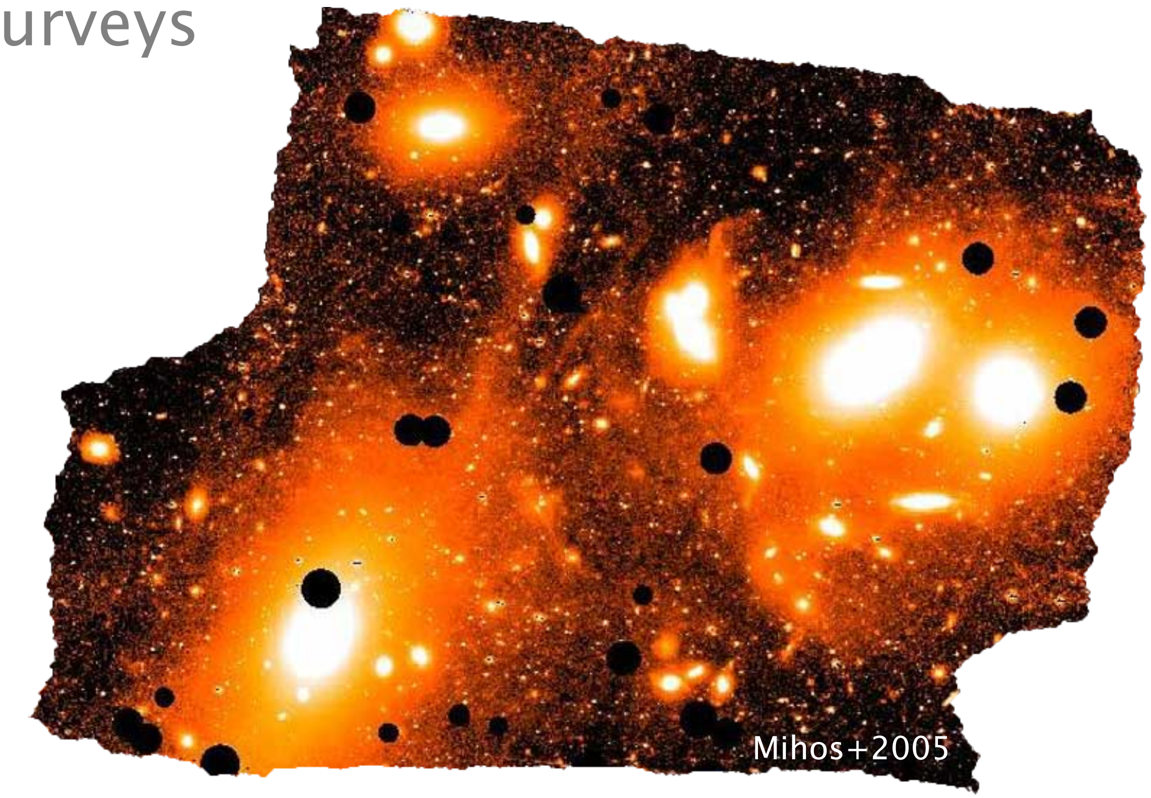
Globular Cluster Systems as Tracers of Galaxy Formation and Evolution

Clues from MOS Surveys



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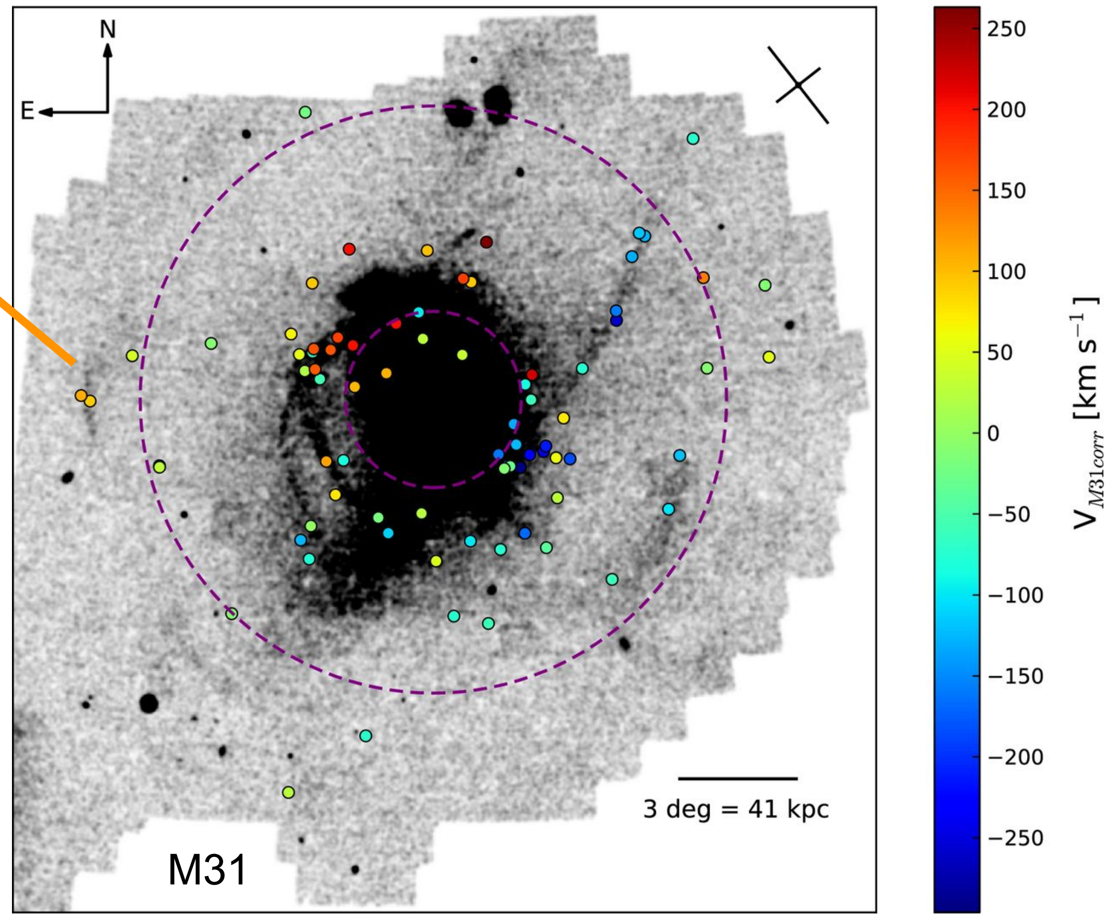
S/C de la Palma
2015-03-03

Stellar haloes hold important records of early star formation and mass assembly processes

low densities and long dynamical times

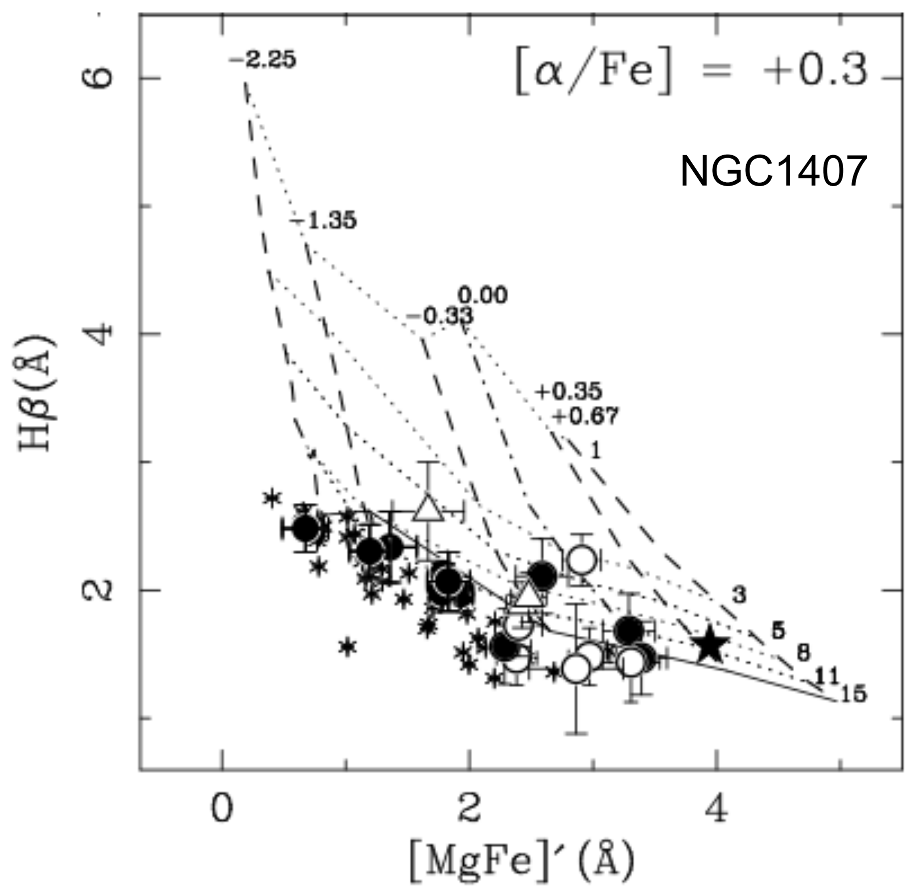
observationally challenging
($\mu_V \sim 33$ mag arcsec^{-2})

use GCs as tracers
of underlying potential



Veljanoski+14

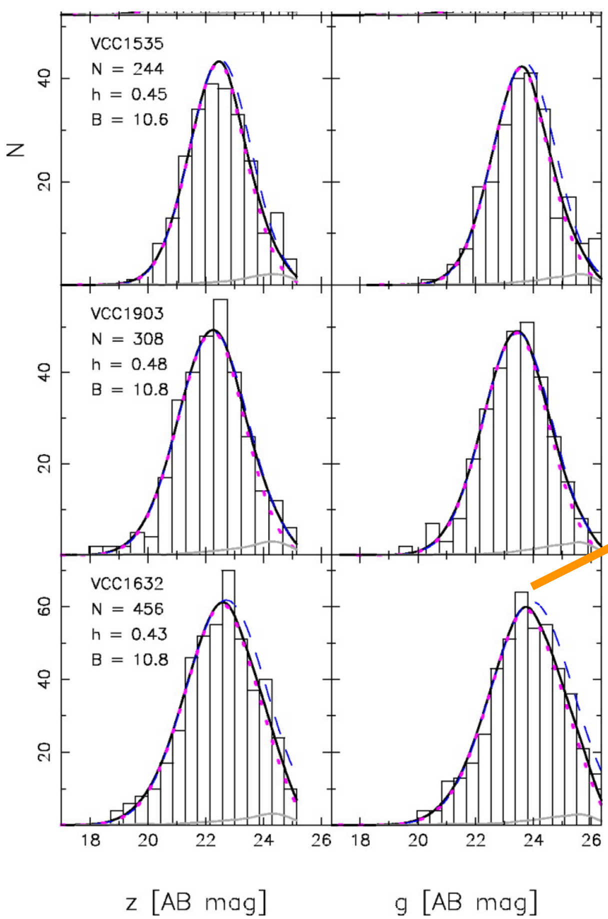
GCs are generally old (>10 Gyr)
have witnessed a large fraction of host's history

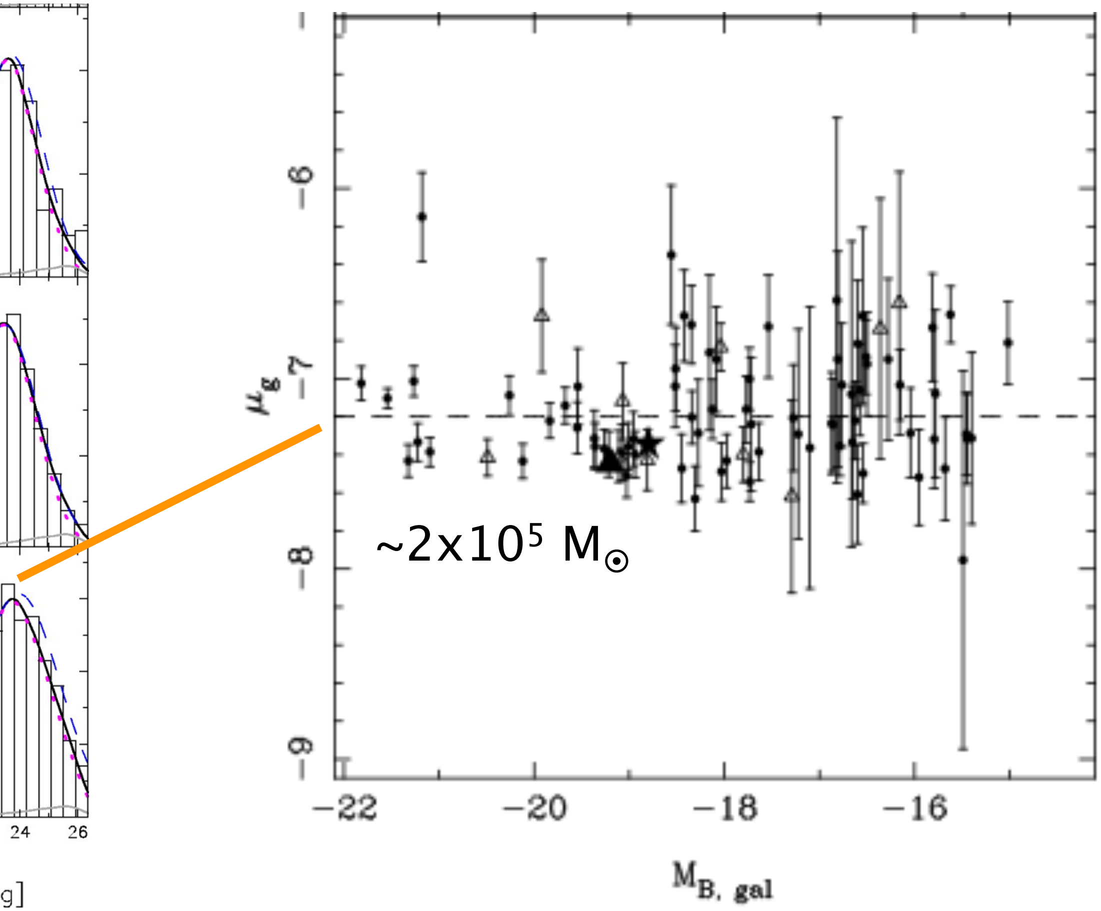


Cenarro+06; Brodie & Strader (2006)

