The Dark Matter distribution of the Milky Way

(its uncertainties and consequences on the determination of new physics)

An empirical approach

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"Dark Matter searches in the 2020s. At the crossroads of the WIMP"

ICRR, The University of Tokyo, Kashiwa. November 12, 2019

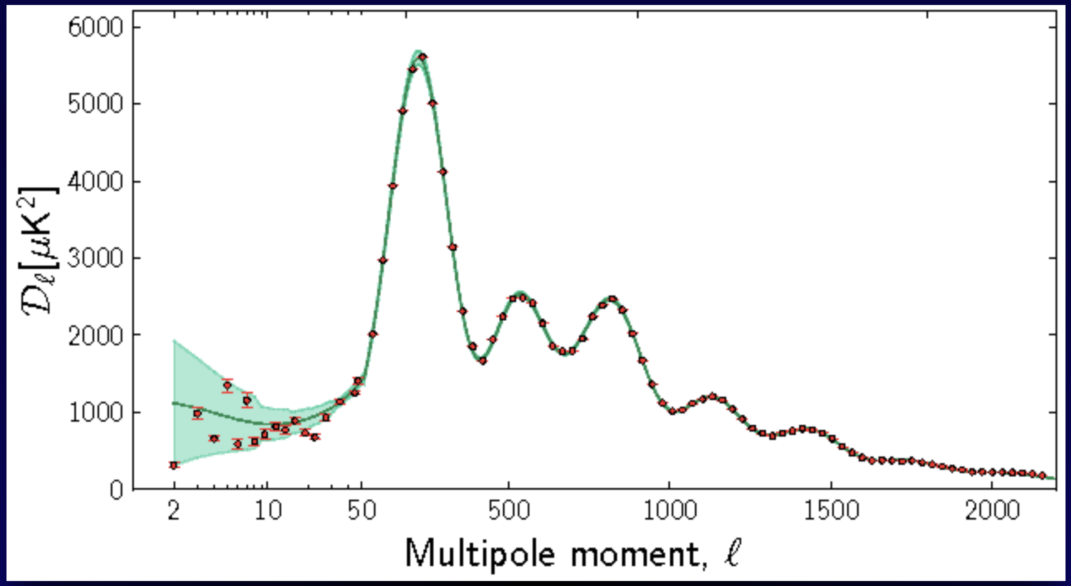
What is the actual distribution of DM in the Milky Way?

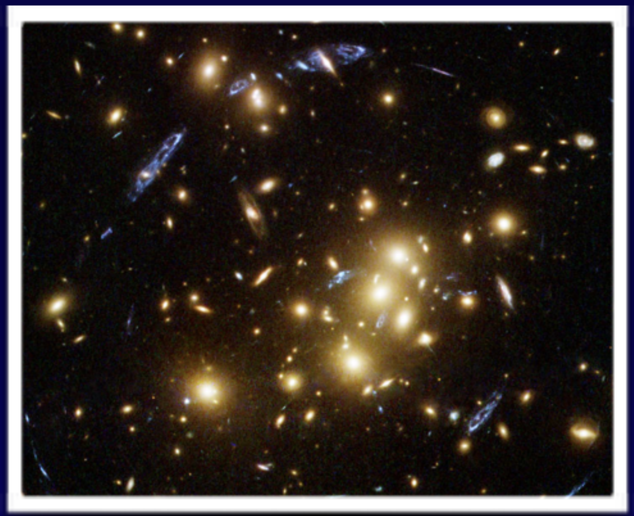
And most notably in the proximity of the Sun?

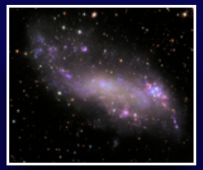
And the Galactic Center, as requested. Please bear with me until the end.

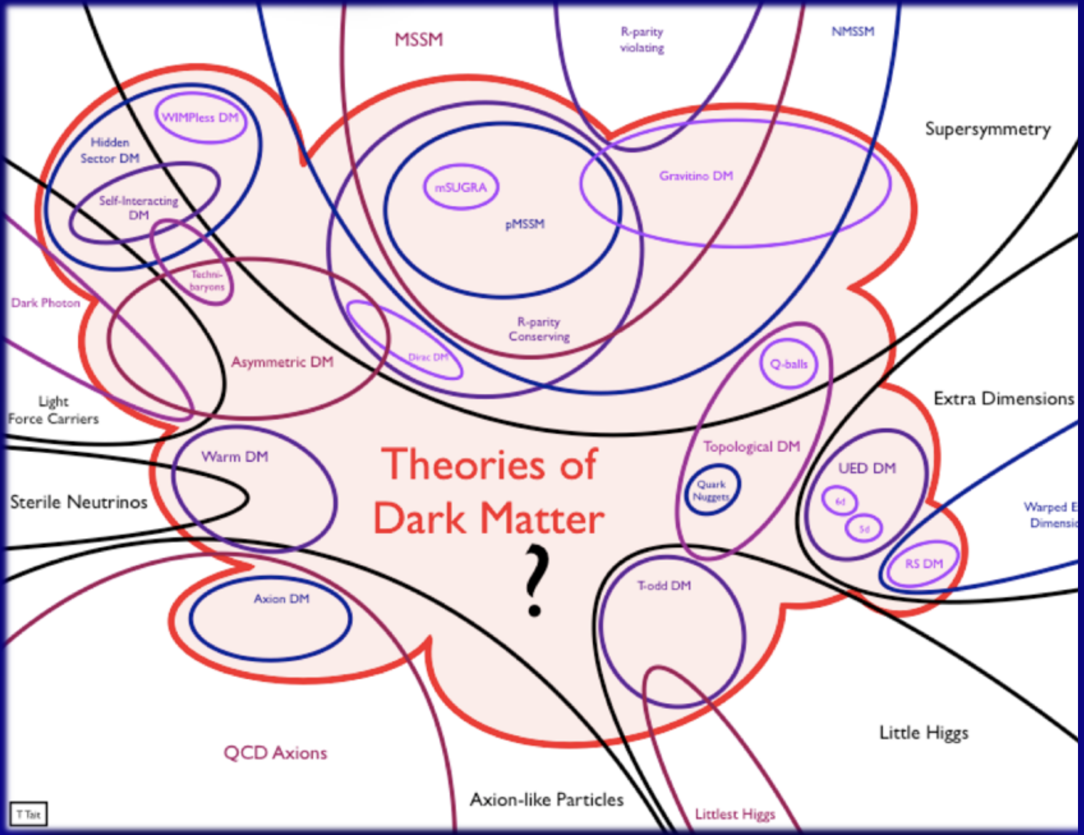
Dark Matter

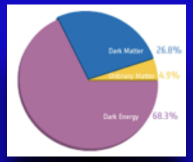
Evidence over large range of scales







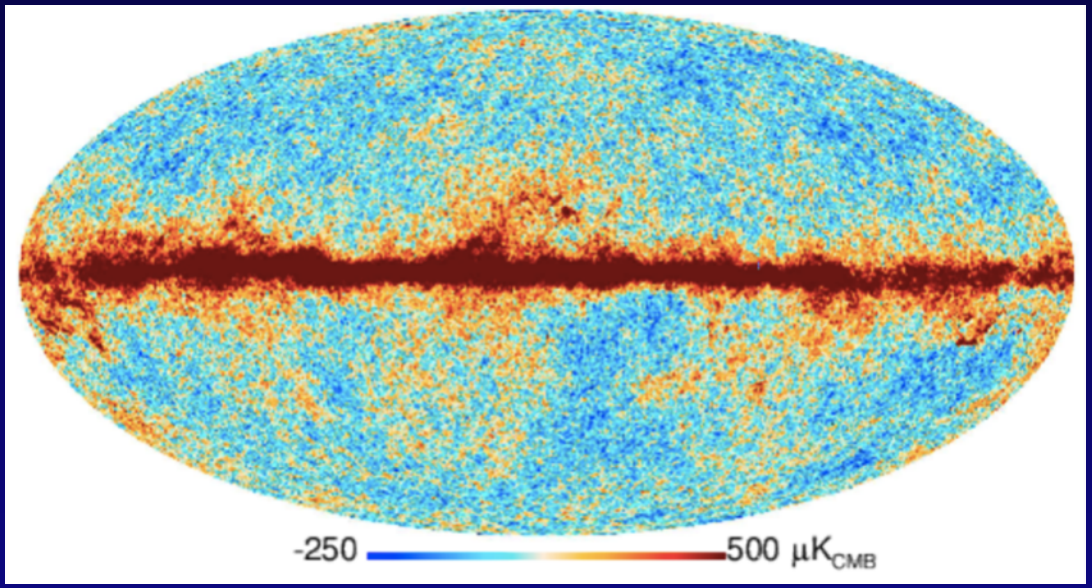


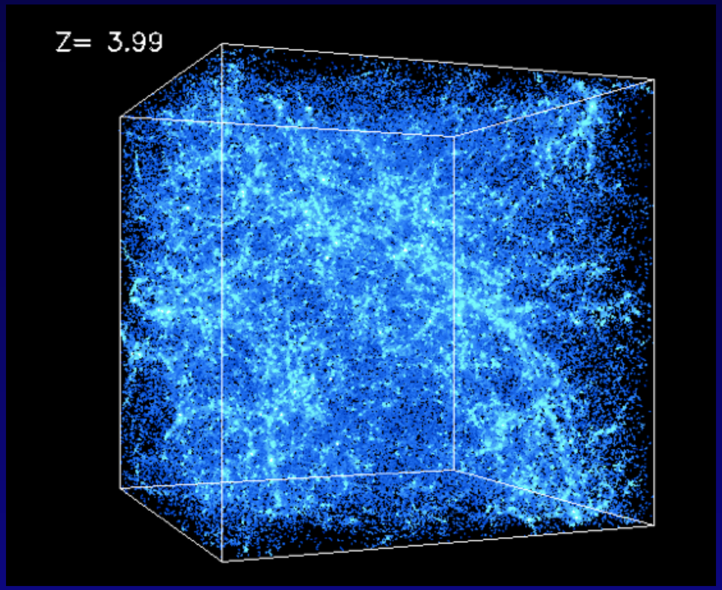


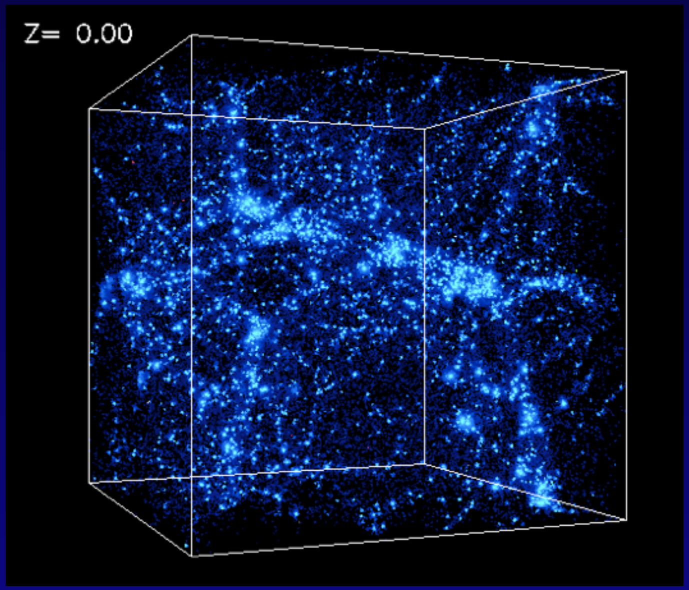
NATURE STILL UNKNOWN

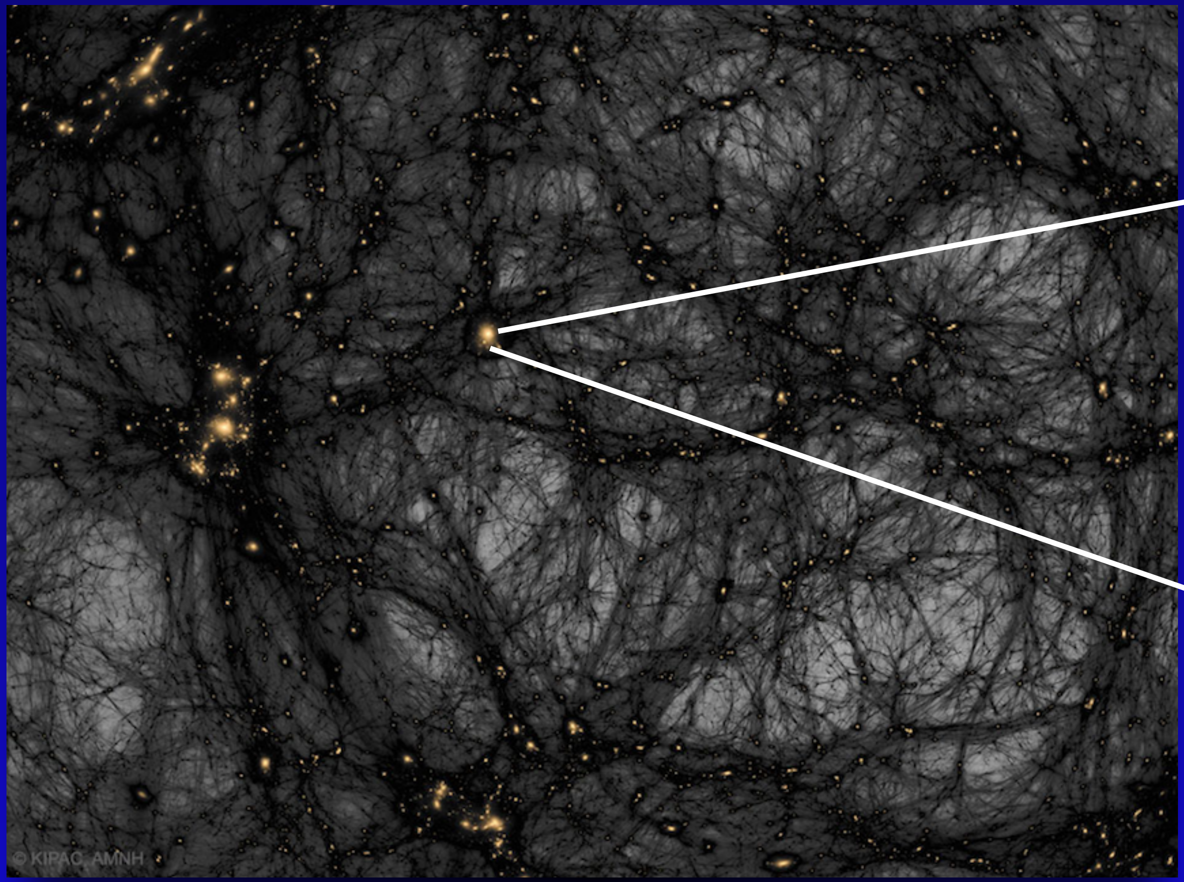
A story of LCDM
I: structure formation

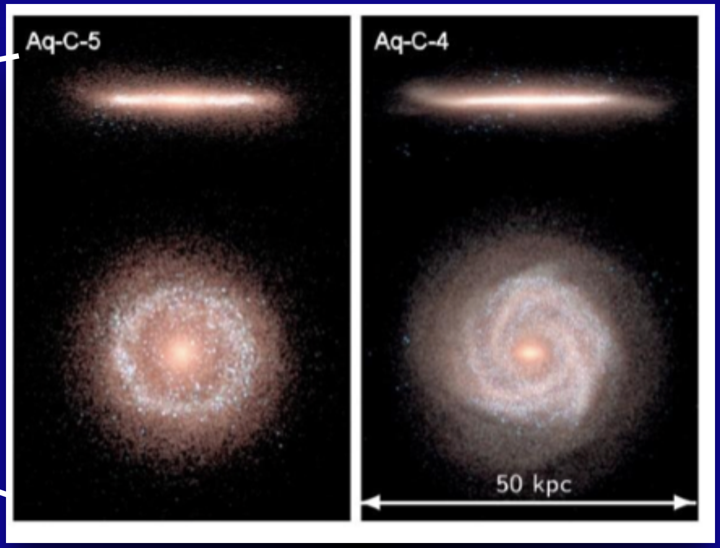
age of Universe





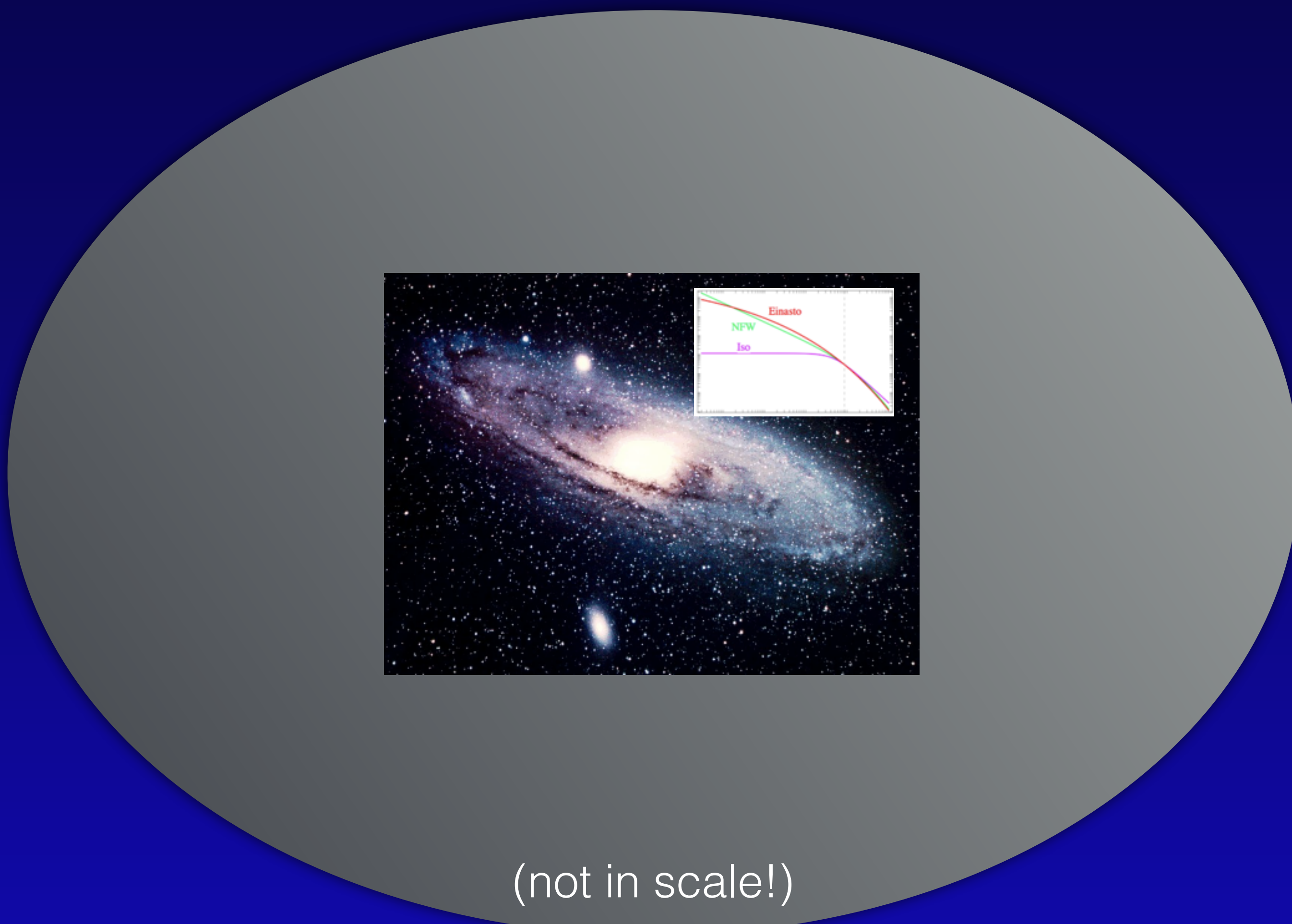




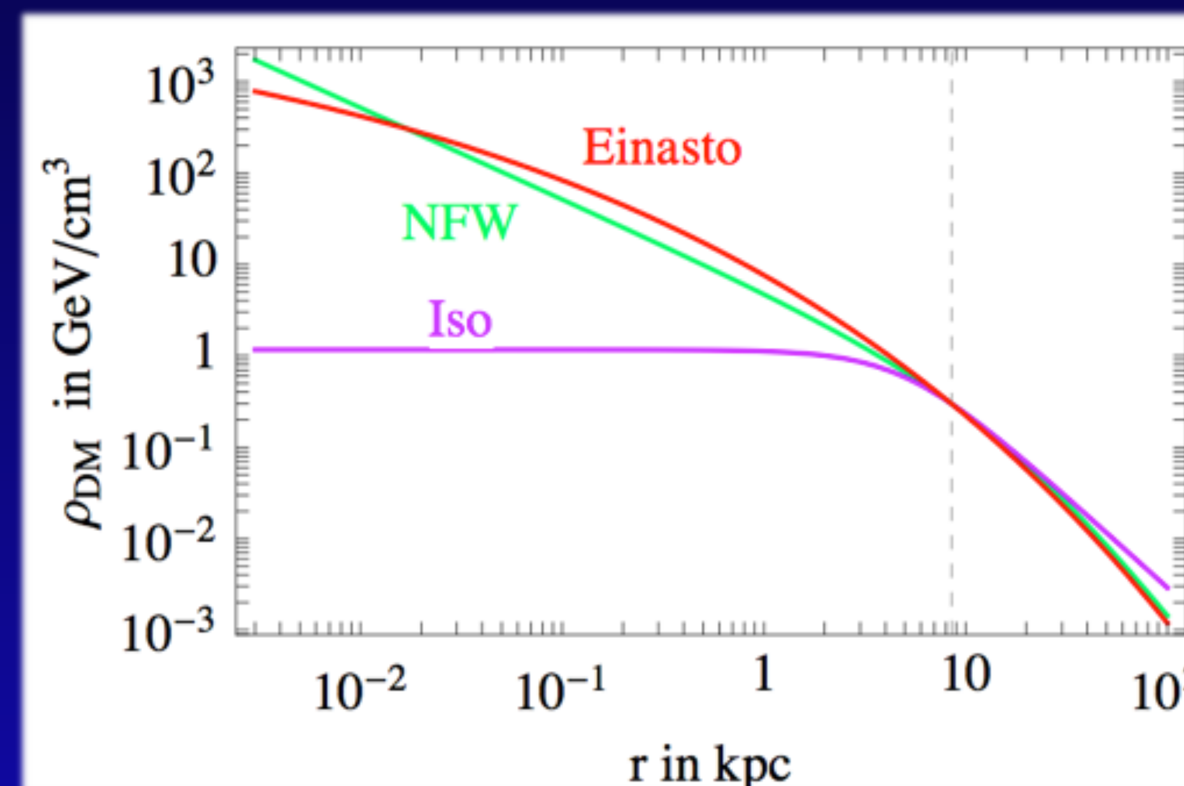


physical size

A story of LCDM
II. the single halo



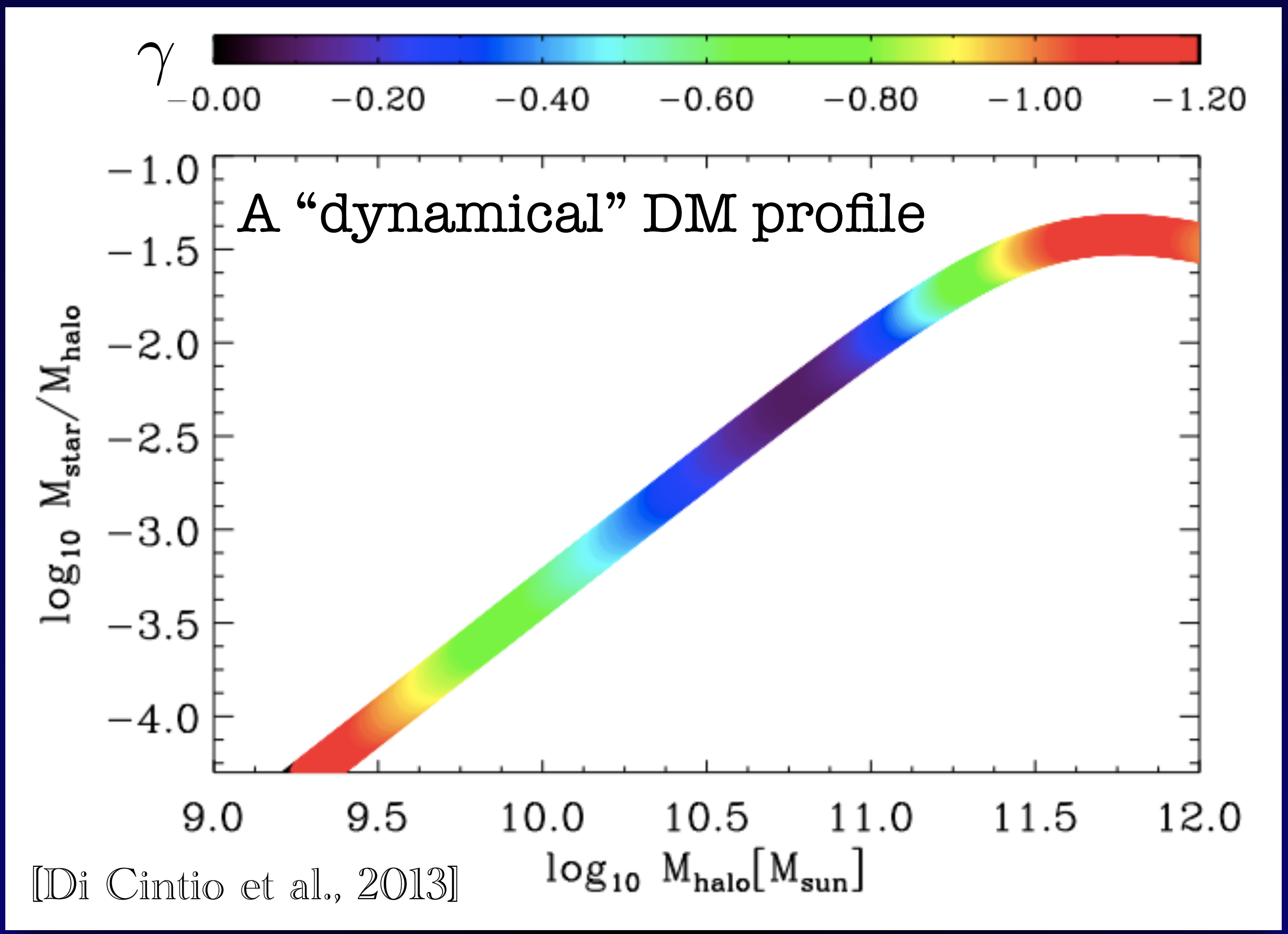
A "universal" DM profile?

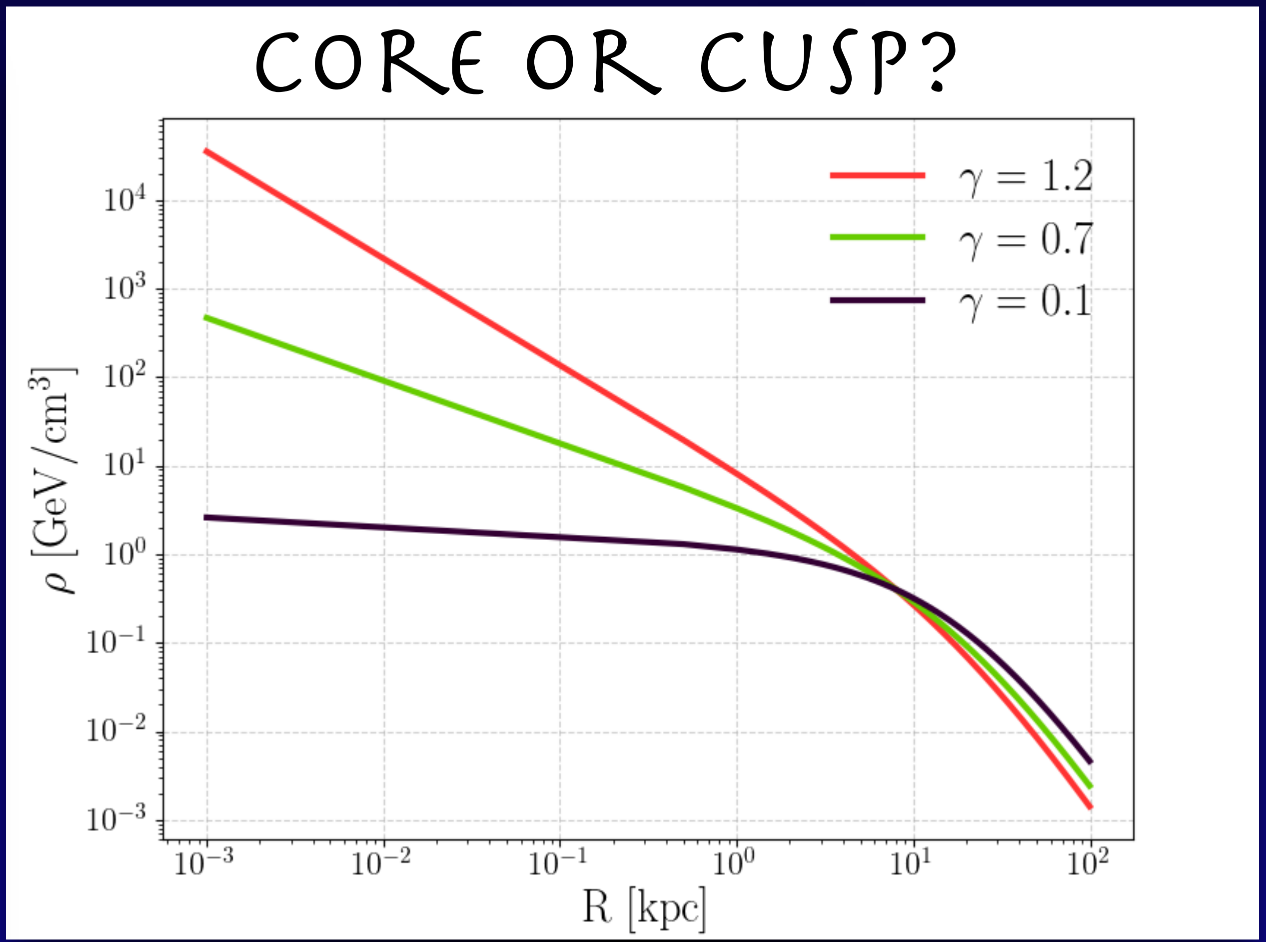


NAVARRO-FRENK-WHITE

$$\rho(R) \propto \frac{R_s}{R}\left(1+\frac{R}{R_s}\right)^{-2}$$

A story of LCDM
III. the dark matter distribution



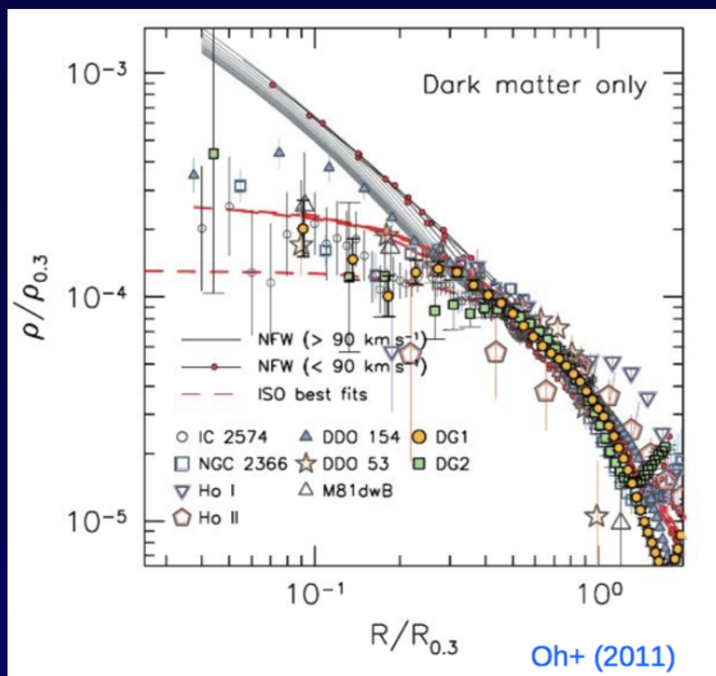


generalized NFW

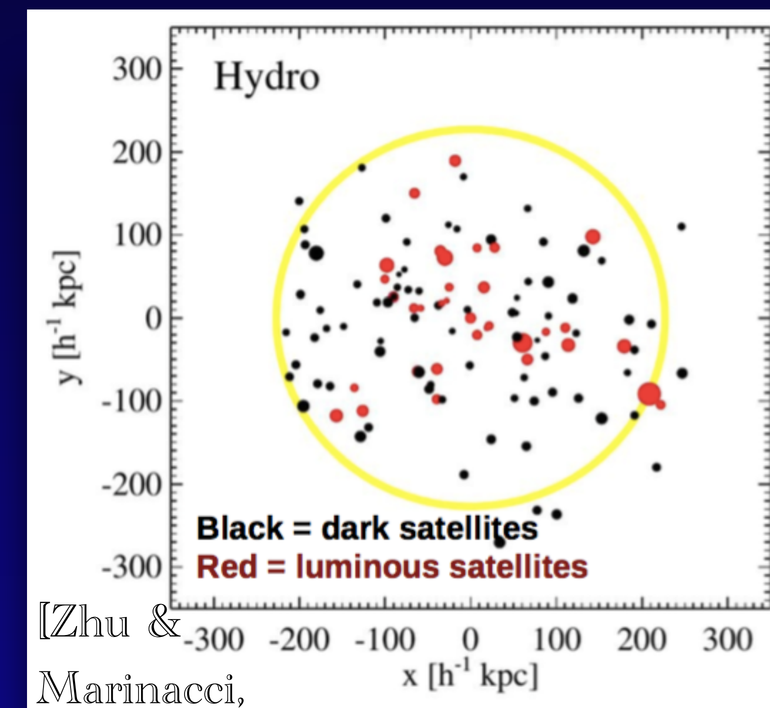
$$\rho_{DM}(R) \propto \rho_0 \left(\frac{R}{R_s}\right)^{-\gamma} \left(1 + \frac{R}{R_s}\right)^{-3+\gamma}$$

