Publ. Astron. Soc. Aust., 1998, 15, 123–7

Hα Emission from Point Sources in the Magellanic Clouds

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Received 1997 August 1, accepted 1997 December 9

Abstract: Large numbers of the many types of emission-line object that are found in the Magellanic Clouds were first identified through Hα surveys of one kind or another. This paper looks at what has been achieved through such surveys and considers how the planned UKST Hα/TechPan Survey can further this kind of work.

Keywords: Magellanic Clouds — stars: emission-line — planetary nebulae

1 Introduction

The Magellanic Clouds (MCs) are rich sources of compact emission-line objects that are at a known distance and bright enough to be studied in detail. Objects include hot stars (WR, Of, B[e], Be, LBV etc.), composite stars (symbiotic stars, VV Cephei systems etc.) and small nebulae such as planetary nebulae. Although some planetary nebulae extend over 2 arcsec and can be resolved, they are usually identified and studied as though they were point sources. Moreover, the Magellanic Clouds readily supply complete flux-limited samples because each Cloud can be observed over its entirety in a practicable observing program.

2 Methods

Many, if not most, emission-line objects in the Magellanic Clouds have been identified through the detection of Hα on photographic plates. Although a single direct exposure in Hα provides a ready means of identifying extended objects, it is insufficient for the identification of point sources with emission lines, for these appear indistinguishable from normal stars. What is needed is information on the Hα line itself and on the neighbouring continuum as well, so that emission-line objects can stand out by appearing different in these two observations. The continuum data can be provided by either obtaining a separate direct plate through an adjacent waveband (or a broader waveband which includes but dilutes the Hα emission) or making a single exposure through an objective prism.

The latter technique has been the more commonly used, especially in the days before fast plate measuring machines and powerful computers. However, in crowded fields such as those of the Magellanic Clouds, it suffers somewhat from the overlapping of neighbouring images. Consequently, most work has been carried out through restricted wavebands sufficiently narrow to minimise this problem. On the other hand, the large numbers of faint stars cause more of a problem when comparing two direct plates because, whereas they are so blended on objective-prism plates that they merely merge into the sky background, they remain as individual objects on direct plates, with the consequence that complex software is required for separating the blended images and for matching the plates. Also, the lists of objects found by comparing two plates taken at different times will include large numbers of variable stars that must be eliminated in another way, usually through comparison with a third plate.

Similar work has been carried out using other emission lines such as [OIII]λ5007 for planetary nebulae and HeIIλ4686 for WR and symbiotic stars.

3 Past Surveys

Table 1 is a list of the main Hα surveys of the Magellanic Clouds. All these surveys used objective-prism plates and most separated emission-line stars from nebulae according to whether a continuum could be seen adjacent to the Hα line. The most important early survey was by Henize (1956) which produced catalogues of Hα emission-line objects in the LMC/SMC containing 172/65 stars and 415/117 nebulae, of which 26/38% were star-like images. The later Hα surveys are progressively deeper through the use of better resolution emulsions and observational configurations. The most recent survey (MA) has quadrupled the numbers of known emission-line objects in the SMC. However, neither of the deeper surveys covers the $\sim$250/$\sim$220 sq. deg. occupied by the Clouds and surveyed for [OIII]λ5007 emission from planetary nebulae (Morgan 1997).

The catalogues of objects identified in these surveys include most classes of bright emission-line object but do not distinguish between them. Although most of the brightest objects have been studied in detail and are some of the most interesting peculiar stars known, even today many of the fainter stars have not been observed spectroscopically, so these Hα catalogues may still include some important

 1323-3580/98/010123$05.00

Table 1. Magellanic Cloud Hα surveys

Survey	Telescope	Gal	A	$\Delta\lambda$	D	$m_{\rm lim}$	$N_{\rm Stars}$	$N_{\rm Neb}$
N,S	Mt Wilson 10 in	LMC	225	620–670	450	13·5	172	415
N,S	Mt Wilson 10 in	SMC	225	620–670	450	13·5	65	117
La	ADH Schmidt	SMC	≥50	590–670	800	∼15	804	109
Lb,LM,AL	ADH Schmidt	LMC	≥120	590–670	800	∼15	543	50
BE	Curtis ST	LMC	25	620–690	420	14·5	625	—
MA	Curtis ST	SMC	12	651–662	420	18	1755	143

Surveys: N,S: Henize (1956); La,b: Lindsay (1961, 1963); LM: Lindsay & Mullan (1963); AL: Andrews & Lindsay (1964); BE: Bohannan & Epps (1974); MA: Meyssonnier & Azzopardi (1993). $\Delta\lambda$ (waveband) is in nm; D (dispersion) is in Å/mm at Hα; $m_{\rm lim}$ is the detection limit of the continuum in magnitudes; A is the survey area in sq. deg.

unclassified objects. For example, several symbiotic stars discovered on the basis of objective-prism spectra with HeIIλ4686 emission and a red stellar continuum were found to be members of these catalogues (e.g. Morgan 1992).

