

# *Particle Dark Matter: effects of Galactic uncertainties on the determination of new physics*

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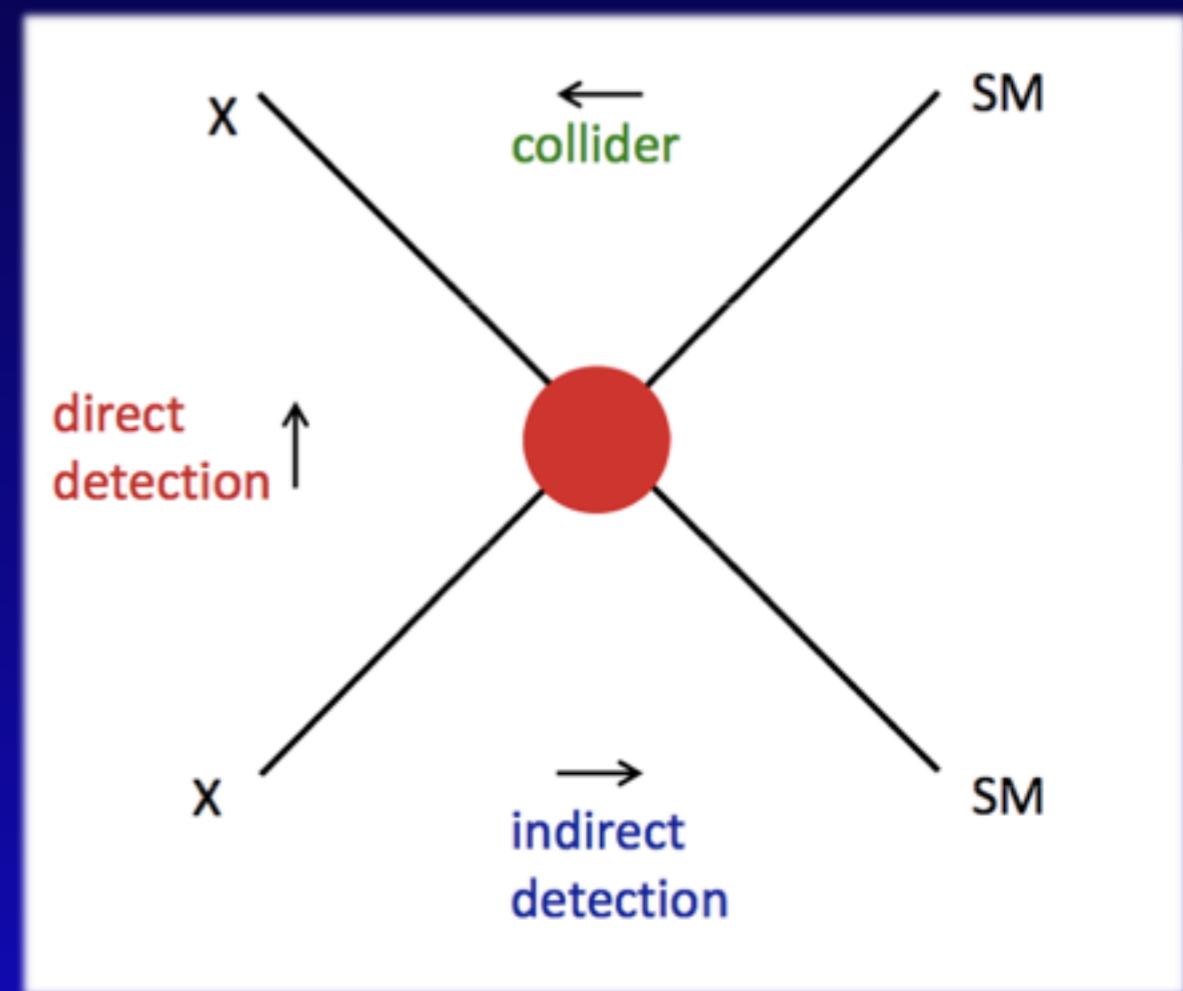
PALS/SLAP/LAPS/????  
Woerden, The Netherlands  
12/10/17

# 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



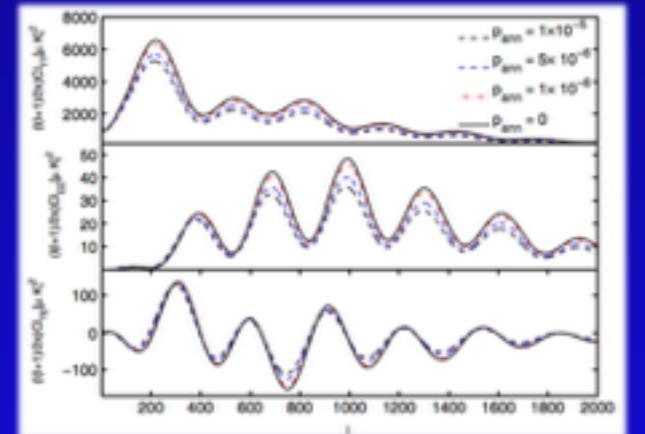
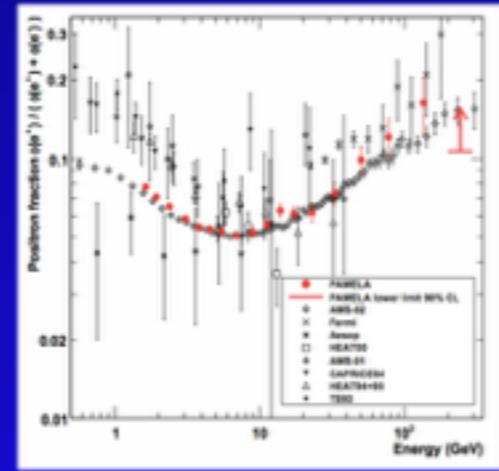
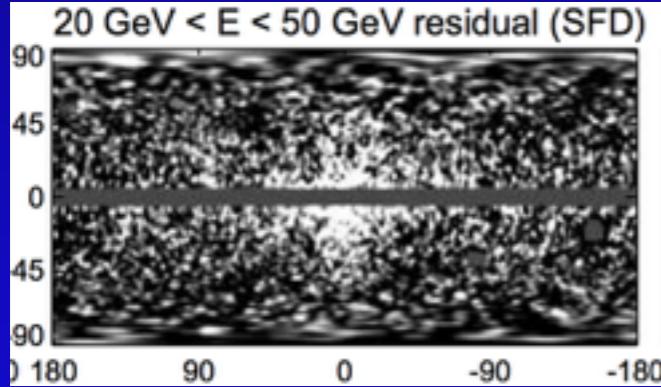
# Indirect Detection: principles and dependencies

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

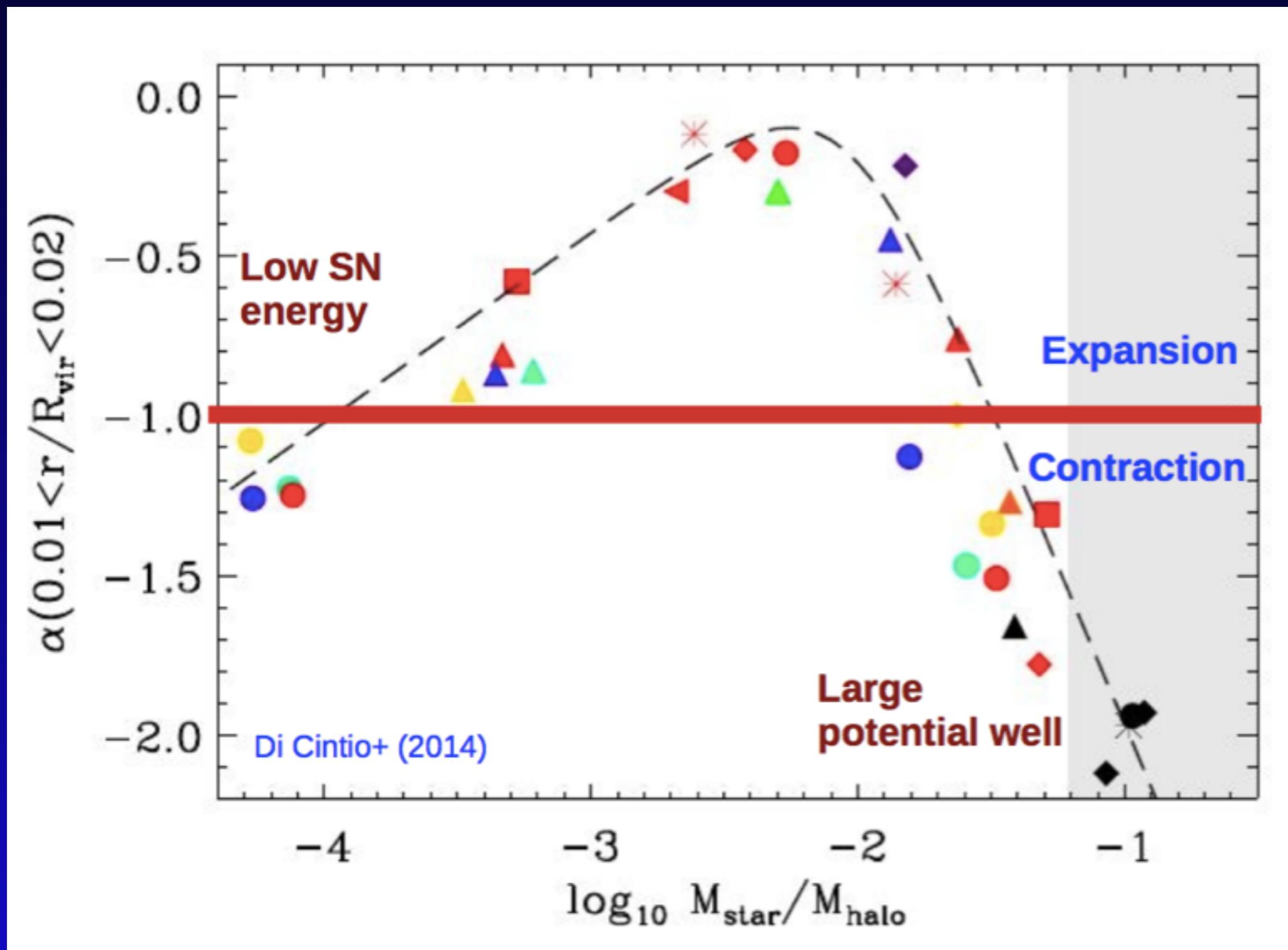
$$F_i \propto \frac{1}{4\pi d^2} B_i \frac{\langle \sigma v \rangle}{m_\chi} \int \rho^2(r) dV$$

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

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



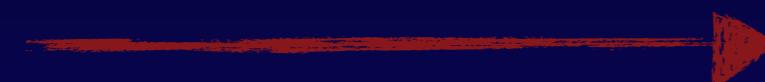
# A “dynamical” DM profile



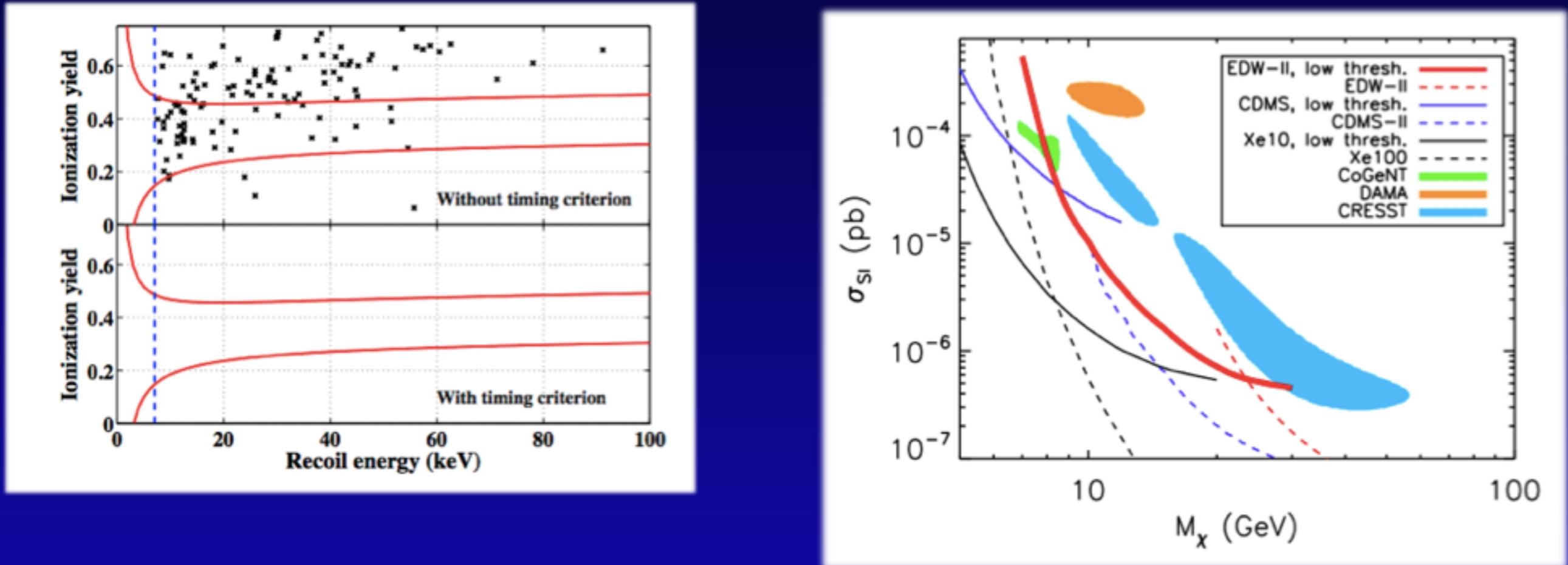
A balance of gravitational potential and SN energy injection

