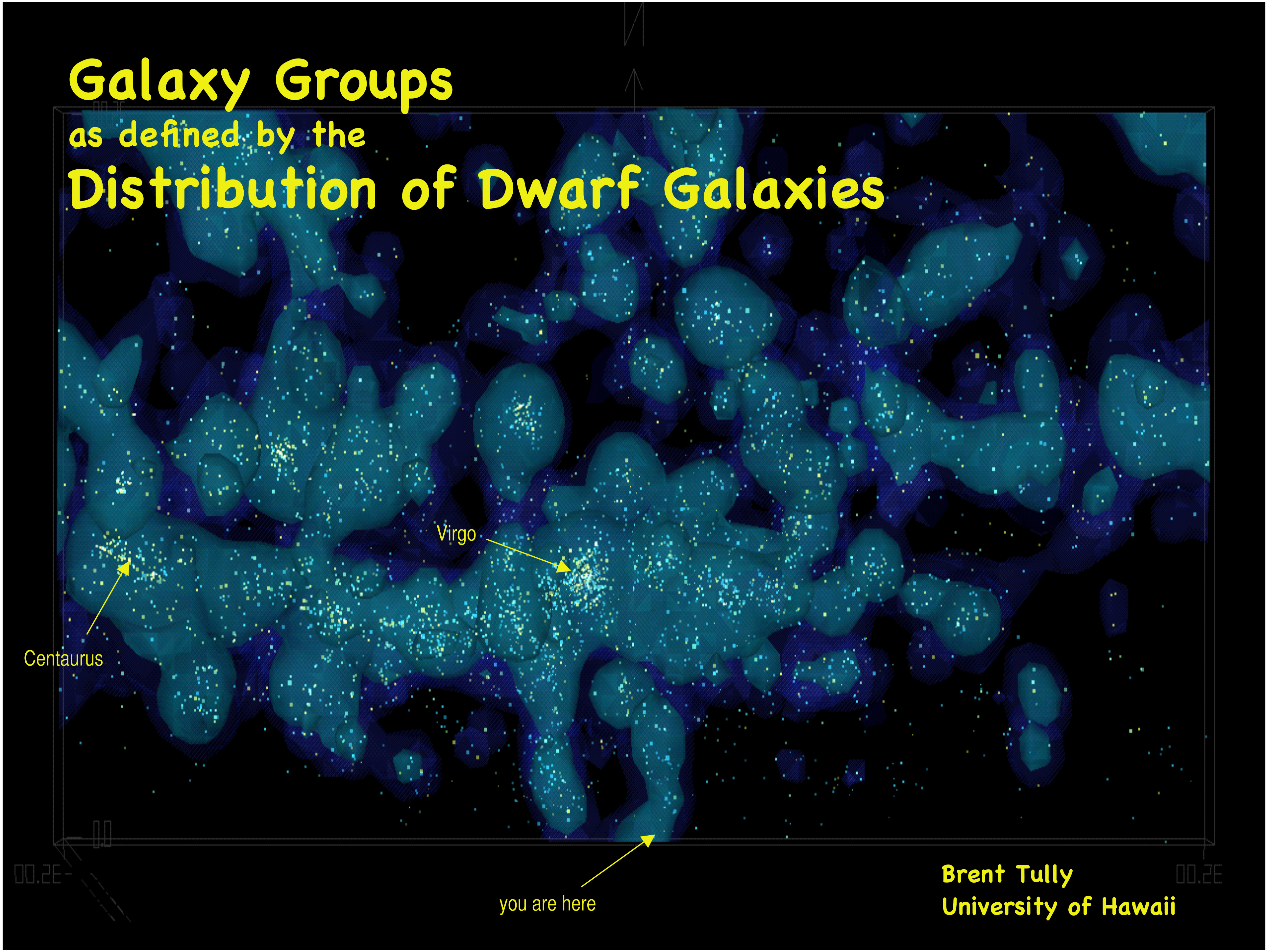
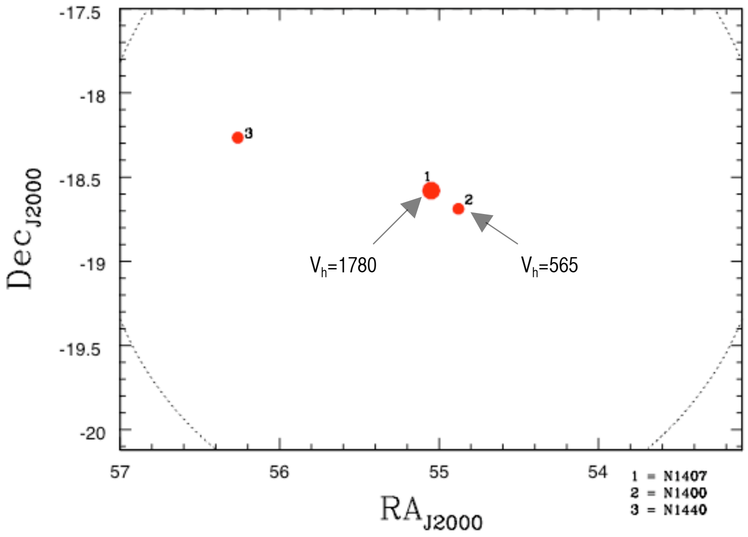
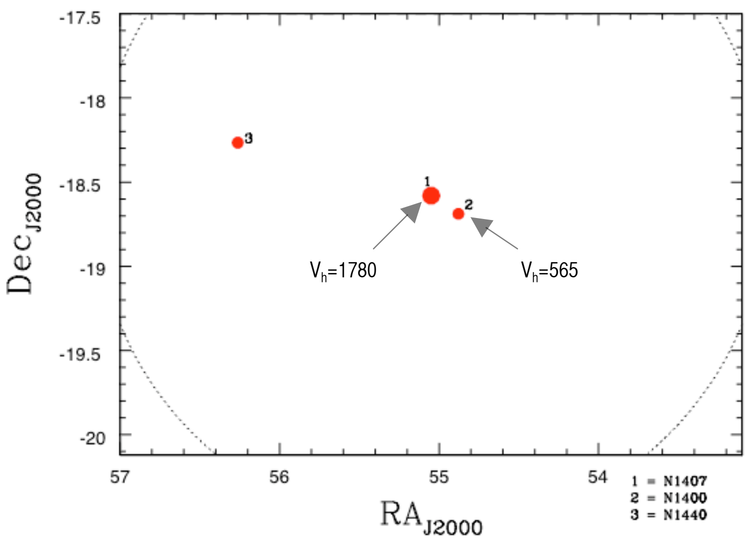

Galaxy Groups
as defined by the
Distribution of Dwarf Galaxies
Virgo
Centaurus
you are here
Brent Tully
University of Hawaii

