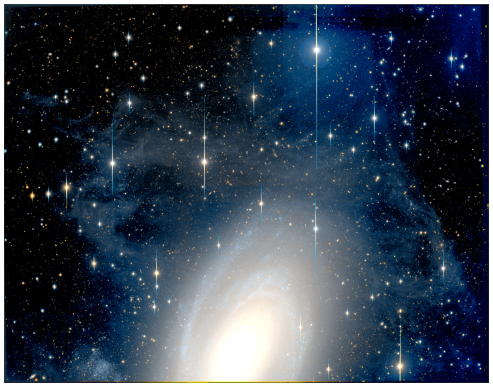
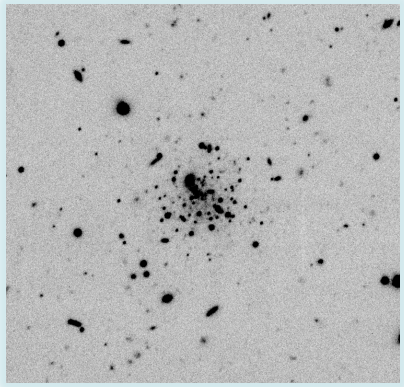
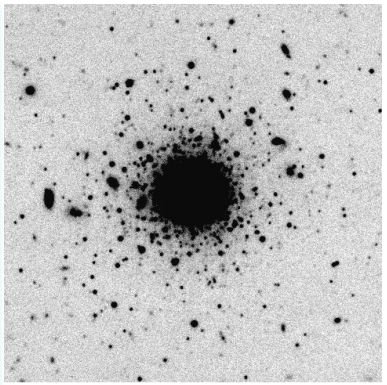
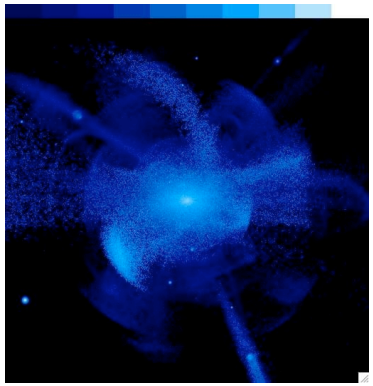
Viewing the Outskirts of Nearby Galaxies with Gemini and Subaru

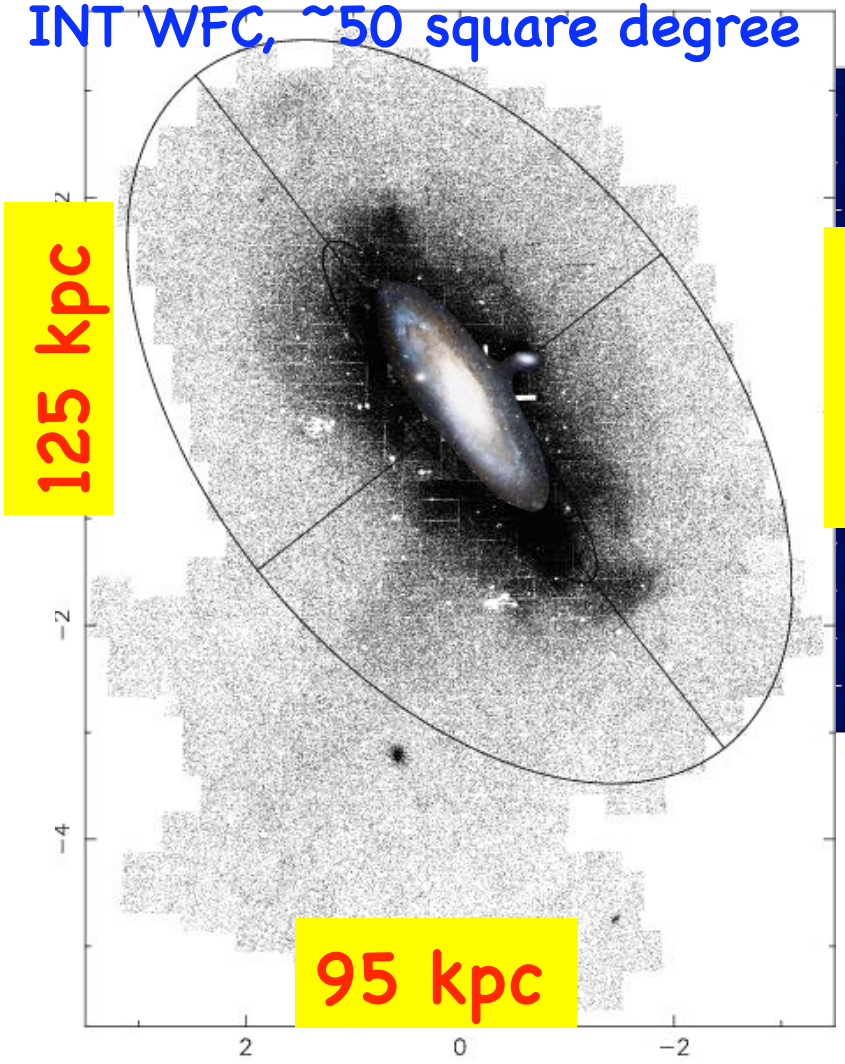
Annette Ferguson

Mike Barker, Dougal Mackey, Sarah Buehler

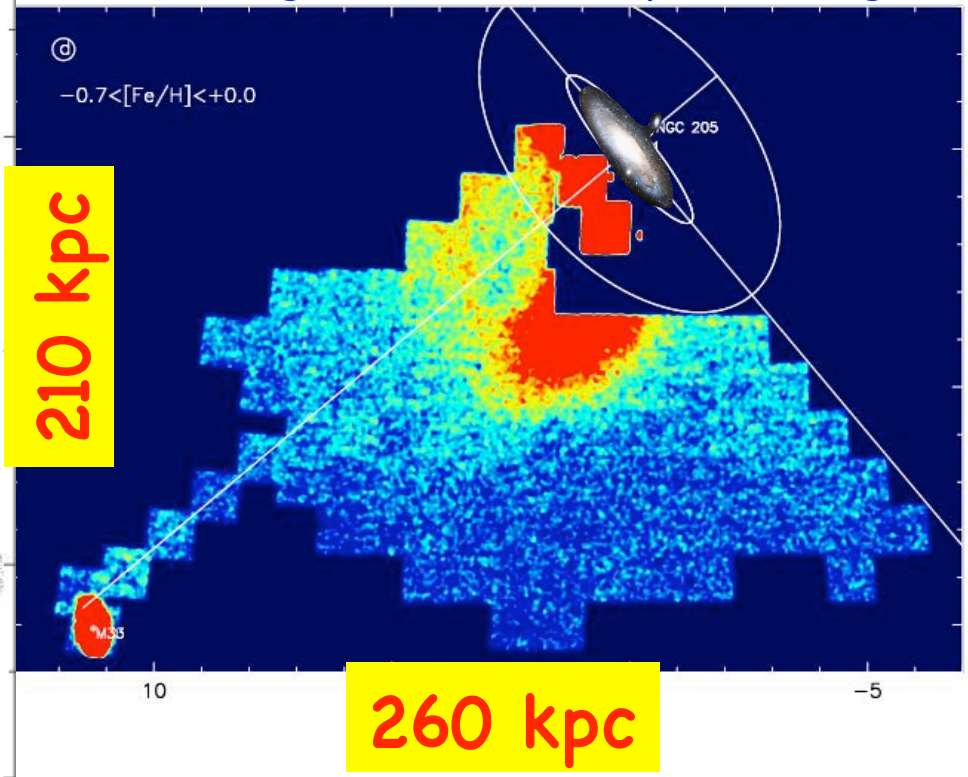
Institute for Astronomy, University of Edinburgh

