Astrophysique de Laboratoire et Spectropolarimétrie nIR

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Outline

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Spectropolarimètres proche infrarouge (2018)

- CFHT/SPIRou + TBL/SPIP
  - Spectro échelle stabilisé + module polarimétrique
  - Proche IR : 0.98–2.35 μm (YJHK)
  - $R \simeq 8.10^4$; Précision RV ~ 1 m/s
    - cryogénique $T \sim 80 \pm 2.10^{-3}$ K
  - Polarimetrie linéaire + circulaire achromatique
    - 2 états orthogonaux mesurés simultanément

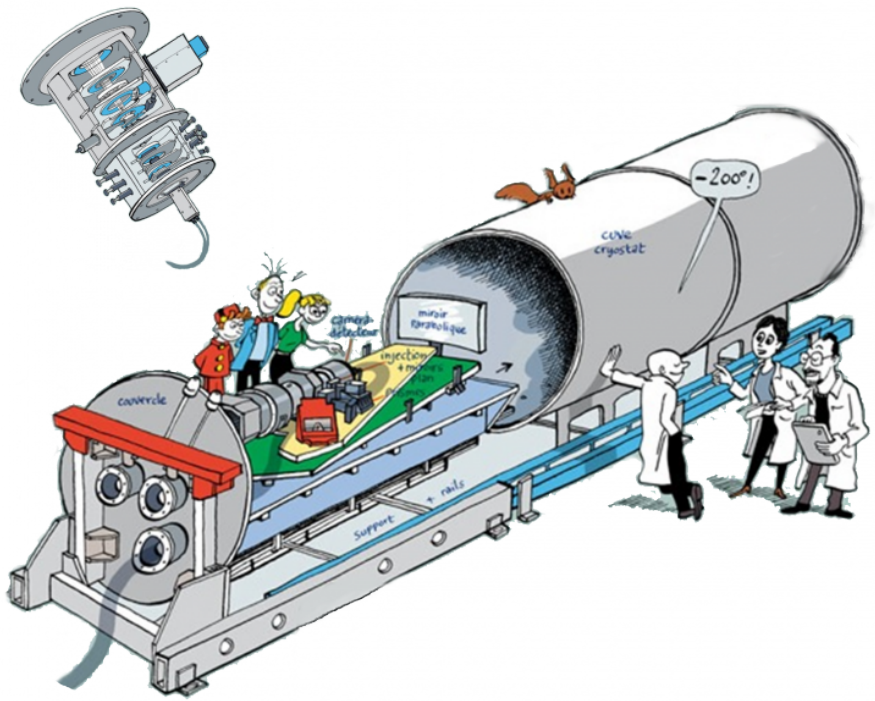
➔ Héritage ESPaDOnS + HARPS

➥ transposé nIR

➔ Optimisé objets froids

- VLT/CRIRES+
  - MàJ CRIRES : Disp croisée/détecteurs/polar

SPiRou



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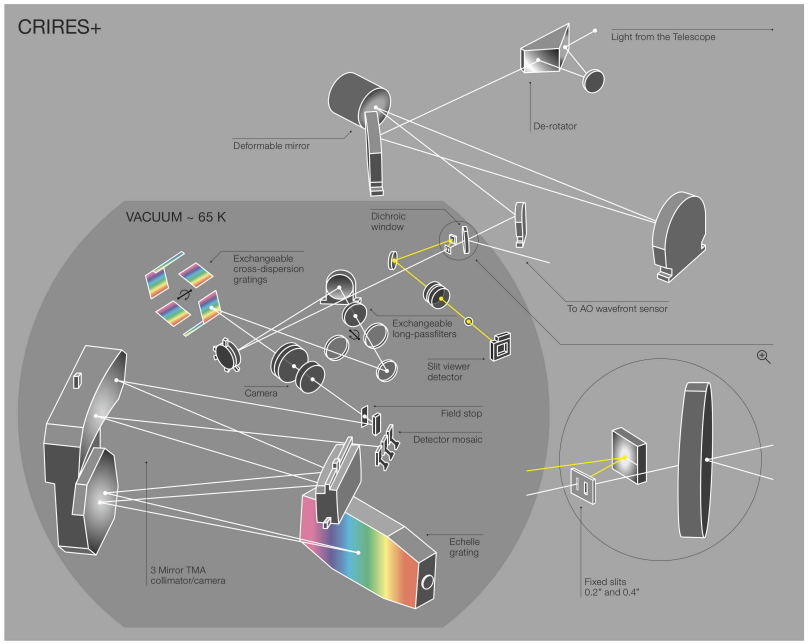

