

## Recent Science Results from the Navy Prototype Optical Interferometer

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**Abstract.** The latest science results from the Navy Prototype Optical Interferometer (NPOI) are summarized. Major areas reviewed include 1) recent results on NPOI imaging and orbits of radio star systems, with emphasis on the delineation of the Algol triple system; 2) NPOI observations that complement speckle interferometry programs by measurement of those portions of the orbits inaccessible at the resolution of speckle; 3) revised orbits for systems of particular astrophysical interest such as  $\epsilon$  Sco; and 4) applications of advanced coherent integration techniques to the determination of ultra-precise stellar angular diameters in exoplanet and other systems.

### 1. Introduction

The NPOI (Armstrong et al. 1998), located on Anderson Mesa, Arizona, is a joint project of the U.S. Naval Observatory and the Naval Research Laboratory in cooperation with Lowell Observatory. The NPOI includes arrays for both imaging and astrometry. The arrays share vacuum feed and delay line systems. The NPOI features rapid tip-tilt star tracking, active group-delay fringe tracking over a wide band (currently  $550\text{nm}-850\text{nm}$  in 16 channels) and a high degree of operational automation. The wide detection bandwidth and rapid observing duty cycle make rapid surveys (Hutter et al. 2004) and snapshot imaging (Zavala et al. 2010) practical. This paper summarizes many of the recent science results from the NPOI made possible by these capabilities.

### 2. Radio Stars

Ongoing NPOI observations are being used to improve the orbits of some half-dozen radio star systems brighter than  $V = 6.5$  for possible use in tying the forthcoming NPOI bright star astrometric catalog (UNAC, Benson et al. (2010)) to the ICRF. In the case of the Algol triple system (Zavala et al. 2010), the NPOI has produced for the first time images resolving all three components (e.g., Figure 1), separating the tertiary component from the binary and simultaneously resolving the eclipsing binary pair, the nearest and brightest eclipsing binary. The NPOI observations led to revised orbital elements for the triple system and rectified the 180-degree ambiguity in the position angle of Algol C (Figure 2). The magnitude differences and masses for this triple system directly determined by the NPOI are consistent with earlier light curve modelling results.

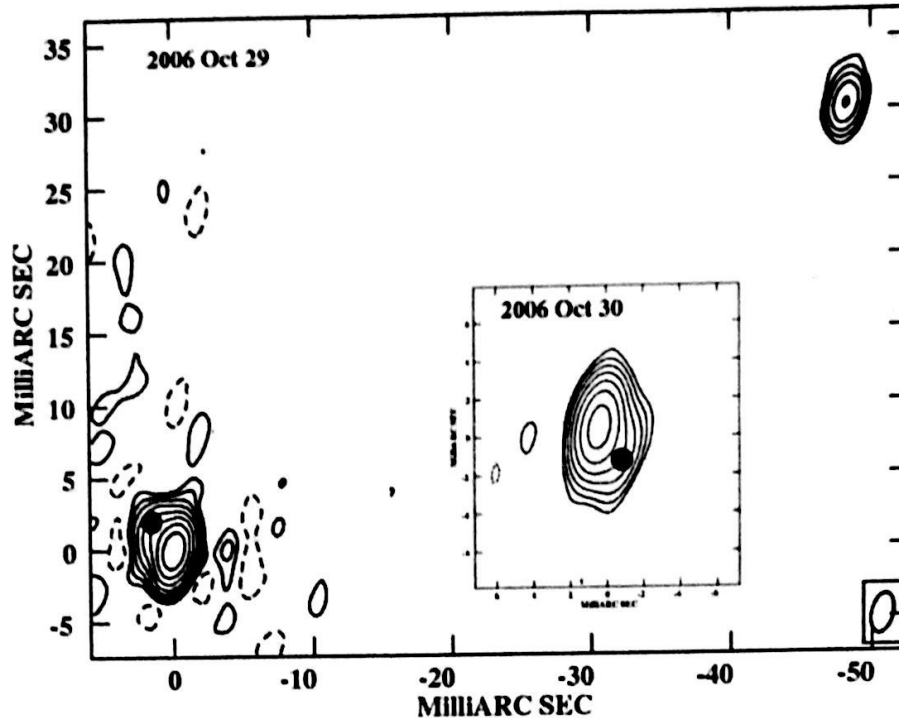


Figure 1. An image of the Algol triple system made from the NPOI data of 2006 Oct 29. Algol C is the component in the upper right hand corner. The insert shows a close-up image made from the NPOI observation of 30 Oct 2006 and emphasizes the motion of Algol B between the two epochs. To guide the eye, the approximate positions of Algol B are indicated at each epoch by a filled black circle. All figures are from Zavala et al. (2010).

