# The star formation environment of the FU Ori type star V582 Aur

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#### ABSTRACT

We have studied the environment of the FU Ori type star V582 Aur. Our aim is to explore the star-forming region associated with this young eruptive star. Using slitless spectroscopy we searched for H $\alpha$  emission stars within a field of 11.5' × 11.5', centred on V582 Aur. Based on UKIDSS and Spitzer Space Telescope data we further selected infrared-excess young stellar object candidates. In all, we identified 68 candidate low-mass young stars, 16 of which exhibited H $\alpha$  emission in the slitless spectroscopic images. The colour–magnitude diagram of the selected objects, based on IPHAS data, suggests that they are low-mass pre-main-sequence stars associated with the Aur OB 1 association, located at a distance of 1.3 kpc from the Sun. The bright-rimmed globules in the local environment of V582 Aur probably belong to the dark cloud LDN 1516. Our results suggest that star formation in these globules might have been triggered by the radiation field of a few hot members of Aur OB 1. The bolometric luminosity of V582 Aur, based on archival photometric data and on the adopted distance, is 150–320 L $\odot$ .

**Key words:** Stars: pre-main-sequence – Stars: formation – Stars: individual: V582 Aur – ISM: clouds – open clusters and associations: individual: Aur OB1

#### 1 INTRODUCTION

FUors, named after their prototype FU Orionis, are young, low-mass stars undergoing powerful, long term (from decades to centuries) outbursts, powered by increased accretion (Hartmann & Kenyon 1996; Audard et al. 2014). During these events, FUors brighten up to 6 magnitudes over a few months, stay in a high state for decades, and as much as one tenth of the stellar mass may be added during these repeated outbursts. These young stars are members of starforming regions both kinematically and spatially (Herbig 1966, 1977; Hartmann & Kenyon 1996). Studying the star forming environment of FUors is important for determining their distances and luminosities.

One of the less studied FU Ori type stars is V582 Aur (Samus 2009; Semkov et al. 2013). The brightening of V582 Aur was discovered by the amateur astronomer Anton Khruslov and the star was reported as a FUor candidate by Samus (2009). Semkov et al. (2013), based on photometric and spectroscopic observations of V582 Aur in its high state, confirmed its FUor nature. V582 Aur is projected on both the Aur OB 1 and Aur OB 2 associations, which are overlapping along the line of sight and situated at  $1.32\pm0.1$ and  $2.8\pm0.27$  kpc from the Sun, respectively (Humphreys 1978; Marco & Negueruela 2016). The region was included in several observational studies of the Galactic structure toward the anticentre (e.g. Marco & Negueruela 2016; Camargo, Bica & Bonatto 2013, and references therein). V582 Aur is projected within the area of the cluster CBB 9, identified by Camargo, Bonatto & Bica (2012), and on the periphery of the large dark cloud Lynds 1516 (Lynds 1962). No molecular cloud associated with Lynds 1516 was listed in Kawamura et al. (1998).

In order to explore the star formation environment of V582 Aur we searched for candidate young stellar objects in the region centred on V582 Aur. We utilized two striking characteristics of low- and intermediate-mass young stars, i. e. their specific near- and mid-infrared excesses, originating from circumstellar discs, and strong H $\alpha$  emission, a signpost of mass accretion. We performed a search for new H $\alpha$  emission line stars via slitless grism spectroscopy, using the University of Hawaii 2.2-m telescope, and used infrared data, available in the UKIDSS Galactic Plane Survey data base (Lucas et al. 2008) and in the Spitzer GLIMPSE360 Cata-

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log and Archive. We further used optical photometric data, available in the IPHAS (Barentsen et al. 2014) DR2 Source Catalogue, to estimate distances and luminosities. We describe our observations and data reduction in Sect. 2. The procedures for young stellar object (YSO) identification in archival data are described in Sect. 3. The results are presented and conclusions are drawn in Sect. 4. We give a short summary in Sect. 5.

## 2 OBSERVATIONS AND DATA REDUCTION

We conducted a search for  $H\alpha$  emission stars in the vicinity of V582 Aur using the Wide Field Grism Spectrograph 2 (WFGS2) at the University of Hawaii 2.2-meter telescope on 2011 January 1. We used a 300 line  $mm^{-1}$  grism blazed at 6500 Å and providing a dispersion of 3.8 Å pixel<sup>-1</sup> and a resolving power of 820. The  ${\rm H}\alpha$  filter had a 500 Å passband, centred near 6515 Å. The detector for WFGS2 was a Tektronix 2048  $\times$  2048 CCD, whose pixel size of 24  $\mu$ m corresponded to 0.34 arcsec on the sky. The field of view was  $11.5' \times 11.5'$ , centred on V582 Aur. We took a short, 60 s exposure to identify the  $H\alpha$  line in the spectra of bright stars, and avoid saturation. Then we obtained two frames of 480 s exposure time, and co-added them to eliminate effects of the cosmic rays. Direct images of the same field were obtained through r' and i' filters before the spectroscopic exposures. One exposure was taken in each filter with integration time of 60 s. The steps of the data reduction were the same as described in detail in Szegedi-Elek et al. (2013).

We examined the co-added spectroscopic image visually to discover young stars showing the  $H\alpha$  line in emission, and found 16 emission-line objects in the observed region. We determined their equatorial coordinates by matching their positions, measured in the coadded grism image. with those of Two Micron All Sky Survey (Cutri et al. 2003) point sources in the direct images. All  $H\alpha$  emission sources had 2MASS counterparts within 1.4 arcseconds. We use 2MASS designations to identify the new H $\alpha$  emission objects. The equivalent width of the H $\alpha$  emission line EW(H $\alpha$ ) and its uncertainty were computed in the manner described by Szegedi-Elek et al. (2013). Due to the faint continuum and/or overlapping spectra we could measure  $EW(H\alpha)$  only in the spectra of nine stars. Table 1 lists the 2MASS designations and derived  $H\alpha$  equivalent widths of the emission objects detected in the WFGS2 images centred on V582 Aur. For comparison, we list EWs estimated from the IPHAS  $r' - [H\alpha]$  vs. r' - i' colour-colour diagram (see Sect. 4.2) in column 5. To indicate the brightness of the stars r' magnitudes are listed in column 6 (see Sect. 3.4). The last column of Table 1 indicates the presence or absence of infrared excess over the 2.2–4.6  $\mu$ m wavelength region (see Sects. 3.1 and 3.2).

