The Eris Project: the effects of baryons on the subhaloes of MW-like galaxies

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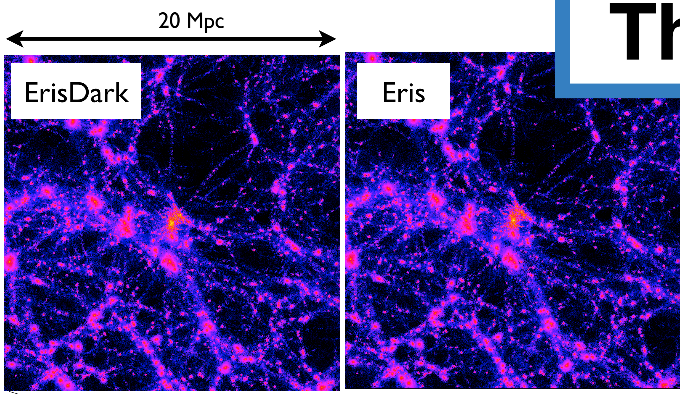
Zoom-in simulation
N-body/SPH: PKDGRAV/GASOLINE
Halo Finder: Amiga Halo Finder

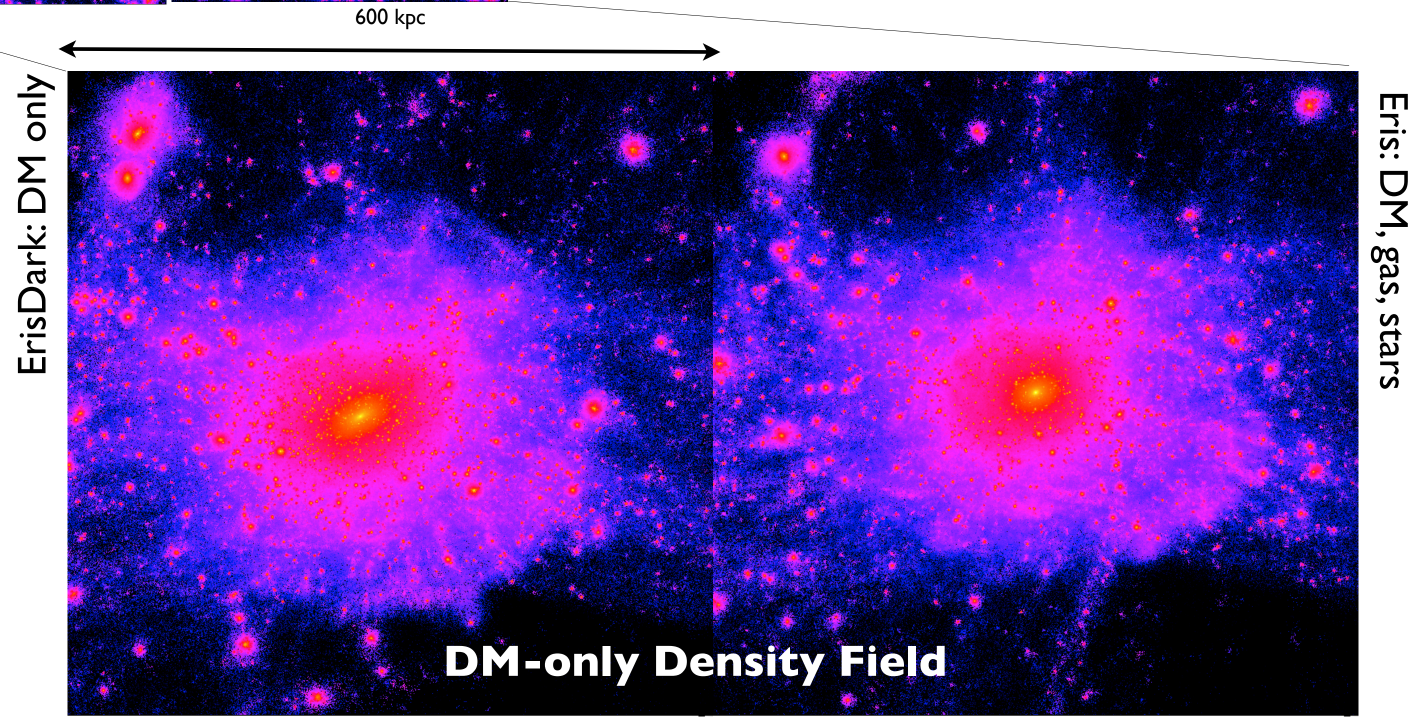
The simulation



Eris Recipe:
(Guedes et al 2011, ApJ 742, 76)

- radiative cooling
  (Compton, atomic, low T metallicity-dependent)
- heating from cosmic UV
  (~ Haardt & Madau 1996)
- Supernova feedback (ϵ_{SN} = 0.8)
  (Stinson et al. 2006)
- Star Formation:
  - threshold n_{SF} = 5 atoms/cm3
  - efficiency ϵ_{SF} = 0.1
  - IMF: Kroupa et al. 1993

NO AGN feedback

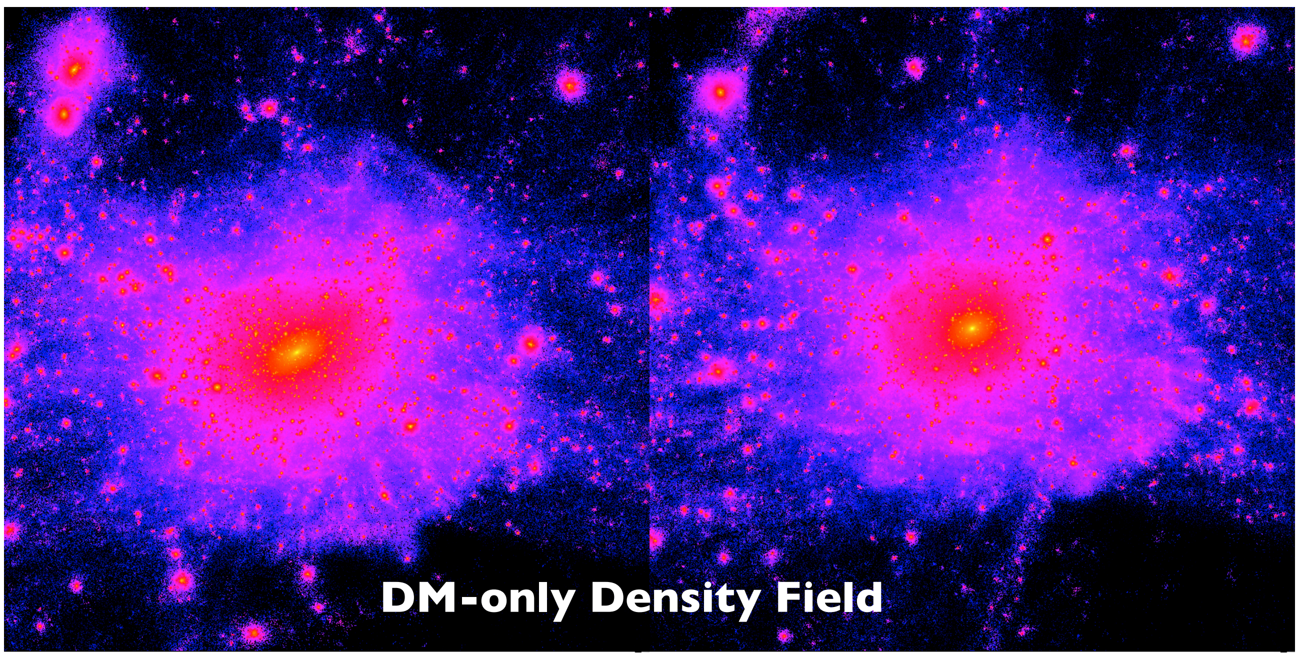


Eris MWs

MW Halo	$M_{\rm vir}$ (M$_\odot$)	$R_{\rm vir}$ (kpc)	Vmax (km/s)	$N_{\rm TOT}$	$M_{\rm DM}$ (M$_\odot$)	$M_{\rm GAS}$ (M$_\odot$)	$M_{\rm STAR}$ (M$_\odot$)
ErisDark	9.1×10^{11}	247	166	7.55×10^{6}	9.1×10^{11}	0	0
Eris	7.8×10^{11}	235	239	1.85×10^{7}	6.9×10^{11}	5.6×10^{10}	3.9×10^{10}

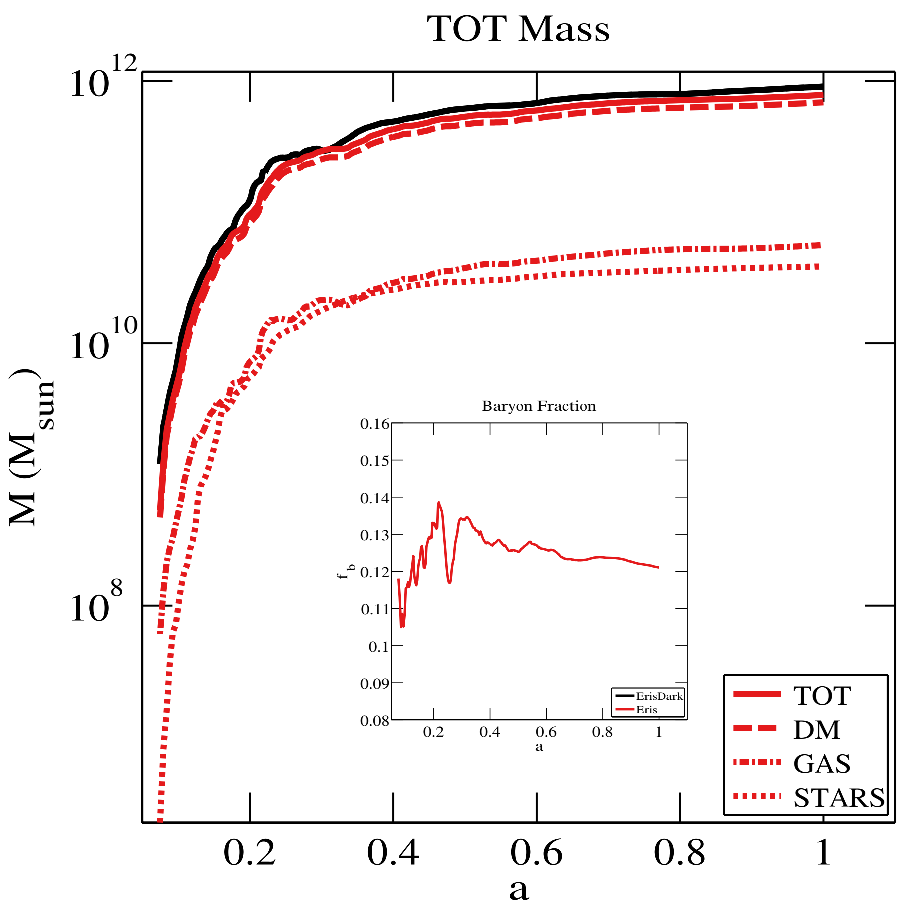
Table 1. Properties of the simulated MW galaxies at $z = 0$

