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# ASTROMETRY WITH *HUBBLE SPACE TELESCOPE* FINE GUIDANCE SENSOR 3: THE PARALLAX OF THE CATACLYSMIC VARIABLE RW TRIANGULUM

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## ABSTRACT

RW Triangulum (RW Tri) is a 13th magnitude nova-like cataclysmic variable star with an orbital period of 0.2319 days (5.56 hr). Infrared observations of RW Tri indicate that its secondary is most likely a late-K dwarf (Dhillon). Past analyses predicted a distance of 270 pc, derived from a blackbody fit to the spectrum of the central part of the disk (Rutten, van Paradijs, & Tinbergen). Recently completed *Hubble Space Telescope* Fine Guidance Sensor interferometric observations allow us to determine the first trigonometric parallax to RW Tri. This determination puts the distance of RW Tri at $341^{-31}_{+38}$, one of the most distant objects with a direct parallax measurement. We compare our result with methods previously employed to estimate distances to cataclysmic variables.

*Subject headings:* astrometry — novae, cataclysmic variables — stars: distances

## 1. INTRODUCTION

Cataclysmic variables (CVs) provide a rich library from which astronomers can study physical phenomena. Magnetic and plasma interactions, winds, nonequilibrium thermonuclear reactions, radiative emissions, and accretion can all be found in the laboratory of these white dwarfs and their donor companions. All CVs are short-period binary systems that transfer matter via Roche lobe overflow from a red dwarf companion to the white dwarf. The nova-like (NL) CVs have accretion disks that remain bright at all times, making it difficult to estimate their distances since the secondary is very difficult to observe. The mass transfer rate of NL CVs is high enough to suppress the disk instability mechanism that causes dwarf nova–type outbursts. RW Triangulum is an eclipsing NL star. A precise parallax would increase our understanding of this class of object. Estimates of the rates of mass transfer are required for quantitative modeling of the emergent spectrum and evolution of these systems. Accurate estimates of the rates of mass transfer can be made only if the distance is known.

Berriman (1987) reviewed the four types of measurements used to determine distances to CVs: (1) parallaxes and proper motions, (2) interstellar reddening, (3) properties of the accretion disks, and (4) the detection of the red dwarf companions. Detection of the red dwarf companion of RW Tri has been done spectroscopically by skew mapping (Smith, Cameron, & Tucknott 1993) and with *K*-band spectroscopy (Dhillon 1998). A fifth model-independent method using linear polarimetry has recently been proposed (Barrett 1996). The different methods give widely varying distances, and some measurements should be regarded as lower limits (e.g., when using the *K*-band magnitude of the secondary star in conjunction with Bailey's relation; see § 4) or upper limits (e.g., from blackbody disk models fitted to spectra or photometry). Only recently has there been instrumentation to improve the astrometric database. *Hipparcos* was scheduled to observe five CVs (V603 Aql, RR Pic, RW Sex, SS Cyg, and AE Aqr), but only AE Aqr yielded a meaningful parallax of 9.8 ± 2.84 mas (Friedjung 1997). To date, a total of four submilliarcsecond precision astrometric parallaxes of CVs have been delivered by the Fine Guidance Sensors (FGSs) on the *Hubble Space Telescope* (*HST*): three dwarf novae, SS Cyg, U Gem, and SS Aur (Harrison et al. 1999), and the NL RW Tri, which is the subject of this Letter.

## 2. OBSERVATIONS AND REDUCTIONS

The observations of RW Tri (J2000: $02^{\mathrm{h}}25^{\mathrm{m}}36\overset{\mathrm{s}}{.}20$, $+28°05'50\overset{''}{.}5$) were made with Fine Guidance Sensor 3 (FGS3) on the *HST*. Astrometry with the *HST* FGSs has been previously described (Benedict et al. 1994, 1993), as has the FGS instrument (Bradley et al. 1991). Ten observations (one orbit each) of RW Tri at maximum parallax factor were made between 1995 and 1998 with FGS3 in POS (fringe-tracking) mode. *HST* FGS parallax observing strategies and reduction and analysis techniques have been described by Benedict et al. (1999), Harrison et al. (1999), and van Altena et al. (1997).

As seen in Table 1, the standard errors resulting from the solutions for relative parallax and proper motion are submilliarcsecond. Figure 1 shows histograms of the residuals of the target and reference frame stars obtained from our astrometric modeling. The proper motions and parallaxes determined with *HST* are relative to the reference frame stars. To determine the correction to absolute parallax, spectrophotometric parallaxes were derived for the reference frame stars from spectra obtained

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TABLE 1
RW TRI AND REFERENCE STAR DATA

| Star | $\xi$ (arcsec) | $\eta$ (arcsec) | $\sigma_\xi$ (mas) | $\sigma_\eta$ (mas) | $V$ Magnitude | Spectral Type |
|---|---|---|---|---|---|---|
| Reference 1 ...... | 9.320 | −41.837 | 0.30 | 0.42 | 14.2 | G1 III |
| Reference 2 ...... | −271.562 | 42.123 | 0.54 | 0.72 | 14.1 | G0 II |
| RW Tri ........... | 30.600 | −88.424 | 0.45 | 0.72 | 13.2 | NL |
| Reference 4 ...... | 109.025 | −55.341 | 0.32 | 0.38 | 11.2 | A6 III |
| Reference 5 ...... | −73.128 | 66.071 | 0.50 | 0.76 | 13.8 | F5 Ib–II |
| Reference 6 ...... | 262.725 | −8.728 | 0.55 | 0.56 | 12.8 | G9 III |

NOTE.—$\xi$ and $\eta$ are relative positions.