# **3 YSO SELECTION FROM DATA ARCHIVES**

# 3.1 UKIDSS

Pre-main-sequence stars, surrounded by protoplanetary discs, are clustered at specific regions in the J-H vs.  $H-K_{\rm s}$  colour–colour diagram. Thus the colour–colour diagram is a useful tool to identify young stars. The region around

V582 Aur was covered by the UKIDSS Galactic Plane Survey, some three magnitudes deeper than the 2MASS survey. We used the UKIDSS-DR6 Galactic Plane Survey data base (UGPS, Lucas et al. 2008), accessible in  $VizieR^1$ , to identify disc-bearing young stars in the area, identical with the field of view of our WFGS2 observations. Figure 1 presents the colour-colour diagram of the UKIDSS sources of the studied region. Small grey crosses show the distribution of all UKIDSS sources detected in each band, classified as stars with a probability pStar > 0.70, and having colour index uncertainties  $\Delta(J-H) < 0.1$  and  $\Delta(H-K_s) < 0.1$ . Candidate YSOs in this diagram are sources whose errorbars are entirely to the right of the band of the reddened main sequence, bordered by the long-dashed lines. Reddened T Tauri stars occupy the grey area (Meyer, Calvet & Hillenbrand 1997). Taking into account the empirical nature of the T Tauri locus (dash-dotted line), we include a 0.1-mag wide band below this line into the T Tauri domain. Sources to the right of this band are candidate embedded protostars, whereas those below the locus of the unreddened T Tauri stars are somewhat uncertain in nature. Herbig Ae/Be stars are located in this part of the diagram (e.g. Manoj et al. 2006). These intermediate-mass pre-main-sequence stars are expected to be brighter than T Tauri stars of the same star-forming region. We checked the magnitudes of the  $K_{\rm s}$ -band-excess sources below the unreddened T Tauri locus and found them to be among the faintest sources of the studied field. We ignore these sources, since their very red  $H-K_{\rm s}$  colour indices probably do not originate from protoplanetary discs. Red diamonds indicate the 42 selected candidate YSOs in Fig. 1. Additionally, twenty extended UKIDSS sources of the studied area, classified as probable galaxies, are located in the same region of the colour-colour plane. Extended sources, projected on a star-forming region, may be embedded protostars, whose appearance in the near-infrared is dominated by scattered light. We examined these sources in the UKIDSS and IPHAS images, and added six of them to the list of candidate YSOs. Black circles indicate these six extended sources in Figs. 1 and 3. The list of the UKIDSS-selected candidate YSOs is presented in Table 2. Ten H $\alpha$  stars, detected in the WFGS2 images, have counterparts in this sample. V582 Aur itself is saturated in the UKIDSS images. Its 2MASS data, however, show it to be a  $K_{\rm s}$ -band excess young star.

#### 3.2 Spitzer

Our target field was also observed by the Spitzer Space Telescope (Werner et al. 2004) during its warm mission, as part of the GLIMPSE360 project (Churchwell et al. 2009). Observations were performed on 2010 May 4 with the Infrared Array Camera (IRAC, Fazio et al. 2004) at 3.6 and  $4.5 \,\mu\text{m}$  (aors 38916864 and 38828288). We examined all sources within the 11.5' × 11.5' environment of V582 Aur to search for additional young stars. We combined UKIDSS JHK<sub>s</sub> magnitudes with Spitzer [3.6] and [4.5] magnitudes and applied the Phase 2 selection criteria established by Gutermuth et al. (2009). This selection process includes dereddening of the colour indices of input stars onto the

<sup>&</sup>lt;sup>1</sup> http://vizier.u-strasbg.fr/

Name	2MASS Id	EW(Ha	α) (Å)	$r'_{\rm IPHAS}$	IR excess
		$WFGS2^{a}$	$IPHAS^{b}$	(mag)	
L1516-Ha1	05252786 + 3457419		25	19.02	Υ
L1516-Ha2	05252963 + 3457551	$8.0{\pm}2.5$	25	17.78	Υ
L1516-Ha3	05253251 + 3457180	$11.6 \pm 2.3$	15	17.16	Υ
L1516-Ha4	05253272 + 3457107	$13.7 \pm 2.2$	50	16.51	Υ
L1516-Ha 5	05253284 + 3455293		< 10	18.52	Ν
L1516-Ha6	05253408 + 3457465		60	19.09	Υ
$L1516-Ha7^{*}$	05254456 + 3450178	$53.3 \pm 10.5$	30	17.85	Υ
L1516-Ha8	05255203 + 3458081	$6.8 {\pm} 0.7$	80	18.36	Υ
$L1516-Ha9^*$	05255439 + 3454391	$37.3 \pm 4.2$	50	17.45	Υ
L1516-Ha $10$	05255537 + 3454418	$6.5 \pm 2.1$	< 10	17.96	Υ
L1516-Ha 11	05255688 + 3451442	$46.6 \pm 5.6$	100	16.96	Υ
L1516-Ha12	05260273 + 3451093		160	20.41	Υ
L1516-Ha 13	05260711 + 3454260		< 10	18.00	Υ
L1516-Ha14	05261468 + 3450052		60	19.73	Υ
L1516-Ha15	05261637 + 3453332	$15.4 \pm 7.7$	< 10	17.72	Υ
L1516-Ha16	05261681 + 3454223		120	20.99	Υ

Table 1. H $\alpha$  emission stars identified during our WFGS2 observations.

<sup>*a*</sup>Measured in the slitless grism spectra. <sup>*b*</sup>Estimated from IPHAS photometry (Fig. 4). \*Catalogued as H $\alpha$  emission star in Witham et al. (2008) from IPHAS photometry.

