SUSY 2015 - Particle Cosmology Session

" Looking for Dark Matter in Dwarf Spheroidal Galaxies "

M.V., P.Ullio (in preparation)

M.Valli

Lake Tahoe (USA),
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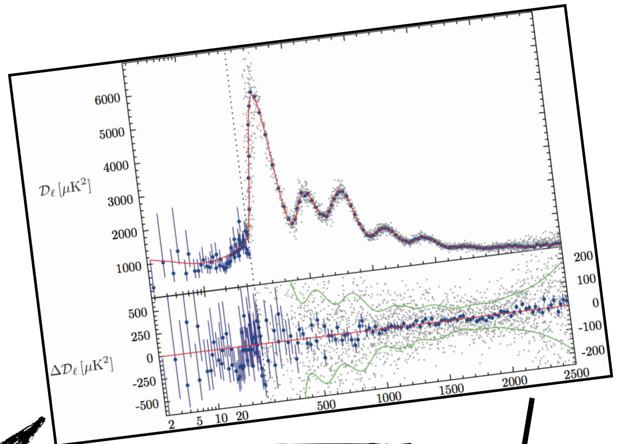
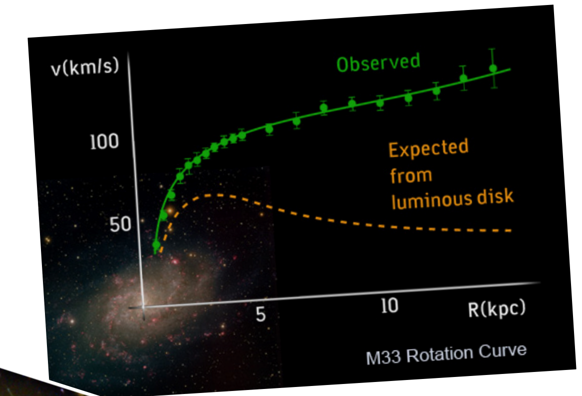
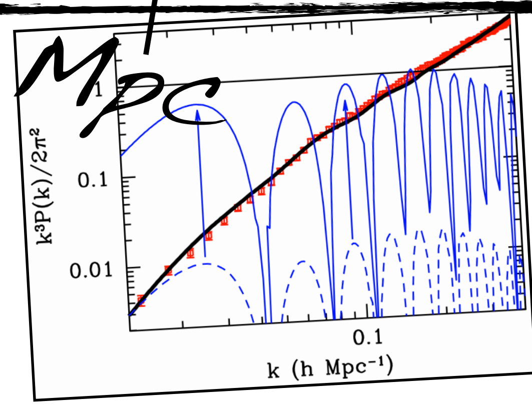
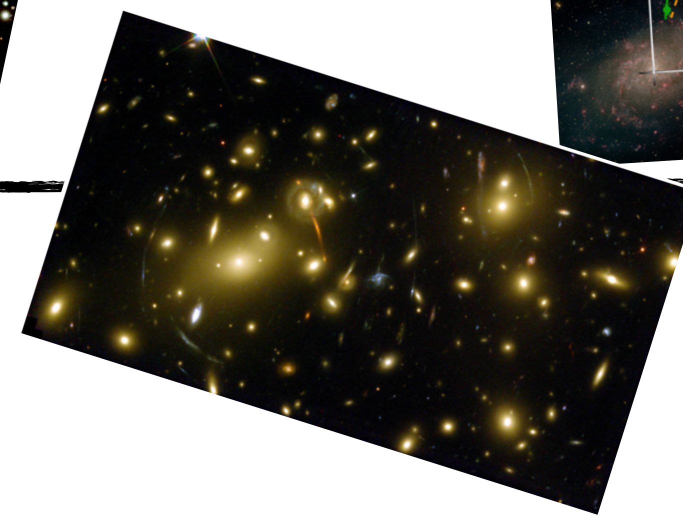
Evidence in favor of Dark Matter existence @ different scales ...





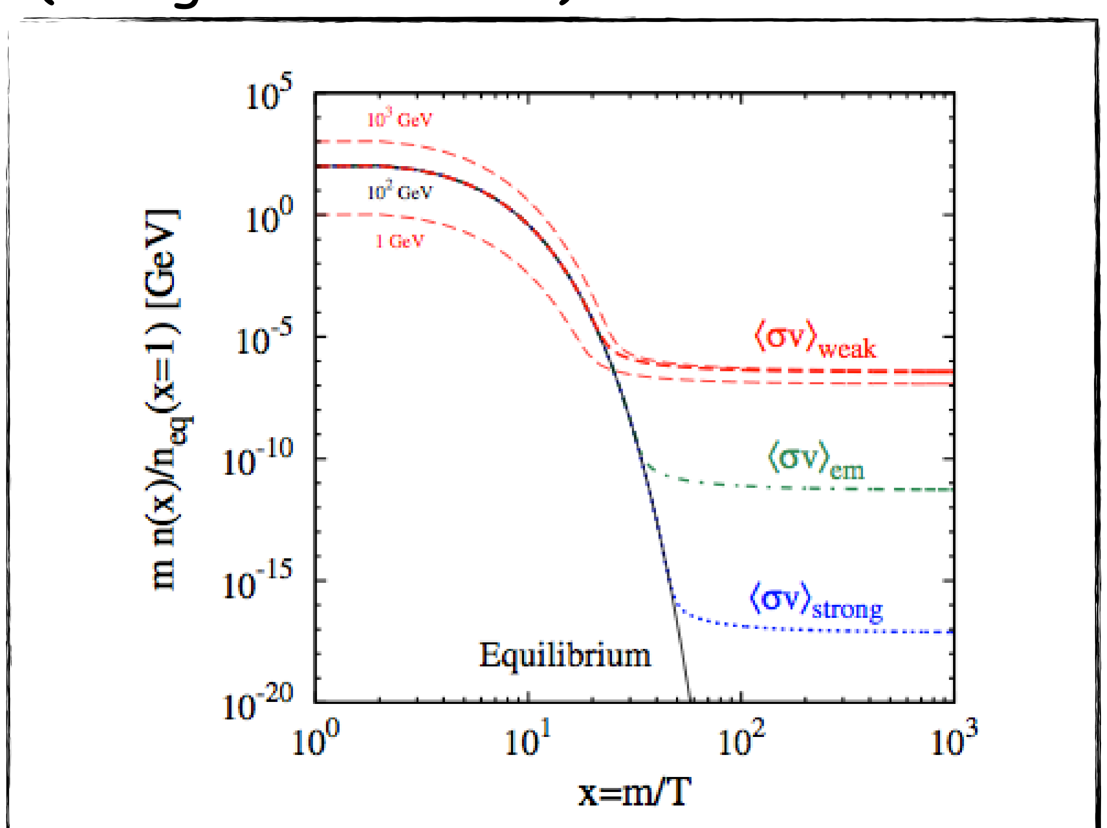
Mpc





kpc

(Steigman et al. '12)

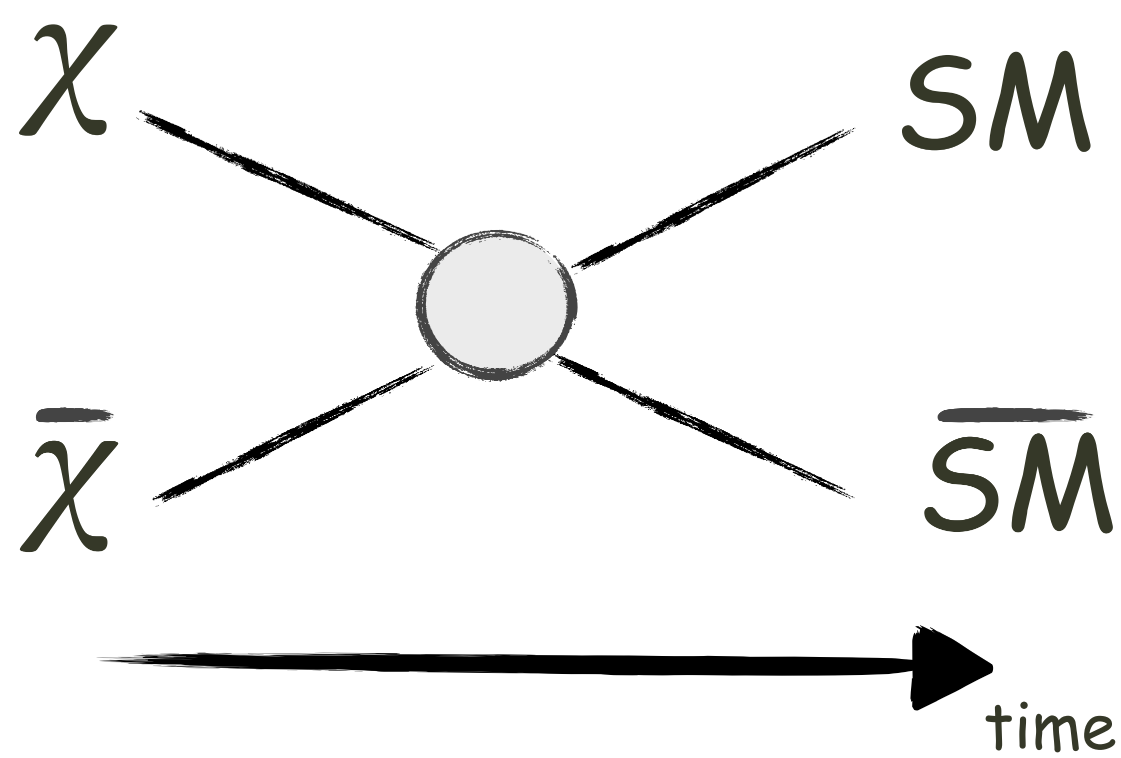


Beyond the Standard Model of Particle Physics opportunity !

