

Francesca Calore

# Spatial signatures of Dark Matter in the Galaxy

**II Anisotropic Universe Workshop**  
12th April 2016, Amsterdam

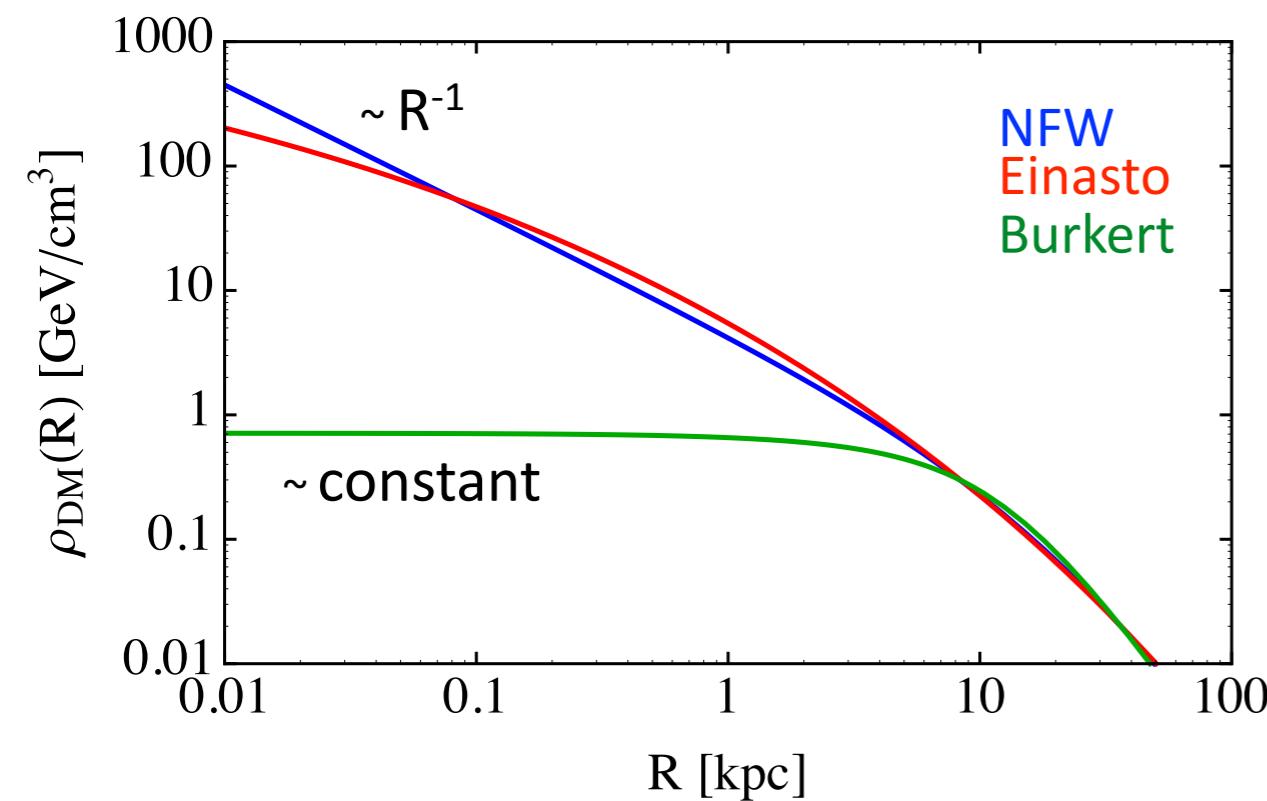
Based on:

F. Calore, V. De Romeri, M. Di Mauro, F. Donato In preparation

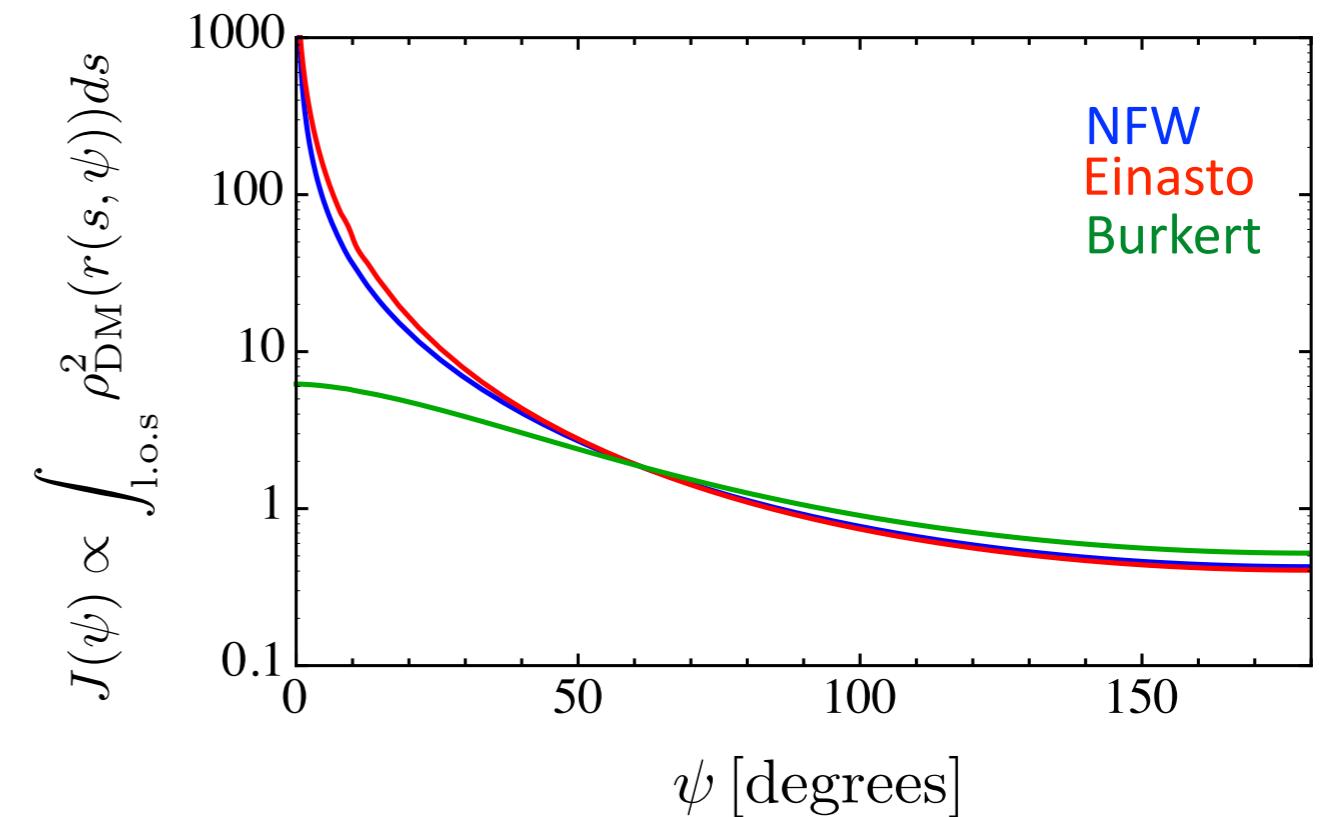
# The dark matter gamma-ray signal

$$\frac{d\Phi_{\gamma}^{\text{DM}}}{dE_{\gamma}} \propto \frac{\langle \sigma v \rangle}{2m_{\text{DM}}^2} \frac{dN_{\gamma}}{dE_{\gamma}} \int_{\text{l.o.s}} \rho_{\text{DM}}^2(r) ds$$

Dark matter density profiles:



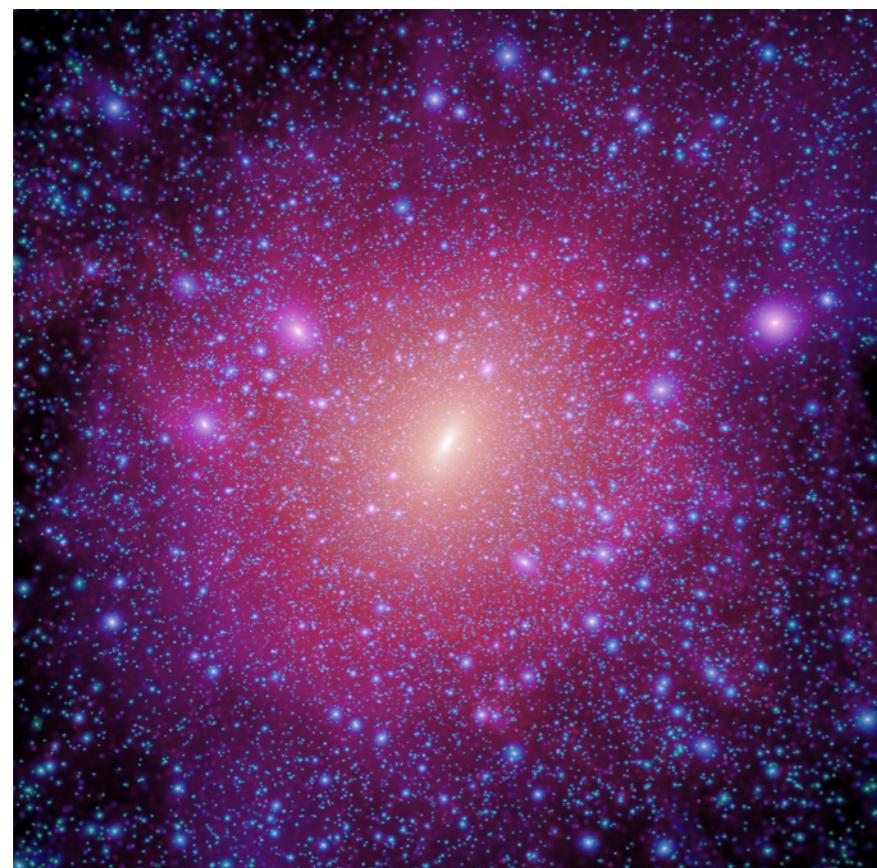
Spatial distribution of the signal:



