A cluster of class I/f/II young stellar objects discovered near the Cepheid SU Cas

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ABSTRACT

Preliminary constraints are placed on a cluster of young stellar objects (J2000 02:54:31.4 +69:20:32.5) discovered in the field of the classical Cepheid SU Cas. The Wide-field Infrared Survey Explorer (WISE) 3.4-, 4.6-, 12- and 22-µm images reveal that the cluster deviates from spherical symmetry and exhibits an apparent diameter of 3 × 6 arcmin. Spectral energy distributions constructed using the Two Micron All Sky Survey (2MASS) Ks (2.2 µm) and WISE photometry indicate that 19 (36 per cent) class I, 21 (40 per cent) class f and 13 (25 per cent) class II objects lie r < 3 arcmin from the cluster centre. Conversely, 11 (18 per cent) class I, 13 (21 per cent) class f and 37 (61 per cent) class II objects were detected for r > 3 arcmin. Approximately 50 per cent of the class I sources within r < 3 arcmin were classified solely using WISE photometry owing to the absence of detections by 2MASS.

Key words: circumstellar matter – stars: formation – stars: protostars – infrared: stars.

1 INTRODUCTION

The latest generation of near- and mid-infrared surveys such as the VISTA Variables in the Via Lactea (VVV; Minniti et al. 2010), UKIRT Infrared Deep Sky Survey (UKIDSS; Lucas et al. 2008), Galactic Legacy Infrared Midplane Survey Extraordinaire (GLIMPSE) and Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010) have fostered the discovery of countless stellar nurseries. Mercer et al. (2005) discovered 92 star clusters using GLIMPSE data (3.6, 5.8, 8.0 and 24 µm), of which ~67 per cent likely host a young stellar demographic. Similarly, a sizeable fraction of the 96 clusters discovered by Borissova et al. (2011) in the VVV survey (YJHKs) house heavily obscured young populations. Infrared photometry is particularly efficient at revealing embedded sources which are otherwise obscured from optical surveys since Aγ ∝ λ−β (e.g. Nishiyama et al. 2009). The total extinction tied to photometry employed here is AKs/AJ ~ 0.1 for the Two Micron All Sky Survey (2MASS) Ks (∼2.2 µm) and A[3.4,4.6,12,22]s ~ 0.05AJ for WISE photometry (e.g. Flaherty et al. 2007).

In this study, initial constraints are placed on young stellar objects (YSOs) discovered in the field of the 1.95-d classical Cepheid SU Cas. In Section 2.1, optical Digitized Sky Survey (DSS) and 3.4-µm (WISE) images of the cluster are compared, and its apparent extent is determined from the latter; in Section 2.2, SEDs are constructed to classify the YSOs according to the prescription outlined by Lada (1987) and to assess whether the YSO class varies as a function of radial distance from the cluster centre; in Section 2.3, JHKs colour–colour diagrams are constructed for cluster stars and an adjacent comparison field.

2 ANALYSIS

2.1 Unveiling the cluster

The field of the classical Cepheid SU Cas hosts two clusters. The first encompasses SU Cas, and Turner & Evans (1984) speculated that the Cepheid is a cluster member. The connection is of particular importance since SU Cas is the shortest period calibrator of the Galactic Vβ Wesenheit function. Such functions are employed to constrain H0 and dark energy (Freedman & Madore 2010). Observations obtained from the Abbey Ridge Observatory (Majaess et al. 2008) for the parent cluster of SU Cas shall be described in a forthcoming study.

The second cluster, detailed here, lies ~30 arcmin north-east of SU Cas (Fig. 1). The cluster is absent from optical images of the region (<0.8 µm). A nearby YSO and an overdensity in 2MASS data were noted previously (e.g. Froebrich et al. 2007; Stražys & Kazlauskas 2010). The 3.4-, 4.6-, 12- and 22-µm WISE images unambiguously reveal a cluster centred at J2000 02:54:31.4 +69:20:32.5.

The cluster deviates from spherical symmetry and exhibits an apparent diameter of 6 arcmin in the north–south direction. The cluster’s extent in the east–west direction is approximately half that value (3 arcmin).

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2.2 Classifying the YSOs via SEDs

The YSOs were classified by assessing the spectral energy distribution according to the approach of Lada (1987). The SED for each star was constructed in the canonical fashion:

\[
\log (\lambda \times F_\lambda ) = \alpha \log \lambda + z, \tag{1}
\]

\[
\log (\lambda \times F_\lambda ) = \log (\lambda \times 10^{m_\lambda - 2.5} F_\lambda (0) k c / \lambda^2), \tag{2}
\]

where \( \lambda \) is the wavelength of the passband (cm), \( m_\lambda \) is the magnitude in that passband, \( c \) is the speed of light (cm s\(^{-1}\)), \( F_\lambda (0) \) is the zero-magnitude flux (Jy), \( k \) is a conversion factor \( (k = 10^{-23} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ Hz}^{-1}) \) and \( \alpha \) is the slope of the function.

