UNIVERSITY COLLEGE LONDON

University Of London Observatory PHAS1510 – Certificate in Astronomy, 1213.01

PHAS1510-09: Emission-Line Objects in the Large Magellanic Cloud

Name:________________________________

This is a relatively challenging practical; students should be prepared to spend up to three sessions working on it, and are not expected to answer all questions fully. (A 'generous' marking scheme is designed to take these issues into account.) You should have completed PHAS1510-07, 'Palomar Sky Survey Prints', before attempting this practical, and feel free to call on demonstrators for advice as necessary.

1 Objectives

The objective of this experiment is to 'discover' emission-line objects in the Large Magellanic Cloud (LMC), and to differentiate between their different emission spectra.

2 Items Required

You will need:

- Edinburgh Dispersion Print UR 7576P and Direct Film Print U 1152;
- light-box;
- transparent grid overlay with 5mm squares;
- masking tape (*do not use any other kinds of tape!*);
- 9× magnifier measuring graticule (or 'lupe');
- print of example spectra ('Fig. 1').

3 Introduction

The transparent 'prints' provided for this exercise are full-scale, high-quality reproductions of plates obtained using the 1.2-m UK Schmidt Telescope (UKST) at Siding Spring Observatory, Australia, and produced by the UK Schmidt Telescope Unit at the Royal Observatory, Edinburgh. Please be extremely careful when handling these prints; hold them by the edges only, and do not touch the photographic surface. When working with them *do not write on paper resting on the prints.*

A light-box will enable you to view the prints more easily, and a transparent grid can be overlaid on the print to give a suitable x–y coördinate system for measurements. Best results will be obtained if the prints and the overlay are cleaned before use in order to eliminate as many dust particles as possible. The light-box should also be cleaned before use. Masking tape can be used to hold the print and the grid securely in place, but take great care not to damage the prints.

Note that these prints are, of course, negatives – stars show up black. The brighter the object, the larger is the object image on the print.

4 The Large Magellanic Cloud

The LMC is one of the nearest external galaxies, at a distance of about 50 kiloparsecs (kpc). It is a companion, or satellite, galaxy to the Milky Way, but is nevertheless a substantial object in its own right, with a mass of about a tenth of that of our own Galaxy. It is the prototype of the class of galaxy called 'Magellanic Irregulars'. The angular size of the LMC as seen from the Earth is almost 20°, too large to be imaged on a single UKST plate.

5 The Edinburgh Prints

The original photographic images were taken on glass plates, covering $6.5^\circ \times 6.5^\circ$ of sky. The prints have North to the top, East to the left, at a scale of $67.1''$ ($1.12'$) per mm. Each plate has an identifying sequence number, and its quoted celestial coördinates correspond to the centre of the image. As can be seen from the coördinates of the pair of prints you will work with, they do not share the same centre. Instead, the bottom (southern end) of print UR 7576P overlaps with the middle of print U 1152. *The following is very important.* When examining a print, align the grid on top of the print so that the origin of the grid is exactly on the bottom left-hand corner of the exposed area and the axes of the grid are aligned with the edges of the print. Place these on the light-box and secure them lightly with masking tape.

Note that coördinates quoted in this script are in units of mm. Small misalignments between your placements of the overlays and the placement used in the preparation of this script means that differences in measurements of 1–2 mm are not unusual. Such displacements may not sound like very much, but can be quite large in the field of a strongly magnifying eyepiece!

5.1 Print U 1152 ($05^{\mathrm{h}}\ 21^{\mathrm{m}}$, $-69^\circ\ 48'$, 1950)

This image is of the central and northern part of the LMC. The long sloping 'bar' to the south of the photograph is the core of the Cloud. North and East of the bar is the conspicuous region of 30 Doradus (the LMC lies in the constellation of Doradus, the Swordfish), also called the 'Tarantula Nebula'. This is a 'starburst' region, huge star-forming complex of luminous young stars and ionized gases, which can be seen with the unaided eye.

