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Twisted Jets from L1551 IRS5

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Subaru Telescope

Abstract. We have carried out high-resolution near-infrared imaging observations of a protostar L1551 IRS 5 with the Subaru Telescope. The jet structure of IRS5 is resolved into two independent jets for the first time from the ground. Successive near-infrared spectroscopy has revealed that the jet emission is dominated by [Fe II] lines in the J and H-bands. While the visual-extinction reaches more than 20 mag in the close vicinity of IRS 5, it decreases rapidly at ~1" from IRS 5 and remains constant around 7 mag at larger distances. The twisted structure and bright emission knots are intrinsic to the jets, not due to a spatial variation of the extinction.

1. Introduction

L 1551 IRS 5 is one of the best-studied young stellar objects associated with an optical jet (Mundt & Fried 1983), a molecular outflow (Snell et al. 1980; Uchida et al. 1987), and Herbig-Haro objects (Davis et al. 1995; Hodapp & Ladd 1995). Recent high-resolution observations have revealed details of L 1551 IRS 5 (hereafter referred as IRS 5) and its close vicinity. VLA observations discovered two thermal dust emission sources separated by ~ 40 AU from each other, suggesting a young binary system embedded in a circumbinary disk (Rodríguez et al. 1998).

At optical wavelengths, extensive studies have focused on the jet emanating from IRS 5. High-resolution observations have revealed two rows of knots, which have been interpreted as a structure caused by the precession of a single jet (Campbell et al. 1988; Fridlund & Liseau 1994) or the limb-brightening of a single jet (Mundt et al. 1991). Recently, however, Hubble Space Telescope (HST) observations have resolved the 'jet' into two separate features showing different velocities and velocity gradients, suggesting two independent jets, possibly arising from each star of the binary system (Fridlund & Liseau 1998).

2. Observations

Near-infrared imaging observations of IRS 5 were carried out on 1999 January 14 using the Subaru Telescope at the summit of Mauna Kea, with the infrared camera CISCO (Motohara et al. 1999) mounted at the F/12 Cassegrain focus. CISCO is equipped with a 1024 × 1024 pixel HgCdTe array with a pixel scale of $0\farcs116$ pixel^{-1}, providing a total field of view of 118″ square. Under a seeing

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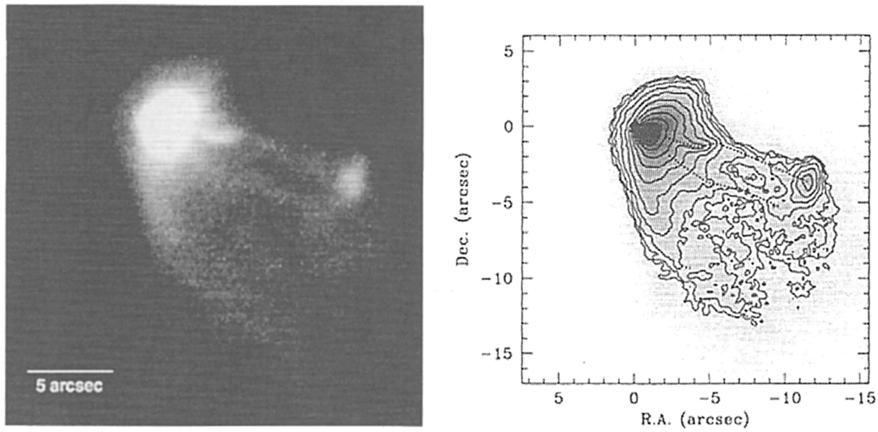

Figure 1. (left) J-band image of IRS 5. The field of view is 23″ × 23″. A logarithmic intensity transfer table was used. North is up, and east is toward the left. (right) J-band contour map of IRS 5. The positions of compact radio continuum sources IRS 5 are shown by filled triangles. The peak-intensity positions along two jets are traced by dotted lines. Contours are drawn in log scale.

condition of 0.″4 (FWHM), sixteen exposures of 10 s each were obtained at the J-band, and fifteen exposures of 0.5 s each at the K' (2.13 μm) band.

The J and H-band spectra were obtained on 1999 February 28 with the Subaru telescope utilizing the JH-grism spectroscopy mode of CISCO, which provided a spectral resolution of $\sim$ 280 at 1.4 μm. Typical FWHM of the point-spread function was again 0.″4 throughout the observations. A 1″ width slit, aligned north-south, was used, and IRS 5 was observed at 9 positions with 15″ dithering along the declination to provide sky subtraction. Three exposures of 20 s each were made at each slit position. The overall uncertainty for the absolute slit positions is $\sim$ 0.″15. SAO 93986 (A3 V) was used as a standard star for spectral calibration.

