Cover page

Title: Magnetic fields of the seismology targets from MOST, CoRoT, and Kepler
Instrument required: ESPaDOnS
Time requested: 480 hours = 380 (≈80%) F + 100 (≈20%) C
Number of semesters: 9
Abstract:

We propose to organize a systematic CFHT/ESPaDOnS spectropolarimetric study of the asteroseismology targets of the space missions, MOST, CoRoT and *Kepler*. The major contribution of CFHT will be the search for and detailed study of magnetic fields of two classes of stars, cool FGK and hot stars. For cool stars, the combined ESPaDOnS and space-based photometric data will provide unprecedented insight into dynamo processes; for hot stars, we will study the coupling of pulsations and magnetic fields, and its impact on the physics of the atmosphere. Combining ESPaDOnS spectropolarimetry and space-based high precision photometry will therefore allow us to better exploit the seismology space data, and will provide an efficient tool to study magnetism in these stars.

This program is carried out within the broader context of the MagIcS initiative. MagIcS is an international project aimed at studying the magnetic fields of various classes of stars throughout the HR diagram. The main goal is to produce up-to-date models of magnetic stars, by (i) investigating the origin of such fields and identifying the physical processes producing them, and (ii) documenting the impact of magnetic fields on the physical processes at work within and around stars and thereby on the long-term evolution of stars. MagIcS also supports several current and future space missions and includes a general-access LEGACY-type database of all collected spectropolarimetric data. For more information about MagIcS: http://www.ast.obs-mip.fr/users/donati/magics/

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1 Scientific justification (5p)

1.1 General background

Magnetic fields constitute an essential ingredient of the Universe, and have a crucial effect on star formation and later evolution. Many studies of stellar magnetic fields all across the HR diagram have been performed in the past years with a variety of approaches, but the commissioning of the ESPaDOnS spectropolarimeter at CFHT in 2005, has quickly brought major results in this area, such as *e.g.* the discovery and study of magnetic fields of young stellar objects, both cool (Donati et al. 2007) and hot (Wade et al. 2005), new and surprising insight in the magnetism of fully convective cool dwarfs, or the discovery and further investigation of magnetic fields in stars hosting hot Jupiters (Catala et al. 2007, Moutou et al. 2007).

In this large program proposal, we suggest to take advantage of yet another family of new instruments to make decisive progress in our understanding of stellar magnetism: the space-based asteroseismology missions. The asteroseismology programs of the space missions MOST, CoRoT and *Kepler*[1] provide us with a unique opportunity to probe directly inside stars and perform measurements that, when coupled to high quality spectropolarimetric observations such as those delivered by ESPaDOnS, can be used to severely constrain theories of stellar magnetic fields.

In addition to their valuable input to the study of stellar magnetism, spectropolarimetric observations of targets of the asteroseismology missions will also provide us with a much needed tool to optimize the exploitation of space-based oscillation spectra, by providing constraints on some stellar parameters, such as the inclination angle of the rotation axis with respect to the line-of-sight, and by giving us input to understand the impact of magnetic fields on stellar oscillations. Since data from MOST and CoRoT are already available and being extensively analyzed in our communities, the follow-up observations proposed here are both extremely important and timely.

This proposal includes two segments, each one concerning a specific class of targets of the asteroseismology missions: the cool solar-like stars, for which convection and internal rotation can be studied by seismic analysis, and the hot pulsating stars (roAp, Be stars, SPB, β Cep) for which the coupling between pulsations and magnetic field plays a crucial role in the physics of the atmosphere.

1.2 Magnetic field and rotation of cool stars

1.2.1 The role of magnetic fields and rotation in stellar evolution

Magnetic fields seem to play a major role at almost all stages of stellar evolution. Their impact in the process of star formation and very early evolution is believed to be essential (Pudritz & Norman 1983), e.g. through magnetically controlled accretion-ejection processes during protostar collapse, or by coupling the stars to their accretion disks, hence strongly impacting the star's angular momentum evolution. Throughout pre-main sequence and main sequence phases, magnetic fields continue to control angular momentum evolution, with crucial consequences on mixing processes in stellar radiative interiors and hence on stellar evolution.

Despite recent progress both on the observational (e.g. Donati et al. 1997) and theoretical (e.g. Brun et al. 2004) points of view, we are still far from understanding how magnetic fields are produced in cool stars. It is very likely that dynamo action is the mechanism by which magnetic fields are produced and

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[1] MOST is a Canadian micro-satellite for asteroseismology, in orbit since 2003. It provides a photometric noise level of 1 ppm at m_V=6, with a monitoring duration up to 2 months. The main targets of MOST are solar-like stars, metal-poor subdwarfs, roAp stars, WR and SPB stars and extrasolar planetary systems.

The French-led CoRoT satellite was launched in December 2006, for a nominal lifetime of 2.5 years. Its scientific goals are the search for exoplanetary transits and the asteroseismic study of stellar interiors. For each pointing, 10 stars with m_V between 5.5 and 9.4 are monitored for up to 150 days. The photometric noise level is 0.7 ppm in 5 days at m_V=6. Cool dwarfs and hot stars are the most numerous targets of the seismology program of CoRoT.

Kepler is a NASA exoplanetary mission that includes a seismology program, scheduled for launch in 2009. It will observe only one static already defined field of 105 deg^2, with more than 100,000 stars with m_V between 8 and 14. The expected noise level is 1 ppm in one month for a m_V=10 star.

maintained in these stars. This mechanism requires both non axisymmetric turbulence and differential rotation, and is believed to result from the interplay of rotation and cyclonic convection in the convective zone (CZ). Differential rotation produces a toroidal field structure from an initially poloidal field, then turbulence reacts back on this toroidal field to turn it into a poloidal field of opposite polarity; most of these phenomena are believed to occur within a thin layer at the base of the CZ, where rotation gradients are large.

