THE QUEST FOR DARK MATTER IN DWARF GALAXIES

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OUTLINE

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2. Main targets for DM indirect detection
3. Estimates of the DM content in dSphs
4. Prospects of DM detection feasibility with CTA
5. The ASTRI/CTA Data Challenge
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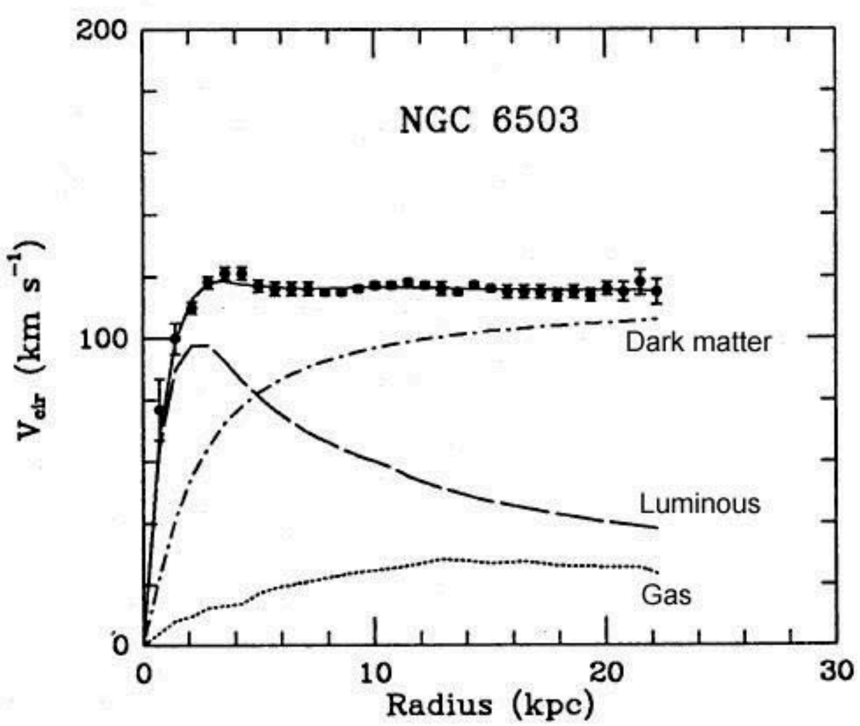
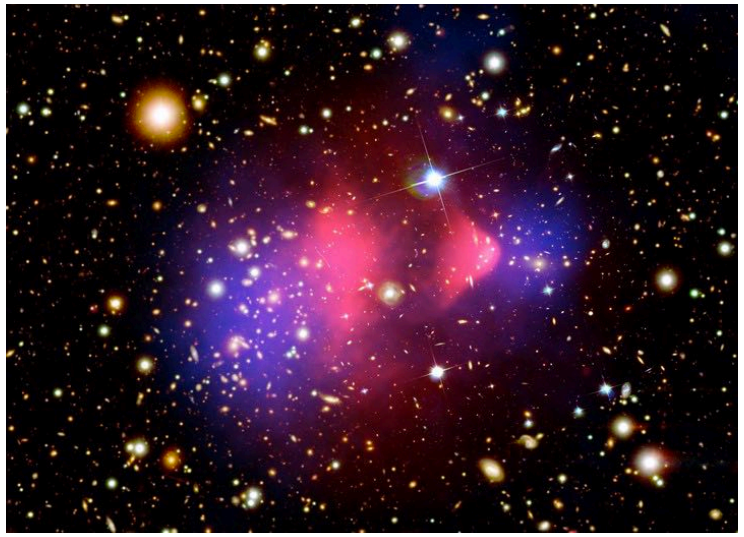
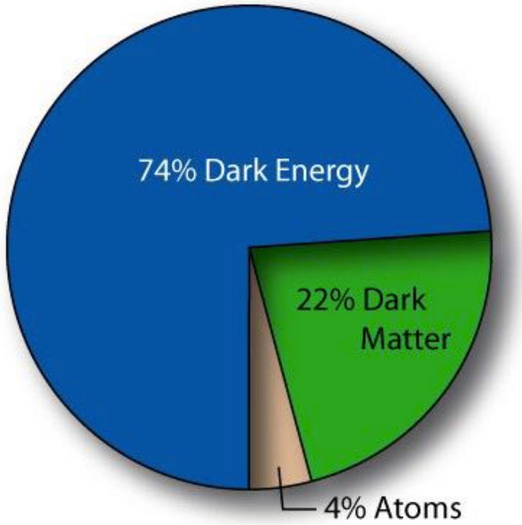
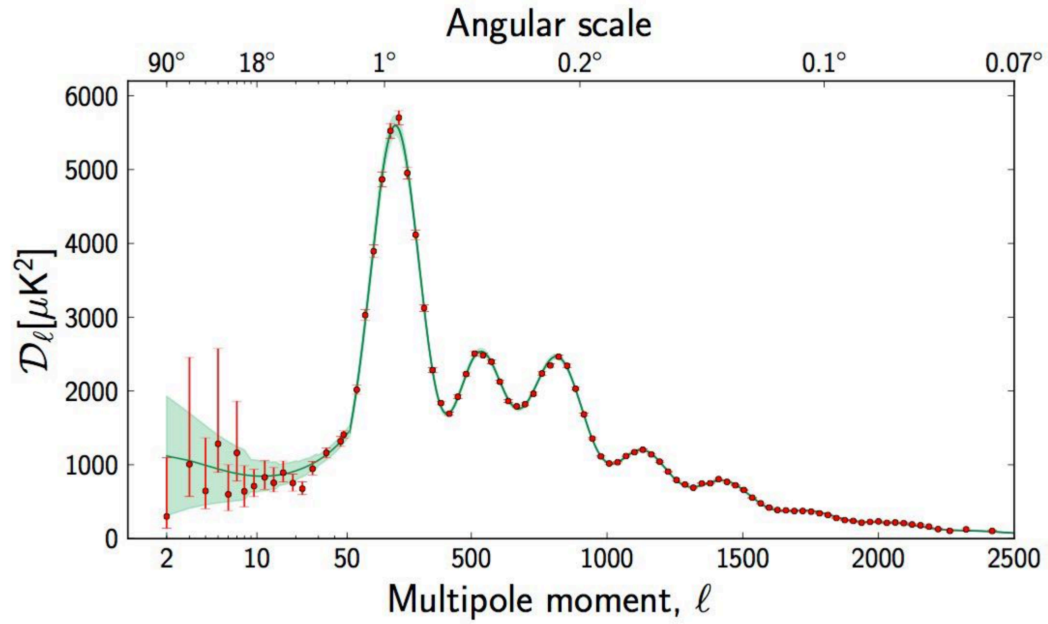
1. The quest for dark matter in the Universe

