Dark Matter, Sky and Earth

Fabio Iocco

ICTP-SAIFR, São Paulo

Federico II, Napoli

Università degli Studi di Napoli Federico II

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

Dip. Galileo Galilei
16/4/2019, Padova

Part I:

The Dark Matter distribution of the Milky Way

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

Fabio Iocco

ICTP-SAIFR, São Paulo

Federico II, NAPOLI

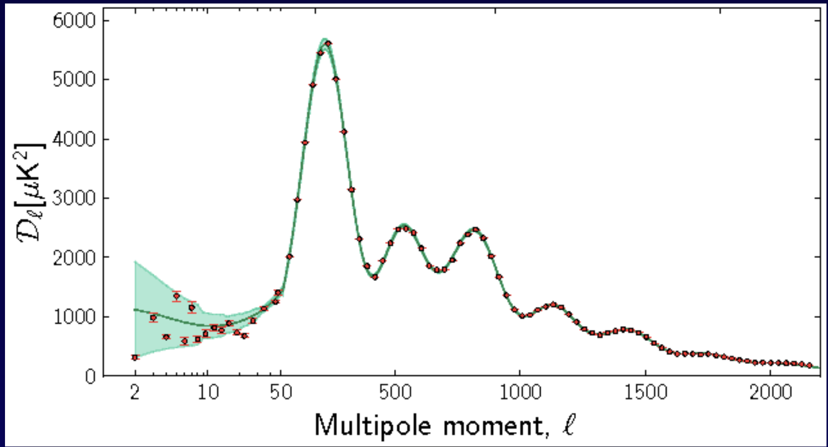
Università degli Studi di Napoli Federico II

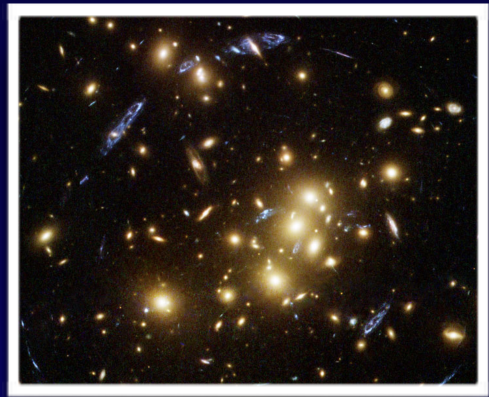
ICTP SAIFR International Centre for Theoretical Physics South American Institute for Fundamental Research

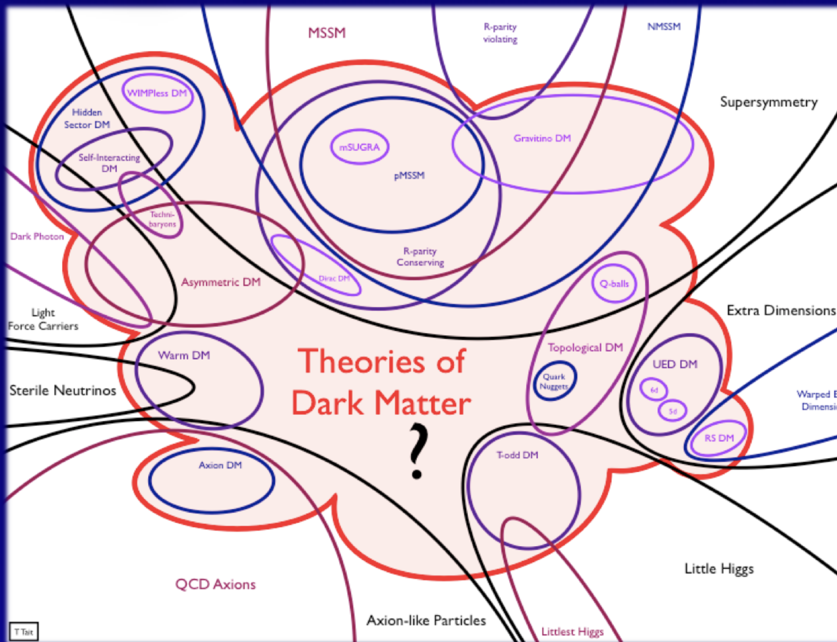
Dip. Galileo Galilei
16/4/2019, Padova

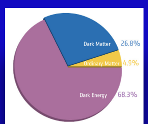
Dark Matter

Evidence over large range of scales





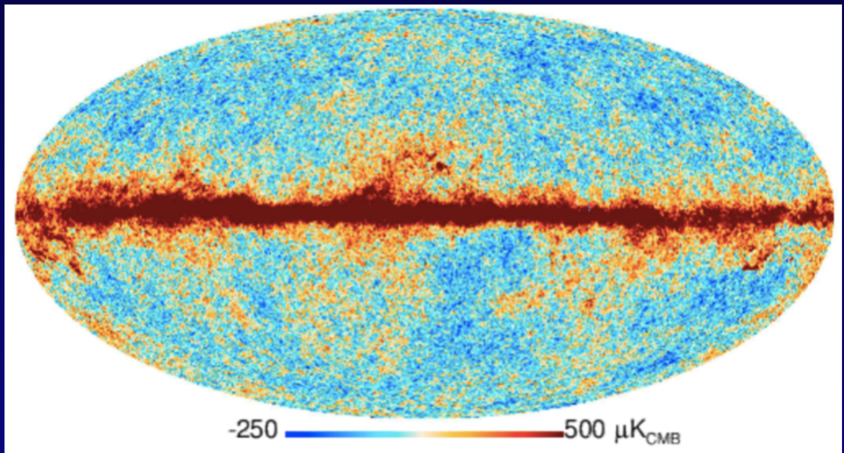


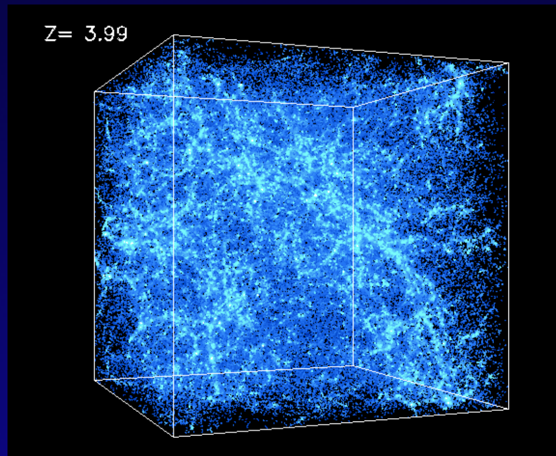


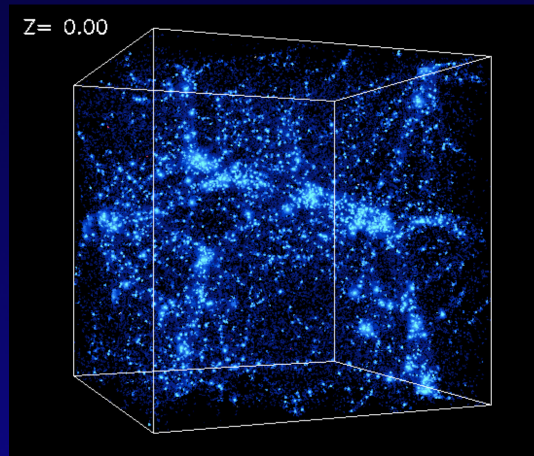
NATURE STILL UNKNOWN

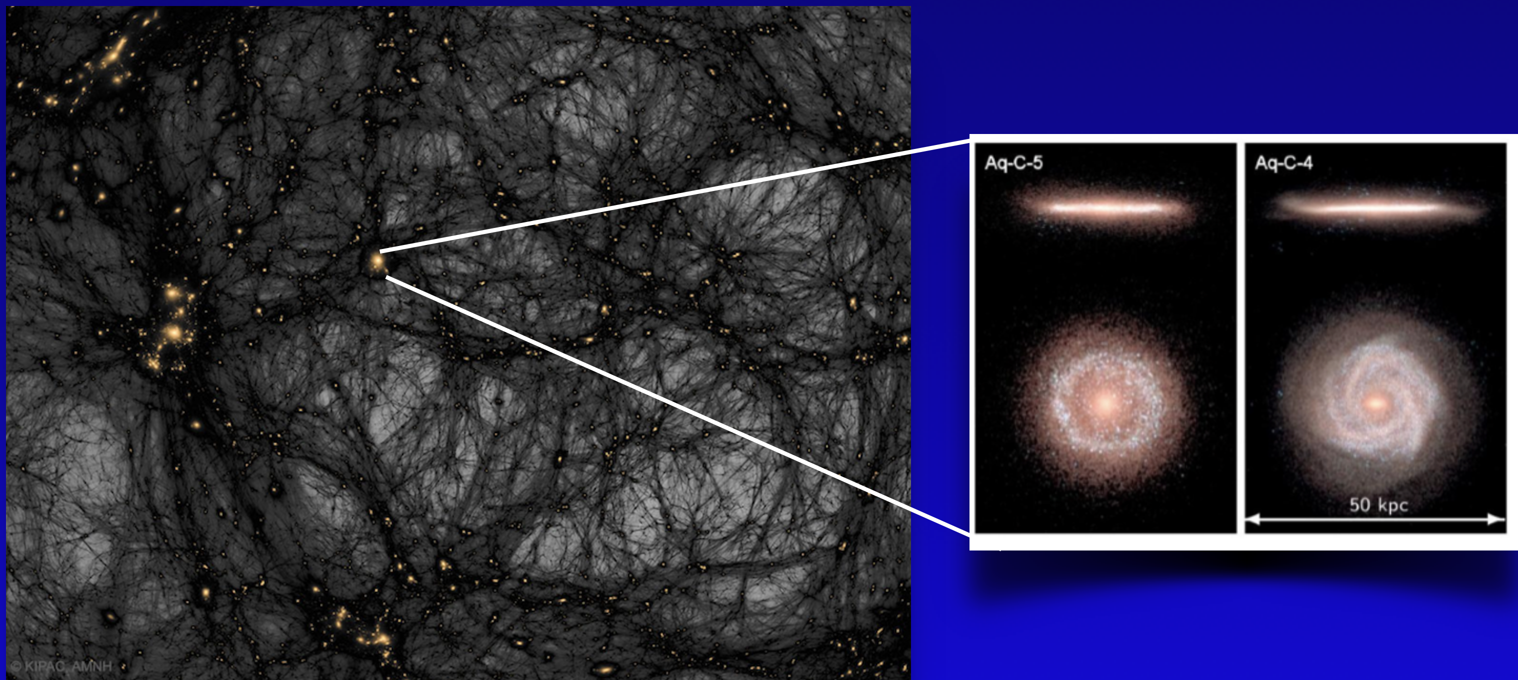
A story of LCDM
I: structure formation

age of Universe





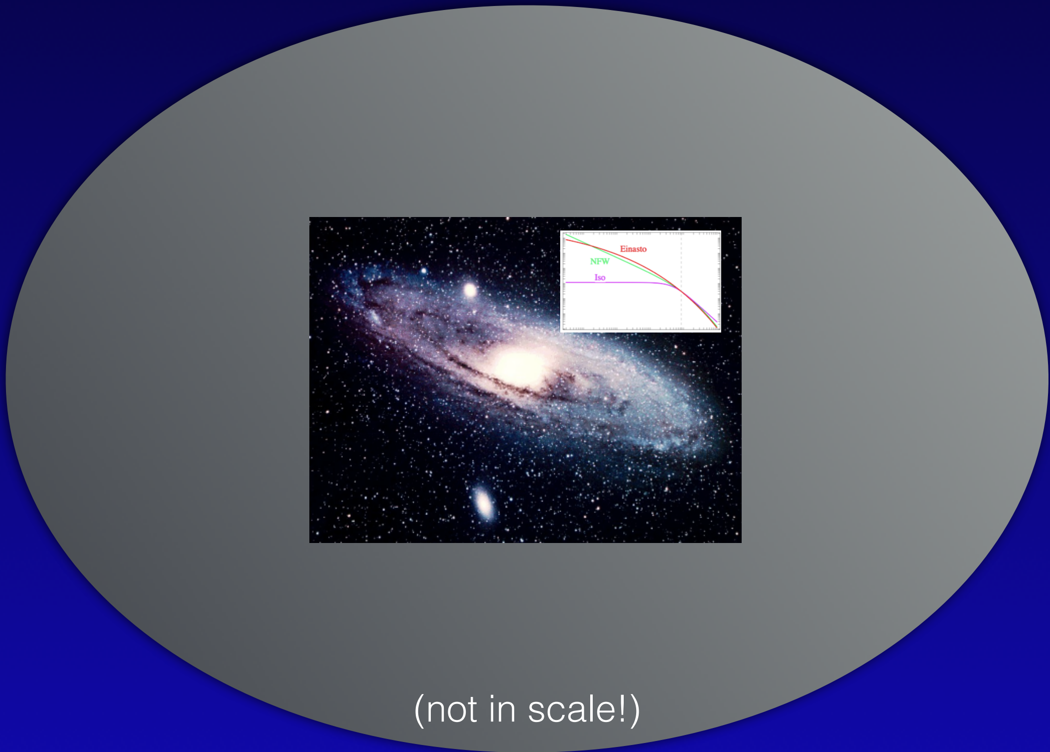


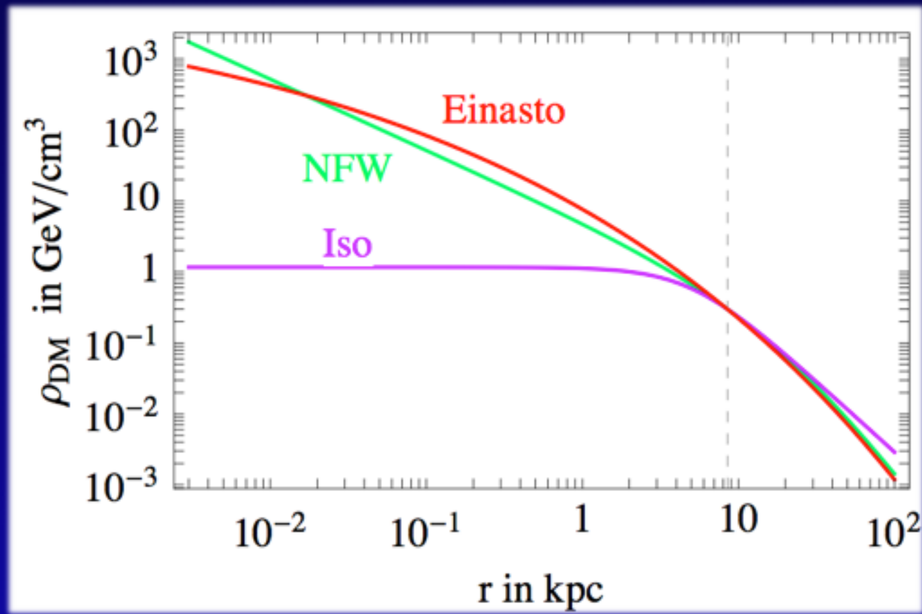


physical size

A story of LCDM
II: the single halo

A “universal” DM profile?

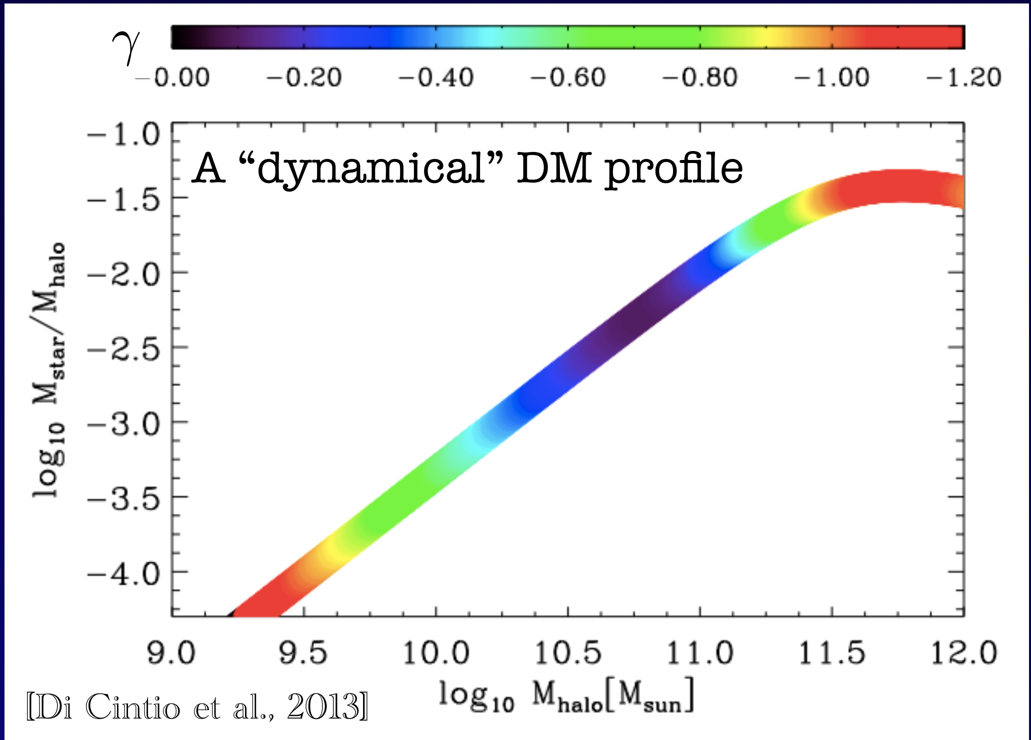


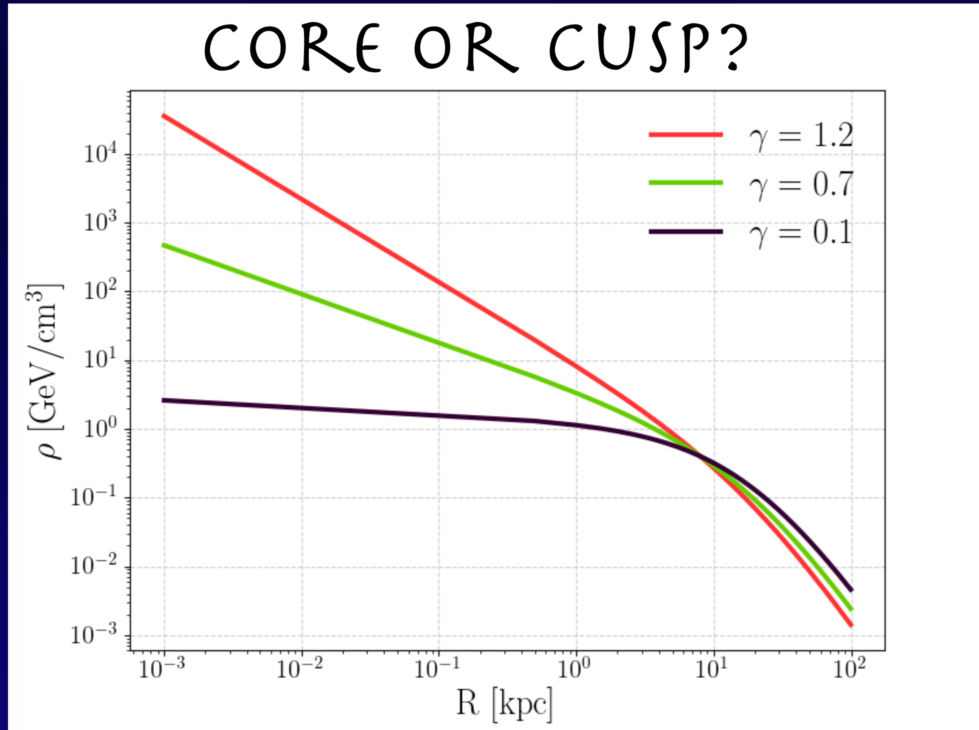


NAVARRO-FRENK-WHITE

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

A story of LCDM
III: the dark matter distribution



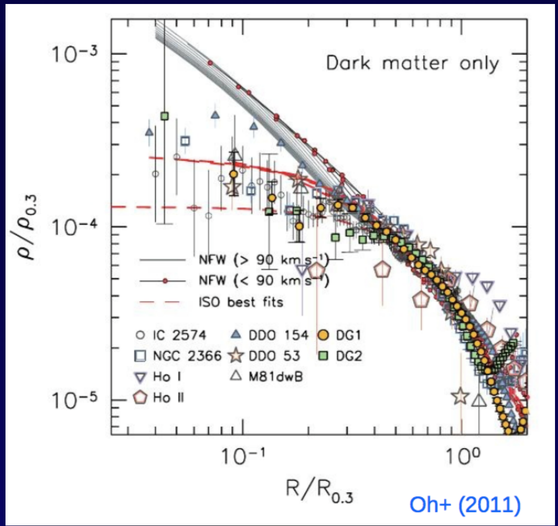


generalized NFW

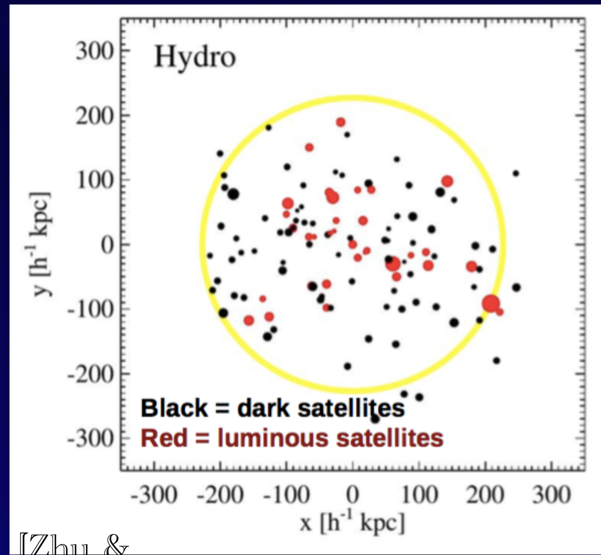
$$\rho_{DM}(R) \propto \rho_0 \left(\frac{R}{R_s}\right)^{-\gamma} \left(1 + \frac{R}{R_s}\right)^{-3+\gamma}$$

A story of LCDM
IV: the small scale problems

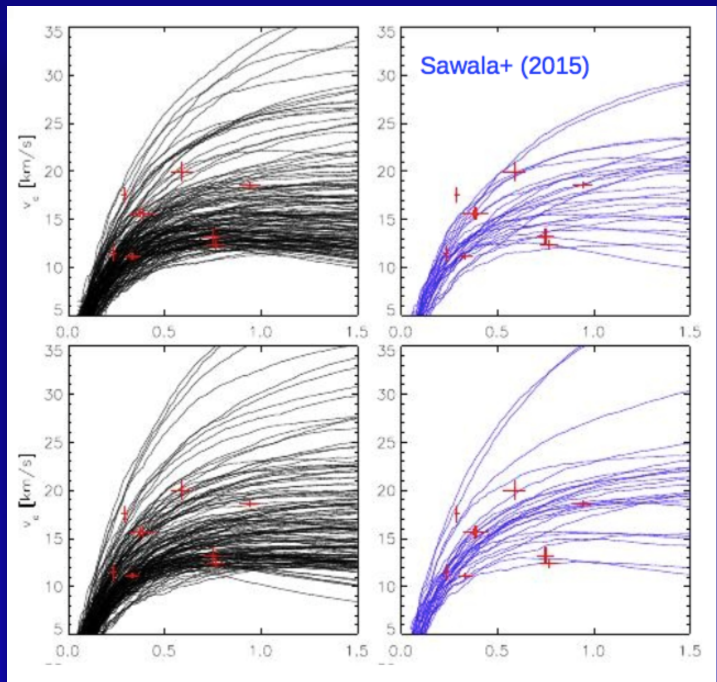
Cusp vs core



Missing satellite



Too big to fail



Many experts
here in Durham,
ask them!

