Wide Binaries in the Sloan Digital Sky Survey

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Abstract

We present a novel approach to photometric parallax calibration based on samples of candidate wide binaries (semi-major axis a > 100 AU). The constraints on the photometric parallax relations are obtained by minimizing the residuals between the difference of predicted absolute magnitudes and the difference of measured apparent magnitudes. The estimated best-fit relations agree with Jurić et al. (2008) photometric parallax at the 0.13 mag level (root-mean-square). We construct a sample with ~20,000 likely binaries, and use it to study the distribution of wide binaries semi-major axis. The observed distribution is well described by the Öpik distribution, $f(a) \propto 1/a$, for $a < a_{break}$, where a_{break} increases linearly with the height above the Galactic plane, Z. The a_{break} also correlates with the local number density of stars as $a_{break} \propto \rho^{-1/2}$. The number density of wide binary systems closely follows the overall number density of stars at 1% level in the Z = 0.2 - 2.0 kpc distance range. The color distribution of wide binaries suggests preference for similar-mass M dwarf – M dwarf systems. We find that ~77% of wide binaries may have an unresolved binary as one of the components.

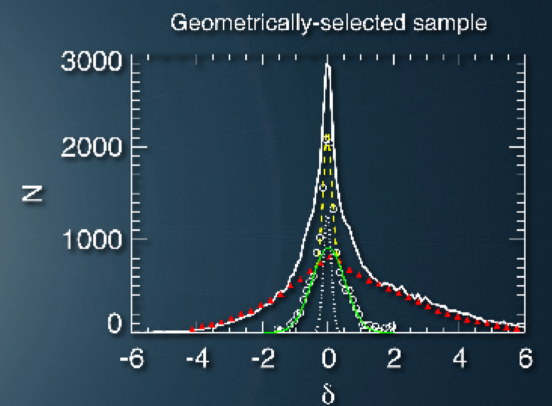
Photometric Parallax Calibration Using Wide Binaries

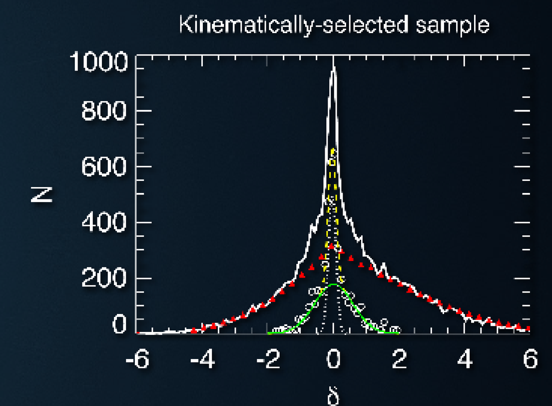
We can reasonably assume that two stars in a binary system have similar distance moduli, i.e. $m_1 - M_1 = m_2 - M_2$, where this relation can be rewritten as $\Delta M - \Delta m = (M_2 - M_1) - (m_2 - m_1) = 0$. The difference in absolute magnitudes, $\Delta M = M_2 - M_1$, can be calculated from an adopted photometric parallax relation and should agree with the measured difference of their apparent magnitudes, $\Delta m = m_2 - m_1$, if the stars are on the main sequence, and if the shape of the adopted photometric parallax relation is correct. The $\Delta M = \Delta m$ equality for binaries must be valid irrespective of color. Also, the distribution of the difference, $\delta = \Delta M - \Delta m$, for real wide binaries should be narrow and centered on zero.

Using two independent samples of candidate binaries selected as i) pairs of unresolved sources with angular separation in the 3'' – 4'' range, and ii) as common proper motion pairs with 5'' – 30'' angular separation, we obtain two best-fit photometric parallax relations. These relations are similar to each other, and to the Jurić et al. (2008) photometric parallax relations, agreeing at the 0.13 mag level (rms) and with a maximum difference of 0.25 mag.