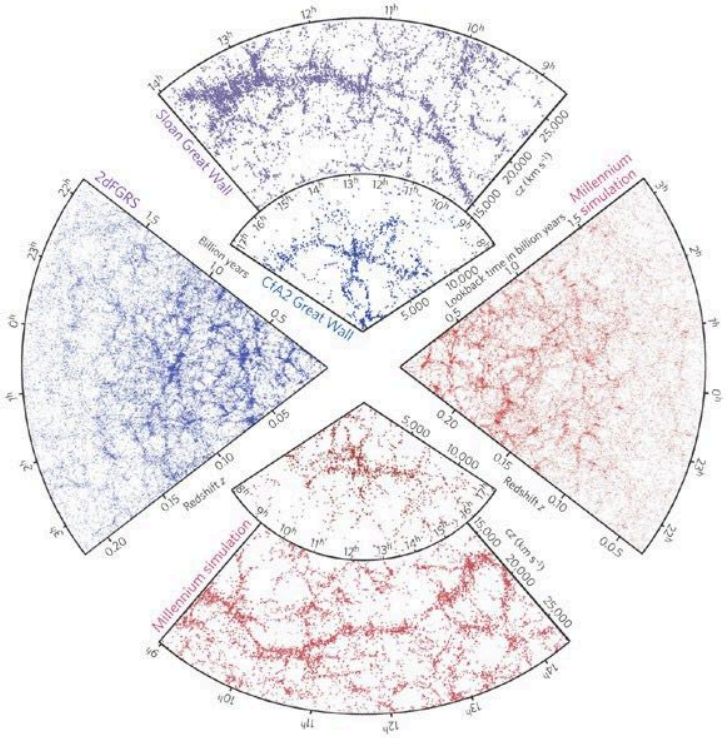
- Dark matter (DM) is the major component of the Universes matter content, whose existence is inferred from several astrophysical/cosmological observations (galactic rotation curves, virial galaxy clusters, gravitational lensing, Universes expansion rate).





