LARGE

European Observing Proposal

donati TBL-08B008

MaPP - studying the impact of magnetic fields on the formation of low-mass stars and planets

Abstract

MaPP aims at studying the impact of magnetic fields on the physics of protostars and accretion discs, and thus on the formation of stars and planetary systems. Youth is indeed the period in the life of non-degenerate stars at which magnetic fields play a key role, through the accretion/ejection processes involved in the collapse of the protostellar cloud. In particular, our study will focus on the core regions of protostellar accretion discs, the newly born star and their potential close-in giant planets. We propose to carry-out (with ESPaDOnS & NARVAL) the first spectropolarimetric survey on a significant sample of low-mass protostars, including a few bright protostellar accretion discs. From this survey, we will study the large-scale magnetic field topologies of protostellar objects using tomographic imaging techniques and will answer (through comparisons with MHD simulations) several major open questions on star formation. MaPP is part of the international MagIcS initiative.

Science category : PNPS **Observing mode :** Service mode

Total requested nights: 7 nights

Telescope	Dark	First	Bright	Last	Instruments
TBL			7		Narval

Details, including preferred dates and periods to be avoided:

This program is the NARVAL counterpart of the ESPaDOnS Large Program submitted to CFHT to be carried out from 2008b to 2012b. This program requires a total amount of 900hr of clear time on 9 semesters (100hr/semester).

In 2008b, we need 6 hrs on 16 consecutive nights (ie about 100hr of clear time) to correctly monitor the rotation cycle of all stars - this is equivalent to 7 full winter (ie 14hr) nights.

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Summary of observations

Number of targets	Telescope	Instrument	Exposure (mins.)
5 targets	TBL	Narval	360

Is this a long term proposal: Yes

This program is the NARVAL counterpart of the ESPaDOnS Large Program submitted to CFHT that will be carried out (if selected) on 9 consecutive semesters (2008b to 2012b). It requires a total amount of 900hr of clear time on 9 semesters (100hr/semester).

No PhD Students involved

Linked proposal submitted to this TAC: No

Linked proposal submitted to other TACs: Yes

This program is the NARVAL counterpart of the Large program submitted with ESPaDOnS at CFHT.

Science justification:

Purpose: Following the success of previous ESPaDOnS/NARVAL runs on low mass protostars (Donati et al 2007, 2008a), we propose to obtain magnetic maps for 5 cTTS in the Taurus/Auriga star forming region. With such maps, we will study the magnetospheric accretion processes linking the protostar to its surrounding accretion disc, and will investigate how magnetospheres and accretion flows of cTTS correlate with the protostar's properties such as mass, rotation rate and ability to drive large-scale outflows. We will also look for giant planets potentially orbiting within the central magnetospheric gap. **This is a new attempt at our allocated Dec07 program, wrecked by dreadful weather and the first step of a Large Program on studying Magnetic Protostars and Planets (MAPP) to be carried out in conjunction with ESPaDOnS@CFHT.**

Background: T Tauri stars are low-mass stars with an age of a few Myr, still contracting towards the main sequence. Many of them, the cTTS, are surrounded by massive accretion discs whose inner regions connect to the surface of the protostar through magnetospheric accretion funnels (eg Valenti & Johns-Krull 2004, Symington et al 2005). Understanding the physics of these accretion processes, clarifying the role of magnetic fields and quantifying the impact on the structure and evolution of low-mass protostars, are **key issues for models of low-mass star formation** (eg Romanova et al 2004, Bouvier et al 2007).

The field geometry: Simulations (eg Jardine et al 2006, Gregory et al 2006, Long et al 2007) indicate that **magnetospheric accretion is expected to depend strongly on the field geometry** and thus potentially on the mass and rotation rate of the protostars, as well as on the ability of the system to drive a large-scale outflow. The variability of Balmer emission line profiles formed in the accretion funnels independently confirms the dependence of accretion flows on stellar parameters (eg Alencar et al 2005). However, the topology of cTTS magnetospheres is still unclear; while spectropolarimetric estimates of magnetic fields at footpoints of accretion funnels first suggested simple dipoles (eg Symington et al 2005), repeated failures at detecting large-scale photospheric fields (eg Valenti & Johns-Krull 2004) did not confirm this view.

Recent ESPaDOnS observations of 3 cTTS allowed us to detect magnetic fields both at the protostar surface and in accretion funnels, and to monitor their signatures over the full rotation cycle. Through tomographic imaging, we produced **consistent magnetospheric models reproducing Zeeman signatures from both photospheric lines and accretion funnels**. The reconstructed field features complex multipolar structures close to the stellar surface and a simpler (though not dipolar) large-scale topology (eg Donati et al 2007, Donati et al 2008a). From these maps, we successfully reconstruct the location of accretion funnels (eg Jardine et al 2008). From our current sample, we find that magnetic topologies are more complex for high-mass rapidly-rotating protostars; the proposed observations are tailored to test such correlations.

