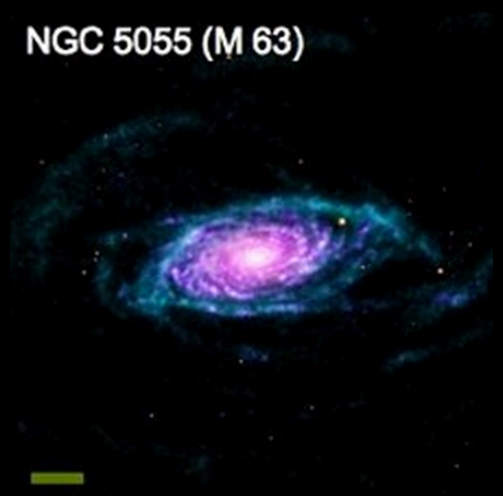
Dark matter in galaxies and clusters:

Implications for dark-matter models



Annika Peter
UC Irvine
The Ohio State University

Standard Paradigm

If you are a particle person:

If you are an astro person:

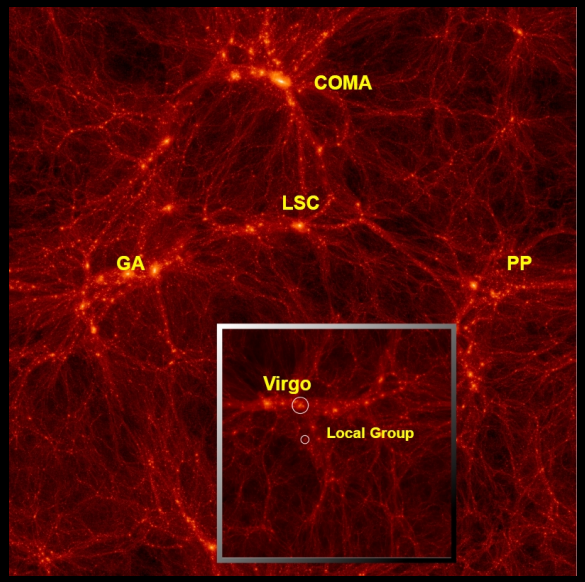
Stable, collisionless COLD DARK MATTER

NB: NOT one-to-one and onto, even though it sometimes seems that way

Observables

|----------**Large scales**----------| |----------**Small scales**----------|

DM type	Clustering	Halo mass functions	Growth function	Halo shapes	Halo density profiles	Subhalos
Cold, stable, WIMP-like DM	On scales down to $<M_\odot$	Sharply falling function of mass	Linear regime--scale independent	triaxial	Cuspy; $\rho \sim r^{-1}$ at center ("NFW")	$dN/dM \sim M^{-2}$ down to $M < M_\odot$



CLUES simulation

NB: predictions from **DM-only** simulations

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observed	Good fit down to $\sim 10^{11}\ M_\odot$	Good for clusters	Consistent so far	Qualitative yes	POSSIBLY NOT	Good fit down to $\sim 10^{11}\ M_\odot$

Results from SDSS, 2dF, WiggleZ, BOSS....
& studies of clusters

This session

Annika Peter

Dark matter density profiles in:

-galaxies (halo mass ~few x 10^{10}-few x 10^{12} $M_\odot$)

-galaxy clusters (halo mass ~10^{14}-10^{15} $M_\odot$)

