THE ASTROPHYSICAL JOURNAL, 598:L115–L119, 2003 December 1

EVIDENCE FOR EVOLUTION OF THE OUTFLOW COLLIMATION IN VERY YOUNG STELLAR OBJECTS

J. M. TORRELLES,[1,2] N. A. PATEL,[3] G. ANGLADA,[4] J. F. GÓMEZ,[2,5] P. T. P. HO,[3,6] L. LARA,[4,7] A. ALBERDI,[4]
J. CANTÓ,[8] S. CURIEL,[8] G. GARAY,[9] AND L. F. RODRÍGUEZ[10]

Received 2003 September 3; accepted 2003 October 15; published 2003 November 21

ABSTRACT

We present Very Long Baseline Array proper-motion measurements of water masers toward two young stellar objects (YSOs) of the W75 N star-forming region. We find that these two objects are remarkable for having a similar spectral type, being separated by $0\rlap{.}''7$ (corresponding to 1400 AU), and sharing the same environment, but with a strikingly different outflow ejection geometry. One source has a collimated, jetlike outflow at a 2000 AU scale, while the other has a shell outflow at a 160 AU scale expanding in multiple directions with respect to a central compact radio continuum source. This result reveals that outflow collimation is not only a consequence of ambient conditions but is something intrinsic to the individual evolution of stars and brings to light the possibility of noncollimated outflows in the earliest stages of YSOs.

Subject headings: ISM: individual (W75) — ISM: jets and outflows — masers — stars: formation

1. INTRODUCTION

Understanding the earliest stages of stellar evolution is a fundamental issue in astrophysics because it is related to how new stars are born and how they interact with their ambient gaseous medium. However, our knowledge of the evolution of protostars has been hampered by the lack of data at the scales of a few astronomical units (AU), where relevant physical phenomena are expected to occur. In this Letter, we report Very Long Baseline Array (VLBA) proper-motion measurements of water masers in order to sample the dynamics and structure at AU scales of two young stellar objects (YSOs) in W75 N, which is an active star-forming region located at a distance of 2 kpc in the Cygnus complex. Several mid-to-early B stars are being formed in this region. It contains a subregion, W75 N (B), which comprises a cluster of ultracompact H II regions and millimeter wavelength sources powering multiple outflows (Haschick et al. 1981; Hunter et al. 1994; Shepherd 2001; Hutawarakorn, Cohen, & Brebner 2002; Slysh et al. 2002; Shepherd, Kurtz, & Testi 2003a; Shepherd, Testi, & Stark 2003b). Using the Very Large Array (VLA) in 1996, we simultaneously imaged, with $0\rlap{.}''1$ resolution, the water vapor maser and continuum emission at 1.3 cm from MM1, the most massive of the millimeter cores in W75 N (B). We detected three radio continuum sources (VLA 1, VLA 2, and VLA 3) within a region of $1\rlap{.}''5$ and two clusters of water masers, one associated with VLA 1 and the other with VLA 2 (Torrelles et al. 1997). The 1.3 cm continuum emission of VLA 1 is elongated, with its associated cluster of water masers spatially distributed in a region of ∼1″ along its major axis, while the radio continuum emission of VLA 2 appears spatially unresolved, with its associated water masers very tightly grouped in space, forming a shell of $\sim 0\rlap{.}''2$ in size. The main characteristics of VLA 1 indicate that this source could be a radio jet in which the water masers are tracing a collimated outflow. On the other hand, the compactness in the distribution of the water masers around VLA 2 suggests that they could trace bound motions in a circumstellar disk (Torrelles et al. 1997). Both objects are probably early B stars, as concluded from their radio continuum emission properties. In fact, Shepherd et al. (2003a) estimate B2 and B1 spectral types for VLA 2 and VLA 1, respectively, although they point out that the spectral type for VLA 1 should be considered as an upper limit because of likely contamination by ionizing flux produced by shock waves in the jet. These differences in the water maser distribution around two YSOs with similar radio continuum luminosities, belonging to the same molecular core and separated by only ∼1400 AU, could provide a unique laboratory to study the different phenomena that may be occurring at scales of a few AU. A priori, water masers could trace both outflows and circumstellar disks surrounding YSOs since water maser emission requires physical conditions of warm (∼500 K) and dense ($\sim 10^8$–10^9 cm^{-3}) molecular gas (Elitzur, Hollenbach, & McKee 1992; Claussen 2002). Such conditions are easily met in the shocked gas compressed by winds as well as in circumstellar disks. This dual behavior is indeed observed, although most masers seem to be tracing outflowing rather than infalling gas (Claussen et al. 1998b; Claussen 2002; Imai et al. 2002; Furuya et al. 2003). Interestingly, this dichotomy also seems to be present in galaxies with evidence of megamasers tracing both outflows and disks (Miyoshi et al. 1995; Claussen et al. 1998a). The reasons for this dichotomy are still unknown.

