Dark Matter in the Milky Way:

Distribution, uncertainties and the impact for the search of new physics

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in collaboration with A. Cuoco, F. Iocco, E. Karukes, R. Trotta & A. Geringer-Sameth

Iocco & MB 2017 / MB + 2019 / Karukes, MB + 2019 / Karukes, MB + (in prep)

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27/03/2019

Outline

Introduction

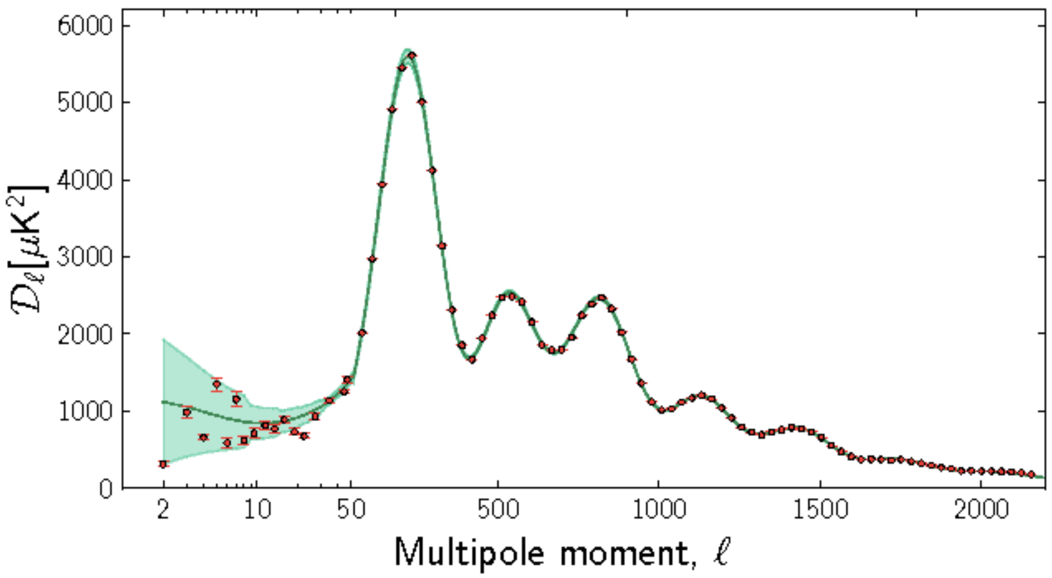
Three Main Blocks:

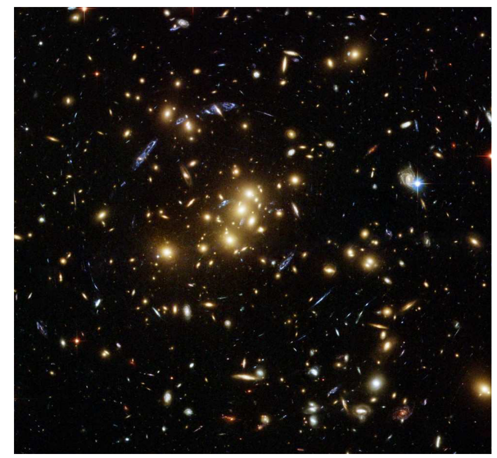
- Reconstruction of the DM density profile in the MW
- Astrophysical uncertainties that affect the determination of the DM profile
- DM density profile in the Galactic bulge region

Dark matter

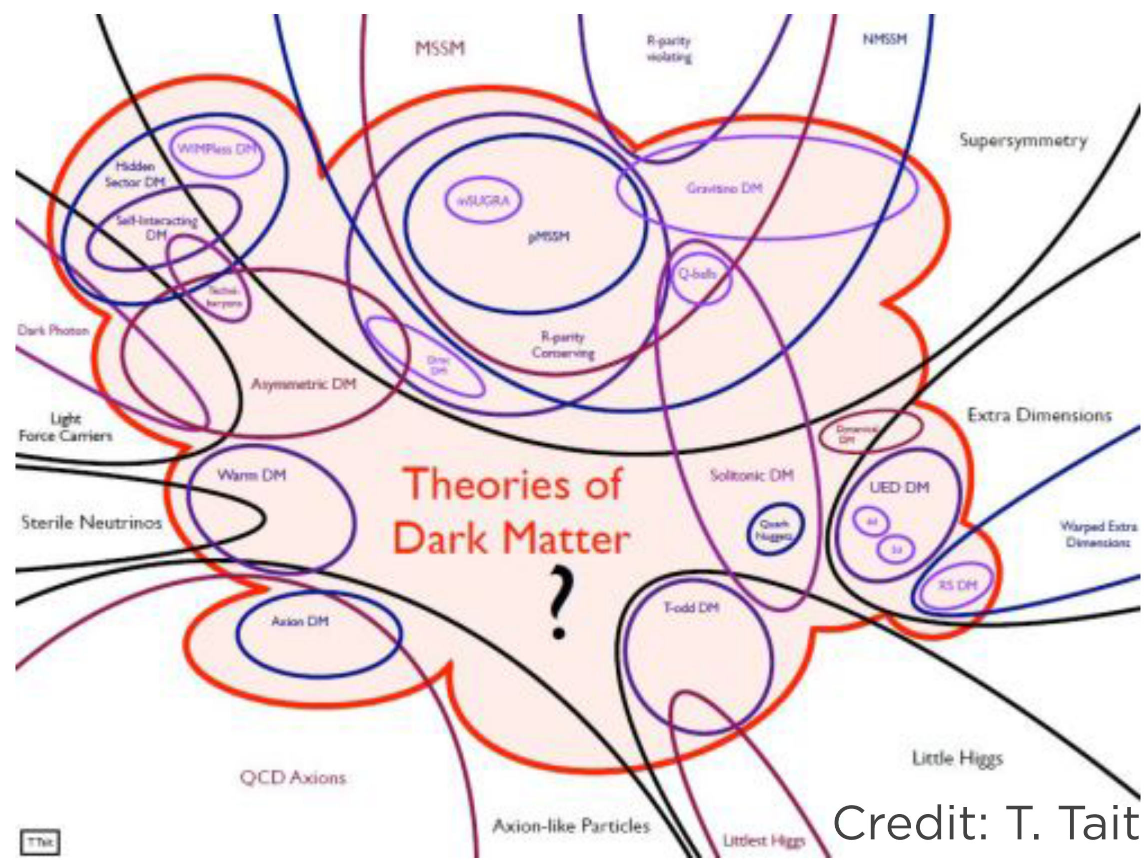
Evidences over large range of scales

physical size





Nature still unknown



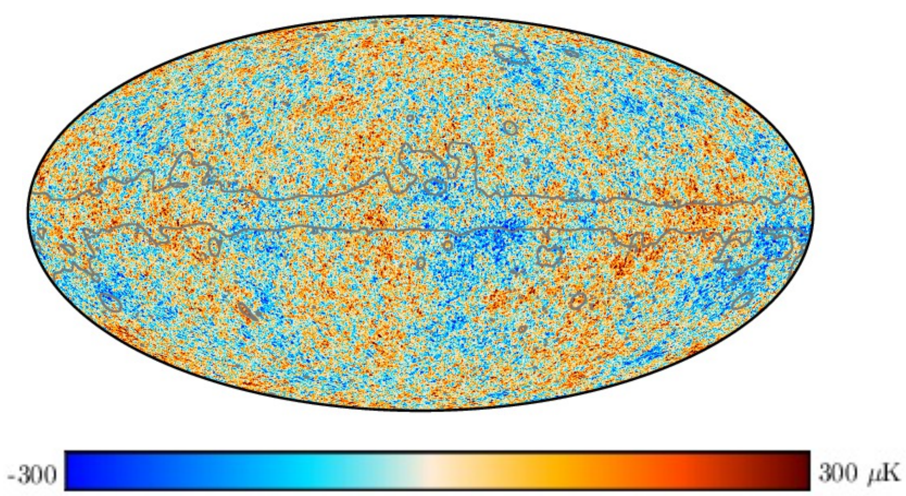
Credit: T. Tait

Dark matter

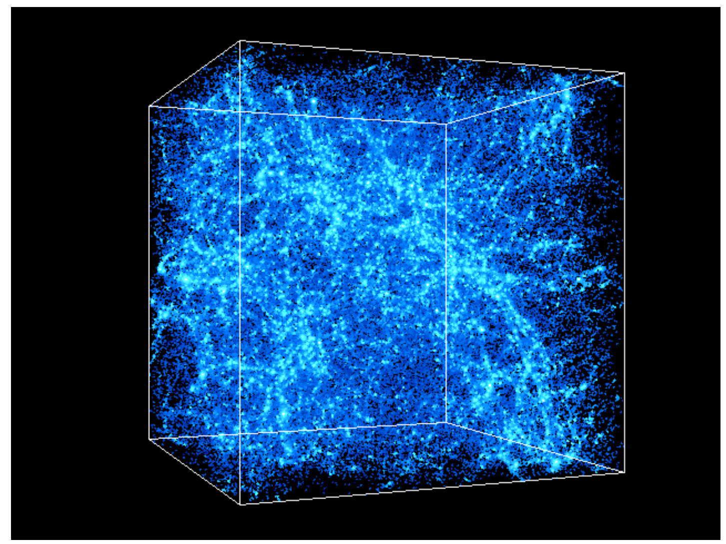
A crucial “brick” in structure formation

age of Universe

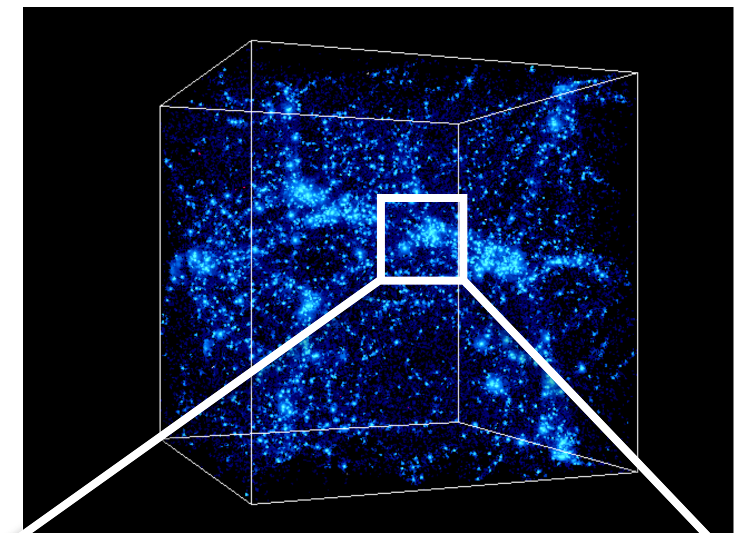
z = 1100

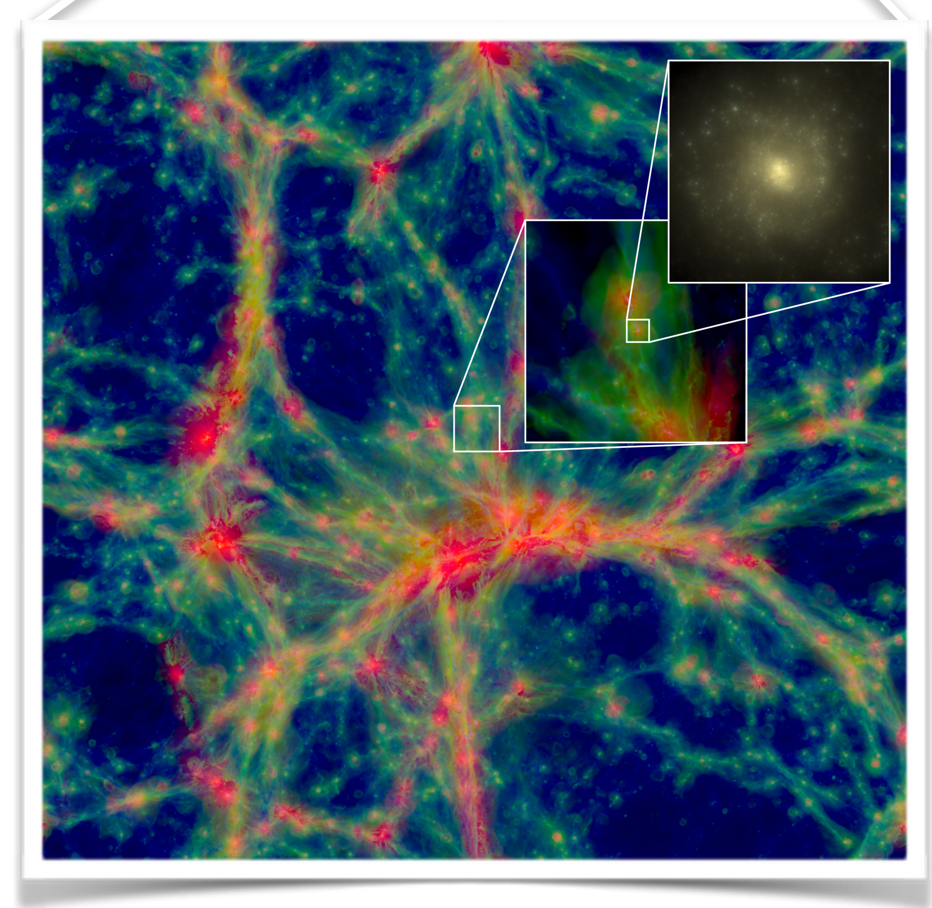


z = 3



z = 0



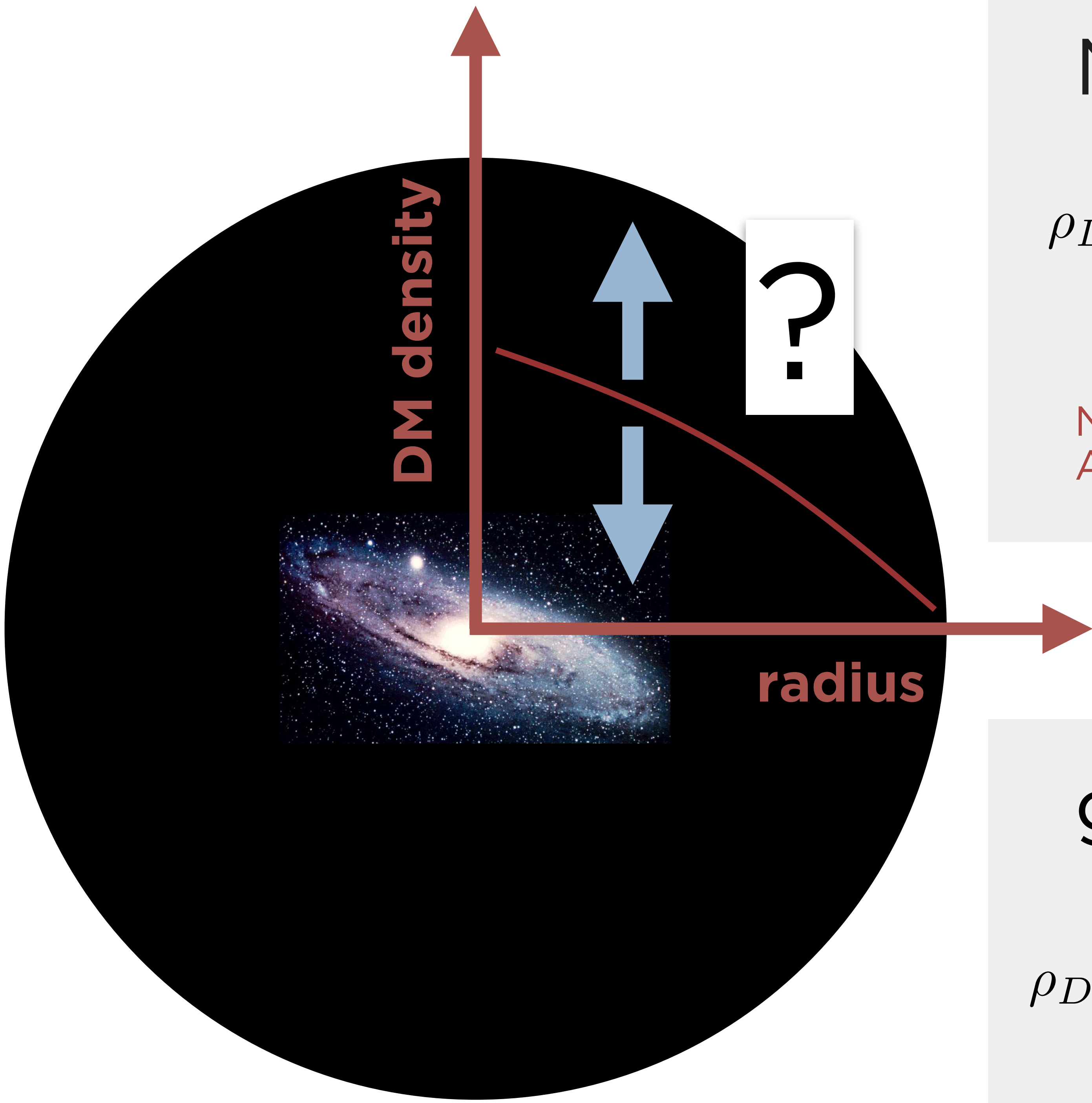


- Before recombination:
  baryonic over-densities couldn’t grow due to radiation pressure of photons

- After recombination:
  baryons fell into deep DM potential well

DM halo profile

Theory



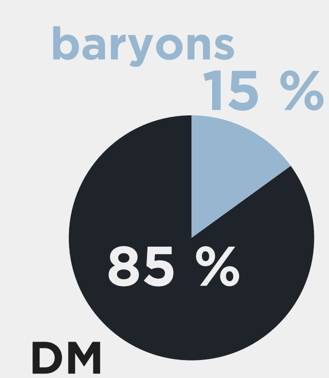
NFW

$$\rho_{DM}(r) = \frac{\rho_s}{\left(\frac{r}{R_s}\right)\left(1+\frac{r}{R_s}\right)^2}$$

Navarro, Frenk & White
ApJ 462 (1996)

generalised NFW

$$\rho_{DM}(r) = \frac{\rho_s}{\left(\frac{r}{R_s}\right)^{\gamma}\left(1+\frac{r}{R_s}\right)^{3-\gamma}}$$



core/cusp profiles?

DM halo profile

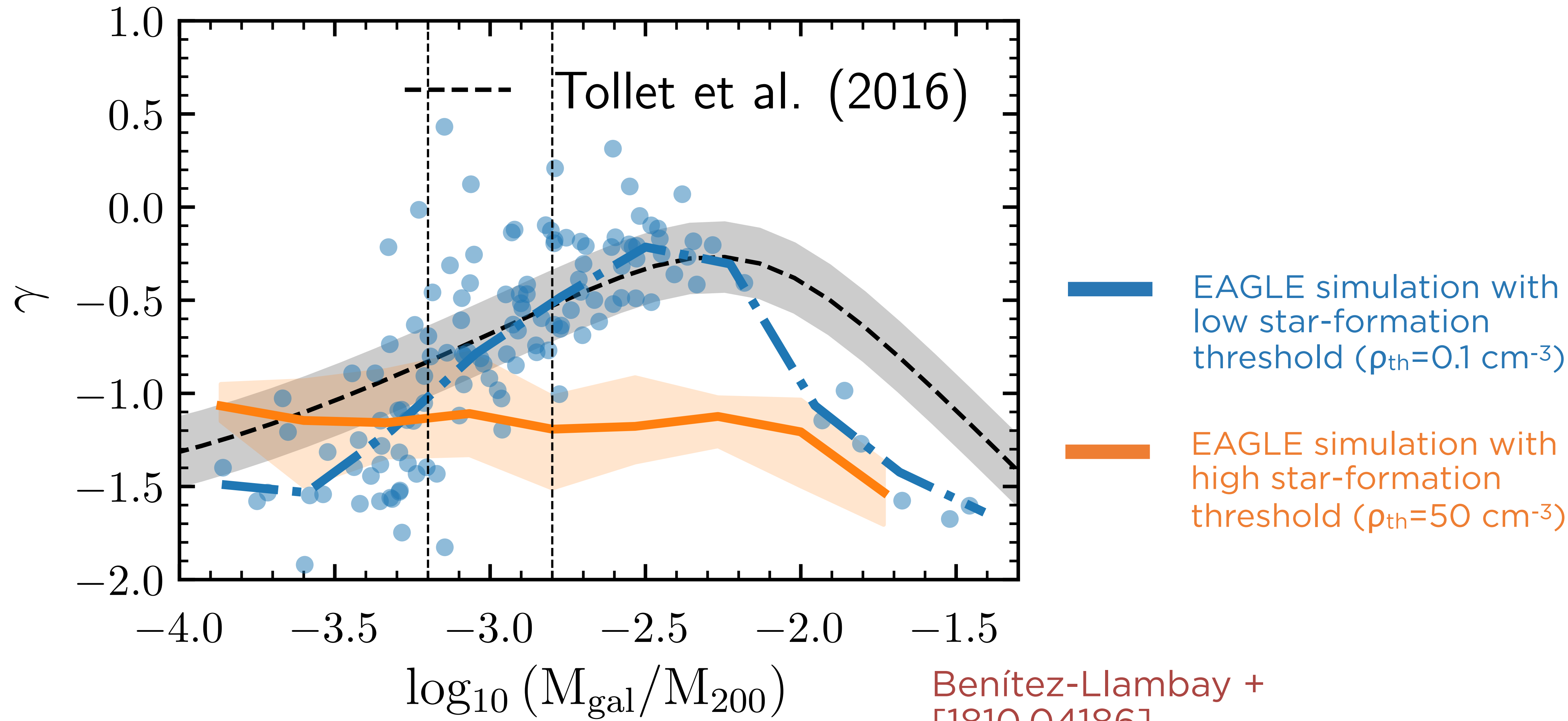
Theory

The precise effect of baryonic feedback processes on the distribution of DM is unknown