Implications for dark-matter models

Michael Boylan-Kolchin

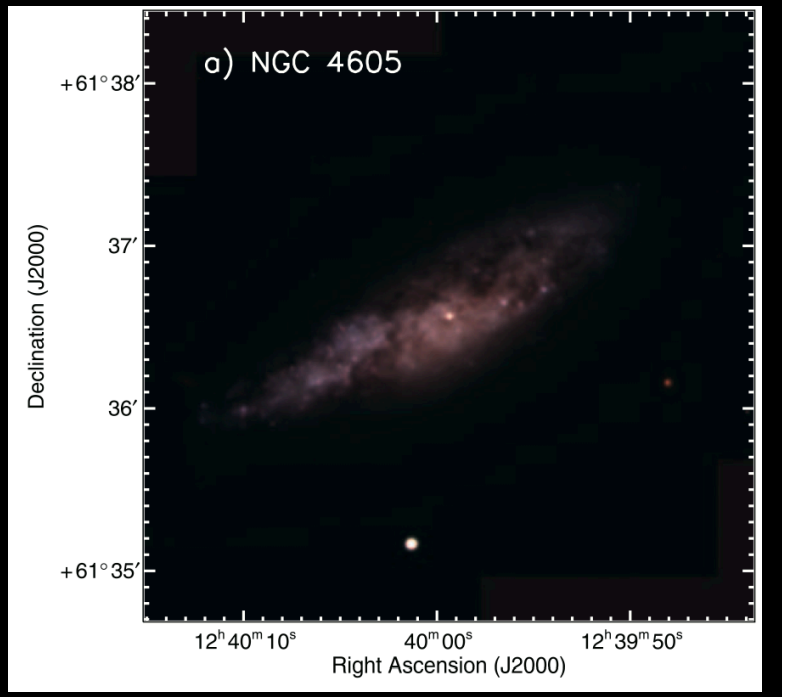
Dark matter in dwarf galaxies

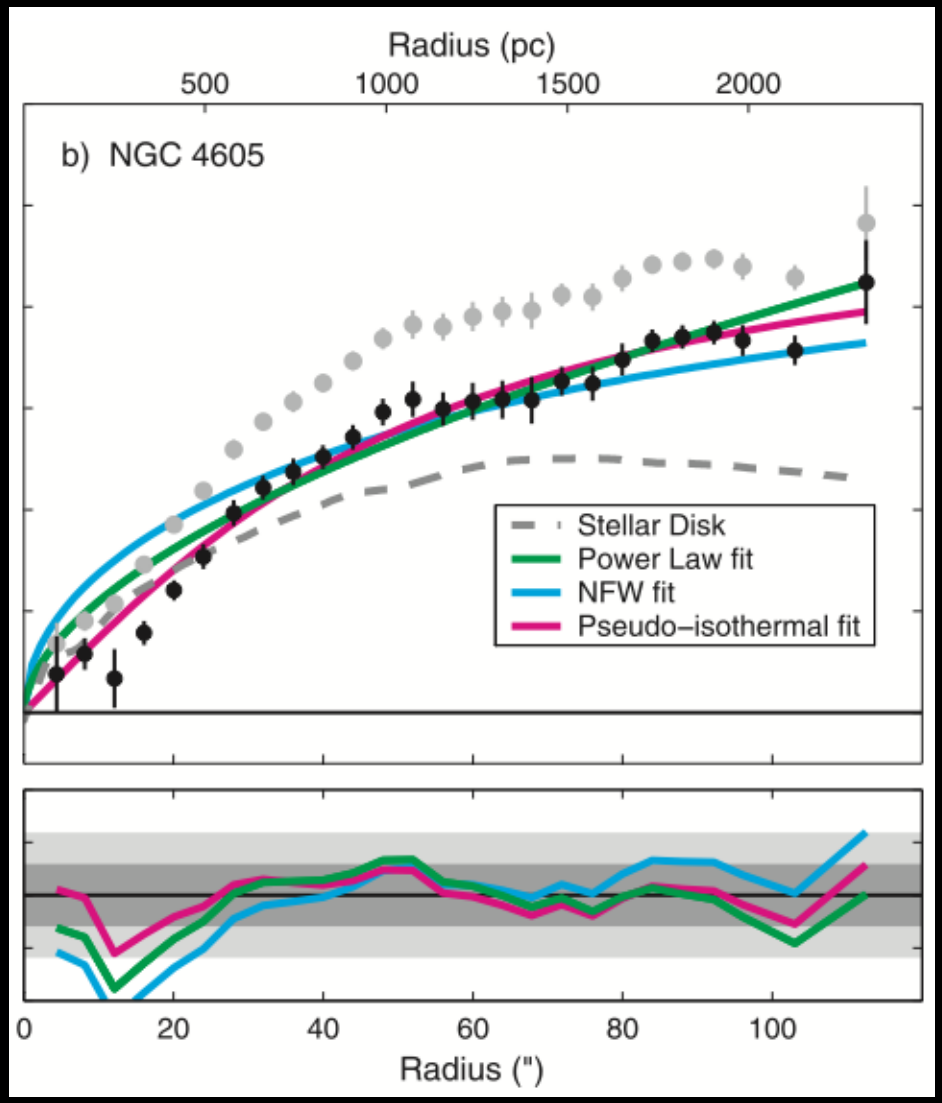
Will Dawson

Dark matter in merging galaxy clusters

See also Hai-Bo Yu's talk on hidden charged dark matter

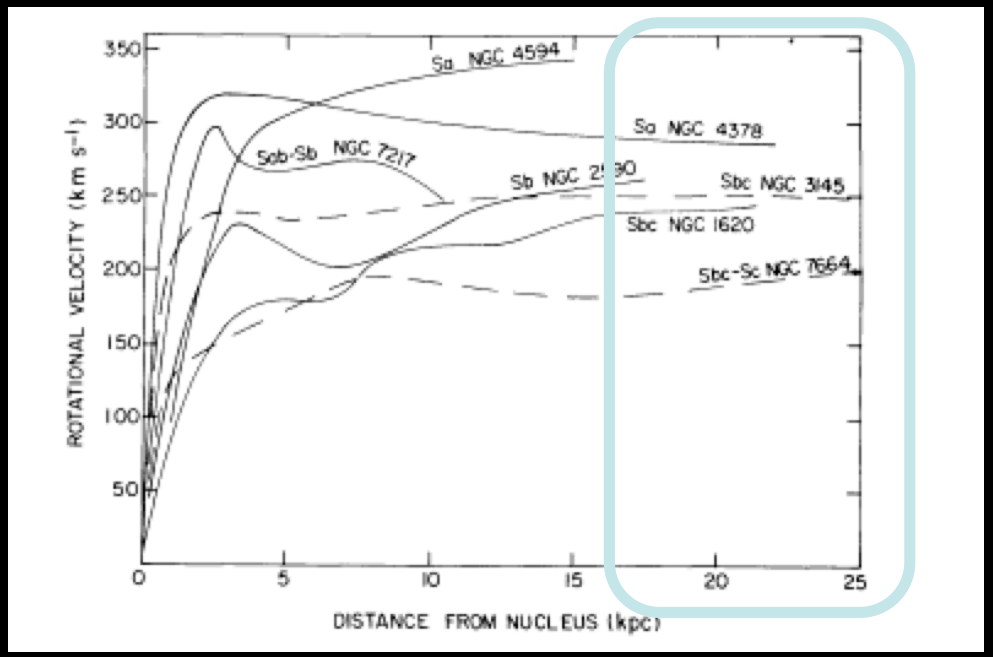
Spiral galaxy rotation curves





From Simon+ 2005

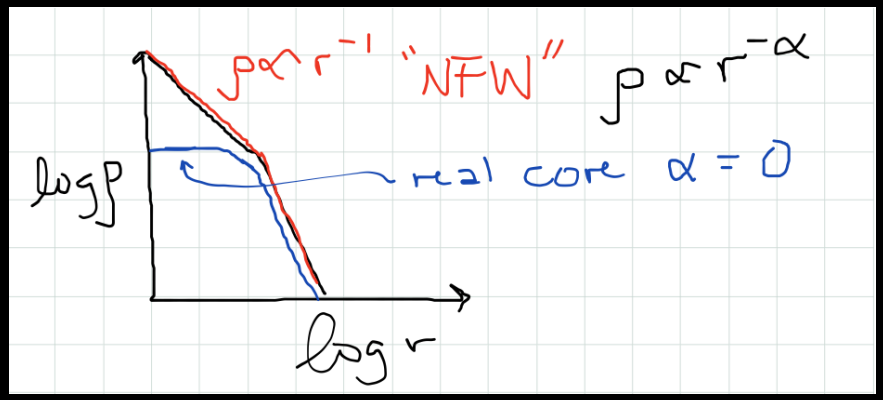
An old subject

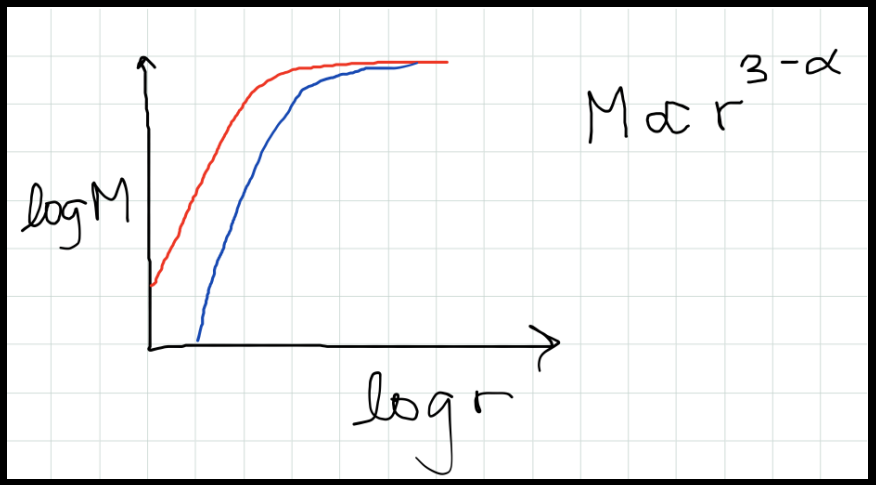


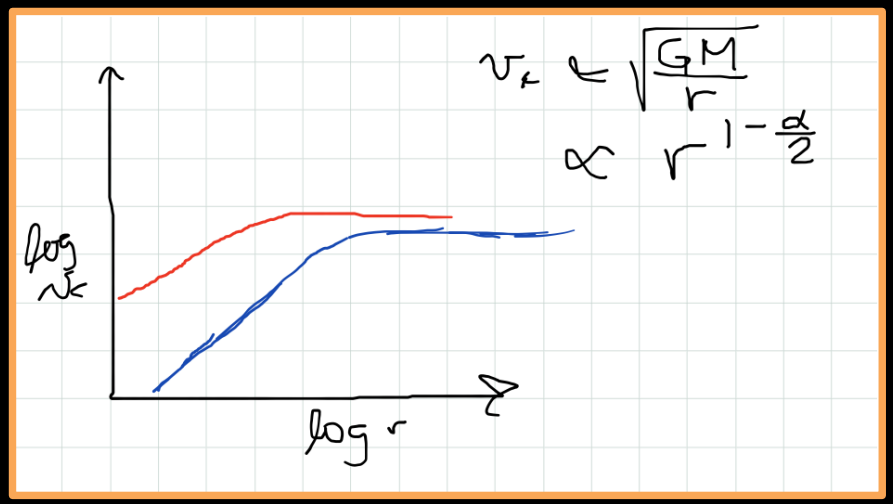
Rubin+ 1978

I can haz dark matter?

New focus


$\rho \propto r^{-1}$ "NFW"
$\rho \propto r^{-\alpha}$
real core $\alpha = 0$
log ρ
log r


$M \propto r^{3-\alpha}$
log M
log r


$v_c = \sqrt{\frac{GM}{r}}$
$\propto r^{1-\frac{\alpha}{2}}$
log v_c
log r

New focus

...and LITTLE THINGS (similar idea, smaller galaxies, no awesome graphics yet)

(see also papers by Bosma, de Blok, Swaters, Salucci, Gentile, McGaugh, Kuzio de Naray, Simon, Oh...)