L*

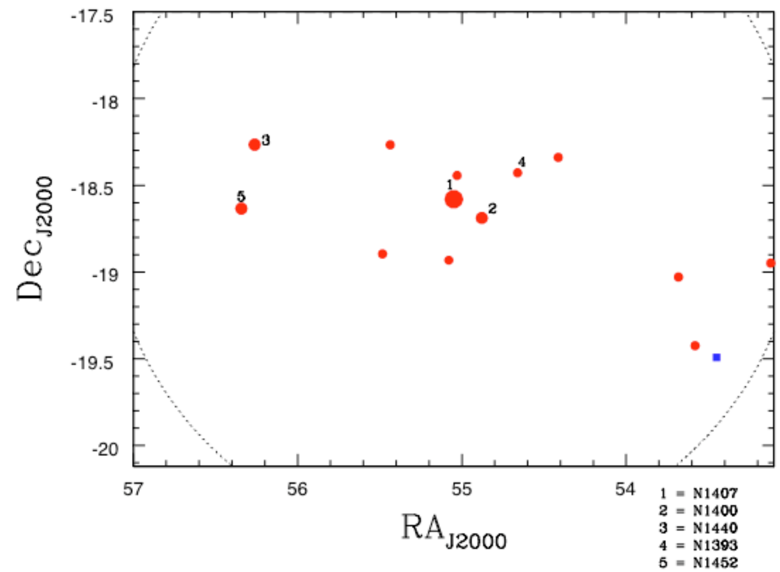


NGC 1407 Group

L*

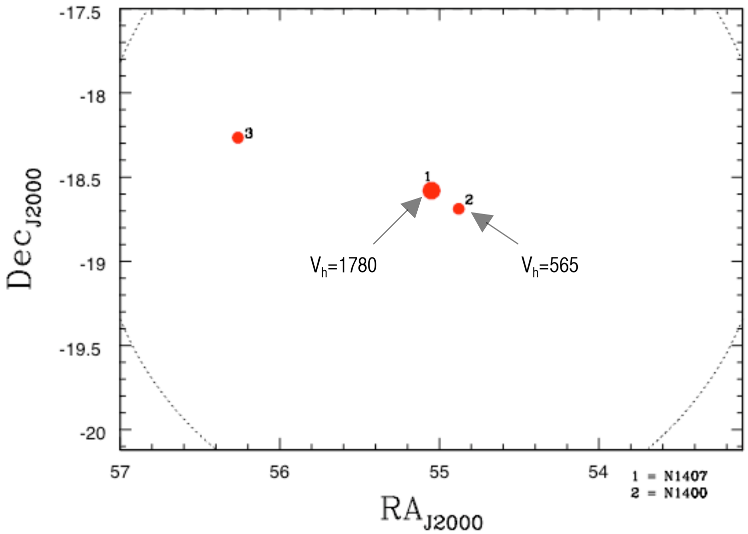


.1 L*

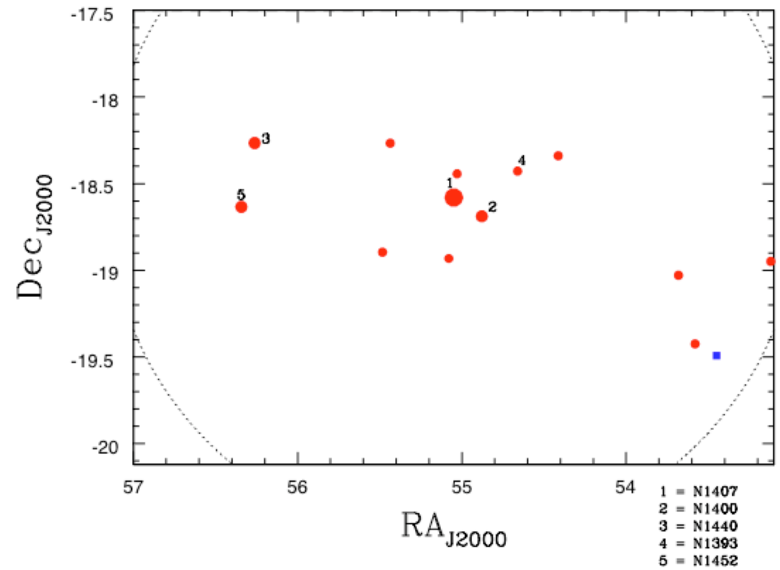


NGC 1407 Group

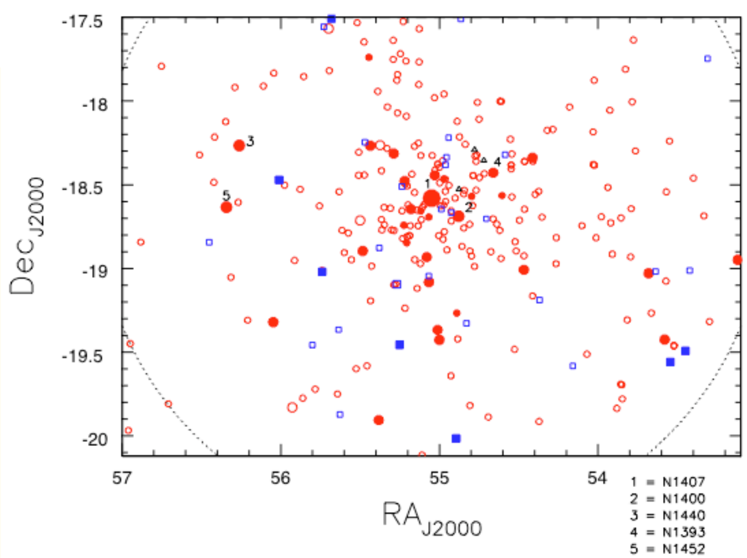
L*



.1 L*



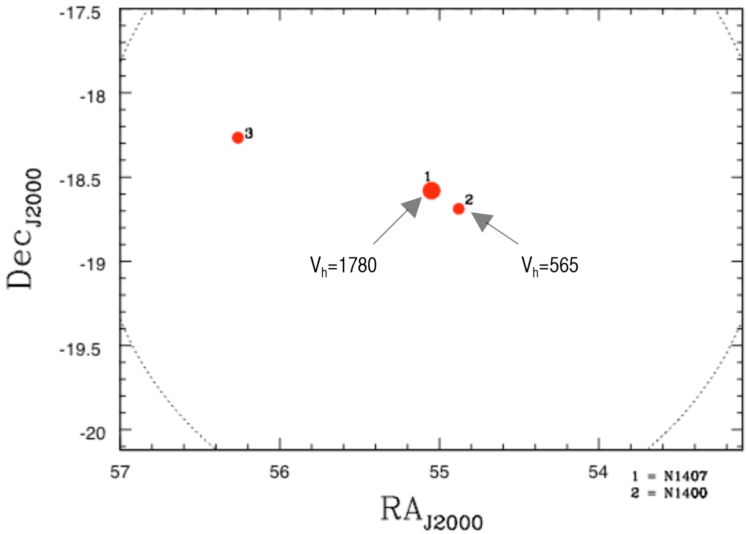
.0002 L*



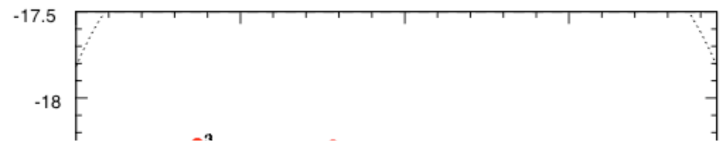
red: E - Sa
blue: Sab - Im

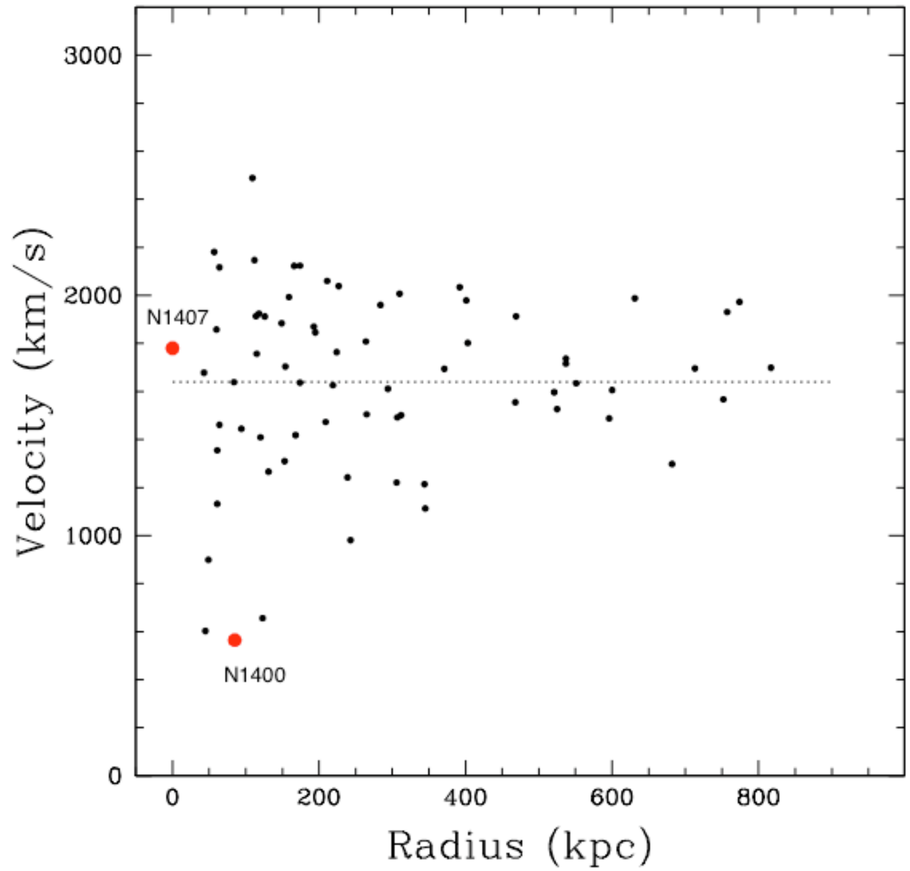
NGC 1407 Group

L*



.1 L*

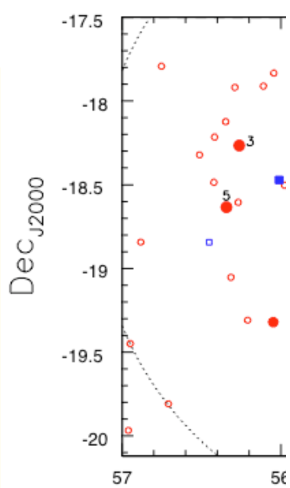




V_{rms}=381 km/s   69 velocities

Mass = $7 \times 10^{13}\ M_\odot$

$M/L_R = 340\ M_\odot/L_\odot$

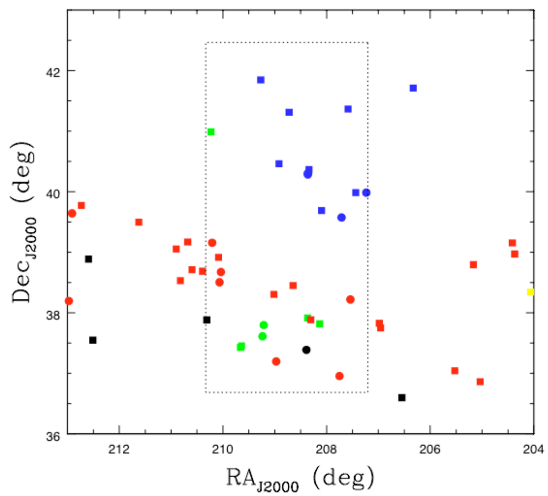


quasi- fossil group

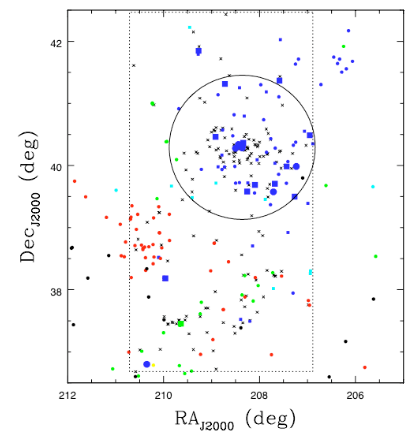
Trentham, Tully, Mahdavi 2006, MNRAS, 369, 1375

