Novel perspective of the Universe: SPA (Updated)

Updated summary for Investigating the plasma property with Synchrotronn 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, including distinguishing Fast/Slow modes with SPA, measuring M_A with SPA, and identifying weak turbulence signature by SPA from observation
- (Update) Despite HLRN-Berlin was offline for Oct. 2019- Feb. 2020, we have a fully functioning code in new environment.
- (Update) The previous work [4] has been recently accepted by Nature Astronomy. We are currently preparing 2 publications in current project.

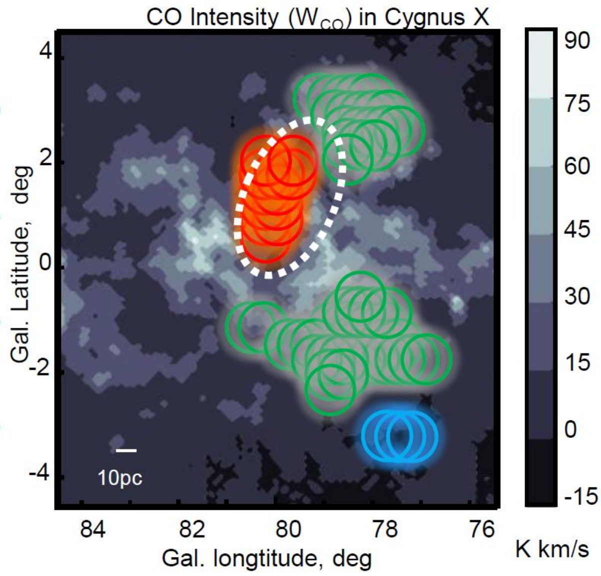

Figure 1: *The multi-wavelength comparison in Cygnus X Region with SPA results, including CO intensity (W_{CO} in $Kkms^{-1}$ unit)[5] (background) and gamma ray observation Cygnus Cocoon from Fermi-LAT survey (in white circle) [6]. The color code for signatures from SPA: Green: "Alfvénic"; Red: "Magnetosonic"; and Blue: "isotropic turbulence". The distance of the object is $1.4kpc$. The spot size is $50pc$. The size of the largest eddy is $\sim 15pc$. It is obvious that the magneto-sonic modes dominant regions have a high-consistency with intense diffuse gamma-Ray emission.*

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: Alfvén, 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 multiphase nature of ISM and the diversity of driving mechanism 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. In addition, SPA is a novel method that requires further development. In previous work [4] (recently accepted by Nature Astronomy), it has been established that the classification parameter r_{xx} in SPA is dominated by one type (Alfvén or magneto-sonic) 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.

SPA has the potential to unveil other plasma properties, including the Alfvénic Mach number of the turbulence, local mean magnetic field, etc. Moreover, there are two types of magneto-sonic modes: fast and slow. Having distinguished magneto-sonic modes dominant region in interstellar turbulence in the previous SPA work [4], we plan to perform more detailed analysis on the magneto-sonic signature identified. It is theoretically expected that the distribution of characterizing parameter in slow modes differs that in fast modes. Therefore, a thorough comparison between the r_{xx} productions from different MHD turbulence data cubes can lead to the distinction of fast/slow magneto-sonic modes observationally. However, the value distribution produced from slow modes differs from fast modes. We plan to perform further investigations on a thorough comparison between the r_{xx} productions from different MHD turbulence data cubes.

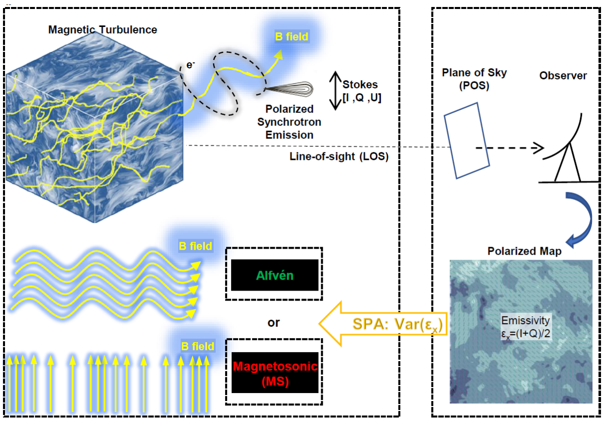

Figure 2: *The schematics for SPA analysis on observations. Relativistic electrons produce the polarized synchrotron emission that carries the plasma statistics, yielding the synchrotron polarized map on POS. Reciprocally, the variance of synchrotron emissivity in the observed map can be used to recover the plasma modes information in the original turbulence.*

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

- Search the applicability of SPA method in more comprehensive parameter space;
- Investigate the capability of other classification parameters for diagnosing turbulence properties beyond the plasma modes;
- Understand the statistical difference between fast and slow magneto-sonic modes with SPA and establish a recipe to distinguish them from real observations

The numerical study we intend to perform is to scan multiple parameter space of MHD turbulence, including its Alfvénic-Mach number $(0.2 \sim 1.0)$, plasma-β (low or high regime), forcing mechanism (Compressible or Solenoidal), dominant modes information (Slow, Fast or Alfvén), projection angle (200 randomized lines of sight), filtering scales for the largest and smallest eddies (within the inertial range), relativistic electron index $(2.0 \sim 3.0)$, inner and foreground Faraday rotation $(0^\circ \sim 100^\circ)$, and amplitude of noise from observation, etc. Thus, the study will benefit substantially from parallel computing.

The execution of this project has encountered great challenge due to the fact that HLRN-Berlin had an update and technical maintenance from Oct. 2019 to Feb. 2020. During this update, no numerical work could be executed, and we lost 90kNPLs in the mean time. When this update was finished, we have modified the code for new environment and currently got a fully functioning code that can run properly and efficiently on HLRN. The parallel scaling efficiency is more than 95%. We are currently aiming to finish 2 publications with this current project.

Another progress is that the leading work before this project has recently been accepted by the journal Nature Astronomy [4]. Therefore, it is perfect timing for the numerical tests proposed by this project. We intend to perform extensive numerical study on SPA in HLRN for the current and incoming season.

WWW

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

More Information

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Project Partners

Deutsches Elektronen-Synchrotron (DESY), Zeuthen

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