Tidal Disruption of Globular Clusters in Dwarf Galaxies

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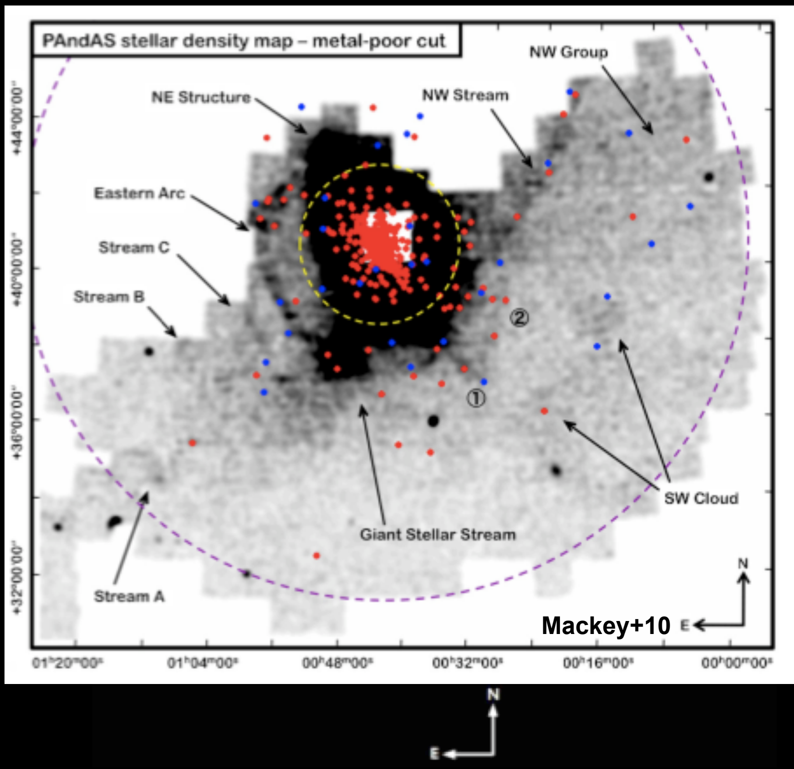
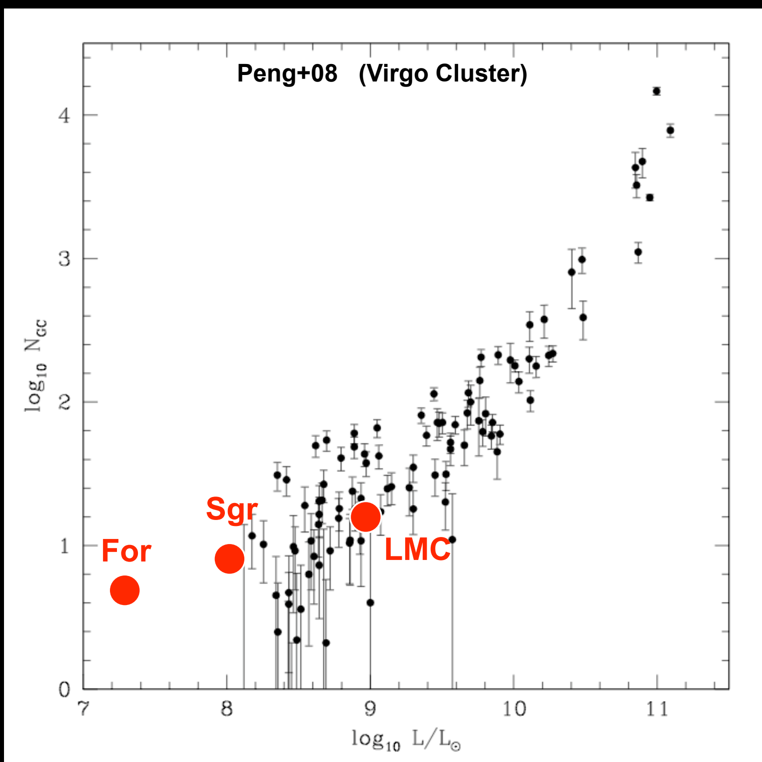
Hierarchical galaxy formation

Springel et al. (2008) Aquarius Simulation (10^{10} particles)