Inner slope DM density profile = $\gamma = +\left.\frac{\mathrm{d}\ln\rho_{\mathrm{DM}}}{\mathrm{d}\ln R}\right|_{R\to 0}$

Cusp: γ ~ -1

Core: γ ~ 0

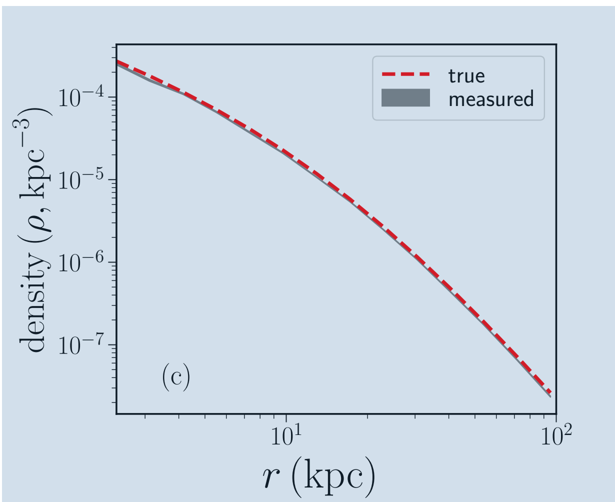


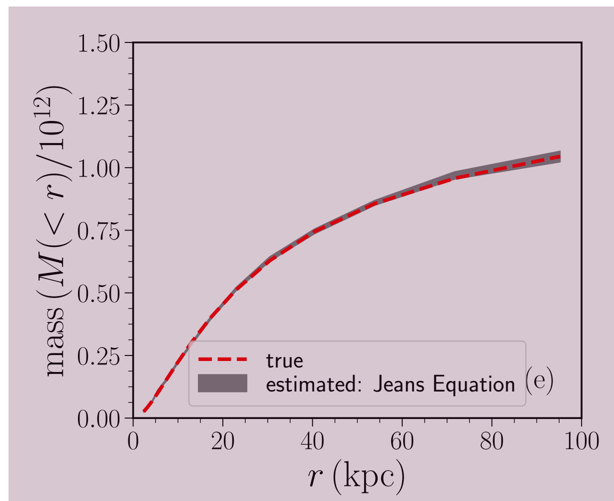
Benítez-Llambay + [1810.04186]

DM halo profile

Observations

Jeans analysis

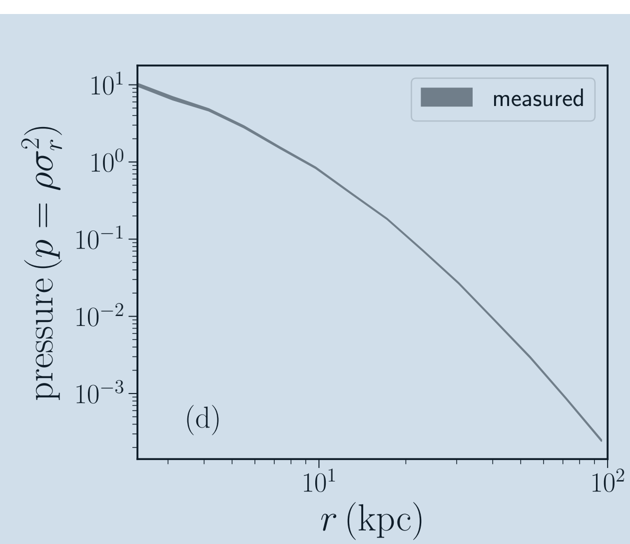


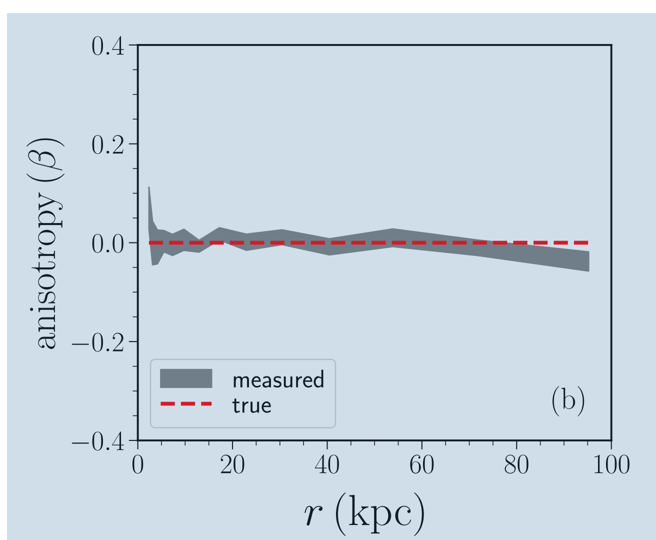


input

output

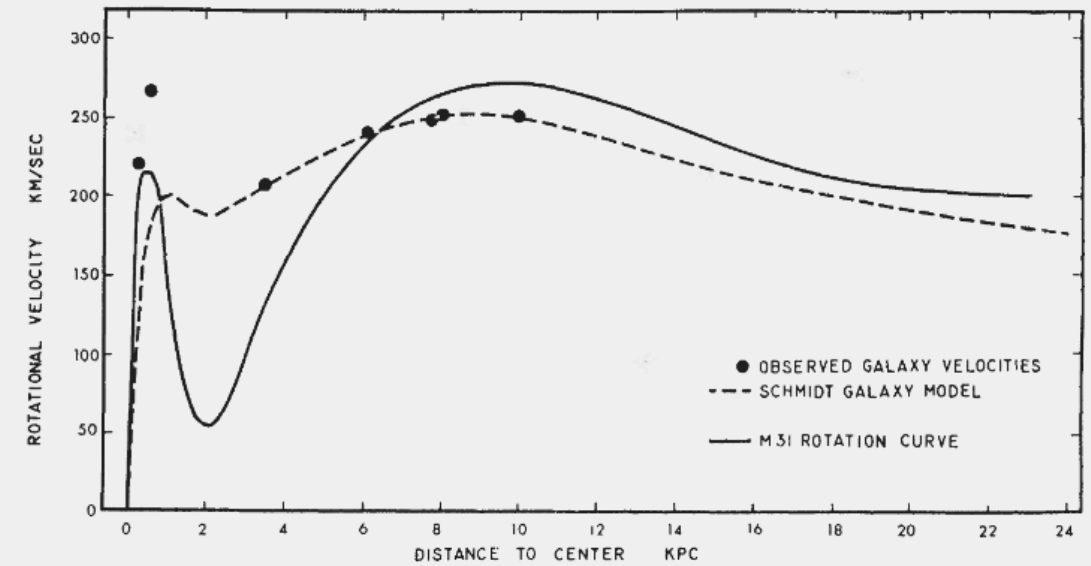
$$\frac{1}{\rho}\frac{\mathrm{d}\left(\rho\sigma_r^2\right)}{\mathrm{d}r} + 2\beta(r)\frac{\sigma_r^2}{r} = -\frac{GM_{\mathrm{tot}}(<r)}{r^2}$$





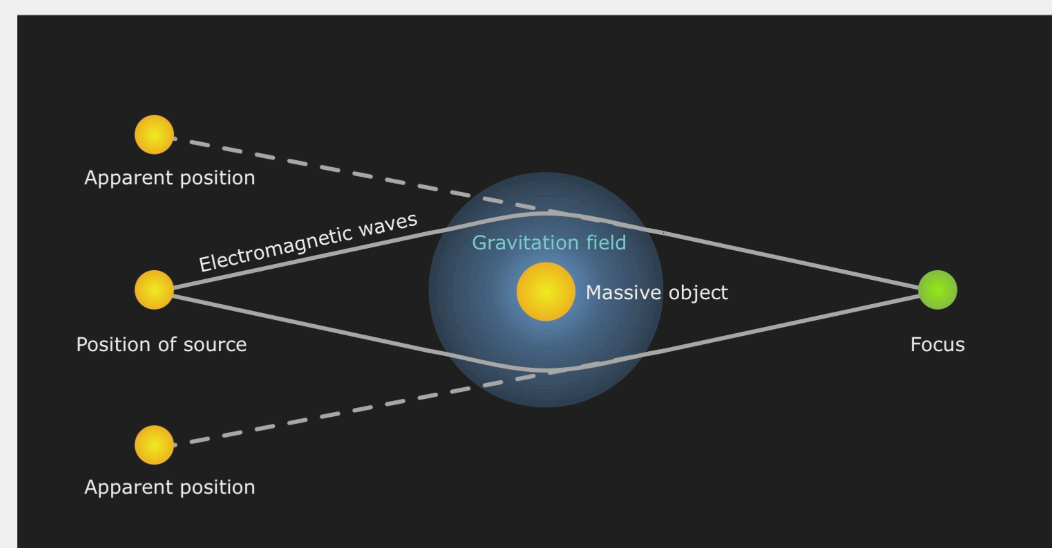
Kafle +
MNRAS 475 (2018)

Rotation Curve



Rubin & Ford
ApJ 159 (1970)

Gravitational Lensing

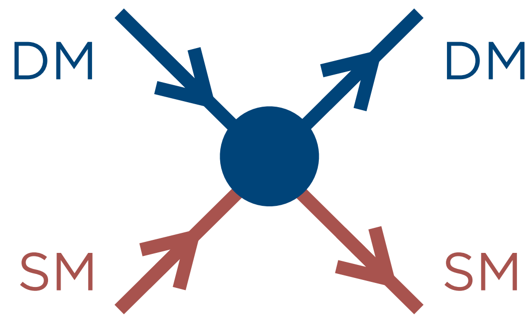


Why it is important?

Direct/Indirect WIMP searches

Simplified version

Direct



Recoil spectrum for DM-nucleus interaction:

$$\frac{\mathrm{d}R}{\mathrm{d}E} \sim C_{\mathrm{PP}}\, \rho_0 \int_{v>v_{\mathrm{min}}} \mathrm{d}^3 v\, \frac{f(\mathbf{v},t)}{v}$$

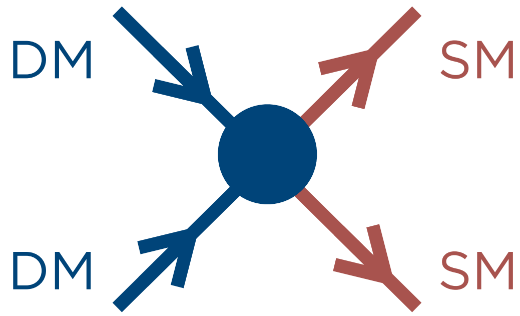
Impact of velocity distribution function:

Bozorgnia & Bertone Int.J.Mod.Phys. A32 (2017)

Bozorgnia + JCAP 1605 (2016)

Dependence on astrophysics

Indirect



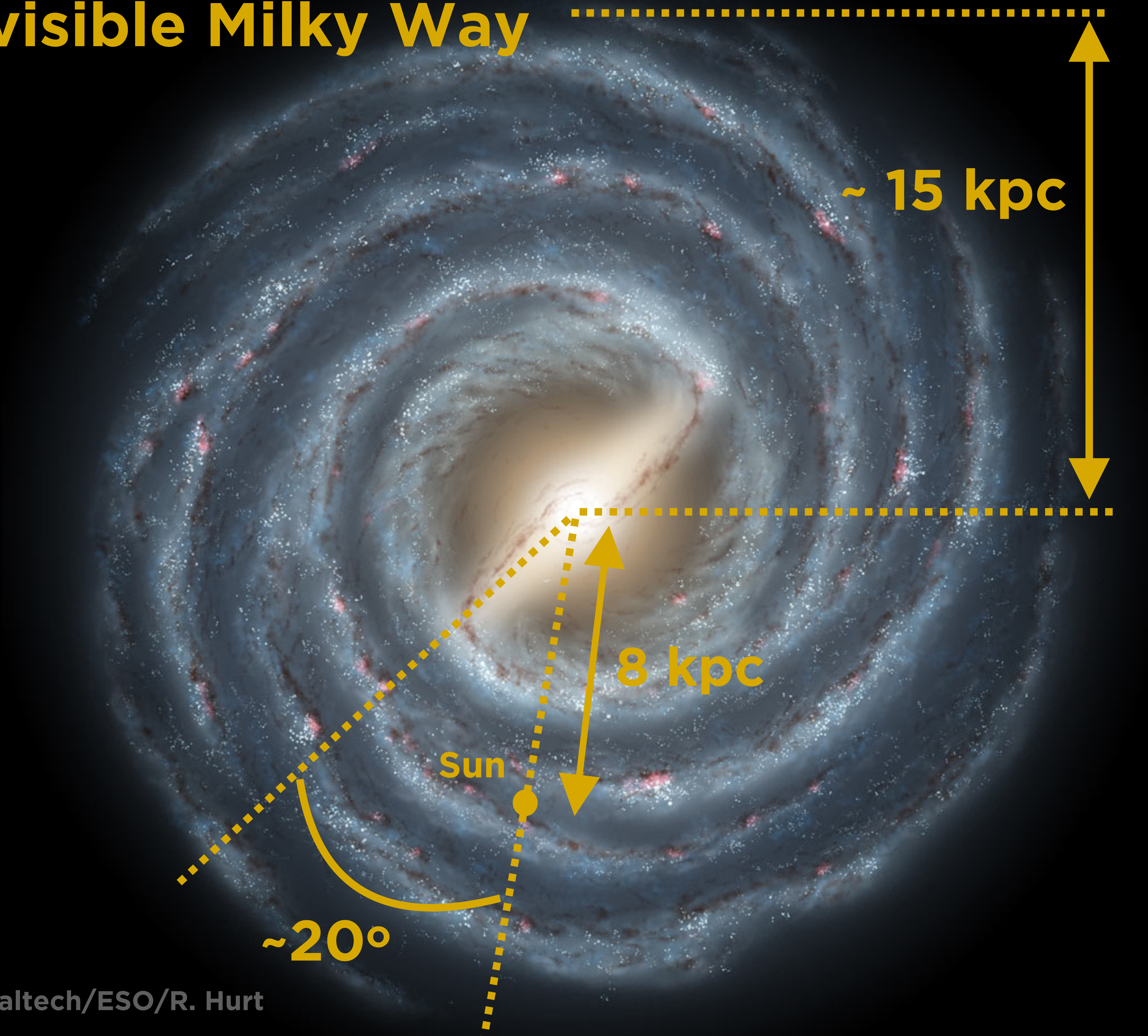
Flux due to DM self-annihilation:

$$\Phi_{\mathrm{DM}} \sim \Phi_{\mathrm{PP}} \int_{\mathrm{l.o.s}} \mathrm{d}l\ \rho_{DM}^2$$

Dependence on astrophysics

The visible Milky Way

The visible Milky Way

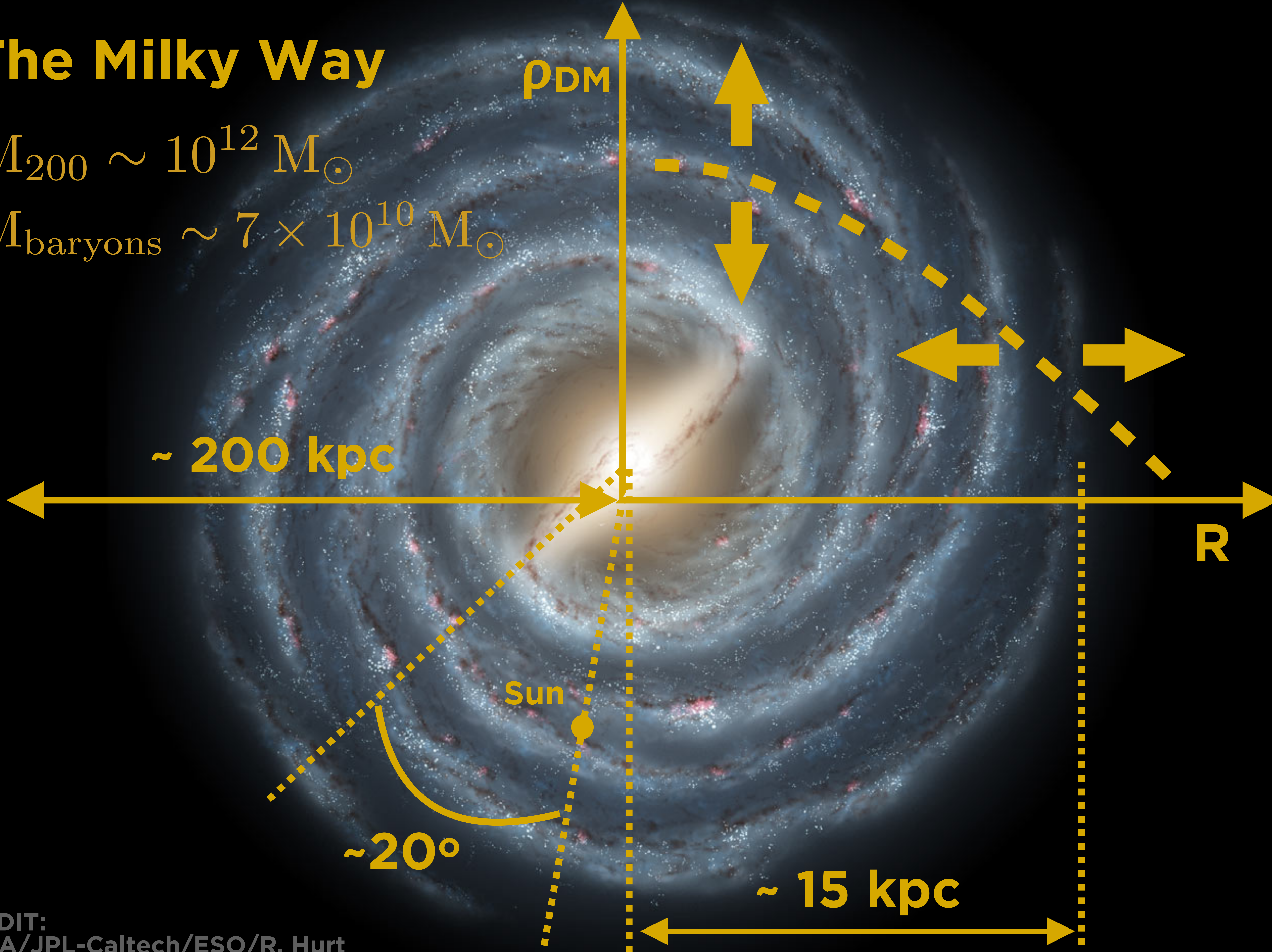


CREDIT:
NASA/JPL-Caltech/ESO/R. Hurt

The Milky Way

$M_{200} \sim 10^{12}\,M_\odot$

$M_{baryons} \sim 7 \times 10^{10}\,M_\odot$



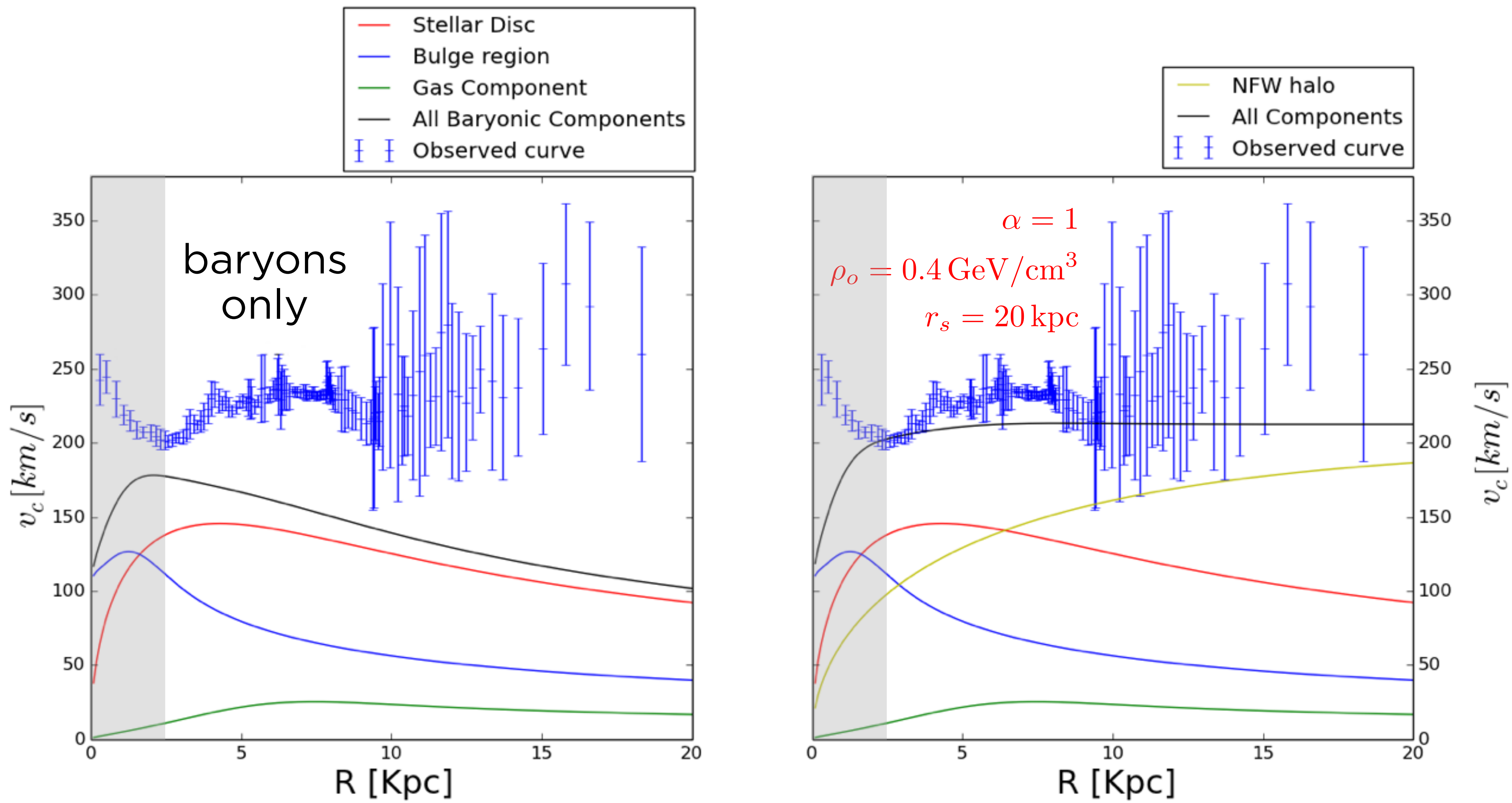
CREDIT:
NASA/JPL-Caltech/ESO/R. Hurt

Determination of the dark matter density profile of the Milky Way

(and how much to trust it)

