Open clusters in Auriga OB2

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ABSTRACT

We study the area around the H\(_\text{II}\) region Sh 2-234, including the young open cluster Stock 8, to investigate the extent and definition of the association Aur OB2 and the possible role of triggering in massive cluster formation. We obtained Strömgren and \(J,H,K_s\) photometry for Stock 8 and Strömgren photometry for two other cluster candidates in the area, which we confirm as young open clusters and name Alicante 11 and Alicante 12. We took spectroscopy of \(\sim 33\) early-type stars in the area, including the brightest cluster members. We calculate a common distance of \(2.80^{+0.27}_{-0.24}\) kpc for the three open clusters and surrounding association. We derive an age 4 – 6 Ma for Stock 8, and do not find a significantly different age for the other clusters or the association. The star LS V\(+34^\circ 23\), with spectral type O8\(\text{II}(f)\), is likely the main source of ionization of Sh 2-234. We observe an important population of pre-main sequence stars, some of them with disks, associated with the B-type members lying on the main-sequence. We interpret the region as an area of recent star formation with some residual and very localized ongoing star formation. We do not find evidence for sequential star formation on a large scale. The classical definition of Aur OB2 has to be reconsidered, because its two main open clusters, Stock 8 and NGC 1893, are not at the same distance. Stock 8 is probably located in the Perseus arm, but other nearby H\(_\text{II}\) regions whose distances also place them in this arm show quite different distances and radial velocities and, therefore, are not connected.

Key words: techniques: photometric – techniques: spectroscopic – stars: early-type–stars: evolution – Hertzsprung–Russell and colour–magnitude diagrams – open clusters and associations: individual: Alicante 11 – open clusters and associations: individual: Alicante 12

1 INTRODUCTION

Stellar associations are large and loose, comoving stellar groups of low-density stars often associated with smaller open cluster groups. OB associations contain O and/or early B-type stars. They must be young (\(\leq 30\) Ma) because they are unstable against Galactic tidal forces. Therefore, most of their low-mass members are still found in the pre-main sequence (PMS) phase. They are excellent targets for detailed studies of the initial mass function and the star formation history because they represent a place where the star formation process has been completed recently. Their space distribution also provides useful information about the spiral structure of the Galaxy (Blaauw 1964, Preibisch & Zinnecker 2007).

OB associations are the natural outcome of star-formation processes in giant molecular clouds (GMCs) in most Milky Way environments. These large clouds demonstrate hierarchical structure in both time and space, resulting in the formation of star clusters that are not bound gravitationally to one another, but share a common distance. A well-studied example of such processes is the W3 region, which contains several small embedded clusters surrounding the optically visible cluster IC 1795 (Bik et al. 2012, Román-Zúñiga et al. 2015, Kiminki et al. 2015). A more dispersed population of early-type stars seems to connect it with IC 1805, the ionizing cluster of W4, which includes a few early O-type stars. The nearby cluster IC 1848, ionizing W5, is also likely connected. Overall stars traditionally considered to belong to Cas OB6 cover more than 6 degrees on the sky. Other examples of large star-forming regions containing moderately massive clusters include the G305 re-
region, centred on the Danks 1 and 2 clusters (Hindson et al. 2013, references therein) and the Carina Nebula (e.g. Preibisch et al. 2011). Other GMCs, such as W33 (Messineo et al. 2015) or W51, lack the central massive clusters, and will very likely evolve into dispersed associations, similar to Cyg OB2 (Wright et al. 2014).

The Perseus arm has been proposed as one of the two main spiral arms of the Galaxy (Churchwell et al. 2009). It emerges from behind obscuring clouds in the Local arm around $l = 75^\circ$ and over a significant fraction of the northern sky, it is clearly delineated by early-type luminous stars (as first redefined by Morgan et al. 1959). Between $l = 100^\circ$ and $140^\circ$, the Perseus arm contains both large active star-forming regions, and more evolved associations, with ages between $\sim 10$ and $\sim 20$ Ma. Among them, some are dispersed and contain small clusters (Cas OB2/OB4/OB5/OB7), while other have massive central clusters, such as the twin clusters NGC 669/884 at the core of Per OB1 or NGC 663 and NGC 654, defining Cas OB8. However, beyond $l = 140^\circ$ stellar and molecular tracers of the Perseus arm suddenly become very rare. Cloud complexes identified with the Perseus arm are seen again in the third galactic quadrant (already at $l = 215^\circ$), but its stellar tracers are still scarce (Vázquez et al. 2008). Partly because of this absence of tracers, we still lack a complete picture of the extent of the Perseus Arm towards the Third Quadrant, and the connection between the Local Feature and the major spiral design (Vázquez et al. 2008 see a recent discussion in Foster & Brunت 2015). Recently, Choi et al. (2014) have used trigonometric parallaxes for water masers in massive star-forming regions to trace the Perseus Arm in the second and third quadrants. They find a number of tracers of the Perseus arm around $l = 190^\circ$, with distances clustered around 2 kpc, but again no tracers are found between $l = 140^\circ$ and $l = 180^\circ$. Over this longitude range, there are a number of young open clusters with distances around $\sim 4$ kpc at $l = 150^\circ$ and $\sim 5$ kpc at $l = 180^\circ$ (Negueruela & Marco 2003 and references therein). They seem to delineate a poorly-populated spiral arm, but their distance is closer than expected for the position of the continuation of the Cygnus (+ II) arm in models such as those of Vallée (2015).

To help casting light on these issues, the aim of this work is to clarify the extent and definition of what has traditionally known as association Aur OB2. Aur OB2 is identified as a distant and compact association lying behind Aur OB1, with boundaries $l = 172^\circ$-$174^\circ$ and $b = -1^\circ8$ to $b = +2^\circ0$ (Humphreys 1978). The star-forming open cluster NGC 1893, containing five O-type stars, was considered the core of this association, but most modern studies based on accurate photometry (Marco et al. 2001, Fitzsimmons 1993) and spectroscopy on a distance around 5 kpc with the distance determined to other presumed members (Humphreys 1978). Visually, IC 410, the H II region illuminated by NGC 1893, seems to form part of a single complex of illuminated clouds together with IC 417 and IC 405. This is just an illusion, as IC 405 is a completely unrelated nebula, associated to a foreground ($d = 450$ pc) cloud illuminated by the runaway star AE Aur, believed to have been ejected from the Orion Cloud (France et al. 2004 and references therein). IC 417, also known as SH2-234, is the H II region illuminated by the open cluster Stock 8. Its Galactic coordinates are $l = 173^\circ37$ and $b = -0^\circ18$. In this paper, we present a photometric and spectroscopic study of Stock 8, the diffuse population of OB stars generally assigned to Aur OB2, and two other young open clusters that we identify in its vicinity.

There have been a few previous studies of Stock 8 and surroundings. However, the extent of the cluster itself has not been clearly defined. The name Stock 8 has been traditionally given to a strong stellar concentration that seems to be embedded in the nebula associated with Sh 2-234. Mayer & Macak (1971) carried out an spectroscopic and $UBV$ photometric study of 11 bright stars in its surroundings, finding a common distance for Stock 8 and some of the OB stars in its vicinity (a few arcminutes to the west; see Fig. 1), namely, a distance modulus ($DM$) of $12.36$ magnitudes ($1965$ pc), Malysheva (1990) used $UBV$ photometric of $\sim 66$ stars brighter than $V = 16$ inside an angular diameter of $20^\prime$ from Stock 8, and obtained a $DM$ of $11.39$ magnitudes ($1897$ pc) and an age of $\sim 12$ Ma. Jose et al. (2008) took $UBV$I, CCD photometry of the compact cluster and found a cluster radius of $\sim 6^\prime$, a variable reddening within the cluster region, going from $E(B-V) = 0.40$ to $0.60$ mag, and a distance of $2.05 \pm 0.10$ kpc. They detected a significant number of young stellar objects (YSOs) inside the cluster and in a Nebulous Stream towards the east side of the cluster (see Fig. 1). The YSOs lying in the Nebulous Stream were found to be younger than the stars in Stock 8. They conclude that the morphology of the region seems to indicate that the ionization/shock front caused by the ionizing sources located inside and west of Stock 8 has not reached the Nebulous Stream and the star formation activity in both regions may be independent.

In this paper, we study a much larger area of $\sim 40^\prime \times 40^\prime$, where we find Stock 8 and two candidates to young clusters, as well as a large number of early-type stars spread over the whole area. We aim to determine accurately the distance to all these objects and analyze how the stellar formation process has developed. The paper is organized as follows. In Section 2 we present the photometric and spectroscopic data used to make the subsequent analysis. This analysis, including the determination of spectral types for individual stars, and the reddening, distance and age for the three clusters studied, is developed in Section 3. In Section 4, we comment the impact of our results on the history of star formation and the position in the Milky Way of Stock 8 and surroundings. Finally, we enumerate our conclusions.

2 OBSERVATIONS AND DATA

2.1 Optical photometry

We obtained Strömgren photometry of three fields in the area of study with the 1-m Jacobus Kapteyn Telescope (JKT) at the Roque de los Muchachos Observatory (La Palma, Spain) during a run in 2003 February, 9–16. The telescope was equipped with the 2048×2048 SITE1 chip CCD and the four Strömgren $uvby$ and the narrow and wide $H\beta$ filters. The camera covers a field of $10^\prime \times 10^\prime$ and has a pixel scale of $0.733$ pixel$^{-1}$.

The first field was the area traditionally assigned to Stock 8, which was observed on the nights of 2003 February,
Table 1. Clusters observed from the JKT in February 2003. The top panel contains the target fields, while the bottom panel includes the clusters that contain the photometric standards. The coordinates are those provided by the WEBDA database: http://www.univie.ac.at/webda/ [Netopil et al. 2012], except for the two newly defined clusters.

| Name   | RA(J2000)     | Dec(J2000)      |
|--------|--------------|----------------|
| Stock 8 | 05h 26m 08.0s | +34° 25' 42" 0 |
| Alicante 11 | 05h 27m 36.2s | +34° 45' 19" 0 |
| Alicante 12 | 05h 28m 20.3s | +34° 47' 13" 5 |
| NGC 2244 | 06h 31m 55.0s | +04° 56' 30" 0 |
| NGC 2169 | 06h 09m 24.0s | +13° 57' 54" 0 |
| NGC 1502 | 04h 07m 40.4s | +62° 00' 59" 1 |
| NGC 1039 | 20h 23m 10.6s | +40° 46' 22" 4 |
| NGC 869  | 02h 19m 04.4s | +57° 08' 07" 8 |
| NGC 884  | 02h 22m 00.6s | +57° 08' 42" 1 |

9 – 10. For each frame, we obtained 7 series of different exposure times in each filter to achieve accurate photometry for a broad magnitude range. The central position for the cluster and the exposure times used are presented in Table 1 and Table 2 respectively.

