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?
Dark Matter (DM):

- Dark Matter (DM) is cold
- non-baryonic
- (almost) neutral
- (almost) invisible

Matter components of the Universe occupying ~25% of its total energy density

Planck 2018

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>dark energy</td>
<td>68.6%</td>
</tr>
<tr>
<td>DM</td>
<td>26.5%</td>
</tr>
<tr>
<td>baryon</td>
<td>4.9%</td>
</tr>
</tbody>
</table>
WIMP:

- Weakly Interacting Massive Particle
- achieve the relic abundance via the thermal freeze-out mechanism
- the mass $m_{DM} \sim \mathcal{O}(\text{GeV}) - \mathcal{O}(\text{TeV})$
- the annihilation cross-section

\[ \langle \sigma v \rangle \sim \mathcal{O}(10^{-26}\text{cm}^3\text{s}^{-1}) \]

We do not see the annihilation signature yet.
**γ-ray search:**

DM + DM -> SM + SM

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

\[
\phi_\gamma = \frac{1}{8\pi} \frac{\langle \sigma v \rangle}{m^2_{\text{DM}}} \int_{E_{\text{th}}}^{m_{\text{DM}}} dE_\gamma \frac{dN_\gamma}{dE_\gamma} \left[ \int_{\Delta \Omega} d\Omega \int_{l.o.s} ds \rho^2_{\text{DM}} \right]
\]

**J-factor:**

\[
J_{\text{tot}} = \int d\Omega \frac{dJ}{d\Omega} = \int d\Omega \int ds \rho^2_{\text{DM}}
\]
Targets: G.C. vs dSphs

We need high J-factor & low bkg targets

Galactic Center

- high J-factor $\mathcal{O}(10^{20-22}) \text{GeV}^2 \text{cm}^{-5}$
- bright in astrophysical emissions
- difficulties in modeling astrophysical emissions
- difficulties in modeling DM distribution

dSphs

- moderately high J-factor $\mathcal{O}(10^{16-19}) \text{GeV}^2 \text{cm}^{-5}$
- inactive star formation activities
- difficulties in finding targets
- difficulties in modeling DM distribution
J-factor of dSphs

Hayashi et al., 2016
Current constraints:

Fermi-LAT & DES collaboration, 2017

We should consider TeV WIMP seriously.
TeV observation with CTA

- improved sensitivity @>100GeV
  We can probe unexplored parameter regions.
- improved angular resolution
  We should be careful of the extension and density structure of dSphs.
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

How does it affect our accessibility?
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

using ctools
1, profile & J-factor map

We test with 16 models for Draco

- (RA, DEC) = (260.052, 57.915)
- \(d \sim 80\) kpc
- \(\sim 1000\) 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

DM + DM → γγ

→ ¯qq → π^0 + ... → γ + ...

→ W^+W^- → ¯qq + ... → e^+ν_ε ¯ν_ε + ... →

→ l^+l^- → l^+, l^-, γ + ... →

→ W^± + ...
3, simulation & analysis

Simulation using ctools (http://cta.irap.omp.eu/ctools/)

- CTA-North, full array
  - IRF prod3b North, z20, average, 50h
  - 4° × 4° around Draco
    - (0.03° × 0.03° spatial bin)
  - position center
    - (RA, DEC)=(260.052, 57.915)
  - 500 hour, c.r bkg only
  - E=0.03-180TeV photon
    - (5bins per decade)

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

95% C.L
sys. only

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

Hiroshima et al., 2019

95% C.L sys. only
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 $\langle \sigma v \rangle \sim \mathcal{O}(10^{-23} - 10^{-24})$ cm$^3$/s for $m_{\text{DM}} \sim \mathcal{O}(1)$ TeV, which could not be accessible with any other experiments.
- Precise measurements of the DM structure of dSphs are important for understanding DM nature.