Optical Observations of Close Binaries with the Mark III Stellar Interferometer

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ABSTRACT

For the first time, four spectroscopic binaries have been directly resolved with the Mark III Stellar Interferometer. Observations in 1988 and 1989 were analyzed, and visual orbits for four binaries have been determined. The semimajor axes for β *Tri*, α *Equ*, α *And* and β *Ari* are approximately 0."008, 0."012, 0."024 and 0."037, respectively. The magnitude differences between two components are 0.5 mag. , 0.7 mag. , 1.8 mag. and 2.6 mag. , respectively. All of the orbital elements for α *And* and β *Ari* were determined from interferometric data only, and agree well with spectroscopic observations. Predictions of relative position between the two components for these binaries is consistent with the measurements to less than 0."001. Combined with data from spectroscopy, masses and distance for the double-lined spectroscopic binary β *Ari* are derived, and the results indicate that both components of β *Ari* agree well with the empirical mass-luminosity relation.

1. INTRODUCTION

Stellar masses are the fundamental parameter for studies of the evolution of stars, and their direct determination comes only from the study of binary stars.

But the collection of accurate masses remains remarkably meager. The lunar occultation technique, the intensify interferometer, and speckle interferometry have determined visual orbits of various binaries. Unfortunately, many spectroscopic binaries cannot be resolved by present observational techniques. Now, the Mark III Stellar Interferometer, a long baseline optical interferometer on Mt. Wilson, California, allows the direct resolution of very close binaries, the accurate determination of the relative orbit of a binary, and the precise measurement of luminosities of the two components. These results, combined with conventional photometric and spectroscopic observations, yield the distance, absolute magnitudes, mass, radius and effective temperature, and provide a benchmark for the study of stellar structure and evolution.

Binary observations with the Mark III Stellar Interferometer started in 1988, which is routinely operated for the observation of binary stars. By the end of 1989, four spectroscopic binaries had been directly resolved for the first time, and three of them: β *Ari*, α *And* and β *Tri*, have had their visual orbits determined. With the Mark III Stellar Interferometer, not only separations of a binary system, but also the luminosity difference between the two components can be accurately determined. The observation results in past two years demonstrate high angular resolution of 0."004 at 5500 Å , high measurement precision (better than 5 %), and good detectability of magnitude differences (less than 4 magnitude).

In the paper, we will describe binary observation and data analysis with the Mark III Stellar Interferometer, and present results for three spectroscopic binaries.

2. OBSERVATION AND DATA ANALYSIS

The description of the Mark III Stellar Interferometer has been previously published[1]. Binary observations with this instrument are mainly conducted with a variable baseline which consists of 12 piers, oriented north-south, at which to locate the sidereostats. Up to 36 different baseline are available, with length ranging from 3 to 32 meters. Fringe tracking uses a wide spectral channel for maximum sensitivity, and simultaneously, fringe visibility measurements use two narrow bandpass filters, typically 250 Å wide at 8000 Å and 5500 Å . The effective aperture for amplitude measurements is usually 2.5 cm. Generally, 75 seconds of fringe tracking of a star, followed by a 5 second measurement of dark count and sky background are recorded, and the square of the fringe visibility, V^2, is estimated for each scan. Approximately 160 - 220 scans per night can be made, and 15 - 25 scans per star per night are scheduled for candidate binaries. In order to calibrate the systematic errors due to the atmosphere and the instrument, typically four unresolved stars, with an intrinsic visibility greater than 98 %, are periodically observed during the night of observation.

The normalized visibilities are used by a least-squares fitting algorithm, and the intensity ratio R, angular separations, S_X, S_Y, between the primary and the companion in a rectangular coordinates system are estimated by the following formulas[2]:

$$V^2(X,Y) = (\Gamma^2(a_2) + (R\Gamma(a_1))^2 + 2R\Gamma(a_1)\Gamma(a_2)\cos\phi)/(1+R)^2,$$

where $\Gamma(\theta) = 2J_1(\pi B\theta/w)/(\pi B\theta/w)$, $a_1 = \pi B\theta_1/w, a_2 = \pi B\theta_2/w$, $\phi = 2\pi(XS_X + YS_Y)/w$, $J_1(x)$ is a first order Bessel function, X and Y are the components of projected baseline on the sky, B is the length of projected baseline, ω is the wavelength, and θ_1, θ_2 are the angular diameters of two components, separately.

Because of the importance of controlling of systematic errors, the calibration stars that we selected are those which have theoretically estimated diameters of $\approx 0.''001$, and have been measured by the Mark III Interferometer with the longest baseline (32 m). There are 17 good nights of data available for the 32 m baseline in 1989. We used data from both channels (8000 Å and 5500 Å), and calculated estimated diameters of observed calibrators for each night based upon the assumption of a wavelength-independent diameter. The final value of the calibrator's diameter we used is the mean of all results for the star. Table 1 lists calibrators and their theoretical and empirical values of diameter.

