Galactic rotation curves vs. ultra-light dark matter

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1805.00122

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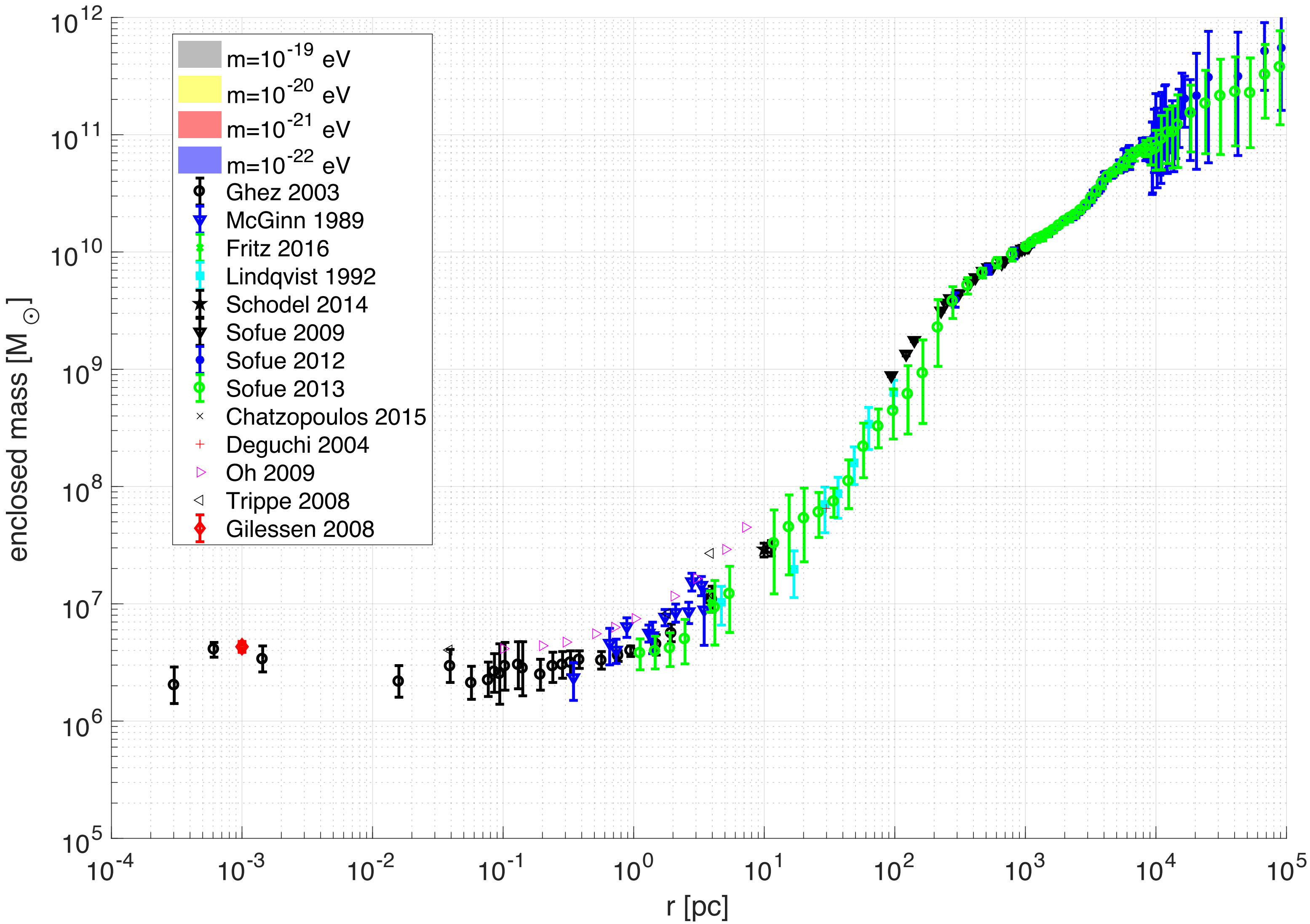
ICTP, *Giant Telescopes*, July 2018

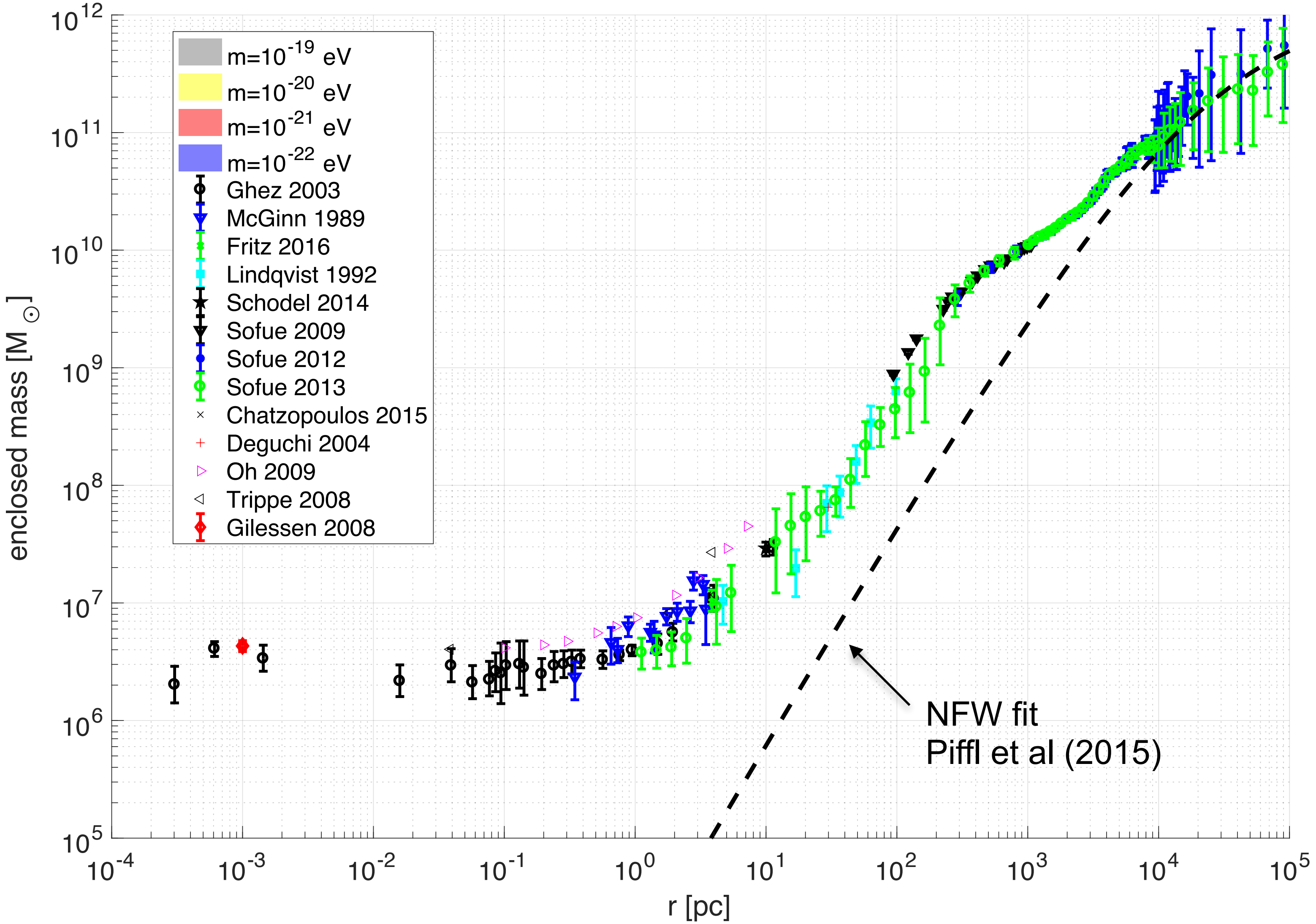
Motivation

(estimated) mass profile of the Milky Way, radially-averaged, from a variety of tracers