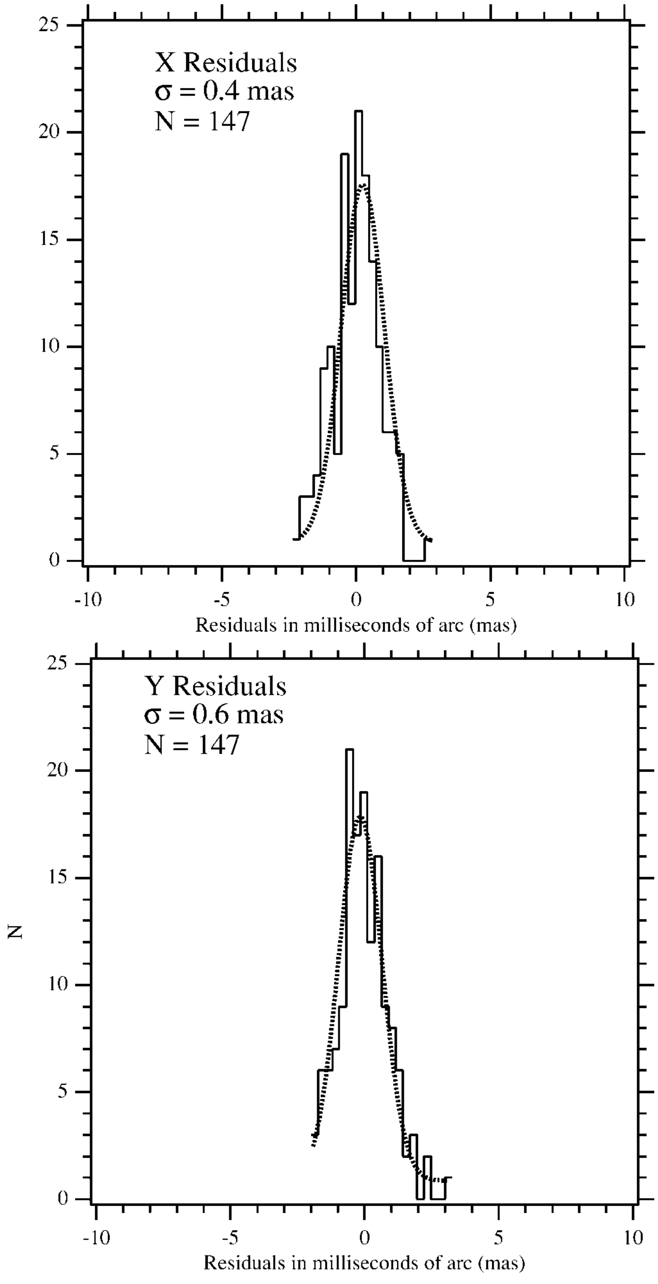

FIG. 1.—Histograms of $X$ and $Y$ residuals obtained from modeling RW Tri and its reference frame. The distributions are fitted with Gaussians.

at the Wisconsin-Indiana-Yale-NOAO (WIYN) telescope[10] multiobject spectrograph (MOS/Hydra) and classified by spectral type and luminosity class. The final correction, 0.34 ± 0.16 mas, is based on $A_v = 0.2$. This $A_v$ is an upper limit derived from Burstein & Heiles (1984), using the Galactic latitude of RW Tri.

## 3. TRIGONOMETRIC PARALLAX AND ABSOLUTE MAGNITUDE OF RW TRI

The modeling of the observations gives an *HST* relative parallax for RW Tri of $2.59 \pm 0.29$ mas. The correction to absolute parallax adds 0.34 mas, giving an absolute parallax of $2.93 \pm 0.33$ mas and a distance of $341^{-31}_{+38}$ pc (Table 2). This distance lies in the range of distances predicted from many other nonastrometric methods (Table 3).

The distance modulus for RW Tri is 7.67. Using Bruch & Engel's (1994) visual magnitude of 13.2 for the apparent magnitude, we obtain an absolute magnitude ($M_V$) of $5.53^{-0.22}_{+0.2}$. When using trigonometric parallaxes to estimate the absolute magnitude of a star, a correction should be made for the Lutz-Kelker (LK) bias (Lutz & Kelker 1973). Because of the Galactic latitude and distance of RW Tri, and the scale height of the stellar population of which it is a member, we do not use a uniform density in space for calculating the LK bias but derive a density law that falls off as the −0.5 power of the distance at the distance of RW Tri. This translates into $n = -3.5$ as the power in the parallax distribution. This $n$ is then used in an LK algorithm modified by Hanson (1979) to include the power law of the parent population. A correction of $-0.12 \pm 0.05$ mag is derived for the LK-Hanson bias, which makes the absolute magnitude $5.41^{-0.23}_{+0.21}$.