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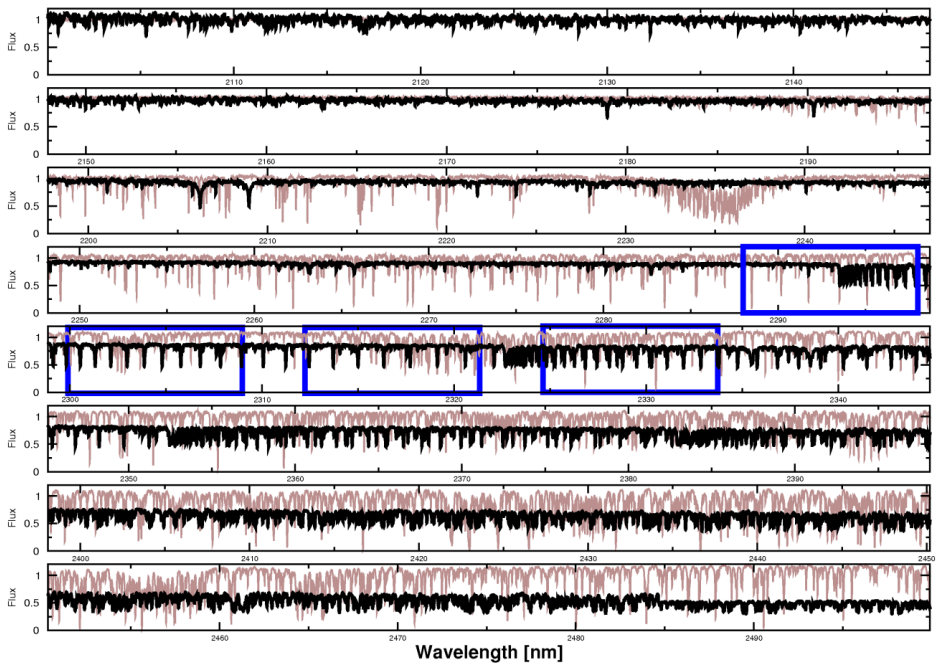

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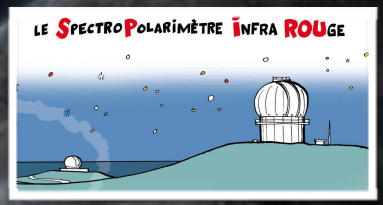
SPIRou @ CFHT

observing red dwarfs in the nIR



- **focussing on nearby M dwarfs**
  80% of stars in the galaxy & in the solar neighborhood
  habitable exoEarths much easier to detect

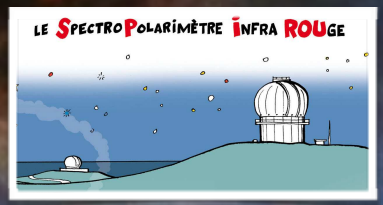
- **nIR velocimetry & spectropolarimetry of ~600 M dwarfs**
  detect & characterize ~300 exoEarths, ~50 of which in HZ
  ⇝ estimate occurrence frequency of habitable planets in solar neighborhood
  model activity & activity jitter using **spectropolarimetry**
  ⇝ improve detection threshold & characterization of habitability

- **follow-up of ~150 TESS transiting planet candidates**
  establish planetary nature of candidates & estimate average planet density,
  ⇝ search for **biomarkers** in atmospheres of nearest HZ exoEarths w/ JWST

- **magnetic fields of M dwarfs & planets**
  dynamo processes / bistability in fully-convective bodies
  impact of stellar / planetary magnetic fields on planet habitability

SPIRou @ CFHT

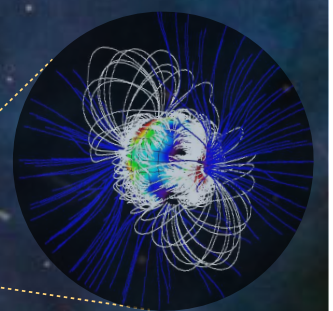
investigating star & planet formation



- **focussing on class-I, -II (cTTSs) & -III (wTTSs) protostars**
  magnetic field of star & disc modifies accretion & outflows
  impacts internal structure & rotation of stars
  impacts formation, migration & survival of planets

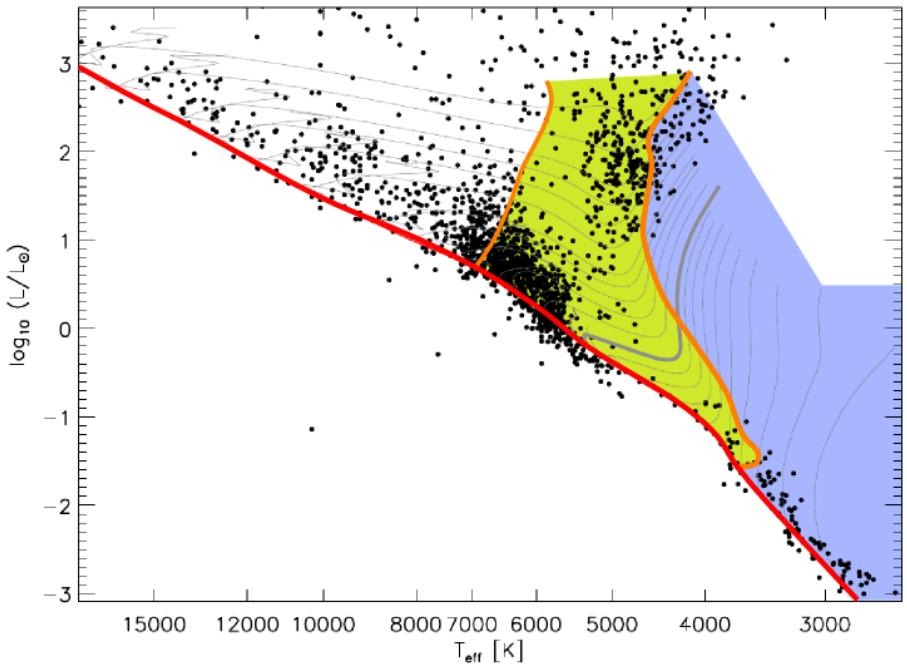
- **nIR spectropolarimetry of ~270 protostars in ~5 SFRs**
  model magnetic topologies of ~40 class-I (embedded) protostars, ~80 cTTSs & ~150 wTTSs in ~5 nearby SFRs (e.g., TW Hya, Tau/Aur, ρ Oph, ONC, Lupus)
  ⇝ origin & evolution of field, impact on star & planet formation

