分開 Class 0 原恆雙星 VLA1623 的兩道噴流

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摘要

早期原恆星的噴流是恆星形成早期的重要機制，因爲噴流可以帶走角動量，使得分子雲得以重力塌縮。我們研究位於ρ蛇夫座分子雲中的原恆星VLA1623。日前高解析度的觀測顯示，VLA1623的連續輻射顯示出兩個相距140AU的原恆星，指出VLA1623可能是一個原恆雙星系統。我們使用次毫米波陣列望遠鏡的緊密配置(compact configuration)來進行觀測。觀測數據顯示VLA1623有非常集中的^{12}CO J(3-2)噴流，且其紅移及藍移的部分重疊，暗示噴流的可能平形於天空平面。然而，從channel map和P-V圖中顯示的噴流位置以及特性並且比較先前的研究和理論的P-V圖，我們推論VLA1623有兩道噴流，每道源自其中一個原恆星。C^{17}O(3-2)顯示原恆星的包層有垂直於噴流的旋轉。SO (9-8)相似於噴流中央藍移的knot的速度梯度，指出可能有噴流造成的衝擊波 (shock)。

Resolving the two outflows from the Class 0 Protobinary VLA1623

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Abstract

Protostellar outflows are important in the early stage of star formation, because they can transfer the angular momentum outward allowing further gravitational collapse to proceed. We study the Class 0 source VLA1623, embedded in the ρ Ophiuchi cloud. Previous high resolution observations have shown that VLA1623's continuum emission breaks up into two almost equal point sources with a separation of ~140AU (Looney et al. 2000) strongly suggesting that VLA1623 is a protobinary system. Our new observations were done using the Submillimeter Array (SMA) in compact configuration. Our data shows that VLA1623 has strong collimated outflows in ^{12}CO J(3-2) with overlapping red- and blue-shifted morphology, which could imply that the outflow is located exactly on the plane of the sky. However, after studying the position and characteristics of the lobes from the channel map and P-V diagram, and comparing to previous studies and theoretical P-V diagrams, we conclude that VLA1623 presents two outflows, one emanating from each source. The envelope material traced in C^{17}O (3-2) shows rotation perpendicular to the outflow axis. The material traced with SO (9-8) shows a velocity gradient similar to that of the outflows' central blue knot, suggesting a shock caused by the outflow.

關鍵字(Keywords)：原恆星形成(star formation)、噴流(outflows)、原恆雙星(protobinary)、VLA1623

1. Introduction

Protostellar outflows are the most spectacular event in a protostar's life, influencing both the environment and evolution of the protostar in the early stages of star formation. VLA1623 is a prototypical Class 0 source (Andre et al. 1993) embedded in the ρ Ophiuchi cloud at a distance of ~125pc, driving a highly collimated extended outflow presenting a puzzling morphology of overlapping red- and blue-shifted lobes (Andre et al. 1990). VLA1623 has also been found to be associated with the HH-object HH313A (e.g. Caratti o Garatti et al. 2006). Previous studies have suggested the presence of two distinct outflows from CO, H_2 and knot kinematics, but have not resolved them (e.g. Dent et al. 1995, Caratti o Garatti et al. 2006). Others suggest that there is only one outflow with inclination close to the plane of the sky (e.g. Andre et al. 1990, Maury et al. 2010). High resolution continuum emission observations determined that VLA1623 is very likely a protobinary system with components A and B roughly separated by ~140AU (Looney et al. 2000). The presence of a protobinary system supports the argument that the morphology of VLA1623's outflow is product of two outflows.

