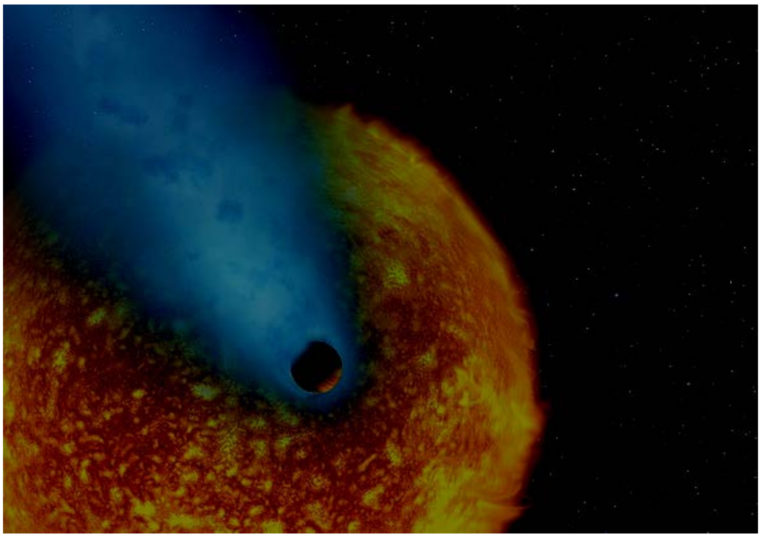
Neo-Narval Science Case



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Summary: This document describe the Science Case of Neo-Narval

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	1.1	23/02/2014		comments C. Baruteau taken into account
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	1.3	07/03/2014	Sect. 2.3	implementing CS TBL members F Martins and C Moutou comments

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GENERAL ASPECTS

This document presents the science case of Neo-Narval, and the primary science requirements.

Applicable documents

N°	Document Title	Document Number	Issue / Date

Reference documents

N°	Document Title	Document Number	Issue / Date

Acronyms

AIT	Assemblage Intégration Test
CFHT	Canada-France-Hawaii Telescope
CPER	Contrat Plan Etat Région
ESPaDOnS	**E**chelle **S**pectro**P**ol**a**rimeter **D**evice for the **O**bservatio**n** of **S**tars (twin of Narval at CFHT)
ETSRC	European Telescopes Strategic Review Committee
IRAP	Institut de Recherche en Astrophysique et Planétologie
MS	Main Sequence (of the stellar evolution)
PLATO	PLAnet Transit Observatory
OSU	Observatoire des sciences de l'Univers
RGB	Red Giant Branch (of the stellar evolution)
RV	Radial velocity
SPIP	SPIROU @ Pic du midi
TBL	Telescope Bernard Lyot
TESS	Transiting Exoplanet Survey Satellite
TTV	Transit Timing Variation
UMS	Unité Mixte de Service
UPS	University of Toulouse Paul Sabatier

EXECUTIVE SUMMARY

The Telescope Bernard Lyot at Pic du Midi (France) is dedicated since almost two decades to the analysis of stellar magnetic fields by the aim of high resolution spectropolarimetry. Since 2007, and together with its sister-instrument Espadons at CFHT, Narval played and still plays a major role in this challenging research domain.

With the rise of exoplanet search in recent years, a promising evolution of the instrument towards a highly radial-velocity stabilised spectropolarimeter is now required. We call this instrumental evolution Neo-Narval.

More precisely, the quest for exoplanets around the magnetically active lower and intermediate mass stars (later than F0) is strongly limited due to the so-called magnetic jitter. Active bright or dark plages on the surface of the stars are linked to magnetic activity and corotate with the star's rotation period. Their signature in radial velocity can exceed by far the signature of an exoplanet, and, if close to its expected orbital period a confusion between both can occur. The simultaneous determination of magnetic structures on the surface of the star, and the subsequent deduction of the induced jitter linked to associated active plages will eventually allow to search for and unambiguously confirm new exoplanet detections, despite a highly "polluted" radial velocity signal. Moreover, the search for exoplanets around lower mass G to M dwarfs, but also more evolved giant stars surrounded by exoplanetary systems in final stages, will be strongly improved thanks to a stabilised instrument with a spectral range extending up to 1 micron. In addition, the classical spectropolarimetric studies of the magnetism throughout the HR diagram (a core task of Narval) can be efficiently pursued with the optimised instrument.

To address these scientific goals a radial velocity long-term stability of better than 3m/s is needed. Different design concepts are under discussion, involving a pressurised vessel (ambient pressure, nitrogen filled), englobing either the entire spectrograph or solely the dispersive and refractive parts of it. The pressure should be stable within a 10microbar level in order to ensure the required stability of the refraction index of the gas. To achieve that, an actively thermalised ($\Delta T \pm 0.01$K) outer enclosure will be required. In order to ensure a stable light injection in the spectrograph, the addition of octagonal fibre segments is foreseen. In parallel to the major upgrade of the Narval instrument, a thorough maintenance project (concerning the camera and mechanical aspects of the polarimetric device) is required, which is part of Neo-Narval.

All technical solutions invoked for the Neo-Narval project do exist already, and a fruitful contact and collaboration has been established with expert teams that have implemented them at the Geneva Observatory (CH), ESO/Garching (D) and OHP (F). No major R&D is required, instead validated "off-the-shelf" solutions will be prefered. A scientific team of specialists in magnetism, exoplanet studies, asteroseismology and more generally stellar physics regularly enrich the science case (T. Böhm (PI), R. Cabanac, Pascal Petit, François Lignières, Clément Baruteau, Frédéric Paletou, Thierry Roudier, Philippe Mathias, Michel Rieutord, Boris Dintrans, Arturo Lopez Ariste, Coralie Neiner, Evelyne Alecian), and additional members are welcome. The project team is established and working.

The calendar deadline for instrumental deployment is targeted for mid 2016. A large majority of the funding has been applied for in the frame of the French call of CPER 2015 (500k€). An important external constraint will be to minimise the instrumental deployment period to less than 6 weeks, in order to ensure a continuous availability of the TBL/Narval to the users community.

1. MAGNETIC FIELD STUDIES AT PIC DU MIDI IN THE PAST

AND TODAY

The Pic du midi has build an extensive experience on polarimetry and spectro-polarimetry, thanks to the contributions of pioneers in polarisation observations. The first polarimeters were designed for Solar observations by Semel and Leroy. When the 2-m telescope was built in the 80's numerous observations of the linear polarisation of the continuum of stars were performed with STERENN on Ap stars (Leroy et al. 1993, A&AS 101, 551), followed by planetary disks observations (e.g. Menard et al 1999, A&A 409, 163). In parallel, the basis of Zeeman doppler technique was developed by Semel and Donati and a polarimetric module was installed (Donati et al. 1999, A&A 134, 149) in the high-resolution spectrograph MUSICOS (Baudrand & Böhm 1992, A&A 259, 711) Pioneering discoveries made with MUSICOS (e.g. Neiner et al. 2003 A&A, 406, 1019) opened the path to the funding of a new instrument; a "classical" echelle spectrograph fed by a polarimeter at cassegrain focus; ESPaDOnS was commissioned at CFHT in 2005 and its twin Narval at TBL in late 2006. The resolving power of Narval is 65000 in its polarimetric mode, and the spectral coverage is 380-1000nm.

TBL has been dedicated to spectro-polarimetry ever since, mostly on stellar magnetism observations, giving the French stellar astrophysicists a confortable lead in this domain. More than 100 publications have been published on stellar magnetism only, among which some presented several seminal works and significant advances in our understanding of stellar magnetic fields, already highly cited.

This wealth of new results over the past seven years only skimmed the potential of discoveries of Narval for the coming years. In a nutshell, Narval has already reached the expectations in terms of science impact in the past five years and the years to come shall allow the French community to explore more deeply the observables of stellar magnetism through the H-R diagram, the variability of stellar magnetism, which in essence requires long-term studies. **While long-term studies are important, pioneering studies are essential for sustained use of a science instrument. Neo-Narval is designed to provide such exciting new science cases for Narval.**

This document presents the science case of the Neo-Narval project, which primarily consist in a significant upgrade in velocimetry stability. The science case is organised in three parts. The exciting synergy on exoplanet search and confirmation around magnetically active stars obtained by combined spectro-polarimetry and accurate velocimetry is presented in the first part. The second part places Neo-Narval in the context of the current exoplanet search and proposes more specifically the exploration of the late stages of exoplanetary system evolution. Finally the third part is dedicated to ongoing and forthcoming projects in Narval now classical studies on stellar magnetic fields accross the HR diagram.

2. THE NEO-NARVAL SCIENCE CASE

The figure 2.1 shows Narval's core competence which is high-resolution spectropolarimetry (red) aimed for studying stellar magnetism throughout the HR diagram. This task is fulfilled in its traditional setup as of today and since 2007. The new domain (green) specifically concerns science cases accessible with a spectrograph highly stabilized in RV. The intersection of both domains reveals emerging science cases, uniquely accessible to RV stabilised spectropolarimeters like Neo-Narval, the most important one being the study of the magnetic activity jitter as described here-below.

Figure 2.1

It is important to review the position of Neo-Narval in the international context for the coming years. In a nutshell, TBL/Neo-Narval will be the only dedicated instrument able to probe stellar magnetic fields in the range 370–1000nm with stability of 3m/s for the period 2015-2020.

