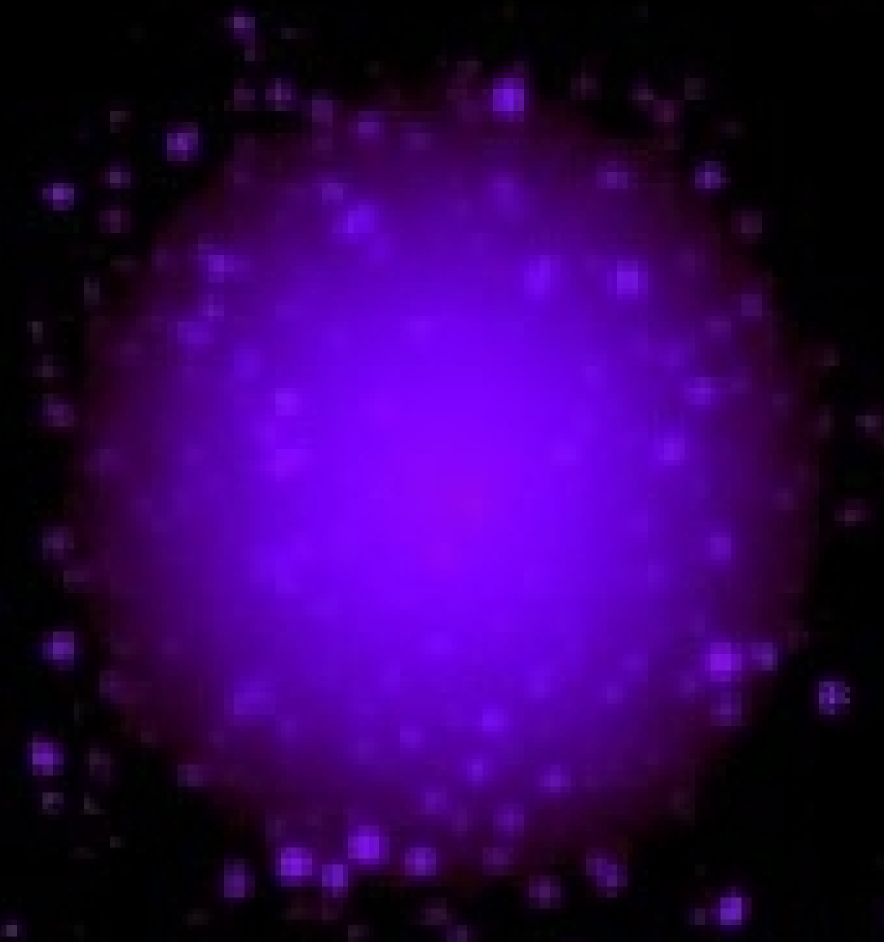
Dwarf spheroidal galaxies (dSphs) as targets



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1st LINK Workshop
12/11/2010

A quick reminder

1. Why dSphs?

- Galactic centre obvious location (Silk & Bloemen 1987)
  => but plagued by a large astrophysical background (Aharonian et al. 2004)
- dSphs next favoured target (Lake 1990, Evans, Ferrer & Sarkar 2004)
  => DM dominated + low astrophysical background

2. How to determine the profile (inner slope γ)?

- Use of kinematical data
  => but accommodate core & cuspy (e.g., Walker et al. 2009)
- Rely on DM collisionless simulation (give cusps, e.g. Nawarro, Frenk, & White 1996)
  => but baryons could erase cusps (e.g., Navarro et al., 1996, Mashchenko et al. 2008)

3. In recent studies for γ-ray detectability (Fermi-LAT, H.E.S.S., ...)

- Core and cusp fitted to kinematical data (Sanchez-Conde et al. 2007, Pieri et al. 2009...)
- Use cosmological priors (e.g., Kuhlen 2010)
- Combination of the two approaches (Strigari et al. 2009, Martinez et al. 2009)

Our approach

(based on 2 papers submitted very soon)

- A new calculation of DM annihilations in dSphs

C. Charbonnier, C. Combet, M. Daniel, M. Funk, J. Hinton, D.M., C. Power, J. Read, S. Sarkar, M. Walker, & M. Wilkinson

=> Relies solely on kinematical data (based on an MCMC approach)
=> Minimal assumptions about DM (not restricted to standard core and cusp)

- The public code CLUMPY: *C. Charbonnier, C. Combet & D.M*

=> calculation of the astrophysical factor 'J' for any configuration of DM clumps and subclumps

Dwarf spheroidal galaxies as targets

I. CLUMPY

II. Key parameters: generic dSphs

III. Jeans/MCMC analysis and CLs

IV. Detectability of the Milky Way dSphs

What is CLUMPY?

CLUMPY is a code that calculates the γ-ray signal from:

- smooth DM halo of the Milky Way
- clump DM distribution in the Galactic halo

Statistical skymap mode

- individual dSphs
- Sub-clumps within dSphs

Dwarf spheroidal mode

[clump treatment: semi-parametric approach based on N-body simulations]

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Goodies:

- C/C++ interfaced with ROOT CERN library (+pop-up graphics)
- Fully documented, using Doxygen

- Deals with annihilations as well as decay
- Integration region can be any 2-parameter function (e.g. a gaussian)

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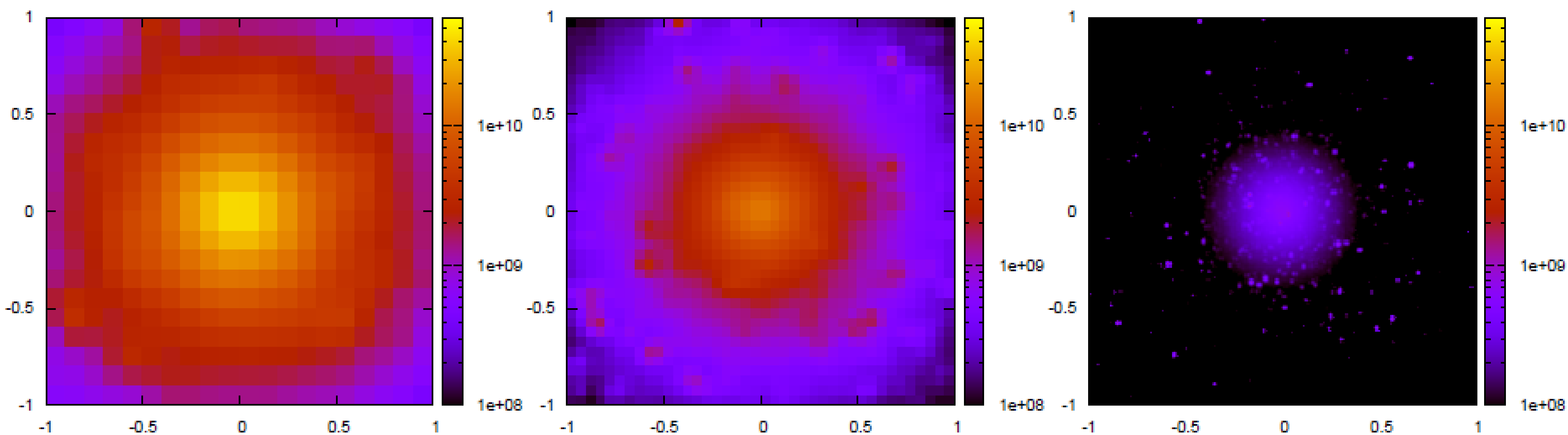
You might be interested in CLUMPY if you are

- An experimentalist looking for realistic skymaps for his/her new instrument
- An astrophysicist working on the DM content of dSphs
- A theoretician testing his/her favourite particle physics model

dSph + sub-clumps (in the dSph)

J for a Dsph: 2° • 2°
[core profile + NFW/B01 subclumps]
[d=100 kpc, no gal. bkgd]

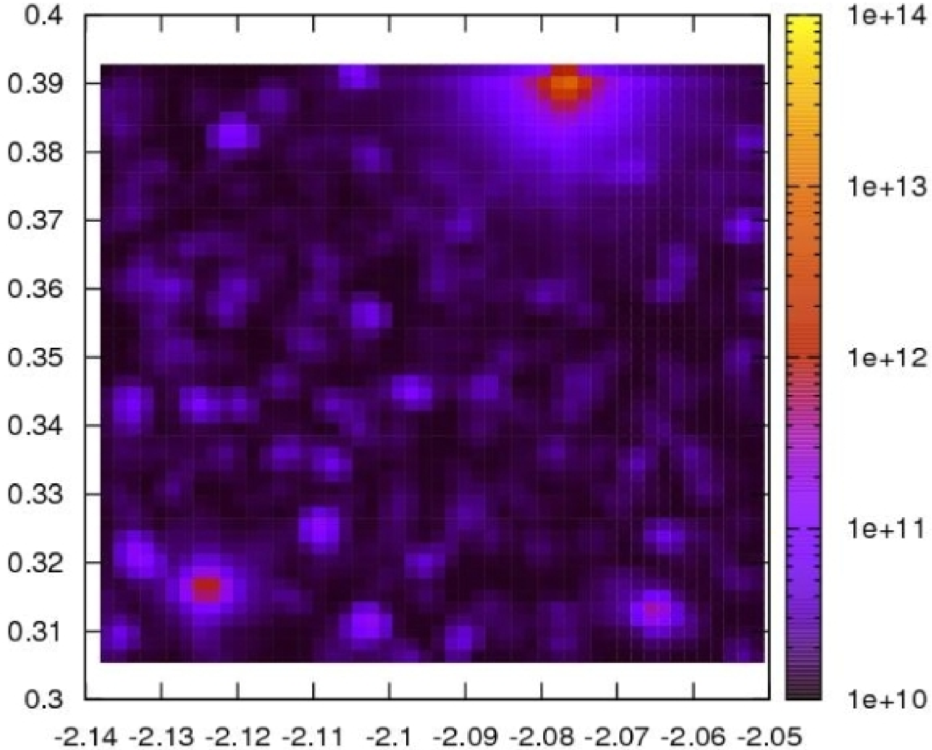
$\alpha_{int} = 0.1°$ $\alpha_{int} = 0.05°$ $\alpha_{int} = 0.01°$



