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The WIYN Open Cluster Study Photometric Binary Survey: Initial Findings for NGC 188

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Abstract. The WIYN open cluster study (WOCS) has been working to yield precise optical ($UBRVI$) photometry for all stars in the field of a selection of "prototypical" open clusters. Additionally, WOCS has been using radial velocities to obtain orbit solutions for cluster member hard-binary stars (with period less than 1000 days). Recently, WOCS has been expanded to include the near-infrared (JHK_s; 2MASS plus new deep ground-based) and mid-infrared ([3.6], [4.5], [5.8], [8.0] micron) photometry from *Spitzer*/IRAC observations. This multi-wavelength data (0.3–8.0 microns) allows us to identify binaries photometrically, with mass ratios from 1.0–0.3, across a wide range of primary masses. The spectral energy distribution (SED) fitter by Robitaille *et al.* (2007) is used to fit the fluxes of 10–12 bands to Kurucz stellar models. *This technique allows us to explore the soft binary population for the first time.* Using this photometric technique, we find that NGC 188 has a binary fraction of 36-49% and provide a star-by-star comparison to the WOCS radial velocity-based hard binary study.

Keywords. open clusters and associations: individual (NGC 188), binaries: general

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We have combined optical ($UBVRI$, Stetson, McClure & VandenBerg 2004), with NIR (JHK_s 2MASS data, Skrutskie *et al.* 2006) and new deep mid-IR photometry from the Spitzer IRAC for NGC 188. We have restricted our sample to overlap the kinematically-studied WOCS sample containing main sequence (MS) stars ($15.2 < V < 16.5$), with good photometry ($\sigma_{mag} < 0.1$) in all bands, and those with membership probability $\geqslant 80\%$ from the proper motion (PM) analysis of Platais *et al.* (2003) (see Fig. 1a). The spectral energy distribution (SED) fitter by Robitaille *et al.* (2007) is used to fit the fluxes of 10–12 bands to Kurucz (1979) stellar models. The fitted Kurucz models consist of the fluxes of single and two combined MS stars (binaries) with varying mass ratios using $T_{\rm eff}$, $\log(g)$, and masses from Padova isochrones (Girardi *et al.* 2002). This multi-wavelength data (0.3–8.0 μm) allows us to identify binaries *photometrically*, with mass ratios (MR) from 1.0–0.3, across a wide range of primary masses, especially on the faint, lower MS where RV surveys are prohibitive.

We find that NGC 188 has a binary fraction of 36–49%. For the ($15.2 < V < 16.5$) sample, we found 63 of 145 "binary" fits yielding a binary fraction of 43%. However since binaries with MR lower than 0.3 are difficult to distinguish from MS stars, we also determined the binary fraction excluding "binary" fits with MR $\leqslant 0.3$ and found 52 of 145 "binary" fits, as shown in Table 1. We have also compared our results to the spectroscopic binaries (SB) for NGC 188 from Geller *et al.* (*in preparation*), which results in a SB fraction of 31–33%. Due to incompleteness in the Geller *et al.* (*in preparation*) sample, we also analysed the sub-sample ($15.2 < V < 16.0$; Fig. 1a) and found similar binary fractions, shown in Table 1. Direct star-by-star comparison of the method (see Fig. 1c) shows that

Table 1. Statistics of Binaries in NGC 188 using Photometric and Spectroscopic Techniques

Proper Motion Member Sample (Prob > 80% and $V > 13.5$)	*# of Stars*	*Photom. Binaries*	*Spectr. Binaries*	*Spec & Phot Binaries*
All Binaries ($V < 16.5$)	145	63 (43%)	45 (31%)	31 (21%)
Binaries MR > 0.3 ($V < 16.5$)	145	52 (36%)	45 (31%)	29 (20%)
All Binaries ($V < 16.0$)	102	50 (49%)	33 (33%)	25 (25%)
Binaries MR > 0.3 ($V < 16.0$)	102	47 (46%)	33 (33%)	24 (24%)

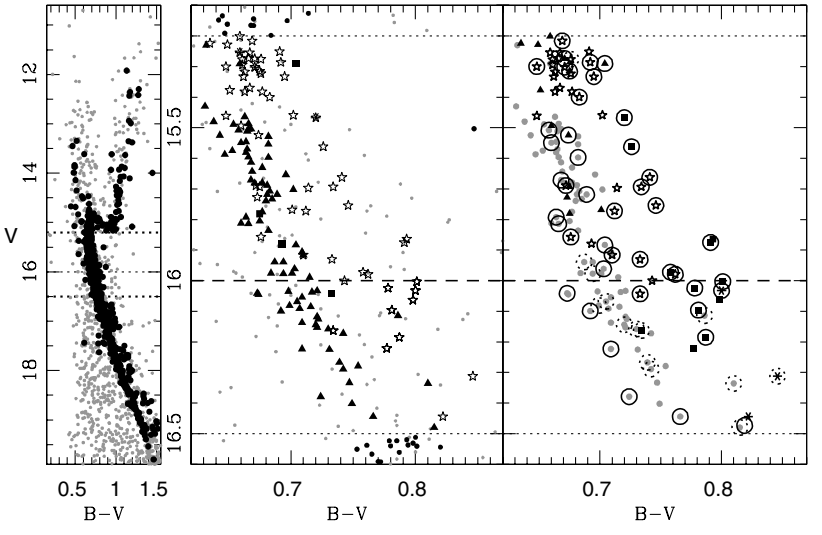

Figure 1. Optical color-magnitude diagram (CMD) for NGC 188 using Stetson, McClure & VandenBerg (2004) data. **a)** Black points have membership probabilities ⩾80%, and grey "non-members" (<80) from Platais *et al.* (2003). The dotted lines delineate the sub-samples of MS stars analysed. **b)** Colors as a) with ⋆ denotes photometric binaries, △ non-binaries, □ possible binaries ($MR < 0.3$). **c)** Grey symbols are non-binaries, black are photometric binaries, having: △: $> 0.95 M_{\odot}$, ⋆: ($0.9 < M_{\odot} < 0.95$), □: ($0.85 < M_{\odot} < 0.9$), and ∗: ($< 0.85 M_{\odot}$). Black solid circles denote spectroscopic binaries from Geller *et al.* (*in preparation*), while dotted circles denote stars with insufficient spectroscopic observations to determine if the star is a binary.

we find roughly 2/3 of the SBs using our photometric method, verifying the reliability of our technique.

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