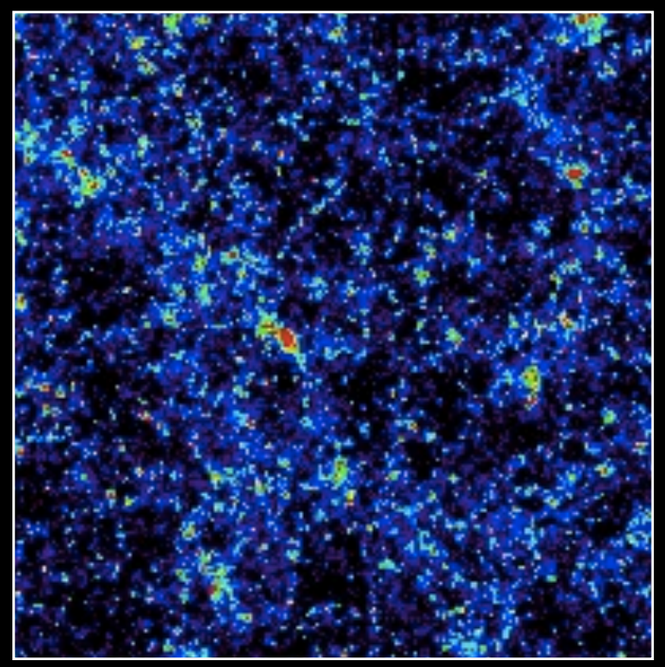
Cross-Correlation of Extragalactic Gamma-ray Background and Luminous Red Galaxies

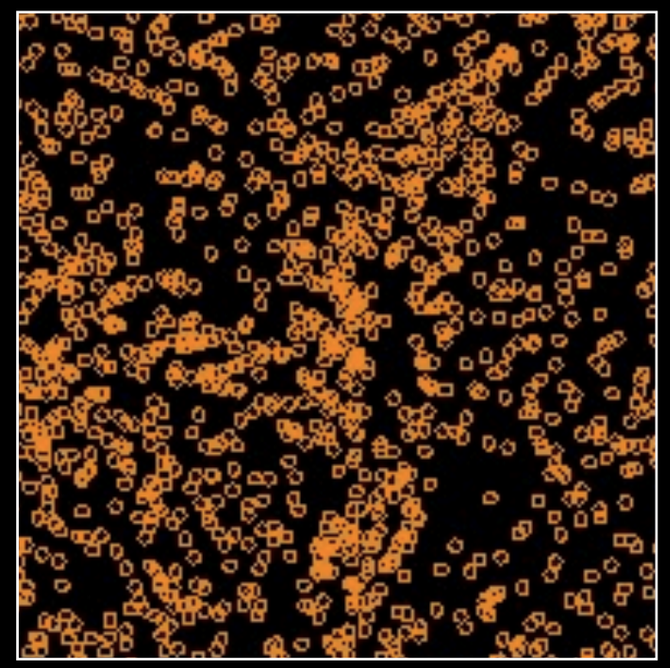
Masato Shirasaki (NAOJ)
with
Naoki Yoshida (KIPMU) & Shunsaku Horiuchi (Virginia Tech)

2015.10.16
Workshop on Astrophysics of Dark Matter@IPMU

Simple Picture



Dark Matter
(gamma-ray)



