# Mk III INTERFEROMETER:
# MILLIARCSECOND "VISUAL" ORBITS
# OF SPECTROSCOPIC BINARIES

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**Abstract.** The spectroscopic binary observing program of the Mark III Optical Interferometer[1] has produced four published orbits and 22 preliminary orbits. The mean (formal) precision is 0.3% for measurements of sin $i$ and 0.7% for measurements of the semimajor axis $a$. We list the stars for which we have obtained orbits or preliminary orbits and describe our data and uncertainty analysis techniques.

**Key words:** stars: binaries: spectroscopic – stars: binaries: visual – techniques: interferometric

## 1. Introduction

The Mark III Optical Interferometer on Mt. Wilson, CA, has been used for astrometry, for stellar diameter measurements, and for observations of spectroscopic binaries since routine operations began in late 1988. For diameter and binary observations, the variable baseline is used; lengths range from 3 m to 31 m. Fringes can be detected on stars as faint as $m_V = 5$. Typically, we obtain 150 to 200 75-sec observations in a night with an observing list of eight to 15 stars, half of which are small-angular-diameter stars for calibration. See Shao et al. (1988) for a description of the Mark III.

## 2. Spectroscopic Binary Observation Program

Some binary observations were started in 1988, and a program of spectroscopic binary observations was started in early 1989 with 255 stars in the initial list. We have a significant amount of data for $\sim$ 80 of these systems; in $\sim$ 40 of them, we see no evidence of their multiplicity (i.e., $\Delta m$ is too large or the separation is too small). From the remainder of the 80, we have orbits or preliminary orbits for 24 systems solely from Mark III data and orbits for two more systems from combining Mark III and speckle data. A list of these systems is shown in Table 1.

## 3. Data Reduction Improvements

The calibration and analysis of Mark III data have been discussed by Mozurkewich et al. (1991) and Armstrong et al. (1992a). In the calibration process, the degradation of the squared fringe visibilities $V^2$ due to the atmosphere and the instrument is evaluated by examining the $V^2$ of the calibrator stars versus seeing index, zenith angle, siderostat mirror angle, and time. Initially, binary data reduction proceeded

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[1] The MkIII Optical Interferometer located on Mt. Wilson, CA, is jointly operated by the Center for Advanced Space Sensing of the Naval Research Laboratory (NRL) and the U.S. Naval Observatory (USNO).

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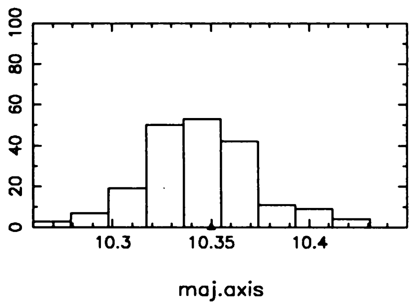
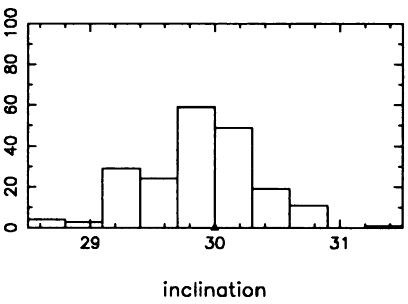
by two steps: first, fitting separation $\rho$, position angle $\theta$, and magnitude differences $\Delta m$ to data from individual nights, then determining the orbit from the set of $(\rho, \theta)$ pairs. The Levenberg-Marquardt method for non-linear least-squares fits was used to find the best fit and evaluate the (formal) uncertainties.

We have recently improved the binary data reduction in two respects. First, we now determine orbital elements and other system parameters (stellar diameters $D$, $\Delta m$'s) directly from the $V^2$ measurements.

Second, we have developed a Monte Carlo technique for estimating uncertainties. This technique includes simulation of systematic $V^2$ calibration errors as well as random errors caused by photon noise. Slow drifts in calibration can cause errors in $\rho$ and/or $\theta$, and can even simulate a system with small separation ($\rho \lesssim 3$ mas) and large magnitude difference; $\Delta m = 4$ corresponds to a 2.5% variation in $V^2$, while for good seeing conditions, we estimate the rms calibration uncertainties at $\lambda$800 nm (the best channel) to be ~ 1% to 2%.

In the following figure we present preliminary results (histograms) from Monte Carlo simulations for the major axis and the inclination of the orbit of $\eta$ Andromedae. Power spectra for the time-dependent calibration error were derived for each night from the calibrator measurements. Calibration errors were simulated by transforming the power spectra with random phases. All parameters of the binary model were then fitted to each of the artificial data sets. We plan to perform these calculations for all binaries; errors quoted in Table 1 are therefore formal uncertainties and are likely to underestimate the true uncertainties.