GCs are compact and ‘bright’

within reach of 8–10m class facilities

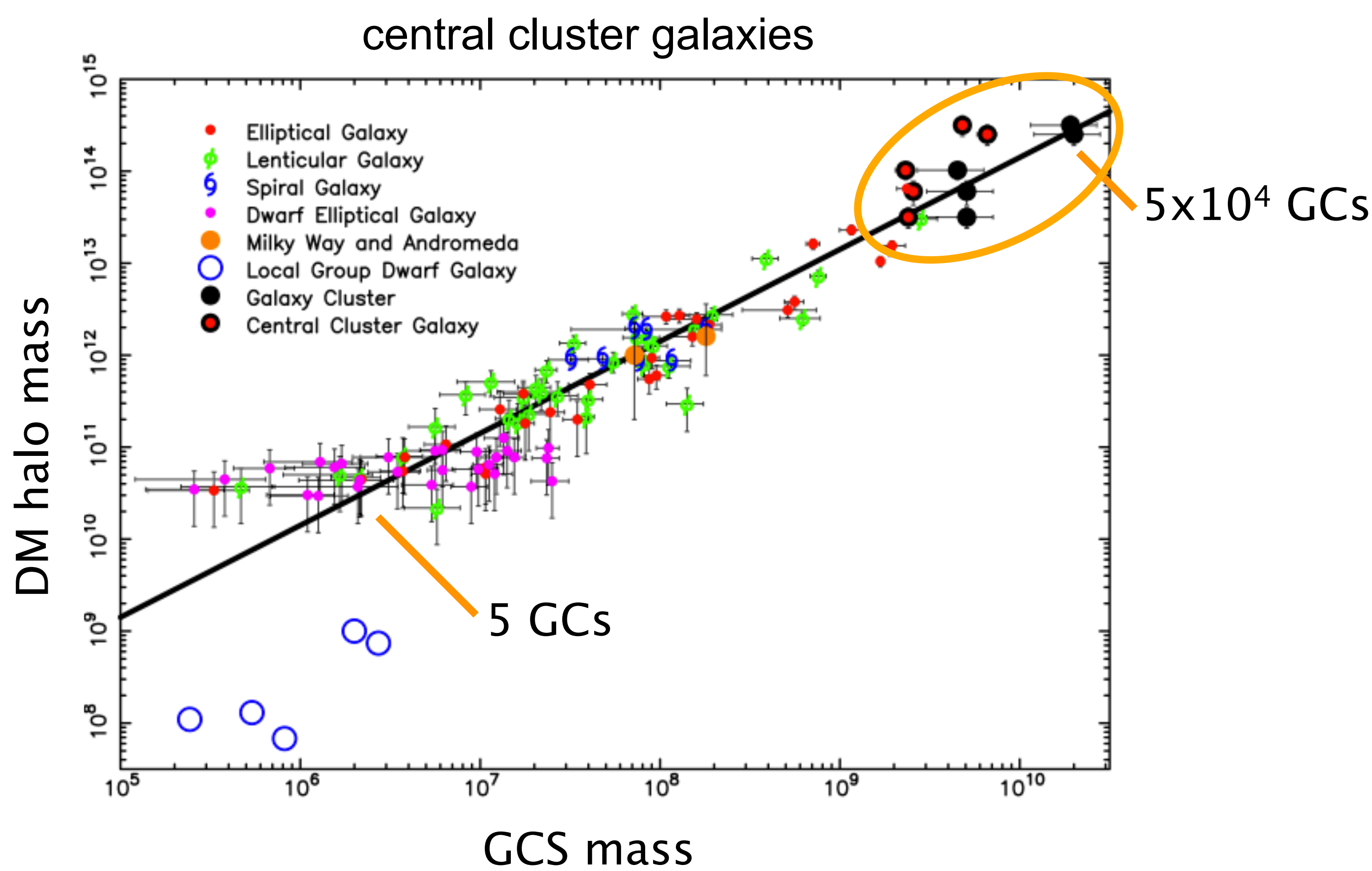




Jordan+07

GCs are almost ubiquitous

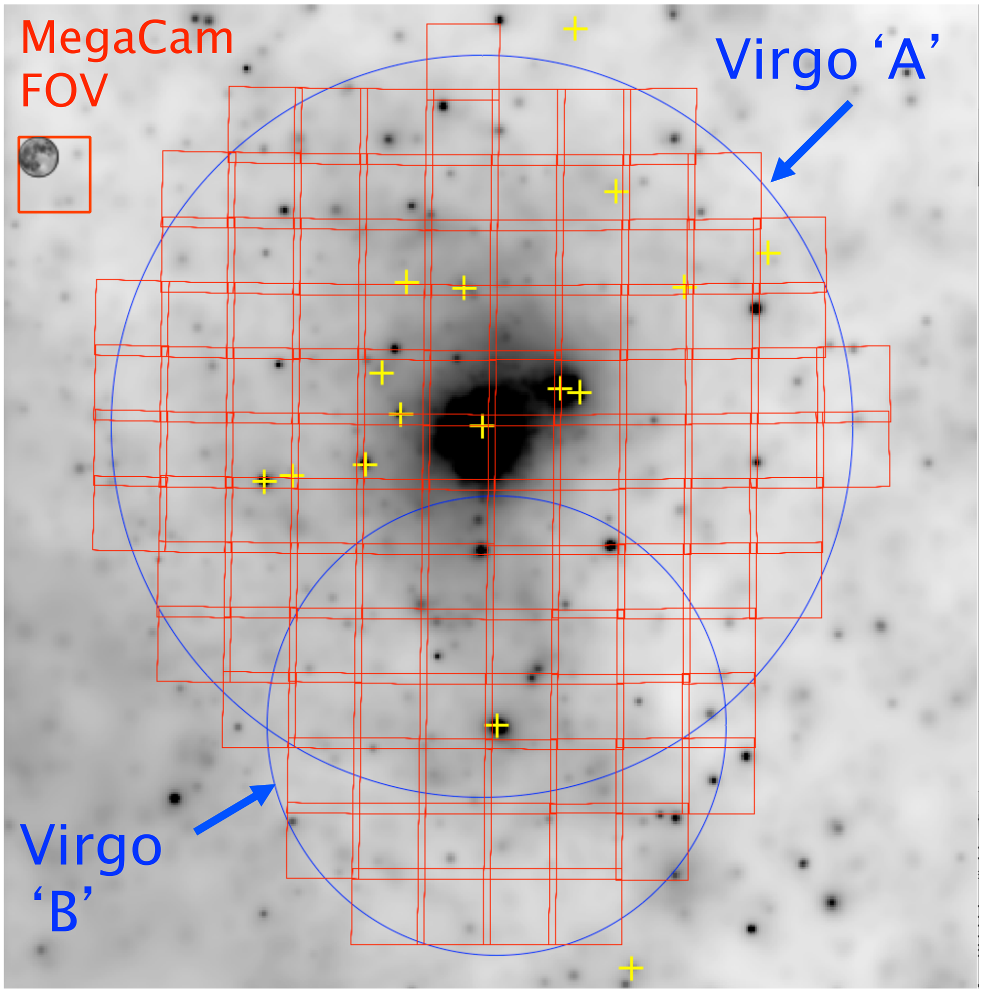
~0.007 per cent of total halo mass in GCs



Spitler & Forbes 2009; Harris+13

Galaxy clusters: the realm of GCs

the Next Generation Virgo Cluster Survey (NGVS)



(M ~ 4x10^14 M$_\odot$)

104 deg^2 w/ CFHT/MegaCam

+dedicated spec. follow-ups

ugiz+r

fwhm = 0.55" (*i*-band)