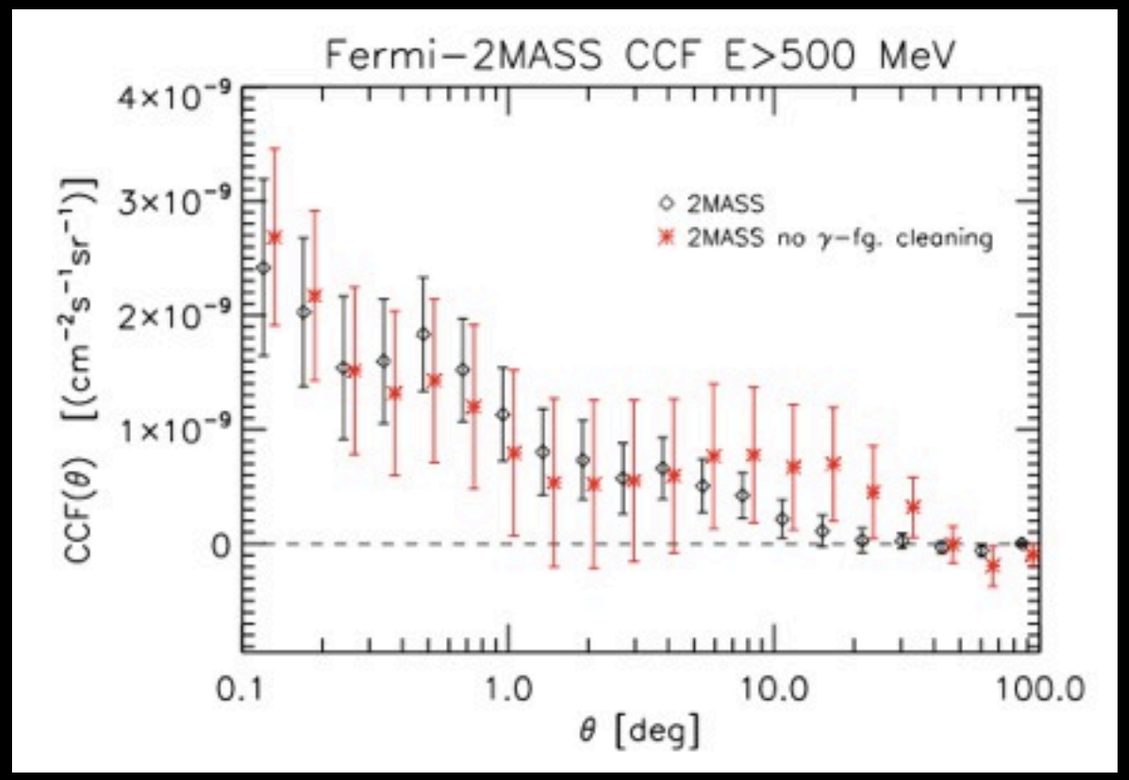
Massive Galaxy

If DM would annihilate, high density region in the Universe would emit gamma rays
Massive galaxies would live in the high density region

Recent progress on Gamma-ray studies

The detection of angular correlation of the position of galaxies and gamma-ray maps!

- Correlation between large-scale structure and gamma-rays would be a probe of dark matter (DM) annihilation
  - If DM would annihilate, the high density region in the Universe would be gamma-ray source
  - The strength of correlation can relate to the production rate of gamma-rays in extragalactic DM halos, or annihilation rate of DM
- Various tracers could be correlated with extragalactic gamma-rays
  - Unresolved star forming galaxies



Xia et al. (2015)

Toward the detection of DM annihilation

- We should consider some optimized targets for indirect search for DM annihilation.
- The conditions to be considered
  - they should live in high density regions in the Universe
  - they should be less affected by astro sources
  - their statistical properties should be well constrained
  - it is desirable to know the relation to their host dark matter halos

LRGs seem to be nice, let us examine the case of LRGs!

SDSS DR7 LRG

- Kazin et al 2010, ApJ, 710, 1444
- Passive galaxies used for cosmological analyses (i.e. galaxy clustering & BAO measurement)
- 30272 spectroscopic galaxies
- exist 160 mock catalogs (LasDamas simulations)
- typical halo mass ~ $10^{13\text{-}14}$ M_{sun}/h (derived from g-g lensing and clustering analysis)