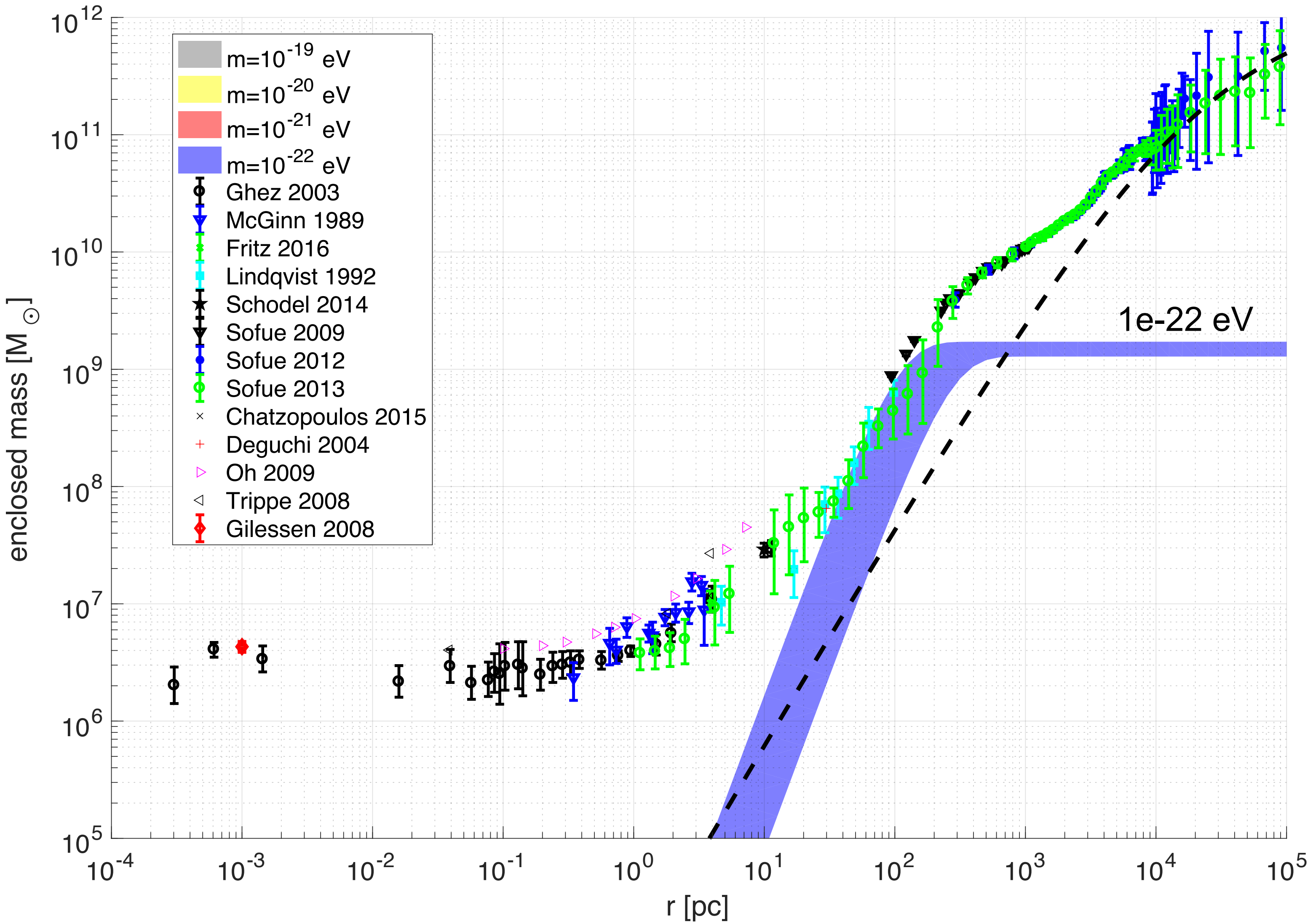
WIMP cold dark matter:

thought to affect outer part of rotation curve



Ultra-Light Dark Matter (ULDM):

makes predictions for the inner part of galaxies



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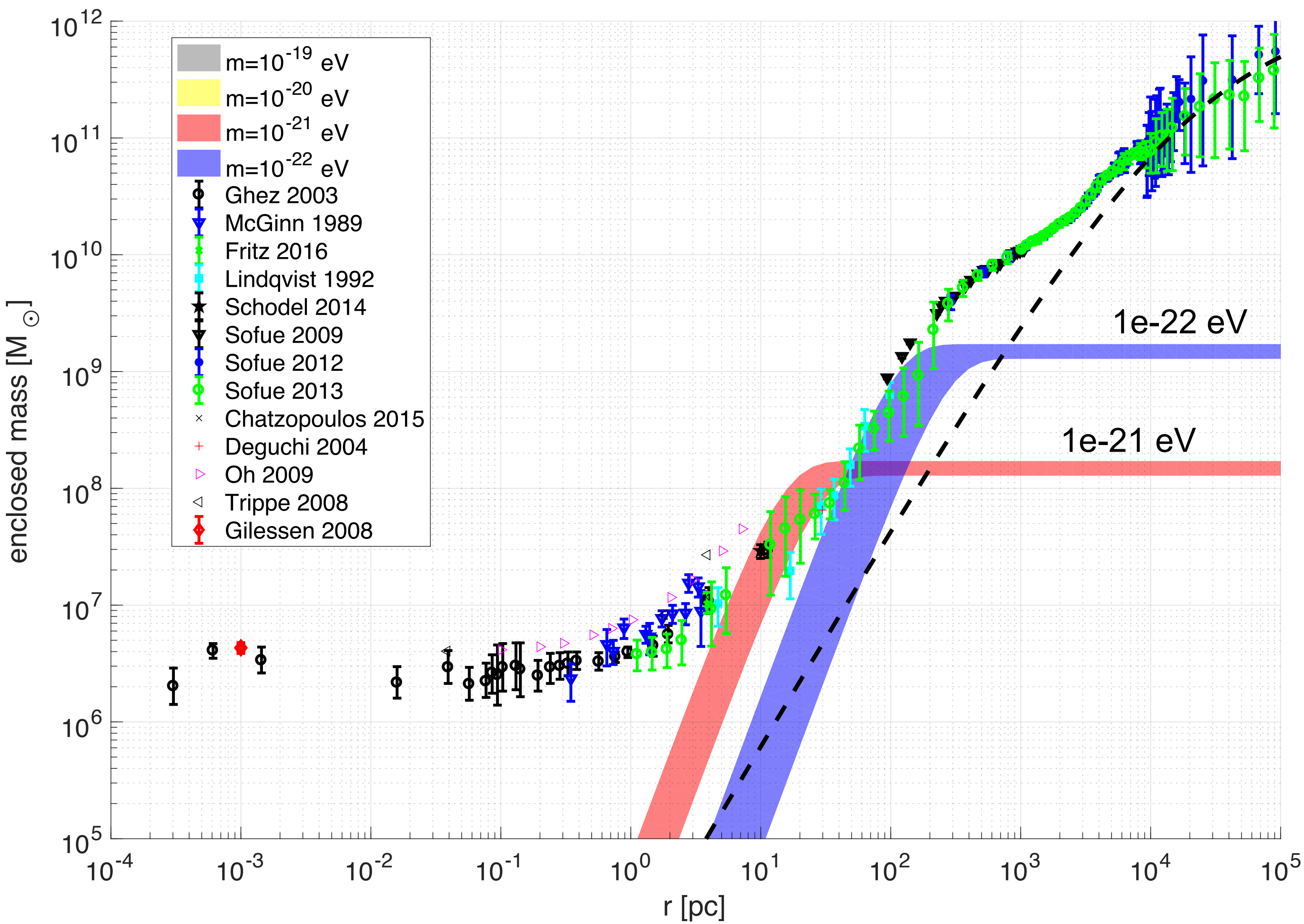

Ultra-Light Dark Matter (ULDM):

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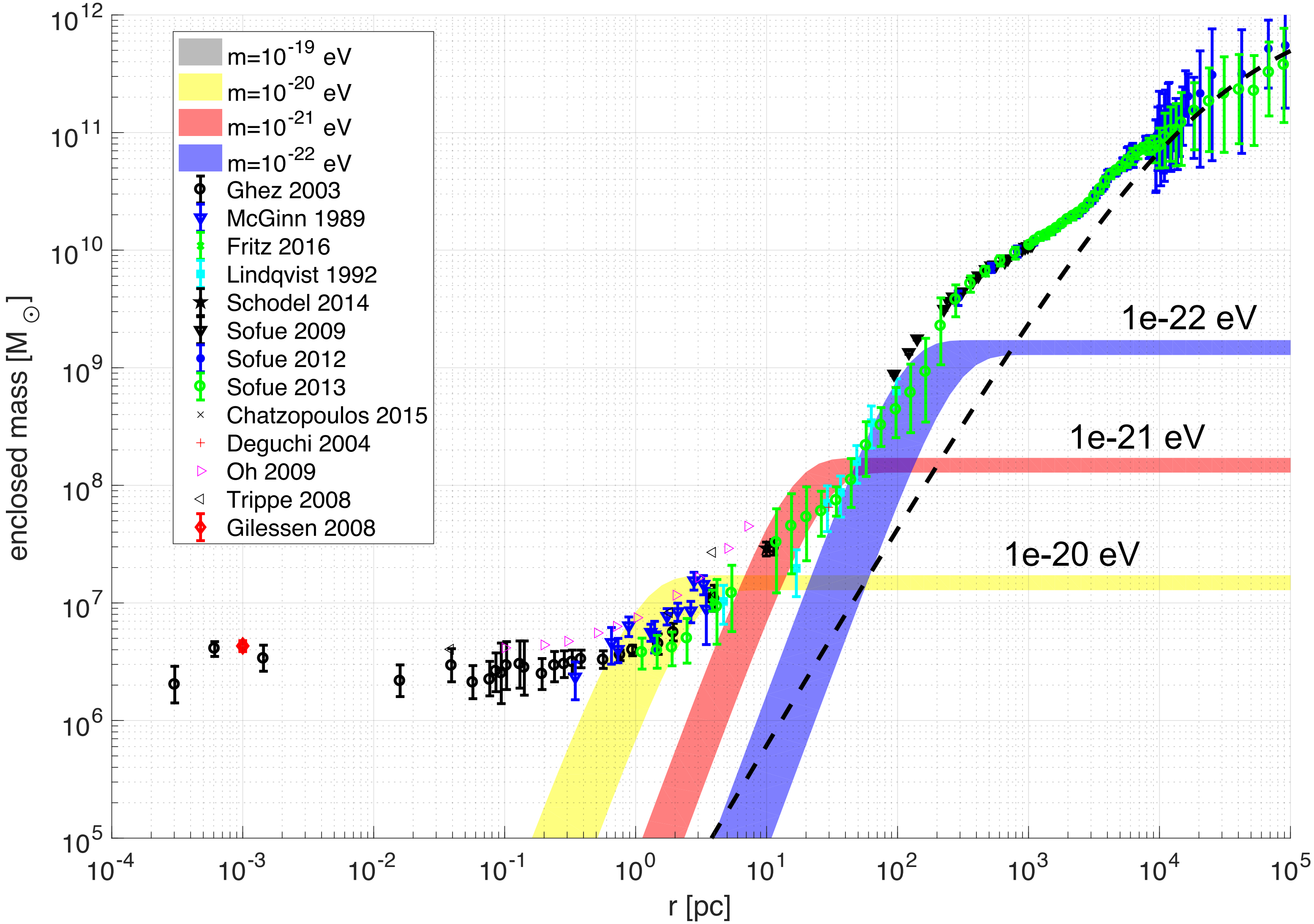


