Photometry of Z Tauri to Minimum

Walter R. Cooney, Jr.
Blackberry Observatory, 1927 Fairview Drive, Port Allen, LA 70767

Arne A. Henden
AAVSO, 49 Bay State Road, Cambridge, MA 02138

John Gross
Sonoita Research Observatory, Sonoita, AZ

Dirk Terrell
Southwest Research Institute, 1050 Walnut Street #400, Boulder, CO 80302

Received July 6, 2009; revised September 3, 2009; accepted September 7, 2009

Abstract The long period Mira variable, Z Tauri, was followed to near minimum magnitude in late 2006 and early 2007. Z Tau reached a minimum *V* magnitude of 18.0, well below the minimum of about 14 as found in the archival AAVSO data. Photometry from previous minima at the USNO confirm similar minima in previous cycles. The presence of a close companion star resulted in the erroneous minima derived from the visual data. A preliminary phased light curve of a field star located near Z Tau that was found to be variable is also presented.

1. Introduction

Z Tau (R.A. = 05^h 52^m 24.855^s, Dec. = +15° 47' 43.81", J2000.0) = BD+15 962a = GSC 01312-02344 = 2MASS J05522485+1547438 is a Mira-type long period variable star. It has been an AAVSO program star since December of 1909 when C. J. Hudson of Amherst College estimated it to be of magnitude 9.7. Since that first AAVSO observation, more than 3,500 observations have been submitted to the AAVSO by dozens of dedicated observers. Their data show that Z Tau reaches a minimum of about 14th magnitude and stays there for some weeks or months until it begins to brighten again. A case of mistaken identity has hidden the real behavior of Z Tau at minimum light. This paper discusses observations of Z Tau as it approached minimum in late 2006 and early 2007 that show it dropped to a minimum of 18.0. Supporting observations from the U.S. Naval Observatory are presented where Z Tau was below 17th magnitude during previous minima.

2. Background

In March 2006 AAVSO member Erwin van Ballegoij posted a note to the AAVSO discussion group that observers should take care when estimating Z Tau at its current minimum. He noted the wide flat bottom of the AAVSO light curve and that there were also reports of it being below magnitude 16. He pointed out that there was a companion star to Z Tau that could easily be mistaken for Z Tau when at minimum. Richard Huziak responded that the chart team had added a note on charts about this issue.

This AAVSO email discussion sparked the interest of the first author. A long-studied Mira with a minimum that had been mostly hidden from a century of observers was worth investigating. An observation of Z Tau from the first author's Blackberry Observatory showed an elongated image of the three involved stars. Z Tau appeared to be at between magnitude 14.5 and 15 through a *V* filter based on estimating the height of its peak relative to the brighter of the companions. It was clear that Z Tau's behavior at minimum had long been disguised by the close companion.

Further research found that Merrill (1956) had suspected that there was an unseen companion to Z Tau based on its long flat minimum. Price and Klingenberg (2005) also pointed out that a companion star could be responsible for the apparent long flat minimum. Indeed, in December 2001 Arne Henden sent photometry of the offending companion and another fainter companion to Mike Simonsen. Simonsen included it in draft updated AAVSO charts and noted in an AAVSO discussion list email in 2003 that "Revised and new charts for Z Tau are also in the 2Bchecked folder. This is a Mira with a troublesome close companion."

3. Observations

The observations reported here were made at the U. S. Naval Observatory Flagstaff Station (NOFS), and at the Sonoita Research Observatory (SRO). Both the 1.0-m and 1.55-m telescopes were used at NOFS, with either a SITe/Tektronix thinned, backside illuminated 1024×1024 or 2048×2048 CCD. SRO is a collaborative effort between John Gross, Walt Cooney, Dirk Terrell, and the AAVSO. This observatory in Sonoita, Arizona, houses a 0.35m Schmidt Cassegrain with an SBIG STL-1001E CCD camera and *BVRI* filters on a Software Bisque Paramount ME robotic telescope mount. The telescope resides in an automated Technical Innovations HomeDome and is run by the collaborators remotely over the internet using ACP observatory control, planning, and scheduling software from DC3 Dreams.

