Flux calibration of the AAO/UKST SuperCOSMOS Hα Survey

David J. Frew,1,2★ Ivan S. Bojičić,1,3 Quentin A. Parker,1,2,3 Mark J. Pierce,1,4 M. L. P. Gunawardhana5 and W. A. Reid1,2

1Department of Physics and Astronomy, Macquarie University, Sydney, NSW 2109, Australia
2Research Centre for Astronomy, Astrophysics and Astrophotonics, Macquarie University, Sydney, NSW 2109, Australia
3Australian Astronomical Observatory, PO Box 915, North Ryde, NSW 1670, Australia
4Department of Physics, University of Bristol, Bristol BS8 1TL, UK
5Sydney Institute for Astronomy, School of Physics, The University of Sydney, Sydney, NSW 2006, Australia

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ABSTRACT
The AAO/UKST SuperCOSMOS Hα Survey (SHS) was, when completed in 2003, a powerful addition to extant wide-field surveys. The combination of areal coverage, spatial resolution and sensitivity in a narrow imaging band, still marks it out today as an excellent resource for the astronomical community. The 233 separate fields are available online in digital form, with each field covering 25 deg². The SHS has been the motivation for equivalent surveys in the north and, new digital Hα surveys now beginning in the south such as VPHAS+. It has been the foundation of many important discovery projects with the Macquarie/AAO/Strasbourg Hα planetary nebula project being a particularly successful example. However, the full potential of the SHS has been hampered by lack of a clear route to acceptable flux calibration from the base photographic data. We have determined the calibration factors for 170 individual SHS fields, and present a direct pathway to the measurement of integrated Hα fluxes and surface brightnesses for resolved nebulae detected in the SHS. We also include a catalogue of integrated Hα fluxes for >100 planetary and other nebulae measured from the SHS, and use these data to show that fluxes, accurate to ±0.10–0.14 dex (≈25–35 per cent), can be obtained from these fields. For the remaining 63 fields, a mean calibration factor of 12.0 counts pixel⁻¹ R⁻¹ can be used, allowing the determination of reasonable integrated fluxes accurate to better than ±0.2 dex (≈50 per cent). We outline the procedures involved and the caveats that need to be appreciated in achieving such flux measurements. This paper forms a handy reference source that will significantly increase the scientific utility of the SHS.

Key words: techniques: photometric – astronomical data bases: miscellaneous – ISM: general – H II regions – planetary nebulae: general – ISM: supernova remnants.

1 INTRODUCTION
The AAO/UKST SuperCOSMOS Hα Survey (SHS; Parker et al. 2005, hereafter Paper I) provides high-resolution, narrow-band, digital imaging data of the Southern Galactic Plane (SGP), making it a powerful tool for detecting emission nebulae over a range of angular scales from arcseconds to degrees. The survey utilized the 1.2-m UK Schmidt Telescope (UKST) at Siding Spring Observatory between 1998 and 2003. Exposures were taken through a monolithic, high specifcation interference filter with a clear aperture of 305 mm, a central wavelength of 6590 Å, a peak transmission of ≈90 per cent and a full width at half-maximum (FWHM) of 70 Å (Parker & Bland-Hawthorn 1998). This was suf cient to cover the Hα and [N ii] emission lines across the full range of radial velocities observed in the Galaxy (±300 km s⁻¹). Each SHS field consisted of a 3-h Hα Tech-Pan exposure and a matching, usually contemporaneous, 15-min broad-band (5900–6900 Å) short-red (SR) exposure taken through an OG590 filter for continuum subtraction purposes. The SHS footprint covers 4000 deg² of the SGP between Galactic longitudes, l = 210°–30°, and to a latitude, |b| ≈ 10–13°. It comprises 233 distinct but overlapping 5° survey exposures on non-standard field centres 4° apart (cf. the normal 5° spacing for UKST fields), together with 40 fields covering a separate contiguous region of 650 deg² in and around the Magellanic Clouds (Morgan, Parker & Phillips 1999). The scanned SHS data at 10 μm (0.67 arcsec) resolution are available online in digital form through the SHS

★E-mail: david.frew@mq.edu.au

1 The effective wavelength of the SR band is bluewards of the widely used R F system (II-aF emulsion + RG630 filter; Couch & Newell 1980). The colour equations of this system are outlined by Morgan & Parker (2005).
website, hosted by the Royal Observatory, Edinburgh. To date, the SHS is the only high-resolution Hα survey covering the full SGP. Earlier work by J. Meaburn and co-workers used a square multielement interference filter on the UKST, with a FWHM of 105 Å when used with the 098-04 emulsion (Elliot & Meaburn 1976), but the plates only covered limited areas of the SGP (e.g. Elliot, Goudis & Meaburn 1976; Davies et al. 1978; Meaburn & White 1982). However, the coverage of the Magellanic Clouds was relatively complete (Davies, Elliot & Meaburn 1976; Meaburn 1980), but these plates are not generally available.

The magnitude limit of the SHS is $R_c \simeq 20.5$ for continuum point sources, and has a faint sensitivity limit to diffuse emission of 2–5 Rayleighs (Paper I). This can be compared to the limit of the best Palomar Observatory Sky Survey (POSS) red plates, on the 103a-E emulsion, of $\sim 20$ R (see Peimbert, Rayo & Torres-Peimbert 1975). Both the POSS-II (Reid et al. 1991) and UKST red plates used the IIIa-F emulsion; these plates have a sensitivity limit of $\sim 10$–12 R. In comparison, sky-limited narrow-band CCD limits are at the $\sim 1$ R level (e.g. Xilouris et al. 1996), comparable to the Southern Hα Sky Survey Atlas (SHASSA; Gaustad et al. 2001) and the Virginia-Tech Spectral-line Survey (VTSS; Dennison, Simonetti & Topasna 1998). Note that the SHS coverage is over a factor of 2 larger than the equivalent northern INT Photometric Hα Survey (IPHAS; Drew et al. 2005), which only extends to $|b| \sim 5^\circ$. The new VST/OmegaCam Photometric Hα Survey of the Southern Galactic Plane (VPHAS+; Drew et al. 2014) is the southern counterpart of IPHAS, and also only extends to $|b| \sim 5^\circ$. VPHAS+ has been underway on the ESO VST telescope in Chile since the start of 2012, but will only supersede the SHS in the Galactic bulge and inner plane ($|b| \lesssim 5^\circ$) regions. For reviews of current and upcoming Hα surveys, see Paper I and Frew, Bojić & Parker (2013, hereafter FBP13).

The scientific exploitation of the SHS is still underway, as it has proven to be an excellent discovery medium for both extended nebulae and compact Hα emitters. One area of success has been in the detection of unprecedented numbers of new Galactic planetary nebulae (PNe), published in the two Macquarie/AAO/Strasbourg Hα (MASH) catalogues (Parker et al. 2008; Kronberger et al. 2010) and when combined with recent IPHAS discoveries (e.g. Mampaso et al. 2009, 2010; Cappa et al. 2011), and other significant contributions (e.g. Jacoby et al. 2010; Kronberger et al. 2012), have pushed the currently known Galactic population up to more than 3200 PNe (FBP13), more than double what it was a decade ago. The SHS also proved useful for finding previously uncatalogued emission features such as knots, jets and outer haloes around known PNe (e.g. Miszalski et al. 2009; Frew, Bojić & Parker 2012) and symbiotic stars (e.g. Miszalski et al. 2012), and for differentiating PNe from their mimics (Frew & Parker 2010; Frew et al. 2010; De Marco et al. 2013).

The survey has likewise been a boon for uncovering the optical counterparts of known Galactic supernova remnants (SNRs) seen previously only in the radio (Stupar, Parker & Filipović 2007a; Stupar et al. 2007b; Stupar & Parker 2009, 2011, 2012; Robbins et al. 2012). Searches by Stupar, Parker & Filipović (2008) also revealed many faint SNRs and candidate SNRs not previously recognized in the radio (see also Walker, Zealley & Parker 2001; Alikakos et al. 2012). Similarly, the survey’s potential for optical detections of SNRs in the Large Magellanic Cloud has been realized by Bojić et al. (2007) and Reid et al. (in preparation). The SHS has also been used to study star-forming regions (e.g. Cohen et al. 2002, 2007, 2011; Urquhart et al. 2007; Zavagno et al. 2007; Cappa et al. 2008; Deharveng et al. 2009; Bik et al. 2010; Murphy et al. 2010; Pinheiro, Copetti & Oliveira 2010; Russell et al. 2010), the diffuse interstellar medium (ISM; Tackenberg et al. 2013), Herbig–Haro objects and related outflows (Girart & Viti 2007; Mader et al. 1999), and circumstellar nebulae around massive stars (e.g. Cohen, Parker & Green 2005; Gvaramadze, Kniazev & Fabrika 2010; Stock & Barlow 2010; Duronea, Arnal & Bronfman 2013). Finally, the SHS has revealed a range of emission-line stars including WR stars (Drew et al. 2004; Hopewell et al. 2005; Miszalski, Mikolajewska & Udalski 2013), Be and T Tauri stars (Pierce 2005), cataclysmic variables (Preториус & Кигас 2008) and symbiotic stars (Boissay et al. 2012; Miszalski et al. 2013). Importantly, using the related SHS imaging data for the central region of the Large Magellanic Cloud, Reid & Parker (2006a,b) uncovered over 2000 compact emission sources, including 450 new PNe and many emission-line and variable stars (Reid & Parker 2012).

Despite these studies, the full potential of the SHS has been hampered by the lack of a clear procedure to establish a reliable, integrated Hα flux or a surface brightness for the any distinct emission structure visible on the survey. Thus we need a reliable method to transform the pixel intensity values from SuperCOSMOS microdensitometer scans (Hambly et al. 1998) of the Hα images into intensity units, which should also be consistent from field to field. Pierce (2005) and Paper I showed that the survey data have been well exposed to capture Galactic emission on the linear part of the photographic characteristic curve (e.g. Smith & Hoag 1979; Parker & Malin 1999). However, no detailed process for achieving reliable flux calibration for discrete sources on the SHS has yet been provided in the literature. To address this deficiency we extend this earlier work, so researchers can derive meaningful results from flux-calibrated SHS data as required, following the precepts outlined in this paper. The motivation for this study is to explore the viability of using the SHS imaging data to establish a reliable mechanism for Hα flux measurements. This study also attempts to address the various limitations of the base data, including the restricted dynamic range (when scanned by the SuperCOSMOS microdensitometer) compared to the inherent density range of the original photographic films (e.g. MacGillivray & Stobie 1984; Hambly et al. 2001a). The structure of this paper is as follows. Section 2 describes the limitations of the photographic survey data and Section 3 describes the flux calibration process for the SHS. In Section 4 we focus on the derivation of SHS Hα fluxes from the imaging data, and in Section 5 we undertake a comparison of the SHS fluxes with independent measurements. Our conclusions and recommendations are given in Section 6.

2 FLUX CALIBRATION OF THE SHS SURVEY IMAGES

The calibration of the SHS survey images is achieved by direct comparison of the continuum-subtracted SHS data with the matching

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2 http://www-wfau.roe.ac.uk/sss/halpha/

3 The Rayleigh (R) is a unit of photon flux (Hunten, Roach & Chamberlain 1956; Baker 1974; van Tassel & Paulsen 1975), where $1 R = 10^9/4 \pi \text{ photon cm}^{-2} \text{s}^{-1} \text{sr}^{-1} = 2.41 \times 10^{-7} \text{erg cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$ at Hα.

4 http://www.vphasplus.org/
continuum-subtracted SHASSA data (Gaustad et al. 2001) which provides narrow-band (actually Hα + [N ii]) and continuum images of the entire southern sky. The preliminary flux calibration process was described by Pierce (2005) and Paper I, and the reader is referred to the latter paper for technical details. Although SHASSA has a low spatial resolution with 48 arcsec pixels, it has the considerable advantage of being continuum subtracted and accurately flux calibrated, using a range of calibrating PNe from Dopita & Hua (1997). The zero-point calibration of SHASSA is defined by Gaustad et al. (2001) and is good to better than 9 per cent. This was confirmed using the independent data from the Wisconsin H-Alpha Mapper (WHAM; Haffner et al. 2003) Northern Sky Survey5 at 1″ resolution. The SHASSA zero-point of SHASSA was independently confirmed by Finkbeiner (2003), also using WHAM data. However, this comparison could only be done north of δ = −30° declination, the southern limit of the WHAM survey. Below this declination, the SHASSA flux calibration was extended using a cosecant law fit (Gaustad et al. 2001), and so may not be particularly reliable on the largest angular scales (≥5°). The WHAM observations are being extended to the southern sky as the WHAM-South Survey (Haffner et al. 2010), which will allow an accurate calibration of the far southern sky when it is eventually completed. Pierce et al. (2004), Pierce (2005), Frew (2008) and FBIP13 also provide independent analyses of the SHASSA data. Indeed, this work has recently culminated in the use of the SHASSA (and complimentary VTSS) data to provide accurate, integrated Hα fluxes for over 1250 Galactic PNe (see FBIP13).

In this paper we have completely redone the SHS calibration process afresh, by selecting data from the unvignetted central regions (see Fig. 2) of all 233 SHS fields (cf. Paper I). This was undertaken using the online6 16× blocked-down data for each field, which have a resolution of 10.7 arcsec pixel−1. These images provide a convenient way of working across large areas for comparison with the calibrated SHASSA data, but were not available in that format to Pierce (2005). It is important to remember that one 13″ × 13″ SHASSA field completely covers a single 5″ × 5″ SHS field, and that the SHASSA data suffer from artefacts resulting from the effects of bright stars (see Gaustad et al. 2001; and Fig. 1).