The key studies for testing the scenarios proposed for VLA 1 and VLA 2 are the proper-motion and line-of-sight velocity component measurements of their water masers to determine whether the kinematics traced by these masers is due to rotation, contraction, or expansion. We used the VLBA because of its ability to track proper motions of masers on a much shorter time baseline (a few weeks) and spatial resolution (∼1 AU) compared with the VLA.

---

[1] Instituto de Ciencias del Espacio (CSIC)–IEEC, Gran Capità 2, E-08034 Barcelona, Spain.

[2] Visiting Scientist, NRAO.

[3] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138.

[4] Instituto de Astrofísica de Andalucía (CSIC), Apartado 3004, E-18080 Granada, Spain.

[5] Laboratorio de Astrofísica Espacial y Física Fundamental (INTA), Apartado 50727, E-28080 Madrid, Spain.

[6] Academia Sinica, Institute of Astronomy and Astrophysics, P.O. Box 23-141, 106 Taipei, Taiwan.

[7] Departamento de Física Teórica y del Cosmos, Universidad de Granada, E-18071 Granada, Spain.

[8] Instituto de Astronomía (UNAM), Apdo Postal 70-264, Cd. Universitaria, 04510-Mexico DF, Mexico.

[9] Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile.

[10] Centro de Radioastronomía y Astrofísica (UNAM), Apdo Postal 72-3, 58089 Morelia, Michoacán, Mexico.

2. OBSERVATIONS AND RESULTS

We have obtained three sets of H_2O maser ($6_{16} \rightarrow 5_{23}$; $\nu = 22235.080$ MHz) data in 1999 spread over a time span of 2 months (April 2, May 7, and June 4) using the VLBA of the NRAO.[11] These short time intervals are crucial for minimizing the time-dependent effects of water masers themselves. A total of 256 channels of 0.4 km s^{-1} width centered at $V_{\rm LSR} = 10$ km s^{-1} were used. The data were correlated at the NRAO Array Operation Center and calibrated and imaged using the Astronomical Image Processing System. Self-calibration for the three epochs was performed with a strong (∼100 Jy) and pointlike water maser spot identified at $V_{\rm LSR} = 4.1$ km s^{-1} and associated with VLA 2. The synthesized beam size was $\simeq$0.5 mas. We detected ∼700 water maser spots in each of the three epochs, most of them distributed in two clusters, associated with each of the VLA 1 and VLA 2 sources. No maser emission was detected toward VLA 3. We fitted two-dimensional Gaussians to each identified maser spot to obtain its position. The spatial distribution and LSR velocities of the water masers, as seen with the two sets of VLBA and VLA data, coincide quite well, considering the different angular and velocity resolutions as well as the different epochs of observation (Fig. 1). The detected masers in the region cover the velocity range from $V_{\rm LSR} \simeq -11$ to $+20$ km s^{-1}. From the integrated intensity of the water maser emission around VLA 1 (∼60 Jy km s^{-1}) and VLA 2 (∼700 Jy km s^{-1}), we find that their isotropic H_2O luminosities are $L(H_2O) \simeq 6 \times 10^{-6}\ L_\odot$ (VLA 1) and $\simeq 7 \times 10^{-5}\ L_\odot$ (VLA 2). These luminosities are consistent with both objects being massive stars, which in general have high maser luminosity values (Anglada et al. 1996), in contrast with the much lower luminosities observed toward low-mass stars [$L(H_2O) \sim 10^{-11}$ to $10^{-9}\ L_\odot$; Furuya et al. 2003].

