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AN ENIGMATIC, EXPANDING, SPHERICAL BUBBLE EJECTED FROM A YOUNG STELLAR OBJECT

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RESUMEN

Mediante observaciones radiointerferométricas de máseres de agua de la región de formación estelar de Cefeo A, realizadas con el "Very Long Baseline Array" (VLBA), hemos encontrado una estructura en arco que se ajusta a una circunferencia de radio 62 UA con una precisión de una parte entre mil y que se expande con una velocidad de $9\,\mathrm{km\,s^{-1}}$. La interpretación física de este arco es que forma parte de una burbuja esférica en expansión expulsada no hace más de 33 años por una estrella recién formada situada en el centro de la circunferencia. Este objeto joven ha sido recientemente detectado en radiocontinuo. En este artículo describimos todas esas observaciones, muy en particular las realizadas con el VLBA. Comentamos también sobre varios posibles modelos que se han propuesto para explicar el origen de esta enigmática burbuja esférica en expansión.

ABSTRACT

Through Very Long Baseline Array (VLBA) multi-epoch water maser observations toward the star-forming region Cepheus A, we have recently found and reported an arc structure defining an expanding ($9\,\mathrm{km\,s^{-1}}$) circle of 62 AU radius with a precision of one part in a thousand. We have interpreted this structure as an expanding spherical bubble short lived (33 years) ejected from a young stellar object (YSO) located at the center of the circle. This YSO has been recently detected at radio continuum wavelengths. In this paper we describe all these observations, in particular those obtained with the VLBA. We also comment on possible scenarios proposed in the literature to explain the origin of this enigmatic, expanding, spherical bubble.

Key Words: **ISM: JETS AND OUTFLOWS — MASERS — STARS: FORMATION**

1. INTRODUCTION

Cepheus A is a high-mass star-forming region with phenomena such as Herbig-Haro (HH) objects, radio continuum sources, molecular outflows, jets, and masers (Rodríguez, Ho, & Moran 1980; Lada et al. 1981; Cohen, Rowland, & Blair 1984; Hughes & Wouterloot 1984; Hughes, Cohen, & Garrington 1995; Garay et al. 1996; Gómez et al. 1999; Hartigan, Morse, & Bally 2000). This is the second source in the sky ever noted to exhibit the phenomenon of bipolar molecular outflow (Rodríguez et al. 1980). The driver of the molecular outflow is a thermal biconical radio jet (Rodríguez et al. 1994). Strong water masers were found with the Very Large Array (VLA) distributed in a flattened disk-like structure, centered on the jet, but perpendicular to it (Torrelles et al. 1996).

In this paper we present some of the main results obtained through VLBA multi-epoch water maser observations toward this star-forming region (Torrelles et al. 2001a,b). The main goal of these VLBA observations was to measure the proper motions of the water maser spots seen previously with the VLA to know their full kinematics.

2. OBSERVATIONS AND RESULTS

The water maser observations were carried out with the VLBA of the National Radio Astronomy Observatory (NRAO).[8] A full description of the observations, results, and discussion have been reported by Torrelles et al. (2001a,b) and we summarize some of the main results here.

The VLBA observations have revealed that some of the "individual" masers detected previously with the VLA unfold into remarkable linear/arcuate "microstructures", with angular sizes in the range 3 to

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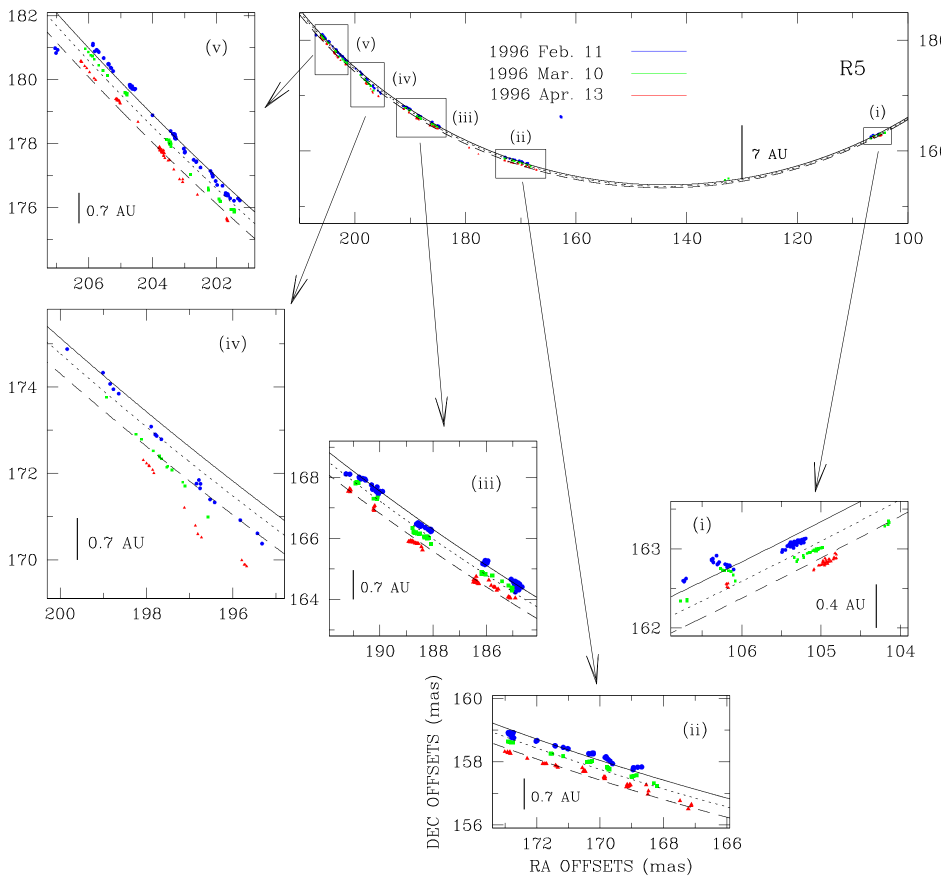