Summary

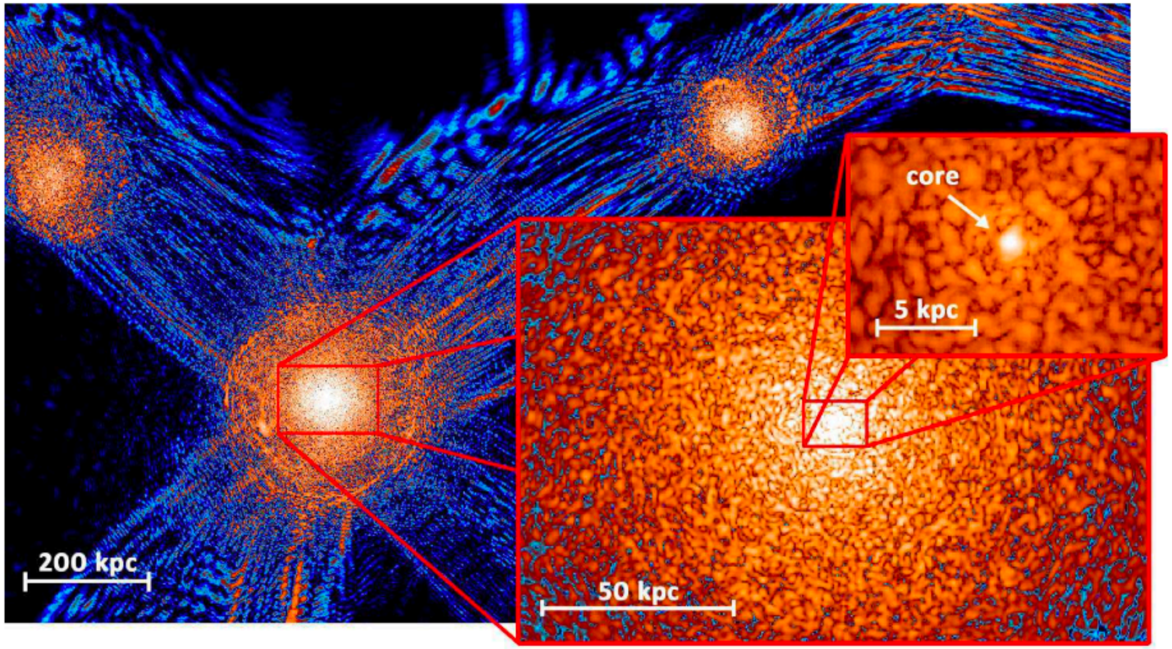
In the last ~five years, numerical structure formation simulations with ULDM have become available.

Schive 1406.6586, Schive 1407.7762, Mocz 1705.05845, Veltmaat 1804.09647, Levkov 1804.05857 (partial list…)

The inner part of simulated galaxies forms a core: “soliton”.

Simulations have discovered a scaling relation, connecting the core to the host halo.

Schive 1406.6586, Schive 1407.7762, Veltmaat 1804.09647



Schive 1406.6586

Soliton—host halo relation predicts a bump in the inner part of rotation curves.

We study the theoretical implications, trying to understand the underlying physics of the soliton—host halo relation. (*Not in this talk*.)

We study high-resolution rotation curves of ~100 intermediate size galaxies, in the ballpark of halo mass that was numerically simulated.

As far as we could see, the bump isn't there.
m~1e-22 - 1e-21 eV seems to be in tension with observations of many galaxies.

Comparable independent constraints from **Ly-alpha** Forest analyses; see **talk by Viel** earlier today.
Armengaud (1703.09126), Irsic (1703.04683), Zhang (1708.04389), Kobayashi (1708.00015)

Soliton—host halo relation predicts a bump in the inner part of rotation curves.

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This particular range of m is of special interest, because it was thought to address small-scale puzzles of LCDM

[1] W. Hu, R. Barkana, and A. Gruzinov, "Cold and fuzzy dark matter," Phys. Rev. Lett. **85** (2000) 1158–1161, arXiv:astro-ph/0003365 [astro-ph].

[2] A. Arbey, J. Lesgourgues, and P. Salati, "Quintessential haloes around galaxies," Phys. Rev. **D64** (2001) 123528, arXiv:astro-ph/0105564 [astro-ph].

[3] J. Lesgourgues, A. Arbey, and P. Salati, "A light scalar field at the origin of galaxy rotation curves," New Astron. Rev. **46** (2002) 791–799.

[4] P.-H. Chavanis, "Mass-radius relation of Newtonian self-gravitating Bose-Einstein condensates with short-range interactions: I. Analytical results," Phys. Rev. **D84** (2011) 043531, arXiv:1103.2050 [astro-ph.CO].

[5] P. H. Chavanis and L. Delfini, "Mass-radius relation of Newtonian self-gravitating Bose-Einstein condensates with short-range interactions: II. Numerical results," Phys. Rev. **D84** (2011) 043532, arXiv:1103.2054 [astro-ph.CO].

[6] D. J. E. Marsh and A.-R. Pop, "Axion dark matter, solitons and the cusp-core problem," Mon. Not. Roy. Astron. Soc. **451** no. 3, (2015) 2479–2492, arXiv:1502.03456 [astro-ph.CO].

[7] S.-R. Chen, H.-Y. Schive, and T. Chiueh, "Jeans Analysis for Dwarf Spheroidal Galaxies in Wave Dark Matter," Mon. Not. Roy. Astron. Soc. **468** no. 2, (2017) 1338–1348, arXiv:1606.09030 [astro-ph.GA].

[8] L. Hui, J. P. Ostriker, S. Tremaine, and E. Witten, "Ultralight scalars as cosmological dark matter," Phys. Rev. **D95** no. 4, (2017) 043541, arXiv:1610.08297 [astro-ph.CO].

[9] H.-Y. Schive, T. Chiueh, and T. Broadhurst, "Cosmic Structure as the Quantum Interference of a Coherent Dark Wave," Nature Phys. **10** (2014) 496–499, arXiv:1406.6586 [astro-ph.GA].

[10] H.-Y. Schive, M.-H. Liao, T.-P. Woo, S.-K. Wong, T. Chiueh, T. Broadhurst, and W. Y. P. Hwang, "Understanding the Core-Halo Relation of Quantum Wave Dark Matter from 3D Simulations," Phys. Rev. Lett. **113** no. 26, (2014) 261302, arXiv:1407.7762 [astro-ph.GA].

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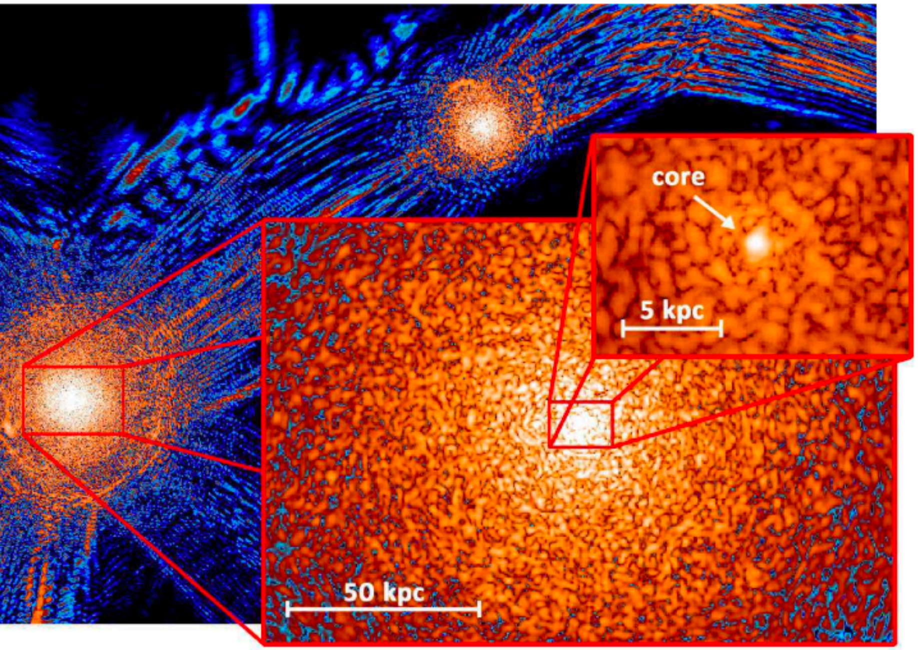
Soliton—host halo relation predicts a bump in the inner part of rotation curves.