In general, VLBA proper-motion observations of water masers are limited by the high time variability of their flux density. The standard method is to phase-reference to a particular maser spot. However, the selected reference spot may have its own proper motion, which therefore results in arbitrary offsets in the proper motions for the whole system. In the VLBA observations reported here, from the tables of Gaussian fits to the maser spots in each channel, we selected the peak intensity maser from each group of neighboring velocity channels. The reference position in the maps was chosen to be the position of the maser that was used for self-calibration. We have been able to measure proper motions of 54 masers that persisted in all three epochs plus 44 features that repeat in only two epochs. We subtracted the mean proper-motion vector of the 98 features from each individual proper motion, to transform to a frame of reference in which the mean proper motion is zero. The fact that after this final realignment, the proper motions of the masers associated with VLA 1 are naturally aligned along the direction of the elongation of the radio continuum emission, indicating a very well collimated water maser jet (see below), gives our proper motions an additional measure of robustness.

The most remarkable result of our observations is the strikingly different characteristics of the water maser distribution around VLA 1 and VLA 2, both morphologically and kinematically (Fig. 1). In particular, the water masers associated with VLA 1 are clearly distributed on a linear structure of ∼1600 AU length along the major axis of the radio continuum emission (with a small spatial dispersion from this axis of ∼200 AU). They have proper motions with a mean value of ∼2 mas yr^{-1} (∼19 km s^{-1}) *parallel* to the elongated radio continuum structure, a mean line-of-sight velocity $V_{\rm LSR} \simeq 12$ km s^{-1}, and a very small LSR velocity dispersion of ∼1.5 km s^{-1}. In contrast, the masers associated with VLA 2 are distributed on a shell of ∼160 AU radius, they move *outward* from the central source with a mean proper-motion value of ∼3 mas yr^{-1} (∼28 km s^{-1}), and have a mean line-of-sight velocity $V_{\rm LSR} \simeq 5$ km s^{-1} with a large LSR velocity dispersion of ∼6 km s^{-1} (Fig. 1). The observed proper motions and the spatial distribution of the masers around these two objects indicate that, while in VLA 1 there is a collimated outflow driven by the associated YSO, in VLA 2 we are observing that a similar YSO is driving a shell outflow that expands in multiple directions. The small dispersion in the line-of-sight velocity of the VLA 1 masers, together with their mean LSR velocity (12 km s^{-1}), close to the systemic velocity of the W75 N cloud ($V_{\rm LSR} \simeq 10$ km s^{-1}; Hunter et al. 1994) implies that this collimated outflow with an opening angle of less than 10° is moving almost on the plane of the sky ($i \geq 80°$, derived from the ratio of the proper-motion velocity to the LSR velocity of the water masers with respect to the cloud systemic velocity). In contrast, the large line-of-sight velocity dispersion observed in the VLA 2 maser shell is consistent with an outflow expanding in multiple directions. In this sense, the observed motions of the VLA 2 water masers would require a binding mass on order of 100 $M_\odot$, which is not observed. Hence, these proper motions are consistent with expansion.

We also note that the different water maser collimation found around these two objects could be roughly explained within an scenario in which VLA 1 is a low-mass star, in which we generally see well-collimated jets, whereas VLA 2 is a massive star, in which it is much less likely to see a well-collimated outflow (see, e.g., G192.16−3.84; Shepherd, Claussen, & Kurtz 2001). However, we think that this scenario is unlikely given the high water maser luminosities and the radio continuum properties of these two objects, pointing out that they are both massive, probably early B stars (see above).

3. DISCUSSION

According to current theories on star formation, stars form through the gravitational collapse of molecular cores, which produces a protostar surrounded by an accretion disk, while simultaneously powering collimated outflows perpendicular to the disk (e.g., Rodríguez 1997). This scenario seems to be valid as a first approximation for both low- and high-mass stars (Garay & Lizano 1999; McKee & Tan 2002). However, this current paradigm of star formation does not predict outflows expanding without any preferent direction, since the driving engine is believed to be the transformation of the rotational energy of the disk into outflowing gas via MHD mechanisms that result in collimated, bipolar outflows. With our VLBA results, we suggest that at the beginning of stellar evolution, there may exist an important, possibly short-lived stage associated with very poor collimated outflows.

