CFHT [2013A - 2016B] Large Programs

Title

**BinaMlcS: Binarity and Magnetic Interactions in various classes of Stars**

Abstract

Magnetic fields are a crucial ingredient in a star’s evolution, influencing its formation, the structure of its atmosphere and interior, as well as controlling the interaction with its environment. For binary stars magnetism is even more significant, as magnetic fields in binary systems will be strongly affected by, and may also strongly affect, the transfer of energy, mass and angular momentum between the components in these important stellar systems. However, the interplay between stellar magnetic fields and binarity has yet to be investigated in any real detail, from either an observational or theoretical point-of-view. Nevertheless, the incidence and characteristics of magnetic fields are key parameters for understanding the physics of binaries. In higher-mass stars (above 1.5 \( M_\odot \)) the incidence of magnetic stars in binary systems provides a basic constraint on the detailed origin of the magnetic field, assumed to be fossil remnant, and whether such strong magnetic fields suppress binary formation. In low-mass stars, tidal interactions are expected to induce large-scale 3D shear and/or helical flows in stellar interiors that can significantly perturb the stellar dynamo. Similar flows may also influence the fossil magnetic fields of higher-mass stars. Magnetically driven winds/outflows in cool and hot close binary systems have long been suspected to be responsible for their orbital evolution, while magnetospheric interactions have been proposed to enhance stellar activity. However, the crucial observational constraints required to test these hypotheses are, at present, nearly nonexistent. The BinaMlcS project represents an innovative large program with ESPaDOnS to study the complex phenomenon of stellar magnetism under the influence of the unique physical processes and interactions occurring in close binary systems. Using cutting-edge observations, sophisticated theory and realistic simulations, we will observe and model the magnetic fields and the magnetospheric structure and coupling, of both components of hot and cool close binary systems over a significant range of evolutionary stages. Our results will confront current theories and trigger new ones, with the aim of qualitatively improving our understanding of the complex interplay between stellar magnetism and binarity.

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I. **Scientific Justification**

1. **Introduction**

**Stellar binary systems:** Binary systems represent powerful astrophysical laboratories that provide us with direct measurements of fundamental stellar parameters, such as masses and radii, contrary to single stars that require stellar evolutionary models to estimate these important quantities. Due to their unique physical configurations, many binary systems display novel physical processes, including direct and indirect interactions between their stellar components, through tidal deformation, mutual heating, wind-wind collisions, and magnetospheric coupling. As binary stars represent about one-half of the overall population of main sequence (MS) stars (e.g. Abt et al. 1983, Duquennoy & Mayor 1991, Sana & Evans 2011), understanding the dynamics and physical properties of binary stellar systems will have a broad impact on our knowledge of the majority of stars populating our Universe.

Binary systems are particularly useful systems for investigating the origin and impact of stellar magnetic fields. Cool stars with spectral types GKM in binary systems are spun up during the process of rotation synchronisation, leading to enhanced dynamo activity. Binary systems containing cool stars therefore provide unique probes of dynamo and magnetospheric physics. Hotter A and late B-type stars with fossil magnetic fields are anomalously rare in binary systems (e.g. Abt & Snowden 1973, Carrier et al. 2002), suggesting an important connection with their formation or magnetic field evolution. The small numbers and relative novelty of massive magnetic B and O-type stars means that no serious investigation of their binary properties has ever been undertaken. This is unfortunate as, based on models, such stars are likely to reveal a variety of intense, unique radiation and wind interactions. Therefore massive magnetic stars in binary systems represent a significant unexplored parameter space with the potential for rich new discoveries.

We consider in this proposal *close* binary systems, i.e. systems in which the components experience a significant mutual interaction via various processes, such as tidal interaction, winds, radiation and mass transfer. As will be developed in the following sections, such interactions are expected to have an important impact on the internal structure and magnetic fields of the stars, as well as modifying the evolution of members of binary systems with respect to single stars. Close binary systems are therefore optimal laboratories to better understand the physical processes controlling the structure, evolution and magnetism of stars.

**The origin of stellar magnetic fields:** The magnetic fields of cool stars are generated by an MHD dynamo operating in their convective envelope, which converts kinetic energy from rotation and convective motions into magnetic energy. These dynamo-generated magnetic fields display a number of specific properties: they are ubiquitous among cool stars, they evolve in time (sometimes in a cyclical manner), they power diverse activity phenomena that are observed across the electromagnetic spectrum and over a wide range of timescales, and their field characteristics (intensity, topology, variability) are strongly correlated with stellar parameters (in particular mass and rotation). At higher mass (above 1.5 $M_{\odot}$), magnetic fields are only observed in a small (~10%) fraction of stars, are highly stable, strong and simply structured. Unlike cool stars, the interiors of hot, higher-mass stars are mainly radiative with a convective core, and can be totally radiative when evolving on the pre-MS. These basic differences strongly indicate a different origin of the fields in higher-mass stars, compared to those in low-mass stars. The favoured hypothesis is that the hot stars fields are fossils, i.e. the remnants of Galactic interstellar magnetic fields, or remnants of fields generated during stellar formation (e.g. Mestel 1999, Moss 2001, Braithwaite & Nordlund 2006).

**Magnetic fields of hot higher-mass single stars:** It has been known for decades that a sub-class of chemically peculiar (CP) stars, the Ap/Bp stars, are magnetic with properties described above. Aurière et al. (2007) have shown that all A/B stars showing Ap/Bp peculiarities are magnetic, and vice-versa. They also concluded that among intermediate-mass A/B stars (between 1.5 and 8 $M_{\odot}$), there is a “threshold” magnetic field of about 300 G below which fields are very rare, and perhaps altogether absent. The commissioning of the second generation of high-resolution spectropolarimeters (ESPaDOnS at the CFHT and Narval at the Télescope Bernard Lyot) has allowed rapid progress in this field. In particular, it has been shown that fields between about 1 and 300 G indeed seem to be absent. On the other hand, recently fields of order 1 G have been detected in a small number of chemically normal A/B stars (Lignières et al. 2009, Petit et al. 2011). It therefore appears that a *dichotomy* of field strengths is present among intermediate-mass stars: very weakly magnetic normal stars and strongly magnetic Ap/Bp stars.

Thanks to the high efficiency of ESPaDOnS, magnetic fields have also been detected in the evolutionary progenitors of A/B stars: Herbig Ae/Be stars. These stars are pre-MS objects, still contracting towards the MS. Their magnetic fields have properties similar to those of MS Ap/Bp stars, making them the probable progenitors of Ap/Bp stars. This results in a strong argument in favour of the fossil field hypothesis (e.g. Alecian et al. 2009).