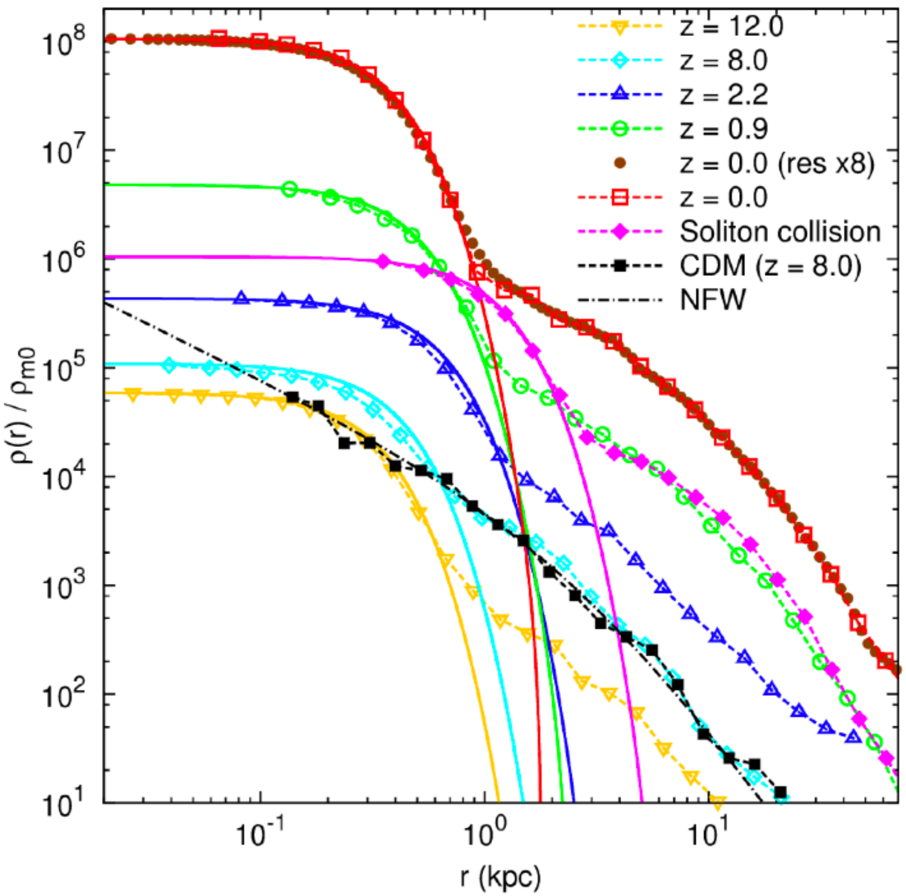
As far as we could see, the bump isn't there.
m~1e-22 - 1e-21 eV seems to be in tension with observations of many galaxies.

m >~1e-20 cannot yet be constrained, because of spatial resolution of rotation curve data: cannot resolve the core.

Better observational resolution may probe m > 1e-20eV

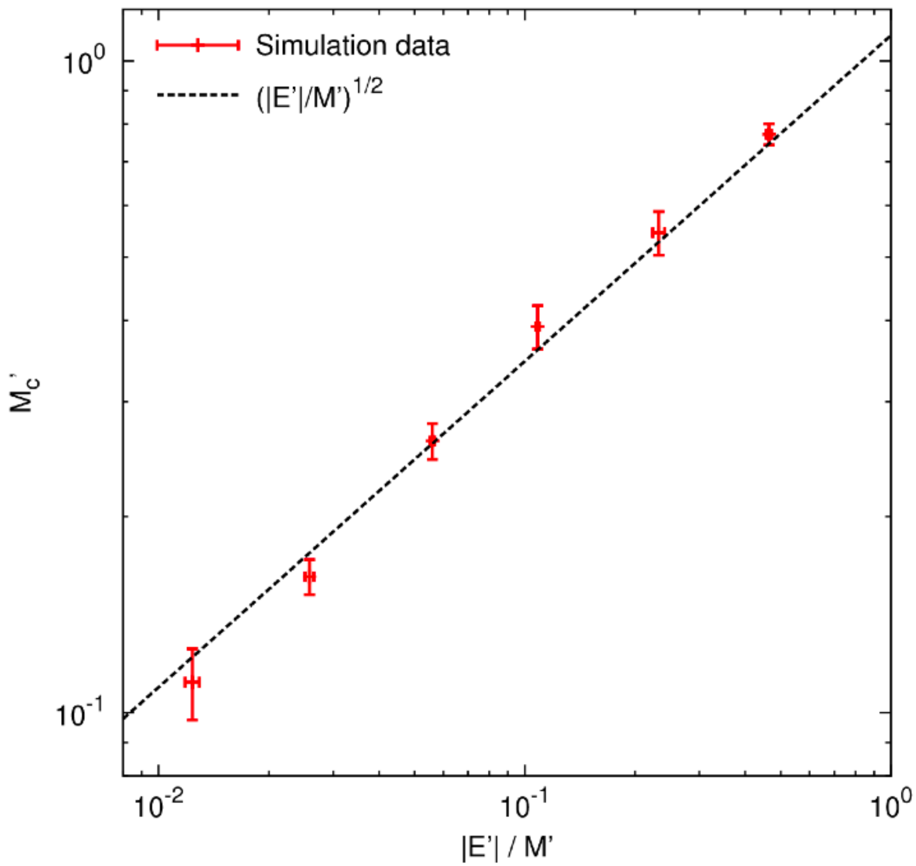
Analysis

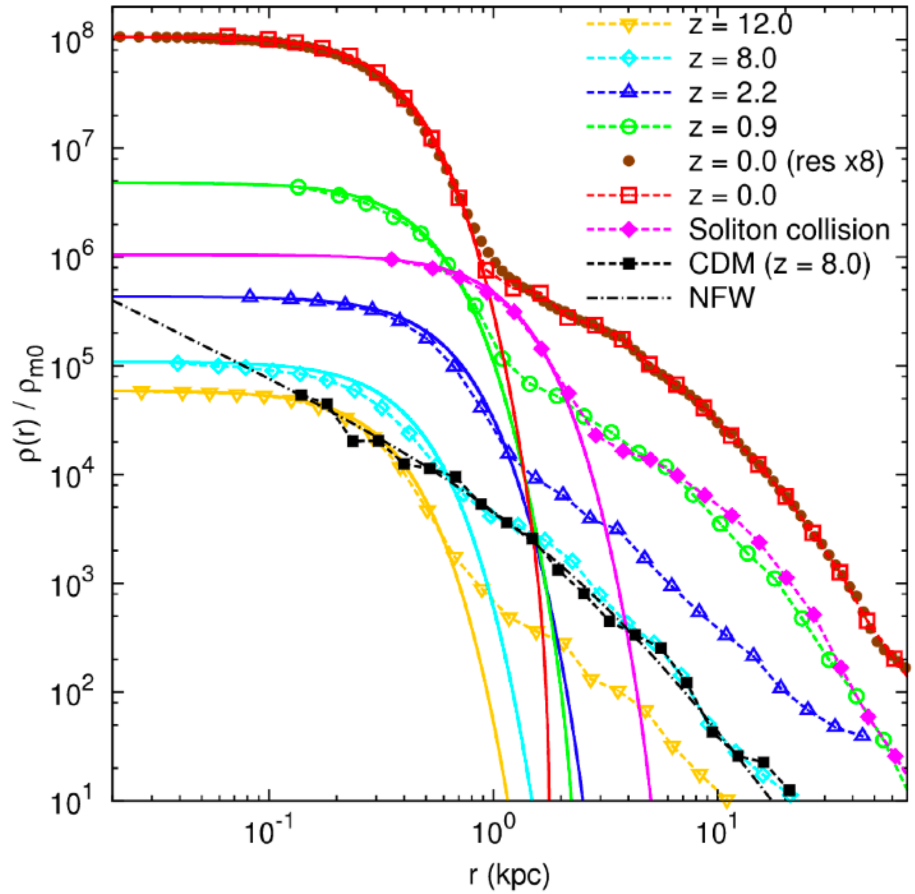




Schive et al 1406.6586

A soliton — host halo relation?



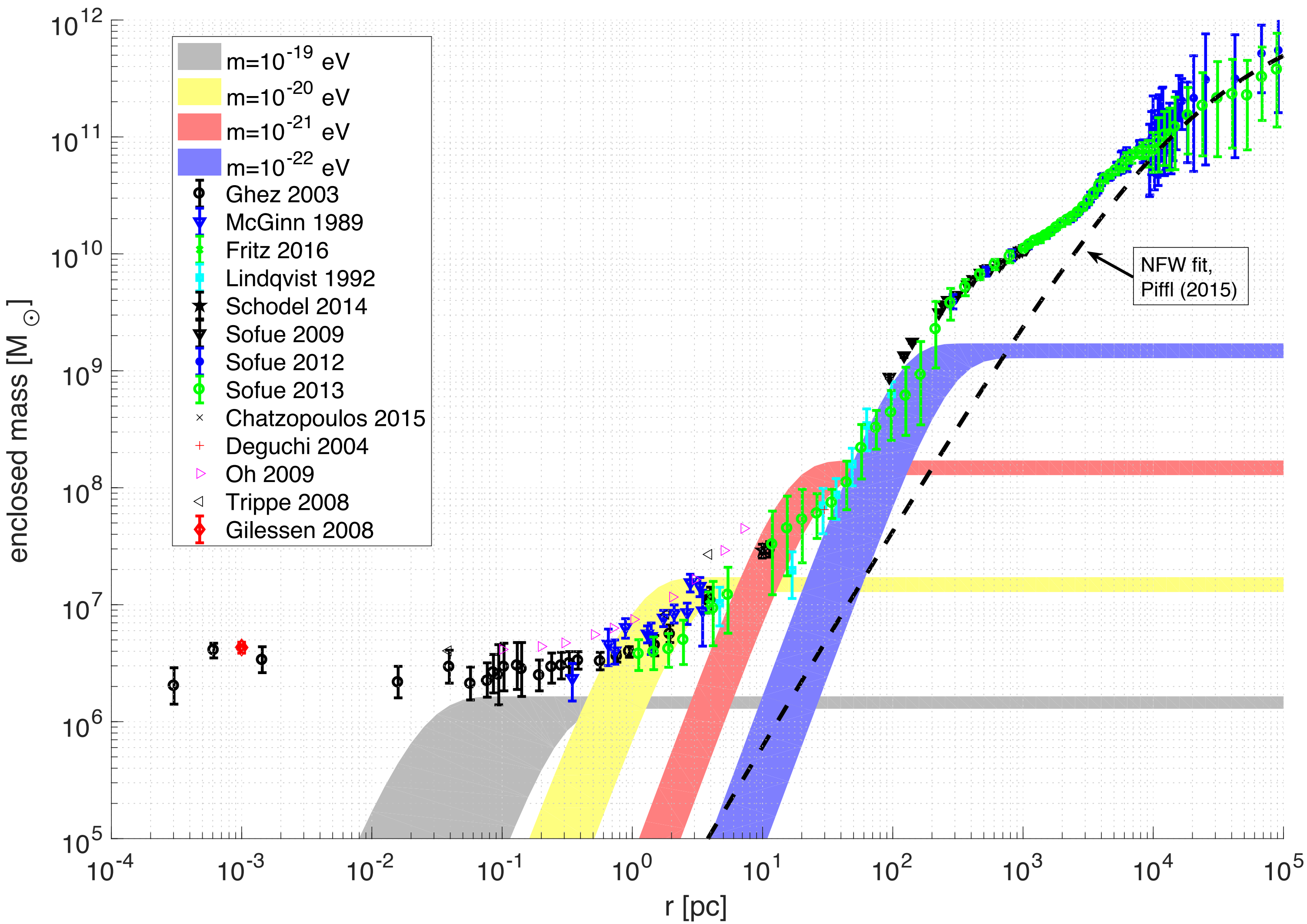


$$M_c \approx \alpha \left(\frac{|E_h|}{M_h}\right)^{\frac{1}{2}} \frac{M_{pl}^2}{m}$$

