Dynamical Masses in the Young Triple Stellar System EC 95

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abstract

We present dynamical mass measurements for the young multiple stellar system EC 95, located in the Serpens star-forming region. EC 95 comprises a triple hierarchical structure: A close binary composed by EC 95A a EC 95B, and a relative distant companion EC 95C. Utilizing multi-epoch observations with Very Long Baseline Interferometry (VLBI) technique, we precisely measured the masses of the components within the close binary EC 95A and EC 95B. Our dataset combines previous and recent observations from the Dynamical Masses of Young Stellar Multiple Systems with the VLBA project (DYNAMO–VLBA), totaling 32 epochs over 12 years.The estimated period is 21.6 ± 0.1 years (i.e., we covered a significant fraction of the orbit), our results reveal masses of 2.14 ± 0.10 M⊙ for the primary component and 1.99 ± 0.12 M⊙ for the secondary.

Introduction

EC 95 is a young multiple stellar system embedded in the main core of the Serpens star-forming region, consisting of a triple hierarchical structure. EC 95 was initially classified as a K2 spectral type proto-Herbig AeBe star, with an estimated age of around 10^5 years and a mass ranging from approximately 4 to 5 $M_\odot$, according to Preibisch (1999). Radio observations conducted by Rodriguez et al. (1980) and Eiroa et al. (2005) using the Very Large Array (VLA) detected EC 95 as a strong, unresolved radio source, suggesting nonthermal coronal radio emission. Subsequent observations with the Very Long Baseline Array (VLBA) by Dzib et al. (2010) revealed that the system consists of two nearby components, with an approximate separation of 15 mas.

Further VLBA observations as part of the GOBELINS project Ortiz-León et al. (2017a) confirmed the binary nature of EC 95 and provided a more detailed perspective on its dynamics. These observations also uncovered the presence of a third component, EC 95C, positioned approximately 145 mas northeast of the binary system barycenter in September 2008 and approximately 138 mas at the same coordinates in January 2012. Consequently, EC 95 emerges as a triple hierarchical system, with each component exhibiting non-thermal radio emission (Ortiz-León et al., 2017a).

Methodology

Observations and data reduction

The radio continuum observations of EC 95 were carried out using the VLBA of the National Radio Astronomy Observatory (NRAO) as part of the DYNAMO-VLBA project at a wavelength (λ) of 6.0 cm (ν = 4.9 GHz) (e.g., Ordóñez-Toro et al., 2024). The observational strategy comprised seven sessions, each spaced every four months, starting in early 2018 and concluding in late 2019. As a result, EC 95 was observed a total of seven times as part of the DYNAMO-VLBA project. Each observation session lasted approximately three hours. The data calibration followed standard VLBI procedures with phase referencing using the Astronomical Image Processing System (AIPS) software (Greisen, 2003). These procedures have been detailed in previous works (Loinard et al., 2007; Dzib et al., 2010; Ortiz-León et al., 2017b).

Astrometric fitting procedure

The astrometric fitting was conducted considering that the displacement of stars in a binary system is described by a combination of the trigonometric parallax (π), proper motions (μ_α, μ_δ), and the orbital motion. The equations describing the motion of the primary component as a function of time are given by:

$$\alpha(t) = \alpha_0 + \mu_\alpha t + \pi f_\alpha(t) + a_1 Q_\alpha(t); \qquad \delta(t) = \delta_0 + \mu_\delta t + \pi f_\delta(t) + a_1 Q_\delta(t), \quad (1)$$

where α_0 and δ_0 are the coordinates of the source for a given epoch, a_1 is the major axis of the primary component of the system, and f_α and f_δ correspond to the projection of the parallactic ellipse (Seidelmann, 1992). The factors $Q_\alpha(t)$ and $Q_\delta(t)$ are functions of the orbital elements (Wehlau, 1967).

To solve these equations, we utilize the procedure originally implemented in IDL and later translated into Python [see e.g. Kounkel et al. 2017 for details]. This routine simultaneously fits the equations to the data using the least squares method with MPFIT, allowing for the fitting of parameters using all available positions of the individual components, including relative positions. The dynamic masses were calculated using Kepler's third law based on the values obtained from the astrometric and orbital parameter fitting.

