Cluster membership for the long period Cepheid calibrator SV Vul*

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Accepted 2020 March 22. Received 2020 March 22; in original form 2020 January 16

ABSTRACT
Classical Cepheids represent the first step of the distance scale ladder. Claims of tension between the locally calculated Hubble constant and the values deduced from Planck’s results have sparked new interest in these distance calibrators. Cluster membership provides an independent distance measurement, as well as astrophysical context for studies of their stellar properties. Here we report the discovery of a young open cluster in the vicinity of SV Vul, one of the most luminous Cepheids known in the Milky Way. Gaia DR2 data show that SV Vul is a clear astrometric and photometric member of the new cluster, which we name Alicante 13. Although dispersed, Alicante 13 is moderately well populated, and contains three other luminous stars, one early-A bright giant and two low-luminosity red supergiants. The cluster is about 30 Ma old at a nominal distance of 2.5 kpc. With this age, SV Vul should have a mass around $10 \, M_\odot$, in good accordance with its luminosity, close to the highest luminosity for Cepheids allowed by recent stellar models.

Key words: stars: evolution – supergiants – Hertzsprung-Russell and colour-magnitude diagrams – stars: variables: Cepheids – open clusters and associations: individual: Alicante 13

1 INTRODUCTION
Cepheid variables were the earliest standard candles in use and still today constitute the first step in the cosmic distance ladder (Feast 1999, and references therein). With the release of Gaia DR2 (Gaia Collaboration et al. 2018) geometrical parallaxes, their role as benchmark distance indicators through the use of Leavitt Law (e.g. Freedman & Madore 2010) is becoming even more paramount. Claims for a statistically significant difference between values of the Hubble constant derived locally and from Cosmic Microwave Background measurements and the standard cosmological models (e.g. Riess et al. 2018b) call for high-precision distance determinations. In this context, Cepheids in open clusters are doubly valuable. The cluster offers an independent way to measure the distance and provides an astrophysical context for the Cepheid. Thanks to this context, the physical properties and evolutionary stage of the Cepheid can be constrained.

The number of Cepheids believed to belong to clusters or OB associations has increased in recent years (Anderson et al. 2013; Chen et al. 2015), but not all of them are well studied. The best characterised stars are included in period-luminosity calibrations. Among them, SV Vul, with a 45 d pulsation period, is one of the brightest. It is indeed the star with the longest period in a number of calibrations (e.g. Tammann et al. 2003; Fouqué et al. 2007). In others (e.g. Storm et al. 2011), it is superseded by the confusingly named 63 d Cepheid S Vul (which is located only 40 arcmin away), whose geometric parallax was recently measured with the HST (Riess et al. 2018a).

By the use of different standard methods, the distance modulus to SV Vul has traditionally been calculated around $\mu = 11.7$ mag ($d = 2.1$ kpc; $\pi = 0.46$; e.g. Fouqué et al. 2007), implying an absolute magnitude approaching $M_V = -6$. Storm et al. (2011) proposed a lower value $\mu = 11.4$, based on the near-IR surface brightness method. Conversely,

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Madore et al. (2017) suggest a higher value $\mu = 12.0$ mag ($\pi = 0.40$ mas) by applying a novel method to treat reddening. This latter value is in good agreement with the Gaia DR2 parallax $\pi = 0.37 \pm 0.03$ mas, although DR2 values for such a bright ($G = 6.9$) star should be taken with care.

SV Vul has long been assumed a member of the Vul OB1 association, following Turner (1984). The core of Vul OB1 is the very young (star-forming) cluster NGC 6823, which contains a few O-type stars, including the O6.5 V((f)) HD 344784. There are, however, older stars belonging to the association, and SV Vul has been connected to the rather older cluster NGC 6834, which lies about 2 degrees North of the Cepheid (Turner 1976). With an estimated age of 80 Ma (Paunzen et al. 2006), NGC 6834 seems too old to be related to SV Vul. In addition, its Gaia DR2 parallax $\pi = 0.27$ (Cantat-Gaudin et al. 2018) places it too far away to belong to Vul OB1. Moreover membership in an association for isolated stars in this direction is difficult to assess, as three distinct OB associations, Vel OB1, Vel OB2 and Vel OB4, are believed to be projected one of top of the other at different distances (we will come back to this issue in the Discussion).