Hierarchical galaxy formation



Hierarchical galaxy formation

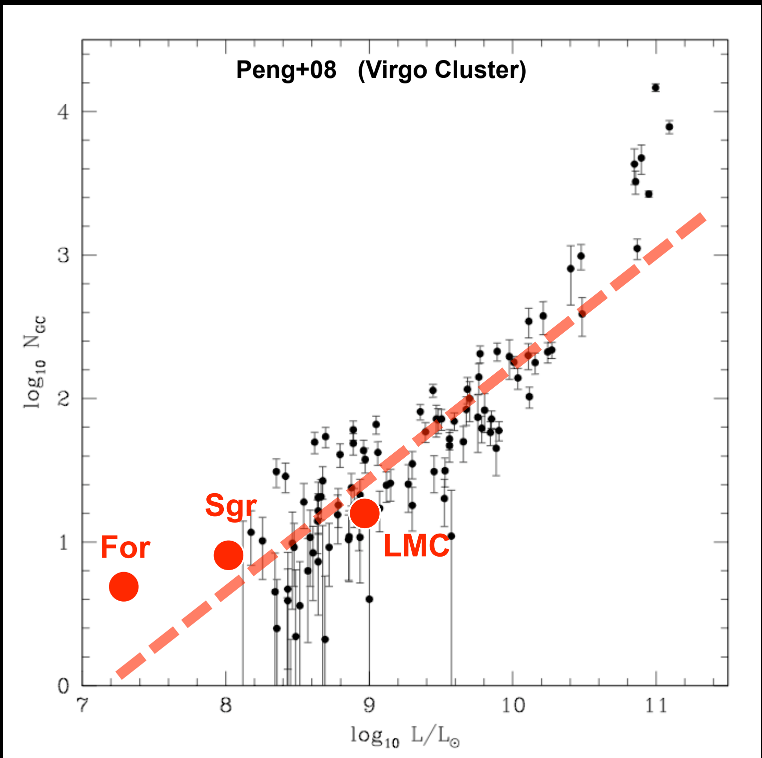


LMC: 13 GCs
(Schommer 91)

Sgr : 9 GCs
(Law & Majewski 2010)

For : 5 GCs
(Mackey & Gilmore 2003)

Hierarchical galaxy formation



LMC: 13 GCs
(Schommer 91)

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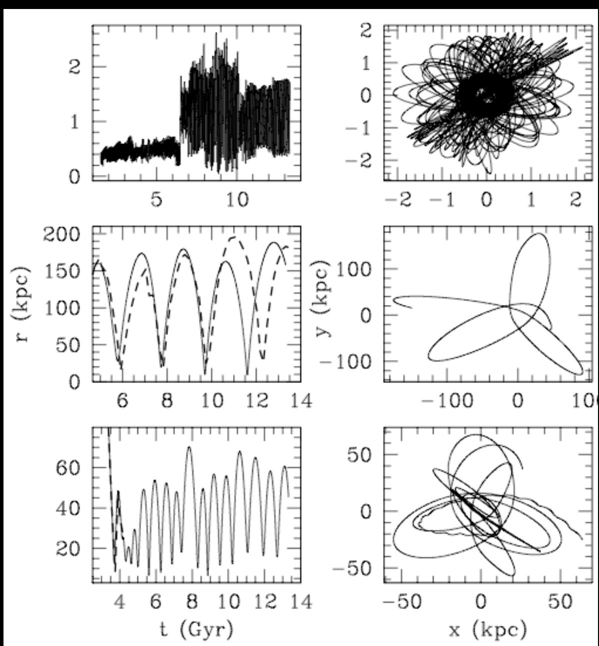
For : 5 GCs
(Mackey & Gilmore 2003)

only satellites with $L >\sim 10^7 L_{sol}$ contribute to the host GC popul.

CDM simulations

$M_{halo} \rightarrow L_{halo} \rightarrow N_{GC}$



Prieto & Gnedin 2008

GCs formed in the host

GCs formed in satellites that survive

GCs formed in satellites that merge

MISSING KEY INGREDIENT:

Evolution of GCs in satellites?

Tidal evolution of GCs in MW dSphs

(Peñarrubia, Walker & Gilmore 2009)

GCs have been detected in **For** (5) and **Sgr** (4) dSphs

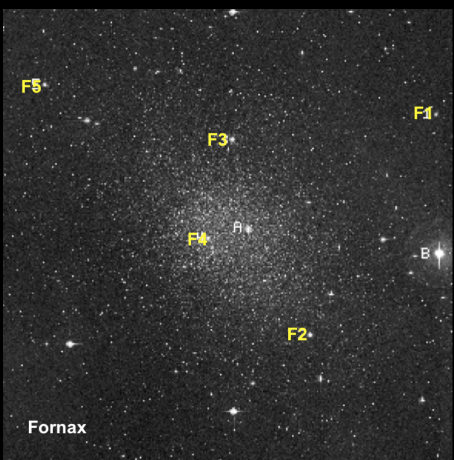


Table 1. Observational properties of the Fornax (Mateo 1998) and Sgr (Majewski et al. 2003) dSphs and their GCs (MacKey & Gilmore 2003).

