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UNVEILING COMPLEX OUTFLOW STRUCTURE OF UY Aur †

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ABSTRACT

We present [Fe II] λ 1.257 μm spectra toward the interacting binary UY Aur with 0.″14 angular resolution, obtained with the Near infrared Integral Field Spectrograph (NIFS) combined with the adaptive optics system Altair of the GEMINI observatory. In the [Fe II] emission, UY Aur A (primary) is brighter than UY Aur B (secondary). The blueshifted and redshifted emission between the primary and secondary show a complicated structure. The radial velocities of the [Fe II] emission features are similar for UY Aur A and B: ~ -100 km s^{-1} and $\sim +130$ km s^{-1} for the blueshifted and redshifted components, respectively. Considering the morphologies of the [Fe II] emissions and bipolar outflow context, we concluded that UY Aur A drives fast and widely opening outflows with an opening angle of $\sim$90° while UY Aur B has micro collimated jets.

Key words: ISM: jets and outflows — techniques: high angular resolution — stars: individual (UY Auriage) — stars: low-mass — stars:formation — stars: pre-main-sequence

1. INTRODUCTION

Many young stars are binary or multiple systems (Mathieu, 1994; Zinnecker & Mathieu, 2001; Duchêne et al., 2007). Recent studies show that binarity is common in protostars (Haisch et al., 2004; Connelley et al., 2008a,b; Chen et al., 2013). The binary frequency in the TMC (Taurus-Molecular Cloud) is 48.9 % ± 5.3 % (Köhler & Leinert, 1998), which is somewhat higher than the 9 %-32 % seen in other nearby star forming regions (King et al., 2012a,b).

Although multiplicity is common in star forming regions, jets or outflows have been observed from a few tens of multiple low-mass young stars (Reipurth, 2000; Takami et al., 2003; Murphy et al., 2008; Mundt et al., 2010). Multiple jets from a binary system can be explained if the jets emanate from each single star-disk system (e.g. L1551 IRS5: Fridlund & Liseau, 1998; Rodríguez et al., 1998; Itoh et al., 2000; Pyo et al., 2002, 2005). Binary systems may show only one single jet or outflow. Murphy et al. (2005, 2008) suggested that one of the binary jets could be destroyed or engulfed by interaction between or merging of the two jets. Machida et al. (2009) and Mundt et al. (2010) showed a single outflow can be launched from a single circumbinary disk. Reipurth (2000) postulated that the dynamical decay of multiple systems causes outflow.

UY Aur is a close binary system of classical T Tauri stars with 0.″89 separation (Close et al., 1998; Duchêne et al., 1999; Hioki et al., 2007). Hirth, Mundt, & Solf (1997) identified an extended micro redshifted jet, HH 386, which has a position angle of $\sim$ 220° in [O I] and [S II] optical forbidden emission lines. They also reported that a blueshifted optical jet was evident in a 1992 observation but not in their published data. The driving source of the jets was not clear in their data due to insufficient spatial resolution to resolve the binary system.

In this paper, we focus on high-resolution [Fe II] λ 1.257 μ emission maps obtained with the integral field spectrograph, *NIFS*, at the Gemini North Observatory,

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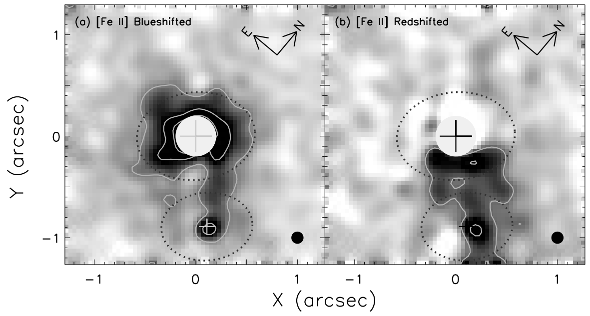

Figure 1. (a) Blueshifted [Fe II] emission integrated over the range $-150 < V_{\rm LSR} < -60$ km s^{-1}. (b) Redshifted [Fe II] emission integrated over the range $+60 < V_{\rm LSR} < +200$ km s^{-1} . The dotted ellipses indicate the effective Roche lobe radii projected on the sky for each star. UY Aur A (primary) is located at the center of the images, while UY Aur B (secondary) is located near the central bottom. The star locations are marked with + symbols. The oval in the lower-right corner of each panel shows the spatial resolution of 0.″14.

