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RADIO PROPER MOTIONS OF WOLF-RAYET STARS

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RESUMEN

Presentamos el análisis de observaciones tomadas del archivo del Very Large Array de seis estrellas Wolf-Rayet con emisión de radio, con el propósito de determinar sus movimientos propios. Típicamente, estas observaciones cubren períodos de tiempo del orden de 10 a 20 años. Para verificar el método, incluimos a WR 140 en la muestra, y encontramos que los movimientos propios determinados por nosotros son varias veces más precisos que los determinados por Hipparcos y consistentes con ellos, dentro del ruido observacional. Las otras cinco estrellas WR no fueron estudiadas por Hipparcos y reportamos sus movimientos propios por primera vez. Los movimientos propios de WR 145a = Cyg X-3 son consistentes con que la fuente esté estacionaria en su marco de reposo local y sugieren que el hoyo negro en este sistema binario se formó por colapso directo de una estrella masiva, sin la expulsión de una remanente de supernova.

ABSTRACT

We present the analysis of observations taken from the Very Large Array archive of six Wolf-Rayet stars with radio emission, with the purpose of determining their proper motions. Typically, these observations cover periods of 10 to 20 years. To verify the method, we included WR 140 in the sample, and found that the proper motions determined by us are a few times more accurate than, and consistent within noise, with those of Hipparcos. The other five WR stars were not studied by Hipparcos and we report their proper motions for the first time. The proper motions for WR 145a = Cyg X-3 are consistent with the source being stationary with respect to its local standard of rest and suggest that the black hole in this binary system formed by direct collapse of a massive star, without expulsion of a supernova remnant.

Key Words: astrometry — radio continuum: stars — techniques: interferometric

1. INTRODUCTION

The Hipparcos satellite obtained accurate proper motions of 118,218 stars with visual magnitudes brighter than 12.5. Fainter stars were not studied by this mission and in many cases these objects do not have measured proper motions from previous studies. Some objects that are faint in the visible (for example, by obscuration or large distances) are easy to detect at radio wavelengths and proper motions can be obtained accurately for the first time from the analysis of radio data.

In this paper we present the analysis of six Wolf-Rayet stars with radio continuum emission that have been observed with high angular resolution at the Very Large Array (VLA) in several occasions over the years, with the purpose of determining their proper motions.

The star WR 140 was included in our study, even though it has an accurate Hipparcos proper motion determination (Perryman et al. 1997), in order to check the reliability of the technique used. The other five stars have visual magnitudes larger than 12.5 and their proper motions are not reported by Hipparcos. Besides determining their proper motions for the first time, we also had an interest in finding additional examples of the relatively small class of

TABLE 1

PHASE CALIBRATORS

Calibrator	Adopted Position $\alpha(2000)$	Adopted Position $\delta(2000)$	Observed Source	Angular Distance $(^\circ)$[a]
2007+404	$20^h07^m44\overset{s}{.}945$	$+40^\circ29'48\overset{''}{.}604$	WR140	4.8
2007+404	$20^h07^m44\overset{s}{.}945$	$+40^\circ29'48\overset{''}{.}604$	WR145a	6.7
2007+404	$20^h07^m44\overset{s}{.}945$	$+40^\circ29'48\overset{''}{.}604$	WR146	7.5
2007+404	$20^h07^m44\overset{s}{.}945$	$+40^\circ29'48\overset{''}{.}604$	WR147	7.5
1925+211	$19^h25^m59\overset{s}{.}605$	$+21^\circ06'26\overset{''}{.}162$	WR125	1.7
1820−254	$18^h20^m57\overset{s}{.}849$	$-25^\circ28'12\overset{''}{.}584$	WR112	6.6

[a]Angular distance between the phase calibrator and the source.

TABLE 2

EQUATORIAL PROPER MOTIONS OF THE WR STARS STUDIED

Star	l $(^\circ)$	b $(^\circ)$	d (kpc)	$\cos(\delta)\mu_\alpha$ (mas yr^{-1})	μ_δ (mas yr^{-1})
WR 112	12.146	−1.186	4.15	−11.2±3.1	−13.5±5.5
WR 125	54.445	1.058	3.06	−2.7±0.5	−5.7±0.6
WR 140	80.930	4.177	1.85[a]	−5.0±0.2	−1.2±0.1
WR 145a	79.846	0.700	9.00	−2.5±0.2	−4.3±0.3
WR 146	80.561	0.445	0.72	−5.2±0.3	−2.5±2.1
WR 147	79.848	−0.315	0.65	−2.0±0.6	−5.1±1.0

[a]From Dougherty et al. 2005.

massive runaway stars, such as those discussed by Moffat et al. (1998).

2. OBSERVATIONS

We searched in the archives of the Very Large Array (VLA) of the NRAO[1] for observations of WR stars taken with high angular resolution ($0\overset{''}{.}4$ or better). For most of the observation we used the A configuration of the VLA, except for WR 140 in the epochs 1990.43 and 1999.76, and for WR 112 in the epoch 2001.14. In these cases the configuration was BnA.

To obtain accurate absolute astrometry for each source, we required the same phase calibrator to be used in all epochs. These phase calibrators are listed in Table 1, with the latest refined positions from the VLA Calibrator Manual adopted in the reduction of all epochs. For each source presented here, we found at least three epochs fulfilling these requirements.

The data were calibrated using the standard routines of the Astronomical Image Processing System (AIPS). Systematic errors of the order of 5 to 20 mas were added in quadrature to the formal errors of the fitting task JMFIT to obtain reduced χ^2 values of 1 in the linear least squares fits to the proper motions.

