An O2If*/WN6 Star Catch in the Act in a Compact H\textsc{ii} region in the Starburst Cluster NGC 3603

A. Roman-Lopes

Department of Physics - Universidad de La Serena - Cisternas, 1200 - La Serena - Chile

ABSTRACT

In this letter we report the discovery of an O2If*/WN6 star probably still partially embedded in its parental cocoon in the star-burst cluster NGC 3603. From the observed size of the associated compact H\textsc{ii} region, it was possible to derive a probable dynamic age of no more than 600,000 years. Using the computed visual extinction value $A_V \sim 6.0 \pm 0.2$ magnitudes, an absolute visual magnitude $M_V = -5.7$ mag is obtained, which for the assumed heliocentric distance of 7.6 kpc results in a bolometric luminosity of $8 \times 10^5 L_\odot$. Also from the V magnitude and the V-I color of the new star, and previous models for NGC3603’s massive star population, we estimate its mass for the binary (O2If*/WN6 + O3If) and the single-star case (O2If*/WN6). In the former, we find that the initial mass of each component possibly exceeded 80 $M_\odot$ and 40 $M_\odot$, while in the latter MTT 58’s initial mass possibly was in excess of 100 $M_\odot$.

Key words: Stars: Wolf-Rayet; Infrared: Stars: Individual: WR20aa, WR20c; Galaxy: open clusters and associations: individual: Westerlund 2

1 INTRODUCTION

Very massive stars (initial masses $\sim 100 M_\odot$ or higher) are key actors in the energy balance and chemical evolution of galaxies. Due to their powerful winds and expanding H\textsc{ii} regions, they inject large quantity of momentum and energetic ultraviolet (UV) photons into the local interstellar medium (ISM), possibly regulating the star formation rate in its vicinity (Vink et al. 2013). However, one of the most fundamental yet still non-answered question in astrophysics is “how do very massive stars form?”. We already have good knowledge on how the formation and early evolution of low mass ($m_\star \lesssim 8 M_\odot$) stars occurs, but the basic processes leading to the formation of massive stars still remain unknown, probably because they are very rare objects whose birthplaces are generally much more distant from us than the nearby sites of low mass star formation. Also, because high mass stars evolve much faster than low mass stars, they are very short lived objects, being usually deeply embedded into their natal environment throughout their very early evolutionary stages.

The very young massive star studied here was first cataloged as MTT 58 by Melnick, Tapia & Terlevich (1989). It probably belongs to NGC 3603, the closest star-burst like cluster (Goss & Radhakrishnan 1966). Melnick, Tapia & Terlevich (1989), Stolte et al. (2004), Nörrbinerger (2004) localized at a heliocentric distance of 7.6$\pm$0.4 kpc (Crowther et al. 2010). With dozens of very massive stars in its core, with some of them possibly presenting initial masses exceeding 100 - 150 $M_\odot$ (Crowther et al. 2010), NGC 3603 is one of the best Galactic sites for studies on the formation and evolution of very massive stars in the local universe.

2 NEAR-INFRARED SPECTROSCOPIC OBSERVATIONS AND DATA REDUCTION

MTT 58 was chosen for near infrared (NIR) spectroscopic follow-up observations based on its near- to mid-infrared colors, H\alpha and X-Ray emission characteristics (the details on the criteria and general selection methodology are fully discussed in a forthcoming paper - Roman-Lopes submitted). The NIR spectroscopic observations were performed with the Ohio State Infrared Imager and Spectrometer (OSIRIS) at the Southern Astrophysics Research (SOAR) telescope. The J-, H- and K-band data were acquired in 9th May 2011 with the night presenting good seeing conditions. Besides MTT 58, we also obtained NIR spectra for HD93129A (O2If*), WR20a (O3If*/WN6 + O3If*/WN6) and WR42e (O2If*/WN6) (Crowther & Walborn 2011; Roman-Lopes 2012). In Table 1 it is shown a summary of the NIR observations used in this work.
The raw frames were reduced following standard NIR reduction procedures. The two-dimensional frames were subtracted for each pair of images taken at the two shifted positions. Next the resultant images were divided by a master normalized flat, and for each processed frame, the J-, H- and K-band spectra were extracted using the IRAF task APALL, with subsequent wavelength calibration being performed using the IRAF tasks IDENTIFY/DISPCOR applied to a set of OH sky line spectra (each with about 30-35 sky lines in the range 12400Å -23000Å). The typical error (1-σ) for this calibration process is estimated as ∼12Å which corresponds to half of the mean FWHM of the OH lines in the mentioned spectral range. Telluric atmospheric corrections were done using J-, H- and K-band spectra of A type stars obtained before and after the target observations. The photospheric absorption lines present in the high signal-to-noise telluric spectra, were subtracted from a careful fitting (through the use of Voigt and Lorentz profiles) to the hydrogen absorption lines and respective adjacent continuum. Finally, the individual J-, H- and K-band spectra were combined by the average (using the IRAF task SCOMBINE) with the mean signal-to noise ratio of the resulting spectra well above 100.