In this work, we demonstrate the presence in this region of a newly recognised open cluster that includes SV Vul as a halo member. The new cluster, which we name Alicante 13, is not apparent to the eye, except as a compact group of three bright stars, namely HD 339063, HD 339064 and BD +27°3542, whose Gaia DR2 astrometric parameters (listed in Table 1) are fully compatible with those of SV Vul, i.e. pmRA = −2.14 mas/yr, pmDec = −5.82 mas/yr, $\pi = 0.37$ mas. This group is located about 9 arcmin to the East from SV Vul. In the following sections we identify the cluster as a concentration of early-type stars, determine its astrophysical parameters and characterise its brighter members.

2 CLUSTER DEFINITION

To identify the cluster, we used the Virtual Observatory tool Clusterix 2.0 (Balaguer-Núñez et al. 2020) working on Gaia DR2 data. Clusterix is an interactive web-based application that calculates the grouping probability of a list of objects by using proper motions and the non-parametric method proposed by Cabrera-Cano & Alfaro (1990) and described in Galadi-Enriquez et al. (1998). In its current version, Clusterix works only in the proper motion plane, ignoring all other information. For ease of computation, we restricted ourselves to DR2 objects with G ≤ 16 and errors in proper motion below 3 mas/yr. We selected a circle of radius 30 arcmin around the position of HD 339063 and run the tool assuming a cluster radius of 3.6 arcmin (this simply informs the tool of where it should find a significant number of objects belonging to a distinct population). Clusterix identifies over 6300 sources brighter than G = 16 and passing its quality criteria. Clusterix then assigns each object a probability of belonging to a distinct population rather than the field population, using an empirical determination of the frequency functions in the vector point diagram (Sanders 1971). After this, we plotted the parallax vs. probability plane, and found a clear overdensity of objects with high probability and similar values of parallax.

The population thus identified is strongly concentrated in the proper motion plane and contains the four stars mentioned above. After removal of a handful of outliers, we calculated the weighted means for the astrometric parameters of the population, which turn out to be pmRA = −2.08 ± 0.21 mas/yr, pmDec = −5.92 ± 0.15 mas/yr, $\pi = 0.37 \pm 0.06$ mas, where the errors quoted are the standard deviations for the whole population selected. The median values of these parameters are pmRA = −2.08 mas/yr, pmDec = −5.87 mas/yr, $\pi = 0.38$ mas. Their modes are pmRA = −2.09 mas/yr, pmDec = −5.87 mas/yr, $\pi = 0.37$ mas. Coincidence of mean, median and mode indicates that the central values are well defined and a more sophisticated analysis is not needed. An iterative process of 2-$\sigma$ outlier clipping leads to essentially identical median values, confirming that the results of Clusterix are statistically solid. In Fig. 1, we plot the spatial distribution of the objects finally selected (around 200 sources). Although the population is spread over the whole field, there is a very strong concentration towards the position of the three bright stars mentioned above.

To quantify this, we used the Automated Stellar Cluster Analysis (ASTeCA) code (Perren et al. 2015). We run ASTeCA on the selection shown in Fig. 1, i.e. stars whose three astrometric parameters fall within 2 $\sigma$ of the average values. Larger red circles are objects whose parameters are less than one $\sigma$ away from these central values.

Figure 1. Spatial distribution of the population selected by Clusterix. Small blue circles are objects whose three astrometric parameters lie within 2 $\sigma$ of the average values. Larger red circles are objects whose parameters are less than one $\sigma$ away from these central values.
be mostly the dispersed population of the cluster halo. In the left panel of Fig. 2, we plot the Gaia photometry for these stars. We can see that around 20 stars (i.e., ~10% of the objects) occupy positions in the Gaia CMD suggesting that they are interlopers. All the other stars seem to belong to a single population. The spread in \((BP-RP)\) is very likely due to differential reddening. For instance, all the bright stars \((G \approx 11 - 12)\) around \((BP-RP) \approx 1.0\) lie to the East of the cluster, mostly at large distances (>15'). All the objects located at the top of the main stellar sequence are catalogued early-type stars. They include LS II +27°23, 24, 25 & 28, TYC 2148-1327-1, and the emission-line star Hen 3-1788.

The cluster is small and disperses into the surrounding association. Of the ~180 likely members of the association shown in the left panel of Fig. 2, there are 47 stars within 6 arcmin of HD 339064 and 90 stars within 12 arcmin. The right panel of Fig. 2 shows the population within 6 arcmin. Differential reddening is reduced to a minimum and the sequence is now much better defined. Only one of the faintest stars is located at some distance from the photometric sequence.