# Direct Detection: principles and dependencies (to go...)

from this



to this



you need this

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

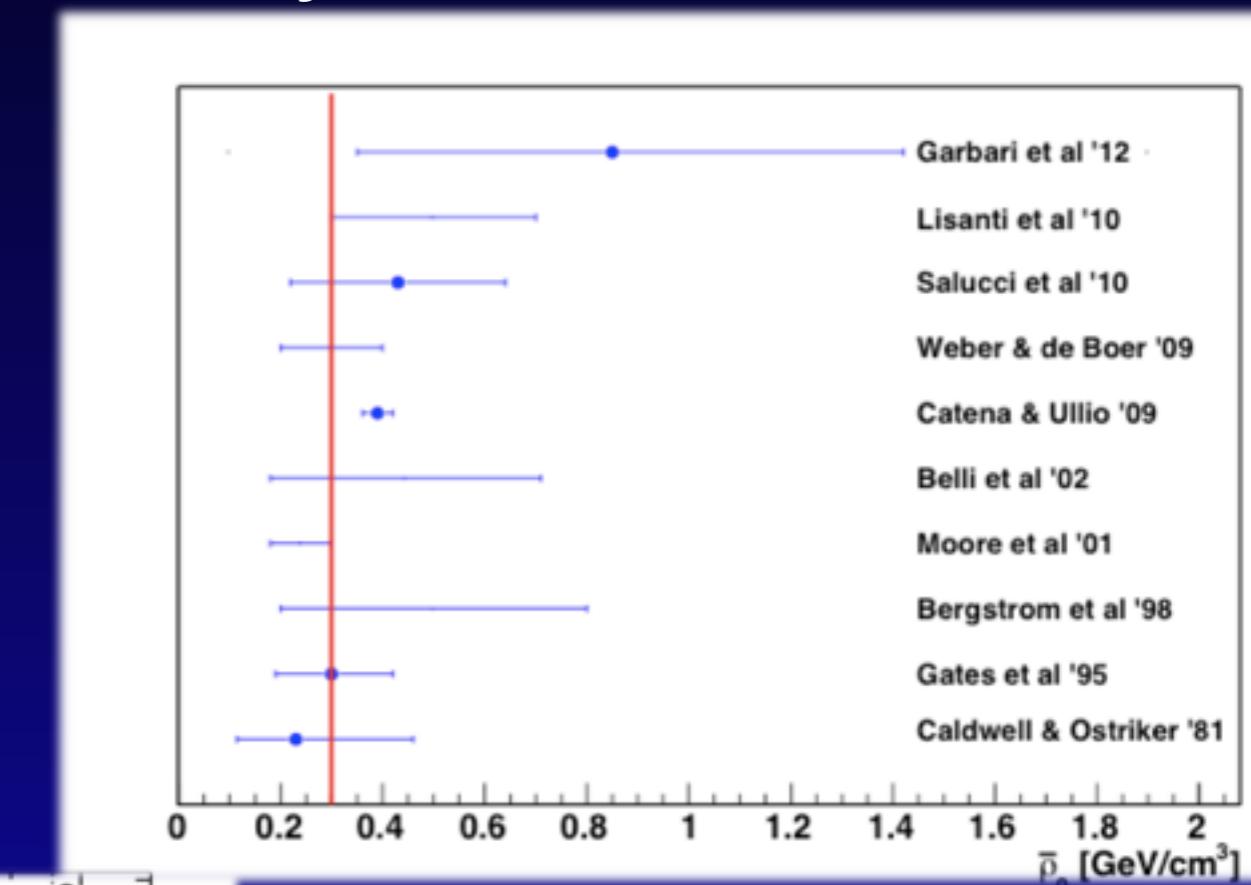
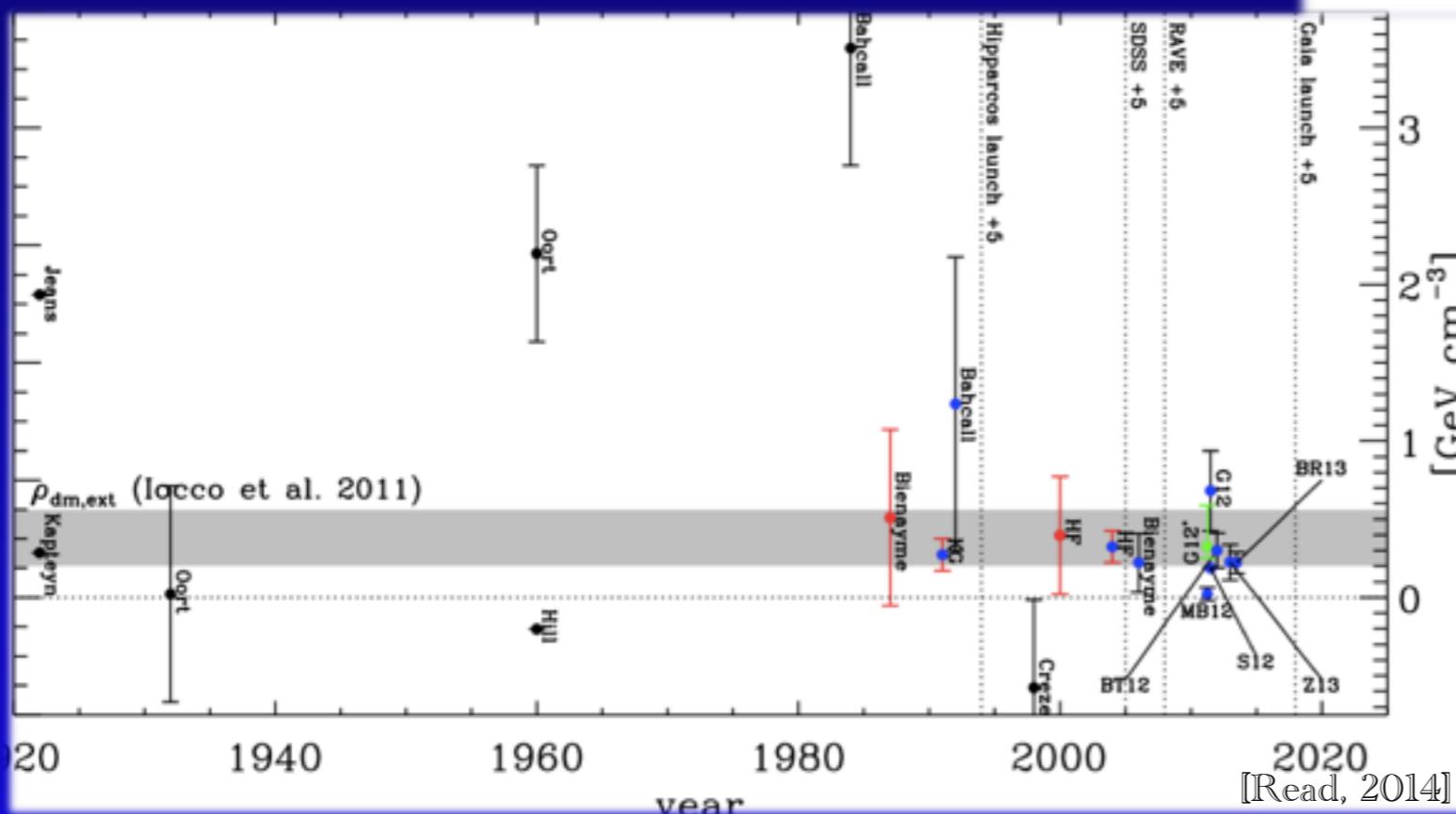
DM density at the Sun = ?



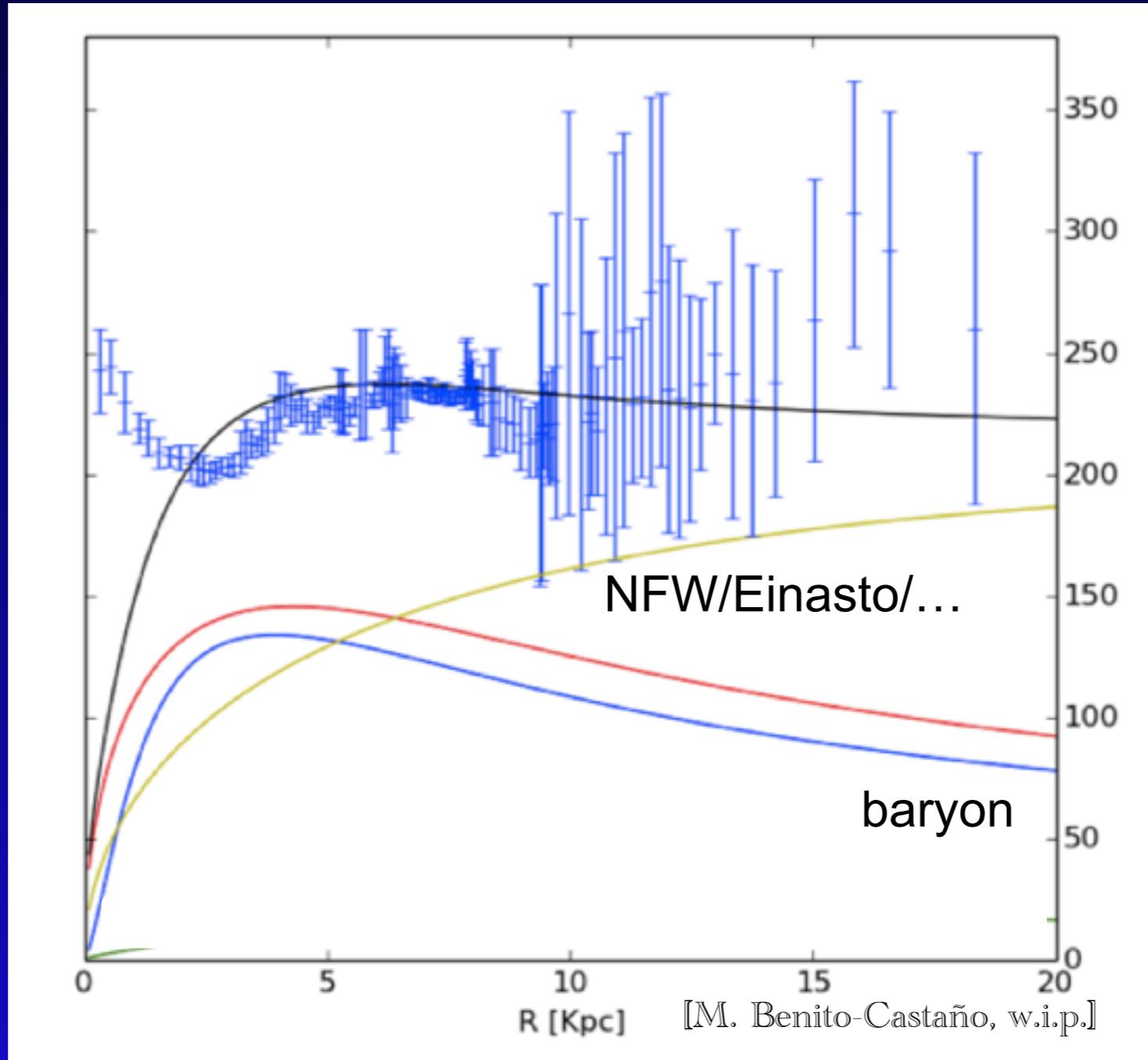
# Determining the relevant astrophysical quantities

## Local DM density

Determinations of local DM density are consistent, but noisy



# Global kinematic methods: fitting halo shapes

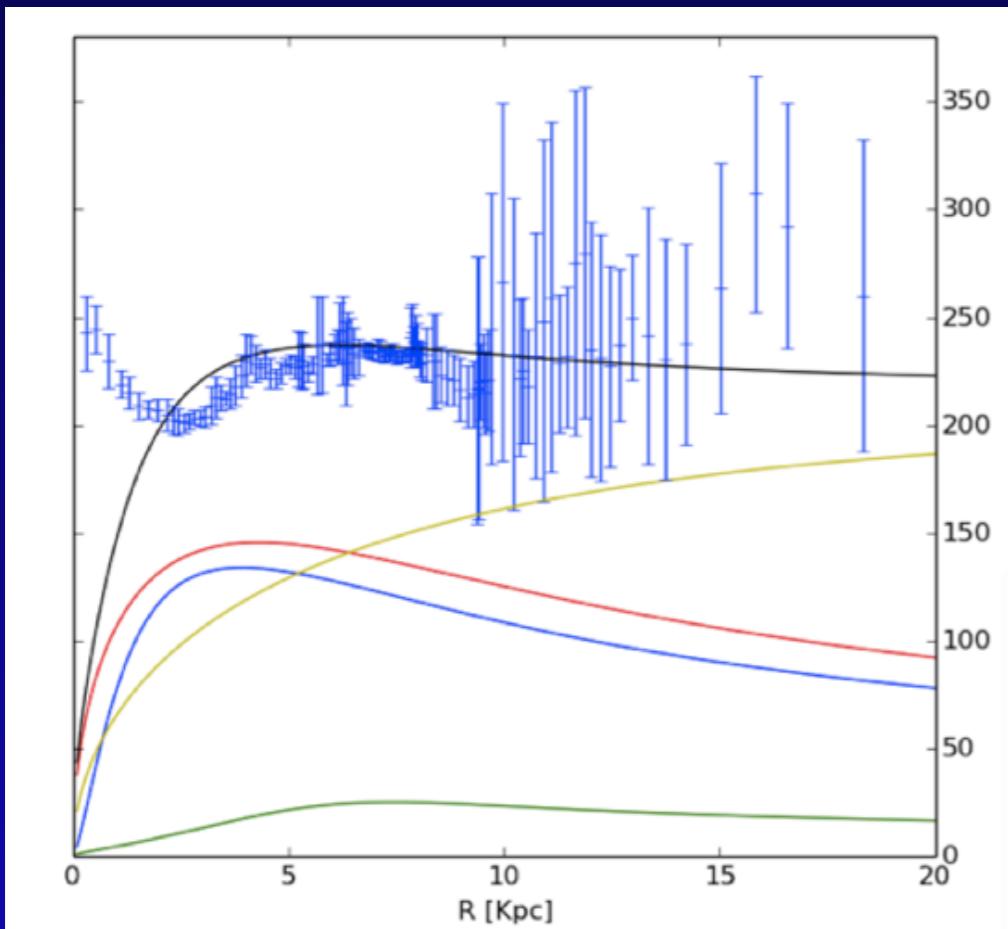


Fitting a DM profile on top of baryons:  $\rho_{\text{DM}} = \rho_0 R^\alpha$

# The Milky Way

## inferring the relevant astrophysical quantities

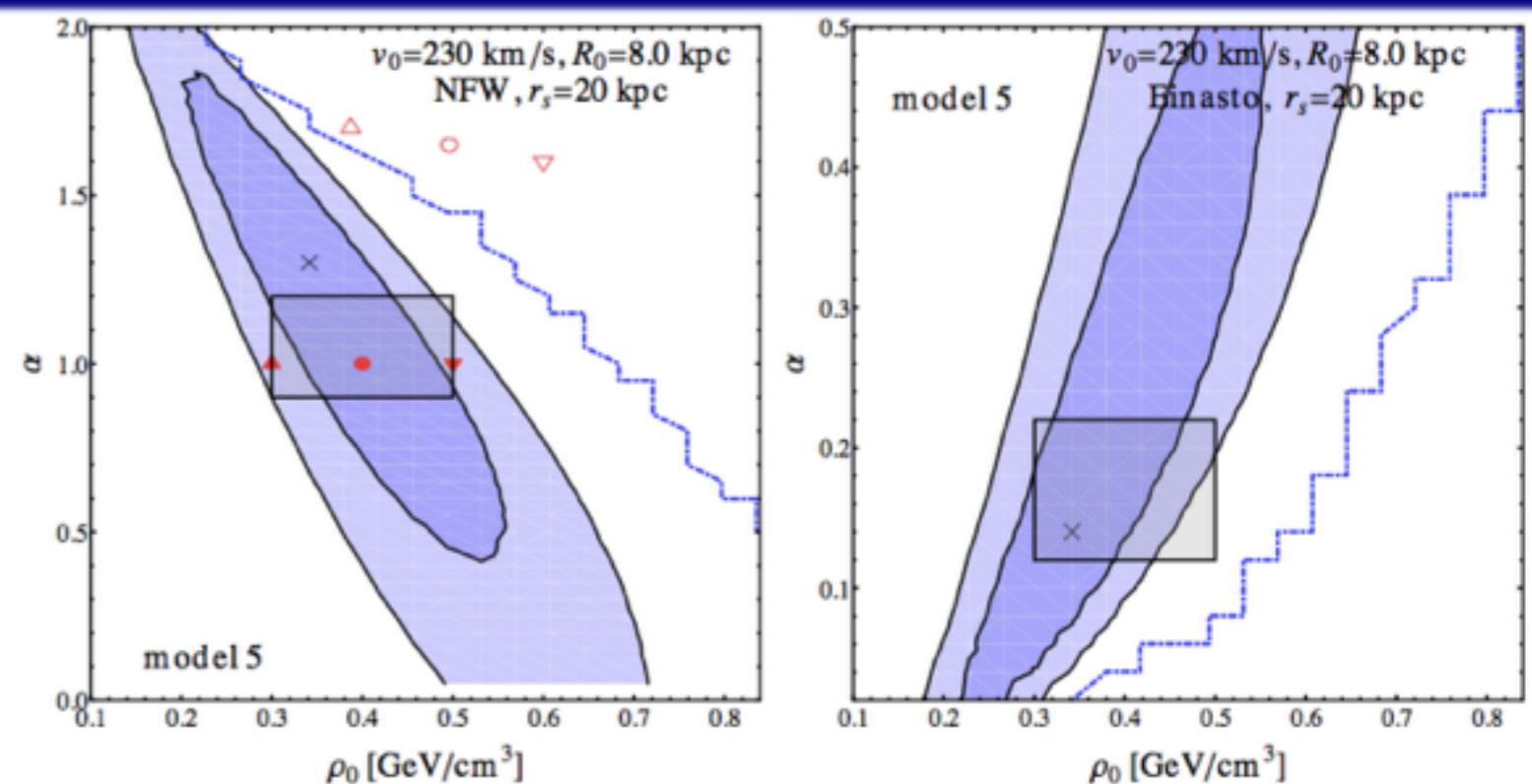
Fitting a pre-assigned shape  
on top of baryons