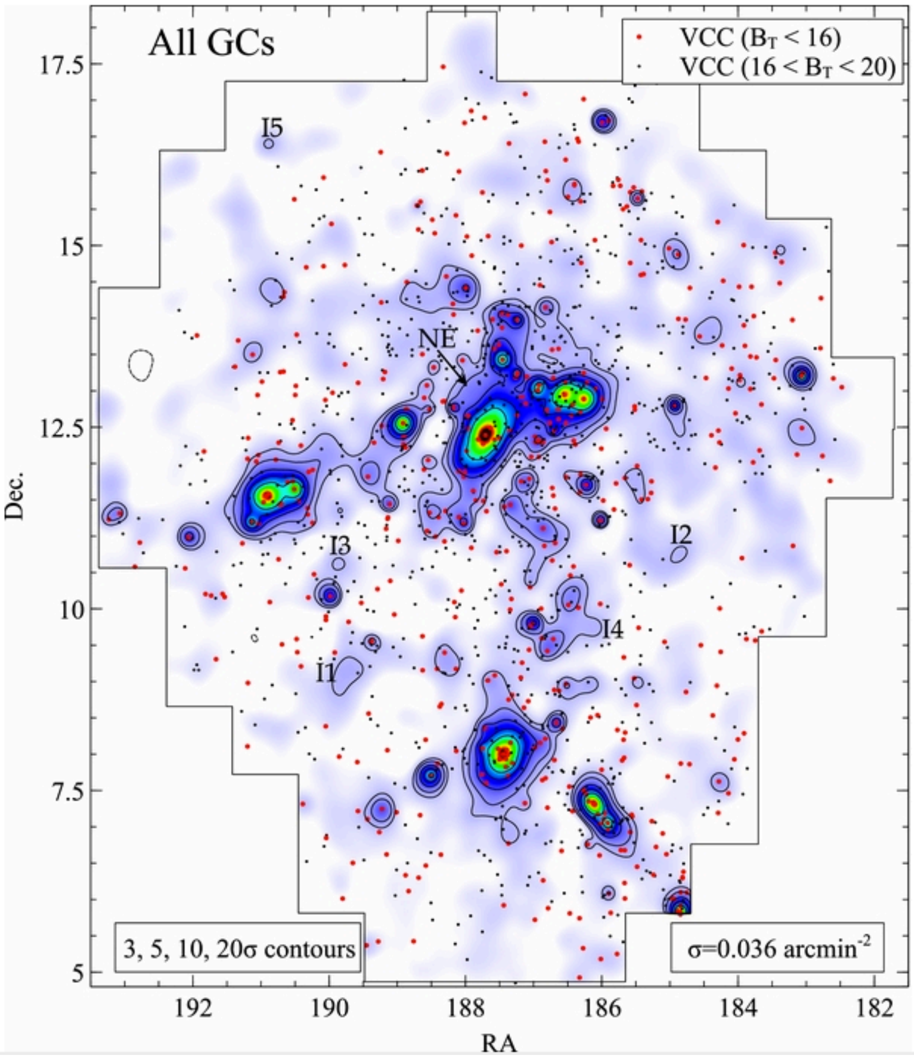
g < 26 mag

μ_g < 29 mag arcsec^2

Ferrarese+12

Galaxy clusters: the realm of GCs

Virgo has ~67,000 GCs

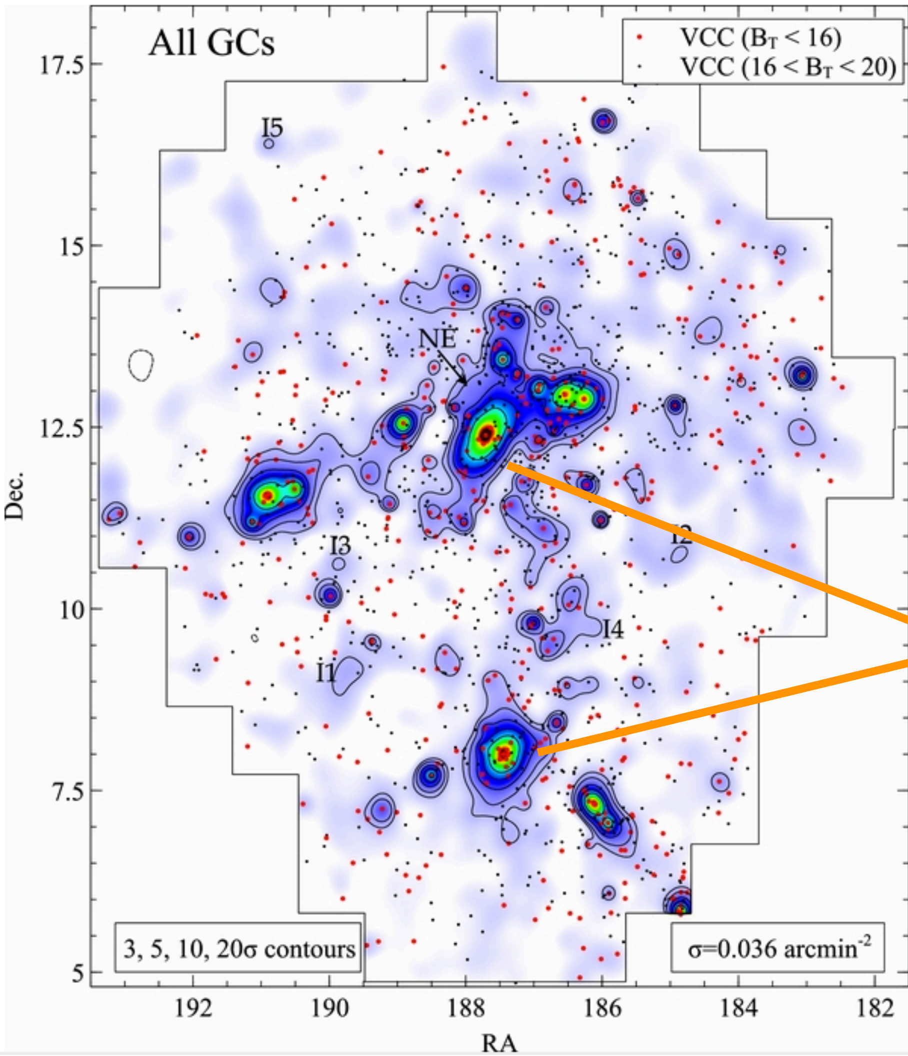


GCs follow galaxies,
and trace their stellar halo shapes

Durrell+14

Galaxy clusters: the realm of GCs

Virgo has ~67,000 GCs



GCs follow galaxies,
and trace their stellar halo shapes

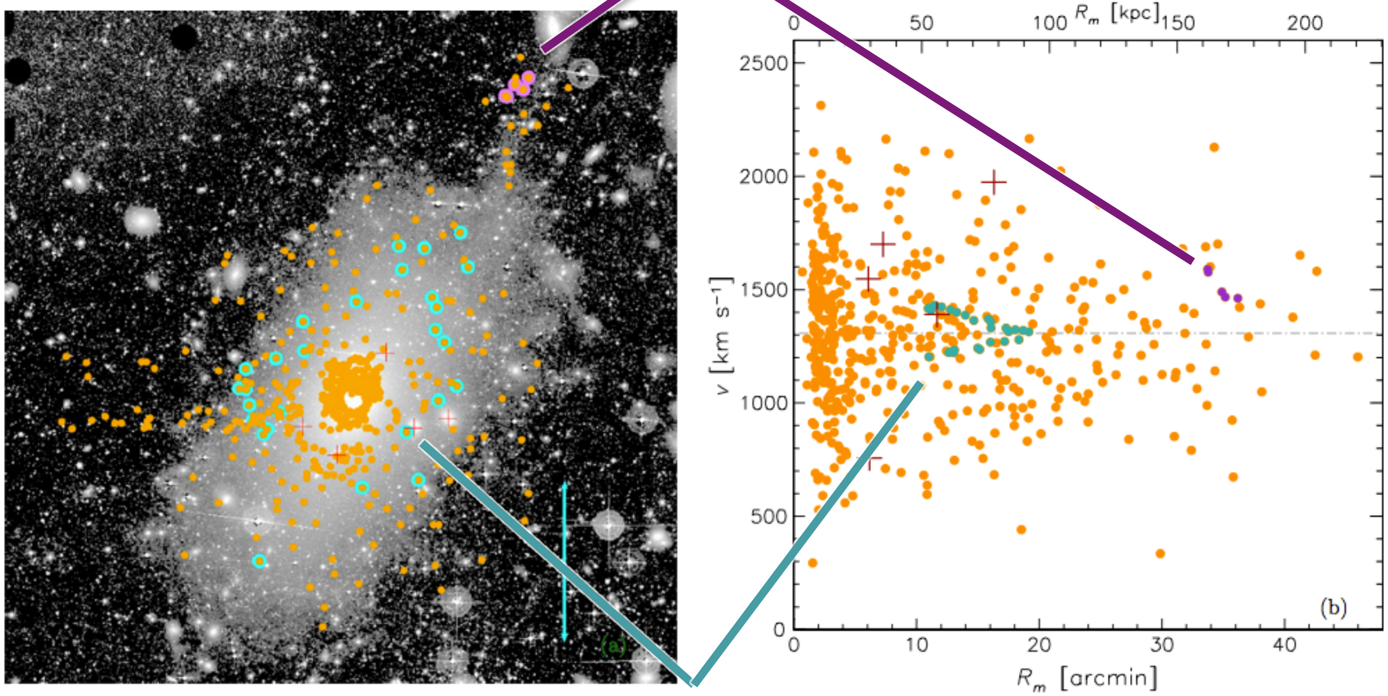
~35% in M87 and M49 alone

Durrell+14

GCSs trace ongoing assembly of M87’s halo

~1 Gyr-old phase-space substructures

stream (dwarf?)



infall caustic
(0.5L* elliptical?)

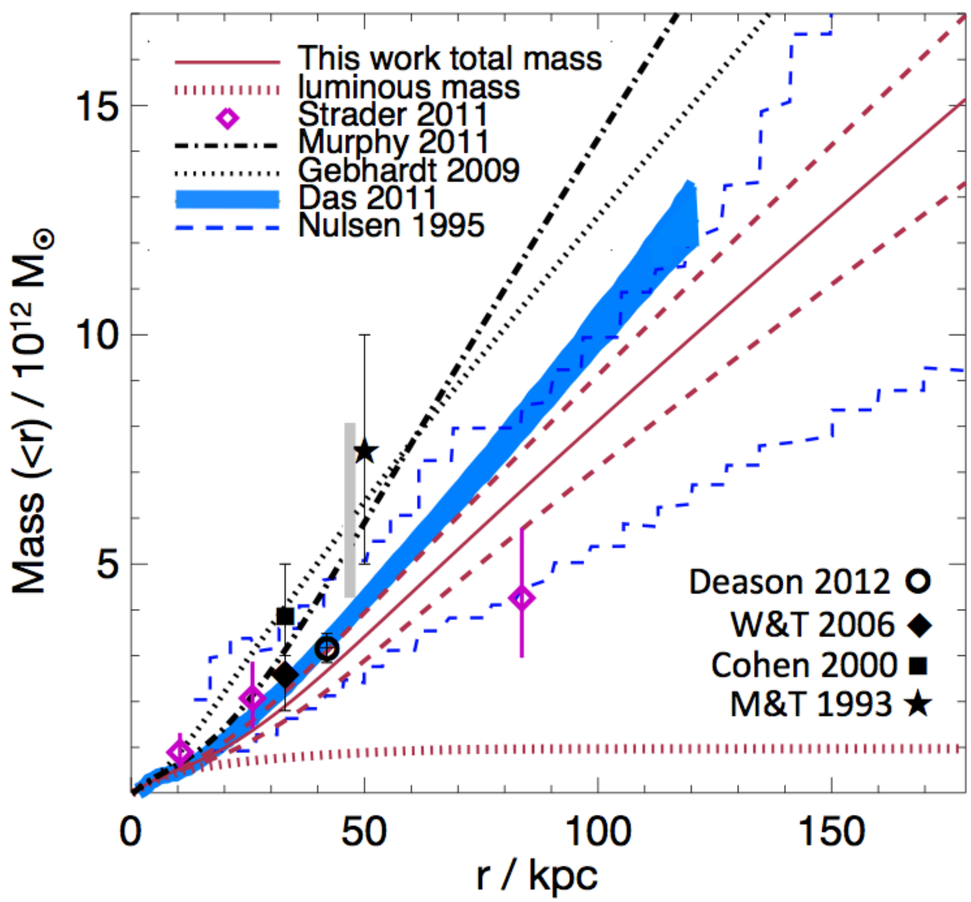
~500 GCs
(Keck/Deimos)

Romanowsky+12

Dynamical modelling of M87

922 GCs out to 180 kpc + SAURON IFS

Keck/Deimos + MMT/Hectospec



$1.5 \times 10^{13}\ M_\odot$

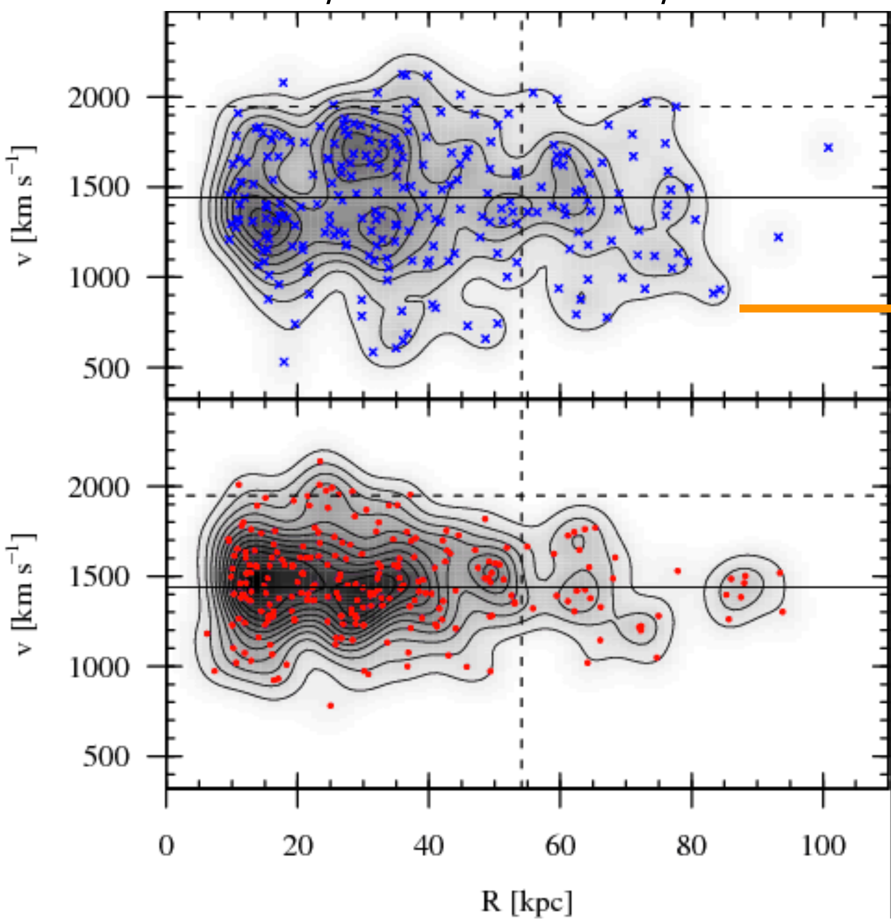
isotropic orbital structure

Zhu+14

Dynamical modeling of NGC1399 in Fornax

700 GCs out to 100 kpc

VLT/FORS + Gemini/GMOS



$9.5 \times 10^{12}\ M_\odot$

but no common halo able to reproduce simultaneously the properties of red and blue GCs

velocities of some blue GCs require very large apogalactic distances – recent accretion?

Schuberth+10

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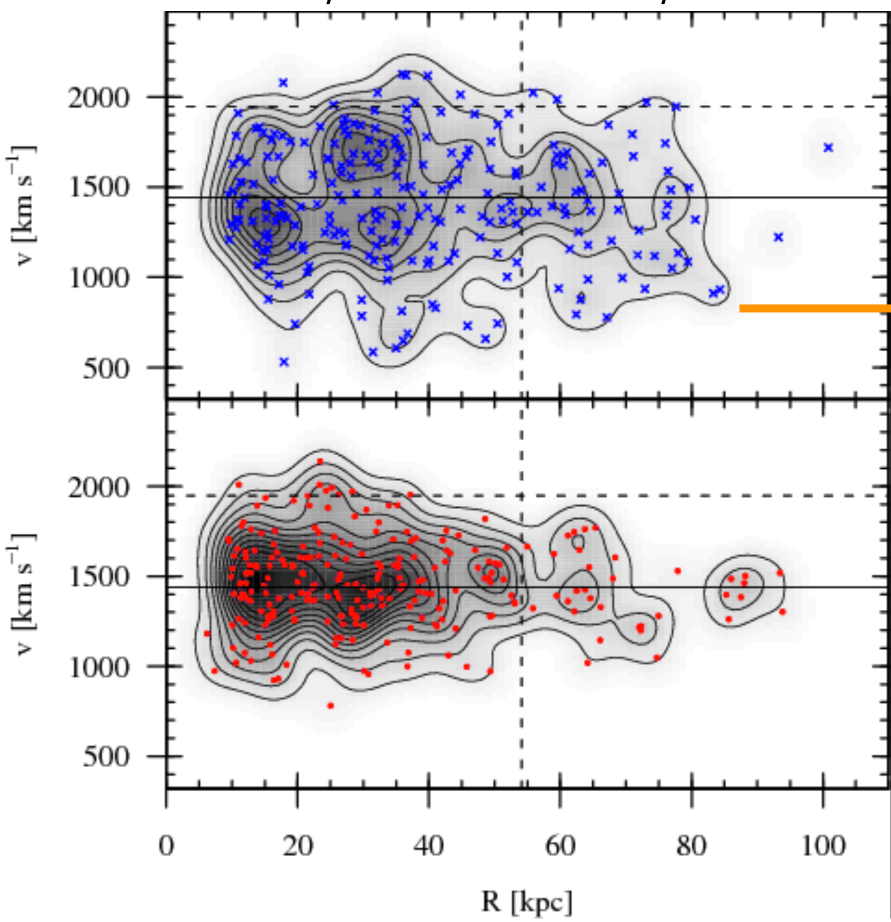