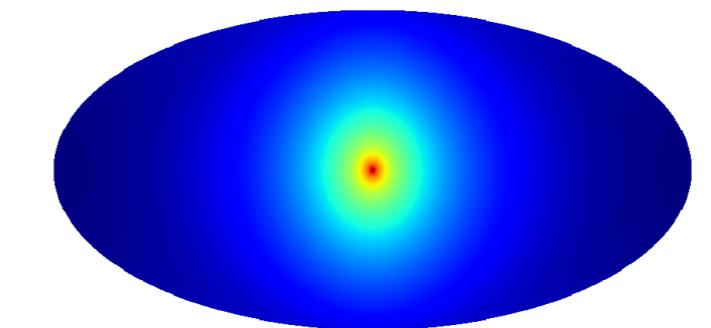
# The dark matter spatial distribution

Simulations of structure formation allow to predict the distribution and size of haloes in cosmological volumes

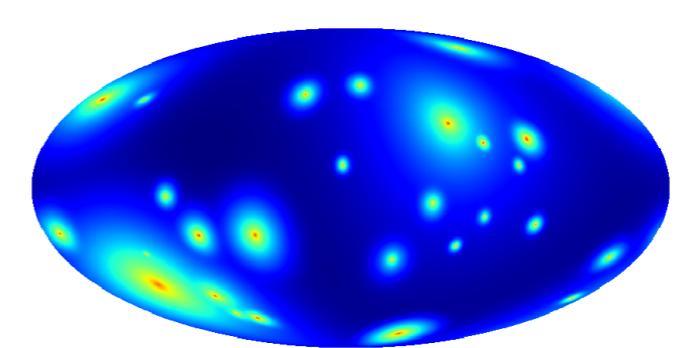
Aquarius DM N-body simulation



Expected gamma-ray flux



Main halo



Sub-haloes  
(SHs)

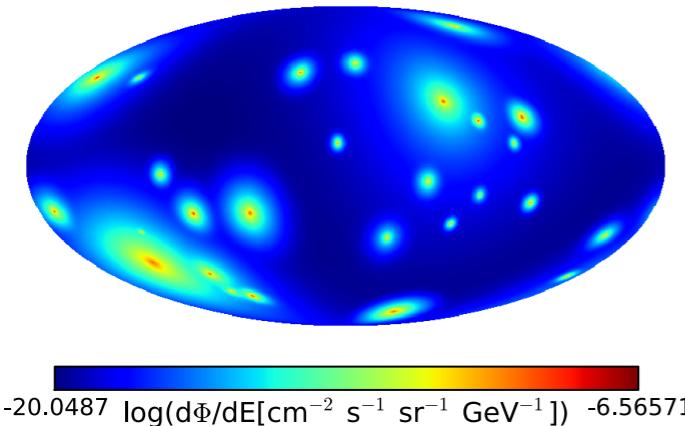
Springel+ MNRAS'08

Calore+ MNRAS'14

## SPATIAL (ANGULAR) FEATURES

# Spatial signature of dark matter

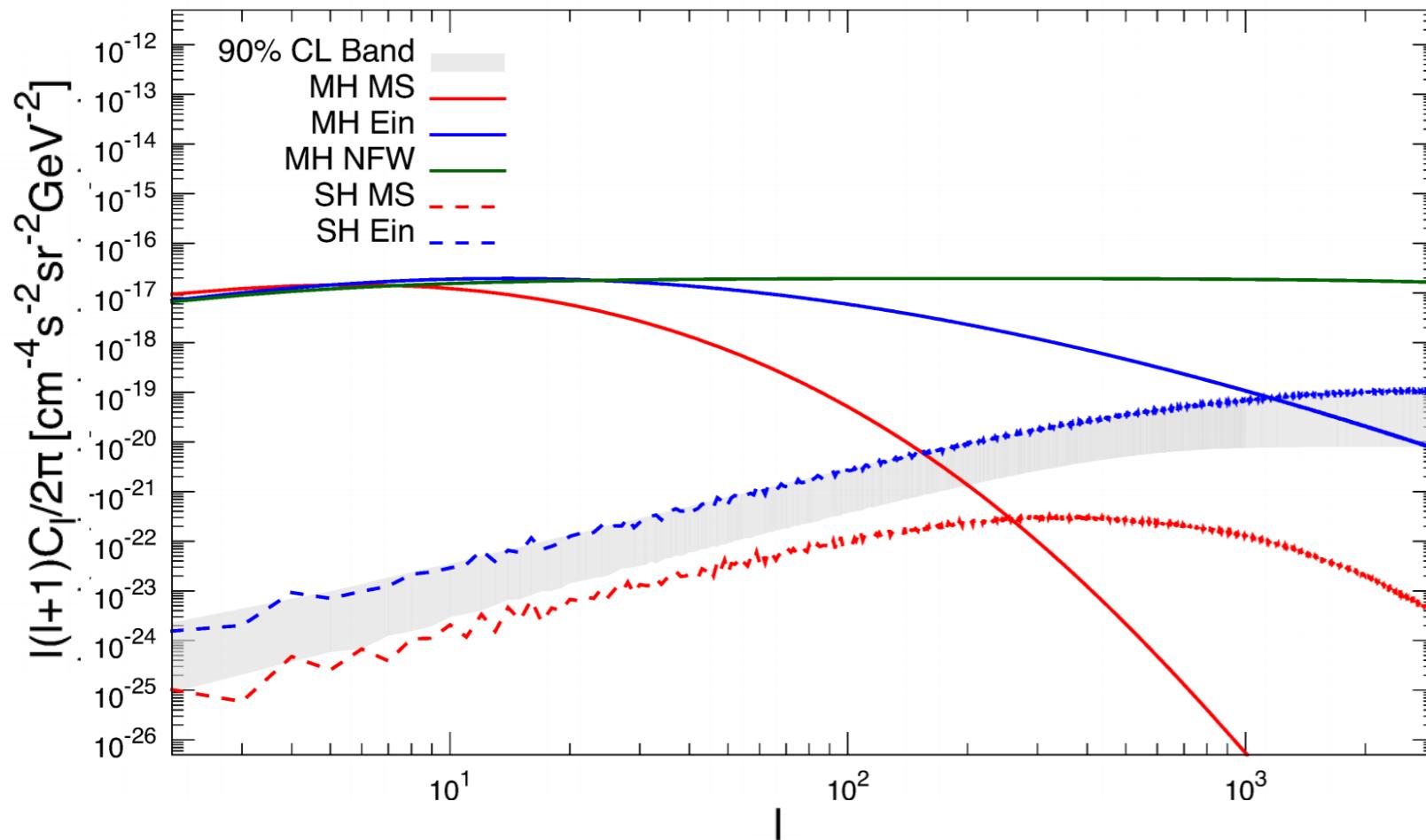
Fornengo's talk



$$I(\Psi) = \frac{d\Phi}{dE}(\Psi) - \langle \frac{d\Phi}{dE} \rangle = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{m=\ell} a_{\ell m} Y_{\ell m}^*(\Psi)$$

$$C_\ell = \frac{1}{2\ell + 1} \left( \sum_{|m| \leq \ell} \langle |a_{\ell m}|^2 \rangle \right) \quad \text{Intensity APS}$$

Calore+ MNRAS'14

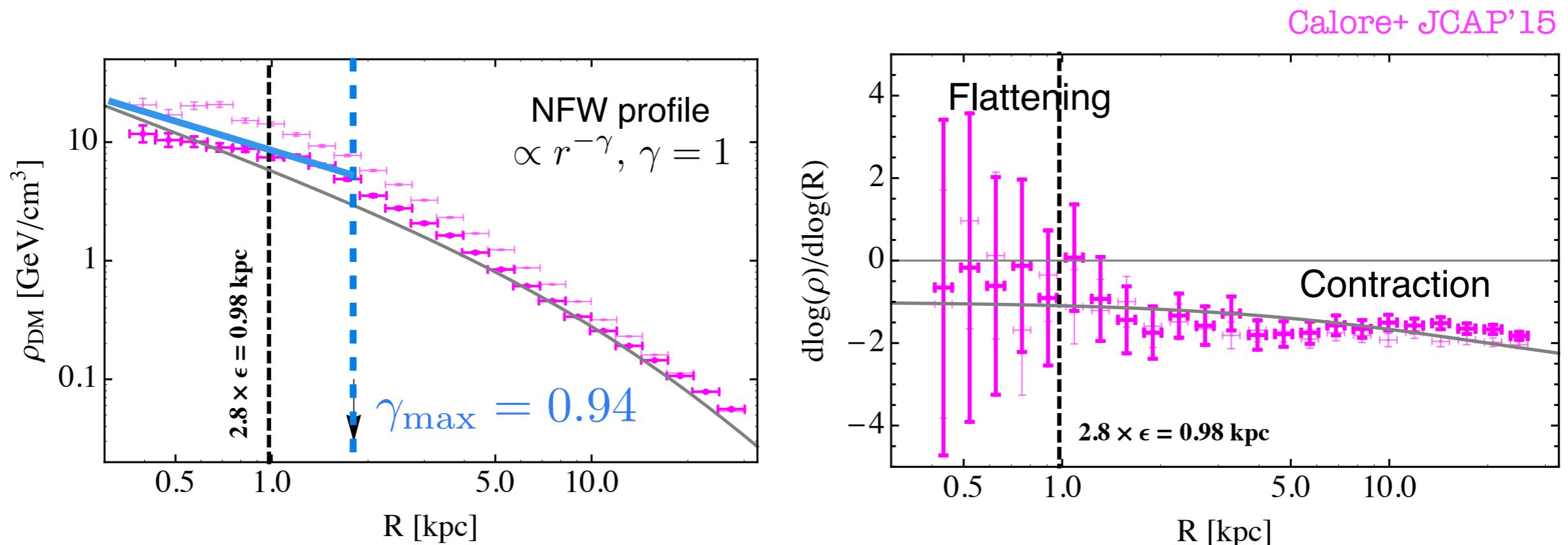


- DMO MW-like halo from MaGICC project.  
Stinson+ MNRAS'10/‘13
- DM annihilation into b-quarks for  $m_{DM}=200$  GeV.
- Dependence on assumed DM profile.
- No mask of the sky, no astrophysical bkg.