The table 2.1 lists all stabilised echelle spectrographs in the visible on 1.5-4m telescopes currently in activity and expected in the coming years. Among the instruments at focus of 2-m+ class telescope listed in the table, 5 are in the North, 3 in the South. Only four instruments are equipped with a polarimetric module: HARPSpol (ESO 3.6), ESPaDOnS (CFHT), PEPSI (LBT) and Neo-Narval. HARPSpol is in the southern hemisphere (pointing limits < +30°), ESPaDOnS is not stabilised and its status is not decided when SPIROU arrives at CFHT (expected 2016 or 2017), PEPSI is still in commissioning at LBT, and will share the telescope with five other instruments. Hence Neo-Narval will be the only northern stabilised spectro-polarimeter able to probe the full visible range until PEPSI starts regular observations on the LBT. What makes Narval (as well as SOPHIE and HARPS) very powerful is the full dedication of all the telescope observing time. Indeed, Neo-Narval will be the only instrument at the TBL cassegrain focus until SPIP (a copy of Spirou/CFHT) arrives, as foreseen, in 2020.

TABLE 2.1: synoptic view of HR spectrographs

Instrument	range	range	POLAR	Stability (< 5m/s)	Resolution

	380-690nm	690-1000nm	QUV	night - long term	
CHIRON (S1.5m)	from 415nm	up to 880nm	NO	7 - ?	up to 136000
HARPSPOL (S4m)	YES	NO	YES	0.2 - 0.2	120000
HARPSNorth (N2m)	YES	NO	NO	0.2 - 0.2	120000
HERMES (N1.2m)	YES	up to 900nm		2.5 - 60	85000
SOPHIE (N2m)	YES	NO	NO	2 - 2	76500
PEPSI (N2x8m)		In project		~3 - 100	up to 300000
Narval (N2m) & Espadons (N3.6m)	YES	YES	YES	30	65000 or 75000
Neo-Narval (N2m)	YES	YES	YES	<3 - <3	65000
UVES (S8m)	YES	YES	NO	~10 - 500	up to 110000
PSF (S6.5m)	YES	NO	NO	1 - 1	40000
HDS (N8m)	YES	NO	NO	5	55000
HIDES (N1.88m)	YES	NO	NO	6	67000

Comments of Claire Moutou, sorted in importance:

-I miss something on 2.3.3, to understand how NeoNarval gets 3m/s on giant stars. How many lines are there in the effective spectral ranges where these stars are bright? Plot says 200, which seems a small number, it cannot be. The relationship between the star type, number of lines, and final RV accuracy is not obvious and should be explained; it is presumably not 3m/s that is expected for any type of star (mass, vsini, magnitude). Telluric contamination may affect the spectral range in the red and should be mentioned.

-Rossiter measurements are invoked in 2.1; not sure they should be discussed exactly here. But anyway, they represent another program that Neo-Narval should push if the 3m/s RV accuracy is achieved. Such precision is sufficient for part of the transiting exoplanets; short-term precision is needed only. I think more investigation should be done on that subject.

-The science case on engulfed planets is exciting. Can you roughly quantify the probability of detecting such event, and how it impacts the required number of targets for a potential survey? Not clear at the end of 2.3.2 if theory expects abundance anomalies related to such events.

-Contribution to space missions is potentially a very important topic. However very few details are given here, regarding the schedules, and actual feasibility. Not clear also why having access to the GAIA/RVS domain is important and what kind of follow-up program would be foreseen with (Neo)Narval. Is the RV-precision upgrade necessary for the GAIA follow-up?

-On the instrumental part, I was wondering whether the requirement for absolute encoders for the polarizer comes from the 3m/s requirement, or is motivated by something else.

In general, it is not clear how the proposed upgrades will allow achieving the 3m/s goal. Maybe a more conservative improvement (10m/s) should also be considered in the science case?

-It would be useful to know when LBT/PEPSI is supposed to be installed. Even if it has to share the focal plane with other intruments, it will still be ~twice as efficient as NeoNarval. And long-term science programs as presented here will not be affected too much by the part-time availability of PEPSI on the telescope. So I do not see the argument (saying that PEPSI will not be a strong competitor because LBT is not dedicated to it) as very strong, especially if PEPSI is coming in the next few years at the LBT. On the other hand, the French community has no access to LBT!

-it is not clear now that Espadons would be decommissioned as soon as Spirou arrives. Nobody knows, so far (I think); obviously there will be more pressure and less time for Espadons, though!

-TTV should be replaced by 'photometric transits' everywhere in the document

-in 2.2.1, for each of the discussed sources of RV jitter, the amplitudes and timescales could be given regarding young and evolved stars, since they are presented as the prime targets. It would better show how the final RV jitter budget is, for each timescale.

-Not clear what is concluded from the cited example of HD166435 in 2.2.2. There are stars with planets and stars witout planets for which magnetic fields have been detected; it is not clear to me what this information is interesting for.

-PLATO and ECHO are misplaced in a parenthesis of coronographic projects in 2.3.2

Comments from Fabrice Martins

1- Activity jitter:

** My main comment is that a description of the technique(s) to filter this activity from RV lightcurves to recover the planetary signal is missing. There are a couple of references, but numbers and more robust explanations should be given. It is probably not so easy to do, but in its current state, the feasibility of the filtering is not fully convincing. We also see that on the CS2M with the ongoing programs : it appears difficult to obtain clear-cut results.*

** The justification of the required stability (3 m/s) could be improved. There are a few numbers across section 2.2, but the choice of 3 m/s is not extensively discussed. According to Fig. 2.2 one may wonder whether 2m/s would be a better choice (a significant number of stars, especially G-K stars, have a jitter between 2 and >3 m/s). I guess there is a feasibily argument, but that could be discussed.*
** Sect. 2.2 ends abruptly: a summary of the key points (observed jitter, technique to filter out, choice of RV stability limit) would be useful.*

2- Late stages of exoplanetary systems:

** As an outsider in this field, I miss a general introduction on the evolution of planetary systems. Sect. 2.3.2 presents two scenarios to explain the apparent lack of planets close to evolved giants, but a few words on what is known (or predicted) about the evolution of planetary systems would be useful.*

** I am not fully convinced by the engulfment studies. As Claire, I was wondering whether it would be possible to quote the probability to observe such systems. Perhaps I missed it, but it was not clear* *to me how an engulfed planet would be traced by surface abundances (I guess there are many other reasons for anormal Li abundance for instance).*

** Numbers regarding the expecting distribution of distances/eccentricities in the two scenarios (nature/nurture) - if they exist - would help to appreciate the possibility to discover new systems.*

** I would change the order of points a and b in Sect. 2.3.3 since the confirmation of potential planets appear a better case to me (at present, depending on the answer to the question just above).*

** I suggest to use the success and leadership of Narval in the field of giant stars magnetism to motivate further more the relevance of Neo-Narval to the study of the planets around evolved stars. Just showing that the science case builds on a strong expertise at TBL.*

3- Other comments:

** Are there any ideas to study stellar pulsations in combination with magnetism? I guess with the expected stability this would become feasible. The "A-stars" team once submitted a proposal to study pulastions in Vega, which has a magnetic field.*
** remove sentence stating that Espadons will be removed when Spirou comes on the mountain.*

2.1. A SHORT OVERVIEW OF EXOPLANET SEARCH IN 2014

The search for exoplanets is thriving in 2014, among a large variety of techniques two are the working horses of the planet candidate discoveries, Transit photometry and Radial Velocity Spectroscopy (RVS). In beginning of 2014, ~800 planets have known orbital parameters (exoplanet.org and exoplanets.eu), among which 50% are detected by radial velocity measurements. In addition, more than 3000 candidates (Transit Kepler) are waiting to be confirmed.

More precisely, the star and its exoplanet constitute a binary couple with a common center of gravity, and the orbital motion induces periodic radial velocity reflex motions on the star's velocity curve- the star being the only directly visible component of this couple. From the fundamental stellar parameters of the host star (most importantly effective temperature and luminosity) its mass is deduced. Frequently, rotational modulation of photospheric lines, or, in some cases, interferometric observations allow the determination of the inclination of the stellar rotation axis. Additional orbital parameters may be extracted from the Rossiter-Laughlin effect (e.g. Narita et al. 2007 PASJ 59, 763). The knowledge of the star's radial velocity modulation, its mass and rotational inclination thereafter enables the observer to deduce the parameters of the exoplanet orbit and its mass (under the assumption that it's orbit is located in the stellar equatorial plane). Typically, the amplitude of the periodic radial velocity motion induced by a 0.1 M_{Jup} planet on a 1 M_{sol} star, at a distance of 0.5 AU and a system seen edge-on is close to 4m/s. At this level of precision, bright or dark spots on the surface of the star and corotating with it can produce radial velocity variations larger than the signature of the star-exoplanet orbital motion.

Most of the research efforts of the coming years is geared towards the discovery of earth-like planets around solar-type stars, in the so-called habitable zone. The final objective is to search for exo-life. Those exciting research goals are, depending on the observing method, either very demanding in spectroscopic stability, or photometric accuracy, or image resolution and contrast. They trigger a lot of developments, new space mission concepts (TESS, PLATO, ECHO, SPICES), and ground-based instruments (SPIROU, CARMENES, SPHERE, EXPRESSO, CODEX) requiring more and more accuracy up to cm/s in spectral stability, micro-magnitudes in photometry, and contrasts >>10^6. The initial concept of Narval (optimized for spectropolarimetry measurements in stellar atmospheric absorption lines) did not need and did not address RV stability requirements. Therefore, an evolution of Narval to the accuracies required by earth-like planet search is not sensible under the known constraints (technical, manpower, calendar, costs).