Name	Angular sep. (kpc)	[Fe/H]	R_c (pc)	R_t (pc)	$\log_{10}(L)$ ($L_\odot$)	$\log_{10}[\rho_\star(0)]$ ($M_\odot$ pc^{-3})
For dSph	0.00	−1.3	400 ± 4	2078 ± 20	7.13 ± 0.2	−1.14 ± 0.20
F1	1.60	−2.25	10.0 ± 0.3	60 ± 20	4.07 ± 0.13	0.48 ± 0.07
F2	1.05	−1.65	5.8 ± 0.2	76 ± 18	4.76 ± 0.12	1.78 ± 0.07
F3	0.43	−2.25	1.6 ± 0.6	63 ± 15	5.06 ± 0.12	3.47 ± 0.07
F4	0.24	−1.65	1.8 ± 0.2	44 ± 10	4.69 ± 0.24	3.18 ± 0.07
F5	1.43	−2.25	1.4 ± 0.1	50 ± 12	4.76 ± 0.20	3.27 ± 0.07
Sgr dSph	0.00	[− 0.5, − 1.3]	1560 ± 20	12600 ± 20	7.24 ± 0.2	−2.96 ± 0.20
M54	0.00	−1.65	0.91 ± 0.04	59 ± 21	5.36 ± 0.08	4.45 ± 0.05
Terzan 7	2.68	−0.64	1.63 ± 0.12	23 ± 8	3.50 ± 0.10	1.97 ± 0.07
Terzan 8	4.40	−2.25	9.50 ± 0.72	66 ± 26	3.67 ± 0.14	0.72 ± 0.23
Arp 2	3.07	−1.65	13.67 ± 1.85	139 ± 49	3.59 ± 0.14	0.35 ± 0.25

Use Fornax and Sagittarius systems as a test case of tidal disruption of GCs in satellites

