Massive Young Star Clusters Near and Far: From the Milky Way to Reionization
2013 Guillermo Haro Conference, Eds. Y. D. Mayya, D. Rosa González & E. Terlevich
INAOE & AMC, June 2014. ISBN: 978-607-8379-01-9

Super Star Clusters in Luminous Infrared Galaxies: the SUNBIRD Survey

P. Väisänen[1,2], Z. Randriamanakoto[1,3], A. Escala[4], E. Kankare[5], A. Kniazev[1,2], J.K. Kotilainen[6], S. Mattila[6], R. Ramphul[1,3], S. Ryder[7], and A. Tekola[1,8]

Abstract We summarize recent results from an Adaptive Optics (AO) imaging survey of 40 Luminous IR Galaxies (LIRGs). We have constructed the first statistically significant sample of Luminosity Functions (LFs) of Super Star Clusters (SSCs) in the near-IR, and find evidence that the LF slopes in LIRGs are shallower than in more quiescent spiral galaxies. Distance and blending effects were investigated in detail paving the way for SSC studies further out than done previously. We have also correlated the luminosities of the brightest clusters with the star formation rates of the hosts and find that the characteristics of the relation suggest an underlying physical driver rather than solely a size-of-sample effect. Finally we present early results of using SSC age and mass properties to trace the histories of the target LIRG systems.

1 Introduction: the SUNBIRD survey

We are conducting a survey of approximately 40 LIRGs using AO NIR imaging with VLT/NACO, Gemini/ALTAIR/NIRI, and recently also multi-conjugate AO on Gemini/GEMS. The instruments deliver images with a spatial resolution perfectly complementing existing *Hubble Space Telescope* (HST) optical data. The sample galaxies are at $d \sim 40 - 180$ Mpc, at various stages of merging, interaction, or isolation and are also observed with optical spectroscopy at SALT/RSS (e.g. Väisänen et al. 2008a). Our survey is dubbed SUperNovae and starBursts in the InfraReD, *SUNBIRD*, for the twofold science aim: we search for very obscured core-collapse SNe close to the nuclei of star-forming galaxies for hidden Star-Formation (SF) in the local Universe (see e.g. Mattila et al. 2012; Kankare et al. 2012), and study the LIRGs themselves to have a uniform sample of local LIRGs to investigate the physical details of SF and its triggering and history as a function of interaction stage and type, environment, and metallicity (Väisänen et al. 2008a, 2012). In these proceedings we report on the galaxies themselves and in particular on their Super Star Cluster (SSC) populations which likely trace extreme forms of SF in the systems.

[1] South African Astronomical Observatory, P.O. Box 9 Observatory, Cape Town, South Africa
e-mail: petri@saao.ac.za
[2] Southern African Large Telescope, P.O. Box 9 Observatory, Cape Town, South Africa
[3] University of Cape Town, Astronomy Department, Rondebosch 7701, South Africa
[4] Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile
[5] Tuorla Observatory, Dep. of Physics and Astronomy, University of Turku, 21500 Piikkiö, Finland
[6] Finnish Centre for Astronomy with ESO (FINCA), University of Turku, 21500 Piikkiö, Finland
[7] Australian Astronomical Observatory, P.O. Box 915, North Ryde, NSW 1670, Australia
[8] Las Cumbres Observatory Global Telescope Network, Goleta, CA, 93117, USA

2 Luminosity functions of SSCs in the NIR

SSCs are ubiquitous in the AO images of our LIRGs. As a first step of the SSC characterisation we have derived the Luminosity Functions (LFs) of 10 of the galaxies in the K-band (Randriamanakoto et al. 2013a). Note that the SSC studies in the *SUNBIRD* sample concern the brightest clusters, those at $M_K < -14$ mag, or typical masses of $> 10^5\,M_\odot$. The LFs of our clusters are reasonably well-fitted by a single power law with values of the index $\alpha = 1.5 - 2.4$ with an average close to 1.9. Interestingly, this value appears to be less steep than the $\alpha \sim 2.2$ in normal spiral galaxies (e.g. Gieles et al. 2006). Fig. 1 shows the combined K-band SSC LF of the pilot sample. Correlations of the α parameter with Star Formation Rate (SFR) and other host galaxy properties are being investigated with the full sample.

Due to the host galaxy distances involved (median $D_L \sim 70$ Mpc) we investigated the effect of blending on the photometry and LF shapes using Monte Carlo simulations, as well as by repeating photometry and LF fits for an artificially redshifted Antennae galaxy system.While blending tends to flatten LFs, our analyses show that $\delta\alpha$ is less than ~0.1 in the luminosity range considered. We show that the extracted SSC luminosities are generally dominated by a single dominant stellar cluster even though the apertures we use are of 20-60 pc size (Fig. 1bc).