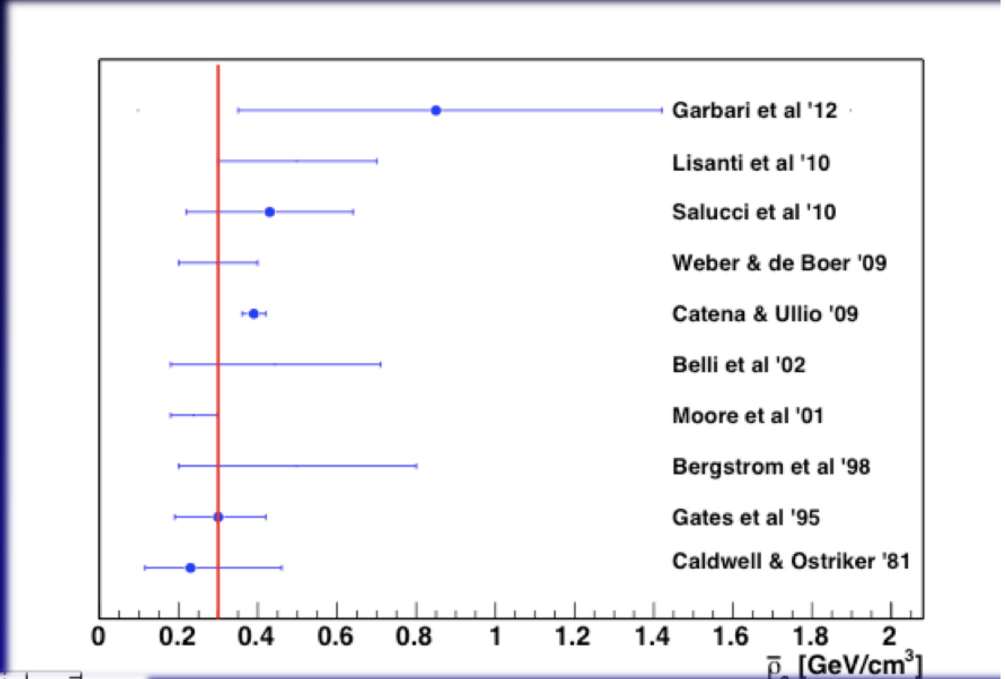
And now for something completely different: the Milky Way

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

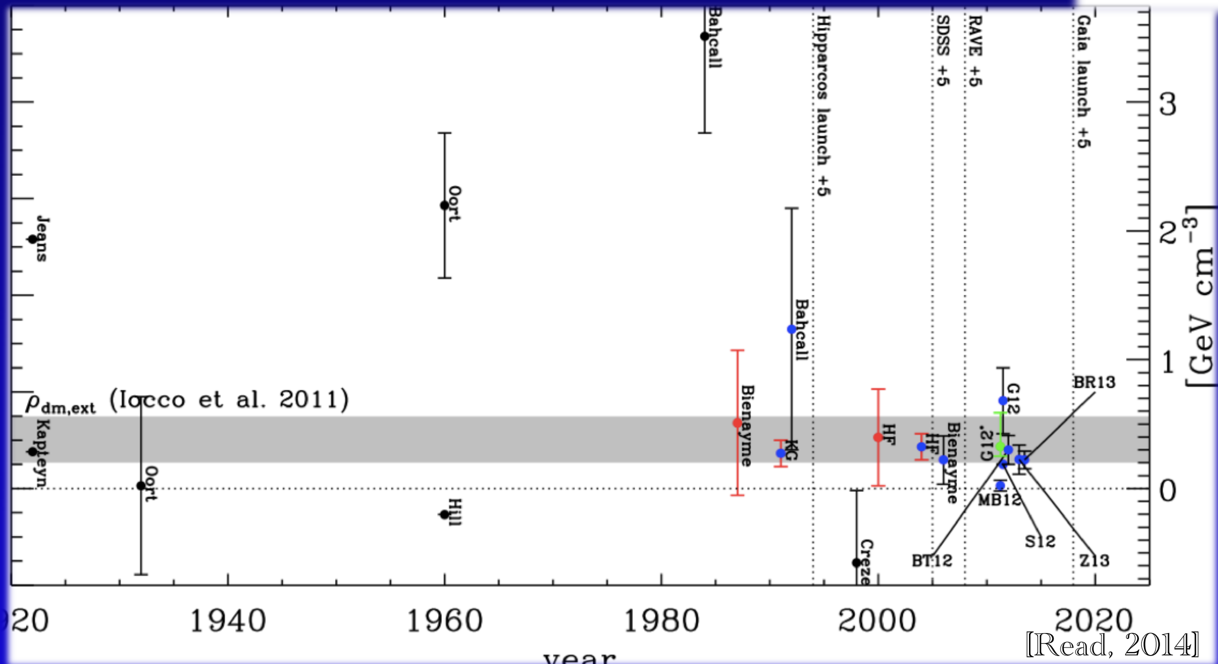
DM density at the Sun = ?

(the path to Stockholm goes through the skies)

Determining the relevant astrophysical quantities
Local DM density

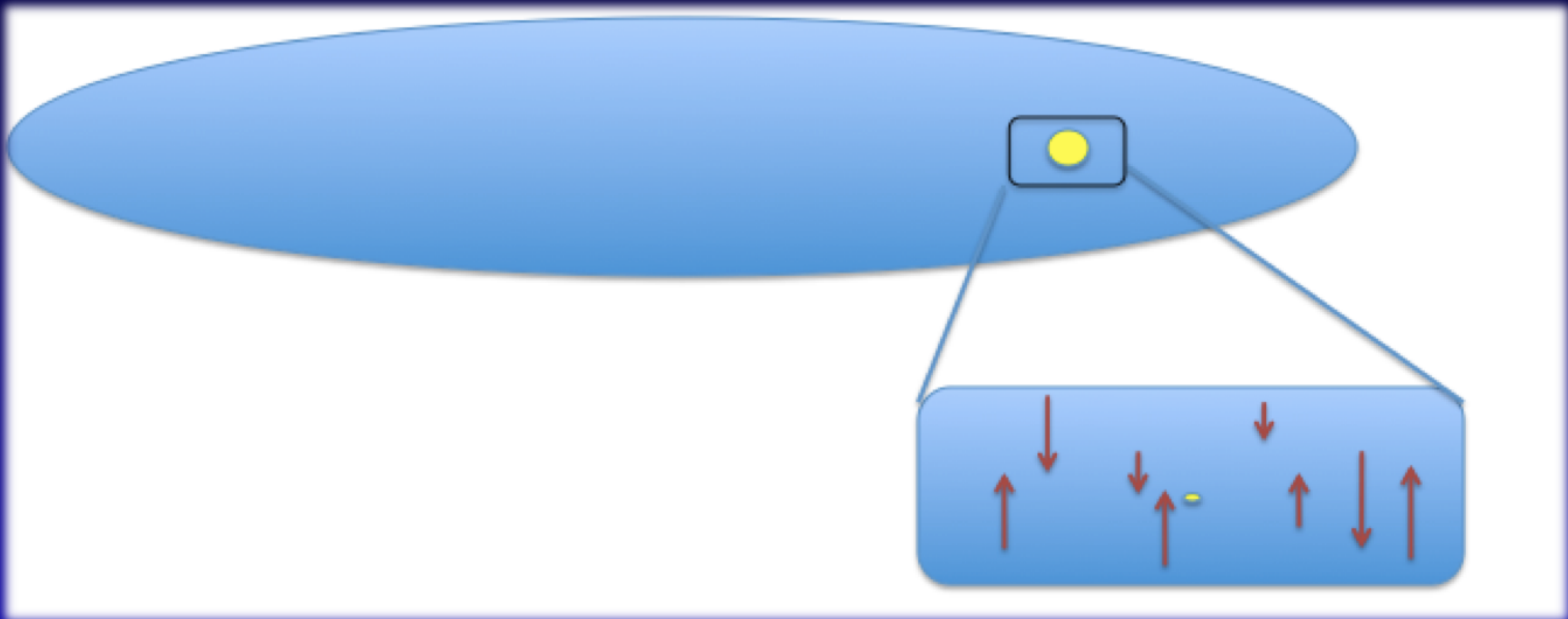


Determinations of
local DM density
are consistent, but noisy



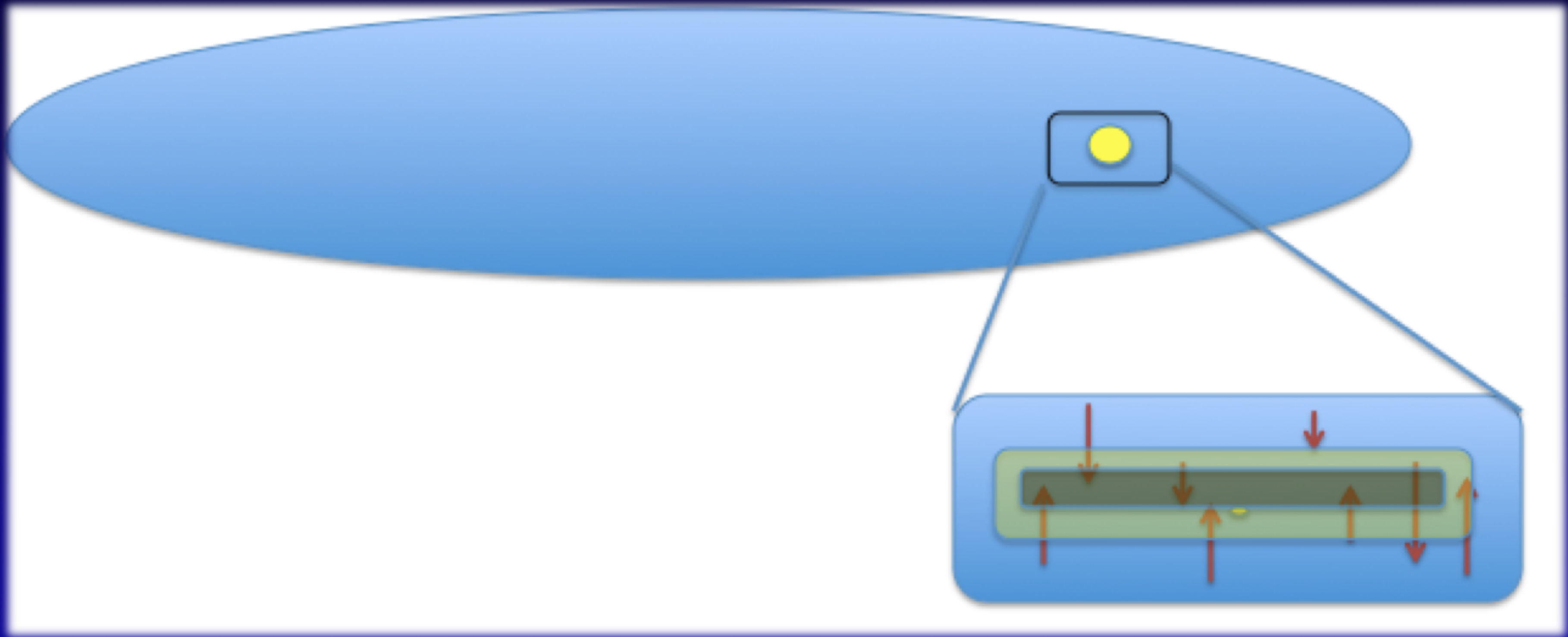
[Read, 2014]

Local determination of ρ_0



Vertical motion of stars, determining the whole local potential

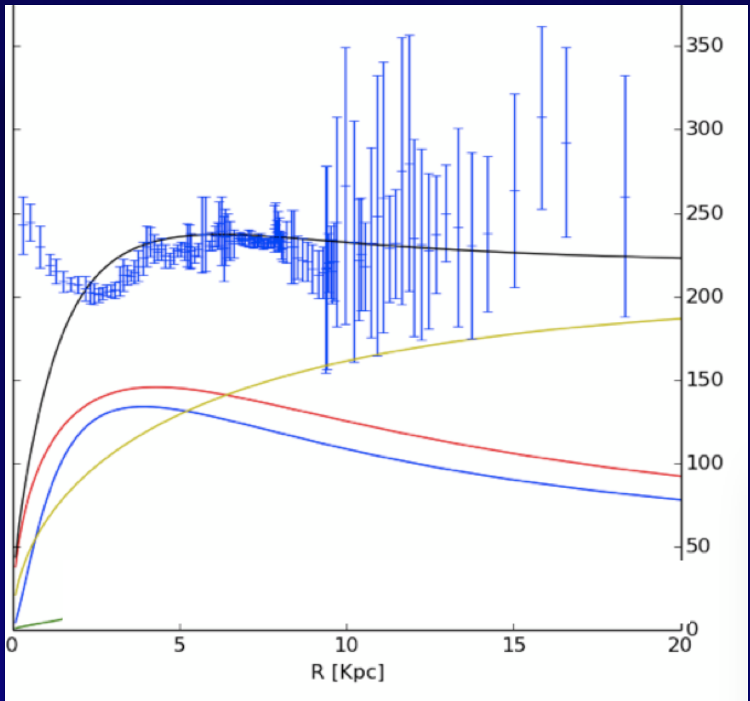
Local determination of ρ_0



Subtracting local baryonic (stellar) contribution to get DM
(no implicit assumption on DM presence)

Inferring the DM density structure

Fitting a pre-assigned shape
on top of luminous

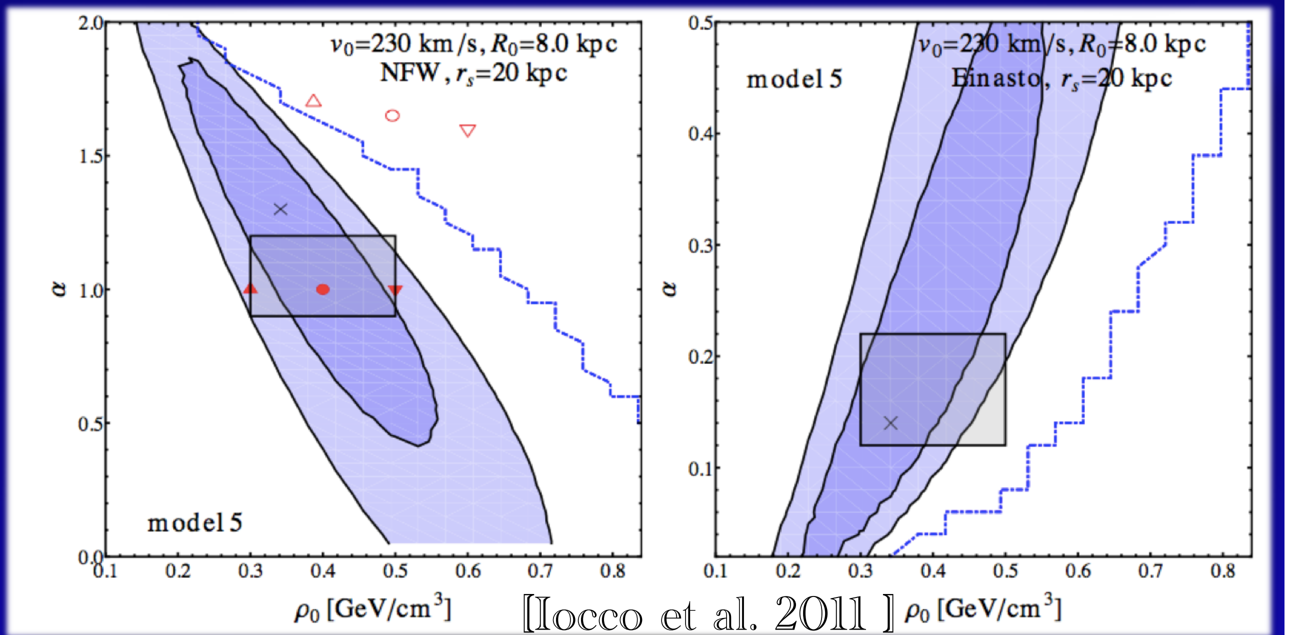


gNFW

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

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

Einasto

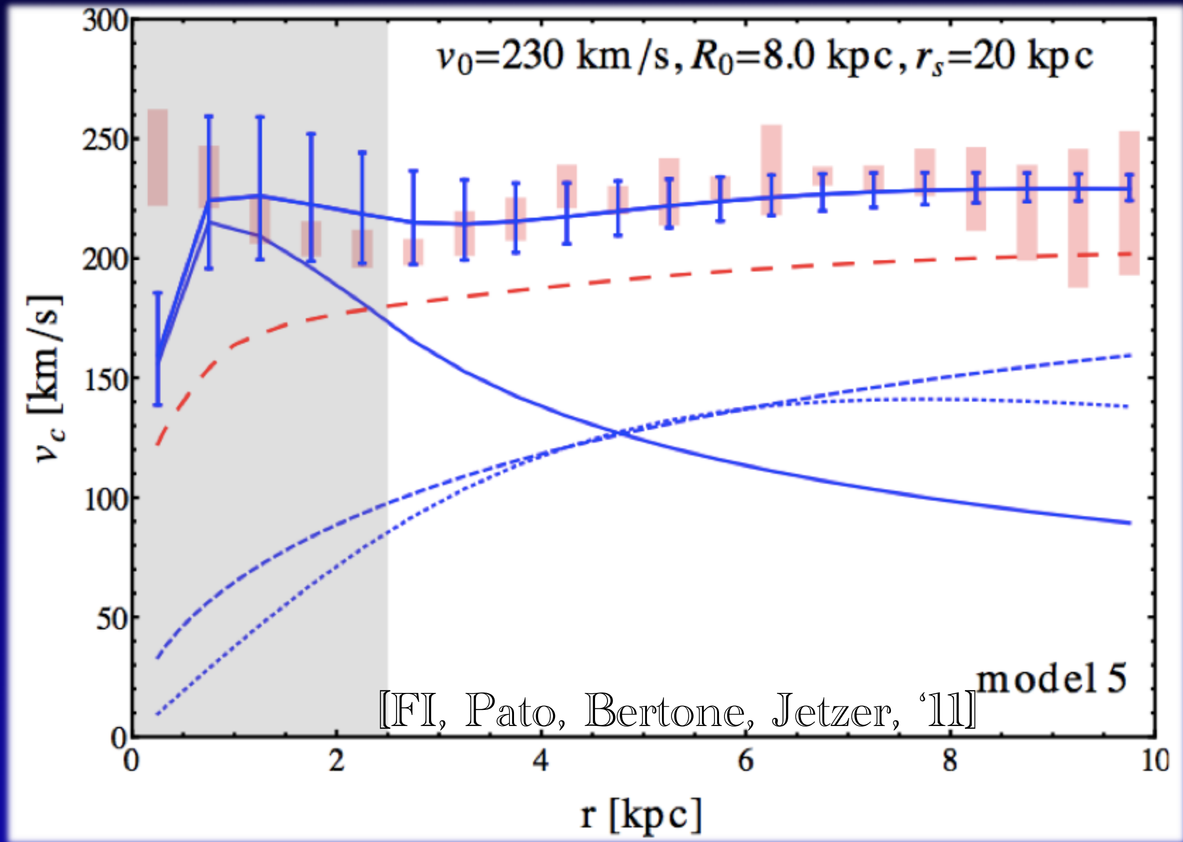


[Iocco et al. 2011]

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

Global determination of ρ(r)

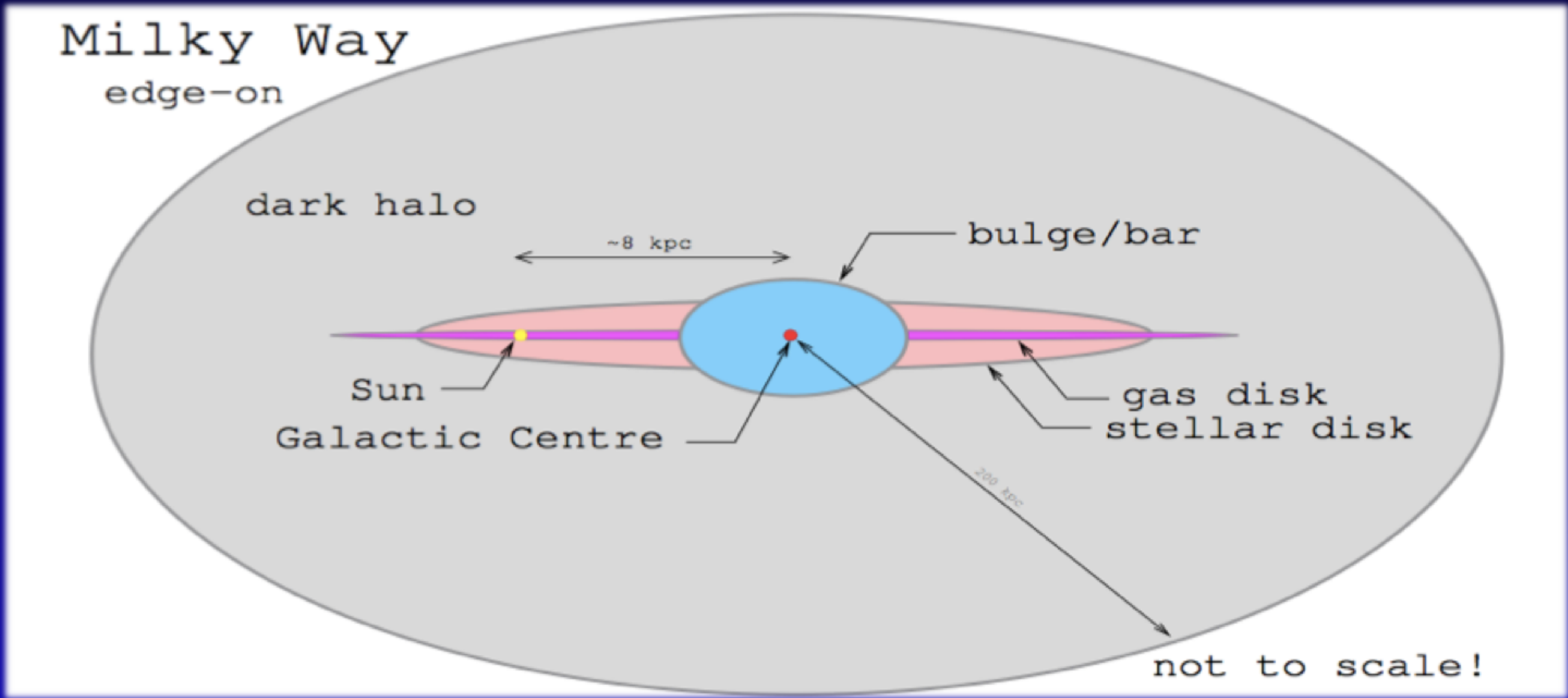
Fitting a DM profile to the Rotation Curve, on top of other components



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

Underlying assumption on DM presence and distribution shape

The case of the Milky Way



Courtesy of Miguel Pato

Dark Matter in the Milky Way: a purely observational approach

Fabio Iocco

Work started with: *Miguel Pato, G. Bertone*
And continued with: *Maria Benito, Ekaterina Karukes*

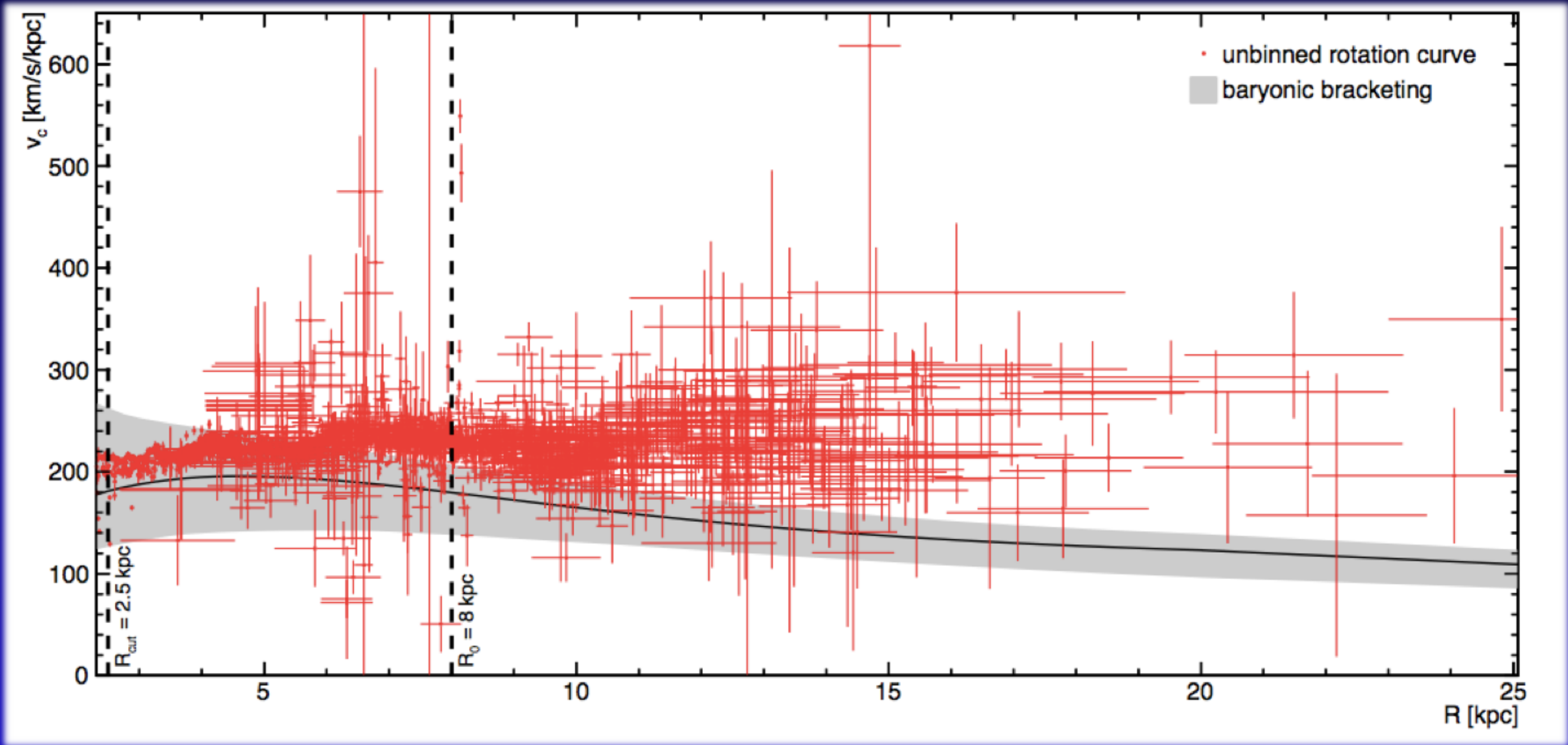
The case of the Milky Way: ingredients

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

- Some “grano salis”