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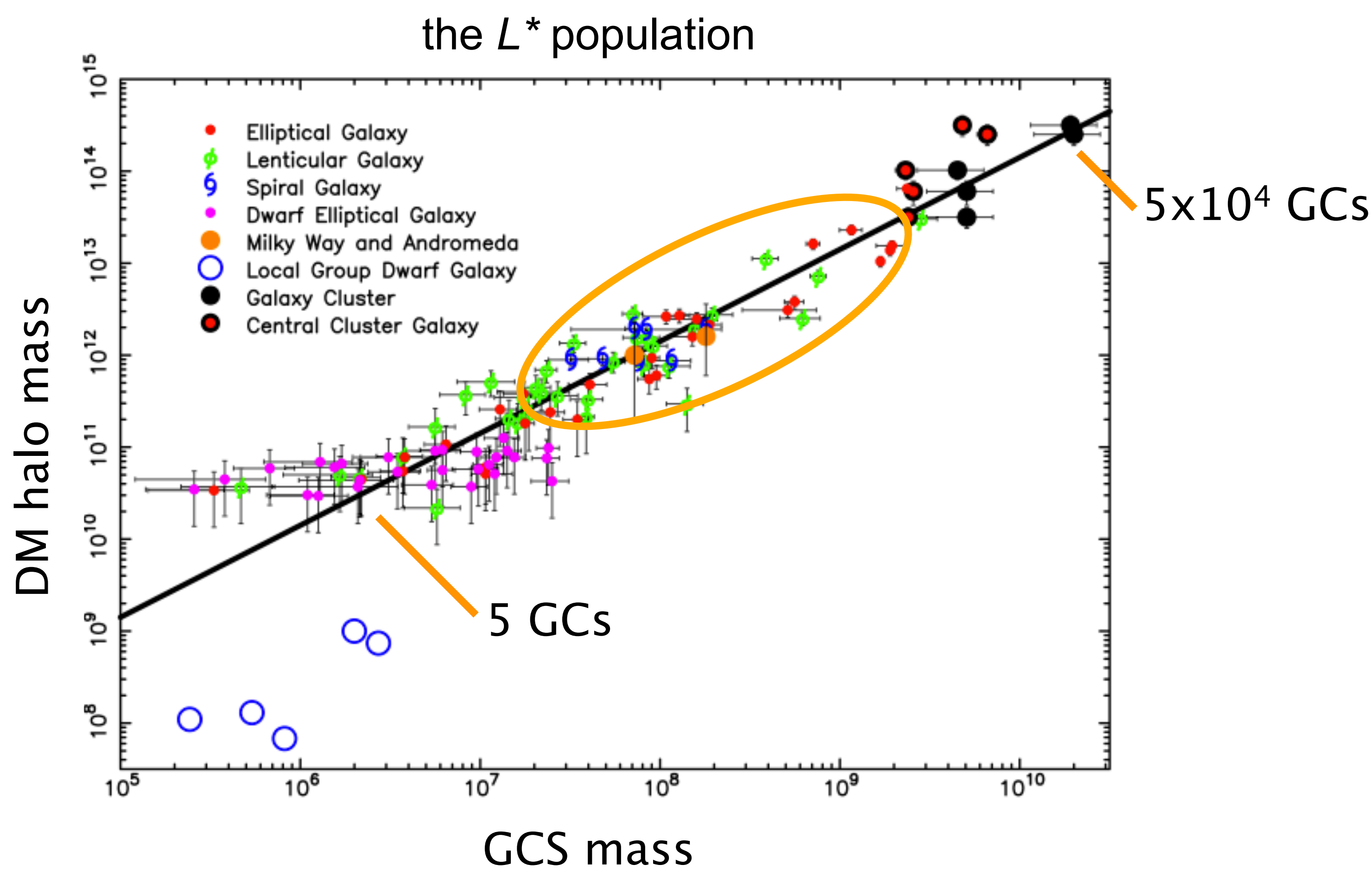
a VLT/VIMOS survey of ~1500 GC candidates in the central 130 kpc around NGC1399

(Napolitano, Hilker et al.)

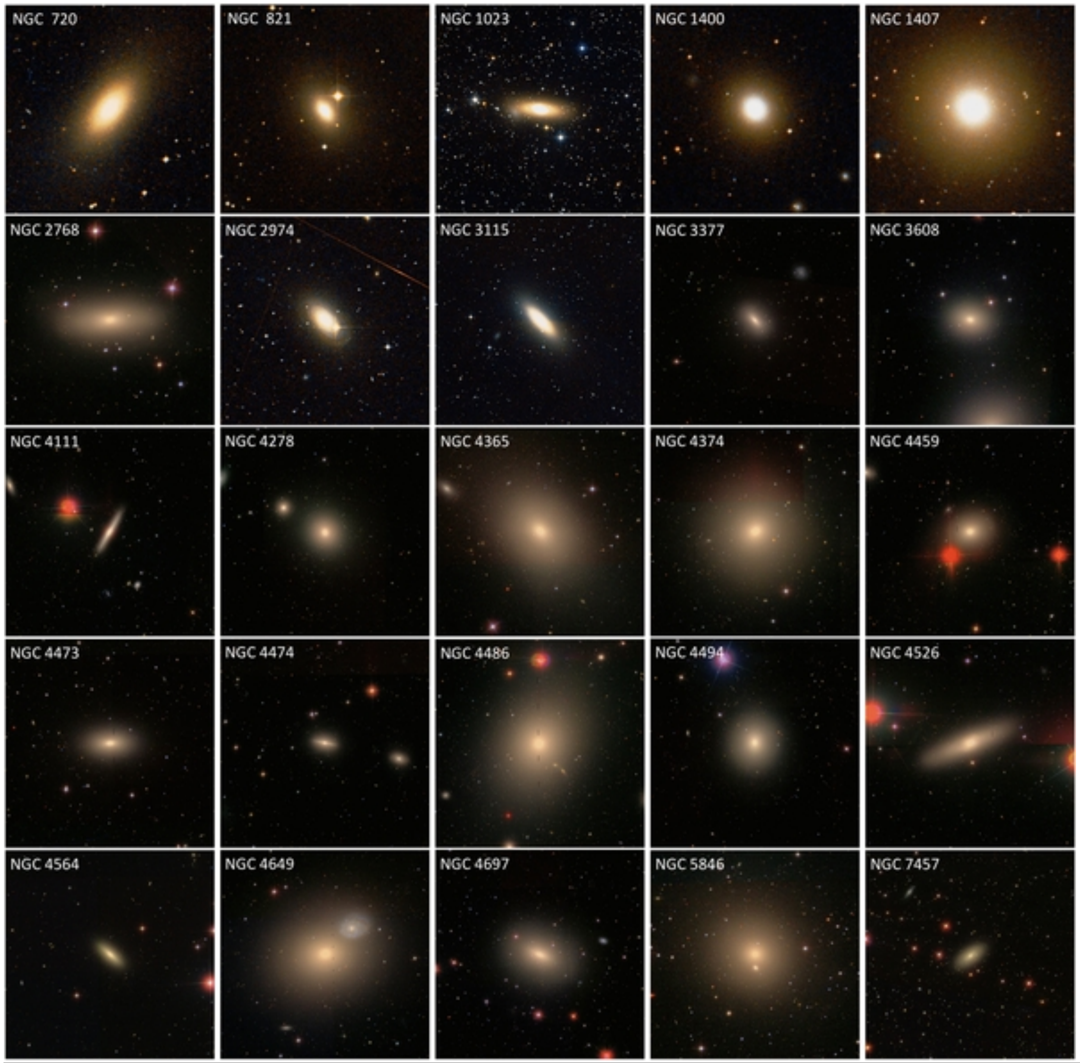
GCs are almost ubiquitous

~0.007 per cent of total halo mass in GCs



Spitler & Forbes 2009; Harris+13

the SLUGGS survey
chemodynamics of 25 nearby early-types



$9 < D < 27$ Mpc

$-26 < M_K < -22$ mag

Keck/Deimos around CaT
(kinematics + stellar pops.)

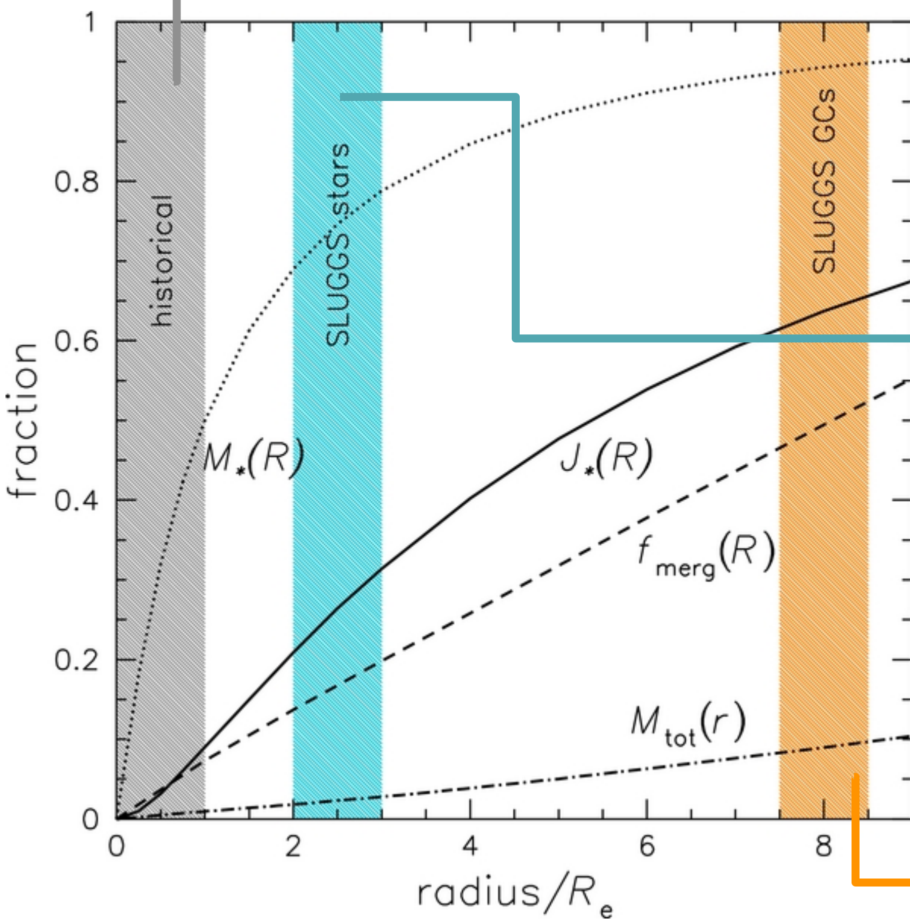
50-500 GCs $i < 23$ mag
out to ~8 R_e
+
slits scattered across
galaxy body out to ~2 R_e

