Dark Matter distribution in the Milky Way: microlensing and dynamical constraints

Fabio Iocco

Marie Curie fellow at
Institut d'Astrophysique de Paris

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G. Bertone, P. Jetzer, M. Pato

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Outline

- Microlensing, an introduction

→Optical depth τ

- Modelling baryons in the MW

→ Modelling the DM, parameters

- Rotation curve observations, an overview

- Results: constraining Adiabatic Contraction and fitting the DM to rotation curve

Microlensing: principles

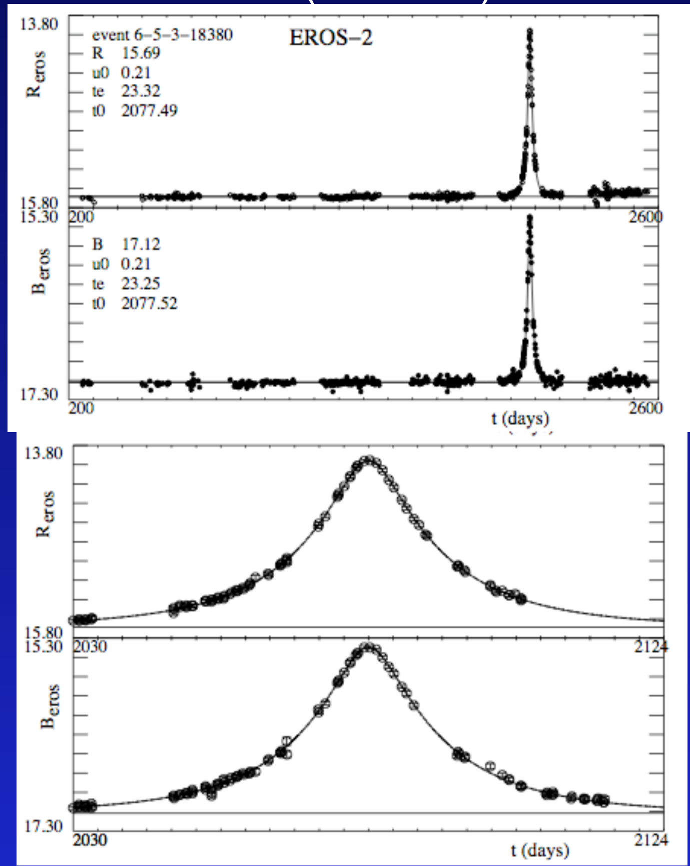
compact object (lens)
between us and source
creates two unresolved object
result: light magnification *A(t)*

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

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:

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

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 opt depth depends on mass distribution only, no IMF!!!