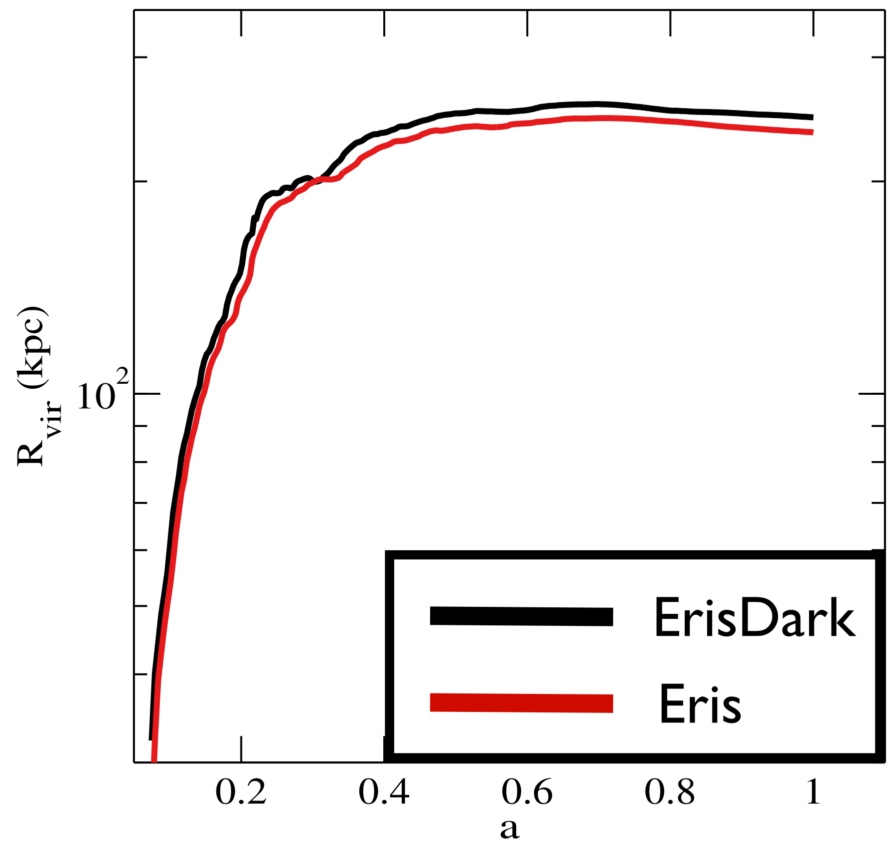
ErisDark: DM only



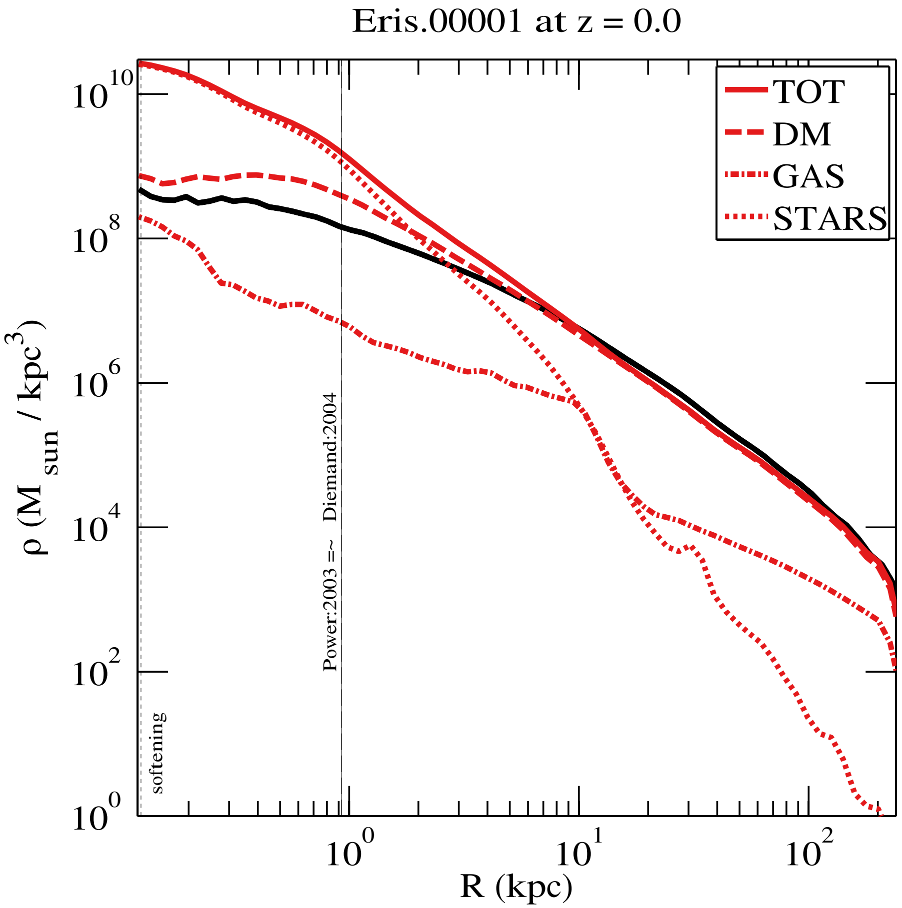
Eris: DM, gas, stars

Eris MWs

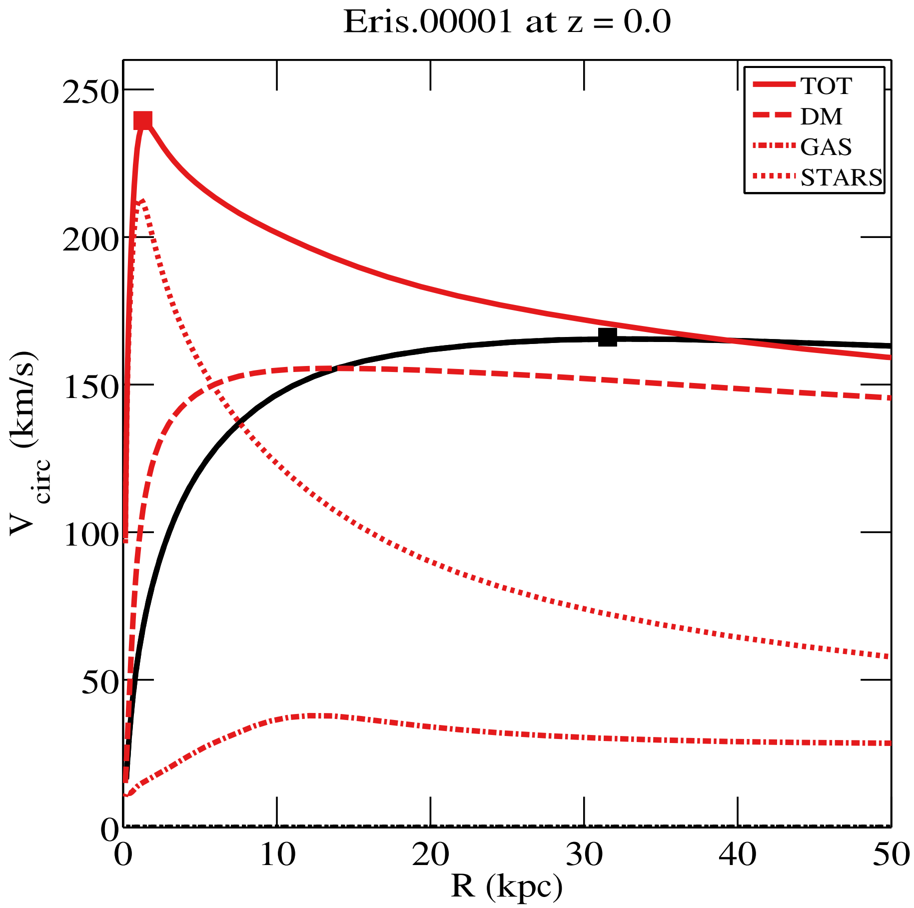

TOT Mass
M (M_sun)
10^12
10^10
10^8
0.2
0.4
0.6
0.8
1
a
Baryon Fraction
f_b
ErisDark
Eris
TOT
DM
GAS
STARS


R_vir (kpc)
10^2
0.2
0.4
0.6
0.8
1
a
ErisDark
Eris

Eris MWs

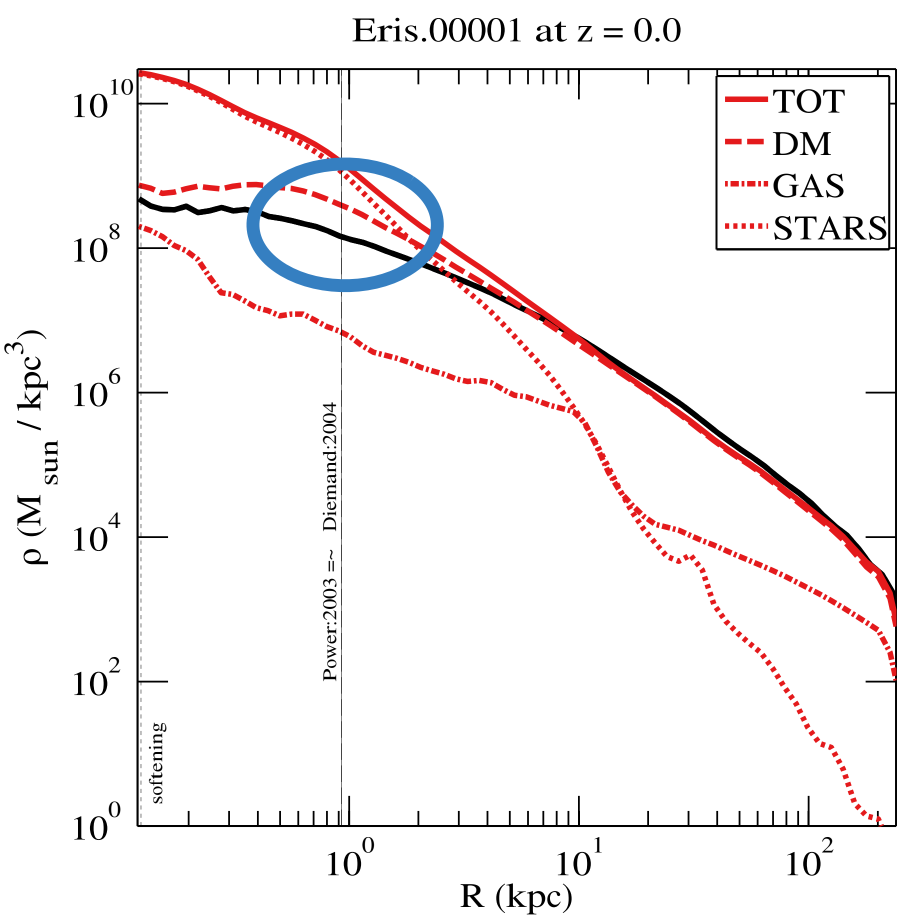


Eris.00001 at z = 0.0
ρ (M sun / kpc^3)
R (kpc)
TOT
DM
GAS
STARS
softening
Power:2003 =~ Diemand:2004

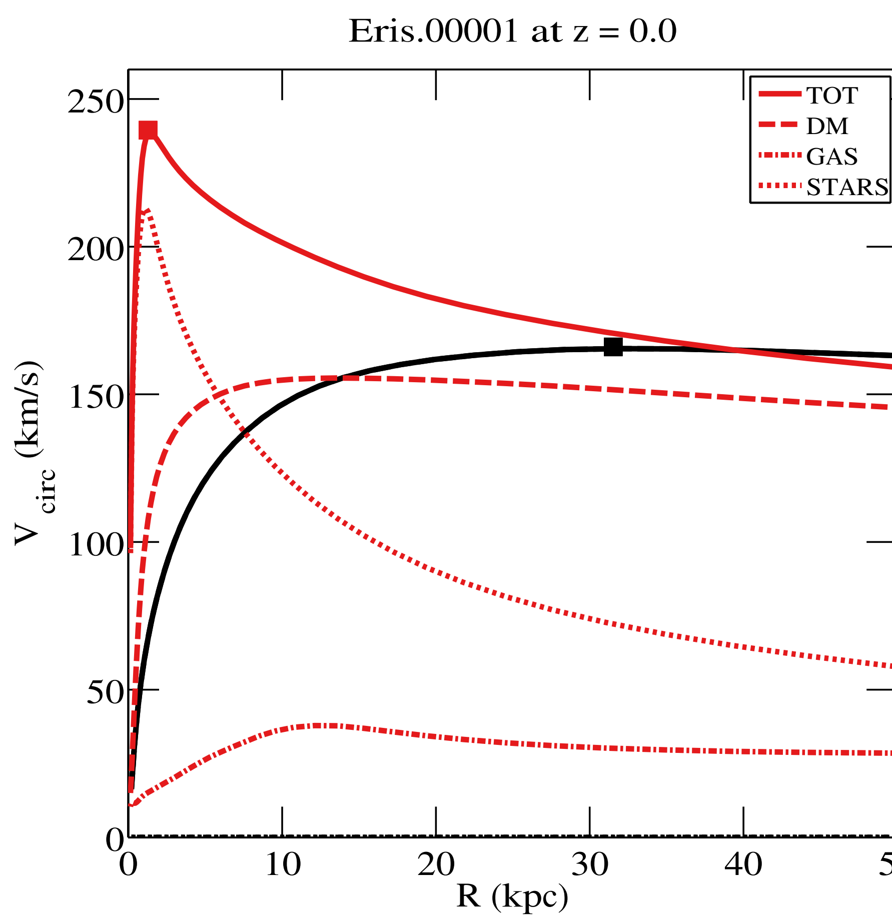


Eris.00001 at z = 0.0
V circ (km/s)
R (kpc)
TOT
DM
GAS
STARS

Eris MWs

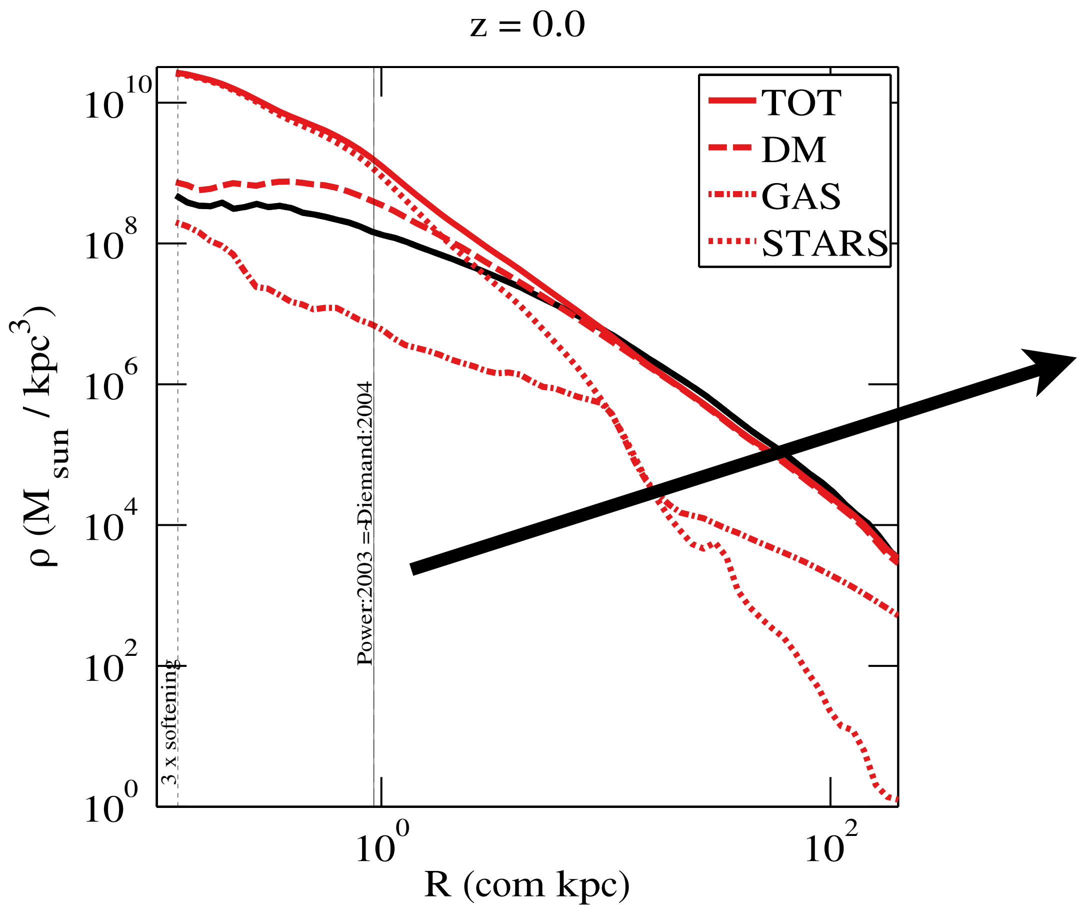


Eris.00001 at z = 0.0
TOT
DM
GAS
STARS
ρ (M sun / kpc^3)
R (kpc)
softening
Power:2003 =~ Diemand:2004



Eris.00001 at z = 0.0
TOT
DM
GAS
STARS
V circ (km/s)
R (kpc)

