Dark matter annihilation and decay factors in the Milky Way's dwarf spheroidal galaxies

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LPSC Grenoble

Dwarf spheroidal galaxies

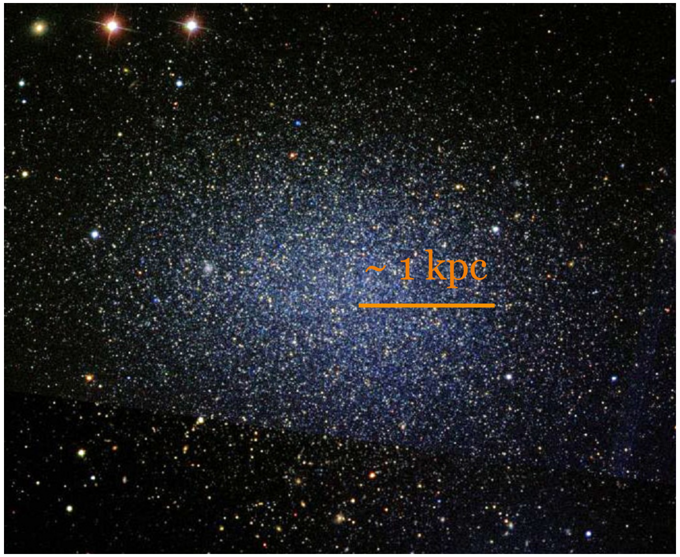
- Dwarf spheroidal galaxies (dSphs) are Milky Way satellites:

  - Highly **dark matter dominated**:
    M/L > 10-1000 M⊙/L⊙

  → Largest DM clumps in which baryonic matter collapsed.

  - ~30 were discovered, ranging from very bright (« classical ») to ultra-faint objects.
  - Free of astrophysical γ-ray emission.

  → Among the best targets for searching γ-ray emission from dark matter annihilation.



Leo I dSph. Credit: WikiSky (SDSS)
$d \sim 250$ kpc; $M \sim 10^7 M_\odot$

- dSphs are primary targets of γ-ray observatories:
  - Fermi-LAT;
  - H.E.S.S., MAGIC, and VERITAS

J-factors

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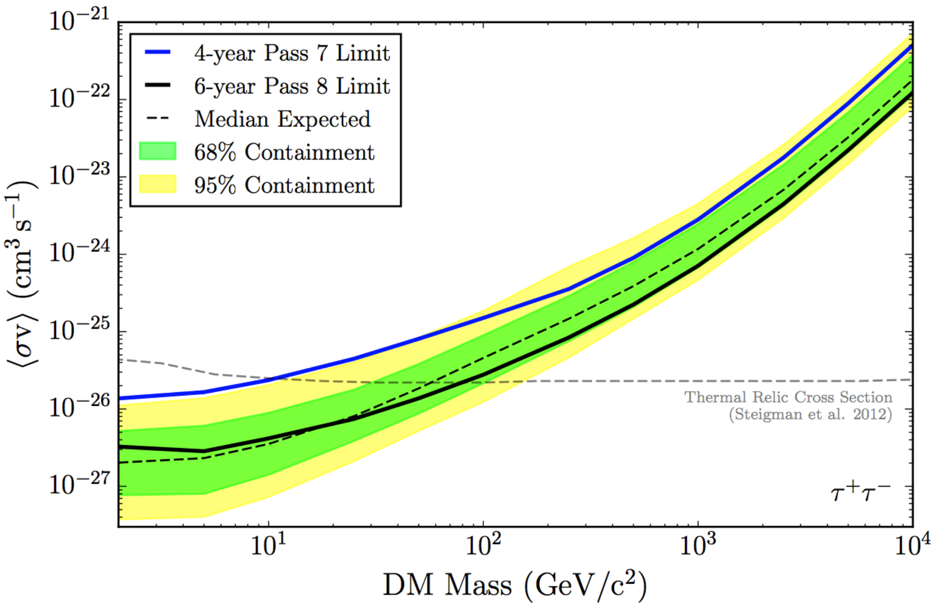
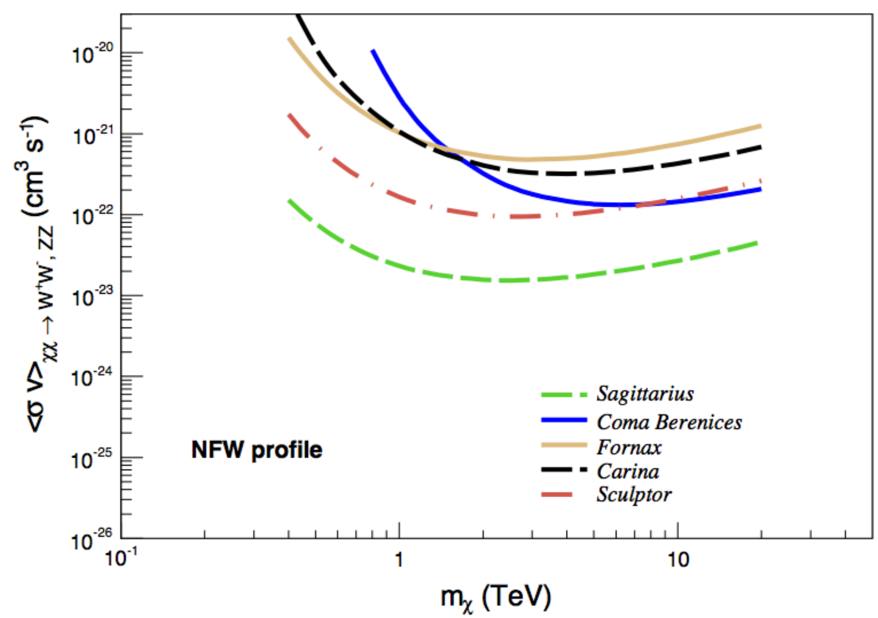
- Absence of γ-ray emission: constraints on DM properties.
- γ-ray differential flux coming from dark matter annihilation:

$$\frac{d\phi_\gamma}{dE} = \frac{1}{4\pi}\frac{dN_\gamma}{dE}\frac{<\sigma_{ann}v>}{2m_\chi^2}\underbrace{\int_0^{l_{\max}}\int_0^{\Delta\Omega}\rho_{DM}^2\, d\Omega\, dl}_{\textbf{J-factor}}$$



Fermi collaboration (2015)
[arXiv:1503.02641]



H.E.S.S. collaboration (2014)
[Phys. Rev. D 90, 112012 (2014)]

Jeans analysis (1)

- J-factor: requires the DM density profile

→ Use the stellar population of the dSph as tracer of its gravitational potential: **Jeans analysis**

Assumptions:
- *Spherical symmetry,*
- *Dynamical equilibrium,*
- *Collisionless,*
- *Negligible rotational support*

[Binney & Tremaine (1987)]