Microlensing observations of GC

MACHO CGR = average of 9 fields

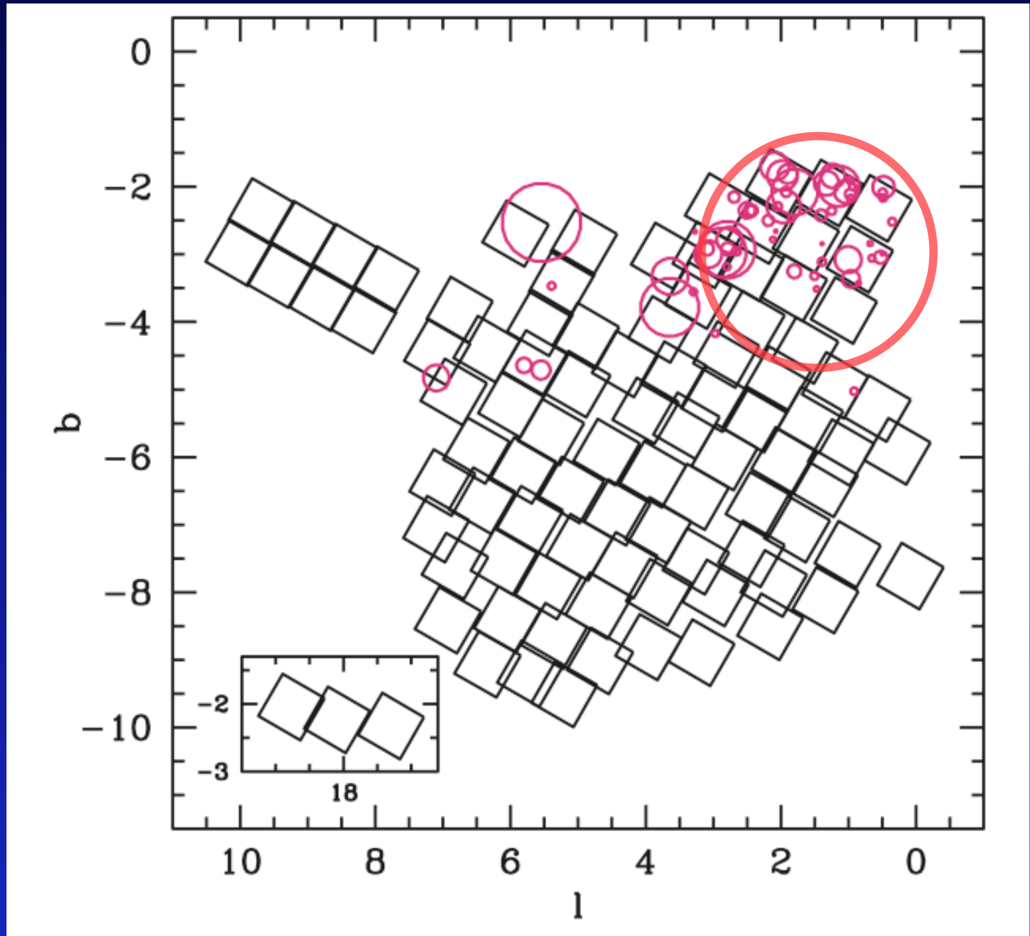
$$(\ell, b) = (1.50°, -2.68°)$$

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

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

Ingredients:
Exponential/Gaussian bulge (with bar)
+ thin / thick disk
Bar at R < 2.5 kpc: bar angle $\alpha \approx 25°$

- **Model 1:** E2 bulge and thin+thick disk;
- **Model 2:** G2 bulge and thin+thick disk;
- **Model 3:** G2 bulge and thin disk;
- **Model 4:** Zhao bulge and thin disk; and

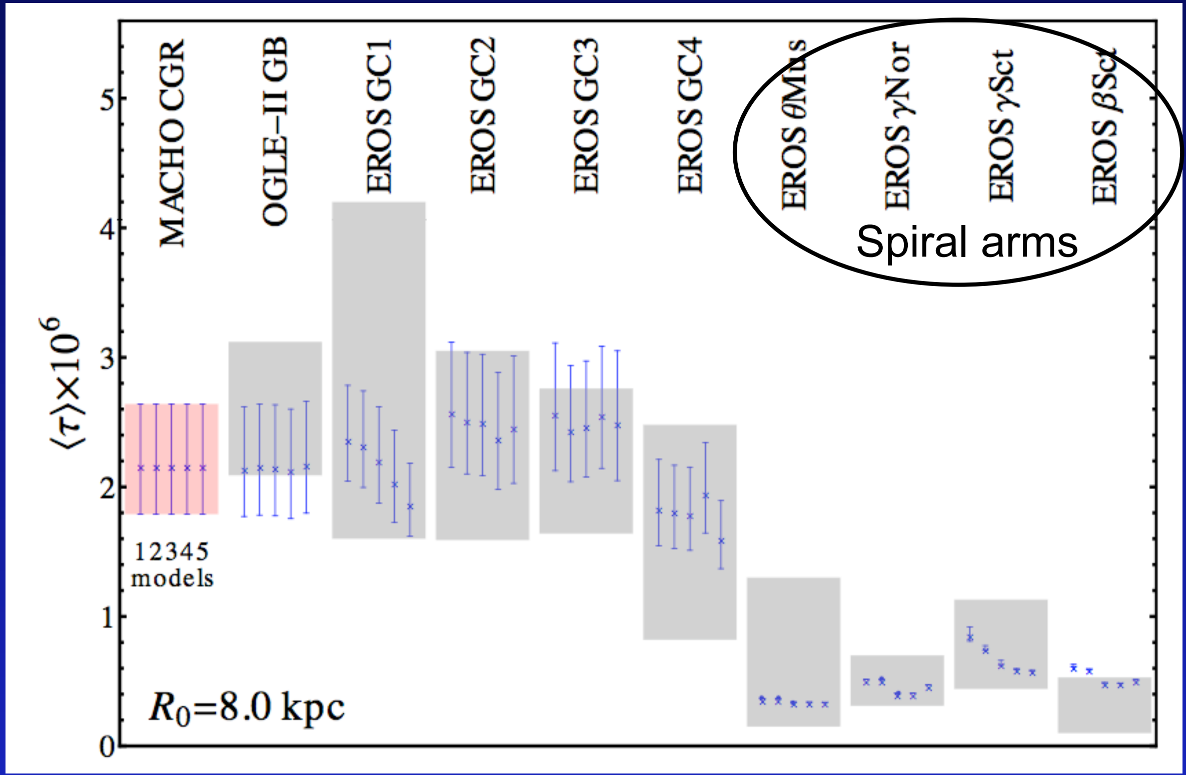
Model 5: bar + disk + <u>gas</u>

Shape fixed, density normalization ρ_b
calibrated to fit the MACHO observations

Galactic baryonic models

They fit quite well other microlensing observations:

GC and beyond!!



