H-alpha Stacked Images Reveal Large Numbers of PNe in the LMC

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Abstract. Our new, deep, high resolution Hα and matching R-band UKST multi-exposure stack of the central 25 sq. degrees of the LMC promises to provide an unprecedented homogeneous sample of >1,000 new PNe. Our preliminary 2dF spectroscopy on the AAT has vindicated our selection process and confirmed 136 new PNe and 57 emission-line stars out of a sample of 263 candidate sources within an initial 2.5 sq. deg. area. To date approximately one third of the entire LMC has been scanned for candidates ($\sim$7.5 sq. deg.). More than 750 new emission sources have been catalogued so far along with independent re-identification of all known and possible PNe found from other surveys.

Once our image analysis is complete, we plan comprehensive spectroscopic follow-up of the whole sample, not only to confirm our PN candidates but also to derive nebula temperatures and densities which, with the aid of photoionization modeling, will yield stellar parameters which are vital for constructing H-R diagrams for these objects. A prime objective of the survey is to produce a Luminosity Function which will be the most accurate and comprehensive ever derived in terms of numbers, magnitude range and evolutionary state; offering significant new insights into the LMC's evolutionary history. The observation and measurement of our newly discovered AGB halos around 60% of these PN will also assist in determining the initial- to final-mass ratios for this phase of stellar evolution.

1 Background

Since Henizes (1956) Hα survey of the Magellanic Clouds, subsequent Hα surveys have gone progressively deeper by increasing resolution and improving observational configurations. Although this resulted in improved sensitivity and increased the number of emission-line detections, observers continued to use single objective-prism plates and separated emission-line stars from nebulae according to whether a continuum could be seen adjacent to the Hα line.

The dominant method for the discovery of LMC PNe has been the identification of the $[OIII]$ 5007, 4959 lines on objective-prism plates. The high number of candidates rejected through follow-up spectroscopy (Morgan 1995) shows that secondary plate images may play an important role in eliminating spurious identifications prior to spectroscopy. The need for a thorough, deep, Hα survey of the LMC to detect PNe became clear. As part of the AAO/UKST Hα survey of the South galactic plane (Parker & Phillips 2003), an equivalent mini-survey of the entire LMC and surrounding regions was also undertaken. This included an additional 12x 2-hour exposures and 6x 15-minute exposures on the central LMC field. The intension was to form a multi-exposure stack of these exposures to gain significant additional depth in order to search for faint emission-line sources.

1.1 The H-alpha Filter

The filter is effectively the world's largest monolithic interference filter to be used in Astronomy. The central wavelength of 6590Å and bandpass 70Å work effectively in the UKST's fast f/2.48 converging beam (305mm dia gives a 5.5deg. field. Peak transmission 85%.) (Parker & Bland-Hawthorn, 1998).

1.2 The imaging detector: Kodak, Tech-Pan emulsion

Generally speaking, in good seeing conditions, Tech-Pan UKST R- band exposures go about 1 magnitude deeper than the equivalent standard IIIaF R band images with better imaging, improved resolution and lower noise characteristics. Both the Hα and contemporaneous red exposures were made on Tech-Pan emulsion. The use of the same emulsion for both Hα and SR exposures ensures an excellent correspondence of their image point spread functions when film pairs are taken under the same observing conditions (Parker and Phillipps 2001). The Schmidt Tech-Pan films (e.g. Parker & Malin 1999) are ideal tools to find large numbers of PNe candidates within the LMC due to their inherent high resolution.

1.3 Data Reduction

The SuperCOSMOS machine in Edinburgh scanned and co-added the individual Hα/SR exposures on a pixel grid creating 0.67 arcsec pixels after 15-bit digitized plate scanning. The exposures reach depths of $\sim$21.5 (4.5 x 10^{-15}cm^2 s^{-1} Å) for broad-band Red and $\sim$22 for the equivalent Hα. This is much deeper than previous LMC Hα surveys such as Lindsay & Mullan (1963) R$\sim$15 and Bohannan & Epps (1974) R$\sim$14.5. Other more recent surveys have touched on the Magellanic Clouds in the process of surveying both hemispheres. The most contemporary of these is Southern H-alpha survey (SHASSA) undertaken at CTIO (Gaustad et.al., 2001). This is a full hemisphere survey however at 48 arcsec resolution, it doesn't offer the level of spacial resolution provided by the UKST H-alpha survey. The UM/CTIO Magellanic Cloud Emission-line Survey conducted by Chris Smith and the MCELS team (1998) uses a CCD detector on a Schmidt telescope covering the central 8 sq. deg. of the LMC. The instrument provides 2.035$'$ pixel^{-1}, giving $\sim$3$''$ resolution with a field of view of 1.1 sq. deg.. Only the UKST survey can therefore detect and identify large numbers of faint point source emitters. Bland-Hawthorn, Shopbell and Malin (1993) have shown that digital stacking of UKST plates and films can achieve canonical poissonian depth gains. We estimate our stacked images reach $\sim$1.35 magnitudes deeper for Hα and 1 magnitudes fainter in Red than an individual exposure.

