

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

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# CONTEXT

## ➤ Herbig stars:

- Higher mass counterparts of T Tauri stars
- Precursors of the  $\beta$ -Pictoris and Vega-type stars

## ➔ **Circumstellar environment: subject of controversy**

## ➤ Sample of stars: 18 stars observed with FUSE

- "Circumstellar Disks Program" : guaranteed time

M. Deleuil, J-C. Bouret, C. Martin (LAM)

A. Vidal-Madjar, A. Lecavelier des Etangs, R. Ferlet (IAP)

P. Feldman, A. Roberge, W. Moos (JHU)

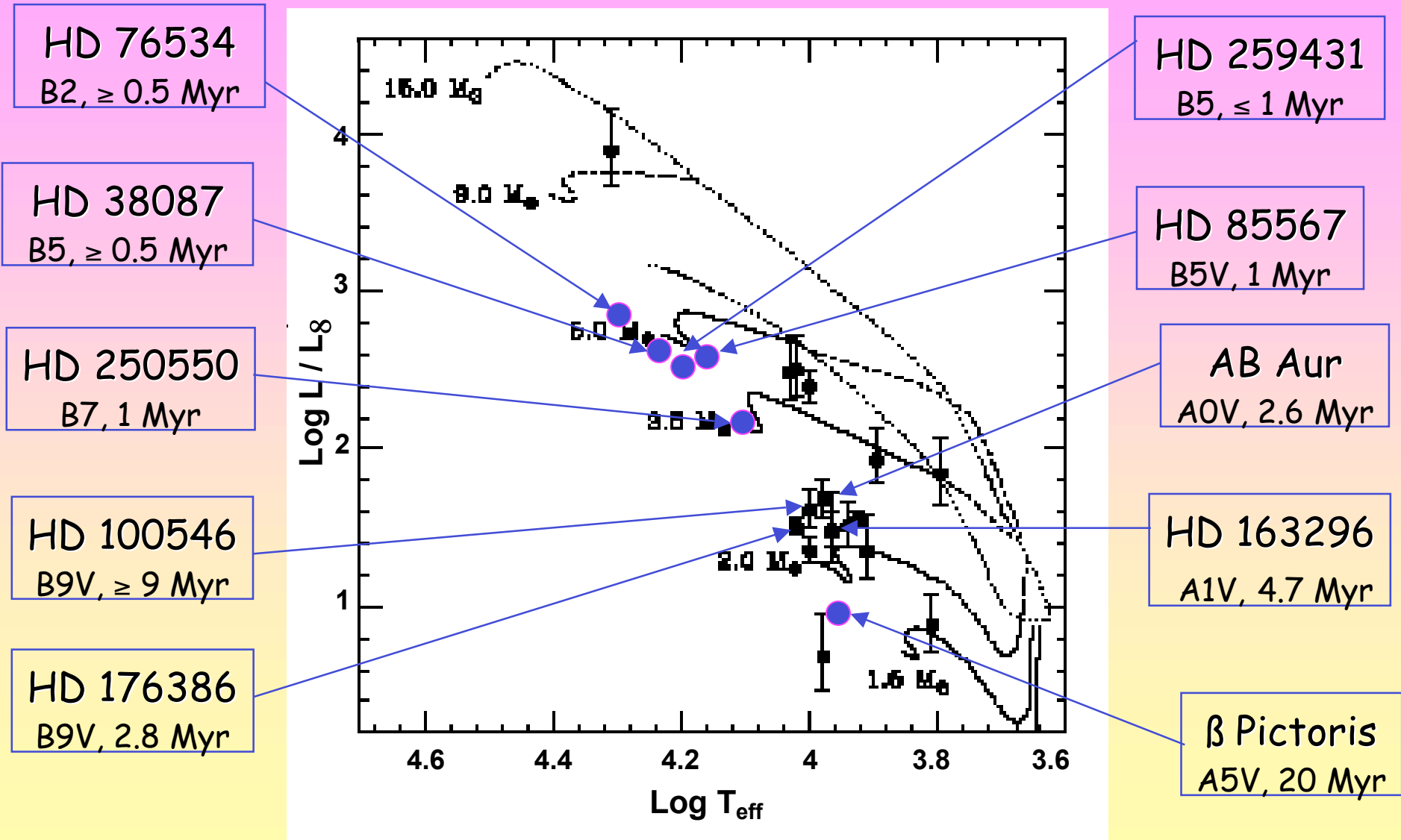
- Guest Investigators programs

C. Catala, T. Simon

## ➤ FUSE Satellite:

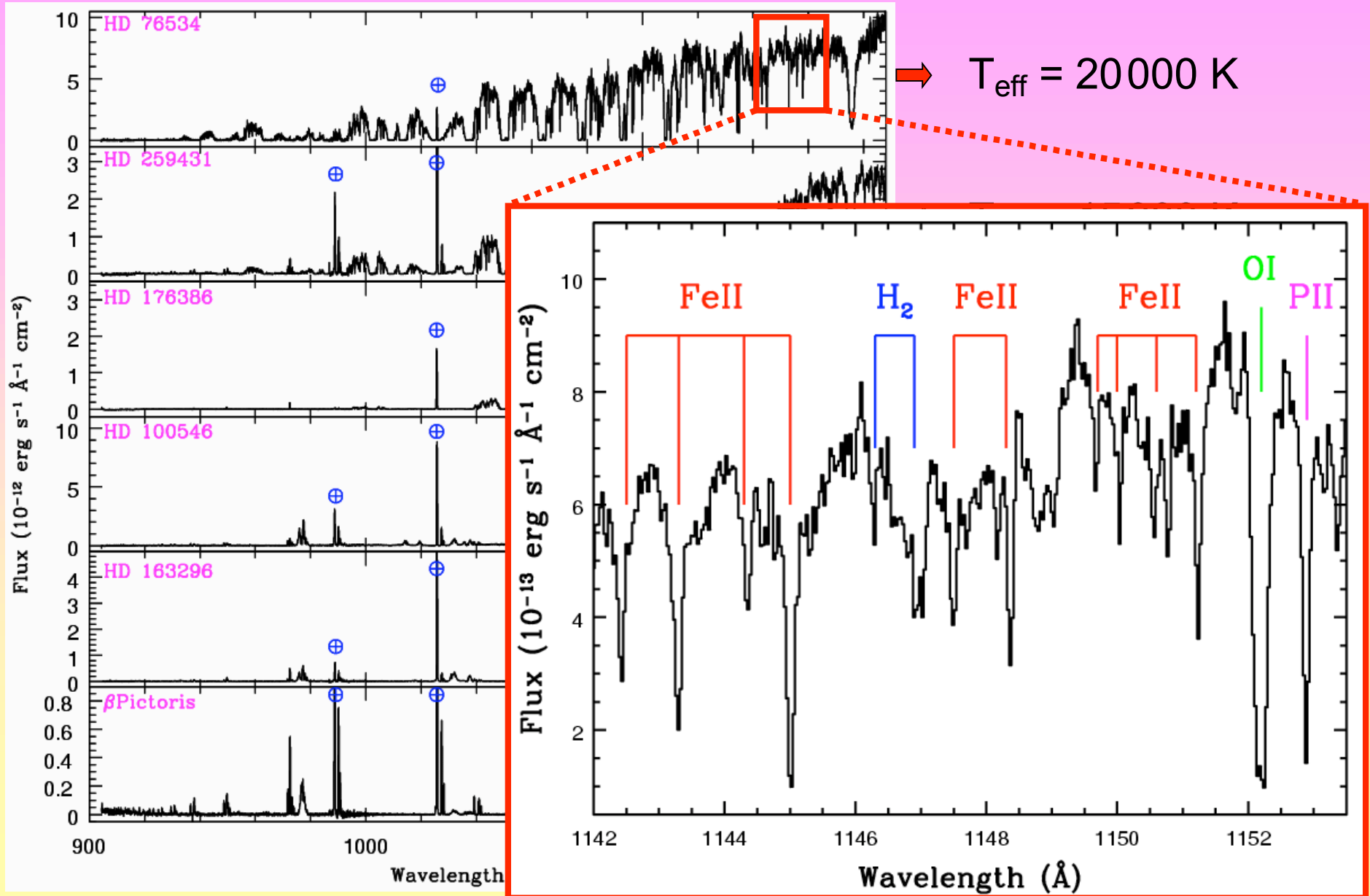
- Spectrograph: 905 – 1187 Å, resolution ~ 15 000

