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

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**Collaborators:**
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TAUP 2015 – 07/09/15

# Dwarf spheroidal galaxies



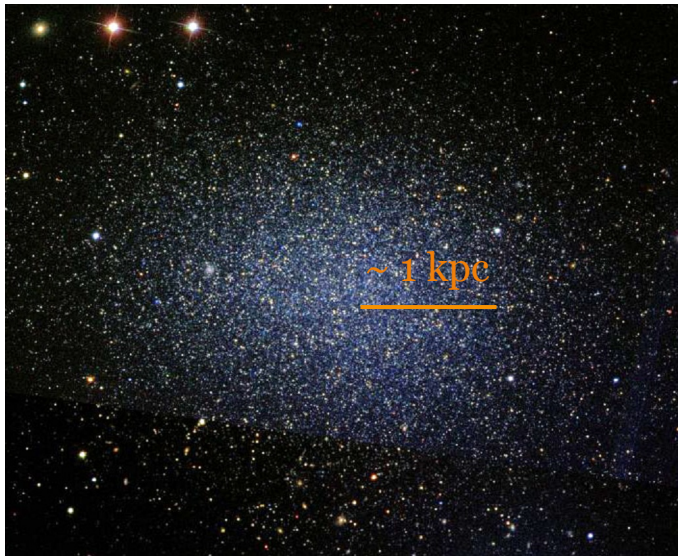
- Dwarf spheroidal galaxies (dSphs) are Milky Way satellites:

  - 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* ~ 250 kpc; *M* ~ $10^7$ *M⊙*

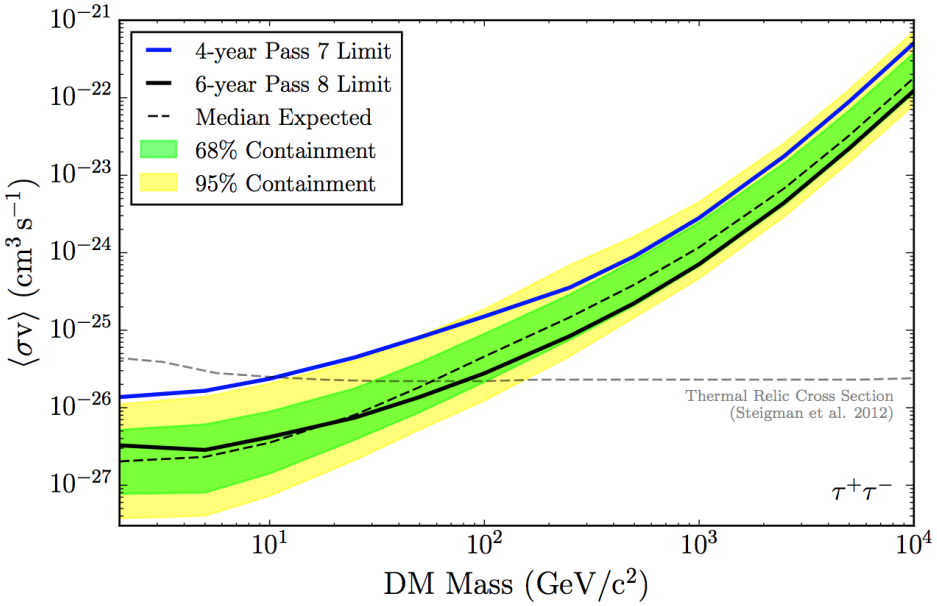
- dSphs are primary targets of γ-ray observatories:
  - Fermi-LAT;
  - H.E.S.S., MAGIC, and VERITAS

# J-factors

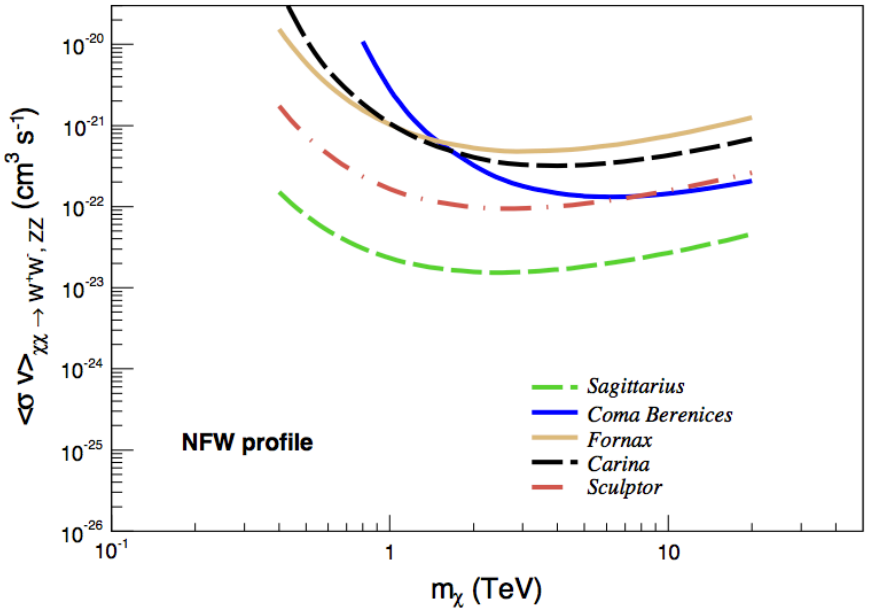


- Absence of γ-ray emission: constraints on DM properties.
- γ-ray differential flux coming from dark matter annihilation:

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




*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**

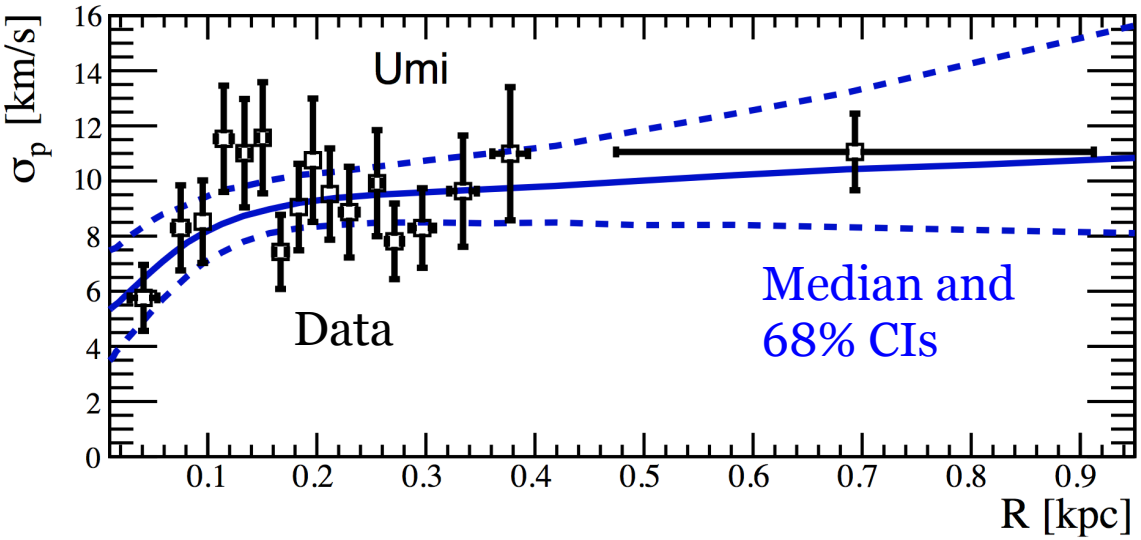
$$\underbrace{\frac{1}{\nu}\frac{d}{dr}(\nu\bar{v_r^2}) + 2\frac{\beta_{\rm ani}(r)\bar{v_r^2}}{r}}_{\textbf{Stellar}} = \underbrace{-\frac{GM(r)}{r^2}}_{\textbf{DM}}$$

