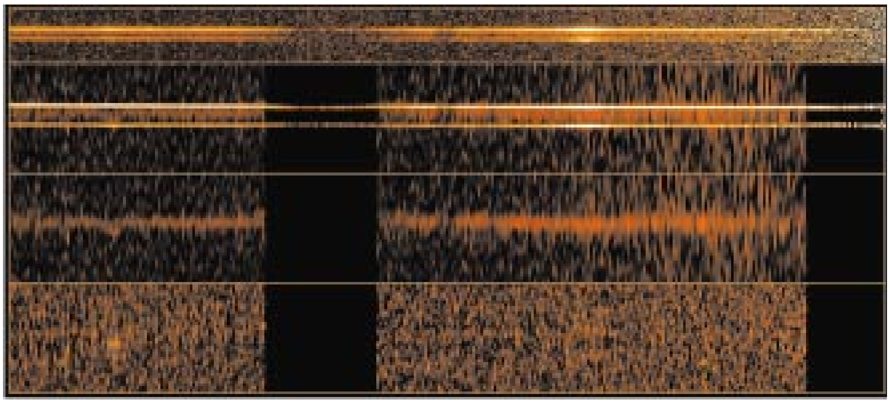

Figure 5: From top to bottom: A near-IR spectrum of the lensed QSO HE 1104–1805, between 1.5 µm (left) and 2.5 µm (right). The seeing is 0.6–0.7 arcsec and the lensing galaxy is situated about 0.5″ away from the brightest QSO image. The spectrum is deconvolved down to a resolution of 0.3″ with improvement of the sampling in the spatial direction. The third panel displays the spectrum of the lens alone and the last panel shows the residual map (RM, see text) in unit of the photon noise, to illustrate the good agreement between the data and their deconvolution. The dark areas are not used, because of strong atmospheric absorption.

QSOs and for which the time delay has been reported (Wisotzki et al. 1998). However, the redshift of the main lensing galaxy remains unknown, which still hampers any attempt to estimate H_0 from this system. As the lensing galaxy is very red (e.g., Courbin et al. 1998b), near-IR spectroscopy appeared an obvious way of determining its redshift.

SOFI spectra were obtained at the NTT between 0.9 and 2.5 microns under good seeing conditions (about 0.6–0.7″) and deconvolved down to a resolution of 0.3″. As no PSF star was observed, the PSF was computed directly from the spectra of the two QSO images (more details about this procedure are given in Courbin et al. 1999). Figure 4 shows the results of the deconvolution performed between 1.5 and 2.5 microns, since the lens is too faint in the 0.9–1.5 micron region. The original data are shown in the top panel of Figure 4. The three other panels, from top to bottom, show the deconvolved spectra with improved sampling (0.145″/pixel) in the spatial direction (this is why the width of the deconvolved 2-D images is twice that of the raw data), the spectrum of the lensing galaxy, as well as the RM (flat with a mean value of 1). The data presented here have a much lower S/N than in the simulations but are sufficient to unveil the spectrum of the faint lens. Since no emission line is detected, we are still left without precise measurement of the lens redshift. However, the prospect of measuring this redshift with optical/near-IR spectroscopy is good: with the improved S/N, sampling, and spectral resolution of future VLT data!

4. Future Prospects

Our new extension to spectroscopy of the MCS image deconvolution algorithm obviously has a wide field of applications. The most original and promising ones may consist in spectroscopic studies involving extended objects hidden by – often brighter – point sources. We have presented an application of the method to gravitationally lensed quasars, where the spectrum of a very faint lensing galaxy can be extracted. A similarly interesting application will be to take full advantage of the ability of the algorithm to decompose spectra, in order to carry out the first systematic spectroscopic study of quasar host galaxies. With current instrumentation mounted on 8–10-m-class telescopes, sufficiently high signal-to-noise spectra can be obtained, at least for low-redshift quasars, in order to derive precise rotation curves of their host galaxy, provided the spectrum of the bright QSO nucleus can be removed accurately. The present spectrum deconvolution algorithm is very well suited for such a purpose and may therefore allow significant progress, not only towards the measurement of the mass of the central black hole in QSO host galaxies, but also in astrophysics in general. We intend to release in the near future a documented public version of our image deconvolution algorithms, followed latter by the spectroscopic version of code illustrated in the present article.