- Working hypothesis (later on)

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



[Iocco, Pato, Bertone, Nature Physics 2015]

The case of the Milky Way: the question

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

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

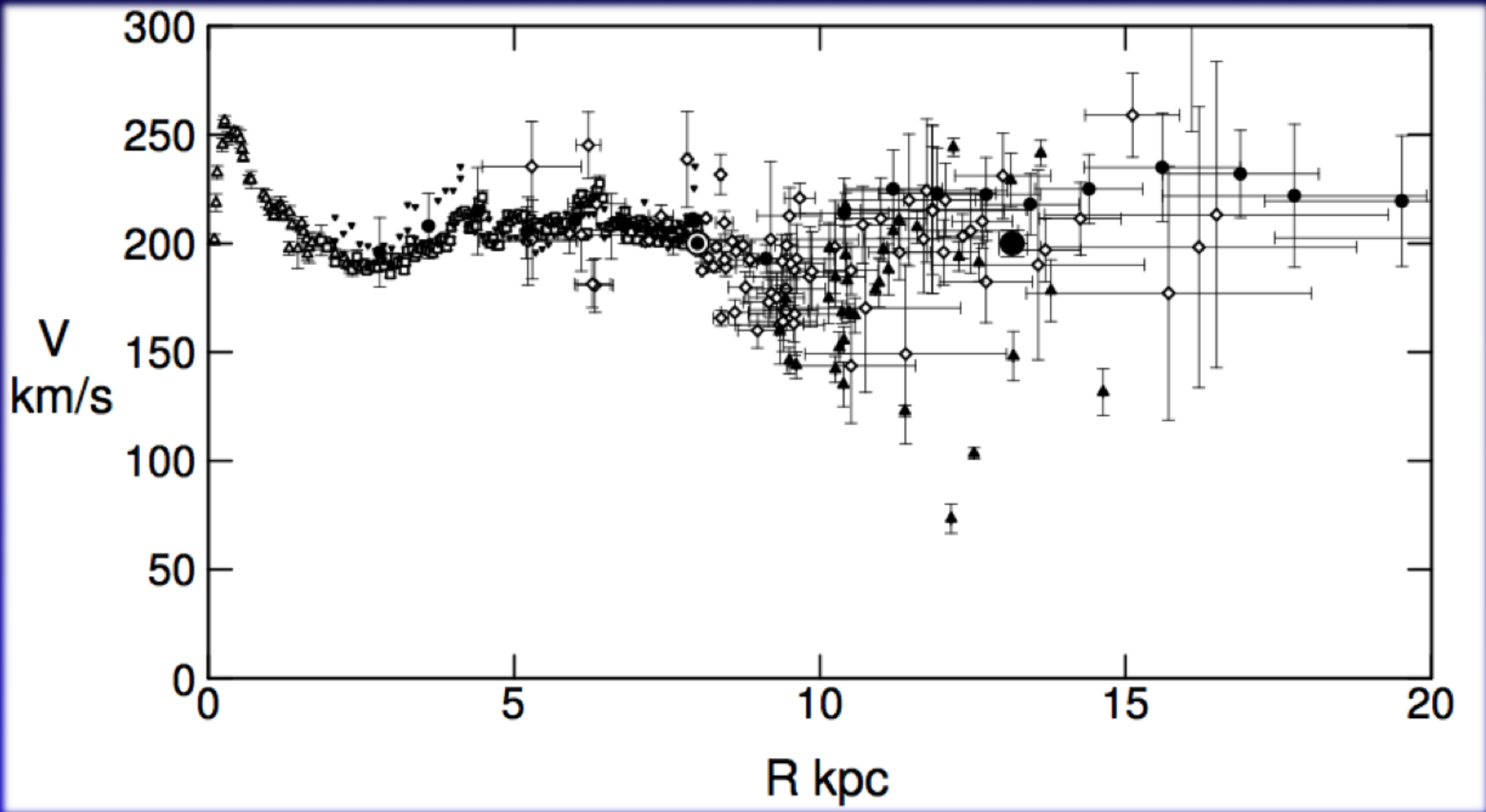
$$v_c^2 = r\frac{d\phi_{\text{tot}}}{dr}$$

Rotation curve as a tracer of the total potential

…and if not…

The Milky Way:

observed rotation curve
III. curve



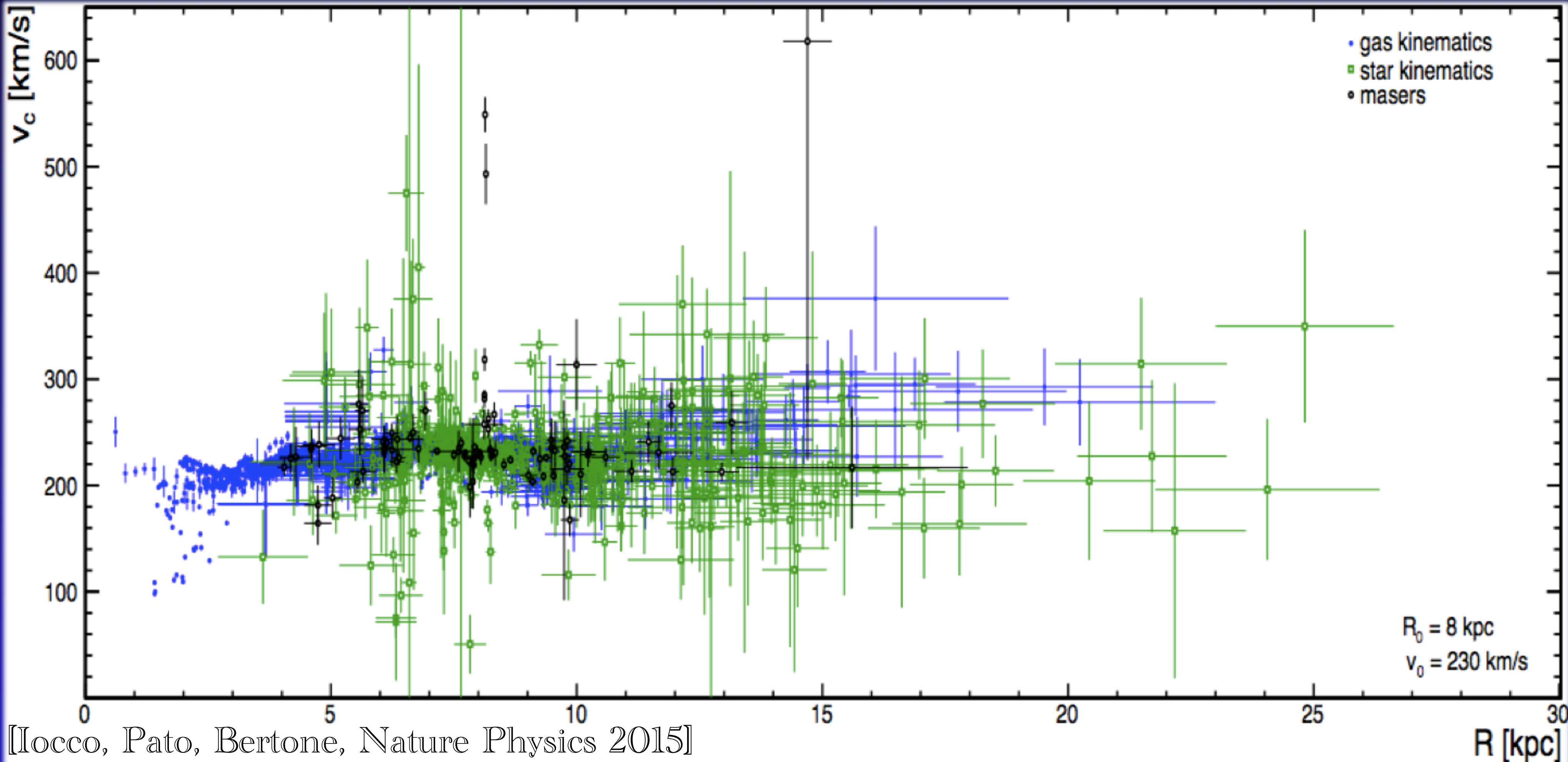
Data compilation by [Sofue et al, '08]

The Milky Way: observed rotation curve II'. data again (a new compilation)

	Object type	R [kpc]	quadrants	# objects
gas	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
	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
stars	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			
	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	masers			
	Reid+ '14	4.0 – 15.6	1,2,3,4	80
	Honma+ '12	7.7 – 9.9	1,2,3,4	11
	Stepanishchev & Bobylev '11	8.3	3	1
	Xu+ '13	7.9	4	1
	Bobylev & Bajkova '13	4.7 – 9.4	1,2,4	7

The Milky Way Rotation Curve

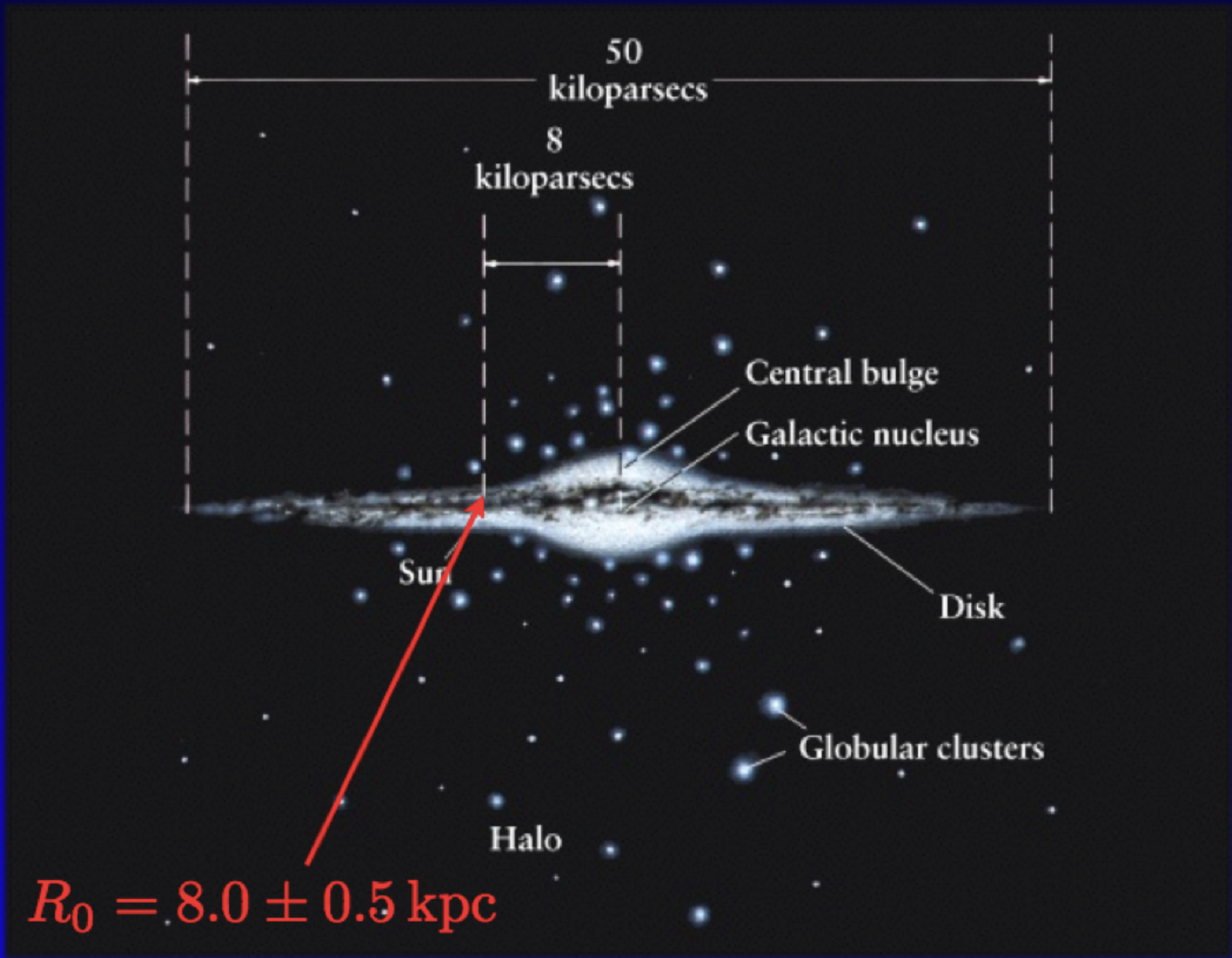
as observed



[Iocco, Pato, Bertone, Nature Physics 2015]

All tracers, optimized for precision between R=3-20 kpc

Dissecting the Milky Way: morphological observations



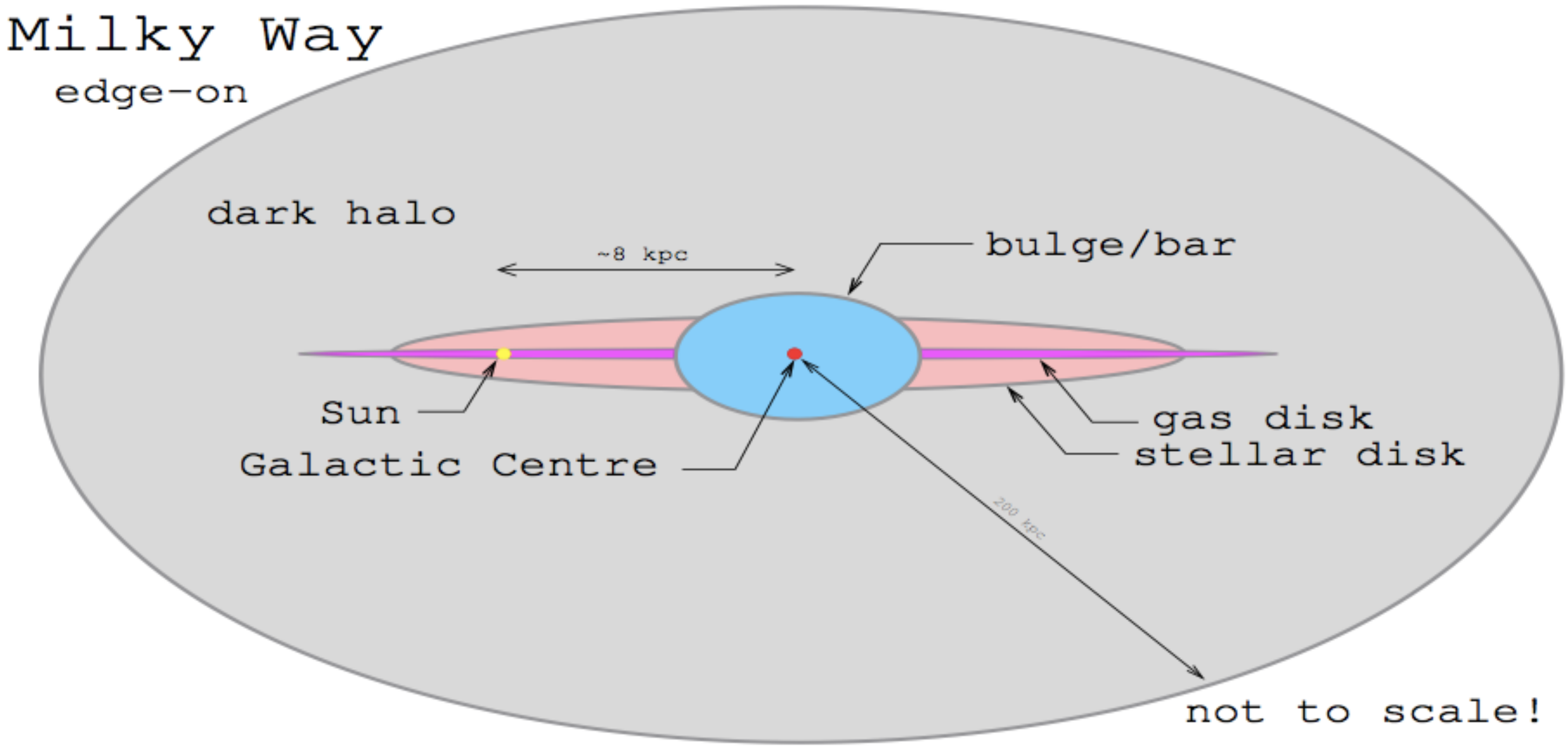
The Milky Way:
expected rotation curve

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

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

Constructing the curve expected from observed mass profiles

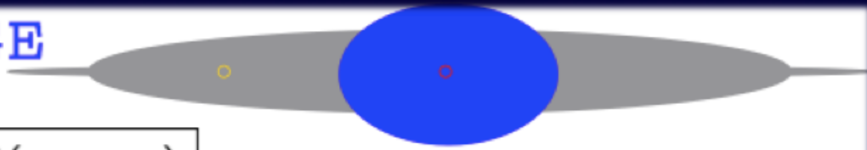
The Milky Way:
expected rotation curve
1. the baryonic components



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

The luminous Milky Way: observations of morphology

2. BARYONS: STELLAR BULGE



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

morphology $f(x,y,z)$

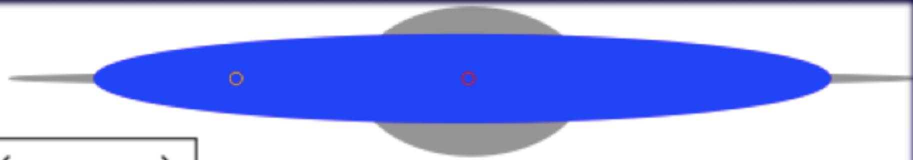
Stanek+ '97 (E2)	e^{-r}	0.9:0.4:0.3	24°	optical
Stanek+ '97 (G2)	$e^{-r_s^2/2}$	1.2:0.6:0.4	25°	optical
Zhao '96	$e^{-r_s^2/2} + r_a^{-1.85} e^{-r_a}$	1.5:0.6:0.4	20°	infrared
Bissantz & Gerhard '02	$e^{-r_s^2}/(1+r)^{1.8}$	2.8:0.9:1.1	20°	infrared
Lopez-Corredoira+ '07	Ferrer potential	7.8:1.2:0.2	43°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

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 $f(x, y, z)$

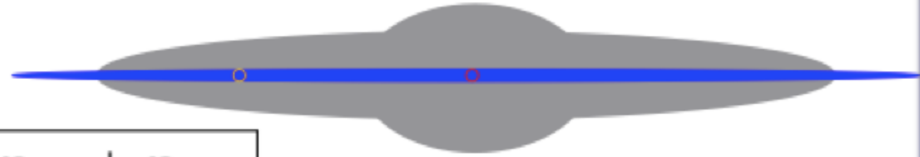
Han & Gould '03	$e^{-R}\text{sech}^2(z)$	2.8:0.27	thin	optical
	$e^{-R-\|z\|}$	2.8:0.44	thick	
Calchi-Novati & Mancini '11	$e^{-R-\|z\|}$	2.8:0.25	thin	optical
	$e^{-R-\|z\|}$	4.1:0.75	thick	
deJong+ '10	$e^{-R-\|z\|}$	2.8:0.25	thin	optical
	$e^{-R-\|z\|}$	4.1:0.75	thick	
	$(R^2 + z^2)^{-2.75/2}$	1.0:0.88	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

normalisation ρ_0

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

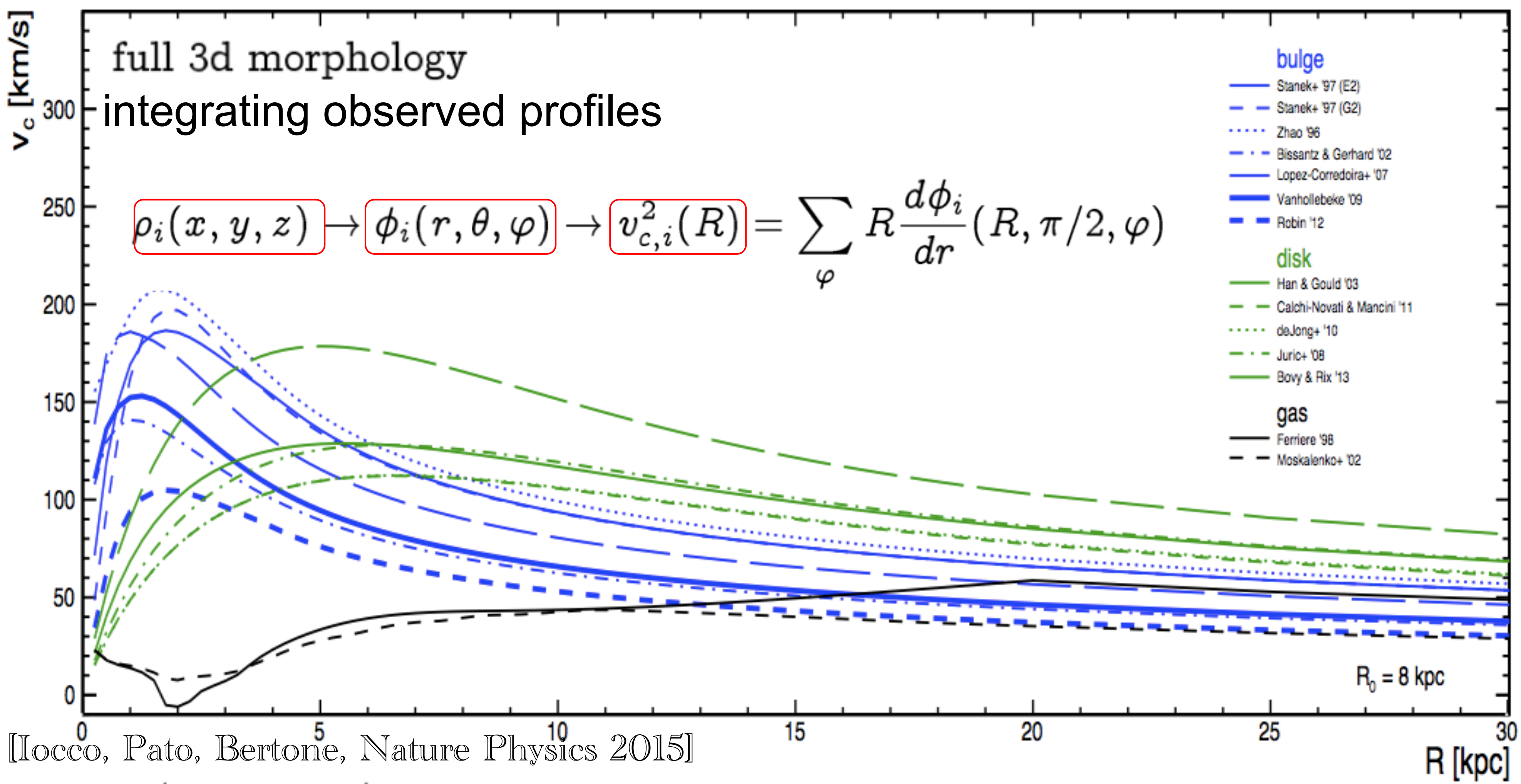
CO-to-H_2 factor: $X_{\rm CO} = 0.25 - 1.0 \times 10^{20}$ cm^{-2} K^{-1} km^{-1} s for $r < 2$ kpc