Although this basic picture is widely accepted, many crucial issues of solar-type dynamos still remain unsolved. For instance, the detailed physical mechanism by which a poloidal field is regenerated by non-axisymmetric turbulence is still essentially a matter of speculation (e.g. Dikpati & Gilman 2001 and references therein). Also, the complex interaction between magnetic field and differential rotation in the CZ is still basically not understood. More generally, we need to understand how magnetic field and rotation interact with each other, first through the details of the dynamo mechanism responsible for the amplification and time variability of magnetic fields, second through the feed-back of magnetic fields on stellar rotation which, as mentioned above, has a severe impact on stellar evolution.

While precious information on these phenomena can be gathered by detailed observations of the solar magnetic field and rotation, observing cool stars other than the Sun is also absolutely necessary to provide hints and checks for dynamo theories that could predict not only the magnetic stellar topologies but also the internal distribution of angular momentum and the whole rotation history of low-mass stars. Unfortunately, while it is now becoming possible to determine the properties of magnetic fields of cool active stars through techniques such as Zeeman-Doppler imaging (Donati et al. 1997), it has not been possible up to now to correlate them directly with the parameters which are believed essential for the dynamo process. These parameters, depth and other properties of the CZ, as well as differential rotation at the base of the CZ have been indeed essentially out of reach of our observations.

1.2.2 The diagnostic power of asteroseismology for cool stars

This situation is bound to change very rapidly, thanks to recent space-based asteroseismology missions: the Canadian-led small stellar seismology MOST satellite (Walker et al. 2003), launched in 2003, and the French-led CoRoT mission for stellar seismology and planet search (Baglin et al. 2006), launched in 2006. Both satellites perform a continuous ultra-high precision photometric monitoring of a sample of bright stars, from which stellar oscillations can be detected and measured. These pioneering missions will be followed in 2009 by the US *Kepler* mission (Borucki et al. 1996), which will also include an asteroseismology programme (Christensen-Dalsgaard et al. 2007).

Cool solar-type stars are known to oscillate in a very large number of modes. These oscillations are acoustic p-modes, driven by convection near the base of the CZ. The surface structure of oscillation modes are represented in terms of surface harmonics $Y_{\ell m}$, where ℓ is the degree, and m the azimuthal order. For a spherical star the azimuthal order m is degenerate, the degeneracy being lifted by a non-radial perturbation, *e.g.* rotation. The relation between the oscillation frequencies and the internal properties of the star is reasonably well understood; based on this understanding one can isolate information about particular properties of the star, or regions within it, by suitably combining the frequencies (Roxburgh & Vorontsov 2003).

The power of seismic analysis has been forcefully demonstrated in the solar case, where helioseismology has provided dramatic insight into the properties of the solar interior. Through inversion of extensive sets of frequencies it has been possible to determine the sound speed in most of the Sun, hence testing in detail models of solar structure, in particular the region at the base of the CZ. Analyses of rotational frequency splittings have yielded detailed determinations of the internal angular velocity of the Sun, in particular at the base of the CZ, where strong angular velocity gradients are present in the tachocline.

Although in contrast to helioseismology, seismology of distant stars is restricted to low-degree modes, detailed information about the structure and rotation of stellar interiors can be obtained through the inversion of a restricted set of frequencies, provided the latter are measured with sufficient accuracy. In particular, accurate oscillation frequencies can be used to detect sharp gradients of sound speed in the stellar interior, such as that present at the base of the CZ, hence providing a rather direct measurement of the depth of the CZ. One method to measure it is to construct the so-called second differences of the oscillation frequencies, defined as $\Delta_2\nu_{n,\ell} = \nu_{n-1,\ell} - 2\nu_{n,\ell} + \nu_{n+1,\ell}$. Discontinuities in the sound speed or its derivatives result in an oscillatory behavior of the second differences as a function of frequency, from which the acoustic depth of the discontinuities can be measured. An example of this behavior is shown in Figure 1, showing that the signature of the base of the CZ can be detected and its acoustic depth measured if oscillation frequencies are known with precision of the order of 0.1μHz.

Rotation removes the m degeneracy in the frequencies; the resulting m-dependence of the frequencies permits the determination of the internal angular velocity $\Omega(r)$ inside the star, as a function of r. The measurement of the so-called *rotational splittings*, *i.e.* the difference between frequencies with the same n, ℓ but different m, for different values of n, can be used to infer the internal rotation rate and its variation with radius (Goupil et al. 1996, Lochard et al. 2005). In solar-type stars, rotational splittings depend strongly upon the details of rotation in surface layers and only mildly upon deeper rotation. However, in the solar case, the exquisite knowledge of surface layers gathered from the observation of high degree modes was used in conjunction with the splittings of low-degree modes to derive the rotation rate in deeper regions. Although more difficult in the case of distant stars for which no high-degree mode can be observed, the determination of internal rotation, and in particular the detection of strong rotational gradients inside the star, is still possible, if the surface rotation is accurately known. The very long, high-precision photometric monitoring enabled by the asteroseismology space missions will provide this exquisite knowledge of surface rotation. In this context, Goupil et al. (in preparation) have studied the diagnostic power of rotational splittings of low-degree modes in solar-type stars, and shown that angular rotation shears of 20% at the base of the CZ can be detected for moderate and rapid rotators (Fig. 2).