YSO locus of the J-H vs.  $H-K_s$  (or  $H-K_s$  vs. [4.5] – [3.6] when J-band photometry is not available) diagram, and defines YSO colour criteria in the plane of the extinctioncorrected  $[K_{\rm s} - [3.6]]_0$  and  $[[3.6] - [4.5]]_0$  colour indices. Fig. 2 shows the distribution of the point sources in the  $[K_{\rm s} - [3.6]]_0$  vs.  $[[3.6] - [4.5]]_0$  colour-colour diagram. To exclude dim extragalactic contaminants we applied [3.6] < 14.0and [4.5] < 14.0 magnitude limits. Candidate YSOs are located in the upper right part of the diagram, bordered by the solid lines. Blue squares indicate the 48 candidate YSOs revealed by this selection. For comparison we plotted with red dots the candidate YSOs selected in the UKIDSS J-Hvs.  $H-K_{\rm s}$  colour-colour diagram. The comparison shows that each previously selected object lies within the region assigned for YSOs, and a sizable part of them are fainter than 14 mag in the IRAC bands. We find 16 candidate YSOs not selected in the UKIDSS data. These stars are listed in Table 3. Their positions in the  $JHK_s$  colour-colour diagram are indicated by blue squares in Fig. 1. A 17th source, G172.7687-00.3577 (UGPS J052547.76+344950.9), classified as a probable UKIDSS galaxy, also fulfils the colour criteria. This very red object is projected on the edge of a dark cloud, therefore we include it in the list of candidate YSOs. Five  $H\alpha$  stars, detected in the WFGS2 images, have counterparts in this sample.

#### **3.3** *WISE*

Marton et al. (2016a) performed a comprehensive all-sky search for candidate YSOs in the *AllWISE* data release. Six objects of their resulting catalogue (Marton et al. 2016b) can be found in our studied area, including V582 Aur itself. Three further among these candidates coincide with sources selected during the previous steps. These stars are marked in Tables 2 and 3. The remaining two objects are new candidate YSOs, listed in Marton et al.'s (2016a) catalogue as AllWISE J052614.87+345225.0 and

AllWISE J052538.15+344805.0. The first source was classified as a probable galaxy (extended source) in the UKIDSS and IPHAS bands, therefore its nature is uncertain. The UKIDSS and *Spitzer* sources, coinciding in position with the second source within one arcsec, exhibit normal stellar colours, indicative of either an evolved (transitional) circumstellar disc, or two distinct sources.

#### 3.4 IPHAS

The field we have studied was covered by the INT Photometric H $\alpha$  Survey of the Northern Galactic Plane (IPHAS) survey (Drew et al. 2005). High-quality (S/N > 10) r' and i', and narrow-band H $\alpha$  magnitudes are available for more than 800 stars of the studied 11.5' × 11.5' region in the IPHAS DR2 Source Catalogue (Barentsen et al. 2014). These data are suitable for selecting further candidate YSOs (see Barentsen et al. 2011). Two of our 16 H $\alpha$  emission stars appear in the first catalogue of H $\alpha$  emission objects based on the IPHAS survey (Witham et al. 2008), containing stars brighter than r' = 19.5 mag. r', i', and H $\alpha$  magnitudes are available for 35 of our candidate YSOs. We use these data to examine the H $\alpha$  emission properties of the stars selected by infrared excesses, and establish the distance of the group of candidate YSOs around V582 Aur.

### 4 RESULTS

# 4.1 Surface distribution of candidate YSOs around V582 Aur

Figure 3 shows the surface distribution of the selected candidate young stars, overplotted on the IPHAS narrow-band H $\alpha$  image of the studied 11.5' × 11.5' region. The underlying H $\alpha$  image reveals that V582 Aur and several candidate young stars are projected on bright-rimmed dark clouds.

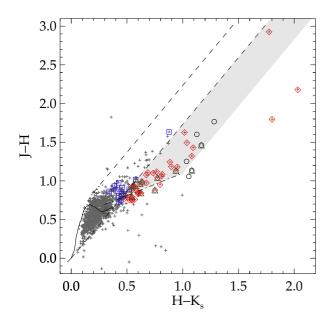
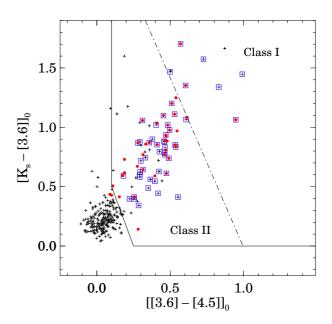


Figure 1. J-H vs.  $H-K_{\rm s}$  colour-colour diagram of UKIDSS sources in a field of  $11.5' \times 11.5'$ , centred on V582 Aur. Small grey crosses indicate all stars having  $\Delta(J-H) < 0.1$  and  $\Delta(H-K_s) <$ 0.1 in the UGPS catalogue. Red diamonds mark the candidate YSOs selected out of this sample. Green triangles show the  $H\alpha$ emission stars identified in the WFGS2 images. Black circles show the extended UKIDSS sources considered as candidate YSOs. The black solid curve shows the colours of the zero-age main sequence. and dotted line is the giant branch. The dash-dotted line is the locus of unreddened T Tauri stars (Meyer et al. 1997). The longdashed lines delimit the area occupied by reddened normal stellar photospheric colours (Cardelli, Clayton & Mathis 1989). The grey shaded band indicates the area occupied by reddened  $K_{\rm s}$ band excess pre-main-sequence stars. For comparison, we plotted with blue squares candidate disc-bearing stars revealed by their 3.6 and 4.5- $\mu$ m excess emission only.

Striking features of the image are the elephant-trunk-like globule near the eastern edge, and the compact group of candidate YSOs clustered at the north-western corner. The dotted circle indicates the catalogued position of the CBB 9 cluster, identified by Camargo et al. (2012), and the dashed circle marks the position of the FSR 775 open cluster candidate, identified by Froebrich, Scholz & Raftery (2007) using 2MASS data, and rejected later as a real cluster by detailed structure studies by Camargo et al. (2012). The distribution of fainter UKIDSS and Spitzer sources suggest a remarkable clustering of candidate T Tauri stars projected near the centre of FSR 775. Some 40 per cent of the candidate YSOs can be found within 2 arcmin to the centre of FSR 775. Study of the radial profile of this group, however, is beyond the scope of the present paper. Our candidate young stars and V582 Aur itself are projected within these overlapping clusters. The B1V type star HD 281147 (Marco & Negueruela 2016), mentioned by Camargo et al. (2012) as a possible member of CBB 9 is also labelled.



**Figure 2.**  $[K_{\rm s} - [3.6]]_0$  vs.  $[[3.6] - [4.5]_0]$  colour–colour diagram of all *Spitzer* sources associated with UKIDSS sources and brighter than [3.6] = 14.0 mag and [4.5] = 14.0 mag in the  $11.5' \times 11.5'$ area centred on V582 Aur. Solid lines delimit the region occupied by candidate YSOs, and the dash-dotted line separates Class I protostars from Class II pre-main-sequence stars according to Gutermuth et al.'s (2009) *Phase 2* method. Blue squares indicate candidate YSOs identified in this diagram, and red dots correspond to the sources selected by their  $K_{\rm s}$ -band excess.

