Molecular hydrogen in the disk of the Herbig Ae star HD97048

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Abstract: We present high-resolution spectroscopic mid-infrared observations of the circumstellar disk around the Herbig Ae star HD97048 obtained with the VLT Imaging Spectrometer for the Mid-Infrared (VISIR). We conducted observations of mid-infrared pure rotational lines of molecular hydrogen (H2) 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 H2 at 17.035 µm and argued it is outgoing 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 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) 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. \( T_{\text{ex}} \geq 570 \text{ K} \). This limit on the excitation 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 \( M_{\odot} \) (\( T_{\text{ex}} \approx 10^4 \text{ K} \)). We also discuss the probable physical mechanisms which could be responsible for the excitation of \( \text{H}_2 \) 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) SIM Aur (Ree et al. 2003), are also suspected of harboring young planets. It is now well established that planets around T Tauri stars form in massive 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. 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 AO/Be 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 (Polycylic Aromatic Hydrocarbons) on the surface of a flared disk (see Fig. 1).
  - Flaring index \( \leq 1.2 \times 10^{-5} \) good agreement with hydrostatic flared disk models
  - large amount of gas should be present to support the flaring structure.

Spectroscopic observations: HD97048 was observed at 3 different epochs. The observations at 17.035 µm presented in Martin-Zaidi et al. (2007) were performed in 2006 June 23, 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-Zaidi et al. (2007) and Martin-Zaidi et al. (2009). Observations obtained at the ESO VLT with VISIR, program number 077.C-0309B, 079.C-0839A and 079.C-0839B).

Data analysis and Results

- **Flux calibration:** (see Figure 2)
  - Observation of an asteroid (some airmass and seeing than for HD97048)
  - Observation of a standard: (some airmass and seeing than for HD97048)
  - Correction from telluric absorption: division of the HD97048 spectrum by that of the asteroid continuum spectra of the asteroid and of the target before telluric correction.
  - **Absolute flux calibration:** Using observed and modeled spectra (Cohen et al. 1999) of standard stars.

- **Wavelength calibration:** fit of the sky background features with a model of Paranal’s atmosphere.

Detection of the H2 S(1) pure rotational line at 6.0 µm in amplitude

- Line not spectrally and spatially resolved.
- Integrated flux: fit of the line with a Gaussian with FWHM = 1 resolution element
- VISIR spatial resolution = 0.27" at 17.035 µm. \( H_2 \) in the inner 35 AU
- Non rotational broadening: \( H_2 \) not in the innermost regions (of Keplerian rotation)
- The northern \( H_2 \) is located in the inner 9 - 35 AU of the disk.

Non detection of the S(2) and S(4) lines

- 3σ upper limit 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, astrophysical radiation
- Levels excited through 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 1σ) and the upper limit on the J = 6 population level (that procedure minimum the slope / maximum temperature and correspond to the solid line in Fig. 3)
- Excitation temperature: \( T_{\text{ex}} \geq 570 \text{ K} \)
- 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 \( M(H_2) < 0.1 M_\odot \) 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) \( \Rightarrow \) there is likely enough gas to form giant planets.
- Cormons et al. (2008) showed that at LTE and with a gas-to-dust mass ratio about 100, the (S) line arising from such a CS disk should not be observable with the existing instruments.
- The disk 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 & McColl 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-Zaidi et al. (2007 and 2009).

Acknowledgments: