Spectropolarimetry at Pic du Midi Observatory

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The oldest high-altitude observatory, and the highest in Europe !

Overview

Spectropolarimeter NARVAL at TBL : full coverage of the optical range (375-1050 nm) in a unique exposure, with a spectral resolution of 65,000.
4 Stokes parameters accessible.
Study of magnetism (& polarisation mechanisms) of all types of stars, including :

- Magnetic field of solar-type stars harboring planets (BCool consortium)
- Magnetic Topologies of Young Stars and the Survival of close-in giant Exoplanets

Part of the OPTICON consortium !

Forthcoming instrumentation :

- Neo-Narval : stabilized (< 3 m/s) spectropolarimeter in the visible $\Rightarrow$ magnetic jitter in late-type stars vs. exoplanet detections
- SPIP ("SpectroPolarimètre Infrarouge au Pic du midi) : 0.98-2.35 μm $\Rightarrow$ search & characterization of habitable exo-Earths orbiting low & very-low mass stars

The Telescope Bernard Lyot (TBL) is 2-m Telescope at Pic du Midi (CFHT design.) Cassegrain focus f/25.

The Pic du Midi observatory has built an expertise in polarimetry over the years (Leroy, Semel, Catala, Donati) : Sterenn, Musicos, LJR (Lunette Jean Rösch) TBL is now specialized in spectro-polarimetry With Narval.

The NARVAL spectropolarimeter is a copy of ESPadONs, mounted at CFHT : Cassegrain Unit (polarimeter + calibration unit + guider camera) + 30m of fibers + cross-dispersed bench-mounted échelle spectrograph.

Bench-mounted ⇒ not attached to telescope, fixed, stable mechanically
Cross-dispersed ⇒ orders overlap, so have to be separated with a cross disperser
The Cassegrain unit is at the telescope, so it moves around with it
The Wollaston prism produces 2 beams of orthogonal polarization ; each beam gets to one of the fibers
The Wollaston only works on linear polarization.
See Donati et al. (1997, MNRAS 291, 58) for more details.

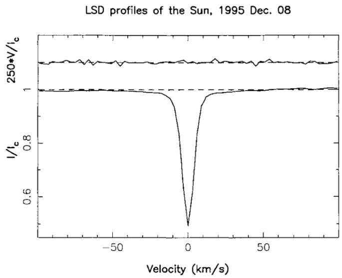


Figure 3. LSD unpolarized (bottom curve of each panel) and circularly polarized (top curve of each panel) profiles, for the Sun on 1995 December 8 (left panel) and the inactive K1 star δ Eri on 1995 December 13 (right panel). Note that the residual circular polarization signature is expanded 250 times, i.e. 10 times more than in all similar plots.

(Donati et al. 1997)

The ESPadONs and NARVAL spectropolarimeters have allowed an exploration of stellar magnetism accros the HR diagram : stars of all masses and evolutionary stages, as shown by the completion of diverse surveys recently completed (examples follow).

At Pic du Midi, NARVAL being mounted permanently offers a unique opportunity to follow the magnetic activity and establish cycles on any timescale.

MiMeS (Magnetism in Massive Stars, Wade et al. 2016) :
"over 4800 circularly polarized spectra of 560 O and B stars with ESPaDOnS, NARVAL & HARPSpol ... the largest systematic investigation of massive star magnetism ever undertaken"
(137 nights, or 1213 h with NARVAL, i.e. 890 validated polarimetric observations of about 35 targets)

The MiMeS survey: introduction and overview 19

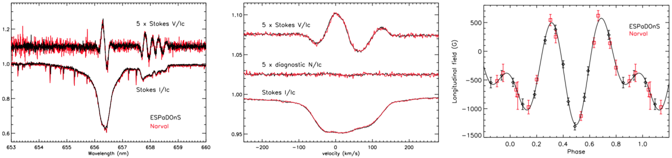


Figure 14. Comparison of ESPaDOnS and Narval observations of HD 37776 (rotational period $P_{\mathrm{rot}} = 1.54$ d). Left – comparison of ESPaDOnS (black) and Narval (red) Stokes *I* and *V* spectra of the TC target HD 37776 at phase 0.34, obtained 21 d apart. A small part of the red region of the spectrum showing the H α line. Middle – comparison of LSD profiles extracted from the full ESPaDOnS and Narval spectra at the same phase. Right – comparison of all longitudinal field measurements of HD 37776 obtained with ESPaDOnS and Narval, phased according to the ephemeris of Mikulášek et al. (2008). The solid curve is a third-order harmonic fit to the combined data. Observations were obtained between JDs 2454845 and 2455967, i.e. over a period of more than 3 yr. The internal and external agreement of the data sets is excellent. Adapted from Shultz et al., in preparation.

"TOwards Understanding the sPIn Evolution of Stars" (TOUPIES) project (Folsom et al. 2016)
(observations ESPaDOnS & NARVAL)

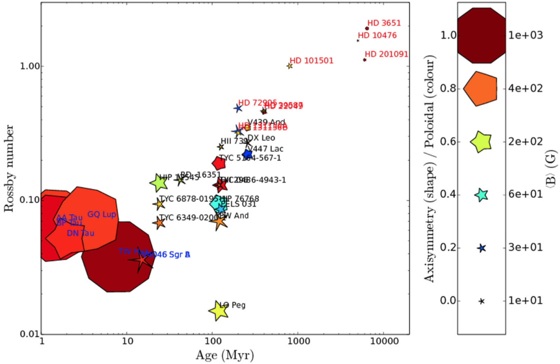
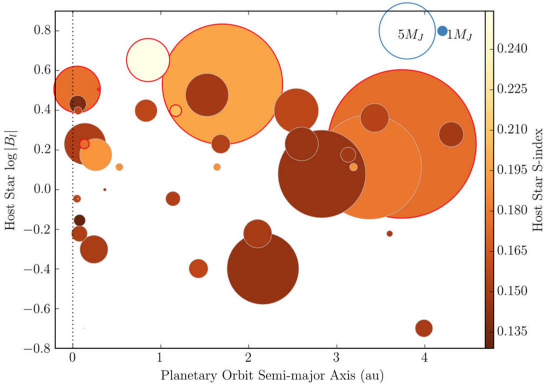