3 RESULTS

Coordinates and photometry of MTT 58 are shown in Table 2. The B-, V- and I-band magnitudes were taken from the work of Sung & Bessell (2004), while the NIR values were obtained from the Two-Micron All Sky Survey (Cutri et al. 2003), with the absorption-corrected 0.5-10keV Chandra X-ray flux taken from the work of Romano et al. (2008).

3.1 The OSIRIS NIR spectra of MTT 58: An O2If*/WN6 star embedded in a compact HII region

Figure 1 shows the telluric corrected (continuum normalized) J-, H- and K-band SOAR-OSIRIS spectra of MTT 58. They present (despite of the previous subtraction of the background extended nebular components) strong residual hydrogen recombination features that are particularly prominent in the Paα and Brγ transition lines. They appear as very narrow lines superimposing the broad emission lines generated by the strong stellar wind of the embedded star. The presence of strong narrow nebular line emission indicates that the star is probably immersed in an ionized region.

Figure 2 shows the MTT 58’s J-, H- and K-band SOAR-OSIRIS spectra, together with those for HD93129A (O2If*), WR42e (O2If*/WN6) and WR20a (O3If*/WN6 + O3If*/WN6), with the main H, He and N emission lines identified by labels. Notice the strong nebular hydrogen recombination narrow lines superimposing the broad emission lines produced by the powerful wind of the embedded star. Besides the nebular emission components, the MTT 58’s J-, H- and K-band spectra resemble well those of WR42e.

Table 1. Summary of the SOAR/OSIRIS dataset used in this work.

| Date       | 09/05/2011 |
|------------|------------|
| Telescope  | SOAR       |
| Instrument | OSIRIS     |
| Mode       | XD         |
| Camera     | f/3        |
| Slit       | 1" x 27"   |
| Resolution | 1000       |
| Coverage (µm) | 1.25-2.35 |
| Seeing (" ) | 1-1.5     |

© 2010 RAS, MNRAS 000, 1–?
Young O2If*/WN6 Star in a Compact H\textsc{ii} region in NGC 3603

Figure 3. (a) The Spitzer false-color RGB image of the region centered on the core of the NGC3603 star-burst cluster. (b) Zooming of the region in the direction of MTT 58, with the associated pillar (delineated by the black line) mostly visible in the red channel. There we also can see the positions of the BMW-Chandra source #6915 (Romano et al. 2008), the molecular cloud MM 2E (Nürnberg et al. 2002) and the H\textsubscript{2}O maser found by Caswell (2004). (c) The HST H\textalpha image of NGC 3603 where we can see the spectacular pillars to the south of the cluster core. (d) Detailed view of the H\textalpha emission in the vicinity of MTT 58, where we can see the H\textalpha counterpart of part of the compact H\textsc{ii} region detected by the ATCA observations.

Table 2. Coordinates (J2000), Optical/NIR photometry, and X-ray parameters of the newly-identified O2If*/WN6 star. The BVI photometry was taken from Sung & Bessell (2004), while the near-infrared magnitudes are from Cutri et al. (2003). Finally, the absorption-corrected 0.5-10keV flux is from the work of Romano et al. (2008).

| RA         | Dec          | B     | V     | I     | J     | H     | K\textsubscript{S} | X-Ray (0.5-10 keV) |
|------------|--------------|-------|-------|-------|-------|-------|---------------------|--------------------|
| 11h15m07.60s | -61d16m54.8s | 16.14 | 14.76 | 12.39 | 10.47 | 9.68 | 9.24                | 4.23x10^{-17} Wm\textsuperscript{-2} |

(Smith & Cont 2008). As a last comment on the MTT 58’s spectra, it is interesting to notice that there are two identified lines that appear in absorption. The first is a line at 1.693\textmu m, that could be due to He\textsc{ii}, while the other is the C\textsc{iv} line at \sim 2.080\textmu m. Such absorption lines could be indicative of the presence of an early-O star companion. Indeed, the presence of an X-ray source gives support for this idea.