NGC 1407 Group

NGC 5353/4 Group

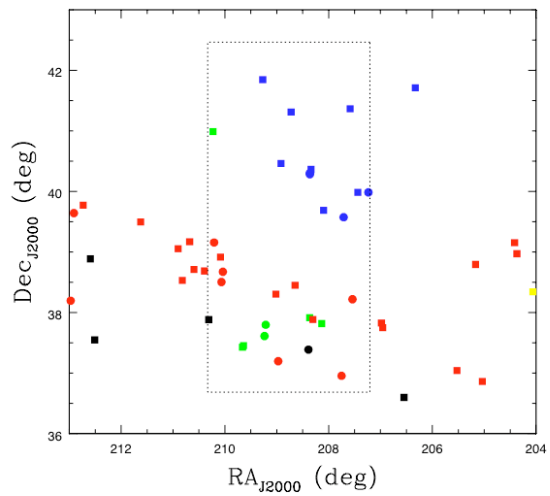


.1L*

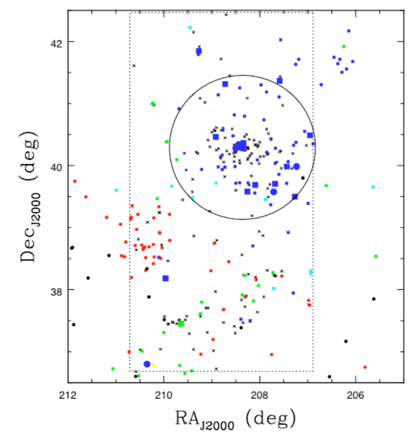


.0002L*

NGC 5353/4 Group



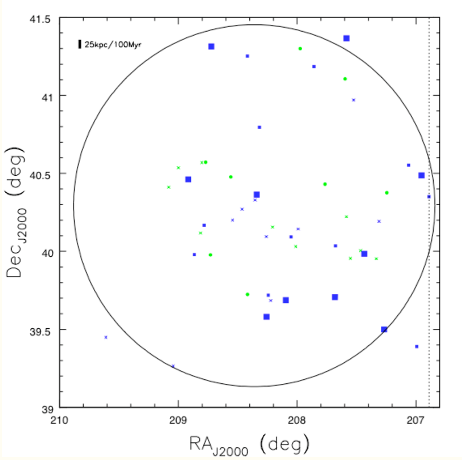
.1L*



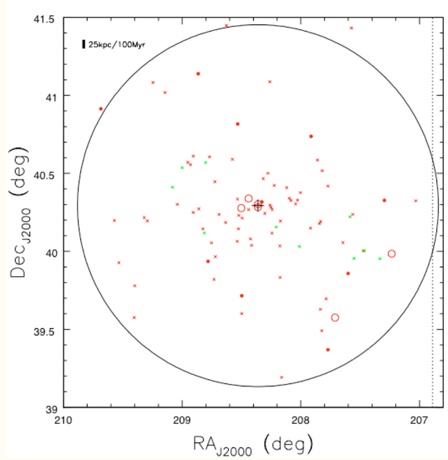
.0002L*

Hickson Compact Group 68

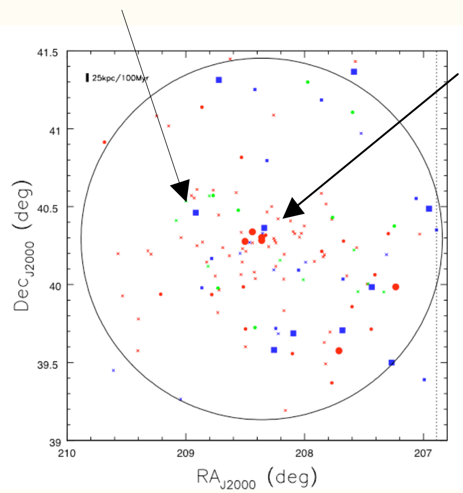
late - transition



early - transition

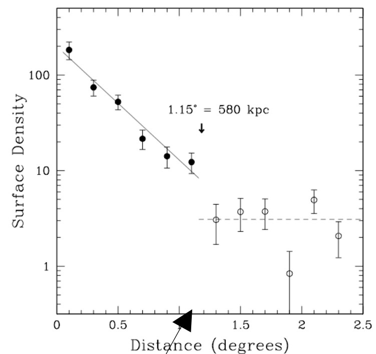


NGC 5371 - brightest galaxy in group

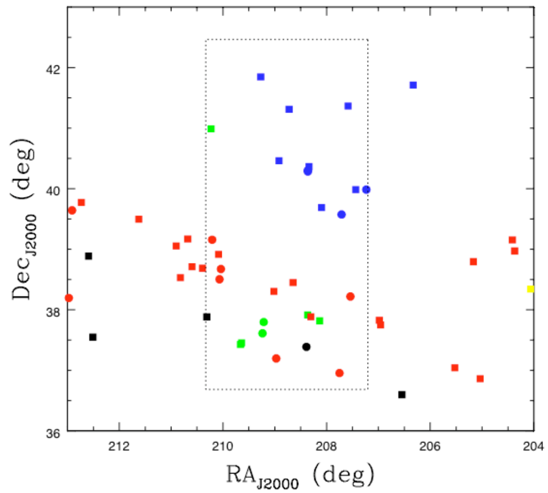


red: early
green: transition
blue: late

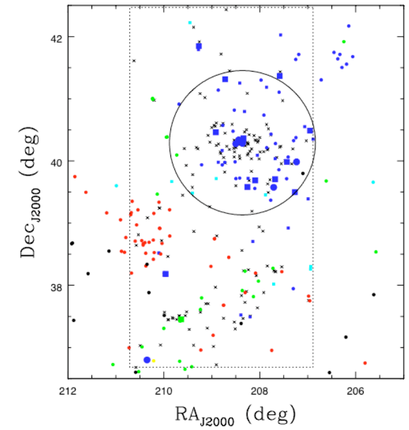
NGC 5353/4 Group



2nd turnaround



.1L*



.0002L*

V_{rms} = 205 km/s   53 velocities

mass = $2 \times 10^{13}\ M_{\odot}$

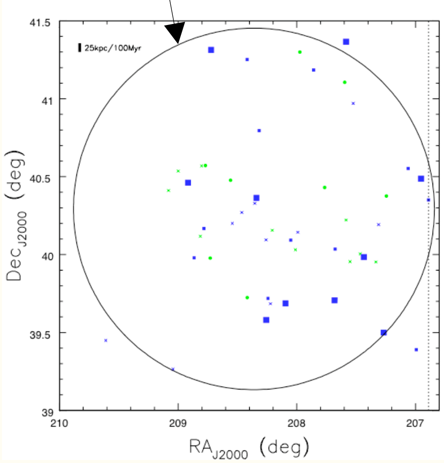
$M/L_R = 105\ M_{\odot}/L_{\odot}$

infall of late types onto an early type core

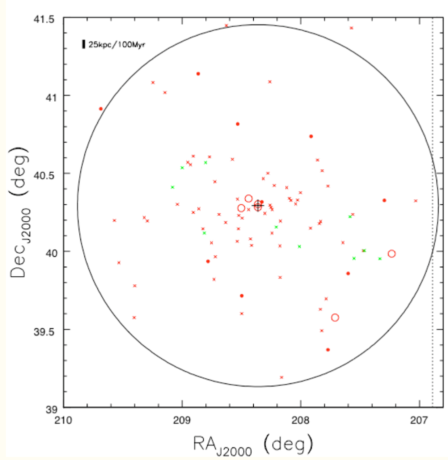
Tully, Trentham 2008, AJ, 135, 1488

Hickson Compact Group 68

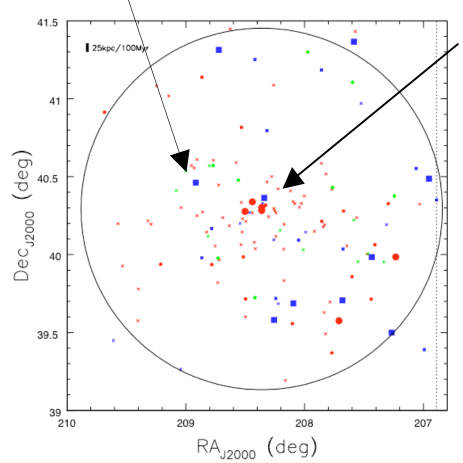
late – transition



early – transition



NGC 5371 - brightest galaxy in group



red: early
green: transition
blue: late

NGC 1023 Group

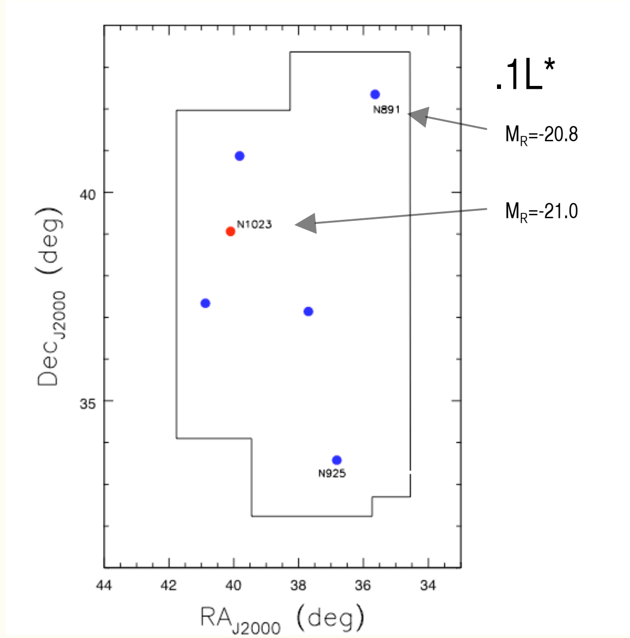
V_{rms} = 128 km/s   20 velocities

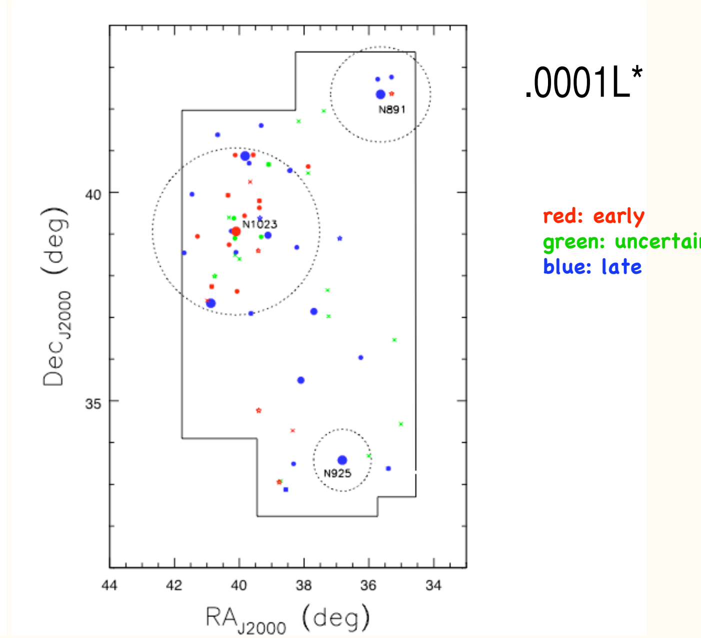
mass = 6×10^{12} $M_\odot$

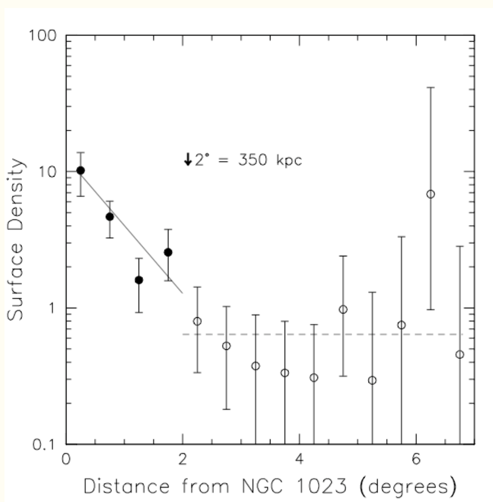
M/L_R = 280 $M_\odot/L_\odot$

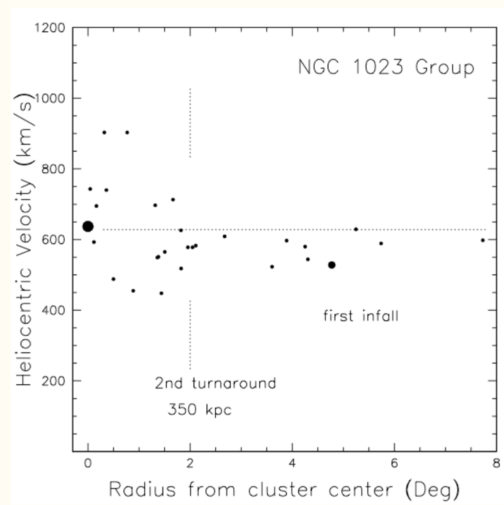
dominant S0

Trentham, Tully 2009, MNRAS (arXiv:0906.2540)



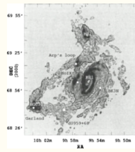


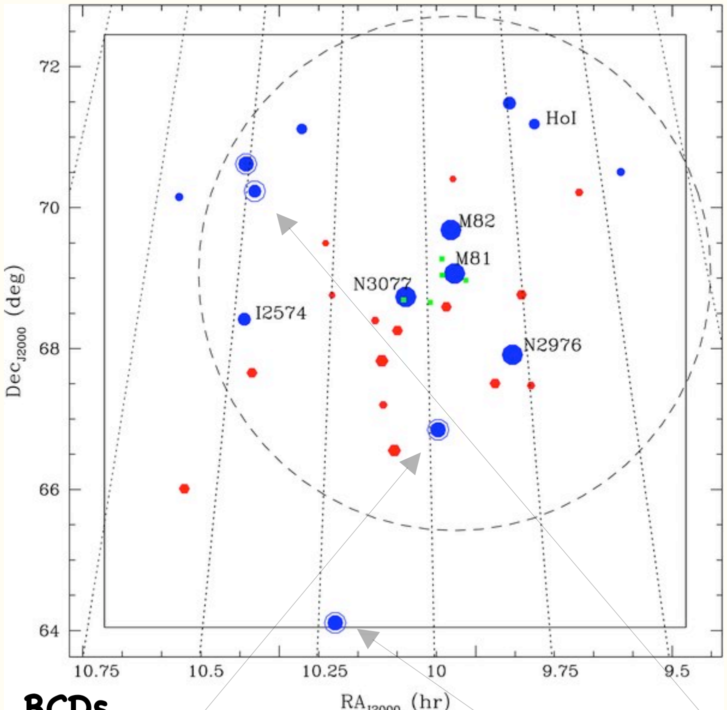


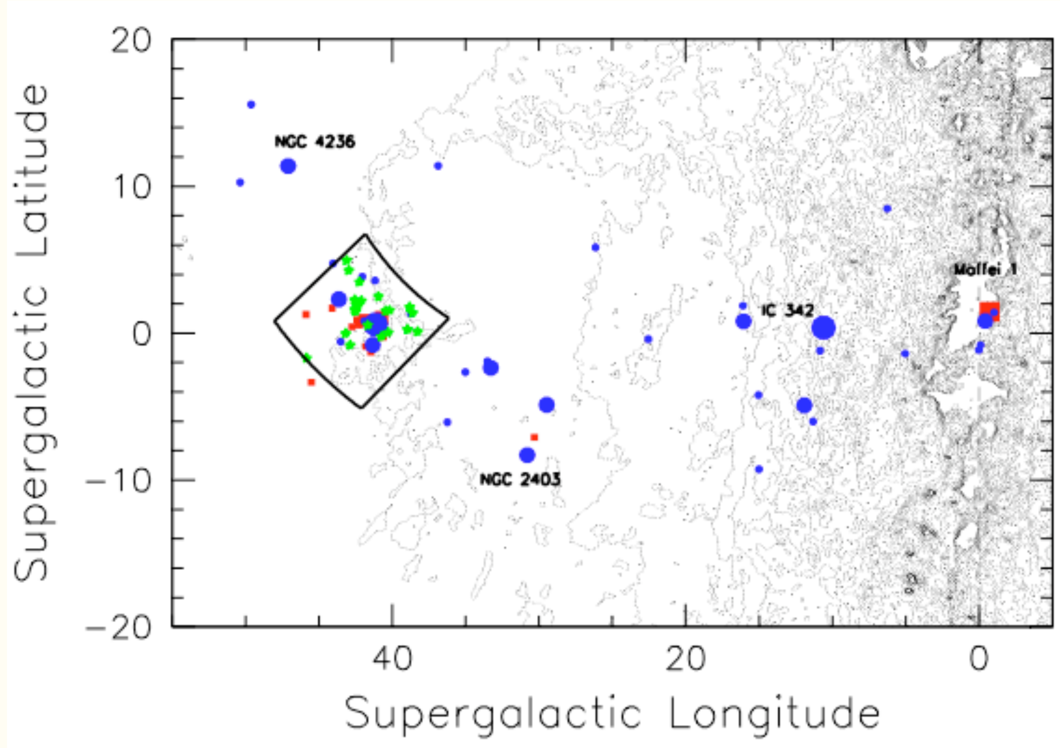


M81 Group

1 galaxy > L*
2 galaxies > .1 L*

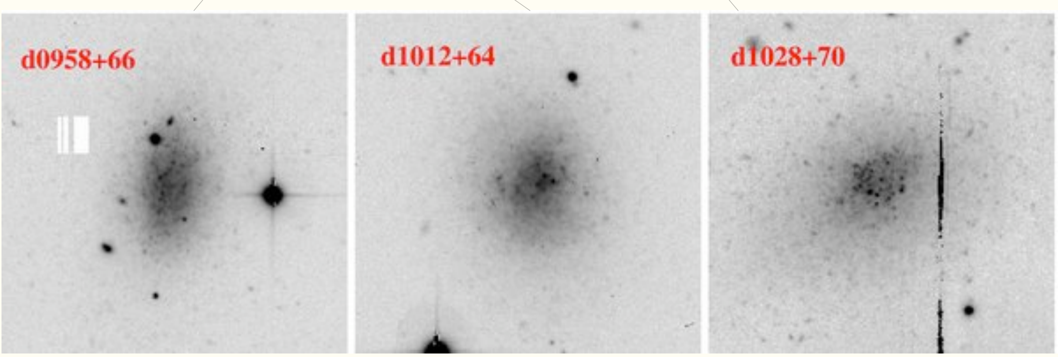






$2x10^{-4}$ L*

BCDs



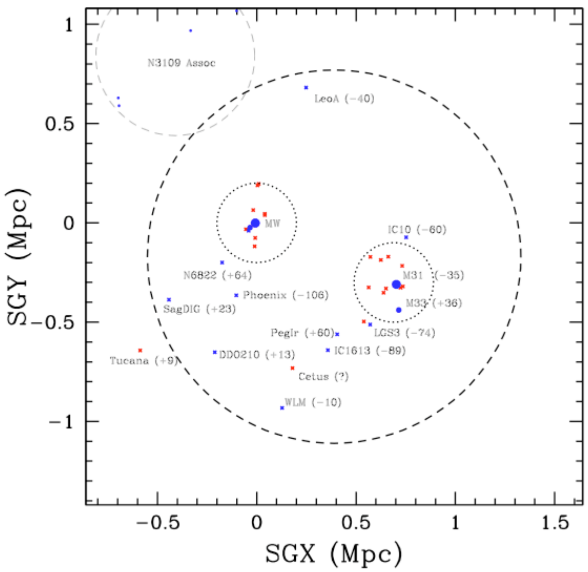
KUG 0954+670

UGC 5497

V_{rms} = 110 km/s   19 velocities
mass = $2x10^{12}$ $M_\odot$
M/L_R = 50 $M_\odot/L_\odot$

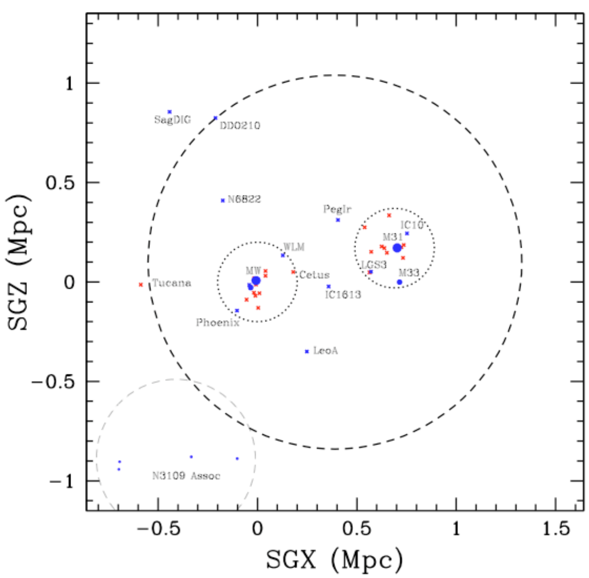
halo with one dominant galaxy

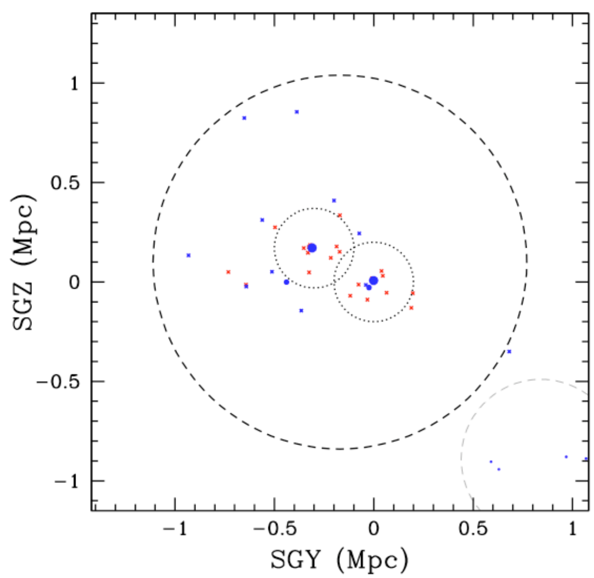
Chiboucas, Karachentsev, Tully 2009, AJ, 137, 3009