5.2 Print UR 7576P ($5^{\mathrm{h}}\ 20^{\mathrm{m}}$, $-66^\circ\ 48'$, 1950)

This print was taken using an 'objective prism' to provide low-resolution spectra of the objects in the field. The technique used is basically just to place a prism over the telescope aperture; this prism spreads the light of stars and other objects into short spectra at the focus of the telescope. Each spectrum appears on the print as a thin

Table 1: Examples of Emission-Line Objects on UR 7576P

H II (x, y)	PN (x, y)	WC (x, y)	WN (x, y)
(163, 114)	(168, 155)	(300, 191)	(112, 122)
(107, 182)	(101, 111)	(284, 121	(112, 144)
	(187, 141)		

streak. Most stars have continuous spectra with absorption lines, but in some cases emission lines are present. Objects with observable emission-line spectra on this print of the LMC include H II regions, planetary nebulae, and Wolf-Rayet stars.

6 H II Regions and Supernova Remnants

In the surroundings of luminous, hot, young stars the interstellar medium (ISM), composed mainly of hydrogen gas, becomes ionized (i.e., the atoms lose electrons). This *photo*-ionization occurs when atoms absorb ultraviolet radiation emitted by the star; if the absorbed photon has sufficient energy, that energy may be used to strip the electron from the atom. Astronomers habitually talk about 'H II regions' (pronounced "H-two"), meaning regions of space where hydrogen is ionized; in our Galaxy, the Orion Nebula is perhaps the best known example of an H II region.

The interstellar medium can also be *collisionally* ionized, by the expansion of the shell of a supernova, which generates a shock wave as it passes through the ISM. Many of the ionized regions in the LMC are supernova remnants (SNRs) – some have been confirmed as such from their radio emission, while others are inferred from their shell-like structure, which may be seen on the print.

Even without magnification, it is immediately obvious that there are many nebulous structures on the direct film, each appearing to have two, three or more images on the objective-prism print. These multiple images reflect the emission-line spectrum of the nebula, with each image displaced according to the wavelength of the corresponding emission line in its spectrum. Look at the examples of ionized regions in the large-scale print of illustrative spectra (hereinafter 'Fig. 1'). The x–y coördinates of these examples are given in Table 1, in the order that they appear in Fig. 1.

The longer-wavelength end of the spectrum* lies close to the true position of the direct image (because prisms refract red light less than blue light). Many emission lines appear in the spectra of individual H II regions, but there are some that are characteristic of all such regions. These lines are included in Table 2.

Hα, in the far red, is generally the most prominent feature. Moving leftwards (i.e., to shorter wavelengths), the next two distinct lines are [O III] and Hβ. (The square brackets around O III and other emission lines denote 'forbidden' lines – i.e., lines produced by a transition with a very low probability of occurrence under laboratory conditions. Such lines are actually reasonably common under astrophysical conditions.) Although [O III] and Hβ are close together, they are readily recognised as two separate features. The [O III] feature consists of two lines are so close in wavelength that cannot quite be resolved on the prints. Instead, the feature appears elongated. As is shown in Fig. 1, H II regions are further characterized by a faint continuous spectrum underlying the prominent emission lines mentioned above.

*On the print the orientation is such that this is the bottom part of the spectrum.

Table 2: Typical Strong Emission Lines

Emission Line	Wavelength (nm)	H II?	PN?	WN?	WC?
Hα	656.3	✓	✓	✓ *	✓ *
C IV	581.0	...	...	...	✓
[O III]	500.7, 495.9	✓	✓	...	...
Hβ	486.1	✓	✓	...	...
He II	468.6	...	...	✓	✓ †
[O II]	372.7	✓	...	...	...
N IV	348.2	...	...	✓	...
O IV	341.0	...	...	...	✓

*He ii 656.3
†He II 468.6 + C III, IV 465.0

7 Planetary Nebulae

Planetary nebulae were originally given their name on account of their telescopic appearance, which showed extended disks instead of point-like stellar images. The name is now widely applied, even though the nebula may not have a 'planetary' appearance.