One sample of ∼50 stars from the Hα catalogues was observed spectroscopically with FLAIR during its commissioning on the UKST. Of 36 previously unclassified objects [four from Henize (1956) and 32 from Bohannan & Epps (1974)], Morgan, Watson & Parker (1992) identified 15 Be stars including one Bep star, one HII region, one VV Cephei system, four red stars with Hα emission including one dM3–4e star, and 15 red stars with no apparent emission. Six of these red stars are galactic stars. The high percentage (36%) of stars with no Hα emission emphasises the need for secondary observational material when working in the spectral region around Hα where the spectra of red stars are by no means smooth.

Planetary Nebulae

The planetary nebulae are the most widely observed subgroup. Within the main surveys for planetary nebulae, the dominant method of discovery is identification of the [OIII]λ5007, 4959 lines on an objective-prism plate. The high number of candidates rejected through follow-up spectroscopy (see review by Morgan 1997) shows that secondary plate material is important in eliminating spurious identifications from the initial candidate lists.

It is interesting to compare the results of the [OIII]λ5007-based UKST SMC Survey (Morgan 1995) with the Hα-based survey of Meyssonnier & Azzopardi (1993). The main difference lies in the large number of VLE (very low excitation) objects listed with the planetary nebulae in the latter survey. Many are previously identified VLE objects which, with some of the newly identified objects (Meyssonnier 1995), are known to have significant continua and are usually considered to be some kind of young emission nebula or peculiar emission-line star. So, excluding these, the Hα survey has 50 objects and the UKST survey has 39. Nine of the 11 absent from the latter survey have published slit spectra (Meyssonnier 1995). Seven of these have [OIII]λ5007/H$\beta < 2$ and all nine except one are faint. The bright exception has [OIII]λ5007/H$\beta = 0{\cdot}27$ and although the remaining two have [OIII]λ5007/H$\beta > 2$, they are very faint. It is therefore clear that some planetary nebulae of very low excitation are missed at the faint limit of [OIII]λ5007 searches. The loss here is ∼20%.

There is no deep Hα-based planetary nebula catalogue for the LMC, but the need for one can be assessed from Figure 1, which shows the line ratio [OIII]λ5007/Hα as a function of log(Hα flux) for those LMC planetary nebulae with published spectra and Hβ fluxes. The source catalogues are based on detection of the [OIII]λ5007, 4959 lines, and the figure shows an absence of low excitation nebulae from the fainter population. An Hα survey would fill this, as it did for the SMC.

4 Current Work

Some work has been started using Hα filters with CCD detectors on large telescopes (see Azzopardi 1993). These systems cover very small areas and are designed to produce highly detailed surveys of emission-line stars and small planetary nebulae in selected areas around objects such as clusters and associations.

Another ongoing survey is by Smith (1998, present issue p. 163) which uses several interference filters including Hα in conjunction with a CCD detector on the Curtis Schmidt Telescope. The survey covers most of the central parts of each Cloud, but, at 3 arcsec resolution, it is designed for extended objects and is not ideal for point sources. It remains to be seen how many new planetary nebulae will be discovered.

Finally, there is an interference filter CCD survey by Dopita et al. (private communication) of a significant part of the centre of the LMC, which is expected to generate significant numbers of planetary nebulae too faint to be seen in the UKST surveys.

5 Use of New Filter

It is clear from the foregoing that an Hα survey of the LMC is needed to identify the many emission-line stars fainter than the 14·5 mag limit of the BE survey, to detect the low excitation planetary

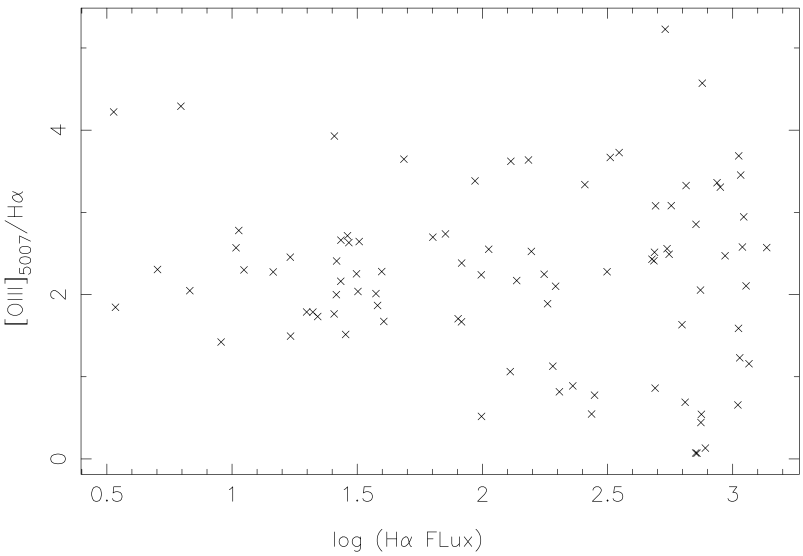

Figure 1—Line ratio [OIII]λ5007/Hα versus log(Hα flux) for LMC planetary nebulae. The unit of flux is 10^{-15} erg cm^{-2} s^{-1}.

