

# Detection of warm molecular hydrogen in the circumstellar disk around 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 with the VLT Imager and Spectrometer for the mid-Infrared (VISIR). We detect the  $S(1)$  pure rotational line of molecular hydrogen ( $H_2$ ) at  $17.035\mu\text{m}$  arising from the disk around the star. This detection reinforces the claim that HD97048 is a young object surrounded by a flared disk at an early stage of evolution. The emitting warm gas is located within the inner 35 AU of the disk. The line-to-continuum flux ratio is much higher than expected from models of disks at local thermodynamic equilibrium (LTE). We investigate the possible physical conditions, such as a gas-to-dust mass ratio higher than 100 and different excitation mechanisms of molecular hydrogen (e.g., X-ray heating, shocks), that would explain the detection. We tentatively estimate the mass of warm gas to be in the range from 10 to nearly  $1 M_{\text{Jup}}$ .

**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)  $\theta$  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 AO/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 =  $1.26 \pm 0.05 \Rightarrow$  good agreement with hydrostatic flared disk models
- $\Rightarrow$  large amount of gas should be present to support the flaring structure

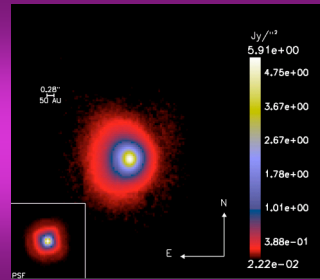


Figure 1: VISIR false-color image of the emission from the CS material surrounding the Herbig star HD97048, after a 30 min. exposure at  $3.6\mu\text{m}$  (PAH1 filter) and with a full width half maximum of  $0.42\mu\text{m}$  was used. The emission is widely extended with a east/west asymmetry, as compared 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 of gas should be present to support this geometry (Lagage et al. 2006).

**Spectroscopic observations:** HD97048 was observed with the high spectral resolution long-slit mode of VISIR during 1800s in 2006 June 22; the central wavelength of the observation was set to  $17.035\mu\text{m}$ . We used the  $0.75''$  slit, providing a spectral resolution about 10 000, i.e.  $\Delta v = 30 \text{ km.s}^{-1}$ . The weather conditions were very good and stable during the observations; the optical seeing was less than  $0.66''$  and the airmass ( $\sim 1.8$ ) was close to the minimum airmass accessible when observing this object from the Paranal ESO observatory. (observations obtained at the ESO VLT (Paranal) with VISIR, program 077.C-0309(B)).

## Data analysis and Results

- > **Flux calibration:**
  - observation of the CERES asteroid (same airmass and seeing than for HD97048): Fig. 2
  - observation of the standard star HD89388 (same airmass and seeing than for HD97048): Fig. 3
  - correction from the telluric absorption: division of the HD97048 spectrum by that of CERES
  - absolute flux calibration: using observed and modelled spectra (Cohen et al. 1999) of HD89388
- > **Wavelength calib:** fit of the sky background features with a model of Paranal's atmosphere

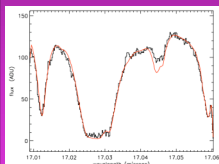


Figure 2: Observed spectrum of the CERES asteroid (red line) overlaid on the observed spectrum of HD97048 (black line).

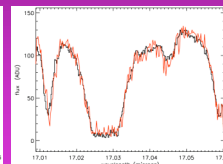


Figure 3: Observed spectrum of the standard star HD89388 (red line) overlaid on the observed spectrum of HD97048 (black line).

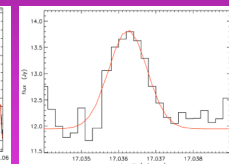


Figure 4:  $S(1)$   $H_2$  emission line from HD97048 CS disk. Black line: observed spectrum, corrected from the telluric absorption. Red line: fit of a Gaussian with  $\text{FWHM} = 30 \text{ km.s}^{-1}$ .

- > **Results:**
    - Detection of the  $H_2$   $S(1)$  pure rotational line at  $6\sigma$  in amplitude: Fig. 4
    - Line not spectrally and spatially resolved
    - Integrated flux: fit of the line with a Gaussian with  $\text{FWHM} = 30 \text{ km.s}^{-1} = 1$  resolution element
    - VISIR spatial resolution  $\sim 0.427''$  at  $17.03\mu\text{m}$ ; distance of the star: 180 pc
- $\Rightarrow$  the emitting  $H_2$  is located in the inner 35 AU of the disk

- > **Mass of warm gas (150K-1000K) in the inner 35 AU of the disk:**
  - Assumptions: homogeneous medium, optically thin,  $H_2$  in LTE, isotropic radiation
  - Mass calculations: using Thi et al. 2001, and Takahashi & Uehara 2001:

$$1.33 \times 10^{-2} M_{\text{Jup}} < M_{\text{H}_2} < 7.37 \times 10^{-1} M_{\text{Jup}} \quad (3 M_{\text{Jup}} = 10^{-3} M_{\odot}) \quad \text{for } 150\text{K} < T < 1000\text{K}$$

- > **Mass of warm dust (150K-1000K) in the inner 35 AU of the disk:**
  - Simple model of optically thin emission of a given mass of dust at the surface of a disk
  - Grains sizes:  $0.01 - 100 \mu\text{m}$ ; Size distribution following a power law with an index of 3.5
  - Fixed-composition mixture of amorphous silicates (50%) and amorphous carbon (50%)

$$9.39 \times 10^{-7} M_{\text{Jup}} < M_{\text{dust}} < 2.23 \times 10^{-2} M_{\text{Jup}} \quad \text{for } 150\text{K} < T < 1000\text{K}$$

$$3260 < \text{gas-to-dust mass ratio} < 14164 !!!$$

## Concluding Remarks

- > Photoevaporation of the gas is expected to clear up the inner part of the disk within 3 Myrs (Takeuchi et al. 2005).

> 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 (Lagage et al. 2006)

$\Rightarrow$  there is likely enough gas to form giant planets

- > We found very high values for the gas-to-dust mass ratios in the inner 35 AU of the disk:  $\rightarrow$  in agreement with more sophisticated models such as two-layer LTE disk models by Carmona et al. (2007) who 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.

$\Rightarrow$  The dust is partially depleted from the disk surface layer, where the  $H_2$  emission originates?

$\Rightarrow$  Dust settling or dust coagulation into larger particles?

- > Other mechanisms of excitation and heating than thermal collisions cannot be excluded. Several competing mechanisms could contribute to the excitation of molecular hydrogen such as UV pumping, shocks, X-rays, etc..., (see review papers by Habart et al. 2004; Snow & McClath 2006) and could be responsible for the observed emission.

- > Further observations of the other pure rotational lines of  $H_2$  have been performed with VISIR in 2007 (work in progress), and will be necessary to better characterize the physical conditions of the gas in the inner 35 AU of this disk. Especially, the observation of these lines would help to better constrain the temperature of the warm gas.

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