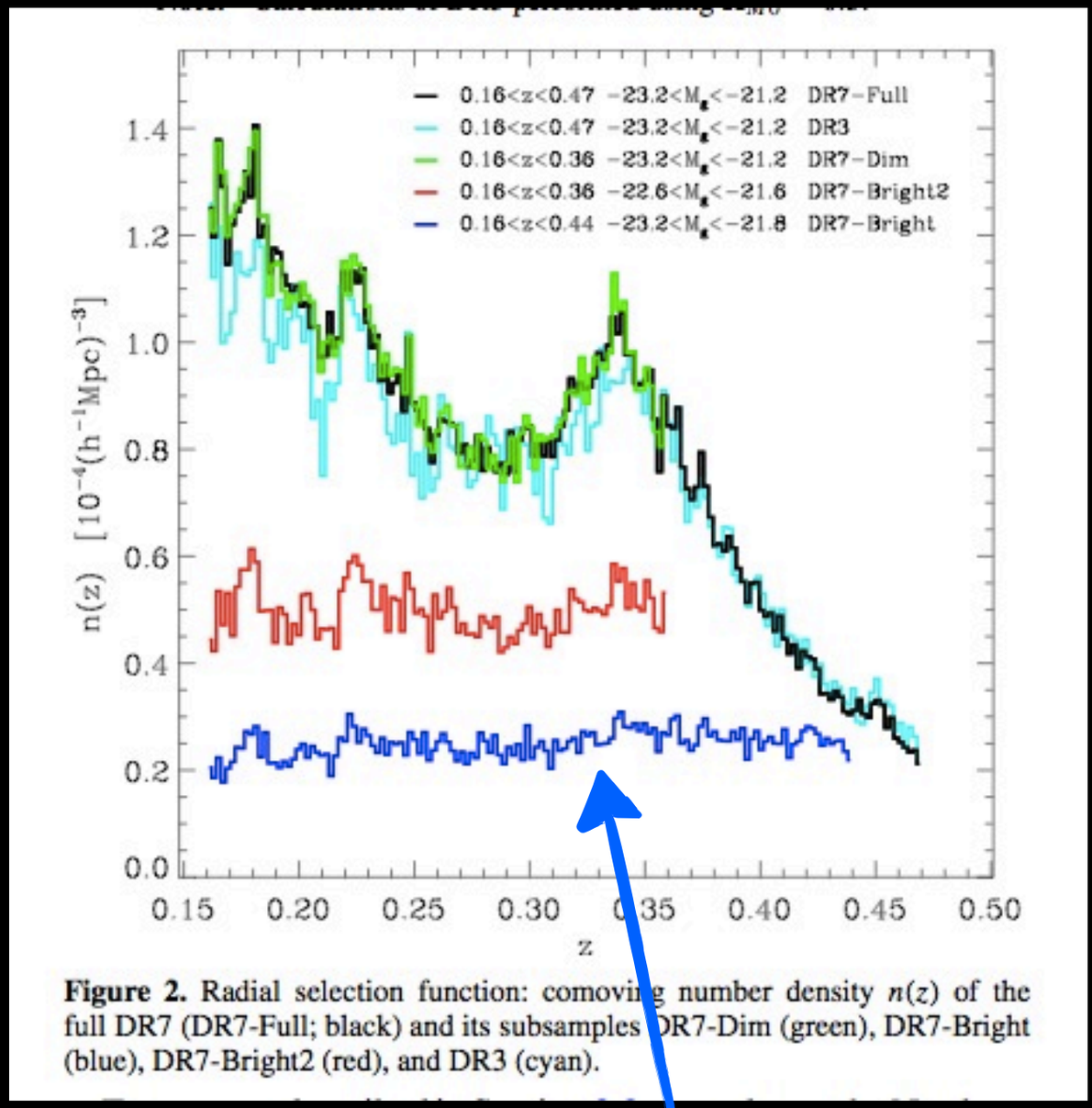
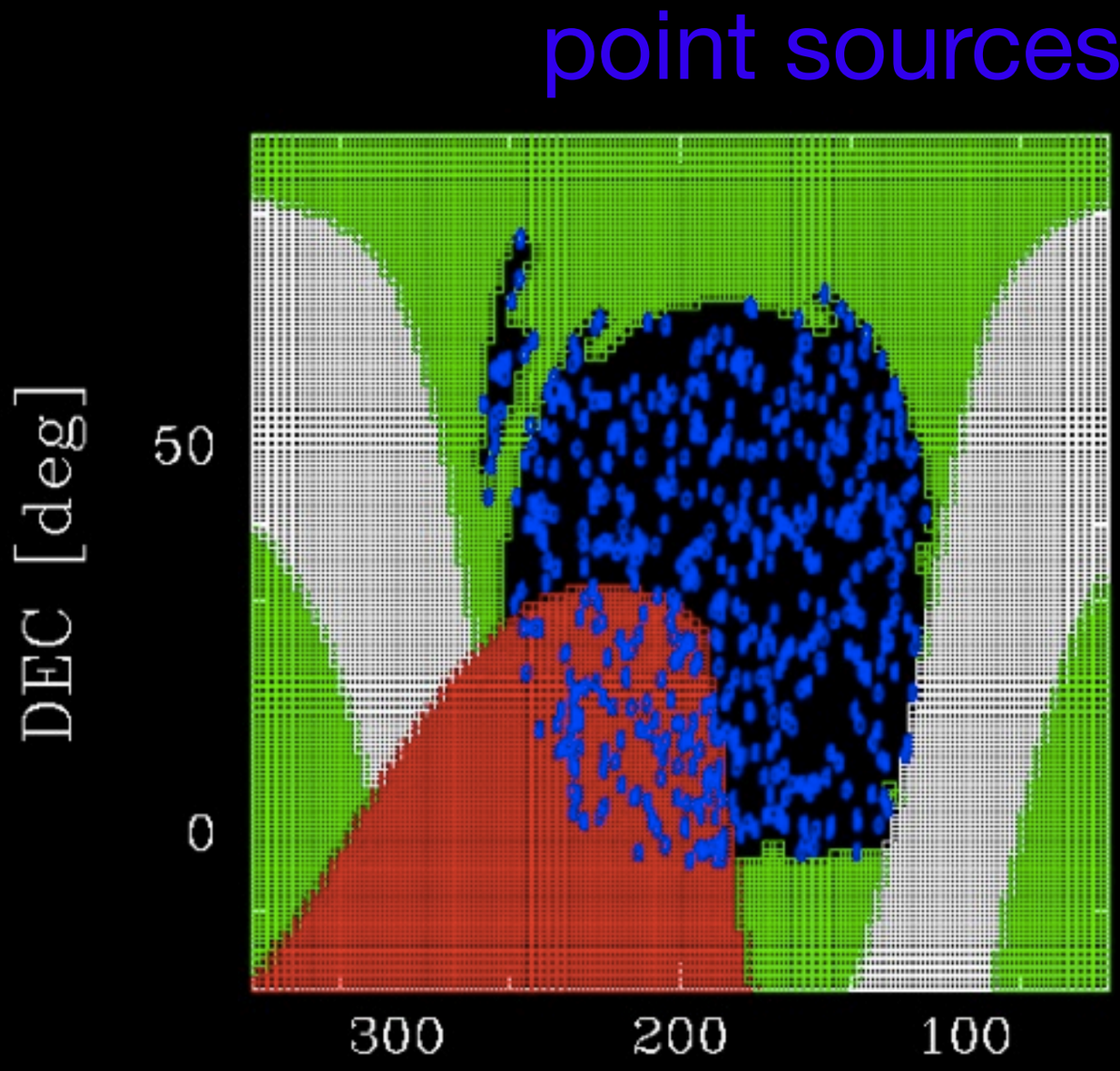


