Velocity dependent SIDM effects on galaxy cluster cores

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Outline

- Strong lensing tension between observations and hydro-simulations

  in galaxy cluster cores (also mentioned in Lisanti talk)
- Results of rare and frequent SIDM zoomed in hydro dynamic simulations of galaxy clusters

Strong-lensed galaxies in simulated and observed galaxy clusters

Piero Rosati (PI),
Pietro Bergamini,
Giovanni Granata,
Antonio Ragagnin,
Massimo Meneghetti,
Elena Rasia,
Cinthia Ragone-Figueroa,
Gian Luigi Granato,
Giulia Despali,
Carlo Giocoli,
Luigi Bassini,
Lauro Moscardini,
et al. …

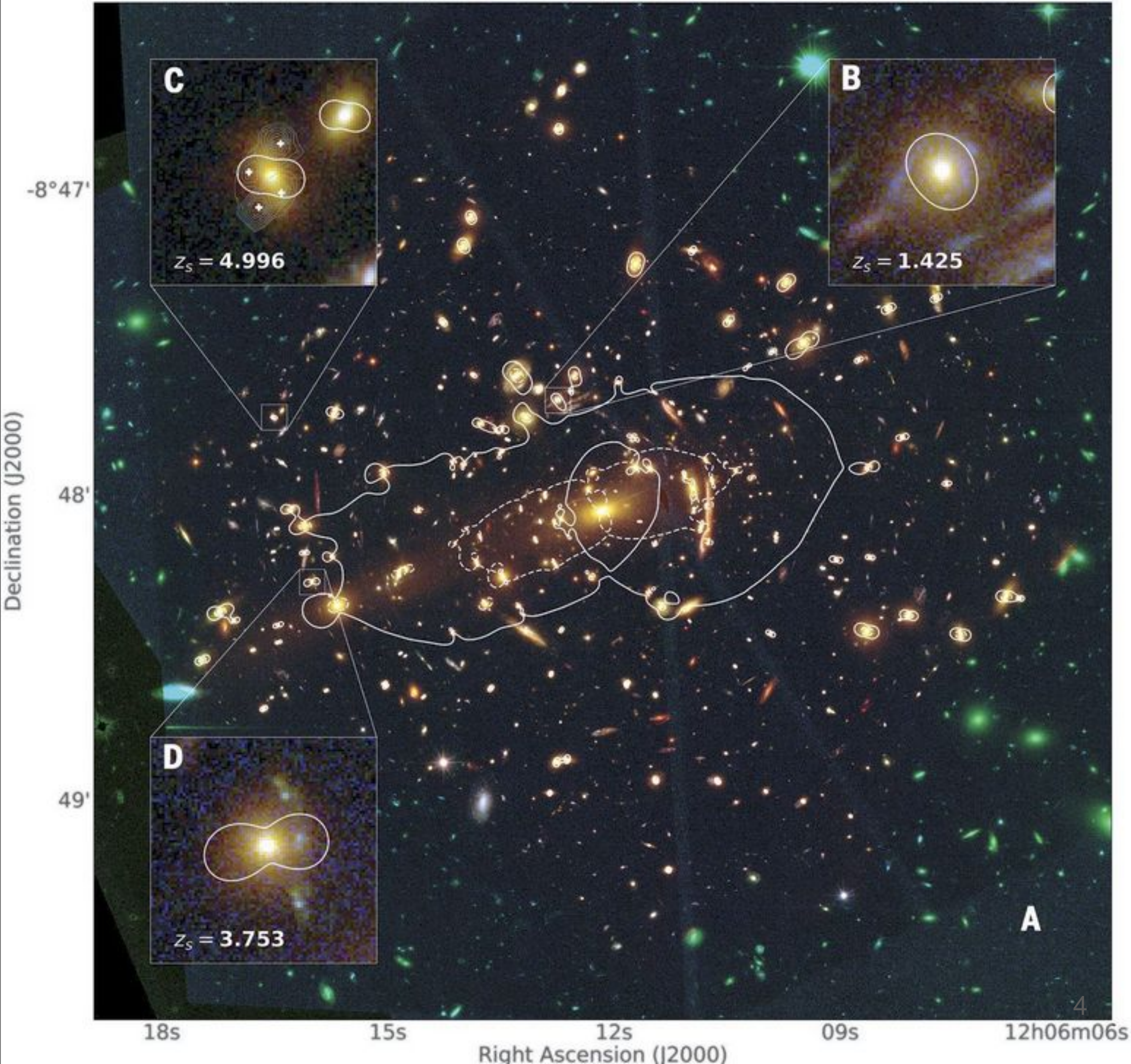
Galaxy-Galaxy Strong Lensing from HST data

Reference Sample:

- MACSJ1206 (z=0.439)
- MACSJ0416 (z=0.397)
- AS1063 (z=0.348)

Subhaloes are concentrated enough to act as individual strong lenses

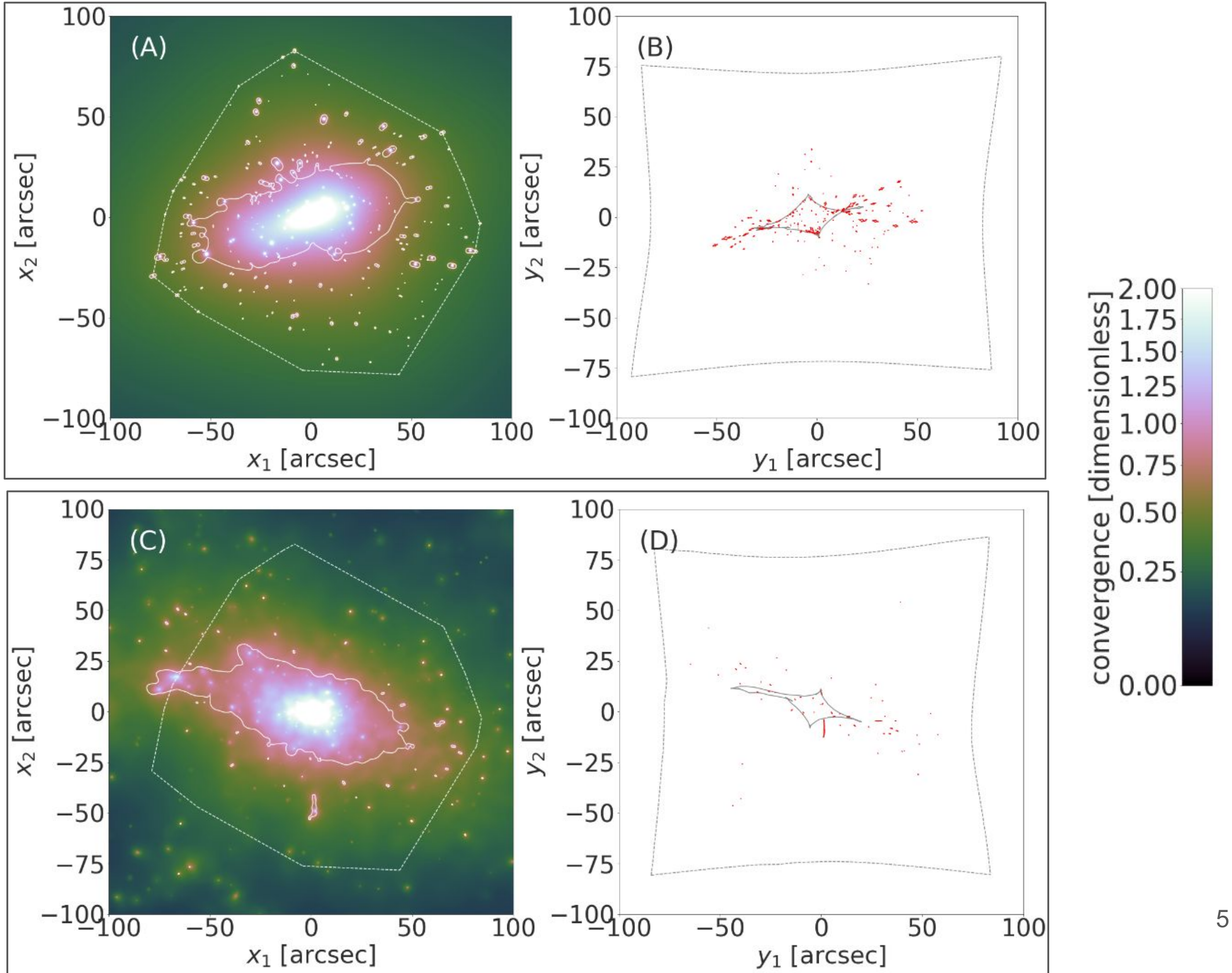
(see Caminha+19,
Bergamini+19,
Meneghetti+20,
Granata+22)



Region of interest:
0.15 Rvir
Cluster masses: ~1e15Msun

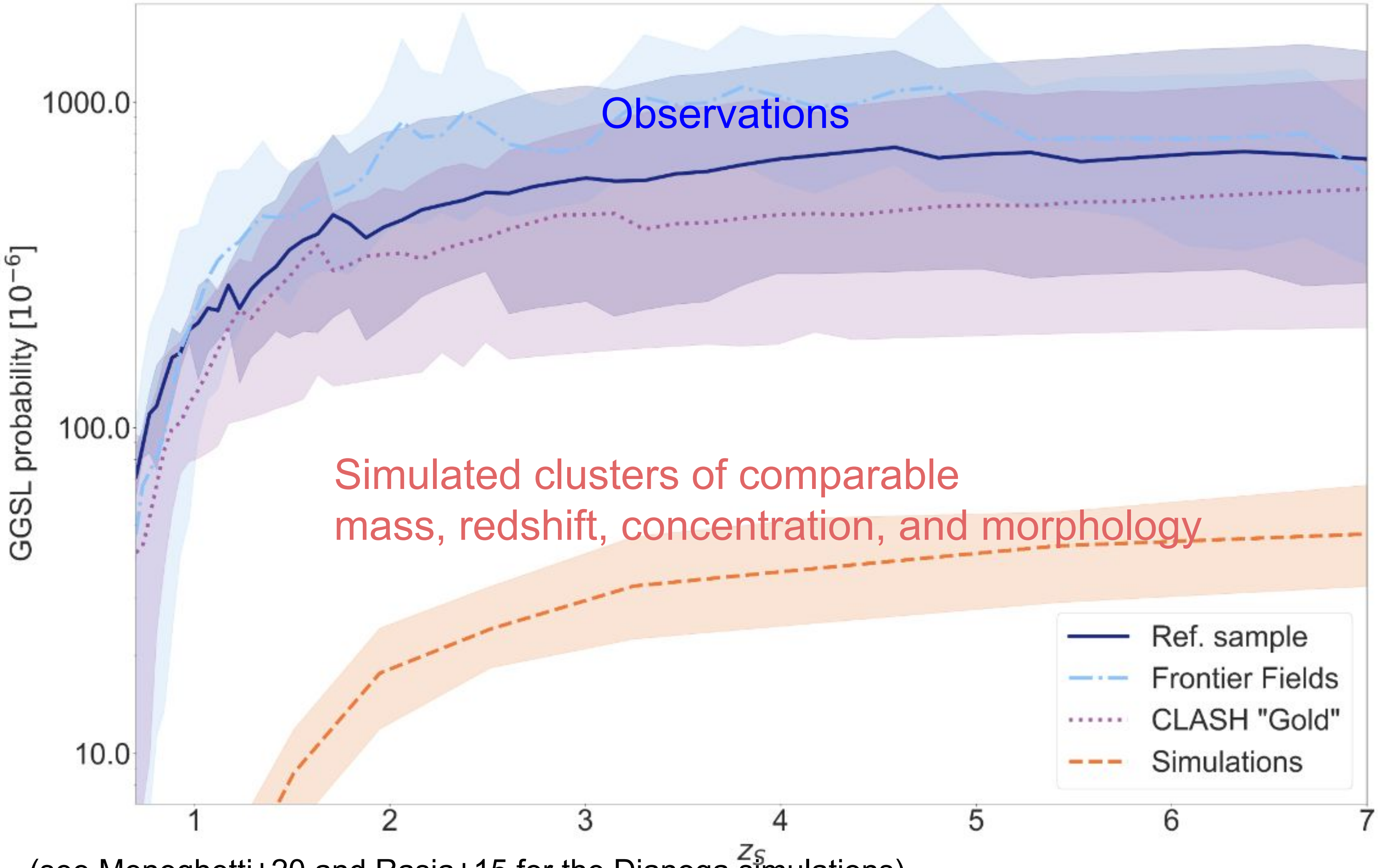
Observations:

Simulations:



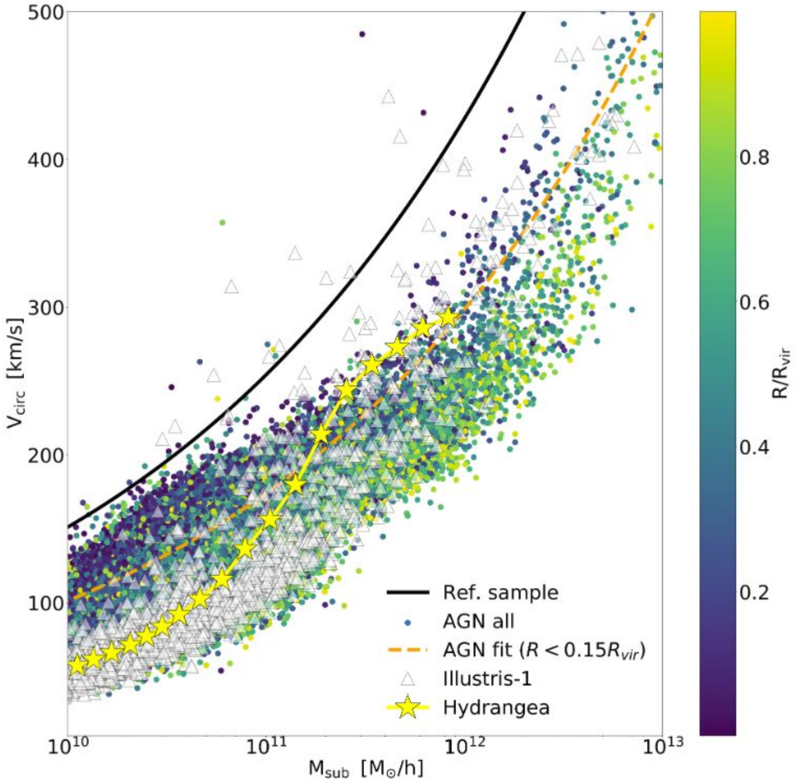
GGSL probability:
area covered by
secondary caustic
divided by FoV
mapped back
in the source plane

(see Meneghetti+20)



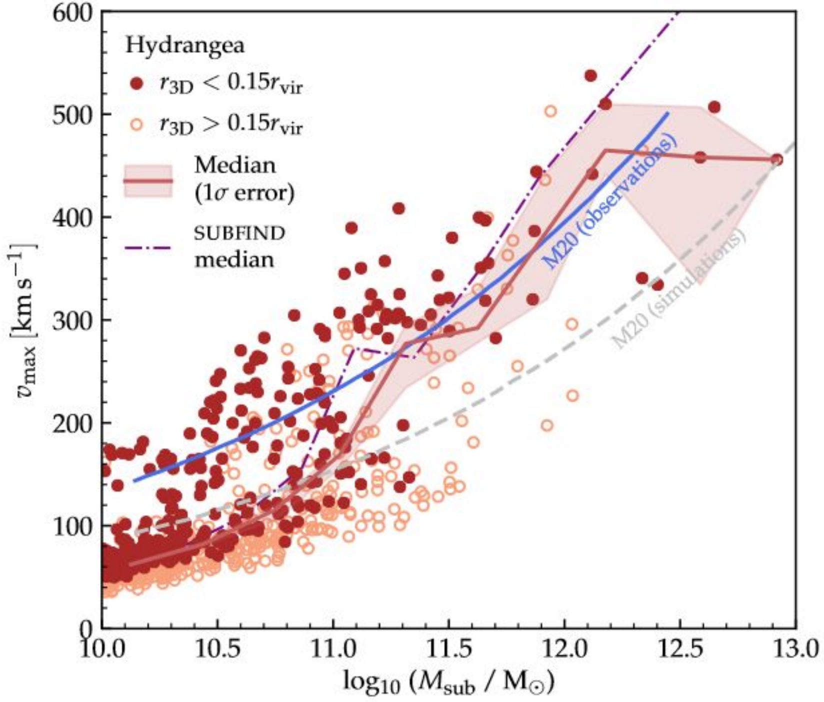
(see Meneghetti+20 and Rasia+15 for the Dianoga simulations)

Subhalo compactness (in the core of galaxy cluster) as proxy for GGSL



(see Meneghetti+20)

Results from Hydrangea



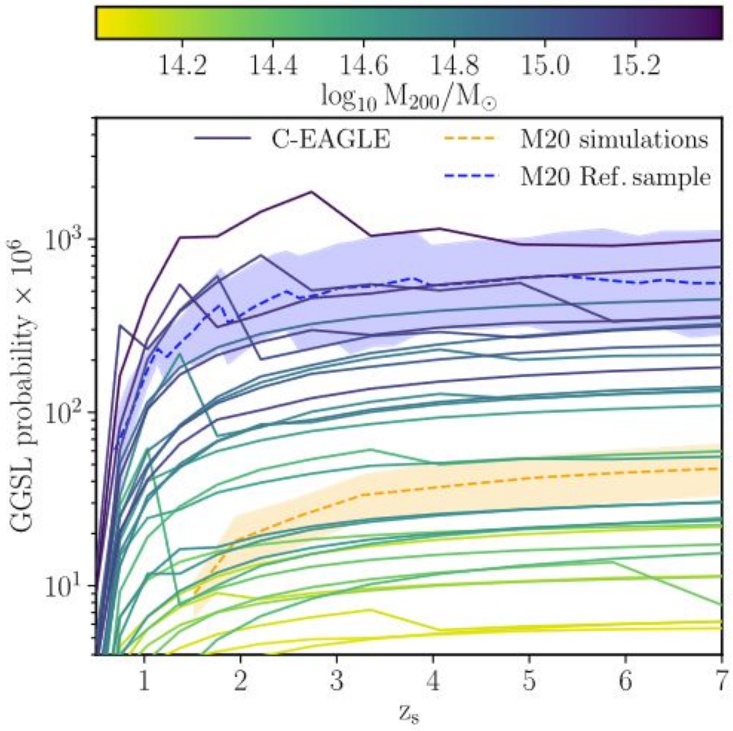


Figure 2. The GGSL probability as a function of source redshift. The dashed lines and associated shaded regions are from M20, while the solid lines are for the C-EAGLE clusters, with the colour indicating the halo mass (see the colour bar at the top).

(see Bahé+21, Robertson+21)

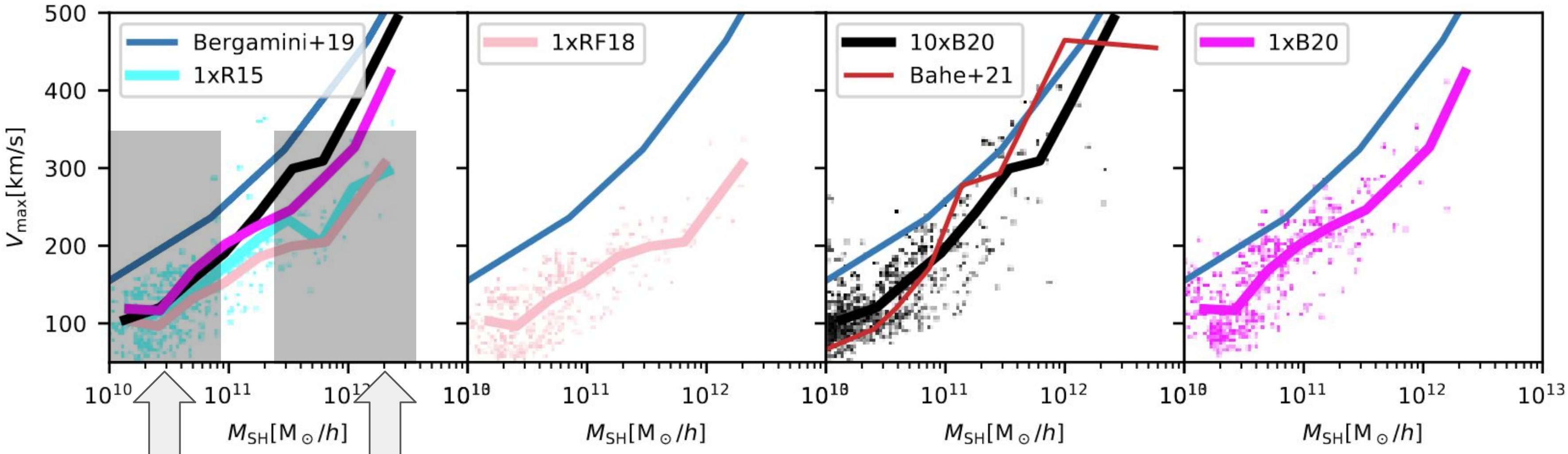
Assessing the role of baryon physics in GGSL

by varying resolution, softening and AGN efficency.

	1xR15	1xRF18	10xB20	1xB20
min T_g[K]	50	50	20	
ϵ_o	0.15	–	–	
ϵ_r	0.1	0.07	0.07	
ϵ_f	0.05	0.1	0.16	
$\epsilon_{\rm DM}[h^{-1}\ a{\rm kpc}]$	3.75	5.62	1.4	3.0
$\epsilon_\star[h^{-1}\ a{\rm kpc}]$	2.0	3.0	0.35	0.75
$m_{\rm DM}[10^8\ h^{-1}{\rm M}_\odot]$	8.3	8.3	0.83	8.3
Reference	R15	RF18	B20	

(see Rasia+15, Ragone-Figueroa+18, Bassini+20, Ragagnin+22, Meneghetti+22)

Subhalo compactenss for different models

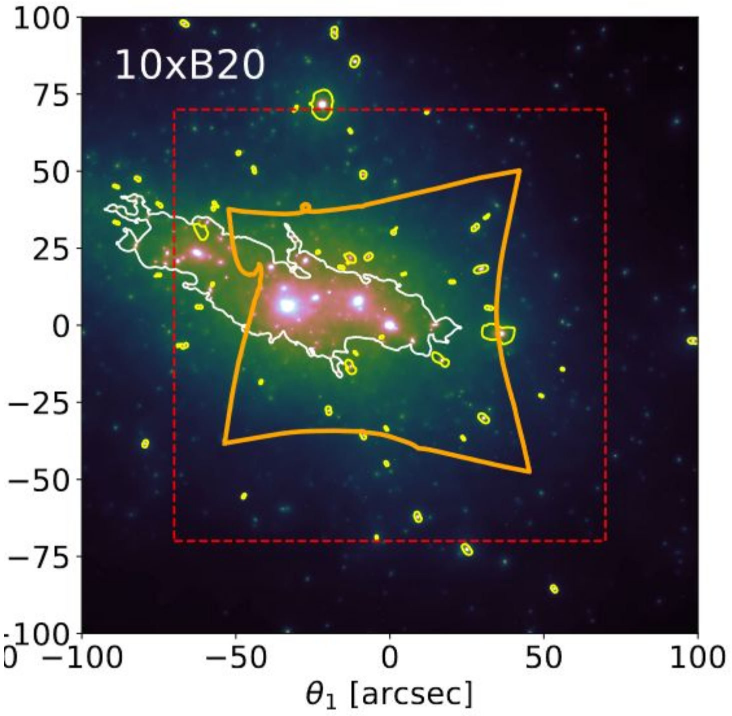


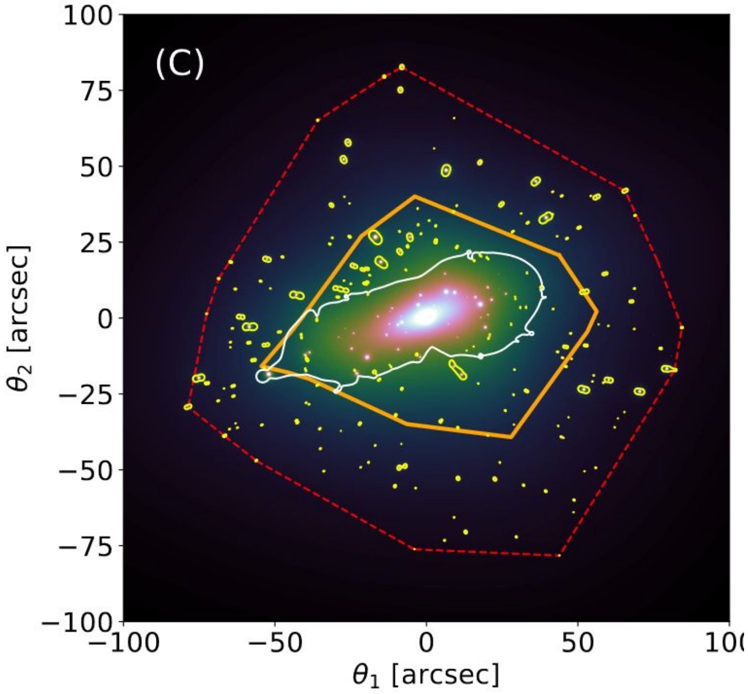
low mass subhaloes: below obs!

