PhD project in Astrophysics

Characterising the magnetic fields of the class I and FS protostars

Thematics:

Protostars ; Stellar physics ; Stellar magnetism ; Spectropolarimetry ; Stellar tomography

Abstract:

Magnetism is an essential ingredient in the formation of stars. It plays an important role in the star multiplicity, disk (hence planetary) formation, rotational evolution, and the protostellar evolution. While magnetism has been well explored in the pre- and post-protostellar phases of star formation, little is known about the magnetic properties during the proto-stellar phase, i.e. during the phase the star builds up, and the protoplanetary disk forms. The proposed PhD project aims at filling this gap by analysing a set of near-infrared spectropolarimetric data obtained with the new instrument SPIRou (installed at the Canada France Hawaii Telescope). The student will have access to a set of pipelines for the analysis that he will have to adapt for the specificities of protostars. She/He will then be able to characterise for the first time the magnetic properties of protostars, to compare them to models developed within the ANR PROMETHEE collaboration, and to conclude on the origin and impact of protostellar magnetic fields.

Context:

During the star formation, from the collapse of the molecular cloud down to the newly formed main-sequence star, it is necessary to extract a large quantity of magnetic field and angular momentum. Otherwise, only very massive stars would form, and planets would not exist. Even after their formation stars must continue to lose angular momentum to understand the rotation rate (of the Sun and stars) we observe. Magnetic field is known to play an important role in the angular momentum regulation. This has been especially well studied for two of the three main phases of star formation: the core-collapse (CC) phase in molecular clouds, and the pre-main-sequence phase (PMS). **The protostellar phase (between the CC and PMS phases) has however been poorly studied until now.**

Indeed, during the core-collapse phase, recent models allowed to follow the magnetic field from the molecular cloud to the newborn protostar (Vaytet et al. 2018). Millimetric observations of pre- and proto-stellar objects allow to measure the large-scale magnetic flux evolution in their envelope and to constrain the models. On the other side, during the last stage of stellar formation (the PMS phase), the magnetic properties of the T Tauri stars are now well constrained (Villebrun et al. 2019, Nicholson et al. 2021). It is however not clear what are the magnetic properties of newborn protostars inherited from the CC phase. How they affect the following protostellar evolution, and how they evolve during the protostellar and PMS phases, remain open fundamental questions (Donati et al. 2008; Moss 2003, Alecian et al. 2019).

To fill this gap, we are conducting a dedicated **observational survey of a large sample of protostars** with the instrument SPIRou[1] recently installed at the Canada France Hawaii Telescope (CFHT). SPIRou is a high-resolution spectropolarimeter working in the near-infrared domain. It allows to measure the intensity and circularly polarised spectra of the observed sources. Our program aims at detecting for the first time the magnetic fields in protostars, and at characterising those detected (i.e. determining their strength and topology). Complementary observations will be obtained for Southern sources with a similar instrument, CRIRES+[2] installed at the Very Large Telescope (VLT,ESO).

The PROMETHEE project:

---

[1] https://spirou.omp.eu/

[2] https://www.eso.org/public/teles-instr/paranal-observatory/vlt/vlt-instr/crires+/

The PROMETHEE[3] project (Protostellar Magnetism: Heritage vs Evolution) has been recently selected by the French Research Agency (ANR), and has started in February 2023. Its main objective is to explore the origin and impact of magnetism in protostars. To this aim we will measure for the first time the magnetic and magnetospheric properties of protostars, and will confront them to accretion/ejection models developed by our collaborators in IPAG, but also to new MHD dynamo models of magnetic protostars that will be developed by us within PROMETHEE in Paris and Lyon.
SPIRou data of about a dozen of class I and FS sources have been recently obtained. A preliminary analysis allows us to detect unambiguously magnetic fields in five sources. These first results are in accordance with what we expected, and are therefore promising for the pursuing of our project. Additional data are currently being acquired to detect more magnetic protostars, while new data have been requested to the telescope to monitor the magnetic sources, necessary for magnetic mapping.

