

Spiral-shells and nascent bipolar outflow in CIT 6: hints for an eccentric-orbit binary?

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Abstract. We present the essential results pointed out in a recently published paper, Kim et al. 2015, *Astrophys. J.*, 814, 61. The carbon star CIT 6 reveals evidences for a binary in a high-resolution CO line emission map of its circumstellar envelope taken with the Submillimeter Array. The morphology of the outflow described by the spiral-shell pattern, bipolar (or possibly multipolar) outflow, one-sided interarm gaps, and double spiral feature point to a plausible scenario that CIT 6 is a binary system in an eccentric orbit with the mass losing star evolving from the AGB.

Many planetary nebulae (PNe) and pre-PNe simultaneously present both outer ring-like patterns and inner asymmetric (bipolar or multipolar) structures. This coexistence is a result of shape transition from spherically-symmetric envelopes of asymptotic giant branch (AGB) stars to highly-asymmetric PNe. The bipolar outflows are hypothesized as the outcome of a *close* binary interaction, while the typical dynamical timescales of the observed ring patterns are consistent with the orbital periods of *wide* binaries. This puzzle may be resolved by binaries in highly eccentric orbits whose close periastron passages facilitate strong binary interactions and consequent accretion onto the companion stars.

In a high-resolution CO $J=2-1$ line observation of a carbon star CIT 6 with the Submillimeter Array, we have found various features expected in a highly eccentric binary system [1]. The circumstellar envelope of CIT 6 unveils its spiral-shell pattern (Figure1) and a bipolar (or multipolar) structure (Figure2) in the CO maps, in a similar manner to the pre-PNe observed in the optical images. The spiral-shell pattern was predicted earlier [2] based on the HC_3N $J=4-3$ segments [3], which are now well connected by the CO pattern. The tiny bipolar outflow was observed in an optical polarization image [4].

In addition, the CO maps further reveal new interesting aspects. The double spiral feature in the innermost region (Figure3) is expected in a slow wind condition, where the flow is captured by the gravitational potential of the companion [5]. The existence of the double spiral in CIT 6 may imply that the companion of the carbon star lies in, or passes through, the wind acceleration zone of the AGB star. A typical size of the acceleration zone is several stellar radii and, therefore, the binary orbit is possibly highly eccentric. The one-sided lowering of interarm emission (Figure4) can be also reproduced by an eccentric orbit binary model [6].



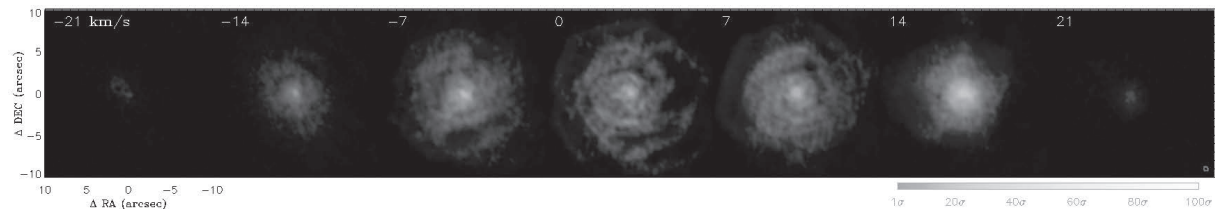


Figure 1. SMA CO $J=2-1$ channel maps of CIT 6 unveiling the circumstellar spiral-shell pattern. The central channel velocity with respect to the systemic velocity is marked at the top left corner of each panel. The color bar labels the line emission intensities of the CO map in units of the noise level. Its synthesized beam size is denoted at the bottom right corner.

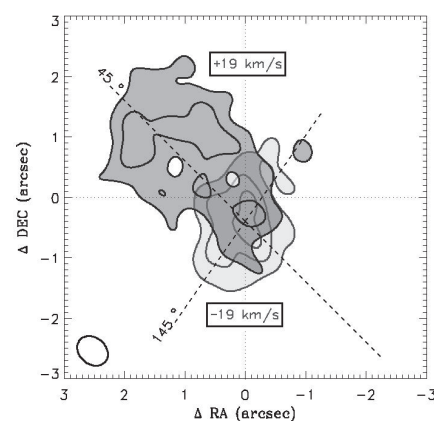


Figure 2. Innermost region of CO line-edge channels present the asymmetric (bipolar, or possibly multipolar) outflow of CIT 6. The outflow directions are marked by dashed lines. The beam size is given by an ellipse at the bottom left. Contour levels are 8σ , 12σ , and 16σ with the noise level σ .

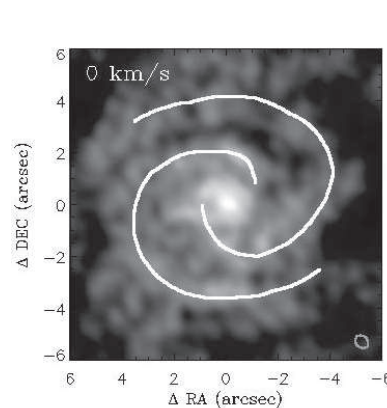


Figure 3. Inner region in the systemic velocity channel of CO emission line reveals the double-spiral feature of CIT 6. This is the same as the middle panel of Figure 1, but for about half the field and with the overlying hand-drawn lines.

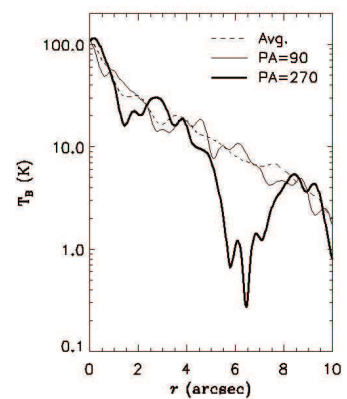


Figure 4. CO brightness temperature of CIT 6 as a function of radius to the east (PA=90°), to the west (PA=270°), and in azimuthal average. The absence of interarm emission to the west is significant and interpreted as a hint of eccentric binary.

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