# Dark matter distribution in the Galaxy: the effect of baryons

Impact of baryons on the DM distribution in MW-like haloes:

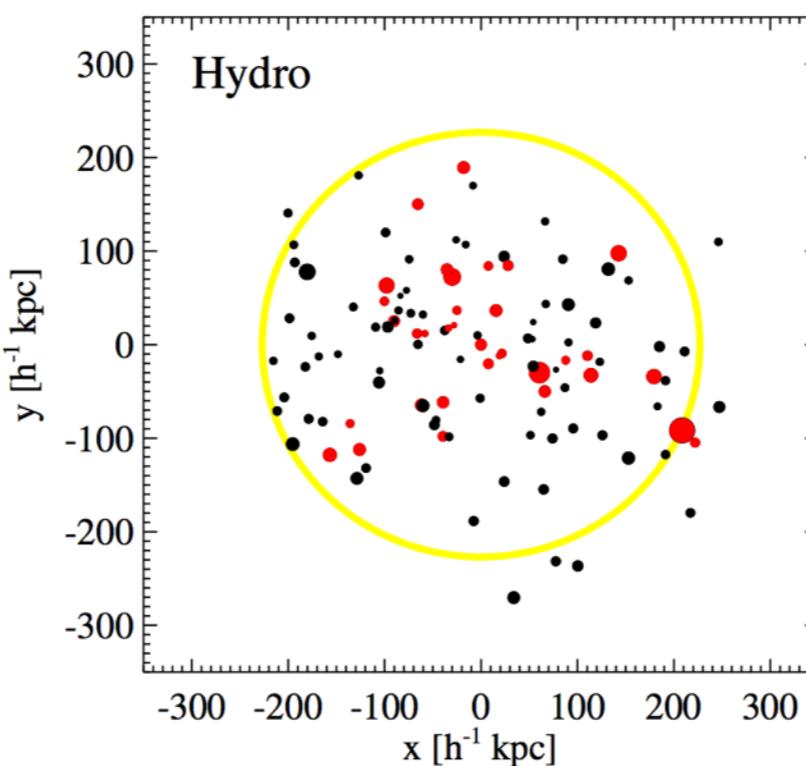
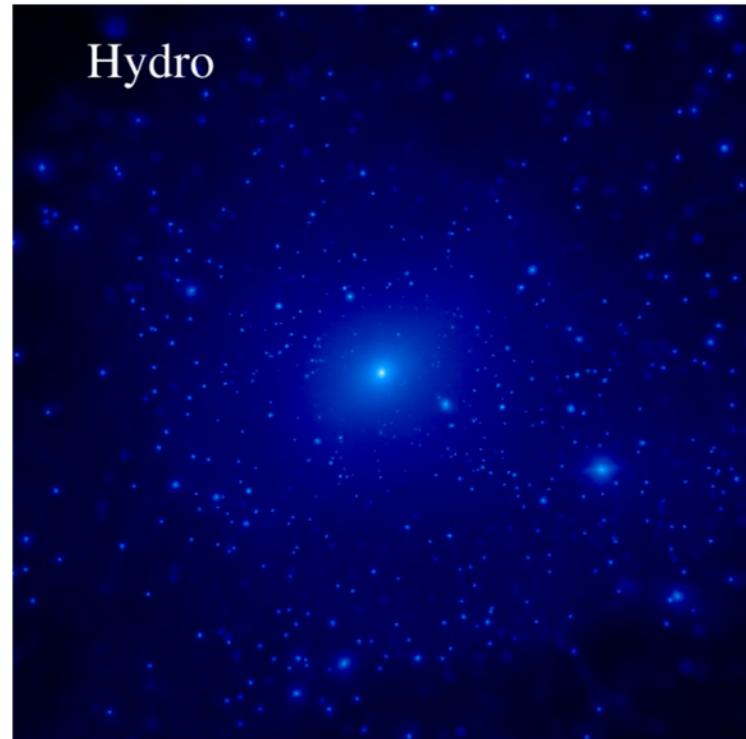
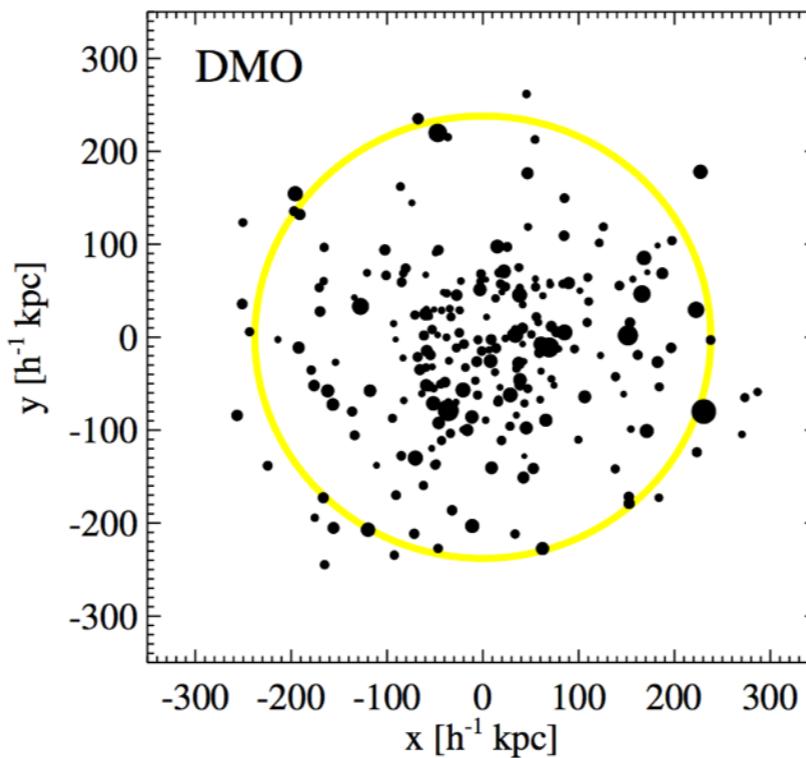
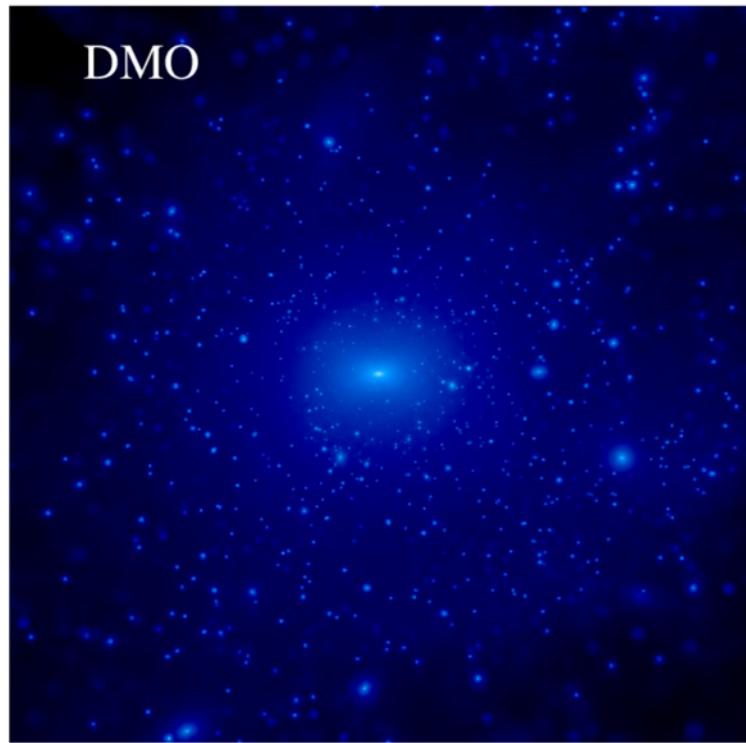
## (1) Main halo distribution



## (2) Distribution of sub-haloes?

“Shaping” processes: adiabatic contraction, tidal disruption and reionization.