Eris MWs

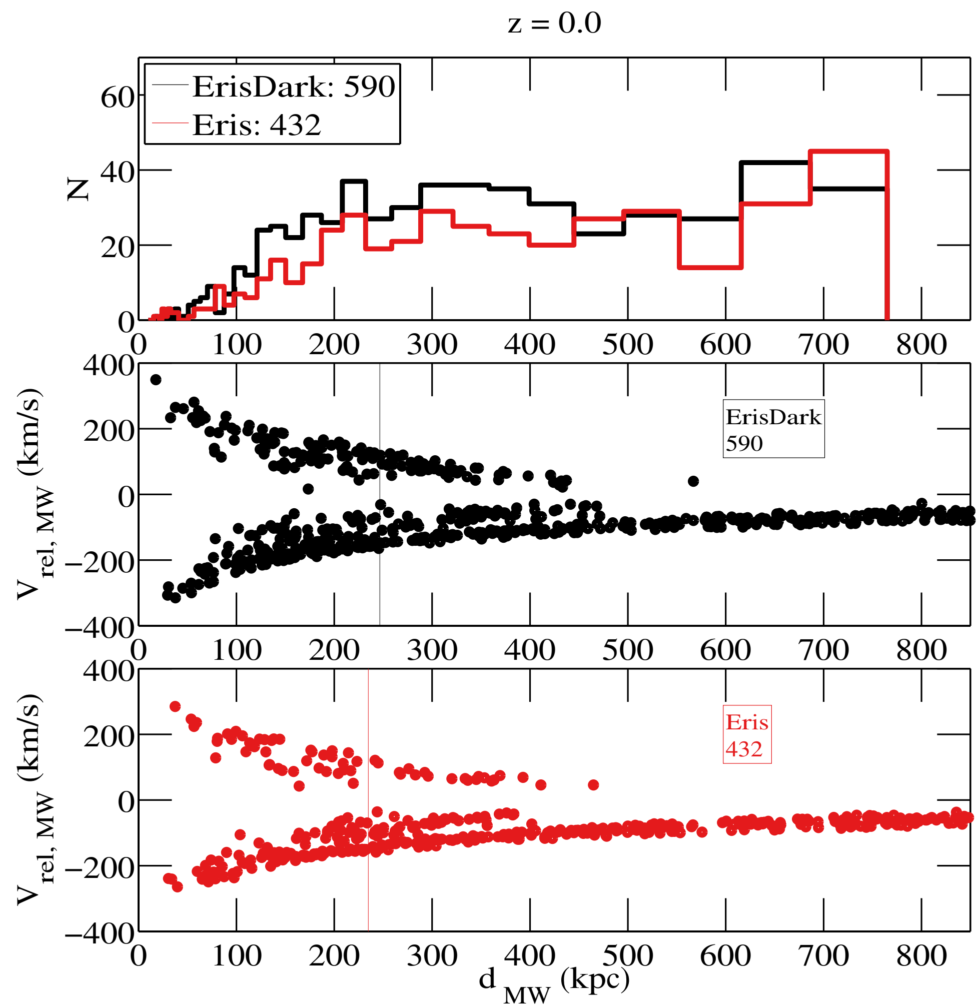


Convergence Estimate

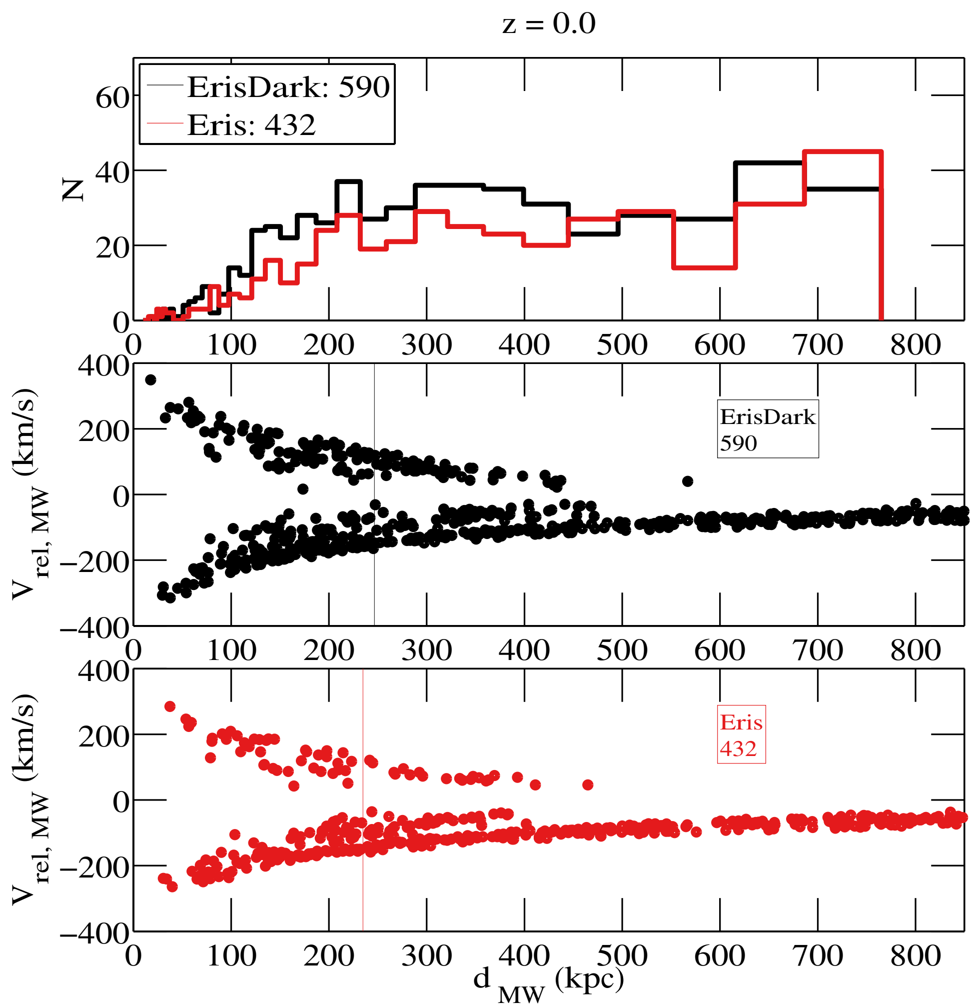
Eris Dark Low Resolution
9.5 10^5 Msun
495 pc

> 0.9 kpc
~ 8 x softening!

Eris Satellites

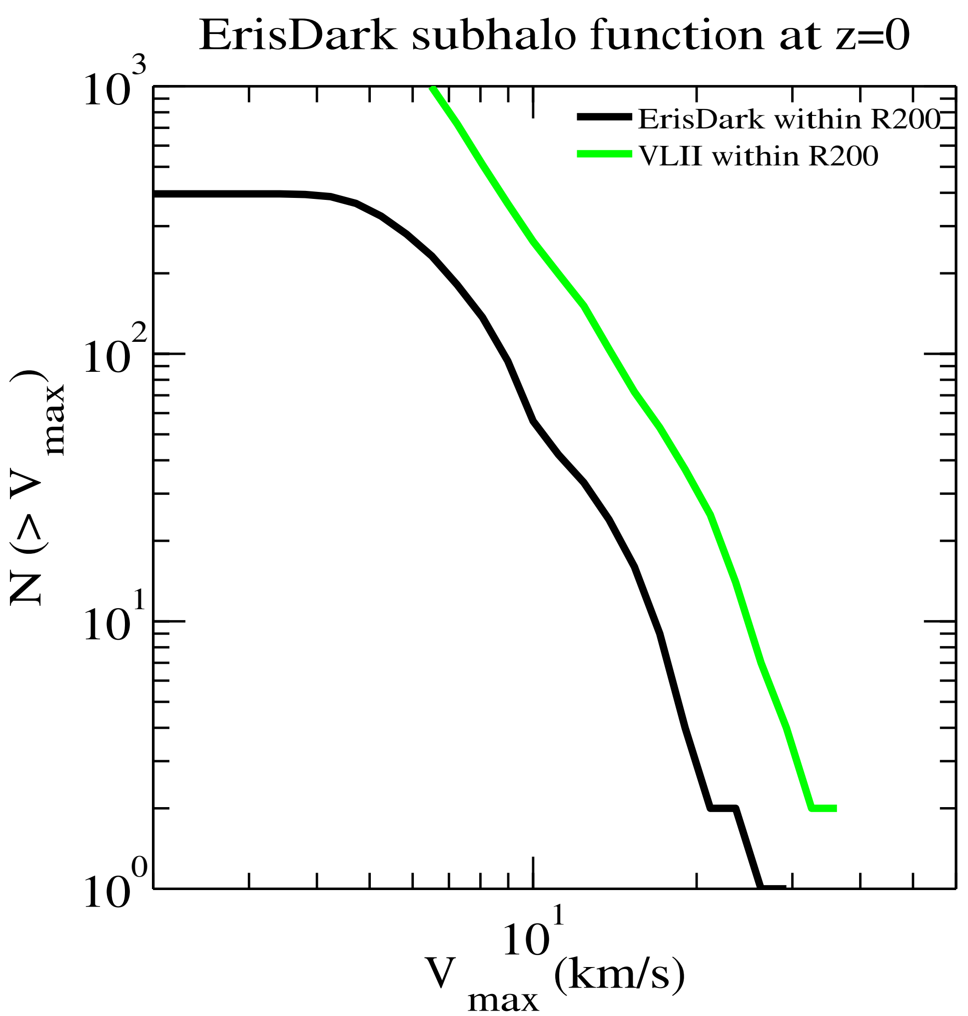


Eris Satellites

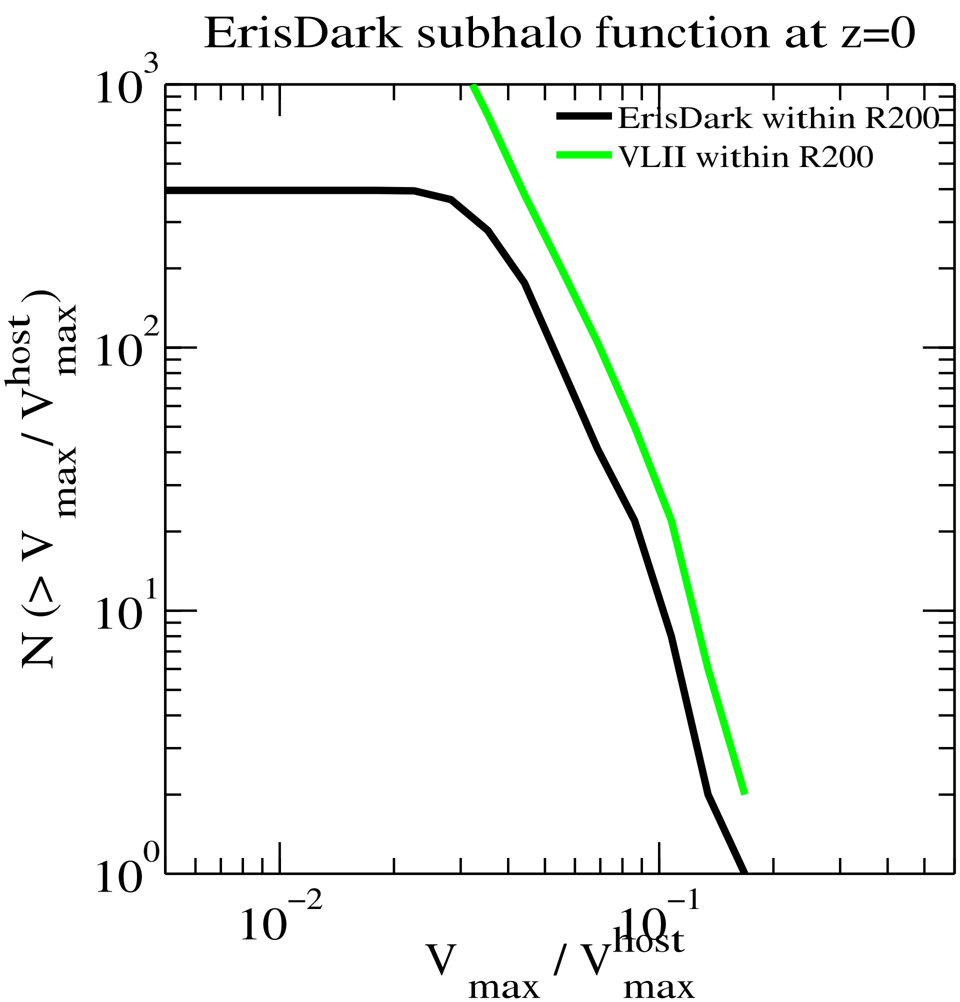


- N_{TOT} > 100, AHF
  Analog pairs by DM particle tracking
- Effective high-res region no further than 850 kpc....
- Many categories of objects!
- Satellite Definition at z=0:
  - within Rvir at any given z
  - within Rvir ever

