*From Interacting Binaries to Exoplanets: Essential Modeling Tools*
*Proceedings IAU Symposium No. 282, 2011*
*Mercedes T. Richards & Ivan Hubeny, eds.*

doi:10.1017/S1743921311027268

# Observing Faint Companions Close to Bright Stars

**Eugene Serabyn**

Jet Propulsion Laboratory, California Institute of Technology,
4800 Oak Grove Drive, Pasadena, CA 91109, USA
email: `gene.serabyn@jpl.nasa.gov`

**Abstract.** Progress in a number of technical areas is enabling imaging and interferometric observations at both smaller angular separations from bright stars and at deeper relative contrast levels. Here we discuss recent progress in several ongoing projects at the Jet Propulsion Laboratory. First, extreme adaptive optics wavefront correction has recently enabled the use of very short (i.e., blue) wavelengths to resolve close binaries. Second, phase-based coronagraphy has recently allowed observations of faint companions to within nearly one diffraction beam width of bright stars. Finally, rotating interferometers that can observe inside the diffraction beam of single aperture telescopes are being developed to detect close-in companions and bright exozodiacal dust. This paper presents a very brief summary of the techniques involved, along with some illustrative results.

**Keywords.** adaptive optics, coronagraphy, interferometry

## 1. Introduction

Although many exoplanets have now been discovered through both the radial velocity and transit techniques, to date very few exoplanets have been resolved from their host stars and imaged directly, because of their combination of close proximity to their host stars and relative faintness. However, a number of technical developments in both imaging and interferometry are bringing about rapid progress in the direct detection area as well. Here, a few recent developments that provide access to new observational regimes are summarized.

To reach small angular separations from stars using a single telescope, both imaging and interferometry have roles to play. The key in both cases is a high degree of wavefront correction, as provided by either current generation adaptive optics (AO) systems, or even more capable extreme adaptive optics (ExAO) systems that are beginning to come on line.

## 2. Imaging

The theoretical Strehl ratios predicted to be provided by typical current-generation AO systems and by more capable next-generation ExAO systems are compared in Fig. 1. This plot makes it clear that extreme adaptive optics can be made use of in two ways: shorter wavelengths can be used to achieve higher angular resolution, and high infrared Strehl ratios can enable effective coronagraphy (i.e., diffraction control). Both cases enable observations closer to bright stars. Figs. 2 and 3 give examples of observations of both types obtained with the Palomar "well-corrected subaperture" (WCS), a 1.5 m off-axis subaperture on the Hale telescope that is corrected to ExAO levels (Serabyn *et al.* 2007). Fig. 2 shows a close binary resolved in the B band, and Fig. 3 shows a faint secondary star near $\epsilon$ Ceph. In the latter image, the primary star has been largely extinguished with a vector vortex coronagraph (Mawet *et al.* 2010). Even higher contrast performance has allowed the Palomar vortex coronagraph to be used to image the three outer exoplanets in the HR8799 system using the WCS's 1.5 m aperture (Serabyn, Mawet, & Burruss 2010).

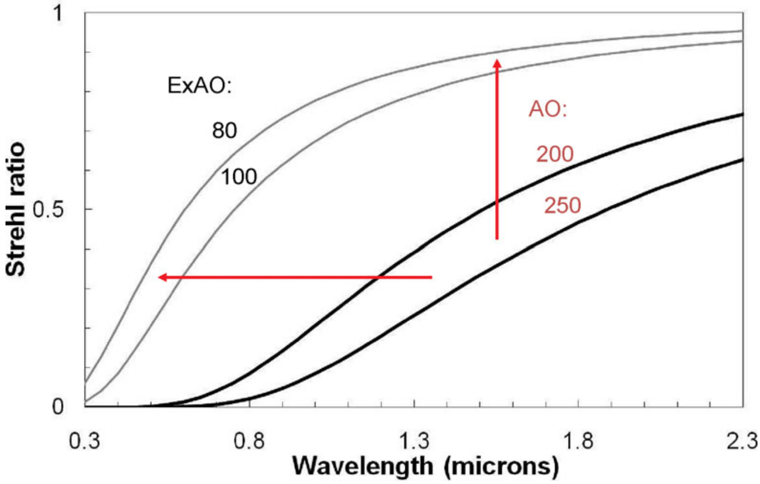

**Figure 1.** Strehl ratios expected with conventional AO (dark curves; shown for 200 - 250 nm of wavefront error) and ExAO (light curves; shown for 80 - 100 nm of wavefront error). ExAO enables very high Strehl-ratio (and high contrast) observations in the infrared (vertical arrow), and high-resolution observations at shorter (visible) wavelengths (horizontal arrow).

