J- and D- factors determination

BAM

WORKSHOP **Barolo**
Astroparticle Meeting
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INFN

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Sezione di Roma

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HOW MUCH PRECISELY CAN WE DETERMINE *J* IN DSPHS?

MNRAS 453 (2015) 849-867

2015 *Bonnivard, V. et al.*

Quantity	Profile	Parameter	Prior range
DM density	'Einasto' equation (5)	$\log_{10}(\rho_{-2}/\mathrm{M}_\odot\ \mathrm{kpc}^{-3})$	[5, 13]
		$\log_{10}(\mathrm{r}_{-2}/\mathrm{kpc})$	$[\log_{10}(r_s^*), 1]$
		α	[0.12, 1]
Anisotropy	'Baes & van Hese' equation (6)	β_0	[-9, 1]
		β_∞	[-9, 1]
		$\log_{10}(r_a)$	[-3, 1]
		η	[0.1, 4]

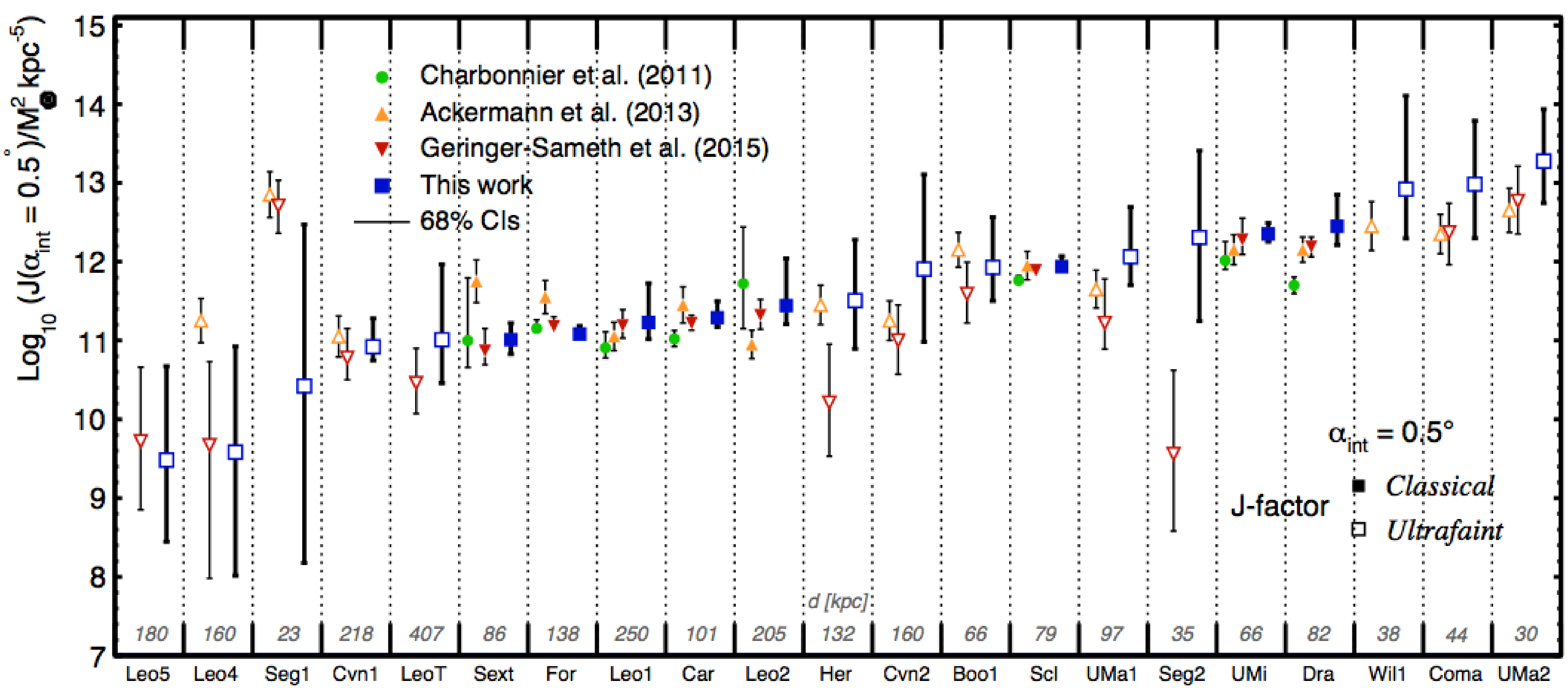
Einasto DM profile

Hernquist-Zhao stellar profile

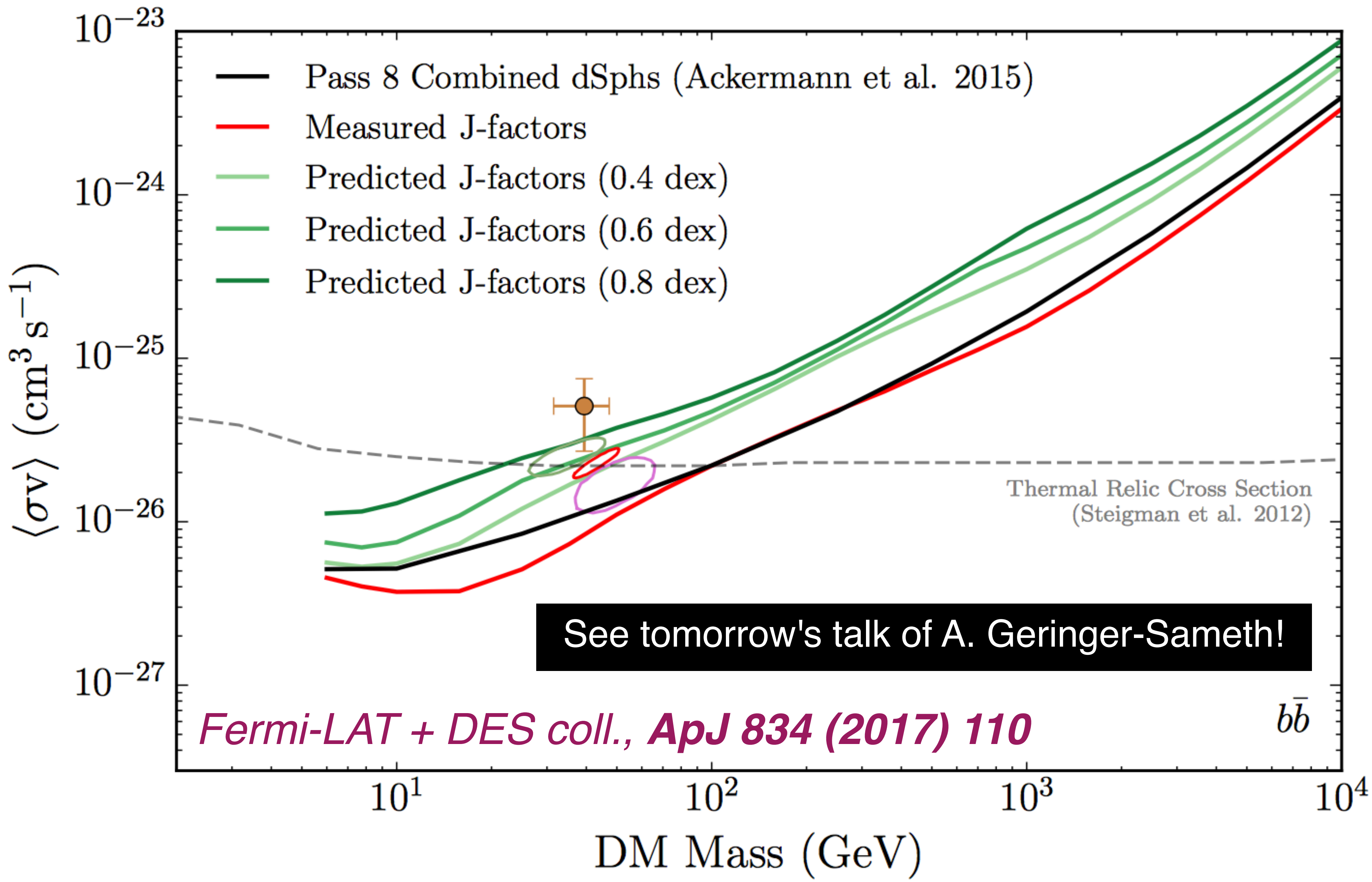
Baes & van Hese anisotropy

$$\beta(r) = \frac{\beta_0 + \beta_\infty (r/r_a)^\eta}{1 + (r/r_a)^\eta}$$

+ phase-space positivity



In light of DES discovery of new Ultra-faint dwarfs, most recent reappraisal of DM particle constraints from gamma-ray observation of MW dwarf satellites:



NOTE: the "measured" J-factors from *Geringer-Sameth et al. '15* include Ultra-faints with (somewhat) smaller errors than what has been found by *Bonnivard et al. '15*. Triaxial systematics not considered!

ROOM FOR MORE CONSERVATIVE / RELIABLE LIMITS! (8 CLASSICALS + Cvn I)

Possible challenges/subtleties even in study of the 8 Classicals!

Different stellar profiles may fit adequately well surface brightness data!

2-PARAMETER MODELS

Plummer, Exponential

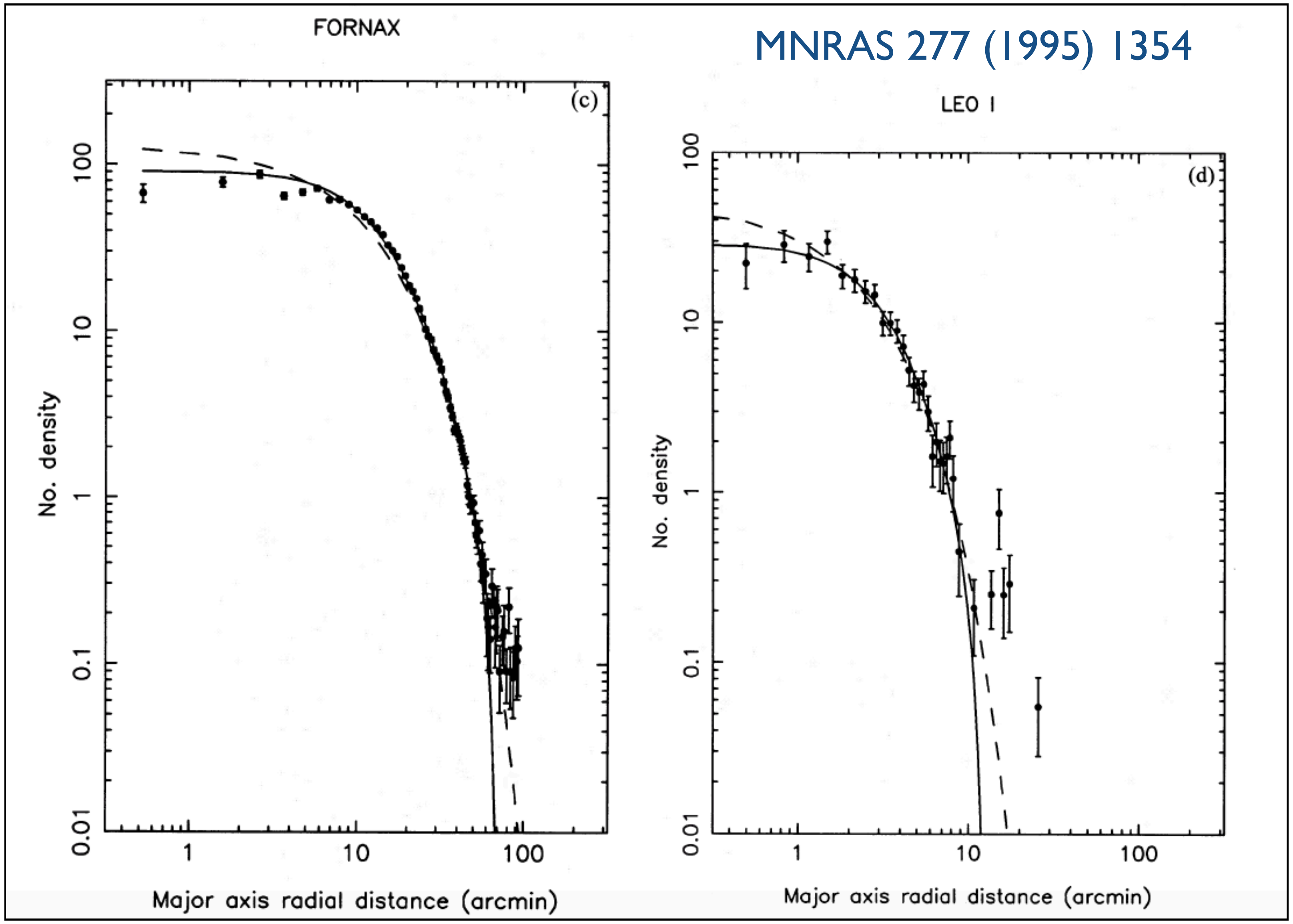
> 2-PARAMETER MODELS

King, Sérsic, Hernquist-Zhao

Slight preference for cored star profiles in the `95 photometric compilation for MW Classicals.

M.Irwin & D.Hatzidimitriou

MNRAS 277 (1995) 1354



URSA MINOR

$\mathcal{D}$ $[kpc]$	66 ± 3	77 ± 4	76 ± 3
$R_{1/2}$ $[kpc]$	0.280 ± 15	0.445 ± 44	0.181 ± 27
adopted, e.g., in:	Walker et al. '09	Wolf et al. '10	Geringer-Sameth et al. '15

J (D) -FACTOR DETERMINATION DEPENDS ON DISTANCE + PHOTOMETRIC DATA!

NOTE: systematics present also in $V_{1/2}$ vs $r_{1/2}$ plot of the Too-Big-To-Fail.

Possible challenges/subtleties even in study of the 8 Classicals!

—> binning of kinematic data may introduce some bias also in the case of the Classicals.

Charbonnier, A. et al. *, **MNRAS 418 (2011) 1526***

$$-2\ln\mathcal{L} = \sum_i^{N_*} \frac{\left(v_{los}^{(obs)}(R_i) - \overline{v_{los}}\right)^2}{\left(\delta v_{los}^{(obs)}(R_i)\right)^2 + \left(\sigma_{los}^{(pred)}(R_i)\right)^2}$$

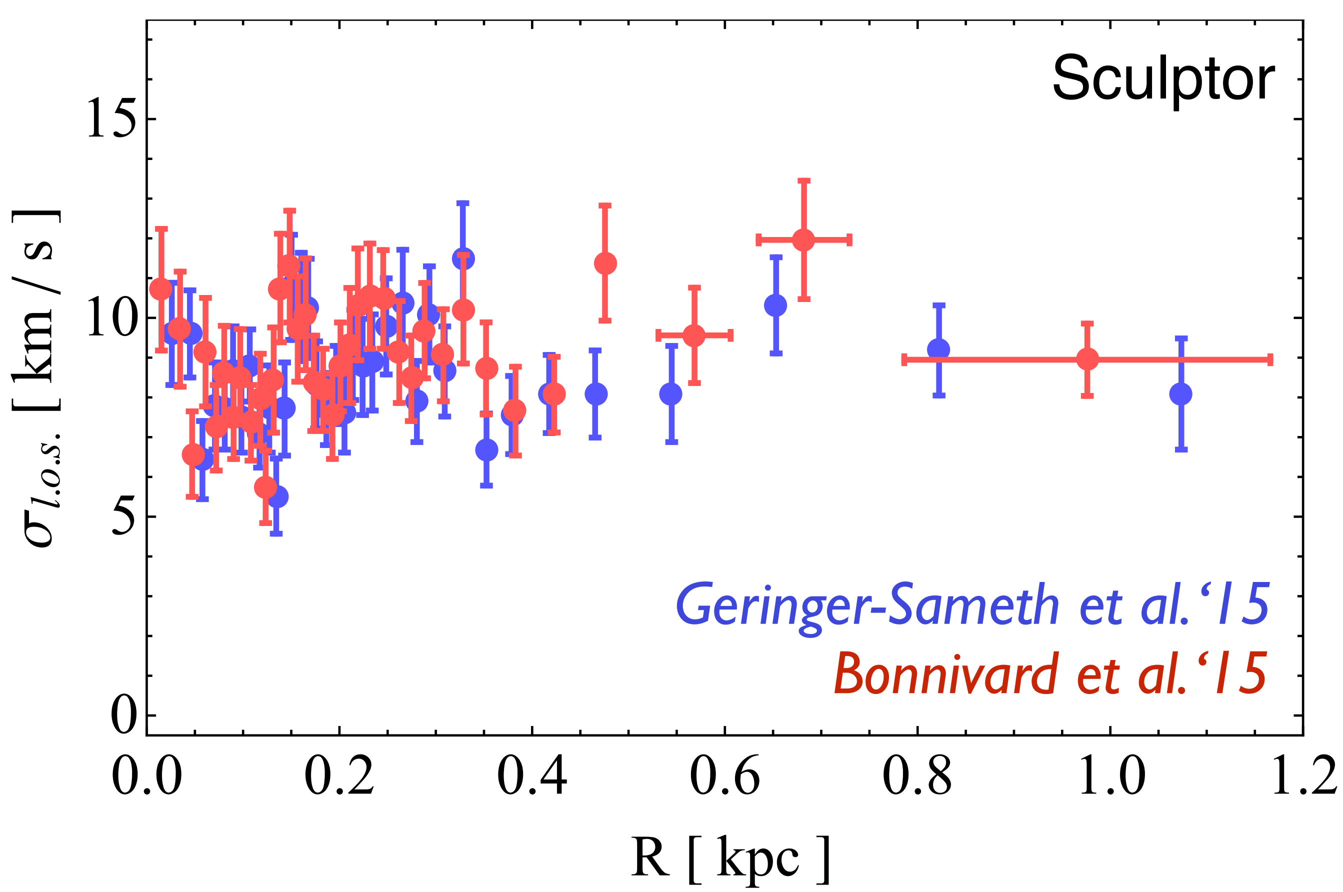
TEST STATISTICS FOR AN UNBINNED ANALYSIS!