Most popular are  
gNFW      Einasto

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

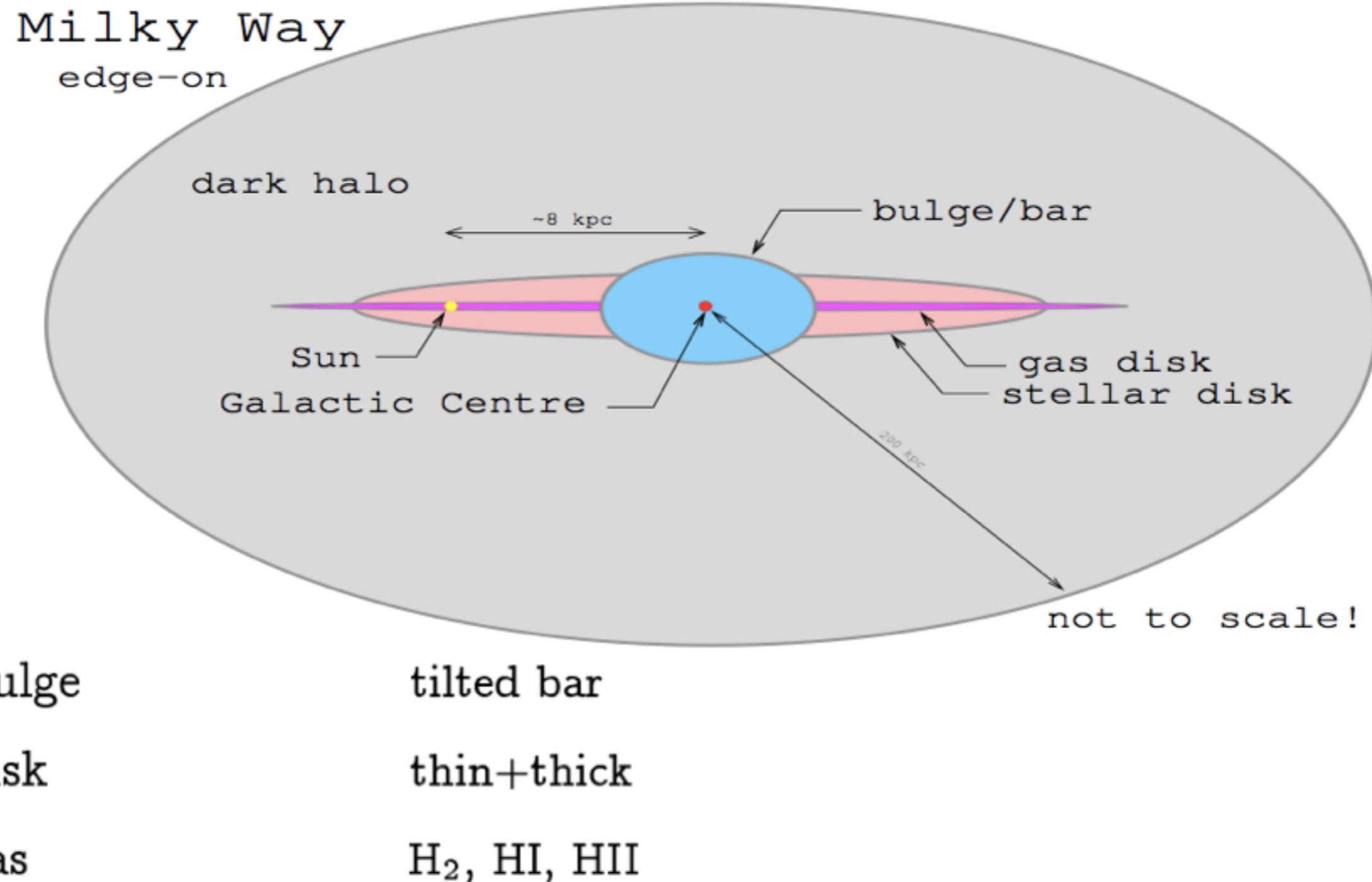
$$\rho_{DM}(R) \propto \rho_0 \exp \left[ -\frac{2}{\gamma} \left( \left( \frac{R}{R_s} \right)^\gamma - 1 \right) \right]$$



# The Milky Way:

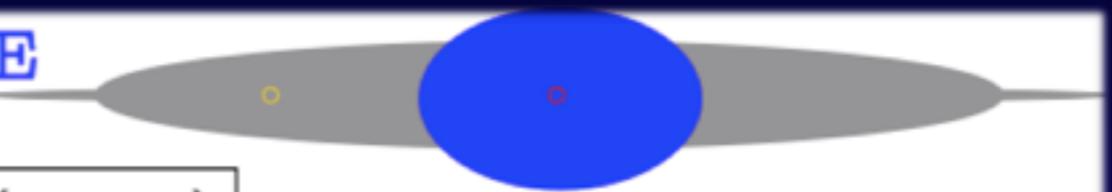
## expected rotation curve

### 1. the baryonic components



# The luminous Milky Way: observations of morphology

## 2. BARYONS: STELLAR BULGE



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

morphology  $f(x, y, z)$

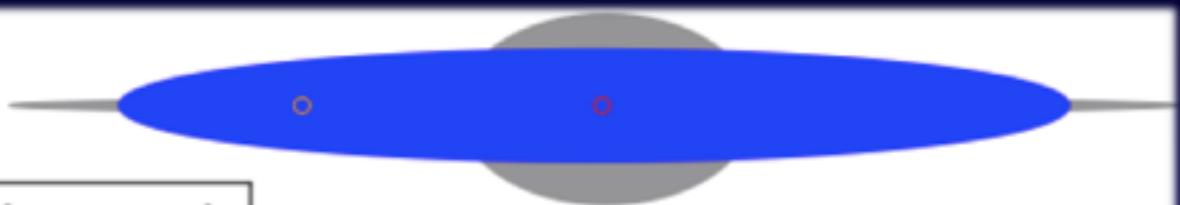
Stanek+ '97 (E2)	$e^{-r}$	0.9:0.4:0.3	24°	optical
Stanek+ '97 (G2)	$e^{-r_s^2/2}$	1.2:0.6:0.4	25°	optical
Zhao '96	$e^{-r_s^2/2} + r_a^{-1.85} e^{-r_a}$	1.5:0.6:0.4	20°	infrared
Bissantz & Gerhard '02	$e^{-r_s^2}/(1+r)^{1.8}$	2.8:0.9:1.1	20°	infrared
Lopez-Corredoira+ '07	Ferrer potential	7.8:1.2:0.2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

normalisation  $\rho_0$

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

# The luminous Milky Way: observations of morphology

## 2. BARYONS: STELLAR DISK



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

morphology  $f(x, y, z)$

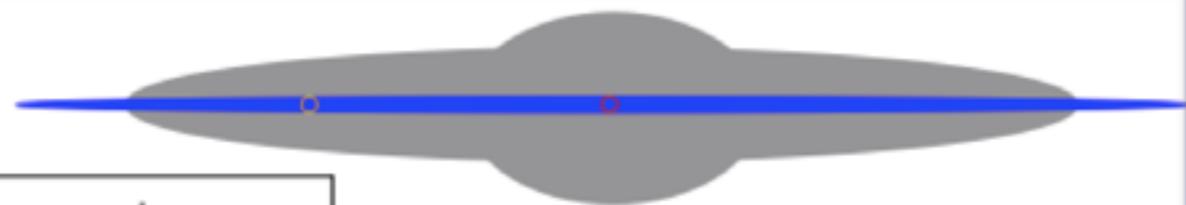
Han & Gould '03	$e^{-R} \operatorname{sech}^2(z)$ $e^{-R- z }$	2.8:0.27 2.8:0.44	thin thick	optical
Calchi-Novati & Mancini '11	$e^{-R- z }$ $e^{-R- z }$	2.8:0.25 4.1:0.75	thin thick	optical
deJong+ '10	$e^{-R- z }$ $e^{-R- z }$ $(R^2 + z^2)^{-2.75/2}$	2.8:0.25 4.1:0.75 1.0:0.88	thin thick halo	optical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

normalisation  $\rho_0$

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

# The luminous Milky Way: observations of morphology

## 2. BARYONS: GAS



$$n_{\text{H}} = 2n_{\text{H}_2} + n_{\text{HI}} + n_{\text{HII}}$$

### morphology

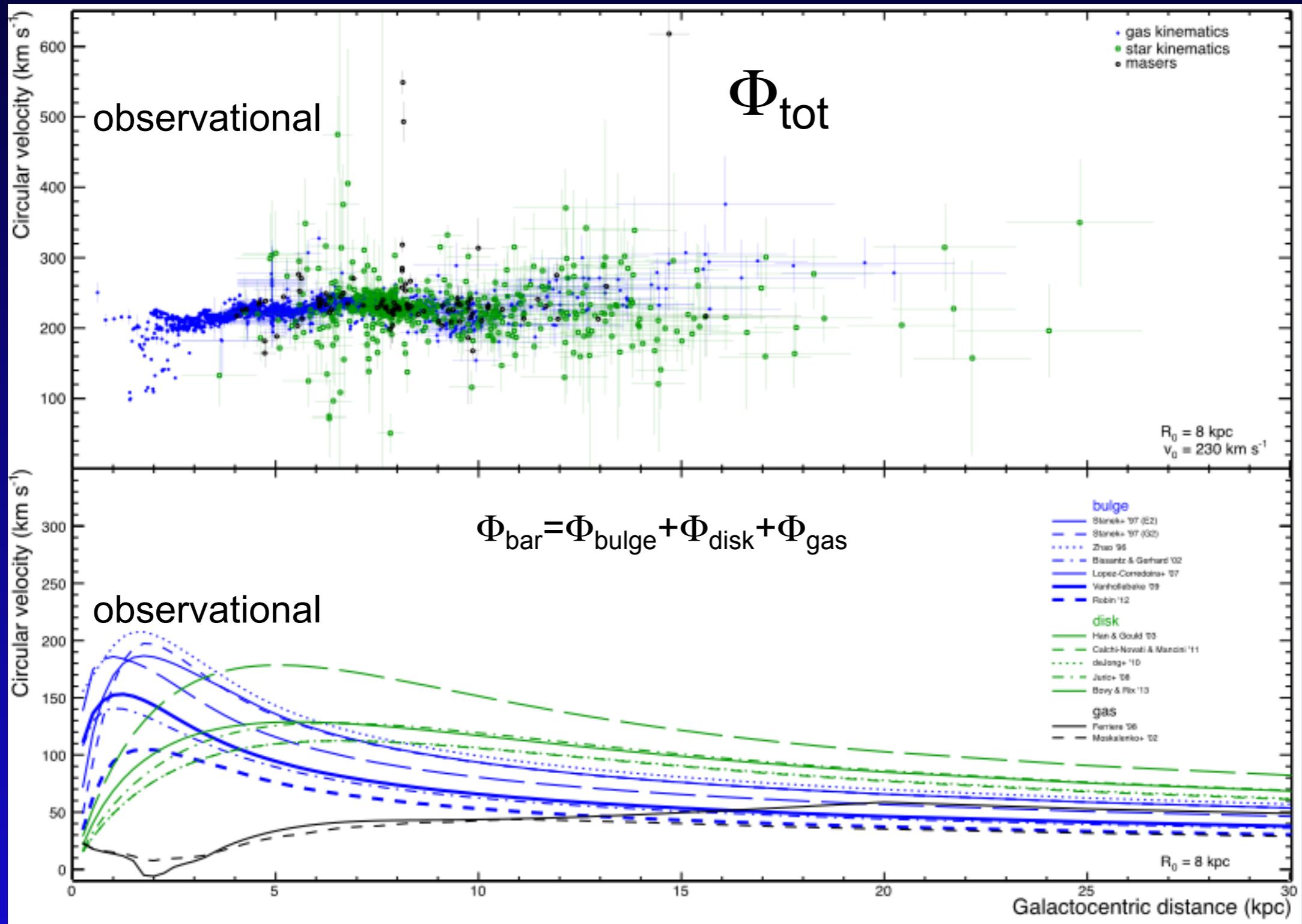
Ferrière '12	$r < 0.01 \text{ kpc}$	$M_{\text{gas}} \sim 7 \times 10^5 \text{ M}_{\odot}$		CO, 21cm, H $\alpha$ , ...
Ferrière+ '07	$r = 0.01 - 2 \text{ kpc}$	CMZ, holed disk CMZ, holed disk warm, hot, very hot	H <sub>2</sub> H I H II	CO 21cm disp. meas.
Ferrière '98	$r = 3 - 20 \text{ kpc}$	molecular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

### uncertainties

CO-to-H<sub>2</sub> factor:  $X_{\text{CO}} = 0.25 - 1.0 \times 10^{20} \text{ cm}^{-2} \text{ K}^{-1} \text{ km}^{-1} \text{ s}$  for  $r < 2 \text{ kpc}$   
 $X_{\text{CO}} = 0.50 - 3.0 \times 10^{20} \text{ cm}^{-2} \text{ K}^{-1} \text{ km}^{-1} \text{ s}$  for  $r > 2 \text{ kpc}$

[Ferrière+ '07, Ackermann '12]