Figure 3(a) shows a false color RGB image made from the 3.6\mu m (blue), 4.5\mu m (green) and 5.8\mu m (red) Spitzer IRAC images of the region centered in the core of the NGC 3603. The bulk of the remnant of the NGC 3603’s parental molecular gas cloud is clearly seen to the south and southwest, where the large-scale star formation is still taking place (de Pree, Nysewander & Goss 1999; McKee & Tan 2002; Nürnberg & Stanko 2003; Nürnberg 2004). As we can see from the figure, MTT 58 is placed at about 1.8 arcmin to the south of the NGC 3603’s center, at the tip of a giant pillar of gas and dust. Figure 3(b) presents a detailed view of the region around MTT 58. There we indicate (besides the star) the position of the X-Ray BMW-Chandra point source #6915 (Romano et al. 2008), and that for the molec-
Figure 4. The continuum subtracted HST H$\alpha$ image (logarithmic scale) of the region to the south of NGC 3603 cluster. For the sake of clarity, we also present the H$\alpha$ intensity contours (yellow lines) in steps of 4500, 5500, 6500, 7500 and 8500 units (arbitrary scale). There we indicate the location of the NGC 3603’s cluster and the position of the compact H$\alpha$ regions D, E, F, G, H and I detected by de Pree, Nysewander & Goss (1999) with the Australia Telescope Compact Array (ATCA). The estimate angular size of the compact H$\alpha$ region G, is indicated by the white dashed circle. Also, the location of the O2If*/WN6 star is indicated by the red diamond. Notice the extended emission in the vicinity of MTT 58.

3.2 Size and age of the MTT 58’s H$\alpha$ region

As mentioned in the previous section, MTT 58 is possibly powering a compact H$\alpha$ region. We searched in the literature for high spatial resolution radio continuum observations that could give us constrains on the size of the MTT 58’s H$\alpha$ region, and found that de Pree, Nysewander & Goss (1999) observed the region towards MTT 58 with the Australia Telescope Compact Array (ATCA), in the continuum (at 8.8 GHz) and the H90α, He90α, C90α and H113β recombination lines (all with rest frequencies around 8.9 GHz), with angular resolution of $7''$. Their source G with angular size of $26''$ and integrated flux density $S_{\text{tot}}=4.4\pm0.3\ Jy$, is one of the strongest sources in the entire region. It has coordinates $\alpha=11:15:08.76$ and $\delta=-61:16:55.7$ (J2000) that matches (considering the associated uncertainties) those of MTT 58. Taking into account the limited ($7''$) ATCA’s spatial resolution, we may consider $26''$ as an upper limit for the angular size of the MTT 58’s compact H$\alpha$ region.

We also searched in the Hubble Legacy Archive looking for H$\alpha$ images of NGC 3603, finding that the region towards MTT 58 was observed in the framework of the proposal ID #11360 (P.I. O’Connell, R. W.). Figure 3(c) shows the HST H$\alpha$ image of the southeast part of the NGC 3603’s region, where we can see the bright H$\alpha$ extended emission generated in the top of a spectacular pillar visible to the north of MTT 58. Figure 3(d) presents a detailed view of the H$\alpha$ emission in the vicinity of MTT 58. By scaling the F658N ([Nii] 6583) image to the F656N (H$\alpha$ 6552) one (using a set of non-saturated stars), and subtracting the former from the last we obtained a continuum subtracted HST H$\alpha$ image of the region to the south of NGC 3603 cluster. The resulting image is shown in Figure 4 with the location of the NGC 3603 cluster, MTT 58 and the ATCA compact H$\alpha$ regions D, E, F, G, H and I indicated by labels. As a complement and in order to compare the H$\alpha$ subtracted image with the positions of the 8.8 GHz compact continuum sources detected by de Pree, Nysewander & Goss (1999), we also present the H$\alpha$ intensity contours (represented by the yellow continuum lines), which correspond to 4500, 5500, 6500, 7500 and 8500 counts (arbitrary scale). The H$\alpha$ contours associated to the ATCA source G, present an arc shaped structure (not spherical like in the radio continuum map of de Pree, Nysewander & Goss (1999), probably due to the presence of very dense foreground molecular material well seen (against the bright background extended emission) in Figure 3(b).