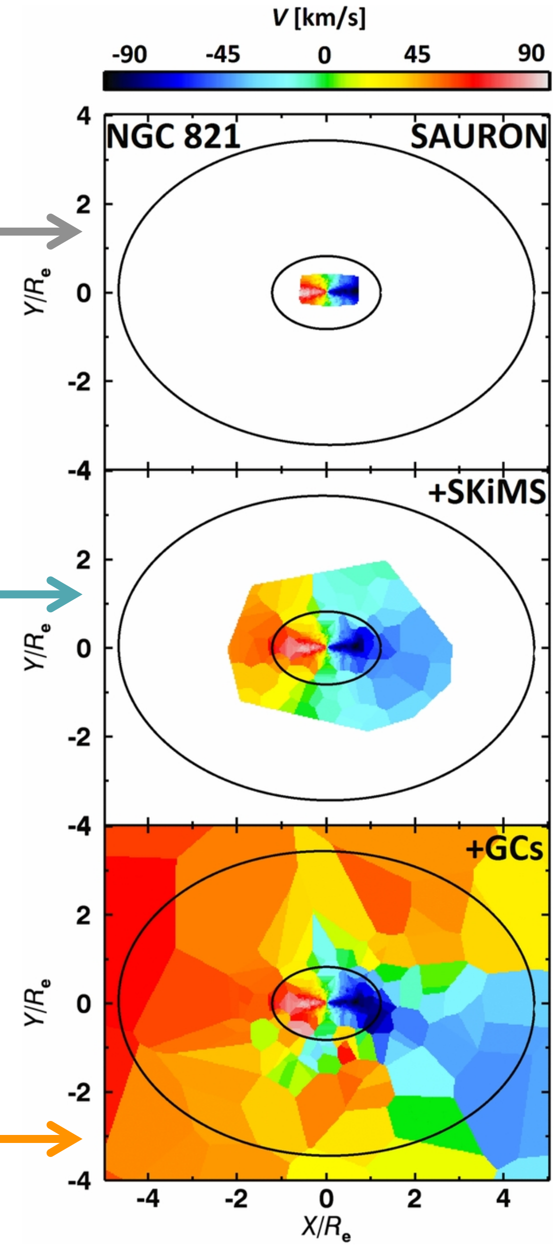
~15 km/s velocity accuracy

Brodie+14

the SLUGGS survey

probing the outer stellar haloes

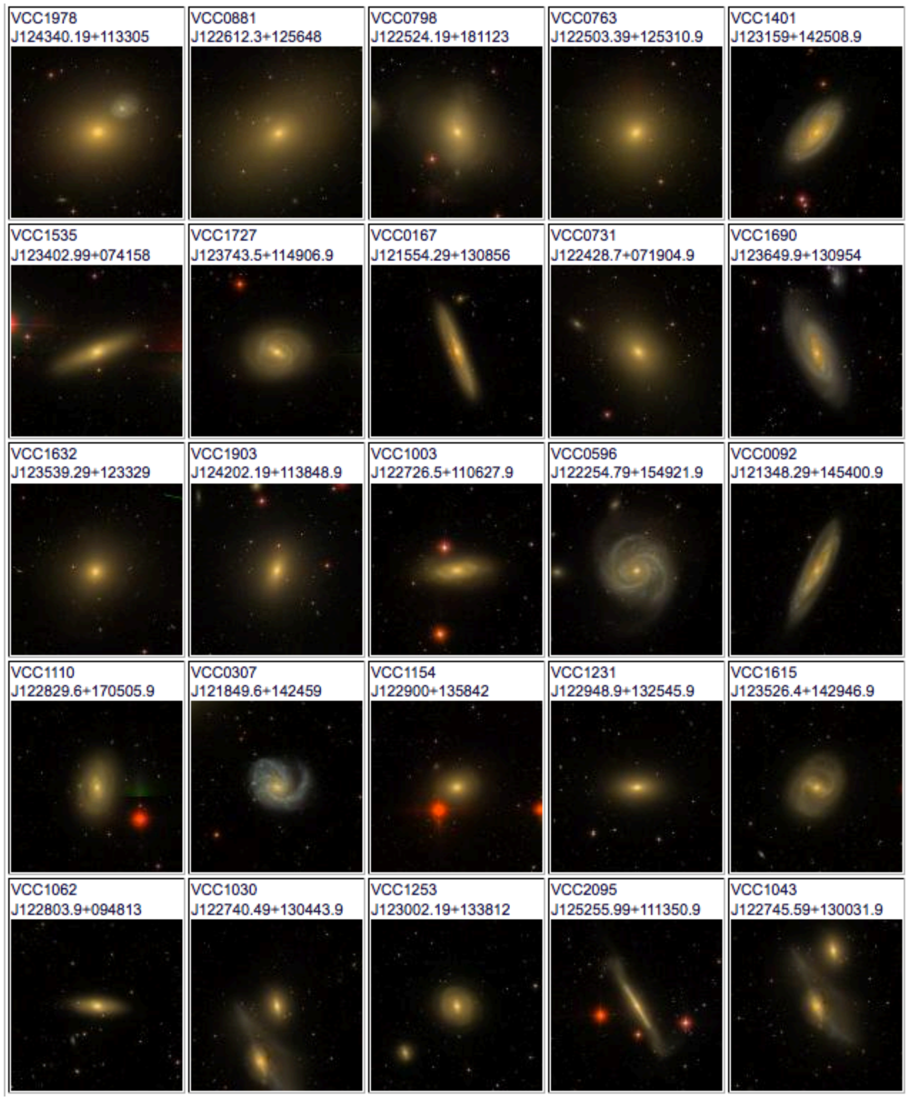




Brodie+14

the NGVS/VIMOS survey on GCSs

the baryonic angular momentum of galaxy haloes



a mass-limited sample of 27 quiescent and star-forming galaxies in Virgo

$\log(M/M_{\odot}) > 10.8$

VLT/VIMOS in $0.48 < \lambda < 1$ μm range

5,000 GC candidates
down to V = 23 mag
and out to $R_p \sim 50$ kpc

~45 km/s velocity accuracy

Puzia, Sánchez-Janssen
& the NGVS team

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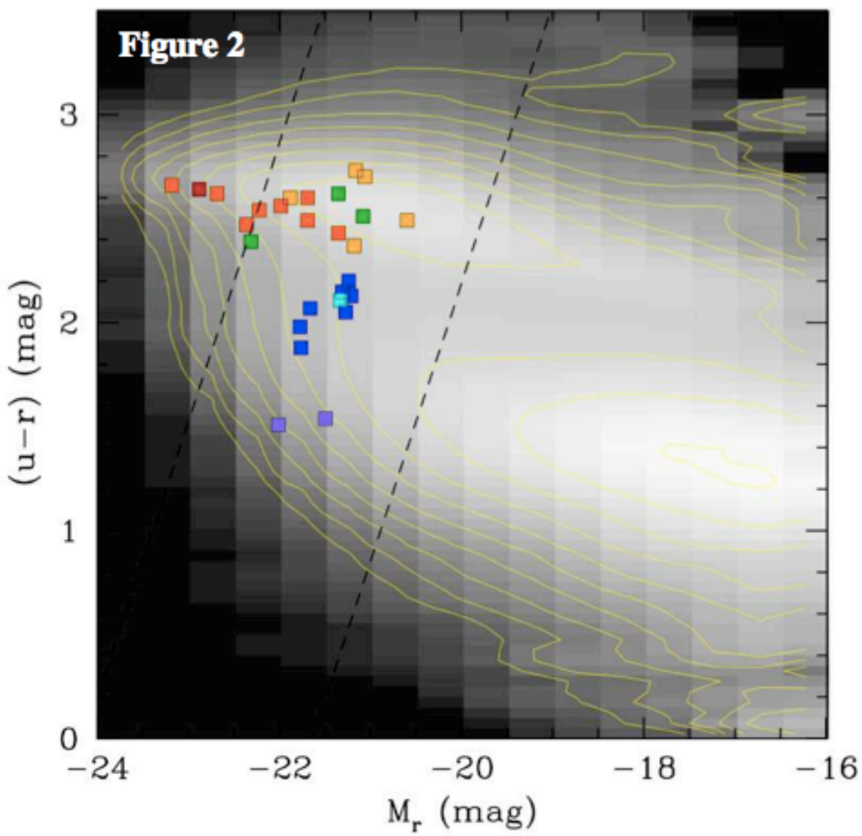

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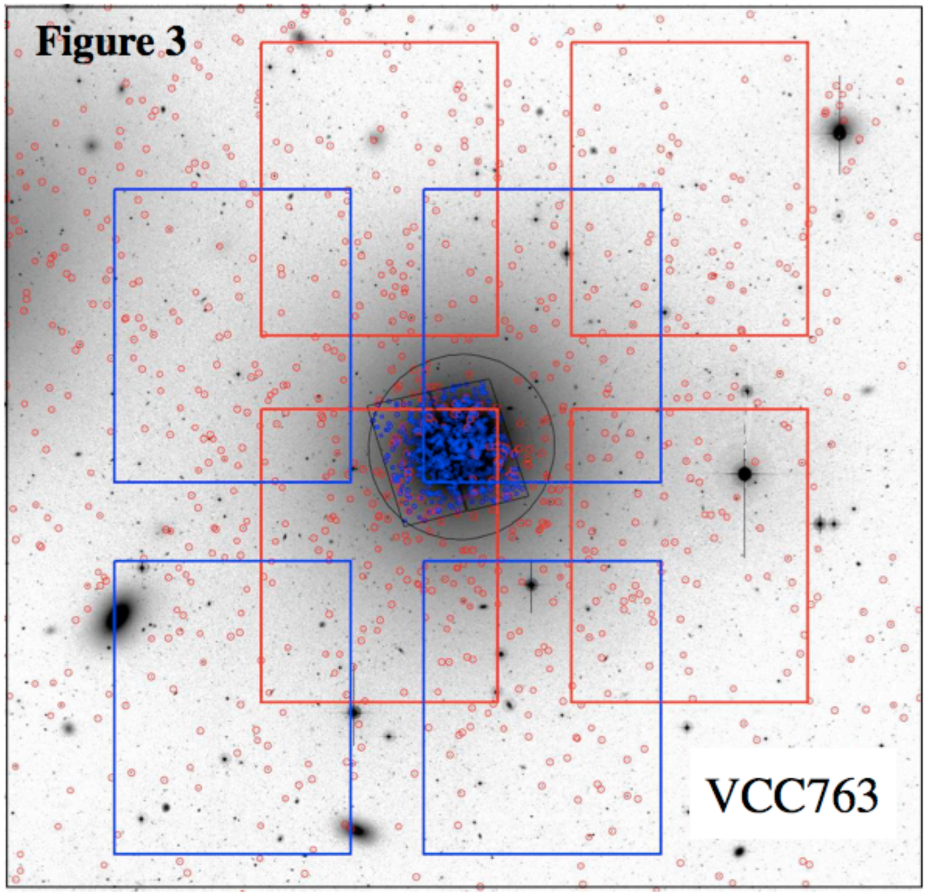

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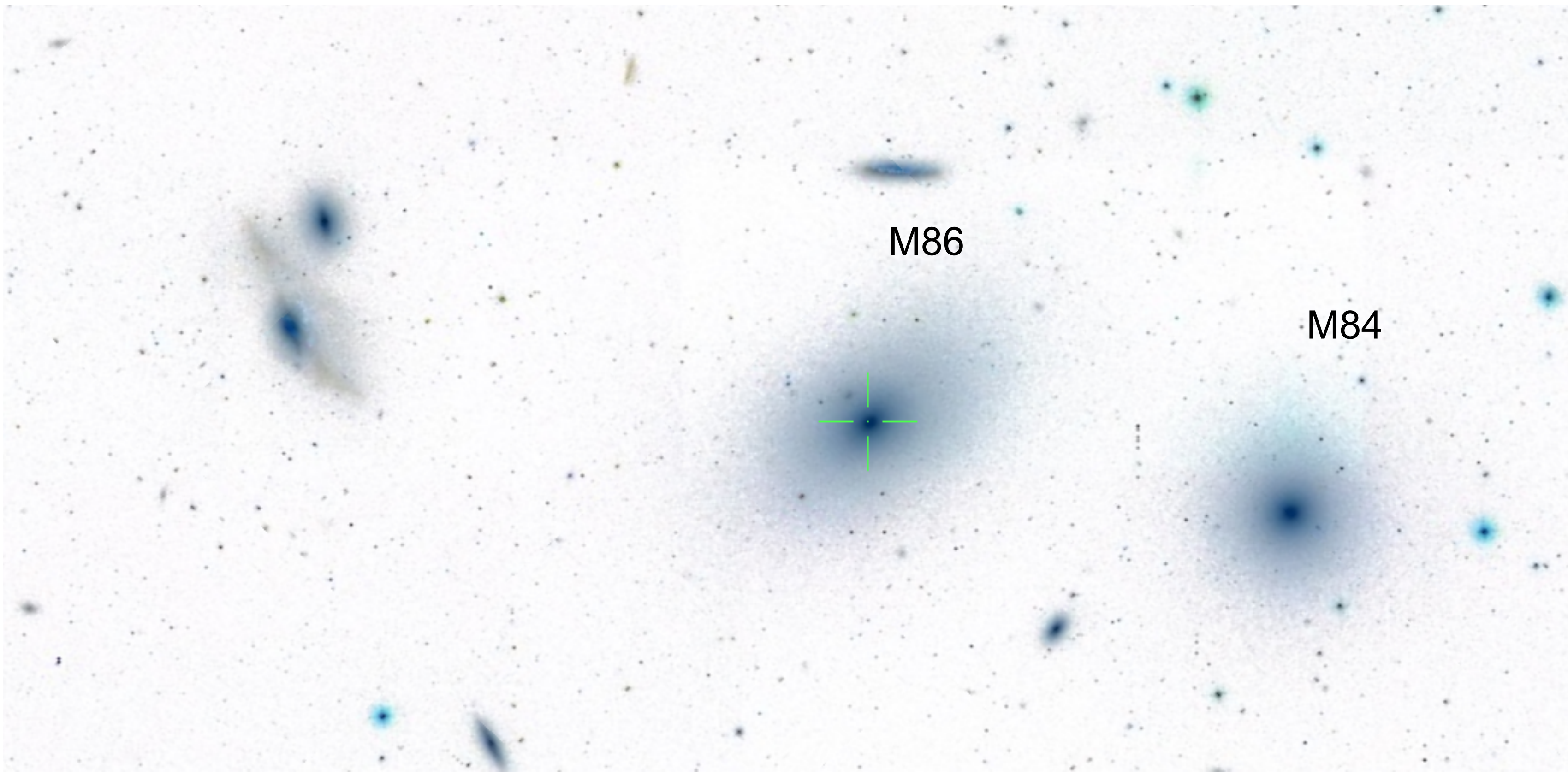
1150 GC candidates across 300 kpc in the M86 group