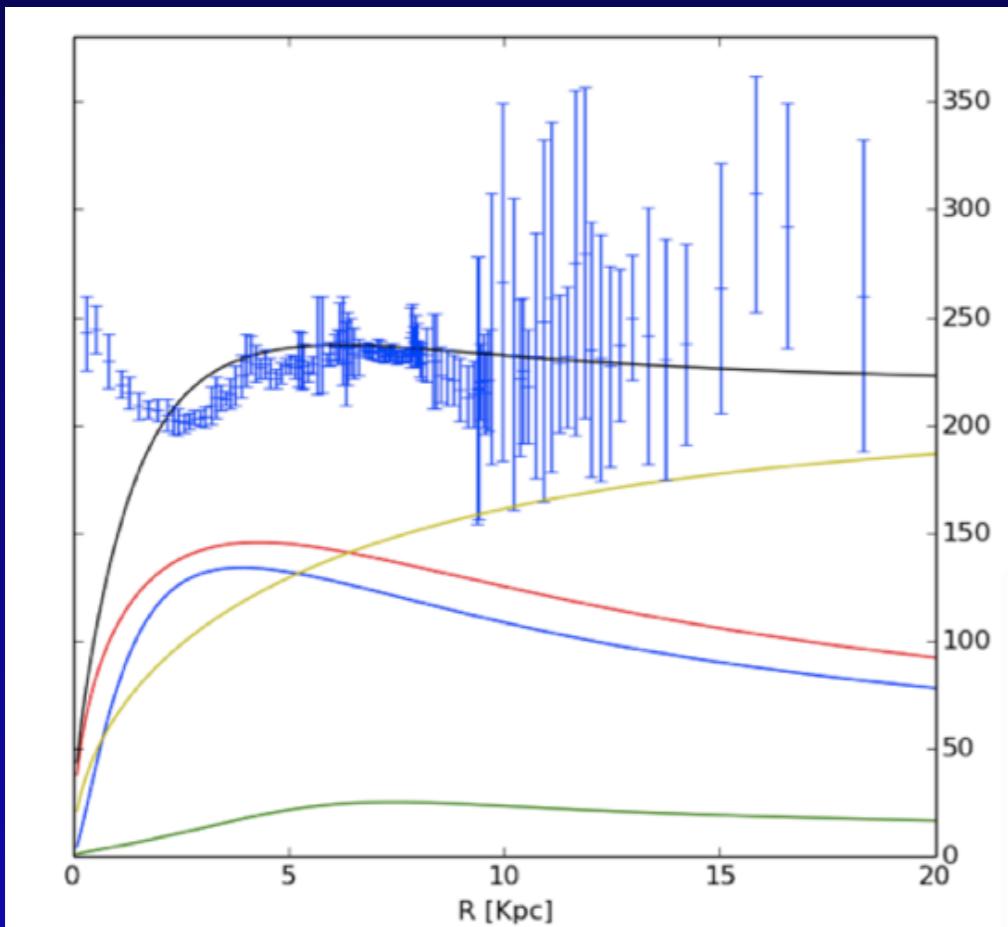
# The Milky Way: testing expectations



# The Milky Way

## inferring the relevant astrophysical quantities

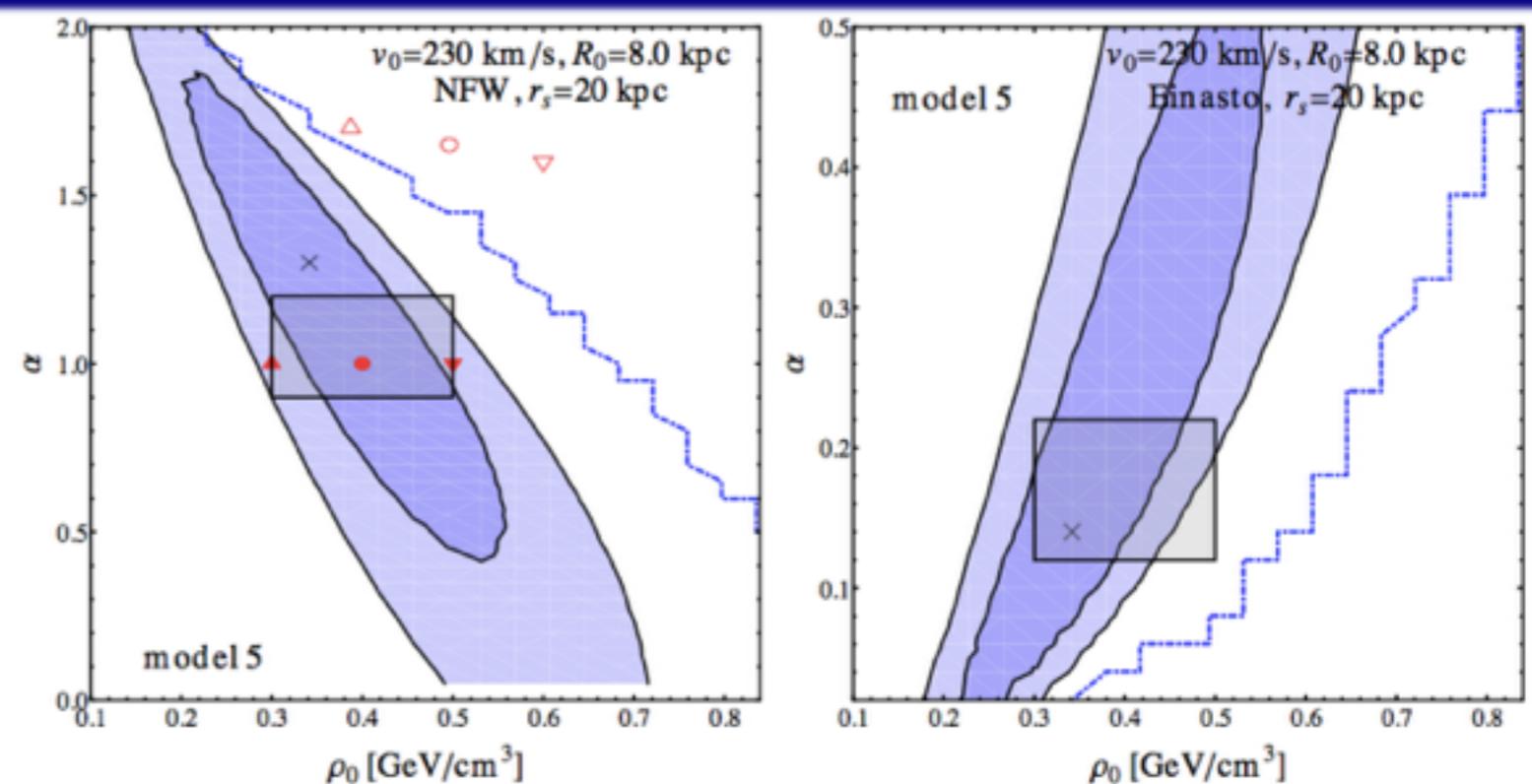
Fitting a pre-assigned shape  
on top of baryons



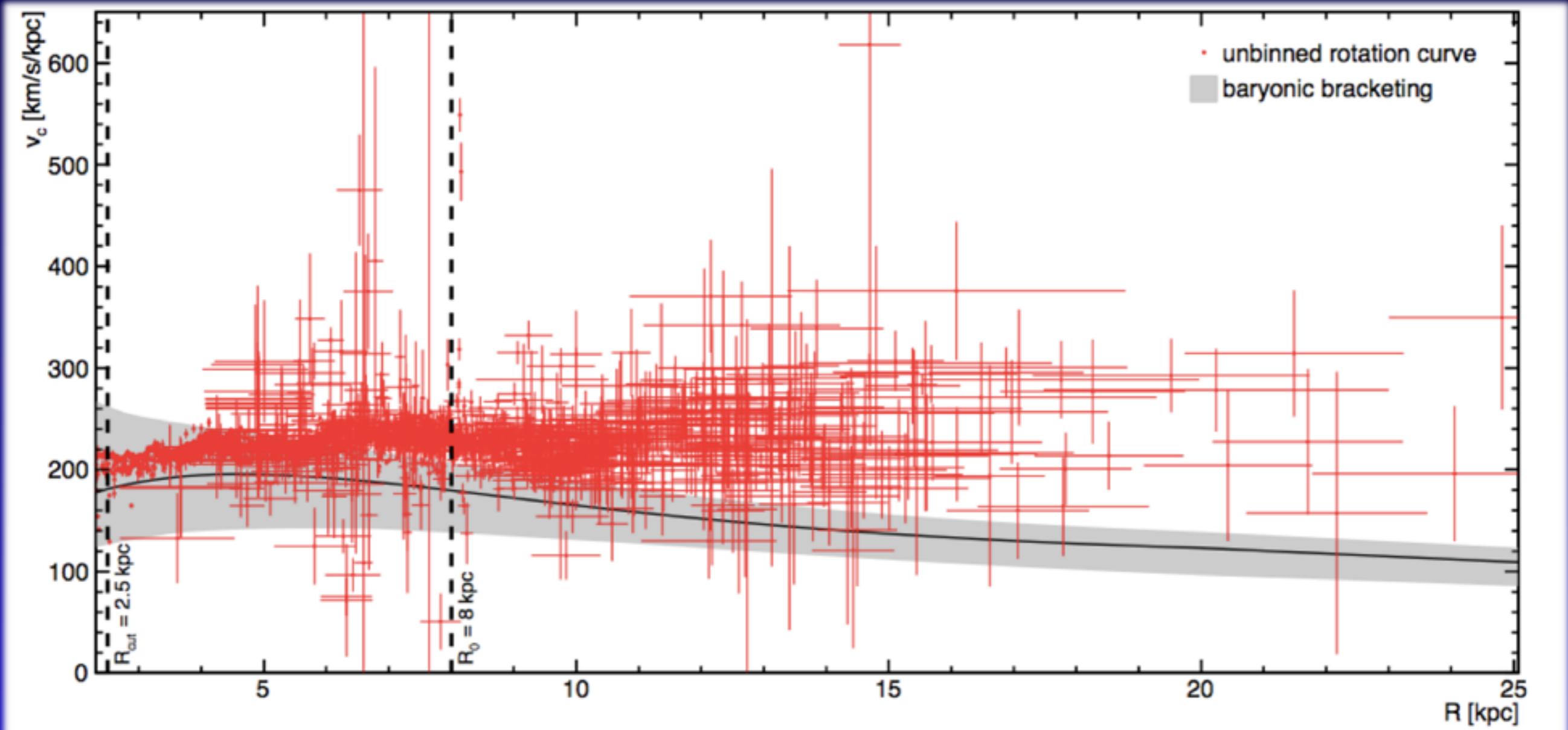
Most popular are  
gNFW      Einasto

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

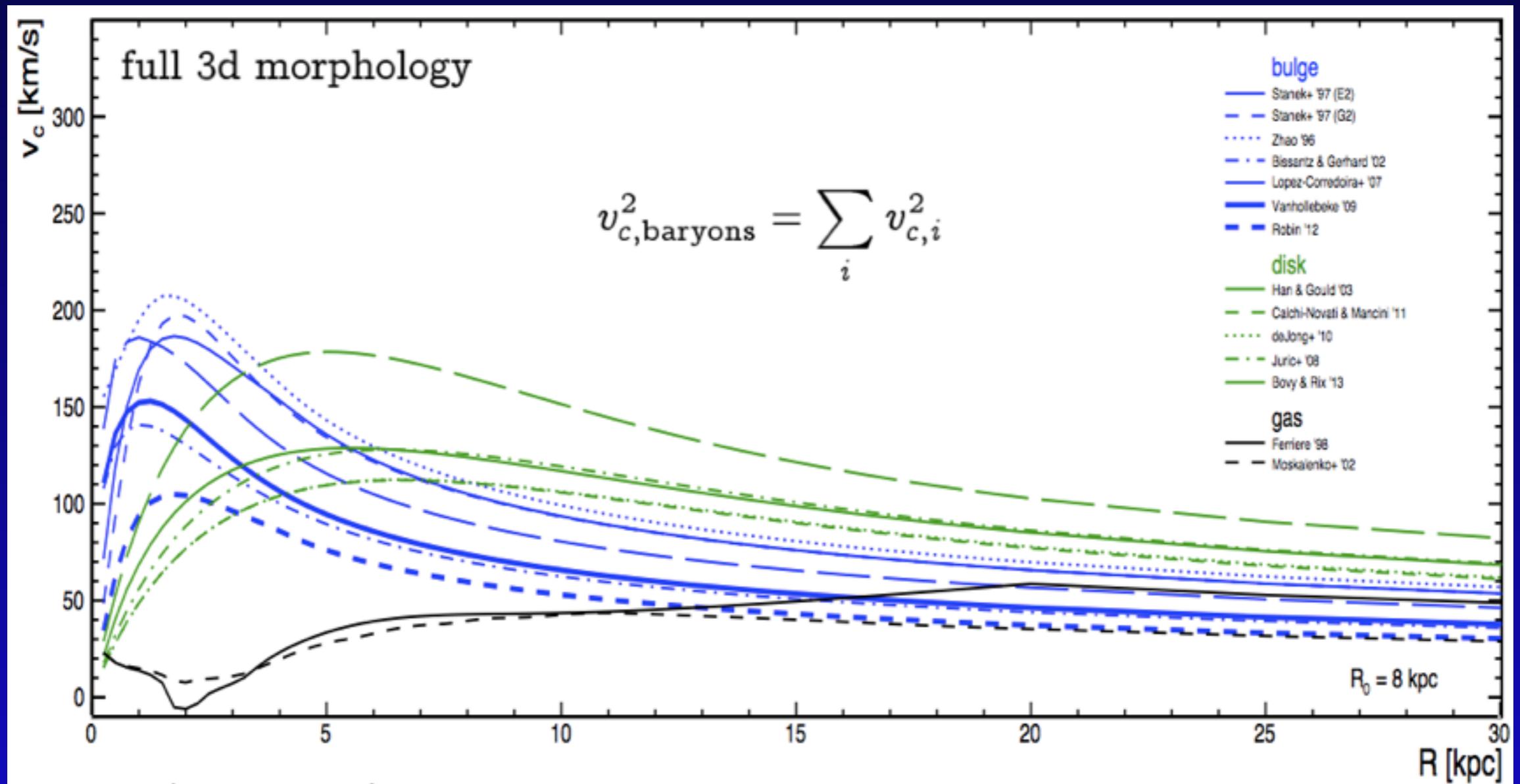
$$\rho_{DM}(R) \propto \rho_0 \exp \left[ -\frac{2}{\gamma} \left( \left( \frac{R}{R_s} \right)^\gamma - 1 \right) \right]$$



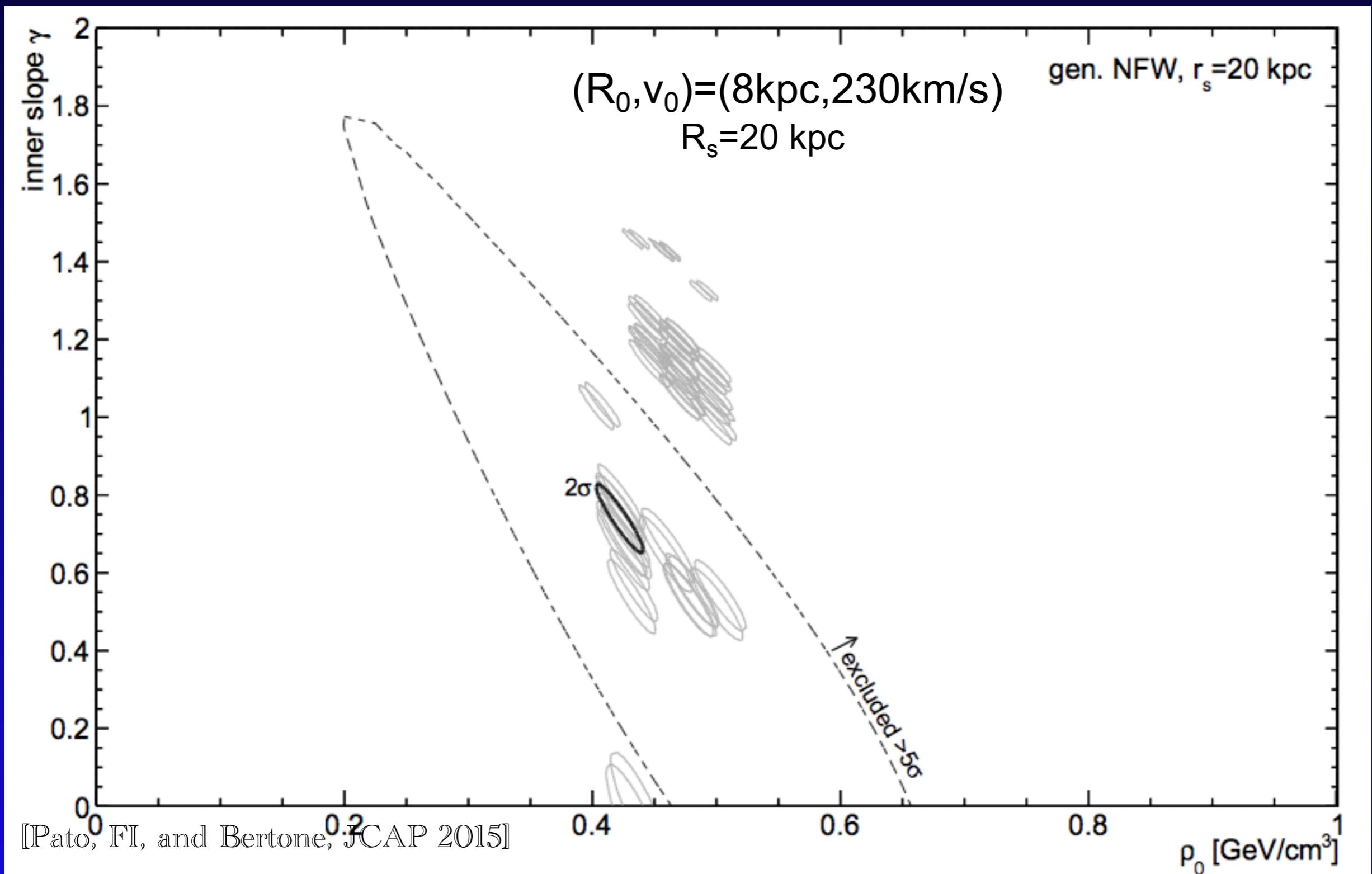
# The Milky Way: a spiral Galaxy (and its Rotation Curve)