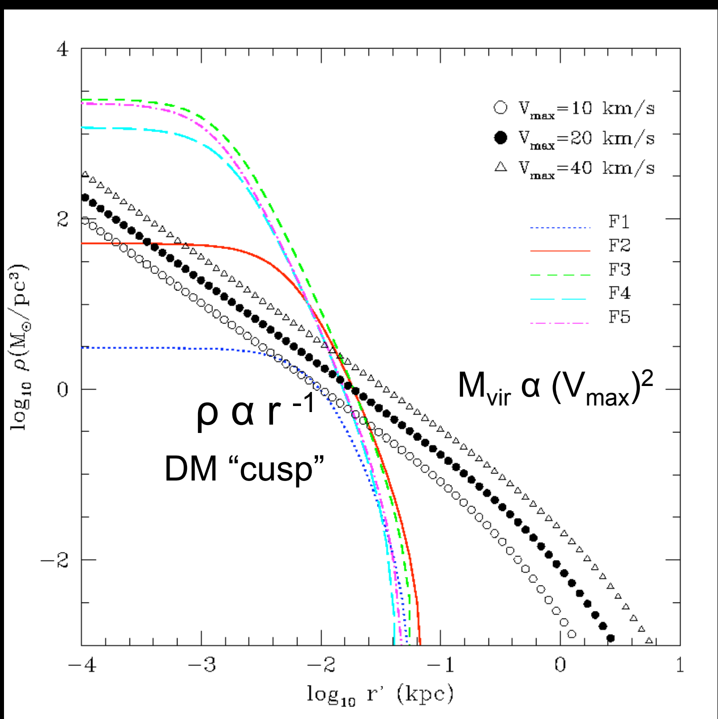
Dwarf Galaxies CDM potentials

cosmological models

- Triaxial NFW DM halo
- Stellar grav. potential neglected

≡

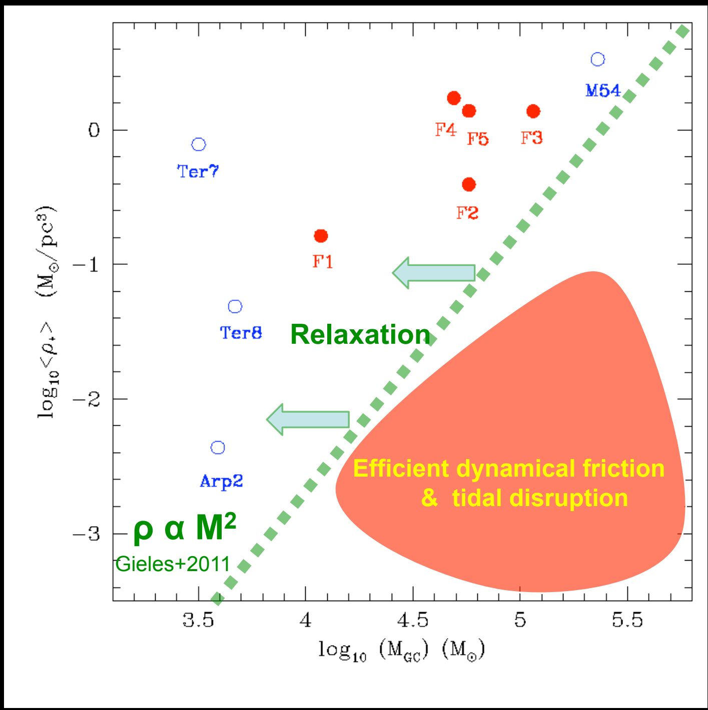
Stellar versus DM densities



- GCs factor 10^4 ρ_*
- DM haloes factor 3 ρ_{DM}

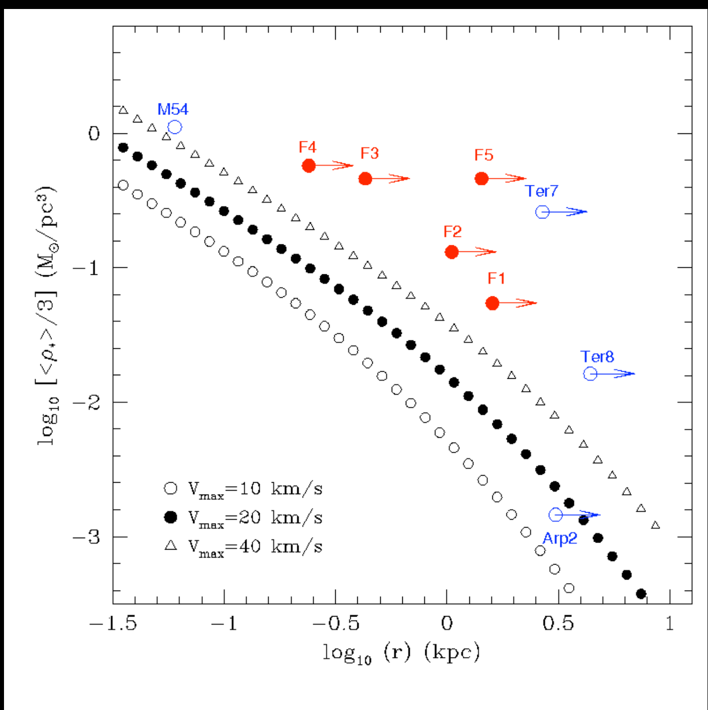
Dynamical evolution of GCs similar in all satellites

GC tracing DM ?



- Mass ←→ Density

GC tracing DM ?

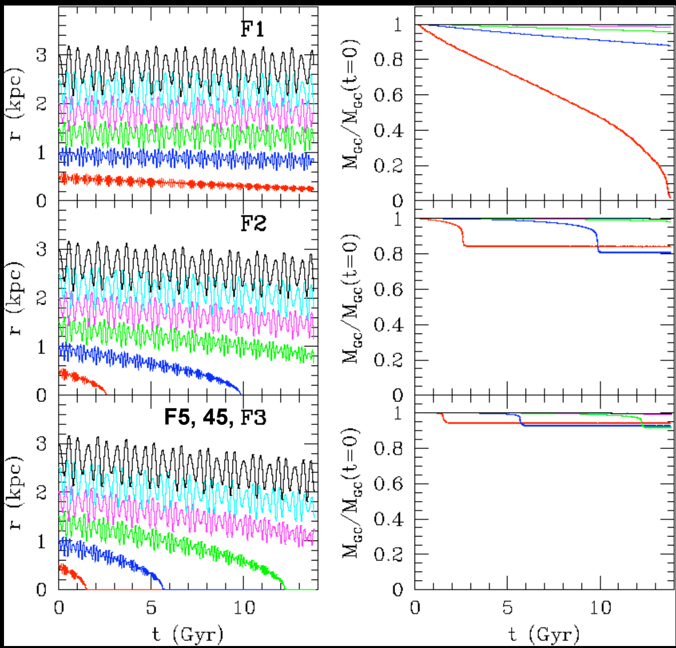


- Mass ←→ Density
- Mass ←→ position

$\langle\rho_*(R_{tid})\rangle / 3 > \langle\rho_{DM}\rangle(r)$

Signatures of dynamical evolution ?

Tidal stripping of GCs



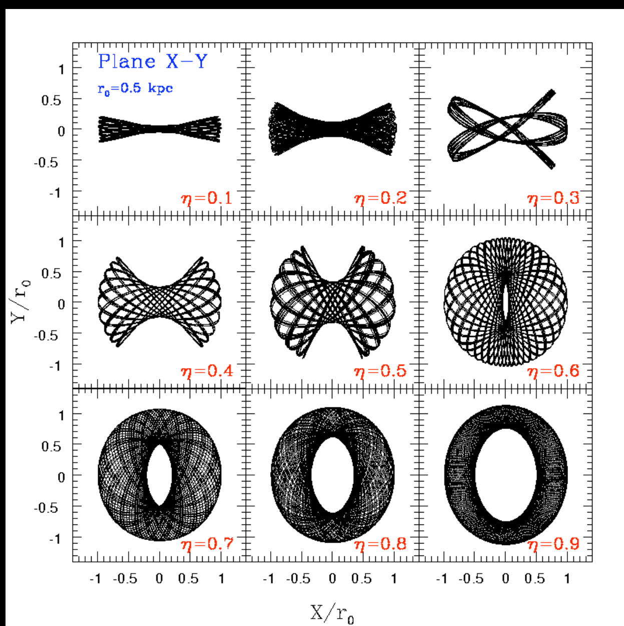
N-body (collisionless) sims of Fornax GCs on loop orbits.