Unresolved Multiplicity in Wide Binaries

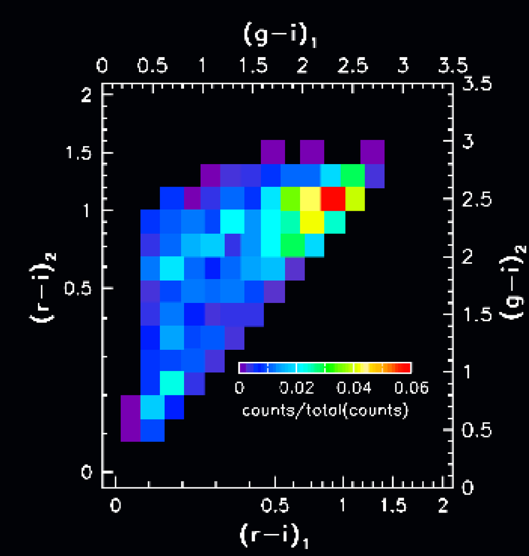
The distribution of $\delta = (M_2 - M_1) - (m_2 - m_1)$ values for wide binaries (*yellow dashed line*), can be modeled as a sum of two Gaussians. The narrow Gaussian (0.12 mag wide, *dotted line*) is due to single star - single star wide binary systems. The wide Gaussian (0.55 mag wide, green *thin solid line*) is due to wide binary systems where both stars are unresolved binary, or multiple, systems. We find that ~77% of wide binaries are such systems.



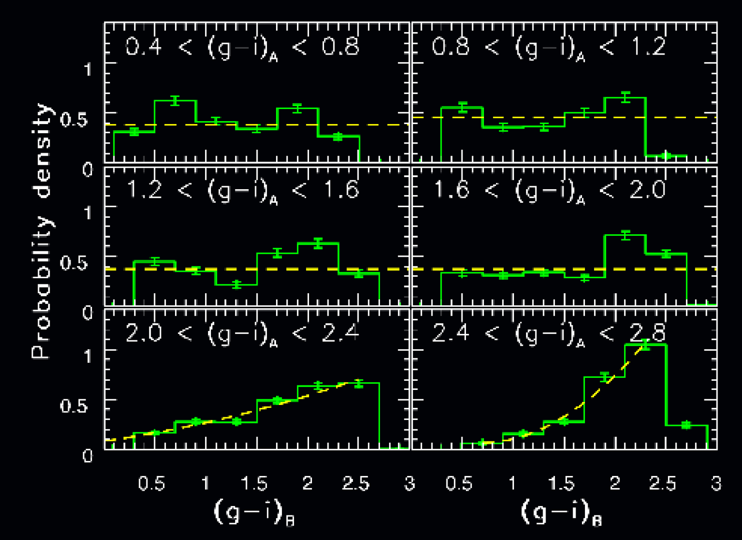


Color Distribution of Wide Binaries

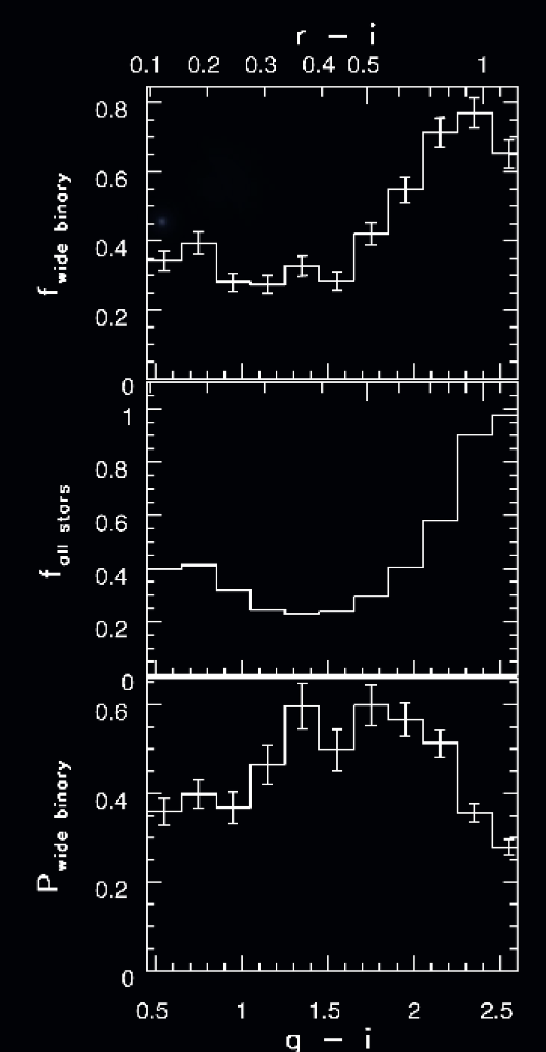
The color of a main sequence star can be used as a proxy for stellar mass. The color-color distribution of wide binaries can, therefore, show the distribution of stellar masses in wide binary systems.