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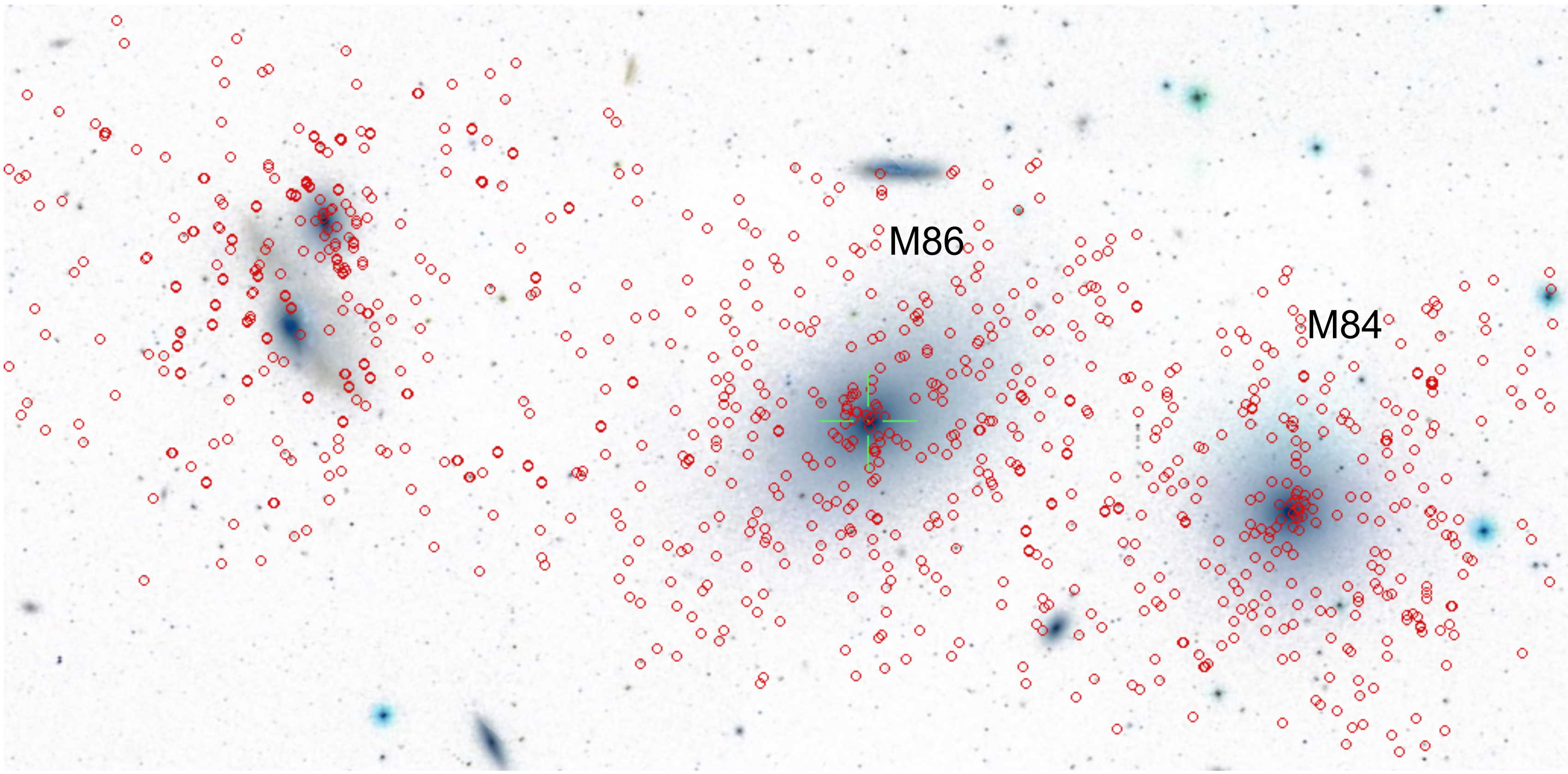

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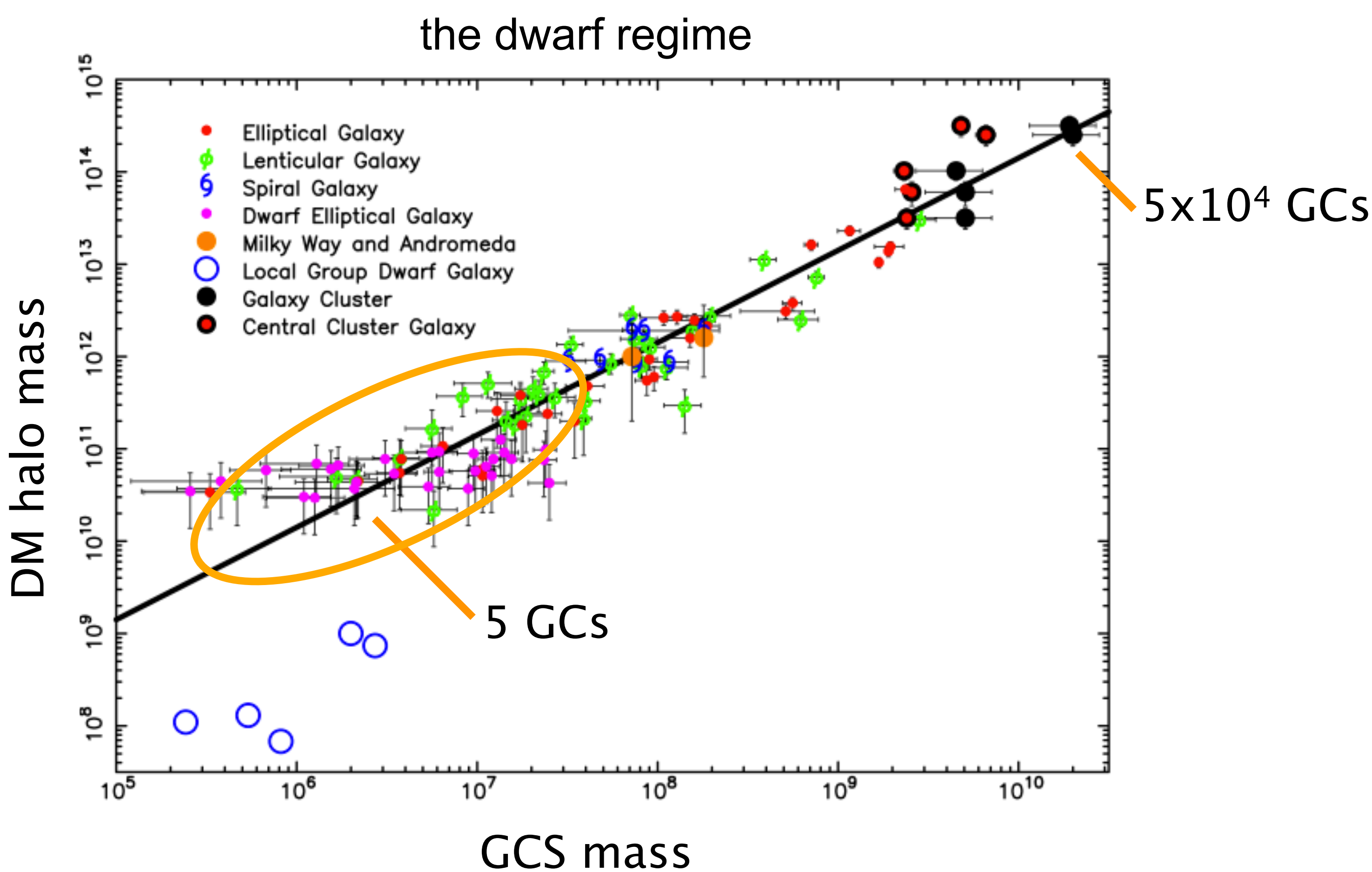
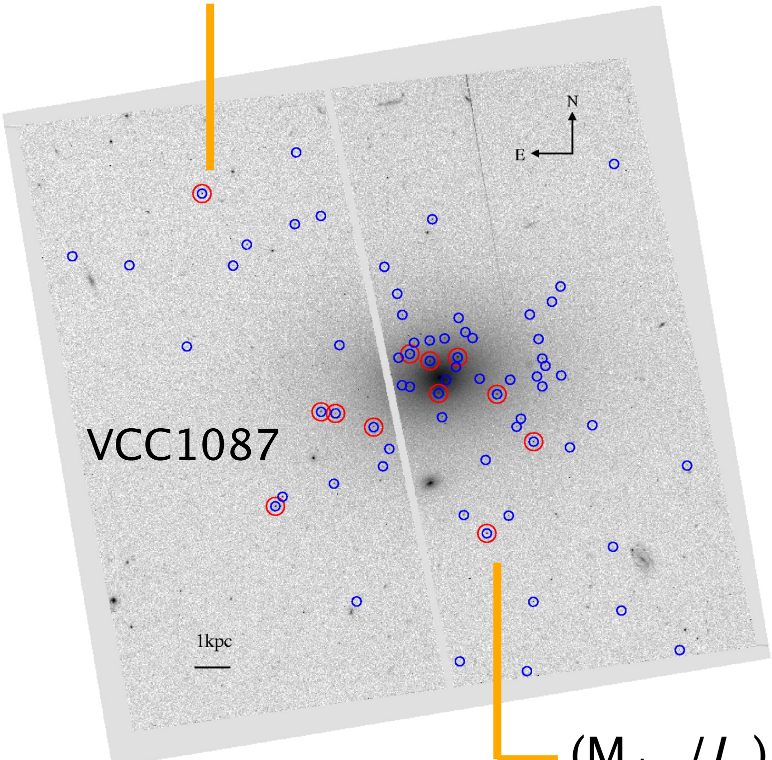


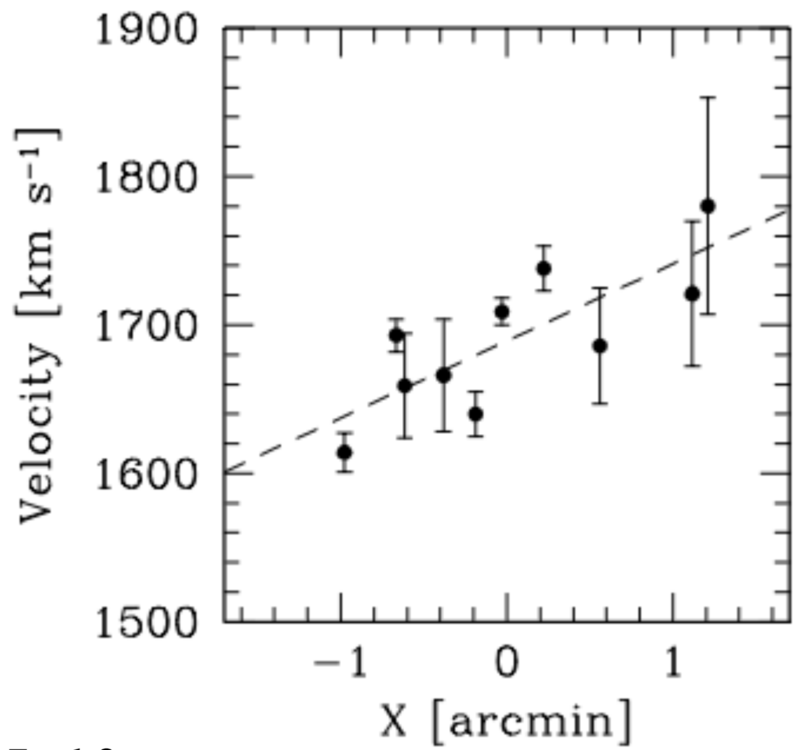
Spitler & Forbes 2009; Harris+13

A disky origin for Virgo dEs?

Keck/Deimos kinematics for a dozen GCs in 3 Virgo dEs



$(M_{dyn}/L_B) \sim 5\text{–}10$

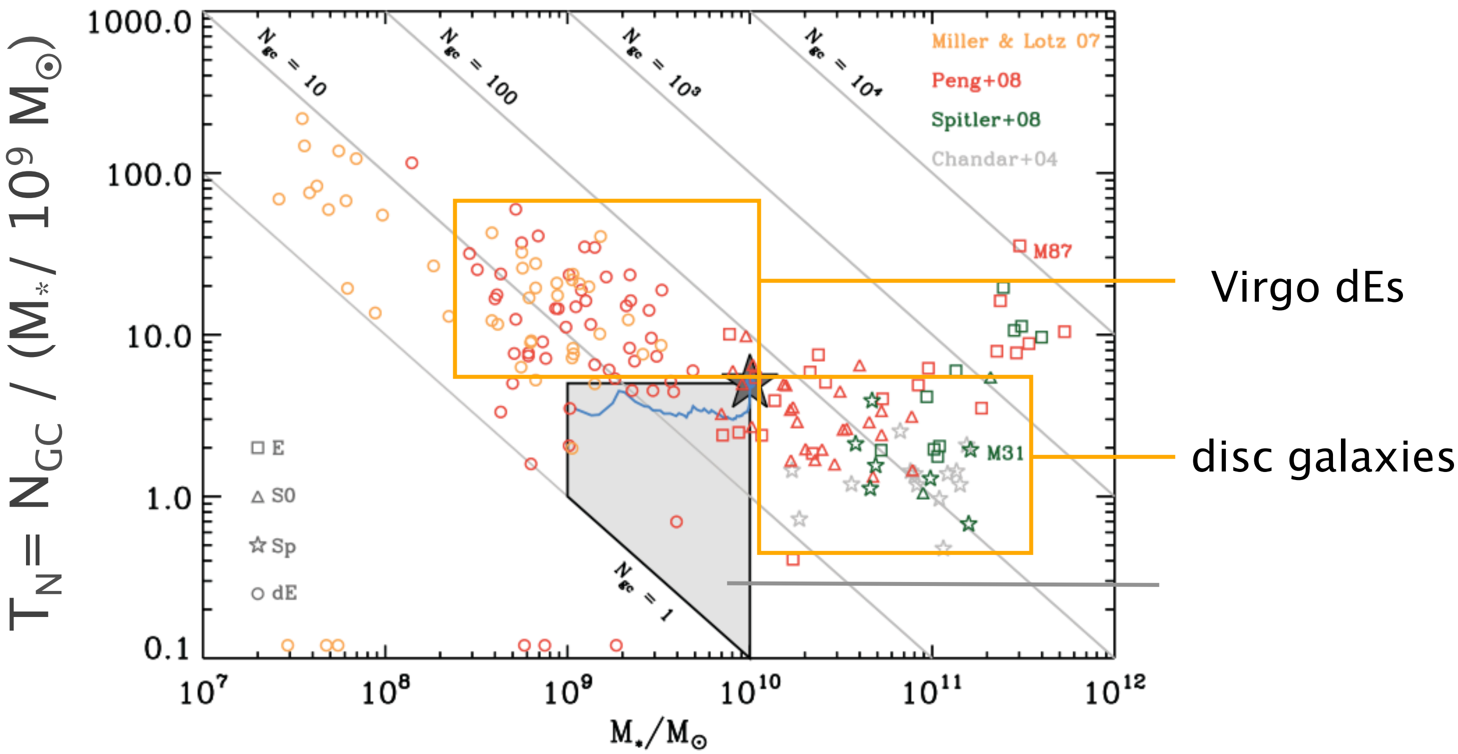


3/3 show (some) evidence for rotation!

