Testing Dark Matter with local astrophysical observations

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12/2/14
LAPTh, Annecy-le-Vieux

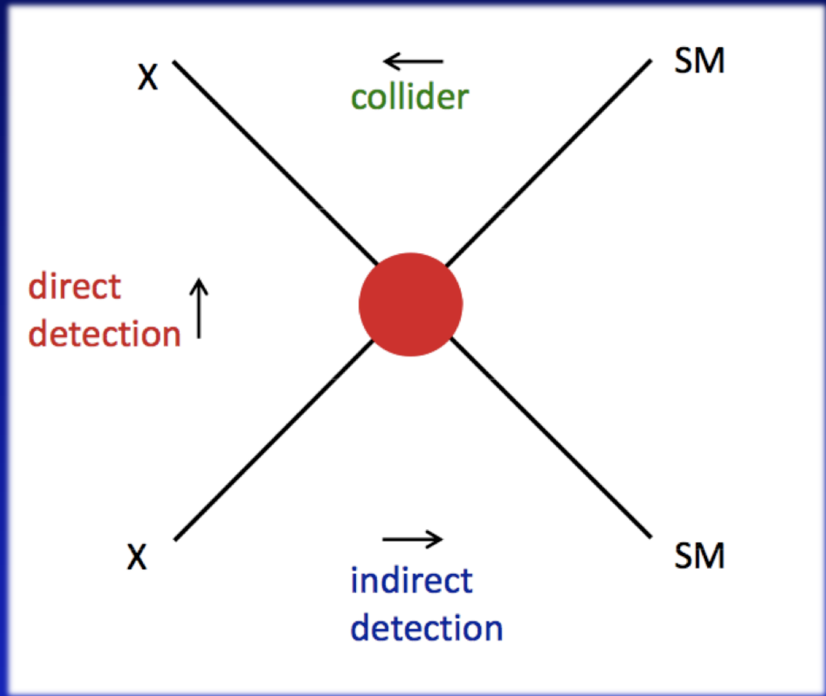
Direct and indirect searches of WIMP DM

complementary to colliders

Direct detection:
DM scattering against nuclei, recoil

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

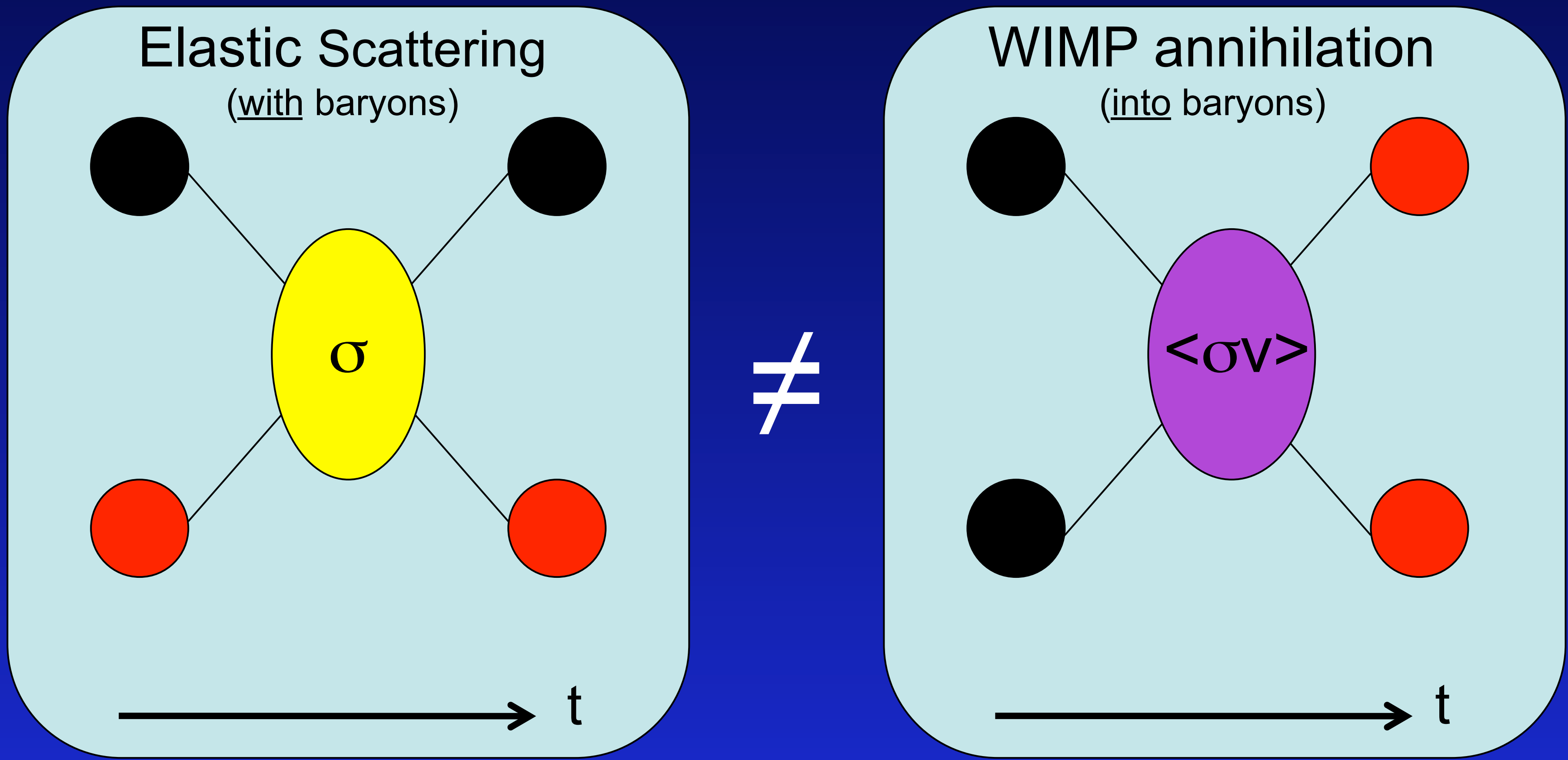
Production at LHC



Notice that:
quantum matrix elements for three processes are related, but…

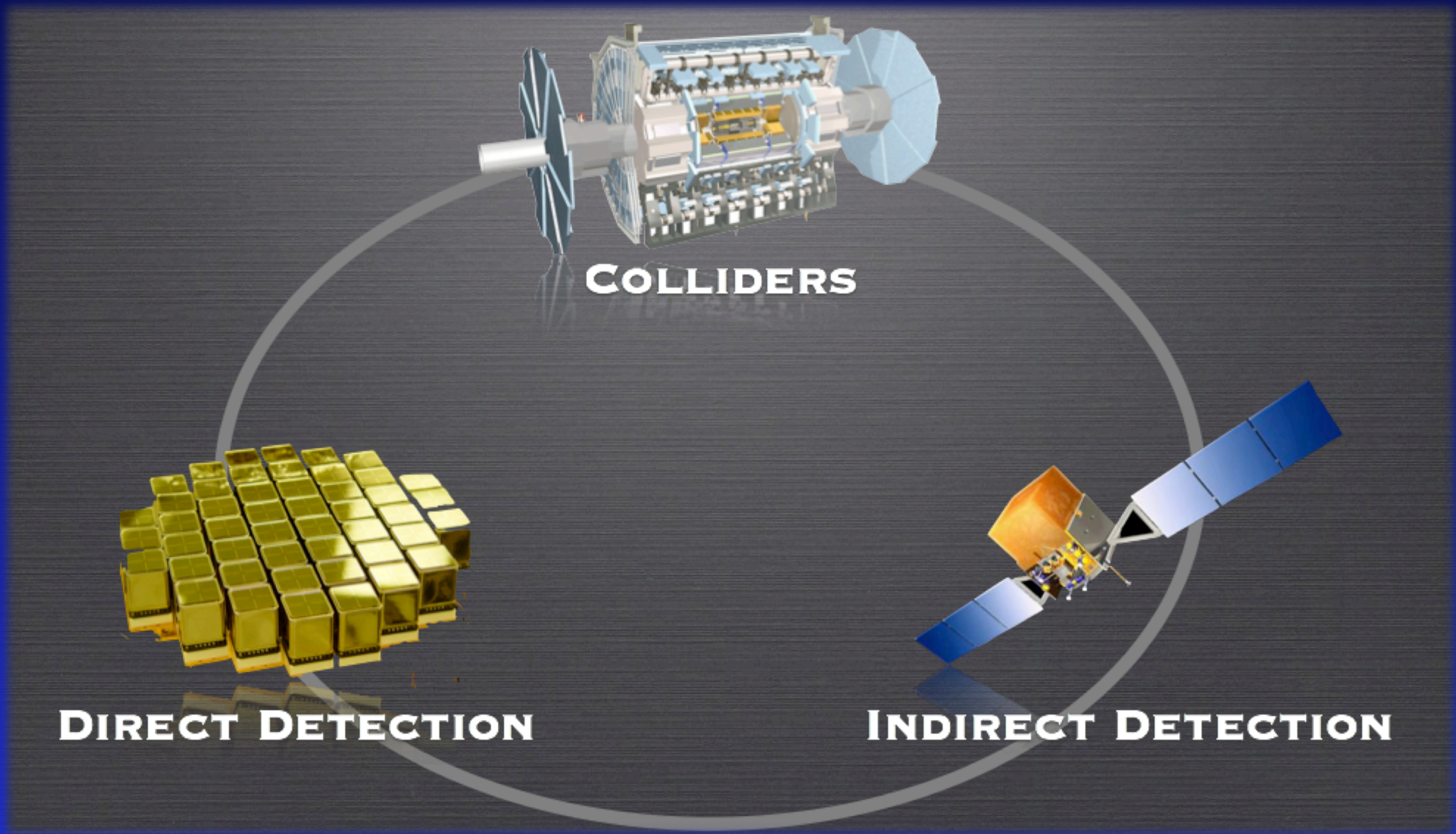
Direct and indirect searches of WIMP DM:

