Abstract. Aiming to improve our understanding of the spatial distribution of Galactic H\textsubscript{II} regions we have started a program with the integral field spectrometer SINFONI on the ESO-VLT (Very Large Telescope) Yepun to observe obscured stellar clusters in H\textsubscript{II} regions. Through the detection and spectral classification of individual cluster stars we are able to obtain a complete census of the nature of the brightest stars and to obtain a spectrophotometric distance to the cluster. Such distance estimates are independent and complementary to kinematic distances and free from the ambiguity inherent to the latter’s determination. Most importantly, our method is based on near-infrared observations, which are much less limited by interstellar extinction than previous optical programmes, allowing studies along lines of sight where optical measurements are impossible.

1. Introduction

Regions of star formation are good tracers of Galactic structure, in particular of the spiral arms. Unfortunately, determinations of their distances are extremely problematic and often rely only on velocities derived from radio observations. The kinematic distances of inner Galactic objects have an intrinsic ambiguity: the H\textsubscript{II} region may be “near” or “far”. Furthermore it is based on an assumed model of Galactic rotation.

The first depiction of Galactic spiral arms [10] was derived from kinematic distances and spectro-photometric distances, the latter from visual observations of OB stars. Indeed spectro-photometric distances of OB stars may solve the ambiguity. The Georgelin’s draw lacked information about the most inner regions of the Galaxy and the far side, directions which are typically not observable in the optical because of high interstellar extinction.

Nowadays the actual number and location of spiral arms is still uncertain [21]. Furthermore, only a few young and massive clusters (the Quintuplet, Arches, and Sgr A clusters) are known to reside inside the central 3 kpc, all of them concentrated within the central 50 parsecs. In contrast to the distribution of late-type stars ([18], [12]), which shows strong signatures of a Galactic bar extending to 3.5 kpc and of a nuclear stellar disk with a radius of about 800 pc, almost all known young stellar clusters are located outside of the co-rotation radius (3.5 kpc) on quasi-circular orbits. This puzzling lack of H\textsubscript{II} regions within 3 kpc of the Galactic centre suggests a “hole” in the gaseous distribution of the inner Galaxy. However, it could be partly
due to the incompleteness in detecting HII regions along lines of sight with high interstellar extinction.

The advent of new and powerful infrared detectors opened a new era of Galactic structure studies. It is now possible to observe highly extincted HII regions at large distances from the Sun. The recent availability of large mid- and near-infrared surveys of the Galactic plane, such as 2MASS, ISOGAL, MSX and GLIMPSE has led to the discovery of several hundreds of new Galactic HII regions, e.g. [11], and candidate infrared stellar clusters. We expect to find many new candidate inner Galactic clusters with the coming UKIDSS data, a deeper near-infrared survey of the Galactic plane, and with future VISTA surveys.

Infrared follow-up studies of these stellar clusters are required in order to resolve each cluster into individual stars and to obtain stellar spectra that provide a complete census of the brightest stars and, thus, allow the determination of the spectro-photometric distance to the cluster.

The study of the clusters’ spatial distribution by combining kinematic and infrared spectrophotometric information will greatly improve our knowledge on the structure, formation, and evolution of the Milky Way.

1.1. Spectrophotometric distances of stellar clusters in HII regions.

Determination of the spectro-photometric distances to the stars exciting an HII region using infrared data appears to be a very promising way to map the Galactic structure, independent and complementary to the kinematic information, and less limited by interstellar extinction than observations at optical wavelengths.

We have compiled a list of 647 Galactic young clusters which were mostly selected by inspecting 2MASS images at the position of known HII regions by [2] and [1], [7], [8], [15], [5]. Their youth is confirmed by associated continuum emission at 1.4 GHz (NRAO VLA Sky Survey) – for 85% of them. Only for some of these clusters infrared follow-up studies already exist.

