

Spectrométrie haute sensibilité de molécules marqueurs des étoiles froides

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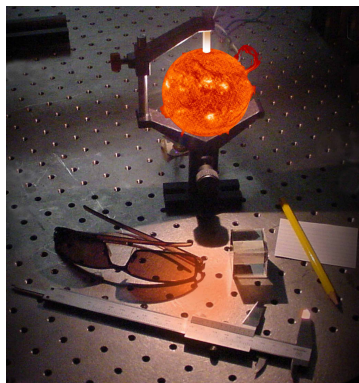


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Spectroscopie Laser de radicaux moléculaires MH (M: Ni, Fe, Cr)

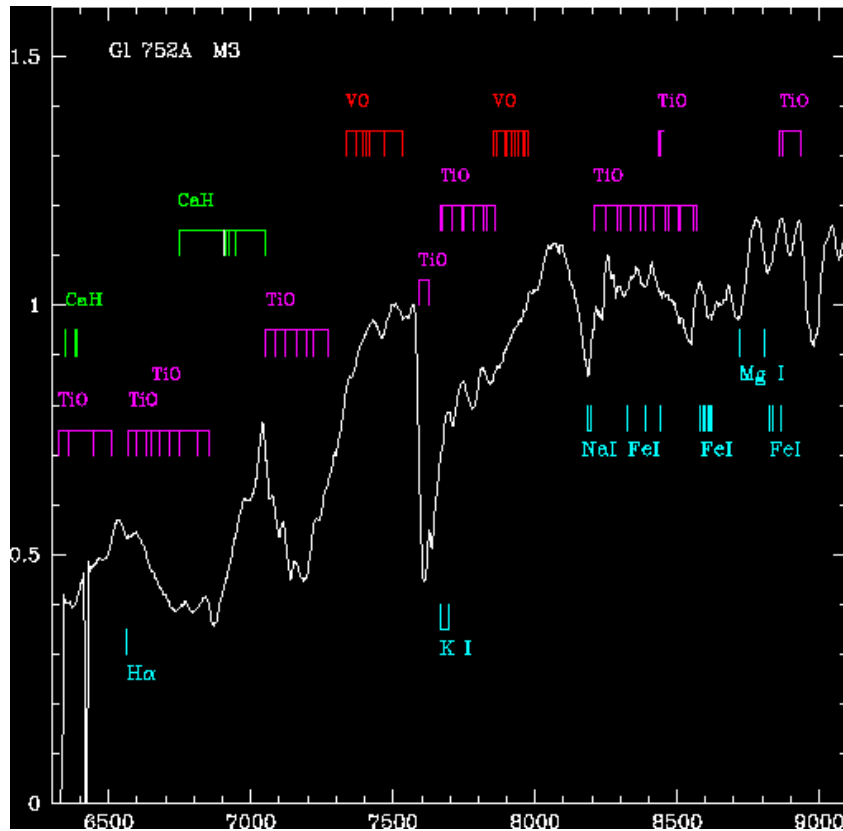
- Source à pulvérisation cathodique ($T < 500\text{K}$)
- Spectrométrie : FTS, LIF, CRDS, Vernier (Résolvançe $> 10^5$)
- Enregistrement de spectres champ nul et Zeeman ($B < 1\text{ T}$)
- Analyse et simulations (Igor Pro, Pqopher...)



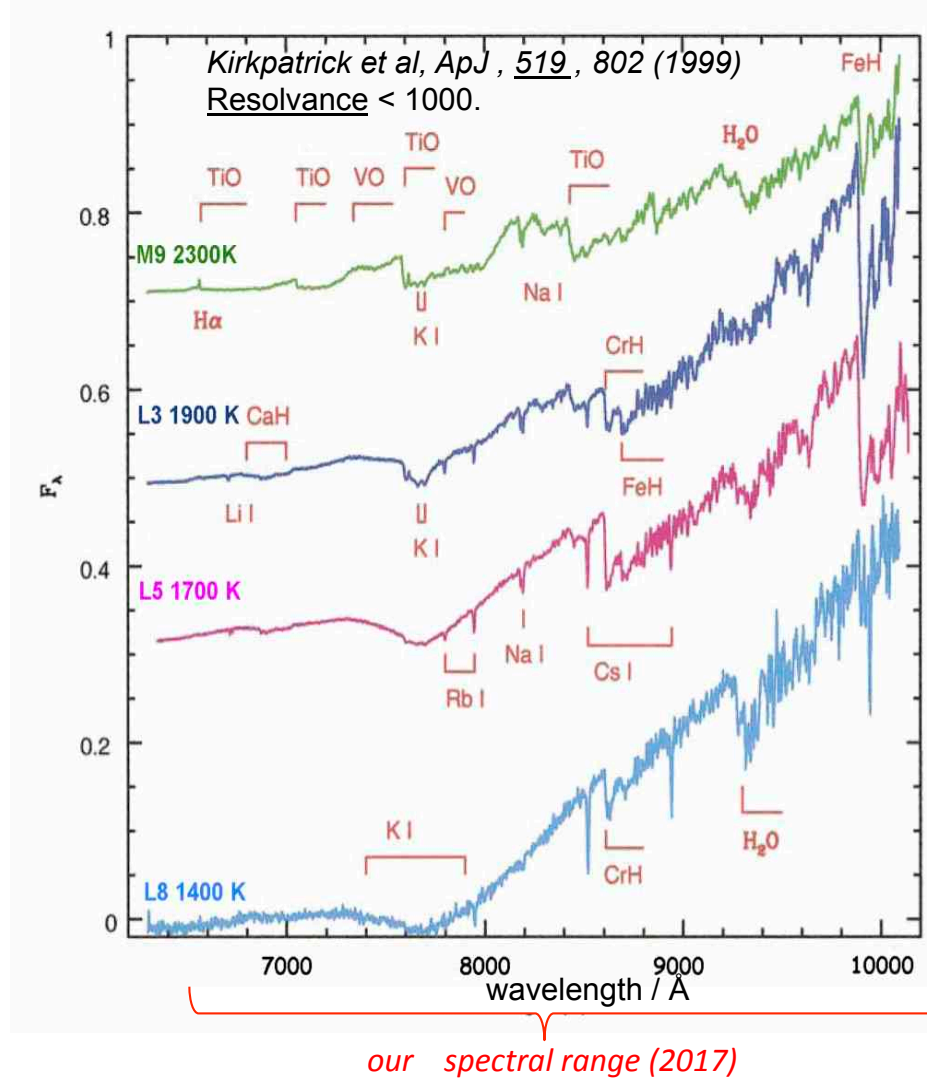
PLAN

- 1. Contexte astro** étoiles froides
- 2. Résultats de labo** FeH, CrH, N₂
- 3. Projets** CSAA, ANR > SPIrou

