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LARGE PROPER MOTIONS IN THE YOUNG LOW-MASS PROTOSTELLAR SYSTEM IRAS 16293–2422

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RESUMEN

Comparamos imágenes VLA de alta resolución angular, en el continuo a 3.6 cm, del sistema protoestelar IRAS 16293–2422; los datos fueron obtenidos en 1989 y 1994. Mostramos que las posiciones de las tres fuentes VLA dentro de IRAS 16293–2422 cambiaron de manera significativa entre las dos épocas. Los movimientos angulares son mucho más amplios que la paralaje de estas fuentes, y las velocidades transversales que implican (10–30 km s^{-1}) son mucho más grandes que las velocidades de rotación keplerianas en un sistema de baja masa como IRAS 16293–2422. Los movimientos propios de dos de las fuentes son muy parecidos uno al otro, así como a los movimientos propios de estrellas de presecuencia principal en la misma dirección del cielo. Proponemos que estos desplazamientos corresponden al movimiento propio general de la pequeña nube (L1689N) en la cual se localiza IRAS 16293–2422. El movimiento de la tercera fuente, sin embargo, es aún más amplio y en una dirección diferente. Se ha propuesto en el pasado que esta componente es el resultado de la interacción de un viento parcialmente ionizado con el medio ambiente. Sin embargo, resulta bastante extraño que los movimientos detectados aquí no estén el la dirección de ninguno de los chorros bipolares de IRAS 16293–2422 conocidos en esta región.

ABSTRACT

We compare high angular resolution VLA 3.6-cm continuum observations of the protostellar system IRAS 16293–2422 obtained in 1989 and 1994, and show that the positions of the three VLA sources in IRAS 16293–2422 have changed significantly between the two epochs. The corresponding angular displacements are much larger than the parallax of those sources, and imply transverse velocities (10–30 km s^{-1}) well above the Keplerian rotation speeds expected for those low–mass sources. The proper motions of two of the components appear to be very similar to one another, and to the proper motions of pre–main sequence stars in the same direction. We argue that they correspond to the overall proper motion of the small cloud (L1689N) harboring IRAS 16293–2422. The displacement of the third source, however, is larger and in a different direction. That component has previously been argued to be a shock between a partially ionized wind and the ambient medium, so some fast motions are not unexpected. It is somewhat puzzling, however, that the direction of the motion does not coincide with the direction of any of the known outflows powered by IRAS 16293–2422.

Key Words: **ASTROMETRY — BINARIES: GENERAL — ISM: JETS AND OUTFLOWS — STARS: FORMATION**

1. INTRODUCTION

IRAS 16293–2422 (e.g., van Dishoeck et al. 1995, Ceccarelli et al. 2000) is a well-studied low-mass protostellar system located in L1689N (Castets et al. 2001), a small cloud in the ρ Ophiuchus molecular complex.[1] High angular resolution radio VLA observations (Wootten 1989) revealed early that it was

[1] In this paper, we will use a distance to ρ Ophiuchus of 120 pc following Knude & Hog (1998). Older references (e.g., Wootten 1989) usually assumed a distance of 160 pc.

comprised of two main components (A and B) separated by 5″ (600 AU). Component A is itself comprised of two sub-condensations (A1 and A2) well separated at 2 cm with the most extended VLA configuration (Wootten 1989). The separation between A1 and A2 is $0\farcs3$ or 35 AU. Two molecular outflows are powered by IRAS 16293–2422 (Walker et al. 1986; Hirano et al. 2001; Castets et al.2001). While one is known to originate from a source within the A component, the origin of the other remains unclear.

At far-infrared and sub-millimeter wavelengths, the three sources cannot be resolved with existing instruments, and appear as a single "blob". The average spectral energy distribution of this entity is well fitted by a single gray-body curve (Mundy, Wilking, & Myers 1986, see also Figure 3 of Wootten 1989), and shows a large fraction of its emission beyond 450 μm. As a whole, IRAS 16293–2422 can be classified as a source of "Class 0" (André, Ward-Thompson, & Barsony 1993). The total bolometric luminosity of the system is $\sim 20 L_\odot$, and the total mass of the envelope seen at sub-millimeter wavelengths is of the order of a few solar masses (André et al. 2000). The stars that will eventually form out of IRAS 16293–2422 will, most likely, resemble the Sun.