- 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)






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

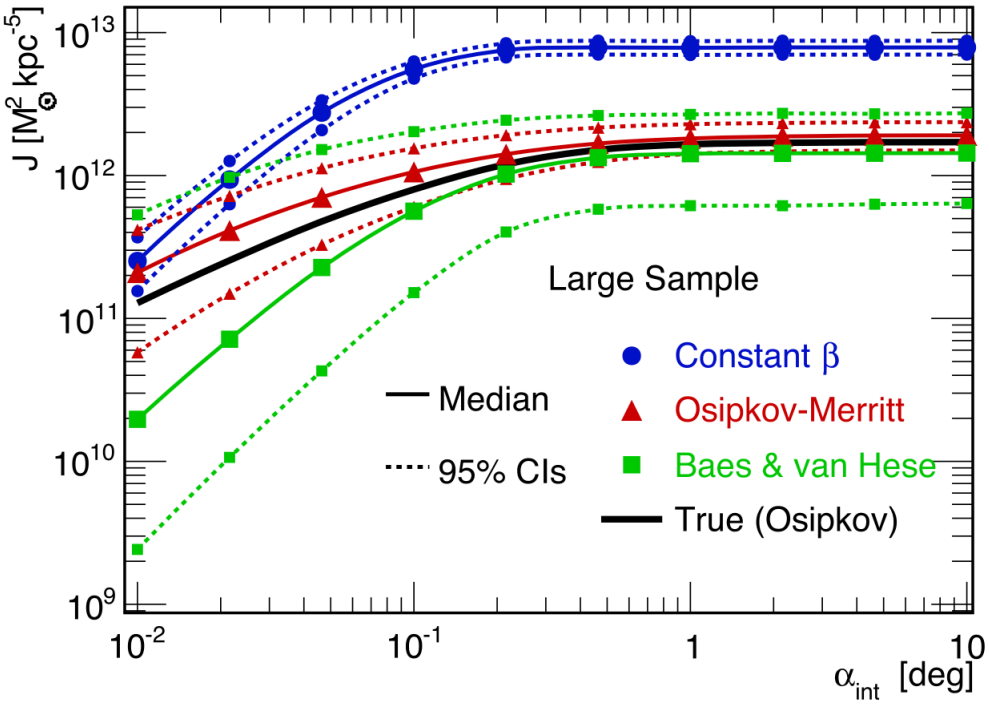
- Method:
  - Assume parametric models for $\beta_{ani}(r)$ and $\rho_{DM}(r)$ [4 – 7 free parameters]
  - Compute $\sigma_p(R)$
  - Compare to the measured velocity dispersion [MCMC analysis – GreAT: http://lpsc.in2p3.fr/great ]
  - Compute J-factor from $\rho_{DM}(r)$ [CLUMPY: http://lpsc.in2p3.fr/clumpy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

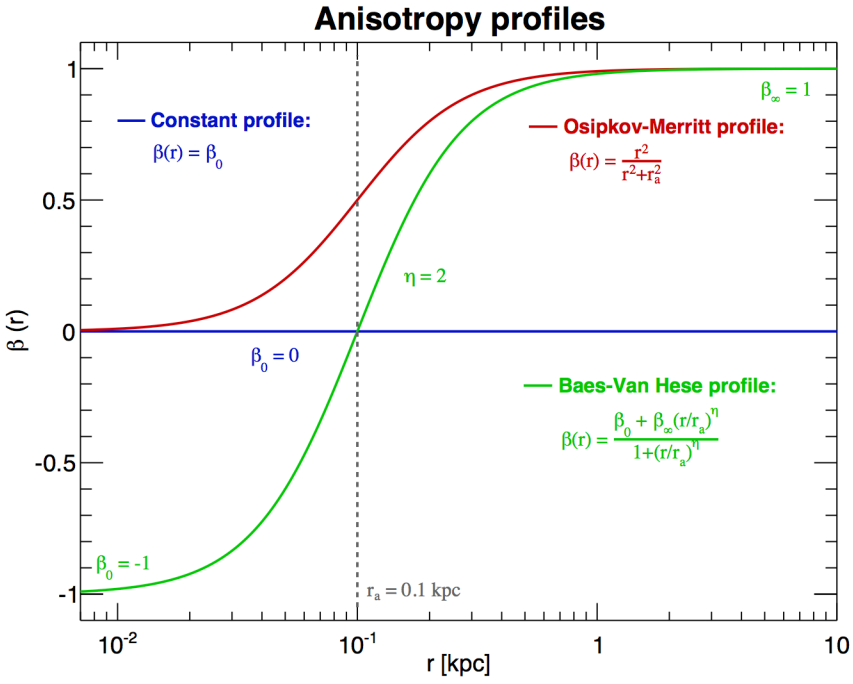
$$\sigma_p(R) \Rightarrow \beta_{ani}(r),\ \rho_{DM}(r) \Rightarrow \textit{J-factor}$$

# Jeans analysis: uncertainties



- 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:

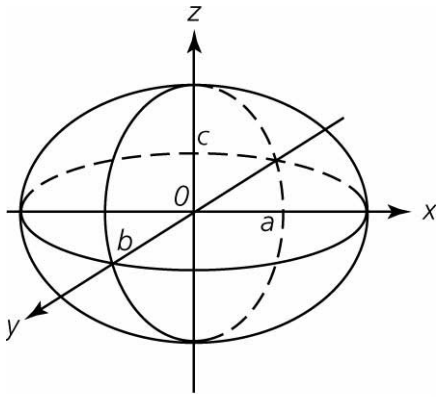


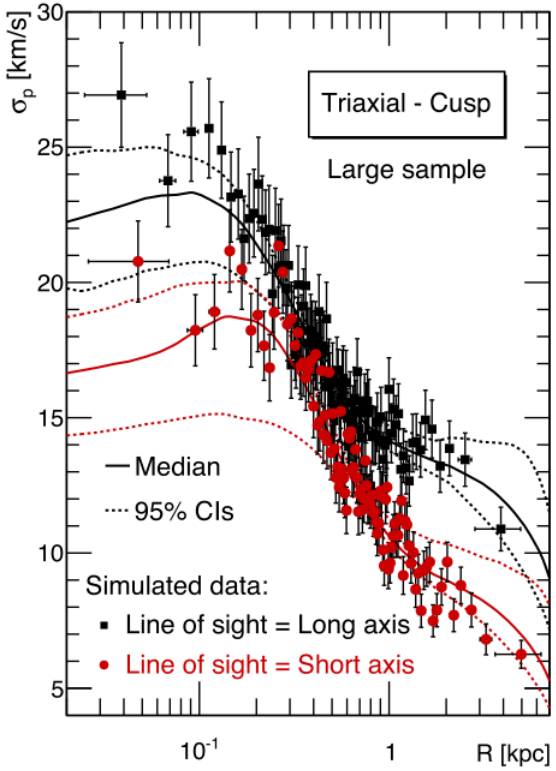
# Jeans analysis: uncertainties

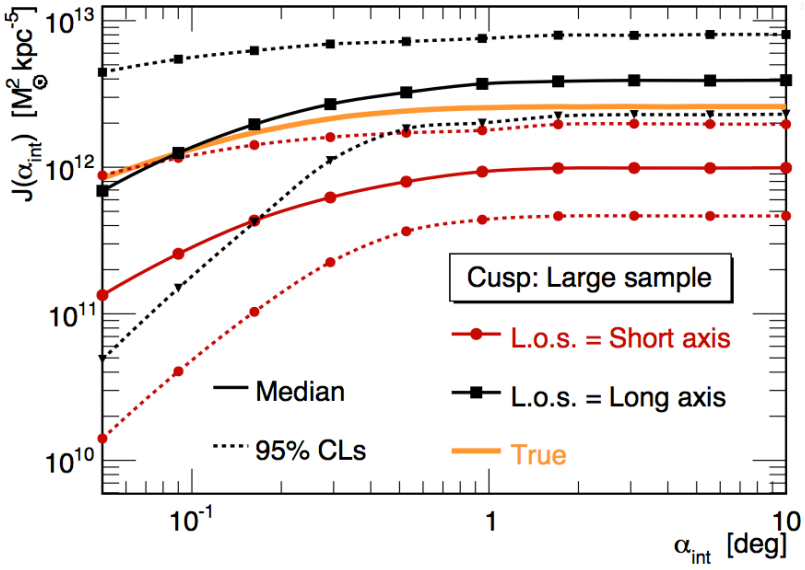


- Using **simulated dSphs** for which the DM and anisotropy profiles are known, we found that several ingredients can **bias** the J-factor reconstruction:
  - Non-sphericity of the DM halo (triaxiality):




→ Halo orientation along the line-of-sight impacts the J-factor



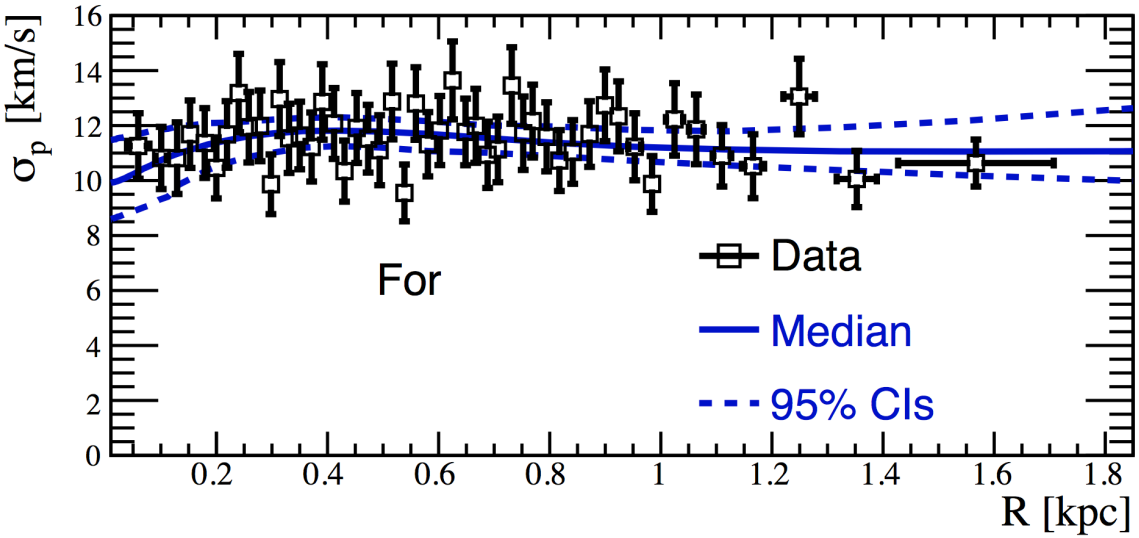




→ We proposed an « optimised » setup in Bonnivard et al. (2015) [MNRAS 446, 3002]

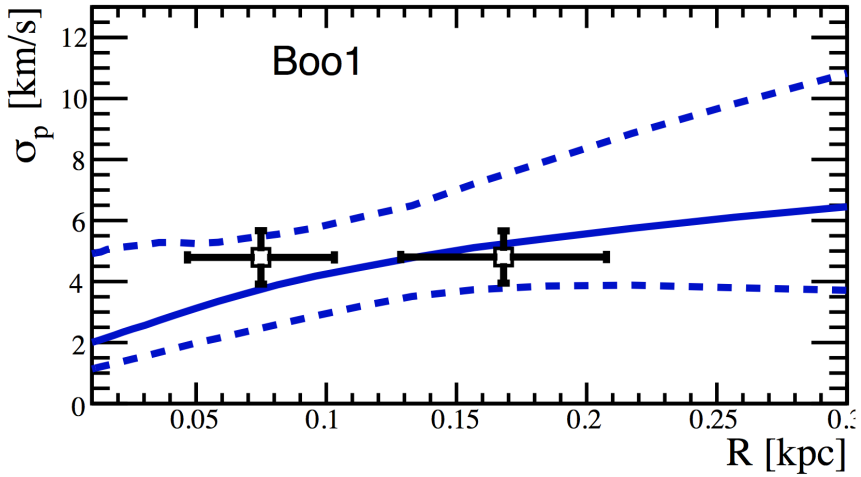
# Jeans analysis: application to real data