The other two fields observed were centred on two stellar aggregates that we considered open cluster candidates. Subsequently to our observations, these open clusters have appeared in the literature as cluster candidates with the names of FSR 777 [Froebrich et al. 2007] and Kronberger 1 [Kronberger et al. 2006]. These two objects are confirmed as young open clusters here and named Alicante 11 and Alicante 12, respectively. The frames, taken on the nights of 2003 February, 15 – 16, were centred on the coordinates displayed in Table 1. We obtained 7 series of different exposure times for Alicante 11 and 3 series for Alicante 12. The exposure times used are presented in Table 2. Since Stock 8 is partially embedded in dark nebulosity, exposure times for this field were longer than those in the other two fields. Our intention was to reach an absolute magnitude that would allow us to trace the whole sequence of B types. As will be seen later, this was effectively achieved.

Standard stars were observed throughout the run in the clusters NGC 869, NGC 884, NGC 1039, NGC 1502, NGC 2169 and NGC 2244, using the exposure times suitable to obtain good photometric values for all stars selected as standards in these clusters. The central positions for the clusters and the exposure times used are presented in Table 1 and Table 2 respectively. If any of the selected standards turned out to be saturated, we repeated the observations with a shorter exposure time.

We reduced the frames for all clusters with IRAF routines for the bias and flat-field corrections. Photometry was obtained by point-spread function (PSF) fitting using the DAOPHOT package [Stetson 1987] provided by IRAF. The apertures used are of the order of the full width at half max-

Table 2. Log of the optical photometric observations taken at the JKT in February 2003.

| Filter | Long times | Short times |
|--------|------------|-------------|
| u      | 1800       | 400         |
| v      | 500        | 175         |
| b      | 200        | 100         |
| y      | 150        | 50          |
| H_n   | 1800       | 400         |
| H_w   | 200        | 100         |
| u      | 450        | 100         |
| v      | 180        | 40          |
| b      | 100        | 20          |
| y      | 50         | 8           |
| H_n   | 400        | 100         |
| H_w   | 60         | 15          |
| u      | 35         | 20          |
| v      | 30         | 20          |
| b      | 15         | 10          |
| y      | 20         | 5           |
| H_n   | 25         | –           |
| H_w   | 10         | –           |
| u      | 50         | –           |
| v      | 30         | –           |
| b      | 20         | –           |
| y      | 20         | 10          |
| H_n   | 50         | –           |
| H_w   | 25         | –           |
| u      | 400        | –           |
| v      | 200        | –           |
| b      | 150        | –           |
| y      | 30         | 10          |
| H_n   | 350        | –           |
| H_w   | 30         | –           |
| u      | 50         | –           |
| v      | 30         | –           |
| b      | 20         | –           |
| y      | 100        | –           |
| H_n   | 25         | 5           |
| H_w   | 50         | –           |

1 IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
imum. In this case, we used a value of 6 pixels for each image in all filters. In order to construct the PSF empirically, we automatically selected bright stars (typically 25 stars). After this, we reviewed the candidates and we discarded those that did not reach the best conditions for a good PSF star. Once we had the list of PSF stars (≈ 20), we determined an initial PSF by fitting the best function between the 5 options offered by the PSF routine inside DAOPHOT. We allowed the PSF to be variable (of order 2) across the frame to take into account the systematic pattern of PSF variability with position on the chip.

We needed to perform an aperture correction of 26, 25 and 30 pixels for the u, v and b filters, respectively. The aperture correction for the rest of the filters: y, Hβ, and Hβ′ was of 28 pixels. The atmospheric extinction corrections were performed using the RANBO2 program, which implements the method described by [Manfroid 1993]. Finally, we obtained the instrumental magnitudes for all stars.

The selection of standard stars has been explained in [Marco & Negueruela 2013]. In this work, we used two new open clusters that fulfilled the requirements to provide standard and their photometric data to be used in the transformations of CCD Strömgren photometry of open clusters are given in Table 3.

With the standard stars, we transformed the instrumental magnitudes to the standard system using the PHOTCAL package inside IRAF. We implemented the following $uvby$ transformation equations, after [Crawford & Barnes 1970a], and the $\beta$ transformation equation after [Crawford & Mander 1966]:

\[
V = (-4.937 + A) - 0.110(b - y) + y_i \\
\pm 0.009 \pm 0.035
\]

\[
(b - y) = (0.231 + B) + 1.037(b - y)_i \\
\pm 0.002 \pm 0.013
\]

\[
m_1 = (-0.668 + C) + 0.923m_1 - 0.159(b - y) \\
\pm 0.047 \pm 0.051 \pm 0.031
\]

\[
c_1 = (0.016 + D) + 1.020c_1 - 0.202(b - y) \\
\pm 0.011 \pm 0.011 \pm 0.030
\]

\[
\beta = (1.198 + E) + 0.703\beta_i \\
R^2 = 0.97
\]

where each coefficient is given with the error resulting from the transformation. The values of A, B, C, D and E represent zero points whose values are different for each filter. These values are provided in Table 3.

The number of stars that can be detected in all filters is limited by the long exposure time in the u filter. We selected for the analysis all stars with good photometry (photometric errors $\leq 0.05$ mag) in all six filters. We identify these stars on the frames that are then shifted and finally stacked into one single image. The procedure for obtaining the photometry from the reduced frames was the same as described in Section 2.3 for the optical images.

The next step is to transform these instrumental magnitudes to the 2MASS magnitude system [Skrutskie et al. 2000]. For this, we selected those stars in our field having $JHK_s$ magnitudes in the 2MASS catalogue with photometric errors smaller than 0.03 magnitudes in every filter (about 80 stars). A linear transformation was carried out between instrumental and 2MASS magnitudes. No color term was needed, since a simple shift in zero point results in a good transformation. This was checked by plotting the transformed magnitudes against 2MASS magnitudes for the stars with 2MASS magnitudes in the field, finding that the best fit corresponds to a straight line of slope 1 in all three filters.
A wavelength range of \( \approx 0.22 \, \text{Å/pixel} \) (resolving power of approximately 7,000), covering a classification region, this configuration gives a dispersion of \( G \). Gillet et al. 1994 for a description of the instrument. In the 2048 \( \times \) 4400 \( \text{Å} \). It is, therefore, necessary to observe two wavelength regions to cover the classical classification region.

For this programme, the two regions selected (identified as Position 1 and 2 in Table 5) were centred at \( \lambda = 4175 \, \text{Å} \) and \( \lambda = 4680 \, \text{Å} \). In principle, all objects were intended to be observed in both regions, resulting in coverage in the \( \lambda 43950 - 4900 \, \text{Å} \) range, with a small gap (\( \sim 60 \, \text{Å} \)) around \( \lambda 4425 \, \text{Å} \). No strong photospheric lines are found in the gap, but the strong diffuse interstellar line (DIB) at \( \lambda 4428 \, \text{Å} \), which is a good indicator of the reddening, is lost. The complete log of observations at the 1.52-m OHP is given in Table 5.

We have near-IR photometry for 589 stars. In Table 4, we list the number of each star, their RA and DEC coordinates in J2000, and the value of \( J \), \( H \) and \( K_S \) with the photometric error for each magnitude. There is only one measurement for each filter. The completeness limits in the 2MASS standard system are \( J \sim 18 \), \( H \sim 17 \) and \( K_S \sim 18 \).

### 2.3 Spectroscopy

Spectra of the brightest stars in the area were taken with the Aurèle spectrograph on the 1.52-m telescope at the Observatoire de Haute Provence (OHP) during two dedicated runs on 2002 January 18 – 22 and 2002 February 25 – 28 (when only the first night was useful because of the weather). The spectrograph was equipped with grating #3 (600 \( \text{ln mm}^{-1} \)) and the Horizon 2000 2048 \( \times \) 1024 EEV CCD camera (see Gillet et al. 1994 for a description of the instrument). In the classification region, this configuration gives a dispersion of 0.22 Å/pixel (resolving power of approximately 7,000), covering a wavelength range of \( \approx 440 \, \text{Å} \). It is, therefore, necessary to observe two wavelength regions to cover the classical classification region.

For this programme, the two regions selected (identified as Position 1 and 2 in Table 5) were centred at \( \lambda = 4175 \, \text{Å} \) and \( \lambda = 4680 \, \text{Å} \). In principle, all objects were intended to be observed in both regions, resulting in coverage in the \( \lambda 43950 - 4900 \, \text{Å} \) range, with a small gap (\( \sim 60 \, \text{Å} \)) around \( \lambda 4425 \, \text{Å} \). No strong photospheric lines are found in the gap, but the strong diffuse interstellar line (DIB) at \( \lambda 4428 \, \text{Å} \), which is a good indicator of the reddening, is lost. The complete log of observations at the 1.52-m OHP is given in Table 5.

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### 3 RESULTS

#### 3.1 Spectral classification

To characterize the morphology of the whole region, we observed spectroscopically almost all the stars in the area that have been classified as early-type stars in the literature. The stars observed cover a region of approximately 40’ \( \times \) 40’ that includes the 3 open clusters studied and a very significant diffuse population scattered over most of the region. These stars are represented by open red squares in Fig. 1 and listed

| Star | \( V \) | \( b - y \) | \( m_1 \) | \( c_1 \) | \( \beta \) | Spectral Type |
|------|------|------|------|------|------|-------------|
| NGC 2244 | | | | | | |
| 114 | 7.590 | 0.207 | -0.048 | -0.081 | 2.608 | O8.5 V |
| NGC 2169 | | | | | | |
| 11 | 10.600 | 0.084 | 0.065 | 0.541 | 2.698 | B8 V |
| 15 | 11.080 | 0.130 | 0.109 | 0.944 | 2.864 | B9.5 V |
| 18 | 11.800 | 0.115 | 0.105 | 0.912 | 2.872 | B9.5 V |

The data are taken from Crawford 1975 and Johnson & Morgan 1953 for NGC 2244 and Perry et al. 1978 for NGC 2169. Spectral types are taken from Walborn 1971 for NGC 2244, and Perry et al. 1978 for NGC 2169.

| Night | A | B | C | D | E |
|-------|---|---|---|---|---|
| 20030209 | 18.079 | 0.174 | 0.816 | 0.431 | 2.105 |
| 20030210 | 18.036 | 0.173 | 0.818 | 0.429 | 2.104 |
| 20030215 | 16.574 | 0.432 | 0.259 | 0.805 | 2.049 |
| 20030216 | 13.784 | 0.805 | 0.156 | 0.478 | 1.687 |

We have near-IR photometry for 589 stars. In Table 4, we list the number of each star, their RA and DEC coordinates in J2000, and the value of \( J \), \( H \) and \( K_S \) with the photometric error for each magnitude. There is only one measurement for each filter. The completeness limits in the 2MASS standard system are \( J \sim 18 \), \( H \sim 17 \) and \( K_S \sim 18 \).