# THE SAMPLE STARS

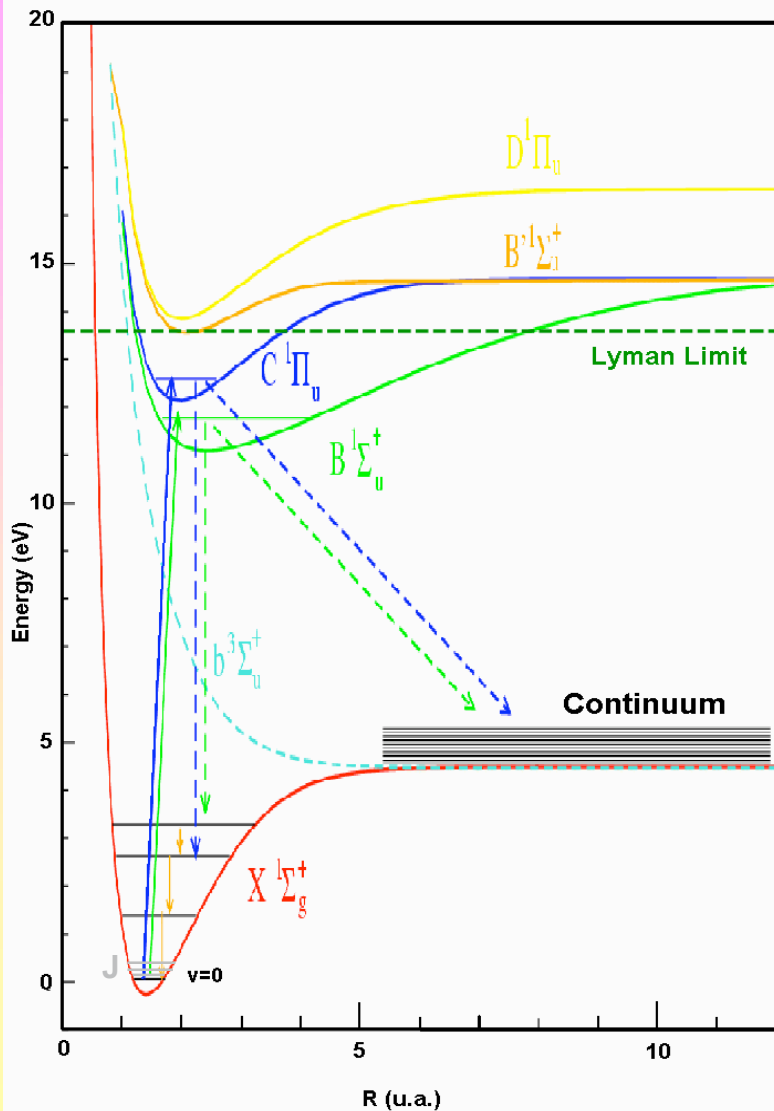


Van den Ancker et al. (1997 & 1998)

# EXAMPLES OF FUSE SPECTRA




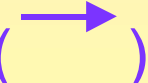
# MOLECULAR HYDROGEN



Franck Le Petit, PhD Thesis (2002)

