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Scientific Background to the UKST Hα Survey

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Abstract: The dominant process in the evolution of spiral galaxies like our own is clearly the formation of new stars, and the leading optical indicator of this is Hα emission. Considering the tremendous importance of star formation and its variation within and between galaxies, it is surprising just how little survey work has been carried out at Hα. After the successful development of Tech Pan films for deep photographic imaging with the UKST, and given the particular sensitivity of Tech Pan at wavelengths near Hα, it was natural to consider the possibilities for a narrowband Hα imaging survey of large angular extent. This idea quickly developed into a full-blown survey of the whole of the Southern Milky Way, of the Magellanic Clouds, and of selected extragalactic regions of interest such as that around the Virgo Cluster. This special issue is devoted to the discussion of the details of making and using this survey.

Keywords: surveys — stars: formation — ISM: atoms — HII regions — galaxies: general

1 Introduction

Why is Hα so important and useful to astrophysics? It provides a sensitive tracer of ionised hydrogen and thus of star formation, especially that of massive stars. To understand why this is so, it is useful to outline the recombination processes which follow the ionisation of hydrogen by ultraviolet photons from such stars. These are summarised in Figure 1.

Since all the Lyman photons are re-absorbed and so are reprocessed, every ionisation eventually gives a Balmer photon. Nearly half of these photons are in the Hα line, which is thus an excellent tracer of ionisation and thus of star formation.

Why is star formation so important? It is the dominant process in the present-day evolution of spiral galaxies such as our own and presumably of the past evolution of old ellipticals. It is thus of great concern to astrophysicists who study (a) galaxies; (b) the interstellar medium, whose properties are largely determined by the effects of massive O and B stars; and (c) stellar evolution.

2 Expectations of the Survey

2.1 The Galaxy

The Galaxy is, of course, the spiral in which we can study the star formation process in most detail. Much of this star formation occurs within the dense parts of molecular clouds and complexes and may proceed as a result of instabilities within the cloud or may be triggered by energetic events near the cloud as discussed briefly below (Section 3).

The spatial extent and detailed morphology of the resulting HII regions, OB associations and the wide variety of structures—shells, rings, holes, loops, bubbles, filaments, superbubbles, supershells, supergiant shells, arcs or cavities (Tenorio-Tagle & Bodenheimer 1988)—can be well studied via Hα imaging (e.g. Rodgers et al. 1960; Brand & Zealey 1975). Because of their proximity, these structures can present very large angular sizes; Barnard's Loop (probably the first structure detected in Hα imaging of the Galaxy) subtends 13° (Pickering 1890), and the Gum nebula is even larger. More distant complexes or groups of HII regions, such as NGC 6334, are still of the order 1° across, yet present fine detail on arcsecond scales in Hα images (Meaburn & White 1982). Given the interaction of these structures with their larger-scale environment (Tenorio-Tagle & Palous 1987), it is clear that photographic techniques are still appropriate for imaging the large areas involved.

In addition, emission lines such as Hα also trace out ionised gas in general in the interstellar medium (see e.g. McCray & Snow 1979; Tenorio-Tagle & Bodenheimer 1988), again providing information on

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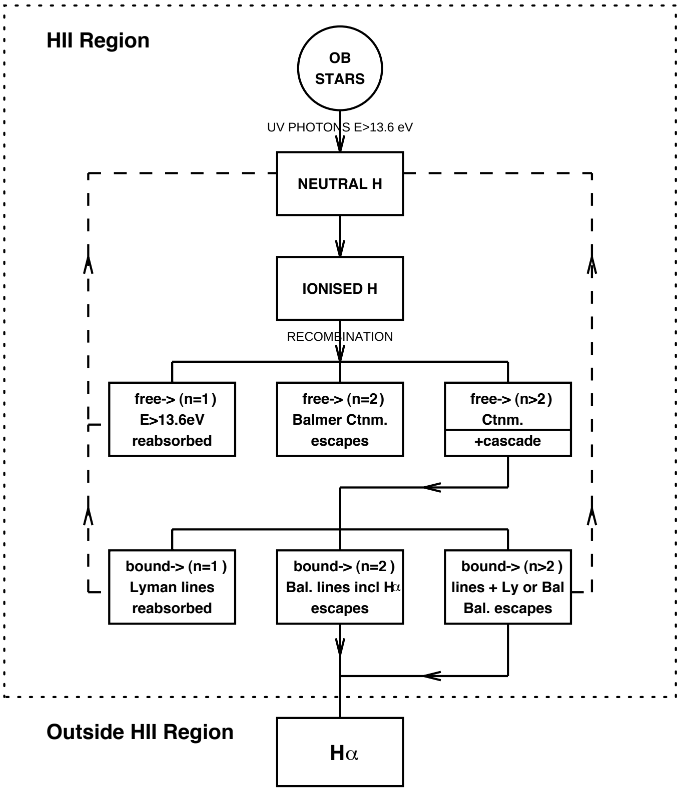