The existence of two molecular outflows emanating from IRAS 16292–2422 (Hirano et al. 2001), implies that it contains at least two protostellar objects. Moreover, the 3-mm flux (most certainly thermal dust emission) is fairly evenly split between components A and B (Mundy et al. 1986), strongly suggesting that both components contain at least one protostar. The centimetric flux of A1 is much too strong to be caused by free-free emission in a low-mass photo-ionized protostellar envelope (Wootten 1989); a B3 star—the presence of which can be excluded given the low mass of the envelope seen at millimeter wavelengths—would be required to provide enough ionizing photons. Consequently, Wootten (1989) proposed that A1 corresponds to a shock between a partly ionized jet (or collimated wind) and the ambient medium. Since velocities in excess of 10 km s^{-1} are required for the shock, proper motions might be detectable for this component, even over fairly short periods of time. In an attempt to detect and study these proper motions, we compare, here, archival high angular resolution 3.6-cm VLA observations of IRAS 16293–2422 obtained in 1989 and 1994. The processing of the data will be presented in § 2, and the results will be given in § 3 and discussed in § 4, while § 5 contains the conclusions and some perspectives.

TABLE 1

OBSERVATION LOG

Date	Configuration	Program
January 20, 1989	A	AW225
April 14 and 15, 1994	A	AR277
May 20, 1994	BnA	AA179

2. DATA PROCESSING

Three sets of data retrieved from the archive of the National Radio Astronomy Observatory[2] (NRAO) Very Large Array (VLA) will be used here (Table 1). They were all obtained at a frequency of 8.41 GHz (3.6 cm) in continuum mode, with a bandwidth of 50 MHz. The first two datasets were obtained in the most extended configuration of the array (A) on January 20, 1989, and April 14 and 15, 1994, respectively. A third dataset was obtained in the BnA configuration (similar to the A layout, but with a shorter East-West arm) on May 20, 1994. These BnA data do not have sufficient angular resolution to separate the sub-components A1 and A2, and will be used only as a check on our results (see below).

The 1994 observations (both A and BnA) were obtained with only the outer part of the array in operation, because the inner nine antennas were used to observe simultaneously at 7 mm. In order to obtain two datasets as compatible with each other as possible, we masked out the inner nine antennas of the array during the reduction of the 1989 observation. Although the coverage of the uv plane is still not completely similar for the two datasets, it is much more similar than using the full 1989 data available. We note, however, that the images eventually obtained with or without the inner part of the array are very similar to each other.

The overall data reduction followed the standard procedure in use at the VLA. During projects AW225 and AR277, the nearby quasar 1622–297 was used to track phase and amplitude variations, whereas 1657–261 was used during the project AA179. For all three datasets, the absolute flux calibration was deduced from observations of 3C286 (1328+307). However, the VLA recommendation for the flux calibration of 3C286 during 3.6-cm observations in the A configuration is to use only the central nine antennas, and the uv range between 50 and 300 kλ. These central nine antennas are precisely those that were absent

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

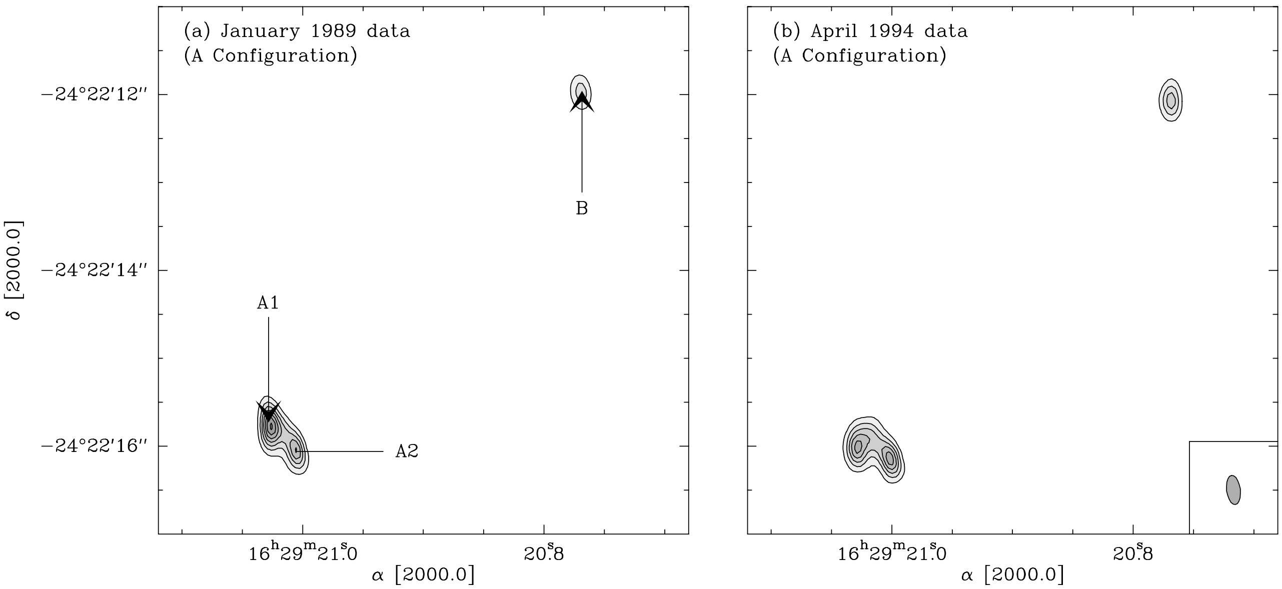

Fig. 1. Comparison of the structure of IRAS 16293–2422 at epochs 1989 and 1994. (*a*) 3.6-cm continuum data obtained on January 20, 1989 in A configuration. The first contour and the contour interval are at 0.2 mJy beam^{-1}. The positions of components A1, A2, and B are indicated by the arrows. (*b*) 3.6-cm continuum data obtained on April 14, 1994 in A configuration. The first contour and the contour interval are at 0.15 mJy beam^{-1}. The synthesized beam (common to both images) is shown at the bottom right of this panel.

in the 1994 data, or masked out in the 1989 data. Consequently, we used the next nine antennas for the calibration of the 3C286 data (still restricting the uv range to 50–300 kλ). Although this procedure will affect the quality of the absolute calibration (which, indeed, will never be used in the rest of the paper), it was checked using the full 1989 dataset that it did not affect the morphology of the sources in the final image.

Once calibrated, the visibilities were imaged using the CLEAN algorithm as implemented in AIPS with a pixel size of $0''.04$. No self-calibration was applied since the simple CLEAN algorithm already yielded a sensitivity close to the theoretical expectation, and the flux density of the sources was insufficient. Initially, the restored beams were left as free parameters during the CLEANing process. This yielded images with restored Gaussian elliptical beams of $0''.35 \times 0''.16$ (P.A. = 10°), $0''.32 \times 0''.15$ (P.A. = 5°), and $0''.53 \times 0''.40$ (P.A. = −85°) for the AW225, AR277, and AA179 projects, respectively.[3] However, in order to facilitate the comparison between the different datasets, we eventually forced CLEAN to restore the data with two specified Gaussian beams. The two A-configuration datasets (AW225 and AR277) were restored with a Gaussian beam of $0''.335 \times 0''.155$ (P.A. = 7.5°, the average of the values obtained with the two A datasets when the restored beams are left as free parameters); while all three datasets were restored with a Gaussian beam of $0''.53 \times 0''.40$ (P.A. = −85°, the restored beam of the BnA data). The former two images will be used to compare the A data directly with each other, while the latter three will be used to compare directly the A data with the lower resolution BnA data.

A simple visual comparison between the A-configuration VLA images of IRAS 16293–2422 obtained in 1989 and 1994 (Figure 1) shows that the structure of the component A of the system has changed significantly between the two epochs. Given the fairly small time span between the observations, this change would imply quite large proper motions, and should be checked carefully. This can be done by checking that (i) the astrometry of the 1989 data is correct; (ii) the astrometry of the 1994 data is correct; and (iii) the relative astrometry between the 1989 and the 1994 data is accurate. As we shall see, those three issues can be checked using independent data.

2.1. *Astrometry of the 1989 Data*

The 1989 data shown on Fig. 1*a* were obtained at 3.6 cm on January 20, 1989. Wootten (1989) published high resolution VLA 2 cm data obtained on August 30, 1987, just about a year and a half earlier.

[3] For the project AR277, the data from January 14, 1994 and January 15, 1994 were averaged to produce a deeper image.

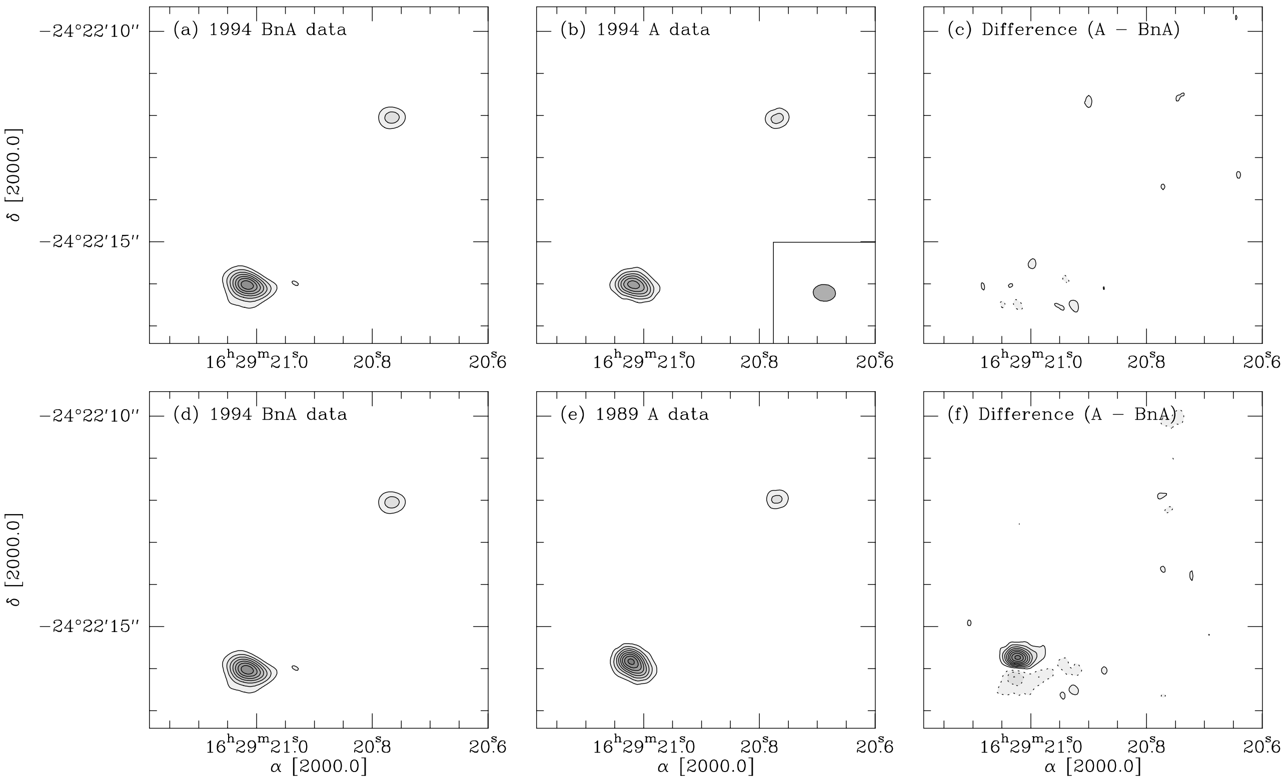

Fig. 2. Comparison between the structure of IRAS 16293–2422 seen on the BnA observations of 1994, the A observations of 1994, and the A observations of 1989. (*a*) and (*d*) BnA data of 1994; the first contour and the contour interval are at 0.2 mJy beam^{-1}. (*b*) The A data of 1994 restored with the same beam as the 1994 BnA data; the first contour and the contour interval are at 0.25 mJy beam^{-1}. (*c*) Difference between the 1994 A data and the 1994 BnA data; the first positive contour (solid lines) and the positive contour interval are at 0.15 mJy beam^{-1}; the first negative contour (dotted lines) and the negative contour interval are at 0.2 mJy beam^{-1}. (*e*) A data of 1989 restored with the same beam as the 1994 BnA data; the first contour and the contour interval are at 0.25 mJy beam^{-1}. (*f*) Difference between the 1989 A data and the 1994 BnA data; the first positive contour (solid lines) and the positive contour interval are at 0.15 mJy beam^{-1}; the first negative contour (dotted lines) and the negative contour interval are at 0.2 mJy beam^{-1}. The synthesized beam (common to all maps) is shown at the bottom right of panel (*b*).

Those two observations can be considered completely independent (different time, different spectral setup, etc.), and their comparison can be used to test the accuracy of their astrometry. The 3.6-cm data published here (Fig. 1), and the 2-cm data published by Wootten (1989—his Figure 2, not reproduced here) display nearly exactly the same structure, with position A1 well to the North of A2. This comparison demonstrates that the structure seen here on the 3.6-cm data of 1989 does indeed correspond to the way IRAS 16293–2422 looked at the end of the 1980s.

2.2. *Astrometry of the 1994 Data*

The 1994 3.6-cm data shown on Fig. 1*b* were obtained on April 14, 1994. Just a month later, IRAS 16293–2422 was observed again at the VLA at 3.6 cm, this time in the BnA configuration, as part of project AA197 (see Table 1). Again, those two datasets have been obtained under different conditions, and can be considered independent. At the resolution of the BnA data, A1 and A2 are not separated. However, a change of structure as pronounced as that found here for the component A should remain easily detectable in that configuration.

In Figure 2, we compare the structure seen in the BnA-configuration data obtained in 1994 with the structure seen in the A-configuration data obtained in 1989 and 1994, when they are restored with the same beam. The most striking visual comparison is obtained by making a direct subtraction between the data at the different epochs. As Fig. 2*c* shows, the residual between the 1994 BnA and the 1994 A data is essentially pure noise, implying that the structure seen in the 1994 A data does indeed correspond to the way IRAS 16293–2422 looked in the mid 1990s. On the other hand, as expected, the