Contexte astro > molecular bands in M & L dwarfs / 0.7-1.0 μm

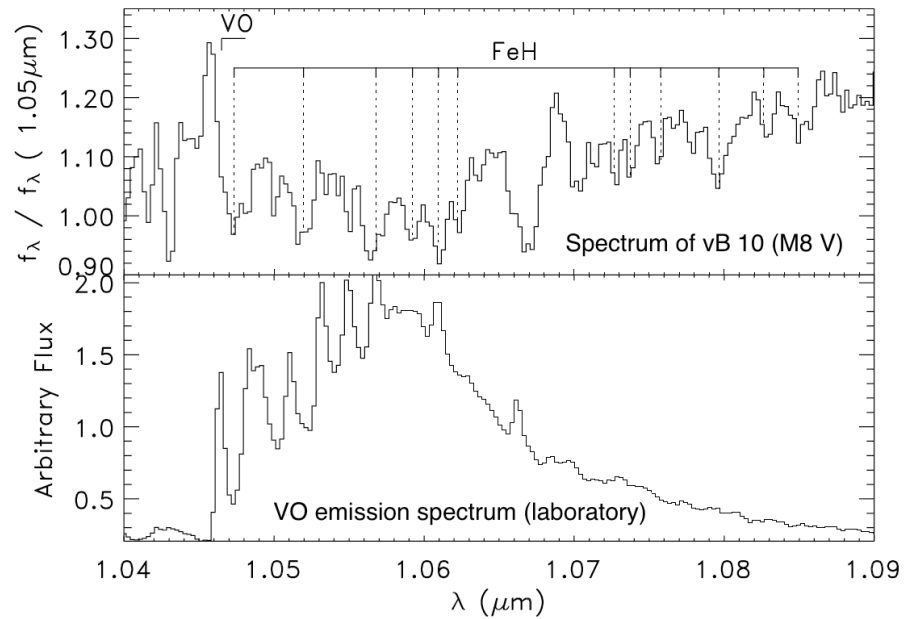


TiO : $\alpha \rightarrow \epsilon$ bands @ 0.5-0.9 μm
VO : B-X band @ 0.73-0.81 μm



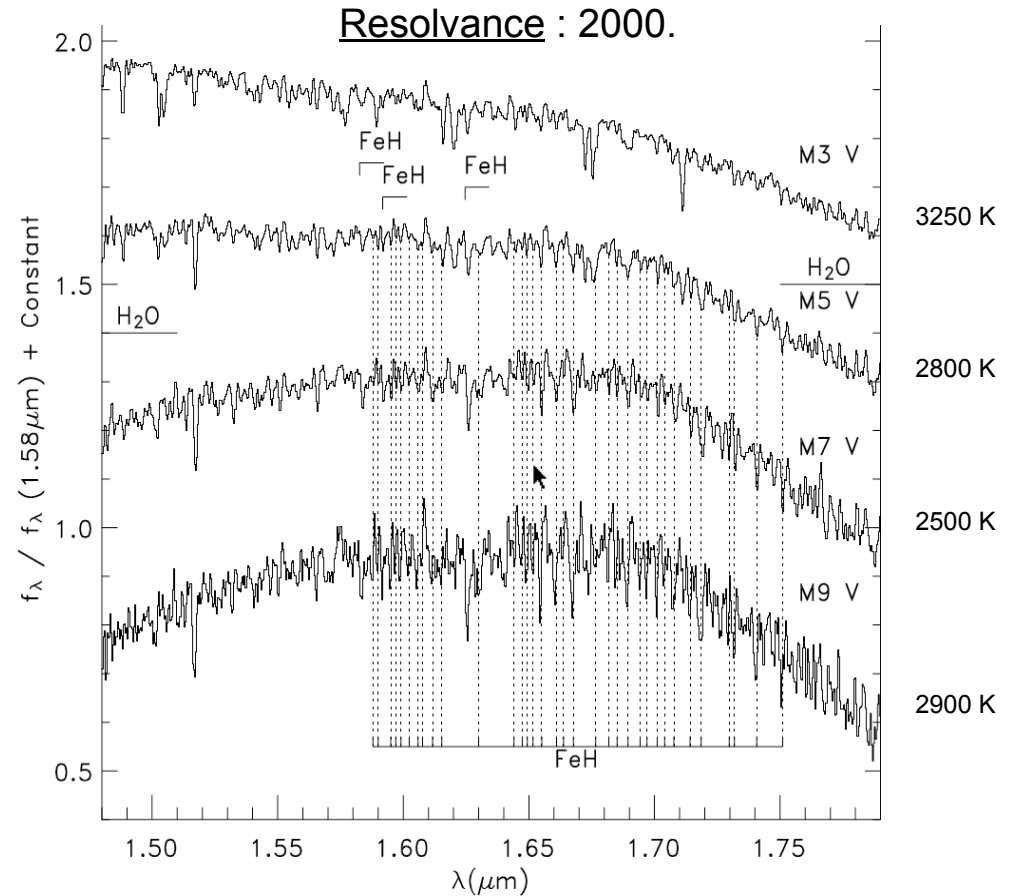
FeH : F-X 1-0 @ 0.87 μm , 0-0 @ 0.99 μm
CrH : A-X 0-0 @ 0.86 μm