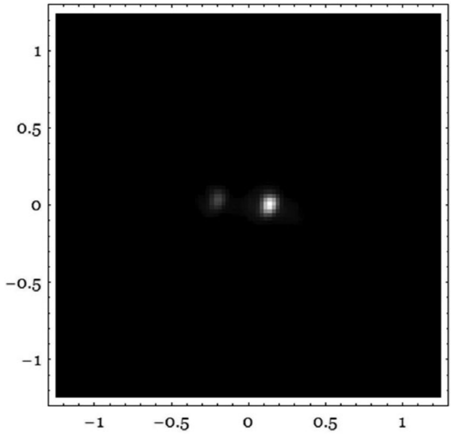

**Figure 2.** Palomar WCS image of the binary SAO37735 in the B band (Serabyn *et al.* 2007). The separation is 0.34".

## 3. Interferometry

However, interferometry within a single-aperture telescope allows observations even closer to the center than is possible with coronagraphic imaging using the full telescope aperture. To take advantage of this, rotating nulling interferometers akin to those suggested for space-based interferometry (Bracewell 1978), but operating within single telescope apertues, are under development (Serabyn *et al.* 2010). At the Palomar Observatory, our rotating fiber-based nuller has already put stringent constraints on potential companions and dust near Vega (Mennesson *et al.* 2011), by using a novel data reduction method that can retrieve deep astrophysical nulls from the distribution of the null depth fluctuations (Hanot *et al.* 2011). Moreover, an initial test observation on one of the Keck telescopes has begun to demonstrate the applicability of rotating baseline interferometers to the detection of close companions (Fig. 4).

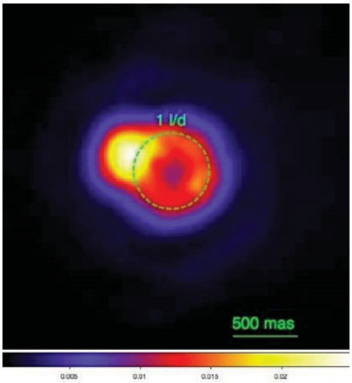

**Figure 3.** Detection of a potential companion to $\epsilon$ Ceph with our vector vortex coronagraph on the Palomar WCS (Mawet *et al.* (2011)). The primary residual appears as a dim ring about the center, and the secondary is located is at approximately 1.1 $\lambda$/D.

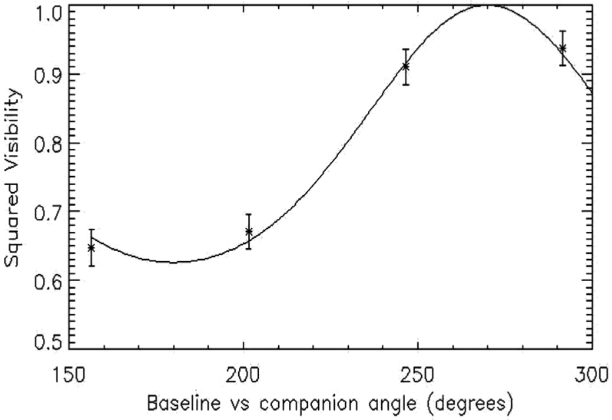

**Figure 4.** Detection of a companion to HIP87895 with a rotating-baseline interferometer on one of the Keck telescopes (Serabyn *et al.* 2010). The brightness difference is $\Delta K = 2.1$ mag and the separation is 39 mas.

## 4. Conclusions

New techniques are allowing for significant progress in both high-contrast imaging and interferometry. In the imaging area, these include extreme adaptive optics wavefront correction, including non-common-path speckle reduction with phase retrieval algorithms (Burruss *et al.* 2010), novel coronagraphs with small inner working angles (Guyon *et al.* 2006), and new data reduction methods, such as the locally optimized combination of images (LOCI) algorithm (Lafreniere *et al.* 2007). Regarding interferometry, deeper nulls can be measured by employing fiber optic beam combiners (Haguenauer and Serabyn 2006), and by carrying out a statistical analysis of the measured null depth fluctuations (Hanot *et al.* 2011). Rotating nulling baselines also allow effective exploration of the interferometric visibility plane, providing information on the spatial distribution of emission sources very close to bright stars, i.e., inside the single-aperture diffraction beam (Serabyn *et al.* 2010).

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA.

## References

Bracewell, R. N. 1978, *Nature*, 274, 780

Burruss, R. S., Serabyn, E., Mawet, D. P., Roberts, J. E., Hickey, J. P., Rykoski, K., Bikkannavar, S., & Crepp, J. R. 2010, *Proc. SPIE*, 7736, 77365X

Guyon, O., Pluzhnik, E. A., Kuchner, M. J., Collins, B., & Ridgway S. T. 2006, *ApJS*, 167, 81

Haguenauer, P. & Serabyn E. 2006, *Appl. Opt.*, 45, 2749

Hanot, C., Mennesson, B., Martin, S., Liewer, K., Loya, F., Mawet, D., Riaud, P., Absil, O., & Serabyn, E. 2011, *ApJ*, 729, 110

Lafreniere, D., Marois, C., Doyon, R. Nadeau, D., & Artigau, E. 2007, *ApJ*, 660, 770

Mawet, D., Serabyn, E., Liewer, K., Burruss, R., Hickey, J., & Shemo, D. 2010, *ApJ*, 709, 53

Mawet, D., Mennesson, B., Serabyn, E., Stapelfeldt, K., & Absil, O. 2011, *ApJ*, 738, L12

Mennesson, B., Serabyn, E., Hanot, C., Martin, S. R., Liewer, K., & Mawet, D. 2011, *ApJ*, 736, 14

Serabyn, E., Mawet, D., & Burruss, R. 2010, *Nature*, 464, 1018

Serabyn, E., Mennesson, B., Martin, S., Liewer, K. & Mawet, D., Loya, F., & Colavita, M. 2010, *Proc. SPIE*, 7734, 77341E

Serabyn, E., Wallace, K., Troy, M., Mennesson, B., Haguenauer, P. & Gappinger, R. 2007 *ApJ*, 658, 1386