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RESOLVING WITH SINFONI THE H_2 EMISSION FROM T TAU'S DISK

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Abstract. We present spatially resolved near IR observations of the H_2 emission in the vicinity of T Tau N using SINFONI, the integral field spectrograph of the VLT. The gas is detected as a ring-like structure within ~80-100 AU from the star. The velocities of the H_2 are close to the systemic velocity of T Tau N, and an analysis of the excitation mechanisms plays in favor of a scenario where the H_2 is linked to the atmosphere of the circumstellar disk. The possible excitation scenarii are evoked here. Eventually, when detected in the disk, H_2 is also a strong tracer of the status of potential planet formation.

1 Introduction

Studying circumstellar disks is essential in understanding the evolutionary path from young gaseous disks to mature planetary systems. Many investigations have focused on broad band studies of the SED, or on scattered light from the disk itself. The detection of molecular line emission from species like CO or HCO^+ is also used as a tracer of the disk. However, these molecules can freeze out on the grains and become undetectable even when the disk still exists. Molecular H_2 in the disk has the advantage of being the main constituent and the last part of the gas to be bound up during the process of planet formation. Therefore, it remains in the disk even after CO or dust have become undetectable. In that sense, H_2 remains a good tracer for exploring the disk evolution since it may be observable for a longer period of time. Several groups have undertaken the study of H_2 IR rovibrational lines, mainly through long slit spectroscopy (Carmona et al. 2007; Bary et al. 2003 & 2008). However this technique is less immediate in terms of spatial distribution since it focuses on one specific position angle. Other authors have focused on the observation of pure rotational lines in the MIR (Martin-Zaidi et al. 2007) or on fluorescent H_2 in the UV (Walter et al. 2003). Here we focus on the circumstellar environment of T Tau, the prototype of the corresponding class of objects. T Tau is a triple star system, with a southern binary ~0.7" away from the northern component and showing a separation of ~0.1". All components are actively accreting and believed to host disks (Duchêne et al. 2005). The north component likely harbors a nearly face-on disk with $i \sim 19°$ (Herbst et al. 1997; Akeson et al. 1998). We used the integral field spectrograph SINFONI at the VLT to obtain diffraction limited K band images with a spectral resolution of 4000 (Gustafsson et al. 2008).

2 IFU principles and observations

SINFONI is based on the use of an optical slicer that samples the image into 32 sections and rearranges them into a pseudo-slit, which input is then spectrally dispersed through a grism. A spectral cube of 2048 images is reconstructed afterwards. The spatial information is maintained within each slice. T Tau N was observed on 30^{th} October 2004 in the K band (1.94 – 2.45 μm), with the 100 mas pixel scale for a FOV of 3.2". The standard star Hip025657 was observed at same airmass and with the same optical setup to correct for the telluric features. We used the SINFONI reduction pipeline to reconstruct the data cube. This final cube contains spatial information in X and Y directions, and spectral information in the Z direction. Among the various spectral lines, the observable H_2 rovibrational lines are : v=1-0 S(1) at 2.1218 μm; v=1-0 S(0) at 2.223 μm; v=2-1 S(1) at 2.2477 μm; v=1-0 Q(1) at 2.4066 μm.

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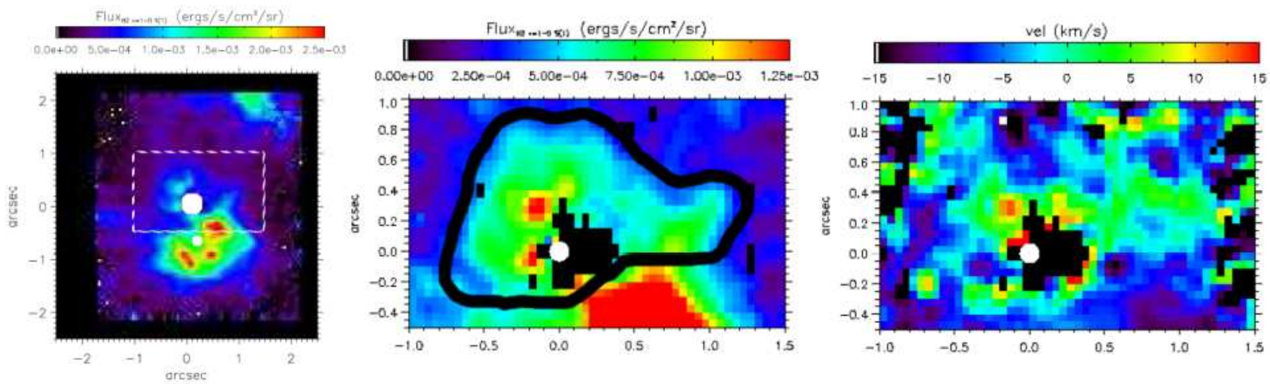