Contexte astro > molecular bands in M dwarfs / 1.0-1.8 μm



M. C. Cushing et al, *ApJ*, 623:1115 (2005).

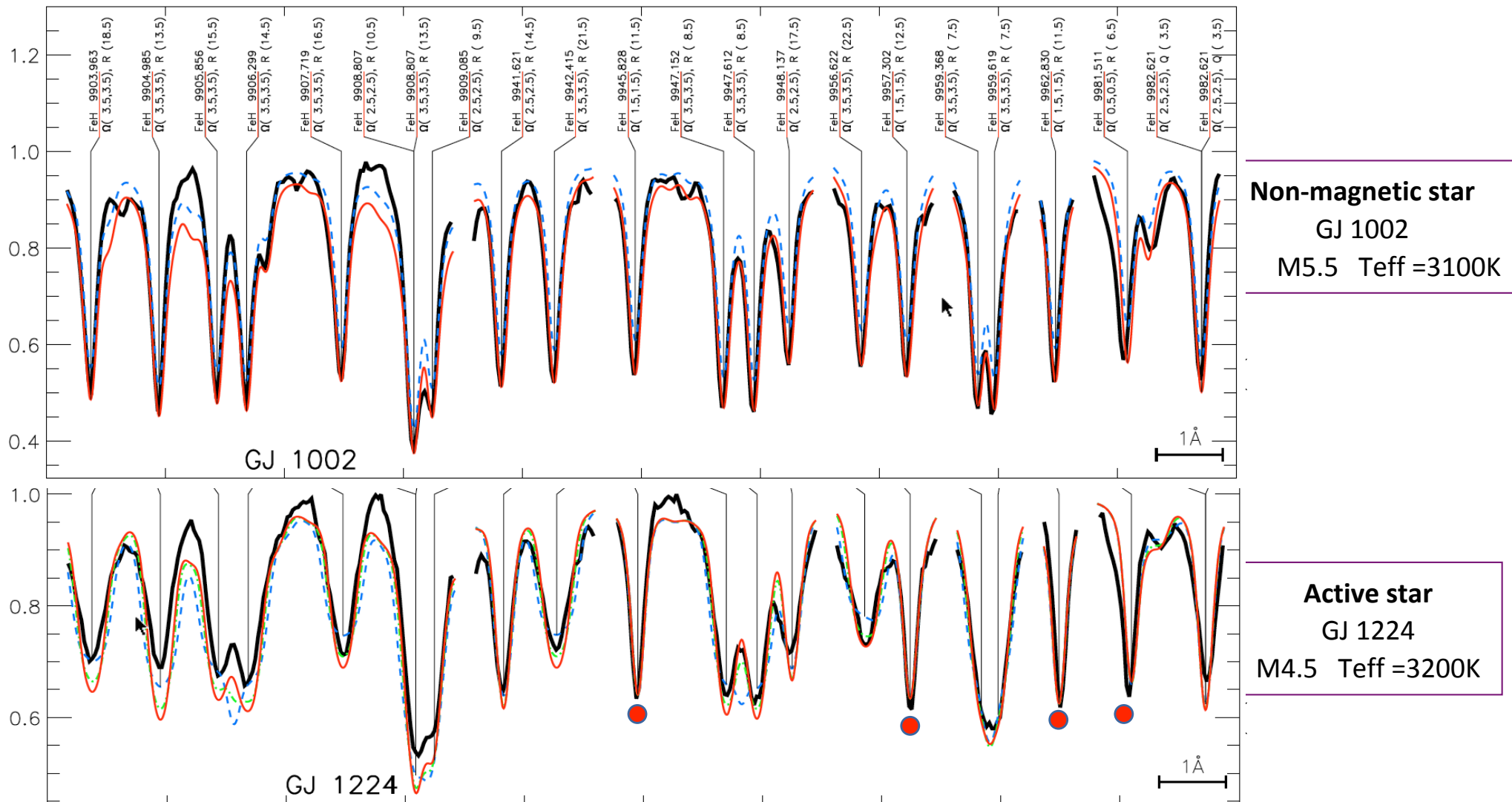
- FeH** : F-X 1-0 , + hot bands ?
- VO** : A-X 0-0 @ 1.05-1.08 μm
- TiO** : ϕ -band @ 1.1-1.25 μm



FeH : E-A 0-0 $\approx 1.65 \mu\text{m}$

SPIRou : 0.98–2.45 μm , R = 75000

Stokes I spectra / CRILES @ R=10⁵ (Shulyak *et al* A&A 523: A37 (2010))

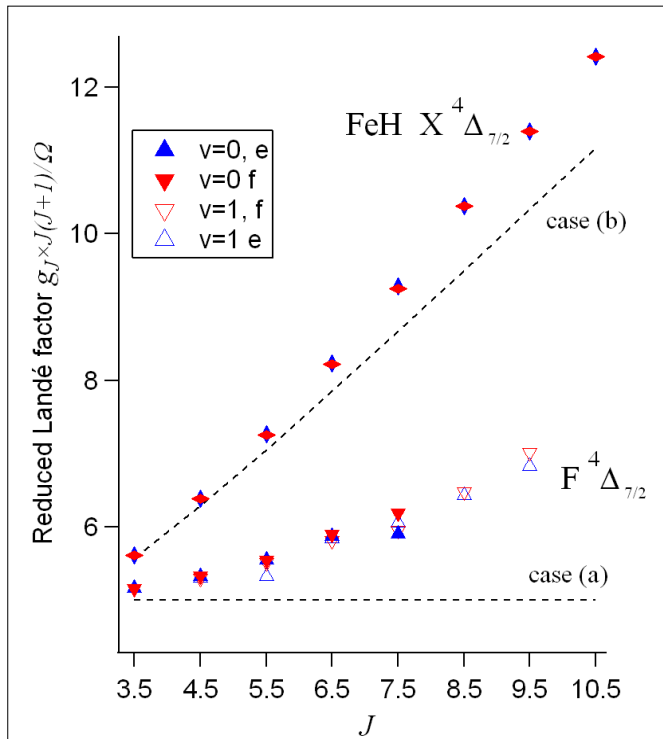


Line profiles based on calculated molecular Landé factors (MZL) constrained estimates of magnetic field, but **optimum values for line widths do not match best values for line depth** (models illustrated with red and blue lines). Estimated field B=1.7-2 kG (30% lower than previous estimations)

