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Near-infrared spectroscopy of the super star cluster in NGC 1705[⋆,⋆⋆] (Research Note)

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ABSTRACT

Aims. We study the near-infrared properties of the super star cluster NGC 1750–1 to constrain its spatial extent, its stellar population, and its age.

Methods. We used adaptive-optics assisted integral field spectroscopy with SINFONI on the Very Large Telescope. We estimated the spatial extent of the cluster and extracted its K-band spectrum from which we constrained the age of the dominant stellar population.

Results. Our observations have an angular resolution of about 0.11″, providing an upper limit on the cluster radius of 2.85 ± 0.50 pc depending on the assumed distance. The K-band spectrum is dominated by strong CO absorption bandheads typical of red supergiants. Its spectral type is equivalent to a K4–5I star. Using evolutionary tracks from the Geneva and Utrecht groups, we determine an age of 12 ± 6 Myr. The large uncertainty is rooted in the large difference between the Geneva and Utrecht tracks in the red supergiants regime. The absence of ionized gas lines in the K-band spectrum is consistent with the absence of O and/or Wolf-Rayet stars in the cluster, as expected for the estimated age.

Key words. galaxies: clusters: individual: NGC 1705–1 – stars: massive – stars: late-type

1. Introduction

Super star clusters are found in various galaxies: starburst galaxies (M82, O'Connell et al. 1995; McCrady et al. 2003; Gallagher & Smith 1999), interacting galaxies (NGC 4038/39, the Antennae, Whitmore & Schweizer 1995), and amorphous galaxies (NGC 1705, O'Connell et al. 1994). Compared to the most massive clusters found in the Galaxy and the Magellanic Clouds, they have larger estimated masses (in excess of 10^5 $M_\odot$ and usually closer to a few 10^6 $M_\odot$, Mengel et al. 2002; Larsen et al. 2004; Bastian et al. 2006). Their mass distribution follows a power law with an index equal to −2 (Fall 2004). Fall & Zhang (2001) have shown that a distribution of young massive clusters with this mass function could evolve into a lognormal mass function similar to that of old globular clusters. Super star clusters may thus be the progenitors of globular clusters, although this is a debated question. Among the difficulties of this scenario, super star clusters have to survive the so-called "infant mortality". Fall et al. (2005) showed that the distribution of the number of clusters as a function of time in the Antennae galaxies was dramatically decreasing: $dN/d\tau \propto \tau^{-1}$, where N is the number of clusters and τ the age. Either clusters are born unbound and dissolve rapidly, or they experience negative feedback effects from the most massive stars. Supernovae explosions and stellar winds can expel interstellar gas on short timescales, leading to the cluster disruption (Goodwin & Bastian 2006). How this feedback affects the cluster's evolution depends on the stellar content and its distribution. If the stellar initial mass function is top-heavy (as seems to be the case in some clusters, Sternberg 1998), the presence of a large number of massive stars will enhance disruption. But if the massive stars are concentrated in the cluster core due to initial or dynamical mass segregation, their effects might be reduced. Information of the stellar content is therefore necessary to better understand the evolution of these mini-starbursts.