In contrast to the ultimate search of exo-life, relatively little efforts are currently devoted to the understanding of the final phases of planetary evolution. In order to detect a planet around a star at any evolutionary stage, one needs to measure and understand all effects contributing to RV modulations. More precisely, many physical mechanisms in stars can generate such variations, the most important being stellar surface spots related to magnetic activity, stellar oscillations, and convective motion (granulation-supergranulation). These mechanisms depend on stellar fundamental parameters, such as stellar age, mass, chemical abundance and rotation velocity. To distinguish between all those potential contributors is fundamental to be able to confirm the presence of a planet.

Neo-Narval is designed to study the RV modulations down to 3m/s, in parallel to measuring the magnetic activity, therefore, understanding and quantifying the impact of stellar magnetism on RV jitter. This unique capability opens a large spectrum of studies from confirmation of planets around magnetically active dwarf stars to the detection of giant planets around RGB stars at different stages of evolution. Moreover, the upgrade of Narval will allow us to proceed with on-going Narval projects on stellar magnetism.

2.2. NEO-NARVAL: UNDERSTANDING MAGNETIC ACTIVITY JITTER

Thanks to the simultaneous measure of RV modulations and magnetic field measurement, Neo-Narval opens a new field of exoplanet research.

2.2..1. MECHANISMS THAT CAN PRODUCE RV JITTER

From an observational point of view RV jitter is due to time-varying asymmetries in photospheric spectral line profiles. These asymmetries can have various physical origins. As stated in the Plato 2.0 Assessment Study Report (ESA, 2013, http://sci.esa.int/plato/53450-plato-yellow-book/#), intrinsic sources of stellar noise contribute at different time-scales and various amplitudes to RV jitter.

Solar-like *p-mode oscillations* induced in stars with convective envelopes have typical periods of a few minutes in solar-type stars and amplitudes per mode of a few tens of cm/s in radial velocity (Kjeldsen, H. et al. 2005, ApJ, 635, 1281). The observed integrated signal is the superposition of a large number of these modes, possibly adding up to several m/s. Amplitudes of the RV variation become larger for early-type and evolved stars.

Granulation and Super-Granulation is the photospheric signature of large-scale convective motions in the outer layers of stars with convective envelopes. However, the large number of granules on the visible stellar surface efficiently averages out these velocity fields, leaving some remaining jitter at the m/s level for the Sun, probably less for K dwarfs (e.g., Palle, P.L. et al. 1995, ApJ, 441, 952; Dravins, D. 1990, A&A, 228, 218). Granulation is also damped within the spots, changing for spotted stars the balance of granulation effect over the surface.

Magnetic activity at the surface of dwarf stars induce radial-velocity variations through the temporal and spatial evolution of spots, plages, and convective inhomogeneities (Saar, S.H. & Donahue, R. 1997, ApJ, 485, 319; Saar et al. 1998, ApJ, 498, 153). **The resulting spectral line asymmetries are modulated by the rotational period of the star and can be confounded with a planetary signal** (e.g., Queloz, D. et al. 2001, A&A, 379, 279; Bonfils, X., et al. 2007, A&A, 474, 293) or potentially inhibit the detection of planetary signals of low amplitude. See Section 2.2.3 for details.

Stellar jitter depends on effective temperature, stellar activity, and projected rotational velocity (e.g., Wright, J. et al. 2004, ApJS, 152, 261). Typical values are below 1 m/s for slowly rotating, quiet G-K dwarfs (Mayor, M. et al. 2009, A&A, 493, 639), but can reach significantly larger values for evolved or intermediate-mass star. (Böhm, T. 2013, ASPC 479, 143).

2.2..2. OBSERVED RV JITTER AMPLITUDES

Main sequence F, G and K stars typically exhibit moderate RV-jitter (σ_{rv}~5m/s) as showed by Wright et al. (2005 PASP 117, 657). Fig 2.2 shows a positive correlation of RV (based on a study of 448 stars from the Carnegie (Keck) survey) with stellar evolution (left) and increasing activity (right).

For intermediate-mass stars close to the main sequence, very few data are available, mostly due to a lack of spectral lines and large projected rotational velocity (*vsini*) values. In contrary, slowly rotating intermediate-mass sub-giants have been studied by Johnson, et al. (2010 PASP 122, 701) on 500 stars selected from the expanded Keck survey), and by Sato et al. (2008, PASJ 60 1317) on 300 intermediate-mass (1,5-5$M_{\odot}$) stars . They announce RV jitter values in the range around 5 m/s , and in some cases reaching 20 m/s.

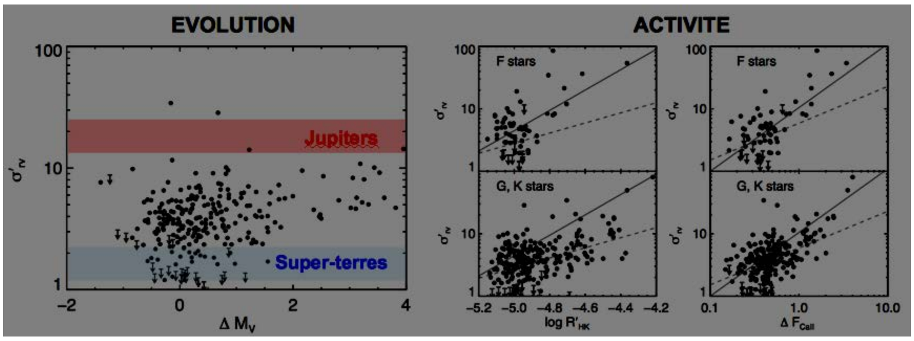


Figure 2.2: (from Wright et al. 2005), RV jitter as a fonction of evolution and activity or main sequence F, G & K stars. The expected RV signature of Jupiter-mass (red) and superearth-mass (blue) surrounding a 1 solar mass star at 0.5-1AU is shown on the left panel.

Hekker et al. (2006 A&A 454 943, 2008) finds a strong correlation between non-periodic radial velocities and log(g) in a larger sample of 179 K giants in the range 10-200m/s, indicating that RV jitter increases along the RGB.

Based on the literature, one can summarise the dependence of RV Jitter with stellar parameters as follows:

- Jitter increases with stellar activity (Wright et al. 2005 PASP 117 657, Saar et al. 1998 ApJ, 498 153)
- Jitter increases with evolutionary stage (Wright et al. ibid 2005, Hekker et al. 2006 A&A 454 943)

- Jitter increases with stellar rotation and masses (Saar et al. 1998, ApJ 498 153)
- Jitter has many time-scales: rotationally modulated spots (days-weeks), other rotationally modulated features (days-weeks), flares, coronal massive ejections, and stellar p-mode oscillations (minutes-days), active longitudes (years)
- Long-term RV jitter variation is suspected (Walker et al. 1995, Deming et al. 1997) and might be linked to magnetic cycles.

Among the physical mechanisms producing RV jitter, all random processes will add-up quadratically to an RV signature of a planet (periodic signal) as a noisy envelope. Those random jitter can, in principle, be filtered-out stacking-up enough data points (e.g. Marcy et al. 2005).

In contrast, all periodic RV jitter (stable activity spots or periodic pulsations) will mimic the RV signature similar to a planet (concerning activity, see Queloz, D. et al. 2001 A&A 379 279; Bonfils, X., et al. 2007 A&A 474 293). Therefore, they must be correctly interpreted to be removed from the RV signature of a planet-hosting star. Boisse et al. (2011 A&A 528, A4) proposes solutions to disentangle between stellar activity and planetary signals, showing in simulations that up to 90% of the radial-velocity jitter could be removed in an ideal case. For data with realistic time-sampling and white Gaussian noise, they used simulations to show that their approach is effective in distinguishing reflex-motion due to a planetary companion and stellar-activity induced RV variations provided that 1) the planetary orbital period is not close to that of the stellar rotation or one of its two first harmonics; 2) the semi-amplitude of the planet exceeds □30% of the semi-amplitude of the active signal; 3) the rotational period of the star is accurately known, and 4) the data cover more than one stellar rotational period. In all other cases, a distinction will not be possible solely based on photometric and spectroscopic observations. It is interesting to note that in case of HD166435, the archetype study of Queloz et al. exhibiting a misinterpration between acxtivity and exoplanet companion, a magnetic longitudinal field has been later on detected by Narval (http://polarbase.irap.omp.eu/; arXiv1401.1082P).

For a sake of completeness, it should be noticed that other parameters influence the jitter evaluation. They add quadratically to the jitter noise and are taken into account in the design of Neo-Narval: instrumental aspects, e.g. spectral resolution, sampling rate, wavelength reference accuracy and stability, stabilised light injection through image scrambling, guiding precision and centering. Also, photon noise which is roughly scaling with the signal-to-noise ratio (S/N) of the spectra can become important for weak sources. With Narval, a photon noise level of 1 m/s is typically achieved in a single exposure of 2 min and for a mag$V$ = 7 K dwarf (following Bouchy, F. et al., 2001, A&A 374, 733). Magnetic field measurements require high S/N ratio, ensuring therefore sufficientlty precise RV measurements. All those requirements are integrated into the global error budget of Neo-Narval.

2.2..3. NEO-NARVAL: A MAGNETIC JITTER PROBE

By giving a simultaneous access to the polarised light, spectropolarimetry observations offers the possibility to correlate the radial velocity jitter with a signal highly sensitive to magnetic activity. Neo-Narval would be a unique facility in the northern hemisphere to investigate the power of this technique.

A simultaneous monitoring of the stellar magnetic field and it’s large scale topology by the aim of spectropolarimetric observations will help to correct this effect. However, the bijective relation between magnetic field surface distribution and active plages and spots on the star is far from being established, and further studies are required to derive correlations and correction mechanisms (work in progress, see E. Hebrard, PhD thesis, IRAP/OMP). Eventually, this technique will enable us to detect radial velocity signatures of exoplanets in activity-“polluted” stellar velocity curves.