Why Care About the Outskirts of Nearby Galaxies?

INT WFC, ~50 square degree

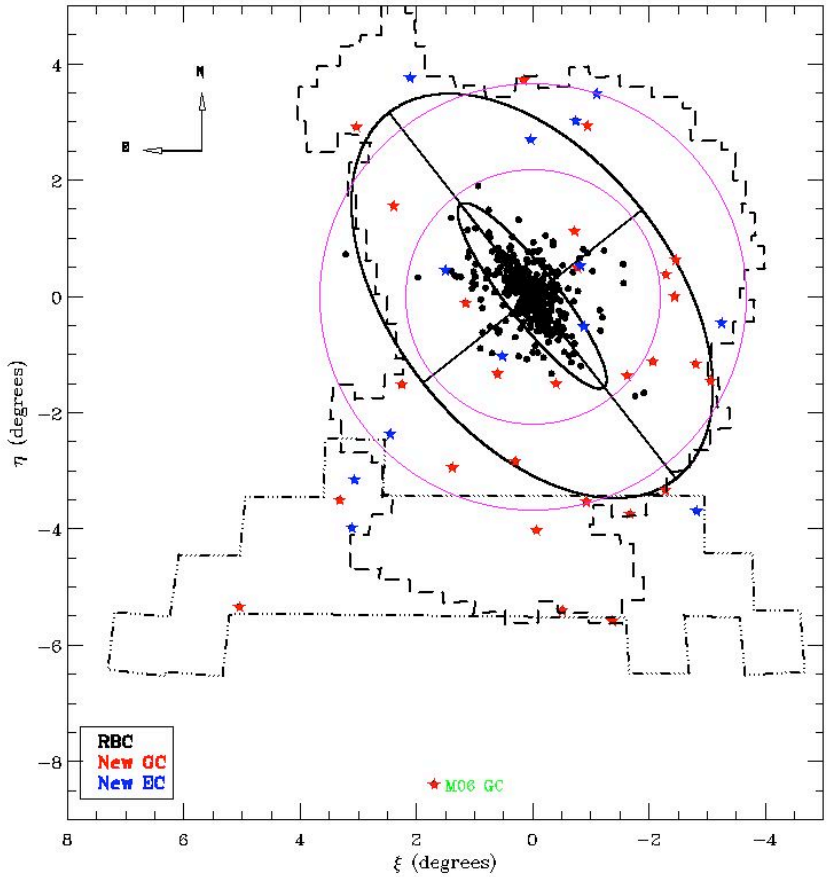


CFHT Megacam, ~85 square degree



Ibata et al 2001, Ferguson et al 2002, Irwin et al 2005, Martin et al 2006, Ibata et al 2007

Globular Star Clusters in the Far Outer Halo of M31



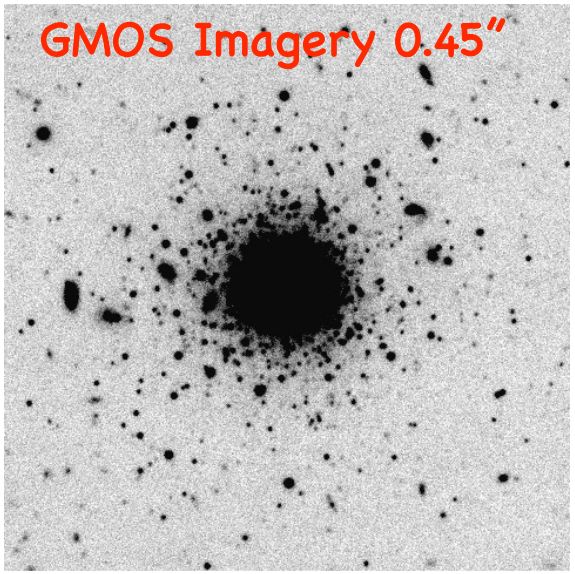
Huxor et al 2005, 2008, 2009
Mackey et al 2006, 2007
Martin et al 2006

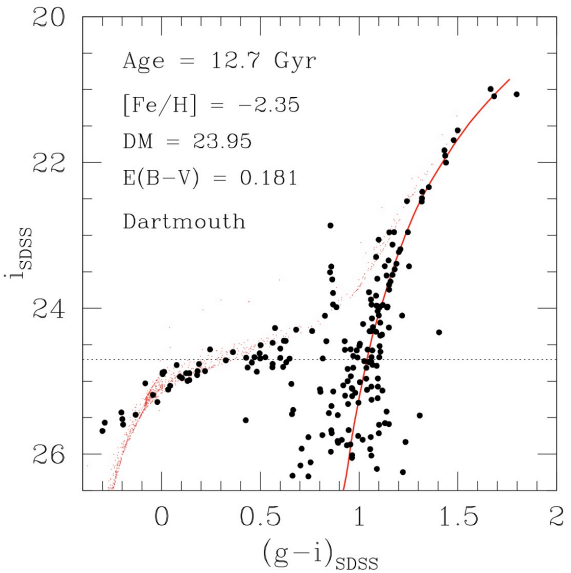
- GCs provide rare probe of baryonic content and mass distribution in galaxies at large R