complementary to colliders



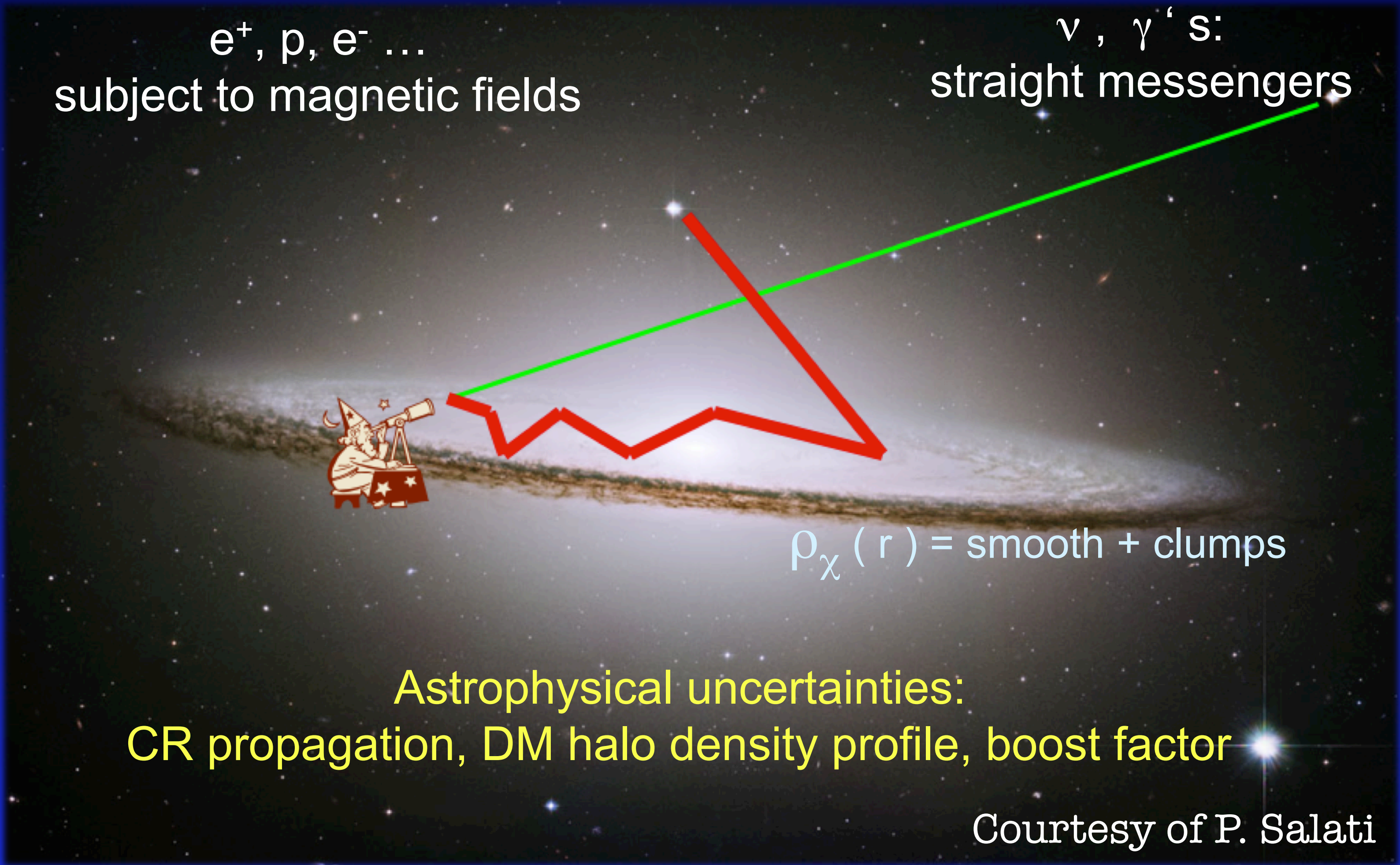
Direct and indirect searches of WIMP DM

complementary to colliders

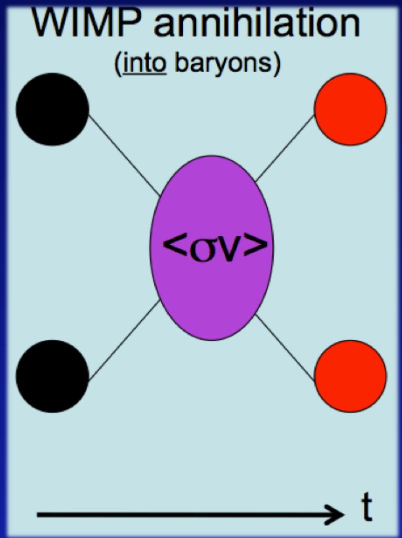


Constraining DM with local observables

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



Local observables for DM annihilation:



$$F = \frac{1}{2}\frac{1}{4\pi d^2}\frac{N_\gamma \boxed{\langle \sigma v \rangle}}{m_\chi^2}\int_0^R \boxed{\rho^2(r)}\, d^3r$$

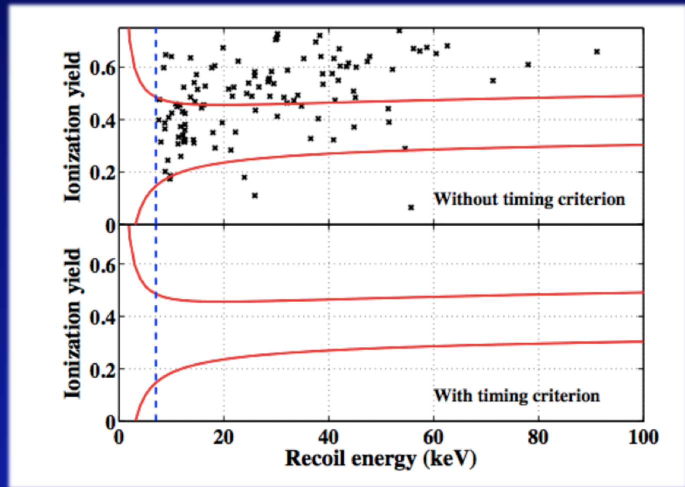
Galactic center, Dwarf Galaxies, Galactic Halo…
dependence on density structure

constraints (or discovery) subject to same uncertainty

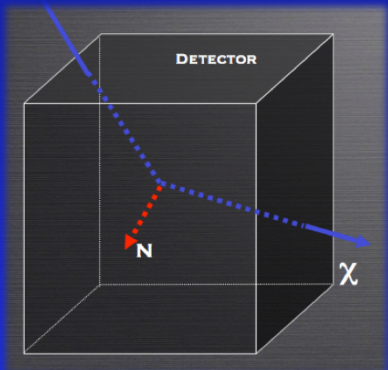
Direct searches of WIMP DM:

Take a big mountain

Look at phonons/ionizations/scintillations

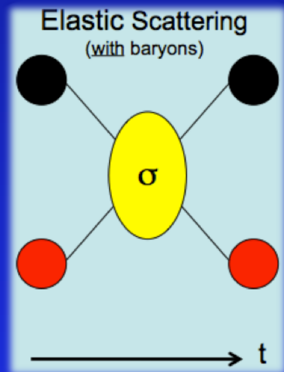


Place a detector underneath

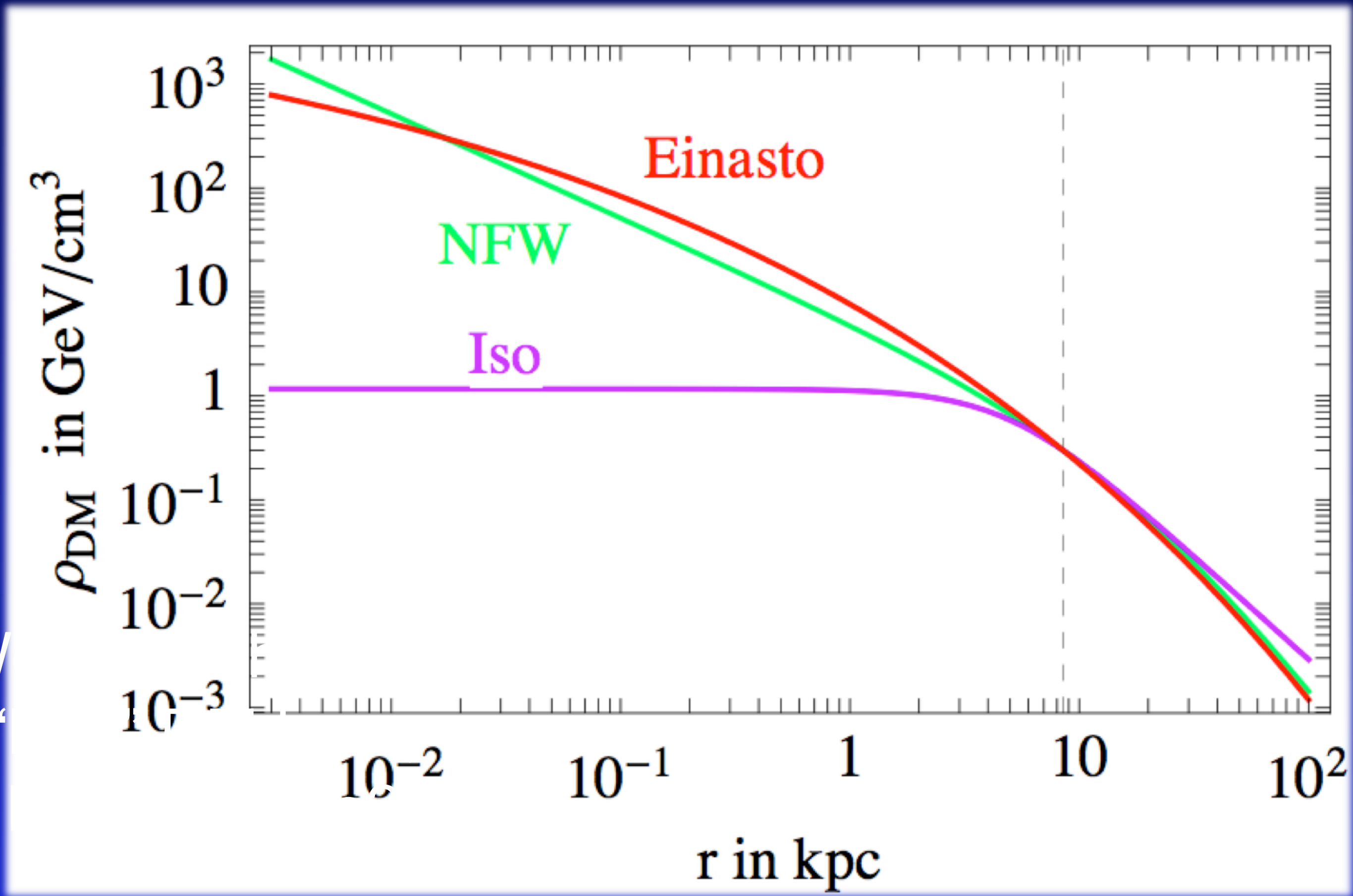


And, ideally:

$$\frac{dR_{A,Z}}{dE} = \boxed{\frac{\sigma_{A,Z}(E)}{2m\mu^2_{A,Z}}}\rho\,\eta(v_{\min}, t)$$

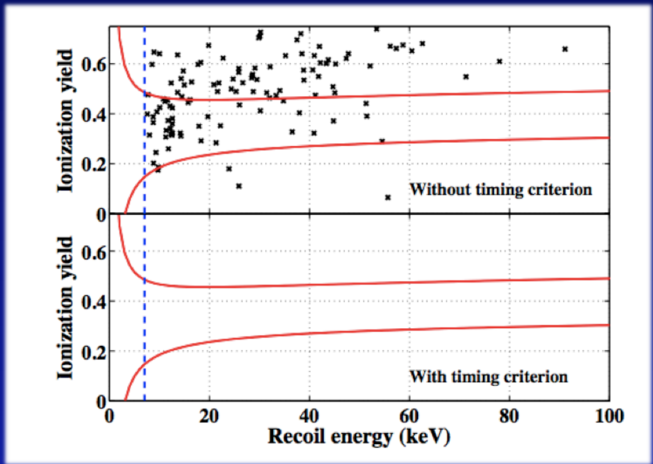


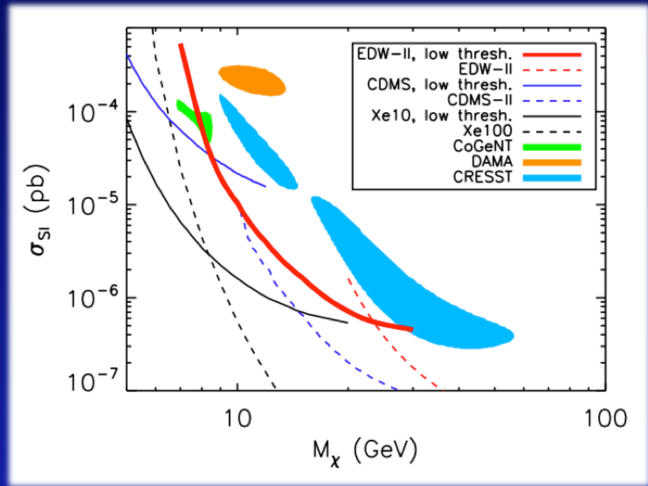
Direct and inDirect crucially depend on DM distribution



Direct searches of WIMP DM:

from this → to this





you have to use this

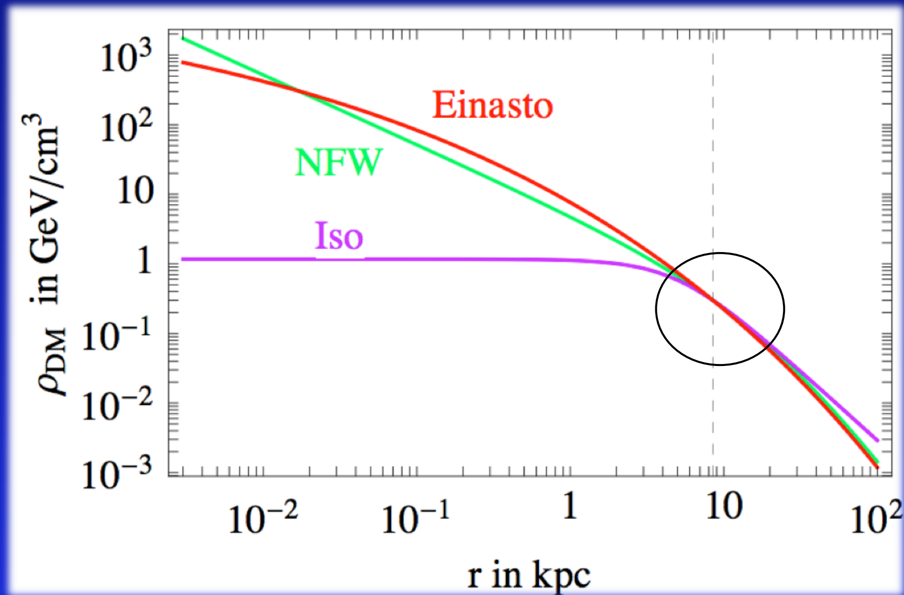
$$\frac{dR_{A,Z}}{dE} = \frac{\boxed{\sigma_{A,Z}(E)}}{2m\mu^2_{A,Z}}\,\boxed{\rho}\,\boxed{\eta(v_{\min},t)}$$