- GCs sink to the dwarf centre in a Hubble time if initial apocentre < 1.5 kpc
- Only F1 can disrupt in the tidal field of Fornax … but its orbit has to bring it **close** to the dwarf centre (!)

Disruption of GCs in triaxial DM haloes: Orbits

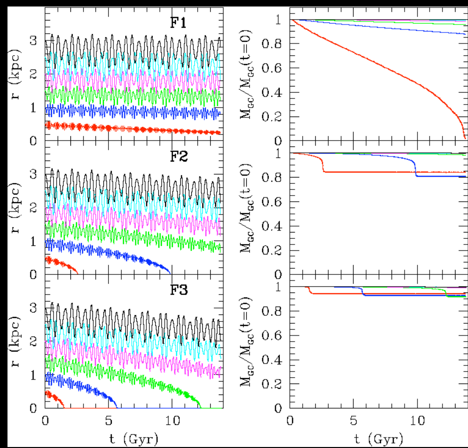
Orbits in triaxial potentials:

1. loops *(centrophobic)*
2. boxes
3. resonances
4. irregular (stochastic)



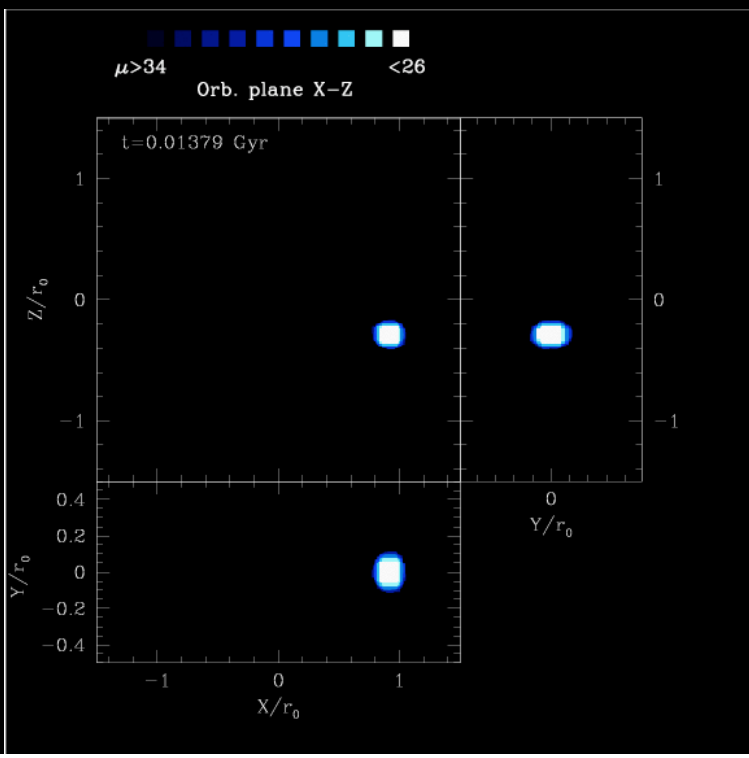
Disruption of GCs in triaxial DM haloes: Orbits

- Clusters that can be disrupted (e.g F1) will be disrupted after a few dynamical times (dSph: t_{dyn} ~ 50—200 Myr) if they move on box, resonant or irregular orbits
- The fraction of non-loop orbits depends on (i) triaxiality and (ii) density profile



Disruption of GCs may be much more efficient in satellites than in the host

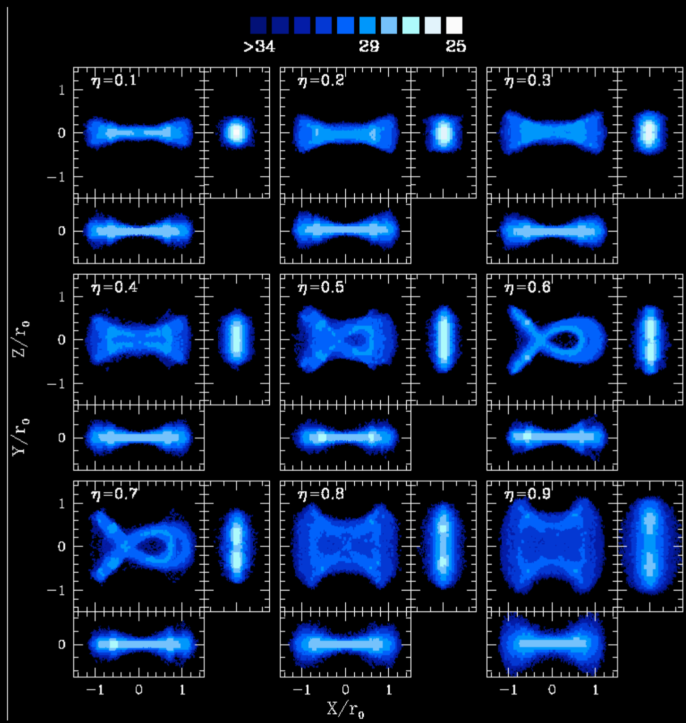
Disruption of GCs in triaxial DM haloes: F1 on an box orbit