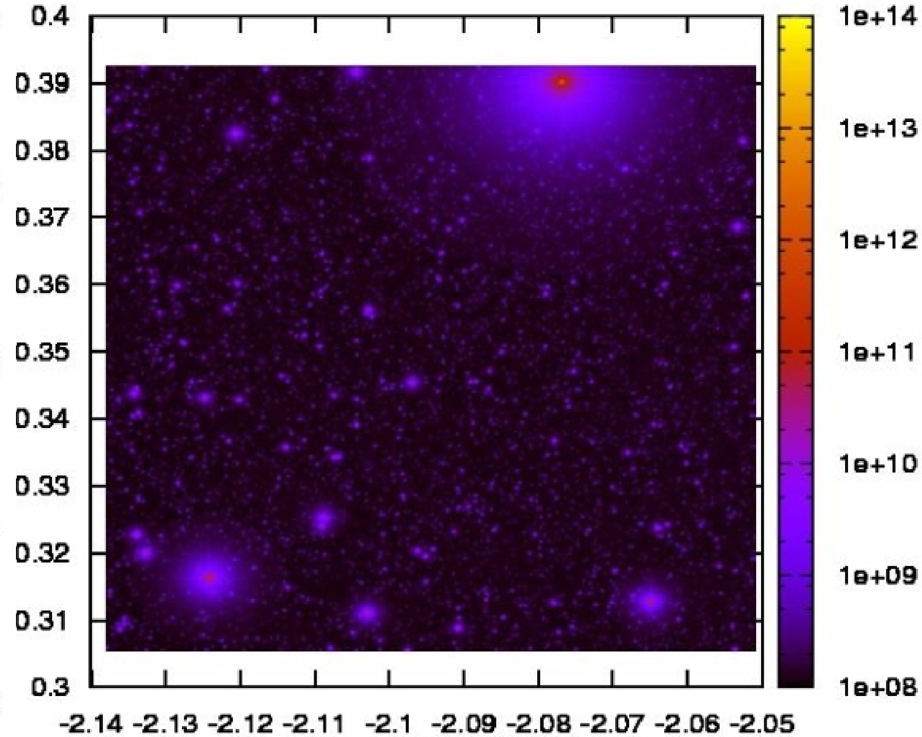
Smooth + clumps

Skymap slice (2°x2°) toward (ψ,θ) = (-120,20)
[ρ(r) + dP/dV(r) + clump profiles = Einasto]

$\alpha_{int} = 0.1°$



$\alpha_{int} = 0.01°$

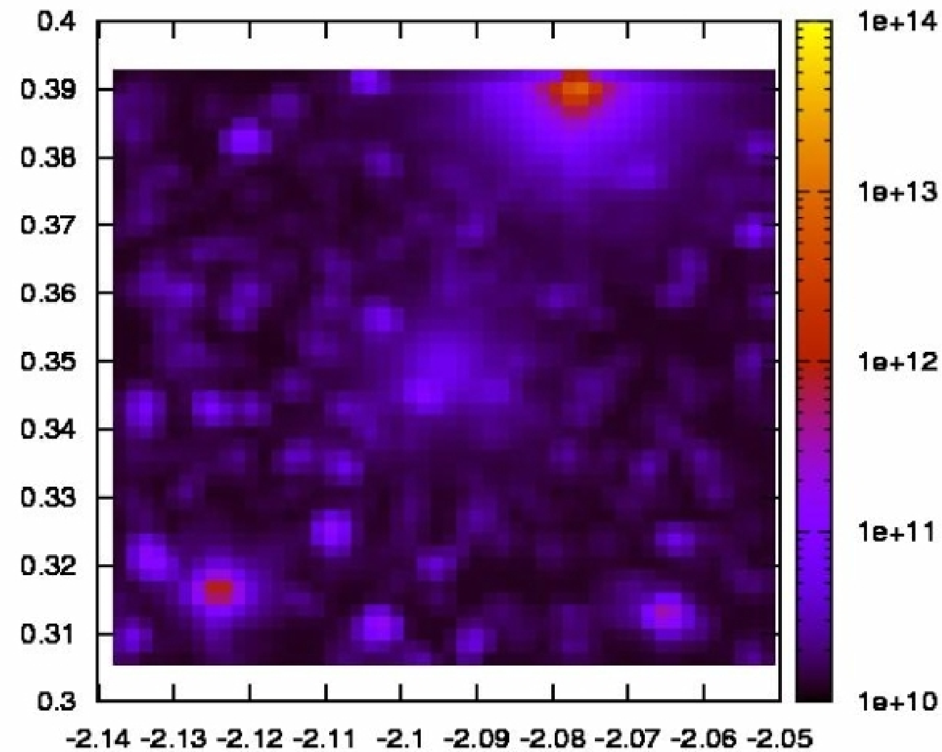


Smooth + clumps + dSph (+sub-clumps)

Skymap slice (2°x2°) toward (ψ,θ) = (-120,20)
[$\rho(r)$ + dP/dV(r) + clump profiles = Einasto]

Only an illustration!

$\alpha_{int} = 0.1°$



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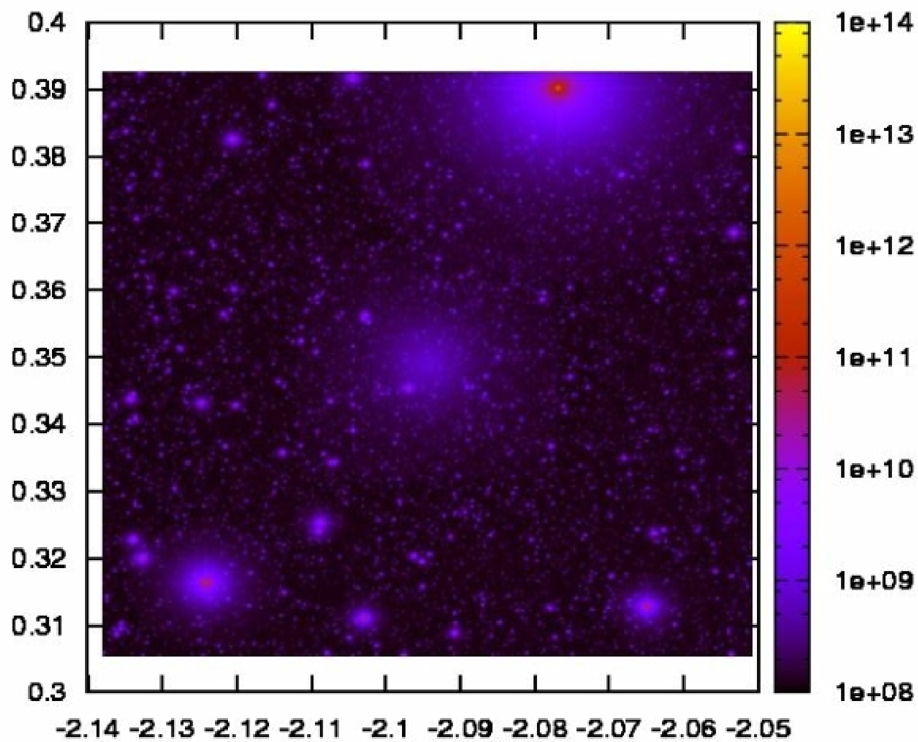


In the following, we are interested only in 'unresolved' observations:
=> clump not drawn, we use <Jsubcl> instead

I. CLUMPY

II. Key parameters: generic dSphs

III. Jeans/MCMC analysis and CLs

IV. Detectability of the Milky Way dSphs

Ingredients

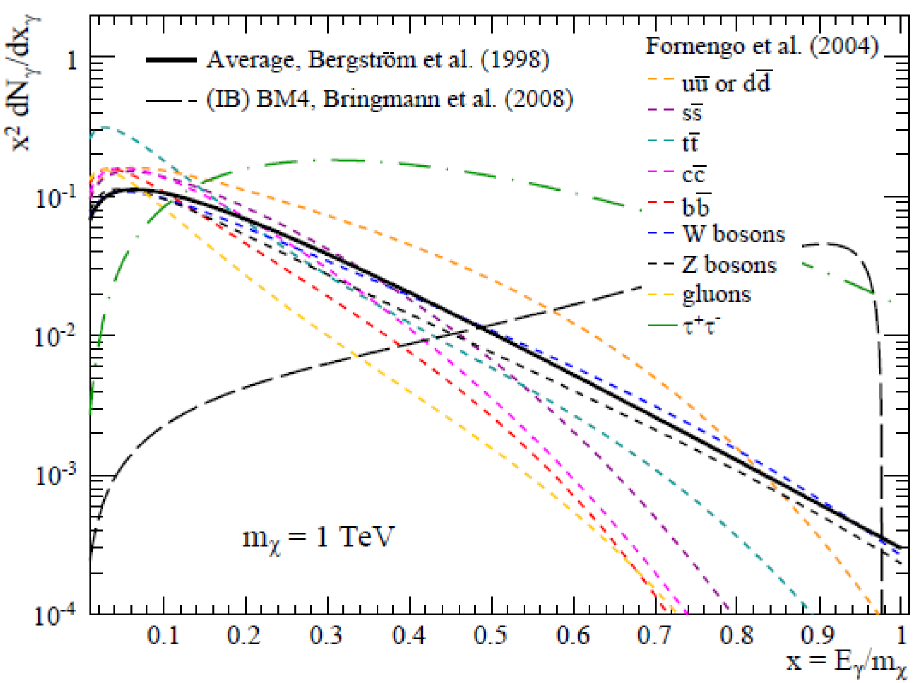
$$\rho(r) = \rho_s \left(\frac{r}{r_s}\right)^{-\gamma} \left[1 + \left(\frac{r}{r_s}\right)^{\alpha}\right]^{\frac{\gamma-\beta}{\alpha}}$$

Particle physics term

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma, \Delta\Omega) = \Phi^{\rm PP}(E_\gamma) \times J(\Delta\Omega)$$

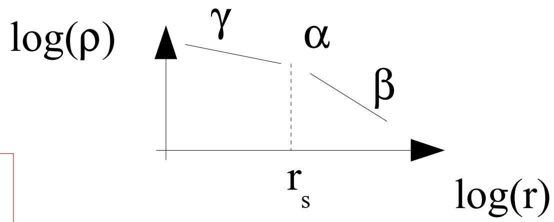
$$\Phi^{\rm PP}(E_\gamma) \equiv \frac{d\Phi_\gamma}{dE_\gamma} = \frac{1}{4\pi}\frac{\langle\sigma_{\rm ann} v\rangle}{2m_\chi^2} \cdot \frac{dN_\gamma}{dE_\gamma}$$

$$\frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma}(E_\gamma) = \sum_i b_i \frac{\mathrm{d}N_\gamma^i}{\mathrm{d}E_\gamma}(E_\gamma, m_\chi)$$