### 4.2 The nature of candidate YSOs associated with V582 Aur

All but one of the H $\alpha$  emission stars detected by the WFGS2 exhibit infrared excesses characteristic of classical T Tauri stars. L1615-Ha 5 has no excess flux in the wavelength region covered by the UGPS and *Spitzer* GLIMPSE observations. Its low-quality *AllWISE* fluxes do not exclude excess emission at longer wavelengths. Its nature is thus uncertain: it may be either a pre-main-sequence star with evolved (transitional) disc, or weak-line T Tauri or M-type main sequence star with H $\alpha$  emission. Another H $\alpha$  source of uncertain nature is L1516-Ha 1, whose associated UKIDSS source was classified as a galaxy.

The  $r' - [H\alpha]$  vs. r' - i' colour-colour diagram allows us to estimate the EW of the H $\alpha$  emission line of the studied stars (Barentsen et al. 2011). Figure 4 shows this diagram for the 35 candidate YSOs detected in each IPHAS band. Synthetic colours of main sequence stars and H $\alpha$  emission objects are taken from Barentsen et al.'s (2011) Table A1. The thick solid line indicates the normal main sequence, and thin solid lines show the main sequence colours modified by H $\alpha$  emission. Each colour was reddened to E(B-V) = 0.40 mag, the lower limit of the foreground reddening towards the line of sight of V582 Aur (Green et al. 2015). It can be seen that not all of our candidate YSOs appear as H $\alpha$  emission stars in this diagram. Nearly half of them (15 objects), including five of the WFGS2-detected H $\alpha$  emission stars are scattered around the main sequence, below the line

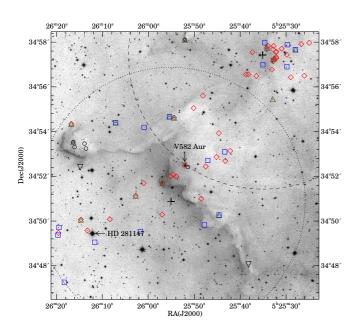
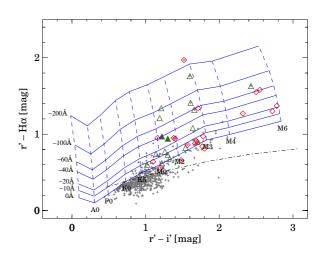


Figure 3. Candidate young stars identified during the present survey, overplotted on the IPHAS narrow-band H $\alpha$  image. Green triangles represent H $\alpha$  emission stars, red diamonds mark UKIDSS-selected sources, and blue squares indicate candidate pre-main-sequence stars exhibiting excess emission only in the *Spitzer* data. Small black circles indicate extended UKIDSS sources considered as candidate YSOs. Inverted triangles show the *AllWISE* sources listed in Marton et al.'s (2016a) catalogue of candidate YSOs. The large dotted circle indicates the position of the CBB 9 cluster, and the dashed circle marks the position and radius of the FSR 775 open cluster candidate. Crosses show the catalogued positions of the cluster centres.

corresponding to EW(H $\alpha$ )=-10 Å. All of these stars, except L1615-Ha 5, have CTTS-like infrared excesses. Their positions may result from their significantly higher extinctions, or they may be variable classical T Tauri stars with temporarily low accretion activities. Figures 4 and 6 (Sect. 4.3) suggest that the L1516-Ha objects with weak H $\alpha$  emission line are bluer and brighter on the average than the whole sample of the candidate YSOs. These properties suggest reddened G and early K type T Tauri stars, in which accretion may result in EW(H $\alpha$ ) below the -10 Å threshold (Barrado y Navascués & Martín 2003).

Figures 1 and 2 suggest that a few selected sources may be Class I protostars (Lada 1991). To confirm their nature we looked for mid- and far-infrared counterparts in the AllWISE, Akari IRC and Akari FIS data. Spectral energy distributions (SED) for three candidate protostars are displayed in Fig. 5. UGPS J052547.76+344950.9 a faint, red source not detected in the UKIDSS is J band. Its 22- $\mu$ m flux indicates a Class I protostar. UGPS J052552.02+345808.2 is projected near the bright rim of a small cometary globule at the northern edge of the region. It is included in the catalogue of WISE YSO Candidates (Marton et al. 2016b). Its SED suggests a flat-spectrum object. UGPS J052616.37+345333.2 (L1516-Ha 15) is situated near the centre of the elephant-trunk-like cometary globule. Its SED suggests a Class I YSO. Another



**Figure 4.**  $r' - [\text{H}\alpha]$  vs. r' - i' colour–colour diagram of 35 candidate YSOs within the  $11.5' \times 11.5'$  box around V582 Aur. Triangles indicate H $\alpha$  emission stars identified in our WFGS2 images, and diamonds mark infrared-excess stars. Filled triangles mark the stars included in the IPHAS emission star catalogue (Witham et al. 2008). Small grey crosses show the colour distribution of the IPHAS sources with S/N > 10 in each band within the same area. Simulated colours of main sequence stars with H $\alpha$  emission, computed by Barentsen et al. (2011) are indicated by the solid blue lines for E(B - V) = 0.40, the lower limit of foreground reddening towards the line of sight of V582 Aur. Dashed blue lines show the colour variations of the spectral types indicated at the lower ends, due to increasing EW(H $\alpha$ ). Dash-dotted line shows the reddening path of a K0 type star between  $0 \leq E(B - V) \leq 4$ .

nearby candidate Class I YSO, UGPS J052616.07+345320.0, may contribute to the Akari FIS fluxes.

# 4.3 Colour-magnitude diagram: the distance of V582 Aur

When plotting the r' vs. r' - i' colour-magnitude diagram one has to keep in mind that r' magnitudes may be modified by the presence of the H $\alpha$  emission line within the r' band (Drew et al. 2005; Barentsen et al. 2011). We applied the correction to the r' magnitudes following Barentsen et al. (2011), and plotted the r' vs. r' - i' colour-magnitude diagram of the candidate YSOs in Fig. 6. We compare their distribution with semi-empirical pre-main-sequence isochrones presented by Bell et al. (2014) for the IPHAS bands, based on the Pisa pre-main sequence tracks and isochrones (Tognelli et al. 2011) and BT-Settl (Baraffe et al. 2015, and references therein) atmosphere models. Isochrones bracketing from  $10^6$  to  $2 \times 10^7$ -year encompasses almost all disc-bearing pre-main-sequence stars, therefore we plotted in Fig. 6 isochrones for the distances and foreground extinctions of both Aur OB1 and Aur OB2. Foreground reddenings of E(B - V) = 0.40 mag and E(B - V) = 0.90 mag were adopted for Aur OB1 and Aur OB2, respectively (Green et al. 2015).