Spherical Jeans equation

$$\underbrace{\frac{1}{\nu}\frac{d}{dr}(\nu\bar{v_r^2}) + 2\frac{\beta_{\rm ani}(r)\bar{v_r^2}}{r}}_{\textbf{Stellar}} = \underbrace{-\frac{GM(r)}{r^2}}_{\textbf{DM}}$$

- From the solution, we can compute the stellar velocity dispersion along the line of sight: $\sigma_p(R)$

$$\sigma_p^2(R) = \frac{2}{I(R)}\int_R^\infty \left(1-\beta_{\rm ani}(r)\frac{R^2}{r^2}\right)\frac{\nu(r)\,\bar{v_r^2}(r)\,r}{\sqrt{r^2-R^2}}{\rm d}r$$

Jeans analysis (2)

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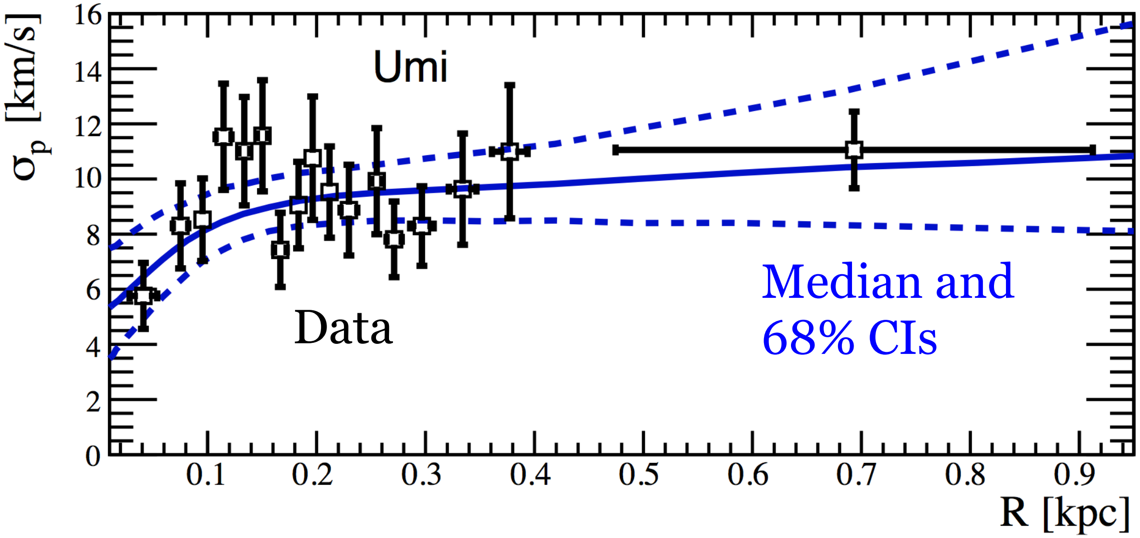

Velocity dispersion profile of the « classical » dSph Ursa Minor.

- Method:
  - Assume parametric models for $\beta_{ani}(r)$ and $\rho_{DM}(r)$ [4 – 7 free parameters]
  - Compute $\sigma_p(R)$
  - Compare to the measured velocity dispersion [MCMC analysis – GreAT: http://lpsc.in2p3.fr/great]
  - Compute J-factor from $\rho_{DM}(r)$ [CLUMPY: http://lpsc.in2p3.fr/clumpy]

$\sigma_p(R)$ → $\beta_{ani}(r),\ \rho_{DM}(r)$ → *J-factor*

Jeans analysis: uncertainties

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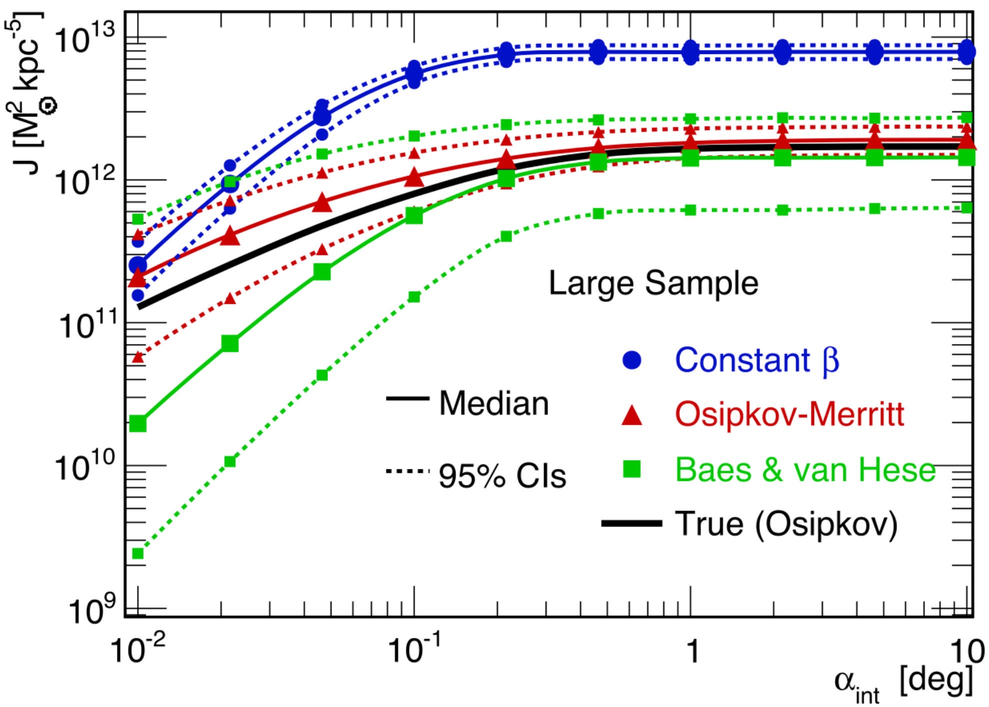
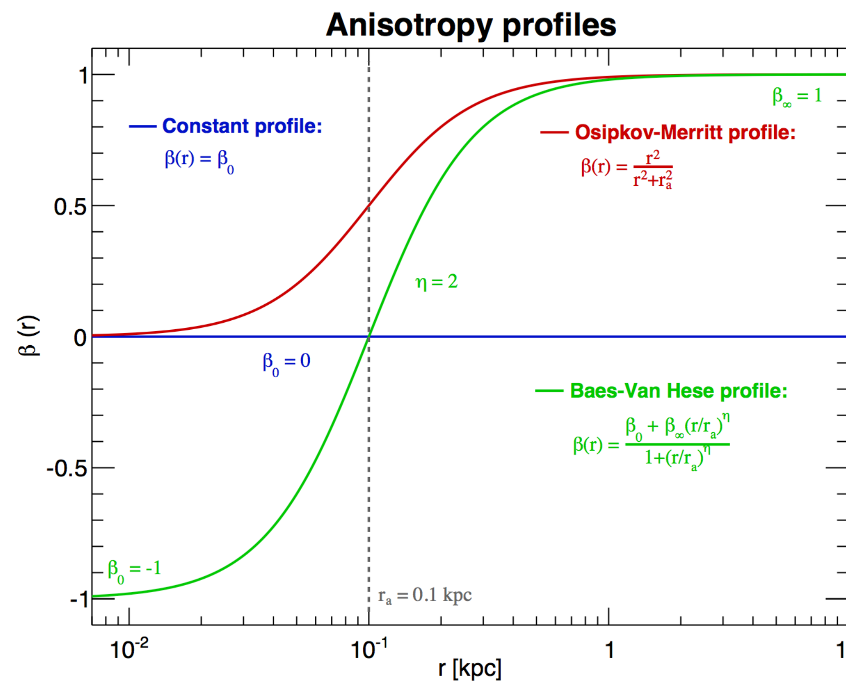
- Using **simulated dSphs** for which the DM and anisotropy profiles are known, we found that several ingredients can **bias** the J-factor reconstruction:
  - Too specific anisotropy parametrizations,