=> we use the average
Bergstrom et al (1998)

Ingredients



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$$J = \int_{\Delta\Omega} \int \rho^2_{\rm DM}(l, \Omega)\, dl d\Omega$$

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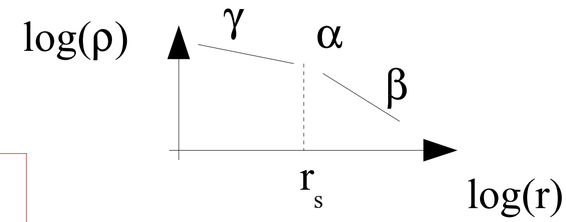

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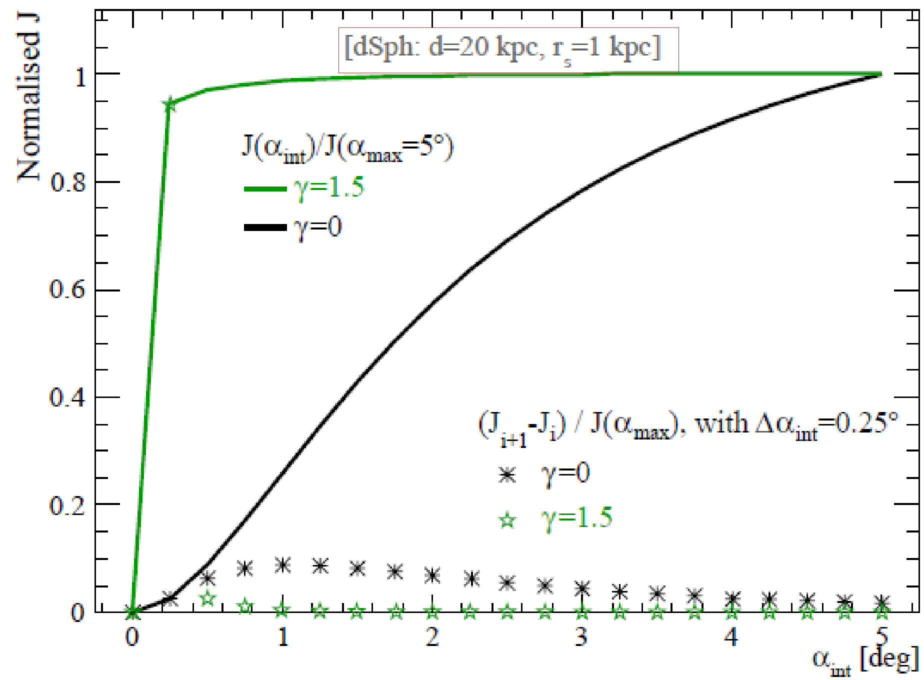
$$\Delta\Omega = 2\pi \cdot (1 - \cos(\alpha_{\rm int}))$$



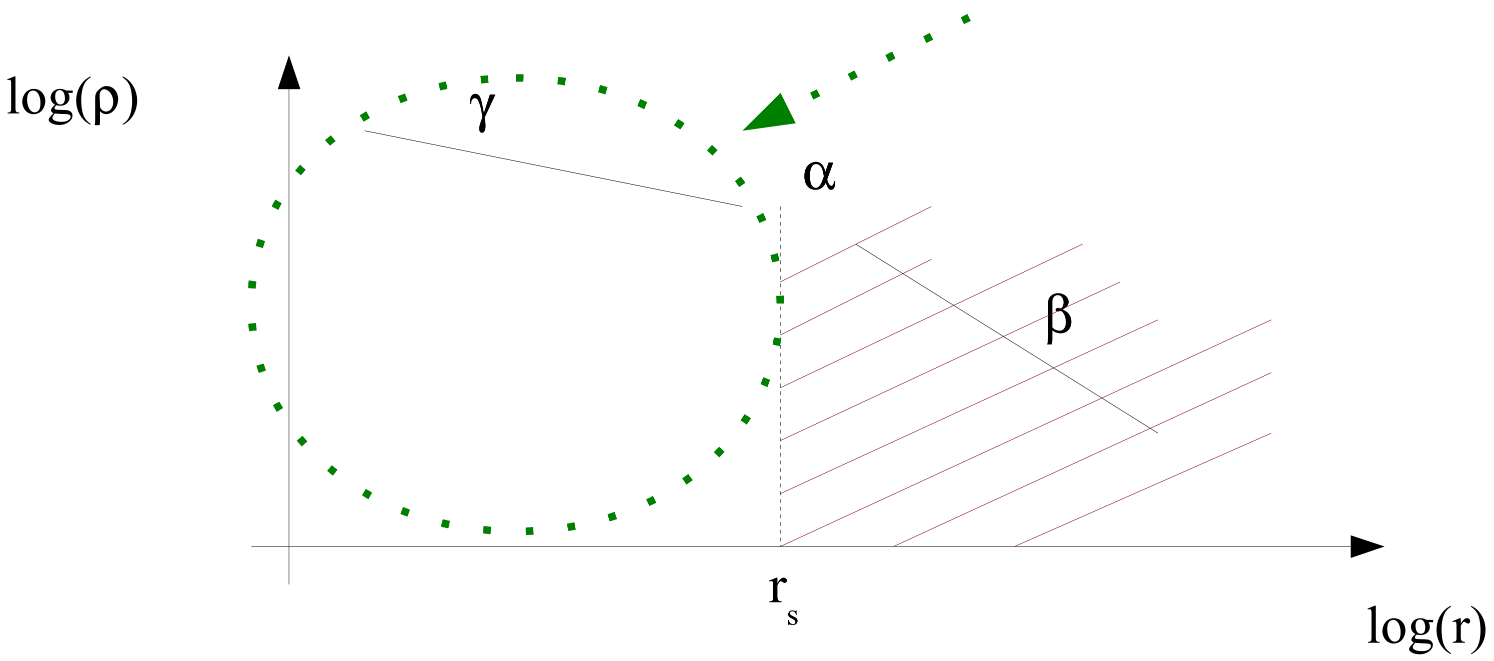
=>N.B.: the 'optimal' integration angle depends on γ

Key parameters: generic study

$$\rho(r) = \rho_s \left(\frac{r}{r_s}\right)^{-\gamma} \left[1 + \left(\frac{r}{r_s}\right)^{\alpha}\right]^{\frac{\gamma-\beta}{\alpha}}$$

1. First approx.: only depends on γ, ρ_s and r_s

$$J_{\rm approx} = \frac{4\pi}{d^2} \int_0^{\min(r_{\alpha_{\rm int}}, r_s)} r^2 \rho^2_{\rm approx}(r) dr. \quad \Rightarrow \quad J_{\rm approx} = \frac{4\pi}{d^2} \cdot \frac{\rho_s^2\, r_s^{2\gamma}}{3 - 2\gamma} \cdot [\min(r_{\alpha_{\rm int}}, r_s)]^{3-2\gamma}$$



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2. Second approx.: all dSphs have $M_{300} \sim 10^7\ M_{\odot}$ (Strigari et al., 2007)

- we set $(\alpha,\beta,\gamma) = (1,3,\gamma)$
- we fix γ and r_s

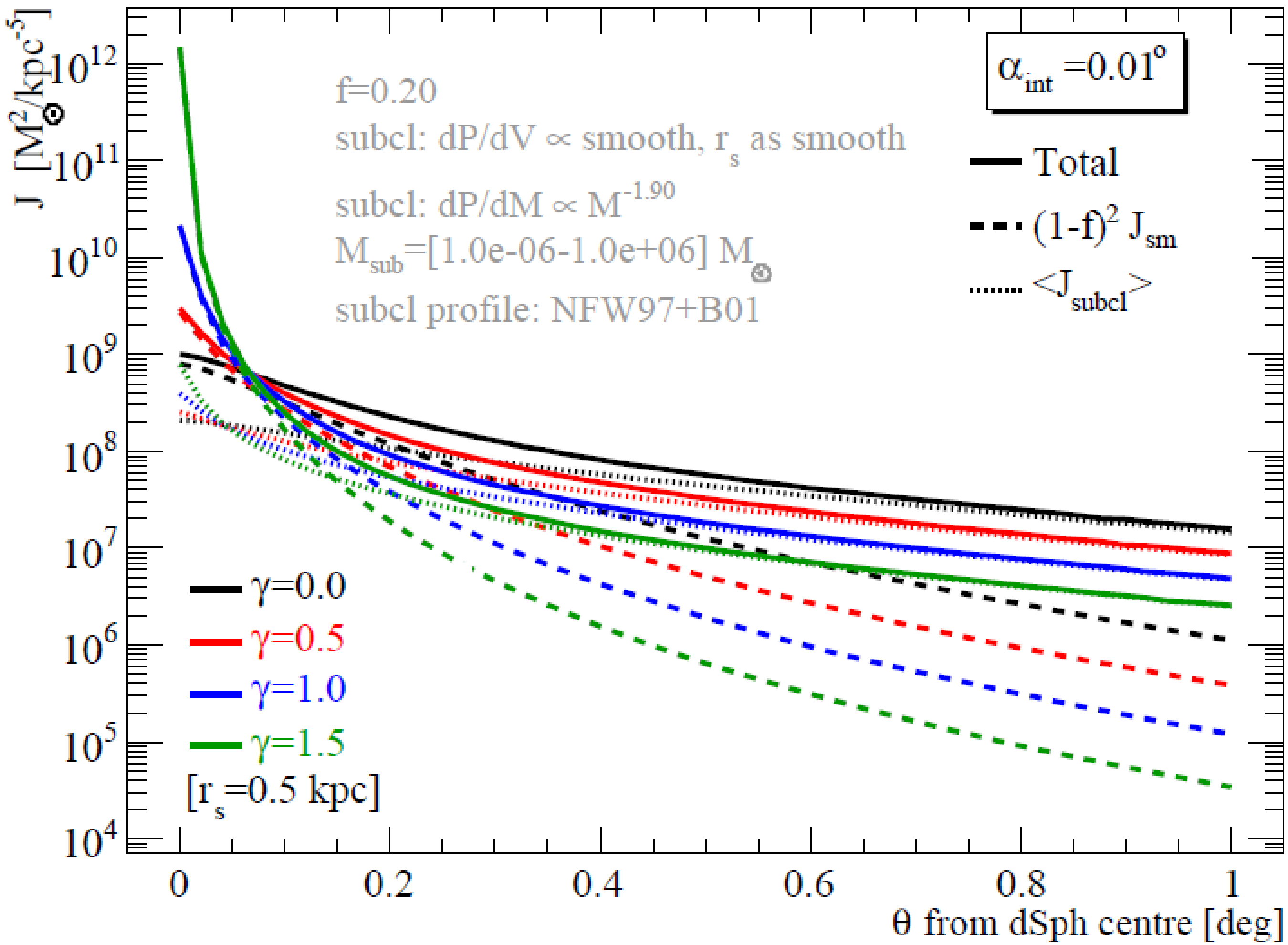
=> ρ_s is fixed

	ρ_s ($10^7\, M_{\odot}$ kpc^{-3})				
γ \ r_s [kpc]	0.10	0.25	0.50	1.0	2.5
0.00	224	54.0	25.8	16.02	11.41
0.50	170	34.2	13.4	6.47	3.13
1.00	125	21.0	6.7	2.52	0.82
1.50	88	12.2	3.2	0.92	0.20

These generic dSphs should be 'representative' of the real ones
=> how do their J behave?

