MOLECULAR HYDROGEN IN THE CIRCUMSTELLAR ENVIRONMENT OF HERBIG Ae/Be STARS

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Abstract: We present our analysis of the molecular hydrogen in the circumstellar environment of a sample of Herbig Ae/Be stars observed with FUSE ***(Far Ultraviolet Spectroscopic Explorer)***. The characteristics of H_2 around Herbig stars give evidence of several mechanisms of excitation. In particular, this suggests structural differences between Herbig Ae and Be stars' environments which could be explained by a faster evolution of the latter combined with stronger radiation fields.

Introduction: Herbig Ae/Be stars (HAeBes) are pre-main sequence stars of intermediate masses. The nature and evolution of their circumstellar environment are still unknown. The advent of far ultraviolet observatories like FUSE offers access to spectral lines that can efficiently probe the circumstellar environment of HAeBes. This is especially true for lines of molecular hydrogen, which is the most abundant molecule in the circumstellar environment of young stars. The analysis of H_2 lines in the FUSE spectral domain allows measurement of the amount of gas surrounding the stars. In order to characterize the physics and evolution of the circumstellar gas, we analysed a sample of 11 stars observed with FUSE including Herbig Ae/Be stars (HAeBes) and main-sequence stars like β-Pictoris.

Data: The sample contains 11 stars and spans the spectral range from A5 to B2. We analysed the H_2 lines by the *Owens* profile fitting procedure (Hébrard et al. 2002; Lemoine et al. 2002; Bouret et al. 2003). From these fits, we determined the column densities, radial velocities and intrinsic line widths.

HD 141569 A

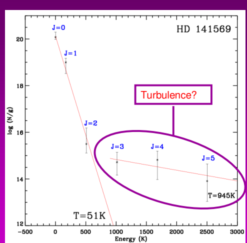


Figure 1: Excitation Diagram of H_2 in the circumstellar environment of HD141569. Martin et al. (2005)

- B9 V star with CS disk
- H_2 thermalized up to J=2
- Excitation temperature = 51K

Excitation Conditions → Interstellar Medium (Gry et al. 2002)

- Excitation temperature levels J>2 = 945K ⇒ turbulence?

Vrad H_2 + atomic species = Vrad L134N

- No gas seen at the velocity of the star

→ **We do not observe the disk in absorption**
→ **CS gas far away from the star**
→ **All the CS gas has had time to collapse into a flat disk**
→ **Confirmed by the CO observations** (Brittain & Rettig 2002)

AB AURIGAE

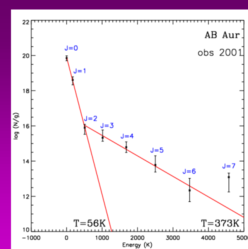


Figure 2: Excitation Diagram of H_2 in the circumstellar environment of AB Aur. (Martin et al. 2005, in prep)

- A0 star with CS disk
- H_2 thermalized up to J=2
- Excitation temperature = 56K
- Temperature of the J>2 levels = 373K

Excitation Conditions → Interstellar Medium (Gry et al. 2002)

- Disk nearly seen face-on
  → we do not see the disk in absorption

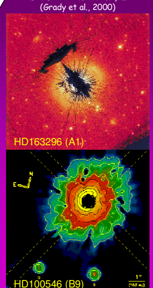
BUT: V_{rad} (H_2 + atomic species) = V_{rad} (star)

→ **Gas bound to the star**

⟹ **Remnant of the original molecular cloud at large scale**

HD 163296 & HD 100546 (Ae stars)

STIS λ = 0.2 to 1.0 μm (Grady et al., 2000)



NICMOS λ = 1.6 μm (Augereau et al., 2001)

- A1 & B9 stars with CS disks
- V_{rad} (H_2+atomic species) = V_{rad} (star)
  ⇒ **Gas bound to the star**
- H_2 thermalized up to J=4
- Excitation temperatures > 400K
- Low column densities

⟹ **Collisionally excited medium close to the star < 5 AU** (Lecavelier des Etangs et al. 2003)

- Disks' inclination angles to the line of sight :
  - HD 163296 ~ 60°
  - HD 100546 ~ 51°

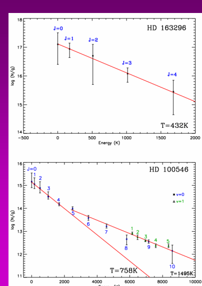
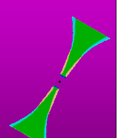


Figure 3: Excitation diagrams of H_2 for HD 100546 and HD 163296.

Location of the H_2 observed with FUSE ? Could we observe the disks in absorption with such angles ?

