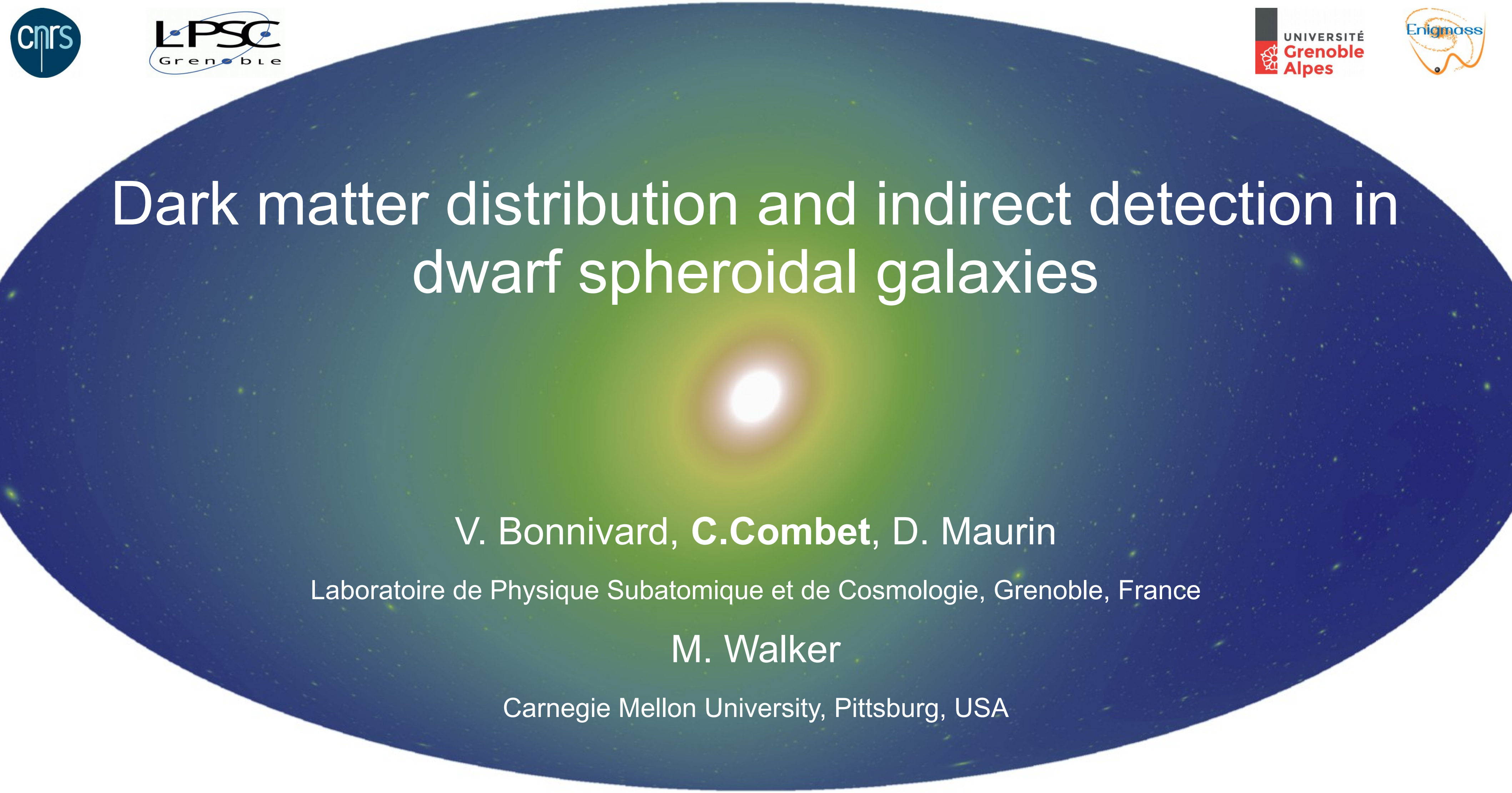

Dark matter distribution and indirect detection in dwarf spheroidal galaxies

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M. Walker

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Walker, Combet, Hinton et al., ApJL 733, 46 (2011)
Charbonnier, Combet, Daniel et al., MNRAS 418, 1526 (2011)
Bonnivard, Combet, Maurin et al., MNRAS 446, 3002 (2015)
Bonnivard, Combet, Daniel et al., MNRAS, 453, 849 (2015)
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Results produced with CLUMPY code
https://lpsc.in2p3.fr/clumpy/

Indirect detection in γ-rays and ν

The gamma or neutrino flux in given by:

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

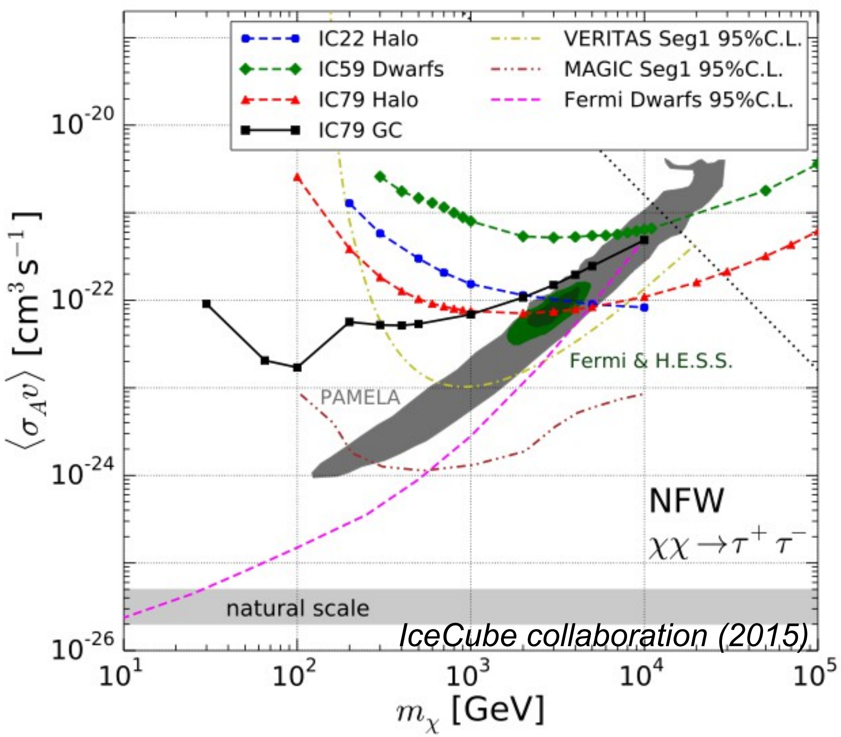
Particle physics

Astrophysics

m $_{WIMP}$ ~ 10 GeV – 100 TeV

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

$$J(\psi, \theta, \Delta\Omega) = \int_0^{\Delta\Omega} \int_{\rm l.o.s} \rho^2(l(\psi, \theta))\ dl\, d\Omega$$



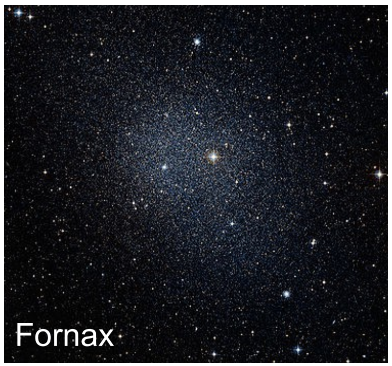
Detection or non-detection

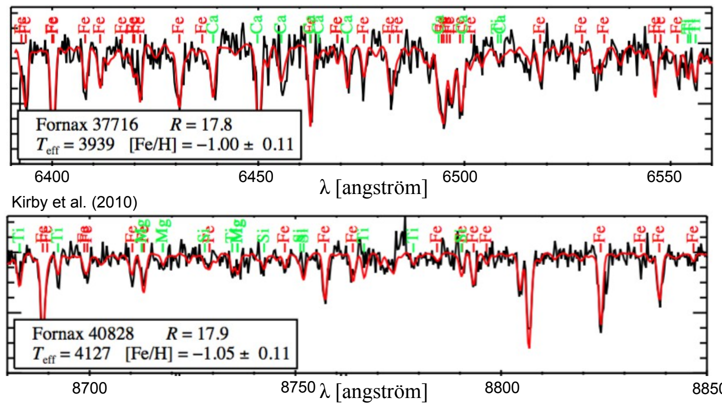
J value and uncertainty must be well-known to put constraints on DM candidate