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

[Ferrière+ '07, Ackermann '12]

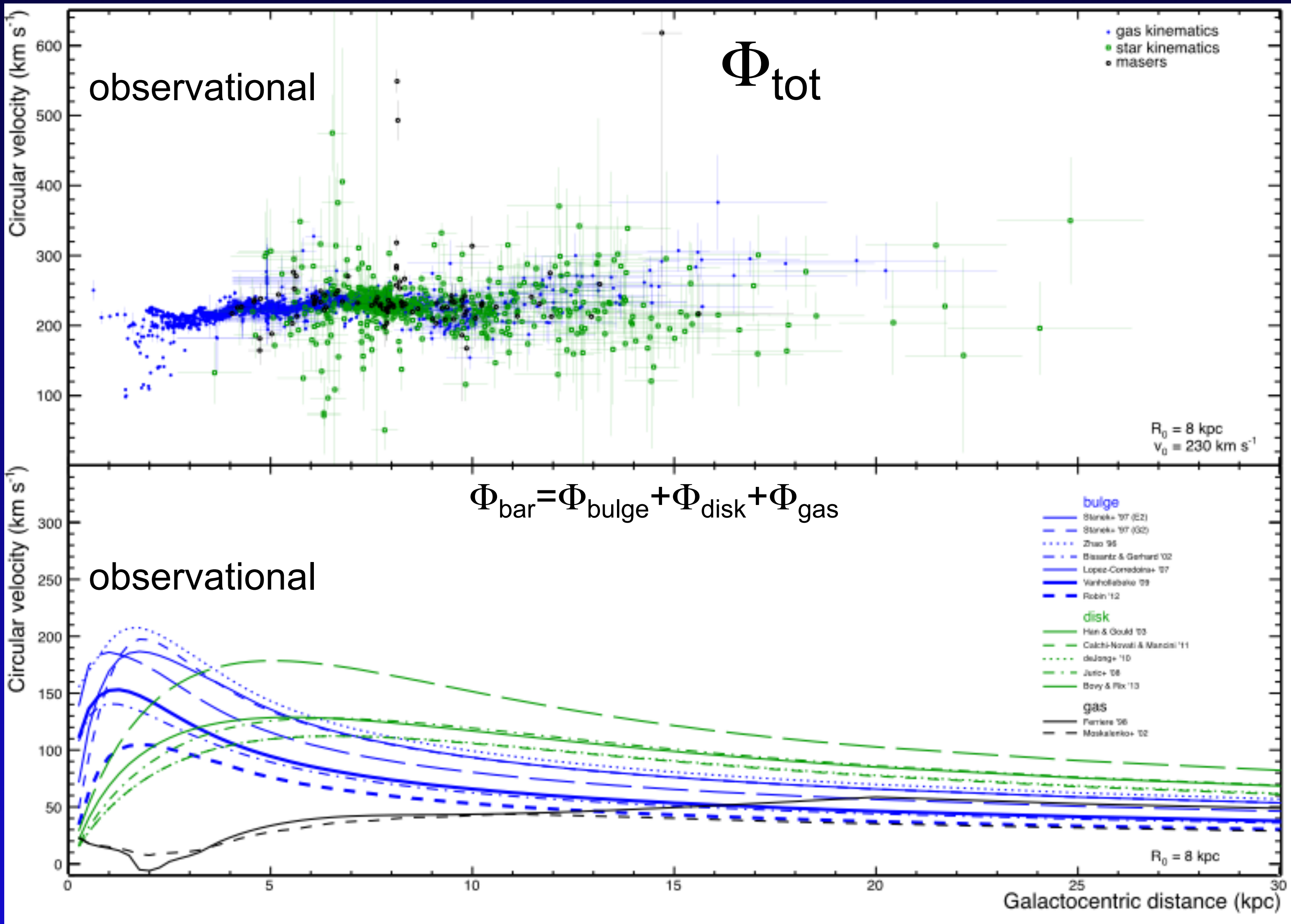
The luminous Milky Way:
expected rotation curve

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

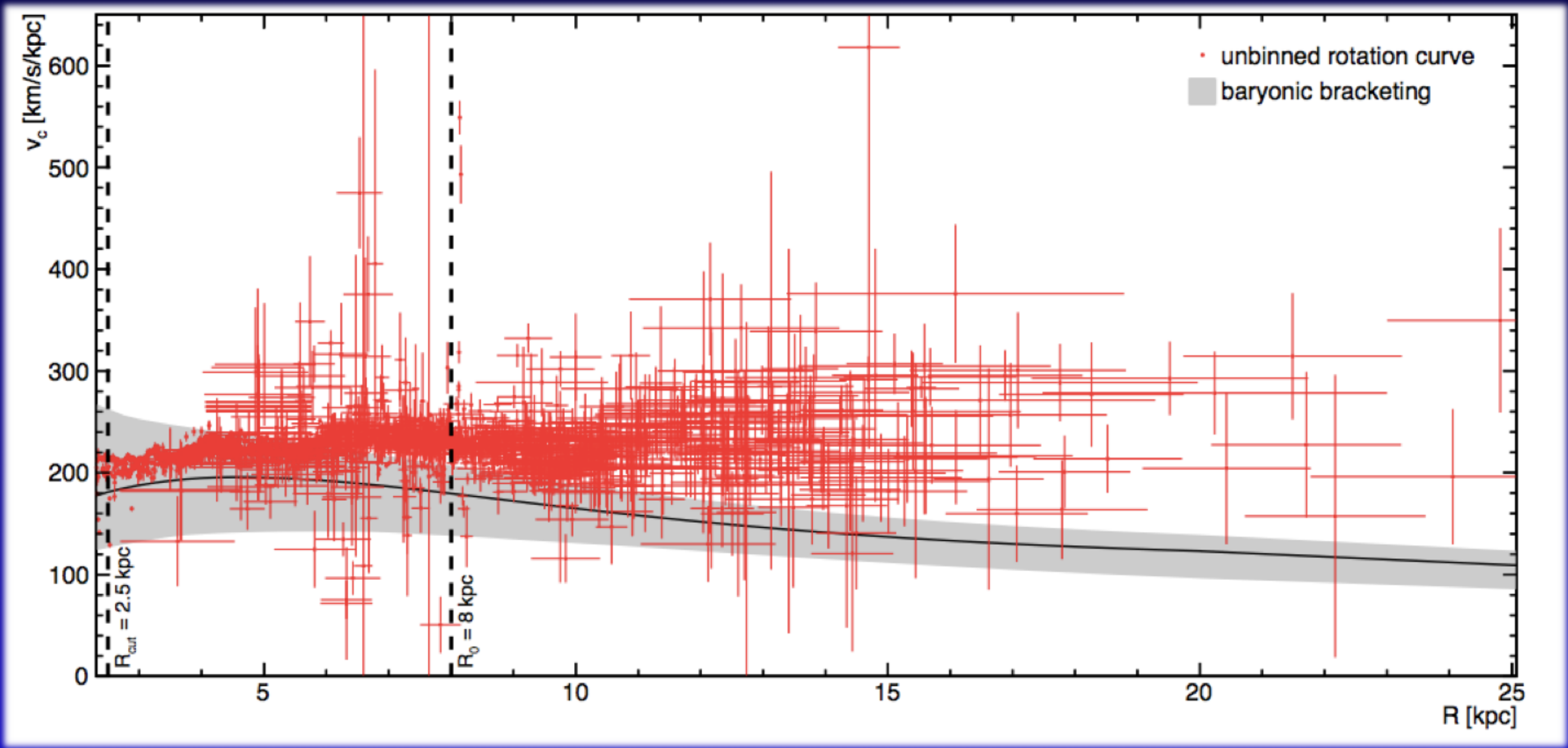


[Iocco, Pato, Bertone, Nature Physics 2015]

The Milky Way: testing expectactions

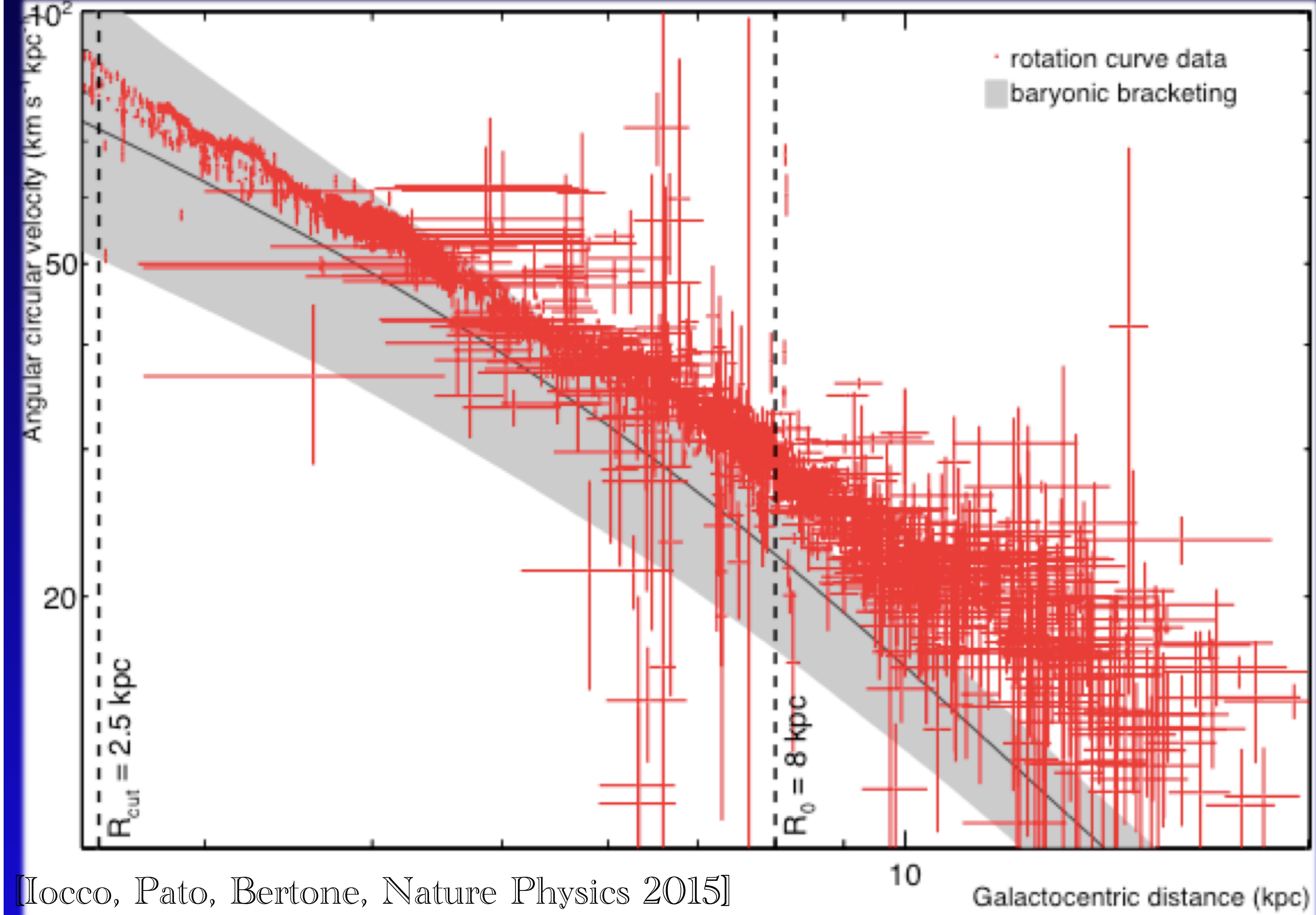


The Milky Way:
testing expectactions
(with no additional assumptions)



[Iocco, Pato, Bertone, Nature Physics 2015]

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

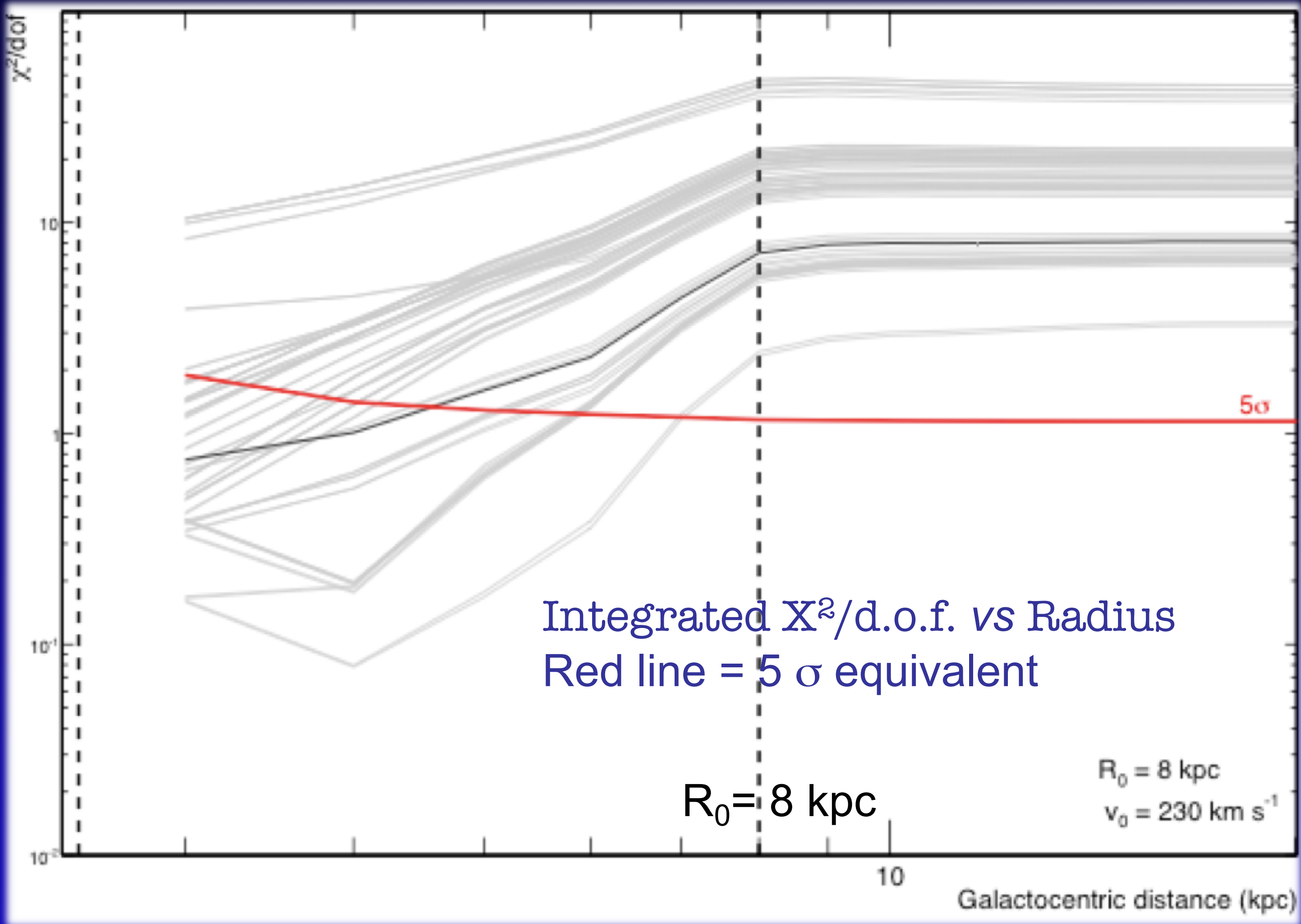
The Milky Way:
testing expectactions
(with no additional assumptions)
((and some technical detail))

- 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)

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

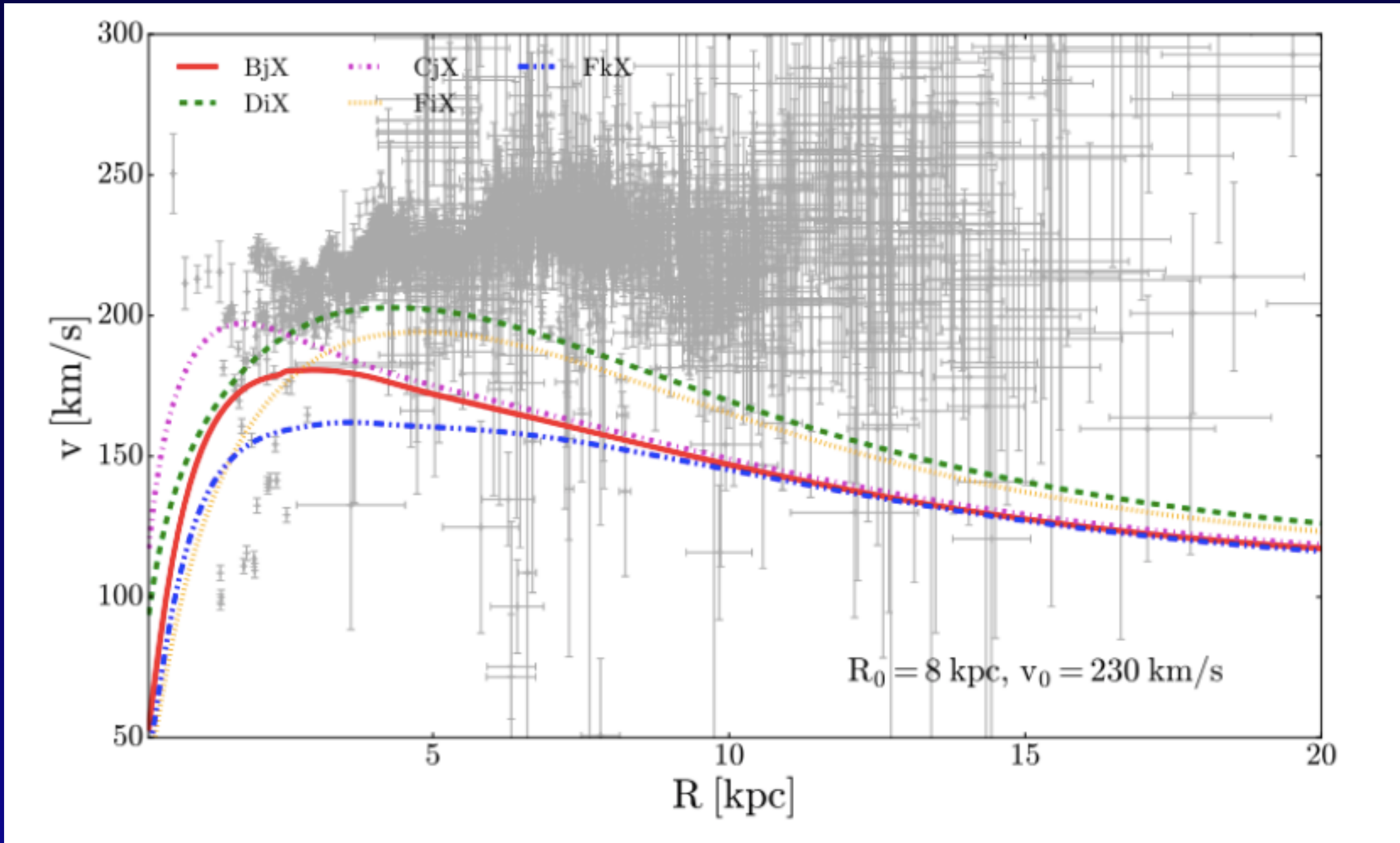
Do the baryon-only curves fit with the observed RC?



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

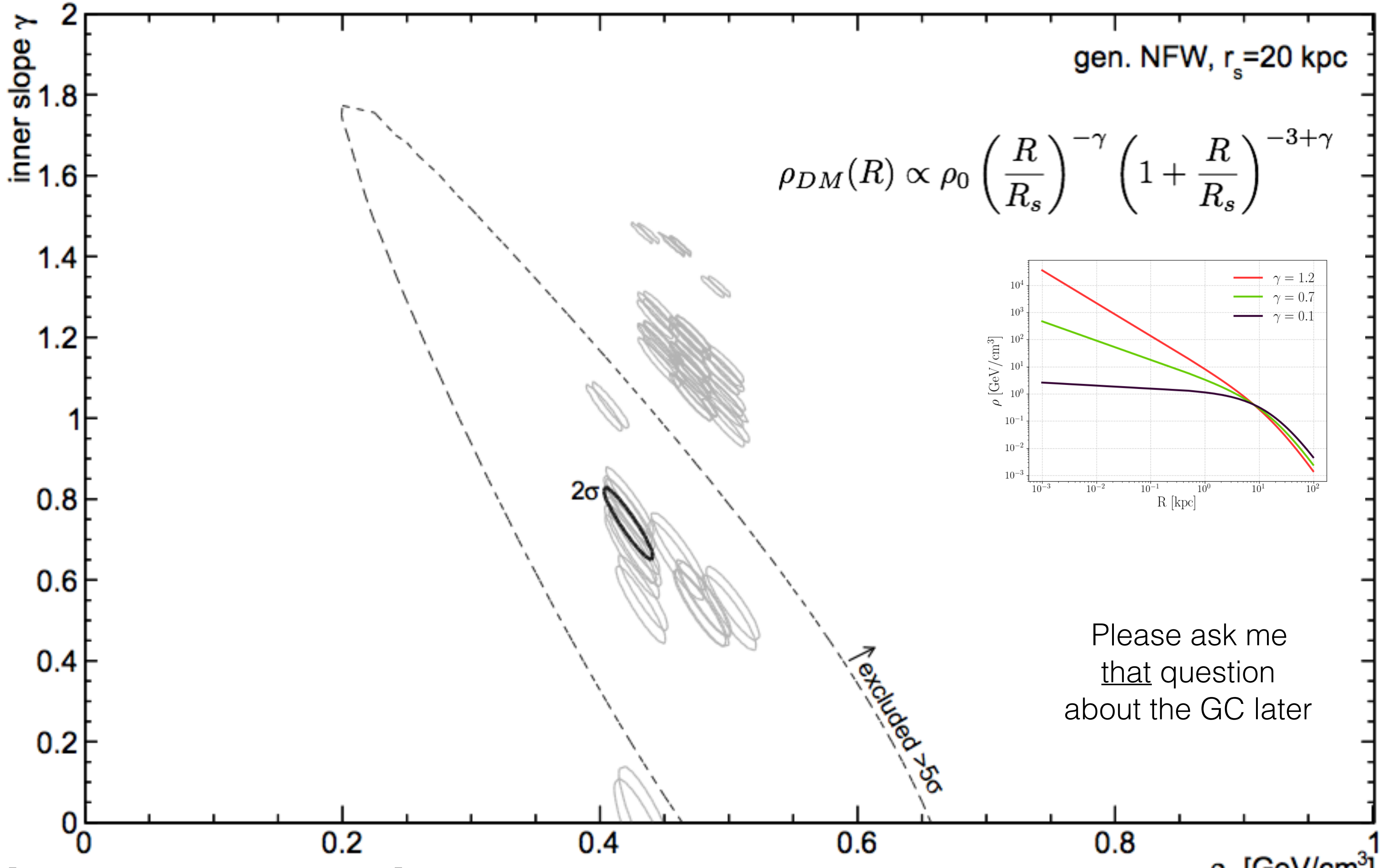
[Iocco, Pato, Bertone, Nature Physics 2015]

Systematic uncertainties
(luminous component)



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

Extracting the DM density structure

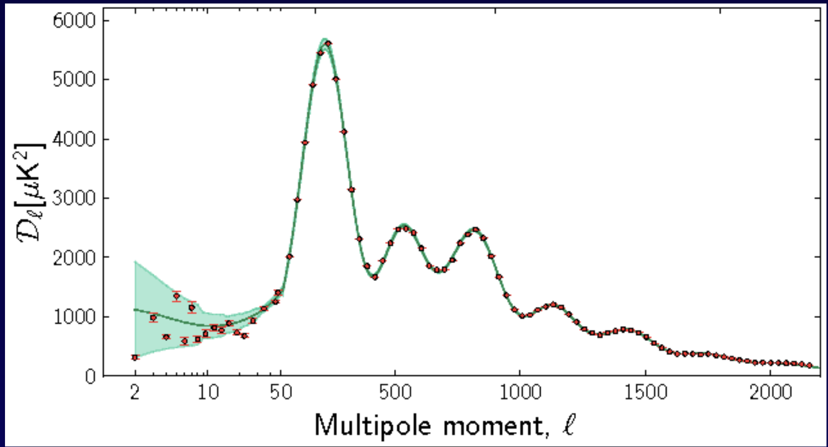


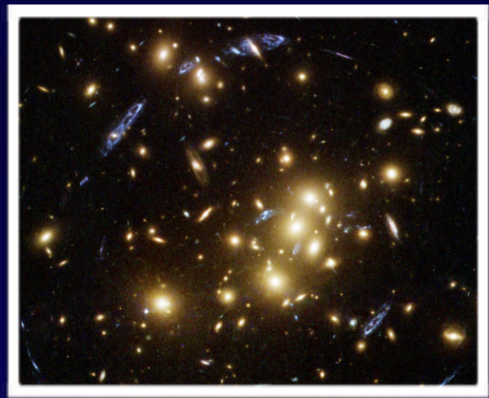
Please ask me
<u>that</u> question
about the GC later