Since typical RV jitters observed in FGKM stars of different evolutionary stages reach down to 5m/s, (cf section 2.2.2) **Neo-Narval must therefore, be designed for a RV stability < 3m/s (short- and longterm).**

The recent work by Aurière et al. (2014, Proceedings of the IAU Symposium 302, M. Jardine, P. Petit and H Spruit, eds) illustrates the power of simultaneous radial-velocity and spectro-polarimetric measurements. Until now, Pollux is considered as an archetype of a giant star hosting a planet. Its radial velocity (RV) presents sinusoidal high amplitude variations with a period of about 590 d, which have been stable for more than 25 years. Using Espadons/CFHT and Narval/TBL, a sub-gauss longitudinal magnetic field at the surface of Pollux has been detected, and its long-term follow-up has revealed a (slightly phase-shifted) covariation with the RV variations. As an alternative to the scenario in which Pollux hosts a close-in exoplanet, Aurière et al. suggest that the magnetic dipole of Pollux can be associated with two temperature and macroturbulent velocity spots which could be sufficient to produce the RV variations. A large fraction of exoplanets detected around giant stars having been attributed very low excentricity orbits, and it would be interesting to see whether systematically the exoplanet hypothesis could be replaced by magnetic activity jitter, changing therefore radically our knowledge of end-of life scenarii of exoplanet evolution.

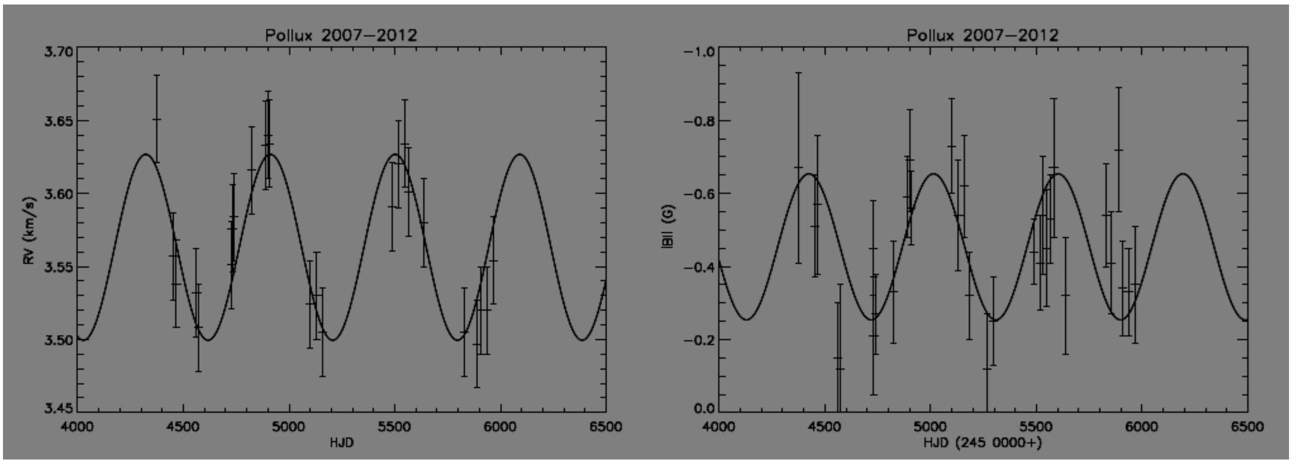


Figure 2.3: Variations of RV (left plot) and of Bl (right plot) with HJD (245 0000+) in 2007-2012. A sinusoid with P= 589.6 4 d is fitted for each parameter.

-The team does not seem very confident on the fact that planet RV signatures can be retrieved in "activity polluted stellar velocity curves." What correction methods are foreseen? What results are expected? What part of the activity jitter budget is easy/difficult to handle and what predictions for the level of correction? Also, there are several known diagnostics on stellar activity (width of CCF, bisector, simultaneous photometry) that are not discussed here. It is not clear today how the magnetic-field diagnostics is better than any of those; especially for evolved stars with large RV jitters.

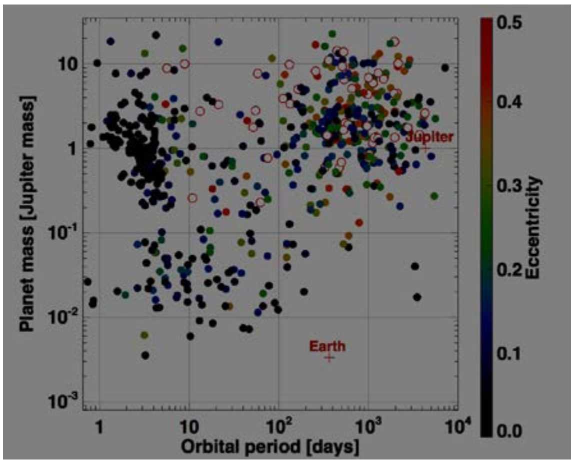
2.3. EXOPLANETS AROUND EVOLVED STARS

What do we know about the end of planetary systems ? What will happen to planets of the solar system at the end of the life of the sun has been a long standing question that interested astronomers since the early times of stellar evolution. After exoplanets began being discovered, the question regained interest because at last theoretical ideas could eventually be tested on exo-systems as soon as techniques would allow astronomers to detect planetary systems at the end of their life. Indeed, the accuracies of stabilised spectrographs now allow astronomers to discover more and more systems around intermediate-mass ($1.5M_{\odot}<M_S<5M_{\odot}$) evolved stars. The science case we propose in this section is to contribute to this young emerging field of observations of the latest stages of planets around evolved stars. As stated by Sato et al. (2008 PASJ, 60, 539) "*Now is the time to* *promote such kinds of studies more extensively, not only for solar-mass stars, but also for intermediate-mass ones, especially in the RGB phase by both theoretical and observational approaches*."

2.3..1. THE OBSERVATIONS OF PLANETS AROUND EVOLVED STARS

In the following, we will use the terms sub-solar mass for $M_s < 0.8M_{\odot}$, solar-mass for $0.8M_{\odot} < M_s < 1.2M_{\odot}$, and intermediate-mass for $1.2M_{\odot} < M_s < 5M_{\odot}$.

In spite of some efforts in the past 10 years, to date, only few tens of planets have been discovered orbiting stars ascending the Red Giant Branch among the hundreds of intermediate-mass stars followed-up (Döllinger et al. 2007 A&A 472, 649; 2009 A&A 499, 935; Frink et al. 2002 ApJ 576, 478; Hatzes et al. 2003 ApJ 599, 1383; 2005 A&A, 437, 743; A&A, 457, 335, 2006; Johnson et al. 2007a ApJ, 665, 785; 2007b ApJ, 670, 833; 2008 ApJ, 675, 784; 2010 PASP 122, 701; Liu et al. 2007 ApJ, 672, 553; Lovis & Mayor 2007 A&A, 472, 657; Niedzielski et al. 2007 ApJ, 669, 1354; Reffert et al. 2006 ApJ, 652, 661; Sato et al. 2007 ApJ, 661, 527; 2008 PASJ, 60, 539; Setiawan et al. 2003 A&A, 398, L19; 2005 A&A, 437, L31; Siess, L. 2006 A&A, 448, 717). They are all published in the exoplanet.eu or exoplanet.org database, and shown in Figure 2.4. Among those planets, 20 are orbiting sub-solar and solar-mass giants/sub-giants, and all others are orbiting intermediate-



mass giants/sub-giants.

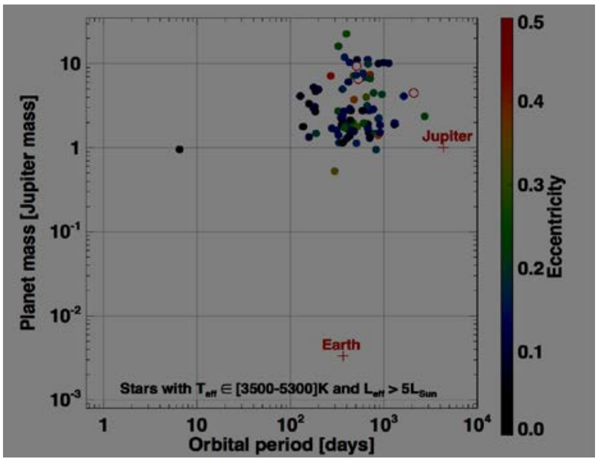


Figure 2.4: mass vs. orbital period for all confirmed exoplanets (left), and the sub-giant/giant sample (right) Color coding indicates orbit eccentricity (empty circles have e > 0.5).

The left panel of Fig. 2.4 shows the complete sample of known exoplanets, the right panel only shows exoplanets orbiting evolved stars (dominated by intermediate-mass stars). One sees a trend in the planet population of evolved stars: there are very few eccentric orbits, and short-period planets are lacking close to evolved intermediate-mass stars (see Johnson et al. ibid. 2007, 2010). This sample is still too lacunar to allow a discrimination between nature or nurture models (cf next section). Part of the small number of planets discovered so far lie in the inefficiency of the sub-Jupiter planet detection due to high RV jitter in giants 20-100m/s(cf section 2.2). In order to progress on our understanding of the latest stages of planetary lives, one needs to increase the present sample by a factor of ten at least. Detecting and following up planets around evolved stars of all masses is essential.

Neo-Narval with its unique capability for detecting magnetic activity and associated vsini modulation will bring a new perspective to the detection and confirmation of planets arounds sub-giants and giants. Typical stellar rotation periods of these stars are long (~1-2 years for 10$R_{\odot}$ stars) and can be confounded with similar associated orbital period of planets at 1-2 AU distance. How many of the hypothetically detected planets are true planets and how many are magnetic spots mimicking planets, similar to the Pollux case (Aurière et al. 2014)?