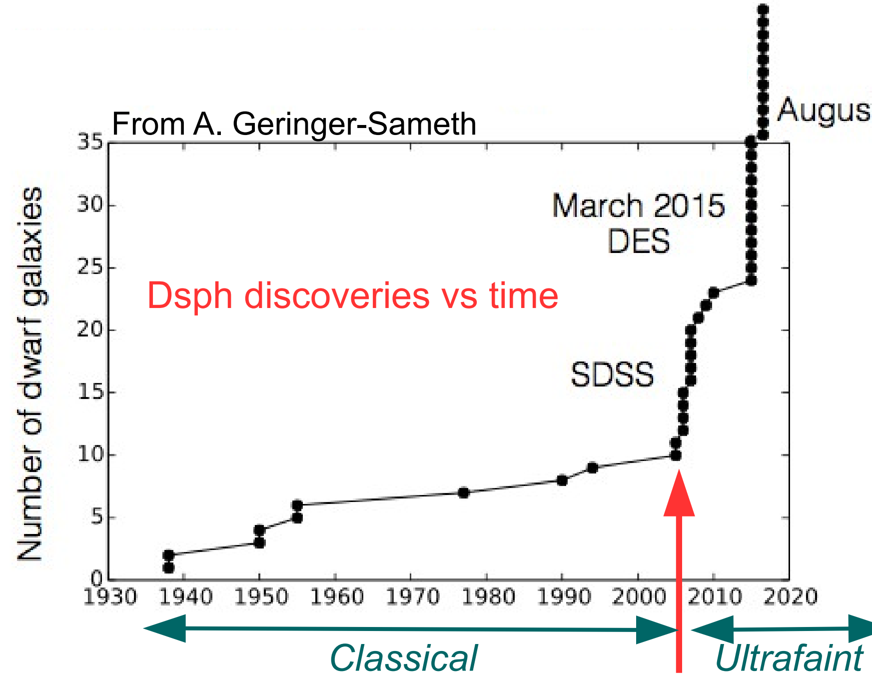
Signal depends crucially on DM distribution

Dwarf spheroidal galaxies

Observables







Photometry → Luminosity profile *I(R)*

Spectroscopy → Dynamics, Velocity dispersion $\sigma^2(R)$

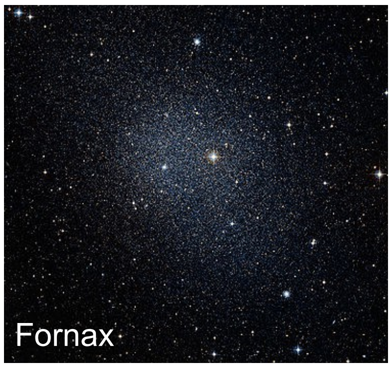
***8 classical* dSph galaxies**: brightest, discovered prior to SDSS, ~ 1000 spectroscopic measurements

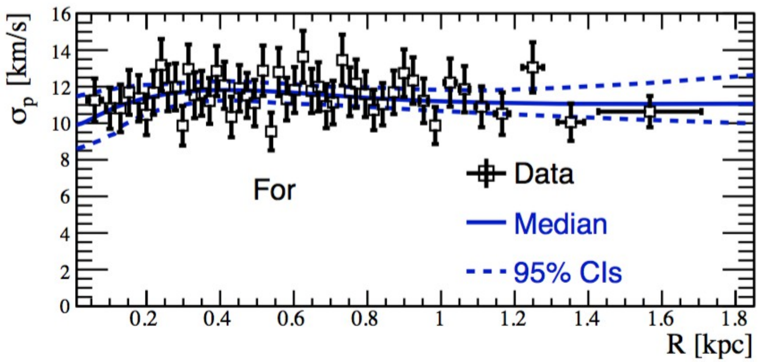
***Ultrafaint* dSph galaxies**: SDSS, DES → a few to 10s of stellar spectra

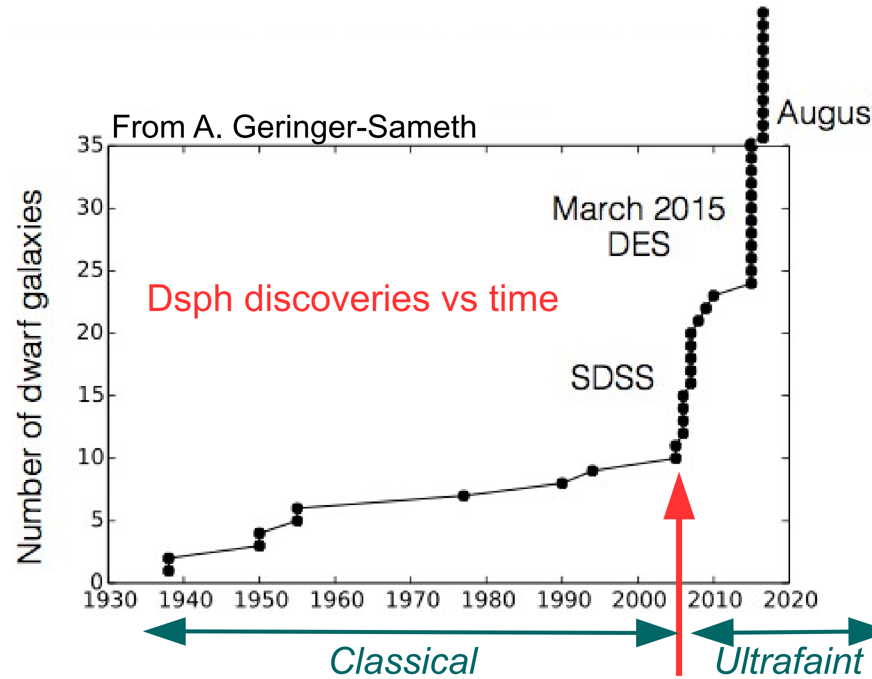
Use kinematics to infer the DM content of these objects

Dwarf spheroidal galaxies

Observables







Photometry

↓

Luminosity profile
I(R)

Spectroscopy

↓

Dynamics
Velocity dispersion $\sigma^2(R)$

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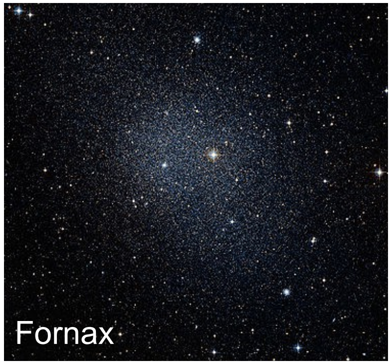