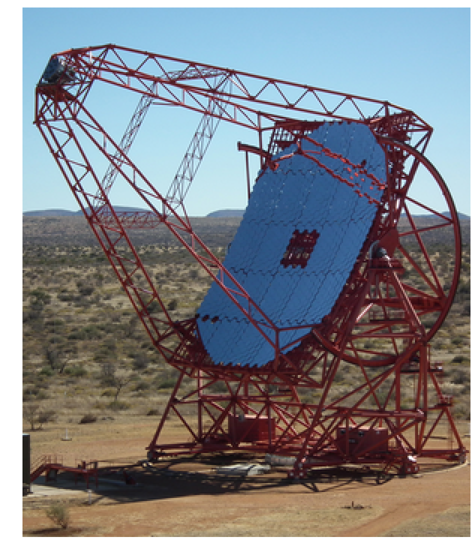
$$\Omega_\chi\, h^2 \sim \frac{3 \times 10^{-27}\, cm^3\, s^{-1}}{< \sigma v >_{f.o.}}$$

Weakly **I**nteracting **M**assive **P**articles **miracle**

WIMP annihilation in the Sky



γ rays



Expected flux of prompt gamma to be detected ?

$$\boxed{\phi_\gamma \;\propto\; <\sigma v> \;\times\; J} \;\rightarrow\; \sim \int d\ell \;\rho_\chi^2(r(\ell))/m_\chi^2$$

Milky Way Galactic Center: J ~ 10^{23} GeV^2/cm^5 ... GC promising target!

... but **complicated background**!

(**unresolved PS**, see R.Bartels et al. arXiv:1506.05105, S.K.Lee et al. arXiv:1506.05124;

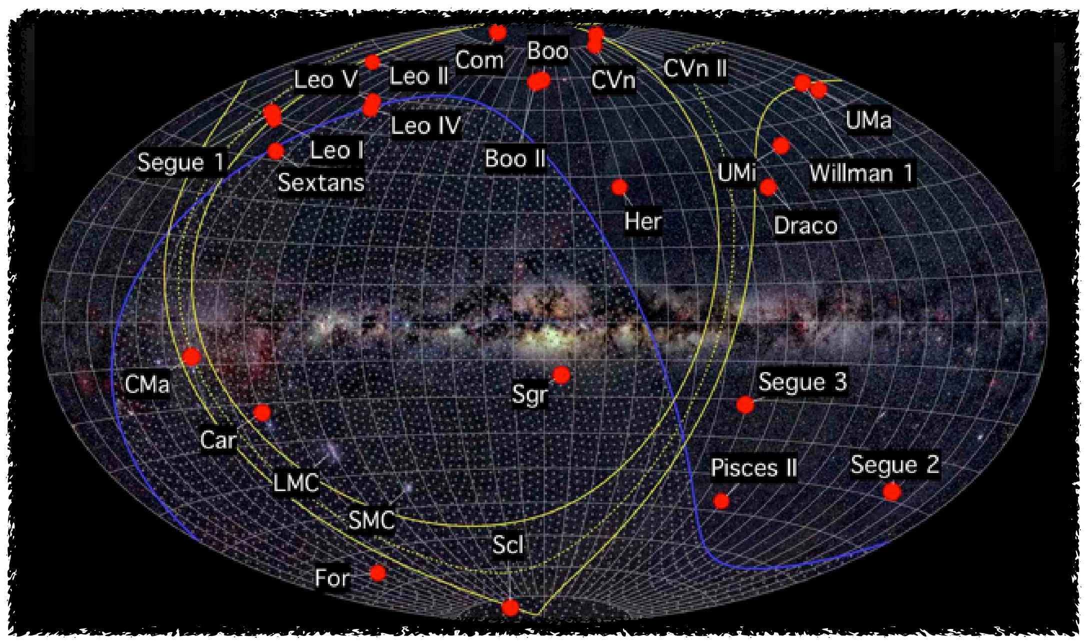
GDE mismodeling, see D.Gaggero, M.Taoso, A.Urbano, M.V., P.Ullio arXiv:1507.06129)

Dwarf spheroidal galaxies (dSphs) are the ideal targets!

$$M/L \sim 10^{2-3} \times M_\odot/L_\odot$$

very faint objects with large mass-to-light ratio!

In particular, for Milky Way satellites:



high latitude position

suppressed gamma-ray flux from standard processes

heliocentric distances about 70 - 250 kpc

high J-value

✓ photometry for stellar density profile , $I(R)$

✓ spectroscopy for line-of-sight kinematics , $\sigma_{los}(R)$

✗ full 3D kinematical knowledge , $\beta(r) \equiv 1 - \sigma_t^2(r)/\sigma_r^2(r)$

Moment-based Dynamical Mass Modeling

dSph as a collisionless system (Binney & Tremaine '08):

$$\partial_t f + \underline{v} \cdot \underline{\nabla}_x f - \underline{\nabla}_x \phi \cdot \underline{\nabla}_v f = 0$$

$f(\underline{x}, \underline{v}, t)$, p.d.f. of system tracer

$\phi(\underline{x})$, total grav. pot. of system

(1) dynamical equilibrium

(2) non rotating spherical system ("spheroidal" galaxies)

$$\frac{d(\nu \sigma_r^2)}{dr} + 2\frac{\beta \nu \sigma_r^2}{r} = -G_N \frac{\nu M}{r^2}$$

where ν is the 3D stellar density, ν (I).

Regarding kinematical observables :

$$\sigma_{los}^2 = \frac{1}{I}\int_{R^2}^{\infty}\left(1 - \beta\frac{R^2}{r^2}\right)\frac{\nu \sigma_r^2}{\sqrt{r^2 - R^2}}\, dr^2$$