Apporte des contraintes sur les modèles de formation et évolution des Jupiter chauds.

2.3..2. PLANET ENGULFMENT

The fate of planetary systems is intimately linked to the evolution of their host star. Although several theories have been proposed, the question of how planets die remains open because the mass and spatial distributions of the exoplanets is still crudely known. Two models (nature vs nurture) seem to explain the lack of planets close to evolved stars. One "nature" model presented by Currie (ApJ 694, L171, 2009) proposes that planet formation processes explain the observed distribution, in particular, that the protoplanetary gas disk from which the planets form disappears faster close to massive stars than to solar mass stars, hence stopping earlier the inward migration of the gaseous planets. The other "nurture" model (e.g. Villaver & Livio ibid. 2009) suggests that tidal interactions can lead to the engulfment of close-in planets by evolved stars. They show contrasted fate for planets depending on (a) the initial conditions, (b) on the exchange of mass between the planet and its star going off the MS, (c) the gravitational and frictional drag, and (d) the tidal force.

In a nutshell, the nurture models, if confirmed, seem to predict that planets of Jupiter mass orbiting within 2 AU of a 1-2$M_{\odot}$ ⬧⧫♋❒ ♒♋❖♏ ♋ ⬧♓♑■♓♐♓♍♋■⧫ ❑❑❑♌♋♌♓●♓⧫⍓ ❑♐ ♌♏♓■♑ engulfed ♋⧫ ⬧❑❍♏ ❑❑♓■⧫ ♎◆❑♓■♑ ⧫♒e RGB ph♋⬧♏✍ What would exactly happen during the engulfment phase? The only star known to have possibly engulfed a planet is BD+48 740 (Adamow et al. 2012 ApJ 754 L15), the only candidate close to being engulfed is Kepler 91b (Lillo-Box et al. arXiv:1312.3943). Radial velocity (RV) variations of BD+48 740 are consistent with a 1.6M_J companion in a highly eccentric, $e = 0.67 \pm 0.17$, and extended, $a = 1.89$AU ($P_{rot} = 771$days), orbit, and a high Li abundance is interpreted as engulfment of a second inner planet (following suggestion of Siess & Livio, 1999 MNRAS 308 1133), but this hypothesis is not confirmed, and the engulfed candidate does not induce any RV oscillation on the host anymore. The engulfment phase lasts few million years (Barker & Olgivie 2009 MNRAS 395 2268) and there is no reason why a planet being engulfed recently shall not be detected by RV oscillations, with an orbit < R_{star}. In turn, Kepler 91b is a ~0.88M_J and a planetary radius of ~1.384 R_J. Asteroseismic analyses predict a stellar radius of ~6.30 $R_{\odot}$ and a mass of ~1.31$M_{\odot}$. Its almost orbit (e = 0.066) has a radius of just 1.32R_{star}. This planet is very close to being engulfed.

Is it possible to observe on-going engulfment? Because engulfment is a fast process, it is also rare. Tidal inspiral time can be calculated using eq. 6 of Barker & Ogilvie (2009 ibid.):

$$/_a \approx 12\ \mathrm{Myr} \left(\frac{Q_1'}{10^6}\right)\left(\frac{m_1}{\mathrm{M}_\odot}\right)^{\frac{8}{3}}\left(\frac{M_J}{m_2}\right)\left(\frac{\mathrm{R}_\odot}{R_1}\right)^{5}\left(\frac{P}{1\mathrm{d}}\right)^{\frac{13}{3}}\left(1-\frac{P}{P_\star}\right)^{-1}.$$

Where Q_1' tidal efficiency coeff (10^6 is a typical value for solar type stars but that coefficient is not well known), et m_1 star mass, m_2 planet mass, R_1 star radius, P planet orbital period, P_* star rotation period. For typical values, $m_1 = 2M_\odot$, $R_1 = 10R_\odot$, P = 5d, $m_2 = 1M_J$, $P_* = 30$d, $/_a \approx$ 1Myr. The Keplerian orbit (stellar surface) for the same values is $P \sim 3$ days $(a/10R_\odot)^{3/2}$ $(M_*/2M_\odot)^{-1/2}$, where a is the semi-major axis of the planet orbit. Hence a planet at P = 5d is close to the star surface. From $/_a$ we estimate an engulfment rate of 10^{-3} to 10^{-2} depending on the star RGB life, and on the planet atmosphere drag. In conclusion, the number of engulfments should allow us to witness them, provided we observe few hundred RGB stars.

Earlier attempts (Massarotti et al. ApJ 135, 209–231, 2008) trying to measure angular momentum excess (hypothetically induced by engulfed giant planets) in a sample of 760 giant stars within 100pc from the sun, did not lead to conclusive results. The huge contrast between a planet and its giant star host (typically $1/10^6$), makes it difficult for ground-based instruments to detect an on-going engulfment. Next generation space missions equipped with coronagraphs (JWST, ECHO-like, SPICES and PLATO) might be able catch such events akin to comet evaporation. But TBL/Neo-Narval is not sensitive enough to make direct detection of planet atmosphere evaporation. Of course Neo-Narval is perfectly adequate for detection of chemical abundance anomalies in the atmosphere of stars. Those anomalies, combined with RV oscillations for orbit < R_{star}, would be a strong evidence for a very recent planet engulfment. (akin to Adamow et al 2012).

Pour le temps de migration par effets de marées, on peut prendre la première équation du §6 de Barker & Ogilvie 2009 (`http://adsabs.harvard.edu/abs/2009MNRAS.395.2268B`) et supposer une étoile (sous-)géante de masse typique Mstar ~ 2Msun, de rayon physique typique Rstar ~ 10RSun, et considérer une planète de masse Mp = MJupiter, de période orbitale typique Torb = 5 jours (là où il y a le pile-up de Jupiters chauds autour d'étoiles moins massives).

Can planets survive engulfment? Models by Passy et al. (ApJ 759, L30, 2010), show that giant planets and brown dwarfs can indeed survive the common envelope phases under specific initial conditions (self-gravitating isothermal spheres with $g>g_{crit}$ survive ram pressure, cf eq. 1-10 of Passy et al.).

Planets and brown dwarfs around white dwarfs and pulsars have been observed: a $1M_J$-planet around the red horizontal branch star HIP10344 orbiting in 16.2 days (Setiawan et al., Science 330 1642, 2010), two earth-mass planet around the white dwarf KIC05807616 orbiting in 5.8 and 8.2 hours (Charpinet et al., Nature, 480, 496, 2011). Again here, a smoking gun could be a short period RV oscillation where $R_{orbit}<R_{star}$ for a $1M_J$ planet connected (or not) to anomalous abundances.

2.3..3. WHAT CAN NEO-NARVAL BRING TO THE OBSERVATIONS OF EXOPLANETS AROUND EVOLVED STARS?

Neo-Narval can significantly contribute to at least three areas: (a) the detection of new candidates (b) the confirmation of known candidates (c) the indirect detection of planet engulfment.

Neo-Narval has a large spectral range among echelle spectrographs (cf Table 2.1). Its sensitivity in the red part of the spectrum (Fig 2.5) makes it more sensitive to mid-K to M stars, in particular for follow-up of GAIA brightest targets (section 2.2.4).

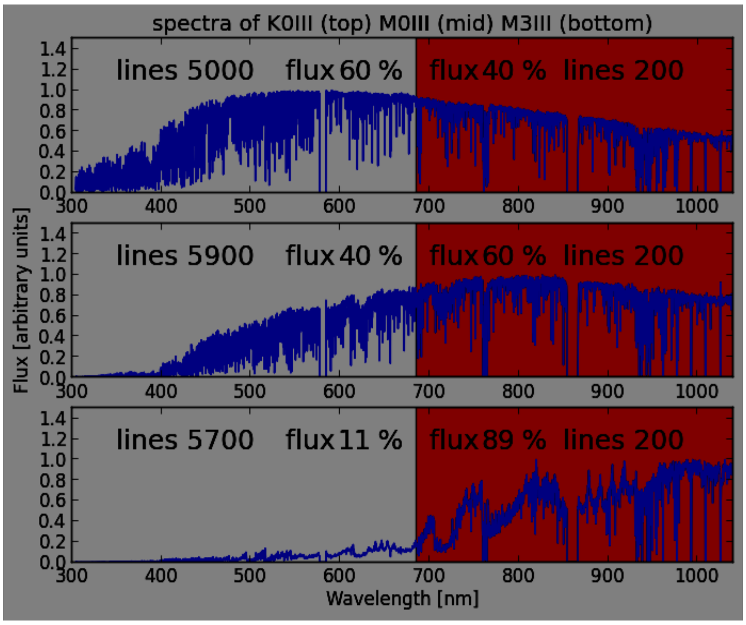


Figure 2.5: Neo-Narval covers the range 680-1000nm where is emitted most of the flux of mid K-M star (T_{eff} < 5000K). Flux is not the only parameter for sensitivity, the number of available lines for a given range is also to be considered. Illustrated here are the lines used in each range by the masks used for magnetic field analyses, that set the absolute lower limit of improvement of S/N gained by adding the range 680-1000nm to the analyses. For late-type stars, flux beyond 680nm becomes a dominant factor and Neo-Narval is optimal.