Figure 2. Radial selection function: comoving number density $n(z)$ of the full DR7 (DR7-Full; black) and its subsamples DR7-Dim (green), DR7-Bright (blue), DR7-Bright2 (red), and DR3 (cyan).

use blue one!

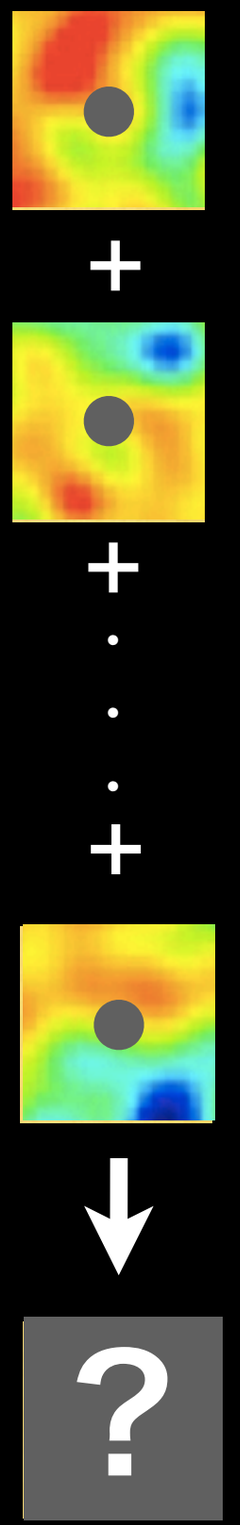
Survey region

- use 3rd year point source catalog
- find 507 sources and use mask with radius of 1 deg
- also remove |b|<20° and Loop-I/bubble regions
- sky fraction of remaining regions ~ 0.10 (corresponding to ~4000 deg^2)



Cross correlation

- use 1-500 GeV gamma-ray intensity
- P7rep ultraclean class
- we have subtracted the galactic component
- use 17465 LRGs
- analysis performed in real space
- estimate covariances by using LasDamas Mocks and poisson photon catalog



Stacked image

Cross correlation signal

measured signal is
consistent with a null signal

our analysis passed
the null test (i.e. correlation of
mock LRGs with EGB)→

sampling variance of LRG
~ photon poisson error

Modeling of correlation

Fourier counterpart of cross correlation

DM property

3D cross power spectrum of galaxies and density-squared

$$C_{\rm gal,dm}(\ell) = \int \frac{{\rm d}\chi}{\chi^2} W_{\rm gal}(\chi) W_{\rm dm}(\chi) P_{{\rm gal},\delta^2}\left(k = \frac{\ell + 1/2}{\chi}, z(\chi)\right),$$

$$W_{\rm dm}(\chi) = \frac{\langle \sigma v \rangle}{8\pi} \left(\frac{\bar{\rho}_{\rm dm}}{m_{\rm dm}}\right)^2 (1+z)^3 \int_{E_{\gamma,\rm min}}^{E_{\gamma,\rm max}} {\rm d}E_\gamma \frac{{\rm d}N_\gamma}{{\rm d}E'_\gamma} e^{-\tau(E'_\gamma, z)},$$

