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UVMAG: A UV+VISIBLE SPECTROPOLARIMETER TO STUDY STELLAR MAGNETOSPHERES

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Abstract. In the last decade magnetic fields have been detected in basically all types of stars. These discoveries gave rise to innovative studies on the mapping of magnetic fields and on their impact on stellar environment. To go even further, the UVMag international consortium proposes to combine UV and visible spectropolarimetry. The UV domain allows us to study stellar winds, while the optical domain allows us to study the stellar surface. With UV and visible spectropolarimetry we can then study magnetospheres as a whole and do this over a complete stellar rotation period thanks to a space mission. UV and visible spectropolarimetry can of course also address many other stellar physics issues.

Keywords: ultraviolet, spectropolarimetry, magnetospheres, stellar winds

1 The UVMag consortium

The UVMag consortium has been created in 2010 to discuss, design and promote space UV and visible spectropolarimetry. The goal is to propose a mission dedicated to stellar physics and in particular magnetospheres. The idea is based on the recent success of ground-based optical spectropolarimeters combined with the use of archival UV data. The consortium is led by France, with collaborations from Belgium, Brazil, Canada, Germany, Ireland, the Netherlands, Sweden, Switzerland and the USA.

2 Science drivers: stellar physics

We propose to study the formation, structure, evolution and environment of all types of stars in particular through the measurement of their magnetospheres, i.e. through the association of spectropolarimetry and spectroscopy in the UV and visible domains. The UV domain is crucial in stellar physics because it is particularly rich in atomic and molecular transitions, and covers the region in which the intrinsic spectral distribution of hot stars peaks. The UV lines are the least influenced by non-LTE effects in stellar photospheres and are thus most useful e.g. for quantitative abundance determinations. The lower levels of these lines are less likely to depopulate in low density environments such as chromospheres, circumstellar shells, stellar winds, nebulae and the interstellar medium, and so remain the only useful diagnostics in most of these environments. Another advantage of observing in the UV is the extreme sensitivity of the Planck function to the presence of small amounts of hot gas in dominantly cool environments. This allows the detection and monitoring of various phenomena that would otherwise be difficult to observe: accretion continua in young stars, magnetic activity, chromospheric heating, corona, starspots on cool stars, and intrinsically faint, but hot, companions of cool stars. The UV domain is also the one where Sun-like stars exhibit their hostility (or not) to Earth-like life, population 0 stars must have shone the brightest, accretion processes convert much kinetic energy into radiation which strongly impacts stellar formation and evolution, the "Fe curtain" features respond to changes in local irradiation, etc.

In addition, most of cool stars and a fraction of hot stars are magnetic and their magnetic field interacts with their wind and environment, modifies their structure and surface abundances, and contributes to the transport of angular momentum. With spectropolarimetry, one can address with unprecedented detail these important

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issues in stellar physics, from stellar magnetic fields to surface inhomogeneities, surface differential rotation to activity cycles and magnetic braking, from microscopic diffusion to turbulence, convection and circulation in stellar interiors, from abundances and pulsations in stellar atmospheres to stellar winds and accretion disks, from the early phases of stellar formation to the late stages of stellar evolution, from extended circumstellar environments to distant interstellar medium. Moreover, measuring polarization directly in the UV wind-sensitive lines has never been done, and would be extremely useful in order to trace the polarization along the field lines. Finally, polarimetry is not restricted to magnetic fields only. The scope of stellar polarimetry is much broader, in particular with respect to circumstellar processes.

The spectropolarimetric capability, both in the UV and visible wavelength domains, will therefore nicely complement the spectrograph to multiply tenfold the capabilities of extracting information on magnetospheres, winds, disks, and magnetic fields. The UV+visible spectropolarimeter will consequently provide a very powerful and unique tool to study most aspects of stellar physics in general and in particular for stellar formation, structure and evolution as well as for stellar environment.