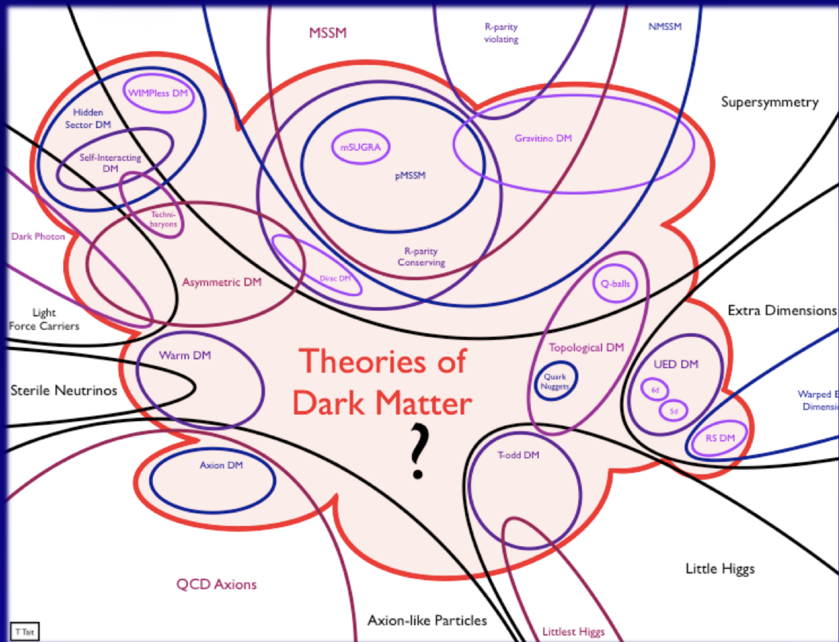
[Pato, Iocco, Bertone, 2015]

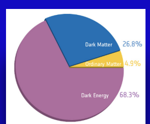
Dark Matter

Evidence over large range of scales









NATURE STILL UNKNOWN

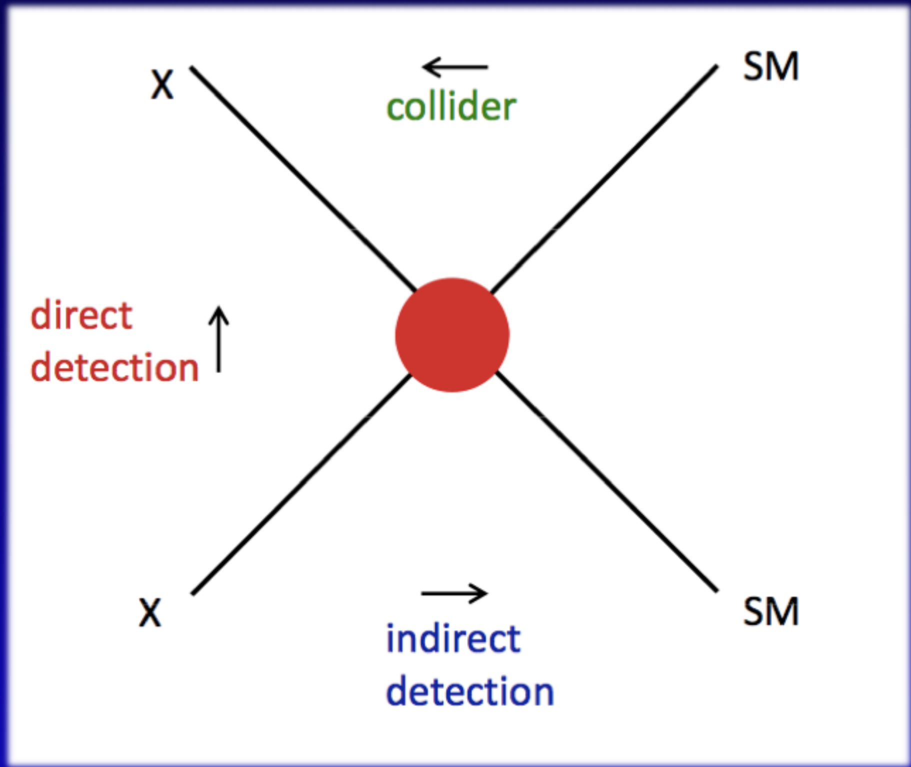
Direct and indirect searches of WIMP DM

complementary to colliders

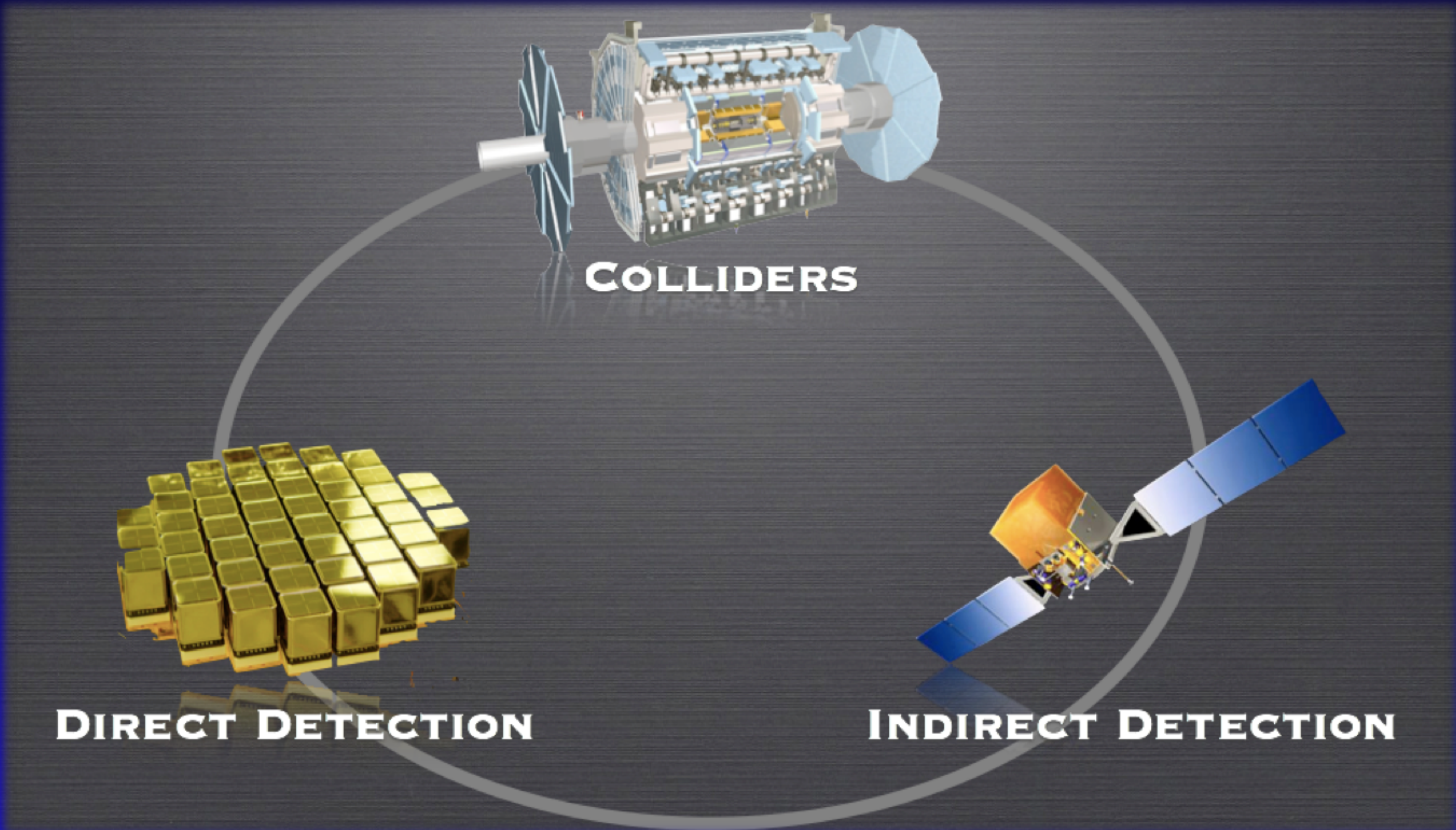
Direct detection:
DM scattering against nuclei, recoil

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

Production at LHC

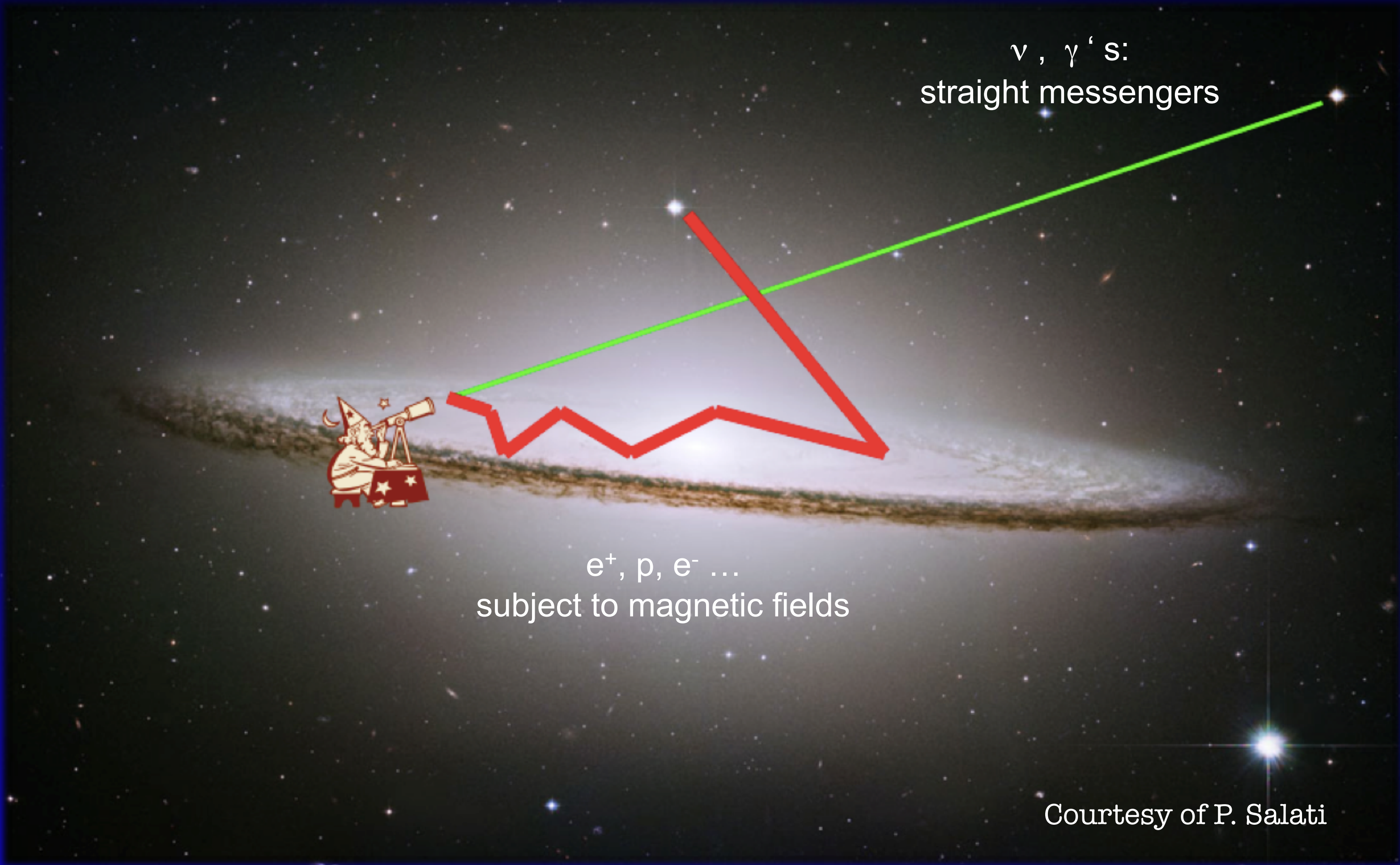


Roundabout of complementarity
(for WIMP DM)



Indirect Detection: principles and dependencies

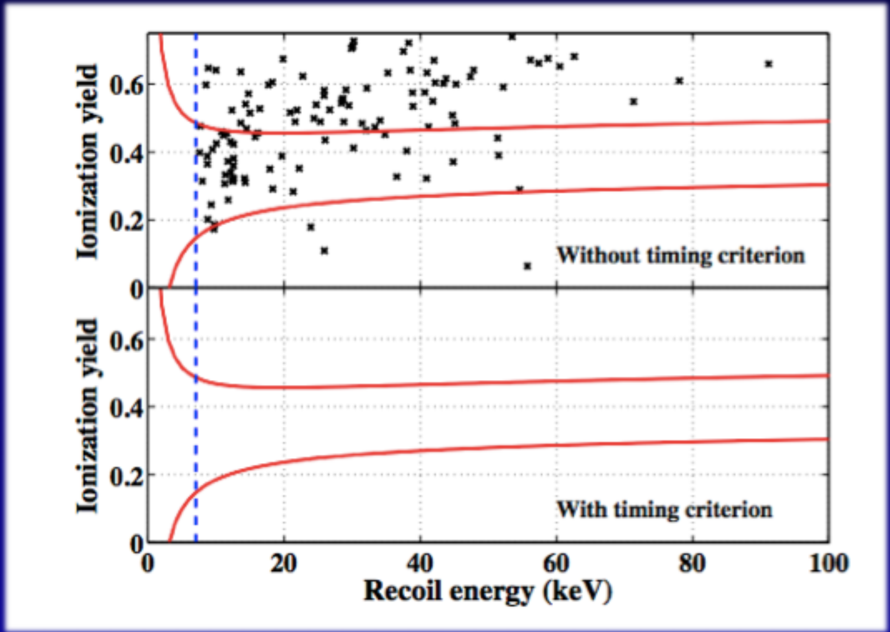
$$\chi + \chi \rightarrow q\bar{q}, W^+W^-, \ldots \rightarrow \gamma, \bar{p}, \bar{D}, e^+ \,\&\, \nu's$$

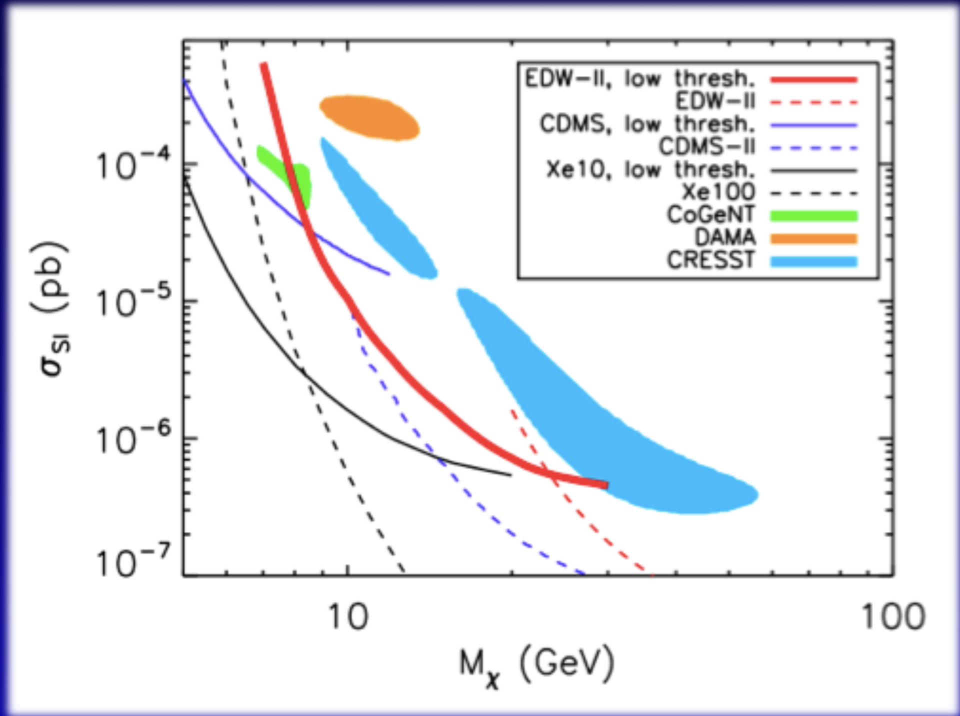


$$F_i \propto \frac{1}{4\pi d^2} B_i \frac{\langle \sigma v \rangle}{m_\chi} \int \rho^2(r) dV$$

Direct Detection: principles and dependencies (to go…)

from this → to this



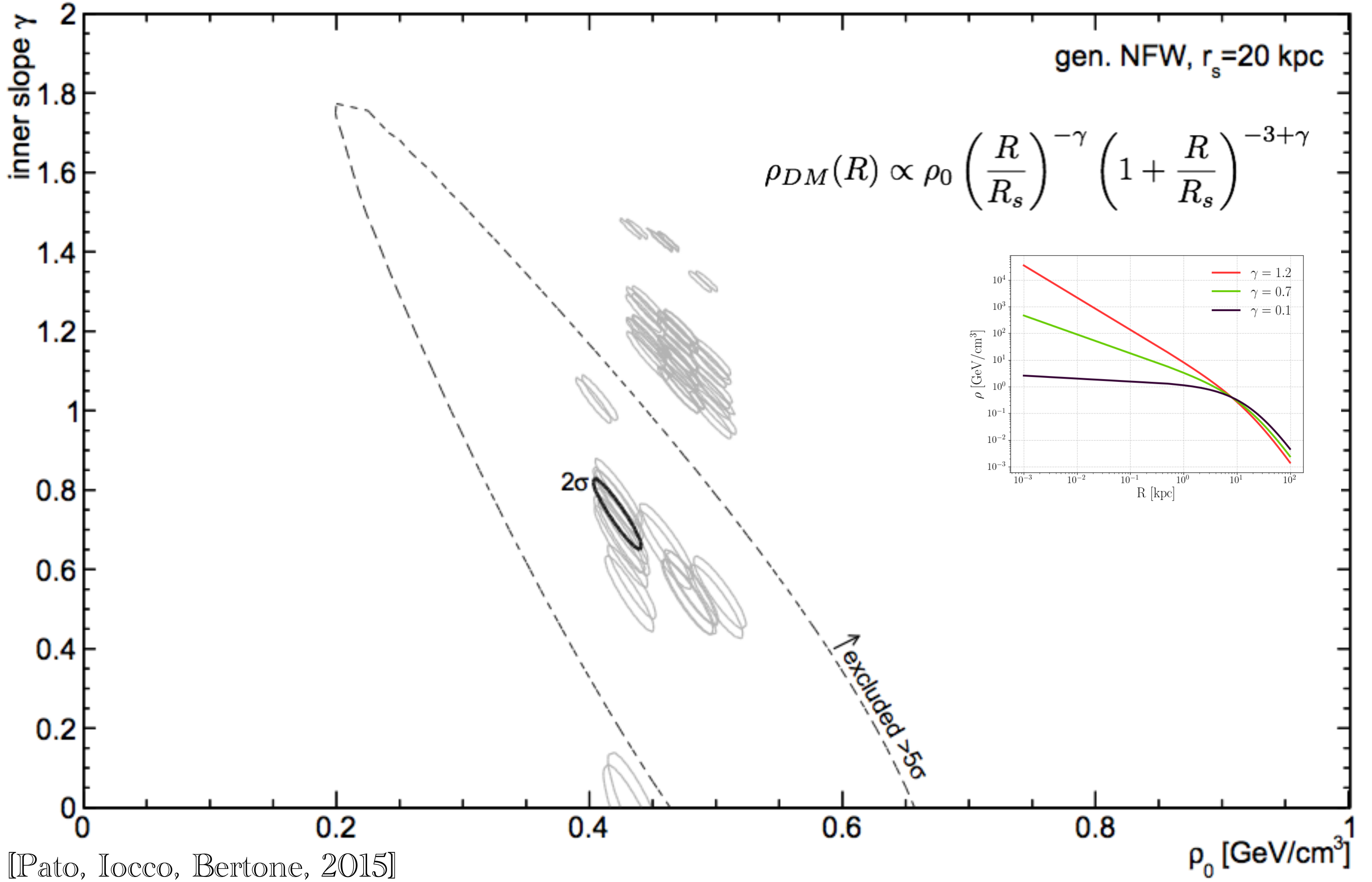


you need this

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

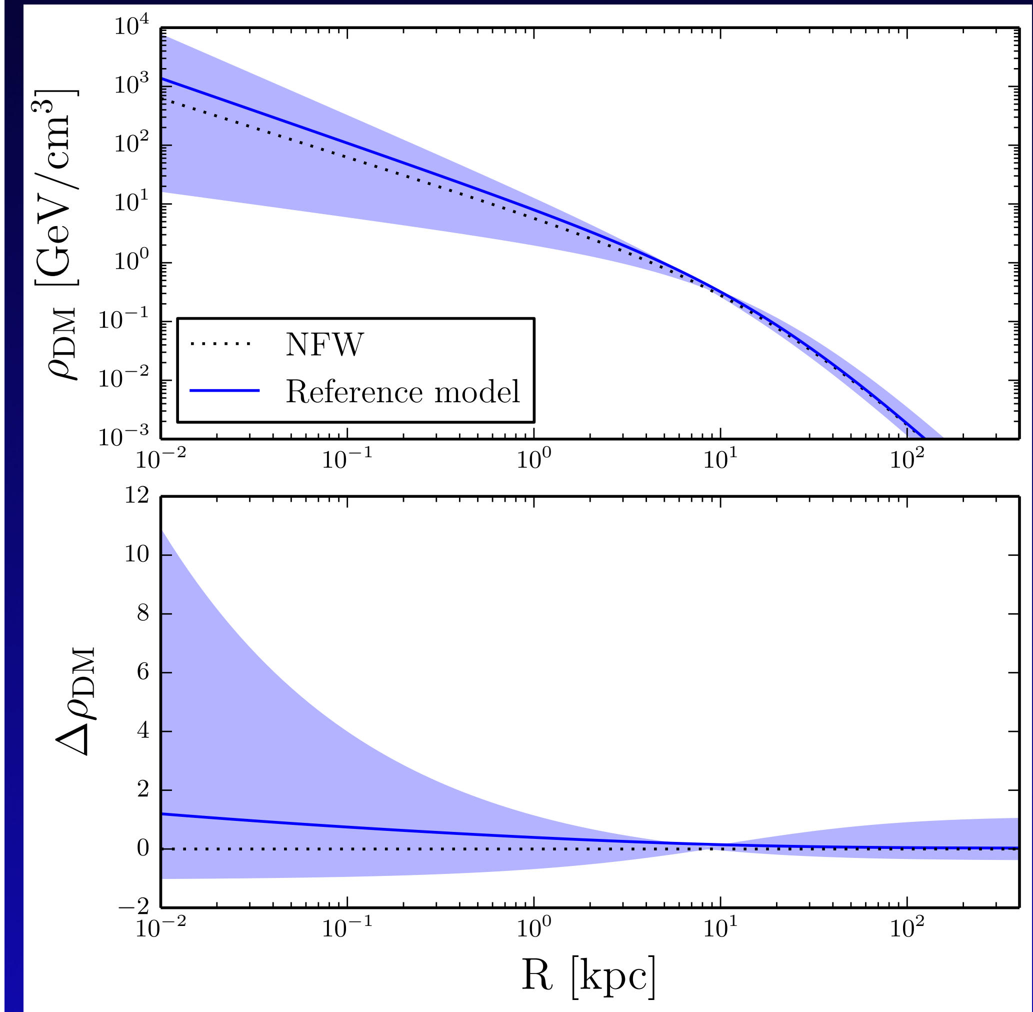
Velocity distr. f(v) not even talking about that

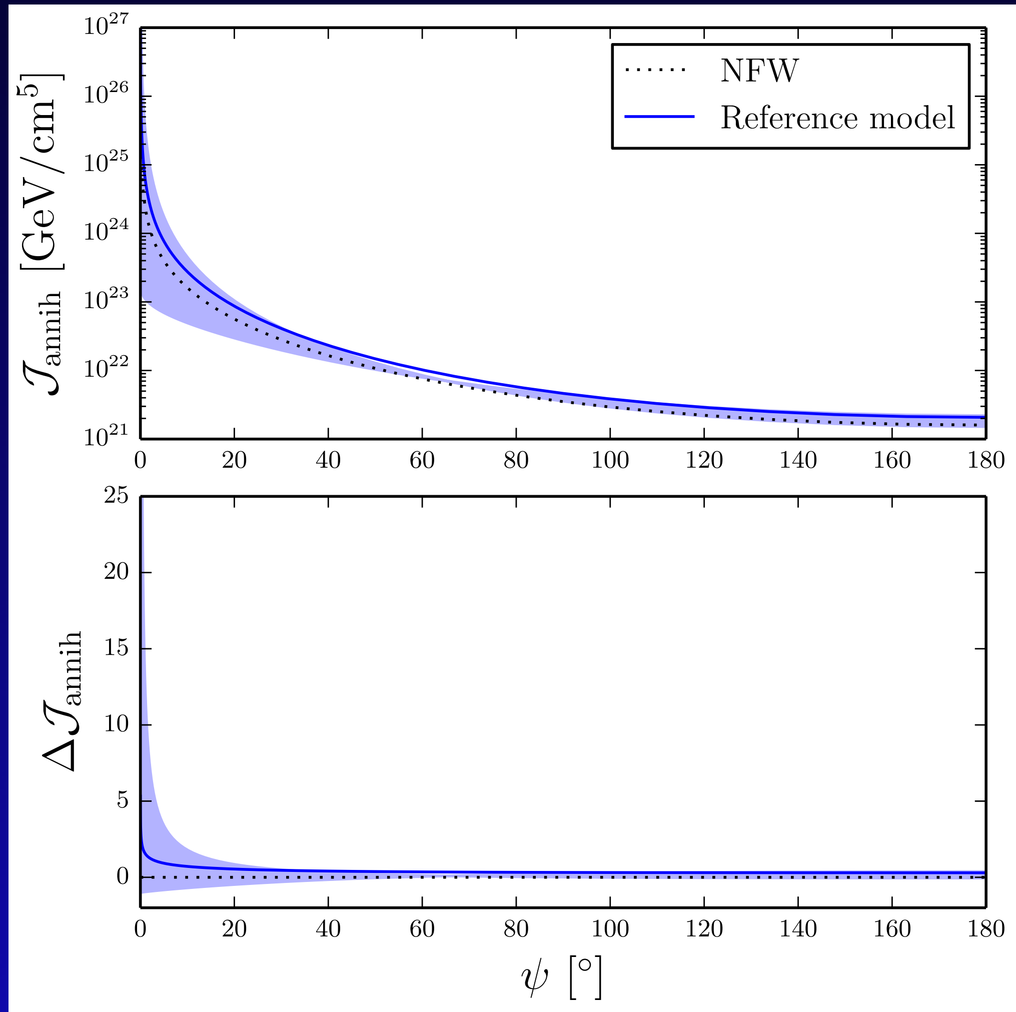
Extracting the DM density structure



[Pato, Iocco, Bertone, 2015]

But do Galactic uncertainties affect PP, for real?

