Discovery Prospects for TeV Halos and Physics Implications

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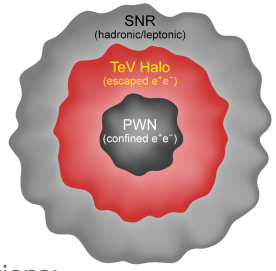
Introduction

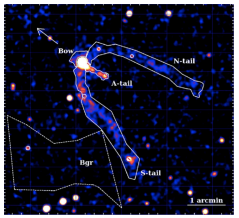
- The discovery of TeV Halos[1,2] introduced a lot of excitement (~150 participants at this workshop!)
- The ATNF catalog is often used to study the detection prospects, but it biases predictions toward pulsars that have radio and/or gamma-ray detection.
- We produced systematic population studies to show the detection prospects for TeV halos.

How To Define TeV Halos?

- **TeV Halos** are produced by particles escaped from the PWN and whose transport is determined by pure diffusion

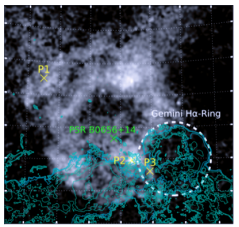


- This picture matches observations:
- **Geminga (330 kyr)** has a bow-shock PWN (well-defined boundary) much smaller than the TeV halo[3]



(Posselt et al. 2017)

- **PSR B0656+14 (110 kyr)** is still inside the parent SNR ("Monogem Ring") much larger than the TeV halo[3]



(Knies et al. 2018)

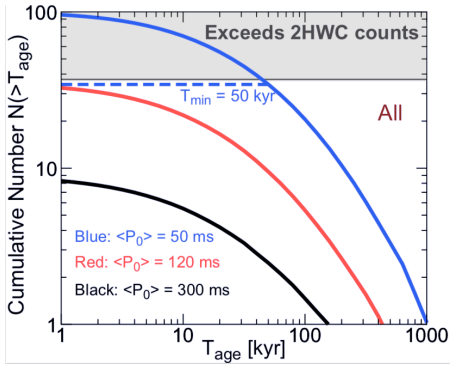
- This definition is motivated by:
- Confined and escaped particles experience substantially different physical conditions.
- Escape of particles from sources is needed to the understanding of cosmic rays observed at Earth.

Population Model

- Standard method for pulsar population synthesis
- Distribution of P_0 (initial spin period) is important but very uncertain[4]
- Introduce a parameter $T_{\rm min}$: typical pulsar age when a TeV halo forms
- Assign TeV halos for all pulsars older than $T_{\rm min}$
- Assume every TeV halo have a gamma-ray efficiency of Geminga halo ($L_\gamma/\dot{E}$ is fixed)

Current Survey

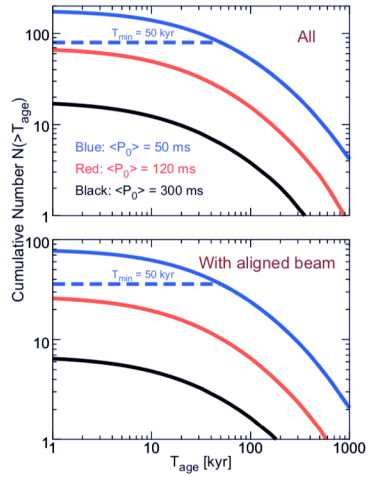
- We predict the number of TeV halos and distribution of associated pulsar age detected in 2HWC survey



- This includes sources that have a radio pulsar beam not aligned toward Earth. Only about ~30% of these halos should be observed with the associated pulsar.
- We can constrain the P_0 distribution and $T_{\rm min}$
- The HESS GP survey should have detected ~ 3 - 40 (for $T_{\rm min}$ = 50 kyr) TeV halos, which may constitute a fraction of PWNe and UNID sources.

Future Survey

- We predict the number of TeV halos that will be detected in ten years of HAWC observations
- For $T_{\rm min}$ = 50 kyr, we expect ~ 8 - 80 detections, of which ~ 3 - 40 are associated with pulsars.
- If we extrapolate our model to $T_{\rm min}$ = 1 kyr, then we expect ~ 20 detections even with the pessimistic case of $\langle P_0 \rangle$ = 300 ms.
- The number counts and age distributions of TeV halos can be used as a new probe of the P_0 distribution.



- Prospects under different definitions of halos[5] should correspond to the case of large $T_{\rm min}$
- CTA may potentially observe ~ 30 - 160 TeV halos in the Galaxy and also could detect TeV halos in LMC.

Summary and Related Work

We modeled population of TeV halos, phenomenologically taking into account the age dependence of halo formation. We quantified their importance in current and future surveys. We also showed that they can provide a new probe of pulsar properties at birth. See our paper for details: arXiv:1902.08203 (PRD, 2019).

In a more recent paper (arXiv:2005.08982) we have explored the implications for the galactic radio emission. Currently we are working on theoretical modeling of UHE gamma-ray sources detected by HAWC in terms of PWNe/TeV Halo interpretations.

Discussions are welcome: sudoh@astron.s.u-tokyo.ac.jp

References : [1] Abdo et al. 2009, [2] Abeysekara et al. 2017, [3] Linden et al. 2017 [4] Faucher-Giguere & Kaspi, 2006; Watters & Romani, 2011 [5] Giacinti et al. 2020 Early theoretical developments in e.g., Aharonian (1995, 2004, 2013), and Yüskel et al. 2009.