Here we adopt two characteristic spectra corresponding to annihilation with 100% branching ratios to bb and $\tau^+\tau^-$ final states

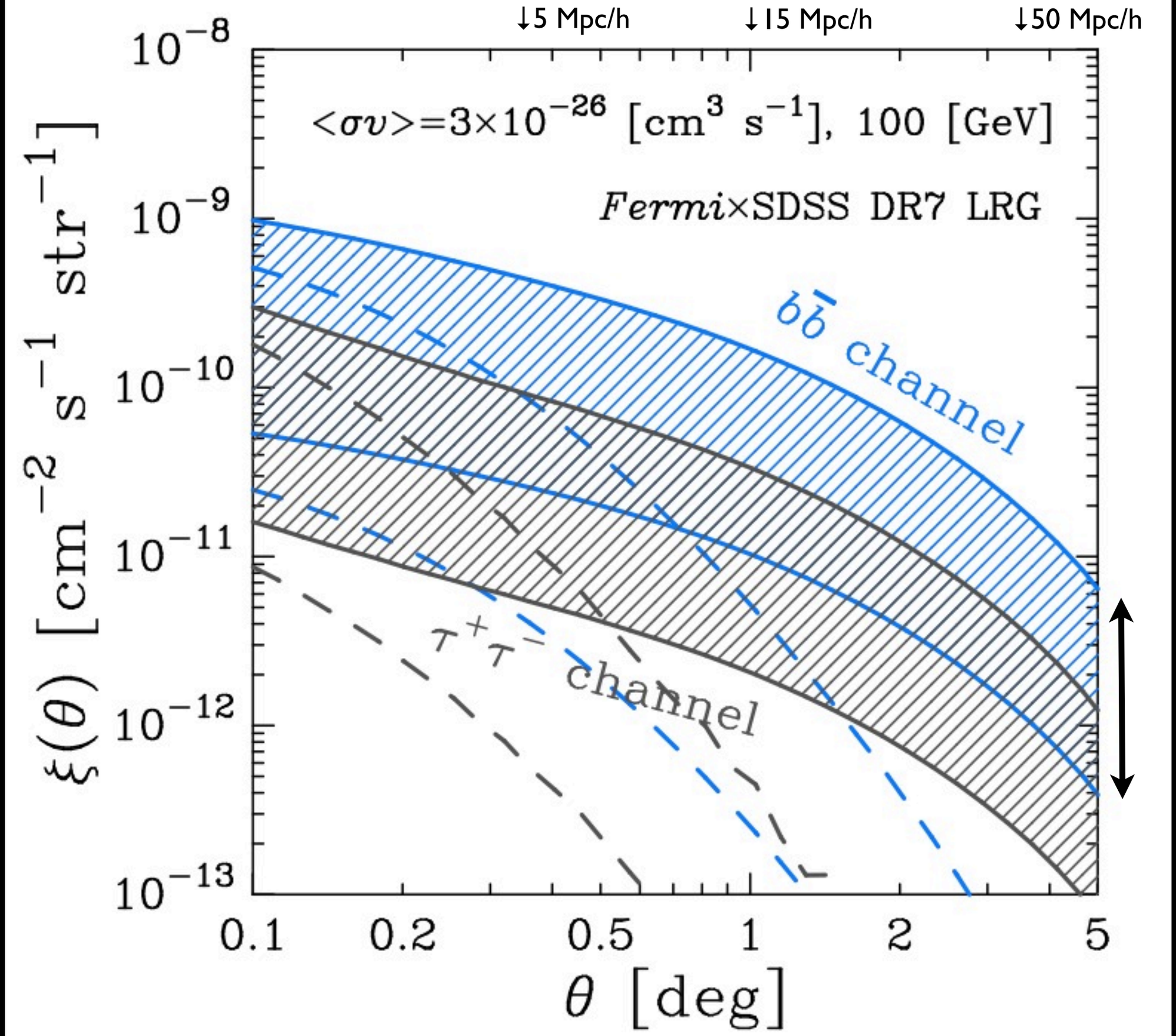
$$P_{{\rm gal},\delta^2}(k,z) = P^{1h}_{{\rm gal},\delta^2}(k,z) + P^{2h}_{{\rm gal},\delta^2}(k,z),$$