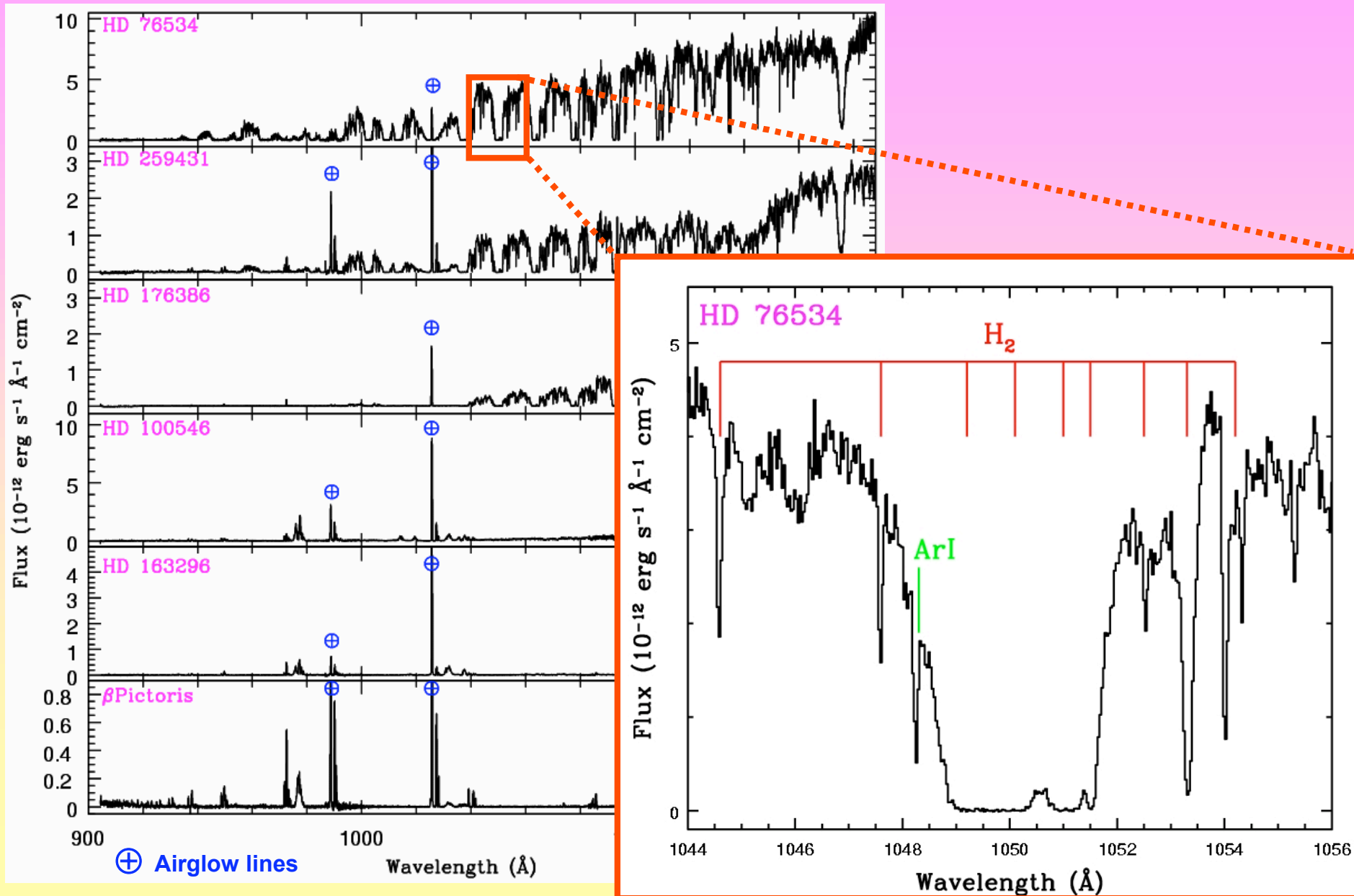
- The most abundant molecule in the CS environment of young stars
- Protected by " Self-Shielding "
- Constrains the reservoir of gas for planets building

## H<sub>2</sub> IN FUSE SPECTRA:

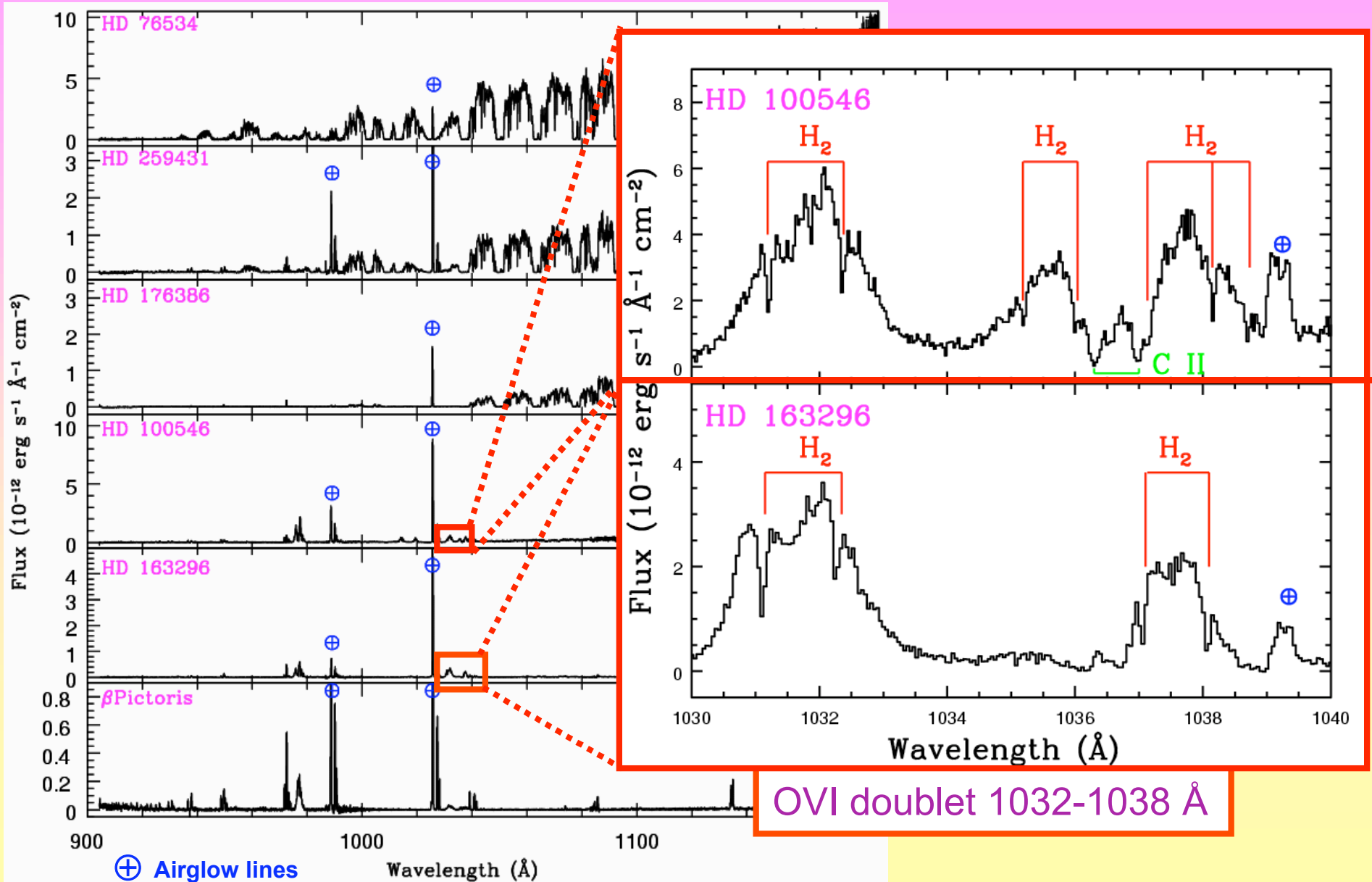
- Lyman transitions B-X (  )
- Werner transitions C-X (  )