Local Group(s)

two halos within a common infall region

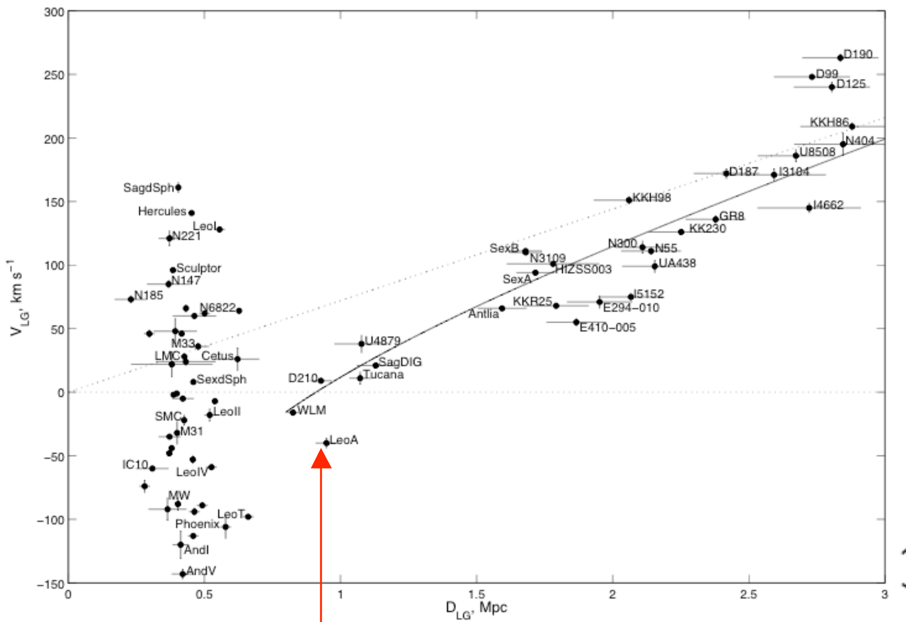




Milky Way:
mass = 1–2 10^{12} $M_\odot$

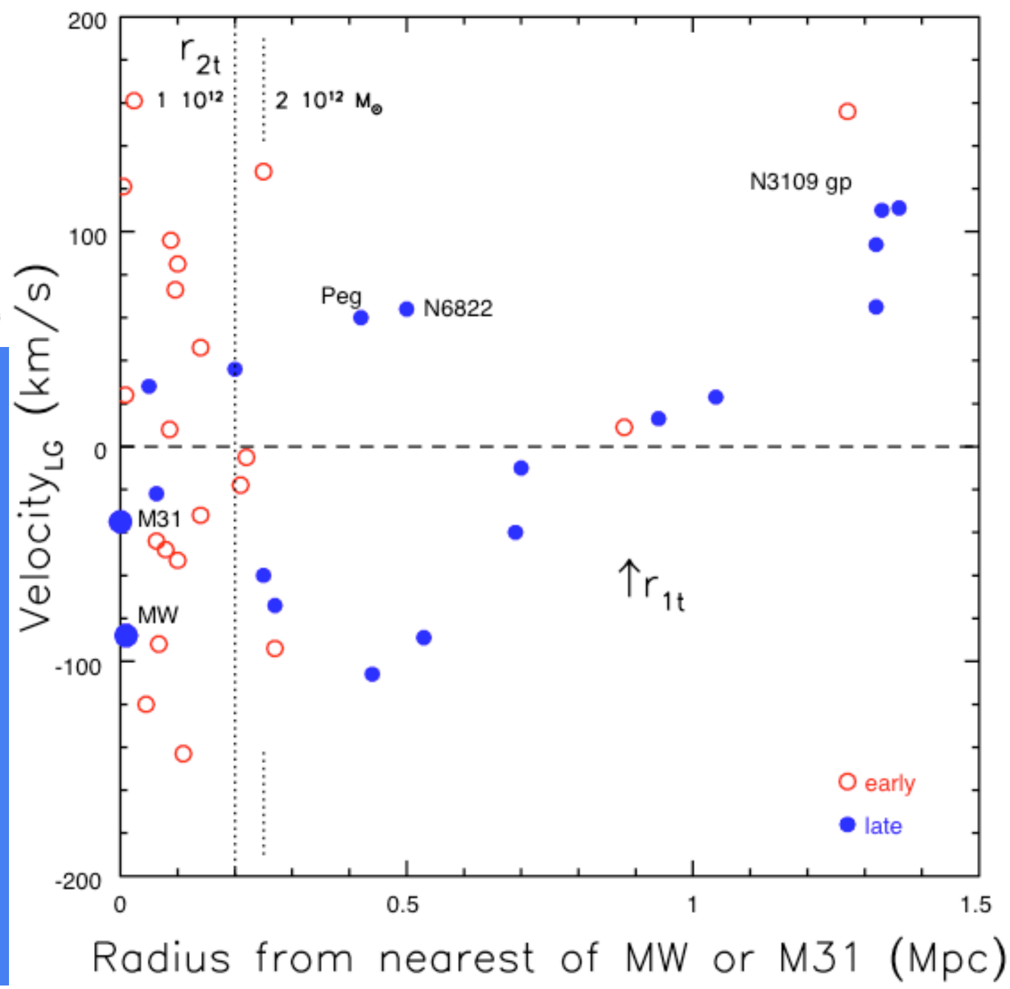
M31:
V_{RMS} = 77 km/s 16 velocities
mass = 2×10^{12} $M_\odot$
M/L_R = 38 $M_\odot/L_\odot$

Local Group(s) (continued)



r_{2t}

r_{1t}



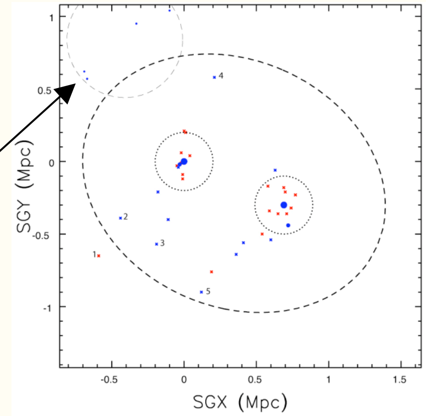
r_{1t} = 960 kpc

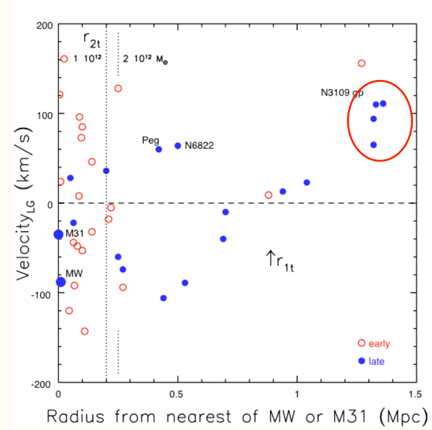
M_T(LG) = 1.9 10^{12} $M_\odot$

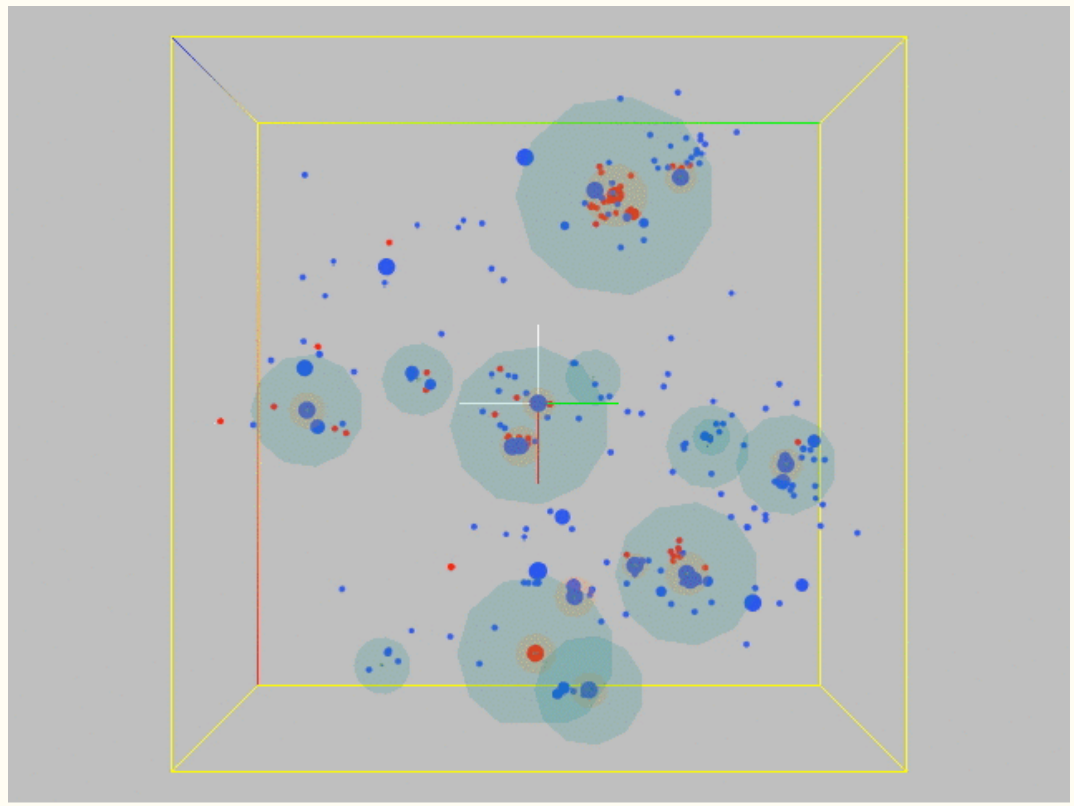
=> $r_{1t} = 0.78 \, M_{12}^{1/3}$ Mpc

Dwarf Associations

	Name	M_B	V_{LG}	D(Mpc)
NGC 3109 Group (14+12)	NGC 3109	-15.5	110	1.34
<d> = 1.37 Mpc	Sex B	-14.0	111	1.44
V_{RMS} = 18 km/s	Sex A	-13.8	94	1.43
mass = $2 \times 10^{11}\ M_\odot$	Antlia	-9.3	66	1.25
$M/L_B = 500\ M_\odot/L_\odot$	KKH 60	-7.8	108	-
NGC 55 Group (14+13)	NGC 55	-17.9	111	2.17
<d> = 2.07 Mpc	NGC 300	-17.7	114	2.04
V_{RMS} = 36 km/s	E407-018	-12.9	99	2.22
mass = $4 \times 10^{11}\ M_\odot$	E410-005	-11.6	176	1.94
$M/L_B = 100\ M_\odot/L_\odot$	E294-010	-11.0	81	1.96
NGC 4214 Group (14+7)	NGC 4214	-17.2	295	2.92
<d> = 2.92 Mpc	UGC 7577	-14.3	240	2.74
V_{RMS} = 41 km/s	NGC 4163	-13.8	171	2.94
mass = $6 \times 10^{11}\ M_\odot$	UGC 6817	-13.5	248	2.64
$M/L_B = 420\ M_\odot/L_\odot$	NGC 4190	-13.5	232	2.82
	NGC 3741	-13.2	263	3.19
	UGCA 276	-11.9	287	3.18
UGC 9240 Group (14+8)	UGC 9240	-14.2	263	2.80
<d> = 3.06 Mpc	UGC 8760	-13.2	257	3.24
V_{RMS} = 11 km/s	UGC 8651	-12.9	272	3.02
mass = $5 \times 10^{10}\ M_\odot$	UGC 8833	-12.4	285	3.20
$M/L_B = 380\ M_\odot/L_\odot$				