Most of the candidate YSOs in this diagram are widely scattered between the isochrones plotted for the distance and foreground extinction of Aur OB 1, and above or along the

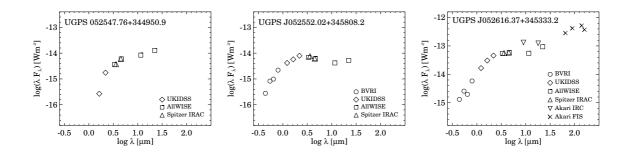
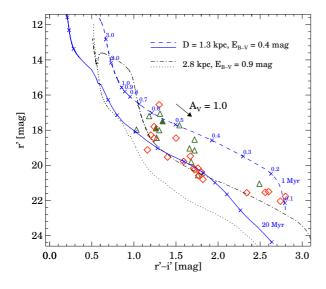


Figure 5. Spectral energy distributions of three candidate protostars in the environment of V582 Aur. Optical data are from the NOMAD Catalog and IPHAS.



**Figure 6.** r' vs. r' - i' colour-magnitude diagram of the 35 candidate YSOs detected by IPHAS. Symbols are same as in Fig. 4. 1 and 20-Myr isochrones (Bell et al. 2014) are drawn for the distances and foreground extinctions of Aur OB1 (blue) and Aur OB2 (black). Stellar masses between 0.1 and  $3.0 \, M_{\odot}$  are marked along the isochrones and labelled along the 1-Myr line.

1-Myr isochrone of Aur OB2. Taking individual extinctions into consideration would modify this distribution so that positions of the stars reddened by E(B-V) > 0.40 mag would move toward slightly younger isochrones and higher masses. The colour-magnitude diagram suggests the conclusion that the star-forming region around V582 Aur is probably associated with Aur OB1, located at 1.32 kpc from the Sun (Humphreys 1978).

#### 4.4 Bolometric luminosity of V582 Aur

Our results suggest that the FUor V582 Aur is a member of a group of young low-mass stars, situated at a distance of 1.32 kpc from the Sun. The adopted distance allows us to estimate the luminosity of this outbursting young star. The SED of V582 Aur, constructed from archival data, is displayed in Fig. 7. The far-infrared source Akari FIS

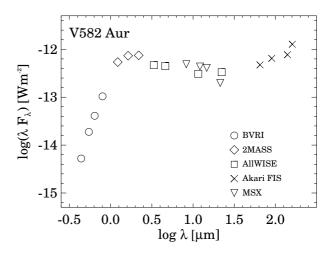


Figure 7. Spectral energy distribution of V582 Aur, based on archival data. *BVRI* data are averaged from Semkov et al.'s (2013) light curves.

0525509+345227, associated with V582 Aur in the Akari FIS YSO Catalogue of Tóth et al. (2014), is separated by 13.5" from the star. Although this separation is smaller than the half-maximum radius of the point-spread function of the FIS (Arimatsu et al. 2014), unresolved nearby sources may contribute to the far-infrared fluxes. We integrated the SED to obtain the bolometric luminosity of V582 Aur, after correcting the fluxes for a foreground extinction  $A_{\rm V} = 1.53$  mag, taken from the IPHAS 3D extinction map of the Northern Galactic Plane (http://www.iphas.org/extinction/), and using Cardelli et al.'s (1989) extinction law. We obtained  $L_{\rm bol} = 324 \, {\rm L}_{\odot}$  with the FIS data included, and  $L_{\rm bol} = 146 \, {\rm L}_{\odot}$  without the far-infrared part of the SED. These values are typical for FUor outburst luminosities (Audard et al. 2014).

#### 4.5 Connection of the new star-forming region with Aur OB 1

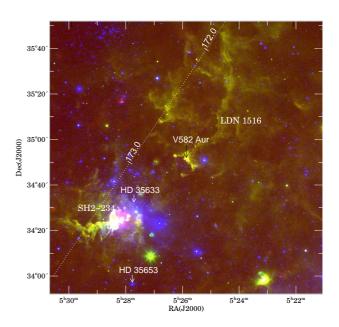
The colour-magnitude diagram of the candidate YSOs around V582 Aur suggests that their associated cometary globules and bright-rimmed dark clouds (Fig. 3) are lo-

cated within the volume of the Aur OB1 associaton. The bright rims indicate interaction of the clouds with hot stars of the association. Aur OB1 is defined by a few O and early B type stars (Humphreys 1978), and the 20-Myr old open cluster NGC 1960 (Reipurth & Yan 2008). Straižys, Drew & Laugalys (2010) established that the dark cloud LDN 1525 (TGU 1192), located some 2 degrees northeast from our studied area and associated with the HII region Sh2-235, is situated at 1.3 kpc from the Sun, within the volume occupied by Aur OB1. Several signposts of ongoing star formation were identified in the region of Sh2-235 (Dewangan et al. 2016, and references therein), which may be a possible young subsystem of Aur OB1. The complex of bright-rimmed clouds, associated with V582 Aur, may represent another region of active star formation within the volume of Aur OB 1.

To find the possible ionizing stars we examined the wide-field environment of V582 Aur. Figure 8 presents a  $2^{\circ} \times 2^{\circ}$  three-color image, centred on V582 Aur, and composed of the Digitized Sky Survey 2 blue (blue),  $WISE 12 \,\mu m$ (green), and WISE  $22 \,\mu \text{m}$  (red) images. The image suggests that the cometary-shaped clouds at the centre are located on the south-eastern boundary of a large complex of clouds, including LDN 1516, and are apparently exposed to disruptive effects from the south-eastern direction. Two luminous members of Aur OB 1 from Humphreys' (1978) list are found within the area of the image. HD 35633 is a B0.5 IV type star, located at an angular distance of 0.51 deg from V582 Aur, corresponding to an 11.8 pc projected separation at 1.32 kpc. HD 35653 is a B0.5 V type star, at a projected distance of some 23 pc from V582 Aur. The ultraviolet radiation of these stars may ionize and compress the clouds. The spectacular H<sub>II</sub> region Sh2-234 is a background object at 2.8 kpc from the Sun. Spectroscopic and photometric data, available for the B1 V type star HD 281147 (see Fig. 3) in VizieR, suggest that this star is also a background object.