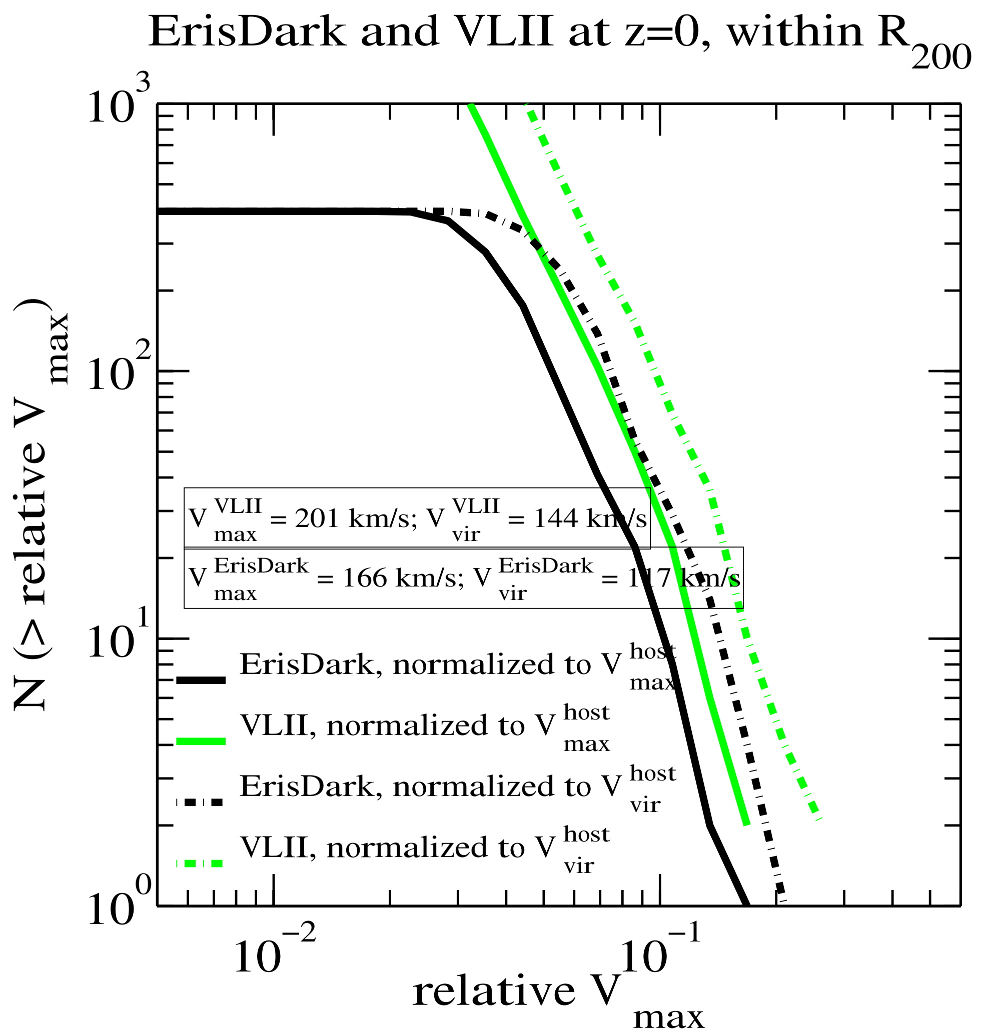
ErisDark Subhaloes



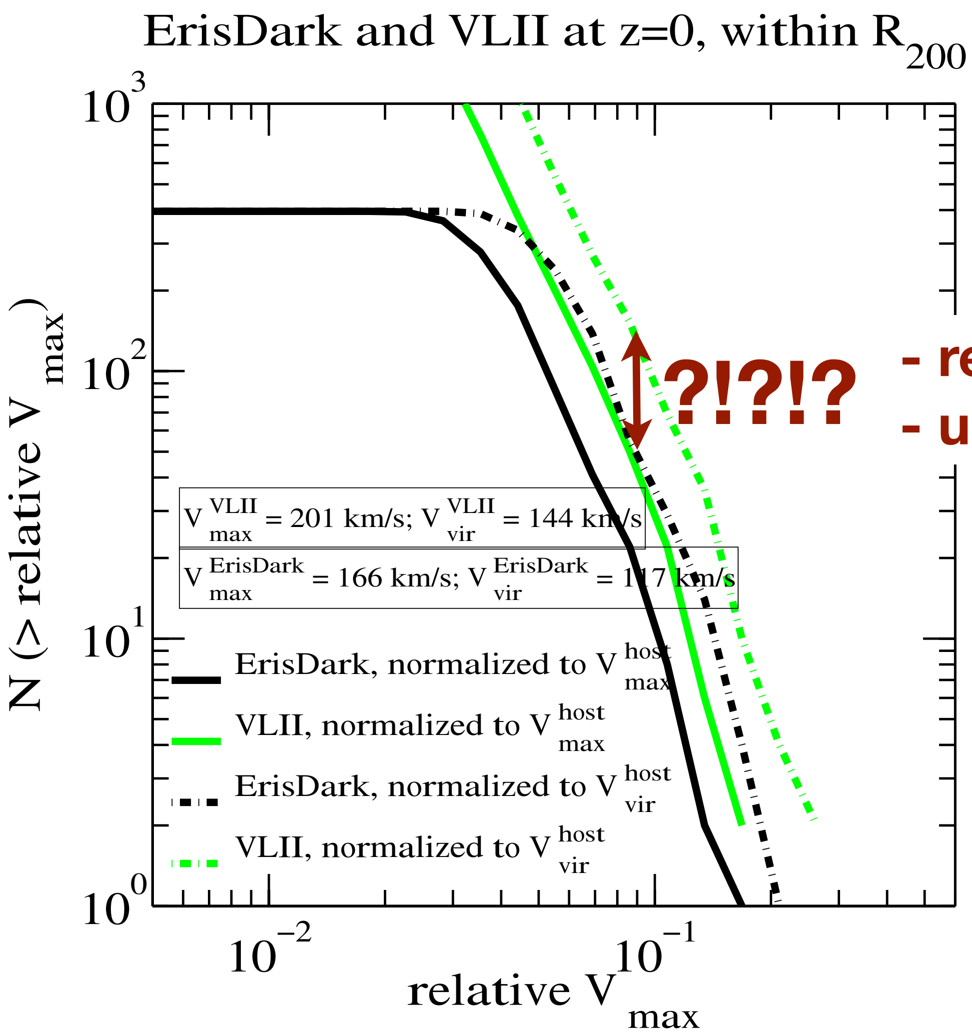
ErisDark Subhaloes



ErisDark Subhaloes



ErisDark Subhaloes



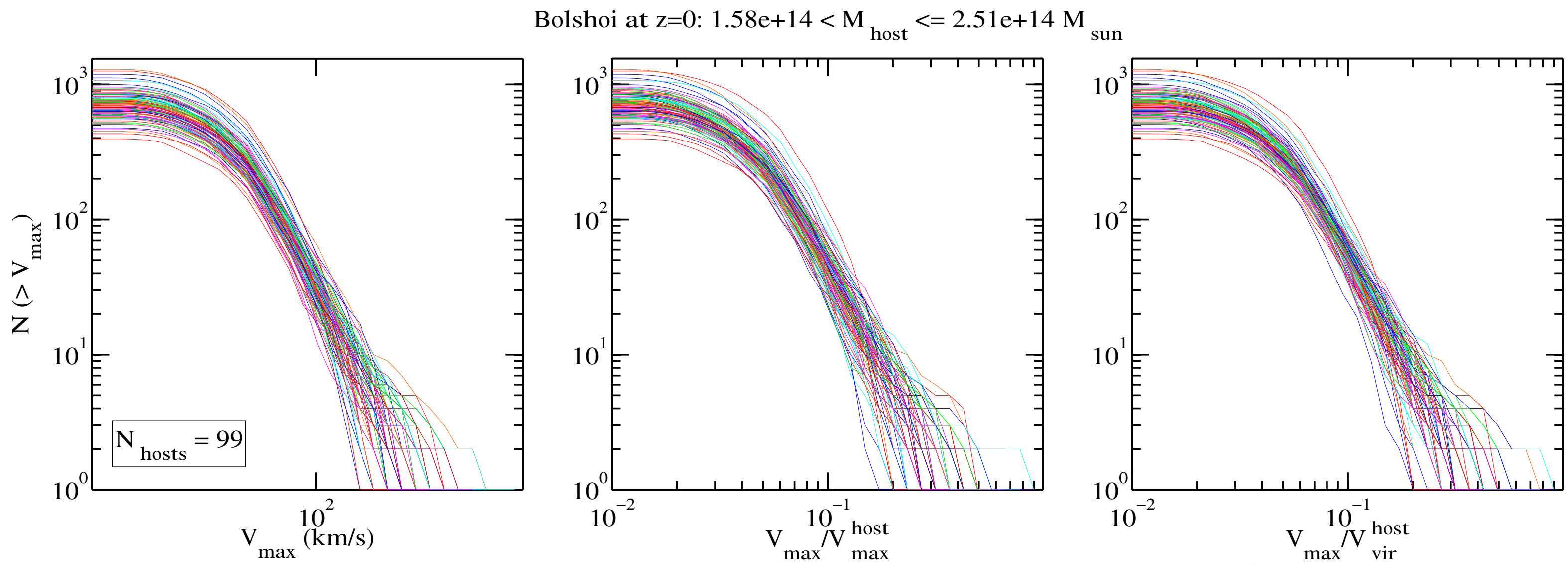
- resolution???
- unlucky realization?

Excursus: scatter in the subhalo velocity function (I)

Bolshoi Simulation, analyzed with Rockstar by P. Berhoozi
(L = 250 Mpc/h, N = 2048^3, m_DM = 1.35 10^8 Msun/h, 1 phys kpc/h)

Thanks to
Joel and Peter

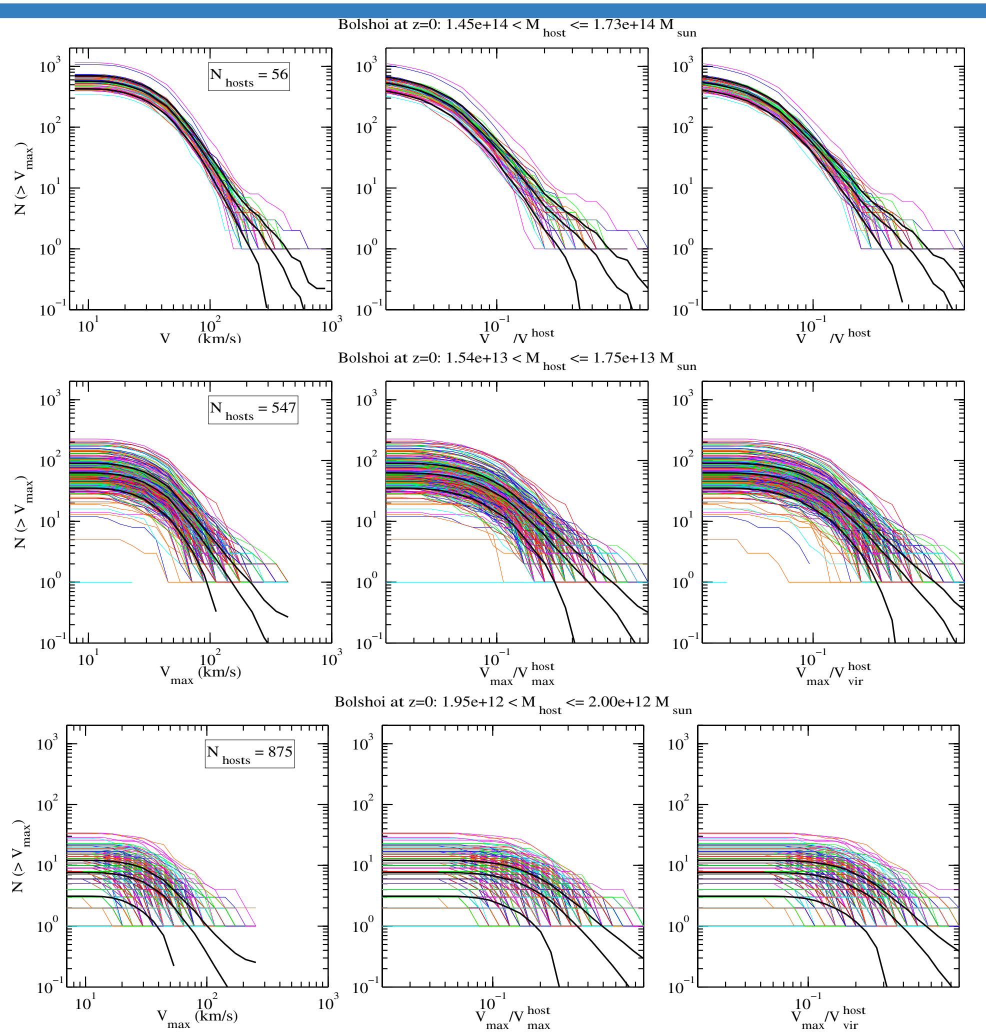
Typical DM subhalo abundance functions, for cluster-size hosts:



μ_{max} = μ_{vir} =

Excursus: scatter in the subhalo velocity function (II)

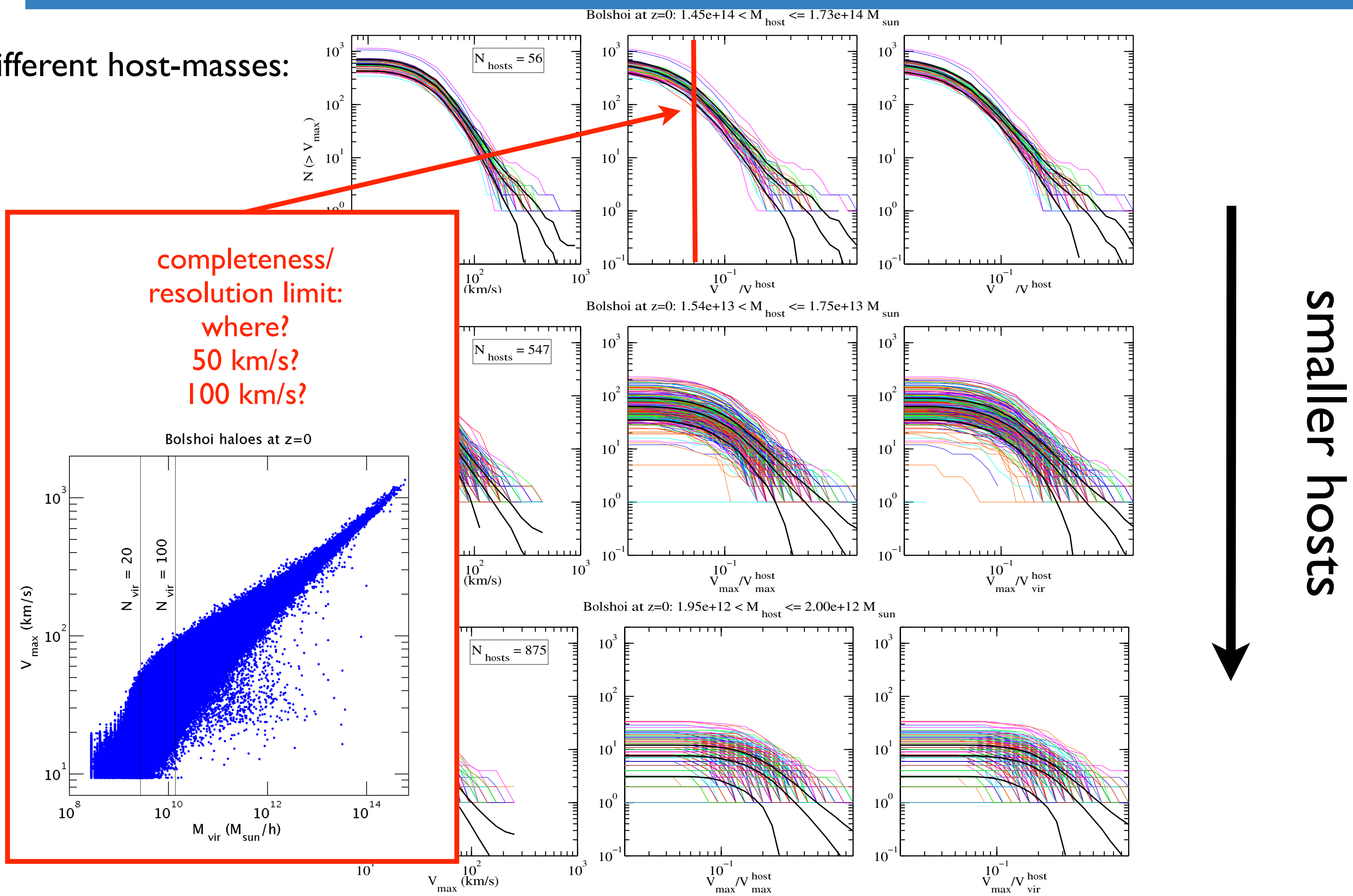
Different host-masses:



smaller hosts

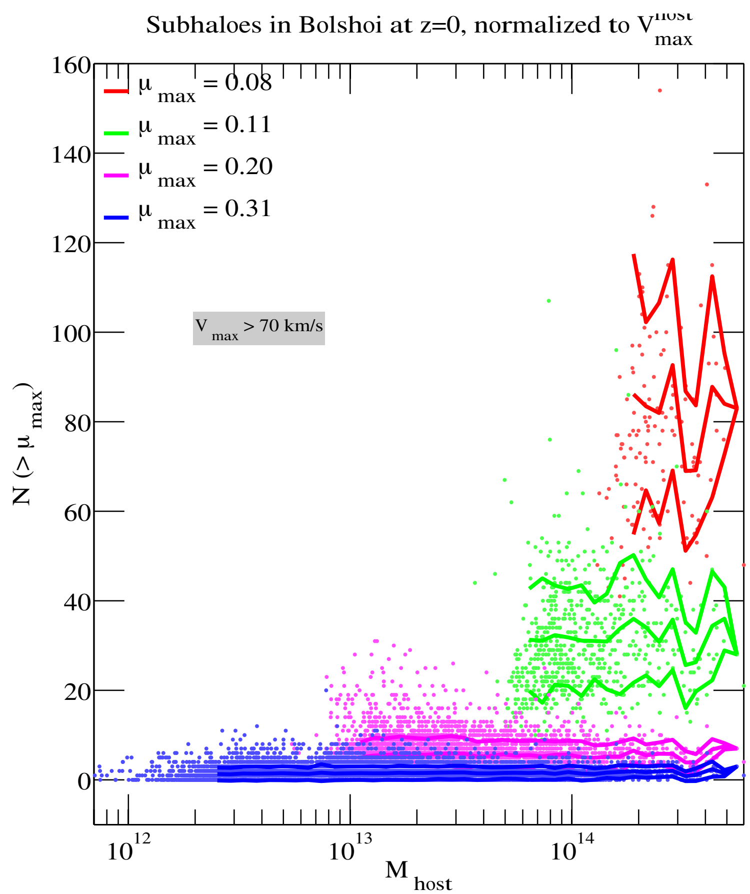
Excursus: scatter in the subhalo velocity function (III)