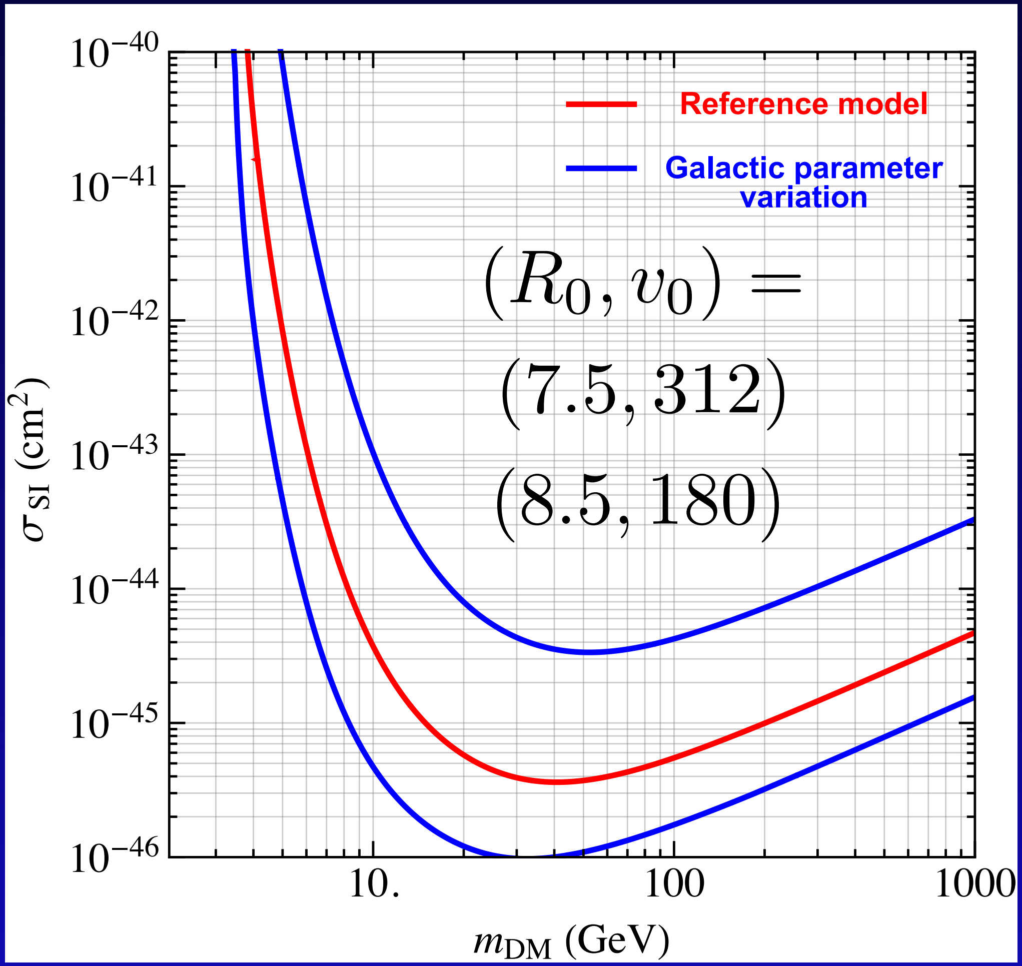




$$J_{annih} \propto \int_{los} \rho^2(r)dV$$

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

It is well known that uncertainties affect 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

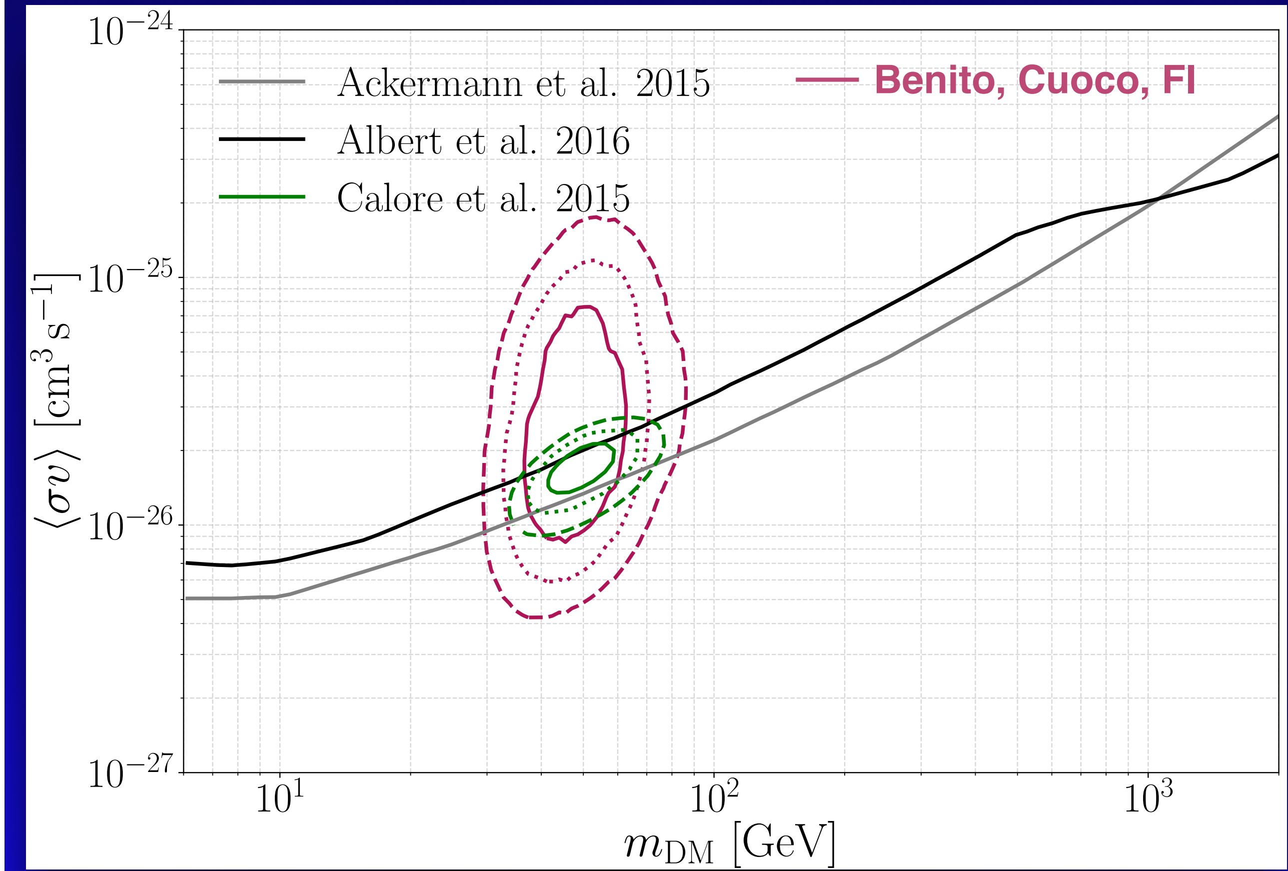
Uncertainties accounted for:

Calore analysis:

observed GC signal
(only stat. on gamma flux)

This analysis:

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



[Benito, Cuoco, Iocco, arXiv:1901.02460]
to appear in JCAP

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

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

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

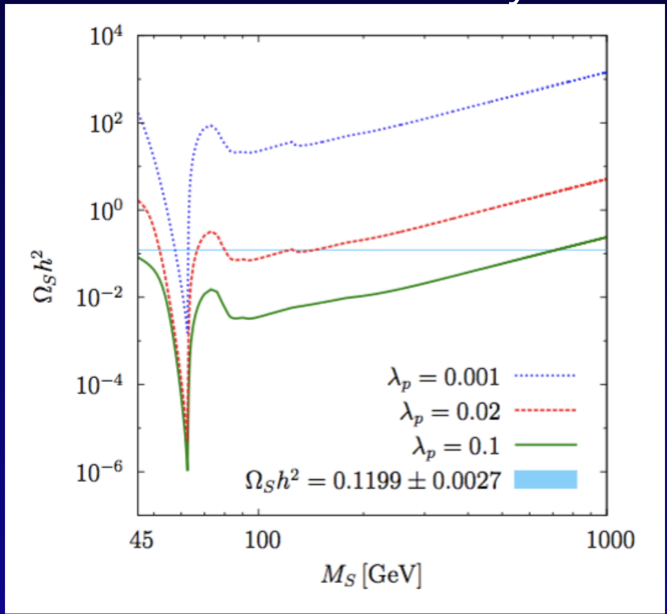
$$m_S^2 = 2 \, \mu_S^2 + \lambda_{HS} \, v_H^2$$

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

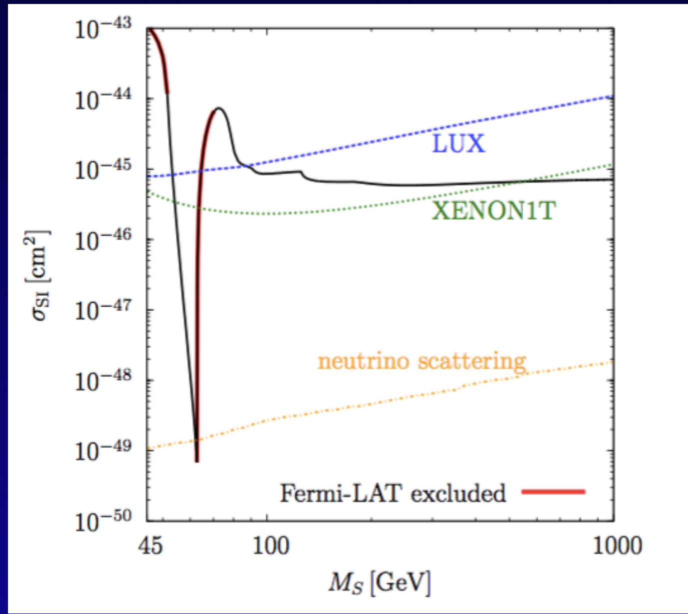
[Mc Donald, 1994] [Burgess, Pospelov, Velthuis, 2001]

Singlet Scalar DM
Constraints and interplay of experiments

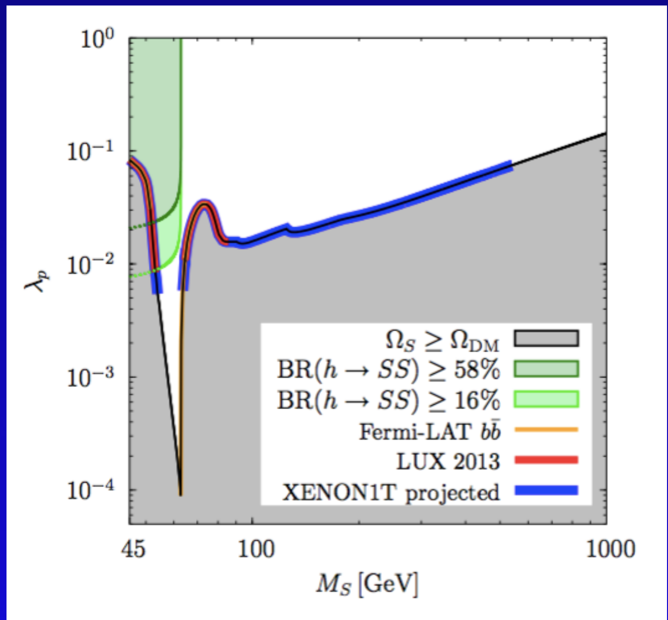
Relic density



Direct detection



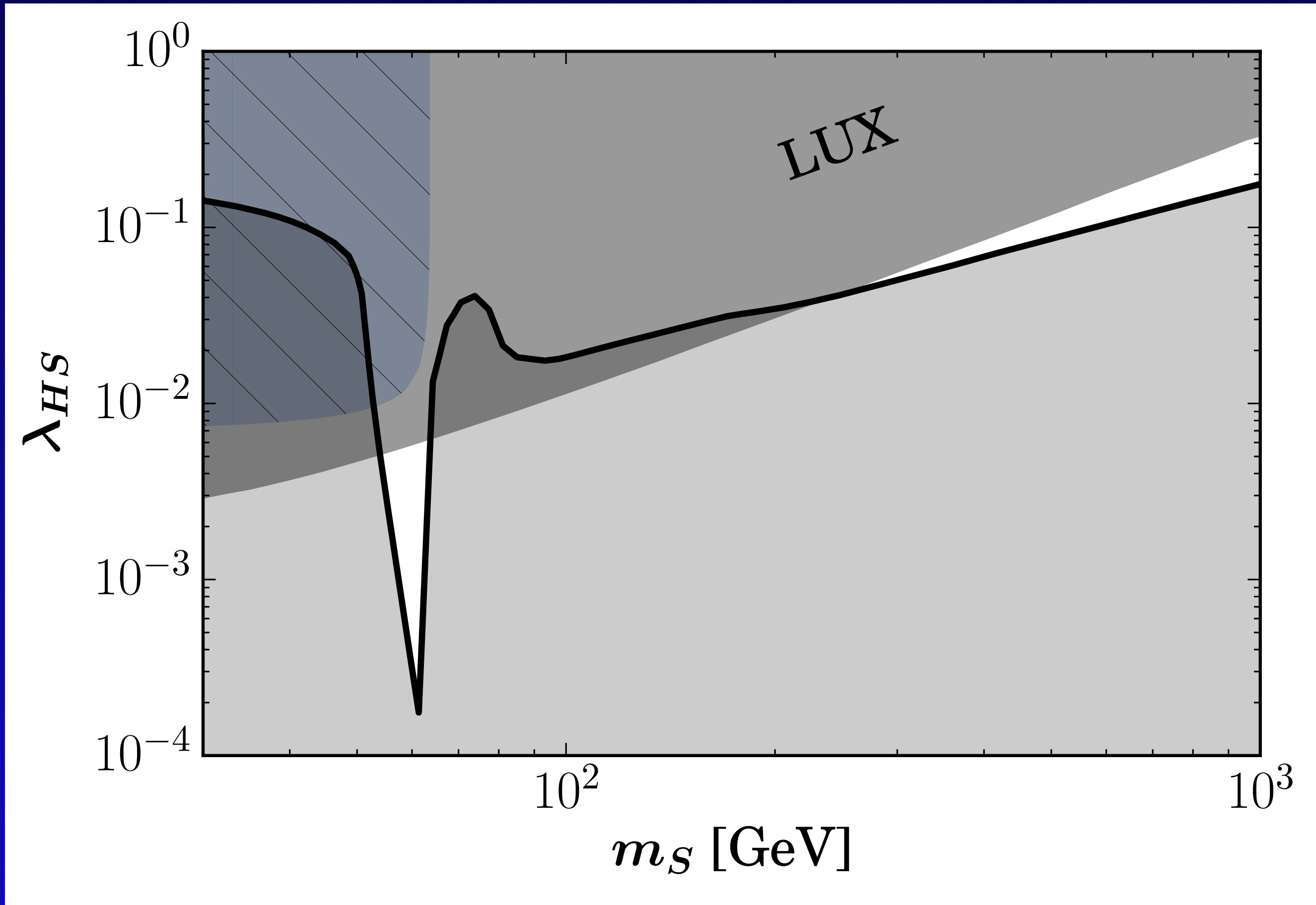
Combined



[Duerr et al, 2015]

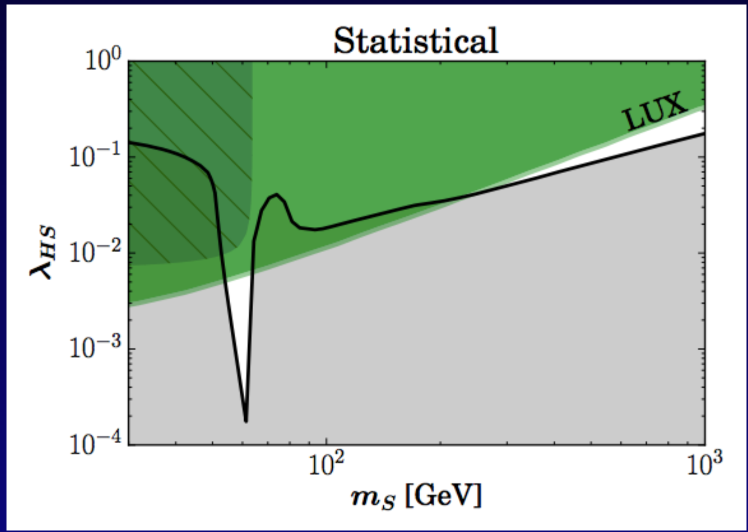
Singlet Scalar DM
Constraints and interplay of experiments

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



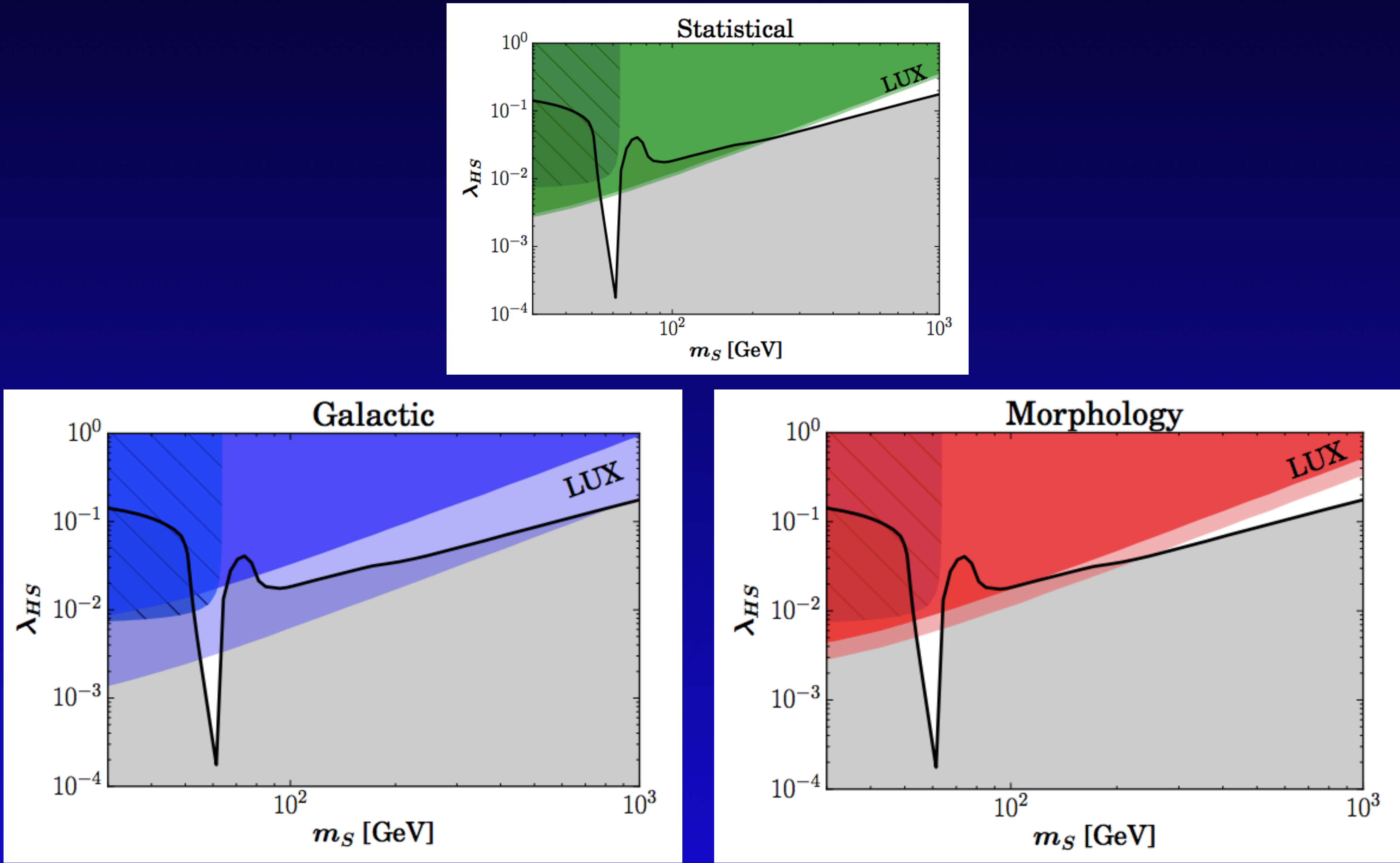
[Benito, Bernàl, Bozorgnia, Calore, Iocco, JCAP 2017; arXiv:1612.02010]