Very poor collimated outflows have been reported previously (Patel et al. 2000; Shepherd et al. 2001; Torrelles et al. 2001; Gallimore et al. 2003), also suggesting that this could represent an important stage in early evolution. The uniqueness of our result is the well-differentiated outflow geometry at scales of AU found simultaneously in two YSOs of the same star-forming region. The presence of noncollimated or collimated outflows in young stars could be attributed to the large-scale characteristics

---

[11] The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

of the region where the star formed. However, our results show that this explanation cannot be correct since the objects studied here are ∼1400 AU apart in the sky, thus sharing the same molecular gas environment. We tentatively propose that the degree of collimation in an outflow is likely determined by the evolutionary state of the star (so that the same star may go through both stages) or by processes that differentiate star formation on a scale smaller than about 10^3 AU. We do not know yet which source (VLA 2 or VLA 1) is at an earlier stage of evolution, or the origin and nature of this kind of shell outflow. In other words, we do not know whether noncollimated ejections are produced before or after the stage of well-collimated ejections. However, given that the noncollimated motions around VLA 2 are observed at a smaller scale in comparison with the scale in which the collimated motions are observed around VLA 1 (Fig. 1), we suggest that VLA 2 could be in an earlier stage than VLA 1. This proposition is at variance with the usual belief that outflows start being very collimated and become less collimated with age (André, Ward-Thompson, & Barsony 2000). Furthermore, we note that the spatial dispersion of the water masers from the major axis of the elongated radio continuum emission in VLA 1 (∼200 AU) is similar to the scale in which the outflow of VLA 2 is observed, suggesting that VLA 2 could evolve in the future into a collimated jet like VLA 1. In addition, since collimated outflows seem to be more commonly detected in star-forming regions and observed at scales up to several parsecs (Reipurth, Bally, & Devine 1997), we tentatively propose that the noncollimated outflow stage has a shorter life. In any case, we think that observations at (sub)millimeter wavelengths with the Submillimeter Array, which will provide angular resolutions of the order of $0''.1$, are the key point for determining the relative stage of evolution of these two YSOs. The ratio of submillimeter to bolometric luminosity is believed to be an indicator of age (decreasing with time) since the submillimeter luminosity traces the mass of the envelope that is being accreted into the star (André et al. 2000).

We have explored several scenarios that could account for the large opening angle in the VLA 2 outflow. First, we have considered a scenario in which the water masers are produced in a shocked layer of ambient molecular material around a very young expanding H II region, as suggested earlier for the water maser bubble around the Cepheus A R5 region (Curiel et al. 2002). In fact, the VLA 2 water maser shell seems to surround the radio continuum source (Fig. 1), which has a spectral index of $\alpha = 0.4 \pm 0.1$ ($S_\nu \propto \nu^\alpha$) in the 2 cm–7 mm wavelength range consistent with either a moderately optically thick H II region or an ionized wind (Shepherd et al. 2003a). However, the high expansion velocities of ∼28 km s^{-1} found in the water masers preclude that this shell may be driven by the expanding motions of an H II region (typically expanding at ∼10 km s^{-1} in its earliest stages).

We have also considered the possibility that the expanding motions in VLA 2 are driven by the radiation pressure of a central star. Let us assume that the water masers trace an isotropic, continuous, and steady outflow. The momentum rate in the outflow can be estimated by $\dot{\Pi}_f = 4\pi R^2 \rho_f V_f^2$, where ρ_f is the mass density in the flow, V_f its velocity, and R the distance from the star. Taking $V_f = 28$ km s^{-1} and $R = 160$ AU, we find $(\dot{\Pi}_f/M_\odot\ \mathrm{yr}^{-1}\mathrm{km\ s}^{-1}) = 3 \times 10^{-2}(n/10^8\ \mathrm{cm}^{-3})$, where n is the particle density in the masing region. On the other hand, the momentum output rate delivered by the stellar radiation field is $(\dot{\Pi}_*/M_\odot\ \mathrm{yr}^{-1}\mathrm{km\ s}^{-1}) = 2.1 \times 10^{-4}\tau(L_*/10^4\ L_\odot)$, where L_* is the stellar luminosity and τ is the average optical depth of a stellar photon. The upper limits for $L_* \simeq 10^4\ L_\odot$ (corresponding to a B0.5 star; Panagia & Felli 1975) and $\tau \simeq 10$ (Lamers & Cassinelli 1999) make radiation pressure an unlikely mechanism for driving the water maser shell.