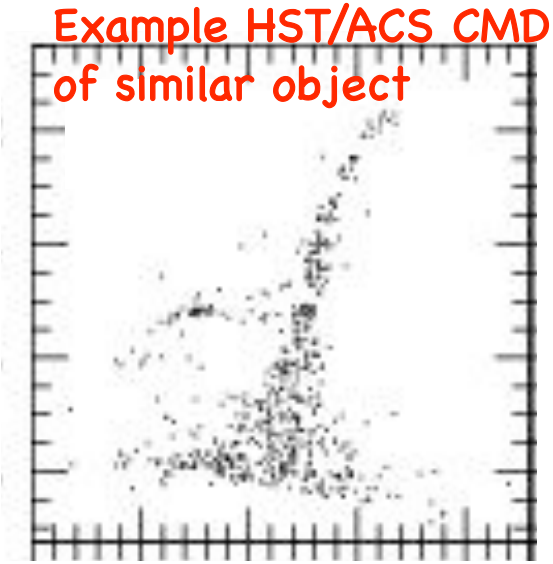
- new sample of 90+ outer star clusters compiled from ~225 □° of INT and CFHT/Megacam survey data (2 quadrants)

- increases total number of confirmed clusters in M31 by ~25% but number of confirmed clusters with R>1° (14 kpc) by a factor of several

Gemini/GMOS Studies of the Most Remote (Yet Known) Halo GC in M31



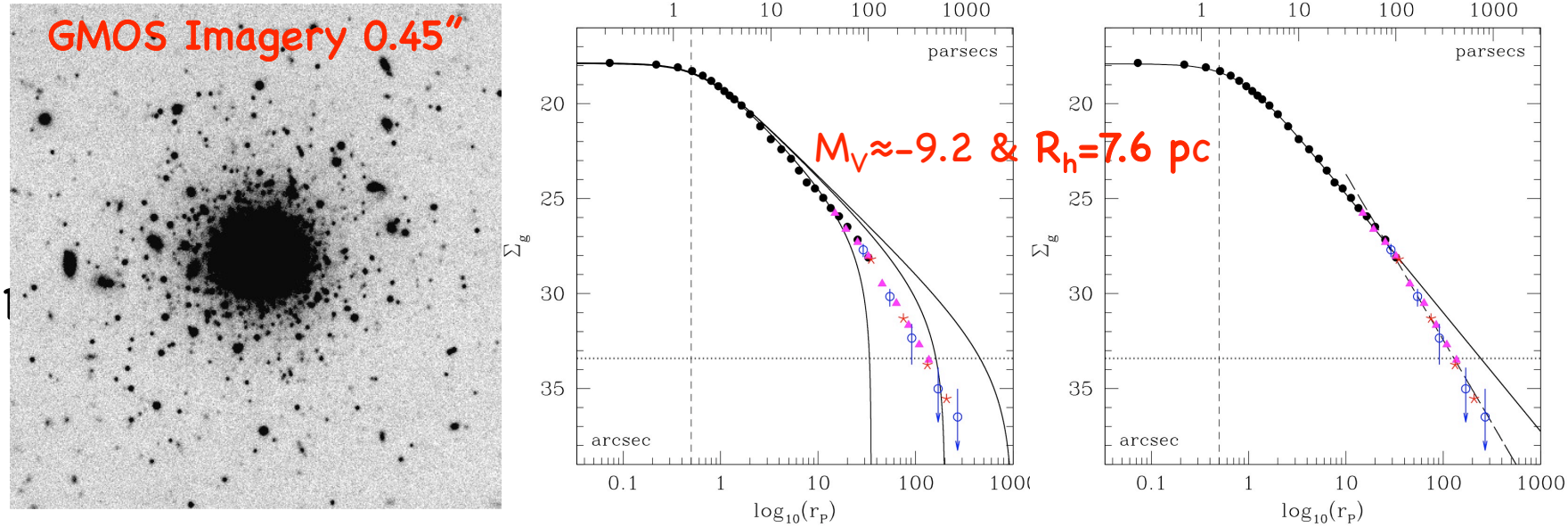




- GMOS 2007B: g′,r′,i′ exposures 2400-3600s in < 0.5" seeing
- CMD morphology supports ancient, metal-poor nature
  - –steep RGB and extended, continuous HB
  - –D_{LOS}= 630 kpc; with R_{proj}=116 kpc (8.5°) -> R_{M31} ≈ 190 kpc
  - –[Fe/H] ≈ -2.4 and > 10 Gyr

