Novel perspective of the Universe: SPA

Instituting the plasma property with Synchrotron Polarization Analysis (SPA)

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In Short

• Synchrotron Polarization Analysis (SPA) is the first method to unveil the plasma modes information of Interstellar medium.

• The multi-wavelength comparison between SPA and Fermi-LAT data has updated our understanding of intensive diffuse CR emission in Cygnus superbubble.

• Apart from the novel perspective SPA has provided, a lot more potential of SPA awaits development by numerical simulations.

• Propose numerical tests to distinguish Fast/Slow modes with SPA.

• Numerical tests on measuring $M_A$ with SPA.

• Identify weak turbulence signature by SPA from observation.

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. The interstellar turbulence can be decomposed into three wave modes: Alfven, fast and slow magnetosonic modes [1–3]. The 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 (see Fig. 1).

The multi-phase nature of ISM and the diversity of driving mechanisms induces the spatial variation of turbulence properties. The advantage of SPA is to establish the statistical parameters that represent specific plasma properties from synthetic observations on MHD datacubes and apply them to the synchrotron polarization data from real observations. For example, it has been demonstrated in previous work that the classification parameter $r_{xx}$ in SPA behaves differently in magnetosonic modes and in Alfvenic modes. Nevertheless, the potential of SPA can be further exploited. We have prepared the MHD simulations in order to obtain turbulence with different properties: including different Alfvenic Mach number $M_A$, plasma $\beta$.

In addition, SPA is a novel method that requires further development. In previous work [4], it has been established that the classification parameter $r_{xx}$ in SPA is dominated by one type (Alfven or magnetosonic) when corresponding plasma modes dominate the turbulence. We want to test numerically the relation between the behavior of $r_{xx}$ and the energy partition of different modes in the turbulence. MHD turbulence datacubes have been prepared with different forcing mechanism (compressible or solenoidal) so that the energy partition among the plasma modes varies.

Moreover, there are two types of magnetosonic modes: fast and slow. Having distinguished magnetosonic modes dominant region in interstellar turbulence in the previous SPA work [4], we plan to perform more detailed analysis on the magnetosonic signature identified. As shown in Fig. 2, both fast and slow modes produce only negative $r_{xx}$. However, the value distribution produced from slow modes differs from fast modes. Therefore, a thor-
Though comparison between the $r_{xx}$ productions from different MHD turbulence data cubes can lead to the discovery of the observational property to distinguish fast/slow magneto-sonic modes.

![Figure 2](image_url): (a–c) Theoretically predicted $r_{xx}$. $M_A$ and the low-/high-$\beta$ regime are specified on the corresponding curves. (d–e) The probability distribution of $r_{xx}$. $x$–axis is the percentage of linear signature $\epsilon_{xx}$. Synthetic observations are performed by tracing 200 randomized lines of sight for each turbulence data cube. The classification in the value space of $r_{xx}$ is labelled with different colors: for “Alfvénic” (Green), for “magnetosonic” (Red). The separations are marked by the dashed lines.

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

- Perform SPA tests on MHD datacubes with different driving mechanisms as well as different plasma properties
- Understand the statistical difference between fast and slow magneto-sonic modes with SPA and establish a recipe to distinguish them from real observations

In order to achieve the aforementioned object, we have prepared MHD simulations to generate datacubes of sub- and trans-Alfvénic turbulence with low- and high- plasma beta from compressible and solenoidal forcing, and decompose these MHD turbulence into 3 linear modes (Alfvén, fast and slow). We will consider non-thermal electrons with a fixed index moving in the decomposed turbulence modes and trace the resulting synchrotron polarization from 1200 different lines of sight. All datacubes’ resolution is 1024, with an inertial range more than a decade (better than the 512, adopted by previous work [4]).

After we perform SPA analysis on those datacubes and achieve the corresponding statistics (e.g., classification parameter $r_{xx}$), we will use probability distribution analysis to study the signatures produced from these observations. We will consider different eddies scales within the inertial range of the turbulence in order to set a proper scale threshold for the analysis on real synchrotron polarization observations.

The analytical results from those numerical simulations will then be applied to synchrotron polarization data observed from different surveys. The plasma properties obtained from those analysis will further be compared with other wavebands (from Hα to γ-ray) in order to investigate the role of turbulence in different physical processes in the universe.

This project will deepen our understanding for the interstellar turbulence. It will provide the observational evidence for the plasma properties of ISM as well as a novel perspective for other physical processes such as CR transport and star forming activities.

**WWW**

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

**More Information**


**Project Partners**

Deutsches Elektronen-Synchrotron (DESY), Zeuthen

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