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



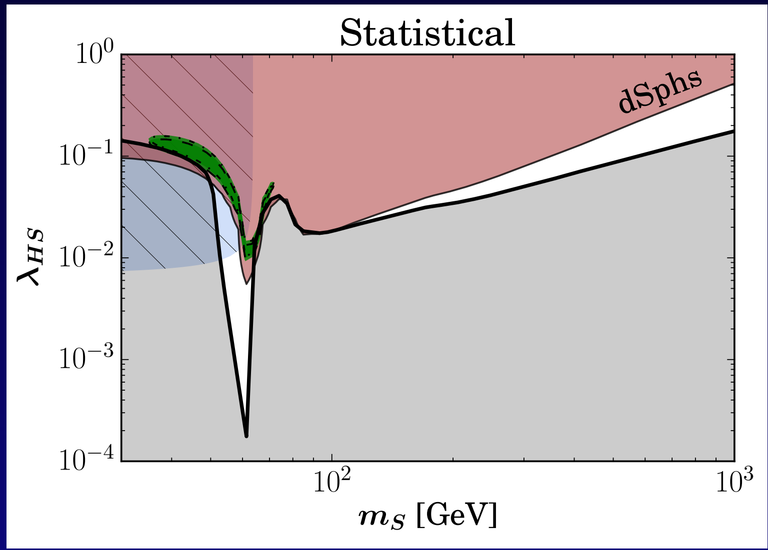
[Benito, Bernàl, Bozorgnia, Calore, Iocco, JCAP 2017; arXiv:1612.02010]

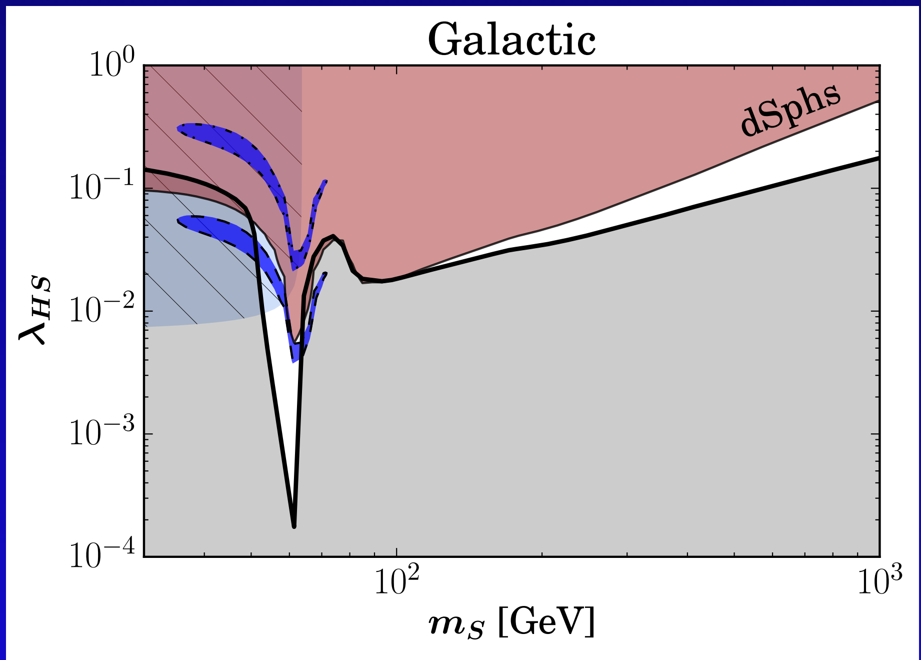
Let's look at the effect of astrophysics uncertainties: Direct Detection

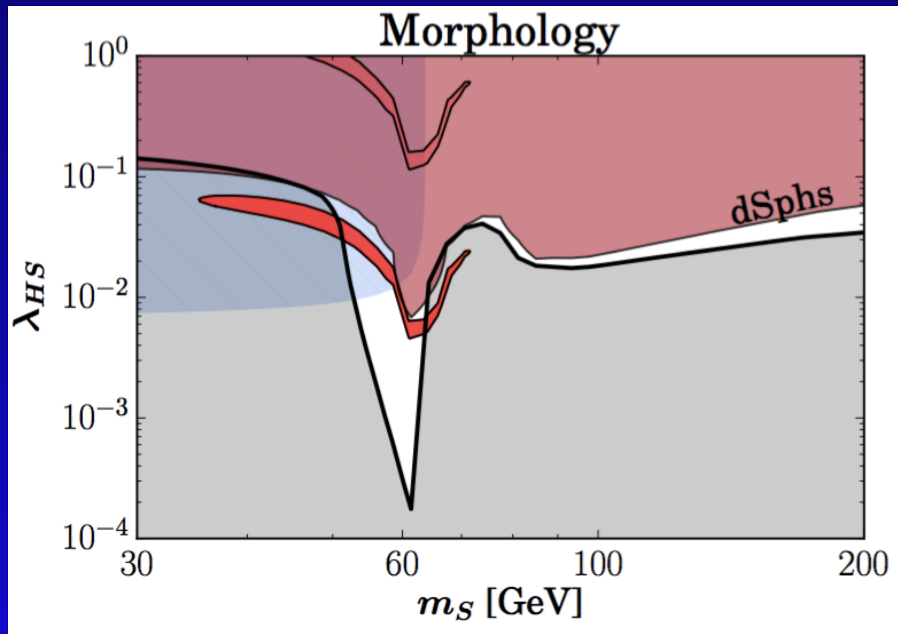


[Benito, Bernàl, Bozorgnia, Calore, Iocco, JCAP 2017; arXiv:1612.02010]

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







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

- Dark Side of the Universe
July 15-19, 2019

Campus Universidad de Buenos Aires
Argentina

Cuncta stricte

- The existence of a gravitational/non-EM interacting species is solid on vaste range of scales.
- Astrophysics and Cosmology are in very good agreement with the scenario of a warm/cold particle constituting the backbone of cosmic structures.
- We are still ignorant over the very nature of this particle(s), but there's plenty of options.
- We are starting now to achieve sensitivity with a host of probes (not only colliders) on the core region of one of the most popular scenarios.
- Astrophysical uncertainties are actually affecting determination of PP, in virtuous interplay with collider physics, direct and indirect probes.

Part II:

High Energy DM photons: CTA & the LMC

Fabio Iocco

ICTP-SAIFR, São Paulo

Federico II, NAPOLI

Università degli Studi di Napoli Federico II

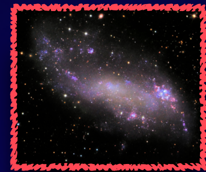
ICTP SAIFR International Centre for Theoretical Physics South American Institute for Fundamental Research

Dip. Galileo Galilei
16/4/2019, Padova

Which targets for DM gamma-ray searches?

Clusters

Dwarf Spheroidals
satellites



Spiral satellites

CTA has its agenda…

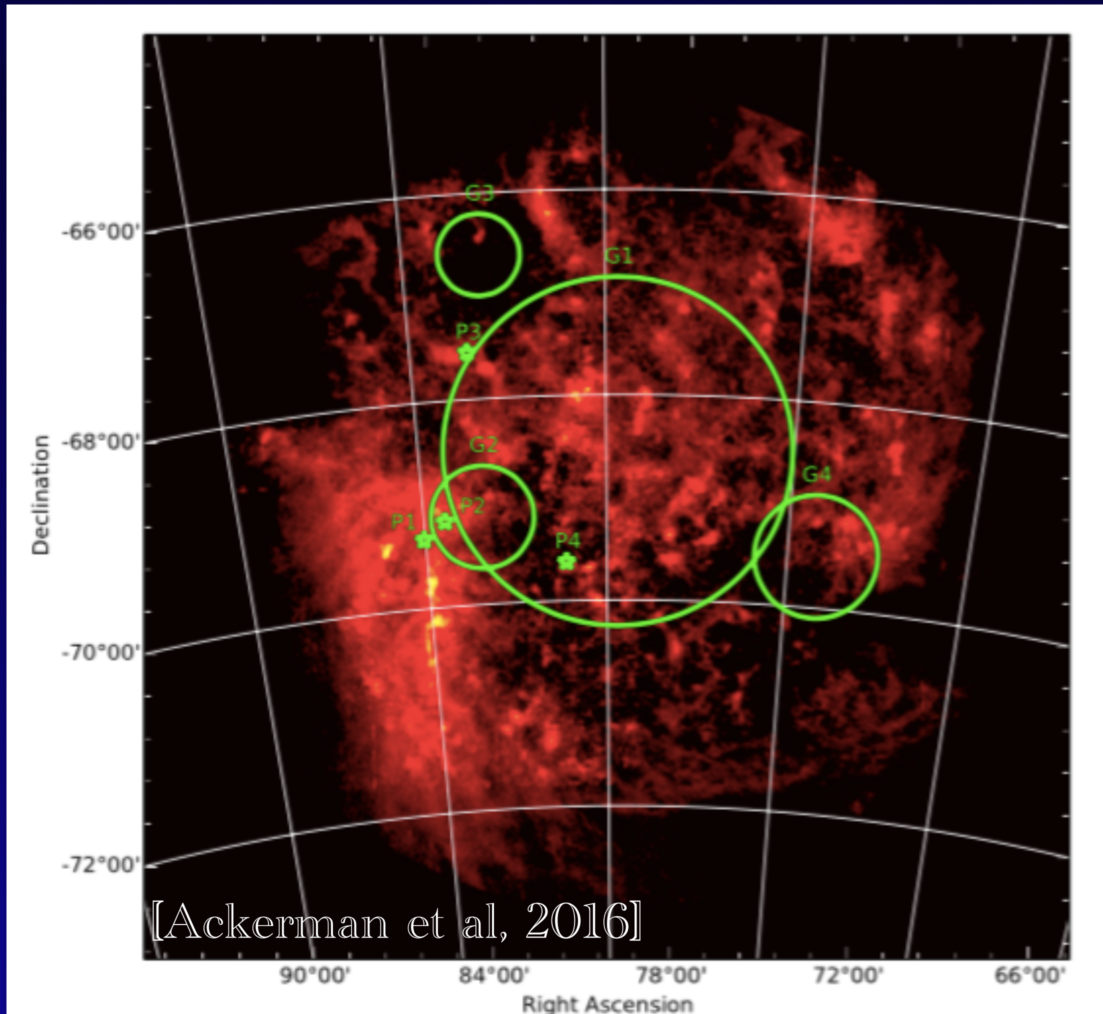
The Large Magellanic Cloud
a Milky Way satellite

Bulge, disk, spiral satellite

$$M_{LMC} \sim 10^{10} M_{\odot}$$
$$d \sim 50 kpc$$

The Large Magellanic Cloud

a gamma-rich region



Extensively studied by *Fermi*

individual sources plus a diffuse within

The Large Magellanic Cloud
Key Science Project of CTA

Very interesting object due to its remarkably high star formation activity for its small volume, proximity to the Milky Way (so it's very well resolved), presence of many high energy gamma-ray sources...

Magellanic Spiral Galaxy, satellite of the Milky Way..

Distance: 50kpc

Mass: 5.3 ±1.0 · 10^{10} $M_\odot$ (Alves and Nelson, 2000)

Diameter: 4.3 kpc (~10º)

Position(RA,dec): 80.0 , -69.5

Known γ ray sources:

- ★ 30 Dor. C superbubble
- ★ PWN N157B
- ★ SNR N 132D
- ★ ...

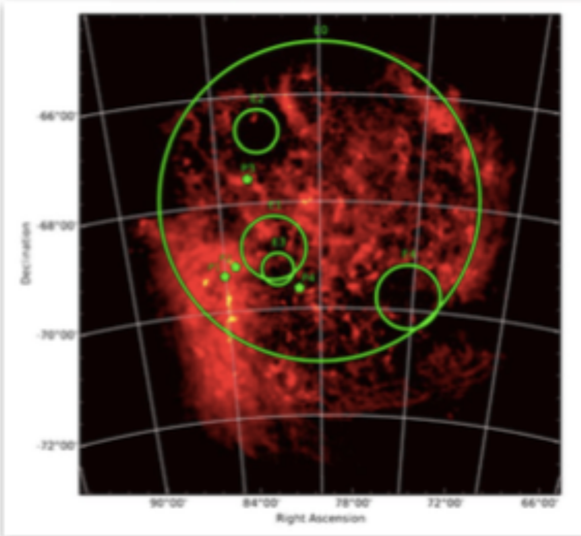
Undetected in Gamma-Rays:

SNR 1987A

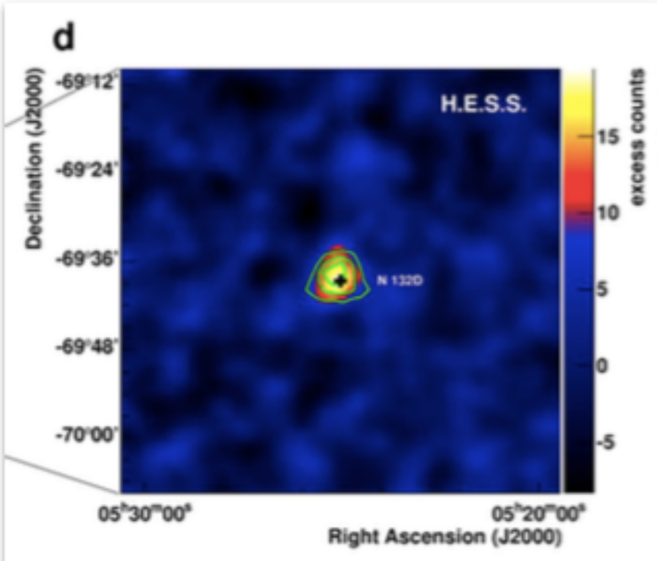
What we know it's there: previous observations

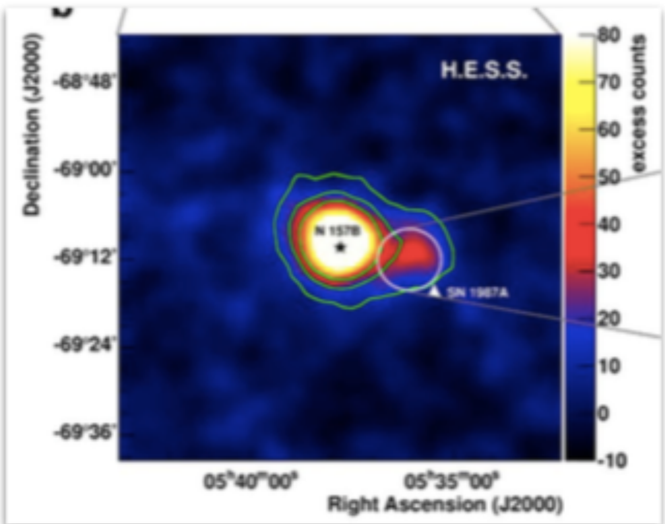
Gamma-Ray sources detected by *Fermi* LAT and H.E.S.S.:

★ Supernova Remnant N132D
★ Pulsar Wind Nebulae N157B
★ 30 Doradus C superbubble
★ Gamma-Ray Binary CXOU 053600.0-673507.
★ Pulsar PSR J0540−6919
★ 4+1 Extended sources detected by Fermi.



LAT collaboration, Ackermann et al. 2015

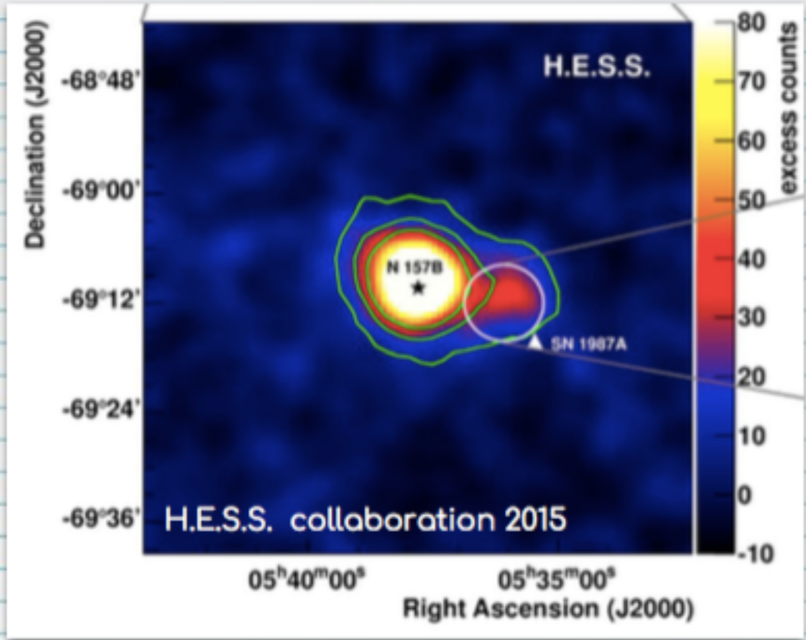


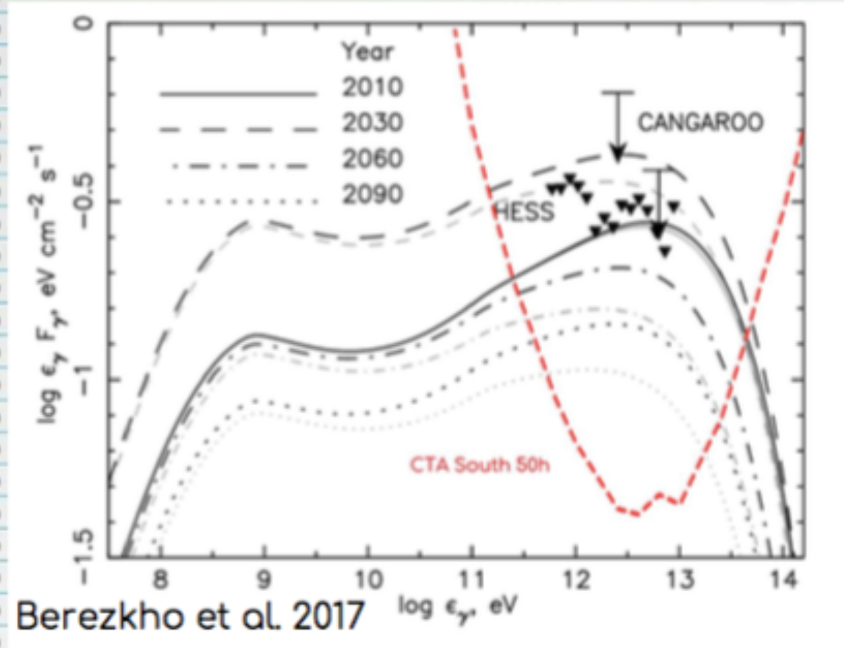


H.E.S.S. collaboration 2015

Individual Point and Extended sources

1987A, the Great Expectation





Recent core collapse SN event visible to the naked eye.

Observed in all wavelengths.

Undetected by H.E.S.S. after ~200h of exposure.

Perfect target for CTA

CTA LMC's working group homework

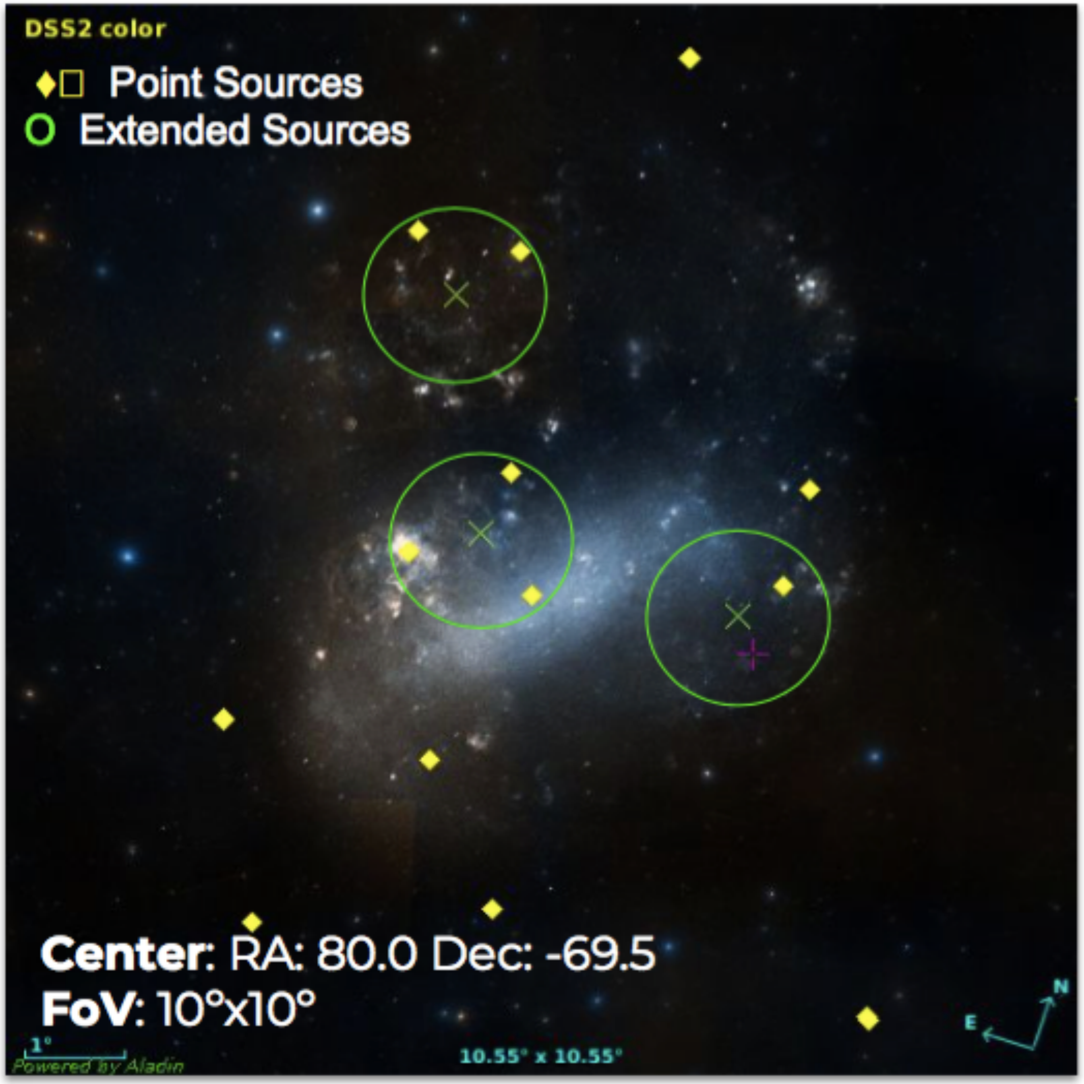
To do List

★ Build an emission model:
- What are the components of LMC?
  - Point Sources
  - Extended Sources
  - Diffuse Emission

★ Simulate CTA observations of ROI:
- LMC model
- Significance of the sources
- Correlations

★ Dark Matter in the LMC with CTA:
- DM models
- Correlations
- Constraints on DM detection.