Mackey et al 2009; discovery in Martin et al 06

Gemini/GMOS Studies of the Most Remote (Yet Known!) Halo GC in M31

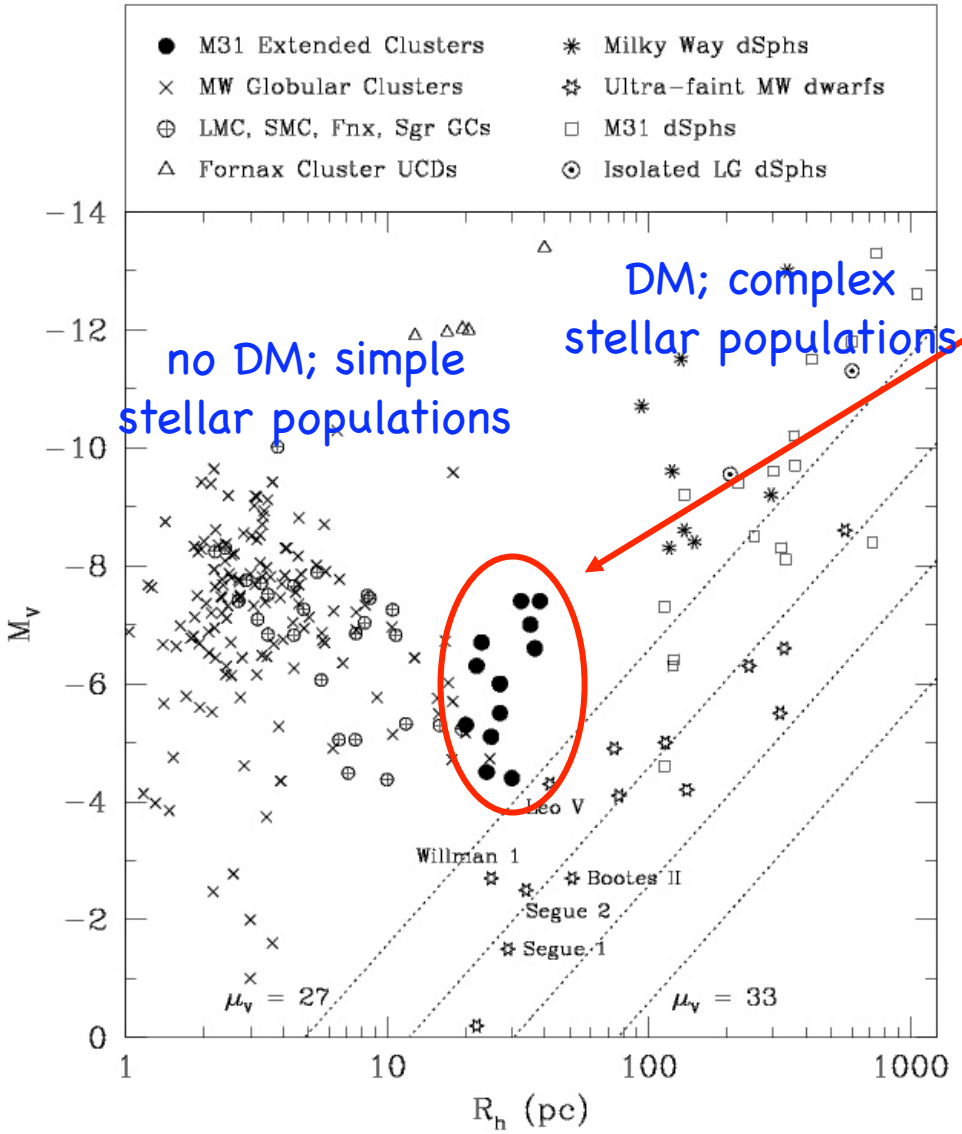


- traditional King profile fits work well at small radii but cannot explain the outer untruncated behaviour
- single power-law fits also fail; change in $\gamma \sim -2.5$ to -3.5 at 35"; **consistent with isolated cluster (re-)populating its halo...?**

Mackey et al 2009

Extended Clusters in the Halo of M31

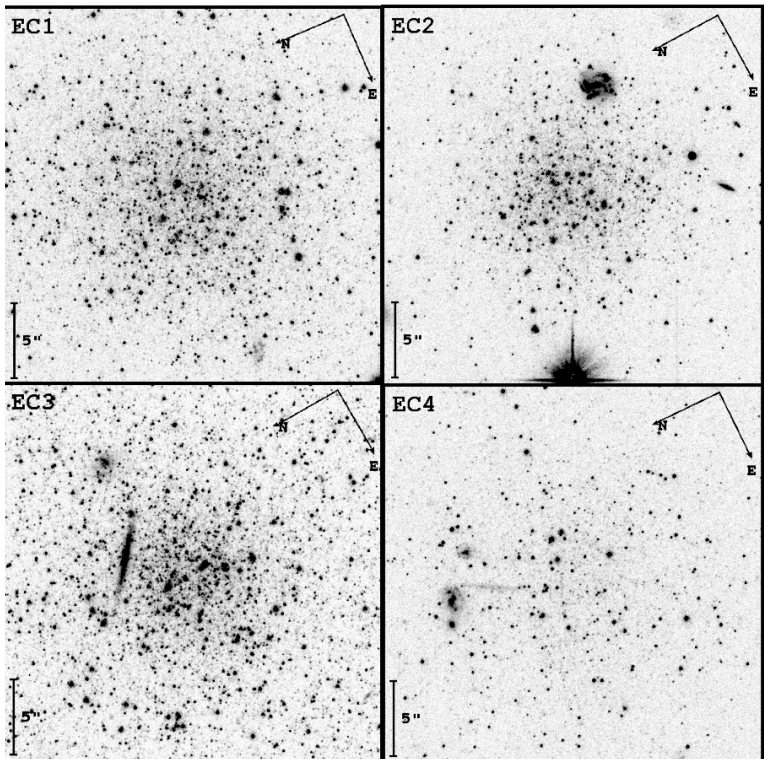
Huxor et al 2009b



M31 posseses a population of luminous extended GCs (ECs) which have M_V and R_h that fill gap between classical GCs and dSph

No known analogues in the MW: closest neighbours are Pal type GCs and newly-discovered ultra-faint satellites

HST/ACS Imagery of M31 Halo ECs



Mackey et al 2006

- sub-sample of 4 extreme objects
- -1.8 < [Fe/H] < -2.1
- no evidence for internal population gradients
- range of HB morphologies: evidence for age spread?
- Despite unusual structures, appear just like classical GCs in terms of stellar content…. caveat limited parameter space probed …..

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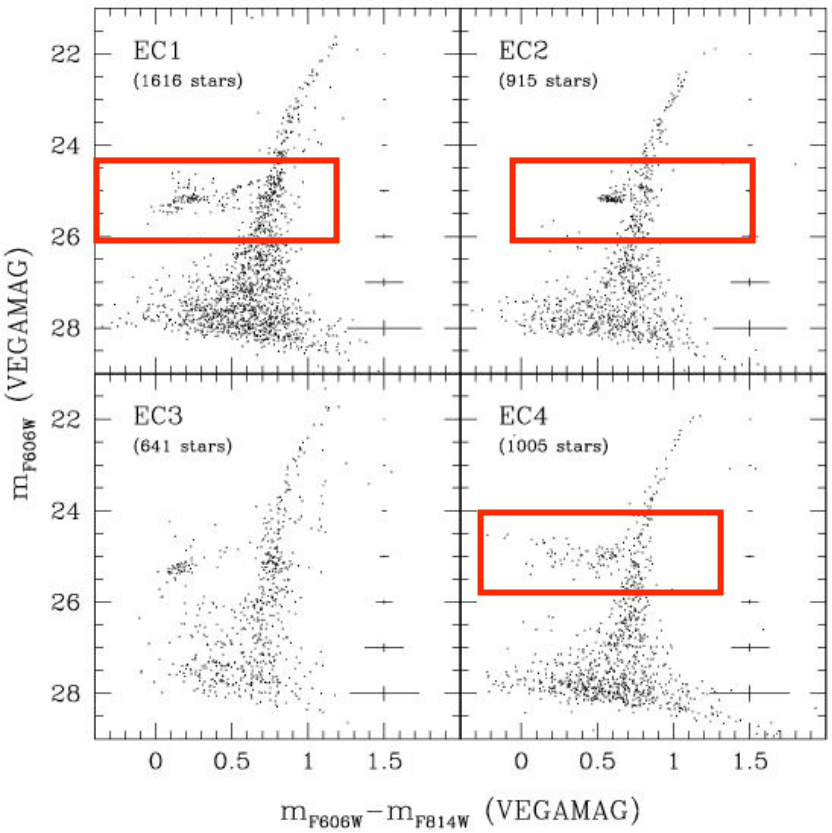