In this paper, we present new observations of the super star cluster in the amorphous galaxy NGC 1705 (Melnick et al. 1985a). NGC 1705–1 is one of the brightest clusters (M_V = −15.4, Maíz-Apellániz 2001). It is also one of the closest, at a distance of 5.1 ± 0.6 Mpc (Tosi et al. 2001). Measuring velocity dispersions and assuming a bound cluster, Ho & Filippenko (1996) determined a mass of 8.2 ± 2.1 × 10^4 $M_\odot$. Using a larger gravitational radius, Sternberg (1998) obtained $M = 2.7 \times 10^5$ $M_\odot$. Sternberg (1998) used the light-to-mass ratio (L/M) derived from photometry and velocity dispersion to constrain the initial mass function (IMF). He found that the IMF is either flatter than the Salpeter IMF (slope <2.0), or that it is truncated at masses below 1–3 $M_\odot$. Smith & Gallagher (2001) confirmed the latter conclusion and Vázquez et al. (2004) showed that a lower mass limit of 1 $M_\odot$ for a Salpeter IMF is still compatible with the observed luminosity to mass ratio. Melnick et al. (1985a) showed that the optical spectrum of NGC 1705–1 was typical of early B stars, excluding the presence of hotter objects such as O and/or Wolf-Rayet stars. This places a lower limit on the age of the cluster of 8−10 Myr. In a subsequent study, Melnick et al. (1985b) detected the presence of CO bandheads in near-infrared narrow band photometry. These features are typical of evolved cool stars such as red supergiants or asymptotic giant branch/red giant branch stars. Ho & Filippenko (1996) obtained

[⋆] Based on observations collected at the ESO/VLT under program 384.D-0301(A).

[⋆⋆] The FITS file of the reduced cluster spectrum is only available at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via
http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/547/A17

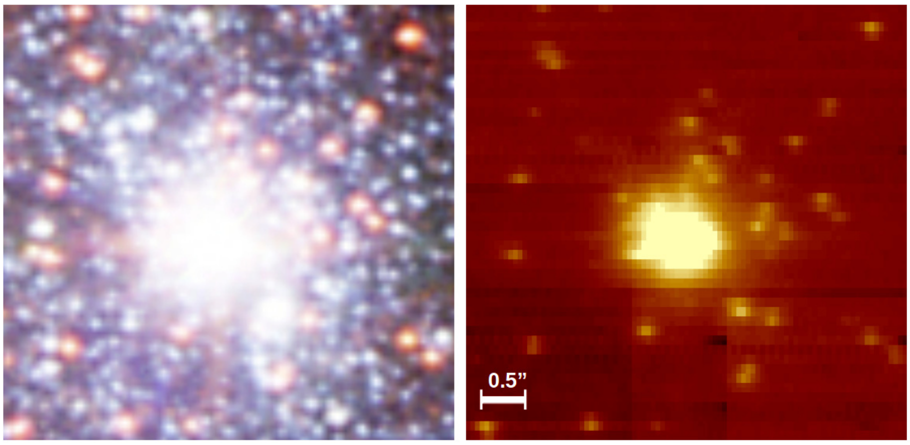

Fig. 1. *Left*: HST UBVI composite image of the super star cluster and its close environment (Tosi et al., Hubble Heritage Team – STScI/AURA, NASA, ESA). *Right*: combination of all three SINFONI mosaics obtained with the 100 mas pixel scale frame.

Table 1. Journal of observations.

Date	Pixel scale [mas]	Exposure time [s]	Seeing ″	Airmass
		NGC 1705–1		
2009-12-06	25	4 × 100	0.81–0.94	1.22–1.26
2009-12-23	25	4 × 100	0.60–0.75	1.40–1.55
2010-01-10	100	4 × 100	0.56–1.00	1.17–1.22
2010-01-11	25	4 × 100	0.96–2.60	1.23–1.31
2010-01-22	100	4 × 100	0.83–1.13	1.18–1.20
		PSF calibrator		
2010-01-10	100	2 × 60	0.68–0.75	1.24–1.24
2010-01-11	25	2 × 60	0.95–0.99	1.38–1.38

high-resolution optical spectra of NGC 1705–1 and confirmed the presence of early B star signatures (from spectral lines below 4500 Å) as well as red supergiant metallic lines (above 4500 Å, see also Meurer et al. 1992). The presence of early B stars was confirmed by the UV spectra of Vázquez et al. (2004) which are typical of B0–1 V/III stars. This average spectral type corresponds to a dominant population of hot stars of age 12^{+3}_{-1} Myr. Marlowe et al. (1995) estimated an age of 10 to 16 Myr for the starbust event in NGC 1705 using UBV colors and the Hα flux, which they compared with starburst models. The metallicity of the host galaxy NGC 1705 is subsolar with $Z = 0.35\ Z_{\odot}$ (Lee & Skillman 2004).