Evolution of cluster **F1**

Orb. Plane X-Z
r_0=0.5 kpc
η= 0.8 (box orbit)

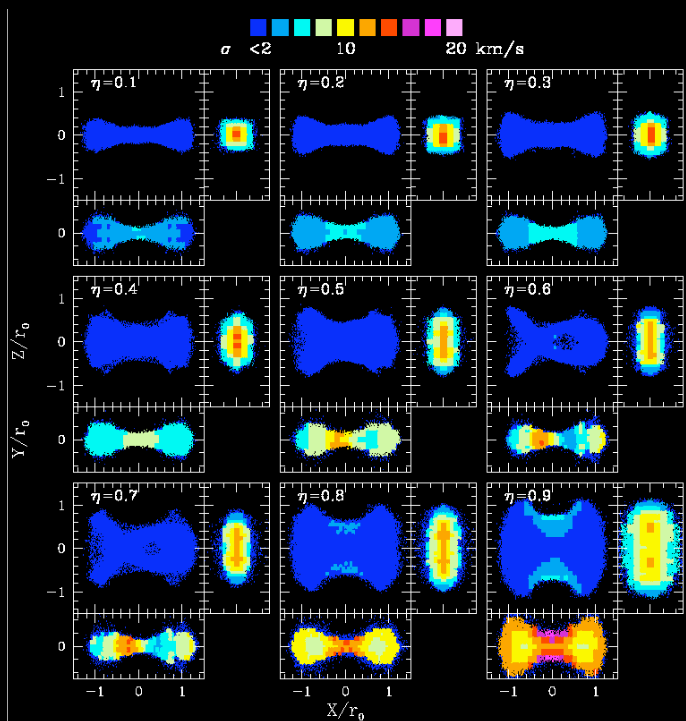
Disruption of GCs in triaxial DM haloes: Morphological signatures



Shells, isolated clumps, elongated over-densities… arise naturally from the disruption of a GC in a triaxial potential

They do not have a transient nature

Disruption of GCs in triaxial DM haloes: Kinematical signatures



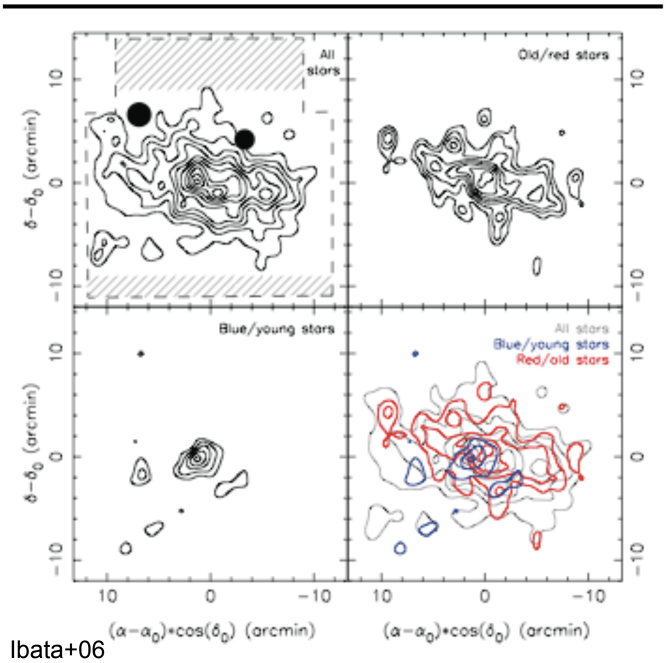
box and resonant orbits

dSphs have flat velocity dispersion profiles

(e.g. Fornax **σ=10 km/s**)

Tidal debris associated to box and resonant orbits can appear *hotter / colder* than the underlying Fornax if the line-of-sight projection is *aligned / perpendicular* to the orbital plane

Observed substructures in dSphs



Ibata+06

Photometric + spectroscopic
Surveys have revealed substructures
(shells, over-densities, clumps, …etc)
in several dSphs (UMi, Fornax, CVel, Scu)