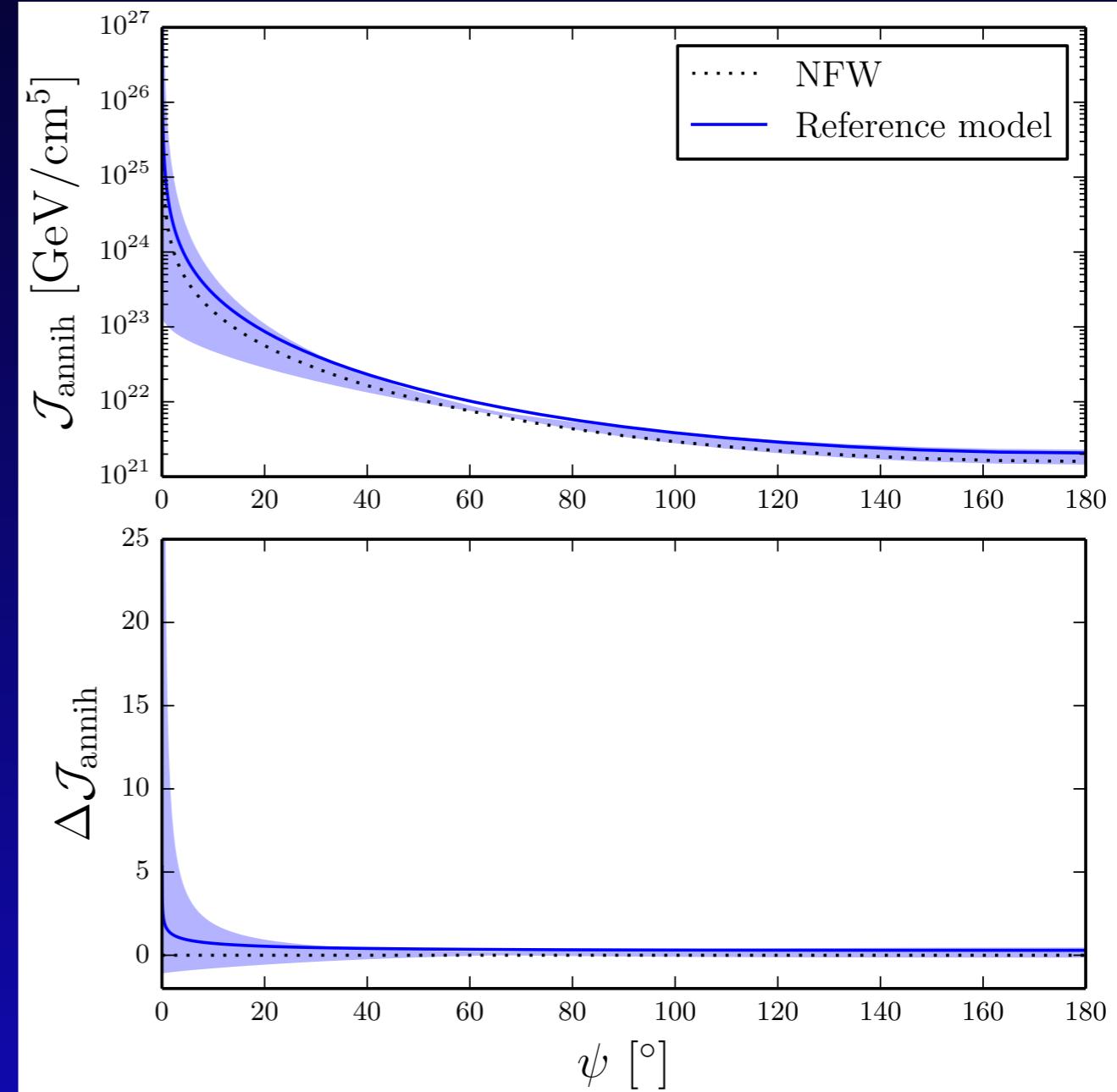
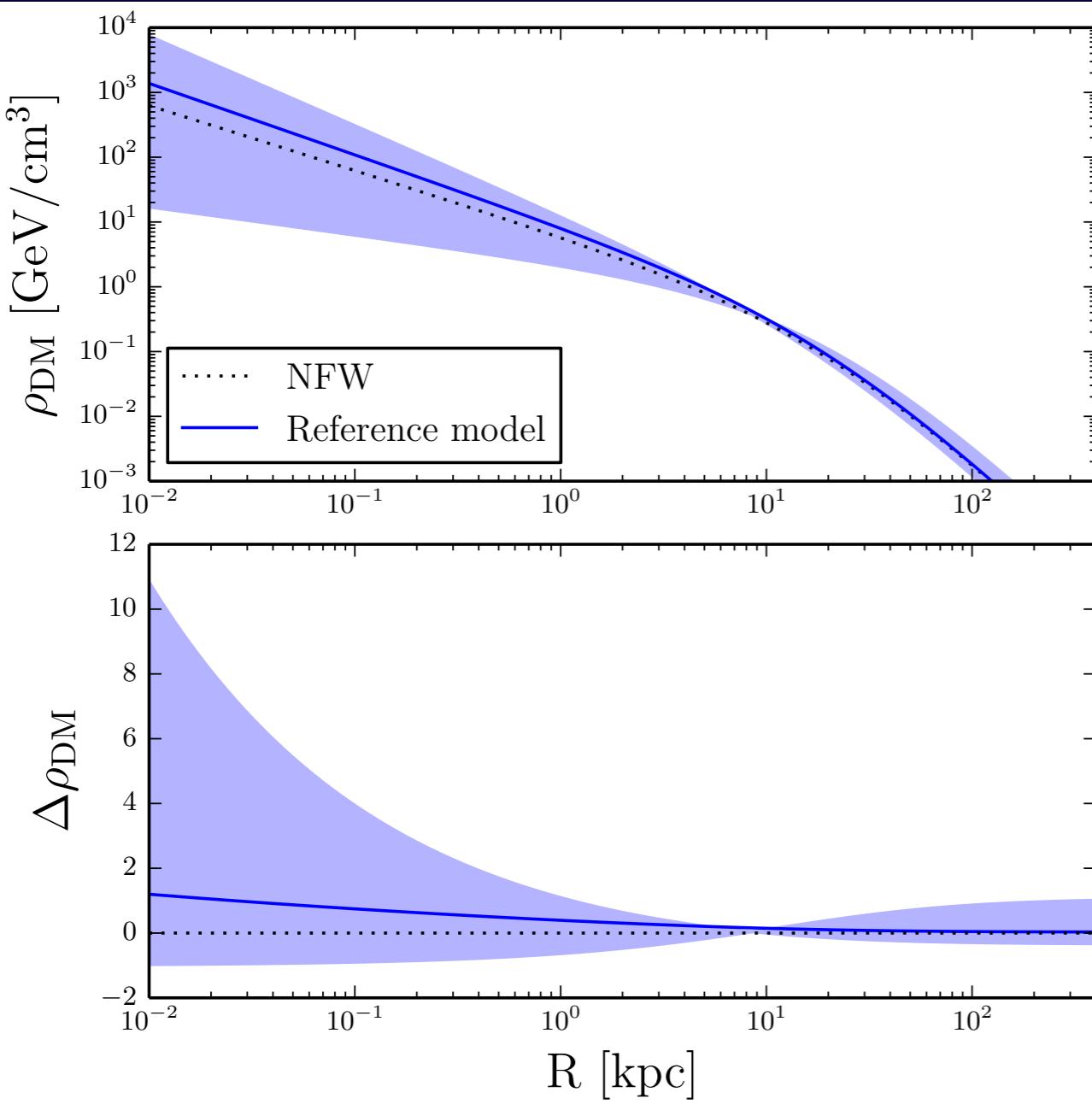
There's more than you are usually told:  
 visible morphology is uncertain  
 (and don't forget the dependence on Gal Parameters)