# Spatial distribution of SHs

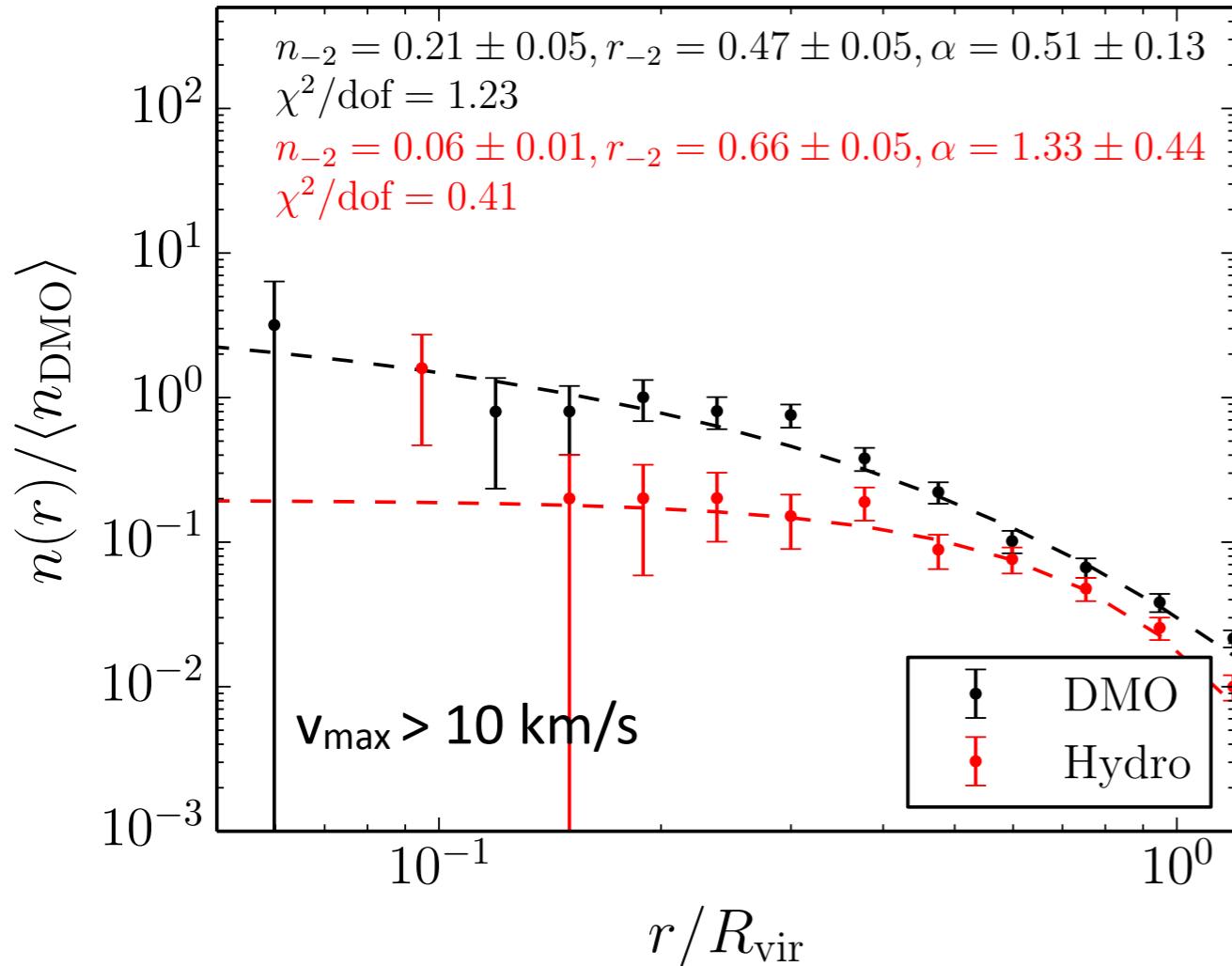


Zoom-in simulation of  
MW-sized disk galaxies  
with Illustris  
implementation of  
baryons, same initial  
conditions of Aquarius.

Marinacci+MNRAS'14

- Fewer SHs in the Hydro simulation.
- Low-mass SHs depleted in the Hydro simulation.
- Depletion mostly near the center.

# Spatial distribution of SHs: DM-only vs Hydro



Einasto fitting function

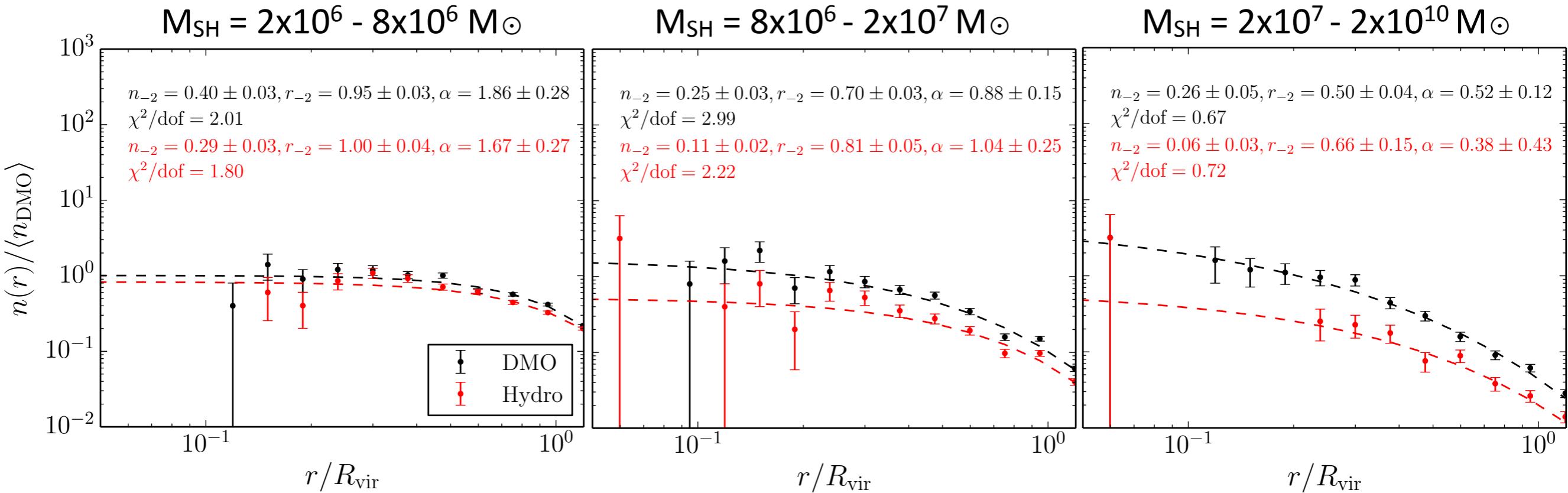
$$n(r)/\langle n \rangle_{\text{DMO}} = n_{-2} \exp \left\{ -\frac{2}{\alpha} \left[ \left( \frac{r}{r_{-2}} \right)^\alpha - 1 \right] \right\}$$

Data sets for DMO and Hydro simulations of [Zhu, Marinacci+2014](#)

- Radial abundance lower for Hydro simulation, mostly in the central region.
- Offset larger for massive SHs (flatter profile).
- $V_{\text{max}}$  ( $M_{\text{SH}}$ ) dependence of radial distribution — stronger for Hydro simulation.