Thus, the most probable scenario is a wind-driven shell. Under this scenario, some important parameters, such as the mass-loss rate ($\dot{M}_w$) and terminal velocity (V_w), of the stellar wind can be estimated. The thermal pressure inside the shell ($P_s = nkT$) is related to these parameters by $P_s = (\dot{M}_w V_w)/(4\pi R^2)$, where n and T are the particle density and temperature of the shell, respectively. Setting $R = 160$ AU, we find $(\dot{M}_w/M_\odot\ \mathrm{yr}^{-1})(V_w/\mathrm{km\ s}^{-1}) = 7.9 \times 10^{-5}(n/10^8\ \mathrm{cm}^{-3})(T/500\ \mathrm{K})$. Assuming that the observed radio continuum emission $S_\nu = 1.6$ mJy at $\lambda = 1.3$ cm (Torrelles et al. 1997) is coming from the (ionized) stellar wind, we obtain $(\dot{M}_w/M_\odot\ \mathrm{yr}^{-1})/(V_w/\mathrm{km\ s}^{-1}) = 8.1 \times 10^{-9}$ (Panagia & Felli 1975). From the above expressions, we find that $(\dot{M}_w/M_\odot\ \mathrm{yr}^{-1}) = 8 \times 10^{-7}(n/10^8\ \mathrm{cm}^{-3})^{1/2}(T/500\ \mathrm{K})^{1/2}$ and that $(V_w/\mathrm{km\ s}^{-1}) = 100(n/10^8\ \mathrm{cm}^{-3})^{1/2}(T/500\ \mathrm{K})^{1/2}$. Such a mass-loss rate and wind velocity are consistent with those expected from a B0.5 star (Panagia & Felli 1975). In addition, the density outside the shell (n_0) can be estimated (assuming a strong shock) by $n_0 = n(a/V_f)^2$, where $a = 1.4$ km s^{-1} is the sound speed inside the shell (corresponding to $T = 500$ K). The result is $(n_0/\mathrm{cm}^{-3}) = 2.6 \times 10^5(n/10^8\ \mathrm{cm}^{-3})$, which is a reasonable density value for the molecular core. Furthermore, by setting $V_f = dR/dt$, one can find a differential equation for the radius of the shell as a function of time whose solution is $R = (\dot{M}_w V_w/\pi\rho_0)^{1/4} t^{1/2}$. Using the numerical values derived above, we find for the age of the shell $t \simeq 13$ yr, which is independent of the assumed density n and temperature T inside the shell.

Given how unlikely it would be to observe this short-lived phenomena if it happened only once in the lifetime of the star, we suggest that these outflows are repetitive. In fact, the northern part of the shell shows two main layers of masers (both detected in all three epochs) with a maximum spatial separation of ∼$0''.01$ (∼20 AU), without any clear differences in their kinematics (Fig. 1). We speculate whether or not these two layers of masers correspond to multiple, episodic gas ejections from the YSO that interact with their nearby environment. These multiple ejections, together with both the nonlinear amplification of the water maser emission and the clumpiness of the molecular core itself, could suggest that the shell around VLA 2 does not present a continuous structure, as observed. However, in spite of this clumpiness and the large LSR velocity dispersion of the masers in the VLA 2 shell, we find that water maser emission tends to exhibit a remarkably coherent and well-ordered spatiokinematical behavior at the very small scales of ∼1 AU (Fig. 1), as was also observed in Cepheus A R5 (Torrelles et al. 2001; Uscanga et al. 2003), which suggests that this is a fundamental scale size for the excitation of circumstellar water masers.

In summary, to know how and when the noncollimated wind ejection stage occurs is a key point for advancing in our knowledge of the earliest stages of stellar evolution. In this sense, we think that further theoretical development of models such as those originally thought to explain the origin of optical jets, but instead predicting large opening angles in the outflows at their base (Shang et al. 2002), and their confrontation against the high angular observations currently available, could cast some light on this new important issue.

We thank an anonymous referee for very useful comments. This work was partially supported by MCYT and Junta de Andalucía (Spain) and by DGAPA and CONACyT (México).