The long-standing as well as new questions in stellar physics will be answered by studying various types of stars: O stars which exhibit very strong clumpy winds, Of?p stars which have very specific spectral characteristic probably related to their magnetic field, active B stars which associate various extreme physical processes, Be stars which are very rapidly rotating and undergo outbursts producing a circumstellar disk, γ Cas stars which emit unexplained variable X-ray flux, Ap/Bp stars which host very strong fossil magnetic fields, A stars that are very weakly magnetized, δ Scu and γ Dor stars which pulsate, roAp stars in which magnetic field and pulsations interact strongly, Herbig Ae/Be stars which are the precursor of main sequence Ap/Bp stars, intermediate-mass T Tauri stars which cover the transition from a fully convective star to a radiative star, classical T Tauri stars which are still accreting mass, weak-lined T Tauri stars which have stopped accreting but have not yet reach the main sequence, solar-type stars with dynamo magnetic fields, young and old Suns to be compared with our Sun, cool supergiants which offer the possibility to study small-scale dynamos, M dwarfs which exist on both side of the full-convection threshold, red giants, planetary nebulae and post-AGB stars which represent later stages of stellar evolution, stars in the Magellanic Clouds which are in a different environment in terms of metallicity, and binaries which probe additional ingredients in stellar evolution and undergo tidal effects.

In addition to stellar physics, several additional science topics could be investigated with no or little changes in the proposed project. This includes for example studies of the ISM, white dwarfs, or novae. Moreover, our project could be enhanced to also study other topics, e.g. exoplanetary magnetospheres. In this example, polarization signals of the order of 10^{-4} (for hot Jupiters) or less (down to 10^{-11} for Earth-like planets around solar-like stars) would be required, i.e. a very high signal-to-noise and very low instrumental polarization.

3 The space mission

3.1 Concept

To observe in the UV domain, as well as to reach faint stars and weak magnetic fields, it is necessary to collect the requested observations from space. In addition, we wish to obtain long continuous spectropolarimetric time series of a number of targets, which is hampered from the ground when the variability period is close to 1 day or a fraction/multiple of 1 day or when the weather does not cooperate over long periods of time (rotation periods can be up to several weeks). Finally, simultaneous spectropolarimetric observations in the UV and visible domains would provide information on the wind and polarization properties at the same time, providing new insights into certain phenomena such as magnetospheric confinement or chromospheric activity. We therefore propose to study a concept of a space spectropolarimeter working in the UV and visible domains. It could be installed either on a medium-size space mission dedicated to solving a number of stellar physics issues and available for long-term monitoring of stars, or on a Large UV and Visible space Observatory (LUVO) with which better statistics could be reached and the spectropolarimeter could benefit other science topics besides stellar physics. However, more instrumental flexibility and complexity might then be needed, e.g. a MOS/IFU mode or an imaging mode, and the instrument availability might not allow as many long time series as a dedicated mission would.

3.2 Scientific requirements for the instrument

The scientific requirements currently considered for the instrument are summarized in Table 1.

Table 1. Basic scientific specifications currently considered for the instrument. The minimal requirement is given, as well as the objective.

Specification	Requirement	Goal
Spectral range	117-320 + 390-870 nm	90-1000 nm
UV resolution	25000	100000 and 2000
Optical resolution	35000	80000
UV S/N	100	200
Optical S/N	100	300
Polarization	V in lines	QUV in lines + continuum
Instrumental polarization	3%	1%
Accuracy in radial velocity	1 km s^{-1}	0.3 km s^{-1}
Target magnitude	$V = 3 - 10$	$V = 2 - 15$
Targeted stars	50	100
Time per targeted star	4 weeks	6 weeks (4+1+1)
Survey stars	4000	8000
Time per survey star	20 min	30 min
Mission duration	4 years	12 years

Table 2. Number of available targets per spectral type, according to Simbad (CDS). An estimate of the number of magnetic stars is also given, according to the approximate statistical occurrence of magnetic fields in each type of targets. Numbers are also given for some examples of rare types of objects. The numbers are given for the minimal magnitude requirement and goal.