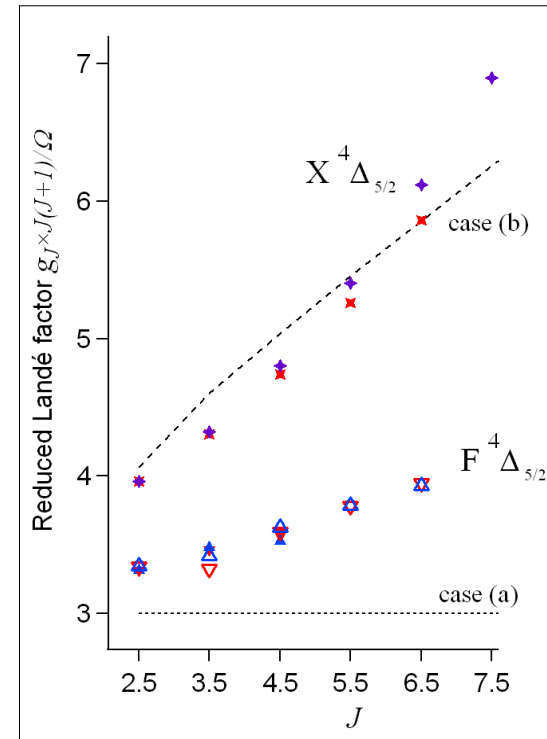
Fit data from $B = 0.2-0.6$ T, and examine results for two nominally $^4\Delta$ states

→ electronic Landé factors $g_J * J(J+1) / \Omega$

X, $F^4\Delta$ $\Omega = 7/2$



X, $F^4\Delta$, $\Omega = 5/2$



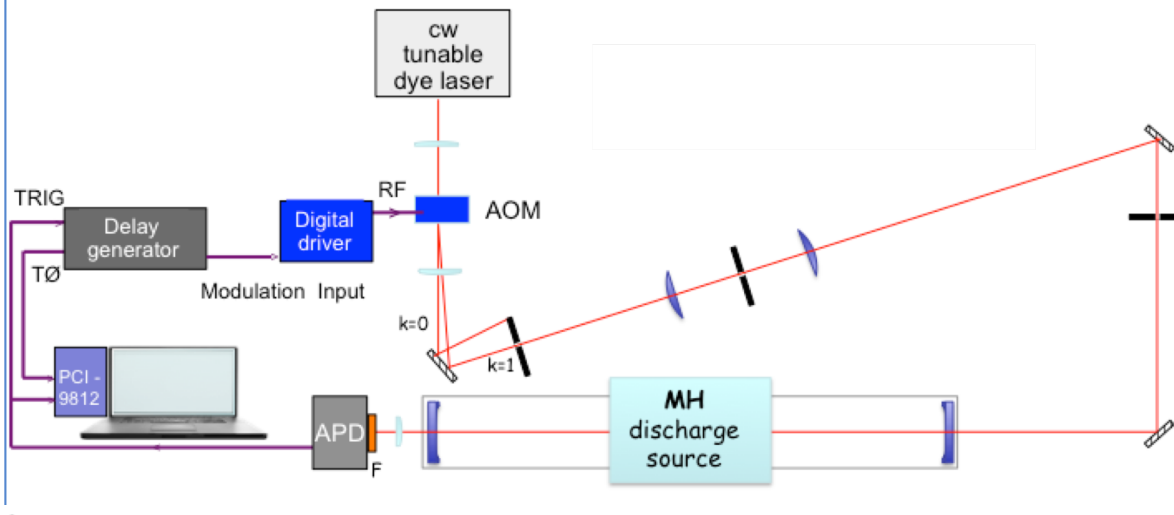
Crozet et al, *J. Mol. Spec.*, **303**, 46 (2014)

F state : match for $v=1, J=3.5$ from molecular beam work (Harrison et al. *ApJ* **679** 854 (2008))

Mismatch ~4% wrt sunspot-derived g-factors Harrison & Brown, *ApJ*, **686** 1426 (2008)

Résultats > expérience CRDS (Cavity Ringdown Spectroscopy)