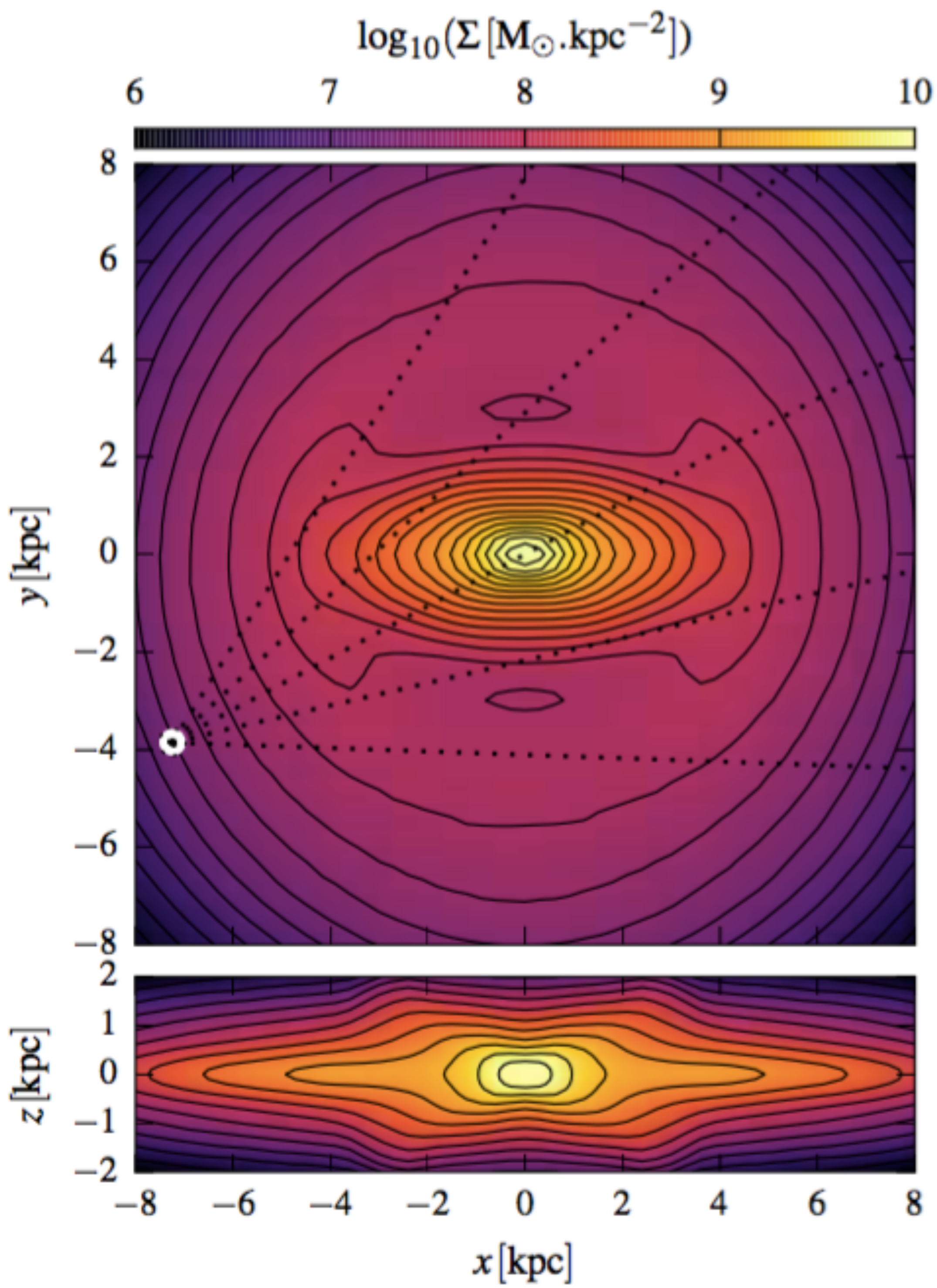
How to determine DM density profile?

Rotation Curve method



How to determine DM density profile?

Rotation Curve method



Assumptions:

- ~~Rotationally supported~~
- ~~Objects move in circular orbits around the GC~~
- ~~The gravitational potential is axisymmetric~~

Only applies for R > 2.5 kpc

Face-on (upper) and side-on (lower) projection of the 3D density of the Galactic bulge

Portail + MNRAS 465 (2017)

How to determine DM density profile?

Rotation Curve method

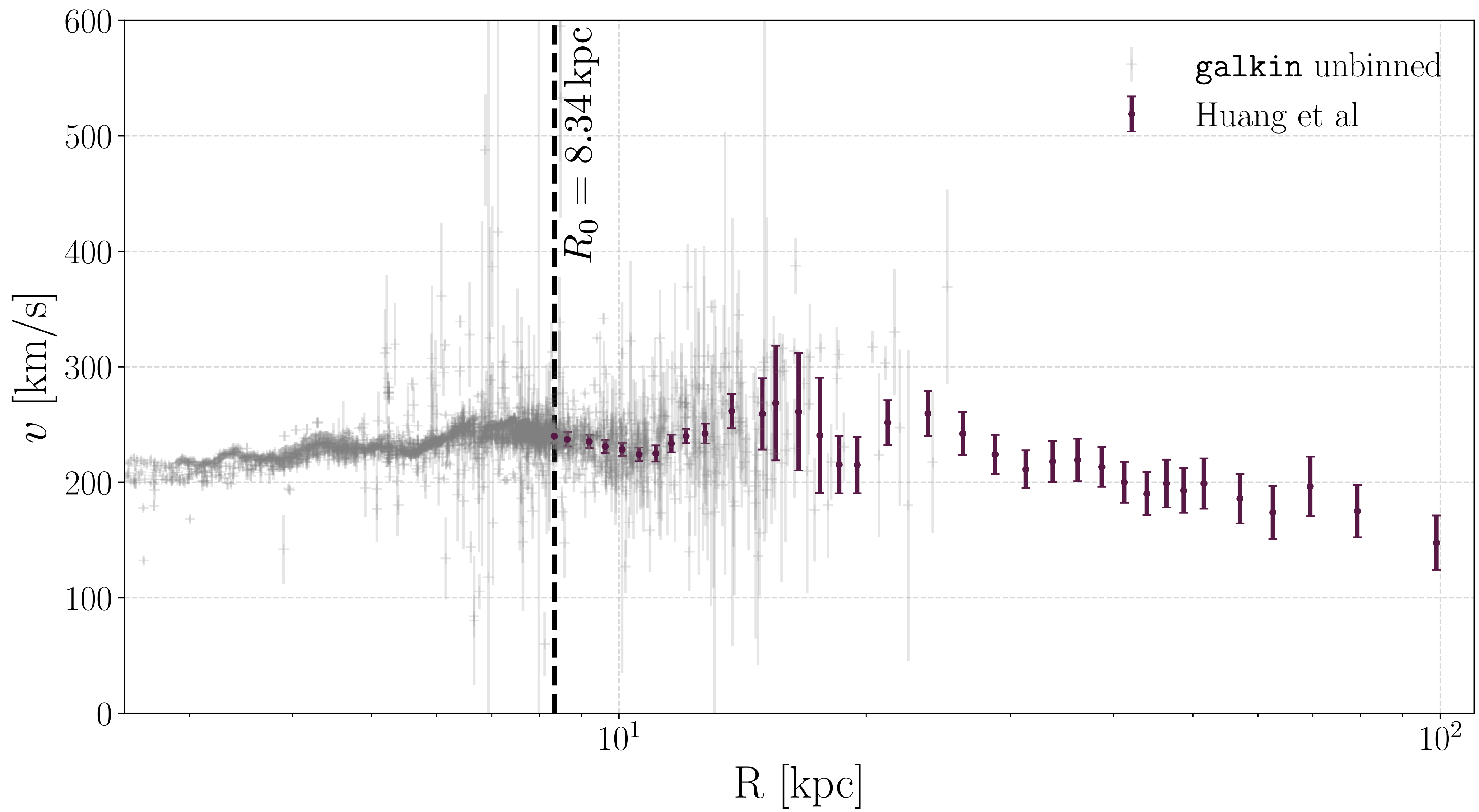
- Observed RC: Two different compilations

`galkin` Pato & Iocco, SoftwareX 6 (2017)
$2.5 < \mathrm{R} < 22$ kpc

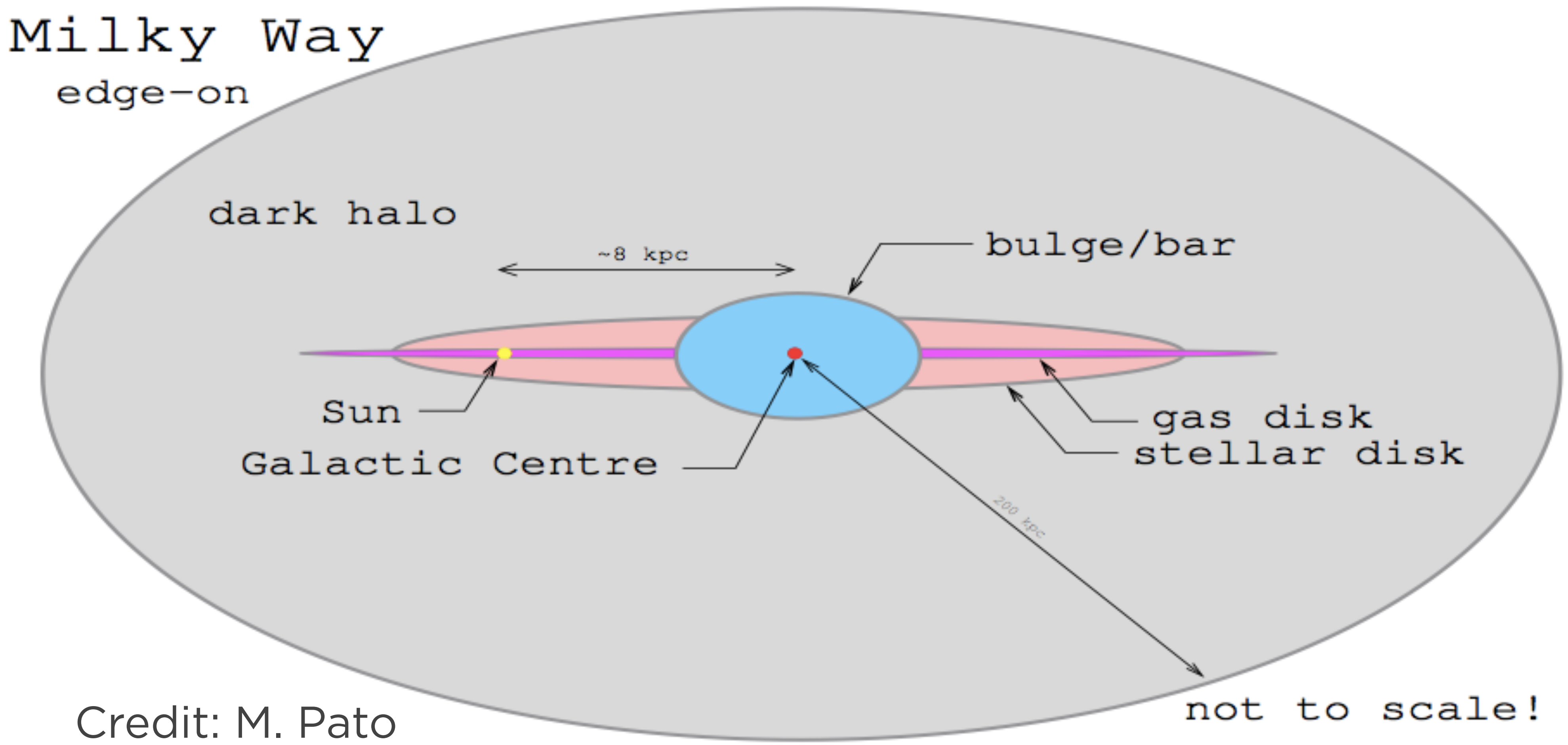
Huang et al Huang +, MNRAS 463 (2016)
$2.5 < \mathrm{R} < 100$ kpc

Galactic parameters:

$$R_0 = 8.34\,\mathrm{kpc} \quad V_0 = 239.89\,\mathrm{km/s} \quad (U_\odot, V_\odot, W_\odot) = (7.01,\ 10.13,\ 4.95)\ \mathrm{km/s}$$



Luminous component of the Milky Way



Credit: M. Pato

$$\rho_{\rm bulge}(x,y,z) \quad \rho_{\rm disc}(r,z) \quad \rho_{\rm gas}(x,y,z)$$

$$\longrightarrow$$

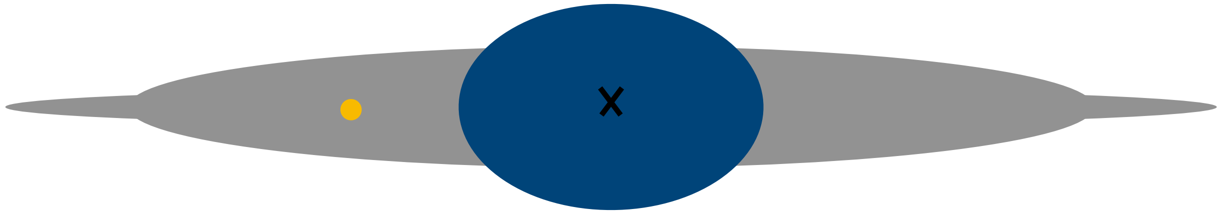
$$\Phi_{\rm bulge}(x,y,z) \quad \Phi_{\rm disc}(r,z) \quad \Phi_{\rm gas}(x,y,z)$$

$$\longrightarrow$$

$$v^2(r) = \sum_i v_i^2(r)$$

$$v_i^2(r) = r\frac{\mathrm{d}\Phi_i}{\mathrm{d}r}$$

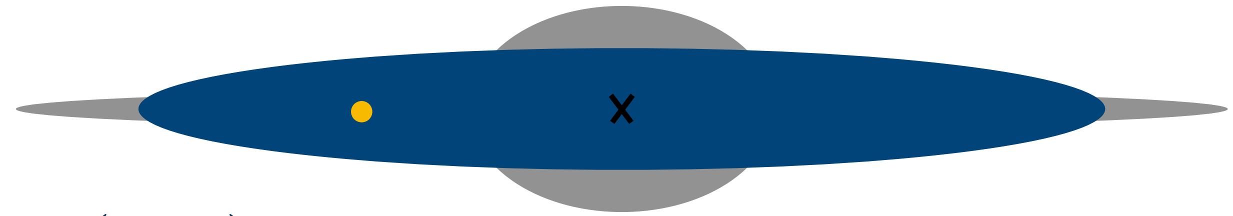
Bulge distribution:



$$\rho_b(x,y,z) = \bar{\rho}_b f(x,y,z)$$

$f(x,y,z)$	Bar angle [°]	$x_0:y_0:z_0$	Reference
e^{-r}	25	2.8 : 1.4 : 1	K.Z. Stanek + (1996) [G2]
$e^{-r_s^2/2}$	24	3.6 : 1.5 : 1	K.Z. Stanek + (1996) [E2]
$e^{-r_s^2/2} + r_a^{-1.85} e^{-r_a}$	20	3.7 : 1.5 : 1	H. Zhao (1996)
$e^{-r_s^2}/(1+r_s)^{1.8}$	20	2.6 : 0.8 : 1	N. Bissantz & O. Gerhard (2002)
$\mathrm{sech}^2(-r_s) + e^{-r_s}$	13	3.7 : 1.3 : 1	A.C. Robin + (2012)
$e^{-r_s^2}/(1+r_s)^{1.8}$	15	3.2 : 2.2 : 1	E. Vanhollebeke + (2013)

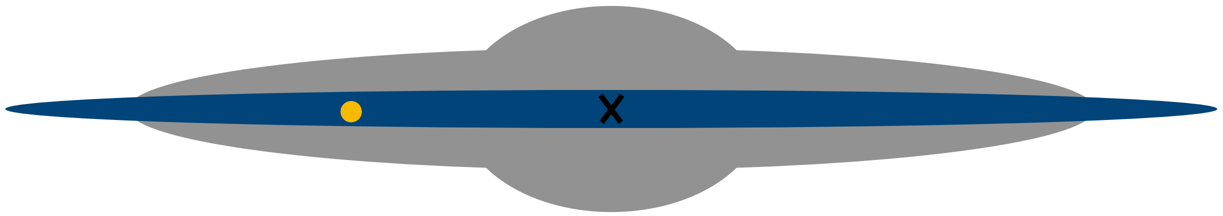
Stellar disc distribution:



$$\rho_d(r, z) = \bar{\rho}_d f(r, z)$$

$f(r, z)$		Scale-length [kpc]	Scale-height [kpc]	Reference
$e^{-r}\,\mathrm{sech}^2(z)$	thin	2.75	0.27 η(r)	C. Han & A. Gould (2003)
$e^{-r}\,e^{-(z+z_0)}$	thick	2.75	0.44 η(r)	
$e^{-r}\,e^{-\lvert z\rvert}$	thin	2.6	0.30	M. Juric + (2008)
$e^{-r}\,e^{-\lvert z\rvert}$	thick	3.6	0.90	
$(r^2+z^2)^{-2.77/2}$	halo			
$e^{-r}\,e^{-\lvert z\rvert}$	thin	2.75	0.25	J. T. A. De Jong + (2010)
$e^{-r}\,e^{-\lvert z\rvert}$	thick	4.1	0.75	
$(r^2+z^2)^{-2.75/2}$	halo			
$e^{-r}\,e^{-\lvert z\rvert}$	thin	2.75	0.25	S. Calchi Novati & L. Mancini (2011)
$e^{-r}\,e^{-\lvert z\rvert}$	thick	4.1	0.75	
$e^{-r}\,e^{-\lvert z\rvert}$	single	2.15	0.4	J. Bovy & H.W. Rix (2013)

Gas distribution:



$$\rho_g(x,y,z) = \rho_{H_2}(x,y,z) + \rho_{H_I}(x,y,z) + \rho_{H_{II}}(x,y,z)$$

Components		Range	Reference
molecular ring	H_2	$r = 3 - 20$ kpc	K. Ferrière (1998)
cold, warm	HI		
warm, hot	HII		
CMZ, disc	H_2	$r = 0.01 - 3$ kpc	K. Ferrière + (2007)
CMZ, disc	HI		
warm, hot, very hot	HII		

Uncertainties

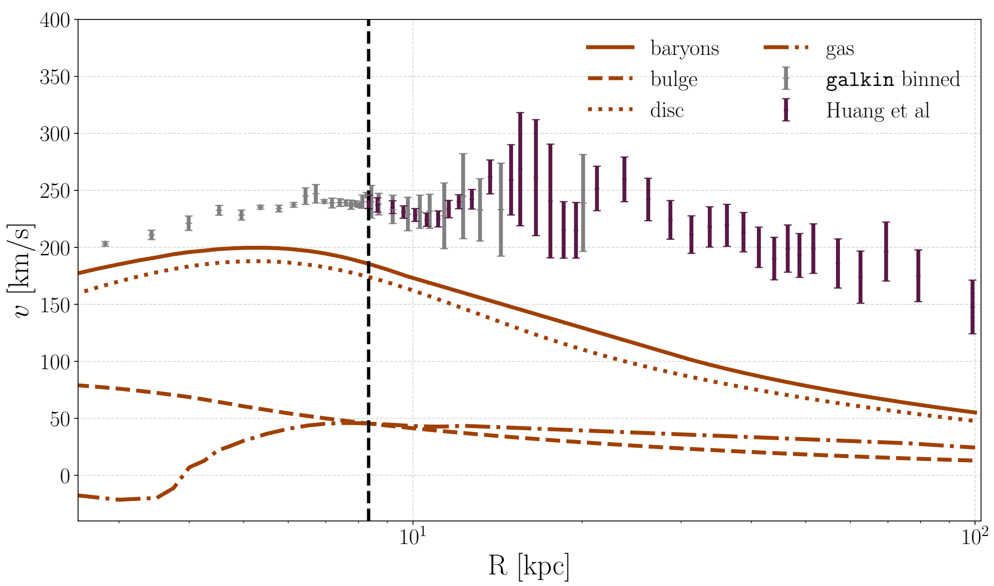
CO-to-H_2 factor: $X_{CO}(r > 3\,\mathrm{kpc}) = (5.0 \pm 2.5) \times 10^{19}\,\mathrm{cm^{-2}K^{-1}km^{-1}s}$

$X_{CO}(r < 3\,\mathrm{kpc}) = (1.9 \pm 1.4) \times 10^{20}\,\mathrm{cm^{-2}K^{-1}km^{-1}s}$

K. Ferriere +
ApJ 467 (2007)

How to determine DM density profile?

