Supernova Remnants as PeVatron candidates by CTA observations

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Outline of my thesis

- AGN flares simulation (with Jonathan Biteau)
  - flare duty cycle simulation for CTA
  - already presented in SF2A meeting
- PeVatrons with CTA (with Tiina Suomijarvi)
  - SNRs as Pevatron candidates
  - work in progress, presented in CTA WG meetings
- Analysis of the first CTA data when the first LST in operation (November 2018)?
Outline

- Introduction
  - VHE gamma-ray and CTA observatory
  - PeVatron and proton-proton collision
  - Supernova Remnant
- SNRs spectrum and CTA sensitivities
  - DC-1 data, Prod3b, and ctools
    - Our results
- Radiation mechanism for SNRs
  - naima python package
    - Our results
- Conclusions
Cherenkov Telescope Array

Small-sized telescopes: 1 TeV - 300 TeV
Medium-sized telescopes: 100 GeV - 10 TeV
Large-sized telescopes: 20 GeV - 200 GeV

north site: La Palma (Spain)  
south site: Paranal (Chile)
observations of CTA

CTA detect the Cherenkov light induced by gamma-ray

MST prototype in DESY
CTA is under construction

La Palma site
CTA: Cosmic-ray PeVatron as a Key Science Project

from R. Ong (2015)
proton-proton collision induces pion decay

For accelerated protons, hadronic interactions with ambient matter produce neutral pion, decaying into two $\gamma$-ray photons.

\[
\pi^0 \rightarrow \gamma_1 + \gamma_2, \\
\pi^+ \rightarrow \mu^+ + \nu_\mu \rightarrow e^+ + \nu_e + \bar{\nu}_\mu + \nu_\mu, \\
\pi^- \rightarrow \mu^- + \bar{\nu}_\mu \rightarrow e^- + \bar{\nu}_e + \nu_\mu + \bar{\nu}_\mu.
\]
SNRs as promising PeVatron candidates

- The detection of an SNR with spectrum up to 100 TeV imply that it is a PeVatron, because ~100 TeV photons are produced by ~ PeV protons.

- SNRs are able to satisfy the cosmic-ray energy requirement by converting the kinetic energy into accelerated particle.
SNRs are the main source in the gamma-ray sky in our Galaxy

Shell-type SNR

SNR interacting with Molecular Cloud

SNRs are the main source in the gamma-ray sky in our Galaxy
SNR spectrum and CTA sensitivity
DC-1 data, Prod3b IRF and ctools

- Data Challenge one (DC-1): simulated data enable the CTA Consortium Science Working Group to derive science benchmarks for the CTA key sciences project
- DC-1 include Galactic Plane Scan (GPS) as one of the key science projects
- Prod3b Instrumental Response Function: based on Monte Carlo simulation and are released for internal usage
- Ctools: a soft package developed for scientific analysis of CTA data
SNRs spectrum and CTA sensitivities

Low Galactic latitude from TeVCat

18 candidates for low Galactic latitude SNRs

By running the pipeline of ctools, we extract 13 candidates from the DC-1 data

- Shell-type SNR: γ-ray from expanding shell of younger SNR

- SNR interacting with Molecular Cloud: γ-ray from the interaction between older SNR shock and the interstellar medium

- Composite SNR: γ-ray from the SNR and the Pulsar Wind Nebula inside
SNRs spectrum and CTA sensitivities

Results 1: CTA south and north sensitivity curves by using Prod3b IRF

Southern site
40 deg zenith angle
50h observation times

Northern site
40 deg zenith angle
50h observation times
SNRs spectrum and CTA sensitivities

Result 2: SNRs DC-1 spectrum and CTA Prod3b sensitivity

Shell-type SNR Spectrum and Sensitivity
SNRs spectrum and CTA sensitivities

Results: SNRs DC-1 spectrum and CTA Prod3b sensitivity

SNR interacting with Molecular Cloud Spectrum and Sensitivity

- Flux [erg cm$^{-2}$ s$^{-1}$]
- Energy [TeV]
Radiation mechanism for SNRs
Four main non-thermal radiative mechanisms for producing $\gamma$-ray

- Synchrotron
- Electron bremsstrahlung
- Inverse Compton scattering
- Pion-decay
Different radiative model contribute to the SED
Radiation mechanism for SNRs
Naima Python package

- Compute non-thermal radiative model (Inverse Compton, Synchrotron, non-thermal Bremsstrahlung, Pion-decay) from population of electrons or protons

- Take an Exponential Cutoff Power Law as particle distribution function (protons, electrons)

\[ f(E) = A(E/E_0)^{-\alpha} \exp\left(-\frac{E}{E_{\text{cutoff}}}\right)^{\beta} \]

amplitude: 6.64 (electrons), 1.42 (protons)
power Law Index: 2.89 (electrons), 2.13 (protons)
cutoff Energy: \(10^{3.18}\) GeV(electrons), \(10^{5.24}\) GeV(protons)
magnetic field: \(B = 23.5\) uG is used for this study
proton number density: \(n = 0.008\) cm\(^{-3}\) is used
Radiation mechanism for SNRs
Results: Examples of radiation mechanism for Shell-type SNRs: RX J1713.7-1946
Conclusions

- For shell-type SNRs, three sources (RX J1713.7-3946 and HESS 1731-347, HESS J1614-518) can be seen by both south and north arrays from 30 GeV to 100 TeV.

- For SNR-MC system, SNR G318.2-00.1 can be seen by both south and north arrays from 30 GeV to 100 TeV.

- For RX J1713.7-3946, bremsstrahlung does not make significant effect to them, and pion decay dominates inverse Compton in the higher energy part of CTA.

- Next steps: add Fermi data; fit the data with model