Another significant advantage of the stacking process is that small emulsion imperfections and adhering dust particles, scratches etc which can be problematic and lead to spurious detections are naturally eliminated as part of the combination process. Likewise the influence of variable stars is considerably alleviated by the time averaging process by stacking multiple exposures taken over a three year period.

2 Detection Technique

Candidate emission sources are found using an adaptation of a technique whereby fits images from the deep SR stack are first coloured red and overlaid upon the matching stacked Hα images coloured blue. The coloured images are then merged and matched for point spread function (psf) which is achieved both visually and through numerical intensity values, constantly displayed in the RGB program of KARMA. All continuum sources such as LMC Stars and background galaxies become a uniform colour but emission nebulosities and candidate compact emission sources develop a blue hue, making discovery and identification straightforward. Careful selection of software parameters allows the intensity of the matching Hα and SR images to be perfectly balanced allowing only peculiarities of one or other band-pass to be observed and measured. **All** previously known LMC PNe have been re-identified either by their extended halos surrounding the central PN shells or as areas of compact dense emission. In each case the Hα emission is seen as a bright blue aura.

Our preliminary application of this technique, applied to several 1-square degree sub-regions of the main LMC field, has produced extremely encouraging results. Areas were chosen which contained known emission sources and PNe, including some of the previous faintest detected sources such as PNeJ07 at m_B21.7, which was easily identified. Scrutiny of the combined, KARMA processed, 1-degree Hα/SR images revealed dozens of new PNe candidates in each sub-field. Several point sources exhibit very centrally concentrated emission, while others display rings and faint outer bubbles, halos or extensions. The enhanced angular widths of many of the emission sources revealed by our technique (up to 4 arcseconds in radius about the central star) strongly favour PNe in these cases.

3 Identification of new candidate LMC emission sources

Only spectroscopic data will unambiguously determine the nature of the new candidate sources whilst their magnitudes ($15\leq$ R $\leq$ 21) and number density (100 sq/deg) make the 2dF spectrograph on the AAT the obvious choice for effective follow-up. All previously known PNe in the preliminary studied regions were successfully re-identified whilst the characteristics of the newly identified sources continue their trend to fainter magnitudes. We are including every strong source that exhibits a halo whose diameter is >20% the diameter of the central source regardless of the fact that many of them will be emission-line stars. The fact that Galactic Bulge Symbiotic stars and compact PNe look the same means we will not discard any star that appears to exhibit Hα emission. Therefore, we can be confident that we are extracting every unidentified PNe to the limit of the stacked data. Figure 1 shows the results of an initial AAT 2dF service time run where we were able to place almost 2/3 of the sources in a 1.25 square degree area onto optical fibres for spectral confirmation. It can be seen that our data is extending the LMC PNe range both in terms of numbers of detections and depth of magnitude.

The apparent visual density of the Hα emission has proven to be a fair indication of the source type. All known PN are strong radiative emitters with thick emission halos that are more than double the visual diameter of the central source. By comparison with HST imaging of LMC PNe, we find film saturation increasing the diameter of the central PN source including shell structure by $\sim$4 times for an average magnitude 16 central PN at logarithmic intensity levels. This figure decreases to $\sim$2 times for the widest, large structure PNe such as SMP 93. Faint, wide- scale structures such as the AGB halos surrounding PNe will not suffer from the same PSF characteristics so we can be more confident about the large diameters we are observing.