Table 1. List of Calibration Stars

Name		Fk5	α (^{h})	δ ($^\circ$)	π ($''$)	m_v (mag.)	Spec.	Dia(O) (mas)	Dia(C) (mas)
γ	Peg	7	0.22	15.18	0.000	2.83	B24	0.63	0.4
ζ	Cas	17	0.62	53.90	0.004	3.66	B24	0.30	0.3
γ	Cas	32	0.95	60.72	0.034	2.47	B01	0.95	1.4
μ	Cas	33	0.95	38.50	0.032	3.87	A55	0.50	0.5
γ	Tri	79	2.28	33.84	0.036	4.01	A15	0.48	0.8
41	Ari	100	2.83	27.26	0.031	3.63	B85	0.46	0.9
17	Tau	136	3.75	24.11	0.019	3.70	B63	0.60	0.4
η	Tau	139	3.79	24.11	0.008	2.87	B73	0.70	0.7
ζ	Per	144	3.90	31.88	0.010	2.85	B11	0.90	0.3
ϵ	Per	147	3.96	40.01	0.009	2.89	B03	0.88	0.3
γ	Ori	201	5.42	6.35	0.026	1.64	B23	0.92	0.7
θ	Gem	261	6.88	33.96	0.021	3.60	A33	0.32	0.7
λ	UMa	383	10.28	42.91	0.030	3.45	A24	0.67	0.9
θ	Leo	423	11.24	15.43	0.019	3.34	A25	0.65	0.8
δ	UMa	456	12.26	57.03	0.052	3.31	A35	0.81	1.0
β	Ser	583	15.77	15.42	0.034	3.67	A24	0.67	1.0
γ	Her	609	16.37	19.15	0.015	3.75	A93	0.95	0.9
ϵ	Her	634	17.00	30.92	0.022	3.92	A05	0.51	0.5
δ	Her	641	17.25	24.84	0.034	3.14	A34	0.90	0.9
γ	Lyr	713	18.98	32.69	0.011	3.24	B93	0.30	0.8
ζ	Aql	716	19.09	13.86	0.036	2.99	A05	0.77	0.8
ι^2	Cyg	733	19.50	51.73	0.005	3.79	A55	0.86	0.7
θ	Peg	834	22.17	6.20	0.042	3.53	A25	1.05	0.9
α	Lac	848	22.52	50.28	0.036	3.77	A15	0.80	0.8
ζ	Peg	855	22.69	10.83	0.023	3.40	B85	0.42	0.6
α	Peg	871	23.08	15.21	0.030	2.49	B93	0.87	1.4
υ	Peg	881	23.42	23.40	0.028	4.41	F83	1.10	1.4
κ	And	1619	23.67	44.33	0.012	4.14	B94	0.40	0.5

3. OBSERVATIONAL RESULTS

From binary observation with the Mark III interferometer, separations S_x and S_y, and the corresponding observation epoch are used for orbit determination by applying the method of differential corrections[3]. Four binaries have had their visual orbits determined, and are described separately as follows.

α And (HD 358, HR 15; R. A. = $0^h03.^m2$, Dec. = $28°32'$ for equinox 1900.0) is a chemically peculiar star which belongs to the subclassification of Mercury-Manganese stars, and has total visual magnitude $m_v = 2.06$ and spectral class B8. This system was determined spectroscopically in 1908, 1936, 1937, 1939 and 1976, and judged to be of 'good' quality[4].

The binary star *α And* was first resolved with the Mark III Interferometer in 1988, and its visual orbit was also determined. The prediction of relative positions between the two components of this system for 1989 is consistent with observations to less than 0."001. Table 2 lists results of its eccentricity and geometric elements for different time intervals assuming period $P = 96.^d640$ and epoch $T = JD2447374.85$ for each case. The excellent consistency of the results in Table 2 indicate very good accuracy of measurements with the instrument. In fact, only 10 measurements in 1988 covering 159° of mean anomaly, or 44 % of a revolution, have already provided a good orbital determination.

Table 2. Orbital Elements of *α And* for Different Time Intervals

	1988		1989		1988 & 1989	
	8000Å	5500Å	8000Å	5500Å	8000Å	5500Å
e	0.528±0.008	0.484±0.006	0.529±0.004	0.529±0.003	0.535±0.001	0.533±0.001
a'' (mas)	24.23±0.22	23.98±0.21	23.91±0.17	24.25±0.12	23.98±0.12	24.06±0.13
$i(°)$	105.47±0.24	106.08±0.25	105.73±0.30	105.44±0.40	105.63±0.25	106.19±0.22
$w(°)$	77.13±0.24	74.98±0.26	77.65±0.40	79.21±0.66	77.31±0.23	76.41±0.28
$\Omega(°)$	104.06±0.41	101.53±0.35	104.26±0.21	104.47±0.40	104.12±0.25	103.83±0.22
B	6.764±0.060	7.371±0.063	6.517±0.087	5.982±0.112	6.645±0.046	7.046±0.051
G	-22.563±0.120	-22.347±0.114	-22.299±0.088	-22.765±0.092	-22.337±0.063	-22.328±0.062
A	4.803±0.060	5.043±0.063	4.879±0.087	5.004±0.112	4.828±0.046	4.979±0.051
F	7.132±0.120	6.315±0.114	7.098±0.088	7.124±0.092	7.084±0.063	7.121±0.062

Using all of the data from 1988 and 1989, which covers a little more than 4 revolutions of its orbital motion, all seven orbital elements are determined independently, and are compared with the results from spectroscopic observations in Table 3. The table shows very good agreement between two completely different techniques. A typical plot of the measured and best-fit fringe visibilities for α *And* at two wavelengths as function of time are shown in Figure 1(a) and 1(b), and the visual orbit of α *And* with its measurement points at 8000 Å is plotted in the Figure 2. The observed (O) and calculated (C) separations S_x, S_y, the residuals to the visual orbit (O - C), the corresponding total separation ρ'', and mean anomaly E, are presented in the Table 4(a) and 4(b).

The estimated magnitude difference from the Mark III interferometer is 1.8 mag. Petrie[5] found the magnitude difference $\Delta m = 1.35$ mag. But A. H. Batten[4] pointed that this is certainly an underestimate since Petrie identified the line λ4479 Mn II of the primary spectrum as the secondary component of λ4481 Mg II on at least some of his tracings. We believe that the magnitude difference of α *And* from the Mark III Interferometer is well determined.

