Molecular hydrogen in the disk of the Herbig Ae star HD97048

C. Martin-Zaïdi[1], E. Habart[2], J-.C. Augereau[1], F. Ménard[1], P-.O. Lagage[3], E. Pantin[3], J. Olofsson[1]

(1) claire.martin-zaidi@obs.ujf-grenoble.fr - Laboratoire d'Astrophysique de Grenoble, 414 rue de la piscine, DU Saint Martin d'Hères, BP53, 38041 Grenoble cedex 9;
(2) Institut d'Astrophysique Spatiale, 91405 Orsay, France; (3) Laboratoire AIM, CEA/DSM - DAPNIA/Service d'Astrophysique, CEA/Saclay, 91191 Gif-sur-Yvette Cedex, France.

Abstract: We present high-resolution spectroscopic mid-infrared observations of the circumstellar disk around the Herbig Ae star HD97048 obtained with the *VLT Imager and Spectrometer for the mid-InfraRed* (VISIR). We conducted observations of mid-infrared pure rotational lines of molecular hydrogen (H_2) as a tracer of warm gas in the disk surface layers. In a previous paper, we reported the detection of the S(1) pure rotational line of H_2 at 17.035 μm and argued it is arising from the inner regions of the disk around the star. We used VISIR on the VLT for a more comprehensive study based on complementary observations of the other mid-infrared molecular transitions, namely S(2) and S(4) at 12.278 μm and 8.025 μm respectively, to investigate the physical properties of the molecular gas in the circumstellar disk around HD97048. We do not detect neither the S(2) line nor the S(4) H_2 line from the disk of HD97048, but we derive upper limits on the integrated line fluxes which allows us to estimate an upper limit on the gas excitation temperature, $T_{ex} < 570$ K. This limit on the temperature is consistent with the assumptions previously used in the analysis of the S(1) line, and allows us to set stronger constraints on the mass of warm gas in the inner regions of the disk. Indeed, we estimate the mass of warm gas to be lower than 0.1 M_{Jup} (1 $M_{Jup} \sim 10^{-3} M_\odot$). We also discuss the probable physical mechanisms which could be responsible of the excitation of H_2 in the disk of HD97048.

Introduction: In the past twenty years, both planets and disks have begun to be observed around nearby stars. Some young stars with disks, e.g. the pre-main sequence solar-type star (T Tauri star) GM Aur (Rice et al. 2003), are also suspected of harboring young planets. It is now well established that planets around T Tauri stars form in massive, gaseous and dusty protoplanetary disks that survive for several million years around the stars (Greaves 2005). The situation is less clear for the more massive Herbig Ae/Be stars (HAeBes). A particular interesting object to study the circumstellar material around a pre-main sequence intermediate mass star is HD97048.

The Herbig Ae star HD97048

- Herbig A0/B9 star
- Distance: 180 pc (van den Ancker et al. 1998)
- Age: ~3 Myrs (kindly computed for us by L. Testi and A. Palacios)
- VISIR imaging observation by Lagage et al. (2006):
  - large extended emission from PAHs (Polycyclic Aromatic Hydrocarbons) at the surface of a flared disk (see Fig. 1).
  - flaring index = 1.26±0.05 ⇒ good agreement with hydrostatic flared disk models

⇒ large amount of gas should be present to support the flaring structure

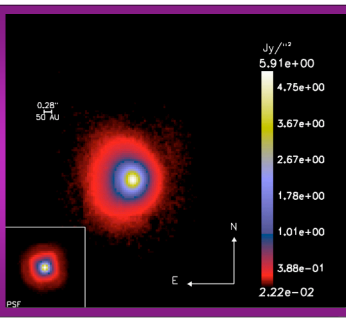

Figure 1: VISIR false-color image of the emission from the CS material surrounding the Herbig star HD97048, after a deep exposure of 36 min. A filter centered at 8.6 μm (PAH1 filter) and with a full width half maximum of 0.42 μm was used. The emission is widely extended with a east/west asymmetry , as compared with the point spread function (inset) obtained from the observation of the pointlike reference star HD102964. From the image it has been possible to infer that the disk was flaring, which implies that a lot a gas should be present to support this geometry (Lagage et al. 2006).

Spectroscopic observations: HD97048 was observed at 3 different epochs. The observations at 17.035 μm presented in Martin-Zaïdi et al. (2007) were performed in 2006 June 22, the 8.025 μm observations in 2007 April 07, and the 12.278 μm observations in 2007 July 03. The three sets of observations were obtained with the high-resolution spectroscopic mode of VISIR. For details on the observations conditions see Martin-Zaïdi et al. (2007) and Martin-Zaïdi et al. (2009). Observations obtained at the ESO VLT with VISIR, programs' number 077.C-0309B, 079.C-0839A and 079.C-0839B.).