Proposed program for 2008b: We propose to apply the same technique on 5 cTTS (AA Tau, DG Tau, RY Tau, T Tau, SU Aur) for which magnetic fields are already detected through ESPaDOnS snapshots. In addition to their dirent rotation periods (from 2.8 to 8.2d) and masses (from 0.5 to 2.0 Msun), these targets have different outflow properties, with DG Tau and RY Tau exhibiting clear jet signatures while the others show none. Both NARVAL & ESPaDOnS will be used to monitor all 5 stars, with **NARVAL observing for 6hr/n over 16 consecutive nights** to adequately cover at least 2 rotation cycles of the slowest rotator and properly disentangle rotational modulation from intrinsic variability. Given the faintness of AA Tau and DG Tau, we may not detect their Zeeman signatures (monitored with ESPaDONS);

we will nevertheless be able to follow the rotational modulation of the emission lines tracing accretion processes. Observing from 2 sites located 11hr in longitude from one another (rather than from one single site) will significantly improve the phase coverage on all stars, and will thus strengthen the constraints on the derived magnetic topologies.
From this first sample, we will look for **correlations between the magnetospheric structure and the protostar's properties** such as mass and rotation rate. We will also check whether the magnetosphere correlates with the protostar's ability to drive large-scale outflows, a crucial test for magnetocentrifugal models. We will then compare our observations with results from MHD numerical simulations of star/disc interactions. By monitoring radial velocities of our target stars, we should also be able to search for giant planets potentially orbiting within the magnetospheric gap with periods of a few d (ie smaller than the rotation period of the star), like the one recently reported for the cTTS TW Hya (Setiawan et al 2008). The large radial velocity fluctuations induced by potential close-in Jupiter-like planets should be easily detectable with ESPaDOnS; the slowly rotating edge-on low-mass cTTS AA Tau is particularly well suited for this purpose.

Long term program on following semesters: This is a Large Program to be carried out (if selected) on 9 consecutive semesters (2008b to 2012b) both with ESPaDOnS and NARVAL. As mentionned above, the broader aim of this large program is to **investigate the role of magnetic fields throughout stellar formation**, and in particular tackle several major issues that are still unresolved:
(a) **what is the origin of disc magnetic fields?** how much angular momentum and magnetic flux is dissipated during the cloud collapse? We can address these issues by unveiling the strength and orientation of the magnetic fields that managed to survive the collapse and the associated angular rotation velocities, in particular within the central regions of the protostellar accretion discs from which the jets are fired;
(b) **how does magnetospheric accretion control the angular momentum and how much does it modify the internal structure of the protostar?** This can be studied by measuring the intensity and complexity of the magnetic fields that protostars host and weave with their accretion disc to funnel the disc material towards the stellar surface;
(c) **why are some discs/protostars showing jets while some others are not?** By using input from (a) and (b), we can investigate how jets relate to the magnetic fields in accretion discs and to those on protostars;
(d) **how do close-in giant planets form and stop their inward migration?** Results from (a) and (b) will show whether (and where) close-in giant planets are present in the central regions of protostellar accretion discs or around more evolved protostars.
Our long-term program is designed to answer these questions through a first spectropolarimetric survey on a significant sample of young stellar objects, including in particular several young low-mass stars (classical T Tauri stars or cTTSs) and a few bright protostellar accretion discs (FUOrs). With this survey, we will study how the magnetic properties vary with the object characteristics (eg accretion rate, outflow properties, protostar's mass and rotation rate); this new body of observations will allow us to select among the various existing theoretical models and provide an updated description of magnetized stellar formation. This project is called MaPP (Magnetic Protostars and Planets). More about this Large Program can be found on `http://www.ast.obs-mip.fr/users/donati/magics/v1/young-lp.pdf`
Altogether, our sample includes 15 cTTSs (V2129 Oph, V2247 Oph, BP Tau, AA Tau, DF Tau, DG Tau, DK Tau, DN Tau, T Tau, RY Tau, SU Aur, COUP 932, TW Hya, RY Lup, GQ Lup, featuring different masses, ages, accretion and rotation rates, and jet properties, see Sec 4) and 3 bright protostellar accretion discs (FU Ori, V1057 Cyg, V1515 Cyg). 8 of the 15

cTTSs (V2129 Oph, BP Tau, AA Tau, DG Tau, T Tau, RY Tau, COUP 932, TW Hya) will be observed twice to study the long term evolution of the field topology, with 2 of them (V2129 Oph, BP Tau) already observed once (Donati et al 2007, 2008). (NARVAL will not be able to help much for the 3 southernmost stars, ie TW Hya, RY Lup and GQ Lup).
We will detail which and how stars are to be observed with NARVAL as the program goes. **The total amount of TBL time needed for this program is about 900 hr of clear time, in 9 chuncks of 16 6-hr blocks on the forthcoming 9 semesters**.