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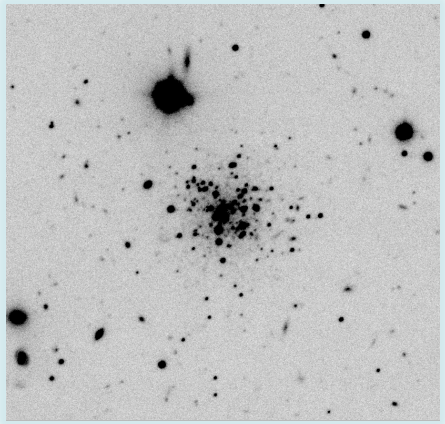
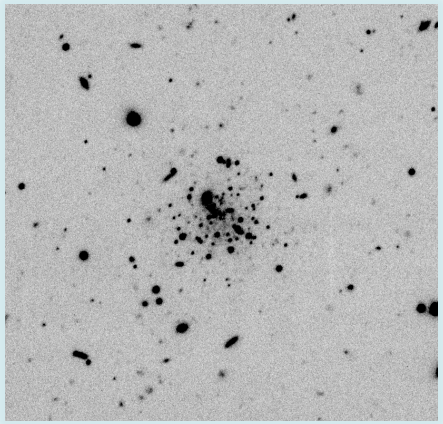
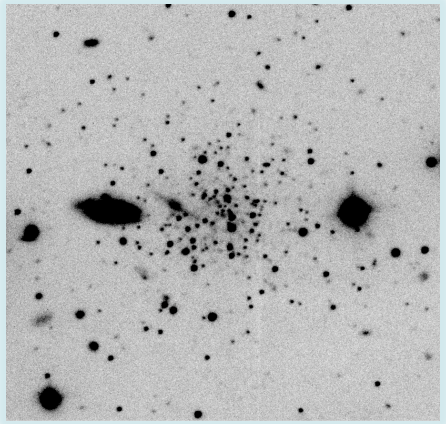


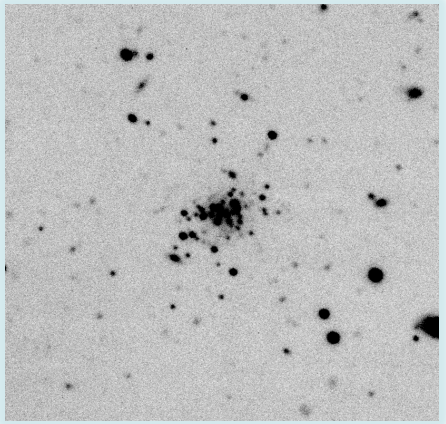
HEC 1 44.9 kpc



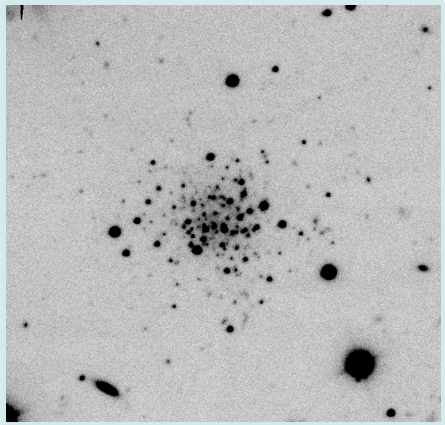
HEC 3 49.9 kpc



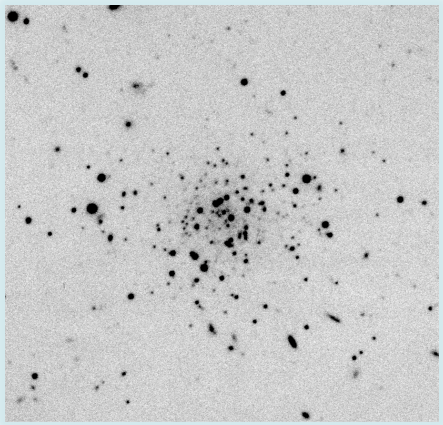
HEC 6 42.5 kpc



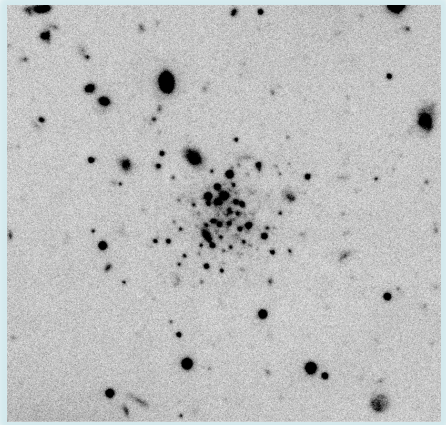
HEC 14 86.0 kpc



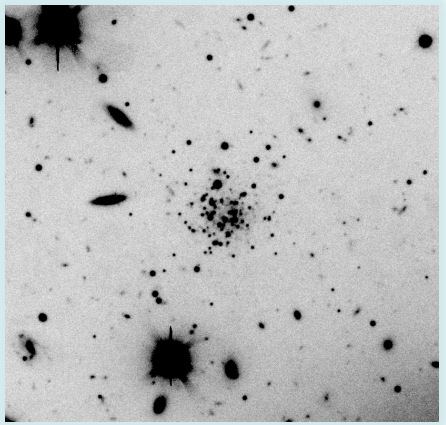
HEC 10 58.7 kpc



HEC 13 68.8 kpc



HEC 16 100.6 kpc



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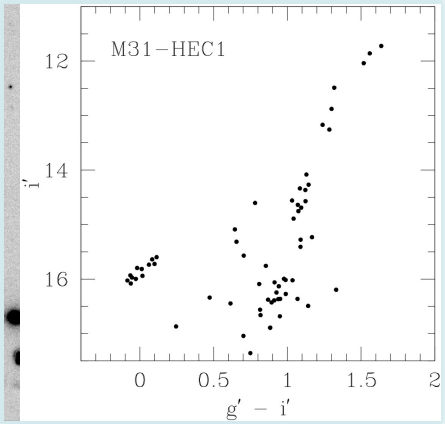
Mackey et al in prep

Gemini/GMOS Imagery of M31 Halo ECs



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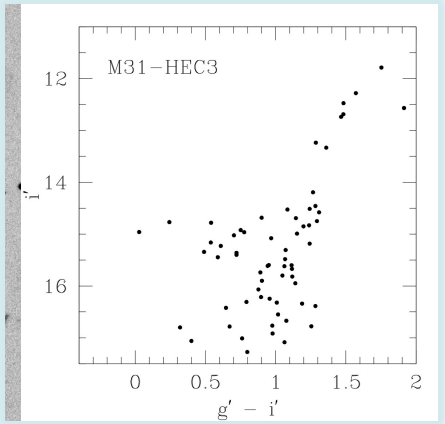

