12-10-2008

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The Astrophysical Journal, 689: L45–L47, 2008 December 10

DIRECT DISTANCE MEASUREMENT TO THE DUSTY WHITE DWARF GD 362[1]

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Received 2008 October 7; accepted 2008 October 20; published 2008 November 5

ABSTRACT

We present trigonometric parallax observations of GD 362 obtained over seven epochs using the MDM 2.4 m Hiltner Telescope. The existence of a dust disk around this possibly massive white dwarf makes it an interesting target for parallax observations. The measured parallax for GD 362 places it at a distance of $50.6^{+3.5}_{-3.1}$ pc, which implies that its radius and mass are $\approx$0.0106 $R_\odot$ and 0.71 $M_\odot$, respectively. GD 362 is not as massive as initially thought (1.2 $M_\odot$). Our results are entirely consistent with the distance and mass estimates (52.2 pc and 0.73 $M_\odot$) by Zuckerman et al., who demonstrated that GD 362 has a helium-dominated atmosphere. Dropping GD 362 from the list of massive white dwarfs, there are no white dwarfs with $M > 0.9$ $M_\odot$ that are known to host circumstellar dust disks.

Subject headings: stars: individual (GD 362, WD 1729+371) — white dwarfs

Online material: color figure

1. INTRODUCTION

Gianninas et al. (2004) reported the discovery of the most massive (1.2 $M_\odot$), hydrogen- and metal-rich DAZ white dwarf ever found, GD 362 (WD 1729+371). In addition to Balmer lines, they detected Ca I, Ca II, Mg I, and Fe I lines in the optical spectra of this star, with estimated $T_{\rm eff} = 9740$ K and $\log g = 9.1$. They measured nearly solar abundances for these metals. The discovery of infrared excess (Kilic et al. 2005; Becklin et al. 2005) and a silicate emission feature at $\approx$10 μm (Jura et al. 2007) demonstrated that GD 362 hosts a circumstellar dust disk and the metals are likely to be accreted from this disk.

The discovery of debris disks around other normal mass white dwarfs ($M < 0.8$ $M_\odot$; Kilic et al. 2006; Kilic & Redfield 2007; von Hippel et al. 2007; Jura et al. 2007; Farihi et al. 2008b) and the lack of disks around massive white dwarfs with $M > 1$ $M_\odot$ (Hansen et al. 2006) showed that, if GD 362 is as massive as 1.2 $M_\odot$, it is unique. García-Berro et al. (2007) proposed to explain the high mass of GD 362 by a merger of two lower mass white dwarfs, a rare event in our Galaxy (see also Livio et al. 1992, 2005). They also suggested that the merger scenario is able to explain the observed photospheric composition of metals and the infrared excess of the surrounding debris disk.

A caveat in the model atmosphere analysis, and therefore surface gravity and mass determinations, of GD 362 is the presence of helium. Helium lines become invisible below $\approx$11,000 K, and weak lines can only be seen if helium is present in significant amounts. García-Berro et al. (2007) found that the Balmer line profiles in the optical spectrum of GD 362 are equally well reproduced even if there is a significant amount of helium in the atmosphere. No helium lines were visible in the low-resolution spectrum of Gianninas et al. (2004). However, a high-resolution and high signal-to-noise ratio spectrum of GD 362 obtained by Zuckerman et al. (2007) revealed a helium absorption line at 5876 Å, demonstrating that helium is present in significant amounts. A detailed model atmosphere analysis of this spectrum implied that GD 362 has $T_{\rm eff} =$ 10,540 $\pm$ 200 K, $\log g = 8.24 \pm 0.04$, $\log\,[{\rm He/H}] =$ 1.14 $\pm$ 0.10, and $M = 0.73$ $M_\odot$; GD 362 may not be unique (in terms of its mass) after all.

The high mass measurement for GD 362 implies a distance of 22–26 pc (Gianninas et al. 2004), whereas the lower mass solution found by Zuckerman et al. (2007) implies twice the distance. Discriminating between these two solutions requires parallax observations. In this Letter, we present trigonometric parallax observations of GD 362. Our observations and reduction procedures are discussed in § 2, while the observed parallax and its implications are discussed in § 3 and § 4.