Table 3. Comparison between The Mark III Interferometer and Spectroscopy for the orbital elements of α *And*

α *And*	The Mark III 8000 Å		The Mark III 5000 Å		Spectroscopy [11]	
P (days)	96.640	±0.066	96.621	±0.136	96.6960	±0.0013
T(JD)	2447374.85	±0.19	2447375.02	±0.16	2442056.32	±0.28
e_1	0.529	±0.004	0.530	±0.003	0.521	±0.008
a''(mas)	23.98	±0.12	24.06	±0.13	-	-
i(°)	105.63	±0.25	106.19	±0.23	-	-
w(°)	77.31	±0.24	76.41	±0.29	77.1	±1.3
Ω(°)	104.12	±0.25	103.83	±0.22	-	-

Table 4 (a). Orbit Residuals at 8000 Å for *α And*

Epoch JD2400000+	S_r(O) (mas)	S_r(C) (mas)	O-C (mas)	S_d(O) (mas)	S_d(C) (mas)	O-C (mas)	ρ (mas)	E(°)
47412.9215	-17.67	-17.67	0.00	-4.23	-4.33	0.10	18.19	154.53
47413.8603	-16.97	-17.07	0.10	-4.62	-4.64	0.02	17.69	156.89
47423.8433	-11.77	-9.70	-2.07	-7.57	-7.53	-0.04	12.28	181.41
47436.7827	2.01	1.42	0.59	-9.92	-9.90	-0.02	10.00	213.57
47437.8351	2.60	2.34	0.26	-9.86	-10.01	0.15	10.28	216.31
47438.7458	3.89	3.13	0.76	-10.09	-10.08	-0.01	10.56	218.69
47457.7650	15.90	16.19	-0.29	-7.91	-7.79	-0.12	17.97	278.50
47458.7741	16.55	16.42	0.13	-7.35	-7.36	0.01	17.99	282.66
47459.8278	16.54	16.54	0.00	-6.81	-6.87	0.06	17.91	287.21
47460.8263	16.56	16.53	0.03	-6.34	-6.35	0.01	17.71	291.73
47751.8909	15.92	16.36	-0.44	-5.65	-5.69	0.04	17.32	297.25
47754.8830	14.12	14.82	-0.70	-3.39	-3.62	0.23	15.26	313.28
47765.9028	-8.49	-8.25	-0.24	4.83	4.76	0.07	9.53	32.97
47769.8954	-15.94	-15.70	-0.24	5.17	5.11	0.06	16.52	56.70
47771.8734	-18.59	-18.25	-0.34	4.94	4.87	0.07	18.89	66.54
47772.8278	-19.47	-19.26	-0.21	4.71	4.70	0.01	19.82	70.94
47774.8952	-21.07	-20.99	-0.08	4.24	4.21	0.03	21.41	79.83
47775.8808	-21.64	-21.64	0.00	4.00	3.93	0.07	21.99	83.80
47777.9070	-22.77	-22.63	-0.14	3.31	3.32	-0.01	22.88	91.52
47778.8882	-23.15	-22.98	-0.17	3.05	3.00	0.05	23.17	95.07
47783.8773	-22.44	-23.58	1.14	1.13	1.25	-0.12	23.61	111.63
47805.8012	-13.52	-13.28	-0.24	-6.29	-6.30	0.01	14.70	170.23
47806.7684	-12.27	-12.55	0.28	-6.70	-6.57	-0.13	14.17	172.59

Table 4 (b). Orbit Residuals at 5500 Å for *α And*

Epoch JD2400000+	S_r(O) (mas)	S_r(C) (mas)	O-C (mas)	S_d(O) (mas)	S_d(C) (mas)	O-C (mas)	ρ (mas)	E(°)
47412.9215	-17.90	-18.24	0.34	-4.27	-4.54	0.27	18.79	154.53
47413.8603	-17.59	-17.65	0.06	-4.80	-4.85	0.05	18.30	156.89
47423.8433	-13.48	-10.31	-3.17	-7.88	-7.77	-0.11	12.91	181.41
47437.8351	2.57	1.80	0.77	-10.21	-10.23	0.02	10.38	216.31
47438.7458	3.13	2.60	0.53	-10.53	-10.30	-0.23	10.62	218.69
47447.7654	9.25	10.19	-0.94	-10.25	-10.25	0.00	14.45	243.99
47457.7650	15.86	16.03	-0.17	-7.82	-7.88	0.06	17.86	278.50
47458.7741	16.43	16.28	0.15	-7.36	-7.44	0.08	17.90	282.66
47459.8278	16.65	16.44	0.21	-6.88	-6.93	0.05	17.84	287.21
47460.8263	16.67	16.46	0.21	-6.32	-6.41	0.09	17.66	291.73
47751.8909	16.45	16.32	0.13	-5.84	-5.73	-0.11	17.30	297.25
47754.8830	15.40	14.88	0.52	-3.51	-3.62	0.11	15.31	313.28
47765.9028	-8.55	-8.13	-0.42	4.80	4.82	-0.02	9.45	32.97
47769.8954	-15.97	-15.69	-0.28	5.18	5.14	0.04	16.51	56.70
47771.8734	-18.59	-18.30	-0.29	4.95	4.88	0.07	18.94	66.54
47772.8278	-19.79	-19.33	-0.46	4.78	4.69	0.09	19.89	70.94
47774.8952	-21.35	-21.13	-0.22	4.26	4.18	0.08	21.54	79.83
47775.8808	-21.86	-21.80	-0.06	3.99	3.90	0.09	22.14	83.80
47777.9070	-22.65	-22.85	0.20	3.25	3.27	-0.02	23.08	91.52
47778.8882	-23.10	-23.22	0.12	3.07	2.94	0.13	23.40	95.07
47783.8773	-22.29	-23.93	1.64	0.61	1.14	-0.53	23.96	111.63
47806.7684	-11.90	-13.16	1.26	-6.63	-6.80	0.17	14.81	172.59

β Ari (HD 11636, HR 553; R. A. = $01^h 49.^m 1$, Dec. = $+20°19'$ for equinox 1900.0) is a well known spectroscopic binary with large orbital eccentricity, and has a total magnitude of 2.64 and spectral type of A5 V. This system was predicted to be resolvable by speckle interferometry for a long time. Several large telescopes with aperture of 4 m, 5 m and 6 m, have been used with different speckle cameras[6,7,8], and 10 years have been spent to try to resolve this binary. Now the Mark III Interferometer successfully resolved it in 1988, and its apparent orbit was determined also[9].