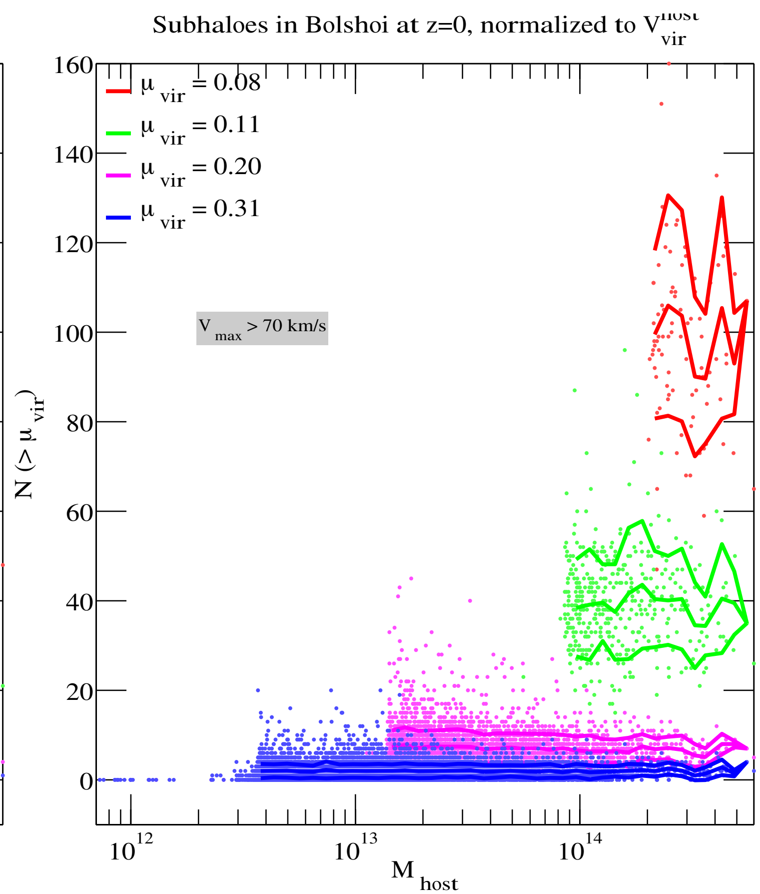
Different host-masses:



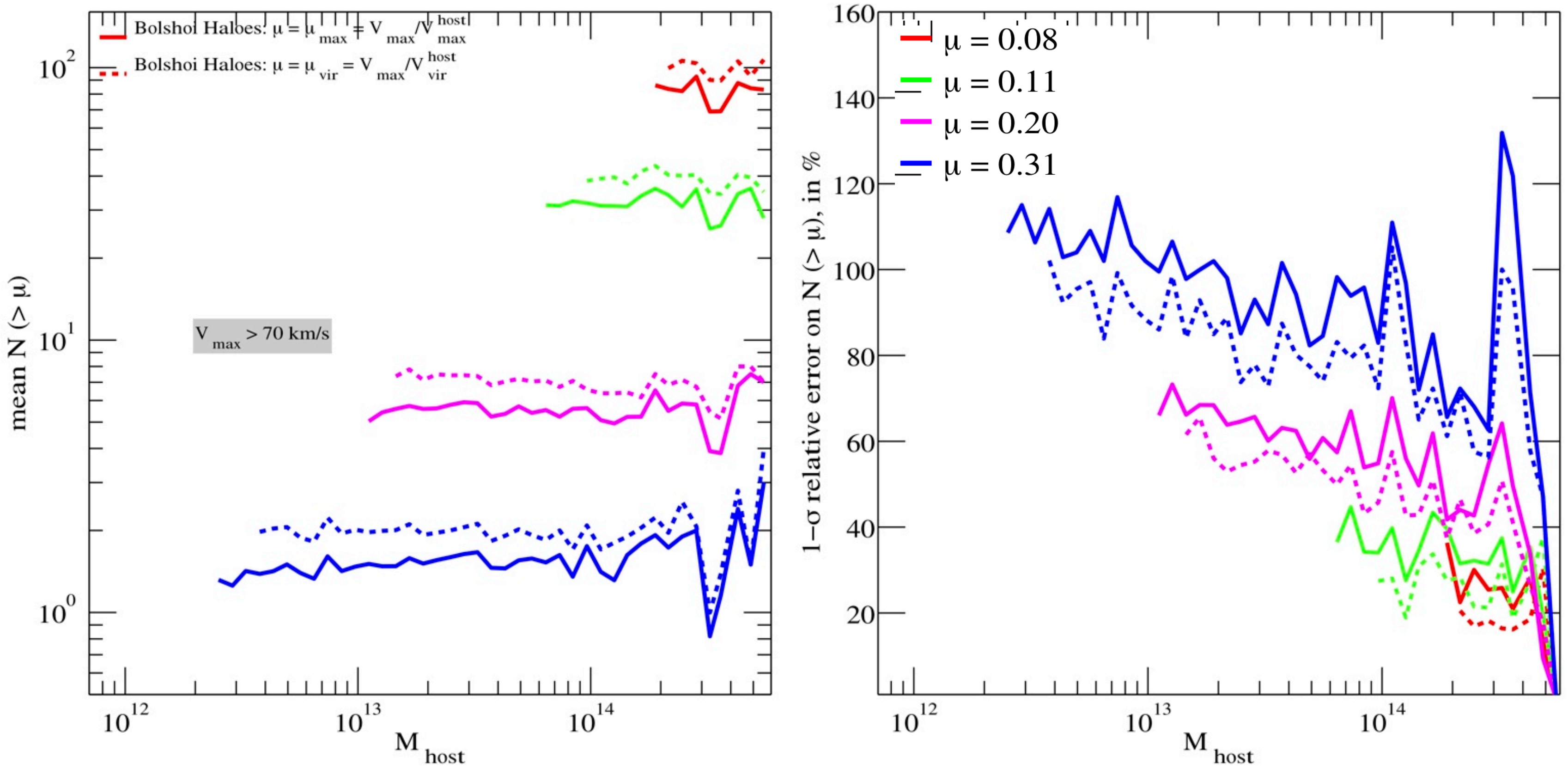
Excursus: scatter in the subhalo velocity function (IV)

Sectioning the subhalo abundance functions at different subhalo relative sizes...

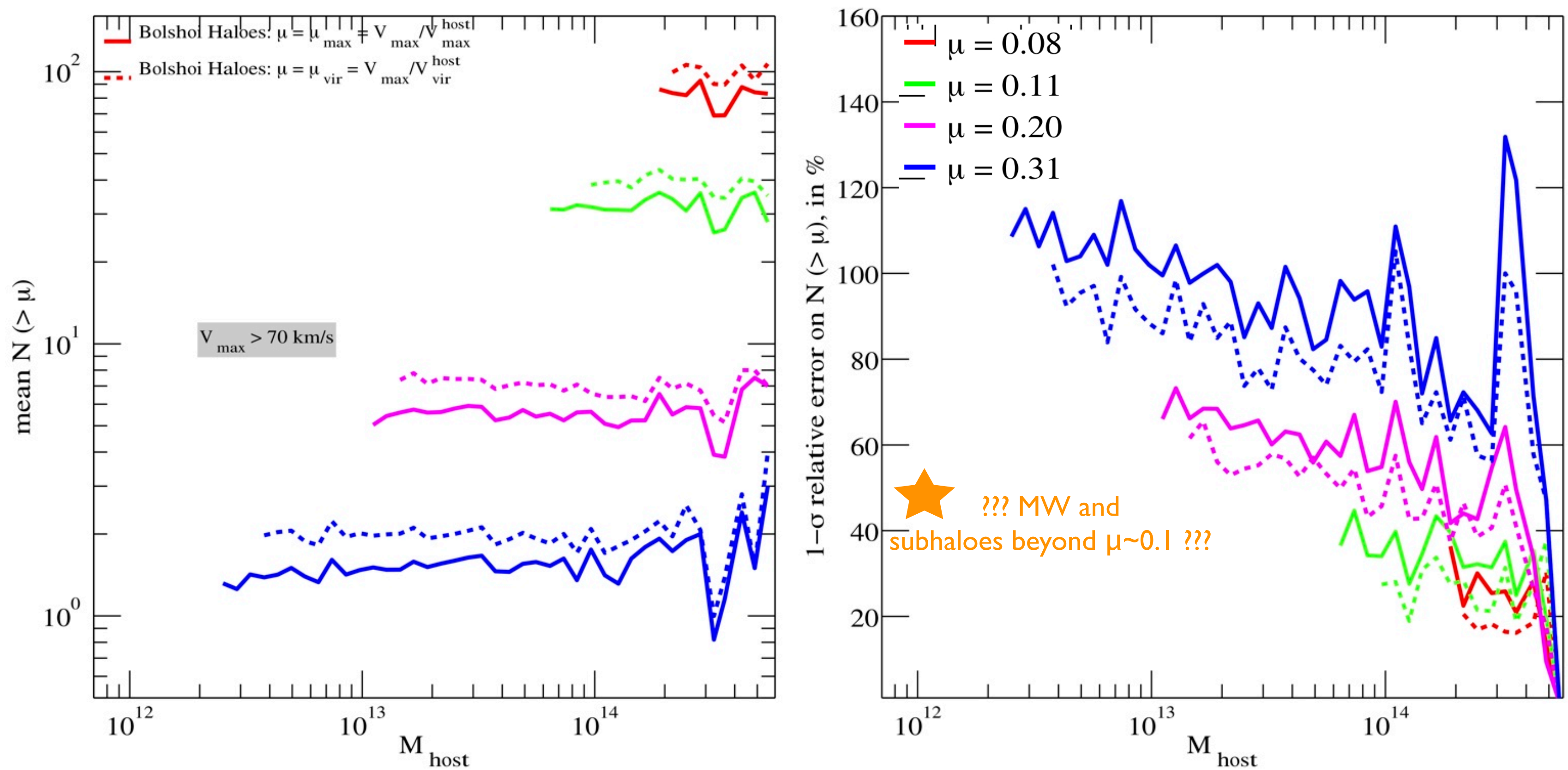




Excursus: scatter in the subhalo velocity function (V)



Excursus: scatter in the subhalo velocity function (V)



Excursus: scatter in the subhalo velocity function (V)

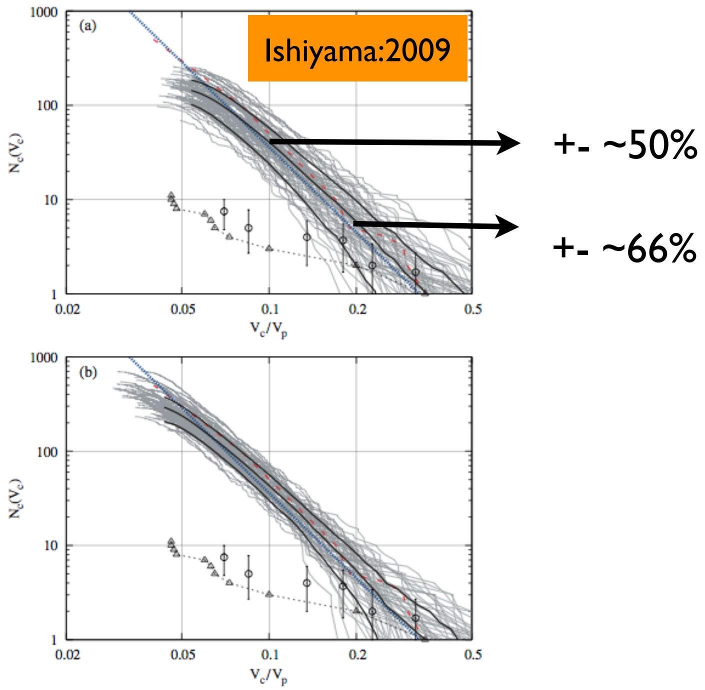
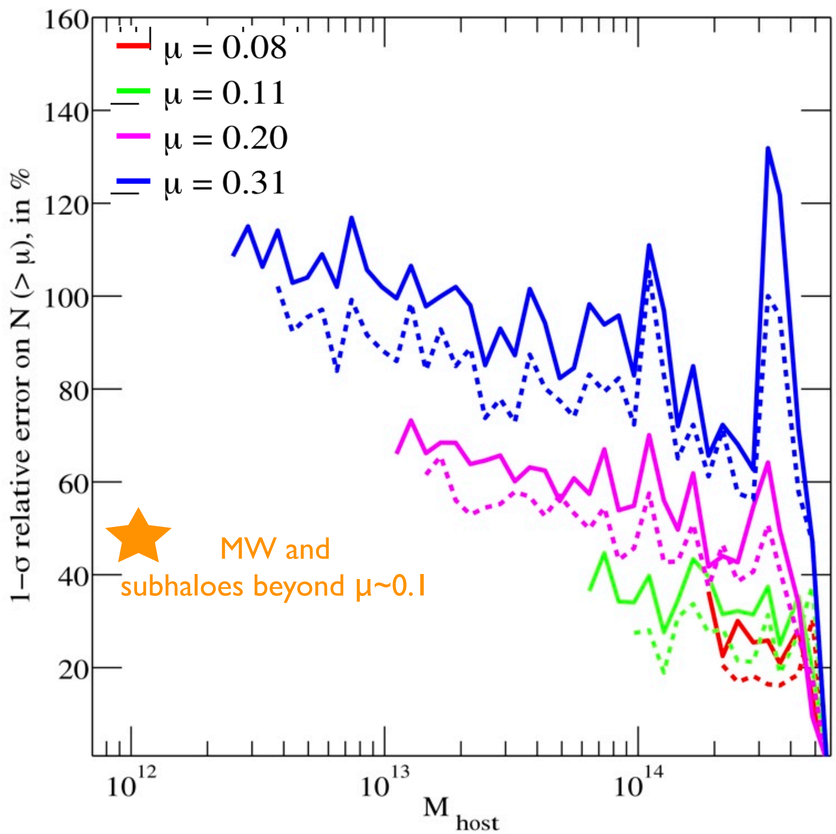
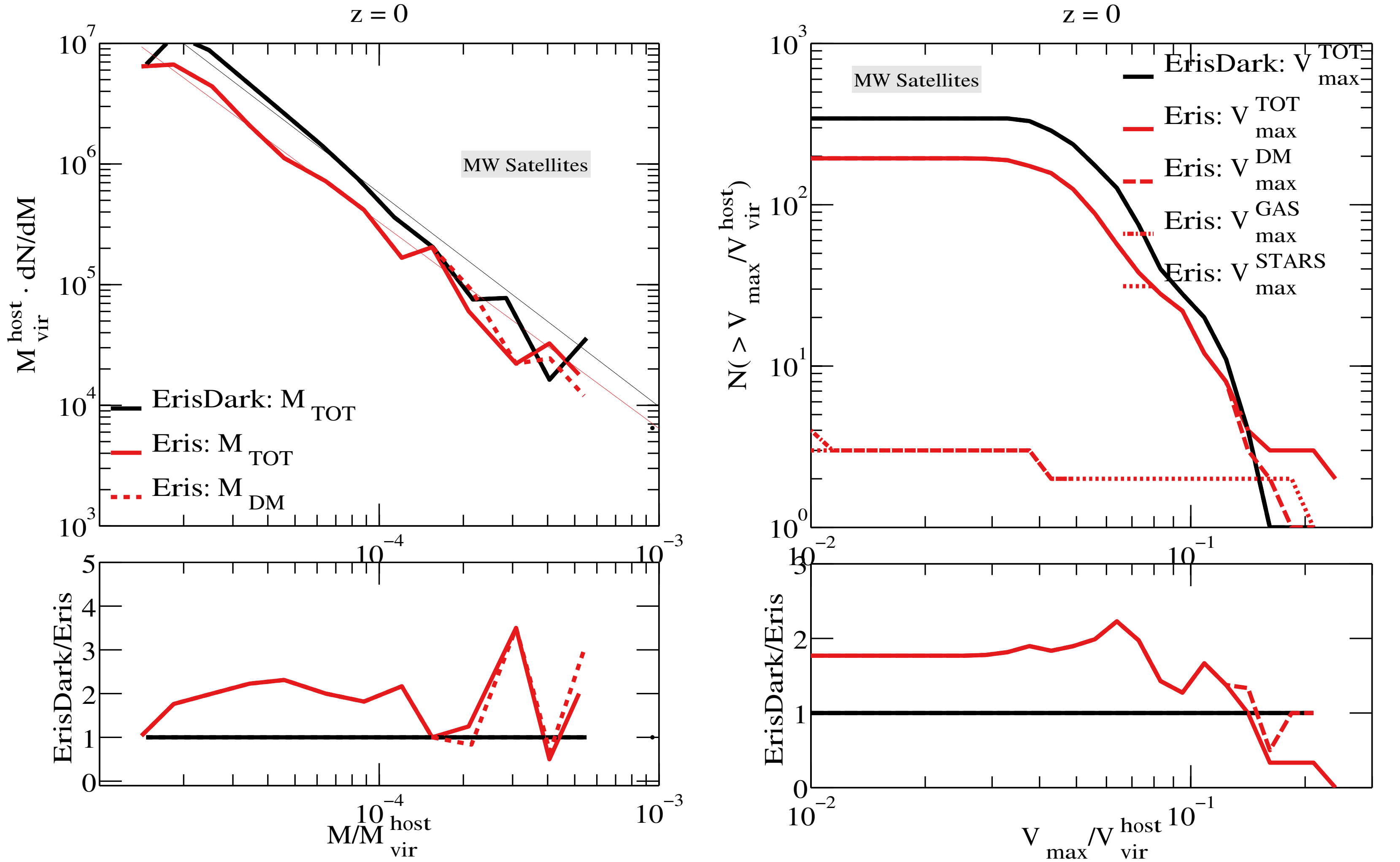