2.1 Continuum subtraction on SHS images

Each matching SR image provides an effective measure of the continuum component for each SHS field, despite including the Hα (and the adjacent [N ii]) emission lines in the bandpass. The issue of [N ii] contamination and how it can be accounted for is described in Section 4.2.1. The Hα and SR images are generally exposed to attain the same depth for continuum point sources (Paper I). However, the nature of photography and the vagaries of the observing conditions (e.g. if the exposure pairs were not contemporaneous and taken in different moon phases or if the seeing changed) mean that the SR and Hα point source depth image quality is similar, but not exactly so. Thus, it is necessary to accurately determine a continuum-subtraction scaling factor (SF) on a field-by-field basis for the continuum subtraction process to be effective. For high-dynamic range CCD exposures, the standard method for determining the appropriate SF to subtract continuum from narrow band is to compare aperture photometry for stars on both images whose exposures are normally interleaved on short time-scales. This does not work so well with the Hα plus SR film exposure pairs (Pierce 2005), often leading to under- or over-subtraction of the continuum. This produces positive or negative residuals around point sources, so care is needed (see Section 4.2).

First, the 16× blocked-down (10.7 arcsec pixel−1) Hα and SR survey images for each SHS field were obtained from the SHS website. Then, a continuum-subtracted Hα (+ [N ii]) image was created from the matching Hα and SR images in IRAF,7 using a SF, as defined in Pierce (2005) and Paper I. A range of values for the SF can be applied to the SHS data until the zero-point of the continuum-subtracted SHS survey images best match the zero-point of the equivalent SHASSA data, indicating the appropriate value to use. The accuracy of the SF is critical in order to avoid incorrect subtraction of the continuum component. Once a suitable SF has been determined, the continuum subtraction process works well, removing most of the stellar images and the diffuse continuum. Only stars that sit in regions with the strongest Hα emission have been over-subtracted, and hence appear as white spots in the image, as do any high-surface brightness knots in fainter extended nebulae.

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5 http://www.astro.wisc.edu/wham/
6 http://www-wfau.roe.ac.uk/sss/halpha/hafields_online.html
7 IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, under cooperative agreement with the National Science Foundation.
For a few fields, we adopt SF = 1, if the comparison is inadequate to determine a formal value.

For example, Fig. 1 shows four images of a 80 arcmin$^2$ region from field HAL0970, which shows H$\alpha$ emission at a range of intensities. The left image is the 16× blocked-down SHS H$\alpha$ image; the second image is the continuum-subtracted H$\alpha$ image; the third image shows this image re-binned to a resolution to match SHASSA, while the right image shows the equivalent SHASSA data. In this example, this continuum subtraction process has worked well, removing most of the stellar images and the diffuse continuum. Only the stars that sit in the strongest emission have been over-subtracted and appear as white spots in the image. Note the residuals around stars seen in the SHASSA image, and the PN M 1-46, marked with a circle.

2.2 Calibration factors

Each SHS field has a corresponding calibration factor (CF) determined by Pierce (2005), but these are not generally available to the community. Consequently, we have first re-calculated and improved the reliability of the CF for each survey field using our somewhat different approach based on the 16× binned SHS data. In addition, in fields lacking obvious large-scale emission, we have attempted to identify isolated nebulae (such as PNe) in order to provide a new calibration.

For each SHS field, we selected the corresponding SHASSA field by minimizing the distance between the respective field centres. Secondly, the 16× blocked-down continuum-subtracted images were re-binned and re-aligned to match the corresponding 48-arcsec-resolution SHASSA image using the MONTAGE toolkit (http://montage.ipac.caltech.edu/). The SHASSA image was then cropped to the re-projected and re-binned SHS image. Now, the pixel intensity counts of the re-binned SHS images can be compared directly with the equivalent pixel intensity values (in R) from SHASSA to yield the CF for that field. The MONTAGE PROJECT module also returns the average value of binned pixels, which means that the final CF, derived from the pixel-to-pixel comparison with SHASSA, applies to the original full resolution SHS image.

Large (typically 30–60 arcmin) representative areas from the normal unvignetted area of each SHS field were selected and matched to give a robust calibration for each field. We emphasize that these regions were generally available for calibration, due to the large field-to-field overlap of the survey. This known vignetting from the H$\alpha$ filter was the original motivation for the SHS field centres being placed on a 4′ grid rather than the standard 5′ grid for Schmidt plates, so this problem can be avoided (see Paper I). Fig. 2 shows the blocked-down SHS H$\alpha$ image of field HAL0970 with overlaid contours of filter response at 70 per cent, 75 per cent, 80 per cent, 85 per cent, 90 per cent, 92 per cent, 95 per cent, 97 per cent and 98 per cent of peak. Selected subregions are marked by rectangles as described in the text. Those numbered 1–4 are taken from the best area of filter response and were chosen to select a range of emission line intensities. Regions 5–7 probe the edges of the field where the filter transmittance drops below 85 per cent and are not normally accessed by the online tool. The dashed box labelled ‘a’ near the field centre is for the region shown in Fig. 1. A colour version of this figure is available in the online version of the article.

If the CF determined from the comparison plot is well behaved, it is applicable to full resolution SHS data for the entire field. Unfortunately, some survey fields exhibited very little diffuse emission making calibration for these fields less straightforward. In such case a careful search for small areas of discrete, low-intensity H$\alpha$ emission in the unvignetted zone of the field was made, including any known large PNe. This enabled pixel-by-pixel comparisons between the two surveys to deliver appropriate CFs.

The process is illustrated for field HAL0970 (Fig. 2). We show the calibration plot of the selected rectangular subregions as Fig. 3. The points from each subregion are plotted as a different colour. The magenta points are from three subregions (1–3) inside the unvignetted part of the field, and the blue points represent the bright H$\alpha$ region M 17 (region 4), also located within the unvignetted part of the field. These align with the magenta points on the one trend, but show the effect of bright photographic saturation, seen above 500 R. A least-squares linear fit to the magenta and blue data points below 500 R is also plotted, with a gradient of 14.0 counts pixel$^{-1}$ R$^{-1}$. This demonstrates that if provided areas are chosen from within the unvignetted field, consistent CFs are obtained giving confidence in its applicability across the field. However, if pixel–pixel comparisons are made from the sub-regions in Fig. 3, which sample data from the vignetted regions of the field (green, red and orange points; regions 5–7), the agreement is poor and varied. The spread in counts is artificial and results from applying the flat-field correction to the underexposed areas of film.

We also illustrate the calibration plot for HAL0175, which is a field of intense H$\alpha$ emission centred on the Carina nebula (Fig. 4).
First-ranked fields have a reliable CF, that, in most cases, is derived from SHS pixel data that exhibit a completely linear relation with equivalent SHASSA data over much of the data range. Such fields are considered to produce the most reliable results. Fields ranked two indicate non-linear pixel relations between the SHS and SHASSA and/or are from SHS fields that exhibit relatively poor dynamic range or suffer from photographic fog. These fields nevertheless do have a reliable CF, and should still produce a good calibration. Rank three is assigned to fields without a reliably estimated CF and displays one or more of the following anomalies: early saturation at the bright (large intensity) end of the data’s dynamic range, small dynamic range, either due to the absence of diffuse Hα emission, or a consequence of elevated levels of photographic fog. For the rank three fields we applied a default value for the SF of 12.0 ± 3.0 counts pixel$^{-1}$ R$^{-1}$.