 Numerous lines in the FUV

# H<sub>2</sub> IN FUSE SPECTRA

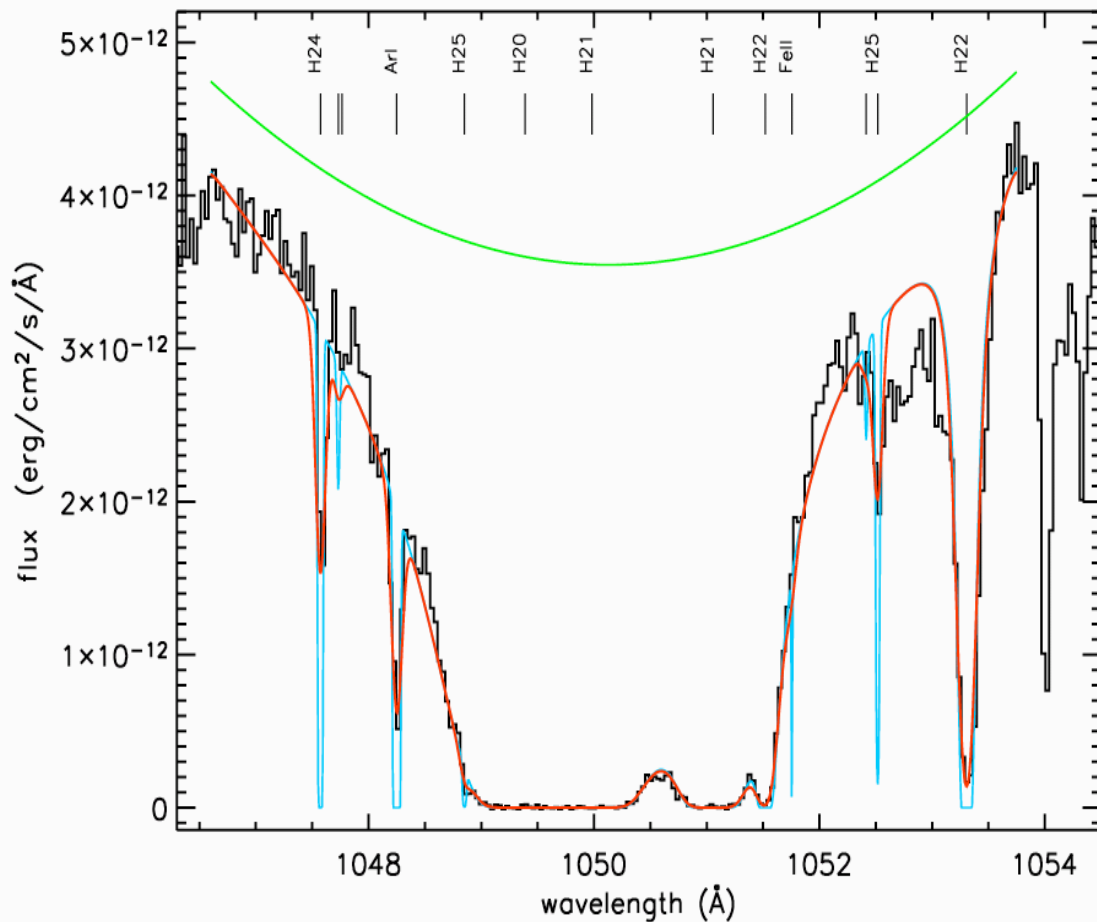


# H<sub>2</sub> IN FUSE SPECTRA



# ANALYSIS OF H<sub>2</sub> LINES

The Owens Profile Fitting Procedure (M. Lemoine et al. 2002)



Martin et al. (2004)

