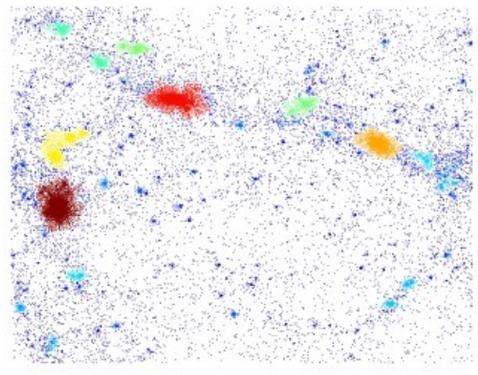
The dark hearts of dwarves and globular clusters - Predictions for dark matter content in low mass objects

Peter Creasey w. L. Sales, Hai-bo Yu, Omid Sameie
Eric Peng, Mark Vogelsberger, Jesús Zavala

University of California at Riverside (UCR)

FOF group finding (arxiv)



DM halos of dwarfs

few kpc

DM halos of GCs

few pc

1. Spreading out and staying sharp - creating diverse rotation curves via baryonic and self-interaction effects
   Creasey, P., Sameie, O., Sales, L. V., Yu, H-B., Vogelsberger, M.; Zavala, J., 2017, MNRAS, 468, 2283

2. Back from the brink: Did some of todays globular clusters originate in the largest halos during the reionization era?
   Creasey, Sales et al., in prep

Outline

- Part I - Self interacting dark matter in dwarf galaxies
    - Physics beyond LCDM
    - Baryonic explanations
    - Self-interacting dark matter (SIDM) overview
    - Dwarf core and cusp simulations
- Part II - Globular clusters
    - DM halos for GCs?
    - N-body infall models
    - Predictions vs. observations

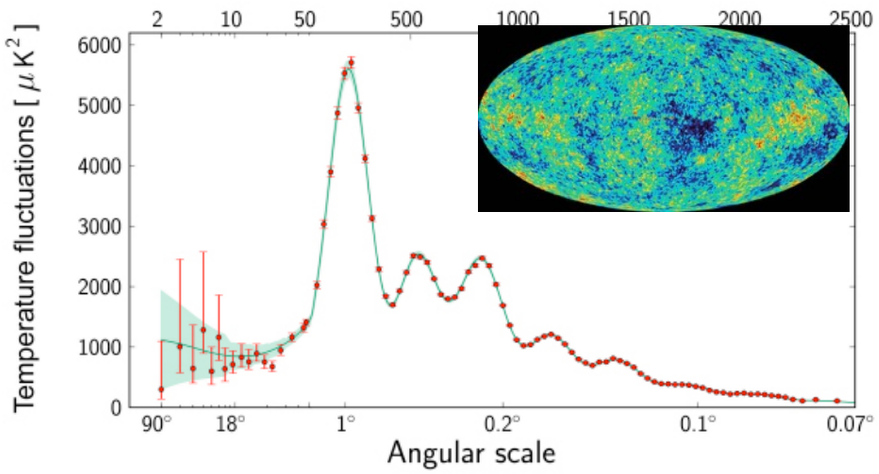
Part I - Dwarf Galaxies with Self Interacting Dark Matter (SIDM)

MITP

Peter Creasey UCR

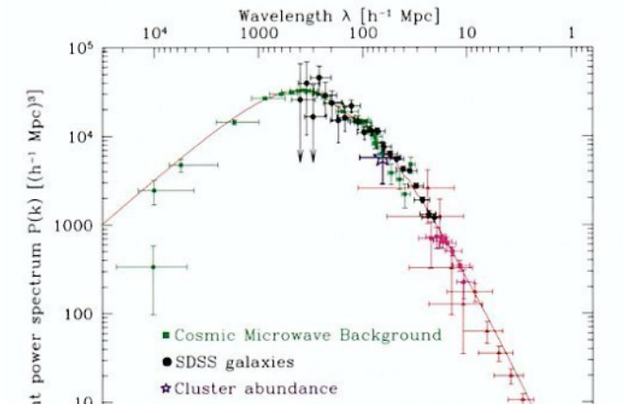
Physics beyond LCDM

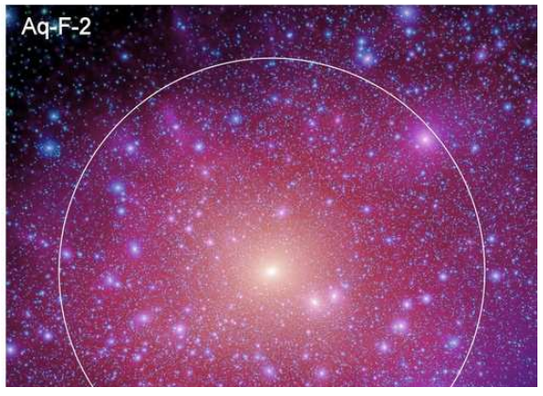
- Lambda a cosmological constant
- Dark matter is dark
- **Dark matter is collisionless**
- Dark matter is cold



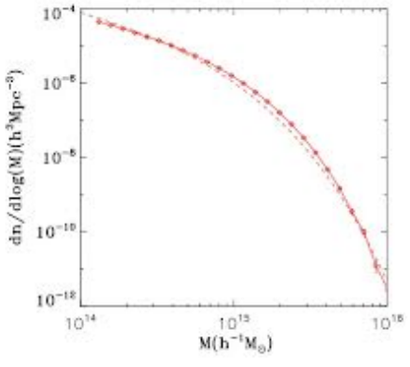
+ Ly-α forest

LCDM - Turtles all the way down

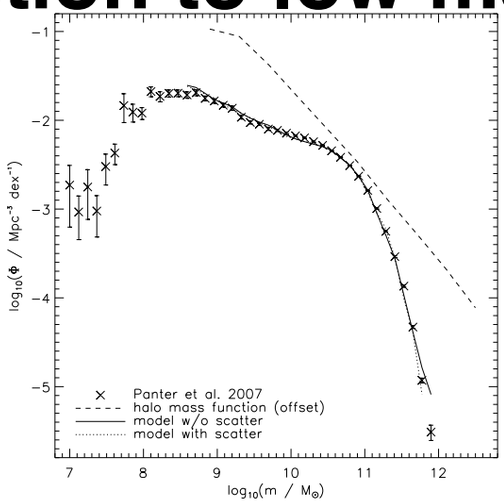




Springel et al. 2008

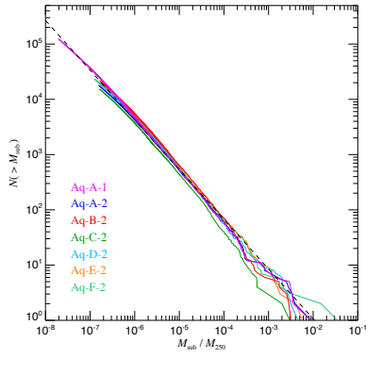


Steep halo mass function to low mass

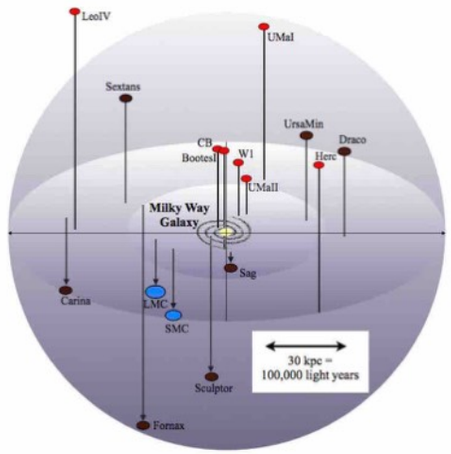


Moster et al. 2010

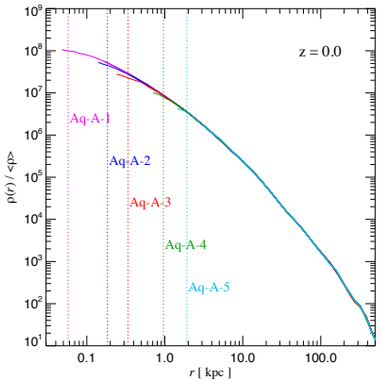
faint end slope



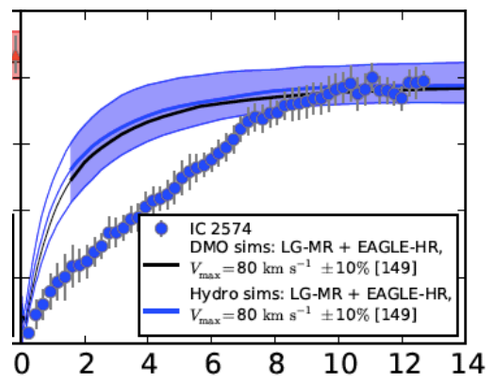
Steep subhalo mass function



MW missing satellites



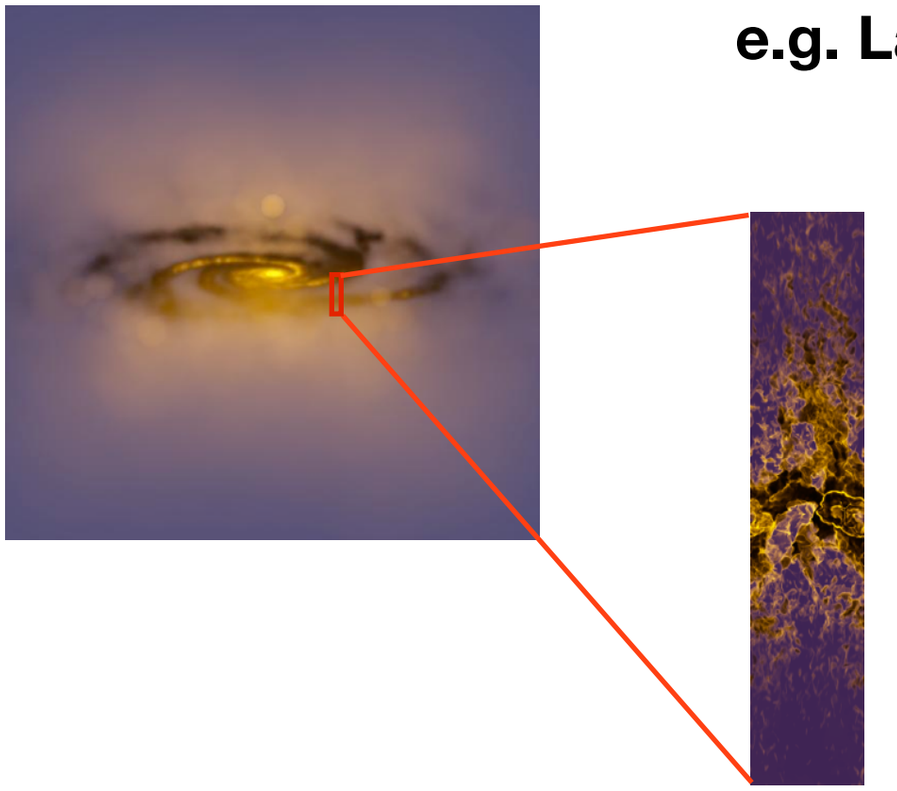
NFW/Einasto profiles



Oman et al. 2015

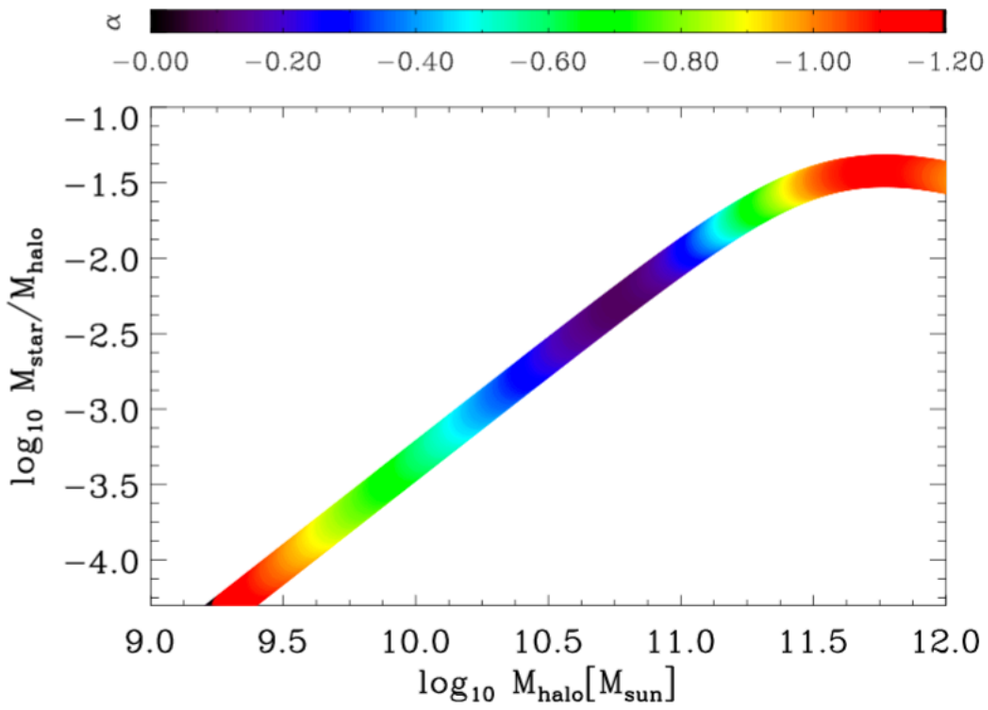
cusp vs core

Baryonic effects?