Astrometric referencing of our images was made using positions of a number of stars from the 2MASS catalog. The PSFs of these stars are not corrupted by the CCD over-saturation effects. We used IRAF tasks ccmp/cctran for the astrometric transformation of the image. Formal rms uncertainties of the astrometric fit for our images are < 0′′10 in both right ascension and declination.
Figure 1. Map of the area showing the full field studied and the three areas for which we obtained Strömgren photometry. The image has been downloaded with Aladin and represents a false-colour composite of WISE bands. The pinkish regions represent extended dust emission. Red squares indicate stars with spectra. Circles in blue, green and yellow are stars with optical photometry in the three areas (Stock 8, Alicante 11 and Alicante 12). The Nebulous Stream of Jose et al. (2008) can be seen just to the east of Stock 8. The cluster candidate CC 14 is the small clump of infrared sources located where the stream meets the grid line corresponding to R.A. = 05h 29m. The size of field is $59'18 \times 47'82$. North is up and east is left.

in Tables 5 and 6. In these tables all the stars are listed by their identifier in the LS V (Hardorp et al. 1965) catalog except for HD 281147, which is missing in this catalog. Cross-correlation with our numbering system is provided for stars with photometry. Other more usual identifiers of the brightest stars, such as HD numbers, are also given.

The stars observed, according to their distribution, can be grouped as follows:

- The two brightest stars illuminating the H II region, at the core of Stock 8, LS V +34°29 (ST93) and LS V +34°31 (ST120), and a set of 5 stars within the limits given for Stock 8 by Jose et al. (2008): ST23, ST25, ST61, ST97 and ST101
- A group of 12 stars spread to the west of Stock 8 that have been assumed to be somehow connected to Stock 8 by previous authors: LS V +34°23, LS V +34°12, LS V +34°21, LS V +34°13, LS V +34°14, LS V +34°11, LS V +34°16, LS V +34°18, LS V +34°15, LS V +34°24, LS V +34°10 and LS V +34°8
- Two stars to the north of Stock 8, clearly detached from the cluster, LS V +34°35 and LS V +34°36
- A more distant star to the NW, HD 281147 and another isolated star to the north of Alicante 12: LS V +34°37
- Four stars in the core of Alicante 12: 20, 21, 24 and 30
- Six stars in the core of Alicante 11: 12, 27, 29, 49, 56 and 57

The spectra obtained were used for spectral classification by comparison to spectra of MK standard stars observed at similar resolution, following the standard classification procedures of Walborn & Fitzpatrick (1990). In a second step, we checked internal consistency by comparing all the spectra obtained amongst themselves. In principle, the much
higher resolution of the OHP spectra allows a much more accurate classification, but in some cases the signal-to-noise ratio in the 4000–4500 Å region is very low, resulting in inaccurate classifications, marked as such in Table 5. Spectra observed with ALFOSC can be considered accurate to ±1 subtype.

All the stars in the LS catalog (Hardorp et al. 1965), as expected, turn out to be of early type. The only object that does not belong to the OB group is LSV +34°8 that, at B4 III, is a bit too late for the catalog, and too old to belong to the same population as the rest of the stars in the region, even though its DM (calculated from the 2MASS data) is readily compatible. All the stars observed within the clusters have spectral types compatible with membership except for two early-type foreground objects, ST101 in Stock 8, and Alicante 11-27. Noteworthy aspects of some of the spectra are discussed below:

- LSV +34°29 (ST 93) is the brightest star in Stock 8. The spectrum suggests it is a moderately fast rotator, but the lines appear very shallow (Fig. 5). Formally, the criterion Si III 4553Å ≃ He II 4542Å defines spectral type O9.7. The relative weakness of He II 4686Å indicates then a luminosity class IV. However, the Si IV lines are quite weak (Si IV 4116Å is not even seen). All metallic lines look too weak and shallow, and this suggests that this object is really a spectroscopic binary whose spectral type results from the combination of a late-O and an early-B star.

- LSV +34°23 has a spectral type O8, rather earlier than previously assigned (Fig. 5). It had been classified as B0.5 IV by Morgan et al. (1953), most likely as a consequence of
Figure 3. Finding chart for stars with photometry in Alicante 11. The image, provided by Aladin, is a DSS2 blue digitization. Numbers and coordinates in J(2000) are listed in Table 13. The size of the field is 18'01 × 10'75. North is up and east is left.

Table 5. Stars observed from the OHP 1.52-m. The first column indicates the volume and number in the Luminous Stars catalog or the name in the Henry Draper Catalog. The second and third columns indicate the dates when the two spectral positions were observed and (between brackets) the exposure time in seconds. The derived spectral types are given in the fourth column. Spectral types marked with a '*' are less secure than the average, because of poor signal to noise or presence of double lines. References for the photometric values in column 7 are: (1) Hiltner (1956) and (2) Mayer & Macak (1971).

| Name Number | Position 1 | Position 2 | Spectral Type | V | (B − V) | Reference | DM ± 0.5 | Ks |
|-------------|------------|------------|---------------|---|---------|-----------|---------|----|
| LS V +34°22 | 18/01 (600) | 19/01 (700) | O7.5 V        | 8.58 | 0.23 | 2 | 11.5 | 7.89 ± 0.02 |
| LS V +34°15 | 18/01 (750) | 19/01 (900) | B1 V         | 10.02 ± 0.05 | 0.20 | 1 | 11.6 | 9.37 ± 0.02 |
| LS V +34°16 | 18/01 (1000) | 19/01 (1000) | B1 V*       | - | - | - | - | - |
| LS V +34°18 | 18/01 (750) | 19/01 (1200) | O9.5 V*     | 10.01 | 0.67 | 2 | 11.0 | 8.04 ± 0.02 |
| LS V +34°21 | 18/01 (1200) | 19/01 (1500) | O9 V       | 10.70 | 0.94 | 2 | 10.9 | 7.88 ± 0.02 |
| LS V +34°29 | 20/01 (1000) | 25/02 (1200) | O9.7 IV     | 8.89 | 0.18 | 2 | 12.0 | 8.32 ± 0.02 |
| LS V +34°31 | 20/01 (1200) | 25/02 (1200) | B0.5 V     | 9.87 | 0.19 | 2 | 12.0 | 9.23 ± 0.02 |
| LS V +34°36 | 18/01 (600) | 19/01 (750) | O8 V(n)    | 8.78 | 0.26 | 1 | 11.4 | 8.02 ± 0.03 |
| LS V +34°23 | 20/01 (750) | 25/02 (900) | O8 II(f)    | 8.04 | 0.32 | 1 | 12.0 | 6.99 ± 0.02 |
| LS V +34°25 | 20/01 (750) | 25/02 (1200) | O9.5 V + B0.2 V | - | - | - | - | 7.59 ± 0.02 |
| LS V +34°11 | 18/01 (900) | 19/01 (1200) | B0.5 V     | 9.70 | 0.17 | 2 | 11.9 | 9.27 ± 0.02 |
| HD 281147   | 18/01 (900) | 19/01 (1200) | B1 V       | - | - | - | - | 9.63 ± 0.02 |

1 HD 35619 = Alicante 11-57; 2 BD +34°1054 = ST93; 3 BD +34°1056 = ST120; 4 BD +34°1058; 5 HD 35633; 6 HD 35652 = Alicante 11-56 (Eclipsing binary IU Aur); 7 HD 281150

Hiltner (1956) and Mayer & Macak (1971).
Figure 4. Finding chart for stars with photometry in Alicante 12. The image, provided by Aladin, is a DSS2 blue digitization. Numbers and coordinates in J(2000) are listed in Table 15. The size of field is 18′01×10′75. North is up and east is left.

Table 6. Classification spectra of stars in the area of Stock 8. These stars were observed with the NOT. References for the photometric values in column 7 are: (2) Mayer & Macak [1971] and (3) Mayer [1964].

| Star              | LS      | Spectral Type | Exposure Time(s) | V  | (B−V) | Reference | DM ± 0.5 | K5 |
|-------------------|---------|---------------|------------------|----|-------|-----------|----------|----|
| Alicante 11-12    | V +34′17| B2 V          | 250              | −  | −     | −         | −        |    |
| Alicante 12-21    | V +34′33| B2 V          | 300              | −  | −     | −         | −        |    |
| Alicante 12-24    |         | B7 V          | 300              | −  | −     | −         | −        |    |
| Alicante 12-20    |         | B9 V          | 300              | −  | −     | −         | −        |    |
| Alicante 11-29    | V +34′19| B2 V          | 400              | −  | −     | −         | −        |    |
| Alicante 12-49    | V +34′20| B1.5 V        | 400              | −  | −     | −         | −        |    |
| ST101             |         | A3 V          | 400              | −  | −     | −         | −        |    |
| ST97              | V +34′30| B1 V          | 400              | −  | −     | −         | −        |    |
| ST61              | V +34′28| B1 V          | 350              | 10.92 | 0.27  | 3        | 12.3     |    |
| ST23              | V +34′27| B2 IV         | 400              | 11.66 | 0.33  | 3        | 13.0     |    |
| ST25              |         | B5 V          | 400              | −  | −     | −         | −        |    |
| −                 | V +34′35| B0.7 V        | 200              | −  | −     | −         | −        |    |
| −                 | V +34′12| B1 V          | 300              | 10.91 | 0.30  | 2        | 12.2     |    |
| −                 | V +34′13| B2 IV         | 400              | −  | −     | −         | −        |    |
| Alicante 11-27    |         | B8 V          | 300              | −  | −     | −         | −        |    |
| −                 | V +34′8 | B4 III        | 300              | −  | −     | −         | −        |    |
| −                 | V +34′24| B1 V          | 350              | 11.24 | 0.40  | 3        | 12.2     |    |
| −                 | V +34′10| B0.2 V        | 200              | 9.43  | 0.16  | 2        | 11.7     |    |
| −                 | V +34′37| O9.7 V        | 200              | 9.22  | 0.19  | 2        | 11.5     |    |

1 BD +34°1053; 2 HD 281151; 3 BD +34°1059
misidentification. The N\textsc{iii} 4634–41–42 complex is in emission, while He\textsc{ii} 4686Å is very weak and flanked by emission components. The object, therefore, presents a rather high luminosity. Just short of being a supergiant according to the criteria of Sota et al. (2011), we classify it as O8\textsc{ii}(f), while noting the complete absence of any absorption N\textsc{iii} lines. If the star is nitrogen deficient, it could probably have a higher luminosity.

