[O III] Emission-Line Sources in Extragalactic Globular Clusters

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As spectroscopic samples of extragalactic globular clusters (GCs) have grown, so have the number of known [O III]-emitting sources in GCs. Some of these sources are planetary nebulae (PNe), and can help constrain theories of the origin and evolution of PNe. However, others can not be explained as PNe, and may be due to supernova remnants, intermediate-mass black holes, or other exotic phenomena. Here, we review the natures of the known [O III] sources in GCs, and propose a plan to search for these objects more systematically in the future.

How do we know the [O III] source is associated with the globular cluster (GC)?

• Spatial coincidence: it is apparent that the [O III] λλ4959,5007 emission lines sit atop the stellar continuum in the 2D spectrum.

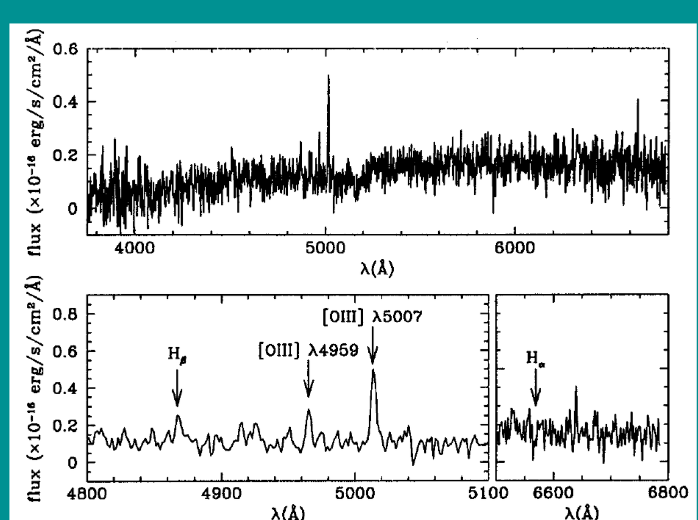
2D spectrum of a GC in NGC 7457

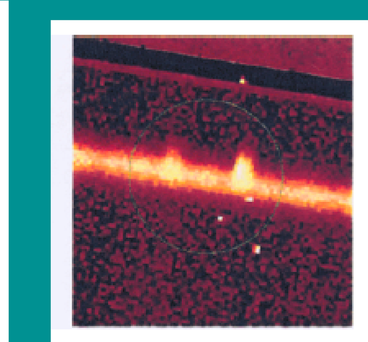
• Consistent radial velocities: the radial velocities of the emission lines are approximately the same as the velocities of the stellar absorption lines.

Planetary Nebulae (PNe)

(The Default Assumption)

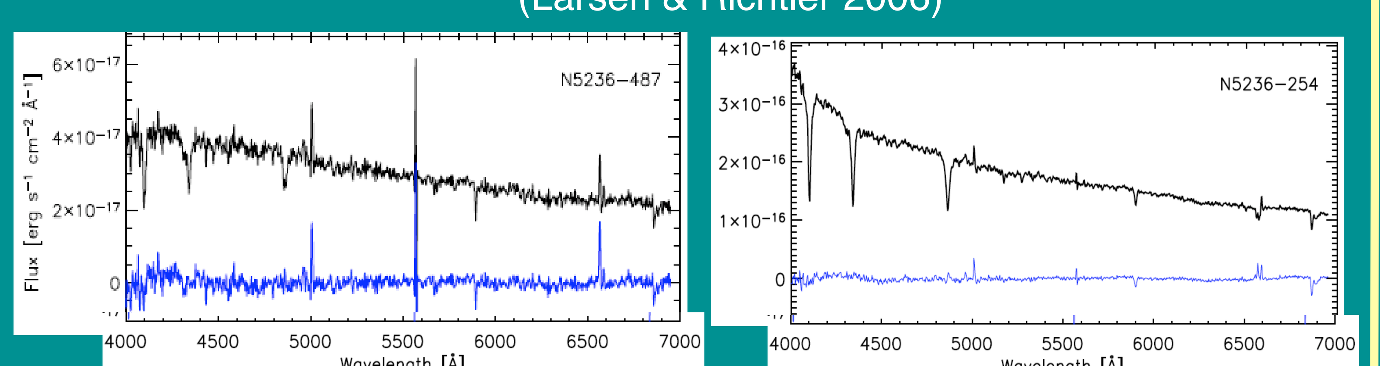
✹ Two PNe in NGC 5128 GCs from Rejkuba et al. (2003)