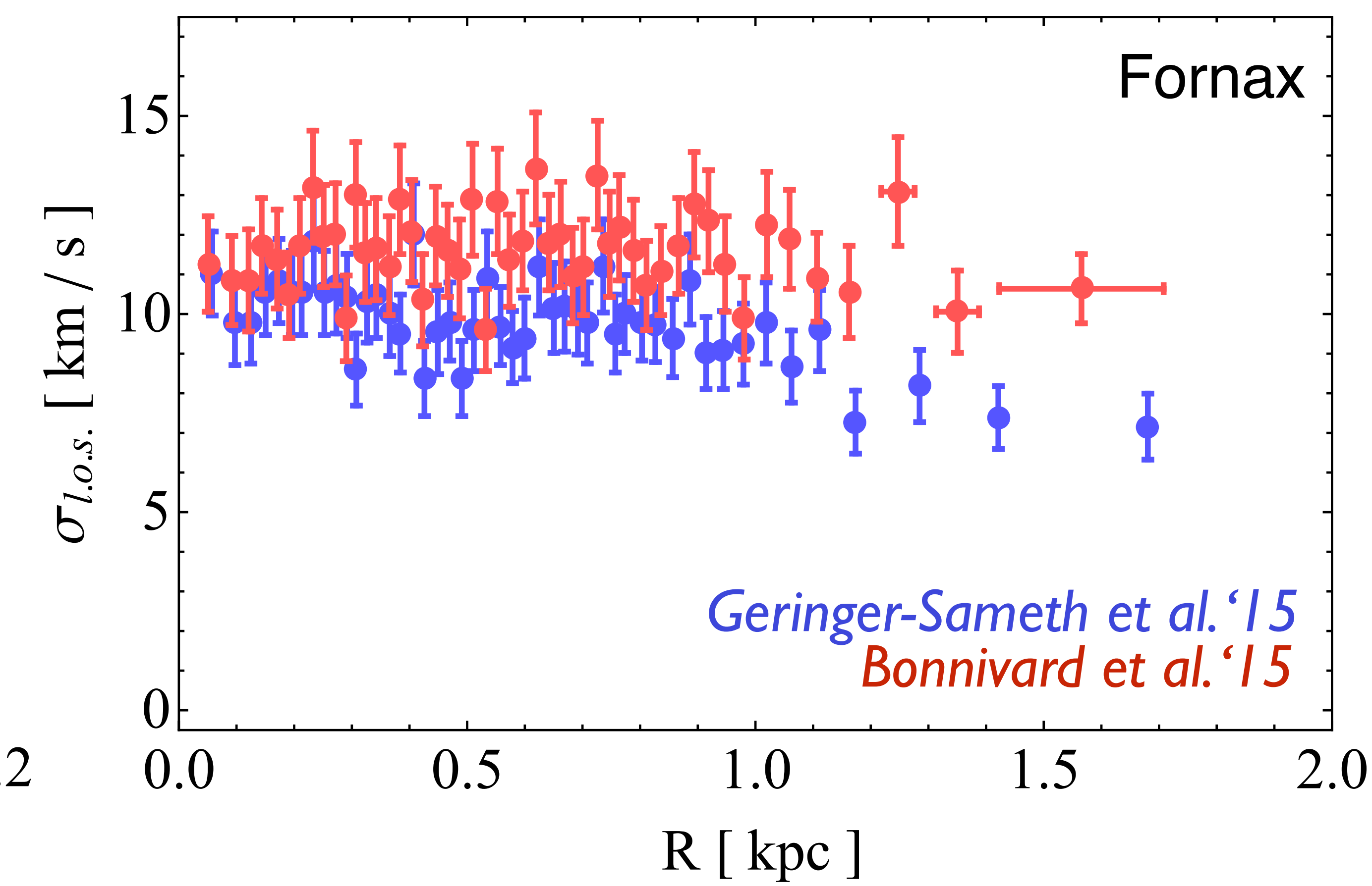
(see, e.g., *Battaglia, G. et al.*, ***New Astron. Rev. 57 (2013) 52***)

UNBINNED ANALYSIS ASSUMES GAUSSIAN DISTRIBUTED L.O.S. VELOCITIES …

l.o.s. kurtosis may provide non-trivial info! See: ***Lokas '09, Richardson & Fairbairn '13***

BEYOND TEST STATISTICS: *treatment of membership probability/contaminants seems to represent a non-negligible source of systematics even for the Classical dwarfs!*



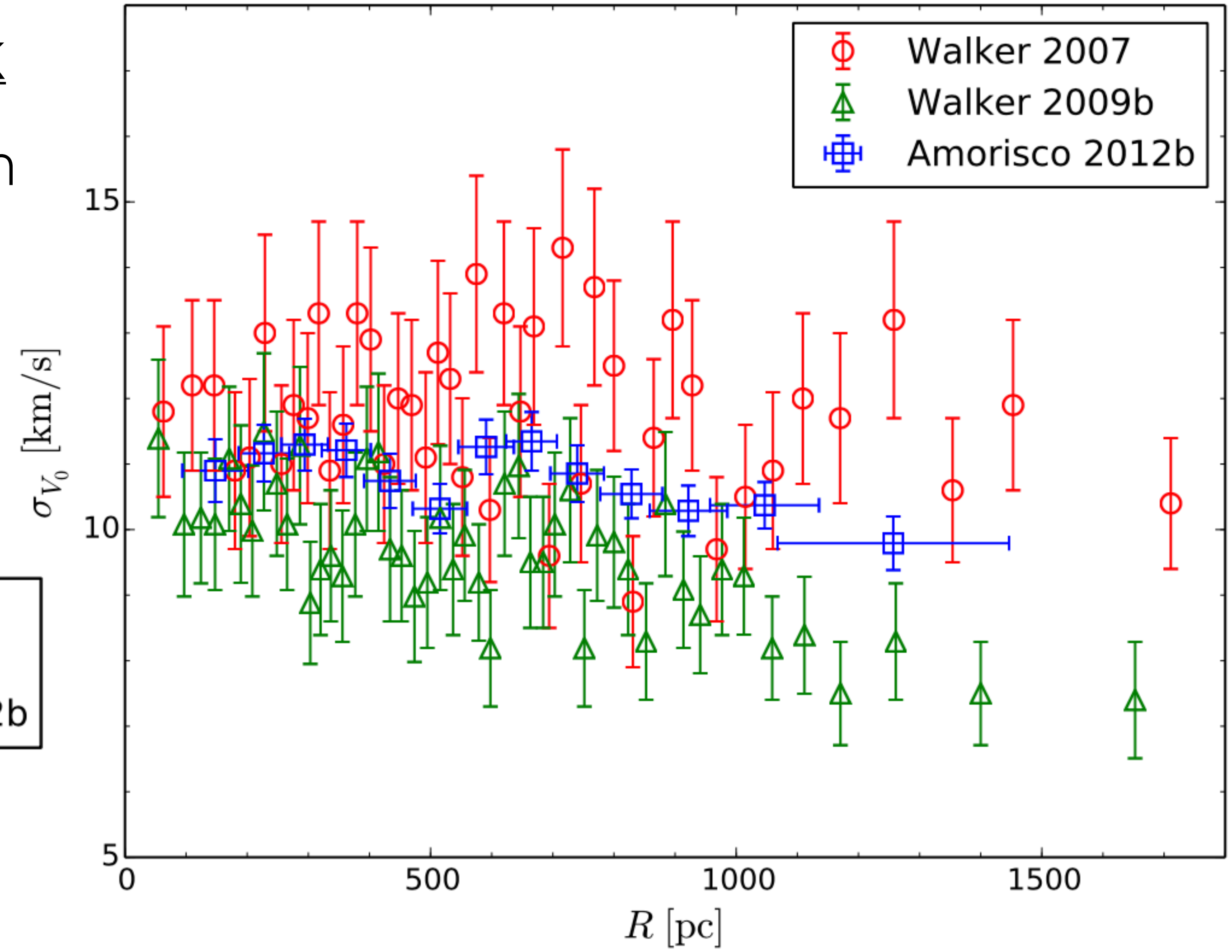


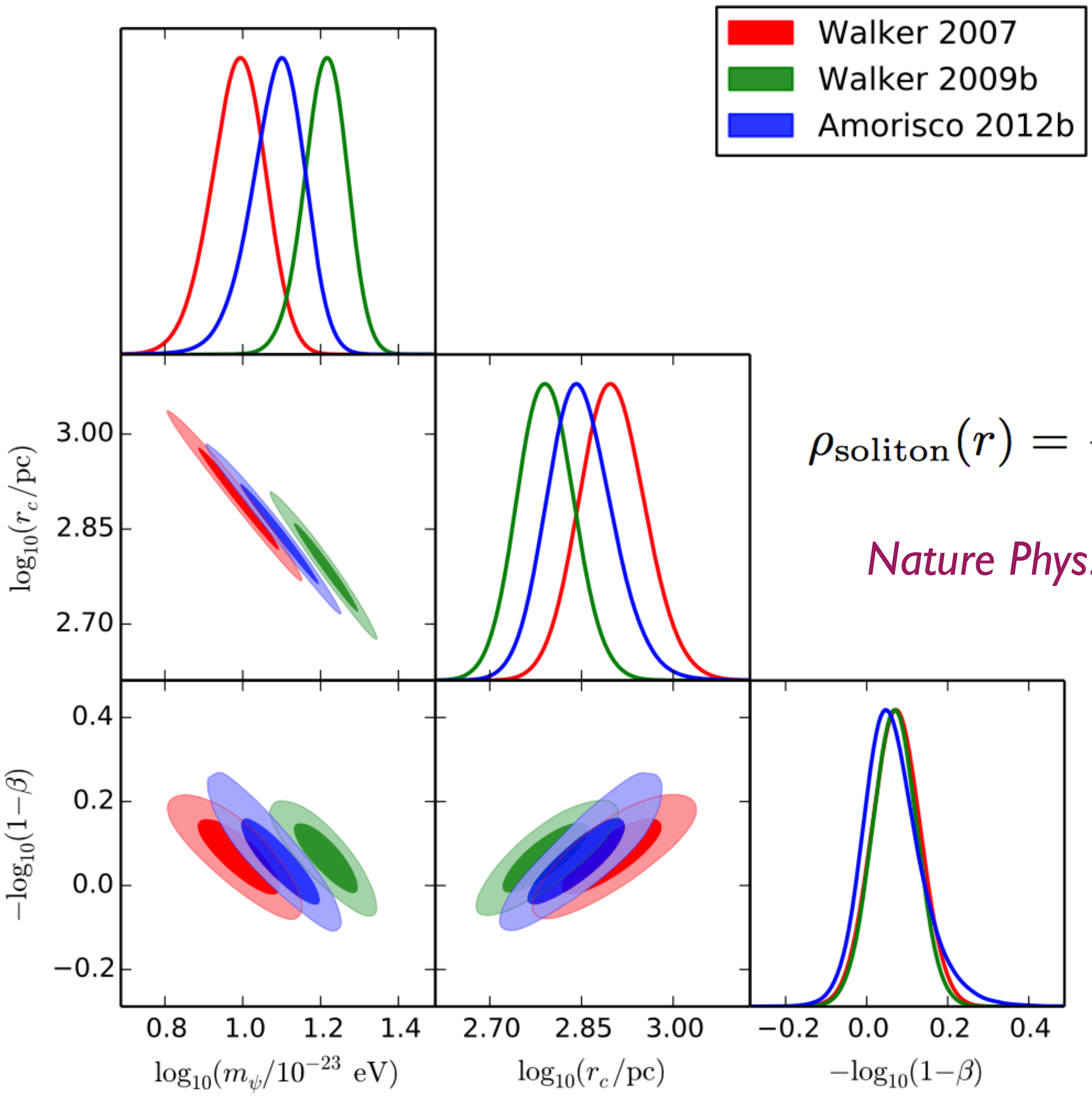
AN EXAMPLE ON THIS SYSTEMATICS AT WORK

Spherical Jeans analysis with axion-like soliton halo profile of Fuzzy / Wave Dark Matter.

MNRAS 468 (2017) 1338-1348 , *Schive, H.Y. et al.*

See tomorrow's talk of A. Gonzalez-Morales!





$$\rho_{\mathrm{soliton}}(r) = \frac{1.9\ (m_\psi/10^{-23}\,\mathrm{eV})^{-2}(\mathrm{r_c}/\,\mathrm{pc})^{-4}}{[1+9.1\times 10^{-2}(r/r_c)^2]^8}\ 10^{12}\, M_\odot\,\mathrm{pc}^{-3}$$

Nature Phys. 10 (2014) 496 , *PRL 113 (2014) no.26, 261302* ,
Schive, H.Y. et al.

Galaxy	$\log_{10}[m_\psi/10^{-23}\mathrm{eV}]$
Fornax	$1.21^{+0.06(+0.10)}_{-0.05(-0.11)}$
	$0.99^{+0.07(+0.13)}_{-0.07(-0.15)}$

Possible challenges/subtleties even in study of the 8 Classicals!

$$0.1 \lesssim \epsilon \equiv 1 - a/b \lesssim 0.5$$

$a := I$ semi-minor axis

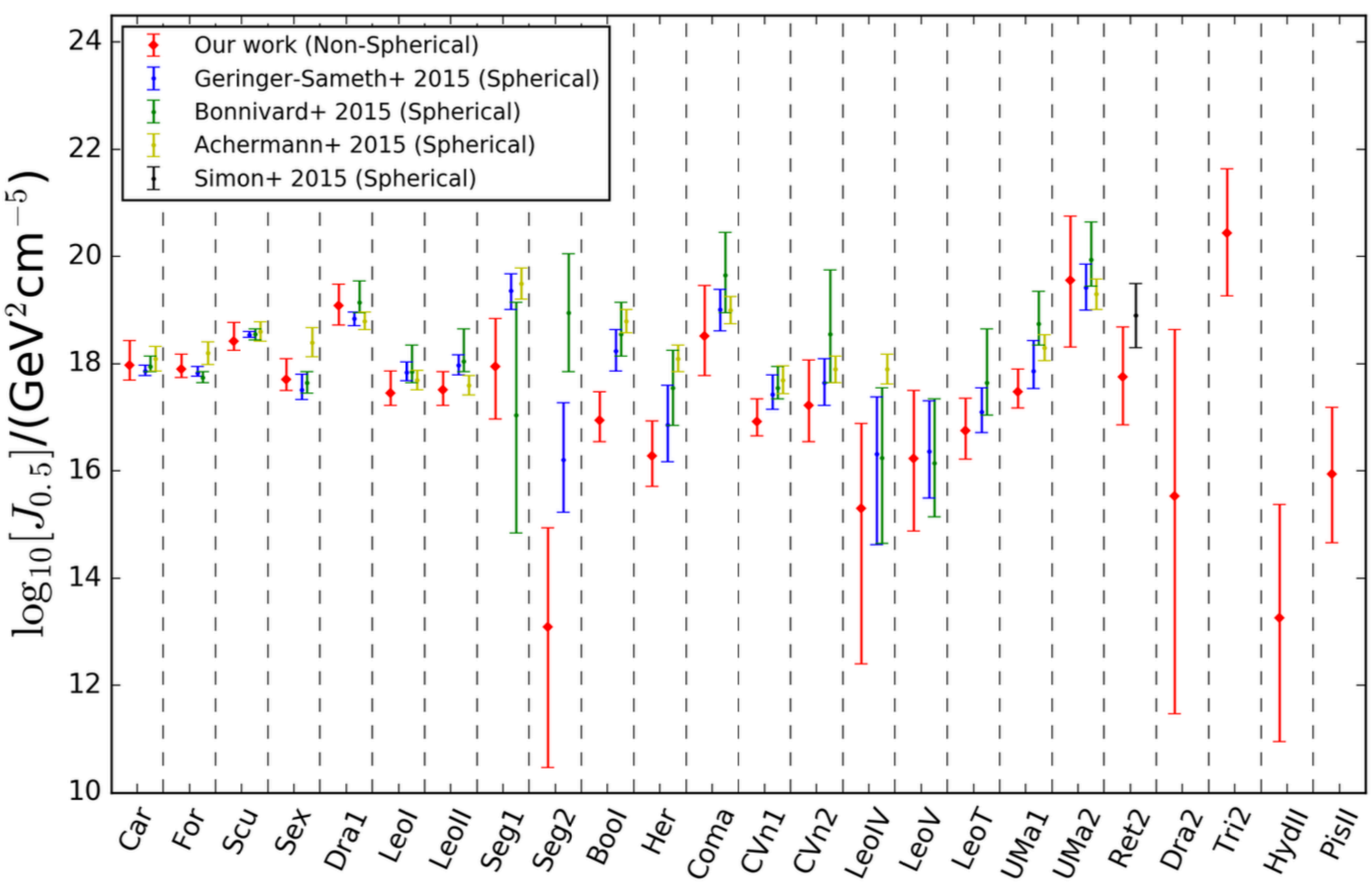
$b := I$ semi-major axis

"Spheroidal" stems from the "small" stellar ellipticity of these 8 galaxies.

Systematics due to a more realistic triaxial-halo shape seems non-negligible, even for Classicals.
MNRAS 453 (2015) , *Bonnivard, V. et al.*

Axi-symmetric Jeans analysis (see *MNRAS 390 (2008) 71* , *M.Cappellari*) applied in this context highlights **important systematics on Ultra-faint dwarfs** (quite milder effects on Classicals).

MNRAS 461 (2016) 2914 , Hayashi, K. et al.



ApJ 755 (2012) 145 ,
ApJ 810 (2015) 22 ,
Hayashi & Chiba

See also recent discussion in:
PRD 95 (2017) no.12,123012
Klop, N. et al.

Geometric + kinematic corrections to Js & Ds from "flattening effects" turn out to be small for 8 Classicals in:
PRD 94 (2016) no.6, 063521,
Sanders, J.L. et al.

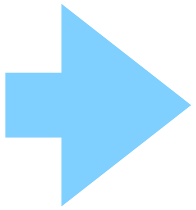
Mass-Anisotropy degeneracy: An elephant in the room …

$\mathcal{Q}$: *Departures of orders of magnitude from the results presented so far?*

Marginalization over an unknown function, with poor theoretical and observational guidance (differently from stellar & DM profiles) …

I) SEVERAL PARAMETERIZATIONS FROM PHASE-SPACE DENSITY MODELING

$$\beta(r) = \frac{r^2}{r^2 + r_\beta^2}$$ *Osipkov '79, Merritt '85*



$$\beta(r) = \frac{\beta_0 + \beta_\infty (r/r_\beta)^\eta}{1 + (r/r_\beta)^\eta}$$ *Baes and Van Hese '07*

AND FEW THEORETICAL CONSTRAINTS (*An, Baes and Van Hese`12*)

E.g.: Anisotropy ≤ 1/2 of Stellar Density Log-Slope (*An & Evans '06+ Ciotti & Morganti '10*)

II) NO FINAL MESSAGE FROM RECENT N-BODY SIMULATIONS

FIRE (*El-Badry et al.'17*) finds anisotropies well-described by Osipkov-Merritt model

APOSTLE (*Campbell et al.'17*) leaves room also for tangential bias in the outer region

Next-gen observational programs (see, e.g., **GAIA**, but also **HST astrometry initiative** and proposals such as **Theia**) may reach **sensitivity to** measure **dwarf proper stellar motion**.

dSphs := GOOD LABORATORIES FOR DM PARTICLE LIMITS?