- Distinct metalicity
- Distinct velocity dispersion (cold clumps)

dSphs have typical crossing times of 30 - 100 Myr

↓

substructures should quickly disperse and mix within the host dwarf

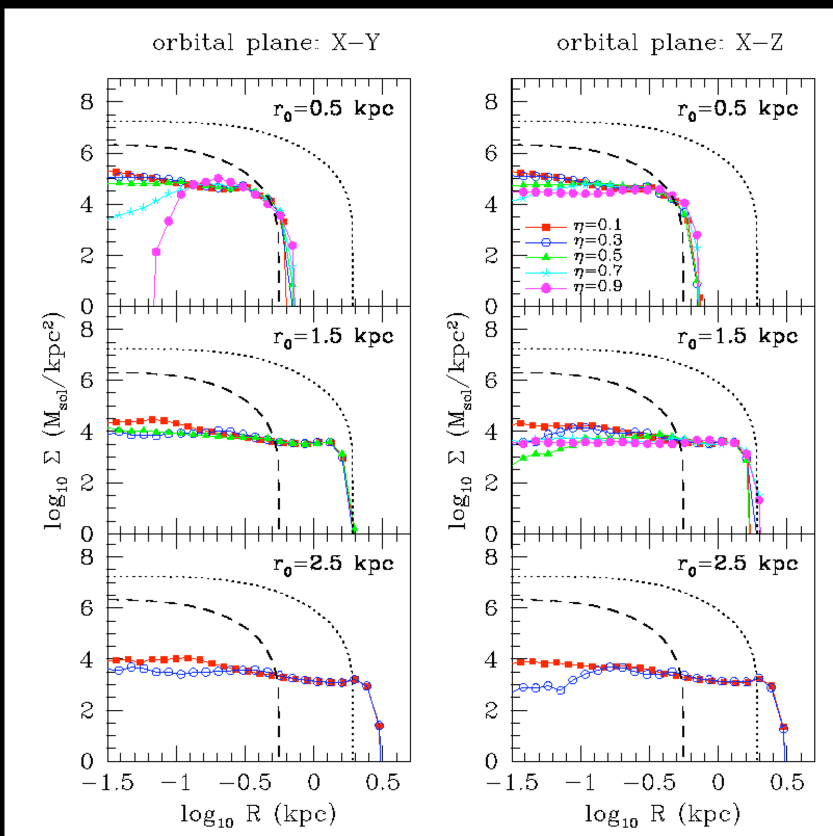
Triaxial potentials?

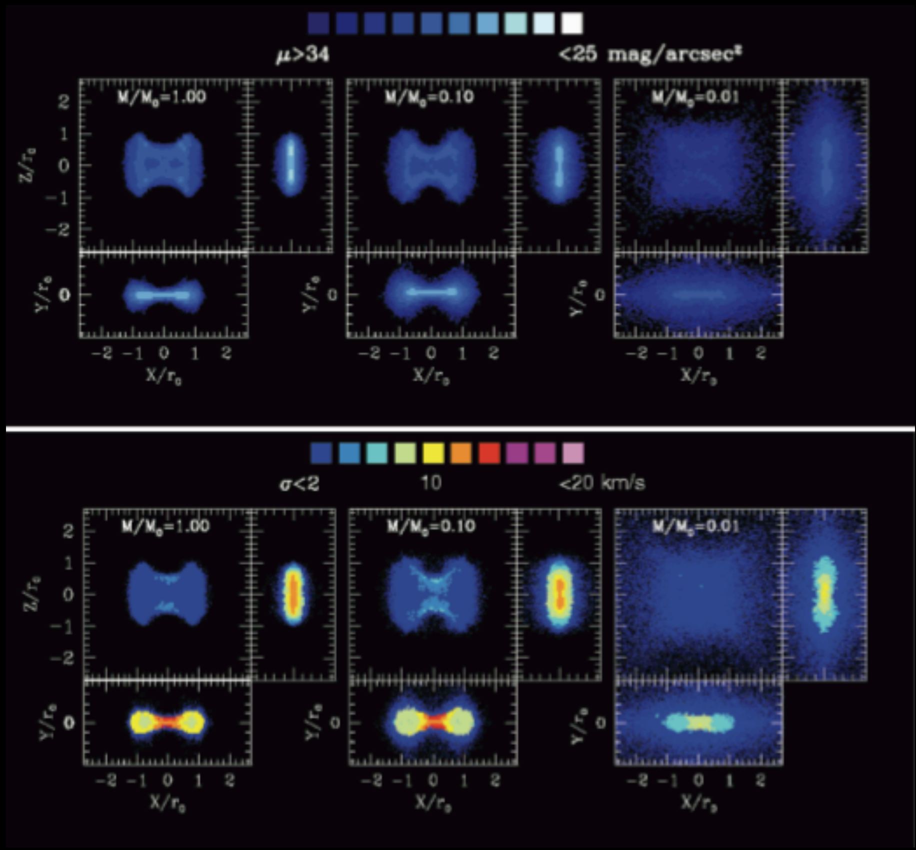
Summary

- Disruption of GCs more efficient in satellites than in the host
- Accreted GCs may be dynamically evolved
- The surviving GC population of For and Sgr dSphs show signatures of dynamical evolution
- If the haloes of dSphs are triaxial, the disruption of a GC leaves morphological signatures such isolated clumps, shells,.., etc that do not dissolve in time
- The disruption of a GC on a loop orbit introduces a rotational component
- Debris associated to box and resonant orbits can be hotter/colder than the host stellar population depending on the line-of-sight projection