$$\alpha = 1$$

Schive et al 1406.6586
Schive et al 1407.7762
Veltmaat et al 1804.09647

The Milky Way



Empirical soliton—host halo relation, equivalent to this statement:

$$\frac{E}{M}\Big|_{\rm soliton} \approx \frac{E}{M}\Big|_{\rm halo}$$

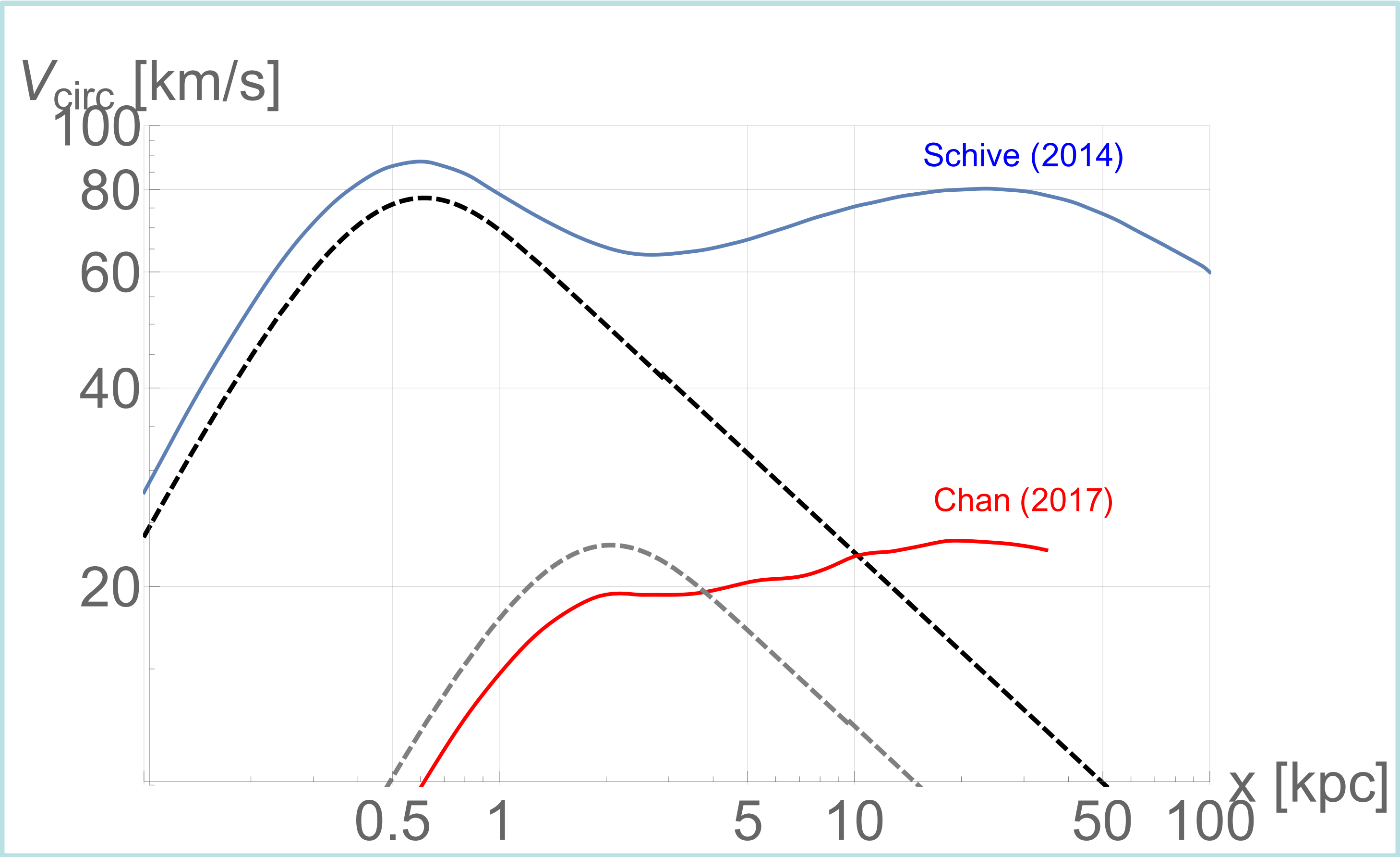
Derivation: Not in this talk… (1805.00122)

Empirical soliton—host halo relation, equivalent to this statement:

$$\frac{E}{M}\Big|_{\text{soliton}} \approx \frac{E}{M}\Big|_{\text{halo}}$$

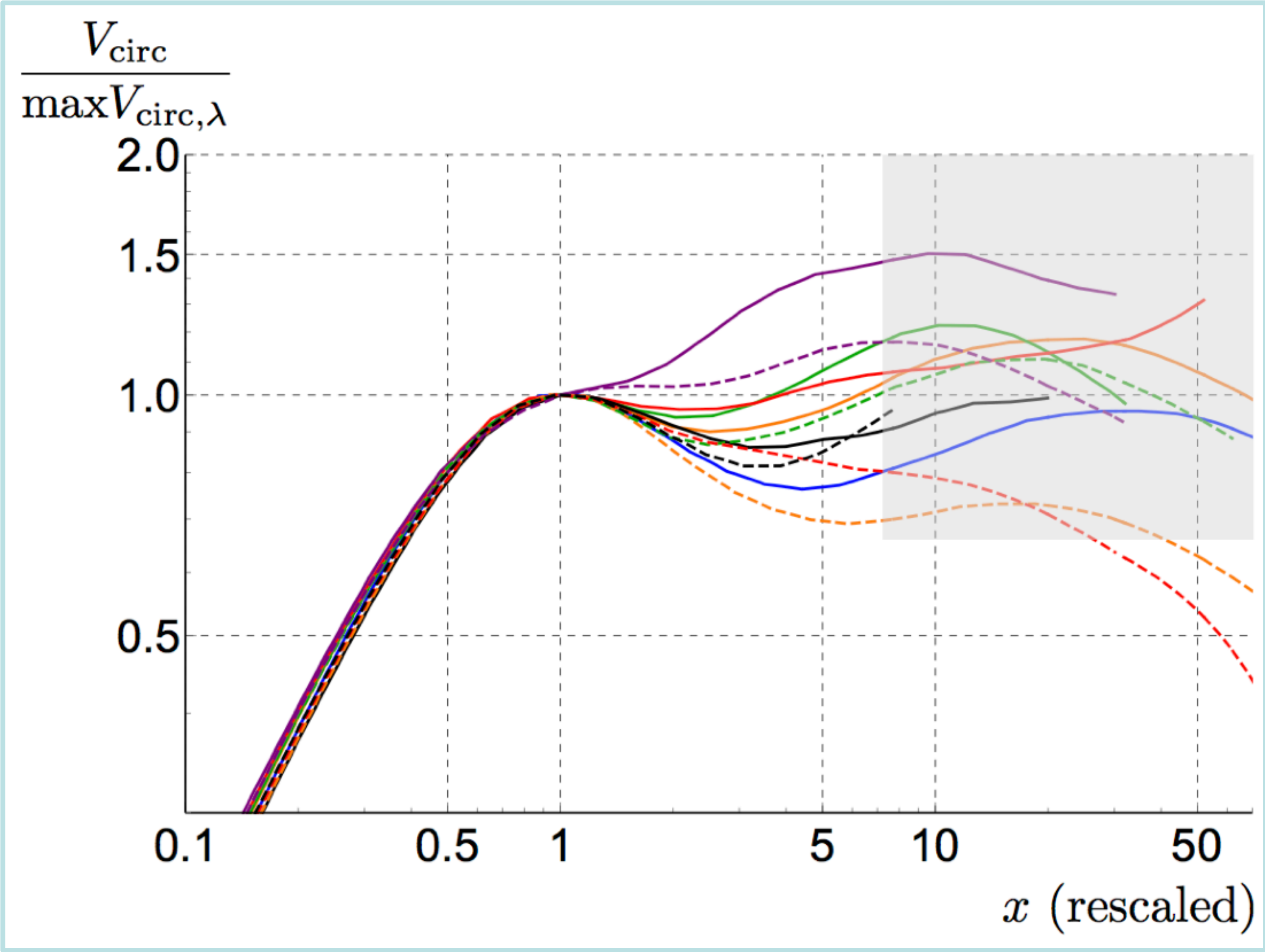
Equal specific energy ==> equal specific kinetic energy
==> ~equal peak rotation velocity