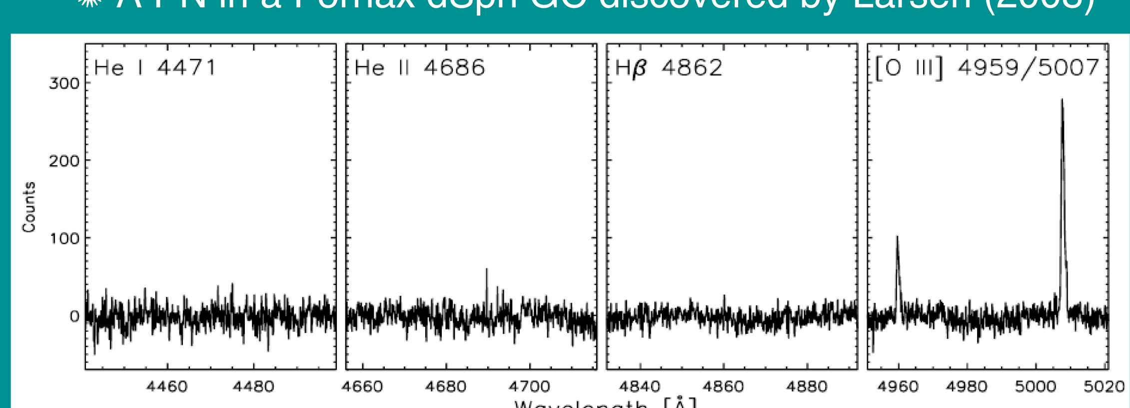


The region around 5000 Å in a raw 2D spectrum of one of the GC PNe.

✹ Two PNe in young clusters (~40--400 Myr) in NGC 5236 (Larsen & Richtler 2006)

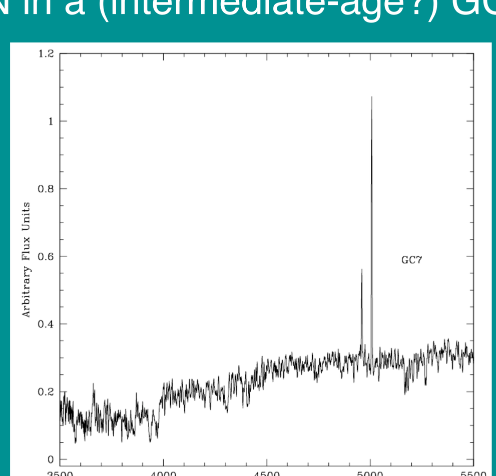


✹ A PN in a Fornax dSph GC discovered by Larsen (2008)



This object is unusual because it lacks Balmer lines ([O III]/Hβ > 25) and has an unusually high expansion velocity of 55 km/s. Larsen hypothesizes that it is a rare PN with extreme H deficiency, not unlike the PN known in the galactic GC M22.

✹ A PN in a (intermediate-age?) GC in NGC 7457 (Chomiuk et al. 2008)



The 2D spectrum around 5000 Å

This source is a high-excitation PN ([O III]/Hβ > 15, also apparent [Ne III] lines) with a central star mass >0.58 $M_\odot$. Such a massive central star is difficult to explain in an old stellar population; it implies a GC age <7 Gyr.

✹ "Outside the scope of this paper" sources

[O III] sources in GCs are usually serendipitously discovered in studies of the underlying stellar absorption spectra. There are several casual mentions of [O III] sources in GCs with no follow-up analysis: e.g., in M87 (Cohen et al. 1998), NGC 4365 (Brodie et al. 2005), and NGC 3379 (Pierce et al. 2006).

Scientific Potential of GC PNe

• The frequency of PNe in GCs will test the claim that all PNe are the products of binary star systems (e.g., Jacoby et al. 1997).

• The frequency of GC PNe may also test stellar evolution models by constraining the lifetimes of PNe (Minniti & Rejkuba 2002).