- LS V +34°25 (Alicante 11-56) is a well known spectroscopic binary (IU Aur), which has received several very discrepant classifications. Though the two components are not very well resolved in the Position 1 spectrum, they are clearly separated in the Position 2 one (Fig. 6), and we derive spectral types of O9.5 V and approximately B0.2 V for the two components, based mainly on the relative strengths of the He\textsc{ii} 4686Å and C\textsc{iii} 4505Å lines. These values are in surprisingly good agreement with the masses $M_1 = 21.3 M_\odot$ and $M_2 = 14.4 M_\odot$ derived by Drechsel et al. (1994). Drechsel et al. (1994) also identify a third body in this system, with a mass $M_3 = 17.8 M_\odot$, which accounts for ~20% of the light. Since a third spectrum is not seen, Drechsel et al. (1994) support the idea that the third body is a close binary consisting of two B2–B3 stars.

- LS V +34°22 (Alicante 11-57) is the brightest star in Alicante 11. Based on standard criteria, we classify it as O7.5 V. Sota et al. (2014) give a more accurate classification O7.5 V((f)), based on higher-quality spectra.

- LS V +34°36, classified as O8\textsc{inm} by Morgan et al. (1955), does not show very broad lines in our spectrum (Fig. 6). The object, though, is a double-lined spectroscopic binary. The combined spectrum has spectral type O8 V, but all the lines are broad and asymmetric, clearly showing the presence of a second companion. Given the width of He\textsc{ii} 4542Å, the two components are O-type stars. Since He\textsc{ii} 4686Å is abnormally weak, at least one of them could be of higher luminosity.

- HD 281147 is given as O8\textsc{inm} in Simbad, after Garmany & Conti (1984). This is almost certainly due to a confusion with BD +34°1058, which is the object observed by IUE. Our spectrum gives a a spectral type B1 V.

- The Position 1 spectra of LS V +34°16, LS V +34°18, and LS V +34°21 are little more than noise, and therefore their spectral types are based on a very limited spectral range, and must not be considered accurate.

### 3.2 Optical photometry for Stock 8

#### 3.2.1 HR diagrams

As a first step, we analyzed the uvby CCD photometry obtained for the cluster Stock 8 (Table 12) to determine the physical parameters of the cluster: reddening, distance and age. Initially, we plotted the diagrams V–(b–y) and V/c1 for all the stars in the field. In Fig. 7, red circles are stars with spectra and green squares are stars that appear misplaced in both diagrams and, therefore, were removed for the following analysis.

The next step in the analysis is the estimate of membership for the stars measured in the field. Given the depth of our observations, and the presence of O-type stars confirmed by spectroscopy, most cluster members in our sample must be B-type stars. Now, we can calculate the reddening-free indices $[m_1]$, $[c_1]$ and $[u-b]$, where:

$$
[m_1] = m_1 + 0.32(b-y) \quad (6)
$$

$$
[c_1] = c_1 - 0.20(b-y) \quad (7)
$$

$$
[u-b] = [c_1] + 2[m_1] \quad (8)
$$

We plot the $[c_1]$–$[m_1]$ and $[u-b]$–$[c_1]$ diagrams for all stars chosen in the V–(b–y) and V–c1 diagrams (see Fig. 8). We can divide the stars according to their spectral type. In this figure we can see that the stars spectroscopically classified (red squares) as B-type stars fall on the B-type star standard line, confirming the validity of this relationship. The only star classified as A3 V falls on the A-type star standard line. We can observe that the majority of the stars are in the same region in both diagrams. Therefore, using these standard relationships, we assign a spectral type for each star. After this, we use those stars falling on the B-type branch in both diagrams to make the following analysis.

Firstly, we calculate individual reddenings. We follow the procedure described by Crawford et al. (1970b): we use the observed $c_1$ to predict the first approximation to $(b-y)_0$ with the expression: $(b-y)_0 = -0.116 + 0.097c_1$. Then we calculate: \(E(b-y) = (b-y) - (b-y)_0\) and use $E(c_1) = 0.2E(b-y)$ to correct $c_1$ for reddening $c_0 = c_1 - E(c_1)$. The intrinsic colour $(b-y)_0$ is now calculated by replacing $c_1$ with $c_0$ in the above
equation for \((b-y)_{0}\). Three iterations are enough to reach convergence in the process. Naturally, this procedure only results in physically meaningful values for B-type stars. As we can see in the maps (see Fig. 1 and Fig. 2), the area of Stock 8 is still embedded in the parental cloud and therefore we expect to find an important degree of differential reddening amongst members. \(E(b-y)\) spans values between 0.3 and 0.8. In Fig. 3 we plot their surface distribution that can be compared with the extent of the cloud. Most of the stars with relatively low reddening (marked in red) fall along a narrow strip, almost vertical, that seems to coincide with a gap in the dark cloud. Stars with higher reddening concentrate almost exclusively close to the illuminated rim of the cloud.

With the aid of these individual values, we calculate the intrinsic colour \((b-y)_{0}\), index \(c_{0}\), and magnitude \(V_{0}\) of the 38 likely B-type members. The values of \(E(b-y)\), \(c_{0}\) and \(V_{0}\) for these likely B-type members are shown in Table 7.

### 3.2.2 Determination of the distance for Stock 8

We estimate the DM to Stock 8 by fitting the observed \(V_{0}\) vs. \((b-y)_{0}\) zero-age main sequence (ZAMS) and \(V_{0}\) vs. \(c_{0}\) ZAMS to the mean calibrations of Perry et al. [1987]. We fit the ZAMS as a lower envelope for the majority of members, deriving a best fit distance modulus of \(V_{0} - M_{V} = 12.2 \pm 0.2\) (the error indicates the uncertainty in positioning the theoretical ZAMS and its identification as a lower envelope; see Fig 10). This DM corresponds to a distance of 2.80$^{+0.27}_{-0.24}$ kpc.

We can check the validity of the distance modulus adopted by eye fitting, by comparing the absolute magnitude \(M_{V}\) obtained for the stars with spectral classification...
Figure 9. Reddening map for B-type stars with optical photometry in the cluster Stock 8. The image, downloaded from Aladin, is a false-colour composite of the three DDS bands, where R (and, hence Hα) is represented by green colours. Red solid squares represent stars with low reddening \( E(b-y) = 0.3 - 0.4 \), Pink solid squares are stars with moderately reddening \( E(b-y) = 0.5 - 0.6 \) and black solid squares are stars with high reddening \( E(b-y) = 0.7 - 0.8 \). North is up and east is left.

and their values in the calibration from \cite{Turner1980}. We can say that all values are compatible within errors, except for the A3V star that is considered a non-member.

3.2.3 Optical photometry for Alicante 11

We used the same procedure described in Sections 3.2.1 and 3.2.2 to analyze the photometric data from Table 14. Firstly, we plotted the \( V(b-y) \) and \( V/c_1 \) diagrams for stars in Alicante 11, where the red points are stars with spectra and green squares are stars that do not occupy the expected position in any of the diagrams. These outliers are considered field population and therefore, not used in the subsequent analysis (see Figure 11). Secondly, we selected B-type stars using the \([c_1]-[m_1]\) and \([b-u-b]\) diagrams. All the early-type stars spectroscopically classified fall on the correct position in both diagrams, except Alicante 11-27 (B8 V), that we consider a non-member. After this, using the procedure described by \cite{Crawfordetal1970}, we calculated the individual reddenings \( E(b-y) \) for 28 stars that we label as likely members. As seen in Figure 1 and Figure 3, the region of Alicante 11 is outside the gas and dust cloud that covers the area where Stock 8 lies. Because of this, stars in this region present rather lower values of reddening compared to those of Stock 8. Most of them have values of \( E(b-y) \) around 0.4, which is the same \( E(b-y) \) that we found for the stars in Stock 8 falling along the narrow strip that seems to coincide with a gap in the dark cloud.

With the aid of these individual values, we calculated the intrinsic colour \((b-y)_0\), index \( c_0 \) and magnitude \( V_0 \) for the 28 likely B-type members. The values of \( E(b-y) \), \( c_0 \) and \( V_0 \) for these likely members are shown in Table 8.

3.2.4 Determination of the distance for Alicante 11

We estimated the distance modulus to Alicante 11 by using the same procedure as for Stock 8. The fit of the ZAMS as a lower envelope for the majority of members in the \( V_0 \) vs. \( (b-y)_0 \) and \( V_0 \) vs. \( c_0 \) diagrams (see Fig 12) gives a distance modulus of \( V_0 - M_V = 12.2 \pm 0.2 \) \((2.80^{+0.27}_{-0.24}\ kpc)\). We can then check the validity of the distance modulus by comparing the absolute magnitude \( M_V \) obtained for the stars with spectral classification. All of them give values compatible within errors with the calibration of \cite{Turner1980}, except for the binary star IU Aur, which, as discussed above, is likely a complex system with no less than four OB stars. The absolute magnitude that we obtain for IU Aur assuming the distance to the cluster is totally compatible with the configuration outlined by \cite{Drechseletal1994}.
Figure 10. Left: Absolute magnitude $M_V$ against intrinsic colour $(b-y)_0$ for Stock 8. Solid magenta squares are stars with spectra. The solid line represents the ZAMS from Perry et al. (1987). Right: Absolute magnitude $M_V$ against intrinsic index $c_0$ for Stock 8. Solid magenta squares are stars with spectra. The solid line represents the ZAMS from Perry et al. (1987).

Figure 11. Left: $V/(b-y)$ diagram for all stars in Alicante 11. Red circles represent stars spectroscopically observed and green squares non-member stars. Right: $V/c_1$ diagram for all stars in Alicante 11. Red circles represent stars spectroscopically observed and green squares non-member stars.

