X-shooter Science Verification Proposal

Title: Magnetospheric accretion and X-ray emission in the CTTS V2129 Oph

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Abstract:

We plan to obtain medium resolution UV+VIS+NIR spectra of the young star V2129 Oph over 2 rotational periods (P_{rot}=6.53 days) in order to determine the geometry and physics of the magnetically-controlled accretion flow between the inner disk and the stellar surface. These observations will be coordinated with *Chandra* X-ray and ESO+CFHT magnetic field measurements in order to investigate the origin of X-ray emission and the role played by magnetic fields in young stars. For the first time, X-shooter will provide a full UV-VIS-NIR spectral coverage together with X-ray observations of a young star, thus allowing us to trace simultaneously the accretion shock at the stellar surface (X+UV), accretion funnel flows between the inner disk and the star (VIS), and the structure of the rotating inner disk edge (NIR). In particular, we will explore the relationship between magnetospheric accretion and its relative contribution to X-ray emission. We request a total of 2.7h on X-shooter, spread over 13 consecutive nights late June 2009.

Scientific Case:

Classical T Tauri stars (CTTSs) represent a key transitional period in the life of a star, between the embedded protostellar phase and the main sequence stage. They are low mass pre-main sequence stars that accrete material from dusty circumstellar disks. They possess strong (∼kG) magnetic fields, which truncate the disk and force in-falling gas to flow along the field lines. Material rains down onto the stellar surface, where it produces hotspots that emit in the optical, UV, and X-ray wavebands. **Magnetospheric accretion** is the preferred framework under which the main characteristics of CTTSs can be described (e.g. Bouvier et al. 2007a). It is a complex theory in which the stellar magnetic field interacts with the disk, thus controlling mass accretion, the evolution of the stellar angular momentum, and affecting the structure of the magnetically confined corona. However, the processes by which CTTSs interact with their disks and how this influences the stellar X-ray emission, remains poorly understood.

Magnetospheric accretion theories have traditionally used simple stellar dipolar fields for CTTSs. However, Zeeman Doppler imaging studies show that CTTSs can possess complex multipolar surface fields (Donati et al. 2007). These more complex topologies can distort the field close to the star, affecting the X-ray emission as well as the amount of open field in the system – and therefore also the efficiency with which angular momentum can be lost from the system (Gregory et al. 2008). In order to study magnetospheric accretion in stars with complex fields in depth we will conduct the first multi-wavelength campaign to map the magnetic field, accretion and X-ray emission in the CTTS V2129 Oph.

The proposed medium resolution spectral observations of V2129 Oph more specifically aim at investigating the relationship between magnetically-controlled accretion in young stars and X-ray emission (from near-simultaneous *Chandra* observations). V2129 Oph is known to have a strong and complex surface magnetic field that interacts with its inner accretion disk (Gregory et al. 2008). X-ray emission is expected to arise both from the plasma-loaded magnetic loops and from the accretion shock at the stellar surface (Jardine et al. 2008). We will measure and map surface activity and derive the structure of its accretion region by monitoring spectral variations over 2 rotational periods (P_{rot}=6.53 d). Time has been granted for this campaign with Chandra on June 27-30, and on CFHT/ESPADONS, ESO/CRIRES, ESO/HARPS and

KPNO/Echelle in June-July 2009. While **X-shooter** provides a lower spectral resolution (R∼10,000) than HARPS, CRIRES or ESPADONS, its instantaneous wavelength coverage from UV to NIR is unique. Access to the UV range in particular (Balmer jump and higher Balmer series, CaII) is crucial as it traces the visibility and activity of the accretion shock at the stellar surface. The visible range contains numerous diagnostics of accretion funnel flows and inner winds (lower Balmer lines, HeI, NaD), and the near-IR spectrum probes the inner disk edge (Paschen series, CO lines). In addition, veiling, i.e., continuous emission from the accretion shock, can be measured on X-shooter spectra continuously from UV to NIR, thus yielding the accretion shock temperature and luminosity. In parallel, the Chandra observations will yield high resolution spectra that should allow us to disentangle the coronal emission from the accretion component.

We plan to monitor V2129 Oph over 2 rotational periods ($P_{\rm rot}$=6.53 d) with X-shooter. V2129 Oph is a CTTS in the ρ Ophiuchi cloud, at a distance of 120pc. In most respects this is a typical CTTS of spectral type K3.5 with a mass accretion rate of $10^{-8}M_\odot yr^{-1}$. Several reasons make V2129 Oph the best suited target for our study. It is a bright (V=11.38) CTTS which suffers little extinction (A_V∼0.6 mag), has a precisely known rotation period ($P_{\rm rot}$ =6.53d), and has a favourable inclination angle (i∼50deg). Most importantly, V2129 Oph is one of the few CTTS for which a magnetogram has already been published (Donati et al. 2007). At each rotational phase, we will measure veiling and emission line strength over the UV-NIR range and investigate the variability of the line profiles. From the observed time variability of the accretion/ejection diagnostics, the structure of the rotating magnetospheric accretion region will be reconstructed all the way from the inner disk to the accretion shock (cf. Bouvier et al. 2007b). Simultaneous (or quasi-simultaneous) ESPADONS and CRIRES observations will yield a magnetic map of V2129 Oph's surface, while the higher resolution (R=115,000) line profiles from HARPS will offer additional insight into the fine structure of the accretion funnel flows. Simultaneous observations with Chandra will allow us to isolate the contribution of the accretion shock to the X-ray emission.