CW-CRDS experiment : $1/C\tau = 1/C\tau_0 + \alpha(\nu) \cdot d/L$

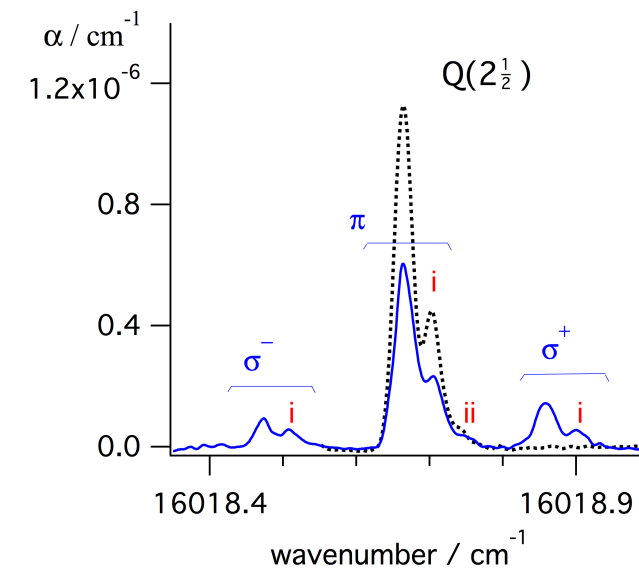
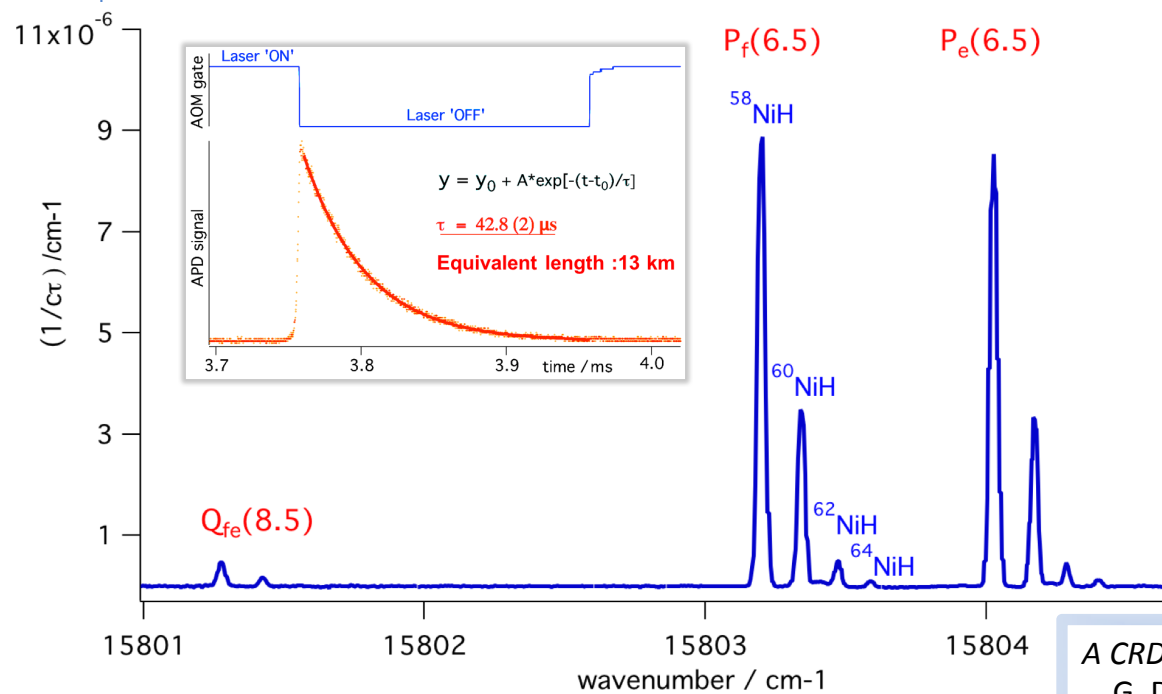


longueur cavité = 69 cm
longueur d'absorption équivalente : 400 m

Source moléculaire :

- cathode Ni + flux Ar/ 10% H₂ (40 sccm)
- i=100 mA , p=0.8 Torr

Puissance laser injectée/cavité : 1.4 mW

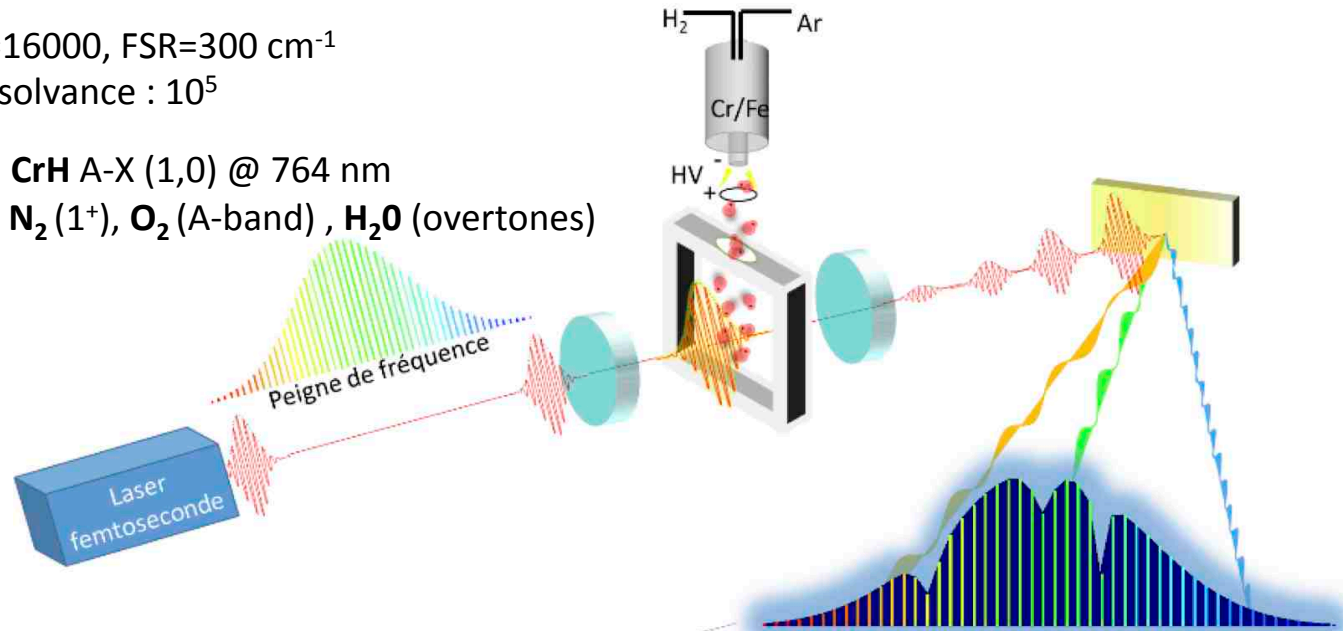


A CRDS sputter-source experiment to study MH radicals
G. Dobrev, J. Morville, D. W. Tokaryk, A. J. Ross & P. Crozet
Mol. Phys., **114**(19) : 2777 (2016).