Z Tau reached maximum brightness during the summer of 2006 and then started heading back down. In order to find out how deep the minimum of Z Tau really was, monitoring of Z Tau started in November of 2006. A pair of

images in both *V* and *I* were recorded on almost every clear night. Exposures were three minutes in *V* and had to be brought down to five seconds in *I* to keep from saturating this Mira.

IRAF was used to do Point Spread Function photometry of the *V* images of Z Tau as well as the two companions and a check star. Although the Landolt (1983) standard star, GD71, was in the field of view, it was not used as a comparison star since it is rather blue with a *B–V* color index of –0.249 while a Mira like Z Tau is quite red. Instead, GSC 1312-2620 was used as a comparison star for the *V*-band PSF photometry. We had previously calibrated the Z Tau field in $UBVR_cI_c$. Per that calibration, GSC 1312-2620 has a *B–V* color index of 0.548. Our $UBVR_cI_c$ calibrated magnitudes for this star are listed in Table 1 and a finder chart for GSC 1312-2620 is shown in Figure 1.

Point Spread Function photometry was not used for the SRO *I*-band photometry since the companion stars were very faint relative to Z Tau in *I*. Instead, aperture photometry was performed with a six-star ensemble and the two companion stars were subtracted using Lew Cook's "Nemesis" spreadsheet (http://www.geocities.com/lcoo/nemesis.htm) to give the resulting I_c magnitude of Z Tau.

The *V* data from SRO are presented in Figure 2. The figure illustrates that over many cycles, the AAVSO visual observations cut off as Z Tau approached 14th magnitude while the SRO data show that Z Tau reached a minimum of approximately 18.0 during the minimum of early 2007.

Our $UBVR_cI_c$ data obtained with the NOFS 1.0-m and 1.55-m telescopes confirm that similar minima have been reached in previous cycles. The NOFS *V* data are shown in Figure 2 with the AAVSO and SRO data. AAVSO members A. Corlan (CUA) and R. Corlan (CXR) submitted *V*-filter data for Z Tau in September 2003 (JD 2452903 and 2452910). Their data are confirmed by the NOFS observations and correctly measured only the magnitude of Z Tau although it was well below 15th magnitude.

The full transformed SRO data set in *V* and *I* for Z Tau is presented in Figure 3. Pairs of measurements for each night were averaged to a single value to improve signal-to-noise. The interference of the Sun prevented SRO from monitoring through minimum and the rise back to maximum light but the shape of the curve does indicate that SRO was able to monitor at least to very close to or just past the minimum of this cycle.

As is expected for a Mira, the color index shows that this very red star continues to redden as its light diminishes reaching a ($V–I_c$) color index of 8 near minimum.

Our complete NOFS $UBVR_cI_c$ data set and the SRO *V* and I_c dataset have been entered into the AAVSO database and can be accessed via the AAVSO website, *http://www.aavso.org*.

4. The companions

The companion stars to Z Tau are shown clearly in the *V*-band image of the Z Tau field taken with the NOFS 1.55-m reflector shown in Figure 4. The brighter companion, star A, is 4.79 arc seconds NNE from Z Tau and the fainter, star B, is 5.84 arc seconds south of Z Tau. Our all-sky calibration using the NOFS 1.0-m and 1.55-m telescopes and PSF fitting to separate the components is presented in Table 2. These are transformed magnitudes.

The untransformed SRO photometry of the companion stars is shown in Figure 5. These stars served as check stars for the PSF photometry. Pairs of data points for each night are not averaged in this figure. The SRO companion star photometry was not transformed because aperture photometry performed on the *I*-band images was not suitable for providing measured magnitudes for these stars.

5. Field variable

A field star was discovered to be variable over the course of the SRO work. The new variable is USNO-B1.0 1057-0097388 at R.A. $05^h\ 52^m\ 55.56^s$, Dec. +15° 42' 07.8", J2000. The star is identified in the Z Tau field shown in Figure 1. At brightest the star is $V = 15.7$ with an amplitude in *V* of approximately 0.38 magnitude. A possible phasing with a period of 9.3576 ± 0.001 hours is presented in Figure 6. The shape, period, and amplitude of the curve are consistent with that of a W UMa eclipsing binary although the identification would not be considered definitive based on the data presented here. The authors have submitted the light curve for this star to the AAVSO International Variable Star Index and the star is now designated as VSX J055255.5+154207. The data have also been submitted to the AAVSO database and are available through the organization's web page at *http://www.aavso.org*.