**Green: Stellar Continuum**

**Blue : Intrinsic Profile**

**Red : Resulting Profile**



**Column densities**

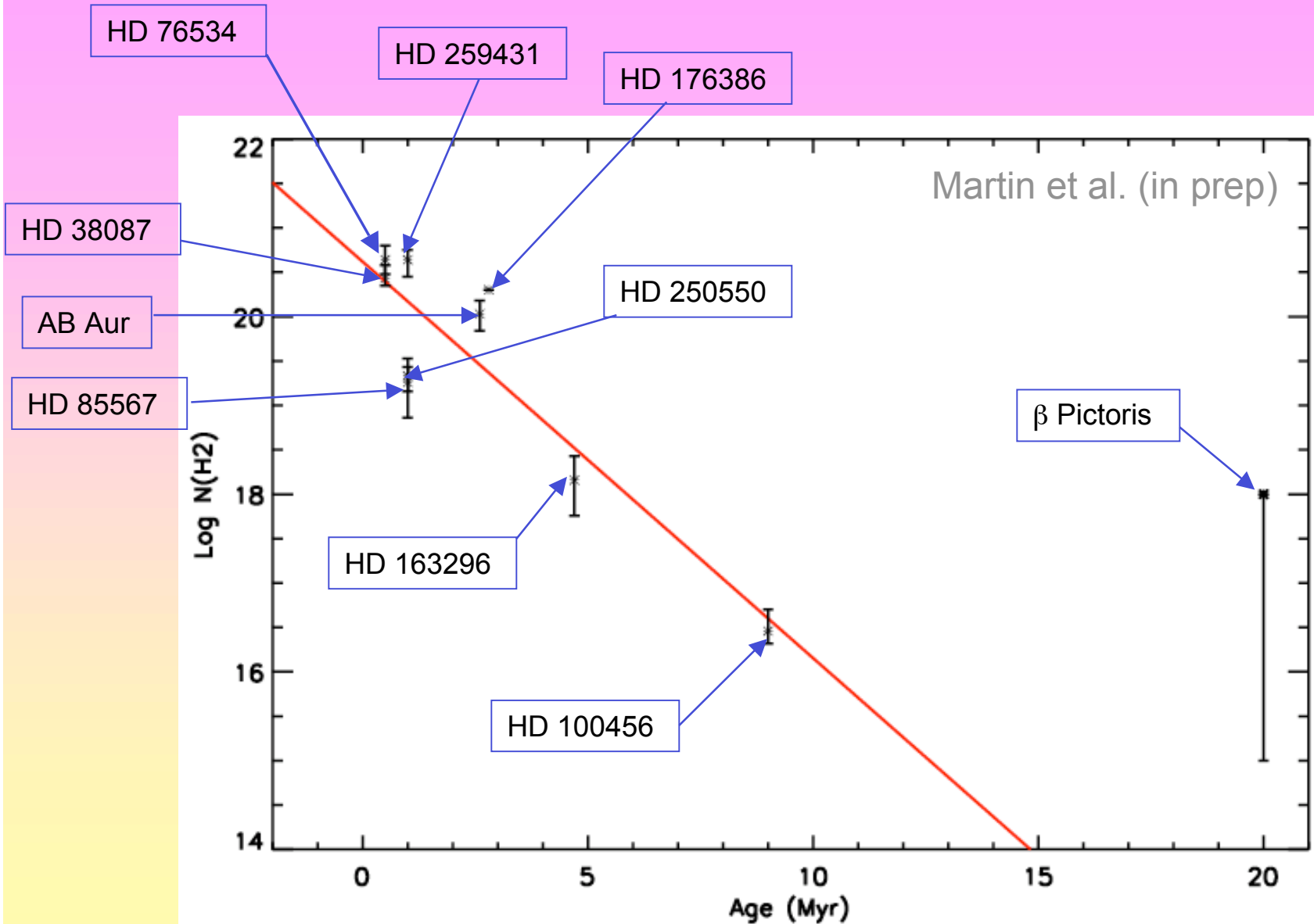
**Radial velocities**

**Line widths (*b*)**

**Gas bound to the star**



# EVOLUTION

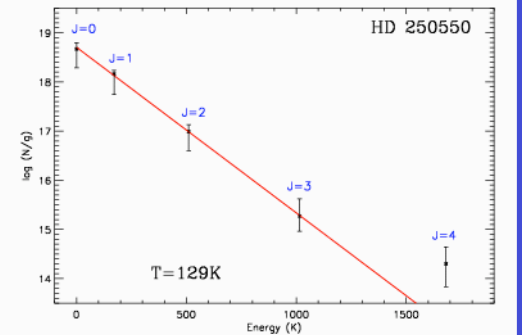
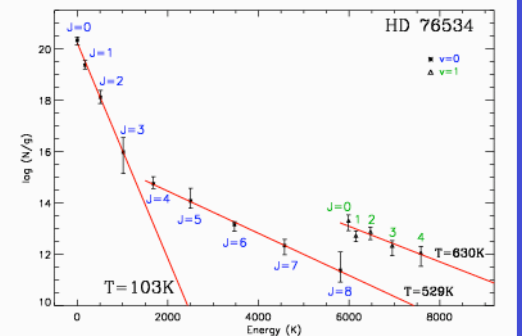
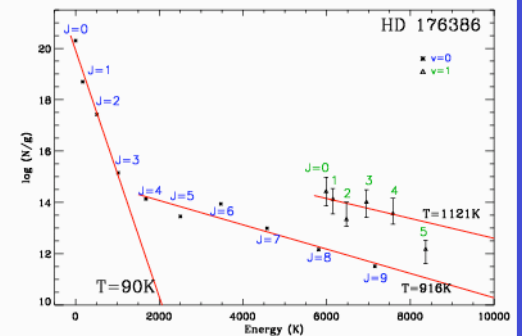
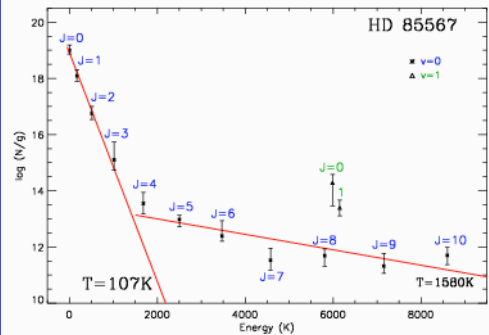
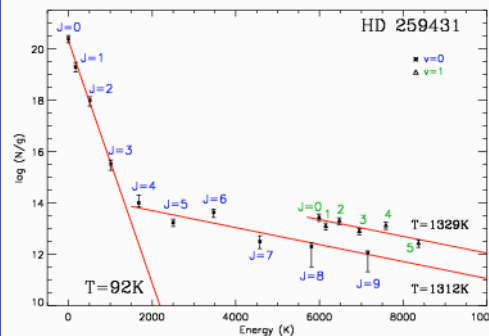
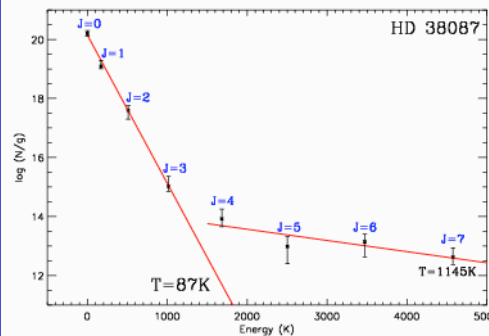
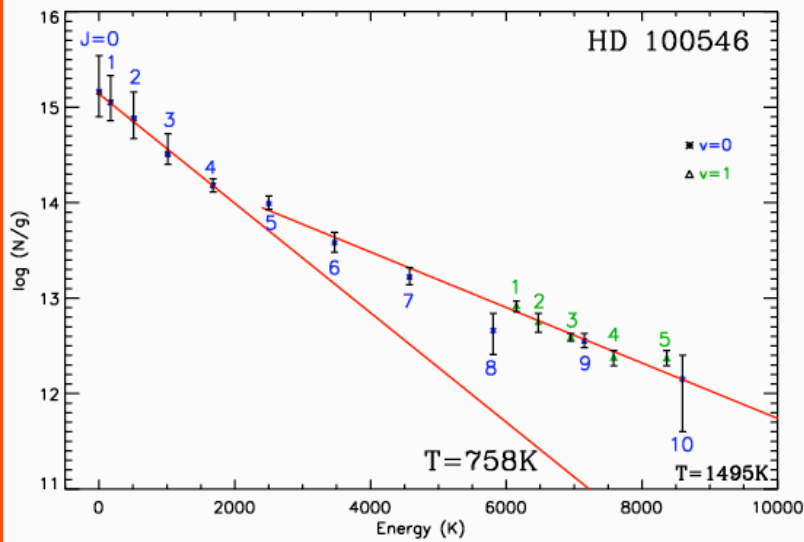
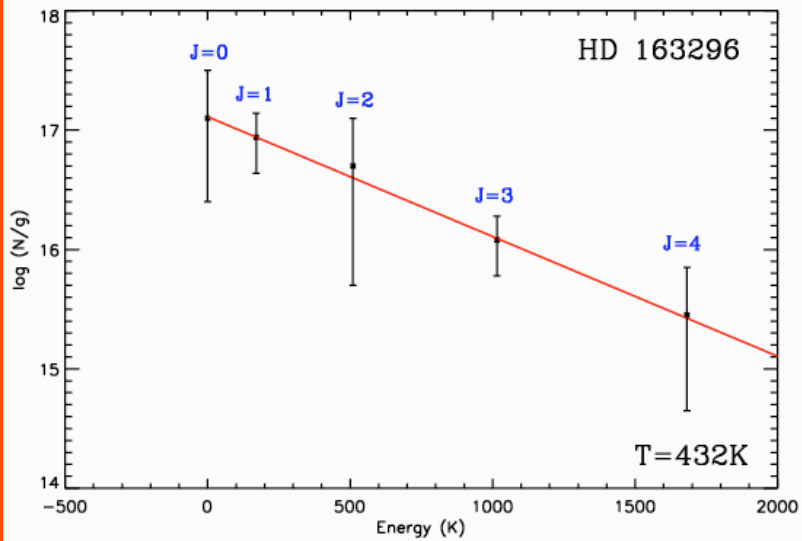