We have now obtained 22 measurements on 12 baselines for βAri covering 4 revolutions. The orbital parameters of β *Ari* are determined completely independently from other sources, and listed in the Table 5 with results from spectroscopy for comparison. It is interesting to notice that the big difference for the longitude of periastron, ω. That means the discussions of periastron advance for βAri will be continued, and further observations with the Mark III Interferometer is neccesary.

It should to be pointed out that using only data from 1988, which covered 98° of mean anomaly, or 27 % of a revolution, we determined the orbit accurately to less than 0."0007. The visual orbit of β *Ari* and measured data are presented in the Figure 3. The magnitude difference, Δm is 2.6 at 8000 Å. The residuals to the orbit for β *Ari* are calculated in Table 6.

Table 5. Comparison between The Mark III Interferometer and Spectroscopy for the orbital elements of β *Ari*

β *Ari*	The Mark III		Spectroscopy [12]	
P (days)	106.952	±0.077	106.9954	±0.0005
T(JD)	2447377.63	±0.40	2444274.276	±0.009
e_1	0.900	±0.008	0.895	±0.003
a''(mas)	37.02	±0.23	-	-
i(°)	46.07	±0.57	-	-
w(°)	35.02	±0.93	24.5	±2.0
Ω(°)	74.94	±0.80	-	-

Combined with data from spectroscopic observations, a distance of (18.87 ± 0.61)pc and a corresponding geometrical parallax of 0."0530 ± 0."0017 are derived. The latter result agrees well with the trigonometric parallax of 0."0590 ± 0."0072[10]. The linear semimajor axis for *β Ari* is (0.68 ± 0.02)a.u., and the masses of the primary and companion are $M_1 = (2.34 \pm 0.10) M_\odot$ and $M_2 = (1.34 \pm 0.07) M_\odot$.

The ephemeris of the star *β Ari* from the newly determined orbit indicates that the maximum separation of *β Ari* is about 0."064. However, the angular separation is more than 0."035 for about 83 days of each 107 day period, which is within the range of speckle interferometry. Thus, it should be possible to resolve this system by speckle interferometry if the magnitude difference $\Delta m = 2.6$ at 8000 Å can be accomodated.

Table 6. Orbit Residuals for *β Ari*

Epoch JD2400000+	S_r(O) (mas)	S_r(C) (mas)	O-C (mas)	S_d(O) (mas)	S_d(C) (mas)	O-C (mas)	ρ (mas)	E (°)
47407.8875	58.66	58.48	0.18	-2.59	-2.69	0.10	58.54	137.01
47421.4948	63.99	63.36	0.63	-8.73	-8.47	-0.26	63.92	162.85
47422.7833	63.28	63.47	-0.19	-8.91	-8.98	0.07	64.11	165.18
47428.6633	63.04	63.30	-0.26	-11.30	-11.20	-0.10	64.28	175.67
47433.1462	62.37	62.42	-0.05	-12.86	-12.77	-0.09	63.71	183.62
47434.8574	61.76	61.92	-0.16	-13.26	-13.33	0.07	63.33	186.65
47435.8800	61.00	61.57	-0.57	-14.01	-13.66	-0.35	63.07	188.47
47436.8541	61.26	61.21	0.05	-14.09	-13.97	-0.12	62.78	190.21
47437.8771	61.31	60.80	0.51	-14.17	-14.28	0.11	62.46	192.04
47438.8312	60.85	60.39	0.46	-14.42	-14.56	0.14	62.12	193.75
47442.0377	59.22	58.80	0.42	-15.73	-15.47	-0.26	60.80	199.54
47457.5316	45.82	46.23	-0.41	-18.25	-18.41	0.16	49.76	229.65
47458.8309	45.16	44.77	0.39	-18.43	-18.52	0.09	48.45	232.44
47459.8405	43.81	43.59	0.22	-18.49	-18.58	0.09	47.39	234.66
47765.9374	56.83	56.98	-0.15	-16.16	-16.25	0.09	59.25	205.14
47769.9291	54.10	54.13	-0.03	-17.04	-17.14	0.10	56.78	212.65
47770.9323	53.30	53.33	-0.03	-17.23	-17.34	0.11	56.07	214.58
47783.8943	38.74	39.56	-0.82	-18.68	-18.64	-0.04	43.73	241.97
47806.8605	4.82	5.39	-0.57	6.05	5.69	0.36	7.83	32.48
47808.8536	14.62	14.74	-0.12	7.01	7.08	-0.07	16.35	52.29
47832.8113	56.39	56.48	-0.09	-1.34	-1.40	0.06	56.49	131.04
47836.7488	58.87	59.12	-0.25	-3.01	-3.16	0.15	59.20	139.13

β Tri (HD 13161, HR 622; R. A. = $2^h03.^m6$, Dec. = 34°31′ for equonix 1900.0) has a period of 31.388 days, and a total magnitude of 3.0 and spectral type A5 III . This system has two sets of orbital elements from spectroscopy which differ from each other considerably. Petries[5] found a magnitude difference $\Delta m = 1.19$, and considered it not of high precision because of difficulty of measurement for the fainter component.