Although RW Tri (Galactic coordinates: $l = 147.03$, $b = -30.33$) is well below the plane of the galaxy, our proper-motion determination gives it a velocity of only 15 km s$^{-1}$ relative to the reference stars. This is consistent with the 14 NL stars with known radial velocities all being less than 40 km s$^{-1}$ (M. Shara 1999, private communication). This indicates that RW Tri is a member of the disk population of our Galaxy.

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[10] The WIYN Observatory is a joint facility of the University of Wisconsin–Madison, Indiana University, Yale University, and the National Optical Astronomy Observatories.

TABLE 2

Parallax and Proper Motion of RW Tri

| Relative $\mu_\alpha$ (mas yr$^{-2}$) | Relative $\mu_\delta$ (mas yr$^{-2}$) | Relative Parallax (mas) | Observed Reference Parallax[a] (mas) | Parallax (mas) | Distance (pc) |
|---|---|---|---|---|---|
| 7.1 ± 0.4 | 0.03 ± 0.7 | 2.59 ± 0.29 | 0.34 ± 0.16 | 2.93 ± 0.33 | $341^{-31}_{+38}$ |

[a] Correction to absolute parallax is derived from WIYN spectra.

## 4. THE BAILEY RELATION

Bailey (1981) presented a formula for surface brightness that has been used to estimate the distances of CVs:

$$\log d = \left(\frac{K}{5}\right) + 1 - \left(\frac{S_K}{5}\right) + \log\left(\frac{R_2}{R_\odot}\right), \qquad (1)$$

where $d$ is the distance in parsecs, $K$ is the observed $K$ magnitude, $S_K$ is the surface intensity in the $K$ band, and $R_2$ is the radius of the secondary. Ramseyer (1994) examined additional data and showed that $S_K$ was not constant over a large range of $V-K$ as previously thought. Using a $V-K$ of 3.08 (the average of $V$ at minimum from Smak 1995, Longmore et al. 1981, and Walker 1963 minus the $K$ from Longmore et al. 1981), and

$$S_K = 4.35 + 0.022 * (V - K) \qquad (2)$$

from Table 1 in Ramseyer (1994) (class V, $V-K$ of 3.0–5.0), we get a $S_K$ of 4.42. Using the mass-radius relation from Warner (1995),

$$R_2 = M_2^{13/15}, \qquad (3)$$

with Smak's (1995) secondary mass of 0.63, we get $R_2 =$ 0.67. Using these numbers in equation (3), we derive a distance of 238 pc. If the period-radius relations of Warner (1995) or Patterson (1984), or the mass-radius relation of Smith & Dhillon (1998), are used, the distance estimate drops further to 217 pc.

The infrared spectroscopic parallax, when compared with the *HST* parallax, shows that excess luminosity is present in the $K$ band of these objects. This causes problems with the Bailey method of distance determination. The distance may be underestimated in equation (3) because of the assumption that the disk is not contributing to the $K$-band luminosity.

## 5. SUMMARY

Trigonometric parallaxes can provide distances that are independent of the assumptions (such as the intrinsic absolute luminosity or shape of the spectral energy distribution of the accretion disk) that have been used in the previous methods of determining the distances for CVs. Our trigonometric parallax places RW Tri at a greater distance than previously thought. The more precise distance reported here will improve our knowledge of the physical processes associated with this interesting object, placing it on an absolute scale.

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TABLE 3

Distance Estimates to RW Tri

| Reference | Distance (pc) | Method |
|---|---|---|
| Young & Schneider 1981 | >107 | Nondetection of M1 dwarf–flux deficit in TiO band |
|  | >161 | Nondetection of M4 dwarf–flux deficit in TiO band |
| Frank & King 1981 | 180 ± 70 | Best fit to the light curves in a quiescent state |
| Borne 1977 | 200 | Spectroscopic parallax |
| Young & Schneider 1981 | >224 | Nondetection of M3 dwarf–flux deficit in TiO band |
| Warner 1987 | 224 | $K$-band magnitude |
| Bailey 1981 | 247 | $V-K$ surface brightness calibration |
| Smak 1995 | 270 ± 40 | Light-curve fitting |
| Rutten, van Paradijs, & Tinbergen 1992 | 270 | Blackbody fit to spectrum of central part of disk |
|  | 330 | Derived from fractional contribution of secondary star |
| *HST* (1998) | $341^{-31}_{+38}$ | Trigonometric parallax (this Letter) |
| Young & Schneider 1981 | >347 | Nondetection of M1 dwarf–flux deficit in TiO band |
| Longmore et al. 1981 | 400 | Light curves at near-IR wavelengths |
| Horne & Steining 1985 | 500 | Modeling of disk properties from eclipse maps |

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