Constraint on the Annihilation Cross-section with Fermi Gamma-Ray Sky & HSC Lower Surface Brightness Galaxies

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INTRODUCTION

Recently, the annihilation cross-section of dark matter particle (typically, neutralinos) has been proved with the observation of the gamma-ray sky. In particular, with dwarf spheroidals and the gamma-ray sky, the cross section have been constrained most strongly. We present a research for constraint on the annihilation cross-section of self-interacting dark matter with gamma-ray sky and new target objects, Lower Surface brightness Galaxies (LSBGs). LSBGs are dark-matter dominated systems being more massive than dSphs. Moreover, those are expected to be gamma-ray quiet. That is able to perform a pure annihilation-signal probe. Note that thanks to improve observational instruments, LSBGs are recently discovered exceedingly abundant, therefore the number of those desirable targets is expected to increase rapidlly.

LAT-DATA

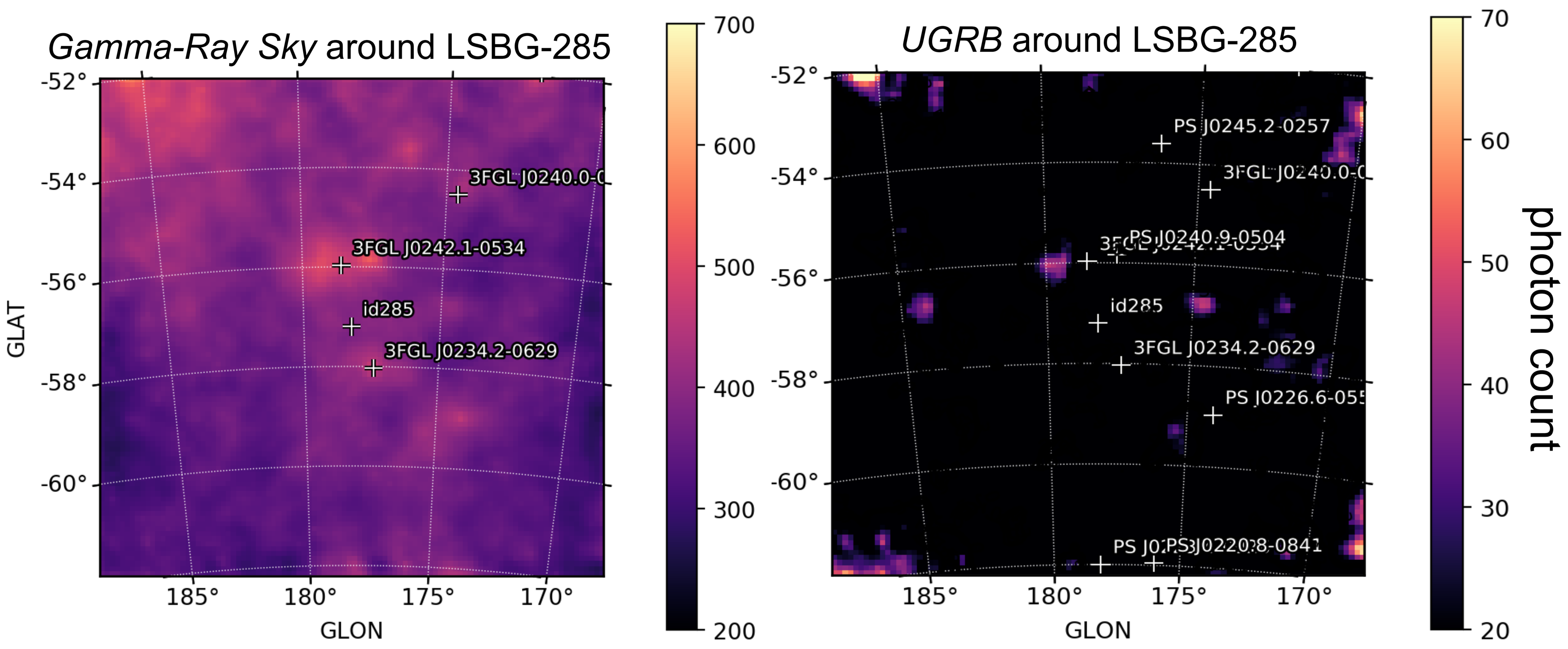
We use the gamma-ray sky with 7years data of Fermi Large Area Telescope (Fermi-LAT) at 0.5-500GeV.