Right: The $(g-i)_2$ vs. $(g-i)_1$ distribution of wide binaries in the $0.7 < d$ / kpc < 1.0 volume-complete sample, where $(g-i)_1$ and $(g-i)_2$ are the colors of the brighter and the fainter component. The distribution is fairly uniform, with a local maximum around $(g-i)_{1,2} \sim 2.5$, suggesting a preference for similar-mass M dwarf – M dwarf systems.



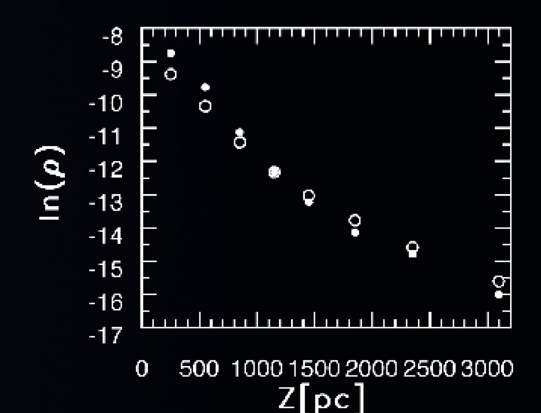
Above: The conditional probability density of having a star with $(g-i)_B$ color in a wide binary system, if the other star in the system has $g-i = (g-i)_A$. The flat probability density in the top and middle panels indicates that $g-i < 2.0$ stars in wide binary systems are equally likely associated with red or blue companions, while for $g-i > 2.0$ stars, redder companions are more likely than blue ones, as shown in the bottom panel.

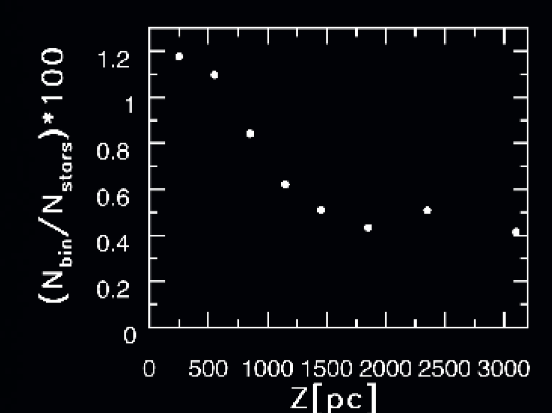


Right: The $g-i$ color distribution of stars in the $0.7 < d$ / kpc < 1.0 volume-complete wide binary sample (*top*), and of all stars in the same volume (*middle*). The probability for finding a star with $g-i$ color in a wide binary system, $P_{wide\ binary}$ (*bottom*), is given as a ratio of the two distributions normalized to an area of 1. The K3 to M2 ($1.3 < g-i < 2.2$) stars are slightly more likely to be in a wide binary system than other spectral types.

Spatial Distribution of Wide Binaries

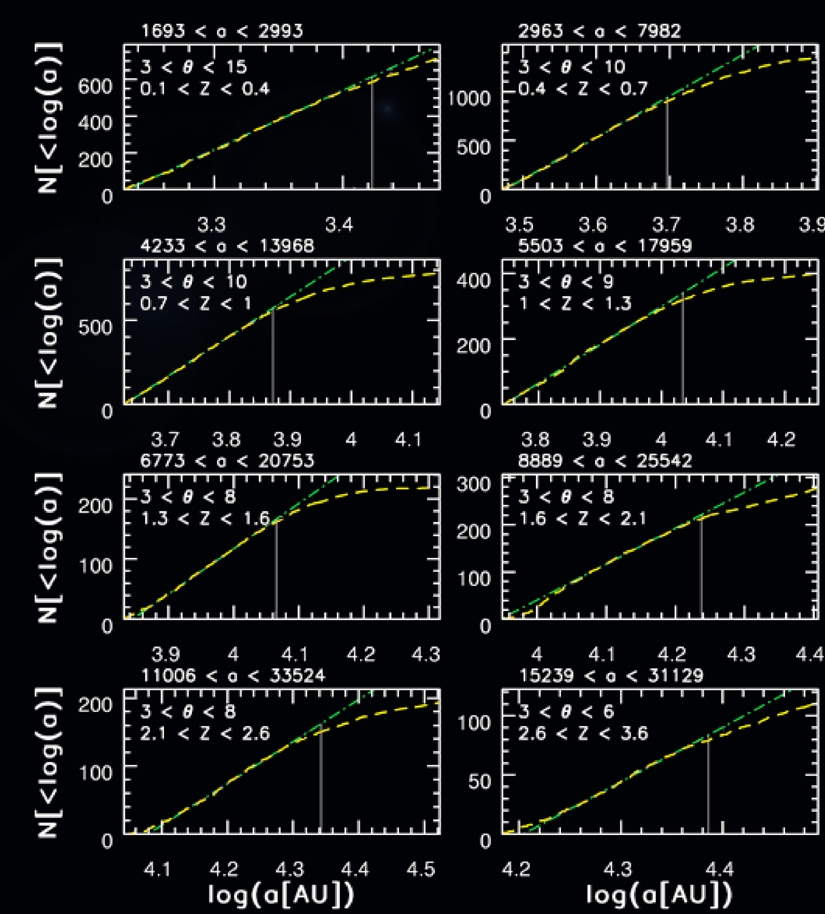
Below left: The local number density of binaries (dots) decreases exponentially in the same manner as the local number density of stars (circles). The density of stars is here normalized to match the density of binaries at 1 kpc. Below right: The fraction of binaries relative to the total number of stars decreases from 1.2% at 250 pc to 0.4% at 1800 pc.