1.2.3 Coupling asteroseismology and spectropolarimetry to study dynamo

With the advent of asteroseismology, the basic ingredients of dynamo can be inferred in a significant sample of cool stars. The CoRoT target list has a dozen cool stars brighter than $m_V = 7$, observed for up to 5 months, while Kepler will also observe about two dozen cool stars in the $m_V = 8-9$ range, bright enough for our study, for several years. For many of these targets, the expected precision on the oscillation frequencies ($0.1, 0.05\mu$Hz for CoRoT and *Kepler* respectively) will be sufficient to detect the signature of the base of the CZ, *e.g.* in the second differences as presented in the previous section. Moreover, such precisions will be sufficient to detect strong internal rotation gradients if present, in those targets that are rotating sufficiently fast.

In addition to these seismic investigations, the high precision, long duration, continuous photometric monitoring performed by the space-based seismology missions will be used to measure very accurately the surface rotation period and eventually its differential rotation. With CoRoT, providing a continuous monitoring over 5 months, the precision on rotation rates will be of the order of 0.07μHz ($0.006d^{-1}$), while *Kepler*, which will observe its targets continuously for several years, will provide measurements of surface rotation rates to within less than 0.01μHz ($0.0009d^{-1}$). Surface differential rotation will also be measured to high accuracy with such high quality light curves. Ultra-high precision, long-term photometric light curves will be inserted in the Doppler and Zeeman-Doppler image reconstruction algorithms (see below), and will be used to study long term evolution of the active patterns, such as spot lifetimes and migration.

High resolution spectropolarimetric observations represent the second essential element of this investigation, by giving access to the products of dynamo, *i.e.* the topology and intensity of magnetic fields. Using indirect imaging techniques, distributions of brightness and magnetic inhomogeneities in stellar photospheres can be reconstructed. Recent studies (Donati et al. 2006, Petit et al. 2005) have demonstrated that, for cool active stars with moderate to fast rotation, sets of rotationally modulated Zeeman signatures in spectral lines obtained throughout a stellar rotation cycle, can be used to recover, not only the location of magnetic regions at the surface of the star, but also the orientation of field lines within these regions. Recently these techniques have been applied to moderately active solar-type stars with rotation periods of a few days (Catala et al. 2007, Donati et al. 2008, Petit et al. 2008), using ESPaDOnS at CFHT and Narval at TBL, resulting in the detection and characterization of magnetic fields with intensities of just a few Gauss (Fig. 3).

Hence weak magnetic fields of moderately active cool dwarfs can be detected in high resolution spectropolarimetry with an instrument such as ESPaDOnS, and mapped with Zeeman-Doppler imaging techniques. The resulting magnetic maps will then be studied in the light of the measurements of the depth of the CZ and the rotational shear inside the star, as derived from the seismic analysis of the same stars.

In addition, provided the spectropolarimetric observations span several rotation cycles, surface differential rotation can also be derived (Petit et al. 2002) in a way which is independent from the photometric determination using the space-based data. We will therefore obtain a very reliable value for the surface differential rotation, which when coupled to the knowledge of internal rotation gradients derived from rotational splittings of oscillation frequencies, will allow us to characterize completely rotation in these stars and study its coupling with the magnetic field.

It is also conjectured that the stochastic excitation of acoustic modes in stars is strongly affected by the presence of a magnetic field. Numerical simulations show that a magnetic field can inhibit some of the convective flux and modify the topology of granules and plumes. We should therefore see a link between the magnetic field intensity and the oscillation mode amplitudes, which can be verified by spectropolarimetric observations of targets of asteroseismology missions.

Finally, solving for the magnetic configuration of the stars will provide us with a measurement of the inclination angle of the rotation axis with respect to the line of sight, which is a crucial parameter for identifying the observed oscillation modes and interpreting oscillation spectra.

1.3 Hot stars

1.3.1 The specificity of hot stars in terms of pulsations and magnetic fields

Pulsating hot stars ($T_{\rm eff} \geq 7000$ K) do not only host pressure-mode oscillations, like cool stars, but also gravity-mode oscillations. The instability driving mechanism is different in this case: the oscillation modes are excited because some layers in the stars are able to trap the energy radiated outwards by the stellar core in a very efficient way during a small contraction of the star and to release the trapped energy during the subsequent expansion. For this so-called κ-mechanism to work, the pertinent layer has to be situated at a suitable position in the star. Transport processes such as microscopic diffusion (segregation effect of gravitation), meridional circulation and turbulence associated with differential rotation can lead to such accumulation. Such oscillations are observed in roAp, β Cep, SPB and Be stars. Therefore these classes of pulsating hot stars are among the targets of the MOST, CoRoT and Kepler satellites.

The magnetic fields of these pulsating hot stars are also qualitatively different from those of cool stars. In particular, they are more stable and organized (often dipolar). Moreover, hot stars only have a very thin CZ and can therefore not maintain a dynamo as the one of cool stars. A dynamo could exist in the convective core, however no transport process is known to transport such a field fast enough to the surface so that it can be observed at the stages where we observe them. A dynamo produced in the radiative zone (e.g. by shear instabilities) could also be considered, however the mechanisms explored until now do not reproduce the observed fields. As of today the best theory, which would also explain the different magnetic characteristics compared to cool stars, is thus that the observed fields are probably fossil, i.e. relics of the field present in the cloud from which the star was formed. This hypothesis tends to be confirmed by the existence of fields similar to those of hot stars in pre-main sequence higher-mass stars. Nevertheless, some facts remain unexplained by the fossil field theory, e.g. binary stars with one magnetic and one non-magnetic hot component. While the magnetic fields of roAp stars can be strong (up to tens of kG), the magnetic fields detected up to now in a few pulsating hot stars (β Cep, SPB and Be stars) are much weaker (a few hundred G, see e.g. Neiner et al. 2003a,b,c).