- **velocimetry of wTTSs**
  model activity & activity jitter of wTTSs w/ & search for hot Jupiters
  ⇝ formation / migration / survival of giant planets



Objectifs Scientifiques Complémentaires

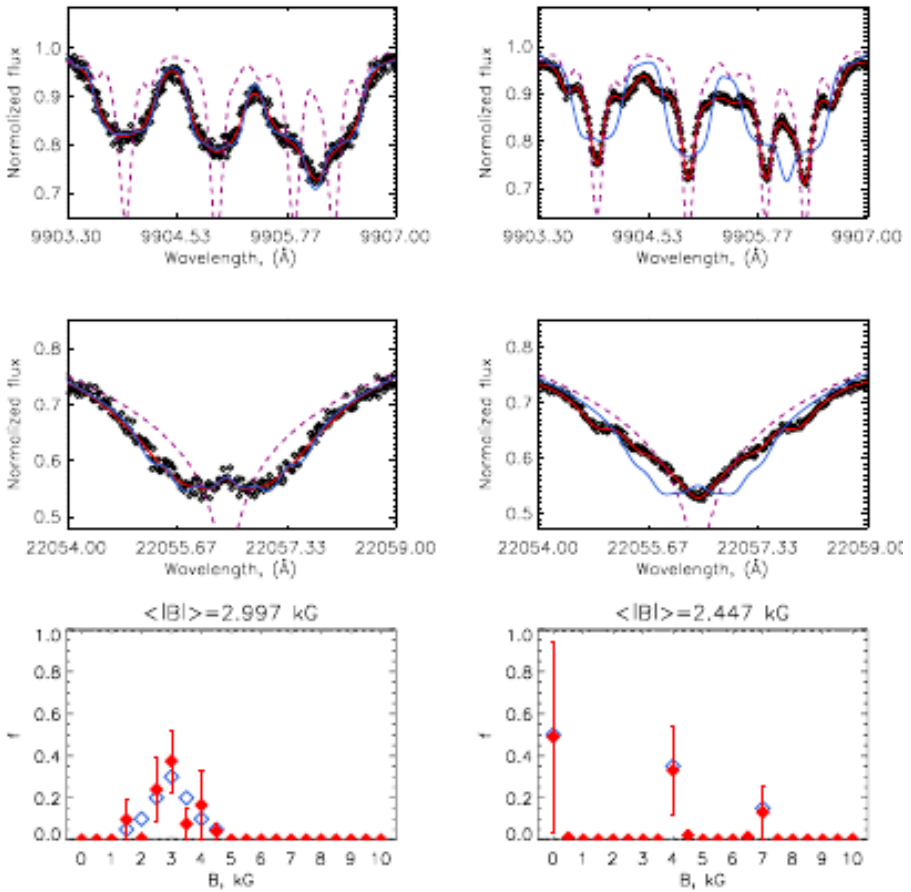
- Optimisés pour objets froids
  - Naines M, T Tauri
  - Naines brunes
  - Taches étoiles F-G-K
  - Étoiles évoluées RGB/AGB/RSG
  - Étoiles interm./massive jeunes
  - Système solaire



Adapted from Reiners (2008)

Magnetic field measurements

- Measurements from atomic lines
- Molecular bands sensitive to Zeeman effect (or PB regime)
  - FeH, TiO, (CrH)
- Present applications
  - FeH Stokes I
  - Detection on other molec
- Aims for SPIRou
  - Extend to other molecules/bands
  - Stokes V (LSD)



AD Leo, Bf measurement

Shulyak et al. (2014)

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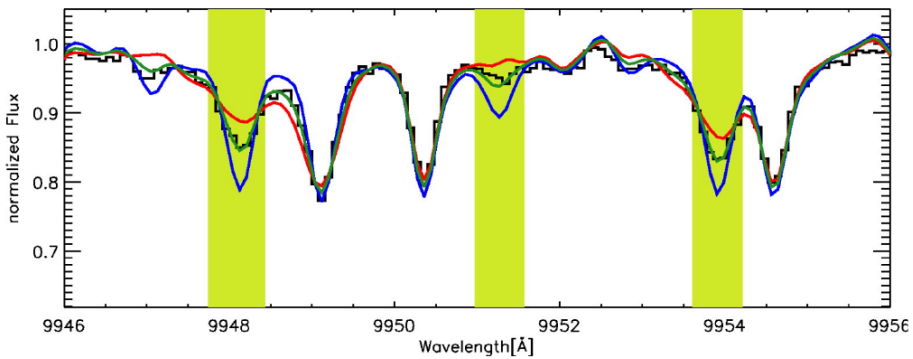