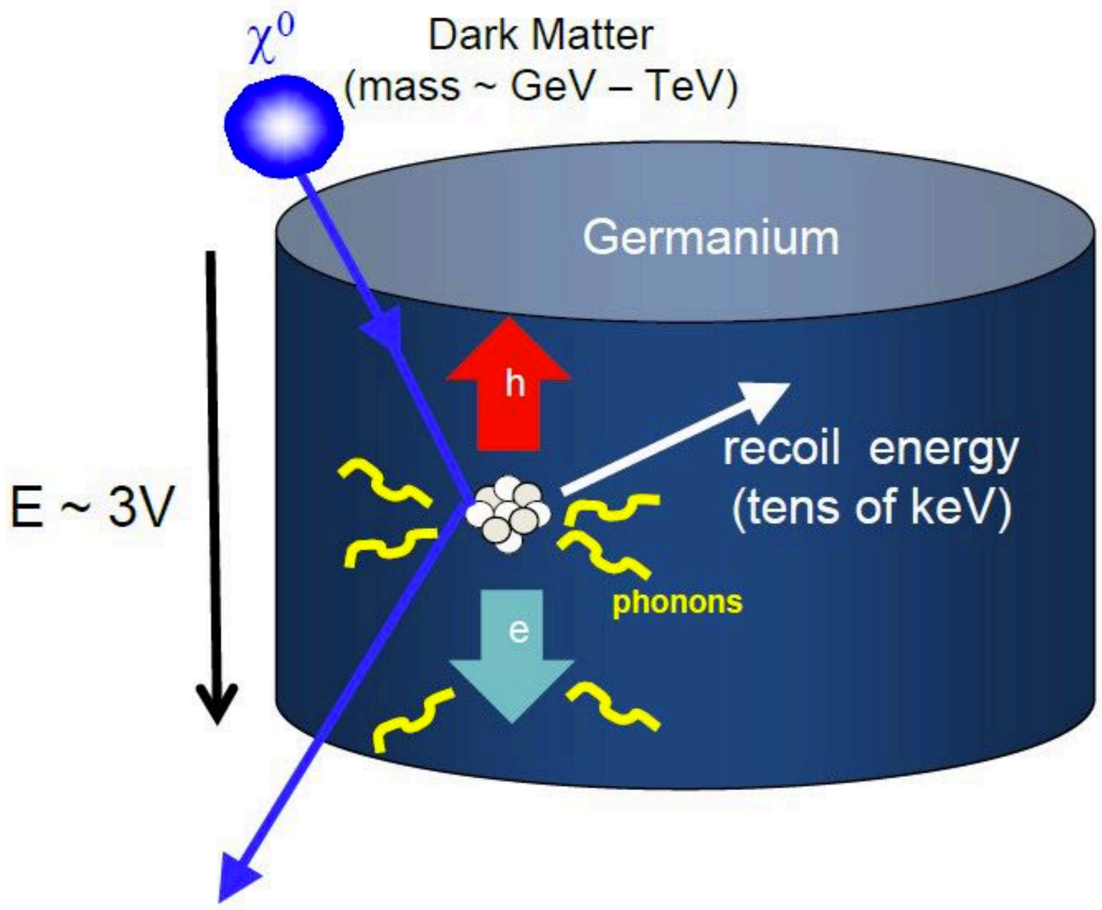




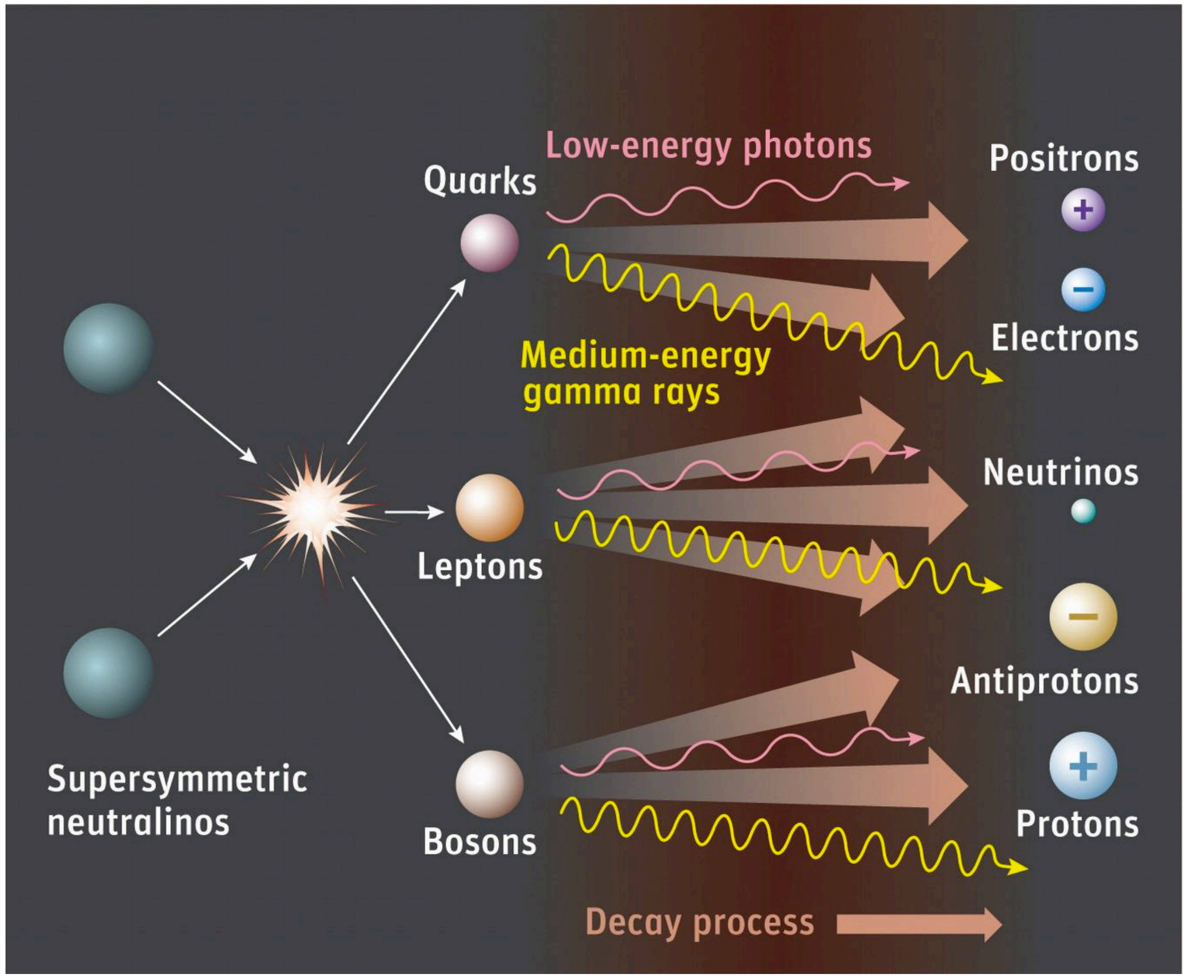


- Since DM cross section for interaction with baryonic matter is extremely small, events of dark-baryonic matter interaction (direct detection) are very rare. *Indirect detection* looks instead for production of gamma-rays from DM self-interaction (annihilation or decay), so it can be attempted with gamma detectors.

DIRECT DETECTION



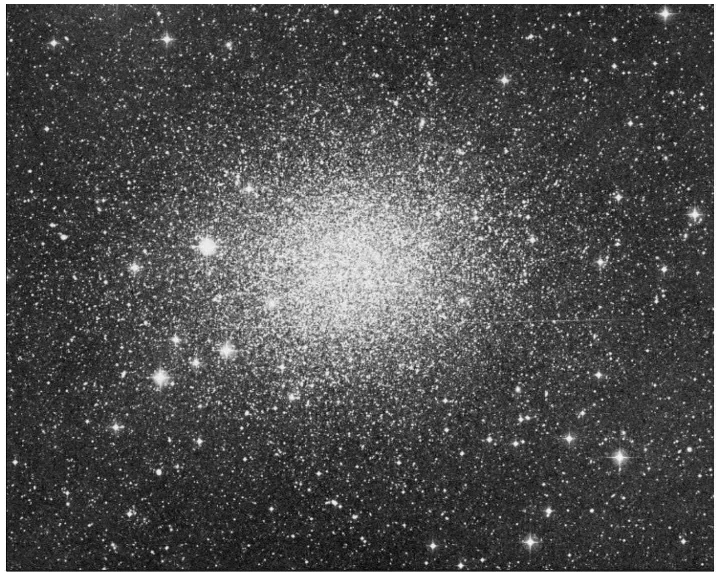
INDIRECT DETECTION



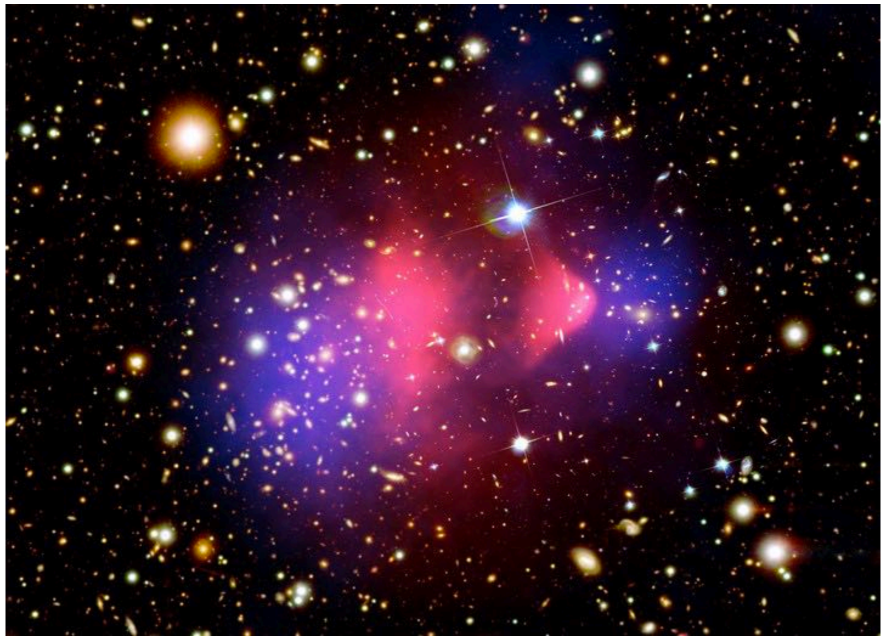
2. Main targets of observation for DM indirect detection

MW center & ridge
(very close, but risk of high bkg due to Galactic sources & central BH)

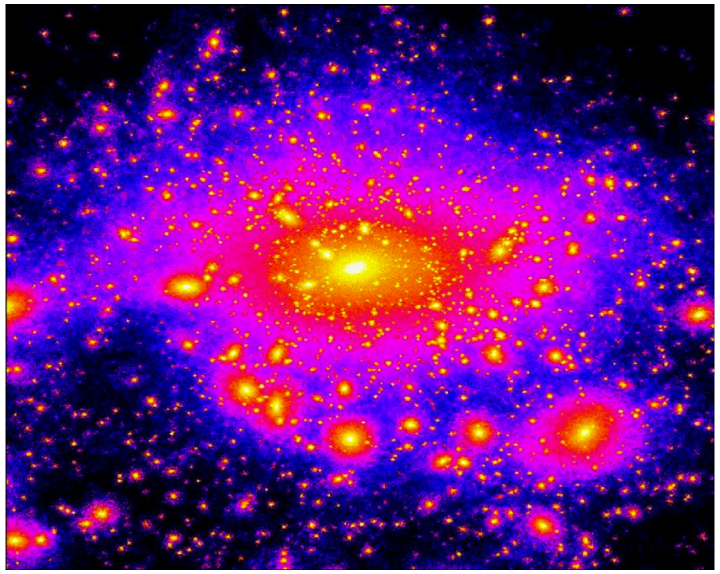
Dwarf spher. galaxies
(high *M*/*L* and almost no bkg, but small haloes under current angular resolution)