The impact of mass-anisotropy degeneracy on the derived DM profile may be the most dramatic systematics … ***are departures of orders of magnitude from outcome of MCMC analyses discussed so far possible?!***

WHAT ABOUT INVESTIGATING THE EFFECT OF THIS SYSTEMATICS WITH A MORE DIRECT APPROACH?

WHAT MAY INDEED BE INTERESTING TO BE ASSESSED …

$$\phi^{(\mathrm{DM})}_{\gamma,\nu,\ldots} \propto \langle \sigma v \rangle \times J$$

$$(\tau \times D)$$

DM LIMITS SCALE INVERSELY WITH J

… IS THE **“MINIMAL” J-FACTOR** VS **ANISOTROPY**, namely the minimum J-value — statistically allowed by dwarf stellar kinematics — yielding the weakest upper-bound in relation to this systematics.

We can exploit Abel inversion to test this !

$$\widehat{f}(y) = \mathbf{A}^{-1}[f(x)] \equiv -\frac{1}{\pi}\int_y^{\infty} \frac{dx}{\sqrt{x-y}}\, f(x)$$

E.g.: $\mathbf{A}^{-1}$[surface brightness] —> stellar density profile

$\mathbf{A}^{-1}\left[I\left(R^2\right)\right]$ $\qquad\qquad$ $\widehat{I}\left(r^2\right)$

P.Ullio & M.V. *JCAP 1607 (2016) 025*

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E.g.: $\mathbf{A}^{-1}$[surface brightness] —> stellar density profile

$$\widehat{P}(r^2) = \mathbf{A}^{-1}[P(R^2) \equiv I\,\sigma_{los}^2]$$

FUNCTION OF L.O.S. OBSERVABLES ONLY

MASS PROFILE FROM INVERSION OF SPHERICAL JEANS EQUATION:

$$\mathcal{M}_\beta(r) = \frac{r^2}{G_N\,\widehat{I}(r)}\left\{-\frac{d\widehat{P}}{dr}[1-a_\beta(r)] - \frac{a_\beta(r)\,b_\beta(r)}{r}\int_r^\infty dr'\mathcal{H}_\beta(r,r')\,\frac{d\widehat{P}}{dr'}\right\}$$

$$a_\beta \equiv -\beta/(1-\beta)\ , \quad b_\beta(r) \equiv 3 - a_\beta + \frac{d\log a_\beta}{d\log r}\,,$$

$$\mathcal{H}_\beta(r,r') \equiv \exp\left(\int_r^{r'} dr''\frac{a_\beta(r'')}{r''}\right)\,.$$

See, also, previous derivations in:

***MNRAS 401(2010)**, Mamon, G. & Boué, G.* ,

***MNRAS 406(2010)**, J.Wolf et al.*

P.Ullio & M.V. *JCAP 1607 (2016) 025*

INVERTED SPHERICAL JEANS ANALYSIS IN A NUTSHELL

$$\sigma_{los}(\mathcal{M},\beta,I) \quad \Rightarrow \quad \mathcal{M}(\beta,\sigma_{los},I)$$

Some **physical conditions** must supplement the inversion formula.

$$i) \quad \mathcal{M}_\beta(r) > 0 \ , \quad \forall\, r > 0$$

$$ii) \quad \mathcal{M}_\beta(r') \geq \mathcal{M}_\beta(r) \, , \quad \forall\, r' \geq r \ .$$

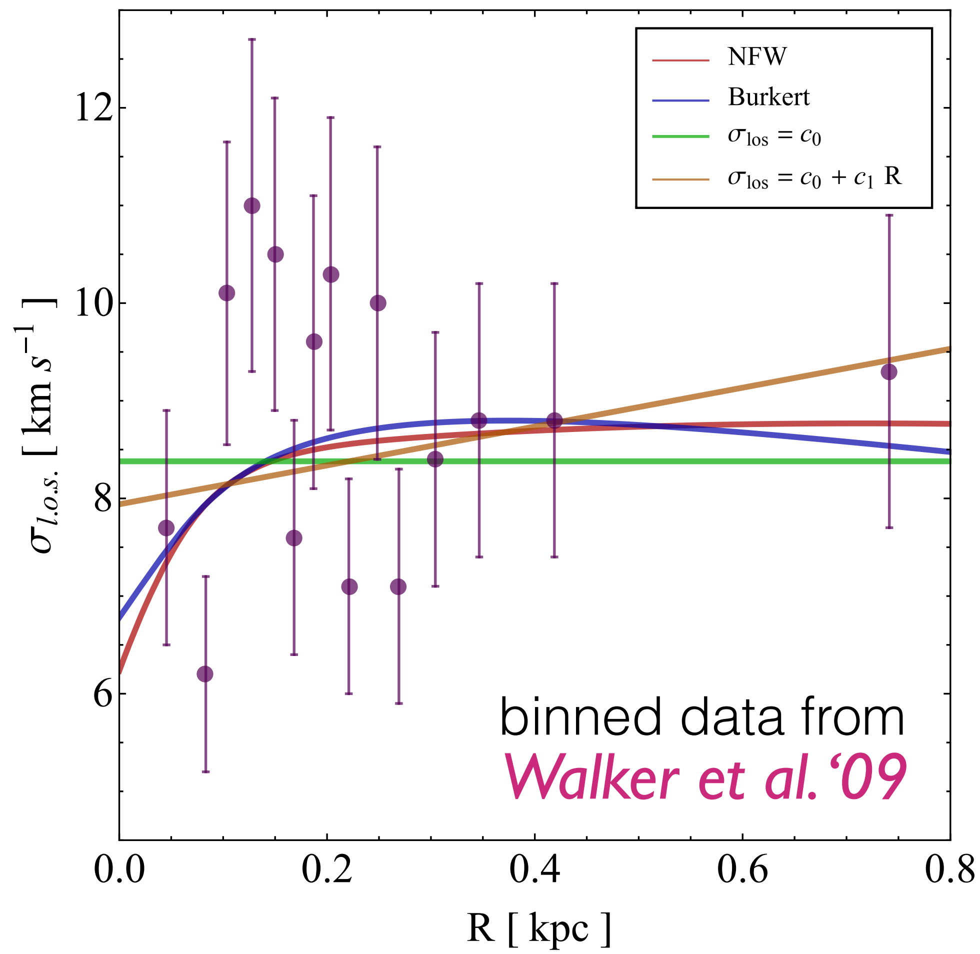
$$\rho_\beta(r) = \frac{1}{4\pi r^2}\frac{d\mathcal{M}_\beta}{dr}$$

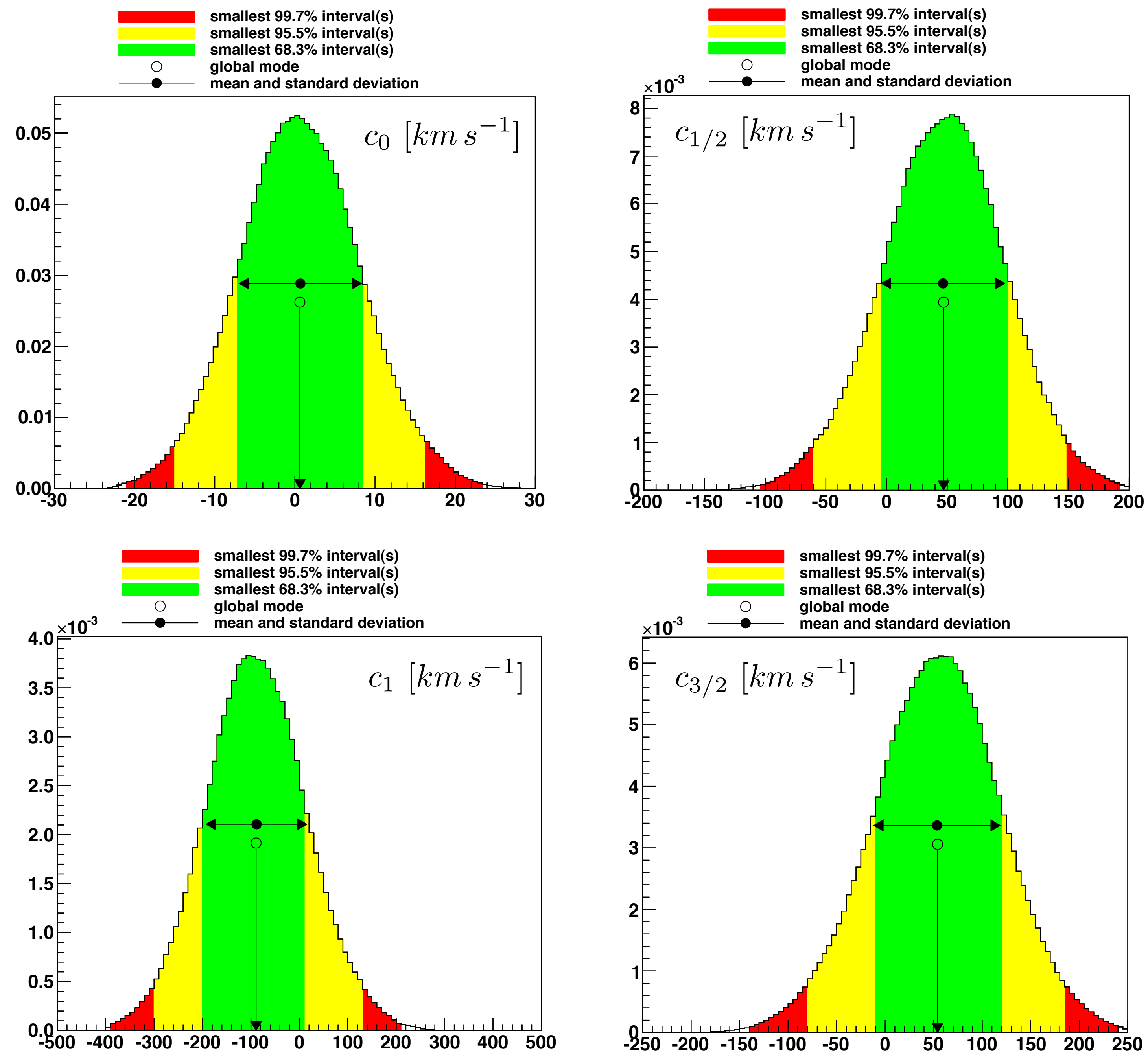
DENSITY PROFILE FOR SPHERICAL SYSTEMS

$$iii) \quad \rho_\beta(r') \leq \rho_\beta(r) \, , \quad \forall\, r' \geq r \ .$$

P.Ullio & M.V. *JCAP 1607 (2016) 025*

THE STUDY CASE OF URSA MINOR





$$\sigma_{los}(R) = \begin{cases} c_0 + c_1 R \\ \sum_{i=0}^{3} c_{\frac{i}{2}} R^{\frac{i}{2}} \end{cases}$$

+ Plummer surface brightness

MCMC with BAT

Bayesian **A**nalysis **T**oolkit

P.Ullio & M.V. *JCAP 1607 (2016) 025*

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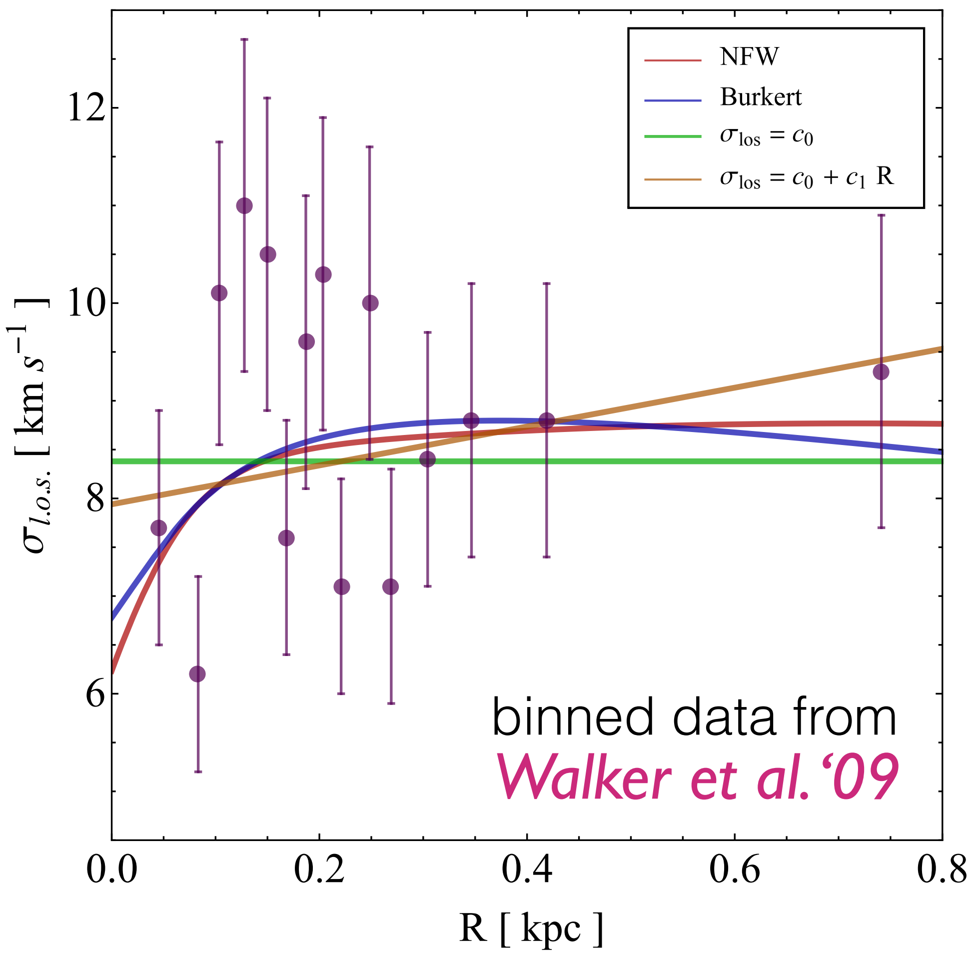

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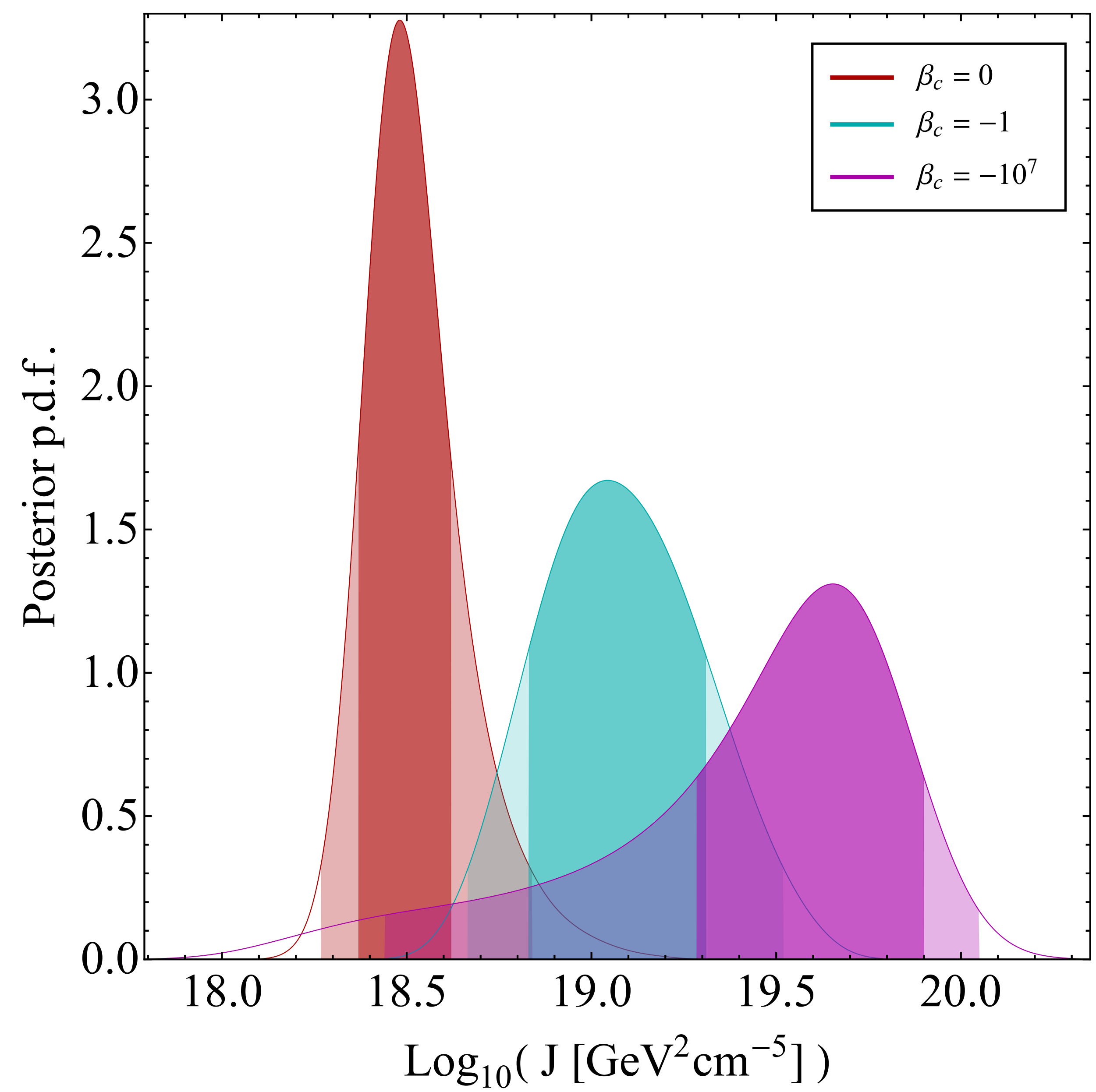
AT EVERY STEP IN THE MCMC, CHECK THE PHYSICAL CONDITIONS. IF SATISFIED:

$$\mathcal{M}_\beta \Rightarrow \rho_\beta \Rightarrow J_\beta$$



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THE STUDY CASE OF URSA MINOR