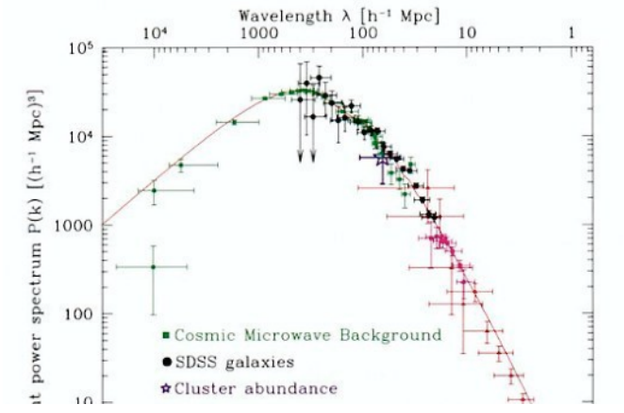
e.g. Larson ‘74

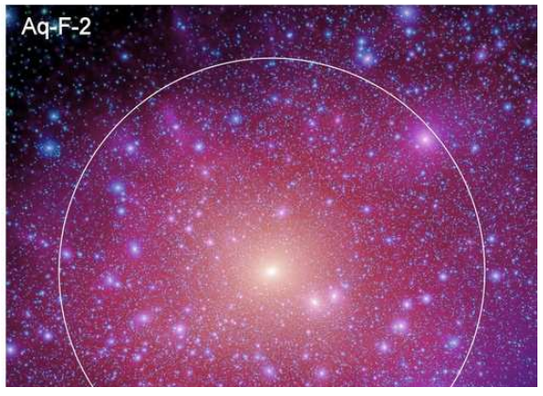
Diagram of a column of an idealised disk (not a resimulation)



Di Cintio, Brook et al. 2014

LCDM - Turtles all the way down





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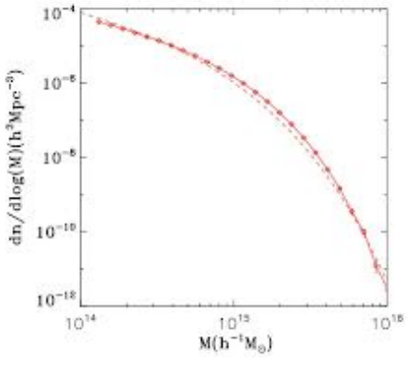

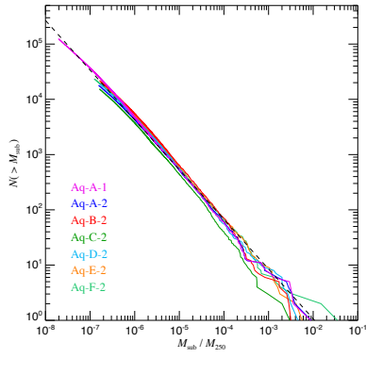

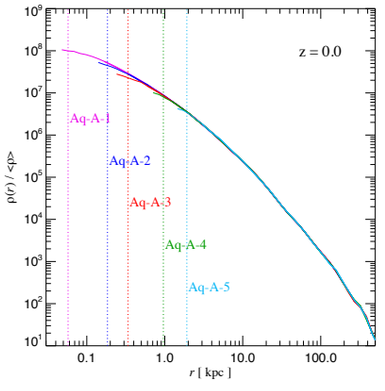

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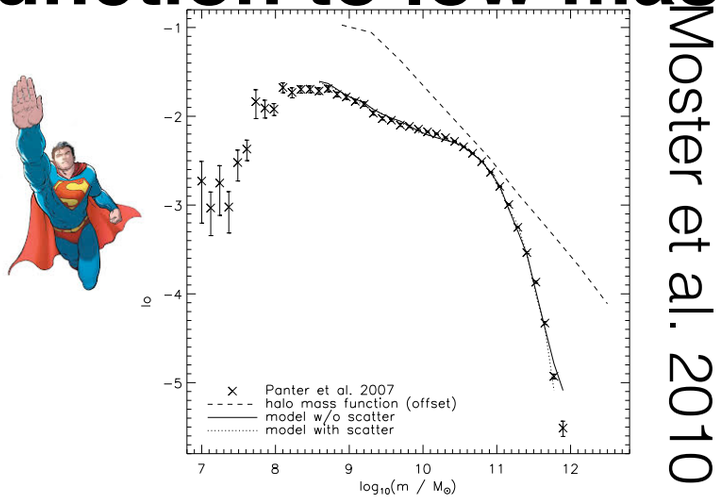

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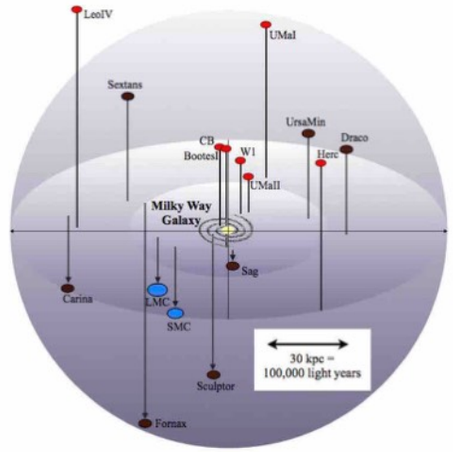

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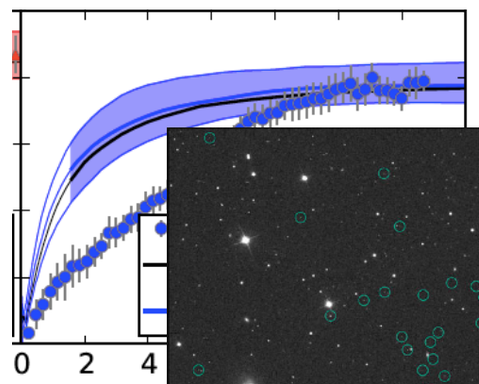
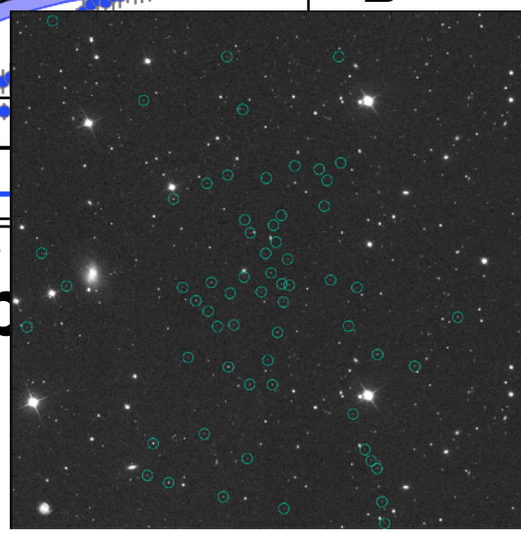


Oman

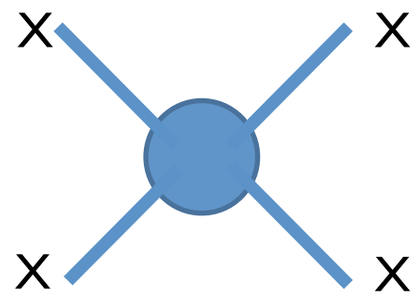
cusp



MITP

Peter Creasey UCR

Self interacting dark matter (SIDM) overview



- Particle interactions between dark matter particles, modelled as being elastic with some cross-section

$\sigma_T/m_\chi\,(\mathrm{cm}^2\ \mathrm{g}^{-1})$

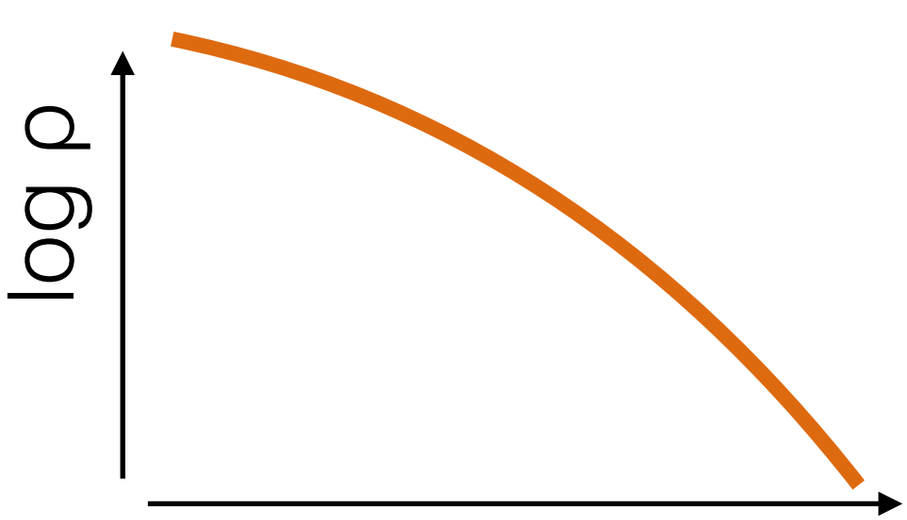
- Elastic collisions evolve the phase space distribution towards a Gaussian (M-B) or the continuum approximation if you're a fluid dynamicist (more on this later)

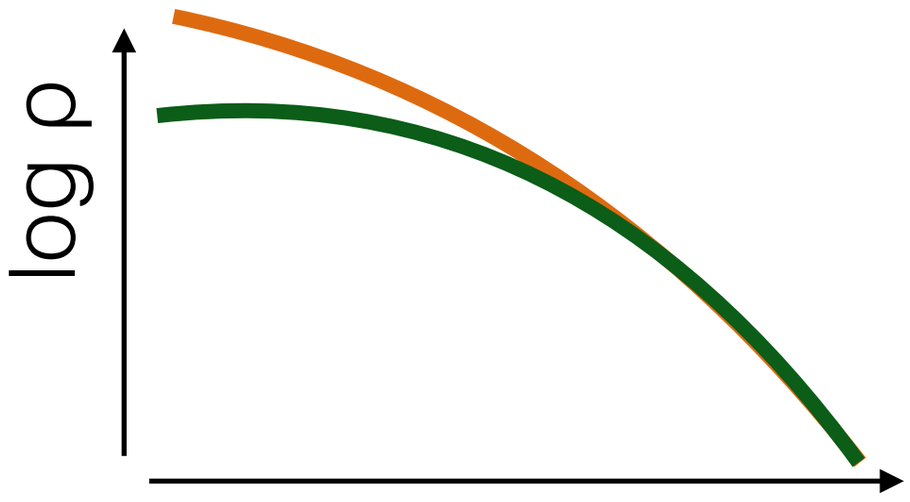
- This process is most effective in regions of higher density and velocity dispersion, (e.g. centres of halos, higher redshift)

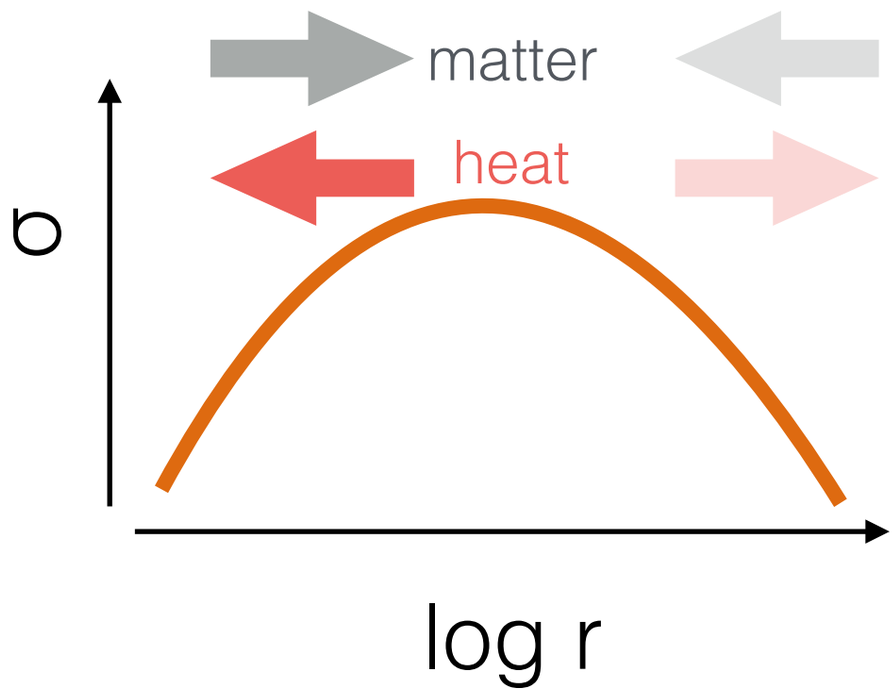
- Also velocity dependence (e.g. Loeb & Weiner 2011) and consequently angular dependent scattering