high mass subhaloes: sometimes catch obs

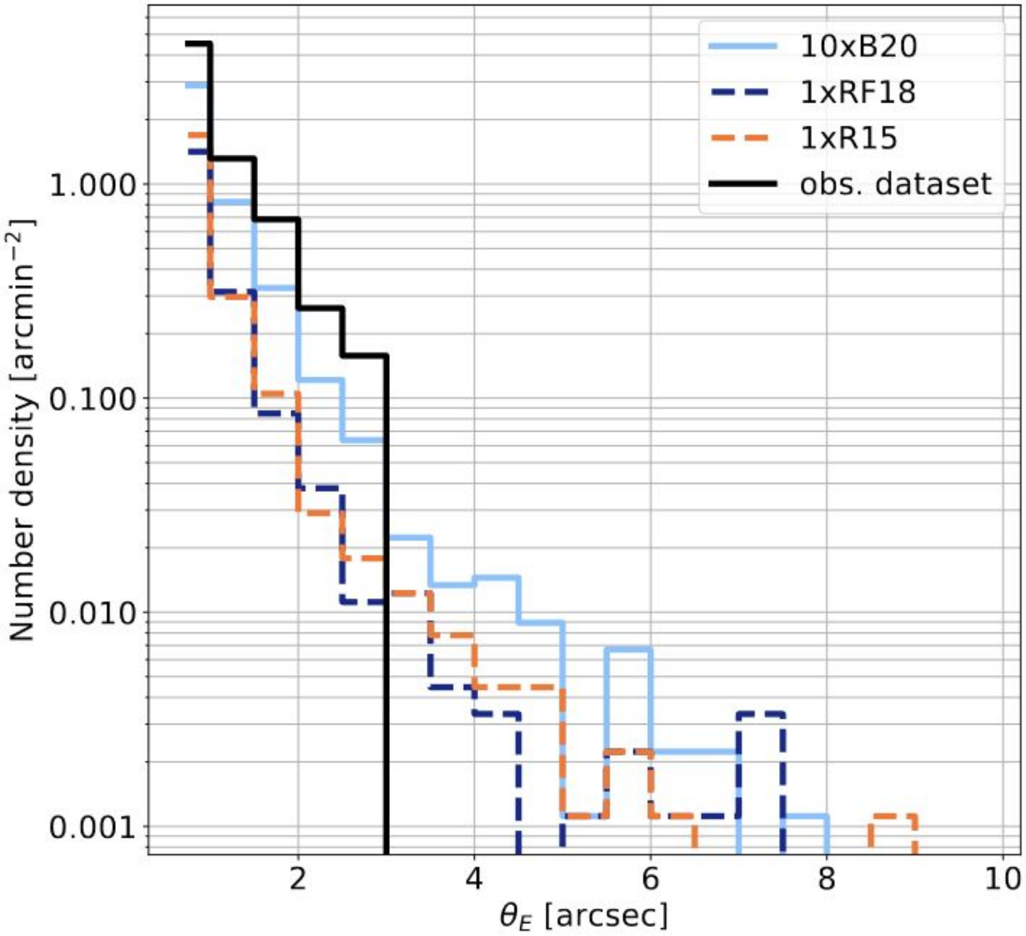
(see Ragagnin+22)

The best simulation in terms of strong lensing still does **differs qualitatively with respect to observations**





(Meneghetti+22)



(see Meneghetti+22)

SIDM

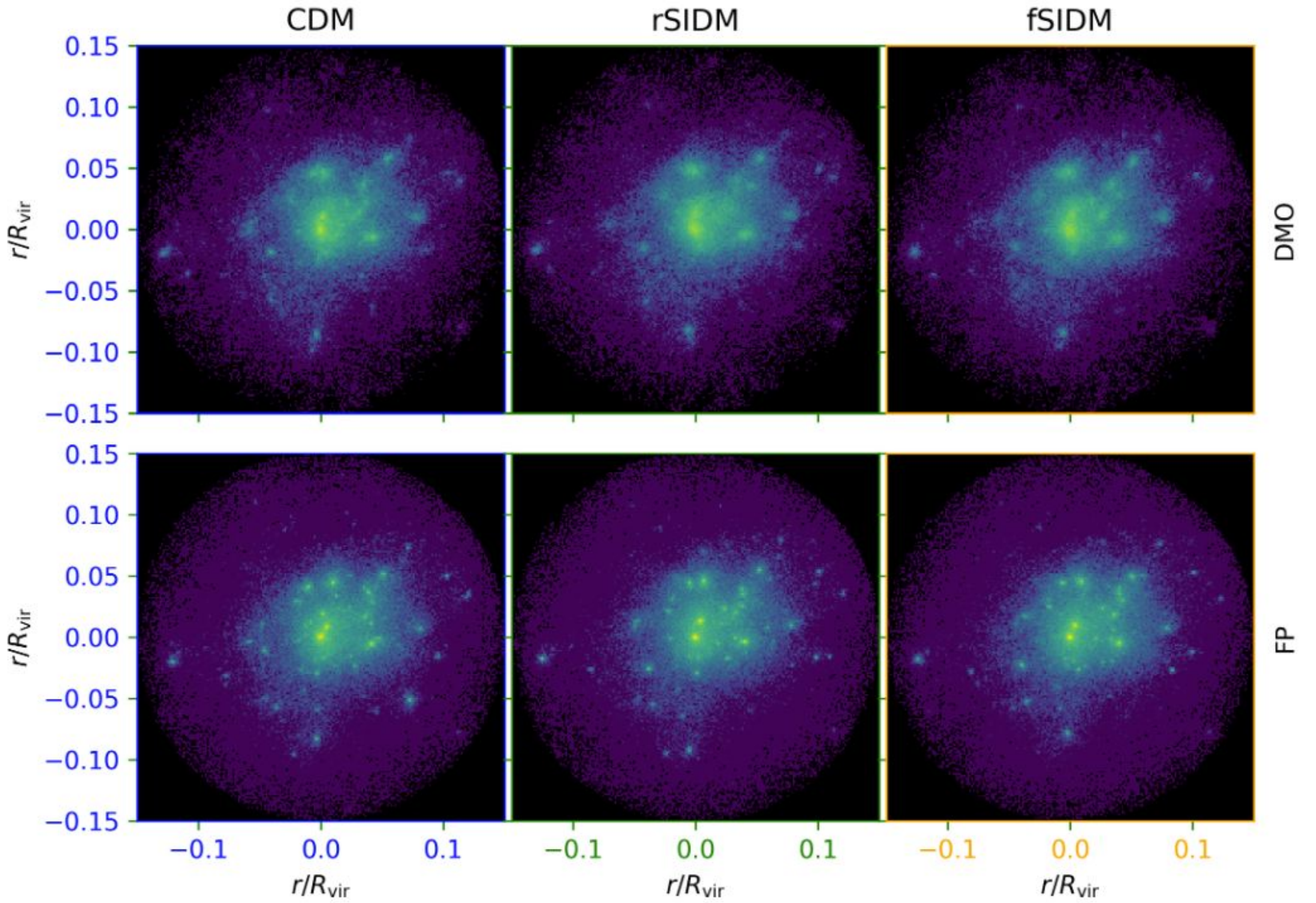
DMO and full physics of six galaxy clusters with resolution of 1x with Mvir ~ 1e14 - 1e15 Msun with **rare** and **frequent** SIDM.

A s a starting point I use momentum transfer sigma/m = 40 cm^2/g, and w=200km/s

region	$M_{\rm vir}[10^{14}h^{-1}{\rm M}_\odot]$	$c_{\rm vir}$ DMO	$c_{\rm vir}$ FP
D3	4.8	4.0	4.6
D4	2.7	4.6	3.9
D5	1.2	6.0	5.5
D10	11.2	4.1	4.5
D15	11.5	4.8	5.9
D16	12.3	4.6	5.0

redshift range of the following analyses:
0.2<z<0.6 (relevant for lensing)

analyses performed within 0.15Rvir



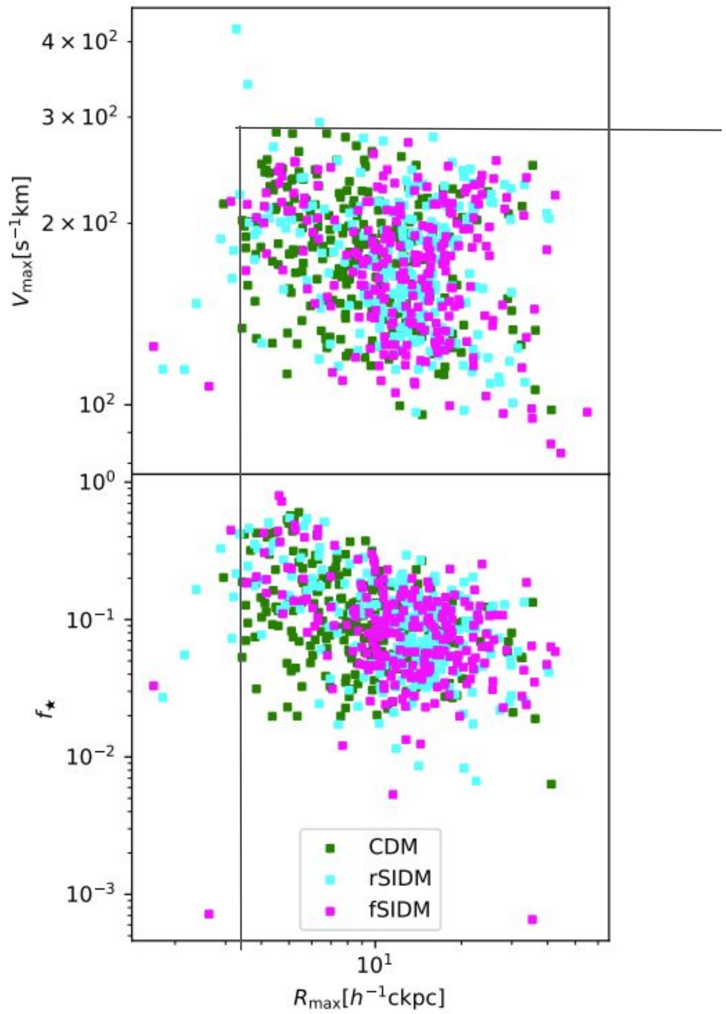
CDM
rSIDM
fSIDM
DMO
FP
r/R_vir
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.1
0.0
0.1

will core collapse play a role?

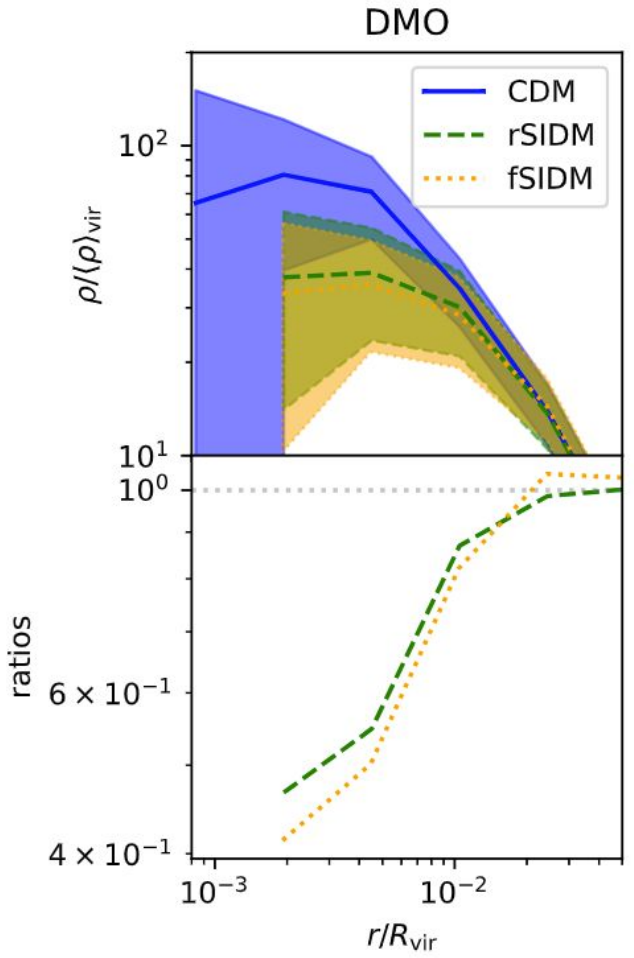
in the **full physics simulation** substructures in the **field** I find that only ~5% have strong compactness.