A story of LCDM
IV. the small scale problems

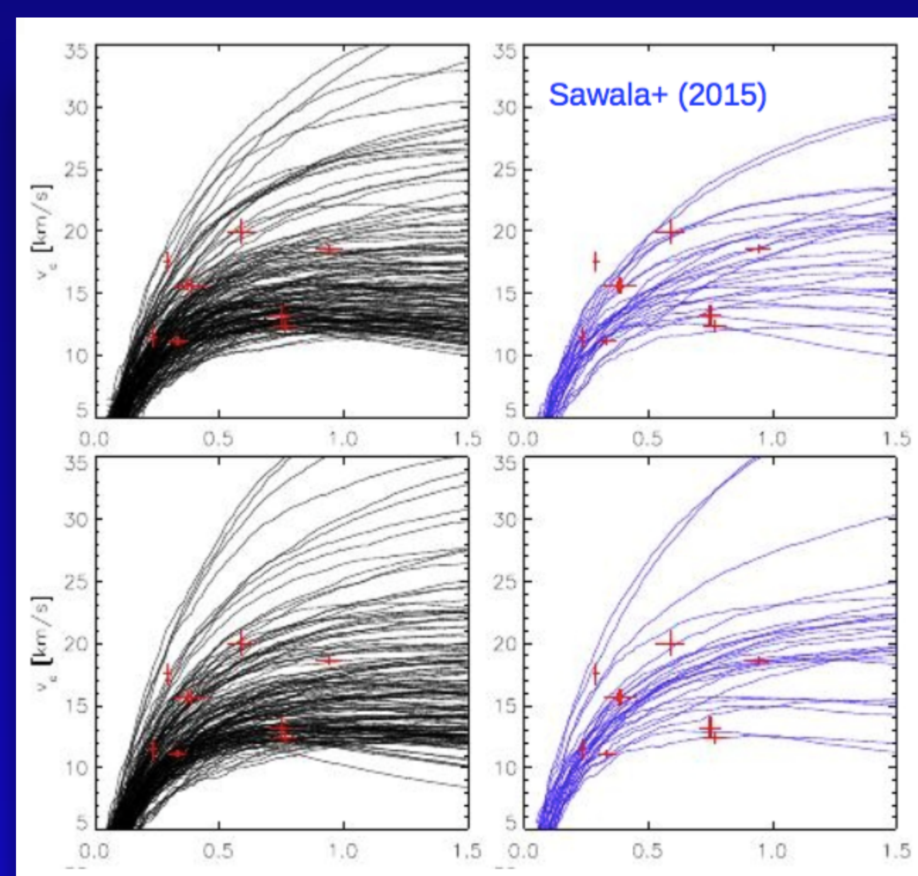
Cusp vs core



Missing satellite



Too big to fail



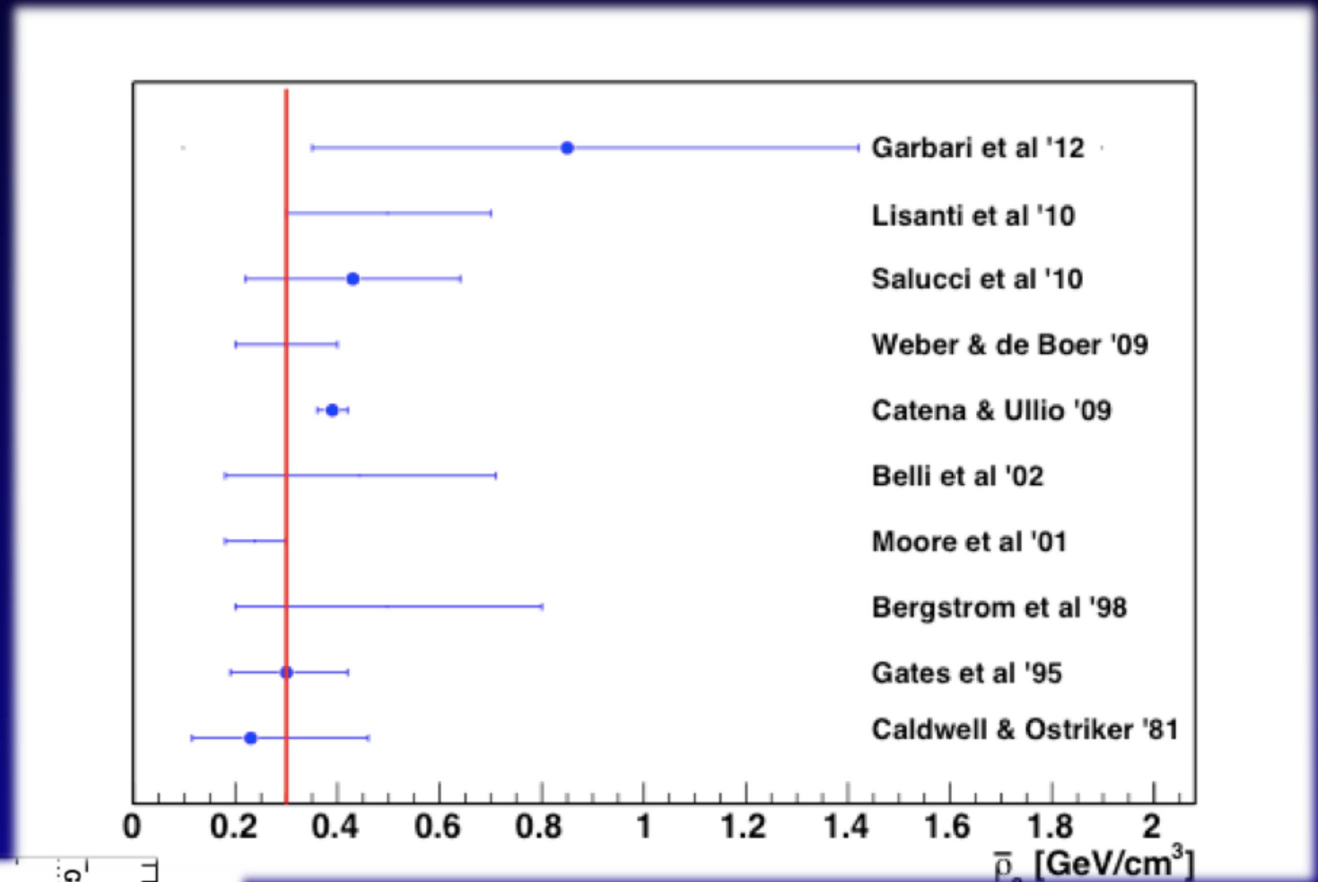
…or lack thereof

What is the actual distribution of DM in the Milky Way?

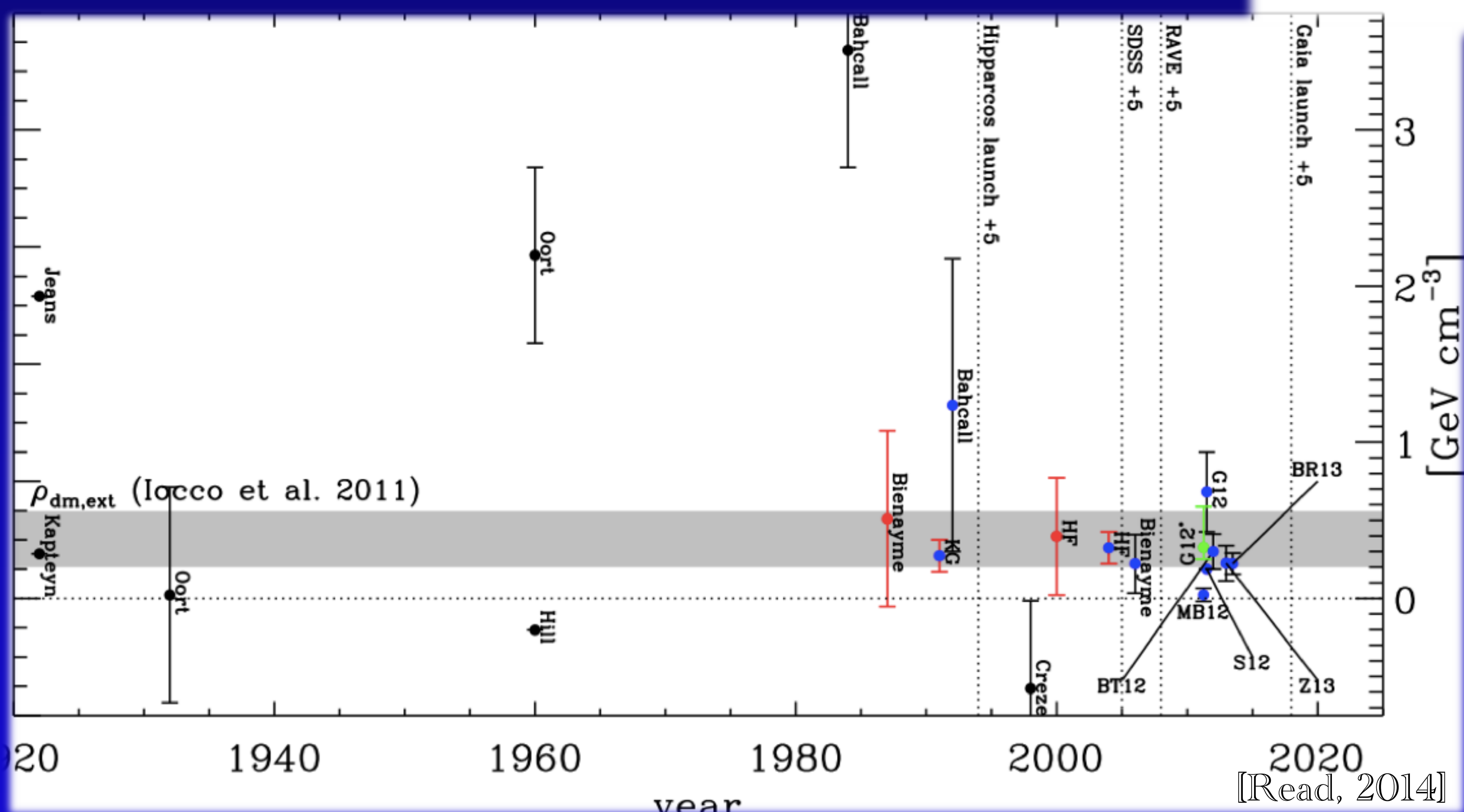
And most notably in the proximity of the Sun?

And the Galactic Center, as requested. Please bear with me until the end.

Empirical determination of local DM density

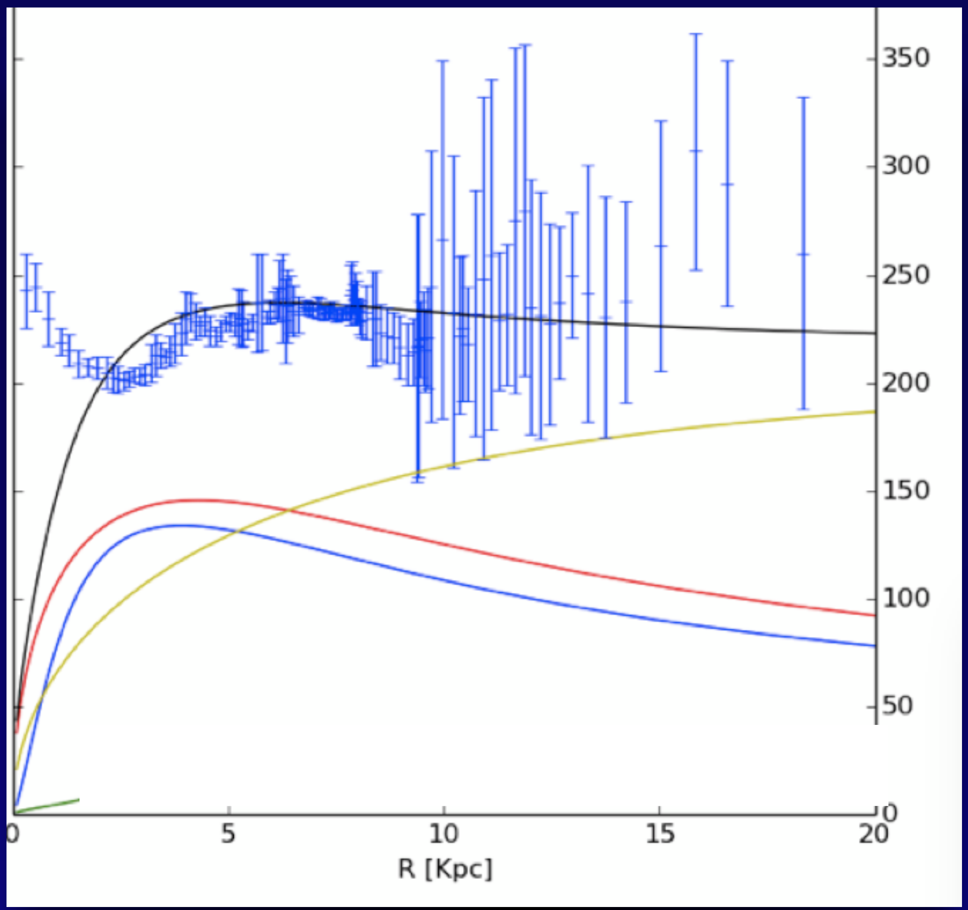


Determinations of
local DM density
are consistent, but noisy



Inferring the whole DM distribution (MW's 'backbone')

Fitting a pre-assigned shape on top of luminous

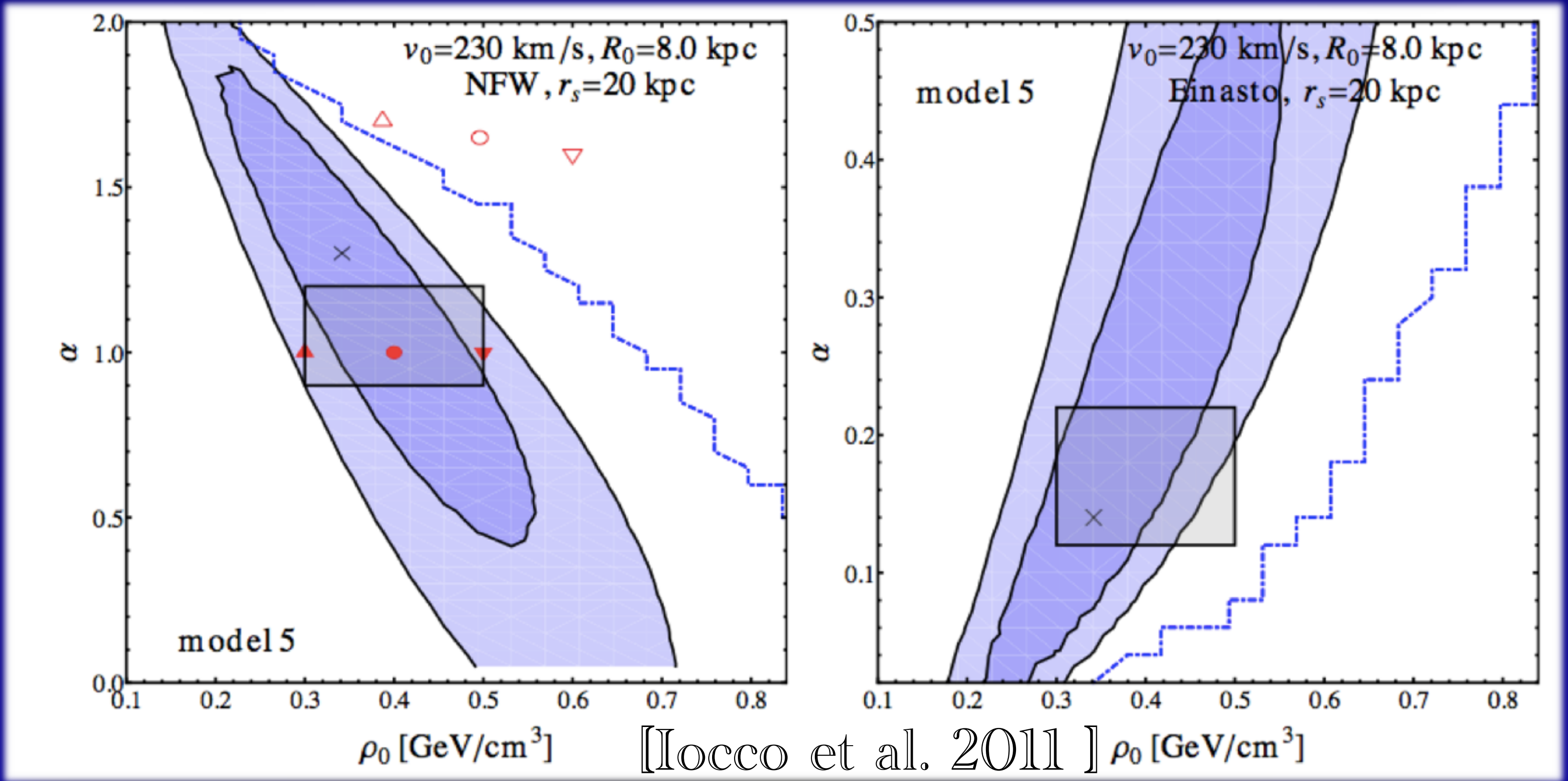


gNFW

$$\rho_{DM}(R) \propto \rho_0 \left(\frac{R}{R_s}\right)^{-\gamma} \left(1 + \frac{R}{R_s}\right)^{-3+\gamma}$$

$$\rho_{DM}(R) \propto \rho_0 \exp\left[-\frac{2}{\gamma}\left(\left(\frac{R}{R_s}\right)^{\gamma} - 1\right)\right]$$

Einasto



[Iocco et al. 2011]

[many autors, e.g. Iocco et al. 2011]

The case of the Milky Way

Ingredients:

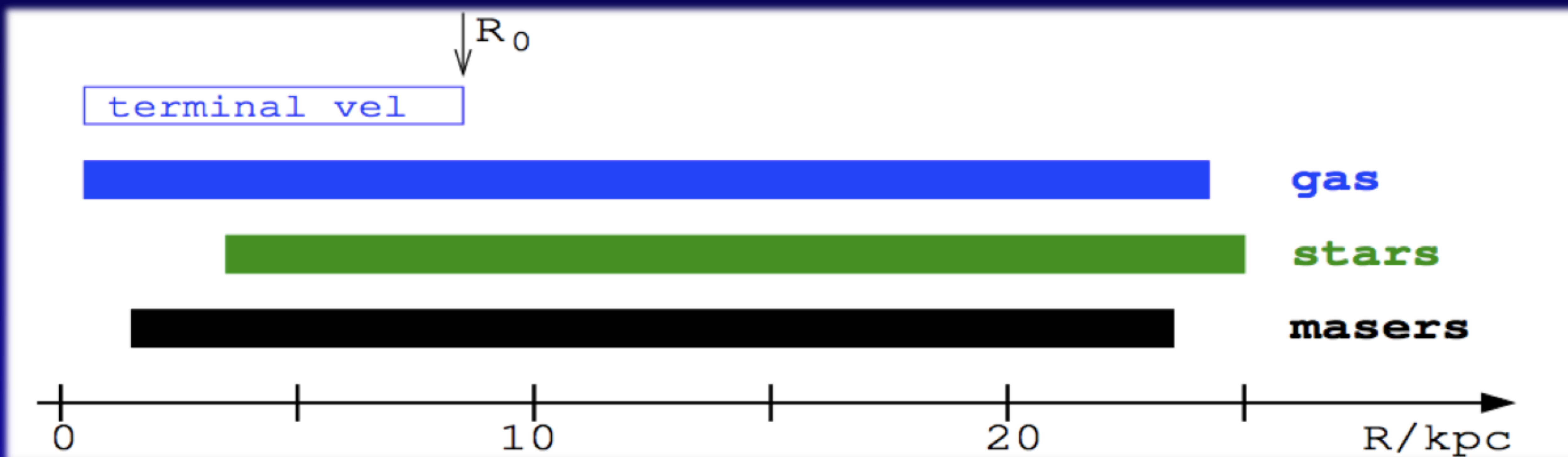
- The observed rotation curve
- The “expected” rotation curve

- Some “grano salis”

- Working hypothesis (later on)

The Milky Way:

observed rotation curve
the tracers of the gravitational potential



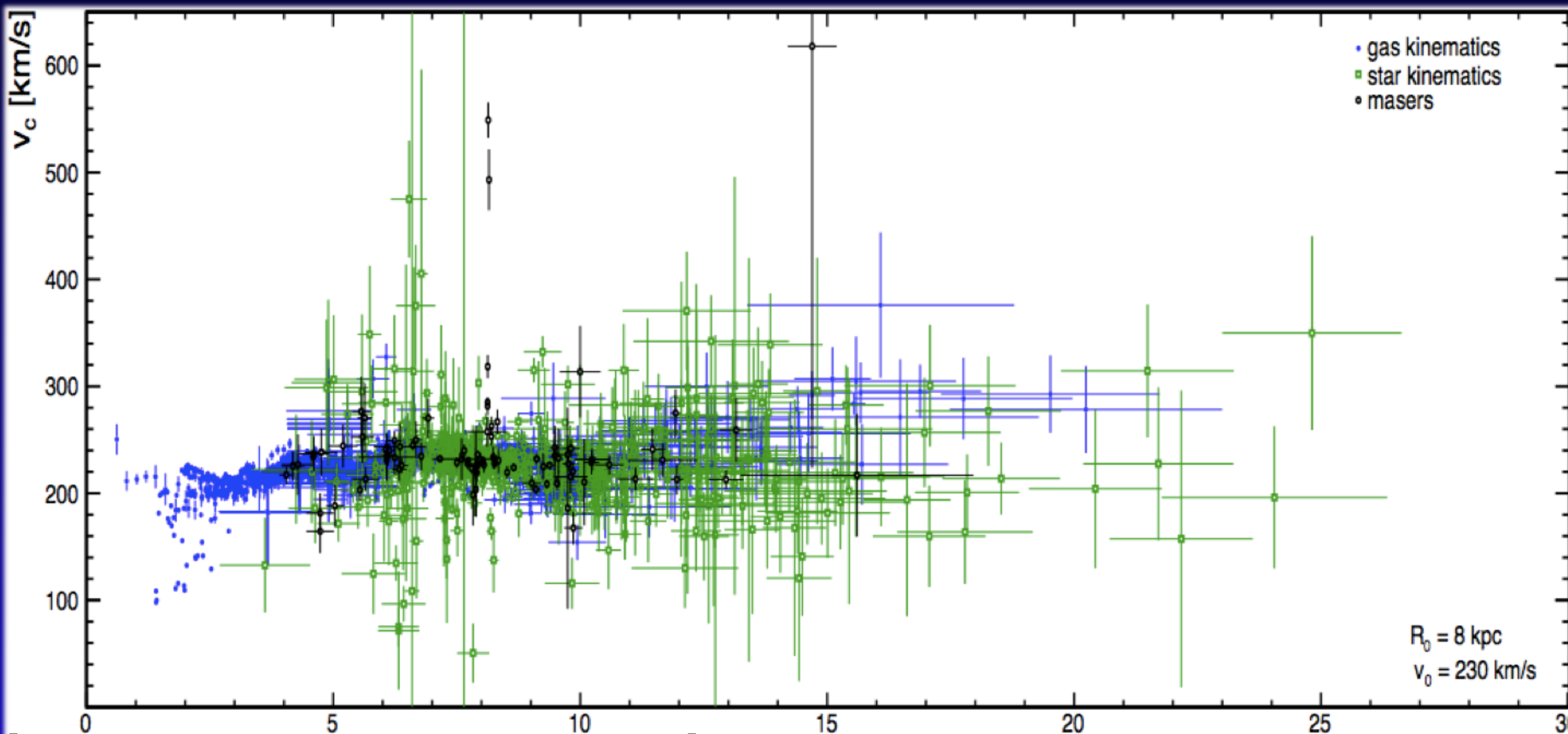
Doppler shift

1.	gas	(21cm, Hα, CO)
2.	stars	(H, He, O, ...)
3.	masers	(H_2O, CH_3OH, ...)

distance

1.	terminal velocities	(gas)
2.	photo-spectroscopy	(stars)
3.	parallax	(masers)

The Milky Way Rotation Curve
as observed



[Iocco, Pato, Bertone, Nature Physics 2015]

All tracers, optimized for precision between R=3-20 kpc
For more details on data treatment (as well as inclusion of different datasets) …

galkin compilation [Pato & FI, arXivV:1703.00020 , Software X (2017)]

The Milky Way:

'expected' rotation curve

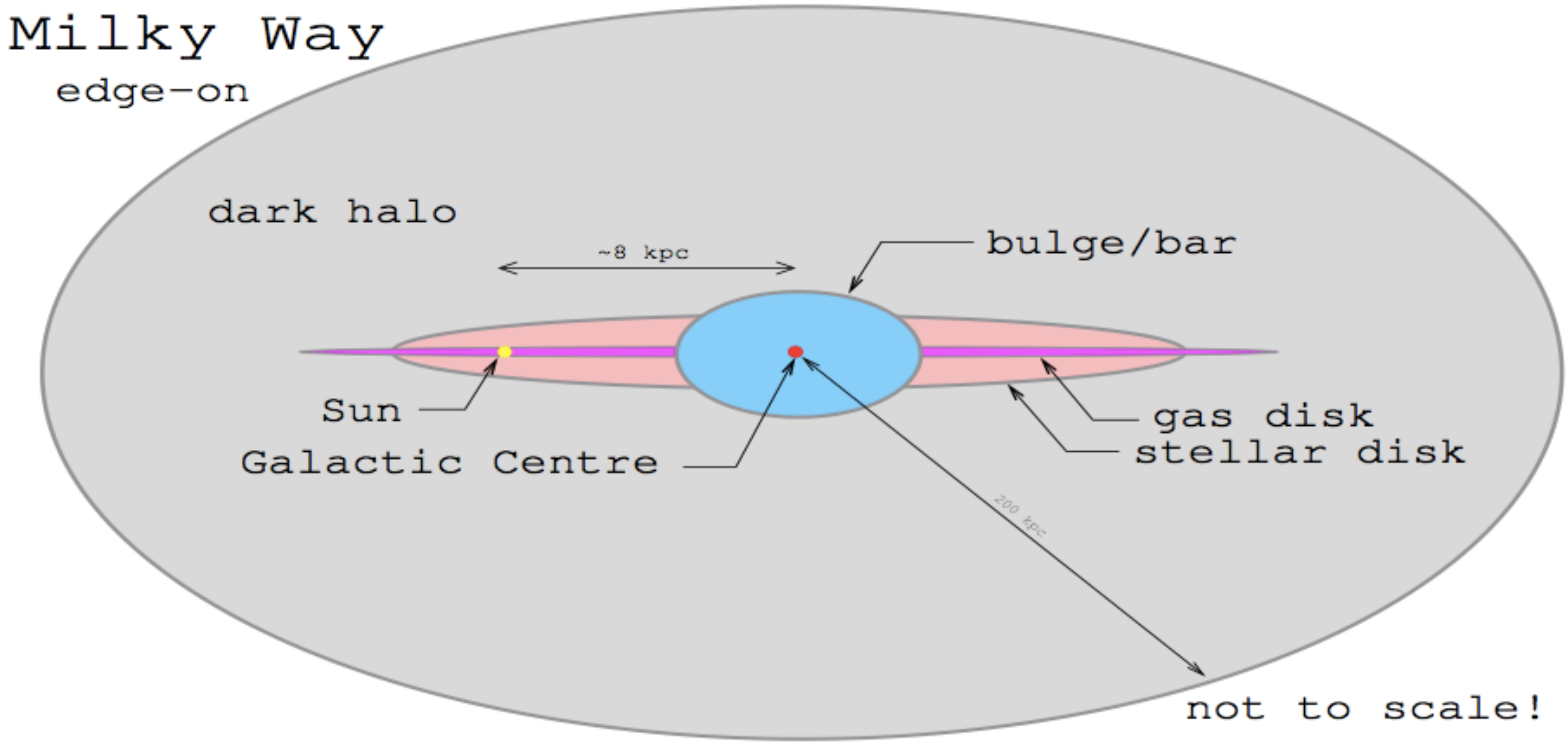
from visible (baryon) component

$$\Phi_{\mathrm{baryon}} = \Phi_{\mathrm{bulge}} + \Phi_{\mathrm{disk}} + \Phi_{\mathrm{gas}}$$

$$\rho_i(x, y, z) \rightarrow \phi_i(r, \theta, \varphi) \rightarrow v_{c,i}^2(R) = \sum_{\varphi} R \frac{d\phi_i}{dr}(R, \pi/2, \varphi)$$

Constructing the curve expected from observed mass profiles

The Milky Way:
expected rotation curve
the baryonic components

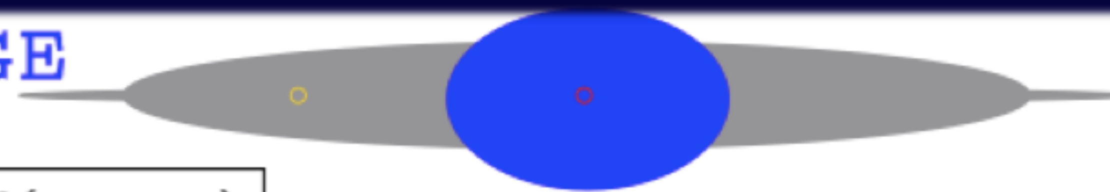


bulge	tilted bar
disk	thin+thick
gas	H_2, HI, HII

Courtesy of Miguel Pato

The luminous Milky Way: observations of morphology

2. BARYONS: STELLAR BULGE



$$\boxed{\rho_{\rm bulge} = \rho_0 f(x,y,z)}$$

morphology $f(x,y,z)$

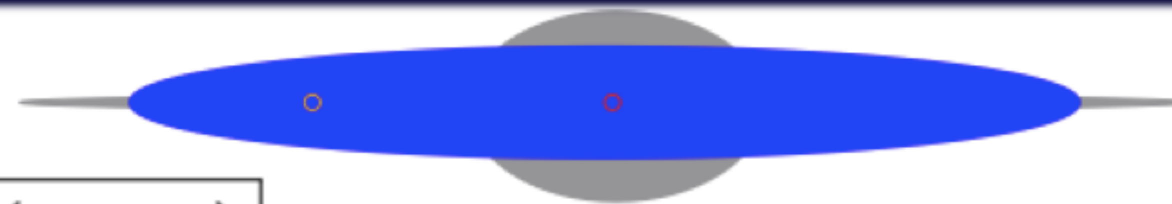
Stanek+ '97 (E2)	e^{-r}	0.9:0.4:0.3	24°	optical
Stanek+ '97 (G2)	$e^{-r_s^2/2}$	1.2:0.6:0.4	25°	optical
Zhao '96	$e^{-r_s^2/2} + r_a^{-1.85} e^{-r_a}$	1.5:0.6:0.4	20°	infrared
Bissantz & Gerhard '02	$e^{-r_s^2}/(1+r)^{1.8}$	2.8:0.9:1.1	20°	infrared
Lopez-Corredoira+ '07	Ferrer potential	7.8:1.2:0.2	43°	infrared/optical
Vanhollebecke+ '09	$e^{-r_s^2}/(1+r)^{1.8}$	2.6:1.8:0.8	15°	infrared/optical
Robin+ '12	$\mathrm{sech}^2(-r_s) + e^{-r_s}$	1.5:0.5:0.4	13°	infrared

normalisation ρ_0 **and its statistical uncertainties**

microlensing optical depth: $\langle\tau\rangle = 2.17^{+0.47}_{-0.38} \times 10^{-6}$, $(\ell, b) = (1.50°, -2.68°)$
(MACHO '05)

