Optical Observations with Milliarcsecond Resolution of Stars, Their Environments and Companions

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Observations with milliarcsecond resolution using the Navy Optical Interferometer have been obtained for a number of stellar systems which include high-mass binaries, eclipsing binaries, and radio stars. These observations also reveal the previously unseen companions in single-lined spectroscopic binaries via directly measured flux ratios. We will present examples of published and ongoing research efforts of these systems to illustrate how an optical interferometer contributes to our knowledge of stars, their environment, and companions. These studies include a conclusive revealing of the previously unseen companion in the single-lined binary Φ Herculis, the direct determination of orbital parameters in the wide and close orbits of Algol, and revealing the orbit of β Lyrae with spatially resolved images of the Hα emission.

Keywords: optical interferometry, binaries, astrometry, Navy Optical Interferometer

1. INTRODUCTION

The Navy Optical Interferometer (NOI), formerly the Navy Prototype Optical Interferometer (NPOI), is a joint project of the Naval Research Laboratory (NRL), and the United States Naval Observatory (USNO) in cooperation with Lowell Observatory, located at Anderson Mesa near Flagstaff, Arizona. For further instrument details see Armstrong et al. (1998) and for details regarding NOI’s observations and data reductions see Hummel et al. (2003), and the references therein.

Optical interferometry offers a method of directly determining stellar diameters, the morphology of Hα emission regions, and astrometric orbital parameters that govern the interactions of binary systems. The fundamental observed quantity for the NOI is the squared visibility ($V^2$, Armstrong et al. 1998), which is the Fourier transform of the source brightness distribution (see Thompson et al. 2001 for an introduction to interferometry). After detecting interference fringes from a binary star an orbit may be fit (Pan et al. 1993). With the orbit, the visibility data from all observations can be used to fit for the magnitude differences of the binary system in question (Hummel et al. 2003). Results of this technique as applied to the binary stars Phi Herculis, Beta Lyrae and Algol are reviewed in this work.

2. RESOLUTION OF SINGLE-LINED SPECTROSCOPIC BINARIES: Φ HERCULIS

Φ Herculis (HD 145389, HR 6023) is a mercury-manganese (HgMn) star, showing a wide variety of spectral abundance anomalies with both depletions and enhancements (Adelman et al. 2004). Aikman (1976) identified Φ Her as a single-lined spectroscopic binary. The secondary component avoided detection until NOI observations became available beginning in 1998. These interferometric observations lead to the identification of the spectral type of the secondary. Identification of the secondary’s spec-
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**ABSTRACT**

Observations with milliarcsecond resolution using the Navy Optical Interferometer have been obtained for a number of stellar systems which include high-mass binaries, eclipsing binaries, and radio stars. These observations also reveal the previously unseen companions in single-lined spectroscopic binaries via directly measured flux ratios. We will present examples of published and ongoing research efforts of these systems to illustrate how an optical interferometer contributes to our knowledge of stars, their environment, and companions. These studies include a conclusive revealing of the previously unseen companion in the single-lined binary Φ Herculis, the direct determination of orbital parameters in the wide and close orbits of Algol, and revealing the orbit of β Lyrae with spatially resolved images of the Hα emission.

Fig. 1. The calibrated squared visibilities of Φ Her for Navy Optical Interferometer observations made on 1998 May 16. This data shows the characteristic cosine wave signature of a binary.

Fig. 2. The left panel shows the observed spectra overlaid on normalized synthetic spectra for Φ Her A (solid blue line) and Φ Her B (red dashed line). In these images we can see the primary and secondary components of Mg I (2) 5183.6042. In the right panel is the same data but now is overlaid with a line representing the summed synthetic spectra for Φ Her A and B.

Fig. 2 illustrates how the synthetic spectra of the components, constrained by the brightness ratio from the NOI, accurately represent the observed spectra. In the right panel of Fig. 2 the DAO spectra are shown with an overlay of the summed synthetic spectra for both Φ Her A and B. In the left panel of Fig. 2 the DAO observed spectra is overlaid on individual normalized synthetic spectra for Φ Her A and B.

3. HA EMISSION IMAGING AND ORBIT DETERMINATION: Β LYRAE

β Lyrae is an interacting eclipsing binary system consisting of a ~3 solar mass B6-8II star which has filled its Roche lobe and a ~13 solar mass early B star, which is completely obscured and hidden within a thick accretion disk (Harmanec 2002). In 2002 the NOI observed β Lyrae as part of an experiment to detect the binarity of this system and the Hα emission associated with the accretion stream. NOI data from this experiment is presented along with images indicating the position of the Hα emitting regions relative to the continuum photo-center as a function of orbital phase, providing a means for analyzing the Hα morphology (Schmitt et al. 2009).

In Fig. 3 (left panel) the position of the Hα emission is plotted relative to the continuum photo-center for the five nights of data. The orbit of the Hα emission is also plotted by fitting a line to the data points with an orbital solution found to be oriented along a position angle of 248.8 ± 1.7°. Using parameters derived by Harmanec et al. (1996), Linnell (2000), and Harmanec (2002), the orbits of the Hα and continuum photo-centers were fit and converted to positions in the sky using the inclination de-
Interferometric observations using the NOI have resulted in the first resolved images of the triple system, as seen in Figs. 4 and 5. These observations have led to an unambiguous determination that the close pair orbit (A-B) is retrograde and nearly orthogonal to the plane of the wide (AB-C) orbit (Zavala et al. 2010). The improvements made to the AB-C orbital plane orientation have removed the time-variable systematic offset expected rived by Linnell et al. (1998). One important observational result is the Hα semi-major axis was observed to be less than the continuum semi-major axis, providing evidence that the NOI was effectively imaging the orbit of this system. This is due to the Hα emission originating within the disk of the more massive star, and the continuum photocenter being located nearer the less massive star (Schmitt et al. 2009). These Hα images each correspond to a different night and are organized in order of increasing orbital phase and are also shown with the correct orbital orientation.

4. DIRECT DETERMINATION OF ORBITAL PARAMETERS: ALGOL

Algol is the prototype for a well-known class of eclipsing binaries. The Algol system is a hierarchical triple system (close binary Algol A-B and triple Algol AB-C) and is well summarized by Söderhjelm (1980). Speckle (Labeyrie et al. 1974) and optical (Pan et al. 1993) interferometry resolved the orbit of the AB-C component, but the ascending node of these orbits differed by 180° from that used in the High Precision PARallaxC0llectingSatellite (HIPPARCOS) double star solution (Lindgren et al. 1997). As Algol is 1 of 12 radio stars used to link the HIPPARCOS optical reference frame to the International Celestial Reference System (ICRS, Kovalevsky et al. 1997), a resolution of this 180° ambiguity was needed to reconcile the time-variable systematic offset of the photocenter between the HIPPARCOS orbital orientation and the interferometric orientation.

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systems will also benefit from the directly measured fundamental parameters that govern these dynamic stellar systems.

REFERENCES