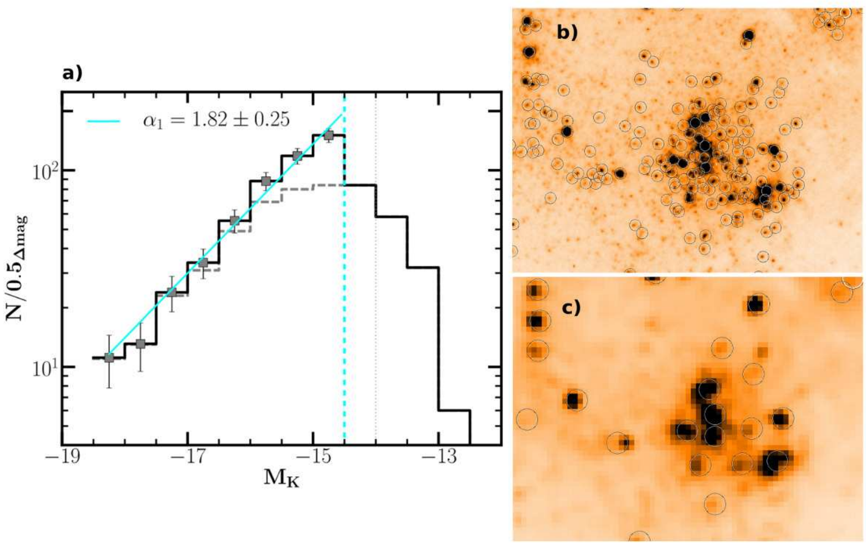

Fig. 1: Left: A combined K-band SSC LF from 10 LIRGs (Randriamanakoto et al. 2013a). Top right: A region in the Antennae system from Whitmore et al. (2010) I-band HST image. The bottom right shows the same, as it would be observed if moved 4-times further, to 80 Mpc. Only a fraction of the SSCs are detected, though the properties of the brightest SSCs remain fairly intact.

3 Magnitude of the brightest cluster vs. SFR

Many studies have shown that there is an empirical relation between the V-band luminosity of the brightest SSC magnitude and the SFR of the host galaxy (e.g. Larsen 2002; Weidner, Kroupa & Larsen 2004; Bastian 2008). We have for the first time derived the relation in the NIR (Randriamanakoto et al. 2013b), and at the same time pushed the relation to significantly higher SFRs than before. Fig. 2. shows our sample with the best-fit relation.The relation is similar to that found in the optical, though it is somewhat steeper as seen in the right panel of Fig. 2. The most simple explanation for the slope difference is a systematic color difference of the brightest SSC as a function of host SFR. This could be an age effect, or an extinction effect. Physically even more interesting is the surprisingly tight relation of our NIR relation. The intuitive size-of-sample argument for the SFR vs. $M_{brightest}$ relation states that SSC populations at higher SFRs are larger, hence it is more likely to detect brighter SSCs from a random sampling of the LF. We ran Monte Carlo simulations of random SSC populations with given LF slopes and 'observing' the brightest ones. In case of LFs in the normal range $\alpha = 1.5$ to 2.5, *and no upper limit to the LF*, the expected scatter is ~ 1 mag. The scatter in the left panel of Fig. 2 is $\sigma \approx 0.6$ mag. A natural explanation producing such small scatter would be e.g. a physical truncation in the LFs at the bright end.

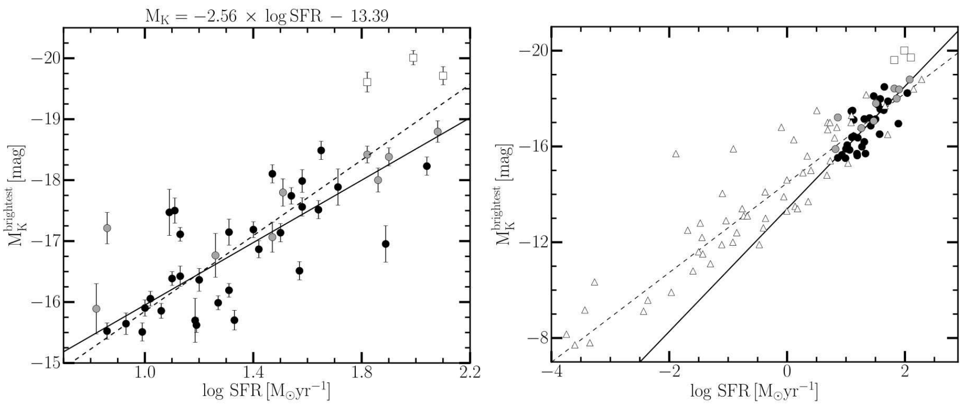

Fig. 2: Left: The K-band magnitude of the brightest cluster and the SFR of the galaxy. The solid line is our adopted fit using the $D_L \leq 150$ Mpc targets shown as circles. Right: Data from the optical (compiled in Adamo, Östlin & Zackrisson 2011) are shown as triangles, with $V - K = 2$ conversion. The dashed line shows a slope of 2 fitting the optical lower SFR data, instead of the extrapolation of our ≈ 2.6 slope (solid line).