Galaxy clusters
(high DM content, but far and possibly contaminated by bkg)



Dark clumps
(conceptually dSphs without stars, but same issues + their existence only theoretical)



3. Estimates of the DM content in dSphs

- Gamma-ray source spectrum dN/dE computed assuming that DM particles annihilate (decay) via Standard Model pair production: **quarks, leptons, vector bosons** (e.g., Cembranos+ 2011, Cirelli+ 2014);

- in cold-DM scenarios, such pairs are slow => they immediately annihilate into final-state photons; the signal intensity from DM self-interaction depends on the DM density along the l.o.s. (**astrophysical factor** J/D):

$$\frac{d\Phi_{\rm ann}}{dE_\gamma} = B_{\rm F}\frac{\langle \sigma_{\rm ann} v\rangle}{8\pi m_\chi^2}\sum_i {\rm BR}_i \frac{dN_\gamma^{(i)}}{dE_\gamma}\cdot J(\Delta\Omega) \qquad J(\Delta\Omega) = \int_{\Delta\Omega} d\Omega \int_{\rm l.o.s.} \rho^2_{\rm DM}(\ell,\Omega)d\ell$$

$$\frac{d\Phi_{\rm dec}}{dE_\gamma} = \frac{B_{\rm F}}{4\pi m_\chi}\sum_i \Gamma_i \frac{dN_\gamma^{(i)}}{dE_\gamma}\cdot D(\Delta\Omega) \qquad D(\Delta\Omega) = \int_{\Delta\Omega} d\Omega \int_{\rm l.o.s.} \rho_{\rm DM}(\ell,\Omega)d\ell$$

- in dSphs, this signal is expected to dominate the gamma-ray bkg; several attempts to estimate J/D from dSph stellar dynamics exist in the literature (Strigari+ 2008, Acciari+ 2010, Geringer-Sameth+ 2015b, Bonnivard+ 2015c).

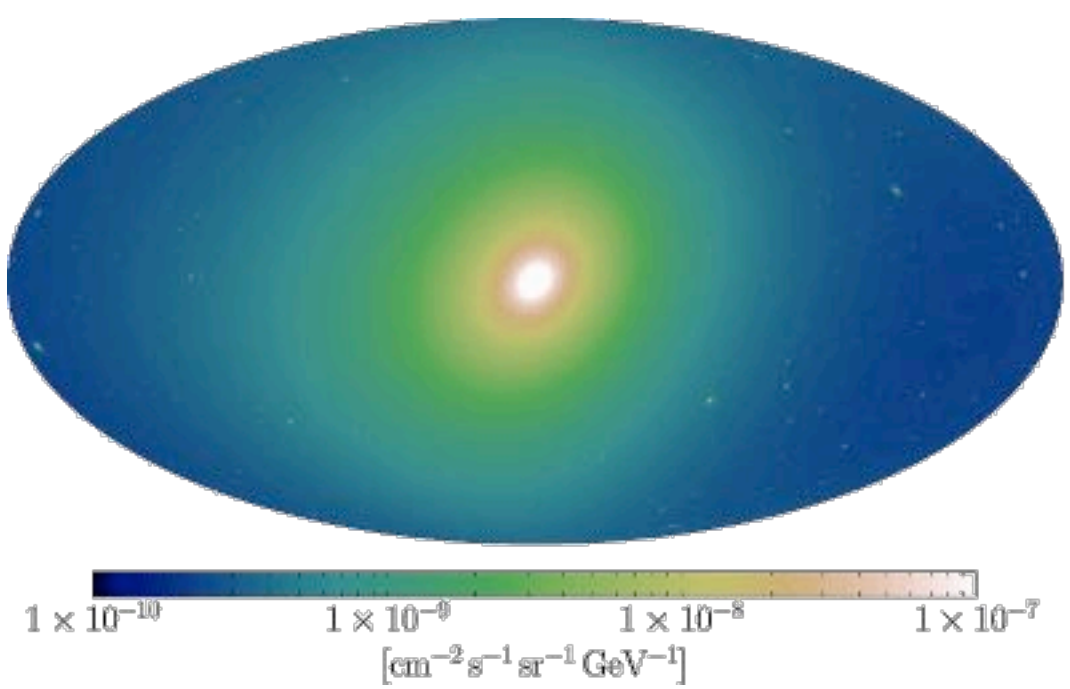
- Here we use the same approach of Bonnivard+ 2015c: **MCMC Jeans analysis with CLUMPY of dSph kinematics and brightness data.**