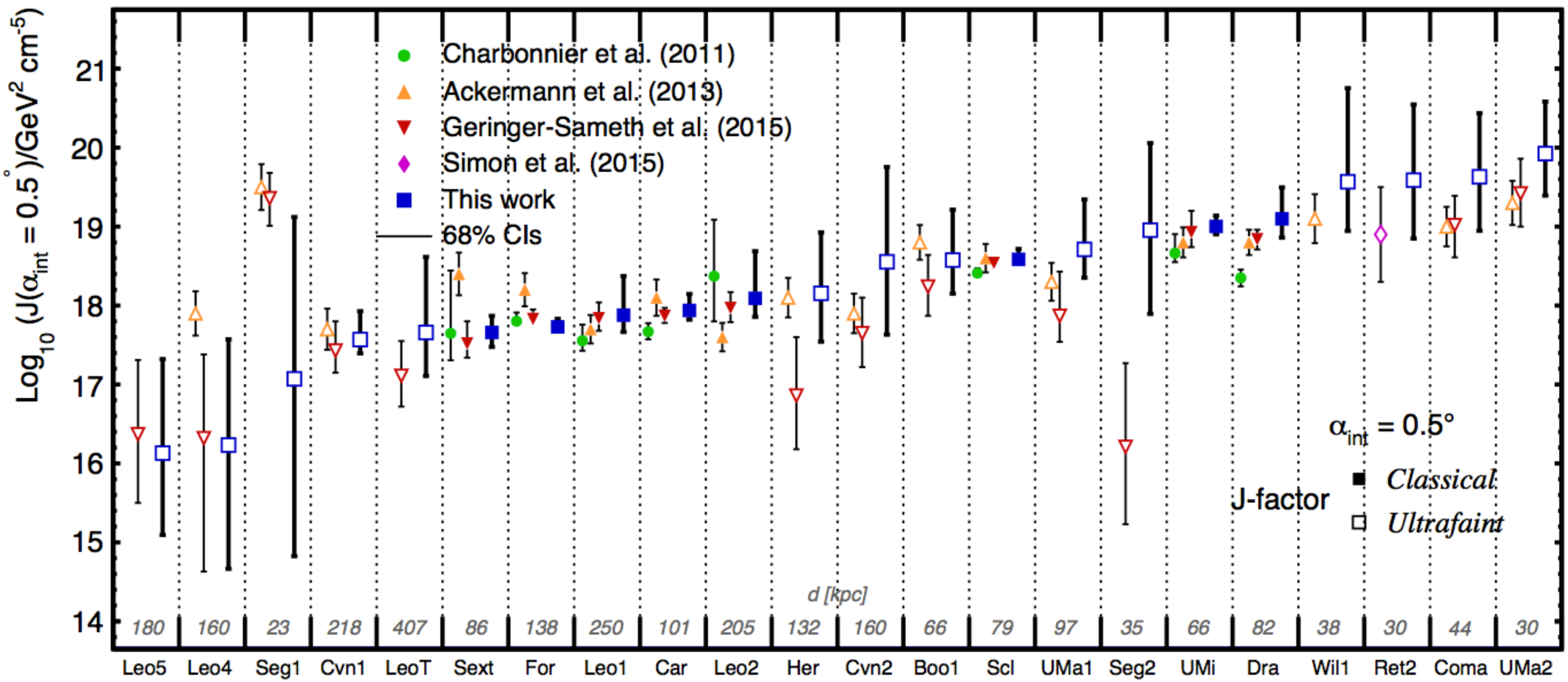


  - Fitting of the stellar number density → external part has an impact.
  - Non-sphericity of the DM halo (triaxiality) → 0.4 dex systematic error.

→ We proposed an « optimised » setup in Bonnivard et al. (2015) [MNRAS 446, 3002]

Jeans analysis: application to real data

- We have applied our setup to real data: 8 « classical » and 14 « ultrafaint » dSphs, including the recently discovered Ret II [arXiv:1504.02048, 2015 ApJ 808 L36]:



→ Consistant analysis of 22 dSphs [for annihilation and decay], with realistic uncertainties.

