Infrared Line Profiles of Shocked CO and H_2 near NGC2071 IRS1.

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ABSTRACT

Two lines of the fundamental vibration-rotation band of CO at 4.7μm have been detected in emission in the vicinity of NGC2071/IRS1. Velocity-resolved spectra of these two lines (P(3) and P(4)) as well as the neighboring H_2 0-0 S(9) line are presented. The H_2 line has a velocity width of 110 km/s. The three lines have similar velocities of maximum line intensity and are broadened, suggesting that the CO emission, like that of H_2, occurs in shocked-heated gas. The absence of the blueshifted wings of the CO line profiles are due to blueshifted CO emission being absorbed by foreground CO moving towards us and to a lesser extent by absorption due to quiescent CO in the NGC2071 cloud.

1. INTRODUCTION

NGC2071 is a bipolar outflow associated with young stellar objects, located in the dark cloud Lynds 1630, which itself is part of the northern region of the Orion complex.

The region located at the center of the bipolar outflow, NGC2071IR, contains several young stellar objects, visible in the near to mid-IR. IRS1 is one such source which shows all the signs of a YSO.

The effects of a shock front propagating through molecular gas are determined largely by the speed of the shock and the preshock density of the gas. In the simplest case they determine the temperature range in the postshock region and the molecular, atomic and ionic species which are major contributors to the postshock cooling.

Pure rotational line emission from shocked CO has been detected in Orion by Storey et al (1981), in the far-infrared and by Geballe & Garden (1987) in the vibrational band at 5 μm. Sensitive instruments might detect similar phenomena in other less

Table 1: Lines Observed at IRS1

Line Identification	Frequency (cm^{-1})	Peak Velocity (LSR km s^{-1})	Flux (10^{-16} W m^2)
^{12}CO 1-0 P3	2131.6	+12 $\pm$8	0.56
^{12}CO 1-0 P4	2127.68	+10$\pm$8	1.69
^{13}CO 1-0 R9	2131.01	0 $\pm$8	0.18
H_2 0-0 S9	2130.06	-10$\pm$8	1.35

luminous star forming regions where shocked H_2 is present.

2. OBSERVATIONS and RESULTS

A spectrum of NGC2071/IRS1 was obtained at 4.69μm with the United Kingdom Infrared 3.8 m telescope on Mauna Kea, Hawaii, using the cool grating spectrometer, CGS4, on 07 October 1993 (UT). The 300mm focal length camera and the echelle of CGS4 in twelfth order produced the 4.69μm spectrum with a resolving power of 20,000. A slit angle of 55°east of north was used and IRS1 was positioned towards the central row of the slit.

Flux calibration and correction for telluric absorption features were performed by dividing the spectra by that of a standard star and then multiplying the resulting ratio by the blackbody spectral intensity corresponding to the temperature of the standard. The standard used was BS 1543, a F6V star of M magnitude = 2.05. A tungsten lamp was used as a flat and the telluric absorption features in the BS 1543 were used for wavelength calibration.

The spectra reveal two lines of ^{12}CO (P3 and P4) and one of ^{13}CO (R9) easily seen in Figure 1. Relevant data pertaining to them and to the H_2 S(9) line are summarized in Table 1.

The two strong CO lines labelled P4 and P3, each have observed FWHM of 30 $\pm$ 8 km s^{-1}. The FWHM of the H_2 S(9) line at this position is 50 km s^{-1}. The shape of the H_2 S(9) line resembles the S(1) line profile seen in Walther, Robson & Geballe (1991) and Persson et al. (1981). The FWHM of the ^{13}CO line is approximately 20 km s^{-1}.

