

## NEW NEBULAR OBJECTS IN THE L1551 REGION (Research Note)

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### RESUMEN

Hemos suavizado a una resolución angular de  $10''$  una imagen digitalizada de la placa roja del Palomar Sky Survey. Esta imagen suavizada revela la presencia de una cadena de 7 nebulosidades, de las cuales las dos más brillantes son los objetos Herbig-Haro 28 y 29. Esta cadena parece delinear el borde sureño de la cavidad de la componente corrida al azul del flujo bipolar molecular. La misma imagen suavizada muestra, al final del lóbulo corrido al rojo del flujo bipolar, dos nebulosidades (posiblemente objetos HH) que podrían ser una manifestación óptica de la componente corrida al rojo del flujo bipolar en L1551.

### ABSTRACT

We have smoothed to an angular resolution of  $10''$  a digitized PSS red image of the L1551 region. This smoothed image reveals the presence of a chain of 7 nebulosities, the two brightest of them being the Herbig-Haro objects 28 and 29. This chain seems to delineate the southern limb of the blueshifted outflow cavity observed in molecular lines. The same smoothed image shows, at the end of the redshifted molecular outflow lobe, two nebulosities (probably HH objects) that may be an optical manifestation of the redshifted component of the L1551 bipolar outflow.

**Key words:** HERBIG-HARO OBJECTS – HYDRODYNAMICS – NEBULAE-INDIVIDUAL

### I. INTRODUCTION

The molecular cloud L1551 contains the best studied bipolar molecular outflow and has been the subject of extensive research since the outflow was detected by Snell, Loren and Plambeck (1980). A recent review of the region has been given by Strom *et al.* (1986). The blueshifted lobe of the bipolar outflow is associated with the HH objects 28, 29 and 102. There is no reported optical manifestation of the redshifted component of the outflow, presumably because these motions are taking place deeper into the cloud.

It is known that HH objects and other nebulosities can be spatially extended over a scale of tens of arc seconds or more. Under these circumstances, spatial smoothing of an optical image can enhance faint, extended structures not obviously evident in the original image. In this note we report the detection of several such structures in the L1551 cloud.

### II. THE DATA

Our data consisted of the L1551 image digitized from the red Palomar Observatory Sky Survey glass plates by Klinglesmith and Hollis (1987). This image has a size of  $1024 \times 1024$  pixels with a pixel size of 1.3 arcsec. This image was convolved with a circular Gaussian function

of HPFW of  $10''$  using the task CONVL of the Astronomical Image Processing System (AIPS) developed by the National Radio Astronomy Observatory. A contour map of the smoothed image is shown in Figure 1.

### III. THE NEW NEBULOSITIES

In Figure 1 we have identified several well known stellar and nebular objects in the region. We have also marked with crosses the positions of the infrared sources L1551 IRS5 (Strom, Grasdalen and Strom 1974) and L1551 NE (Emerson *et al.* 1984). We note the presence of two interesting sets of nebulosities. The first set is a chain of 7 nebulosities (marked with arrows in Figure 1) to the SW of L1551 IRS5. The positions of these nebulosities are given in Table 1. The two brightest of these nebulosities are the HH objects 28 and 29. Another two objects in the chain have been recently studied by Stocke *et al.* (1988), who found them to have spectra of HH objects. These two nebulosities are marked, following Stocke *et al.*, with the numbers 229 and 220 in Figure 1. The 7 nebulosities form an arc that extends over  $\sim 10'$ . The nebulosities seem to have a characteristic separation of  $\sim 1'$ , about 0.05 pc at a distance of 160 pc. The arc formed by these nebulosities seems to be symmetric with respect to the less complete arc delineated by HH102.

It is known, from high-angular resolution maps of the high-velocity CO (Uchida *et al.* 1987; Moriarty-Schieven and Snell 1988), that the blueshifted lobe in L1551 ex-