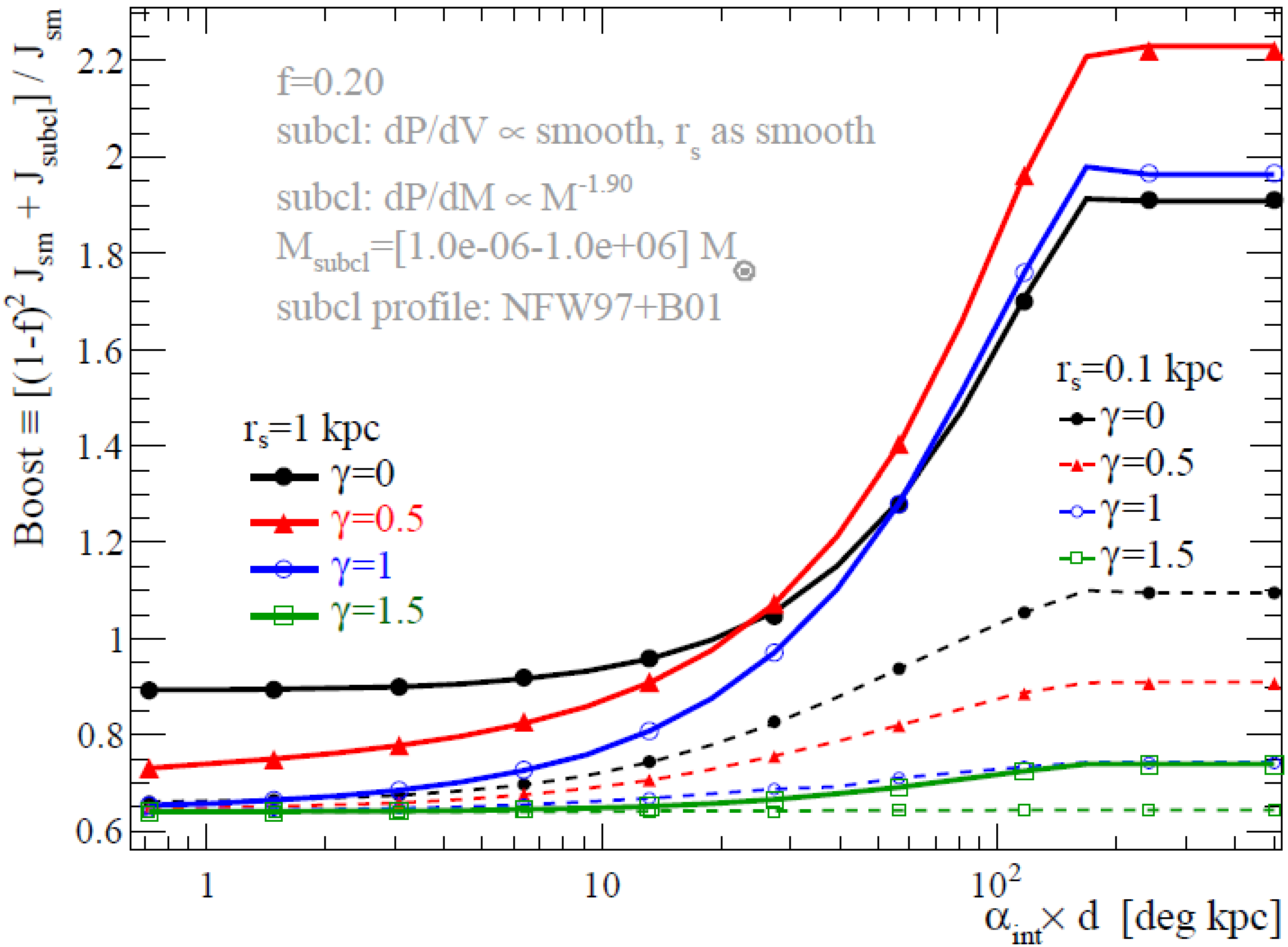
Radial dependence J(θ)

Jsm ≡ J from the smooth DM halo in the dSph
<Jsubcl> ≡ mean J from sub-clumps in the dSph
f ≡ fraction of DM in the sub-clumps



=> Jsm dominates in the central regions (dashed lines)
=> <Jsubcl> dominates in the outer parts (dotted lines)

Boost factor



- Boost<1 if small integration angle
- Integrating over all the signal, boost ~ *O(1)*
  => clumps neglected in the following

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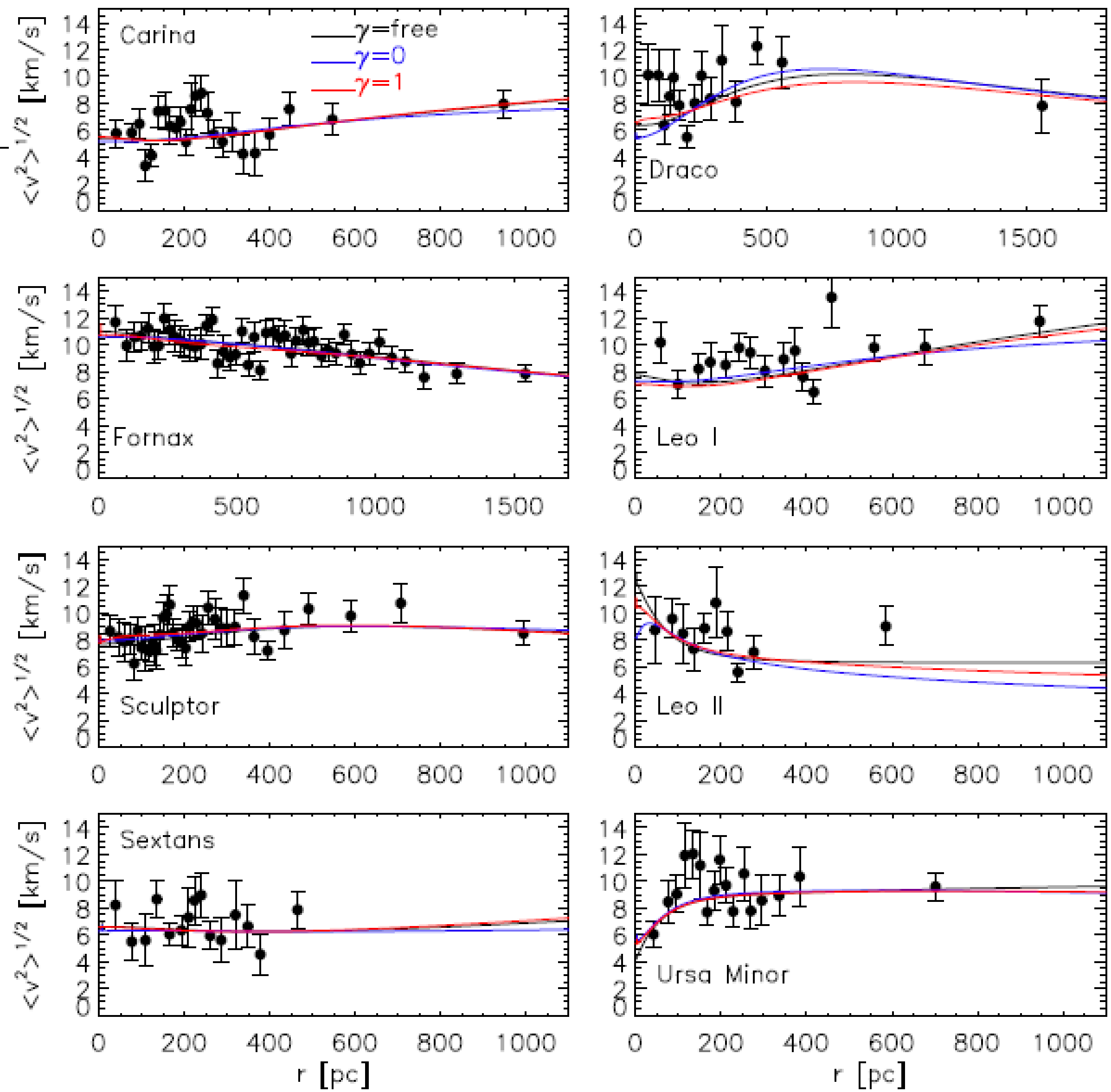
From velocity dispersion to DM profile

1. 'Theory'

Jean's equations + spherical sym. + projection along the l.o.s.:

=> relates $M_{tot}(r)$ to

- stellar density I(r)
- velocity dispersion



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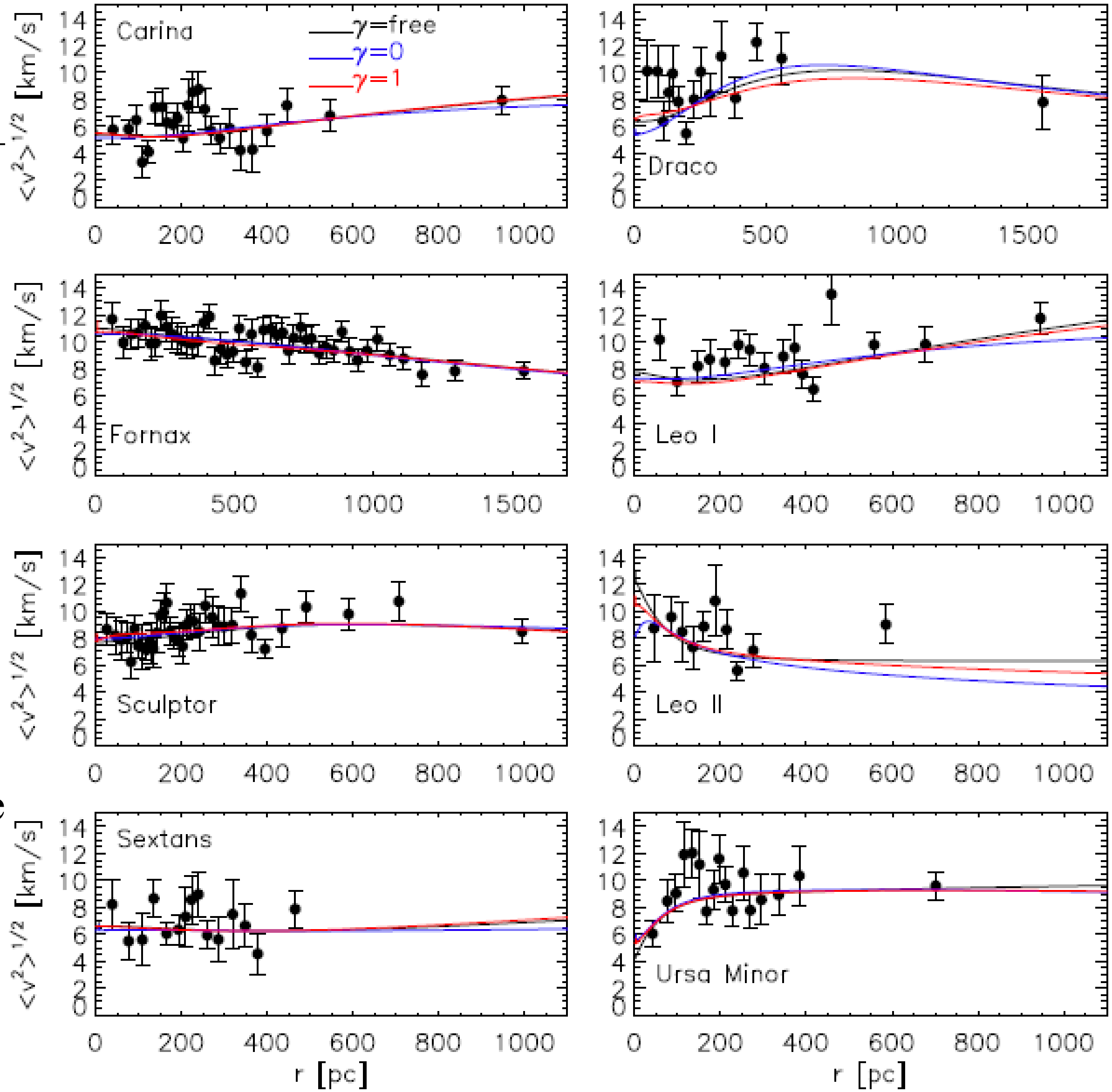

2. Statistical analysis

i) assume, e.g.,

- Plummer profile for I(r)
- (α,β,γ) profile for $\rho_{DM}(r)$

ii) measure velocity dispersion

=> fit data to constrain DM profile

=> γ=0 or γ=1 fit equally well the data

MCMC approach: PDF and correlation plots

[using CosmoMC]

Ensures efficient sampling of the parameter space: (α,β,γ), r_s, and ρ_s

Allows to get PDF and correlations

MCMC approach: PDF and correlation plots

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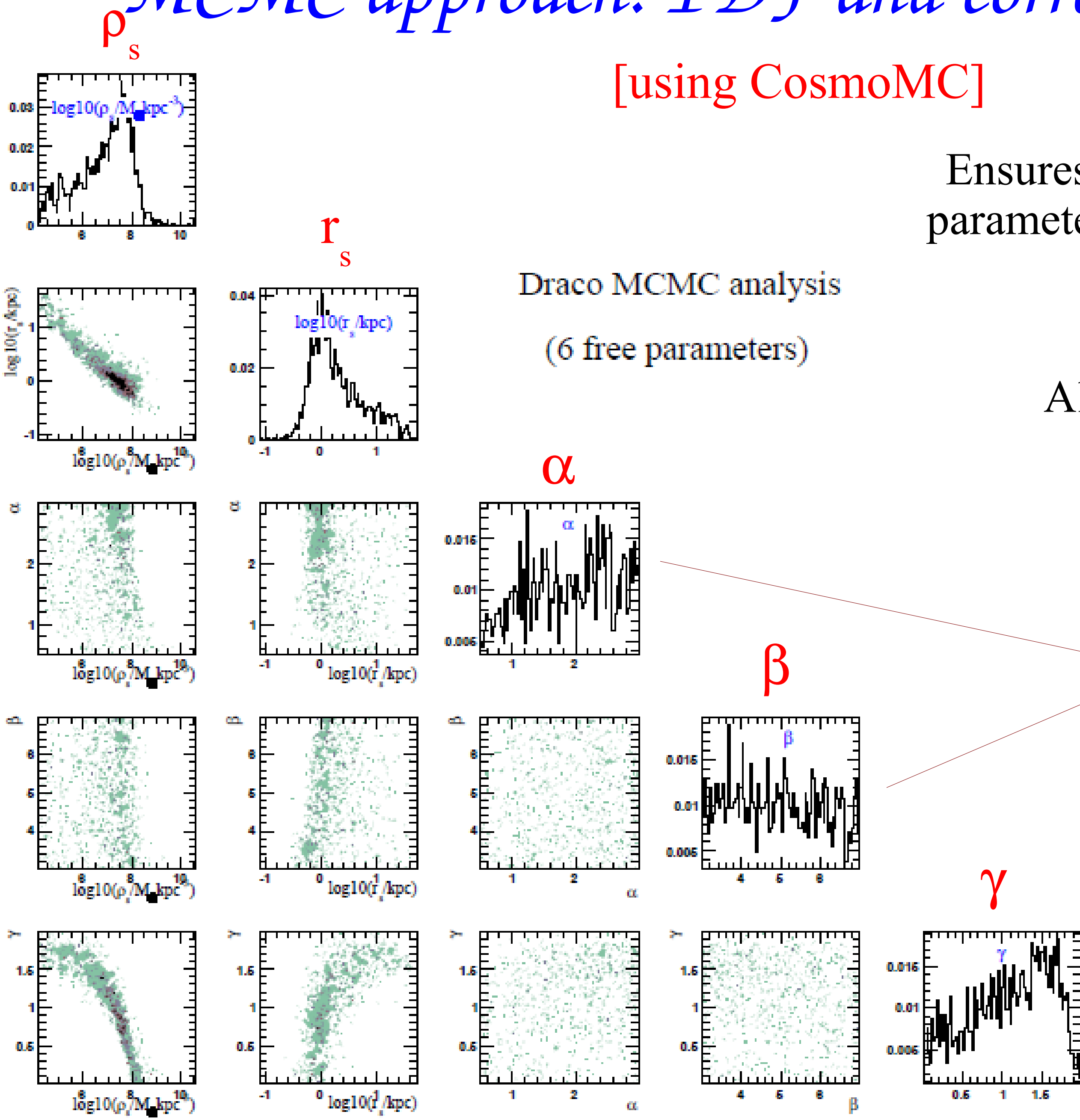


Draco MCMC analysis

(6 free parameters)

Ensures efficient sampling of the parameter space: (α,β,γ), r_s, and ρ_s

Allows to get PDF and correlations

Unconstrained

Loose constraint!

MCMC approach: median and confidence levels

[using CosmoMC]

Ensures efficient sampling of the parameter space: (α,β,γ), r_s, and ρ_s

↓

Allows to get PDF and correlations

↓

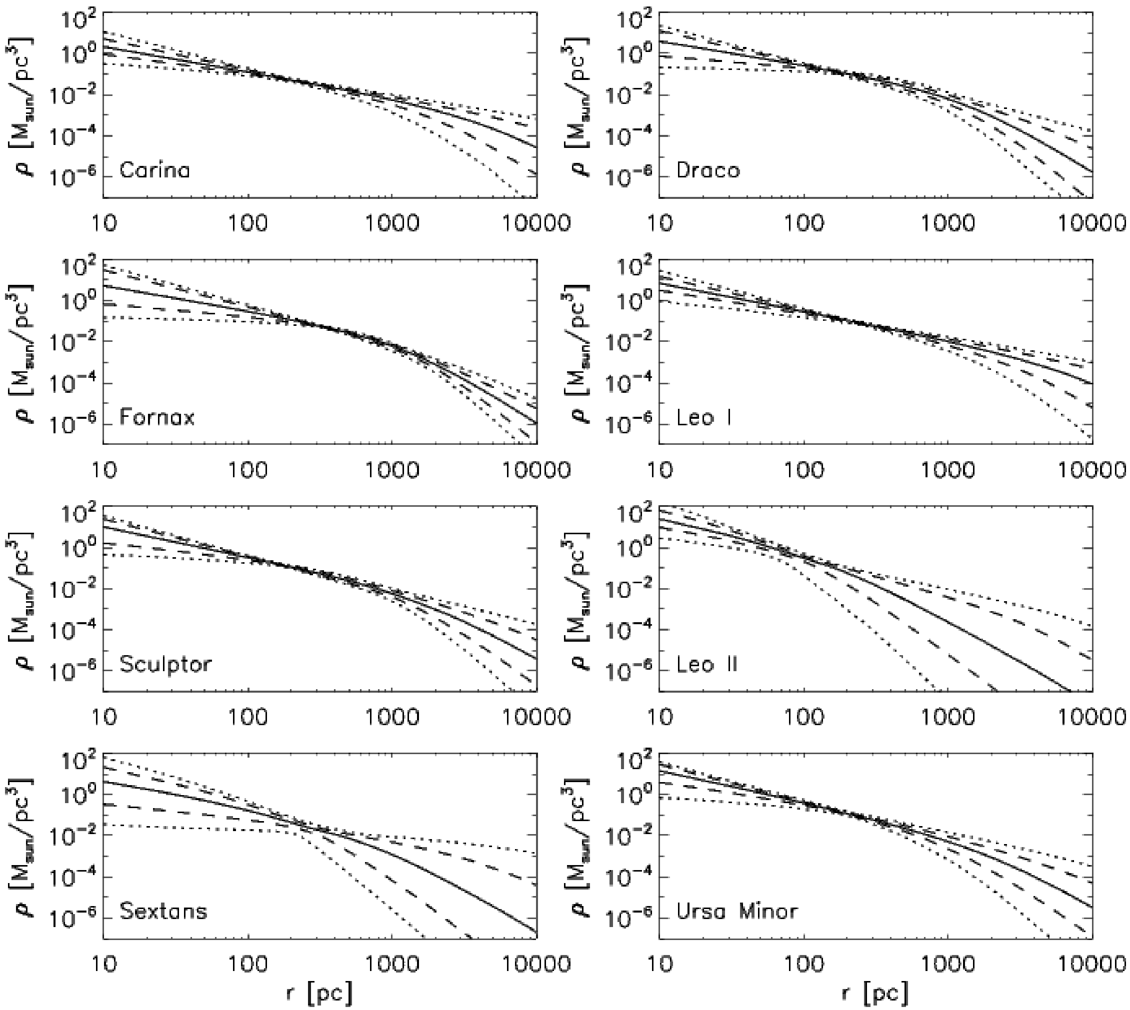
Enables to calculate PDF of any quantity deriving from the above parameters, e.g., $\rho(r)$, $J(\alpha_{int})$...

