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SEARCHING FOR MOLECULAR HYDROGEN MID-INFRARED EMISSION IN THE CIRCUMSTELLAR ENVIRONMENTS OF HERBIG STARS.

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Abstract. We present a review of high-resolution spectroscopic mid-infrared observations of the pure rotational S(1) line of H_2 at 17.035 μm, as a tracer of warm gas in the surface layers of circumstellar (CS) disks around Herbig Ae/Be stars with the VLT Imager and Spectrometer for the mid-InfraRed (*VISIR*).

1 Introduction

The detection of H_2 provides the most direct information about the gaseous content of disks, setting limits on the timescales for the dissipation of CS matter and possibly planet building. The pure rotational mid-infrared H_2 lines are useful probes because the level populations are expected to be in local thermodynamic equilibrium (LTE) at the local gas temperature, and so line ratios allow the determination of the excitation temperature and mass of the warm gas. Using the high spectral resolution long slit mode of *VISIR*, we observed 10 Herbig Ae/Be stars (HAeBes) with well known disks, and/or whose CS environments are rich in gas (Martin-Zaïdi et al. 2008a). We focussed the observations on the S(1) pure rotational line of H_2 at 17.0348 μm since it is the most intense mid-IR H_2 line that could be detected from the ground. For details on the observation and data reduction techniques, we refer the reader to papers by Martin-Zaïdi et al. (2007, 2008b, 2009a).

2 Numerous non-detections

All but one, namely HD 97048, of the target's spectra show no evidence for H_2 emission near 17.035 μm. By integrating over a Gaussian of full width at half maximum (FWHM) equal to a spectral resolution element, and an amplitude of about $3\sigma \times (flux)$, centered on the expected wavelength for the S(1) line, we derived 3σ upper limits on the integrated line fluxes and upper limits on the total column densities and masses of H_2 as a function of adopted temperatures (Table 1). For this purpose, we used the method detailed in Martin-Zaïdi et al. (2008b, 2009a), by assuming that the line is optically thin at LTE and that the radiation is isotropic.

3 Only one detection

We have detected the H_2 pure rotational S(1) line in the spectrum of the Herbig Ae star HD 97048. We deduced a 6σ detection in amplitude for the line. The line is not spectrally resolved as we can fit it with a Gaussian with a FWHM equal to a spectral resolution element. From our fit, we derived the integrated flux in the line (see Table 1). From the wavelength position of the Gaussian peak, we considered that the radial velocity of the H_2 is compatible with zero (at the *VISIR* resolution) and therefore similar to that of the star, implying that the emitting gas is gravitationally bound to the star, and likely arising from the disk and not from an outflow.

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Table 1. Integrated fluxes F_{ul} ($\mathrm{ergs\,s^{-1}\,cm^{-2}}$) and intensities I_{ul} ($\mathrm{ergs\,cm^{-2}\,s^{-1}\,sr^{-1}}$) of the S(1) line, and total column densities and masses of H_2 as a function of the adopted temperature. (a) The line is not spatially resolved, we calculated a lower limit on the intensity, and thus obtained lower limits on the total column densities.

Star	F_{ul}	I_{ul}	$N(H_2)$ upper limits ($\mathrm{cm^{-2}}$)			H_2 mass upper limits ($M_{\rm Jup}\sim10^{-3}\ M_\odot$)		
HD	$(\times10^{-14})$	$(\times10^{-3})$	150K	300K	1000K	150 K	300 K	1000 K
Non detections at 17.035μm								
142527	<1.0	<2.5	9.4×10^{22}	6.1×10^{21}	1.4×10^{21}	1.9×10^{-1}	1.2×10^{-2}	3.3×10^{-3}
169142	<1.8	<4.2	1.6×10^{23}	1.0×10^{22}	2.4×10^{21}	3.5×10^{-1}	2.1×10^{-2}	6.1×10^{-3}
150193A	<2.1	<5.0	1.9×10^{23}	1.2×10^{22}	2.8×10^{21}	4.5×10^{-1}	2.7×10^{-2}	7.7×10^{-3}
163296	<2.8	<6.7	2.5×10^{23}	1.6×10^{22}	3.8×10^{21}	3.9×10^{-1}	2.4×10^{-2}	6.9×10^{-3}
100546	<14	<33	1.2×10^{24}	7.9×10^{22}	1.9×10^{22}	1.4	8.4×10^{-2}	2.4×10^{-2}
98922	<1.2	<1.2	1.1×10^{23}	6.9×10^{21}	1.6×10^{21}	3.3	2.0×10^{-1}	5.9×10^{-2}
250550	<1.6	<3.8	1.5×10^{23}	9.3×10^{21}	2.2×10^{21}	$5.5^{+8.8}_{-4.7}$	$3.4^{+5.4}_{-2.9}\times10^{-1}$	$1.0^{+1.6}_{-0.8}\times10^{-1}$
259431	<1.8	<4.2	1.6×10^{23}	1.0×10^{22}	2.4×10^{21}	$1.4^{+0.9}_{-0.7}$	$8.6^{+5.7}_{-4.3}\times10^{-2}$	$2.5^{+1.7}_{-1.3}\times10^{-2}$
45677	<1.6	<3.7	1.4×10^{23}	9.1×10^{21}	2.1×10^{21}	3.7	2.3×10^{-1}	6.7×10^{-2}
The only one detection at 17.035μm								
97048	2.4	5.7	(a) $>2.2\times10^{23}$	(a) $>1.4\times10^{22}$	(a) $>3.3\times10^{21}$	7.4×10^{-1}	4.5×10^{-2}	1.3×10^{-2}

The H_2 line is not resolved spatially either. Given the *VISIR* spatial resolution, and the star distance, we can assess that the emitting H_2 is located within the inner 35 AU of the disk. Assuming that the H_2 gas follows the same (Keplerian) kinematics as the disk, the emitting gas observed with *VISIR* is likely not concentrated significantly in the innermost AU of the disk ($<$ 5 AU) otherwise rotational broadening would be observed. The emitting H_2 is thus more likely distributed in an extended region within the inner disk, between 5 AU and 35 AU of the disk. Assuming the emission arises from an isothermal mass of optically thin H_2, we estimated the corresponding column densities and masses of H_2 as a function of prescribed temperatures (Table 1).

HD 97048 spectra showed no evidence for H_2 emission neither at 12.278 μm nor at 8.025 μm. From the derived upper limits on the column densities of the rotational levels of H_2, and assuming that all three levels are populated by thermal collisions (LTE), we estimated the excitation temperature of the observed gas to be lower than 570 K, and re-evaluated the mass of gas to be lower than 0.1 $M_{\rm Jup}$ in the inner 35 AU of the disk.

4 Discussion

In our sample of 10 stars, only one spectrum present H_2 emission at 17.035 μm. We stress that in their sample of 6 Herbig Ae stars, Carmona et al. (2008) have not detected any S(1) line of H_2 with *VISIR*. Those authors demonstrated that in LTE conditions, mid-IR H_2 lines could not be detected with the existing instruments. However, the S(1) line of H_2 has been already detected in the disk of another Herbig star, namely AB Aur (Bitner et al. 2007; with *TEXES*). The main goal now, is to explain these detections. Why HD 97048 and AB Aur seem to be peculiar stars? Are the physical conditions of the gas typical of a particular stage of evolution of the disk ? At the present time, a detailed model (of gas and dust) of the disk of HD 97048 is in progress, using the McFOST code (Pinte et al. 2006), in order to answer these questions.

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