Big galaxies don't say much

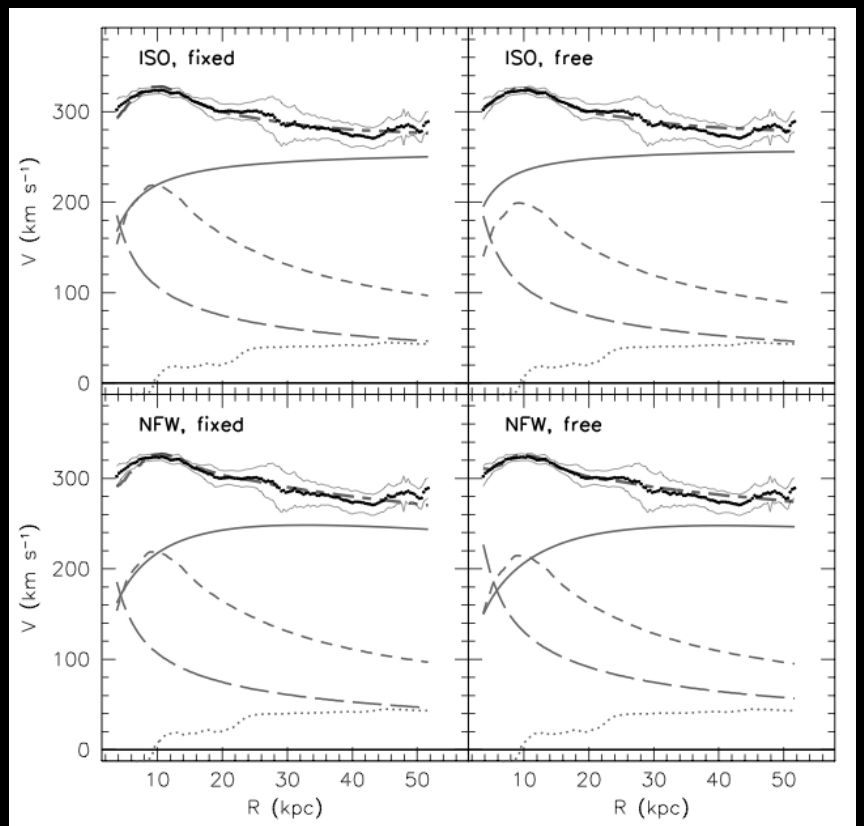
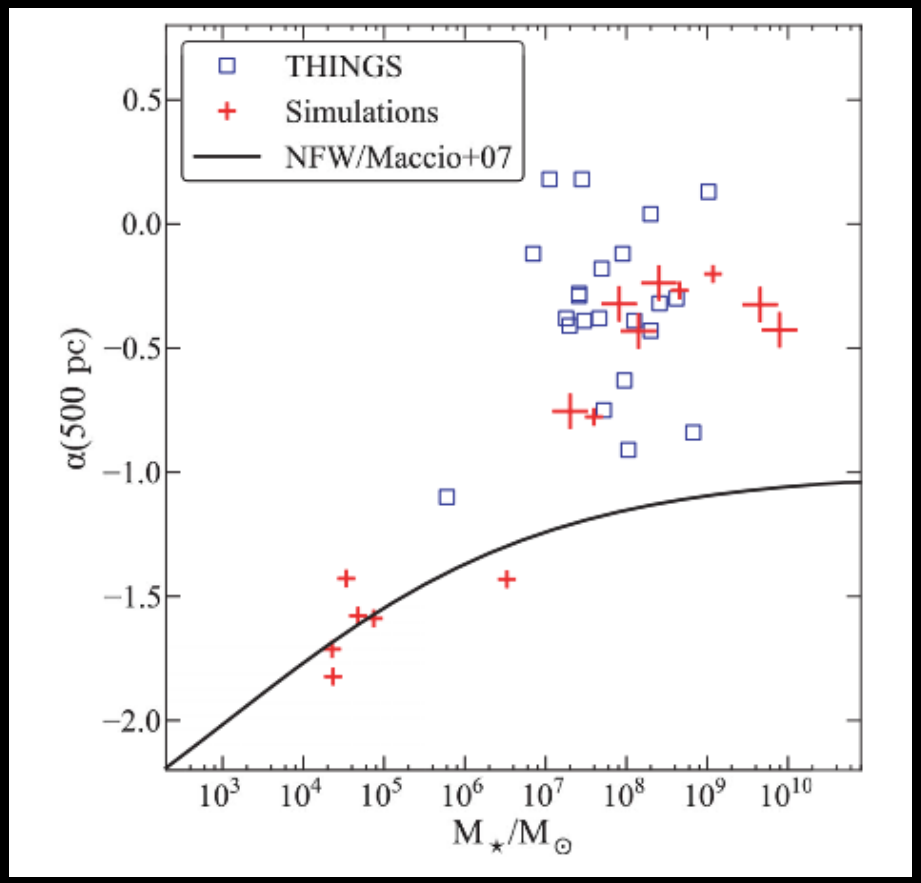


Figure 28. ISO and NFW rotation curve fits for NGC 2841. Lines and symbols are as in Figure 26.

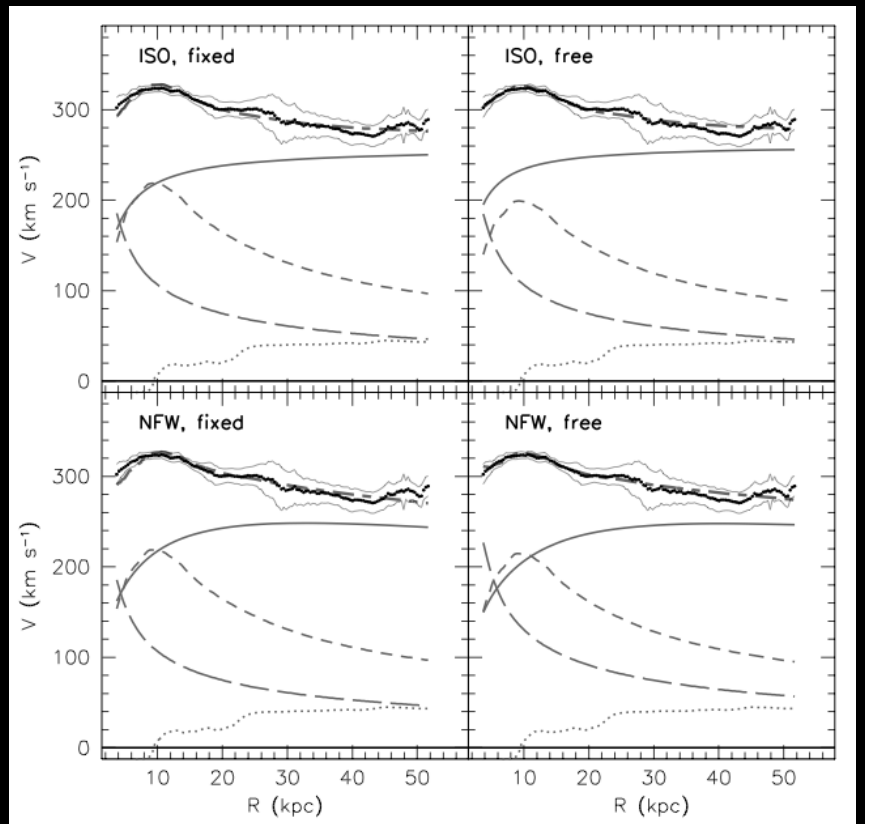
de Blok+ 2008

Little galaxies prefer "cores"



