M2 internship

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Detecting and measuring magnetic fields in class I protostars

Context

To explain the rotational and magnetic properties of known stellar and planetary systems, it is necessary to extract a large quantity of magnetic field and angular momentum during their formation. Those well-known angular momentum and magnetic flux problems (Hennebelle & Teyssier 2008 ; Mestel et al. 1965), have been intensely 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). We now understand that to be able to extract enough, but not too much, magnetic flux and angular momentum it requires the interplay of several processes: turbulence, radiation, rotation and magnetic field (McKee & Ostriker 2007). Fundamental questions remain however still open, and in particular during the protostellar phase (between the CC and PMS phases), which has been poorly studied until now.

During the first and second core collapse (Larson 1969), magnetic flux transport is regulated via non-ideal magneto-hydrodynamical (MHD) effects (Wurster & Li 2018), which affect the coupling between the gas and magnetic field (Marchand et al. 2016). It is however not clear what are the magnetic properties of newborn protostars (2nd Larson core) inherited from the CC phase. How they affect the following protostellar evolution, whether they persist or affect the dynamo processes during the protostellar and PMS phases, remain open questions (e.g. Donati et al. 2008; Moss 2003).
Angular momentum (AM) regulation is done via magnetic braking in the collapsing envelope (Hennebelle & Fromang 2008). During the PMS phase, AM regulation continues via magnetic interaction between the stars and their disks (Bouvier et al. 2007b; Gallet & Bouvier 2013; Pantolmos, Zanni & Bouvier 2020). At the same time, the magnetic field is thought to drive the powerful jets and outflows observed at all stages where a young star is actively accreting, i.e. mostly during the protostellar phase (Frank et al. 2014). Our knowledge in magnetic properties in protostars is currently very limited as only two of them are known to be magnetic (Johns-Krull et al. 2009, Flores et al. 2019). A dedicated observational study of a large sample of protostars is therefore necessary, and is now feasible thanks to the French instrument SPIRou recently installed at the Canada France Hawaii Telescope (CFHT), and thanks also to the SPIRou observing program that has just been selected for this topic.

The project

The PROMETHEE[1] project (Protostellar Magnetism: Heritage vs Evolution) has been recently selected by the French Research Agency (ANR), and will start 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 advanced 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.

As of today (October 2022), we have obtained pilot observations of three class I protostellar objects. 10 more will be observed between November 2022 and February 2023. The work of the proposed

[1] https://promethee-anr.github.io

internship will consist in (i) analyzing these data using existing tools but that will require to be translated in python, (ii) in interpreting the data to obtain the fundamental parameters of the stars, and to measure their magnetic fields through Zeeman effect in the Stokes V spectra, and (iii) to compare the results to what is expected in case of a fossil field (i.e. flux conservation) between the end of the collapse and the beginning of the T Tauri phase. While unlikely, if no new data are acquired before the beginning of the internship, the current data will be enough to develop the tools and perform primary analysis. Following the achieved results, the work performed during the internship may be published in an Astronomy & Astrophysics paper.
A linked PhD project will be proposed (check frequently the PROMETHEE website[1]).

Duration: 3 to 6 months

Required qualification: Master of physics

Required skills:
- Basic knowledge in stellar physics and spectroscopy
- Programming (python, ideally)
- Curiosity and open-mindedness

Work environment:

The student will join the ODYSSey[2] (Origin of Disks and Young Stellar Systems) team of the IPAG institute, which has a long history and a solid international reputation in the study of star formation and young stellar objects. The IPAG institute hosts about 70 researchers who address all phases of stellar and planetary formation, including about 20 scientists studying the physical processes implied in accretion/ejection processes around young stellar objects. The student will have the opportunity to interact with members of the ODYSSey team, but also with French and international collaborators, expert in stellar magnetism, protostars, and star formation, but also in the SPIRou instrument.

Contact:

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More information on:

Protostars: White R.J. et al., 2007, Protostars and Planets V, 117
Measuring magnetic fields in cool stars: Kochukhov O., 2021, A&AR 29, 1
Angular momentum problem: Mestel L., 1965, QJRAS 6, 161
Magnetic flux problem: Hennebelle P. & Teyssier R., 2008, A&A 477, 25
Theoretical understanding of star formation: McKee C. F. & Ostriker C. F., 2007, ARA&A 45, 565

[2] https://ipag.osug.fr/english/research/research-teams/odyssey/