↓

Median values and CLs can be drawn!

MCMC approach: median and confidence levels

[using CosmoMC]



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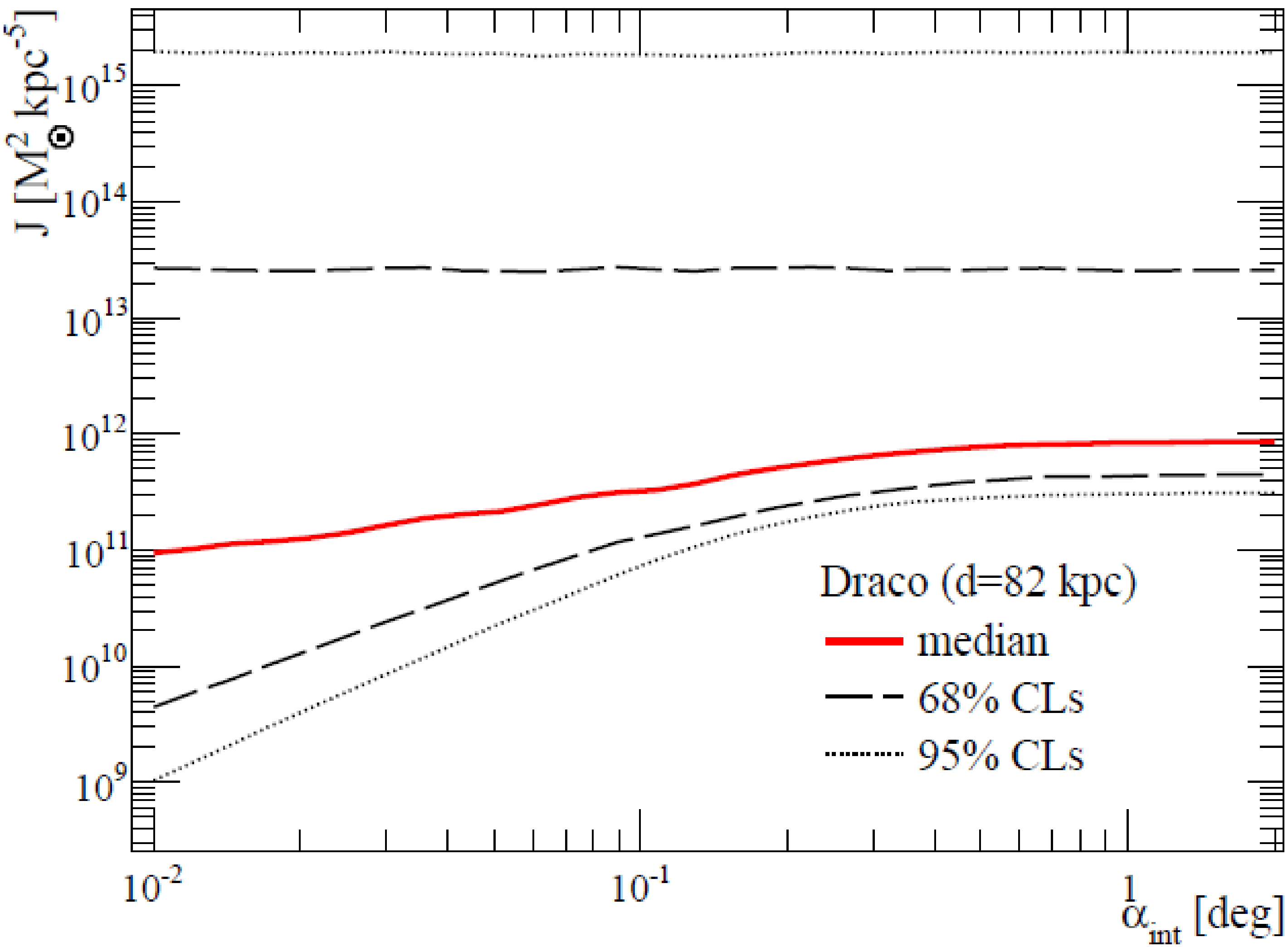
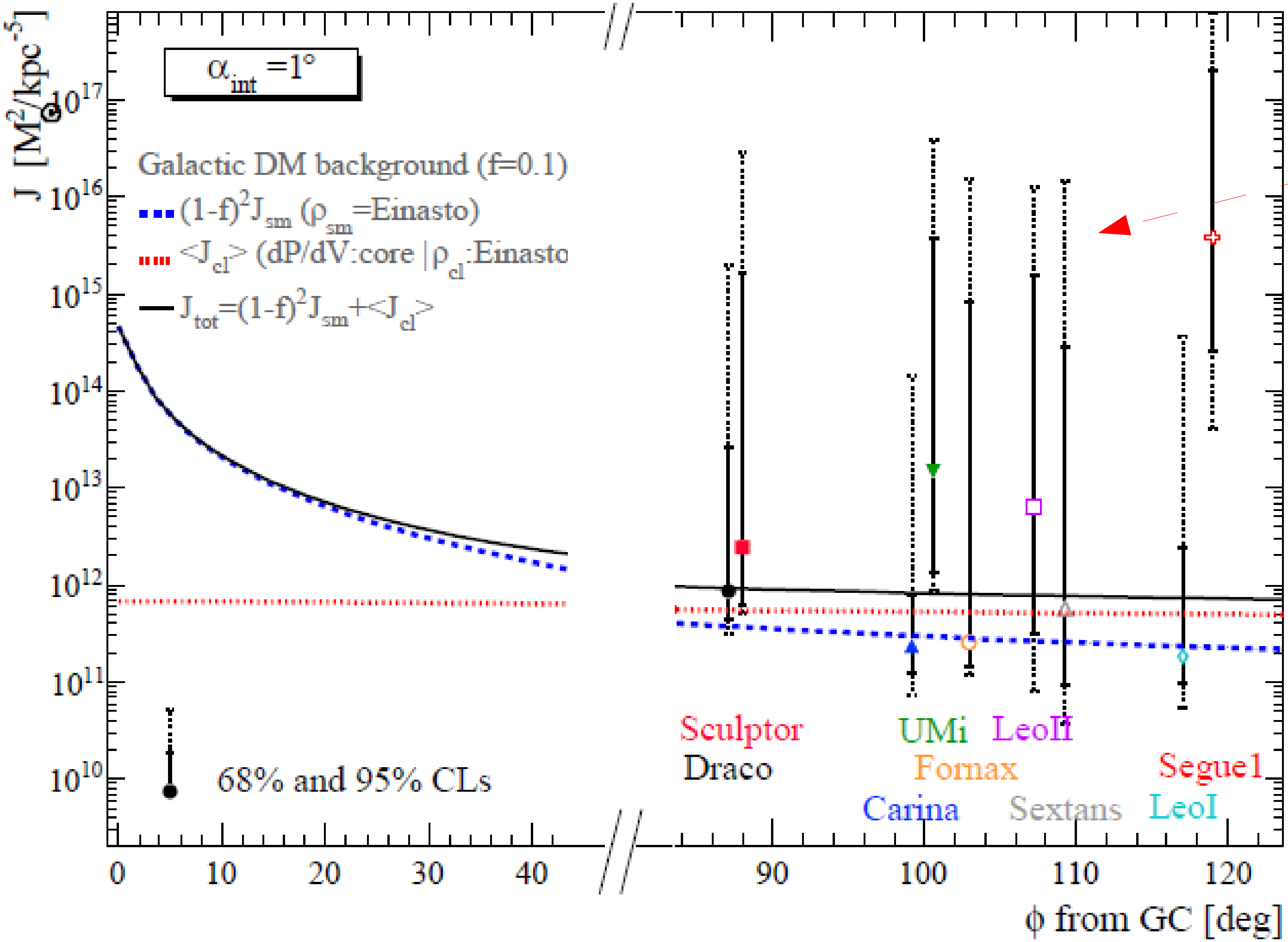
Median values and CLs can be drawn!

Illustration with Draco: $J(\alpha_{int})$ and CLs



=> 95% Cls correspond to ~ 4 orders of magnitude uncertainty!