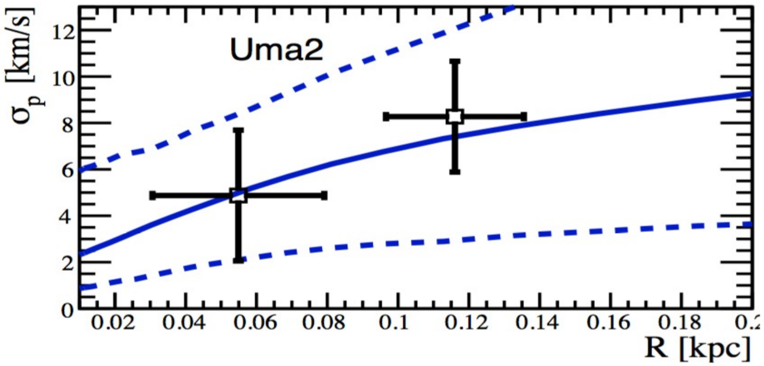

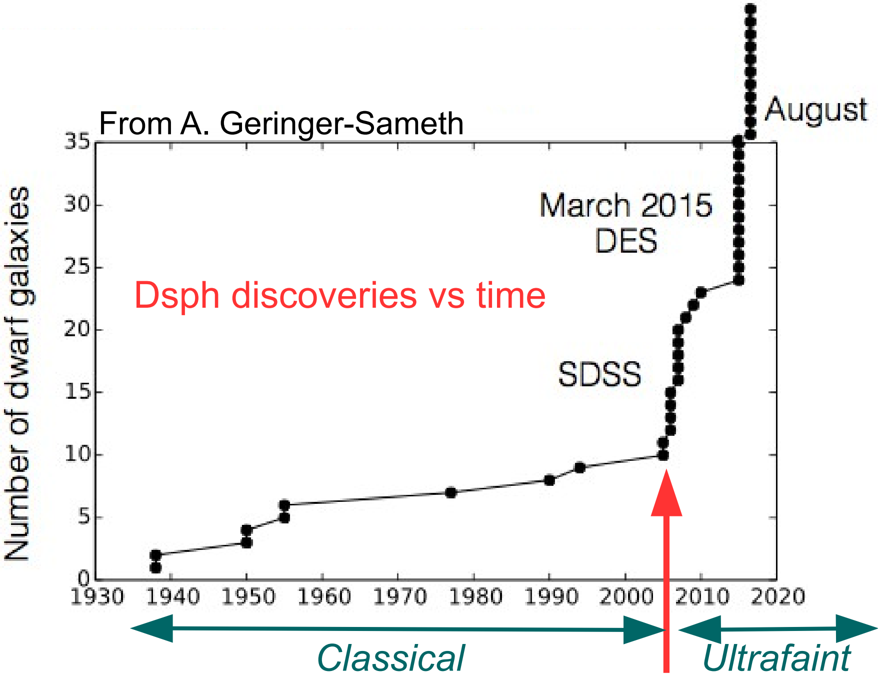

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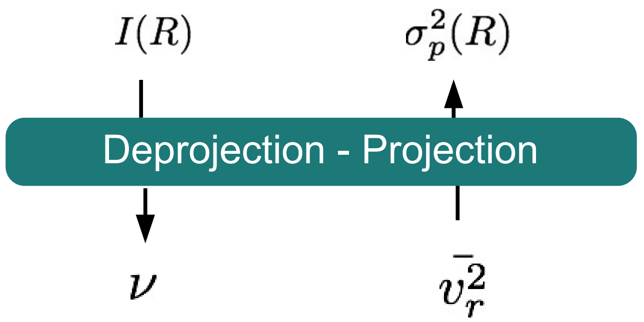
Use kinematics to infer the DM content of these objects

From stellar kinematics to DM profile

- **Light profile and velocity dispersion**



- **Jeans equation: solve for $\bar{v_r^2}$**

Anisotropy $\beta_{\rm ani} = 1 - \bar{v_\theta^2}/\bar{v_r^2}$

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

Enclosed mass

$$M(r) = \int_0^r 4\pi s^2 \rho(s) ds$$

- **Dark matter profile, e.g. Zhao profile**

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

$\rho_s,\ r_s,\ \alpha,\ \beta,\ \gamma,$ (and $\beta_{\rm ani}$)

From stellar kinematics to DM profile

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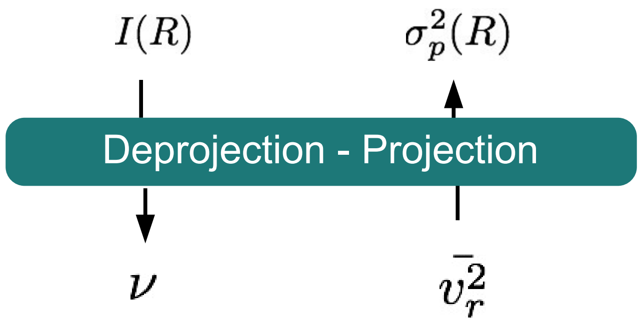

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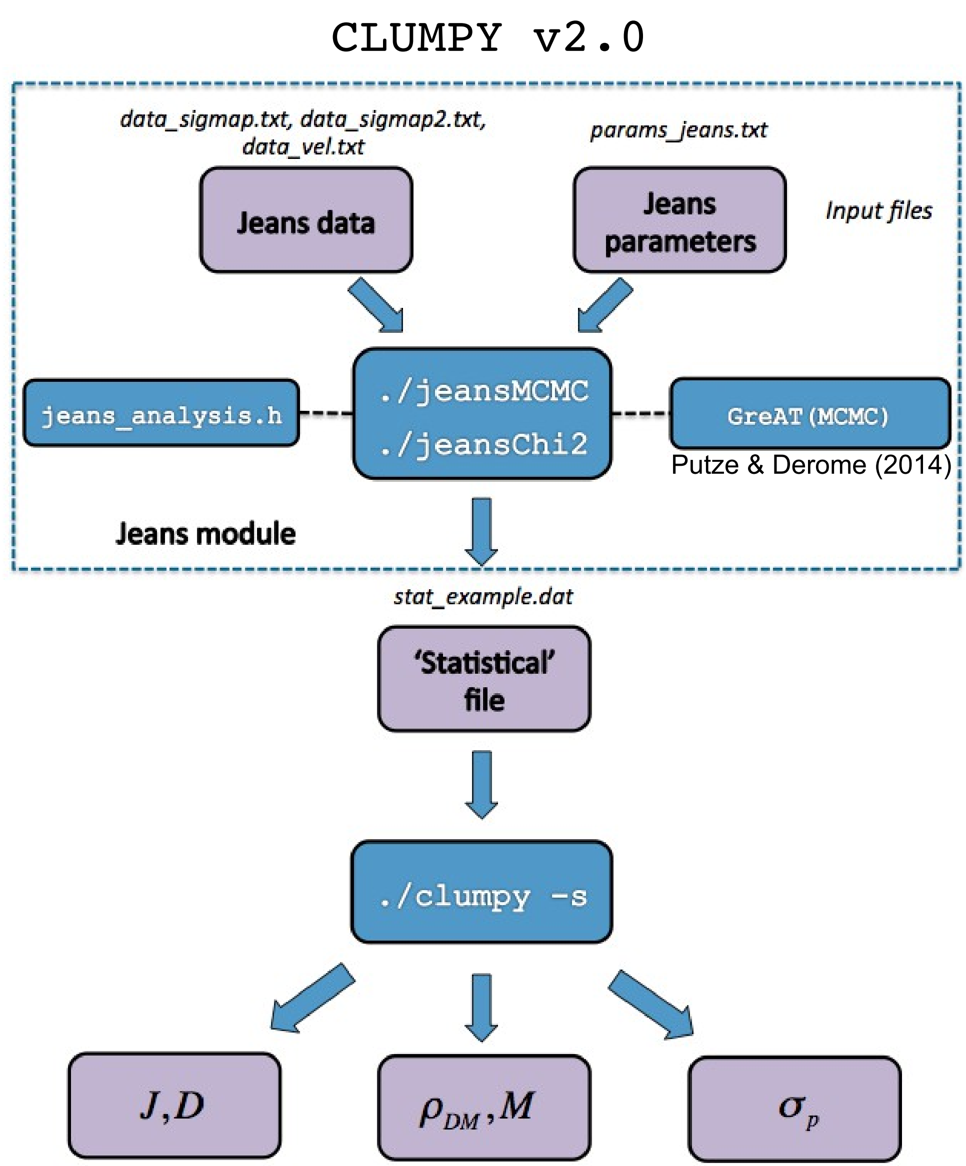
ρ_s, r_s, α, β, γ, (and $\beta_{\rm ani}$)



