Origin and dynamics of magnetized filaments

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Project duration: 2 years in Chile + 1 year in China

Abstract:
The formation and evolution of magnetized filaments is a hot topic in current investigations of the interstellar medium (ISM), with a particularly high relevance for our understanding of star formation. Observations have pointed towards a bimodal distribution in the alignment of magnetic fields and filamentary clouds (Li et al. 2013), with recent results suggesting that clouds with perpendicular magnetic fields have consistently lower specific star formation rates (star formation rates per unit mass). The Orion A cloud, the most nearby high-mass star-forming region, is known to have a helical magnetic field structure (Heiles 1987; Bally 1989; Heiles 1997), and recent measurements of the gas and stellar dynamics suggest an oscillation of the filaments, which is needed to explain the enhanced velocity dispersion in the stars compared to the gas (Stutz & Gould 2016). As we demonstrated through analytic estimates, this oscillation of the filament can be driven by the effect of magnetic tension, consistent with both the observed field strengths and the required timescale of the oscillation (Schleicher & Stutz 2017). Through stellar dynamical simulations, we further demonstrated such such an oscillatory motion indeed explains the observed kinematics of the stars (Boekholt et al. 2017).

In this project, our goal is to further explore the underlying physics that are responsible for the observed correlations. It consists of two main parts:

<u>1) Exploration of the origin of magnetic structures in filaments:</u>
To explore the origin of the initial bimodal distribution, we will run magneto-hydrodynamical simulations of decaying turbulence with self-gravity, using a modern magneto-hydrodynamics code like Enzo (Bryan et al. 2014) or FLASH (Fryxell et al. 2000). In these simulations, we will vary the initial turbulent Mach number and the initial plasma beta (ratio of magnetic-to-thermal energy), as well as the initial properties of the turbulence, which can be predominantly compressive, predominantly solenoidal, both of which may or may not include helical components. The thermodynamics of the gas will be initially modeled with a piece-wise polytropic equation of state, which is initially isothermal and gets closer to adiabatic in the high-density regime.

Using this setup, we will then follow the decay of the turbulence and investigate the structures that form, with a particular emphasis on self-gravitating filaments and the properties of their magnetic fields. Specifically, we will check if that naturally leads to a bimodal distribution between filament structure and field alignment, as found in the observational studies by Li et al. (2013). In addition, we will check whether the magnetic field structures are predominantly aligned or perpendicular, or if (and how frequently) they also include helical configurations, as found in Orion, but also in other filaments (observational studies in this respect are still limited, as combined measurements of polarization and the Zeeman effect need to be employed). From this study, we expect to learn which magnetic field structures can be expected in filaments given a turbulent ISM.

2) Evolution of filaments:

The second part of the project concerns the evolution of filaments and their magnetic field structures. Particularly, we want to address how the magnetic field structures affect star formation in the filament, and if they can drive oscillatory motions, as suggested from the observed kinematics in Orion A. For this purpose, we will use both idealized initial conditions as proposed by Seifried & Walch (2015), but also filaments that have dynamically formed through our previous simulations in part 1 of the project. Our numerical setup will be extended to include sink particles, which represent small ensembles of protostellar clumps, and allow us to infer star formation rates from the simulations. An examination of the dynamics of these systems in particular will allow us to test how the specific star formation rate correlates with magnetic field structures in the cases considered here, thereby providing a direct test if the employed physics are sufficient to reproduce the observational results. In addition, while following the dynamics particularly in filaments with helical and/or axial fields, we can check if oscillatory motions similar to the integral shaped filament in Orion A can be found. The second part of the project thus provides the crucial link from filament structures to star formation. It further allows to test if protostellar clumps are ejected from the filaments through their dynamics, thereby providing a natural mechanism to disconnect them from their gas supply.

As the main results, we expect at least one publication based on the first half of the project, which will explain if bipolar magnetic field structures are consistent with a turbulent ISM. The second half of the project may lead to two publications, one exploring the connection between magnetic field structures and the star formation rate, and one focusing on the oscillations of filaments.

Scientific Justification:

The project proposed here will answer fundamental questions on the physics of star-forming filaments. While observations provide a number of first indications on filaments and their magnetic properties, the theoretical investigations of such structures are just at the beginning. In our team, we unify the expertise on magneto-hydrodynamical simulations of star-forming filaments with the known observed properties of filaments, that will further be complemented through ongoing observational efforts.

Chile-China connection:

The project is ideally suited to foster the China-Chile connection. With Prof. Hua-Bai Li as a Chinese partner who plays a leading role in the investigation of magnetized filaments, we are in an ideal position to directly compare the simulations that will be pursued in Concepción with current observational results. This connection is further strengthened via Prof. Amelia Stutz and Dr. Hongli Liu, who are actively collaborating with Prof. Li and thereby strengthen the China-Chile connection. The project proposed here will extend this work through a theoretical component, ensuring that observations and simulations are pursued within the same team.