Governato+ 2012

Big galaxies don't say much



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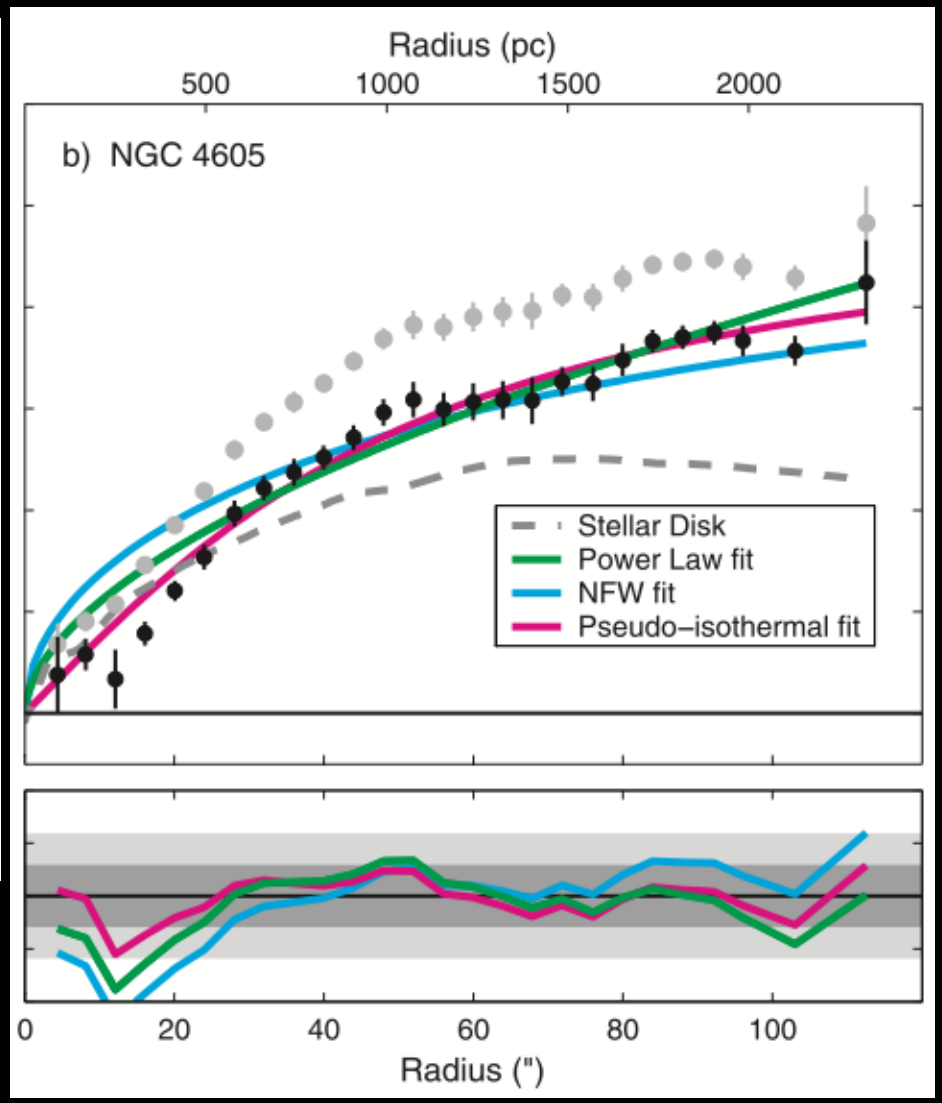
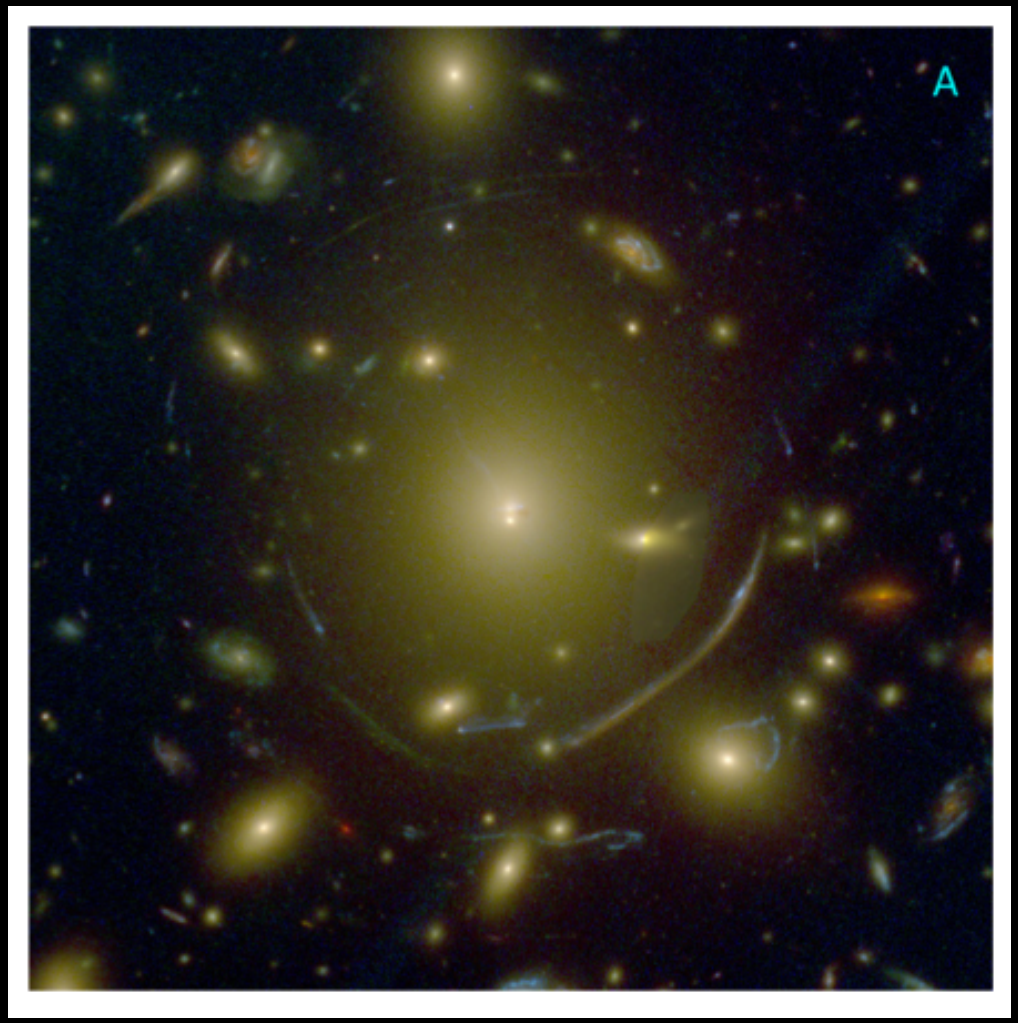
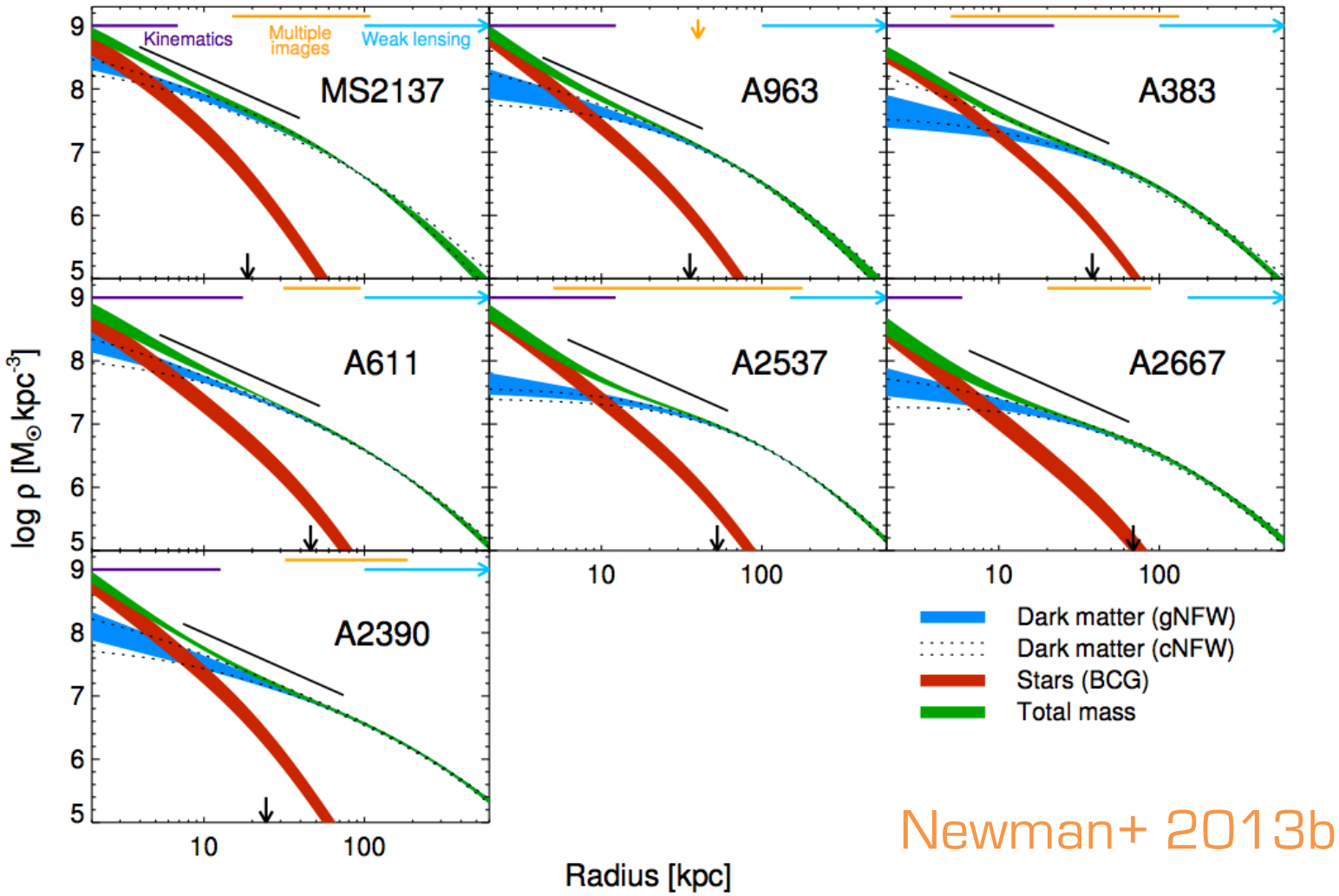