Acknowledgements

F. Courbin acknowledges financial support through the Chilean grant FONDECYT/3990024. S. Sohy is supported by contracts ARC 94/99–178 “Action de Recherche Concertée de la Communauté Française (Belgium)” and “Pôle d'Attraction Interuniversitaire” P4/05 (SSTC Belgium).

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Emission-Line-Object Survey in the LMC with the WFI: New Faint Planetary Nebulae

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1. Introduction

Until now, all emission-line-object surveys in the two Magellanic Clouds (MCs) have been made with Schmidt plates, either with prism objective or with the 2-filter (ON, OFF) method. The only deep survey, dedicated to the central part of the MCs, dates from 1980, and suffers from large biases because it was done using only two filters to select the candidates (about 30% of false candidates). No

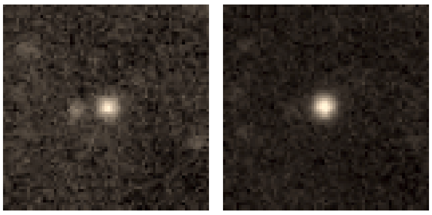

Figure 1: PN1 in Hα and [O III]. Note the high excitation object (ratio [O III]/Hα = 10).

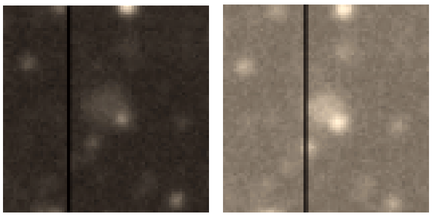

Figure 2: PN 2 in Hα and [O III]: extended object ~ 2.5″ (or 0.6 pc).

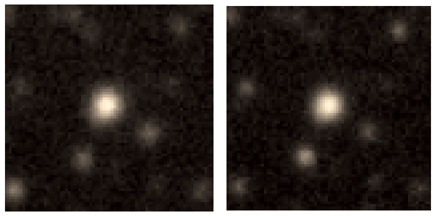

Figure 3: PN 3 in Hα and [OIII] Low excitation object.

large emission-line survey has been published with CCD devices until now.

Our final goal is a large survey (10 square degrees in total) of two regions in the SMC and the LMC, to identify new fainter emission-line objects (as PNe, HII regions, Be stars, symbiotic stars, young stars, etc.).

We concentrate our efforts mostly on PNe and HII regions. The new candidates will allow us to derive accurately the full PNe luminosity function in the Magellanic Clouds (MCs), which is still poorly known for faint objects.

Imaging with the WFI will hopefully be followed up with EFOSC2 and/or FORS to take, for the first time, spectra of the new very faint PNe but also the close-by HII regions, in order to determine the physical properties and accurate abundances of these emission-line objects.

2. Overview

LMC and SMC are ideal targets for at least three reasons:

– they are close enough so that we can have a good spatial resolution and very good S/N spectra

– their PNe and HII regions are bright enough so that a detailed analysis of their chemical composition is feasible with the current instrumentations.

– the metallicities are lower than our Galaxy

The study of all types of PNe (with different brightness, age and metallicity) is one of the cornerstone of our understanding of Intermediate-Mass Stars and the chemical evolution of galaxies. PNe are used as probes to determine the past abundances of the progenitor stars and also the current abundances of the light elements released at the end of the AGB.