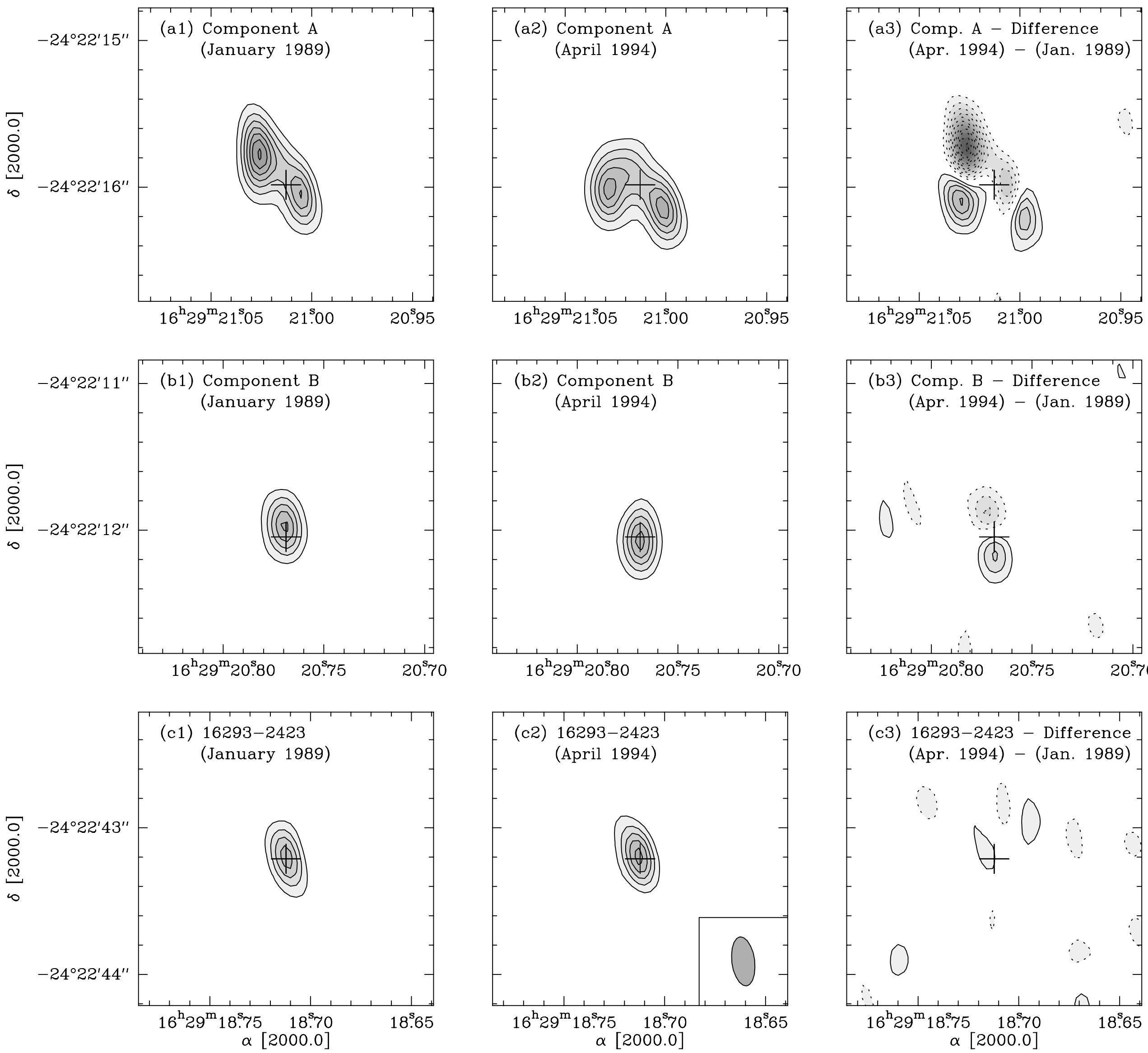

Fig. 3. (*a*) Comparison between the structure of the various sources in the field of IRAS 16293–2422 seen in the A-configuration observations of 1994 and of 1989. (*a*) Component A of IRAS 16293–2422; (*a1*) 1989 data; the first contour and the contour interval are at 0.2 mJy beam^{-1}; (*a2*) 1994 data; the first contour and the contour interval are at 0.15 mJy beam^{-1}; (*a3*) Difference between the 1989 and 1994 data; the first positive contour (solid lines) and the positive contour interval are at 0.1 mJy beam^{-1}; the first negative contour (dotted lines) and the negative contours interval are at 0.1 mJy beam^{-1}. (*b*) Component B of IRAS 16293–2422; (*b1*) 1989 data; the first contour and the contour interval are at 0.1 mJy beam^{-1}; (*b2*) 1994 data; the first contour and the contour interval are at 0.1 mJy beam^{-1}; (*b3*) Difference between the 1989 and 1994 data; the first positive contour (solid lines) and the positive contour interval are at 0.075 mJy beam^{-1}; the first negative contour (dotted lines) and the negative contours interval are at 0.060 mJy beam^{-1}. (*c*) Extragalactic source 16293–2423; (*c1*) 1989 data; the first contour and the contour interval are at 0.1 mJy beam^{-1}; (*c2*) 1994 data; the first contour and the contour interval are at 0.1 mJy beam^{-1}; (*c3*) Difference between the 1989 and 1994 data; the first positive contour (solid lines) and the positive contour interval are at 0.075 mJy beam^{-1}; the first negative contour (dotted lines) and the negative contours interval are at 0.050 mJy beam^{-1}. The synthesized beam (common to all maps) is shown at the bottom right of panel (*c2*); the size of the field of view is the same for all panels. In each row of the figure, a cross is used to indicate the average position of the source between the two epochs. This cross does not represent any particular object, but since its position is the same in all three panels of each row, it helps visualize the changes of position of the sources.

difference between the 1994 BnA and the 1989 A data (Fig. 2*f*) shows important non-zero residuals for component A.