4 Ages and masses of the LIRG SSCs and histories of hosts

We aim to use the distribution and characteristics of SSCs to trace the history of violent SF in the host galaxies. Age and mass characteristics of the SSCs must be obtained with high confidence for this purpose. In addition to the K-band, approximately a quarter of the galaxies have HST B and I-band, some also V,J,H-bands for Spectral Energy Distribution (SED) fitting based on 3 or more filters. To help in breaking the various degeneracies we constrain the extinctions and metallicities based on our optical spectra. We highlight some preliminary results on one of the targets, IRAS 18293-3413 a LIRG with $log(L_{IR}) \sim 11.7$, which has $BIHK$ photometry available for some 500 SSCs.

Approximately 300 SSCs with good quality data were modelled using models of Zackrisson et al. (2011). Half of them appear to be less than 6 Myr of age and concentrated towards the inner 1-2 kpc. A significant population, nearly 1/3 of all, are several hundred Myr old and their spatial distribution is more spread out. Fig. 3 presents the mass and age distributions of these SSCs. The mass functions of all age populations are fairly well described by a $dN/dM \propto M^{\beta}$ relation with a $\beta \approx -2$ index, as is often found for more quiescent spirals as well. The age distribution, fit as a $dN/dt \sim t^{\gamma}$ relation, is often used to study cluster disruption models, though cluster *formation*, with its further correlation to variations of SFR in the host, is intricately involved as well. This is still ongoing for our sample, and we merely note that the significant amount of older SSCs, the 'extra' hump in the age distribution in Fig. 3, suggests a previous interaction episode where SSC production has been higher than currently. This galaxy has thus likely been a ULIRG some 0.3 to 1 Gyr ago.

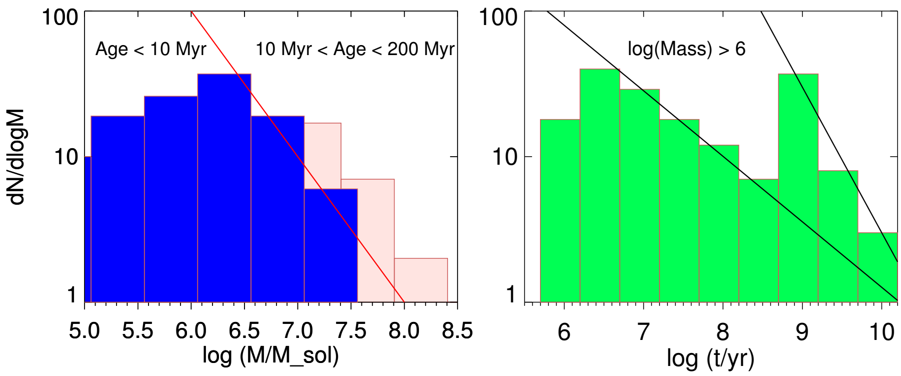

Fig. 3: Left: Mass function of SSCs in IRAS 18293-3413. The dark blue histogram shows those younger than 10 Myr, while the light red is for intermediate ages. The oldest population is not shown here, but is also fit by the power law slope $\beta \sim -2$ displayed. Right: The age distribution of SSCs, selected above $10^6 M_{\odot}$. A power law slope of $\gamma \sim -0.4$ fits the young and intermediate ages, while the older SSCs appear to have their own relation with $\gamma \sim -1.0$.

References

Adamo, A., Östlin, G., & Zackrisson, E. 2011, MNRAS, 417, 1904
Bastian, N. 2008, MNRAS, 390, 759
Gieles, M., et al. 2006, A&A, 450, 129
Kankare, E., et al. 2012, ApJ, 744, L19
Larsen, S.S. 2002, AJ, 124, 1393
Mattila, S., et al. 2012, ApJ, 756, 111
Randriamanakoto, Z., et al. 2013a, MNRAS, 431, 554
Randriamanakoto, Z., et al. 2013b, ApJ, 775, L38
Väisänen, P., et al. 2008a, MNRAS, 384, 886
Väisänen, P., et al. 2008b, ApJ, 689, L37
Väisänen, P., et al. 2012, J.Phys.Conf., 372,1, arXiv:1202.6236
Weidner, C., Kroupa, P., & Larsen, S. S. 2004, MNRAS, 350, 1503
Whitmore, B.C., et al. 2010, AJ, 140, 75
Zackrisson, E., et al. 2011, ApJ, 740, 13