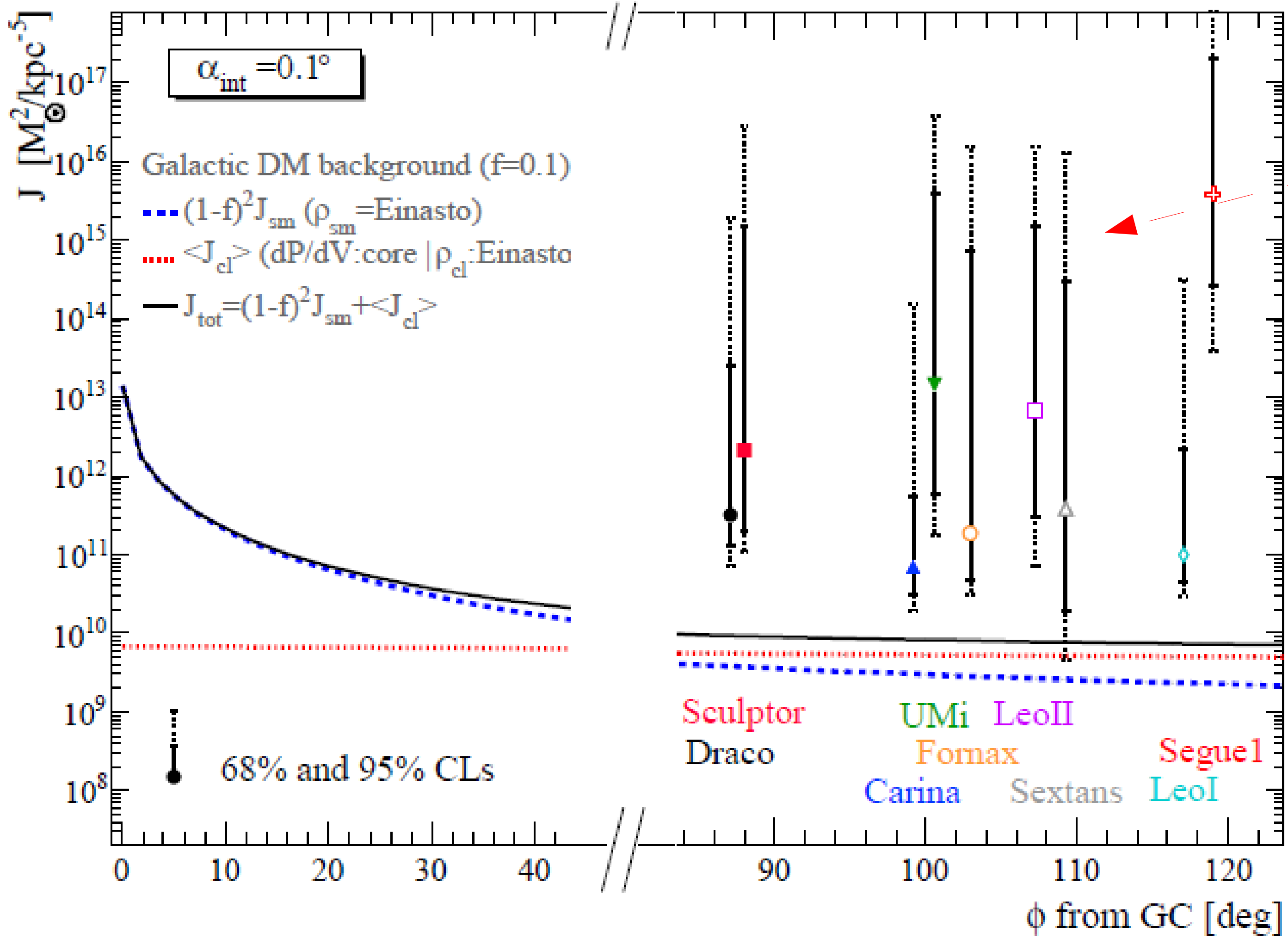
Dsphs in the Galactic DM halo (α_{int}=1.0°)



large upper limit because data do not exclude γ>1.5

=> Large integration angle: dominated by DM galactic background if dSphs are corish!

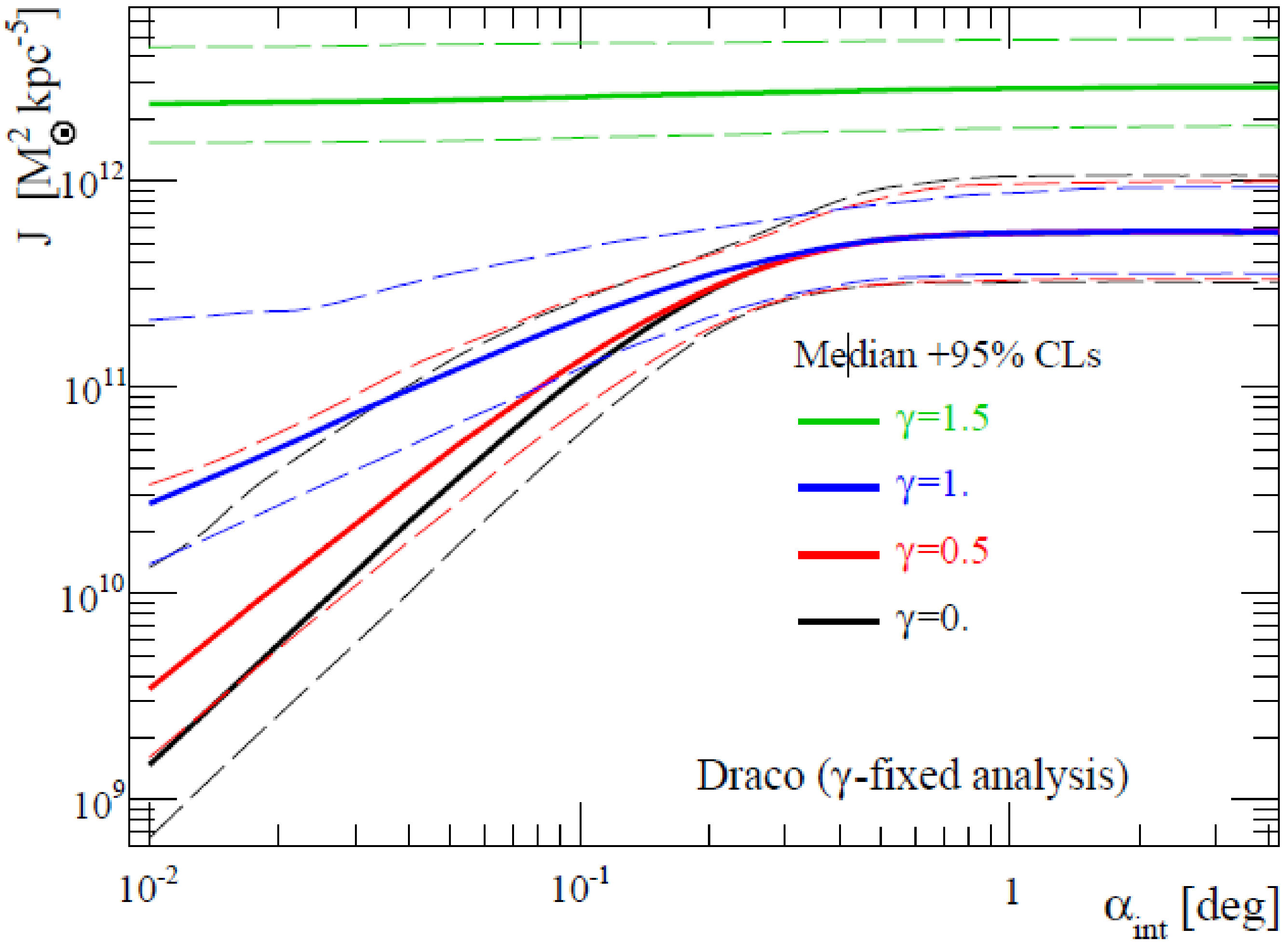
Dsphs in the Galactic DM halo (α_{int}=0.1°)



large upper limit because data do not exclude γ>1.5

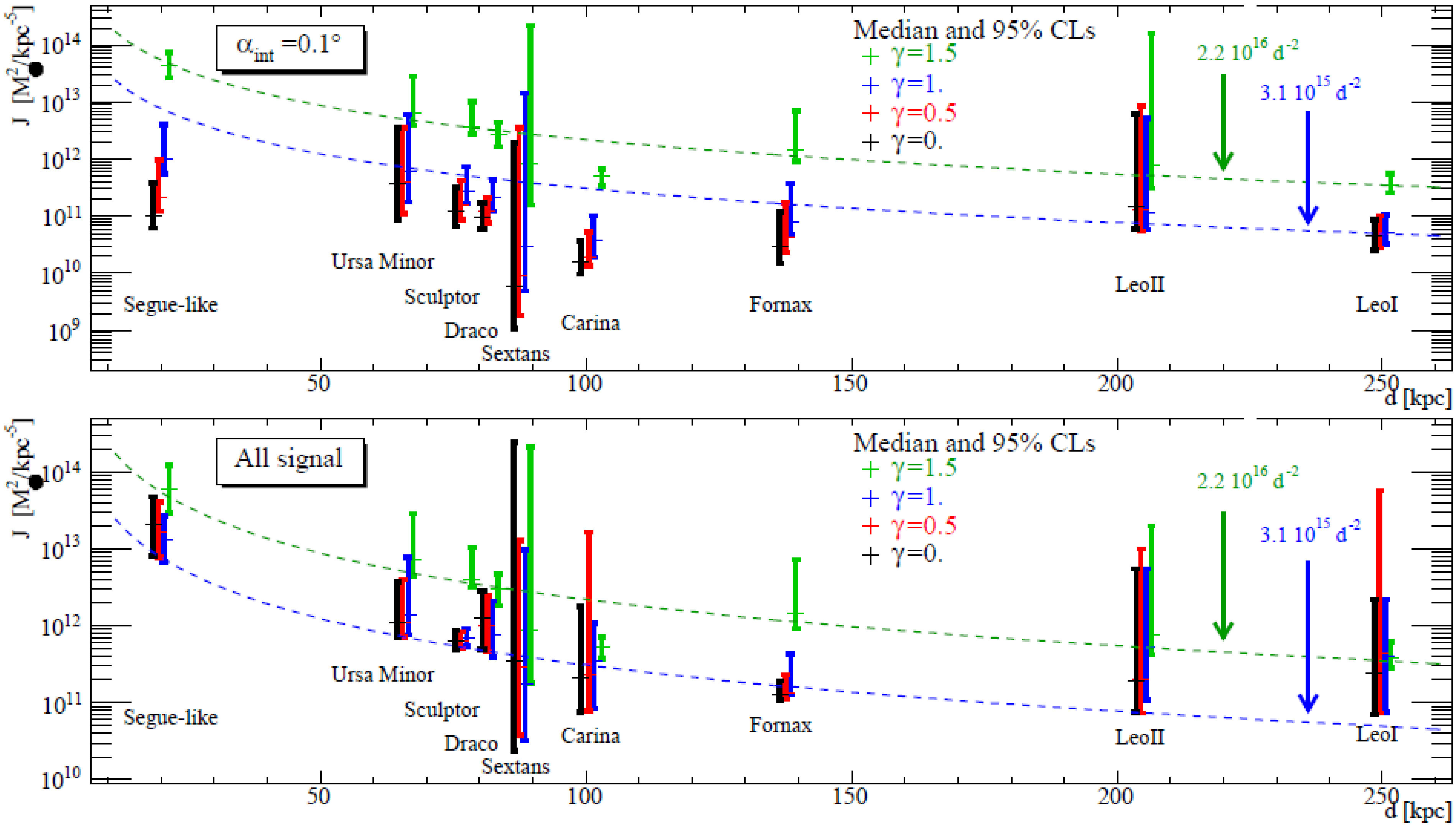
=> Uncertainties are quite large: what if we could pinpoint γ?

