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ISAAC-VLT (2-5 μm) observations of the IRS17 protostellar jet

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Abstract. VLT-ISAAC medium resolution (2-5 μm) spectroscopy of a hydrogen jet in the Vela-D Molecular Cloud is presented. Such a jet had been previously identified through narrow band imaging in the H_2 2.12 μm transition, resulting in several knots of emission extending up to 0.3 pc from the central source. VLT-ISAAC observations allowed us to investigate the nature of this remarkable example of collimated molecular jet. In particular, we show here some results about both the jet velocity structure through medium resolution observations of the H_2 2.12 μm line profiles and the extreme physical conditions constrained by the H_2 (0–0) transitions in the L and M bands.

Key words. Stars:formation – ISM:lines – ISM:jets and outflows

1. Introduction

A large number of molecular jets has been so far investigated in the near infrared with the current ground-based instrumentation through large field ($\leq$ 10 arcmin) imaging and intermediate resolution spectroscopy (R$\sim$10^3) (e.g. Eislöffel J. 1997). In particular, molecular hydrogen imaging and high resolution spectroscopy of the v=1-0 S(1) at 2.122 μm are extensively used for identifying knots of molecular emission and for studying their dynamics, while low resolution spectroscopy of the H_2 rovibrational lines lying in the 1.6-2.5 μm range is largely effective both to probe the molecular gas at thousands of Kelvin and to infer the prevailing excitation mechanism, fluorescence, C-ontinuos or J-ump shocks, (see e. g. Black & van Dishoeck 1987; Kaufman & Neufeld 1996; Hollenbach & McKee 1989). Recently, space-born spectroscopy evidenced the advantages of observing in the mid-IR the ground state H_2 pure rotational transitions. These latter, besides to be practically unaffected by extinction problems, are characterized by significantly different critical densities, circumstance which makes them particularly suitable to trace collisionally excited gas in NLTE conditions. Unfortunately, these observations are severely limited by the unavoidably poor spatial resolution. Now, VLT-ISAAC has opened a window in the thermal IR (3-5 μm) investigable with in-

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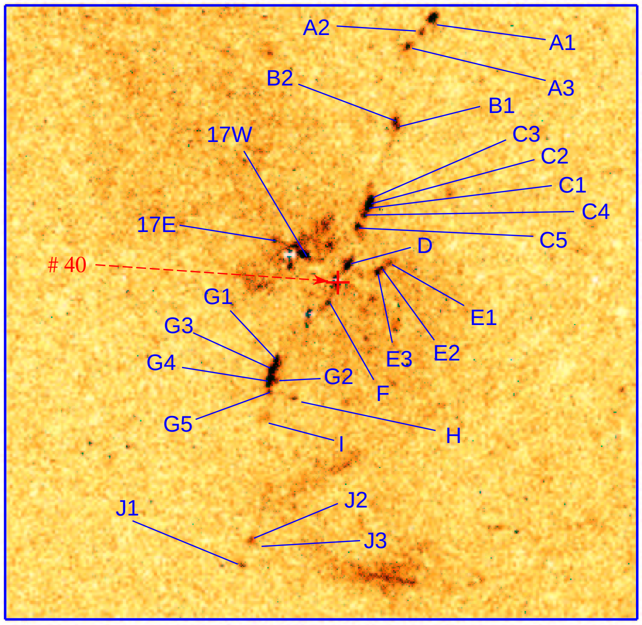

Fig. 1. H_2(2.122 μm)-K (continuum subtracted) image of the IRS17 jet. A molecular jet is recognizable and results composed in about 20 knots of H_2 emission emanated by the candidate exciting source (# 40).