Velocity distribution properties of DM

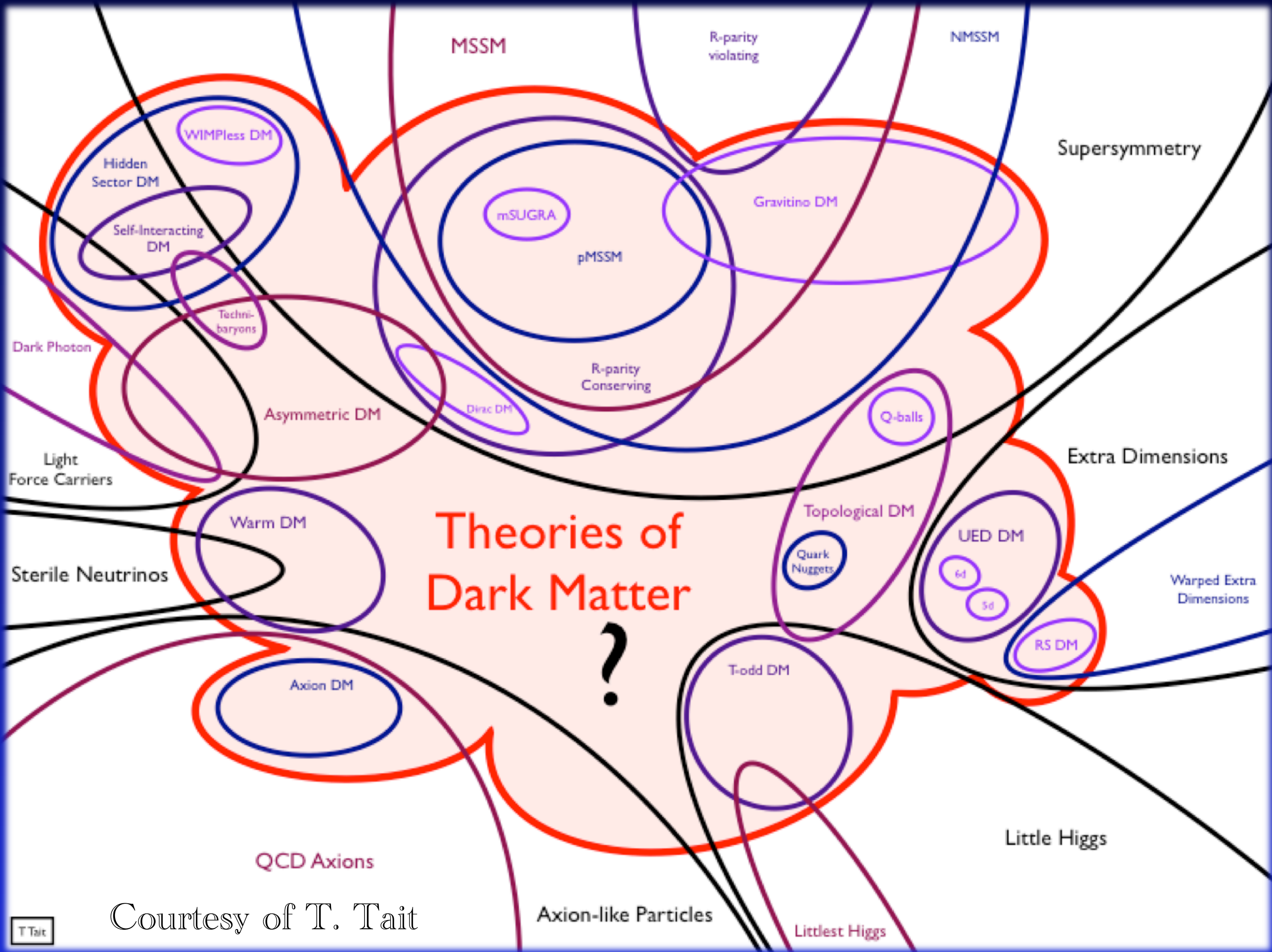
DM density at the Sun's location, ρ_0

DM density at the Sun: ρ_0 = ?

We know there is
"little" DM here,
But how little?



A polite disclaimer: *WIMP* DM

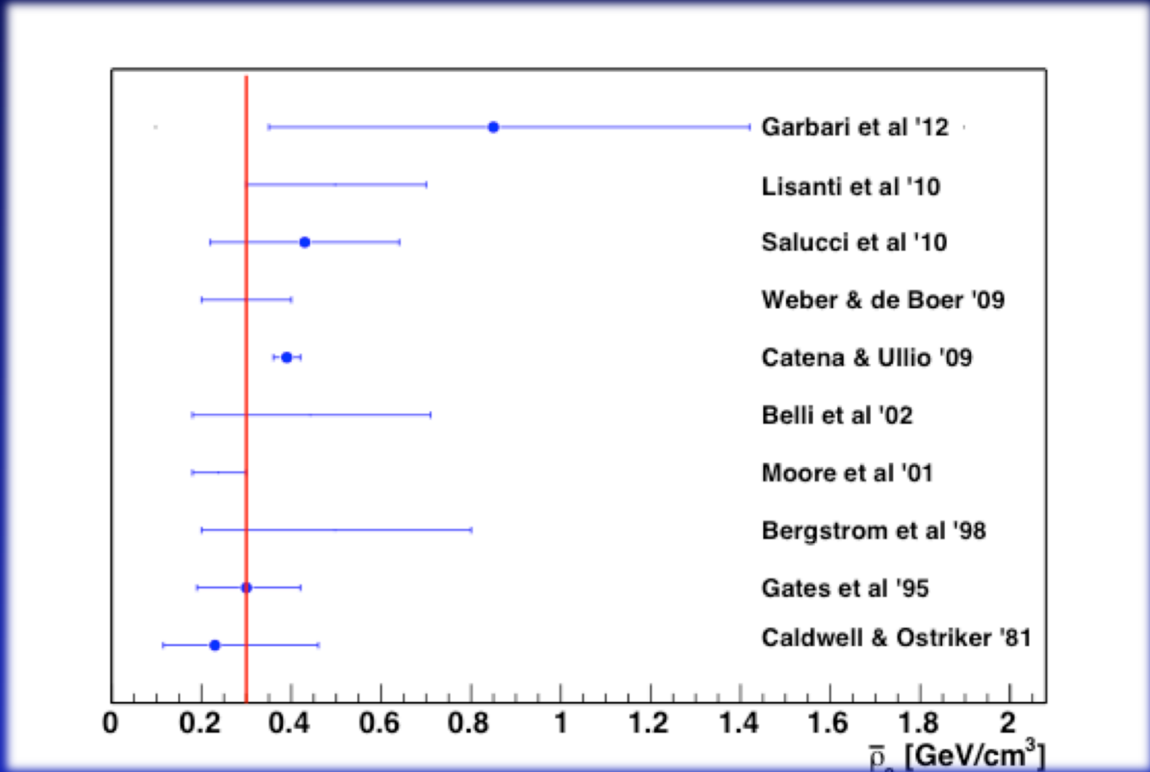


Different techniques exist for determination of ρ_0

Local observables
(e.g. Garbari et al.)

vs

global modelling of MW
(e.g. Catena & Ullio)



Give consistent results

Basic idea: take home

Rotation curves (all matters)

-

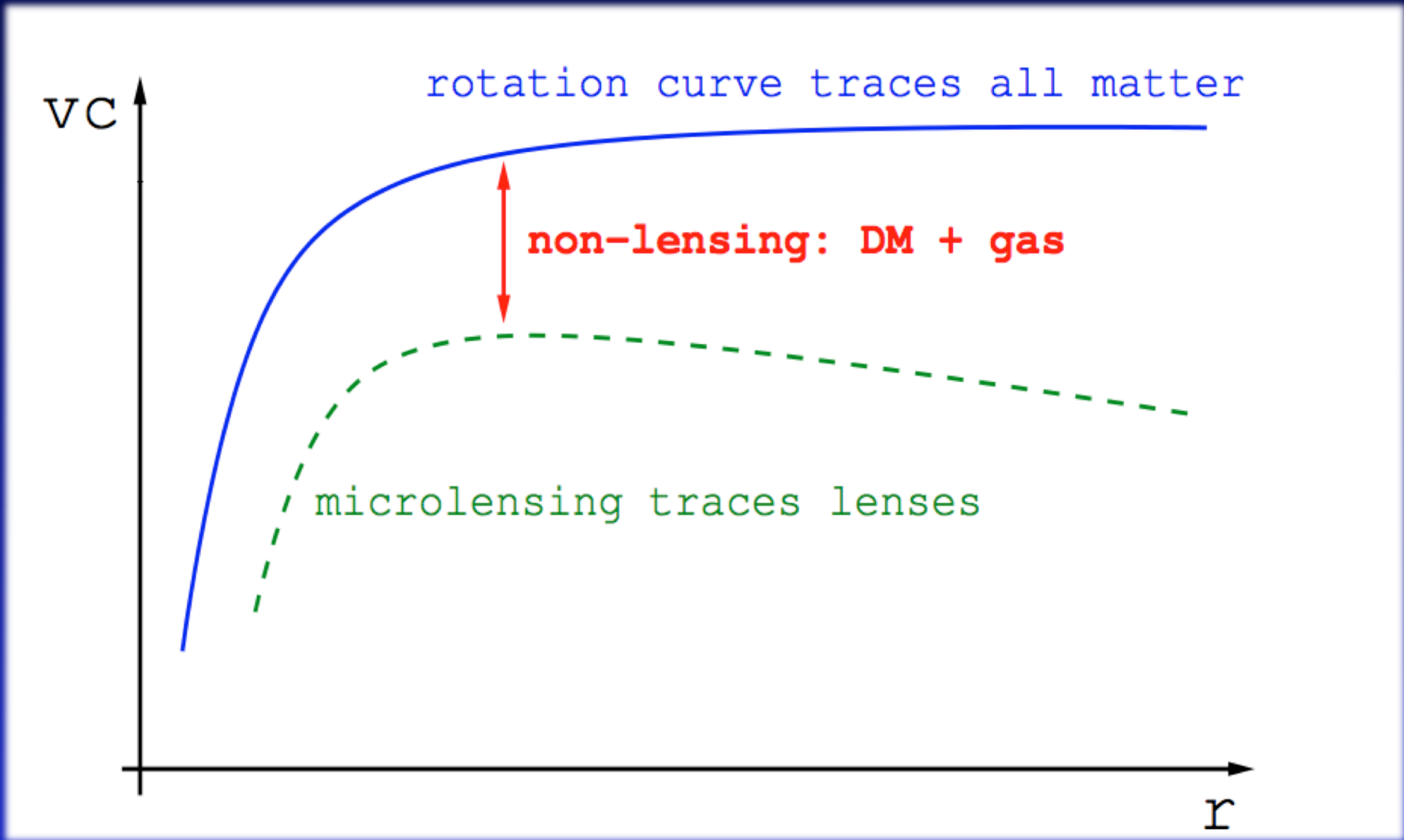
Microlensing optical depth (only compact bodies)

=

Diffuse components (DM and Gas)