[1]The National Radio Astronomy Observatory is operated by Associated Universities Inc. under cooperative agreement with the National Science Foundation.

3. RESULTS

The equatorial proper motions determined by us for the six WR stars are given in Table 2. In this table we also give the distances to the stars, taken from van der Hucht (2001), with the exception of WR 140, for which the distance was taken from Dougherty et al. (2005).

In Table 3 we give the observed proper motions in galactic coordinates, the expected galactic proper motions, and the difference between the observed and the expected motions. To obtain the expected galactic proper motions we used the galactic rotation model of Brand & Blitz (1993) and the velocity of the Sun with respect to the local standard of rest from Dehnen & Binney (1998).

A comparison between the measured and the expected galactic proper motions (see Columns 6 and 7 of Table 3) indicates that four (WR 125, WR 145a,

TABLE 3

GALACTIC PROPER MOTIONS OF THE WR STARS STUDIED

Star	$\cos(b)\mu_l(o)$[a] (mas yr^{-1})	$\mu_b(o)$[a] (mas yr^{-1})	$\cos(b)\mu_l(e)$[b] (mas yr^{-1})	$\mu_b(e)$[b] (mas yr^{-1})	$\Delta[\cos(b)\mu_l(o-e)]$[c] (mas yr^{-1})	$\Delta[\mu_b(o-e)]$[c] (mas yr^{-1})
WR 112	−17.2±5.1	+3.4±3.8	−1.1	−0.3	−16.1±5.1	+3.7±3.8
WR 125	−6.3±0.6	−0.3±0.5	−4.5	−0.5	−1.8±0.6	+0.2±0.5
WR 140	−3.8±0.1	+3.5±0.2	−4.4	−0.8	+0.6±0.1	+4.3±0.2
WR 145a	−4.9±0.3	−0.5±0.2	−4.2	−0.2	−0.7±0.3	−0.3±0.2
WR 146	−5.1±1.7	+2.7±1.3	−2.8	−2.1	−2.3±1.7	+5.0±1.3
WR 147	−5.3±0.9	−1.5±0.8	−2.5	−2.3	−2.8±0.9	+1.3±0.8

[a]Observed galactic proper motions.

[b]Expected galactic proper motions from model discussed in text.

[c]Difference between the observed and the expected galactic proper motions.

TABLE 4

ARCHIVE DATA FOR WR 140

Epoch	Project	Wavelength (cm)	Beam Angular Size[a]
1983 Oct 30 (1983.83)	AB252	6.0	0″.36 × 0″.33; 19°
1990 Jun 07 (1990.43)	VH54G	6.0	0″.47 × 0″.36; 68°
1999 Oct 03 (1999.76)	BB117	3.6	0″.31 × 0″.24; 79°
2004 Oct 18 (2004.80)	AJ315	3.6	0″.26 × 0″.11; 71°
2006 Apr 22 (2006.31)	BD114	3.6	0″.22 × 0″.17; −7°

[a]Major axis × minor axis; position angle.

WR 146, and WR 147) of the six stars have observed galactic proper motions consistent with the stars being approximately stationary with respect to their respective local standard of rest. In the case of WR 140 and WR 112, we obtain significant differences between the expected and the observed galactic proper motions, as discussed below. We have used as a criterion for a runaway star to depart by more than 42 km s^{-1} from its expected local standard of rest velocity (Moffat et al. 1998).

All six systems studied are binaries. One can then ask if the radio emission is originating from one or both stars, or even from the interacting wind shock region. In the case of WR 145a, the binary separation is of order 10^{11} cm (Achterberg 1989), equivalent to ∼0.001 mas at a distance of 9 kpc. This angular separation is much smaller than our typical positional errors (∼10–20 mas) and we can consider this binary as a point source. Even in the cases of WR 140, WR 112, WR 125, and WR 146, where the binary separation is expected to be of order 4×10^{14} cm, the angular separations are expected to be, for distances of order 1 kpc or larger, smaller than ∼30 mas. This is comparable with our positional errors, but much smaller than our angular resolution of ∼300 mas. We are then unable to correct for this effect and assume that it will not significantly alter our results. Finally, in the case of WR 147, the angular separation is large enough to allow separate imaging of the southern star and of the northern shock interaction zone, and we can perform individual astrometry for each component.

In the next section we discuss each source individually.

4. COMMENTS ON INDIVIDUAL SOURCES

4.1. *WR 140*

This is a WR+O colliding-wind binary system with a 7.9 year period that has been studied in detail by Dougherty et al. (2005) with VLBA observations. These authors find a semimajor axis of 9.0 ± 0.5 mas for the orbit in the plane of the sky, a total mass of $74 \pm 11\ M_\odot$, and a distance of 1.85 ± 0.16 kpc.