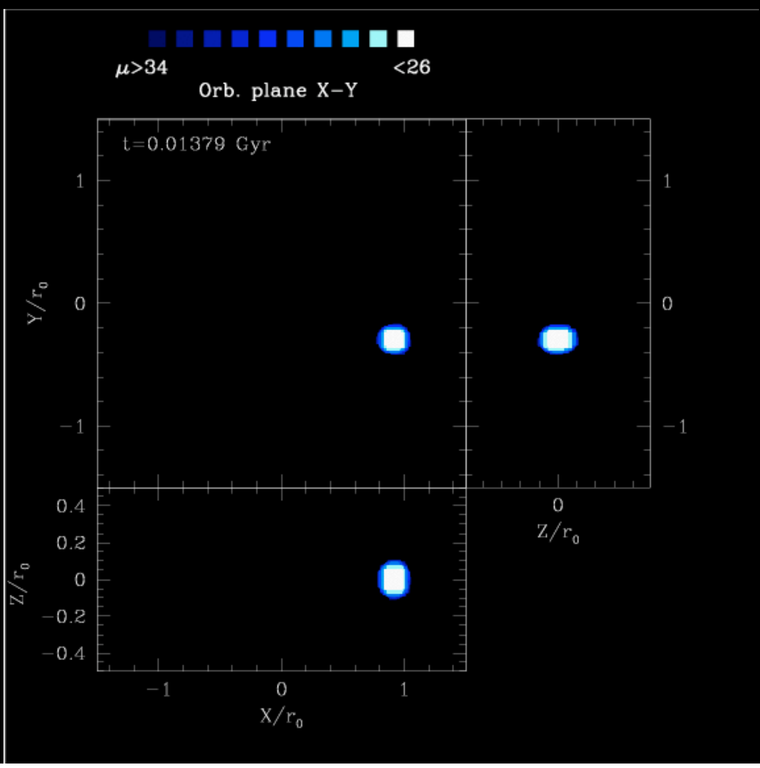
Future

- Collisional-Nbody simulations of GCs on triaxial potentials (F. Renaud)
- Distribution of cluster masses, densities and orbits in DM haloes with different triaxialities and density profiles
- Follow-up of accreted GCs in a MW-like galaxy





Disruption of GCs in triaxial DM haloes: Morphological signatures

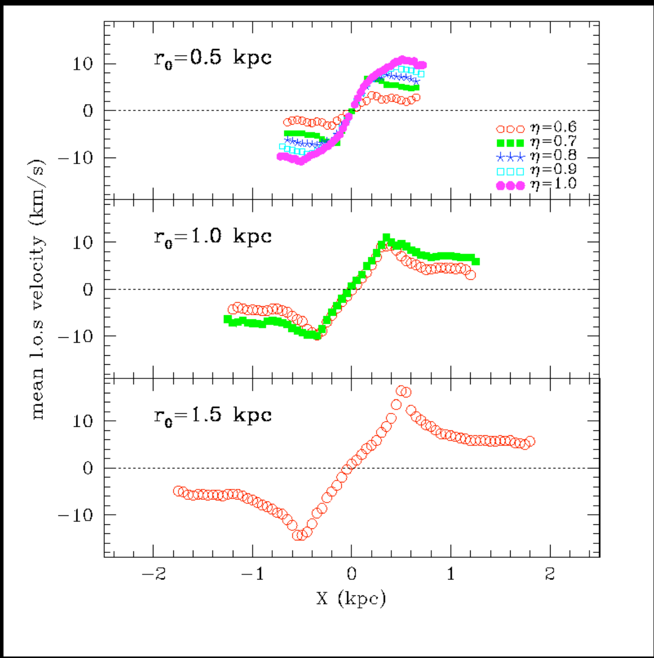


Evolution of cluster **F1**

Orb. Plane X-Y
r_0=0.5 kpc
η= 0.8 (loop orbit)

Disruption of GCs in triaxial DM haloes: Kinematical signatures

loop orbits



dSph are non-rotating systems

The disruption of a GC on a loop orbit introduces velocity gradients in the host dwarf

note: velocity gradients in dSphs are often interepreted as a signature of tidal disruption