Figure 12. Left: Absolute magnitude $M_V$ against intrinsic colour $(b-y)_0$ for Alicante 11. Solid magenta squares are stars with spectra. The solid line represents the ZAMS from Perry et al. (1987). Right: Absolute magnitude $M_V$ against intrinsic index $c_0$ for Alicante 11. Solid magenta squares are stars with spectra. The solid line represents the ZAMS from Perry et al. (1987).
3.2.5 Optical photometry for Alicante 12

We performed the same analysis done in Sections 3.2.3 and 3.2.4 for Stock 8 and Sections 3.2.3 and 3.2.4 for Alicante 11. We plot the $V(b-y)$ and $V(c_1)$ diagrams for stars in Alicante 12, where the red points are stars with spectra and green squares are stars considered non-members by applying the same criteria as in the other clusters (see Figure 13). We selected the B-type members from the $[c_1]-[m_1]$ and $b-[n-b]$ diagrams, checking that their $V$ values corresponded to their spectral types and, then, we calculated their individual $E(b-y)$. We find that the average value is $E(b-y) = 0.4$, similar to the value for the stars in Alicante 11. We can observe in Figure 1 and Figure 4 that the cluster is not inside the parental cloud. Finally, we calculate the dereddened values $(b-y)_0$, $c_0$ and $V_0$ of the 17 likely B-type members (displayed in Table 9).
solvent magnitude $M_V$ obtained for the stars with spectral classification to the calibration of Turner (1980). All stars are compatible within errors, except for the star classified as B9 V that we do not consider a member.

**3.2.7 A common distance for Stock 8, Alicante 11 and Alicante 12**

We have obtained optical photometry for the three different regions indicated in Figure 13. The first region corresponds to the known open cluster Stock 8 that is still partially embedded in its parental cloud. The two other regions are approximately 20° north of Stock 8 and not associated with the nebulosity. Strömgren photometry allows us to study the population of these three regions and to determine their distances with accuracy. We have calculated a distance for Stock 8 of $2.80_{-0.27}^{+0.22}$ kpc using 38 likely early type members. In the other two regions, we find clear sequences of early type stars that define two new clusters that had not been studied before, and we name Alicante 11 and Alicante 12. We have found 28 likely B-type members for Alicante 11 and 17 likely B-type members for Alicante 12, and we have estimated the same distance as for Stock 8. Their coordinates are shown in Table 1. The typical $E(b-y)$ values for B-type members in the two new clusters are very similar, and also similar to those found for the stars placed in a hole in the cloud surrounding Stock 8. This concordance suggests that the two new open clusters are fully detached from their parental cloud, and therefore, the reddening in their directions is entirely caused by intervening foreground material. In Figure 15, we plot the absolute magnitude $M_V$ against intrinsic index $c_1$ for all the stars considered members in Stock 8 (blue), Alicante 11 (green) and Alicante 12 (cyan). Squares are stars with spectra. We can see that all of them are placed at the same distance modulus of $V_0 - M_V = 12.2 \pm 0.2$, corresponding to a distance of $2.80_{-0.24}^{+0.27}$ kpc.

**3.2.8 Bright stars with spectra. Determination of their distance modulus**

In addition to the three open clusters, there is a large, diffuse population of OB stars scattered over the whole area. Many of them have $UBV$ photometry available in the literature, and all of them have $JHK_S$ photometry from 2MASS. We used their spectral types to calculate their distance moduli and check if they are compatible with the common $DM$ that we find for Stock 8, Alicante 11 and Alicante 12 ($V_0 - M_V = 12.2 \pm 0.2$). For objects with $UBV$ photometry, we utilized the calibration of intrinsic colours from Fitzgerald (1970) and the calibration of average absolute magnitude against spectral type from Turner (1980). The results are shown in Tables 5 and 6.

We find that essentially all the stars with $UBV$ photometry have a distance modulus compatible within errors with the value obtained for the three open clusters studied. Generally, calibrations are assumed to have an intrinsic dispersion around $\pm 0.5$ magnitudes. Possible exceptions would be LS V +34°18, LS V +34°21, and LS V +34°36. For the latter, we have already mentioned that the spectral type is simply the average of two components, one of which is likely more luminous, and so the discrepancy in $DM$ is only apparent. The other two are marked as the less reliable spectral types, as their spectra are very poor. In many cases early-type stars are binaries or multiple systems, and then the spectral type derived from a single spectrum of moderate resolution can be an average of the spectral types of the components. Therefore, we do not think that any of these stars is ruled out as a member of the association, while LS V +34°36 is very likely a member, and one of the main sources of ionizing photons in the area.

For the stars without $UBV$ photometry, we can use the $(J-K)_S$ colour to check that the extinction is not higher than that of members of Alicante 11 and 12, and the $K_S$ magnitude to check that their brightness is not incompatible with its spectral type at the $DM$ of the clusters. Thus, we can conclude that all of the isolated stars seen in the area are compatible with the common distance of all three clusters, and therefore they form an OB association extending over...
at least the region studied, i.e., over ~50′ corresponding to ~40 pc at 2.80 kpc.

3.2.9 2MASS diagram

Most of the stars observed lie in areas completely devoid of not only Hz nebulosity, but also dust emission (see Fig. 1). The obvious exception is the region of the open cluster Stock 8, which lies in a typical H II “blister” on the wall of a molecular cloud (see Fig. 2). This area, as can be seen in Fig. 1 also shows strong dust emission. It is therefore important to use infrared wavelengths to detect and study the population hidden by nebulosity. To this purpose, we have used our own TNG near-IR photometry, combined with the 2MASS catalog (see Tables 10 and 11 for Stock 8).

Initially, we plot the $K_S$ magnitude against the $(J-K_S)$ colour in Fig. 16. Since we have already determined a distance modulus of $V_0 - M_V = 12.2 \pm 0.2$ and a minimum $E(b-y) = 0.4$ with the optical photometry, we use these values to draw the ZAMS. We use isochrones from Siess et al. (2000) with $Z = 0.020$ and no overshooting. The ZAMS extends from spectral type M6 until B3. The PMS isochrones for ages $4 \times 10^6$ and $6 \times 10^6$ years are also plotted in Figure 16. We calculated $E(J-K_S) = 0.3$ using the standard relationships: $E(b-y) = 0.74E(B-V)$ and $E(J-K_S) = 0.476E(B-V) + 0.007E(B-V)^2$. In Fig. 16, the likely B-type members (from the optical analysis) are represented as black solid circles, while the pink dots are stars with TNG photometry. We can observe that there is clearly a PMS star population associated with the B-type likely members. We can see a gap between $K_S$ of 14 and 15 mag, where there are no stars and so we fit the PMS isochrones to the stars on the top of this gap. From their position, we conclude that all the PMS stars formed in a single process of star formation between $4 \times 10^6$ and $6 \times 10^6$ years ago. We have no stars already leaving the upper-main sequence (because of evolution) and, therefore, we cannot use post-main-sequence isochrones to estimate the age of the cluster. Taking into account the position of the PMS isochrones, we can interpret that the pink dots with $(J-K_S) < 1$ are foreground stars and the rest of the stars are the PMS population of the cluster together with some field contamination that we estimate below.

test

Figure 14. Left: Absolute magnitude $M_V$ against intrinsic colour $(b-y)_0$ for Alicante 12. Solid magenta squares are stars with spectra. The solid line represents the ZAMS from Perry et al. (1987). Right: Absolute magnitude $M_V$ against intrinsic index $c_0$ for Alicante 12. Solid magenta squares are stars with spectra. The solid line represents the ZAMS from Perry et al. (1987).

Figure 15. Absolute magnitude $M_V$ against intrinsic index $c_0$ for Stock 8 (blue), Alicante 11 (green) and Alicante 12 (cyan). Squares are stars with spectra. The thick line represents the ZAMS from Perry et al. (1987).
diskless stars are B-type likely members already on the main sequence or stars not considered members (field stars). All green squares are placed on the right side of the diagram. This is only natural, as they should have an excess in the $(J-K_S)$ colour arising from the disk. We have to emphasize that the limiting magnitude reached by WISE corresponds in most cases to stars with $K_S = 14$ in this area. Moreover, WISE images have much worse spatial resolution than our IR images. For these two reasons, most of the stars seen in our IR diagram have no WISE counterpart, either because they are too faint or because of confusion. The WISE objects with disks therefore must represent a population of moderately massive PMS stars ($M \geq 3M_\odot$).

To complement this analysis, we can use the $(J-H) - (H-K_S)$ diagram, or equivalently the IR $Q$ reddening-free index. Stars with disks or strong infrared excess have negative values of $Q$ (Negueruela et al. 2007). The use of this index to identify different types of red luminous stars is discussed by Messineo et al. (2012) and González-Fernández et al. (2015). Red giants have $Q \geq 0.35$. In Fig. 16, we plot with crosses stars having $Q < -0.1$. Most of the stars classified as PMS stars with disk from the WISE analysis are also selected by this criterion. In addition, this population extends to fainter magnitudes, covering the same range of $(J-K_S)$.

We interpret them as lower mass PMS objects.

The degree of contamination by background stars is very low. There are very few stars with $Q > 0.35$ in our sample. Almost all of them are very faint, with $K_S \geq 16 - 17$ mag. They must therefore be field red dwarfs. In Fig. 16, we show with a large empty square the approximate position of unreddened red clump stars at the distance of the cluster, using typical photometric intrinsic parameters (Alves 2000 and Cabrera-Lavers et al. 2005). If we project this locus along the reddening vector (indicated on the top of Fig. 16), we can see that very few stars are compatible with being background red giants. Indeed, most of the stars in this part of the diagram are PMS stars with disk according to the WISE criteria. This is not surprising, as we are looking at a distant cluster in the direction of the Anticenter. The background contamination must thus be low.

4 DISCUSSION

We have studied a region with a size of $\sim 40' \times 40'$ located close to the known open cluster Stock 8. Much of this area shows evidence for dust emission. We provide spectral types for almost all the cataloged early-type stars in the region, many of which are part of a diffuse population scattered over the field. Our spectral types confirm that all of them are early-type stars (see Tables 1 and 2). The spectral types range between O7.5 V and B4 III. The surface distribution of all the OB stars in the region can be seen in Fig. 17. The population can be roughly divided in two clumps. The first one, to the north, comprising Alicante 11 and Alicante 12 and a few other stars, lies in the area devoid of dust emission (Fig. 1) and with weak Hα emission (Fig. 17). The second one, on the southern half of the field, is formed by Stock 8 and a large population of stars scattered to the west of the cluster. This second group lies in an area showing evidence for diffuse dust emission and stronger Hα emission. The spectral types observed, however, do not evidence any difference in age between the two groups, with the earliest spectral type found in the northern clump.