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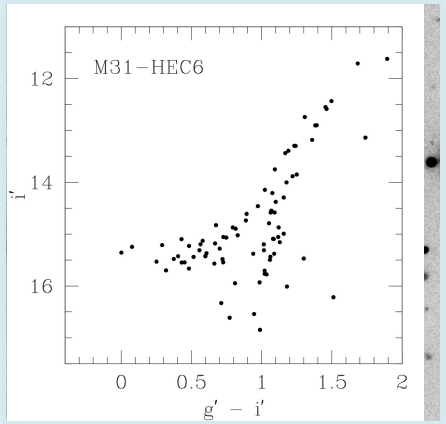

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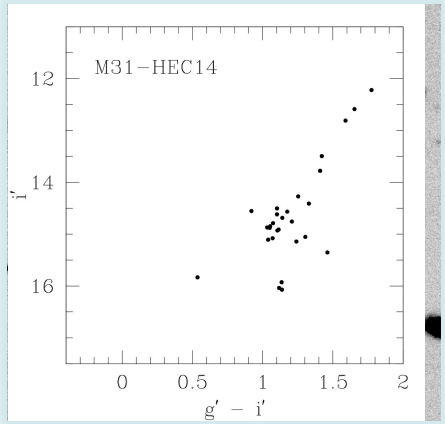

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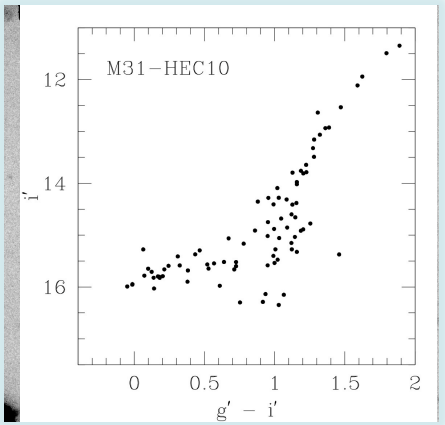

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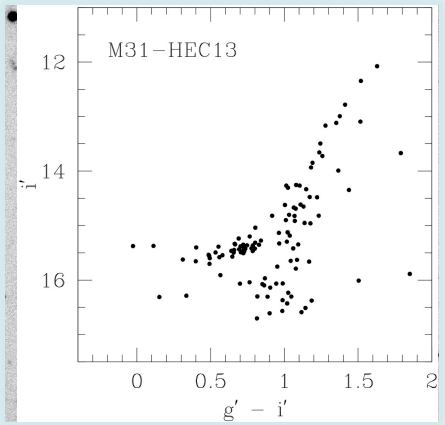

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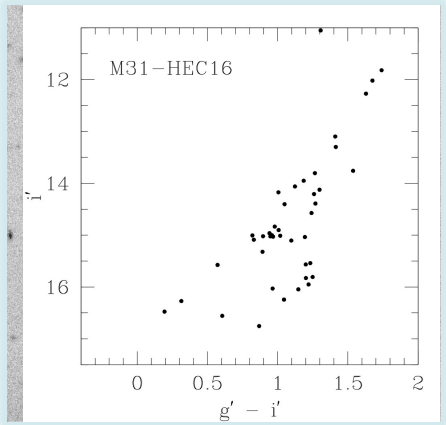

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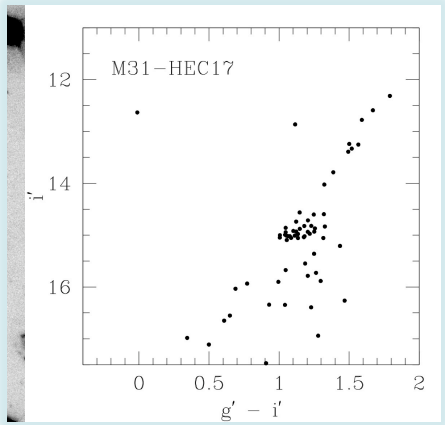

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- GMOS 2008B: g′,i′ exposures 2400-3600s in 0.3-0.55″ seeing

Mackey et al in prep

Open Questions: The Nature of ECs

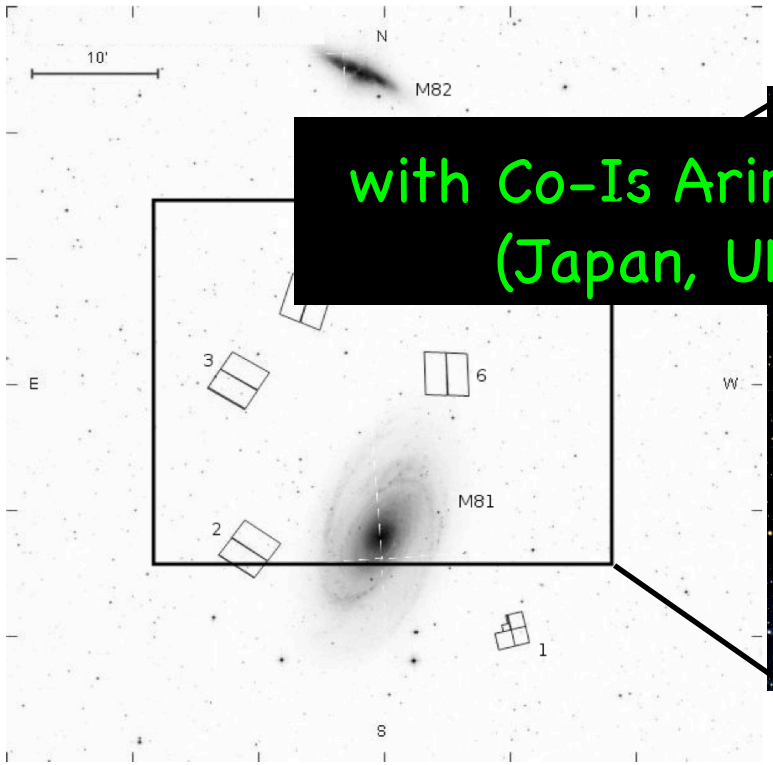
- evidence to date suggests ECs most likely composed of simple populations but dispersions need to be established

- tentative M/L measurement for one object: M/L= $6.7^{+15}_{-6.7}$ (Collins et al 2009) – if confirmed, suggests little DM

- if ECs are star clusters, why so extended compared to classic GCs? Continuum of sizes or bimodality? Halo natives or immigrants? Formation channel? Tidal shocking via disk passages? Survivability and timescales...

- if ECs are dwarfs, why metallicities higher and dispersions lower than in other (ultra-faint) dSphs?