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V. Bonnivard – ICRC 2015

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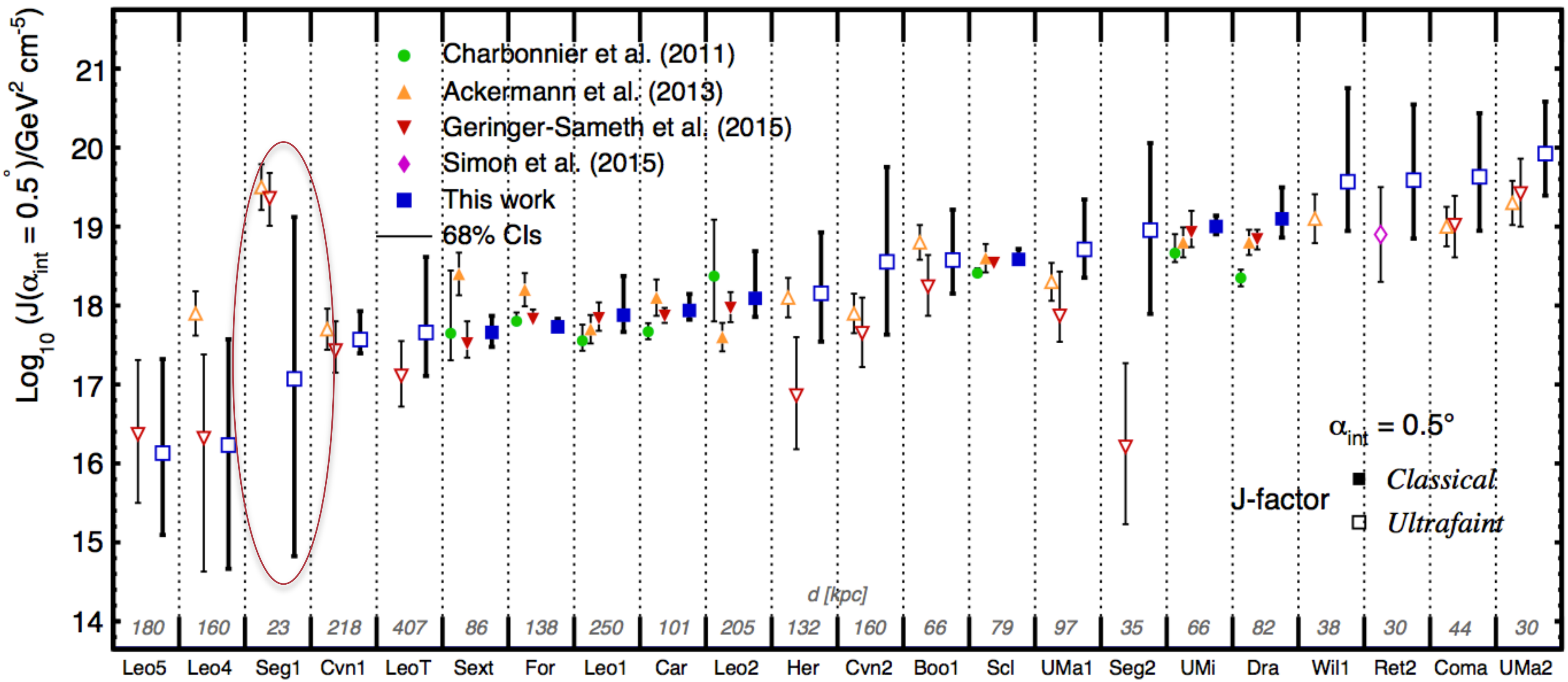
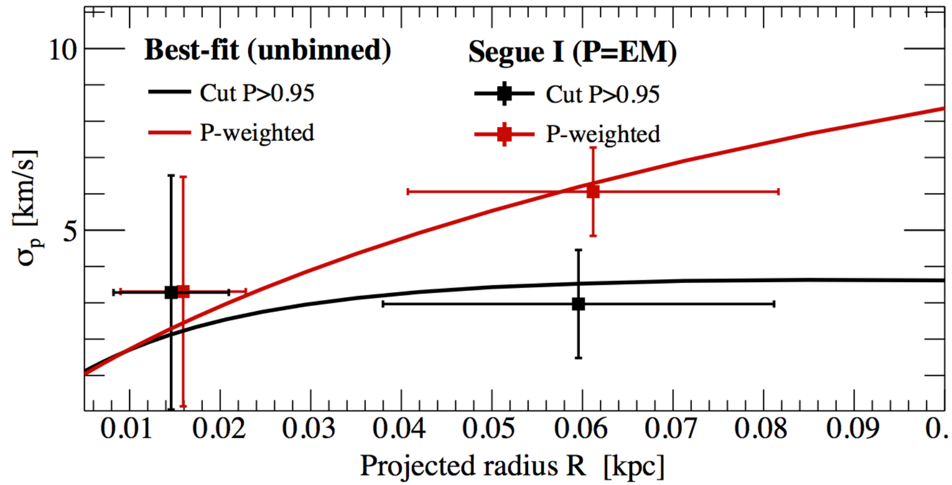


→ Consistant analysis of 22 dSphs [for annihilation and decay], with realistic uncertainties.

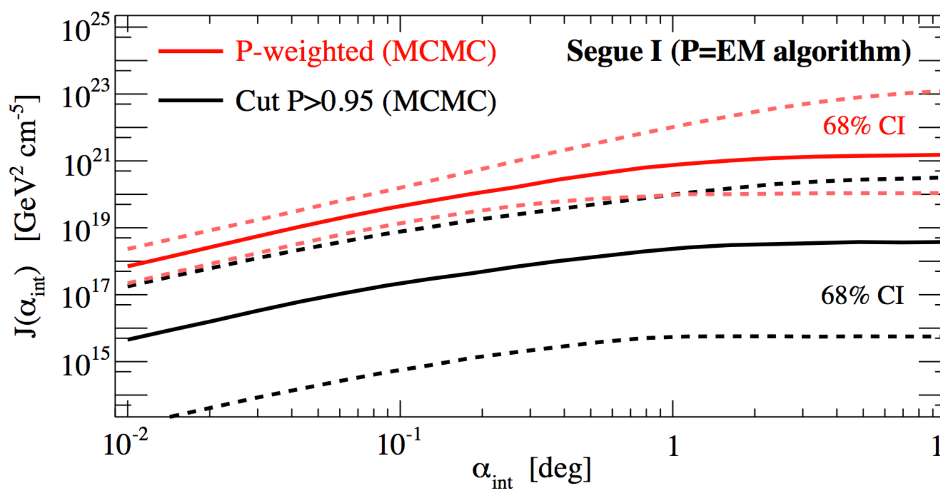
The Segue I case

- The ultrafaint **Segue I** is often promoted as the « best target » among the dSphs.



- However, its kinematic sample might be contaminated by Milky Way foreground stars.

→ Our analysis is very sensitive to these ambiguous stars.



- Segue I's behaviour is very similar to what we observed in contaminated mock dSphs.

→ Its J-factor might be not reliable (Bonnivard et al. 2015, arXiv:1506.08209).

Conclusions

- dSphs for DM indirect detection:
  - Among the **best targets** for searching γ-rays from DM annihilation or decay;
  - Used to put strong constraints on the DM particle properties.

- J-factor reconstruction:
  - « **Optimised** » Jeans setup to reduce biases [MNRAS 446, 3002],
  - Application to **22 dSphs**, including the recently discovered Ret II [arXiv:1504.02048, 2015 ApJL 808 36],
  - Segue I's J-factor might be **not reliable** because of Milky Way contamination [arXiv:1506.08209].

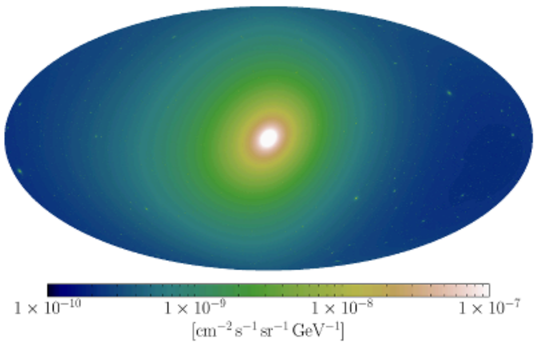
All these analyses were done with the new version of the CLUMPY code! [arXiv:1506.07628]