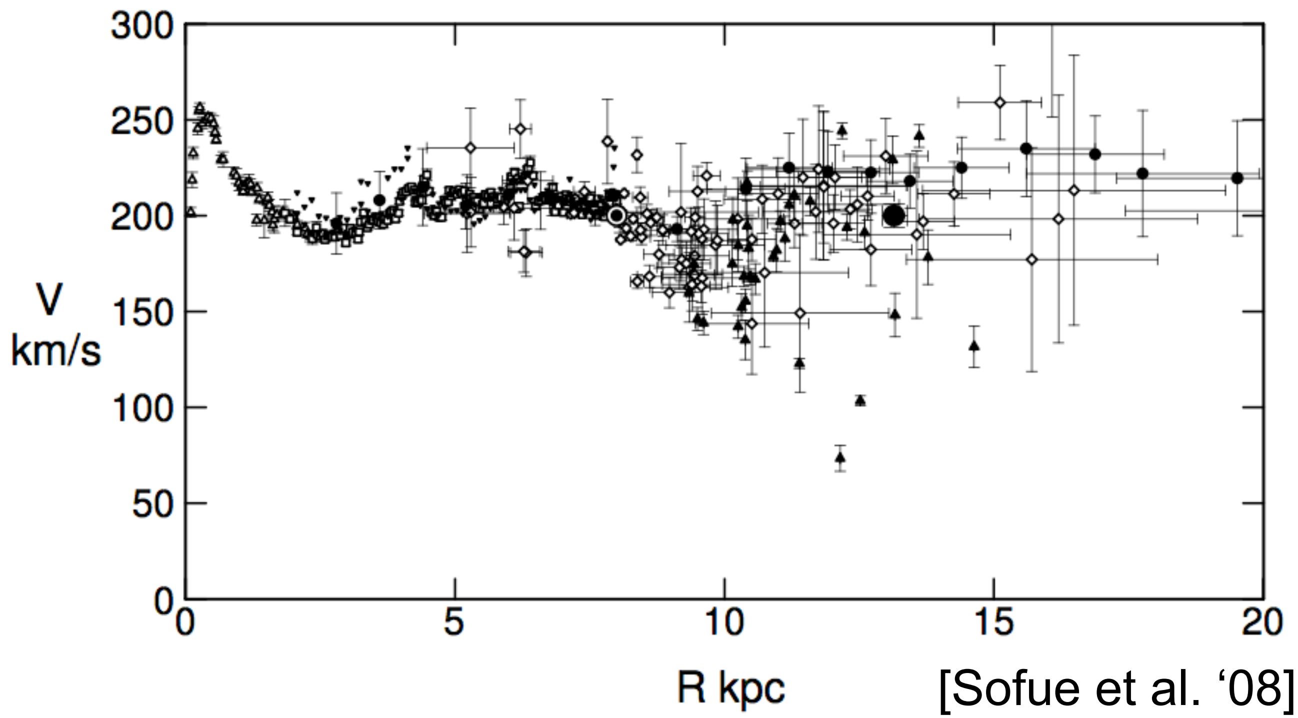
Mass ditribution used to obtain gravitational potential
(circular velocities) using non-spherical Poisson equation;
And adding DM (see the following…)

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)*



[Sofue et al. '08]