# Radial distribution of SHs

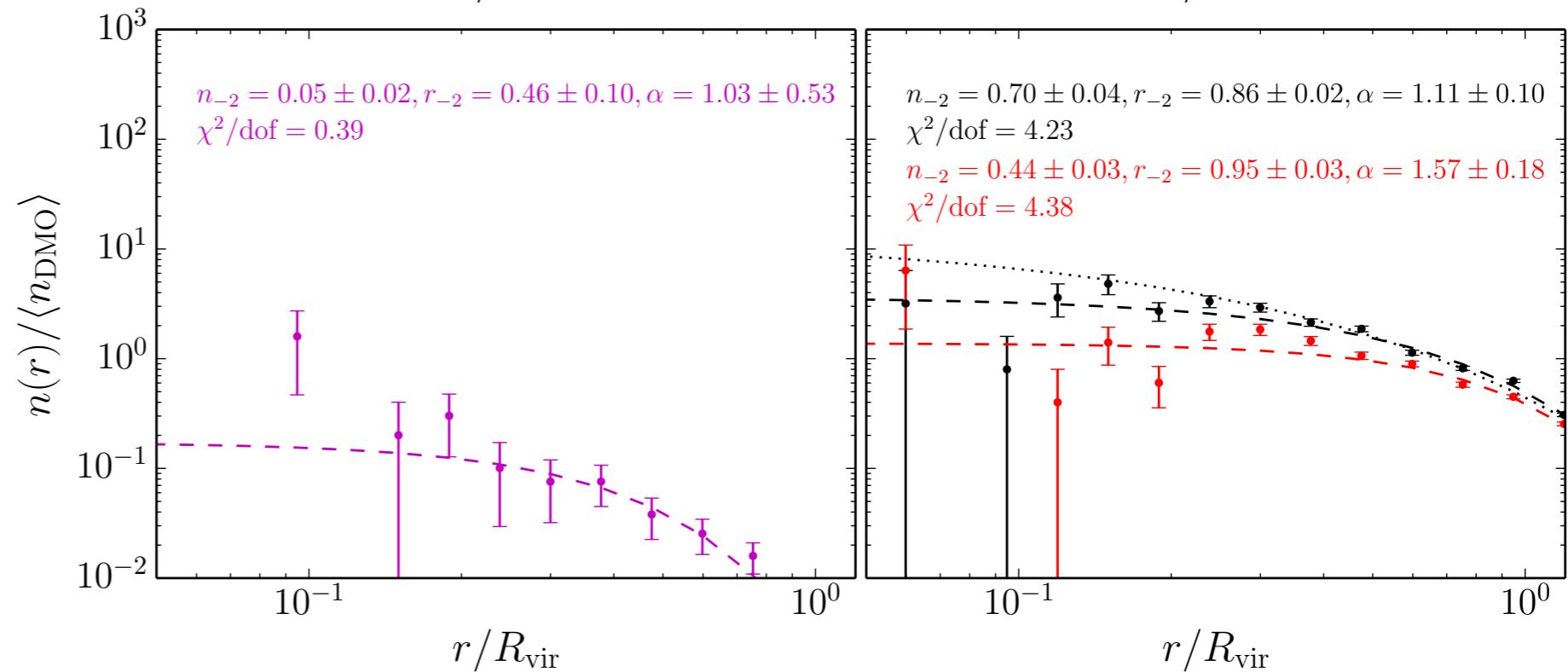
## Dark SHs



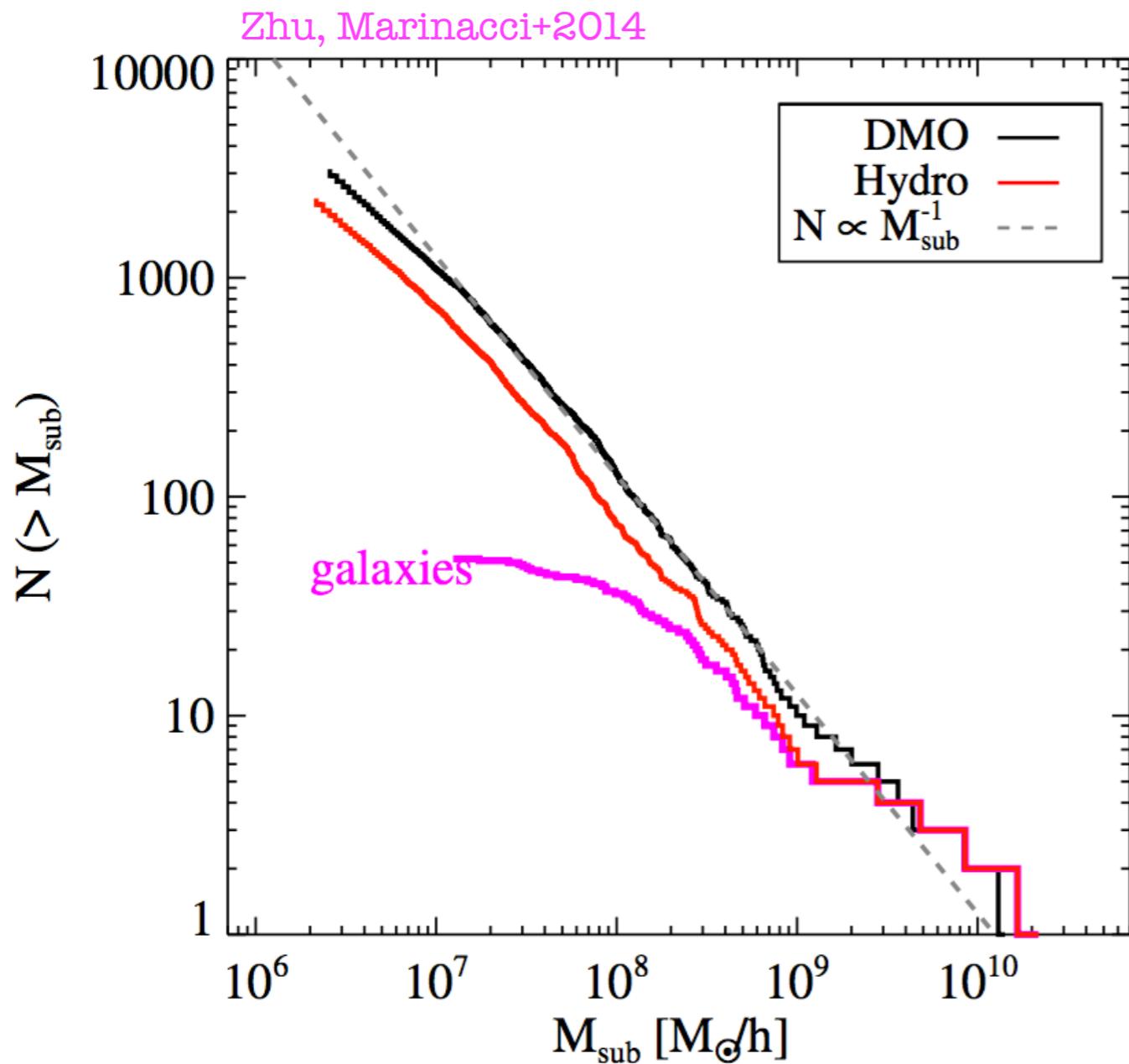
## Luminous SHs

$M_{\text{SH}} = 2 \times 10^6 - 2 \times 10^{10} M_{\odot}$

$\alpha_{\text{Springel08}} = 0.678$



# Mass distribution of SHs

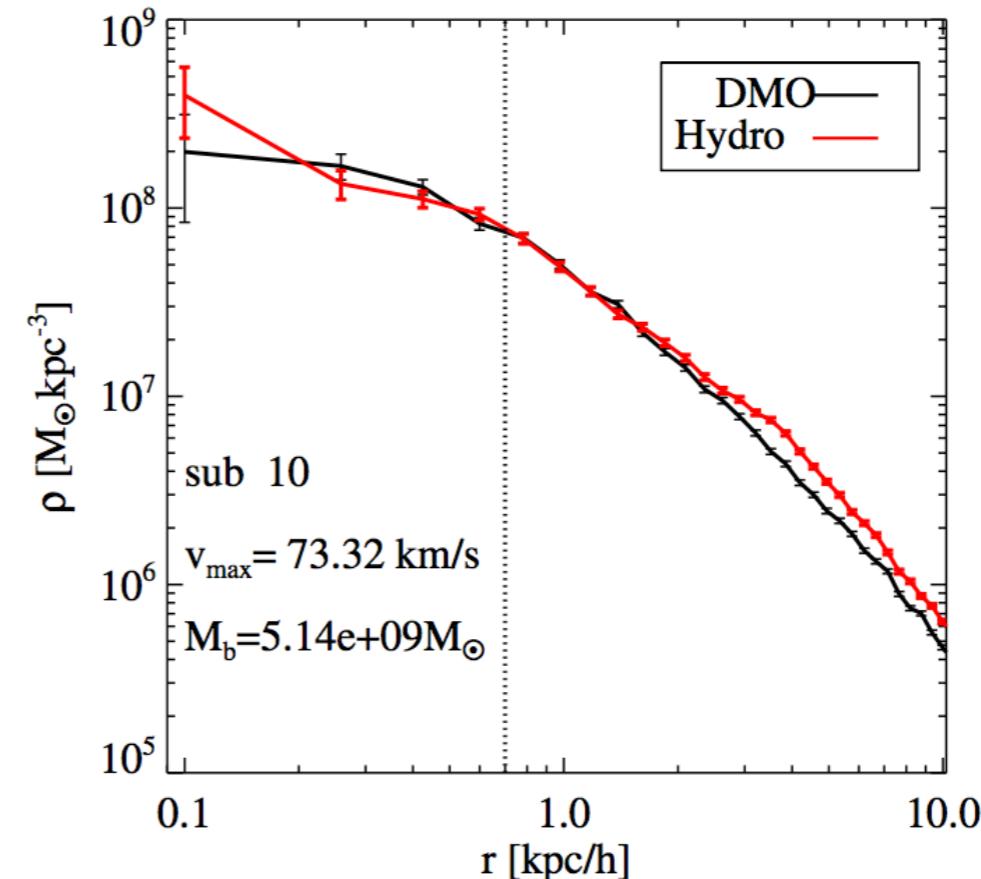
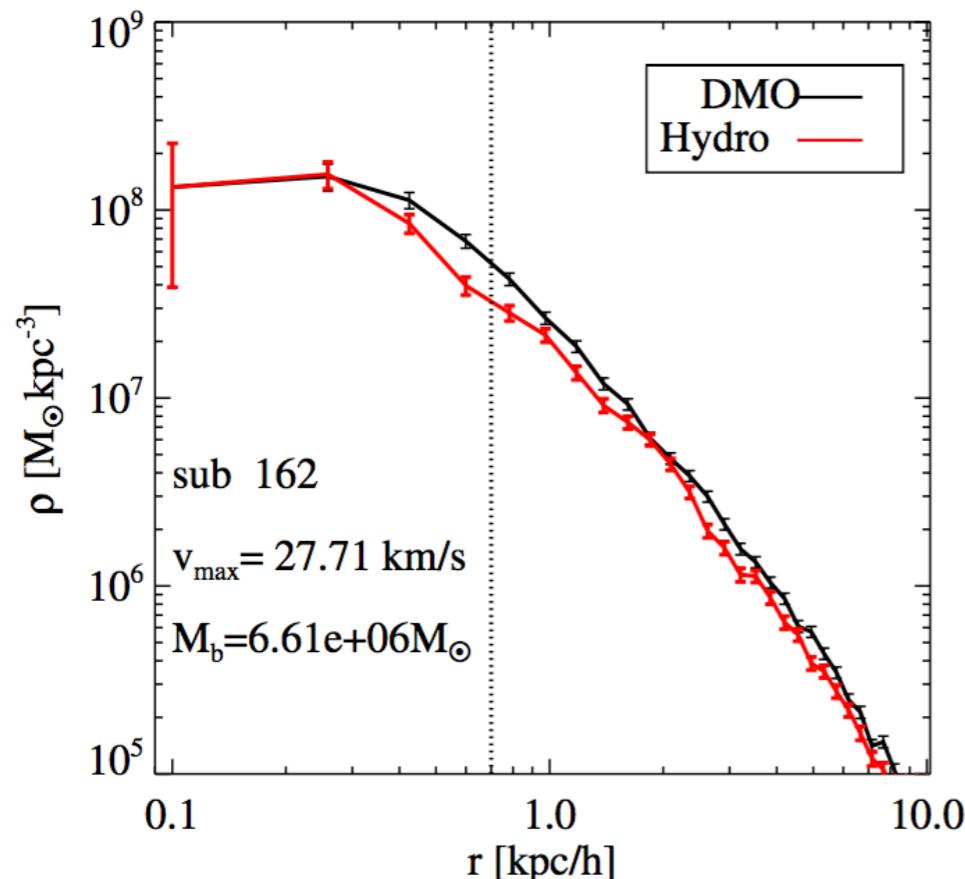


- Mass distribution slope consistent with DMO simulation.
- 30% reduction in the total number of SHs in Hydro simulation.

# Dark matter profile of individual SHs

“[...] the density profiles of SHs from the Hydro simulation match their DMO counterparts quite closely.”