GJ 729, FeH Wing-Ford band

Reiners & Basri (2006)

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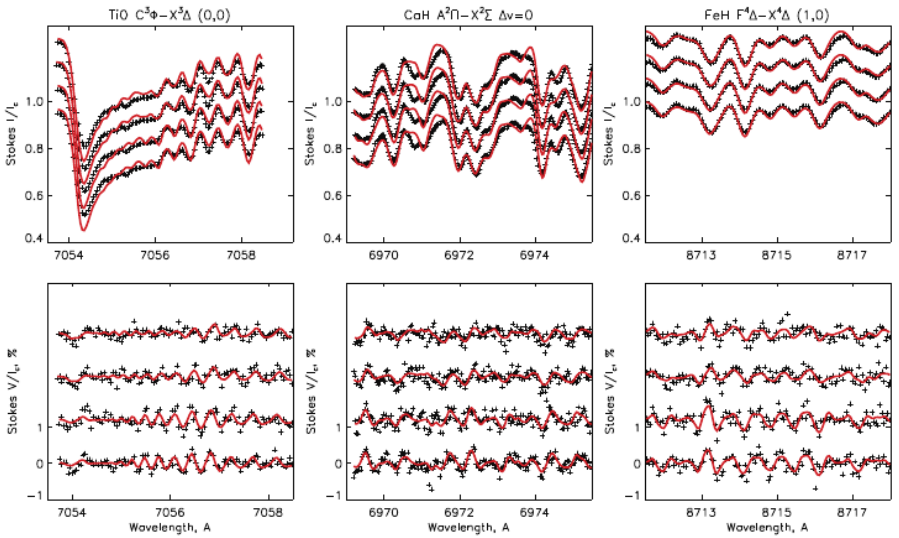
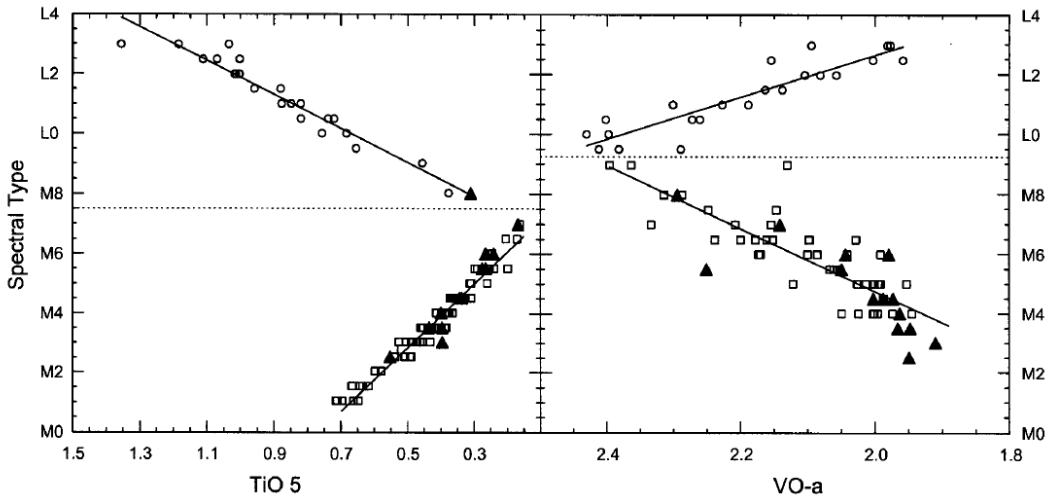


AU Mic Berdyugina (2011)

...and much more

- Radial velocities
  - Activity jitter
  - Direct observation of exoplanets' atmospheres
- Stellar parameters
- Circumstellar environments
- Earth atmosphere



Cruz & Reid (2002

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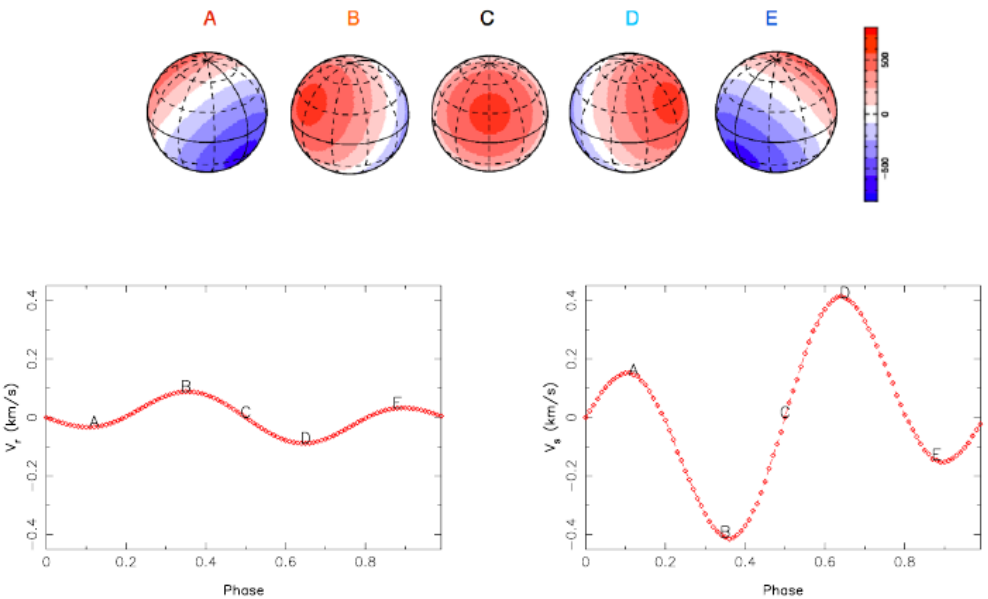

