"Mirage" and large offsets in the data as a result of asymmetric CR diffusion

Yiwei Bao (byw19952008@163.com)
Co-author: Gwenael Giacinti, Ruo-yu Liu, Hai-ming Zhang, Yang Chen

Nanjing University 1902

Tsung-Dao Lee Institute

Abstract

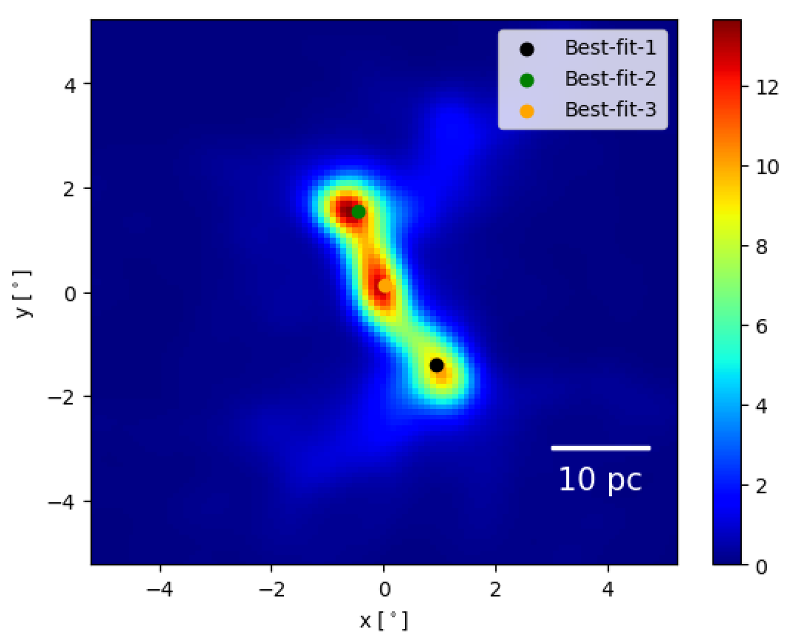
We show that a large asymmetric halo may be misidentified as multiple "mirage" sources, and that asymmetric diffusion could lead to a very large offset between the injection site and the identified halo. We add background noise into the region and try to identify the sources. We utilize the concept of asymmetric diffusion to elucidate several observed sources that were previously challenging to interpret. Our model offers intuitive explanations for these observations and has the potential to help identify a broad range of sources in the future.

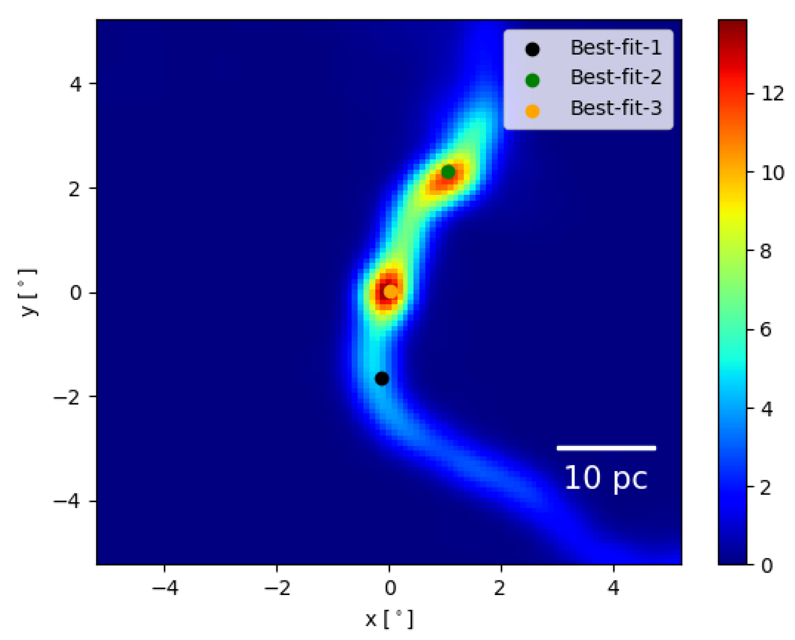
1. Methods

We utilize a first-principle method, injecting electrons into a chaotic magnetic field. Their motion is dictated by the Lorentz force. The field is represented as a sum of $N_{\rm m}$ plane waves. i.e., $\boldsymbol{B}(\boldsymbol{r}) = \sum_{n=1}^{N_m} A_n \epsilon_n \exp(i\boldsymbol{k}_n \cdot \boldsymbol{r} + i\beta_n)$. The simulations implement a maximum time step of 1/100 of a gyration period and account for synchrotron/IC losses. To mimic the continuous injection of electrons, we inject $\approx 10^4$ numerical particles continuously over time with energy $\gamma(t_{\rm inj}) = \int_{t_{\rm age}}^{t_{\rm inj}} \left[\dot{\gamma}_{\rm sync}(\gamma) + \dot{\gamma}_{\rm IC}(\gamma)\right] + 100\,{\rm TeV}/m_e c^2$. This ensures they are all cooled down to 100 TeV at time $t_{\rm age}$. We assume the halos are observed by LHAASO KM2A, yielding a PSF of 0.3° at 20 TeV. Using three times the γ-ray luminosity of the Geminga pulsar as a benchmark. We use a background noise consistent with the Crab Nebula region, results in 1 event/hour within a 1° cone (In all figures shown, the noise has been removed). For smoothing, we apply a PSF of 0.3°. The fraction of total counts in each bin is computed by summing the Gaussian of 10240 numerical particles in each observation bin (of 0.1°). We employ the on-off method for analyzing these observational counts as is used by LHAASO collaboration.