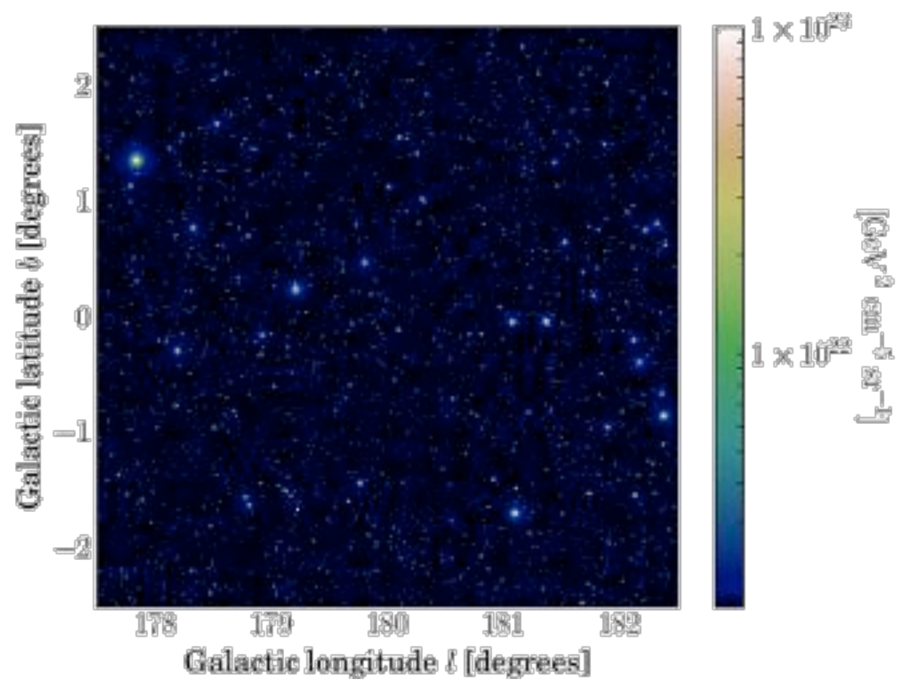
CLUMPY

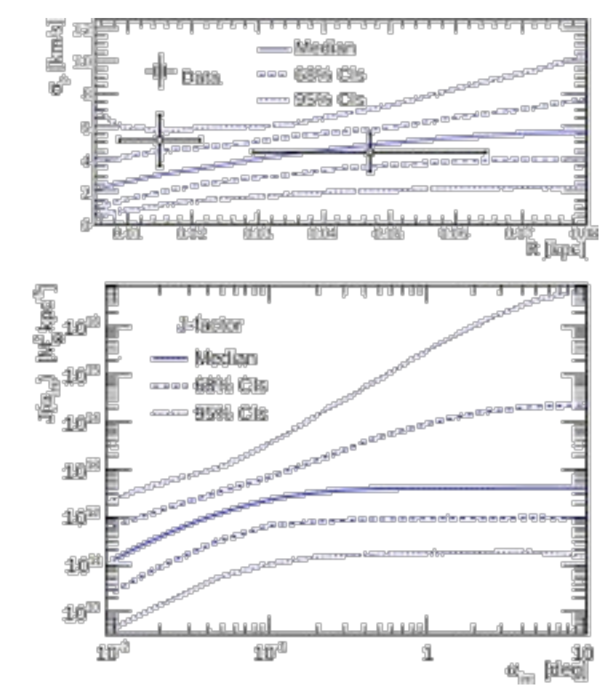
- v1: http://cdsads.u-strasbg.fr/abs//2012CoPhC.183..656C

- v2: http://cdsads.u-strasbg.fr/abs/2016CoPhC.200..336B

- v3: http://adsabs.harvard.edu/abs/2018arXiv180608639H







- CLUMPY input data: surface brightness profile + kinematics of member stars of dSphs;
- surface brightnesses fitted by projecting 3D Zhao-Hernquist luminosity profiles on 2D literature data:

$$\Sigma^*(R) = 2\int_R^{+\infty} \rho^*(r)\frac{rdr}{\sqrt{r^2 - R^2}}$$

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

- results are profile quantities (scale luminosity density, scale radius, exponents) to be passed to CLUMPY as fixed parameters.