H<sub>2</sub> content decreases with age  $\Rightarrow$  Youngest stars still embedded

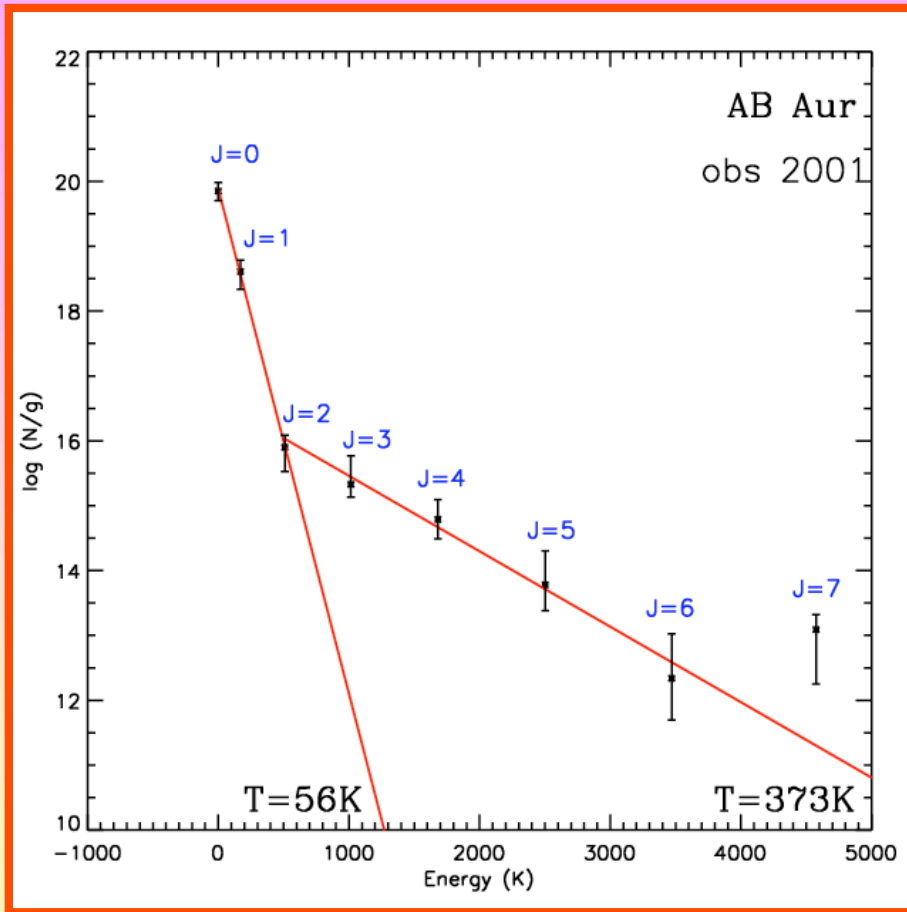
# EXCITATIONS DIAGRAMS OF H<sub>2</sub>

H<sub>2</sub> thermalized up to J=4

H<sub>2</sub> thermalized up to J=3



# THE CASE OF AB AURIGAE



**Excitation Conditions**  
=  
**Interstellar Medium**

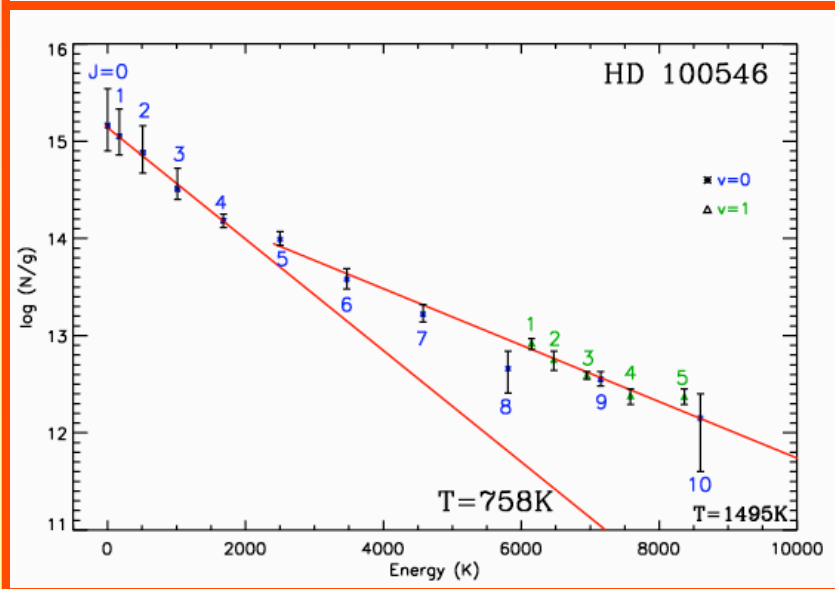
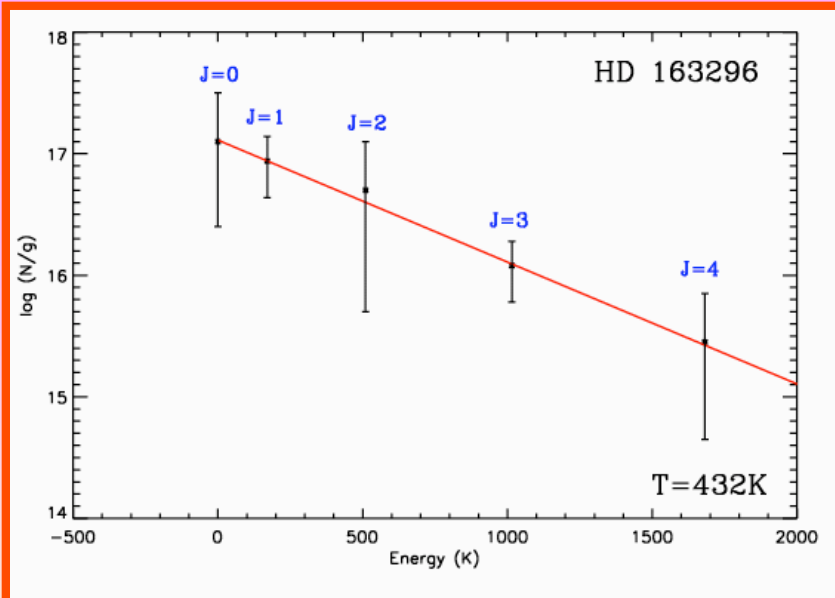
Gry et al. (2002)