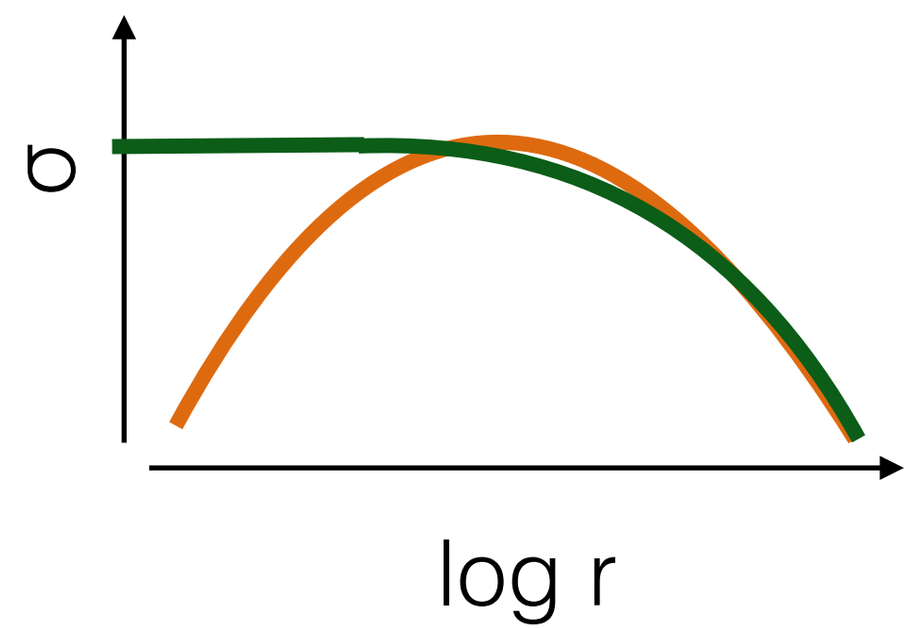
Primer on SIDM effects on halos

Particle interactions between dark matter particles, modelled as being elastic with some cross-section σ_T/m_χ (cm^2 g^{-1})