Recently, the MiMeS (Magnetism in Massive Stars) project, by performing a large spectropolarimetric survey of about 400 massive OB stars, has shown that – similar to intermediate-mass A/B stars – a fraction of massive OB stars are also magnetic. Some show photospheric chemical peculiarities as well as significant
interactions between their winds and the magnetic field, leading to a confined magnetosphere that is more or less dynamically active, depending on the magnetic field strength, the wind energy and the rotation period of the stars (e.g. Townsend et al. 2005, Petit et al. 2011, Grunhut et al. 2012).

**Magnetic fields of cool single stars:** Partly convective cool stars possess an internal structure similar to that of the Sun, i.e. an inner radiative zone and an outer convective envelope supposedly separated by a shear layer, the so-called tachocline. Hence, it is generally assumed that their magnetic fields – as revealed by chromospheric activity, X-ray emission or direct measurements – are generated by a solar-like dynamo. Theoretical studies have stressed the crucial role that the tachocline plays in the solar dynamo, being the place where large-scale toroidal fields can be stored and strongly amplified (e.g. Charbonneau & MacGregor 1997). With the advent of ESPaDOnS and Narval, a systematic study of partly convective stars spanning a wide range of parameters (in particular mass and rotation) has become possible. These studies have, in particular, revealed the progressive transition from a mainly poloidal topology at slow rotation to a topology dominated by a large-scale toroidal component for fast rotators (Petit et al. 2008). They have also allowed the direct detection of N-S magnetic polarity reversals and stellar cycles (Fares et al. 2009, Morgenthaler et al. 2011).

MS stars less massive than ~0.35 M⊙ (e.g. Chabrier & Baraffe 1997) as well as some pre-MS low-mass stars (T Tauri stars) are fully convective and therefore do not possess a tachocline. If the tachocline is indeed an essential part of the solar dynamo, magnetic field generation in these fully convective objects must rely on different physical processes. The first spectropolarimetric survey of M dwarfs located on both sides of the fully-convective threshold, carried out with ESPaDOnS and Narval, has revealed the existence of a rapid change in stellar magnetic properties close to the fully-convective boundary (Morin et al. 2008). In parallel, the MaPP (Magnetic Prostostars and Planets) LP has focused on T Tauri stars and revealed a dependence of the large-scale magnetic topology on stellar internal structure, similar to that observed on the MS (e.g. Donati et al. 2011).

Spectropolarimetric studies of the magnetic topologies of cool stars have greatly contributed to our improved understanding of the dynamo action in single cool stars during the past few years, by contradicting previous conceptions (e.g. turbulent dynamos in fully-convective stars, Dorch & Ludwig 2002), by triggering new theoretical developments (e.g. Brun 2011, Morin et al. 2011) and by promoting the emergence of a global picture of magnetism in cool stars (Donati & Landstreet 2009). In addition, recent surveys, such as the Herbig Ae/Be study (Alecian et al., submitted) and MiMeS project, have led to a considerably improved knowledge of the magnetic properties of higher-mass single stars, as well as their magnetospheres (Grunhut et al. 2009, Oksala et al. 2010, Petit et al. 2011, Wade et al. 2011, ud-Doula et al. 2009). In the same time, new related theoretical studies of fossil fields have been achieved (e.g. Braithwaite 2008, Duez & Mathis 2010, Duez, Braithwaite & Mathis 2010). With these results at hand, we can now make the next important and innovative step: study the interplay between binarity and magnetism during stellar formation and evolution. This will provide new crucial information to further constrain theories and trigger new ones.

2. **Scientific problematic**

1. **What is the impact of magnetic fields during stellar formation, and vice-versa?**

Massive intermediate-mass and low-mass stars are believed to form in the same way, i.e. through accretion from a massive disk onto a low-mass protostar. High- and low-mass stars are therefore assumed to share a similar history (e.g. Palla & Stahler 1993). The fossil field hypothesis assumes that magnetic flux from the interstellar medium (ISM) has been swept up during star formation to form slowly-decaying large-scale magnetic fields, as observed in high-mass stars, or that magnetic fields have been generated during convective phases of star formation (Browning 2008). The resulting fields are expected to be stored inside the radiative zones of all newborn stars, whatever their mass, and to evolve with the star at almost constant flux, and are likely to be destroyed by dynamo action into the convective layers. One possible test of this theoretical picture is to measure directly the magnetic fields in stellar radiative zones using the Zeeman effect. As this method probes only fields in the photospheric layers of the star, only those stars with radiative envelopes, i.e. higher-mass stars, can teach us about the magnetic history of stellar formation at all mass.

The previous survey of magnetism in Herbig Ae/Be stars has demonstrated that a fossil link exists between pre-MS and MS higher-mass stars, which supports the fossil field hypothesis. Nonetheless, this and other recent investigations of the magnetic fields in higher-mass stars have led to the detection of fields in only a small fraction of them. This is difficult to reconcile with the fossil hypothesis, which naively suggests that all such stars should display magnetic field at their surface. The same investigations have found that magnetic fields, if detected in binary systems, are only present in the primary component. However, these investigations have often shown that if a similar magnetic field was present in the secondary it would not have been detected due to a combination of higher vsini, lower luminosity, or low S/N of the data. Furthermore, these investigations include a number of binaries that is too small (<20 targets in the MiMeS sample) to derive any serious conclusions. For these reasons we cannot rule out an observational bias. In other words, the question of the presence of a
magnetic field in only one of the components of a binary system is still an open issue. Recent modeling of molecular cloud contraction including a magnetic field has shown that strong magnetic fields tend to suppress fragmentation (Hennebelle et al. 2011), reducing the fraction of magnetic high-mass binaries. However, of 5 magnetic stars detected in the Herbig Ae/Be survey, 3 are members of binary systems (Alecian et al., submitted). It is therefore unclear what the role of magnetic field on stellar formation, and vice versa.

In this large program we propose to investigate these issues in a profound new way in order to evaluate the following scenarios. By obtaining sensitive magnetic measurements of both components of double-lined spectroscopic binaries, we will determine if: (i) only one component of all close magnetic binary systems is magnetic, possibly suggesting that binarity plays a role in the absence of magnetic field in the secondary, (ii) both components of all close magnetic binary systems are magnetic, which would support the fossil field hypothesis, and imply that the initial conditions of stellar formation (such as location within star forming regions, or metalliclicity) are important parameters in determining future magnetic characteristics, or (iii) both components of only some magnetic binary systems are magnetic, possibly implying that the actual incidence statistics concerning single stars (i.e. 10% of higher-mass stars are magnetic) also holds true for binary systems, and therefore the cause of the absence of magnetic fields in most stars is likely neither binarity or initial conditions.