Galaxy clusters



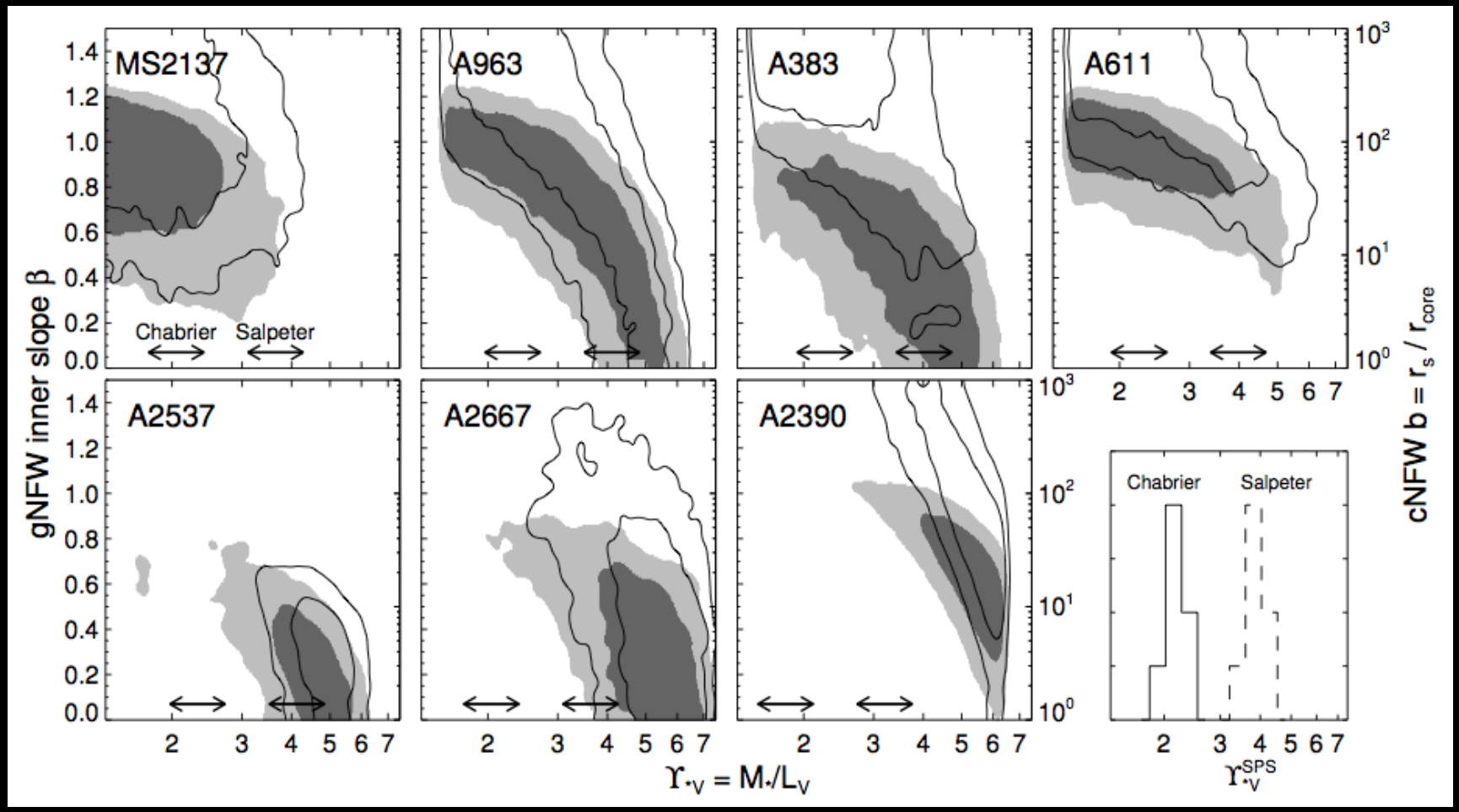
Postman+ 2011: CLASH survey, Abell 383

Profile measurement



Newman+ 2013b

Baryons make life hard(er)



Newman+ 2013b

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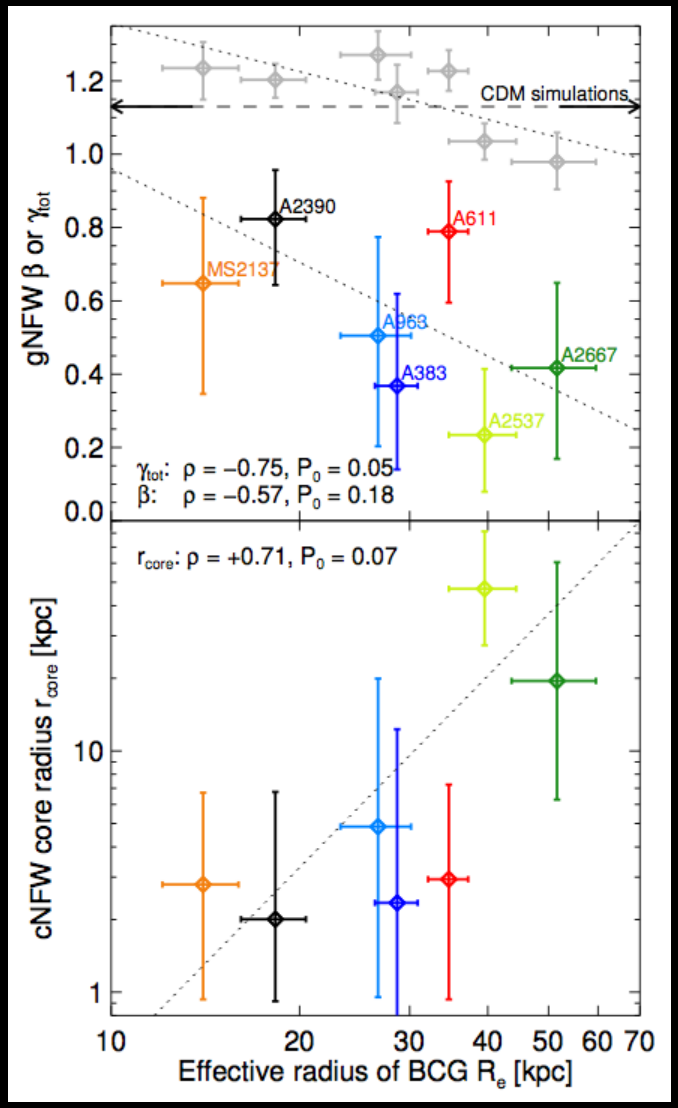
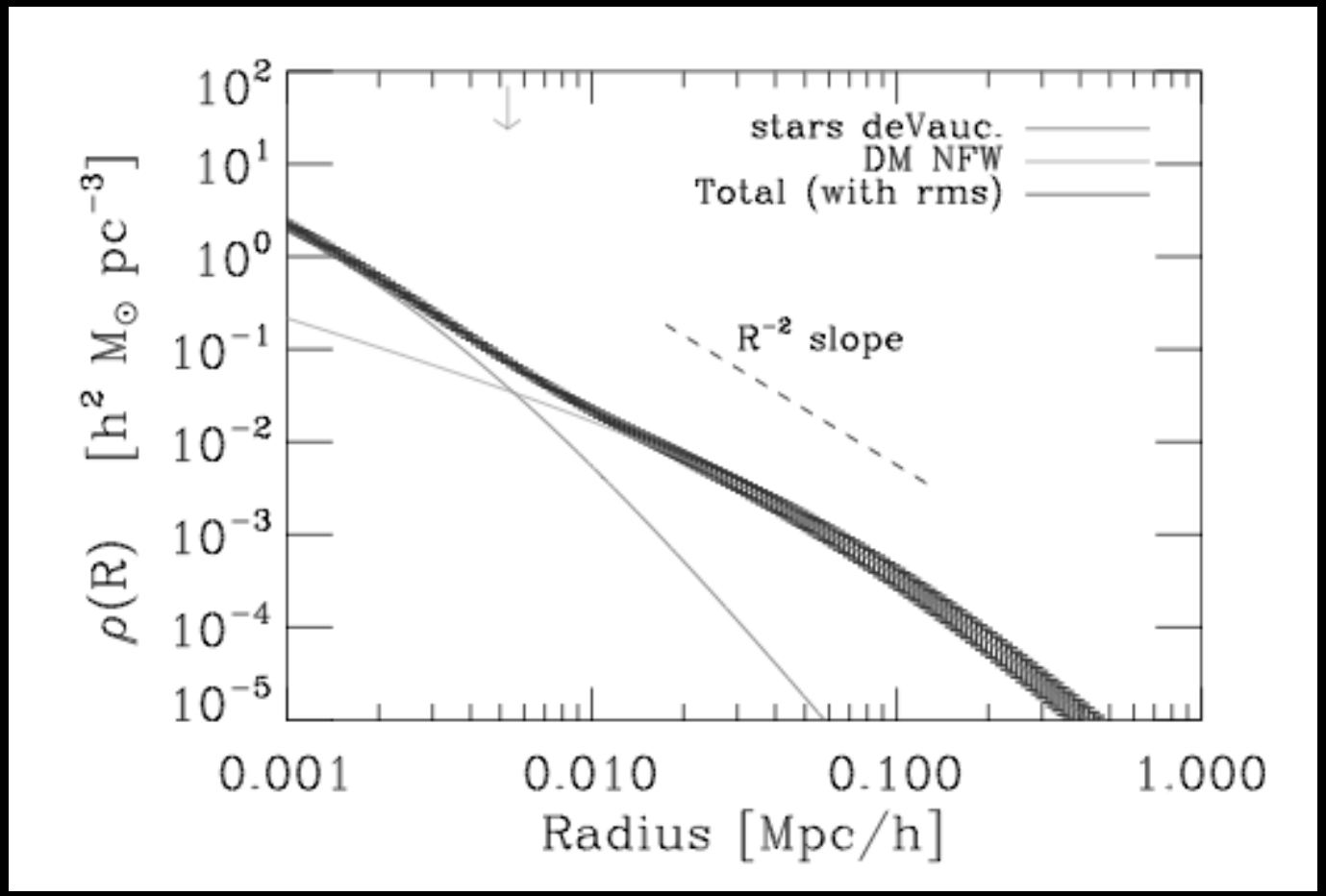