Beasley et al. (2006, 2009)

Probably not, but complex picture

can't strip mass while preserving N_{GC} and rotation support

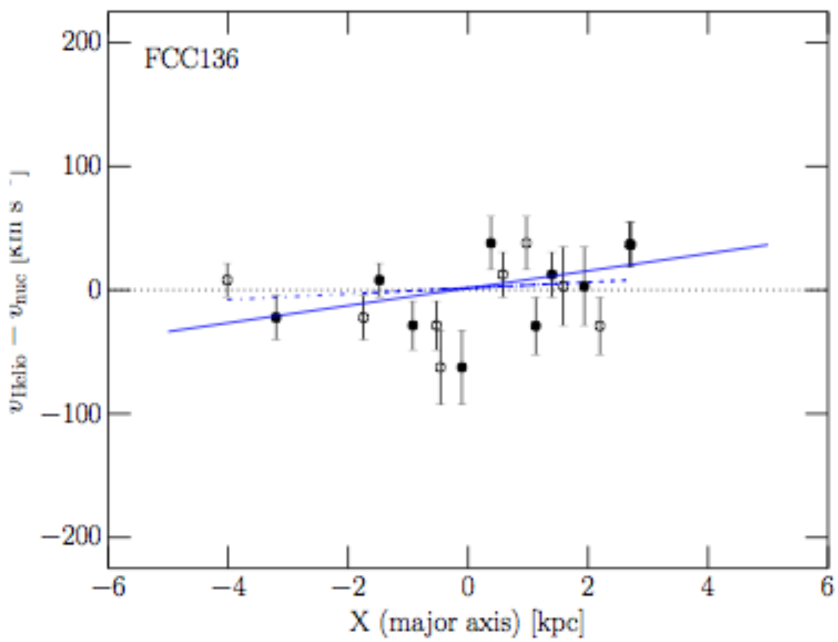


RSJ & Aguerri (2012); Smith, RSJ+13

Probably not, but complex picture

not all GCSs in dEs rotate

Gemini/GMOS kinematics of ~10 GCs in a sample of 4 cluster dEs



no measurable rotation (Miller+15, submitted)

+ Keck/Deimos kinematics of ~80 GCs in ~20 Virgo dEs (Toloba+ in prep.)

+ GTC/OSIRIS kinematics of GCSs in ~10 Virgo dEs (Beasley+ in prep.)

the future

exciting times ahead for GC MOS studies

what we need:

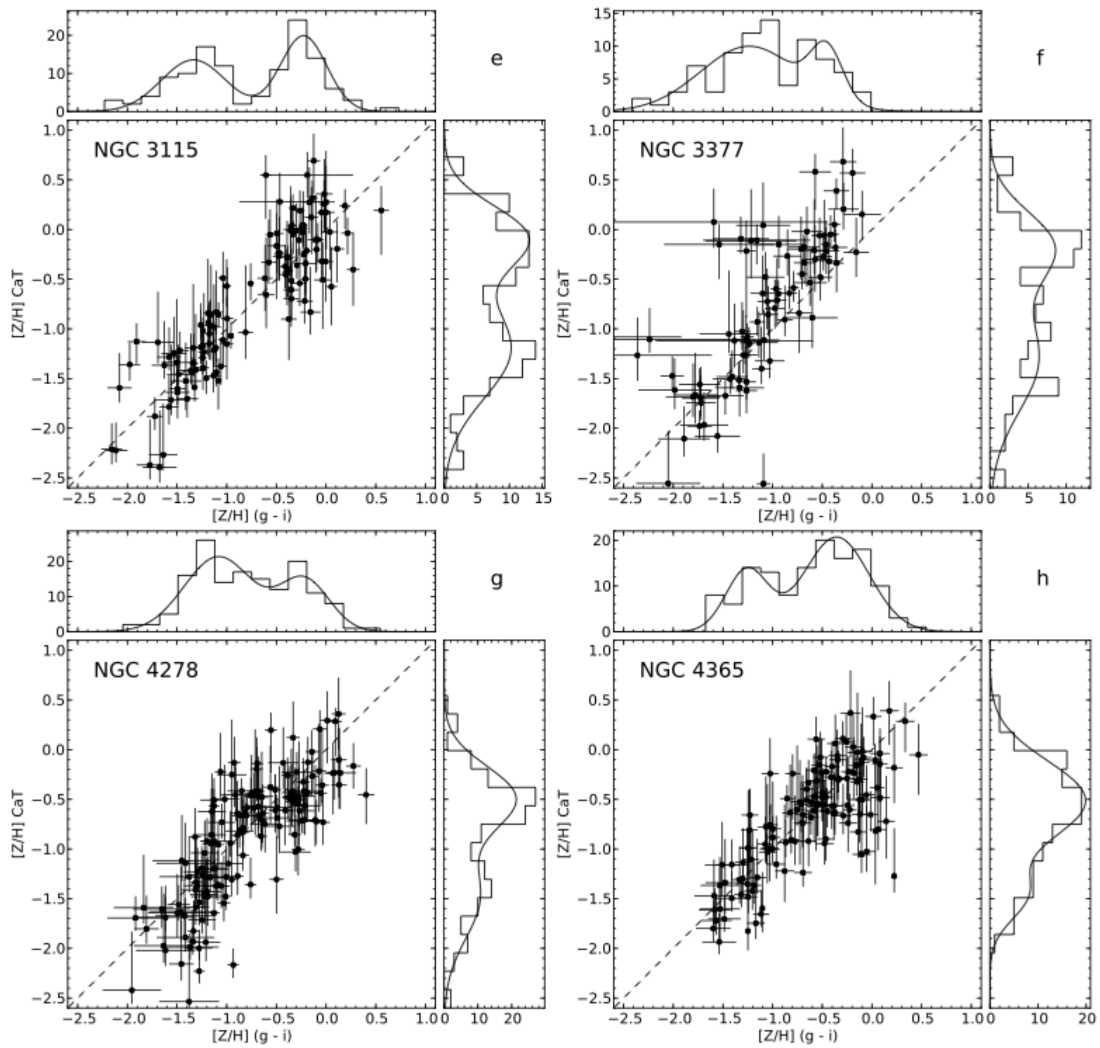
- high multiplexity (# 50–1000) in the optical
- *R* > 2,000 (kinematics + stellar populations)
- 5 arcmin < FOVs < 1 deg

what we can use:

- existing MOS instrumentation in 8–10m class telecopes
  (Deimos, VIMOS, OSIRIS, FORS, GMOS, IMACS…)
- upcoming instrumentation (PFS, Megara, MSE)
- E–ELT / TMT/ GMT if we want to go beyond *D* ~ 30 Mpc!

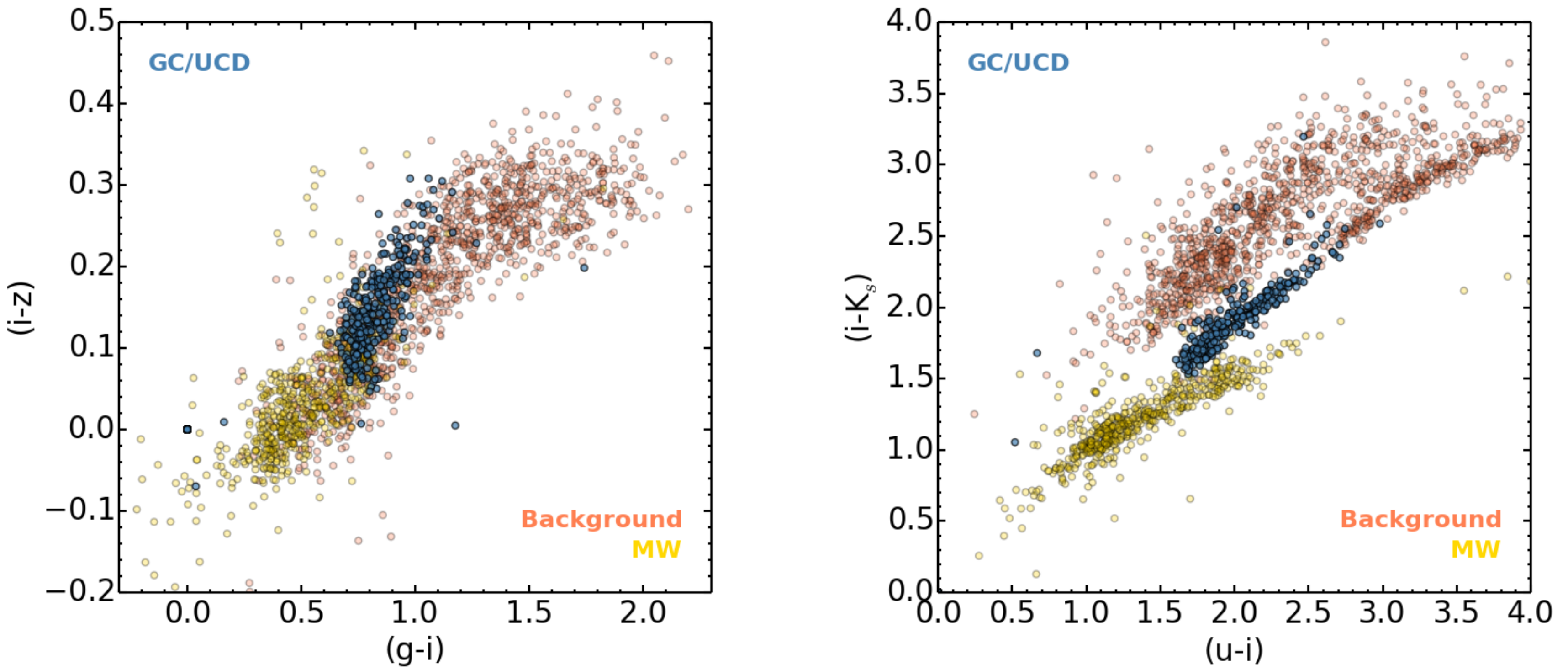
the SLUGGS survey

exploring the GC colour-metallicity relation



Usher+12

the NGVS
a clean GC photometric selection



Muñoz+14

Cluster early-type dwarfs

early or late origin?