The comparison plots for six well-behaved first rank SHS fields are shown in Fig. 5. Here an essentially linear pixel-intensity relation can be seen between the SHS and SHASSA data and the linear fits are overlaid. A further six fields with some caveats are illustrated in Fig. 6. In Fig. 6, we show the comparison plots for six second-ranked SHS fields, which have linear fits that are not as precise as the first-ranked fields. In the case of HAL1018, subtle changes in the [N II]/Hα ratio across an ionization front in the large H II region IC 2177 will produce a variable ratio of SHS counts R$^{-1}$ across the nebula. Furthermore, in other fields, discrete but widely separated H II regions may occur in areas of the filter response that vary at the 2–3 per cent level. HAL0137 is such a case, where the slight inconsistencies around the linear fit seen are due to the slightly varying filter response in different areas of the field where the discrete H II regions occur. HAL1150 is an example of a field with a limited intensity range of emission, while the other fields show varying levels of photographic fog (Tritton 1983), which restricts the dynamic range of these survey exposures.

These various effects can conspire to produce a formal fit with apparent curvature, or the appearance of two or more closely spaced trends on the calibration plot. These effects are usually small however, and should not compromise the utility of the fit in these SHS fields. The CFs determined from the linear fits can be applied with some confidence to the full (0.67 arcsec) resolution pixel data for the relevant survey field.
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Figure 5. SHASSA-SHS pixel-by-pixel comparison plots for six first-ranked SHS fields. Some SHS fields (e.g. HAL0350, HAL0482 and HAL0555) show evidence of saturation where the intensity exceeds $\sim$500–600 R. Below this level, most fields show a linear relation between the SHASSA and SHS. Note that fields HAL0134 and HAL1060 show evidence of photographic fog, which elevates the sky level on these SHS fields.

Figure 6. SHASSA-SHS pixel-by-pixel comparison plots for six second-ranked SHS fields. The slight inconsistencies around the linear fit seen in HAL0137 are due to the slightly varying filter response in different areas of the field where the discrete H$\alpha$ regions occur. HAL1150 is an example of a field with a limited intensity range of emission, while the other five fields show varying levels of photographic fog.

The full sky coverage of the SHS is illustrated in Fig. 7, where the quality flag for each field is colour-coded. Note that the third-ranked fields are essentially devoid of diffuse H$\alpha$ emission. Fig. 8 shows the CF distribution for 170 fields (of 233) that could be fit with a linear function. The distribution of the first-ranked fields has a mean value of $11.9 \pm 2.9$ counts pixel$^{-1}$ R$^{-1}$ (1σ dispersion), while the second-ranked fields have a mean $12.2 \pm 3.2$ counts pixel$^{-1}$ R$^{-1}$.

The weighted mean is $12.0 \pm 3.0$ counts pixel$^{-1}$ R$^{-1}$, which can be used as a default value for those fields without a formal CF determination. This approach then provides a direct mechanism to determine H$\alpha$ fluxes for individual emission structures not resolved by SHASSA, including, for example, many new compact PNe discovered from the SHS data (Parker et al. 2006; Miszalski et al. 2008).
Figure 7. The sky coverage of the SHS in equatorial J2000 coordinates (note the truncated RA and DEC coordinates). The green, amber and white boxes represent first-, second- and third-ranked fields, respectively, and the field numbers are given. A ‘clickable’ version (though without colour-coding) is available on the SHS website. A colour version of this figure is available in the online version of the article.

Figure 8. Histogram of derived CFs for 170 SHS fields. The green and orange bars represent the numbers of first- and second-ranked fields, respectively. A colour version of this figure is available in the online version of the article.

3 THE LIMITATIONS OF THE SHS SURVEY DATA

As previously mentioned not all SHS fields provide reliable flux measurements. Some fields are also naturally devoid of extensive Hα emission, especially those at higher Galactic latitudes. In these cases it can be problematic to find unvignetted areas with emission features that demonstrate sufficient dynamic range to provide a large enough lever-arm for a reliable calibration. Unlike CCD data, photographic exposures have a limited linear response and saturate at a photographic density\(^8\) of \(D \sim 4\) (e.g. Hambly et al. 2001a). However, the automated SuperCOSMOS microdensitometer used to digitize the photographic exposures imposes its own limitations, restricting the density range even further to \(D \leq 2\) (Hambly et al. 1998). The data scanning and calibration processes are affected not only by the relatively low dynamic range of SuperCOSMOS, but also because some Hα and SR pairs are not contemporaneous, being taken on different nights, and under different seeing conditions and lunar phase. Furthermore, these differences in exposure date may mean different hypersensitized emulsion batches were used, which may have different levels of chemical fog and speed. Some fields have a higher than average level of photographic chemical fog due to the Tech Pan films being push-processed. These factors can introduce variations in background and sensitivity from exposure to exposure within the same ‘matching’ Hα and SR pair.

Further uncertainties in the emission levels across survey fields can arise from the presence of continuum emission, night-sky auroral lines and geocoronal Hα emission as well as the effects of variable atmospheric extinction (Paper I). Ideally, all of these components would need to be disentangled to extract the true Galactic Hα emission. In practice, the geocoronal and auroral emission is considered as a low-level, temporally varying wash, which elevates the general background on each exposure to a slightly varying degree. This is considered to be less than 2 R across the SHS (Nossal et al. 2001), based on Hα data from the WHAM Northern Sky Survey (Haffner et al. 2003).

The original set of pixel-by-pixel comparison plots for selected SHS fields given by Pierce (2005), demonstrated the spread of dynamic range and linearity exhibited by the SHS data on a field by

\[^8\] The photographic density, \(D\), is the logarithm of the ratio of incident light to transmitted light through a region of a developed emulsion.
field basis. Many fields have a well-defined linear trend but some are less well-behaved due to some of the factors previously mentioned. As a consequence fields were allocated a quality flag to reflect this diversity (see Section 2.2). This is based on a fresh examination of all survey fields where each SHS field was ranked according to suitability for obtaining accurate Hα fluxes. These flags are given in Table 1. Representative samples of first- and second-ranked fields are shown in Figs 5 and 6.

In summary, 50 SHS fields (21 per cent of the total) are well constrained by a linear fit below 500 R and so have the top ranking of 1, while a further 120 fields (52 per cent) also have a linear fit, but with some caveats, and have been given a rank of 2. The 63 remaining SHS fields (27 per cent) have little diffuse emission, making the determination of reliable CFs less straightforward, primarily due to a very restricted dynamical range of emission. A default value of 12.0 counts pixel$^{-1}$ R$^{-1}$ can be safely used for these fields. For ease of use, we give the CFs for 170 SHS fields in Table 1.

4 RELIABILITY OF THE FLUX CALIBRATION

In the previous section we have established revised CFs for each SHS field. In order to demonstrate the capability of these fields to provide accurate integrated fluxes for discrete sources such as PNe, H II regions, WR shells and Herbig–Haro objects, we identified a variety of suitable calibration objects across a range of SHS fields that have independent integrated Hα fluxes from the literature, or determined by us from SHASSA measurements. This process is described below.