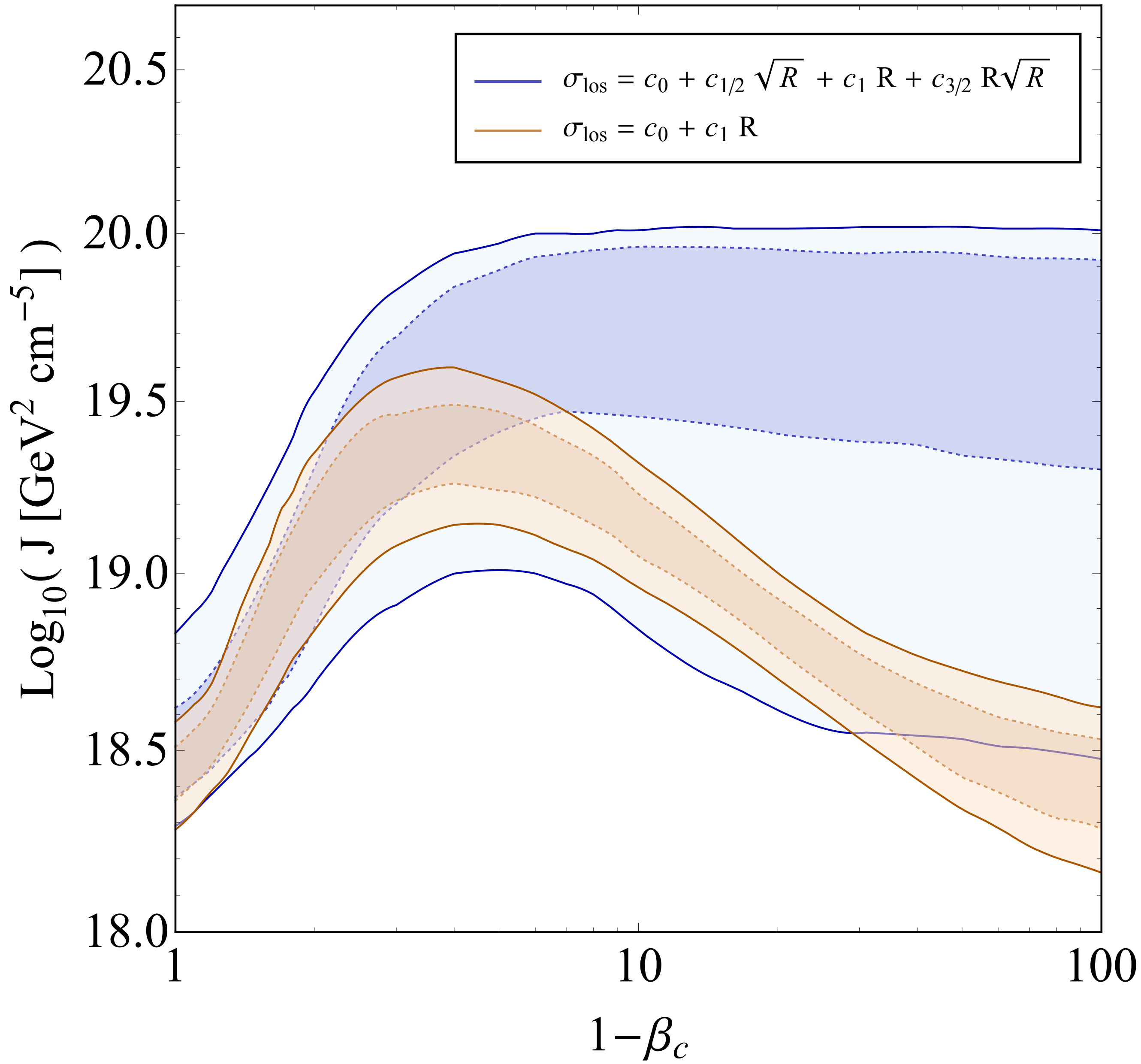
CONSERVATIVE WORKING ASSUMPTION

OUR JEANS INVERSION APPROACH IS INTIMATELY CONNECTED TO DATA.

INNER DENSITY (I.E. BELOW FIRST BINNED RADIUS OF DATA) **ASSUMED TO BE CONSTANT** IN THE EVALUATION OF THE L.O.S. INTEGRAL OF J.

$$\sigma_{los}(R) = \begin{cases} c_0 + c_1 R \\ \sum_{i=0}^{3} c_{\frac{i}{2}} R^{\frac{i}{2}} \end{cases}$$

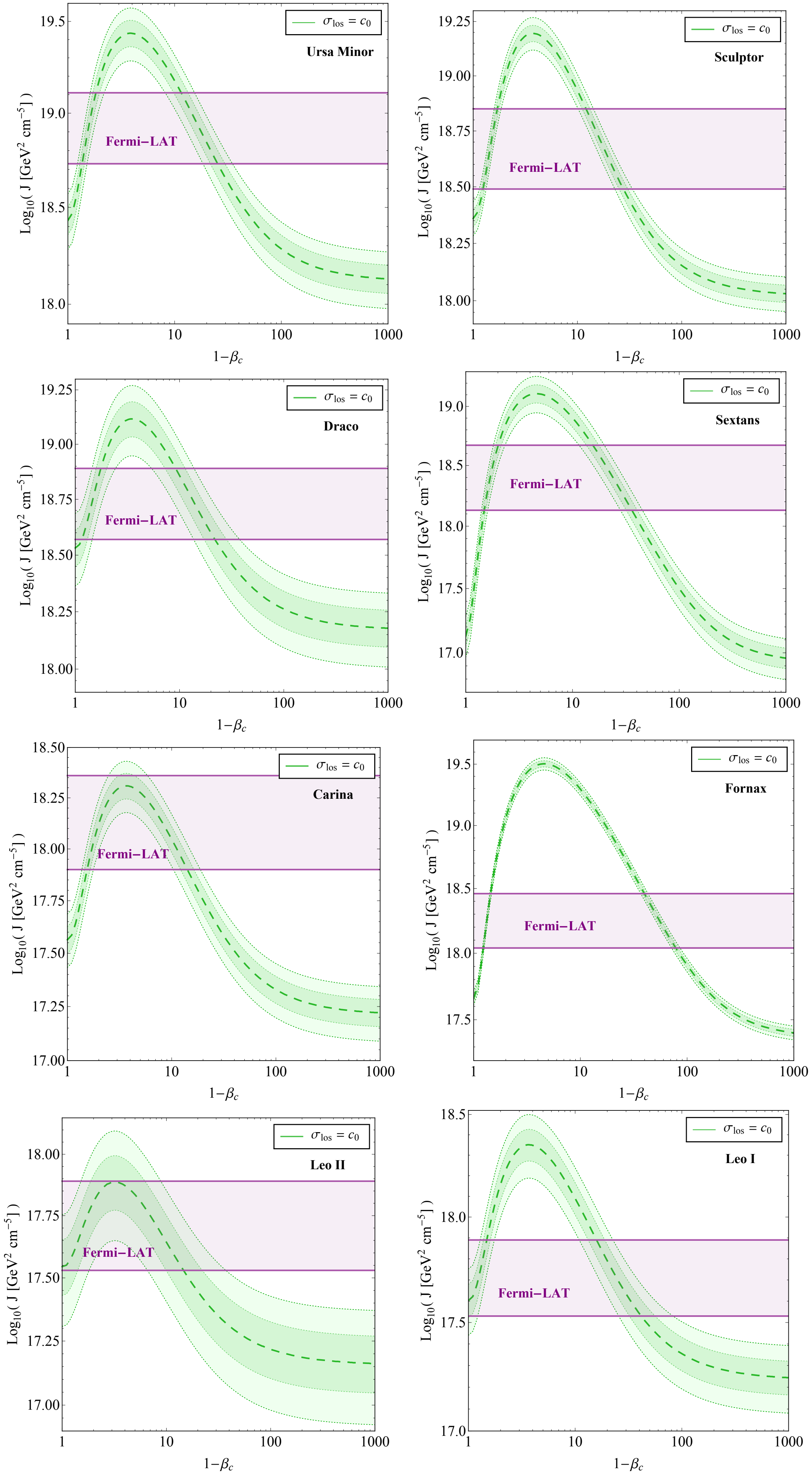
+ Plummer surface brightness



MINIMAL J OBTAINED FOR $\sigma_{LOS} = c_0$ IN THE LIMIT OF STELLAR CIRCULAR MOTION

—> extreme "academic case" under scrutiny

(more details in the backup)



P.Ullio & M.V. *JCAP 1607 (2016) 025* + M.V. *Ph.D. thesis ('16)*

http://inspirehep.net/record/1495762/files/Valli_PhdThesis

RADICAL CONSERVATIVE APPROACH CONSIDERED.

AT MOST, FACTOR ~ 4 OF DIFFERENCE ON MINIMAL J WRT OTHER ANALYSES.

X = *Ackermann et al.'13* , *Bonnivard et al.'15*

Classical dSph	$\min J^{(X)}_{@2\sigma} / \min J_{@2\sigma}$ (Ackermann et al.'13)	$\min J^{(X)}_{@2\sigma} / \min J_{@2\sigma}$ (Bonnivard et al.'15)
Ursa Minor	3.80	3.76
Sculptor	2.36	2.64
Draco	2.59	3.36
Sextans	12.88	1.56
Carina	3.94	3.98
Fornax	3.34	1.81
Leo II	2.70	1.43
Leo I	1.91	2.76

Classicals := DM astro-labs that leave **room for robust limits in indirect DM searches!**

BEYOND THE STANDARD LORE — *J & PHASE-SPACE* —

When "particle" & "astro" do not naively factorize anymore …

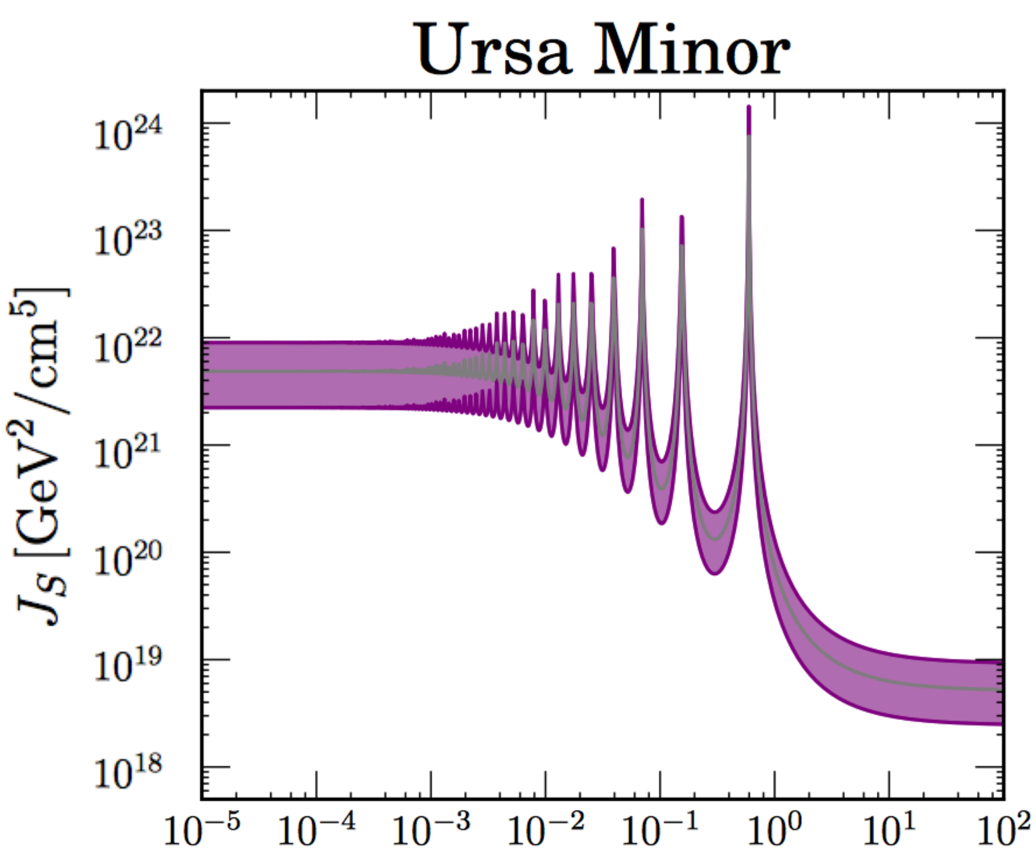
Role of velocity dependence in DM phenomenology may be extremely important.

See previous talk by Torsten B.!

—> Sommerfeld-enhanced J-factors & dSphs:

Phys.Rev. D95 (2017) 123008, *Boddy, K. et al.* (See also: ***JCAP 1309 (2013) 005***, *Ferrer & Hunter*)

$$J_S(\Delta\Omega) \equiv \int_{\Delta\Omega} d\Omega \int d\ell \int d^3v_1 f(r(\ell,\Omega),\vec{v}_1) \int d^3v_2 f(r(\ell,\Omega),\vec{v}_2)\, S(|\vec{v}_1-\vec{v}_2|/2)$$



$$\epsilon_\phi \equiv \frac{m_\phi}{\alpha_X m_X}$$

Spherical symmetry + isotropy in order to apply Eddington's formula for both DM & stars.

$$f_{DM,\star}(\epsilon) = \frac{1}{\sqrt{8}\pi^2}\int_\epsilon^0 \frac{d^2\rho_{DM,\star}}{d\psi^2}\frac{d\psi}{\sqrt{\epsilon-\psi}}$$

Relative potential assumes a NFW profile, while stellar profile matched to Plummer.

Error band obtained using mass-concentration relation from N-body + stellar kinematics:

$$\langle\sigma_{los}^2\rangle \simeq 3\frac{\int\langle\sigma_\star^2\rangle\rho_\star r^2 dr}{\int\rho_\star r^2 dr} = 3\frac{\int \frac{\int f_\star v^4 dv}{\int f_\star v^2 dv}\rho_\star r^2 dr}{\int \rho_\star r^2 dr}$$

BEYOND THE STANDARD LORE — *J & PHASE-SPACE* —

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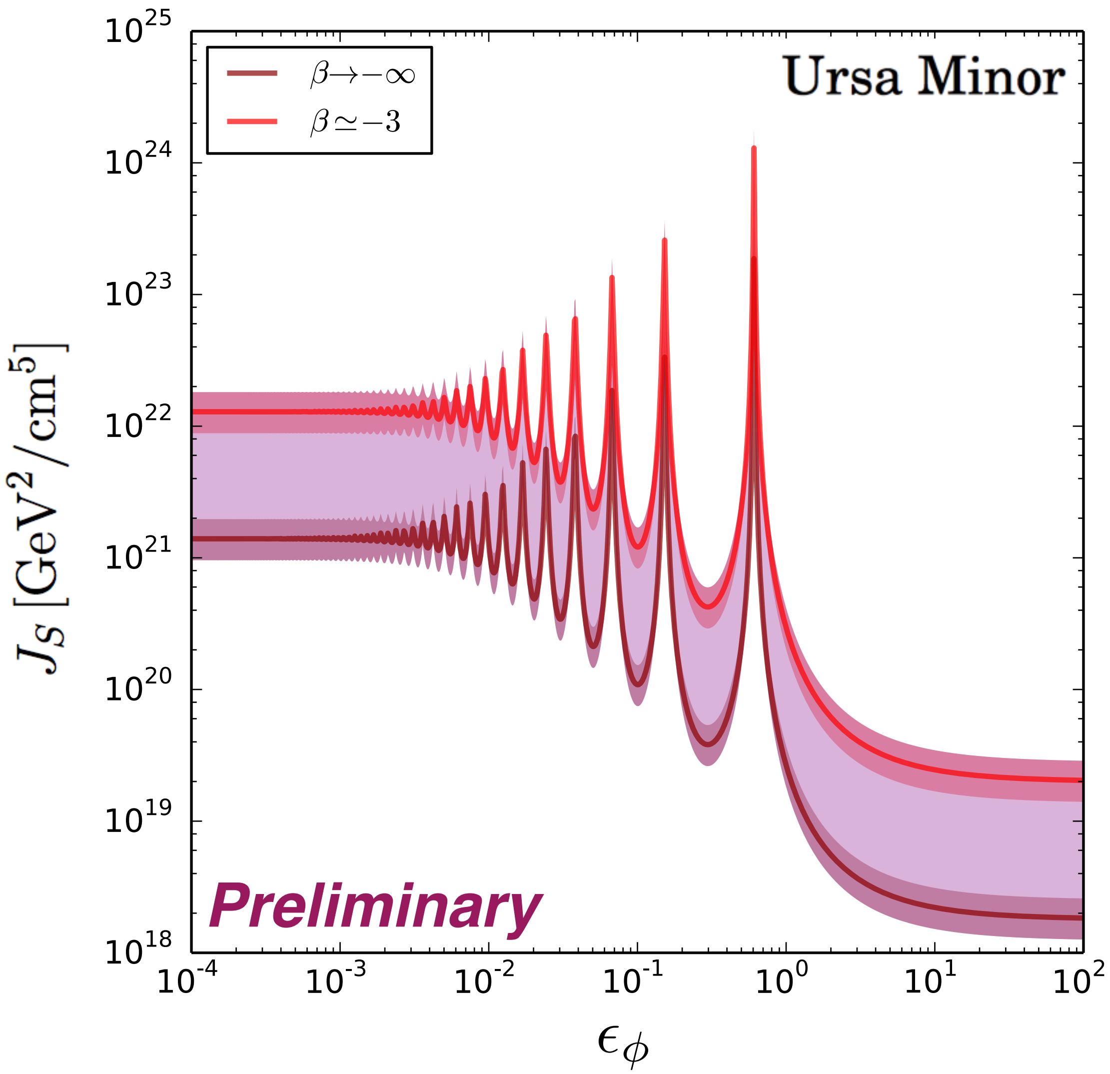