It is likely that the coupling of magnetic field with pulsations is essential in the physics of the atmospheres of hot stars, and may explain some of the characteristics of these stars, such as e.g. the so-called 'Be phenomenon'. In particular the interplay of the thermal and magnetic instabilities in the transport of chemical elements is very important (Maeder & Meynet 2005). This makes magnetic pulsating hot stars prime targets to constrain models of massive stellar interior. Indeed the additional knowledge of the magnetic parameters provides strong limits on the evolutionary stage and transport processes in those stars and thus allows a better interpretation of asteroseimic data.

1.3.2 Coupling asteroseismology and spectropolarimetry to study the internal physics of hot stars

As for cool stars, observations performed with MOST, CoRoT and *Kepler* will provide exquisite knowledge of the internal structure of hot stars. The simultaneous presence of both p-modes and g-modes in some of these stars will enable us to probe different layers.

The way magnetic fields interact with pulsations in hot stars is not well understood yet. Several effects of magnetic fields on pulsations are however already known and observed: in the same way as rotation removes the m degeneracy, magnetic fields break the spherical symmetry of the system and change the observed pulsation pattern, a phenomenon known as *magnetic splitting.* The presence of a magnetic field shifts pulsation frequencies and causes new frequencies to appear. Moreover, pulsations are damped due to the generation of magnetic slow waves (Saio & Gautschy 2004). The effect of a magnetic field on the intermediate-to-high-order p-modes is not monotonic but cyclic with respect to the pulsation frequency and the magnetic field strength. The diminished magnetic damping is favourable for the corresponding modes, if they are excited by the classical κ-mechanism, to survive even in the presence of a strong magnetic field. For a low-order p-mode, the damping rate increases as the strength of the magnetic field increases. In the presence of a magnetic field of a few kG, magnetic damping could exceed the driving owing to the κ-mechanism of oscillations. There is also an influence of the magnetic distortion of the eigenfunction on the pulsation amplitude modulation with respect to the rotation phase.

Moreover, if the magnetic effects on the pulsation dominate over the effects due to the Coriolis force, the symmetry axis of the eigenfunctions is the magnetic axis rather than the rotation axis. However, if rotation dominates (e.g. for Be stars which rotate very rapidly), the symmetry axis is the rotation axis. Solving for the magnetic field configuration will provide us with precious information on stellar rotation and geometrical configuration, which in the case of hot stars may be inaccessible even to CoRoT. Rotation periods will be derived from the rotational modulation of the circular polarisation signal, and the inclination angle between the rotation axis and the line of sight, as well as the angle between magnetic and rotation axis, will be determined in the Zeeman-Doppler reconstruction process. These determinations will be of great importance in the exploitation of the asteroseismology data, since they will greatly reduce the number of free parameters for modelling the pulsation signal.

1.4 Connection to other large program proposals

The present proposal is connected to the MiMS LP proposal (Magnetism in Massive Stars, PI: G. Wade). Both proposals include a component on the study of the relationship between magnetic fields and pulsations in massive stars. Although aimed at similar long term science objectives, both proposals are complementary in terms of observing strategy. While the MiMS proposal's approach concentrates on a few, already well studied, hot pulsating stars, as part of a much broader investigation of magnetism in massive stars, the goal of the present proposal is to organize a systematic magnetic survey of hot pulsating stars for which we expect a very complete seismic analysis from space-based data. We emphasize that both approaches to the coupling of magnetic fields with pulsations in these stars are necessary.

References and figures (2p)

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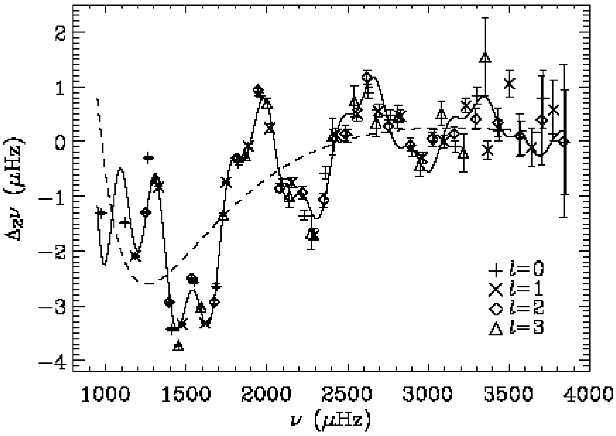

Figure 1: Second differences constructed from solar low-degree modes, as observed by GOLF (Ballot et al. 2004). Two different oscillatory components can be seen. The large amplitude, long period one is due to the He II ionization zone, while the smaller amplitude, shorter period oscillation originates from the base of the convective zone. The period of this signal measures the acoustic depth of the CZ. Similar quality data are expected from oscillation spectra obtained with CoRoT. Figure from Houdek & Gough 2007.

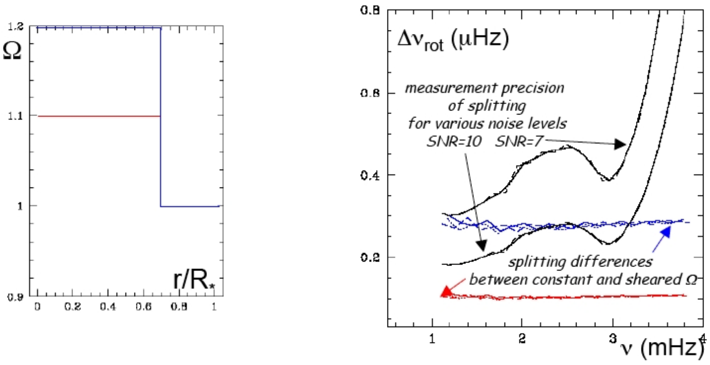

Figure 2: Detection of rotation rate gradients at the base of the CZ of solar-type stars. Left panel: assumed normalized rotation profiles. All models assume a surface rotation of 3 days. Right panel: In blue and red, resulting differences in rotational splittings between solid rotation and assumed rotation profiles. In black, expected precision in the measurement of rotational splittings for signal-to-noise ratios of 7 and 10 in oscillation amplitude spectra. This figure shows that strong internal rotation gradients (blue curves) can be detected in high quality oscillation spectra. From Goupil et al. 2008 (in preparation)