We can invoke other scenarios to explain the absence of magnetic fields in most stars. For example, differential rotation (caused e.g. by angular momentum losses) may be the key ingredient. If the field is weak, magnetic torques are unable to freeze the shear that leads to unstable configurations. On the other hand, if the field is strong, the Lorentz force is able to damp the differential rotation and the initial magnetic configuration is stable (Aurière et al. 2007, Braithwaite & Cantiello 2012). However we cannot yet rule out the initial conditions as the most probable scenario to explain the observed dichotomy. This large program will allow us to disentangle the initial conditions from other effects not only by searching for magnetic fields in a large sample of higher-mass binary systems but also by putting stringent constraints on the magnetic fields of both binary components, identifying systematic properties (e.g. is the primary always magnetic?), and comparing the results to already existing higher-mass single star magnetic surveys. This study will ultimately provide qualitative improvements of our knowledge of the magnetic field history during stellar formation.

ii. How do tidally-induced internal flows impact fossil or dynamo fields?

In close binary systems, tidal interactions have a significant impact on their evolution. They drive the evolution of their orbit and the rotation of each component. If there is sufficient angular momentum in the system, an initially eccentric system with non-synchronised and non-aligned components tends toward an asymptotic state where the orbit is circular, the stars’ rotations are synchronised with the orbital motion, and the spins are aligned (Hut 1981). Such phenomena are due to the conversion of the kinetic energy of excited tidal flows into heat. Until a system reaches its asymptotic state, different types of velocity fields are generated in both stars: i) the equilibrium tide, a 3-D large-scale flow, induced by the hydrostatic elongation of both stars along the line joining their centres (see Fig. 4a, Zahn 1966, Remus, Mathis & Zahn 2012) ; ii) the dynamical tide, generated by the excitation of low-frequency helical oscillation eigen-modes (inertial modes in convective regions, gravito-inertial modes in radiative regions, Zahn 1975, Ogilvie & Lin 2007, see Fig. 4b) ; iii) the spin-over flow of the tidal elliptic instability, triggered by the instability of (gravito)-inertial waves in a rotating fluid of ellipsoidal shape (Cébron et al. 2010 and Fig. 4c). The question that we address here is how such plasma flows within the stars can affect the fossil fields observed in the radiative (stratified) envelopes of intermediate-mass and massive stars, or the solar-type dynamo process inside the convective envelope of cool stars.

Theoretical studies have shown that such velocity fields can generate magnetic fields (e.g. Moffatt 1970, Le Bars et al. 2011). Besides, recent observations of an active cool star in a binary system suggest an orbital dependence of the spectroscopic magnetic activity indicators (HD 123351; Strassmeier et al. 2011). Furthermore, the recent detections of magnetic polarity reversal on a few cool stars may result from an orbiting companion (a hot Jupiter, or a low-mass stellar object, Donati et al. 2008, Petit et al. 2009), although this interpretation is contentious (e.g. Poppenhaeger 2011). While these studies demonstrate that binarity can have a measurable effect on the magnetic fields of stars, they represent only a small part of the investigation required to address the above question. The surface magnetic topology of both components of the observed binary systems, as well as the surface differential rotation, will be modelled by means of Zeeman-Doppler Imaging. In the case of binaries with circular orbits, the derived magnetic properties will be compared with magnetic topologies of single field stars (e.g. Petit et al. 2008, Morgenthaler et al. 2011). In the case of eccentric systems, the magnetic topology and differential rotation derived close to periastron, where the tidal interaction is maximal, will be compared with observations taken at periastron, where a weaker tidal torque is expected. Such a dedicated investigation of the magnetic fields in binary systems will represent an unprecedented opportunity to challenge the above theories and lead to new ones.
iii. How do magnetospheric Star-Star interactions modify stellar activity?

In hot or cool close systems, with two magnetic components, we expect important magnetic interactions between the components' magnetospheres. Intense magnetic reconnection phenomena may develop during the motion of the secondary (and its magnetosphere) through the magnetosphere of the primary, as may be the case of magnetic Star-Planet Interaction (SPI) for hot Jupiters orbiting around stars (Shkolnik 2008, Poppenhaeger et al. 2011). Such phenomena have been proposed to explain the cyclical variability of flaring activity over an orbital period in the T Tauri star V774 Tau A (Torres et al. 2012, Adams et al. 2011). Because of such reconnections, the magnetic activity of each component may be modified. We will therefore study the magnetic field and magnetosphere of both components of binary systems in order to understand the properties of magnetospheric interactions in binary stars and the related modification of the stellar magnetic activity.

iv. What is the magnetic impact on angular momentum exchanges and mass transfers?

Magnetic fields in low-mass stars are at the origin of stellar winds: the stronger the magnetic activity, the more intense the winds. In massive stars, winds are driven by spectral line absorption of the stellar radiation field ("line-driving"). In both cases, these winds carry away angular momentum and slow down the rotation of the surface layers of the stars (Bouvier 2007, ud-Doula et al. 2009). Hence, in addition to tidal torques applied to the components, such angular momentum extraction must be taken into account to understand angular momentum exchanges in binaries and to understand their evolution (Barker & Ogilvie 2009). These winds can also be at the origin of the exchanges of matter between both components. In cataclysmic variable systems (composed of a white-dwarf primary and a mass transferring donor secondary), the orbital evolution of the system is thought to be driven by magnetic braking due to the magnetic wind of the secondary star (Knigge et al. 2011). In interacting binaries with a low-mass star component, the angular momentum evolution over a large range of orbital periods is best explained by magnetically driven winds (Hussain 2011, Stepień 2011) and transfer of orbital angular momentum form orbital motions to spin (Mestel 1968, Verbunt & Zwaan 1981). Moreover, in very close binary systems (such as the W UMa-type stars where both stars are in contact and fill their Roche lobes), mass transfer is present. In such systems, magnetic fields can influence the mass transfer by channeling matter from one star to another. The cyclical period variations observed in these W UMa systems (e.g. Kim 1997) have been proposed to be magnetic cycles. These cycles could be caused by a variation of the distribution of angular momentum, producing a variation in oblateness. The changes are communicated to the orbit by gravity, changing the orbital periods (Applegate 1992, Kim et al. 1997). All these studies reflect the need for magnetic fields as an ingredient in binary evolutionary models in order to understand the observed orbital period changes. It is therefore crucial to bring observational constraints on these magnetic fields into the picture.

3. Target selection

Higher-mass binaries: The binary frequency of MS stars increases with mass, reaching its highest value among O-type stars (~60%, Sana & Evans 2011). Binarity is therefore common among higher-mass stars. However, the general magnetic properties of higher-mass binaries, particularly those with components of spectral types B and O, have not been well investigated, and only a small number of higher-mass magnetic binaries are known. In addition, only a small fraction (~10 %) of higher-mass stars are magnetic (e.g. Wolff 1968, Grunhut & Wade 2009) and many of them – particularly those of spectral types B and O - do not generally display other observational characteristics clearly indicative of the existence of magnetic fields. We therefore need to search for magnetic higher-mass binaries by observing a large sample of such systems. This large survey will have the advantage of establishing the frequency and other statistical properties of magnetic higher-mass binaries, but will also provide us with suitable targets to study and model in detail.