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




*Velocity dispersion profile of the « classical » dSph Fornax.*

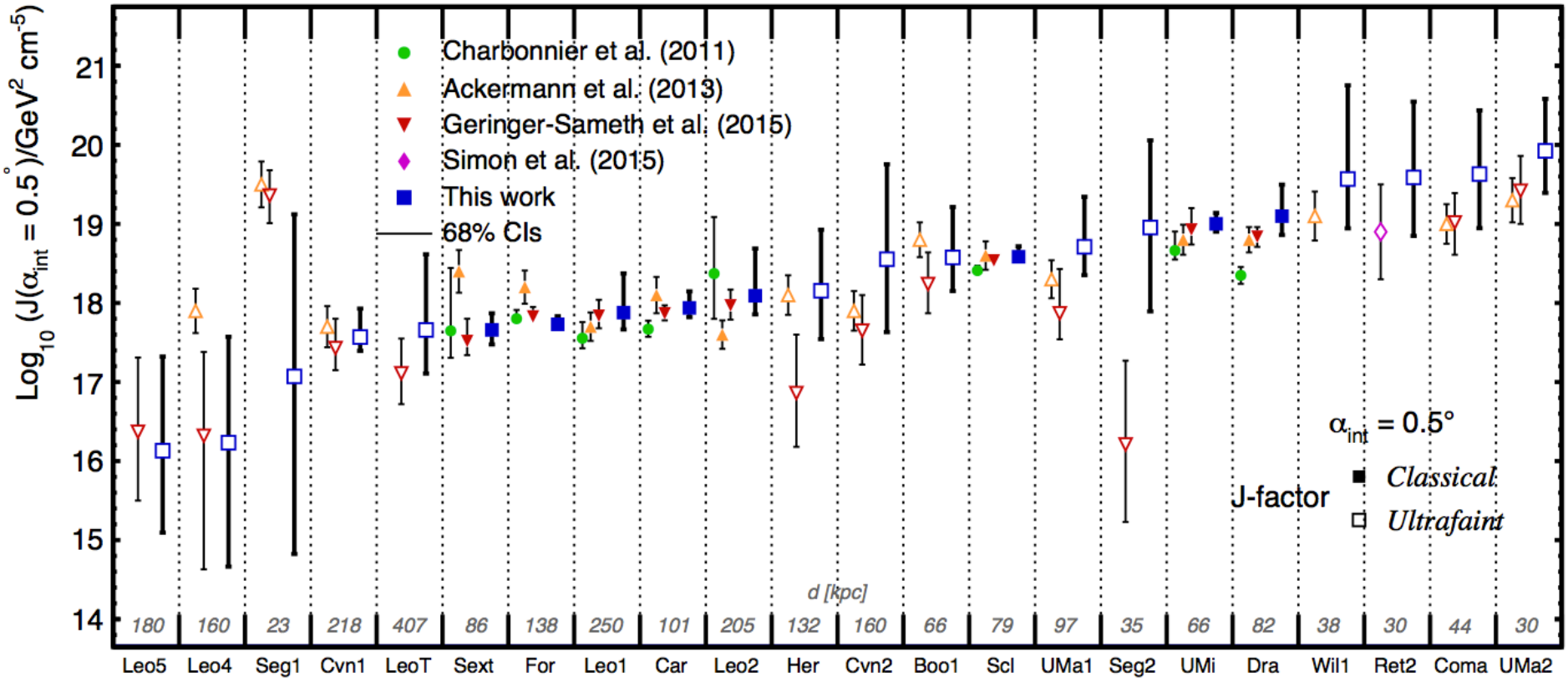



*Velocity dispersion profile of the « ultrafaint » dSph Bootes I.*

# Jeans analysis: application to real data



- J-factors and comparison to other works:

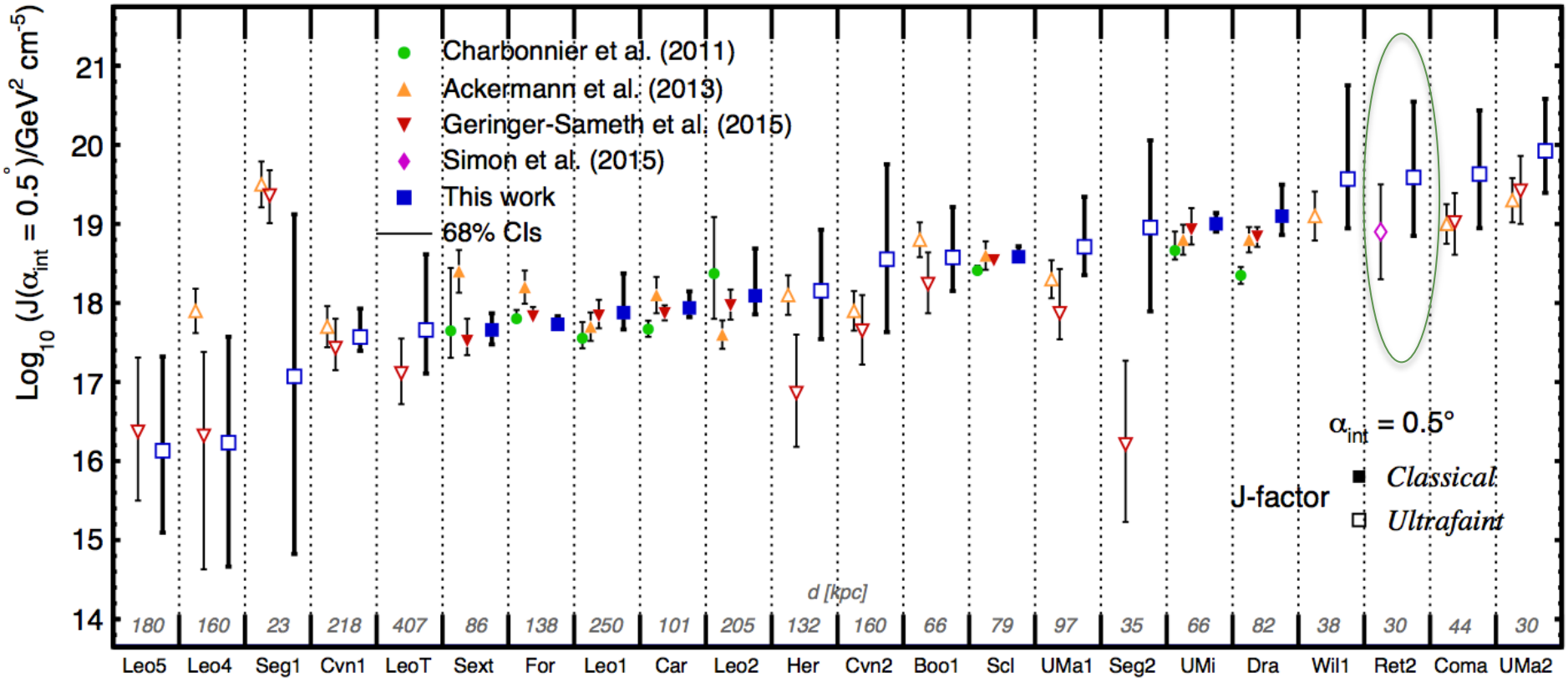



→ Consistant analysis of 22 dSphs [for annihilation and decay], with realistic uncertainties.

# Jeans analysis: application to real data

*V. Bonnivard – TAUP 2015*

- J-factors and comparison to other works:



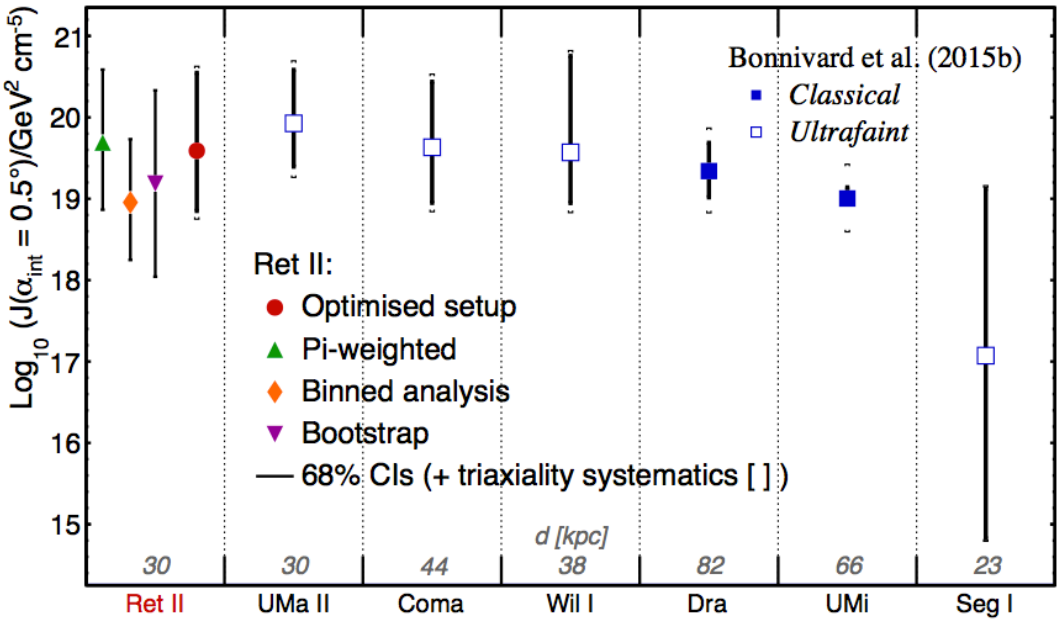

→ Consistant analysis of 22 dSphs [for annihilation and decay], with realistic uncertainties.

# Reticulum II



- Reticulum II: a new close dSph in the Southern Sky (Koposov et al. [2015 ApJ 805 130K], DES collaboration [2015 ApJ 807 50]).
- Evidence of γ-ray emission toward its direction was observed by Geringer-Sameth et al. [arXiv:1503.02320] and Hooper et al. [arXiv: 1503.06209] using Fermi-LAT PASS7 data, see Alex Geringer-Sameth's talk on Thursday!
- The Fermi-LAT collaboration found no excess using PASS 8 data [Fermi-LAT collaboration, 2015 ApJ 809 L4].

