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# Cyg OB2 Unveiled: The Search for Astrometric Companions

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**Abstract:** We present results from a high angular resolution survey of the most massive stars in the nearby Cygnus OB2 association. Using the NIRI instrument and ALTAIR AO system on Gemini North, we obtained $J$, $H$ and $K$ band observations of 75 O- and B-type association members to search for astrometric companions. This search is sensitive to companions in the separation range of 0.08 - 10$''$ with a magnitude difference less than 11 mag. The detected sample begins to fill in the period gap between astrometric and spectroscopic binaries. From photometric colors, we find that many of these companions appear to be very young, red stars. Using a statistical method to estimate field contamination, 42% of our targets have at least one highly probable companion.

## 1 Introduction

Massive stars have a higher frequency of multiplicity than cooler, less massive stars, especially when they are found in clusters (Mason et al. 2009). At a distance of 1.7 kpc (Massey & Thompson 1991), Cygnus OB2 provides a nearby, young stellar environment, rich in high-mass stars. The association is close enough, that with modern-day adaptive optics (AO), we are able to resolve wide companions. Due to extinction towards the cluster, the cluster begins to be unveiled in the infrared (IR).

## 2 Observations

Our observations were part of three queue observing programs at the Gemini North Observatory during the 2005B, 2008A and 2008B semesters. Using the Near Infrared Imager and Spectrograph (NIRI) with the Altair AO system, we collected high resolution images (0.022$''$/pixel) of 75 O- and B-type stars in Cyg OB2 with a field of view of approximately $22'' \times 22''$ (Hodapp 2003). Every target was observed in the $K$-band to detect possible companions. Most of those with a star detected in the field were followed up with $J$-band observations. The seven targets observed during the 2005B semester were also imaged in the $H$-band.

In addition to the NIRI $K$-band observation, MT421, was observed with the Palomar High Angular Resolution Optics (PHARO) AO system on the 200-in Hale telescope during an engineering night in

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2009 July. We were able to get observations in all three IR bands, $J$, $H$, and $K_S$, with a comparable field of view as NIRI.

# 3 Results

In every $K$-band frame, we identified at least one candidate companion near our target. We determined that 32 out of our 75 targets or 42% have at least one statistically probable companion. The statistical probability for each object was calculated using the Correia et al. (2002) equation:

$$P(\Sigma_K, \Omega) = 1 - e^{-\pi \Sigma_K \Omega^2} \tag{1}$$

Here $P$ is the probability of a star being a chance alignment at a separation of $\Omega$, in arcseconds, from the target. $\Sigma_K$ is the surface density of stars in the surrounding field down to a magnitude of $K$. The stellar field density was determined using a combination of data from 2MASS (Skrutskie et al. 2006) and UKIDSS (Lawrence et al. 2007). A star with $P(\Sigma_K, \Omega) < 0.01$ has a very high probability of being a physical companion. In Table 1 we list the number of stars found with $P(\Sigma_K, \Omega) < 0.01$. Of note are MT465 and WR145 that have more companions in the Washington Double Star Catalog (WDS; Mason et al. 2001) than we detected in our study. This is due to the fact that the additional companions detected in the WDS fall outside our field.

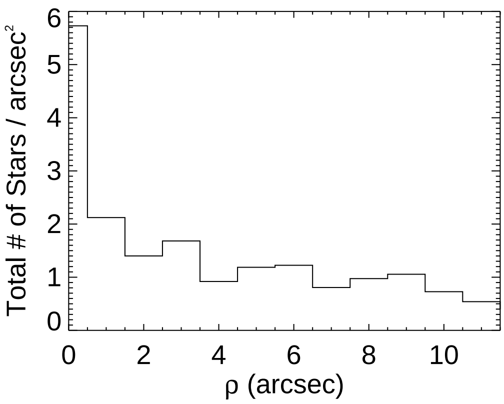


Figure 1: The graph shows how the number density of stars falls with angular separation but levels off at larger distances. At a distance of $1.7 kpc$, the distance to Cyg OB2, $1''$ corresponds to a projected size of $121 AU$.

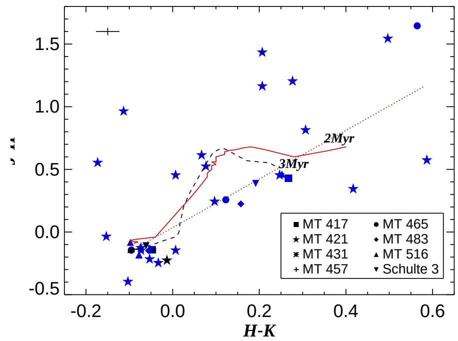


Figure 2: Intrinsic color-color diagram of a few of our targets and their companions (blue symbols), dereddened according to estimates from Negueruela et al. (2008). Overlaid are a ZAMS isochrone at 3 Myr (dashed, black line) from Girardi et al. (2006), a Pre-MS track at 2 Myr (solid, red line) from Siess et al. (2000) and standard reddening vector (dotted, blue line) from Fitzpatrick (1999), the length shows the amount of extinction for $E(B-V) = 4$ mag. Top left is a representative error bar.