To construct a list of potential survey targets, we employed the 9th Catalogue of Spectroscopic Binary Orbits (Pourbaix et al. 2009). Starting from the complete catalogue, we limited potential targets to double-lined spectroscopic binaries (SB2s) for which both components are of spectral types A, B or O (except for A stars, for which we also included the possibility of an F-type secondary). We further limited this list to stars with declinations north of ~45 degrees and brighter than magnitude V=8. Finally, we excluded those systems with sufficiently wide orbits that no significant mutual interaction was expected. This left a list of 91 binaries.

We then cross-referenced this list with the observations acquired within the MiMeS survey, and found that 13 of these systems had been observed by that LP (see Figs. 1 and 2). Only one of those observations resulted in the detection of a field (HD 136504; Fig. 1). In addition, 3 of the A-type binaries in our list had already been observed for fields rather extensively: HD 98088 (a magnetic Ap binary observed with the now-decommissioned MuSiCoS spectropolarimeter, see below and Fig. 3), and 2 HgMn star binaries (both non-magnetic).

We therefore ultimately identify 75 SB2 systems with primary and secondary components of spectral types O, B or A (and F, in the case of A-type primaries) that will comprise the Survey Component of the LP. We point out that 14 of these targets are eclipsing binaries, for which precise, fundamental masses and radii are available.

In addition to this large survey sample, a small number of magnetic higher-mass stars in SB2 systems are
already known. According to the literature, amongst the Ap stars there exist 7 more known SB2s: HD 5550, HD 56495, HD 22128 (Carrier et al. 2002), HD 55719 (Bonsack 1976), HD 59435 (Wade et al. 1999), HD 135728 (Freymhammer et al. 2008), and HD 98088 (Abt et al. 1968). Furthermore, the MiMeS survey has detected magnetic fields in 3 SB2 systems: HD 25558, HD 136504 (Shultz et al. 2012) and HD 47129. These 10 known SB2s containing a magnetic ABO star will comprise the hot Targeted Component (hot-TC) of the LP. This sample covers a large range in mass (1.5 – 50 M_☉) and spectral type (A7 to O7). Three of the TC systems (HD 5550, 22128 and 56495) lack modern magnetic field measurements. A goal of the LP would then be the verification of the magnetic nature of these systems for each of the components, the follow-up to model the physical and magnetic properties of the whole hot-TC sample, and the modeling of the magnetospheric interactions in systems in which both components are magnetic.

**Binary systems with cool components**: Contrary to hot stars, we expect to detect magnetic fields at the surface of every cool star with a significant rotation rate, and therefore do not require a survey. Magnetically active cool stars can be identified thanks to direct indicators, such as X-ray chromospheric emission, or Hα and Ca II H and K chromospheric emission

We propose to study the effect of tidal interaction on binary cool stars. Compared to star-planet systems, binary stars are precious because the companion is more massive and magnetic than a planet, hence the related effects on magnetic topologies and activity (and on the differential rotation) should be stronger and therefore more easy to detect. We therefore need to explore binary systems of various parameters, such as spectral type and mass ratio. We also want to explore systems that are at different stages of synchronisation and circularisation, and therefore systems of different ages.

We used the catalogue of Chromospherically Active Binaries (3rd version, Eker et al. 2008) to make a selection of binary systems spanning a range of parameters (spectral type, mass ratio, eccentricity) and with a high activity level ensuring that we will be able to detect magnetically induced circular polarization in spectral lines. All stars of the sample either have measured vsini, rotation period or X-ray luminosities showing that they are in or close to the regime of magnetic activity saturation (Delfosse 1998, Strassmeier 2002, Makarov 2003, Szczygiel 2008, Flesch 2010). We will study both main sequence dwarf binaries (two active components) and RS CVn systems (evolved binaries with one active giant or subgiant). We will study systems over a wide range of eccentricities, from 0 to 0.34. For each low-eccentricity system we will obtain one magnetic map of each active component. For the most eccentric systems, with observations densely sampling the orbital cycle, we will investigate the dependence of activity on orbital phase. If such a dependence appears to be strong, we will reconstruct two different maps from two subsets of spectra taken close to periastron and close to apastron.

As obtaining a magnetic map for a cool star is time consuming (at least 20 observations at different rotation phases are required) we have limited our sample to a total of ~40 stars and plan to observe them not only with ESPaDOnS but also with Narval and HARPSpol. While we reserve the T Tauri stars (mainly situated in the Tau-Aur and Orion star forming regions) for HARPSpol (HARPS is a dedicated instrument on the 3.6m ESO telescope, which is scheduled classically and therefore avoids imposing RA conflicts on the CFHT LP), we have chosen to observe with ESPaDOnS stars well distributed in RA. The ESPaDOnS sample contains 12 MS stars of various eccentricities (from 0.00 to 0.34), various masses (from 0.16 to 1.4 M_☉) and various orbital periods (from 2.17 to 49.4 d) and includes 2 eclipsing binaries. They all show magnetic activity indicators, assuring a detection of magnetic fields in at least one of the components (for RS CVn systems), and most likely in both components (for MS systems). This cool-TC sample covers a wide range in parameter space, implying that even if no HARPSpol or Narval observations occur for this project, although we will not be able to extend our study towards very young cool stars, we will still be able to achieve the main objectives of this large program.

In addition we have also selected three W UMa systems (including 2 systems to be observed within this ESPaDOnS LP). W UMa systems, a class of contact binaries, are very close binaries with periods from ~0.2 and ~1 day and consisting of moderately evolved binaries distributed along the MS. They show the shortest known rotation periods of late-type stars, thus they are expected to be the most magnetically active. The analysis of these W UMa systems will allow us to explore magnetic activity under the most extreme conditions. The two W UMa stars of the ESPaDOnS sample are AW UMa and VW Cep, which have orbital periods of 0.4387 and 0.2783 d, and very different spectral types. As observing such systems with ESPaDOnS is exploratory, we will start by obtaining three polarised spectra at random times to try and detect the magnetic fields, then if the field is detected, we will observe them more intensely to estimate the magnetic flux of these rapidly rotating stars as they evolve along the orbit.

These 14 SB2s with cool components will constitute the cool Targeted Component (cool-TC) of this LP.
II. TECHNICAL JUSTIFICATION

Need for/appropriateness of CFHT and ESPaDOnS: With its high R=65000 spectral resolving power and robust polarimetric analysis in all 4 Stokes parameters, ESPaDOnS is the most powerful stellar magnetometer in the world. The past 8 years have shown the remarkable capability of ESPaDOnS for studying surface magnetic fields of all kind of stars at a level of detail that was previously unachievable. Mapping the magnetic fields of stars require multiple observations well sampled over the rotation period ($P_{\text{rot}}$), of short exposure times with respect to $P_{\text{rot}}$, to avoid phase smearing. Reaching these constraints is even more challenging in the fast rotating members of close binary systems. Although we plan to employ the ESPaDOnS twin Narval (TBL, Pic du Midi, France) to supplement the data acquired at CFHT for the few bright and slow rotating targets, and the HARPSpol polarimeter built for the 3.6m ESO telescope (Chile) to access the most Southern targets, it must be recognized that only ESPaDOnS is capable of acquiring the high S/N required for the majority of our targets.

