Plasma properties in Galaxy with SPA

Investigating the plasma properties in Galactic turbulence with synchrotron polarization II: trans-Alfvénic and Multi-layer regimes

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In Short

- Synchrotron Polarization Analysis (SPA) provides a novel perspective to unveil the plasma properties of Interstellar medium
- The multi-wavelength comparison between SPA and other observational data has updated our understanding of Galactic diffuse medium
- We propose to exploit the potential of SPA further with numerical simulations
- Propose numerical tests on higher Alfvenic Mach number MHD datacubes with SPA
- Numerical tests on measuring multi-layer Galactic turbulence
- Close cooperation with observational experts for realistic simulations

Interstellar medium (ISM) is magnetized and turbulent. The magneto-hydrodynamic (MHD) nature of the interstellar turbulence is indicated by the equipartition of magnetic and thermal energy in ISM. Therefore, the plasma properties of Galactic turbulence (e.g, plasma modes [1–3], Mach number, plasma-β) are important for the proper understanding of physical processes such as Cosmic Ray transport and star formation, etc. Our novel method "Synchrotron Polarization Analysis" (SPA) is the first to unveil the plasma modes composition in Galactic turbulence. The multi-waveband comparison between the detected plasma modes and the Fermi-LAT observation has updated the understanding on the nature of diffuse intense CR emission from Cygnus superbubble [4]. The detected magnetosonic modes have shown a high-consistency with the enhanced CR emission, indicating the vital role that magnetosonic modes play in CR propagation and acceleration. The idea for SPA is demonstrated in Fig. [1], utilizing the 2D synchrotron polarization map. Based on theoretical analysis, we establish the unique feature of the corresponding turbulence properties. Following [4], we have developed SPA with our previous HLRN project bbp00025 (ongoing, until 2020 phase 4). The previous project has allowed us studying in depth the signature for low-MA turbulence. We have achieved robust simulation results that have shown high consistency with theoretical expectations. We start to prepare manuscripts for those good quality results and aim to submit 2 papers to peer-reviewed journal as outcomes of the previous project.

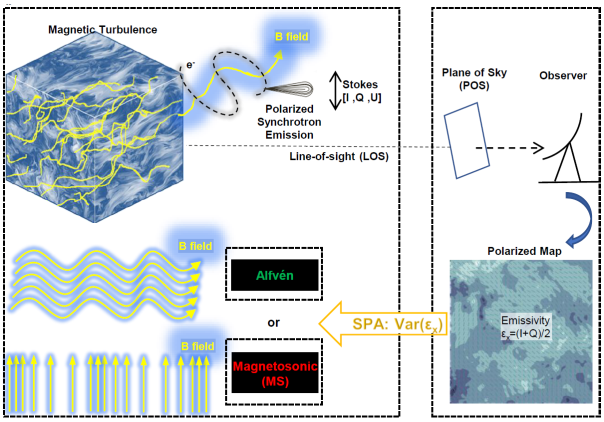

Figure 1: *The schematics for SPA analysis on observations. Relativistic electrons produce the polarized synchrotron emission that carries the plasma statistics, yielding the synchrotron polarized map on POS. Reciprocally, the variance of synchrotron emissivity in the observed map can be used to recover the plasma properties in the original turbulence.*

In this new proposal, we plan to further investigate the SPA method potential in a broader parameter space. The advantage of SPA is to establish the statistical parameters that represent specific plasma properties from synthetic observations on MHD datacubes, which have direct observational application. Two major challenges will be addressed in this proposal. Firstly, we plan to expand our analysis on Alfvénic-Mach number (M_A) from low-M_A regime to trans-M_A regime. As demonstrated in Fig. [2]a, the trend of analytical expectation for r_{xx} is the same as that of higher rotation. We have made a detailed comparison in the Figure 2 of Project Description. Hence, we plan to investigate other observables provided by SPA, as shown in Fig. [1]b. Secondly, we plan to investigate the influence of multi-layer turbulence on the signature production of our analysis.