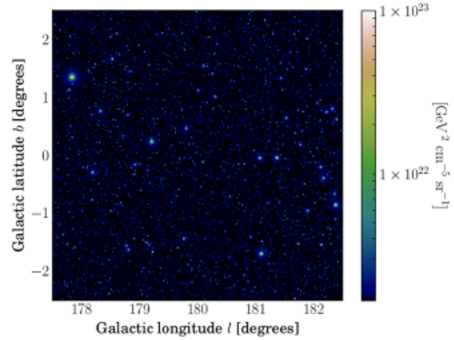
CLUMPY Documentation

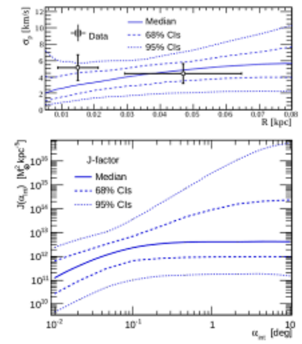
If you use CLUMPY, please cite
Charbonnier, Combet, Maurin, CPC 183, 656 (2012)
Bonnivard, Hütten, Nezri, Charbonnier, Combet, Maurin (2015arXiv150607628B)

To install the code and have a quick overview before getting started, please visit the following pages:

- **Introduction** – J-factor calculation and conventions
- **Download / Installation instructions** – Archives of the code + installation instructions (README)
- **Quick checks / examples** – Command lines and outputs to quickly check CLUMPY
- **Contact, bug reports, ASCII files**







06/2015 – Second release (v2015.06) – Bonnivard, Hütten, Nezri, Charbonnier, Combet, Maurin (2015arXiv150607628B)

Hi! In this release, we included the following new features:

- Jeans' analysis (interfaced with the MCMC GreAT): see, e.g., Bonnivard et al. (2015);
- Use of HEALPix coordinates, FITS and .root output files;
- Gamma-ray and neutrino spectra from PPPC4DMID;
- Map smoothing by Gaussian beam;
- Triaxiality option for Galactic halo and halo lists;
- Concentration of haloes drawn from a distribution, boost up to any level of substructures.

Versions and patches:

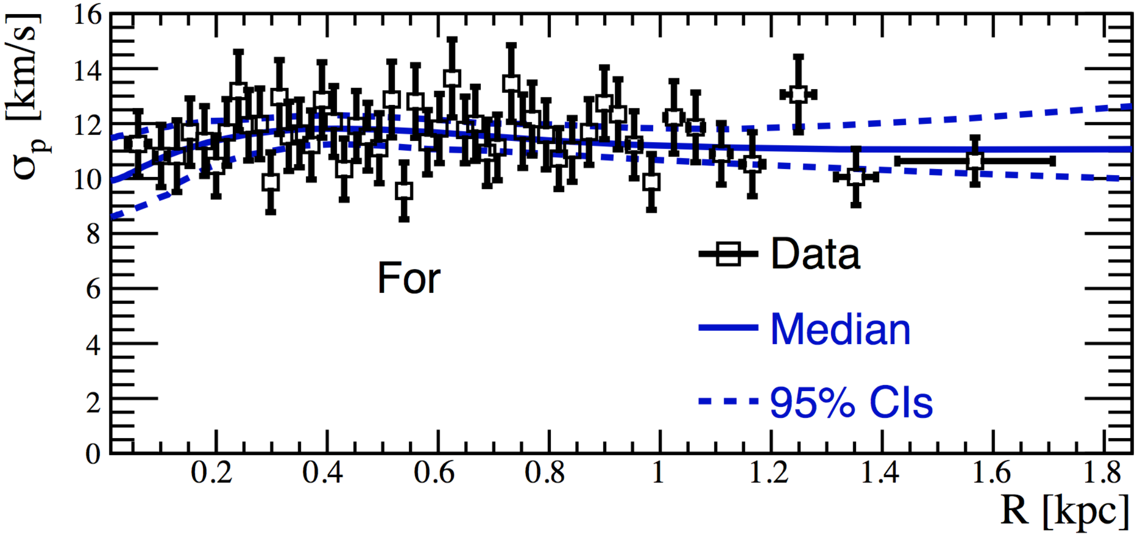
- **06/2015:** V2015.06

The new CLUMPY crew
Vincent, Moritz, Emmanuel, Aldée, Céline, and David

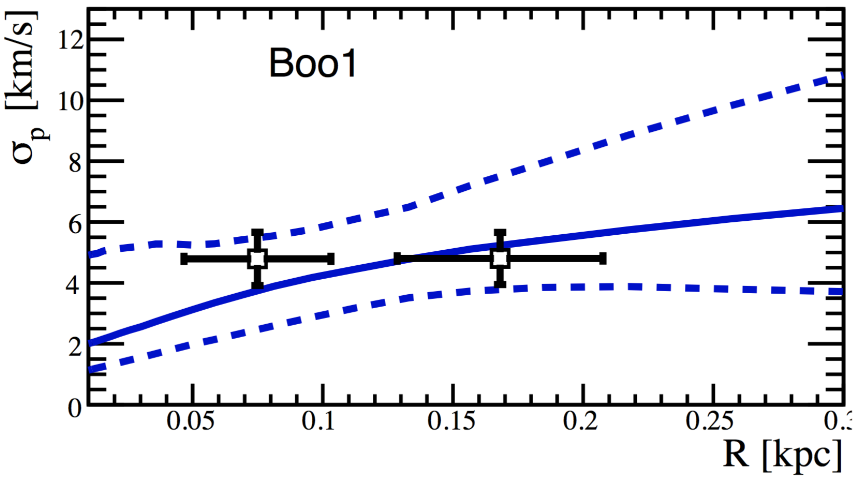
09/2011 – First release (v2011.09) – Charbonnier, Combet, Maurin, CPC 183, 656 (2012)
Hi guys! *[click here to access the doxygen documentation for this version]*