2. Multiple sub-halos

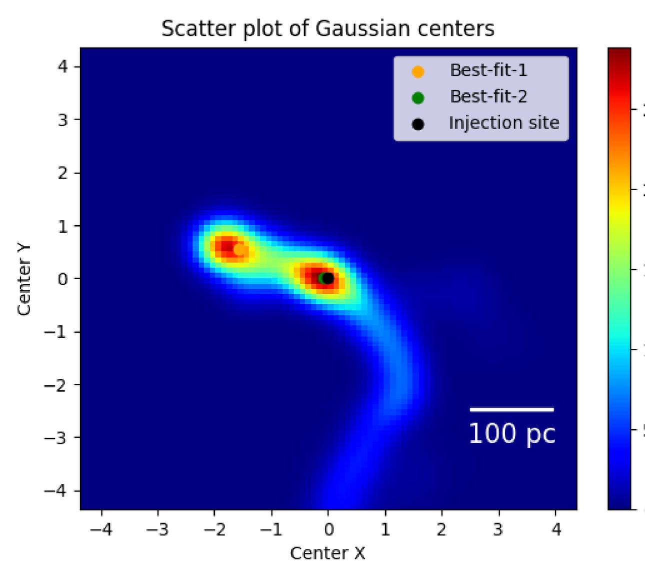
a single large halo could potentially be misinterpreted as triple halos. The existence of mirage source may be the origin of the multiple-halos 1LHAASO J0206+4302u and 1LHAASO J0212+4254u. Mirage sources form when electrons diffuse along large-scale magnetic field lines. These magnetic field lines bend at a scale comparable to the coherence length. When these bent field lines align roughly with our line of sight, a projection effect occurs, causing electrons to accumulate and produce a mirage source, and therefore, the separation between the primary source and the mirage source is comparable to the coherence length.

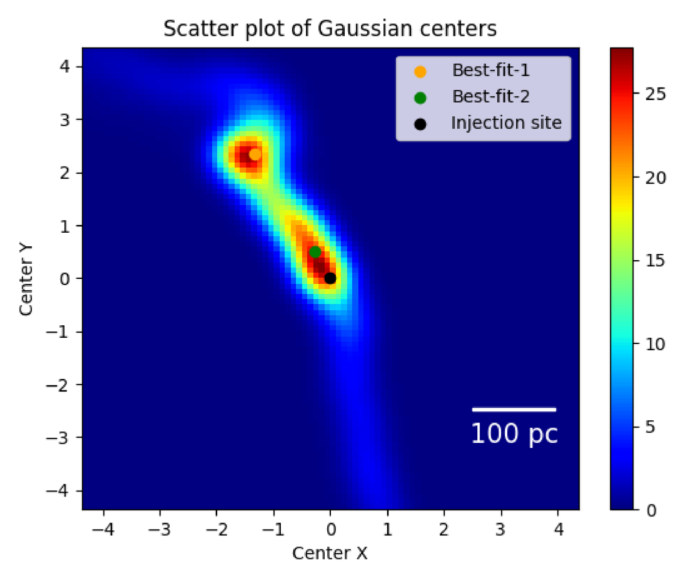




3. Application to 1LHAASO J0206+4302u and 1LHAASO J0212+4254u

We show two configuration which can reproduce the 1LHAASO J0206+4302u and 1LHAASO J0212+4254u. The offset from 1LHAASO J0206+4302u to the millisecond pulsar J0218+4232 can be attributed to the BSPWN whose tail can extend for tens of pc before gets destroyed by neutral mass loading. The fluid speed in the tail of is comparable to c and therefore the electron density inside the BSPWN tail is extremely low, and therefore the tail can hardly be seen. When the tail is destroyed, the velocity of the tail is slowed down the actual injection happens.





4. Large offsets

If the primary halo is dimmer than its adjacent halos – a phenomenon that can arise when the magnetic field weakens to around 1 μG, thereby reducing the cooling efficiency as increase the larmor radius (and the diffusion coefficient)– the main halo might become elusive. As a result, the only detectable halo could be the brighter adjacent one. For each, we put the sources at a distance of 1 kpc, and the parameters are set to $L_{\rm c} = 200$ pc, $B_{\rm r} = 0$ and $B_{\rm t} = 0.5\,\mu$G. Using this model, the offsets observed in many TeV halos, such as 1LHAASO J0542+2311u and 1LHAASO J0635+0619, can be naturally accounted for.