Zhu, Marinacci+2014

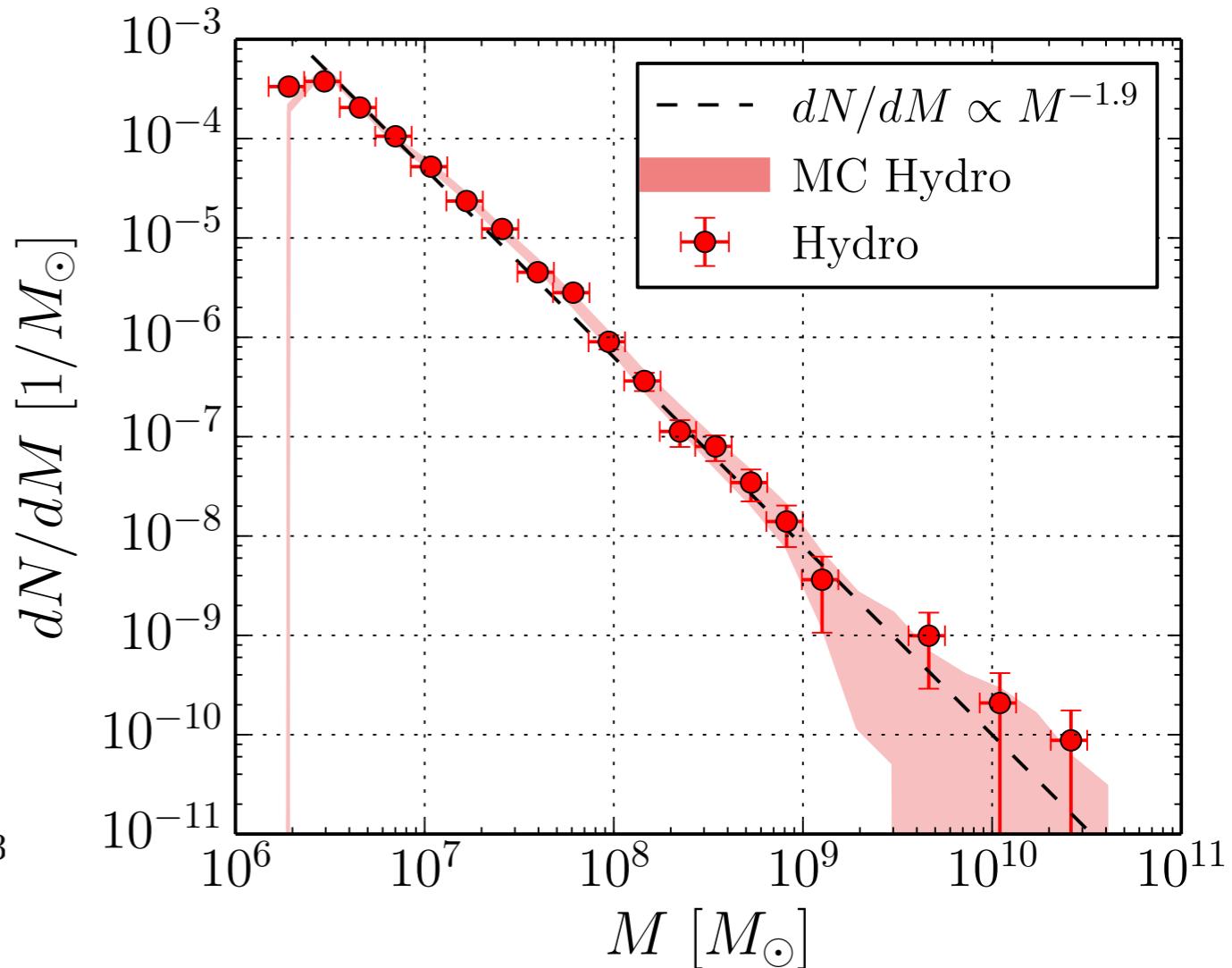
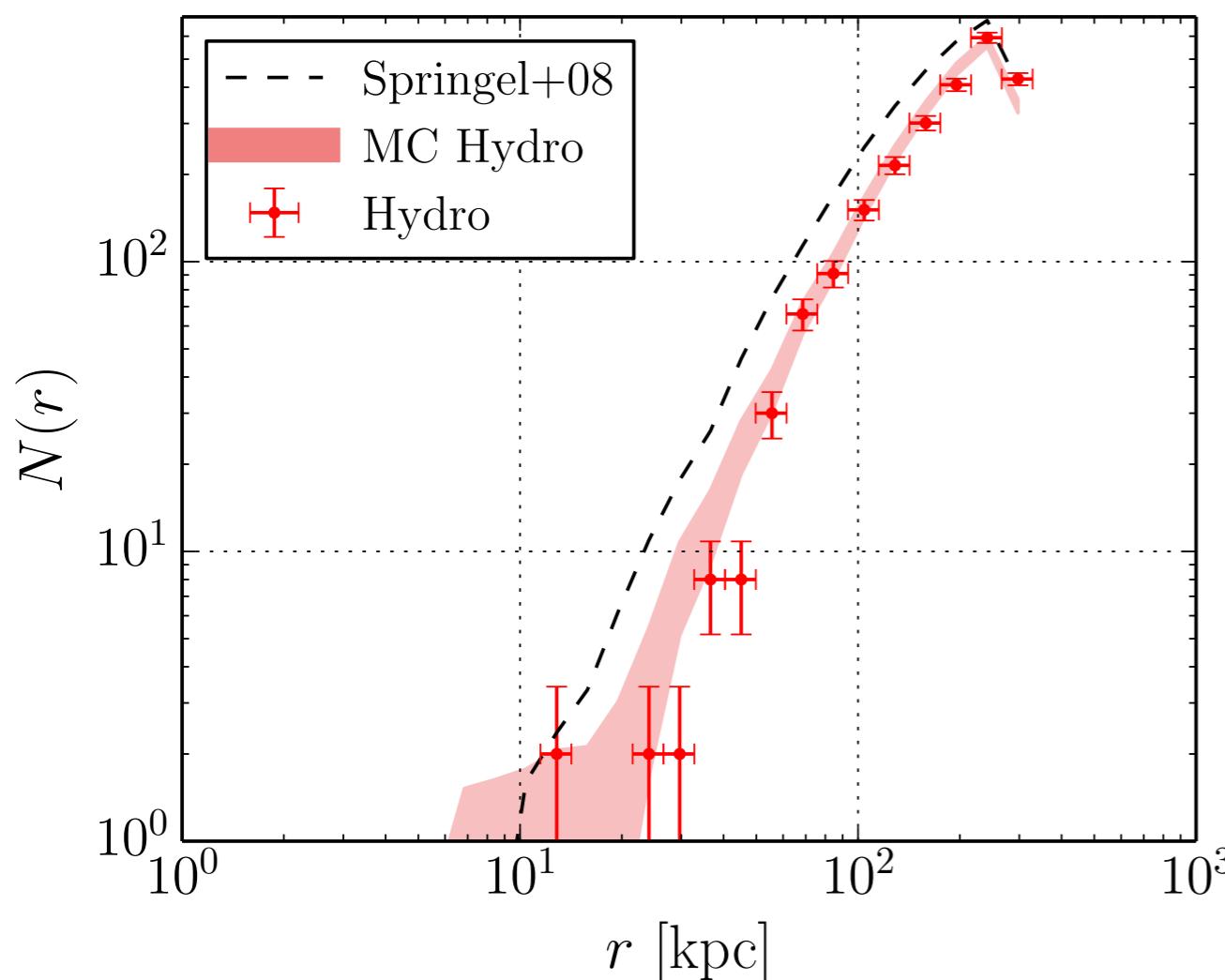


How do we model SHs?

- Concentration - Mass relation from Aquarius simulation.
- Einasto DM density profile,  $\alpha = 0.16$ .