Figure 1 shows the velocity profiles of the CO and H_2 lines. Figure 2 shows the S9 V_{lsr} profile emission from IRS 1. The position of IRS1 shows a strong S9 velocity peak which is blueshifted. Moving up in Figure 2, the molecular hydrogen continues to be blueshifted, fading a bit and then appearing as a peak at position IRS5. The distance from IRS1 to IRS5 is approximately 5". The S9 line from IRS1 towards the bottom of Figure 2 appears to behave in a similar manner, where the line strength fades a bit before peaking at the position of IRS8a, and the lines appear redshifted in this direction. IRS 5 and IRS8a are suggested to be clumps of shocked H_2 by Walther et al. 1993.

3. DISCUSSION

Comparison of line emissions from different molecules provides information about the physical conditions in shocks (Geballe, 1995). The similarity of the red sides of the line profiles of the CO and H_2 suggests that the line emission occurs in the same gas. Since the H_2 emissions are due to shocks we deduce that the CO emissions are also due to the same shocks, rather than from resonant scattering from nearby infrared sources.

The vibration-rotation band lines of CO are observed in positional coincidence with H_2 lines that are known to be excited by shock waves. When the S(9) line is scaled to the P3 and P4 line the red sides of the profiles match very well, indicating that the CO emission arises in the same shocked gas as the H_2 emission.

Motion, Location and Shape

The presence of broad lines implies a wide range of velocities. The region of H_2 2μm emission is extended well beyond IRS1. Our observations of the H_2 and CO emission at 4.7μm are not as extensive as the 2μm observations, but show that these emissions are extended as well. H_2 S(9) emission is detected as far away as 0.033pc.

Probably one of the more interesting features of the CO line profiles, is the absence of the blueshifted emission, when compared to the H_2 S(9) profile. The CO line emissions appear to be cut off sharply on their blueshifted sides. We suggest that the cut-off at low velocities is due to absorption by foreground quiescent CO in the cloud and at high blueshifted velocities is due to absorption by blueshifted CO in the portion of the outflow which is approaching us. Any successful model must allow redshifted sides of the CO line profiles, which presumably originate on the far side of the outflow, to be detectable.

Figure 2, exhibits the H_2 jet extending 0.033pc from IRS1 in the northeast-southwest direction. H_2 peaks are seen at IRS5, SE of IRS2 and IRS8a. The H_2 found between these positions are fainter. IRS5 is a positions which have been seen to vary over a four year period (Walther et al. 1993). They suggest this is an irradiated part of the cloud, caused by a blueshifted collimated jet from IRS1, and that IRS8a is caused by the reshifted jet. Both IRS5 and IRS8a show no continuum. Northeast of the SE of IRS2 peak the H_2 emission gradually drops away as it reaches the edge of the cloud. To the southwest we see the H_2 peak at position IRS8a before the intensity goes to zero. The red shifted jet terminates at a bowshock approximately 60arcsec southwest (Walther & Geballe, 1995) of IRS1.

4. CONCLUSIONS

1. The CO and H_2 line emission near NGC2071 IRS1 occur in the same shocked gas.

2. The absence of blue sides of the CO line profiles can be explained by absorption of quiescent and blueshifted CO in the foreground, the former from the quiescent molecular cloud and the latter from the outflow. This also suggests a larger opening angle of the outflow.

3. The H_2 data suggests a bipolar jet emanating from IRS1. The jet is blueshifted towards the northeast and reshifted towards the southwest. No continuum is seen in the H_2 spectra, except for close to IRS1 and a hint of it near SE of IRS2. This suggests IRS5, IRS8a and SE of IRS2 are true clumps of shocked H_2 caused by the jet from IRS1.

