Study of ISM trubulence from SPA eye

Investigation of MHD turbulence properties in instellar medium using Synchrotron Polarization Analysis (SPA)

S. Malik[1]***, P. Pavaskar***[1,2] ***H. Yan***[1,2]***,,*** *Institute für Physik & Astronomie, Universität Potsdam; Deutsches Elektronen-Synchrotron (DESY), Zeuthen*

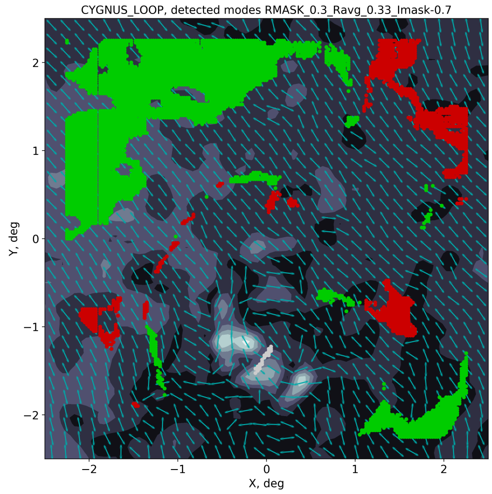

Figure 1: *Plasma-mode decomposition in the Cygnus-loop region using SPA on the 21 cm Effelsberg polarisation data of* $5° \times 5°$ *map. From these primarily result, we noticed that the magneto-sonic modes dominant regions has overlapping region with intense diffuse gamma-Ray emission.*

In Short

- Investigate the decomposition of plasma mode in the interstellar MHD turbulence using Synchrotron Polarization Analysis (SPA) in multi-frequency radio map.
- Unleash the potential of powerful SPA technique by using it in high-resolution MHD cubes and also study the SPA with consideration of Faraday effect in numerical simulations.
- Perform the statistical test on the MHD datacubes to understand the various depolarization mechanisms such as beamwidth, bandwidth and due to small scale magnetic fields.
- The multi-wavelength comparison between SPA and Fermi-LAT data has updated our understanding of particle accerlation in the intensive diffuse CR emission in Cygnus loop.
- Perform the two point correlation of magnetic field fluctuations to understand the fast and slow magneto-sonic modes.

The magnetized and turbulent nature of the astrophysical fluids provides us a good environment to study the magneto-hydrodynamic (MHD) turbulence in our galaxy. The energy contained in the interstellar medium (ISM) turbulence is found to be equipartitioned in the magnetic and thermal energy budget of the ISM. The characteristic length scales of ISM turbulence ranges from a few AU to hundreds of parsecs. MHD turbulence can primarily be decomposed into three modes: Alfvén mode, and the fast and slow magnetosonic modes (also known as magneto-acoustic modes) [1–3]. To identify and characterise these plasma modes in the trubulent galatic medium, the novel method of "Synchrotron Polarization Analysis" (SPA) has been developed by [**?**]. The method was used for the classification of plasma modes and analysis of the plasma properties in Cygnus-X region. The method works by analyzing the polarized emission from synchrotron radiation, which is observed as the Stokes parameters (I,Q,U). This polarized radiation reflects on the fluctuations in the embedded magnetic fields caused due to the turbulence, which in turn allows us to study its properties. With the advent of the SPA technique, we aim to understand the plasma properties in the highly turbulent medium around two supernova remnants in Cygnus-loop regions, through mode classification. Furthermore, we want to combine the analysis from SPA with the Fermi-LAT observations in the $0.1 - 100$ Gev energy range to investigate the strong Cosmic Ray (CR) emission from this region (see Fig. 1 for initial results).

These turbulence affects the particle density as well as the emission, absorption, and propagation of radiation in the ISM, various observational methods, diagnostics and traces have been used in previous studies of the properties of turbulence and/or magnetic fields in the ISM. In a recent work by [4], a new and efficient method has been developed and tested in different turbulent environments in the ISM. The method, named "Synchrotron Polarization Analysis" (SPA), characterized the MHD plasma modes in the Cygnus-x region based on the spatial distribution of variance of the synchrotron emission from the region. They noticed that the main classification parameter r_{xx} in SPA behaves differently in the magneto-sonic and Alfvénic modes, and the corresponding dominating plasma modes also dominate the turbulence. Nevertheless, the potential of SPA can be exploited even further. We want to generate MHD simulations in order to obtain turbulence with different properties:

including different Alfvénic Mach numbers M_A and plasma β. The turbulence in these data-cubes will be driven with different forcing mechanisms (compressible and incompressible/solenoidal) so that the energy partition among the plasma modes varies. We want to test numerically the relation between the behavior of r_{xx} and the energy partition of different modes in the turbulence. We also note that weak turbulence has been observed in previous MHD simulations. It is crucial, therefore, to test SPA in both strong and weak turbulence regimes to produce a complete recipe for the mode-identification in the ISM.