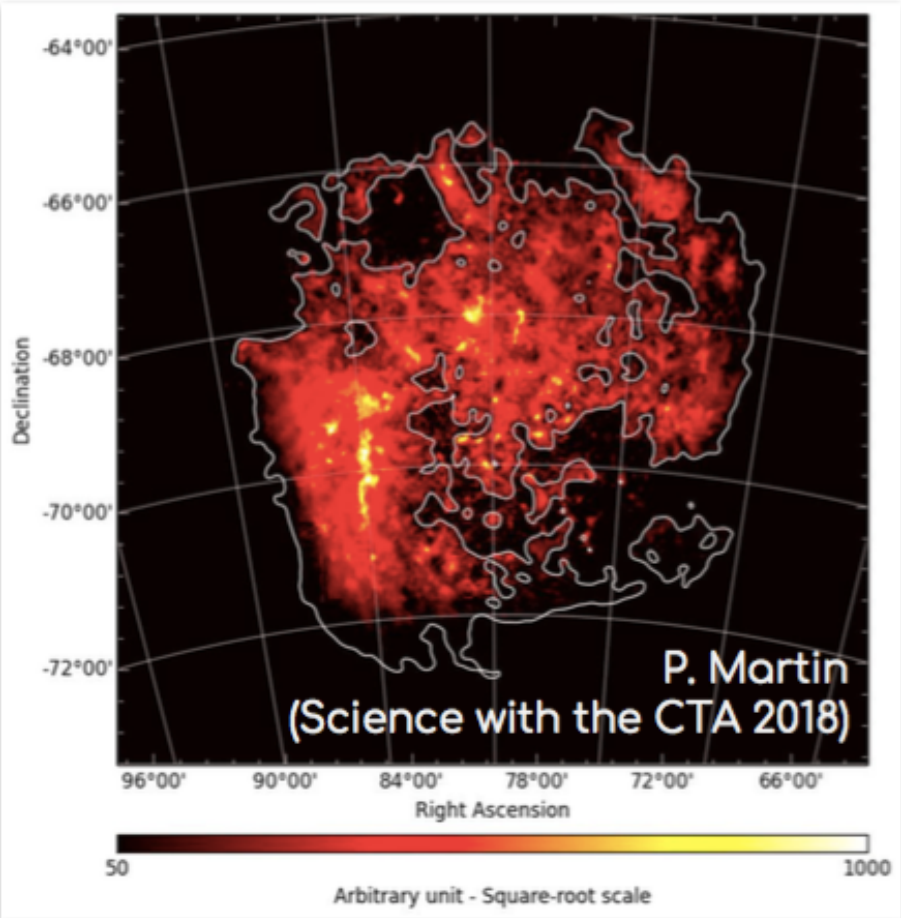
The individual sources



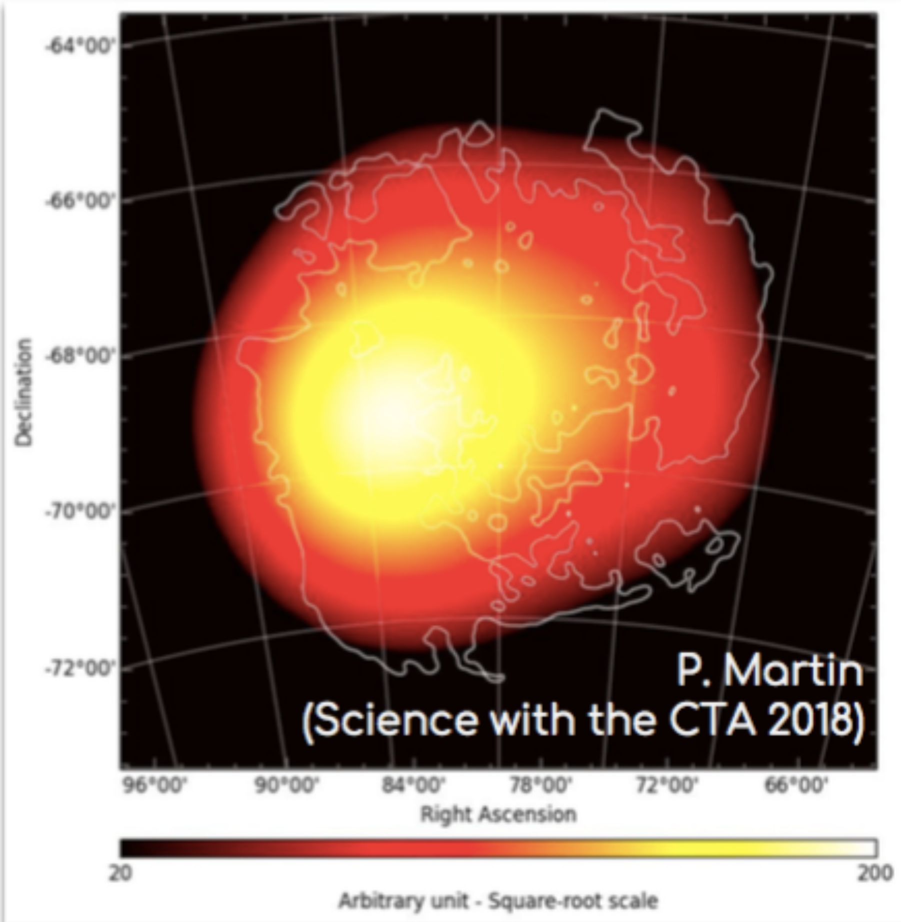
Source Catalogs:

- ★ 3FGL(2015): 3rd Fermi LAT source catalog (3FGL) of sources in the 100MeV–300 GeV range. Based on the first four years of science data from the Fermi Gamma-ray Space Telescope mission.
- ★ 3FHL(2017): 3rd catalog of Hard Fermi-LAT sources characterized in the 10 GeV–2 TeV energy range.
- ★ Ackermann et al.(2015) arXiv:1509.06903 [astro-ph.HE] from Fermi Collaboration.
- ★ H.E.S.S. Collaboration(2015) arXiv:1501.06578 [astro-ph.HE]
- ★ Komin, Haupt (2017) from H.E.S.S. Collaboration.

The diffuse emission



<u>Hadronic</u> emission from CR protons/nuclei interacting with interstellar gas in the LMC and producing pions.



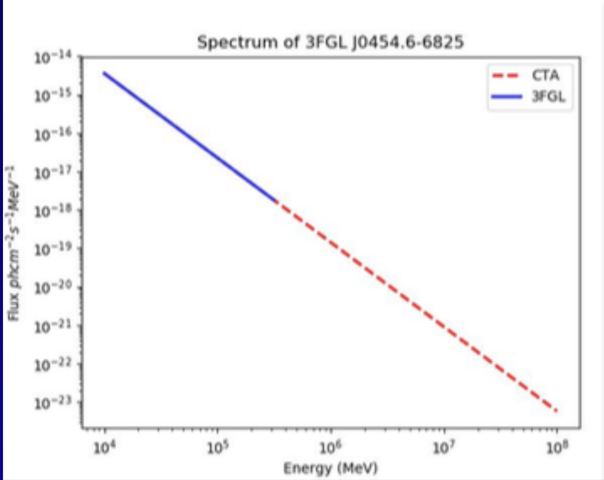
<u>Leptonic</u> emission from CR electrons inverse-Compton scattering off the radiation field.

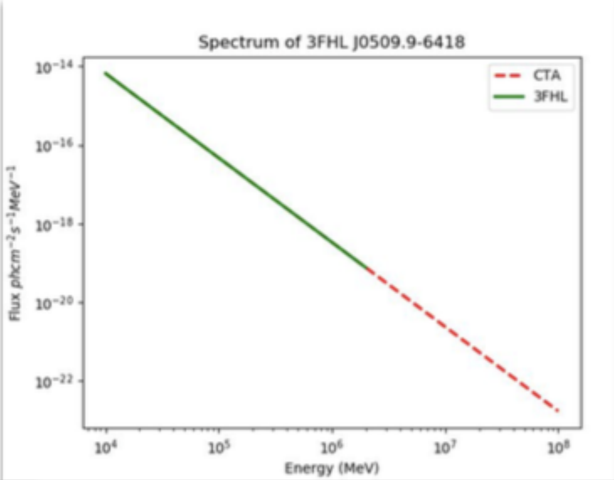
Let's get things done
I. individual spectra

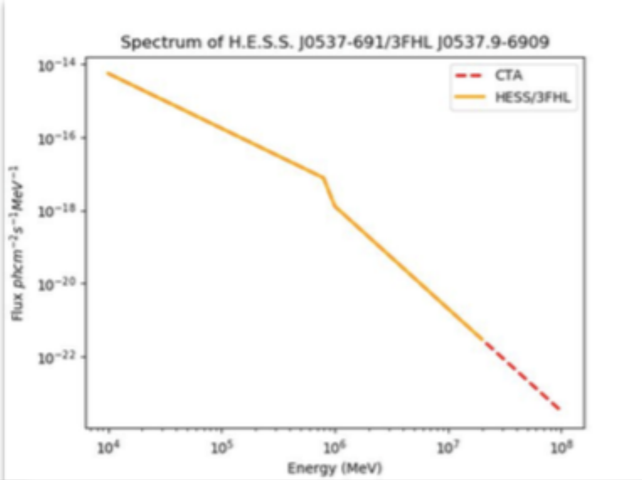
We don't have real data from CTA, so we take the observations from *Fermi* LAT/H.E.S.S. and extrapolate their results to CTA energies.

From catalogs we obtain spectral shapes (usually a power law) with parameters (spectral index and normalization):

$$M_{\text{spectral}}(E) = k_0 \left(\frac{E}{E_0} \right)^{\gamma}$$







only 3 sources with known redshift
(more to be done for EBL)

Let's get things done
II. observation settings

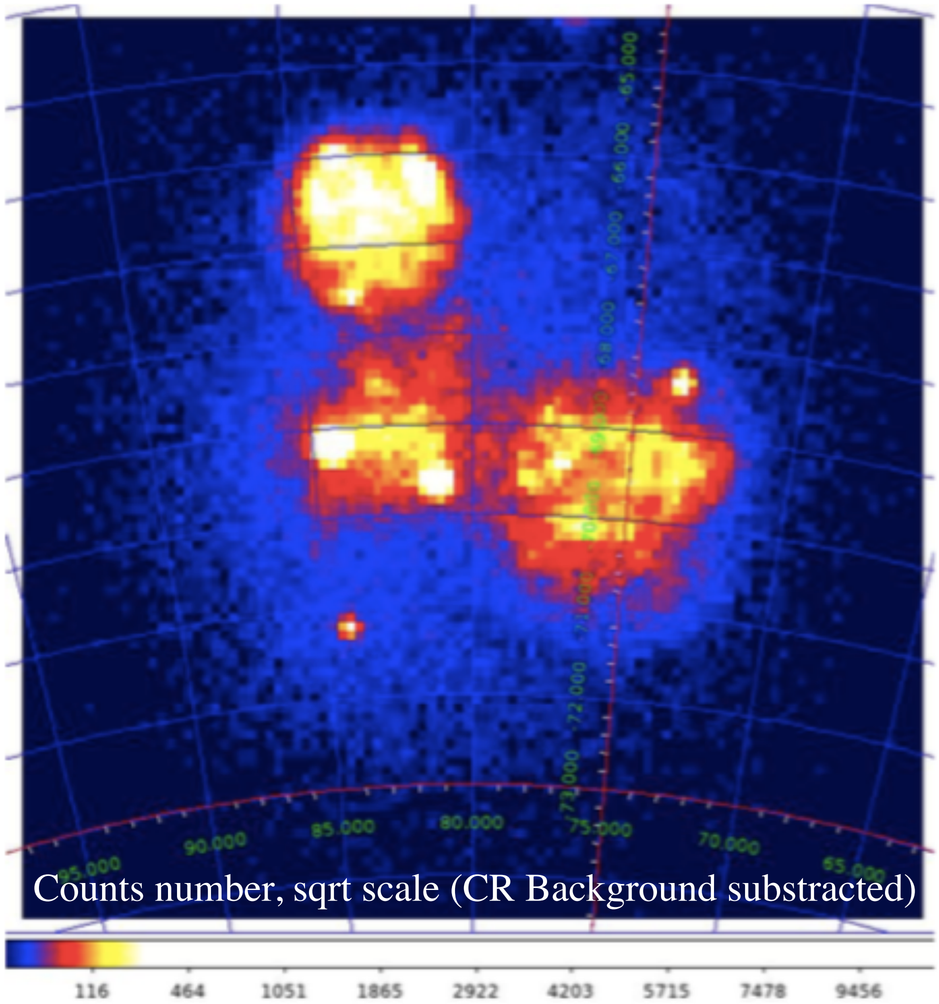
We use software ctools to simulate LMC observations.

<u>Observation settings:</u>

- ★ **Pointing:** 6 Pointings around LMC center.
- ★ **Exposure time:** 50h per pointing, 300h.

<u>Analysis settings:</u>

- ★ 3D binned maximum-likelihood analysis.
- ★ **Energy:** 0.03 TeV to 100 TeV.



Counts number, sqrt scale (CR Background substracted)

IRF: prod3bv1, South_z40_average_50h

Let's get things done
III. statistics and significance

Statistics reminder

$$L = \prod_{i}^{N} \frac{m_i^{n_i}}{n_i!} e^{-m_i}$$

n_i = number of observed counts in the bin i (simulated data)

m_i = number of predicted number of counts in the bin i (model):

$$m_i = K_0 Srcmodel_{0,i} + K_1 Srcmodel_{1,i} + .. + K_N Srcmodel_{N,i}$$

Parameters "K" (Normalization) maximize the likelihood.

Significance:

$$TS = 2log\frac{L}{L_{null}}$$

"Detection"
TS > 25

Point sources

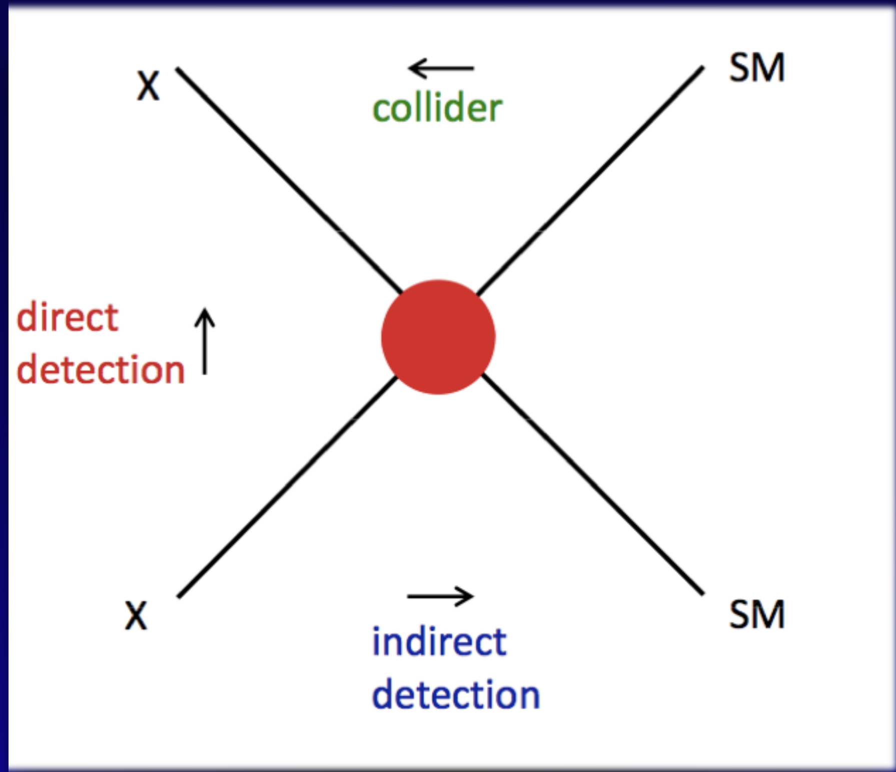
Source name	Significance(σ)
J0500.9-6945e	163,64
J0530.0-6900e	35,62
J0531.8-6639e	127,15
J0537-691	550,33
J0524.5-6937	226,74
J0534.1-6732	68,37
J0525.2-6614	94,64
J0535.3-6559	73,95
J0454.6-6825	79,38
J0537.0-7113	17,07
J0535-691	46,32
J0525-696	96,43

Let's get things done
V. Dark Matter

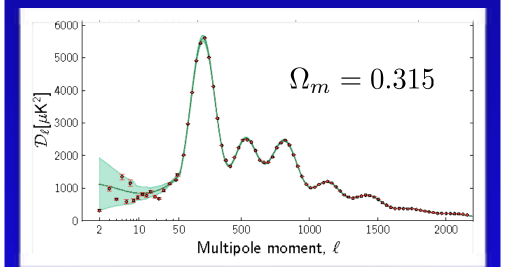
Direct detection:
DM scattering against nuclei, recoil

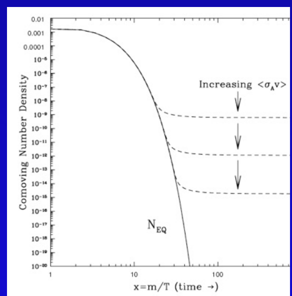
Indirect detection:
Annihilation in astrophysical envir.
Observation of SM products of annih.

Production at LHC



Motivated by cosmological/PP arguments
but not only DM candidate!

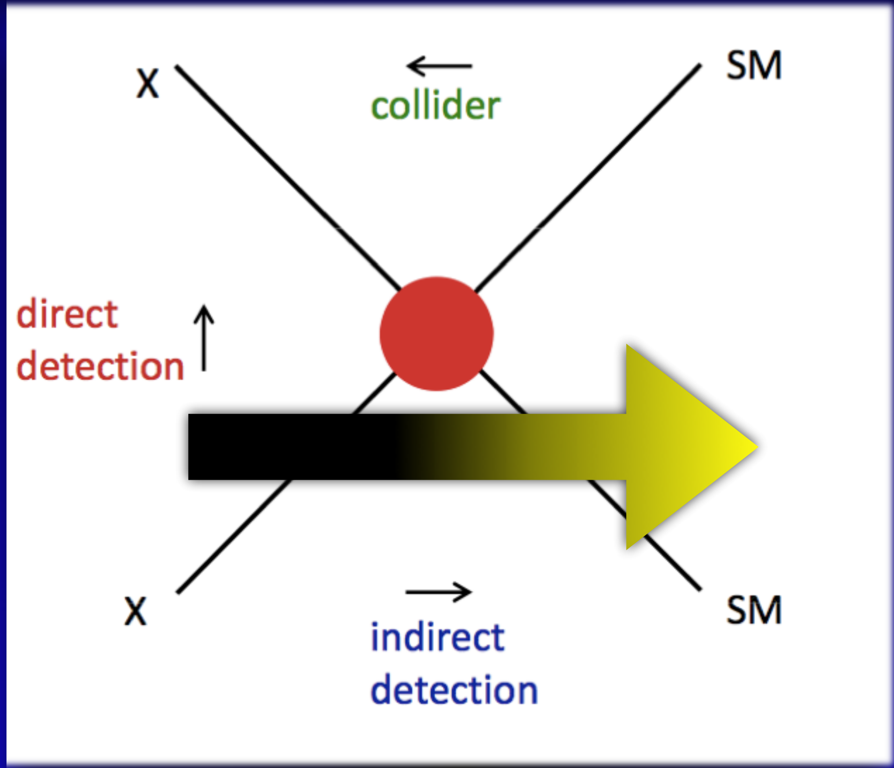




Let's get things done
V. Dark Matter

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

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

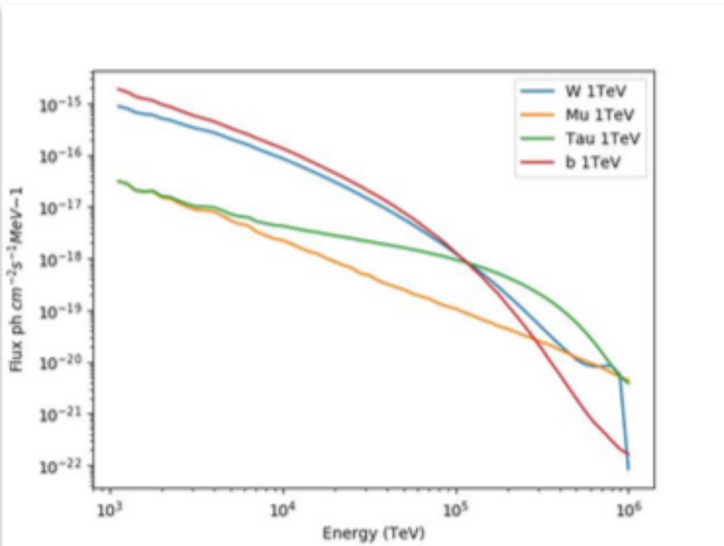


Let's get things done
V. Dark Matter

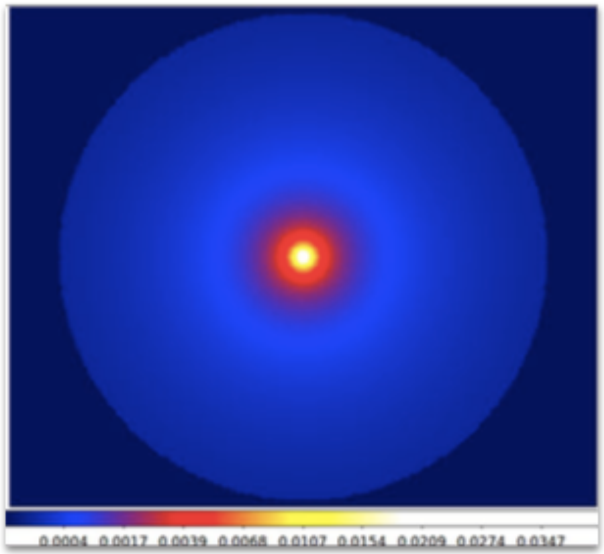
Dark Matter Model in the LMC

$$\frac{d\Phi}{dEd\Omega} = \frac{1}{4\pi}\frac{<\sigma v>}{km_{DM}^2}\frac{dN_\gamma}{dE}\int_{l.o.s} dl\rho^2(l,P)$$

Particle Physics term
Spectra from Cirelli et al. 2011

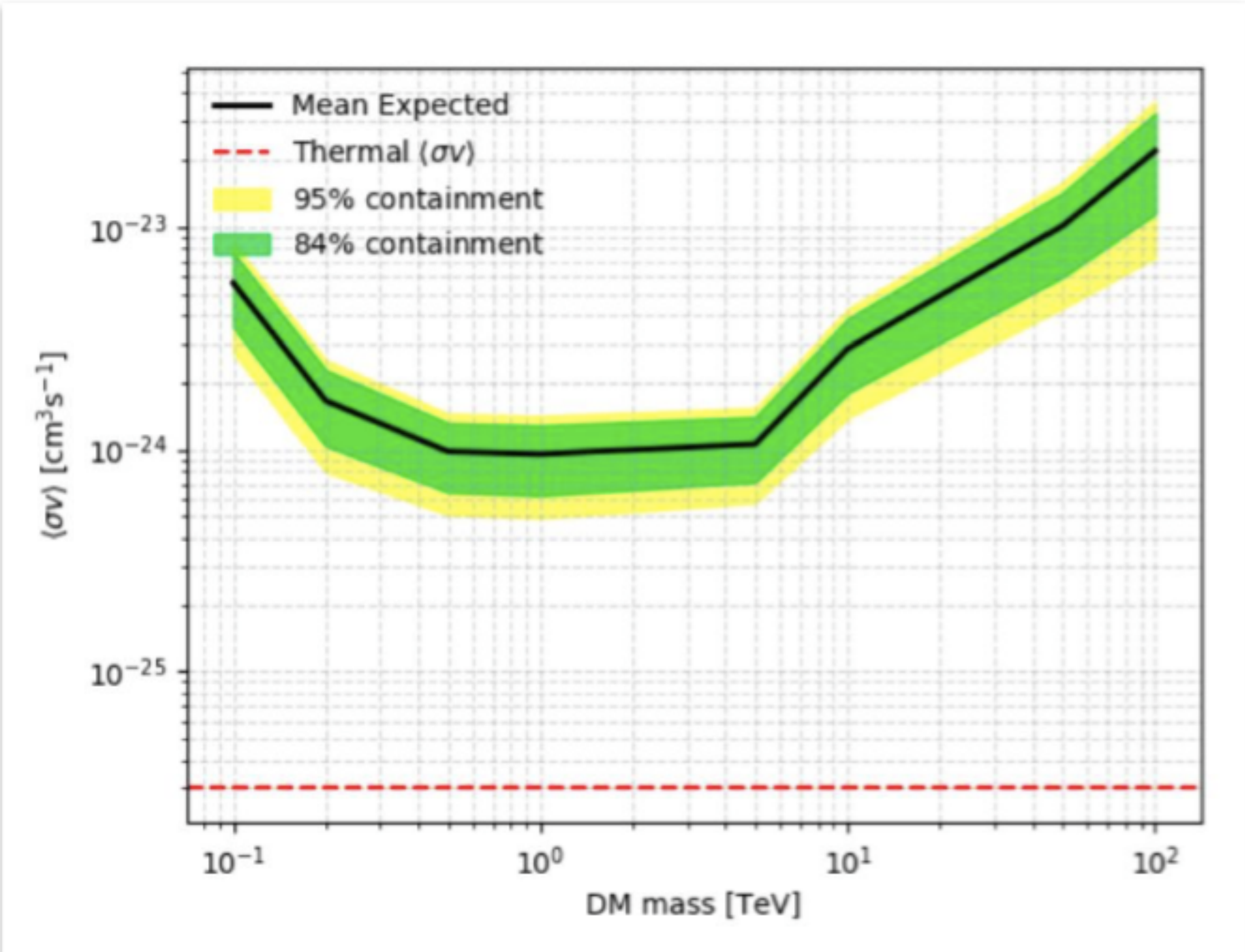


Astrophysics term
J-Factor computed with Clumpy software



Counts (sqrt scale)

Let's get things done
V. Dark Matter



W^+W^- annihilation channel, 100 realizations of LMC data.

- School on High Energy Astrophysics
August 5-16, 2019

ICTP-SAIFR
São Paulo,
Brazil
(not Rio de Janeiro!)

Cuncta stricte

- Characterization of all known sources in LMC ROI: completed.
- Some refinement for diffuse components possible, but not crucial at this stage.
- DM potentially detectable above thermal cross section, as expected.
- A Consortium paper under way, corresponding authors: M.I. Bernardos(student), FI, P. Martin