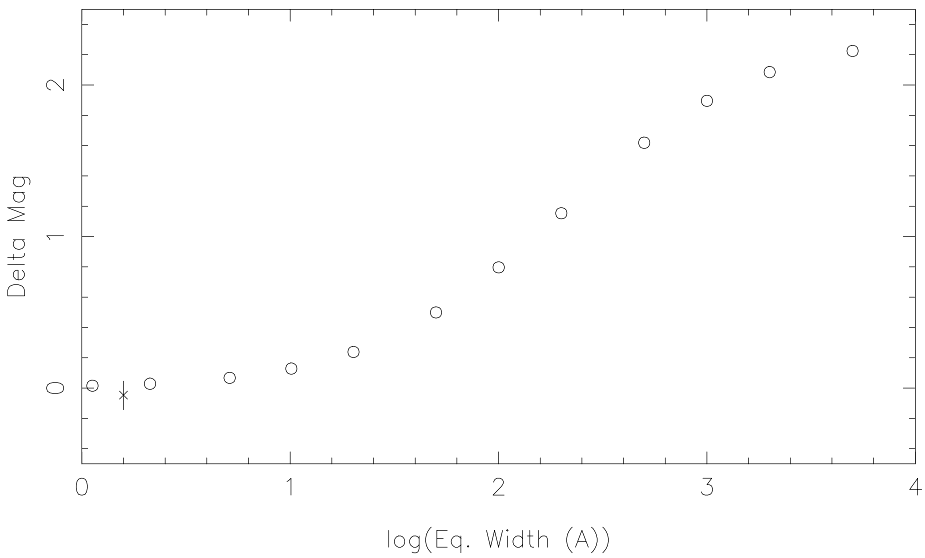

Figure 2—Change in difference in magnitude between an Hα-emitting star and a neighbour seen when comparing an Hα film with an SR survey plate, assuming both spectra to be flat and smooth. The point at 0·2 on the abscissa is the mean and range of magnitude differences between real stars in the SR and Hα bands, also normalised to a flat spectrum (see text).

nebulae not seen in the published [OIII]λ5007-based surveys, and to extend the planetary nebula searches to fainter limits. Some, but not all, of this is in progress with the CCD surveys mentioned above. The UKST is still the best telescope for obtaining complete surveys of the Magellanic Clouds because of its large areal coverage.

An Hα survey for emission-line objects cannot be done with the UKST and its objective prisms because the best dispersion available at Hα is 2050 Å/mm which is many times poorer than that used in the other surveys. Nor does combining the new filter with this objective prism help because that would produce almost circular images of ~2 arcsec in diameter in which no useful continuum would be discernible. What can be done is to use SuperCOSMOS or another plate measuring machine to measure direct on/off-band images in Hα and to search the data for objects that are bright on the Hα image. With the very crowded fields found in the MCs, the best method of analysis is not to use the object catalogues created by standard image deblending software, but to subtract one film or plate from another in pixel space using software similar to that used by Knox et al. (1998) to coadd plates. This is now a practicable proposal with the large amount of computing power available. One difficulty is that there is no suitable wide-angle off-band filter available at the UKST. Nevertheless, the work can be done using the SERC SR Sky Atlas plates, which include Hα but have a passband ten times wider than the new filter. With this method, the SR plate is not at the same epoch as the Hα plate and comparison of the two will reveal variable stars as well as emission-line objects. This problem can be minimised by using the other UKST SR plates that are available for each Magellanic Cloud field but are not part of the official SR Sky Atlas, and also by using the SERC I Sky Atlas plates, which will in turn be useful for selecting the planetary nebulae which are usually invisible in I and for identifying red stars. Ideally, a contemporaneous red exposure should be made on TechPan emulsion. This will achieve a better match in depth and resolution to the Hα exposure and will eliminate the problem caused by variable stars.