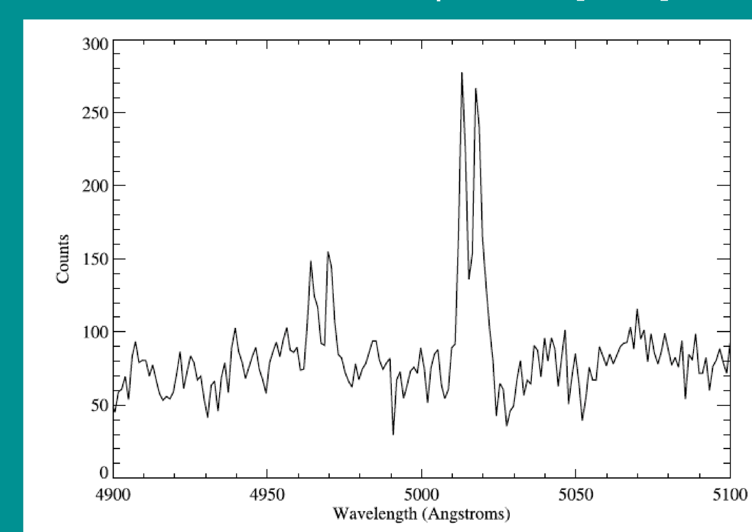
• GC PNe can probe abundances of light elements like O and N which are difficult to measure from stellar absorption lines.

• Observations of PNe in star clusters provides knowledge of the progenitor mass--- e.g., one can constrain the range of progenitor masses leading to PNe (Larsen & Richtler 2006).

Caveat: Some interacting binary stars (like symbiotic stars) can have optical spectra closely resembling PNe; it should not be blindly assumed that [O III] sources are PNe (also see these weird sources at right ➔).

Supernova Remnants (SNRs)?

✦ A GC with double-peaked [O III] in NGC 5128 (Peng et al. 2004)



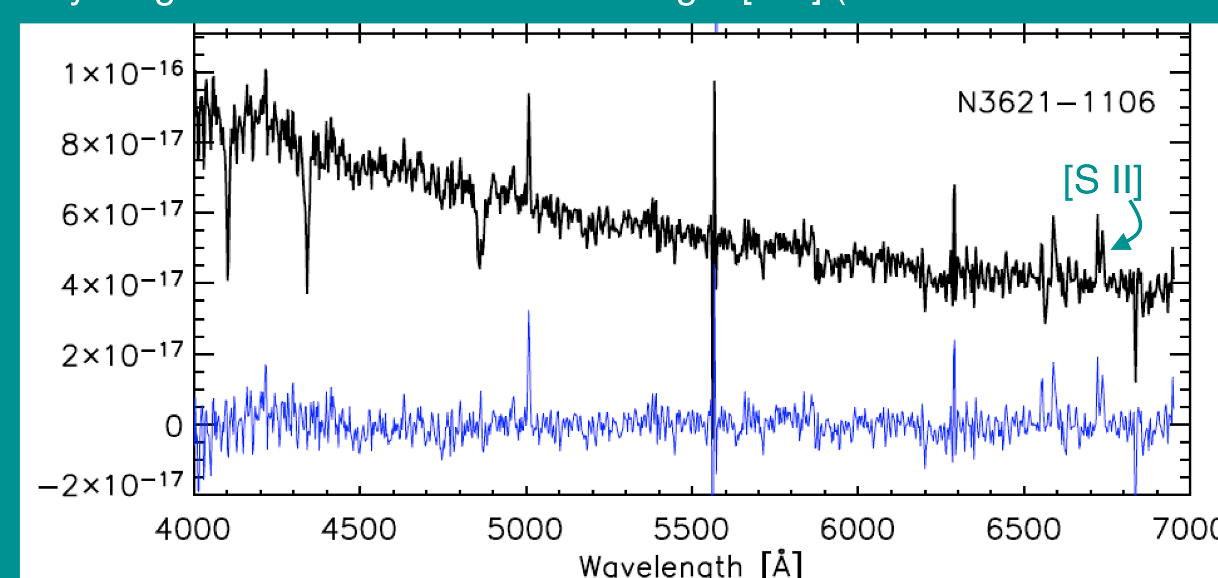
• This source (G169) was the first recognized [O III] source in a GC (Minniti & Rejkuba 2002) and was first assumed to be a PN.