On the other hand is impressive that we can produce them with a low stellar fraction!

mass range in plot:
Msub>1 - 10 x $10^{11}\,M_\odot$

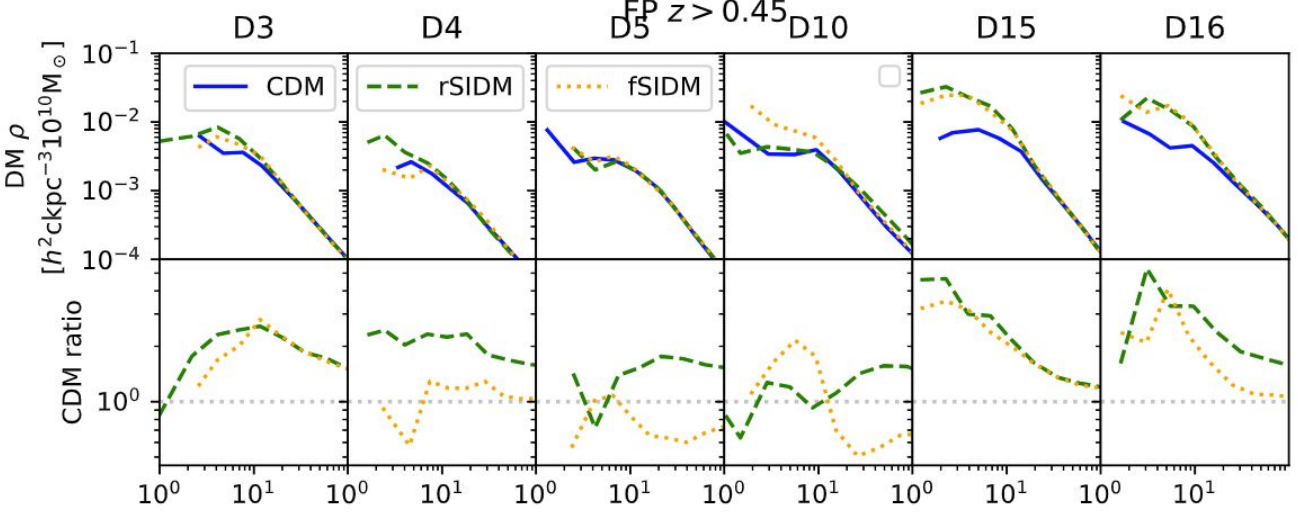


DM Density profiles of the galaxy cluster cores:

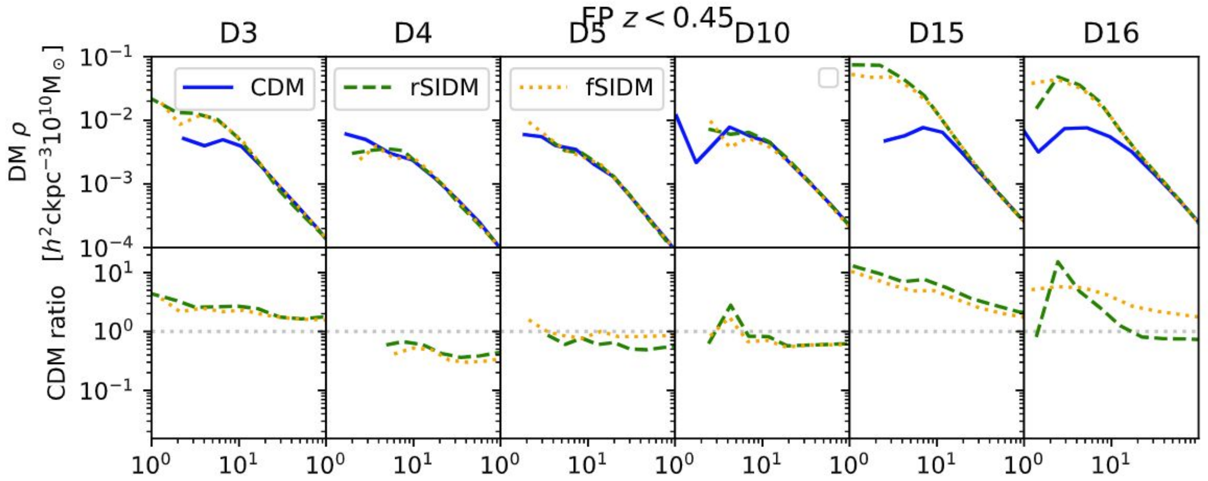


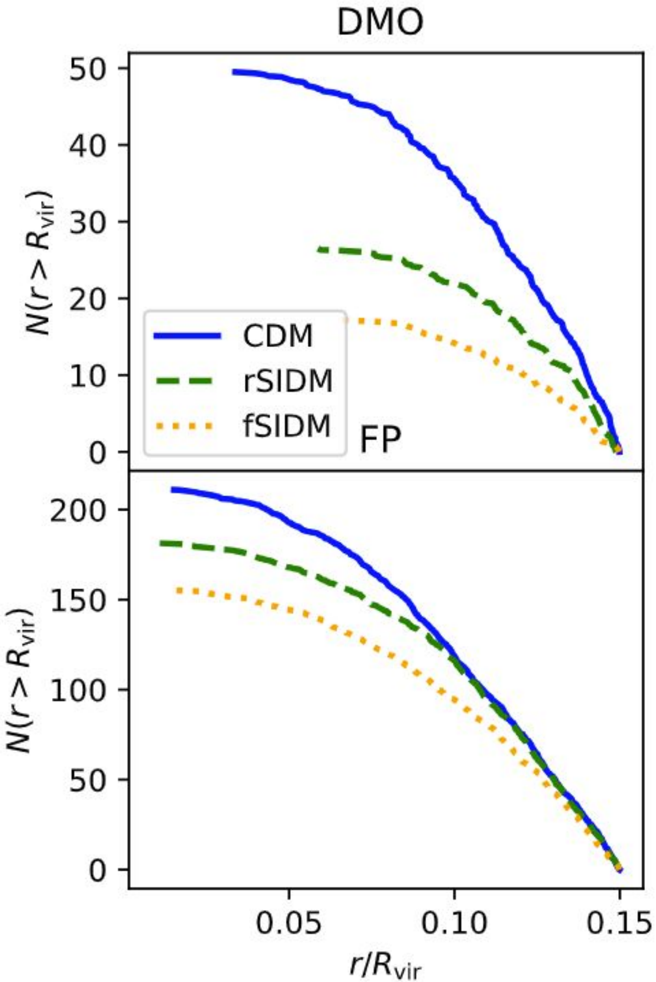
Here I show:
dark matter central density profiles of the six simulated galaxy clusters

at 0.45<z<0.6----->



at 0.2<z<0.45------>





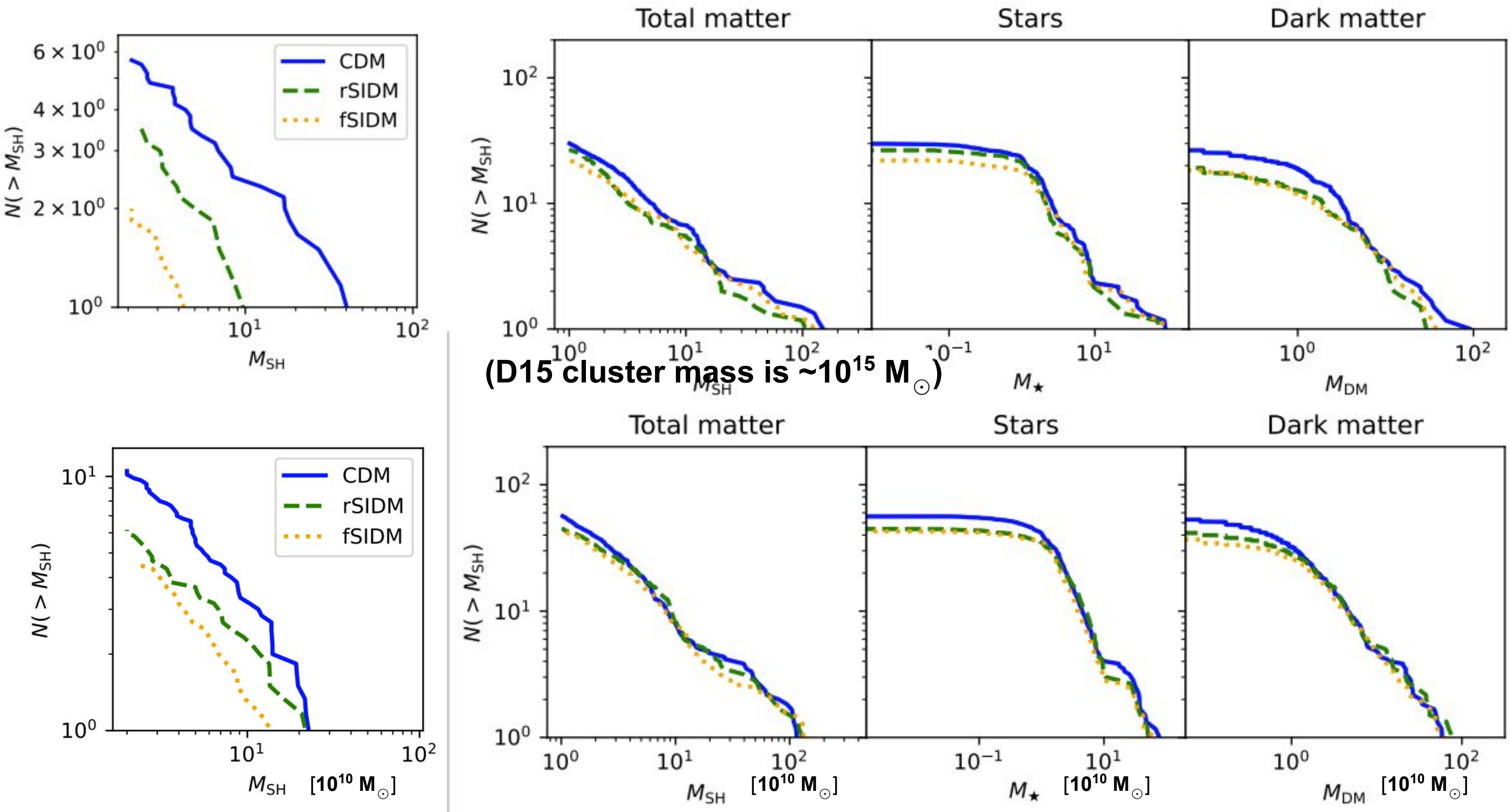
DMO
FP
CDM
rSIDM
fSIDM
$N(r > R_{\rm vir})$
$r/R_{\rm vir}$
0.05
0.10
0.15

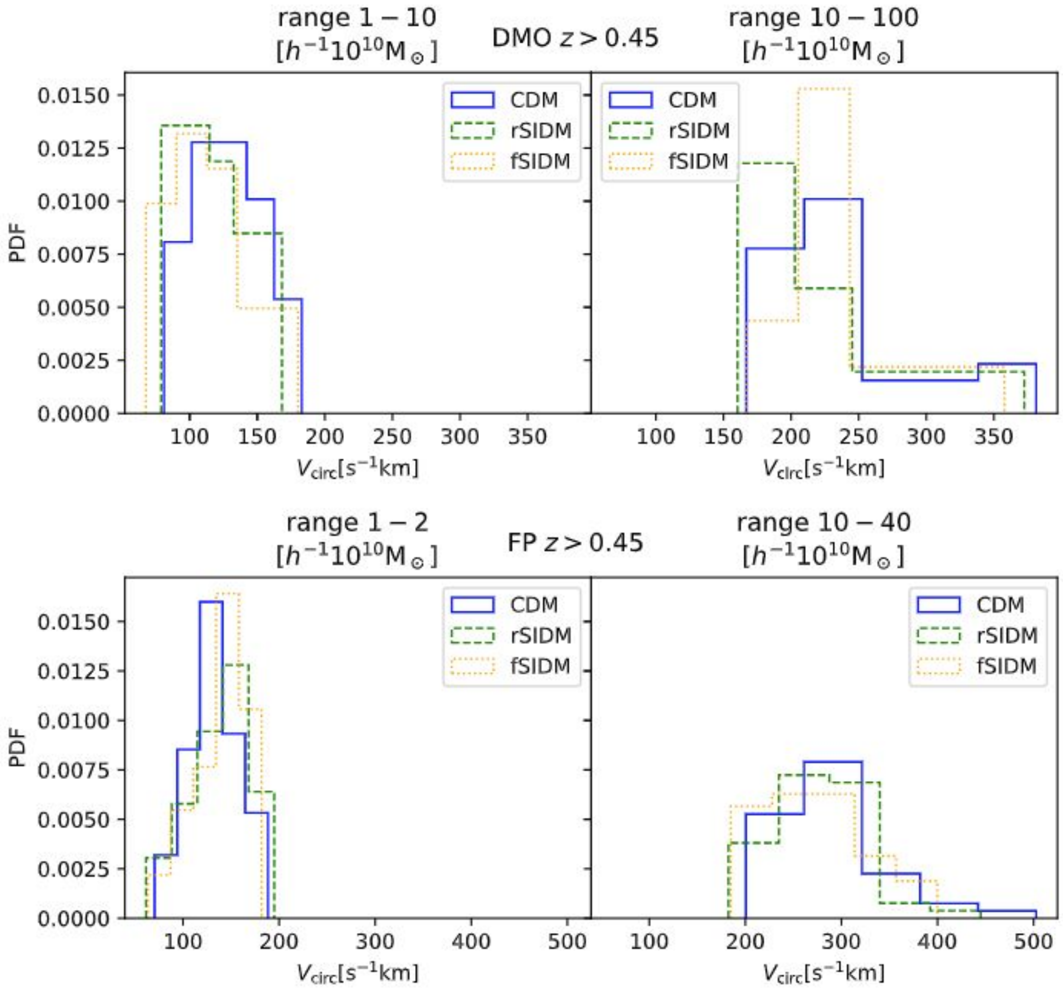
(D3 cluster mass is ~10^{14} $M_\odot$)