We have obtained a common distance of $2.80^{+0.27}_{-0.24}$ kpc ($DM = 12.2 \pm 0.2$) for the three open clusters in the area studied (Stock 8, Alicante 11 and Alicante 12) and an age between $4 - 6$ Ma for Stock 8. These values are compatible with the previous estimation of the distance ($DM = 12.4$) for Stock 8 by Mayer & Macak (1971). They show rather worse agreement with the values of $DM = 11.4$ of Malysheva (1990) and $d = 2.05^{+0.10}_{-0.05}$ kpc ($DM = 11.6$) of Jose et al. (2008). The discrepancy with Malysheva (1990) is likely due to her derivation of an age of 12 Ma (at least double than the value that we find, 4 – 6 Ma). Her analysis, based on photographic photometry, cannot be so accurate as Strömgren photometry combined with spectroscopy. The presence of several O-type stars in the area and the PMS population in Stock 8 rule out such a high age. In the case of Jose et al. (2008), the discrepancy can have two procedural reasons. The main one is the value adopted for the reddening in calculating the distance. The reddening is variable because of the presence of the parent cloud, and for this reason, we have used individual values for B-type members. The second reason is our choice of the ZAMS as a lower envelope to the position of cluster stars. Conversely, their fit in their Fig. 9 is almost an upper envelope to the early-type stars (perhaps, again, because of their value for the reddening). Given the width of the main sequence, this difference alone can account for 0.3 or 0.4 mag in the $DM$ derived.

4.1 Morphology of the region

The most remarkable feature in the region is the bright Hα and dust shell lying immediately to the east of Stock 8 (Fig. 17). This shell, which is also bright in radio (Jose et al., 2008), must be ionized by some of the OB stars in its vicinity. Jose et al. (2008) suggest that LS V +34°29, the brightest star in Stock 8, can emit enough ionizing photons to account for the photoionisation of the whole shell. In spite of this, they argue that the O-type stars LS V +34°18 and LS V +34°21 can contribute to the ionizing flux. However, we note that these two stars are much more reddened than any other OB star in the area (compare their V and K_S in
Table 5, and seem to be partially immersed in dust in the WISE image.

Our new spectral type for LSV +34°23 (HD 35633), O8II(f), undoubtedly means that this is the main source of ionizing photons in the area. The morphology of the shell is perfectly compatible with this (see Figures 1 and 5). This star was classified as B0IV by Morgan et al. (1953). This classification is almost certainly due to a misidentification.

Simón-Díaz & Herrero (2014) classify it as O7.5II(f)(n) in good agreement with our value. They measure a $v_{\text{hel}} \approx 170\,\text{km}\,\text{s}^{-1}$. LSV +34°23 is the only star in the area that is clearly evolved away from the ZAMS that can ionize this filament is LS V perpendicular to our line of sight in projection. The only star marking a photoionisation front that appears almost perpendicular to Stock 8. The wide-field Hα images suggest that the filament is not directly associated to Stock 8. They also find that all these YSOs are younger than Stock 8. Indeed, the images suggest that the filament is not directly associated to Stock 8. The wide-field Hα image (see Fig. 17) shows a bright filament of H II emission that is probably marking a photoionisation front that appears almost perpendicular to our line of sight in projection. The only star that can ionize this filament is LSV +34°36 (BD +34°1058). This star, situated to the north of Stock 8 and in relative isolation, is an SB2 with integrated spectral type O8V that probably contains a moderately-luminous O-type star.

As discussed in Sect. 3.2.5, the hypothesis that all the OB stars that we have observed are at the same distance is perfectly consistent with observations. Unfortunately, there is no CCD optical photometry available in the literature for the area to the west of the cluster containing a large number of early-type stars to study if there is an underlying population of stars accompanying the concentration of 6 OB stars in an area $\sim 3' \times 4'$. (LSV +34°11, 13, 15, 16, 18 and 21), which could represent a diffuse cluster similar to Alicante 11. However, observation of 2MASS images and simple star counts in the 2MASS catalog suggest that, even though most of the OB stars are outside the area covered by our photometry, most of the intermediate-mass stars are inside the area covered. This configuration is very reminiscent of that found in the very young open cluster NGC 1893, which also sports a number of OB stars at some distance of the cluster core, in a region where there are essentially no intermediate-mass stars (Negueruela et al. 2007).

4.2 History of star formation in the region

Kang et al. (2012) have suggested the presence of a large-scale star-formation structure in this area. They present the results of H i 21 cm-line observations to explore the nature of the high-velocity H i gas at $l = 173^\circ$. They designated this feature as Forbidden Velocity Wing (FWW) 172.8+1.5. Since this direction lies very close to the Galactic Anti-centre, the Galactic rotation curve predicts very low radial velocities, and high-velocity components are not expected. FWW 172.8+1.5 seems to be associated with the H ii complex G173+1.5, interpreted as one the largest star-forming regions in the outer Galaxy. Kang et al. (2012) consider that the complex is composed by two groups of Sharpless H ii regions and a surrounding population of OB stars, distributed along a radio continuum loop of size $4.4' \times 3.4'$. The geometry of the area (in two dimensions) can be seen in their Fig. 5.

Two groups of H ii regions can be seen in the area studied by Kang et al. (2012). To the northeast, the H ii regions Sh 2-231, Sh 2-232, Sh 2-233 and Sh 2-235 have been claimed to be associated with a single molecular cloud. The distances determined by the spectrophotometry of the exciting stars of the individual H ii regions are between 2.3 kpc and 1.0 kpc, while their radial velocities are: $-18.1 \pm 0.9$, $-23 \pm 0.5$, $-18.4 \pm 0.5$ and $-18.8 \pm 1.7$, respectively (from the catalogue of Blitz et al. 1982). Kang et al. (2012) adopt a distance of 1.8 kpc, after Evans & Blair (1981). However, a recent comprehensive study of the extinction in this area (Straizys et al. 2010) finds a lower distance of 1.3 kpc for the complex (though these authors suggest that Sh 2-231 may not belong to the complex, but rather be a background object with a much higher distance). Since this distance is compatible with the estimate for Aur OB1 found by Humphreys (1978) from a few isolated OB stars, Straizys et al. (2010) identify the complex as the core of Aur OB1. To the southwest, the H ii regions Sh 2-234 and Sh 2-237 are associated with the open clusters Stock 8 and NGC 1931, respectively.

Kang et al. (2012) assume that all the high-velocity structures in the area are connected, concluding that the H i-line feature FWW 172.8+1.5 is well correlated with a radio continuum loop, and the two seem to trace an expanding shell. The expansion velocity of the shell would be $55\,\text{km}\,\text{s}^{-1}$ (well beyond the velocities allowed by Galactic rotation) and the kinetic energy of the shell would then be $2.5 \times 10^{50}$ erg, suggesting that it represents an old ($\sim 0.33$ Ma) supernova remnant produced inside this complex. They propose that the progenitor belonged to a stellar association near the center of the shell, and that this association could have triggered the formation of the OB stars currently exciting the H ii regions on both edges of the shell. The H ii complex G173+1.5 would then be an excellent example of sequential star formation over several stellar associations.

Our data do not seem to provide support for this interpretation. A close connection between Stock 8 and NGC 1931 seems unlikely, in spite of their proximity on the sky. The radial velocities of the associated molecular clouds are $-13.4 \pm 0.7\,\text{km}\,\text{s}^{-1}$ and $-43 \pm 0.7\,\text{km}\,\text{s}^{-1}$, respectively (as measured by CO velocities in Blitz et al. 1982). Fich et al. (1990) observed the radial velocity and line width of $\text{H}\alpha$ emission from 284 objects listed in Galactic H ii regions catalogs. The values measured for Sh 2-234 and Sh 2-237 were $-14.3 \pm 0.5\,\text{km}\,\text{s}^{-1}$ and $+1.4 \pm 0.4\,\text{km}\,\text{s}^{-1}$, respectively. Differences of a few $\text{km}\,\text{s}^{-1}$ are regularly observed between the cold and ionized components (Fich et al. 1990), as is the case...
for Sh 2-237. However, the values of radial velocities from both measurements for Sh 2-234 (Stock 8) match within errors. This does not suggest the presence of perturbed gas, as would be expected if star formation was triggered by a shock wave. Moreover, the geometry of the shell, as discussed in the previous section, clearly demonstrates that it is ionized by stars to its west, and this is very difficult to reconcile with a shock wave coming from the east as the triggerer of star formation.

Independently of these measurements, the main difficulty with the scenario proposed by Kang et al. (2012) is the lack of cataloged OB stars inside the giant shell. If the supernova happened 0.33 Ma ago, it cannot have triggered the formation of a cluster that is >4 Ma old. Kang et al. (2012) suggest that the progenitor of the supernova was part of a population that might have triggered large-scale star formation, but there are very few stars that could belong to this population. The only O-type star that has a DM compatible is the multiple system LY Aur (Mayer 2013).

With these characteristics, our distance to Stock 8 is just compatible with a location in the Perseus arm, within errors. We have to caution, however, that the simple picture of Galactic structure based on four main arms is not shared by many authors. The Orion arm, as observed by Xu et al. (2013) is a major structure. According to some authors, it extends for many kpc towards $l = 240^\circ - 250^\circ$, intersecting the Perseus and even the Outer arm (Vázquez et al. 2008; Costa 2015). On the other hand, the Perseus arm is very poorly traced beyond $l = 193^\circ$. All the possible tracers given by Reid et al. (2014) lie at very large distances from their fit. Conversely, a large number of stellar tracers seem to lie between the Orion and the Perseus arm all the way between $l = 180^\circ$ and $l = 240^\circ$, perhaps suggesting a more fluffy structure.

### 4.3 Position in the Milky Way

The current understanding of Galactic structure towards the Anticentre and in the third quadrant is very poor, in spite of many important recent developments. Several models of the structure and dynamics of the Galaxy have been published in the past few years, based on improved information (e.g. Bobylev & Bajkova 2010; McMillan & Binney 2010; Honma et al. 2012; Vallee 2015). In particular, Reid et al. (2014) have used more than 100 trigonometric parallaxes and proper motions for water and methanol masers associated with high-mass star-forming regions, measured by Very Long Baseline Array (VLBA), VLBI Exploration of Radio Astrometry (VERA) and the European VLBI Network (EVN), to fit axially symmetric models of the Milky Way. In their model (see their Fig. 1, and also Choi et al. 2014), the Perseus arm lacks tracers between $-135^\circ$ and $-170^\circ$.