### 3 OBSERVATIONS AND ANALYSIS

High-resolution spectra of the three bright stars and SV Vul itself were taken with the Fibre-fed Echelle Spectrograph (FIES) attached to the 2.56 m Nordic Optical Telescope (NOT; La Palma, Spain) in service mode during the night of 2019, June 4. FIES is a cross-dispersed high-resolution echelle spectrograph, mounted in a heavily insulated building separated from and adjacent to the NOT dome, with a maximum resolving power \(R = 67000\). The entire spectral range 370–830 nm is covered without gaps in a single, fixed setting. Extended coverage up to 900 nm is available with minor inter-order wavelength gaps. In the present study, we used the low-resolution mode with \(R = 25000\). The spectra were homogeneously reduced using the FIEStool\(^2\) software in advanced mode. Using a complete set of bias, flat, and ThAr arc frames, the FIEStool pipeline provides wavelength calibrated, blaze corrected, order merged spectra.

Classification spectroscopy of blue stars in the area was obtained in service mode during the night of 2019, June 10, with the imager and spectrograph ALFOSC attached to the NOT. We used the grism #18 combined with a 1" slit to obtain intermediate resolution spectroscopy. Grism #18 covers the 3450–5350 Å range with a nominal dispersion of 0.9 Å/pixel. The resolving power for this configuration is \(R \sim 1000\). These data were reduced following standard procedures with reduction software inside the Starlink suite (Currie et al. 2014).

Spectral classification of the early-type stars has been carried out by comparison to a grid of standards (Negueruela et al. 2019) degraded to the same resolution and application of classical criteria. Spectral classification of late-type supergiants has been carried out by following the procedure specified in Dorda et al. (2018) on their spectra degraded to classification resolution.

Radial velocities (RVs) were calculated for stars with high-resolution spectra by using iSpec\(^3\) (Blanco-Cuaresma et al. 2014; Blanco-Cuaresma 2019). As a first step, telluric features were removed to improve the radial velocity determination. Then we cross-match correlated each of our spectra against a high-resolution linelist of the Sun (provided by iSpec) covering our whole spectral range, and we obtained the corresponding mean velocities by fitting a second order polynomial near the peak to the velocity profile. The errors were automatically calculated by iSpec following the procedures described in Zucker (2003). The RVs measured are shown in Table 1, where they are compared to the DR2 values (note that HD 339063, being a blue star has no DR2 RV).

### 4 RESULTS

#### 4.1 Stellar content

There are four luminous stars that appear as astrometric and photometric members of the cluster. Their derived parameters are listed in Table 1. The brightest among them is the well-studied Cepheid SV Vul, located in the cluster halo. Spectra of the four stars in the Gaia RVS spectral region are shown in Fig. 3. SV Vul appears as an F8 IV supergiant. Its spectral type is known to vary between F7 and K0 (Code 1947). Its radial velocity oscillates periodically between \(+20\) km s\(^{-1}\) and \(−25\) km s\(^{-1}\) with a systemic velocity \(\approx −1\) km s\(^{-1}\) (Bersier et al. 1994). The high dispersion of the Gaia RV measurements testifies to this variability. Our measurement is typical of the velocity seen at early spectral types.

The position of BD +27°3542 in the Gaia CMD suggests a yellow star, similarly to SV Vul. However, its spectrum shows it to be a composite, containing a very luminous red star and a B-type object. The red star, for which we derive a K3 III spectral type, completely dominates the red spectrum (see Fig. 3). The blue star can be seen up to \(5000\) Å, and dominates the spectrum bluewards of \(4500\) Å. We display this region in Fig. 4, together with comparison spectra. The lines of the blue component are very narrow, indicating a very low projected rotational velocity. The wings of the Balmer lines can be used to estimate its luminosity, which turns out higher than that of the B3 III standard HD 21483. We estimate a spectral type B3 II–III, with some uncertainty due to the strong contamination by the red star. Given that Gaia does not separate the two stars, they are very likely to form a physical binary. Against this, our RV measurement is not significantly different from the Gaia value, which is the median of observations taken between 2014 and 2016, i.e. more than three years before our observation. On the other hand, a chance projection is highly unlikely, especially if we consider that the blue component is the second most luminous blue star in the cluster.

As can be seen in Fig. 2, HD 339063 is a blue star. Its spectrum in the Gaia RVS spectral region is shown in Fig. 3.

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2 http://www.not.iac.es/instruments/fies/fiestool/FIEStool.html

3 A free integrated spectroscopic software powered by python, available at https://www.blancocuaresma.com/iSpec

4 The systemic velocity cannot be determined with high accuracy because the oscillation period is not stable (e.g. Bersier et al. 1994).
I. Negueruela et al.