REFERENCES

André, P., Ward-Thompson, D., & Barsony, M. 2000, in Protostars and Planets IV, ed. V. Mannings, A. P. Boss, & S. S. Russell (Tucson: Univ. Arizona Press), 59

Anglada, G., Estalella, R., Pastor, J., Rodríguez, L. F., & Haschick, A. D. 1996, ApJ, 463, 205

Claussen, M. J. 2002, in IAU Symp. 206, Cosmic Masers: From Proto-Stars to Black Holes, ed. V. Migenes & M. J. Reid (San Francisco: ASP), 27

Claussen, M. J., Diamond, P. J., Braatz, J. A., Wilson, A. S., & Henkel, C. 1998a, ApJ, 500, L129

Claussen, M. J., Marvel, K. B., Wootten, A., & Wilking, B. A. 1998b, ApJ, 507, L79

Curiel, S., et al. 2002, ApJ, 564, L35

Elitzur, M., Hollenbach, D. J., & McKee, C. F. 1992, ApJ, 394, 221

Furuya, R. S., Kitamura, Y., Wootten, A., Claussen, M. J., & Kawabe, R. 2003, ApJS, 144, 71

Gallimore, J. F., Cool, R. J., Thornley, M. D., & McMullin, J. 2003, ApJ, 586, 306

Garay, G., & Lizano, S. 1999, PASP, 111, 1049

Haschick, A. D., Reid, M. J., Burke, B. F., Moran, J. M., & Miller, G. 1981, ApJ, 244, 76

Hunter, T. R., Taylor, G. B., Felli, M., & Tofani, G. 1994, A&A, 284, 215

Hutawarakorn, B., Cohen, R. J., & Brebner, G. C. 2002, MNRAS, 330, 349

Imai, H., Watanabe, T., Omodaka, T., Nishio, M., Kameya, O., Miyaji, T., & Nakajima, J. 2002, PASJ, 54, 741

Lamers, H. J. G. L. M., & Cassinelli, J. P. 1999, Introduction to Stellar Winds (Cambridge: Cambridge Univ. Press)

Panagia, N., & Felli, M. 1975, A&A, 39, 1

Patel, N. A., Greenhill, L. J., Herrnstein, J., Zhang, Q., Moran, J. M., Ho, P. T. P., & Goldsmith, P. F. 2000, ApJ, 538, 268

McKee, C. F., & Tan, J. C. 2002, Nature, 416, 59

Miyoshi, M., Moran, J. M., Herrnstein, J., Greenhill, L., Nakai, N., Diamond, P., & Inoue, M. 1995, Nature, 373, 127

Reipurth, B., Bally, J., & Devine, D. 1997, AJ, 114, 2708

Rodríguez, L. F. 1997, in IAU Symp. 182, Herbig-Haro Flows and the Birth of Stars, ed. B. Reipurth & C. Bertout (Dordrecht: Kluwer), 83

Shang, H., Glassgold, A. E., Shu, F. H., & Lizano, S. 2002, ApJ, 564, 853

Shepherd, D. S. 2001, ApJ, 546, 345

Shepherd, D. S., Claussen, M. J., & Kurtz, S. E. 2001, Science, 292, 1513

Shepherd, D. S., Kurtz, S. E., & Testi, L. 2003a, ApJ, in press

Shepherd, D. S., Testi, L., & Stark, D. P. 2003b, ApJ, 584, 882

Slysh, V. I., Migenes, V., Val'tts, I. E., Lyubchenko, S. Yu., Horiuchi, S., Altunin, V. I., Fomalont, E. B., & Inoue, M. 2002, ApJ, 564, 317

Torrelles, J. M., Gómez, J. F., Rodríguez, L. F., Ho, P. T. P., Curiel, S., & Vázquez, R. 1997, ApJ, 489, 744

Torrelles, J. M., et al. 2001, Nature, 411, 277

Uscanga, L., Cantó, J., Curiel, S., Torrelles, J. M., & Rodríguez, L. F. 2003, Rev. Mexicana Astron. Astrofis. Ser. Conf., 15, 147