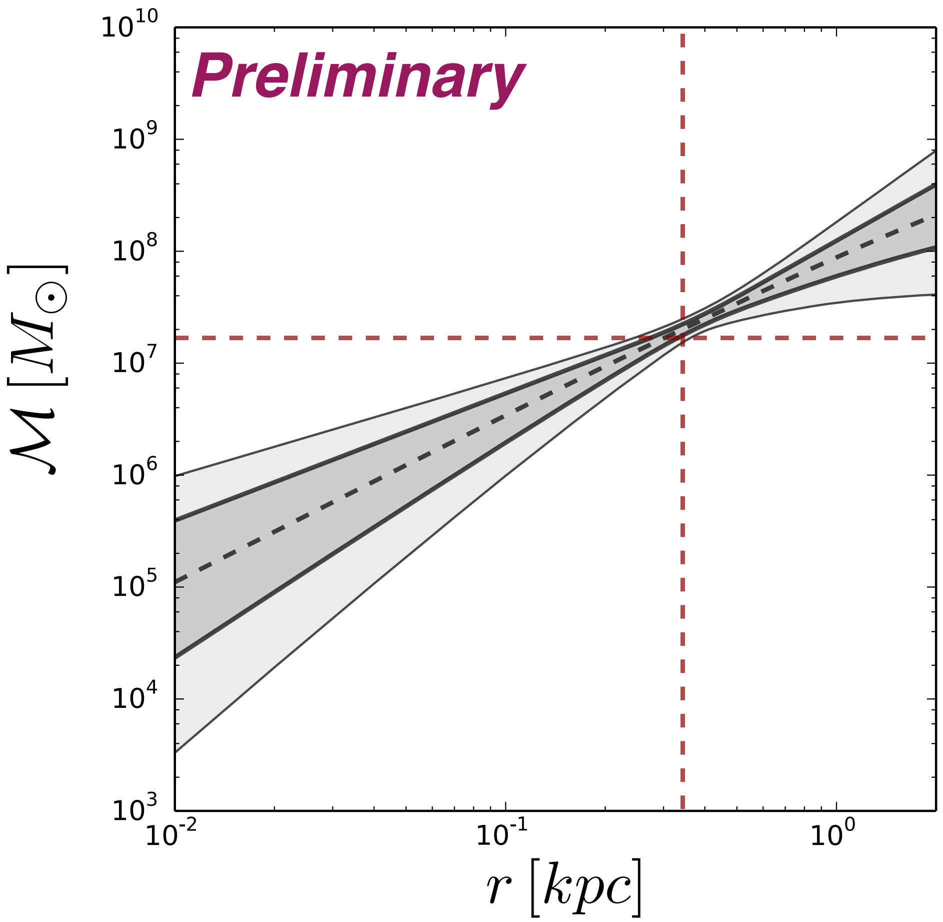
Isotropy for DM particles + spherical symmetry

$$f_\beta^{(DM)}(\epsilon) = \frac{1}{\sqrt{8}\pi^2} \int_\epsilon^0 \frac{d^2\rho_\beta}{d\psi^2} \frac{d\psi}{\sqrt{\epsilon - \psi}}$$

We can join the Jeans inversion formalism to the Eddington's formula in order to study DM phase-space distribution in terms of the fit to l.o.s. observables!

***work in progress**,*
M. Petac, P.Ullio & M.V.

BEYOND THE STANDARD LORE — *DM HALO ESTIMATORS* —



IF $\gamma_\beta, \gamma_{\sigma_r^2}$ PHENOMENOLOGICALLY NEGLIGIBLE:

$$\mathcal{M}_\beta(r) - \mathcal{M}_{\beta=0}(r) \simeq \frac{\beta(r)\, r\, \sigma_r^2(r)}{G_N} \left(\gamma_{\widehat{I}}(r) - 3\right)$$

THEN ,THE MASS ESTIMATOR IS EXPECTED AT:

$$r_* \;:\; \gamma_{\widehat{I}}(r_*) = 3 \;\Rightarrow\; r_* = \sqrt{3/2}\, R_{1/2} \simeq r_{1/2}$$

$$\mathcal{M}(r_*) \simeq \mathcal{M}_{\beta=0}(r_*) = \gamma_{\widehat{P}}(r_*) \frac{r_*}{G_N} \frac{\widehat{P}(r_*)}{\widehat{I}(r_*)} \simeq 3 \frac{r_*}{G_N} \langle \sigma_{los}^2 \rangle$$

6 parameter MCMC for Ursa Minor

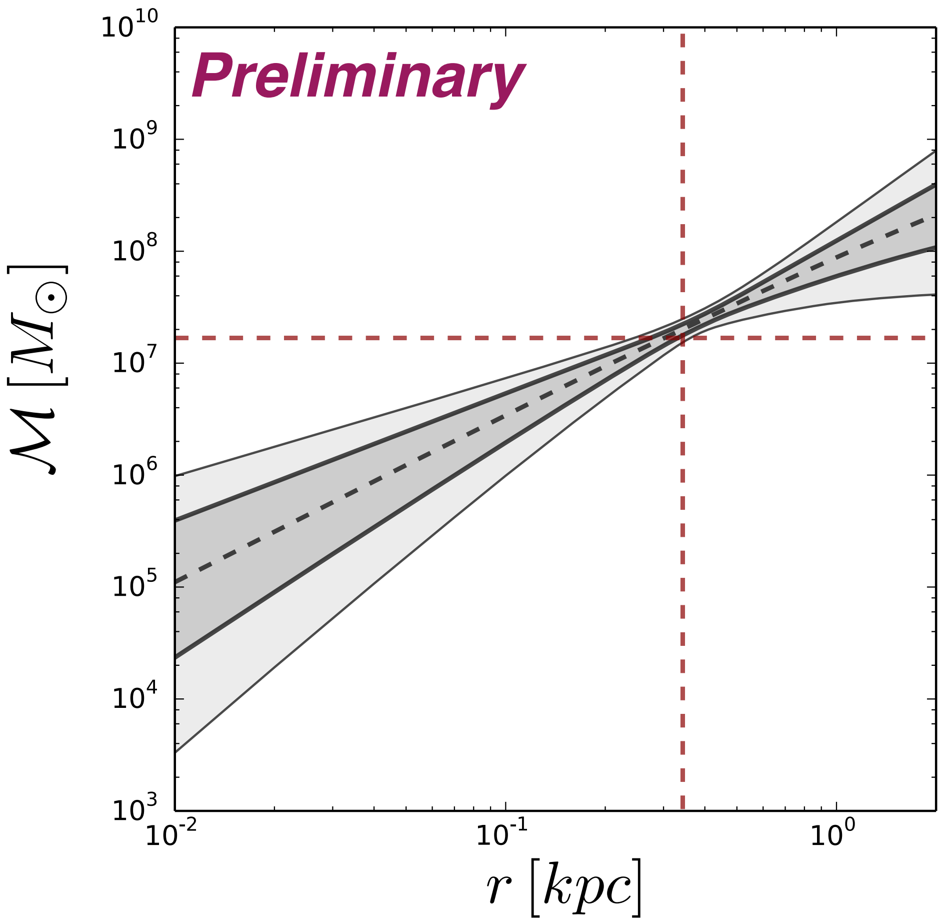
(fit on binned kinematic data)

- *Plummer stellar model* ***($R_{1/2}$ kept fixed)***
- *Constant orbital anisotropy* ***(1 param)*** —> largest range possible: $0 \leq a_\beta \equiv \beta/(\beta-1) \leq 1$
- *Zhao DM profile* ***(5 params)*** —> priors as investigated in *Bonnivard et al.'15*

P.S.

Log-slope of $\mathcal{O}$ is: $\gamma_{\mathcal{O}} \equiv -\dfrac{d\log\mathcal{O}}{d\log r}$

BEYOND THE STANDARD LORE — *DM HALO ESTIMATORS* —



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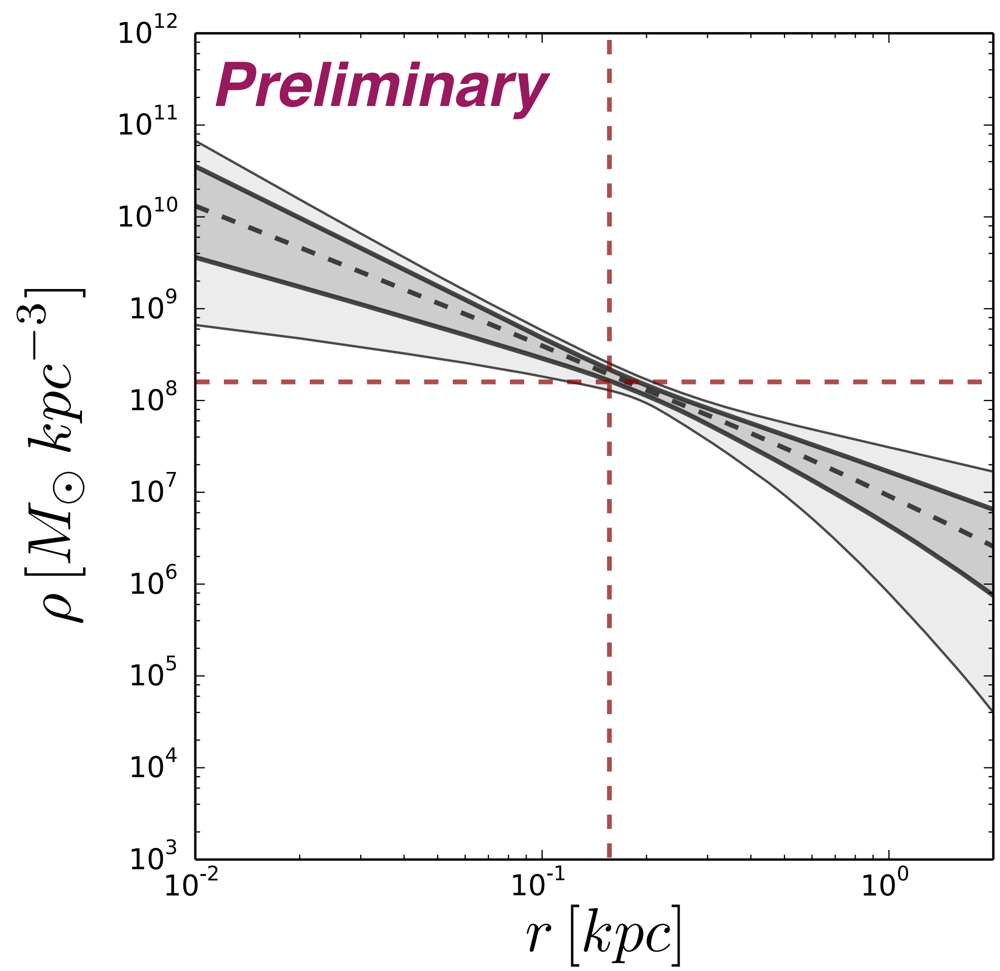
$$r_{**} \;:\; \gamma_{\widehat{I}}(r_{**}) \left(1 - \gamma_{\gamma_{\widehat{I}}}(r_{**})\right) \;\Rightarrow\; r_{**} \simeq 2\, r_{1/2}/3$$

$$\rho_{\beta=0}(r_{**}) = \left[\frac{\mathcal{M}_{\beta=0}}{4\pi r^3} \left(1 - \gamma_{\widehat{P}} - \gamma_{\gamma_{\widehat{P}}} + \gamma_{\widehat{I}}\right) \right] \Bigg|_{r=r_{**}}$$

$$\rho(r_{**}) \simeq \frac{\langle \sigma_{los}^2 \rangle}{4\pi r_{**}^2 G_N} \gamma_{\widehat{I}}(r_{**}) (1 - \gamma_{\gamma_{\widehat{I}}}(r_{**})) = 3 \frac{\langle \sigma_{los}^2 \rangle}{4\pi r_{**}^2 G_N}$$



***work in progress**, M. Petac, P.Ullio & M.V.*

WAY BEYOND THE STANDARD LORE — *SIDM!* —

M.V. & H.B.Yu (in prep.)

MW dSph	$\langle\sigma v\rangle$ [cm^3 g^{-1} s^{-1}]	$\langle v\rangle$ [km s^{-1}]	σ/m [cm^2 g^{-1}]
Ursa Minor	$1.2^{+2.2}_{-0.7}\times 10^2$	52^{+11}_{-7}	$2.9^{+2.7}_{-1.8}$
Sculptor	$0.53^{+0.22}_{-0.22}\times 10^2$	$39.5^{+3.0}_{-3.5}$	$1.23^{+0.62}_{-0.37}$
Draco	$0.65^{+0.54}_{-0.28}\times 10^2$	$45.7^{+3.7}_{-5.5}$	$1.60^{+0.93}_{-0.64}$
Sextans	$0.6^{+4.0}_{-0.3}\times 10^2$	51^{+16}_{-7}	$0.3^{+8.1}_{-0.2}$
Carina	$1.3^{+1.2}_{-0.6}\times 10^2$	$46.9^{+5.6}_{-4.8}$	$2.7^{+2.3}_{-1.1}$
Fornax	$0.28^{+0.16}_{-0.09}\times 10^2$	$30.9^{+2.5}_{-1.3}$	$0.93^{+0.66}_{-0.38}$
Leo II	$2.1^{+2.0}_{-1.3}\times 10^2$	53^{+13}_{-3}	$3.7^{+2.9}_{-1.7}$
Leo I	$1.04^{+0.76}_{-0.43}\times 10^2$	$45.7^{+3.4}_{-4.6}$	$2.4^{+1.5}_{-0.9}$

$$1\,\mathrm{cm}^2\mathrm{g}^{-1} \lesssim \sigma/m \lesssim 3\,\mathrm{cm}^2\mathrm{g}^{-1}$$
$$30\,\mathrm{km\,s}^{-1} \lesssim \langle v\rangle \lesssim 70\,\mathrm{km\,s}^{-1}$$

Our study on SIDM halo in MW dSphs shows:

I) X-sec range in agreement with current indications from N-body simulations.

Zavala, J. et al. '13, Elbert, O. et al. '15

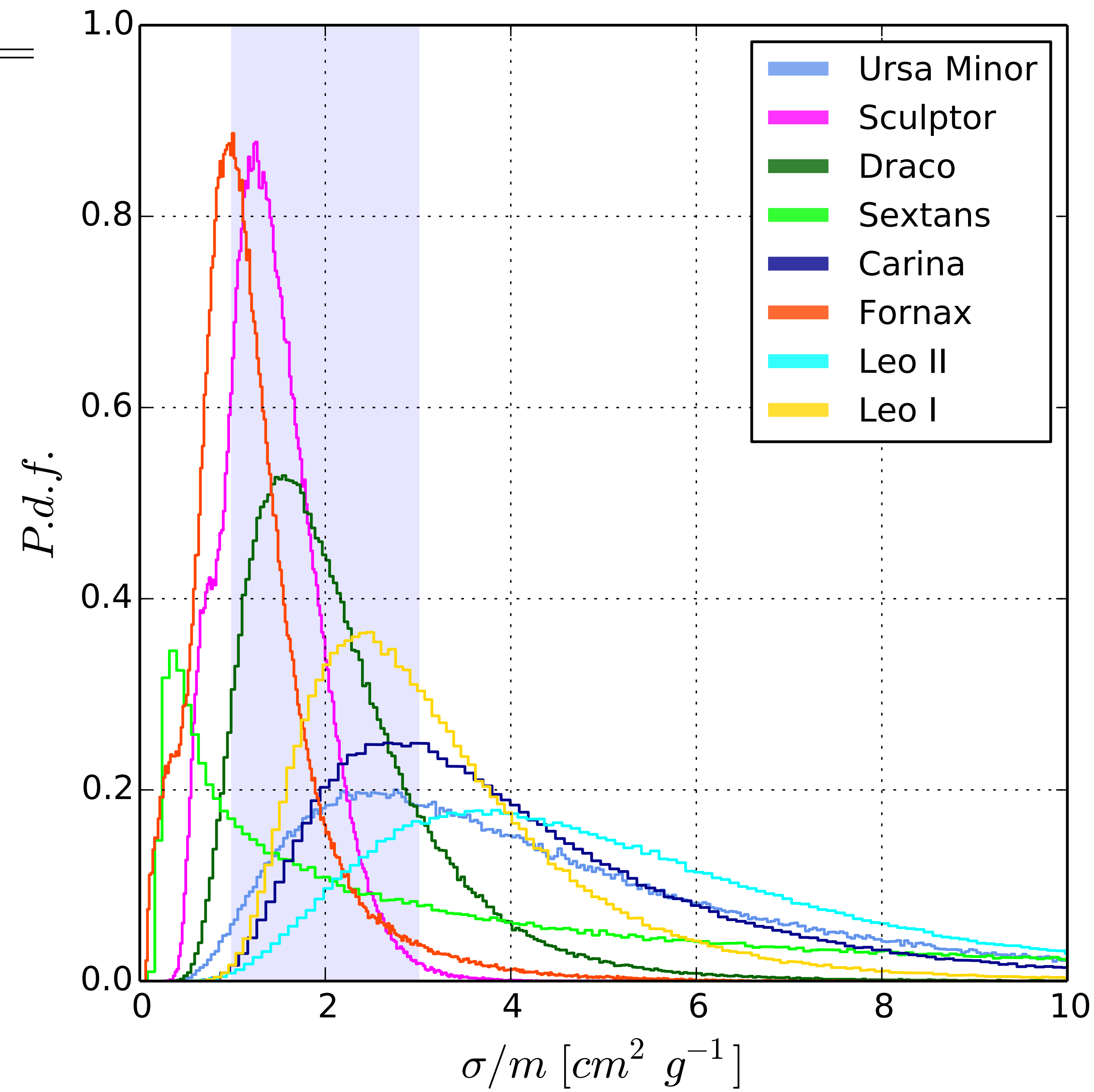
II) Same SIDM ballpark to address "Core VS Cusp" in other kpc-sized systems.

Kaplinghat, M. et al. '16, Kamada, A. et al. '17

III) Some tension left btw goodness of the fit of kinematic data & outer match to CDM.

—> SIDM ameliorates TBTF problem!

Vogelsberger, M. et al. '16 (ETHOS)



CONLUSIONS

Several "basic systematics": estimate of structural parameters, raw data analysis of stellar kinematics, spherical symmetry …

FOR CLASSICALS, potential variations up to ~ $\mathcal{O}(50\%)$ on estimated mass at $r_{1/2}$, may naively affect *J*-factor estimates up to $\Delta J / J \sim \mathcal{O}(1)$.