The gamma-ray sky is composed from *resolved gamma-ray source emission*, *the Galactic gamma-ray foreground emission* and the residual component (*Unresolved Gamma-Ray Background: UGRB*).

In our research, we are interested the UGRB, therefore it needs to subtract the resolved emission and the Galactic foreground from the gamma-ray sky.

The Galactic gamma-ray emission is dominantly produced by ***decay of pions*** produced by interaction of cosmic-ray nuclei and interstellar gas or the ***inverse Compton scattering*** with cosmic-ray leptons and interstellar photons.

In bellow figures, examples of a gamma-ray sky and a UGRB around example LSBG (LSBG-285).



LSBGs

8 LSBGs with known redshift in our work are obtained by the LSBG catalog (781 LSBGs contained) by HSC observation (Greco et al. 2018).

The advantage of using LSBGs in such this work:

1. They are highly dark-matter dominated systems.
2. They can have purer annihilation signal than that for general galaxies or galaxy clusters.
   - *They are relatively quiescent, so they have less astronomical gamma-ray contamination.*
3. They are more massive than dSphs.
   - *They have $10^{10\text{-}11}$ M_sun, in contrast, dSphs have ~10^9M_sun.*
4. Analysis is easier than that in case of other nearby targets.
   - *Due to Fermi-LAT PSF larger than the angular scale of typical LSBGs, They can be assumed to point sources reasonably. Therefore, the analysis is robust due to less effect for systematics of the Galactic foreground.*
5. They are expected to be discovered numerously in near future.

FLUX MODEL

In our analysis, to limit the cross section we compare a flux model of gamma-ray emission for the dark-matter annihilation with the UGRB flux.
Here, we illustrate the flux model.

Model flux for annihilation Φ

$$\frac{d\Phi}{dE\gamma} = J \times \frac{\langle\sigma v\rangle}{8\pi m_\chi^2} \sum_i Br_i \left.\frac{dN_i}{dE'_\gamma}\right|_{E'_\gamma=(1+z)E_\gamma}$$

$\langle\sigma v\rangle$: cross-section
Br_i : i-th branching ratio
m_χ : dark matter mass

J-factor — Property of dark matter particle (Including a energy spectrum)

J-factor

- Astronomical factor, depending on the target object properties

General formulation

$$J = (1+b_{\rm sh})\int_\Omega d\Omega' \int_l dl \rho_{\rm DM}^2(l,\Omega')$$

l : vector along the line of sight
Ω : angular scale of the target
$b_{\rm sh}$: boost factor

Assuming the NFW profile

$$= \frac{M_{\rm halo}}{9}\Delta\rho_{\rm cri}c^3\left(\log(1+c)-\frac{c}{1+c}\right)^{-2}\left(1-\frac{1}{(1+c)^3}\right)\Big/ d_A^2$$