2.3. *Relative Astrometry of the 1989 and 1994 Data*

The relative astrometry of the 1989 and 1994 data can be tested accurately, thanks to the fortuitous presence in the 3.6-cm VLA field of view of another source: 16293–2423, located about 40″ to the South-West of IRAS16293–2422 itself. The existence of 16293–2423 was—to our knowledge—first noticed by Wootten (1989), who also found that it had a steep spectrum and was, therefore, most probably extragalactic. As Fig. 3*c* shows, the position and structure of 16293–2423 is indeed found to be the same in the 1989 and 1994 data. The subtraction between the images obtained at the two epochs shows only noise (Fig. 3*c3*), and a 2-dimensional Gaussian fit to the images shows that the position of 16293–2423 is the same at the two epochs to better than $0''\!.02$ (half a pixel) in both directions (see Table 2). This shows that the accuracy of the astrometry between the two epochs considered here is better than about $0''\!.025$.

For completeness, we should mention, here, that while the same extragalactic source (1622–297) was used as phase and flux calibrator for both series of A observations (AW225 and AR277), the nominal coordinates used in the VLA catalog for that quasar had been modified between the two epochs. The coordinates given for 1622–297 in the VLA catalog for the 1989 data is $\alpha(1950.0) = 16^{\rm h}22^{\rm m}57^{\rm s}\!.2460$; $\delta(1950.0) = -29°44'41''\!.150$, while the coordinates given for the 1994 data was $\alpha(1950.0) = 16^{\rm h}22^{\rm m}57^{\rm s}\!.2435$, $\delta(1950.0) = -29°44'41''\!.396$. This slight change is a natural consequence of the constant improvement in the absolute astrometric reference frame used at the VLA and has been accounted for here. The absolute labeling used in Figs. 1, 2, and 3 corresponds to the newest (April 1994) reference frame, and is therefore different from the absolute labeling used by Wootten (1989).

3. RESULTS

In Figure 3, we show the high angular resolution images of all the sources in our field at the two epochs, as well as the differences between the images obtained at the two epochs. It can be seen quite clearly that not only has the structure of component A changed, but also that *the positions of all three components of IRAS 16293–2422 (A1, A2, and B) have changed significantly between 1989 and 1994*. In all three cases, significant symmetric non-zero residuals are seen in the image corresponding to the subtraction between the two epochs, whereas (as mentioned above) no such residuals are seen for the extragalactic source 16293–2423. The value of the offsets between the positions at the two epochs has been estimated by fitting 2D Gaussian ellipsoids to the three peaks (A1, A2, and B). The results are tabulated in Table 2, where the result obtained by applying the same procedure to the extragalactic source 16293–2423 is also given. Assuming that the difference in position found for 16293–2423 represents our 1σ error in the relative astrometry between the two epochs, the proper motions in all three sources A1, A2, and B are above 3σ. At the distance of IRAS 16293–2422, the transverse velocity corresponding to a proper motion of Δr arcseconds in Δt years is: $V = 569\Delta r/\Delta t$. Hence, the velocity of component A1 in IRAS 16293–2422 appears to be nearly 30 km s^{-1} (Table 2). Our uncertainty on the velocities (again, assuming that 16293–2423 provides a 1σ error) is about 3 km s^{-1}

TABLE 2

POSITIONAL OFFSETS

Position	$\Delta\alpha$	$\Delta\delta$	Δr	Velocity
	(arcseconds)			(km s^{-1})
16293–2423	+0.019	+0.018	0.026	2.8
A1	+0.035	−0.247	0.250	27.1
A2	−0.054	−0.090	0.105	11.4
B	−0.011	−0.095	0.096	10.4

4. DISCUSSION

4.1. *Components A2 and B*

While the detection of a proper motion in the component A1 of IRAS 16293–2422 was quite expected, no displacement was expected for the components A2 and B of the system. At the distance of ρ Ophiucus (120 pc), the expected parallax between the months of January and April is at most of $0''\!.005$, well below the detected offsets for A2 and B ($\sim 0''\!.1$). The velocities implied ($\sim$ 10 km s^{-1}) by the proper motions are also significantly higher than the Keplerian rotation velocities for binaries with the large separations found here between A1, A2, and B ($V <$ 1 km s^{-1} for a separation of 35 to 600 AU).