ABOUT ULTRA-FAINT DWARFS …

IN DYNAMICAL EQ.?! IF SO, PAUCITY OF KINEMATIC DATA + OTHER OBSERVATIONAL SYSTEMATICS CALL ANYWAY FOR CAUTION …

—> PROMISING DETECTION TARGETS / POTENTIAL BIAS IN DM LIMITS !

J (D)-factor estimates from *Bonnivard et al.'15* are **reasonably conservative against mass-anistropy degeneracy**, take into account uncertainties from stellar fits to photometric data & include triaxial-halo corrections!

Axial-symmetric Jeans analysis from *Hayashi et al.'16* ***points to comparably "conservative" estimates*** for J & D (*leaving room for further improvements*).

PRESENT DM LIMITS FROM MW dSphs CAN BE MADE MORE ROBUST !

Backup

BEYOND J (D) - FACTORS: DISTANCE & HALF-LIGHT RADIUS SYSTEMATICS AT WORK

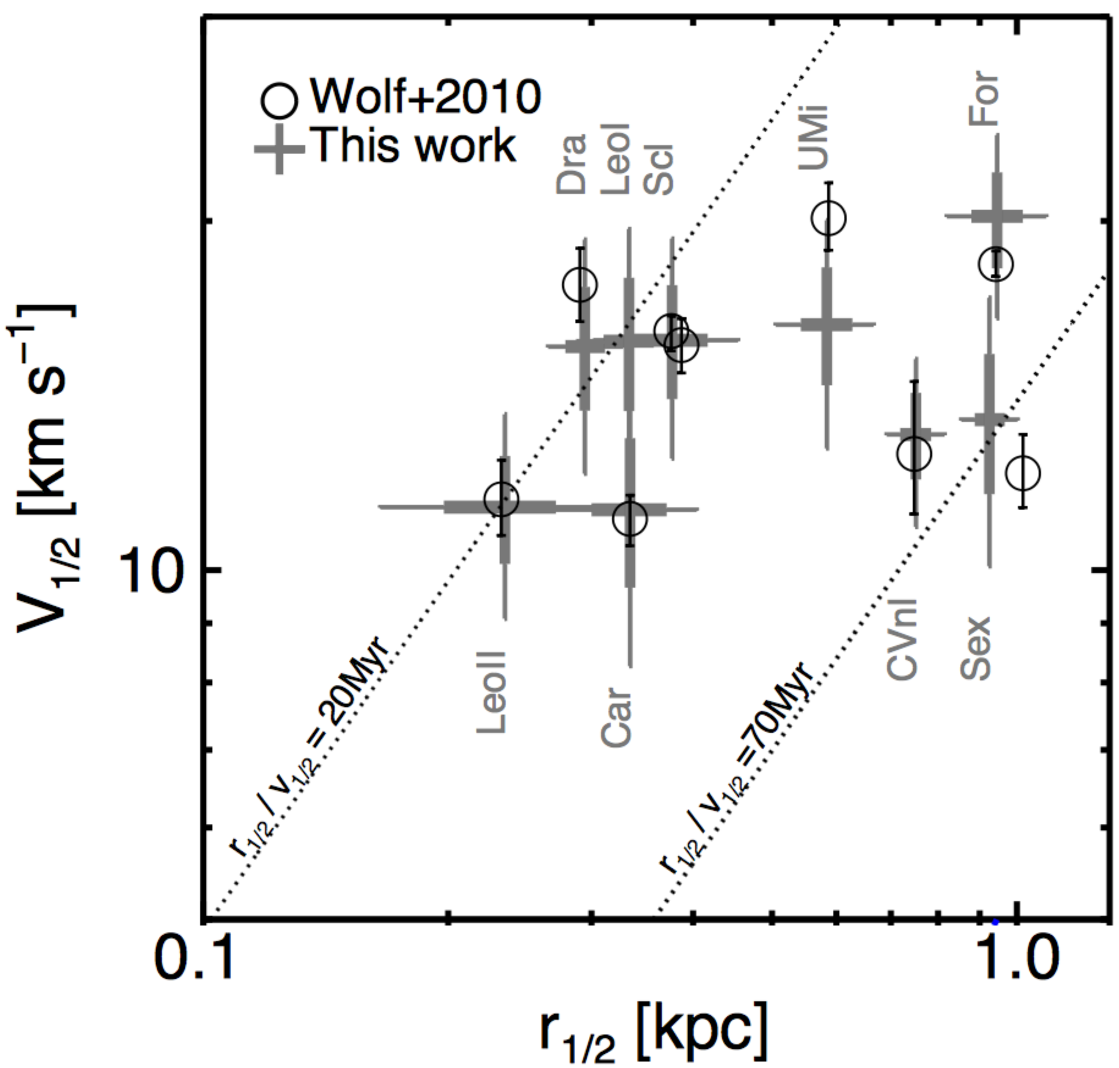
TOO-BIG-TO-FAIL PROBLEM

See previous talk by Manoj K.!

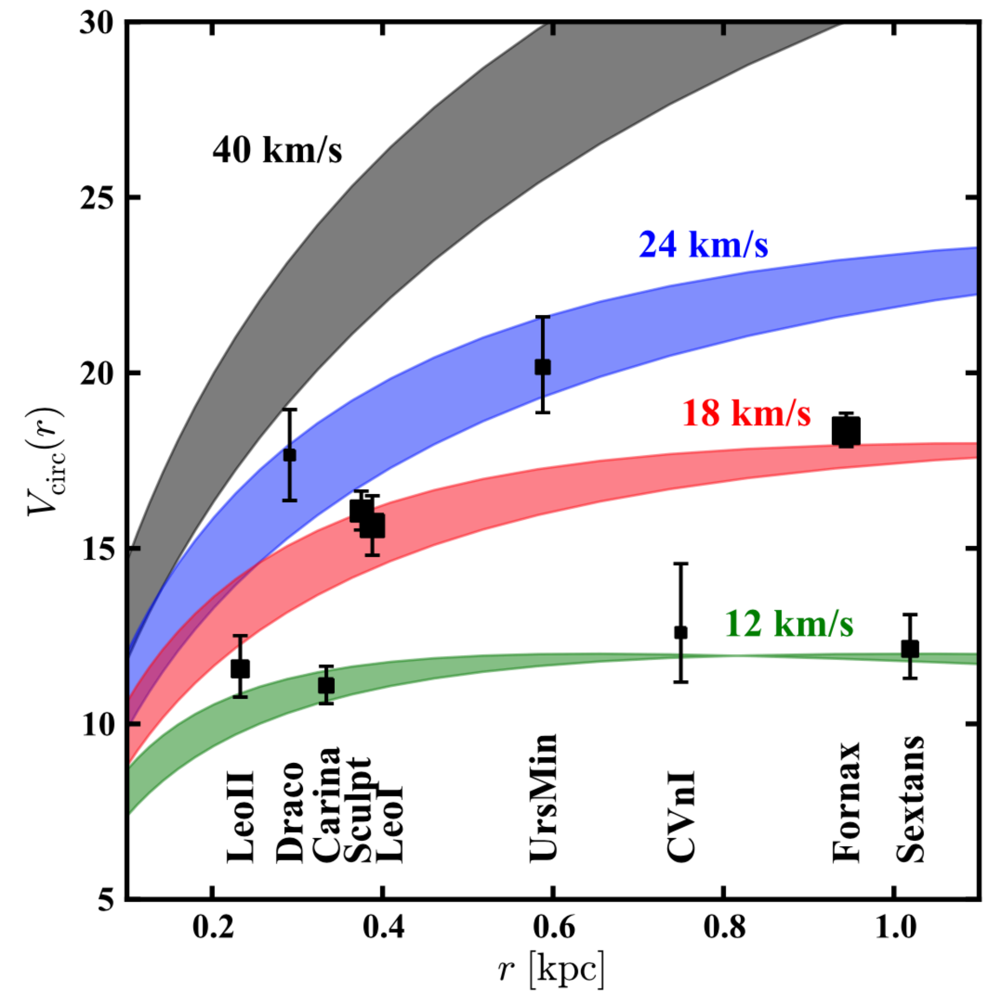
M. Boylan-Kolchin, J.S. Bullock & M. Kaplinghat

MNRAS 415 (2011) L40, MNRAS 422 (2012) 1203

Most massive subhalos in CDM seem to be too dense to host the brightest observed dSphs: so, where are they?



arXiv:1607.06479, Fattahi, A. et al.



To formulate TBTF, it is essential to have a notion of a **good "mass estimator"** for MW dSphs.

MNRAS 496 (2010) 1220, Wolf, J. et al.

$$\mathcal{M}(r_{1/2}) \;\Rightarrow\; V_{circ}(r_{1/2}) = \sqrt{3\langle\sigma^2_{los}\rangle}$$

independent of 3D half-light radius …

… BUT WHEN COMPARING WITH N-BODY, UNCERTAINTIES ON 3D HALF-LIGHT RADIUS SHOULD NOT BE REALLY FORGOTTEN!

Possible challenges/subtleties even in study of the 8 Classicals!

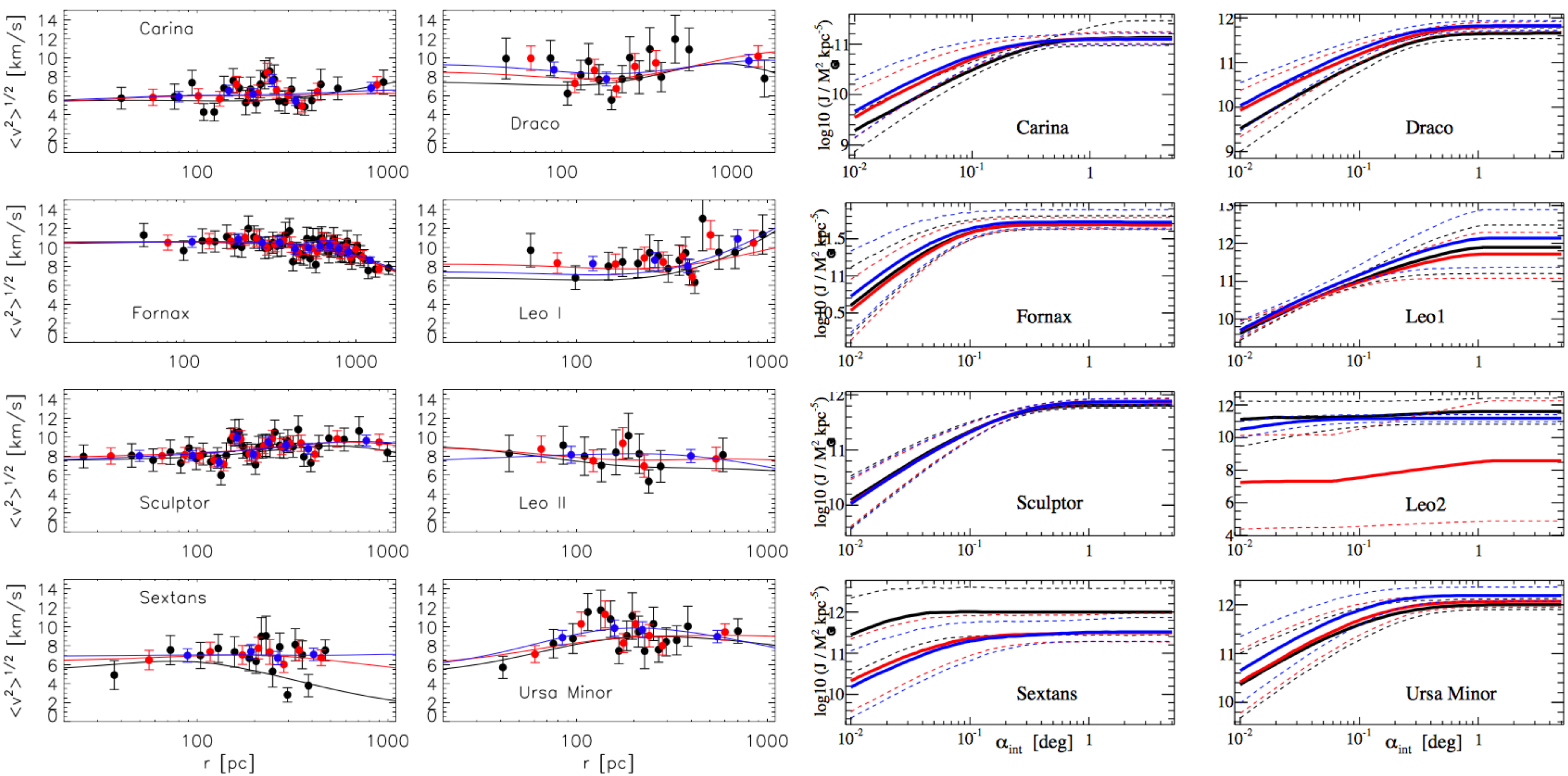
Different choice in binning of l.o.s. velocity dispersions may lead to different results.

$$-2\ln\mathcal{L} = \sum_i^{N_{bins}} \left(\frac{\sigma_{los}^{(obs)}(R_i) - \sigma_{los}^{(pred)}(R_i)}{\delta\sigma_{los}^{(obs)}(R_i)} \right)^2$$

- black: $\sqrt{N_*}$ bins
- red: $\sqrt{N_*}/2$ bins
- blue: $\sqrt{N_*}/4$ bins

$N_* \equiv$ tot star members

MNRAS 418 (2011) 1526, *Charbonnier, A. et al.*



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MASS ESTIMATOR IN DWARF SPHEROIDALS ?

MINIMAL DEPENDENCE ON ANISOTROPY

Nature 454 (2008) , *Strigari, L. et al.*
MNRAS 406 (2010) , *Wolf, J. et al.*

$$\frac{\mathcal{M}_\beta - \mathcal{M}_{\beta=0}}{\mathcal{M}_{\beta=0}} = \text{const.}$$

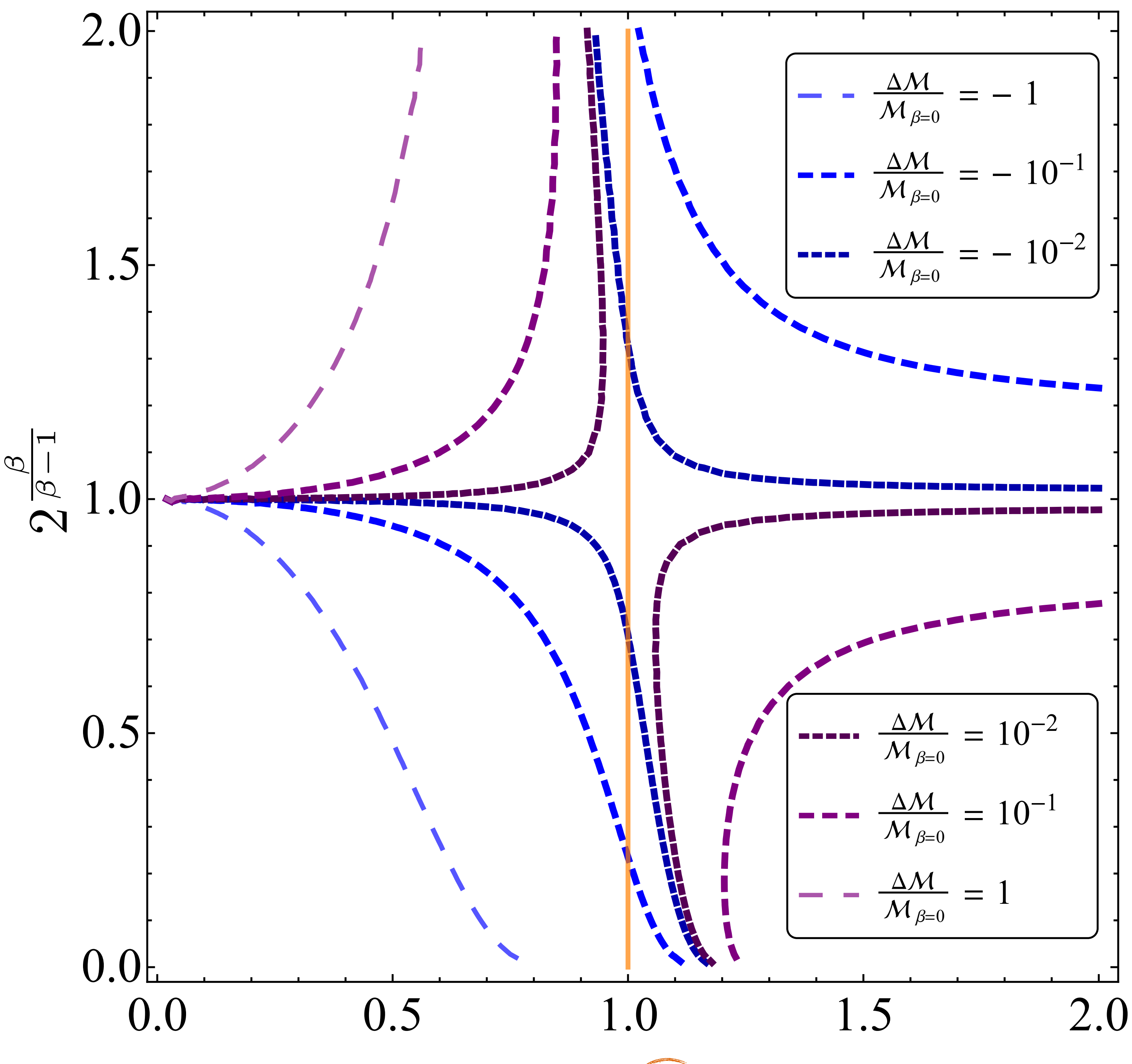
circular limit

10%

isotropic limit

80%

radial limit



CLOSE TO HALF-LIGHT RADIUS

WORKING HYPOTHESIS

I) CONST σ_{los} AROUND r_*

II) CONST β AROUND r_*

CONCLUSIONS STILL HOLD ALSO BEYOND SUCH FIDUCIAL SCENARIO IF ANISOTROPY IS NOT "FASTLY" VARYING @

work in progress, M. Petac, P.Ullio & M.V.

DENSITY ESTIMATOR IN DWARF SPHEROIDALS ?