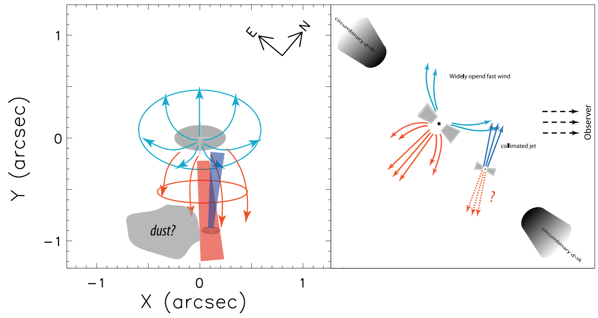

Figure 2. ($left$) Interpretation of the redshifted and blueshifted [Fe II] emission. ($right$) Schematic drawing of the UY Aur binary and their outflow and jet.

which show the complicated structure associated with the UY Aur system.

2. OBSERVATIONS AND DATA REDUCTION

The observation was done with the AO-fed NIR integral field spectrograph NIFS (McGregor et al., 2002) at the Gemini North Observatory on 2007 February 13 through the Subaru-Gemini time exchange program. We acquired spectra in the 1.06 – 1.28 μm range in order to get He I λ 1.0833 μm, Paγ λ 1.094μm, and [Fe II] λ 1.257 μm, simultaneously. The spectral resolution is R $\sim$ 5000. The field of view is 3″×3″ with a pixel scale of 0.″1×0.″04. The total on-source integration time was 1680 s (= 120 s × 14 frames). The position angle was 40° along the Y-axis. The final spatial resolution was 0.″14 with AO correction, while the average natural seeing was 0.″6–0.″85.

We reduced our data following the standard NIFS data reduction process with the Gemini IRAF reduction packages (Beck et al., 2008). More detailed information about the observation and data reduction is described in Pyo et al. (2014).

3. BLUESHIFTED AND REDSHIFTED [Fe II] emission

The [Fe II] λ 1.257 μm emission was marginally detected at greater than 3σ of the background noise from both stars (Figure 1 in Pyo et al., 2014). The emission lines show double peaks at -100 km s^{-1} and $+130$ km s^{-1}

Figure 1a and 1b show images of the blueshifted and redshifted [Fe II] emission, respectively. Note that we exclude the ambient emission between -60 and $+60$ km s^{-1} in Figure 1. The blueshifted emission is surrounding the primary and shows a 'bridge' structure connected to the secondary, while the redshifted emission is widespread to the south-west of the primary with 0.″2 offset at Y $< -0.″1$ and an extended narrow ridge beyond the secondary. The [Fe II] emission is brighter around the primary than around the secondary.

The velocity structure between the primary and secondary is complicated due to overlapping blueshifted and redshifted emission features. A narrow 'bridge' structure connecting the primary and secondary disks has been predicted in simulations of circumbinary disks as a shock front between colliding accretion flows (Günther & Kley, 2002; Hanawa et al., 2010; Fateeva et al., 2011). However, it is difficult to understand the high velocity features seen in our data as a result of colliding flows between the two circumstellar disks. The accretion flows should have Keplerian velocities about a few km s^{-1} at the edge of the circumstellar disks. On the other hand, the terminal velocity of an outflow is comparable to the Keplerian rotation velocity of a disk at the launching region (Kudoh, Matsumoto, & Shibata, 1998). Thus the fast velocities of the emission can be explained by outflows launched from the vicinity of the central stars.