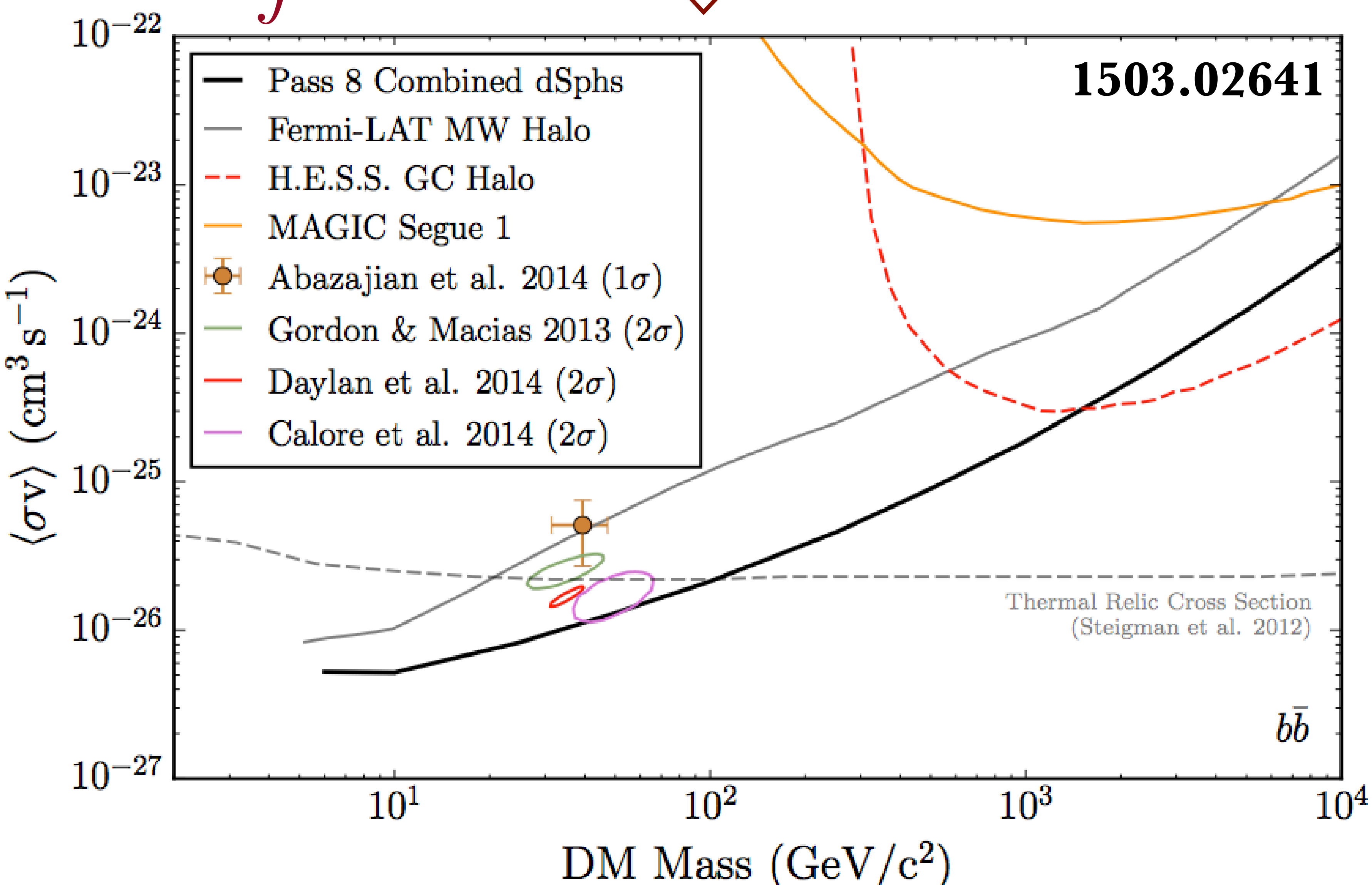
Jeans analysis

dSph ≡ collisionless spherical system in dynamical equilibrium

SPHERICAL JEANS EQUATION

$$\boxed{\sigma_{los}(R) = f(I, \rho_\chi, \beta)}$$

$$\int d\beta\ p(\beta)$$



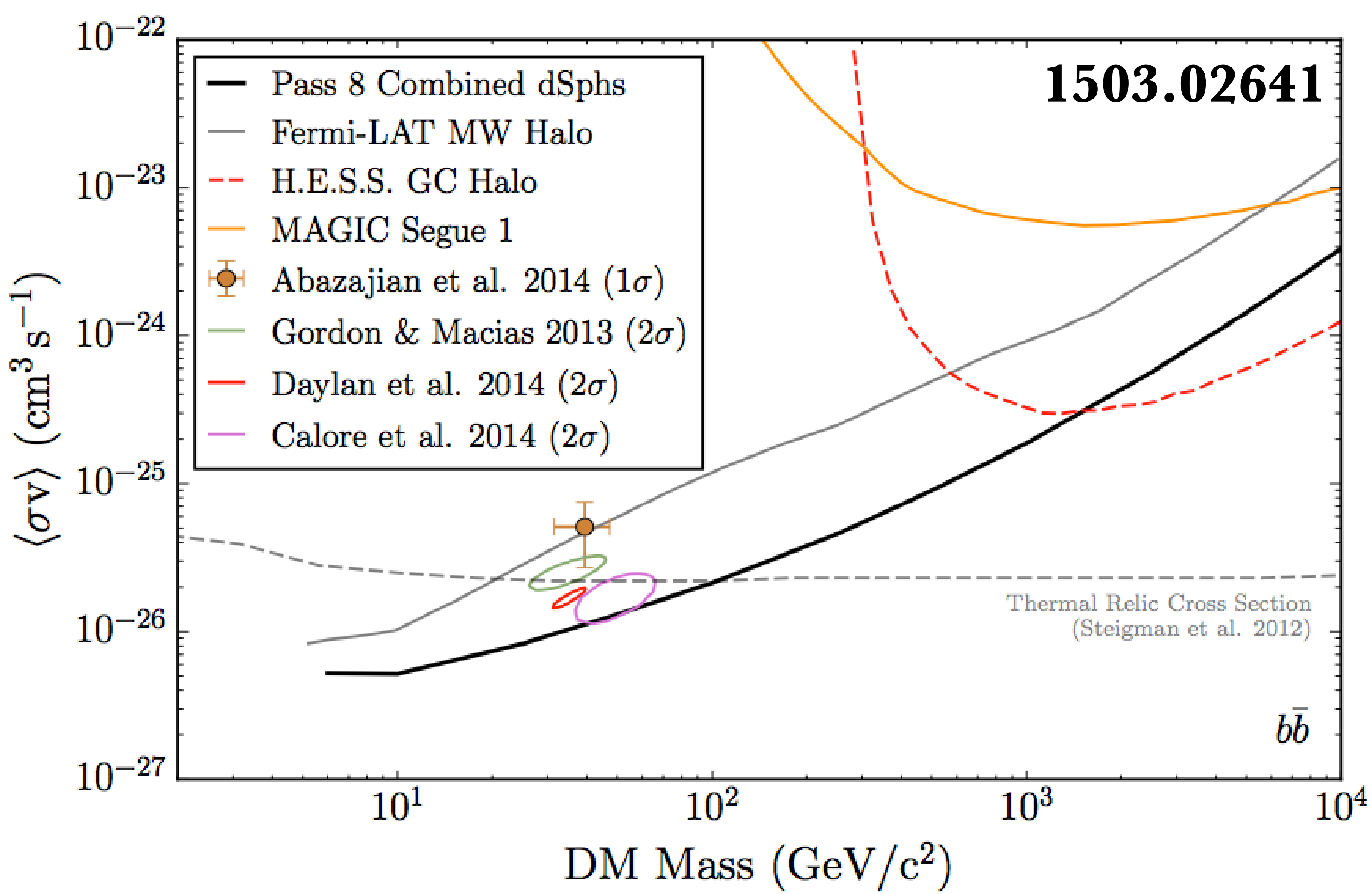
dSph ≡ collisionless spherical system in dynamical equilibrium

SPHERICAL JEANS EQUATION

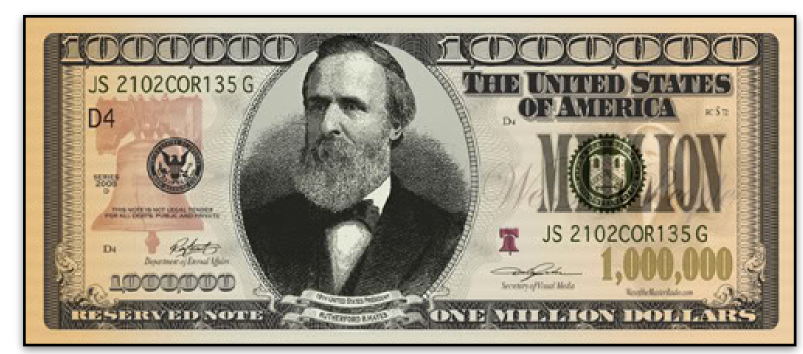
$$\boxed{\sigma_{los}(R) = f(I, \rho_\chi, \beta)}$$

