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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) K_s (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 (*YZJHK*$_s$) house heavily obscured young populations. Infrared photometry is particularly efficient at revealing embedded sources which are otherwise obscured from optical surveys since $A_\lambda \propto \lambda^{-\beta}$ (e.g. Nishiyama et al. 2009). The total extinction tied to photometry employed here is $A_{K_s}/A_V \sim 0.1$ for the Two Micron All Sky Survey (2MASS) K_s (∼2.2 μm) and $A_{[3.4]}$:$A_{[4.5]}$:$A_{[12]}$:$A_{[22]} \sim 0.05A_V$ 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, *JHK*$_s$ 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 VI_c Wesenheit function. Such functions are employed to constrain H_0 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; Straižys & 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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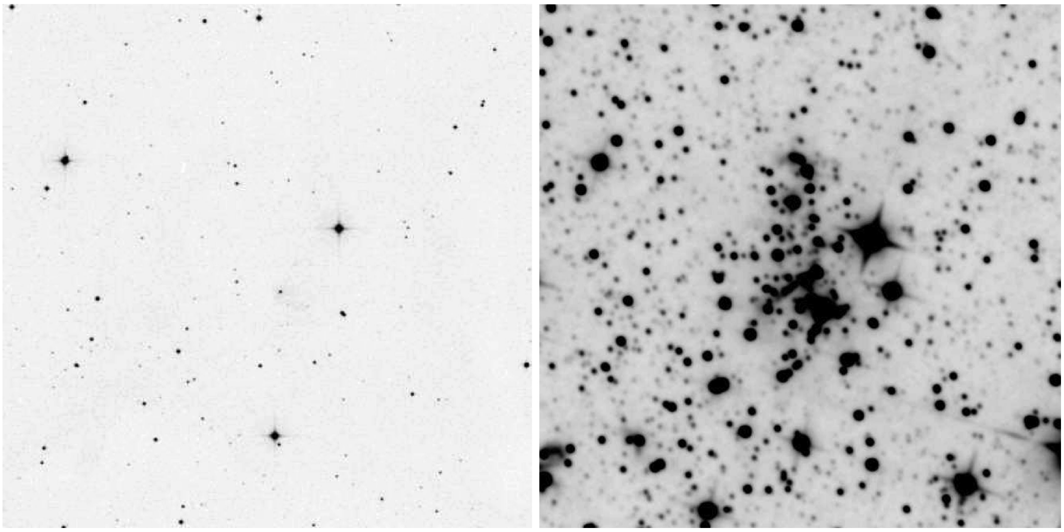

Figure 1. Left- and right-hand panels: optical DSS and *WISE* 3.4-μm images centred at J2000 02:54:31.4 +69:20:32.5. The images span ∼15 × 15 arcmin and were aligned using the ALADIN software environment (Bonnarel et al. 2000). The YSOs are absent from the optical image owing to significant interstellar and circumstellar extinction. West is left, and north is up.

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:

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

$$\log(\lambda \times F_\lambda) = \log(\lambda \times 10^{m_\lambda/-2.5} F_\lambda(0) kc/\lambda^2), \tag{2}$$

where λ is the wavelength of the passband (cm), m_λ 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 ($k = 10^{-23}$ erg cm^{-2} s^{-1} Hz^{-1}) and α 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 (α) of equation (1) is determined from 2MASS K_s and photometry extending redwards of 2.2 μm. 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 α 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 α based solely on *WISE* photometry since the passbands display nearly equivalent extinction ratios ($A_{[3.4]}$:$A_{[4.5]}$:$A_{[12]}$:$A_{[22]} \sim 0.5 A_{K_s}$). In the cases where K_s was unavailable, the determination of α resulted from *WISE* photometry. The correlation between the slope (α) 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 >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, α 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 Straižys & 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 ($d = 418 \pm 12$ pc; Storm et al. 2011) at $d \lesssim 0.95$ kpc. The latter sets a soft upper limit since most young clusters exhibit a height Z less than that implied (note that $\ell, b \sim 133.5, 9°$). 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 α

Table 1. YSO Candidates <3 arcmin from the cluster centre.