E. Hébrard et al. (2014)

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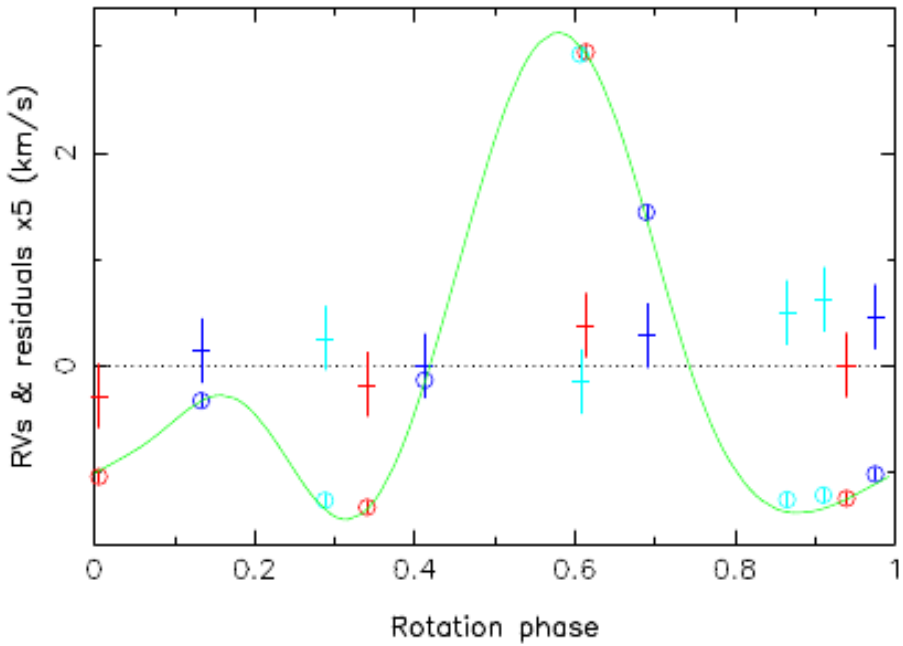

Donati et al. (2015)

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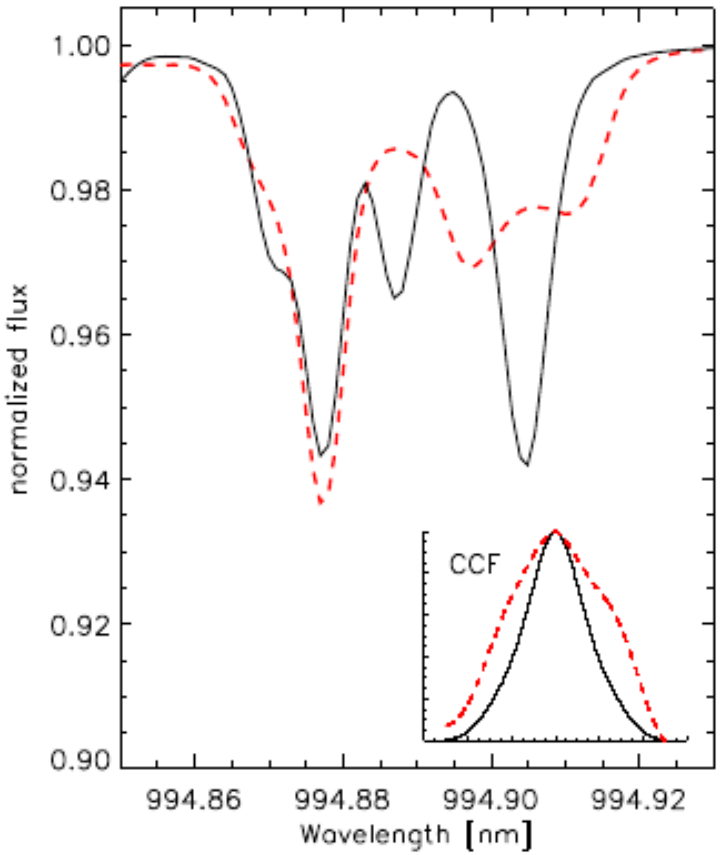

Reiners et al. (2013)