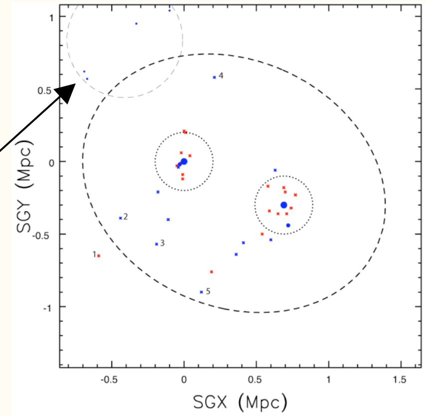


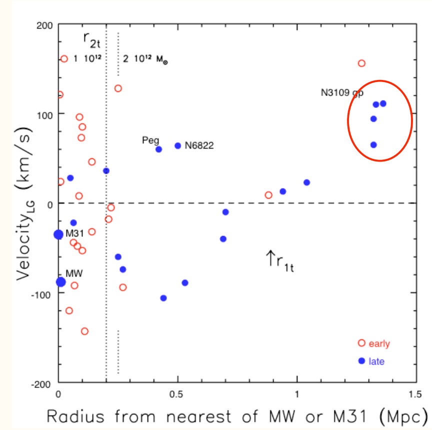


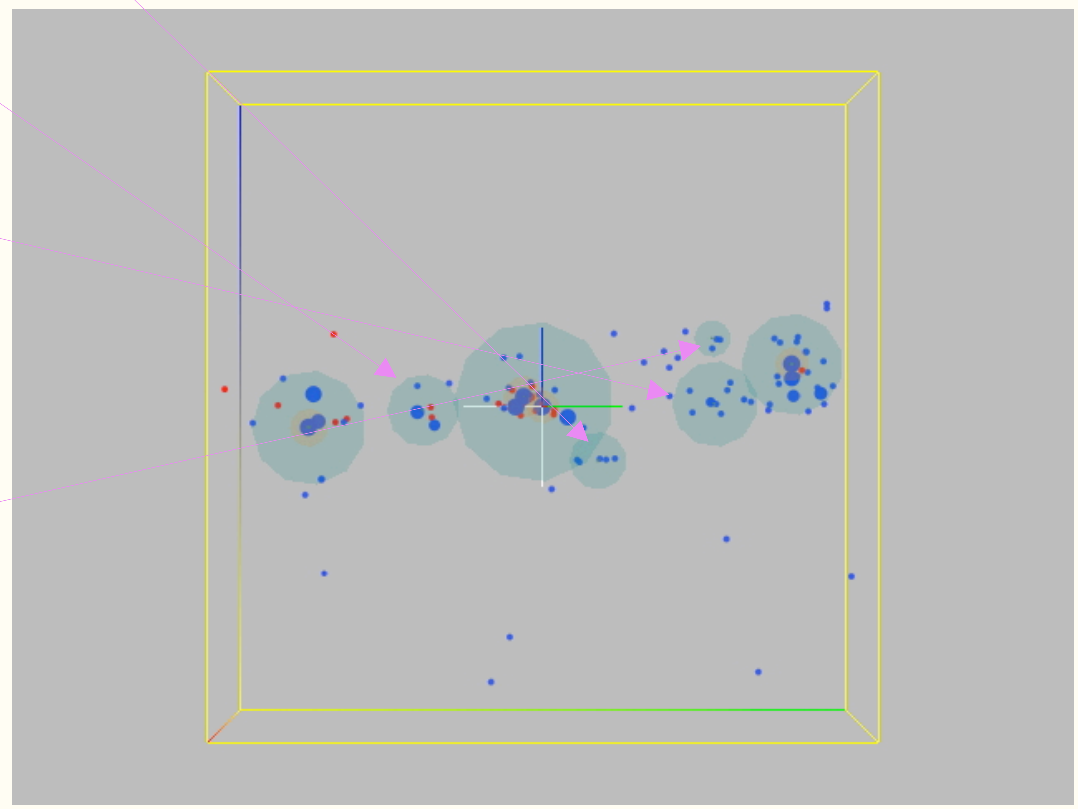


Dwarf Associations

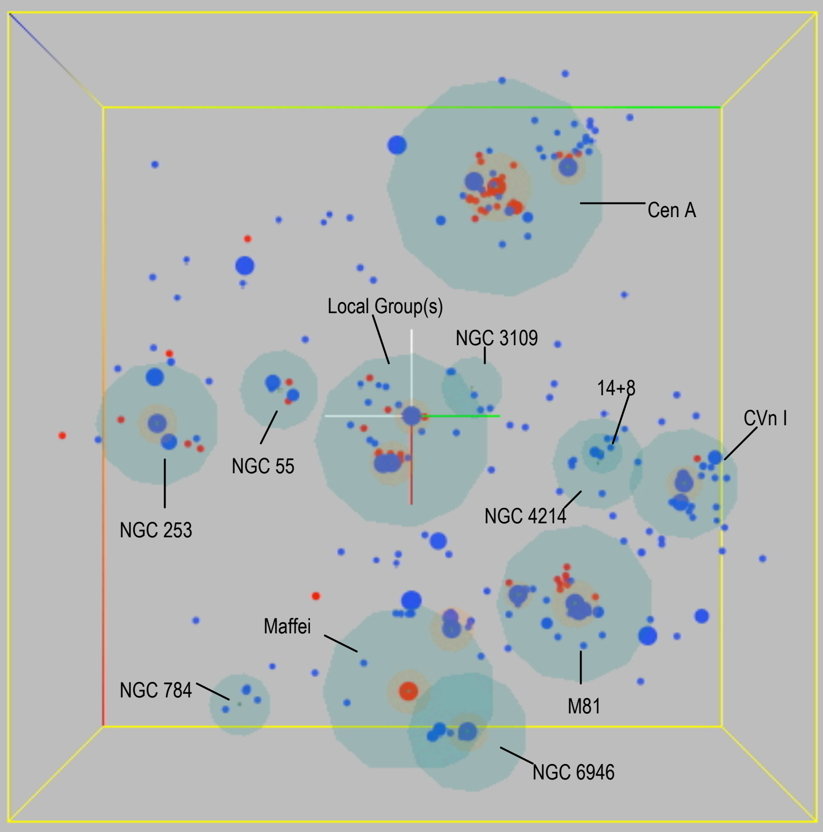
	Name	M_B	V_{LG}	D(Mpc)
NGC 3109 Group (14+12)	NGC 3109	-15.5	110	1.34
$\langle d \rangle$ = 1.37 Mpc	Sex B	-14.0	111	1.44
V_{RMS} = 18 km/s	Sex A	-13.8	94	1.43
mass = 2×10^{11} $M_\odot$	Antlia	-9.3	66	1.25
M/L_B = 500 $M_\odot/L_\odot$	KKH 60	-7.8	108	-
NGC 55 Group (14+13)	NGC 55	-17.9	111	2.17
$\langle d \rangle$ = 2.07 Mpc	NGC 300	-17.7	114	2.04
V_{RMS} = 36 km/s	E407-018	-12.9	99	2.22
mass = 4×10^{11} $M_\odot$	E410-005	-11.6	176	1.94
M/L_B = 100 $M_\odot/L_\odot$	E294-010	-11.0	81	1.96
NGC 4214 Group (14+7)	NGC 4214	-17.2	295	2.92
$\langle d \rangle$ = 2.92 Mpc	UGC 7577	-14.3	240	2.74
V_{RMS} = 41 km/s	NGC 4163	-13.8	171	2.94
mass = 6×10^{11} $M_\odot$	UGC 6817	-13.5	248	2.64
M/L_B = 420 $M_\odot/L_\odot$	NGC 4190	-13.5	232	2.82
	NGC 3741	-13.2	263	3.19
	UGCA 276	-11.9	287	3.18
UGC 9240 Group (14+8)	UGC 9240	-14.2	263	2.80
$\langle d \rangle$ = 3.06 Mpc	UGC 8760	-13.2	257	3.24
V_{RMS} = 11 km/s	UGC 8651	-12.9	272	3.02
mass = 5×10^{10} $M_\odot$	UGC 8833	-12.4	285	3.20
M/L_B = 380 $M_\odot/L_\odot$				

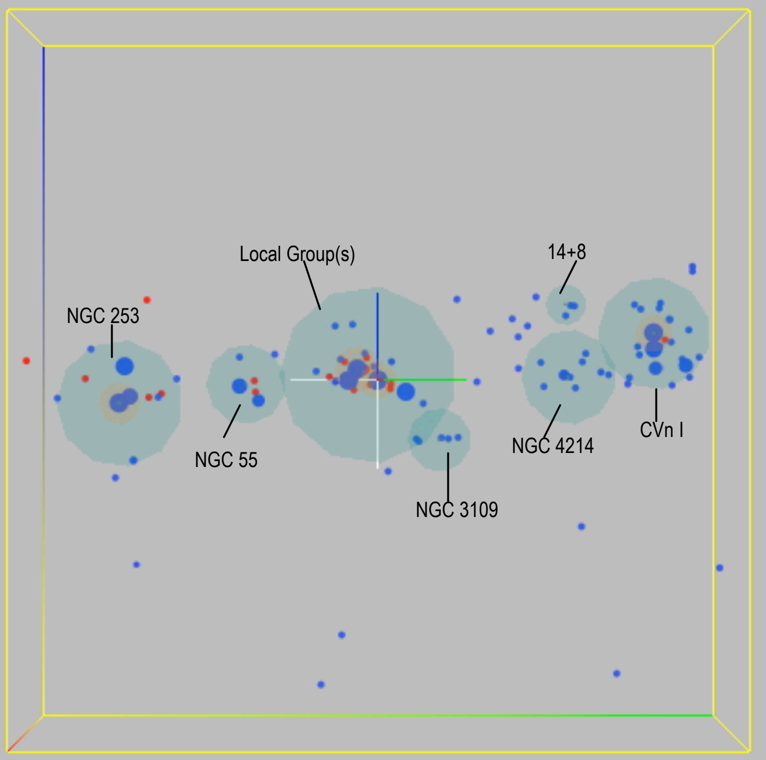




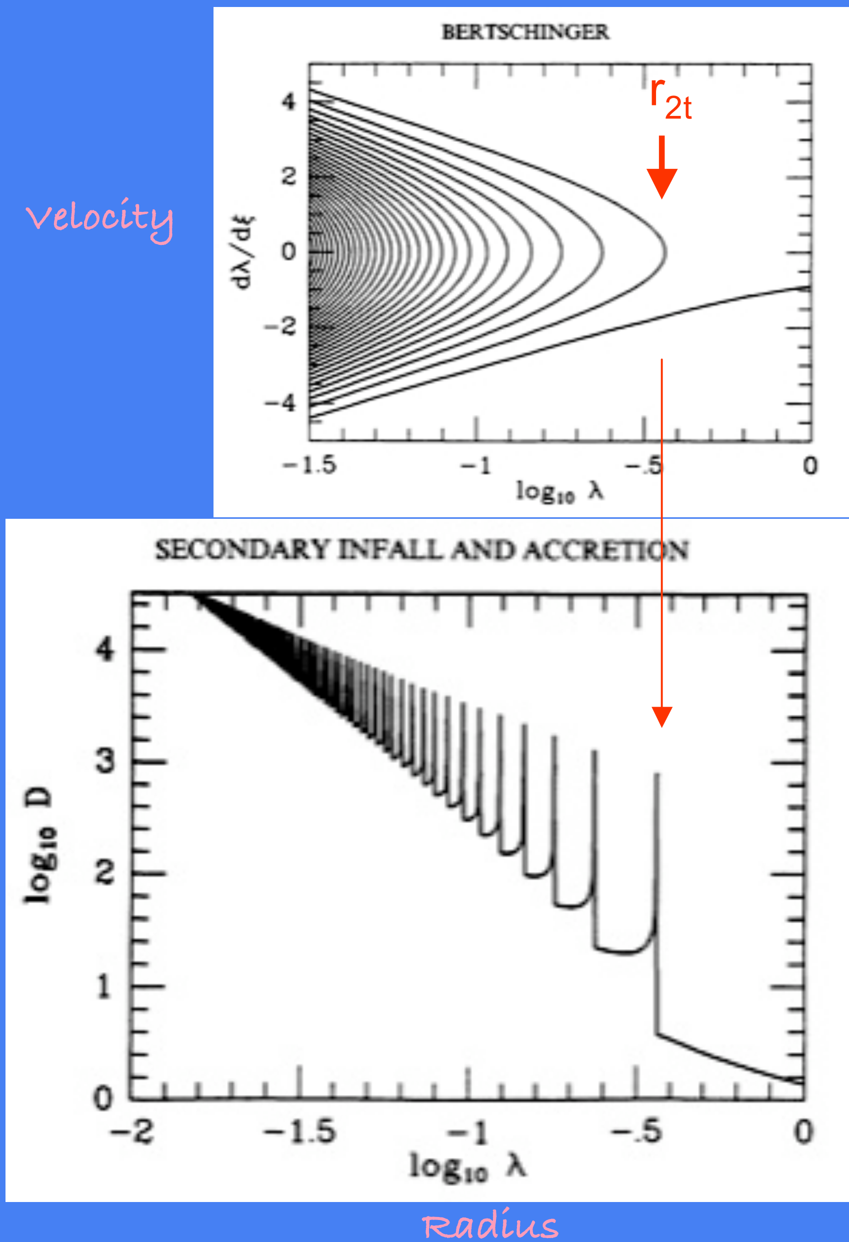


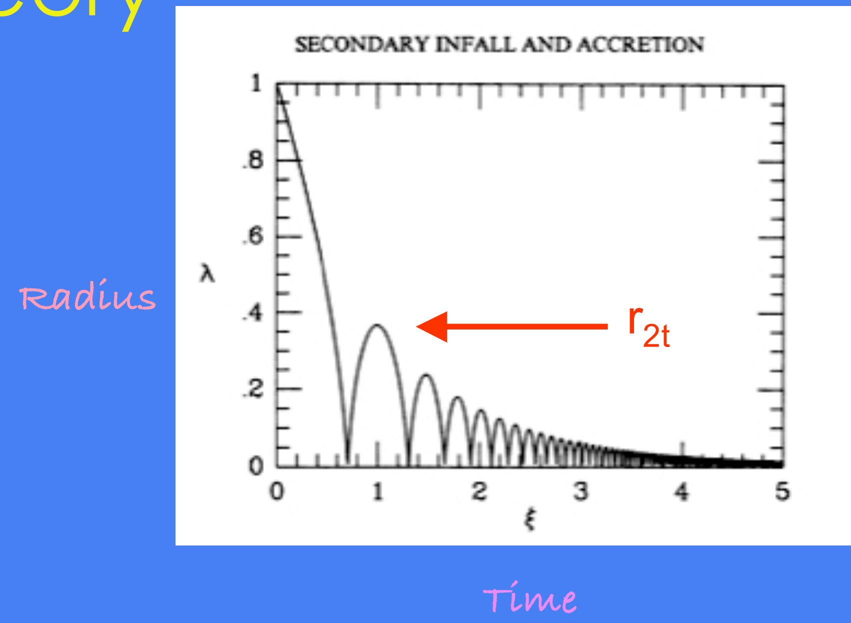
The Nearest Groups / Associations





Considerations from theory





Spherical infall of cold, collisionless particles:

- object at first turnaround today at t_0 (radius r_{1t}) will fully collapse by $2t_0$
- object at second turnaround today (radius r_{2t}) was at first turnaround at $0.37\ t_0$

Useful observable manifestations of infall and caustics?

I. Mass - radius scaling relations

$$t_{collapse} \sim \rho^{-1/2} \sim (r^3/M)^{1/2}$$

Useful observable manifestations of infall and caustics?

I. Mass - radius scaling relations

$$t_{collapse} \sim \rho^{-1/2} \sim (r^3/M)^{1/2}$$

For two structures at the same phase of collapse today:

$$r_1{}^3/M_1 = r_2{}^3/M_2$$

$$\boxed{r_1 = r_2\,(M_1/M_2)^{1/3}}$$

Useful observable manifestations of infall and caustics?

I. Mass - radius scaling relations

$$t_{collapse} \sim \rho^{-1/2} \sim (r^3/M)^{1/2}$$

$M \sim \sigma_{rms}^2 \, r_{2t}$

So at $t_{collapse}$ = today $\quad r_{2t}^3 / \sigma_{rms}^2 \, r_{2t}$ = constant

$$\sigma_{rms} \sim r_{2t}$$

Useful observable manifestations of infall and caustics?

I. Mass - radius scaling relations

$r_{2t} \sim M^{1/3}$ $\sigma_{rms} \sim r_{2t}$

Useful observable manifestations of infall and caustics?

I. Mass - radius scaling relations

$$r_{2t} \sim M^{1/3} \qquad \sigma_{rms} \sim r_{2t}$$

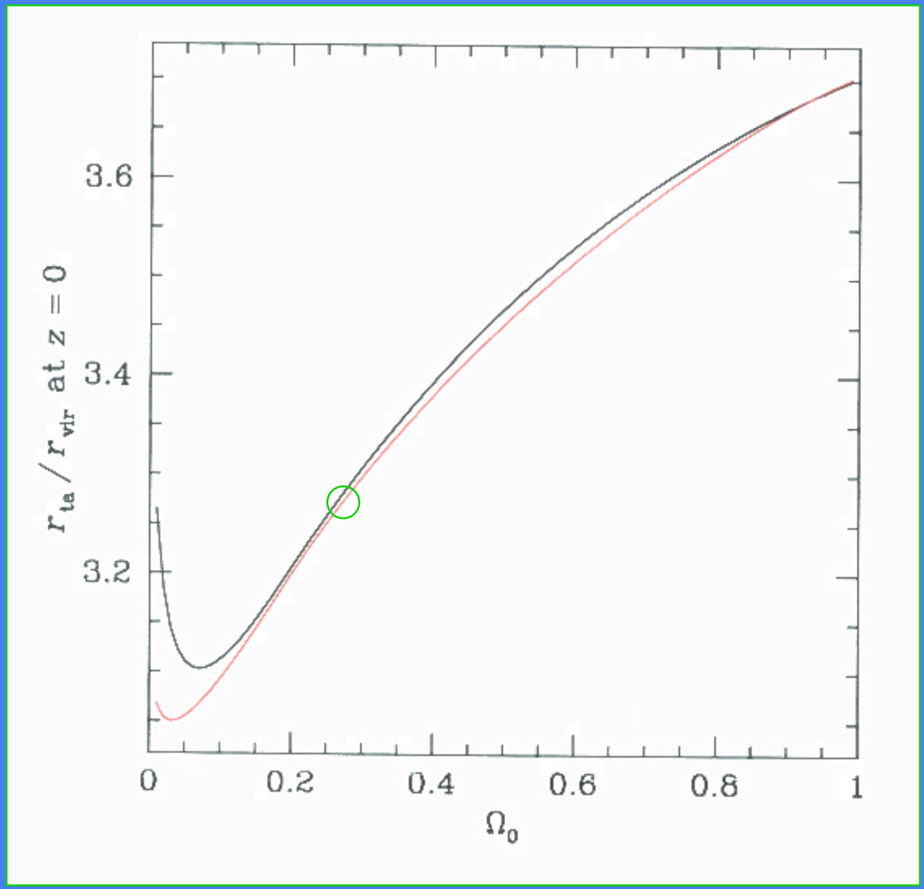
$$\boxed{M \sim \sigma_{rms}^{3}}$$

II. Manifestation of Dark Energy:

almost no effect on relation between mass and 2nd turnaround radius r_{2t}

but affects the rate of the development of structure so affects the relation between 1st and 2nd turnaround r_{1t} / r_{2t}