Technical justification:
Feasibility: Observations will consist in recording circular polarisation spectra, following a specific procedure designed for suppressing all systematic errors to first order and reach photon noise limited polarimetric accuracies down to a relative level of about 10^{-5} (Donati et al 1997). For AA Tau and DG Tau (mv=13), NARVAL yields a peak S/N ratio of about 90 per 2.6 km/s velocity bin in Stokes V and I spectra for a 4×1200s-exposure polarisation sequence. For RY Tau, T Tau and SU Aur (mv=9.4–10), NARVAL yields a peak S/N ratio of about 190–250 per 2.6 km/s velocity bin in Stokes V and I spectra for a 4400 s-exposure polarisation sequence.
Using cross-correlation routines such as Least-Squares Deconvolution (Donati et al 1997), we extract the polarisation information in photospheric lines through some 8,000 line profiles simultaneously and improve the S/N ratio in V spectra by a factor of about 40 with respect to a single line with average magnetic sensitivity. It yields polarisation noise levels of order 10^{-4} per 2.6 km/s velocity bin in the resulting LSD Stokes V profiles of RY Tau, T Tau and SU Aur (whose Zeeman signatures are smaller as a result of the largest rotation velocity), and about twice as much for AA Tau and DG Tau. Zeeman signatures will easily be detected and monitored with NARVAL on RY Tau, T Tau and SU Aur. We may not detect those of AA Tau and DG Tau (given their relative faintness), but will be able to follow the rotational modulation of emission lines forming at the footpoints of accretion funnels.

Time justification: Only NARVAL and ESPaDOnS can carry out the proposed program. To improve our results with respect to those already published (Donati et al 2007, 2008a), we need denser phase sampling, which can only be obtained with both instruments working together on a timespan of at least one rotation cycle and preferably two (in order to properly disentangle rotational modulation from intrinsic variability).

Progress report: In 2007b, the ESPaDOnS time allocated for this program was totally wrecked due to dreadful weather conditions. The NARVAL time was partly lost (about 50%) and we concentrated on T Tau and RY Tau mainly. Data are being analysed and will be published with those of the forthcoming observing campaign.
We propose to repeat the 2007b program in 2008b. Previous results (Donati et al 2007, 2008a) demonstrate that observing procedures, tomographic imaging from rotationnally modulated spectropolarimetric data and magnetospheric modeling from surface magnetograms work fine on cTTS and are adequate for our needs, for both slow and fast rotators. Spectropolarimetric observations of stars hosting close-in giant planets (eg Moutou et al 2007; Donati et al 2008b) demonstrate that radial velocity fluctuations are easily detectable with ESPaDOnS and NARVAL.

New 2008b observations: This 2008b run will concentrate on 5 stars on which magnetic fields were already detected through previous ESPaDOnS/NARVAL data. We now want to obtain full coverage of the rotation cycle for all 5 stars, and derive the magnetospheric topology from the rotational modulation of the spectropolarimetric Zeeman signatures and accretion proxies. While AA Tau and DG Tau are low-mass slowly-rotating cTTS with low and high

accretion/ejection mass rates respectively, T Tau, SU Aur and RY Tau are high-mass rapidly-rotating cTTS with different accretion/ejection mass rates; this should allow us to retreive independantly the effect of mass/rotation and accretion/ejection rate on the magnetospheric topologies and accretion flows. Note that rotational modulation in photospheric lines and/or in accretion proxies is already detected for all selected targets.
For this project, we need **6hr slots over 16 consecutive nights (ie 100hr of clear time in total) in 2008b** to monitor at least 2 rotation cycles for the longest rotators (AA Tau, DG Tau and RY Tau). In each night, the 6hr observation slots will be used to collect (i) 1 polarisation sequence for AA Tau and DG Tau with a total exposure time of 4×1200s for each star, and one polarisation sequence for RY Tau with a total exposure time of 4×400s; (ii) two polarisation sequences for T Tau and SU Aur bracketing those of AA Tau, DG Tau and RY Tau, each with a total exposure time of 4×400s, ensuring that short term rotational modulation over one night is also monitored for these faster rotators. Our targets are observable for most of the night from late October to late December.
Completing this Large Program will require 100hr of clear NARVAL time for each of the nine forthcoming semesters (2008b to 2012b, 900hr of clear time altogether) to observe in conjunction with ESPaDOnS@CFHT.