Résultats > Spectromètre Vernier à peigne de fréquences

Specs : $F=16000$, $FSR=300\text{ cm}^{-1}$
resolvance : 10^5

1st Results : **CrH A-X (1,0) @ 764 nm**
 $\text{N}_2(1^+)$, $\text{O}_2(\text{A-band})$, H_2O (overtones)

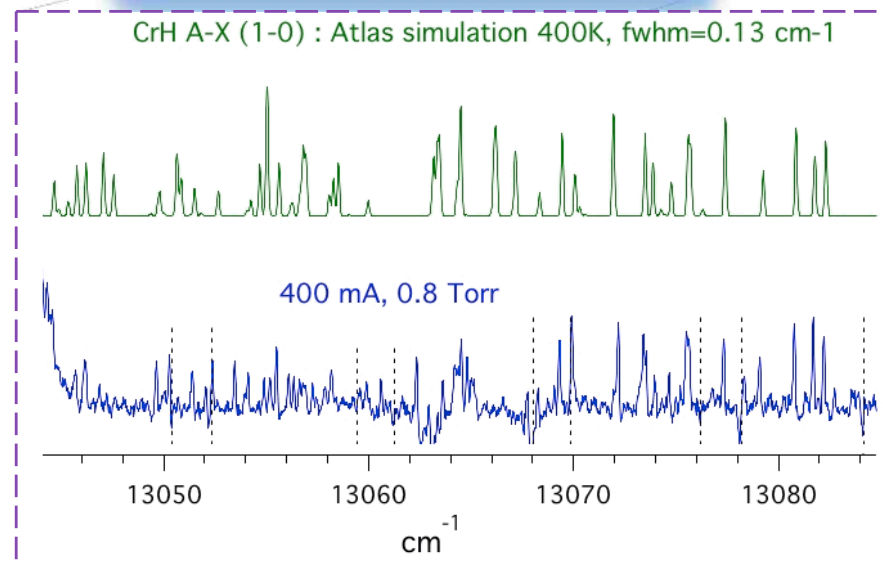


"A new broadband Cavity-Enhanced Direct-Frequency-Comb-Spectroscopy using a continuous Vernier filtering"

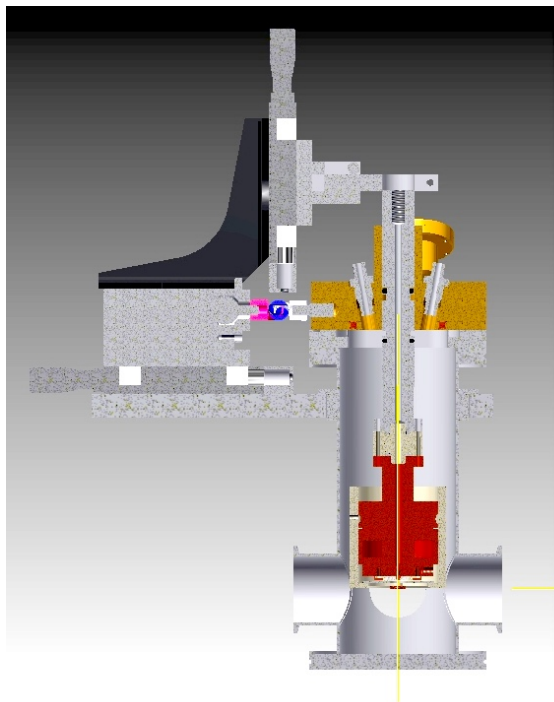
J. Morville, L. Rutkowski, P. Crozet, and A. J. Ross