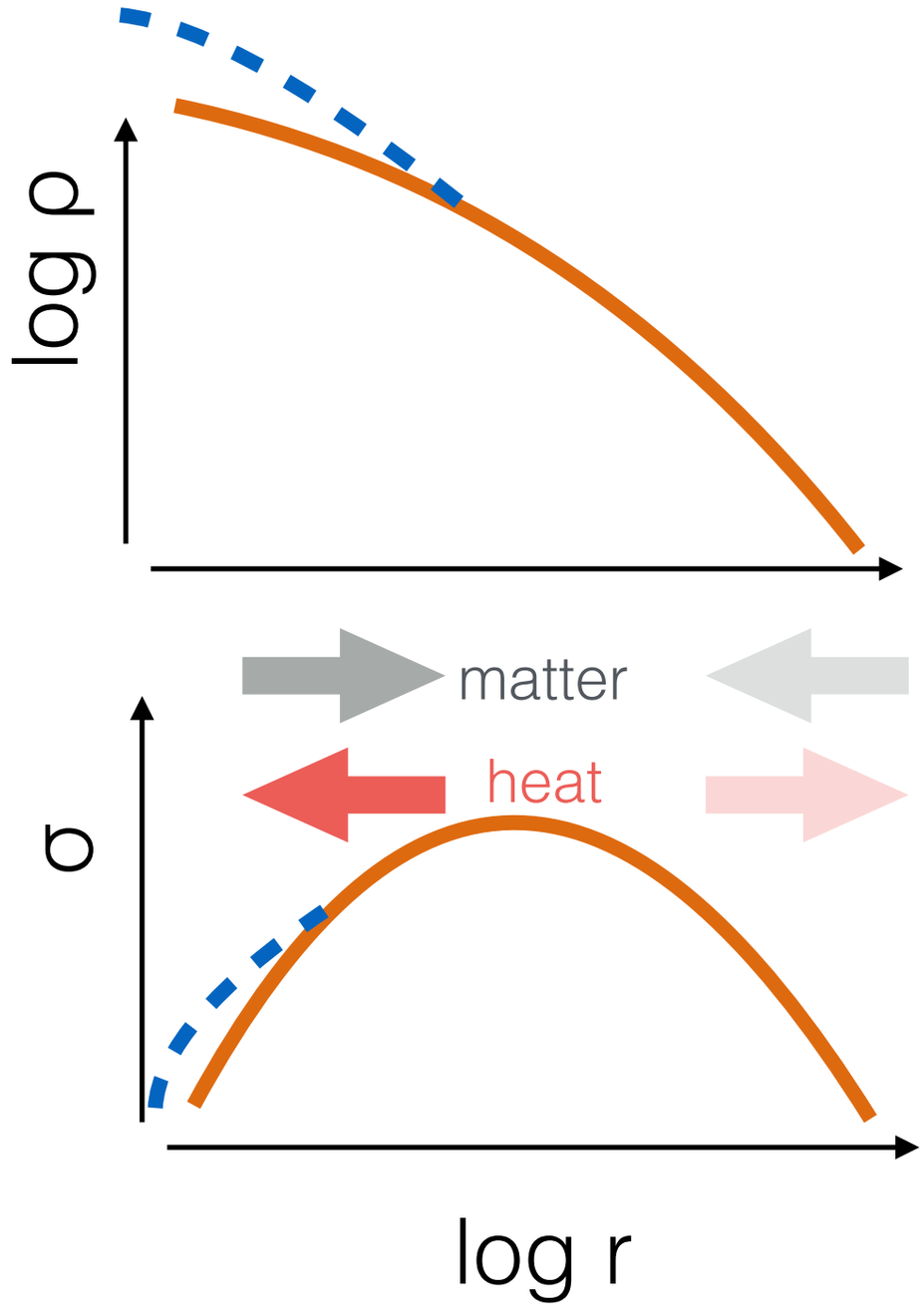


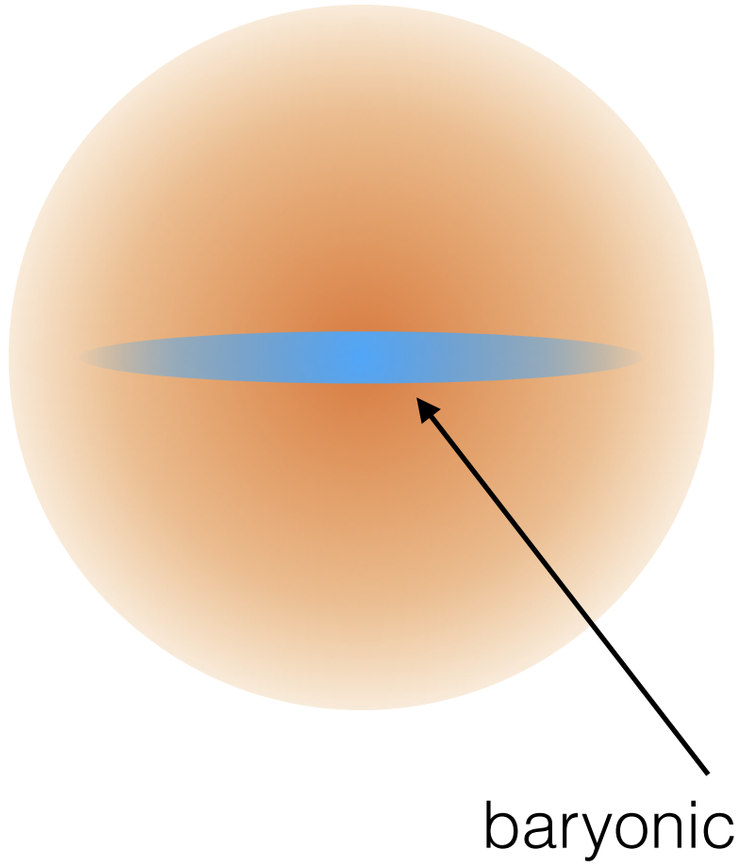




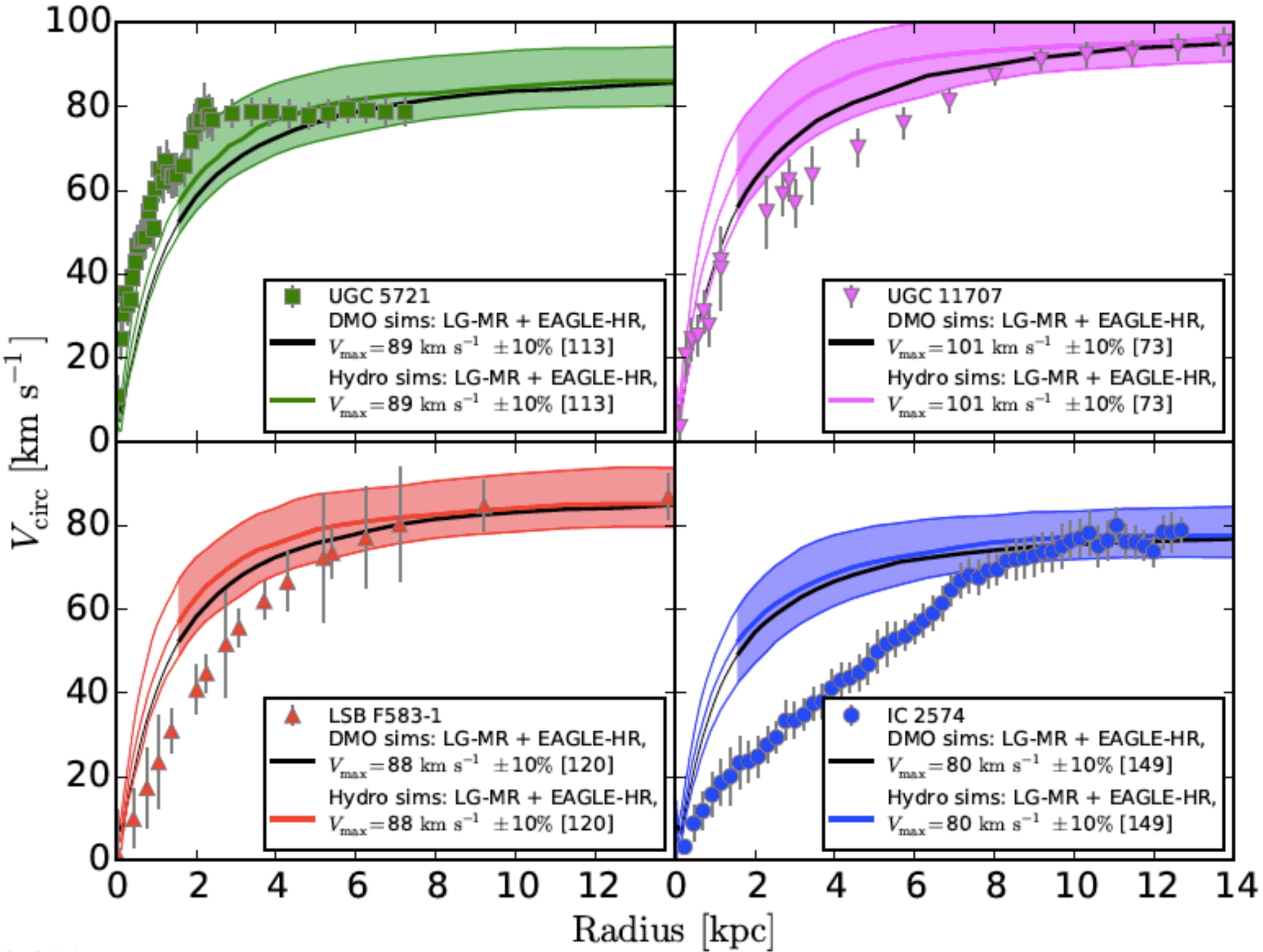


SIDM + baryons



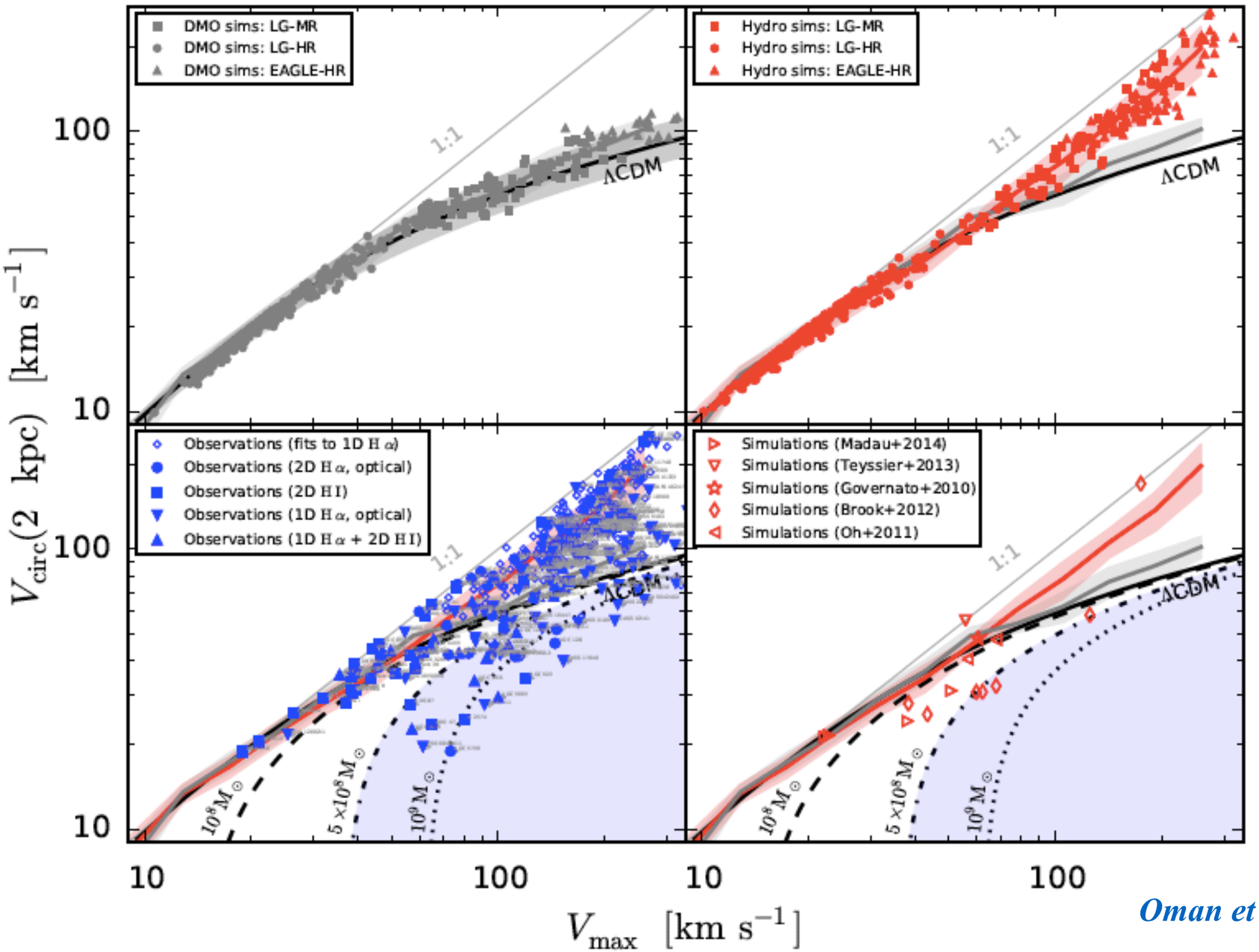


Unexpected diversity on the rotation curves of dwarfs



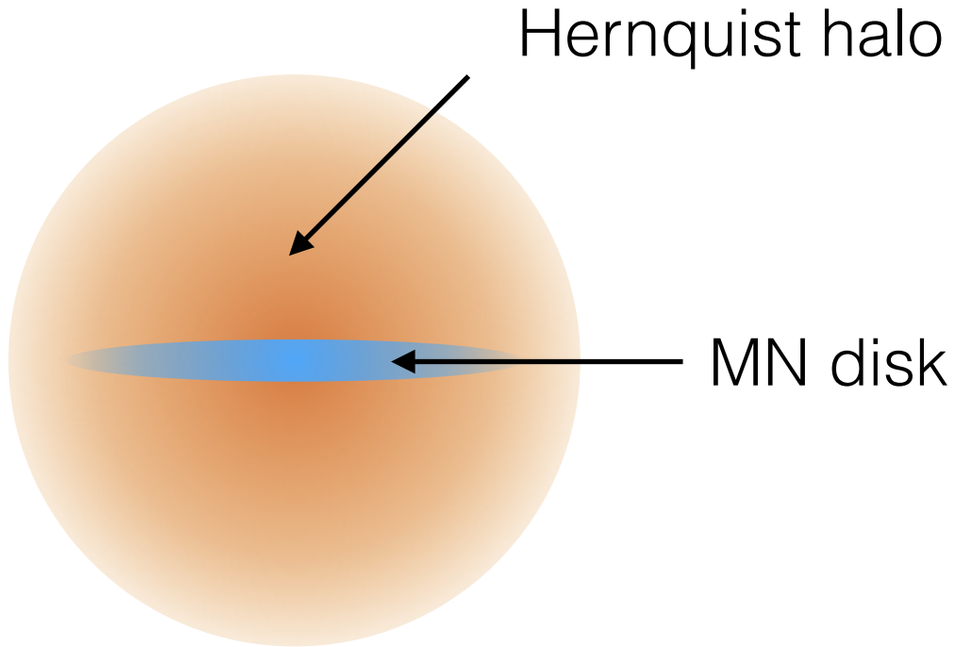
Oman et al. 2015

Unexpected diversity on the rotation curves of dwarfs



Oman et al. 2015

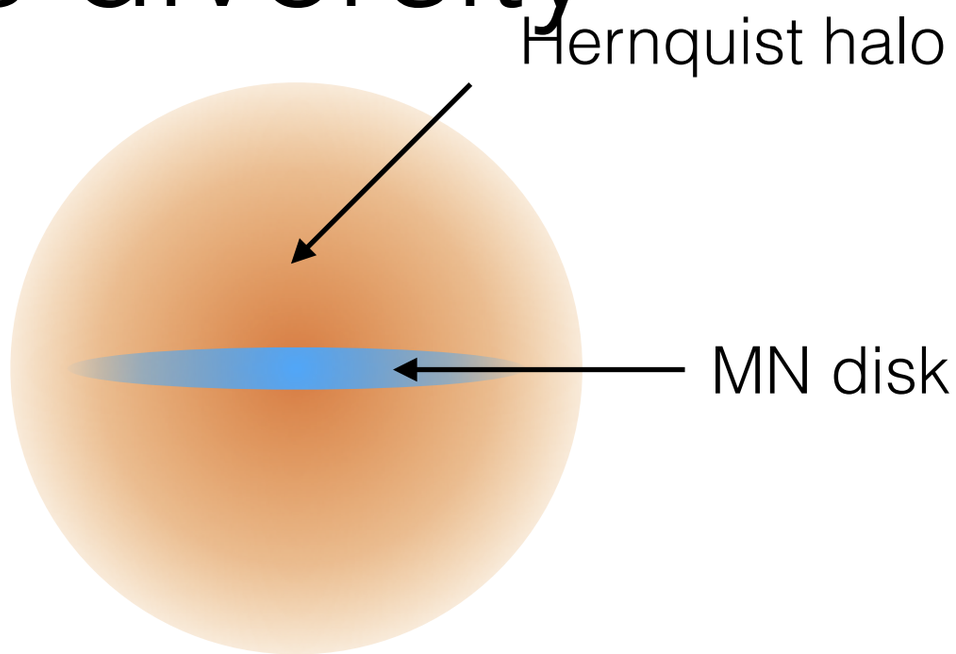
Isolated galaxy simulations



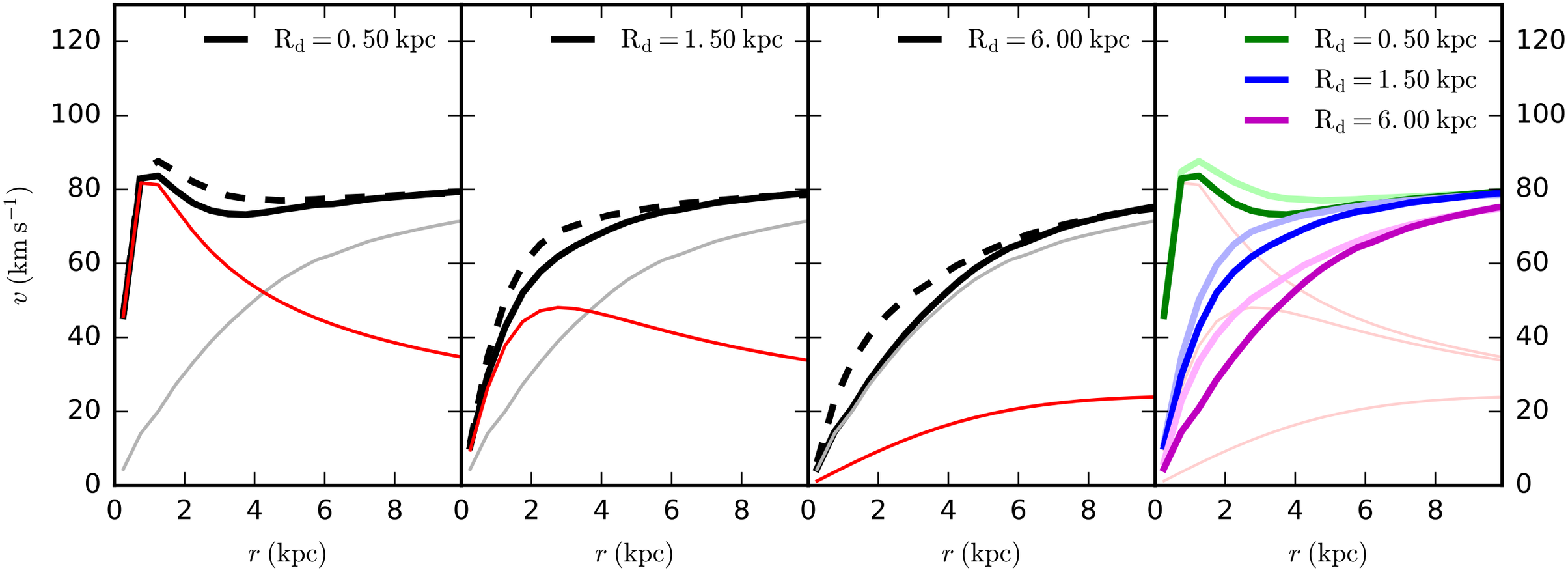
- Baryons removed and replaced with static Miyamoto-Nagai potential (avoid instabilities in baryonic disk with Hubble time too may dynamical times for a dwarf)