(a) detection of new candidates: **Taking in account only RV oscillations, at 3m/s stability, Neo-Narval would be able to detect all Jupiter-mass planets up to 1 AU (~200$R_\odot$), and most Saturn-mass planets up-to 0.1AU around intermediate-mass giant.** Because of the giant stars RV jitter amplitudes (20-100m/s) is poorly understood, planets detected around evolved stars are currently limited to M_{Jup} or higher. In the northern hemisphere, Neo-Narval is the only instrument able to probe RV signals connected to stellar magnetic activity, hence might help understanding part of the RV jitter. Neo-Narval might be able to detect sub-M_{Jup} planet close to evolved stars by the combination of the red range and magnetic activity analyses.

(b) confirmation of planet discovery claims: **Neo-Narval will bring a unique perspective in the northern hemisphere to probe possible jitter mimicking planet modulation** (cf section 2.2), thus confirming the bona-fide planets among existing RV and Transit candidates (cf Pollux case; Aurière et al., 2014), the only other spectropolarimeter able to explore these domains in the northern hemisphere is ESPaDOnS for now (only for large amplitudes, since not stabilised), and then in the close future SPIROU, the latter one being mainly dedicated to earth-mass planets around low-mass stars, and this in the period 2016-2020+.

(c) the detection of planet engulfment: this goal is obviously more speculative, but also exciting. As said earlier, direct observation of a planet being engulfed is unlikely because it is a fast and transient phase. But in principles the RV modulation of an engulfed planet of 1 M_{Jup} should be large enough to be detectable by Neo-Narval, the inward migration is expected to be fast (few thousand years). Increasing periodic RV variations would be a fascinating measurement to achieve on long-term follow-ups. An indirect detection could be an abundance anomaly as the one detected by Adamow et al. (2012 ApJ 754 L15)

In conclusion:

- Neo-Narval should be able to detect any 1-M_J planet around a 2-solar mass star (I<8) closer than 2AU.
- Thanks to its red range (680-1000nm) Neo-Narval will be able to probe mid-K to M stars with good

sensitivity.

- ⑩ Neo-Narval will be able to probe magnetic activity of planet-host stars and RV signatures at once, and test known candidate planets.

2.3..4. POTENTIAL EVOLVED STAR TARGETS FOR NEO-NARVAL

The Hipparcos database alone delivers a sample of more than 930 evolved stars (*magI*<8) that can be followed-up to a high S/N for giant planet search and probe the lacunar space of 0.1AU < R_{orbit} < 2 AU. (see also samples of Johnson, Sato and Massarotti).

The Table shows the distribution of Targets according to Spectral Type from SIMBAD.

	G0 V	G0 III	K0 V	K0 III	M0 V	M0 III	M3III	M5III
CDS/SIMBAD #obj (*mag I* < 8)	323 (G*)	50 (G*IV) 68 (G*III)	238 (K*)	29 (K*IV) 145(K*III)	31 (M*)	0 (M*IV) 49 (M*III)	-	-
CDS/SIMBAD #obj (*mag I* <10)	490 (G*)	77 (G*IV) 99 (G*III)	369 (K*)	38 (K*IV) 209(K*III)	141 (M*)	0 (M*IV) 58 (M*III)	-	-
CDS/SIMBAD #obj (*mag I* <12)	536 (G*)	82 (G*IV) 117 (G*III)	422 (K*)	52 (K*IV) 224(K*III)	210 (M*)	0 (M*IV) 63 (M*III)	-	-
Massarotti et al. # Obj (<100 pc)	761 Hipparcos giants between 20°<δ<60°							

On can try to evaluate at first order a typical

How many measurements per targets: The RV period needs to be sampled, hence close planets will need few measurements per night, whereas 1-AU orbits will requires one measure per month.

How long in polar mode per individual measurement: exposure time is dominated by magnetic sensitivity, RV measures will be free byproducts of Polar measures.

Total observing time needed: for 8mag star,, a typical observing time 1h to reach S/N~700.

What expectations in terms of planets; between 1/2 and 1/10 of stars are expected to have giant planets.

Same information missing for potential space-mission follow-up programs.

2.4. SPECTROPOLARIMETRY WITH NARVAL - ONGOING PROJECTS

2.4..1. NARVAL: 7 YEARS OF SEMINAL WORKS

As written in the introduction, TBL/Narval (and CFHT/ESPaDOnS) have revolutionised the realm of stellar magnetism. Narval has observed all phases of stellar evolution that are influenced by the presence of magnetic fields in the interior and close environment of stars. (see e.g. Donati, JF, et al., 2008, Magnetospheric accretion on the T Tauri star BP Tauri, 2008MNRAS.386.1234, Donati, JF, et al., 2008, Large-scale magnetic topologies of early M dwarfs, 2008MNRAS.390..545D , Aurière, M., et al., 2007, Weak magnetic fields in Ap/Bp stars. Evidence for a dipole field lower limit and a tentative interpretation of the magnetic dichotomy, 2007A&A...475.1053A , Donati, JF., et al. 2008, Magnetic cycles of the planet-hosting star τ Bootis, 2008MNRAS.385.1179D, Donati, JF., et al., 2010, Magnetospheric accretion and spin-down of the prototypical classical T Tauri star AA Tau, 2010MNRAS.409.1347D, Aurière, M., et al., 2009, Discovery of a weak magnetic field in the photosphere of the single giant Pollux, 2009A&A...504..231A, Lignières, F., et al., 2009, First evidence of a magnetic field on Vega. Towards a new class of magnetic A-type stars, 2009A&A...500L..41L, Aurière, M., et al., 2008, EK Eridani: the tip of the iceberg of giants which have evolved from magnetic Ap stars,2008A&A...491..499A, Aurière, M., et al., 2010, The magnetic field of Betelgeuse: a local dynamo from giant convection cells?, 2010A&A...516L...2A , Fares, R., et al., 2009 Magnetic cycles of the planet-hosting star τ Bootis - II. A second magnetic polarity reversal, 2009MNRAS.398.1383F, Alecian, E., et al., 2008 Characterization of the magnetic field of the Herbig Be star HD200775, 2008MNRAS.385..391A, Bouret, JC, et al., 2008 The weak magnetic field of the O9.7 supergiant ζOrionisA,2008MNRAS.389...75B, Martins, F, et al., 2010, Detection of a magnetic field on HD108: clues to extreme magnetic braking and the O phenomenon, 2010MNRAS.407.1423M, Silvester, J., et al., 2009, On the incidence of magnetic fields in slowly pulsating B, β Cephei and B-type emission-line stars, 2009MNRAS.398.1505S, Fares, R., et al., 2010, Searching for star-planet interactions within the magnetosphere of HD189733, 2010MNRAS.406..409F).

The following section illustrates possible studies using Narval in spectropolarimetry. The total amount of hours that could be devoted to those studies is important (13000 hours). This explains the healthy pressure that Narval continuously shows since its first light.

2.4..2. MAGNETIC FIELDS AND STELLAR EVOLUTION

Magnetic fields dominate the dynamics of circumstellar environments controlling the spindown, the accretion or the mass-loss of stars at various phases of stellar evolution. Within stars, magnetic fields also play a central role in the transport of angular momentum and thus indirectly on chemical elements distribution. When strong enough, they can even affect heat transport in convection zones. Beyond the standard model, today's main challenge of stellar evolution theory is to account for the transport processes induced by rotation, convection and magnetic fields. In the coming years, astrometry (Gaia), seismology (Plato/TESS…) and interferometry (VLTI instruments) will probe these processes in details. Direct magnetic field measurements will provide a unique and complementary constraint in this context.

Another major challenge in stellar magnetism is to understand how magnetic fields are generated within stars and how they drive active phenomena in their outer atmosphere. The variety of stellar conditions across the HR diagram offers a unique opportunity to investigate stellar dynamos and activity in a broad range of parameters. This multi parameter approach is also crucial to understand the magnetic field of the Sun, its time evolution and its impact on the Earth. In the last ten years, new generation echelle spectro-polarimeters have permitted the first direct field measurements in various regions of the HR diagram. Many new directions of research, including new types of magnetism, have emerged from this first exploration. In the future, the possibility to couple direct field measurements with activity tracers (GAIA) or seismic diagnostic (Kepler/Plato…) will also be key to progress on the origin of stellar magnetism and activity.

Here below we describe some typical research fields in spectropolarimetry, particularly suited for Narval/TBL, and representing a challenging task for the decade.

2.4..3. STELLAR DYNAMOS

The turbulent envelope of cool stars is able to sustain the amplification of magnetic fields through dynamo processes, leading to a widespread magnetism of stars of spectral type cooler than about F6, at all evolutionary stages. The resulting magnetic fields at photospheric level generally display a high complexity, both in their topology and temporal evolution. The Zeeman signatures of their largest-scale spatial components are detectable through optical spectropolarimetry, providing us with precious boundary conditions to constrain theoretical dynamo models.

The current generation of spectropolarimeters has widely increased the number of categories of cool stars in which magnetic fields can be investigated. Objects explored up to now include solar twins (Petit et al. 2008), slowly rotating giants (Aurière et al. 2008, 2009), cool supergiants (Aurière et al. 2010, Grunhut et al. 2010), T Tauri stars (Donati et al. 2007), M dwarfs (Morin et al. 2008). After a number of studies carried out on limited stellar samples, most of these program would now benefit from a rigorous parameter study on larger samples, sometimes coordinated with other observing facilities.

