

ESO 1.52m FEROS
\( R = 6 \text{ km/s} \)
Liu 2006, in PNe beyond the Milky Way, eds. Walsh et al., p.169

NGC 7009 (adf ~ 5)

Gemini/South gHROS
\( R = 2 \text{ km/s} \)

NGC 6153 (adf ~ 10)

Gemini/South gHROS
\( R = 2 \text{ km/s} \)
Barlow et al. 2006, PNe in our Galaxy and beyond, eds. Barlow M. J. and Mendez R. H., p.367

O II < [O III] < [O II]

O II ORLs arise from either
- colder ionized regions or
- different spatial regions than those emitting [O III] and [O II] CELs

The observed different line widths can be explained by the H-deficient inclusion model, but not by a chemically homogeneous nebula (Zhang, 2008arXiv0805.2198Z)
H-deficient PNe, only five known:
Abell 30, Abell 58, Abell 78,
IRAS 15154-5258,
IRAS 18333-2357 (in GC M22)

WHT/ISIS spectral analyses of knots J3 and J1 in Abell 30

Properties of the H-deficient knots in Abell 30 and 58

- O II ORLs arise from ~ 500 K plasma
- C/O = 0.32 – 0.36 (Abell 30 J1 and J3), 0.085 (Abell 58)

Problems with the “born-again” scenario

- In Abell 30, H contributes only 1% of the mass of the knots, whereas for the postulated H-deficient inclusions in NGC6153, H contributes 22% by mass (H:He:O = 1:2:0.7). But the difference could be caused by mixing of H-deficient material with “normal” gas in NGC 6153
- It is unclear by what mechanism and by how much the He- and C-rich stellar surface material is ejected?
- Observations show that the knots are O-rich (C/O < 1), contradictory to the “born-again” scenario

Table 15. Elemental abundances in units such that log N(H) = 12.0.

<table>
<thead>
<tr>
<th>Ion</th>
<th>ORLs</th>
<th>CELs</th>
<th>ORLs</th>
<th>CELs</th>
</tr>
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<tbody>
<tr>
<td>He</td>
<td>13.03</td>
<td></td>
<td>13.07</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>11.65</td>
<td>8.88</td>
<td>11.66</td>
<td>9.22</td>
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<tr>
<td>N</td>
<td>11.49</td>
<td>9.26</td>
<td>11.43</td>
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</tr>
<tr>
<td>O</td>
<td>12.15</td>
<td></td>
<td>12.10</td>
<td></td>
</tr>
<tr>
<td>Ne</td>
<td>11.51</td>
<td>9.70</td>
<td>11.99</td>
<td>9.78</td>
</tr>
<tr>
<td>Ar</td>
<td>7.45</td>
<td></td>
<td>7.22</td>
<td></td>
</tr>
</tbody>
</table>


ORLs from C, N, O & Ne ions and their relative strengths remarkably similar to those observed in other PNe such as Hf 2-2, M 1-42 and NGC 6153
Origins of cold, metal-rich plasmas – evaporating planetesimals or nova ejecta?

- What happens to the orbiting planetary system when the Sun turns into a WD and its envelope into a PN?
- In the Orion Nebula, protoplanetary disks are being evaporated by the strong UV radiation fields from the $\theta^1$ C.
- Difficult to explain the high ORL abundance of inert gas such as Ne.
- The central star of Hf 2-2 is known to be a close binary with a period of 0.4 days (Lutz, et al., 1998, BAAS, 30, 894).

[Images of the Orion Nebula and Abell 58]
LAMOST surveys – site conditions

Not many clear nights for the north Galactic polar region!

Newberg, Deng et al., 2007, AAS, 211, 1428

Sky background brightens steadily over the years!

The kinematics and elemental abundance distribution of M 31 – a science commissioning program for LAMOST

$m_{5007} = -2.5 \log F_{5007} - 13.74$ (in cgs units)
Are oxygen and neon enriched in PNe and is the current solar Ne/O abundance ratio underestimated?

- Ne/H and Ne/O increase with increasing O/H in both PNe and H II regions.
- The enrichment of neon in the ISM lags behind oxygen. The variations of Ne/O versus O/H agree well with the theoretical calculations of Kobayashi et al. (2006).
- Both oxygen and neon are significantly enriched in LIMS at low metallicity but not at metallicity higher than the SMC.
- That Ne/O(PNe) \sim Ne/O(H II), regardless of metallicity, suggests a very similar production mechanism of neon and oxygen in LIMS of low initial metallicity and in more massive stars.
- The solar Ne abundance and Ne/O ratio should be revised upwards by \sim 0.22 \text{ dex} from the Asplund et al. (2005) values or by \sim 0.14 \text{ dex} from the Grevesse & Sauval (1998) ones.