termediate spectral resolution at an adequate plate scale for sampling the individual knots within the molecular jets, thus offering the opportunity to diagnose the local variations of the physical conditions by using the unique capabilities of the pure rotational H_2 lines. In this framework we have recently conducted with VLT-ISAAC a spectroscopic study of the IRS 17 jet (Figure 1) we discovered in Vela-D cloud (Lorenzetti et al. 2002). This results in about 20 knots of emission extending up to 0.3 pc from the candidate driving source. Profiles of the H_2 2.12 μm line in different knots have been obtained with ISAAC SWS1 in medium resolution mode ($\lambda/\Delta\lambda \sim 8900$ with a 0.3″ slit) in order to define their membership to the same jet and to study the velocity pattern as a function of the distance from the exciting source. In addition, six knots (groups C and G) have been observed at a resolution of ~ 1000 in the 3-5 μm domain. The same knots had been observed with SOFI at low resolution (R ~ 600) between 1.6-2.5 μm (Lorenzetti et al. 2002).

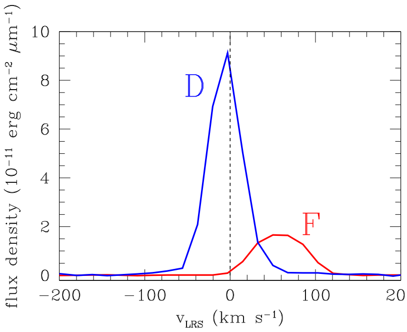

Fig. 2. Line profiles of the D and F knots.

2. Dynamics of the H_2 jet

Figure 2 shows the H_2 2.12 μm line profiles observed towards the knots closest to the source #40 (knots D and F in Figure 1). The $V_{\rm LSR}$ velocity has been corrected for the local systemic velocity of $+4.2$ km s^{-1} (Wouterloot & Brand 1999). Knot F appears strongly red-shifted ($\sim +60$ km s^{-1}) relative to the cloud, while knot D is only slightly blue-shifted (~ -5 km s^{-1}) indicating that the jet has not a definite symmetry in radial velocity with respect to the systemic velocity. The two lines have also very different intensities, likely because the strong red-shifted line is much weaker, as expected, due to a larger intervening extinction. In panel b) the $V_{\rm LSR}$ velocities measured for each knot are plotted as a function of the distance from #40. The South-East (SE) jet (knots F-I) appears to have a velocity decreasing going away from the central source, while the North-West (NW) jet (knots D-A) shows an opposite behaviour. A possible explanation is that the SE and NW jets originate from the same driving source but their dynamical behaviour is modified by the clumpiness of the surrounding medium. In particular, the SE jet can be strongly deflected, with a significant change in its original radial velocity, and then slowed down as it travels inside the cloud. Alternatively, as suggested by the presence of other knots not aligned with the main jets (E1,E2,E3,17E,17W), the occurrence of multiple outflows having different orientations can be invoked. Their interaction with the SE jet may cause its deflection. Both these hypotheses are in agreement with the CO map of the region (Wouterloot & Brand 1999), which shows a bipolar emission with a poor separation of the outflow lobes.

3. Mid-infrared observations

The line fluxes derived from our ISAAC observations have been combined with those previously derived in the 1.6-2.5 μm domain. The extinction corrected fluxes have been used to calculate the data points of rotation diagrams such that depicted in Figure 4 for the knot G2[1]. The dashed line

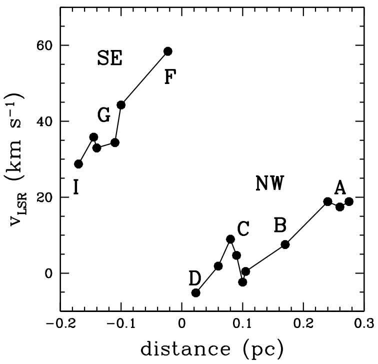

Fig. 3. V$_{LSR}$ measured for each knot as a function of the distance from the exciting source.