Inferring the magnetic field from the Zeeman effect: For all targets we will exploit the longitudinal Zeeman effect in metal lines, as well as helium lines in hot stars, to detect and measure photospheric longitudinal magnetic fields. Splitting of a spectral line into oppositely-polarized σ components produces a variation of circular polarization across the line (commonly referred to as a “(Stokes V) Zeeman signature” or “magnetic signature”; see Fig. 1. The amplitude and morphology of the Zeeman signature encodes information about the strength and structure of the visible magnetic field. In slowly rotating ($\text{vsin}i<10$ km/s) M-type stars we will also measure the Zeeman broadening inside molecular lines to provide the field modulus at the surface of the star.

Crosstalk: ESPaDOnS polarization crosstalk is well established to be below 1%. Based on our previous experience and our choice of targets, crosstalk will have no significant impact on our measurements.

Least-Squares Deconvolution: After reduction of the polarized spectra using the Upena pipeline feeding the Libre-Esprit optimal extraction code, we will employ Least-Squares Deconvolution (LSD; Donati et al. 1997) multi-line analysis procedure to combine the Stokes V Zeeman signatures from many lines into a single high-S/N mean profile, substantially enhancing our ability to detect magnetic fields in both components of a binary system (see Figs. 1 and 2). LSD requires a “line mask” to describe the positions, relative strengths and magnetic sensitivities of the lines in the stellar spectrum. The line mask characteristics are sensitive to the parameters describing the stellar atmosphere. We have computed a set of such line masks covering all spectral types and surface gravity values present in our sample. These masks have already proved to allow detection of weak polarimetric signals in spectral lines of a number of cool and high-mass stars.

Exposure times: The exposure duration required to detect a Zeeman signature of a given strength varies as a function of stellar apparent magnitude, spectral type and projected rotational velocity ($\text{vsin}i$). This results in a large range of detection sensitivities for our targets. The SC exposure times are based on an empirical relation derived from real ESPaDOnS observations of OB stars obtained with the new detector Olapa, and takes into account detection sensitivity gains resulting from LSD and velocity binning, and sensitivity losses from line broadening due to rapid rotation, as well as from flux dilution of the spectral lines of both stars due to the continuum of the companion. In all cases we have adopted the most pessimistic exposure time, i.e. that required to obtain a field detection at the specified level in both the primary and secondary components.

Exposure times for our SC targets correspond to the time required to definitely detect (with a false alarm probability below $10^{-5}$) the Zeeman signature produced by a surface dipole magnetic field with a specified polar intensity. The targeted field intensity (1 kG, 0.5 kG, 0.25 kG or 0.1 kG) is determined primarily based on the required exposure times determined from the observational properties of the targets. In particular, all selected targets for which the exposure time necessary to detect a 0.1 kG (0.25 kG, 0.5 kG, 1 kG) field is shorter than 2 hours are observed at the 0.1 kG (0.25 kG, 0.5 kG, 1 kG) level. Although our calculated exposure times correspond to definite detections of the specified field, marginal detections of weaker or more complex fields may also be obtained. As examples, a 1 kG threshold is sufficient to allow us to detect the magnetic field of the magnetic O7 star θ¹ Ori C, whereas a threshold of about 500 G is necessary to detect the field of the magnetic B0 star τ Sco.

Exposure times for our hot-TC targets were determined based primarily on observations already published or in our possession, and/or using synthetic Zeeman profiles computed assuming published field models. Typically, these times correspond to exposures necessary to detect the Stokes signature(s) at about 10σ (the quality we have established is necessary for detailed modeling).

All stars in our cool-TC sample lie in or close to the saturated regime of the rotation-activity relationship, therefore the expected typical amplitude of the Stokes V signatures we aim to detect mostly depends on $\text{vsin}i$. This typical amplitude is assessed from our previous observations of cool stars, e.g., 0.5% of the unpolarised continuum level for $\text{vsin}i < 10$ km/s. We empirically account for a lower amplitude of the polarized signal in targets which do not show saturated activity. We then compute the exposure time allowing us to detect the Stokes V signal at the 10-σ level in the average line profile taking into account the spectral type dependence of the LSD multiplex gain (from 15 for spectral type M to 40 for G). As a typical example of a target observed with
ESPaDOnS, for a binary system composed of two early K dwarfs, with a rotation period of 2 d, vsin=15 km/s and V=10, an exposure time of 4x600s or 43 min (including readout) is required to reach a S/N of 500 and hence to detect signatures having a peak-to-peak amplitude of 0.1% of the unpolarised continuum. Collecting the 20 polarimetric sequences needed to map such a system will thus require a total observing time of 15 hrs (including readout). For the most eccentric systems, we will densely sample the orbital period with 40 spectra in order to be able to identify activity modulation along the orbit.

The exposure times of the 2 W UMa stars have been chosen to have a short exposure time (12 mn for AW UMa and 8 mn for VW Cep) with respect to $P_{rot}$, to avoid phase smearing.

The total time required for this Large Program is approximately 582 hours: 146 hours for the hot-TC, 146 hours for the (hot) SC, and 290 hours for the cool-TC. The hot-TC includes a reserve of 80 hours for follow-up of SC targets detected as magnetic.

**Observing strategy and constraints:** All targets in the LP can be observed at any phase of the moon, and under significantly degraded seeing and transparency conditions. Each SC target will be observed twice during the duration of the LP, to increase the probability of registering fields near the threshold of detection. In the event that an SC target is detected, it will be transferred to the TC for follow-up observations. There are essentially no constraints on when the SC targets should be observed (except that 2 observations of each target should generally not be acquired on the same night).

Each cool-TC target will also be observed a specified number of times (see above) during the duration of the LP, with the aim of obtaining full rotational phase coverage. In cool stars the surface magnetic configurations change on a short timescale relative to the duration of the LP, requiring to obtain a full set of data, well sampled over the rotation period, within a few weeks. While this could be considered as a strong time constraint, we choose targets well distributed in right ascension to be able to offer flexible observing times. The selected orbital periods are shorter than 15 days (except one target), the typical duration of an ESPaDOnS run. It will therefore be possible to sample the full orbital cycle in a time shorter than the typical timescale for the evolution of the surface magnetic field (~1 month). In addition, we have avoided rotation periods very close to 1 d which do not allow sampling of the full stellar rotation cycle during a typical ESPaDOnS run.

As explained in the technical justification, we will first obtain three observations of the two W UMa-type stars. Then, if magnetic fields are detected, we will observe them at random times during a few weeks to monitor their magnetic flux and study it as a function of time. For VW Cep we will also perform a rapid monitoring during one night to check for very short time variability (i.e. within an orbit).