In Figure 1 we show the number density of the entire sample over square area as a function of separation. At larger separations, the density levels off. This very likely corresponds to the average number density of the association. Stars found at these separations are more likely to be chance alignments (see above equation). The number density per area increases greatly with $\rho < 1''$ and stars found within this separation are more likely to be physical companions.

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Cyg OB2's high content of massive stars indicates that it is a relatively young association. The color-color diagram (Fig. 2) plots the intrinsic color in $JHK$ of eight of our targets and their respective companions. Overlaid are a 2 Myr Pre-Main Sequence track (Siess, Dufour & Forestini 2000) and a 3 Myr Zero-Age Main Sequence isochrone (Girardi et al. 2006). In determining the intrinsic color, we assumed that all stars in a frame were at the same distance and had the same reddening as the target star. The empirical data follows the Fitzpatrick (1999) reddening vector (dotted blue line) but the fact that we see a large scatter implies that our assumption might not be true for all the stars in the field. This may be due to circumstellar reddening for young stars or they may be foreground objects or reddened early type stars. Further color and spectroscopic information is needed to determine the nature of these objects. However, the position of the target stars with respect to the isochrones indicates that these stars are at the same distance, young and coeval.

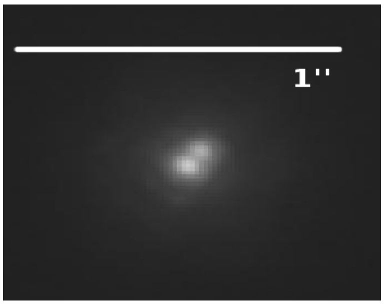


Figure 3: NIRI AO, $K$-band image of MT429, the closest pair ($\rho = 0.08''$) found in our survey.

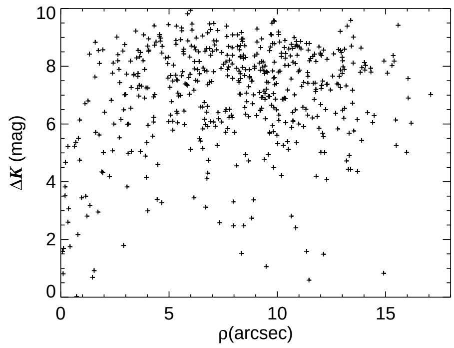


Figure 4: This figure shows the dynamic range of our observation as a function of projected radius. Within $0.5''$ we are still able to detect objects with $\Delta K \approx 5$ mag.

The closest, resolved pair found in our survey, MT 429A and MT429B (see Fig. 3) have a $\Delta K$ = 1.59 mag and are at a separation of $0.08''$, which is at the limits of the AO capabilities. Figure 4 shows the dynamical range of the AO system as a function of separation for our sample. We detected stars with a magnitude difference as large as $\Delta K \approx 5$ mag even with small separations of $\rho < 0.5''$ from the target. This figure demonstrates the sensitivity and completeness of our survey.

We detected 47 objects in the $22''$ area around the star MT421, significantly the most stars detected in our sample. Statistically, only 3 stars are likely to be gravitationally bound to MT421. They are the three brightest stars within the 10 000 AU circle in Figure 5. The 10 000 AU radius is approximately the radius where the orbital speed is on the order of the random motion in a cluster. Companions found at separations larger than this are easily disrupted in dense clusters. We found that 65 stars in our sample had at least one star within that radius. While all of our statistically probable companions are within that projected radius, they constitute 55% of the 65 stars.

Figure 5 is a false-color image composed of the $J$, $H$, $K_S$ images taken with the PHARO AO. Many of the fainter objects are much brighter in the $K_S$ band due their red color, the high extinction towards Cyg OB2, and/or contamination by foreground, cooler stars.

# 4 Summary

We made one epoch imaging of 75 O- and B-type stars in Cyg OB2 with high angular resolution methods in the infrared $JHK$ bands. We found that:

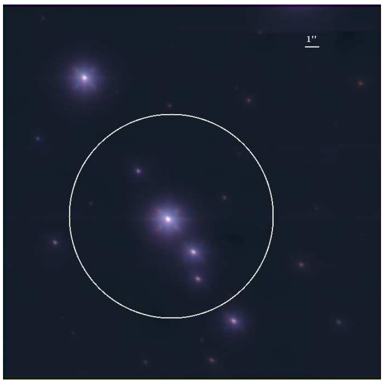


Figure 5: False color Palomar image ($J$=blue, $H$=green, $K$=red) of MT421, the most populated field with 47 sources detected. The circle is at a projected radius of 10 000 AU (5.88″).