2. PARALLAX OBSERVATIONS AND REDUCTIONS

Our parallax images are from the 2.4 m Hiltner reflector at MDM Observatory on Kitt Peak, Arizona. We used a total of 117 images taken on seven observing runs spanning two seasons; Table 1 summarizes the observations. The instrumentation, observing protocols, and reduction techniques used were very similar to those described in Thorstensen (2003) and Thorstensen et al. (2008). We used a 2048^2 SITe CCD detector at the f/7.5 focus; each 24 μm pixel subtended 0.275″. At each epoch we took many exposures in the Kron-Cousins *I*-band, as near to the meridian as we could to minimize differential color refraction (DCR) effects (Monet et al. 1992). There were some differences from the earlier work, namely (1) we used a 4 inch (10 cm) filter, which allowed us to use the full imaging area of the detector; and (2) the chip was oriented with the columns east-west rather than north-south. The parallax reduction and analysis pipeline was unchanged from the previous work. In the GD 362 field, we measured 83 stars, and used 43 of them to define the reference frame.

Standardized magnitudes and colors are used in the parallax analysis, to correct for DCR effects and also to estimate the correction from relative to absolute parallax (Thorstensen 2003). We took images of GD 362 in *V* (as well as the *I* used for astrometry) on two observing runs (2008 June and Sep-

[1] Based on observations obtained at the Michigan-Dartmouth-MIT (MDM) Observatory, operated by Dartmouth College, Ohio State University, Columbia University, the University of Michigan, and Ohio University.

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TABLE 1
Journal of Observations

Mean Date	N	First H.A.	Last H.A.	p_X	p_Y
2007 May 27	27	+0:17	+2:01	0.31	0.83
2007 Jul 4	15	+0:09	+1:04	−0.32	0.84
2007 Sep 26	7	+1:36	+1:59	−0.99	−0.12
2008 Mar 30	8	−0:06	+0:13	0.96	0.21
2008 May 14	42	+0:17	+1:34	0.50	0.75
2008 Jun 23	4	+0:36	+0:48	−0.15	0.87
2008 Sep 6	14	+0:38	+1:29	−0.99	0.17

Notes.—Summary of the parallax observations. Cols. (1)–(2): Mean date of the observing run and the number of parallax images used in the analysis. Cols. (3)–(4): Easternmost and westernmost hour angles of the images used from that run, in hours and minutes. Cols. (5)–(6): Mean parallax factors in X (eastward) and Y (northward).

tember), and calibrated the instrumental magnitudes from these images with numerous observations of Landolt (1992) standard star fields from the same runs. The photometry of the GD 362 field from the two runs agreed within a few hundredths of a magnitude in V and $V-I$.

To arrive at a final distance estimate, we use procedures detailed in Thorstensen (2003). For GD 362, we measure a proper motion of $\mu = 211.8 \pm 2.0$ mas (milliarcsecond) yr^{-1} with an angle $\theta = 173.5° \pm 0.4°$, and we find a relative parallax and formal error of 19.0 ± 0.7 mas. Our proper-motion measurement is relative to the chosen reference stars, and is not reduced to an absolute reference frame. Corrections to absolute proper motions are generally of the order of <10 mas yr^{-1} (Lépine & Shara 2005), and our measurement is consistent with the $\mu = 224.2 \pm 7.8$ mas yr^{-1} found by Salim & Gould (2003). Figure 1 displays the trajectory of GD 362 on the sky, and the same trajectory with proper motion component taken out. This figure shows that our observations cover a large range of parallax factor for GD 362, and the parallax is well constrained. Using the scatter observed among the parallaxes of comparably bright field stars located near the program star, we estimate an external error of 1.3 mas. The magnitudes and colors of the reference stars yield a correction to absolute parallax of 0.9 mas. Combining these gives an absolute parallax and external uncertainty $\pi_{\rm abs} = 19.9 \pm 1.3$ mas, corresponding to $50.3^{+3.5}_{-3.1}$ pc. The parallax accuracy is good enough that further corrections have only a small effect on the distance. Nonetheless, the full Bayesian formalism described in Thorstensen (2003) adjusts this slightly, to $50.6^{+3.5}_{-3.1}$ pc. This formalism includes (1) the Lutz-Kelker correction (Lutz & Kelker 1973), which increase the inferred distance to 51.0 pc, and (2) prior information from the proper motion and very liberal limits on the luminosity, which work to decrease the distance slightly.

3. RESULTS

Our parallax measurement shows that GD 362 is farther away, and therefore more luminous and less massive, than predicted from the pure hydrogen atmosphere fits by Gianninas et al. (2004). We now compare our result to the distance implied by the model atmosphere fits by Zuckerman et al. (2007).

