Speckle Interferometry at NSF's NOIRLab

Andrei Tokovinin

Speckle interferometry is a vital technique for follow-up observations of exoplanet candidates identified by the *Kepler* and *TESS* space probes.[1] Many large telescopes operated by NSF's NOIRLab (Gemini,[2] SOAR,[3] WIYN, and the guest Robo-AO at 2.1 m) are equipped with speckle instruments for diffraction-limited imaging in optical light. These instruments also provide an exciting capability to survey binary-star statistics or study the orbital motion and architecture of multiple-star systems. The new generation of speckle instruments offers increased sensitivity, large productivity (at SOAR ~300 stars can be observed in a single night), and data-reduction pipelines.

Speckle follow-up of exoplanet host stars at first sight appears to be only a technical activity needed to detect false positives or to account for close stellar companions that can dilute the amplitude of planetary transits or mimic them if they contain an eclipsing binary. However, the results from speckle observations throw new light on planet formation. It turns out that the frequency of planets in close stellar-binaries (separation < 50 au) is much lower than that seen in single stars or wide stellar-binaries (2020AJ....159...19Z; Figure 1). Suppression of planet formation in close binaries is believed to be related to the faster dissipation of their disks. The same phenomenon (fast disk disappearance) causes differences in the stellar rotation: young stars in close binaries rotate faster than single stars. This has been recently proven by speckle imaging of pre-main sequence stars in the Upper Scorpius stellar association for which Kepler found several photometric periods, hinting at their binary nature (2018AJ....156..138T). Subsequent comparison of rotation periods of single and binary stars has highlighted the role of disks in braking stellar rotation (2019A&A...627A..97M). This example shows how links between binary stars and exoplanets become stronger as exoplanet science comes into maturity.

Stimulated by the *Kepler* study of multi-periodic stars in the Upper Scorpius association, we used speckle with SOAR to uniformly survey 614 known association members down to 0.4 solar masses for close binary companions (2020AJ....159...15T2; Figure 2. The combination of speckle coverage with *Gaia* astrometry more than doubled the number of known binaries in this association. The study revealed that the binary population of the association differs from similar binaries in the field in several ways, e.g., there is a larger frequency of close pairs among low-mass stars and a mysterious deficit of equal-mass pairs with intermediate separations of a few hundred au. This finding implies that formation of binaries (and, by extension, of stars and planets) critically depends on the environment.

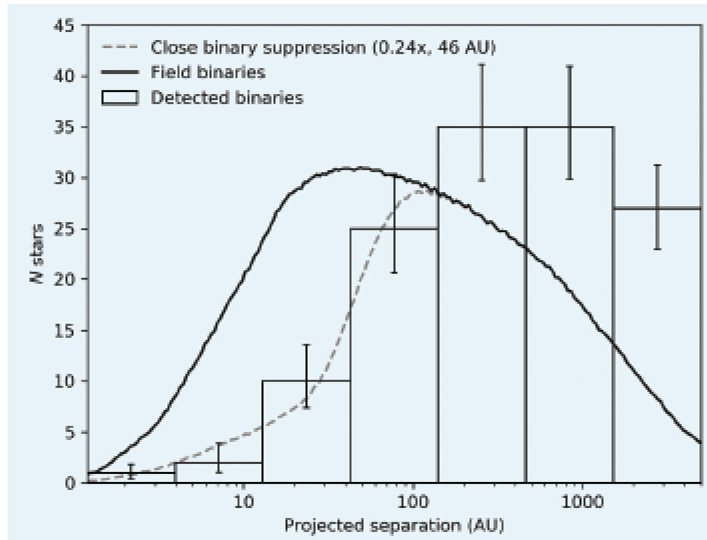

Figure 1: The separation distribution of *TESS* exoplanet hosts observed at SOAR reveals a reduced frequency of pairs closer than ~50 au, compared to the field stars. The apparent excess of wide pairs is likely explained by contamination of the *TESS* sample by close eclipsing binaries that indeed frequently have wide tertiary companions.