Rotation Curve method



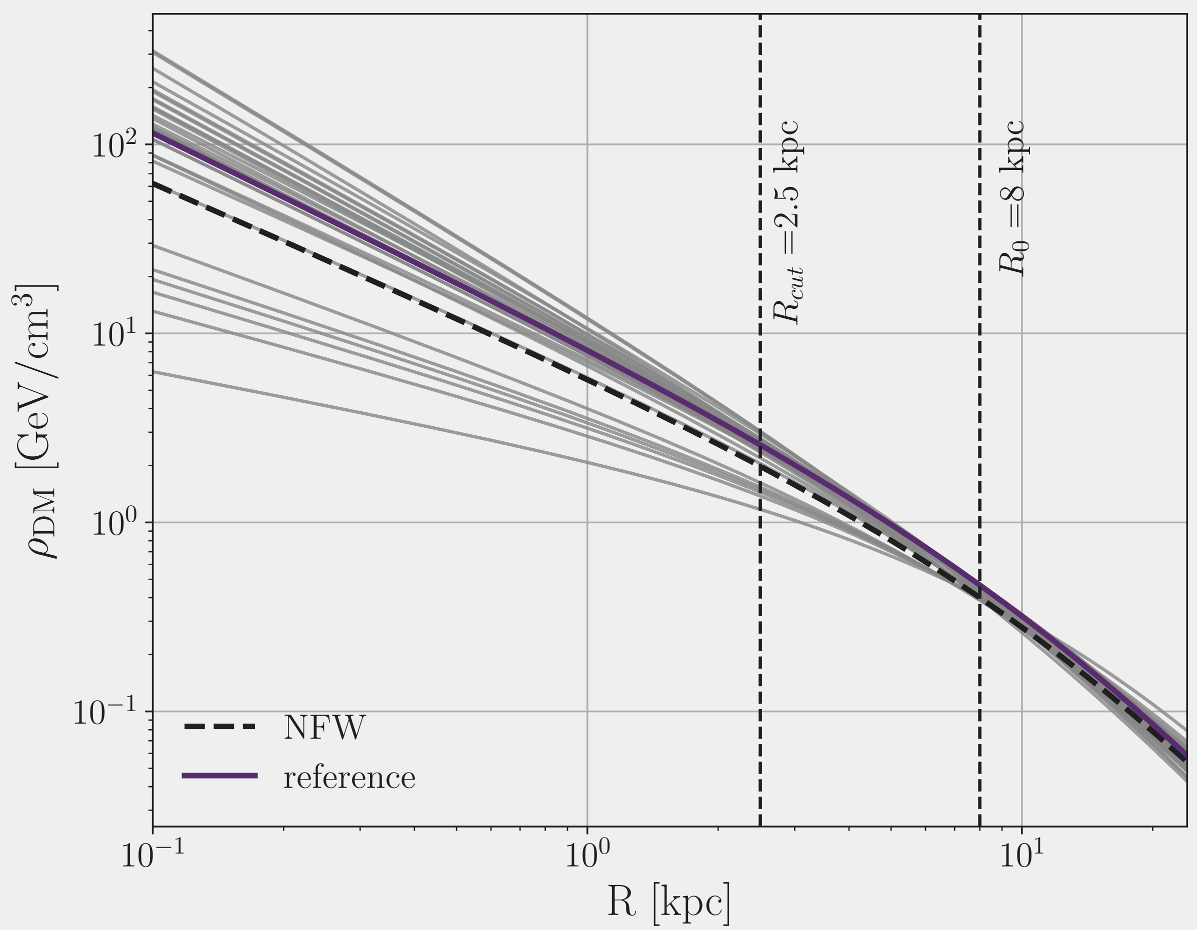
1) Observed RC

2) RC for the luminous component

gNFW density profile

$$\rho_{DM}(r) = \rho_0 \left(\frac{R_0}{r}\right)^{\gamma} \left(\frac{R_s + R_0}{R_s + r}\right)^{3-\gamma}$$

Three free parameters: γ, R_s, ρ_0



Methodology

Bayesian reconstruction procedure

Likelihood

$$\mathcal{L}(\mathrm{d}) = \mathcal{L}(v^{obs}, \Sigma_*^{obs}, \langle\tau\rangle^{obs}) = \mathcal{L}(v^{obs}) \times \mathcal{L}(\Sigma_*^{obs}) \times \mathcal{L}(\langle\tau\rangle^{obs})$$

Gaussian approximation!!!

$$\mathrm{P}(\mathrm{d}|\Theta_{\mathrm{DM}}, \Sigma_*, \langle\tau\rangle) = \prod_j \left\{ \frac{1}{\sqrt{2\pi}\sigma_{v_j^{obs}}} \exp\left[-\frac{1}{2} \frac{\left(v_j - v_j^{obs}\right)^2}{\sigma^2_{v_j^{obs}}} \right] \right\}$$

$$\times \frac{1}{\sqrt{2\pi}\sigma_{\Sigma_*^{obs}}} \exp\left[-\frac{1}{2} \frac{\left(\Sigma_* - \Sigma_*^{obs}\right)}{\sigma^2_{\Sigma_*^{obs}}} \right] \times \frac{1}{\sqrt{2\pi}\sigma_{\langle\tau\rangle^{obs}}} \exp\left[-\frac{1}{2} \frac{\left(\langle\tau\rangle - \langle\tau\rangle^{obs}\right)}{\sigma^2_{\langle\tau\rangle^{obs}}} \right]$$

Model fitting: 3 DM parameters + 2 baryonic (nuisance) parameters

Normalisation bulge

$$\langle\tau\rangle^{obs} = 2.17^{+0.47}_{-0.38} \times 10^{-6} \quad (\ell, b) = (1.50^{\mathrm{o}}, -2.68^{\mathrm{o}})$$

Popowski +
ApJ 631 (2005)

Normalisation disc

$$\Sigma_*^{obs} = 38 \pm 4\,\mathrm{M}_\odot\mathrm{pc}^{-2}$$

Bovy & Rix
ApJ 779 (2013)

Methodology

$$\mathcal{L}\left(v^{obs}\right) = \prod_j \left\{ \frac{1}{\sqrt{2\pi}\sigma_{v_j^{obs}}} \exp\left[-\frac{1}{2} \frac{\left(v_j - v_j^{obs}\right)^2}{\sigma^2_{v_j^{obs}}} \right] \right\}$$

assumes $v_i \sim \mathcal{N}(v_{true}, \sigma_i)$

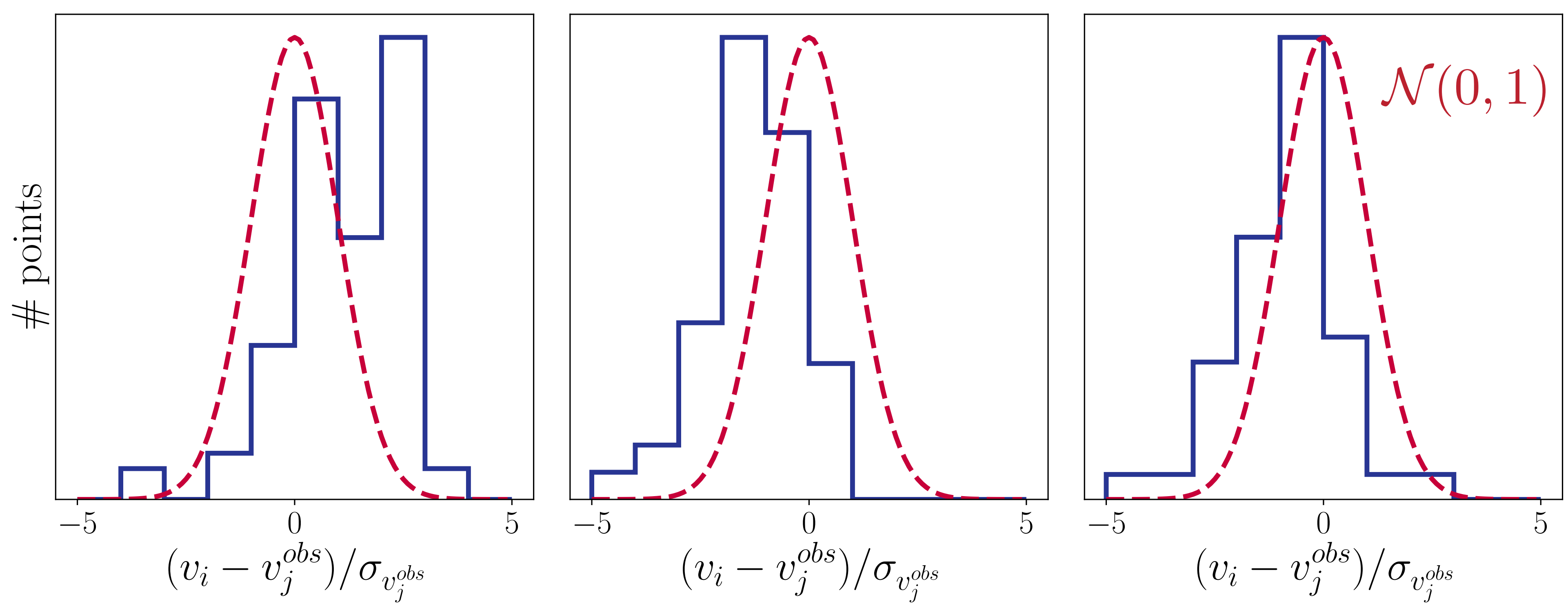
(i data points within j-bin are Gaussianly distributed)

j runs for bins
i runs for data points within bin

Relative deviation = $\dfrac{(v_i - v_j^{obs})}{\sigma_{v_i}} \sim \mathcal{N}(0,1)$

PROBLEM!

- For three randomly selected bins:



Methodology

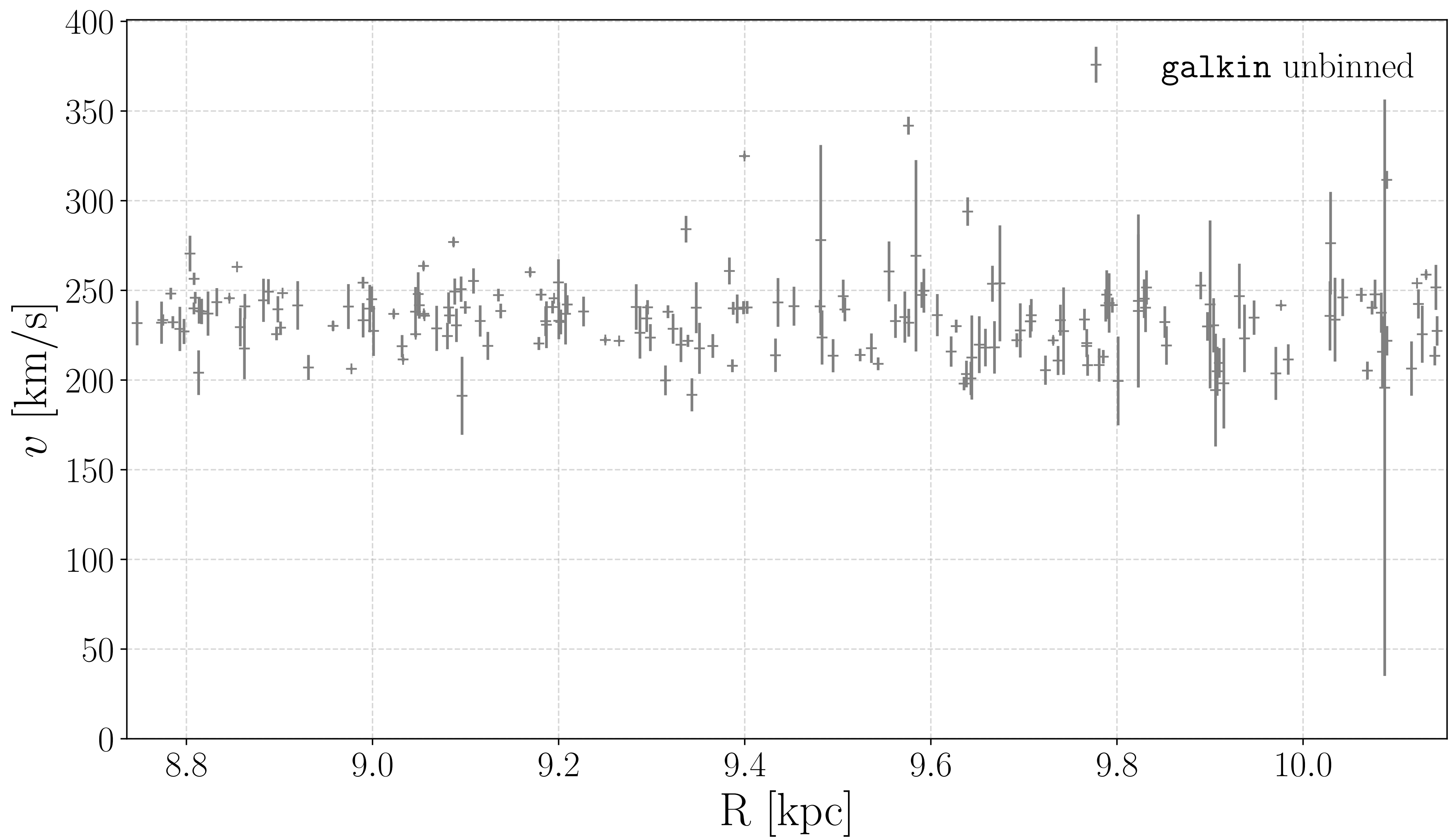
`galkin` Pato & Iocco, SoftwareX 6 (2017)

$2.5 < \mathrm{R} < 22$ kpc

It is a combination of 25 data sets

Galactic parameters:

$$R_0 = 8.34\,\mathrm{kpc} \quad V_0 = 239.89\,\mathrm{km/s} \quad (U_\odot, V_\odot, W_\odot) = (7.01,\ 10.13,\ 4.95)\ \mathrm{km/s}$$



Methodology

- Testing compatibility of d_1 and d_2 data sets:

$$B = \frac{\mathrm{P}(d_1, d_2 | H_0)}{\mathrm{P}(d_1 | H_1) \times \mathrm{P}(d_2 | H_1)}$$

H_0 : our model jointly fits the two observables

H_1 : the two observables prefer different regions in the parameter space

Examples : Feroz +, JHEP 0810 (2008), Trotta +, ApJ 729 (2011)

Bayesian evidence:

$$\mathrm{P}(d|H_i) = \int \mathrm{P}(d|\Theta_{\mathrm{DM}}, \Sigma_*, \langle\tau\rangle)\, \mathrm{P}(\Theta_{\mathrm{DM}})\, \mathrm{P}(\Sigma_*)\, \mathrm{P}(\langle\tau\rangle)\, \mathrm{d}\Theta_{\mathrm{DM}} \mathrm{d}\Sigma_* \mathrm{d}\langle\tau\rangle$$

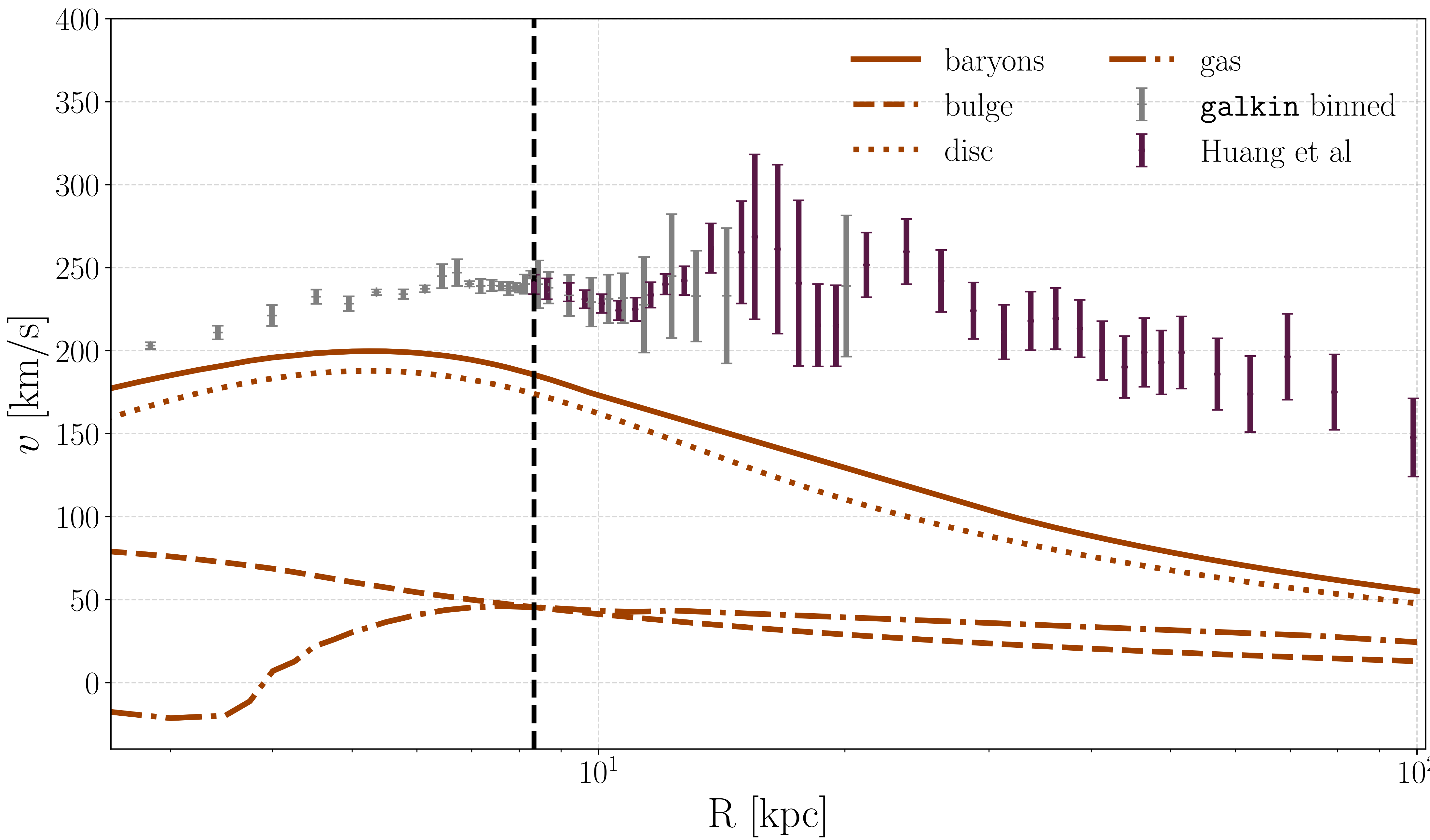
If $B > 1$: d_1 and d_2 **are compatible** (constraints obtained by using them jointly will overlap significantly with those obtained when using each data set individually)

Methodology

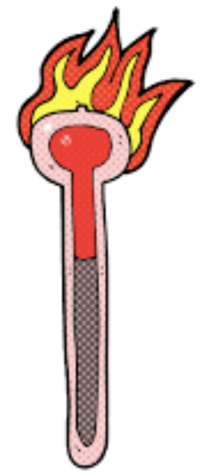
Final compilation of Milky Way RC:

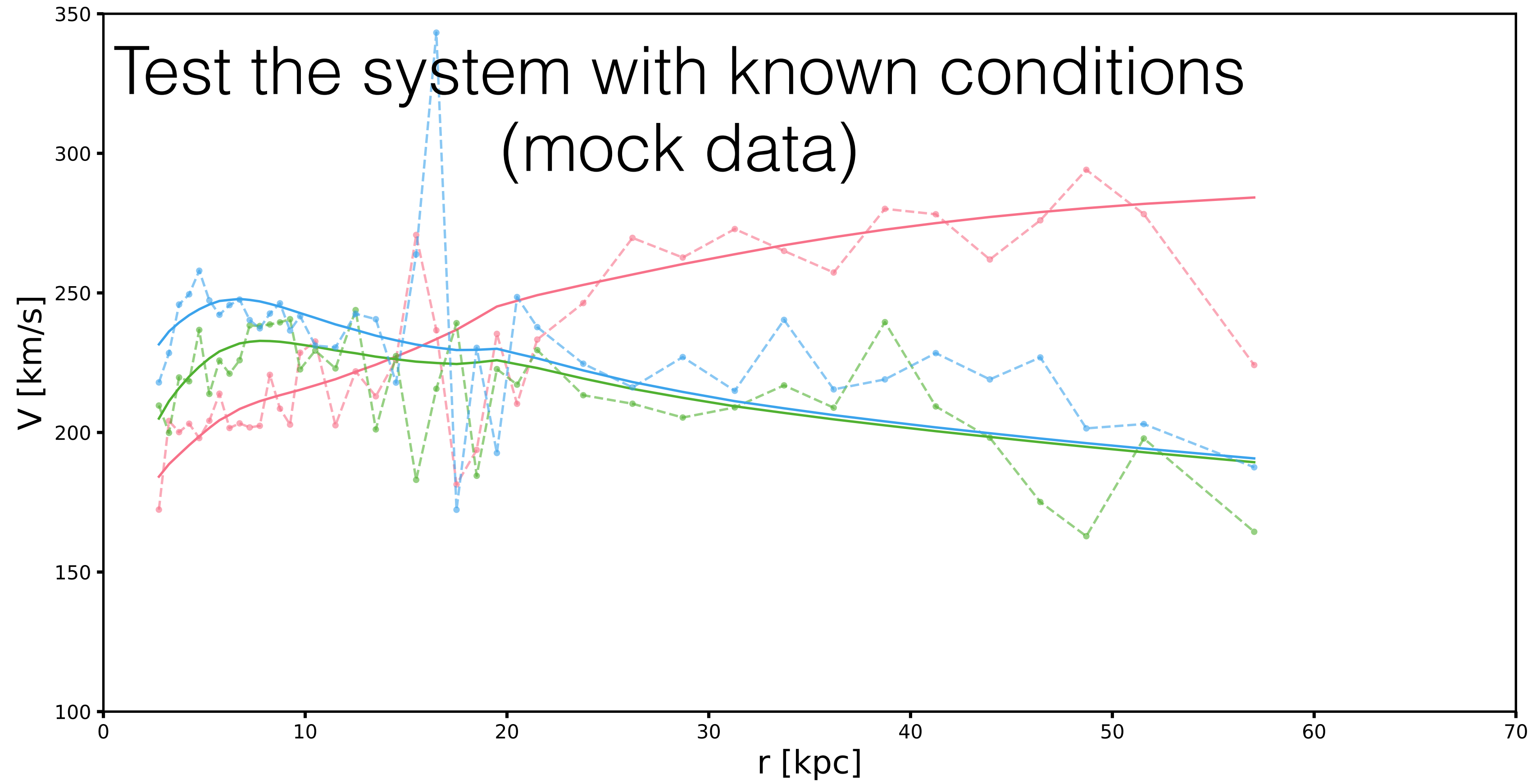
12 `galkin` data sets + Huang et al

Pato & Iocco, SoftwareX 6 (2017) — Huang +, MNRAS 463 (2016)