Figure 2. Cumulative numbers of subhalos as a function of their maximum rotation velocities V_c normalized by those of the parent halos V_p. (a) 68 galaxy-sized halos with $1.5 \times 10^{12}\ M_\odot \leqslant M < 3 \times 10^{12}\ M_\odot$ (top). (b) 57 giant-galaxy-sized halos with $3 \times 10^{12}\ M_\odot \leqslant M < 1 \times 10^{13}\ M_\odot$ (bottom). Three thick solid curves show the average (middle) and $\pm 1\sigma$ values (top and bottom). Thick dotted and dashed curves are the fitting formula from Diemand et al. (2008) and the result of Moore et al. (1999a) for a galaxy-sized halo, respectively. The thin dashed curve with open triangles denotes the number of dwarf galaxies in our galaxy (Mateo 1998). The open circles with error bars show the number of dwarf galaxies in the Local Group (D'Onghia et al. 2007).

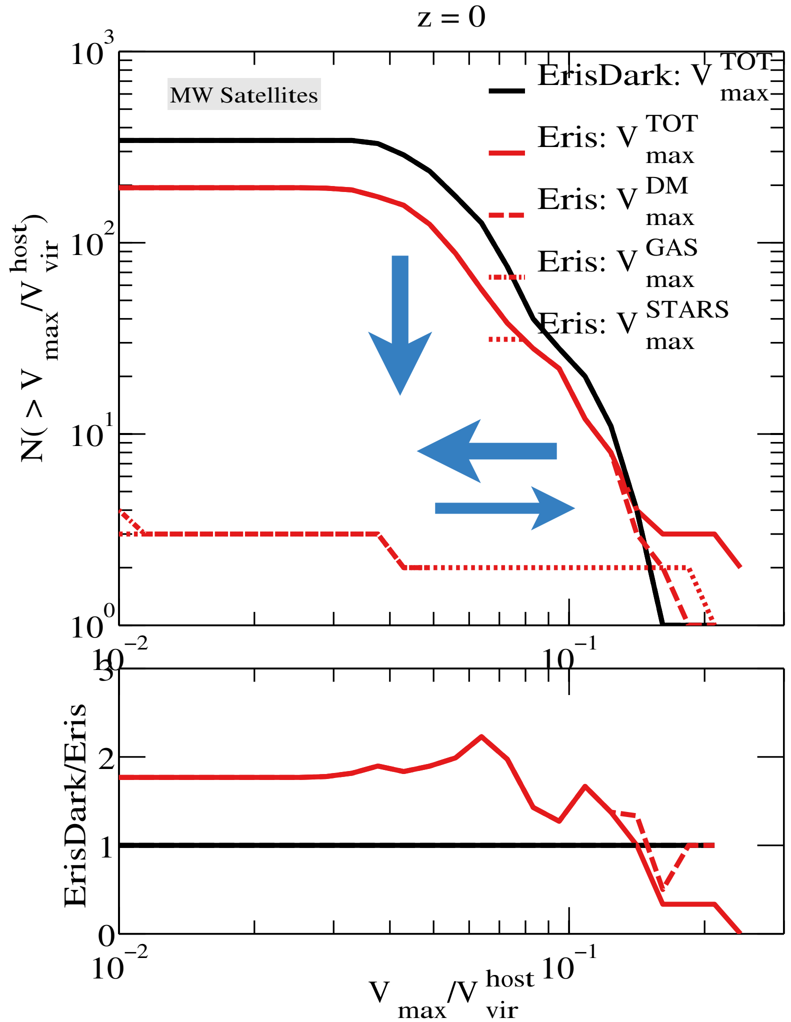


...also Wang:2012

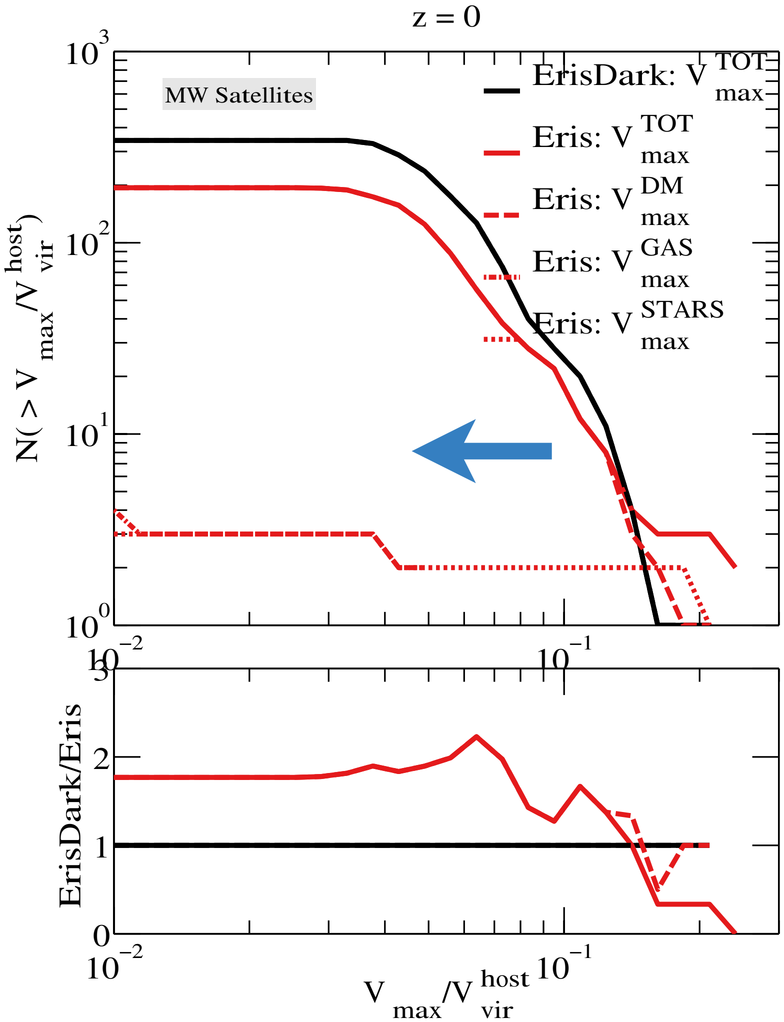
Satellites Abundances



Satellites Abundances



Satellites Abundances



see Zolotov&co talks and papers:

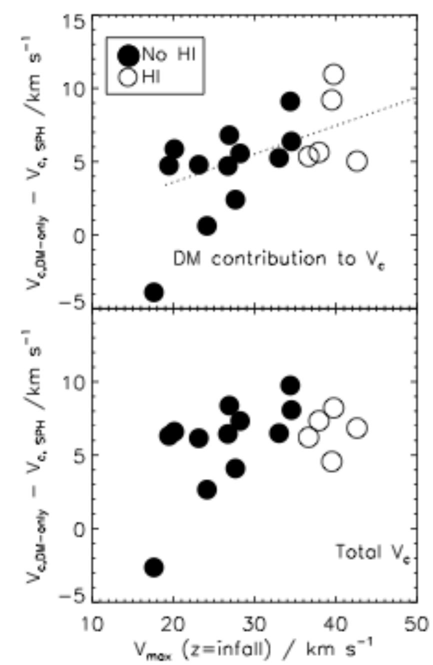
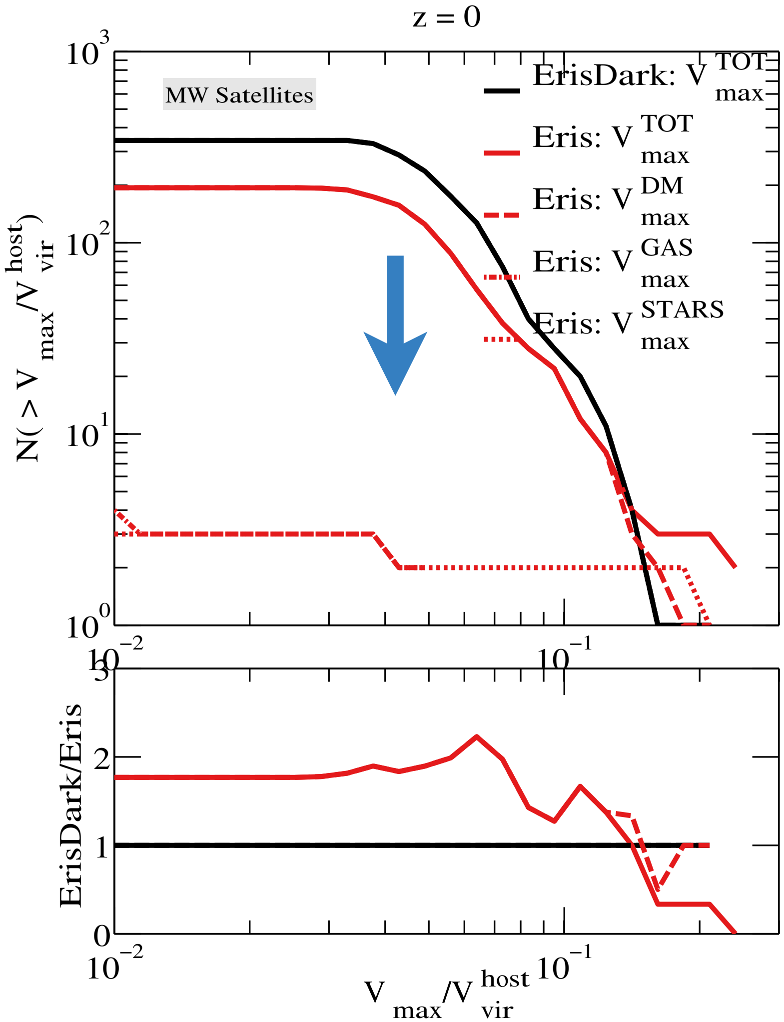


FIG. 9.— The difference in v_c at 1 kpc at $z = 0$ between the SPH and DM-only counterparts, as a function of V_{max} of the DM-only satellite at infall. *Top panel:* The difference in the DM contribution to v_c at 1 kpc for matched SPH and DM-only subhalos. *Bottom panel:* The difference in total v_c at 1kpc.