Results

Figure 1 Final radio images of EC 95 at 4.9 GHz corresponding to each epoch observed during the DYNAMO-VLBA project.

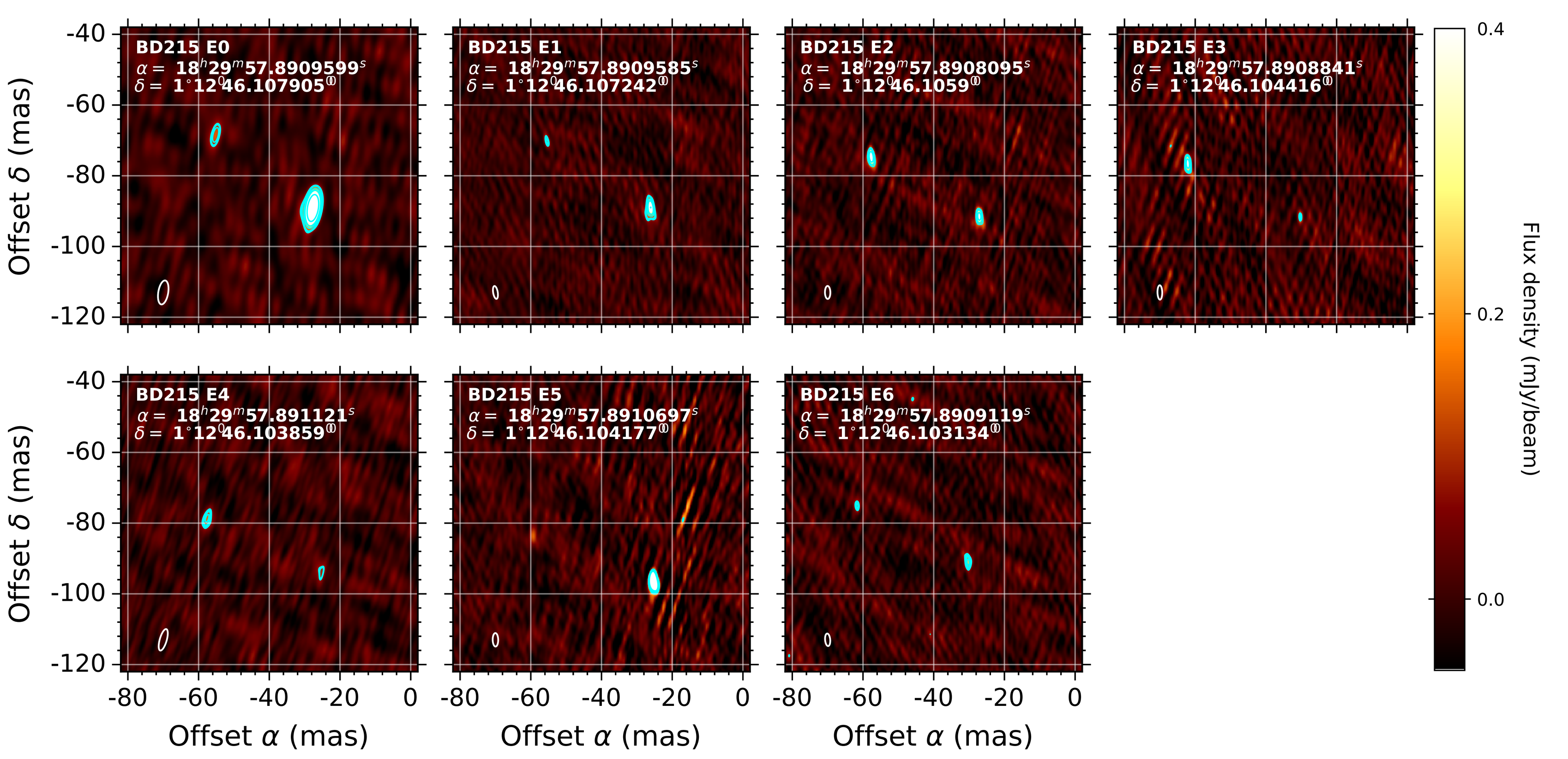


Figure 2 (Left) Measured positions of EC95A (red dots) and EC95B (blue dots) shown as offsets from the position of EC95A in the first detected epoch with modern VLBA observations (2007 December 22). (Right) Relative positions and the orbital fit model.