The Stellar Outskirts of Galaxies Beyond the Local Group



Barker et al 2009a

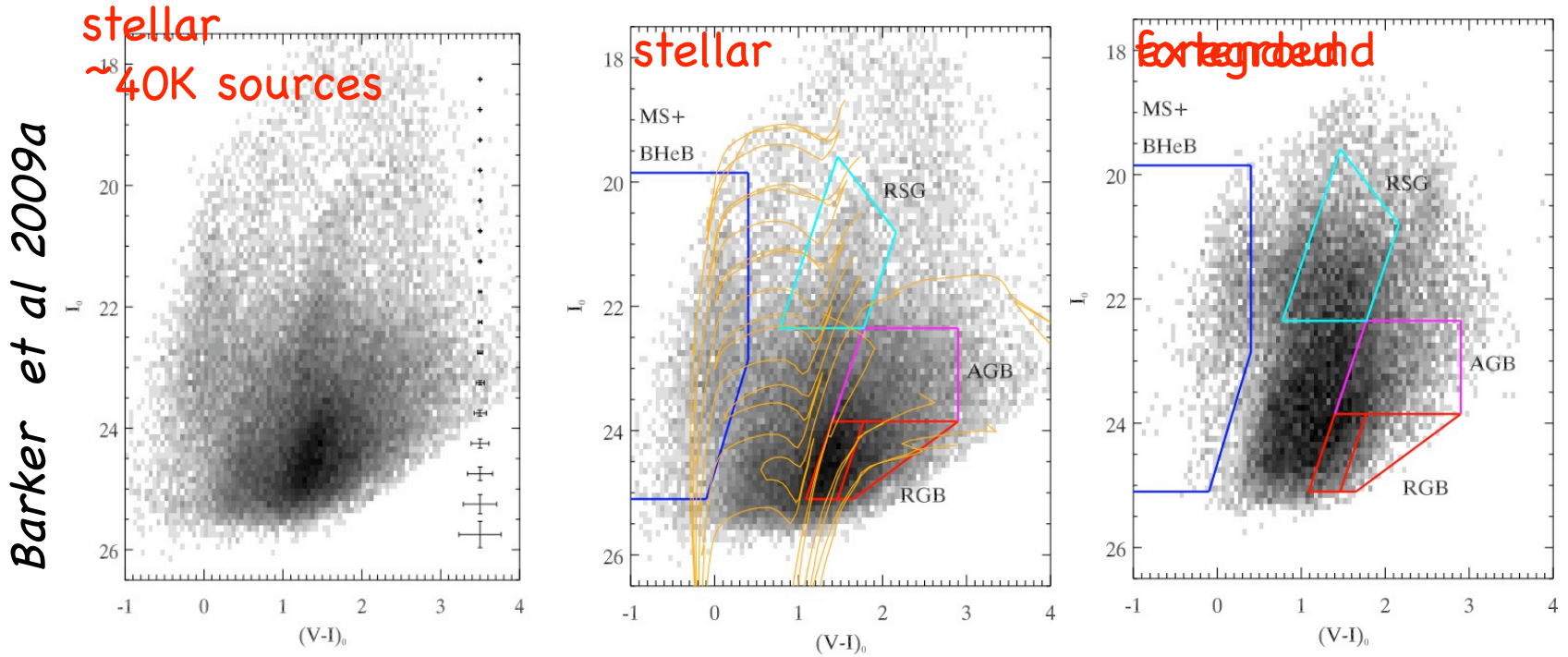
30 kpc

with Co-Is Arimoto, Irwin, Jablonka
(Japan, UK, Switzerland)

25 kpc

M81 (Sab) at 3.6 Mpc, a Milky Way analogue:
Suprime-Cam 2005A V, i' exposures 4300-6300s in 0.7-1.1" seeing

The Stellar Outskirts of Galaxies Beyond the Local Group

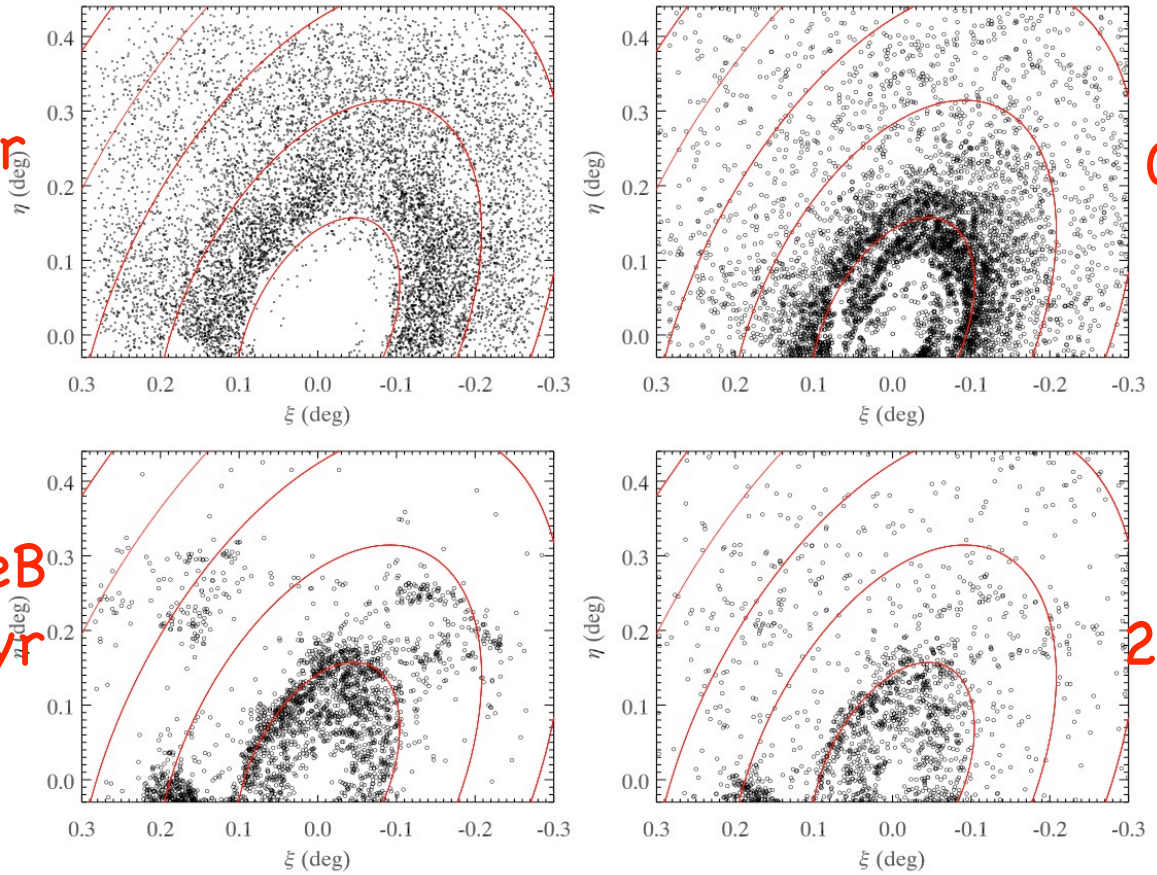


Star-galaxy separation is the greatest challenge for ground-based resolved stellar populations beyond the Local Group: source and CMD morphologies help as does background fields for statistical decontamination