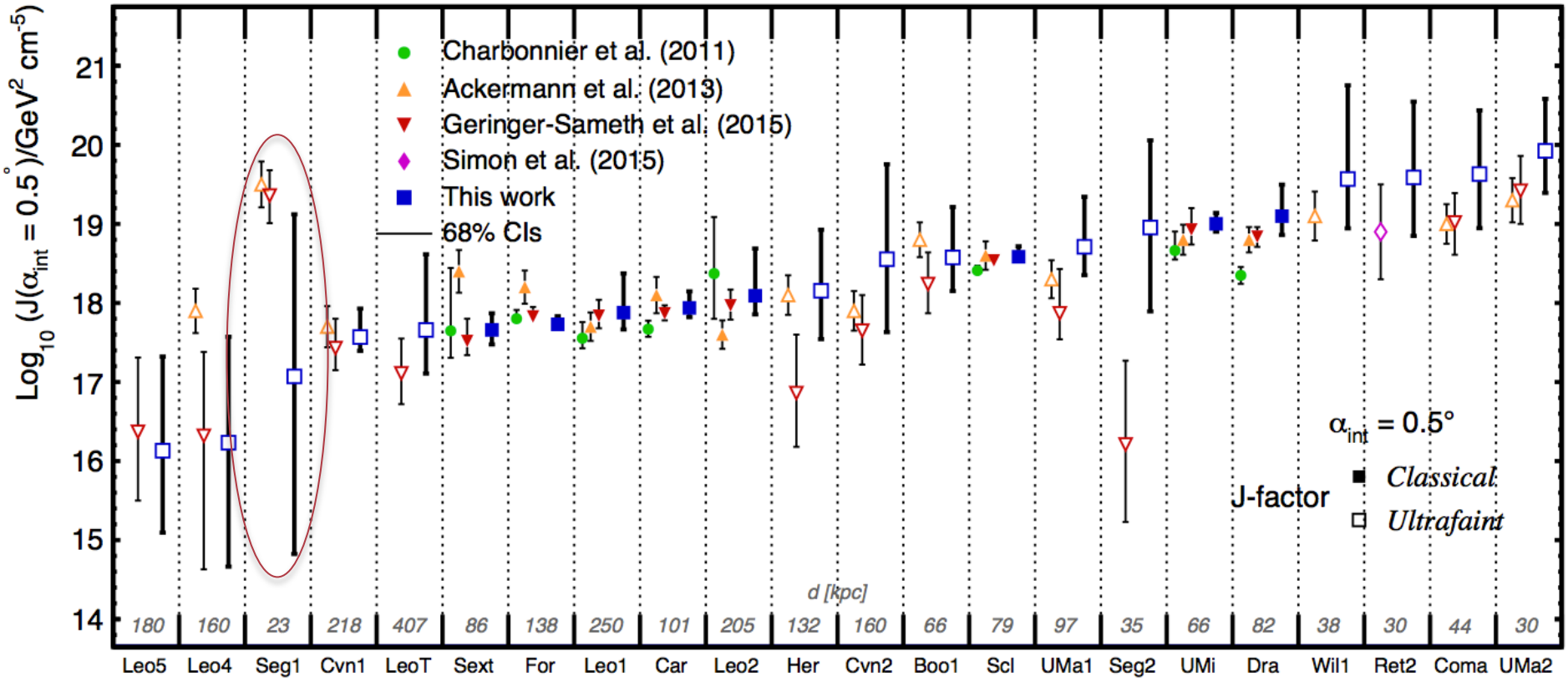
→ We find that Reticulum II's J-factor is among the largest of any Milky Way dSph [Bonnivard et al., 2015 ApJ 808 L36]



# Jeans analysis: application to real data



- J-factors and comparison to other works:




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

# The Segue I case



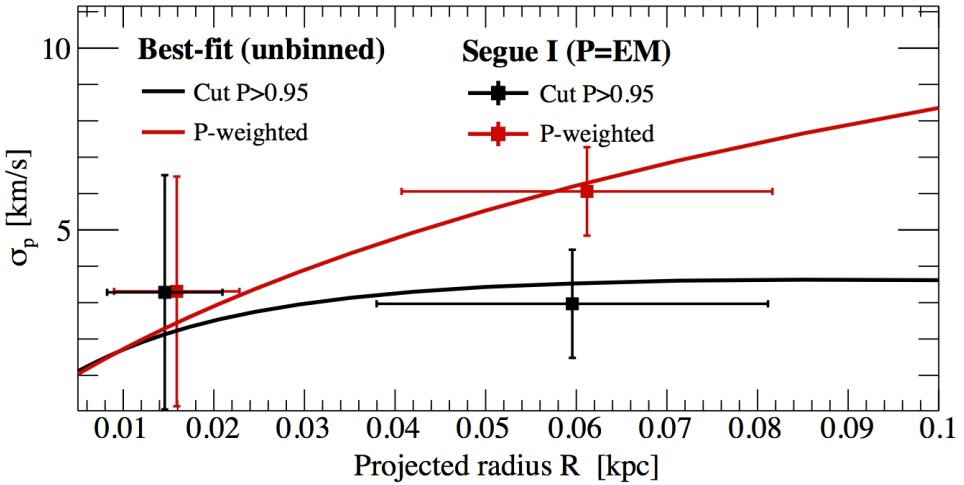
- The ultrafaint **Segue I** is often promoted as the « best target » among the dSphs.

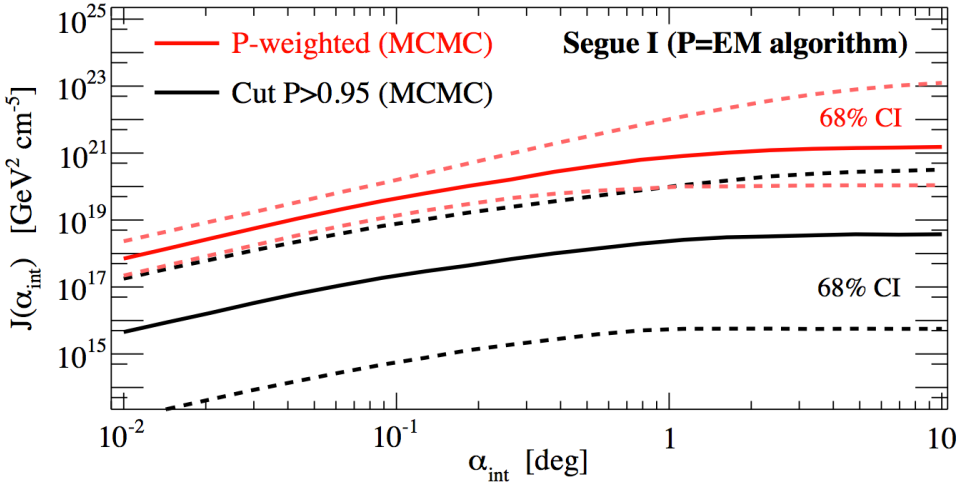
- However, its kinematic sample might be contaminated by Milky Way foreground stars.