The luminous Milky Way: observations of morphology

2. BARYONS: STELLAR DISK



$$\rho_{\text{disk}} = \rho_0 f(x, y, z)$$

morphology $f(x, y, z)$

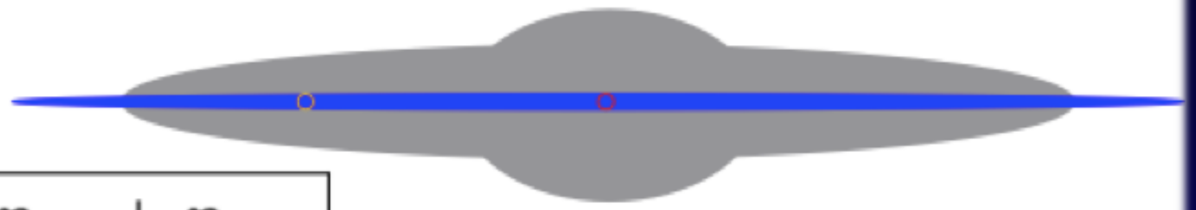
Han & Gould '03	$e^{-R}\text{sech}^2(z)$	2.8:0.27	thin	optical
	$e^{-R-\|z\|}$	2.8:0.44	thick	
Calchi-Novati & Mancini '11	$e^{-R-\|z\|}$	2.8:0.25	thin	optical
	$e^{-R-\|z\|}$	4.1:0.75	thick	
deJong+ '10	$e^{-R-\|z\|}$	2.8:0.25	thin	optical
	$e^{-R-\|z\|}$	4.1:0.75	thick	
	$(R^2+z^2)^{-2.75/2}$	1.0:0.88	halo	
Jurić+ '08	$e^{-R-\|z\|}$	2.2:0.25	thin	optical
	$e^{-R-\|z\|}$	3.3:0.74	thick	
	$(R^2+z^2)^{-2.77/2}$	1.0:0.64	halo	
Bovy & Rix '13	$e^{-R-\|z\|}$	2.2:0.40	single	optical

normalization and its statistical uncertainties

local surface density: $\Sigma_* = 38 \pm 4 M_\odot/\text{pc}^2$ [Bovy & Rix '13]

The luminous Milky Way: observations of morphology

2. BARYONS: GAS



$$n_{\rm H} = 2n_{\rm H_2} + n_{\rm HI} + n_{\rm HII}$$

morphology

Ferrière '12	$r < 0.01$ kpc	$M_{gas} \sim 7 \times 10^5$ $M_\odot$		CO, 21cm, Hα, ...
Ferrière+ '07	$r = 0.01 - 2$ kpc	CMZ, holed disk	H_2	CO
		CMZ, holed disk	H I	21cm
		warm, hot, very hot	H II	disp. meas.
Ferrière '98	$r = 3 - 20$ kpc	molecular ring	H_2	CO
		cold, warm	H I	21cm
		warm, hot	H II	disp. meas., Hα
Moskalenko+ '02	$r = 3 - 20$ kpc	molecular ring	H_2	CO
			H I	21cm
			H II	disp. meas.

uncertainties

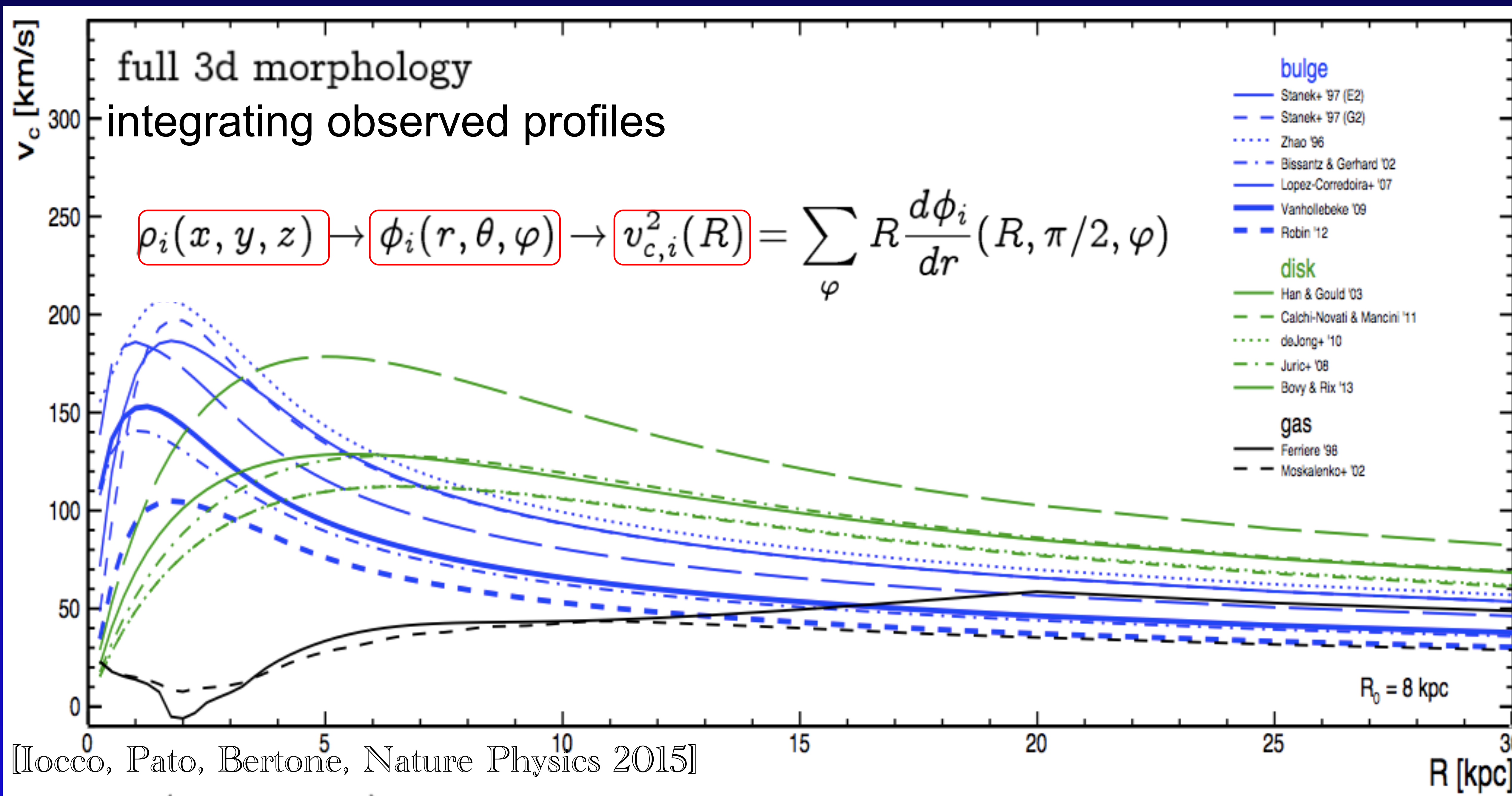
CO-to-H_2 factor: $X_{\rm CO} = 0.25 - 1.0 \times 10^{20}$ cm^{-2} K^{-1} km^{-1} s for $r < 2$ kpc

$X_{\rm CO} = 0.50 - 3.0 \times 10^{20}$ cm^{-2} K^{-1} km^{-1} s for $r > 2$ kpc

[Ferrière+ '07, Ackermann '12]

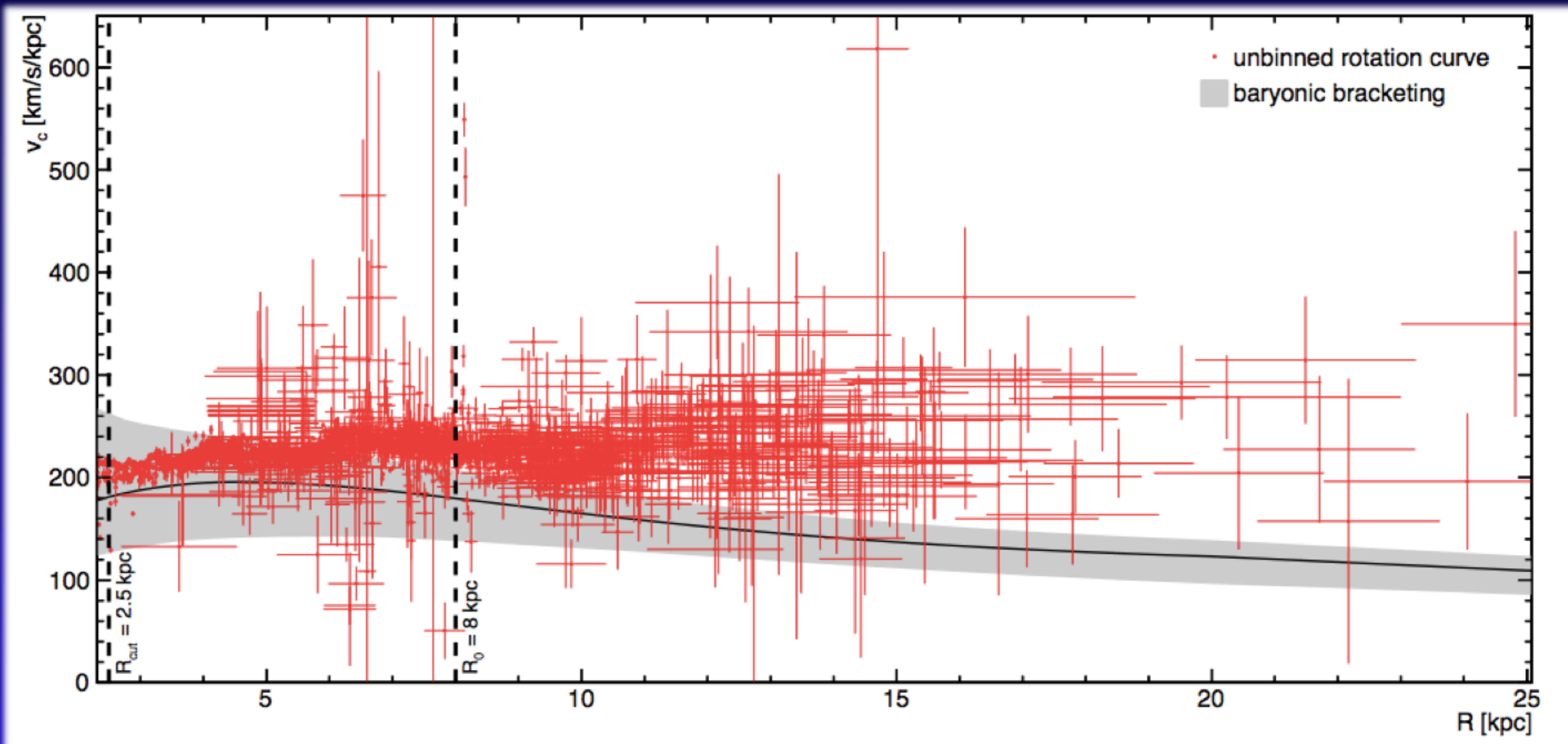
The luminous Milky Way:
expected rotation curve

$$\phi_i(r,\theta,\varphi) = -4\pi G \sum_{l,m} \frac{Y_{lm}(\theta,\varphi)}{2l+1}\left[\frac{1}{r^{l+1}}\int_0^r \rho_{i,lm}(a)\,a^{l+2}\,da + r^l \int_r^\infty \rho_{i,lm}(a)\,a^{1-l}\,da\right]$$



[Iocco, Pato, Bertone, Nature Physics 2015]

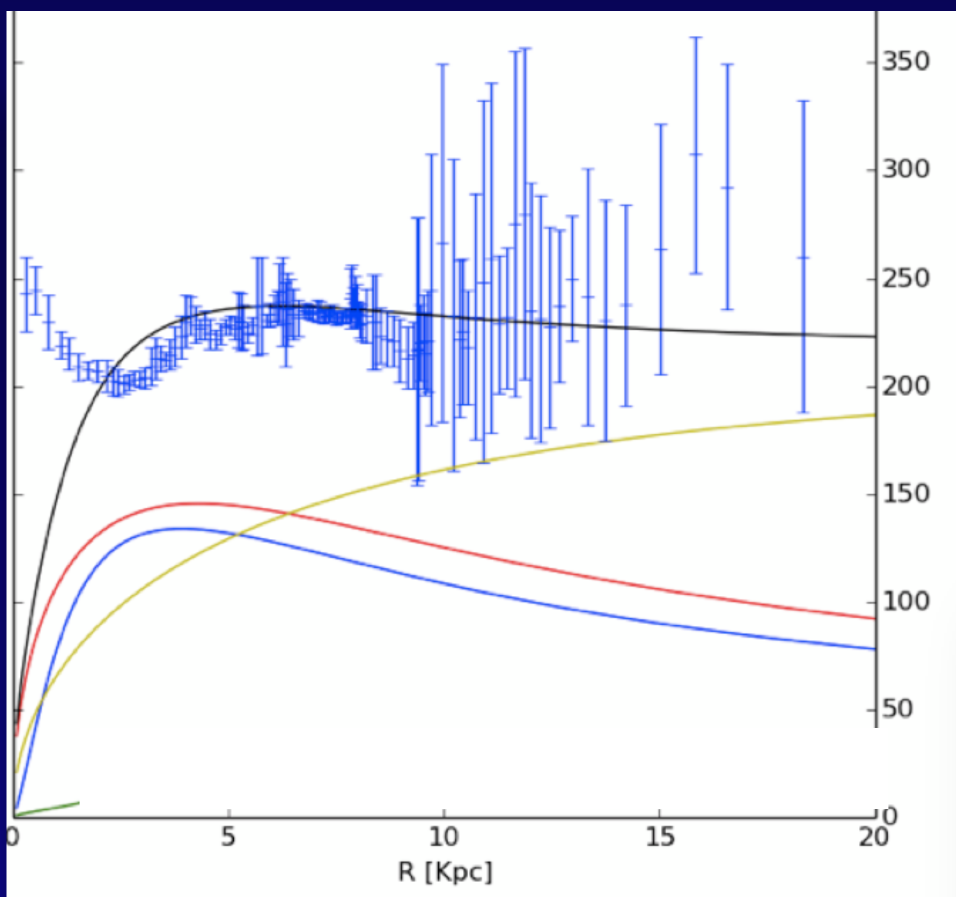
The Milky Way: testing expectactions (with no additional assumptions)



[Iocco, Pato, Bertone, Nature Physics 2015]

Inferring the DM density structure

Fitting a pre-assigned shape
on top of luminous

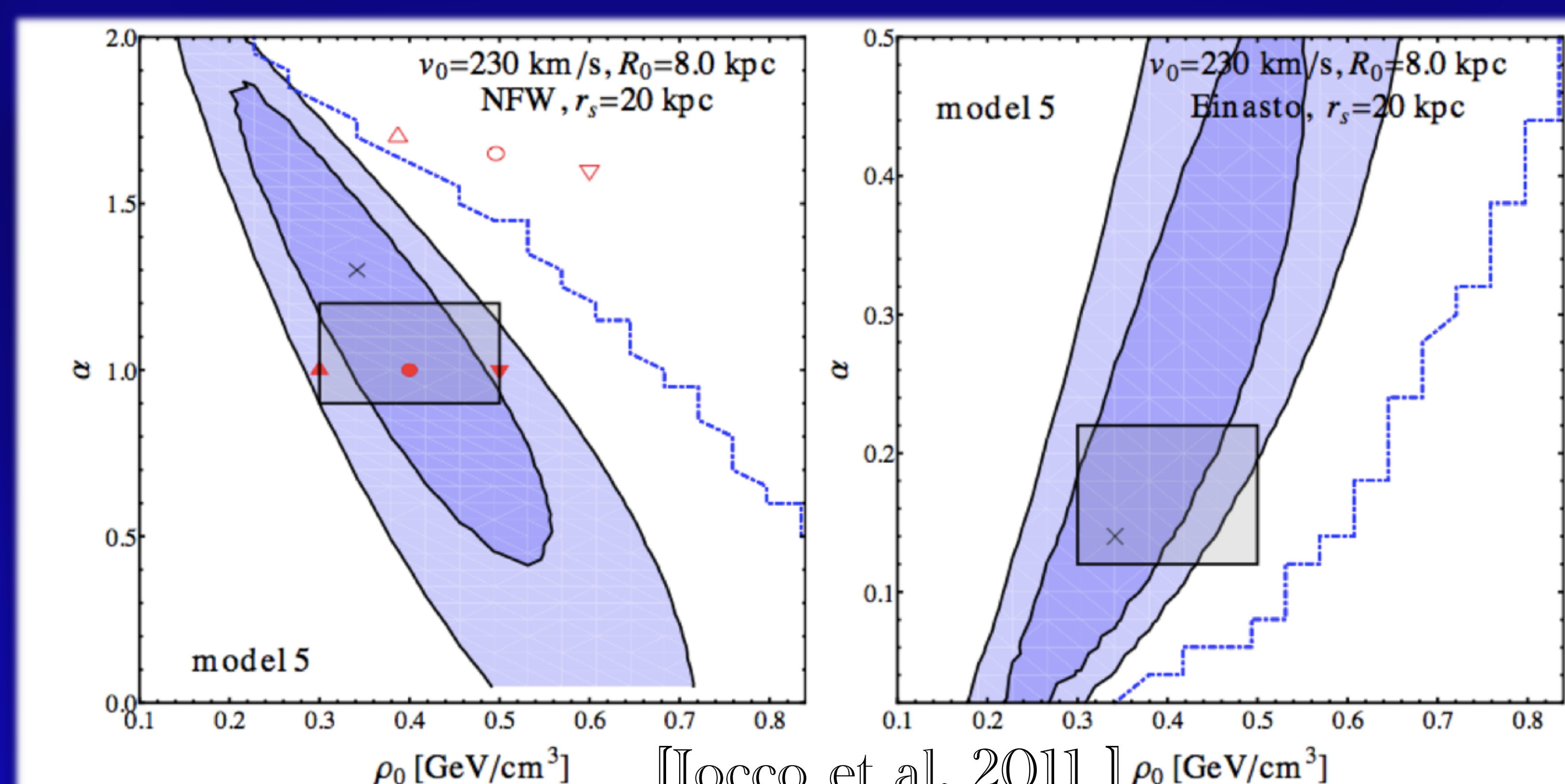


gNFW

$$\rho_{DM}(R) \propto \rho_0 \left(\frac{R}{R_s}\right)^{-\gamma} \left(1 + \frac{R}{R_s}\right)^{-3+\gamma}$$

$$\rho_{DM}(R) \propto \rho_0 \exp\left[-\frac{2}{\gamma}\left(\left(\frac{R}{R_s}\right)^{\gamma} - 1\right)\right]$$

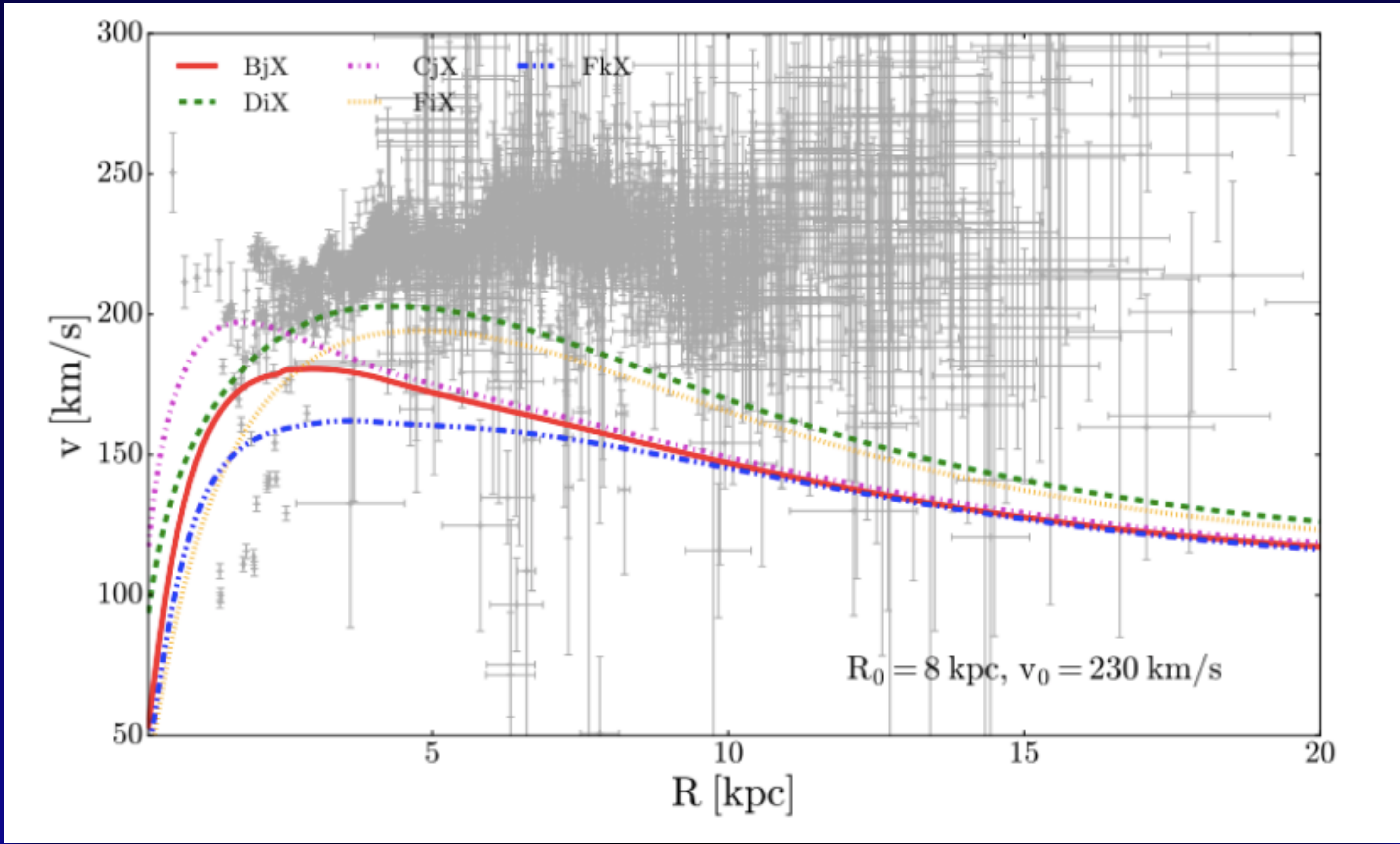
Einasto



[Iocco et al. 2011]

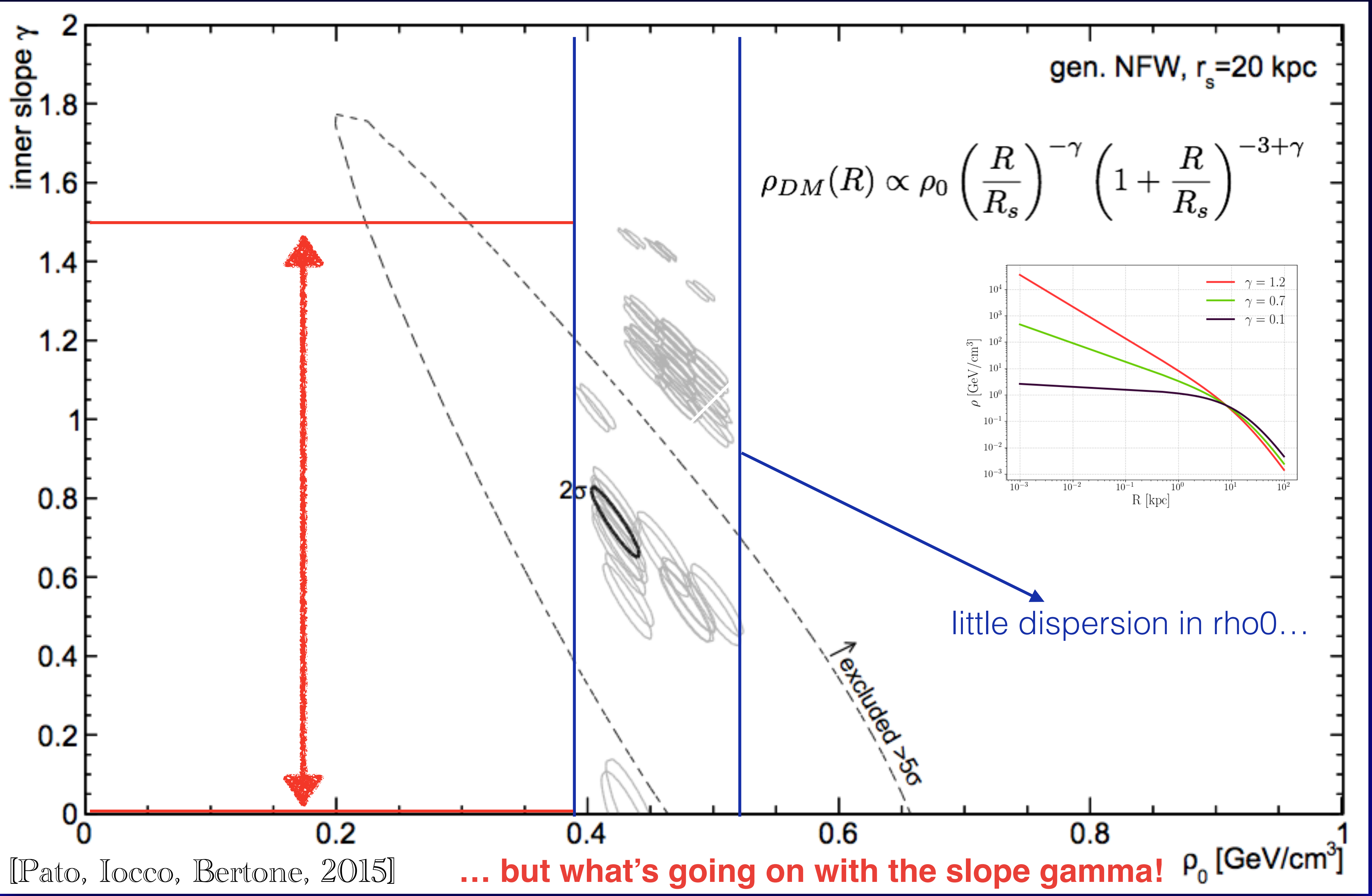
[many autors, e.g.
Iocco et al. 2011]

Systematic uncertainties
(luminous component)



[Benito, Bernàl, Bozorgnia, Calore, Iocco, JCAP 2017] [Iocco, Pato, Bertone, Nature Physics 2015]

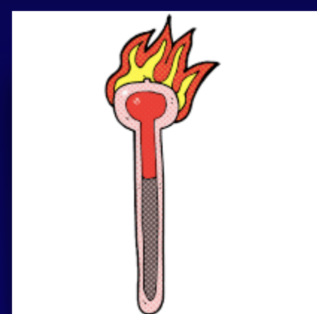
Extracting the DM density structure

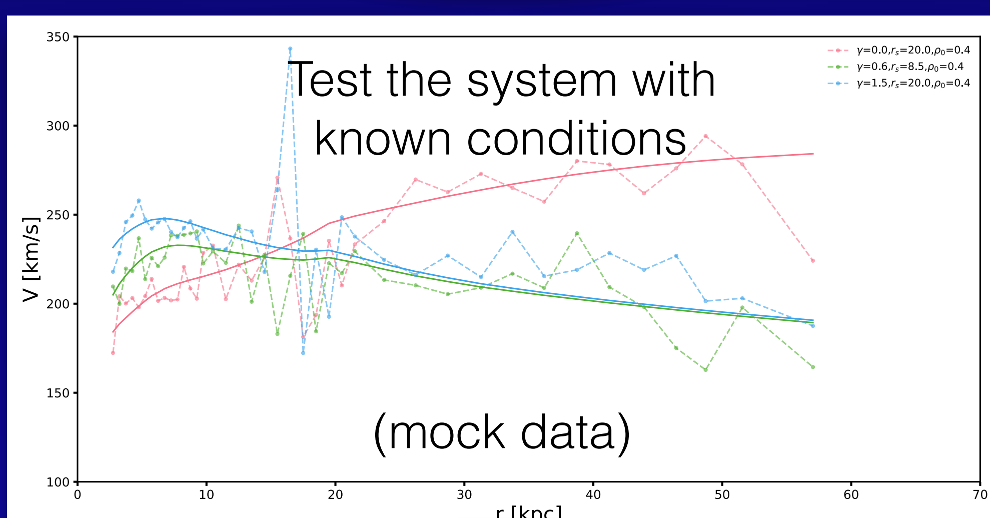


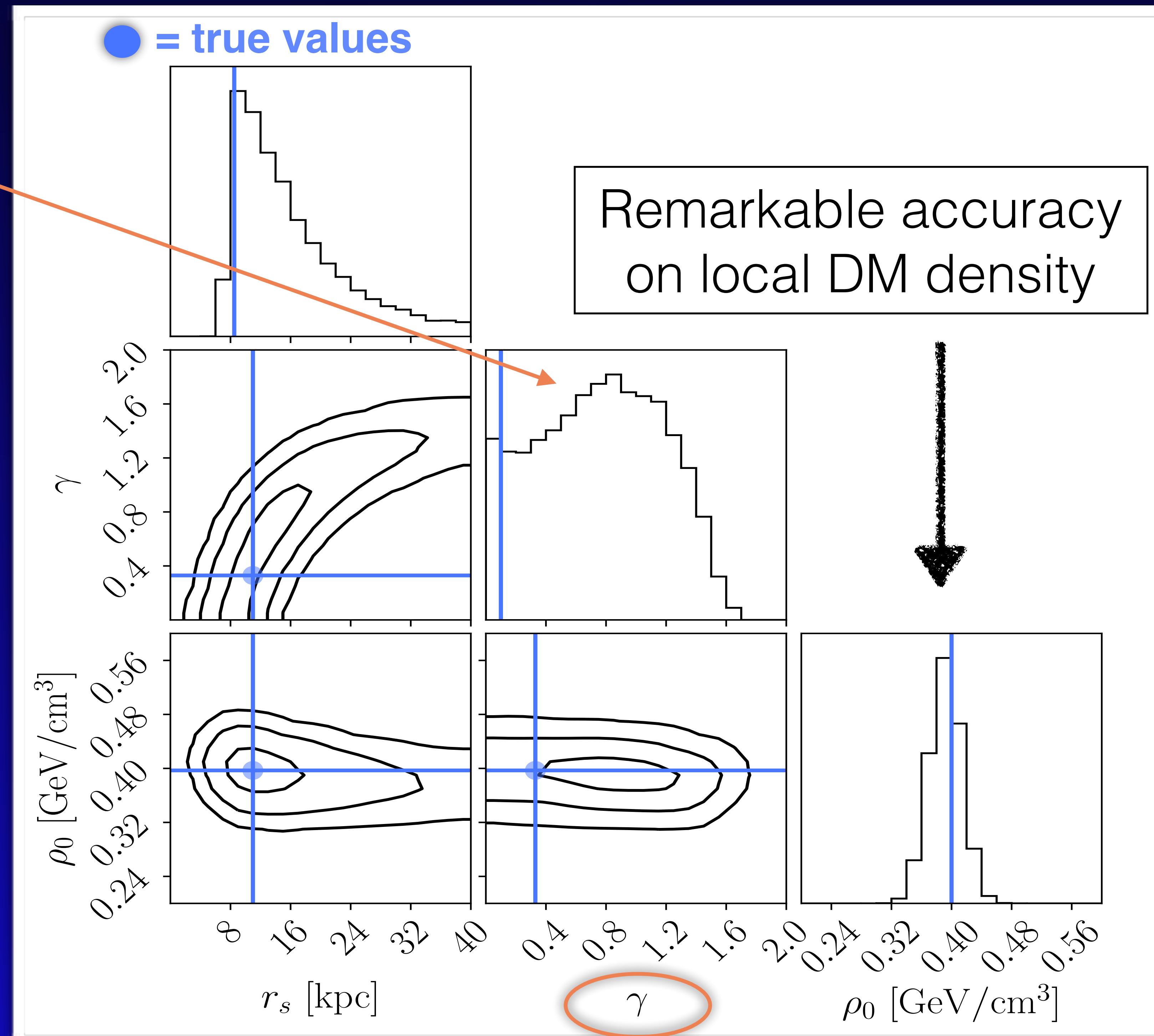
[Pato, Iocco, Bertone, 2015]

What to do of our measurement?

(Our instrument is very precise. Is it accurate?)