The systematic monitoring of a sample of 20 F-G-K dwarfs, spanning a range of masses and rotation rates, was initiated with NARVAL in early 2007. Since then, most of these targets are re-observed once a year, with a rotational sampling sufficiently dense to reconstruct their large-scale magnetic geometry and evaluate their latitudinal surface shear. The aim of this project is to provide observers and theoreticians with the first long-term monitoring (15+ years) of the magnetic evolution of Sun-like stars, in the first direct investigation of the series of magnetic reversals related to activity cycles. The first results of this project can be found in Petit et al. (2008, 2009) and Morgenthaler et al. (2011, 2012). More particularly, forthcoming studies will be focused on:

- **Long-term monitoring of Sun-like stars over 15 years -** With a current timespan limited to 7 years, this project is now delivering a first harvest of magnetic cycles (Petit et al. 2009, Morgenthaler et al. 2011). The polarity switches reported so far all concern rapidly-rotating stars (Prot < 10d), while stars rotating slower still display their initial magnetic polarity, confirming that short magnetic cycles are more frequent in rapid rotators (Baliunas et al. 1995). The necessity to cover full cycles of the whole sample is a strong motivation to pursue this program over at least 15 yr, which should provide us with at least one polarity switch for slow rotators. For more active targets, gathering data over several cycles will bring information about the regularity of their cycles and about the existence of different periods in their magnetic activity. The 20 stars observed for this project are relatively bright, so that their yearly monitoring takes about 250 hr. Assuming a monitoring running until 2021, **another 2,500 telescope hours are needed to collect the final data set.**

- **Influence of tidal forces on magnetic topologies and magnetic cycles.** One natural goal of the long-term monitoring of Sun-like stars is to serve as a reference sample for similar studies probing a same range of mass and rotation rates, but with at least one physical parameter differing from the initial target list. We propose here to investigate the impact of a strong tidal coupling on the magnetic topologies by duplicating part of the initial stellar sample, in a new sample constituted of close binaries. The new sample can be constituted of 10 stars and should keep as close as possible to the fundamental parameters of the initial target list. The new list of objects will be observed on a yearly basis over 10 years. About 200 hours are requested each year to collect a dense rotational sampling for the selected binaries. **The total amount of telescope time to complete this program is therefore of 2,000 hours**.

- **Variations of magnetic topologies and magnetic cycles across stellar evolution.** The magnetic field generation in cool stars is strongly influenced by the depth of the convective envelope and by the intensity of vertical/horizontal velocity gradients in internal layers. Another extension of the long-term monitoring program is the duplication of part of the initial sample to evolutionary status outside of the main sequence (PMS stars or subgiant/giants). Such study is of crucial importance to understand the origin of magnetic fields in the early and advanced phases of stellar evolution, two evolutionary stages during which strong internal velocity gradients are predicted (Bouvier 2008) or observed through seismic observations (Beck et al. 2012). The second goal of this study is to understand the impact of stellar magnetism on stellar evolution, through the ability of magnetic fields to influence the spin evolution, mass-loss and vertical settling of chemical elements. We propose to undertake this program with a sample of 10 cool PMS stars, 10 cool subgiants and 10 cool giants, with repeated observations of the sample over 10 years. This would require an effort of 600 hrs per year, i.e. **6,000 hours over 10 years**.

- **Magnitude-limited snapshot survey of solar-type stars.** The high polarimetric sensitivity of NARVAL is sufficient to detect Zeeman signatures in most solar-type stars, including low-activity objects like solar-twins. In a legacy approach, we propose to run a systematic, Stokes V snapshot survey with the aim to obtain a final noise level (of LSD profiles) below 10^{-4} Ic. This threshold can be obtained within about 1 hour of integration for stars brighter than mV=7. Such systematic survey is already under way and concerns today around 200 solar-type stars and 40 evolved stars. To complete this program and get the first homogeneous catalogue of magnetic measurements on cool stars, new observations must be collected for another 400 solar-type stars of appropriate declination and of spectral types cooler than F6 and hotter than K9, requiring 400 telescope hours. In addition, 160 subgiants have to be observed (160 hr), 1400 normal giants (1,400 hr) and 60 bright giants (60 hr). **The total telescope time to complete this survey is therefore of 2,000 hours**.

- **Cool descendants of Ap stars**. Spectropolarimetric observations of EK Eridani have revealed that a small fraction of slowly-rotating, intermediate-mass giants hosts strong (~500 G) and stable surface fields that seem difficult to reconcile with a dynamo scenario (due to the low rotation rate). This magnetism is probably inherited from an earlier evolutionary stage and is likely originating from the strong magnetic fields exhibited by Ap/Bp stars on the main sequence (Aurière et al. 2008, 2011, 2012, Tsvetkova et al. 2012). After the main-sequence, the survival of strong magnetic fields is expected to affect the internal structure of the star as it evolves towards the giant branch, by imposing a strong magnetic coupling between the contracting core and the expanding envelope, therefore modifying the internal velocity profile of the star (and presumably reducing radial velocity gradients). The strong field pervading the convective envelope is also expected to limit the efficiency of convection and result in a measurable increase of the stellar radius (Lopez-Morales 2007). Given the strong amplitude of Zeeman signatures associated with the surface magnetic field of EK Eridani, their detection is possible, within one hour of integration and at the 3σ level, for stars up to mV=11. Such relatively high limit magnitude is ensuring that a number of Ap stars descendants in the KEPLER sample can be observed using NARVAL, which will enable to derive simultaneously their large-scale surface field and their internal properties.

2.4..4. ORIGIN AND IMPACT OF MAGNETIC FIELDS IN MASSIVE AND INTERMEDIATE-MASS STARS

From the first Zeeman effect measurement (Babcock 1947) to the early 90s, all magnetic field detections in the upper-main-sequence have been achieved among late B, A and early F stars belonging to the class of Ap/Bp chemically peculiar stars. Their fields have a simple topology, dominated by a dipole component with strengths ranging from 0.3 to 30 kilo-Gauss, and they are stable over time. The incidence of Ap stars among A-type stars led to an estimate of 5% magnetic stars among main-sequence intermediate-mass stars.

Contrary to solar-type magnetism where the presence of a magnetic field is attributed to a solar-type dynamo in the convective envelope, basic questions about the magnetism of intermediate to massive stars such as: "What is the origin of the observed field? Why only a small fraction of the stars possess a magnetic field? What about the field of the 95% left?" remain unanswered. From the point of view of stellar evolution, these questions translate into : What is the impact of the strong magnetic fields of Ap stars on their evolution ? Can this class of stars be traced along their giant phase ? For the majority of stars where a magnetic field has not been detected, is there any observational constraint on the amplitude of their hypothetical magnetic field ? Should stellar evolution of typical intermediate to massive stars take magnetic fields into account ?

Recent results obtained with Narval and Espadons have nevertheless profoundly modified our vision of hot star magnetism. First spectropolarimetric surveys dedicated to massive stars have inferred a similar fraction of strongly magnetic stars, suggesting a common origin of intermediate-mass and massive star magnetism (Grunhut et al. 2012). Meanwhile, deep spectropolarimetric surveys among intermediate mass stars revealed a lower bound to Ap magnetic fields and a two orders of magnitude magnetic desert among A-type stars between this lower bound and a new type of sub-Gauss magnetism, first discovered in Vega (Auriere et al., 2007, 2010, Lignieres et al. 2009). These dramatic progress have opened new perspectives towards the understanding of the origin of massive and intermediate mass star magnetism. Some of the long-term programmes associated to this new directions are listed below:

- **Vega-like magnetism**. Ultra-deep spectropolarimetric observations enabled to detect for the first time a polarimetric signal in the spectral lines of the A-type, non Ap/Bp stars, Vega and Sirius. The amplitude of the signal is the smallest one detected to date with NARVAL or ESPaDOnS for any intermediate-mass star, with a longitudinal magnetic field of -0.6 ± 0.3 G and -0.2 ± 0.1 G, respectively. Adding yet unpublished detections of two other tepid stars, Beta Uma and Theta Leo, the detection rate in this 8500-10000 K temperature range is 100%. This strongly suggests that this new Vega-like magnetism is widespread among intermediate-mass star and by extension among massive stars. Such a new window on stellar magnetism open the doors for the first direct constraint on the magnetic field of typical intermediate-mass and massive stars. It is of primary importance for stellar evolution models and the other domain in astrophysics hat depends on them (such as galaxy evolution). Due to the ultra-weak polarised signature, exploring Vega-like magnetism is a new challenge for stellar spectropolarimetry that will required a large amount of telescope time. To illustrate this point, we estimated the resource needed to complete a first survey limited in magnitude, temperature range (B8-A6), and projected rotational velocity (< 50 km/s). The exposure time is built from the amount of photons required to obtain a clear detection on Vega and Sirius. With Narval in its actual configuration, about 800 hours of TBL time are required to survey the 6 best targets with mv< 4.5. Beyond this first survey, other scientific objectives will be to : (i) extend the temperature (mass) range and the projected rotational velocity range of the survey, (ii) monitor the time evolution of Vega-like magnetism, (iii) characterize the surface field distribution, (iv) characterize the peculiar Zeeman signature of Am stars.

- **The lower bound of Ap/Bp magnetic fields**. The discovery of a lower bound to Ap magnetic fields and the subsequent magnetic desert between 100 Gauss and 1 gauss (Auriere et al. 2007, 2010) has prompted new ideas about the origin of intermediate mass magnetism. It is believed that this lower bound carries crucial informations about the origin of Ap magnetism as it separates stable large scale field configurations from the unstable ones. A simple relation Bmin □Ω, between the lower bound and the star rotation, has even been proposed. It is therefore crucial to determine observationally the relation between the magnetic lower bound stellar parameters such as rotation and mass. In the coming years, this will requires large sample spectropolarimetric surveys because one has to find a lower bound and also to take care of the mass and rotation coverage. For each target, observations at different epochs are also necessary to determine the rotation rate from the periodic modulation of the polarized signal. Finally an accurate determination of the Bmin(Ω,M) relation is important to put tight constraints on the fastly developping theories for Ap/Bp magnetism.