one-halo: two-point correlation in a single halo

two-halo: two-point correlation due to the clustering of halos

Modeling of correlation

- Halo Occupation Distribution (HOD): the mean number of galaxies in a host halo of mass of M
- HOD constrained by number count, clustering and lensing
- we apply so-called Halo model approach
- Redshift distribution of LRGs determined by spec-z
- （Almost the only）remaining uncertainty = **boost factor**
  - model A : Gao et al (boost factor~300 for DM halo with mass of $10^{13\text{-}14}$ M_{sun}/h)
  - model B : Sanchez et al (boost factor~30 for DM halo with mass of $10^{13\text{-}14}$ M_{sun}/h)
- PSF effect is also taken into account



model uncertainty due to substructure in a single halo

Likelihood Analysis
95% confidence level

model uncertainty due to substructure in a single halo

Systematic error due to modeling of galactic components

repeat the same analysis
for different 35 galactic
model templates

typical uncertainty

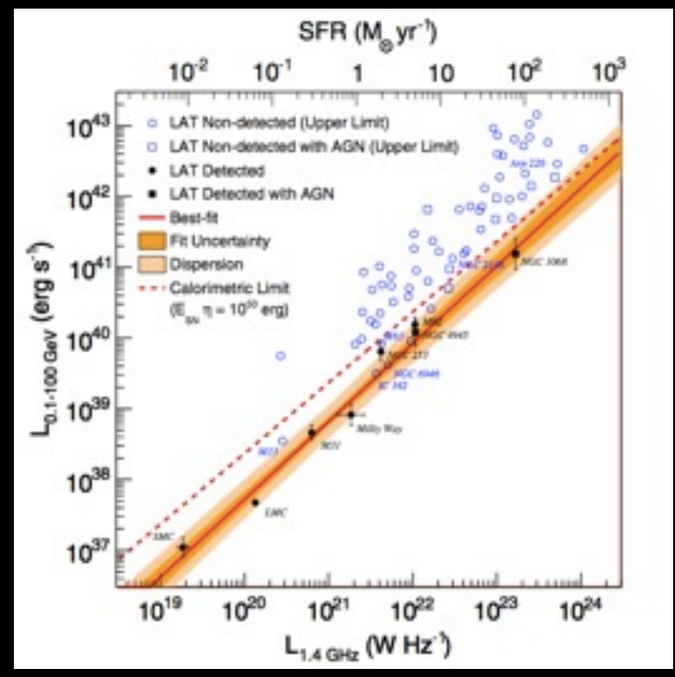
$\Delta\chi^2 \sim 1$

stat. error
~ 10 times syst. error

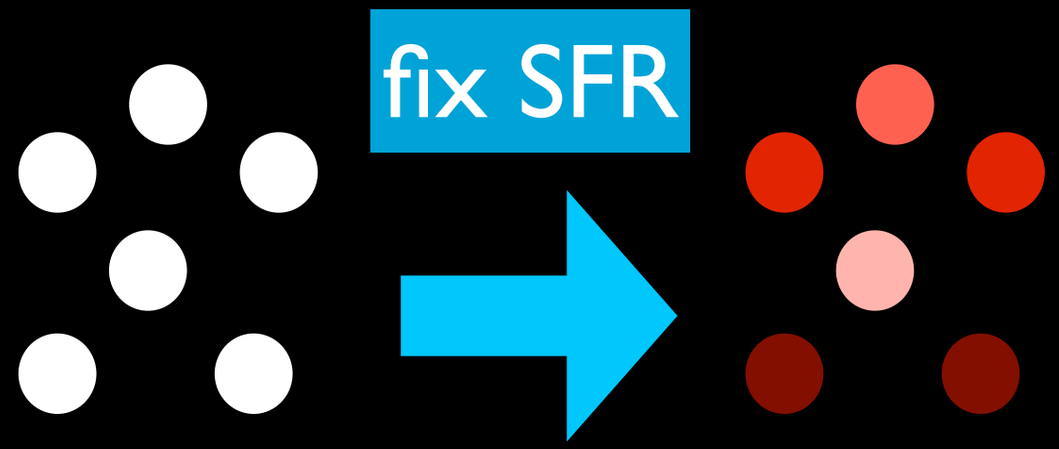
Less important for future surveys

Possible correlation by star forming in LRG

- already detected the gamma-rays from nearby star forming galaxies
- we examine how large correlations would be found if LRGs form stars with some rate
- Let us consider the simplest case: all the LRGs have the same star forming rate (SFR)
- Using the correlation of L_γ and SFR, we can evaluate the gamma-ray flux of each LRG in our catalog



Ackermann et al (2012)



Possible correlation by star forming in LRG

Gamma-rays due to star forming would have **less** affect on our analysis even in the case of SFR = 10 M_{sun}/yr