- 87% of our sample has another star within 10 000 AU, the nominal distance for two objects to be gravitationally bound, about half of which are statistically significant
- 42% of stars have a statistically probable companion, based on magnitude, separation and surrounding stellar density
- several stars have companions near the 0.08″ angular resolution limit of the AO that span a large differential magnitude range
- the presence of O- and B-type stars supports the idea that Cyg OB2 is a young association, but some of the fainter, redder stars detected may be foreground objects.

Future observations would be useful to detect orbital motion and to further establish the true binarity of some of these systems.

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Table 1: Multiplicity properties of stars in Cyg OB2

| **Star**[a] | **No. of stars in field**[b] | $P(\Omega,\Sigma)^c$ | **WDS**[d] | **Star**[a] | **No. of stars in field**[b] | $P(\Omega,\Sigma)^c$ | **WDS**[d] |
|---|---|---|---|---|---|---|---|
| **A11** | 6 | 3 | ... | **MT421** | 47 | 3 | ... |
| **A12** | 2 | ... | ... | **MT429** | 8 | 1 | ... |
| **A15** | 3 | ... | ... | **MT431** | 1 | ... | ... |
| **A18** | 11 | ... | ... | **MT448** | 16 | ... | ... |
| **A20** | 5 | 1 | ... | **MT455** | 19 | ... | ... |
| **A23** | 1 | ... | ... | **MT457** | 1 | ... | ... |
| **A24** | 2 | ... | ... | **MT462** | 11 | 3 | ... |
| **A25** | 7 | 1 | ... | **MT465** | 6 | 3 | 7 |
| **A26** | 6 | 1 | ... | **MT470** | 11 | ... | ... |
| **A27** | 2 | ... | ... | **MT473** | 15 | ... | ... |
| **A29** | 1 | ... | ... | **MT480** | 10 | ... | ... |
| **A32** | 6 | ... | ... | **MT483** | 4 | ... | ... |
| **A37** | 5 | ... | ... | **MT485** | 9 | ... | ... |
| **A38** | 11 | 1 | ... | **MT507** | 6 | ... | ... |
| **A41** | 2 | 1 | ... | **MT516** | 3 | 2 | 2 |
| **A46** | 3 | ... | ... | **MT531** | 5 | 1 | ... |
| **B17** | 4 | ... | ... | **MT534** | 5 | ... | ... |
| **MT5** | 14 | 1 | ... | **MT555** | 3 | ... | ... |
| **MT59** | 3 | 1 | ... | **MT556** | 5 | 1 | ... |
| **MT70** | 8 | ... | ... | **MT588** | 10 | ... | ... |
| **MT83** | 2 | ... | ... | **MT601** | 11 | 1 | ... |
| **MT138** | 8 | 1 | ... | **MT605** | 8 | 1 | ... |
| **MT140** | 8 | ... | ... | **MT611** | 8 | 1 | ... |
| **MT145** | 13 | ... | ... | **MT632** | 3 | 2 | ... |
| **MT213** | 6 | ... | ... | **MT642** | 4 | 1 | ... |
| **MT217** | 5 | 1 | ... | **MT692** | 9 | ... | ... |
| **MT227** | 6 | ... | ... | **MT696** | 7 | 1 | ... |
| **MT250** | 21 | ... | ... | **MT716** | 16 | ... | ... |
| **MT258** | 15 | 1 | ... | **MT734** | 1 | ... | ... |
| **MT259** | 15 | ... | ... | **MT736** | 2 | ... | ... |
| **MT299** | 8 | 1 | ... | **MT745** | 2 | ... | ... |
| **MT304** | 2 | 1 | ... | **MT771** | 4 | 1 | ... |
| **MT317** | 3 | ... | ... | **MT793** | 6 | ... | ... |
| **MT339** | 10 | ... | ... | **S03** | 3 | 1 | ... |
| **MT376** | 7 | ... | ... | **S05** | 2 | 1 | 2 |
| **MT390** | 9 | ... | ... | **S73** | 12 | 1 | ... |
| **MT403** | 10 | 1 | ... | **WR145** | 1 | ... | 2 |
| **MT417** | 11 | 2 | 2 | | | | |

[a] Names of the stars. *A#* or *B#* use nomenclature from Comerón et al. (2002). *MT#* designations are from Massey & Thompson (1991). *S#* are stars named according to their Schulte (1958) designation.
[b] Total number of the stars found in the field around the target.
[c] Number of stars that have a high probability of being real companions.
[d] Number of companions listed in the Washington Double Star Catalog.