DMO D3

FP D3

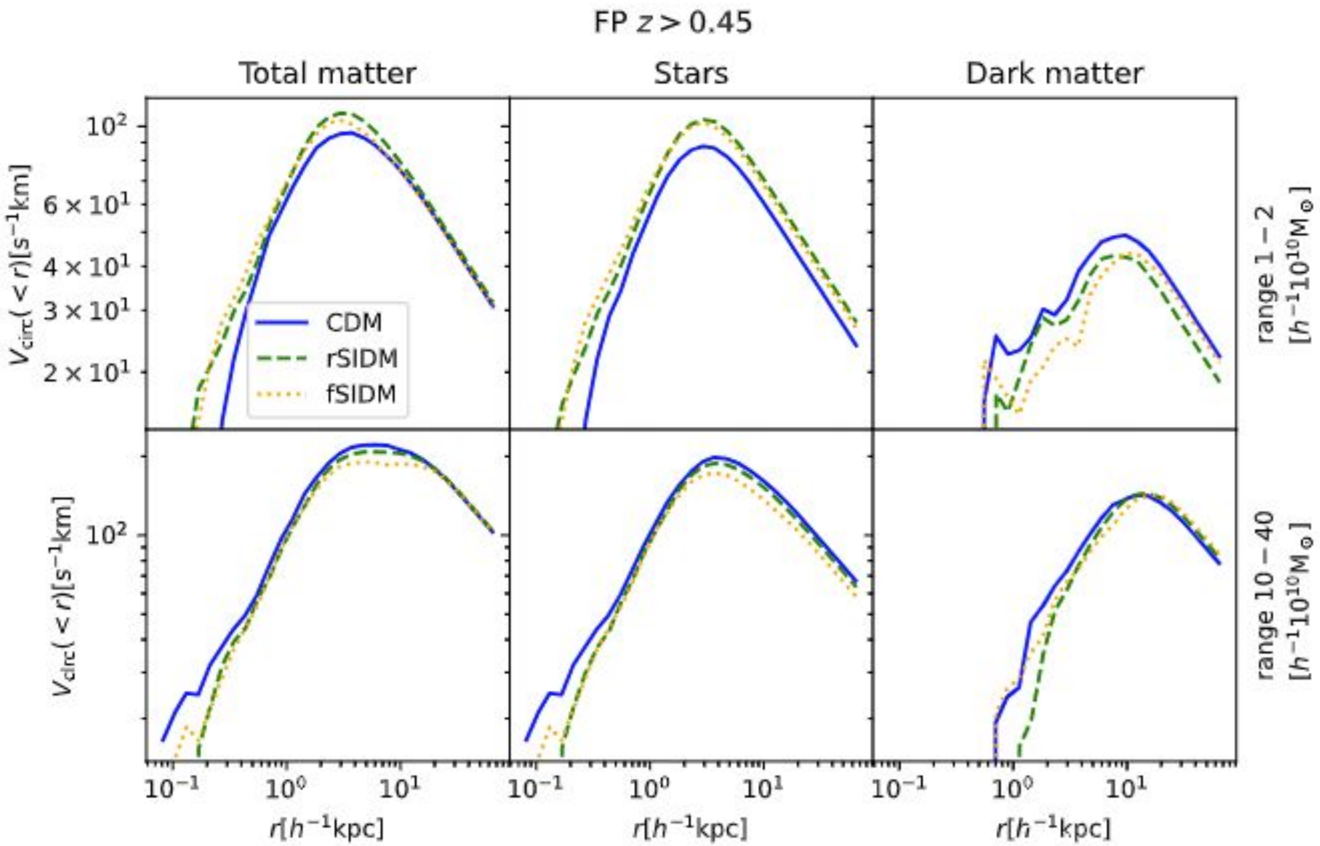
(D15 cluster mass is ~10^{15} $M_\odot$)



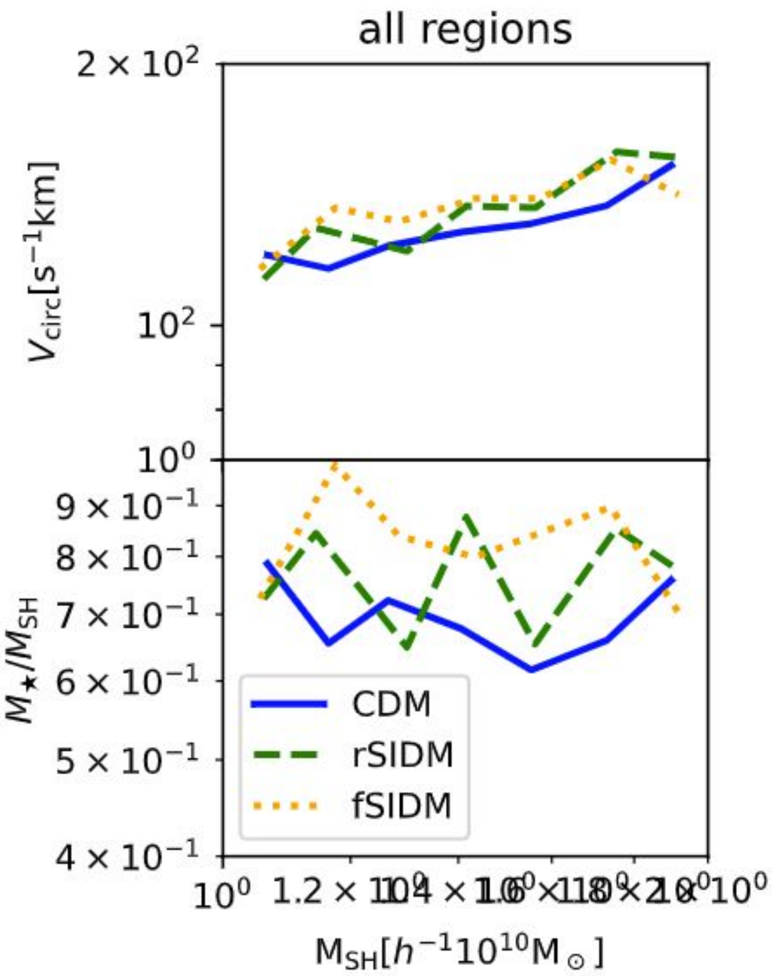


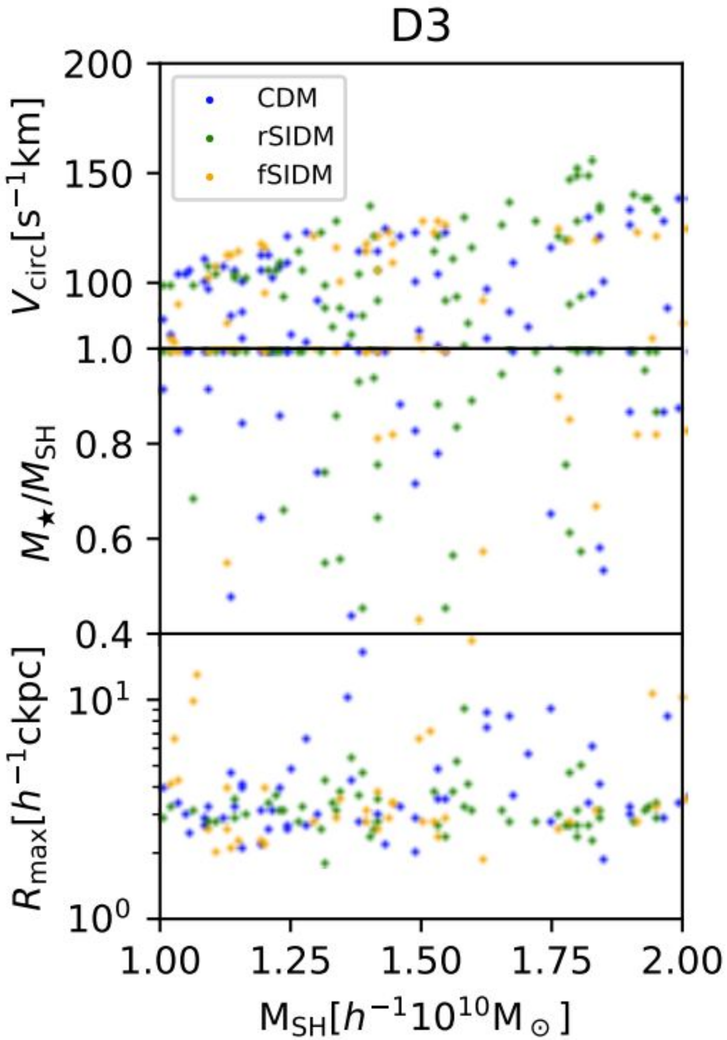
←- DMO runs

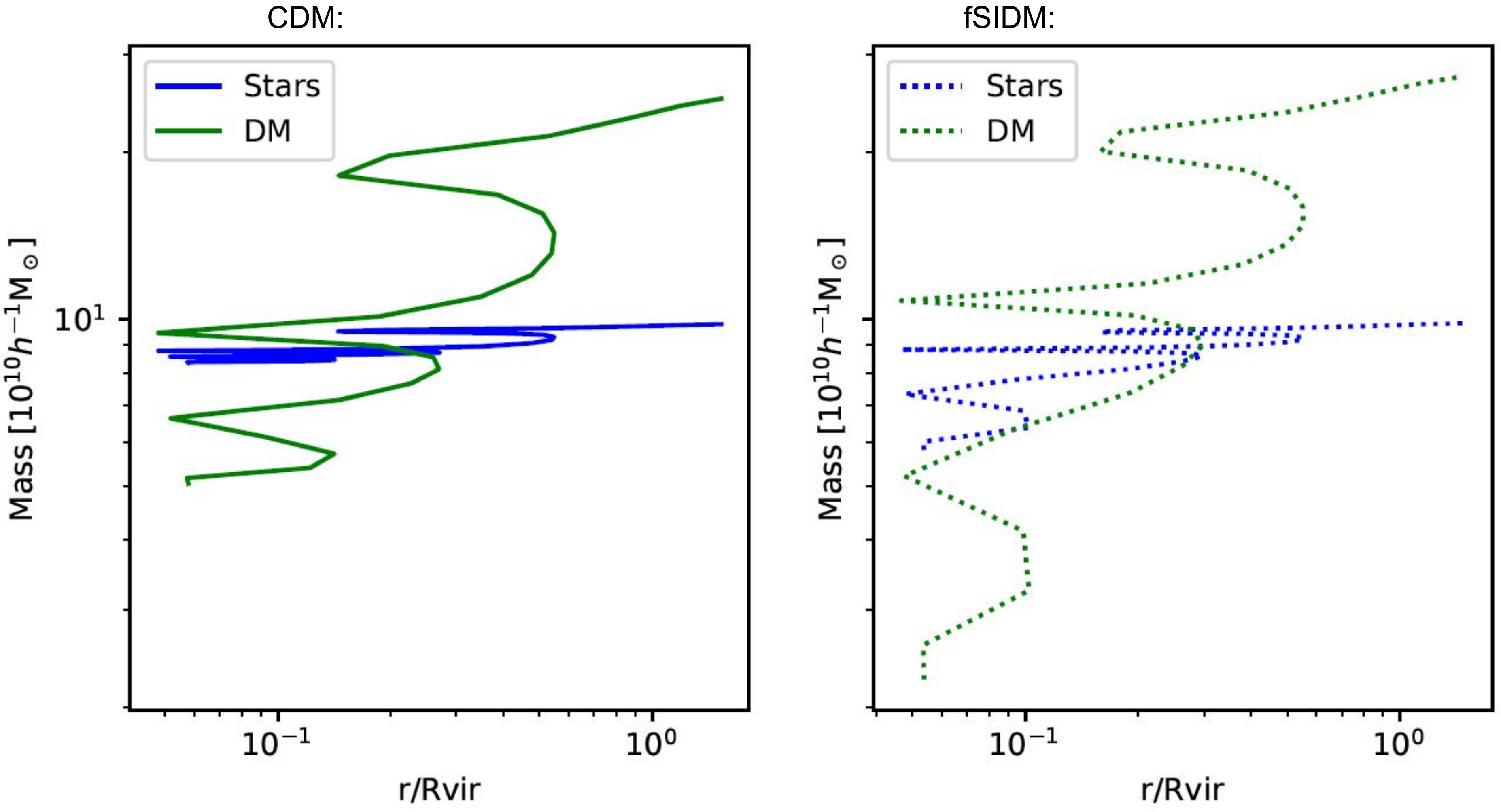
←- full physics runs



FP $z > 0.45$
Total matter
Stars
Dark matter
$V_{\rm circ}(<r)[\rm s^{-1}km]$
10^2
6×10^1
4×10^1
3×10^1
2×10^1
CDM
rSIDM
fSIDM
range $1-2$ $[h^{-1}10^{10}\rm M_\odot]$
range $10-40$ $[h^{-1}10^{10}\rm M_\odot]$
10^{-1}
10^0
10^1
$r[h^{-1}\rm kpc]$


all regions
2×10^2
10^2
10^0
9×10^{-1}
8×10^{-1}
7×10^{-1}
6×10^{-1}
5×10^{-1}
4×10^{-1}
$V_{\rm circ}[\rm s^{-1}km]$
$M_\star/M_{\rm SH}$
CDM
rSIDM
fSIDM
$\rm M_{SH}[h^{-1}10^{10}M_\odot]$


D3
200
150
100
1.0
0.8
0.6
0.4
10^1
10^0
CDM
rSIDM
fSIDM
$V_{\rm circ}[\rm s^{-1}km]$
$M_\star/M_{\rm SH}$
$R_{\rm max}[h^{-1}\rm ckpc]$
1.00
1.25
1.50
1.75
2.00
$\rm M_{SH}[h^{-1}10^{10}M_\odot]$

