X-ray observations of Dark Particle Accelerators

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• What is Dark Particle Accelerators?
  = TeV gamma-ray unID objects
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  –Gamma-ray brightest: HESS J1614-518
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TeV gamma-ray view of Milky way

2400 Lyr

Galactic Center
What are they?

From TeVCat
(http://tevcat.uchicago.edu/)

• Pulsar, Pulsar Wind Nebula (33)
• Supernova Remnant (22)
• Others (4) (binaries etc.)
• Unidentified (28)

TeV unID objects
= dark particle accelerators
Many of them are unidentified.

- Observe them in other wavelengths.
- But, in the Galactic plane region.
  - interstellar medium
  - Heavy extinction.

Let’s observe in the X-ray band!
X-ray observatory: Suzaku

X-ray telescope (developed by Nagoya Univ.) + X-ray CCD

• High sensitivity in the high-energy band (E>2keV)
  • Little extinction.

Ideal for obs. of dark particle accelerators
Gamma-ray brightest dark particle accelerator: HESS J1614-518

TeV gamma-ray image

Squares = Suzaku field of view

~100 Lyr
Suzaku X-ray image (3-10keV band)

X-ray counterpart

X-ray object at γ-ray valley

No X-ray object
1\textsuperscript{st} gamma-ray peak

TeV gamma-ray image

Suzaku X-ray image (3-10keV)

Discover X-ray counterpart
X-ray spectrum of the counterpart

Unfolded Spectrum

What can we know?
Power-law emission

\[ \text{Flux} \propto E^{\Gamma} \]
\[ \Gamma = 1.7 \pm 0.1 \]

Particle distribution is not Maxwellian. → Non-thermal X-ray emission.
Interstellar extinction

\[ F \propto E^{-1.7} \]

Column density \( N_H = (1.2+/-.0.4)e22 \text{ cm}^{-2} \)
Distance to HESSJ1614

Milky way galaxy

Column density
NH~2.2e22 cm^-2

HESSJ1614
NH~1.2e22 cm^-2

D ~ 30,000 Lyr
X-ray Flux

Unfolded Spectrum

Flux(2-10keV) = 5.3e-13 erg/s/cm^2
Very Dim in X-ray

\[
\begin{align*}
\text{Flux}(1-10\text{TeV}) &= 1.8 \times 10^{-11} \text{ erg/s/cm}^2 \\
\text{Flux}(2-10\text{keV}) &= 5.3 \times 10^{-13} \text{ erg/s/cm}^2 \\
F(\text{TeV})/F(\text{X-ray}) &= 34
\end{align*}
\]

What does this mean?
Two scenarios of TeV gamma-ray

High-E Proton
- Protons
- $\pi^0$
- TeV $\gamma$-ray
- Interstellar matter

High-E Electron
- Magnetic field
- Electrons
- 3K CMB
- TeV $\gamma$-ray
- Synchrotron X-ray
If electron origin...

- X-ray ... B + e-
- TeV ... CMB + e-

\[
\frac{F(\text{TeV})}{F(\text{X-ray})} = \frac{U(\text{CMB})}{U(B)} < 1 \ (B > \text{a few } \mu\text{Gauss})
\]

**HESSJ1614**

\[
\frac{F(\text{TeV})}{F(\text{X-ray})} = 34
\]
Support proton origin of TeV gamma-ray

High-E Proton

protons

$\pi^0$

$\pi^0$

TeV $\gamma$-ray

Interstellar matter

HESS J1614

$F(\text{TeV})/F(\text{X-ray}) = 34$

Dark Particle Accelerators are a possible origin of cosmic-rays.
What is HESSJ1614-518?

Hint: X-ray object at the gamma-ray valley
X-ray Spectrum

\[ F \propto E^{-\Gamma} \]
\[ \Gamma = 3.6 \pm 0.2 \]
\[ NH = (1.2 \pm 0.1) \times 10^{22} \text{cm}^{-2} \]

See Sakai’s poster (#31) for detailed analysis.
Distance to the valley object

X-ray counterpart

NH $\sim 1.2 \times 10^{21}$ cm$^{-2}$

Valley object

NH $\sim 1.2 \times 10^{21}$ cm$^{-2}$

Same distance

D $\sim 30,000$ Lyr
Photon index $\Gamma \sim 3.6$: very large

Candidate: Anomalous X-ray Pulsar (AXP)
- Kind of a pulsar (neutron star)
- X-ray bright
- Slow spin ($P=2\sim12s$)
- Slow spin down ($dP/dt=1e^{-13}\sim1e^{-10}$)

Energy source
- Cannot be spin.
- May be extremely strong B ($>10^{15}$ G)

**AXPs may be “magneters”**.
What is HESSJ1614-518?
Maybe a remnant of peculiar supernova producing an AXP.

Similar results
- CTB37B (Nakamura et al. 2009)
- HESSJ1427-608 (Fujinaga et al. 2011).

Some of Dark particle accelerators = Peculiar supernova remnants?
Summary

• X-ray counterpart of HESSJ1614-518 was discovered.

• $F(\text{TeV})/F(\text{X-ray}) = 34$
  – Origin of TeV gamma-ray is protons.
  – May be origin of cosmic-rays.

• Some of Dark particle accelerators may be remnants of peculiar supernovae producing AXPs.