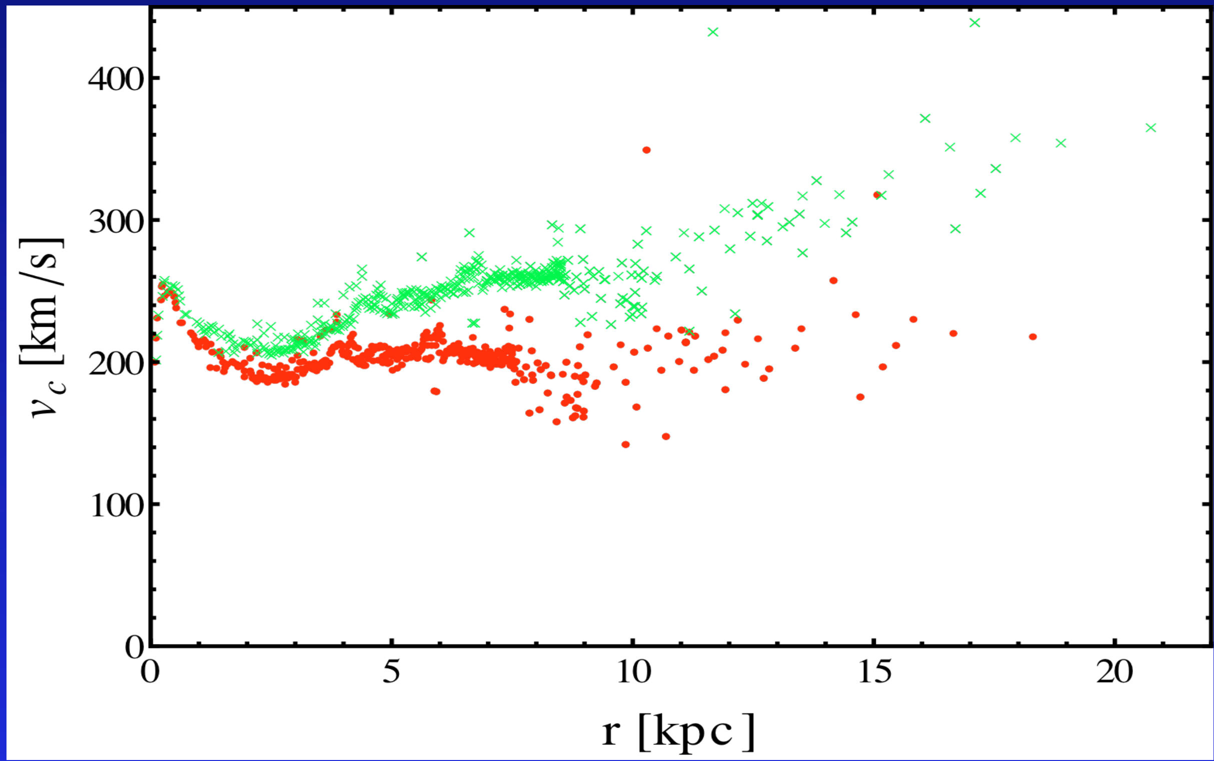
Rotation curve: uncertainties

We bracket the uncertainty in the
determination of (R_0, v_0)
7.5 kpc < R0 < 8.5kpc
200 km/s < v0 < 260 km/s

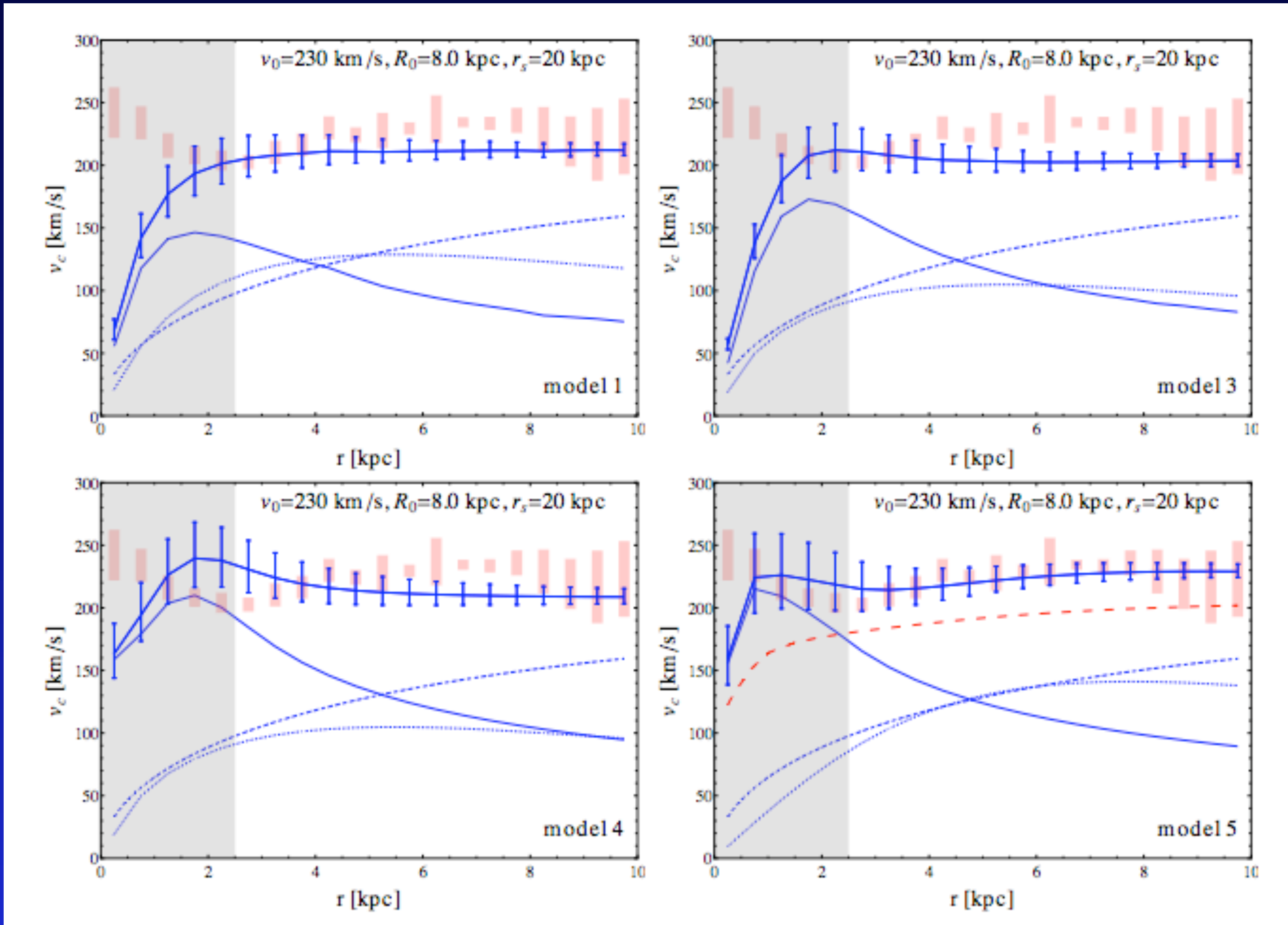
Transformations valid only in the inner circle (safe, see later)

$$R' = R\frac{R'_0}{R_0}$$

$$v'_t = v_t + \frac{R}{R_0}(v'_0 - v_0)$$



Checking our baryonic models



With DM: NFW r_s=20kpc ; α=1 ; ρ_0 = 0.4 GeV/cm3

Let's use this to constrain DM!