4.1 Selection of individual sources

The object sample chosen for this flux calibration study includes a variety of astrophysical sources exhibiting a range of angular scales and emission intensities across the full range of SHS field exposure characteristics. These should be sufficient to determine if the CFs derived in the previous section are correct. The selected objects range in angular size from a few arcsec to nearly 2$''$ across, and cover an Hα flux range of over ~7 dex. The sample comprises 88 PNe, several H II regions and Wolf–Rayet shells, and an isolated filament of the Vela SNR. For each object the SHS Hα flux is measured following the recipe described in detail below, and is either compared with the SHASSA-derived Hα flux from FBP13, or with other independent Hα fluxes from the literature where available. For the ejecta nebulae Hf 39 and Wray 15-751, the Hα fluxes, uncorrected for reddening, have been derived from the reddening-corrected fluxes and extinction values given in Stahl (1986, 1987), Hutsemekers & van Drom (1991) and Hutsemekers (1994).

4.2 Measurement process

Suitably sized Hα and matching SR images from each SHS field that contain the selected calibrating objects were either downloaded as full 0.67 arcsec pixel$^{-1}$ FITS images from the SHS website or extracted from the 16 × blocked-down data depending on the object’s angular size. The SR image was then subtracted from the Hα equivalent in IRAF using the SF provided in Table 1. This is straightforward thanks to the in-built World Coordinate System (WCS) for each field. These continuum-subtracted Hα images were then used for flux measurements.

A photometric aperture was defined to carefully enclose the entire object in IRAF, and sky background subtraction was achieved by using a suitably chosen sky annulus positioned to avoid, as far as possible, stellar residuals and other artefacts. Unlike SHASSA, the superior resolution of the full-resolution SHS data often enables the fine structures and extended haloes of most target sources to be seen. The background-corrected photometry counts were then used to measure the source Hα flux using algorithms similar to those described in FBP13. In Fig. 9 we present two examples to illustrate the fitting procedure we employ to derive sky-subtracted integrated SHS counts for our calibrating sources.

A problem often encountered is the presence of stellar residuals within the image area of extended objects. In the Galactic plane, the stellar number density is high so residuals may also be present in the immediate region surrounding the chosen calibrator (Fig. 10), making selection of suitable sky apertures more challenging. Stellar residuals can also sometimes appear around bright, saturated stars or compact emission sources in the continuum-subtracted products (Pierce 2005; Paper I). Other challenges include residuals of the same angular size or larger than some compact PNe, which partly overlap the PN image. Although these saturated residuals were removed via the same method as above, there can be some contamination of the PN emission in a few cases. Residuals were present at some level in the images of most objects, but not all intensity contributions from these were corrected. This was because the majority of the calibrating objects studied (mainly PNe) were of moderate to large angular extent and consequently their images were populated by many small stellar residuals. Correcting for such large numbers of stellar residuals is difficult and time-consuming, and in many cases the effect of these residuals is accounted for quite effectively in the sky-subtraction process.

![Figure 9](https://example.com/figure9.png)

**Figure 9.** SHS continuum-subtracted images showing the photometric apertures (solid circles) and background sky annuli (dotted circles) for three PNe: IC 1295 (left), SB 4 (middle) and the compact object JaSt 36 (right). The nominal catalogued diameter of each PN is given by the dashed circle in each panel. The images are 400 arcsec, 135 arcsec and 50 arcsec on a side, respectively, and have NE at top left.
Furthermore, recall the SR exposures also record Hα emission, which, when subtracted from the matching Hβ exposures, can lead to an underestimation of the true Hα flux. Fortunately, in most cases this process appears to be self-compensating for the addition of Hα emission by residuals, as our excellent calibration results testify (see below). These results show that the integrated fluxes seem little affected for nebulae below an intensity limit of ~7000 counts per pixel. If the contribution to the total Hα emission of a particular source from stellar residuals seems significant, we attempt to correct for this so as to provide the most accurate possible continuum-subtracted Hα fluxes. A correction was also applied in the presence of a particularly bright PN central star, or if the calibrating object is located close to a bright, saturated star or stars being embedded in the object of interest. In the case of Hf 39, the ionizing star is prominent relative to the nebula (Fig. 10). We simply measured the flux of the star with a small aperture and subtracted this from the total flux. This technique can also be applied to estimate fluxes for faint, extended PNe containing emission-line central stars (e.g. DePew et al. 2011).

4.2.1 Deconvolution of [N II] emission

Another factor that must be considered in determining accurate Hα fluxes is the close proximity of the [N II] λ6548 Å and λ6584 Å emission lines either side of Hα, which are included in the SHS filter bandpass (Paper I). This is the case for most Galactic sources of modest radial velocity. The contribution from the [N II] lines to the total signal through the filter can vary significantly among emission sources. For example, for Type I PNe (Peimbert 1978), the [N II]/Hα ratio is usually more than three and can sometimes exceed 10 (Corradi et al. 1997; Perinotto & Corradi 1998; Kerber et al. 1998; Tajitsu et al. 1999; Frew, Parker & Russeil 2006b). This must be taken into account when comparing SHS Hα fluxes with those determined independently in the literature. This can be easily done when slit spectroscopy is available as this provides the observed [N II]/Hα ratio. We have chosen calibrators that have spectra available, so the [N II]/Hα ratios are known. These are taken from the literature sources listed in FBP13, or elsewhere. The observed ratios, usually obtained from long-slit spectroscopy, are deemed representative of the whole object. This is a safe assumption in most cases, though significant internal variation across some PNe and SNRs has been observed.

The calculation of the SHS filter transmission properties is made more difficult by the blue shifting of the band pass with respect to incident angle in the fast f/2.48 converging beam of the UKST (see Parker & Bland-Hawthorn 1998). The effect was modelled by breaking down the contribution from the converging light cone into a series of concentric rings (see Paper I). The responses from each ring of the beam are weighted according to the areas of the ring and summed to generate a smeared filter response. This allows the calculation of the contributions from the [N II] lines to the total flux recorded by the survey. The reader is referred to fig. 3 of Paper I for an illustration of the modelled Hα filter transmission profile. Based on this profile, the SHS filter transmits Hα at 80 per cent and [N II] λ6548 and λ6584 Å at 82 per cent and 50 per cent, respectively. Given that the intrinsic ratio between the λ6548 Å and λ6584 Å [N II] line strengths is quantum mechanically fixed at ~3.0, the SHS filter transmits approximately 58 per cent of [N II], compared to 80 per cent transmission of the Hα flux. This gives a [N II]/Hα filter transmittance ratio of 0.725, which is the constant in equation (2).

While the filter transmission falls towards the off-axis edge of each survey field (see Fig. 2), this is not considered significant in this study due to the purposely large overlap between adjacent SHS fields on a 4° grid (Paper I). This enables the data of interest to be preferentially selected from the non-vignetted 3° 3 3° central region of an available field, where the transmission is better than 95 per cent relative to the peak. The filter transmission constant will vary at large off-axis angular distances but this is only relevant for the few fields at the eastern edges of the SHS region.