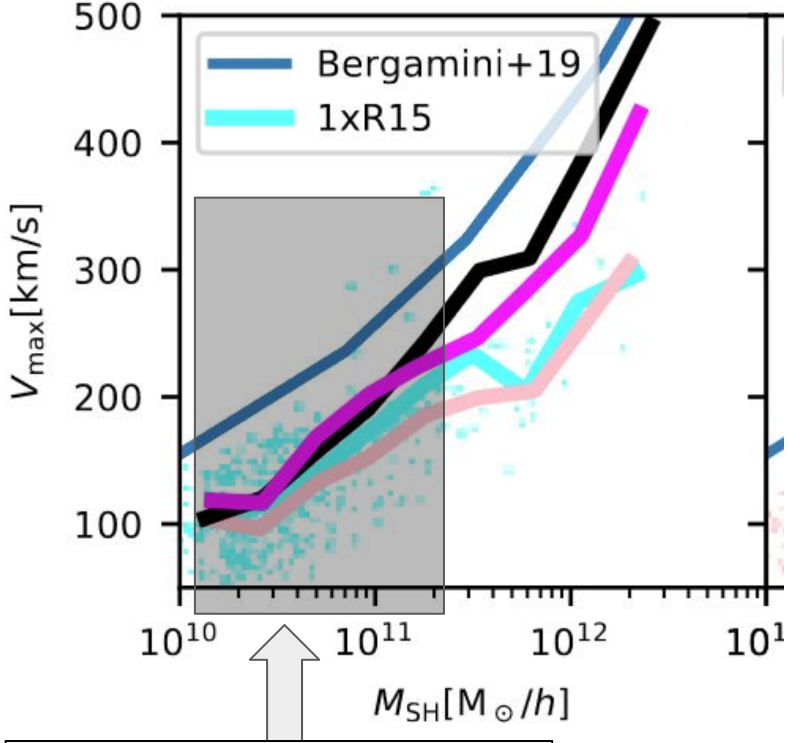


CDM:
fSIDM:
Stars
DM
Stars
DM
10^1
10^{-1}
10^0
10^{-1}
10^0
Mass $[10^{10}h^{-1}\mathrm{M}_\odot]$
Mass $[10^{10}h^{-1}\mathrm{M}_\odot]$
r/Rvir
r/Rvir

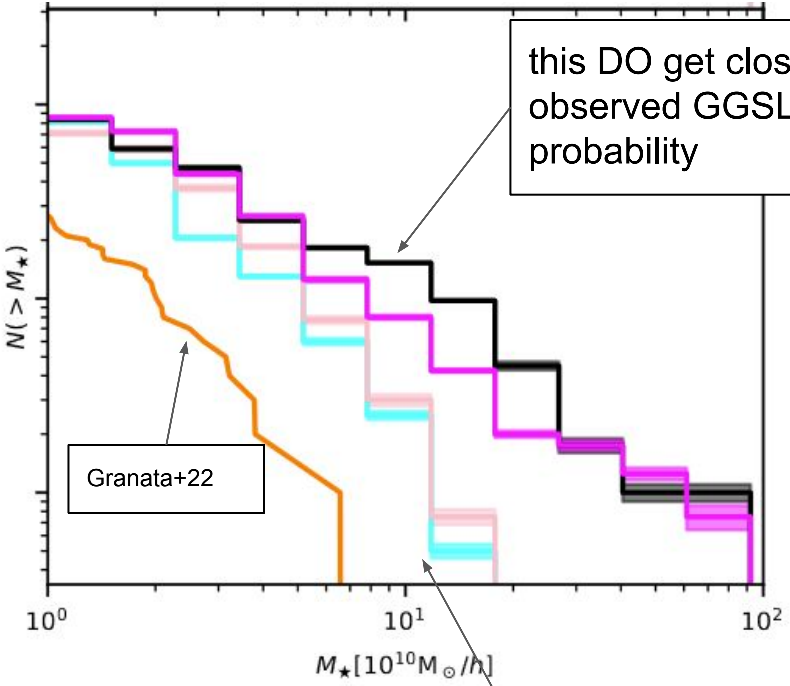
to conclude

- discrepancy between galaxy cluster lensing signal still unsolved for LCDM simulations: they fail to recover lensing signal of 1e10 Msun subahloes in cluster cores
- I tested SIDM with sigma0/m = 30 and w = 200 km/s, and found frequent and rare interaction to produce different central DM distribution at z>0.45, and in general much larger suppression of sub haloes
- both frequent and rare produce more systematically more compact object in the 1e10 Msun regime, due to a different stripping mechanism w.r.t. to CDM
- the price to pay is a larger stellar fraction in galaxies near cluster cores
- future plans: more aggressive sigma? higher resolution?

backup slides



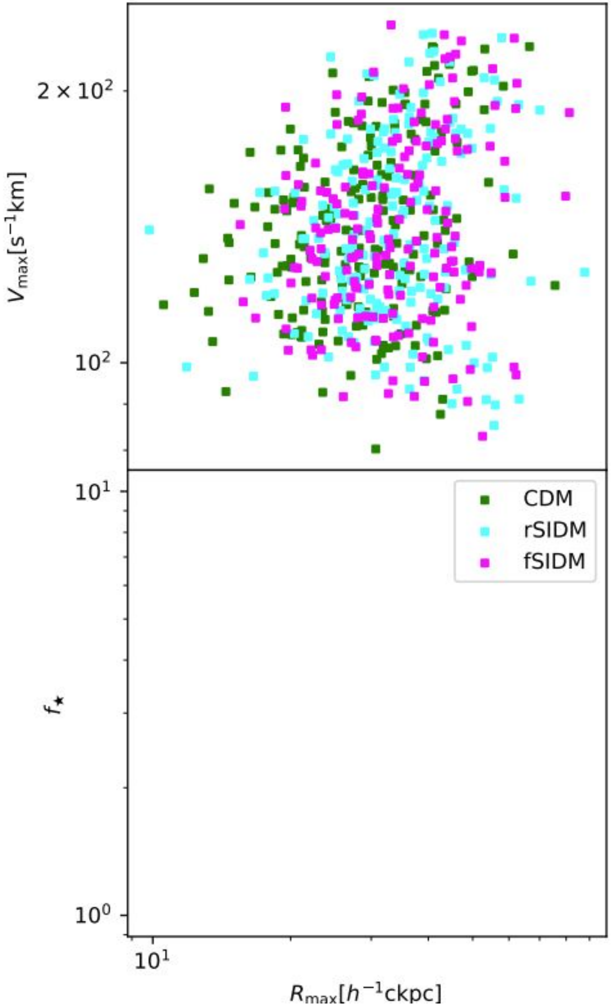
low mass subhaloes: always below observations



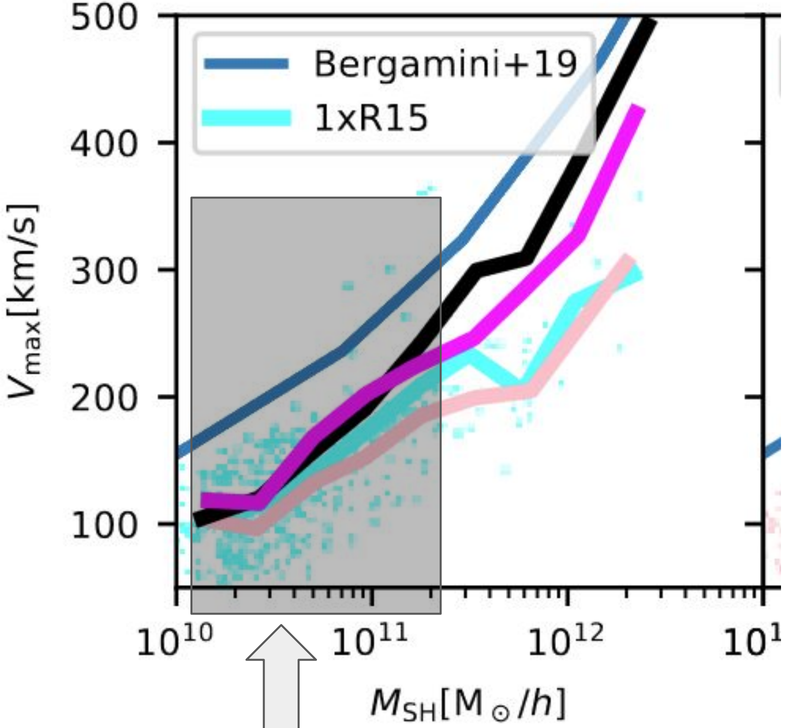
this DO get close to observed GGSL probability

this DON´T match GGSL probability at all

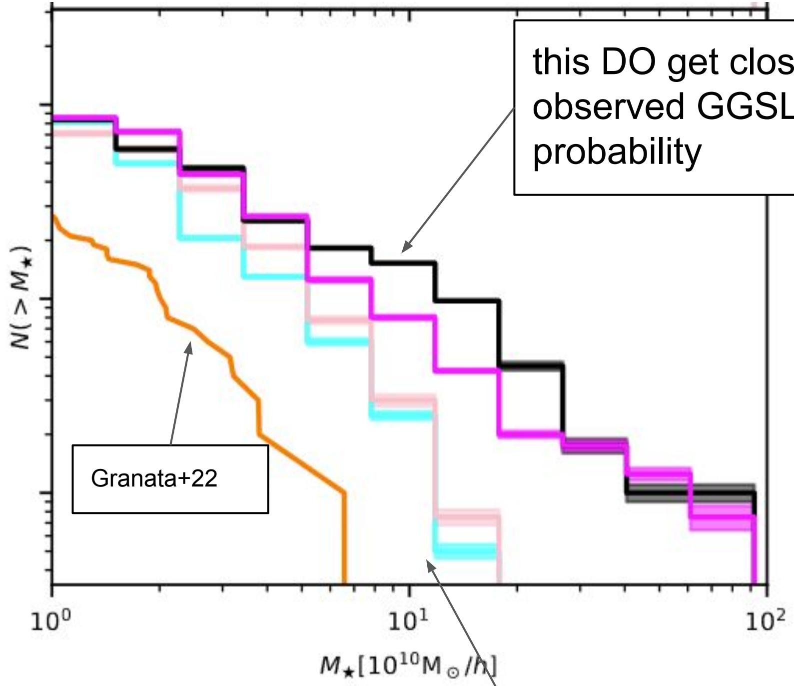
(see Ragagnin+22, Granata+22, Bergamni+19)



2×10^2
10^2
$V_{\rm max}[{\rm s^{-1}km}]$
10^1
10^0
$f_\star$
CDM
rSIDM
fSIDM
10^1
$R_{\rm max}[h^{-1}{\rm ckpc}]$



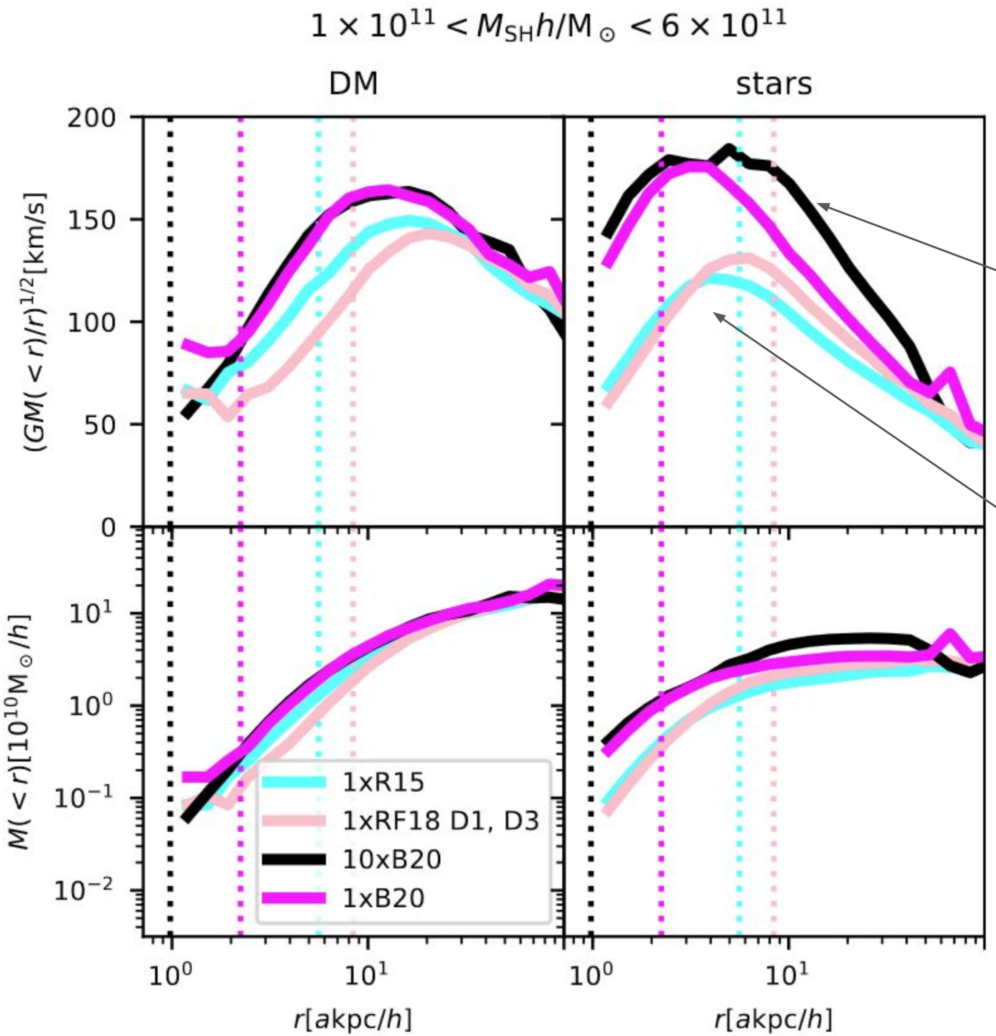
low mass subhaloes: always below observations