$$-\infty < \beta(r) \leq 1$$

$$\int d\beta \; p(\beta)$$



1 Million Dollar Question



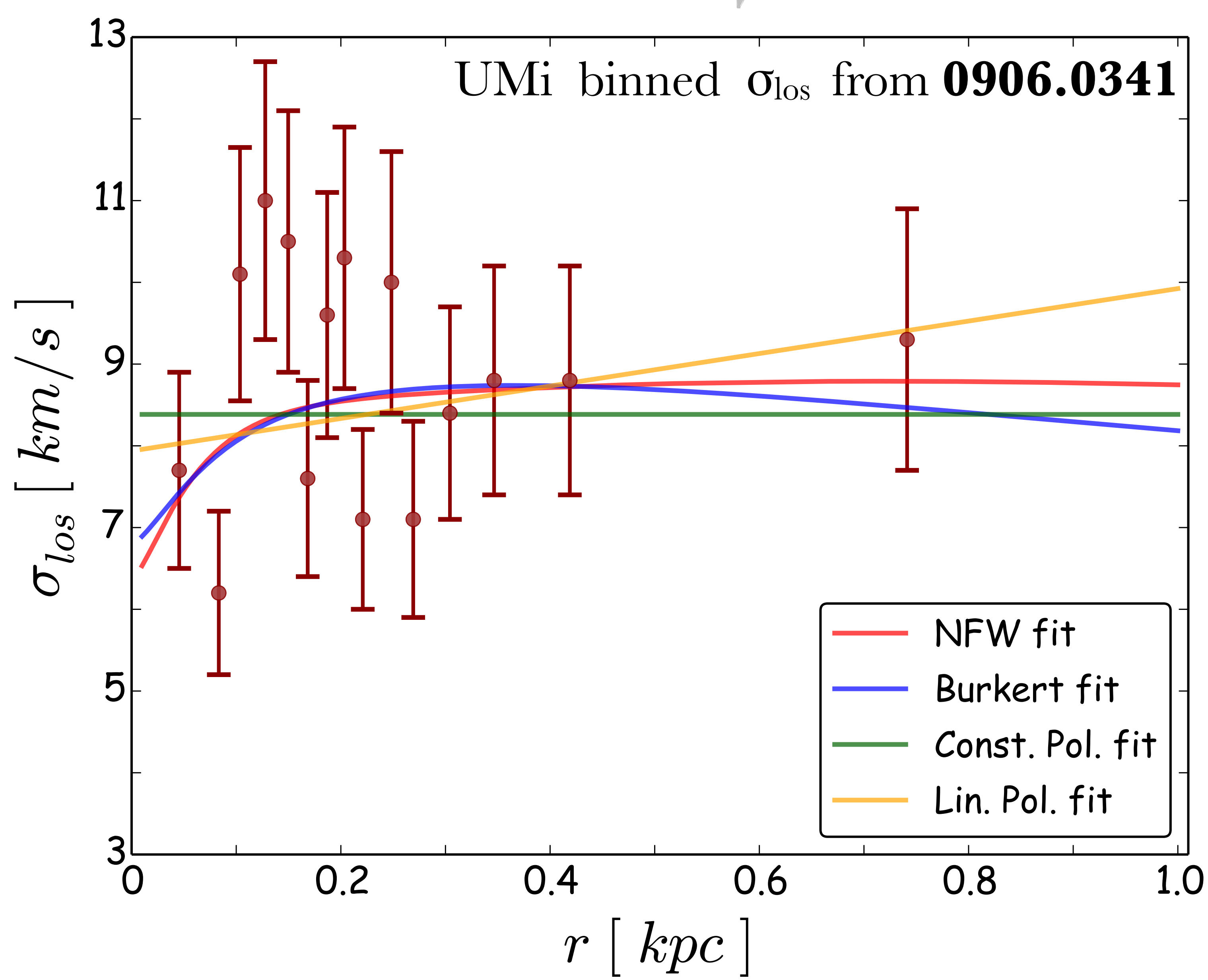
How do you marginalize on something you do not know?

OUR NOVEL APPROACH

to attack the problem in a different way it may be worth inverting standard logic!

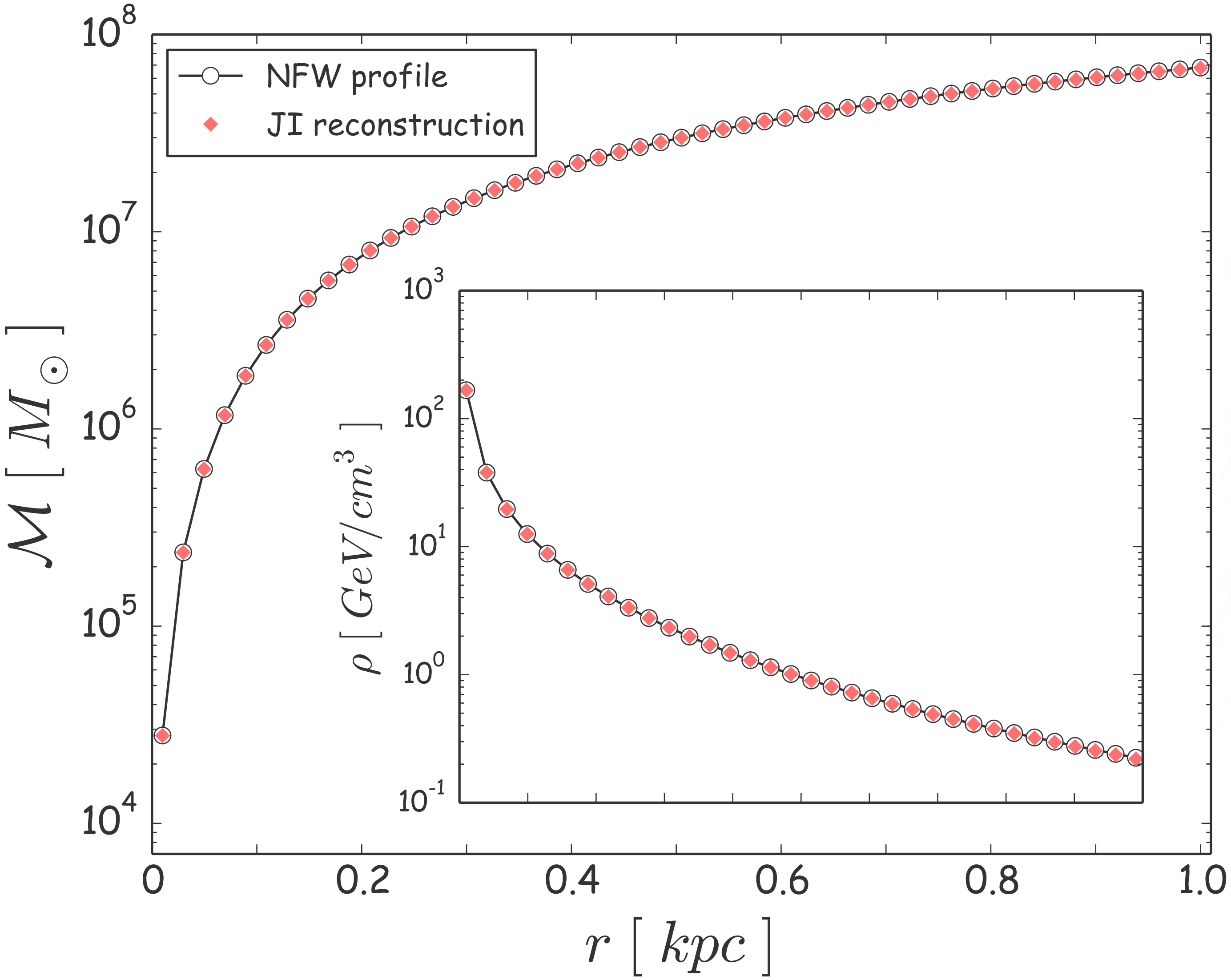
Jeans inversion

$$\sigma_{los}(R) = f(I, \rho_\chi, \beta) \quad \Rightarrow \quad \boxed{\mathcal{M}_\beta(r) = \mathcal{F}\left(\sigma_{los}, I, \beta\right)}$$



FOR A GIVEN FIT OF LINE-OF-SIGHT DISPERSION DATA ONE GETS A MASS PROFILE IN TERMS OF $\beta(r)$

WE BREAK MASS-ANISOTROPY DEGENERACY!



The general expression for the Jeans inversion is of the form:

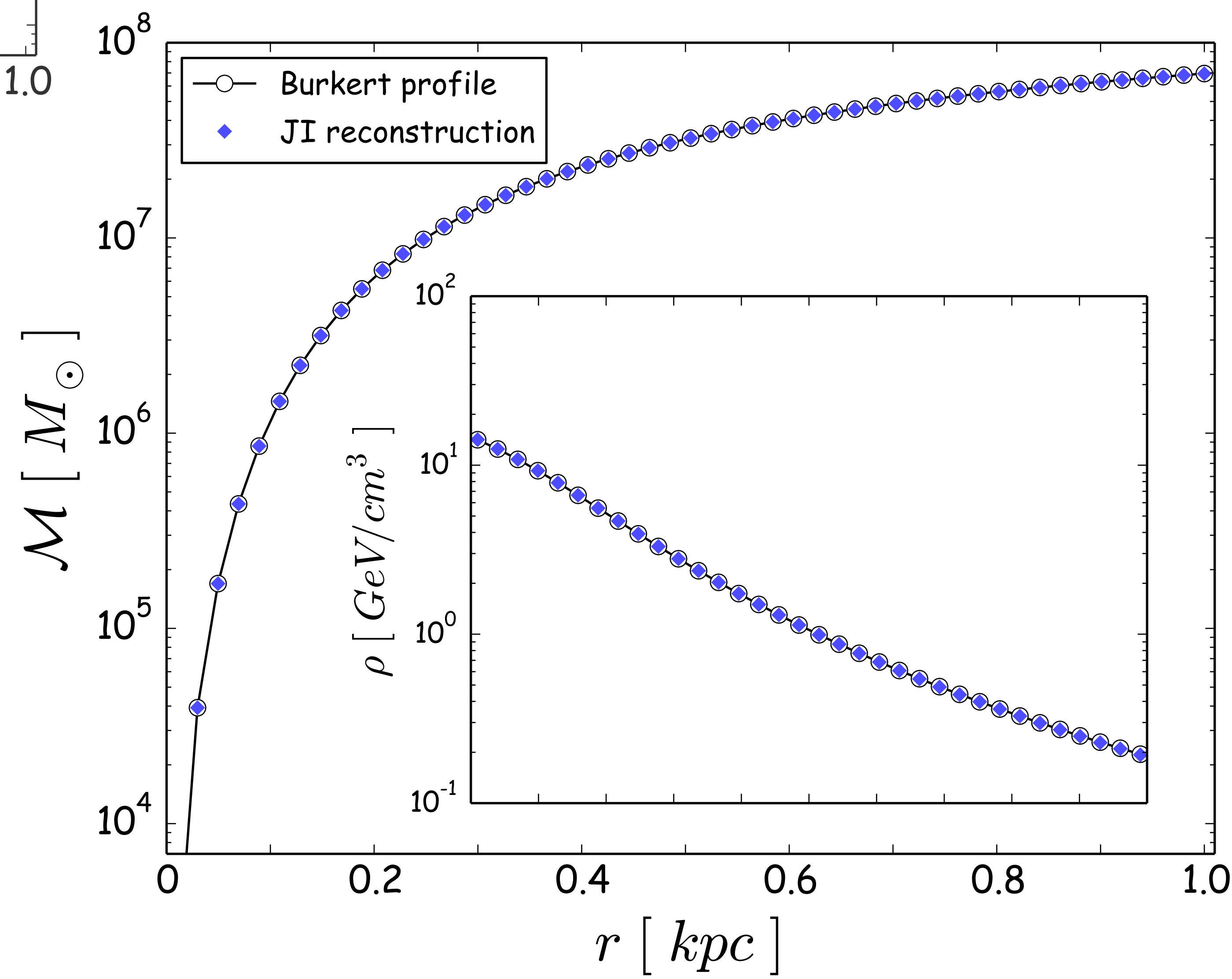
$$\mathcal{M}_\beta = \mathcal{A}_\beta(I) \int_r^\infty dR \frac{d^2 P}{(dR^2)^2} W_\beta(R, r)$$

where the pressure P is defined as

$$P = I\,\sigma^2_{los}$$

The inversion works pretty well also for the halo density.

$$\rho_{\chi\,\beta} = \frac{1}{4\pi r^2}\frac{d\mathcal{M}_\beta}{dr}$$



The simplest case one can consider is β(r) = const. and can be worked out in great detail. Even for this simple case, one needs to check:

$$1)\ \ \mathcal{M}_\beta > 0$$

$$2)\ \ \mathcal{M}_\beta(r') - \mathcal{M}_\beta(r) \geq 0 \ \ \text{if} \ \ r' \geq r$$

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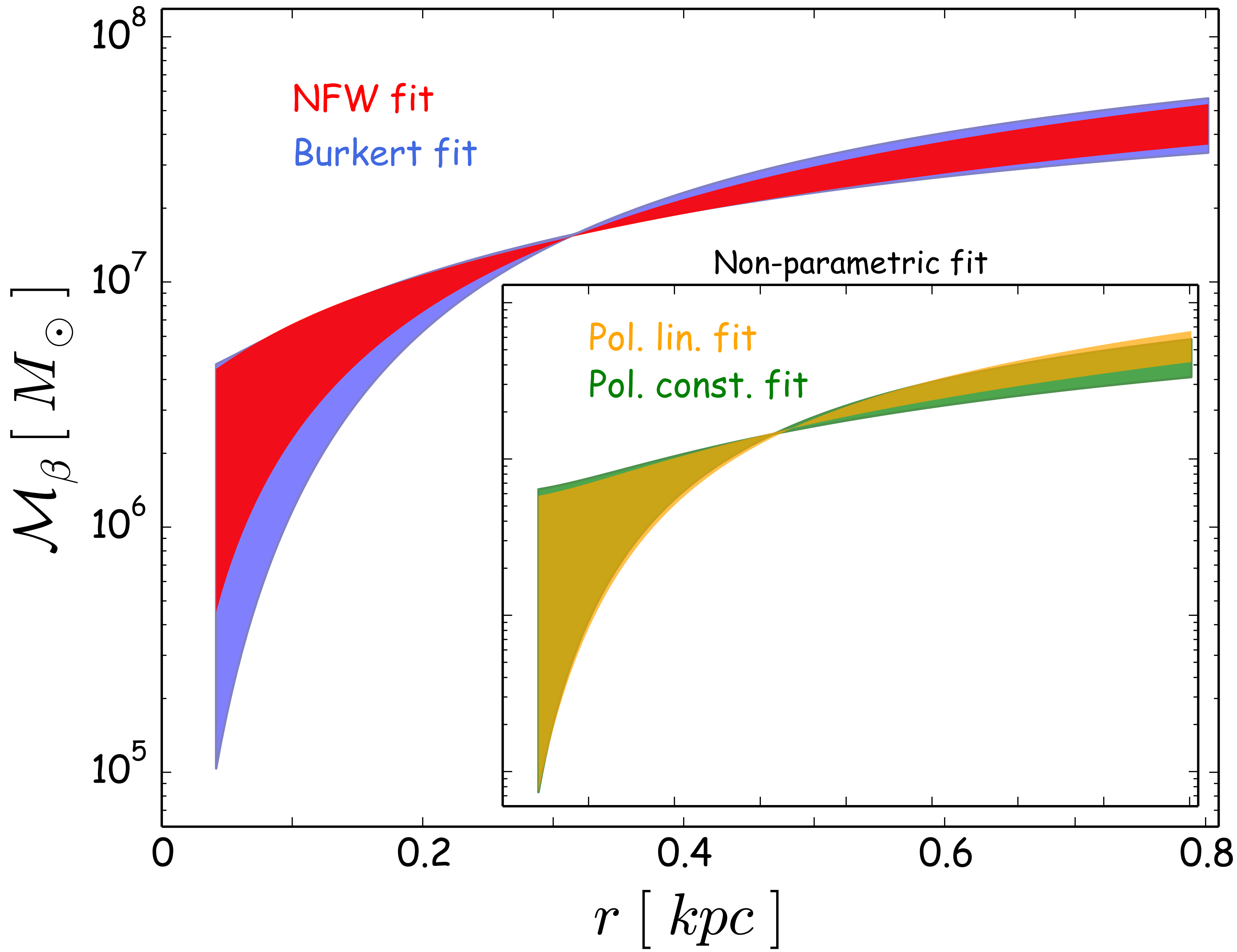
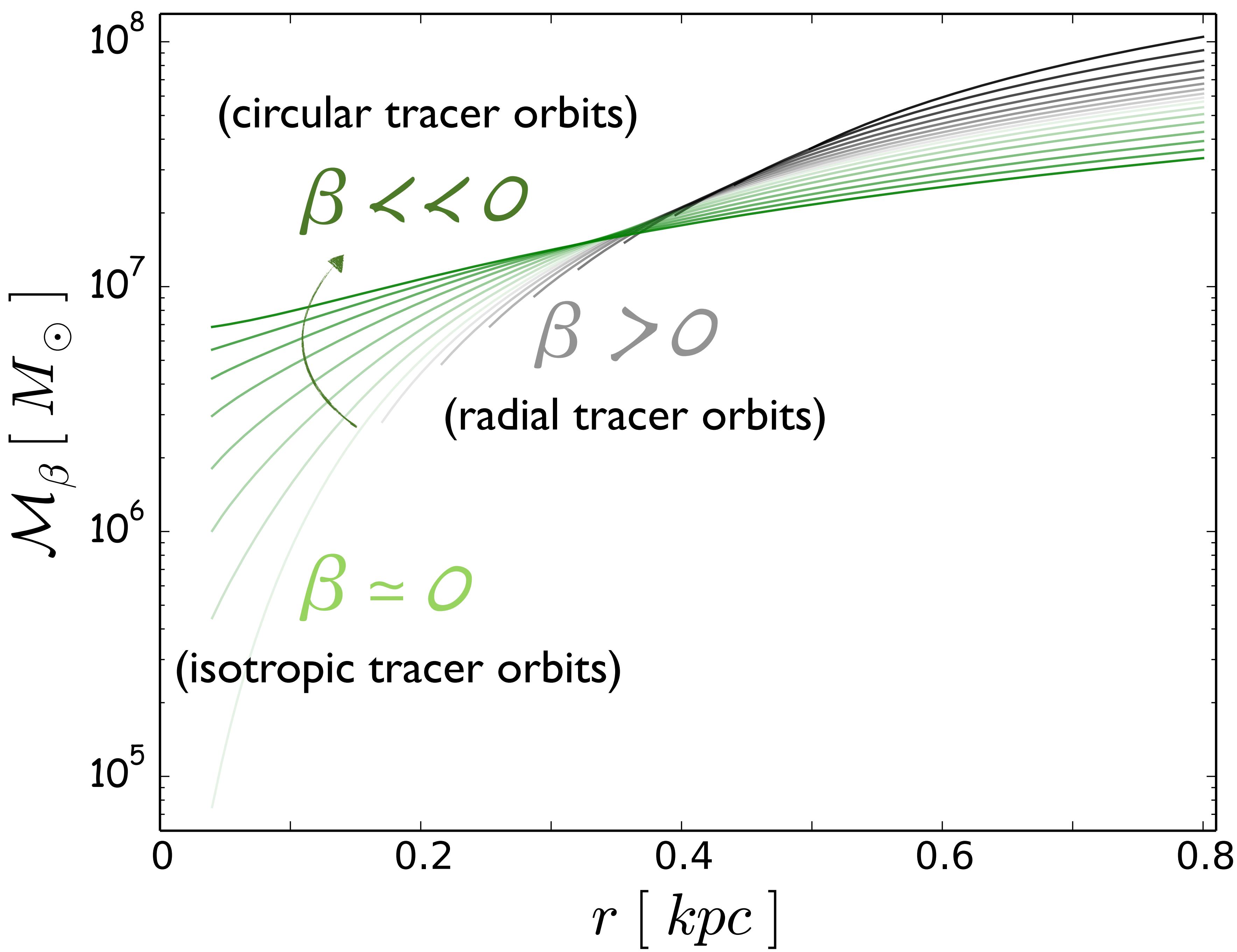