1 http://hla.stsci.edu/hlaview.html
We can now estimate the age of the embedded star from the H\textsc{ii} region’s size, assuming that it reached its initial Strömgren radius in a very short time (a few $10^4$ yrs), corresponding to a rapid expansion phase dominated by an R-type shock (Spitzer 1978), and that after this phase it has been expanding in a uniform medium owing to the pressure difference between the hot ionized gas and the outer cool molecular gas. This corresponds to a condition where the H\textsc{ii} region expansion is governed by a weak D-type ionization front, with a rate of expansion that can be estimated using the equation (Spitzer 1978):

$$R_f(t) = R_i \left(1 + \frac{7c^2}{16n_i^2} t^2\right)^{1/2}$$

where $R_i$ and $R_f$ are the initial and final values for the Strömgren radius, and $c$ is the speed of light in the H\textsc{ii} region (typically varying from 0.4 to 10 km/s [Israel 1978; Pedlar 1980; Zhu et al. 2002; Mac Low et al. 2007; Gendelev & Krumholz 2012; Minier 2013]). In order to be conservative, in the calculation we will assume a mean sound speed of $4 \text{ km s}^{-1}$ and that the numerical density in the beginning of the ultra-compact phase was about $10^5 \text{ cm}^{-3}$ (Churchwell 2002), and that the number of Lyman continuum photons ($N_{\text{Ly}}$) emitted by second by an O2If*/WN6 star right in the very beginning of its life-time is about $10^{49}$ photons (Churchwell 2002), and that the number of Lyman continuum photons ($N_{\text{Ly}}$) for an initial numerical density of $10^4 \text{ cm}^{-3}$ is equal to $10^4 \text{ cm}^{-3}$. The Strömgren radius of an early-O super-giant stars is believed to emit much more than $10^{49}$ s$^{-1}$ Lyman continuum photons during its main sequence life-time (Smith, Norris & Crowther 2002).

From the angular size of the source $G$ obtained by de Pree, Nysewander & Goss (1999), we can estimate its corresponding dynamical age. The Strömgren radius (Strömgren 1939) for an initial numerical density of $10^{5} \text{ cm}^{-3}$ and $N_{\text{Ly}}=10^{49} \text{ s}^{-1}$ is $R_i \sim 0.025 \text{ pc}$. The upper limit for the final radius $R_f$ can be computed from the angular size ($26''$) estimated from the ATCA observations. Assuming a distance of 7.6 kpc, the corresponding value is $R_f \sim 0.48 \text{ pc}$, which applied in Equation 1 results in a dynamical age of $\sim 580,000$ years. On the other hand, in the case in which MTT 58’s $N_{\text{Ly}}=10^{49} \text{ s}^{-1}$ (Crowther & Walborn 2011), the dynamical age would drop by a factor $\sim 3.8$, resulting in a much lower age of 150,000 yrs! In any scenario, we conclude that MTT 58 is possibly the youngest Galactic O2If*/WN6 star found to date.

Recently, Roman-Lopes (2012) reported the discovery of an O2If*/WN6 star (WR42c) that is thought to have been ejected from the NGC 3603 cluster core. In this sense we may argue that in the MTT 58’s case the situation is probably different. Indeed, considering that an O2If*/WN6 star produces much more Lyman continuum photons than the template (O7V star with $Q_0 \sim 10^{49} \text{ s}^{-1}$) we used in our previous calculations, in this case the tremendous ionization front of the O2If*/WN6 star could propagate much quicker than the associated star travel velocity, destroying and dissociating any molecular cloud in its way much earlier of its arrive there. On the other hand, another argument favoring the idea that we are probably looking at an in-situ formation case, is the fact that the observed morphology of the compact H\textsc{ii} region studied by de Pree, Nysewander & Goss (1999) is not cometary, like the expected when the ionizing source is traveling with a relatively high transverse velocity (Churchwell 2002).