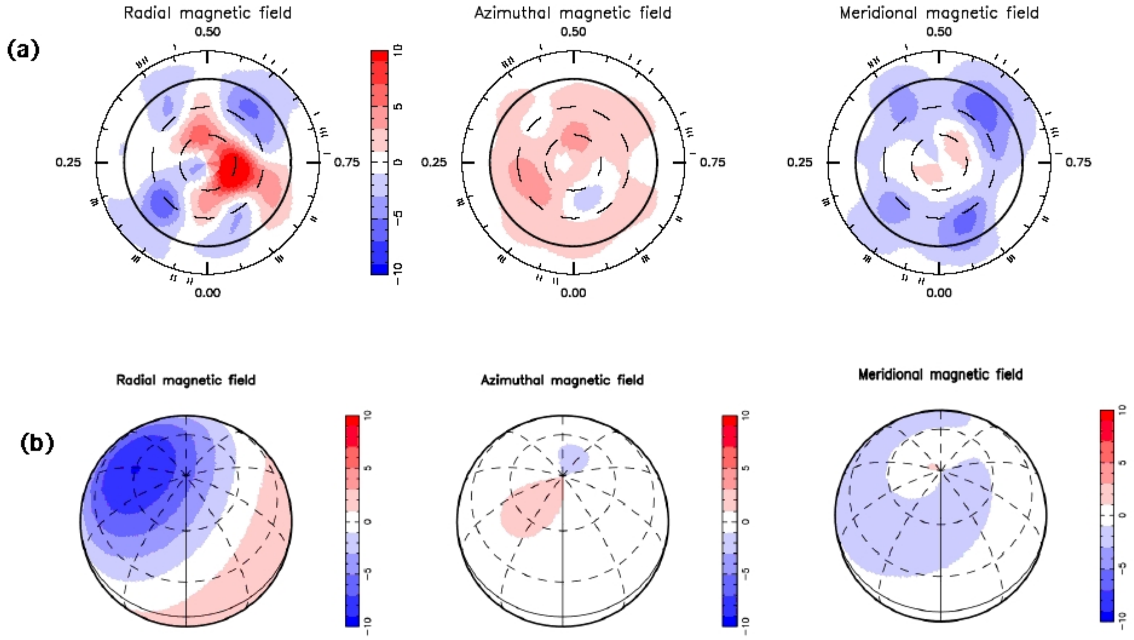

Figure 3: Magnetic images derived from Zeeman-Doppler imaging techniques on moderately active solar-type stars. (a) the F5V star τ Boo, observed with ESPaDOnS (exposure time = 4 × 200 sec), showing a complex magnetic field topology with intensities of 4–6 G (from Donati et al. 2008); (b) the solar-twin HD 76151, observed with Narval at TBL (exposure times = 4 × 800 sec), showing a global field with intensities of a few Gauss (from Petit et al. 2008).

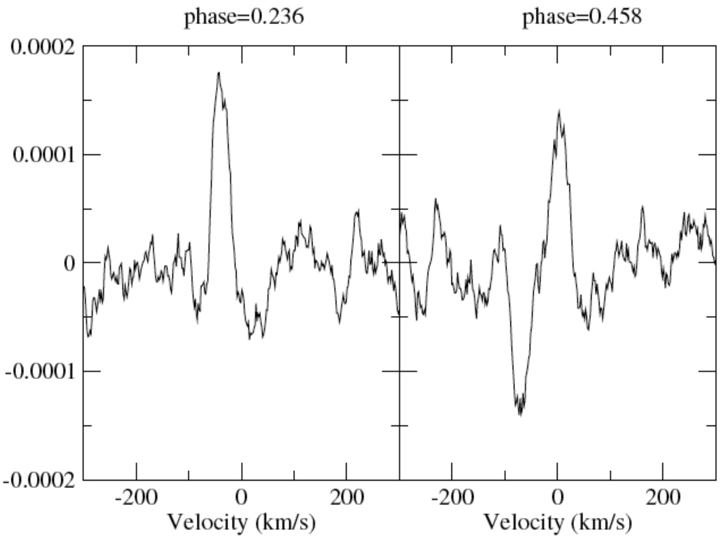

Figure 4: The signature in Stokes V of a magnetic field in the β Cep star V2052 Oph (m_V=5.8), observed with Narval in July 2007 (exposure time = 4 × 420 sec). The spectra from which these LSD mean profiles were derived have a S/N ratio of 1600 per 2.6 kms^{-1} (from Neiner et al. 2008, in preparation).

2 Technical justification (3p)

2.1 Observing strategy: survey phase and monitoring phase

As a first step, we propose to obtain a high S/N spectrum in Stokes I and V of each cool dwarf and hot star observed or to be observed by MOST and CoRoT. These data will be used to detect magnetic fields at the surface of these stars. Later on, when the final target list of the asteroseismology program of *Kepler* is definitely known, we will add to our targets cool dwarfs and hot stars from the *Kepler* list with magnitudes below $m_V = 9$ and $v\sin i$ above 7 kms^{-1}, for which the chances of detecting Zeeman signatures in Stokes V in a reasonable time are high. This first step will be called "survey phase". We will use the longitudinal Zeeman effect in the numerous metal lines of cool stars, and metal + helium lines in hot stars, to detect and measure magnetic fields. The detection threshold will be defined using the criterion described by Donati et al. (1992), with a false alarm probability of 10^{-3} (resp. 10^{-5}) for marginal (resp. definite) detection.