**Observational Feasibility:** That the observational goals of the TC and SC are feasible is clearly demonstrated by the success of analogous observations undertaken with ESPaDOnS during the past years (Donati, Grunhut, Petit, Wade/Catala/Alecian, etc.) and by the success of the MiMeS and MaPP Large Programs. In particular, magnetic reconstruction at the surface of both components of a few binary systems has been successfully realised within the past years (e.g. Dunstone et al. 2008) using ESPaDOnS.

**Spectral disentangling:** Whenever the phase coverage is sufficient, in binary systems showing constancy in at least one spectrum, we will disentangle the intensity spectra using the KOREL code (Frémat et al. 2005) and similar codes at our disposal – see for example Folsom et al. (2010), or Gonzalez & Levato (2006). This will provide individual spectra of each component. These spectra will be subsequently analyzed as usually done for single stars. We will thus obtain the stellar and wind properties of the primary and secondary components, which is crucial to draw reliable constraints on the evolution of the system (e.g. Mahy et al. 2011).

**Field characterisation and modeling:** The detection of magnetic fields in SC targets will be diagnosed using the Stokes V detection criterion described by Donati et al. (1992), but with the false alarm probability (FAP) threshold values employed by Donati et al. (1997; these are the values that are currently in general use). Specifically, we will require FAP<10^{-5} (FAP<10^{-3}) within the LSD line profile for the definite (marginal) detection of a Zeeman signature, combined with no detection outside the line or in the associated diagnostic null LSD profile. For each observation in which no magnetic field is detected, we will determine quantitative field upper limits using the Bayesian estimation technique of Petit & Wade (2012; See Fig. 3) and the method applied by Alecian et al. (2008) to correct from the second component in the composite spectrum of the system.

Zeeman signatures will be detected in all spectra of TC targets. The spectropolarimetric timeseries of the disentangled individual stellar or combined spectra will be interpreted using several magnetic field modeling codes at our disposal. For those stars for which Stokes V LSD profiles will be the primary model basis, the Zeeman Doppler Imaging code of Donati et al. (2008), the modeling codes of Alecian et al. (2008) or a modified version of the code of Hussain et al. (2009) to interpret spectra of binaries (see Figs. 3 and 5), will be employed. For those stars for which the signal-to-noise ratio in individual spectral lines is sufficient to model the polarisation spectrum directly, we will employ the Invers10 Magnetic Doppler Imaging code to simultaneously model the magnetic field, surface temperature and abundance structures (Piskunov & Kochukhov 2002, Kochukhov et al. 2004), or the code of Vincent et al. (1993) dedicated to the analysis of binaries. A comparison of the results from these independently developed modeling codes will be performed.
Binarity and Magnetic Interactions in various classes of Stars

**Photospheric Models:** Photospheric models of hot stars (>15000 K) will be constructed with the model atmosphere code TLUSTY (Hubeny & Lanz 1995). Departures from LTE are explicitly allowed for a large set of chemical species and arbitrarily complex model atoms. A detailed synthetic spectrum is then calculated with SYNSPEC, varying if necessary the abundance of individual species or the microturbulent velocity. Note that for this work we will first extract fully blanketed non-LTE models from the existing extensive OSTAR2002 and BSTAR2006 grids (Lanz & Hubeny 2003) and re-compute tailored models whenever necessary. Photospheric models of cooler stars will be constructed with the LTE ATLAS 9 (Kurucz 1993) atmosphere models. Synthetic spectra will then be calculated with SYNTH3 (Kochukhov 2007) and atomic data of the VALD (Kupka et al. 1999) database. For the coolest stars (< 5000 K) we will use the recently revised MARCS model atmosphere grid (Gustafsson et al. 2008), which includes the latest atomic and molecular opacities.

**Magnetospheric models:** Magnetospheric interactions of stellar wind outflows are being diagnosed using the ESPaDOnS data (e.g. optical emission lines), but also with complementary data (interferometric high-angular resolution constraints, UV line profiles, X-ray photometry and spectroscopy, etc.). Our group is developing detailed dynamical models of magnetospheric wind channeling in hot, massive stars, using both analytic and semi-analytic methods, as well as full 2-D and 3-D MHD simulations. Such models account for the centrifugal support from stellar rotation, and the rotational spindown resulting from angular momentum loss in the magnetic torqued wind outflow. Comparison of observations with model synthesis diagnostics provide detailed constraints on the physical properties, origin and consequences of massive-star magnetospheres (e.g. ud Doula et al. 2002, Russell et al. 2011; see Fig. 6). For cool stars, we will develop 3D models of magnetospheres and of their interactions and the associated diagnosis, which can be compared to observations, using the PLUTO code (Mignone et al. 2007).

**Expertise of the team:** Our team consists of internationally-recognized experts, both observational and theoretical, in stellar magnetometry and analysis of spectropolarimetric data, mapping of surface magnetic field topologies, analysis of binary systems, interpretation of stellar spectra of all kind of stars, modeling of stellar atmospheres, winds, magnetospheres and their interactions, and physics of stellar interiors. We have extensive experience with ESPaDOnS, as well as with complementary instruments. Many of our collaborators are members of the highly-successful MiMeS and MaPP CFHT Large Programs.

**Questions and Answers**

**Doesn’t it make better sense to investigate hot and cool binaries in independent proposals?** Not at all. The basic physical interactions occurring in cool and hot systems are the same. While they may ultimately result in different phenomena and observable characteristics, it is ultimately these basic physical interactions that we wish to investigate. Therefore combining hot and cool stars together in a single proposal has the potential to yield significant new synergies by bringing together experts from separate communities to study similar physics.

**Isn’t a sample of 75 survey (SC) targets likely to yield very few hot magnetic binaries?** Based on statistics from the MiMeS survey, this sample should yield approximately one dozen new magnetic binary systems. While this is a relatively small number, it more than doubles the number of currently-known higher-mass magnetic close binaries, and could potentially increase by a remarkable factor of 5 the number of known massive (i.e. spectral types O and early B) magnetic close binaries. Each new discovery has the potential to exhibit unique phenomena and apply new constraints on models.

**Why are 80 reserve hours required for follow-up of detected SC targets?** Based on the literature and our experience from the MiMeS survey, approximately 8% of the SC stars should exhibit magnetic fields. Our 75 systems include 150 stars, suggesting that we will detect ~12+/3 new magnetic stars. Assuming typical observational parameters for 10 new magnetic systems, we require ~8 hours to characterise each system, for a total of 80 hours.

**What if no Narval and/or HARPSpol observing time is allocated?** The vast majority of our science goals rely only on ESPaDOnS data. Narval will only be used to complement ESPaDOnS by extending the datasets. Note however that all previous ESPaDOnS LPs have been allocated Narval LP status as well, and a BinaMicS Narval LP is highly probable if the ESPaDOnS LP is attributed. HARPSpol would be very useful to study young cool stars in certain Southern associations, but this only concerns a small part of our project. A HARPSpol LP has been obtained to complement MiMeS, which shows that this is possible for BinaMicS as well. Nevertheless, we do not rely on this time allocation.