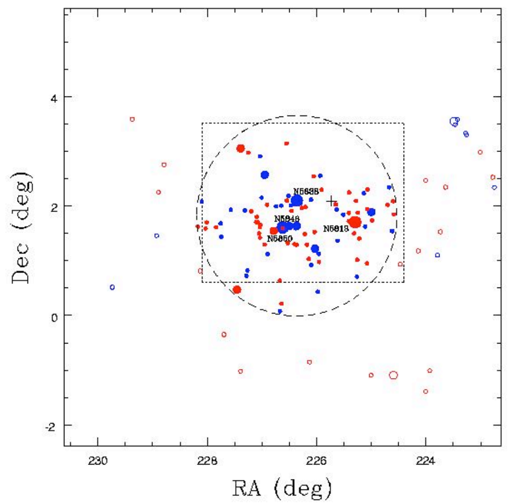
$r_{vir} = .92\ r_{2t}$

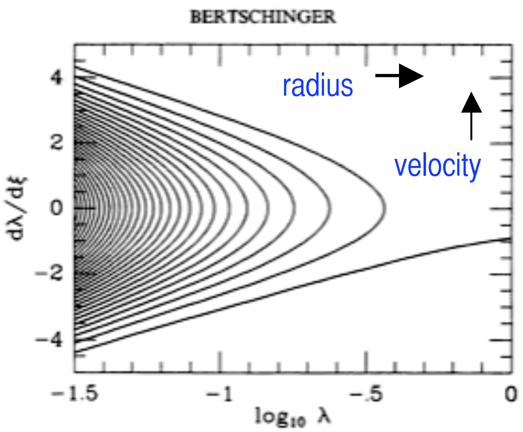


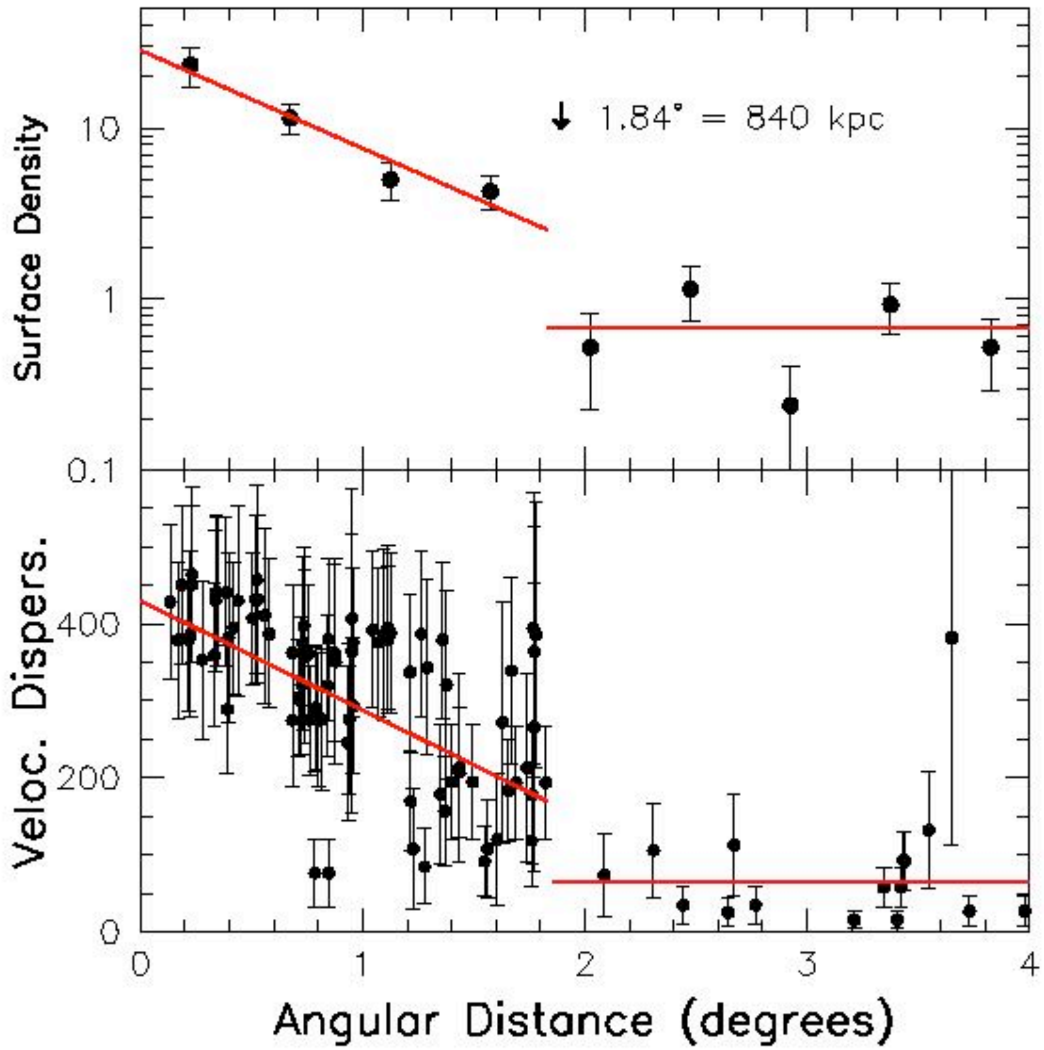
Mamon

Ω_m in a flat universe

Caustic of 2nd turnaround in N5846 group (continued)



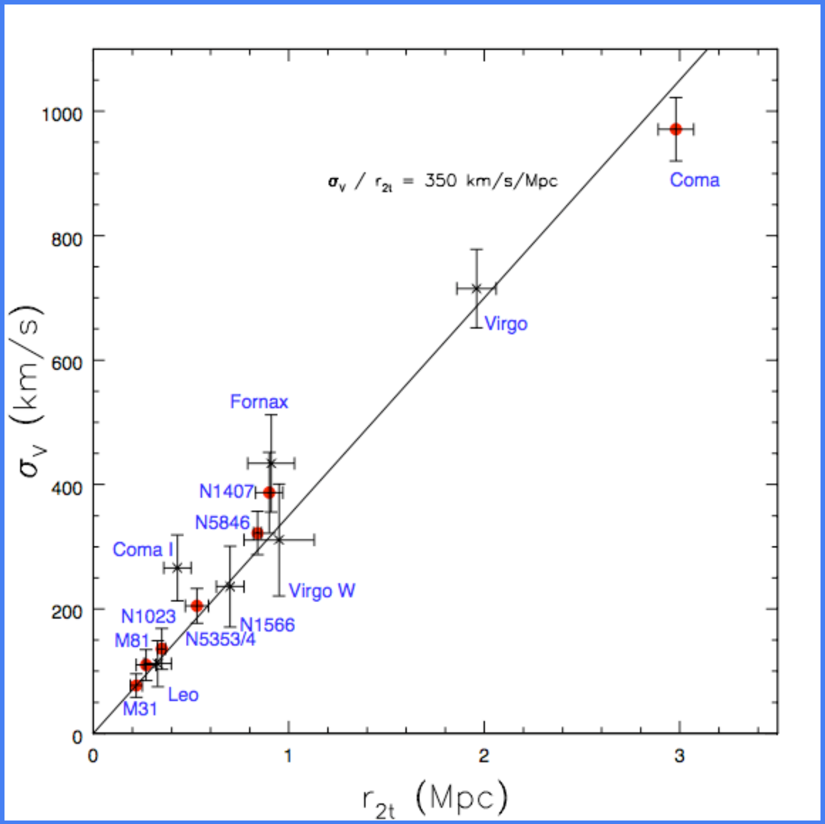


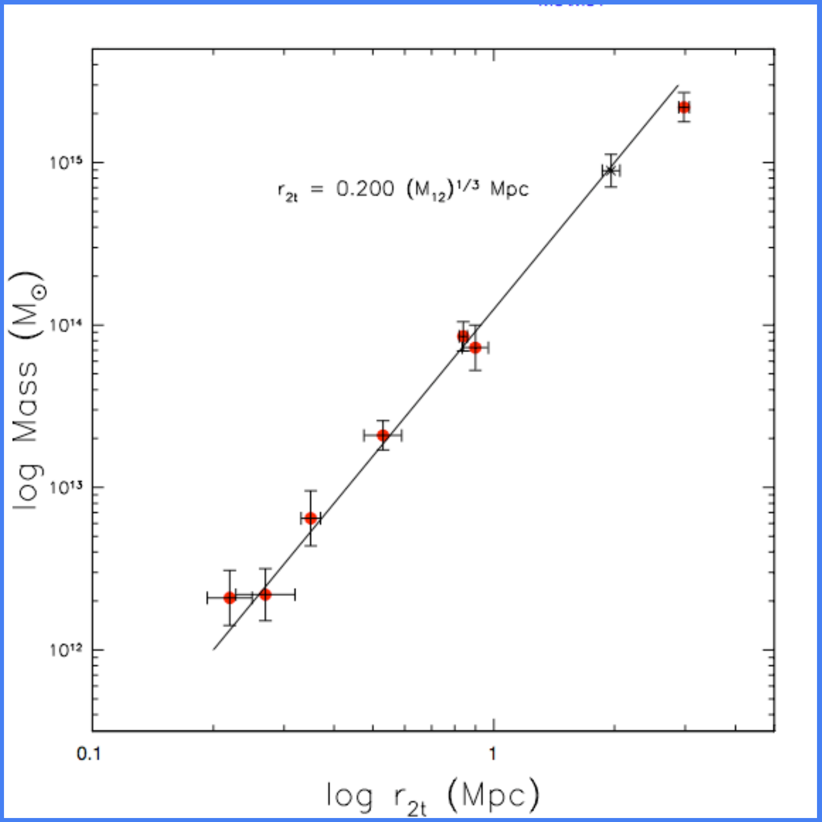


σ_{rms} = 322 km/s

r_{2t} = 840 kpc

Caustic of 2nd turnaround r_{2t} correlations





Red: results from wide field imaging with CFHT MegaCam

N5846: Mahdavi et al. 2005, AJ, 130, 1502

N1407: Trentham et al. 2006, MNRAS, 369, 1375

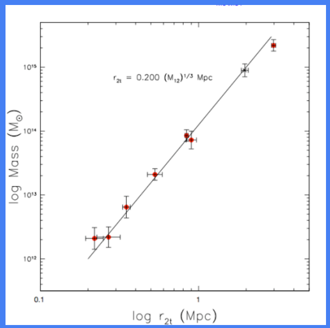
N5353/4: Tully & Trentham 2008, AJ, 135, 1488

N1023: Trentham & Tully 2009, MNRAS, in press

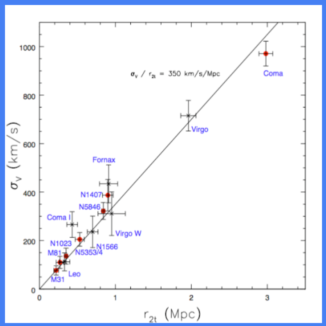
M81: Chiboucas et al. 2009, AJ, 137, 3009

Cluster Mass - Velocity Dispersion Relation

$r_{2t} = .2(M_{12})^{1/3}$



$= \sigma_V/350$



implies

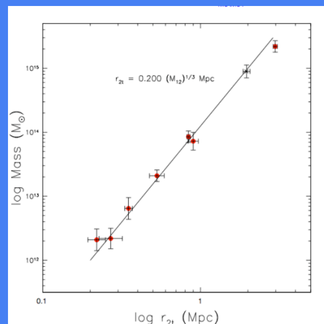
$$M = 2.5\ 10^6\ \sigma_V^{\ 3}$$

virial mass ($M_\odot$)

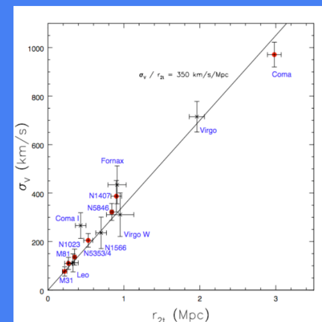
1D velocity dispersion within r_{2t} (km/s)