Choi et al. (2014) identify a single tracer close to Stock 8, the small embedded cluster IRAS 05168+3634 ($l = 170^\circ$), with a parallax distance of $1.9 \pm 0.2$ kpc and a radial velocity of $v_{LSR} = -15.5 \pm 1.9$ km s$^{-1}$ (Sakai et al. 2012). These values seem compatible with the Sh 2-231–235 complex, which is located about 4° away. Reid et al. (2014) also identify a number of tracers of the Perseus arm between $l = 184^\circ$ and $193^\circ$, all of them with distances $d < 2$ kpc, slightly shorter than their best fit for the arm, which gives a distance of $\sim 2$ kpc around $l = 180^\circ$. The typical width of the spiral arm should be around 0.5 kpc on each side of its mid-point.

With these characteristics, our distance to Stock 8 is just compatible with a location in the Perseus arm, within errors. We have to caution, however, that the simple picture of Galactic structure based on four main arms is not shared by many authors. The Orion arm, as observed by Xu et al. (2013) is a major structure. According to some authors, it extends for many kpc towards $l = 240^\circ - 250^\circ$, intersecting the Perseus and even the Outer arm (Vázquez et al. 2008; Costa 2015). On the other hand, the Perseus arm is very poorly traced beyond $l = 193^\circ$. All the possible tracers given by Reid et al. (2014) lie at very large distances from their fit. Conversely, a large number of stellar tracers seem to lie between the Orion and the Perseus arm all the way between $l = 180^\circ$ and $l = 240^\circ$, perhaps suggesting a more fluffy structure.

### 4.4 Is there an association Aur OB2?

As mentioned in the Introduction, in the classical list of OB associations by Humphreys 1975, Aur OB2 was described as composed by the open clusters Stock 8 and NGC 1893, together with some OB stars lying between them. However, all modern studies of NGC 1893 that make use of its upper main-sequence obtain distances $d \sim 5$ kpc (Fitzsimmons 1993; Massey et al. 1995; Marco & Negueruela 2002; Negueruela et al. 2007). Other works using fits to the low-mass star sequence tend to give lower distances (around 3.5 kpc; Sharma et al. 2007; Prisinzano et al. 2011; Lim et al. 2014). The reasons for this discrepancy are unclear. Lim et al. (2014) attribute it to the inaccuracies in the spectroscopic parallaxes. However, given the almost universal (hidden) multiplicity of OB stars, spectroscopic parallaxes based on calibrations will most likely underestimate (rather than overestimate) the distance. Whatever the case, the distances to NGC 1893 and Stock 8 are not compatible, and the radial velocities...
of their associated H II regions are quite different. Even at 3.5 kpc, NGC 1893 would be too far away to belong to the Perseus arm as traced in all modern models.

In this paper we have shown that three small clusters located close to the H II region Sh2 234 have the same photometric distance and that there is a large population of OB stars in the same area whose spectroscopic distances are compatible. However, the picture of the region of the Galactic Plane around $l = 173^\circ$ is complex. Several H II regions have distances ranging from 1.3 kpc to 2.8 kpc. Their radial velocities range from +1.4 to $-25.7$ km s$^{-1}$ (Fich et al. 1990), suggesting that they are determined mostly by peculiar motions rather than by the Galactic rotation curve (which predicts velocities between $-5$ and $-8$ km s$^{-1}$ for this range of distances). Therefore we are likely seeing a number of star forming complexes projected over most of the expected width of the Perseus arm.

Are there any other open clusters placed between the limits of Aur OB2 defined by Humphreys (1978), i.e., between $l = 172^\circ$ and $l = 174^\circ$? NGC 1912 ($l = 172.3^\circ; b = +0.7^\circ$) seems to be an intermediate-age cluster with an age around log $t = 8.5$ (Subramaniam & Sagat 1999; Pandey et al. 2007). The nearby NGC 1907 ($l = 172.6^\circ; b = +0.3^\circ$) has a similar age, and a distance of $\sim 1.8$ kpc (Subramaniam & Sagat 1999; Pandey et al. 2007). The distance to NGC 1912 is similar or slightly shorter. In any case, none of these two clusters is a spiral-arm tracer. We do not find any young cluster in addition to those already discussed.

Apart from the stars observed in this paper, there are a few objects in the area with spectroscopic distances compatible with our value for Stock 8, among them, LY Aur (mentioned above, O9II+O9.5III), HD 36212 (B2.5II) or HD 36280 (B0.5IVn), as well as a moderate number of stars from the LS catalog that could also be associated. However, the high concentration of OB stars studied here does not extend significantly beyond the limits of the area that we have studied. The few cataloged OB stars lying between our area of study and NGC 1893 are likely foreground objects. This spatial concentration gives strong support to the association of the diffuse population with the three clusters studied in this paper. Therefore, the area studied in this paper seems to be a closed group, with an age around 5 Ma and only residual present-day star formation.

5 CONCLUSIONS

These are the main conclusions of our work:

(i) We have obtained a distance of $2.80^{+0.27}_{-0.24}$ kpc for the open cluster Stock 8 using accurate photometry and spectroscopy.

(ii) We have found two new open clusters located $\sim 20'$ north of Stock 8, named Alicante 11 and Alicante 12, which are placed at the same distance that Stock 8.

(iii) We have calculated spectroscopic distances for 14 other early-type stars in the area, finding that all of them could be located at the same distance as the 3 open clusters.

(iv) We have estimated an age for Stock 8 between 4 Ma and 6 Ma using pre-main sequences in the $K_S/(J - K_S)$ diagram. There is no evidence for any of the other clusters or the diffuse population around them to have a significantly different age.
(v) We have detected a pre-main sequence population associated with the likely B-type members lying on the main sequence. From analysis of WISE and 2MASS data, we find that many of them present disks, also showing an excess in the $(J-K_S)$ colour.

(vi) Star LSV +34°23 (HD 35633), located NW of Stock 8, has spectral type O8II(f), and is likely the main source of ionization in the nebula in the cluster region.

(vii) The picture that emerges is that of an area of recent star formation, where the H II region Sh 2-234 represents the last remnant of the cloud, and there is only some residual ongoing star formation, concentrated towards the Nebulous Stream and the small obscured cluster CC 14.

(viii) The classical picture of Aur OB2, as a concentration of OB stars extending between Stock 8 and NGC 1893 cannot be held, as NGC 1893 is clearly more distant. Stock 8 and the surrounding association are likely located on the Perseus arm, as defined by Choi et al. (2014). Other nearby H II regions, such as Sh 2-237 or the Sh 2-231–235 complex are also likely located on the Perseus arm, but their differing radial velocities and distances do not support a close connection with Stock 8 and the surrounding association.

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This work is based in part on observations obtained with the Jacobus Kapteyn Telescope operated on the island of La Palma by the Isaac Newton Group, in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias.

This work is based in part on observations made with the Italian Telescopio Nazionale Galileo (TNG) operated on the island of La Palma by the Fundación Galileo Galilei of the INAF (Istituto Nazionale di Astrofisica) at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias.

Based on observations made with the Nordic Optical Telescope, operated on the island of La Palma jointly by Denmark, Finland, Iceland, Norway, and Sweden, in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias.

Some of the data presented here have been taken using ALFOSC, which is owned by the Instituto de Astrofísica de Andalucía (IAA) and operated at the Nordic Optical Telescope under agreement between IAA and the NBIFAFG of the Astronomical Observatory of Copenhagen.

Based in part on observations made at Observatoire de Haute Provence (CNRS), France.

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REFERENCES

Alves, D. R. 2000, ApJ, 539, 732
Bik, A., Henning, Th., Stolte, A., et al. 2012, ApJ, 744, 87
Blaauw, A. 1964, ARA&A, 2, 213
Blitz, L., Fich, M., & Stark, A.A. 1982, ApJS, 49, 183
Bolyev, V.V., & Bajkova, A.T. 2010, MNRAS 408, 1788
Cabrera-Lavers, A., Garzón, F., & Hammersley, P. 2005, A&A, 433, 173
Chen, Y., Yao, Y., Yang, J., Zeng, Q., & Sato, S. 2005, ApJ, 629, 288
Choi, Y.K., Hachisuka, K., Reid, M.J., et al. 2014, ApJ, 790, 99
Churchwell, E., Babler, B. L., Meade, M. R., et al. 2009, PASP, 121, 213
Costa, E., Motilhon, A., Radisnez, M., et al. 2015, A&A, 580, A4
Crawford, D. L., & Mander, J. 1996, AJ, 71, 114
Crawford, D. L., & Barnes, J. V. 1970a, AJ, 75, 978
Crawford, D. L., Glasper, J., & Perry, C. L. 1970b, AJ, 75, 822
Crawford, D. L. 1975, PASP, 87, 481
Draper, P.W., Taylor, M., & Allan, A. 2000, Starlink User Note 139.12, R.A.L.
Drechsel, H., Haas, S., Lorenz, R., & Mayer, P. 1994, A&A, 284, 853
Evans, N. J., II, & Blair, G. N. 1981, ApJ, 246, 394
Fich, M., Trefers, R.R., & Dah, G.P. 1990, AJ, 99, 622
FitzGerald, M.P. 1970, A&A, 4, 234
Fitzsimmons, A. 1993, A&AS, 99, 15
Foster, T., & Brunt, C.M. 2015, AJ, 150, 147
France, K., McCandliss, S.R., Burgh, E.B., & Feldman, P.D. 2004, ApJ, 616, 257
Froeblich, D., Scholz, A., & Raftery, C. L. 2007, MNRAS, 374, 399
Garmany, C. D., & Conti, P. S. 1984, ApJ, 284, 705
Gillet, D., Burnage, R., Kohler, D., et al. 1994, A&AS, 108, 181
González-Fernández, C., Dorda, R., Negueruela, I., & Marco, A. 2015, A&A, 578, A3
Hardorp, J., Theile, I., & Voigt, H.H. 1965, Hamburger Sternw., Warner & Swasey Obs., 5
Hiltner, W. A. 1956, ApJS, 2, 389
Hindson, L., Thompson, M., & Urquhart, J.S., et al. 2013, MNRAS, 435, 2003
Honma, M., Nagayama, T., Ando, K., et al. 2012, PASJ, 64, 136
Howarth, I., Murray, J., Mills, D., & Berry, D.S. 1998, Starlink User Note 50.21, R.A.L.
Humphreys, R. M. 1978, ApJS, 38, 309
Ivanov, V. D., Borissova, J., Bresolin, F., & Pessev, P. 2005, A&A, 435, 107
Jarrett, T. H., Cohen, M., Masci, F., et al. 2011, ApJ, 735, 112
Johnson, H.L., & Morgan, W.W. 1953, ApJ, 117, 413
Jose, J., Pandey, A.K., Ojha, D.K., et al. 2008, MNRAS, 384, 1675
Kang, J.H., Koo, B.C., & Salter, C. 2012, AJ, 143, 75
Kiminki, M.M., Kim, J.S., Bagley, M.B., Sherry, W.H., & Rieke, G.H. 2015, ApJ, 813, 42
Koenig, X. P., Leisawitz, D.T., Benford, D.J., et al. 2012, ApJ, 744, 130
Koenig, X. P., Leisawitz, D. T. 2014, ApJ, 791, 131
6 PHOTOMETRIC TABLES