⟶ **Flared disk model** (Dullemond et al. 2001)



HYPOTHESIS:

$T_{inner\ rim} = T_{hot\ gas} = T_{dust}$
Dust/gas ratio = 100
Disk mass ~ 10^{-2} to 10^{-3} $M_\odot$
Disk scale (~ 400AU)

RESULTS:

Distance star/gas = 0.4 AU
Inner rim height = 0.15 AU

⇒ **17 - 18 % of the surface of the star is covered by the disk**

The hot H_2 observed with FUSE is at the surface of the inner rim of the disk

HERBIG Be STARS OF THE SAMPLE

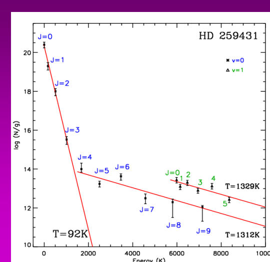


Figure 4: Excitation diagram of H_2 for HD259431 (Bouret et al. 2003). All the excitation diagrams for Be stars are similar to this one.

- Spectral types: B8 to B2
- V_{rad} (H_2+atomic species) = V_{rad} (star)
  ⇒ **Gas bound to the stars**
- H_2 Thermalized up to J=3
- J=0-3 Temperature: ~ 100 K
- Temperature of the higher J-levels ≥ 1000 K

Excitation conditions similar to those observed for photodissociation regions (PDRs)

⟶ **Model of PDRs** (Le Bourlot et al.)
http://aristote.obspm.fr/MIS/

RESULTS:

Excitation diagrams reproduced with the PDRs' model:
- HD 38087 and HD 85567: one component at low density
- HD259431: two components at low and high densities

→ **The presence of one or two media is compatible with IR images (MSX, IRAS, DSS2)**

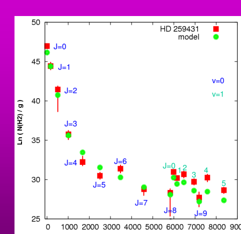


Figure 5: comparison between th excitation diagram of H_2 for HD259431 (red) and the results obtained with the PDRs' model with two components (Martin et al. 2005 in prep).

Stars surrounded by CS envelopes, remnant of their original molecular clouds

Martin et al. 2004; Martin et al. 2005 (in prep)

SUMMARY & CONCLUSIONS

MECHANISMS OF H_2 EXCITATION

✓ **Excitation of H_2 typical of that observed in the diffuse ISM:**
- Interstellar molecular cloud along the line of sight: HD141569
- Remnant of the original molecular cloud at large distance from the star: AB Aur

✓ **Youngest stars of the sample: Be stars**
- Stars rurrounded by a CS envelope, remnant of their original molecular cloud
- Excitation diagrams reproduced by PDRs' model with one or two components
  → **The analysis must be completed for the whole sample**

✓ **Stars with CS disks: Ae stars**
- Collisionally excited medium very close to the star
  → **Surface of the inner rim of the disk**
- Goal: modelling of their excitation diagrams

⟹ **Structural differences between Herbig Ae and Be stars**
Previously emphasized by Natta et al. (2000)

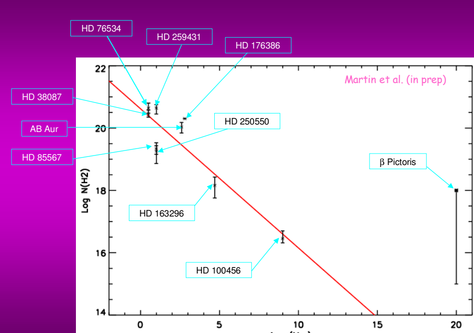


Figure 6: Total column densities of H_2 versus the ages of the stars.

EVOLUTION

Circumstellar H_2 content decreases with the age of the stars (Figure 6).

But column densities are derived from absorption lines, then our results do not take into account the spatial distribution of the gas.

The youngest stars of the sample (Be) are still embedded in the remnant of their original molecular cloud, while the oldest one (Ae) habour disks seen with high inclination angles. For the latter, all the cricumstellar gas has probably had time to collapse into a disk.

References: J.-C. Augereau et al. 2001, A&A, 365, 78; S.D. Brittain & T.W. Rettig, 2002, Nature, 418, 57; J.-C. Bouret, C. Martin, M. Deleuil, T. Simon, C. Catala, 2003, A&A, 410, 175; C.P Dullemond et al. 2001, ApJ, 560, 957; C.A. Grady et al. 2000, ApJ, 544, 895; C. Gry et al. 2002, A&A, 391, 675; G. Hébrard et al. 2002, ApJS, 140, 103; A. Lecavelier des Etangs et al., 2003, A&A, 356, 691; M. Lemoine et al., 2002, ApJS, 140, 67; C. Martin, J.-C. Bouret, M. Deleuil, T. Simon, C. Catala, 2004, A&A, 416, L5; C. Martin, M. Deleuil, T. Simon J.-C. Bouret, A. Roberge, P.D. Feldman, A. Lecavelier des Etangs, A. Vidal-Madjar, 2005, A&A, accepted; C. Martin et al. 2005, in preparation; A. Natta et al. 2000, Protostars & Planets IV, 559.