**H<sub>2</sub> detected by FUSE:**  
Remnant of the original  
molecular cloud

Very extended disk with inclination angle:  
 $27^\circ \leq \alpha \leq 35^\circ$  from the plane of the sky

(Eisner et al. 2003, Mannings & Sargent 1997)

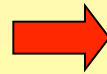
# HD 100546 & HD 163296



- Stars surrounded by disks
- H<sub>2</sub> Thermalized up to J=4
- ➔ Collisionally excited medium close to the star < 5 AU  
(Lecavelier des Etangs et al. 2003)

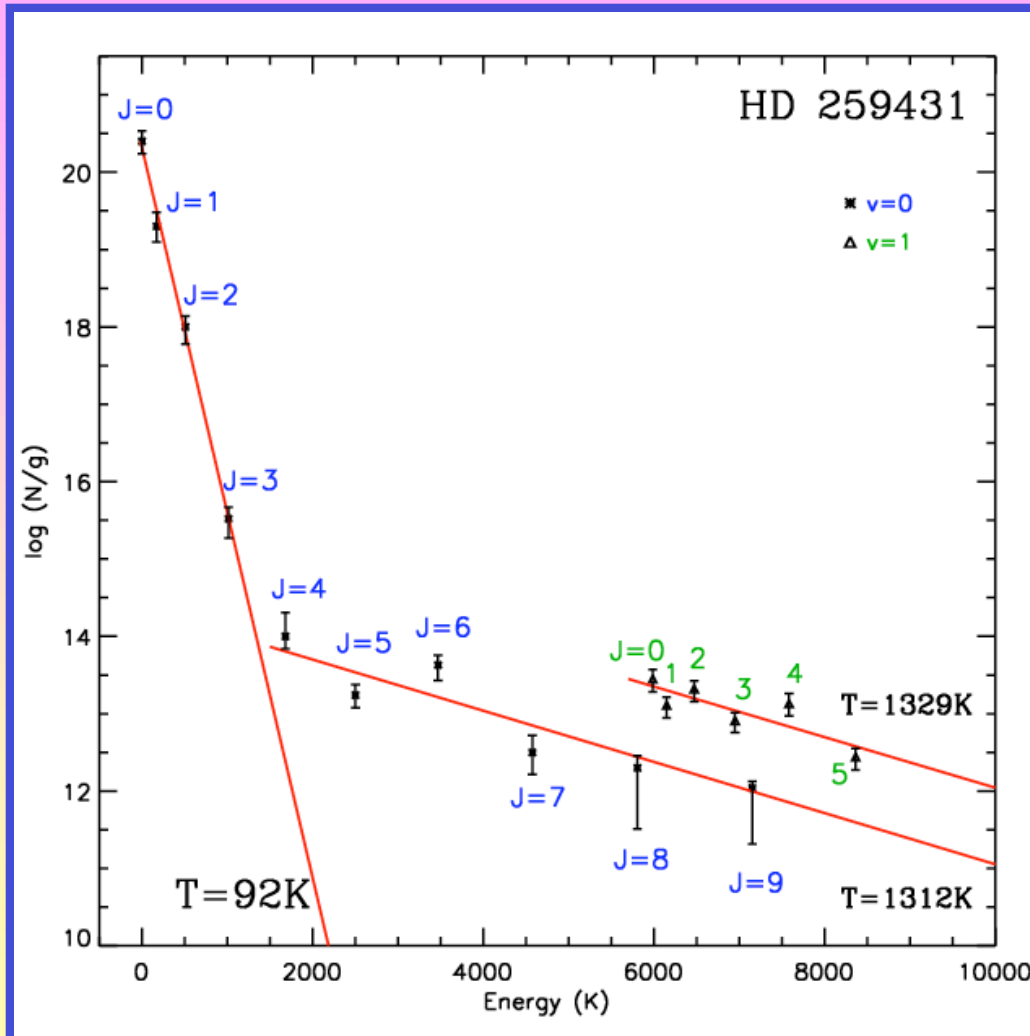
- Disks inclination angles to the lines of sight:  
(Grady et al. 2000; Augereau et al. 2001)

- HD 163296:  $\alpha = 60^\circ \pm 5^\circ$
- HD 100546:  $\alpha = 51^\circ \pm 3^\circ$



**Extended chromosphere located above the disk ?**

# HERBIG Be STARS



Bouret, Martin et al. (2003)

For the second subclass:

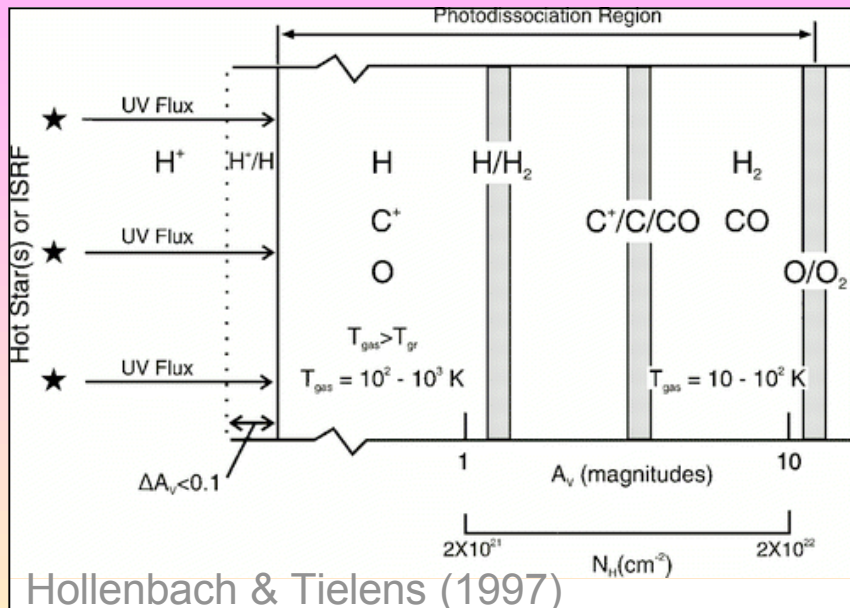
- B8 – B2 stars
- H<sub>2</sub> Thermalized up to J=3
- J=0-3 Temperature: ~100 K
- Higher J-levels ~1300 K