5. REFERENCES

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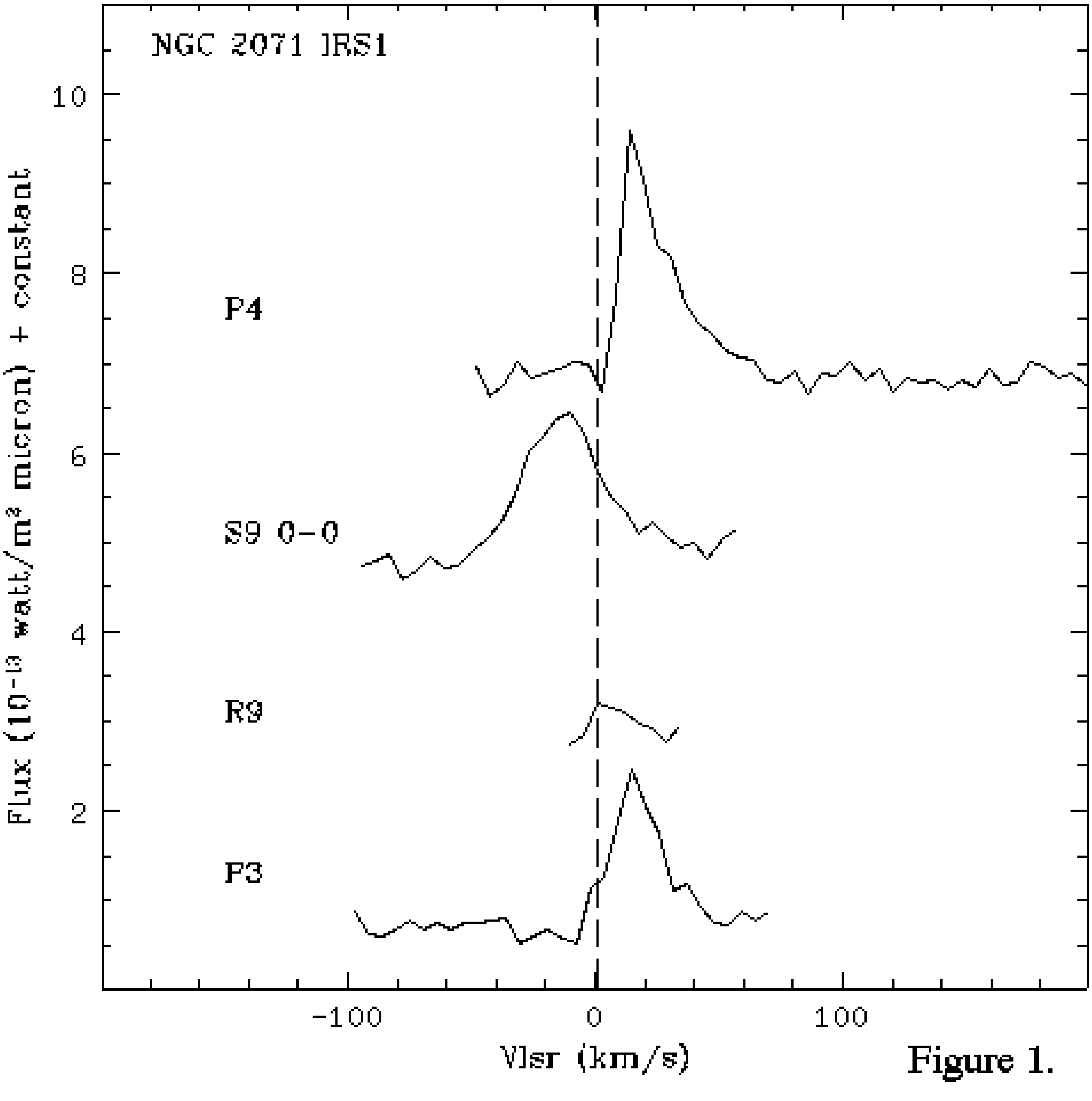
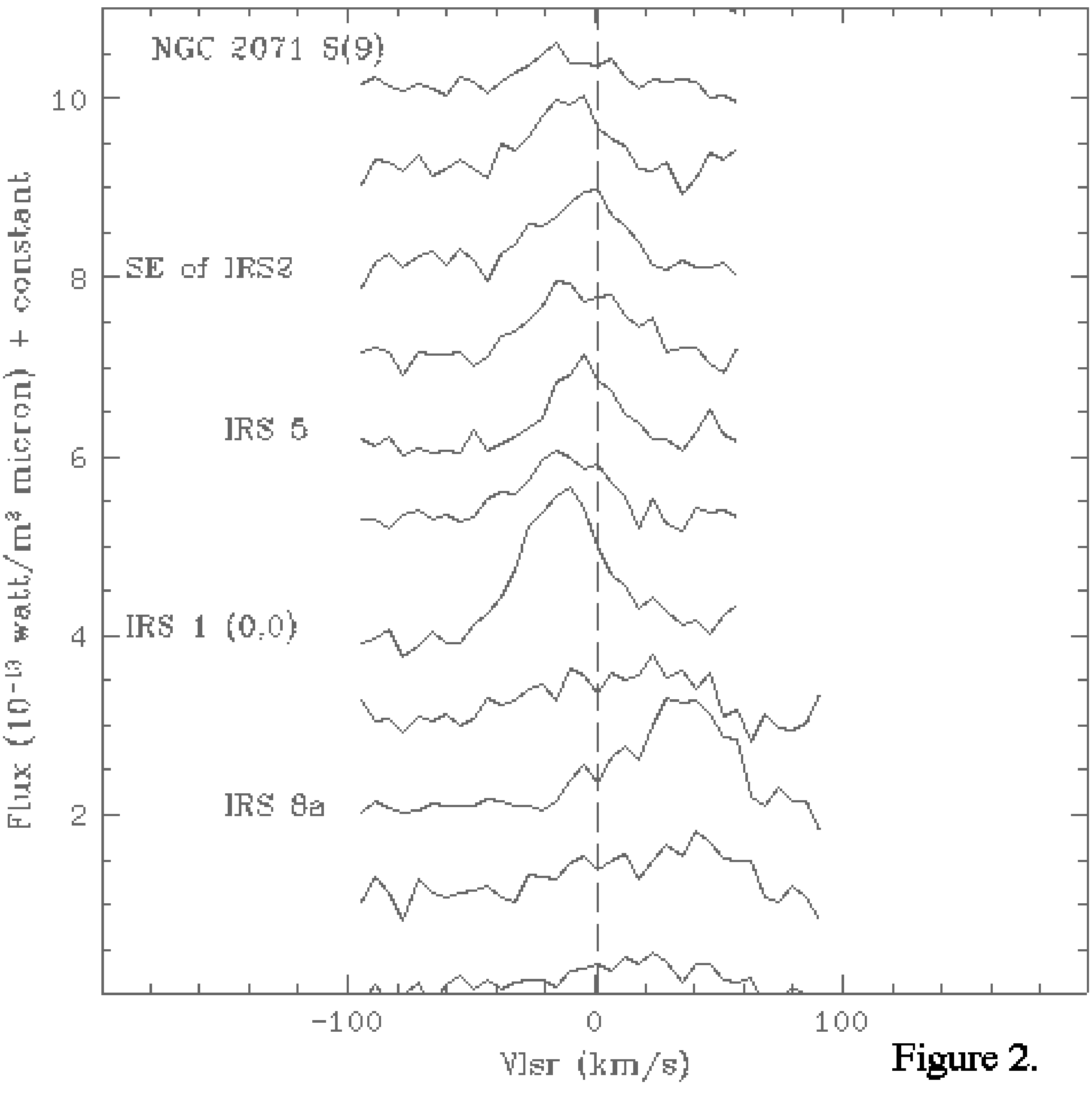

NGC 2071 IRS1
P4
S9 0-0
R9
P3
Flux (10^{-13} watt/m² micron) + constant
Vlsr (km/s)
10
8
6
4
2
-100
0
100

Figure 1.



NGC 2071 S(9)
SE of IRS2
IRS 5
IRS 1 (0,0)
IRS 8a
10
8
6
4
2
-100
0
100
Flux (10^{-13} watt/m² micron) + constant
Vlsr (km/s)

Figure 2.