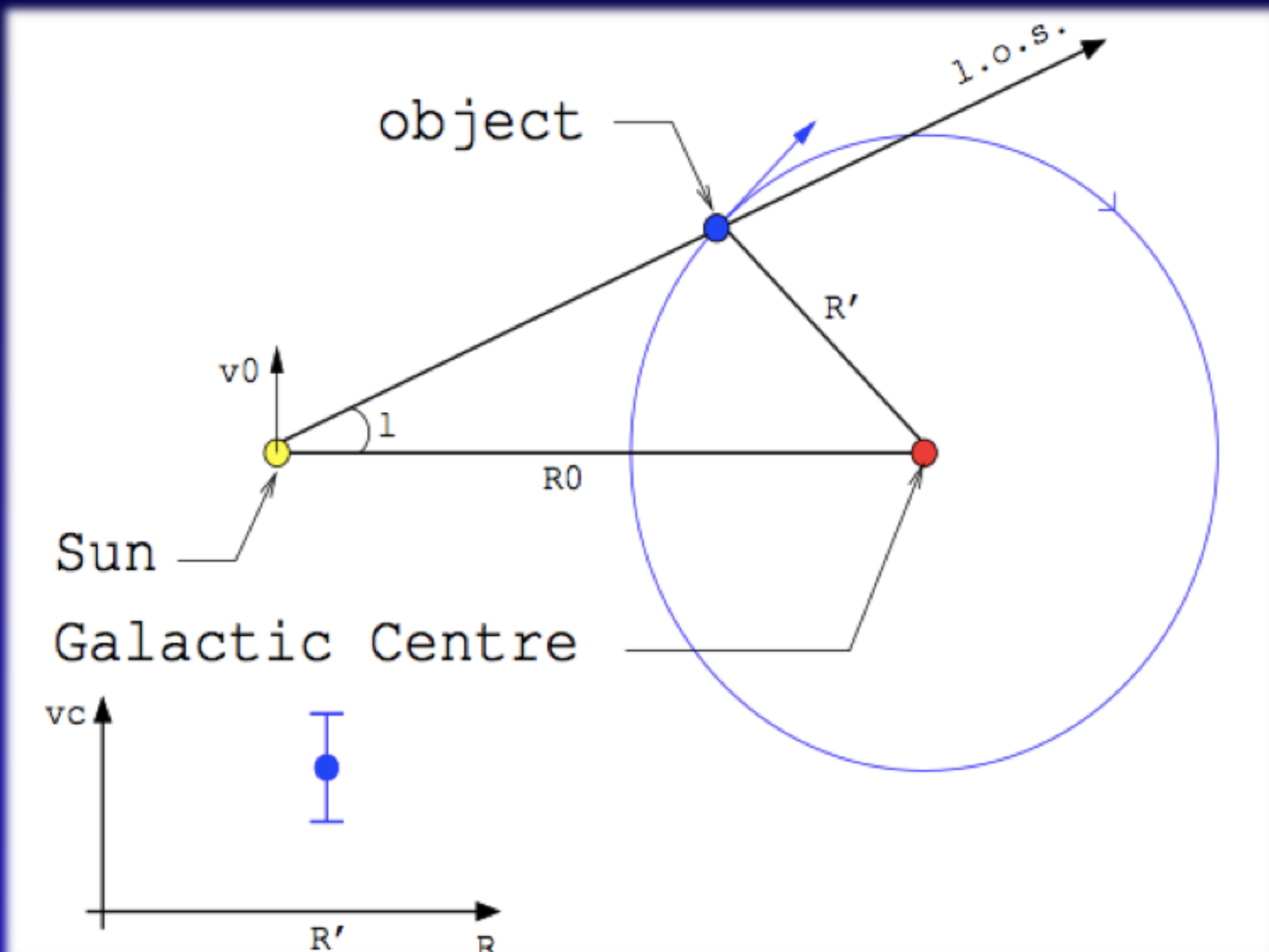


[Karukes, Benito, F.I., Geringer-Sameth, Trotta] arXiv:1901.02463

The Milky Way:

observed rotation curve

Neglecting some quite remarkable uncertainties (for now)



$$v_{\rm LSR}^{\rm l.o.s.} = \left(\frac{v_c(R')}{R'/R_0} - v_0 \right) \cos b \sin \ell$$

observing tracers from our own position, transforming into GC-centric reference frame

Uncertainties on (R0,v0) ultimately affects our determination of (rho0, gamma)

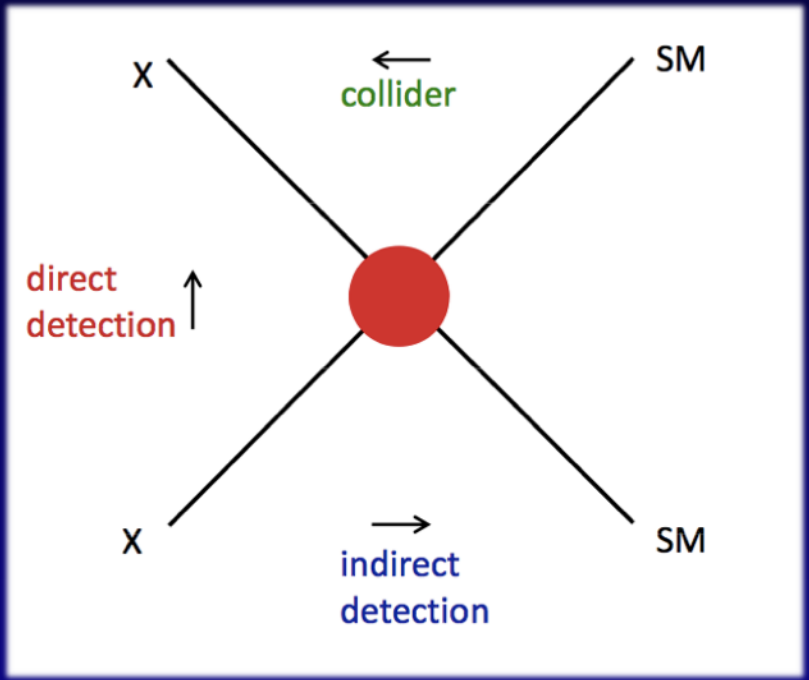
Direct and indirect searches of WIMP DM

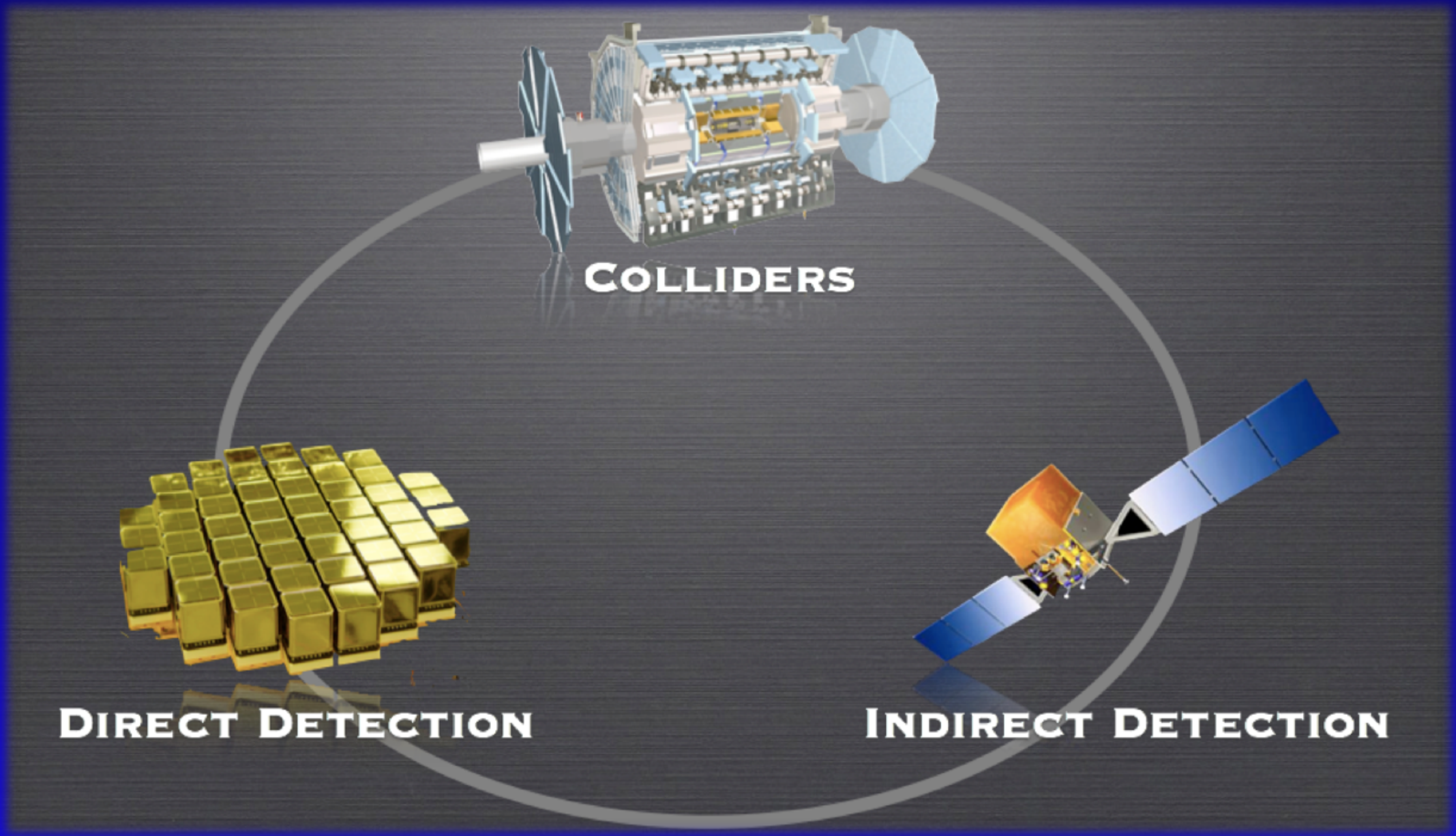
complementary to colliders

Direct detection:
DM scattering against nuclei, recoil

Indirect detection:
Annihilation in astrophysical envir.
Observation of SM products of annih.

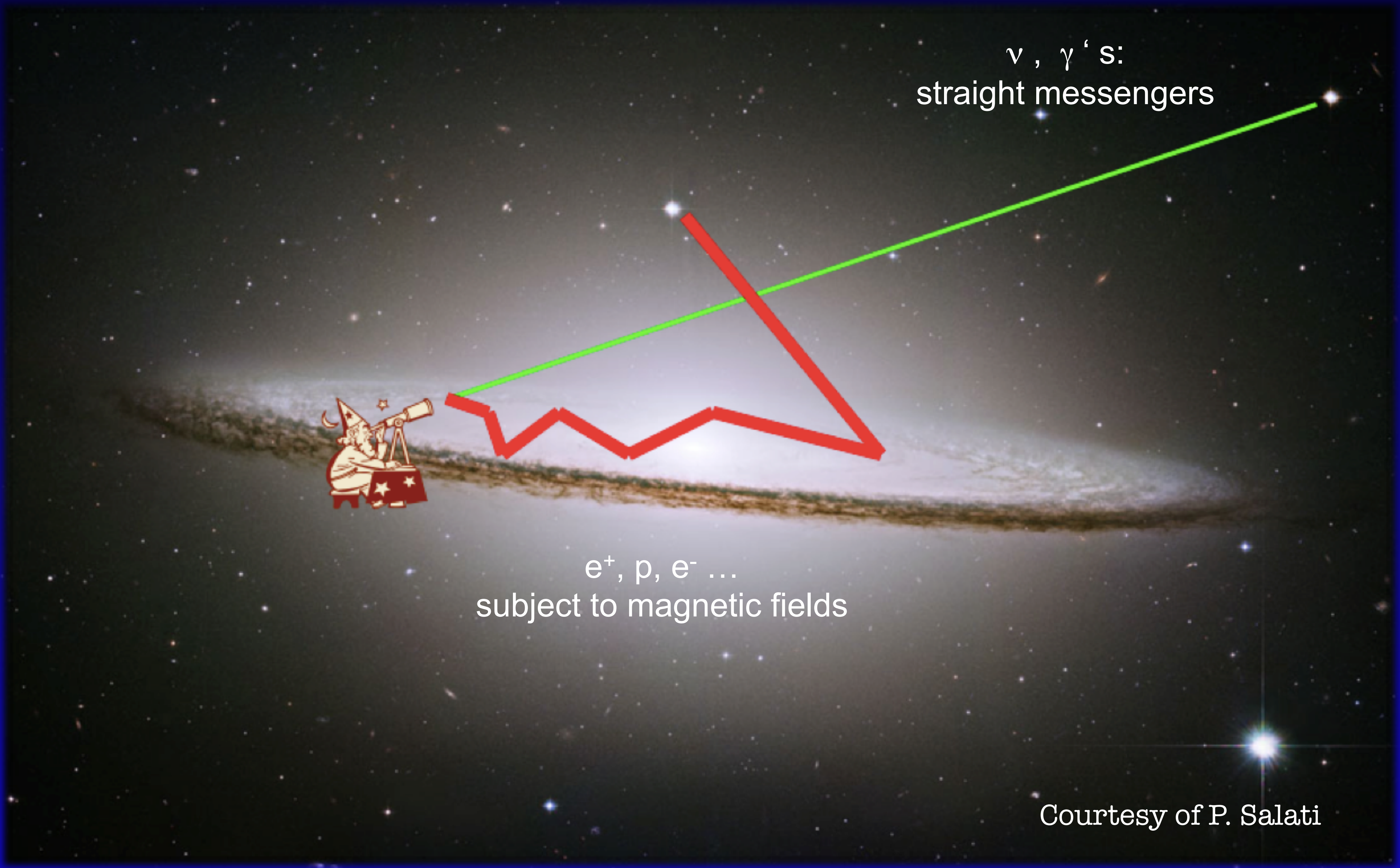
Production at LHC





Indirect Detection: principles and dependencies

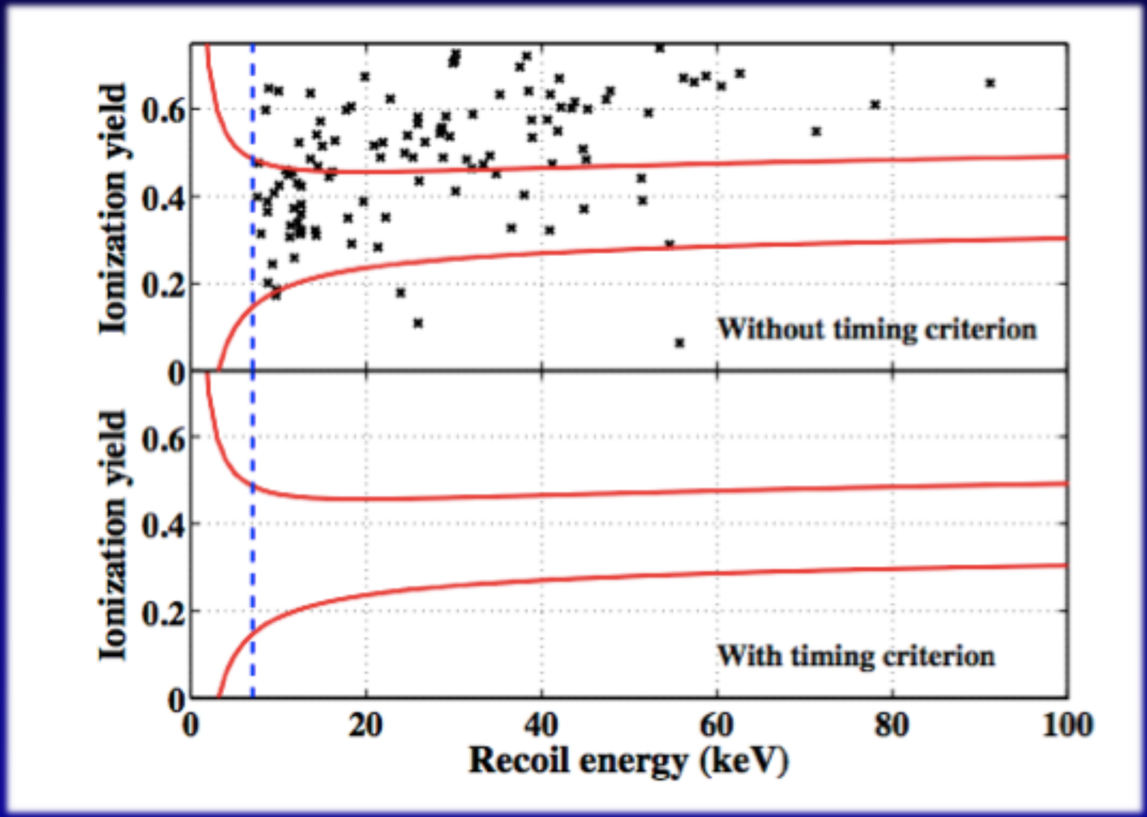
$$\chi + \chi \rightarrow q\bar{q}, W^+W^-, \ldots \rightarrow \gamma, \bar{p}, \ \bar{D}, \ e^+ \ \& \ \nu' s$$

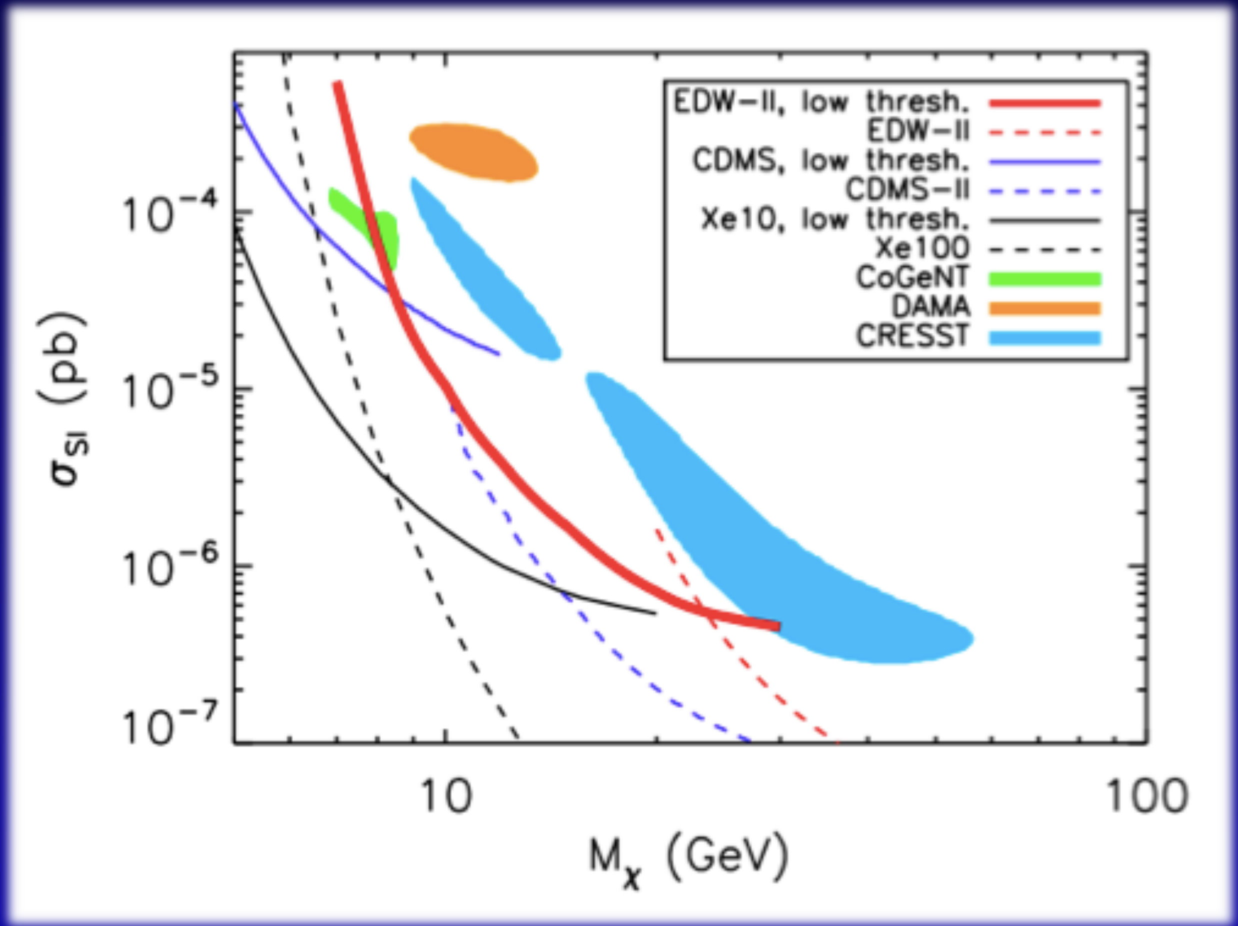


$$F_i \propto \frac{1}{4\pi d^2} B_i \frac{\langle \sigma v \rangle}{m_\chi} \int \rho^2(r) dV$$

Direct Detection: principles and dependencies (to go…)

from this → to this





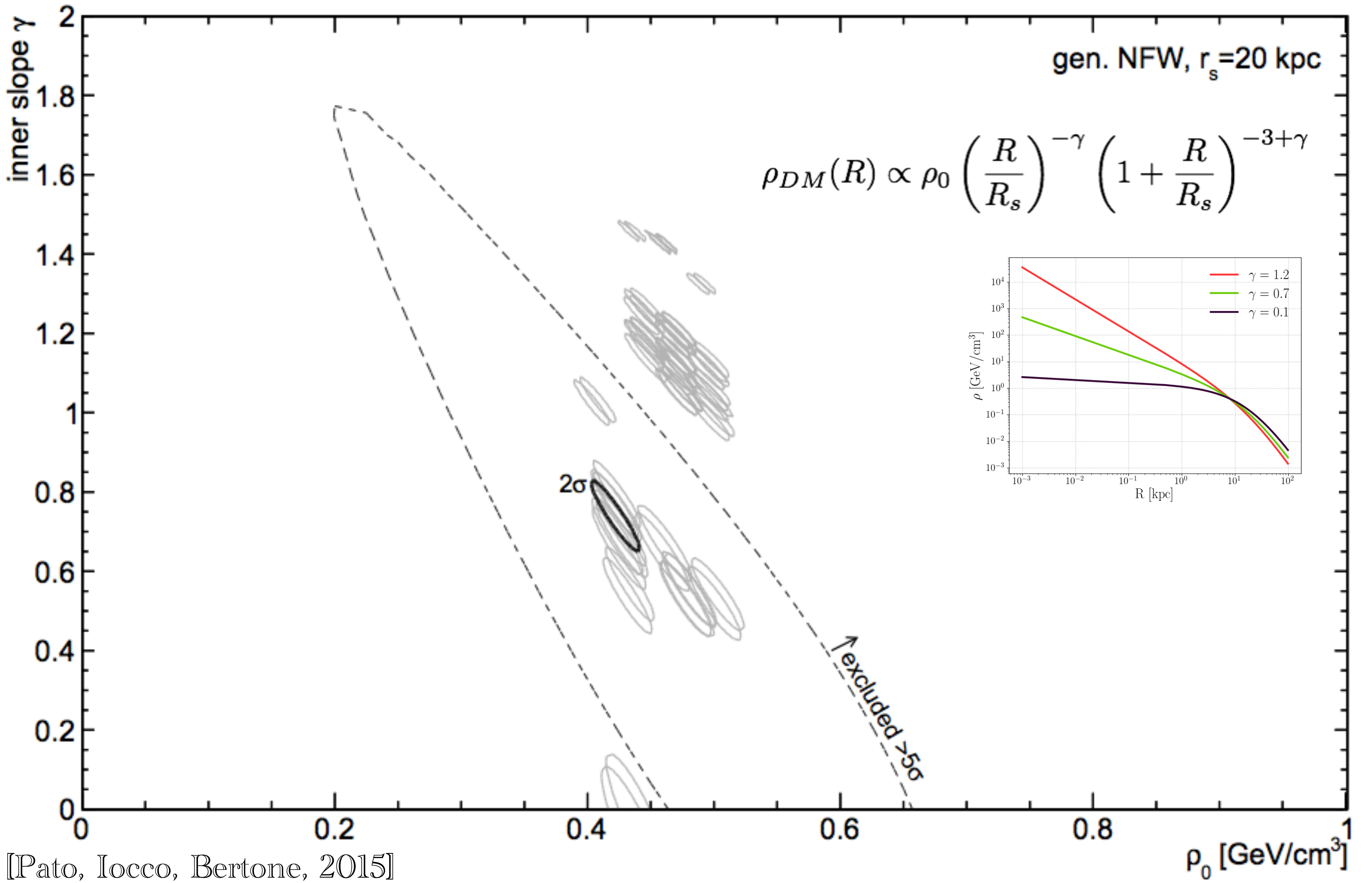
you need this

$$\frac{dR}{dE} \propto \frac{1}{\mu^2}\frac{\sigma_\chi}{m_\chi}\rho_0\,\eta(v,t)$$

see talk by M. Yamashita

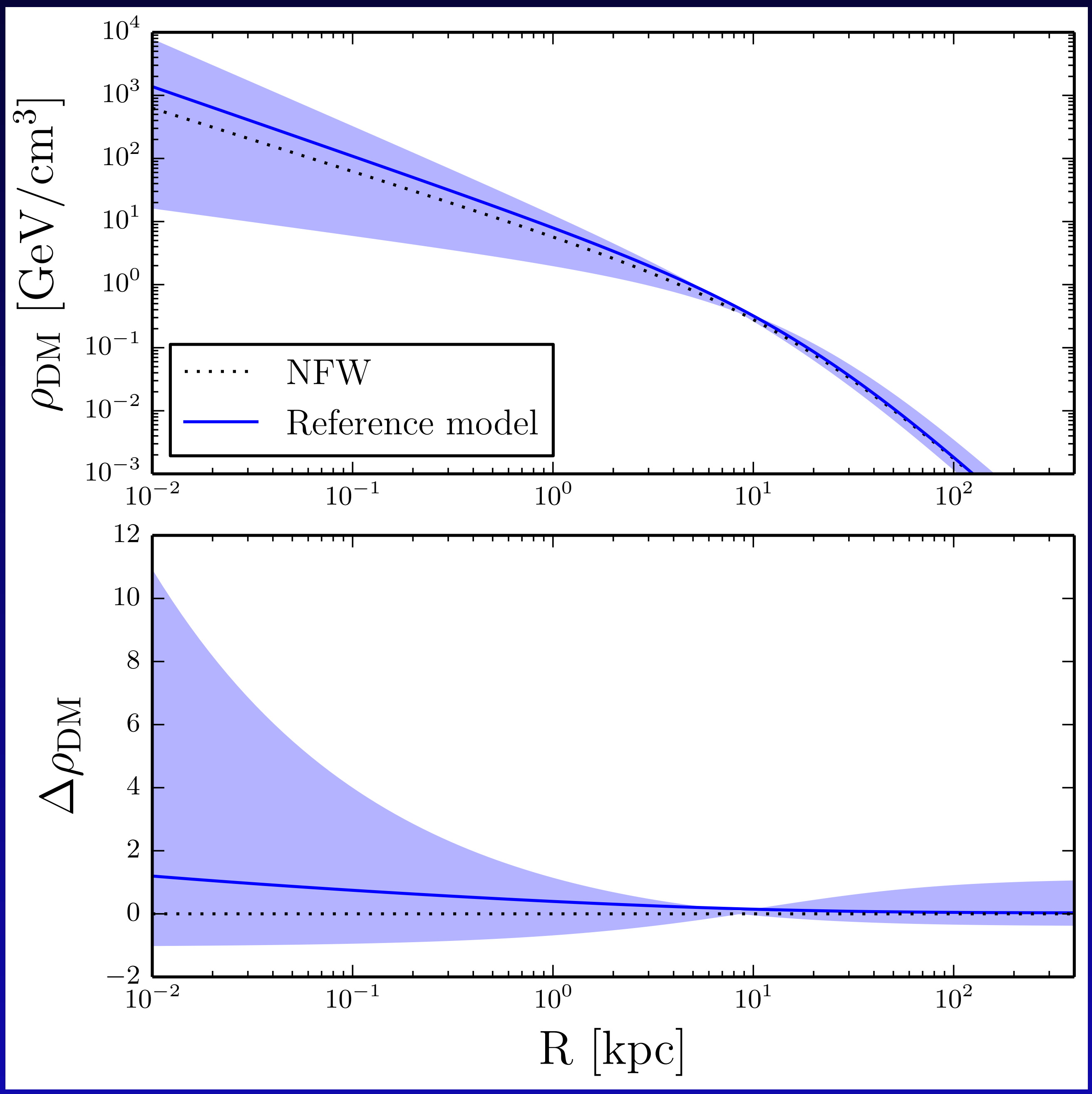
see talk by G. Gelmini

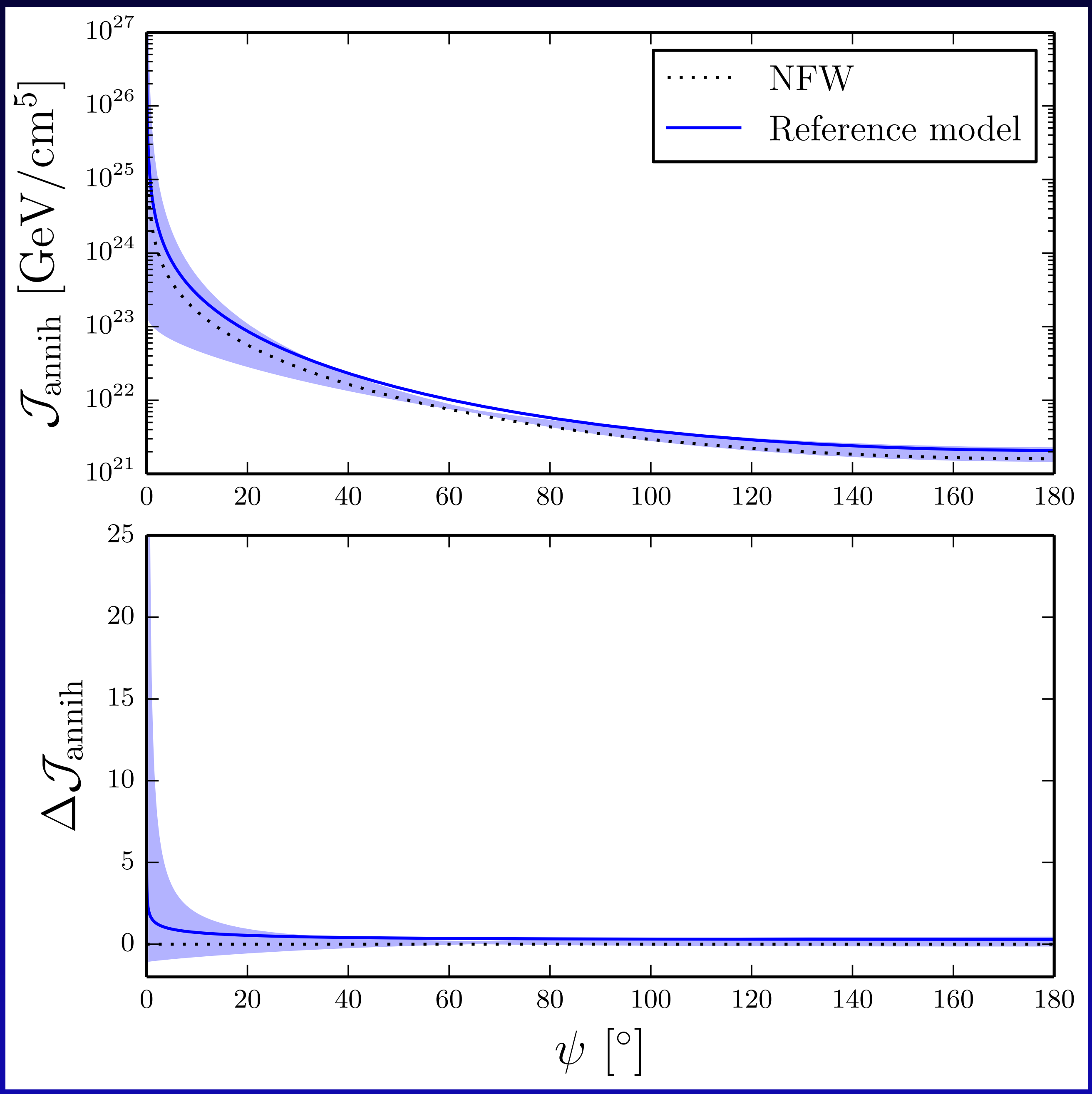
Extracting the DM density structure



[Pato, Iocco, Bertone, 2015]

But do Galactic uncertainties affect PP, for real?