The velocities of sources A2 and B are significantly lower than that of A1, but appear to be quite similar to one another (of the order of 10 km s^{-1}). Moreover, the direction of motion is also similar for A2 and B, although it is different from the direction of motion of A1. A plausible interpretation is that the motion of A2 and B represent the overall proper motion of L1689N, the small cloud which harbors the IRAS 16293–2422 system.

In order to test this possibility, we first searched the Hipparcos catalog (Perryman et al. 1997) for the stars located within 90′ from the nominal position of IRAS 16293–2422. Seventeen entries are found, but only 9 have a parallax between 6 mas and 10 mas (corresponding to distances between 100 and 165 pc), and are, therefore, physically close to the ρ Ophiuchus molecular complex. The average proper motion measured for those 9 stars is $\Delta\alpha = -19.9$ mas yr^{-1}, and $\Delta\delta = -36.2$ mas yr^{-1}. Over the 5.25-year timespan covered by our observations, this would imply a change of position of $-0\overset{''}{.}105$ in right ascension, and $-0\overset{''}{.}190$ in declination. Although they appear to be roughly in the correct direction, and roughly of the correct order of magnitude, the changes of position we find for components A2 and B, are somewhat smaller than those values.

Even limiting oneself to the stars with a distance close to that of ρ Ophiuchus, one will necessarily include stars that are in front or behind the molecular complex, and not physically associated with it. This problem can be circumvented by restricting oneself to the pre-main sequence (PMS) stars. Being young, those are indeed more likely to be associated with the molecular complex. Teixeira et al. (2000) did measure the proper motion of several PMS stars in the direction of ρ Ophiuchus (their Table 5). Three of their PMS stars (HD 145718, HD 147889, and HD 150193) are within a few degrees of IRAS 16293–2422, and have measured parallaxes between 6 and 8 mas (Perryman et al. 1997), putting them at the correct distance. The average proper motions of those three stars are $\Delta\alpha = -6.4$ mas yr^{-1}, and $\Delta\delta = -22.8$ mas yr^{-1}. Over the 5.25-year timespan covered by our observations, this would imply a change of position of $-0\overset{''}{.}034$ in right ascension, and $-0\overset{''}{.}120$ in declination. This is in remarkable agreement with the values found here for components A2 and B of IRAS 16293–2422. We conclude that the motions found here for A2 and B indeed reflect the general proper motion of L1689N. This is—to our knowledge—the first measurement of a protostellar proper motion. Given the astrometric quality of the VLA, and the existence of archival deep images of star-forming regions obtained a decade ago, the present technique could be applied successfully to a number of other protostars. A systematic study would help decide whether protostellar objects (age $< 10^5$ yr), and therefore, interstellar matter share the kinematics of more evolved PMS stars (age $\sim 10^6$–10^7 yr), an important issue for the general Galactic dynamics.

4.2. *Component A1*

The displacement of component A1 is significantly larger and in a different direction than that of components A2 and B, and cannot be ascribed to the overall proper motion of the region. As mentioned earlier, A1 is believed to trace the interaction between a jet powered by a protostar located somewhere within the A component, and ambient material (Wootten 1989). The analysis of Wootten (1989) suggests a velocity for the shock above 10 km s^{-1}, of the order of magnitude found here for the velocity of component A1. It is somewhat surprising, however, that the displacement found for component A1 is not in the direction of the outflow that is known to be powered by the protostar located within the A component, as would have been expected from the analysis of Wootten (1989). The position angle of that outflow is at about $+50°$ (Wootten 1989, Mundy, Wootten, & Wilking 1990), whereas the position angle of the displacement of component A1 is almost exactly at $+180°$ (Fig. 3). There is a second outflow powered by a protostar in IRAS 16293–2422 (e.g., Hirano et al. 2001). Unfortunately, because it cannot be traced all the way to its source, it is unclear whether this second flow is powered by component B, or another protostar in component A. In any case, the position angle of this second outflow is about $-60°$, not in the direction of the motion of A1 either. Hence, if A1 was ejected, it is quite unclear where the powering source might be: the direction of motion of A1 is not along any of the known outflows, and the line joining the two successive positions of A1 does not pass through any known source. Moreover, a velocity of about 30 km s^{-1} is fairly low for such an object. Ejecta, even from low-mass protostars, tend to move at velocities in excess of 100 km s^{-1} (e.g., Curiel et al. 1994). Of course, only the transverse component of the velocity is detected here, and it cannot be excluded that the motion is primarily along the line of sight.