GD 362 is included in the Sloan Digital Sky Survey (SDSS) Data Release 6 imaging area. We converted the SDSS photometry into the AB system using the offsets given in Eisenstein et al. (2006). GD 362 has $u = 16.25$, $g = 16.02$, $r = 16.18$, $i = 16.30$, and $z = 16.47$ AB mag. Using the $T_{\rm eff}$, $\log g$, and mass measurements from Zuckerman et al. (2007) and the model atmospheres from Koester et al. (2005), we estimate the theoretical colors for GD 362 and use these to constrain the solid angle $\pi(R/D)^2$, which relates the flux at the surface of the star to that received at Earth. The mass-radius relation of Wood (1992) gives a radius of 0.0109 $R_\odot$ for a 0.73 $M_\odot$ white dwarf with thin hydrogen layers (thin layers because GD 362 is helium-rich). Using this radius, the distance for the model atmosphere fit parameters presented in Zuckerman et al. (2007) is 52.2 pc, entirely consistent with our parallax observations.

If we use our parallax measurement directly to constrain the

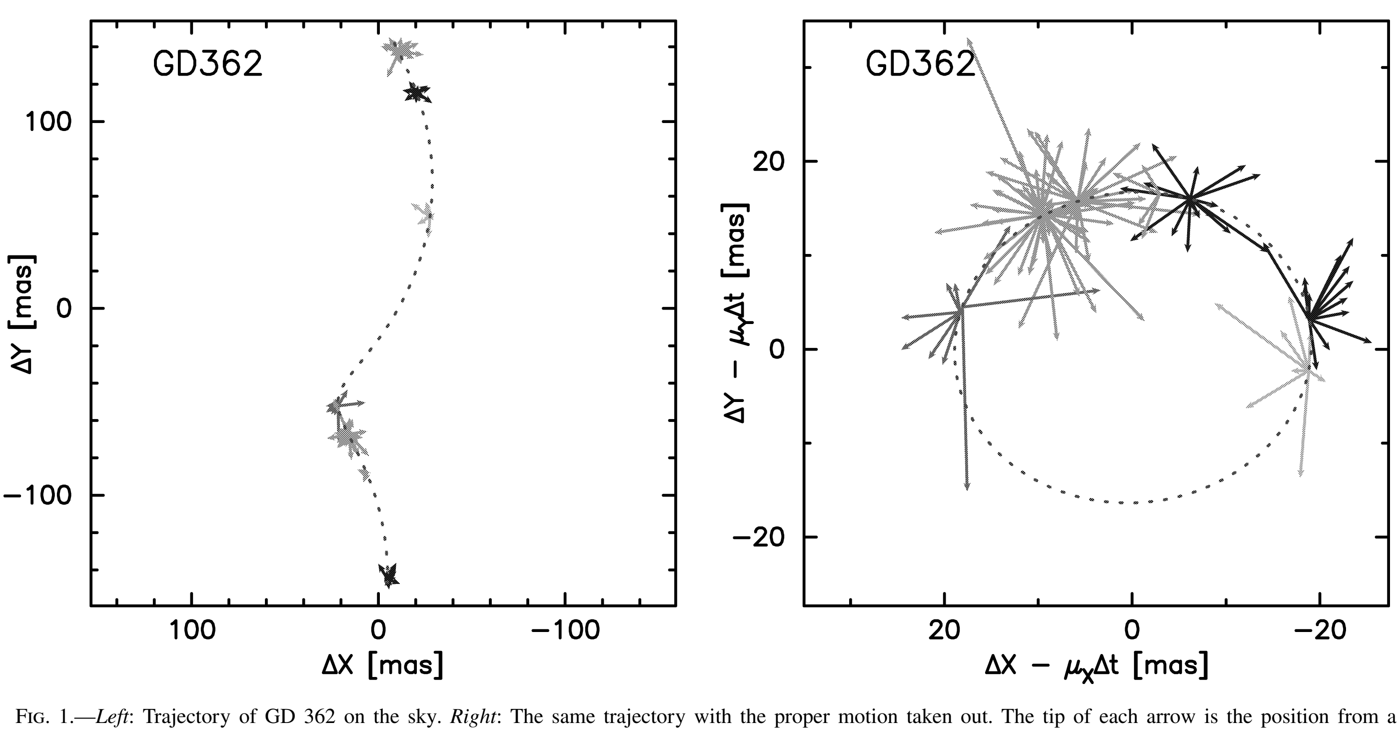

Fig. 1.—*Left*: Trajectory of GD 362 on the sky. *Right*: The same trajectory with the proper motion taken out. The tip of each arrow is the position from a single image, and the tail is the computed location based on the fitted trajectory including zero point, proper motion, and parallax. [*See the electronic edition of the Journal for a color version of this figure*.]

radius of the star, we can use the surface gravity and the radius to constrain the mass. Replacing the distance in the solid angle $\pi(R/D)^2$ with 50.6 pc, we find a radius of 7.357×10^8 cm, or 0.0106 $R_\odot$ for GD 362. Using the surface gravity of $\log g = 8.24$, we estimate a mass of 0.71 $M_\odot$. Again, this mass estimate is entirely consistent with the mass estimate of 0.73 ± 0.02 $M_\odot$ from Zuckerman et al. (2007).