In this research note, we present the first near-infrared spectrum of the super star cluster NGC 1705–1 obtained from integral field spectroscopy with SINFONI on the ESO/VLT. We provide an upper limit on the spatial extent of the cluster and determine its K-band spectral type. We give age estimates and discuss their uncertainties.

2. Observations and data reduction

The observations were performed with the integral field near-infrared spectrograph SINFONI (Eisenhauer et al. 2003; Bonnet et al. 2004) on the ESO/VLT in service mode between December 6, 2009 and January 22, 2010. The seeing was usually good, between 0.7 and 1.0″. We used the adaptive optics system with the cluster itself as guide star. We used both the 100 mas and the 25 mas plate scale to probe the cluster itself as well as its immediate surrounding. Table 1 provides the journal of observations.

Data reduction was performed with the SPRED software (Abuter et al. 2006). After flat-field correction and bias/sky subtraction, wavelength calibration was performed with Ne-Ar lamp calibration data. Fine-tuning based on atmospheric features provided the final wavelength calibration. Telluric lines were removed using early-B star spectra taken just after the science data from which the stellar Brγ (and He I 2.11 μm feature when present) were corrected.

To estimate the spatial resolution of our data, we observed two point sources (stars) of similar magnitude to NGC 1705–1 immediately after the observations of the cluster on January 10 and January 11, 2010. These data were used to derive the width of the point spread function (PSF). Figure 1 shows our 100 mas pixel scale mosaic (right) together with an *Hubble* Space Telescope UBVI composite image at the same scale (left).

3. Spatial distribution

We used the 25 mas pixel scale mosaics taken on December 9, 2009, December 23, 2009 and January 11, 2010 to estimate the spatial extent of NGC 1705–1. Performing 2D Gaussian fits to the data, we obtain the following values for the full width at half maximum (FWHM): 0.112″ × 0.114″, 0.110″ × 0.121″, and 0.132″ × 0.150″. On January 11th 2010, we observed a standard star used as a PSF calibrator. The 2D Gaussian fit gives a 2D FWHM of 0.102″ × 0.111″. These measurements indicate that the core of NGC 1705–1 is not resolved by our observations. The variations of the cluster FWHM from night to night are mainly due to varying seeing conditions. On January 11, 2010, the PSF was about 30% smaller on the standard star, but the average seeing was also poorer during the observation compared to the cluster observation (see Table 1).

In Fig. 2, we show the spectrum obtained in two different regions of the 25 mas mosaic: a circle centered on the cluster core of spatial radius ~0.12″, and a ring-like region located between ~0.13″ and ~0.18″. The resulting spectra are shown in the upper panel. The main lines are indicated. There is very little difference between the two spectra (see the plot of the difference as a function of wavelength in the bottom panel). This most likely indicates that we are observing the far wing of the PSF in the annulus region, confirming that we are not resolving the cluster with our observations. We can provide upper limits on its half-light radius. According to the values of FWHM given above, the cluster core is smaller than 0.11–0.12″. At the distance of NGC 1705, this corresponds to a physical radius of less than 2.85 ± 0.50 pc (using the dispersion of the FWHM measurements as error on the angular size and for the distance of 5.1 ± 0.6 Mpc of Tosi et al. 2001).

