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EDITED AND REVIEWED BY
Konstantinos Tassis,
University of Crete, Greece

*CORRESPONDENCE
Siyao Xu,
sxu@ias.edu

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Editorial: Multi-scale magnetic field measurements in the multi-phase interstellar medium

Siyao Xu[1]*, Alex Lazarian[2,3], Martin Houde[4] and Thiem Hoang[5]

[1]Institute for Advanced Study, Princeton, NJ, United States, [2]University of Wisconsin-Madison, Madison, WI, United States, [3]Centro de Investigación en Astronomía, Universidad Bernardo O'Higgins, Santiago, Chile, [4]Western University, London, ON, Canada, [5]Korea Astronomy and Space Science Institute, Daejeon, South Korea

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Editorial on the Research Topic
Multi-scale Magnetic Field Measurements in the Multi-Phase Interstellar Medium

Despite the ubiquity and importance of cosmic magnetic fields, their measurements are very challenging. The contributions to this Research Topic include reviews and articles on recently developed novel techniques and improved traditional techniques of measuring magnetic fields in the interstellar medium, supernova remnants, molecular clouds, star-forming regions, and on the roles of (turbulent) magnetic fields in star and disk formation and cosmic ray propagation.

The progress made in magnetohydrodynamic (MHD) turbulence theories enable the development of new techniques of measuring turbulent magnetic fields. Their application to the observables in diverse astrophysical environments further improves our understanding on turbulence and magnetic fields. Turbulence induces fluctuations in magnetic fields, synchrotron intensity, and polarized synchrotron intensity. Both, Zhang and Wang and Shimoda discuss probing turbulent magnetic fields with synchrotron emission. Zhang and Wang review the recent development on the Synchrotron Fluctuation Technique. When polarization measurements are available, the application of the polarization spatial analysis (PSA) to diffuse synchrotron emission and the application of the polarization frequency analysis (PFA) to a point source observed at multiple frequencies can reveal the underlying properties of MHD turbulence in both diffuse astrophysical media and high-energy astrophysical systems. With only synchrotron intensity measurements available, the synchrotron gradient technique provides a promising way to map magnetic field orientations in faint radio sources detected by current and next-generation radio telescopes (e.g., LOFAR, SKA).

The turbulent magnetic fields in supernova remnants (SNRs) are important for understanding the confinement and acceleration of cosmic rays (CRs), and the synchrotron emissions from the accelerated electrons. Shimoda reviews the recent investigation on the magnetic field structure in SNRs obtained by the radio synchrotron polarimetry and the statistical properties of turbulent magnetic fields in SNRs diagnosed by a new method using the spatial two-point correlation analysis of synchrotron intensity. The latter, in combination with the future X-ray atomic line observations, can impose observational constraint on the CR injection efficiency at the shock.

Turbulent magnetic fields play an important role not only for the shock acceleration of CRs, but also for their propagation in interstellar media (ISM). In the multiphase ISM, with turbulence-induced density and magnetic fluctuations, the Alfvén speed can have a significant spatial variation. By using a large ensemble of compressible MHD turbulence simulations, Beattie et al. studies the effect of the spatially varying Alfvén speed on the transport of streaming CRs, which can have their streaming speed close to the Alfvén speed. The turbulence-dependent propagation of streaming CRs has important implications on modeling the macroscopic diffusion coefficient of CRs in the complex ISM.

Mapping the magnetic fields in molecular clouds and star-forming regions is essential for quantifying their roles in star formation. The principal way of tracing magnetic fields in such regions is based on the polarization of thermal emission and absorption by aligned dust grains. The alignment of dust grains is far from trivial, and its understanding for decades presented one of the astrophysical puzzles of the longest standing. The solution came as the RAdiative Torques (RATs), which were identified as the dominant alignment mechanism, and Analytical MOdel (AMO) was introduced to describe the process of grain alignment. It is important to note that RATs not only align grains but also can disrupt grains by centrifugal stress, which consitutes a newly discovered effect called RAdiative Torque Disruption (RAT-D). The latter effect occurs as aligned grains get into the critical rotational state with centrifugal stress exceeding the binding energy of grain constituents. The alignment and disruption of grains by RATs produce key signatures on dust polarization, which were observationally tested. Tram and Hoang review these important developments in both theory and observational studies, and discuss the broader implications of the RAT paradigm on dust evolution, time-domain astrophysics and astrochemistry.

On the plane-of-sky component of magnetic field orientations in the ISM and molecular clouds, Liu et al. review the advances, limitations, and applications of the Davis-Chandrasekhar-Fermi (DCF) technique of obtaining magnetic field strength, as well as recently developed Histogram of Relative Orientations (HRO) and the polarization-intensity gradient (KTH) method. It is pointed out that the energy non-equipartition can be the biggest uncertainty in the DCF. The angular dispersion function (ADF) accounts for the beam-smoothing effect, interferometric filtering effect, and the ordered field structure. The differential measure approach (DMA) represents a recent important improvement of the DCF. Compared to the DCF, the KTH method has the advantage that it does not require the information on the velocity dispersion, but more tests are required for its uncertainty. Tahani reviews the progresses recently achieved in improving the observational techniques in measuring either the line-of-sight component or the plane-of-the-sky component of magnetic fields, and their integration to obtain 3D ordered magnetic fields. The forthcoming Zeeman measurements, Faraday rotation measures, starlight polarization observations, and their synergy hold a great promise in providing 3D magnetic fields of many molecular clouds.

Down to smaller scales, Maury et al. review the progresses made in the past decade on the properties and roles of magnetic fields in shaping young protostars, their envelopes, disks, and stellar systems. The recent progresses made in both observations and simulations enable detailed confrontation between observed protostellar properties and magnetized model predictions and improved understanding on the roles of magnetic fields in star and disk formation.

This Research Topic provides the reader the recent progresses and new insights in both the methods of measuring multi-scale magnetic fields and their importance in studying diverse astrophysical problems.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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