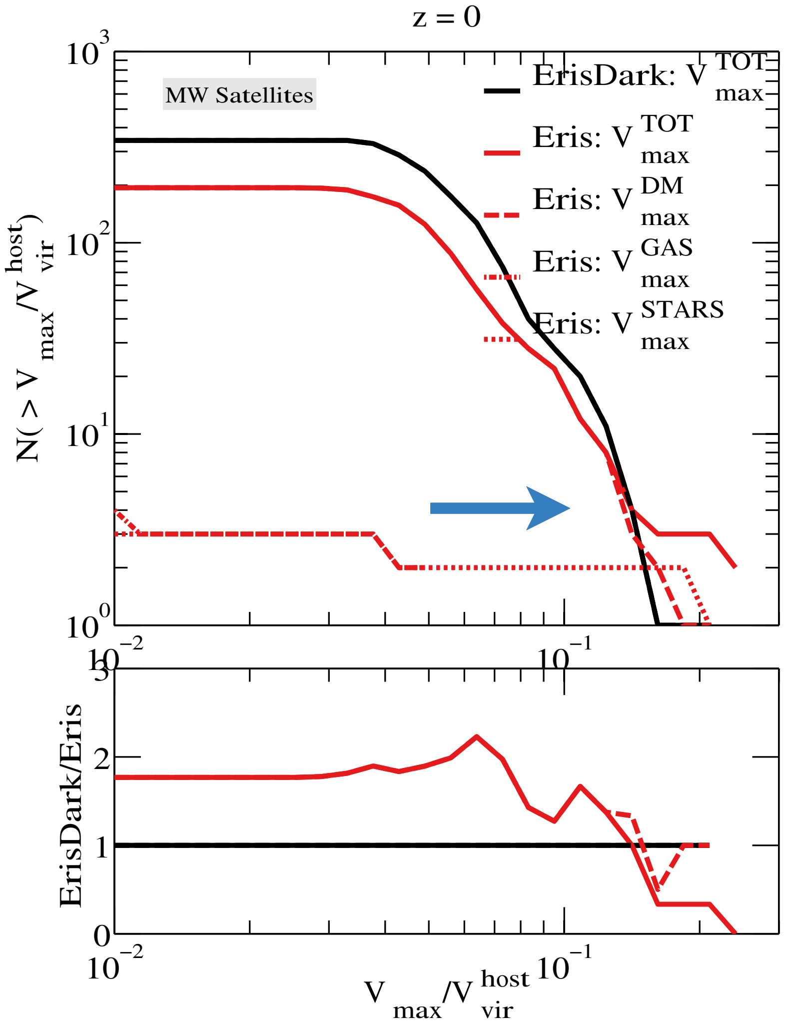
Satellites Abundances



Mayer et al. in preparation.

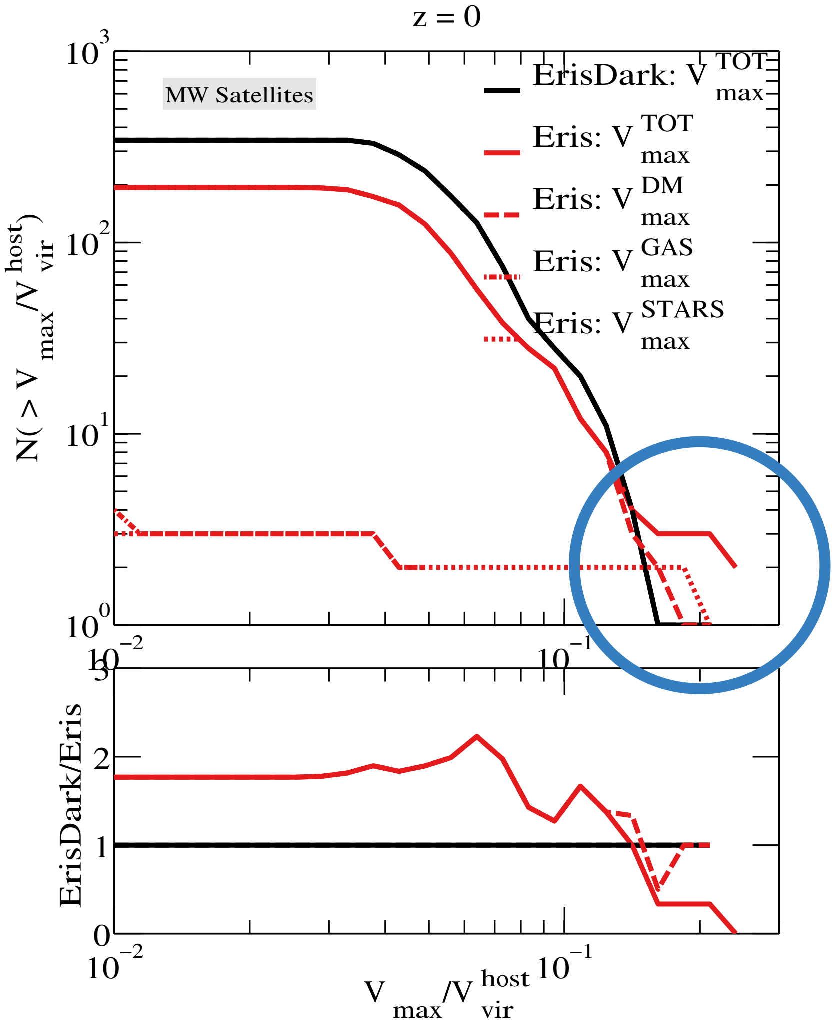
- The most massive objects undergo strongest stripping
- The amount of stripped material depends on the slope of the inner densities, on the orbits, on the distance of the pericenter, ...
- Haloes which are massive and with flatter inner density profiles are more likely to get completely destroyed, as the dependence of tidal shock on halo mass is stronger than linear!

Satellites Abundances

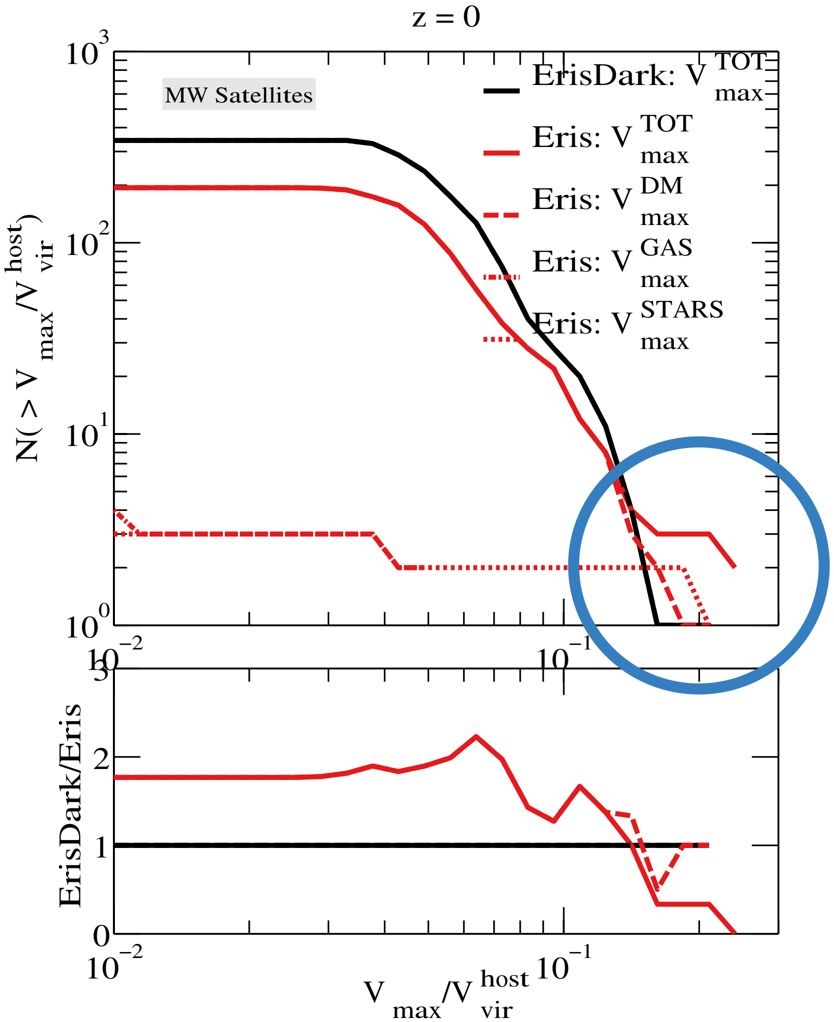


Baryons not always produce reduced inner densities and shallower density profiles....

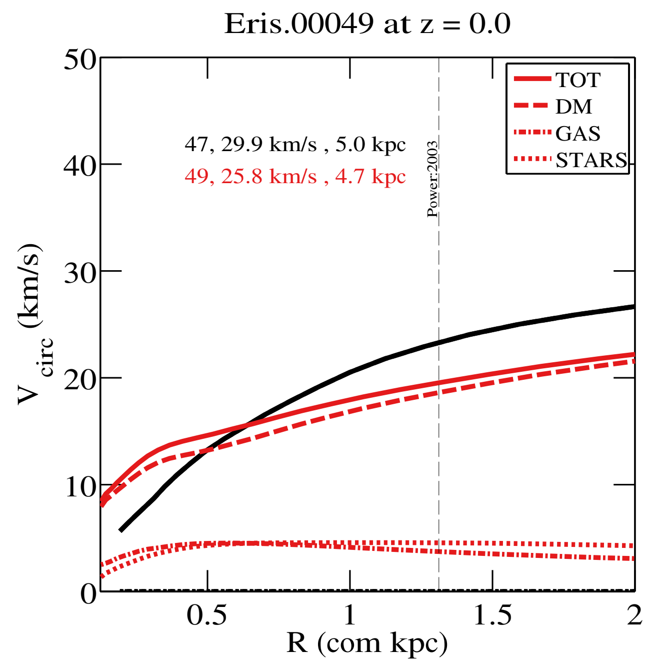
Eris luminous satellites



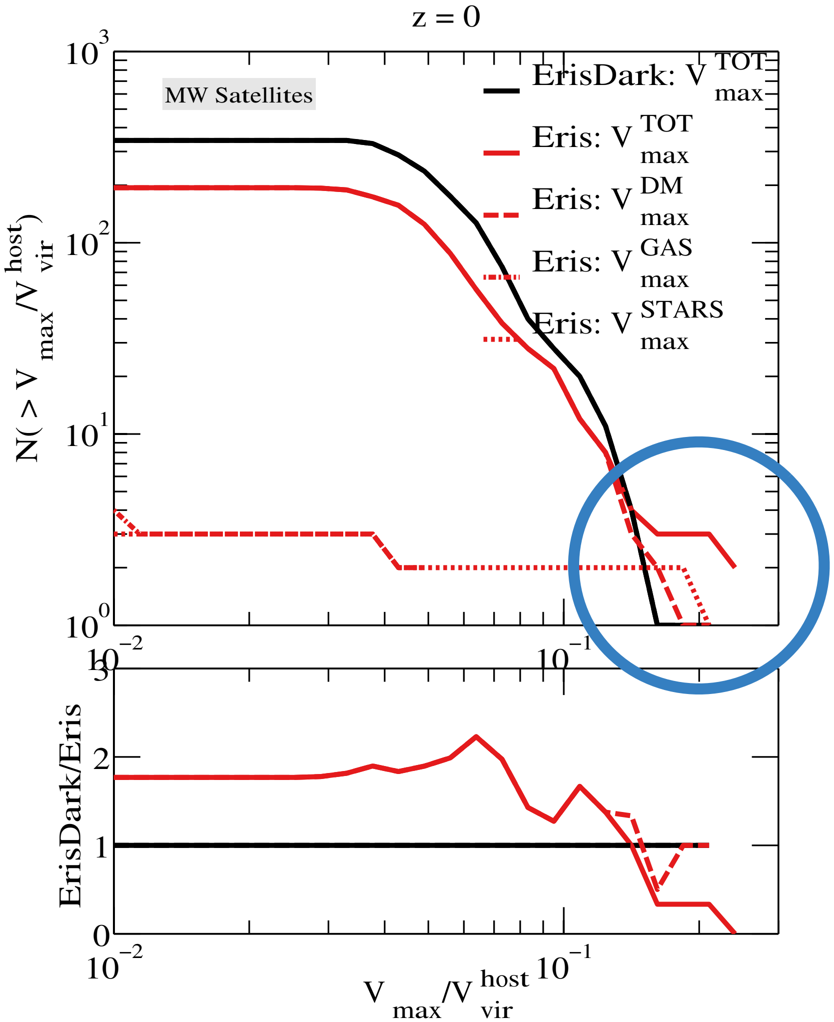
Eris luminous satellites



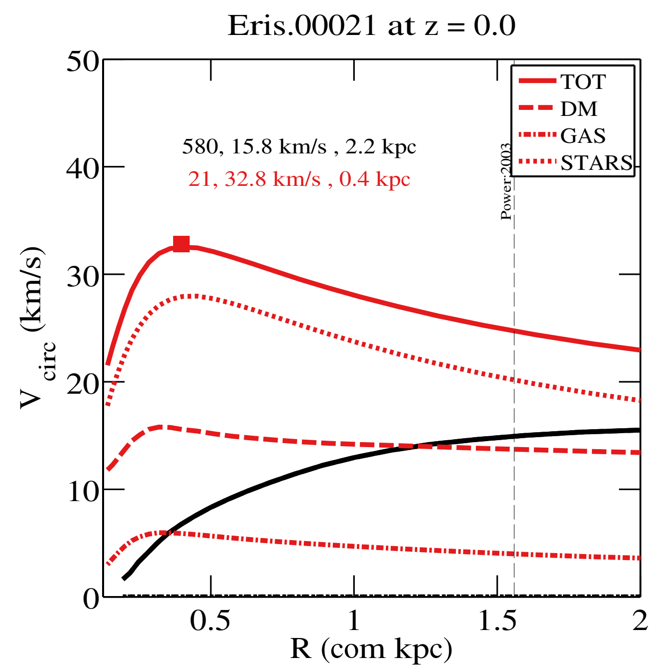
MTOT = 2e9 Msun
Mstellar ~ 1e7 Msun
Mass loss ~ 50 %
z infall = 0.99
dMW = 215 kpc