Distribution of Semi-major Axes

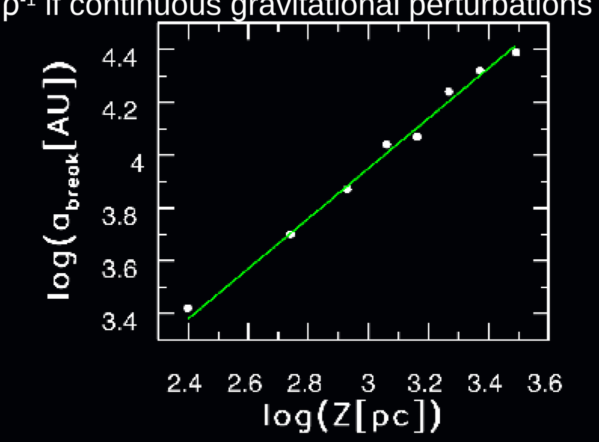
The distribution of semi-major axes of binary stars is a fossil record of the conditions at star formation, as well as of the processes of dynamical evolution, such as the disruption of wide binaries by molecular clouds or passing stars.

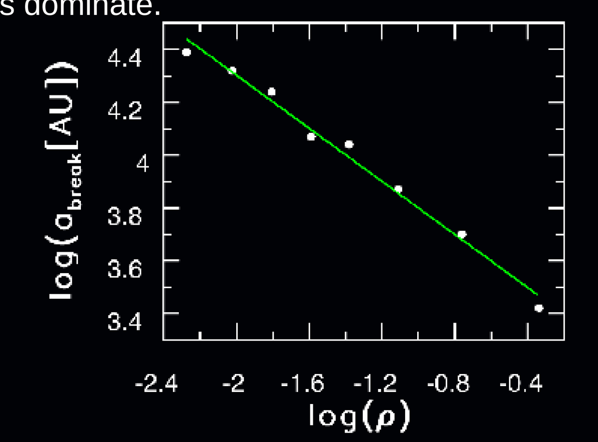


Above: The cumulative distributions of log(a) (*yellow dashed lines*) in different Z (height above the Galactic plane) bins follow the Öpik distribution, $f(a) \propto 1/a$ (*green dot-dashed lines*) until log(a_{break}) (*vertical lines*). The sampled range of average semi-major axes and angular separations is given for each panel.

Below left: The dependence of log(a_{break}) values on log(Z) is modeled as log(a_{break}) = k log(Z) + l, where k = 0.95 ± 0.05 and l = 1.1 ± 0.2, or approximately, a_{break}[AU] = 10Z[pc].

Below right: The dependence of log(a_{break}) on log(ρ), where ρ is the local number density of stars, is modeled as log(a_{break}) = k log(ρ) + l, where k = -0.50 ± 0.02 and l = 3.30 ± 0.04, or $a_{break} \propto \rho^{-1/2}$. Theory predicts $a_{break} \propto \rho^{-2/3}$ if close encounters perturb binaries, or $a_{break} \propto \rho^{-1}$ if continuous gravitational perturbations dominate.





References and Acknowledgments

- Jurić, M. et al. 2008, ApJ, 673, 864
- Sesar, B. et al. 2008, in preparation

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