Rotation Curves (all matters)

-

Microlensing optical depth (only compact bodies)

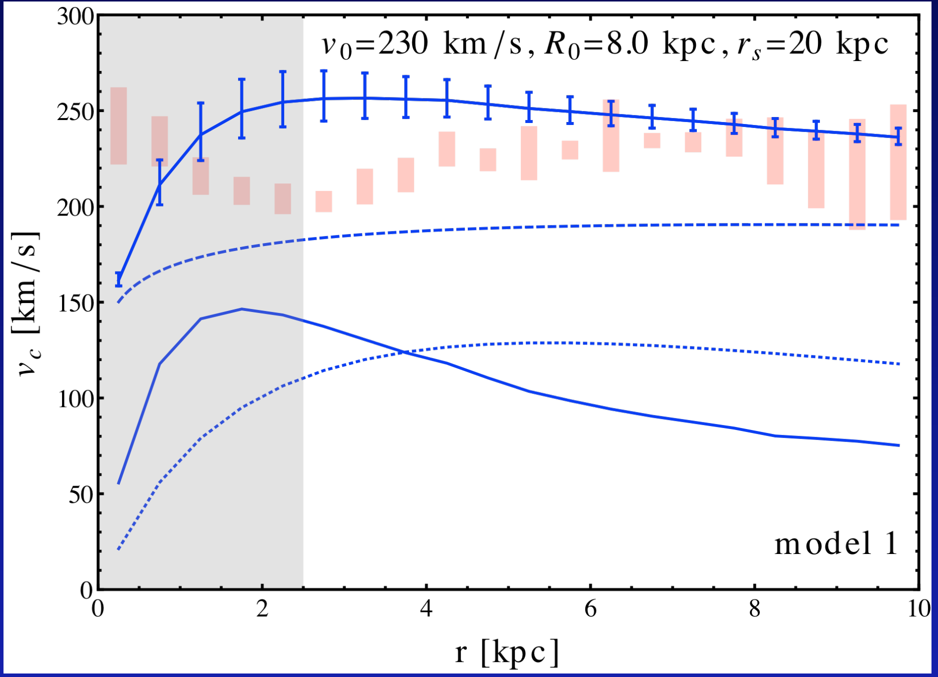
=

Diffuse components (DM and Gas)

[Binney & Evans '01]