In order to check the reliability of our method, we determined the proper motions of this star, which

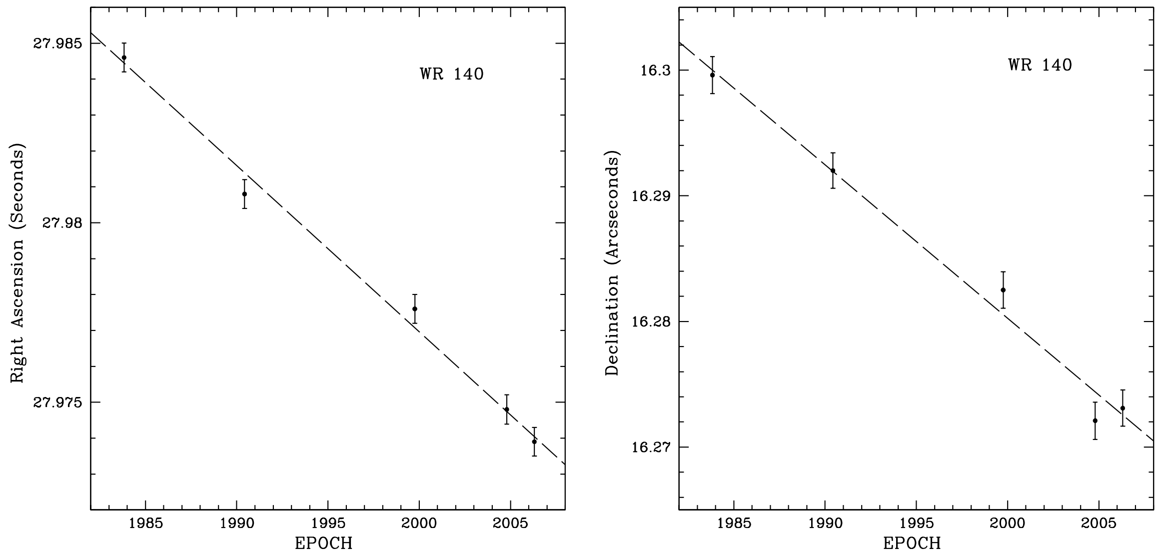

Fig. 1. Right ascension (left) and declination (right) of WR 140 as a function of time. The right ascension is 20^h 20^m and the declination is $43°\ 51'$. The dashed lines are least squares fits to the data.

has previously reported optical and radio determinations. We used the epochs given in Table 4. The positions of the star as a function of time are shown in Figure 1. The proper motions of this star were first studied by the Hipparcos satellite (Perryman et al. 1997), which yielded $\cos(\delta)\mu_\alpha = -5.26 \pm 0.58$ mas yr^{-1} and $\mu_\delta = -2.37 \pm 0.49$ mas yr^{-1}. More recently Boboltz et al. (2007), used the VLA plus Pie Town, to measure its proper motion at radio frecuencies. They obtained $\cos(\delta)\mu_\alpha = -4.72 \pm 0.66$ mas yr^{-1} and $\mu_\delta = -1.89 \pm 0.64$ mas yr^{-1}. We obtained $\cos(\delta)\mu_\alpha = -5.0 \pm 0.2$ mas yr^{-1} and $\mu_\delta = -1.2 \pm 0.1$ mas yr^{-1}. Our determination is a few times more accurate than the previous measurements and coincides with them at the 1 to 2-σ error level.

Using VLBA observations, Dougherty et al. (2005) have determined accurate proper motions for the wind-collision region, from where most of the radio emission originates. Their values, using only observations obtained during the night, are $\cos(\delta)\mu_\alpha = -5.44 \pm 0.25$ mas yr^{-1} and $\mu_\delta = -0.84 \pm 0.46$ mas yr^{-1}, and thus very similar to those obtained by us.

Comparison between the observed and the expected galactic proper motions given in Table 3 indicates that WR 140 has a peculiar motion of orden $\Delta\mu_b \simeq +4.3 \pm 0.2$ mas yr^{-1}, that at a distance of 1.85 kpc is equivalent to a peculiar velocity of $\sim 34 \pm 2$ km s^{-1}. Practically all of the peculiar velocity is in the direction of positive galactic latitude. Since WR 140 is at a galactic latitude of $b = +4\overset{\circ}{.}2$, these results suggest that it may be moving away from an original position located in the galactic plane, near $l = +80\overset{\circ}{.}9$. In any case, the peculiar velocity is below our adopted velocity criterion for a runaway star.

4.2. *WR 112*

WR 112 belongs to the small group of WC stars with dense dust envelopes (van der Hucht et al. 1996). Assuming that the variable infrared emission is produced by dust formed in the wind-wind collision zone of a massive binary system, Marchenko et al. (2002) suggest that this is a WR+OB system with a period of ∼25 years. Assuming a total mass of $\sim 50\ M_\odot$ for the system, this period implies a semimajor axis of ∼30 AU. The radio study of Chapman et al. (1999) indicates a nonthermal nature for the centimeter wavelength emission.

In order to measure the proper motions, we used the epochs given in Table 5. The positions of the star as a function of time are shown in Figure 2. The comparison between observed and expected galactic proper motions indicates that WR 112 has peculiar motions of order $\cos(b)\Delta\mu_l \simeq -16.1 \pm 5.1$ mas yr^{-1} and $\Delta\mu_b \simeq +3.7 \pm 3.8$ mas yr^{-1}, that at a distance of 4.15 kpc are equivalent to peculiar velocities of $v_l \simeq -320 \pm 100$ km s^{-1} and $v_b \simeq 74 \pm 76$ km s^{-1}. If these large proper motions are confirmed, WR 112 will fall in the category of the runaway stars.

Inspection of Figure 2 suggests that the proper motions of WR 112 in declination are not smooth.