This is, to our knowledge, the first coordinated multi-wavelength campaign on a T Tauri star that includes (quasi-)simultaneous UV, optical, NIR and X-ray spectra. X-shooter data enable accurate measurements of accretion diagnostics (e.g., the shock temperature and luminosity) that are essential to building accurate models of magnetospheric accretion. This approach promises to address the fundamental causes behind the energetic and highly variable X-ray emission from young stars and will provide the most accurate determination to date of the structure of the magnetospheric accretion region of a young star interacting with its disk. The X-shooter observations should preferably be obtained as close as possible to the *Chandra* observations scheduled on June 27-30, but the magnetic field is stable on the timescales of 3-4 weeks (Bouvier& Appenzeller 1992; Donati et al. 2007) so that observations any time in June 2009 are acceptable.

REFERENCES: Bouvier & Appenzeller 1992, AAS 92, 481; Bouvier et al. 2007a, Protostars and Planets V, p.479; Bouvier et al. 2007b, A&A 463, 1017; Donati et al. 2007, MNRAS 380, 1297; Gregory et al. 2008, MNRAS, 389, 1839; Jardine et al. 2008, MNRAS 386, 688

Calibration strategy:

No special needs are required for calibration, besides the standard calibration plan for ESO/X-shooter (telluric and spectrophotometric standards). We will ask to observe once during the run a bright K5 template dwarf, which will be used as a reference spectrum in order to measure veiling on V2129 Oph's spectra.

Targets and number of visibility measurements

Target	**RA**	**DEC**	**V** mag	**Mode** (slit/IFU)	**Remarks**
V2129Oph	16 27 40.32	-24 22 02.7	11.4	slit (0.8, 0.7, 0.6″)	P_{rot}=6.53 days

Time Justification:

The rotation period of V2129 Oph is 6.53 days. Ideally, we would like to cover 2 rotational phases (13 days) to monitor the spectral accretion/ejection diagnostics at all rotational phases with some redundancy. A minimum of 7 consecutive nights is required to cover a full rotation cycle. **Note that the target is not observable before June 10 or after June 30, due the nearby bright moon.**

We will use X-shooter at a resolution of 6200, 11000, and 8100 in the UV, VIS and NIR ranges respectively, with corresponding slit widths of 0.8, 0.7 and 0.6 arcsec. For a K7, V=11.4 target as V2129 Oph, an exposure time of 120s (2*60s) in UV will yield S/N=50 at 400nm and 150 at 500nm, under average seeing conditions. In the visible range, a total exposure time of 60s (4*15s) will yield S/N of 100-200 over the whole range. In the NIR, an AB sequence with a total exposure time of 120s (4*30s) provides S/N$\geq$300 over JHK.

The longest exposure is in the UV range, with 2*(60s + 19s 1x1 fast read-out) = 158s. Adding overheads (570s for pointing-acquisition-slit, 30s for 2 telescopes offsets AB), the total exposure time per spectrum is 758s. We ask for a spectrum being taken every night over 13 consecutive nights, leading to a request of 13*758s = 2.7 hours of X-shooter observations near end of June. In case the SV run does not last for 13 nights, a viable alternative would be to obtain 2 spectra per night separated by a few hours over 7 successive nights.

Strategy for Data Reduction and Analysis:

Our team consists of experts in every aspect of this proposal including: accretion and surface imaging, stellar magnetic fields, coronal modelling and X-ray analysis.

All the X-shooter spectra will be reduced using either its specific reduction pipe-line if available or our own echelle spectroscopy tools. Spectral analysis will be done with specific tools we have developed to characterize the variability of spectral lines, search for periodic patterns resulting from the rotational modulation of the accretion diagnostics (line profiles, veiling), and reconstruct surface maps. These tools have been successfully applied on e.g. HARPS data for the CTTS AA Tau (Bouvier et al. 2007b).

Science Verification bonus:

Besides providing unprecedented insight into the magnetospheric accretion process in young stars, the proposed observations will be most suitable for X-shooter's Science Verification. As we will acquire (quasi-)simultaneous high resolution spectra of the same object over the same timescale with ESO/HARPS, ESO/CRIRES and CFHT/ESPADONS, the performances of X-shooter can be compared relative to these well-characterized instruments. By degrading the spectral resolution of HARPS and ESPADONS spectra in the optical, and of CRIRES spectra in the infrared down to the spectral resolution of X-shooter, a detailed comparison between the output of the various instruments can be performed.