represents the LTE best fit to the population distribution at the indicated temperature. As a general result we note that all the data points do not deviate from this straight line. Such behaviour allows to rule out excitation by non thermal processes, because in this latter case vibrational and rotational temperatures should be different, and thus lines coming from various vibrational states should lie onto straight lines with different slopes (see e. g. Hora & Latter 1994). Moreover, the presence of multiple gas components, which should result in a smoothly curved line, rising toward higher excitation temperatures $E_{v,\rm J}$, is also rejected by our observations, which on the contrary demonstrate that the H_2 gas is thermalised at a single temperature up to values of $E_{v,\rm J} \sim 22\,000$ K. This finding, together with the fact that the critical densities of the involved levels span over three orders of magnitude (10^3 - 10^6 cm^{-3}), suggests to use the observed lines to infer a stringent lower limit to the gas density. To examine this possibility we developed a NLTE model for the population of the first 51 levels of H_2, from which are emitted transitions up to the vibrational state v=3. We adopted an abundance ra-

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[1] such points are given by the ratio $\ln[(N_{v,\rm J})/(g_{\rm J})]$ of the natural logarithm of the column density of the upper level of each transition ($N_{v,\rm J}$), divided by the statistical weight ($g_{\rm J}$).

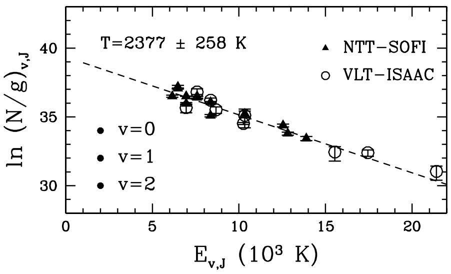

Fig. 4. H_2 excitation diagram for the knot G2. Triangles and circles indicate the lines observed with SOFI and ISAAC respectively. The line fit at T=2377 K is the best fit through the lines. No deviation with respect to a pure collisionally excited gas is observed up to E_{up} = 22 000 K.

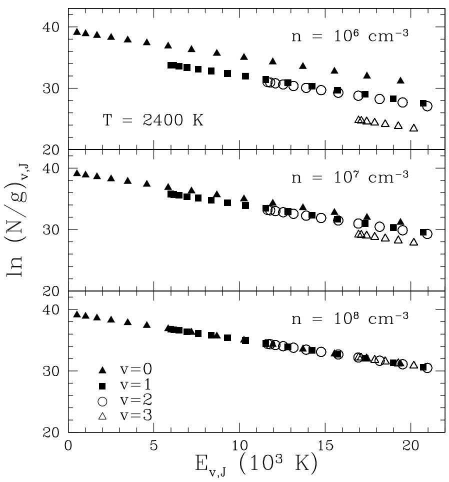

Fig. 5. Theoretical diagrams for three different density values obtained with a NLTE model for the H_2 excitation, in which both H_2–H_2 and H–H_2 collisions are taken into account (see text)

tio $n(H)/n(H_2) = 5 \times 10^{-3}$, consistent with the predicted value in dark clouds with A_V larger than 4 mag (Hollenbach et al. 1991). As an example, the rotation diagrams obtained at temperature T=2400 K for three different values of the gas density are reported in Fig. 5. Here is evident how the v=1 and v=2 lines are still not thermalised for n=10^6 cm^{-3}, while the v=3 lines reach the thermal equilibrium at densities even larger than 10^7 cm^{-3}. By comparing the observative diagrams of Fig. 4 with the models of Fig. 5, and by noting that the points relative to the 0-0 lines are well aligned with those of the other transitions, we can infer a lower limit to the gas density of 10^7 cm^{-3}. We remark that the v=3 transitions, although in principle could be used as density indicators in analogy with the 0-0 lines, are predicted to be $\sim$ 100 times weaker than the 2.12 μm line.

4. Conclusions

We have presented the VLT-ISAAC (2-5)μm medium resolution spectroscopy of the IRS 17 jet in Vela-D Molecular Cloud. For the first time the H_2 pure rotational lines in the (3-5)μm domain have been observed in a protostellar jet, and the unique capabilities of such lines in diagnosing the physical conditions of the gas have been used. In addition, from the line profile of the (1-0)S1 line we inferred the dynamical properties of the jet.

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