http://lpsc.in2p3.fr/clumpy/

Velocity dispersion profiles

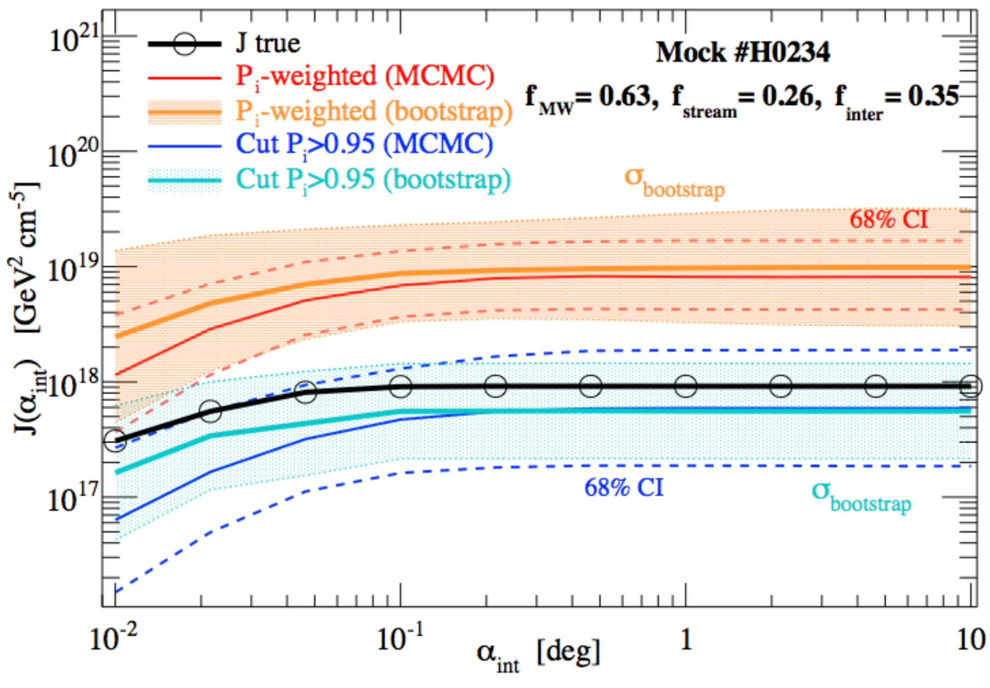


Velocity dispersion for the classical dSph Fornax

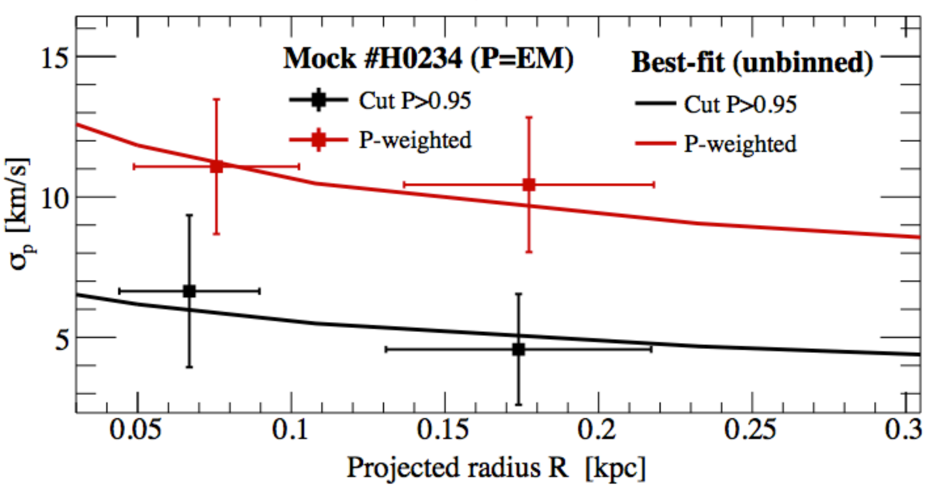


Velocity dispersion for the ultrafaint dSph Bootes 1

Segue I