this DO get close to observed GGSL probability

(see Ragagnin+22, Granata+22, Bergamni+19)

this DON´T match GGSL probability at all



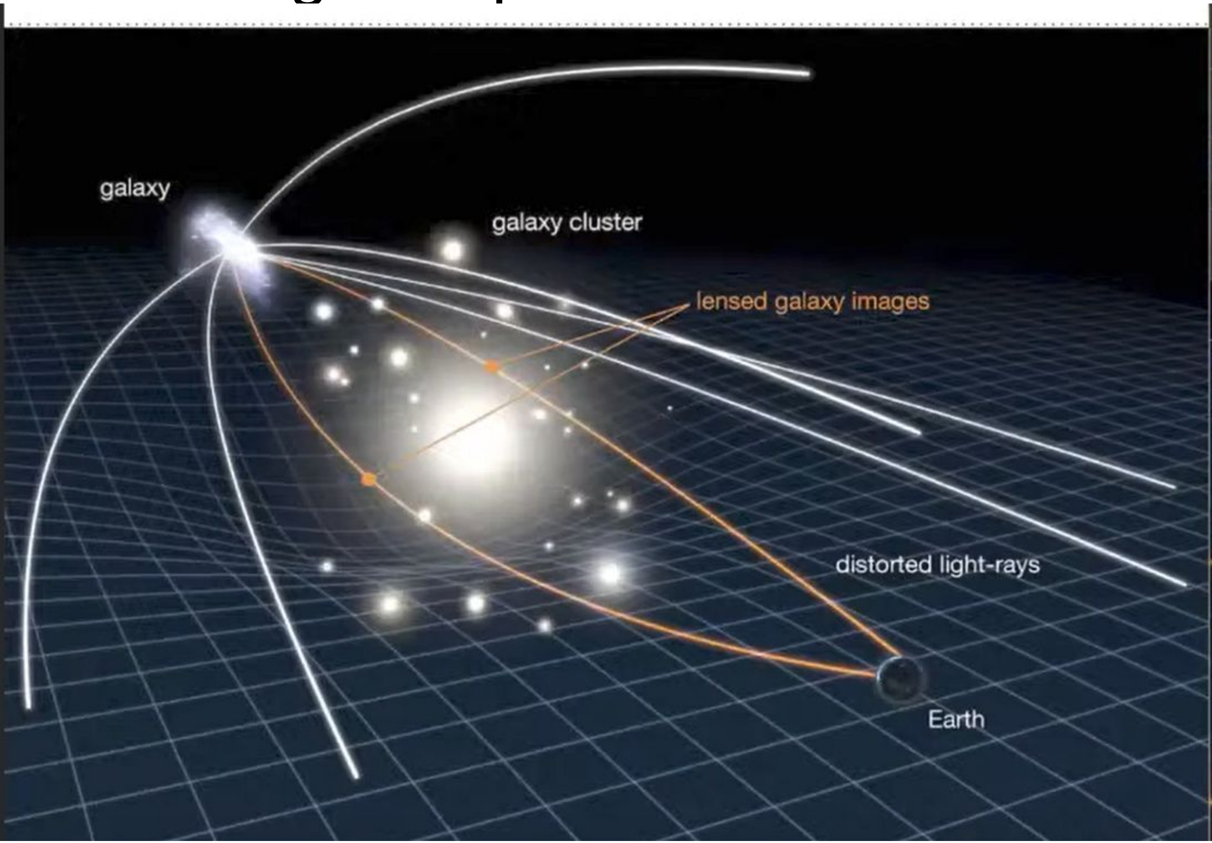
Why some simulations have high compactness?

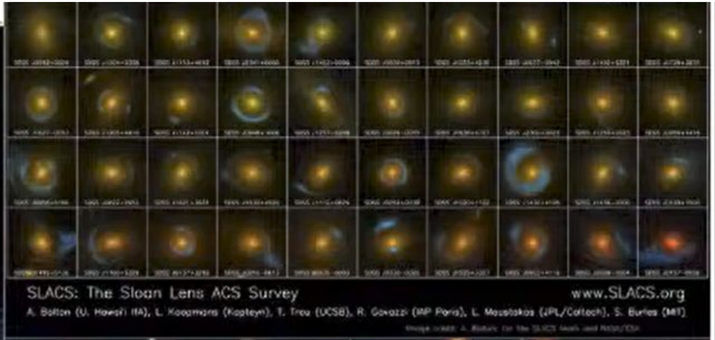
this DOES get closer to GGSL probability

this DOESN´t match GGSL probability at all

(see Ragagnin+22)

Lensing as a probe for dark matter





Credits: NASA

Mass modelling from lensing within ~15% the virial radius

Mass modeling with:

- HST images for halo and galaxy-galaxy strong lensing
- spectroscopy with MUSE (e.g. Vanzella+20) validates source of multiple images
- internal kinematics (e.g. Bergamini+19) breaks profile degeneracy
- Chandra data for hot gas

Assumptions:

$$\rho_{sub-halo}(r) = \frac{\rho_0}{(1 + r^2/r^2_{core})(1 + r^2/r^2_{cut})}$$

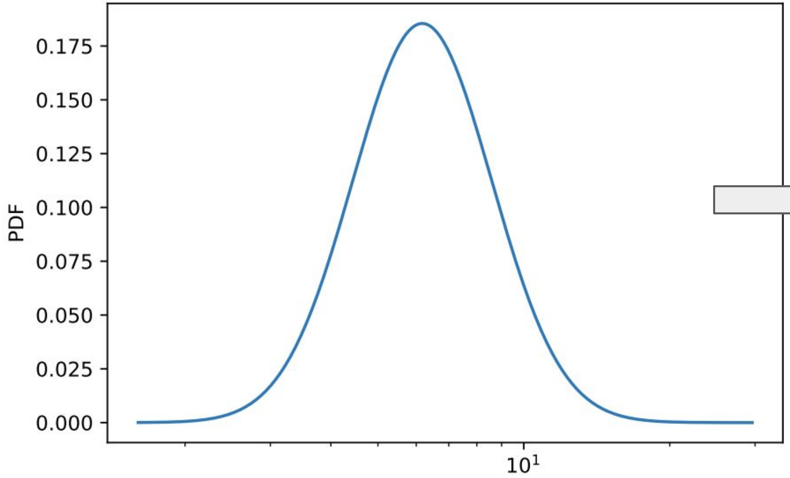
$$\sigma^{gal}_{LT,i} = \sigma^{ref}_{LT}\left(\frac{L_i}{L_0}\right)^{\alpha},$$

$$r^{gal}_{cut,i} = r^{ref}_{cut}\left(\frac{L_i}{L_0}\right)^{\beta_{cut}},$$

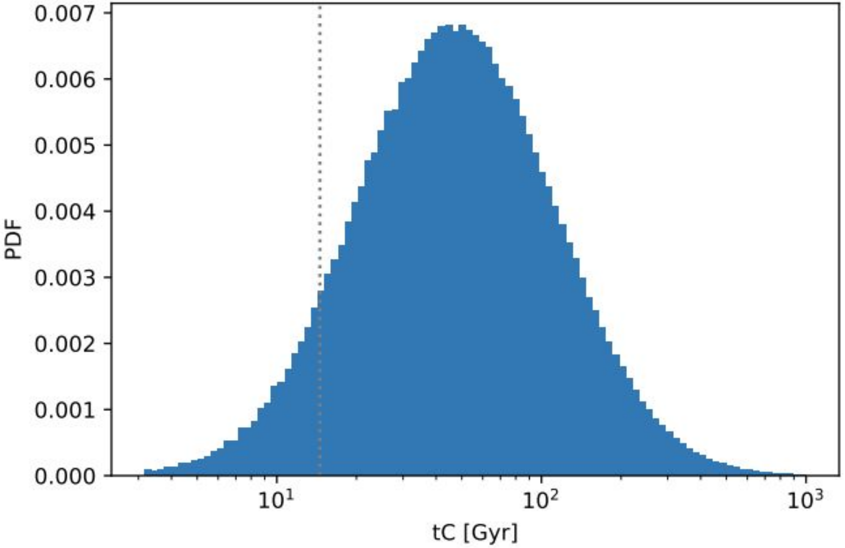
$$\phi_{tot}(\vec{\xi}) = \sum_{i=1}^{N_h} \phi_i^{halo}(\vec{\xi}_{halo}) + \sum_{k=1}^{N_{gal}} \phi_k^{gal}(\vec{\xi}_{gal}) + \phi_{shear}(\vec{\xi}_{shear}) + \phi_{gas}$$

SIDM estimates

concentration distribution for 1e11 Msun DM haloes
has c200c ~ 6 (Ludlow+16)
and logscatter of ~33% (Heitman+14)



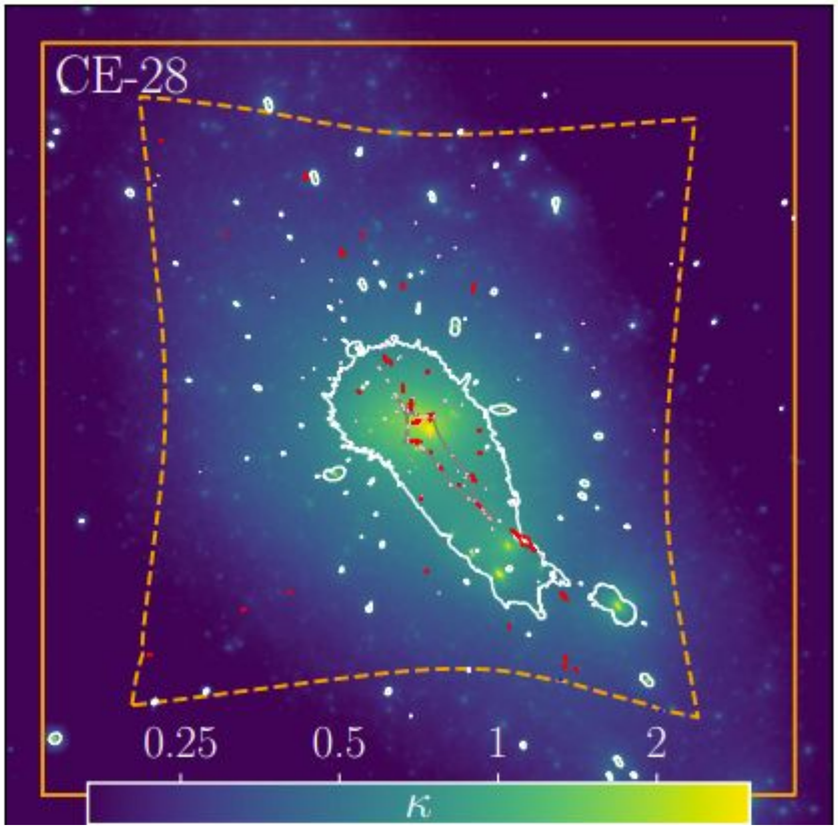
if I put sigma/m ~ 30 cm^2/g:



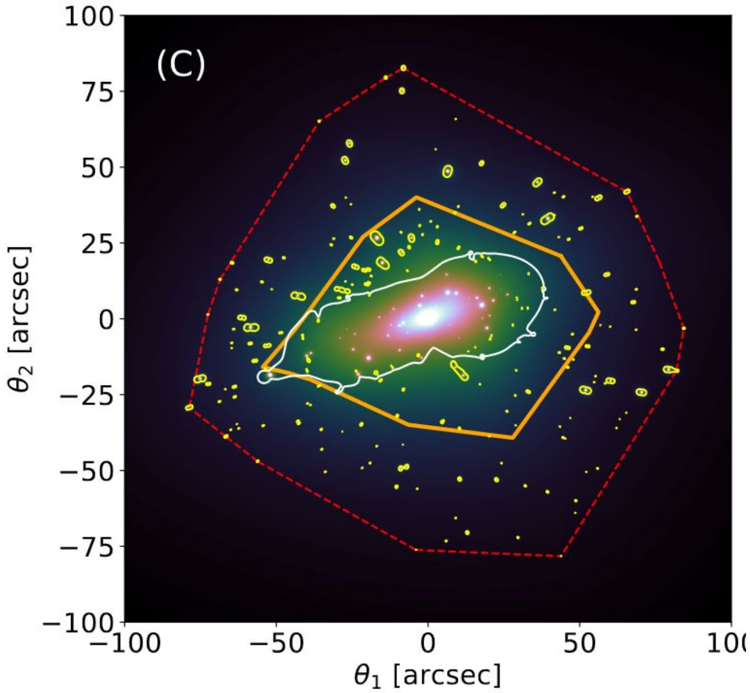
$$t_c(200c) = 8.23 \times 10^7 \left(\frac{\sigma/m}{\mathrm{cm}^2/\mathrm{g}}\right)^{-0.74} \left(\frac{M_{200c}}{M_\odot}\right)^{-0.24} c_{200c}^{-2.61}\ \mathrm{Gyr}, \tag{8}$$