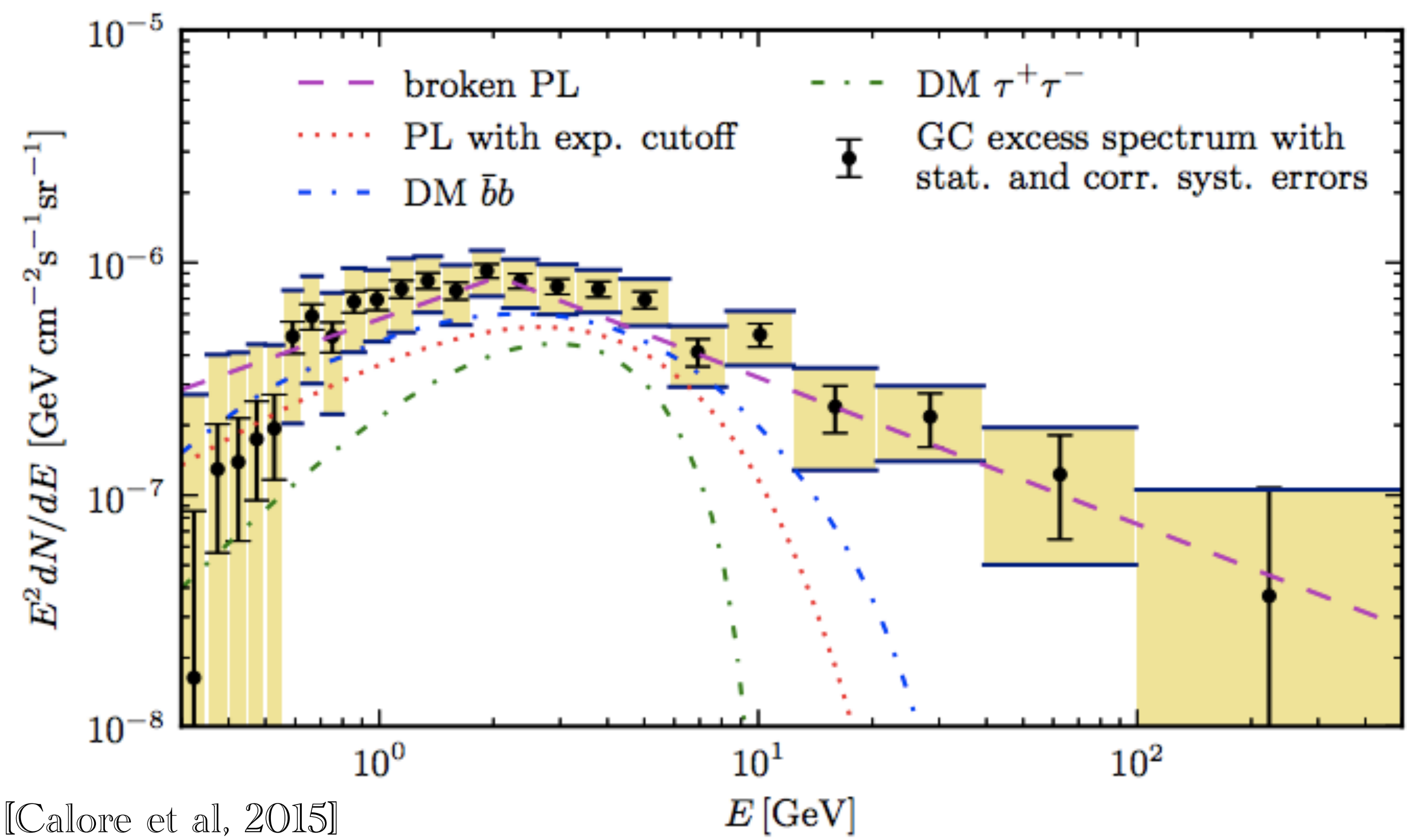




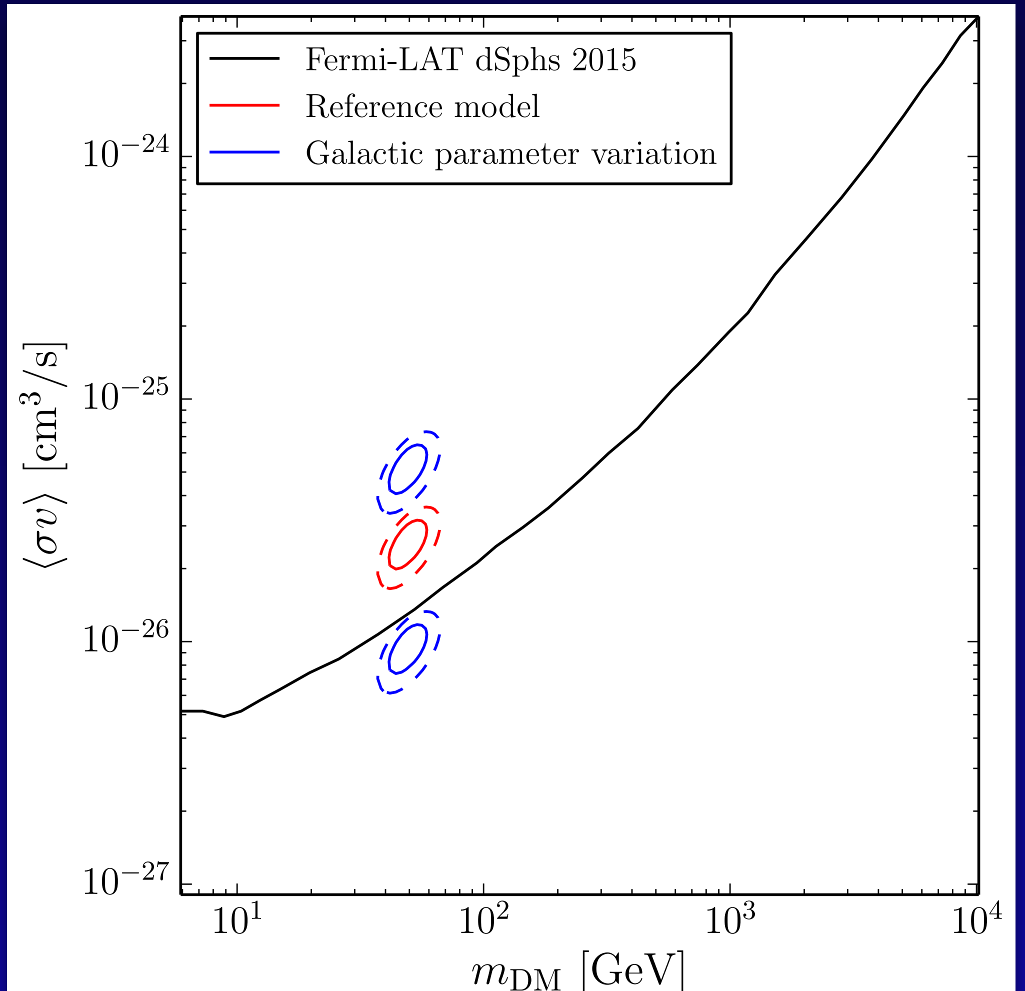
$$J_{annih} \propto \int_{los} \rho^2(r)dV$$

[Benito, Bernàl, Bozorgnia, Calore, Iocco, JCAP 2017, arXiv:1612.02010]

It is well known that uncertainties affect inDirect (some more, some less) and its interpretation

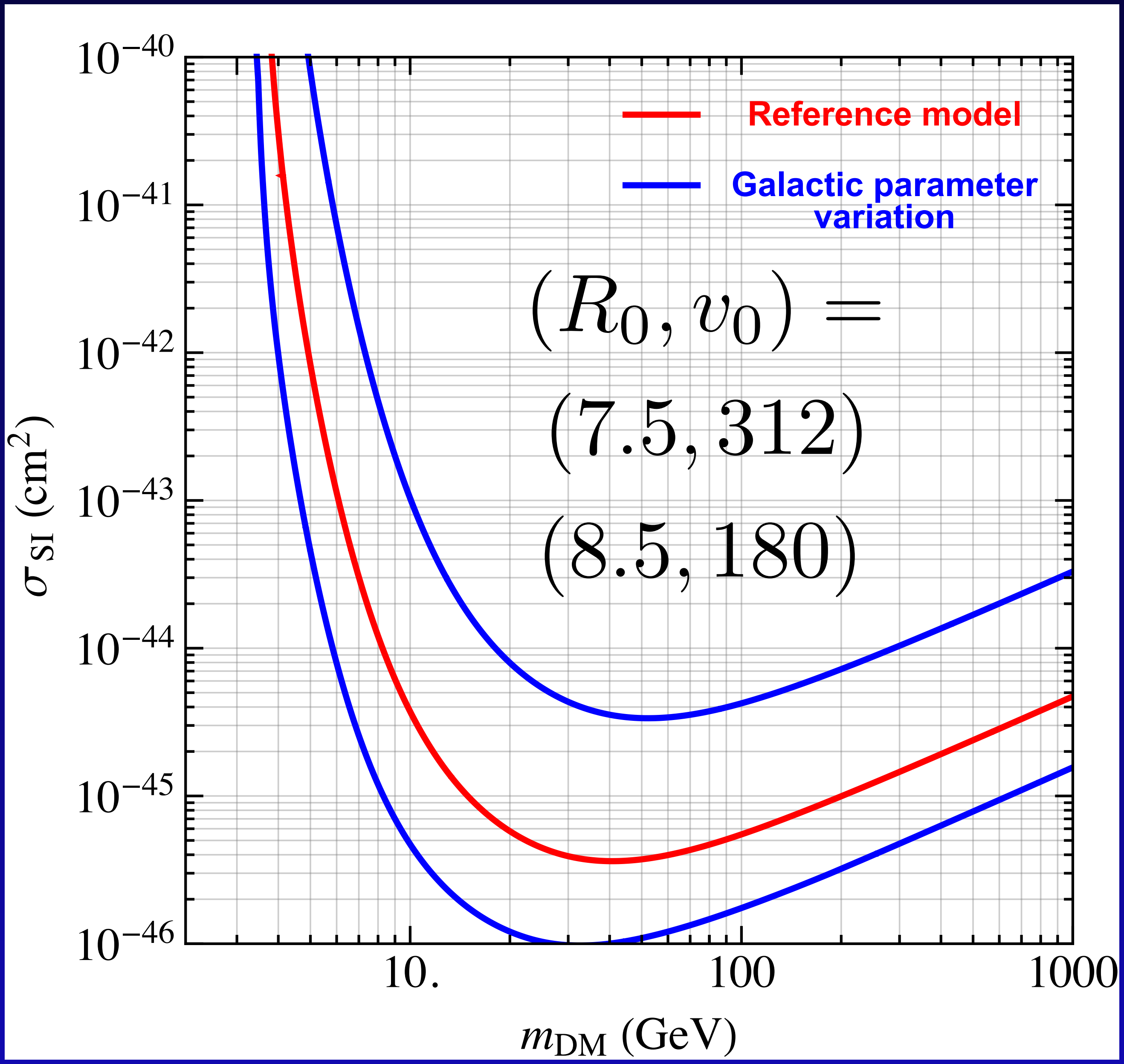


[Calore et al, 2015]



[Benito, Bernàl, Bozorgnia, Calore, Iocco, JCAP 2017, arXiv:1612.02010]

It is well known that uncertainties affect Direct Detection



Current LUX limits, but varying astrophysical uncertainties

[Benito, Bernàl, Bozorgnia, Calore, Iocco, JCAP 2017, arXiv:1612.02010]

The effect of astrophysical uncertainties
on the determination of new physics

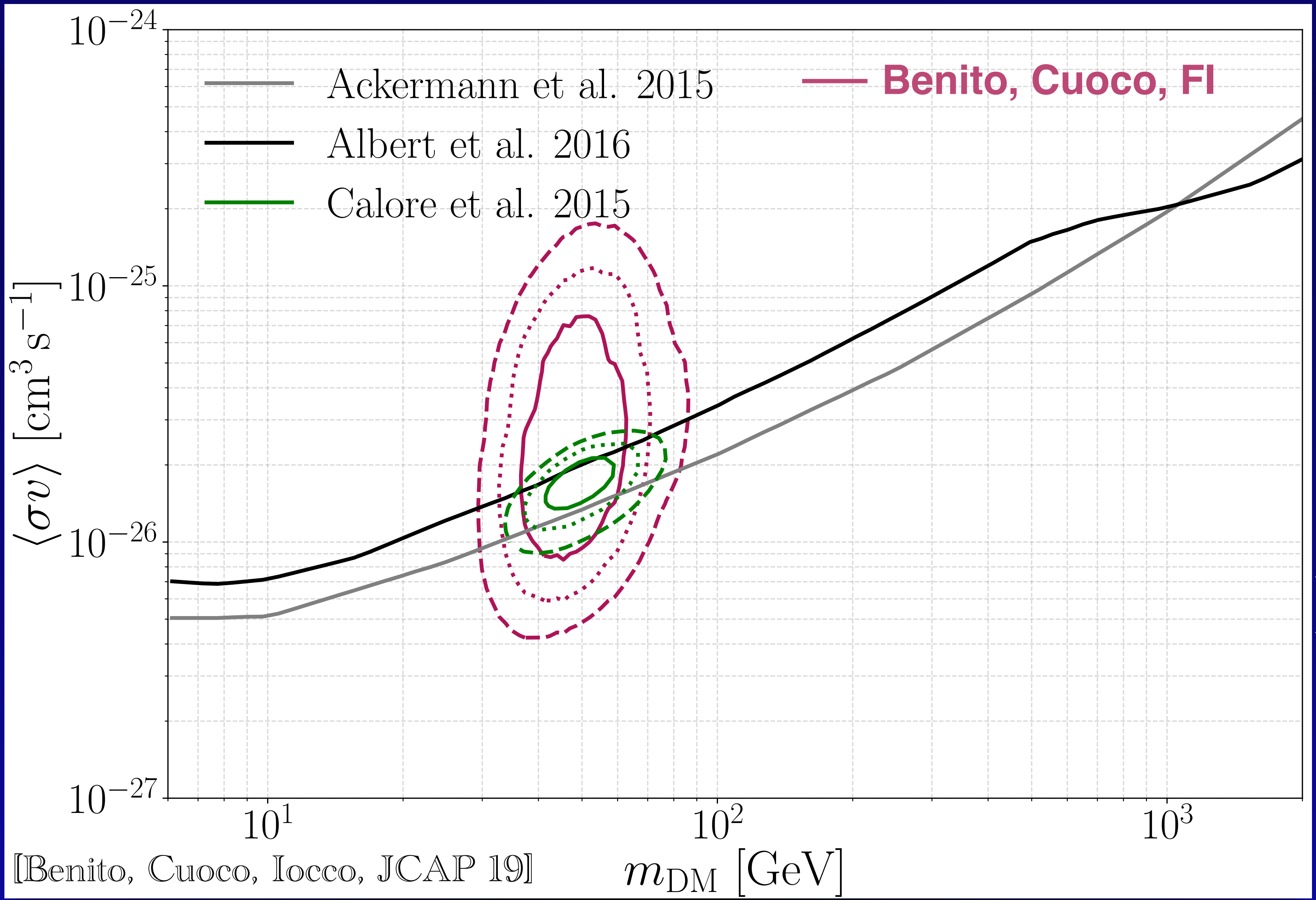
Uncertainties accounted for:

Calore analysis:

observed GC signal
(only stat. on gamma flux)

This analysis:

observed GC signal
+
DM density profile
(Gal. Param. + Morphologies + stat)



Ready-to-use likelihood publicly available @

https://github.com/mariabenitocst/UncertaintiesDMinTheMW

with Gaia-era (R0,v0) determination, update in progress

Let's quantify this effect in a specific case: Singlet Scalar DM

$$V = \mu_H^2\,|H|^2 + \lambda_H\,|H|^4 + \mu_S^2\,S^2 + \lambda_S\,S^4 + \lambda_{HS}\,|H|^2\,S^2$$

$v_H = 246\ \mathrm{GeV}$ $\quad \langle S \rangle = 0$

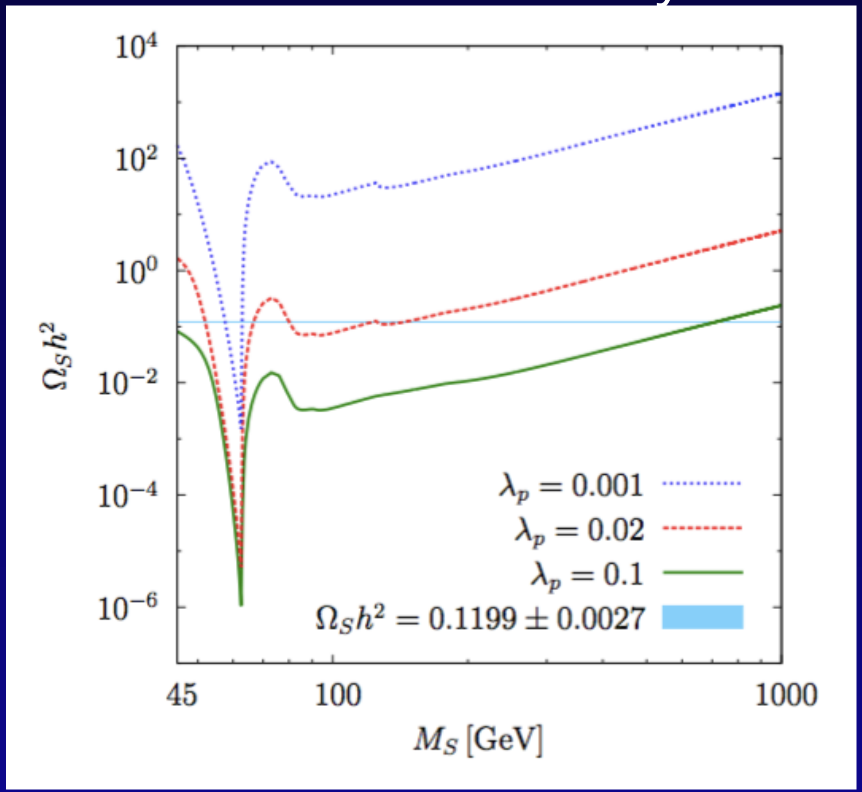
$$m_S^2 = 2\,\mu_S^2 + \lambda_{HS}\,v_H^2$$

"WIMP phenomenology" entirely dictated by the Higgs coupling and physical DM mass.

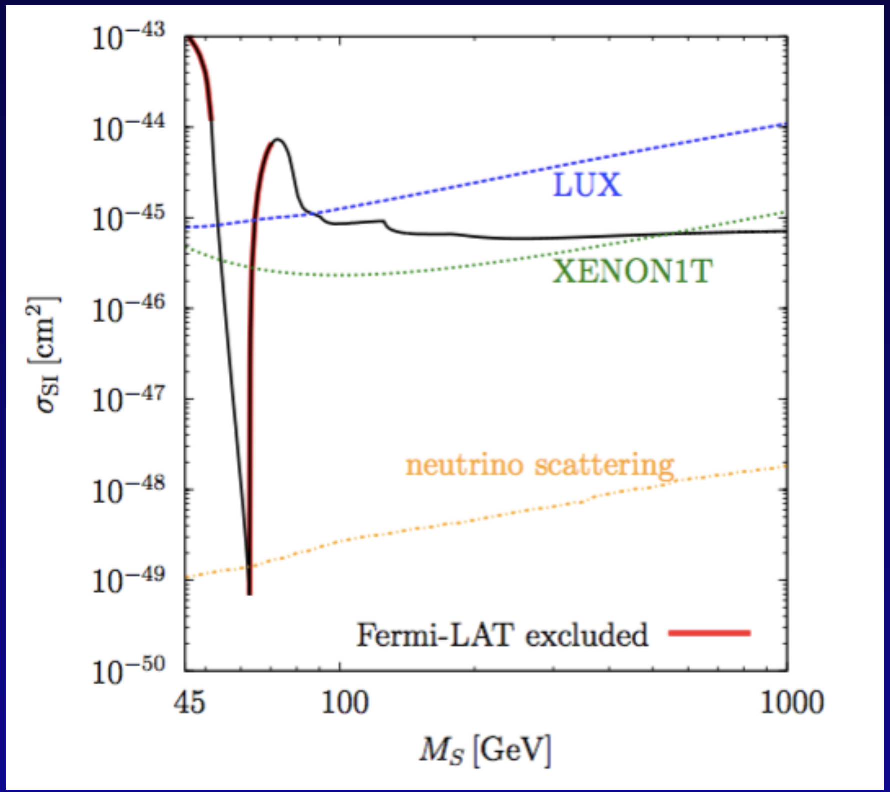
[Mc Donald, 1994] [Burgess, Pospelov, Velthuis, 2001]

Singlet Scalar DM
Constraints and interplay of experiments

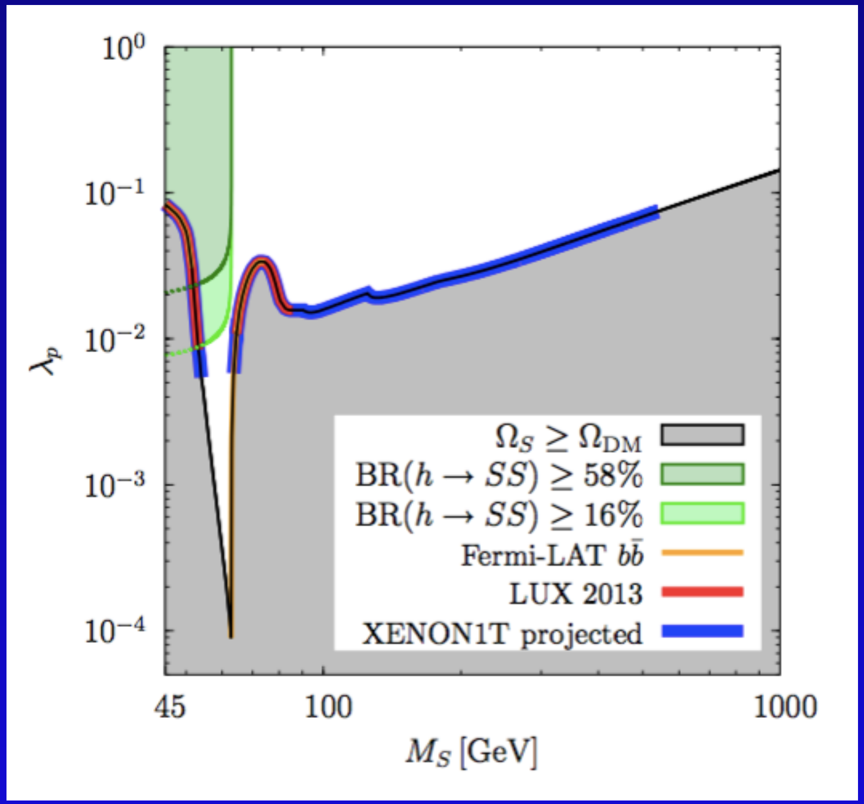
Relic density



Direct detection



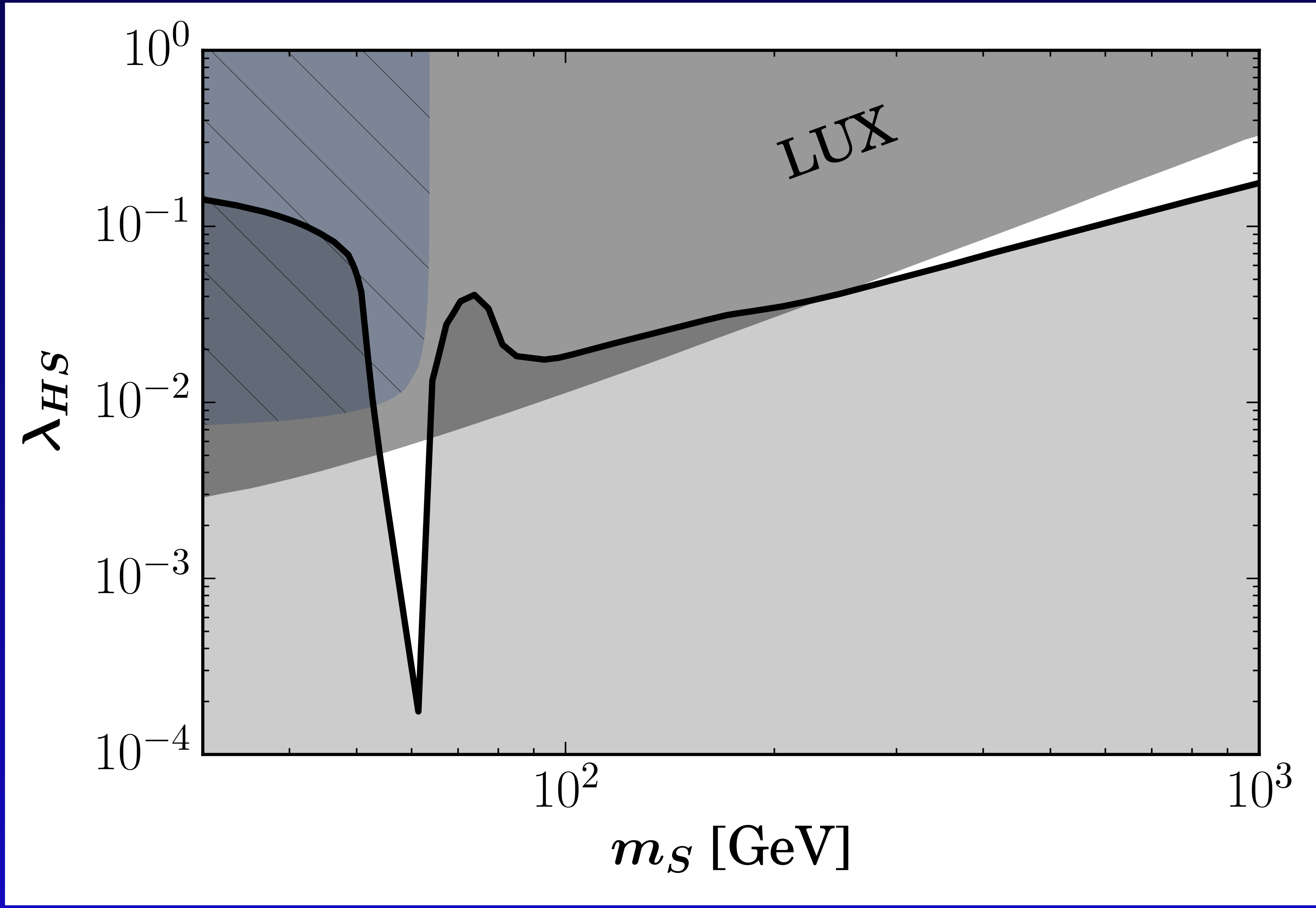
Combined



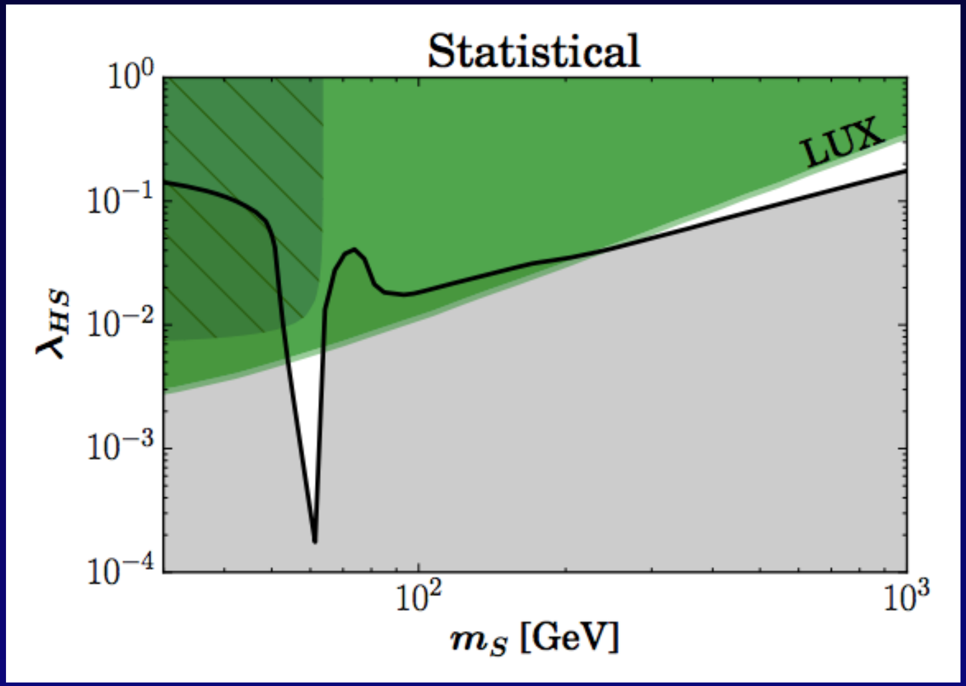
[Duerr et al, 2015]

Singlet Scalar DM
Constraints and interplay of experiments

$$V = \mu_H^2 \, |H|^2 + \lambda_H \, |H|^4 + \mu_S^2 \, S^2 + \lambda_S \, S^4 + \lambda_{HS} \, |H|^2 \, S^2$$

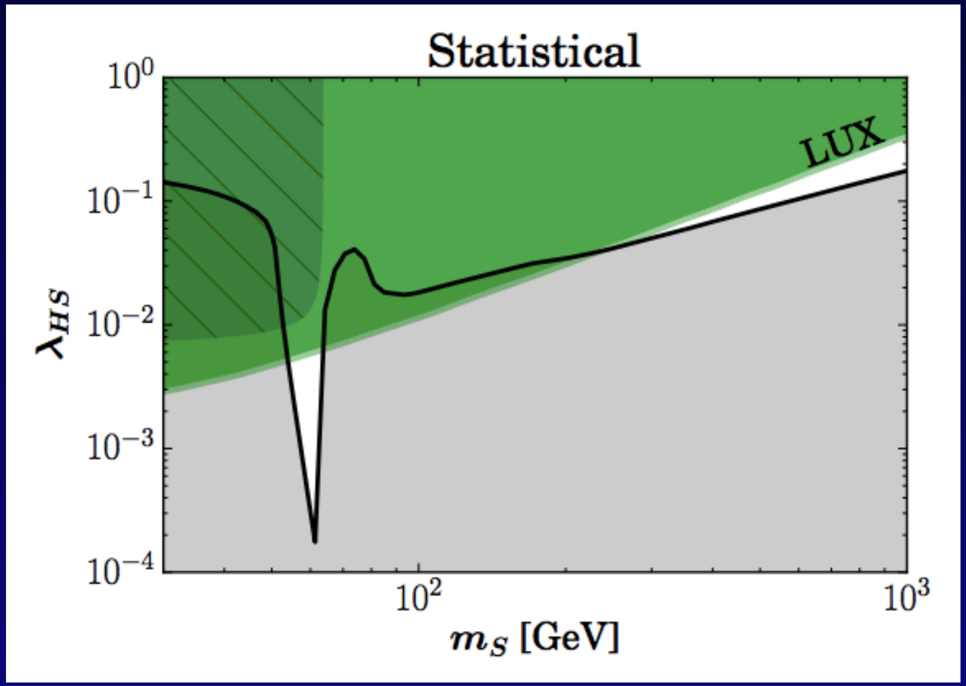


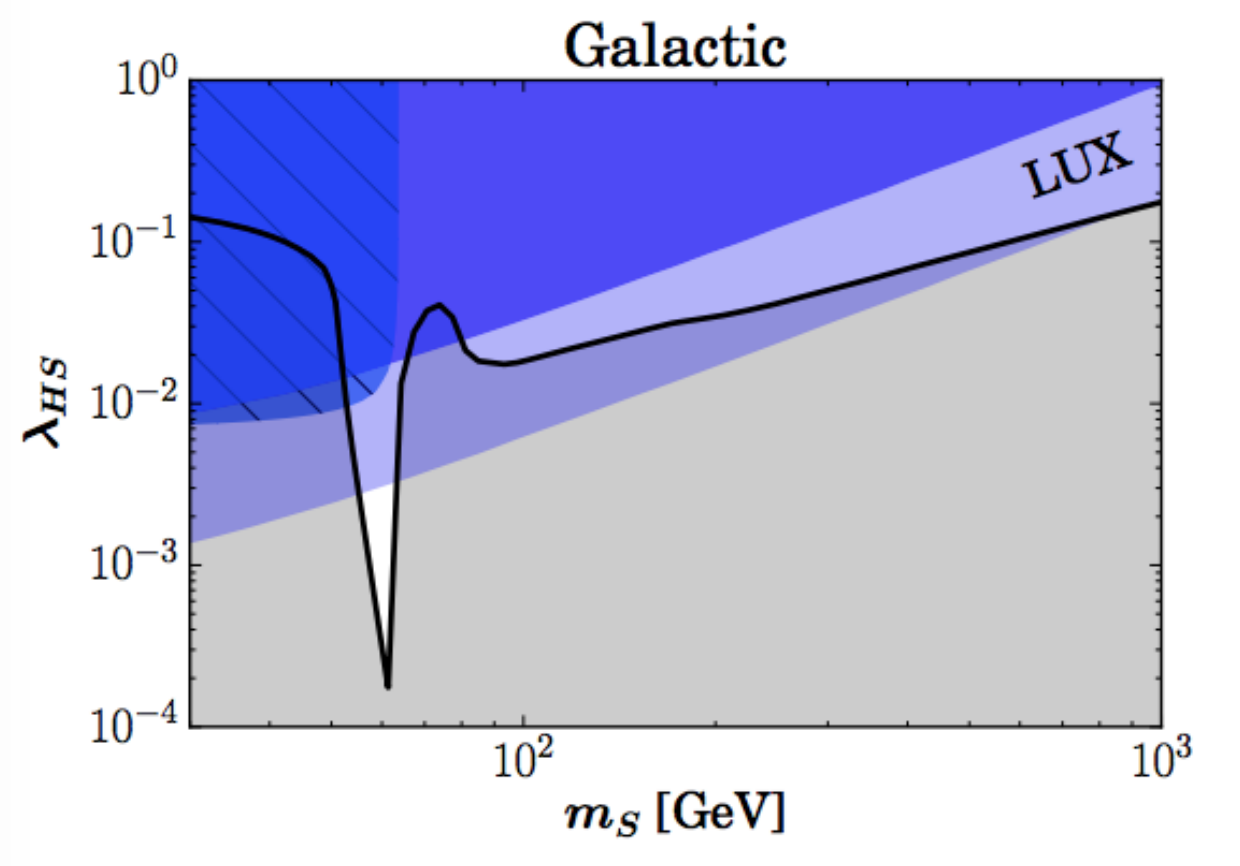
Let's look at the effect of astrophysics uncertainties: Direct Detection