#### 5 SUMMARY

We have investigated the star-forming environment of the less studied FUor V582 Aur. Based on H $\alpha$  emission detected in slitless spectra and infrared excesses revealed by UKIDSS, Spitzer, and WISE archival data we identified 68 candidate low-mass young stars in the  $11.5' \times 11.5'$  area centred on V582 Aur, among them two bona fide low-mass protostars. An optical colour-magnitude diagram of 35 members of the group, compared with pre-main-sequence evolutionary models, suggests that they represent a new, active starforming subsystem of the Auriga OB1 association, located at a distance of 1.32 kpc from the Sun. The narrow-band  $H\alpha$  image of the region, available in the IPHAS archive, reveals a system of bright-rimmed, cometary clouds associated with the newly identified young stars. Our results suggest that star formation in these clouds might have been triggered by the radiation field of a few hot members of Aur OB1. The bolometric luminosity of V582 Aur, based on archival photometric data and on the adopted distance, is  $146 \lesssim L_{\rm bol}/L_{\odot} \lesssim 324$ .



**Figure 8.** Three-colour image of the  $2^{\circ} \times 2^{\circ}$  environment of V582 Aur, composed from the DSS2b (blue), *WISE* 12  $\mu$ m (green), and *WISE* 22  $\mu$ m (red) images. The newly identified bright-rimmed clouds can be seen in the middle of the image. The possible exciting stars are labelled. The dotted line shows the Galactic equator.

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 Table 2. UKIDSS sources classified as candidate YSOs