(formula from Zeng+22)

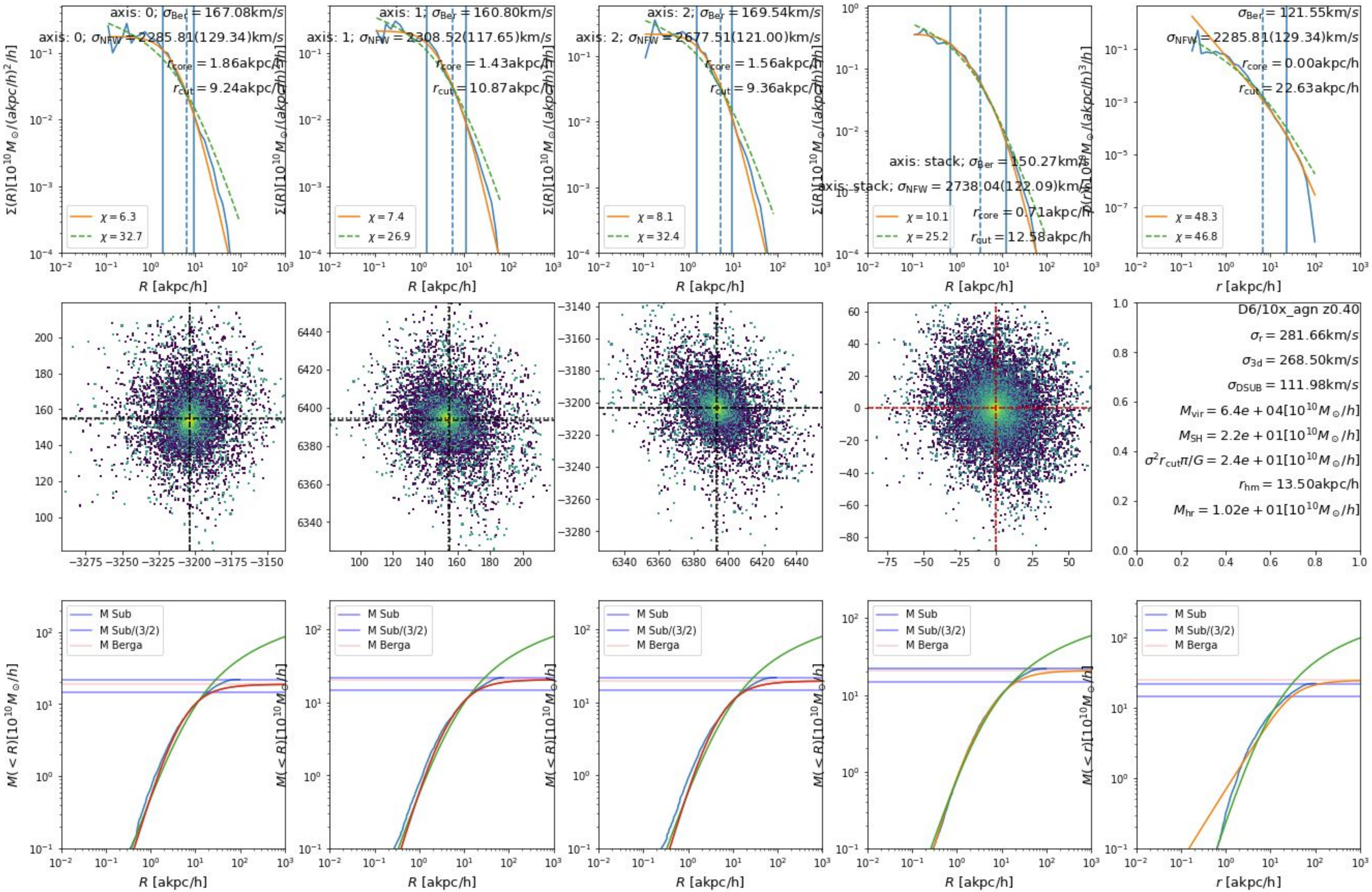
fraction of core collapsed objects:
~1%



from Robertson+21 Fig. 1.

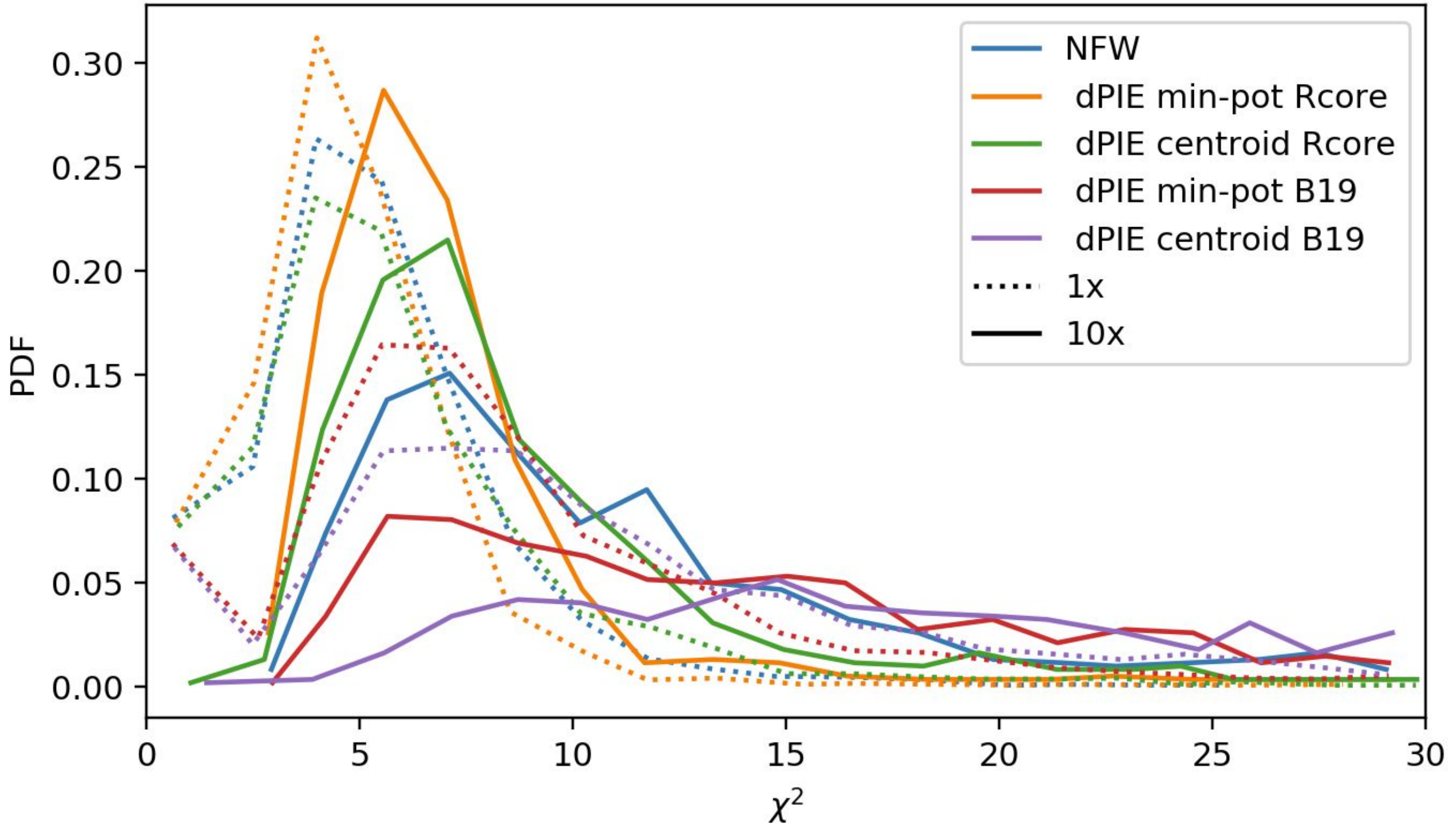


From Meneghetti+22



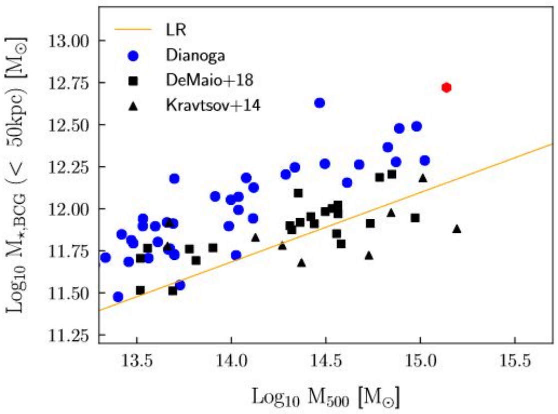
axis: 0; $\sigma_{\rm Ber} = 167.08$km/s
axis: 0; $\sigma_{\rm NFW} = 2285.81(129.34)$km/s
$r_{\rm core} = 1.86$akpc/h
$r_{\rm cut} = 9.24$akpc/h
$\chi = 6.3$
$\chi = 32.7$
axis: 1; $\sigma_{\rm Ber} = 160.80$km/s
axis: 1; $\sigma_{\rm NFW} = 2308.52(117.65)$km/s
$r_{\rm core} = 1.43$akpc/h
$r_{\rm cut} = 10.87$akpc/h
$\chi = 7.4$
$\chi = 26.9$
axis: 2; $\sigma_{\rm Ber} = 169.54$km/s
axis: 2; $\sigma_{\rm NFW} = 2677.51(121.00)$km/s
$r_{\rm core} = 1.56$akpc/h
$r_{\rm cut} = 9.36$akpc/h
$\chi = 8.1$
$\chi = 32.4$
axis: stack; $\sigma_{\rm Ber} = 150.27$km/s
axis: stack; $\sigma_{\rm NFW} = 2738.04(122.09)$km/s
$r_{\rm core} = 0.71$akpc/h
$r_{\rm cut} = 12.58$akpc/h
$\chi = 10.1$
$\chi = 25.2$
$\sigma_{\rm Ber} = 121.55$km/s
$\sigma_{\rm NFW} = 2285.81(129.34)$km/s
$r_{\rm core} = 0.00$akpc/h
$r_{\rm cut} = 22.63$akpc/h
$\chi = 48.3$
$\chi = 46.8$
$\Sigma(R)[10^{10}M_\odot/(akpc/h)^2/h]$
$\rho(r)[10^{10}M_\odot/(akpc/h)^3/h]$
R [akpc/h]
r [akpc/h]
D6/10x_agn z0.40
$\sigma_{\rm r} = 281.66$km/s
$\sigma_{\rm 3d} = 268.50$km/s
$\sigma_{\rm DSUB} = 111.98$km/s
$M_{\rm vir} = 6.4e+04[10^{10}M_\odot/h]$
$M_{\rm SH} = 2.2e+01[10^{10}M_\odot/h]$
$\sigma^2 r_{\rm cut}\pi/G = 2.4e+01[10^{10}M_\odot/h]$
$r_{\rm hm} = 13.50$akpc/h
$M_{\rm hr} = 1.02e+01[10^{10}M_\odot/h]$
M Sub
M Sub/(3/2)
M Berga
$M(<R)[10^{10}M_\odot/h]$
$M(<r)[10^{10}M_\odot/h]$

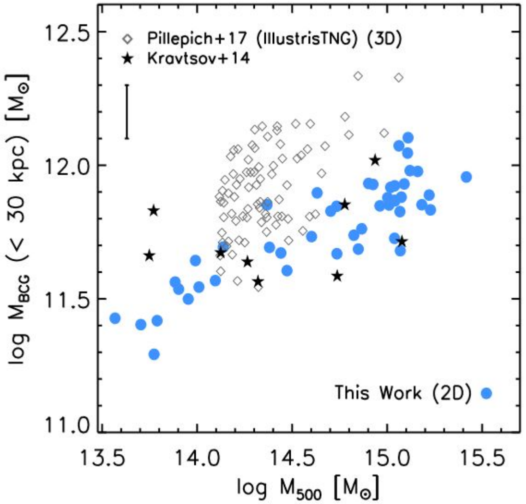
Msub>2e10

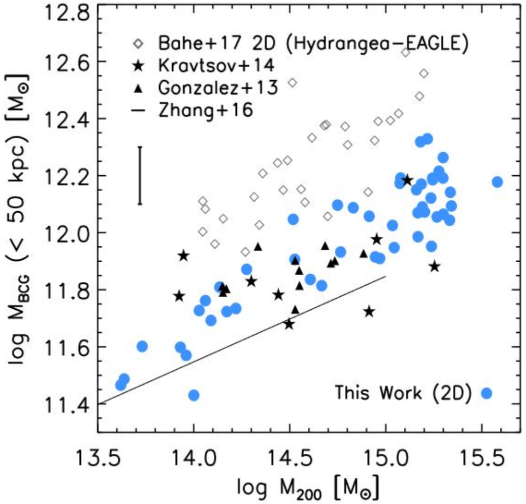


NFW
dPIE min-pot Rcore
dPIE centroid Rcore
dPIE min-pot B19
dPIE centroid B19
1x
10x
PDF
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0
5
10
15
20
25
30
χ^2

Lowering stellar masses us already a problem for many sims







(see Bahe+17, Ragone-Figueroa+18, Bassini+20)