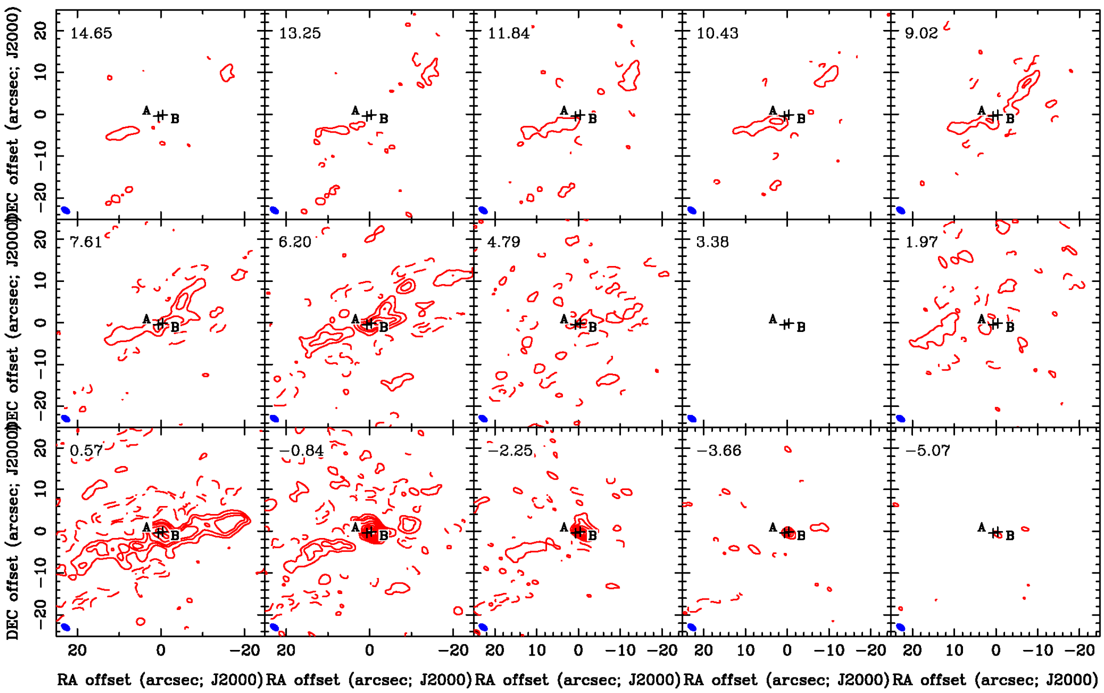

Fig. 1: ^{12}CO channel Map: Contours are in steps of -7, -3, 3, 7, 11, 15, 19, 27, 35, 43, 51 times an rms noise of 0.33 Jy/beam. The marked positions of VLA1623 A and B were taken from Looney et al. (2000). The blue-shifted components are in the -6 to 1 km/s velocity range and the red-shifted components in the 3 to 14 km/s with systemic velocity at 3.7 km/s.

2. Observations and Results

Our observations of VLA1623 were carried out with the Submillimeter Array (SMA) in compact configuration at 345 GHz on July 2007, producing three lines: ^{12}CO (3-2) and SO (9-8) and C^{17}O (3-2), and dust continuum (λ=0.87mm). The synthesized beam of of our observations is 2.32" × 1.41" with a velocity resolution of 0.7 km/s.

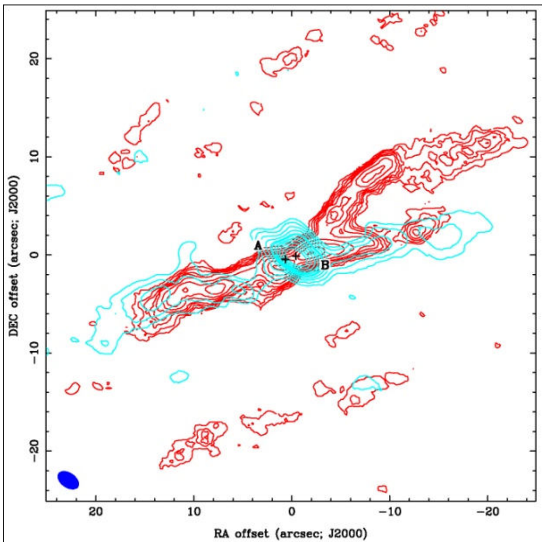

Fig. 2: ^{12}CO Intensity Integrated map: Blue and red shifted components are shown in Cyan and Red, respectively. Contours are in steps of: Cyan: 4, 7, 11, 15, 19, 21, 25, 29, 35, 43, 51; Red: 5, 9, 13, 17, 21, 29, 37, 45, 53; times an rms noise of 0.33 Jy/beam km/s. Source positions were taken from Looney et al. (2000)

2.1. ^{12}CO (3-2):

The ^{12}CO emission traces the outflow of VLA1623 with its overlapping red- and blue-shifted lobe morphology. Figure 1 and 2 show the outflow morphology. We propose the presence of two outflows based on the comparison of the red- and blue-shifted components. From Figure 1 we observe that the blue-shifted knot around the sources diminishes at higher velocities but does not disappear throughout the respective velocity range, whereas the red-shifted lobes break up in the center at higher velocities and at lower velocities have a pinched shape. The lobes also present different structures, most noticeably the branched red lobe in contrast to the collimated blue lobe in the NW.