UGPS	J	Н	Ks	[3.6]	[4.5]	SST GLMC	Note
J052524.85+345800.3	$17.590 \pm 0.021$	$16.529 \pm 0.015$	$15.720 \pm 0.020$	$14.826 \pm 0.056$	$14.281 \pm 0.046$	G172.6121-00.3464	
J052525.94 + 345631.7	$17.306 \pm 0.016$	$16.474 \pm 0.014$	$15.875 \pm 0.023$	$15.166 \pm 0.065$	$14.983 \pm 0.063$	G172.6346-00.3572	
$J052526.60 + 345756.5^{b}$	$15.258 \pm 0.003$	$14.078 \pm 0.002$	$13.127 \pm 0.002$	$11.965 \pm 0.032$	$11.494 \pm 0.029$	G172.6164-00.3421	
J052528.89 + 345627.6	$16.367 \pm 0.008$	$15.047 \pm 0.002$	$13.967 \pm 0.002$	$13.031 \pm 0.048$	$12.465 \pm 0.036$	G172.6412-00.3494	
J052529.76+345728.1	$16.181 \pm 0.007$	$15.414 \pm 0.006$	$14.939 \pm 0.010$	$14.542 \pm 0.049$	$14.290 \pm 0.052$	G172.6290-00.3376	
J052530.87+345744.5	$15.992 \pm 0.006$	$15.198 \pm 0.005$	$14.656 \pm 0.008$	$14.065 \pm 0.054$	$13.884 \pm 0.041$	G172.6273-00.3319	
J052532.03+345736.7	$16.497 \pm 0.008$	$15.314 \pm 0.005$	$14.416 \pm 0.006$	$13.357 \pm 0.049$	$12.838 \pm 0.047$	G172.6314-00.3298	
J052532.08+345721.8	$17.016 \pm 0.013$	$16.269 \pm 0.012$	$15.723 \pm 0.020$	$14.891 \pm 0.060$	$14.426 \pm 0.053$	G172.6349-00.3320	
J052532.08+345718.4	$16.558 \pm 0.009$	$15.775 \pm 0.008$	$15.269 \pm 0.013$	$14.859 \pm 0.064$	$14.763 \pm 0.085$	G172.6356-00.3325	
J052532.12+345734.7	$17.197 \pm 0.015$	$16.223 \pm 0.012$	$15.549 \pm 0.017$	$14.005 \pm 0.004$ $15.007 \pm 0.104$	14.705±0.005	G172.6320-00.3299	
J052532.51+345718.0	$17.197 \pm 0.013$ $13.918 \pm 0.002$	$10.223 \pm 0.012$ $12.878 \pm 0.001$	$15.349 \pm 0.017$ $12.105 \pm 0.001$	$11.000 \pm 0.043$	$10.042 \pm 0.030$	G172.6366-00.3313	L1516-Ha 3
J052532.60 + 345751.9	$13.918 \pm 0.002$ $18.132 \pm 0.033$	$12.878 \pm 0.001$ $16.336 \pm 0.013$	$12.105 \pm 0.001$ $14.535 \pm 0.007$	$11.000 \pm 0.043$ $13.048 \pm 0.045$	$10.042 \pm 0.030$ $12.406 \pm 0.033$	G172.6289-00.3258	L1010-11a 0
		$10.330 \pm 0.013$ $12.162 \pm 0.001$					L1516-Ha4
J052532.73+345710.7	$13.125 \pm 0.001$		$11.544 \pm 0.001$	$10.641 \pm 0.058$	$10.217 \pm 0.035$	G172.6386-00.3319	L1510-па4
J052532.74+345742.6 <sup>b</sup>	$16.038 \pm 0.006$	$14.609 \pm 0.003$	$13.516 \pm 0.003$	$12.154 \pm 0.047$	$11.600 \pm 0.031$	G172.6314-00.3269	
J052533.03+345648.2	$15.858 \pm 0.005$	$14.740 \pm 0.003$	$13.974 \pm 0.005$	$12.636 \pm 0.044$	$12.072 \pm 0.035$	G172.6444-00.3345	
J052533.85+345752.1	$16.598 \pm 0.009$	$15.745 \pm 0.008$	$15.144 \pm 0.012$	$14.266 \pm 0.053$	$13.806 \pm 0.042$	G172.6313-00.3222	T I FIO TT
J052534.08+345746.6	$15.062 \pm 0.003$	$14.122 \pm 0.002$	$13.561 \pm 0.003$	$12.894 \pm 0.036$	$12.405 \pm 0.039$	G172.6330-00.3225	L1516-Ha6
J052536.40 + 345631.1	$18.169 \pm 0.035$	$16.926 \pm 0.021$	$16.041 \pm 0.026$	$15.328 \pm 0.068$	$14.899 \pm 0.067$	G172.6548-00.3277	
J052537.27+345734.7	$16.165 \pm 0.007$	$15.406 \pm 0.006$	$14.862 \pm 0.009$	$13.980 \pm 0.039$	$13.521 \pm 0.043$	G172.6418-00.3153	
J052538.17 + 345635.5	$17.281 \pm 0.016$	$16.331 \pm 0.013$	$15.534 \pm 0.017$	$14.469 \pm 0.050$	$13.861 \pm 0.050$	G172.6572-00.3220	
J052538.69 + 345635.1	$16.154 {\pm} 0.007$	$15.394{\pm}0.006$	$14.825 \pm 0.009$	$14.108 \pm 0.042$	$13.808 \pm 0.045$	G172.6582-00.3205	
J052542.12 + 345309.8	$16.718 \pm 0.010$	$15.092 \pm 0.004$	$14.077 \pm 0.005$	$13.006 \pm 0.047$	$12.462 \pm 0.029$	G172.7121-00.3427	
J052543.22 + 345243.1	$18.313 \pm 0.039$	$17.237 \pm 0.029$	$16.564 \pm 0.043$	$16.326 \pm 0.120$	$16.018 \pm 0.108$	G172.7203-00.3438	
J052544.59 + 345357.7	$17.715 \pm 0.023$	$16.920 \pm 0.022$	$16.378 {\pm} 0.037$	$15.987 \pm 0.088$	$15.840 \pm 0.087$	G172.7057-00.3284	
J052545.12 + 345253.5	$18.905 \pm 0.066$	$15.979 {\pm} 0.009$	$14.205 \pm 0.006$	$12.291 \pm 0.032$	$11.541 \pm 0.032$	G172.7216-00.3368	
J052547.46 + 345228.3	$19.162 {\pm} 0.083$	$16.984 {\pm} 0.023$	$14.953 {\pm} 0.010$	$12.970 \pm 0.054$	$12.323 \pm 0.039$	G172.7318-00.3341	
J052548.08 + 345538.3	$16.595 {\pm} 0.009$	$15.495 {\pm} 0.006$	$14.760 {\pm} 0.009$	$13.802 {\pm} 0.045$	$13.498 {\pm} 0.043$	G172.6893-00.3028	
J052548.45 + 345101.4	$16.553 {\pm} 0.009$	$15.447 {\pm} 0.006$	$14.760 {\pm} 0.009$	$14.215 {\pm} 0.100$	$14.096 {\pm} 0.069$	G172.7537-00.3448	
J052550.09 + 345504.9	$17.493 {\pm} 0.019$	$16.000 {\pm} 0.010$	$14.963 {\pm} 0.011$	$14.153 {\pm} 0.058$	$13.919 {\pm} 0.062$	G172.7008-00.3023	
$J052551.33 + 345226.6^{a}$	$17.463 {\pm} 0.019$	$15.697 {\pm} 0.007$	$14.410 {\pm} 0.007$				
$J052552.02 + 345808.2^{a,b}$	$14.901 {\pm} 0.003$	$13.766 {\pm} 0.002$	$12.685 {\pm} 0.002$	$11.218 {\pm} 0.032$	$10.719 {\pm} 0.024$	G172.6624-00.2683	L1516-Ha
J052553.87+345201.5	$16.995 {\pm} 0.013$	$15.909 {\pm} 0.009$	$15.093 {\pm} 0.012$	$14.300 \pm 0.070$	$13.795 {\pm} 0.053$	G172.7413-00.3141	
J052554.39 + 345439.2	$13.628 {\pm} 0.001$	$12.496 {\pm} 0.001$	$11.558 {\pm} 0.001$	$10.500 {\pm} 0.027$	$10.006 {\pm} 0.030$	G172.7150-00.2941	L1516-Ha
J052554.52+345206.2	$16.215 {\pm} 0.007$	$15.403 {\pm} 0.006$	$14.917 {\pm} 0.010$	$14.405 \pm 0.073$	$14.294{\pm}0.085$	G172.7504-00.3175	
J052555.20 + 345201.2	$17.561 {\pm} 0.020$	$16.712 {\pm} 0.018$	$16.114 \pm 0.029$	$15.266 {\pm} 0.083$	$14.936 {\pm} 0.073$	G172.7529-00.3164	
J052556.88+345144.2	$13.530 {\pm} 0.001$	$12.649 \pm 0.001$	$11.899 {\pm} 0.001$	$10.973 {\pm} 0.038$	$10.438 {\pm} 0.027$	G172.7600-00.3143 <sup>c</sup>	L1516-Ha
J052556.97+345018.9	$16.619 \pm 0.009$	$15.775 \pm 0.008$	$15.169 \pm 0.013$	$14.149 \pm 0.046$	$13.745 \pm 0.042$	G172.7798-00.3273	
J052600.97+345143.2	$16.386 {\pm} 0.008$	$15.477 \pm 0.006$	$14.907 \pm 0.010$	$14.229 \pm 0.057$	$13.905 \pm 0.047$	G172.7681-00.3029	
J052602.74+345109.3	$16.000 \pm 0.006$	$15.014 \pm 0.004$	$14.377 \pm 0.007$	$13.386 \pm 0.039$	$12.901 \pm 0.037$	G172.7792-00.3031	L1516-Ha
J052608.38+345006.3	$17.028 \pm 0.014$	$16.277 \pm 0.013$	$15.754 \pm 0.022$	$15.125 \pm 0.054$	$14.860 \pm 0.062$	G172.8046-00.2969	
J052613.27+344936.1	$14.817 \pm 0.003$	$13.940 \pm 0.002$	$13.396 \pm 0.003$	$12.501 \pm 0.047$	$12.137 \pm 0.038$	G172.8209-00.2877	
J052613.58+345316.0 <sup>a</sup>	$17.950 \pm 0.030$	$16.698 \pm 0.019$	$15.664 \pm 0.021$	12.001±0.041	$14.249 \pm 0.108$	G172.7708-00.2527	
J052613.92+345329.4 <sup>a</sup>	$16.387 \pm 0.008$	$14.786 \pm 0.004$	$13.660 \pm 0.004$	$12.865 \pm 0.043$	$14.249\pm0.108$ $12.401\pm0.037$	G172.7684-00.2496	
J052614.68+345005.2	$15.802 \pm 0.005$	$14.730 \pm 0.004$ $14.870 \pm 0.004$	$14.320 \pm 0.004$	$12.805 \pm 0.043$ $15.125 \pm 0.054$	$12.401 \pm 0.037$ $14.860 \pm 0.062$	G172.8046-00.2969	L1516-Ha
$J052616.07 + 345320.0^{a}$	$15.719 \pm 0.005$	$14.662 \pm 0.004$	$13.608 \pm 0.004$	$12.169 \pm 0.054$	$11.570 \pm 0.035$	$G172.7747-00.2449^c$	11010-114
$J052616.07 + 345320.0^{\circ}$ $J052616.37 + 3453333.2^{a}$	$13.410 \pm 0.001$	$14.002 \pm 0.003$ $11.948 \pm 0.001$	$13.008 \pm 0.004$ $10.781 \pm 0.001$	$12.109 \pm 0.030$ $9.053 \pm 0.080$	$8.284 \pm 0.042$	G172.7722-00.2449	L1516-Ha
J052616.80+345422.3	$15.410 \pm 0.001$ $15.500 \pm 0.004$	$11.948 \pm 0.001$ $14.657 \pm 0.003$	$10.781 \pm 0.001$ $14.031 \pm 0.005$	$9.053 \pm 0.080$ $13.247 \pm 0.045$	$8.284 \pm 0.042$ $12.784 \pm 0.030$	G172.7617-00.2332	L1516-Ha
0004010.0070404444.0	10.000±0.004	TH:001 TO:009	$14.001\pm0.000$	10.241 ±0.040	12.104±0.000	GT12.1011-00.2002	LIJIU-118 .