### 3. Binaries

The NPOI routinely observes a dozen binary systems to provide observations, especially when the systems are near periastron, that complement the speckle interferometry program at USNO-DC (Figure 3; Mason, private communication). Observations of various bright (e.g.,  $\gamma$  Ori; Hummel (2011)) and faint ( $V \sim 6.7$ ) binary systems, including Pop II systems, are also being made for various members of the NPOI collaboration. Observations of triple systems, observations for the determination of O-star masses (e.g., Patience et al. (2008)), and a B-star multiplicity survey (De Rosa et al. 2011) continue.

### 4. Be Star Disks and Binaries

In anticipation of the possible collision between the circumstellar disk of the Be star component and the secondary star in the highly eccentric binary system  $\alpha$  Sco, NPOI observations were used to revise the orbital parameters. The NPOI spatially resolved the binary components in 2000 and over a period between 2005 and 2010, leading to a

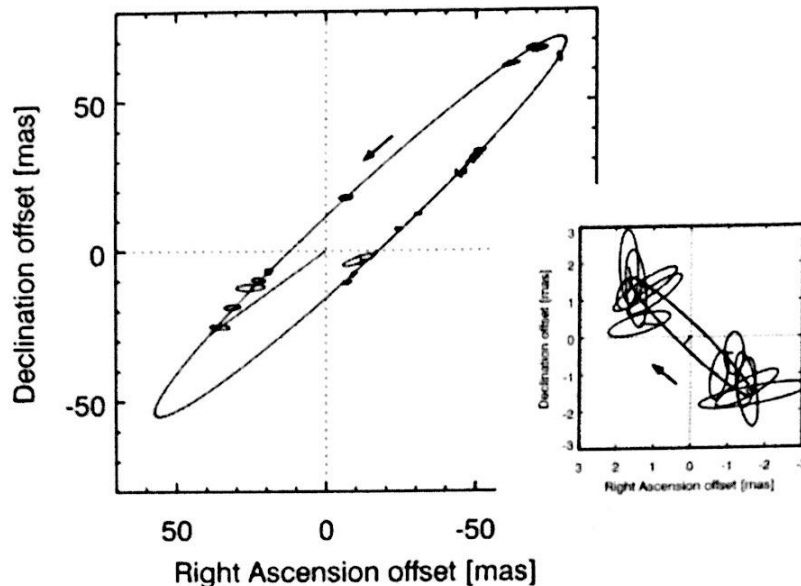


Figure 2. The large figure illustrates the AB-C orbit of Algol. A vector from the origin indicates the periastron point. The inset figure shows the A-B orbit. The astrometric results of (Zavala et al. 2010) are plotted with the astrometry of Pan et al. (1993) rotated by 180 degrees. Arrows show the direction of the orbital motion on the sky. All figures are from Zavala et al. (2010).

revised orbit (Figure 4) and a refined prediction of the time of periastron (6 July 2011 UT  $\pm$  2 days; Figure 5; Tycner et al. (2011)).

## 5. Stellar Diameters

The NPOI continues its long-standing observing program to obtain high-precision angular diameters of stars. The goal of one program (Baines 2011a), combining observations from the NPOI and CHARA arrays, is to obtain limb-darkened angular diameters of sufficient precision ( $\pm$  2%) to eventually combine with asteroseismological data to obtain stellar masses. Angular diameter measurements of exoplanet host stars are also ongoing (Baines 2011b). The analysis of the data from all these observations utilizes advanced coherent averaging (Jorgensen 2011) and improved error estimation using bootstrap Monte Carlo techniques (Tycner et al. 2010).