A radical, but possible alternative is that the source labelled A1 in the 1994 data is a different object from the source labelled A1 in the 1989 data. Let us call those two sources A1(1989) and A1(1994); A1(1989) corresponding to the source called A1 in Wootten (1989). A1(1989) and A1(1994) could then be interpreted as two distinct ejection events powered by two distinct protostellar sources. The powering source would have to be a proto-binary system, located somewhere around the position of the crosses in Fig. 3*a*. Sources A1(1989) and A2(1989) might then correspond to a bipolar ejection event powered by one of the components. The position angle of the line joining A1(1989) to A2 is about $+50°$, similar to the position angle of one of the known outflows in the region (Mundy et al. 1990). The source A1(1994), on the other hand, would be interpreted as a second ejection event, this time powered by the second source in the proto-binary system. Again, assuming that the hypothetical powering proto-binary system is located close to the crosses in Fig. 3*a*, the position angle for this second ejection would be about $+110°$, not too different from the position angle of the second molecular outflow present in the region (Hirano et al. 2001). The possibility that the source labelled A2 is also different in the 1989 and 1994 data cannot be excluded either. While A2(1989) would be interpreted as one side of a bipolar ejection event which produced A1(1989), A2(1994) could be a second ejection (this time mono-sided) from the same source which ejected A2(1989). Alternatively, A2 could be the same source at the two epochs, but correspond to a rather slow ejection.

A great advantage of this interpretation is that it explains the motions (or variations) in the component A of IRAS 16293–2422 using only "standard" ejection events, and known outflow directions. We note, however, that the displacement of component A2 is very similar in direction and amplitude to that of component B and of the PMS stars in the same direction (see § 4.1). It would be quite remarkable that the overall motion of the region, and that of one of the outflows in it, would share the same speed and direction. Moreover, this interpretation would require that the flux of source A1(1989) has decreased by a factor of about 10 between 1989 and 1994, while that of A1(1994) has increased by about the same amount in the same time.[4] Meanwhile, the flux of A2 would have to do the same—if A2 is interpreted as two distinct sources—or would have to stay remarkably constant—if it is interpreted as a single source. Although significant flux variations have been detected over short periods of time in other ejecta associated with star-formation (Martí et al. 1995, 1998) the variations required here appear to be rather large, and finely tuned with one another.

A somewhat bolder interpretation should be mentioned here, in relation with the recent analysis of the structure of the HH flow in PV Ceph by Goodman & Arce (2002). HH flows are known to correspond to usually episodic ejection events (e.g., Reipurth & Bally 2001) powered by young stellar objects. Misalignments between successive ejection events are often found, and, in many cases, convincingly ascribed to precession. However, in the case of the flow in PV Ceph, those misalignments seem to imply that the powering source has moved between the successive ejections (Goodman & Arce 2002). The velocity required for the powering source is of several tens of km s^{-1}, of the order of those reported here for component A1 in IRAS 16293–2422.

It should be noticed that such large velocities are highly supersonic in the low-temperature environments of star-forming regions. If protostars are moving through their parental cloud at such high speeds, shocks should appear. In his original analysis of the VLA data of IRAS 16293–2422, Wootten (1989) concluded that component A1 could not be a protostellar source on the basis that its centimetric emission was too high to be ascribed to free-free emission in a photo-ionized low-mass protostellar envelope. Instead, he had to invoke a shock to explain the intensity of the centimetric emission. The existence of nearby fast-moving water masers, and of other evidence of outflowing material in the same direction, made the hypothesis that A1 was either an ejection or the result of the interaction between a jet and the ambient matter quite plausible.

As we have seen above, however, the motion of A1 reported here is not easily explained in this context. The present observation might favor the possibility that component A1 is, instead, a fast moving protostar, such as that required to explain the structure of the HH flow in PV Ceph. The shock resulting from the interaction between the protostar and the ambient cloud would then provide the excess centimetric emission. Additional observations and some theoretical work will clearly be required to investigate this possibility further.

5. CONCLUSION

The detection of the proper motions in IRAS 16293–2422 reported here could easily be confirmed by new high resolution VLA observations. More time has elapsed since the last observation than between the two observations used here. Obtaining those new observations would be important, in particular to see whether component A1 has kept moving in the same direction. Such new observations would help decide whether A1 indeed traces the interaction of a jet with ambient material, whether or not it is the same source in 1989 and 1994, or whether it is a fast moving protostellar object.

In retrospect, it appears that the case of IRAS 16293–2422 was very favorable to an astromet-

[4]We note that, within our rather large uncertainties, the flux of A1(1989) and A1(1994) are quite similar.

rical study. First, thanks to the existence of a background extragalactic radio source within the field of view, which allowed a precise check on the astrometry. And second, because ρ Ophiuchus is so nearby. Most low-mass star-forming sites are located at least two to three times farther (see, e.g., the list of *bona fide* Class 0 protostars in André et al. 2000). On the other hand, high angular resolution VLA observations of many protostars have been obtained in the late 80s, and early 90s. The possibility of a systematic study of proper motions in protostellar systems using VLA data appears to be within reach. This could provide useful astrometrical information and sometimes help estimate the distance to star-forming regions. As mentioned above, if a number of fast-moving protostars were found, we would be forced to reconsider some of our views on star-forming processes.

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