In preparation for this project, we have performed the MHD simulations in order to obtain turbulence with different properties: including different M_A, plasma β. The MHD simulations have been performed with different forcing mechanism (compressible or solenoidal) so that the energy partition among the plasma modes varies. These prepared MHD datacubes have covered larger range of Alfvénic-Mach number than the previous project. Additionally, we will perform numerical tests on synthetic turbulence datacube directly from analytical equation with a global anisotropy, which will provide us with a benchmark for the derivation of better theoretical description.

We will also utilize this new project to expand the scope of SPA in observational applications. The Galactic medium is composed of multiple phases and the embedded structure can only be revealed by considering the variation of synchrotron emission at with different wavelength. We will cooperate with observational experts on radio astronomy, Prof. X. Sun (Yunnan Univ.) and Dr. X. Gao (NAOC) in order that our simulation can represent better the Galactic turbulence. In our project, we will simulate the polarized radiation from the same medium with different wavelength.

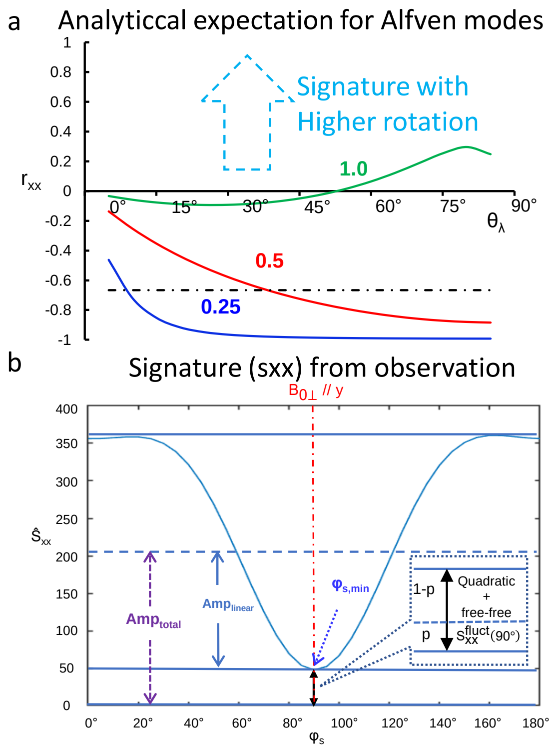

__Figure 2:__ (a) The analytical expectation of r_{xx} with different M_A. The blue arrow indicates the trend of r_{xx} with the same M_A but higher rotation. See in Project Description Figure 2 for a more comprehensive comparison. (b) An example signature (s_{xx}) from observation. The applicable parameters beyond r_{xx} includes axisymmetry, linear amplitude, etc.

In this project, we propose to use numerical simulations with SPA for the following goals:

- Search the applicability of SPA method in higher M_A range;
- Investigate the capability of other classification parameters for diagnosing turbulence properties;
- Understand the multi-layer turbulence with simulation and establish an applicable recipe to analyze it from real observations

In this project, we plan to scan multiple parameter space of MHD turbulence, including its Alfvénic-Mach number ($0.5 \sim 2.0$), plasma-β (low or high regime), forcing mechanism (Compressible or Solenoidal), projection angle (200 randomized lines of sight), filtering scales for the largest and smallest eddies (within the inertial range as well as the gradient of r_{xx} on filter scales), relativistic electron index ($2.0 \sim 3.0$), Faraday rotation ($Var(\theta^{FR}) \in [0°, 100°]$), amplitude of noise from observation, number of turbulence layers etc. In methodology, we will perform simulation on different wavebands and investigate the observables beyond the previous SPA method r_{xx}. Thus, the study will benefit substantially from parallel computing.

We expect to submit 2 publications to peer-reviewed journals for this proposal.

WWW

http://www.unipotsdam.de/astroparticle/plasmaastrophysik.html

More Information

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Project Partners

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