Cluster Mass - Velocity Dispersion Relation

$r_{2t} = .2(M_{12})^{1/3}$



$= \sigma_V/350$

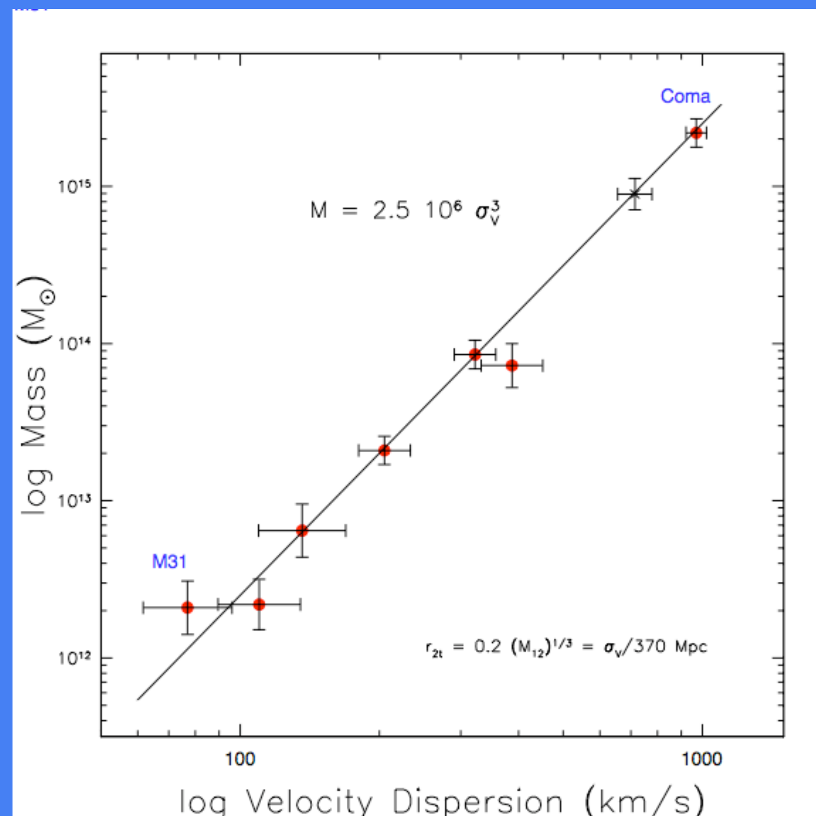


implies

$$M = 2.5\ 10^6\ \sigma_V^3$$

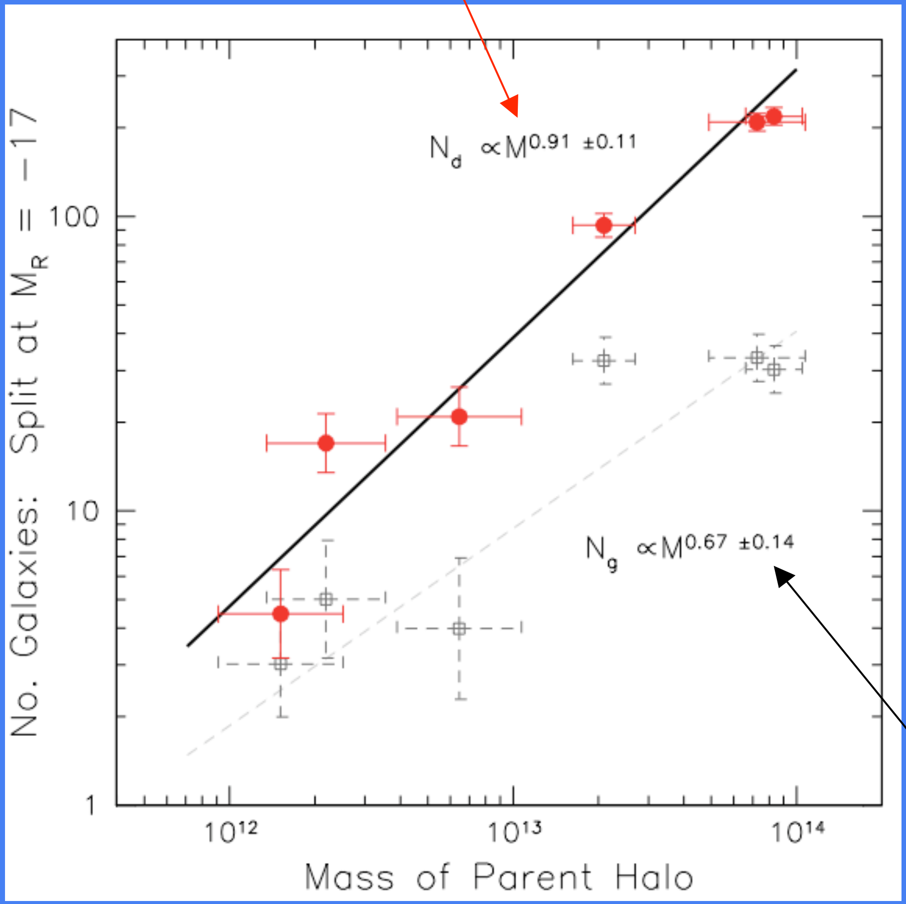
virial mass ($M_\odot$)

1D velocity dispersion within r_{2t} (km/s)



Correlation between group mass and dwarf population!

No. dwarfs per unit parent halo mass ~ constant

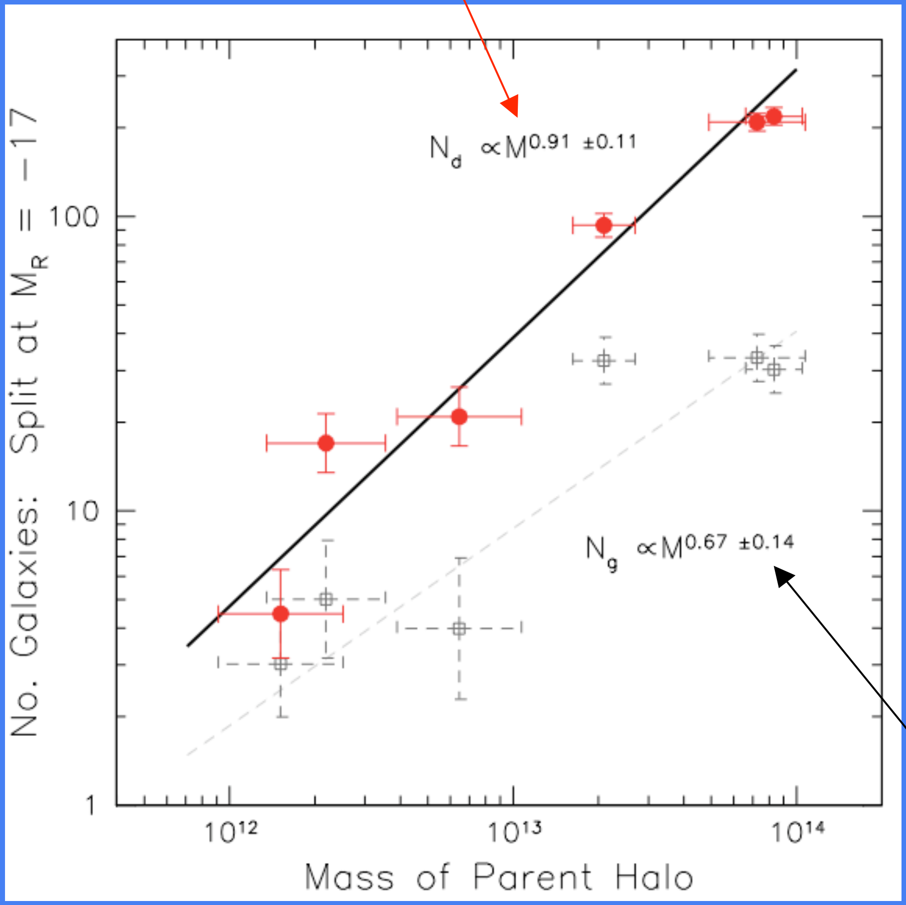


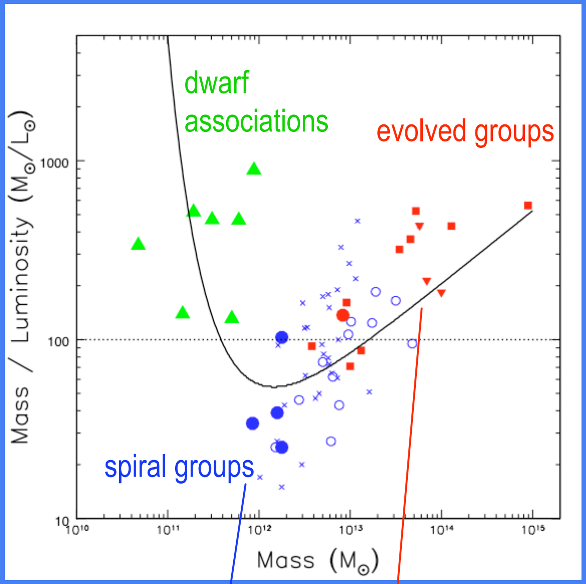
dwarf: $-17 < M_R < -11$ giant: $M_R < -17$

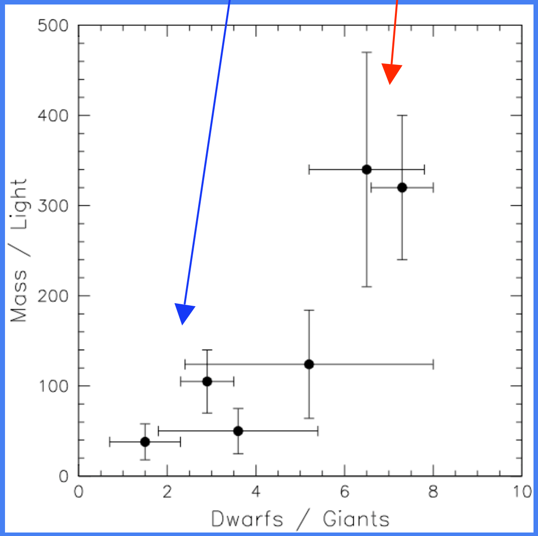
Fewer giants per unit parent halo mass in more dynamically evolved halos

Correlation between group mass and dwarf population!

No. dwarfs per unit parent halo mass ~ constant



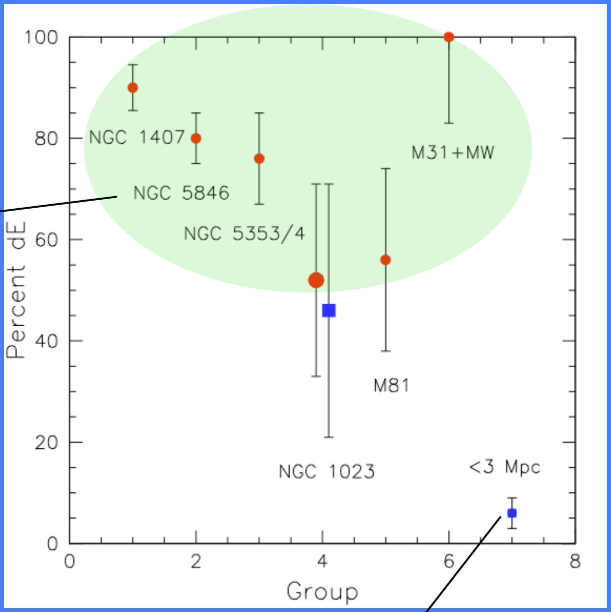




dwarf: $-17 < M_R < -11$ giant: $M_R < -17$

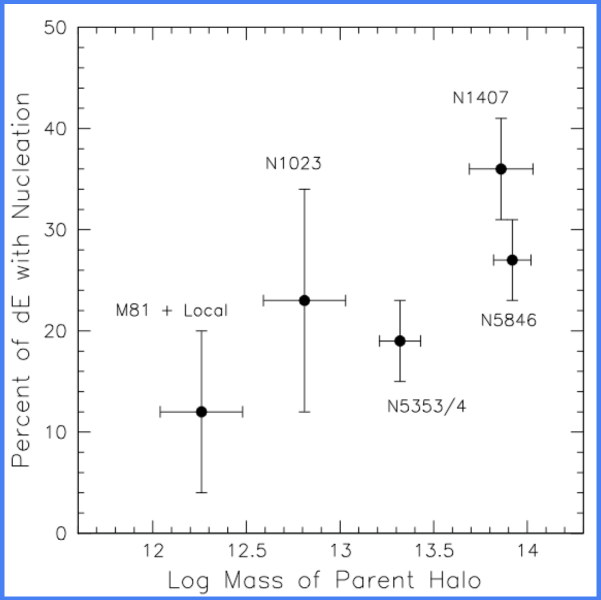
Fewer giants per unit parent halo mass in more dynamically evolved halos

dwarf properties



most dwarfs within the radius of 2nd turnaround are gas-poor, particularly in the most dynamically evolved environments

most dwarfs outside massive halos are gas-rich

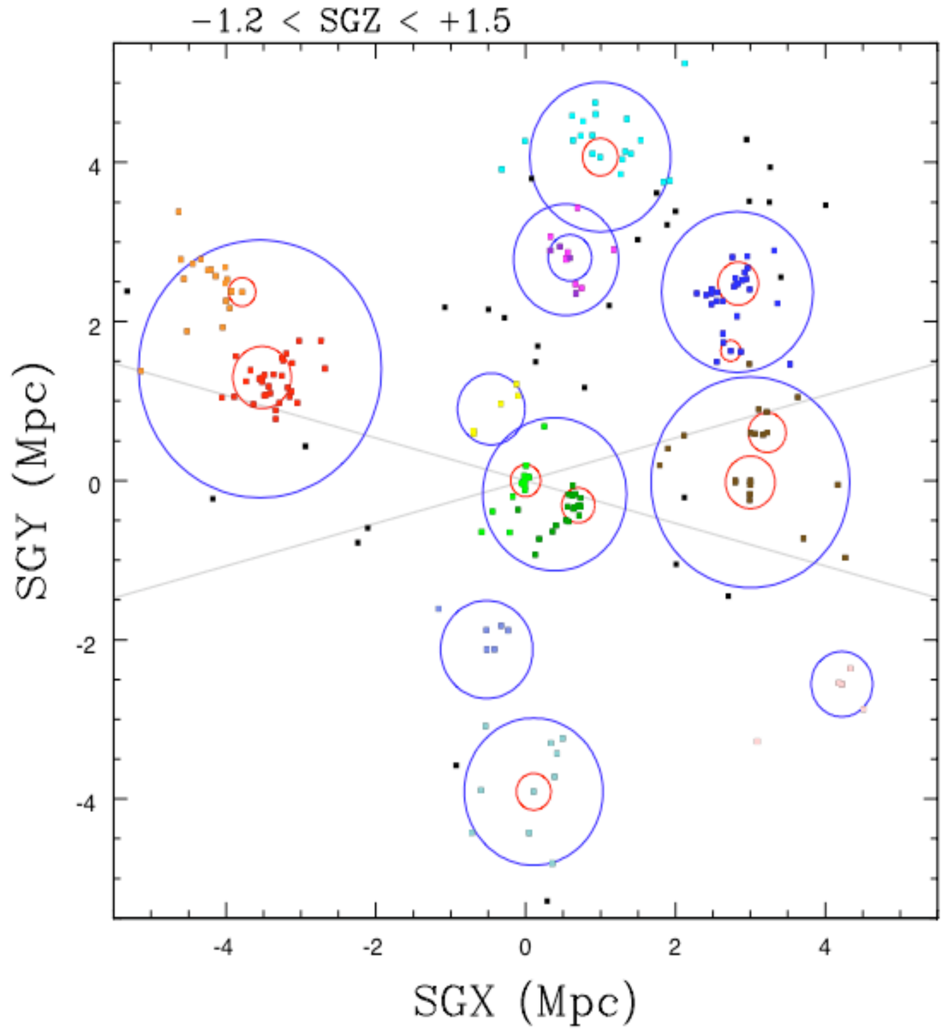


a higher fraction of gas-poor dwarfs are nucleated in more massive, dynamically evolved halos