Compare directly to simulations



This is a powerful prediction. It is easy to compare to data:

i. Look at galaxies
ii. Find halo peak rotation curve
iii. This determines the soliton & soliton peak velocity in the inner part of the galaxy

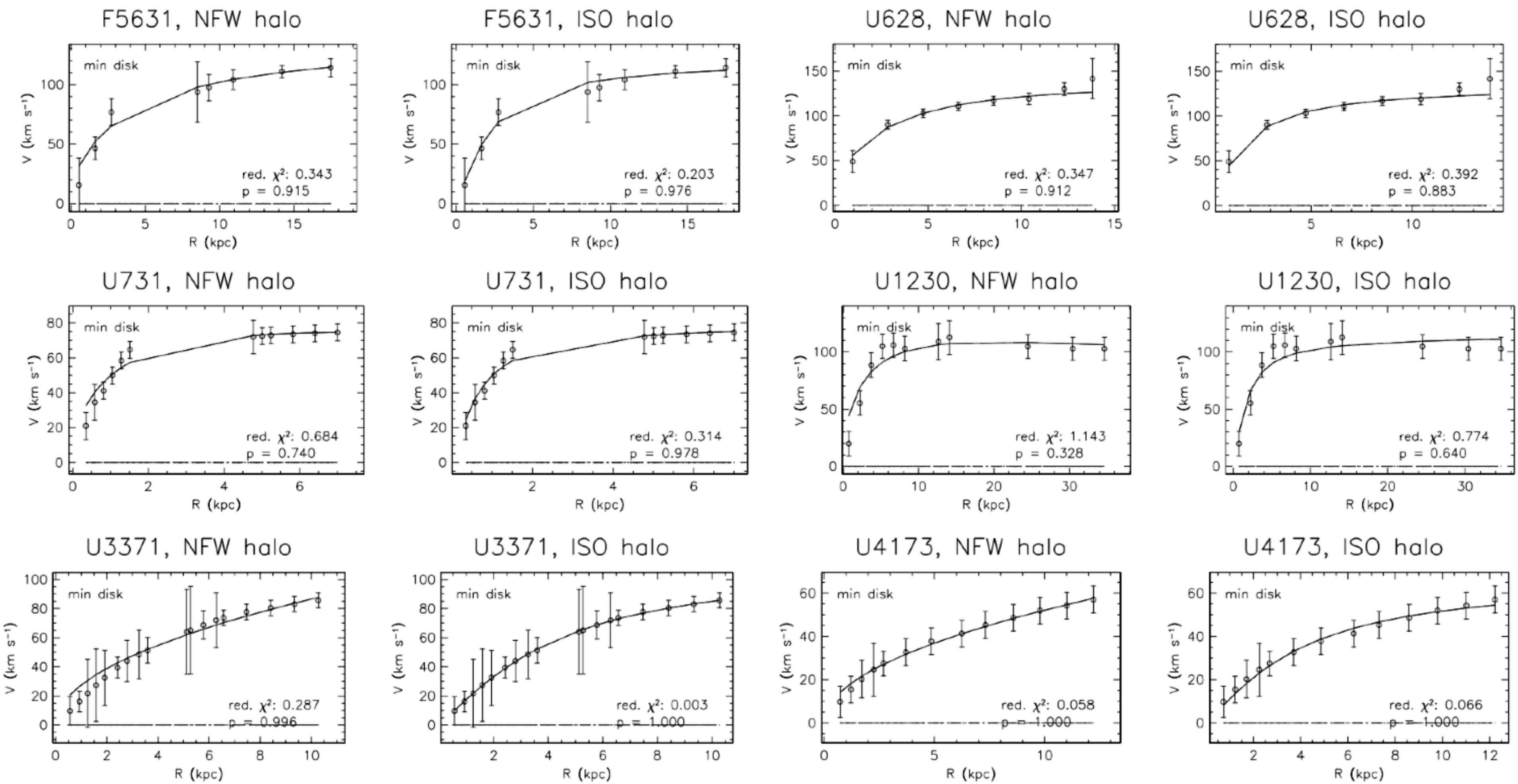


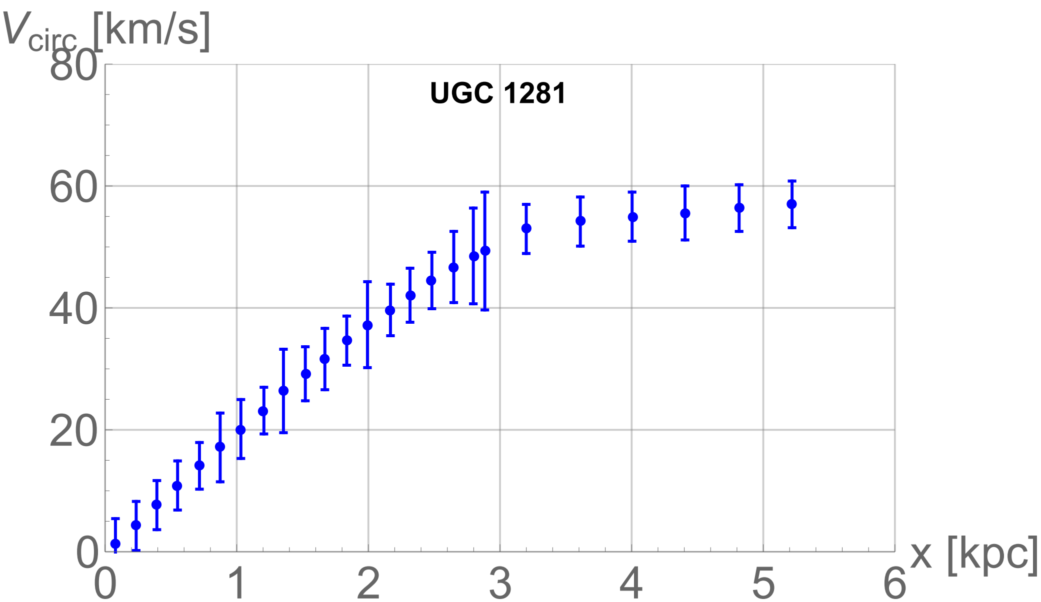
A&A 385, 816–846 (2002)
DOI: 10.1051/0004-6361:20020080

Astronomy & Astrophysics

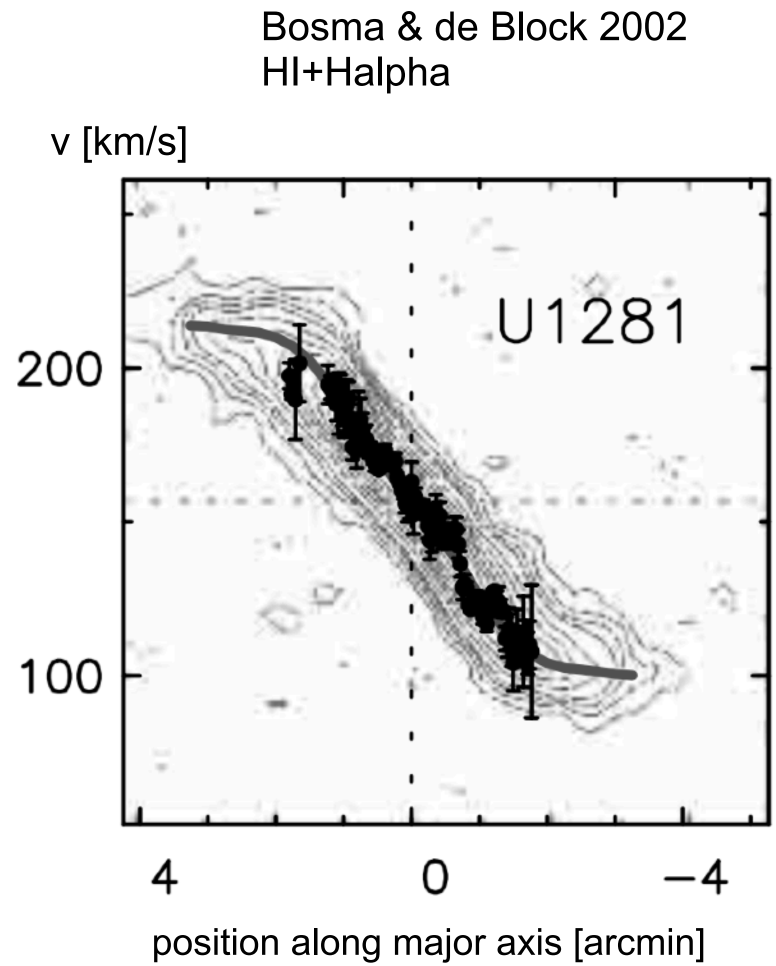
High-resolution rotation curves of low surface brightness galaxies*