Figure 2. *Gaia* CMD for the sample selected using astrometric data. **Left panel:** The large (red) circles have astrometric parameters within one $\sigma$ of the average values for the population selected by Cluster ix. The small blue circles represent stars within 2 $\sigma$ of the same values. **Right panel:** Only stars within 6 arcmin of HD 339063 are shown. The large green circles are stars within 3 arcmin. In both diagrams the brightest stars are labeled with their catalogue names.

Table 1. Parameters for the stars observed at high resolution. Spectral type and a measurement of RV are from our spectra, while the other parameters are from *Gaia* DR2.

| Star          | Spectral type | $\pi$ (mas) | $G$ (mag) | BP-RP (mag) | RV (*Gaia*) (km s$^{-1}$) | RV (km s$^{-1}$) |
|---------------|---------------|-------------|-----------|-------------|--------------------------|-----------------|
| SV Vul        | F8 Iab        | $-2.14 \pm 0.05$ | $-5.82 \pm 0.05$ | $0.37 \pm 0.03$ | 6.87 | 1.89 | $+3.2 \pm 4.3$ | $-14.5 \pm 0.3$ |
| HD 339063     | A2 II         | $-2.22 \pm 0.05$ | $-5.89 \pm 0.05$ | $0.41 \pm 0.03$ | 8.51 | 0.94 | $-1.5 \pm 0.6$ |           |
| HD 339064     | K1 Ib         | $-2.24 \pm 0.05$ | $-5.72 \pm 0.06$ | $0.35 \pm 0.03$ | 8.56 | 2.30 | $+6.58 \pm 0.39$ | $-3.5 \pm 0.1$ |
| BD +27°3542   | B3 II + K3 Iab| $-2.24 \pm 0.05$ | $-5.92 \pm 0.05$ | $0.37 \pm 0.03$ | 7.95 | 1.85 | $-0.14 \pm 0.25$ | $-0.5 \pm 0.2$ |

Figure 3. Spectral sequence of luminous stars around the region covered by the *Gaia* RVS. The small gaps are due to the lack of order overlap in FIES for the extreme red.

Figure 4. The blue component of BD +27°3542 (middle) compared to stars of similar spectral types. Contamination by the K-type brighter companion is evident beyond 4 200 Å. The top spectrum is 3 Gem (HD 42087; B3 Ib). The bottom spectrum is HD 21483 (B3III).

while its classification spectrum is presented in Fig. 5, together with comparison spectra. The strong metallic spectrum and lack of He I lines imply an A spectral type. Its lines are somewhat broader than those of the Ib stars displayed as comparison, suggesting a lower luminosity. The
main temperature diagnostic, the ratio of CaII K to Hα suggests that HD 339063 is not much later than A2. Comparison to BD +60°51 shows a slightly stronger and more complex metallic spectrum, except for those lines that are sensitive to luminosity, such as FeIi 4233Å, the FeIi and TiI blend at 4172–8Å, and the SiIi doublet at 4128–30Å. In view of this, we classify HD 339063 as A3II. Our RV measurement, $-1.5 \pm 0.6\,\text{km}\,\text{s}^{-1}$, is fully compatible with the systemic velocity of SV Vul and BD +27°3542.

Finally, HD 339064 is a slightly less luminous red star, for which we estimate a spectral type K1 Ib. Our radial velocity measurement, $-3.5 \pm 0.1\,\text{km}\,\text{s}^{-1}$, is very different from the Gaia value and much more in line with the velocities of the other members. We do not find evidence for a second stellar component, while the dispersion of the Gaia DR2 RVs does not suggest high variability. The reasons for this discrepancy are thus unclear.

We also obtained classification spectra of the brightest stars of the main sequence in the photometric CMD. These spectra are displayed in Fig. 6 and their main parameters are listed in Table 2. The two brightest members are the catalogued early-type objects LSII +27°23 & 24. Their spectra are very similar, and we classify both as B2.5 V. A slightly fainter member is TYC 2148-1327-1, catalogued as an emission line star (HBHA 2703-20). It has features typical of a Be star, with double-peaked emission in Hβ, a shell-like profile in Hγ and several moderate-strength FeIi emission lines. This Be nature explains its peculiar position in the CMD, somewhat to the red of the sequence. We classify it as B3Ve. Finally, TYC 2148-3261-1 has a similar brightness. We classify it as B5 V. However, all lines are broad and very shallow. This, together with the very poor Gaia DR2 fit (see formal errors in Table 2) strongly suggests that it is a binary.