- M. Vogelsberger's SIDM code for 10 Gyr to see what happens…

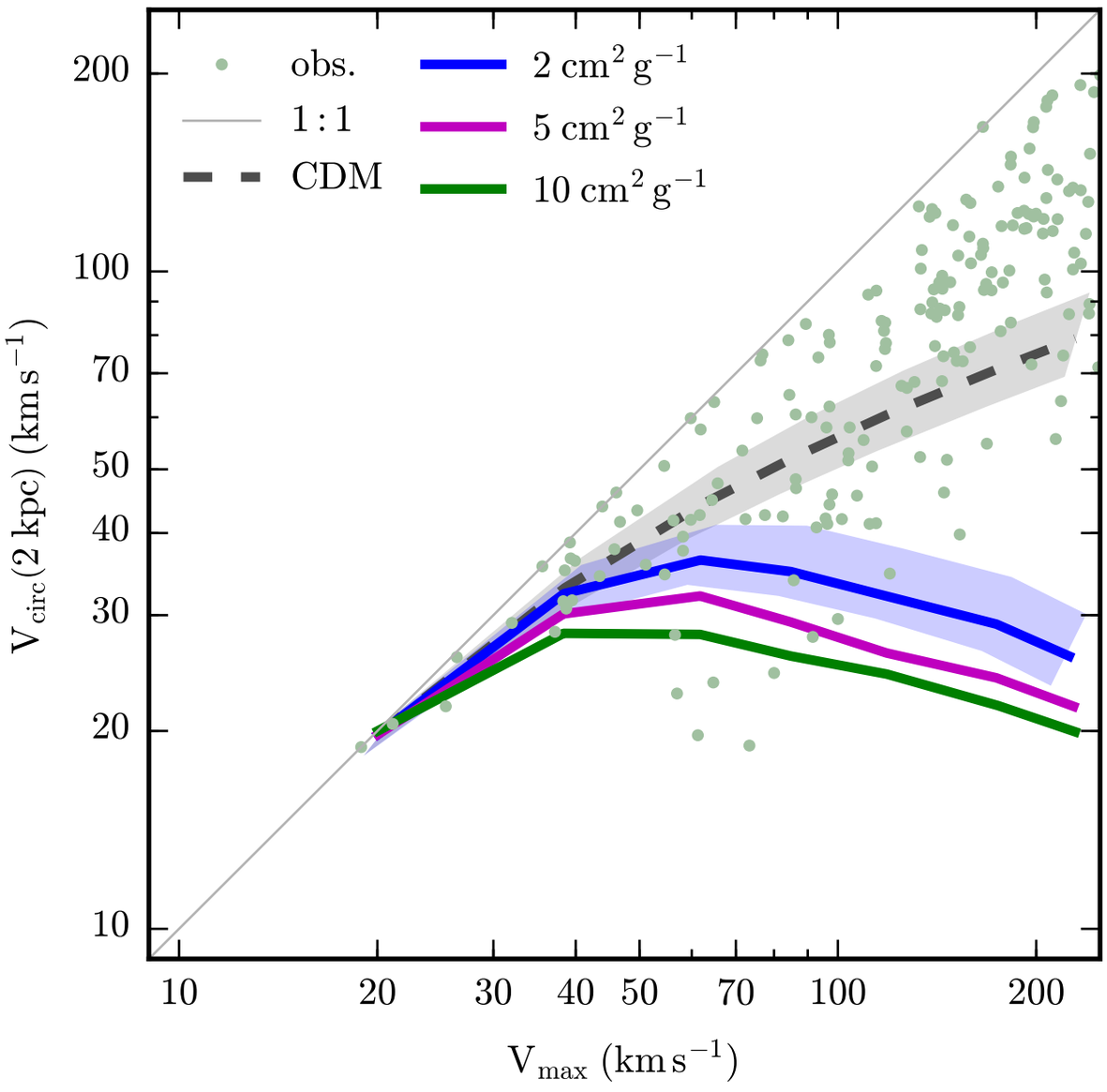
SIDM+baryons diversity



σ_T/m_χ =2 cm^2 g^{-1}



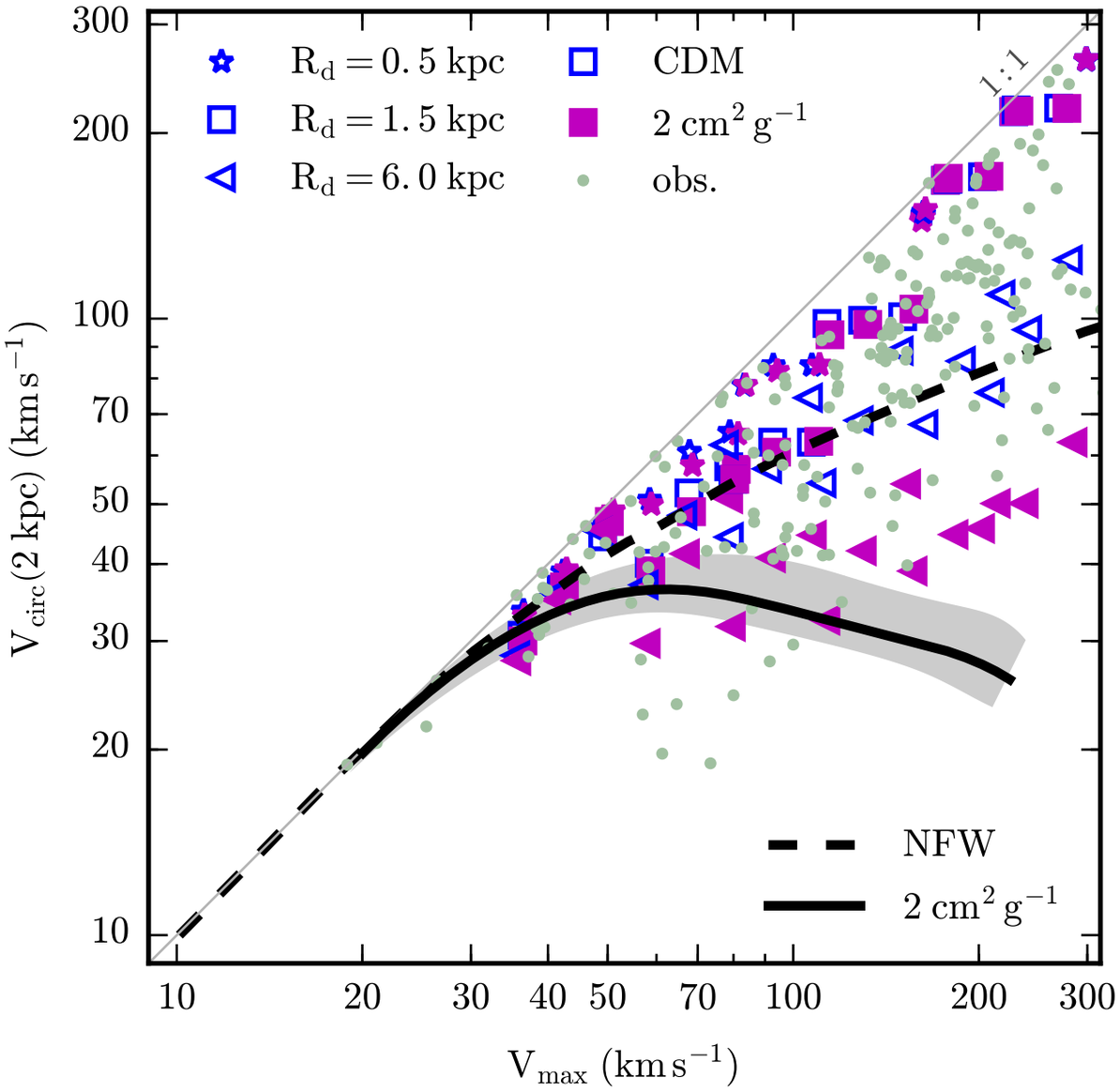
SIDM diversity



- DM only

SIDM diversity

- Take halos with concentrations sampled from mass-conc relation (Ludlow 2014)
- Realistic disk masses (abundance matching) in gas and stars,
- Sizes 0.5-6 kpc to span observables, (later resampled onto observed Shen ’03 relations)
- Disk size and halo concentration assumed to be independent



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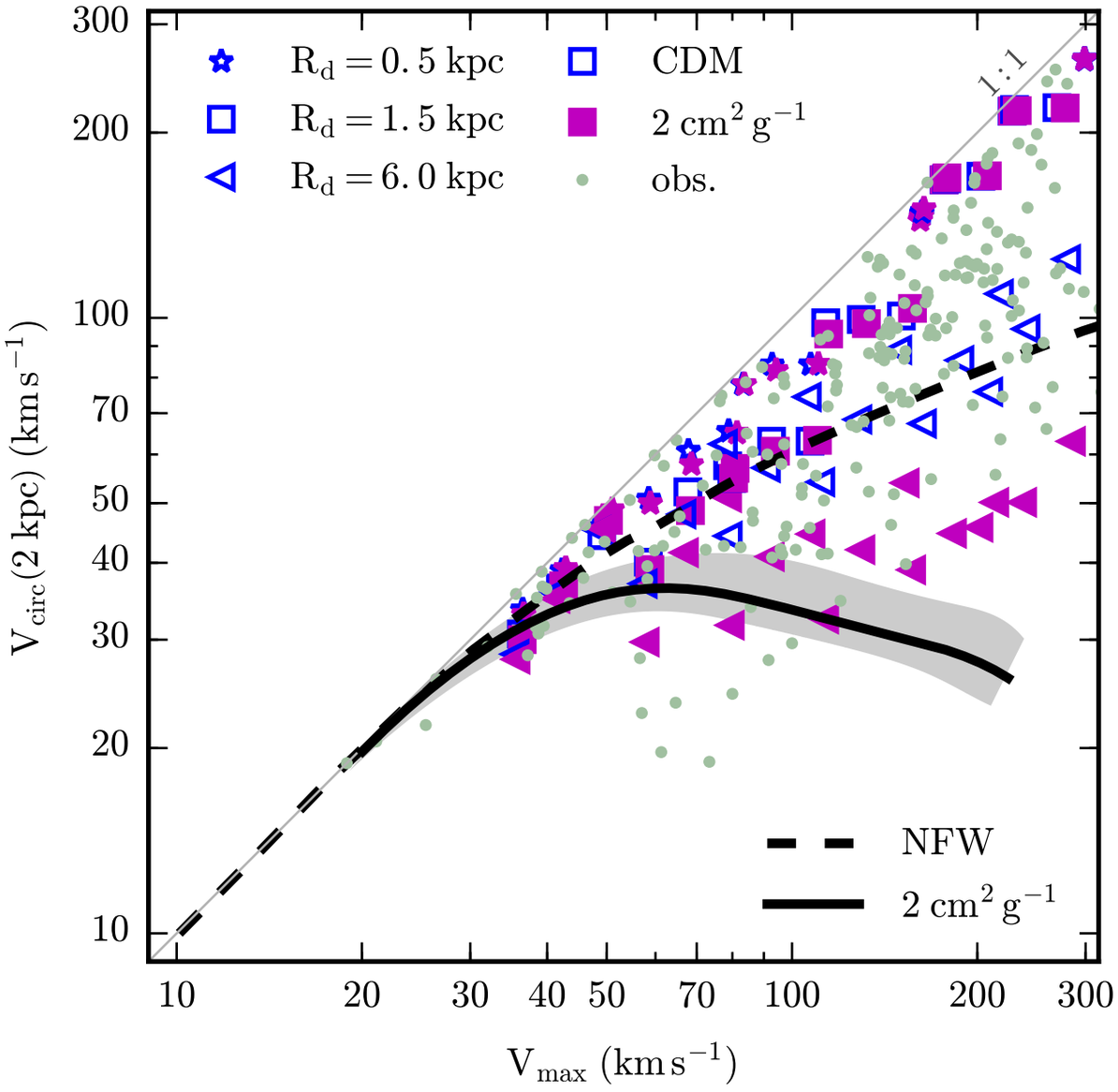
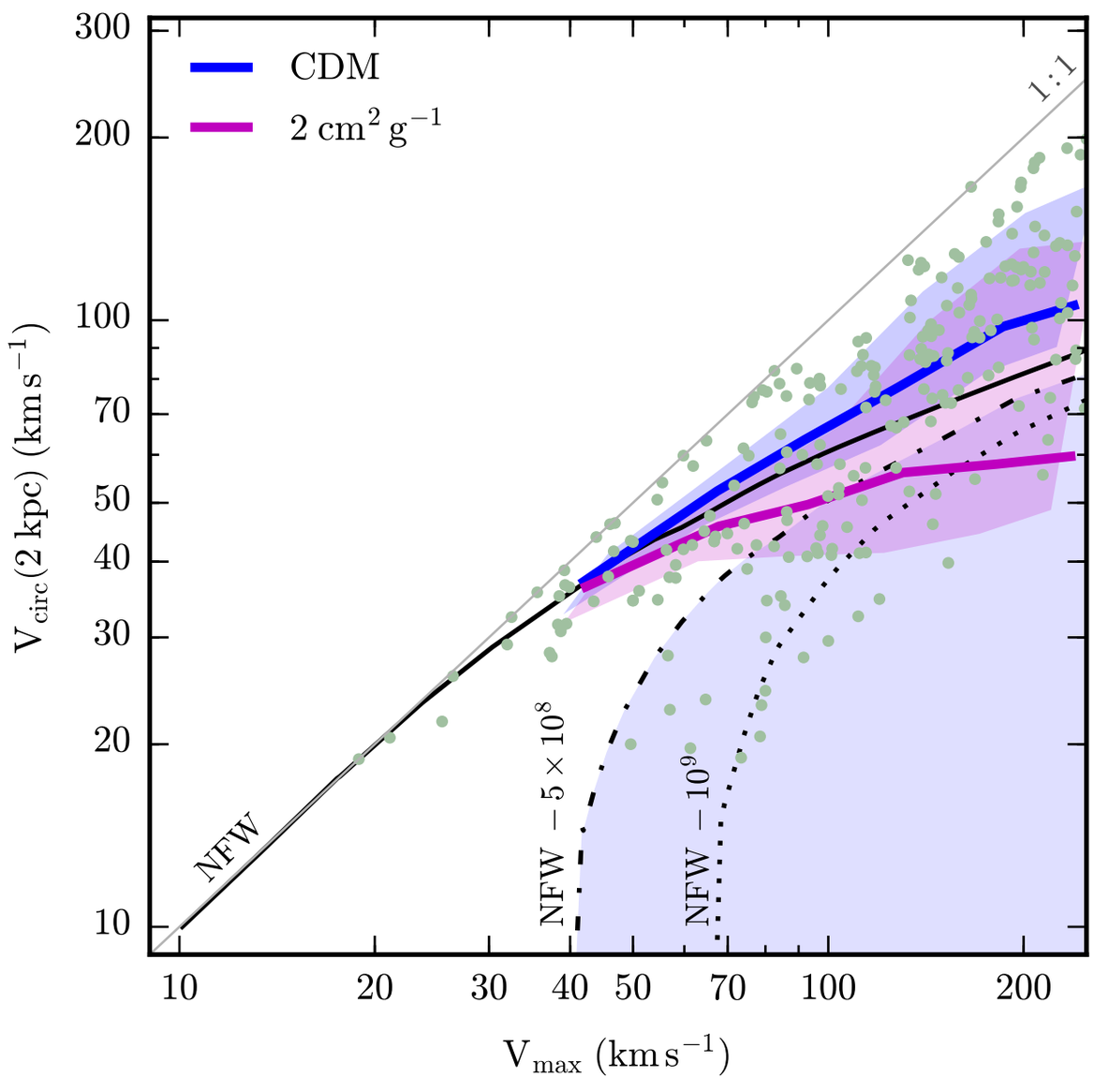
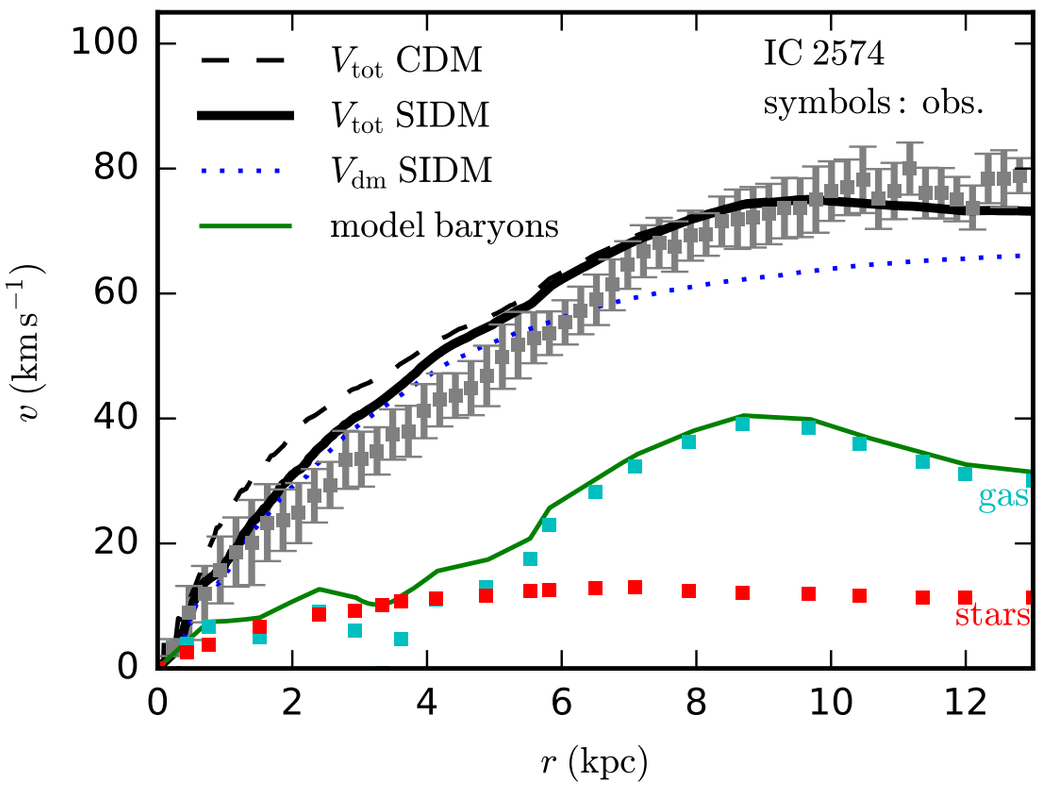
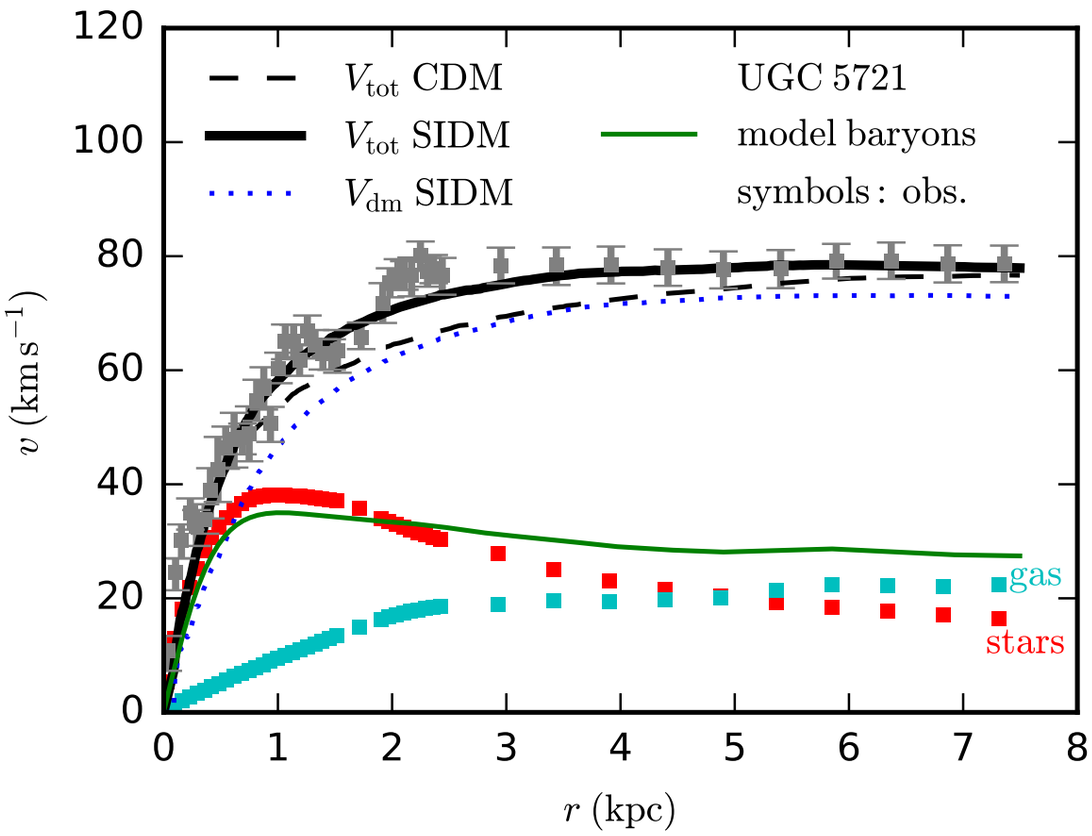