Data analysis and Results

- **Flux calibration:** (see Figure 2)
  - observation of an asteroid (same airmass and seeing than for HD97048)
  - observation of a standard star (same airmass and seeing than for HD97048)
  - correction from telluric absorption: division of the HD97048 spectrum by that of the asteroid
  - absolute flux calibration: using observed and modeled spectra (Cohen et al. 1999) of standard stars
- **Wavelength calib:** fit of the sky background features with a model of Paranal's atmosphere

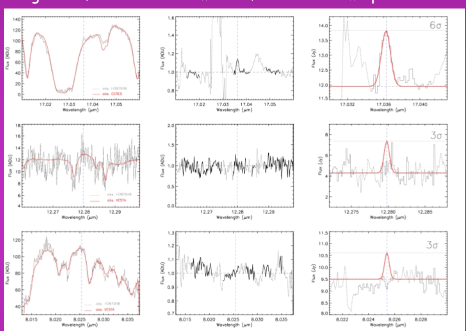

Figure 2: VISIR spectra of HD97048 at 17.035 μm (top panel), 12.278 μm (middle panel) and 8.025 μm (bottom panel). *Left panel*: continuum spectra of the asteroid and of the target before telluric correction. *Central panel*: full corrected spectra: dotted lines show spectral regions strongly affected by telluric features. *Right panel*: zoom of the region where the H_2 lines should be observed (dashed vertical lines). The spectra were corrected neither for the radial velocity of the targets nor the Earth's rotation velocity.

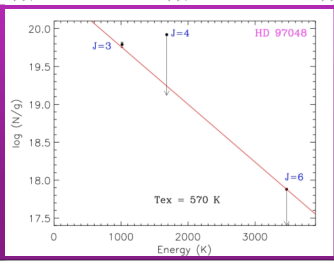

Figure 3: Excitation diagram for H_2 towards HD97048. If the three rotational levels are populated by thermal collisions, their populations follow the Boltzmann law, and the upper limit on the excitation temperature is given by considering the lower limit on the column density of the J=3 level and the upper limit on the J=6 population level (red line). Thus, in this case, the gas temperature should be lower than 570~K.

- **Detection of the H_2 S(1) pure rotational line at 6σ in amplitude**
  - radial velocity = radial velocity of the star ⇒ **the H_2 emission arises from the disk**
  - Line not spectrally and spatially resolved
  - Integrated flux: fit of the line with a Gaussian with FWHM = 1 resolution element
  - VISIR spatial resolution ~0.427'' at 17.03μm ⇒ **H_2 in the inner 35 AU**
  - No rotational broadening: H_2 not in the innermost regions (if Keplerian rotation)

⇒ **the emitting H_2 is located in the inner 5 - 35 AU of the disk**

- **Non detection of the S(2) and S(4) lines**
  - 3σ upper limits on the integrated fluxes
  - Integrated flux: fit of the line with a Gaussian with FWHM = 1 resolution element
- **Column densities of the corresponding rotational levels**
  - **Assumptions**: homogeneous medium, optically thin, H_2 in LTE, isotropic radiation
  - Levels excited by thermal collisions: their populations follow the Boltzmann law

⇒ **Excitation diagram for H_2** (Figure 3)

- **Constraints on the excitation temperature**
  - Since the temperature is inversely proportional to the slope on the excitation diagram, in order to obtain the upper limit on the excitation temperature, we considered the lower value of the column density of the J = 3 level (i.e., the measured value minus 1 σ) and the upper limit on the J = 6 population level (that procedure yields the minimum slope / maximum temperature and corresponds to the solid line on Fig. 3)
  - Excitation temperature: $T_{ex} < 570$ K
  - New constraint on the column density of the J=4 level
- **Upper limit on the mass of the warm H_2 in the surface layer of the disk**

$M(H_2) < 0.1\ M_{Jup}$ in the inner 35 AU of the disk

Concluding remarks

- HD97048: **H_2 gas is still present after 3 Myrs in the inner 35 AU of the disk**
- Taking into account that cold gas is present much deeper in the disk (Lagage et al. 2006) ⇒ there is likely enough gas to form giant planets
- Carmona et al. (2008) showed that at LTE and with a gas-to-dust mass ratio about 100, the S(1) line arising from such a CS disk should not be observable with the existing instruments.

⇒ Tgas > Tdust in the surface layers of the disk and /or gas-to-dust ratio >> 100

- The dust is partially depleted from the disk surface layer where the H_2 emission originates? **Dust settling** or **dust coagulation** into larger particles ?
- Other mechanisms of excitation and heating than thermal collisions could be invoked such as UV pumping, shocks, X-rays, etc..., (see review papers by Habart et al. 2004; Snow & McCall 2006) to explain the detection of the S(1) line and the excitation of H_2.

All these results are detailed in the papers by Martin-Zaïdi et al. (2007 and 2009)

Acknowledgements:

References: Carmona et al. 2008, A&A, 477,839; Cohen et al. 1999, LPI Contributions, 969, 5; Greaves 2005, Science, 307, 68; Habart, E. et al. 2004, A&A, 414, 531; Lagage, P.-O. et al. 2006, Science, 314, 621; Martin-Zaïdi et al. 2007, ApJL, 666, L117; Martin-Zaïdi et al. 2009, ApJ in press (2009arXiv0902.1614); Rice et al. 2003, MNRAS, 342, 79; Snow & McCall 2006, ARA&A, 44, 367; van den Ancker et al. 1998, A&A, 330, 145;