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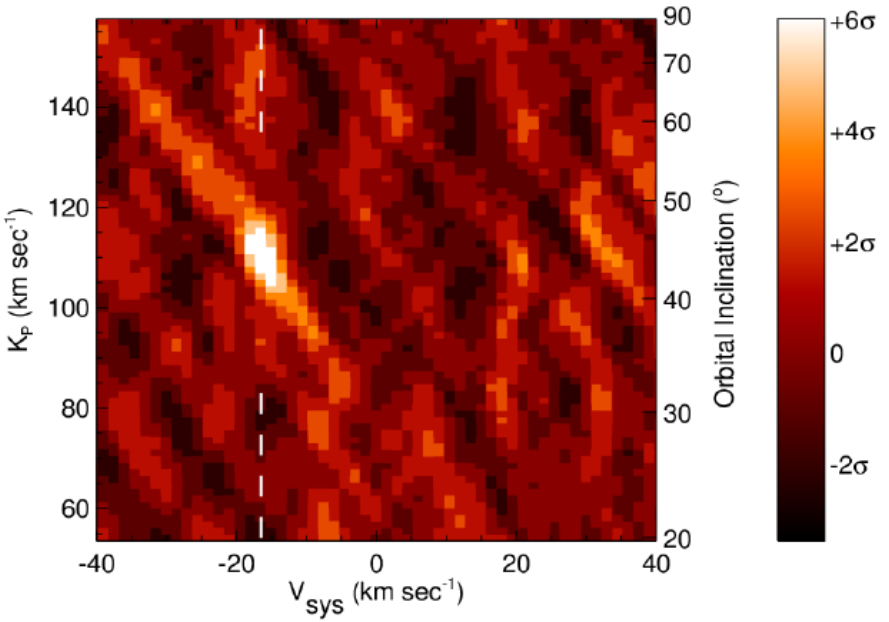


CO CCF of τ Boo Snellen et al. (2012)

Outline

Spectral line lists (1/2)

- Magnetometry: LSD
- RV: jitter filtering
- Stellar parameters

➥ Accurate line parameters

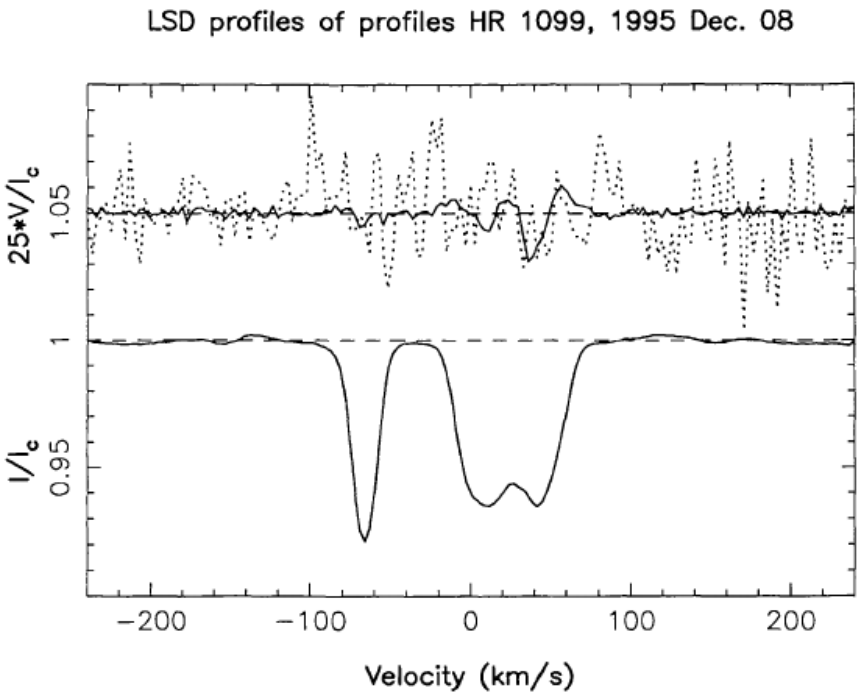
- positions
- depths
- Landé factors

- Present situation

- Atomic lines only
- Kurucz Atlas9 models

➥ Limitations at low Teff

➥ $\mathrm{Teff}_{\mathrm{min}} = 3\,500$ K



LSD Donati et al. (1997)

Spectral line lists (1/2)