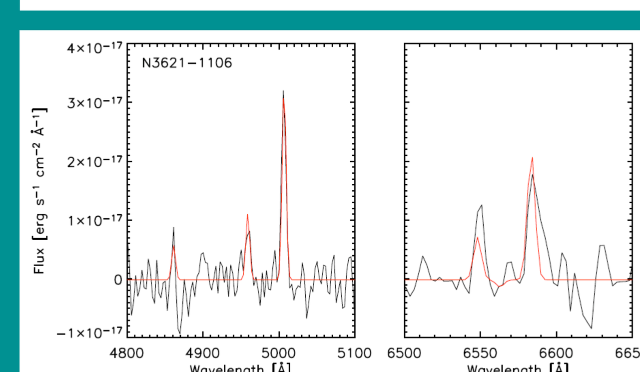
• Higher resolution spectroscopy from Peng et al. showed double-peaked line profiles with a separation of 300 km/s (much too fast for PN expansion); these authors suggested that G169 may host a SNR.

• Peng et al. also note that the [O III] source is offset from the GC by 1.4'' (24 pc).

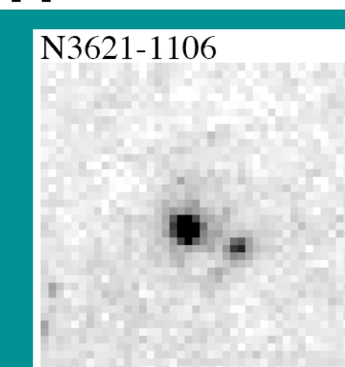
• Broader wavelength coverage from a recent VLT spectrum does not reveal the bright [O II] or [S II] expected from an SNR. G169 may be a chance superposition of two PNe along the line of sight (D. Minniti & M. Rejkuba, private communication).

✦ A young cluster in NGC 3621 with bright [S II] (Larsen & Richtler 2006)





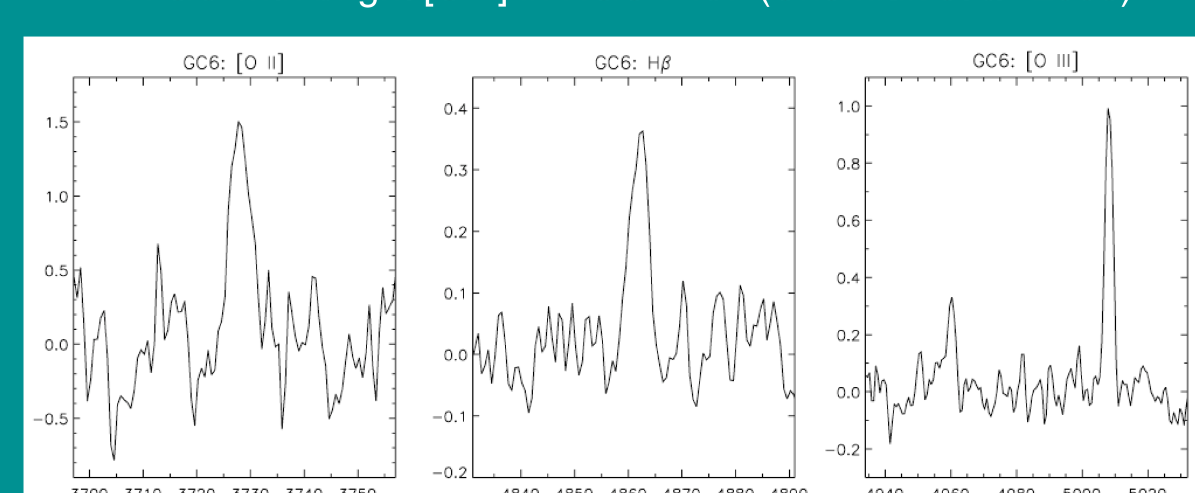
Faint Balmer lines (no Hα!)

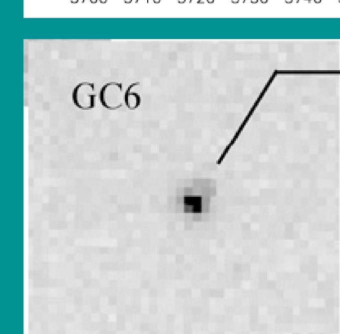


It may have a companion (in this WFPC2 F606W image, the cluster resolves into two sources separated by 0.7'' or ~22 pc, and both are extended).

A new VLT/UVES spectrum has been obtained of this object and further analysis is pending (S. Larsen, private communication).