Figure 11. Magnetic parameters plotted for different physical parameters. Stars labelled in blue are from the MaPP project, stars labelled in red are from the BCool project, and stars labelled in black are from our study. Symbol size indicates mean magnetic strength, symbol colour indicates how poloidal the magnetic field is (red is more poloidal and blue is more toroidal), and symbol shape indicates how axisymmetric the poloidal component of the magnetic field is (more circular is more axisymmetric). In the upper panel, dashed lines are rotational evolutionary tracks for fast and slow rotators at 0.8 $M_{\odot}$ from Gallet & Bouvier (2015).

Magnetic field of solar-type stars harboring planets :
A BCool survey of the magnetic fields of planet-hosting solar-type stars (Mengel et al. 2017)
"14 planet-hosting stars observed as part of the BCool magnetic snapshot survey + observations of 19 planet-hosting solar-type stars"
(observations NARVAL)



MaTYSSE (Magnetic Topologies of Young Stars and the Survival of close-in giant Exoplanets) (Donati et al. 2017)

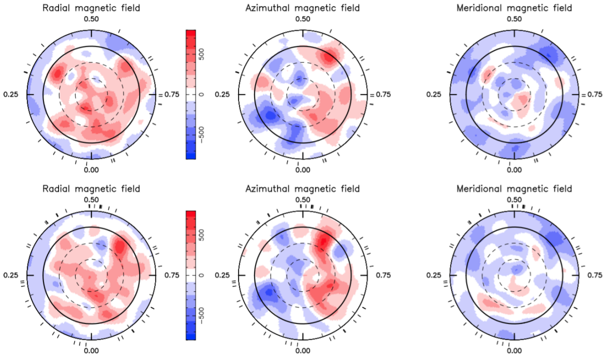
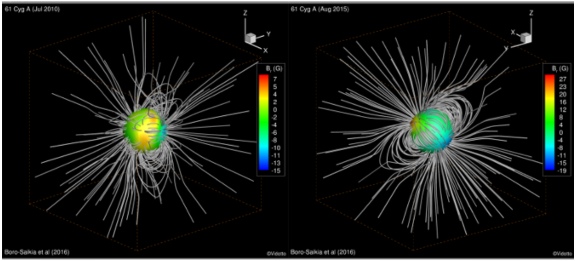
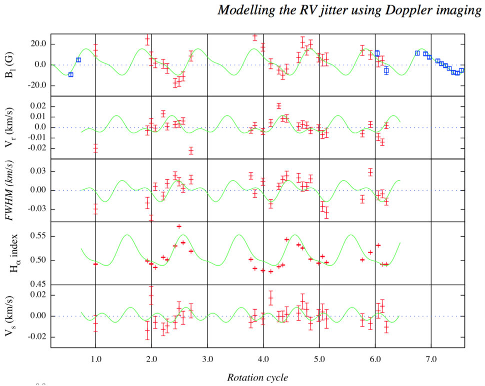


Figure 5. Maps of the radial (left), azimuthal (middle), and meridional (right) components of the magnetic field ***B*** at the surface of V830 Tau in early 2016 (top) and late 2015 (bottom). Magnetic fluxes in the colour lookup table are expressed in G. The star is shown in flattened polar projection as in Fig. 3.

(61 Cyg A : Boro Saikia et al. 2016)



"The large-scale magnetic geometry of 61 Cyg A exhibits polarity reversals in both poloidal and toroidal field components, in phase with its chromospheric activity cycle. During the observational time span of nine years, 61 Cyg A exhibits solar-like variations in its large-scale field geometry as it evolves from minimum activity to maximum activity and vice versa."
(Activity cycle period $= 7.2 \pm 1.3$ yr)



Temporal variations of B_l, v_{rad}, FWHM of Stokes I LSD profile, Hα and velocity span v_s (average velocity at the top and bottom parts of the bisector) for GJ 410. The blue data are the B_l values computed from NARVAL LSD profiles.

(Hebrard et al. 2016, MNRAS 461, 1465)

"NARVAL is in average 8.4 times more efficient than HARPS-Pol" ...
... but lacks precision in velocity ...

Forthcoming instrumentation

- Neo-Narval : stabilized (< 3 m/s) spectropolarimeter in the visible
  $\Rightarrow$ magnetic jitter in late-type stars ($>$ F0) vs. exoplanet detections
  Technological challenge : stability in $v \Rightarrow \Delta T < 0.01$ K ; $\Delta P < 5\ \mu$bar !
  1st light in 2019
- SPIP ("SpectroPolarimètre Infrarouge au Pic du midi) :
  Copy of SPIRou @ CFHT
  0.98-2.35 μm, R = 75 000
  S/B $\sim$100 per pixel of 2.3 km/s @ H=11.0 / 9.5 (CFHT / TBL)
  main scientific goals :
  - search & characterization of habitable exo-Earths orbiting low & very-low mass stars
  - explore the impact of magnetic fields on Sun-like star & planet formation
  1st light in 2020