### 3.3 Estimating the luminosity of MTT 58

In order to compute estimates for the luminosity and mass of MTT 58, we need to evaluate its visual extinction taking into account that the interstellar reddening law for NGC 3603 is probably abnormal (Pandey, Ogura & Sekiguchi 2004; Sung & Bessell 2004), with a ratio of total to selective extinction value $R_V=3.55\pm0.12$ (Sung & Bessell 2004). From Table 2, we can see that MTT 58 presents (B-V) color $\sim 1.4$ mag, which for an assumed mean intrinsic (B-V)$_0$ value of $0.3$ mag (typical for the hottest early-type stars), corresponds to a color excess $E$(B-V) $\sim 0.7$ mag $A_V=4.4\pm0.1$, but still compatible with what is expected for an early-type member of NGC 3603 (Sung & Bessell 2004). Assuming that the additional amount of reddening $A_V=1.6$ is generated by the gas and dust present in the compact H\textsc{ii} region (e.g. local), we can speculate that the embedded star could be close to disrupt the border of the cavity that is facing the MTT 58’s line of sight.

From the computed color excess, one can estimate the MTT 58’s absolute magnitude using the distance modulus equation, assuming that the star is placed at an heliocentric distance of 7.6$\pm$0.4 kpc (Crowther et al. 2010). We computed $M_V=-5.7$ mag (or $M_K=-5.9$ considering $A_K_0=0.12A_V$ - Crowther et al. 2010), which are values that are a bit lower that those obtained by other researchers for stars of similar type (Crowther et al. 2010; Roman-Lopes, Barbá & Morrel 2011; Crowther & Walborn 2011). However, it is also known that massive stars at their very beginning stages are expected to be less luminous then similar stars at the more evolved main-sequence phase. Considering the derived absolute visual magnitude and assuming a mean bolometric correction $BC_V=-4.3$ mag (Crowther et al. 2010; Crowther & Walborn 2011), we estimate the bolometric magnitude of MTT 58 as $M_{bol} \sim -10.0$, which corresponds to a total stellar luminosity above $8\times10^{5}\ L_\odot$.

### 3.4 Binarity

In Section 3.1 it was mentioned that the H-band MTT 58’s spectrum shows the He\textsc{ii} line at 1.693$\mu$m in absorption, which could indicate the presence of an early-O star companion. As MTT 58 has an associated X-ray source, it is useful to compare its bolometric and X-ray luminosities. From its absorption-corrected 0.5-10keV flux (Table 2), and using the adopted heliocentric distance of 7.6$\pm$0.4 kpc (Crowther et al. 2010) we compute an X-ray luminosity $L_X \sim 2.9\times10^{32}\text{ erg}\text{ s}^{-1}$ that compared with the bolometric luminosity derived in Section 3.3 results in $L_X/L_{bol} \sim 10^{-6}$. This result is about ten times greater than the canonical value expected for single stars, e.g. $L_X/L_{bol} \sim 10^{-7}$ (Chlebowski et al. 1989), favoring the idea that the O2If*/WN6 star probably has an early-O star companion.

If we assume that MTT 58 is a binary star, and from an inspection of their NIR combined spectra (Figure 1), in principle we may conclude that the absence of any H\textsc{ii} line in absorption (e.g. at 1.701$\mu$m or at 2.113$\mu$m) indicates that the companion of the O2If*/WN6 star should be of spectral...
Figure 5. The V × (V-I) diagram (based on Figure 7 of the work of Sung & Bessell (2004), with MTT 58 represented by the green star (single star case) and red dots (binary system case), and WR42e ∼ 130 M_☉ - (Gvaramadze et al. 2013) by the violet star. The non-reddened main sequence at the quoted distance of 7.6 kpc (Crowther et al. 2010) for masses between 7 M_☉ to 120 M_☉ is represented by the black dotted line, with the black stars indicating the position of each mass bin. Also, the reddening vector taken from the work of Sung & Bessell (2004) is represented by the line-dotted arrows. From this diagram we can see that the initial mass of the new O2If*/WN6 star (in the single star case) possibly exceed 100 M_☉. On the other hand, if MTT 58 is assumed to be a binary system compound by a O2If*/WN6 + O3If* system, the individual masses should exceed 80 M_☉ and 40 M_☉, respectively.