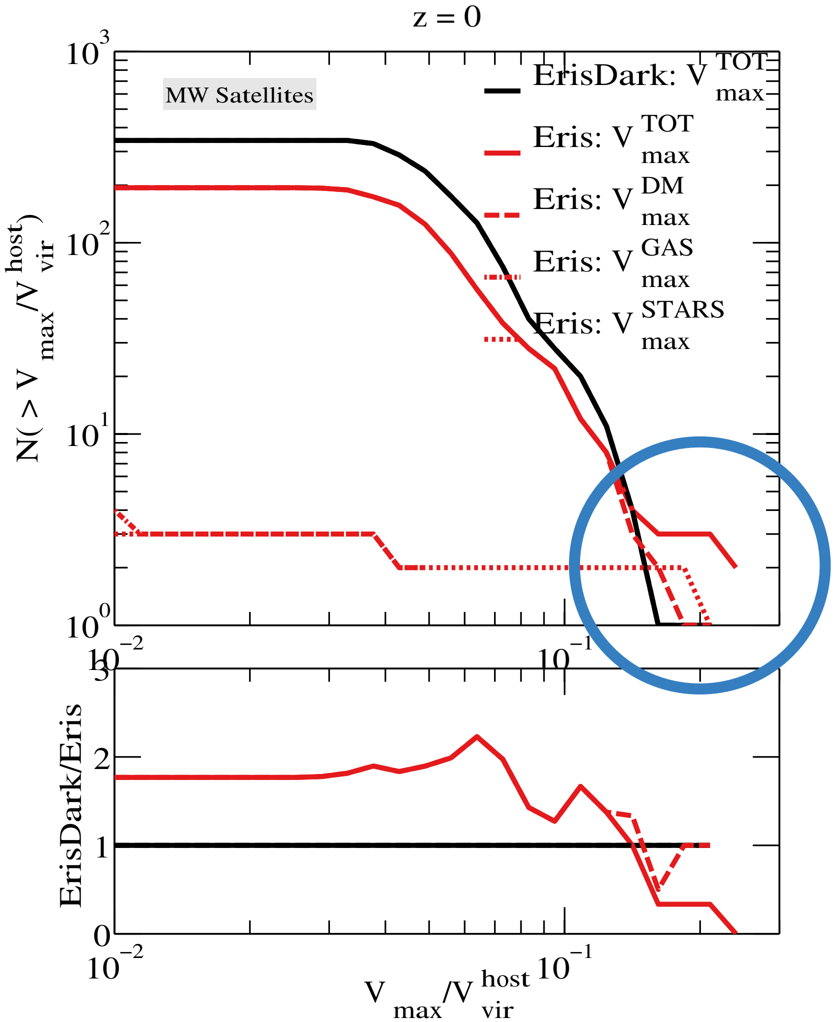
Eris luminous satellites



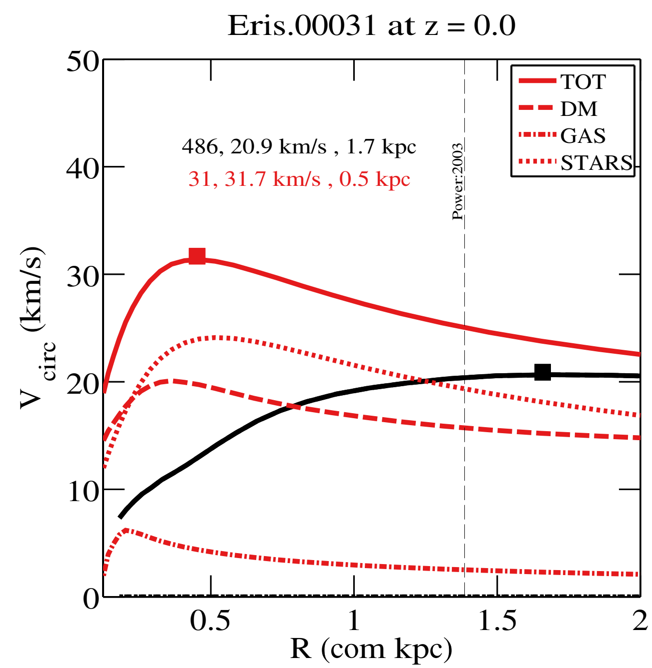
MTOT = 3.7e8 Msun
Mstellar ~ 1.8e8 Msun
Mass loss ~ 96 %
z infall = 1.2
dMW = 34 kpc



Eris luminous satellites

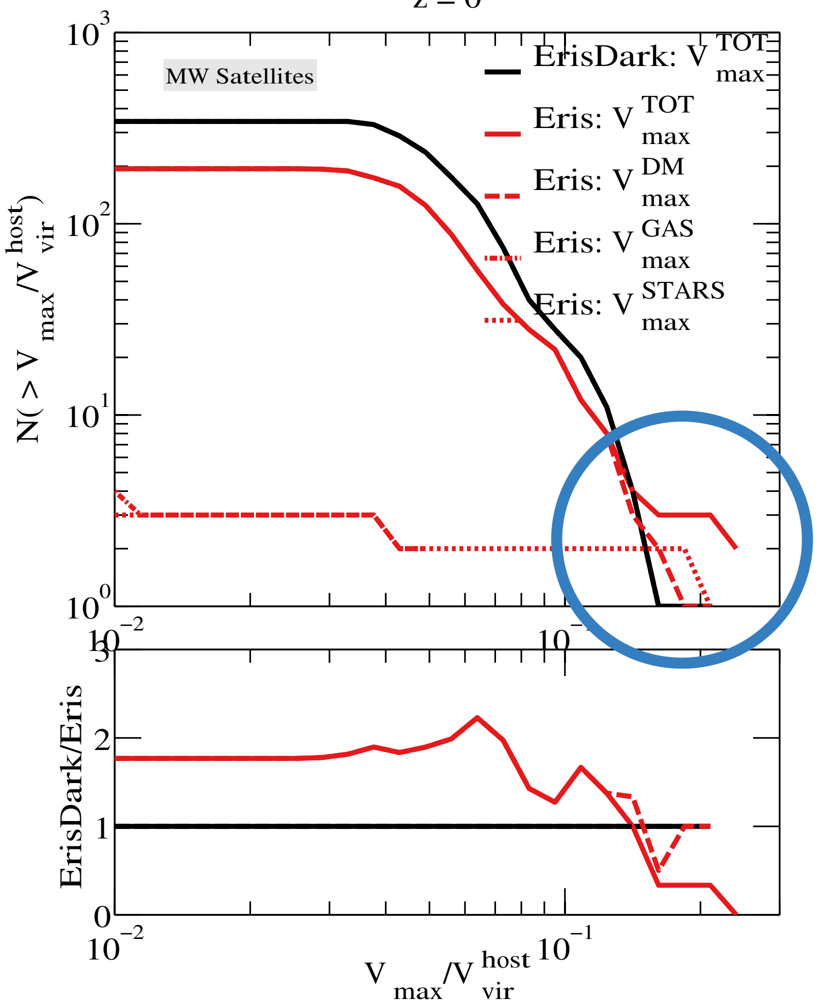


MTOT = 3.1e8 Msun
Mstellar ~ 1.6e8 Msun
Mass loss ~ 97 %
z infall = 1.8
dMW = 30 kpc

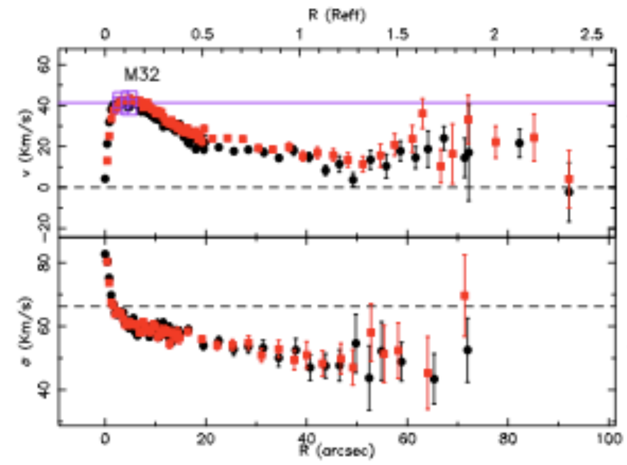


Eris luminous satellites

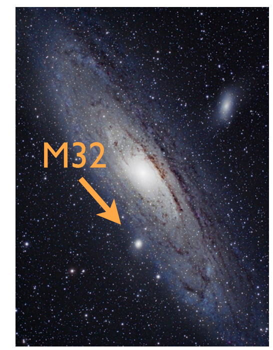
z = 0



e.g: M32 in Andromeda

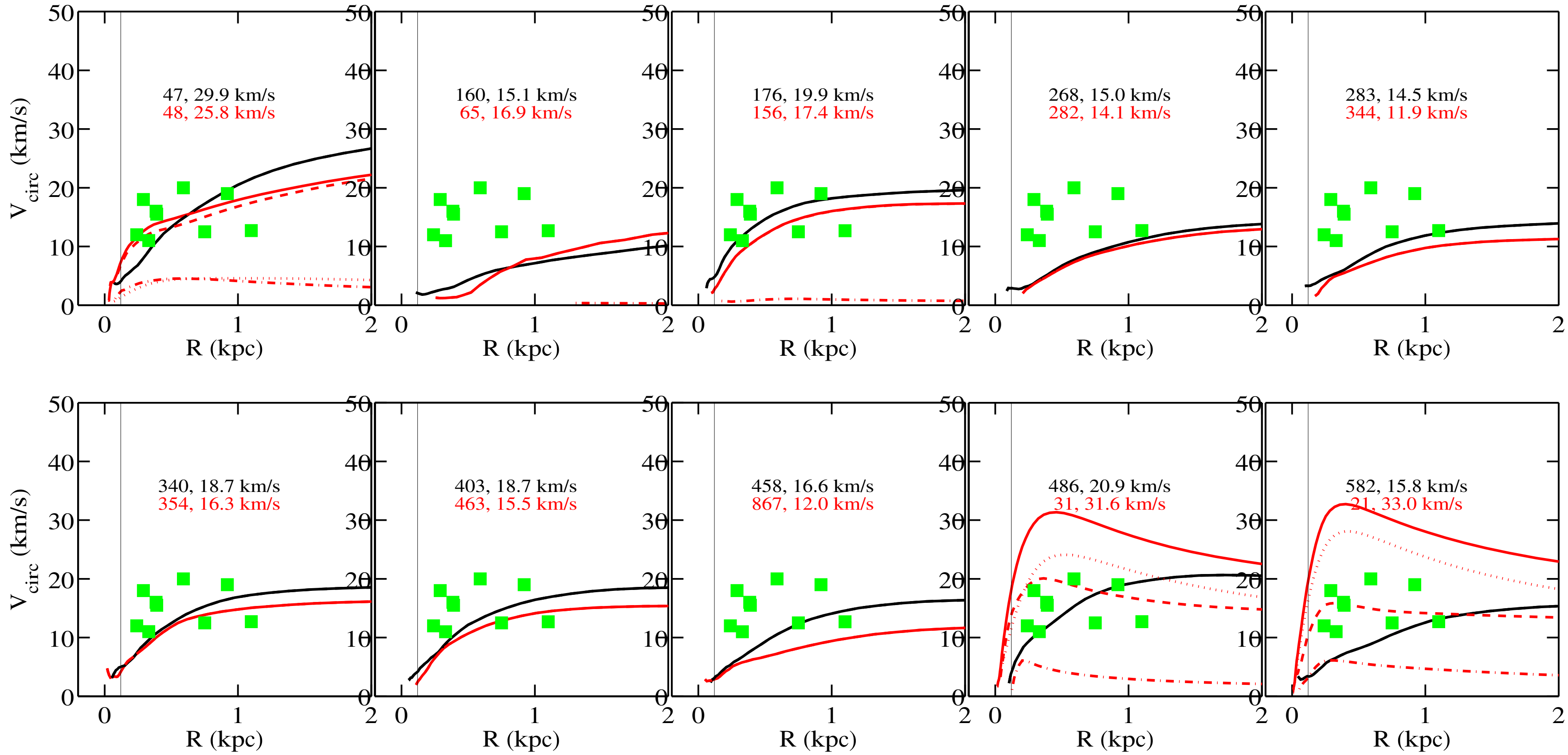


ref. Toloba:2011

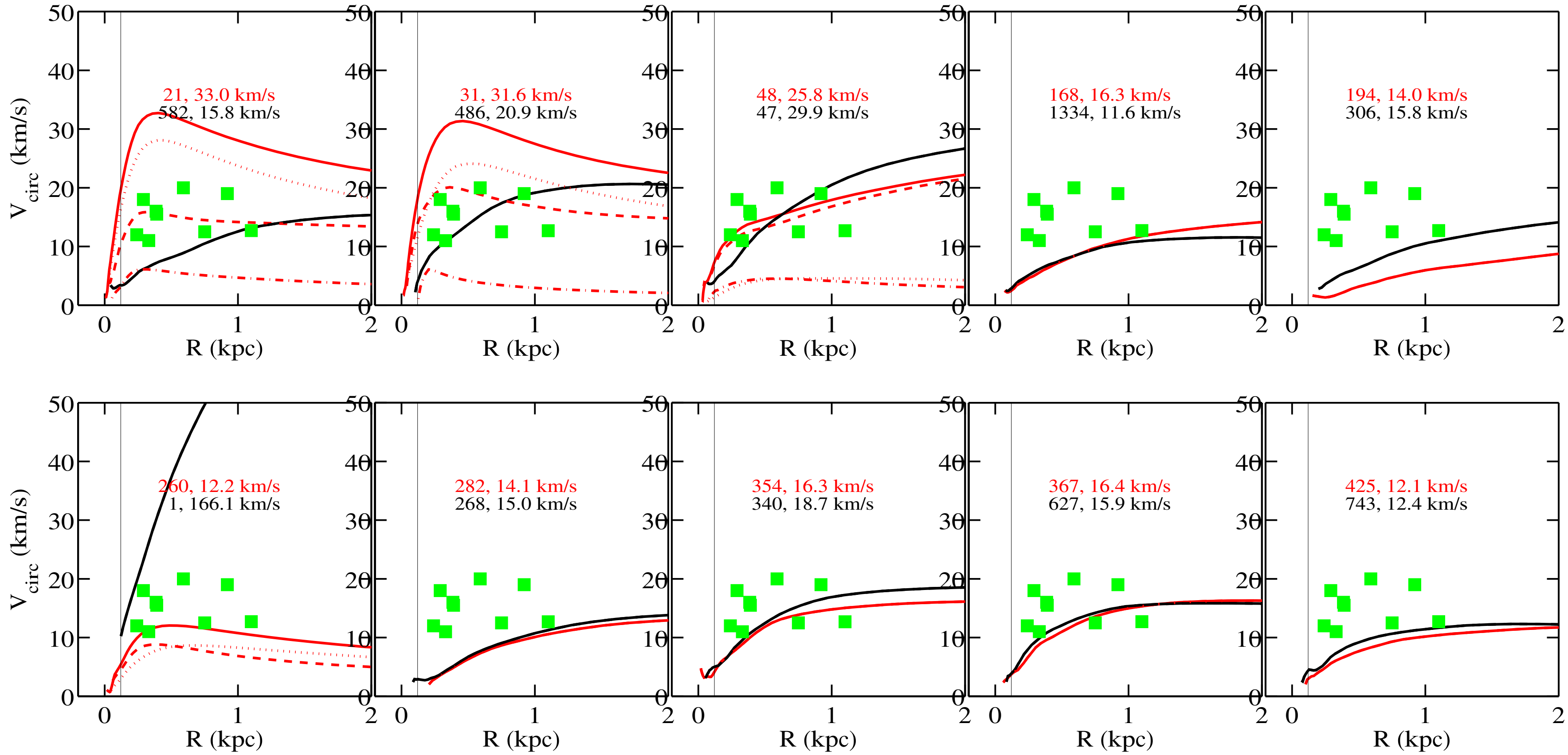


e.g: all past SPH satellites

Top10 satellites in ErisDark (Vmax selected)



Top10 satellites in Eris (Vmax selected)



Conclusions

- ErisDark seems to be a subhalo-poor realization of a (low-mass) MW
- Even with Eris, resolution limits lie in ambush (!!!)
- The MW subhalo cumulative Vmax function at z=0 is **suppressed** with the presence of baryons
- Yet, in Eris we have an **ankle** at the high luminosity end of the subhalo cumulative Vmax function at z=0
- The interpretation of such decrement and ankle is not at all straightforward, even modulo the physics recipe
- The histories of the satellites must be studied in details: i.e. we have to understand the different tidal responses
  - of the different categories of satellites falling in the MW (dark satellites vs baryonic satellites, with flatter/cuspier inner profiles, different orbits...)
  - in relation to the different hosts in which they are falling in (disk vs no disk, different host shapes, thus different orbits)