Fig. 1. Offset positions of all the water maser spots measured in the arc structure in Cepheus A. The circles, squares, and triangles correspond to the maser spots observed in the first, second, and third epochs, respectively. Least-squares fitted circles for each epoch are also shown (continuous, dotted, and dashed lines). See Torrelles et al. (2001a,b) for more details.

100 mas, 2 to 70 AU at a distance of 725 pc (Johnson 1957). Moreover, some of these structures unfold into even smaller linear "building-blocks" (down to scales of 0.4 AU) shaping the "larger" structures. The flattened appearance of the "building-blocks" argues strongly for a shock nature according to the theoretical models by Elitzur, Hollenbach, & McKee (1992) and Kaufmann & Neufeld (1996). Both the spatial distribution and the measured proper motions of the maser microstructures have allowed us to identify three different centers of star-formation activity in a radius of 300 mas (200 AU).

One of these centers is related to the thermal radio continuum jet Cepheus A HW2 (Rodríguez et al. 1994). For this source, the VLBA data suggest the presence of a wide-angle wind ($\sim 130°$) associated with the central object at distances of 150 AU.

The second center of activity is related to a "microstructure" of water masers (located $\simeq$ 200 mas south from HW2) with an arcuate shape of $\simeq$ 35 mas size ($\simeq$ 25 AU). The velocity field of the masers is consistent with an expanding shell, moving at velocities of $\sim$ 10 to 30 km s^{-1}, resembling that of a bow-shock commonly found in association with HH objects and optical jets (e.g., Raga 1995). We have proposed that this bow-shock structure is excited by the wind of an unidentified YSO in the very first stages of evolution, located close but displaced to the southeast of the bow-shock structure. This structure in Cepheus A resembles also the U-shaped distribution of water masers found by Furuya et al. (2000) in the star-forming region S106 (source S106 FIR).

The third center of activity is traced by the presence of a remarkable, unusual arclike distribution, defining an expanding (9 km s^{-1}) circle of 62 AU radius with a precision of one part in a thousand. The total flux density of the water masers in this structure ($\simeq$ 500 Jy) represents a very large fraction ($\simeq$ 50%) of the total flux density of the maser emission in the entire Cepheus A star-forming region. An additional, very important result has been the discovery that the arc structure is constituted by a string of smaller ($\simeq 0.4$ to 1 AU in size) linear structures of maser spots, with different orientations, all of which are tangential to the arc curvature (see Fig. 1). These small, linear "building-blocks" have a coherent structure and a well-defined velocity gradient in the position-velocity diagrams, with a velocity (LSR) trend persisting in all three epochs (Uscanga et al. 2003). Uscanga et al. (2003) have modeled an individual building-block of water masers as a thin disk with flowing material on its surface and a linear velocity gradient. In this way, these authors explain both the velocity (LSR) field and the flux density distribution in these building-blocks.

We have interpreted the arc structure as due to a spherical ejection of material 33 years ago from a YSO located at the center of the circle. The observed proper motions and morphology of the water maser arc structure as a whole suggest that it represents a spherical bubble, driven by a central star. The physical processes involved to produce such highly symmetric spherical ejection are not well known since it cannot be explained by the current star-formation theories where ejection of material is expected to occur in two opposite directions.

The central YSO of this expanding bubble has recently been detected by Curiel et al. (2002) and Porras et al. (2002) at centimeter wavelengths with the VLA. A possible alternative scenario to explain this structure was analyzed by Curiel et al. (2002), in which it is proposed that the detected radio continuum source at the center of the circle could represent a very young (≤ 33 yr) expanding H II region, with the observed water maser emission produced in the shocked layer of ambient molecular material around the H II region. However, as noted by these authors, the probability of witnessing the birth of an H II region is very low, since it is a very short-lasting event. In any case, these two scenarios (direct ejection of material or an expanding H II region) can be tested with multi-wavelength VLA-Pie Town continuum observations and new multi-epoch water maser VLBA observations.

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