The faintest PNe are also of interest because they contain two important classes of objects. Either they are old objects (low mass with longer lifetime) which gives

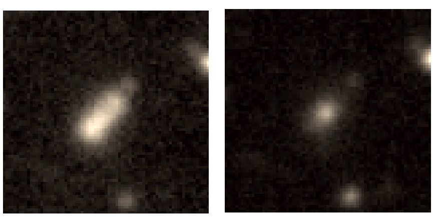

Figure 4: PN 4 in Hα and [O III]: Bipolar extended object ~ 5″ in Hα, but more compact in [O III].

information on the chemical composition at the early stages of the galaxy (to trace the chemical evolution over the past 10 billion years) or they are objects at the very end of their evolution in a state which allows us to look into deeper layers of their envelope.

To improve our understanding of the chemical evolution of the nearby galaxies, it is crucial to use the largest spatial, temporal and metallicity coverages. The PNe will help us in our understanding of the enrichment processes in He, C, N in the Intermediate-Mass stars, because they tell us about the dredge-up mechanisms occurring during the last stages of evolution of intermediate-mass stars and how they depend on the metallicity. Helium, Nitrogen, and Carbon are, directly manufactured by the PNe's star and their abundances thus provide the yield of those elements in the corresponding galaxy. In particular, we have shown in the Magellanic Clouds (Leisy and Dennefeld,1996), in a sample of 70 objects, that enrichment or destruction are strongly metallicity dependent. We obtain metallicity relations, but they are still hampered by the too few studied objects, particularly in the very low metallicity range. The Nitrogen and Carbon production are by far more effective when the initial metallicity is low. Apparently, in the SMC, the lower-mass stars produce also Oxygen, but our results are based on a small sample (8 objects).

These abundances have also been directly compared with those of adjacent HII regions which provide "recent" abundances. Until now, only very old, inhomogeneous, data are available in some galaxies, and moreover, the number of studied HII regions is always too small for a detailed comparative study. They come from various authors, are of poor quality (the forbidden emission line [OIII] λ4363Å is often missing or its uncertainty is greater than 50%). Moreover, in a given galaxy, the metallicity determined from HII regions shows a large dispersion. The metallicity determinations have mostly been based on the abundances of Oxygen because it is easily measured by optical spectroscopy. However, it may not be representative of the metallicity of the object since the ejection of various elements from stellar wind, Supernovae and Planetary Nebulae involves different times and length scales. The existence of spatial inhomogeneities in the distribution of various chemical elements within a HII region is still a matter of debate.

As the information coming from PNe and HI regions is by far uncomplete and biased to the brightest objects, a survey of PNe's and HII regions in nearby galaxies is necessary to derive proper chemical abundances and check the different elements as metallicity indicators.

3. Observations

The main advantage of using WFI over existing "uncomplete surveys" is that it provides a high spatial resolution (pixel size 0.24″) which is mandatory in such crowed regions. Moreover a large deep survey of emission-line objects in the MCs can be done covering several degrees. Our data provide at the same time: accurate positions (~0.2″) catalogue and finding charts, and the absolute fluxes. Nevertheless, this observation step is needed to prepare further observations with bigger or space telescopes, which require accurate positions and photometry in order to save as much observing time as possible.

Three nights were allocated at the beginning of January 1999, but because the 2.2-m WFI was offered in February with delay to the community, we got two nights in March and could only observe the LMC.

The two nights (March 3rd and 4th, 1999) were photometric with an average seeing of about 1.0″ (from 0.8″ to 1.3″) at airmasses between 1.3 to 1.9.

We observed three spectrophotometric standard stars per night in order to calibrate the images in absolute fluxes.

We were able to observe two fields per night, and therefore cover a full square degree on the sky. We observe each LMC field in Hα, [OIII], Continuum and B for centring purposes (and further finding charts). Each exposure was divided in 5 jittered exposures (total time between 20 and 30 min) in each filter (1 min in B). This procedure was adopted to avoid spurious identifications, and to fully cover the gaps between the 8 CCDs. Therefore, for each field, taking into account the overheads of focusing, pointing and reading (20 ×) of the CCD, an amount of ~ 2 h 30 min was needed.