# The Milky Way: the importance of baryon modelling

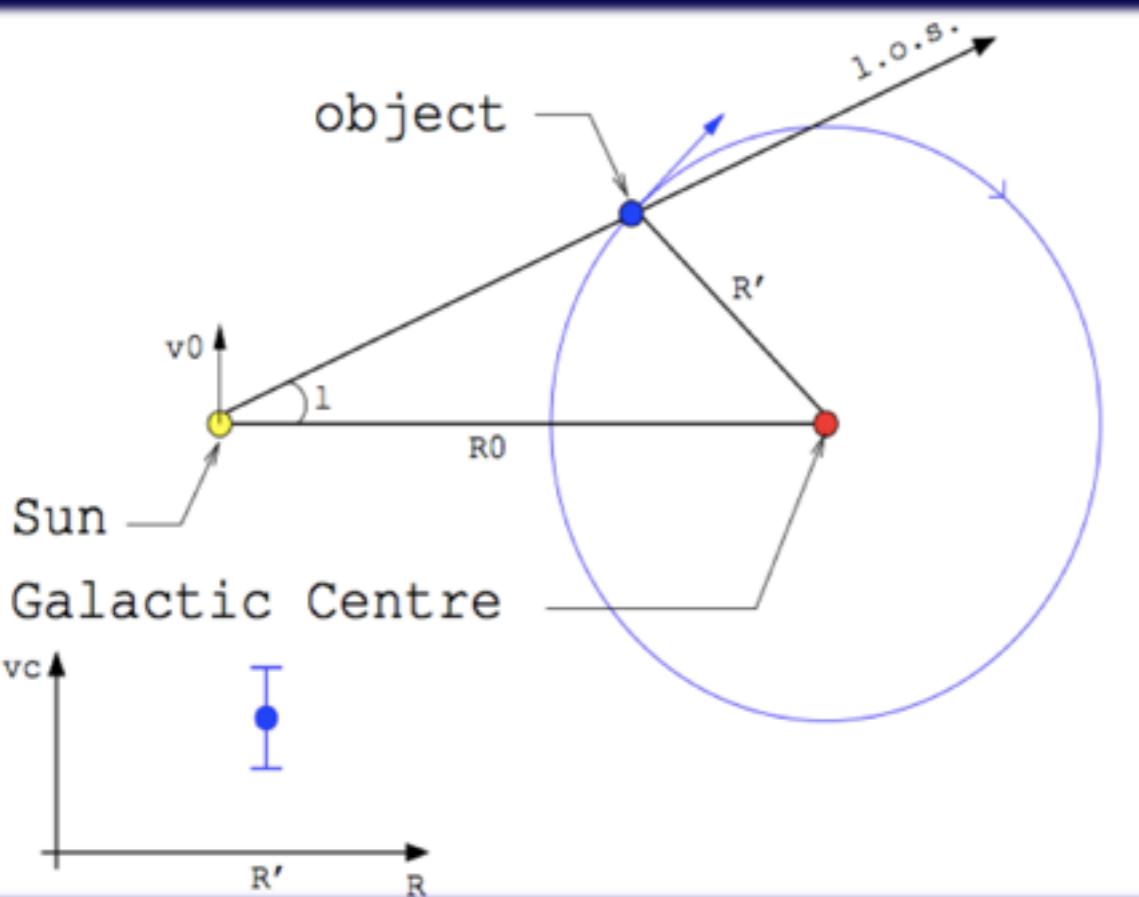


# But do Galactic uncertainties affect PP, for real?

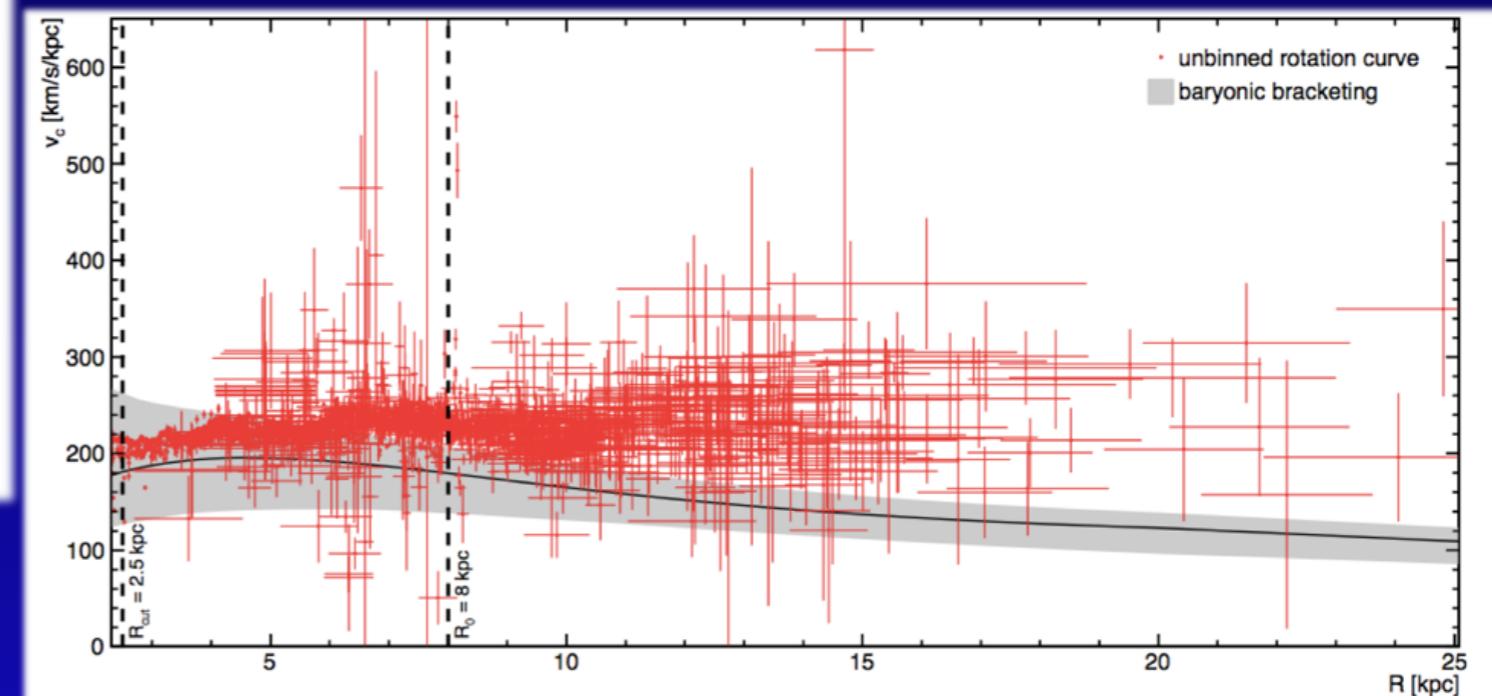


$$J_{\text{annih}} \propto \int_{\text{los}} \rho^2(r) dV$$

# The Milky Way: observed rotation curve (and some intrinsic uncertainty)

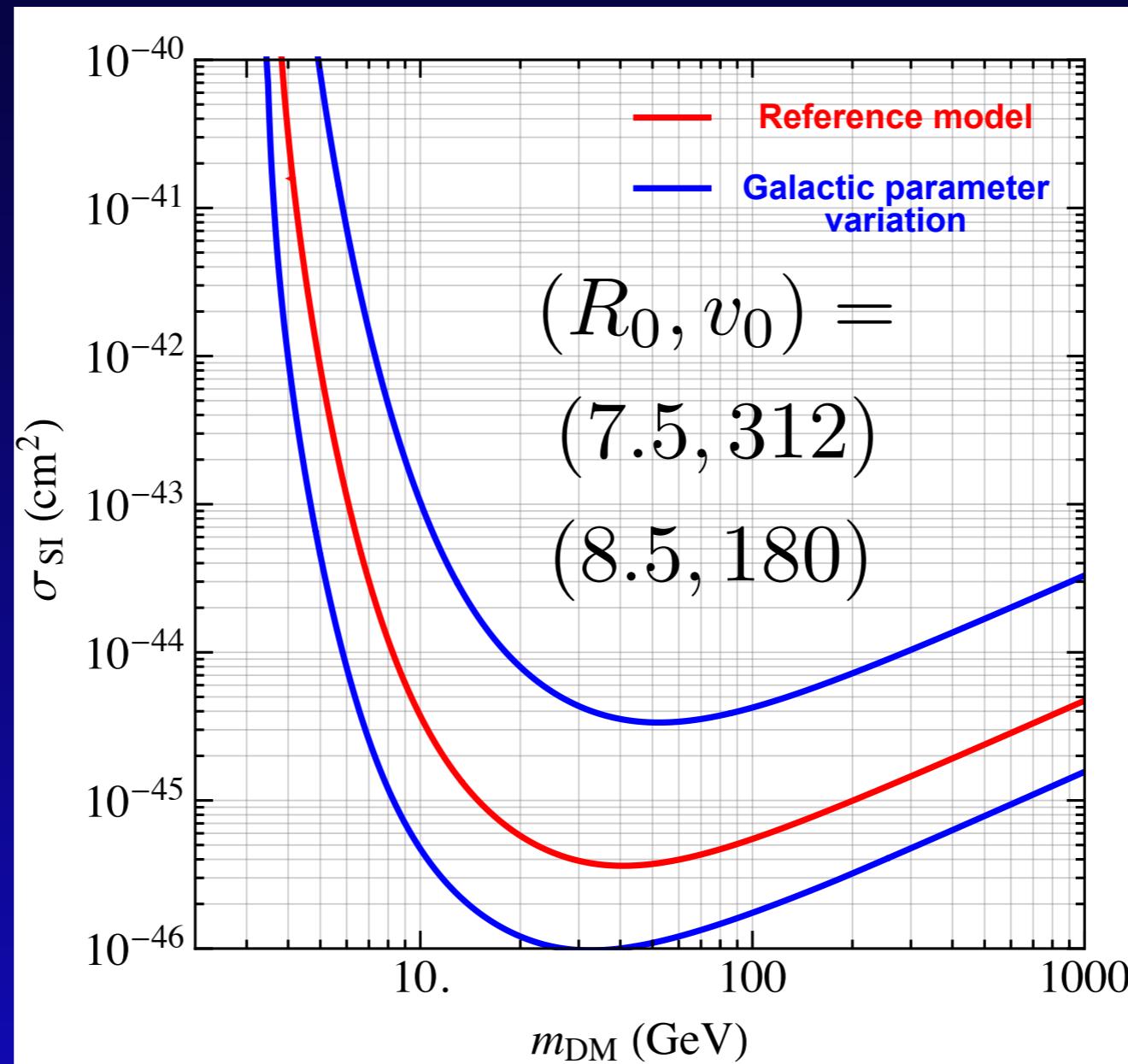


$$v_{\text{L.S.R.}}^{\text{l.o.s.}} = \left( \frac{v_c(R')}{R'/R_0} - v_0 \right) \cos b \sin \ell$$



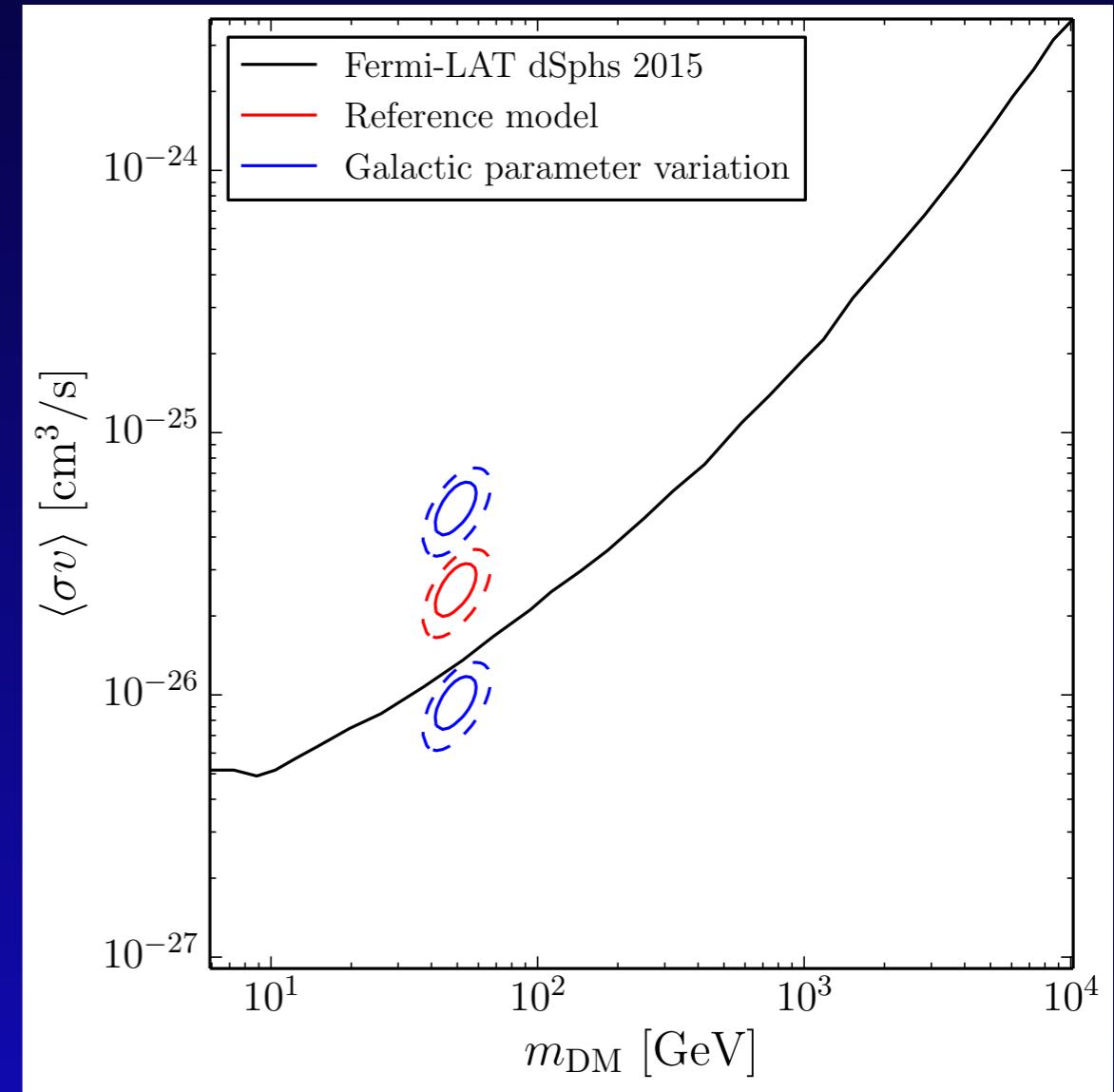
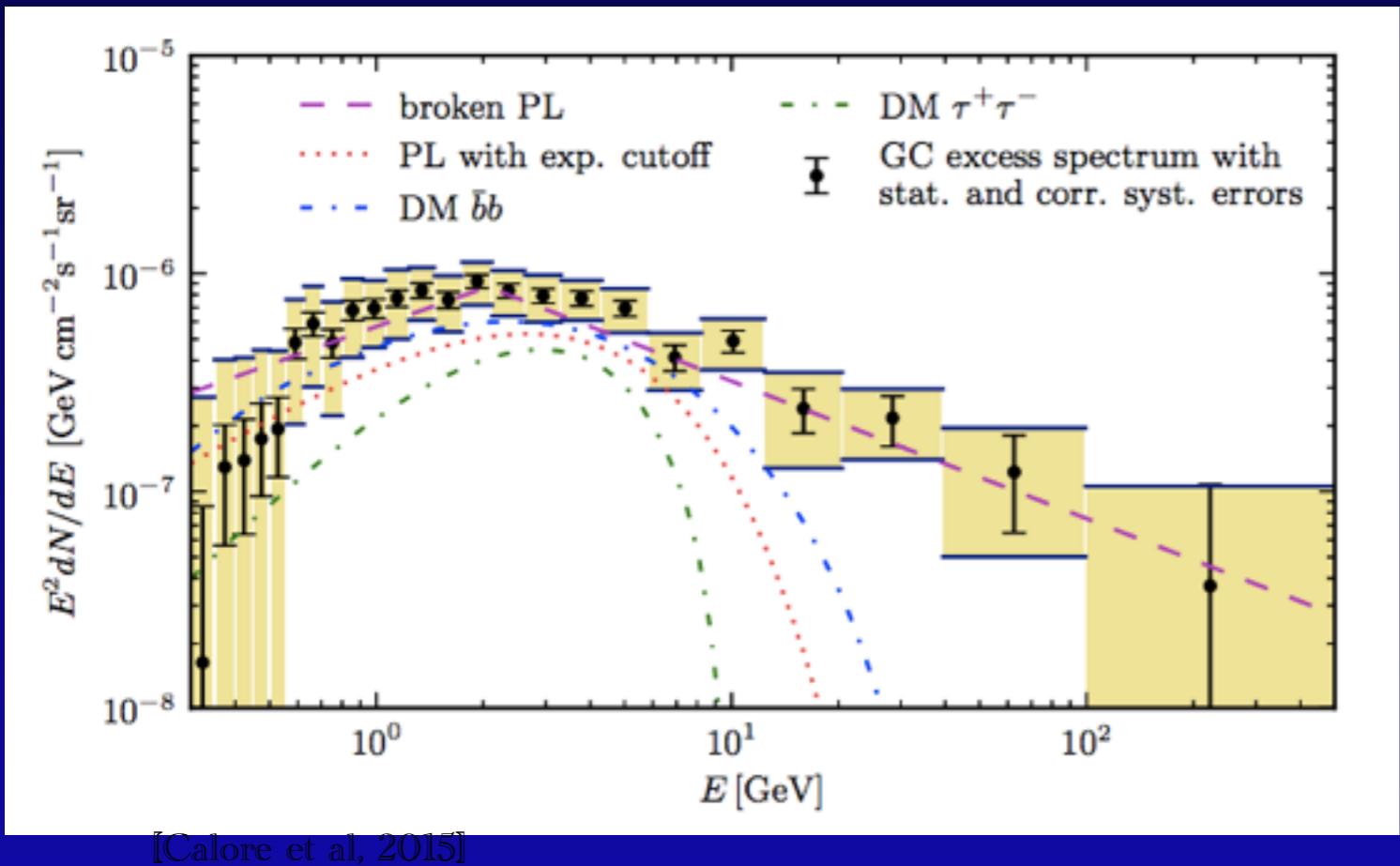
observing tracers from our own position,  
transforming into GC-centric reference frame

It is well known that uncertainties affect Direct Detection



Current LUX limits, varying astrophysical uncertainties

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



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

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

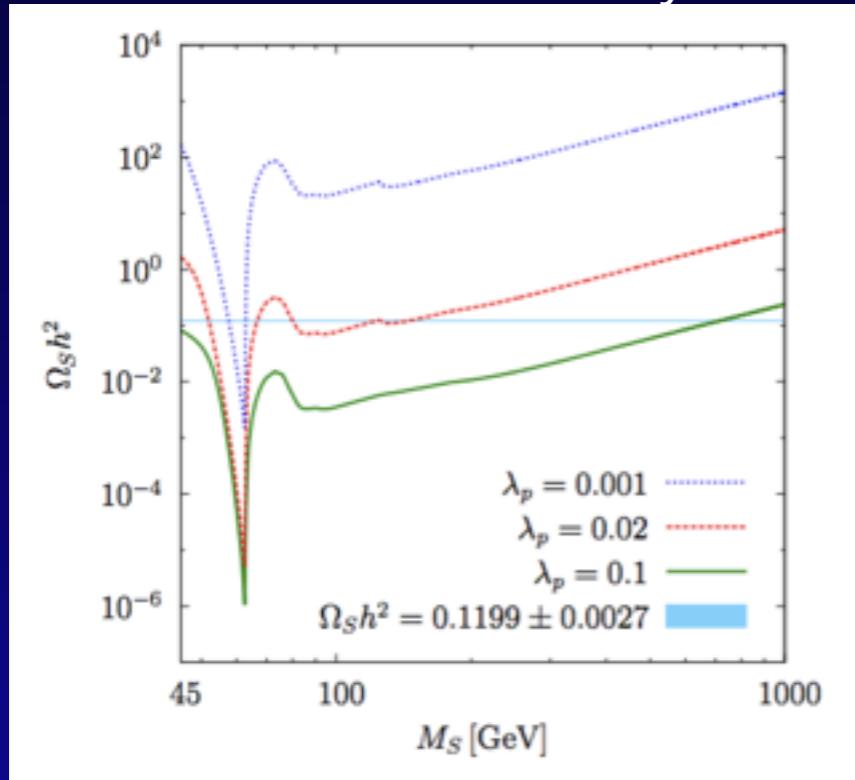
$$v_H = 246 \text{ GeV} \quad \langle S \rangle = 0$$

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

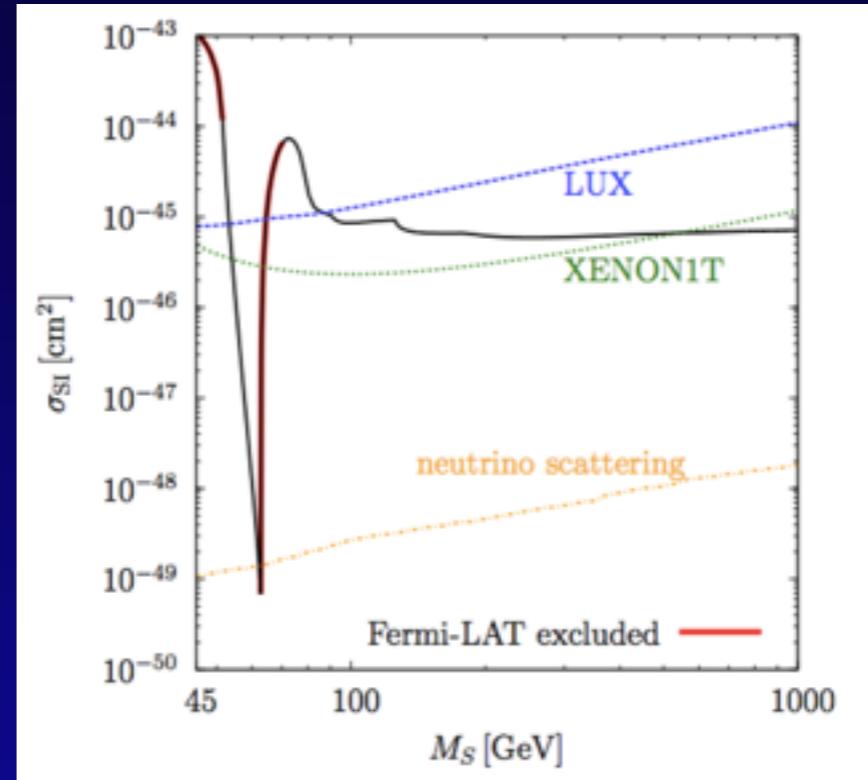
“Wimp phenomenology” entirely dictated by the  
Higgs coupling and physical DM mass.