TABLE 5

ARCHIVE DATA FOR WR 112

Epoch	Project	Wavelength (cm)	Beam Angular Size[a]
2000 Oct 17 (2000.80)	AM661	3.6	$0\farcs37 \times 0\farcs20$; -7°
2001 Feb 21 (2001.14)	AM661	3.6	$0\farcs69 \times 0\farcs49$; -80°
2002 May 07 (2002.35)	AM727	3.6	$0\farcs36 \times 0\farcs20$; -9°
2003 Jul 06 (2003.51)	AM766	3.6	$0\farcs36 \times 0\farcs20$; -9°
2004 Sep 21 (2004.72)	AM793	3.6	$0\farcs36 \times 0\farcs20$; -9°
2005 Jan 12 (2005.03)	AM793	3.6	$0\farcs38 \times 0\farcs30$; $+3^\circ$
2006 Apr 22 (2006.31)	AM831	3.6	$0\farcs36 \times 0\farcs18$; -2°

[a]Major axis × minor axis; position angle.

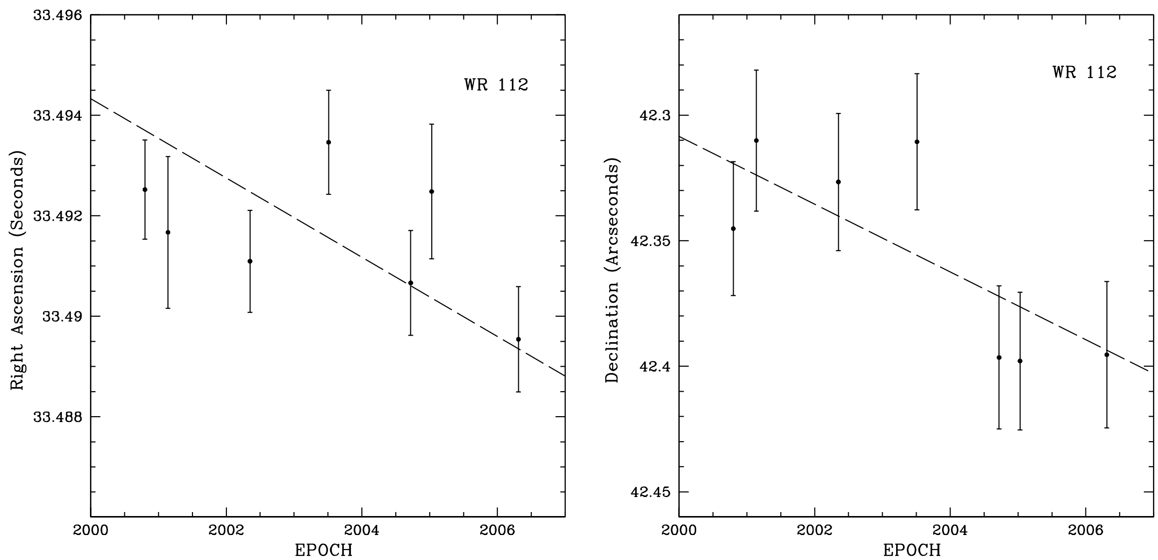

Fig. 2. Right ascension (left) and declination (right) of WR 112 as a function of time. The right ascension is $18^h\ 16^m$ and the declination is $-18^\circ\ 58'$. The dashed lines are least squares fits to the data.

More than a smooth gradient, there seems to be an abrupt change in position between epochs 2003.51 and 2004.72. This change is of the order of $0\farcs08$, that at a distance of 4.15 kpc is equivalent to $\sim$330 AU. Since this position shift took place over a period of $\leq$1.2 years, it implies (assuming a true physical motion) velocities of order 1,300 km s^{-1} in the plane of the sky. This abrupt change cannot be attributed to one of the members of the binary turning on while the other turned off because their estimated semimajor axis is only $\sim$30 AU. Wallace, Moffat, & Shara (2002) found an optical companion about $0\farcs94$ SW of WR 112. This separation is too large to explain the observed position shift. Finally, we note that Monnier et al. (2002) have proposed that WR 112 is associated with a "pinwheel" nebula (as is the case of WR 104 and WR 98a). These are spiral gaseous structures that surround a few WR stars and that could be related to the colliding winds found in binary systems (Monnier et al. 2002). Their presence may produce shifts in the apparent position of the source. In summary, we conclude that the observed position shift in WR 112 should be studied further.

4.3. *WR 125*

WR 125 is believed to be a WC7+O9III binary system with a period larger than 18 years (Williams et al. 1994; van der Hucht 2001).

In order to measure the proper motions, we used the epochs given in Table 6. The positions as a func-

TABLE 6

ARCHIVE DATA FOR WR 125

Epoch	Project	Wavelength (cm)	Beam Angular Size[a]
1985 Feb 16 (1985.13)	AC116	6.0	$0''.42 \times 0''.35$; $-62°$
1993 Jan 16 (1993.04)	AV193	6.0	$0''.36 \times 0''.34$; $-27°$
2000 Oct 19 (2000.80)	AW546	6.0	$0''.37 \times 0''.34$; $1°$
2002 Mar 03 (2002.17)	AW563	6.0	$0''.39 \times 0''.34$; $-5°$
2004 Dec 06 (2004.93)	AW638	6.0	$1''.11 \times 0''.34$; $36°$
2006 Feb 18 (2006.13)	AW672	6.0	$0''.39 \times 0''.33$; $-16°$

[a]Major axis × minor axis; position angle.