4.3 SHS Hα fluxes

The equation used to derive the integrated SHS Hα+[N II] (or ‘red’) flux is essentially the same as the expression given in FBP13. The flux in cgs units is given by

\[ F_{\text{red}} = 5.66 \times 10^{-18} \times P_3^2 \times \left( \frac{\text{SUM}}{\text{CF}} \right) \text{ erg cm}^{-2} \text{s}^{-1} \]  

(1)

where the first constant in the expression is the conversion factor from Rayleighs to cgs units and \( P_3 \) is the ‘plate scale’ of the digital SHS data (0.67 arcsec per pixel for the full resolution images, and 10.7 arcsec per pixel for the 16\( \times \) blocked-down images). The summed counts obtained from the aperture photometry procedure (SUM) need to be divided by the relevant CF taken from Table 1, in order to determine the integrated red flux in units of erg cm\(^{-2}\) s\(^{-1}\). The SHS field number can be obtained from the header of any downloaded FITS image.
The integrated Hα flux is then obtained by correcting for the contribution from the contaminant [N ii] lines (Frew 2008; FBP13) and is given by the following expression:

\[ F(\text{H} \alpha)_{\text{SHS}} = \frac{F_{\text{red}}}{K_\alpha R(\text{N} \text{ ii}) + 1} \]  

(2)

where \( R(\text{N} \text{ ii}) \) is the observed spectroscopically determined [N ii]/Hα ratio for the emission object in question (mainly PNe) and the constant, \( K_\alpha = 0.725 \), takes into account the throughput of the SHS filter. Following FBP13, the [N ii] flux refers to the sum of the \( \lambda 6548 \) and \( \lambda 6584 \) lines. If only the brighter \( \lambda 6584 \) line is measurable in a spectrum, \( F[\text{N} \text{ ii}] \) is estimated as \( 1.33 \times F(\lambda 6584) \) as the \( 6548 \) to \( 6584 \) Å [N ii] line ratio is 3:1.

The uncertainty budget for the SHS Hα flux is determined following the procedure presented in FBP13. Additionally, the uncertainty in the CF for the particular SHS field, as measured from the fit, was added in quadrature to the uncertainty in aperture intensity counts. We emphasize that the [N ii] transmission differs between the SHS and the SHASSA survey filters (70 and 32 Å FWHM, respectively), so the SHS filter passes considerably more [N ii] emission. The transmissible [N ii]/Hα ratios of the two survey filters are 0.725 and 0.375, respectively. In the original calibration of the SHS from SHASSA data (Paper I), both H ii regions and the diffuse ionized gas were assumed to have negligible [N ii] emission. However, the median [N ii]/Hα ratio for a large number of Galactic H ii regions is \( \sim 0.4 \) (see the data graphically presented by Frew & Parker 2010), which is in reasonable agreement with the average \( \lambda 6584$/Hα ratio of \( \sim 0.3 \) seen in a sample of faint H ii regions (Madsen, Reynolds & Haffner 2006a). These authors also noted that the \( \lambda 6584$/Hα ratio in the warm interstellar medium (WIM) generally increased below an Hα intensity of 10 R, approaching unity at the faintest measured intensities. Owing to these points, there is an offset of \( \sim 10–15 \) per cent in the flux obtained from using the CF values presented in Table 1. We therefore recommend that the SHS Hα fluxes given by equation (2) be increased by this factor, i.e. the logarithmic Hα fluxes should be brightnessed by 0.05 dex.

The total uncertainty on the SHS Hα flux is given by the following expression, which includes a SHASSA uncertainty term as the SHS is bootstrapped to this survey:

\[ \sigma^2_{F(\text{H} \alpha)} = \sigma^2_{\text{phot}} + \sigma^2_R + \sigma^2_{\text{cal}} + \sigma^2_{\text{SHASSA}} \]  

(3)

where \( \sigma_{\text{phot}} \) is the proportional uncertainty in the photometry measurement, \( \sigma_R \) is the uncertainty in the deconvolved Hα flux due to the uncertainty in \( R(\text{N} \text{ ii}) \), \( \sigma_{\text{cal}} \) is the calibration uncertainty for the respective SHF field, and \( \sigma_{\text{SHASSA}} \) is the known SHASSA calibration uncertainty of 8 per cent (Gaustad et al. 2001).

4.3.1 Emission measures

The SHS pixel data can also be used in the study of the WIM and low-surface brightness H ii regions on spatial scales down to 2–3 arcsec, showing fine detail that is not seen on SHASSA. For ionized hydrogen, the surface brightness, \( S_{\text{H} \alpha} \) (in R) and the emission measure (EM; in units of \( \text{cm}^{-6} \text{ pc} \)) is related by the following expression (Haffner et al. 2003; Madsen et al. 2006a; cf. Reynolds & Ogden 1982):

\[ \text{EM} = \int n_e^2 \, dV = 2.75 T^{0.9} S_{\text{H} \alpha} e^{2.25(\theta-\nu)} \, \text{cm}^{-6} \text{ pc} \]  

(4)

where \( T \) is the electron temperature in units of 10⁵ K. As before, the pixel counts can be converted into Rayleighs using the CF for the specific SHS field, and then the contribution from the contaminant [N ii] lines needs to be deconvolved from the total measured intensity to determine an Hα surface brightness or EM (see Section 4.2.1).

The resulting data have wide application to the study of the structure and ionization of H ii regions and the WIM (Reynolds 2004; Cox 2005; Sembach et al. 2000), and can be readily compared with current and planned imaging surveys at other wavelengths across the electromagnetic spectrum, particularly at radio (e.g. Green et al. 1999; Murphy et al. 2007; Norris et al. 2011; Hoare et al. 2012) and infrared wavelengths (Churchwell et al. 2009).

5 COMPARISON OF SHS Hα FLUXES AGAINST INDEPENDENT ESTIMATES

Table 2 gives our measured SHS Hα fluxes for selected PNe and other calibrating emission-line sources. The fluxes are based on our newly determined individual field calibrations. We also list the independent integrated Hα fluxes for these objects. The SHASSA Hα fluxes are primarily taken from FBP13, or measured here in the same manner, while Hα fluxes for the other nebulae are drawn from Stahl (1987), Hutsemekers (1994), Nota et al. (1995), Duerbeck & Benetti (1996), Weinberger, Kerber & Gröbner (1997), Pollacco (1999), Beaulieu, Dopita & Freeman (1999), Boumis et al. (2003, 2006), Jacoby & Van de Steene (2004), Ruffle et al. (2004), Madsen et al. (2006b), Parker et al. (2011, 2012b) and Frew et al. (2014). FBP13 showed that the uncertainties from Cappellaro et al. (2001) are substantial, so we have not used these in our comparison.

Fig. 11 presents our SHS Hα fluxes plotted against independent measurements from the literature for all 101 objects in the calibrating sample. A tight linear relation is obtained over a range of 7 dex (10 million) in integrated Hα flux. The lower panel plots the logarithmic flux difference (in the sense of SHS minus literature) against the SHS flux. Unsurprisingly, the first-ranked fields permit the measurement of the most accurate fluxes, and the accuracy is slightly less for second-ranked fields. Our fluxes show a dispersion with the literature data of 0.12 dex from first-ranked fields, and 0.15 dex for second-ranked fields. Considering the uncertainties on the literature fluxes, this translates to nominal uncertainties of 0.10 dex and 0.14 dex, respectively. Thus, photographic data, if carefully treated, are useful sources for emission-line intensities and fluxes, accurate to \( \sim 25–35 \) per cent, as seen for the flux data of Abell (1966), as reduced by FBP13.