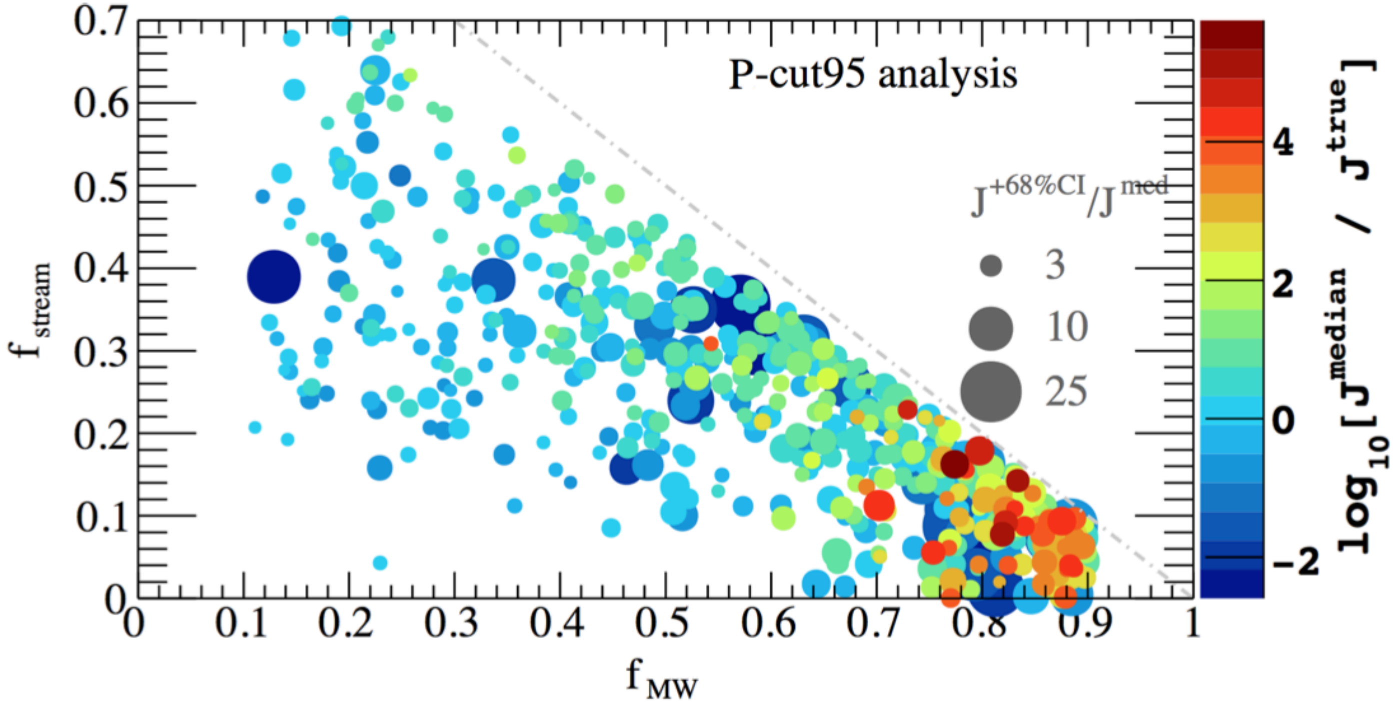


Mock contaminated dSph similar to Segue I



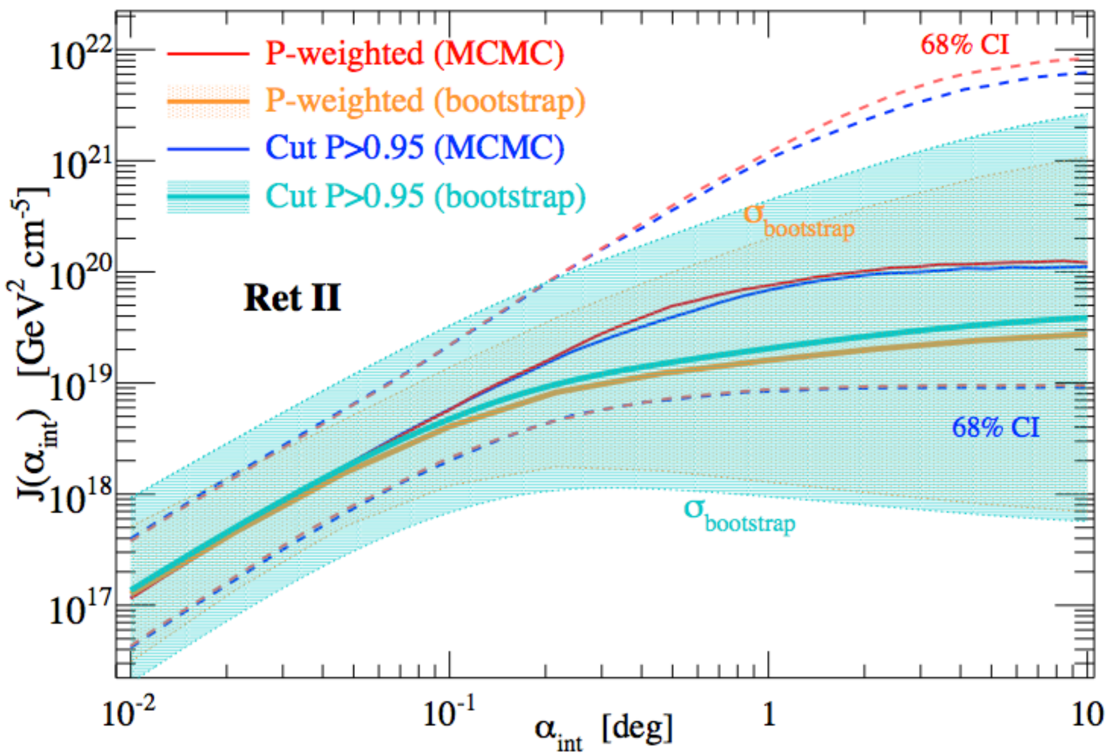
Velocity dispersion profile of the mock

Segue I



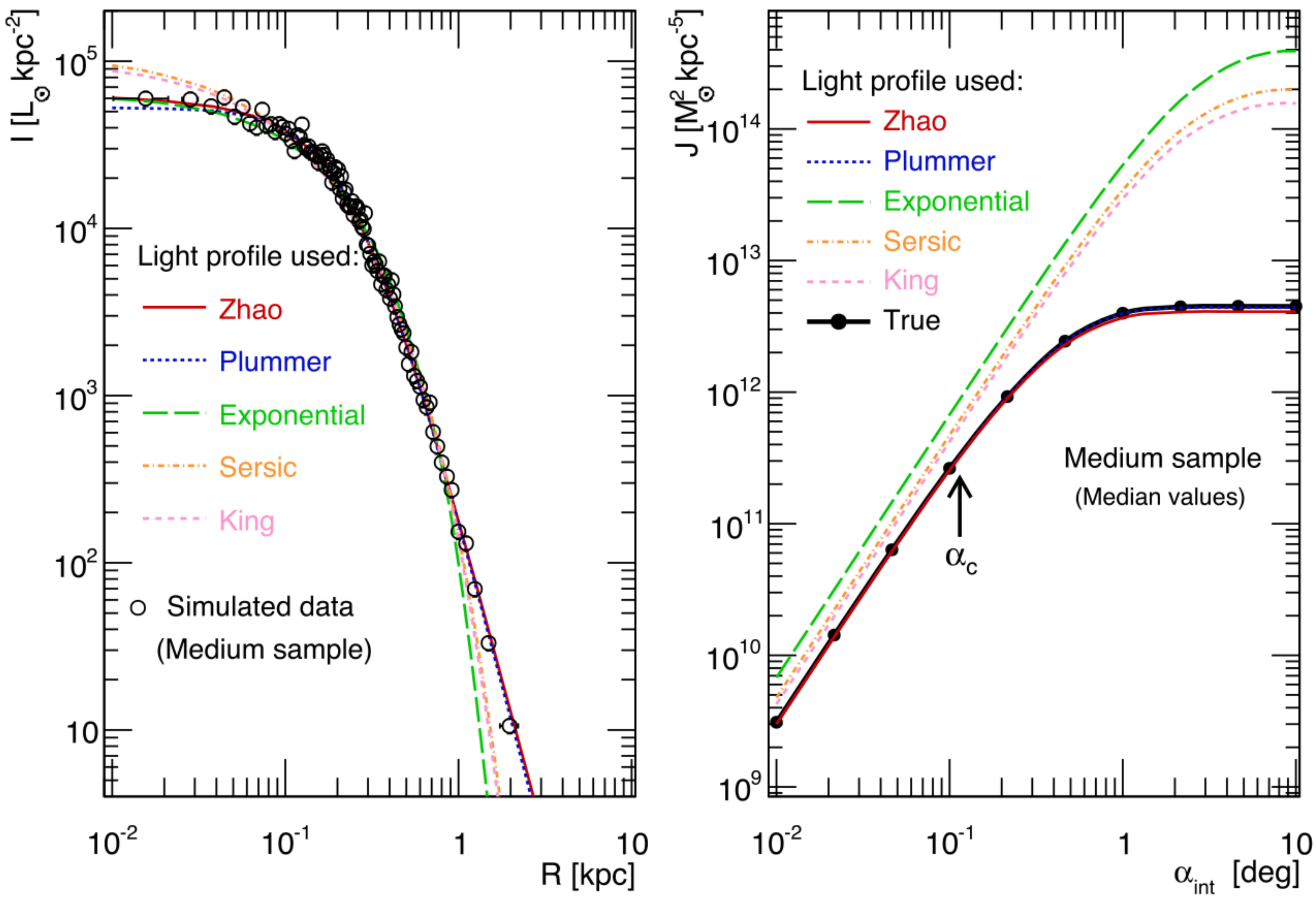
Impact of contamination on J-factor reconstruction