W. J. G. de Blok[1] and A. Bosma[2]



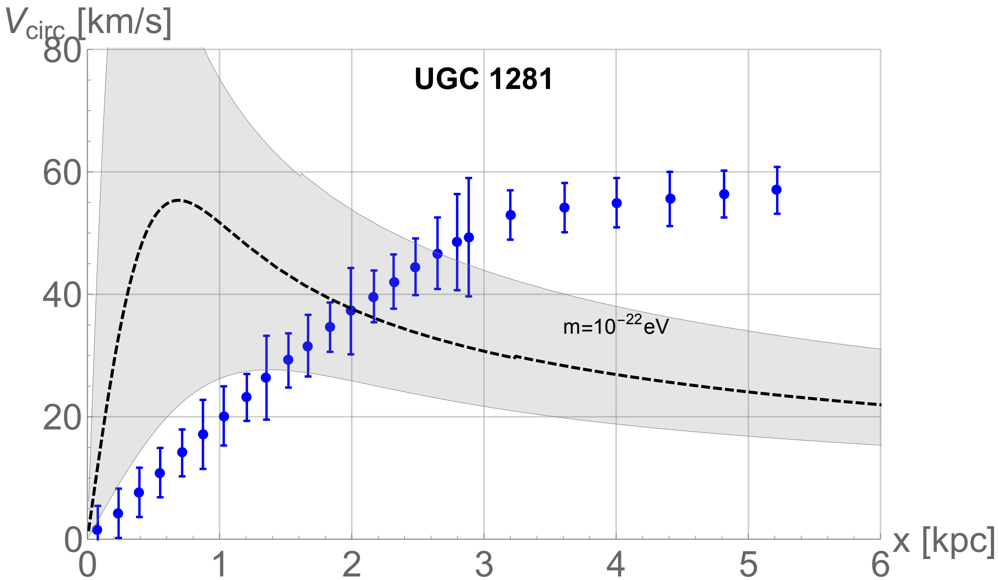


V_{circ} [km/s]
UGC 1281
x [kpc]
0
20
40
60
80
0
1
2
3
4
5
6

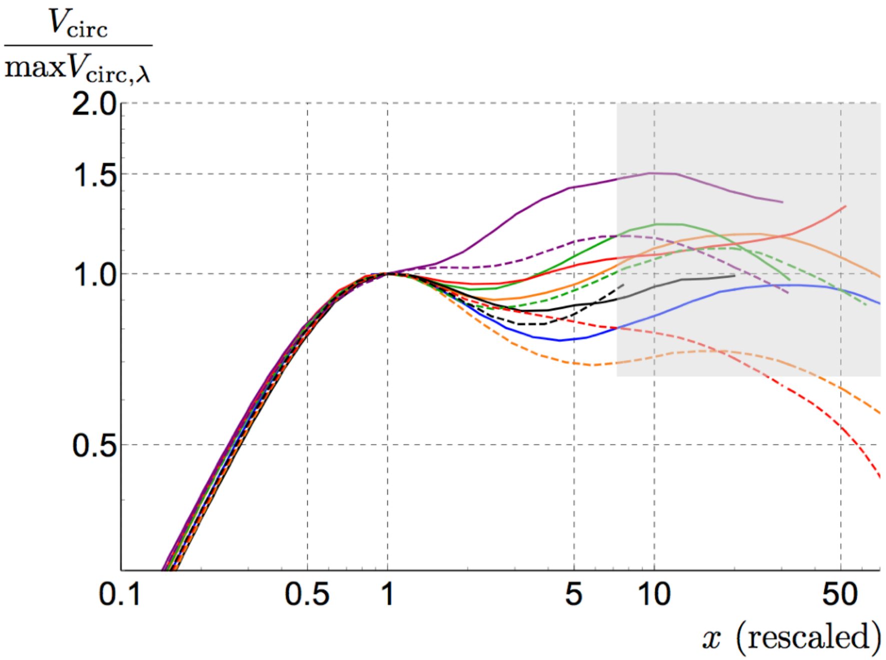


Bosma & de Block 2002
HI+Halpha
v [km/s]
U1281
200
100
4
0
−4
position along major axis [arcmin]

m=1e-22 eV

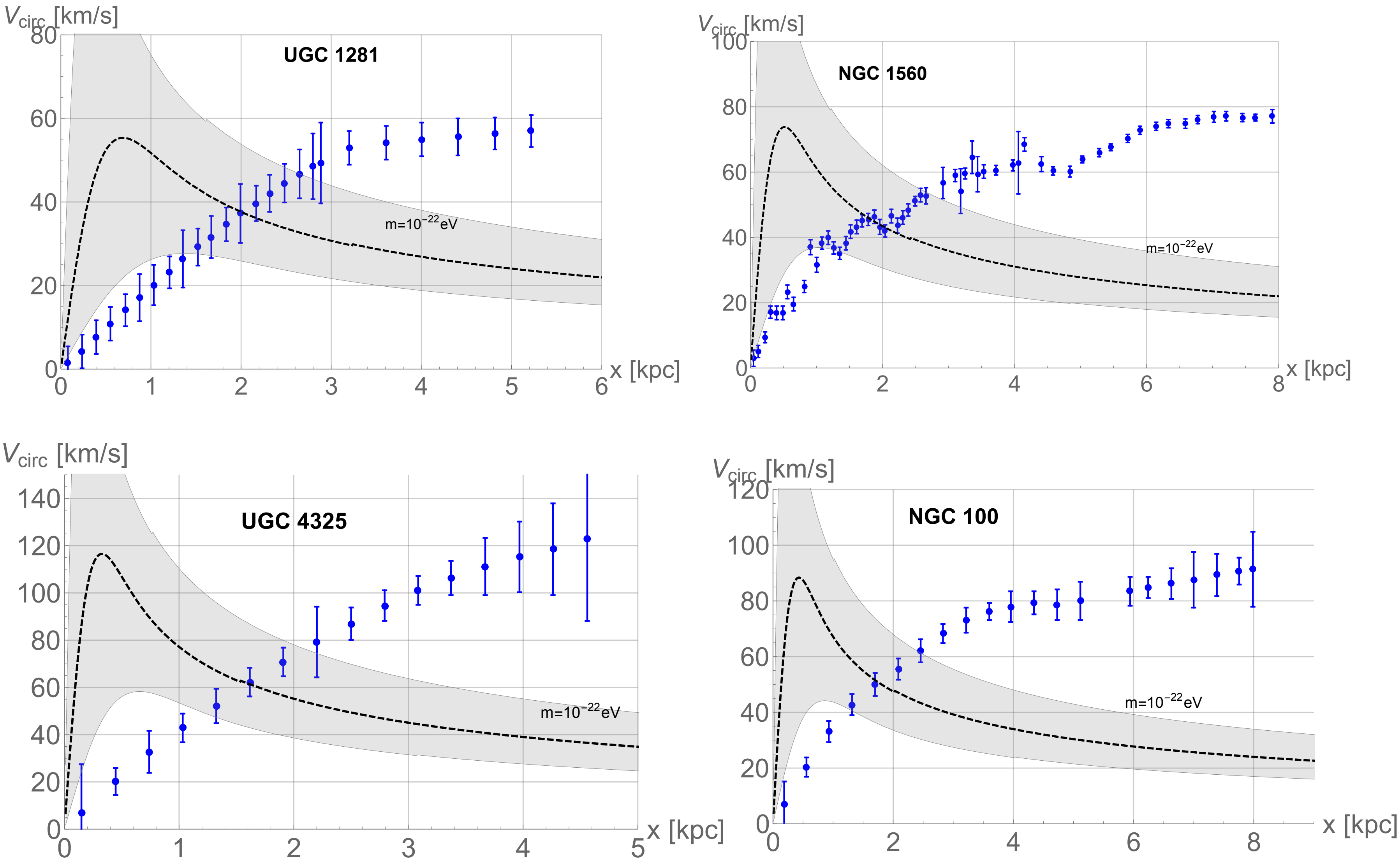


V_circ [km/s]
UGC 1281
m=10^-22 eV
x [kpc]
0
1
2
3
4
5
6
20
40
60
80



V_circ / max V_circ,λ
2.0
1.5
1.0
0.5
0.1
0.5
1
5
10
50
x (rescaled)