One of our benchmark cases for the fit of σ_{los} data is a constant.

For this simple fit, assuming also the orbital anisotropy to be constant in radius, an analytic expression holds in our Jeans inversion approach.

Studying the analytical mass profile:



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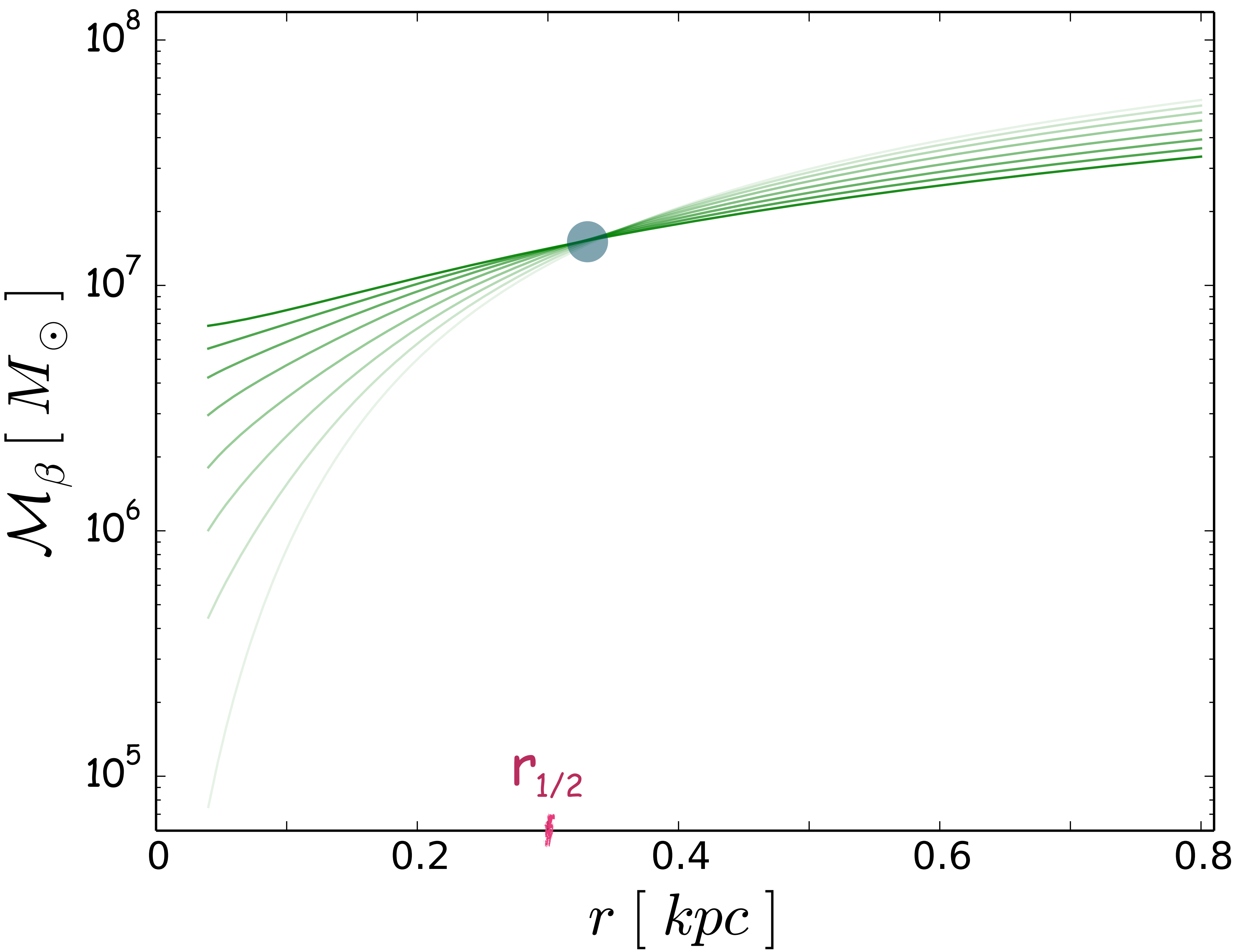
If one restricts it to the physical mass profiles:

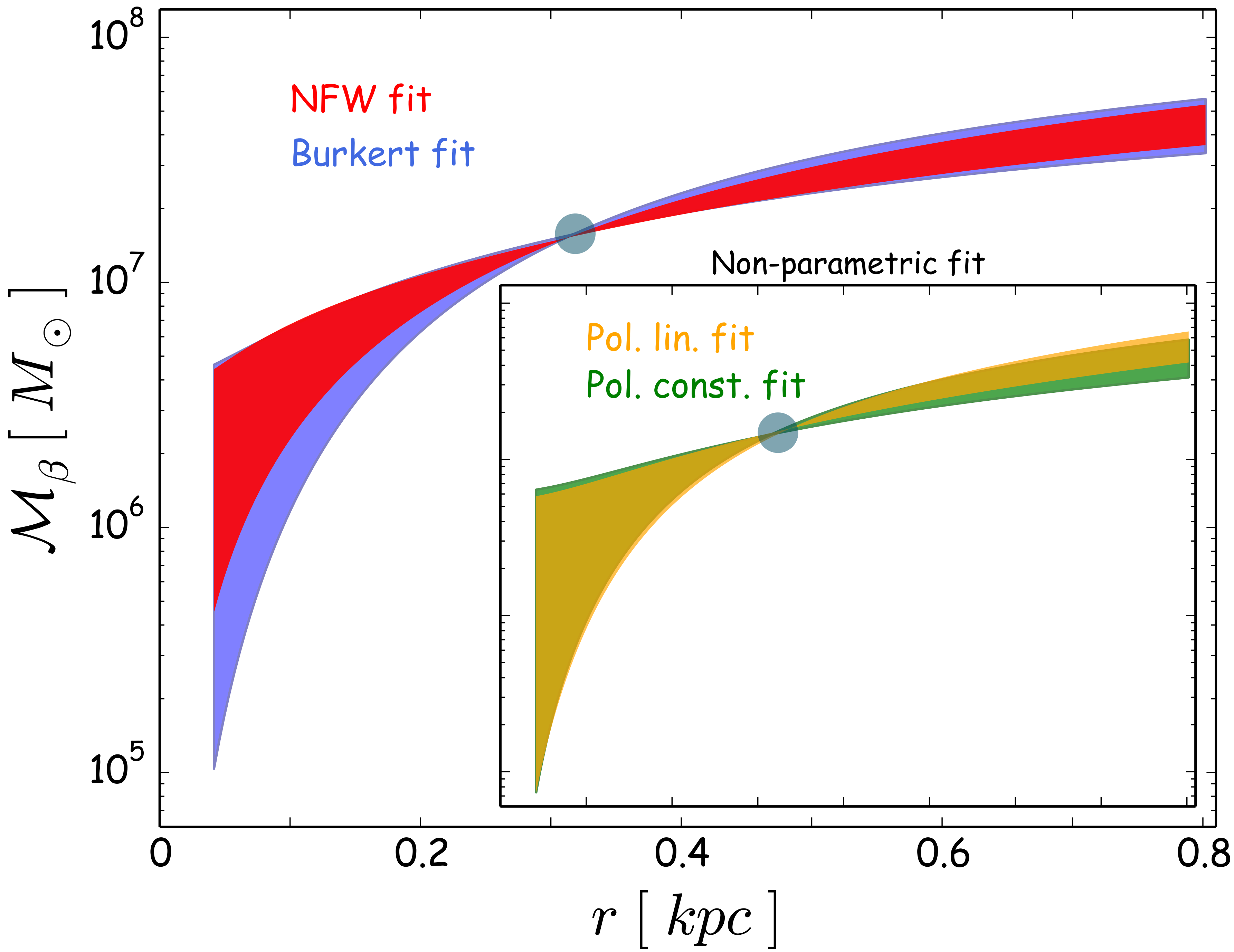


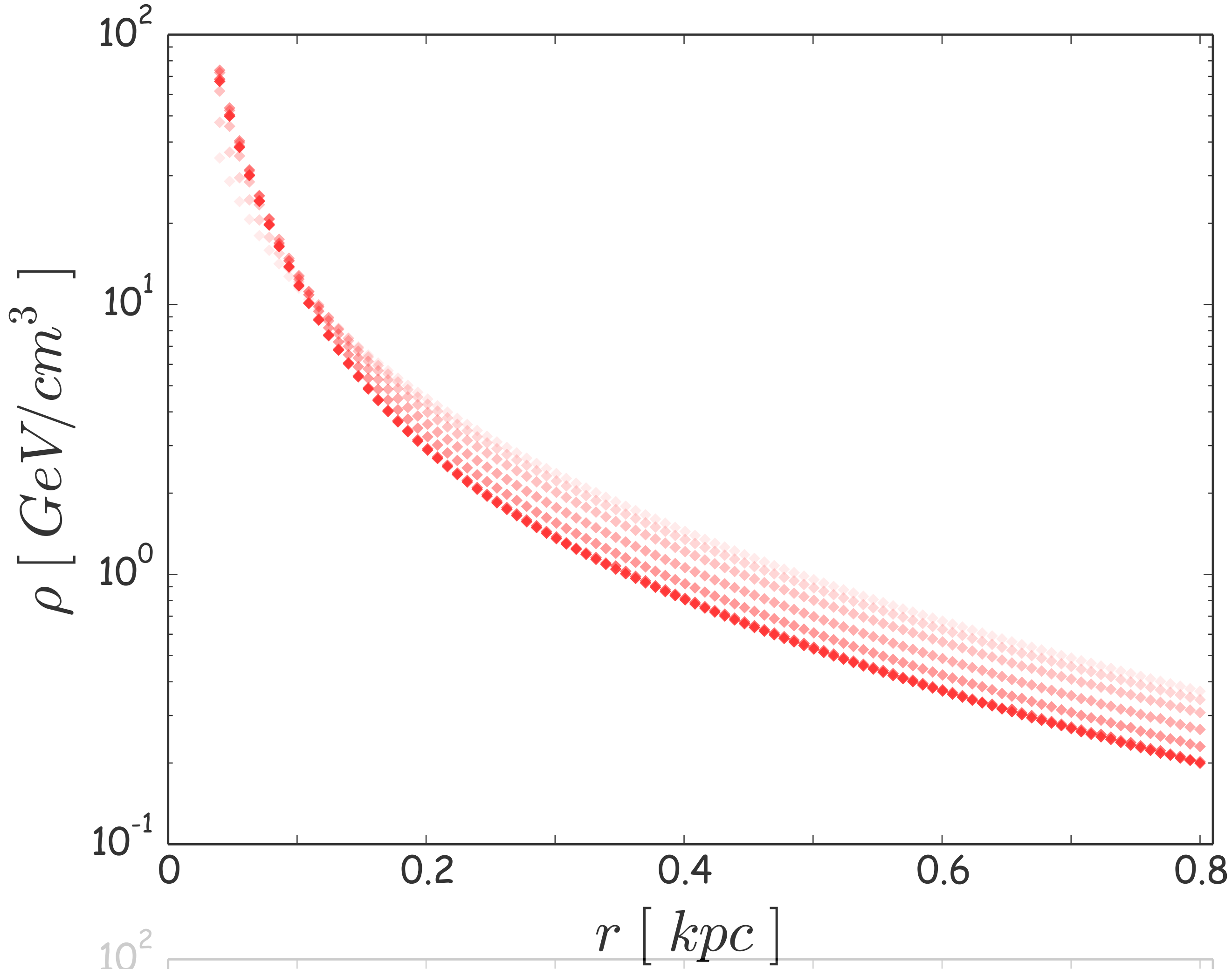
We give a proof of existence for a very good (but not exact) mass estimator

(see e.g. **0908.2995**)

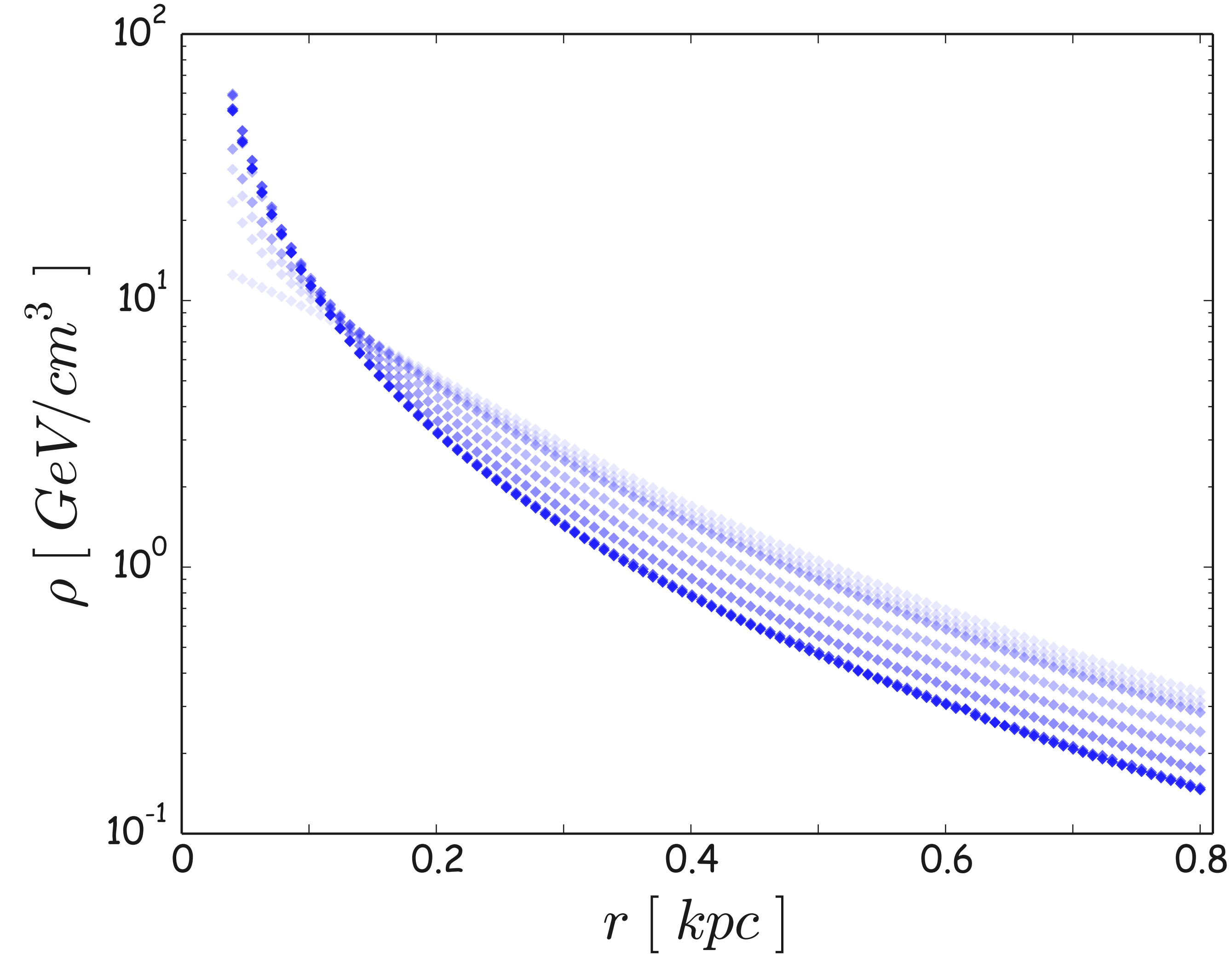
$$\boxed{\mathcal{R}_{\bar\beta} \equiv 1 - \mathcal{M}_{\bar\beta}/\mathcal{M}_0} \rightarrow \mathcal{R}_{\bar\beta}(r_\star) = 0 \; , \; r_\star = r_{\star\,\bar\beta}$$