From stellar kinematics to DM profile

- **Light profile and velocity dispersion**

$I(R)$ → **Deprojection - Projection** → ν

$\bar{v_r^2}$ → **Deprojection - Projection** → $\sigma_p^2(R)$

- **Jeans equation: solve for $\bar{v_r^2}$**

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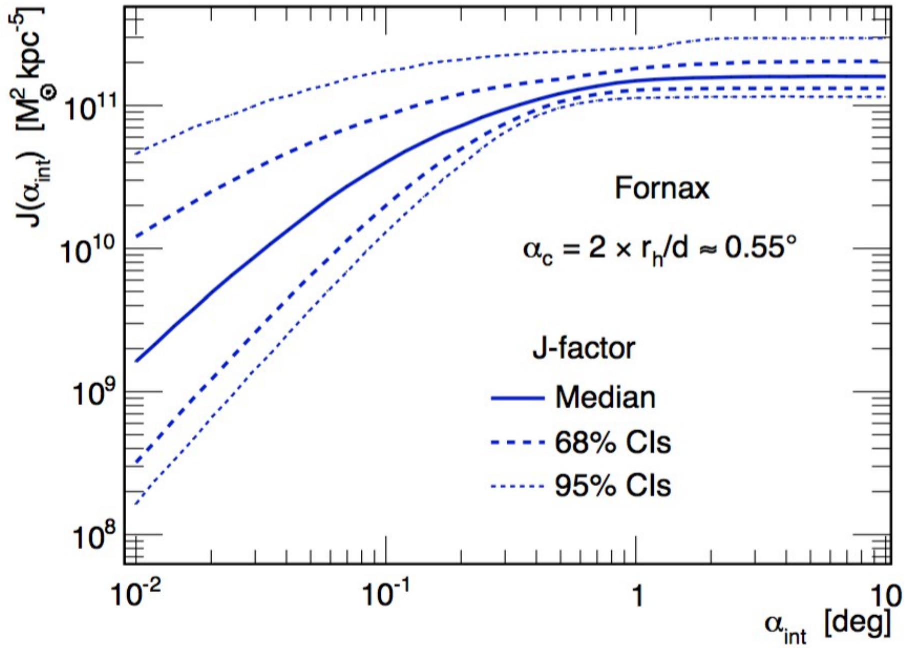

Jeans + MCMC analysis assumes

- Spherical symmetry
- Light profile parametrisation
- Anisotropy parametrisation
- DM profile parametrisation

+ choice of likelihood (binned or unbinned)

Use simulations to find the "best" configuration (unbiased, robust error bars)

Apply "optimised" setup to real data

Mock dSph data

		Walker et al. (2011) Charbonnier et al. (2011)	"Gaia Challenge"	
	Mock data	Spherical*	Spherical$^{\circ}$	Triaxial†
98 models	# of models	64	32	2
DM profile	γ	$[0, 1]$	$0 - 1$	$0.23 - 1$
	r_s [kpc]	$[0.2, 1]$	1	1.5
Light profile	γ^*	$[0, 0.7]$	$0.1 - 1$	0.23
	r_s^* [kpc]	$[0.1, 1]$	$[0.1, 1]$	0.81
Anisotropy	$\beta_{\rm ani}$ profile	Cst	Cst+Osipkov	Baes & van Hese

Mock dSph data

Walker et al. (2011)
Charbonnier et al. (2011) — "Gaia Challenge"

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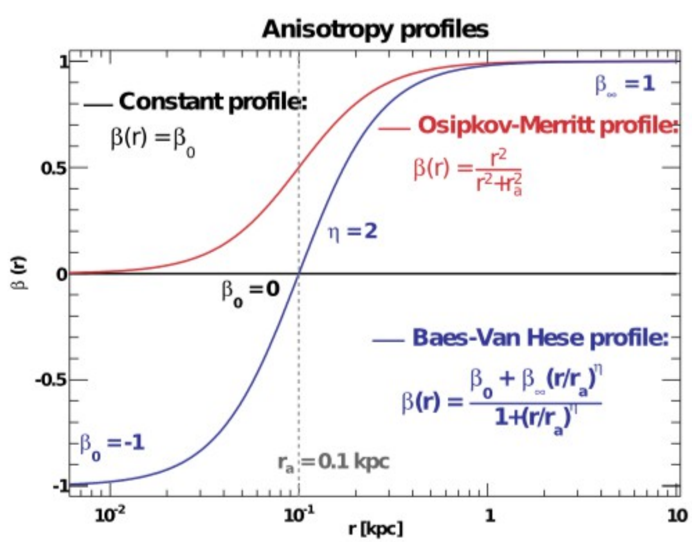
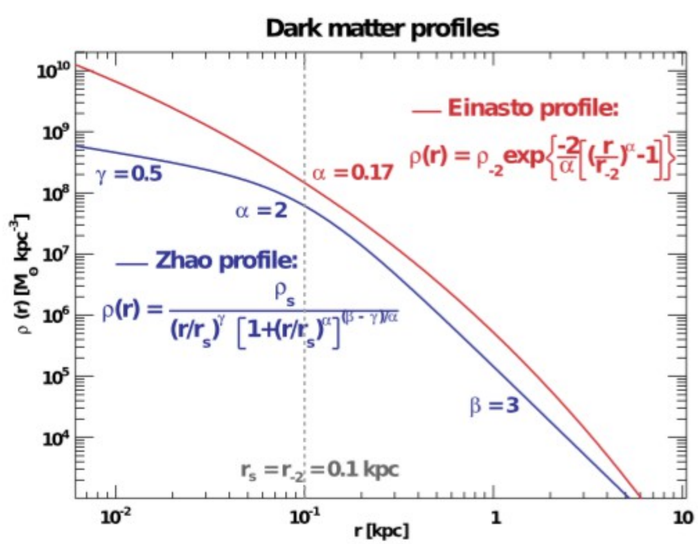
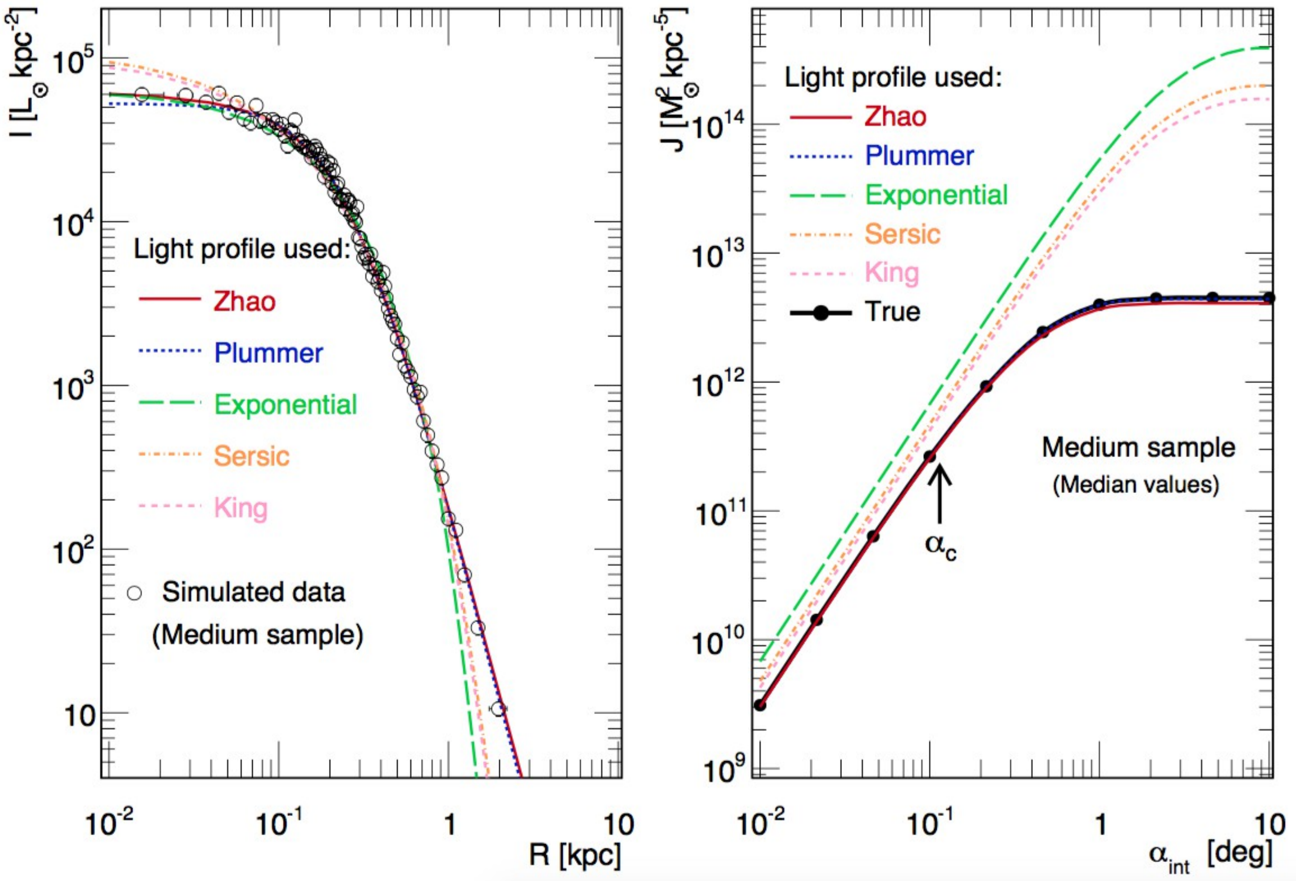