New atlases of spectra and line modeling of nearby early type stars have been recently published ([13], [20]) showing that medium resolution (R ≈ 2000–5000) spectra in H- and K-band with a signal-to-noise ratio above 100 yield a classification of early type stars consistent with that derived in the visual within 2 spectral subclasses. The near-infrared spectral classification is based on photospheric hydrogen, H, and helium, He, lines and other infrared lines such as those from carbon and nitrogen – e.g. the He I(4-3) line at 1.700 μm, the Brackett H I(11-4) transition (1.681μm), the Brγ line at 2.16μm, the NIII(2.1155μm) and CIV(2.078μm) lines, and the He I atomic lines at 2.058μm and 2.1126μm.

Luminosity classes are more uncertain, but they can be estimated from comparison with the spectra in the infrared atlases by considering the fact that the line-widths of the Brackett (Br) lines are broader in dwarf stars than in supergiants. Furthermore, supergiants have He I absorption lines at 2.161μm and at 2.1621μm in the blue wing of the Brγ ([13], [19]).

Photometric calibration of optical and infrared magnitudes of early type stars are also available, e.g. from [16] and [4] and a new consistent set has recently been published by [17].

The classification of the spectral type of a star and the measurement of its apparent magnitude with the assumption of a photospheric infrared colour and an absolute magnitude yield simultaneously an estimate of the interstellar extinction and the stellar distance. Although the uncertainty of the spectrophotometric distance to each star can be up to 20 – 30%, the accuracy of the distance to the cluster can be improved by averaging the distances to several cluster stars.

1.2. Observations with SINFONI and first results.

We have obtained observations with the Integral Field Spectrometer SINFONI [9] on the ESO-VLT (Very Large Telescope) of eight obscured stellar clusters in HII regions – in W31, W42, W43, W51 and the cluster [DBS2003]8 – in order to determine their spectrophotometric distance.
Figure 1. SINFONI K-band data of the stellar cluster W31. The mosaic was obtained with one single observing block (about 1 hour).

Figure 2. K-band spectra of 5 of the brightest stars in W31 are shown.

Figure 3. SINFONI K-band data of the stellar cluster W42. The mosaic was obtained with one single observing block (about 1 hour).

Figure 4. H-band image of the stellar cluster W43 obtained with 1 hour of observation.
The program includes observations of candidate OB stars in both the H (1.45 – 1.85 \( \mu \)m) and K (1.95 – 2.45) bands at the highest SINFONI resolution (R \( \sim \) 3000 and 4000, respectively). For each cluster, when resolved in the 2MASS K-band image, candidate stars were selected having 2MASS K < 12 mag and (H–K) > 0.6 mag – the latter constraint to exclude foreground objects. Furthermore, the targets are located near the cluster’s centre. Since high-mass stars are known to form at such locations, the selected stars are thus highly probable cluster members. Typically, 4 – 6 stars per cluster were chosen.

Why is SINFONI a suited instrument for our project? By performing integral field spectroscopy with SINFONI we simultaneously image and resolve the core of the stellar clusters and obtain spectra. Since often in one field more than one star can be measured, it is typically possible to obtain a complete census of the cluster’s brightest stars by employing a few telescope offsets in a single 1 hr observation sequence (e.g. Figs. 1,3,4). Furthermore, SINFONI enables us to detect simultaneously nebular emission (Fig. 6) (such as molecular hydrogen lines, HI recombination lines and ionized iron) and the spectrum of the candidate ionizing star, allowing us to distinguish between these contributions. Finally, the detection of Br\(_\gamma\) emission from the H\(_{\text{II}}\) region provides an estimate of the extinction to the H\(_{\text{II}}\) region when compared with radio continuum flux measurements. We have successfully detected photospheric lines in several stars of each cluster considered.

W31
W31 is a large H\(_{\text{II}}\) complex, with three main H\(_{\text{II}}\) regions. From \(^{12}\)CO and \(^{13}\)CO emission lines and NH\(_3\) absorption features, it was concluded [6] that the complex can be decomposed in two main components: one at a distance of a few kpc and the other at about 15 kpc. A spectro-photometric distance of 3.4 kpc was derived only for one cluster in the complex ([3]). We have obtained SINFONI observations for two different fields in W31. In both cases our preliminary results seem to confirm the near kinematic distance. Five of the brightest stars detected in K-band are shown in Figs. 1 and 2. Four of them have NIII and CIV lines in emission, Br\(_\gamma\), HeI and HeII lines in absorption. Such lines are typical for stars of spectral type O5 \pm 1. The profile of the Br\(_\gamma\) suggests that these are dwarfs stars. A young stellar object with the CO band in emission was also discovered.

