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Investigating hadronic PeVatrons with X-ray and CO observations

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In the recent (sub-)PeV gamma-ray astronomy, we can pinpoint locations of Galactic PeV cosmic-ray accelerators, known as PeVatrons, as LHAASO has detected 43 sources with E>100 TeV. Such ultra-high-energy (UHE) photons likely originate from protons, since the Klein-Nishina effect would suppress leptonic gamma-ray emission. Some of these UHE sources are poorly explored in other wavelengths, making them "dark" sources without any known counterpart. Here, we report our extensive campaign of multiwavelength observations of hadronic PeVatron sources.

First, X-ray observation can be a new diagnostic tool to probe protons. The proton-proton interaction (which emits hadronic gamma rays) produces charged pions that decay into muons and subsequently into electrons. These secondary electrons from PeV protons are energetic enough to produce synchrotron emission, which can be tested in the X-ray band. We apply this X-ray emission model to observational data (e.g, HESS J1641-463 and the Cygnus bubble) and demonstrate the detectability with future observations and missions.

Second, radio observation of molecular line emission is also crucial for probing hadronic PeVatrons. An extensive survey of CO counterparts in the UHE sources is currently underway using the Nobeyama 45-m radio telescope. We report our first investigation of LHAASO J0341+5258, which detected some molecular clouds and allowed us to infer physical parameters such as distance and density. We will discuss the origin of the gamma rays, combined with newly taken X-ray data by XMM-Newton.

With these new results, we present the importance of multiwavelength observations to understand the origin of PeVatrons.

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