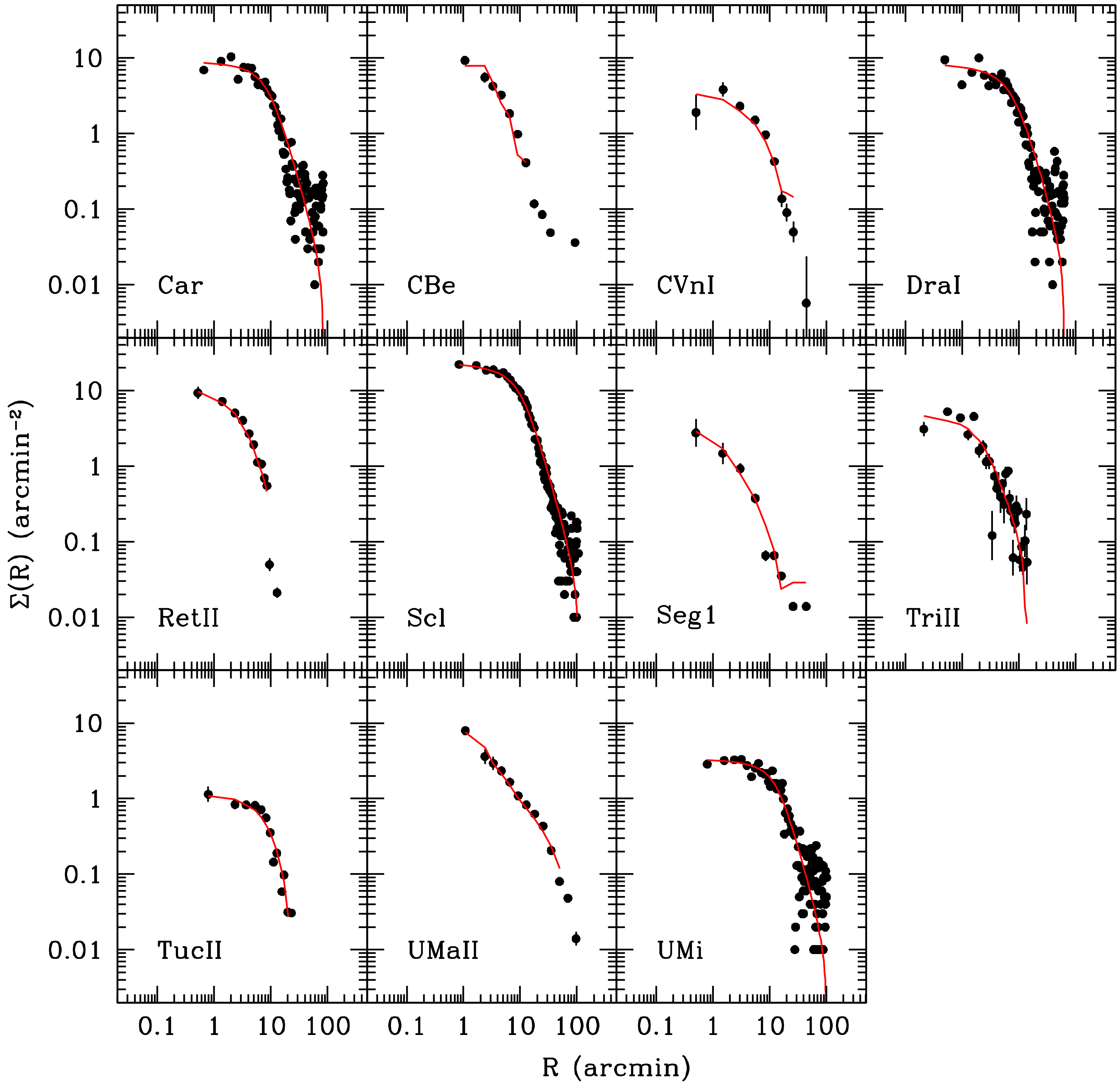


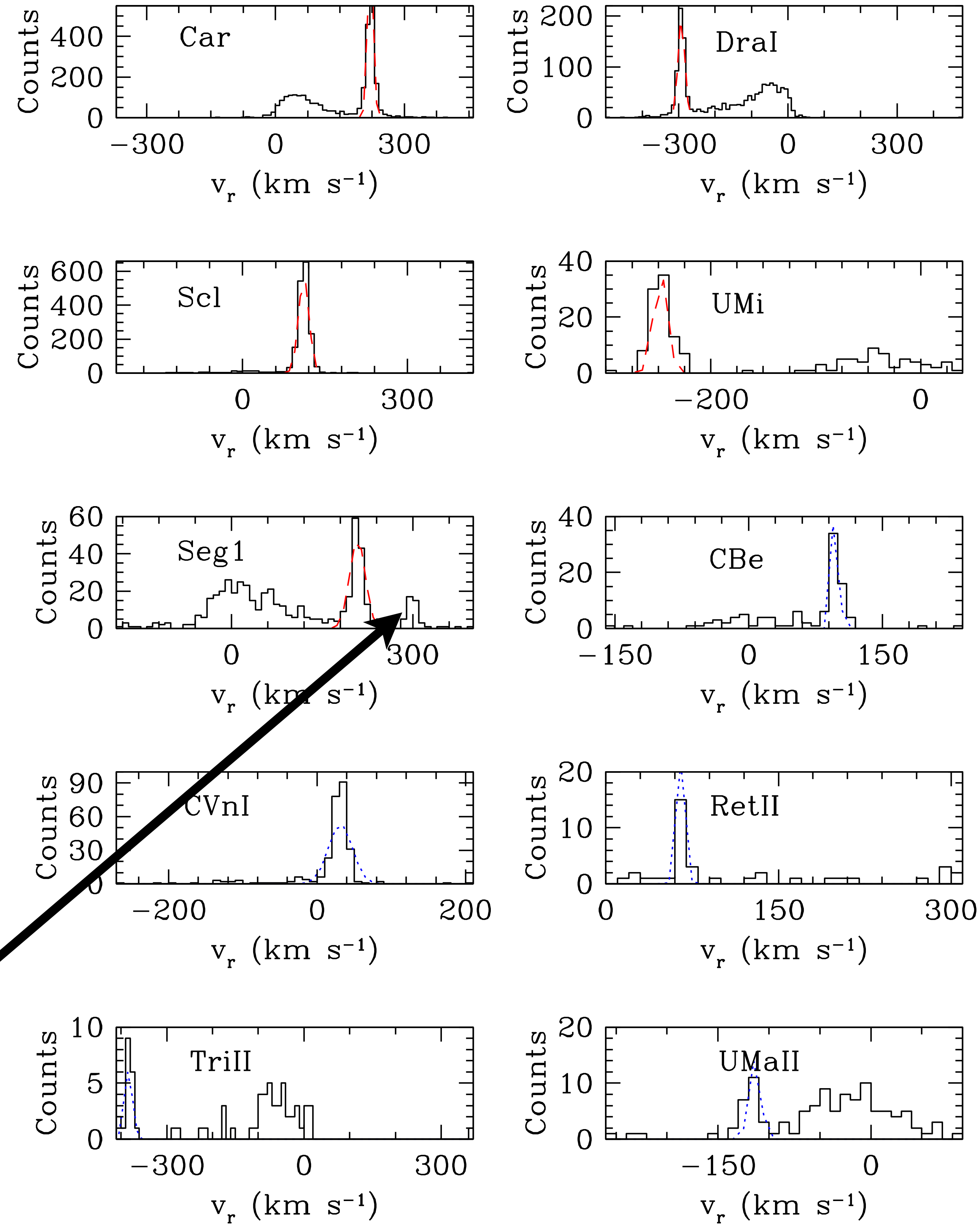
Table 1: New surface brightness parameters for the dSph analyzed with CLUMPY.

Name	Ref.	ρ^*_s (10^5 L$_\odot$ kpc^{-3})	r^*_s (kpc)	α^*	β^*	γ^*	χ^2	$N_{d.o.f.}$
Car	[1]	24.0 ± 11.1	0.254 ± 0.015	3.8	3.8	0.0	23.66	123
CBe	[2]	3.70 ± 1.70	0.092 ± 0.008	3.8	3.8	1.4	5.55	6
CVn I	[3]	2.15 ± 0.50	0.568 ± 0.033	3.2	3.8	0.2	3.34	5
Dra I	[1]	466 ± 136	0.170 ± 0.016	2.8	3.8	0.2	38.06	123
Ret II	[4]	157 ± 23.6	0.023 ± 0.003	3.2	3.8	0.4	7.53	14
Scl	[1]	152 ± 70.0	0.250 ± 0.017	3.4	3.8	0.2	11.54	123
Seg 1	[3]	13.1 ± 11.4	0.034 ± 0.007	3.6	3.8	0.8	0.30	5
Tri II	[5]	45.4 ± 23.5	0.020 ± 0.002	3.6	3.2	0.2	32.12	34
Tuc II	[4]	2.50 ± 0.691	0.141 ± 0.032	3.4	3.8	0.0	0.68	11
UMa II	[2]	6.21 ± 3.43	0.035 ± 0.004	2.4	1.6	2.6	2.24	8
UMi	[1]	40.3 ± 18.6	0.183 ± 0.031	3.4	3.6	0.2	3.65	123

