Proper Motions and New HH Knots in the L1551 Region

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Abstract
We present proper motions of Herbig Haro (HH) objects in the star forming region of Lynds 1551, using CCD optical images obtained in 1997 and 2001 with the MOSAIC detector mounted on the Mayall 4 meter telescope at Kitt Peak National Observatory. We used narrow-band filters centered on the H$_\alpha$ and [SII] emission lines. The proper motion values and directions provide clues to the probable sources of each set of HH objects. We have also detected new HH knots in the optical images.

Introduction
Star formation processes are accompanied by outflows that shock and excite the surrounding material in the molecular clouds. As this material cools down, it emits, appearing to us as Herbig Haro (HH) objects.

The Lynds 1551 dark cloud is a nearby (140 pc) star-forming region that has been extensively studied using various techniques (e.g., Strom et al., 1976; Stroh et al., 1998). It is a very active star-forming region, with several young stars driving outflows that sometimes overlap, creating a very complex array of HH objects. The outflows in L1551 are of particular importance for the study of the shock interaction with a molecular cloud.

The L1551 cloud contains two centers of outflow activity. The northern one encompasses jets and outflows from sources such as HL Tau, TX Tau and H340 IRS. The southern one contains numerous HH knots, like HH 28, 29, 258, 259, among others. The two main probable sources are L1551-IR5 and L1551-NE, two very young embedded stars. It was previously thought IRS 5 was responsible for most of this lobe, but Devine et al. (1999) argued that HH 28 and HH 29 are most likely driven by L1551-NE.

Observations
We have used the wide field CCD imager MOSAIC at the KPNO Mayall 4 m telescope to obtain images of the L1551 region in October 1997 and October 2001. MOSAIC consists of eight 2048 X 2048 pixel CCDs arranged as an 8192 X 8192 pixel detector. The CCDs are separated by 50 pixel gaps. On the 4 m telescope, pixels are 0.26 arcsec on the sky, providing a field of view of approximately 365 x 365. We used the H$_\alpha$ and [SII] narrow-band (FWHM = 80 Å) filters, centered at 6562Å and 6730Å, respectively, in sets of 5 dithered 600 second exposures. We also used the SDSS 1 broadband filter, centered on 7532Å with FWHM of 154Å, to obtain one 60 second exposure used for comparison. The images were reduced using the IRAF package MSCRED, which is designed especially for the reduction of images from mosaic CCD detectors (Valdes, 2001). In order to measure the proper motions of the HH knots, the images were scaled in intensity, rotated to the same orientation and corrected for geometric distortions using standard procedures from IRAF. Around one thousand stars in the whole field were used as reference for the registration, statistically avoiding systematical errors due to proper motion of some stars. The final images are aligned with a precision of ~0.2 pixel, corresponding to 0"05, which varies accordingly to the star density in the area.

Proper Motions
The proper motions were measured using a code written by Jon Morse (Morse et al., 2001), based on a difference squared cross correlation algorithm developed by Currie et al. (1996). It calculates the square differences between an emission feature from one epoch to another, inside a rectangular region, for a set of shifts on both axes. This generates a correlation image whose maximum is at the position of the shift that corresponds to the best alignment of the features. Using a centroid algorithm, the position of the maximum, and thus of the shifts, is determined.

The figures 2 to 4 show details of selected regions with the boxes used for the proper motions determination and the arrows indicating the amount of proper motion between 1997 and 2001.

New Outflow Features
Examining the H$_\alpha$ and [SII] images and comparing with the broad-band filter image, we found a few new HH knots. HH 492, 493 and 707, to the northeast and southwest of the main complex. They are indicated in the figure 6. HH 707 is seen only in H$_\alpha$, it consists of two knots, of which the easternmost is bow shaped. They are located along well defined flow axes of L1551-NE and L1551-IRS5, and therefore are likely to be a result of either of these two outflows. The pronounced bow of HH 707A faces towards the two embedded sources, making it likely that we are seeing a small clump of dense gas that is being overtaken by the aforementioned outflows.

References

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