Calibration of the Methodology





- Recipe for mock RC generation:

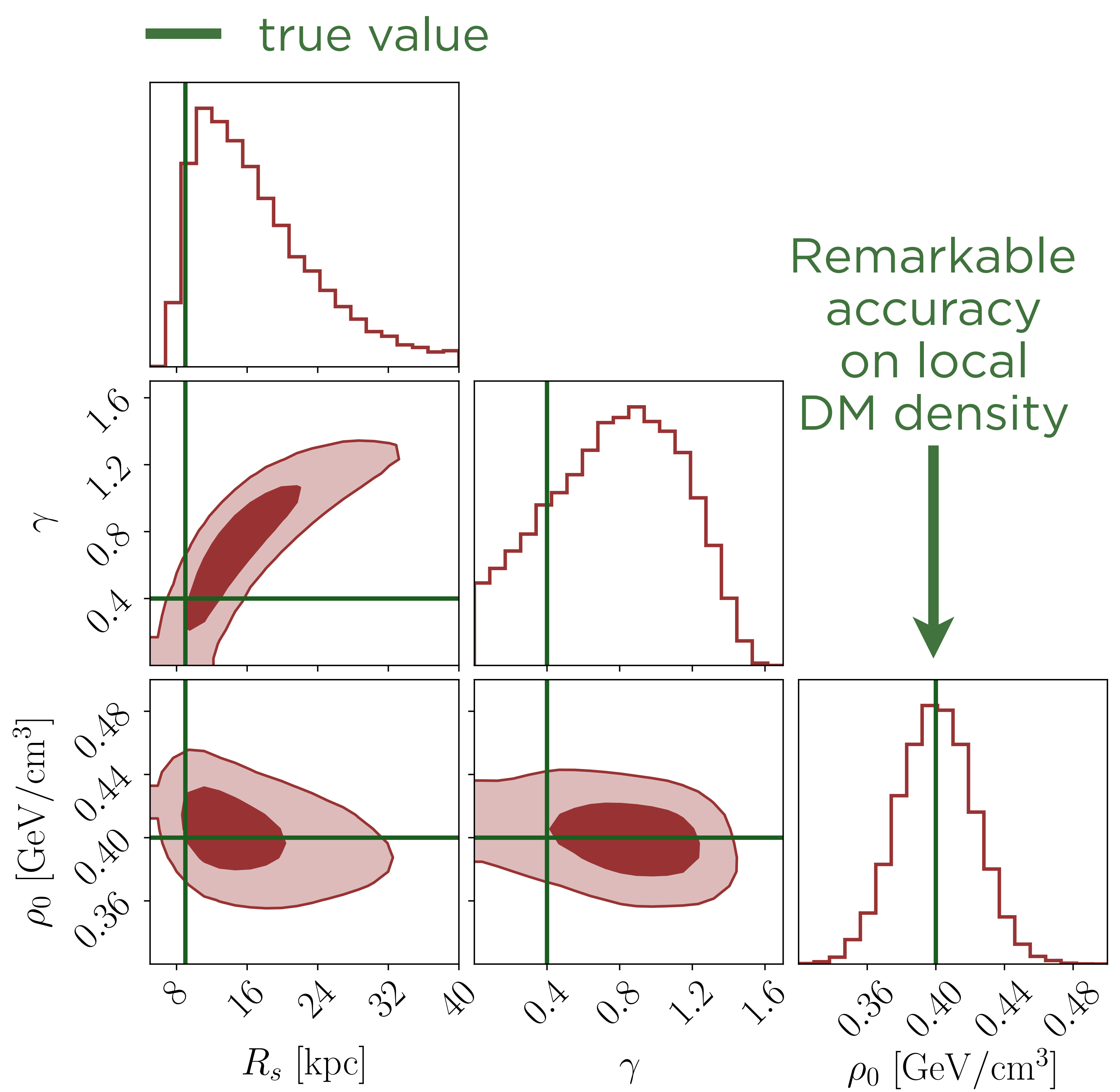
$$v_j^{mock} = v_j^{fiducial} + \delta_j \qquad \textit{j} \text{ runs for bins}$$

$$v_j^{fiducial} = \sqrt{v^2_{gNFW}(\gamma, R_s, \rho_0, r_j) + v^2_{baryons}(\Sigma_*, \langle\tau\rangle, r_j)}$$

$$\delta_j \sim \mathcal{N}(0, \sigma_{v_j^{obs}})$$

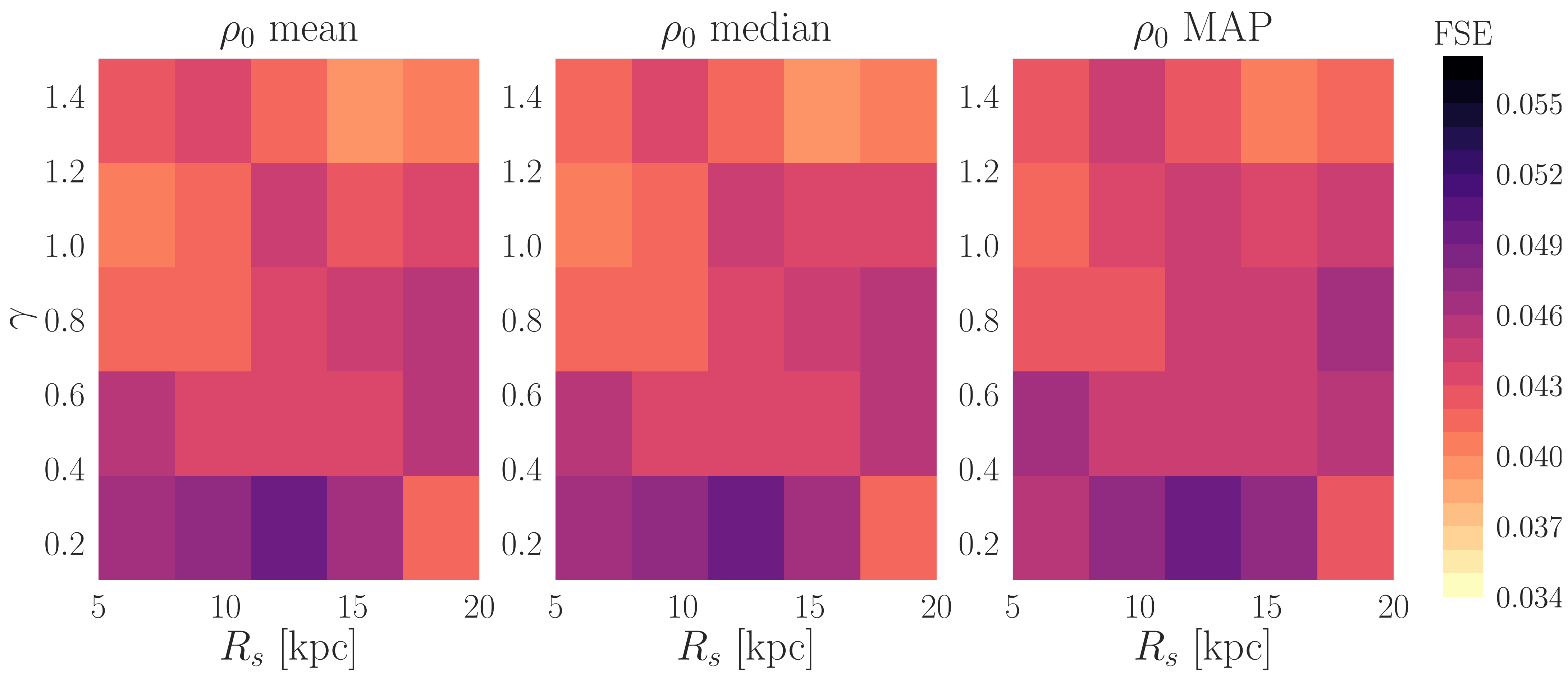
- 25 fiducial points in the DM parameter space
- Each fiducial point, 100 data realisations

Calibration of the Methodology: mock RC



Results - mock catalog

Fractional Standard Error = $\mathrm{FSE} = \frac{\sqrt{\frac{1}{n_k}\sum_{k=1}^{100}\left(\hat{\theta}_k - \theta_{\mathrm{true}}\right)^2}}{\theta_{\mathrm{true}}}$



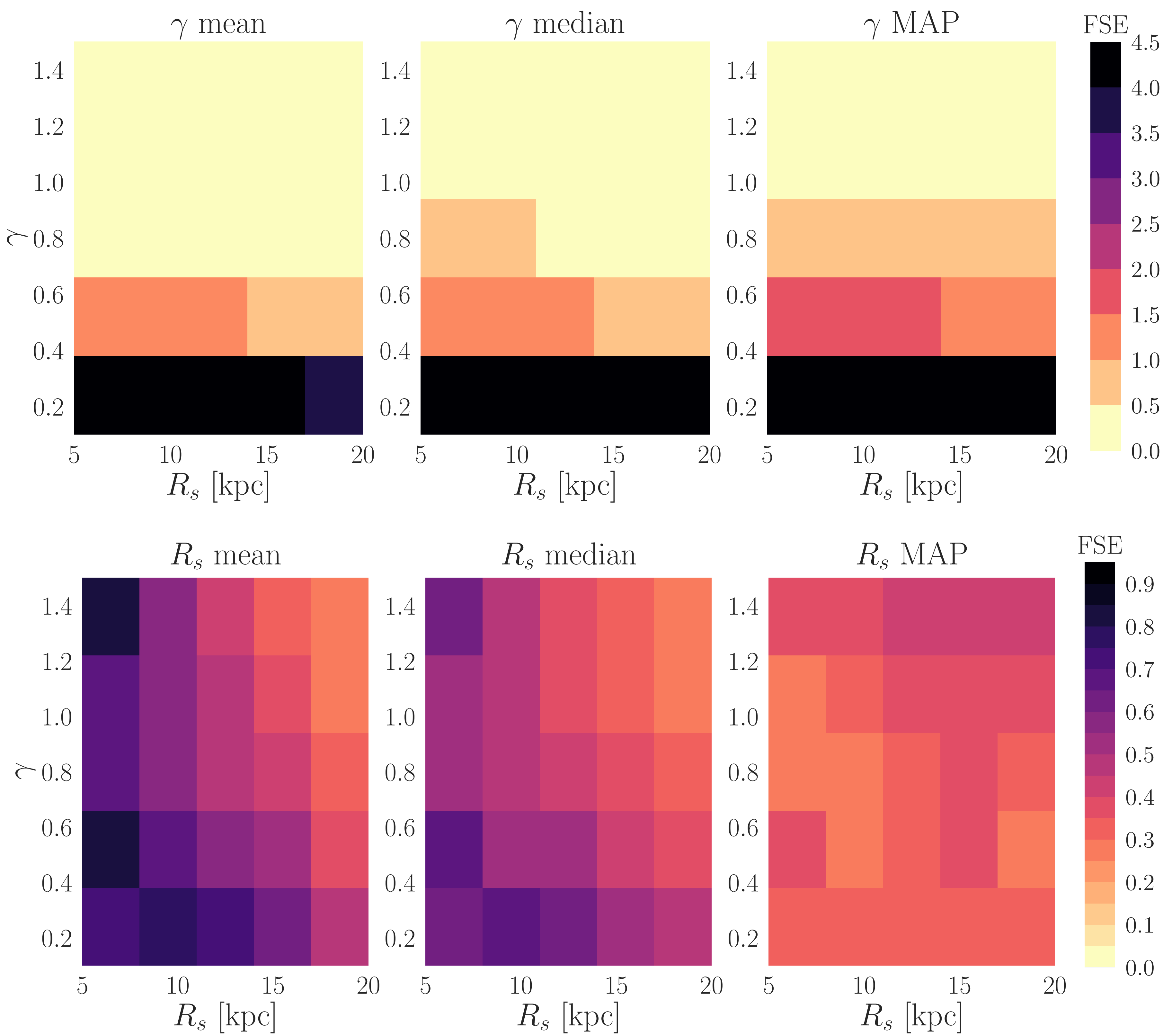
Karukes, MB, Iocco, Trotta, Geringer-Sameth [1901.02463]

- ρ_0 recovered with an accuracy better than 94 % (independently of estimator)

Results - mock catalog

Fractional Standard Error for γ and R_s

$$\mathrm{FSE} = \frac{\sqrt{\frac{1}{n_k}\sum_{k=1}^{100}\left(\hat{\theta}_k - \theta_{\rm true}\right)^2}}{\theta_{\rm true}}$$

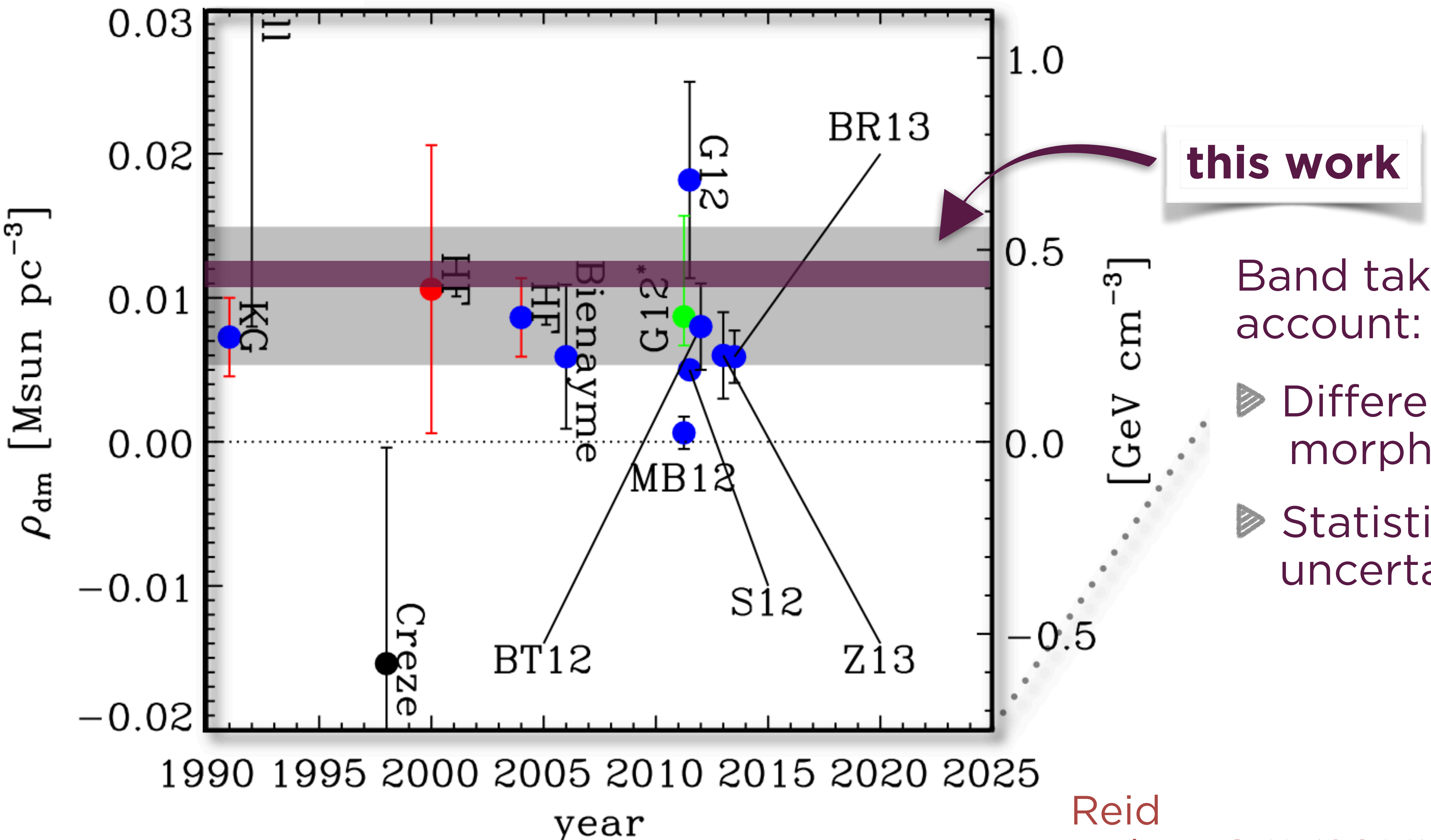


- accuracy on R_s and γ gets better for higher values

Karukes, MB + [1901.02463]

Results - actual RC

$$\rho_0 = 0.43 \pm 0.02\,(\text{stat}) \pm 0.01\,(\text{sys})\ \text{GeV/cm}^3$$



Band takes into account:

- Different baryonic morphologies
- Statistical uncertainties

Reid
J.Phys. G41 (2014)

Virial mass

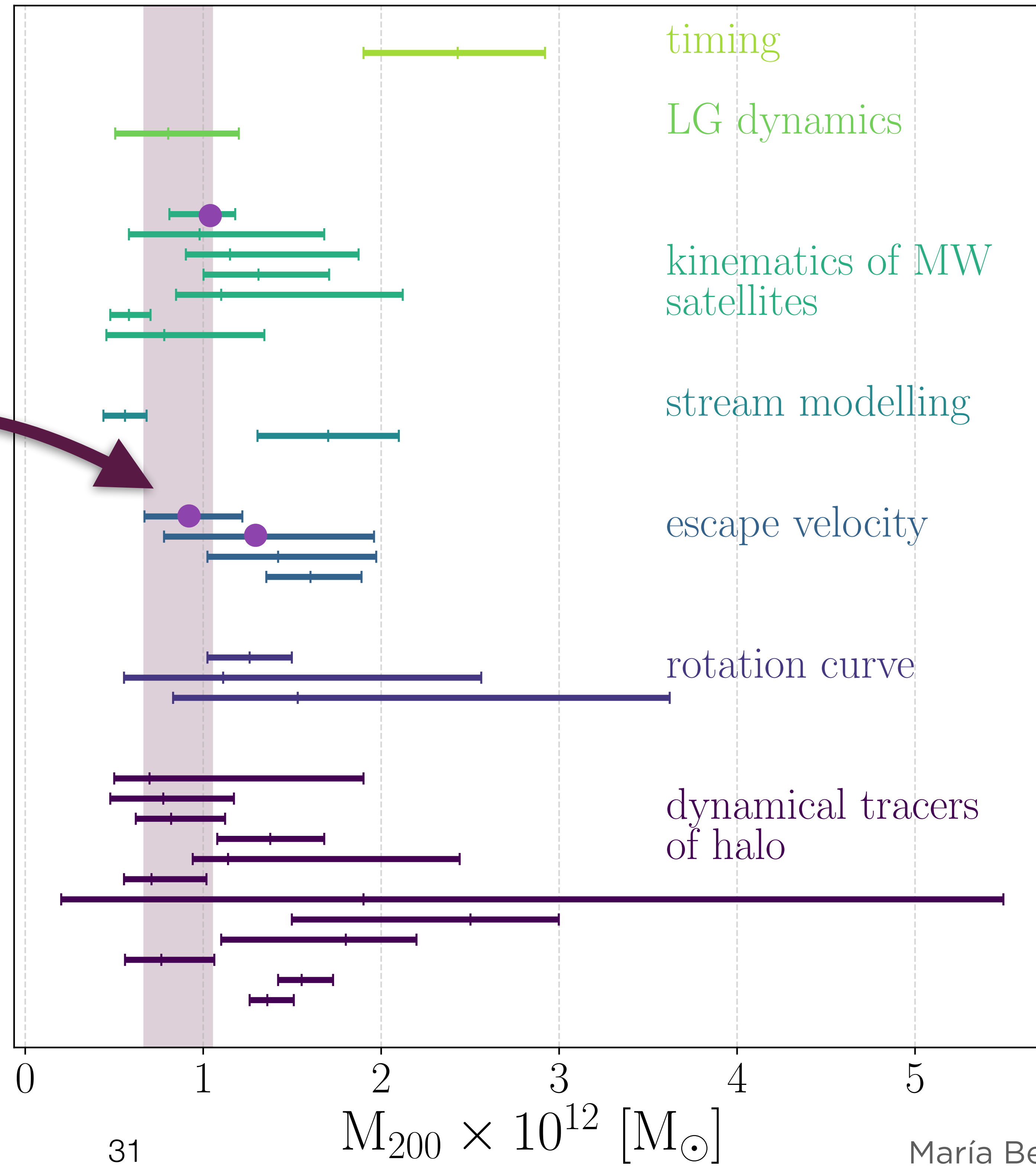
$$M_{tot} = \left[8.7^{+1.0}_{-0.8}\,(\text{stat})^{+1.4}_{-0.8}\,(\text{sys})\right] \times 10^{11}\ M_{\odot}$$