# Constraints and interplay of experiments

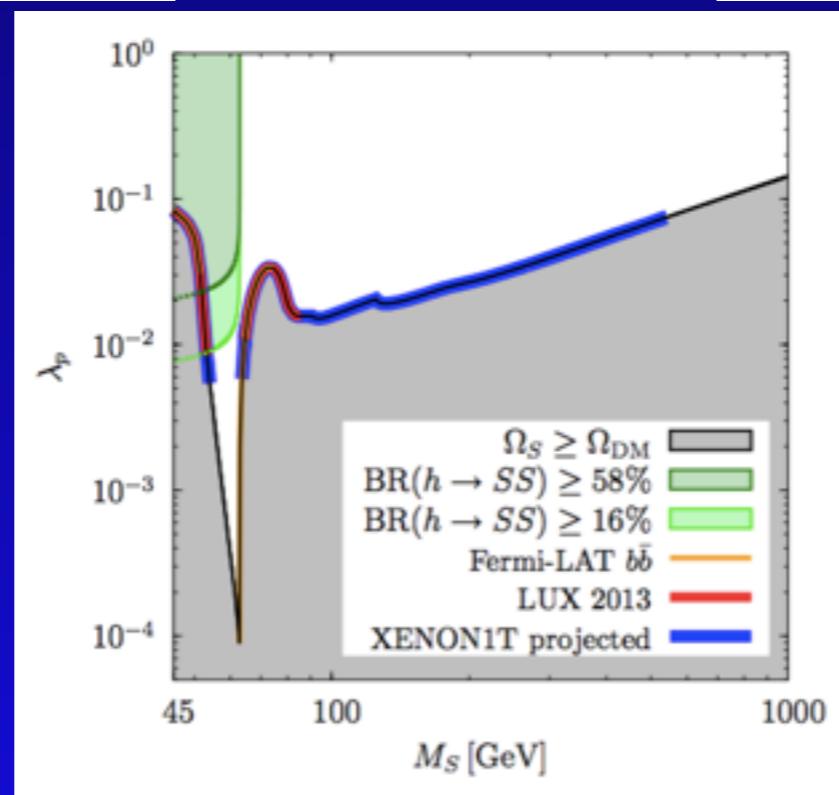
## Relic density



## Direct detection



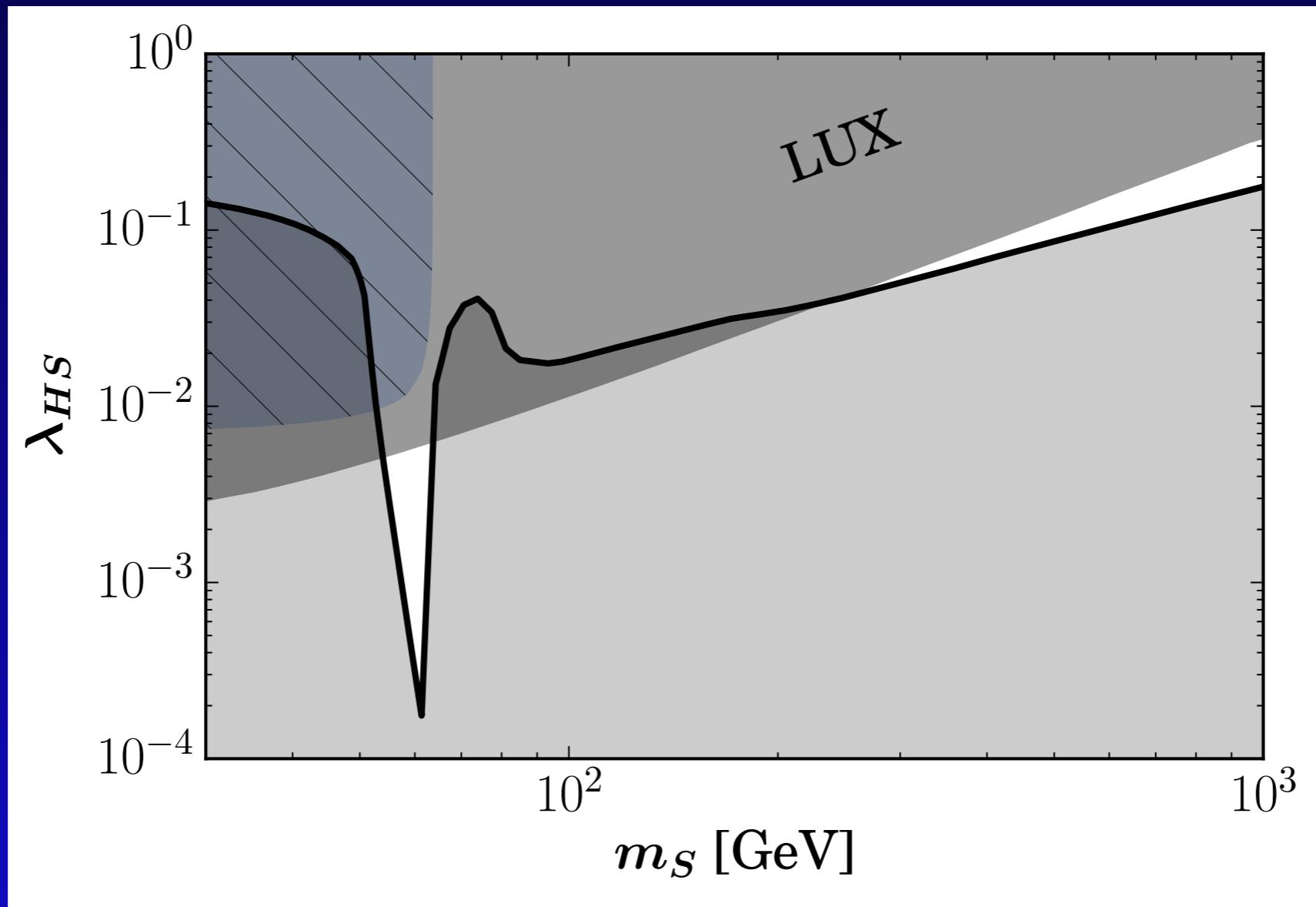
## Combined



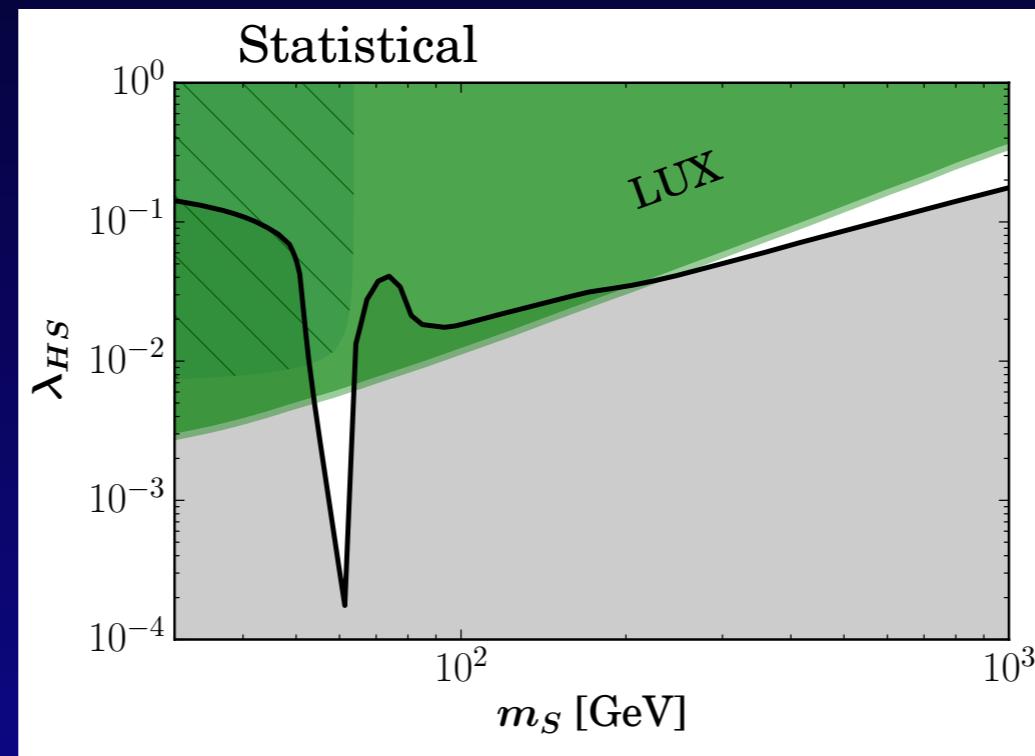
[Duerr et al, 2015]

# Constraints and interplay of experiments

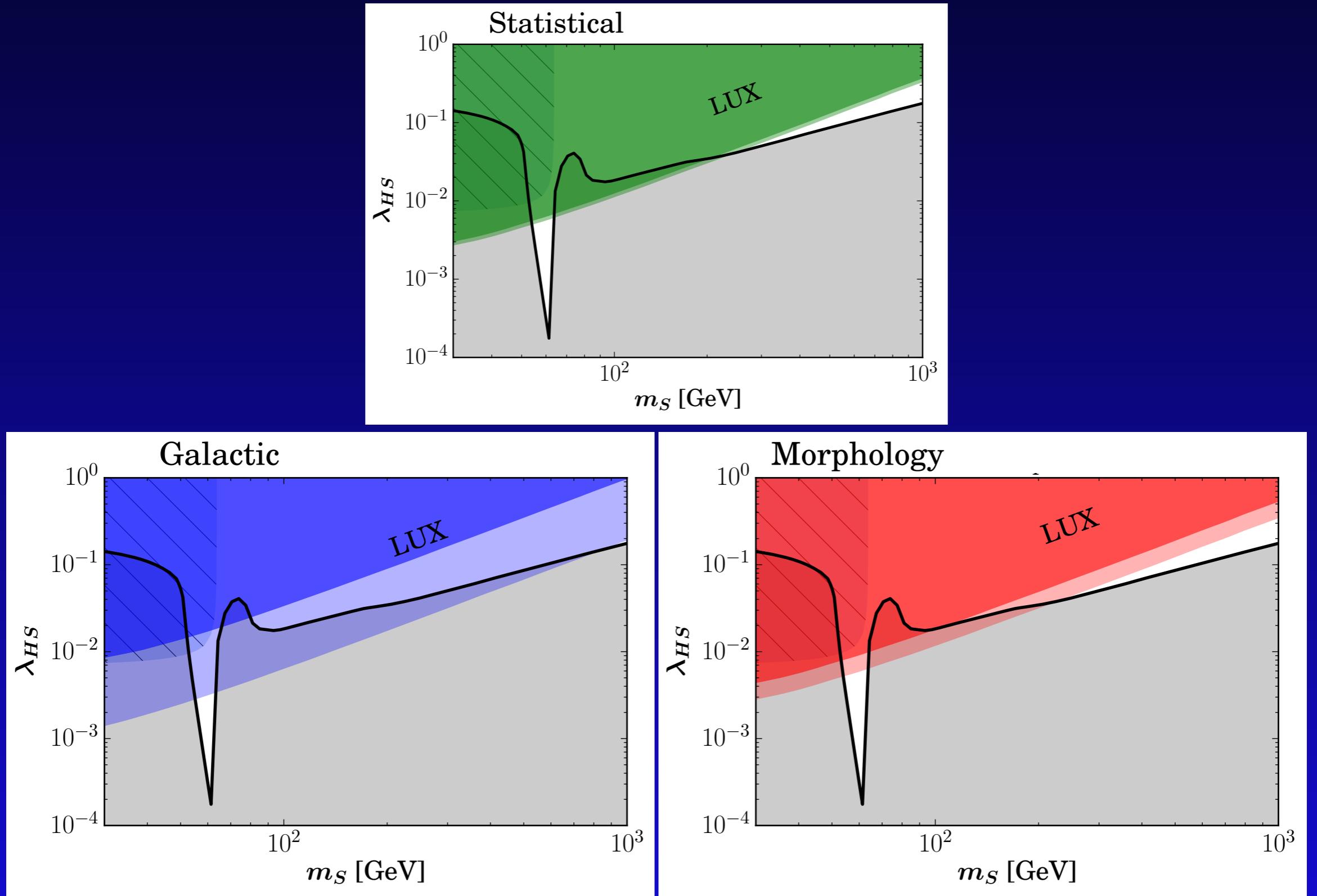
$$V = \mu_H^2 |H|^2 + \lambda_H |H|^4 + \mu_S^2 S^2 + \lambda_S S^4 + \lambda_{HS} |H|^2 S^2$$