[Binney & Evans '01]

That's the idea, yes



see how much (/ if) room is left for DM,
varying DM parameters

Microlensing: principles

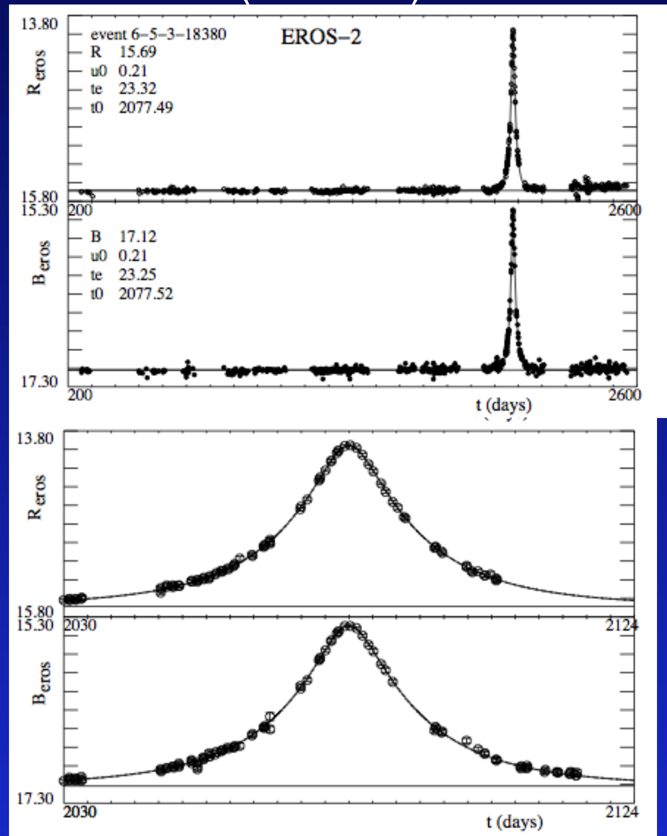
compact object (lens)
between us and source
creates unresolved images
result: light magnification *A(t)*

$$A(t) = \frac{u(t)^2 + 2}{u(t)\sqrt{u(t)^2 + 4}}$$

Lens need to be close to *los*:
Einstein radius

$$R_E = 2.85\ \mathrm{AU}\sqrt{\frac{MD_d[1-(D_d/D_s)]}{1\ \mathrm{kpc}}}$$

Optical/NIR surveys:
I field (620-920) nm
B field(420-720) nm



[EROS 2006]

Microlensing caused by compact objects only

Microlensing optical depth τ

The integrated probability of having a luminosity enhancement: events with A>1.34

Observationally:

$$\tau = \frac{1}{N_{\rm obs}\Delta T_{\rm obs}} \frac{\pi}{2} \sum_{\rm events} \frac{t_{\rm E}}{\epsilon(t_{\rm E})}$$

Theoretically,
we need models for the source ad lens distribution

$$\tau(\ell, b, D_s) = \frac{4\pi G}{c^2} \int_0^{D_s} dD_l \; \rho_l(\ell, b, D_l)\, D_l \left(1 - \frac{D_l}{D_s}\right)$$

$$\langle\tau\rangle(\ell, b) = \frac{\int_0^{r_\infty} dD_s \; \tau(\ell, b, D_s)\, dn_s/dD_s}{\int_0^{r_\infty} dD_s \; dn_s/dD_s}$$

Notice that τ depends on total mass of population, no IMF!!!

Microlensing observations of GC

MACHO CGR = average of 9 fields

$$(\ell, b) = (1.50^\circ, -2.68^\circ)$$

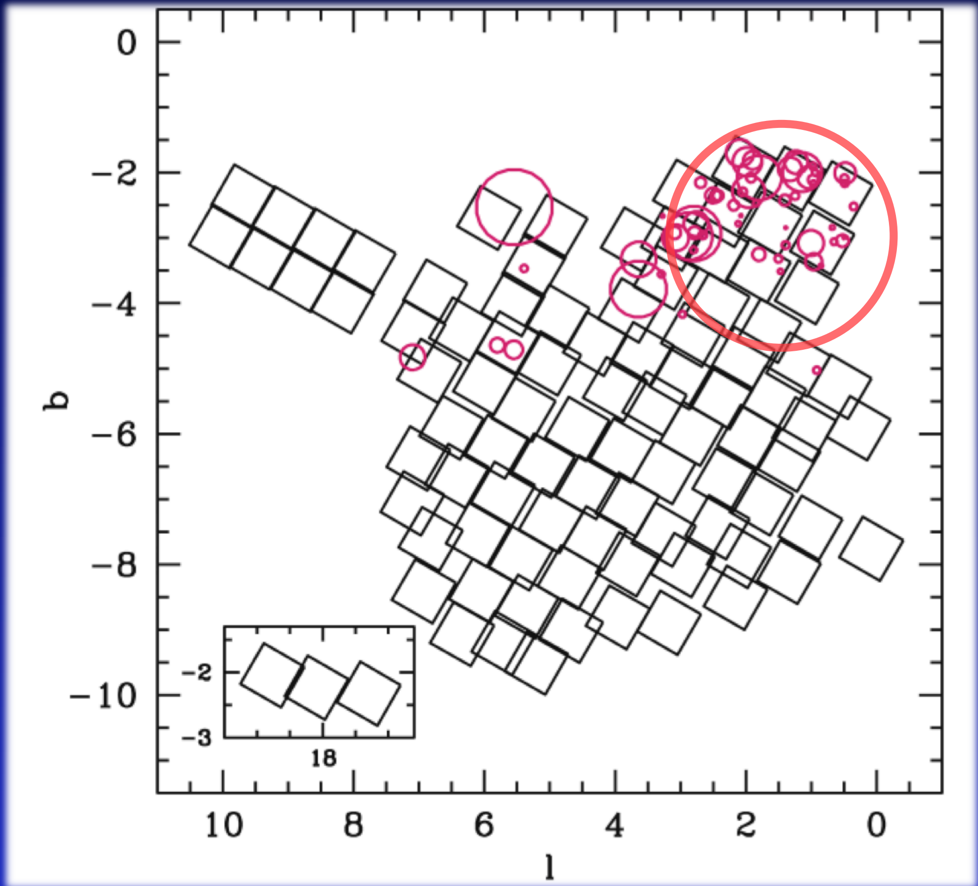
$$\langle \tau \rangle = 2.17^{+0.47}_{-0.38} \times 10^{-6}$$

few < t_E/days < 700

10^{-3} < M_l/Msun < 80

Sources: red clump giant in the bulge

Insensitive to recently discovered Jupiter mass objects, However, below uncertainty: 0.1% mass content

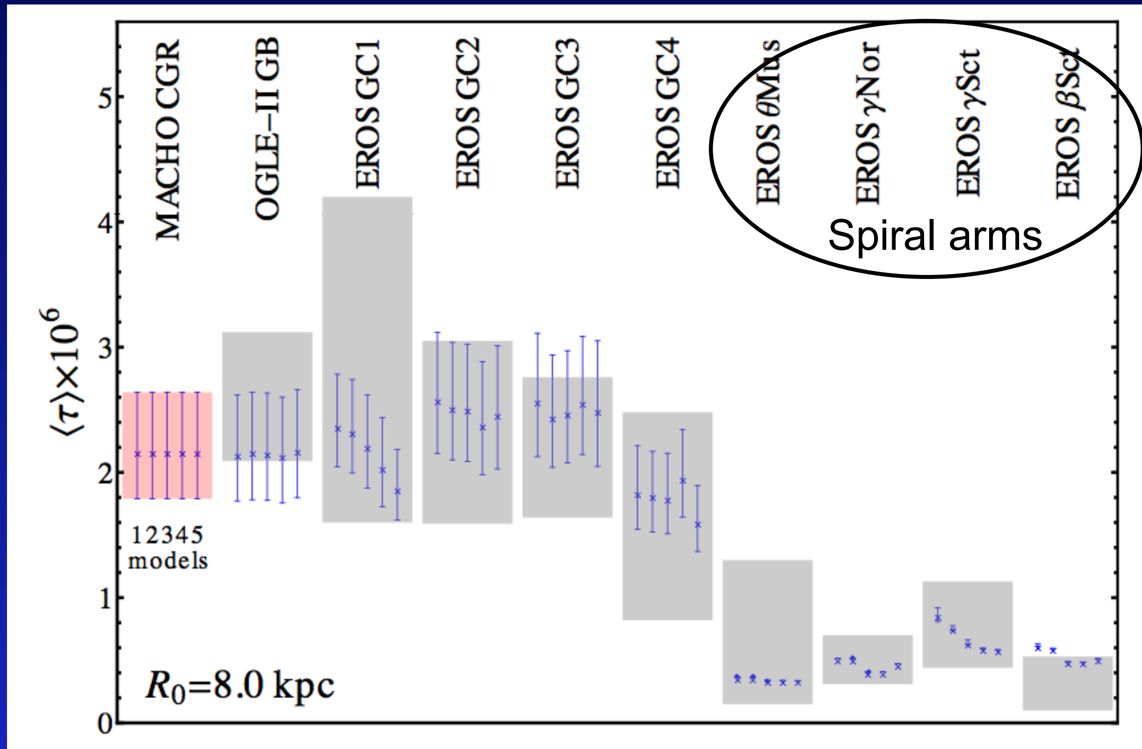


MACHO [Popowski et al. 2005]

Galactic baryonic models

They fit quite well other microlensing observations:

GC and beyond!!