Newman+ 2013b

Counter-example: elliptical galaxies



Gavazzi+ 2007

Round-up

- Density profile shallower than CDM alone in smallish galaxies.
- Hard to tell/maybe strongly cuspy in big galaxies.
- Density profile shallower than CDM alone in galaxy clusters.

- Hints of physics beyond CDM?

Astrophysicists' classification

Sigurdson, Kaplinghat, AP in prep.

Early Universe—typical velocity at creation epoch
[also, any ELASTIC interactions w/other species]

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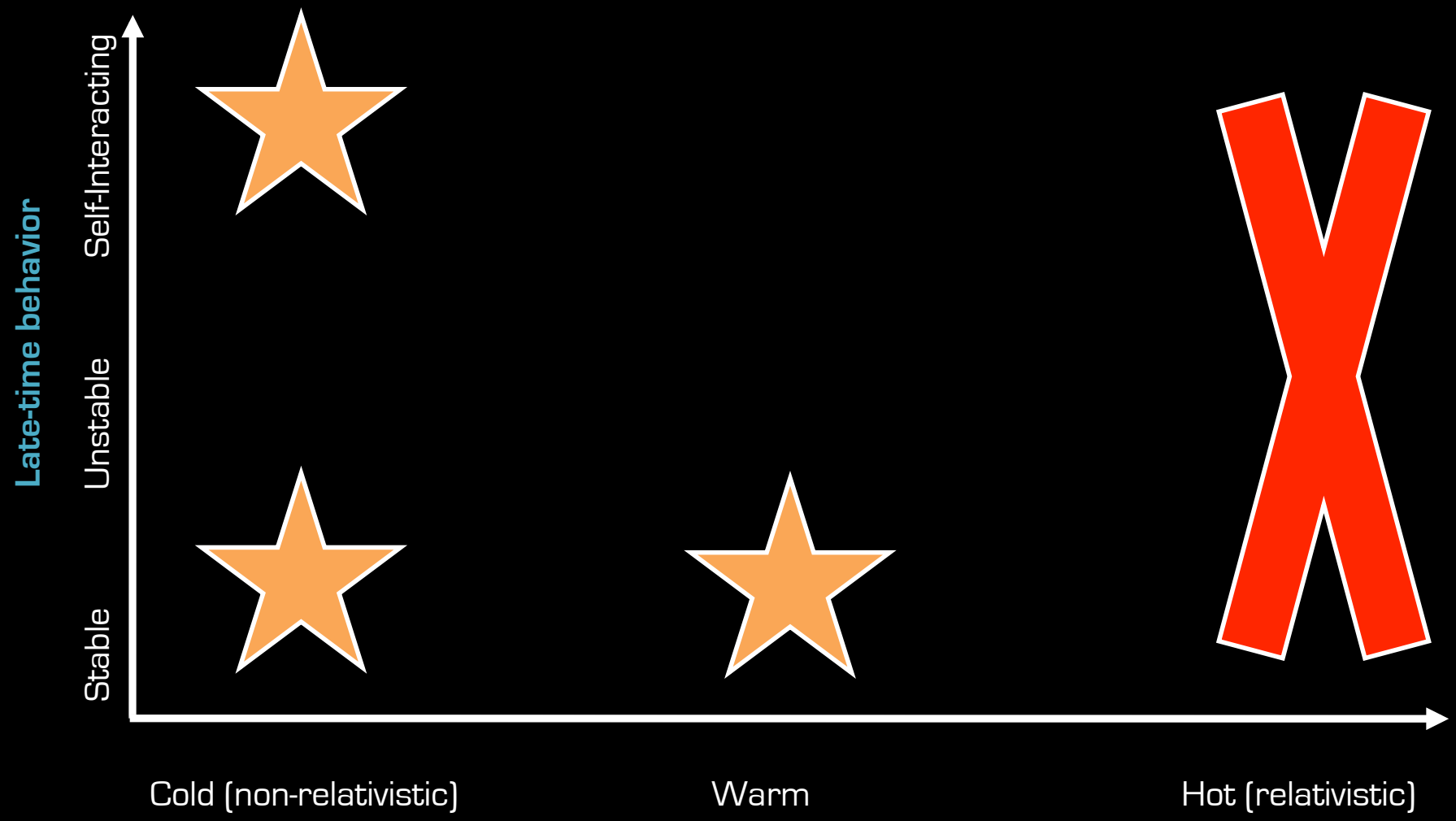


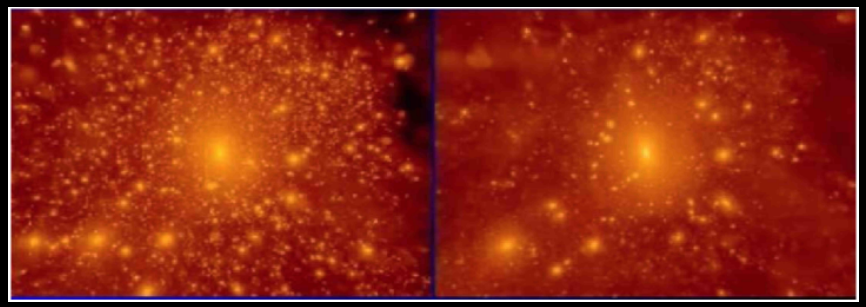
Early Universe—typical velocity at creation epoch
[also, any ELASTIC interactions w/other species]

Warm dark matter

Halo shapes:
Triaxial, except for maybe the smallest halos (Colín+ 2000)

Halo profile:
Less-concentrated CUSPs; only get cores at cut-off scale, where there are few halos anyways (Avila-Reese+ 2001, Villaescusa-Navarro & Dalal 2011; Macciò+ 2012)

Substructure:
Much less below scales corresponding to the free-streaming length (Colín+2000; Polisensky & Ricotti 2011; Lovell+ 2012)



Cannot get both reduced substructure and cores simultaneously.