The best-known planetary nebula is the Ring Nebula, in the constellation Lyra, which looks like a ring surrounding a faint central star. The ring-like appearance is the effect of projection on the sky of a shell or bubble surrounding the star, the result of the outer layers of the star being ejected during an earlier (red-giant) evolutionary phase. The time taken for stars to evolve from their formation to this phase is of the order of thousands of millions of years (the planetary-nebula phase is much shorter). Examples of Planetary Nebulae shown in Fig. 1 are listed in Table 1.

The central stars of planetary nebulae are too faint to be observed at the distance of the LMC on objective-prism spectra. In general, the envelope is also too small to be spatially resolved on UKST photographs. Planetary nebulae in the LMC are therefore identified by the emission spectrum of their gaseous envelope, which shows up as a series of emission lines, with no evident continuous spectrum. Since the object is very small, the lines in the spectrum take the form of small dots, one at the position of each emission line. The spectrum of a planetary nebula and an H II region have many lines in common (both are regions of photoionized gas), but the [O III] and Hβ lines appear smaller in a planetary nebula (and may therefore be better resolved spectrally). These lines are listed in Table 2.

8 Wolf-Rayet Stars

Wolf-Rayet (WR) stars are named after the two French astronomers who discovered them. They are very hot, luminous stars, which show broad, strong emission lines in their spectra. WR stars, of which 200 or so are known in our Galaxy, have strong lines of ionized helium in their spectra, accompanied by lines of doubly and triply ionized carbon, nitrogen and oxygen. Hydrogen, though the most abundant element in normal stars, is usually absent in the spectra of Wolf-Rayets. This is explained in terms of the stars' evolution. In the first phase of the evolution of massive stars, hydrogen is converted into helium by nuclear fusion in the star's interior, with modifications to the abundances of other elements according to the particular nuclear processes involved. Meanwhile, the outer layers are carried off by 'stellar winds', exposing the helium-rich inner layers.

These stars were originally very massive (up to $\sim 100 M_{\odot}$) and therefore cannot be very old, since massive stars evolve very rapidly. Wolf-Rayet stars are individually no more than a few million years old. Such young objects belong to the age group known as 'Population I' (whereas planetary nebulae are 'Population II' objects).

Wolf-Rayet stars are subdivided into types WN and WC according to the relative importance of lines of nitrogen or carbon in their spectra (helium which is common to both types). Both varieties are found in the LMC. Examples of these can be seen in Fig. 2, with x–y coördinates given in Table 1.

It should be noted from Table 2 that the pattern of lines in the spectra of Wolf-Rayet stars is quite different from that in planetary nebulae and H II regions. Unlike planetary nebulae, Wolf-Rayet stars have an underlying continuous spectrum, which is another distinguishing feature. WC stars are more easily detected than WNs. This is because the emission features in WCs appear stronger than those in WNs compared to the continuum; the emission lines in some WN stars can be relatively difficult to see against the strong, continuous spectrum.

The main difference between WC and WN stars is the prominent presence of the C IV line in WC spectra. Another difference is, in WN spectra, the He II line is a single feature, whereas in the WC spectra, the 468.6 nm He II line is broadened by the very close presence of the C III and C IV lines. The O IV line is sometimes difficult to detect in WC stars.

9 Clusters

Galactic (or open) clusters are small groups of ∼ten to a few thousand gravitationally bound Population I (young) stars, found in or near the plane of the Galaxy. Globular clusters are gravitationally-bound groups of $\sim 10^5$–10^6 older Population II stars, symmetrically shaped and found in the halo of the Galaxy. In the Milky Way galaxy, there exists a clear-cut distinction between open clusters and globular clusters. No such dichotomy is observed for star clusters in the LMC, which contains a class of populous clusters that have no Galactic counterpart. The fact that the Milky Way does not contain supergiant H II regions like 30 Doradus shows that it does not presently form young clusters as rich as the populous clusters in the LMC.