The increase in brightness caused by adding an emission line to a star with a flat spectrum (in λ-space) will be much greater on a plate taken through the new Hα filter than on the SR Sky Atlas plate, and this difference increases as the equivalent width (W_α) of the line increases, reaching a limit of 2·33 mag. This is shown in Figure 2. Thus, if 0·1 mag is a realistic photometric detection limit, it is expected that stars with $W_\alpha < 10$ Å will be detected. However, real spectra are not flat and smooth. The point at 0·2 on the abscissa of Figure 2 is the mean and range of magnitude differences between real stars in the SR and Hα bands, similarly normalised to a flat spectrum, for 16 spectra taken with FLAIR of stars in the spectral type range B2–M3. These differences are small and mostly negative (i.e. in the opposite sense to the effects of adding an Hα emission line). Typical Hα equivalent widths for emission-line stars are 30–60 Å, with a significant number rising to several hundred Å (see Morgan et al. 1992) and are clearly much larger than the limit set by the expected photometric errors and the effects of spectral type in normal stars.

Once the survey is photometrically calibrated, it can be used for providing large numbers of Hα fluxes for the planetary nebulae. To date, most of the brighter planetary nebulae have published Hβ and [OIII]λ5007 photometry, but this is just a third of the whole population. Leisy et al. (1997) have used the SERC J Sky Atlas to provide B_J broadband magnitudes for all the LMC planetary nebulae, but these objects are extremely faint (14–21 mag) in the broad B_J survey waveband, with respect to the neighbouring population. In relative terms they are many times brighter and consequently easier to measure in Hα light. These data could be used to extend many of the evolutionary diagnostic diagrams and provide a check on the interstellar reddening, which could be subject to errors of wavelength-dependent light loss in standard slit spectroscopy.

The principal uses of a large catalogue of early-type emission-line stars are twofold: (1) it will allow the delineation of structures of star-forming regions, and (2) it will be a source of many interesting objects that can be identified by comparing it with data from other wavebands (e.g. X-ray) or photometric colours. One example is the symbiotic star population, which is still very small (Morgan 1992). Its importance in the Magellanic Clouds has been to provide absolute luminosities for the cool donors which, for the larger Galaxy population, are uncertain because of the unknown stellar distances. The Magellanic Cloud objects identified to date are bright giants probably on the AGB, but this could be a selection effect. It is important to search for fainter symbiotic stars. The MA survey yielded 59 candidate red stars with Hα emission, most of which still need to be observed in greater detail. An LMC survey would produce proportionately more.

A particularly useful approach would be to add the pixel maps of several exposures on the same centres to provide images that are much deeper than are available now, matching the depths reached by CCDs and extending over much larger areas.

6 Conclusions

Past Hα surveys carried out using objective-prism plates have been the source of many interesting stars and nebulae. The UKST does not have the facilities to carry out a useful Hα-based objective-prism survey, but it can carry out a high-resolution survey for emission-line stars and small nebulae using pairs of direct images taken on TechPan emulsion through the new Hα filter and the existing standard survey filter. These will be measured using SuperCOSMOS and pixel maps will be compared to reveal objects bright in Hα. It is expected that such a survey of the LMC will identify faint, low-excitation planetary nebulae that are too weak in [OIII]λ5007 to have been identified on IIIa-J objective prism surveys, and will generate a catalogue of emission-line stars from which new symbiotic and other composite stars can be found. Also, by extending the sky coverage to the outer parts of the LMC, new outlying Hα stars will be identified. This sort of extension can also be applied to the SMC, for which a deep modern Hα survey of its central parts has already been completed. Finally, by digitally adding several films on the same centre, new deep images will be produced from which to survey large areas of the Clouds to even greater depths.

Andrews, A. D., & Lindsay, E. M. 1964, Irish AJ, 6, 241
Azzopardi, M. 1993, in New Aspects of Magellanic Cloud Research, Lecture Notes in Physics 216, ed. B. Baschek et al. (Berlin: Springer), p. 86
Bohannan, B. E., & Epps, H. W. 1974, A&AS, 18, 47

Henize, K. G. 1956, ApJS, 2, 315
Knox, R. A., Hambly, N. C., Hawkins, M. R. S., & MacGillvray, H. T. 1998, MNRAS, in press
Leisy, P., Dennefeld, M., Alard, C., & Guibert, J. 1997, A&AS, 121, 407
Lindsay, E. M. 1961, AJ, 66, 169
Lindsay, E. M. 1963, Irish AJ, 6, 127
Lindsay, E. M., & Mullan, D. J. 1963, Irish AJ, 6, 51
Meyssonnier, N. 1995, A&AS, 110, 545
Meyssonnier, N., & Azzopardi, M. 1993, A&AS, 102, 451
Morgan, D. H. 1992, MNRAS, 258, 639
Morgan, D. H. 1995, A&AS, 112, 445
Morgan, D. H. 1997, in Wide-Field Spectroscopy, ASSL 212, ed. E. Kontizas et al. (Dordrecht: Kluwer), p. 161
Morgan, D. H., Watson, F. G., & Parker, Q. A. 1992, A&AS, 93, 495
Smith, R. C., & the MCELS team 1998, PASA 15, 163