In Fig. 12, we show the offset between the SHS and literature Hα flux plotted as a function of Hα surface brightness (in erg cm⁻² s⁻¹), in turn derived from the literature flux and the angular size of the object. The sample comprises the objects from Table 2, plus another 45 saturated PNe, including very bright PNe like NGC 3918 and NGC 2440 (Fig. 10). The fluxes for these PNe are taken from FBP13 (and references therein) and the angular diameters are from Tylenda et al. (2003), Frew (2008), or the references given in the footnotes to Table 2. The twin effects of photographic saturation and flux over-subtraction occur for the brighter nebulae with a surface brightness, \( \log (S(\text{H} \alpha)) \gtrsim -4.0 \), where an inflection point in the plot is clearly seen.

In a follow-up paper (Bojičić et al., in preparation), we will provide new Hα fluxes for all measurable PNe found in the SHS footprint that were too faint to be measured from SHASSA. These fluxes will complement the recent flux catalogue of FBP13. In particular, the new SHS Hα fluxes for faint Galactic bulge PNe will be valuable, as they can be compared with new radio continuum fluxes (e.g. Bojičić et al. 2011a,b) to estimate extinction values, or be compared with integrated fluxes in other wavebands, e.g. the [O iii] fluxes of Kovacevic et al. (2011), in order to investigate the
faint end of the bulge PN luminosity function in different emission lines (e.g. Ciardullo 2010).

6 POINT SOURCE PHOTOGRAPHY

For completeness, we give a brief account of the SHS as a provider of photometric data for point-source emitters. Each Hα and matching SR survey field has been automatically processed through the standard SuperCOSMOS photometric and image processing pipelines (Hambly et al. 1998, 2001a). These provide so-called image-analysis mode (IAM) data for detected point-source and compact non-stellar sources in each survey passband above a locally thresholded background. An image-deblending algorithm, based on areal profile fitting at image levels equally spaced in log (intensity), is also applied (Beard, MacGillivray & Thanisch 1996; Hambly, Irwin & MacGillivray 2001b). This is useful in the crowded star fields of the Galactic plane. Consequently, large catalogues of detected sources, including accurate positions, photometry and other image parameters, are provided for each field from the SHS website.9 A significant advantage of the SHS data is the ability to detect point sources that have been photometrically calibrated to CCD standards (Boyle, Shanks & Croom 1995; Croom et al. 1999). The narrow-band Hα images are also calibrated to an ‘R-equivalent’ scale.

The 3-h Hα and 15-min broad-band SR exposure times are chosen so that both reach similar depths of $R_S \approx 20.5$ for point sources (Paper I). Where an object is detected in one band but not in the other, a default value of 99.99% is given in the online IAM catalogue data for the magnitude in the missing bandpass. Positional and magnitude-dependent errors are corrected for in the data that are available through the SHS website. Photometric consistency is achieved by using the field overlap regions to establish zero-points across the survey. These corrected magnitudes provide a means, for example, of selecting point-source Hα emitters by looking for significant brightening on the Hα source compare to its SR counterpart, especially when combined with the SSS I-band photometry which effectively eliminates late-type stellar contaminants (Paper I). The IAM data were successfully used by Pierce (2005) to discover a range of emission-line stars, by Hopewell et al. (2005) who found several WO and WC stars, and in the discovery of numerous compact PNe by Miszalski et al. (2008).

Modest variations in measured IAM stellar parameters from SHS data occur as a function of field position and the resulting variable point spread function due to the effects of field rotation on the sky. This is apparent when comparing point sources taken on the long 3-h Hα exposures with the short 15 min SR exposures, and also from field vignetting, especially at large radii from the field centres. To better account for such effects requires that photometric comparisons are performed over limited 1° areas such that the true Hα emitters show a bona fide enhanced Hα magnitude compared with the continuum SR magnitude. At the bright end of the magnitude

Table 2. A comparison of our SHS Hα fluxes (in erg cm$^{-2}$ s$^{-1}$) for 88 PNe and 13 other nebulae with independent integrated Hα fluxes taken from the literature, as explained in the text. The table is published in its entirety as an online supplement, and a portion is shown here for guidance regarding its form and content.

| Name          | log(F(Hα)) (other) | Reference | log(F(Hα)) (SHS) | SHS field | Remarks |
|---------------|--------------------|-----------|------------------|-----------|---------|
| Abell 18      | $-12.00 \pm 0.09$  | FBP13     | $-11.92 \pm 0.09$ | HAL1197   | ...     |
| Abell 23      | $-11.86 \pm 0.09$  | FBP13     | $-11.82 \pm 0.08$ | HAL0526   | ...     |
| Abell 26      | $-12.24 \pm 0.08$  | FBP13     | $-12.31 \pm 0.15$ | HAL0601   | ...     |
| Abell 27      | $-12.01 \pm 0.05$  | FBP13     | $-12.01 \pm 0.15$ | HAL0602   | ...     |
| Abell 44      | $-11.49 \pm 0.10$  | FBP13     | $-11.56 \pm 0.08$ | HAL0970   | ...     |
| Abell 45      | $-11.26 \pm 0.10$  | FBP13     | $-11.35 \pm 0.15$ | HAL1060   | ...     |
| Abell 48      | $-11.58 \pm 0.06$  | FBP14     | $-11.55 \pm 0.10$ | HAL1241   | ...     |
| Abell 58      | $-12.28 \pm 0.06$  | FBP13     | $-12.32 \pm 0.11$ | HAL1333   | ...     |
| BMP J1613−5406| $-11.60 \pm 0.09$  | FBP13     | $-11.50 \pm 0.12$ | HAL0289   | ...     |
| BMP J1808−1406| $-11.68 \pm 0.09$  | FBP13     | $-11.78 \pm 0.14$ | HAL0969   | ...     |
| CGMW 3−2111   | $-12.38 \pm 0.10$  | B06, FBP13| $-12.40 \pm 0.10$ | HAL1058   | ...     |
| CVMP 1        | $-11.50 \pm 0.10$  | FBP13     | $-11.63 \pm 0.14$ | HAL0232   | ...     |
| DPV 1         | $-12.5 \pm 0.3$    | DB96, P99 | $-12.50 \pm 0.11$ | HAL0968   | Sakura’s object |
| FP J0711−2531 | $-10.69 \pm 0.04$  | FBP12     | $-10.51 \pm 0.11$ | HAL0756   | ...     |
| FP J1824−0319 | $-10.40 \pm 0.10$  | FBP13     | $-10.44 \pm 0.10$ | HAL1240   | ...     |
| Fr 2−7        | $-10.82 \pm 0.10$  | FBP13     | $-10.86 \pm 0.12$ | HAL0097   | ...     |
| G4,4+6,4      | $-11.25 \pm 0.06$  | FBP13     | $-11.31 \pm 0.10$ | HAL0878   | ...     |
| GLIP J1530−5557| $-13.86 \pm 0.10$  | PC12$^a$  | $-14.17 \pm 0.12$ | HAL0233   | ...     |
| GLIP J1537−5430| $-14.79 \pm 0.15$  | PC12$^a$  | $-14.70 \pm 0.15$ | HAL0234   | ...     |
| GLIP J1642−4453| $-14.94 \pm 0.15$  | PC12$^a$  | $-14.88 \pm 0.15$ | HAL0413   | ...     |

Reference codes: ASTR91 – Acker et al. (1991); B03, B06 – Boumis et al. (2003, 2006); BDF99 – Beaulieu et al. (1999); DB96 – Duerbeck & Benetti (1996); FBP13 – Frew et al. (2013a); FBP14 – Frew et al. (2014); H94 – Hutsemekers (1994); HDM98 – Hua, Dopita & Martinis (1998); JâSt04 – Jacoby & Van de Steene (2004); KH93 – Kistakowsky & Helfand (1993); FPR06 – Frew, Madsen & Parker (2006a); P99 – Pollacco (1999); PC12 – Parker et al. (2012b); PFM11 – Parker et al. (2011); RZ04 – Ruffle et al. (2004); S87 – Stahl (1987); SKS9 – Satchell & Kastner (1989); WKG97 – Weinberger et al. (1997); XP94 – Xilouris et al. (1994); XPPT – Xilouris et al. (1996).