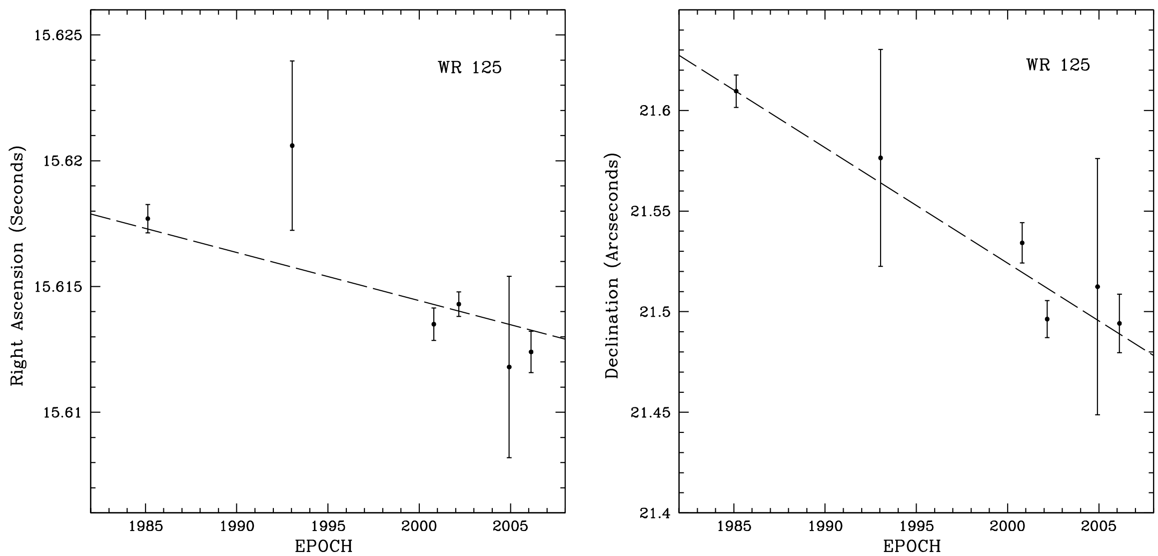

Fig. 3. Right ascension (left) and declination (right) of WR 125 as a function of time. The right ascension is $19^h\ 28^m$ and the declination is $19°\ 33'$. The dashed lines are least squares fits to the data.

tion of time are given in Figure 3. The observed and expected galactic proper motions agree well, suggesting that this source is stationary with respect to its surrounding medium.

4.4. *WR 145a*

This system is also known as Cyg X-3. It is a WR+C system, where C stands for compact object, in this case most likely a massive black hole (Schmutz, Geballe, & Schild 1996), although other possibilities cannot be excluded (Stark & Saia 2003). Its period is ∼4.8 hours.

To measure the proper motions, we used the epochs given in Table 7. The proper motions shown in Figure 4 exhibit a smooth behavior with the exception of the point at epoch 2000.81, which shows a significant deviation in declination from the main trend. This epoch corresponds to the north-south ejection event studied by Martí, Paredes, & Peracaula (2001). Since this ejection event most probably affected the determination of the position, in particular the declination, this point is not included in our fits.

Comparison between the observed and expected galactic proper motions given in Table 3 indicates that WR 145a has a relatively small peculiar motion with respect to its environment, $\cos(b)\Delta\mu_l = -0.7 \pm 0.3$ mas yr^{-1} and $\Delta\mu_b = -0.3 \pm 0.2$ mas yr^{-1}. With the adopted distance of 9 kpc, we obtain velocities of $v_l = -30 \pm 13$ km s^{-1} and $v_b = -13 \pm 9$ km s^{-1}, consistent with this system being approximately stationary with respect to its local standard of rest.

One of the currently accepted explanation for runaway stars is the so-called Blaauw kick: mass

TABLE 7

ARCHIVE DATA FOR WR 145a

Epoch	Project	Wavelength (cm)	Beam Angular Size[a]
1983 Sep 15 (1983.71)	AJ95	6.0	$0''.40 \times 0''.36$; $-37°$
1985 Mar 05 (1985.18)	AH172	6.0	$0''.43 \times 0''.36$; $-69°$
1987 Aug 28 (1987.66)	AC204	6.0	$0''.24 \times 0''.24$; $-45°$
1997 Jan 10 (1997.03)	AW426	6.0	$0''.42 \times 0''.36$; $-61°$
2000 Oct 21 (2000.81)	AM669	6.0	$0''.40 \times 0''.34$; $-23°$
2004 Sep 13 (2004.70)	AR545	3.6	$0''.22 \times 0''.20$; $4°$
2006 May 16 (2006.37)	AM858	3.6	$0''.26 \times 0''.19$; $-78°$

[a]Major axis × minor axis; position angle.