The Stellar Outskirts of Galaxies Beyond the Local Group

RGB
1-10 Gyr

AGB
0.5-8 Gyr



Barker et al 2009a

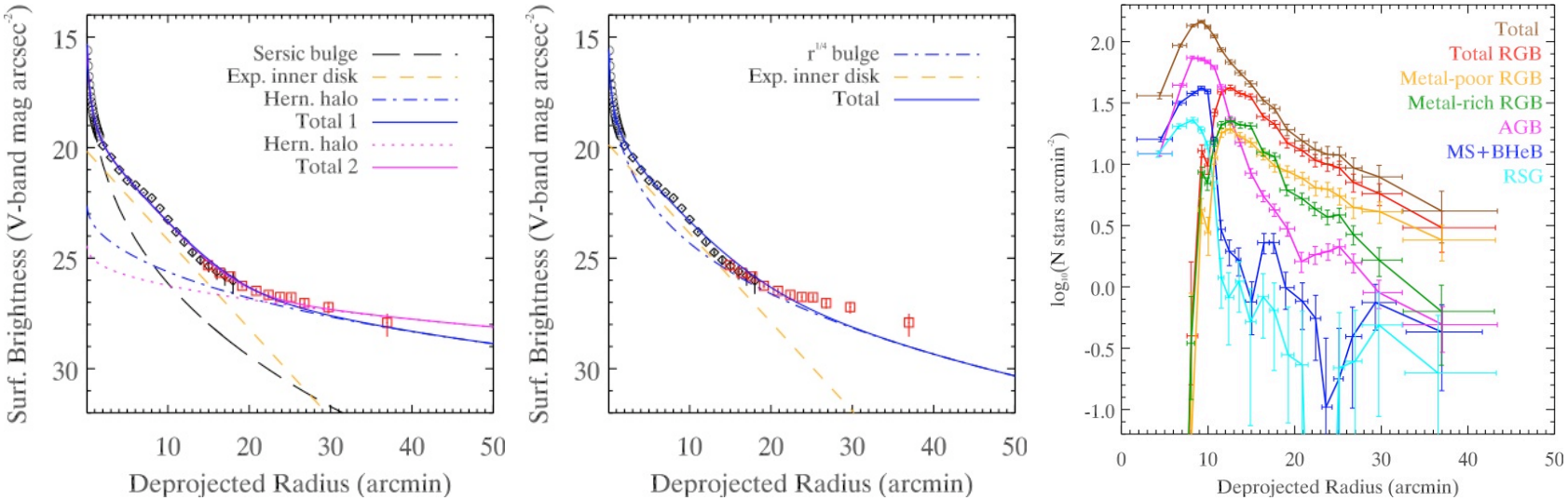
MS+BHeB
<100 Myr

RSG
20-200 Myr

Discrete overdensities largely due to young star forming regions; older stars more smoothly distributed

The Stellar Outskirts of Galaxies Beyond the Local Group

Barker et al 2009a

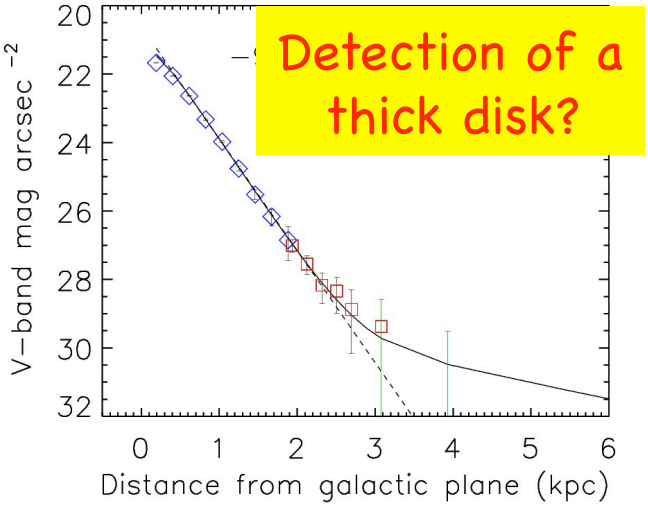


- bulge + exponential (h~3′) disk dominate light profile to 17′ beyond which profile unexpectedly flattens
- outer profile fit by exponential of h=13′ or power-law γ~-2
- [M/H] ~-1.1 and L~3-6 x 10^9 L_{Sun} (~10-15% L_{Total})
- nature and origin of this faint stellar envelope: stellar halo, thick disk, tidal perturbation, bulge extension, ….?

The Stellar Outskirts of Galaxies Beyond the Local Group

NGC4244, Sd at 4.4 Mpc

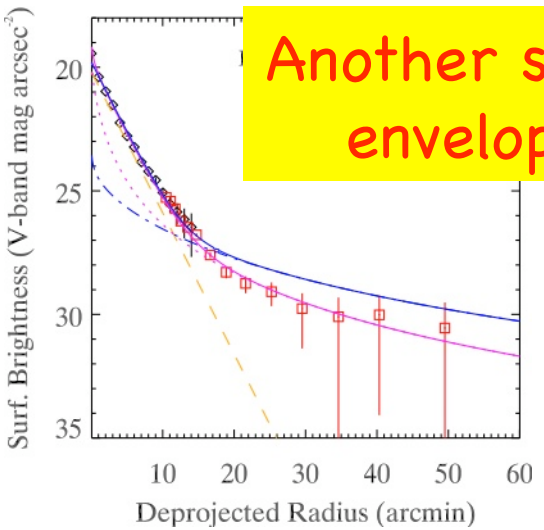
Buehler et al 2009



Detection of a thick disk?

NGC2403, Sc at 3.6 Mpc

Barker et al 2009b



Another stellar envelope?

Summary

- the high resolution imaging capability of Gemini/GMOS is providing a view of newly-discovered M31 halo GCs that rivals HST:
  - most remote known GC in the Local Group at R_{M31}≈190 kpc; metal-poor, ancient & highly extended (R≥1 kpc!)
  - imagery of enigmatic ECs promises to shed new light on nature of objects at faint end of baronyic mass spectrum

- the wide-field imaging capability of Subaru/Suprime-Cam is allowing the outskirts of galaxies beyond the Local Group to be surveyed to unprecedented depth:
  - discovery of previously-unknown and unexpected low surface brightness components: nature, origin, ubiquity?

Thanks for your attention!!!