1. *https://www.nasa.gov/tess-transiting-exoplanet-survey-satellite*
2. *https://www.gemini.edu/sciops/instruments/alopeke-zorro/*
3. *http://www.ctio.noao.edu/~atokovin/speckle/*

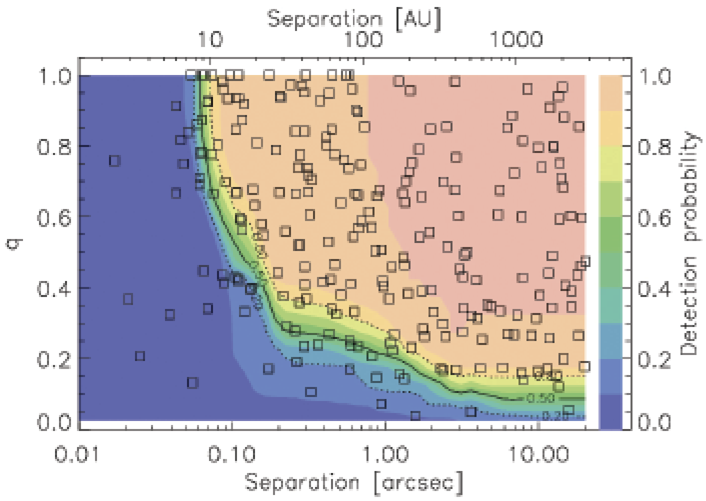

Figure 2: Projected separation and mass ratio q of 250 binaries in the Upper Scorpius stellar association. The colors indicate completeness and is dominated by the SOAR speckle survey (a few binaries closer than 8 au were discovered at Keck). Note the mysterious paucity of pairs with q ~ 1 wider than 100 au, despite the ease of their detection. This effect has been noted before, but the small size of prior surveys could not ascertain its reality.

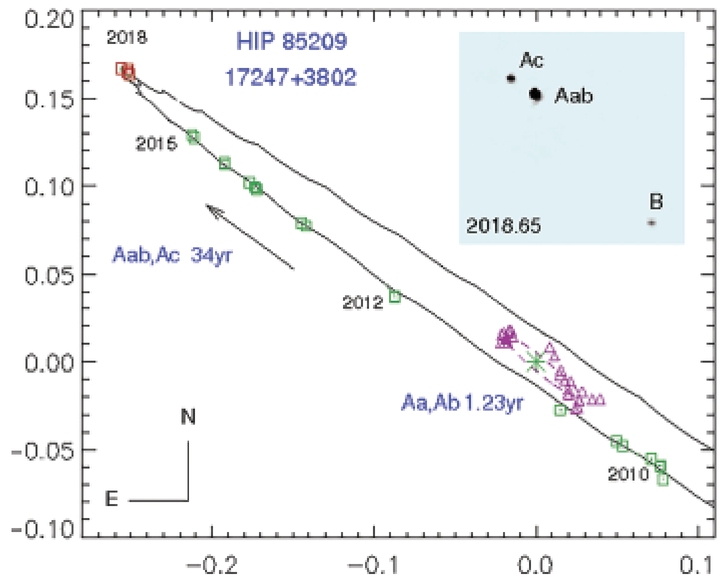

Figure 3: Orbits in the nearby (48 pc) quadruple system HIP 85209 studied at WIYN (scale in arcseconds). The insert shows the reconstructed speckle image where the closest pair Aab is not resolved. The intermediate 34-year orbit of Aab, Ac shows waves caused by the inner subsystem, while the distant star B moves very slowly (estimated period 500 yr). All orbits appear to be approximately co-planar, resembling the architecture of a planetary system.

While binary surveys and support of space exoplanet missions require only a single visit per target, repeated measurements with high accuracy are needed to determine binary orbits. The high angular resolution provided by speckle interferometry gives access to orbits of fast pairs with separations of 1–10 au, which are comparable to the size of the Solar System. Time-domain speckle data accumulated at SOAR over a decade have resulted in hundreds of new orbits (e.g., 2019AJ....158...48T). Recently, the study of orbital architecture of multiple systems has been extended to the northern sky using WIYN (2019AJ....158..167T; see Figure 3).

Millions of new close binaries will be revealed in the *Gaia* data release 5 (still several years off). Following all of those pairs by speckle interferometry will be impractical, but also unnecessary. Nevertheless, large subsets of *Gaia* binaries will certainly require ground-based observations for various reasons; therefore, efficient speckle instruments will continue to be in high demand in the coming decade. The current fleet of speckle cameras will benefit from improved observing procedures and data reduction to further boost their productivity and assure a steady flow of high-resolution data.