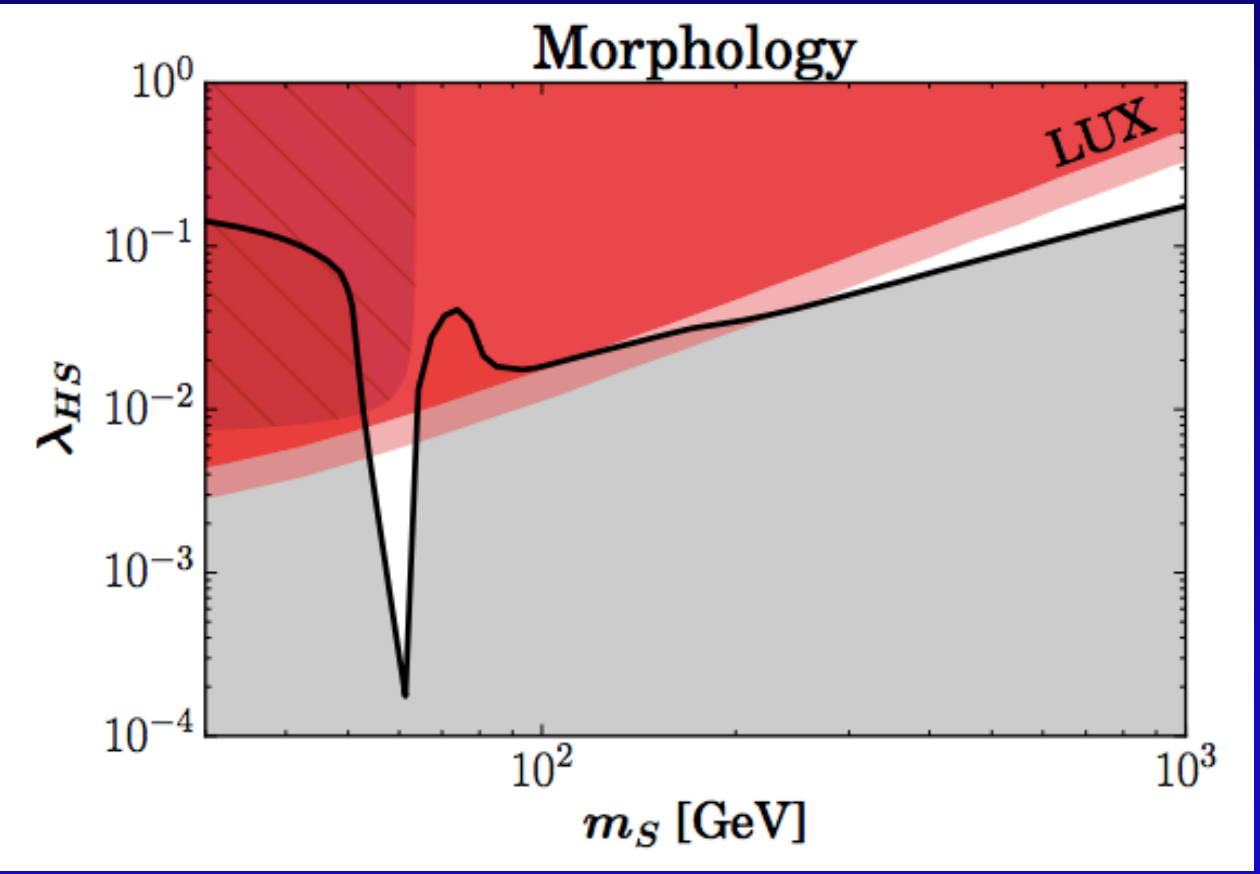


[Benito, Bernàl, Bozorgnia, Calore, Iocco, JCAP 2017; arXiv:1612.02010]

Let's look at the effect of astrophysics uncertainties: Direct Detection

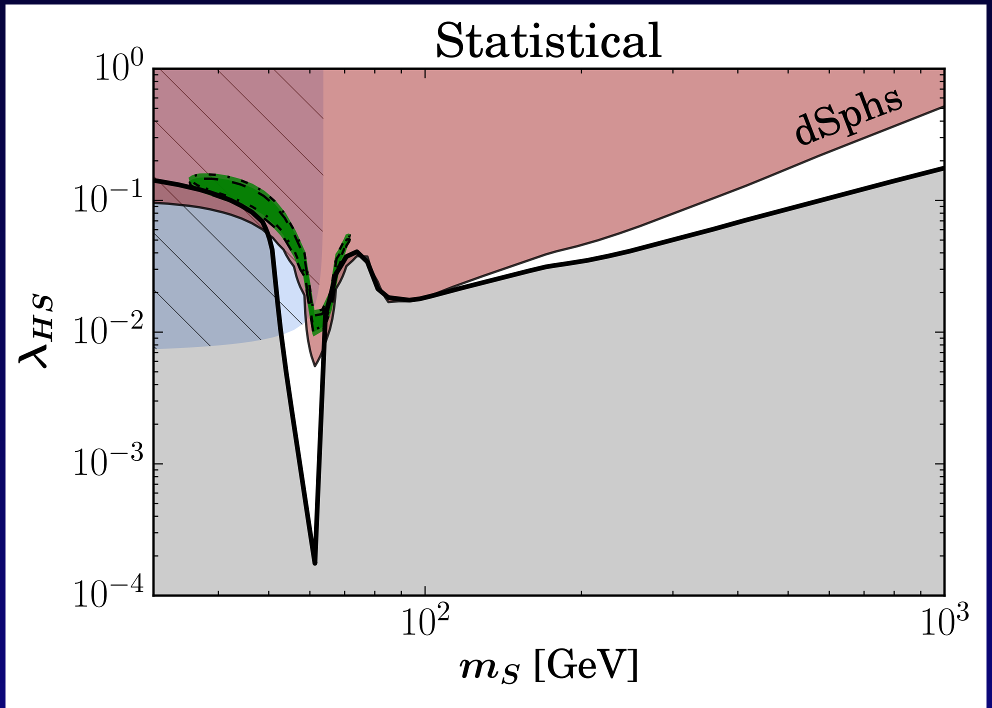


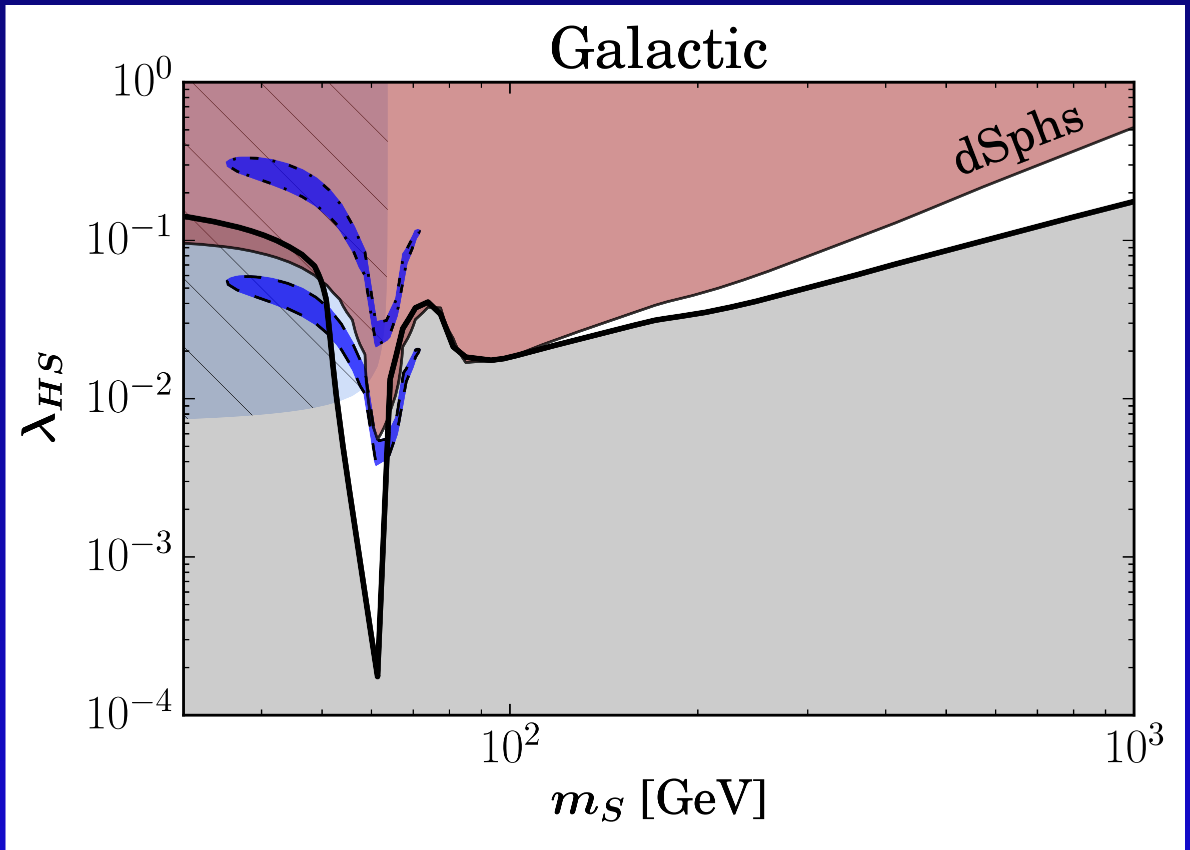


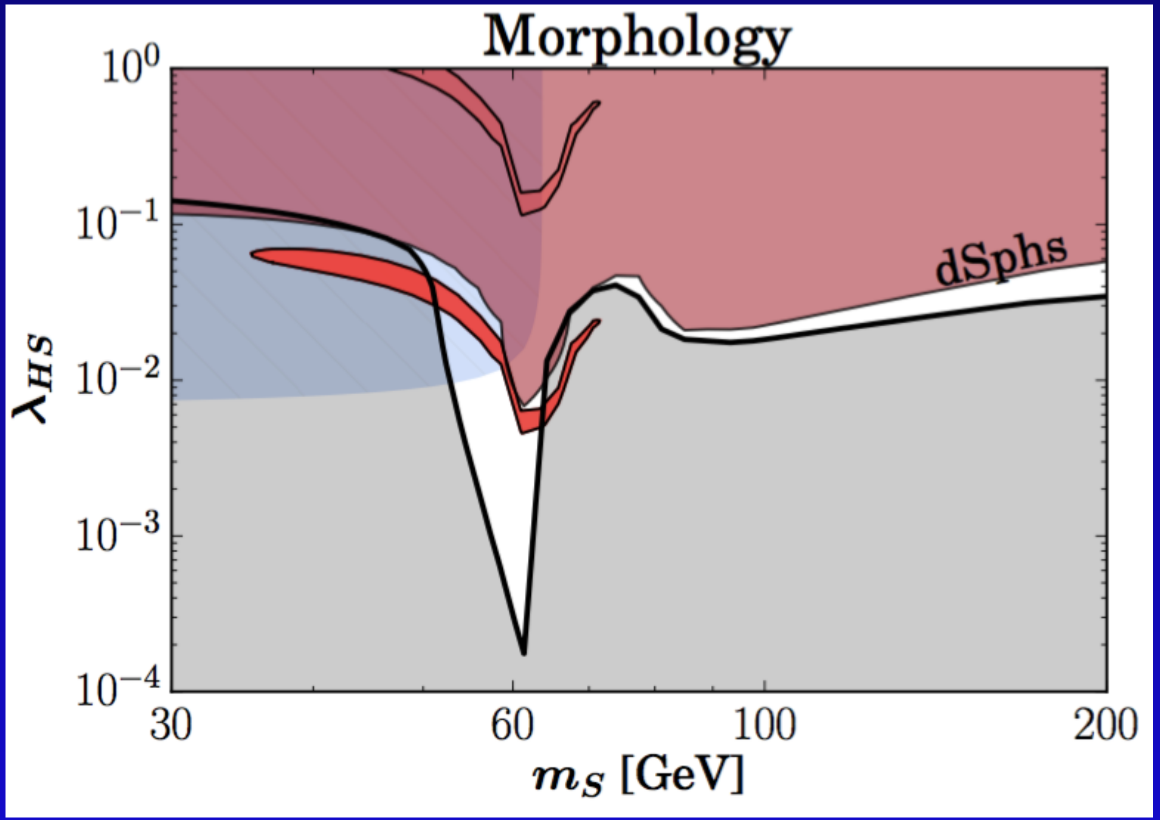


[Benito, Bernàl, Bozorgnia, Calore, Iocco, JCAP 2017; arXiv:1612.02010]

Let's look at the effect of astrophysics uncertainties: Indirect Detection

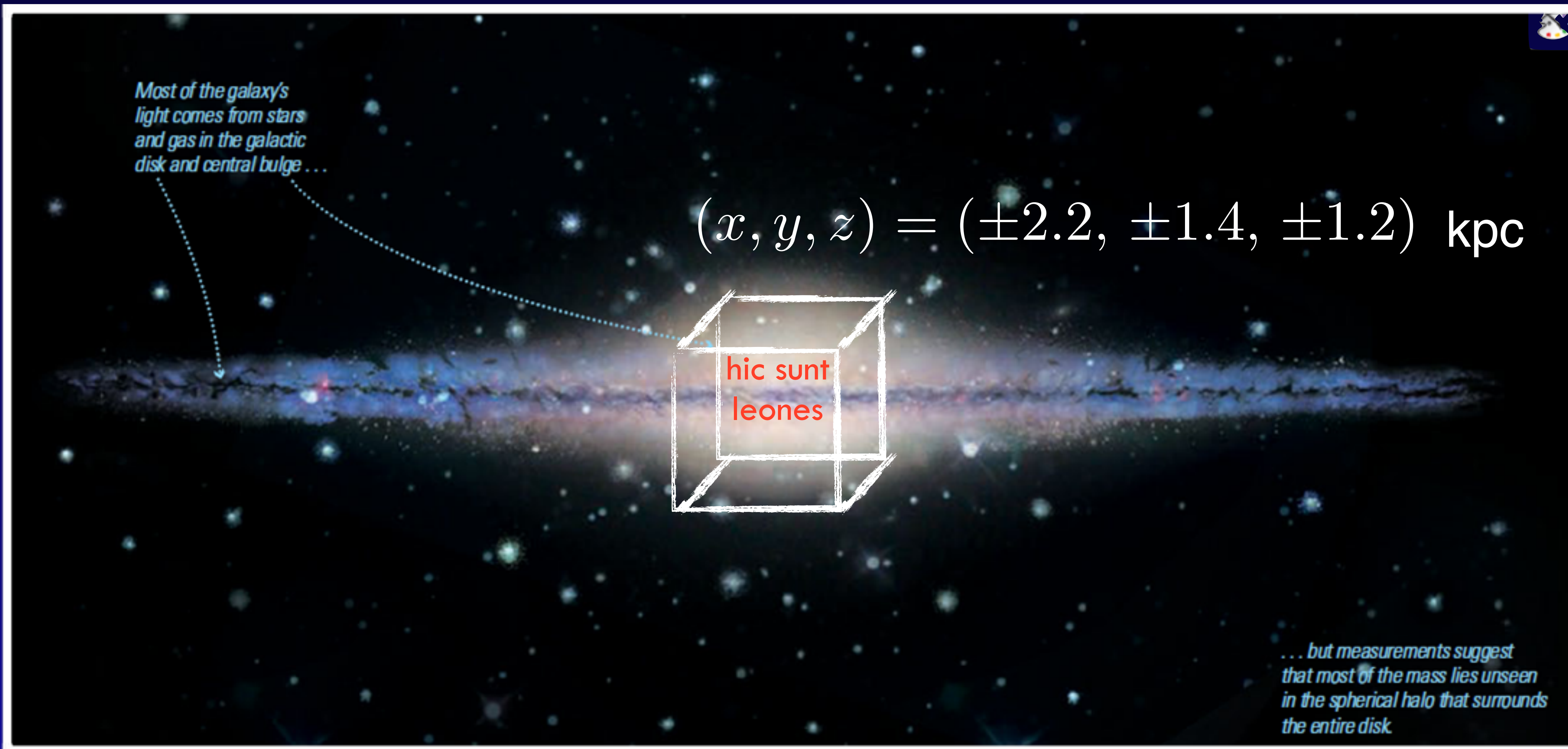






[Benito, Bernàl, Bozorgnia, Calore, Iocco, JCAP 2017; arXiv:1612.02010]

Galactic Center:
a beast of its own



Total mass

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

Portail +
MNRAS 465 (2017)

Stellar mass

$$M^i_* = \int_{box} \rho^i_*(x, y, z)\,\mathrm{d}V$$

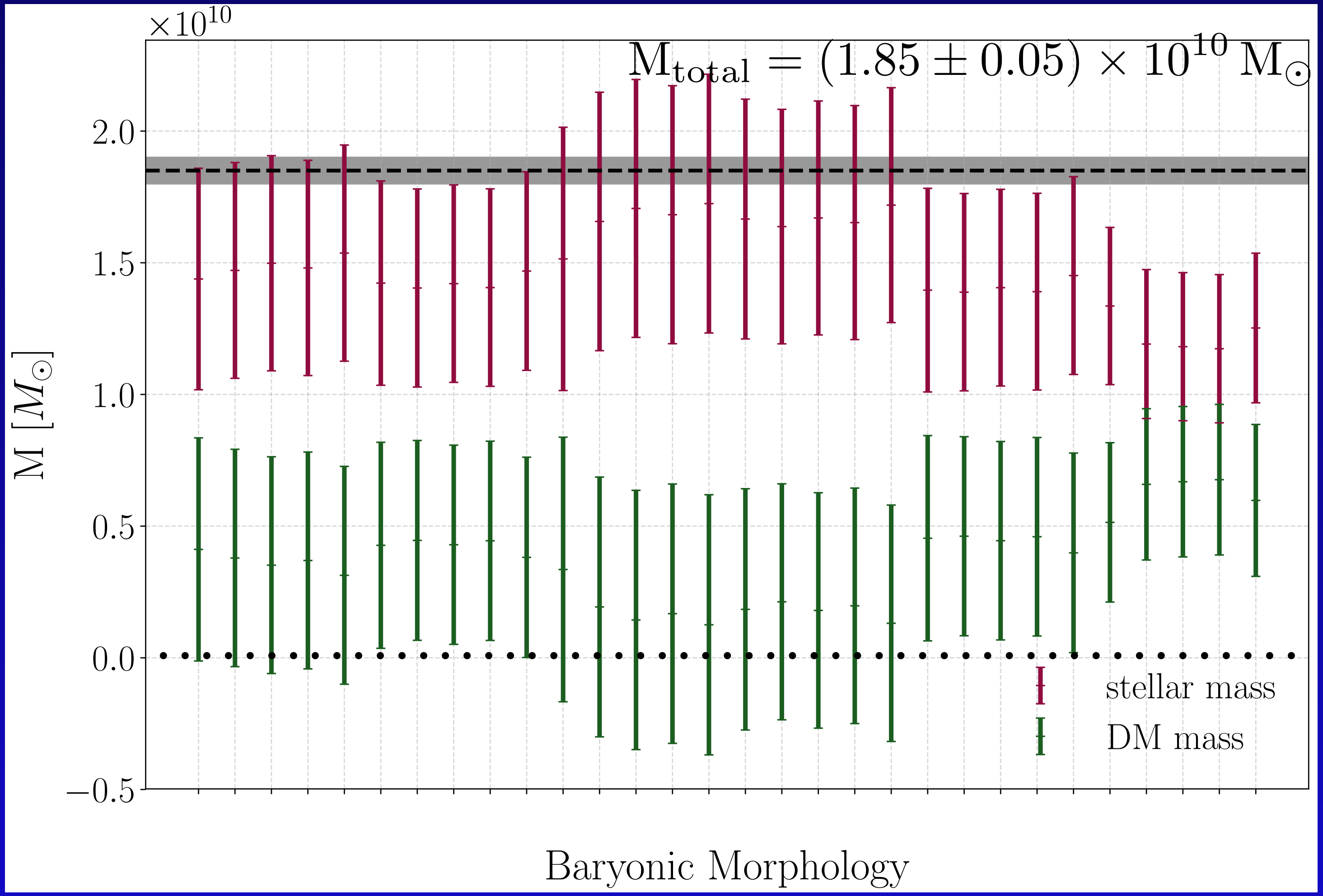
[Iocco & Benito] PDU 15 (2017)

Methodology:
Allowed DM mass

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

$$M_* = (1.1 - 1.7) \times 10^{10}\,M_\odot$$
$$M_{DM} = (0.1 - 0.7) \times 10^{10}\,M_\odot$$

DM mass corresponds to 7-37%



[Iocco & Benito, PDU 2017] arXiv:1611.09861

(+ M. Benito's thesis)

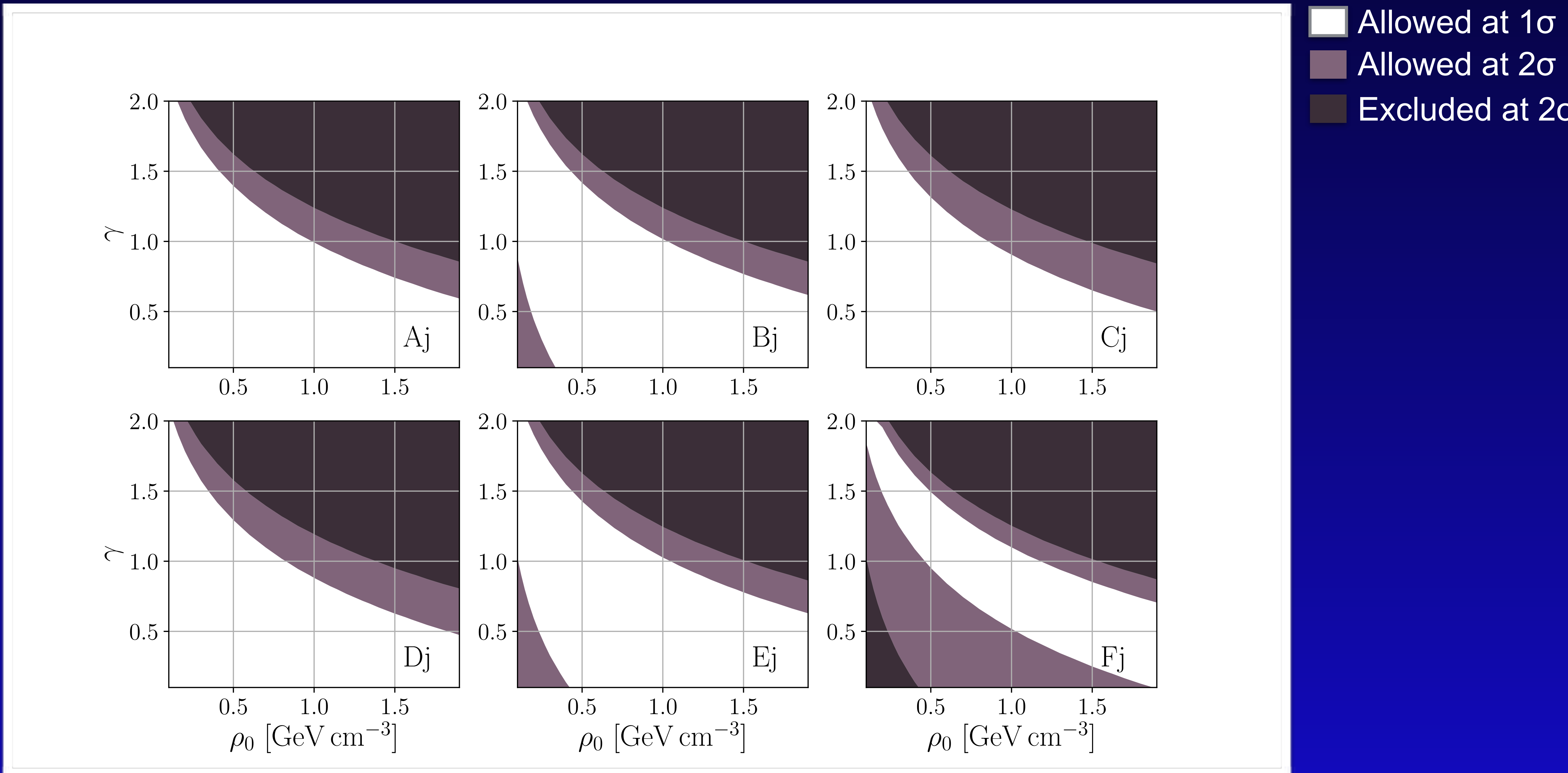
gNFW density profile

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

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

Galactic Bulge Region

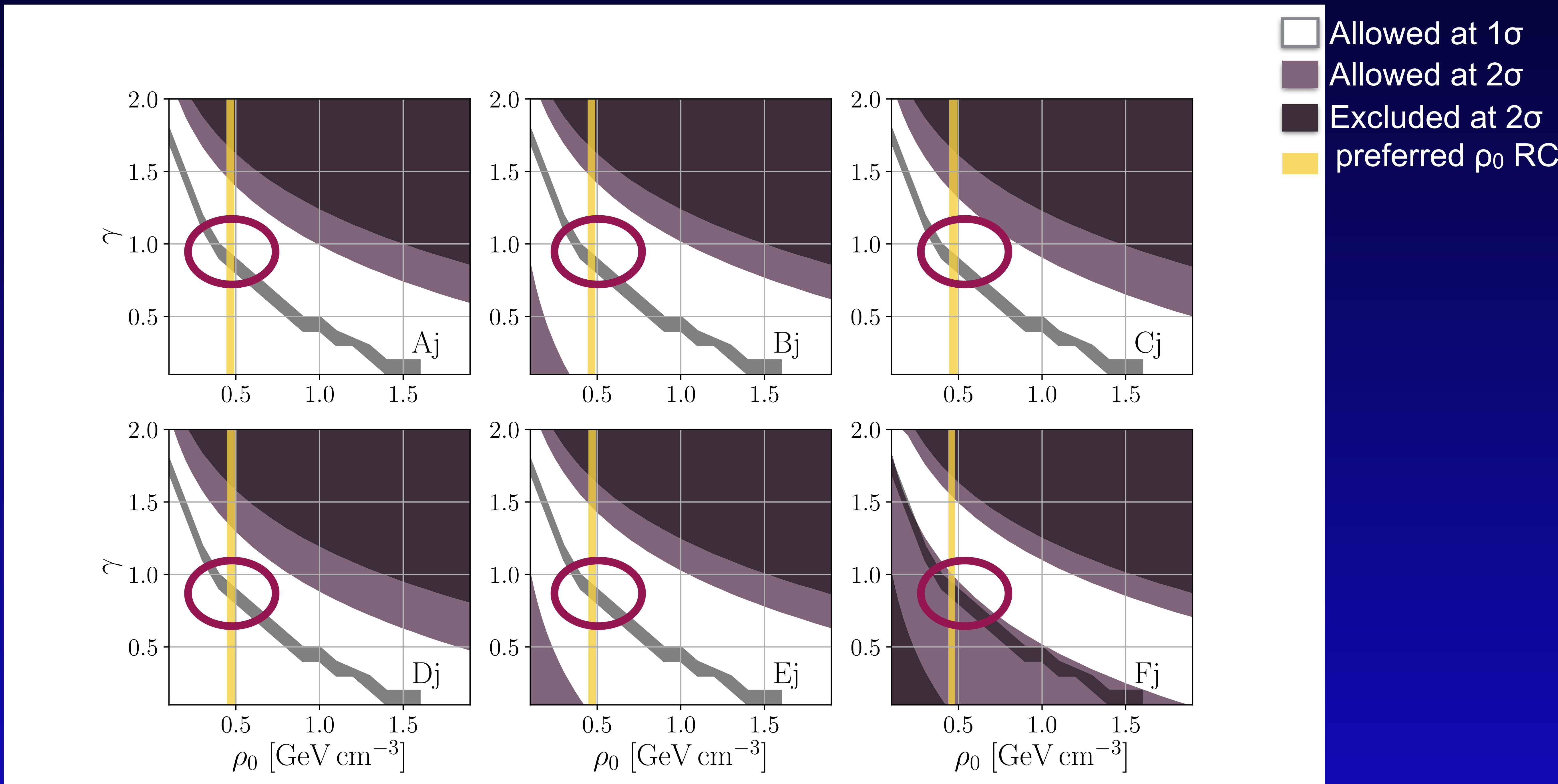
Results: varying bulge morphology



[Iocco & Benito, 2017] arXiv:1611.09861

(+ M. Benito's thesis)

Galactic Bulge Region and RC curve compatibility



$$\mathrm{M_{DM}} = (0.32 \pm 0.05) \times 10^{10}\,\mathrm{M}_\odot$$

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

Portail + MNRAS 465 (2017)

[Iocco & Benito, 2017]
arXiv:1611.09861
(+ M. Benito's thesis)

- South American Dark Matter workshop
December 2-4, 2020

Third of a new series (2017, 2018)
www.ictp-saifr.org/DMw2018

Previous speakers included:

… Azadeh Fattahi
Graciela Gelmini
Christopher McCabe
Cecilia Scannapieco
Tomer Volansky …

ICTP SAIFR | International Centre for Theoretical Physics
South American Institute for Fundamental Research

São Paulo,
Brazil
(not Rio de Janeiro!)