4. DISCUSSION

GD 362 is only slightly more massive than the average mass for the field DA (0.60 ± 0.13 $M_\odot$; Liebert et al. 2005) and DB (0.60 ± 0.07 $M_\odot$; Voss et al. 2007) white dwarfs. Therefore, there is no evidence of and no need to invoke a binary merger scenario to explain this star and its surrounding debris disk. The photospheric abundances of metals in GD 362 are also several orders of magnitude different from the nucleosynthetic predictions of a merger event (Zuckerman et al. 2007). Dropping GD 362 from the list of massive stars, there are no known white dwarfs with $M > 0.9$ $M_\odot$ that host dust disks. However, massive stars comprise only about 15% of the local white dwarf population (Liebert et al. 2005), and about two dozen of them have been searched for excess infrared radiation from dust disks (Farihi et al. 2008a). A large survey of massive white dwarfs will be useful to constrain the fraction with debris disks.

Using the initial–final mass relations by Dobbie et al. (2006), Williams (2007), and Kalirai et al. (2008), we estimate the progenitor of GD 362 to be a 3.0–3.3 $M_\odot$ star. The main-sequence lifetime of a solar-metallicity 3.0 $M_\odot$ star is 320–650 Myr, depending on the assumptions on convective overshooting (M. H. Pinsonneault 2008, private communication). The white dwarf cooling age of GD 362 is ≈700–800 Myr; therefore the total main-sequence plus white dwarf age of GD 362 is 1–1.5 Gyr. Using the proper motion and distance, we estimate that GD 362 has a tangential velocity of 51 km s^{-1}. Including the radial velocity measurement from Zuckerman et al. (2007, after subtracting the gravitational redshift component) we estimate that GD 362 has U, V, and W velocities of 57.7, 0.5, and −5.3 km s^{-1}, respectively. These velocities are consistent with thin disk membership. GD 362 seems just like all the other known white dwarfs with debris disks (Kilic et al. 2008), except that it has a mixed H/He atmosphere, and it has more metals than the rest of them.

Jura et al. (2007) modeled the mid-infrared spectral energy distribution of GD 362 with a flat disk between 12 and 50 stellar radii and warped disk between 50 and 70 stellar radii. Using our radius estimate of 0.0106 $R_\odot$, we can convert these numbers into observables. The dust disk lies between 0.13 and 0.74 $R_\odot$. In addition, based on a distance of 25 pc, the mass of circumstellar dust was estimated to be 3×10^{17} g. Since the real distance to GD 362 is about twice as large, the actual dust mass is four times higher, or $\approx 1.2 \times 10^{18}$ g. Of course, this is only a tiny fraction of the metals ($\geq 10^{22}$ g; Zuckerman et al. 2007) present in the convective envelope of the star.

5. CONCLUSIONS

We obtained trigonometric parallax observations of GD 362 over seven epochs separated by 1.3 yr. Our direct distance measurement of $50.6^{+3.5}_{-3.1}$ pc is incompatible with GD 362 being as massive as 1.2 $M_\odot$. Using the parallax to constrain the radius and the mass, we find that GD 362 has a mass ≈0.71 $M_\odot$. The model atmosphere analysis presented in Zuckerman et al. (2007) demonstrated that GD 362 has significant amounts of helium in its photosphere and $M = 0.73 \pm 0.02$ $M_\odot$. Our parallax observations confirm their result.

M. K. is grateful to the Ohio State University Astronomy Department, and especially to K. Stanek, for large amounts of time allocated on the MDM 2.4 m Telescope. Support for this work was provided by NASA through the *Spitzer Space Telescope* Fellowship Program, under an award from Caltech. J. R. T. acknowledges support from the National Science Foundation through grants AST-0307413 and AST-0708810. We thank the MDM Observatory staff for their excellent support, and J. Subasavage for a quick and constructive referee report.

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