Mass ditribution used to obtain gravitational potential (circular velocities) using non-spherical Poisson equation; <u>Not adding DM</u> yet (see the following…)

Rotation curves: observations

Gas clouds moving in the disk: inner Galaxy

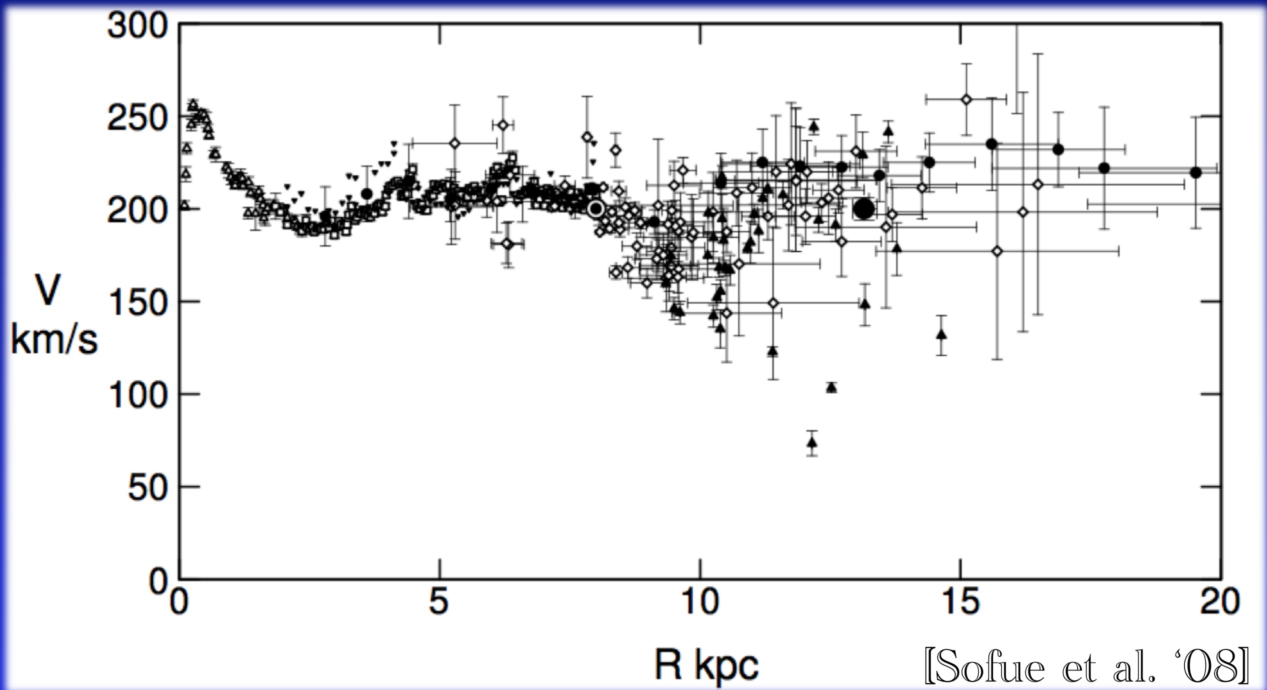
HI or CO line used as tracers

circular velocity assumption

$$v_c(R_0 \sin \ell) = v_t(\ell) + v_0 \sin \ell \qquad v_0 \equiv v_c(R_0)$$

Need to adopt *(R_0,v_0)*: different values in literature

unified rotation curve for *(8 kpc, 200km/s)*



Let’s use this to constrain DM!

Rotation Curves (all matters)

-

Microlensing optical depth (only compact bodies)

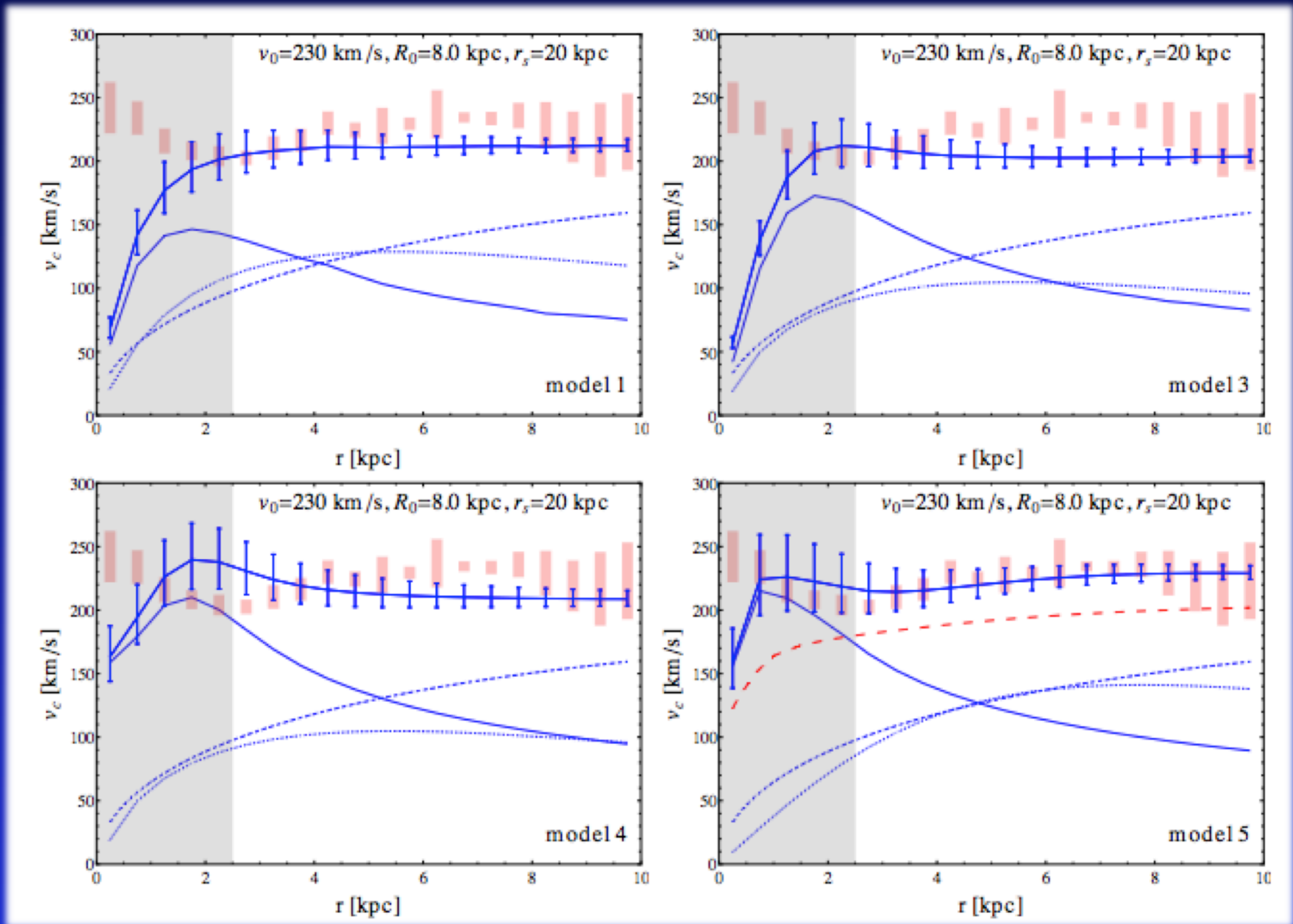
=

Diffuse components (DM and Gas)

[Binney & Evans ‘01]

Checking our baryonic models

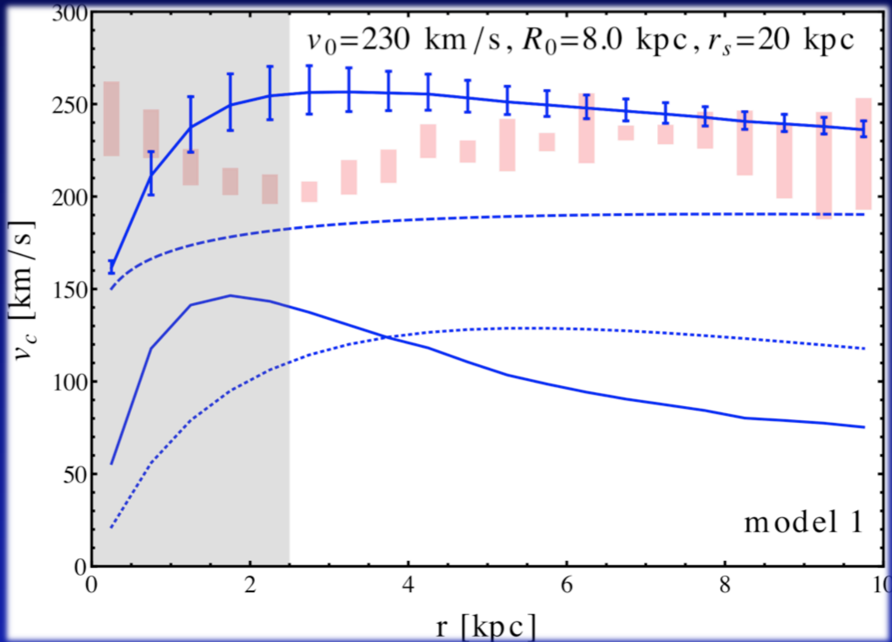
(and adding DM)