### 4.2 Cluster parameters

The stellar content described in the previous section identifies Alicante 13 as a young open cluster. The brightest stars still close to the main sequence have spectral type B2.5 V. At solar metallicity, this earliest spectral type is typical of clusters in the age range 25 – 35 Ma. To derive global parameters, we used $JHK_s$ photometry from the 2MASS catalogue (Skrutskie et al. 2006). For this, we cross-matched the population selected within 12 arcmin of HD 339063 with the 2MASS point-source catalogue, admitting only objects with well-defined errors in all three bands. Given the high-quality astrometry of both catalogues, we only accepted matches separated by less than 0.3 arcsec. The completeness limit of this catalogue is set at $K_S = 14.2$.

The mean value of the cluster parallax in DR2 data is 0.37 mas, in total agreement with the DR2 value for SV Vul itself ($\pi = 0.37 \pm 0.03$ mas). However, there are systematic errors affecting all astrometric parameters in DR2 (Luri et al. 2018). In particular, there is a zero-point offset (Lindegren et al. 2018), which seems to depend on colour and perhaps position in the sky (Zinn et al. 2019; Khan et al. 2019). Given this uncertainty, we simply assume a nominal $\pi = 0.40$ mas ($d = 2.5\,\text{kpc}$), i.e. $DM = 12.0$ mag, in agreement with the values obtained by Madore et al. (2017) for SV Vul. In Fig. 7, we plot the 2MASS CMD for the population selected on the basis of their astrometric parameters together with Padova PARSEC isochrones. A 30 Ma isochrone provides a very good fit to the whole blue sequence and the position of the two red supergiants (note that only the red component of BD +27°3542 contributes in these bands), with an extinction $A_V = 1.67$ mag, again fully consistent with the value derived by Madore et al. (2017) for SV Vul. In particular, the location of HD 339063 on this diagram is a strong constraint on the fit. Older clusters at shorter distances fail to give a good fit for the upper main sequence. As an example, we show a 35 Ma isochrone with $DM = 11.5$ mag (the other end of the range suggested for SV Vul in the literature) and the same extinction. A small decrease or increase of the reddening does not improve the fit, ruling out the older age.

A younger cluster with the same extinction can provide a good fit to the blue sequence for a slightly higher distance. However, it fails to fit the red supergiants, as the gap in magnitude between the blue and red supergiants increases with age. As an example, in Fig. 7 we also show a 25 Ma isochrone with $DM = 12.2$ mag.

Despite the excellent fit to the 2MASS CMD, the Gaia photometry cannot be fit with the same parameters. In particular, Padova PARSEC isochrones using the passbands of Maíz Apellániz & Weiler (2018) can only fit the sequence with $A_V = 2.0$ mag, a much higher value than implied by the 2MASS data. Given this higher extinction, isochrones give a good fit to the main sequence for a shorter $DM = 11.7$ mag. As shown in Fig. 8, this shorter distance requires a slightly older cluster (35 Ma) to fit the location of the supergiants.
Table 2. Observed parameters for blue stars with classification spectra. The four stars in the top panel have astrometric parameters compatible with membership. The star in the bottom panel is not an astrometric likely member.

| Star       | Spectral type | pm (RA) (mas) | pm (Dec) (mas) | π (mas) | G (mag) | BP-RP (mag) |
|------------|---------------|---------------|---------------|---------|---------|-------------|
| LS II +27°23 | B2.5 V        | −2.18 ± 0.05  | −5.81 ± 0.05  | 0.42 ± 0.03 | 11.74   | 0.71        |
| LS II +27°24 | B2.5 V        | −2.02 ± 0.05  | −5.91 ± 0.05  | 0.32 ± 0.03 | 11.46   | 0.75        |
| TYC 2148-1327-1 | B3 Ve    | −2.07 ± 0.04  | −5.86 ± 0.05  | 0.40 ± 0.03 | 12.22   | 0.85        |
| TYC 2148-3261-1 | B5 V      | −2.10 ± 0.25  | −6.01 ± 0.31  | 0.47 ± 0.16 | 12.13   | 0.82        |
| LS II +27°19  | B2.5 III      | −2.75 ± 0.05  | −5.77 ± 0.05  | 0.27 ± 0.03 | 11.21   | 0.88        |

Figure 7. Infrared CMD for the population of Alicante 13, built with 2MASS data. As with the Gaia photometry, there is a small number of astrometric members that do not fit the sequence at \((J - K_S) \geq 0.7\). The thick continuous (maroon) line is a 30 Ma isochrone with \(DM = 12.0\) mag and \(A_V = 1.67\) mag. The dotted (orange) line is a 35 Ma isochrone with \(DM = 11.5\) mag and the same extinction. The dashed (red) line is a 25 Ma isochrone with \(DM = 12.2\) mag. The large square is SV Vul (as it is saturated in 2MASS, we have taken its average magnitudes from Fouqué et al. 2007). The blue stars lying immediately to the right of the main sequence can be considered candidate Be stars.