m=1e-22 eV

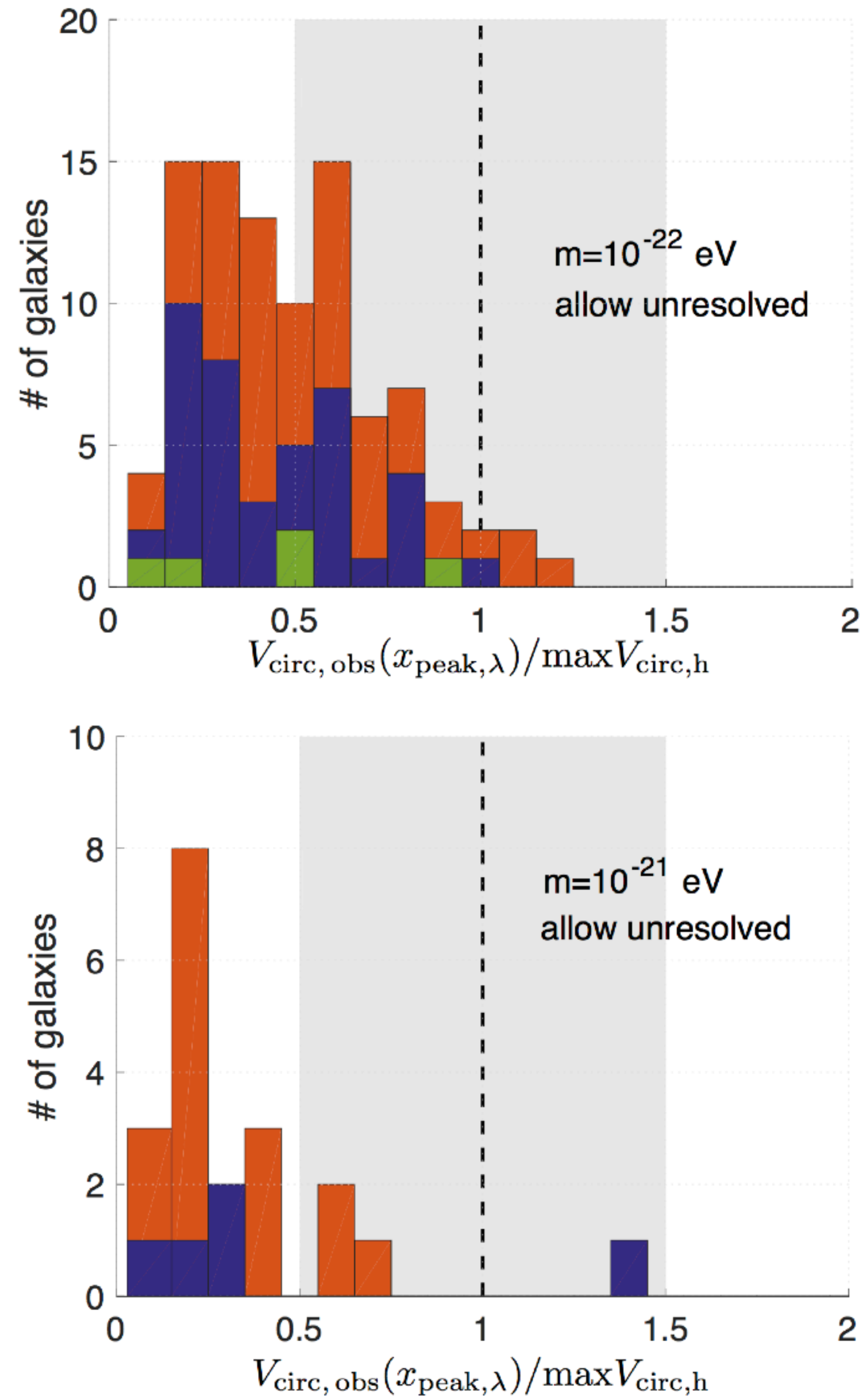


SPARC data base:
175 rotation curves
Lelli et al, 1606.09251

max V_{bar}/V_{DM} < 1

max V_{bar}/V_{DM} < 0.5

max V_{bar}/V_{DM} < 0.3



* 3.6mum surface photometry
* HI + Halpha rotation curves

Conclusions:

Soliton—host halo relation predicts an inner bump in the rotation curve.

As far as we could see, the bump isn't there.

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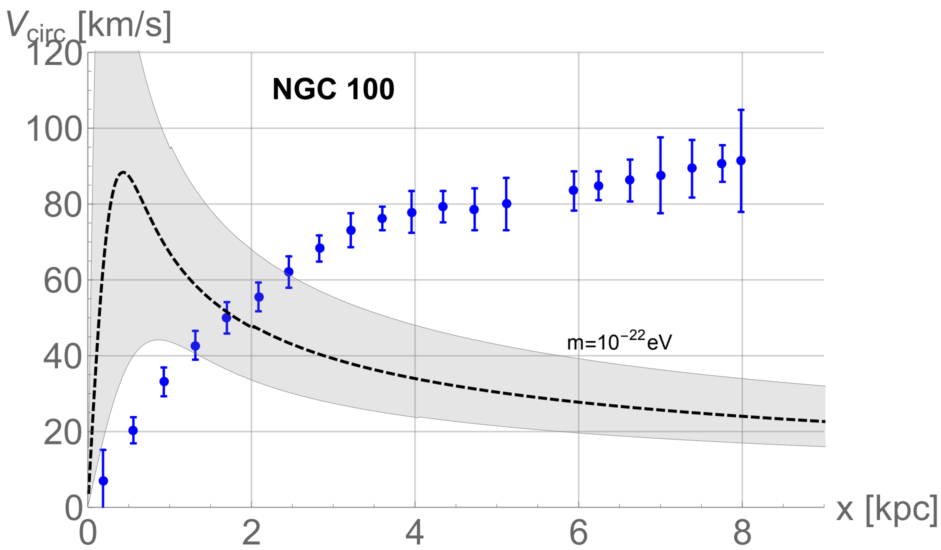
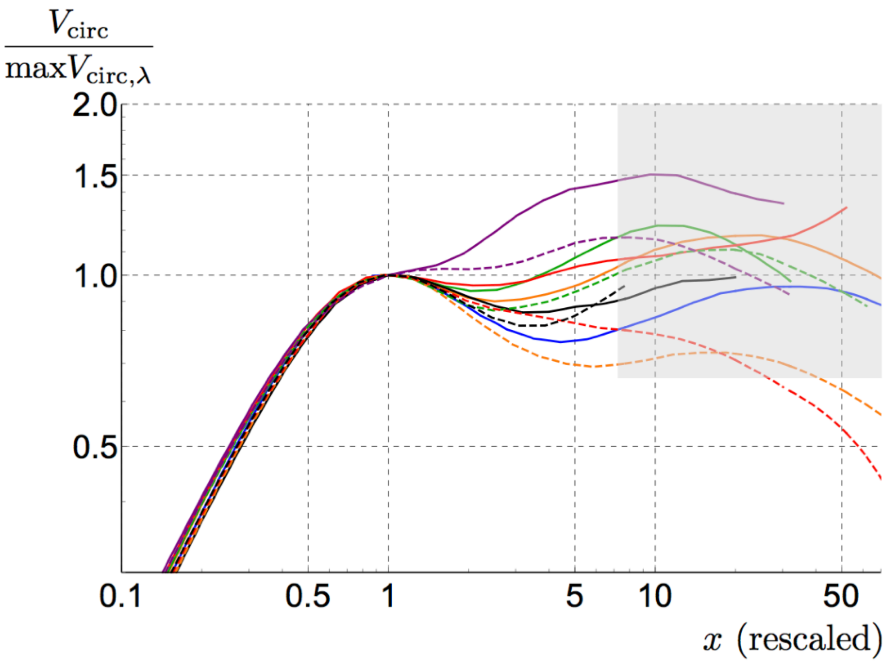
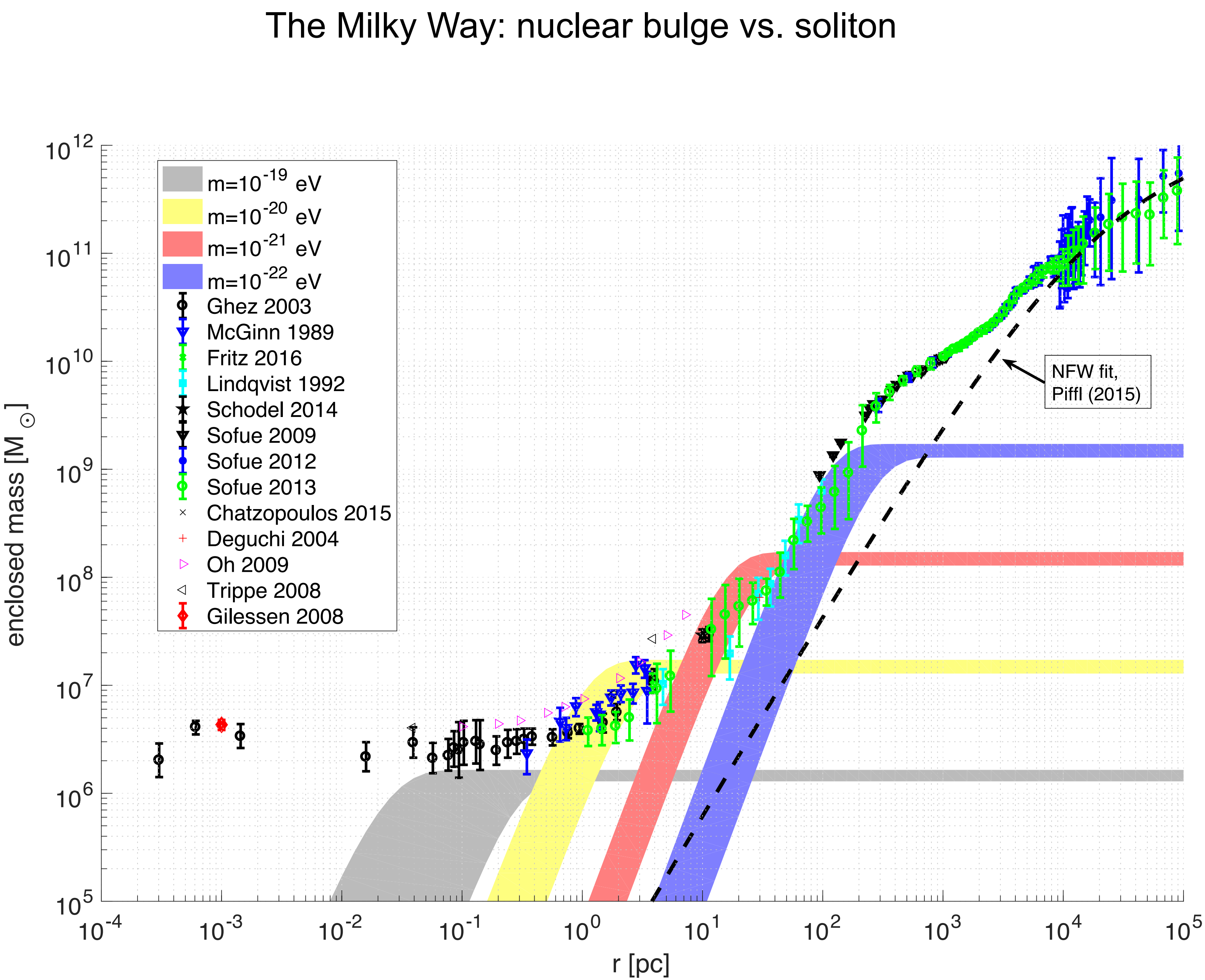




Xtra



The Milky Way: nuclear bulge vs. soliton
enclosed mass [M☉]
r [pc]
m=10^-19 eV
m=10^-20 eV
m=10^-21 eV
m=10^-22 eV
Ghez 2003
McGinn 1989
Fritz 2016
Lindqvist 1992
Schodel 2014
Sofue 2009
Sofue 2012
Sofue 2013
Chatzopoulos 2015
Deguchi 2004
Oh 2009
Trippe 2008
Gilessen 2008
NFW fit,
Piffl (2015)

The Milky Way: nuclear bulge vs. soliton