- True J-factors are known for all mock dSph galaxies
- Run analysis on all mock dSphs allowing for fits with the “wrong” parametrisations

How are the reconstructed J-factors affected?

Mock dSph data: light profile



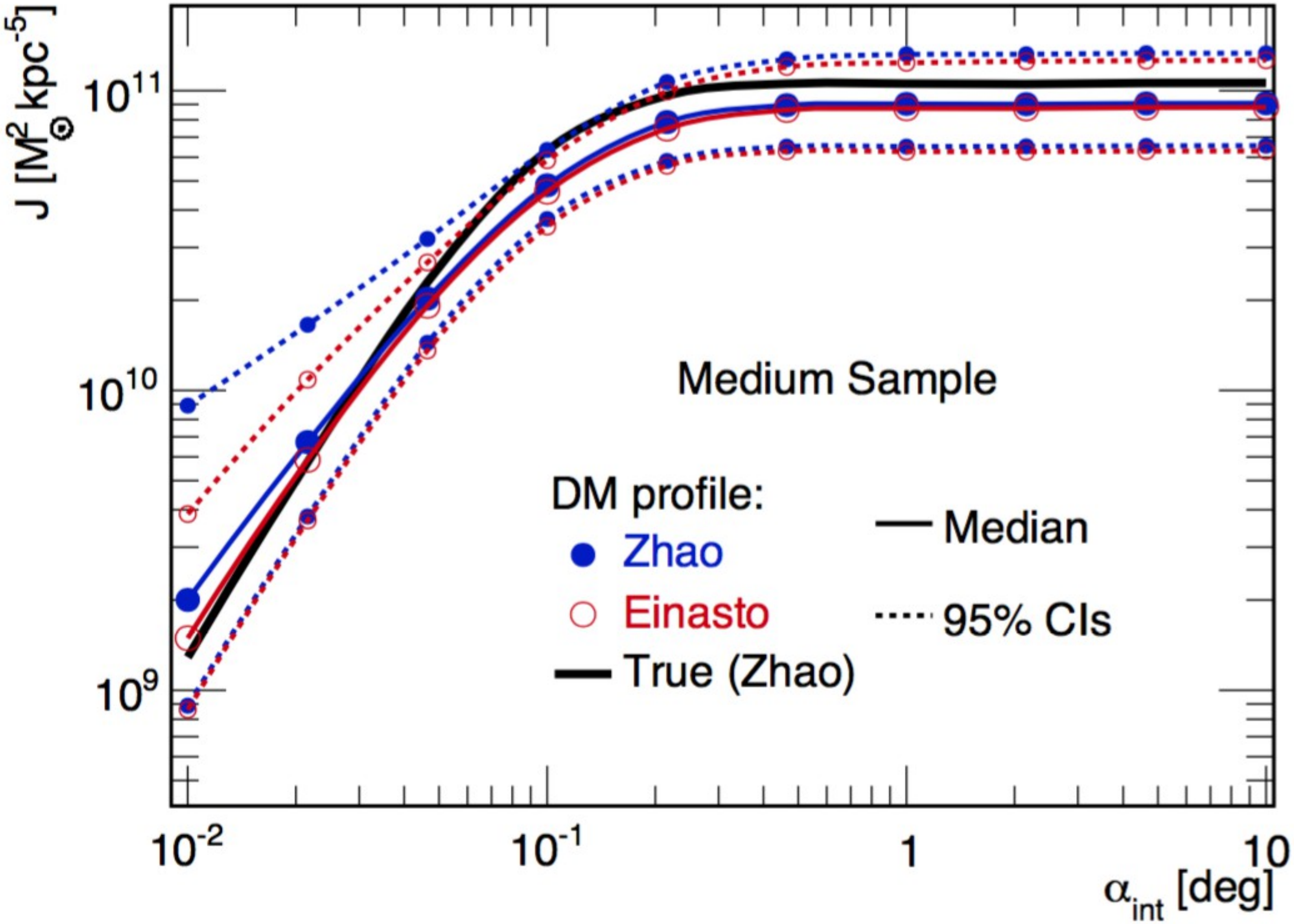
Choice of light profiles:

- Zhao (5 parameters)
- Sersic, King (3 parameters)
- Plummer, Exp (2 parameters)

Undershooting I(R) at large radii → bias in J-factor ⚠

Select Zhao parametrisation as more flexible to describe the light profile

Mock dSph data: DM profile



Choice of DM profiles:

- Zhao (5 parameters)
- Einasto (3 parameters)