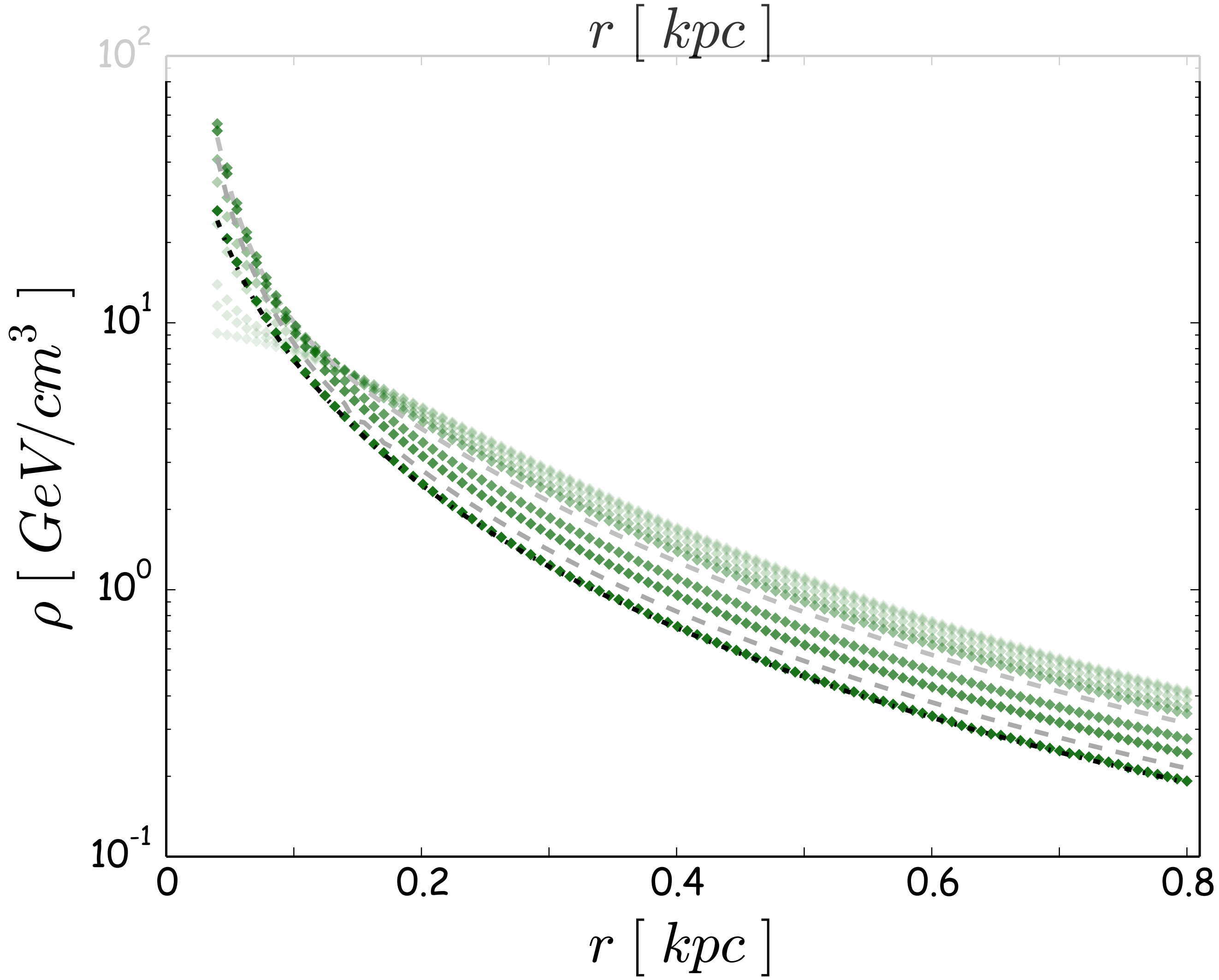
$r_\star \cong r_{1/2}$
mild dependence on β (% effect)





Negative anisotropy seems to require cuspier profiles.



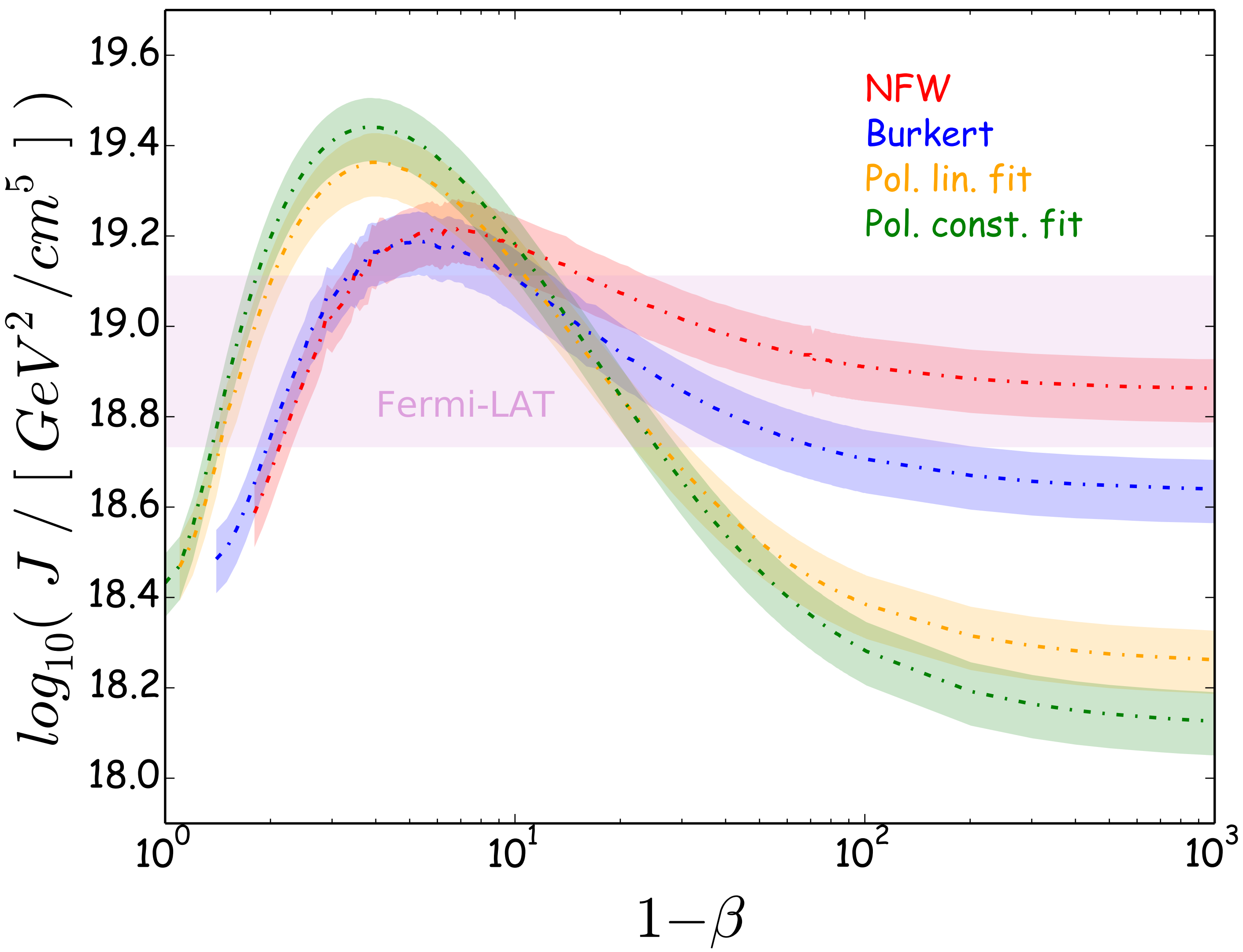


In the constant fit case, $M_{1/2}$ constraint turns out to be slightly milder.

The halo density then can "shift down" a bit more.

For the J-factor, one needs to integrate the squared halo density along the l.o.s. .

Since the Jeans inversion is defined only in the range of data, we make a conservative assumption for the halo density nearby the center, i.e. $\rho(r < r_I) = \rho(r_I)$, $r_I \simeq 10$ pc .



1. Fermi-LAT 1σ band does not capture well the whole uncertainty related to β.

2. In all our 4 benchmark cases, J_{min} results to be close to the most recent estimate of the J-factor used by the Fermi coll. to obtain DM bounds.

We extensively test the value of J_{min} against different choices of $\beta(r)$, finding it to be solid even in the case of wildly varying radial profiles.

Final Remarks

dSph galaxies represent a unique Dark Matter laboratory
(both for Indirect Searches as well as for N-body simulations)

They can confirm/falsify the Dark Matter interpretation of the GeV excess @ the GC

In this work we actually probed the robustness of the current tight upper-bound on $\langle \sigma v \rangle$ against what can be considered the greatest theoretical bias in the modeling of these DM dominated objects.

From this perspective, dSph constraints turned out to be quite solid ... maybe a sort of milestone for DM Indirect Searches!

Thank You!