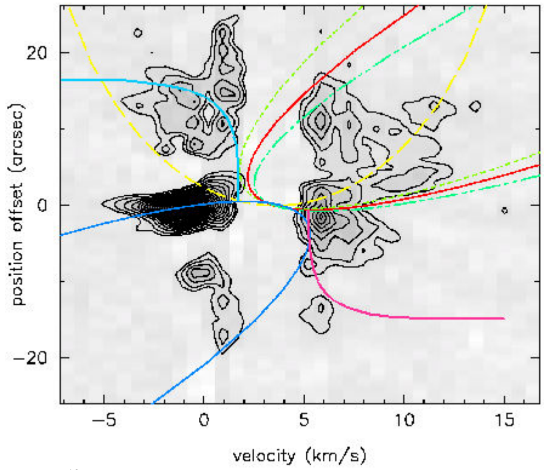

Fig 3: ^{12}CO P-V Diagram: Black dashed lines indicate the systemic velocity (vertical) and source position (horizontal). Parabolic curves correspond to different inclinations of the Wind-driven P-V model: yellow dashed i=0, green dash and dot-dash i=30 and i=40 respectively, solid red and blue i=35. Cyan and Magenta curves are illustrations of the Jet-driven P-V model.

2.1.1. Position-Velocity (P-V) Diagram

To further study the outflows, we produce a P-V diagram of ^{12}CO along the outflow axis (Figure 3) and compare it with the theoretical P-V diagrams by Lee et al. (2001). The wind-driven case is characterized by a parabolic structure extending to higher velocities at large inclinations, whereas the jet-driven case shows spur structures with shorter projected distances as inclination increases. From this we determine that the NW red and SE blue lobes are closer to the wind-driven case, while the SE red and NW blue lobes are similar to the jetdriven case. To fit the NW Red and SE Blue lobes we use Lee et al. (2001)'s P-V diagram model for the wind-driven outflow which is a modified version of the original Momentumdriven shell to include the mass added to the shell by the wind. The fitting is merely illustrative as the parameters used are those given in Lee et al. (2001) with a time scale of ~3000yr (Andre et al. 1990, 1993). For the SE red and NW blue lobes, the curves are only illustrative.

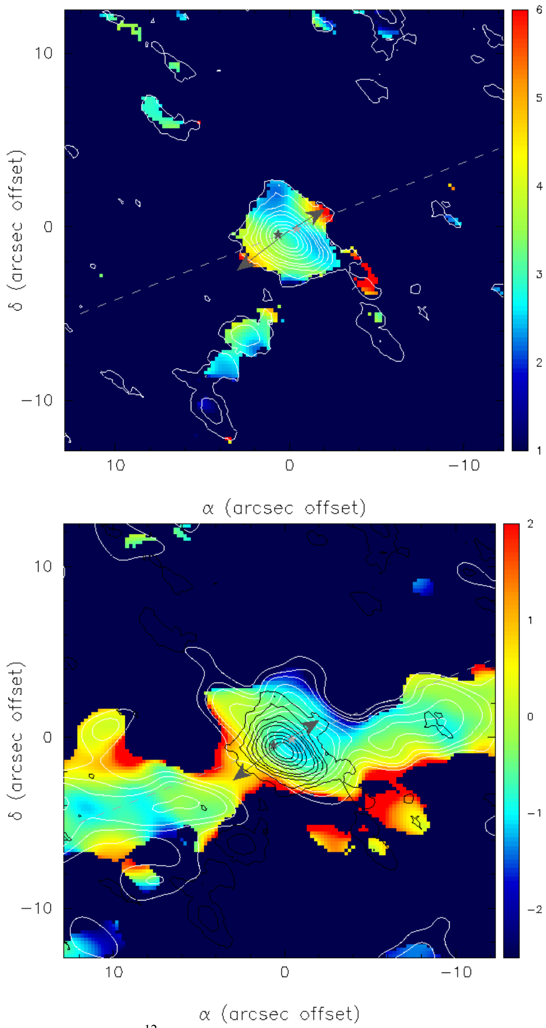

Fig. 4. SO and ^{12}CO Integrated maps: Above: SO emission. Below: ^{12}CO (color scale and white contours) with SO (black ontours) emissions. The color scale shows the velocity integrated map while the contours show the intensity integrated maps. Source positions are marked with dark grey (A) and light grey (B) pentagrams. Dashed line indicates the outflow axis and the arrows the velocity gradient direction.