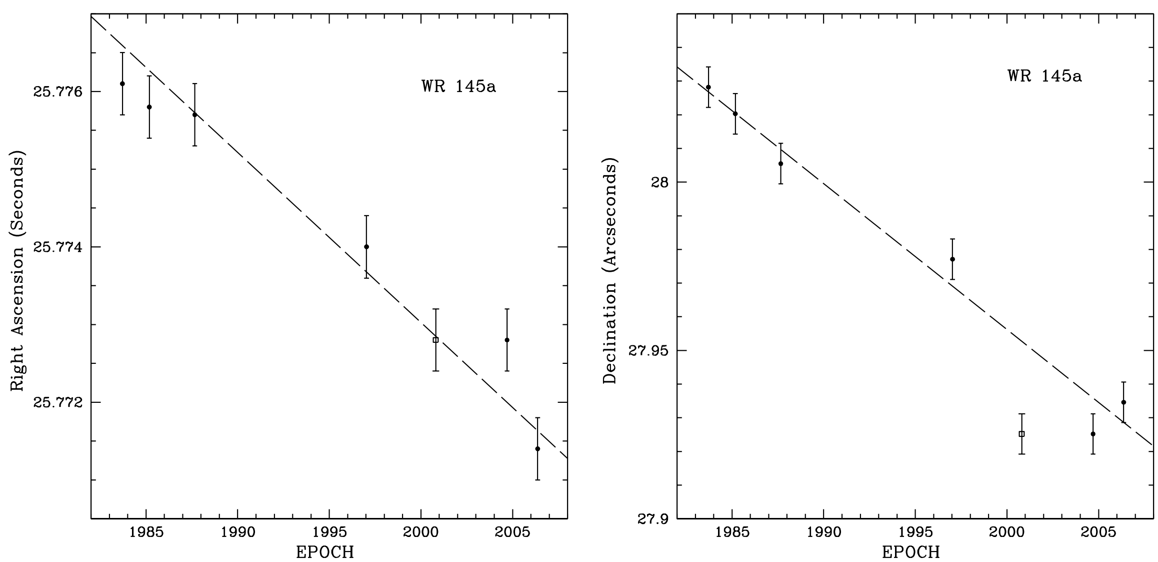

Fig. 4. Right ascension (left) and declination (right) of WR 145a as a function of time. The right ascension is $20^h\ 32^m$ and the declination is $40°\ 57'$. The point for 2000.81 (indicated with an empty square) was taken during a major ejection event and is not included in the fit. The dashed lines are least squares fits to the data.

ejected suddenly and symmetrically by the supernova explosion forces the binary to recoil with a momentum opposite to that of the unbound mass at the time of ejection. So, one expects recoil velocities in binary systems with a black hole, since the mechanism by which they form is believed to be a supernova explosion. Dhawan et al. (2007) discussed five binaries with a black hole component, and showed that two of them are not runaways. These authors propose that in the formation of the most massive black holes ($\geq 10\ M_\odot$), no kick velocities are expected if they were formed by direct collapse, with no supernova explosion, as proposed by Fryer & Kalogera (2001). Mirabel & Rodrigues (2003) measured the proper motion of Cyg X-1, a $\sim 10\ M_\odot$ black hole, and found no evidence of peculiar velocities. The Cyg X-3 system may be another example of this kind of massive black hole formation, called by them a "dark birth". Another example could be GRS 1915+105 (Dhawan et al. 2007). These sources may be the ones responsible for the gamma-ray bursts of long duration in the near Universe, without associated luminous supernovae (Della Valle et al. 2006; Fynbo et al. 2006; Mirabel 2008).

In summary, the kinematics that we determined for WR 145a appear to indicate that it also formed without a significant natal kick. Its small peculiar motion could be due to a dynamical diffusion pro-

TABLE 8

ARCHIVE DATA FOR WR 146

Epoch	Project	Wavelength (cm)	Beam Angular Size[a]
1991 Jul 12 (1991.53)	AM305	3.6	$0''.22 \times 0''.19$; $-33°$
1996 Oct 26 (1996.82)	AD391	6.0	$0''.48 \times 0''.36$; $-17°$
2004 Oct 1 (2004.75)	AD502	3.6	$0''.22 \times 0''.12$; $44°$

[a]Major axis × minor axis; position angle.

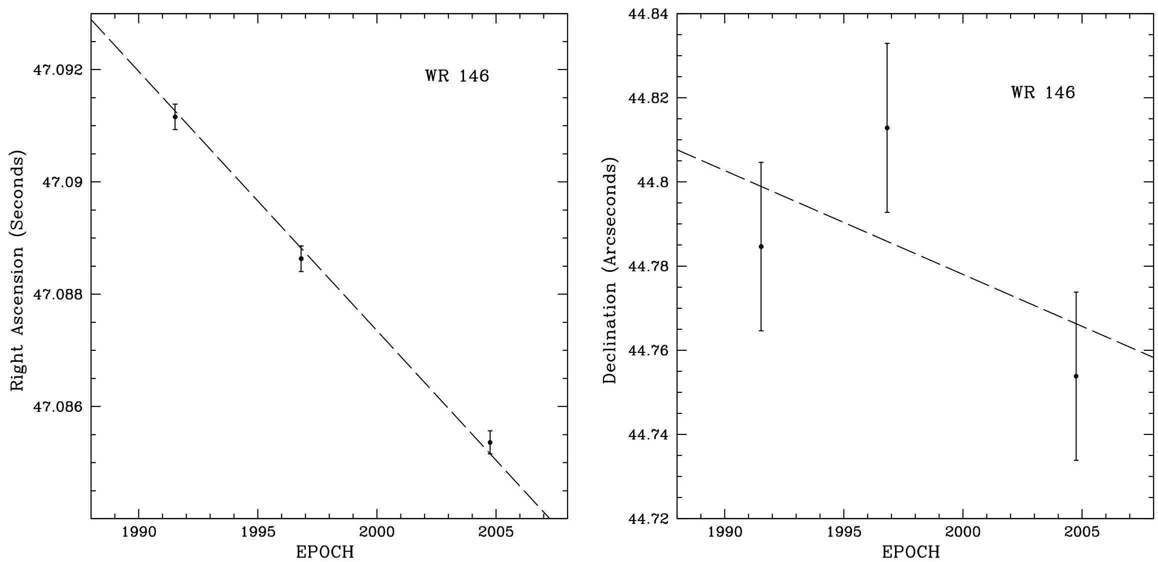

Fig. 5. Right ascension (left) and declination (right) of WR 146 as a function of time. The right ascension is 20^h 35^m and the declination is $41°$ $22'$. The dashed lines are least squares fits to the data.