As candidates are discovered, we record position, check data bases including (but not restricted to) SIMBAD for previous detections, allot an ID number and give each a probability rating. A note is made relating to any peculiarities associated with the source such as nearby bright or overlapping stars, bi-polar emission, shape, intensity, optical diameter, density, and proximity of the emission to any nearby *HII* regions. Magnitudes are found with the STARLINK PHOTOM package which has been calibrated to several catalogues and the SuperCOSMOS on-line UKST R-band catalogue.

4 Future Plans

With such a large number of PNe at relatively the same 50Kpc distance, the primary objective will be the creation of a comprehensive luminosity function. This will be achieved for the Hα line to allow us to better understand the evolutionary types in the LMC. It will also provide a probe into the structure and origin of the LMC as well as providing a distance probe when applied to other Hubble-type galaxies. Spectroscopic analysis will add further to our knowledge of AGB phase evolution as well as chemical enrichment in the LMC, especially when that information is combined with morphology and evolutionary types. HR Diagrams are useful tools for examining the evolution of stars and understanding the different phases that evolve from differing stellar and nebula parameters. Extended late AGB phase Halos, which we have discovered for the first time in LMC PNe, will be examined, particularly for their diameters and shapes with relation to the central PNe. The initial- to final-mass relation is another important area of stellar physics that can now be re-examined by virtue of measuring halo parameters; since all of our sources are at the same general distance. Our data-base will provide a comprehensive catalogue which will be published and on-line for general access.

5 Conclusion

So far 6 out of 16 image cells have been analyzed. The detection rate increases 3-fold on the main bar. Approximately half the 263 candidates followed-up on 2dF have been confirmed as PN, 57 are emission-line stars, 33 require longer exposure times, while 33 are non-PNe detections which include late-type stars. At these rates, we expect to confirm more than 1,000 new PNe in December when we return to 2dF on the AAT. Also in December we will be using VLT FLAMES to observe very faint candidates and gain faint diagnostic lines from a large sample covering a wide evolutionary range and various positions on and off the main bar.

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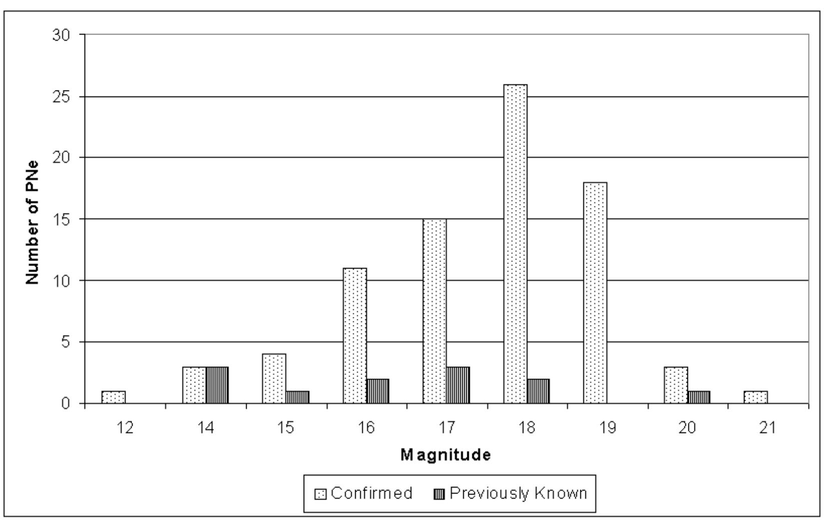


Fig. 1. Results of spectroscopic confirmation in a 1.25 sq. deg. area; number vs. magnitude