Organizers: I. Albuquerque, E. Bertuzzo, F. Iocco

Cuncta stricte

- Determining the local DM density from actual data is possible
- RC method is accurate and precise, in spite of large range of observational systematic and statistical uncertainties.
- Slope (i.e. full profile of MW) is not very accurate, and quite depending from several systematics. (Galactic Center region further complicated.)
- Astrophysical uncertainties are actually affecting determination of PP, in virtuous interplay with collider physics, direct and indirect probes.
- Providing a ready-to-use likelihood for PP use, including astrophysical uncertainties on DM distribution

One place among the many: home
The Milky Way

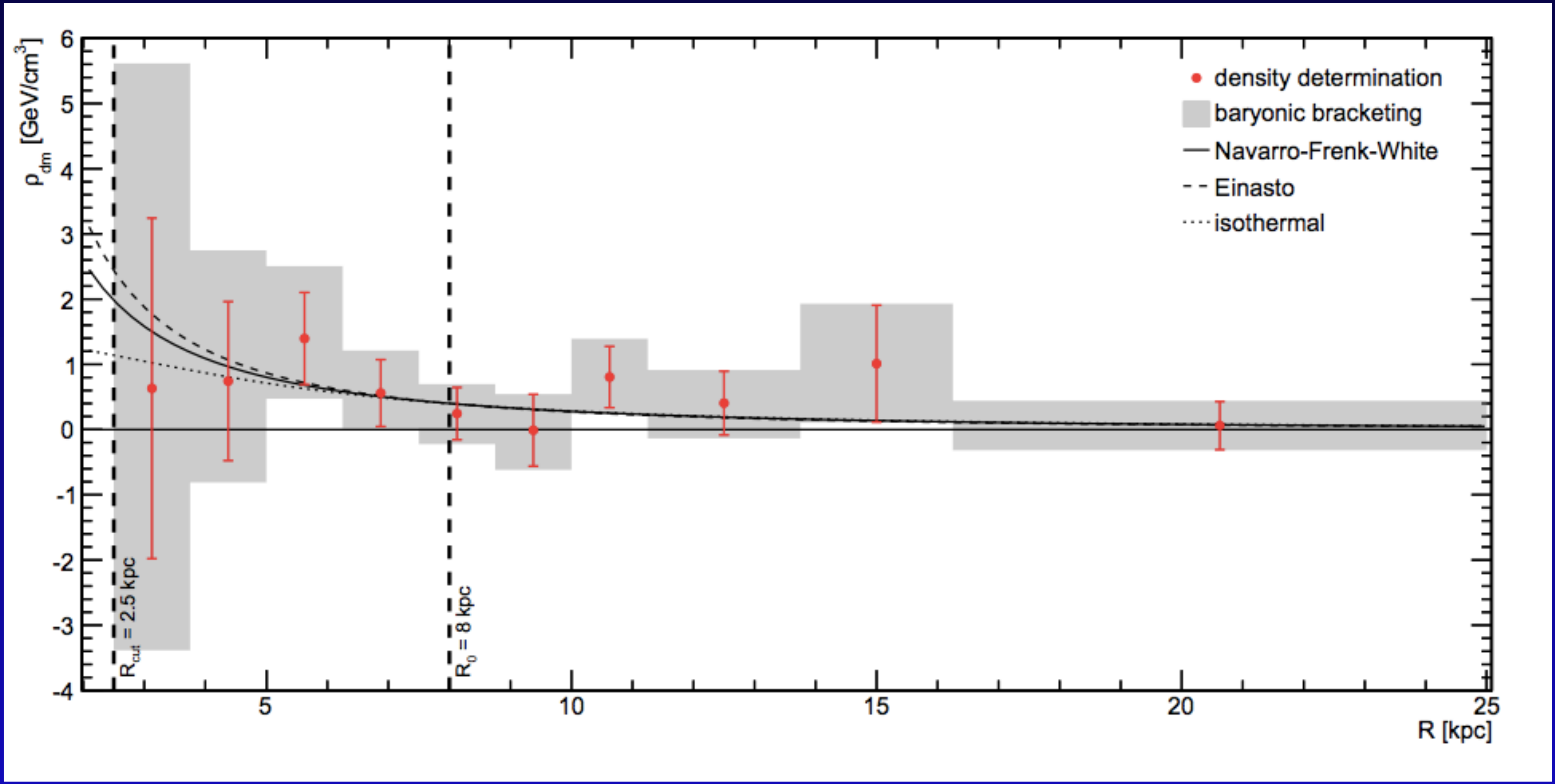
The road to Zeus' mansion on Olympus
The sacred path of Iberian pilgrims
An average-sized 10^12 Msun spiral,
but the truth is…

The Milky Way:
observed rotation curve
the data: a new compilation

	Object type	R [kpc]	quadrants	# objects
	HI terminal velocities			
	Fich+ '89	2.1 – 8.0	1,4	149
	Malhotra '95	2.1 – 7.5	1,4	110
	McClure-Griffiths & Dickey '07	2.8 – 7.6	4	701
	HI thickness method			
	Honma & Sofue '97	6.8 – 20.2	–	13
	CO terminal velocities			
	Burton & Gordon '78	1.4 – 7.9	1	284
	Clemens '85	1.9 – 8.0	1	143
gas	Knapp+ '85	0.6 – 7.8	1	37
	Luna+ '06	2.0 – 8.0	4	272
	HII regions			
	Blitz '79	8.7 – 11.0	2,3	3
	Fich+ '89	9.4 – 12.5	3	5
	Turbide & Moffat '93	11.8 – 14.7	3	5
	Brand & Blitz '93	5.2 – 16.5	1,2,3,4	148
	Hou+ '09	3.5 – 15.5	1,2,3,4	274
	giant molecular clouds			
	Hou+ '09	6.0 – 13.7	1,2,3,4	30
	open clusters			
	Frinchaboy & Majewski '08	4.6 – 10.7	1,2,3,4	60
	planetary nebulae			
	Durand+ '98	3.6 – 12.6	1,2,3,4	79
	classical cepheids			
stars	Pont+ '94	5.1 – 14.4	1,2,3,4	245
	Pont+ '97	10.2 – 18.5	2,3,4	32
	carbon stars			
	Demers & Battinelli '07	9.3 – 22.2	1,2,3	55
	Battinelli+ '13	12.1 – 24.8	1,2	35
	masers			
	Reid+ '14	4.0 – 15.6	1,2,3,4	80
	Honma+ '12	7.7 – 9.9	1,2,3,4	11
masers	Stepanishchev & Bobylev '11	8.3	3	1
	Xu+ '13	7.9	4	1
	Bobylev & Bajkova '13	4.7 – 9.4	1,2,4	7

[Iocco, Pato, Bertone, Nature Physics 2015] [Pato & FI, arXivV:1703.00020 , Software X (2017)]

“Mom look, no hands!”
A non-parametric reconstruction of the DM profile

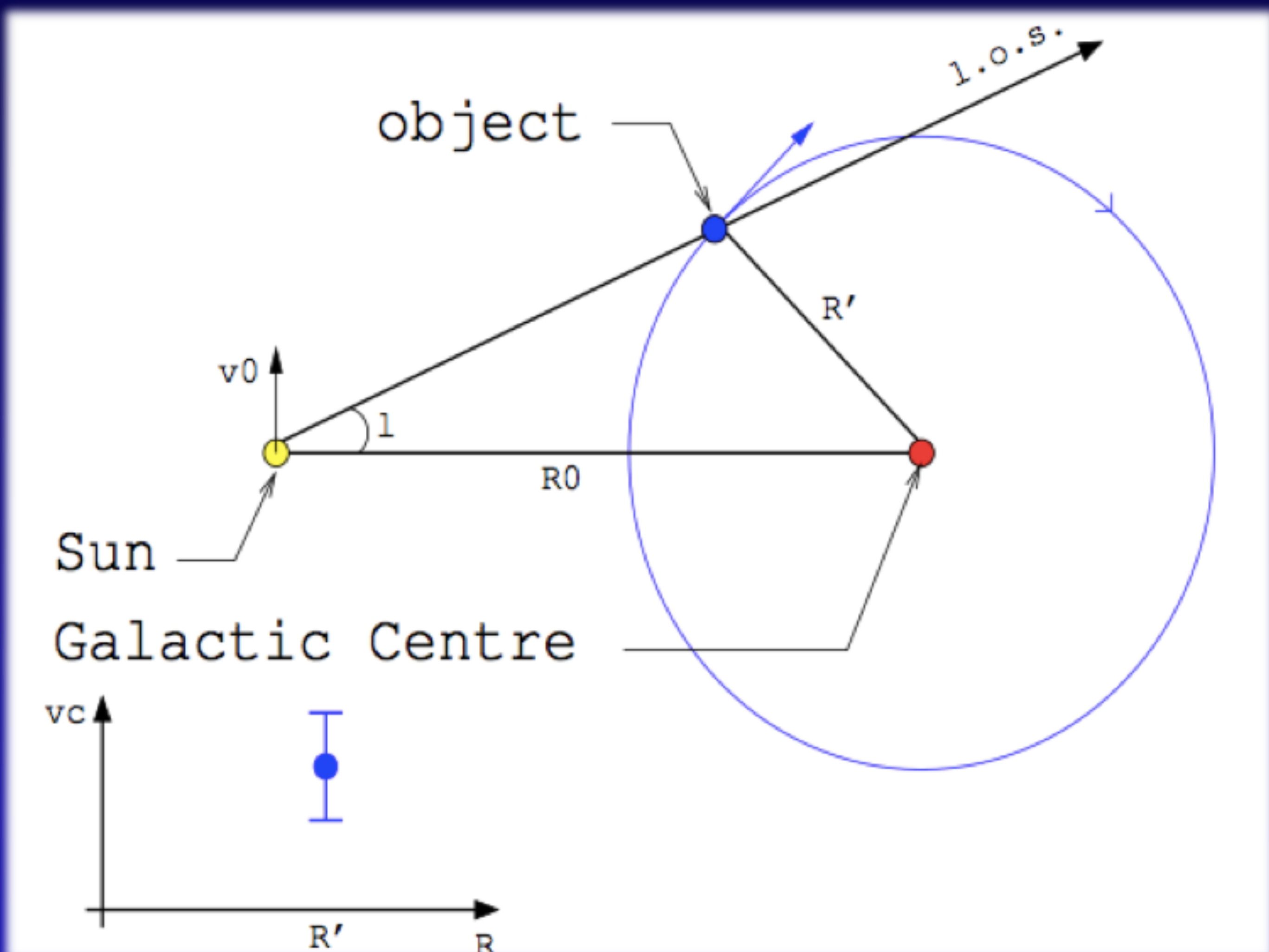


[Pato & FI, 2015]

The Milky Way:

observed rotation curve

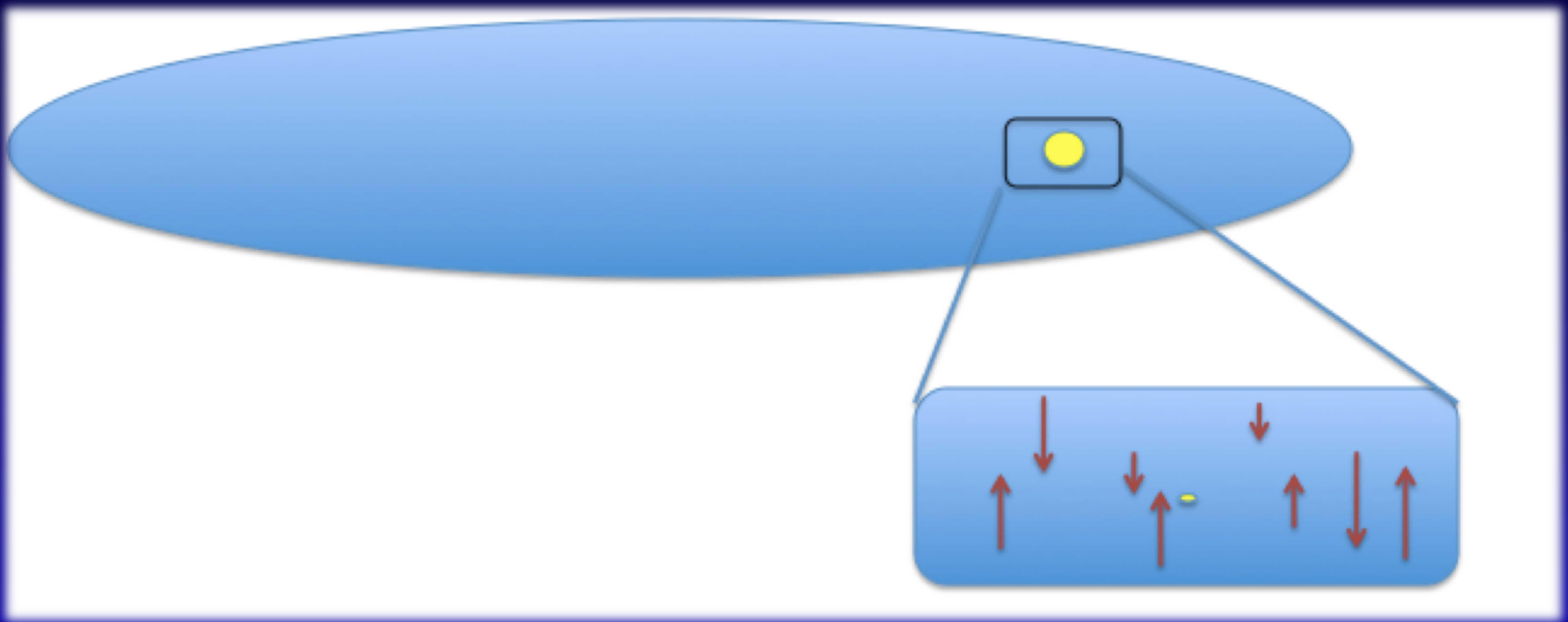
I. principles



$$v_{\mathrm{LSR}}^{\mathrm{l.o.s.}} = \left(\frac{v_c(R')}{R'/R_0} - v_0 \right) \cos b \sin \ell$$

observing tracers from our own position,
transforming into GC-centric reference frame

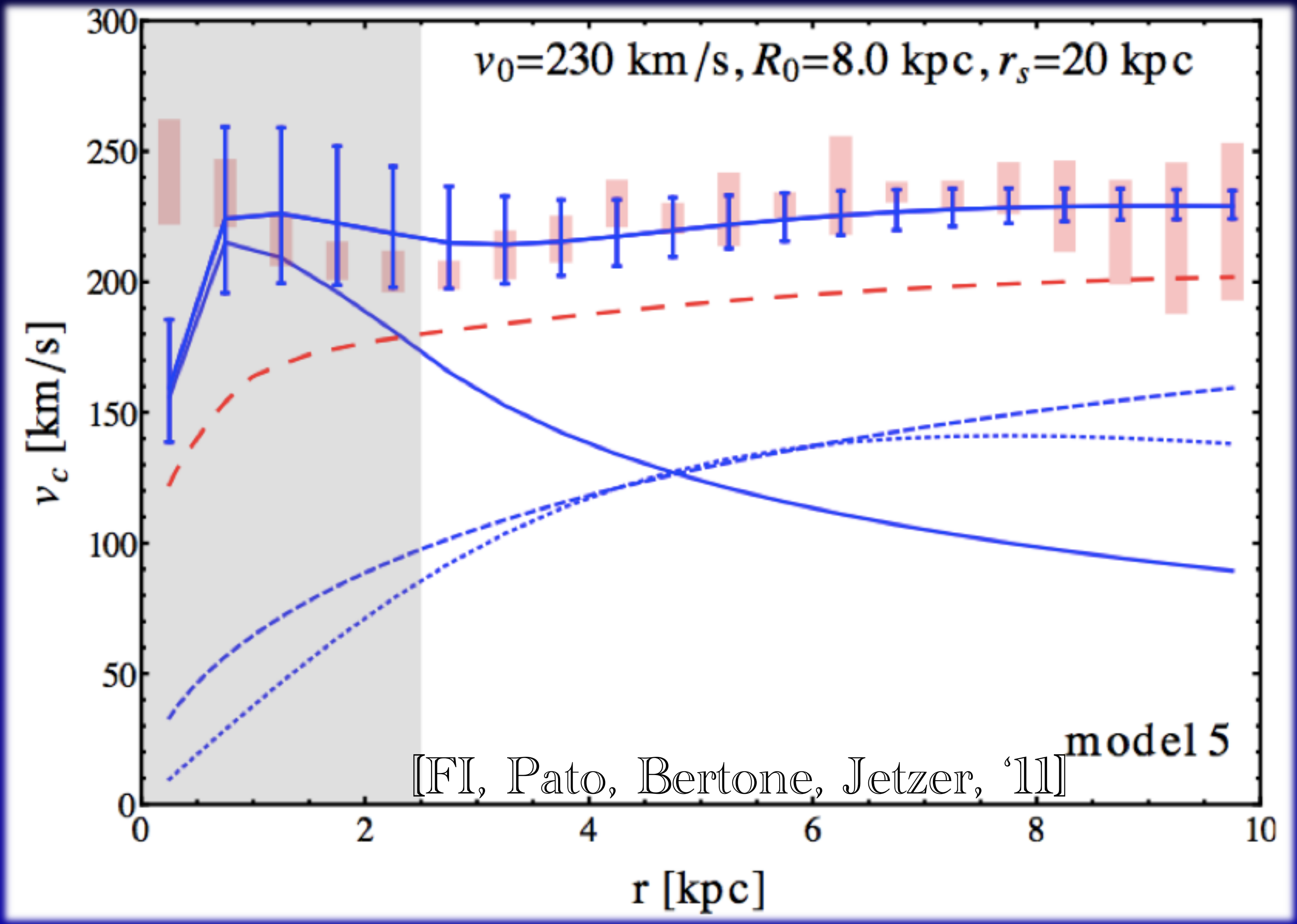
Local determination of ρ_0



Vertical motion of stars, determining the whole local potential

Global determination of ρ(r)

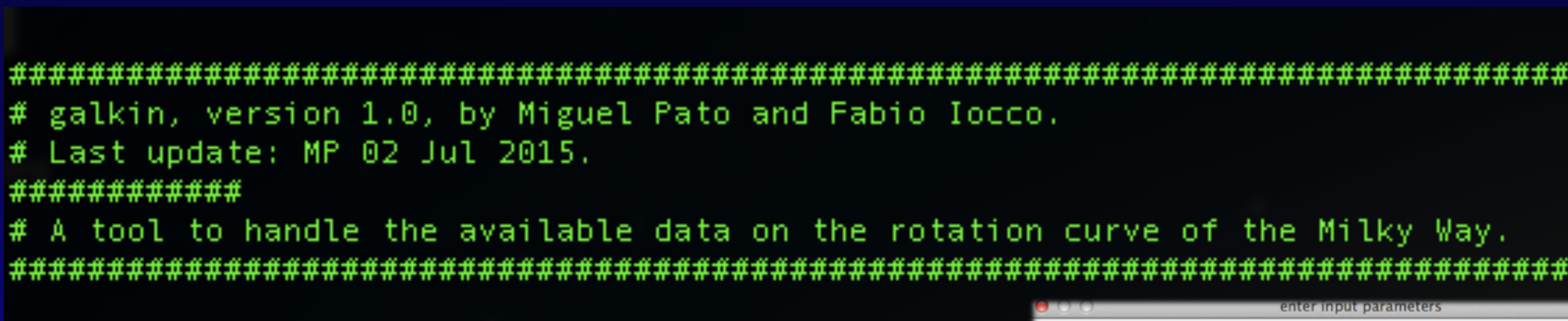
Fitting a DM profile to the Rotation Curve, on top of other components



$$\phi_{\rm tot} = \phi_{\rm bulge} + \phi_{\rm disk} + \phi_{\rm gas} + \phi_{\rm dm}$$

Underlying assumption on DM presence and distribution shape

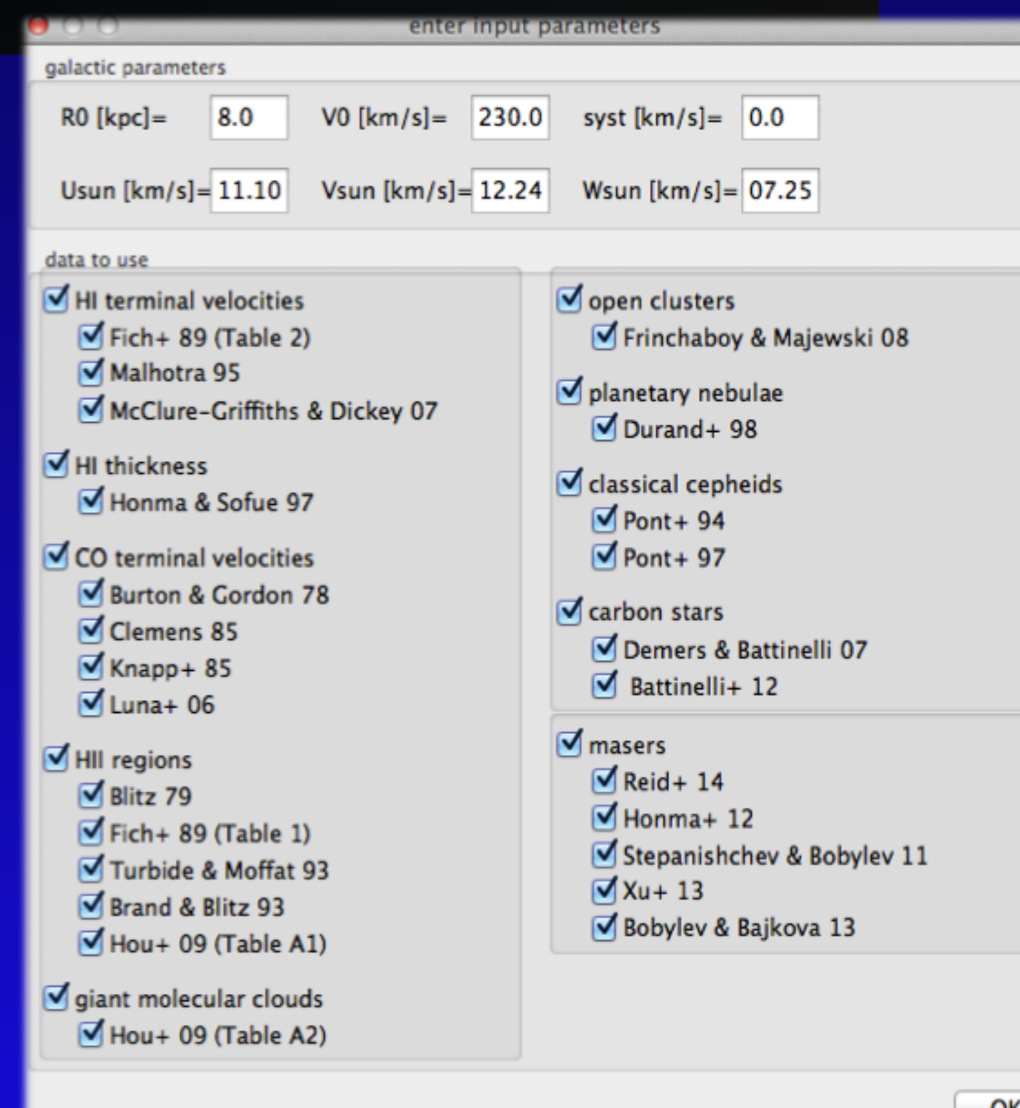
The Milky Way:
observed rotation curve
IV. public tool: galkin



Customizable galactic parameters
(R_0,V_0)
peculiar motions, etc…

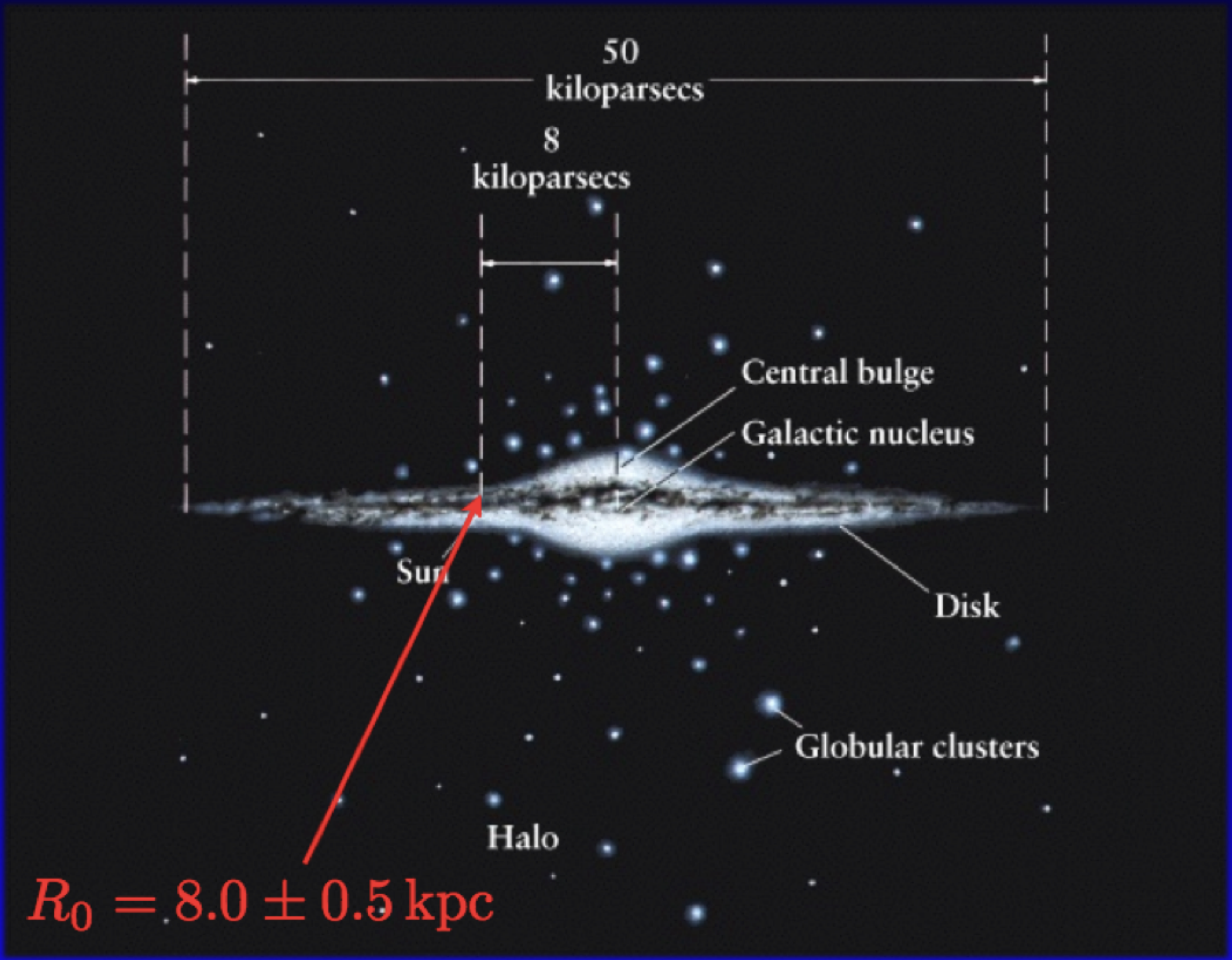
Finally available:
download your copy now

github.com/galkintool/galkin

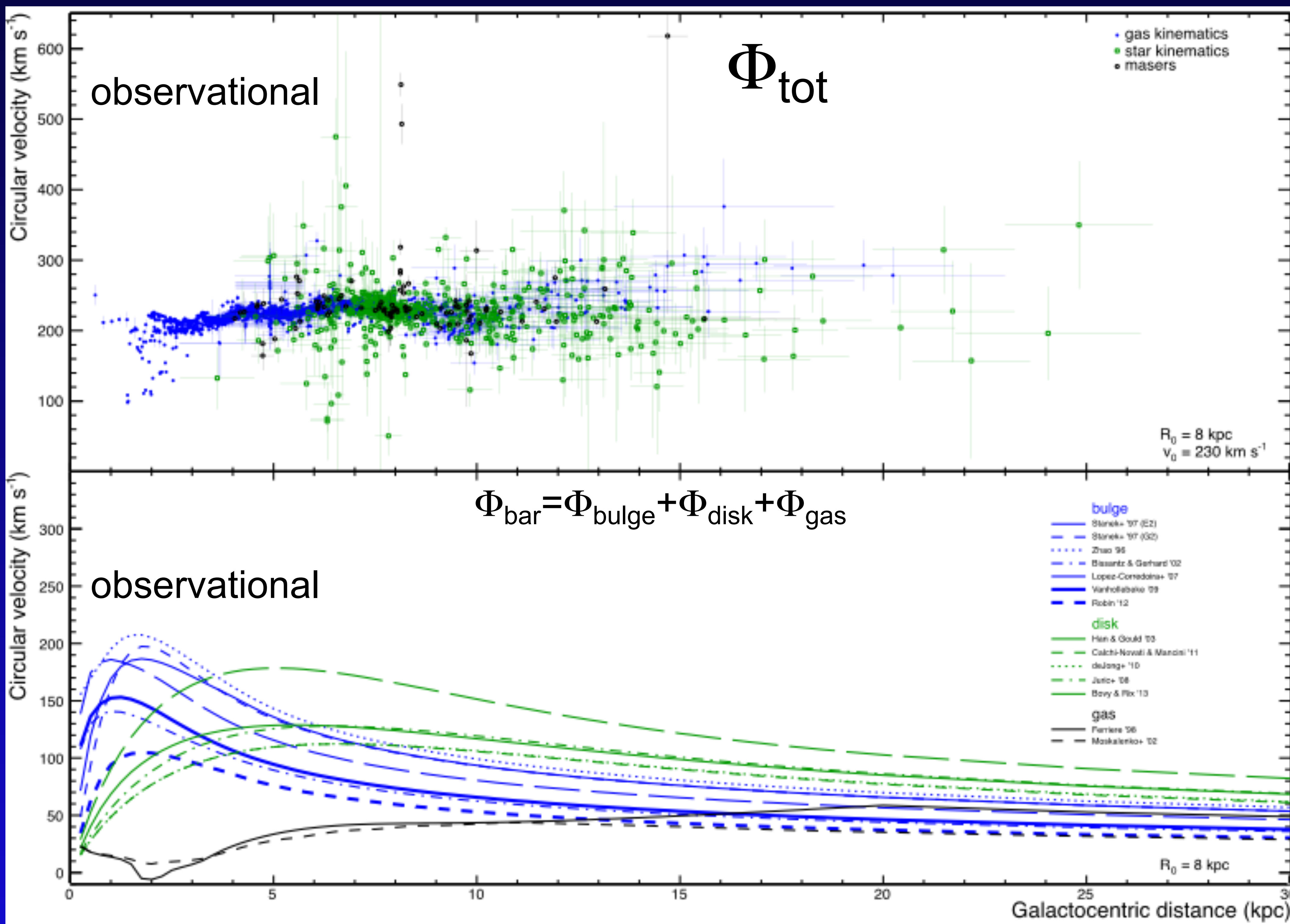


[Pato & FI, arXivV:1703.00020 , Software X (2017)]

Modeling the Milky Way: morphological observations



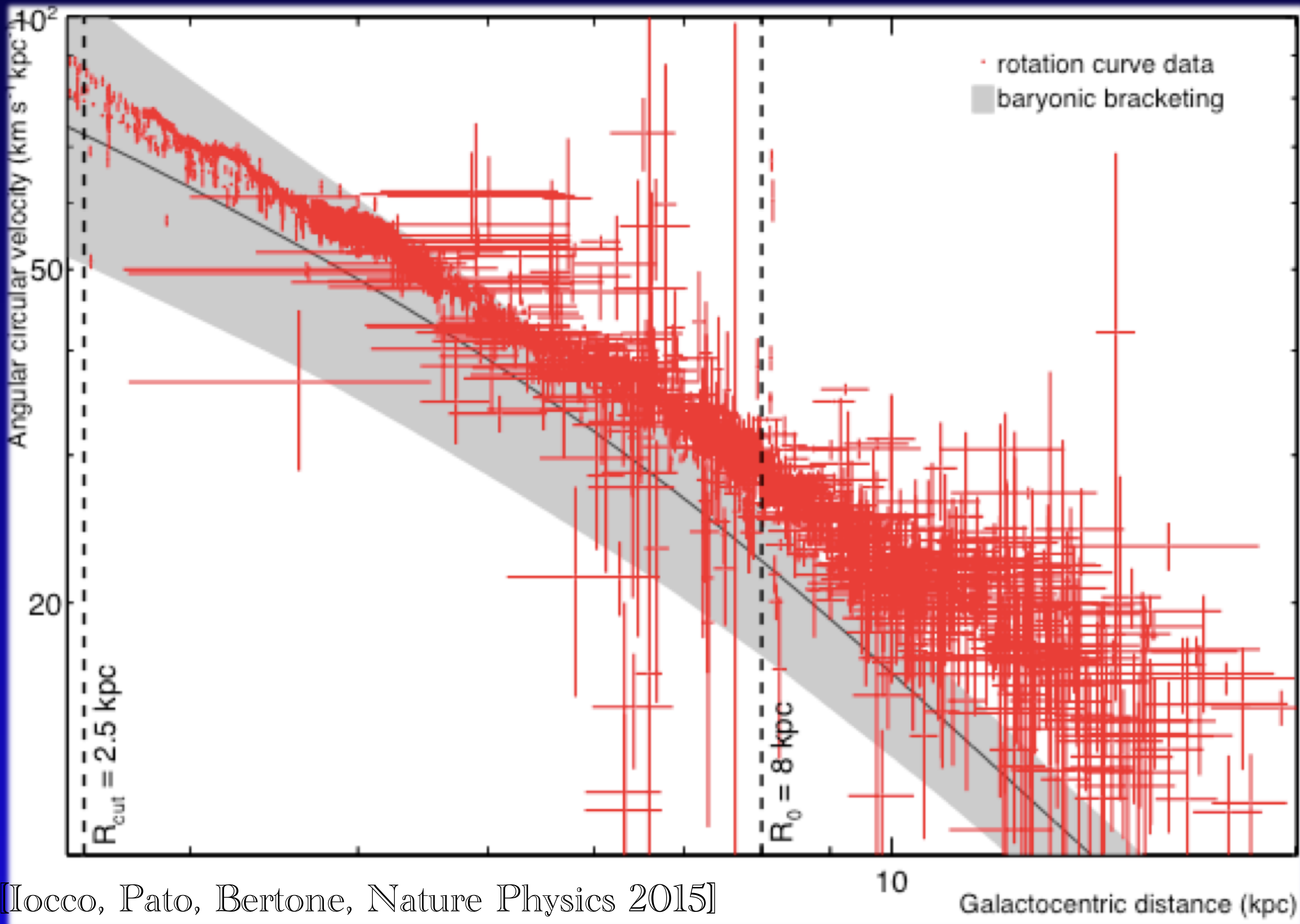
The Milky Way: testing expectactions



The Milky Way: testing expectactions

(with no additional assumption)