γ-fixed analysis: CLs for Draco



=> If $0 < \gamma < 1$, only ~ factor of 3 uncertainty for Draco !

γ-fixed analysis: CLs for two values of α_{int}



- Large integration angles best to have the strongest signal
- Large integration angle non-optimal for Cerenkov Telescopes!

=> trade-off to be found

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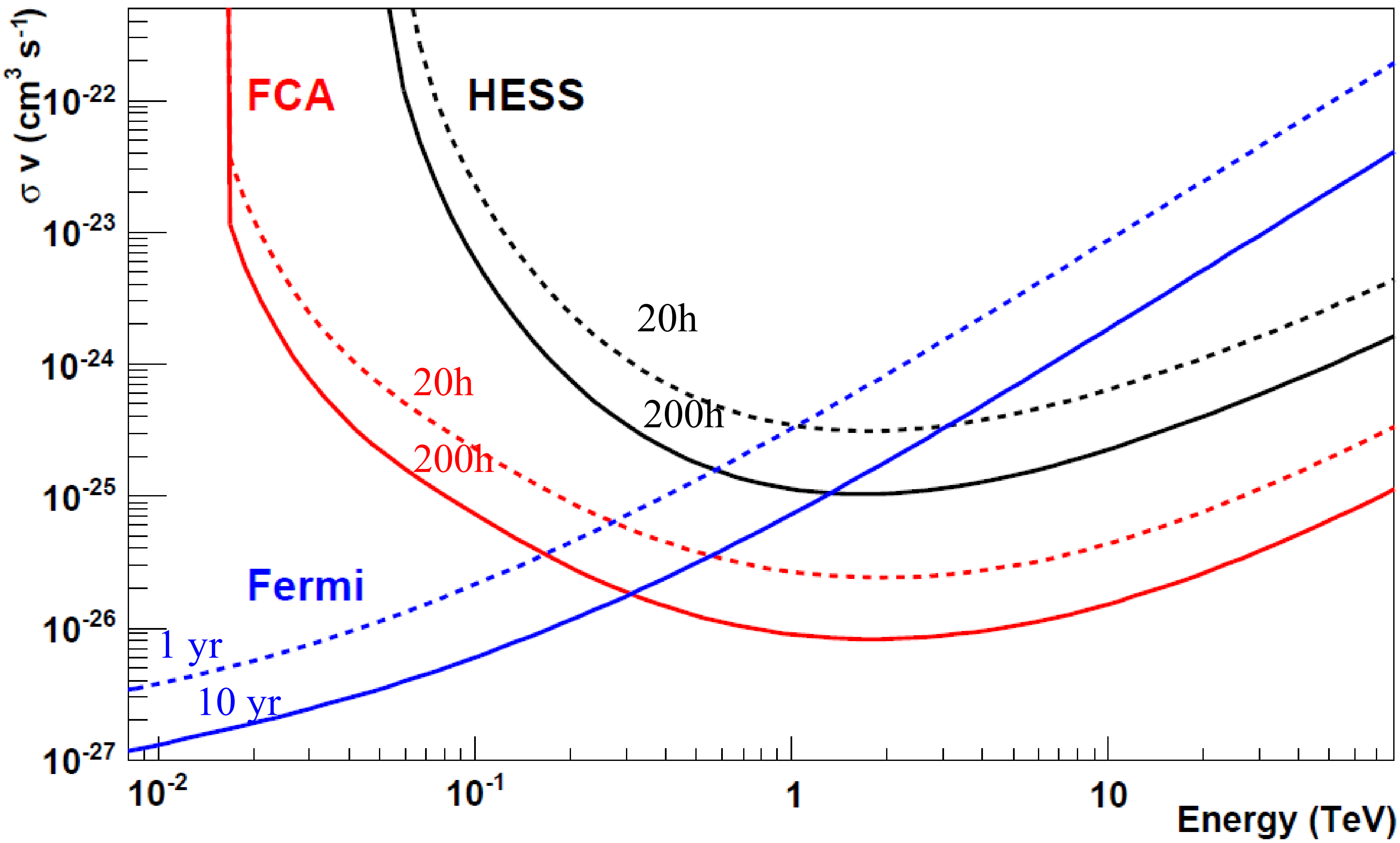
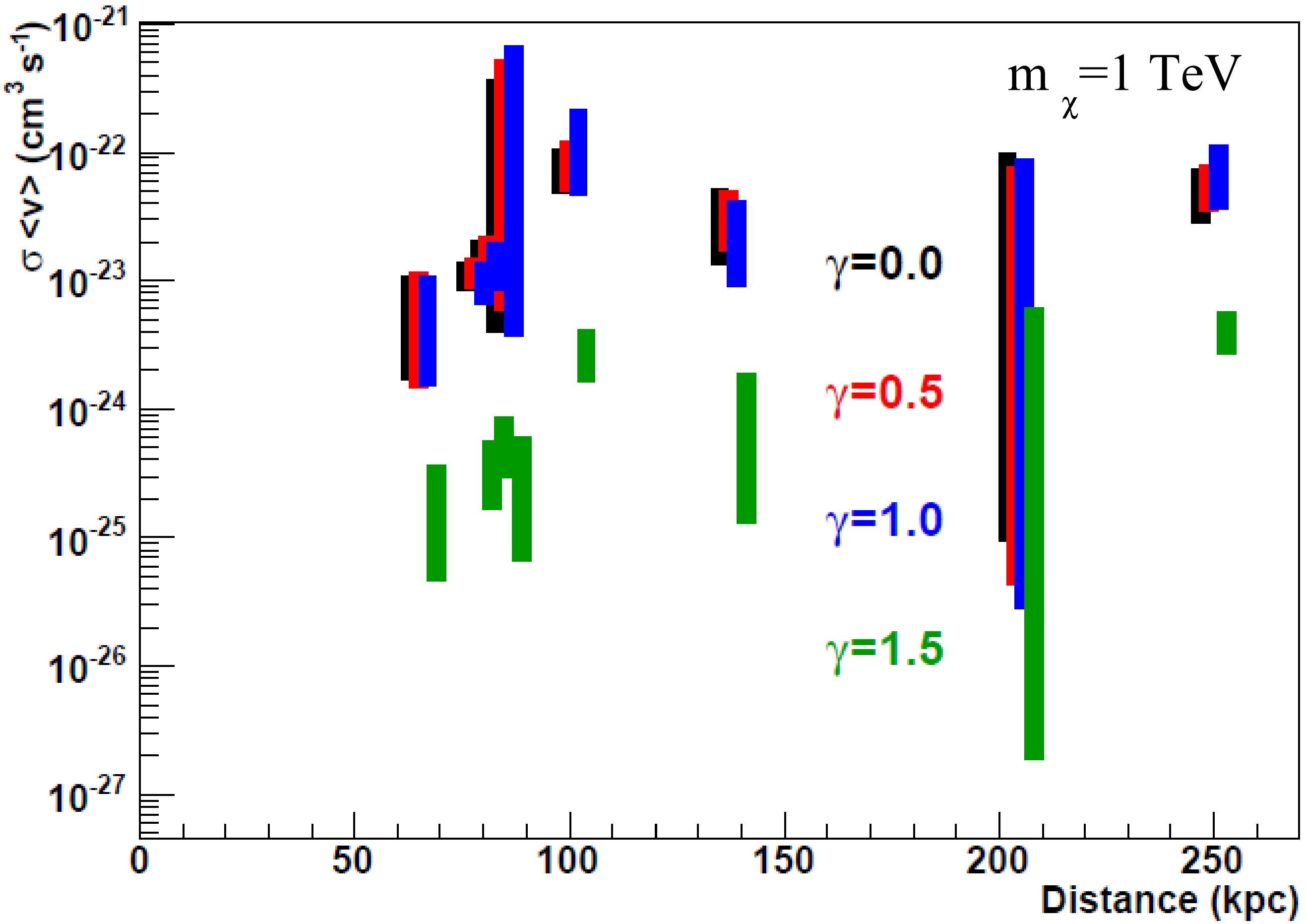
Sensitivity...



+ sensitivity degraded if source has large angular extension
+ sensitivity increased if mass/spectrum known in advance

...and prospects for 200 h (preliminary)



N.B.: stuff to finish (before submitting our study)

- Segue 1 (possibly most DM-dominated system) is being added
- cross-checks with fake data for the MCMC analysis (to address biases)

Conclusions

- Generic study: J variations for a wide class of models
  => no boost from sub-clumps for standard configurations

- Jeans/MCMC analysis on the classical dSphs
  => CLs on $J(\alpha_{int})$
  => do not constrain γ, $\mathcal{O}(4)$ uncertainties... but $\mathcal{O}(1)$ if $0<\gamma<1$

- Sensitivity of future ACTs
  => Angular extension of the source matters
  => beats FERMI if m_χ >~ 300 GeV

- Information that will be provided with/in the paper
  => 'optimum' integration angle for each dSph
  => 'ranking' of the dSphs
  => ASCII files for CLs on $J(\alpha_{int})$

Possible improvements for the future

=> 'improved' Jeans' analysis for some dSphs (Wilkinson et al., in prep.)
=> 'improved' data analysis to have smaller error bars on $\langle v^2\rangle^{1/2}$

N.B.: morphology to disentangle decay/annihil. (Palomares-Ruiz & Siegal-Gaskins, 2010)