The reason for this discrepancy between the extinction derived from optical and infrared photometry is unclear, but it points towards non-standard extinction law. Turner (1980) derives \(E(B - V) = 0.65\) and \(0.69\) for LS II +27°23 & 24, respectively, in agreement with the reddening estimated from the Gaia photometry, implying that there are no systematics affecting the optical photometry. Any anomaly in the extinction law, however, will have a smaller impact on the near infrared magnitudes and colours, and thus we favour the age derived from the fit in the 2MASS CMD.

5 DISCUSSION

We have identified a previously unknown cluster in the region of Vul OB1, which we name Alicante 13. The long period classical Cepheid SV Vul is a halo member, located about 9 arcmin West from the centre. About half of the classical Cepheids confirmed as cluster members lie in their respective halos (Anderson et al. 2013). At a distance of 2.5 kpc, 9 arcmin correspond to 6.5 pc, comparable to the distances of V Cen, EV Sct or QZ Nor to their respective clusters, and much shorter than the distance from V379 Cas to the centre of NGC 129, of which it is an obvious astrometric member (cf. Anderson et al. 2013, and Gaia DR2 data).

The 2MASS CMD is best fit by a 30 Ma isochrone, which agrees well with the spectral type of the brightest main-sequence members. According to the isochrone, the mass of the cluster supergiants should be \(\sim 9.2 M_\odot\). SV Vul is clearly brighter than the location of the blue loop in the isochrone (about 0.6 mag in \(K_S\) and 0.9 mag in \(G\)). This is not unusual (cf. the position of V340 Nor with respect to the best-fit isochrone for NGC 6067 in Alonso-Santiago et al. 2017) and could be due to moderately high initial rotation. As an example, Anderson et al. (2014) state that a 9 \(M_\odot\) star with high initial rotation will reach the blue loop \(~ 5\) Ma later than a star with zero initial rotation, and so will considerably outlive stars of the same mass with slow rotation. Using isochrones by Georgy et al. (2013), we find that \(M_* = 10 M_\odot\) star with "standard" initial rotation will traverse the blue loop after \(\sim 28\) Ma, reaching a luminosity of \(\log L/L_\odot = 4.3\). For SV Vul, the \(P/L\) relation...
of Anderson et al. (2013) gives $M_V = -5.8$, while that of Madore et al. (2017) gives $M_V = -5.7$. Assuming a $BC$ not very different from zero for an "average" spectral type around G0, this means log $L/L_\odot \approx 4.2$. On the other hand, a star of $M_\star = 9.2\,M_\odot$ with low initial rotation will be leaving the loop (i.e. becoming a red supergiant) after 30 Ma, at a log $L/L_\odot = 3.9$. Therefore the timescales and luminosities agree very well with the fit to the rest of the cluster obtained with a PARSEC isochrone. Interestingly, according to Anderson et al. (2014), fast rotators with masses higher than $10\,M_\odot$ do not experience blue loops. Therefore SV Vul would be very close to the highest mass for which a fast rotator may appear as a Cepheid variable\(^5\).

Membership in a cluster allows a good estimation of the mass of SV Vul. In the past, it had been considered a field member of the Vul OB1 association, but this region of the sky is very complex: three different OB associations are believed to be projected on top of the other, Vul OB4 at $\sim 1$ kpc, Vul OB1 at $\sim 2$ kpc and Vul OB2 at $\sim 4$ kpc (Turner 1980). Figure 9 shows the relative positions of relevant objects in this area. The star forming cluster NGC 6823, generally identified as the core of Vul OB1 lies about four degrees South of SV Vul and has $Gaia$ DR2 astrometric values pmRA $= -1.7$ mas/yr, pmDec $= -5.3$ mas/yr, $\pi = 0.45$ mas (Cantat-Gaudin et al. 2018). The few stars visible in the vicinity of the nearby H\textsc{ii} region NGC 6820 have compatible values. The nearby cluster NGC 6830, which is much older ($\sim 100$ Ma), has pmRA $= -3.2$ mas/yr, pmDec $= -5.8$ mas/yr, $\pi = 0.42$ mas. More to the North, Roslund 2 has pmRA $= -1.7$ mas/yr, pmDec $= -5.1$ mas/yr, $\pi = 0.46$ mas, fully compatible with the values for NGC 6823. Roslund 2 is also a very young cluster, although somewhat older than NGC 6823, as it contains the blue supergiant HD 186745 (B8 Ia).