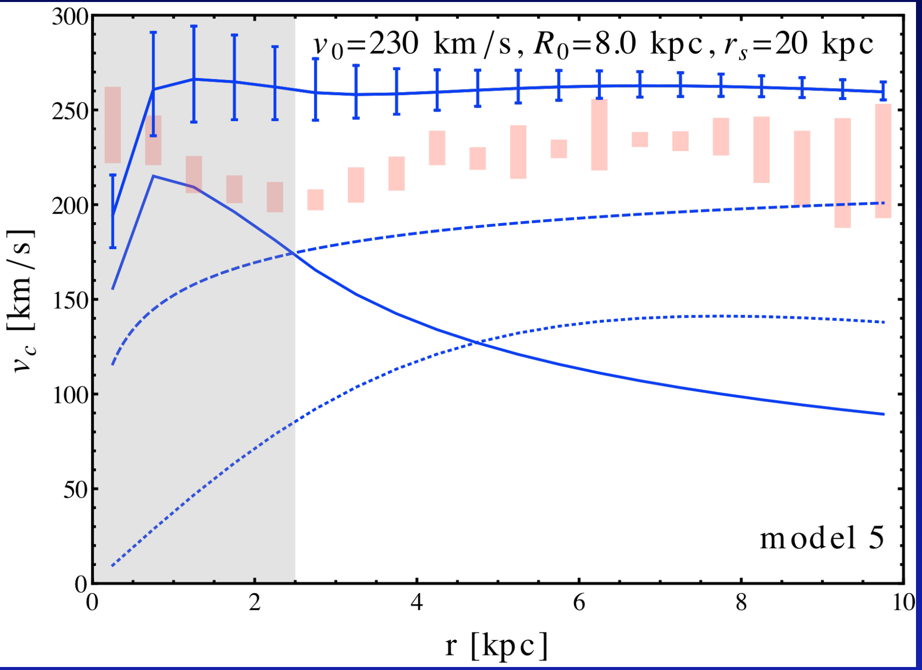
Test failure: 2 sigma overshoot

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



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

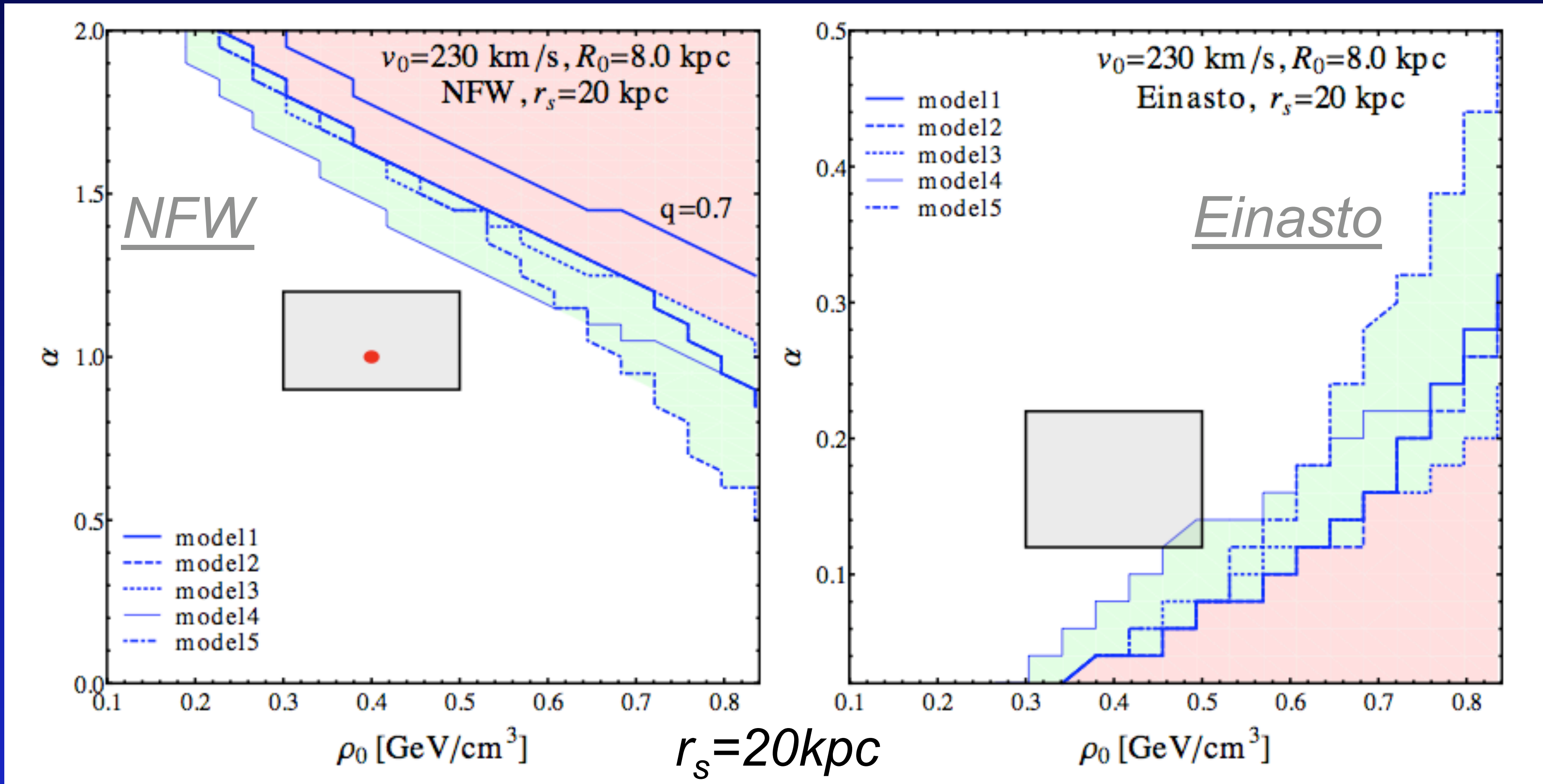
Einasto $(\alpha,\rho_0) = (0.05,0.5)$



Theoretically reconstructed uncertainties:
MACHO 2005 statistical propagated

The constraints that follow are quite conservative