We have obtained 10 useful measurements for wavelength of 8000 Å in 1989, which cover 58 days — almost two revolutions. The calculated semimajor axis is only $\approx 0.''008$. The preliminary orbit and measured data are plotted in Figure 4. The magnitude difference is ≈ 0.5 mag.

α Equ (HD 202447, HR 8131; R. A. = $21^h10.^m8$, Dec. = 04°50′ for equonix 1900.0) has a period of 98.81 days, and a total magnitude of 3.92 and spectral types G2 II and A5 V for two components respectively. The orbital elements from spectroscopy are of poor quality[4]. Data from the Mark III interferometer can be used to estimate the semimajor axis of $\approx 0.''012$, and magnitude difference of ≈ 0.7 mag. Its visual orbit and observation data are shown in Figure 5. It is necessary to obtain more scans per night for β $Tr1$ and α Equ, and refine the determination of orbital parameters.

Successful resolution of several spectroscopic binaries with the Mark III Stellar Interferometer demonstrate its excellent performance with high resolution and high measurement precision. We expect that more close binary stars will be resolved in the near future.

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Literature survey is based on the SIMBAD data retrieval system, database of the Strasbourg, France, Astronomical Data Center.

5. REFERENCES

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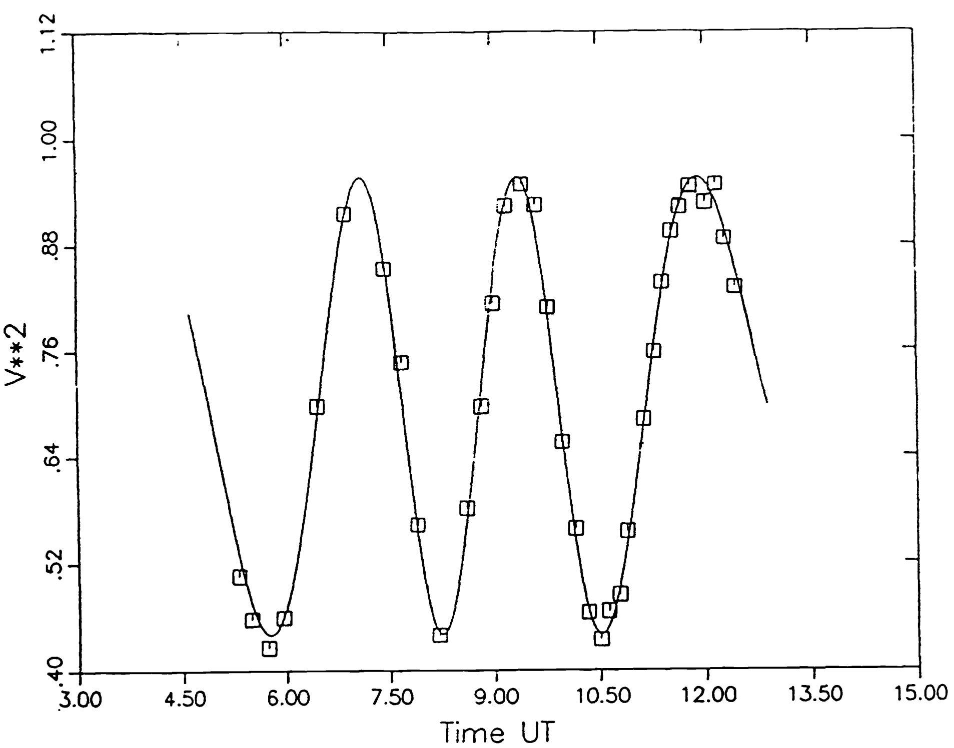


Figure 1-(a). Measured and best-fit fringe visibilities for *α And* at 8000 Å on baseline # 38 (32 m), August 31, 1989. The best-fit curve corresponds to intensity ratio $R = 0.199$, and separations in *R. A.* and *Dec.* of -15.96 mas and 5.16 mas, respectively.