Figure 1—Balmer photons, in particular Hα, are the natural end-products of the recombination processes which occur within HII regions. In the diagram, dotted lines represent the Lyman photons which are reabsorbed by neutral hydrogen in the ground state, either within the HII region or in the surrounding ISM.

star-forming processes and the star formation history of a given region. The high efficiency of Tech Pan means that we should be able to detect the Hα background from the DIG (diffuse interstellar gas) in the Galactic Plane. Taking a strength of 5–10 Rayleigh*, which seems typical, this corresponds to about 30–60 detected photons per hour per square arcsecond for a UKST film with an assumed 50% filter efficiency and 5% film DQE.

Of particular interest on the large scale will be the comparisons between the Hα emission and the distributions of other indicators of interstellar gas and star formation activity, such as radio continuum (e.g. Phillipps et al. 1981a, b), molecular lines (Oliver, Masheder & Thaddeus 1996), neutral hydrogen (Burton 1985; Hartmann & Burton 1997), masers (e.g. Cohen, Masheder & Walker 1991), dust clouds (Hartley et al. 1986) or IRAS flux (e.g. Wouterloot & Brand 1989). Structures of interest in the context of triggered star formation would include shells of Hα, HI or CO around star formation regions or Hα seen outside CO clouds due to background ionisation.

The high resolution available to Tech Pan Hα imaging also represents a significant advance in the ability to resolve point sources from extended emission and to determine accurately the surface brightness variations in the extended regions. We will also be able to define better the sharp fronts expected around ionised gas clouds, investigate in more detail the morphology and environment of Herbig–Haro objects and search for more distant or less spatially extended examples. HH objects, being known to exhibit structural changes over timescales of years, may be studied in follow-up work.

2.2 The Magellanic Clouds

Old ‘supergiant’ shells, up to 1000 pc across, can be seen particularly well in the external, but very near neighbour galaxies, the Large and Small Magellanic Clouds (Meaburn 1980; Hunter 1994). The perimeters of these shells appear to enclose the locations of more recent star formation, which generates further SNe and stellar winds (Dopita, Matthewson & Ford 1985), so their morphology gives information on the processes by which star formation is propagated (e.g. Elmegreen & Lada 1977; Gerola & Seiden 1978). The star formation history in the Magellanic Clouds, individually or as nearby examples of irregular and dwarf galaxies, is of particular topical interest (see e.g. papers in Haynes & Milne 1991).

HII regions in the SMC, along with bubbles and SN remnants, have recently been surveyed by le Coarer et al. (1993), who emphasised the usefulness of homogeneous wide-area, high-sensitivity

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* 1 Rayleigh = $10^6/4\pi$ photons $\mathrm{cm^{-2}\,s^{-1}\,sr^{-1}} = 2{\cdot}41\times10^7$ erg $\mathrm{cm^{-2}\,s^{-1}\,sr^{-1}}$ at Hα

observations. See also the HII region catalogue of Davies, Elliott & Meaburn (1976), obtained from early UKST plates. Other discrete emission-line objects in the Clouds, such as planetary nebulae (Morgan & Good 1992), usually detected using objective prism plates, should also be easily detectable in the Hα imaging.

Clearly, too, most dynamical studies of star formation regions, in our Galaxy or the Magellanic Clouds, with their implications for the energetics of the central stars and the structure of the ambient ISM, also depend on prior deep Hα imaging. Meaburn (1980), in particular, has emphasised the advantages of being able to detect the faintest nebulosities (see also le Coarer et al. 1993).

2.3 External Galaxies

We should also be able to resolve HII structures in other galaxies. In this regard Hunter, Hawley & Gallagher (1993) have recently studied ionised gas outside normal HII regions in three or four nearby irregular galaxies. They find that the relation to current massive star formation is far from clear. Martinbeau, Carignan & Roy (1994), on the other hand, have looked at the connection between HI and Hα in an irregular galaxy, while another important relationship is that between far-infrared emission and Hα as star formation indicators (Phillipps & Disney 1988; Devereux & Young 1993). However, any conclusions at the moment are tentative at best because of the sparseness of suitable image data.