The Local Sheet

red circles: 2nd turnaround r_{2t}

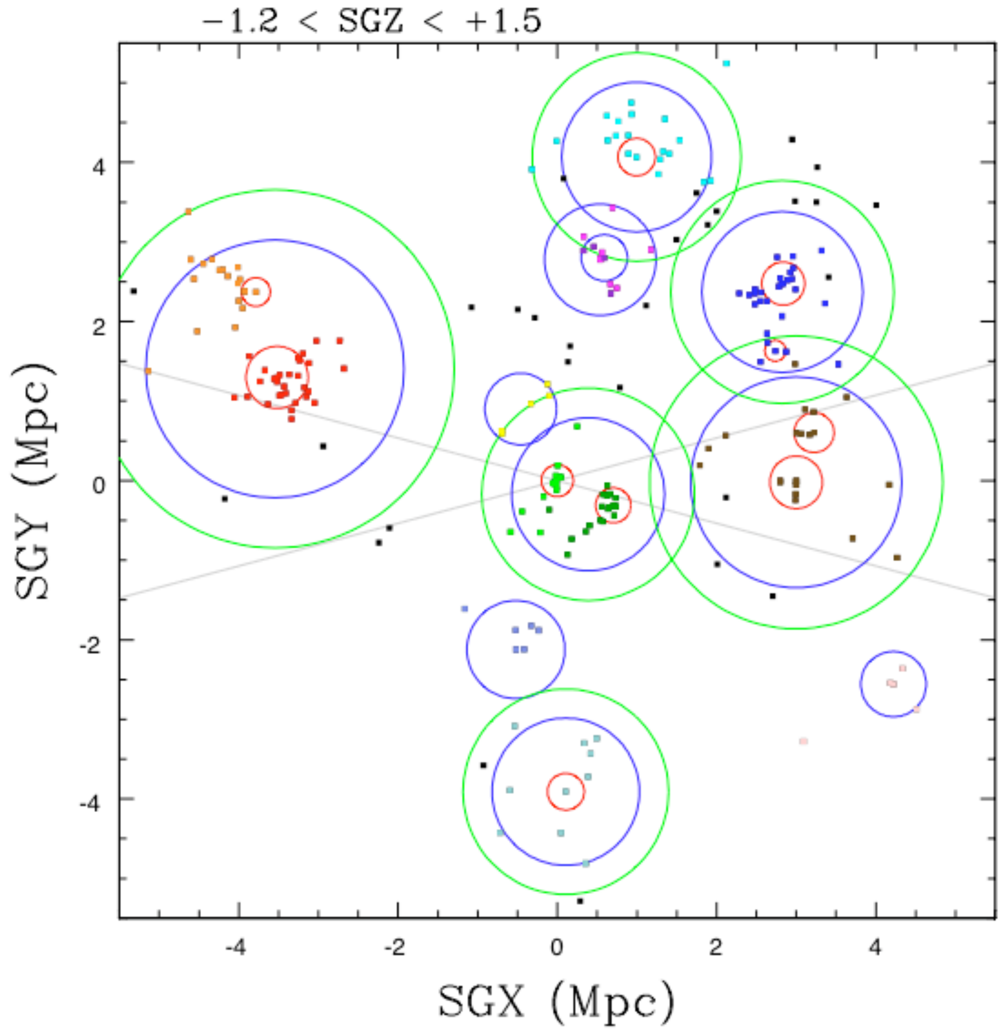
blue circles: zero velocity r_{1t}



The Local Sheet

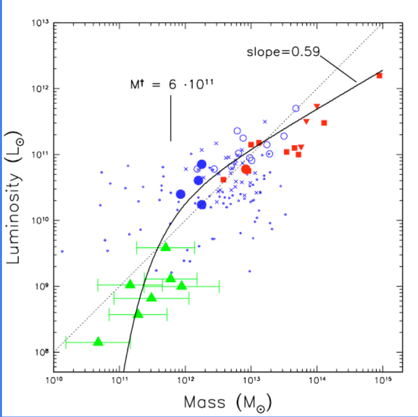
red circles: 2nd turnaround r_{2t}
blue circles: zero velocity r_{1t}

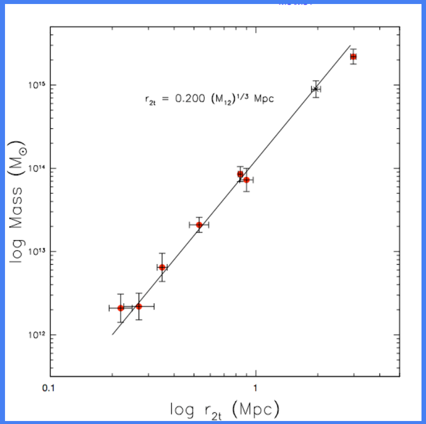
green circles: zero gravity surface
(Ω_Λ=0.7, spherical infall, no angular momentum)



Summary

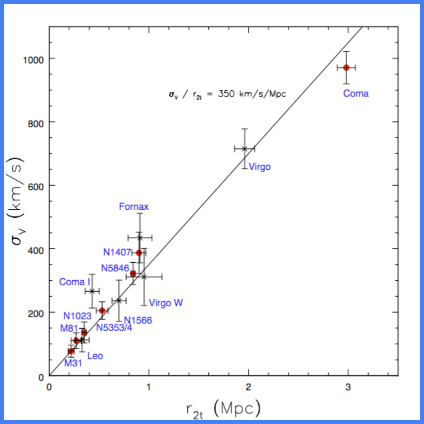
Light to mass varies with environment
$L_B = 3.25\ 10^{10}\ M_{12}^{.59}\ e^{-(0.6/M_{12})}$





Observed caustic of 2nd turnaround
strongly correlated with virial mass
$r_{2t} = 0.200\ (M_{12})^{1/3}$ Mpc

and with velocity dispersion
interior to 2nd turnaround
$r_{2t} = \sigma_v$ / 350 Mpc

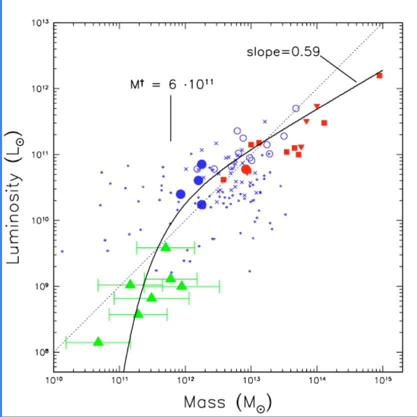


⇒ mass of parent halo
$M_{12} = 2.5\ 10^{-6}\ \sigma_v^{\ 3}$

Summary

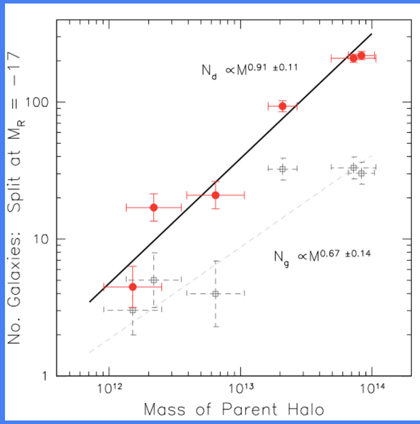
Light to mass varies with environment

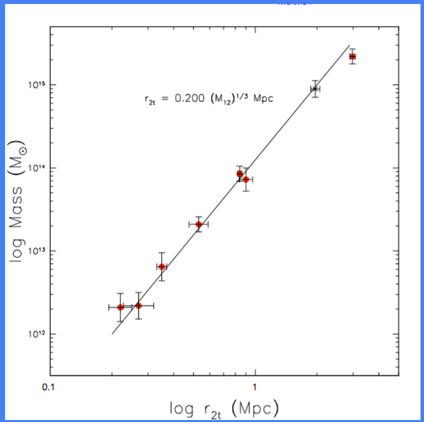
$L_B = 3.25\ 10^{10}\ M_{12}^{.59}\ e^{-(0.6/M_{12})}$



No. dwarfs correlated with halo mass

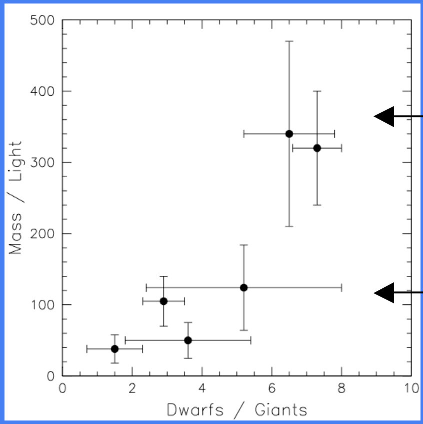
$N_d \sim M^{.91}$





Observed caustic of 2nd turnaround strongly correlated with virial mass

$r_{2t} = 0.200\ (M_{12})^{1/3}$ Mpc

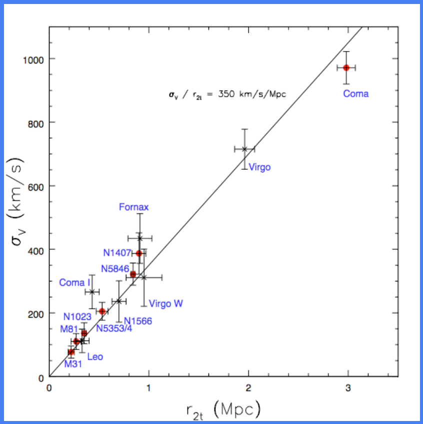


dynamically evolved

spiral rich

and with velocity dispersion interior to 2nd turnaround

$r_{2t} = \sigma_v / 350$ Mpc



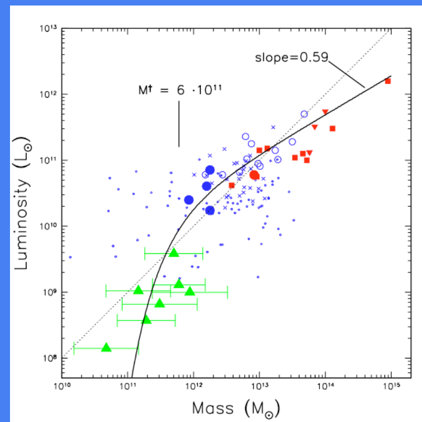
$\Rightarrow$ mass of parent halo

$M_{12} = 2.5\ 10^{-6}\ \sigma_v^{\ 3}$

Summary

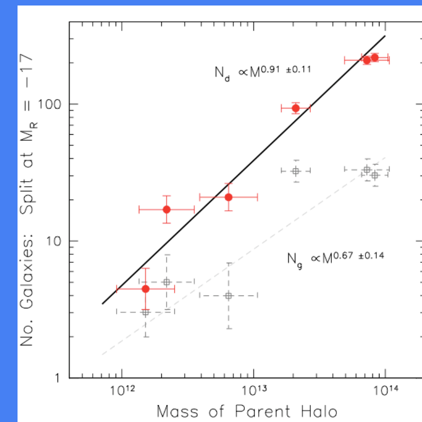
Light to mass varies with environment

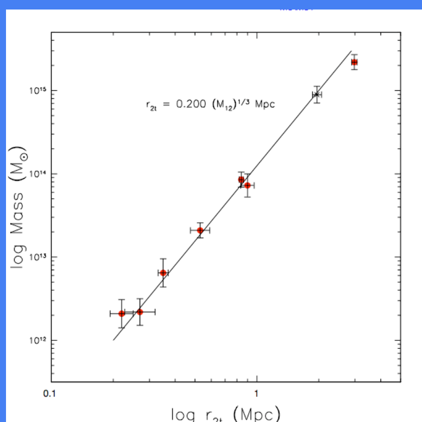
$L_B = 3.25\ 10^{10}\ M_{12}^{.59}\ e^{-(0.6/M_{12})}$



No. dwarfs correlated with halo mass

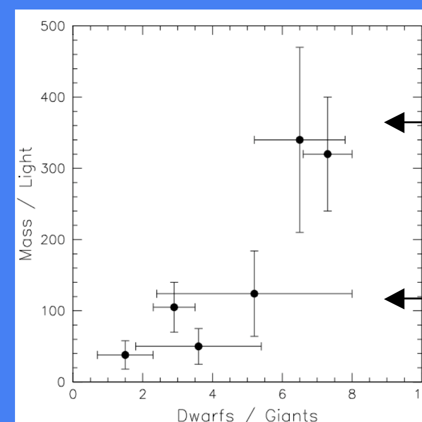
$N_d \sim M^{.91}$





Observed caustic of 2nd turnaround strongly correlated with virial mass

$r_{2t} = 0.200\ (M_{12})^{1/3}$ Mpc



dynamically evolved

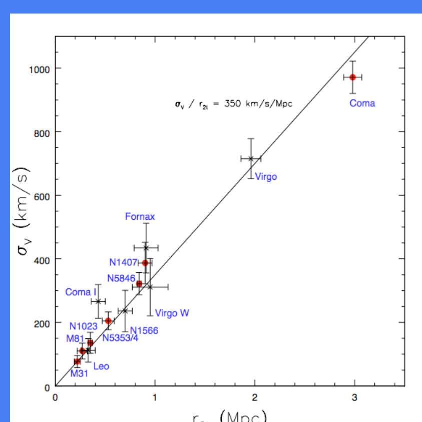
spiral rich

and with velocity dispersion interior to 2nd turnaround

$r_{2t} = \sigma_v / 350$ Mpc

$\Rightarrow$ mass of parent halo

$M_{12} = 2.5\ 10^{-6}\ \sigma_v^{\ 3}$



most dwarfs inside r_{2t} are gas-poor spheroidals

gas-poor fraction is greatest in most dynamically evolve halos

higher fraction of nucleated dwarfs in more dynamically evolved halos

most dwarfs outside r_{2t} are gas-rich irregulars

signatures of dark energy

If $\Omega_\Lambda = 0.7$ $\quad r_{1t} \sim 3\ r_{2t}$ $\quad$ ($3.4\ r_{2t}$ if $\Omega_\Lambda = 0$)

and $r_{ZG} \sim 1.4\ r_{1t}$