MINIMAL DEPENDENCE ON ANISOTROPY

$$\frac{\rho_\beta - \rho_{\beta=0}}{\rho_{\beta=0}} = \text{const.}$$

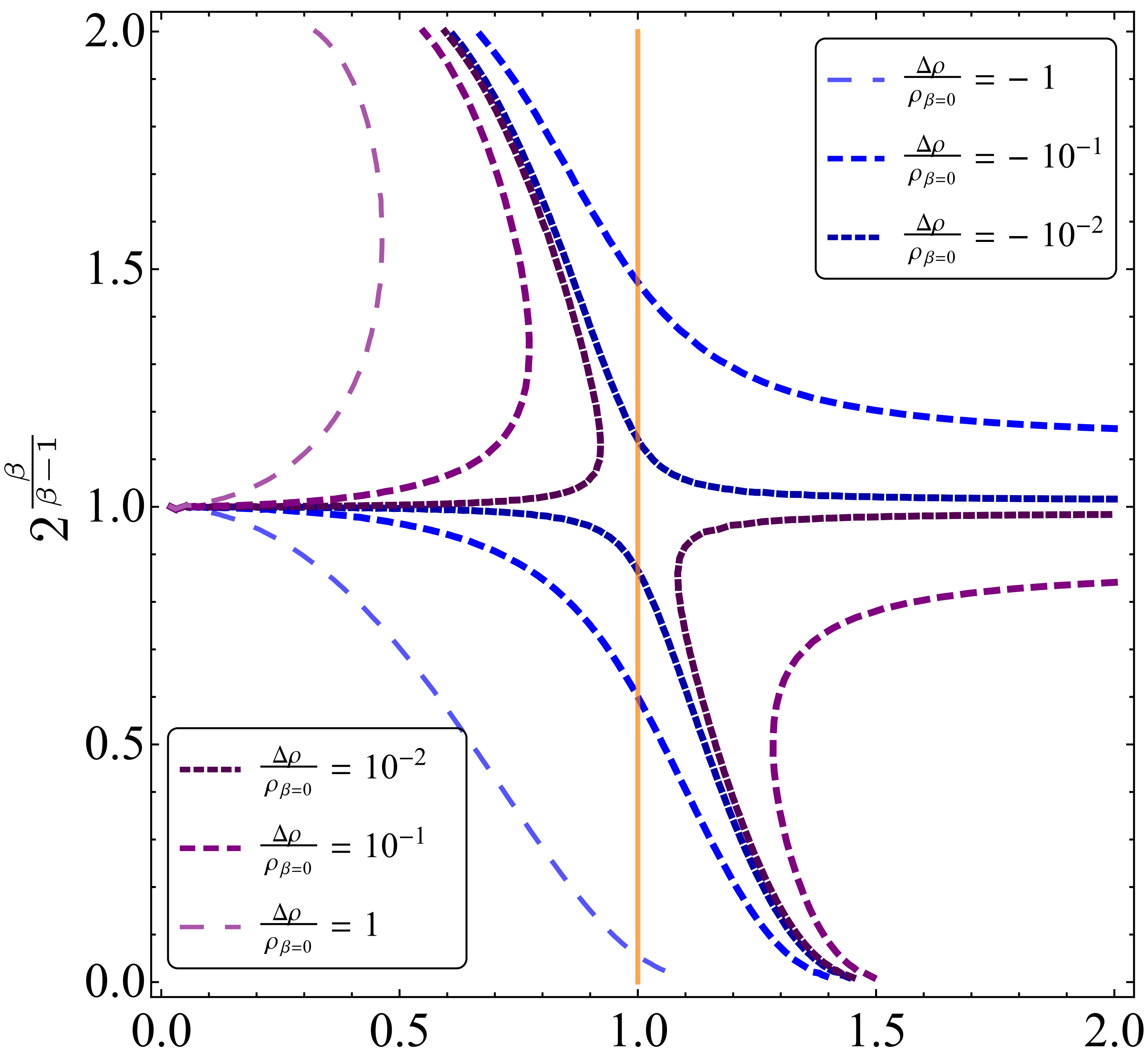
circular limit

< O(1)

isotropic limit

~ O(1)

radial limit



CLOSE TO 0.7 x HALF-LIGHT RADIUS

WORKING HYPOTHESIS

I) CONST σ_{los} AROUND r_{**}

II) CONST β AROUND r_{**}

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From a well-defined mass estimator we can compute the **minimal J-factor**.

DENSITY AS A SET OF POWER LAWS

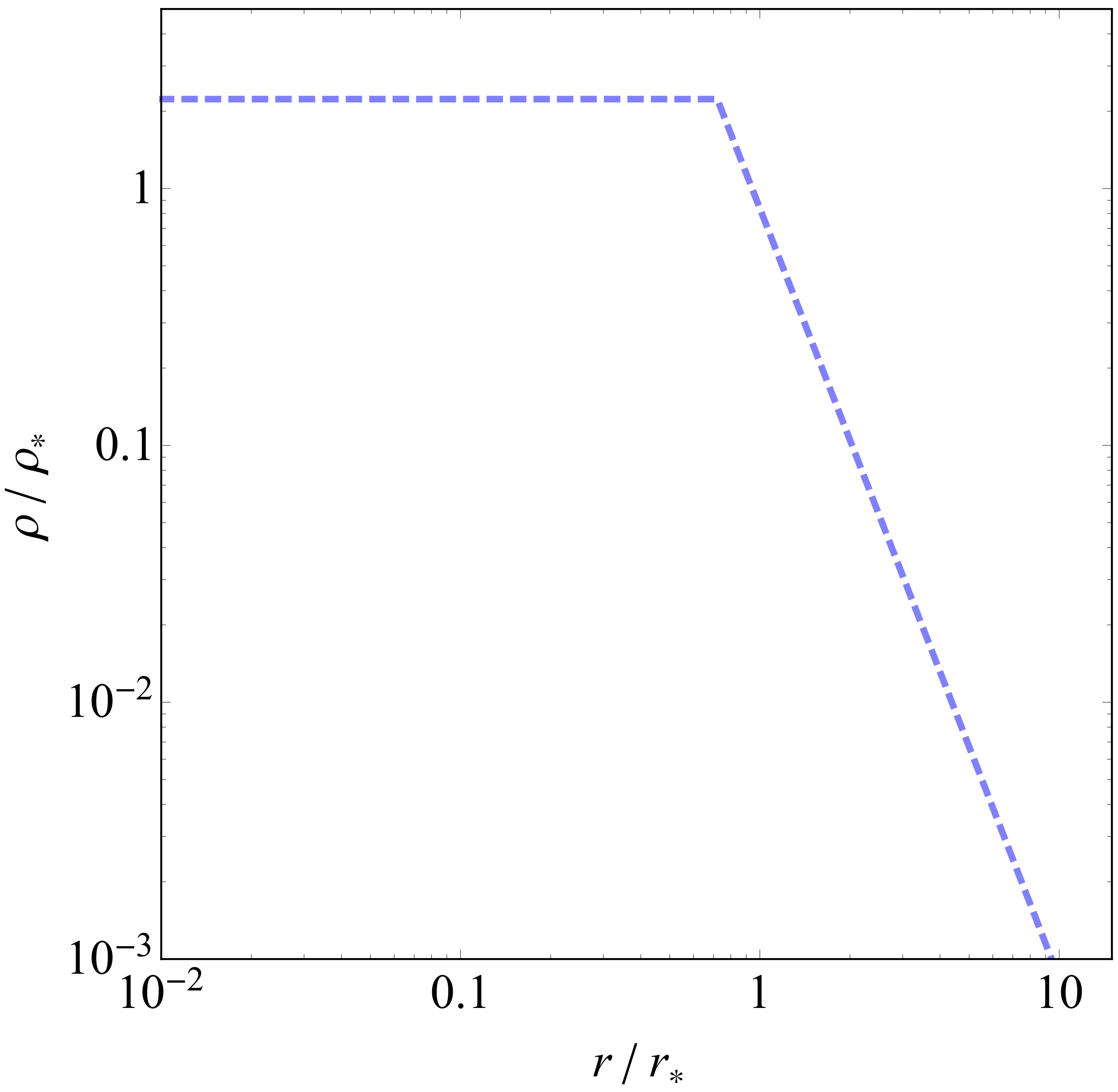
$$\rho \sim r^{-\alpha_i}$$

OVERALL NORMALIZATION FIXED BY

$$4\pi \int_0^{r_*} d\tilde{r}\, \tilde{r}^2 \rho(\tilde{r}) = \mathcal{M}(r_*)$$

MINIMIZE L.O.S. INTEGRAL OF DENSITY^2

$$\min_{\alpha_i} J\left[\alpha_i\right]$$



WITHIN THE INTRODUCED FIDUCIAL MODEL, ISOTROPIC ORBITS PREFERRED

PLUMMER + CONST SIGMA LOS + CONST BETA

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From a well-defined mass estimator we can compute the **minimal J-factor**.

DENSITY AS A SET OF POWER LAWS

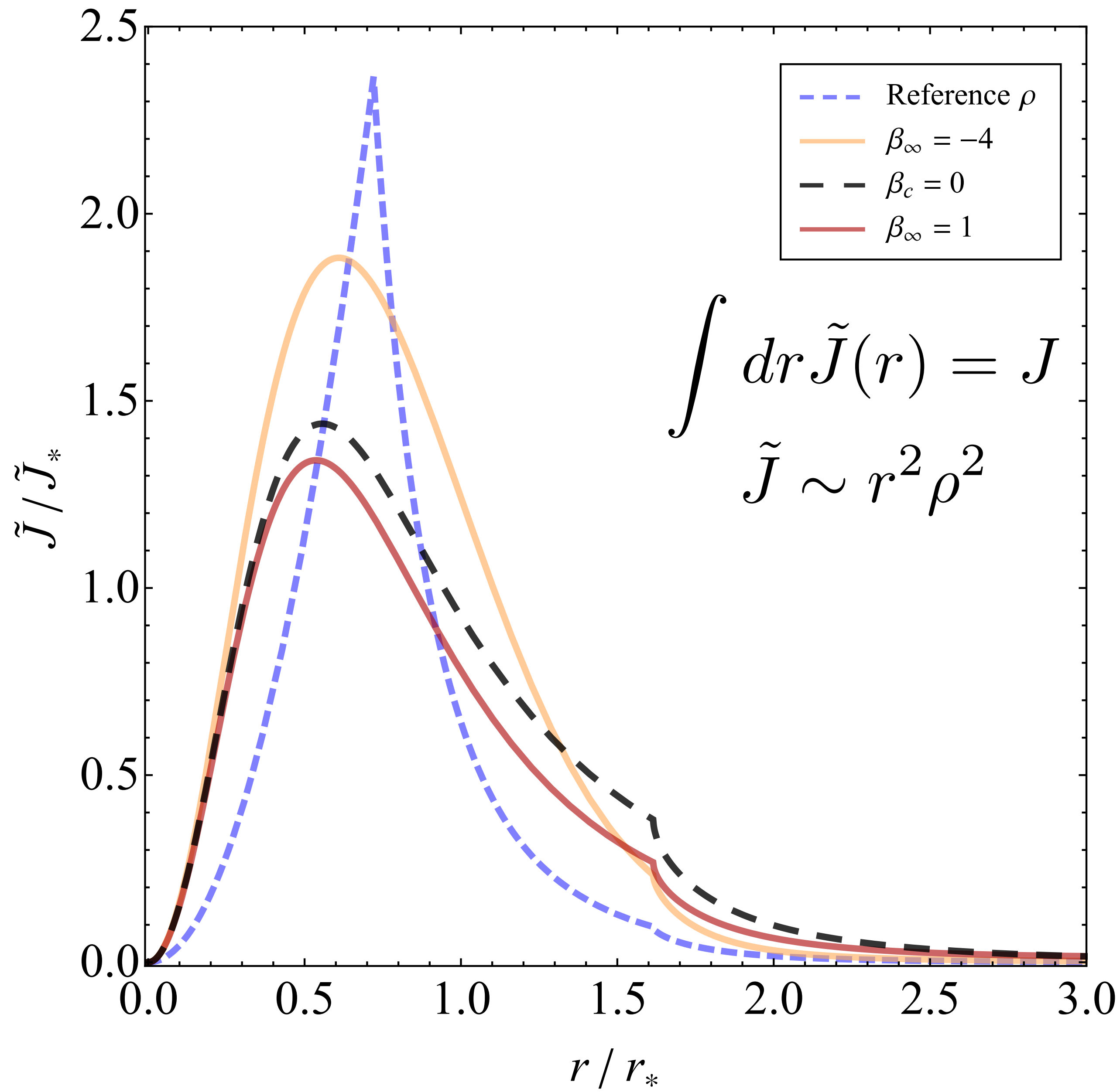
$$\rho \sim r^{-\alpha_i}$$

OVERALL NORMALIZATION FIXED BY

$$4\pi \int_0^{r_*} d\tilde{r}\, \tilde{r}^2 \rho(\tilde{r}) = \mathcal{M}(r_*)$$

MINIMIZE L.O.S. INTEGRAL OF DENSITY²

$$\min_{\alpha_i} J\left[\alpha_i\right]$$



PLUMMER + CONST SIGMA LOS + CONST BETA

WITHIN THE INTRODUCED FIDUCIAL MODEL, ISOTROPIC ORBITS PREFERRED

$$\beta_c \;\to\; \frac{\beta_0 + \beta_\infty (r/r_a)^\eta}{1 + (r/r_a)^\eta}$$ IMPACTS VERY MILDLY THE MINIMAL J-VALUE

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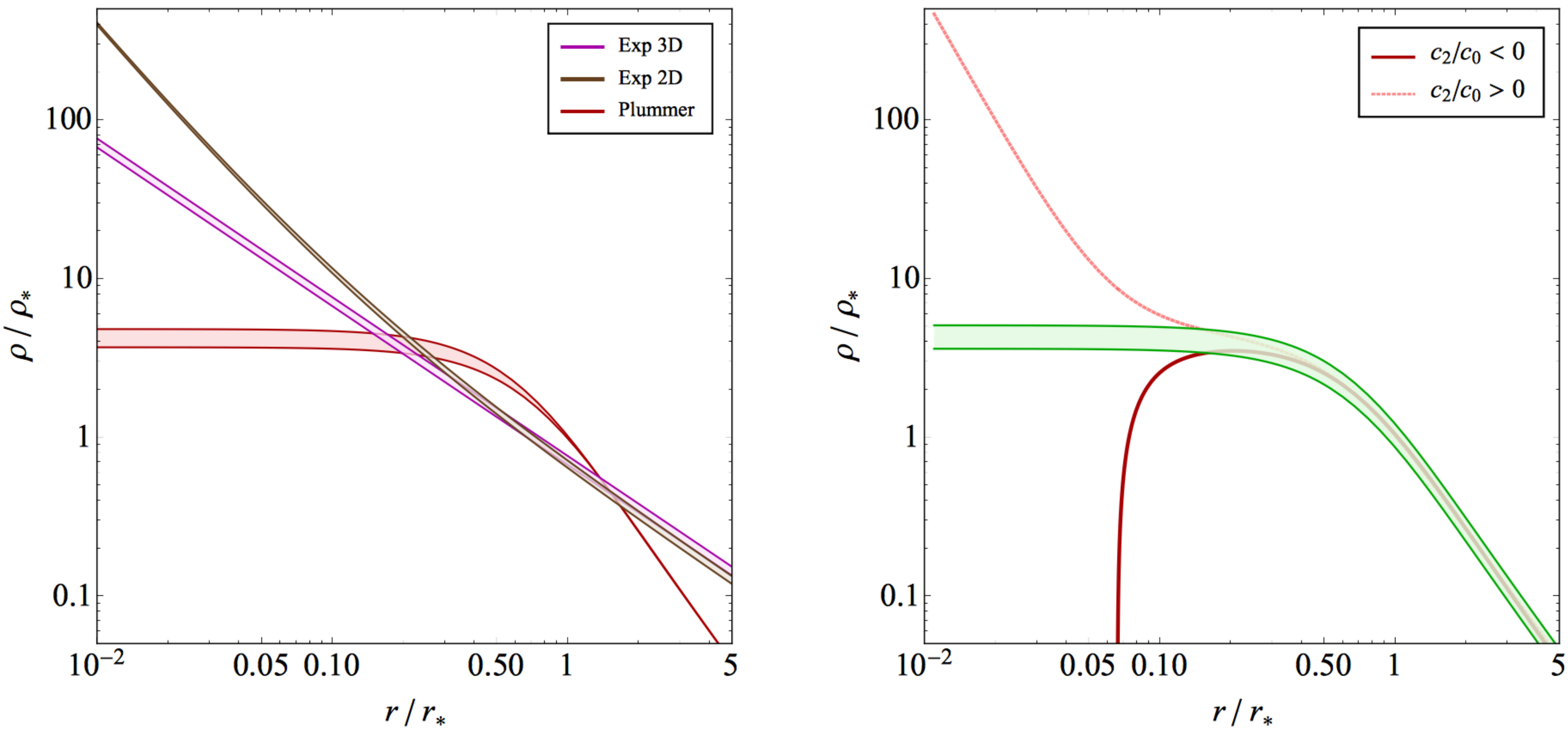
A **change of stellar profile** in our fiducial model **typically increases** the **minimal J**.



Conclusion on minimal J unchanged if we tilt the l.o.s. velocity dispersion profile:

- *an inner concave departure from constant sigma los increases J*
- *an inner convex departure from constant sigma los yields unphysical density*

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Departure from isotropic limit corresponds to cuspier profiles (therefore, higher J).