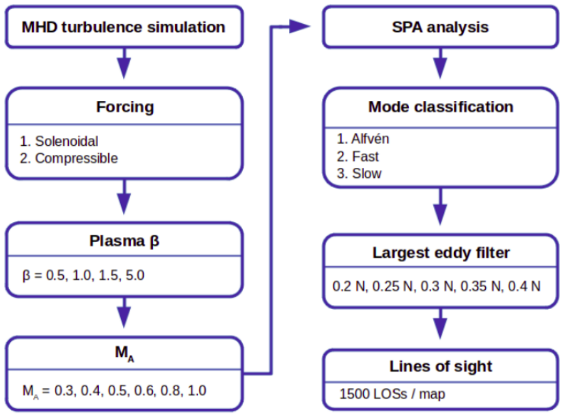

Figure 2: *Flochart of MHD datacubes parameter space along with SPA details.*

In this project, we propose to simulate the MHD datacubes and use them together with SPA for the following goals:

- Perform SPA tests on high resolution MHD datacubes with different driving mechanisms as well as different plasma properties
- Perform statistical tests on the MHD data-cubes to understand the various depolarization mechanisms such as the effect of beamwidth, bandwidth and small scale magnetic fields.

To accomplish the above objectives of understanding MHD turbulence in astrophysical fluids, we intend to use the state-of-the-art MHD code PLUTO to generate solenoidally and compressibly driven turbulence. The use of tow separate forcing mechanism makes it possible to achieve turbulence with different energy partitions among modes. PLUTO solves the conservative laws of MHD using a variety of finite-difference methods. It is especially designed to target high Mach number flows in astrophysics. We will prepare the MHD simulations upto resolutions of 1024^3 with sub- and trans-Alfvénic turbulence, and with low- and high- plasma β. The recently developed method ,SPA, will be employed to decompose MHD turbulence into its 3 linear modes (Alfvén, fast and slow). We will further consider non-thermal electrons with varying spectral indices moving in the decomposed turbulence modes, and trace the resulting synchrotron polarization from 1500 different lines of sight.

In the ongoing efforts to understand the nature of magnetized and trubulent nature of ISM, this project will further deepen our understanding for the interstellar turbulence with high resolution MHD datacubes. It will provide the observational evidence for the theorized plasma properties of ISM, as well as a novel perspective for other physical processes such as CR transport and star formation processes.

WWW

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

More Information

[1] N. Herlofson, *Nature* **165**, 1020–1021 (1950). doi:10.1038/1651020a0

[2] Y. Lithwick, P. Goldreich, *Astrophys. J.* **562**, 279–296 (2001). doi:10.1086/323470

[3] J. Cho, A. Lazarian, *Mon. Not. R. Astron. Soc.* **345**, 325–339 (2003). doi:10.1046/j.1365-8711.2003.06941.x

[4] H. Zhang, A. Chepurnov, H. Yan, K. Makwana, R. Santos-Lima, S. Appleby, *Nature Astronomy* **4**, 1001-1008 (2020) 10.1038/s41550-020-1093-4

[5] K. D. Makwana, V. Zhdankin, H. Li, W. Daughton, and F. Cattaneo *Phys. Plasmas* **22**, 042902 (2015), 10.1063/1.4916492

[6] K. D. Makwana, H. Li, F. Guo, and X. Li *J. Phs.: Conf. Ser.* **837**, 012004 (2017), 10.1088/1742-6596/837/1/012004

Project Partners

Deutsches Elektronen-Synchrotron (DESY), Zeuthen

Funding

This project is funded by the base funds that Prof. Dr. H. Yan received from the DESY institute on her dual appointments as leading scientist at the institute and as professor at the University of Potsdam.