$^a$ Fluxes revised using updated CFs from this work.

9 http://www-wfau.roe.ac.uk/ss/alpha/
distribution, severe saturation effects also come in to play, limiting stellar photometry to $R$ of about $\sim 12$ in both the $H\alpha$ and SR passbands. Further details are given in Paper I.

7 CONCLUSIONS AND RECOMMENDATIONS

We have established CFs (Table 1) for 170 of the 233 SHS fields (73 per cent), so these can be used directly to derive accurate integrated $H\alpha$ fluxes for a wide range of objects including PNe, H$\textsc{ii}$ regions, Wolf–Rayet shells and SNRs (refer to Fig. 11). Based on the significant number of calibrating objects we have used, we can demonstrate that our derived fluxes agree to $\pm 0.1$ dex ($\approx 25$ per cent) with independent fluxes from the literature over a remarkable range of 7 dex in integrated flux. There is a small systematic bias where SHS fluxes seem to be approximately 10–15 per cent fainter than the equivalent SHASSA fluxes. The origin of this bias is attributed to the differing filter transmission of the [N$\textsc{ii}$] lines between SHASSA and the SHS, and the fact that the original analysis assumed that the diffuse emission from the ISM was solely $H\alpha$ emission. Better agreement can be obtained by scaling up the SHS $H\alpha$ fluxes by 0.05 dex.

Determining fluxes for extended objects within the first-ranked SHS fields can be performed with confidence. For most of the second-ranked fields, the flux uncertainties are somewhat larger, though still usable. There are currently 63 relatively featureless fields in Table 1 for which we could not determine the CF. These fields either have high chemical fog levels or the fields have a poor dynamic range. This does not mean there is anything wrong per se with the exposures, just that the fields are mostly devoid of variable intensity $H\alpha$ emission making it difficult to determine the CF. Such fields may still contain significant numbers of small localized emission nebulae such as PNe. In the meantime, we use the mean CF for all first-ranked fields of 1.20 counts pixel$^{-1}$ R$^{-1}$ as a default value for fields with indeterminate values. The $H\alpha$ surface brightnesses and integrated fluxes so derived should be accurate to better than $\pm 0.2$ dex (or $\approx 50$ per cent). Many of these fields still could be used with more confidence if local CF values were established, even for fields affected by high chemical fog.

The adopted SF and CF values and rank status of each of the 233 SHS fields are given in Table 1, and is the main legacy material from this work. The SHS fields can be used not just for exploratory science and discovering new astronomical objects, but now for deriving their integrated $H\alpha$ fluxes and surface brightnesses. The SHS will remain useful for many years to come, and will be superseded by the new VPHAS+ $H\alpha$ survey (Drew et al., in preparation) only in the region along the SGP within $|b| \leq 5^\circ$. Even there, the SHS will be the source of first-epoch properties for emission-line stars and other exotica for future studies on variability.

In summary, the following notes and caveats should be considered when using the SHS data to provide $H\alpha$ intensities and integrated flux measurements.

1. The pixel data have been treated by a filter flat-field as described in Paper I. This is a one-off correction that is assumed valid for all survey fields.
2. We recommend that objects located more than 1.8 from the SHS field centre not be measured for flux if accuracy is a requirement. Excepting for the fields on the east, south and northern edges of the SHS zone, the generous overlap between field centres means that a neighbouring field should be available for flux measurement. Note that when full 0.67 arcsec pixel$^{-1}$ resolution areas are obtained from the SHS webpage using the ‘Get Image’ tool, the best data...
are automatically selected from the unvetted central region of an available field.

(3) The effect of geocoronal Hα emission should be low. Paper I found from a random sample of six SHS fields that the Earth shadow height for the whole 3-h observation and across the 5° field of view was greater than 6000 km, so low-level geocoronal emission (<2 R) is not problematic, as most fields covered by the SHS will contain significantly stronger diffuse emission.

(4) Telluric OH emission contaminates the images at low flux levels, but this is also altitude dependent and can be safely ignored.

(5) The image data are non-linear at high intensities. Photographic saturation sets in at around 500–600 R, or approximately 6000–7000 counts per pixel (for a typical CF value). Objects showing values above this, or showing ‘negative’ residuals after continuum subtraction, should be treated with caution, and the total fluxes can be considered to be firm lower limits. Consider point-source algorithms if the nebula is bright and compact.

(6) Brighter nebulae that are too extended for the application of point-source algorithms should be conspicuous enough to be detected in SHASSA. We recommend the use of this survey in such cases.

(7) Emission from the red [N ii] lines often contributes significantly to the Hα+[N ii] flux, especially for PNe and SNRs (Frew & Parker 2010; Sabin et al. 2013). This contribution needs to be carefully de-convolved from the total flux using the observed spectroscopic ratio for individual objects, and following the procedure described in Section 4.3.

(8) Owing to the different passbands of the SHASSA and SHS filters, the SHS Hα fluxes determined from equation (2) show a small systematic bias, and should be increased by an additional factor, i.e. the logarithmic Hα fluxes should be brightened by 0.05 dex.

(9) Integrated fluxes accurate to ±0.10–0.14 dex (~25–35 per cent) can be generally obtained across the 170 survey fields for which have a determined a CF, with the second-ranked fields have the larger systematic errors.

(10) A default value of 12.0 ± 3.0 counts pixel−1 R−1 can be used as the CF for the 63 SHS fields with no formal determination of this parameter (see Fig. 7). The integrated Hα fluxes for any objects derived from these fields should be accurate to better than ±0.2 dex (or ≈50 per cent). Alternatively, any unsaturated PNe or other small nebulae with an independent flux can be used to calibrate the whole field. In such cases, the CF value for the field can be treated as a free parameter and varied until the measured integrated SHS flux matches the independent value.

(11) The nature of photography and the scanning process produces a range of artefacts and spurious images on the SHS. The user should be aware of these, and can find more details in Paper I.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table 1. Data summary for all 233 SHS survey fields.
Table 2. A comparison of our SHS Hα fluxes (in erg cm$^{-2}$ s$^{-1}$) for 88 PNe and 13 other nebulae with independent integrated Hα fluxes taken from the literature, as explained in the text.

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