FLAIR 2016

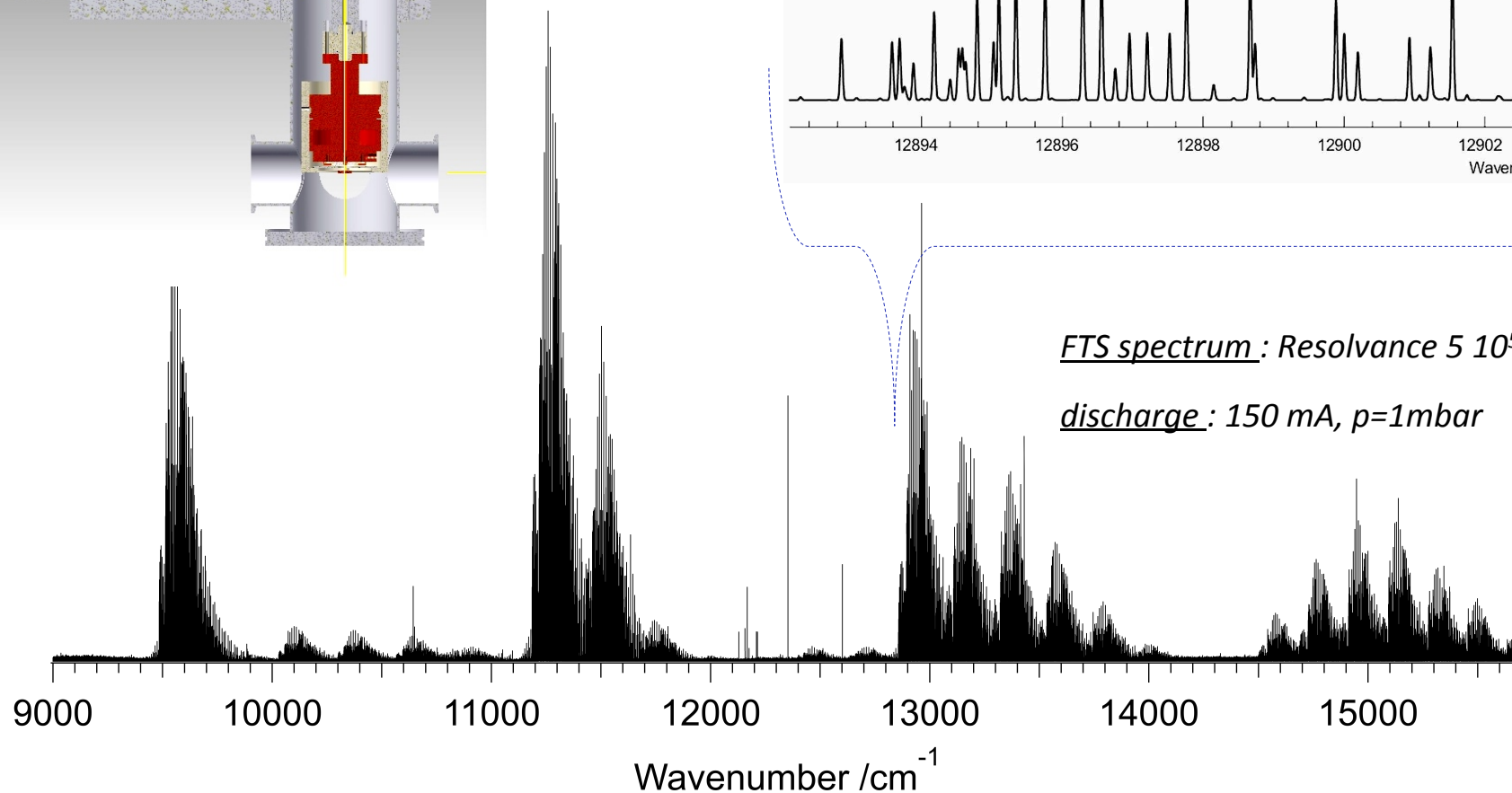
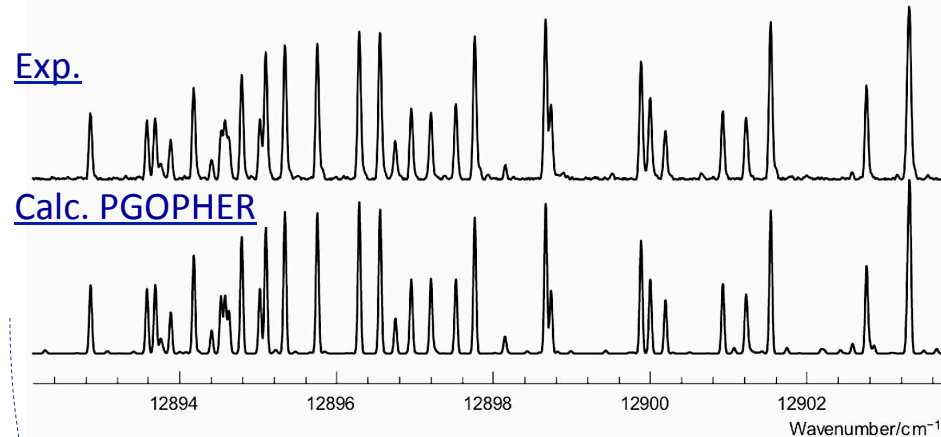
(5th International Conf. on Field Laser Applications in Industry and Research).



Résultats > Nouvelle source moléculaire : spectre de référence de $N_2^+ 1^+$: 0.64 - 2.2 μm



The spectrum of N_2 from 4500 to 15700 cm^{-1} revisited with PGOPHER
C. M. Western, P. Crozet, A. J. Ross, J. Morville, D. Tokaryk, and L. Carter-Blatchford,
(to be submitted : *JQSRT* 2018)



Expérience de laboratoire : Spectromètres Vernier et CRDS ; champ nul , puis + champ magnétique.

- spectromètre Vernier : 1 scan = 22 nm, resolvance 10^5 .
- spectromètre CRDS : 1 scan = 0.1 nm, résolution $> 3 \cdot 10^8$ + Lambdamètre : précision absolue = 0.2 pm

Cibles principales : CrH A-X 0-0 @ 861 nm, FeH F-X 1-0 @ 869 nm et F-X 0-0 @ 989 nm

Magnetic response : NOT MUCH ...

- LMR /discharge : $X^2\Delta, v''=0, N''<6$:

S.Corkery et al, J. Mol. Spectrosc. 149,257 (1991)

- LIF/beam A-X, $J''<5 v'=0,1$:

J. Chen et al, PCCP, 9, 949 (2007)

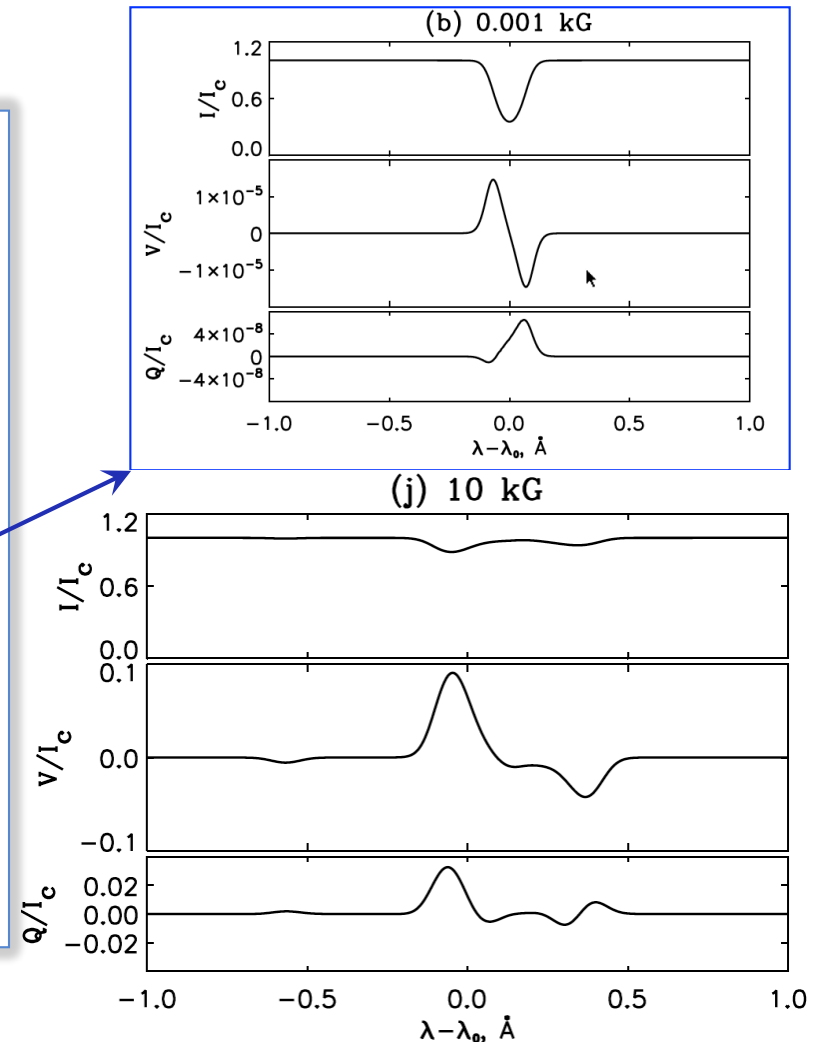
- Heff model : O. Kuzmychov, A&A, 558, A120 (2013).