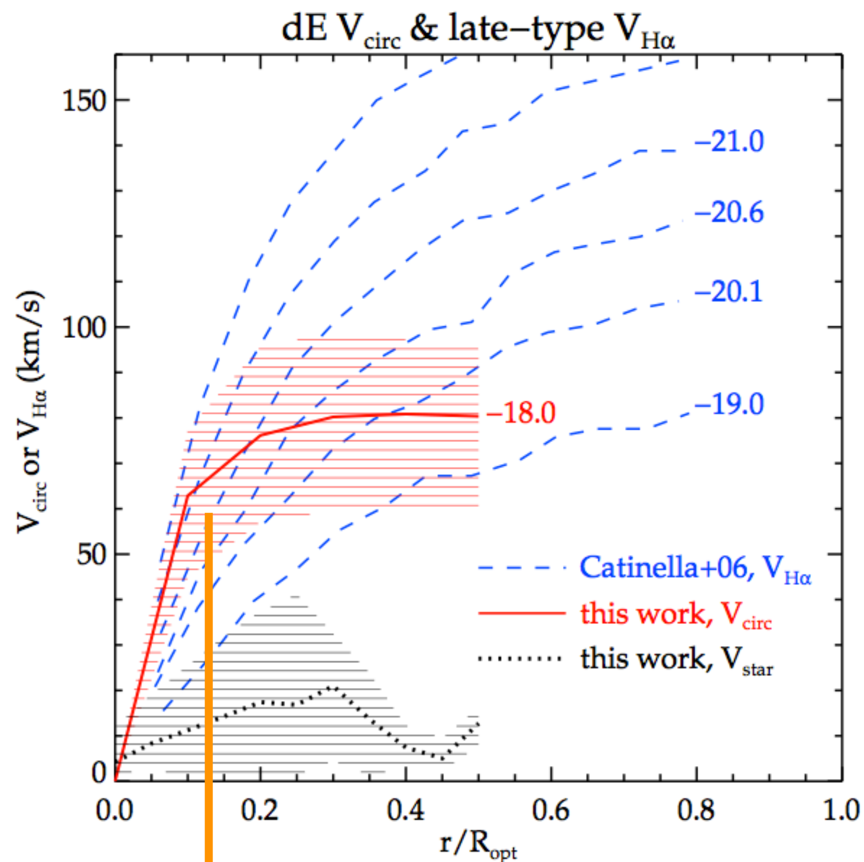
Evidence for late origin from

late (< 6 Gyr) red sequence buildup at low masses

similar shapes, structure and kinematics

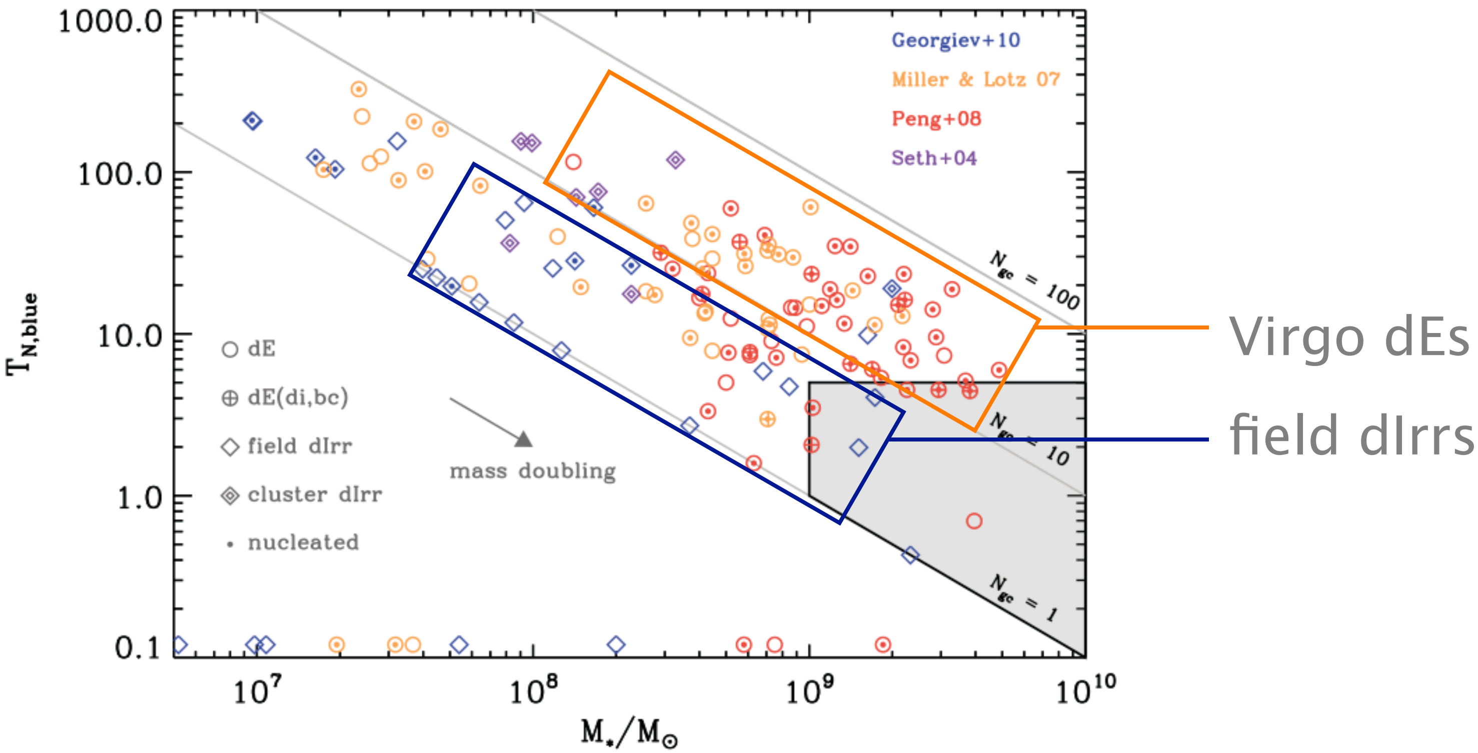
presence of disc-like components…

“transformation due to tidal harassment is able to explain all of the above, *unless the dE progenitors were already compact and had lower angular momenta at higher redshifts*”



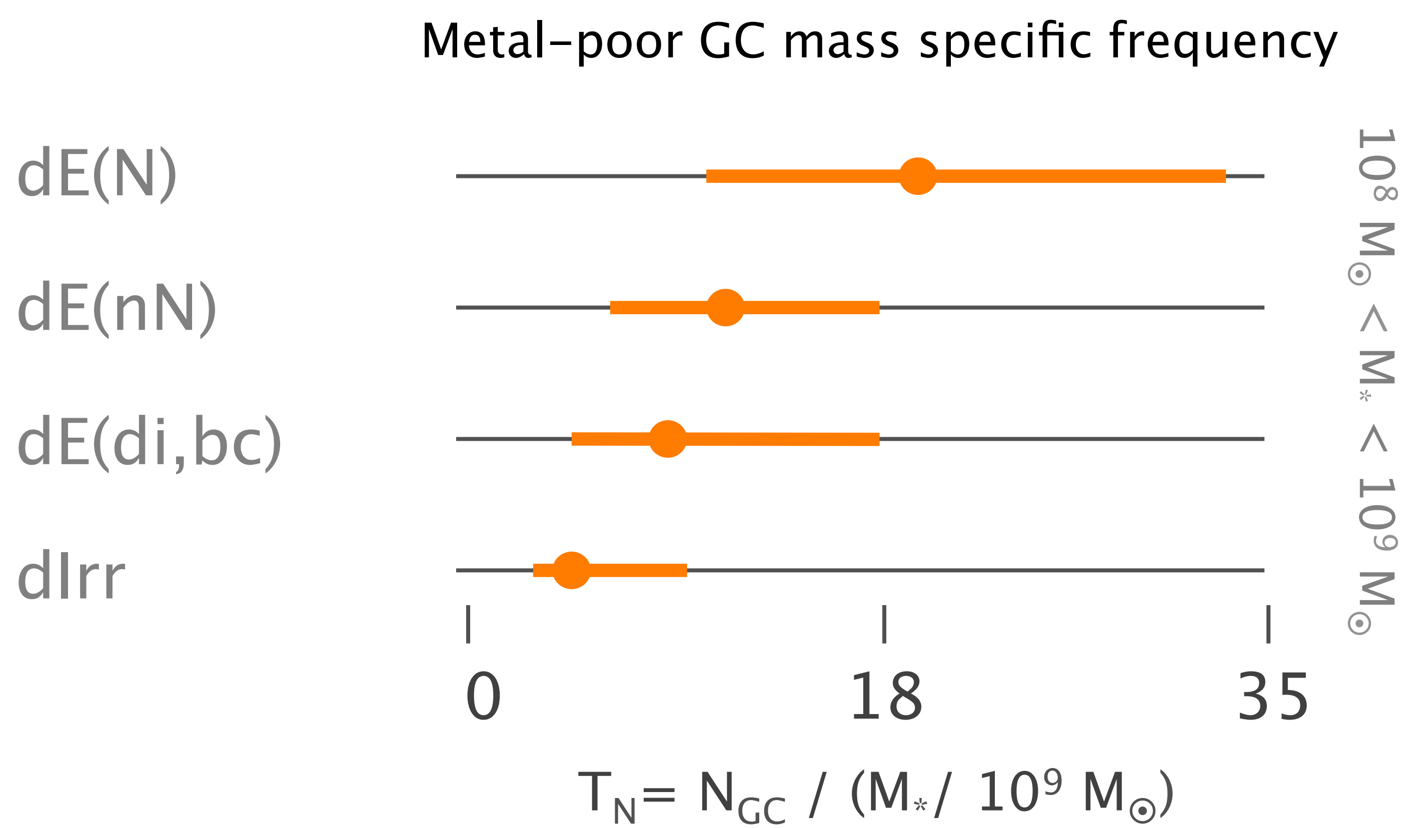
Rys et al. (2014)

...disfavour a *recent* origin from gas- or stellar mass-stripped *field* dIrr



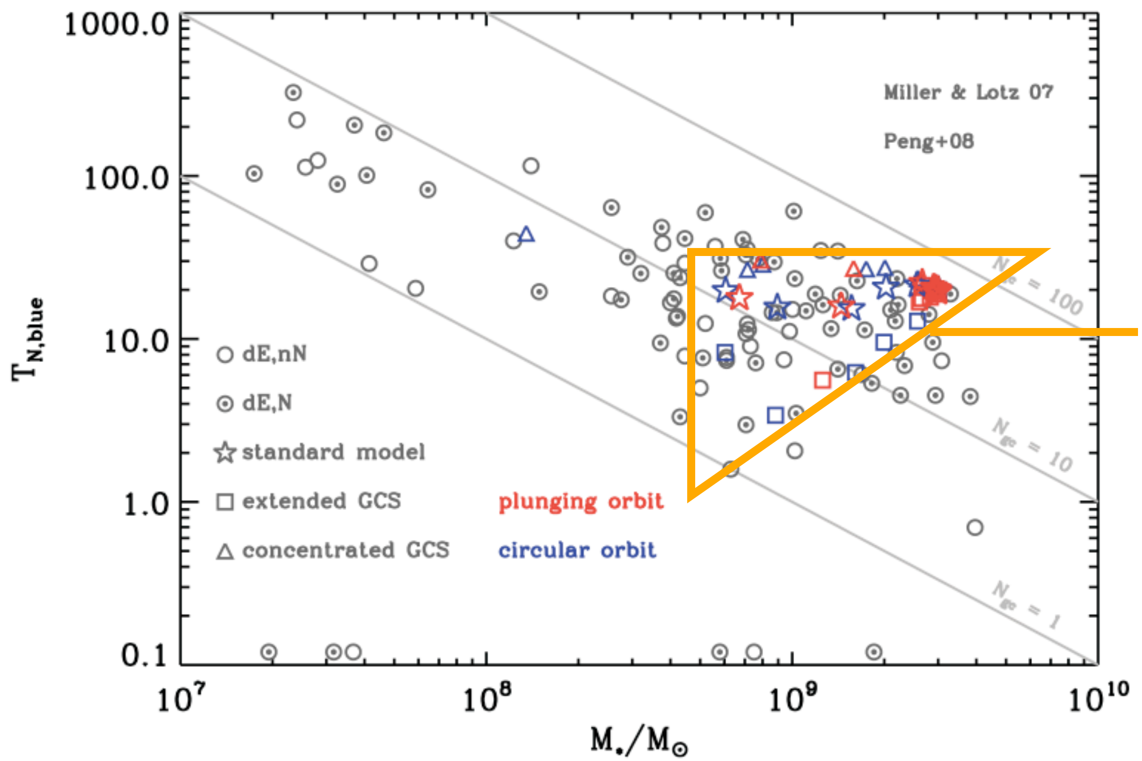
RSJ & Aguerri (2012)

Earlier dwarf (sub)types contain richer GCSs



Strong dependence on final DM content,

orbit type and specific tidal history



orbit type
stochasticity
spatial distribution

stars/GCs stripped
when f_{DM} is ~15%

Smith, RSJ et al. (2013)

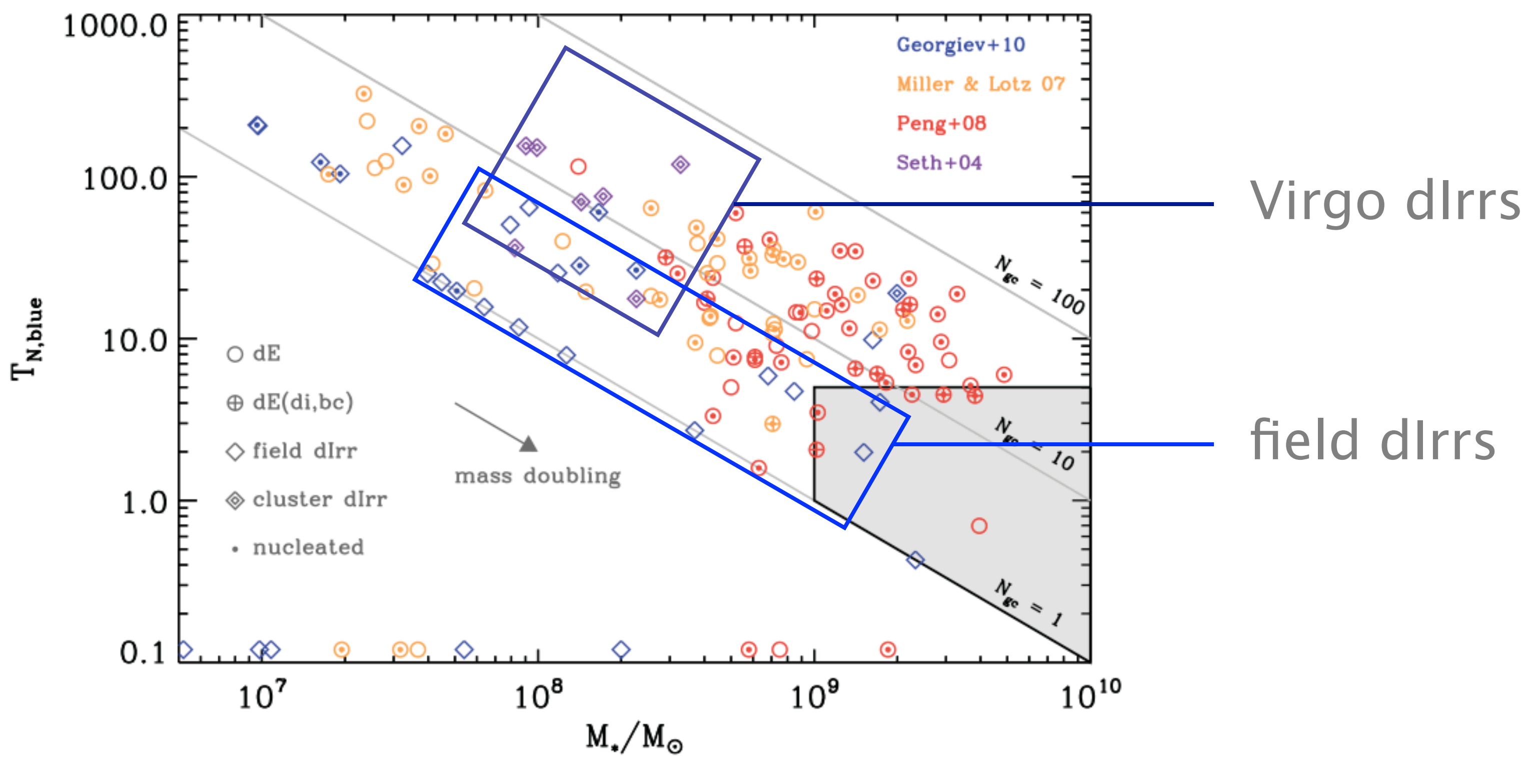
Kinetic energy increase in the impulse approximation

energy gain from outside-in

$$(\Delta E/m) = G^2\, M_{\rm P}^2\, v^{-2}\, b^{-4}\, \boxed{r^2}\, \boxed{f(P,\, A)}$$

adiabatic + extended perturber correction
(Gnedin+99)

The high GC mass specific frequencies of Virgo dIrrs



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