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  - positions
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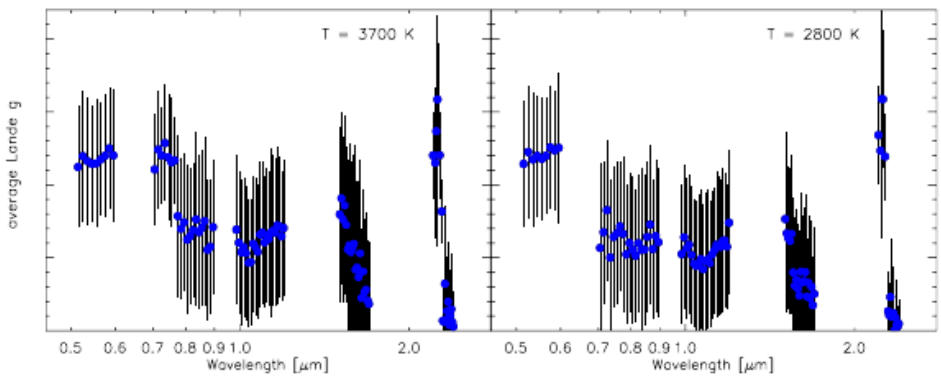
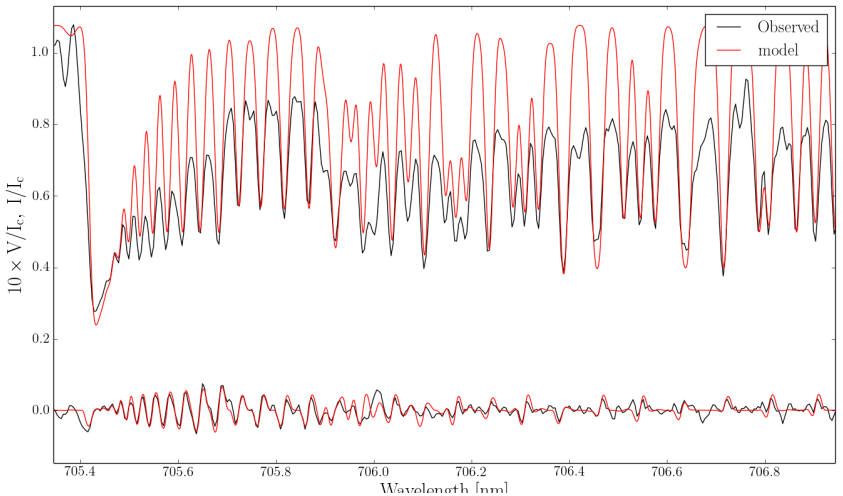
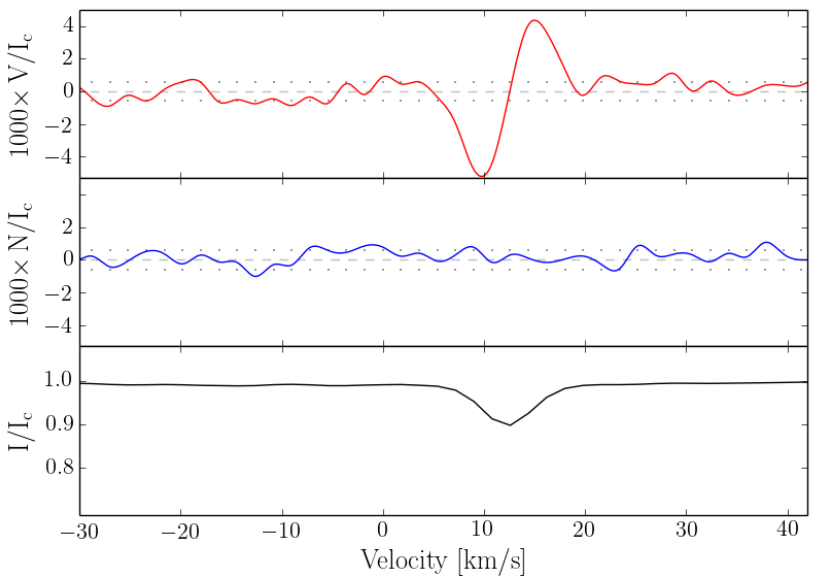


Landé factors Reiners et al. (2013)

Spectral line lists (2/2)

- Aims for SPIRou
  - model atmospheres for M dwarfs
    - Montpellier VALD mirror
    - Tests on MARCS models
    - PHOENIX for reference line lists
  - Molecular lines
    - Compile existing data
    - LSD tests
    - ➥ TiO, FeH
    - Additional data
    - ➥ exp: P. Crozet et al.
    - ➥ FeH, NiH, CrH
    - ➥ high-J extrapolation
    - Identify best nIR molec/bands
    - Extend methodology