Class I, class flat (hereafter class f) and class II YSOs exhibit \( \alpha > 0.3 \), \( -0.3 < \alpha < 0.3 \) and \( \alpha < -0.3 \) accordingly (see also Liu et al. 2011). The slope \( \alpha \) of equation (1) is determined from 2MASS \( K_s \) and photometry extending redwards of 2.2 \( \mu \)m. However, the wavelength dependence of extinction invariably biases the perceived slope. Radiation emitted at 2MASS \( K_s \) exhibits higher sensitivity to extinction than WISE passbands. Simulations for J025427.46+692012.8 (class I) and J025435.68+692222.7 (class f) indicate that \( \alpha \) varies according to \( \alpha_{(K_s+W)} \sim \alpha_{(K_s+W),0} - 0.13 \times \delta A_{K_s} \). That bias may be mitigated by determining \( \alpha \) based solely on WISE photometry since the passbands display nearly equivalent extinction ratios \( (A_{(3.4+4.5+12)}:A_{22}) \sim 0.5A_{K_s} \). In the cases where \( K_s \) was unavailable, the determination of \( \alpha \) resulted from WISE photometry. The correlation between the slope \( \alpha \) derived including and excluding 2MASS \( K_s \) is described by \( \alpha_{(K_s+W)} \sim 0.98 \times \alpha_{W} - 0.15 \).

For 53 objects detected within 3 arcmin of the cluster centre, 19 (36 per cent) are class I, 21 (40 per cent) are class f and 13 (25 per cent) are class II objects. Beyond \( r > 3 \) arcmin from the cluster centre, the detection rates change to 11 (18 per cent) class I, 13 (61 per cent) class f and 37 class II objects. Within \( r < 3 \) arcmin, 10 (20 per cent) class I, 5 (10 per cent) class f and 0 class II sources lack 2MASS photometry. Beyond \( r > 3 \) arcmin, a total of 9 (15 per cent) class I, 6 (10 per cent) class f and 3 (5 per cent) class II sources were not catalogued by 2MASS.

The aforementioned statistics reaffirm that the YSO class varies with radial distance from the cluster centre. The fraction of less evolved objects decreases as a function of increasing radial distance. Admittedly, \( \alpha \) may be biased by the effects of photometric contamination for stars near the crowded cluster core.

2.3 Colour–colour diagram

\( JHK_s \) colour–colour diagrams were constructed for the cluster stars and a comparison field 20 arcmin distant (Fig. 3). The sequence of YSOs is absent from the comparison field. The latter is dominated by unreddened late-type field stars according to the intrinsic \( JHK_s \) relation of Stražys & Laugalys (2008). Conversely, several cluster members are heavily obscured \( (A_V \sim 35) \). Indeed, radiation emitted from the 10 class I sources lacking \( K_s \) photometry may suffer additional extinction.

The YSOs are highlighted on the colour–colour diagram by class (Fig. 3). Identifications for the objects, which include their J2000 coordinates and classifications, are provided in Table 1. Discrete CO and HI emission indicate that the cluster may be coincident with a complex foreground to SU Cas (Turner & Evans 1984), or beyond the Cepheid \( (d = 418 \pm 12 \text{ pc); Storm et al. 2011}) \) at \( d \lesssim 0.95 \text{ kpc} \). The latter sets a soft upper limit since most young clusters exhibit a height \( Z \) less than that implied (note that \( \ell, b \sim 133.5, 9^\circ \)). Additional research is required.

3 CONCLUSION

Countless YSOs were discovered at J2000 coordinates 02:54:31.36 +69:20:32.5 (Fig. 1), which is 30 arcmin north-east of the classical Cepheid SU Cas. The cluster appears non-symmetric and displays an apparent diameter of 6 arcmin (Fig. 1). SEDs constructed using 2MASS and WISE photometry indicate that the cluster hosts 19 (36 per cent) class I, 21 (40 per cent) class f and 13 (25 per cent) class II objects (Fig. 2). At a distance beyond 3 arcmin from the cluster centre, the sampling changes markedly to 11 (18 per cent) class I, 13 (20 per cent) class f and 37 (60 per cent) class II objects. The statistics reaffirm that the YSO class exhibits a radial dependence. 10 class I sources lacking 2MASS \( K_s \) photometry were classified via SEDs tied to WISE observations. The slope \( \alpha \)
The YSO is a class I source (equation 1) inferred from that approach appears less biased by the wavelength dependence of extinction since WISE passbands exhibit nearly equivalent extinction ratios (as compared to $K_s$). The extreme extinction obscures many of the cluster’s YSOs ($A_V \sim 35$) beyond optical detection (Fig. 3).

The latest generation of infrared surveys (e.g. WISE, GLIMPSE, etc.) shall continue to foster the detection and characterization of new stellar clusters, as reaffirmed here. Additional research, which includes spectroscopic follow-up of the cluster and broader region, is required.

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