✦ A GC with bright [O II] in NGC 7457 (Chomiuk et al. 2008)





This object appears to have a "tail" in both F555W and F814W WFPC2 images.

Such a high [O II]/[O III] is difficult to obtain in all but the most massive PNe (which would have to come from a young stellar pop, inconsistent with the underlying stellar absorption spectrum). The line ratio is more consistent with shock heating--- perhaps by an SNR.

Follow-up spectroscopy will be obtained with MMT in September and should decide the nature of this object.

Scientific Potential of GC SNRs

Because star clusters are simple stellar populations, if a SN explodes in one, the age and metallicity of the progenitor are known! SNRs are relatively long-lasting markers of these explosions.

This is of particular interest in old GCs because the SN was certainly of Type Ia, and the age and metallicity of the GC can place important constraints on Type Ia models (Pfahl et al. 2009).

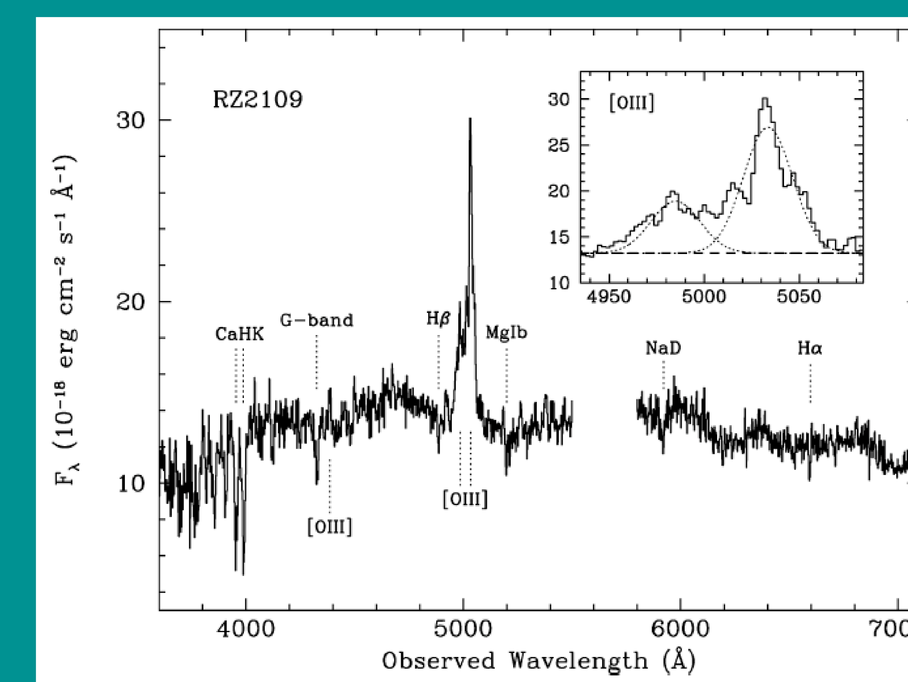
Also, exotic thermonuclear explosions are expected in GCs (e.g., WD--WD collisions; Raskin et al. 2009) and SNRs may trace their properties.

Caveat: The true natures of all three GC SNR candidates are currently highly uncertain. They all have low expansion velocities (≤300 km/s) which would imply that they are evolved SNRs, having plowed through significant quantities of ISM. Such large quantities of gas have never been observed in GCs.

Another possible explanation for the curious emission lines in these clusters is "hybrid" PNe. The diameter of a PN is large enough that it may envelop a significant fraction of the GC, providing the PN with multiple central stars and unusual emission lines. This possibility is under consideration with E. Ramirez-Ruiz, S. Sigurdsson, and J. Strader.

Intermediate-Mass Black Holes (IMBHs)?