Summary

- Cross correlation of SDSS DR7 LRGs and Fermi EGB
- **LRG is one of the best targets to search for DM annihilation**
  - well-studied HOD/typical halo mass
  - passive star forming (less contaminated by astrophysical sources)
  - spec-z is available and they are relatively closer (z=0.1-0.4)
- The main model uncertainty = boost factor only (except for dN/dE)
- **Our measurement is consistent with null detection**
  - put constraints on DM annihilation for DM halos with mass of $10^{13\text{-}14}$ M_{sun} and redshift of z=0.1-0.4
- impact of model uncertainty of galactic gamma-ray
- One of possible contaminants = Star forming in LRGs
  - gamma-rays by star forming phenomena would have a small influence on our correlation analysis

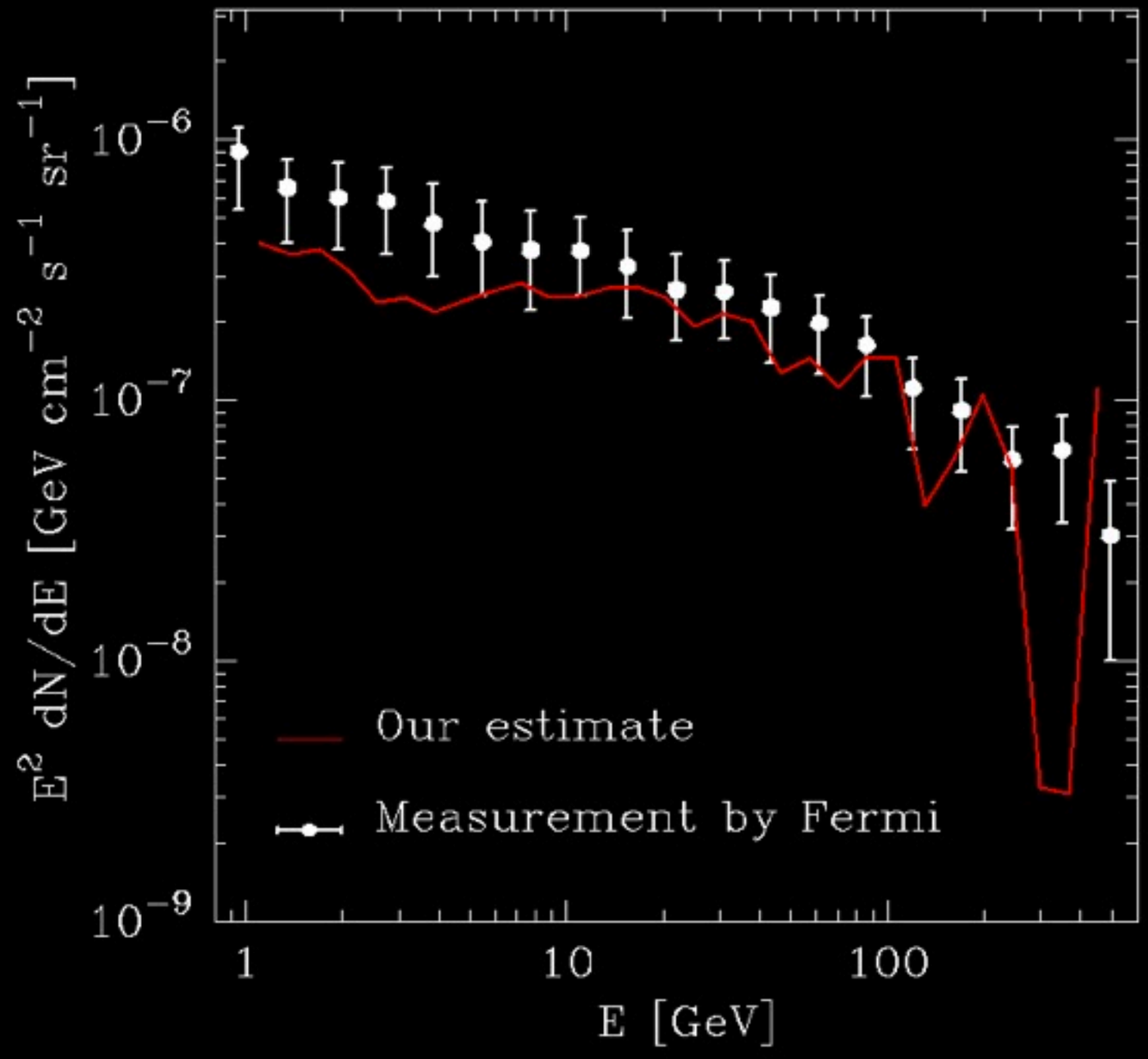
Future Prospect

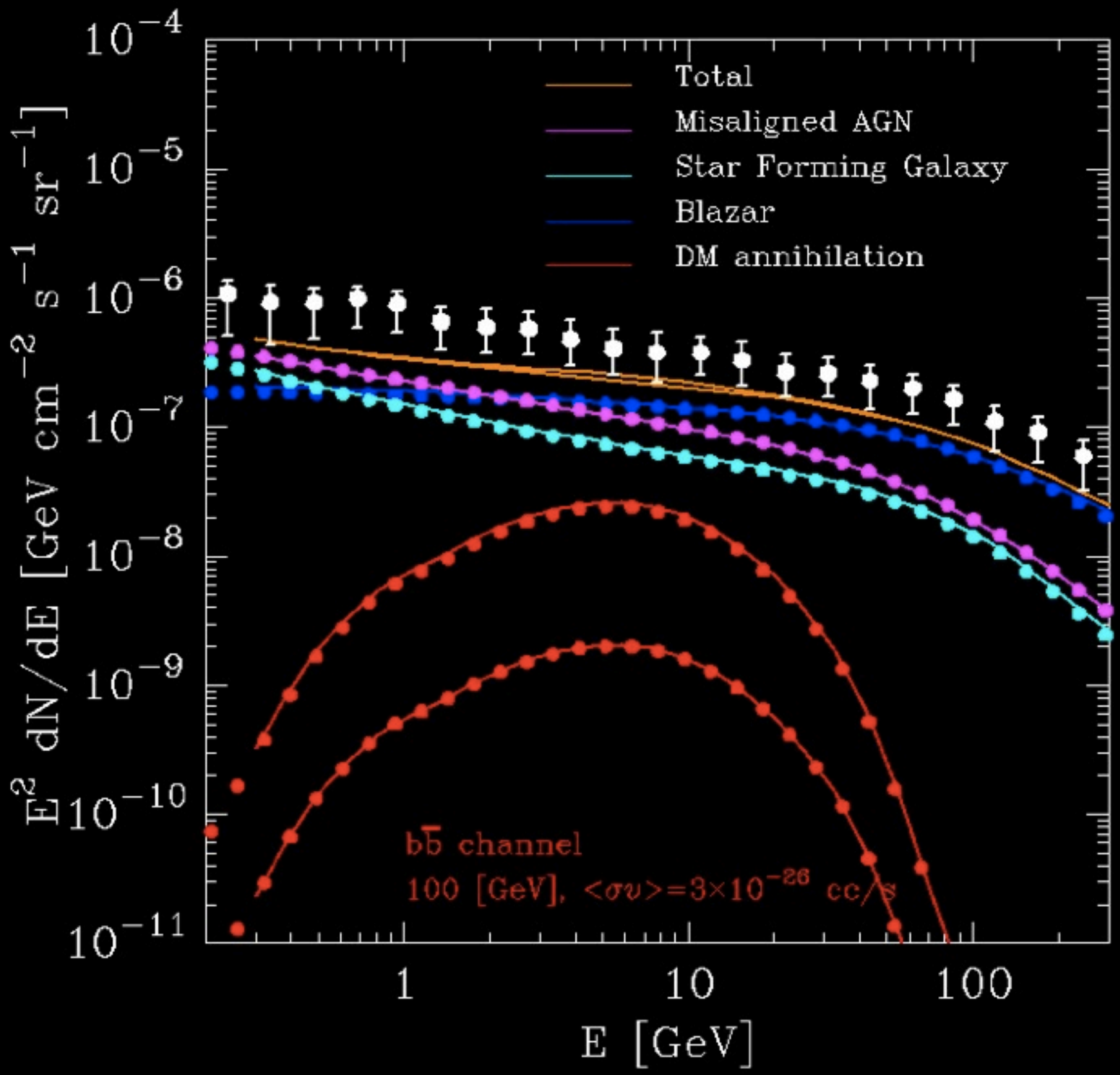
Cross-correlation with LRGs would be promising for probe of annihilating DM with mass of tens of GeV

Question.
How can we reduce the model uncertainty of boost factor in an *observational* way?

DM mass [GeV]

EGB intensity




Total
Misaligned AGN
Star Forming Galaxy
Blazar
DM annihilation
$b\bar{b}$ channel
100 [GeV], $<\sigma v>=3\times10^{-26}$ cc/s
E^2 dN/dE [GeV cm^{-2} s^{-1} sr^{-1}]
E [GeV]
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
1
10
100