References

Landolt, A. U. 1983, *Astron. J.*, **88**, 439.
Merrill, P. 1956, *Publ. Astron. Soc. Pacific*, **68**, 162.
Price, A., and Klingenberg, G. 2005, *J. Amer. Assoc. Var. Star Obs.*, **34**, 23.

Table 1. NOFS calibration of GSC 1312-2620.

U	*B*	*V*	R_c	I_c
13.263±0.015	13.216±0.011	12.668±0.029	12.33±0.013	12.008±0.019

Table 2. NOFS astrometry and all-sky photometry of Z Tau and companion field stars.

	R. A. (2000) *h m s*	*Dec. (2000)* ° ′ ″	*V*	*B–V*	*V–R*$_c$	*R*$_c$*–I*$_c$
Z Tau	05 52 24.855	+15 47 43.81 ±30mas	—	—	—	—
Star A	05 52 25.079	+15 47 47.99	13.707 ±0.027	0.380 ±0.012	0.223 ±0.020	0.210 ±0.020
Star B	05 52 24.785	+15 47 37.63	16.672 ±0.040	0.731 ±0.010	0.562 ±0.080	

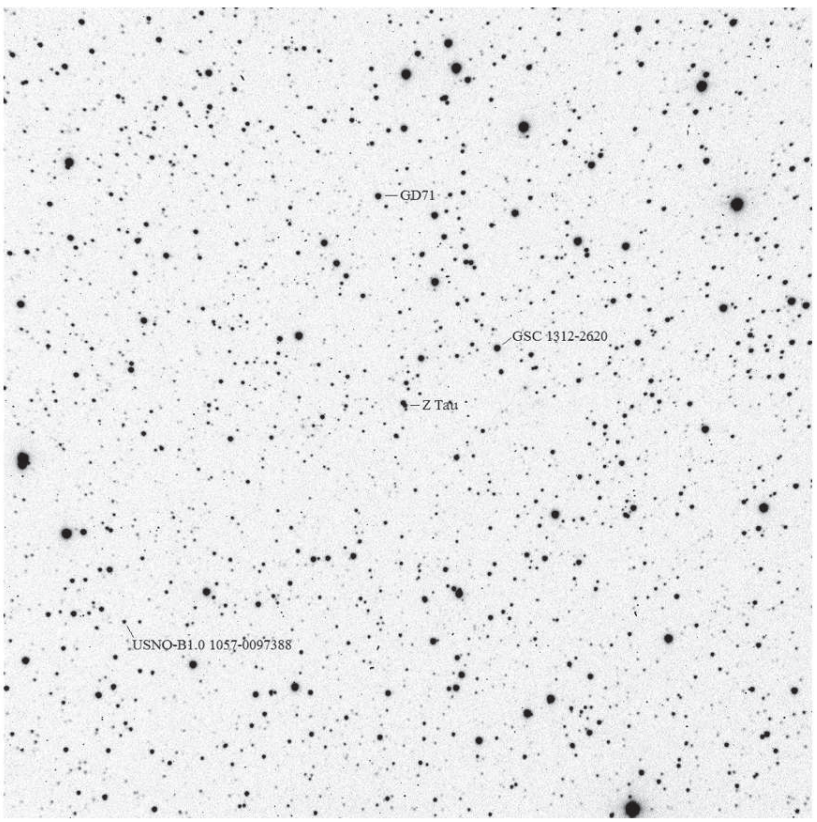

Figure 1. Z Tau and the comparison star used for V-band photometry. The field variable star, USNO-B1.0 1057-0097388, discussed in Section 5 is also identified. North up, east to the left. 21 arc minute wide field. SRO image.