3. Results and Discussion

3.1. Two Jets of Ionized Iron

Figure 1 (left) shows the J-band image of the central 23″ region around IRS 5 in log scale, as well as a contour presentation in figure 1 (right). On the contour plot the peak positions along each jet are traced. While the two jets are relatively straight and parallel to each other at positions more than 4″ away from IRS 5, they change flow directions in the inner section and converge on a compact region, where two sources were discovered emitting a thermal dust continuum (Rodríguez et al. 1998). The northern jet is ejected along a position angle (PA) of 254° near to the origin, changing its direction slightly to the north with PA = 280° at a distance of 4.″3, and then turning to the south with PA = 247° at a distance of 5.″7. The southern jet, on the other hand, is initially ejected toward

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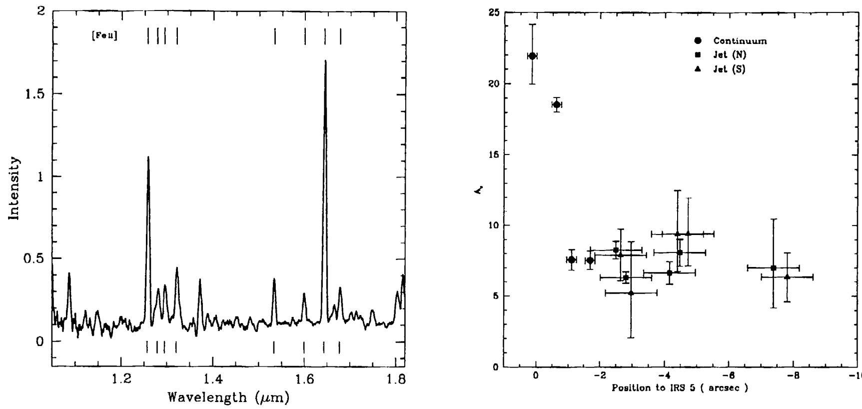

Figure 2. (left) JH-band spectrum of the northern jet. The wavelength of the [Fe II] lines are shown by bars at the top and bottom of the figure. (right) Visual extinction estimated from the line ratios of the [Fe II] lines. The positions are measured in the direction of the jets.

the southwest with PA = 233°, making a change of direction to the north with PA = 258° at 6.″0, and turning to PA = 245° at 8.″2 from IRS 5.

Figure 2 (left) shows a JH-grism spectrum of the northern jet at 2.″4 west of the radio continuum source along the northern jet. Most of the spectral features are identified as [Fe II] emission lines, as indicated in the figure.

3.2. Extinction

The extinction to the jets was estimated from the flux ratio of the [Fe II] 1.644 μm / 1.257 μm lines, assuming an intrinsic ratio of 0.74 (Nussbaumer & Storey 1988). The spatial variation of visual extinction toward the jets is shown in figure 2 (right). A maximum visual extinction of 22 mag was observed toward the center of IRS 5, consistent with the previous measurements (Ladd et al. 1995; Fuller et al. 1995). The high extinction toward of IRS 5 and its rapid decrease at a distance of 1″ may be due to the compact dust disk (Lay et al. 1994) or the inner part of the infalling gas disk (Ohashi et al. 1996; Momose et al. 1998).

The extinction in the outer section (more than 1″ away from IRS 5) is around 7 mag, and is constant within the measurement uncertainties. This again demonstrates that the brightness variation and twisted structure of the jets is not due to inhomogeneities in the circumstellar matter distribution, but is intrinsic to the jets.

3.3. The Twisted Structure

The similarities in the morphology between the J and HST-R-band jets, together with the relatively homogeneous extinction toward them, affords evidence that the twisted pattern and knotty appearance is intrinsic to the jets. It may not be straightforward, however, to understand the physical mechanism responsible for such a zigzag structure.

The precession of the driving stars is often invoked as the cause of such wiggly patterns observed in galactic and extragalactic objects (Terquem et al. 1999). It may be difficult to apply the to the present case, however, when we consider the dynamical time scales. The time scale of the jets is $\sim$ 30 yr if we assume a jet speed of 300 km s^{-1}. The precession time scale, if the twisted pattern is produced by precession, might thus have a time scale of $\sim$ 10 yr, which is more than an order of magnitude smaller than the orbital period of $\sim$ 250 yr for a binary system of 0.5 $M_{\odot}$ stars separated by 40 AU. Moreover, the jet appearance is not sinusoidal either, which we would expect if periodic precession is the main cause of the zigzag pattern.

Several small jets may emanate from IRS 5 with various directions of ejection. Alternatively, twisted magnetic fields may affect the structure of the jets.

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