Estimates using Gaia data

this work

Band takes into account:

- Different baryonic morphologies
- Statistical uncertainties



Take away points (1)

- The reconstructed value of the local DM density is always compatible with the true value within < 5% (systematic uncertainty ~ 3%; statistical uncertainty ~ 5%).

$$\rho_0 = 0.43 \pm 0.02\,(\mathrm{stat}) \pm 0.01\,(\mathrm{sys})\ \mathrm{GeV/cm^3}$$

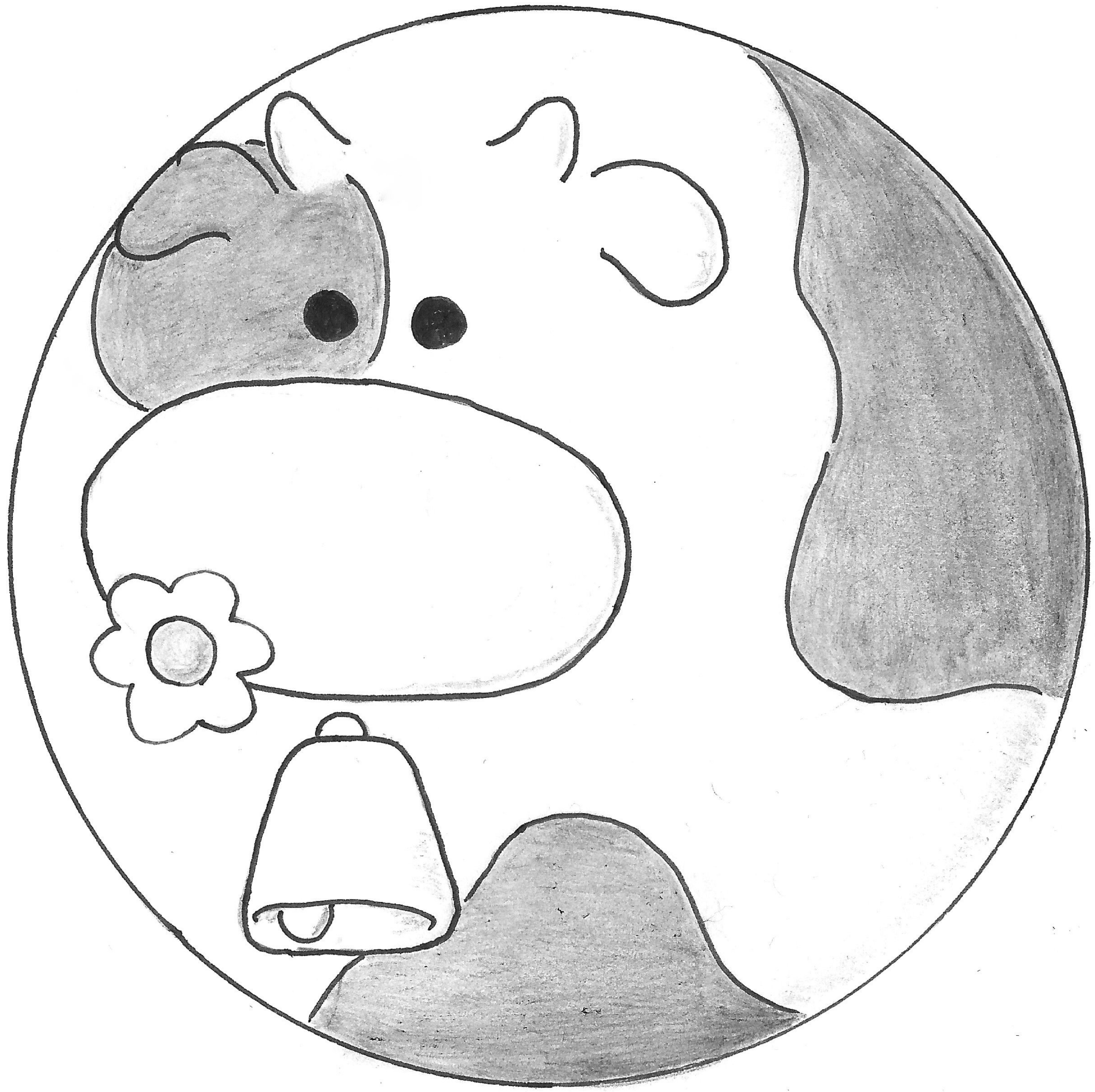
- The inner DM density slope and the scale radius are poorly reconstructed.

- We still need to improve the kinematic data of the MW in order to be able to probe the inner DM density slope and the scale radius!

- Inference of M_{200} compatible with recent estimations using Gaia (systematic uncertainty ~ 14%; statistical uncertainty ~ 19%).

$$\mathrm{M_{tot}} = \left[8.7^{+1.0}_{-0.8}\,(\mathrm{stat})^{+1.4}_{-0.8}\,(\mathrm{sys})\right] \times 10^{11}\ \mathrm{M_\odot}$$

In the assumption of sphericity a good approximation of reality?

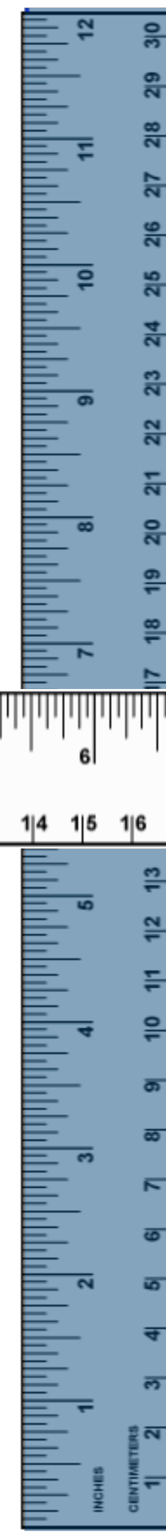
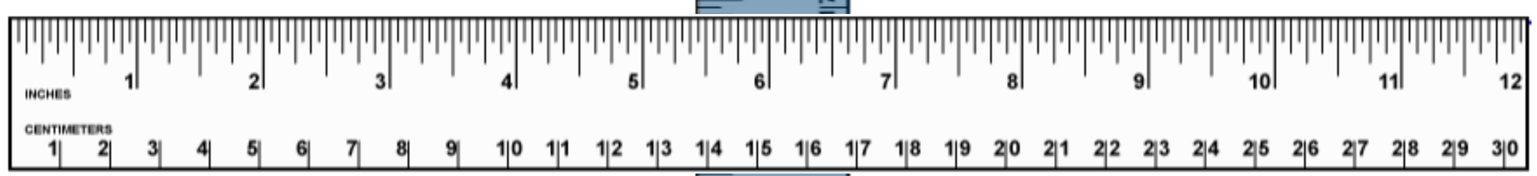


Sphericity of inner DM halo:

Bowden + MNRAS 449 (2015)

Bovy + AJ 833 (2016)

DM distribution in the MW

Up to now

How much we can rely it?

Now

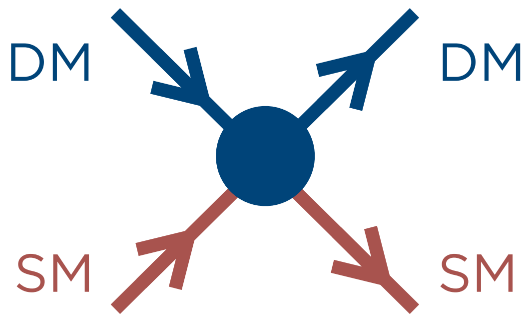
Quantify astrophysical uncertainties

Why it is important?

Direct/Indirect WIMP searches

Simplified version

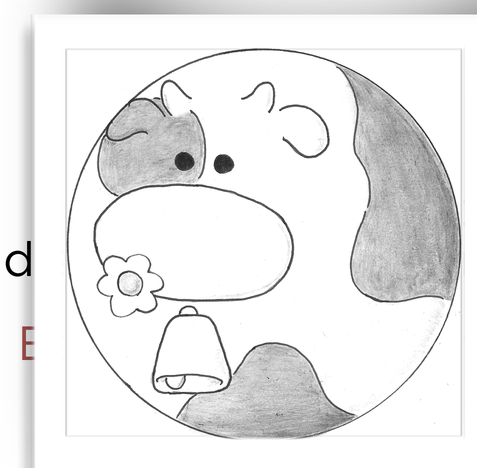
Direct



Recoil spectrum for DM-nucleus interaction:

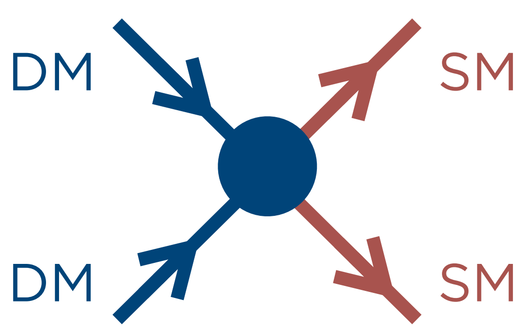
$$\frac{\mathrm{d}R}{\mathrm{d}E} \sim C_{\mathrm{PP}}\, \rho_0 \int_{v>v_{\mathrm{min}}} \mathrm{d}^3v \, \frac{f(\mathbf{v},t)}{v}$$

Dependence on astrophysics



[1601.04707]

Indirect

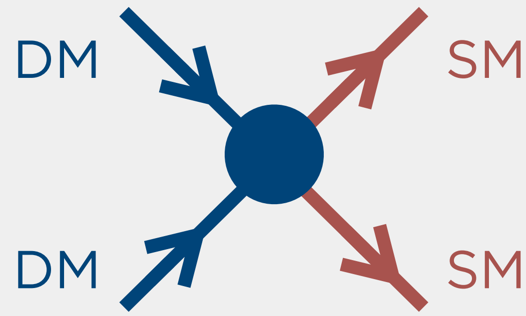


Flux due to DM self-annihilation:

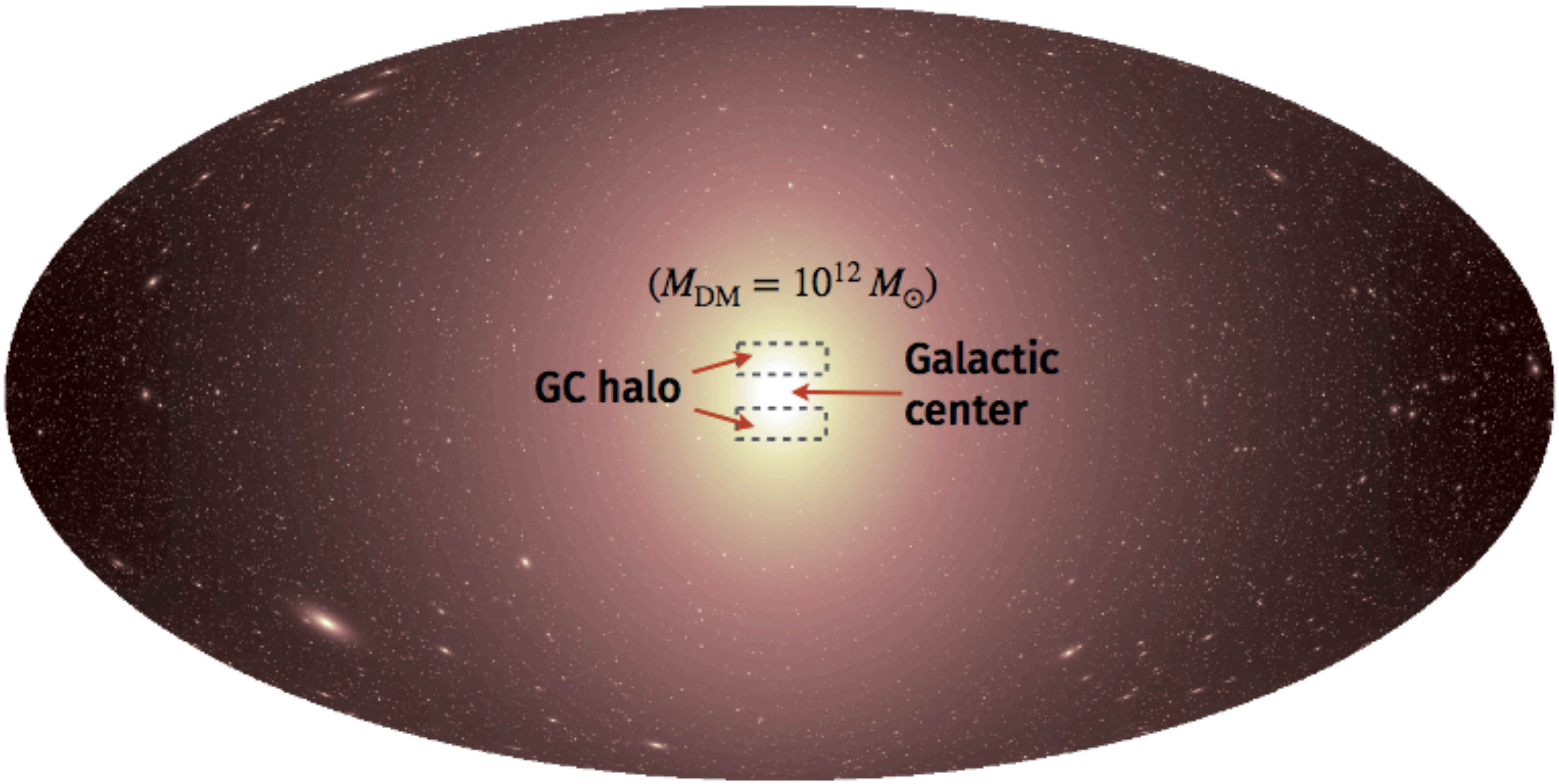
$$\Phi_{\mathrm{DM}} \sim \Phi_{\mathrm{PP}} \int_{\mathrm{l.o.s}} \mathrm{d}l \;\rho^2_{DM}$$

Dependence on astrophysics

Targets for indirect WIMP searches: our Galaxy



$$\Phi_{\rm DM} \sim \Phi_{\rm PP} \int_{\rm l.o.s} {\rm d}l \; \rho^2_{DM}$$

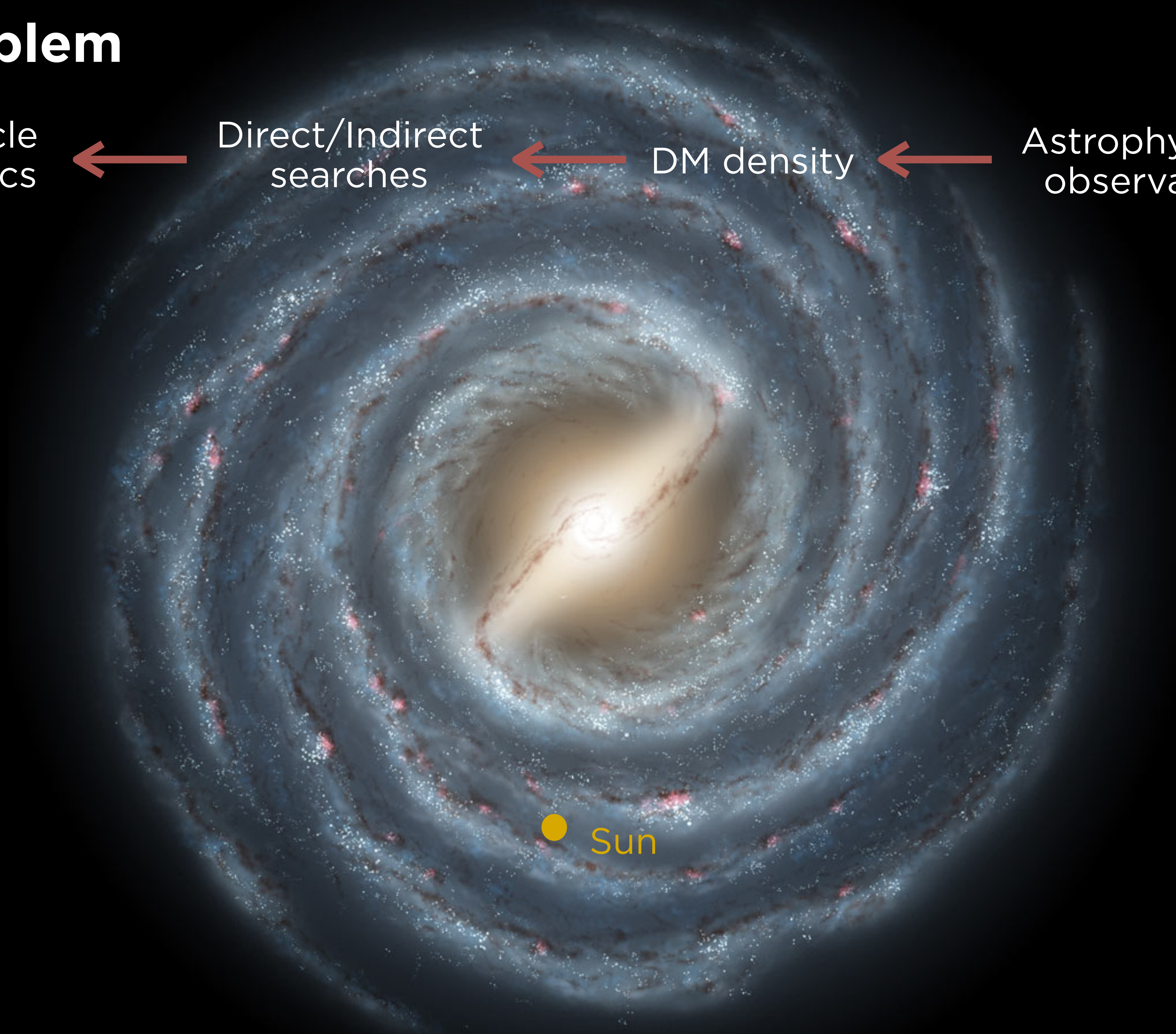


Synthetic γ-ray intensity map from DM annihilation (created with CLUMPY)

Credit: M. Hütten

Problem

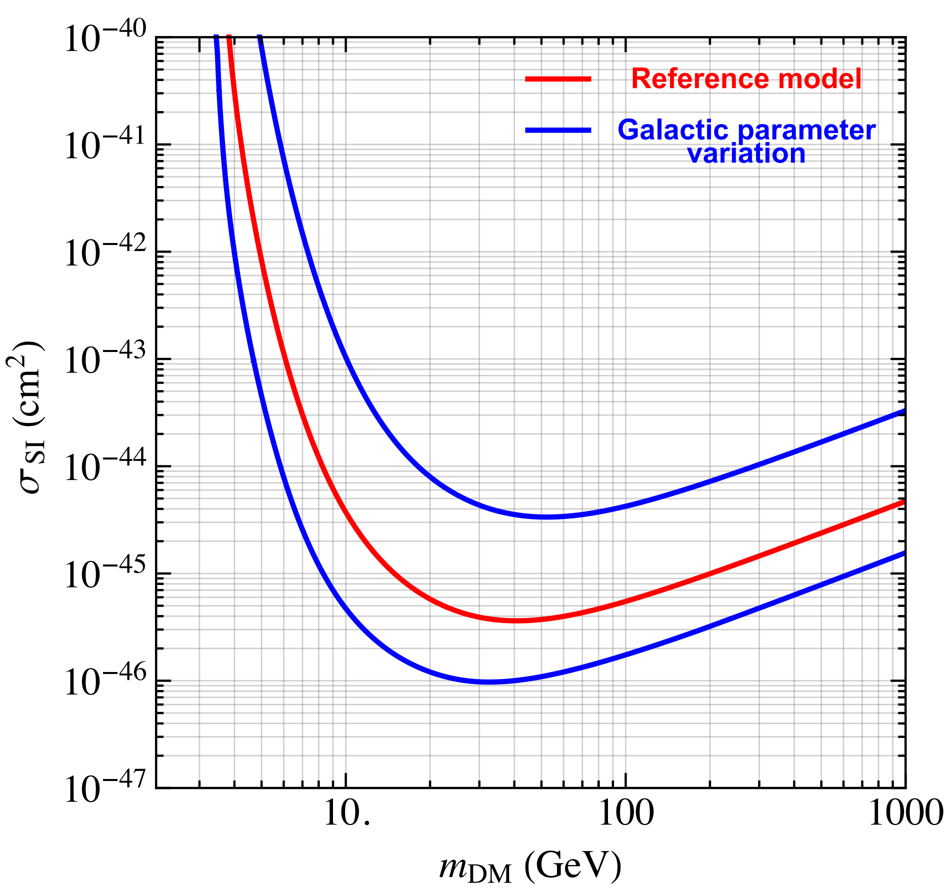
Particle physics ← Direct/Indirect searches ← DM density ← Astrophysical observable



Problem:

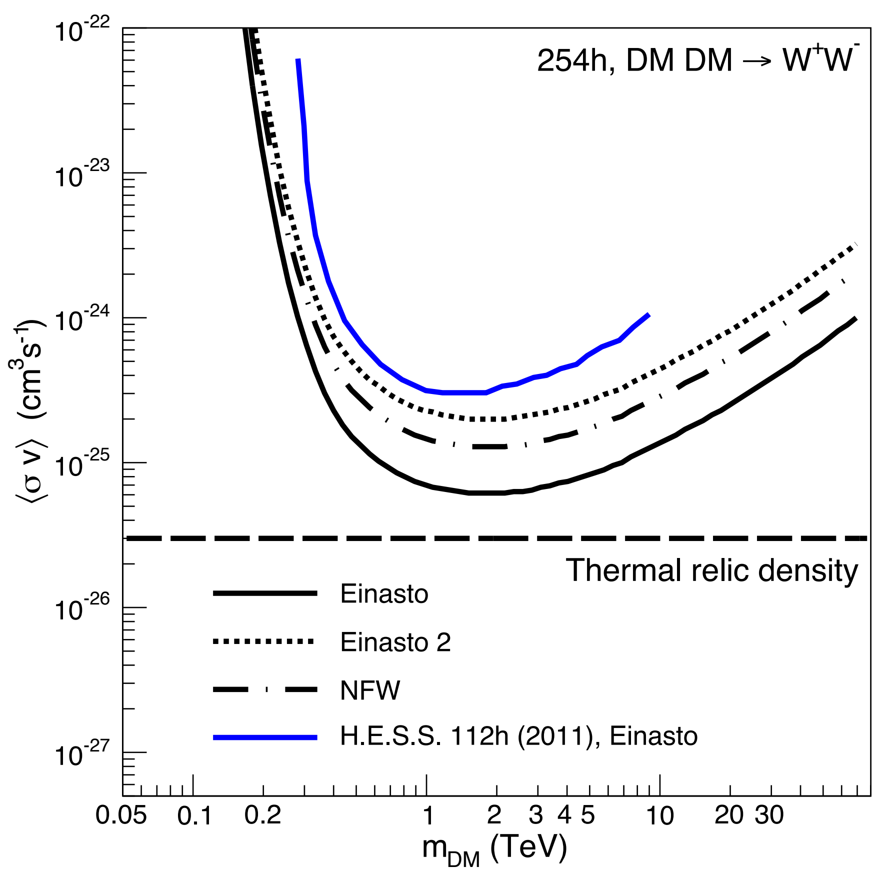
Particle physics ← Direct/Indirect searches ← DM density ← Astrophysical observable

Direct



MB +
JCAP 1702 (2017)

Indirect



H.E.S.S. collaboration
PRL 117 (2016)

How to reconstruct DM density profile?