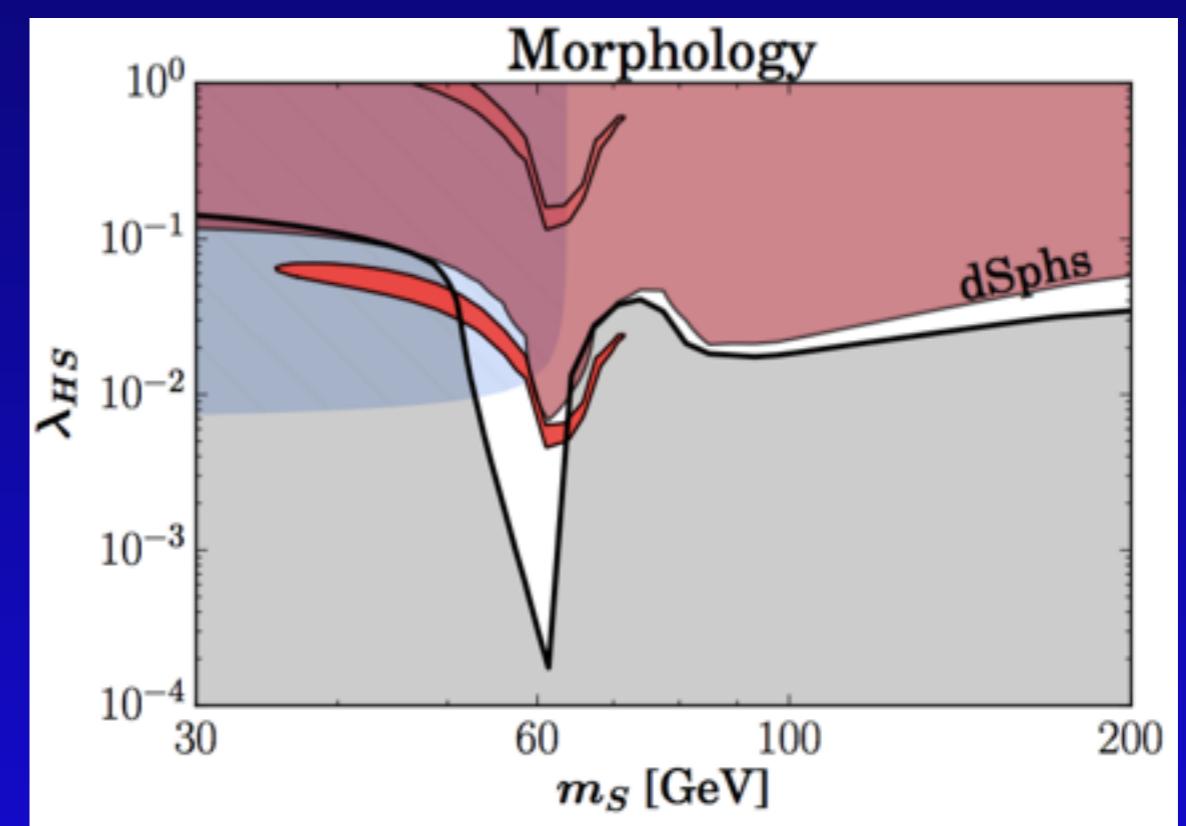
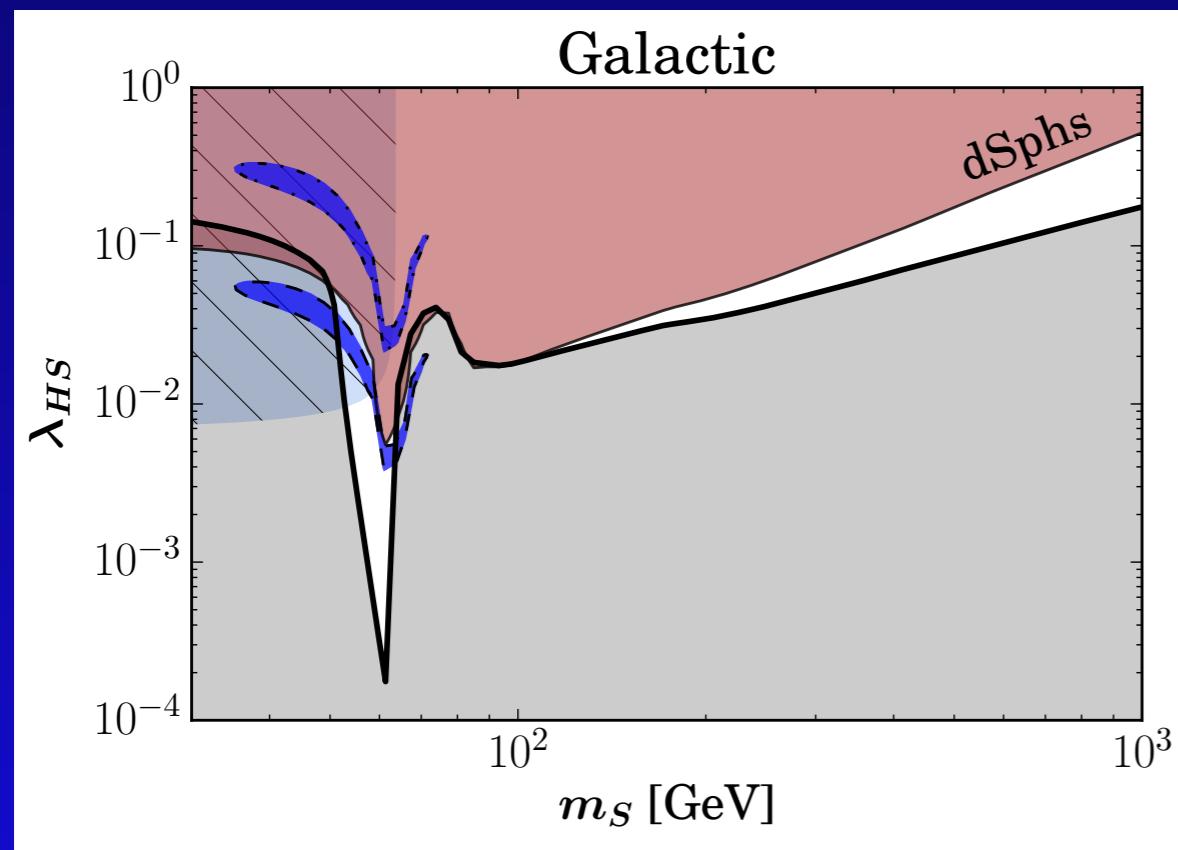
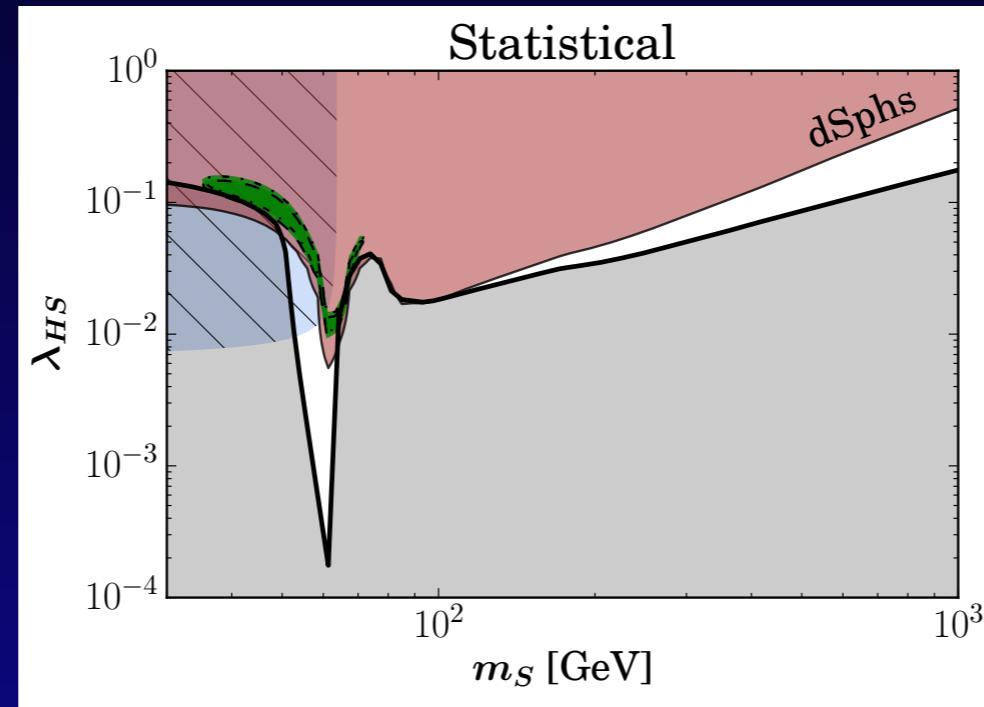
# Let's look at the effect of astrophysics uncertainties: Direct



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



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



# *Cuncta stricte*

- We have a good idea of what DM distribution in the MW is: actual data & some good guidance from simulations (cum grano salis, please)
- Yet, intrinsic (still unavoidable) uncertainties exist and become relevant in the precision scenario we face today (thankfully).
- Astrophysical uncertainties actually hinder determination of PP scenarios.
- This is ,thankfully, because of increased sensitivity of a host of probes (not only colliders) on the core region of one of the most popular scenarios.
- For as positive as this may be, we must cope with it.

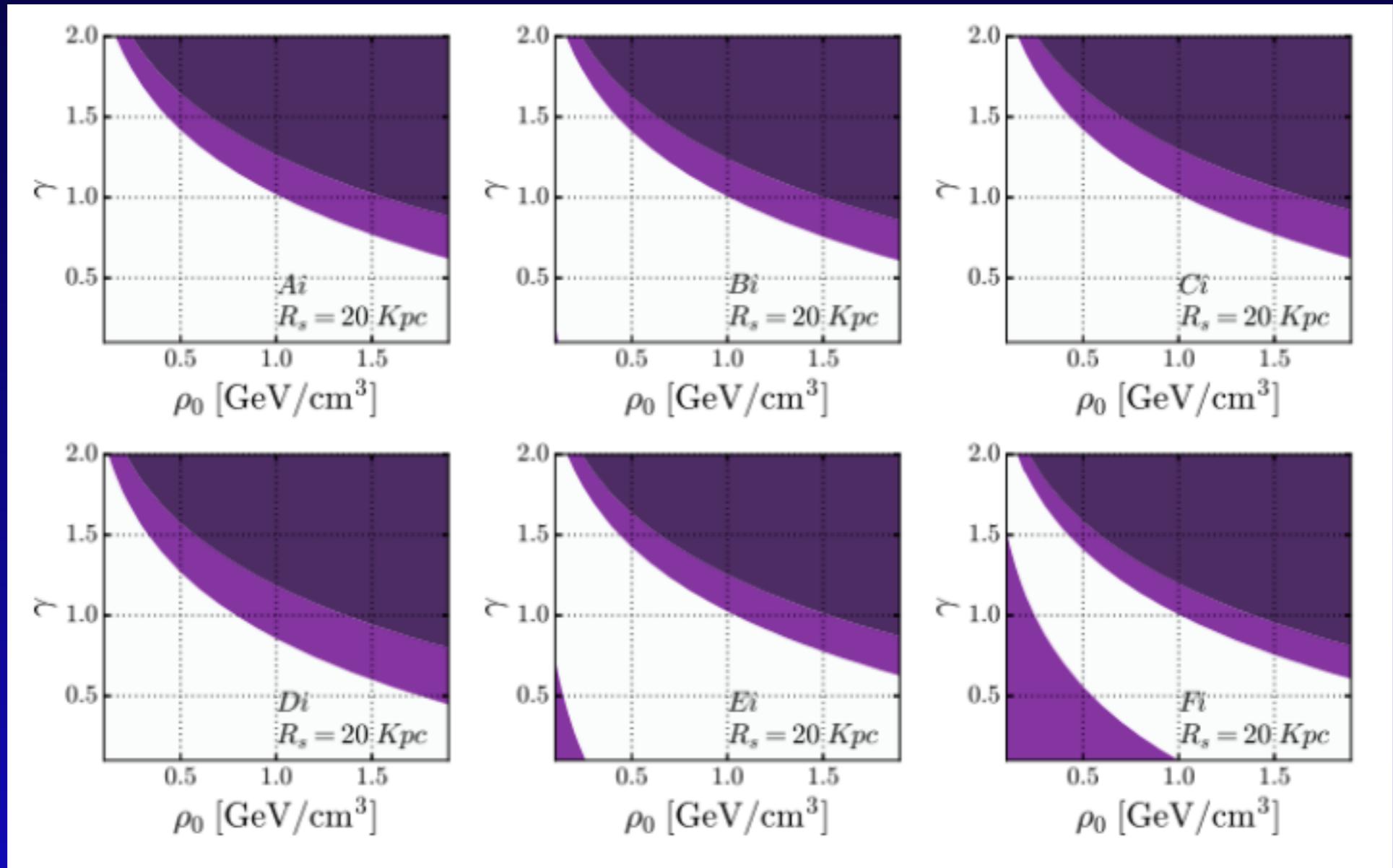
# That's what happens, Larry



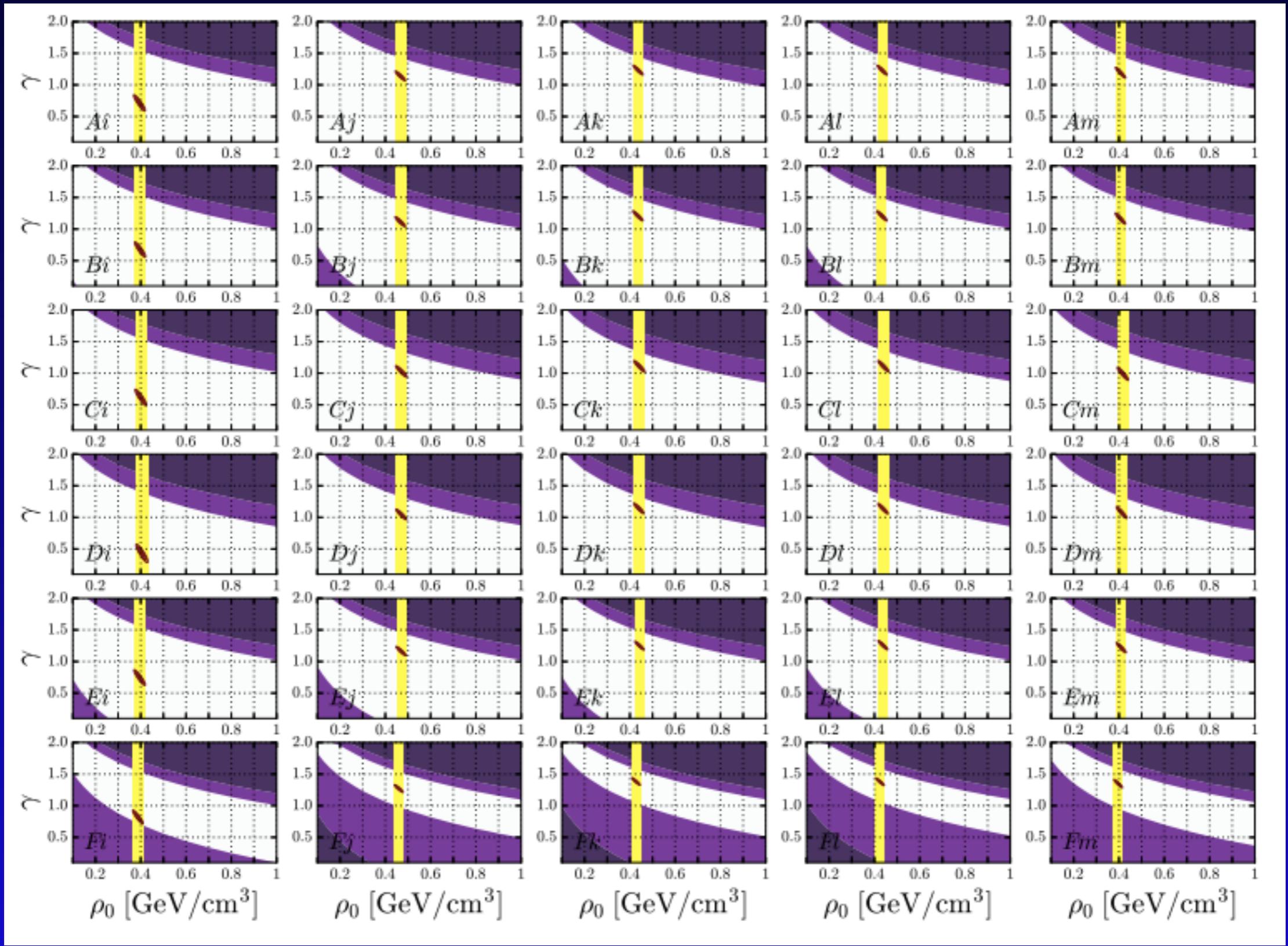
When you fight  
a stranger in the ALPS



# The Galactic Bulge region ( $R < 2.5$ kpc) constraints on the DM distribution



# The Galactic Bulge region ( $R < 2.5$ kpc) constraints on the DM distribution



# “Mamma guarda, senza rotelle!”

## A non-parametric reconstruction of the DM profile