With DM: gNFW r_s=20kpc ; α=1 ; ρ_0 = 0.4 GeV/cm^3

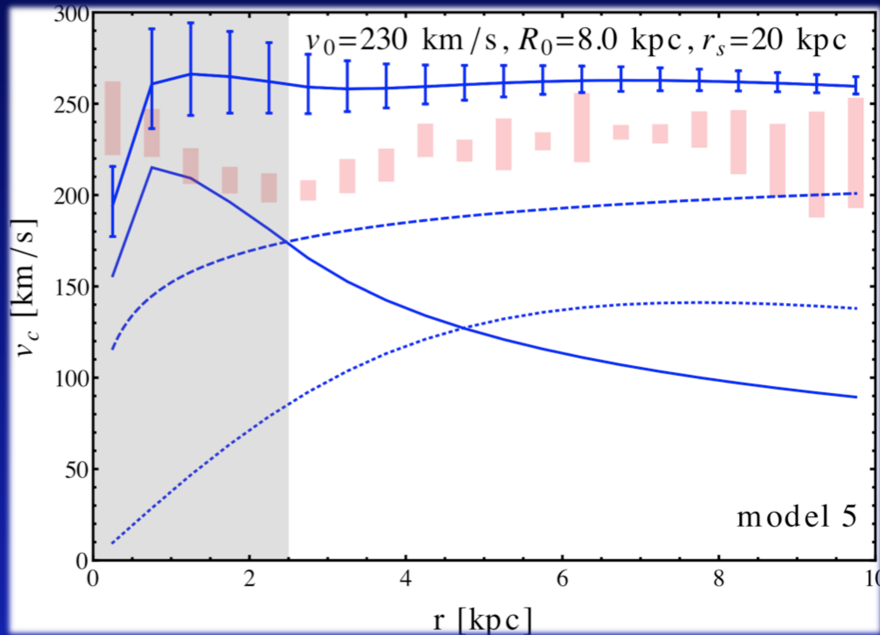
Test failure: 2 sigma overshoot

gNFW $(\alpha,\rho_0) = (1.8,0.4)$



Observational velocity uncertainties:
statistical + systematic
(average of literature spread in 0.5 kpc bin)

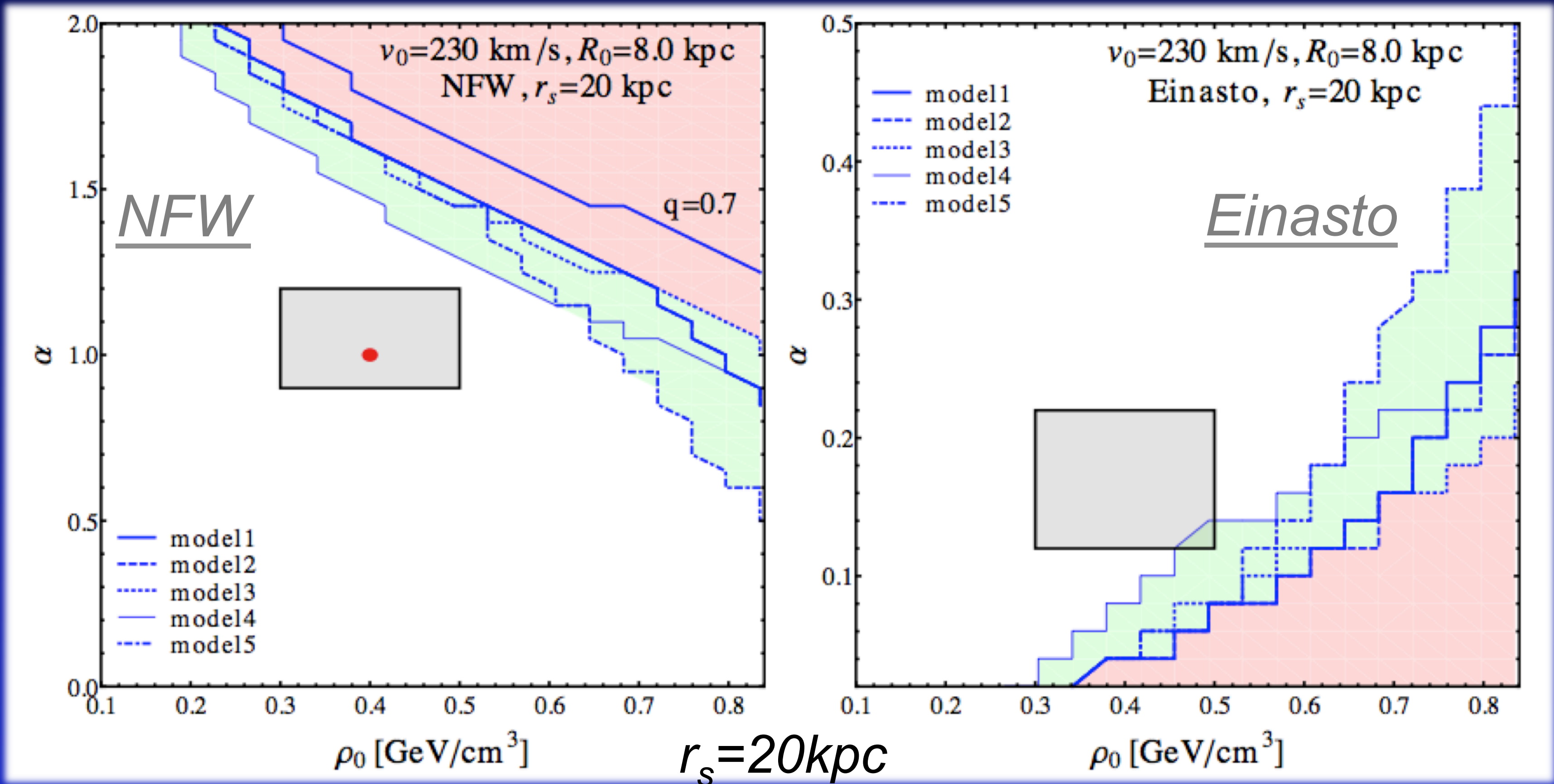
Einasto $(\alpha,\rho_0) = (0.05,0.5)$



Theoretically reconstructed uncertainties:
MACHO 2005 statistical propagated

The constraints that follow are quite <u>conservative</u>

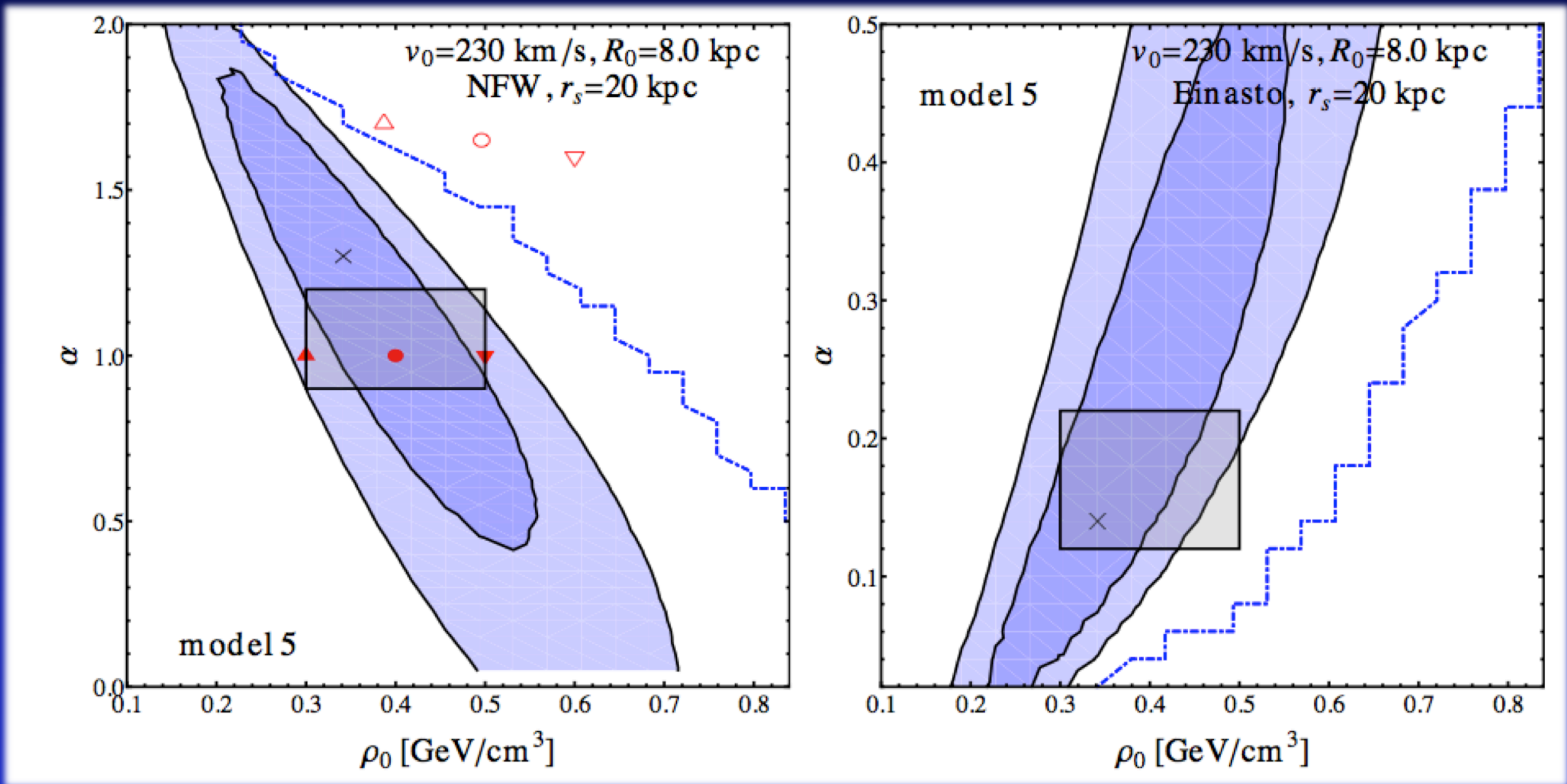
Constraining the parameter space: the "fiducial" configuration