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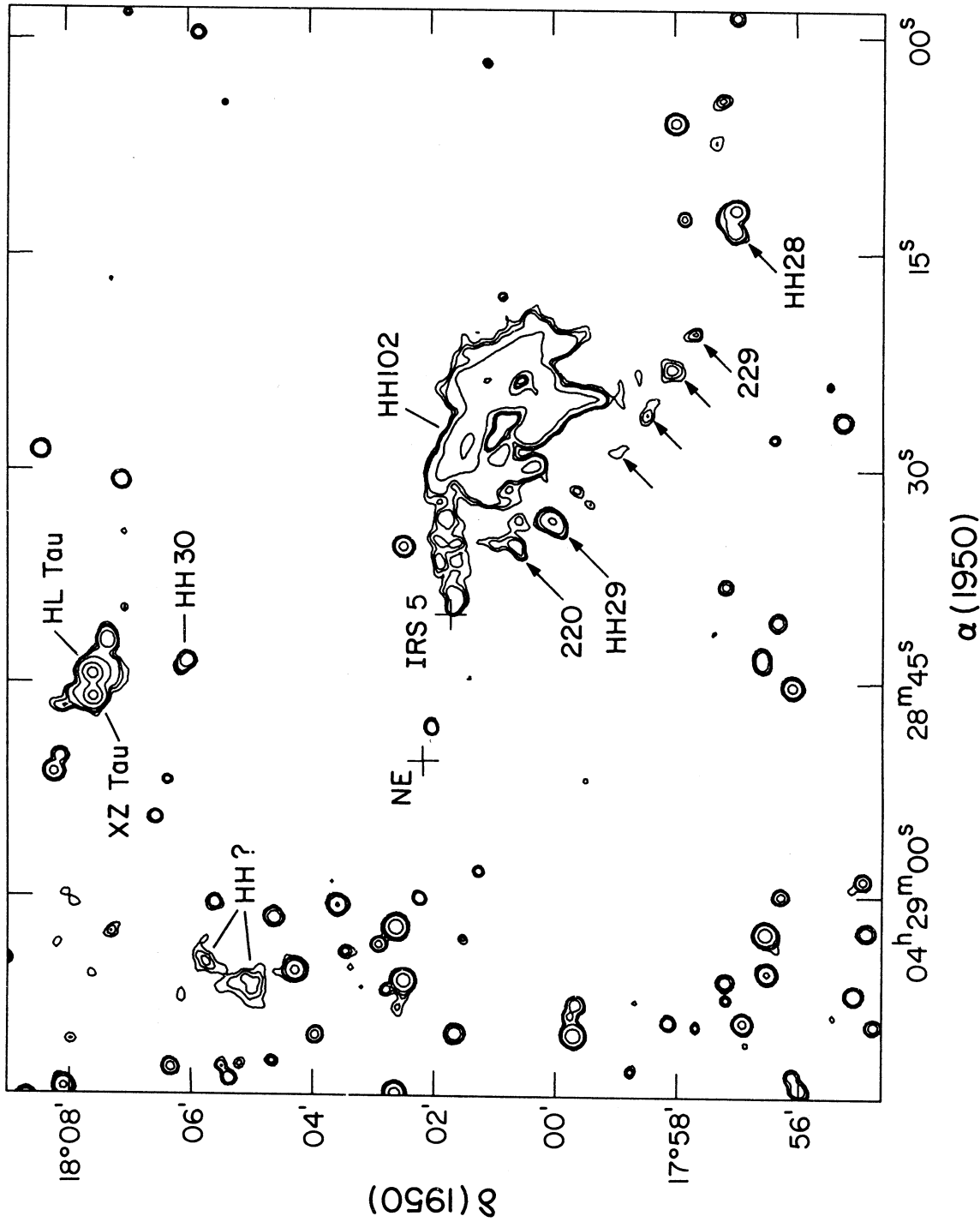


Fig. 1. Contour map of the smoothed L1551 image. Contours are 3.7, 3.9, 4.1, 5.0, 10.0, and  $20.0 \times 10^3$  density units per beam. The peak value in the map is  $27.2 \times 10^3$  density units per beam. These values have only a relative meaning since the PSS plates do not have a reference density wedge for absolute calibration. Several objects in the region are indicated. The infrared sources L1551 IRS5 and L1551 NE are marked with crosses. The 7 nebulosities forming the arc-shaped chain are indicated with arrows. The numbers 229 and 220 are after the nomenclature of Stoeckel *et al.* (1988). The two suspected HH objects to the NE of L1551 IRS5 are marked as (HH?).

TABLE 1

## NEBULOSITIES IN ARC-SHAPED CHAIN

Number	$\alpha(1950)$	$\delta(1950)$	Comment
1	04 <sup>h</sup> 28 <sup>m</sup> 12.5 <sup>s</sup>	17°57'00"	HH Object (HH28)
2	04 28 20.5	17 57 39	HH Object (229)
3	04 28 23.0	17 58 02	...
4	04 28 26.1	17 58 27	...
5	04 28 28.8	17 58 59	...
6	04 28 33.6	18 00 01	HH Object (HH29)
7	04 28 35.3	18 00 37	HH Object (220)