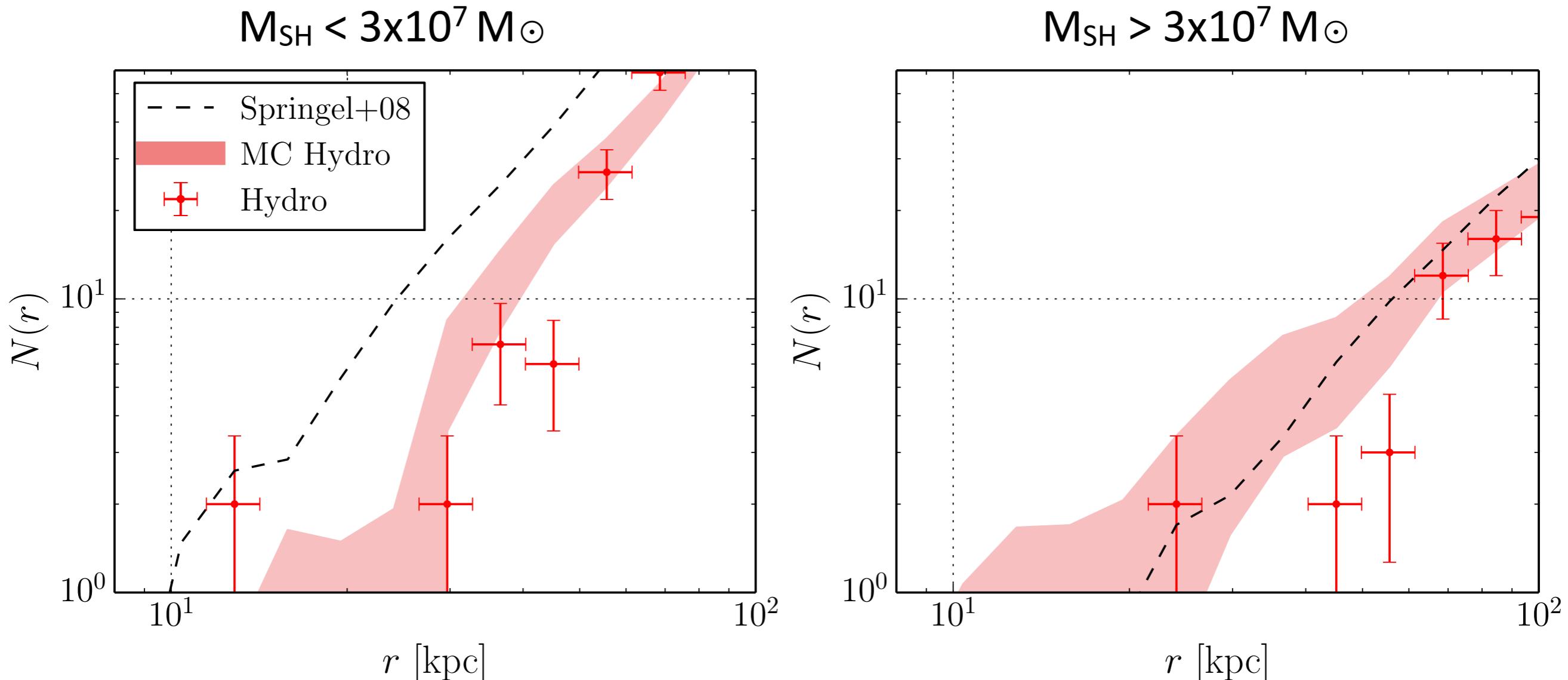
Springel+MNRAS'08  
Pieri+PRD'11

# Setting up the Monte Carlo



100 MC realisations  
~3000 SHs for single DMO realisation  
~2000 SHs for single Hydro realisation

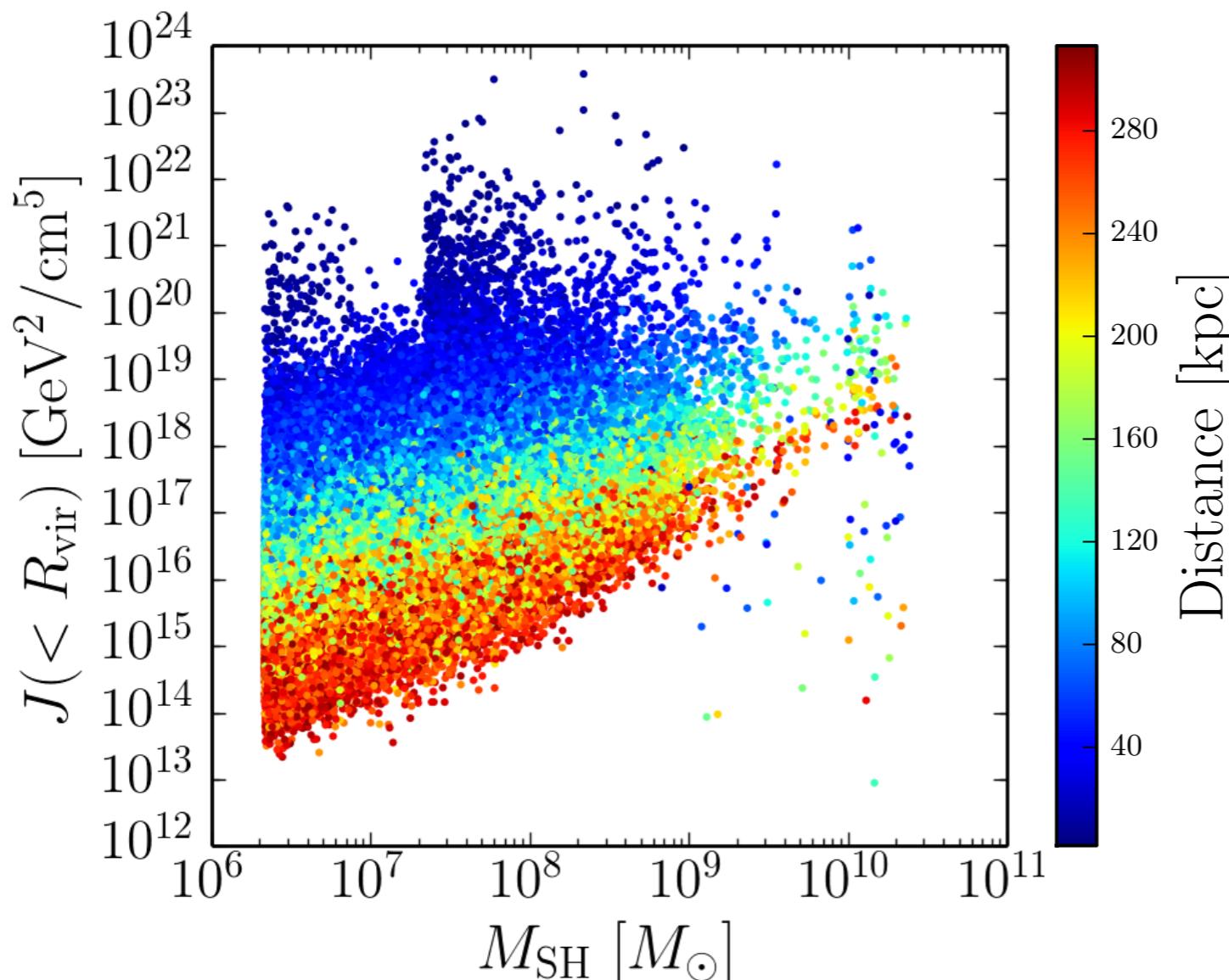
# Setting up the Monte Carlo



Depletion of low-mass SHs in the center for the Hydro simulation.

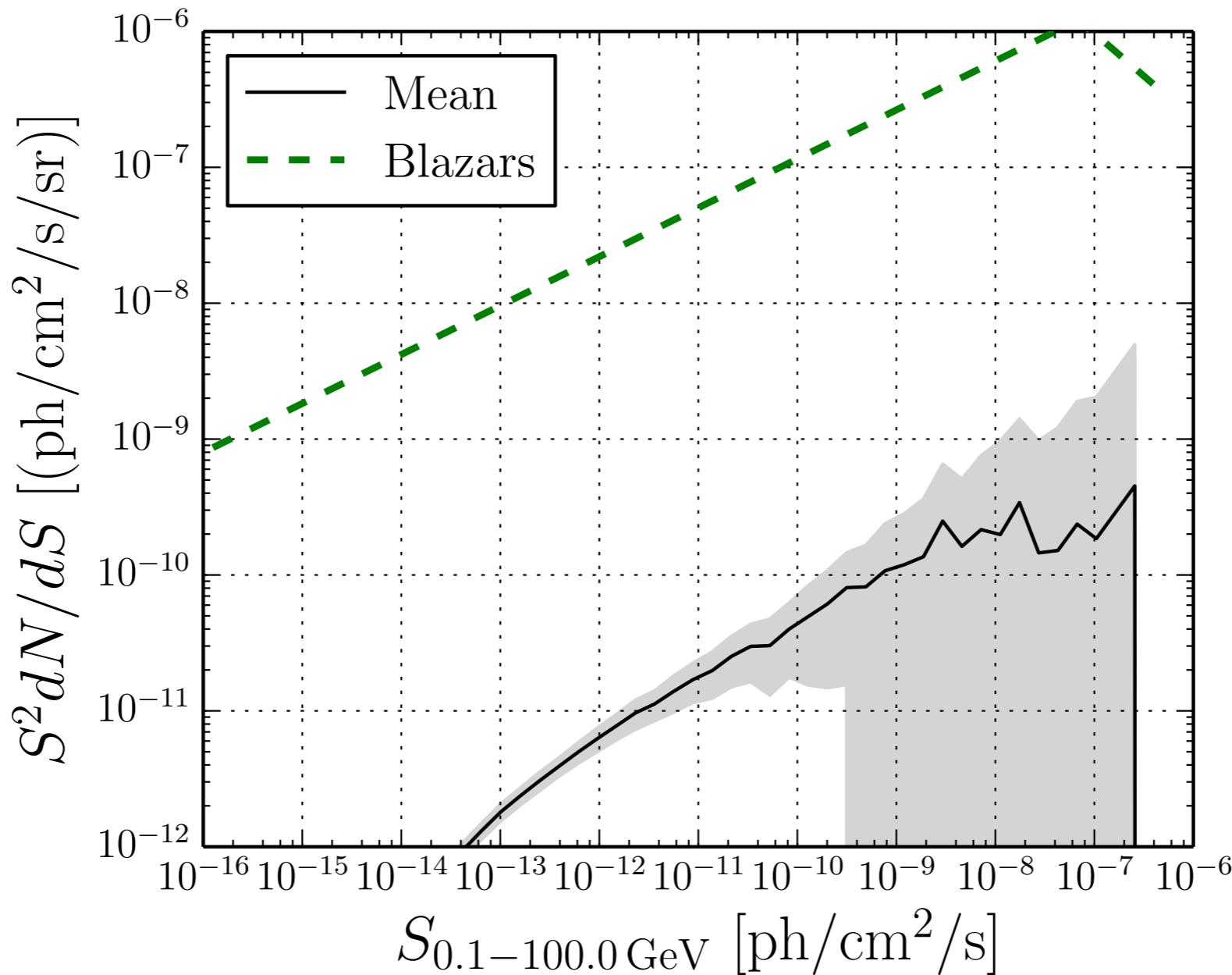
# SHs gamma-ray luminosity

$$J(\psi) \propto \int_{\text{l.o.s}} \rho_{\text{DM}}^2(r(s, \psi)) ds$$



- J-factor is mildly correlated with the SH mass.
- SH close to Earth and with low masses can have J-factor  $\sim 1\text{e}19 \text{ GeV}^2/\text{cm}^5$ .
- Difference in the number of local SHs might be relevant.
- Compare prediction for Springel +08 vs Hydro Aquarius.