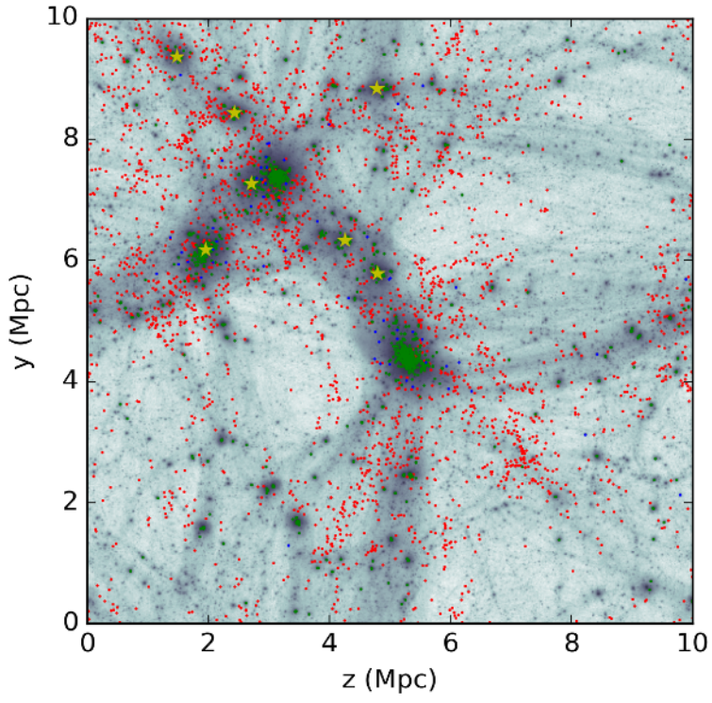


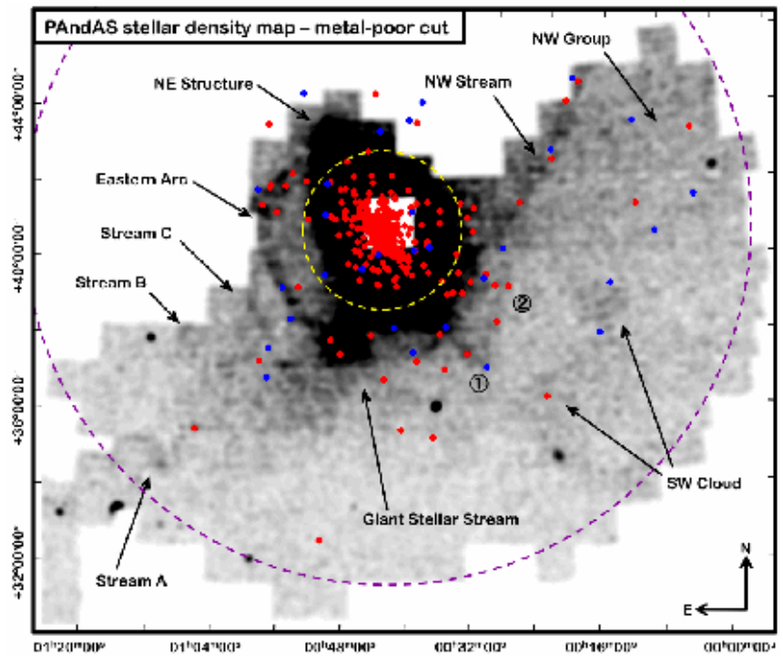
Individual dwarfs

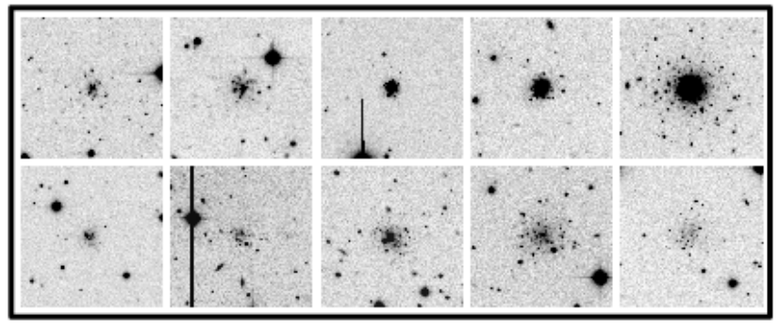




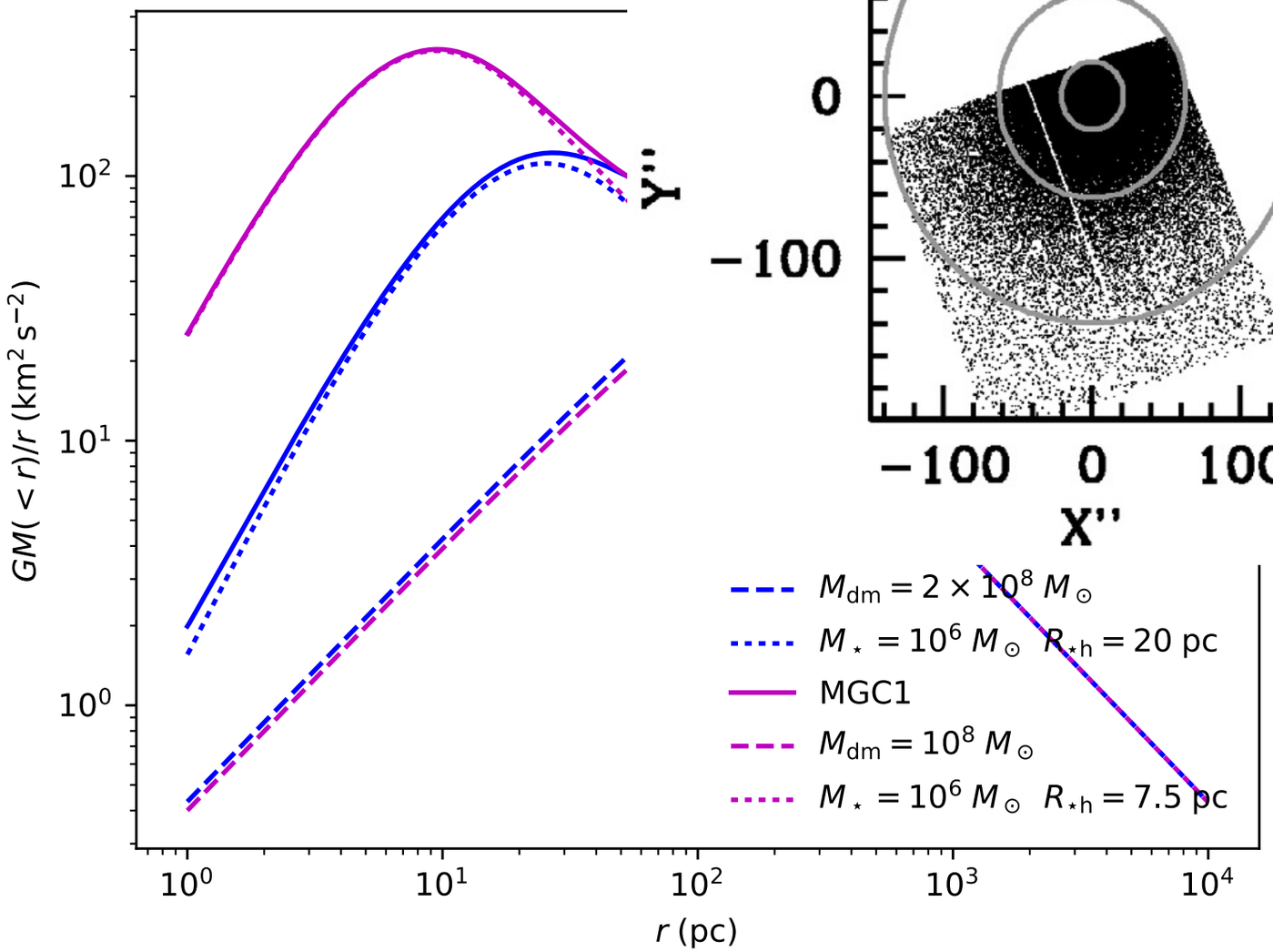
Part II - Old Metal Poor Globular Clusters in LCDM

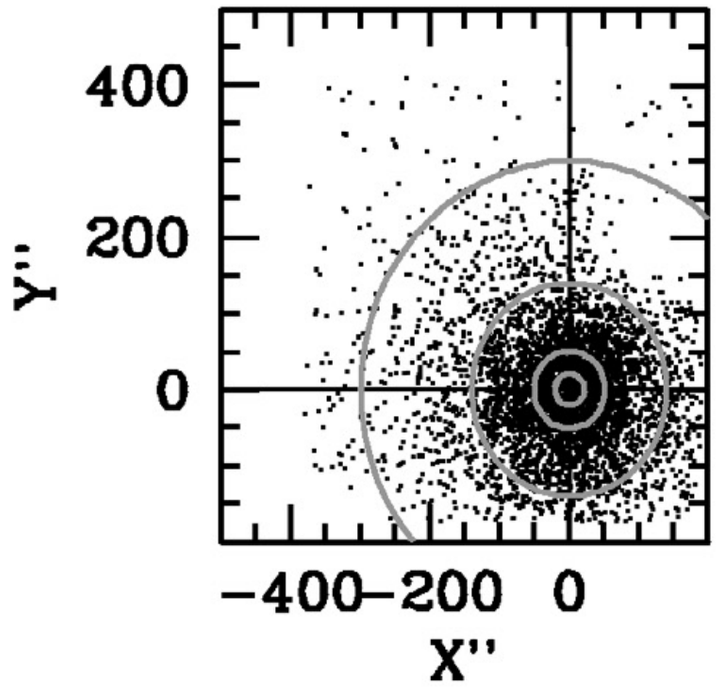






GCs are not observed to have any dark matter





Bellazzini 2007 (HST & S05) NGC2419

91 kpc away (1” = 0.44 pc)