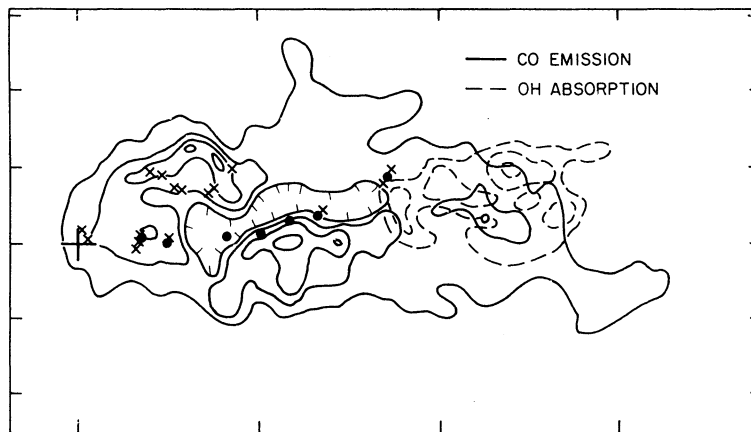


Fig. 2. Blueshifted lobe of the L1551 bipolar outflow. The solid lines are selected contours from the high-velocity blueshifted CO map of Moriarty-Schieven and Snell (1988). Note the depression at the center of the lobe, that indicates a possible shell-like morphology for the high-velocity CO. The dashed contours mark the location of the high-velocity blueshifted OH, observed in absorption by Rodríguez *et al.* (1989). The large cross indicates the position of L1551 IRS5, the exciting source of the system. The positions of the HH-like nebulosities discussed by Stocke *et al.* (1988) are marked with an X, while those discussed here are marked with a solid circle. Note that most of the HH objects appear projected along the inner walls of the cavity. The horizontal axis of this figure is aligned at a position angle of 45° in the sky. The tick marks in the horizontal axis are separated by 5 arcmin.

hibits limb brightening, suggestive of a shell geometry. We have superposed the positions of the HH-like nebulosities studied by Stocke *et al.* (1988) and those discussed here on the CO map of the blueshifted lobe shown by Moriarty-Schieven and Snell (1988). This superposition is shown in Figure 2. In this figure we also show the position of L1551 IRS5 and the blueshifted OH lobe seen in absorption by Rodríguez *et al.* (1989).

Figure 2 shows that the nebulosities delineate the inner walls of the cavity seen in high-velocity CO. We conclude that the nebulosities are probably located at the interface between the stellar wind (with velocities of a few hundred km s<sup>-1</sup>) and the accelerated molecular gas (with velocities of a few tens of km s<sup>-1</sup>). The char-

acteristic spacing of the nebulosities suggests that they may have its origin in a Kelvin-Helmholtz instability.

The second set of interesting nebulosities consists of two nebular objects about 7' to the NE of L1551 IRS5 (Figure 1). The positions of these objects are given in Table 2. These nebulosities appear at the end of the redshifted lobe of the bipolar outflow, at a position near the cloud boundary. There is no spectroscopic information on these objects, but we speculate they may be redshifted HH objects. In Figure 1 it can be seen that these new nebulosities and HH28 are located symmetrically with respect to L1551 IRS5, supporting the proposition that the NE nebulosities may be a redshifted counterpart of the known blueshifted HH objects. Detailed radial

TABLE 2

POSITIONS OF SUSPECTED HH OBJECTS

Number	$\alpha(1950)$	$\delta(1950)$
1	04 <sup>h</sup> 29 <sup>m</sup> 04.6 <sup>s</sup>	18°05'45"
2	04 29 05.8	18 05 06

velocity and proper motion studies of these nebular objects are required to test if they are indeed powered by L1551 IRS5, and are thus counterparts of HH28.

IV. CONCLUSIONS

A spatially-smoothed, digitized image of L1551 shows the presence of two remarkable sets of nebulosities. The first is a chain of objects that may be delineating the southern limb of the blueshifted lobe of the bipolar outflow. The second set is formed by two nebulosities about 7' to the NE of L1551 IRS5. We propose that these nebular objects may be the redshifted counterparts of the known HH objects in the region.

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REFERENCES

Emerson, J.P. *et al.* 1984, *Ap. J. (Letters)*, 278, L49.  
Klinglesmith, D.A. and Hollis, J.M. 1987, *Ap. J. Suppl.*, 64, 127.  
Moriarty-Schieven, G.H. and Snell, R.L. 1988, *Ap. J.*, 332, 364.  
Rodríguez, L.F., Cantó, J., Mirabel, I.F., and Ruiz, A. 1989, *Ap. J.*, 337, 712.  
Snell, R.L., Loren, R.B., and Plambeck, R.L. 1986, *Ap. J. (Letters)*, 239, L17.  
Stocke, J.T. *et al.* 1988, *Ap. J. Suppl.*, 68, 229.  
Strom, S.E., Grasdalen, G., and Strom, K.M. 1974, *Ap. J.*, 191, 111.  
Strom, K.M., Strom, S.E., Wolff, S.C., Morgan, J., and Wenz, M. 1986, *Ap. J. Suppl.*, 62, 39.  
Uchida, Y. *et al.* 1987, *Pub. Astr. Soc. Japan*, 39, 907.

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