# Source count distribution of SHs



SHs Hydro simulation vs detected blazars

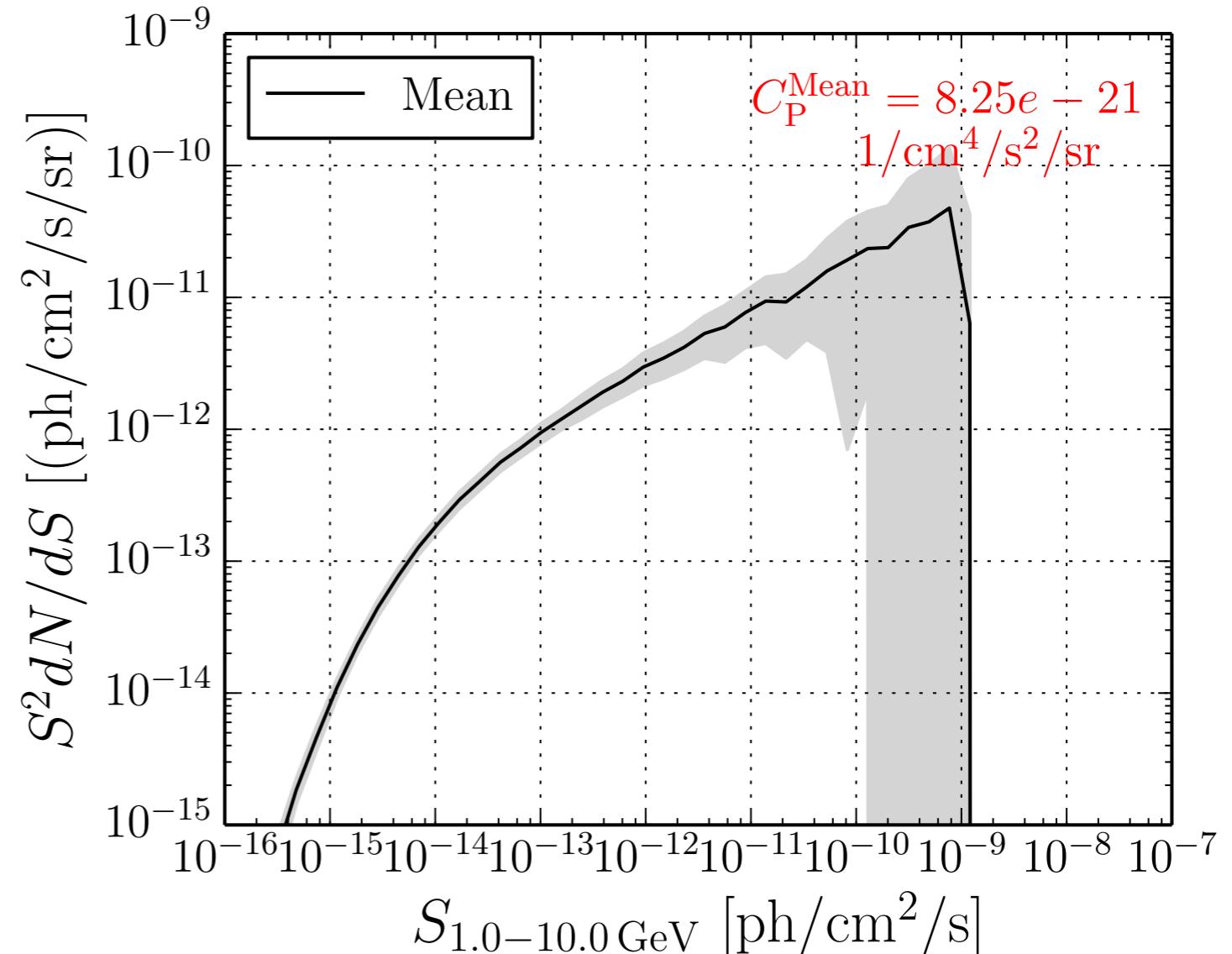
# Anisotropy from SHs: Poisson term

$m_{DM} = 100 \text{ GeV}$   
 $\langle \sigma v \rangle$  from dSph limits

$$C_P = \int_0^{S_t} \frac{dN}{dS} S^2 \, dS$$

Cuoco+PRD'12

Detection threshold:  
 $1 \times 10^{-9} \text{ ph/cm}^2/\text{s}$



2012 *Fermi*-LAT results

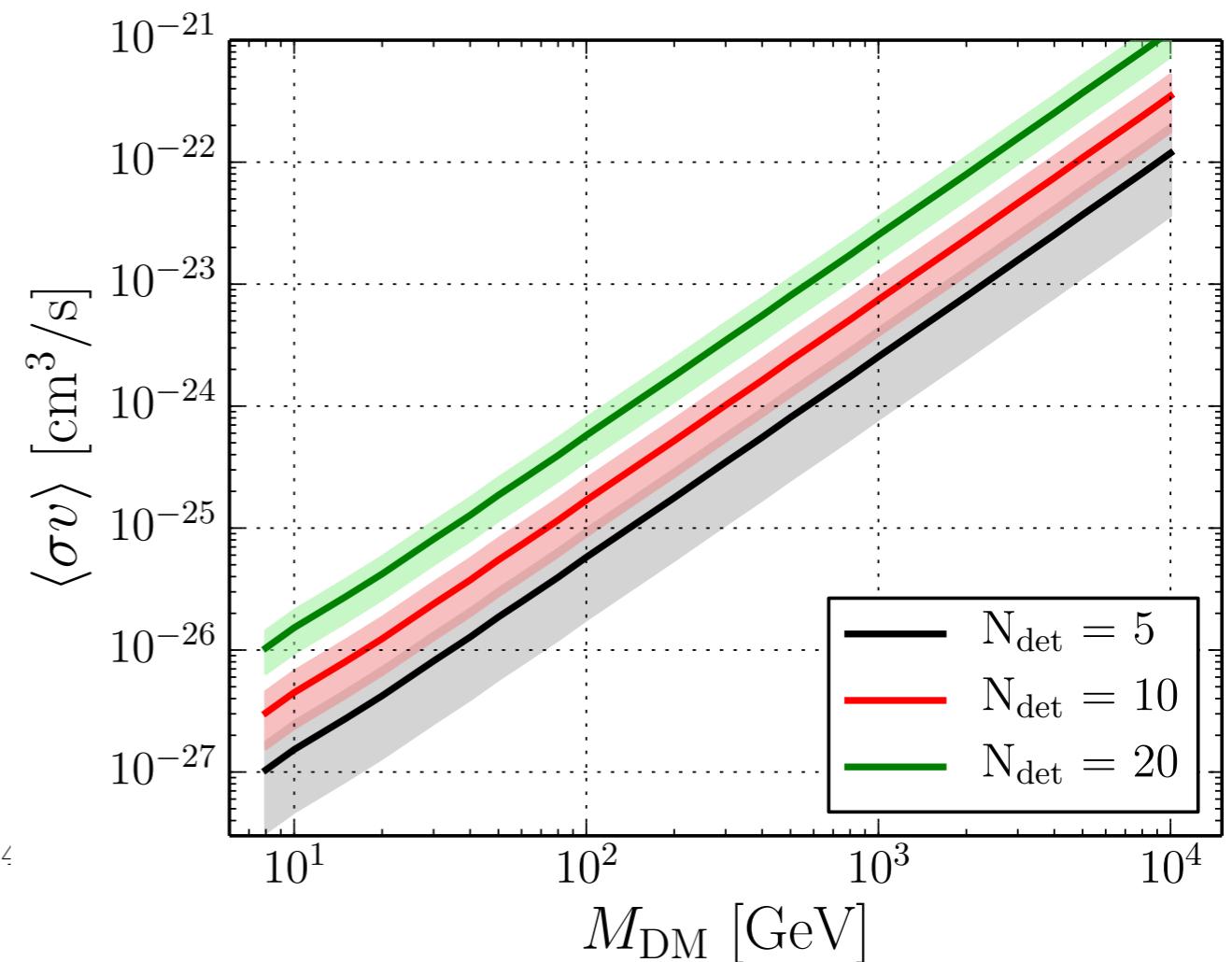
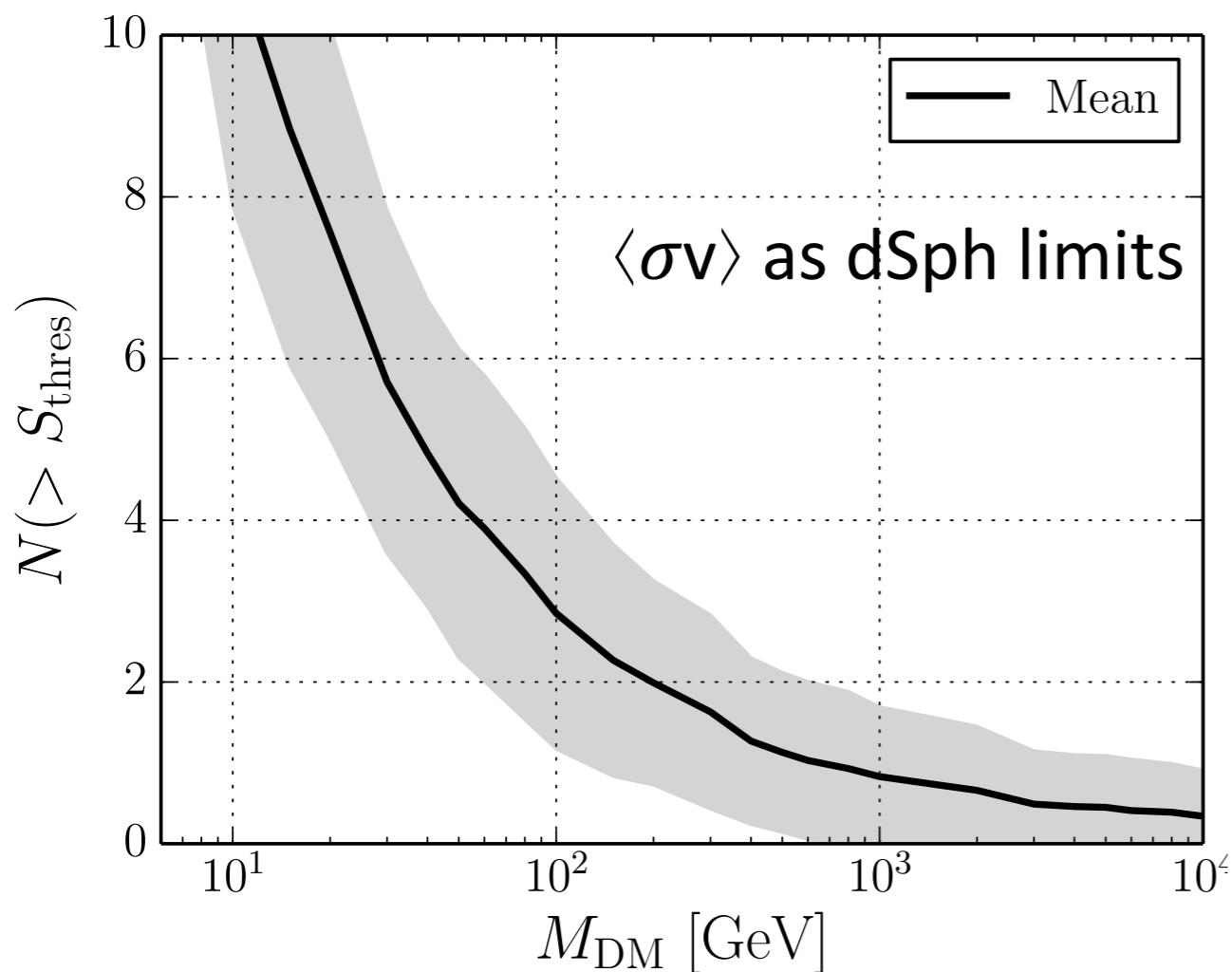
Ackermann+PRD'12

Zechlin, Fornasa's talk

$E_{\text{min}}$ [GeV]	$E_{\text{max}}$ [GeV]	$C_{P,\text{data}}$ [( $\text{cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ ) $^2 \text{ sr}$ ]
1.0	10.0	$110 \pm 12 \text{ } 10^{-19}$

# SHs as unassociated *Fermi-LAT* sources

$$S_{\text{thres}} = 1 \times 10^{-9} \text{ ph/cm}^2/\text{s}$$
$$|b| > 10^\circ$$



Bertoni+1504.02087

Schooneberg+1601.06781

# What's next?

- Estimate *Fermi*-LAT sensitivity to DM spectra from 3FGL and 2FHL detected sources.
- Derive corresponding expectations for:
  - (1) Source count distribution and poisson anisotropy term.
  - (2) Number of detectable SHs at high-latitudes.
  - (3) Upper limits on DM annihilation cross-section.
- Analysis performed for different annihilation channels (b-quark and tau-leptons pairs).