In a second step, the "monitoring phase", targets with a detected magnetic field, presumably $\approx 10\%$ of the surveyed stars, will be re-observed in an optimized monitoring scheme, providing high quality spectra at at least 10 rotational phases, in order to reconstruct magnetic images. For both cool and hot stars, the high precision light curves obtained with the asteroseismology satellites will provide accurate measurements of the rotation period, so that this monitoring phase can be optimally planned. The resulting spectropolarimetric time series will then be inverted using the Zeeman-Doppler imaging code of Donati et al. (2006).

We do not require simultaneity between ESPaDOnS and space-based observations, although it would represent a bonus. Note however that MOST has a "target of opportunity" policy that would allow us to schedule observations at the time of ground-based monitoring, and that *Kepler* will monitor some of its seismology targets continuously for several years, so that simultaneity will be automatically ensured.

2.2 Needed exposure times, target list and observation plan

The detection and characterization of weak magnetic fields in cool dwarfs and hot stars require high resolution spectropolarimetry at very high S/N ratios, as well as the construction of ultra-high S/N mean photospheric line profiles using the Least-Square Deconvolution (LSD) technique (see Sect. 3.1). Recent observations of magnetic fields of a few Gauss in cool stars with slow to moderate projected rotation velocities, such as τ Boo (Catala et al. 2007), indicate that peak S/N ratios of the order of 1500 - 2000 per velocity bin of 2.6 kms^{-1} are needed. This requires exposure times of about 2400 sec (=4×600 sec) at m_V=6, based on our extensive experience of ESPaDOnS and on the on-line exposure time calculator.

For hot pulsating stars, we expect fields of the order of a few hundred Gauss, such as observed in the SPB ζ Cas (Neiner et al. 2003), or the β Cep V2052 Oph (Fig. 4). For these stars, most of which are fast rotators, and whose photospheric spectra contain only a few dozen lines, S/N ratios of at least 1300 per 2.6 kms^{-1} are necessary to detect such fields, which requires 1200 sec (=4×300 sec) at m_V=6. The stronger magnetic fields of roAp stars can be studied with S/N ratios of about 700 per 2.6 kms^{-1}.

The resulting total exposure times for magnetic field detection are indicated in the last column of Table 1, using the above reference numbers.

We have selected all suitable targets from the space mission input catalogues. From all three input catalogues, we selected stars brighter than m_V=9, in order to keep the needed exposure times within reasonable limits. For cool stars, we down-selected only targets with $v\sin i \geq 7$ kms^{-1}, so that to obtain at least three resolution elements across the photospheric line profile.

The observation plan of MOST is known, so that the MOST list of targets is considered frozen. That of CoRoT is known at least up to spring 2009, hence our first CoRoT target list, corresponding to stars observed with CoRoT from early 2007 to spring 2009 (*i.e.* about half the mission) is also frozen. Observations in years 2009+ will be planned later, and the target lists will have to be revised accordingly. Provision for this second sample is made in Table 1. The asteroseismology targets of *Kepler* have not been chosen yet. When ready, we will select from this list stars complying with the above critera. The target list given in Table

1, extracted from a preliminary proposal of seismic targets to the *Kepler* science team, is just given as an example, and will be subject to revision after the target list is confirmed in late 2008.

Before *Kepler* starts science operations, presumably in the summer 2009, we will focus on MOST and CoRoT targets only, which are less demanding. The first 3 semesters of this programme will therefore require modest allocations of time. The allocation will have to ramp up as soon as we are able to include *Kepler* targets in the programme.

Whenever possible, we will expose the stars for the total time indicated in Table 1, in series of Stokes V sequences of 4 sub-exposures each. The sub-exposures will be kept below 15 minutes in order to avoid severe perturbations by cosmic rays, and the required total integration time will be obtained by simply adding up as many individual sequences as necessary. However, for magnetic field detection, we will not rely on adding up spectra taken on different nights, which means that the needed total integration time must be accumulated within a single night. Moreover, for hot pulsating stars, the integration time is also limited by the pulsation period of the star, typically the total exposure time of one serie should not exceed 1/20th of the pulsation period. The observation of the faintest targets, requiring more than 6 hours, will therefore need to be scheduled optimally so that the stars are visible for the longest time possible during the night. The stars requiring in principle more than 6 hours to reach the needed S/N ratio will be integrated for the longest time possible, i.e. up to 8 hours, leading to a slightly degraded, but still acceptable, performance compared to brighter targets.

Adding up the integration times in Table 1 and extrapolating to further years, we come up to a total time of about 240 hours for the survey phase. Since we expect about 10% of our targets to have detectable magnetic fields, for which we will need to cover 10 rotational phases each, the cost of the subsequent monitoring phase will be equivalent, leading us to a grand total of 480 hours for the whole programme.

2.3 Need for CFHT and ESPaDOnS

This programme requires high resolution, ultra-high S/N spectropolarimetry for both cool dwarfs and hot stars. ESPaDOnS at CFHT and Narval at TBL are the only instruments in the world capable of carrying out the required observations. However, most of our targets would require integrations of more than 7 hours on Narval to reach the required S/N ratios, which cannot be accumulated in a single night. We would then have to spread the integration on several consecutive nights, during which the magnetic configuration with respect to the line of sight is very likely to vary, jeopardizing the measurement process. Therefore, ESPaDOnS on the 3.60m CFHT remains the only instrument in the world capable of carrying out this programme. Nevertheless, the brightest among our targets will be observed with Narval at TBL as well, as a complement to this large programme.