TABLE 9

ARCHIVE DATA FOR WR 147

Epoch	Project	Wavelength (cm)	Beam Angular Size[a]
1985 Feb 16 (1985.13)	AC116	6.0	$0''.37 \times 0''.30$; $-50°$
1995 Jul 21 (1995.55)	AM482	3.6	$0''.22 \times 0''.18$; $-54°$
1996 Dec 14 (1996.95)	AC468	3.6	$0''.20 \times 0''.17$; $17°$
1999 Sep 03 (1999.67)	AC530	6.0	$0''.43 \times 0''.35$; $-15°$

[a]Major axis × minor axis; position angle.

cess, such as discussed by Dhawan et al. (2007) for GRS 1915+105.

4.5. *WR 146*

This is a WR+O system with a 30.8 year period. It is the brightest WR star at radio wavelengths. Its companion was first reported by Dougherty et al. (1996) and confirmed by Niemela et al. (1998).

In order to measure the galactic proper motion, we used the epochs given in Table 8. The proper motions are shown in Figure 5. From the comparison between observed and expected galactic proper motions given in Table 3, we conclude that the peculiar motion in b is $\sim 16 \pm 5$ km s^{-1}. This difference is relatively small and we conclude that this is not a runaway star.

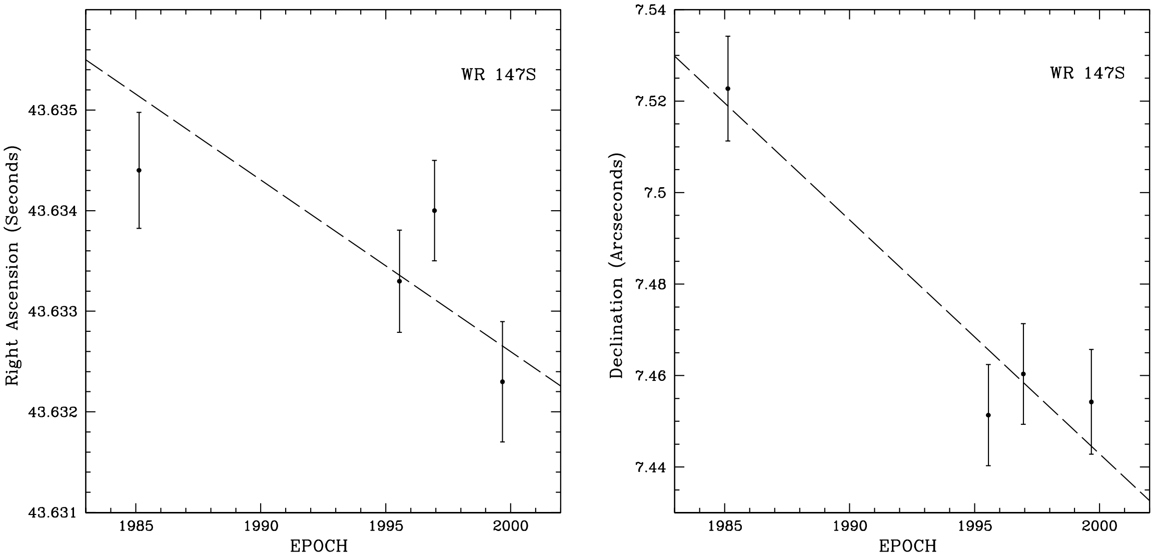

Fig. 6. Right ascension (left) and declination (right) of WR 147S as a function of time. The right ascension is $20^h\ 36^m$ and the declination is $40°\ 21'$. The dashed lines are least squares fits to the data.

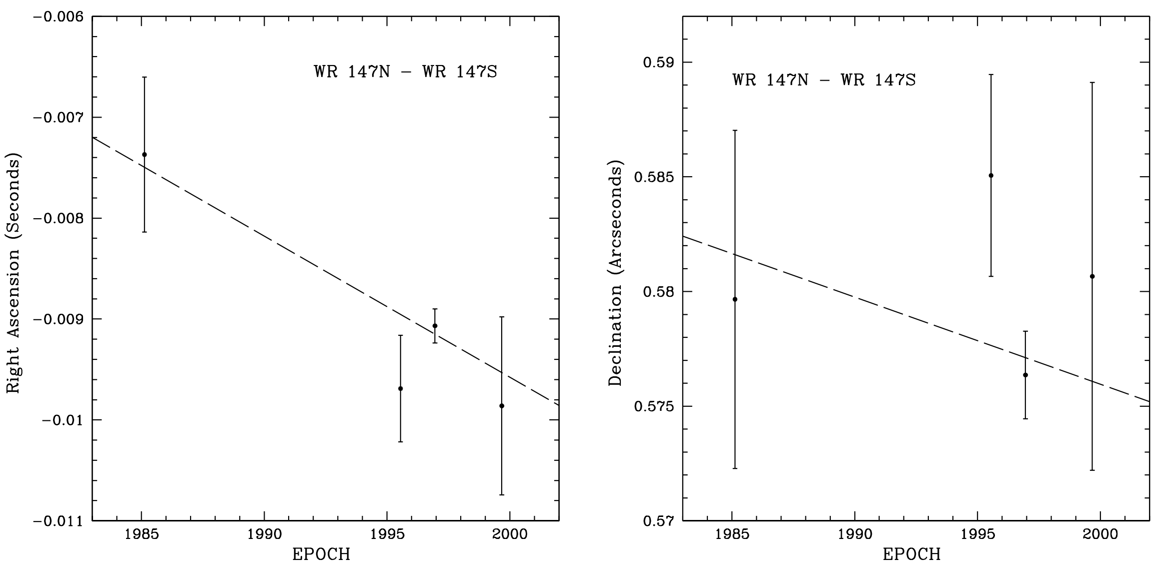

Fig. 7. Relative proper motions in right ascension (left) and declination (right) of WR 147N with respect to WR 147S as a function of time. The dashed lines are least squares fits to the data.