→ 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! [Bonnivard et al., arXiv:1506.07628]

# CLUMPY Version_2015.06

Main Page | Related Pages | Namespaces | Classes | Files | Search

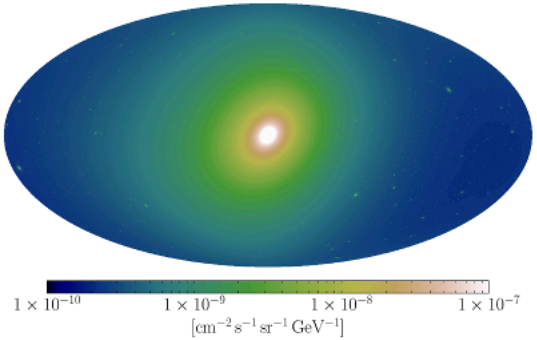
- CLUMPY
  - Introduction
  - Download / Installation instructions
  - Quick checks / examples
  - Contact, bug reports, ASCII files
- Namespaces
- Classes
- Files

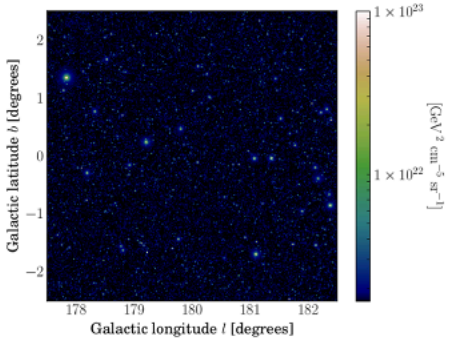
## CLUMPY Documentation

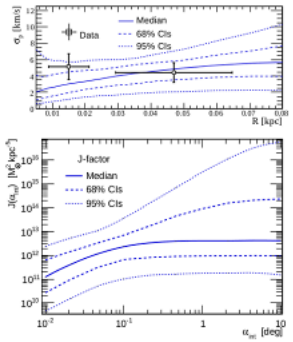
**If you use CLUMPY, please cite**
*Charbonnier, Combet, Maurin*, CPC 183, 656 (2012)
*Bonnivard, Hütten, Nezri, Charbonnier, Combet, Maurin* (2015arXiv150607628B)

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

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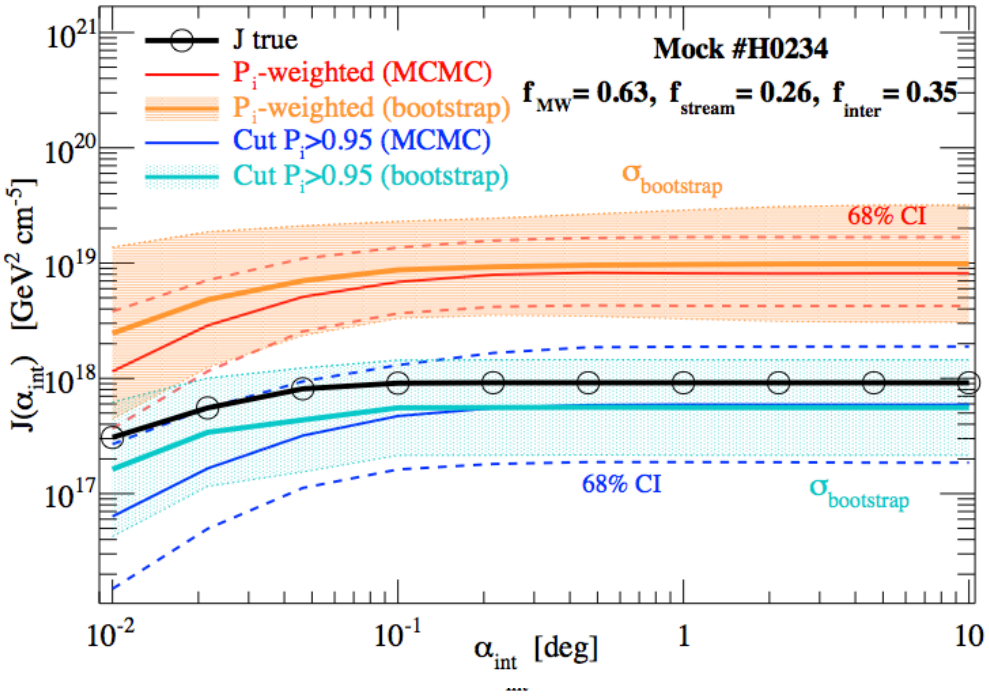
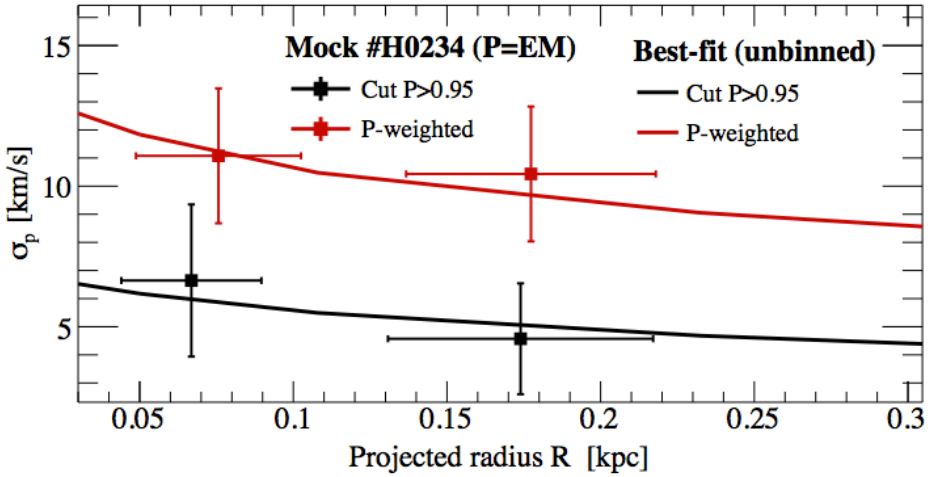
**09/2011 – First release (v2011.09)** – Charbonnier, Combet, Maurin, CPC 183, 656 (2012)
Hi guys! *[click here to access the doxygen documentation for this version]*