Ret II

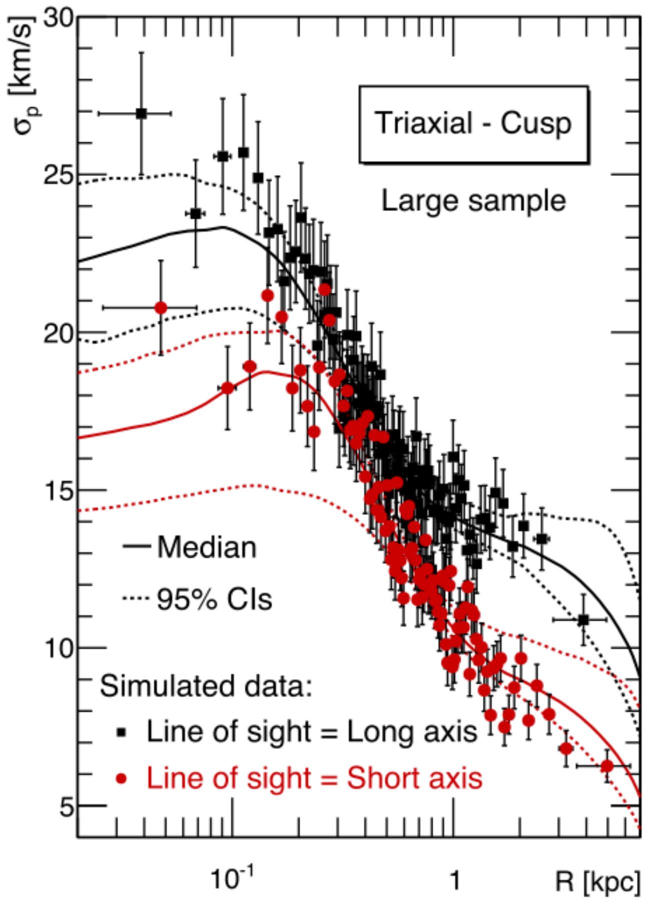


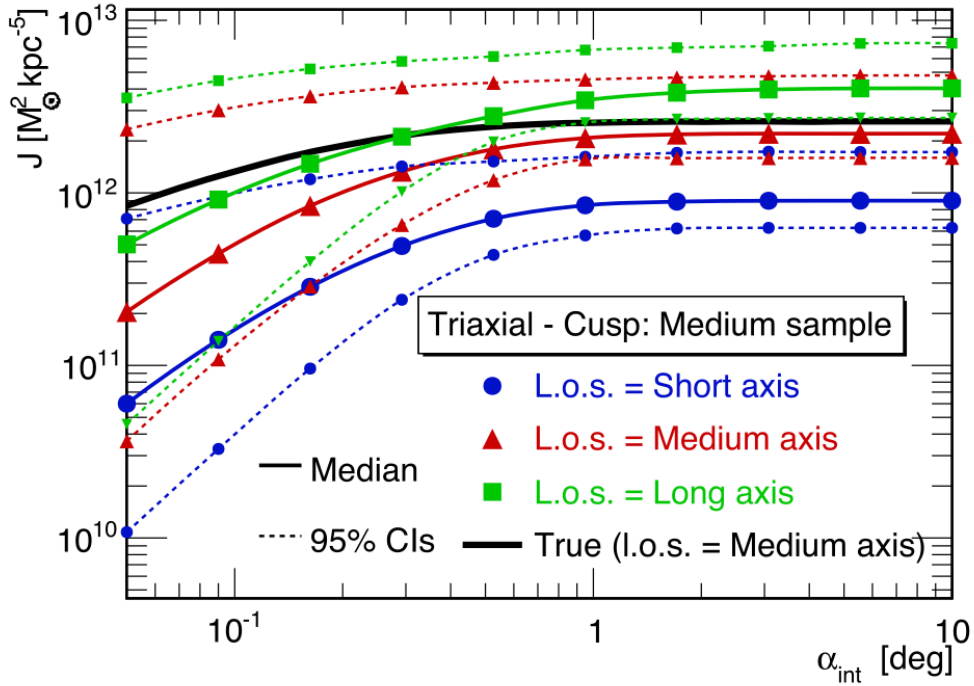
No impact of contamination on Ret II

Light profile



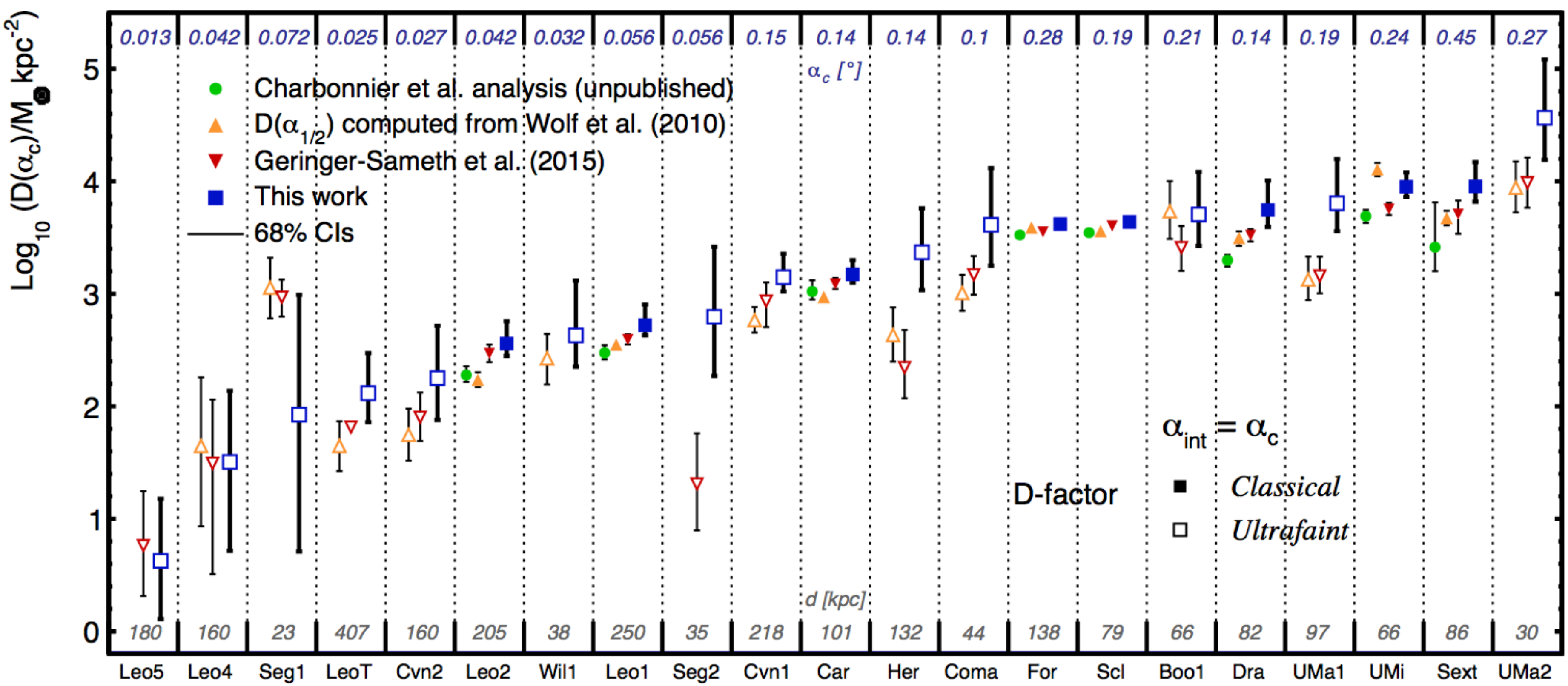
Triaxiality





Decay

$$\frac{d\phi_\gamma}{dE} = \frac{1}{4\pi}\frac{dN_\gamma}{dE}\frac{1}{\tau}\int_0^{l_{max}}\int_0^{\Delta\Omega}\rho_{DM}\,d\Omega\,dl$$



J vs background