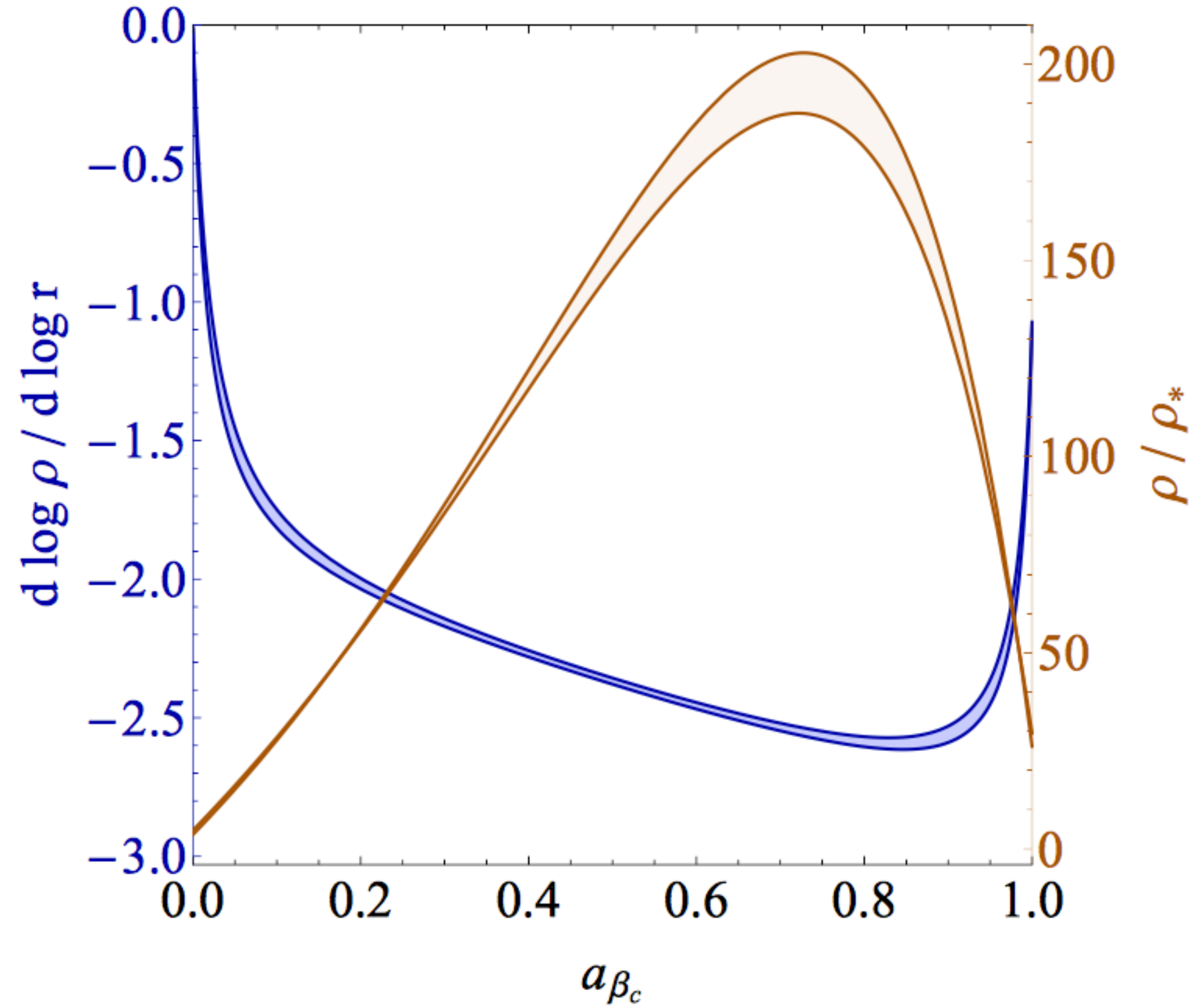
BOTTOM LINE FROM FIDUCIAL MODEL

In order to get an inner core in dSph DM density, a cored stellar profile + flattish los sigma require isotropic motion

However, discontinuity of this trend in the limit of perfectly circular stellar orbits:

$$\rho_{a_\beta \to 1}(r=0) \propto r^{-1}$$

$$\mathcal{M}_{a_\beta \to 1}(r=0) = \frac{4}{3}\frac{\sigma^2_{los} R_{1/2}}{G_N}$$



A PHENOMENOLOGICALLY MOTIVATED INNER CUT-OFF ON THE DENSITY SMOOTHES THE DISCONTINUITY WITH THE LIMIT CASE OF NEGATIVE INFINITE ANISOTROPY

IN THIS APPROACH THE MINIMAL J-FACTOR CORRESPONDS NOW TO CIRCULAR-LIKE ORBITS!

Dwarf “spheroidals” —> J (D) - factors in spherical symmetry !

$$J = 2\pi \int_0^{\cos\psi_{max}} d\cos\psi \int_{\ell_-(\psi,\mathcal{R})}^{\ell_+(\psi,\mathcal{R})} d\ell\, \rho^2\big(r(\psi,\ell)\big) \;\rightarrow\; J = 4\pi \int_0^{\mathcal{R}} dr\, \rho^2(r) \underline{\mathcal{A}(r/\mathcal{D};\psi_{max})}$$

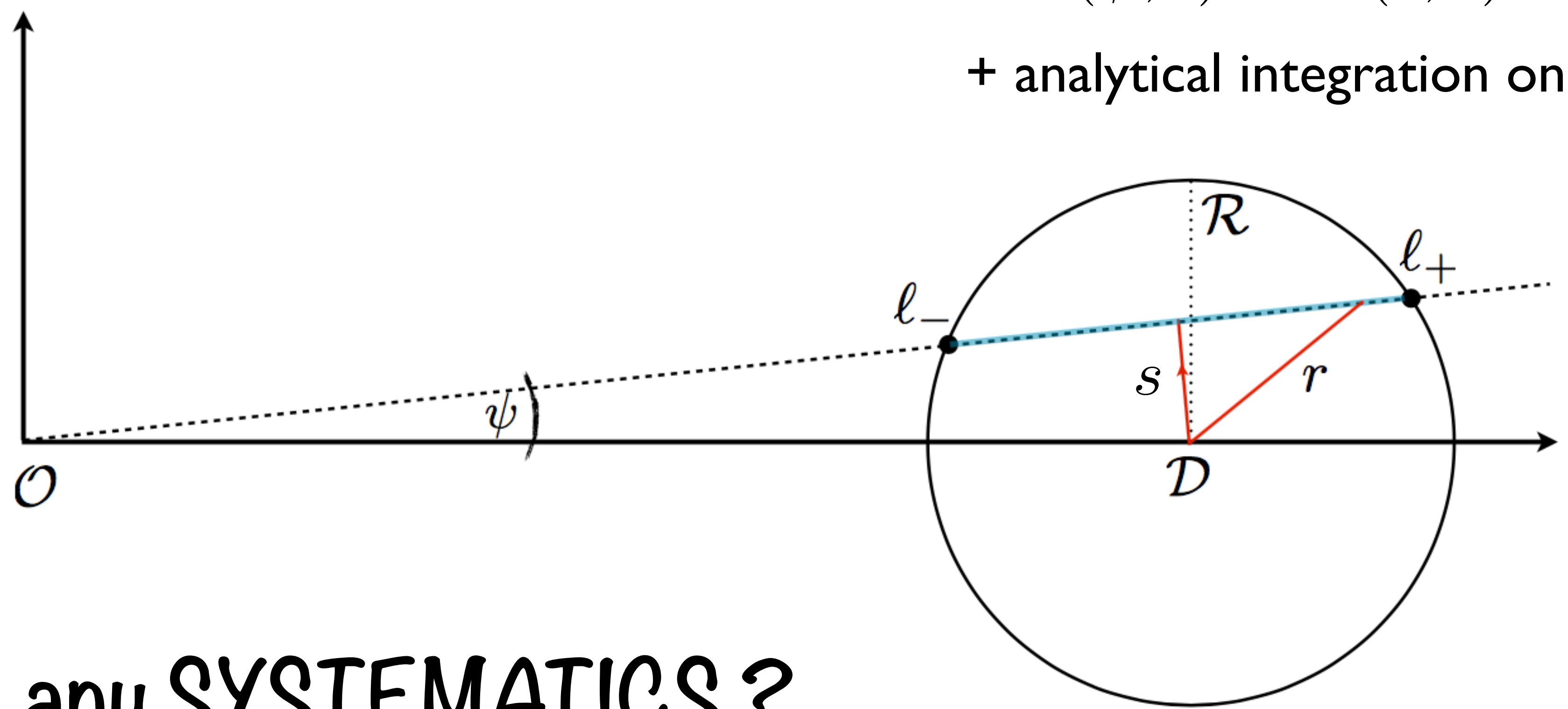
$$\mathcal{A}(r/\mathcal{D};\psi_{max}) \underset{\text{small } \psi_{max}}{\simeq} r^2/\mathcal{D}^2$$

NOTE: for all details, see for example appendix B in *JCAP 1607 (2016) 025*

change of coordinates

$$(\psi,\ell) \rightarrow (s,r)$$

+ analytical integration on *s*



$\mathcal{D}$	*distance from obs*
$\mathcal{R}$	*tidal / outer halo cut*
ψ_{max}	*obs angular aperture*
$\rho(r)$	*DM halo density*

... any SYSTEMATICS ?

DIFFERENT ESTIMATES FOR MW DWARF DISTANCES.

—> see, e.g., *Mateo ‘98* and *McConnachie ‘12*

HALO TRUNCATION IS ESSENTIALLY UNKNOWN ...

—> recent investigation in *Geringer-Sameth et al. ‘15*

... AS BOOST FACTORS FROM SUBSTRUCTURES!

—> DM signal enhancement! See *Strigari et al. ‘06, Bovy ‘09*

Dwarf "spheroidals" —> J (D) - factors in spherical symmetry !

$$J = 2\pi \int_0^{\cos\psi_{max}} d\cos\psi \int_{\ell_-(\psi,\mathcal{R})}^{\ell_+(\psi,\mathcal{R})} d\ell\, \rho^2\left(r\left(\psi,\ell\right)\right) \;\to\; J = 4\pi \int_0^{\mathcal{R}} dr\, \rho^2(r)\underline{\mathcal{A}\left(r/\mathcal{D};\psi_{max}\right)}$$

$$\mathcal{A} \underset{\text{small } \psi_{max}}{\approx} r^2/\mathcal{D}^2$$

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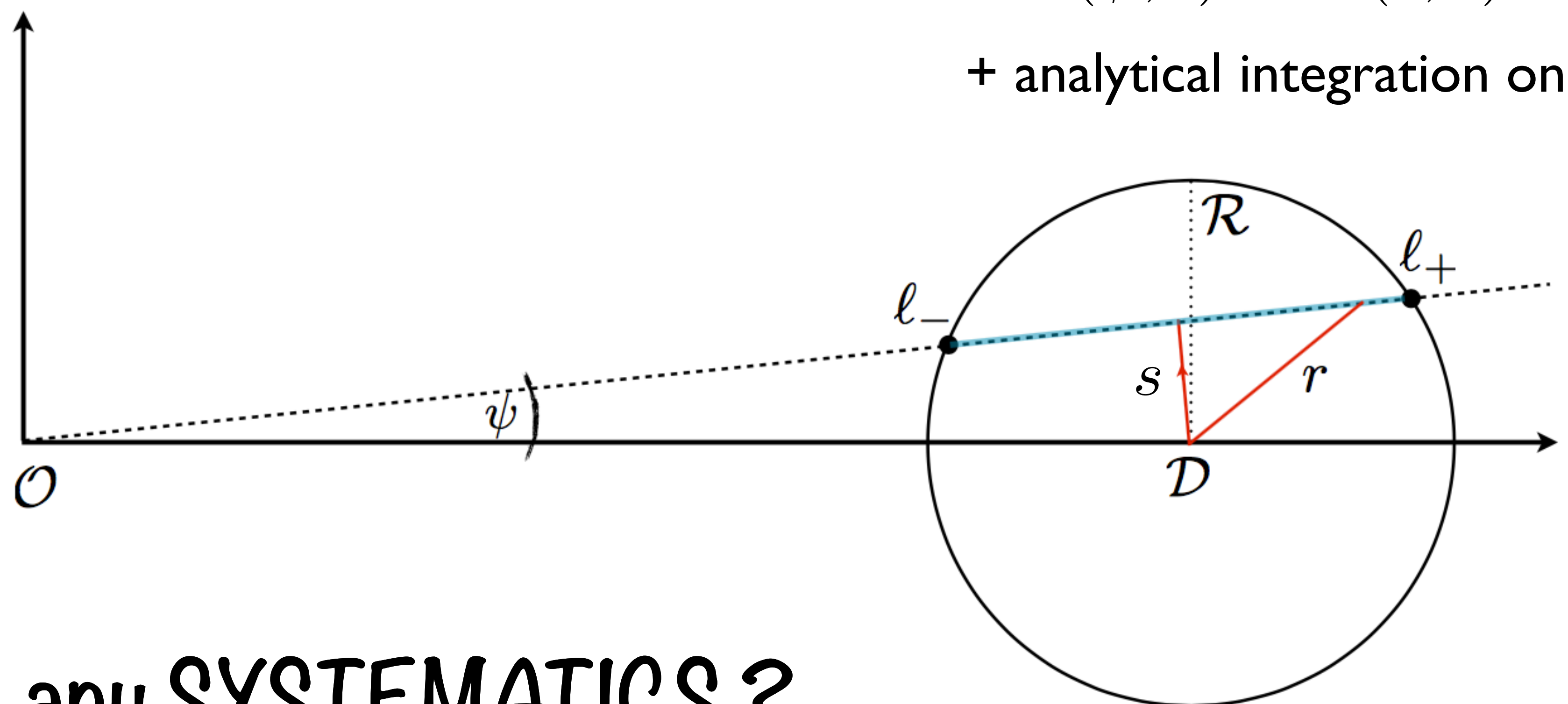
change of coordinates

$$(\psi,\ell) \;\to\; (s,r)$$

+ analytical integration on s



$\mathcal{D}$	*distance from obs*
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ψ_{max}	*obs angular aperture*
$\rho(r)$	*DM halo density*

... any SYSTEMATICS ?

DM HALO COMMONLY STUDIED WITH SPHERICAL JEANS EQ. :

$$\sigma_{los} = \sigma_{los}(\mathcal{M},\beta,I)$$

$\mathcal{M}$ *~ Dark Matter* β *= Stellar Anisotropy* I *= Surface Brightness*

DEGENERACIES *AMONG 3 PARAMETRIC PROFILES!*

Dwarf "spheroidals" —> J (D) - factors in spherical symmetry !

$$J = 2\pi \int_0^{\cos\psi_{max}} d\cos\psi \int_{\ell_-(\psi,\mathcal{R})}^{\ell_+(\psi,\mathcal{R})} d\ell\, \rho^2\left(r\left(\psi,\ell\right)\right) \;\rightarrow\; J = 4\pi \int_0^{\mathcal{R}} dr\, \rho^2(r)\mathcal{A}\left(r/\mathcal{D};\psi_{max}\right)$$

$$\underset{\psi_{max}}{\overset{\text{small}}{\wr}}\quad r^2/\mathcal{D}^2$$

NOTE: for all details, see for example appendix B in *JCAP 1607 (2016) 025*

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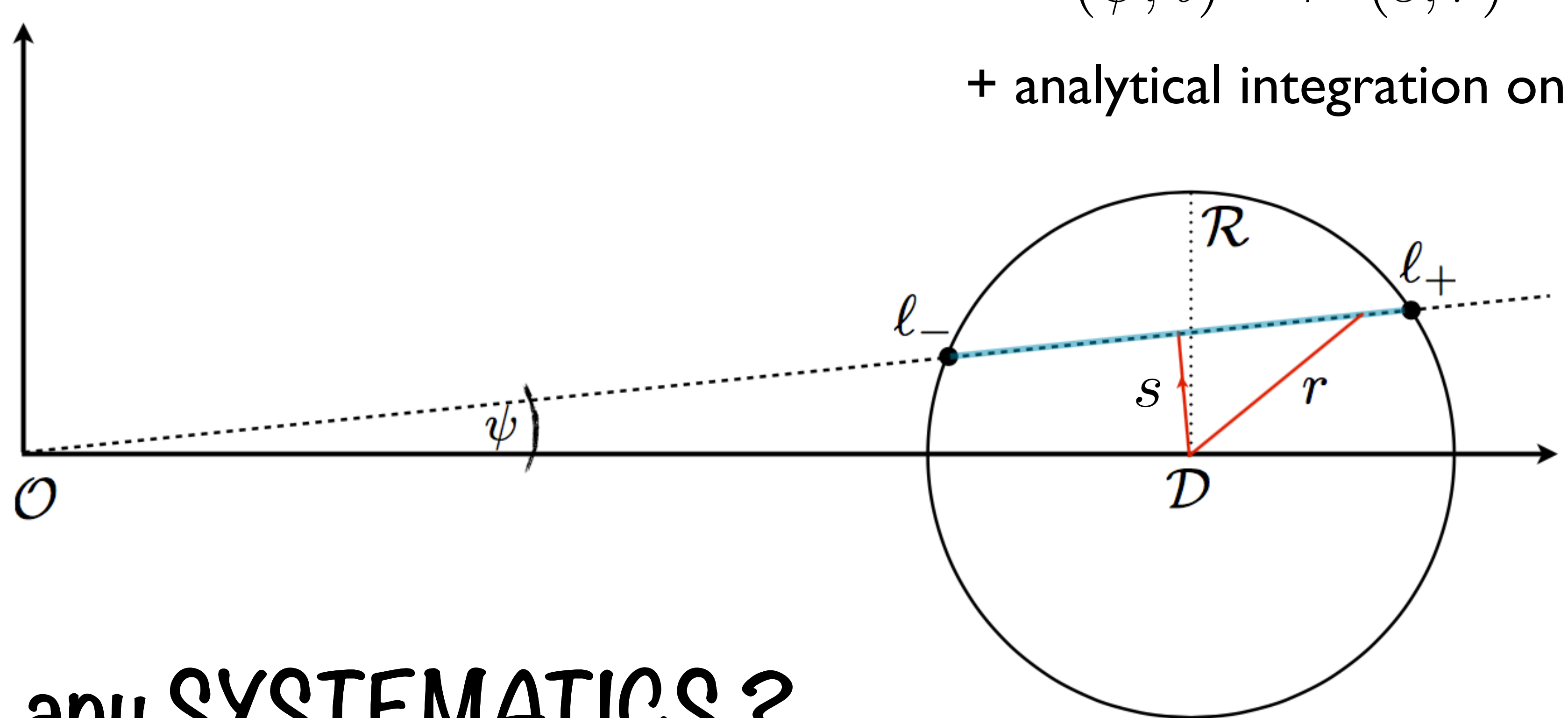

$\mathcal{D}$	*distance from obs*
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ψ_{max}	*obs angular aperture*
$\rho(r)$	*DM halo density*

... any SYSTEMATICS ?

NUMERICAL EVIDENCES FOR AN OPTIMAL CHOICE :

$$\psi_{max} \simeq \arctan\left(2\,R_{1/2}/\mathcal{D}\right) \sim 0.5^\circ$$

—> see, e.g.,*Walker et al. '11, Charbonnier et al. '11*

COMPROMISE BTW UNCERTAINTIES & FLUX DETECTION

... ANY FURTHER INSIGHT (SEE,E.G.,THE MASS AT $r_{1/2}$) ?