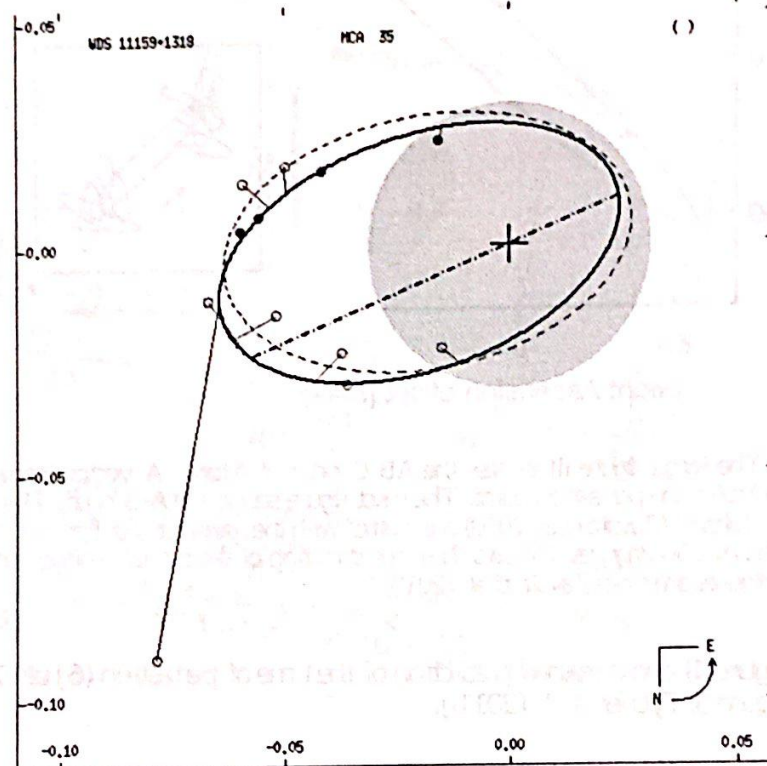


Figure 3. Plot of data for 73 Leo. The figure shows the relative visual orbit of the system (Mason, private communication); the x and y scales are in arcseconds. NPOI measurements are shown as filled circles, while previous speckle interferometry measurements are shown as open circles. The dashed curve represents the best orbital fit based on the speckle measurements (Hartkopf & Mason 2011), while the solid curve is a revised orbit including the NPOI measurements. The dot-dash line indicates the line of nodes of the revised orbit. All measurements are connected to their predicted positions on the revised orbit by O-C lines. The direction of motion is indicated on the north-east orientation in the lower right of the plot. The grey area represents that region where the pair is too close to be resolved by speckle interferometry with a 4m telescope.