3.5 Mass

We can estimate the mass of MTT 58 by comparing its observed V magnitude and V-I color with those of other NGC 3603 cluster members, presented in Figure 7 of the work of Sung & Bessell (2004). We do that taking into account both, the scenario where it is assumed to be a binary system, as well as that where it is considered as a single star. Also in order to be conservative, we assume that the difference in magnitudes between two stars of O3If* and O2If*/WN6 types is about 1 magnitude (Crowther & Walborn 2011), and to simplify the process we assume that both stars have approximately the same bolometric corrections (a reasonable assumption considering their probable very early spectral types).

Figure 5 shows an adapted version of the V × (V-I) diagram for NGC 3603 (Sung & Bessell 2004), with MTT 58 (single and binary cases) and WR42e (estimated mass of ∼ 130 M_☉ - Roman-Lopes 2012; Gvaramadze et al. 2013) represented by a green star (single star case) and red dots (binary system case) and violet star, respectively. We added WR42e in the mentioned diagram for comparison purpose because it is of the same spectral type of MTT 58.
and probably belongs to the same complex. From this diagram we can see that for the scenario where MTT 58 is considered to be a binary system, the masses of each component would be about 80 M⊙ (for MTT 58a) and 40 M⊙ (for MTT 58b). This numbers can be considered reasonable if compared with those from two know very massive binary systems (with similar spectral type and morphology) WR20a (O3If*/WN6 + early-O), for which (Niemela et al. 2000) estimated minimum masses of 87 and 53 M⊙, for which (Smith & Conti 2008), and WR21a (O3If*/WN6 + early-O), with masses of 83 and 82 M⊙ respectively. Finally, in the case in which MTT 58 is assumed to be a single star, its initial mass could exceed 100 M⊙.

4 SUMMARY

In this work we report the discovery of an O2If*/WN6 star probably still embedded in its parental cocoon in the starburst cluster NGC 3603. The new O2If*/WN6 star was previously cataloged as MTT 58 by Sun & Bessell (2004), being apparently placed at the tip of a giant pillar of gas and dust at about 1.8 arcmin (~ 4 pc for the quoted distance of 7.6 kpc - Crowther et al. (2010) to the south of the NGC 3603’s cluster center. The proximity to a non-destroyed molecular cloud, suggests that MTT 58 yet had no time to completely dissipate its parental molecular cocoon, indicating that it is probably an extremely young O2If*/WN6 star.

Another interesting result is that the new O2If*/WN6 star may be the main component of a binary system. Indeed, the presence of a BMW-Chandra X-ray point source coincident with the MTT 58’s coordinates and the fact that its NIR spectra present two absorption lines (the He I 1.693µm and the 2.080µm Crv lines) possibly generated by an O3If* companion, give strong support for this idea.

From the observed size of the associate compact Hα region detected at 3.4 cm by de Pree, Nysewander & Goss (1999) using the Australian Telescope Compact Array (ATCA), it was possible to derive a probable dynamic age of no more than 600,000 years. From the computed visual extinction value AV ~ 6.0 ± 0.2 mag an absolute visual magnitude Mv = -5.7 mag is obtained, which for the assumed heliocentric distance of 7.6 kpc results in a bolometric luminosity of 8 × 10^5 L⊙.

Finally, from the V magnitude and V-I colour of the new O2If*/WN6 star and the Figure 7 of the work of Sun & Bessell (2004), we estimate the MTT 58’s mass considering the cases in which it is assumed to be a binary system (O2If*/WN6 + O3If* stars), and the one in which it is thought to be a single O2If*/WN6 star. In the first case we found that the initial masses of MTT 58a and MTT 58b should be above 80 M⊙ and 40 M⊙ respectively. On the other hand, in the scenario were MTT 58 was assumed to be a single star, its initial mass possibly exceeded 100 M⊙.

ACKNOWLEDGMENTS

This research has made use of the NASA/ IPAC Infrared Science Archive, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. Based on observations obtained at the Southern Astrophysical Research (SOAR) telescope, which is a joint project of the Ministério da Ciência, Tecnologia, e Inovação (MCTI) da República Federativa do Brasil, the U.S. National Optical Astronomy Observatory (NOAO), the University of North Carolina at Chapel Hill (UNC), and Michigan State University (MSU). Also, this research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. This work was partially supported by the Department of Physics of the Universidad de La Serena. ARL thanks financial support from Diretoria de Investigação - Universidade de La Serena through Project “Convenio de desempeño DIULS CD112”.