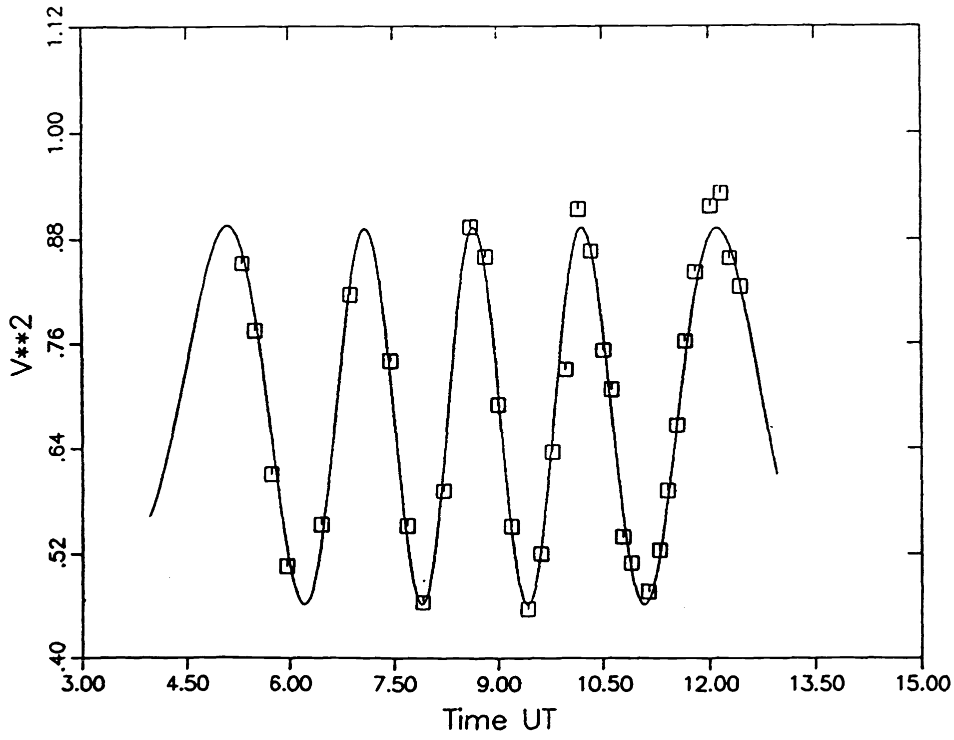
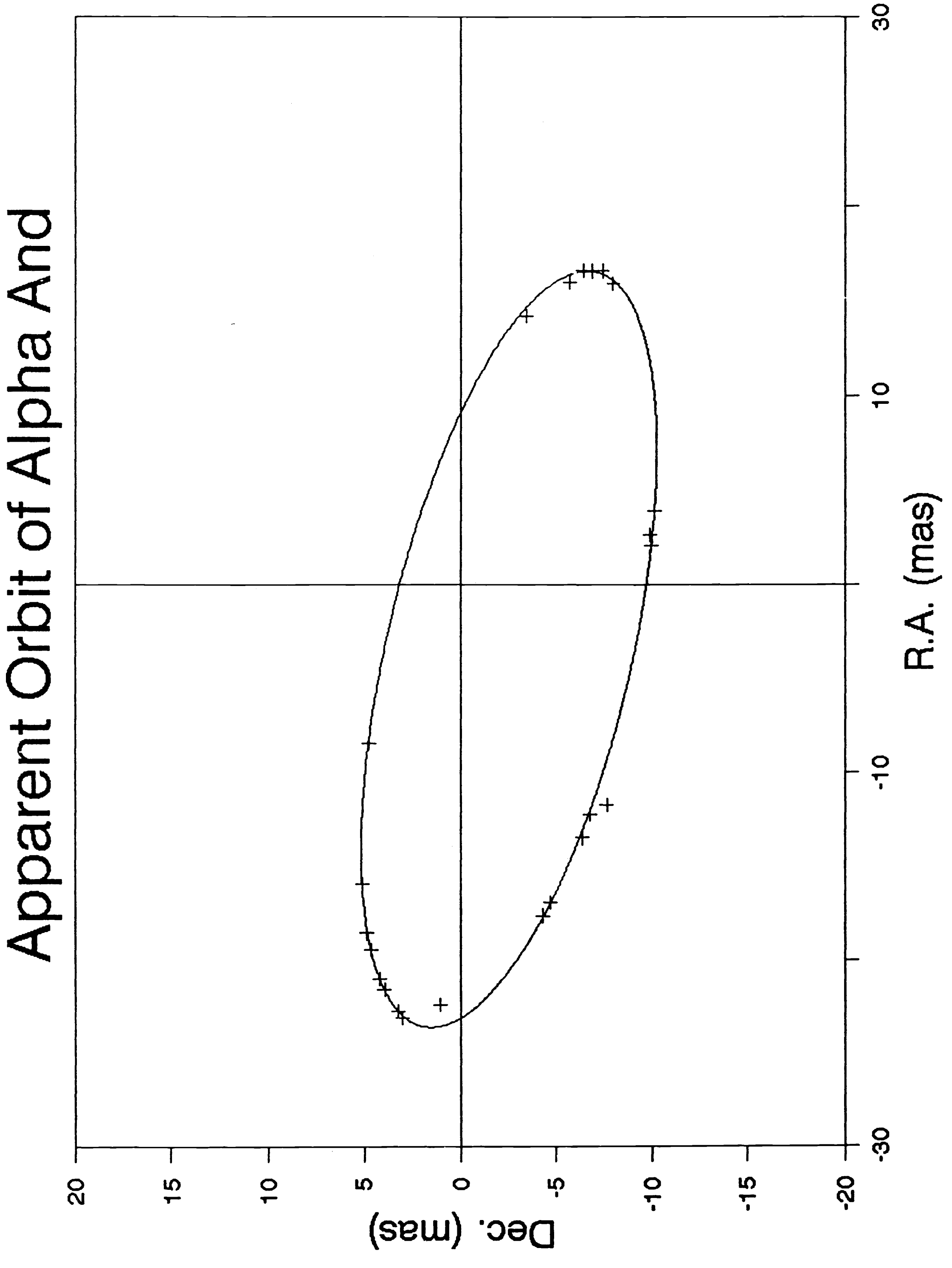
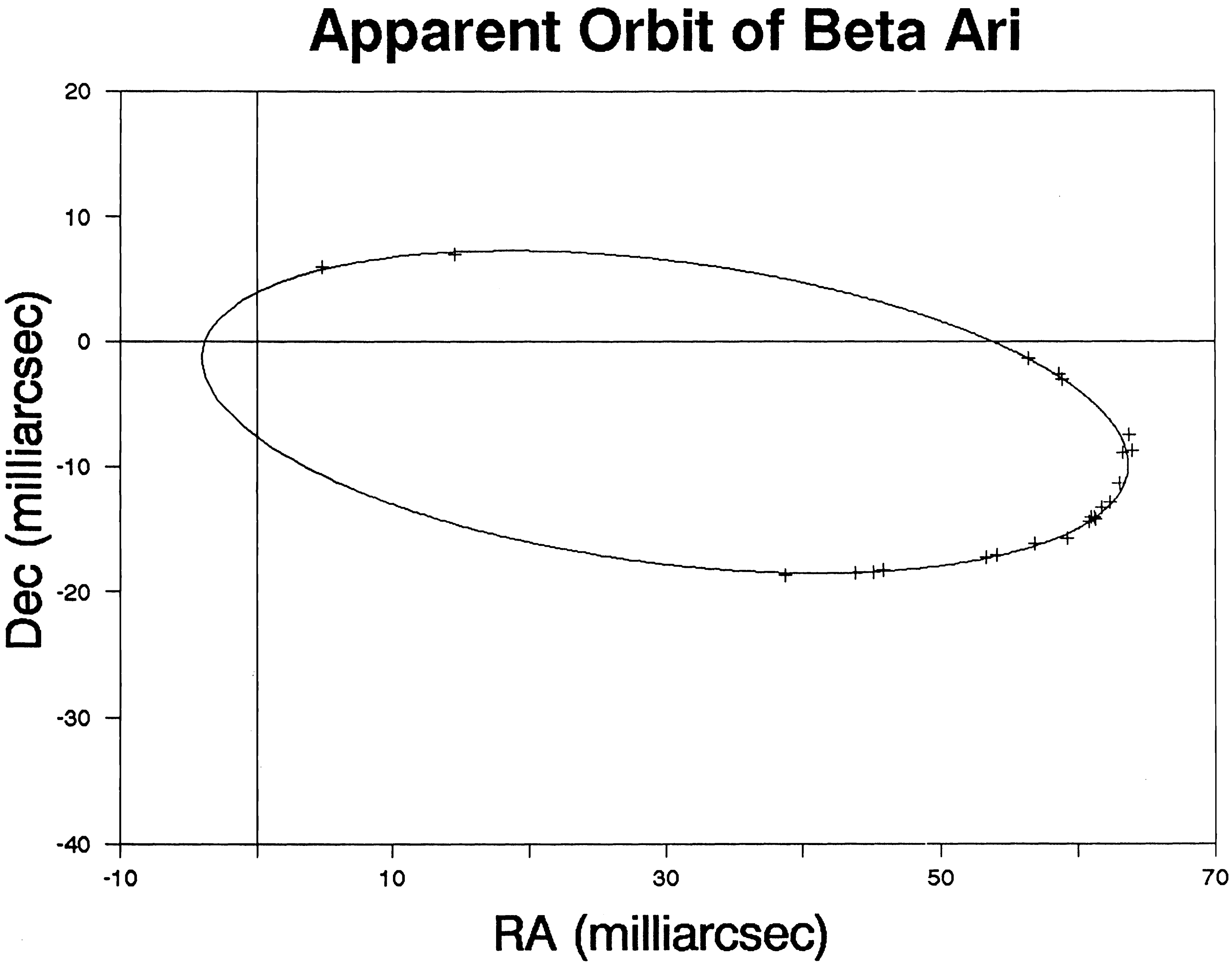
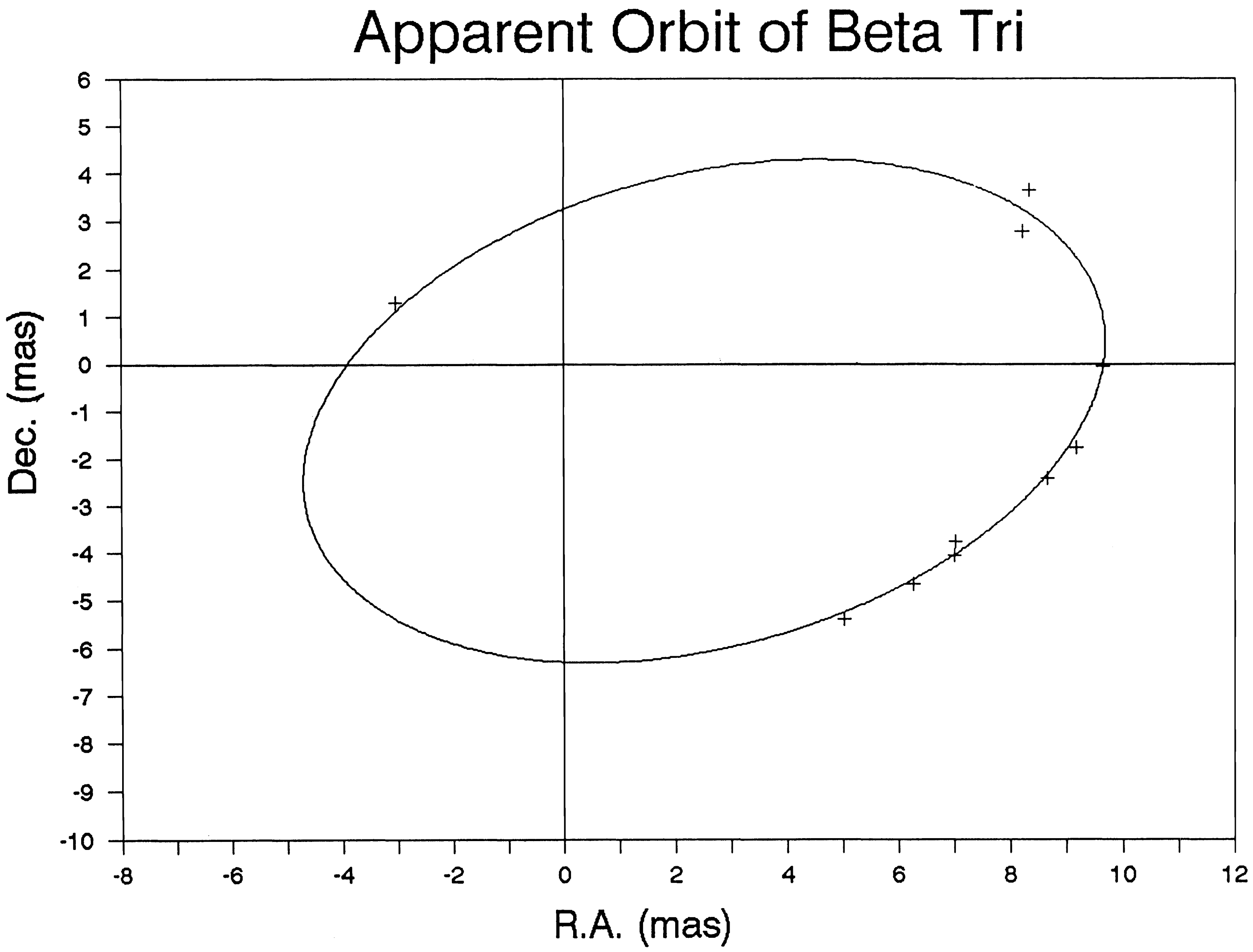
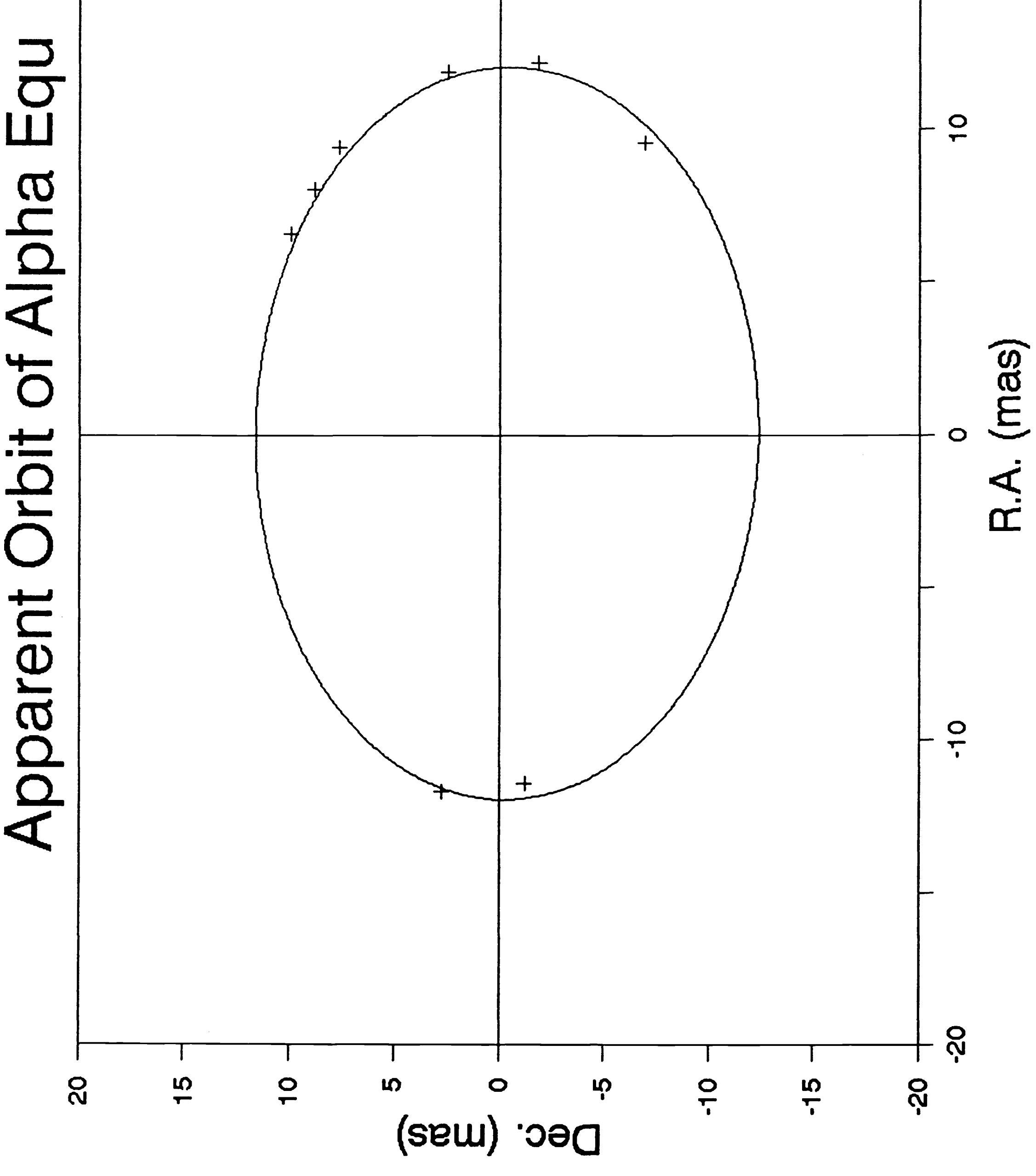


Figure 1-(b). Measured and best-fit fringe visibilities for *α And* at 5500 Å on baseline # 38 (32 m), August 31, 1989. The best-fit curve corresponds to intensity ratio $R = 0.175$, and separations in *R. A.* and *Dec.* of -15.94 mas and 5.17 mas, respectively.


Apparent Orbit of Alpha And
Dec. (mas)
20
15
10
5
0
-5
-10
-15
-20
R.A. (mas)
-30
-10
10
30


Apparent Orbit of Beta Ari
Dec (milliarcsec)
20
10
0
-10
-20
-30
-40
-10
10
30
50
70
RA (milliarcsec)


Apparent Orbit of Beta Tri
Dec. (mas)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
R.A. (mas)


Apparent Orbit of Alpha Equ
R.A. (mas)
Dec. (mas)
20
10
0
-10
-20
20
15
10
5
0
-5
-10
-15
-20