This paper has been typeset from a TeX/LaTeX file prepared by the author.
| Name  | Number | RA(J2000) | DEC(J2000) | J       | $\sigma_J$ | H       | $\sigma_H$ | K$_S$   | $\sigma_{K_S}$ |
|-------|--------|-----------|------------|---------|------------|---------|------------|---------|---------------|
| ST1   | 05:27:51.82 | +34:30:48.1 | 9.075 | 0.027 | 8.441 | 0.020 | 8.219 | 0.018 |
| ST2   | 05:28:06.39 | +34:30:40.3 | 13.820 | 0.024 | 13.501 | 0.027 | 13.419 | 0.036 |
| ST3   | 05:27:49.91 | +34:30:43.7 | 12.767 | 0.019 | 12.592 | 0.019 | 12.492 | 0.023 |
| ST4   | 05:28:15.51 | +34:30:36.3 | 14.248 | 0.026 | 13.876 | 0.027 | 13.777 | 0.041 |
| ST5   | 05:28:04.60 | +34:30:36.6 | 14.359 | 0.023 | 13.979 | 0.031 | 13.743 | 0.040 |
| ST6   | 05:28:09.92 | +34:30:32.5 | 13.820 | 0.023 | 13.210 | 0.025 | 13.057 | 0.029 |

Table 11. Near-IR photometry obtained by us for stars in the cluster Stock 8. Material on-line

| Name  | R.A(J2000) | DEC(J2000) | J       | $\sigma_J$ | H       | $\sigma_H$ | K$_S$   | $\sigma_{K_S}$ |
|-------|------------|------------|---------|------------|---------|------------|---------|---------------|
| 1     | 05:28:00.83 | +34:22:44.7 | 17.168 | 0.013 | 16.393 | 0.016 | 15.986 | 0.013 |
| 2     | 05:28:15.89 | +34:22:47.2 | 15.499 | 0.012 | 14.513 | 0.010 | 14.261 | 0.010 |
| 3     | 05:28:03.07 | +34:22:45.5 | 14.585 | 0.010 | 14.168 | 0.009 | 14.049 | 0.009 |
| 4     | 05:28:13.87 | +34:22:49.9 | 14.910 | 0.011 | 14.118 | 0.009 | 13.893 | 0.010 |
| 5     | 05:28:13.76 | +34:22:50.4 | 15.220 | 0.013 | 14.380 | 0.011 | 14.131 | 0.011 |

Table 12. Optical photometry for stars in the open cluster Stock 8. The values with label $^*$ are not considered in the analysis because their photometric errors are around 0.1. Material on-line

| Name  | V       | $\sigma_V$ | $(b-y)$ | $\sigma_{(b-y)}$ | $c_1$ | $\sigma_{c_1}$ | $m_1$ | $\sigma_{m_1}$ | N   |
|-------|---------|------------|---------|-----------------|-------|-----------------|-------|-----------------|-----|
| ST1   | 11.435  | 0.021      | 0.964   | 0.027           | -0.250| 0.040           | 1     | 0.574           | 0.039| 2.597           | 0.032| 1               |
| ST2   | 15.131  | 0.004      | 0.525   | 0.010           | -0.135| 0.036           | 3     | 0.252           | 0.060| 2.616           | 0.052| 2               |
| ST3   | 13.568  | 0.034      | 0.353   | 0.008           | 0.367 | 0.037           | 6     | 0.347           | 0.025| 2.603           | 0.029| 5               |
| ST4   | 15.859  | 0.008      | 0.629   | 0.038           | 0.124 | 0.111           | 2     | 0.134           | 0.097| 2.597           | 0.040| 2               |
| ST5   | 15.947  | 0.045      | 0.678   | 0.009           | -0.046| 0.119           | 2     | 0.179           | 0.075| 2.597           | 0.061| 2               |
| ST6   | 15.864  | 0.002      | 0.702   | 0.013           | 0.031 | 0.200           | 2     | 0.227           | 0.078| 2.578           | 0.064| 2               |

Table 13. Coordinates in J2000 and 2MASS photometry for stars with optical photometry in the new cluster Alicante 11. Material on-line

| Name | RA(J2000) | DEC(J2000) | J       | $\sigma_J$ | H       | $\sigma_H$ | K$_S$   | $\sigma_{K_S}$ |
|------|-----------|------------|---------|------------|---------|------------|---------|---------------|
| Alicante 11-1 | 05:27:55.48 | +34:50:21.3 | 10.858 | 0.018 | 10.234 | 0.016 | 10.062 | 0.017 |
| Alicante 11-2 | 05:27:57.72 | +34:49:25.5 | 12.051 | 0.019 | 11.788 | 0.018 | 11.683 | 0.020 |
| Alicante 11-3 | 05:27:24.26 | +34:49:26.0 | 11.243 | 0.022 | 11.113 | 0.027 | 11.003 | 0.019 |
| Alicante 11-4 | 05:27:27.63 | +34:48:53.7 | 12.208 | 0.023 | 11.886 | 0.030 | 11.812 | 0.023 |
| Alicante 11-5 | 05:27:54.47 | +34:48:43.7 | 12.982 | 0.021 | 12.815 | 0.022 | 12.749 | 0.023 |

Table 14. Optical photometry for stars in the new open cluster Alicante 11. The values with label $^*$ are not considered in the analysis because of their error are around 0.1. Material on-line

| Name | V       | $\sigma_V$ | $(b-y)$ | $\sigma_{(b-y)}$ | $c_1$ | $\sigma_{c_1}$ | $m_1$ | $\sigma_{m_1}$ | N   |
|------|---------|------------|---------|-----------------|-------|-----------------|-------|-----------------|-----|
| Alicante 11-1 | 13.225  | 0.029      | 0.863   | 0.047           | 0.308 | 0.071           | 0.292 | 0.066           | 2.689| 0.045| 1               |
| Alicante 11-2 | 13.334  | 0.028      | 0.425   | 0.019           | 0.042 | 0.030           | 0.899 | 0.030           | 2.840| 0.023| 3               |
| Alicante 11-3 | 12.201  | 0.007      | 0.313   | 0.017           | 0.074 | 0.026           | 0.476 | 0.018           | 2.790| 0.022| 5               |
| Alicante 11-4 | 13.636  | 0.012      | 0.470   | 0.005           | 0.115 | 0.016           | 0.444 | 0.025           | 2.712| 0.007| 5               |
| Alicante 11-5 | 13.860  | 0.023      | 0.327   | 0.035           | -0.007| 0.050           | 0.909 | 0.055           | 2.821| 0.049| 3               |
Table 15. Coordinates in J2000 and 2MASS photometry for stars with optical photometry in the new cluster Alicante 12. Material on-line

| Name         | RA(J2000) | DEC(J2000) | J     | $\sigma_J$ | H     | $\sigma_H$ | K$_S$ | $\sigma_{K_S}$ |
|--------------|-----------|------------|-------|------------|-------|------------|-------|----------------|
| Alicante 12-1| 05:28:17.33 | +34:51:57.0 | 13.027 | 0.021      | 12.689 | 0.019      | 12.590 | 0.025          |
| Alicante 12-2| 05:28:15.50 | +34:51:51.4 | 12.557 | 0.019      | 12.198 | 0.018      | 12.098 | 0.023          |
| Alicante 12-3| 05:28:05.04 | +34:51:41.2 | 11.829 | 0.019      | 11.672 | 0.019      | 11.562 | 0.022          |
| Alicante 12-4| 05:28:13.83 | +34:51:24.1 | 11.504 | 0.019      | 11.173 | 0.018      | 11.108 | 0.019          |
| Alicante 12-5| 05:28:28.12 | +34:50:34.6 | 11.743 | 0.018      | 11.551 | 0.016      | 11.466 | 0.019          |

Table 16. Optical photometry for stars in the open cluster Alicante 12. The values with label $^*$ are not considered in the analysis because of their error are around 0.1. Material on-line

| Name         | V     | $\sigma_V$ | $(b-y)$ | $\sigma_{(b-y)}$ | $m_1$ | $\sigma_{m_1}$ | $c_1$ | $\sigma_{c_1}$ | $\beta$ | $\sigma_{\beta}$ | N  |
|--------------|-------|------------|---------|------------------|-------|-----------------|-------|-----------------|---------|------------------|----|
| Alicante 12-1| 14.580 | 0.048      | 0.586   | 0.050            | 0.051 | 0.093$^*$      | 0.423 | 0.040           | 2.732   | 0.097$^*$        | 3  |
| Alicante 12-2| 14.250 | 0.019      | 0.607   | 0.011            | 0.026 | 0.041           | 0.511 | 0.008           | 2.740   | 0.046            | 2  |
| Alicante 12-3| 12.730 | 0.043      | 0.357   | 0.034            | 0.010 | 0.010           | 0.221 | 0.037           | 2.743   | 0.073            | 3  |
| Alicante 12-4| 12.855 | 0.036      | 0.486   | 0.032            | 0.106 | 0.066           | 0.520 | 0.047           | 2.716   | 0.057            | 3  |
| Alicante 12-5| 12.868 | 0.027      | 0.367   | 0.037            | 0.079 | 0.055           | 0.920 | 0.016           | 2.835   | 0.038            | 3  |