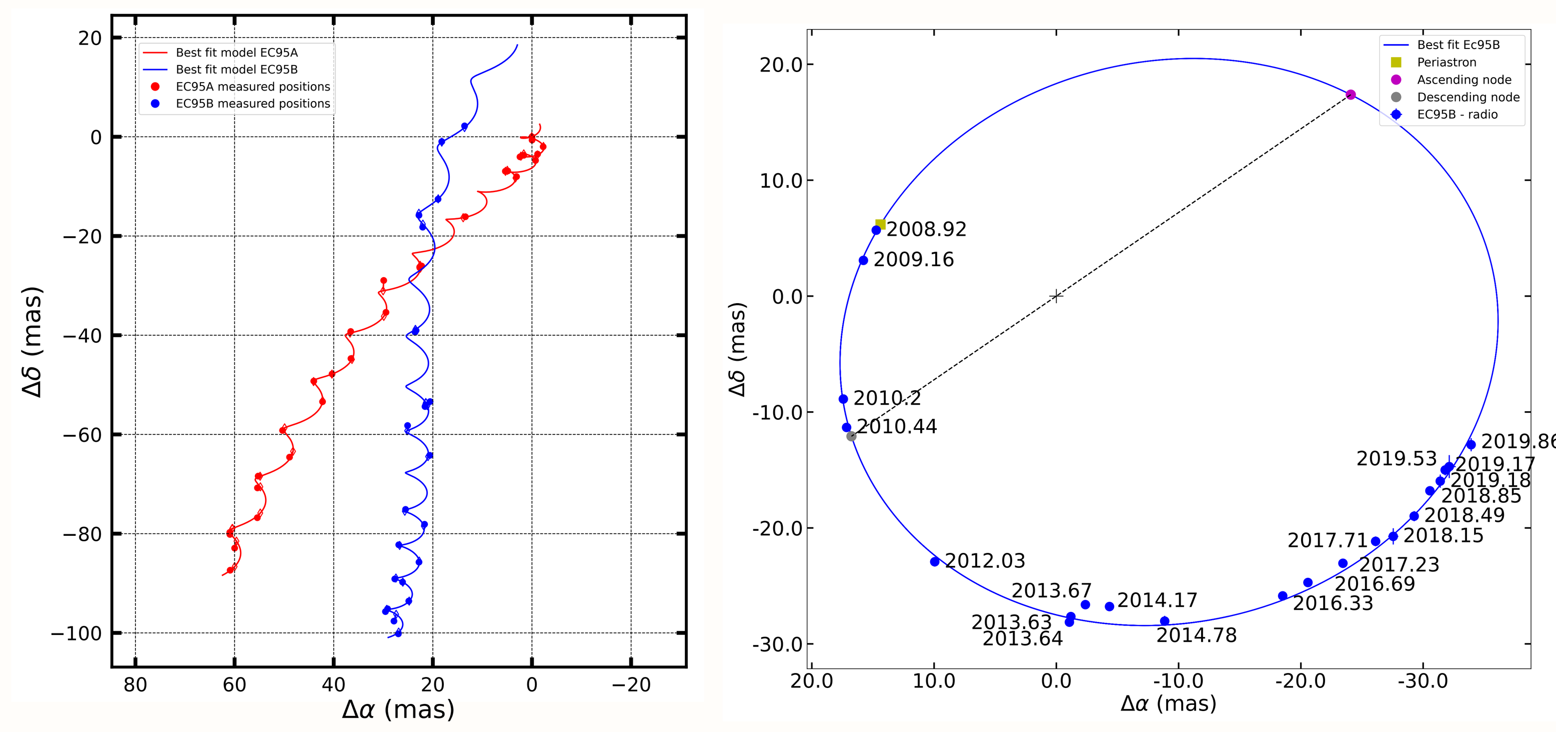
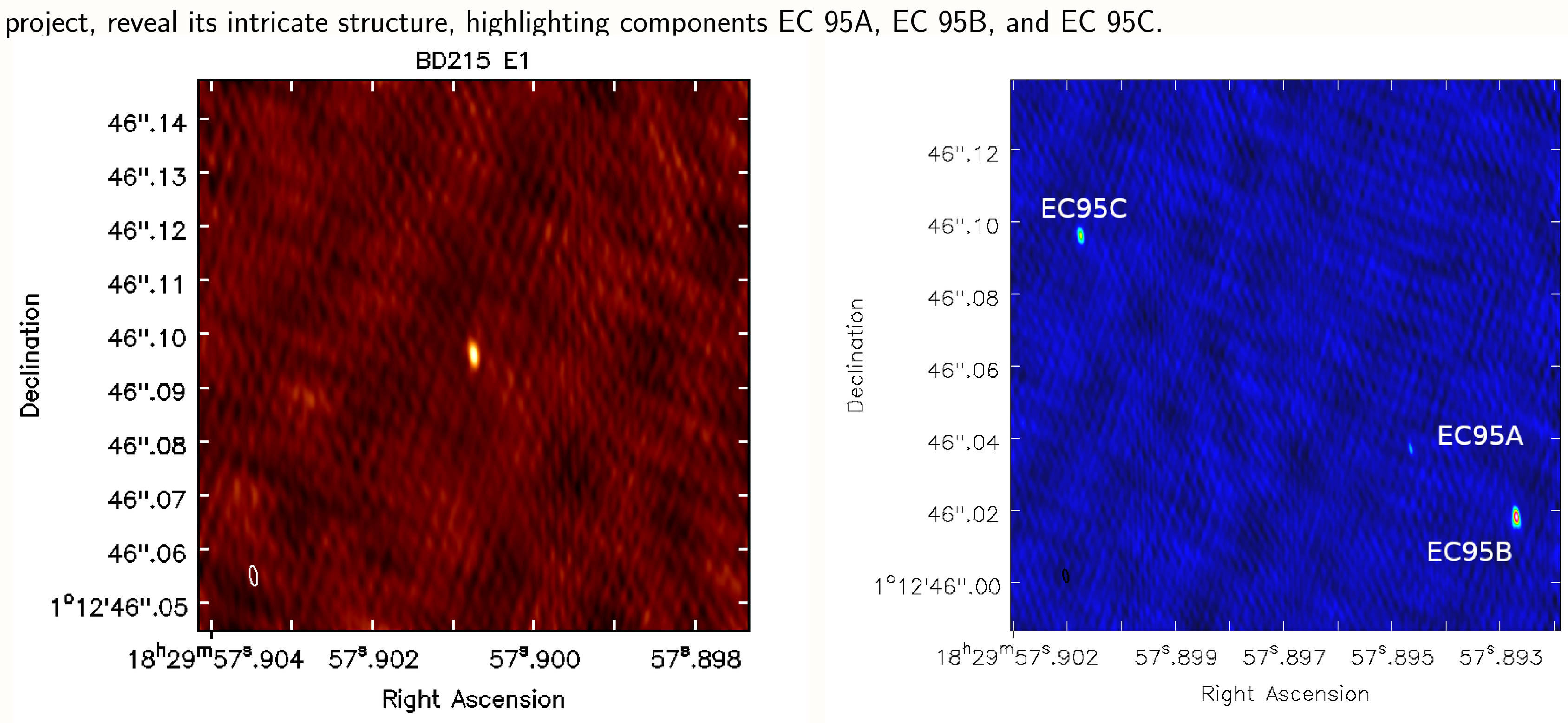


Figure 3 (Left) Final radio map of EC 95C at 4.9 GHz corresponding to the observation epoch BD215E1 the DYNAMO-VLBA project. (Right) Radio map of EC 95 at 4.9 GHz corresponding to the observation epoch BD215E1 the DYNAMO-VLBA project, reveal its intricate structure, highlighting components EC 95A, EC 95B, and EC 95C.



Conclusions

- We utilized VLBA multi-epoch observations to analyze the EC 95 binary system, determining dynamical masses of 2.14 ± 0.10 M⊙ for the primary and 1.99 ± 0.12 M⊙ for the secondary through astrometric fitting.
- *Work in progress:* We now have four detections of EC 95C and are attempting to estimate its mass roughly.

Referencias

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