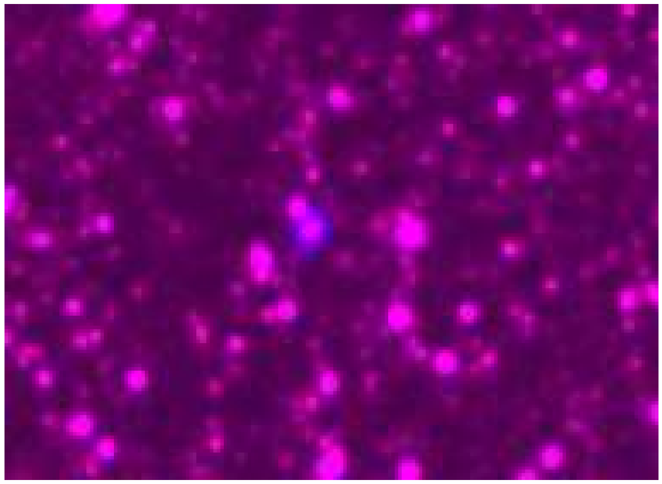


Fig. 2. Combined colour image of a newly discovered PN

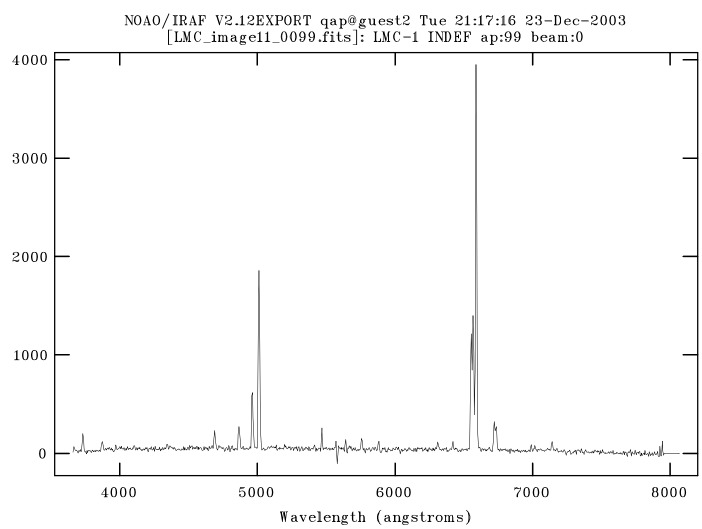
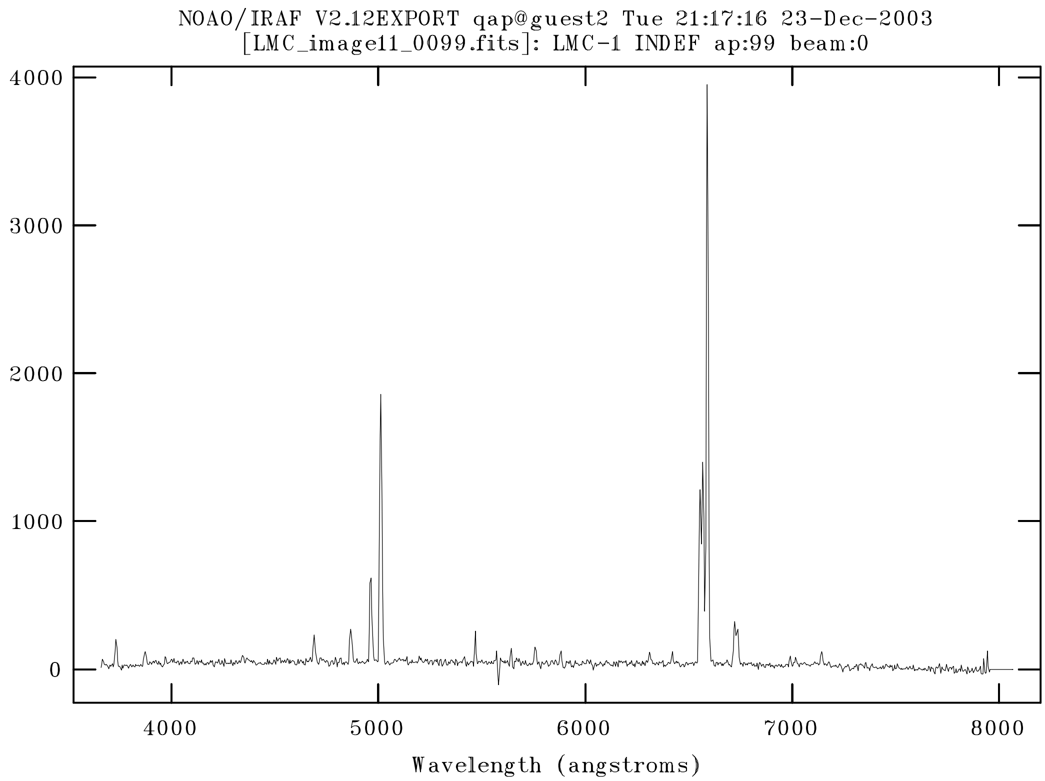


Fig. 3. Spectroscopic confirmation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