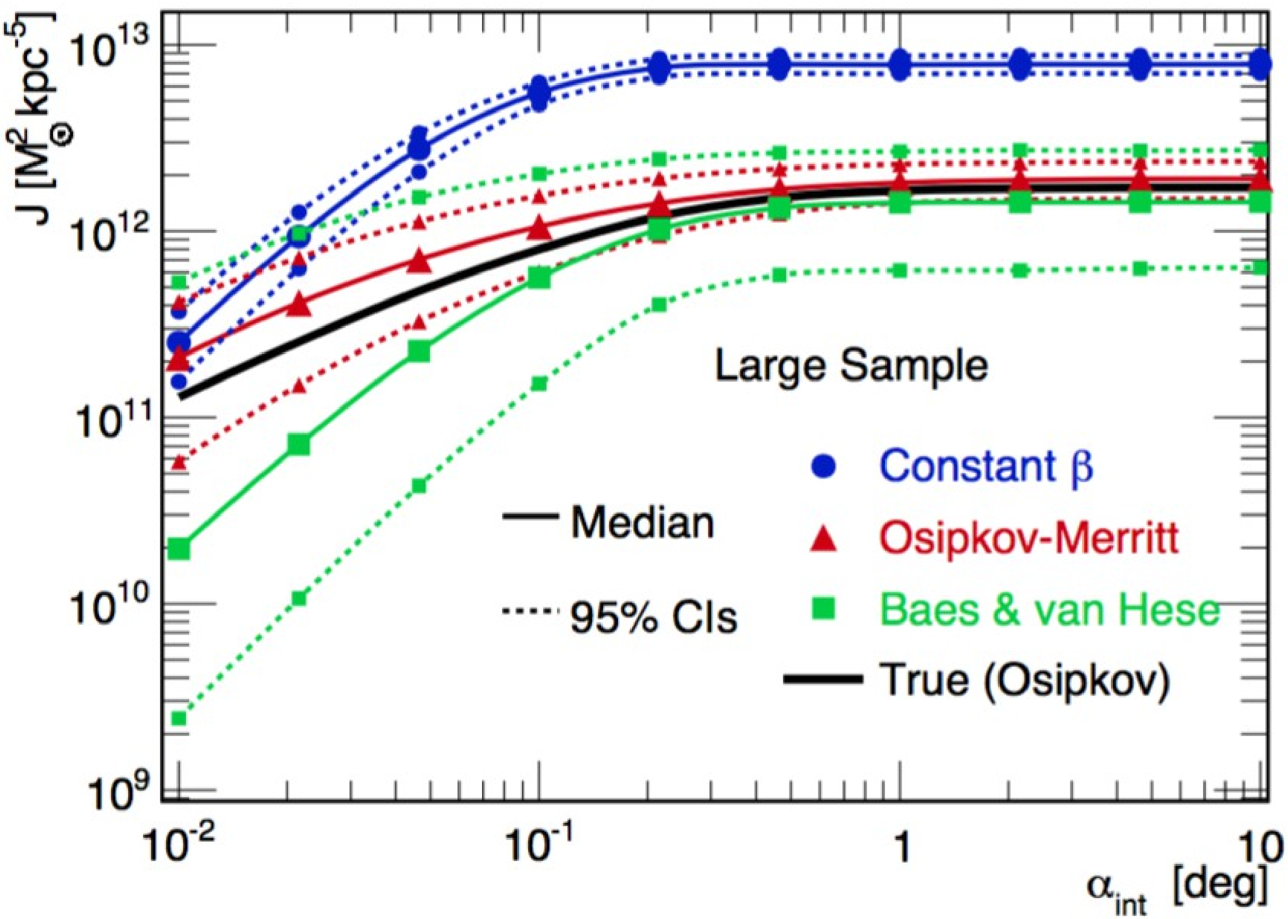
⬇

Median value + CIs are not affected by the parametrisation

Independent on sample size

Select Einasto parametrisation as less free parameters → Speed-up MCMC

Mock dSph data: anisotropy profile



Choice of anisotropy profiles:

- Constant (β_0, 1 parameter)
- Osipkov-Merritt (β(r), 1 parameter)
- Baes (β(r), 4 parameters)

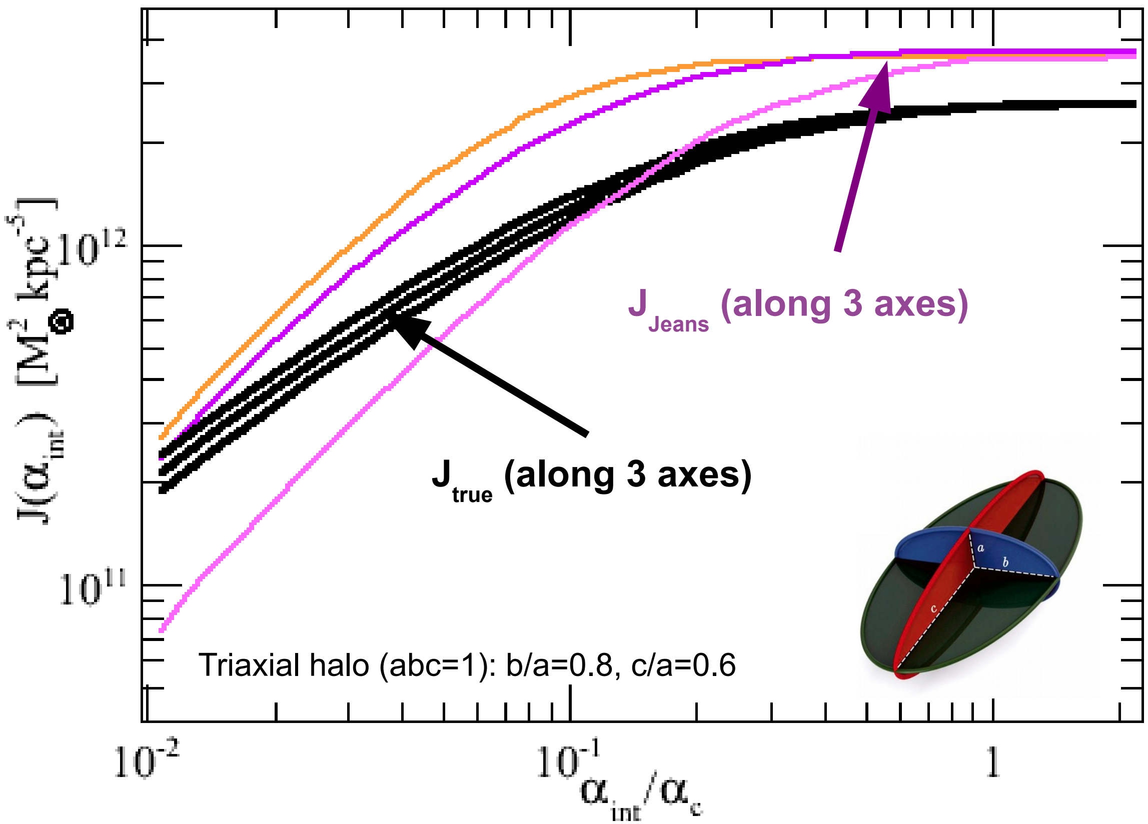
'Bad' anisotropy choice
→ bias in J-factor ⚠

NB: Less critical for ultrafaint dSphs
→ larger error bars encompass the 'true' value

For classical dSphs, use Baes & van Hese anisotropy profile (but time consuming)

For ultrafaint dSphs, constant anisotropy profile suffices (and runs much faster)