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

# Segue I

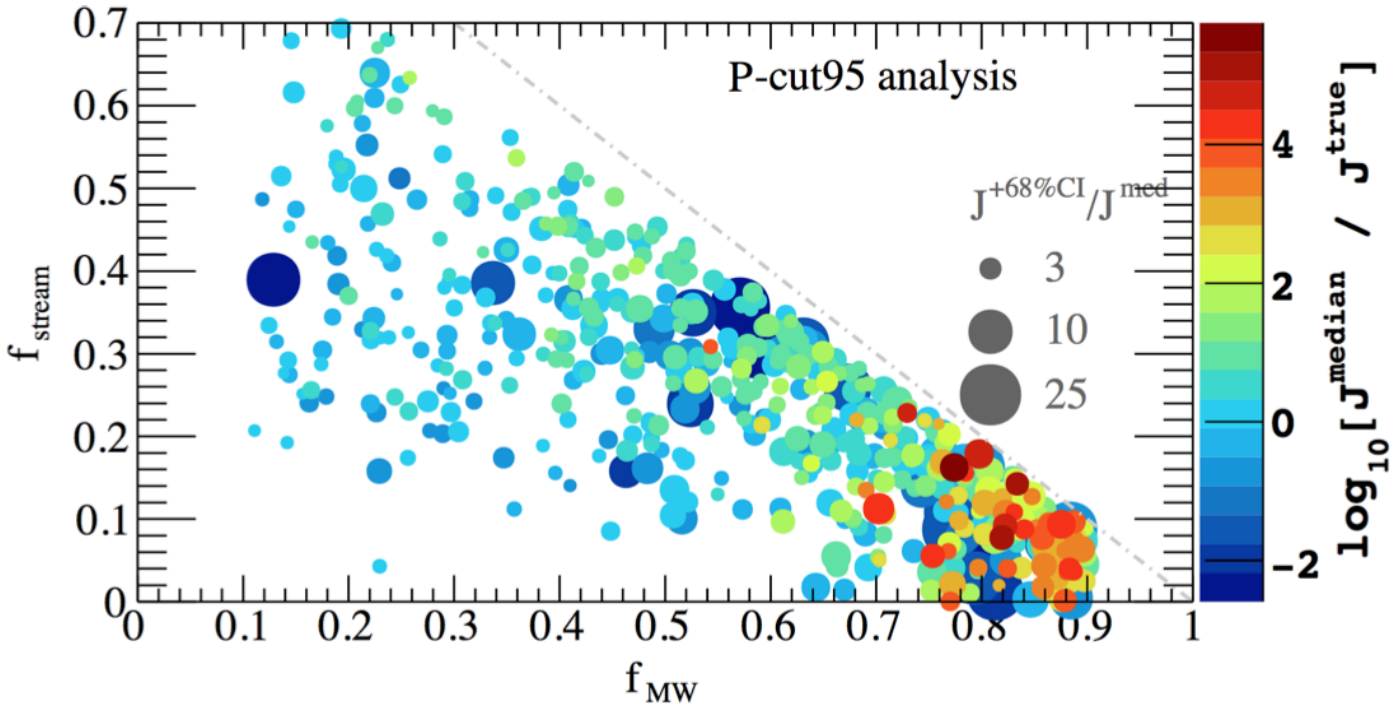



Mock contaminated dSph similar to Segue I

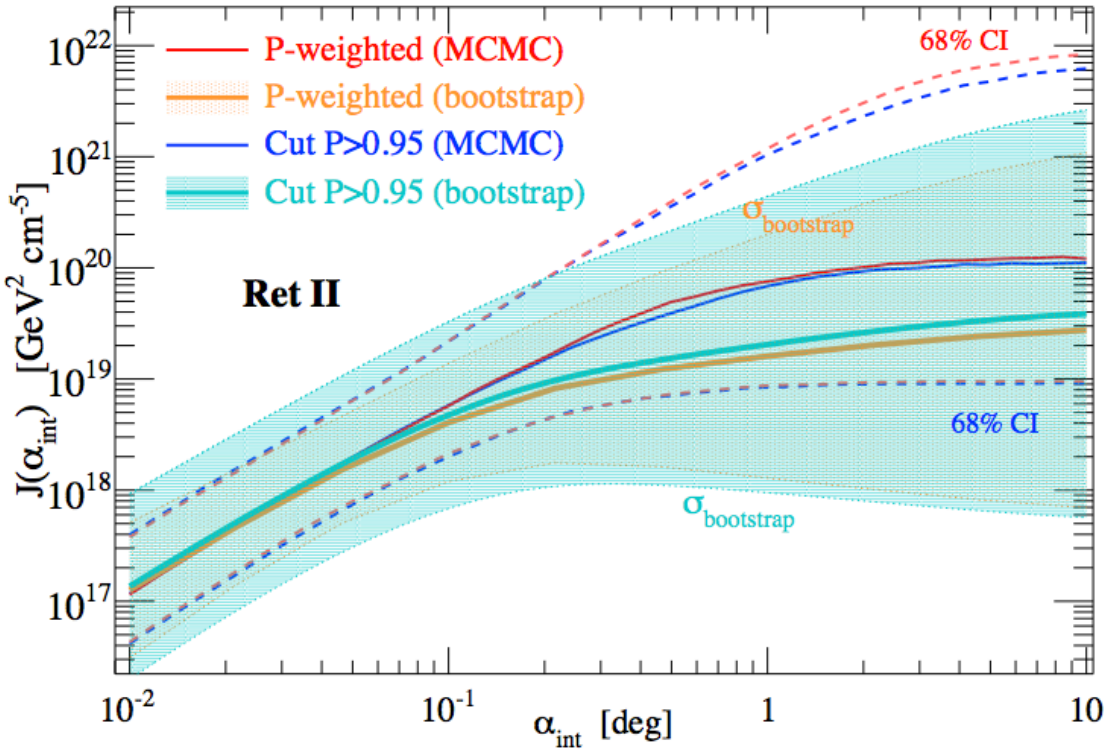
Velocity dispersion profile of the mock

# Segue I



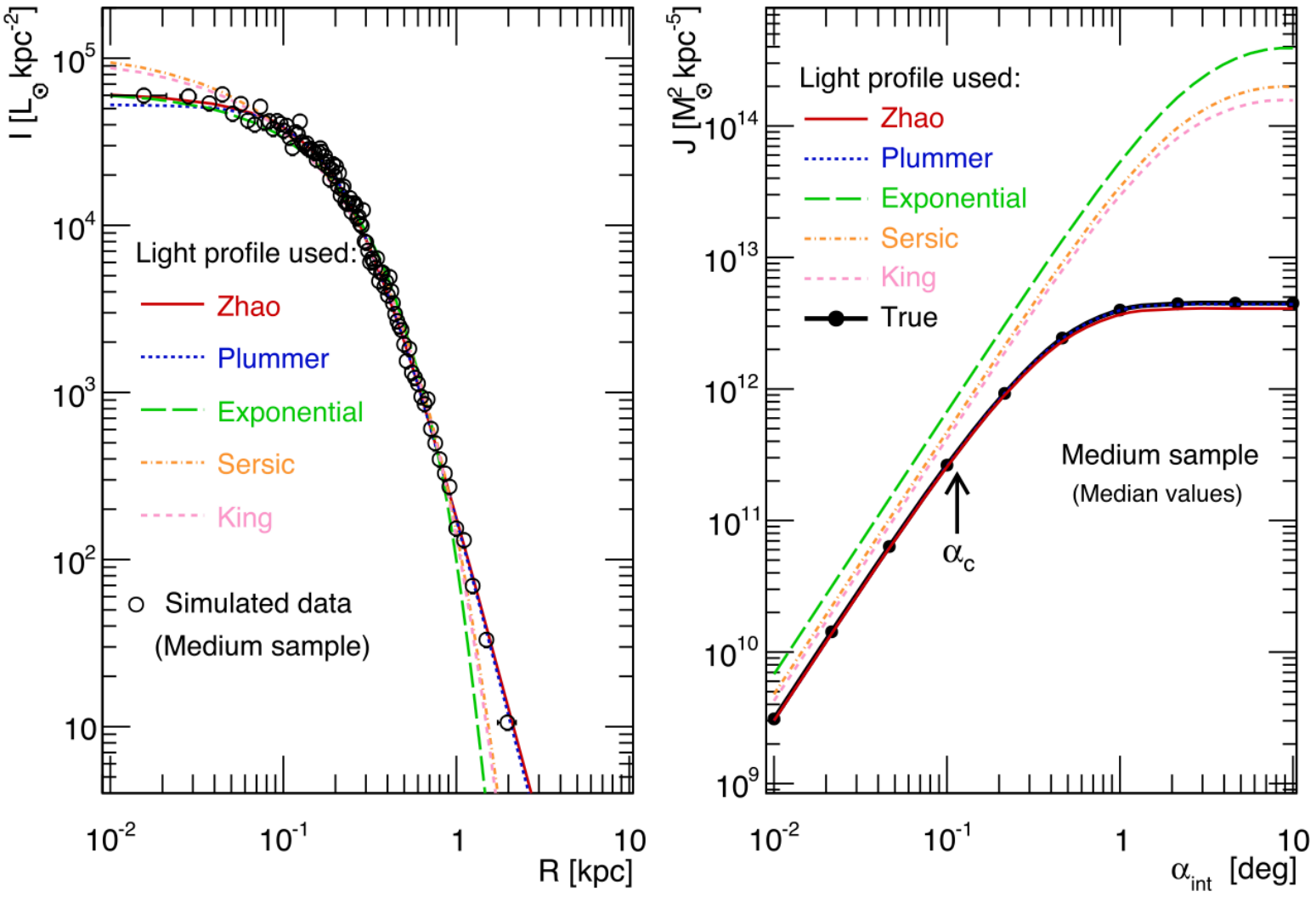