As we move further to the North, we find the small star-forming cluster Dolidze 53 (pmRA $= -1.5$ mas/yr, pmDec $= -4.6$ mas/yr, $\pi = 0.48$ mas), and a number of early-type stars associated with the H\textsc{ii} region Sh2-S88B, such as HD 338926 (pmRA $= -2.05 \pm 0.06$ mas/yr, pmDec $= -3.37 \pm 0.06$ mas/yr, $\pi = 0.45 \pm 0.04$ mas) or HD 338916 (pmRA $= -3.39 \pm 0.06$ mas/yr, pmDec $= -3.39 \pm 0.05$ mas/yr, $\pi = 0.49 \pm 0.04$ mas), whose parallaxes are fully compatible with those of the association, but presenting very different proper motions. Based on their radial velocities, both Sh2-S88B and Sh2-89 are considered members of Vul OB1, conforming a large star-forming complex (e.g. Turner 1986). The parallax to Alicante 13 ($\pi = 0.37$ mas) is not sufficiently far away from the value for this complex to completely rule out an association (especially given the possibility of important systematics affecting sources that are more than four degrees away), but the cluster is considerably older. Two nearby clusters have very similar astrometric parameters in the catalogue of Cantat-Gaudin et al. (2018), Czernik 41 (pmRA $= -2.9$ mas/yr, pmDec $= -6.2$ mas/yr, $\pi = 0.37$ mas) and

\(^5\) We can also speculate that SV Vul is brighter than the other supergiants because it is a mass gainer in a binary interaction, which resulted in a higher mass than those of other members. However, it is unlikely that mass gain would have resulted in a slow rotator, while the difference in magnitude does not allow for a very large mass difference. Therefore the hypothesis of a somewhat more massive fast rotator seems to fit better.
(Turner 1980) has to be abandoned. The emerging picture is much more complex, with objects projected over a wide range of distances. As an example, within the central region of Alicante 13, we find the catalogued OB star LS II +27°19, with DR2 parameters pmRA = -2.75 ± 0.05 mas/yr, pmDec = -5.77 ± 0.05 mas/yr, π = 0.27 ± 0.03 mas. As can be seen in Fig. 10 and Table 2, this is a giant star of the same spectral type as those at the top of the cluster sequence. Its parallax is inconsistent with that of the cluster at > 2σ and it is only very slightly brighter than the main sequence stars, indicating a longer distance modulus. Its reddening, however, is only very slightly higher. Using the UBV photometry from Turner (1980) and our spectral type, we calculate a DM = 12.8 (d = 3.6 kpc), in good agreement with its parallax. All this suggests that, beyond the obscuring clouds associated to Vul OB1, at about 2 kpc, the reddening increases very little in this direction until at least close to 4 kpc, resulting in the projection of large numbers of stars at different distances on to what seems to be a single association.

With the current Gaia DR2, this hypothesis cannot be tested. As long as systematic errors as high as 0.1 mas are possible (Luri et al. 2018), differentiating between 2 and 4 kpc is not straightforward. Despite this, it is worth noting that the Gaia parallaxes for the two Cepheids (SV Vul and S Vul), which are complicated Gaia targets, are fully consistent with previous estimates (including the HST parallax for S Vul). At the same time, stars in their neighbourhoods that were classified as members of Vul OB2 by Turner (1980) have parallaxes ranging from π = 0.42 ± 0.03 (LS II +27°23) to 0.15 ± 0.04 (HD 332848), which strongly suggests that they are not all at the same distance. Further Gaia releases will clarify this issue.

Whatever the case, it is clear that SV Vul is not directly linked to the star-forming clusters in Vul OB1, but to a rather older population. Its membership in Alicante 13 shows that one of the most luminous Cepheid variables in the Milky Way has a mass of only ≈ 10 M⊙. Indeed, there is no strong reason to believe that the even more luminous S Vul belongs to a younger population. This is in agreement with the models presented by Anderson et al. (2014), where the highest mass for a star with typical rotation (their “average” rotation rate of ω = 0.5) to experience a blue loop is slightly higher than 10 M⊙. Models with zero rotation allow Cepheids as massive as 11.5 M⊙. Such null rotation is in fact unphysical, but stars with low rotational velocities do indeed exist, and they could become Cepheids for masses of at least 11 M⊙, although with a luminosity comparable to that of the most luminous “ rotating” Cepheids (log L/L⊙ ≈ 4.3), considered by Anderson et al. (2014) the upper limit in luminosity for Cepheids.