REFERENCES

Bonanos, A. Z., Stanek, K. Z., Udalski, A., Wyrzykowski, L., ebru, K., Kubiak, M., Szymaski, M. K., Szewczyk, O., Pietrzyński, G., Soszyński, I. 2004, ApJ, 611L, 33B
Caswell, J. L. 2004, MNRAS, 351, 279
Chlebowski, T., Harnden, F. R., Jr., Scuorio, S. 1989, ApJ, 341, 427
Churchwell E. 2002, ARA&A, 40, 27
Crowther, P. A., Schnurr, O., Hirschi, R., Yusof, N., Parker, R. J., Goodwin, S. P., Kassim, H. A. 2010, MNRAS, 408, 731
Crowther, P. A. & Wallborn, N. R. 2011, MNRAS, 416, 1311
Cutri, R. M., Skrutskie, M. F., van Dyk, S., Beichman, C. A., Carpenter, and 20 more authors 2003, "The IRSA 2MASS All-Sky Point Source Catalog, NASA/IPAC Infrared Science Archive. [http://irsa.ipac.caltech.edu/applications/Gator/]

de Pree, C. G., Nysewander, M. C., Goss, W. M. 1999, AJ, 117, 2002

denelev, Leo; Krumholz, Mark R.

Goss, W. M., Radhakrishnan, V. 1969, ApL, 4, 199

Gyramadzhe, V. V., Kniazev, A. Y., Chen, A.-N.; Schnurr, O. 2013, MNRAS, 430, L20

Hanson, M. M., Kudritzki, R.-P., Kenworthy, M. A., Puls, J., Tokunaga, A. T. 2005, ApJS, 161, 154

Israel, F. P. 1978, A&A, 70, 769

Mac Low, Mordecai-Mark, Toraskar, Jayashree, Oishi, Jefrey S., Abel, Tom 2007, ApJ, 668, 980

Minier, V., Tremblin, P., Hill, T., Mott, F., Andr., Ph., and 16 co-authors 2013, A&A, 550, 50

Niemela V. S., Gamen R. C., Barbá R. H., Fernández Lajús E., Benaglia, P., Solivella, G. R., Reig, P., Coe M. J., 2008, MNRAS, 389, 1447

Nünnerberger, D. E. A., Bronfman, L., Younge, H. W., Zinnecker, H. 2002, A&A, 394, 253

Nünnerberger, D. E. A., Stanke, T. 2003, A&A, 400, 223

© 2010 RAS, MNRAS 000, 000
A. Roman-Lopes

Nünnberger, D. E. A. 2004, ASPC, 322, 75
Pandy, A. K., Ogura, K., & Sekiguchi, K. 2000, PASJ, 52, 847
Pedlar, A. 1980, MNRAS, 192, 179
Roman-Lopes, A., Barba, R. H. & Morrell, N. I. 2011, MNRAS, 416, 501
Roman-Lopes, A. 2012, MNRAS, 427, 65
Romano, P., Campana, S., Mignani, R. P., Moretti, A., Mottini, M., Panzera, M. R., Tagliaferri, G. 2008, A&A, 488, 1221
Smith, L. J., Norris, R. P. F., Crowther, P. A. 2002, MNRAS, 337, 1309
Smith, N. & Conti, P. S. 2008, ApJ, 679, 1467
Spitzer L., 1978, Physical Processes in the Interstellar Medium. Wiley-Interscience, New York
Stolte, A., Brandner, W., Brandl, B. Zinnecker, H., Grebel, E. K. 2004, AJ, 128, 765
Strömgren, B. 1939, ApJ, 89, 526
Sung, H., Bessell, M. S. 2004, AJ, 127, 1014
Vink, J. S., Heger, A., Krumholz, M. R., Puls, J. and 24 more authors 2013, astro-ph arXiv:1302.2021v2
Zhu, Qing-Feng, Lacy, John H., Jaffe, Daniel T., Richter, Matthew J., Greathouse, Thomas K. 2005, ApJ, 631, 381