((and some technical detail))



[Iocco, Pato, Bertone, Nature Physics 2015]

$\omega = V_c / R_c$

Uncorrelated uncertainties

R_0=8 kpc

V_0=230 km/s

The Milky Way: testing expectactions (with no additional assumptions) ((and some technical detail))

- Computing the "badness-of-fit" (discrepancy) of each baryon rot. curve (no DM!!) to observed one

- One COULD bin (and we have done it) but loss of information: using 2D chi-square (uncertainties on R, as well)

$$\chi^2 = \sum_{i=1}^{N} d_i^2 \equiv \sum_{i=1}^{N} \left[\frac{(y_i - y_{b,i})^2}{\sigma_{y,i}^2} + \frac{(x_i - x_{b,i})^2}{\sigma_{x,i}^2} \right]$$

The case of the Milky Way: the question

$$\Phi_{tot} = \Phi_{bulge} + \Phi_{disk} + \Phi_{gas} \;\; ??$$

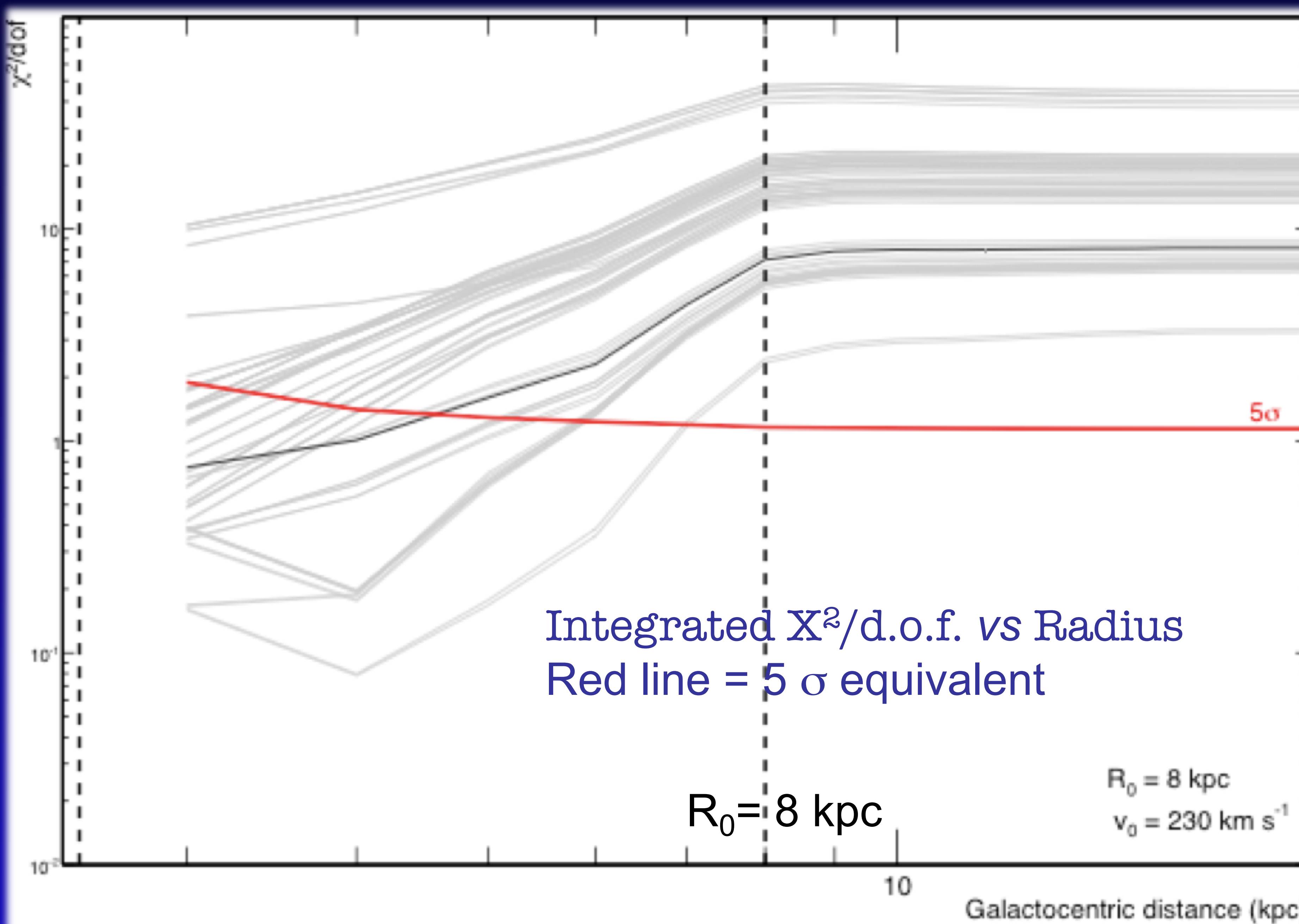
[can the observed, luminous components make up to the whole gravitational potential?]

$$v_c^2 = r\frac{d\phi_{\rm tot}}{dr}$$

Rotation curve as a tracer of the total potential

…and if not…

Do the baryon-only curves fit with the observed RC?

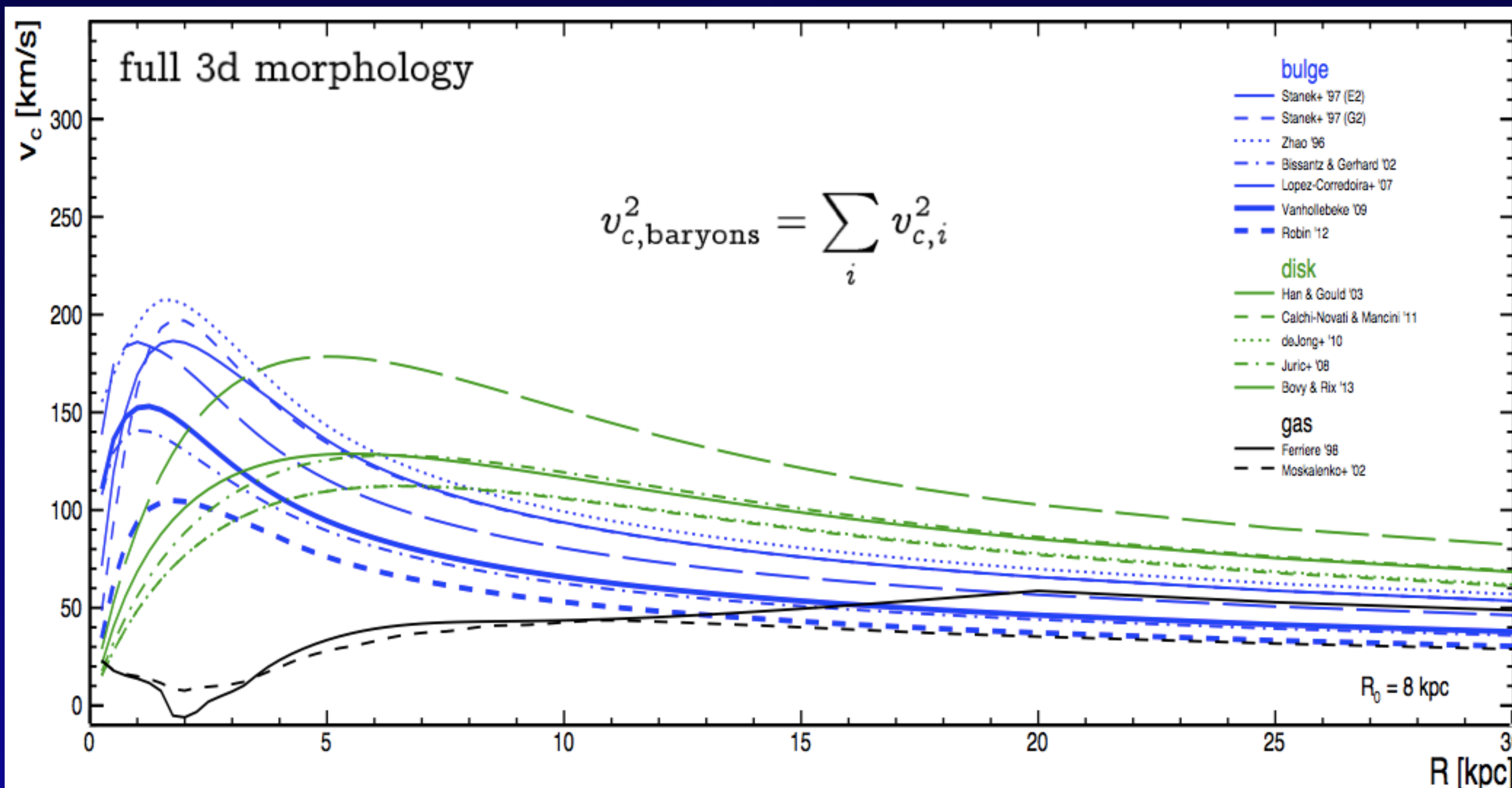


Answer is NO:
Every single model above 5 σ, already at $R<R_0$!!

[Iocco, Pato, Bertone, Nature Physics 2015]

There's more than you are usually told: visible morphology is uncertain

(and don't forget the dependence on Gal Parameters)



[Iocco, Pato, Bertone, Nature Physics 2015]

Also possible to determine the total mass of the MW

$$M_{200} = \left[8.0^{+1.1}_{-0.8}\,(\mathrm{stat})^{+1.5}_{-0.7}\,(\mathrm{sys})\right] \times 10^{11}\ \mathrm{M}_\odot$$

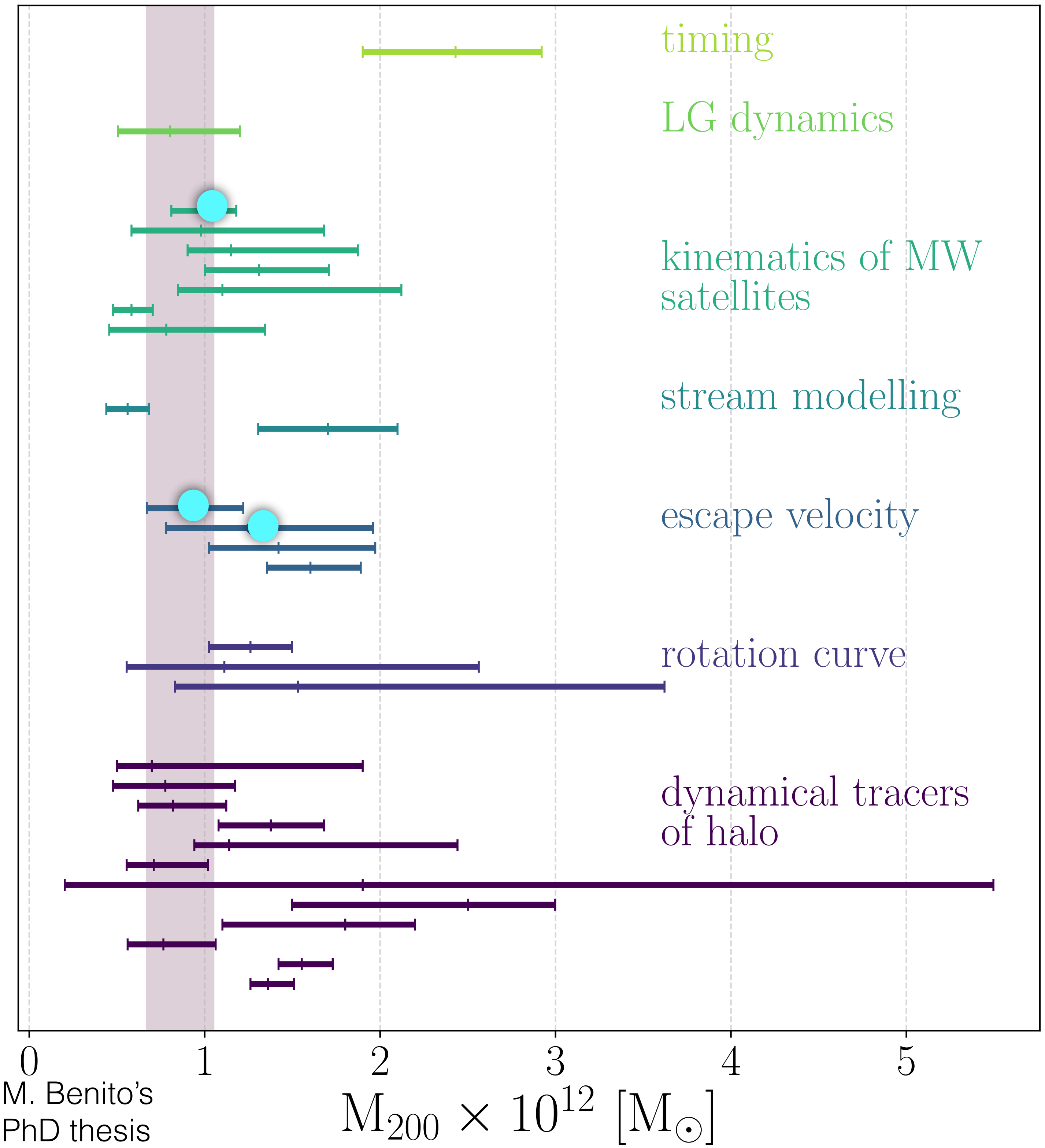
$$M_{\mathrm{bar}} = \left[0.65 \pm 0.04\,(\mathrm{stat})^{+0.04}_{-0.07}\,(\mathrm{sys})\right] \times 10^{11}\ \mathrm{M}_\odot$$

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

Band (our result) takes into account:

- **Different baryonic morphologies (syst)**
- **Statistical uncertainties**

Determinations with Gaia data



M. Benito's PhD thesis

[Karukes, Benito, FI, Trotta, Geringer-Sameth] in progress

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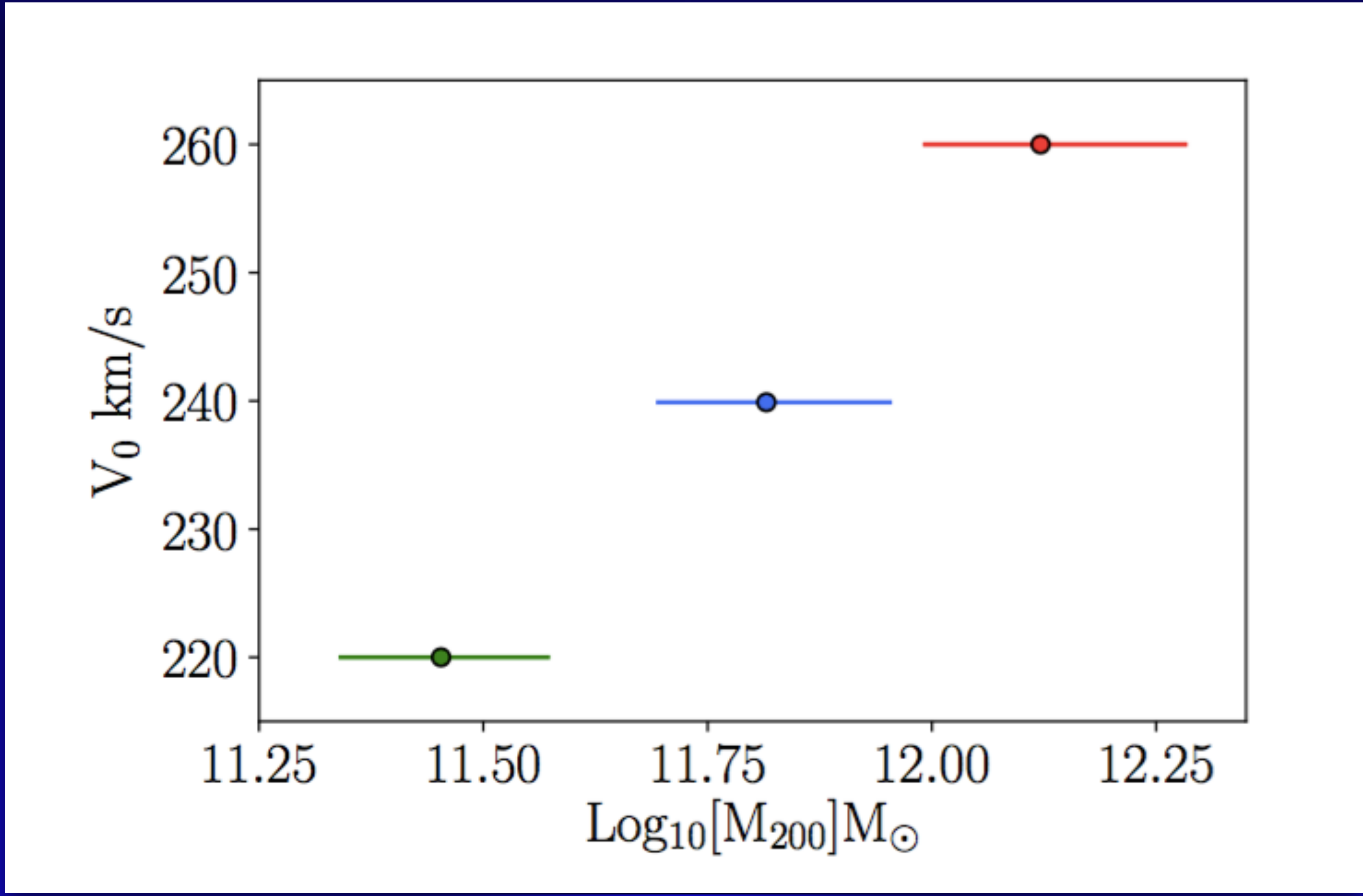
$$M_{\mathrm{tot}} = [8.7^{+1.0}_{-0.8}\,(\mathrm{stat})^{+1.4}_{-0.8}\,(\mathrm{sys})] \times 10^{11}\,M_\odot$$

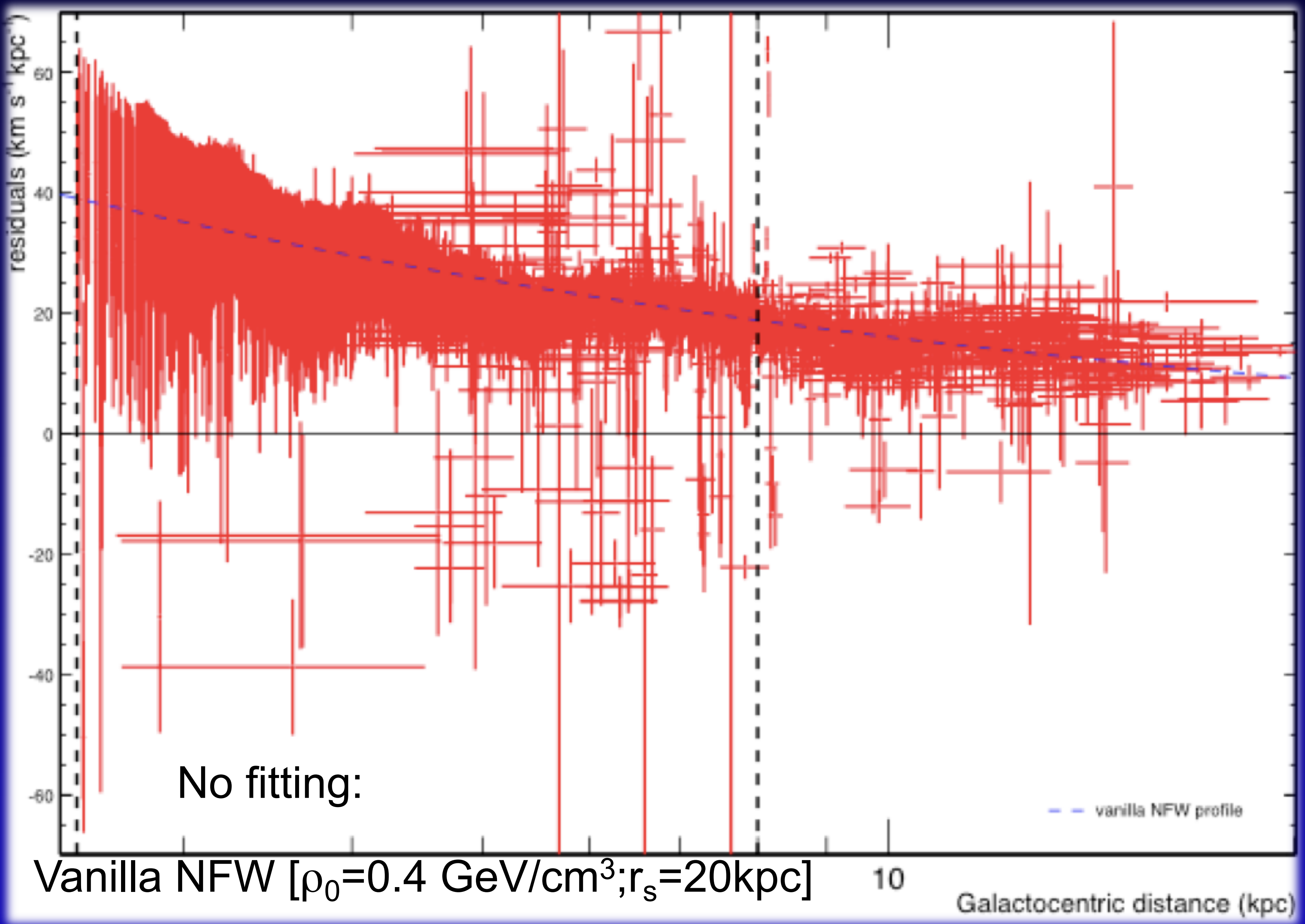
Determination of mass integrates out uncertainties on gamma

Still (mild) dependence on Galactic Parameter(s) V_0



[Karukes, Benito, FI, Trotta, Geringer-Sameth] in progress

Motivating dark haloes



$$v_{Residual} = (v^2_{tot} - v^2_{bar})^{1/2}$$

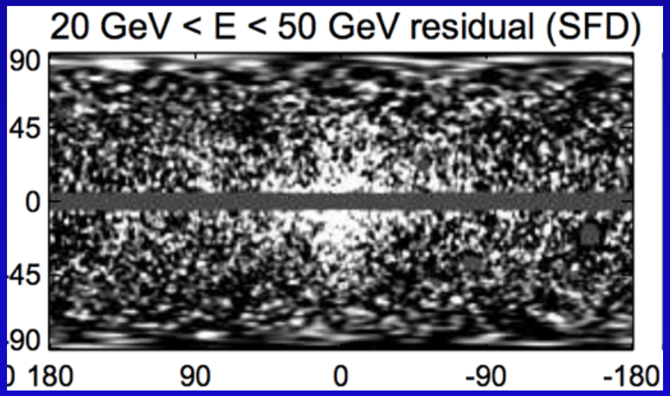
Indirect Detection: principles and dependencies

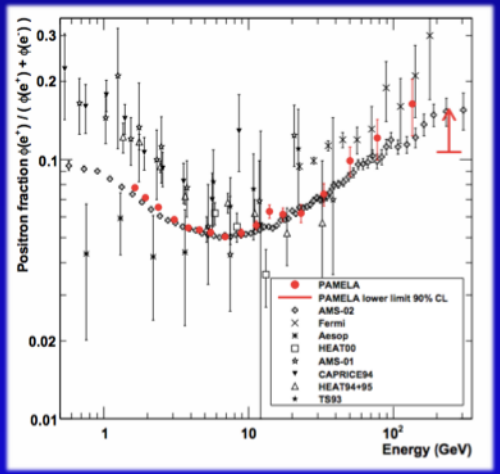
Galactic center, Dwarf Galaxies, Galactic Halo…
dependence on density structure
discovery (or constraints) subject to same uncertainty

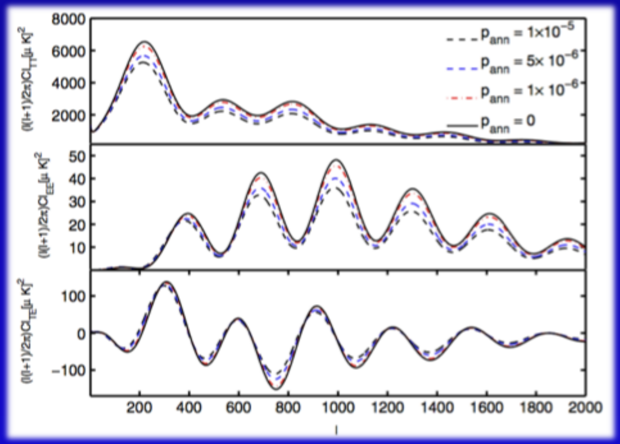
$$F_i \propto \frac{1}{4\pi d^2} B_i \frac{\langle \sigma v \rangle}{m_\chi} \int \rho^2(r) dV$$

$$J_{annih} \propto \int_{los} \rho^2(r) dV$$

$$\Phi_{DM}(E) = \Phi_{PP}(E) \mathcal{J}$$



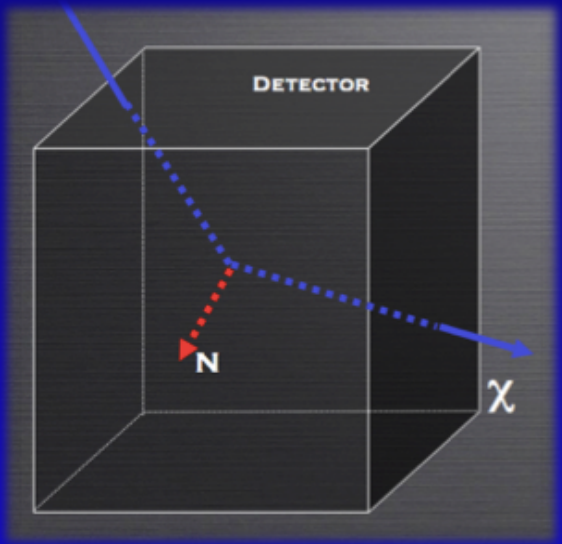




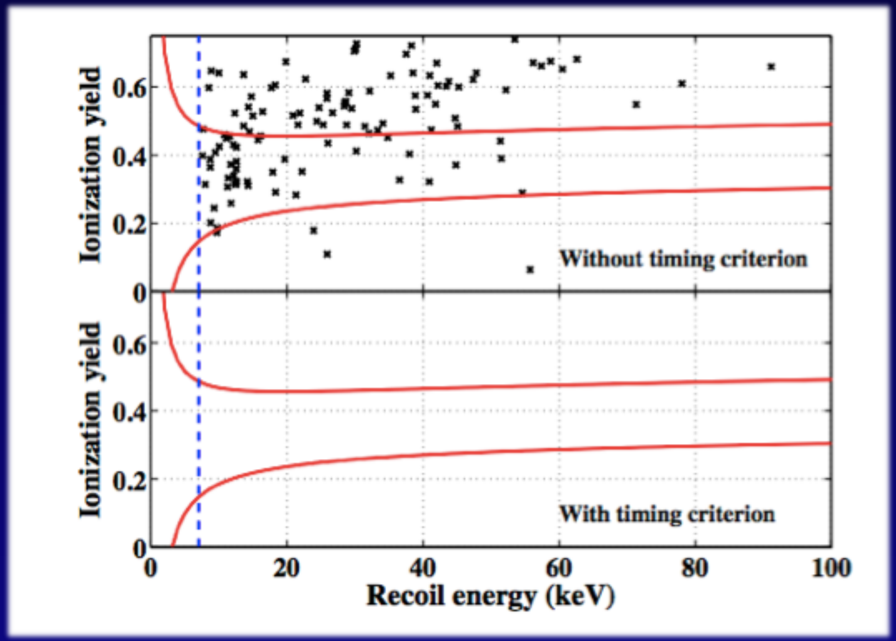
Direct Detection: principles and dependencies

A big mountain
(or a deep mine)

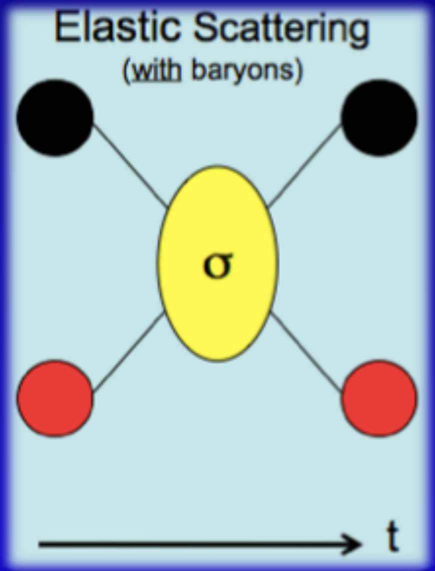
a relatively cheap detector



Your observed data



Your ticket to Stockholm



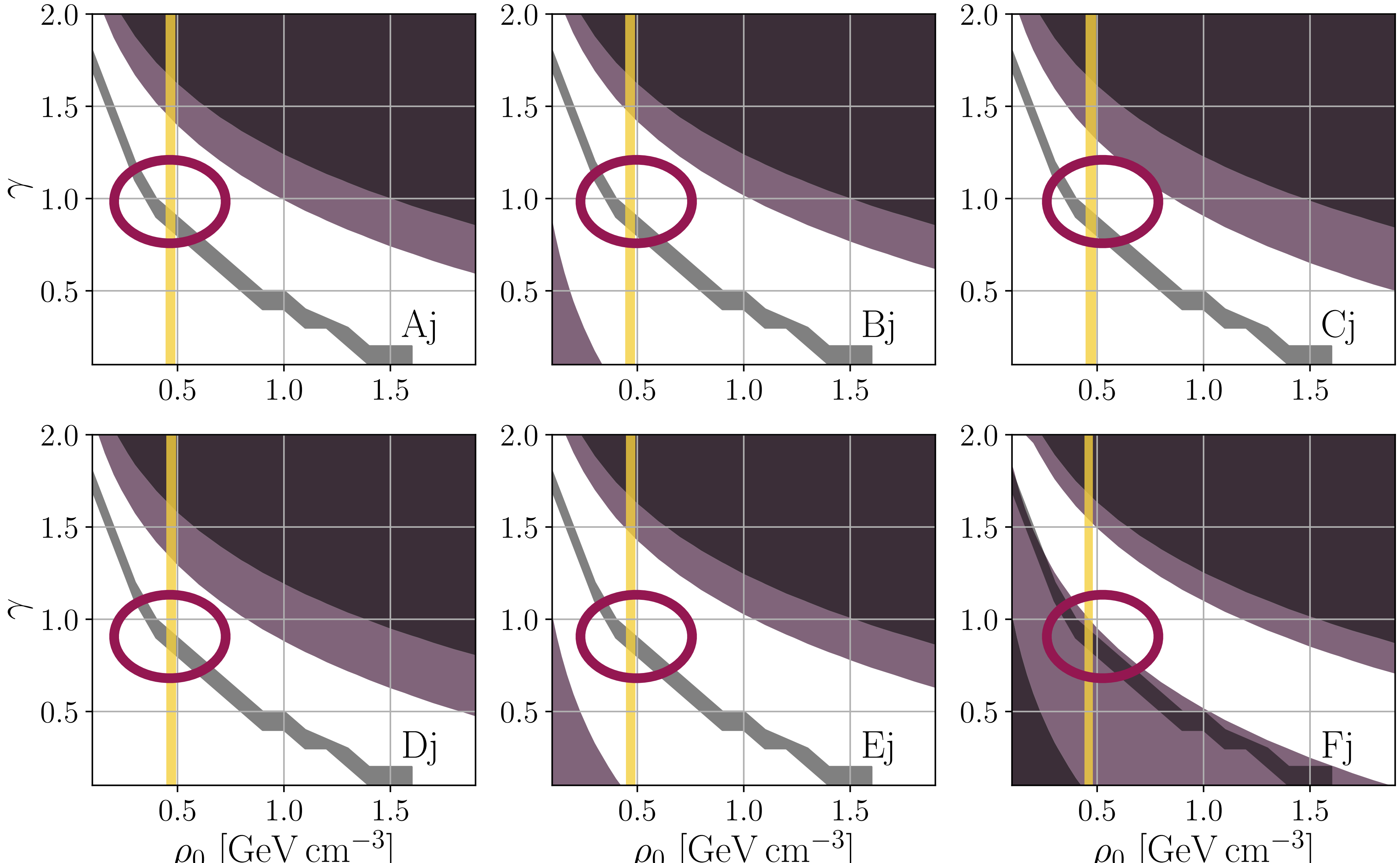
Galactic Bulge Region - Results: varying bulge morphology

“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)

Allowed at 1σ
Allowed at 2σ
Excluded at 2σ
preferred ρ_0 (RC)



$\gamma \sim 1$

Core is not a necessary condition!

[Iocco & Benito, 2017]
arXiv:1611.09861
(+ M. Benito’s thesis)