Impact of contamination on J-factor reconstruction

# Ret II



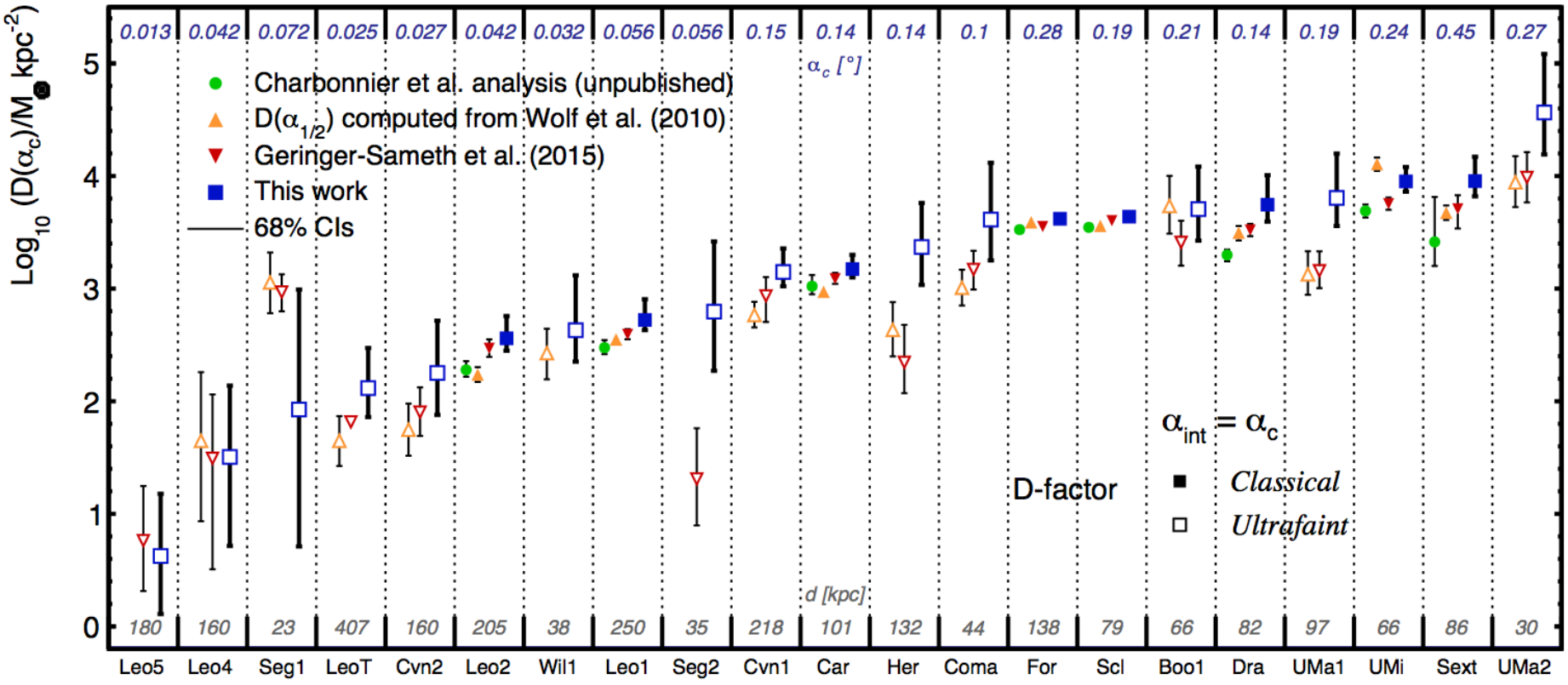
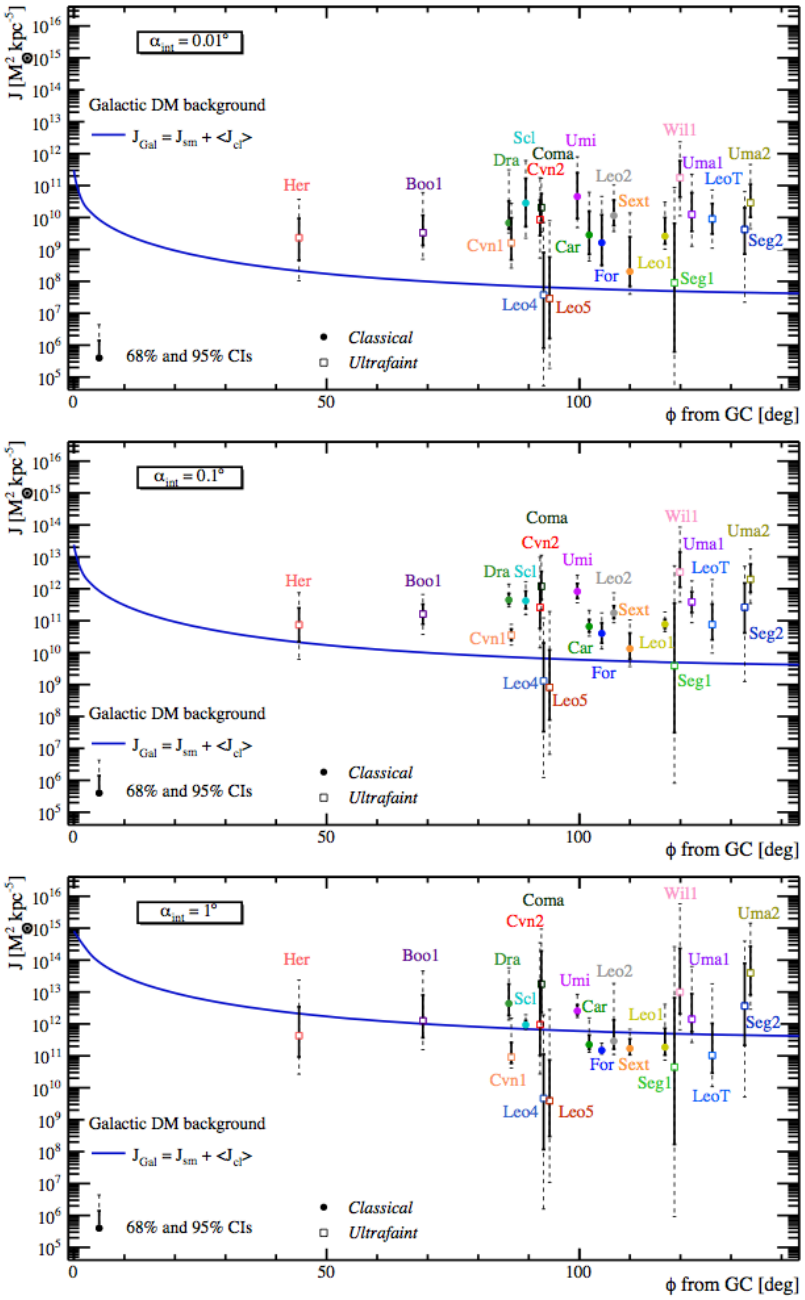

No impact of contamination on Ret II

# Light profile



# 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