Self-interacting dark matter

(Rocha+ 2013; Peter+ 2013)

$$\Gamma \sim \rho \left(\frac{\sigma}{m}\right) v_{rel}$$

Halo shapes:

Rounder where scattering is "cosmologically frequent"

$$\Gamma / H_0 \gtrsim 1$$

Halo profiles:

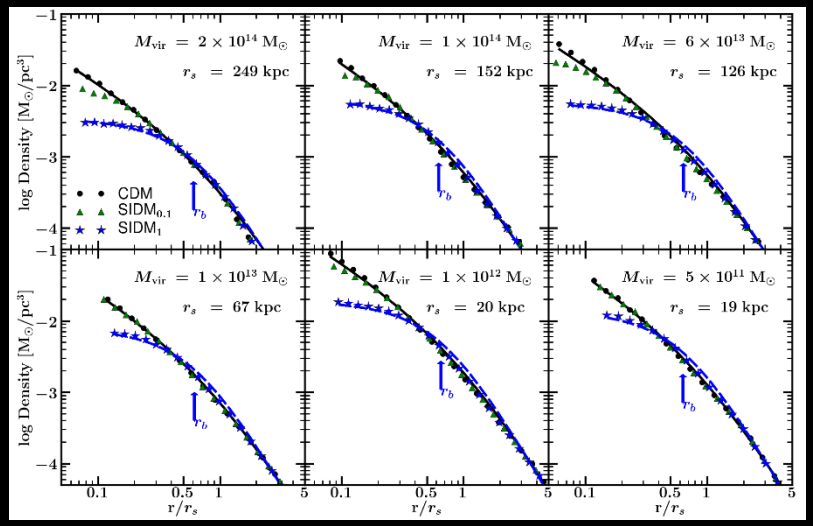
Cored

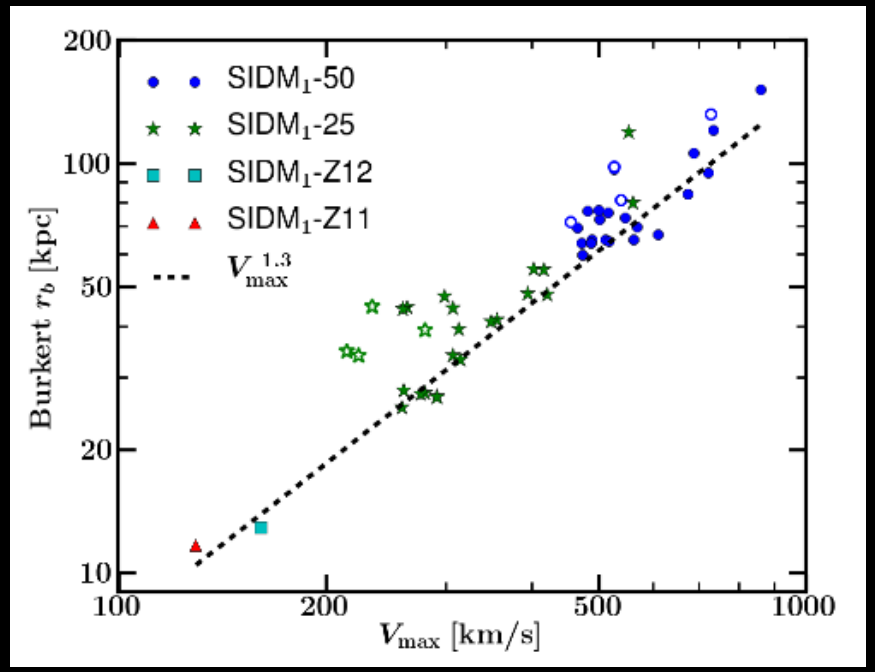
Halo substructure:

Not drastically less than CDM

Cannot get both reduced substructure and cores simultaneously.

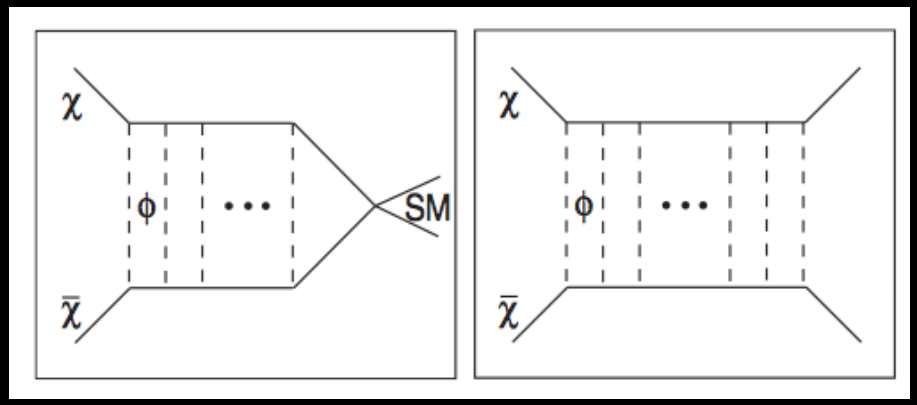
Velocity-independent scatter





SIDM and hidden-sector models

(Feng, Kaplinghat & Yu 2009; Buckley & Fox 2010; Loeb & Weiner 2010; Tulin, Yu & Zurek 2012)



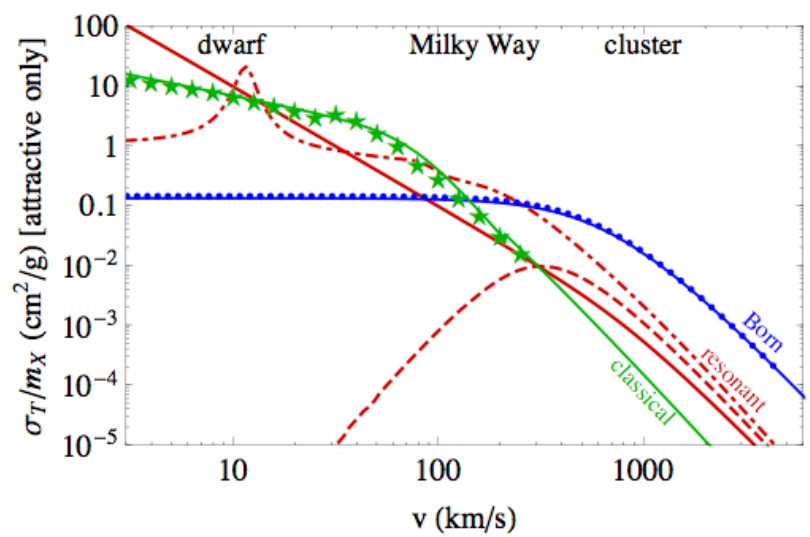
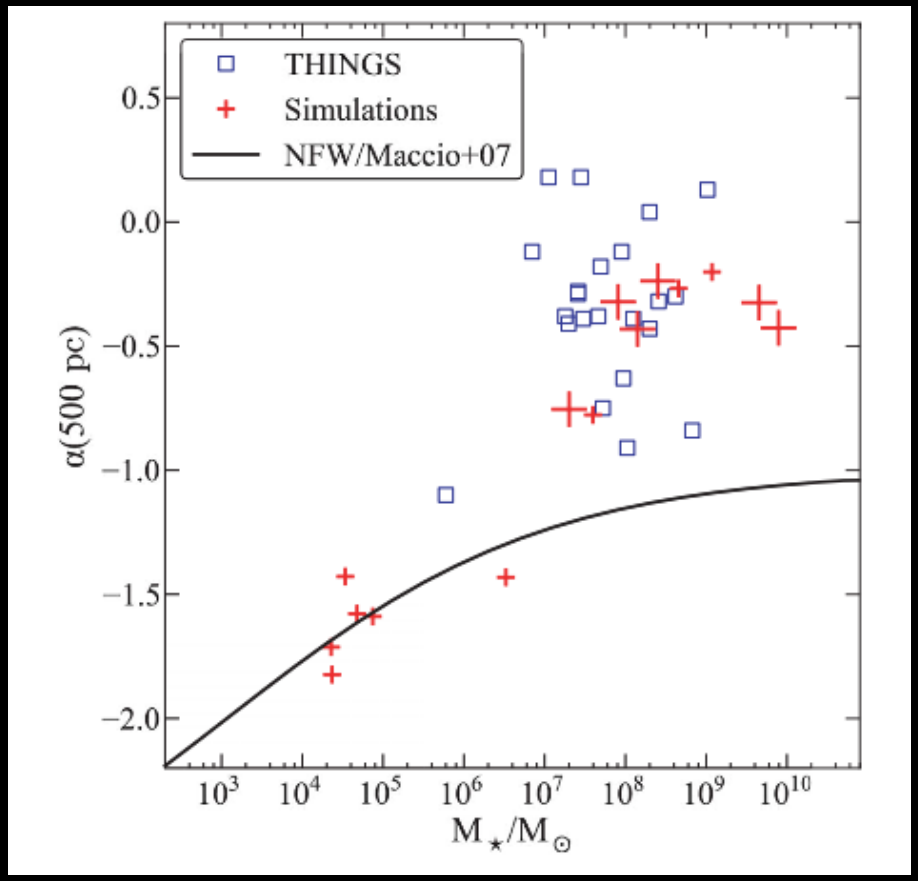