AD Leo: TiO *B. Tessore & Th. Masseron*

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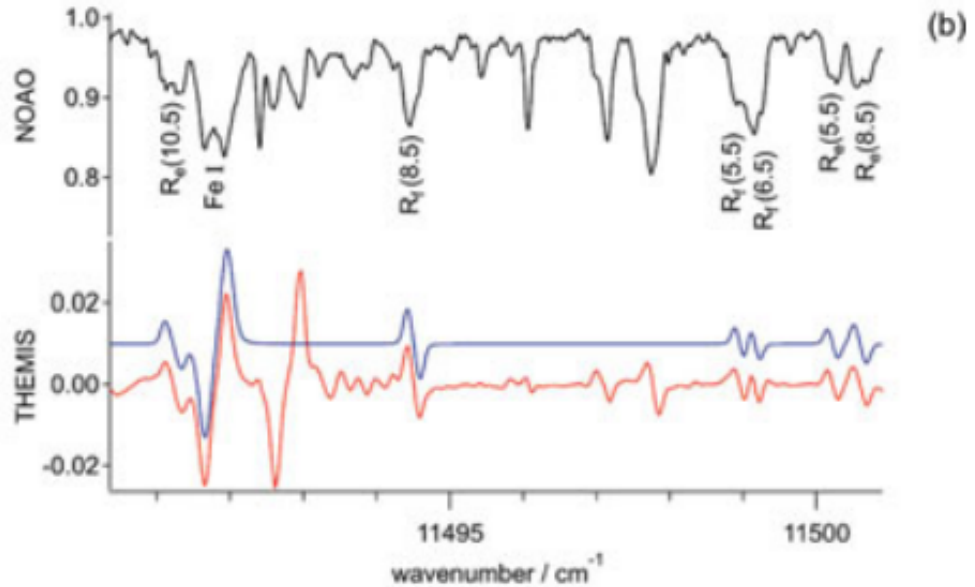
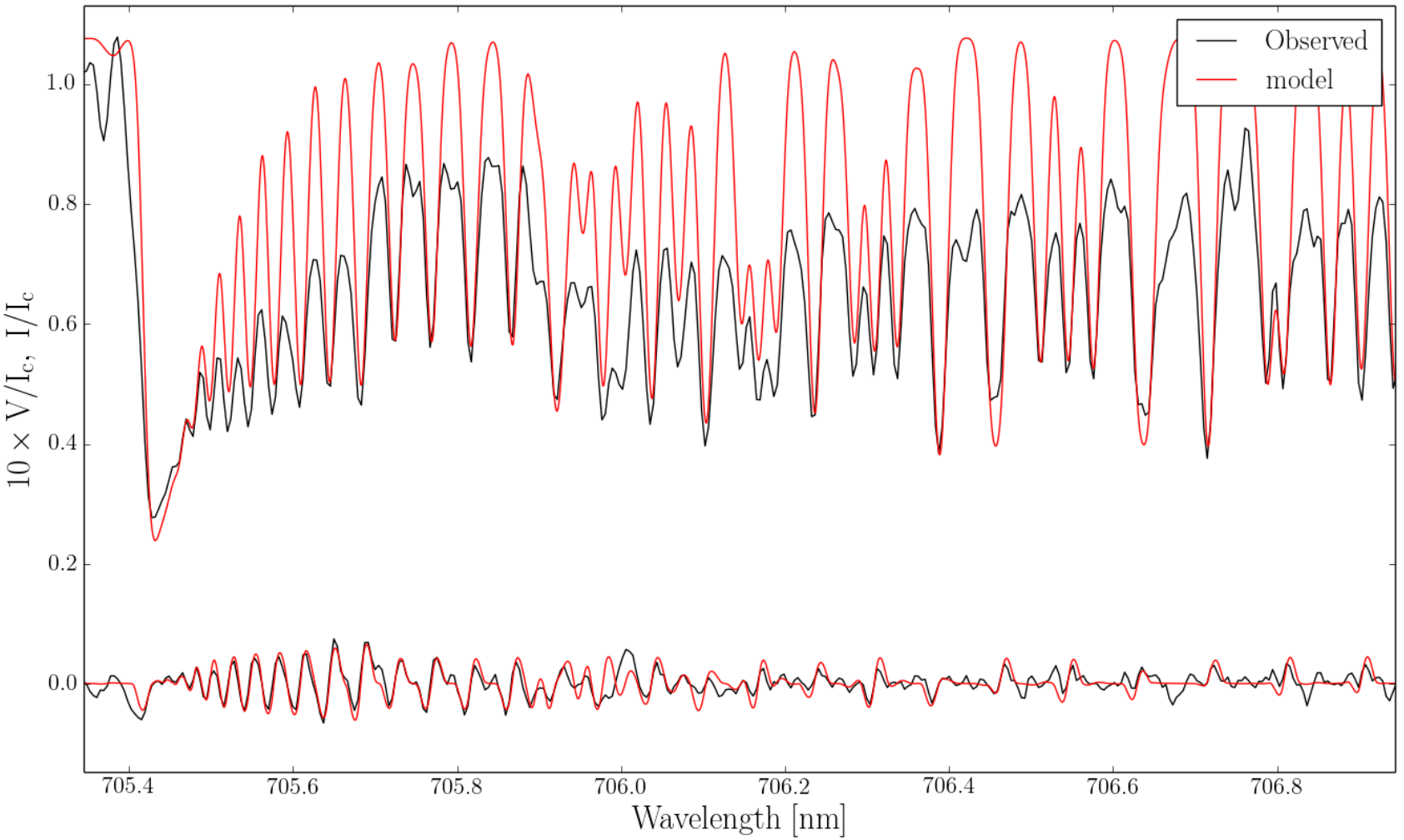


Sunspot: FeH Crozet et al. (2014)

Spectral line lists (2/2)



Molecules/molecular bands of interest

- FeH
  - many studies + actual applications to M dwarfs *(Shulyak et al. 2010)*
  - difficult to address theoretically
  - 0.99 μm and 1.58–1.66 μm bands
- TiO
  - ubiquitous at visible wavelengths
  - ongoing work on 705 nm band
- CaH, CrH, MgH, OH
  - some studied/mentionned in *Berdyugina (2002)*
  - large Stokes V amplitudes for CaH
- CO
  - already accurate positions, geff = 0 (radial velocities)
- CH, CN, C_2
  - ubiquitous in carbon-rich evolved stars (+ carbon dwarfs)