Mock dSph data: triaxiality



Simulations → DM halos are triaxial

Observations → signs of ellipticity

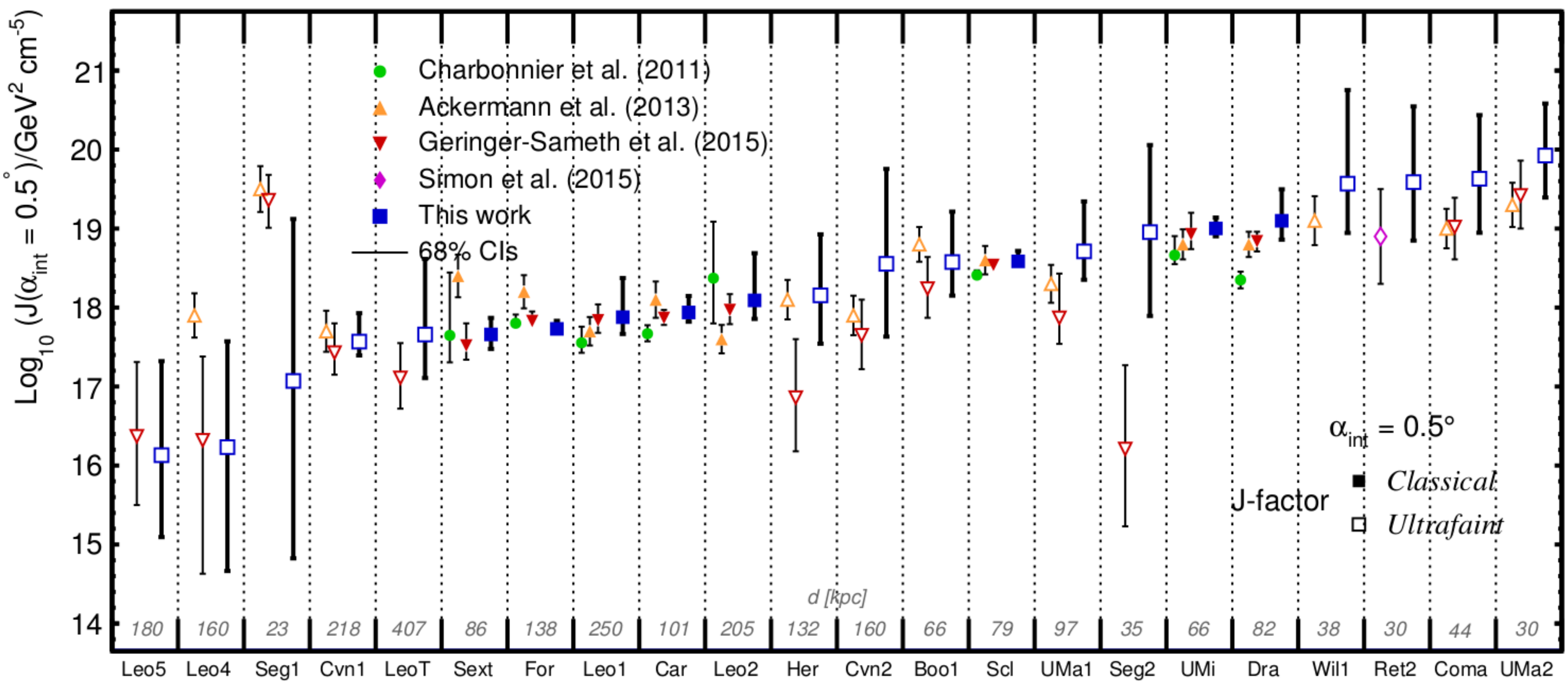
1) Known triaxility parameters but unknown orientation
   → 30% uncertainty (minimum) ⚠

2) Spherical Jeans analysis on triaxial mock data
   → Bias reconstructed J-factor
   → True value not necessarily encompassed in 95% CIs.

Cannot do much about it as dSphs actual shapes and orientations are unknown…

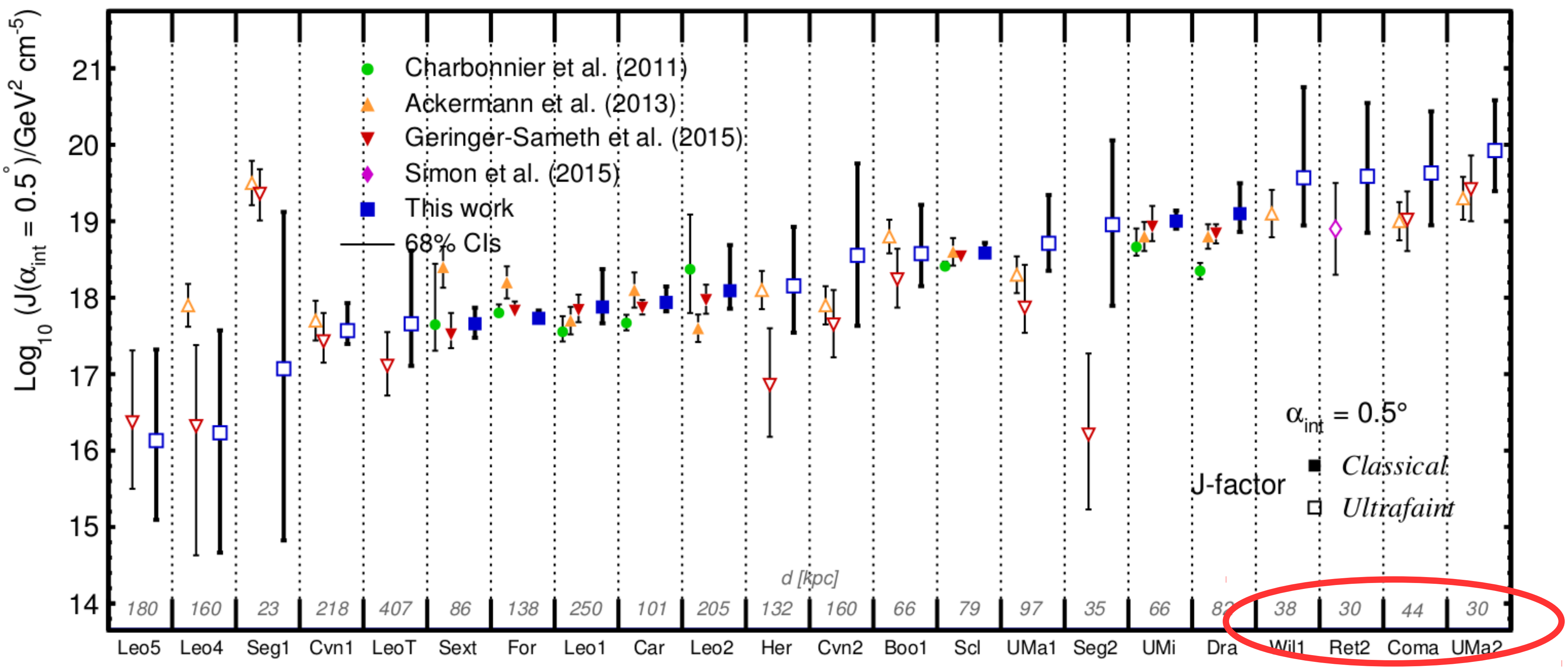
So, keep working assuming spherical symmetry but consider a ~ 30% extra systematic error in the error budget

Application to real dSphs – J(0.5°)



- **Larger error bars to ultrafaint dSph.** Not necessarily the case depending on the analysis (e.g. yellow triangles).

Application to real dSphs – J(0.5°)



- **Larger error bars to ultrafaint dSph.** Not necessarily the case depending on the analysis (e.g. yellow triangles).
- **Distance is the main driver** – the largest J-values belong to the closest objects.