## 4. Conclusion

This list of binary systems represents the bulk of the orbits that will result from Mark III observations. Measurements of binaries fainter than ~ $5^m$ and/or with smaller orbits ($a \lesssim 3$ mas) await the development of interferometers with apertures larger than 2 cm and baselines longer than 31 m, while measurements of systems with $\Delta m \gtrsim 4$ requires calibration at the 1% level and better.

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TABLE I

Spectroscopic binaries from the Mark III Interferometer. The following orbits were published: $\alpha$ And (Pan et al. 1992), $\beta$ Ari (Pan et al. 1990), $\phi$ Cyg (Armstrong et al. 1992b), $\alpha$ Equ (Armstrong et al. 1992a). Elements of all other orbits are *preliminary*! The orbits of $\gamma$ Per and $\beta$ Cep were fitted to Mk III *and* speckle data (McAlister and Hartkopf 1988)

| HR | Name | Type | Nights | Inclination | $a$ [mas] |
|---|---|---|---|---|---|
| 15 | $\alpha$ And | SB1 A0p | 31 | 105.70 ± 0.05 | 24.20 ± 0.04 |
| 154 | $\pi$ And | SB2 B5V+B5V | 32 | 103.0 ± 0.1 | 6.69 ± 0.04 |
| 271 | $\eta$ And | SB2 G8III-IV+G8III-IV | 23 | 30.0 ± 0.4 | 10.35 ± 0.03 |
| 553 | $\beta$ Ari | SB2 A5V | 24 | 49.0 ± 0.7 | 36.1 ± 0.2 |
| 622 | $\beta$ Tri | SB2 A5III | 35 | 129.8 ± 0.2 | 8.05 ± 0.02 |
| 660 | $\delta$ Tri | SB1 G0V | 21 | 167 ± 2 | 9.93 ± 0.07 |
| 788 | 12 Per | SB2 F9V | 10 | 130 ± 2 | 50 ± 2 |
| 854 | $\tau$ Per | SB1 G4III+A4V | 15 | 92.7 ± 0.2 | 57 ± 1 |
| 915 | $\gamma$ Per | SB2 G8III+A3V | 9 | 90.87 ± 0.09 | 142 |
| 936 | $\beta$ Per A-BC | SB2 B8V+Am | 11 | 83.6 ± 0.4 | 93 ± 6 |
| 1412 | $\theta^2$ Tau | SB1 A7III | 27 | 47.6 ± 0.2 | 18.78 ± 0.03 |
| 1708 | $\alpha$ Aur | SB2 G5III+G0III | 20 | 137.30 ± 0.06 | 56.42 ± 0.04 |
| 2088 | $\beta$ Aur | SB2 A2IV+A2IV | 25 | 75.9 ± 0.2 | 3.39 ± 0.02 |
| 3852 | $o$ Leo | SB2 A5V+F6II | 7 | 58.3 ± 0.7 | 4.56 ± 0.02 |
| 5054 | $\zeta^1$ UMa | SB2 A2V | 36 | 59.4 ± 0.3 | 9.58 ± 0.06 |
| 5291 | $\alpha$ Dra | SB1 A0III | 14 | 84.9 ± 0.6 | 5.67 ± 0.09 |
| 6493 | -4 4275 | SB2 F3V | 6 | 54 ± 2 | 8.2 ± 0.3 |
| 6927 | $\chi$ Dra | SB2 F7V | 16 | 75.10 ± 0.08 | 124.2 ± 0.2 |
| 7133 | 113 Her | SB1 G4III+A6V | 35 | 40.0 ± 0.8 | 10.1 ± 0.1 |
| 7478 | $\phi$ Cyg | SB2 G8III-IV+G8III-IV | 39 | 78.4 ± 0.4 | 23.7 ± 0.4 |
| 7710 | $\theta$ Aql[1] | SB2 B9III+B9III | 22 | 149 ± 2 | 3.03 ± 0.05 |
| 8131 | $\alpha$ Equ | SB2 G5III+A5V | 27 | 152.1 ± 0.5 | 12.03 ± 0.04 |
| 8238 | $\beta$ Cep | SB1 B2III | 10 | 88.8 ± 1.0 | 204 |
| 8417 | $\xi$ Cep A | SB2 Am+F2III-IV | 20 | 73.3 ± 0.1 | 79.9 ± 0.3 |
| 8579 | 6 Lac | SB1 B2IV | 15 | 132.6 ± 0.8 | 8.26 ± 0.08 |
| 8650 | $\eta$ Peg | SB1 G2II-III | 22 | 68.2 ± 0.2 | 45.04 ± 0.08 |

[1]: Orbit revised

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