W42
There is only one published spectro-photometric distance (2.2 kpc, [4]) for the cluster W42 which relies only on one out of the three taken K-band spectra. We have extracted 7 stars from the SINFONI datacubes detected in both H and K-bands (Fig. 3).

W43
In the cluster W43 (Fig. 4) we detected photospheric lines in several of the 13 brightest stars – 9 stars in K and 4 in H band. The census includes 1 WR star, 3 early O-type supergiants, 1 late O-type supergiants, 4 YSOs.

[DBS2003]8
Figure 5 shows the Galactic stellar cluster [DBS2003]8, successfully resolved with SINFONI. The spectrum of the central star shows absorption features at the position of the Br-gamma, Br10, Br11, Br12, Br13, and of the HeI lines at 1.70 and 2.11 \( \mu \)m. which suggest the star is a dwarf O9-B1 star. The spectral type and the determination of apparent magnitudes yield an estimate of the interstellar extinction (\( A_K = 3.1 \) mag) and a spectrophotometric distance of 2 kpc \( \pm 0.8 \) kpc. The derived distance agrees well with one of the two gas complex distances detected along the line of sight ([22]).

These are preliminary considerations, because we are currently completing the data reduction of the full dataset. A detailed study of the spectro-photometric distances will follow soon thereafter.
Figure 5. H-band image of the Galactic stellar cluster, [DBS2003]8. The cluster center is resolved and several stars are detected in both H and K band.

Figure 6. Image of the Brγ emission detected around the central star of the cluster [DBS2003]8. We also detected H2 emission, and [FeII] emission at 1.644 μm.

[1] Bica E., Dutra C. M. and Barbuy B. 2003a A&A 397 177
[2] Bica E., Dutra C. M., Soares J. and Barbuy B. 2003b A&A 404 223
[3] Blum R. D., Damineli A. and Conti P. S. 2001 AJ 121 3149
[4] Blum R. D., Conti P. S. and Damineli A. 2000 AJ 119 1860
[5] Borissova J., Pessev P., Ivanov V. D. and et al. 2003 A&A 411 83
[6] Corbel S. and Eikenberry S.S. A&A 419 191
[7] Dutra C. M. and Bica E. 2000 A&A 359 L9
[8] Dutra C. M., Bica E., Soares J. and Barbuy B. 2003 A&A 400 533
[9] Eisenhauer F., Abuter R., Bickert K. and et al. 2003 SPIE 4841 1548
[10] Georgelin Y. M. and Georgelin Y. P. 1976 A&A 49 57
[11] Giveon U., Becker R. H., Helfand D. J. and White R. L. 2005 AJ 129 348
[12] Habing H. J., Sevosten M., Messineo M. and et al. 2005 submitted to A&A
[13] Henson M. K., Kudritzki R.-P. and Kenworthy M. 2005 ApJS 161 154
[14] Ivanov V. D., Borissova J., Bresolin F. and Pessev P. 2005 A&A 435 107
[15] Ivanov V. D., Borissova J., Pessev P. and et al. 2002 A&A 394 L1
[16] Koornneef J. 1983 A&A 128 84
[17] Martins F. and Plez B. 2006 accepted by A&A, astro-ph/0606587
[18] Messineo M., Habing H. J., Sjouwerman L. and et al. 2002 A&A 393 115
[19] Paumard T., Genzel R., Martins F. and et al. 2006 ApJ 643 1011
[20] Repolust T., Puls J., Hanson M. and et al. 2005 A&A 440 261
[21] Russell D. 2003 A&A 397 133
[22] Russeil D., Georgelin Y. M., Georgelin Y. P. and et al. 1995, A&AS 114 557