Building an environment-sensitive synthetic TeV halo catalog for HAWC and SWGO observations

Lucas de Sá, Franziska Leitl, Vikas Joshi

May 2023

TeV halos are the product of inverse Compton scattering of the electrons and positrons from a pulsar's wind nebula, for which age- and $\dot{P}$-dependent analytical models for their gamma-ray spectrum have already been established from observations by HAWC in the northern sky. As the age of a pulsar is not an observable, it needs to be indirectly estimated, most often being approximated to the object's characteristic age, $\tau_{\rm ch} = P/2\dot{P}$

Population synthesis, either of binaries or isolated stars, has in the past decade shown itself to be an efficient way of modeling physical populations of astronomical objects from the observed populations and better-constrained star/binary formation and evolution models. They proved to be an important tool for predicting gravitational observations before the first gravitational observatory runs, and today are used to constrain formation and evolution models from observations. Crucially, these codes can also generate representative pulsar populations, where each object will have a well-defined $\dot{P}$ and an exact age $\tau_{\rm synth}$.

We propose here the implementation of the (binary and single star) population synthesis open-access code `COMPAS` for generating pulsar populations that can be used to make predictions for the observation of TeV halos, particularly for the future SWGO. The gamma-ray spectrum can be modeled from the pulsar parameters generated by `COMPAS` with the existing HAWC models, which, due to isotropy, should be valid for the southern sky as well. For a simple local population, a synthetic sample of TeV halos allows for the evaluation of the effect of approximating the pulsar age (equal to $\tau_{\rm synth}$) to $t_{\rm ch}$ in pre-existing HAWC observations.

For a detailed Milky Way star-formation history or extragalactic populations, metallicity, star formation rate and redshift-dependent initial conditions allow for more accurate predictions of the production of TeV halos and their observation. Further, taking into account the pulsar spatial distribution and beaming fraction can provide a more precise relation between actual and observed populations.