**How did you select “close” binary systems for the survey for which a “significant mutual interaction” is expected?** We selected systems for which the tidal force was larger than 0.1% of the gravitational force due to the primary. This corresponds approximately to an orbital period of 50 days for a binary consisting of two early B-type stars.
III. OBSERVING STRATEGY

Table 1 shows the load imposed by the BinaMicS LP on any resource (time pressure, seeing, etc), while Table 3 shows the detailed distribution of the targets in RA per semester summarized in Table 2. Thanks to the distribution of the selected targets in the sky (see Fig. 7 below), the lack of constraints on moon phase and seeing, BinaMicS is easy to schedule in the telescope observing queue. Only the 14 cool-TC targets will require their full datasets to be obtained within a few weeks for each target, but since they cover many different RAs, this will not impose much constraint either (maximum 1 target per semester per RA bin). The completion of the acquisition of the BinaMicS data is thus regarded as low-risk. Should BinaMicS nevertheless gather less data per semester than requested, we can adapt the observing strategy during the last few semesters of the LP to reduce the number of TC targets and insure the completion of those targets that have already been partly observed. Indeed, the study of each TC target is effectively independent of the other TC targets.

The full list of TC and SC targets is available upon request.

The numbers below do not include Brazilian and Chinese time. If the Brazilian and Chinese Agencies wish to allocate 24h and 36h, respectively, for this project, this extra time will be used to extend the SC sample towards binaries containing Wolf-Rayet stars (with the Brazilian time), and to observe one additional eccentric cool-TC target (with the Chinese time). While this additional time would allow us to extend our sample, and even explore another class of objects, we do not rely on such an extra allocation to fulfil the requirements of our project.

Table 1: Load on observing resources.

<table>
<thead>
<tr>
<th>Moon</th>
<th>Any</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeing</td>
<td>Any</td>
</tr>
<tr>
<td>Telescope time</td>
<td>Below 9.7% of the F+C telescope time per semester</td>
</tr>
<tr>
<td>RA pressure</td>
<td>Below 39.8% of the telescope time for any RA bin and any semester</td>
</tr>
<tr>
<td>A vs B semesters</td>
<td>42% of observations in A semesters, 58% in B semesters</td>
</tr>
</tbody>
</table>

Table 2: Distribution of targets and observing time as a function of right ascension for the full BinaMicS programme. The percentage of French + Canadian telescope time was estimated assuming 62 F and 62 C nights per semester and 7.5 hours of ESPaDOnS observations per night.

<table>
<thead>
<tr>
<th>Semester</th>
<th>Hot SC</th>
<th>Hot TC</th>
<th>Cool TC</th>
<th>All</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>RA</td>
<td># Stars</td>
<td>Hours</td>
<td># Stars</td>
</tr>
<tr>
<td>B</td>
<td>00-04</td>
<td>10</td>
<td>22.75</td>
<td>2</td>
</tr>
<tr>
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<td>04-08</td>
<td>12</td>
<td>18.31</td>
<td>5</td>
</tr>
<tr>
<td>A</td>
<td>08-12</td>
<td>6</td>
<td>6.49</td>
<td>1</td>
</tr>
<tr>
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<td>12-16</td>
<td>5</td>
<td>4.72</td>
<td>2</td>
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<td>0</td>
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<tr>
<td>B</td>
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<tr>
<td>Total</td>
<td></td>
<td>75</td>
<td>146.19</td>
<td>10</td>
</tr>
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</table>

Table 2: Distribution of targets and observing time as a function of right ascension for the full BinaMicS programme. The percentage of French + Canadian telescope time was estimated assuming 62 F and 62 C nights per semester and 7.5 hours of ESPaDOnS observations per night.
<table>
<thead>
<tr>
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<td>RA</td>
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<td>Hours</td>
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<tr>
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<td>14.22</td>
<td>+18.34</td>
<td>5.33</td>
<td>+6.67</td>
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</tr>
<tr>
<td>Total</td>
<td>51.2</td>
<td>79</td>
<td>68.1</td>
<td>79.88</td>
<td>75.12</td>
<td>90.23</td>
<td>47.57</td>
<td>90.67</td>
</tr>
</tbody>
</table>

Table 3: Distribution of observing time as a function of right ascension for each semester. 80 hours have been added to semesters 2015A to 2016B for the follow-up of magnetic SC targets discovered in semesters 2013A to 2014B. Since we do not know in advance their RA, they are spread over RA bins in this Table. Colour coding: red = cool-TC, blue = hot-TC, green = SC, black = new discoveries from SC.

**Fig. 7** Distribution of the hot-TC (blue), cool-TC (red) and SC (green) targets in right ascension. This plot shows that the BinaMicS targets are well spread over all RAs.
IV. DATA MANAGEMENT PLAN

Data collection, reduction, quality control and archive publication:

ESPaDOnS data: Following their acquisition in QSO mode, ESPaDOnS polarized spectra will be reduced by CFHT staff using the Libre-Esprit (or Opera) reduction package and downloaded to the dedicated BinaMicS server at LESIA in Meudon, France. Reduced spectra will be carefully normalized to the continuum using existing software tailored to stellar spectra. [Alecian, Petit P. and LESIA+IRAP co-I]

Possible Supplementary data: Data acquired with Narval will be subject to essentially the same reduction procedure as the ESPaDOnS data. Data acquired with HARPSpol will be reduced with the REDUCE code (Piskunov & Valenti 2002). Other supplementary data will be acquired, reduced and processed as appropriate. In particular, the French community has a favoured access to the unique interferometer CHARA. [Various]

Quality control: Each reduced spectrum will be subject to an immediate quick-look analysis to verify nominal resolving power, polarimetric performance and S/N. Preliminary LSD profiles will be extracted using our generic line masks to perform an initial magnetic field diagnosis and further quality assurance. [Alecian and LESIA co-I]

Archive publication: Each ESPaDOnS spectrum will be carefully processed to determine a variety of critical physical data for each observed target: effective temperature, surface gravity, mass, radius, age, magnetic measurements, variability characteristics, vsini, radial velocity and orbit parameters [Monier, Shultz] and uploaded, in addition to the reduced spectra, for publication in the ESPaDOnS/Narval Database (PolarBase to be available in 2012). The delay for the publication in the database should be less than 2 weeks. The data access will be restricted to participating Agencies during the first year [Petit P. and IRAP co-I]

Legacy: The BinaMicS data will constitute a unique database of binary star polarisation data as well as intensity spectra, which can be used for many other scientific studies than the ones we propose in this LP, e.g. to compare the chemical content in binary stars versus single stars to test evolutionary models.