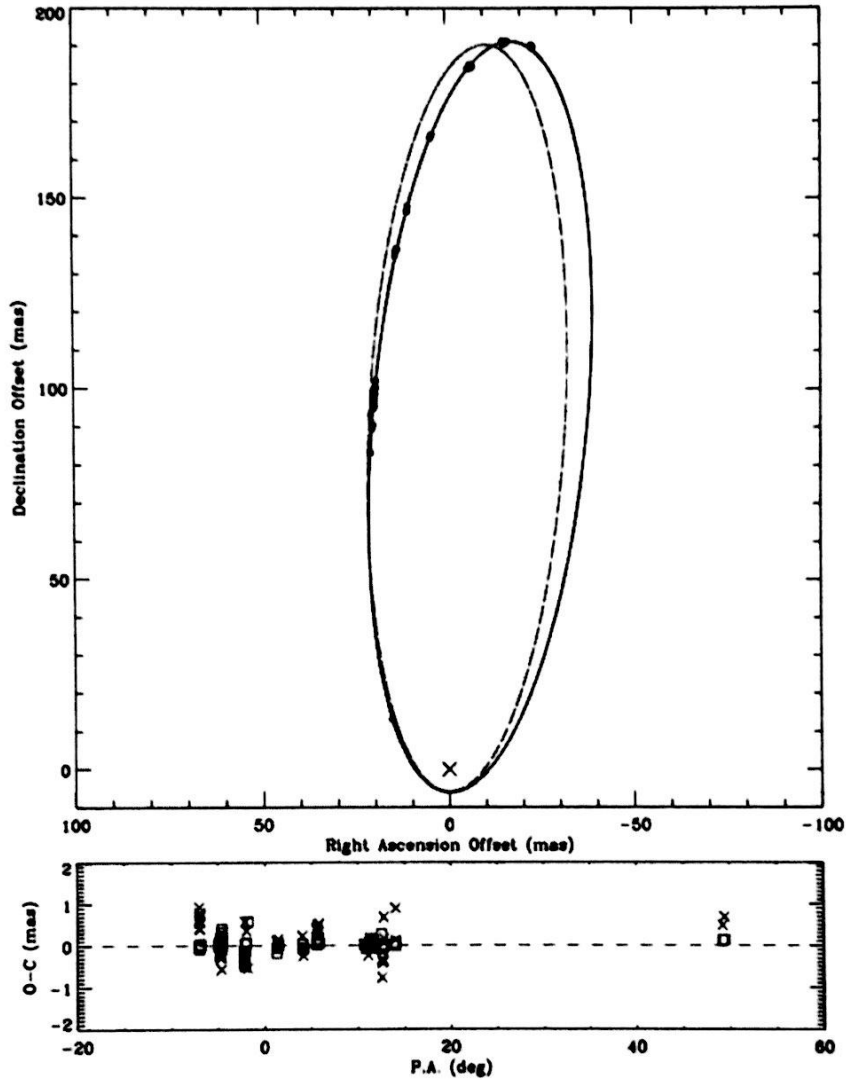


Figure 4. Top: Plot of data for  $\delta$  Sco. The figure shows the relative visual orbit of the system; the x and y scales are in milliarcseconds. NPOI measurements are shown as solid circles, with the corresponding best-fit orbit shown as a solid curve. The dashed curve represents the best orbit from Tango et al. (2009). The uncertainty ellipses of the NPOI data are generally smaller than the size of the plotted symbols. The location of the primary is marked with a cross. Bottom: The east-west (squares) and north-south (crosses) components of the O-C vectors as a function of the P.A. of the secondary.

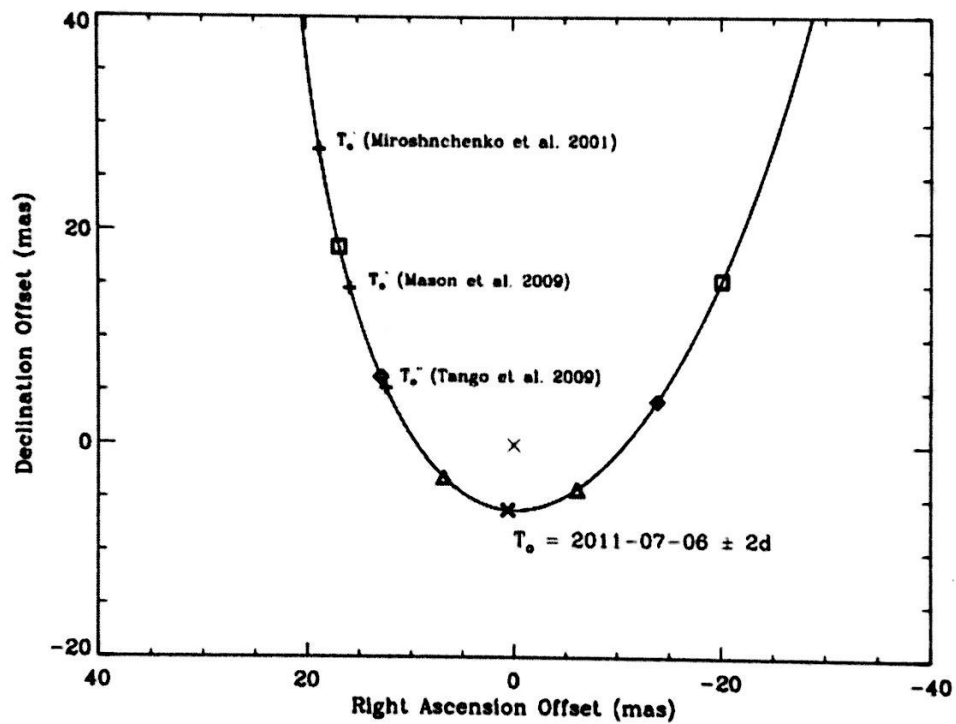


Figure 5. Predicted positions of the secondary during the 2011 periastron passage at 10 days (triangles), 30 days (diamonds), and 60 days (squares) before and after the periastron passage (cross). Locations of the secondary along the newly revised orbit based on periastron timings from previous studies are also shown (pluses). All positions are measured with respect to the primary, which is located at the origin of the plot. All figures are from Tycner et al. (2011).

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