Designation	YSO class	Designation	YSO class
J025426.03+691837.2	I (K_s+W)	J025428.46+691851.6	II (K_s+W)
J025423.45+692011.6	I (K_s+W)	J025441.33+691911.1	II (K_s+W)
J025423.60+692221.4	I (K_s+W)	J025432.89+692008.7	I (K_s+W)
J025425.93+692251.4	f (K_s+W)	J025436.88+691911.3	f (K_s+W)
J025437.43+692113.6	I (K_s+W)	J025434.48+692316.0	f (K_s+W)
J025435.68+692222.7	f (K_s+W)	J025424.19+692051.9	f (K_s+W)
J025439.36+691838.6	f (K_s+W)	J025437.54+691902.6	f (K_s+W)
J025433.11+691753.3	f (K_s+W)	J025429.86+692221.9	I (K_s+W)
J025425.62+691755.5	II (K_s+W)	J025437.03+692020.0	II (K_s+W)
J025427.46+692012.8	I (K_s+W)	J025434.66+691933.9	II (K_s+W)
J025430.67+692100.6	I (K_s+W)	J025438.85+691919.0	f (K_s+W)
J025441.82+691945.9	f (K_s+W)	J025430.94+692034.8	I (W)
J025421.04+691932.9	II (K_s+W)	J025429.32+692000.0	f (W)
J025439.47+692244.1	f (K_s+W)	J025428.12+692057.3	I (W)
J025420.10+691954.7	f (K_s+W)	J025428.92+692122.1	I (W)
J025436.28+692154.2	I (K_s+W)	J025427.83+691953.5	I (W)
J025422.57+691948.7	f (K_s+W)	J025433.74+692139.4	I (W)
J025420.65+692122.5	II (K_s+W)	J025429.20+692141.1	I (W)
J025434.16+691824.0	f (K_s+W)	J025426.00+691951.3	I (W)
J025431.31+691929.6	II (K_s+W)	J025435.57+692139.0	f (W)
J025428.03+691801.1	II (K_s+W)	J025425.68+692121.3	f (W)
J025430.92+691919.1	II (K_s+W)	J025426.03+692207.7	f (W)
J025436.07+691844.0	II (K_s+W)	J025424.17+691915.3	f (W)
J025434.47+691835.3	II (K_s+W)	J025432.46+691805.3	I (W)
J025435.30+692246.0	f (K_s+W)	J025431.18+692311.2	I (W)
J025424.17+692136.5	f (K_s+W)	J025429.68+691742.5	I (W)
J025420.46+691919.5	II (K_s+W)		

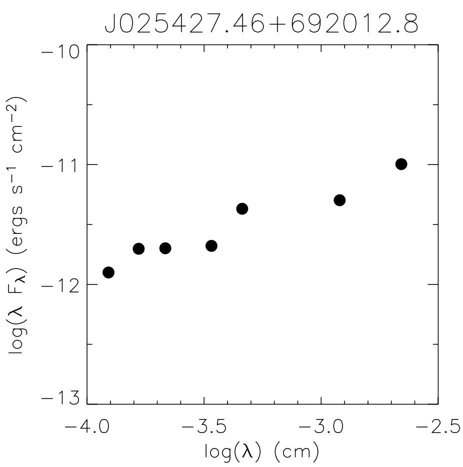

Figure 2. A SED for the YSO designated J025427.46+692012.8 constructed from 2MASS and *WISE* photometry. The YSO is a class I source which lies ∼1 arcmin from the cluster centre.

(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.

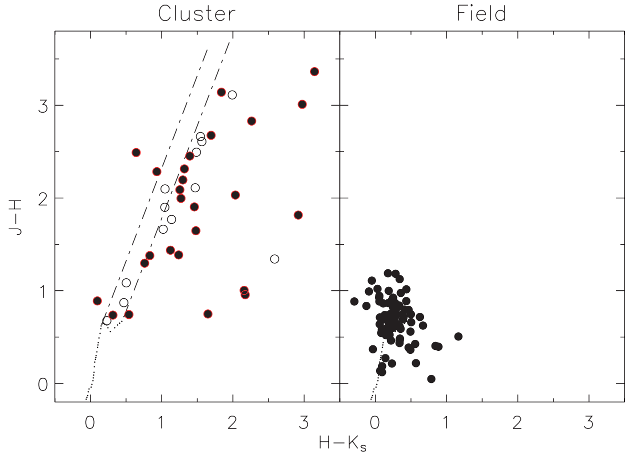

Figure 3. 2MASS *JHK*$_s$ colour–colour diagrams for cluster stars (left-hand panel) and a comparison field (right-hand panel). YSOs are absent from the latter, which is dominated by unreddened late-type field stars. The intrinsic *JHK*$_s$ main-sequence relation of Straižys & Laugalys (2008) is shown. Reddened main-sequence stars typically lie within the region bounded by the parallel lines (dot–dashed). Left-hand panel: open circles and red encircled black dots are class II and class I/f candidates, respectively. Right-hand panel: black dots denote late-type field stars.

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