Rotation Curve method

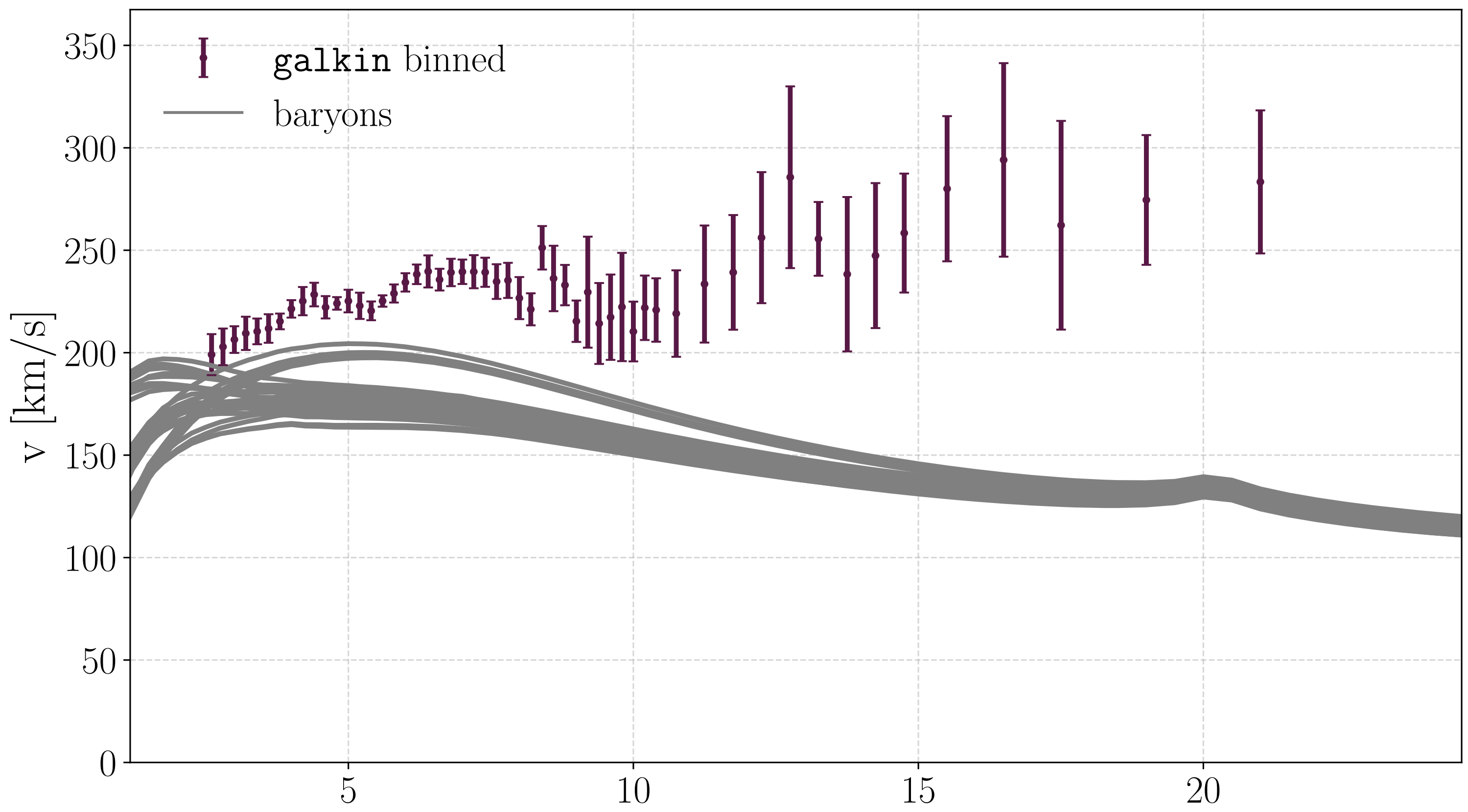
Observed RC

`galkin` Pato & Iocco, SoftwareX 6 (2017)

RC for the luminous component

$$\rho_{\rm bulge}(x,y,z) \quad \rho_{\rm disc}(r,z) \quad \rho_{\rm gas}(x,y,z) \;\longrightarrow\; \Phi_{\rm bulge}(x,y,z) \quad \Phi_{\rm disc}(r,z) \quad \Phi_{\rm gas}(x,y,z) \;\longrightarrow\; v^2(r) = \sum_i v_i^2(r)$$

$$v_i^2(r) = r\frac{\mathrm{d}\Phi_i}{\mathrm{d}r}$$



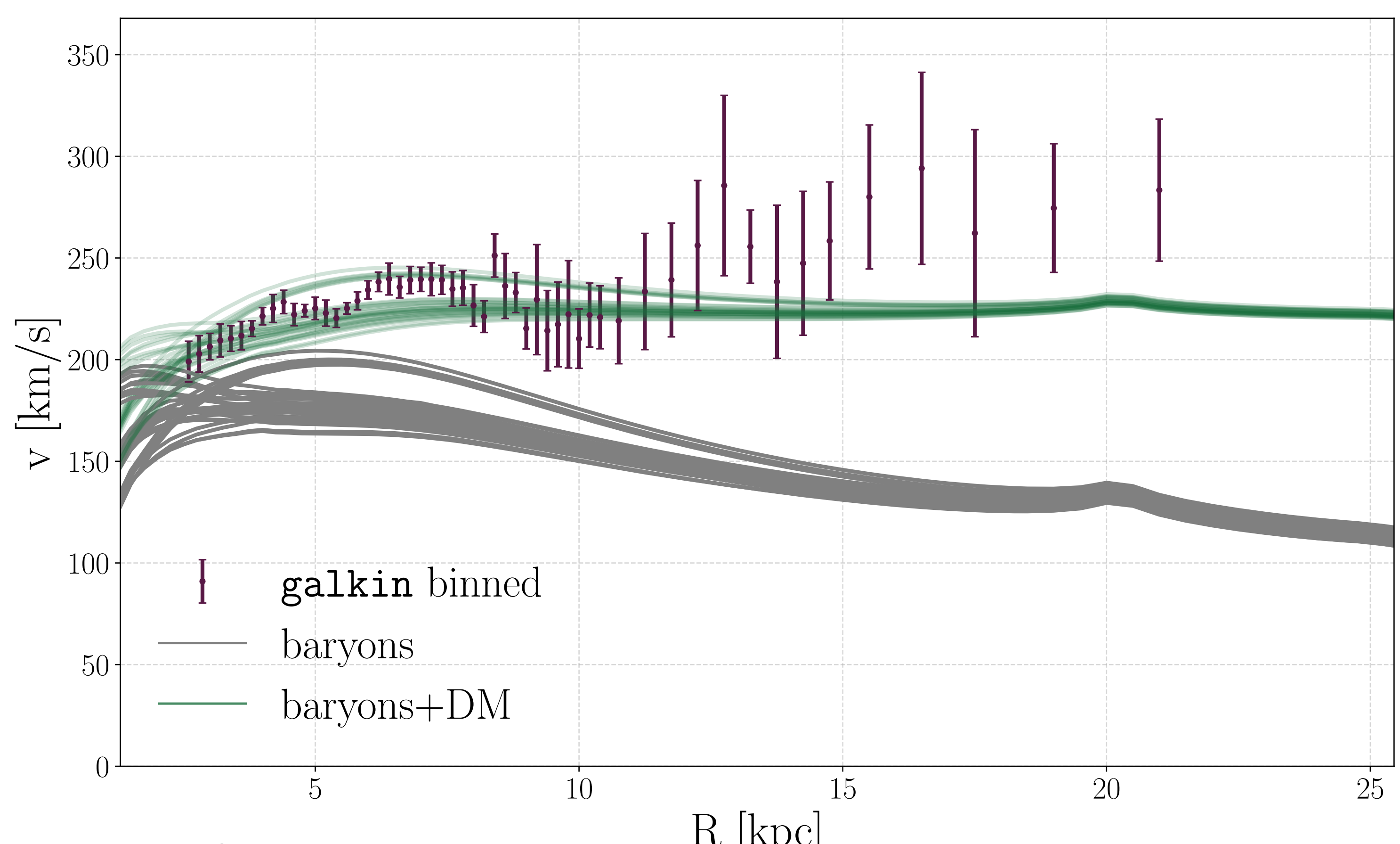
How to reconstruct DM density profile?

Rotation Curve method

gNFW density profile

$$\rho_{DM}(r) = \rho_0 \left(\frac{R_0}{r}\right)^{\gamma} \left(\frac{R_s + R_0}{R_s + r}\right)^{3-\gamma}$$

Three free parameters: γ, R_s, ρ_0



How to reconstruct DM density profile?

Rotation Curve method

No.	Parameters of our analysis	
1	$\mathcal{M}_i$	30 baryonic morphologies
2	ρ_0	DM parameters
3	R_s	
4	γ	
5	R_0	Sun's galactocentric distance
6	Σ_*	baryonic normalisation
7	$\langle\tau\rangle$	

7D parameter space: $\mathcal{M}_i,\ \gamma,\ R_s,\ \rho_0,\ R_0,\ \Sigma_*,\ \langle\tau\rangle$

$$\chi^2 = \sum_j \frac{\left(v_j - v_j^{obs}\right)^2}{\sigma^2_{v_j^{obs}}} + \frac{\left(\langle\tau\rangle - \langle\tau\rangle^{obs}\right)^2}{\sigma^2_{\langle\tau\rangle^{obs}}} + \frac{\left(\Sigma_* - \Sigma_*^{obs}\right)^2}{\sigma^2_{\Sigma_*^{obs}}}$$

Normalisation bulge

$\langle\tau\rangle^{obs} = 2.17^{+0.47}_{-0.38} \times 10^{-6} \quad (\ell, b) = (1.50^{\circ}, -2.68^{\circ})$

Popowski +
ApJ 631 (2005)

Normalisation disc

$\Sigma_*^{obs} = 38 \pm 4\,\mathrm{M_{\odot}pc^{-2}}$

Bovy & Rix
ApJ 779 (2013)

Scan the 7D parameter space to obtain the Likelihood profile

Further profile over $\mathcal{M}_i,\ \langle\tau\rangle, \Sigma_*$

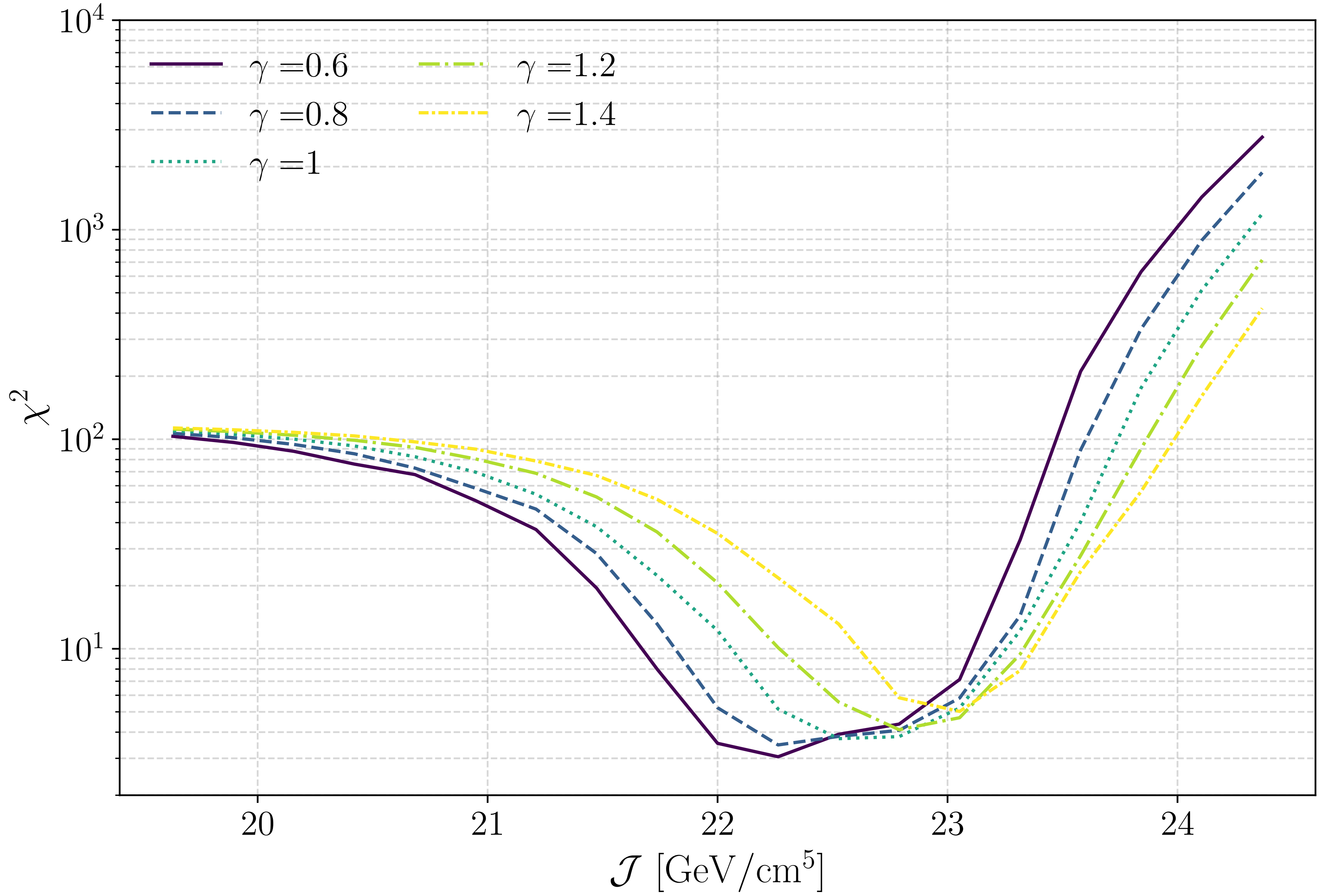
$$\chi^2_{\mathrm{RC}}(R_s, \rho_0, \gamma, R_0)$$

Publicly available!

Example: Galactic Center γ-ray excess

χ^2 profiled over:

- baryonic morphology and normalisation,
- Sun's distance to GC,
- DM parameters (scale radius and local DM density)



$$\mathcal{J} = \int_{\Delta\Omega} d\Omega \int_{\text{l.o.s.}} ds\, \rho^2_{\text{DM}}(r(s,\psi))$$

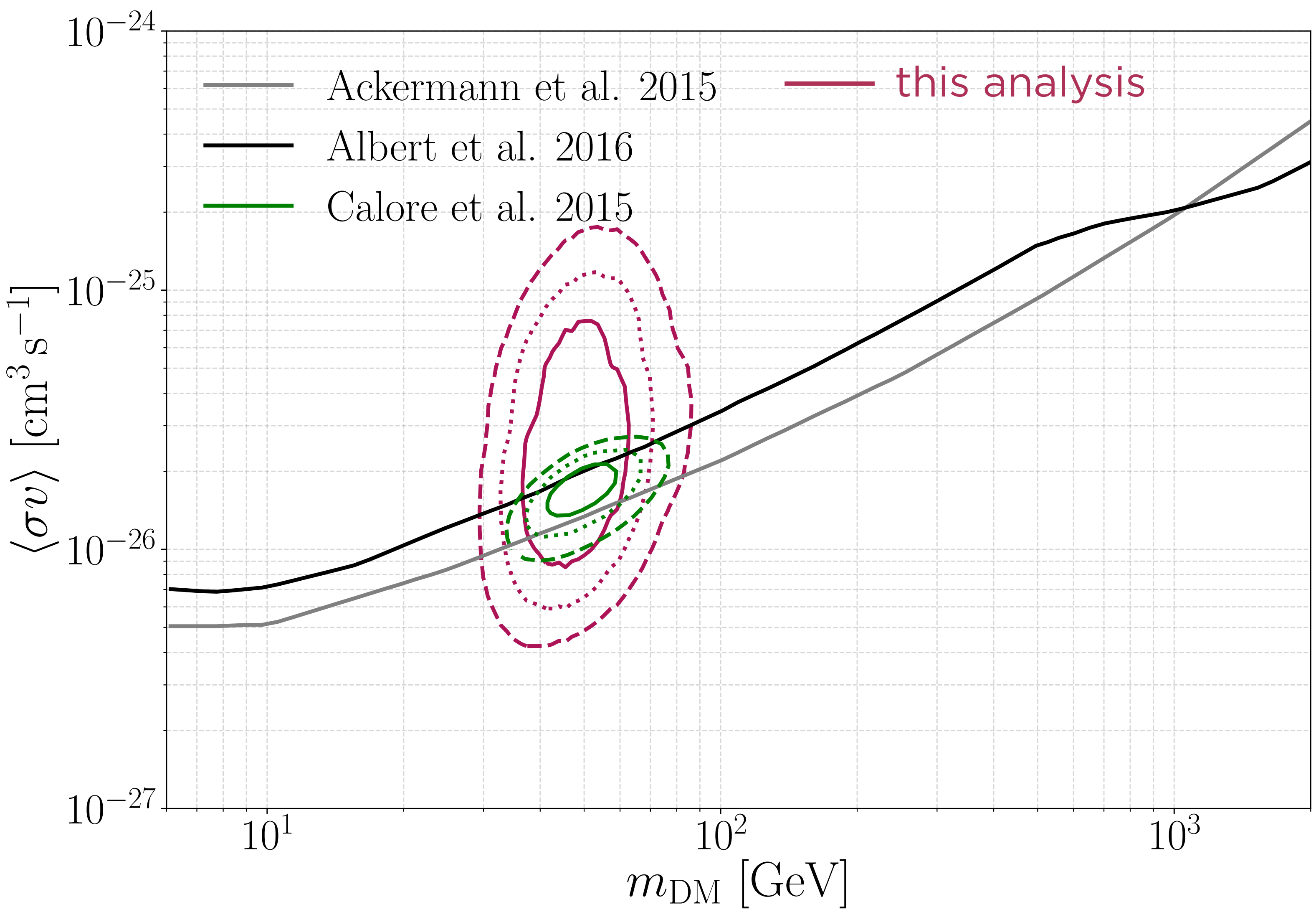
ROI:

40°x40° around GC with a strip of ±2° along the Galactic plane excluded

Example: Galactic Center excess

$$\chi^2_{\rm total} = \chi^2_{\rm GCE}(\langle\sigma v\rangle, m_{\rm DM}, \mathcal{J}) + \chi^2_{\rm RC}(R_s, \rho_0, \gamma, R_0) + \chi^2_{R_s,\rho_0,\gamma,R_0}$$

GCE analysis | RC analysis | Priors



$b\bar{b}$ DM annihilation channel

Take away points (2)

Likelihood profile (based on real data) for the reconstructed DM density profile in the MW.

It represents state-of-the-art from observations only (no simulations).

It takes into account astrophysical uncertainties on:

- 3D distribution of baryons (stars+gas) in the Galaxy;
- weight of baryons with respect to total mass budget;
- Sun's galactocentric distance and
- observed RC.