**Very similar to the H<sub>2</sub> excitation in PDRs**

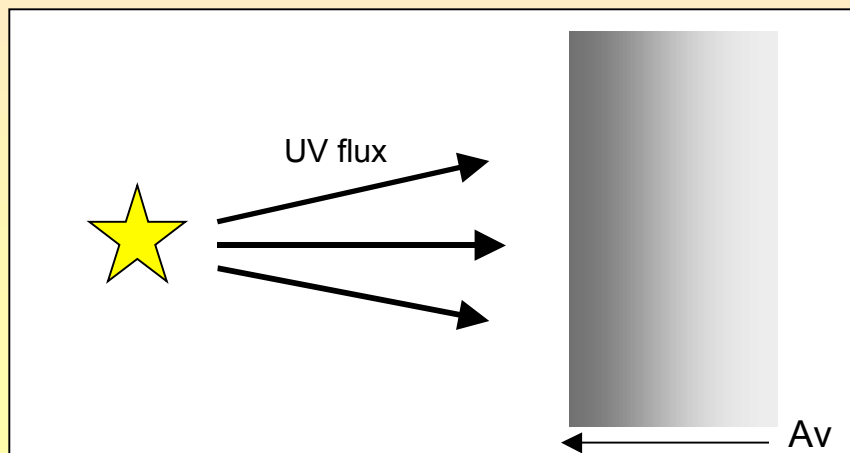
# PHOTODISSOCIATION REGIONS MODEL

J. Le Bourlot, "Molecules in the Universe" Team, Observatoire de Paris

Free code: <http://aristote.obspm.fr/MIS/>



- Plan parallel
- Gas and Dust
- Constant density
- Stationary state
- Model including:
  - the radiative transfer
  - the chemistry (~200 species, 4000 chemical reactions)
  - the statistical equilibrium
  - the thermal balance



# RESULTS FOR HD 259431

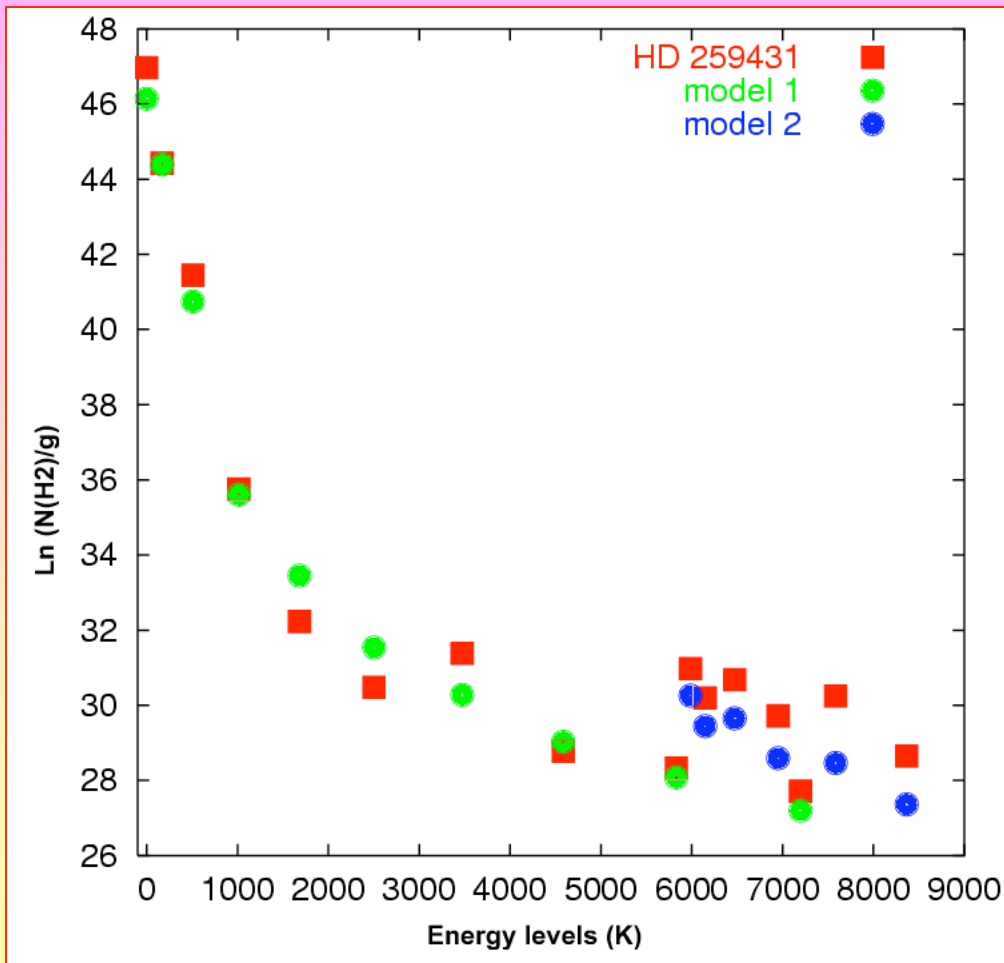
To reproduce the excitation diagram:

**2 PDRs are needed:**

- a large PDR with low density ● for the lower J-levels
- a dense PDR close to the star ● for the higher J-levels

**Compatible with images:**

- MSX (A band 8.8  $\mu\text{m}$ ):  
Hot dust close to the star
- DSS2 (R and I bands):  
Very large dark cloud



Martin et al. (in prep)

# CONCLUSIONS

## ➤ 2 different mechanisms of H<sub>2</sub> excitation

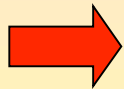
### ✓ Youngest stars of the sample

- Embedded in the remnant of their original cloud
- HD 259431: PDRs models with 2 components

➔ **Complete the analysis for the whole sample**

### ✓ Stars with circumstellar disks:

- Collisionally excited medium close to the star
- Goal: explain the excitation diagrams of stars with disks



**INCLUDE IN MODELS OF DISKS  
RADIATIVE TRANSFER FOR H<sub>2</sub>**

## ➤ Measurement in the FUV of the circumstellar H<sub>2</sub> content:

New constraints for the nature and evolution of the circumstellar environment of Herbig Ae/Be: disks, envelopes, halos...