- Theoretical equipartition of stellar and dark components around 100 pc

- c.f. Conroy, Loeb and Spergel ’11, but also Ibata et al. ‘13

Interest in GC DM -> Implications for formation of old metal-poor GCs

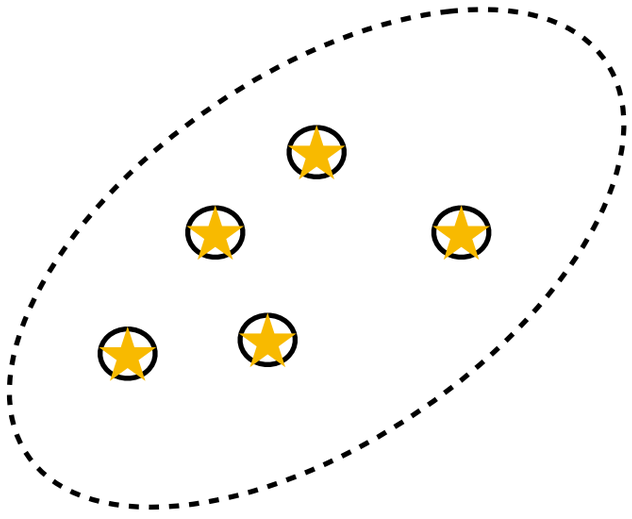
Age

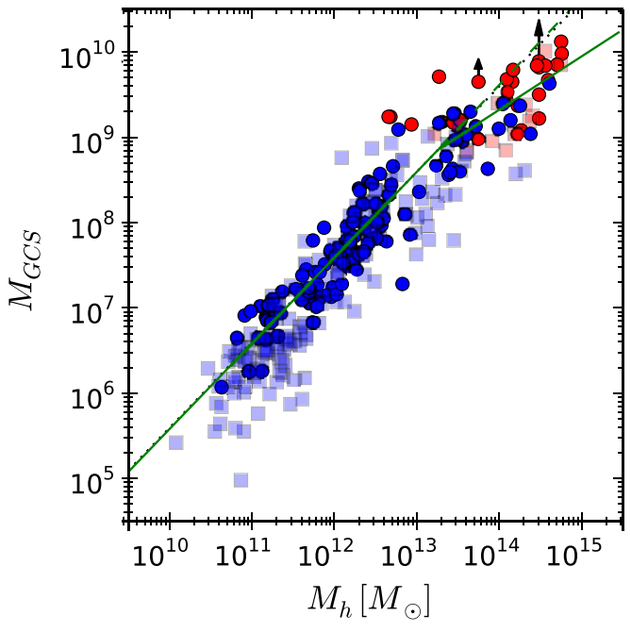
Early

Late

Form **early** at centres of their **own halos** (e.g. age~z_reion, Peebles ’84, fall into galaxies, now mostly **subhalos**)

Form **late** in some galactic process, not associated to DM

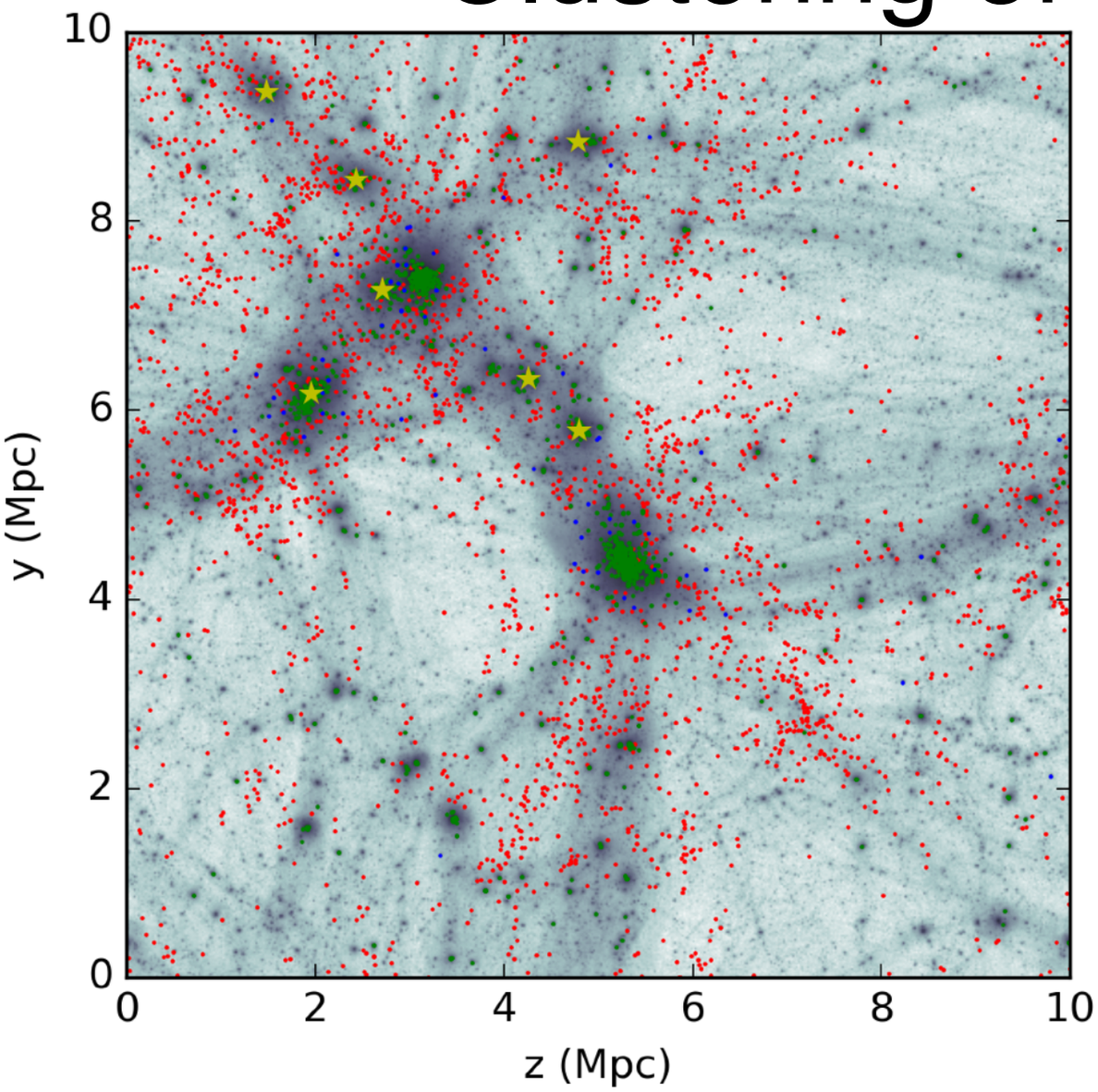




Hudson, Harris & Harris ‘14

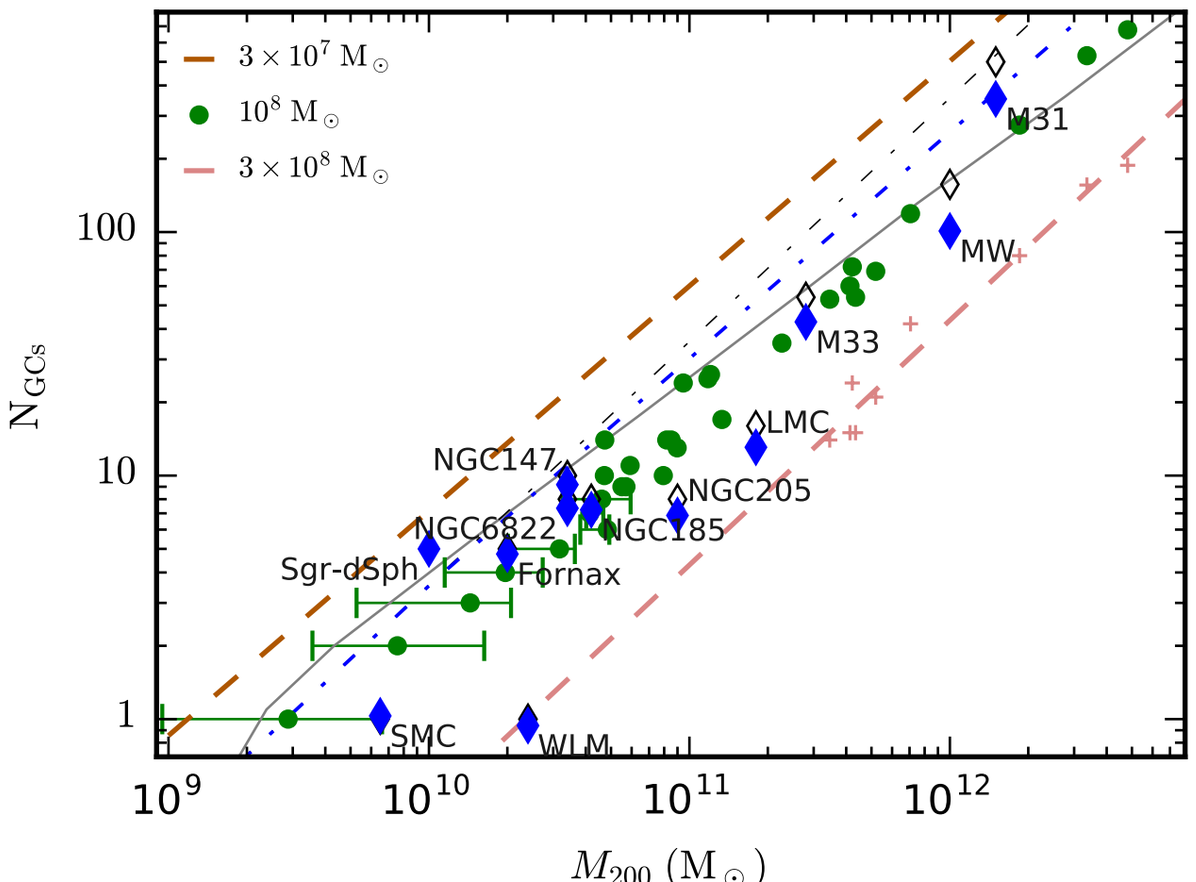
- M_{GC} ~= 4x10^{-5} M_{200}
- or for metal poor only ~= 2.5-3x10^{-5} M_{200}
- (see also MBK ’17, El Badry, Quataert et al. ’18)

Clustering of halos at high z

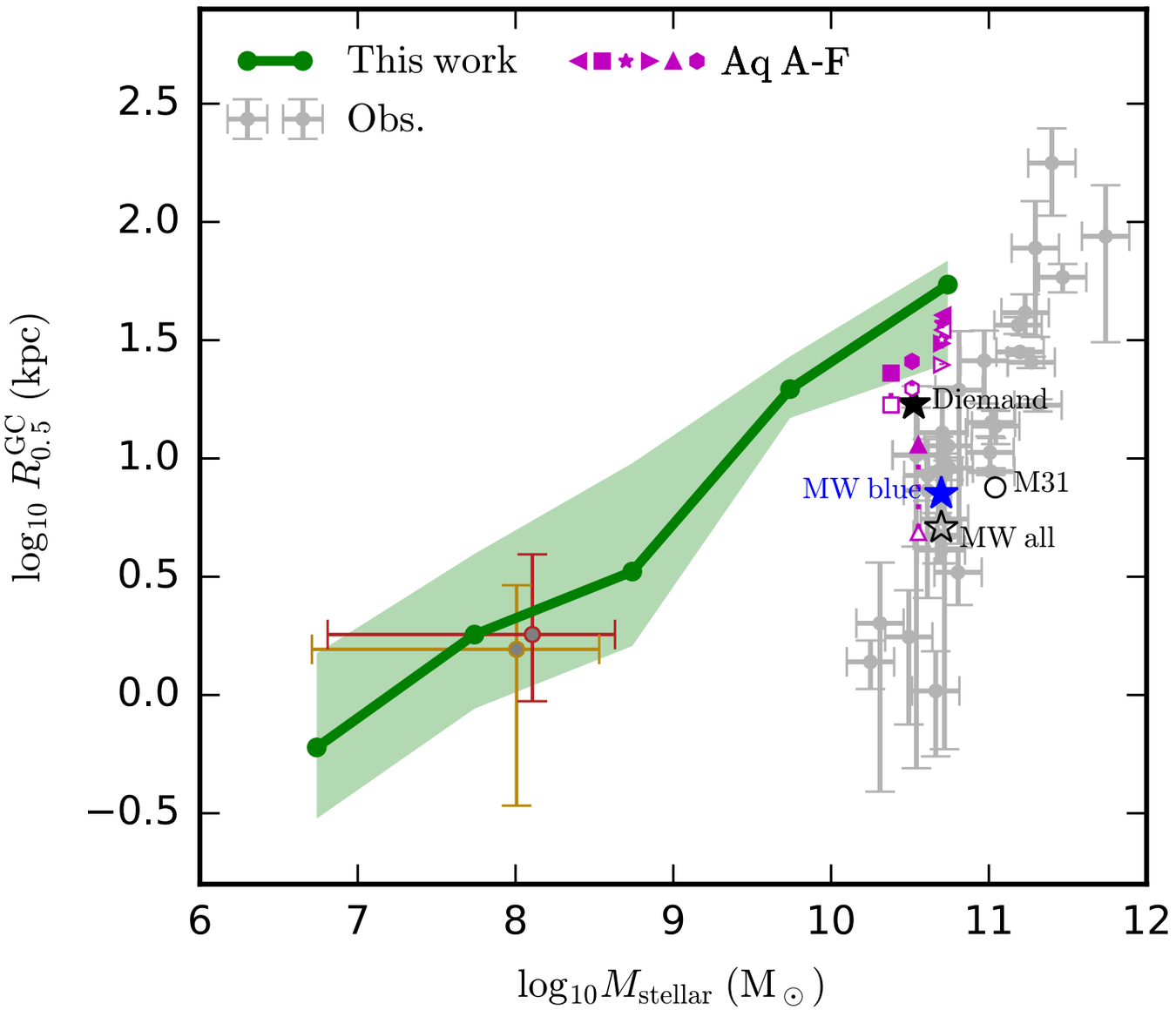


Creasey, Sales, et al. in prep., see also Diemand & Moore ’05, Bekki ’05, Boylan Kolchin ‘17

- Paint in GCs
- Halos around 10^8 Msun at z~10 give you the right number density



Infalling halos not compact enough at z=0?

