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Observation of MHD modes and its implications on cosmic ray transport

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The interstellar medium is magnetized and turbulent. Magneto-hydrodynamic (MHD) turbulence plays an important role in many astrophysical phenomena. Hence, measuring the plasma properties in the interstellar turbulence is crucial for the proper interpretation of astronomical observations. Most observational studies of turbulence focus on the one-dimensional spectrum in the inertial range. This is inadequate, however, in the case of MHD turbulence, which has three-dimensional (3D) structures and anisotropies (Goldreich & Sridhar 1995). Unlike hydrodynamic turbulence, MHD turbulence can be decomposed into three plasma modes with different dispersion relations and characteristics (incompressible Alfvenic modes, and compressible slow and fast magnetosonic modes). Particularly, the Alfven and slow modes have scale-dependent anisotropy, whereas the fast modes are much more isotropic (Cho & Lazarian 2003, Makwana & Yan 2020). As a result, the scattering of the high energy cosmic rays is dominated by magnetosonic modes (Yan & Lazarian 2002, Lynn et al. 2014). Nonetheless, to analyze the plasma properties from the interstellar turbulence is very challenging.

In this talk, we discuss the identification of different plasma modes in the Galactic interstellar medium (ISM) using our novel method, signatures from polarization analysis (SPA, Zhang et al. 2020). The polarized synchrotron emission is produced when relativistic electrons travel in the interstellar magnetic fields. The signatures of the plasma properties in the interstellar magnetic turbulence are encoded in the synchrotron polarization data. We utilize the fact that MHD turbulence is statistically axis-symmetrical with respect to the direction of local mean magnetic field. Utilizing analytical study and synthetic observations on various turbulence data generated from MHD simulations, the SPA method has established the link between the synchrotron polarization properties and the underlying turbulence statistics associated with different plasma modes. By applying the SPA method to real synchrotron observational data, different plasma modes are identified in the Cygnus X region, as demonstrated by Figure 1. Through multi-wavelength comparison, we have found a high consistency between the identified magneto-sonic modes and the enhanced diffuse gamma-ray emission identified by Fermi-LAT and HAWC. We demonstrate that it is important to consider the plasma properties of the ISM when studying the cosmic ray propagation.

References

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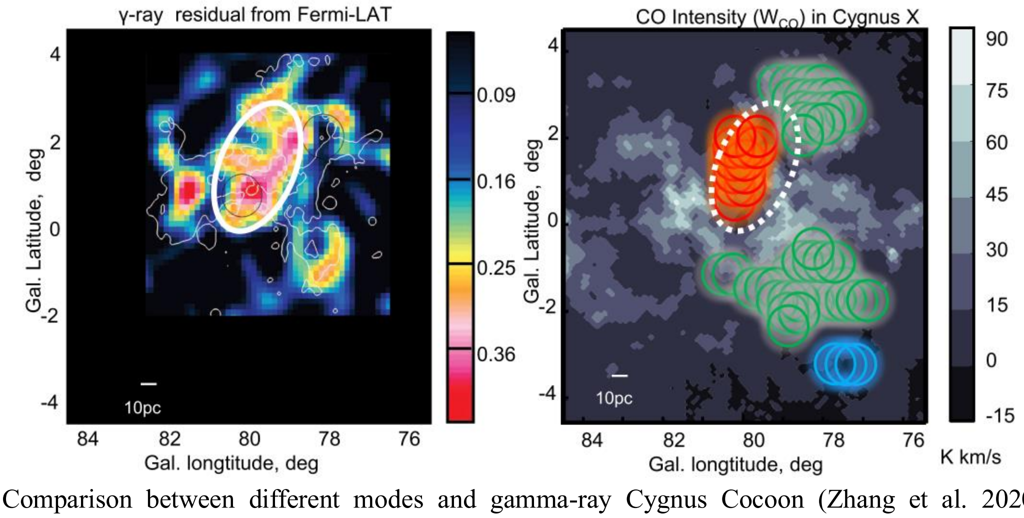

Figure 1. Comparison between different modes and gamma-ray Cygnus Cocoon (Zhang et al. 2020). *Left:* An illustration forthe photon count residuals of gamma-ray emission from Fermi-LAT showing the extended emission excess, the "Fermi cocoon" (in white circle, Ackermann et al. 2011). *Right:* Turbulence modes identified in Cygnus X region plotted over the CO intensity contour (background, Dame et al. 2001). Color codes of the circles indicating the dominant plasma modes by - Red: magnetosonic modes; Green: Alfven modes; Blue: isotropic signatures.