2.4 Expertise of the team

Our team gathers all necessary expertise for this work. First it includes specialists of the analysis of spectropolarimetric data, in particular at LATT (Donati, Petit), and at LESIA (Catala). We also have a strong expertise in all aspects of stellar magnetic fields and stellar activity (LATT, LESIA, Exeter, Vienna, GEPI groups). These groups have all necessary tools and skills to analyze spectropolarimetric observations as delivered by ESPaDOnS, compute the mean photospheric profiles using LSD, and invert series of observations into Zeeman-Doppler images in brightness and magnetic field.

Our team also includes the PIs and many co-Is of MOST (UBC and Vienna groups) and CoRoT (LESIA and GEPI groups), as well as the leaders of the *Kepler* asteroseismology programme (Aarhus group). The LESIA, UBC and Vienna groups have a deep expertise in seismology and modelling of both cool and hot stars, while the GEPI group is specialized in the observation and analysis of hot star pulsations. The Danish group's experience in seismology and modelling of cool stars is also well known. These groups possess all necessary experience and tools to invert observed sets of oscillation frequencies as delivered by the space missions, and derive the stars internal structure and internal rotation.

star	α (2000)	δ (2000)	m_V	spectral type	$v\sin i$ kms^{-1}	mission	comment	int. time (hr)
MOST								
HD 261938	06 41 01.9	+09 52 48	8.9	B6V		MOST	SPB	4.8
HD 165783	18 08 27.1	-19 52 08	8.3	B4IIIe		MOST	Be	2.8
HD 165918	18 09 04.6	-19 52 31	8.2	B5IV/V		MOST	SPB	2.6
HD 165892	18 09 04.8	-21 24 25	9.1	B2II		MOST		5.8
HD 165971	18 09 24.2	-21 30 33	9.0	B5Ib		MOST		5.2
HD 165998	18 09 30.8	-21 34 21	8.5	B9Ib		MOST		3.4
HD 166167	18 10 14.1	-21 19 38	8.6	B9.5Iab/Ib		MOST		3.7
HD 166291	18 10 38.2	-19 10 01	8.9	B3II		MOST		4.8
HD 166293	18 10 47.1	-21 18 41	8.3	B3/B4III		MOST	SPB	2.8
HD 9289	01 31 16.5	-11 07 08	9.4	A3		MOST	roAp	2.7
HD 99563	11 27 16.6	-08 52 08	8.2	F0		MOST	roAp	0.9
HD 213637	22 33 12.3	-20 02 22	9.6	A		MOST	roAp	3.2
subtotal MOST								43
CoRoT: targets observed 2007 thru spring 2009								
HD 49933	06 50 49.8	-00 32 27	5.7	F5V	9.4	CoRoT	note 1	6
HD 49385	06 48 11.5	+00 18 18	7.4	G0	7.5	CoRoT		2.4
HD 175272	18 54 30.6	+01 53 51	7.4	F5V	23.6	CoRoT		2.4
HD 175726	18 56 37.2	+04 15 54	6.7	G5	13.5	CoRoT		1.3
HD 181420	19 20 27.1	-01 18 35	6.6	F2	21.0	CoRoT		1.2
HD 181906	19 22 21.3	+00 22 59	7.6	F8	18.2	CoRoT		2.9
HD52265	07 00 18.0	-05 22 02	6.3	GOIII-IV	7.0	CoRoT		1.0
HD 50209	06 52 10.4	-00 17 44	8.4	B9Ve	200	CoRoT	Be	3.0
HD 49330	06 47 57.3	+00 46 34	8.9	B0e	270	CoRoT	Be	4.8
HD 180642	19 17 10.4	+01 03 33	8.3	B1.5III		CoRoT	β Cep	2.8
HD 181231	19 19 42.4	-00 02 59	8.5	B9e	250	CoRoT	Be	3.4
HD 175869	18 57 16.6	+02 32 07	5.6	B9IIIe	167	CoRoT	Be; Narval	0.25
HD 51452	06 57 20.6	-04 11 37	8.1	B0IIIe	298	CoRoT	Be	2.4
HD 51193	06 56 19.1	-03 48 26	8.1	B1V	215	CoRoT	Be	2.4
HD 50891	06 54 58.8	-03 42 01	8.9	B0e	220	CoRoT	Be	4.8
subtotal CoRoT targets observed 2007 thru spring 2009								41
subtotal CoRoT further observations								50
Kepler								
HD 187055	19 45 30.3	+50 46 22	8.2	K0V		Kepler		5.1
V1154 Cyg	19 48 15.5	+43 07 37	8.4	G2	12.3	Kepler	Cepheid	6.1
HD 225327	19 40 03.9	+40 52 02	8.5	K2		Kepler		6.7
BD+42 3421	19 41 08.4	+42 54 59	8.5	K2		Kepler		6.7
BD+49 3113	19 49 11.1	+49 54 01	8.6	K2		Kepler		7.3
HD 177858	19 04 43.4	+38 53 54	8.7	K0		Kepler		8.1
BD+42 3320	19 22 36.3	+42 26 11	8.7	G5		Kepler		8.1
BD+40 3668	19 19 18.7	+40 36 08	8.8	K5		Kepler		8.8
BD+37 3463	19 27 24.5	+38 09 20	8.8	F5		Kepler		8.8
BD+38 3661	19 34 46.9	+38 58 54	8.9	F5		Kepler		9.6
HD 177723	19 03 45.1	+45 36 30	8.9	F5		Kepler		9.6
HD 190254	20 02 13.4	+44 26 47	8.7	B2III		Kepler		4.0
HD 187035	19 45 52.1	+44 55 07	8.8	B5V		Kepler		4.4
HD 183558	19 27 49.4	+48 10 36	8.3	B5		Kepler		2.8
HD 184939	19 35 07.8	+40 01 29	8.9	B6V		Kepler		4.8
HD 182550	19 23 37.0	+38 59 36	8.6	B8V		Kepler		3.6
HD 187139	19 46 36.6	+43 45 48	8.2	B2III		Kepler		2.6
HD 183416	19 27 41.3	+41 39 14	8.7	B8Vn		Kepler		4.0
subtotal Kepler								111