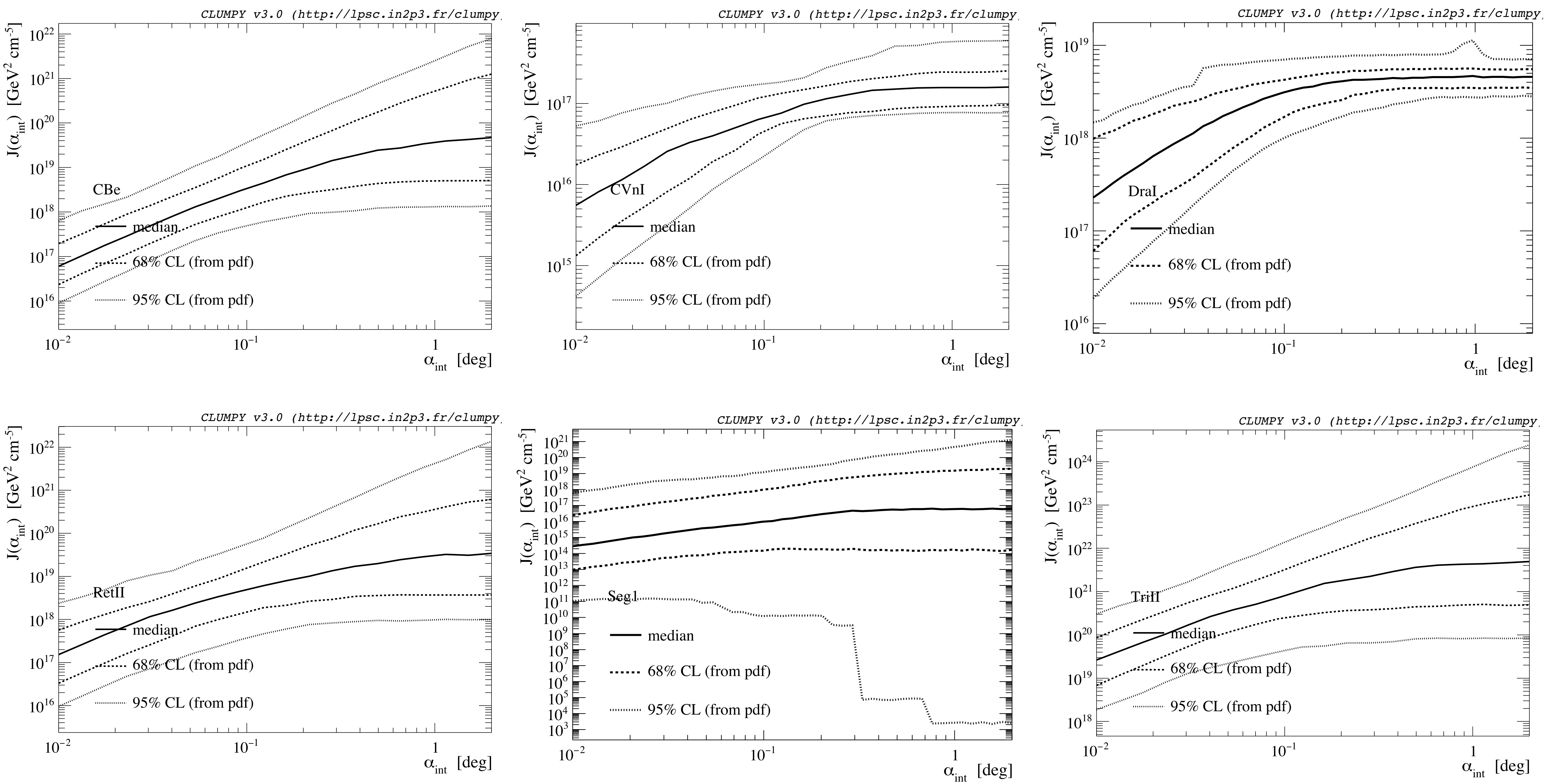
[1] Irwin, M. J., & Hatzidimitriou, D. 1995, MNRAS, 277, 1354
[2] Muñoz, R. R., Geha, M., & Willman, B. 2010, AJ, 140, 138
[3] Martin, N. F., de Jong, J. T. A., & Rix, H.-W. 2008, ApJ, 684, 1075
[4] Bechtol, K., Drlica-Wagner, A., Balbinot, E., et al. 2015, ApJ, 807, 50
[5] Laevens, B. P. M., Martin, N. F., Ibata, R. A., et al. 2015, ApJL, 802, L18

Possible indication of halo anomalies (e.g., tidal disruption?)

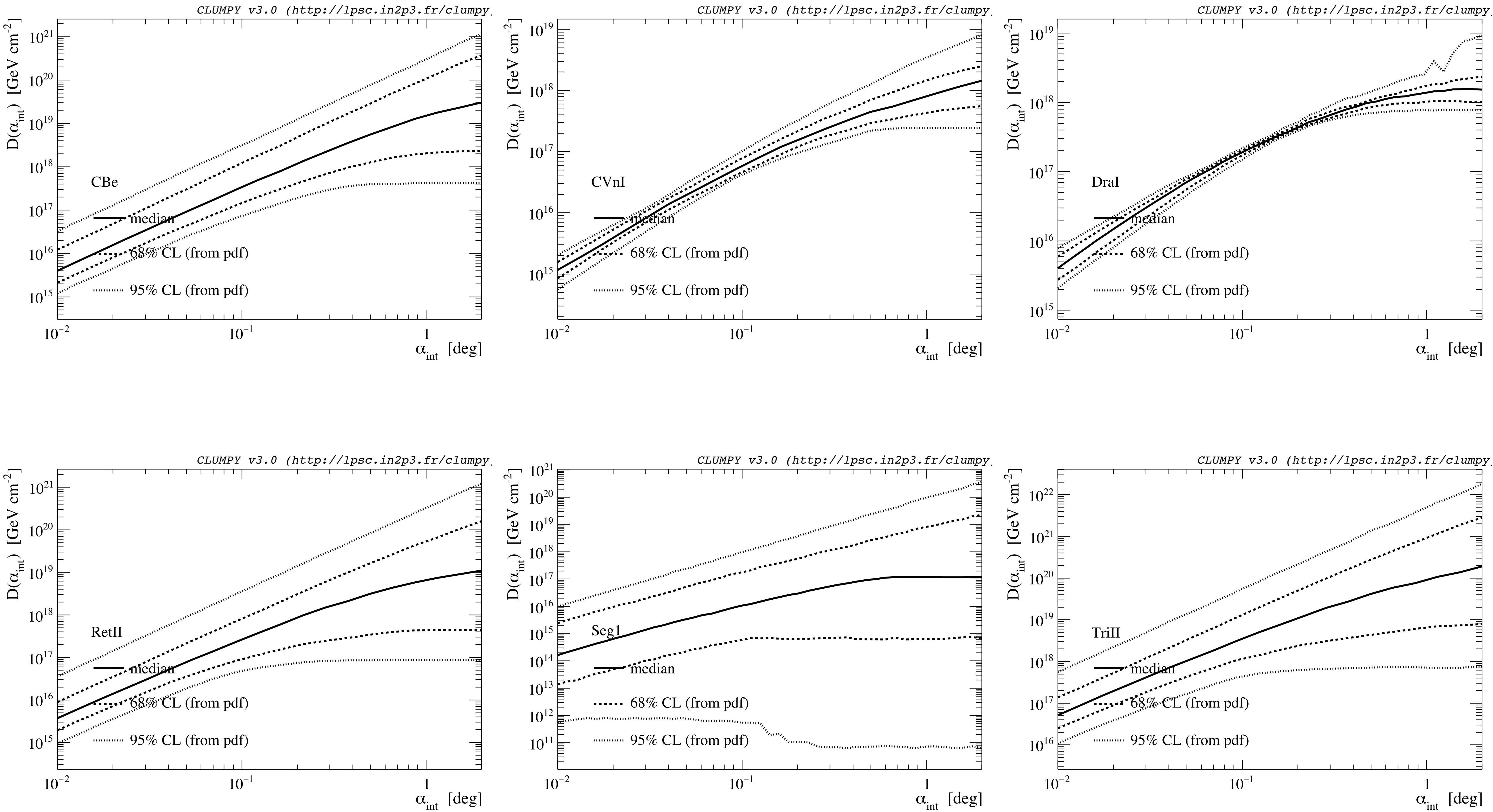
- Two classes of dSphs: classical and ultra-faints;
- stellar memberships for classical dSphs + Seg 1 estimated through an EM algorithm (Walker+ 2009) with confidence cut at $P > 0.95$;
- binary (0/1) stellar membership for ultra-faint dSphs taken from the literature for each target;
- **Membership for Seg 1 at risk of contamination by high-velocity stars!**



- Adopted DM profile: Einasto (3 free parameters) + adopted velocity anisotropy profile: Baes & van Hese 2007 (4 free parameters);
- total of 100k MC extractions for each dSph; astrophysical factors for annihilation (J-factors) computed for integration angles up to 2 deg.



