Sparse Aperture Masking of Massive Stars

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Abstract. We present the earliest results of our NACO/VLT sparse aperture masking (SAM) campaign to search for binarity in a sample of 60 O-type stars. We detect $\Delta K_s < 5$ mag companions for 20-25\% of our targets with separations in the range 30-100 mas (typically, 40 - 200 A.U.). Most of these companions were unknown, shedding thus new light on the multiplicity properties of massive stars in a separation and brightness regime that has been difficult to explore so far. Adding detections from other techniques (spectroscopy, interferometry, speckle, lucky imaging, AO), the fraction of O stars with at least one companion is 85\% (51/60 targets). This is the largest multiplicity fraction ever found.

1. Introduction

With masses $\gtrsim 16 \, M_\odot$, massive stars of spectral type O are among the brightest and most luminous stars in galaxies. One of their most striking properties is their high multiplicity rate (for recent reviews, see [Sana & Evans 2011] and Gies – this volume): above 40\% for visual systems ([Turner et al. 2008] [Mason et al. 2009] and up to $\sim$60\% for spectroscopic binaries (Mason et al. 2009) [Sana & Evans 2011]). In nearby clusters, at least 75\% of the massive stars are part of a binary or higher multiplicity systems ([Sana et al. 2008] [2009] [2011]). The multiplicity fraction and distribution of the binary parameters (periods, mass ratios, eccentricities) are one of the few observable quantities that can help constrain the formation and early dynamical evolution of these objects (see e.g., Kratter et al. this volume) and can potentially discriminate between the various scenarios (see e.g., Zinnecker & Yorke 2007, for a review). However, the census of the properties of the massive star population remains incomplete.
Figure 1. Magnitude difference vs. separation for all the pairs in our sample. Different symbols/colors indicate different observing techniques. Objects observed with various instruments have multiple entries in the figure, possibly with slightly different $\Delta \text{mag}$ due to the different bands in which the techniques are operating. Using SAM, we are now able to probe the short separation/high contrast regime.

References: MAS98 – Mason et al. (1998), NEL04 – Nelan et al. (2004), TUR08 – Turner et al. (2008), MAS09 – Mason et al. (2009), MAI10 – Maíz Apellániz (2010).

2. Early results

In March 2011, we observed a sample of 60 O stars with $K < 7.5$ mag with the SAM mode of NACO, providing an almost bias-free detection up to a flux contrast of 100 in the range 30-200 mas. Under the adopted configuration (512×512 windowing), the NACO field of view extends over 6''×6'' and provides simultaneous, AO-corrected imaging of the surroundings of the targets. Our preliminary results are:

- **Multiplicity fraction**: 20-25% of our targets has a very close companion detected by SAM (Fig. 1). Most of these detections are new. This fraction increases to over 50% if we include the wider pairs seen in the NACO field of view. Adding the results from other high-angular resolution imaging techniques (speckle, lucky imaging, AO) and from spectroscopy, only nine stars have no companion at all (among which two are known runaways).

- **Separation distribution**: Fig. 2 (left panel) shows the cumulative number distribution of the measured separations in the range 30-6,000 mas and $\Delta \text{mag} < 5$. The distribution is clearly double-peaked with an overabundance of pairs between 30 and 100 mas and between 1'' and 6''.

- **Brightness ratio distribution**: In these two separation ranges, the $\Delta \text{mag}$ distributions show different properties (Fig. 2, right panel), as confirmed by a Kolmogorov-Smirnov test at the 0.01 significance level. The wide pairs are dominated by fainter (most likely lower mass) companions while the distribution is almost uniform for the very close pairs. This suggests that the two populations have different natures.
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3. Perspectives and conclusions

The SAM mode at NACO/VLT offers a new observing window to study massive binaries allowing us to probe efficiently the short angular separation/high contrast regime. Future work involves (i) converting observational parameters to physical quantities, and (ii) investigating whether observational biases can explain the lack of companions in the 0.1-1.0 range.

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