- **Massive stars**. An ambitious magnetic field search among stars hotter than B3 has been performed with Narval and Espadons (The Mimes programme). It already led to 14 new magnetic stars and confirmed the existence of a class of strongly magnetic stars which incidence is similar to Ap/Bp magnetic stars among intermediate-mass.

2.5. NEO-NARVAL CONTRIBUTION TO SPACE MISSIONS

Neo-Narval will play a major role in ground-based follow-up of of forthcoming space missions.

The space missions TESS (aimed at stars mag 4-12), GAIA and the future PLATO have announced an enormous need for spectroscopy follow-up on 2-4m telescopes. Because those missions are aimed at earth-size planets around solar-mass stars, most of the detections will be beyond reach of Neo-Narval. other exiting stable spectrographs such as SOPHIE/OHP, Spirou/CFHT, CARMENES/CA, HARPS/ESO, ESPRESSO/VLT and later CODEX/E-ELT will be called to contribute. Still, a large sample of heavier (sub-jupiter and jupiter-mass) planets around stars on and above the main sequence will be detected as by-products, and Neo-Narval will stand in good position for following-up those candidates. Its unique capacity of probing the magnetic activity and correlating to RV jitter will represent a major asset. Interestingly enough, Neo-Narval's range around 850-870nm (GAIA RVS range) makes its particularly optimised for GAIA follow-ups of the brightest targets of opportunity (cf Munari et al. on GAIA RVS science case, and PLATO yellow book).

Radial velocity precision	Telescope	Type of objects	Example time distribution
10m/s	1-2m	Giant planets on short/medium orbits	50 nights/yr for 6 yrs on 3 tel.
1m/s	4m	Giant planets, long orbits. Super-Earths on short medium orbits	40 nights/yr for 6 yrs on 3 tel.
<20cm/s	8m	Earths/Super-Earths on long orbits	40 nights/yr for 6 yrs on 1 tel.

Table 2.2: Required PLATO follow-up observations

How many measurements per targets: The RV period needs to be sampled, hence close planets will need few measurements per night, whereas 1-AU orbits will requires one measure per month.

How long in polar mode per individual measurement: exposure time is dominated by magnetic sensitivity, RV measures will be free byproducts of Polar measures.

Total observing time needed: for 8mag star,, a typical observing time 1h to reach S/N~700.

What expectations in terms of planets; between 1/2 and 1/10 of stars are expected to have giant planets.

Same information missing for potential space-mission follow-up programs.

3. SCIENCE AND TECHNICAL SPECIFICATIONS

This section is only a summary of the science requirements and high-level technical specifications of Neo-Narval.

Important requirement on science operation: Narval must continue operation as much as possible. Neo-Narval commissioning should not last more than 6 weeks. This requirement will contribute to the choice of technical solution.

Science requirements	Technical spécification
Detect 1-Gauss magnetic fields on MS and evolved stars	Narval polarimeter is already on specs
Detect 1-M_J planet at 1 AU of a 8-mag 2-$M_{ღ}$ ⬧⧫♋❒	long-term stability of the spectrograph = 3m/s
Detect a magnetic modulation on activity jitter on MS and sub-giant stars	long-term stability of the spectrograph = 3m/s

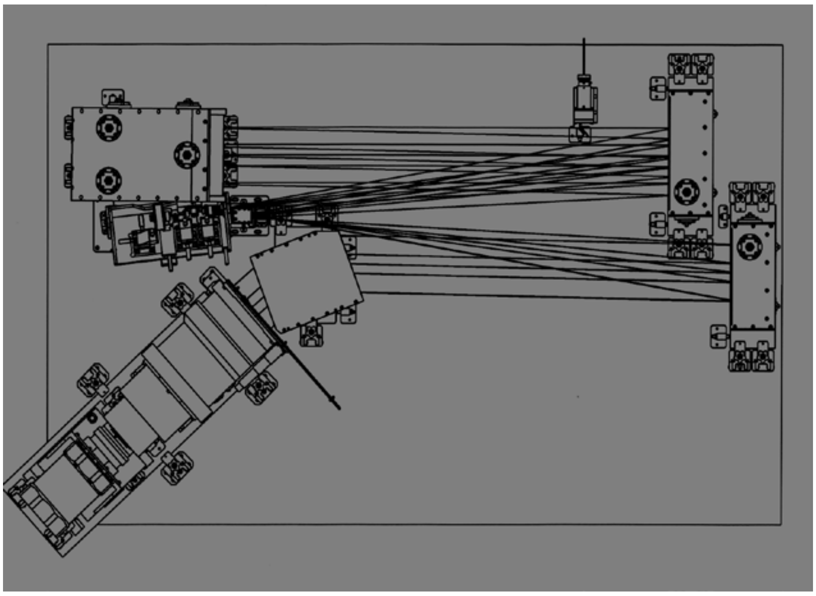
Exoplanet confirmation of Transit candidates around evolved stars	long-term stability of the spectrograph = 3m/s

The science requirements leads to a small number of new technical specifications, assuming Narval keeps its existing capabilities, the new specifications are given in the table below.

Long-term stability of the spectrograph = 3m/s = 1/800th CCD pixel = 16 nm		
Component	primary specification	secundary specification
Science Camera	Long-term autonomy > 1 year.	Ultra-Vacuum specs
	IR sensitive CCD > 80% QE 700-1000nm	Deeply-depleted chip
Spectrograph	Refraction index between optics must not vary by more than $2x10^{-8}$ (grating, prisms, camera lenses)	Pressure ΔP < 10µbar Temperature ΔT < 0.01K
	homogeneous illumination on pupil.	octogonal fiber injection specs
Polarimeter	Achromatic rhomboedra	
	Rhomboedra retardance < 1deg	positioning to better than 1 arcmin

4. INSTRUMENTAL CONCEPTS

4.1. THE NARVAL SPECTROPOLARIMETER, CURRENT STATUS



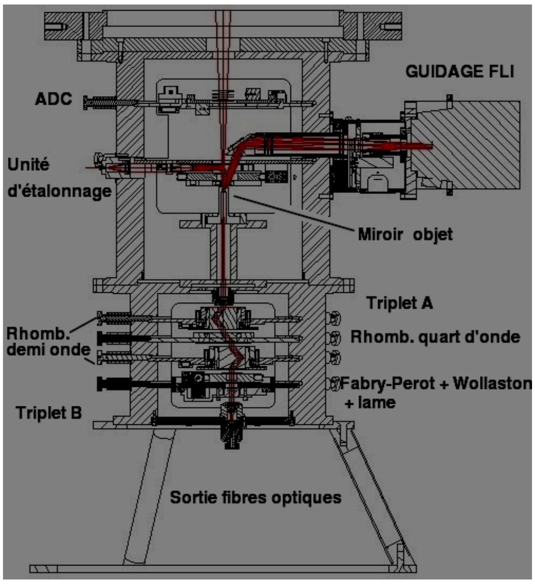


Figure 4.1: Mechanical drawings of the spectrograph (left) and polarimeter (right) of Narval

As of today, Narval at TBL is optimised for high-resolution spectropolarimetry, ie deriving magnetic field measurements out of the polarimetric analysis of a large number of stellar absorption lines. After 8 years of intensive use, Narval is well characterised (http://www.ast.obs-mip.fr/projets/narval/v1/). In it's initial concept, Narval was optimized for polarimetric measurements at very high efficiency (up to 15% overall efficiency in the V band) and resolution (R = 65000 in polarimetric mode). its current performance in radial-velocity stability is rather low and corresponds to the expectations of a classical échelle spectrograph (several hundreds of m/s on the longer-term). It should be emphasized that Narval was not designed initially to achieve any specific radial velocity requirements.

4.2. NEO-NARVAL: A RADIAL-VELOCITY STABILISED SPECTROPOLARIMETER

The Neo-Narval project is aiming for a radial-velocity stabilisation of the instrument, which does imply major modifications with respect to the atmospheric environment of the spectrograph itself. More specifically, most of the error budget on spectral stability is due to refraction index variations, which can be directly related to temperature and pressure variations within the spectrograph enclosure. Index variations have major effects on the grating response but also on the refraction by the cross-dispersing prisms. In addition, defocusing effects on the optical camera cannot be neglected neither. In order to expose these optical elements to a stable refractive index we plan to place them in a stabilized environment. The best solution, in theory, would be to relocate the entire spectrograph in a vacuum vessel. This would ensure perfect stabilisation, but the spectrograph parts employed in the initial design are not vacuum-proofed. We therefore follow a solution of a stabilized nitrogen atmosphere at atmospheric level. Two options are currently analysed, invoking either two separate small vessels englobing i) the grating and ii) the prisms and camera, or, placing the entire spectrograph in a stabilized vessel. Many optical, mechanical, thermal and pressure-related aspects are taken into account. The derived design concepts are thoroughly discussed with experts from the Geneva Observatory (HARPS/EXPRESSO), as well as specialists at ESO/Germany.

In addition, it is planned to optimize the stability of light injection by the integration of a double-scrambling octagonal fibre device; such devices are currently successfully employed in several highly stabilized spectrographs (eg. Sophie/OHP, HARPS/ESO).

Eventually, and on the longterm, a simultaneous calibration source injection is studied, involving potentially optical laser combs.

4.3. NECESSARY SERVICE OPERATIONS

While Narval still performs close to initial specifications, ageing has brought its toll on the instrument moving parts. A major upgrade concerns the employment of absolute encoders in the polarization analysing rotating device.

The replacement of the CCD camera by a new cryostat and a recent CCD chip is required and planned.