Constraining the parameter space: the “fiducial” configuration

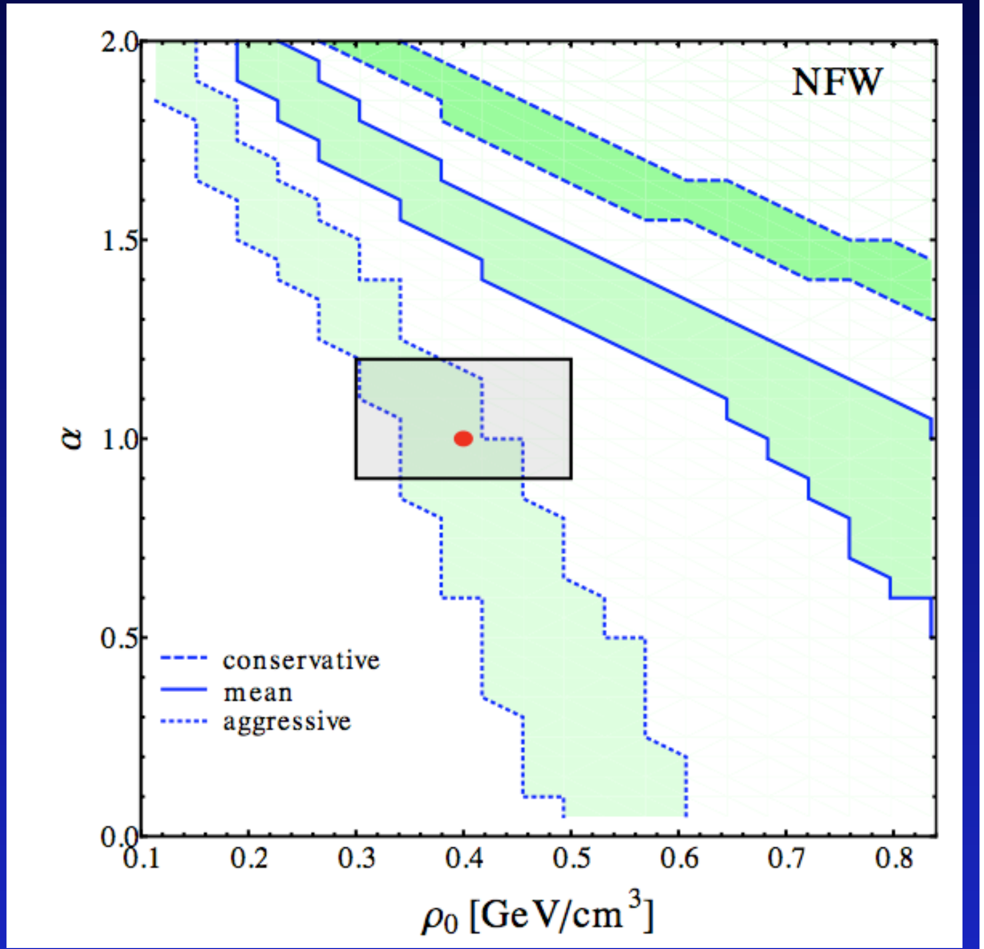


Constraints come from 2.75kpc, 7.75kpc bins, thus no worries about kinematic transformations

Getting at the extremes
(bracketing)

What DM configurations
can we esclude if we change
Solar radius and local velocity?

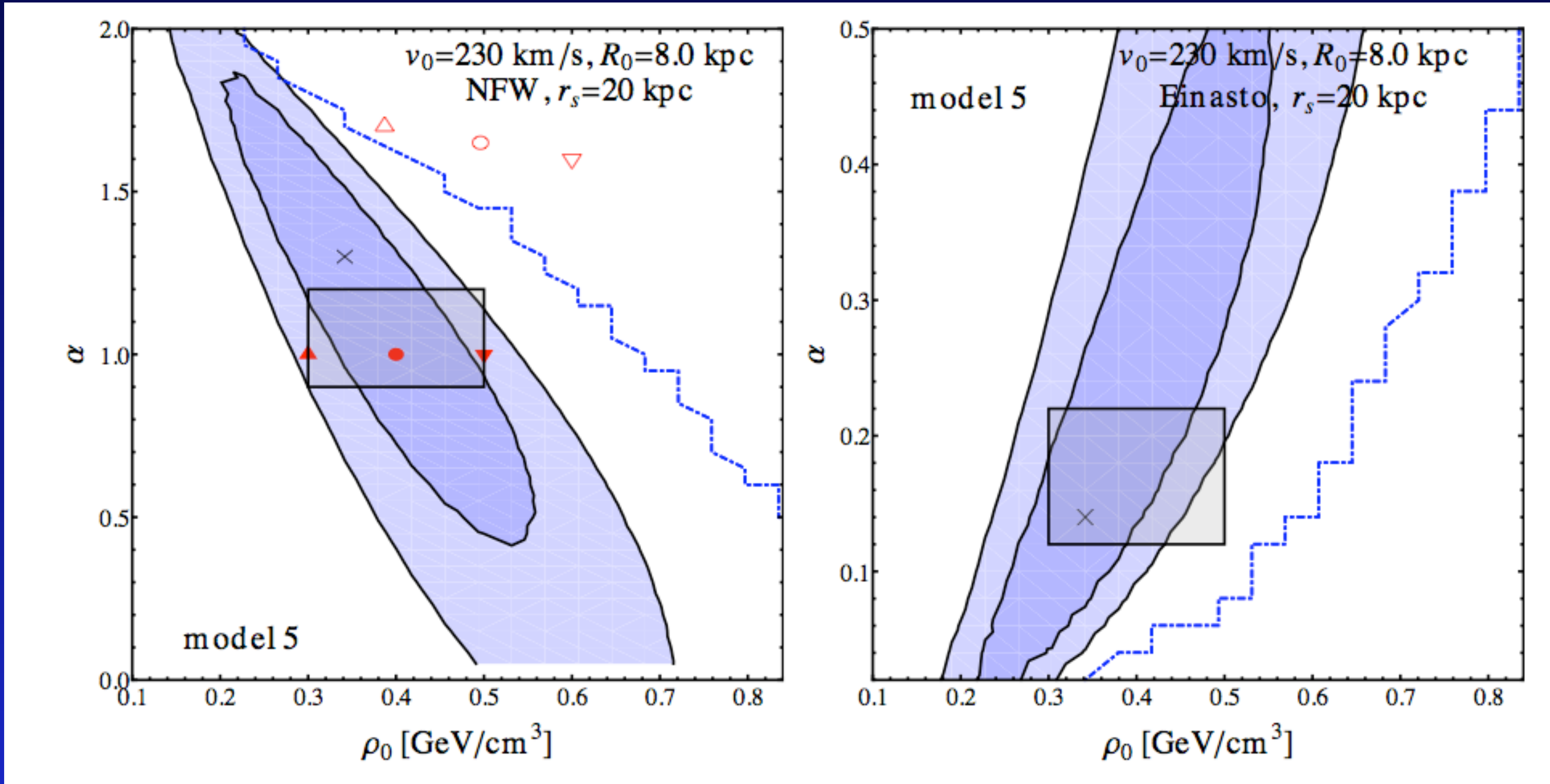
Rescaling:
rotation curve
baryon modelling
DM halo



