Dependence of accessible DM annihilation cross-sections on the density profile of dSphs

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Introduction

Why is it important to consider DM distributions?
DM: evidence & candidates

Evidence
- large scale structure
- rotation curves of galaxies
- bullet clusters
- etc...

Candidates
- WIMP
- SIMP
- PBH
- axion and ALP,
- etc ...

We need much information about the DM nature!
WIMP:
- achieve the relic abundance via the thermal freeze-out mechanism
- \( m_{\text{DM}} \sim \mathcal{O}(\text{GeV}) - \mathcal{O}(\text{TeV}) \)
- annihilation cross-section
  \( \langle \sigma v \rangle \sim \mathcal{O}(10^{-26}\text{cm}^3\text{s}^{-1}) \)

DM should annihilate also in the current Universe.

Saikawa & Shirai, 2020
**γ-ray search:**

$\text{DM + DM } \rightarrow \text{SM + SM}$

- γ-rays are emitted in any of the annihilation channels.
- Propagate straight from the source.
- Do not attenuate in $z \ll 1$ if $E < \mathcal{O}(\text{PeV})$

$$\phi_\gamma = \frac{1}{8\pi} \frac{\langle \sigma v \rangle}{m_{\text{DM}}^2} \int_{E_{\text{th}}}^{m_{\text{DM}}} dE_\gamma \frac{dN_\gamma}{dE_\gamma} \int_{\Delta \Omega} d\Omega \int_{\text{l.o.s.}} ds \rho_{\text{DM}}^2$$

**J-factor:**

$$J_{\text{tot}} = \int d\Omega \frac{dJ}{d\Omega} = \int d\Omega \int ds \rho_{\text{DM}}^2$$
Current limits for WIMP

Fermi-LAT, 11y, 27 dwarf spheroidal galaxies (dSphs)

Hoof et al., 2020

\[
\text{canonica}l \sim 3 \times 10^{-26} \text{cm}^3/\text{s}
\]
TeV-WIMP search: CTA

- improved sensitivity $\gg 100\text{GeV}$
  We can probe unexplored parameter regions.
- improved angular resolution
  We should be careful of the extension and density structure of the targets.
Targets: dSphs

Dwarf spheroidal galaxies (dSphs) are ...

- satellites of the Milky Way
- little star formation activities

\[ d \sim \mathcal{O}(100) \text{ kpc}, \quad \Delta \theta \sim \mathcal{O}(1) \text{ deg}, \]

\[ J \sim \mathcal{O}(10^{16} - 10^{19}) \text{ GeV}^2 \text{ cm}^{-5} \]

good targets of high J-factor & low bkg

- difficulties in modeling DM distribution
J-factor of dSphs

Hayashi et al., 2016
Motivation

• WIMP is a well-motivated DM model.
• $\gamma$-ray observations of dSphs are powerful in searching DM annihilation signature.
• TeV WIMPs are to be probed in future with future $\gamma$-ray observations.
• We have to quantify the effect of spatial structure of dSphs for CTA search.
Our analysis & Results

Realistic calculation for DM search with CTA
Procedure

1. collect models for DM distribution in dSphs
   test using Draco dSph
2. generate J-factor maps
3. generate model spectrum
   $\bar{b}b, W^+W^-, \tau^+\tau^-$ spectrum using pythia8
4. simulate $\gamma$-ray observation data
5. conduct likelihood analysis
profile & J-factor map

We test with 16 models for Draco

- \((\text{RA, DEC}) = (260.052, 57.915)\)
- \(d \sim 80\text{kpc}\)
- \(~1000\) member stars
- outermost member star \(\theta_{\text{max}} \sim 1.3^\circ\)
- \(J \sim \mathcal{O}(10^{19})\) GeV\(^2\)cm\(^{-5}\)
2, DM annihilation spectrum

\[ \text{DM} + \text{DM} \rightarrow \gamma\gamma \]

\[ \rightarrow \bar{q}q \rightarrow \pi^0 + \ldots \rightarrow \gamma + \ldots \]

\[ \rightarrow W^+W^- \rightarrow \bar{q}q + \ldots \rightarrow e^+\nu_e\bar{\nu}_e + \ldots \rightarrow \]

\[ \rightarrow l^+l^- \rightarrow l^+, l^-, \gamma + \ldots \rightarrow \]

\[ \rightarrow W^\pm + \ldots \]
3, simulation & analysis

Simulation using ctools (http://cta.irap.omp.eu/ctools/)
- CTA-North, full array
- IRF prod3b North, z20, average, 50h
- $4^\circ \times 4^\circ$ around Draco
  $(0.03^\circ \times 0.03^\circ$ spatial bin)
- Position center
  $(RA, DEC)=(260.052, 57.915)$
- 500 hour, c.r bkg only
- $E=0.03$-$180$TeV photon
  (5 bins per decade)

Example: 92188344 events in total
Our accessibility (1):

95% C.L
sys. only

Hiroshima et al., 2019
Our accessibility (2):

95% C.L sys. only

Hiroshima et al., 2019
Conclusion
Conclusion

- We can access TeV WIMP with CTA.
- dSphs are good targets for $\gamma$-ray searches of DM with high J-factor and low background.
- The spatial distribution as well as the its integral of the J-factor is important especially for CTA.
- We can probe $\langle \sigma v \rangle \sim \mathcal{O}(10^{-23} - 10^{-24}) \text{ cm}^3/s$ for $m_{\text{DM}} \sim \mathcal{O}(1) \text{ TeV}$, which could not be accessible with any other experiments.
- Precise measurements of the DM structure of dSphs are important for understanding DM nature.