Spectropolarimetry simulation : strong asymmetric splitting for Stokes Q @ $B > 1$ G Paschen-Back regime

"a considerable signal in both circular and linear polarization, up to 30% @ $B \geq 3$ kG in early L dwarfs"

=> Needs from the lab :

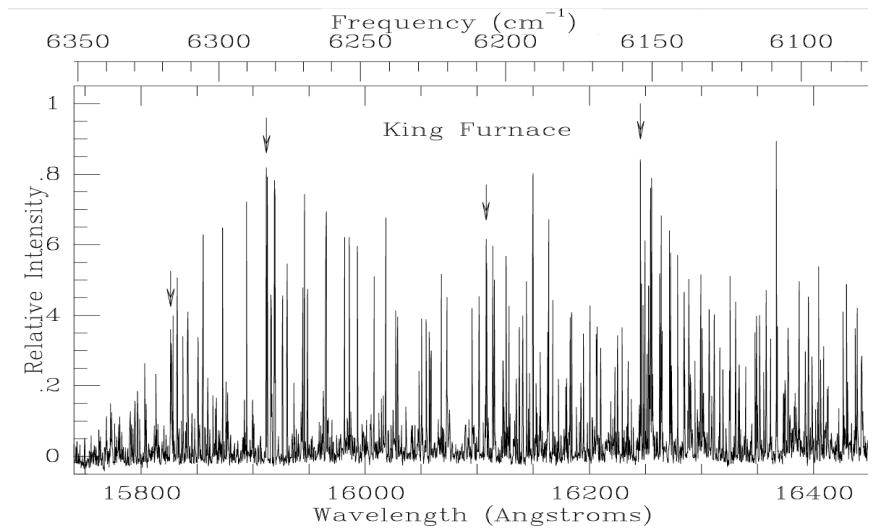
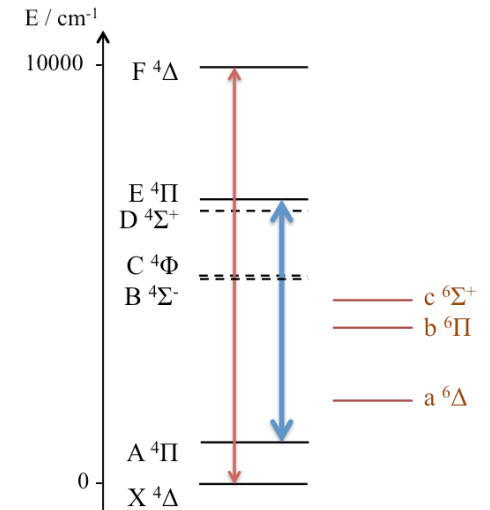
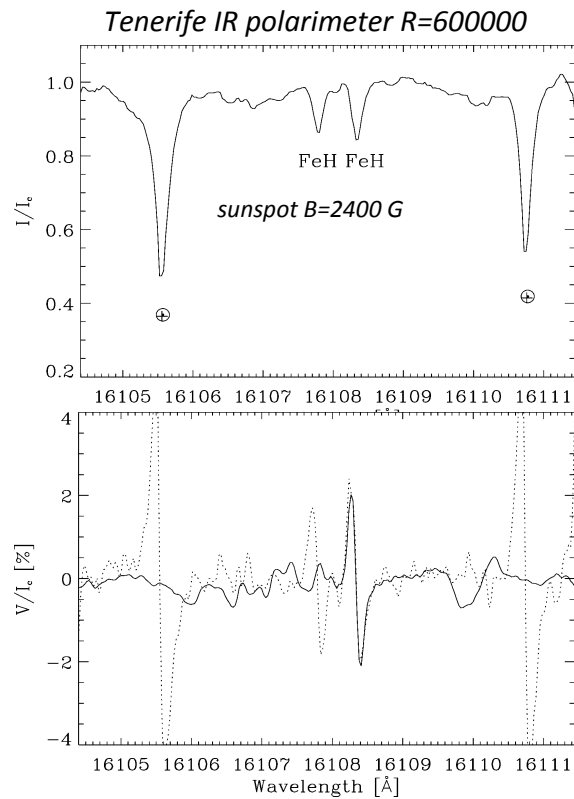
- absorption cross-sections ($B=0$)
- g_{eff}



Projet : mesures de référence sur FeH, VO ...

- opacités, par mesure directe de $\alpha(\nu) = \kappa(\nu) \rho$
- facteurs de Landé g_j

Cibles principales : VO A-X 0-0 @ 1.06 μm , FeH E-A 0-0 @ 1.6 μm



Wallace & Hinkle, ApJ. 559: 424 (2001).

A. Asensio Ramos et al., ApJ. 603:L125 (2004) :
*theoretical and/or laboratory investigations of this molecular system are
urgently needed for exploiting its promising diagnostic capabilities.*

- Précision en λ ET en $\alpha(\nu) = \kappa(\nu) \rho$: référencement par peigne de fréquence asservi / Rb + GPS
- Développement source MW : peupler l'état A de FeH (1000 cm^{-1} > état fondamental)