Data analysis and modeling:

Survey component: Detailed LSD line masks will be constructed based on the unique spectral characteristics of each SC target. Final LSD profiles will be extracted and the diagnosis of the presence of a Zeeman signature performed [Neiner, Martins, Wade, Petit V., Moffat and UdeM co-I]. This procedure has been tested and refined as part of the MiMeS survey. Detected targets will be transferred to the TC for follow-up. Undetected targets will be analyzed to provide an estimation of the strength of undetected fields. [Alecian and LESIA+RMC co-I]

Targeted component: Field and surface mapping of primary TC targets will be coordinated amongst the co-Is as datasets are acquired [Neiner – pulsating and Be stars, Alecian – Herbig stars, Kochukhov/Wade/Martins – B and O stars, P. Petit/Morin – G to M dwarf stars, Hussain/Marsden – T Tauri stars, Rucinski – W UMa]. Detected SC targets transferred to the TC will be re-observed to confirm detection and determine field properties.

Simulations and theory: Once field and surface mapping of a TC target has been completed, the field maps will be combined with supplementary data (interferometry, optical/UV/X-ray spectra, radio fluxes,) to serve as input data for magnetospheric extrapolation and modeling [ud-Doula, Owocki]. Ongoing numerical simulations and theoretical models of fossil and dynamic field generation/evolution mechanisms [Braithwaite, Brun, Cébron, Mathis, Zahn] taking into account the action of tidal [Mathis, Zahn, Rieutord, Cébron, Remus, Le Bars, Le Gai] and magnetospheric interactions [Owocki, ud-Doula, Brun, Matt, Strugarek] and of related MHD wind dynamics [Owocki, ud-Doula, Brun, Matt, Strugarek] will be developed. Moreover, impact on the evolution of the components of studied binaries will be evaluated [Meynet]. Then they will be confronted with the field maps and previous obtained magnetospheric models for guidance in observations interpretation and to constrain physical processes. SC results will be ultimately used to evaluate the various scenarios described in Sect. 2, and to refine our observational knowledge of the statistical properties of magnetic ABO stars in binary systems. Confrontation with stellar formation numerical simulations will be achieved [Hennebelle].

Coordination, scheduling and publications: General coordination of the LP will be the responsibility of the PIs. The SC observations will be obtained uniformly throughout the 2 years, allowing the publication of the SC survey within the third year. Because known massive magnetic stars in binaries are currently so rare, each detected SC target will form the basis of a paper, to be published relatively quickly after detection and confirmation. TC targets have been prioritized to achieve an approximately uniform production of complete datasets as the LP progresses. Once the first TC datasets have been acquired (requiring between 1 and 4 semesters, depending on the orbital periods of the systems), this will allow for continuous modeling and publication of TC results. The BinaMicS team will coordinate activities via a dedicated organizational BinaMicS-Wiki page, as well as periodic teleconferences. We will organize quarterly meetings of local BinaMicS subteams, and annual BinaMicS workshops.

Outreach: A public BinaMicS website will advertise the results of the project.
Fig 1 LSD Stokes V (top), Stokes I (bottom) and and diagnostic null (middle) profiles are shown for two SB2 systems.
Left: The magnetic massive binary, L Lupi which was detected by the MiMeS collaboration (e.g. Shultz et al. 2012). This system consists of two physically similar early B-type main sequence stars. The more massive component, in addition to being magnetic, is a pulsating β Cephei star. The secondary exhibits no evidence of a magnetic field at this precision.
Right: The low mass star binary, HD 155555, a tidally locked pre main sequence binary system (G5IV+K0IV). Both of the component cool stars show evidence of strong complex magnetic field distributions; with the magnetic field of the secondary showing a significantly tilt with respect to the rotation axis of the system.

Fig 2 Stokes I (bottom), V (top) and diagnostic null (middle) LSD profiles of the early-type SB2 HD 1337. This target, observed by the MiMeS project, is comprised of 2 spectral type O9III stars, and yields no detection of a magnetic field with upper limits on the longitudinal fields of the two components of 59 and 83 G, respectively.

Fig 3 Stokes I (left) and V (right) LSD profiles of the magnetic SB2 HD 98088 (Likuski, 2010). This system contains two A-type stars: an early A-type magnetic Ap star primary, and a slightly later A-type Am star secondary. The Stokes V signature, which clearly follows the motion of the primary's line, varies with the same period as the radial velocities of the components, indicating that the primary's rotation is synchronized with the orbit. No evidence of a magnetic field is observed in the (weaker) spectral line of the secondary.

Fig 4 a) 3-D view of the adiabatic equilibrium tide velocity field at the surface of a primary (black arrows), the color-scaled background represents the normalised tidal potential intensity (blue and red for the minimum and maximum values respectively). The red and orange arrows indicate the direction of the primary’s rotation axis and the line of centers respectively. (From Remus, Mathis & Zahn 2012)
b) Axisymmetric inertial mode excited in a spherical shell at the origin of the dynamical tide velocity field (from Rieutord & Valdetarro 1997). Left: kinetic energy of the mode. Right: dissipation of the mode.
c) MHD numerical simulation of the spin-over mode induced by the tidal elliptic instability with an imposed uniform magnetic field along the rotation axis. The induced magnetic field is represented by arrows which scales with its local value. The ohmic dissipation is represented in the equatorial plane. (From Cébrbron 2011)
Fig. 5 Top: Reconstruction of the radial component of the surface magnetic fields on both components of the cool binary system, HD 155555 (Dunstone et al. 2008). These maps were derived by inverting Stokes $I$ and $V$ datasets that sample the full orbital period of the system (a sample of the data is shown in Figure 1) using a dedicated binary ZDI code. Red and blue represent magnetic field of opposite polarity while white denotes regions of null polarity. Bottom: This 3-D magnetospheric model of the system has been derived by extrapolating surface magnetic field maps to model the locations of closed coronal field lines (Dunstone & Holzwarth, priv. comm.). As the magnetic fields for the secondary star is significantly tilted with respect to the rotation axis (75 degrees compared to ~15 degrees for the primary) the magnetospheric interaction in this system is complex and should result in enhanced magnetic activity (e.g., flares). Models such as these can be used to model the coronal emission from binaries and the locations of open field from which magnetically driven winds would originate.

Fig. 6 Illustration of simulations of colliding stellar wind (left) and magnetic wind (right) in massive stars. The left panel shows the orbital plane density from a 3-D Smoothed Particle Hydrodynamics (SPH) simulation of colliding stellar winds in an eccentric binary system, at a time snapshot near periastron (Russell et al. 2011). The right panel shows the density (color) and field lines in a 2-D MagnetoHydroDynamics (MHD) simulation of a magnetically channeled stellar wind in a single magnetic massive star (ud-Doula & Owocki 2002). Current theory work in our group aims to combine these efforts to develop simulations of colliding winds for the case when one or both of the stellar components has a strong magnetic field.

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