Table 1: The target list. Notes: (1) already observed with ESPaDOnS and Narval - no detection at the 5G limit. Need 6 hrs (6× longer than previous observations) to lower detection threshold

3 Observing strategy (1p)

The distribution of time proposed below optimally complies with the requirements of having a survey phase followed by a monitoring one. The pressure of this proposal on 'A' semesters is higher because of the position of the *Kepler* field. If necessary some pressure on 'B' semesters, starting at semester '09B', can be redistributed to later semesters.

Semesters 08B - 09B: survey phase only

08B RA	hours
00-04	2.7
04-08	31.6
08-12	0
12-16	0
16-20	0
20-24	3.2

09A RA	hours
00-04	0
04-08	0
08-12	0.9
12-16	0
16-20	42
20-24	0

09B RA	hours
00-04	0
04-08	60
08-12	0
12-16	0
16-20	0
20-24	0

Semesters 10A - 10B: survey phase + monitoring phase

10A RA	hours
00-04	0
04-08	0
08-12	0
12-16	0
16-20	100
20-24	0

10B RA	hours
00-04	0
04-08	25
08-12	0
12-16	0
16-20	0
20-24	0

Semesters 11A - 12B: monitoring phase only

11A RA	hours
00-04	0
04-08	0
08-12	0
12-16	0
16-20	101
20-24	0

11B RA	hours
00-04	0
04-08	0
08-12	0
12-16	0
16-20	0
20-24	0

12A RA	hours
00-04	0
04-08	0
08-12	0
12-16	0
16-20	120
20-24	0

12B RA	hours
00-04	0
04-08	0
08-12	0
12-16	0
16-20	0
20-24	0

4 Data management plan (1p)

4.1 Data reduction and processing

We will use the standard Libre-Esprit software to produce calibrated spectra of I and V Stokes parameters. For cool stars, we will also rely on Libre-Esprit to normalize the spectra, while a specific normalization procedure will be applied to hot stars, whose emission lines make automatic normalization difficult.

We will construct ultra-high S/N mean photospheric line profiles in both I and V Stokes parameters, using the LSD (Donati et al. 1997) technique, which builds the mean photospheric line profile by deconvolving the observed spectrum (both in I and V) from a line mask including all lines present in a synthetic spectrum of the star. For cool stars, we will use a set of already available masks computed using Kurucz Atlas 9 models on a grid of effective temperatures, surface gravities and metallicities. For hot stars, a custom mask, computed using non-LTE atmospheric models and synthetic spectra, will be produced for each star, eliminating from the list the lines appearing in emission in the observed spectrum.

4.2 Real-time analysis requirements

The data of the "survey" will be analyzed shortly after the observations have been secured on year y, then the stars with a magnetic detection will be added to the target list of the "monitoring" phase, to be observed on year $y+1$ in an optimized way based of the rotation period measured from the satellite-based photometry.

4.3 Data analysis plan

During the "survey" phase, the LSD algorithm will be run with the appropriate line mask to decide whether a magnetic field is detected or not. Expertise and tools for doing so (the LSD code and mask grid) are available in our groups. The spectra of the survey phase will also be analyzed to derive relevant stellar fundamental parameters, such as $v\sin i$, T_{eff}, $\log\, g$, M_{bol}. For fundamental parameter determination, we plan to rely on the MagIcS Legacy Database (see below), but will also lean on the expertise in several of our groups (LESIA, GEPI, LAM, Vienna), accumulated in the preparation of CoRoT, and for which the necessary tools, both for cool and hot stars are available (model atmospheres, synthetic spectra, both LTE and nonLTE). The magnetic field detections and preliminary measurements, as well as the derived fundamental parameters of all observed targets, will be published on the basis of the "survey" phase observations.

During the subsequent "monitoring" phase, Zeeman-Doppler images of the field topology/intensity and of surface brightness and abundance inhomogeneities will be constructed using inversion codes, based *e.g.* on maximum entropy regularization schemes, as described in Donati et al. (2006). All necessary tools exist in our team to apply this technique, in particular at LATT for cool and hot stars, but also at GEPI or Vienna for hot stars. These results will then be used in conjunction with the asteroseismological inversions mentioned earlier to reach the final scientific objectives of this programme.

4.4 Data management

Once fully reduced, all spectropolarimetric data will be implemented in the publicly accessible MagIcS Legacy Database, and post-processed for a homogeneous determination of the basic properties of the observed stars, including effective temperature, surface gravity, mass, radius, age, variability characteristics, projected rotational velocity, radial velocity and binarity, as well as mass loss rate in the case of hot stars.

Stellar fundamental parameters derived from our spectra will be communicated to the science teams of the asteroseismology space missions. In the case of CoRoT, these parameters will be fed into the CoRoTSky database, which includes all ancillary data relevant to the analysis of the CoRoT lightcurves, and which is interoperated with the final CoRoT database. A similar database is being prepared by the *Kepler Asteroseismic Science Operations Centre* (KASOC), to which we will submit the measured parameters of the *Kepler* targets.