It is available at:

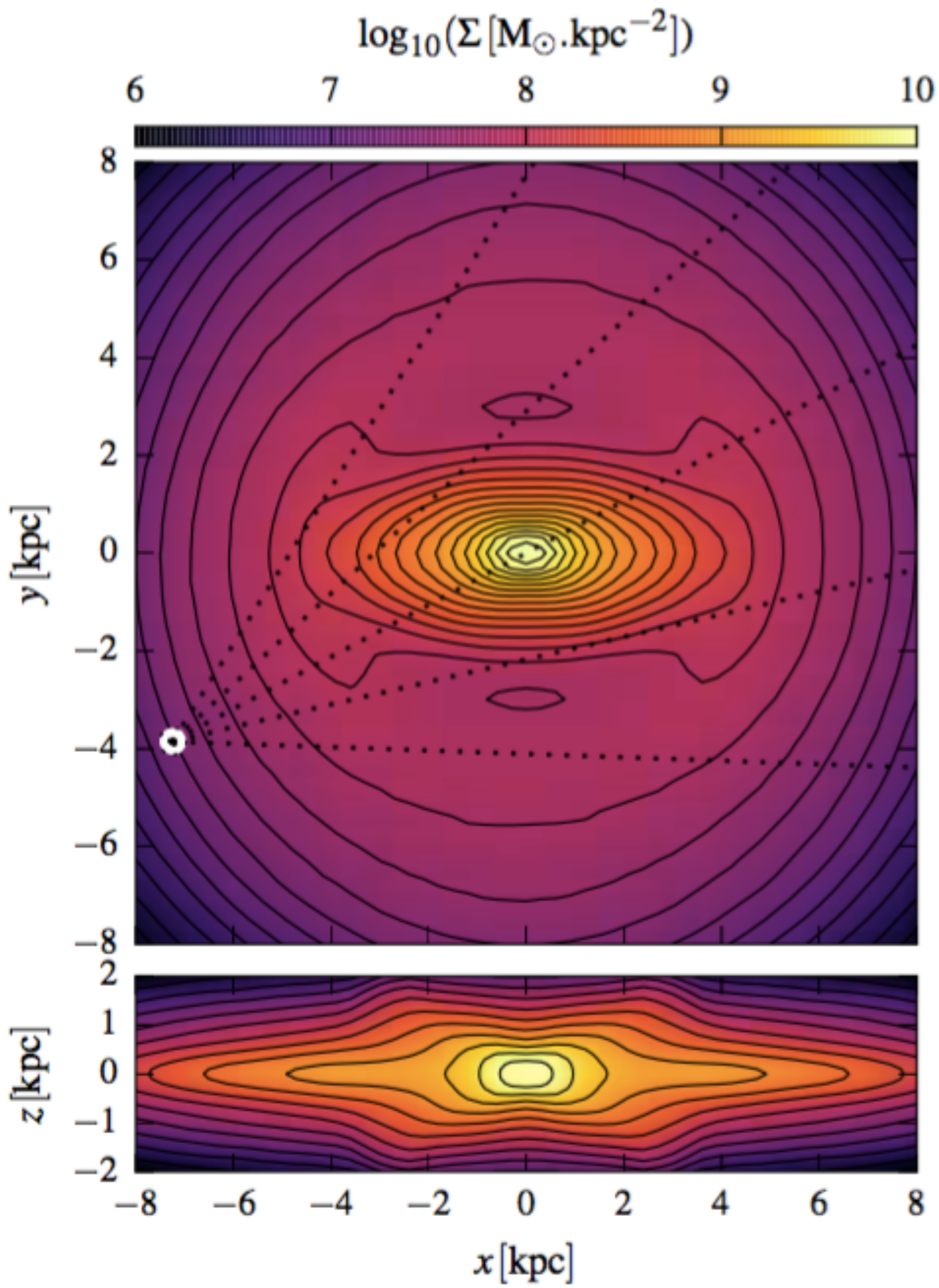
https://github.com/mariabenitocst/UncertaintiesDMinTheMW

It can be used in direct/indirect searches (e.g. GC/Galactic halo DM searches in gamma-rays, DM neutrinos searches, direct DM searches and local DM searches with antimatter).

Rotation Curve method

Only applies for R > 2.5 kpc

CAVEAT



Assumptions:

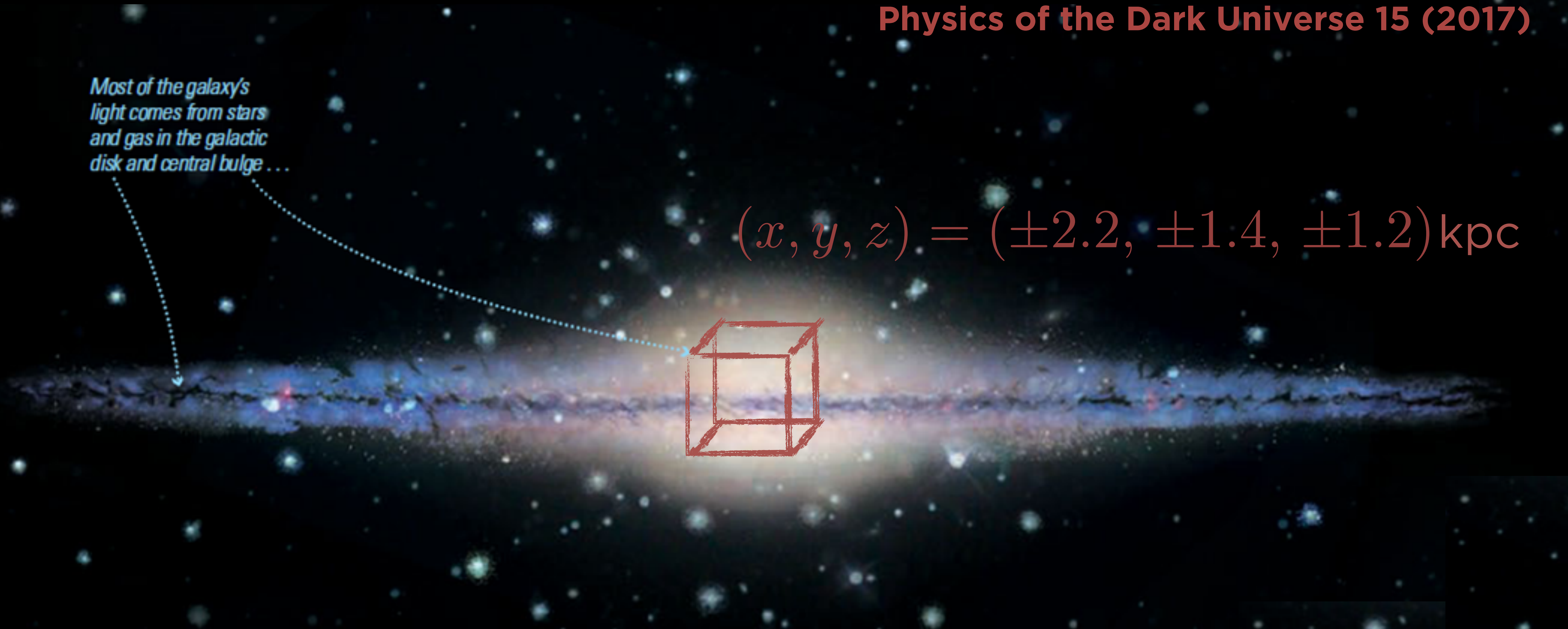
- ~~Rotationally supported~~
- ~~Objects move in circular orbits around the GC~~
- ~~The gravitational potential is axisymmetric~~

Face-on (upper) and side-on (lower) projection of the 3D density of the Galactic bulge

M. Portail + [1608.07954]

How to reconstruct DM density profile in Galactic Bulge region?

Iocco & MB
Physics of the Dark Universe 15 (2017)



$$(x, y, z) = (\pm 2.2, \pm 1.4, \pm 1.2)\,\text{kpc}$$

Total mass

$$M_{total} = (1.85 \pm 0.05) \times 10^{10}\,\mathrm{M}_\odot$$

Portail +
MNRAS 465 (2017)

Stellar mass

$$M_*^i = \int_{box} \rho_*^i(x, y, z)\,\mathrm{d}V$$

Methodology

Allowed DM mass

$$M_{total} - M_*^i = M_{DM}^i$$

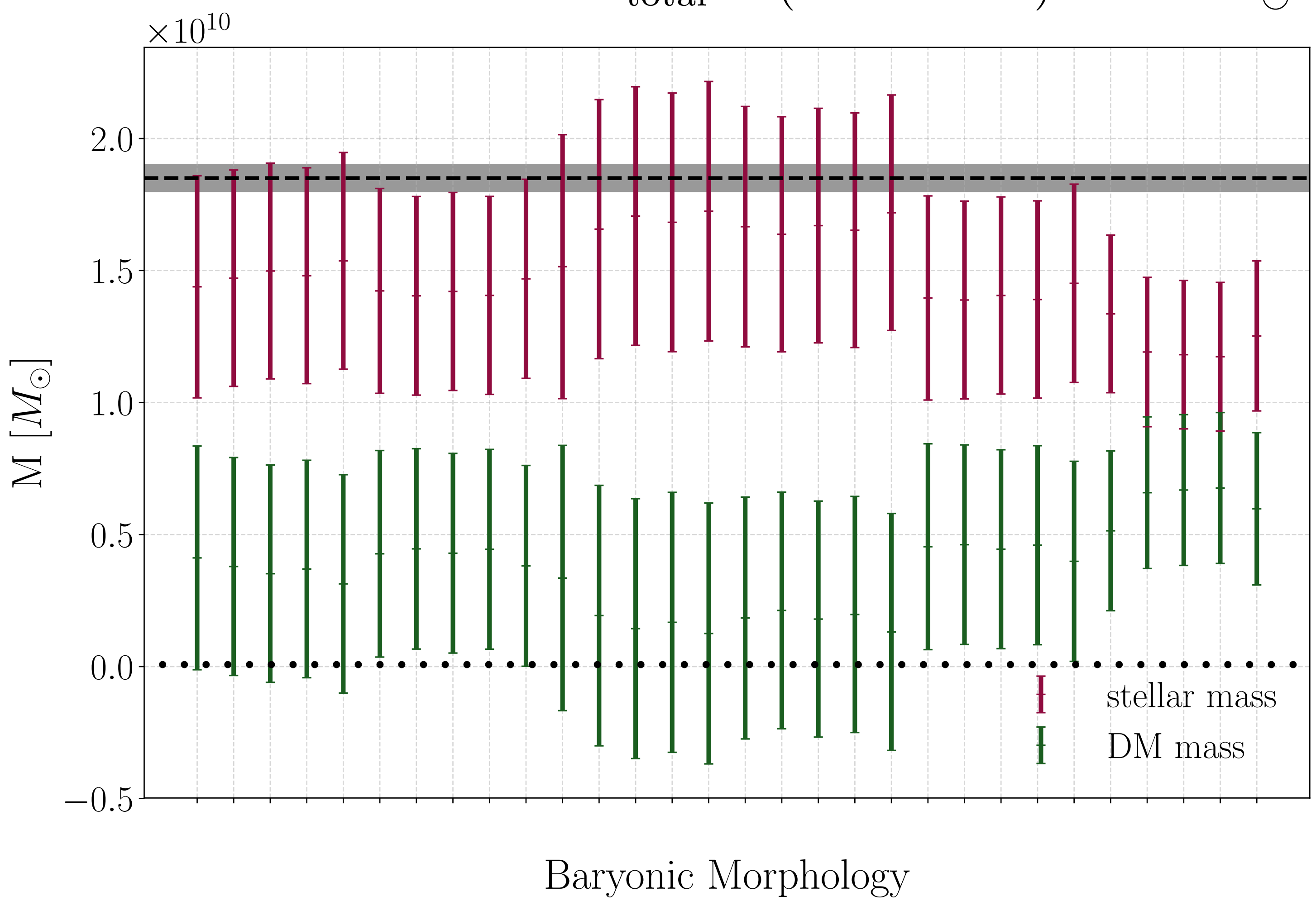
$$\sigma_{M_{DM}^i} = \sqrt{\sigma^2_{M_{total}} + \sigma^2_{M_*^i}}$$

$$\mathrm{M_*} = (1.1 - 1.7) \times 10^{10} \mathrm{M_\odot}$$

$$\mathrm{M_{DM}} = (0.1 - 0.7) \times 10^{10} \mathrm{M_\odot}$$

DM mass corresponds to 7-37%

$$\mathrm{M_{total}} = (1.85 \pm 0.05) \times 10^{10}\, \mathrm{M_\odot}$$

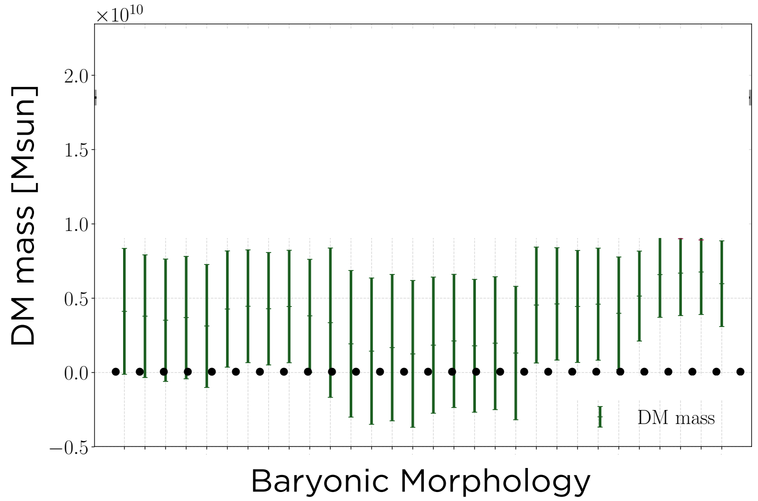


gNFW density profile

$$\rho_{DM}(r) = \rho_0 \left(\frac{R_0}{r}\right)^{\gamma} \left(\frac{R_s + R_0}{R_s + r}\right)^{3-\gamma}$$

Study parameter space that gives a mass in excess or defect with respect to the allowed DM mass

Galactic Bulge Region - Results: varying bulge morphology



$$R_s = 20\,\mathrm{kpc}$$

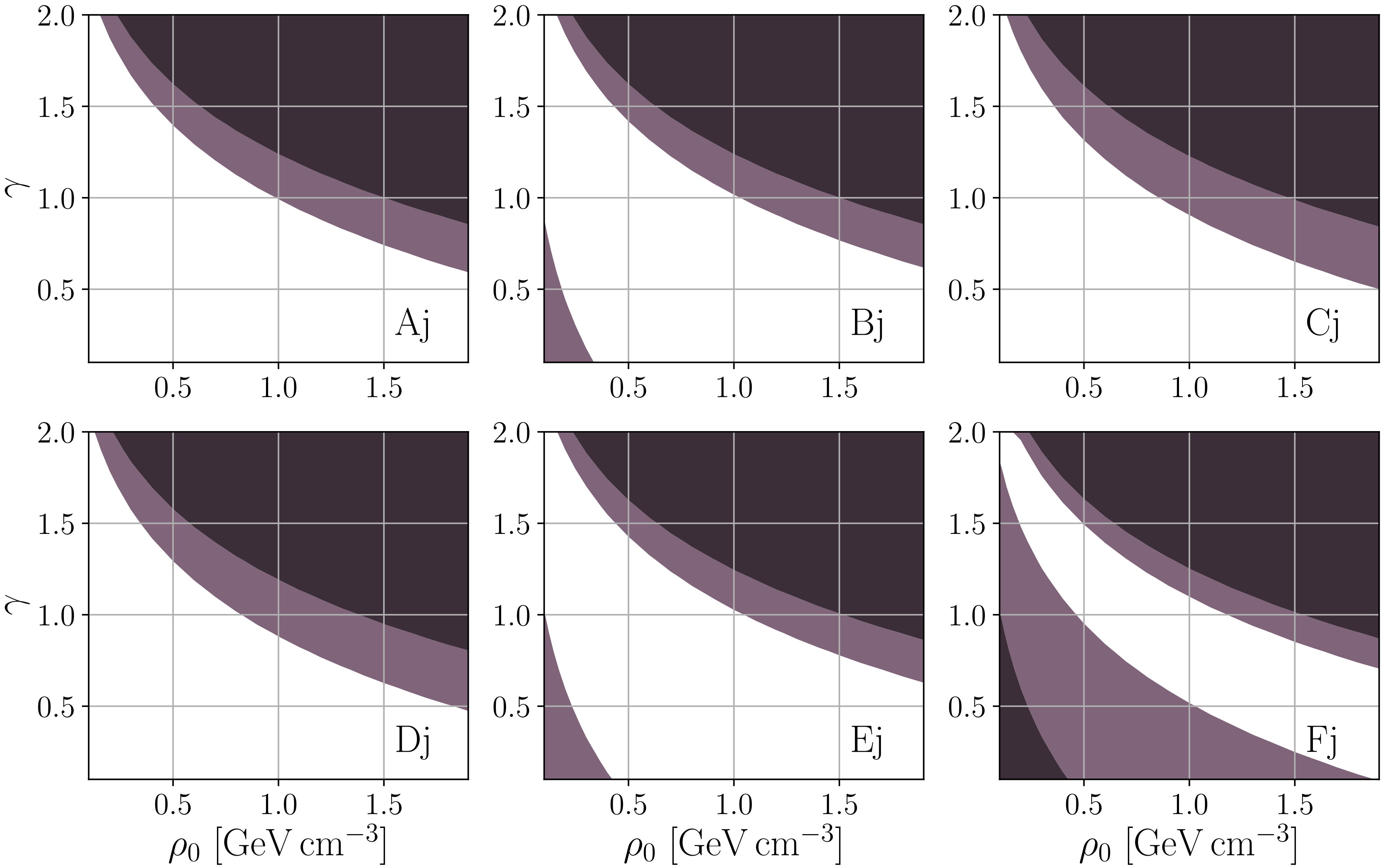
$$R_0 = 8\,\mathrm{kpc}$$

Same disc, varying bulge

Allowed at 1σ

Allowed at 2σ

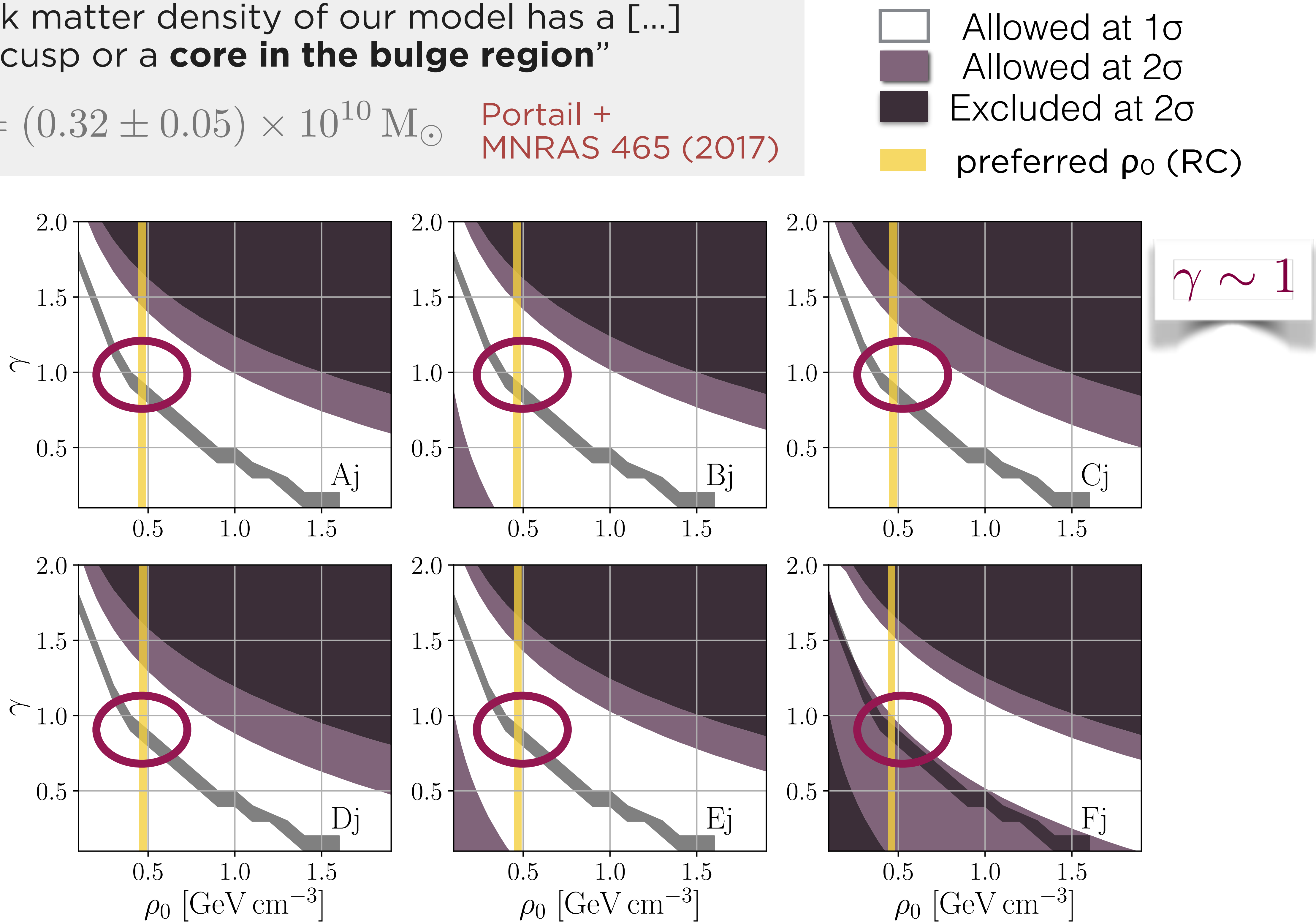
Excluded at 2σ



Galactic Bulge Region - Results: varying bulge morphology

"the dark matter density of our model has a [...] shallow cusp or a **core in the bulge region**"

$M_{DM} = (0.32 \pm 0.05) \times 10^{10}\, M_{\odot}$ Portail + MNRAS 465 (2017)



Core is not a necessary condition!

Take away points (3)

- Our ignorance about the morphology of the bulge and the normalisation of the visible component **prevents strong conclusions on the DM distribution in the inner 2.5 kpc**.

- Larger uncertainties for the slope of the profile (γ), **DM distribution remain yet inconclusive.**

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