The geometrical distribution of [Fe II] emission from the primary suggests a wind with a wide opening angle. We note that a similar wide opened fast wind has been reported from L1551 IRS 5 (Pyo et al., 2002, 2005, 2009). The gap of 0.″2 between the primary and the redshifted emission can be explained by the optically thick circumstellar disk of UY Aur A. A similar gap between the central star and redshifted emission was found in DG Tau and HL Tau (Pyo et al., 2003, 2006). The narrow blueshifted and redshifted ridges can be understood as well collimated micro jets emanating from the secondary and from the primary, respectively. Figure 2 shows a schematic drawing of the outflow/jet structure of the UY Aur binary system. Figure 3 is the artistic view of the UY Aur system.

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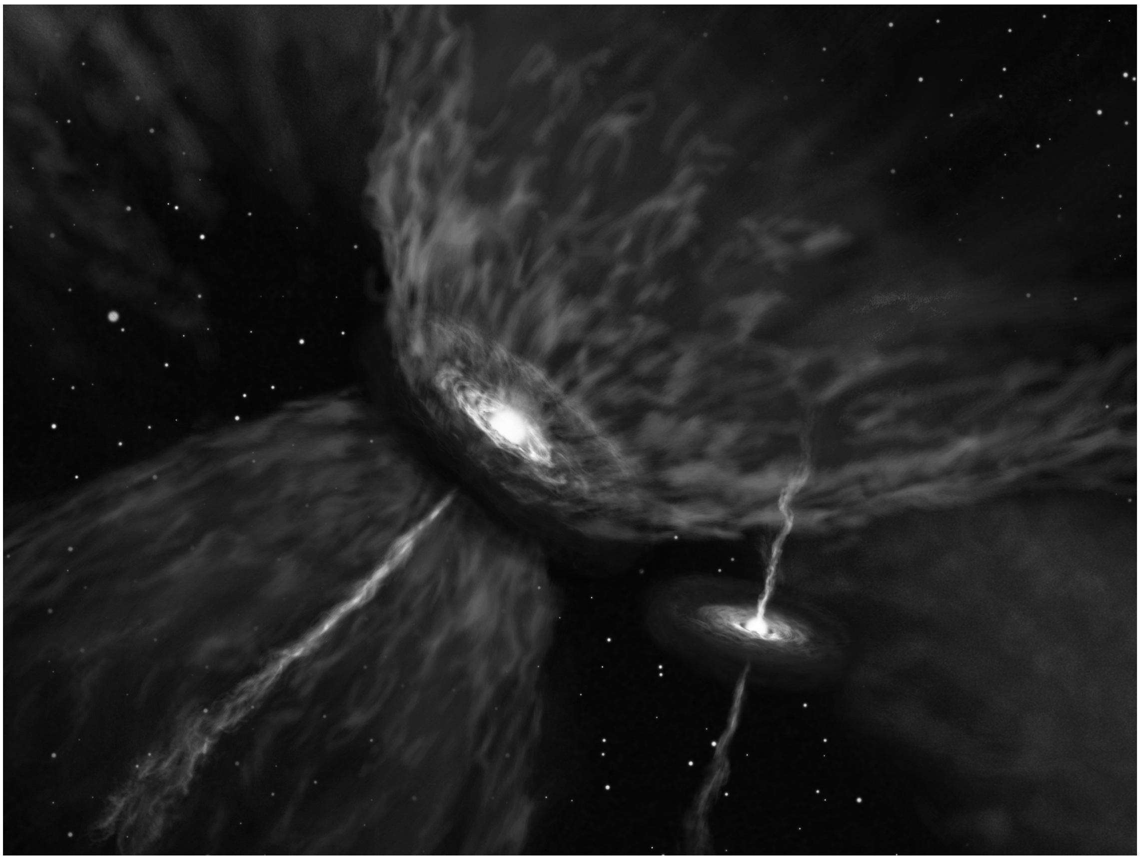

Figure 3. Artistic view of the outflows and jets of UY Aur binary system. Image courtecy of Subaru Telescope, National Astronomical Observatory of Japan (NAOJ).

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