Among Cepheids in clusters, the only strong evidence for a mass higher than ≈ 10 M⊙ is given by the 23 d Cepheid in vdBH 222 (Clark et al. 2015). At the distance implied by the Cepheid properties (∼ 6 kpc), the cluster has an age ≈ 20 Ma (Marco et al. 2014) and thus the properties of this Cepheid, which has a luminosity similar to that of SV Vul can be explained by a ≥ 11 M⊙ star with low rotation. For example, using isochrones by Georgy et al. (2013), we find that an M* = 11.2 M⊙ star with low rotation (ω = 0.1) will be in the blue loop at an age of ≈ 20.3 Ma, with log L/L⊙ = 4.3. Again, we find very good agreement, even if we have to consider that all tracks by Georgy et al. (2013) between 9 and 12 M⊙ are interpolated, and not directly calculated. Although further study of vdBH 222 is needed for a better characterisation, all observations of Milky Way Cepheids in clusters seem to agree to a very good degree with the models of Anderson et al. (2014). Further Gaia data releases will undoubtedly provide us with a larger number of high-luminosity Cepheids with accurate distances.

Meanwhile, the very accurate proper motions provided by DR2 are already allowing us to discover new clusters with very low background contrast, such as Alicante 13, which would be completely inconspicuous except for the fortunate presence of three (super)giants within one arcmin. With an accurate distance to the cluster, successive Gaia releases may turn SV Vul into a key landmark for the local distance scale and the study of the evolutionary status of long-period Cepheids.

6 CONCLUSIONS
We find that the 45 d classical Cepheid SV Vul is a certain astrometric halo member of a new young open cluster, Alicante 13. The star is slightly brighter than predicted by the best fit isochrones, suggesting that it started its life as a fast rotator. With the best fit age, stars close to the main sequence have M* ≈ 9 M⊙ and SV Vul has a mass of M* ≈ 10 M⊙, in agreement with the highest mass compatible with a fast rotator entering the blue loop (Anderson et al. 2014). Isochrone fit to the cluster CMD favours a distance of 2.5 kpc, in good agreement with its Gaia parallax and the distance proposed by Madore et al. (2017). There is, however, a discrepancy between the amount of extinction needed to fit the optical and the infrared photometry, suggestive of a moderately non-standard reddening law. The connection of Alicante 13 to the Vul OB1 association, dominated by NGC 6823, is unclear. In fact, only clusters with current star formation seem to be certain members of the association. With upcoming Gaia releases providing a definitive distance, SV Vul will...
become an anchoring point in the study of long-period classical Cepheids.

**NOTE ADDED IN PROOF**

After submission of this paper, Castro-Ginard et al. (2020) presented results of a systematic search for clusters, conducted by applying a machine learning methodology to Gaia DR2 data. Among their 245 class A candidate clusters, they find Alicante 13, under the name UBC 130, with centre at RA: 19:52:12.17, Dec: +27:26:42.9. Their estimated parameters are $\pi = 0.39 \pm 0.03$ mas, pmRA = $-2.11 \pm 0.08$ mas/yr, pmDec = $-5.85 \pm 0.08$ mas/yr, fully consistent with the values derived in this paper. According to their criteria, TYC 2148 - 3299 - 1 is an outlying cluster member. If so, it must be a third red supergiant. Its Gaia DR2 radial velocity $0.86 \pm 0.24$ km s$^{-1}$ is compatible with those of other members. However, both its Gaia and 2MASS magnitudes, $K_S = 5.44$, $(J - K_S) = 1.21$, place it below the cluster isochrone. Spectroscopic data will be needed to assess its membership.

**ACKNOWLEDGEMENTS**

We thank the anonymous referee for their prompt response and encouraging comments. This research is partially supported by the Spanish Government under grants AYA2015-68012-C2-2-P and PGC2018-093741-B-C22 (MICIU/AEI/FEDER, UE).

The Nordic Optical Telescope is operated by the Nordic Optical Telescope Scientific Association at the Observatorio del Roque de los Muchachos (La Palma, Spain) of the Instituto de Astrofísica de Canarias. Observations have been taken as part of the Spanish service time, and we gratefully acknowledge the work of the support astronomers. The Starlink software (Currie et al. 2014) is currently supported by the East Asian Observatory. This work has made use of data from the European Space Agency (ESA) mission Gaia (https://www.cosmos.esa.int/gaia), processed by the Gaia Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement.

This research has made use of the Simbad, Vizier and Aladin services developed at the Centre de Données Astronomiques de Strasbourg, France. It also 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.

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