Conservative $(r_s,R_0,v_0) = (35,7.5,260)$
Mean $(r_s,R_0,v_0) = (20,8.0,230)$
Aggressive $(r_s,R_0,v_0) = (10,8.5,200)$

Fitting the best DM parameters

using Model 5 (includes gas, best shape fitting)



Excellent agreement with simulation parameter space,

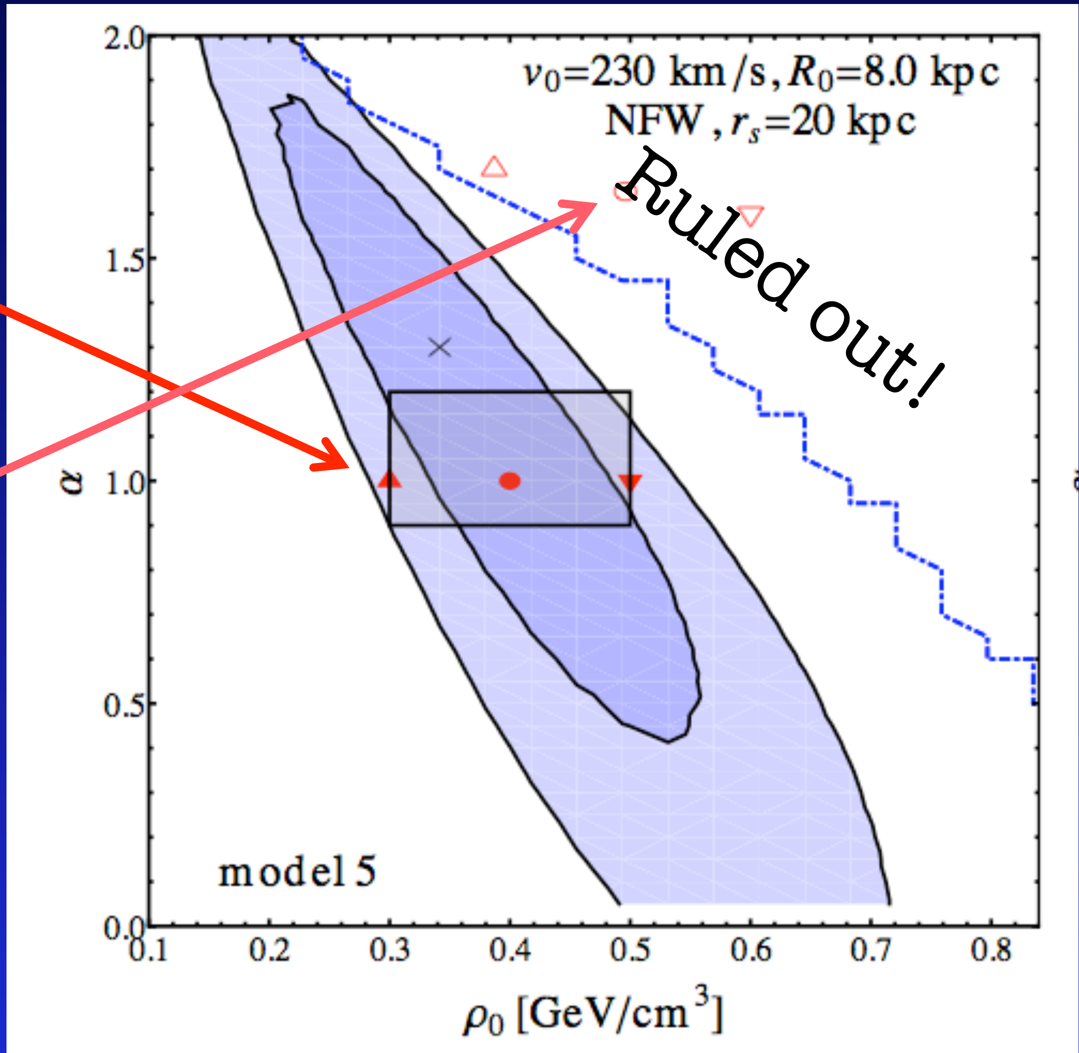
And determination of ρ_0 [Catena&Ullio 09] and following talk by S Garbari

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



Concluding

- Combining Microlensing observations of galactic Bulge 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)