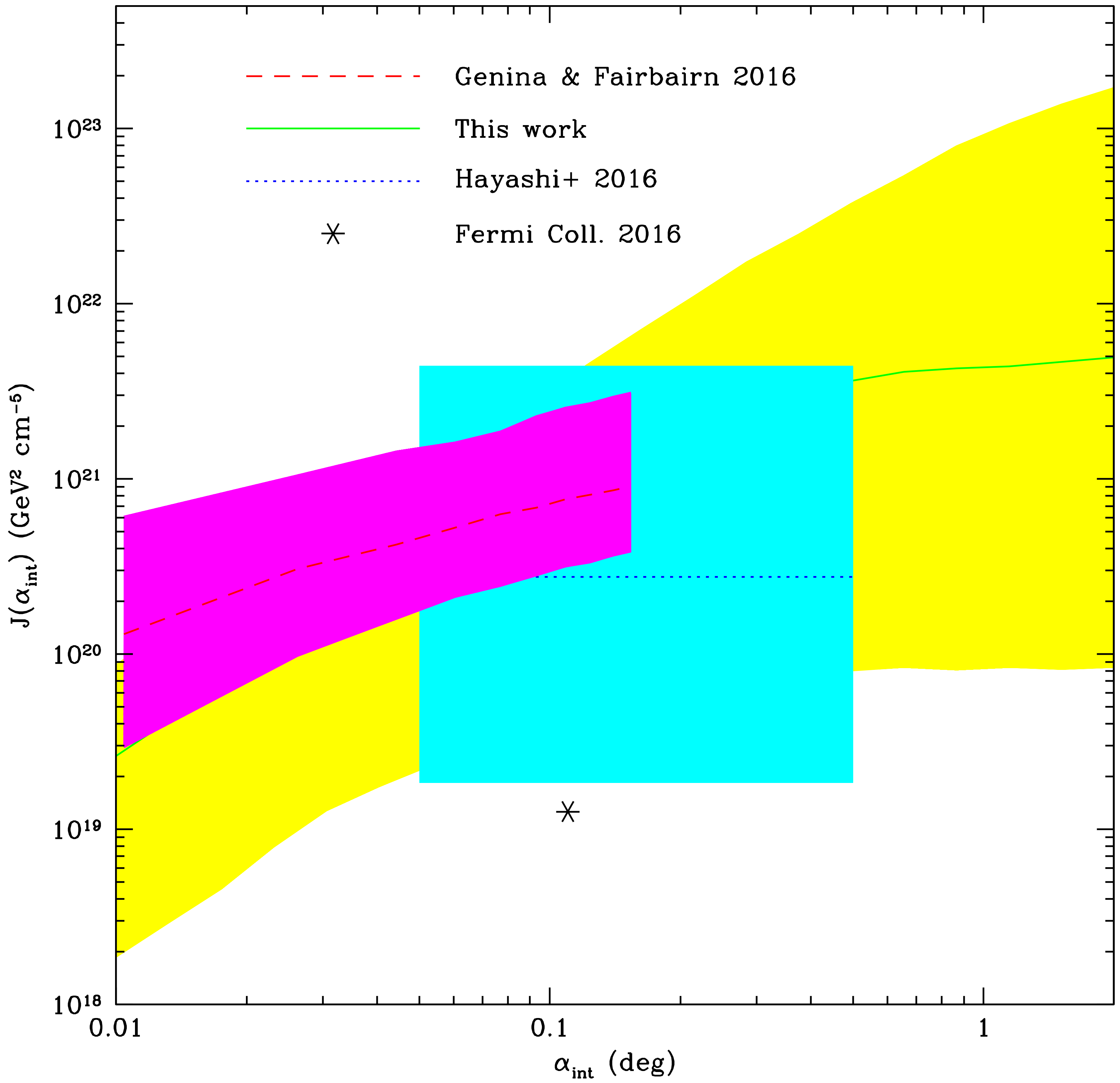
- Same for decay astrophysical factors (D-factors):



- Ranking dSphs for expected DM content (color-coded, annihilation only):

dSph	α_J (deg)	logJ(0.5 deg) ($GeV^2\ cm^{-5}$)	logJ(α_J) ($GeV^2\ cm^{-5}$)
CBe	0.24 *(0.20)*	$19.4^{+0.9}_{-0.7}$ *($19.7^{+0.8}_{-0.7}$)*	$19.1^{+0.7}_{-0.6}$ *($19.2^{+0.6}_{-0.5}$)*
CVn I	0.30 *(0.30)*	$17.2^{+0.2}_{-0.2}$ *($17.6^{+0.4}_{-0.2}$)*	$17.1^{+0.2}_{-0.2}$ *($17.6^{+0.3}_{-0.2}$)*
Dra I	0.26 *(0.28)*	$18.6^{+0.1}_{-0.1}$ *($19.2^{+0.4}_{-0.2}$)*	$18.6^{+0.1}_{-0.2}$ *($18.9^{+0.3}_{-0.1}$)*
Ret II	0.09 *(~0.08)*	$19.3^{+0.9}_{-0.7}$ *($19.6^{+1.0}_{-0.7}$)*	$18.6^{+0.5}_{-0.5}$ *($18.7^{+0.6}_{-0.5}$)*
Seg 1	0.17 *(0.14)*	$16.7^{+2.3}_{-2.5}$ *($17.1^{+2.1}_{-2.2}$)*	$16.3^{+2.1}_{-2.1}$ *($16.5^{+2.0}_{-2.1}$)*
Tri II	0.08 *(~0.08)*	$21.6^{+1.0}_{-0.9}$ *($21.2^{+1.0}_{-1.1}$)*	$20.8^{+0.6}_{-0.5}$ *($20.5^{+0.7}_{-0.3}$)*

- The case of Tri II: very high J-factors from various studies (sim + obs)! **Potentially observable with CTA as single target.**



6. Summary

- (Nearby) dwarf spheroidal galaxies are potentially among the best targets to search for gamma-ray signals from dark matter self-interaction (annihilation or decay);
- accurate estimates of the dark matter content of dwarf-galaxy halos based on surface brightnesses and stellar kinematics are crucial in this framework to select the potential best and most robust targets;
- at present, the Tri II dwarf galaxy is possibly observable as a single target with CTA (other dSphs can be observed for stacking analyses).

Future work

- Derive estimates of astrophysical factors for other dSphs, with also different choices of the DM profiles (Zhao-Hernquist, Burkert);
- include such estimates in simulations of dark matter detection feasibility with CTA (CTOOLS and/or gLike), ASTRI Mini-Array and MAGIC;
- discuss best observational strategies (single targets, sources for stacking, etc.).