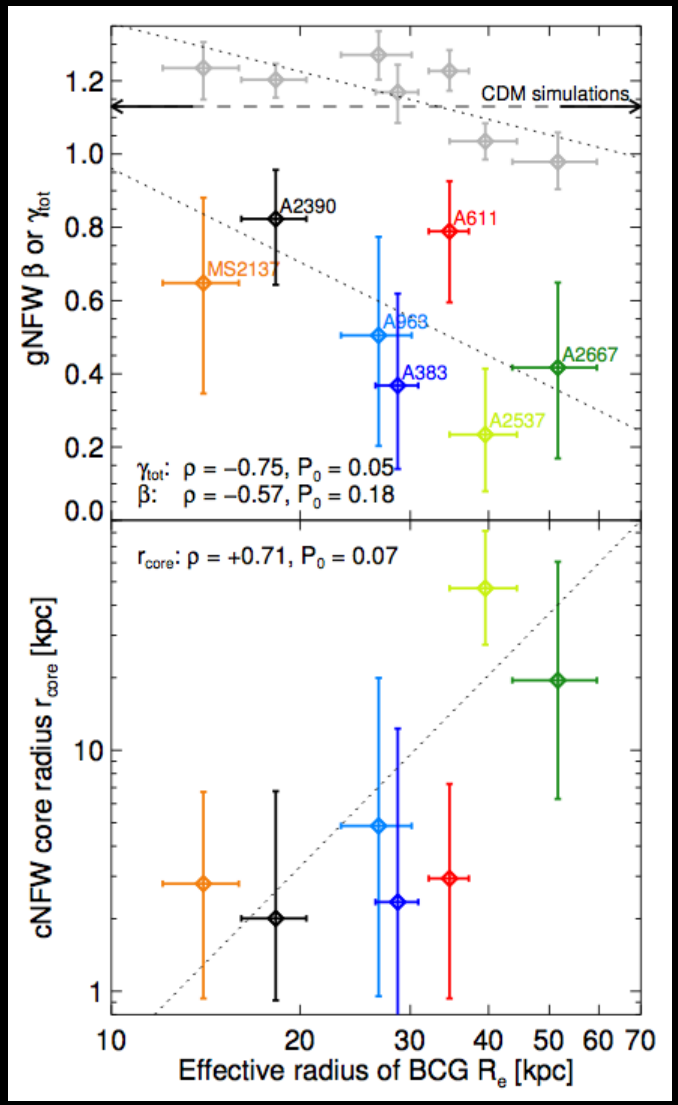
FIG. 1: Velocity-dependence of σ_T for sample parameters within different regimes. Blue line shows Born formula (4), in agreement with numerical results (blue dots), for $m_X = 4$ GeV, $m_\phi = 7.2$ MeV, $\alpha_X = 1.8 \times 10^{-4}$. Green line shows classical formula (5), in agreement with numerical results (stars), for $m_X = 2$ TeV, $m_\phi = 1$ MeV, $\alpha_X = 0.05$. Red lines show σ_T in the resonant regime for $m_X = 100$ GeV, $\alpha_X = 3.4 \times 10^{-3}$, illustrating s-wave resonance (solid, $m_\phi = 205$ MeV), p-wave resonance (dot-dashed, $m_\phi = 20$ MeV), and s-wave antiresonance (dashed, $m_\phi = 77$ MeV).

WDM vs. SIDM

WDM	SIDM
Effects apparent only near cut-off scale (i.e., only small halos)	Effects apparent whenever density is high (i.e., centers of all halos-, from dweeby dwarfs to “El Gordo”)
Halos have cusps (although maybe lower concentration for low-mass halos)	Halos have cores, scale of which depends on halo mass and cross section
Can have a cut-off in the subhalo mass function	Mild suppression in subhalo mass function, most apparent at halo centers

Baryons?


THINGS
Simulations
NFW/Maccio+07
α(500 pc)
0.5
0.0
−0.5
−1.0
−1.5
−2.0
10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10}
$M_\star/M_\odot$


CDM simulations
gNFW β or γ_{tot}
1.2
1.0
0.8
0.6
0.4
0.2
0.0
A2390
A611
MS2137
A963
A383
A2667
A2537
γ_{tot}: ρ = −0.75, P_0 = 0.05
β: ρ = −0.57, P_0 = 0.18
r_{core}: ρ = +0.71, P_0 = 0.07
cNFW core radius r_{core} [kpc]
10
1
10 20 30 40 50 60 70
Effective radius of BCG R_e [kpc]

Summary

- Cold-dark-matter only simulations predict NFW CUSPS.
- Observations of (smallish) galaxies and galaxy clusters prefer SHALLOWER cusps OR cores.
- Warm dark matter does NOT produce cores on the right scales.
- Self-interacting dark matter (e.g., in hidden sectors) CAN.
- Can baryons do things for us?

Future directions

THEORETICAL MODELING!!!

There is a place for dark-matter-only simulations, but...

WTF, baryons?

We would like to model dark-matter physics and baryon physics simultaneously (UW/UCI/OSU/Rutgers collaboration)

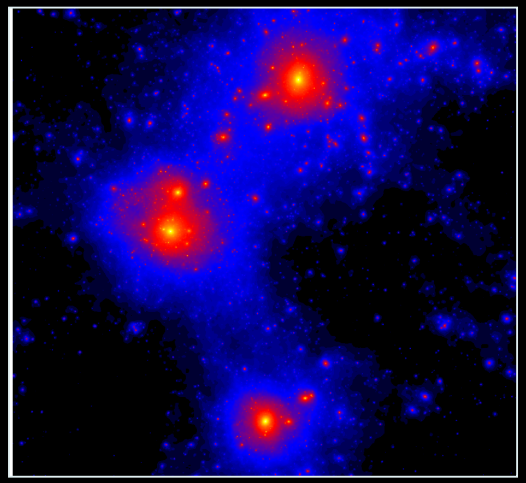
Observations

Newman et al. work highlights the importance of stellar kinematics for clusters

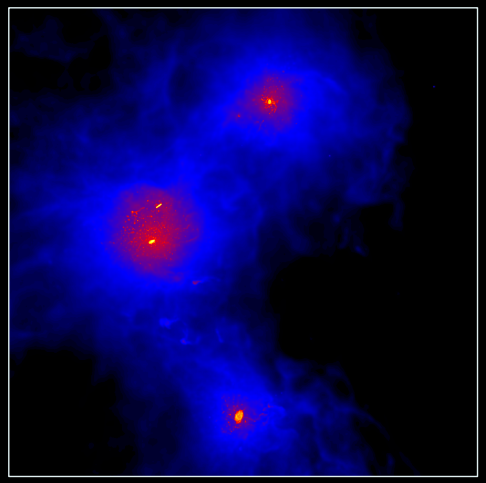
Initial mass function (cf. Conroy & van Dokkum)

Dark matter in galaxies

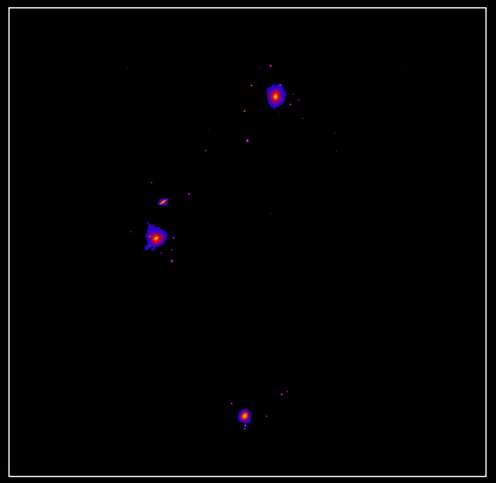
dark matter



gas



stars



Can probe the dark-matter distribution using the dynamics of stars and gas, gravitational lensing.