O’Connell et al. (1994) determined a half-light radius of 0.14″ corresponding to 3.4 pc using a distance of 5.0 ± 2.0 Mpc. Meurer et al. (1995) found a significantly lower

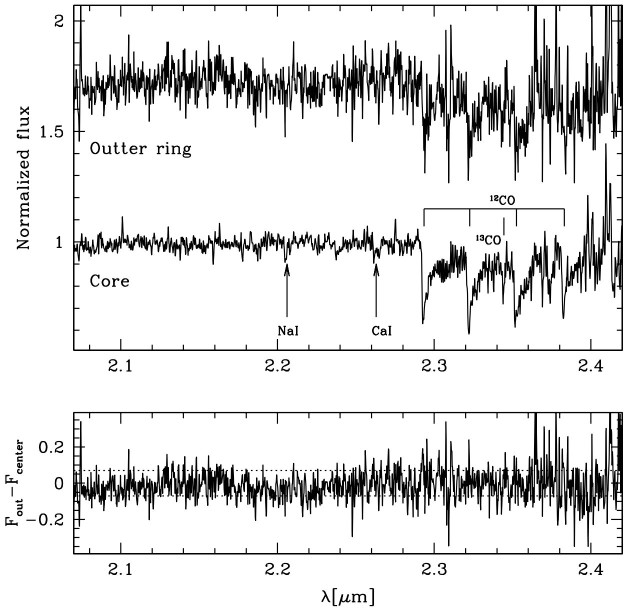

Fig. 2. Comparison between the spectrum extracted from a region of radius ∼0.12″ centered on the cluster core and the spectrum extracted from a ring of radius 0.13–0.18″. The *bottom panel* shows the difference between both spectra. The dotted lines indicate the 1σ deviation.

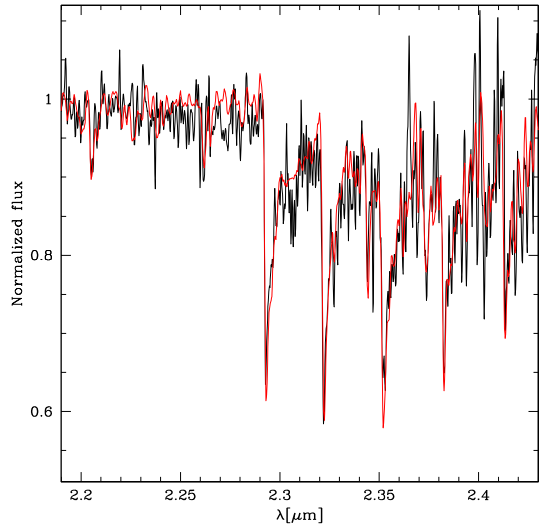

Fig. 3. Comparison between the *K*-band spectrum of NGC 1705–1 (black) and the spectrum of the Galactic K4.5Ib red supergiant HD 78647 (red). The latter spectrum is taken from the atlas of Wallace & Hinkle (1997). The SINFONI spectrum has been degraded to the resolution of the template spectrum (R = 2000).

value (0.04″, 1.1 pc) using the same set of HST/WFPC data. Smith & Gallagher (2001) concluded from their HST/WFPC2 observations that the half-light radius was 1.6 ± 0.4 pc for a slightly larger distance (5.3 ± 0.8 pc). Our *upper limit* on the cluster size is consistent with the highest values derived previously, and compatible with the small radius quoted by Meurer et al. (1995) and Smith & Gallagher (2001). The size of the cluster NGC 1705–1 remains poorly constrained at present, and future observations with ELTs and/or JWST are necessary to probe the spatial structure of this (and other) super star cluster.