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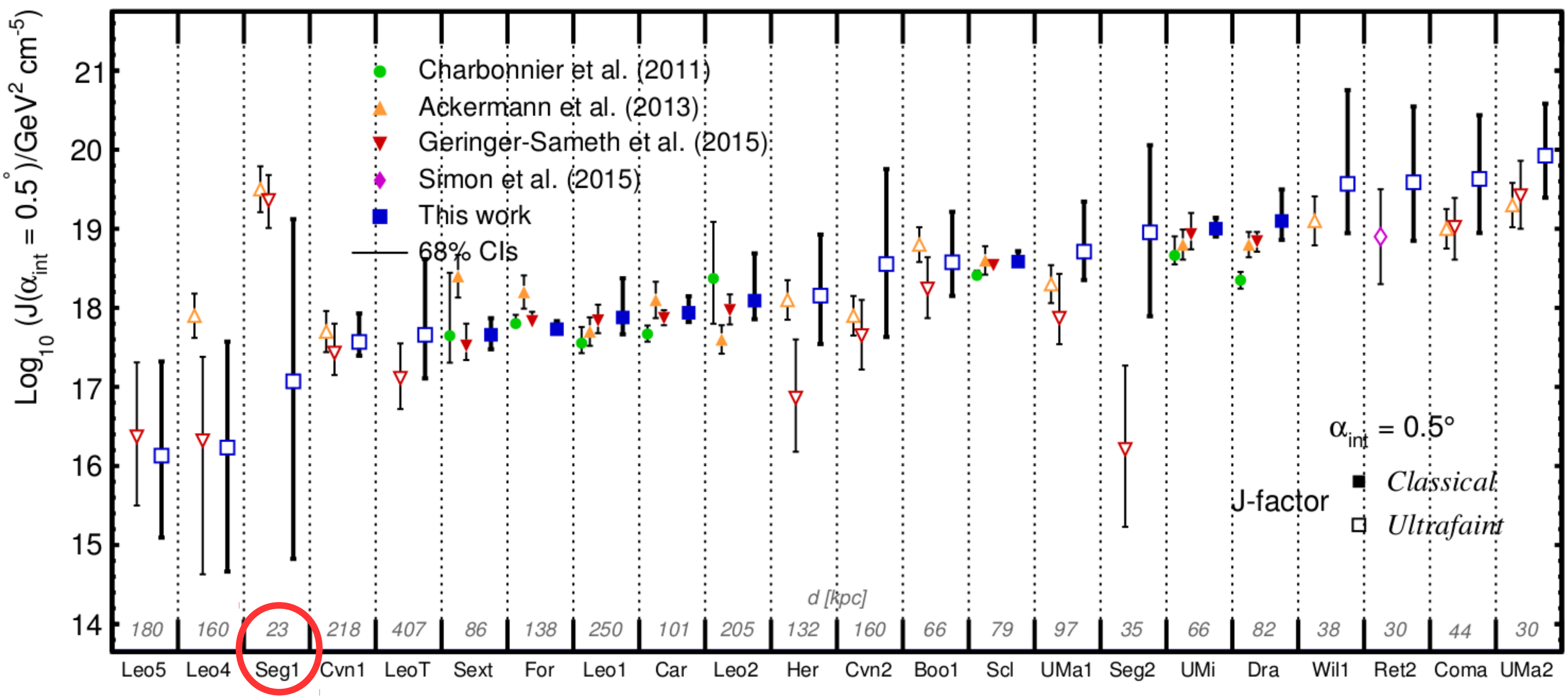


- **Larger error bars to ultrafaint dSph.** Not necessarily the case depending on the analysis (e.g. yellow triangles).
- **Distance is the main driver** – the largest J-values belong to the closest objects.
- **Segue I** is found to be **very uncertain**, possibly suggesting stellar contamination (ongoing work...).

Conclusions

- Jeans analysis tested on variety of mock dSph galaxies
  → **Choosing the “right” parametrisations is crucial**

- Definition of an **optimised setup for the Jeans analysis** on mock data
  → minimum bias
  → robust errors bars

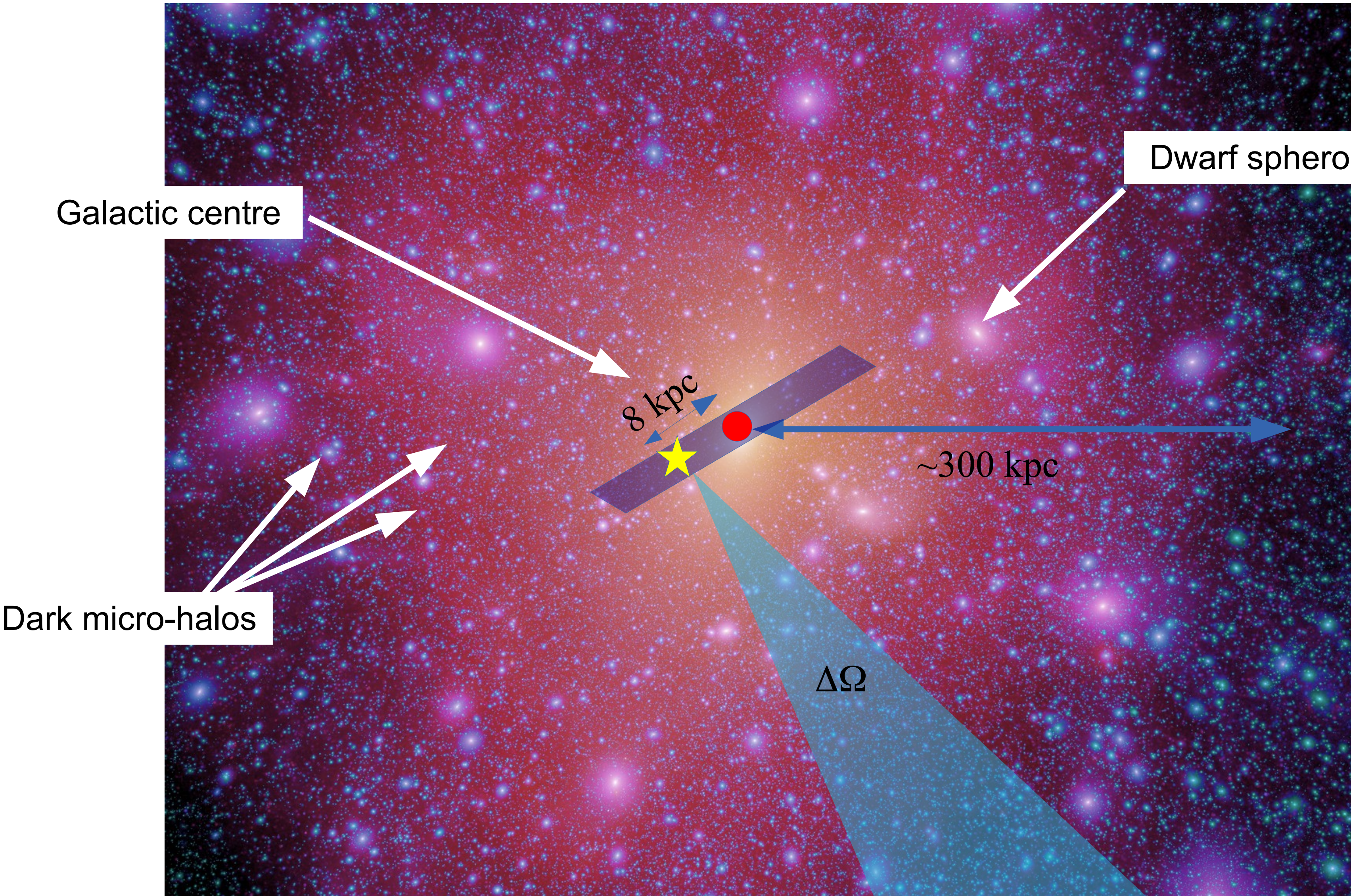
- **Application to 22 (classical and ultrafaint) dSph galaxies**
  → J-factors (annihilation and decay) with robust error bars
  → Ursa Minor and Draco are the best 'safe' targets
  → Coma and Ursa Major 2 are more uncertain but possibly more promising
  → Segue 1 is very uncertain – possible stellar contamination

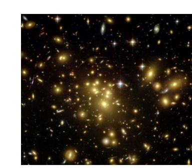
- More dSph galaxies recently discovered in DES
  → Reticulum 2 and Triangulum 2 could prove particularly interesting

Indirect detection in γ-rays and ν

Where to look?

Dense ($\sim \int \rho^2$) – Close ($1/d^2$) – No astrophysical background





Aquarius simulation – Springel et al. (2008)