4.6. *WR 147*

This system consists of a WN8 star plus an OB companion whose winds are interacting to produce a colliding wind shock. The southern component WR 147S is the WN8 star (van der Hucht 2001). Near-IR images clearly reveal a second source (WR 147N) located ≈ 0.64 arcsec north of the WN star which was classified as a B0.5V star by Williams et al. (1997). An earlier O8-O9 V-III spectral type was proposed on the basis of Hubble Space Telescope (HST) observations (Niemela et al. 1998). The $E(B-V)$ values of WR 147N and WR 147S are similar (Niemela et al. 1998), confirming that they are physically associated.

In order to measure the proper motions, we used the epochs given in Table 9. The proper motions are shown in Figure 6. Comparing the observed and expected galactic proper motions, we conclude that WR 147S does not have large peculiar proper motions.

We measured the relative proper motions of the radio source WR 147N with respect to WR 147S, obtaining $\cos(b)\mu_l = -1.6 \pm 0.7$ mas yr^{-1} and $\mu_b = -0.4 \pm 0.6$ mas yr^{-1}. We conclude that these relative proper motions are consistent at the 2-σ level with no motion (see Figure 7). It is important to emphasize that the radio source WR 147N is *not* coincident with the northern star, but it actually traces the wind interaction zone between the stars (e. g. Contreras & Rodríguez 1999).

5. CONCLUSIONS

The proper motions measured for WR 125, WR 145a, WR 146 and WR 147 are in good agreement with the expected proper motions using the galactic rotation model of Brand & Blitz (1993) and the velocity of the Sun with respect to the local standard of rest from Dehnen & Binney (1998). In the case of WR 145a, the Cyg X-3 binary system, proper motions due to the Blaauw kick were expected, but we do not measure significant proper motions with respect to the local standard of rest of the source. We propose that this source may be another example of a dark birth, the collapse of a massive star without a supernova ejection.

The measurements of WR 140 indicate that it has peculiar proper motions of the order of ~ 30 km s^{-1}; it is moving away from an original position located in the galactic plane, near $l = +80\overset{\circ}{.}9$.

The proper motions measured for WR 112 are quite large. This indicates either that we are dealing with a runaway star or that we may not be measuring the true position of the star in all the epochs used.

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REFERENCES

Achterberg, A. 1989, Nature, 342, 51
Boboltz, D. A., Fey, A. L., Puatua, W. K., Zacharias, N., Claussen, M. J., Johnston, K. J., & Gaume, R. A. 2007, AJ, 133, 906
Brand, J., & Blitz, L. 1993, A&A, 275, 67
Chapman, J. M., Leitherer, C., Koribalski, B., Bouter, R., & Storey, M. 1999, ApJ, 518, 890
Contreras, M. E., & Rodríguez, L. F. 1999, ApJ, 515, 762
Dehnen, W., & Binney, J. J. 1998, MNRAS, 298, 387
Della Valle, M., et al. 2006, Nature, 444, 1050
Dhawan, V., Mirabel, I. F., Ribó, M., & Rodrigues, I. 2007, ApJ, 668, 430
Dougherty, S. M., Beasley, A. J., Claussen, M. J., Zauderer, B. A., & Bolingbroke, N. J. 2005, ApJ, 623, 447
Dougherty, S. M., Williams, P. M., van der Hucht, K. A., Bode, M. F., & Davis, R. J. 1996, MNRAS, 280, 963
Fryer, C. L., & Kalogera, V. 2001, ApJ, 554, 548
Fynbo, J. P. U., et al. 2006, Nature, 444, 1047
Marchenko, S. V., Moffat, A. F. J., Vacca, W. D., Côté, S., & Doyon, R. 2002, ApJ, 565, L59
Martí, J., Paredes, J. M., & Peracaula, M. 2001, A&A, 375, 476
Mirabel, I. F. 2008, preprint (arXiv:0805.2378)
Mirabel, I. F., & Rodrigues, I. 2003, Science, 300, 1119
Moffat, A. F. J., et al. 1998, A&A, 331, 949
Monnier, J. D., Greenhill, L. J., Tuthill, P. G., & Danchi, W. C. 2002, ApJ, 566, 399
Niemela, V. S., Shara, M. M., Wallace, D. J., Zurek, D. R., & Moffat, A. F. J. 1998, AJ, 115, 2047
Perryman, M. A. C., et al. 1997, A&A, 323, L49
Schmutz, W., Geballe, T. R., & Schild, H. 1996, A&A, 311, L25
Stark, M. J., & Saia, M. 2003, ApJ, 587, L101
van der Hucht, K. A. 2001, VizieR Online Data Catalog: III/215
van der Hucht, K. A., et al. 1996, A&A, 315, L193
Wallace, D. J., Moffat, A. F. J., & Shara, M. M. 2002, in ASP Conf. Ser. 260, Interacting Winds from Massive Stars, ed. F. A. J. Moffat & N. St-Louis (San Francisco: ASP), 407
Williams, P. M., Dougherty, S. M., Davis, R. J., van der Hucht, K. A., Bode, M. F., & Setia Gunawan, D. Y. A. 1997, MNRAS, 289, 10
Williams, P. M., van der Hucht, K. A., Kidger, M. R., Geballe, T. R., & Bouchet, P. 1994, MNRAS, 266, 247

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