Spectral type	$V = 3 - 10$	$V = 2 - 15$	Magnetic rate	Magnetic $V = 3 - 10$	Magnetic $V = 2 - 15$
O	428	1823	6%	26	109
B	19940	42891	6%	1196	2573
A	53143	102442	20%	10629	20488
F	61867	105487	50%	30934	52744
G	55780	97365	50%	27890	48683
K	88358	121052	50%	44179	60526
M	10276	18367	50%	5138	9184
Be stars	1225	1705	1%	12	17
Herbig Ae/Be	44	60	10%	4	6
M dwarfs	94	693	50%	47	347

To measure the line and Stokes profiles, we should obtain spectropolarimetric data with a high resolution. In addition, to fulfill our goals we need to reach a high signal-to-noise ratio and therefore to observe bright stars. We also wish to reach fainter stars to be able to observe certain rare classes of stars (such as M dwarfs or Herbig Ae/Be stars) and to probe other environments, e.g. the Magellanic Clouds. Thus our dynamical range needs to be very large.

Moreover, we would like to point in any direction in the sky, to reach any interesting target. We wish to observe once several thousands of stars of all types forming a statistical survey. We also require to be able to remain stably pointed on a shorter list of stars (targeted objects) continuously for 2 rotation cycles. Such time series document phenomena on stars that can be impulsive (flares, infall), periodic (pulsations, rotational migration of spots, corotating clouds), quasi-periodic (evolution of blobs from hot winds), and gradual (evolution of spots). While some hot stars rotate very fast (of the order of 1 day), other targets have rotation periods of several weeks. In Table 2 we considered that on average the rotation period is 2 weeks. The mission duration derives from this mean rotation period and the number of targets, at least 4 years. A mission of 12 years would not only allow to study 2 times more targeted and survey objects but to probe stellar magnetic cycles (similar to the 22-year solar cycle).

Precise radial velocity is requested for example for Doppler Imaging of active binary systems or probing the redshifts of high temperature emission lines in the subcoronal atmospheres of cool stars.

Polarization in Stokes V in spectral lines is the minimum requirement to be able to infer magnetic properties. However, polarization in QUV would allow full 3D mapping of the magnetospheres and linear polarization (QU) would also allow us to measure other physical processes such as depolarization from a circumstellar disk, probing scales well beyond what is feasible with interferometry. In addition, polarization of the continuum would be very useful to study dusty environments, providing important information about e.g. star forming regions or protostars.

4 Ongoing activities

Previous UV instruments (e.g. IUE, STIS or FUSE), combined to ground-based optical spectropolarimetry, have provided valuable data for the first studies of stellar magnetospheres. HIRDES on the future WSO would also provide the instrumental capabilities needed to address the scientific rationale exposed here. However, these instruments are either unavailable anymore or available for too short periods of time to perform a time series over a full stellar rotation cycle. This is why we need a new UV spectrograph.

In addition, ground-based optical spectropolarimeters provide important datasets for all types of bright stars. However, there are no space high-resolution stellar spectropolarimeters, to reach fainter targets and to obtain continuous timeseries. Moreover, UV spectropolarimetry cannot be achieved from the ground. There are already several ongoing projects in this field in the optical (e.g. for SST, Solar Orbiter or SPEX), but not in the UV. Therefore, in the frame of UVMag, a Research & Technology (R&T) study funded by the French space agency CNES has just started at the IRAP and LESIA laboratories, to design a space-based high-resolution UV and visible spectropolarimeter.

5 Conclusions

The UVMag consortium has set the basic requirements for a space mission to study the magnetospheres and winds of all types of stars. Simultaneous UV and visible spectropolarimetry over long periods of time is indeed the only way to comprehend the full interaction between the stellar magnetic field and stellar wind. This is the next step to progress on the characterization and modeling of the formation, structure, evolution and environments of stars.

The UVMag project is described in the more detailed documents available on the UVMag website[i].

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[i] http://lesia.obspm.fr/UVMag