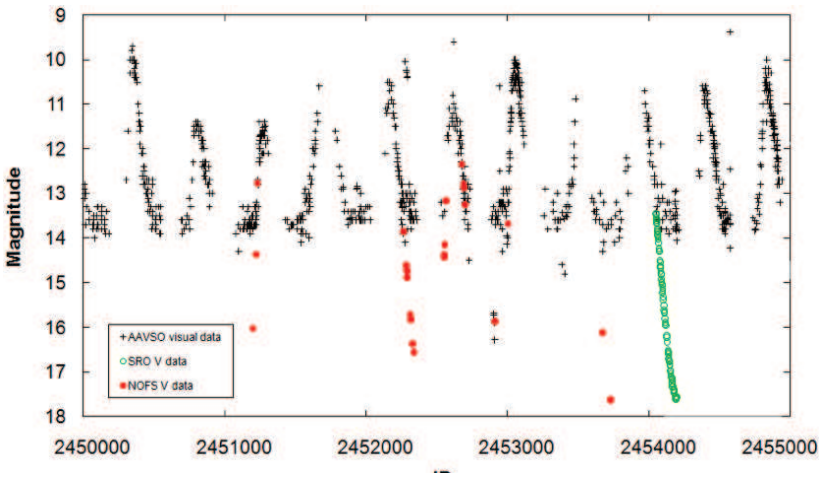

Figure 2. AAVSO, SRO, and NOFS *V* data for Z Tau.

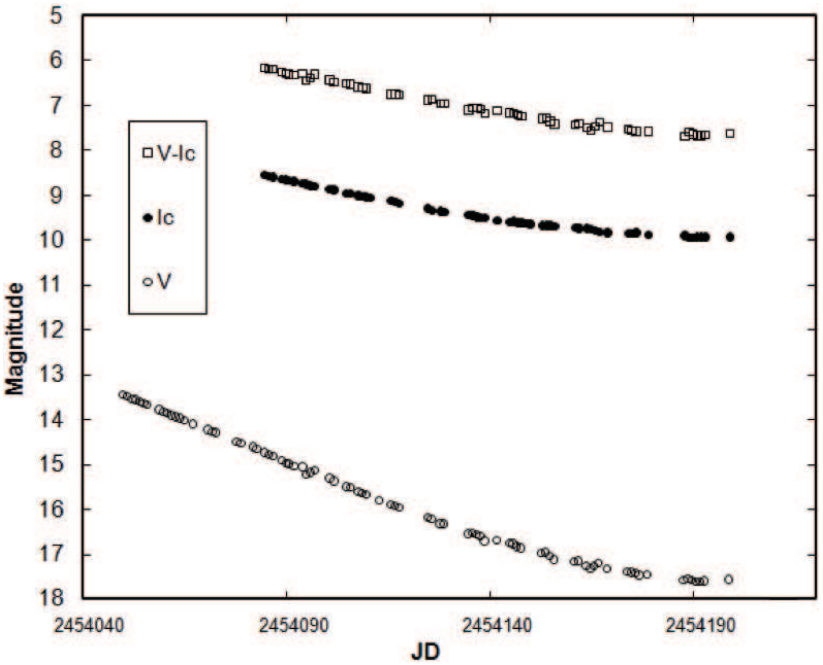

Figure 3. Transformed SRO photometry for Z Tau in *V* and I_c.