Fig. 1. Molecular H_2 maps around T Tau N. See the text for explaination

2.1 Velocities maps

Fig. 1.a shows the H_2 v=1-0 S(1) emission in the T Tau system in the 3"x3" FOV. T Tau N is represented as a large white dot and T Tau S as a smaller one. The strong emission close to T Tau S was already detected by Herbst et al. (2007) and corresponds to an outflow, as well as the emission seen in the right upper corner. A weaker emission is detected in a ring-like structure around T Tau N, which escaped previous detection. This emission is contained within the white box in Fig. 1.a. Fig. 1.b is a zoom in the vicinity of T Tau N. The region used for further analysis is confined inside the black contour. The emission south-west of T Tau N corresponds to outflows from T Tau S. Fig. 1.c presents the velocities map of the H_2 emission relative to the system velocity. Although the resolution of SINFONI is 70 km/s, much higher accuracy can be obtained through a Lorentzian fit of the line position. The velocity map shows small variations between -10 km/s and 10 km/s in the ring-like structure.

2.2 Gas kinematics

In our data, we have full access to the spectral distribution of the emitting gas. We have derived the radial velocity corresponding to every H_2 emitting position by fitting a Gaussian profile to the unresolved line profiles on a pixel by pixel basis. The velocities have been corrected for the Earths motion toward T Tau at the time of observation and are quoted with respect to the heliocentric velocity of T Tau N of 19.1 ± 1.2 km/s (Hartmann et al. 1986). The H_2 emission shows small variations between -10km/s and +10km/s with respect to the intrinsic velocity of T Tau N. There is no evidence of Keplerian rotation of the disk. However, if the inclination of the disk is $\sim 20°$, the radial velocity component of Keplerian rotation around a $2M_\odot$ star is only $\sim$5km/s at 10 AU and $\sim$2km/s at 100 AU. Such small velocity differences within the disk would be difficult to detect with the present data. In order to improve the signal-to-noise ratio, we constructed a global H_2 profile of the ring-like structure by adding all spectral profiles of H_2 v=1-0 S(1) emitting positions within the mask in Fig. 1.b (black continuous line). This also allows a direct comparison with previous spatially unresolved measurements of H_2 in the circumstellar environment of T Tauri stars. The Lorentzian fitting function provides the best match to the instrumental profile of SINFONI which dominates the unresolved H_2 profile. The profile is found to peak close to the rest velocity of T Tau N. From the Lorentzian fit we find the peak velocity to be 2.5 ± 2.1km/s (1-σ uncertainty). Considering the uncertainty in the rest velocity of T Tau N of 1.2km/s (Hartmann et al. 1986), the velocity of the H_2 emission is consistent with the rest velocity of the star within the errors. The same was found to be true of the H_2 emission from disks around other stars (Bary et al. 2003; Carmona et al. 2007).

3 Origin of the H_2 emission and excitation mechanisms

From gas kinematics, it appears that the extended H_2 emission is linked to the system of T Tau N. Could this emission correspond to a scenario in which the gas is part of a face-on disk atmosphere? Which mechanisms would then drive the excitation? Considering the scenario of a pure outflow exciting the gas, this appears not much plausible because of the typically high velocities of an outflows (60–200 km/s) and their property of being collimated, which are both unobserved with these data. The option of an envelope cleared out by a bipolar outflow and which inside walls sustain shocks from a wide-angle wind could be plausible, but this would require poorly collimated outflow compared to what is typically found in other T Tauri stars. Finally, we consider the case of the wide-angle low velocity wind that impinges on the atmosphere of a flared disk. SED modeling and observed H_2 extent suggests that the disk is $\sim$85 AU, with a total mass of $\sim 0.15\,M_\odot$. Concerning the excitation mechanism, two scenarii are suggested: shocks from a stellar wide-angle wind interacting with a flared disk, or irradiation by UV photons and X-rays. Both cases require a substantial disk around T Tau N. In the latter case however, models and observations indicate that the irradiation from the central star does not excite the H_2 much further than 20 AU, which is in contradiction with our observations (Herczeg et al. 2006). Consequently, the most likely scenario is the one of a wind-angle wind which shocks are able to excite out to 85 AU the H_2 located of an almost face-on disk around T Tau N.

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