4. Cluster age

We first note the absence of Brγ emission in the spectrum of NGC 1705–1 (we determine an upper limit on the Brγ equivalent width of 0.1 Å), consistent with the absence of hot massive stars and thus of a very young population. As seen above, CO bandhead absorption dominates the *K*-band spectrum, as in late-type stars. We compared the cluster spectrum by eye with templates spectra of cool, evolved stars taken from the atlas of Wallace & Hinkle (1997). We find that the former is best accounted for by the spectrum of a K4.5Ib star (Fig. 3). For later spectral types, the CO bandheads are too deep. A supergiant luminosity class is also preferred, since giant star spectra do not have sufficiently broad CO overtones[1]. This result is confirmed by the calculation of the first CO overtone equivalent width (38.2 Å measured between 2.2900 and 2.3200 μm). From Fig. 8 of Figer et al. (2006), in which the CO equivalent width was measured on the same interval as we used, we see that such an equivalent width is observed in K3–4I stars, as well as marginally in M5–6 giants. The two independent estimates favor a K4–5I spectral type for the entire cluster, which is thus dominated by the near-infrared light of red supergiants. If we assume that the supergiants of NGC 1705–1 are in their coolest evolutionary state, the fact that their spectral type is K and not M is an indication that the metallicity of the cluster is sub-solar. As shown by Massey & Olsen (2003), the distribution of spectral types among red supergiants shifts toward earlier spectral types when the metallicity decreases. While M2I is the spectral type that is most often represented in the Galaxy, M1I stars populate mainly the Large Magellanic Cloud (LMC) and K5–7I the Small Magellanic Cloud (SMC). This is consistent with the study of Meurer et al. (1992) and Storchi-Bergmann et al. (1994), who reported a sub-solar global metallicity for the entire galaxy NGC 1705: the former authors derived 12 + log (O/H) = 8.46, while the others reported 8.36. These values are similar to the LMC (respectively SMC) metallicity.

This estimate of the dominant population in NGC 1705–1 can be used to derive the age of the cluster. Vázquez et al. (2004) proceeded this way to report an age of 12^{+3}_{-1} Myr using a HST/STIS UV spectrum of the cluster. In Fig. 4 we show the position of a typical SMC K4–5 supergiant in the HR diagram, using parameters from Levesque et al. (2006), i.e., $T_{\rm eff}$ = 3925 ± 50 K and $\log \frac{L}{L_\odot}$ = 4.98 ± 0.10. The evolutionary tracks of Brott et al. (2011) are overplotted. They include rotational mixing (for an initial rotation rate of 300 km s^{-1}) and have an SMC composition. Ages are indicated in Myr by filled circles along the tracks. From that figure, we see that an age of about 7 to 10 Myr can be inferred for NGC 1705–1. If we were to use the LMC tracks and average LMC properties of K4−5I stars (still from Levesque et al. 2006), we would derive an age of 5.5 to 7.5 Myr. These numbers are significantly lower than the value reported by Vázquez et al. (2004). The reason is the use of different sets of evolutionary tracks. Vázquez et al. (2004) relied on the non rotating Geneva tracks, while we used the rotating Utrecht tracks. Using the non rotating Geneva tracks, we find ages of 8–14 Myr and 12–17 Myr for the LMC and SMC cases, respectively. These values much better agree with those of Vázquez et al. (2004). We can therefore conclude that our results are consistent with theirs. But the main conclusion is that the choice of evolutionary tracks is crucial in establishing the age of the cluster. Depending on the tracks used, systematic differences of about 50% of the cluster age can be made.

To additionally quantify the effects of evolutionary tracks on age determinations, we compared the results obtained from the

[1] Note that the Wallace and Hinkle atlas does not contain all spectral types and luminosity classes. Hence, the best representative spectral type should not be trusted at the level of a sub-spectral type.

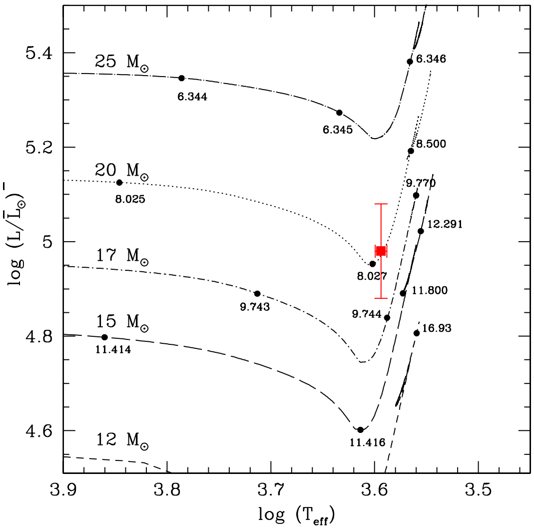

Fig. 4. HR diagram showing the position of an SMC K4–5I star. The evolutionary tracks are taken from Brott et al. (2011) and have an initial rotational velocity of 300 km s^{-1} and the SMC composition. The dots on the tracks indicate the ages in Myr. The uncertainty on the red supergiant parameters reflect the range of values determined for SMC K4–5I stars in the study of Levesque et al. (2006).

Geneva and Utrecht *rotating* tracks. At solar metallicity[2], significant differences in the behavior of the tracks are found at $T_{\rm eff}$ lower than 10 000 K. The Geneva tracks have an almost constant luminosity until the lowest temperatures, where the luminosity increases suddenly. The Utrecht tracks show a decreasing luminosity until approximately 4000 K before a rise at lower $T_{\rm eff}$. As a consequence, a star with $T_{\rm eff}$ = 4000 K and $\log \frac{L}{L_\odot} = 4.80$ is reproduced by the 20 $M_\odot$ Utrecht track at 8.7 Myr, and by the 15 $M_\odot$ Geneva track at 13.9 Myr. There is a 5 Myr difference in the age estimate. A detailed understanding of these differences is beyond the scope of this paper. It may be due to a different treatment of convection. The conclusion one can draw is that, as illustrated by our analysis of NGC 1705–1, the ages derived using the Utrecht tracks are much lower than those determined with the Geneva tracks. Hence, an accurate age determination cannot be performed, not because of the quality of the observational data, but because of the uncertainties in the theoretical tracks.

We used the equivalent width of the first CO overtone to derive an independent estimate the age of the population (Mengel et al. 2001). Population synthesis models predict the evolution of the strength of this feature as a function of time, depending on the assumed star formation history, initial mass function, stellar libraries, and isochrones. We measure an equivalent width of 12.8 Å for the first CO overtone (measured between 2.2924 and 2.2977 μm according to Origlia et al. 1993). Using the starburst models of Leitherer et al. (1999) (including non rotating tracks, a Salpeter IMF, and a burst of star formation), we see from their Fig. 101c that at a slightly sub-solar metallicity the first CO overtone equivalent width (computed at the same interval as we did) is in the range 10–16 Å for ages between 7 and 30 Myr. This is consistent with our estimates.

In conclusion, performing an age determination for NGC 1705–1 proved to be a difficult task given the current uncertainties on evolutionary models in the red supergiant phase. Based on our estimates, we can quote a value of 12 ± 6 Myr. This is still compatible with the absence of ionized gas emission (Brγ) that would be produced by a large population of ionizing sources (O and Wolf-Rayet stars).

5. Conclusion

We have presented the first near-infrared integral field spectroscopy of the super star cluster NGC 1705–1 obtained with SINFONI on the ESO/VLT. The cluster is found to have an angular size smaller than about 0.11–0.12″ and is not resolved by our AO-assisted observations. This places an upper limit of 2.85 ± 0.50 pc (depending on the distance) on its radial extension. The *K*-band spectrum of the cluster is dominated by strong CO absorption bandheads. It is similar to the spectrum of a red supergiant of spectral type K4–5. There is no sign of ionized gas in the spectrum. This confirms previous studies indicating that the cluster contains massive stars, but no O and/or Wolf-Rayet objects. Using different evolutionary tracks, we estimate the age to be 12 ± 6 Myr. The large uncertainty is rooted in the considerable differences between the Geneva and Utrecht evolutionary tracks in the supergiant regime, and not in the quality of the observational data. Depending on the type of tracks used, ages can systematically differ by 5–7 Myr.