4. Reductions

For interferencial imaging, the moon background is not crucial because after a 5-min exposure time, even with full moon, the sky level is of the order of 150–200 ADUs.

Preliminary reductions of the WFI data have been made, but a powerful computer was still missing at that time. Remember that a full frame is 300 Mb!

Here are the different reduction stages adopted:

– Bias substraction and FF division
– Cosmic-event removing
– Combine the 5 images per filter (not yet done)
– Frame recentring (Continuum as reference)
– Flux calibration
– Continuum frame substraction
– ([OIII]-Continuum) divided by (Hα-Continuum)
– Accurate astrometry using the ESO Starcat package facility (not yet done)

5. Results

These observations demonstrate that, as expected, we still can find a lot of new emission-line objects. Moreover, these observations provide, in the survey area, an unbiased and complete survey (range greater than 8 magnitudes).

As a first product this study, preliminary to further spectroscopic study, will lead to the publication of a catalogue with precise coordinates and good finding charts of more than 1000 emission objects (PNe, HII regions, SNR, Hα-emission stars, etc.) per square degree.

The performance of the WFI is very encouraging:

– Firstly, we were able to (easily) find the 6 known PNe present in our 4 fields, and moreover our photometry agreed within 10–20% with the fluxes derived spectroscopicaly.

– Secondly, with the calibration in fluxes, we confirm that we easily reach fluxes down to $F\alpha = 10^{-16}$ erg.cm^{-2} s^{-1}, and therefore that we are able to find objects 20–50 times fainter than the last deep survey (Jacoby 1980).

With a bigger area covered and better statistics, we will derive an unbiased PNe luminosity function.

In each of the two first 30′ by 30′ reduced fields we discovered more than 100 emission-line objects. In one field we found 2 new PNe, 8 compact HII regions and ~ 80 Hα-emission-line stars. In the other field, also 2 new PNe, 4 compact HII regions and ~140 Hα- emission line stars.

All 4 PNe are very faint and 2 of them are fully resolved (diameter > 1.0″). The PNe have fluxes of the order of 10 10^{-16} erg.cm^{-2}.s^{-1}, which one can compare to brigthest (3000 10^{-16} erg.cm^{-2}.s^{-1}) or the faintest (~ 200 10^{-16} erg.cm^{-2}.s^{-1}) PNe already known.

Figures 1 to 4 show the finding charts in both Hα and [OIII] filters.

5.1. Expected PNe number in the LMC

In 1978 Sanduleak et al. have estimated the total PNe number to 400 in the LMC (and 100 in the SMC accordingly to the LMC/SMC mass ratio equal to 4). In 1980 Jacoby determined these numbers to be 996 and 285, respectively.

The current number of known PNe in the Magellanic Clouds are respectively 282 and ~ 85 for the LMC and the SMC.

This study demonstrates that many PNe have been missed by the previous surveys and that probably a few hundred can be discovered with the current instrumentation.

In the studied area we double the known sample of PNe, therefore, we can extrapolate to find more than 250 new PNe in the LMC. Statistically, we can at least expect to find about 50–100 new faint and extended PNe in the Bar. These PNe are of particular interest because they are old, allowing to determine galaxy abundances at epoch up to 10 billions years.

6. Conclusion

The WFI has proved with this study that it is an excellent efficient instrument which can be used to survey large areas (like nearby galaxies) and still discover many faint interesting objects.

We hope that we will soon be able to cover several other square degree and determine an accurate PNe luminosity functions over this complete and unbiased sample.

The next step, with such faint objects, will be a follow-up with VLT telescopes (FORS) to obtain very good S/N spectra and derive accurate abundances.

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ANNOUNCEMENTS

PERSONNEL MOVEMENTS

International Staff

(1st July 1999 – 30th September 1999)

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