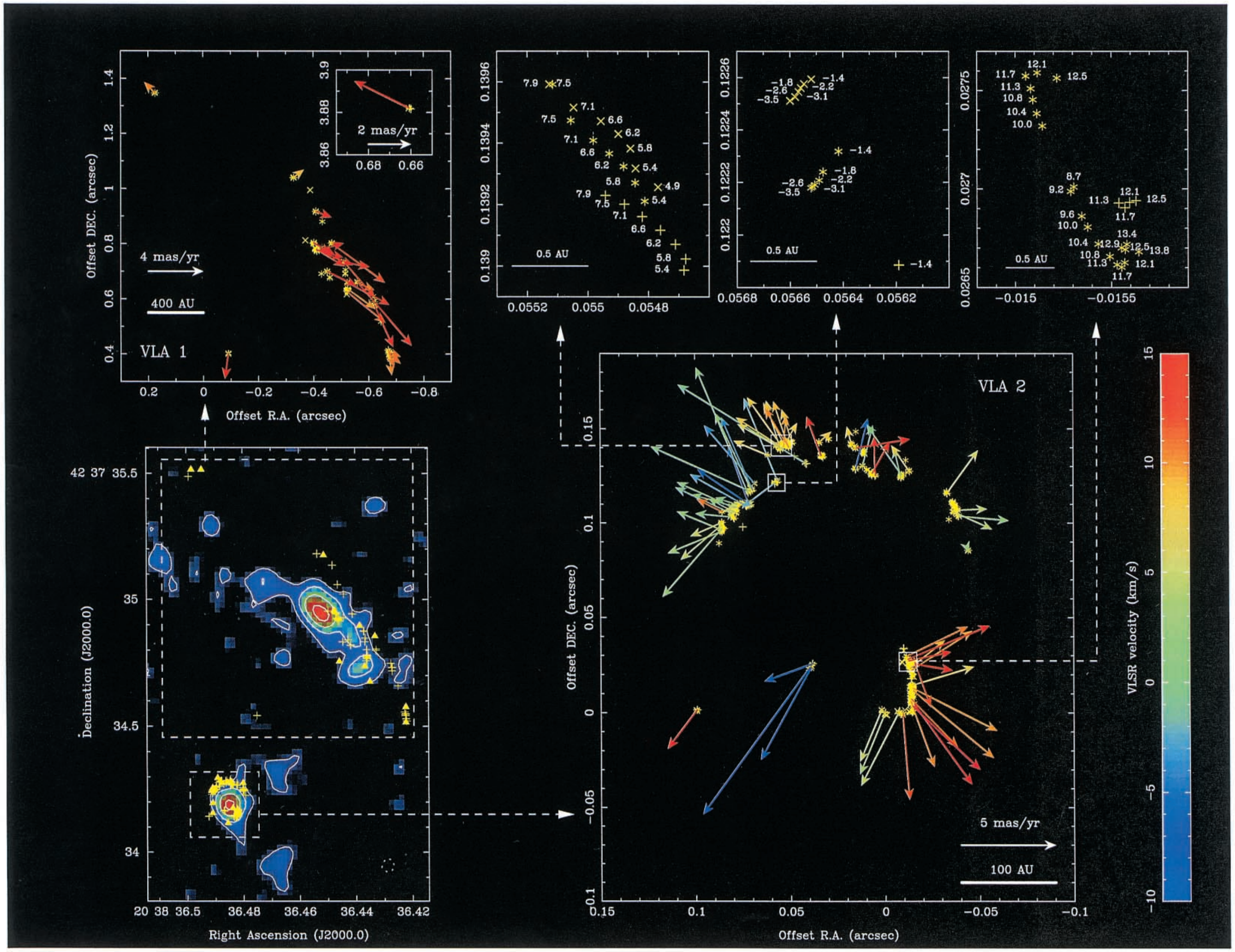

FIG. 1.—*Bottom right and top left*: Positions of the water maser spots (marked by plus signs, asterisks, and mult crosses corresponding to the first, second, and third observed epochs, respectively) measured with the VLBA in VLA 1 and VLA 2. Arrow lengths represent the corresponding measured proper-motion vectors, and their color code indicates the LSR velocity of the individual maser features. *Bottom left:* 1.3 cm continuum (*contour plot*) and water maser emission (*triangles*) in VLA 1 and VLA 2, detected previously with the VLA in 1996, together with the VLBA water maser spots (*plus signs*). *Three top right panels:* Close-up of three small sections of the VLA 2 water maser shell. The LSR velocity for each spot is labeled in units of kilometers per second. The accuracy in the relative positions of the VLBA maser spots within each epoch is better than 0.05 mas.