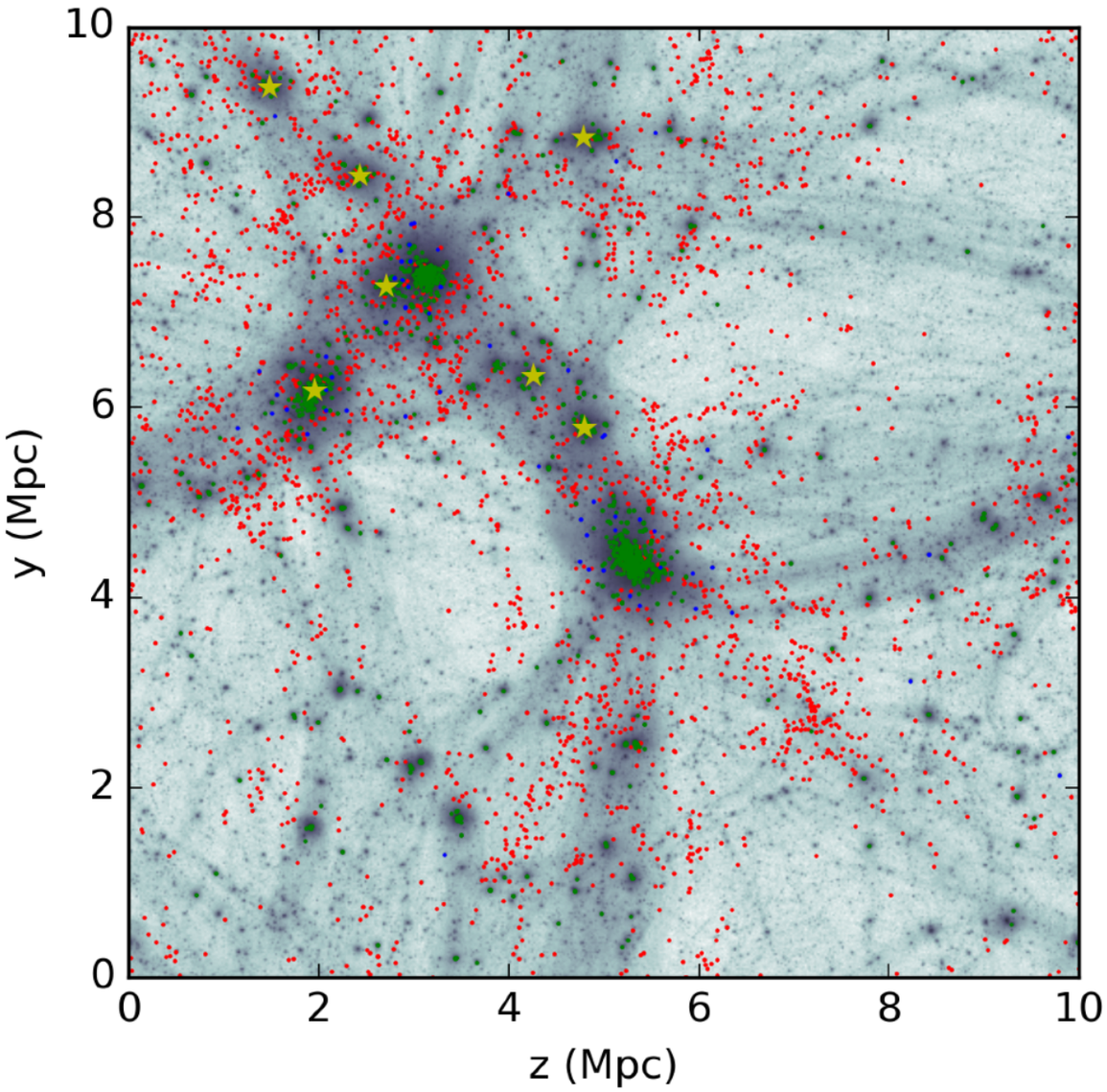


- Median GC radius vs stellar mass
- baryonic contraction reduces tension, stripping increases it

Intergalactic GCs?

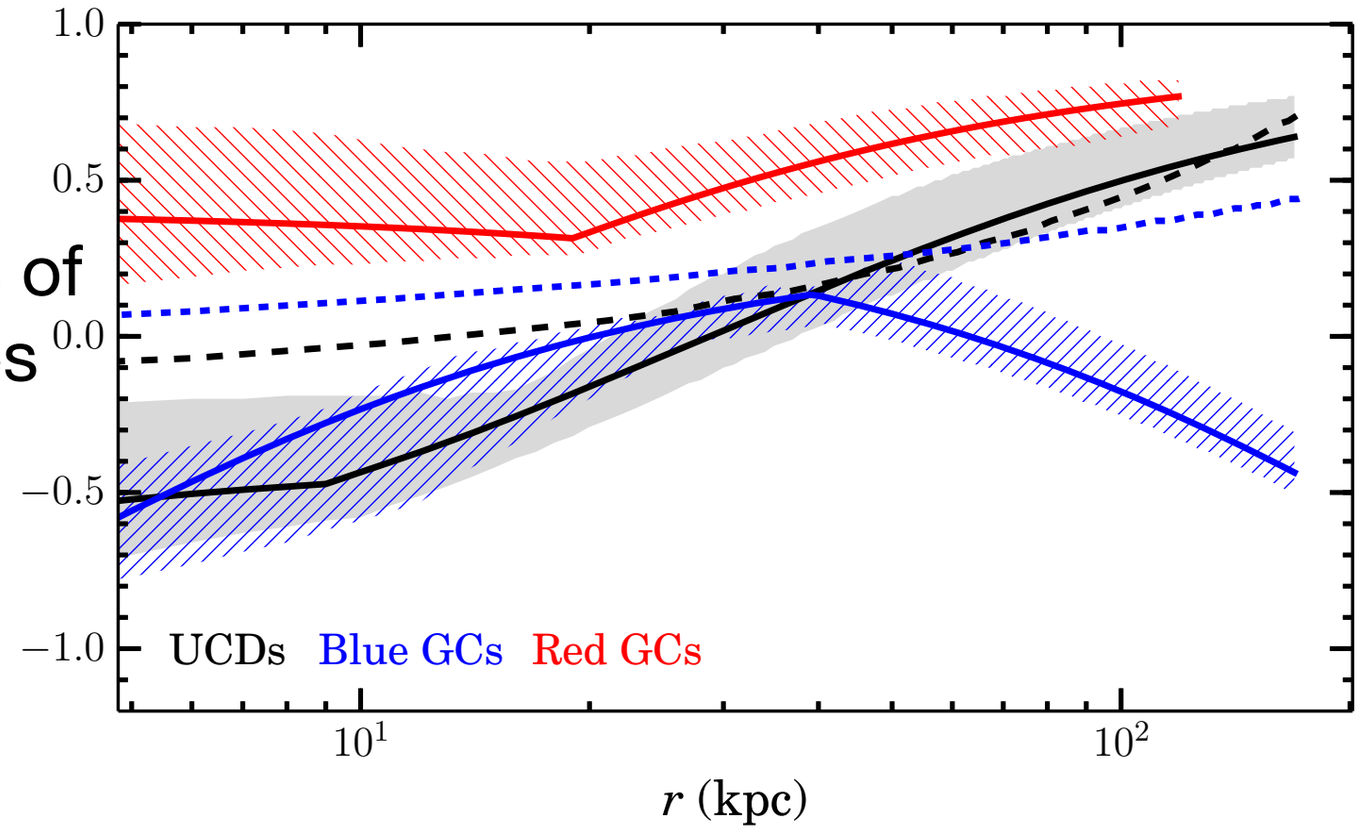
- How many GCs in the LG (say <1 Mpc of the MW) not associated with a galaxy?

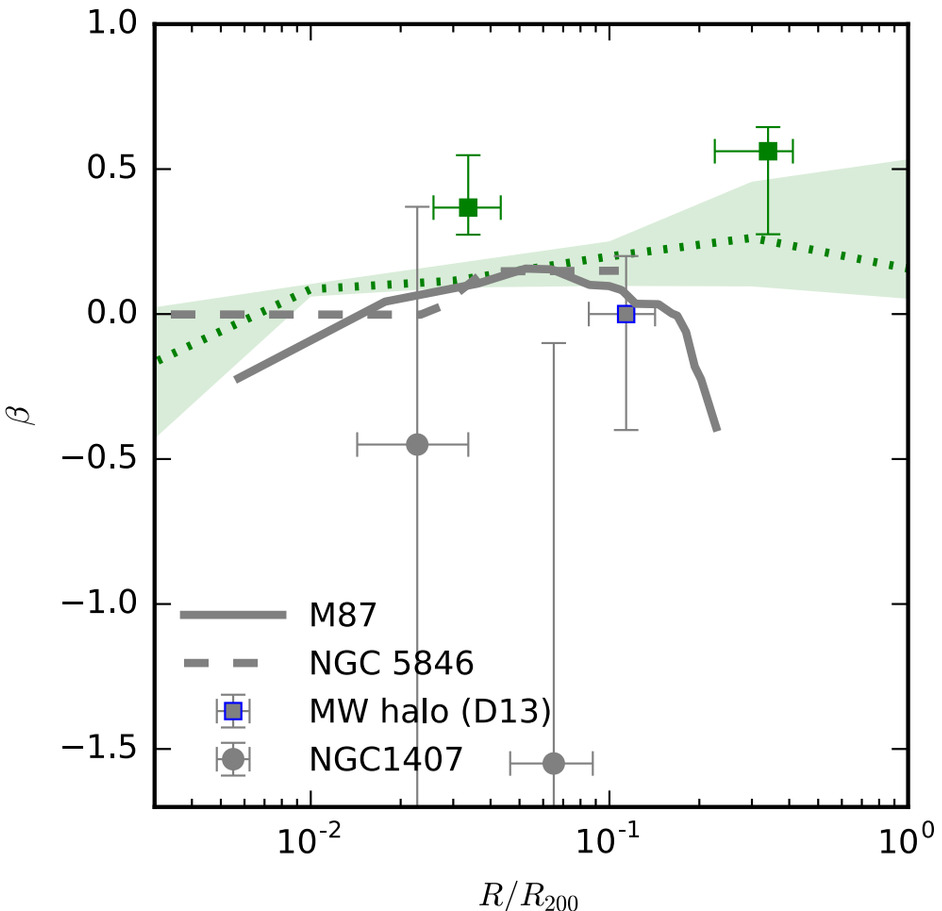
- (given in SDSS we see none, e.g. di Tullio Zinn & Zinn ’15)



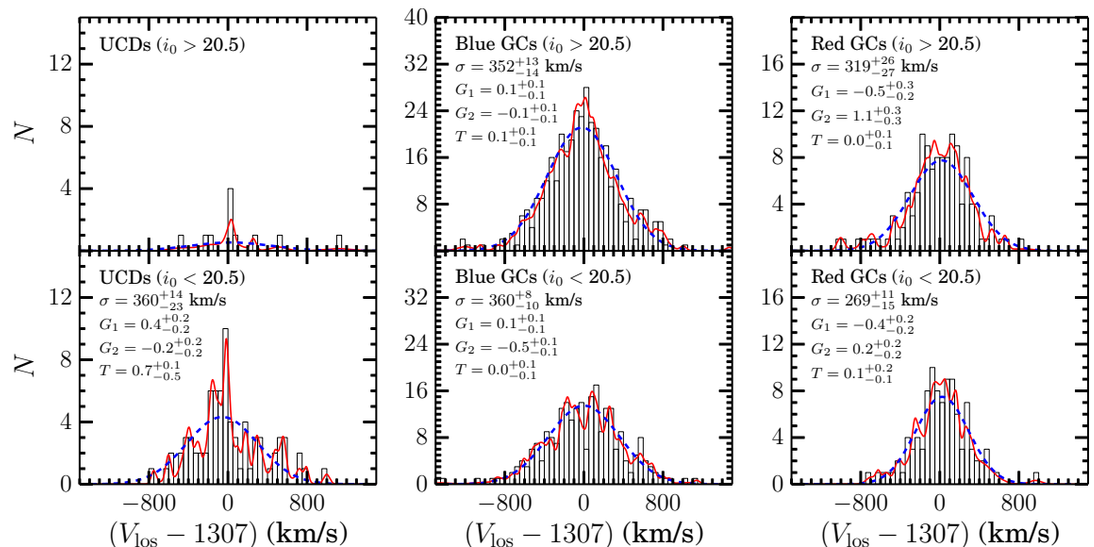
Orbital velocity anisotropies

- Kurtosis measurements of the LOS vels. of the GCs around M87





Zhang, Peng et al. 2015



Conclusions:

Dwarf galaxy cores & cusps

- Dwarfs also have quite diverse rotation curves (some more core-like, but some cusp-like also).

- Significant scatter in the central (2kpc) densities of dwarfs seems hard to achieve in hydro sims of LCDM (requires moving DM out of cusp)

- SIDM systematically turns cusps into cores. SIDM + baryons can make cores *and* cusps. Works very well at 100 km/s, struggles a bit at 60 km/s.

Globular clusters in their own halos

- Metal poor GC formation in their own DM halos poorly constrained by intergalactic GC counts (field density)

- Median GC distance from the MW seems to exclude *all* metal poor GCs forming in this mechanism (a fraction still possible)

- Velocity anisotropies curious, seems hard to explain with GCs in halos or outside