In the LMC, globular clusters containing young stars appear very bright, and can be spatially resolved. The older globular clusters contain fainter stars that can barely be resolved from a fuzzy patch.

10 Supernovae and their remnants

Enlargements of direct photographs of a small area of the LMC where a famous supernova, SN1987A, occurred are available for inspection on request. The lower photograph shows the supernova, close to the 30 Doradus nebula. On the other photograph, taken from film U1152, an arrow marks the same star before it developed into a supernova.

A supernova creates a supernova remnant: an expanding gas cloud produced from the ejected layers of the star. They usually appear as roughly symmetrical – like many planetary nebulae, but less dense.

The N70 nebula is a probable supernova remnant which is visible on the transparencies. However, it is thought not to be solely a supernova remnant, but also incorporates a ‘superbubble’ of hot interstellar gas generated by a cluster of hot, massive stars. Their radiation ionized the gas to form an H II region. There is controversy over how the region became so big. One theory suggests that the bubble expanded under the influence of stellar winds of the hot, massive stars and was then ‘shocked’ by one of them going supernova. The supernova explosion would have vastly increased the expansion rate of the bubble, blowing it out into a superbubble.

11 References

1. Freedman, R.A. & Kaufmann, W.J., *Universe,* 7th edition; Chapters 5 (especially §§5–6 – 5–8) and 22 (especially §22–3, 22–7, 22–10).

2. Zeilik, M. & Gregory, S. *Introductory Astronomy and Astrophysics*, (4th edition). The 3rd edition, by Zeilik, Gregory & Smith, is very similar.

1. Find a young globular cluster on the direct print, U1152. Give its x–y coördinates and sketch it. (Remember: whenever you make a sketch, be sure always to include a scale, orientation, and identifying label.)

2. Find an old globular cluster (cf. section 9). Give its x–y coördinates and sketch it.

3. The coördinates of N70 are $x, y = (57, 231)$ (cf. section 10). Find and sketch it.

4. Measure its diameter in mm, then use the given plate scale and distance to the LMC to calculate its diameter in parsecs.

   The measured expansion rate of N70 is around 70 km s^{-1}. Estimate the age of the nebula, *and* the uncertainty in your result.

5. Examine the UR 7576P transparency carefully. In the table provided on the next page, classify the emission-line objects at (or very near) the given x–y coördinates as H II regions, planetary nebulae, or Wolf-Rayet stars; in the case of Wolf-Rayet stars, classify them as WN or WC types. (All objects listed are spatially unresolved, and therefore appear as point sources.)

   This is the major part of this practical; as a guide, you should expect to spend a full session on this question. Significant effort may be required to locate and classify some objects, and you may find it difficult to distinguish between emission-line spectra and overlapping 'ordinary' stellar spectra. Examination of the direct print, U1152, may help in such cases. *Do not spend too long searching for, or deliberating over, a particular object – go to the next on the list if you are stuck, going back to re-examine troublesome objects when you have developed some experience.*

   Full marks can be achieved for correct classification of $\sim \frac{2}{3}$ the objects in this list, although you should attempt classification of as many as possible. In each case, you should include a sketch of the observed spectrum. In this case, exceptionally, you may omit scale and orientation, but it is important that all sketches are to a consistent scale to allow direct comparison between one sketched spectrum and another.

Classification Table

x	y	Classification	Sketch	Comment
41	**145**			
52	**6**			
88	**31**	**WC**		**v. diff (crowded!)**
104	**10**	**WC**		
104	**27**			
110	**10**	**H II**		**(spatially resolved)**
111	**82**			
119	**135**			
124	**130**			
125	**57**			
140	**60**			
145	**80**			
150	**78**			
163	**159**			
174	**87**			
242	**116**			
245	**68**			
254	**6**			
273	**104**			
281	**60**			
283	**78**			
291	**36**			
292	**34**			
293	**186**			
295	**29**			
297	**126**			
302	**24**			
310	**13**			
315	**168**			