For external galaxies in general, interest is primarily in their integrated (or, if possible, spatially resolved) star formation *rate* (SFR), with the obvious implications for galaxy evolution. Again this can most conveniently be obtained from the Hα emission. The most quoted reference in this area is still that of Kennicutt & Kent (1983), which contains spectroscopic Hα measurements for just 200 galaxies. In fact their primary sample of detected normal field spirals contains just 77 objects (Phillipps & Disney 1985). Hα imaging, as opposed to spectroscopy, can clearly have great advantages in the investigation of these problems, since a Schmidt telescope can observe a very large number of galaxies simultaneously, obtaining spatially resolved images directly. CCD narrowband imaging would also be an alternative here, giving high S/N, but this is typically limited to single objects [see e.g. Aparicio & Rodriguez-Ulloa (1992) for Sextans A]. Imaging external galaxies at Hα with the UKST has previously been limited by the relative coarseness of the older emulsions but these difficulties should now be overcome by the use of Tech Pan. Besides measuring the integrated star formation rates, we will also be able to identify individual HII regions and star-forming complexes. Kennicutt, Edgar & Hodge (1989) have discussed in detail the information on the star formation process that can be derived from HII-region luminosity functions and size distributions and their positional spread across a galaxy (see also Phillipps & Edmunds 1991; Vila-Costas & Edmunds 1992).

3 The Astrophysics

Much of the interest in the survey thus hangs on questions of star formation rates and efficiencies, and the mechanisms by which star formation is triggered and/or propagated. To try to answer these questions, the first step, of course, is to collect the data with which to identify and map in detail the diverse types of star-forming regions and their wider environments. Star formation might be expected to proceed in dense molecular clouds either because of instabilities within the clouds themselves, or because of triggering by external energetic events near the cloud, i.e. by sequential or self-propagating star formation. Triggers for the star formation activity might include expanding ionisation regions around young star clusters (Elmegreen & Lada 1977), expanding stellar wind bubbles around clusters of O stars (Williams, Blitz & Stark 1995), supersonic protostellar winds or supernova shocks (McCray & Kafatos 1987). To understand the nature of star formation we therefore also need to identify and study regions where such triggering can occur. Since massive star formation leads to the production of HII regions, regions of star formation are readily located via their line emission, in particular that at Hα, which thus provides one of the most direct optical indicators of star formation.

One example of how we might proceed is given by our extant CO surveys and the opportunities for further specific, high-resolution CO survey observations. (See for example, the contribution on current λ-Orionis work by Lang & Masheder 1998, this issue p. 70.) Given the velocity resolution of the CO data, and the generally well ordered velocity field in the molecular ISM, we will have immediate access to distance estimates and hence three-dimensional positions for the star forming regions within the Milky Way disk.

Questions of Star Formation

Some major questions we might seek to investigate fall basically into either of two areas.

(1) How does star formation (SF) proceed through a molecular cloud or cloud complex? Does SF occur sporadically throughout a cloud independent of the SF history, or does it spread systematically? Especially in the latter case, is the SF via collapse of cloud cores/clumps triggered by previous activity of the types discussed in the previous paragraphs. [See Williams et al. (1995) for an excellent recent discussion of these problems with particular regard to the Rosette Molecular Cloud and neighbouring Rosette Nebula.] Once we have a catalogue of star-forming regions, we

can study their physical make-up by making comparisons between the distributions of the molecular gas (e.g. Oliver, Masheder & Thaddeus 1996; Oliver 1996), the ionised gas, as seen in Hα, and other indicators of interstellar gas and/or star formation activity, in particular neutral hydrogen (e.g. Burton 1985; Stark et al. 1992), or IRAS far-infrared flux (Wouterlout & Brand 1989). Structures that would be of especial interest include shells of Hα, HI or CO around SF regions, or Hα seen outside CO clouds due to background ionisation.

(2) Which parameters within or external to a molecular cloud determine its star formation efficiency (SFE), the fraction of the available mass which is turned into stars? Internal parameters obviously include mass, velocity dispersion and density, and the radial density profile, all obtainable from the CO meaurements. The external influences include neighbouring, or even relatively distant, ionising sources, visible in Hα, which may alter the ionisation temperature (Elmegreen & Lada 1977), and the interaction with surrounding HI envelopes (Wannier et al. 1991), since the ram pressure is comparable to the self-gravity of a typical cloud. An important point in favour of external influences would be regular gradients in SFE across complexes (Williams et al. 1995). We can obviously attempt to use the ratio of Hα to CO emission as a measure of the mass of young stars compared to the mass of molecular material, and hence of the SFE. Although precise quantitative measurements may be difficult because of extinction in the clouds, the observed ratio should certainly provide good qualitative and relative estimates of SFE.

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