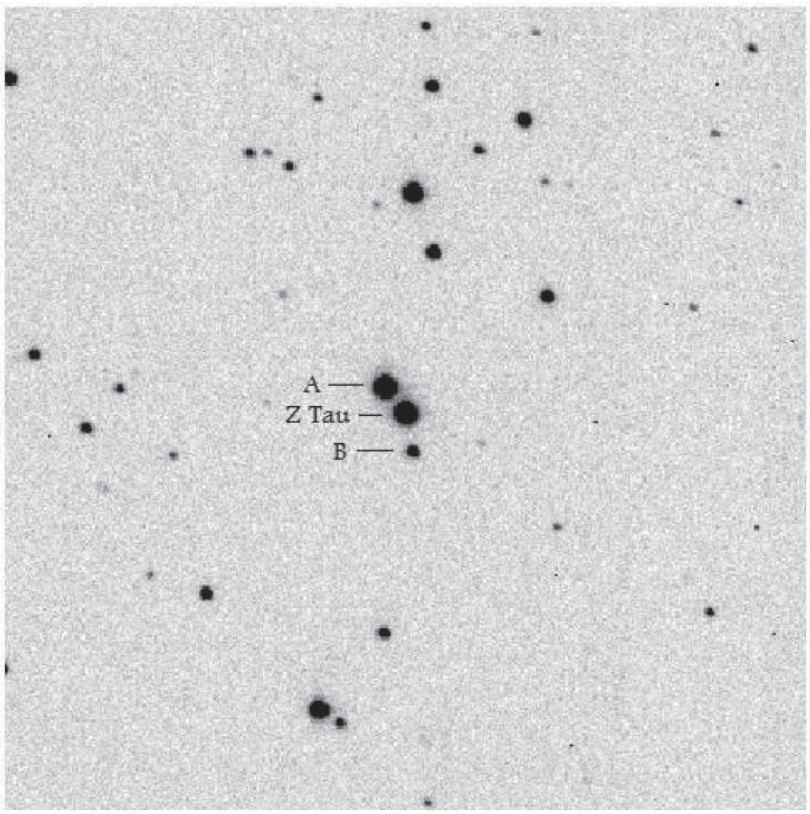

Figure 4. Z Tau and companion field stars. North up, east to the left. 2 arc minute wide field. USNO image.

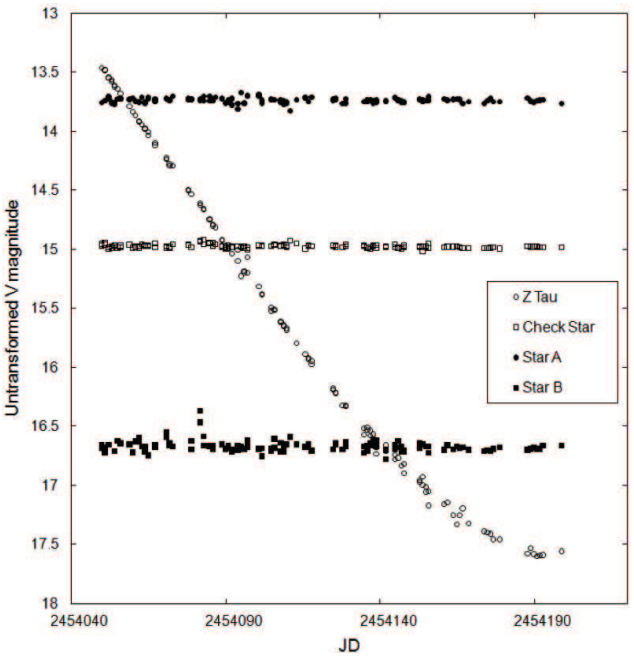

Figure 5. Untransformed SRO photometry of Z Tau, companion stars, and check star.

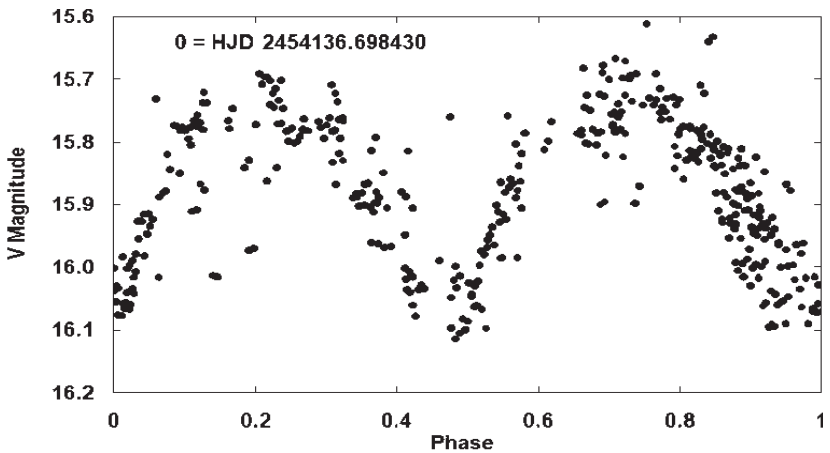

Figure 6. Phased differential photometry for USNO-B1.0 1057-0097388. Period = 9.3576 hours.