PhD objectives and methods:

The proposed PhD project will focus on the analysis of the infra-red spectropolarimetric data obtained with SPIRou and CRIRES+ within the PROMETHEE project. The objectives are:

- Producing magnetic maps at the surface of the protostars, and estimating the large-scale toroidal and poloidal magnetic fields, using the Zeeman Doppler Imaging technique (ZDI, Kochukhov et al. 2013,2016).
- Estimating the large-scale magnetic strength limit in the protostars in which no magnetic field has been detected (as in Villebrun et al. 2019)
- Estimating the total magnetic flux at the surface of the protostars thanks to the Zeeman effect affecting some magnetic-sensitive spectral lines of the Stokes I spectra (Kochukhov et al. 2020b)
- Compare the results to the dynamo models developed within the PROMETHEE project, and conclude on the origin of the protostars magnetic fields.

The student will have access to existing codes for the analysis and modelling of the data, and will have to adapt some of them to the specificities of protostars. The codes are coded in various languages, including fortran, c++, python, and IDL. The student will have to convert some of them in python for a broader usage, and to develop a python pipeline for a smooth and semi-automatic analysis of SPIRou and CRIRES+ data for protostars, so that the analysis of the full observed sample can be efficient.

Work environment:

The supervisor will be Evelyne Alecian[4], expert in stellar magnetic fields of young and/or massive stars. In addition, the data analysis, and the CRIRES+ observations acquisition, will be done in collaboration with Oleg Kochukhov[5] (Uppsala Univ., Sweden), expert in ZDI and magnetic analysis of stellar objects. To this aim the student will do one or several visits of a few weeks at the University of Uppsala.
The student will join the PROMETHEE collaboration, and will profit from regular meetings and exchanges with experts in stellar magnetism, stellar formation, and magnetic star-disk interaction in young stars. The student will also join the ODYSSey[6] team specialized in stellar formation, very active in the analysis of young stellar objects, and gathering a large number of students and post-docs. The IPAG[7] institute the student will join is one of the largest astrophysical research institutes in France, with an international reputation in various domains of astrophysics, from planetology, to AGN, through interstellar medium, compact objects, exoplanets, and young stellar objects.

---

[3] https://promethee-anr.github.io
[4] https://promethee-anr.github.io/#Team
[5] https://www.astro.uu.se/~oleg/
[6] https://ipag.osug.fr/english/research/research-teams/odyssey
[7] https://ipag.osug.fr/?lang=en

The student will benefit of a three-year CNRS doctoral contract, and will have to register every year for the doctorate school of Physics of the University Grenoble Alpes[8] (annual registration fee ≈ 400 euros). The monthly salary will be about 1350 euros. It includes the social security health insurance taking care of about 70% of health costs, as well as other social security benefits. For additional information on the PhD rules in France: https://www.campusfrance.org/fr/FAQ-doctorat-France-questions. If desired, the student will have the possibility to perform academic teaching.

Risks and constraints:

Potential missions of observation in international observatory at high altitude (>2500 m).

Duration: 36 months

Required qualification: Master in astrophysics

Required skills:

- Solid knowledge in stellar physics, spectroscopy, and quantum mechanics
- Programming (python, ideally)
- Correct speaking and reading English
- Curiosity and open-mindedness

Application documents:

- CV
- Master 1 and Master 2 report card marks (M1: 1st and 2nd terms, M2: 1st term)
- Letter of motivation
- 2 letters of recommendation
- A copy of a manuscript of an academic thesis/dissertation written by the candidate

Mandatory application procedure:

On-line application on the CNRS job portal:
https://emploi.cnrs.fr/Offres/Doctorant/UMR5274-EVEALE-001/Default.aspx?lang=EN

Contact:

Evelyne Alecian
IPAG – Université Grenoble Alpes
414 rue de la piscine
38400 Saint-Martin d'Hères
France
evelyne.alecian@univ-grenoble-alpes.fr

Bibliography:

Bouvier, J. ; 2017, MmSAI 88, 587
Frank, A. ; 2014, Protostars & Planets VI, 451
Kochukhov, O. ; et al. ; 2013, A&A 2526, A550
Kochukhov, 0. ; et al. ; 2016, LNP 914, 177
Nicholson, B. A. ; Hussain, G. ; et al. ; 2021, MNRAS 504, 2461
Vaytet, N. ; Commerçon, B. ; et al. ; 2018, A&A 615, A5
Villebrun, F. ; Alecian, E. ; et al. ; 2019, A&A 622, A72
Wurster, J. ; Li, Z.-Y. ; 2018, FrASS 5, 39

[8] https://doctorat.univ-grenoble-alpes.fr/doctoral-college/doctoral-schools