Constraints come from 2.75kpc, 7.75kpc bins, thus no worries about kinematic transformations

Fitting the best DM parameters

using Model 5 (includes gas, best shape fitting)



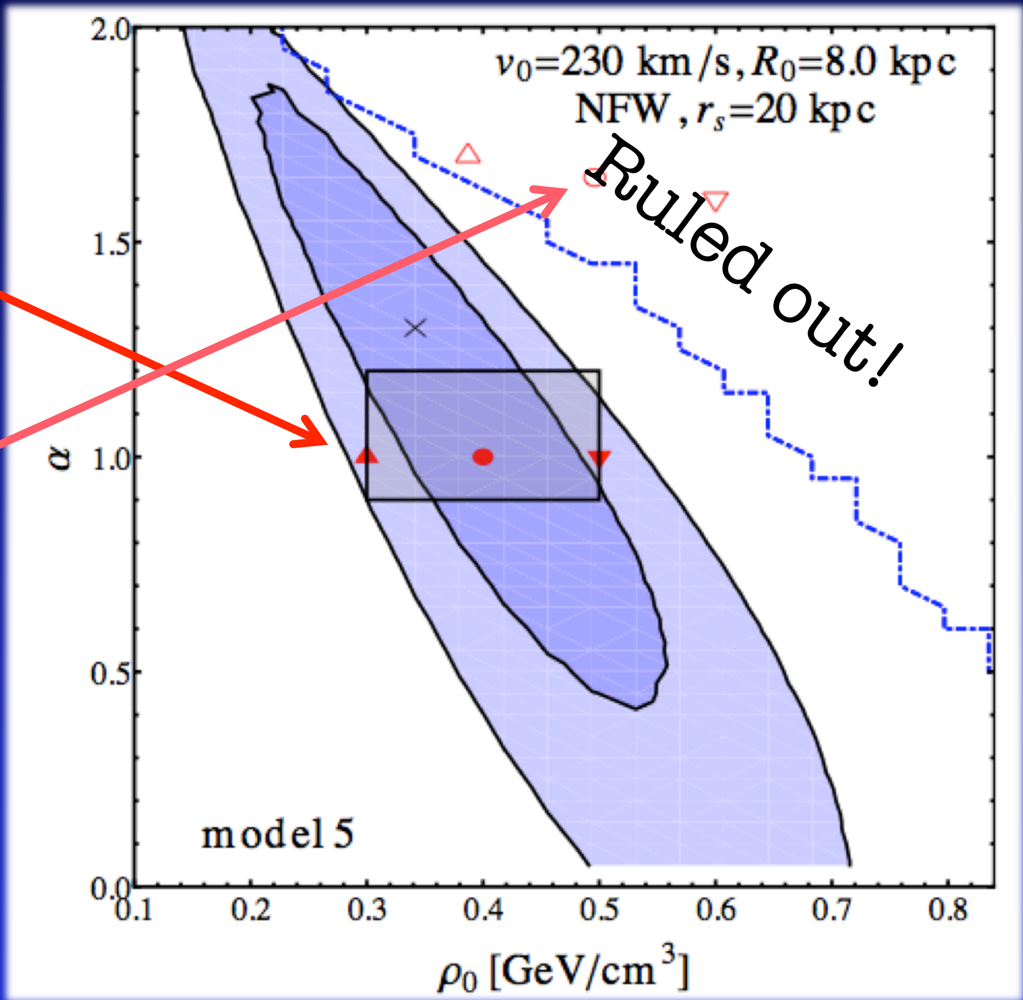
Excellent agreement with simulation parameter space,
And determination of ρ_0 [Catena & Ullio '09]

Adiabatic Contraction
the embarassing guest

Starting point

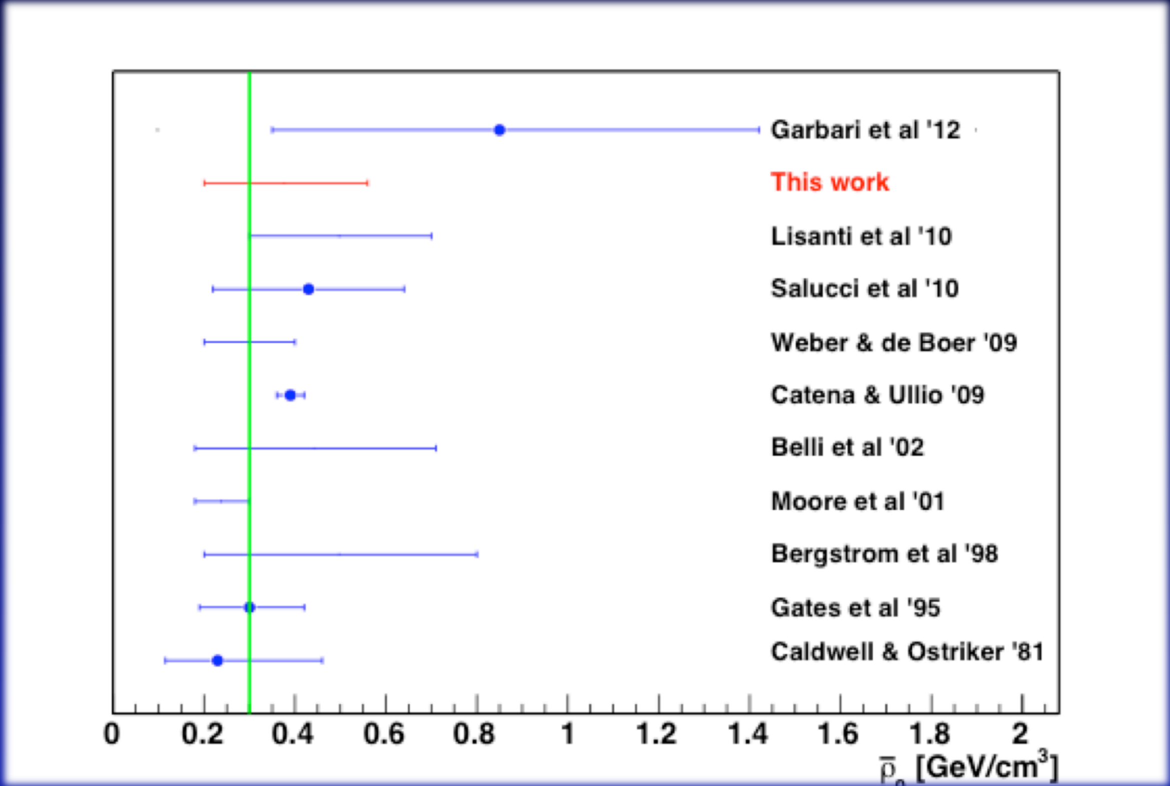
apply adiabatic invariant
M(R)R=const

Blumenthal flavor of AC:
still need to test
Gnedin/Gustafsson
models



Summarizing results on ρ_0

A complementary technique,
results in agreement
with alternative approaches



Spherical halo

$$\rho_0 = 0.20 - 0.56\ \mathrm{GeV/cm^3}\ \mathrm{(NFW)}$$

$$\rho_0 = 0.22 - 0.55\ \mathrm{GeV/cm^3}\ \mathrm{(Ein)}$$

Concluding

- Combining Microlensing observations of galactic center with observations of rotation curves, possible to have information about DM distribution in the Galaxy

- Agreement with NFW and Einasto suggested by numerical simulations

- Rule out extreme flavor of Adiabatic Contraction

- Using a specific baryonic model, possible to find the best fitting NFW/Einasto parameters, obtaining

the 1 σ interval ρ_0=[0.20-0.55] for spherical halos

(R_0=8kpc, v_0=230km/s, r_s=20kpc , varying α)