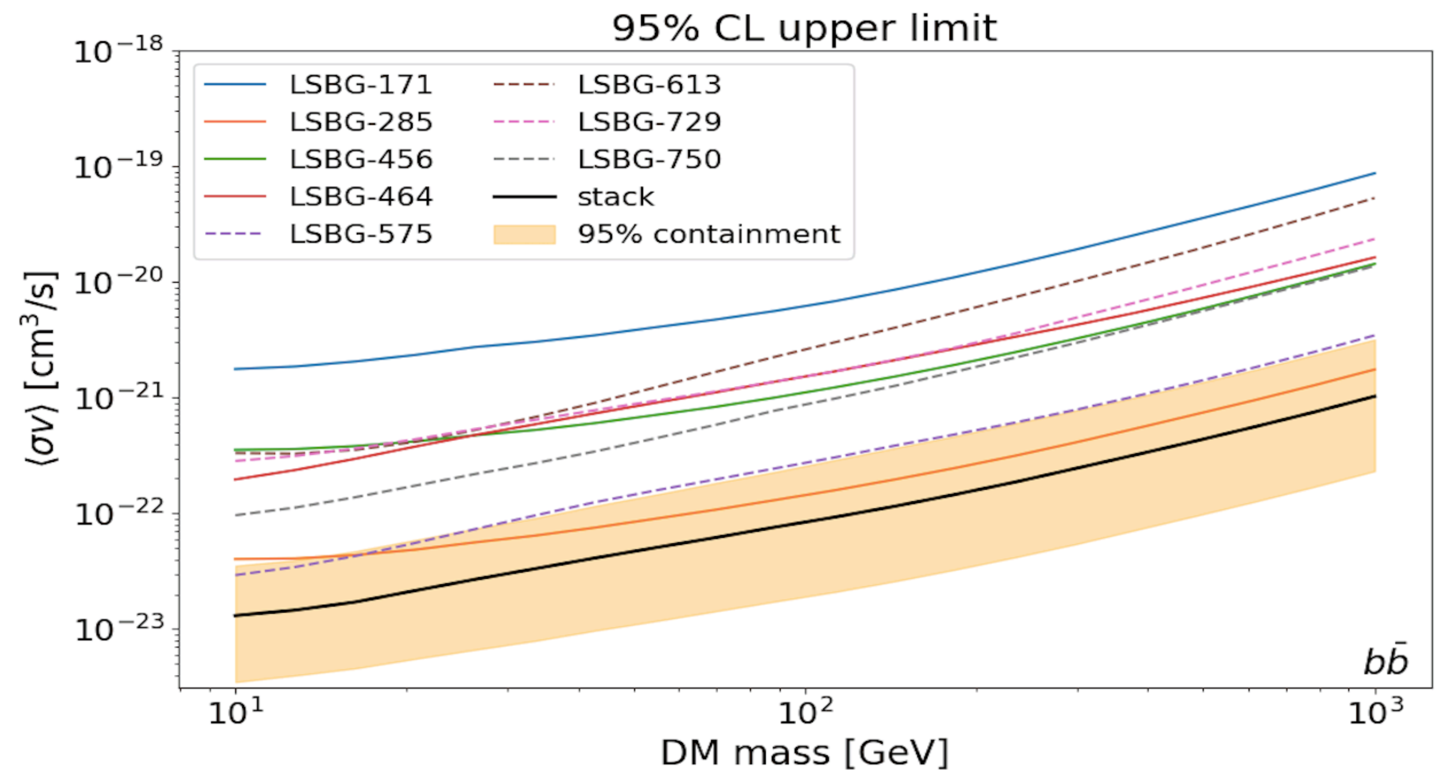
C : concentration parameter
$M_{\rm halo}$: halo mass
d_A: angular diameter distance

Energy spectrum

: Various annihilation channel
$b\bar{b}, \tau^+\tau^-, t\bar{t}, W^+W^-, \gamma\gamma$ etc.
: decay into more stable particles and finally create following particles
$e^+e^-, p\bar{p}, \nu\bar{\nu}, \gamma\gamma$

* calculate the energy spectrum using DarkSUSY

RESULT



We provide the annihilation cross-section upper limit for 95% confidence level for each LSBG and for in case of stack of 8 LSBGs for [bottom quark - anti-bottom quark] channel. In this figure, different color lines represent upper limits for each LSBG and black one represents that of stack of 8 LSBGs. A orange shaded region corresponds to 2σ error due to uncertainties for J-factor of LSBGs. The uncertainty is estimated from uncertainty of LSBG's halo mass (~60%) and of concentration parameter (~30%).

CONCLUSION & DISCUSSION

We have provided the upper limit on the annihilation cross-section for self-interacting dark matter with 8 HSC-LSBGs. We find the upper limit of ~10^{-23} [cm^3/s] at dark matter mass of 10 GeV for bb_bar. This limit is quite weaker than that using dSphs (~10^{-26} [cm^3/s]). This is due to the distance of LSBGs ~100 times further than that of dSphs.

In HSC survey ...

As a further analysis, to estimate the redshift distribution of LSBGs being able to be observed by HSC, we will conduct all LSBGs in the HSC LSBG catalog. Potentially and statistically, because of increasing the number of LSBGs (from 8 to ~800) the upper limit of the cross section is ~10 times stronger than that of this work. Furthermore, in HSC survey, the observation area will expand to ~1400 deg^2 finally and statistics will increase up to ~5000 accordingly.

VS dSphs in the future ...

In case of dSphs

In recent works, potential number of local dSphs is indicated to be less than ~150. Therefore, the upper limit of annihilation cross-section will be not so stronger than that of the present limit.

In case of LSBGs

Not only increase of the number of LSBGs, but also it should be noted that by future observation objects closer than LSBGs in this work will be discovered with highly probability according to recent works for LSBGs. That brings significant effect of the upper limit for the cross section because of the strong dependency of J-factor with respect to the distance of the target object. Therefore, the upper limit of the cross section with LSBGs will be stronger by order of magnitudes than that of the present limit.