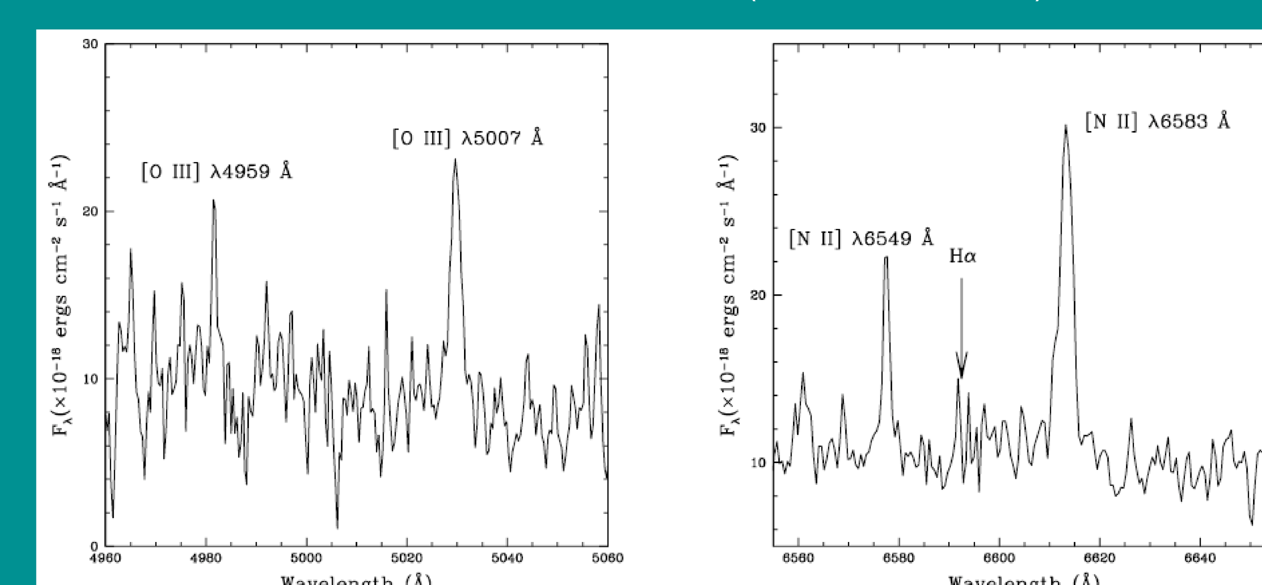
☀ An X-ray black hole binary with broad [O III] in a NGC 4472 GC (Maccarone et al. 2007, Zepf et al. 2007)



• Zepf et al. (2008) claim that the ~2000 km/s line widths imply a strong wind generated by a black hole accreting at ~the Eddington limit. The X-ray luminosity then implies a stellar-mass black hole (~10 $M_\odot$).

• Irwin et al. (2009) assert that this object *could* be the signature of an IMBH---if we are observing a tidally-induced thermonuclear explosion due to a white dwarf (WD) passing near an IMBH (as suggested by Rosswog et al. 2008). This would also neatly explain the lack of hydrogen lines in the spectrum.

☀ An ultra-luminous X-ray source (ULX) with narrow [N II] and [O III] lines in a NGC 1399 GC (Irwin et al. 2009)



• Irwin et al. claim that the narrow line widths (~140 km/s) and lack of hydrogen lines can be explained by the tidal disruption of a WD by an IMBH. They cite models by Ramirez-Ruiz & Rosswog (2009), who find that low-level accretion may continue for ~100 years after such a disruption event, glowing in X-rays and optical emission lines.

Scientific Potential of GC IMBHs

• Optical emission lines can help determine if ULXs are fueled by IMBHs and if ULXs in GCs are different than those in the field (Irwin et al. 2009).

• [O III] emission can enable the determination of black hole mass in GCs, and the placement of GCs on the M_{BH}-σ relation (Zepf et al. 2008).

Some Outstanding Issues

• At first glance, [O III] sources in GCs often appear to be standard PNe--- but with a deeper look, many reveal oddities.

• [O III] sources in GCs appear deficient in hydrogen; most spectra exhibit weak Balmer emission lines or none at all.

• Why do the potential SNR GCs all have strange morphologies?

• Is there a link to the host galaxy? Do some galaxies' GC systems host significantly more [O III] sources than others? Why?

The Need for a Systematic Survey

To meet the science goals discussed here, we need to develop significant sample sizes with well-defined selection effects. Large imaging surveys for GCs already exist, as do [O III]-selected surveys for PNe; these data sets only need to be optimally combined. One complication is that published PN catalogs may not be of use, as PNe are selected to have no underlying stellar continuum.

Extragalactic GCs are faint, and high-quality spectra of these sources require significant amounts of time on large telescopes. Follow-up observations of the sources found in an [O III] GC survey should probably be obtained in collaboration with programs to observe large samples of GCs and/or PNe in multi-slit mode. Ideally there would be spectral coverage from [O II] λ3727 through [S II] λ6717.

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