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References

Abuter, R., Schreiber, J., Eisenhauer, F., et al. 2006, New Astron. Rev., 50, 398
Bastian, N., Saglia, R. P., Goudfrooij, P., et al. 2006, A&A, 448, 881
Bonnet, H., Abuter, R., Baker, A., et al. 2004, The Messenger, 117, 17
Brott, I., de Mink, S. E., Cantiello, M., et al. 2011, A&A, 530, A115
Eisenhauer, F., Tecza, M., Thatte, N., et al. 2003, The Messenger, 113, 17
Fall, S. M. 2004, in The Formation and Evolution of Massive Young Star Clusters, eds. H. J. G. L. M. Lamers, L. J. Smith, & A. Nota, ASP Conf. Ser., 322, 399
Fall, S. M., & Zhang, Q. 2001, ApJ, 561, 751
Fall, S. M., Chandar, R., & Whitmore, B. C. 2005, ApJ, 631, L133
Figer, D. F., MacKenty, J. W., Robberto, M., et al. 2006, ApJ, 643, 1166
Gallagher, III, J. S., & Smith, L. J. 1999, MNRAS, 304, 540
Goodwin, S. P., & Bastian, N. 2006, MNRAS, 373, 752
Ho, L. C., & Filippenko, A. V. 1996, ApJ, 472, 600
Larsen, S. S., Brodie, J. P., & Hunter, D. A. 2004, AJ, 128, 2295
Lee, H., & Skillman, E. D. 2004, ApJ, 614, 698
Leitherer, C., Schaerer, D., Goldader, J. D., et al. 1999, ApJS, 123, 3
Levesque, E. M., Massey, P., Olsen, K. A. G., et al. 2006, ApJ, 645, 1102
Maíz-Apellániz, J. 2001, ApJ, 563, 151
Marlowe, A. T., Heckman, T. M., Wyse, R. F. G., & Schommer, R. 1995, ApJ, 438, 563
Massey, P., & Olsen, K. A. G. 2003, AJ, 126, 2867
McCrady, N., Gilbert, A. M., & Graham, J. R. 2003, ApJ, 596, 240
Melnick, J., Moles, M., & Terlevich, R. 1985a, A&A, 149, L24
Melnick, J., Terlevich, R., & Moles, M. 1985b, Rev. Mex. Astron. Astrofis., 11, 91
Mengel, S., Lehnert, M. D., Thatte, N., Tacconi-Garman, L. E., & Genzel, R. 2001, ApJ, 550, 280
Mengel, S., Lehnert, M. D., Thatte, N., & Genzel, R. 2002, A&A, 383, 137
Meurer, G. R., Freeman, K. C., Dopita, M. A., & Cacciari, C. 1992, AJ, 103, 60
Meurer, G. R., Heckman, T. M., Leitherer, C., et al. 1995, AJ, 110, 2665
O'Connell, R. W., Gallagher, III, J. S., & Hunter, D. A. 1994, ApJ, 433, 65
O'Connell, R. W., Gallagher, III, J. S., Hunter, D. A., & Colley, W. N. 1995, ApJ, 446, L1
Origlia, L., Moorwood, A. F. M., & Oliva, E. 1993, A&A, 280, 536
Smith, L. J., & Gallagher, J. S. 2001, MNRAS, 326, 1027
Sternberg, A. 1998, ApJ, 506, 721
Storchi-Bergmann, T., Calzetti, D., & Kinney, A. L. 1994, ApJ, 429, 572
Tosi, M., Sabbi, E., Bellazzini, M., et al. 2001, AJ, 122, 1271
Vázquez, G. A., Leitherer, C., Heckman, T. M., et al. 2004, ApJ, 600, 162
Wallace, L., & Hinkle, K. 1997, ApJS, 111, 445
Whitmore, B. C., & Schweizer, F. 1995, AJ, 109, 960

[2] Comparisons are not possible at LMC/SMC metallicities because Geneva rotating tracks are not available at those metallicities for stars with $M < 25\ M_\odot$.