2.2. SO (9-8):

The SO emission is centered around the sources, with a weak south branch and a mainly blue-shifted velocity range of 0.17 to 4.4 km/s. Previous studies indicated VLA1623's SO emission traced envelope material (Jorgensen et al. 2004). The velocity integrated map of the emission reveals an expanding velocity gradient from the center outwards which is parallel to the outflow axis, suggesting the SO emission traces a shock instead. This is supported by comparing the SO and ^{12}CO emissions, although their velocity gradient range differs, their velocity gradient direction closely match, with both of them showing expansion from the center outwards, parallel to the outflow axis (Figure 4).

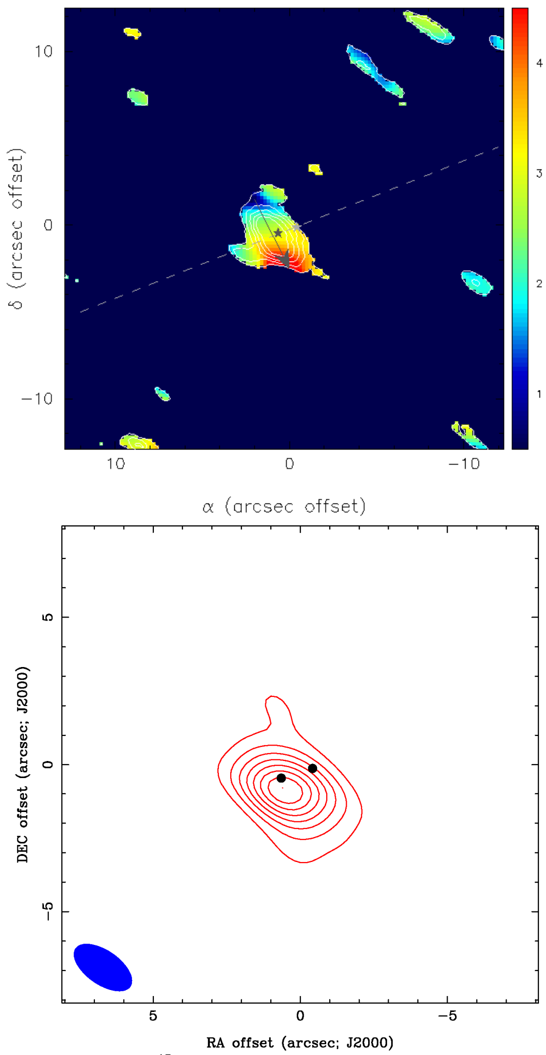

Fig. 5: Above: $C^{17}O$ Intensity and Velocity integrated map: The color scale shows the velocity integrated map and the contours show the intensity integrated map. The dashed line indicates the outflow axis, with the arrow showing the direction of the velocity gradient. Sources are marked with a dark grey (A) and light grey (B) pentagrams. Below: Dust Continuum: Contours are in steps of 1, 2, 3, 4, 5, 6, 7 times an rms noise of 0.078. The synthesized beam (2".32 × 1".41) of our observations in shown on the bottom left. Sources are marked with black circles.

2.3. $C^{17}O$ (3-2) and Dust Continuum:

VLA1623's envelope is traced by the $C^{17}O$ emission. The detected emission is centered about VLA1623A with a velocity range of 1.3 to 4.9 km/s which is closer to the systemic velocity. $C^{17}O$'s velocity gradient is perpendicular to the outflow axis and in the direction of the emission's elongated structure (Figure 5. Above), suggesting that VLA1623's envelope presents rotation.

Continuum (λ=0.87mm) provided strong dust emission surrounding the two sources without resolving the two sources VLA1623 A and B.

3. Conclusions

We propose that the morphology of VLA-1623's outflow is product of two outflows, each one being driven by one source of the binary system. Furthermore, we suggest that outflow interaction between the two blue-shifted lobes occurs with the SO emission tracing the interaction shock. This strengthens the argument that VLA1623 is in fact a protobinary system with each source driving its own outflow. The velocity gradient of the $C^{17}O$ emission tracing VLA1623's envelope shows rotation perpendicular to the outflow axis with an elongated structure. Dust continuum presents a smooth structure surrounding the two sources without resolving them.

Although we are able to discern two outflows from their morphology and structure, we can not pinpoint each outflow's driving source nor resolve the two sources due to the resolution of our observations. Higher resolution observations are thus required. In addition, further observations with higher velocity and spatial resolution will allow us to further study the origin of the $C^{17}O$ and SO emissions.

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