Figures: Illustrating figures can be obtained from the full text of the ESPaDOnS Large Program at `http://www.ast.obs-mip.fr/users/donati/magics/v1/young-lp.pdf`

Publications:

Alencar SHP, Basri G, Hartmann L, Calvet N, 2005, A&A 440, 595
Bouvier J, Alencar SHP, Harries TJ, Johns-Krull CM, Romanova MM, 2007, in Protostars and Planets V, eds. Reipurth B, Jewitt D and Keil K, University of Arizona Press
Donati JF, Semel M, Carter BD, Rees DE, Cameron AC, 1997, MNRAS 291, 1
Donati JF, Jardine MM, Petit P, Bouvier J, Menard F, Dougados C, Gregory S, Cameron AC, Harries T, Jeffers SV, Paletou F, 2007, MNRAS 380, 1297
Donati JF, Jardine MM, Gregory S, Petit P, Paletou F, Bouvier J, Dougados C, Menard F, Cameron AC, Harries T, Hussain GAJ, Unruh Y, Morin J, Marsden SC, Manset N, Auriere M, Catala C, Alecian E, 2008a, MNRAS in press (astro-ph 0802.2052)
Donati JF, Moutou C, Fares R, Bohlender D, Catala C, Deleuil M, Shkolnick E, Cameron AC, Jardine MM, Walker GAH, 2008b, MNRAS in press (astro-ph 0802.1584)
Donati JF, Howarth JF, Jardine MM, Petit P, Catala C, Landstreet JD, Bouret J-C, Alecian E, Barnes JR, Forveille T, Paletou F, Manset N, 2006, MNRAS 370, 629
Gregory SG, Jardine MM, Simpson I, Donati JF, 2006, MNRAS 371, 999
Jardine MM, Cameron AC, Donati JF, Gregory SG, Wood K, 2006, MNRAS 367, 917
Jardine MM, Gregory SG, Donati JF, 2008, MNRAS in press (astro-ph 0802.2213)
Johns-Krull CM, Valenti JA, Hatzes AP, Kanaan A, 1999, ApJ 510, L41
Long M, Romanova MM, Lovelace RVE, 2007, MNRAS 374, 436
Moutou C, Donati JF, Savalle R, Hussain G, Alecian E, Bouchy F, Catala C, Cameron AC, Udry S, Vidal-Madjar A, 2007, A&A 473, 651
Romanova MM, Ustyugova GV, Koldoba AV, Lovelace RVE, 2004, ApJ 610, 920
Setiawan J, Henning T, Launhard R, Muller A, Weise P, Kurster M, 2008, Nature 451, 38
Symington NH, Harries TJ, Kurosawa R, Naylor T, 2005, MNRAS 358, 977
Valenti JA, Johns-Krull CM, 2004, ApSS 292, 619

Justify the nights

In 2008b, we need 6 hrs on 16 consecutive nights to correctly monitor the rotation cycle of all stars. This is equivalent to 7 full winter (ie 14hr) nights.
AA Tau, DG Tau and RY Tau will be observed once per night and we will cover 2-3 successive rotation cycles in order to be able to disentangle rotational modulation from intrinsic variability.
SU Aur and T Tau will be observed twice per night to improve phase coverage (given their shorter rotation period) and detect surface differential rotation.
Observing both at CFHT and TBL is crucial to obtain as dense as possible a coverage of the rotational modulation of photospheric and emission lines.

Relevant previous Allocations: Yes

13 half nights were allocated on a similar program in 2007b (also coordinated with ESPaDOnS). However, the CFHT time was totally lost to bad weather, while the NARVAL observations (on T Tau and RY Tau mainly) were only fragmentary. NARVAL data are being analysed now and will be published in conjunction with the 2008b data requested here.

No additional remarks

Observation details

Telescope: TBL

Narval Instrument details

Observing mode: POL3 (polarimetry R=65000)

Required scheduling constraints

observe simultaneously with ESPaDOnS observations - presumably in Dec08, all stars being at RA=4-5hr.

we need 6hrs of observing on 16 consecutive nights to adequately monitor at least 2 rotation cycles of all stars.

No preferred scheduling constraints

Field	RA	Dec	Epoch	Exposure (min.)	Moon	Seeing	Water	S/N	Magnitude	Comments
AA Tau	04:34:55.40	+24:28:53.1	J2000	80	bright	>0.9	don't care	90	12.8	Prot=8.2d
RY Tau	04:21:57.40	+28:26:35.5	J2000	40	bright	>0.9	don't care	200	10.2	Prot=5.7d
T Tau	04:21:59.40	+19:32:06.4	J2000	80	bright	>0.9	don't care		10	Prot=2.8d
DG Tau	04:27:04.70	+26:06:16.3	J2000	80	bright	>0.9	don't care	90	12.8	Prot=6.3d
SU Aur	04:55:59.30	+30:34:01.5	J2000	80	bright	>0.9	don't care		9.4	Prot=2.8d