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 Table 3. Spitzer sources classified as candidate YSOs

UGPS	J	Н	Ks	[3.6]	[4.5]	SST GLMC	Note
J052527.87+345741.9	$14.983 {\pm} 0.003$	$14.150 {\pm} 0.002$	$13.679 {\pm} 0.004$	$13.158 {\pm} 0.045$	$12.914 {\pm} 0.038$	G172.6222-00.3407	L1516-Ha 1
J052529.63 + 345755.1	$14.591{\pm}0.002$	$13.700 {\pm} 0.002$	$13.181{\pm}0.002$	$12.729 {\pm} 0.034$	$12.464{\pm}0.030$	G172.6225-00.3337	L1516-Ha $2$
J052529.74 + 345655.8	$15.004{\pm}0.003$	$14.117 {\pm} 0.002$	$13.719 {\pm} 0.004$	$13.242{\pm}0.033$	$12.997 {\pm} 0.043$	G172.6364-00.3426	
J052534.55 + 345800.3	$16.121 {\pm} 0.006$	$15.373 {\pm} 0.006$	$14.929 {\pm} 0.010$	$14.328 {\pm} 0.057$	$14.036 {\pm} 0.049$	G172.6308-00.3190	
J052534.98 + 345701.1	$16.505 {\pm} 0.009$	$15.641 {\pm} 0.007$	$15.301{\pm}0.014$	$14.874{\pm}0.070$	$14.566 {\pm} 0.065$	G172.6452-00.3270	
J052543.31 + 345307.2	$18.492 {\pm} 0.045$	$16.860 {\pm} 0.021$	$15.983 {\pm} 0.026$	$14.754{\pm}0.060$	$14.364{\pm}0.057$	G172.7150-00.3398	
J052544.56 + 345017.8	$14.758 {\pm} 0.003$	$13.827 {\pm} 0.002$	$13.439{\pm}0.003$	$12.919 {\pm} 0.040$	$12.336{\pm}0.031$	G172.7563-00.3626	L1516-Ha 7
J052546.99 + 345244.3		$17.018 {\pm} 0.024$	$14.569 {\pm} 0.008$	$12.425 {\pm} 0.048$	$11.374 {\pm} 0.040$	G172.7272-00.3329	
$J052547.76 + 344950.9^{a}$		$17.096 {\pm} 0.025$	$14.320{\pm}0.006$	$11.993 {\pm} 0.065$	$10.761 {\pm} 0.037$	G172.7687-00.3577	
J052555.37 + 345441.9	$15.465 {\pm} 0.004$	$14.447{\pm}0.003$	$13.869 {\pm} 0.004$	$13.030{\pm}0.038$	$12.673 {\pm} 0.036$	G172.7162-00.2909	L1516-Ha 10
J052600.91 + 345413.1	$15.949 {\pm} 0.006$	$14.974{\pm}0.004$	$14.549 {\pm} 0.008$	$13.633 {\pm} 0.044$	$13.173 {\pm} 0.038$	G172.7334-00.2797	
J052601.71 + 344933.5	$16.706 {\pm} 0.010$	$15.898 {\pm} 0.009$	$15.473 {\pm} 0.017$	$14.961 {\pm} 0.055$	$14.604 {\pm} 0.050$	G172.7993-00.3209	
J052607.10 + 345425.9	$14.791{\pm}0.003$	$13.959 {\pm} 0.002$	$13.505 {\pm} 0.003$	$12.916{\pm}0.045$	$12.544{\pm}0.036$	G172.7423-00.2601	L1516-Ha 13
J052611.65 + 344904.5	$16.640 {\pm} 0.010$	$15.909 {\pm} 0.009$	$15.479 {\pm} 0.018$	$14.580{\pm}0.056$	$14.202 \pm 0.041$	G172.8250-00.2972	
J052618.28+344716.9	$15.480{\pm}0.004$	$14.666 {\pm} 0.003$	$14.198 {\pm} 0.006$	$13.557 {\pm} 0.038$	$13.130 {\pm} 0.033$	G172.8625-00.2951	
J052619.46+344943.9	$15.410{\pm}0.004$	$14.501{\pm}0.003$	$14.045 {\pm} 0.005$	$13.392{\pm}0.048$	$13.079 {\pm} 0.038$	G172.8309-00.2689	
J052619.67 + 344923.7	$16.267 {\pm} 0.007$	$15.405 {\pm} 0.006$	$14.956 {\pm} 0.011$	$14.465 {\pm} 0.065$	$14.035 {\pm} 0.041$	G172.8359-00.2715	

<sup>a</sup>Classified as a candidate galaxy in UKIDSS.

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