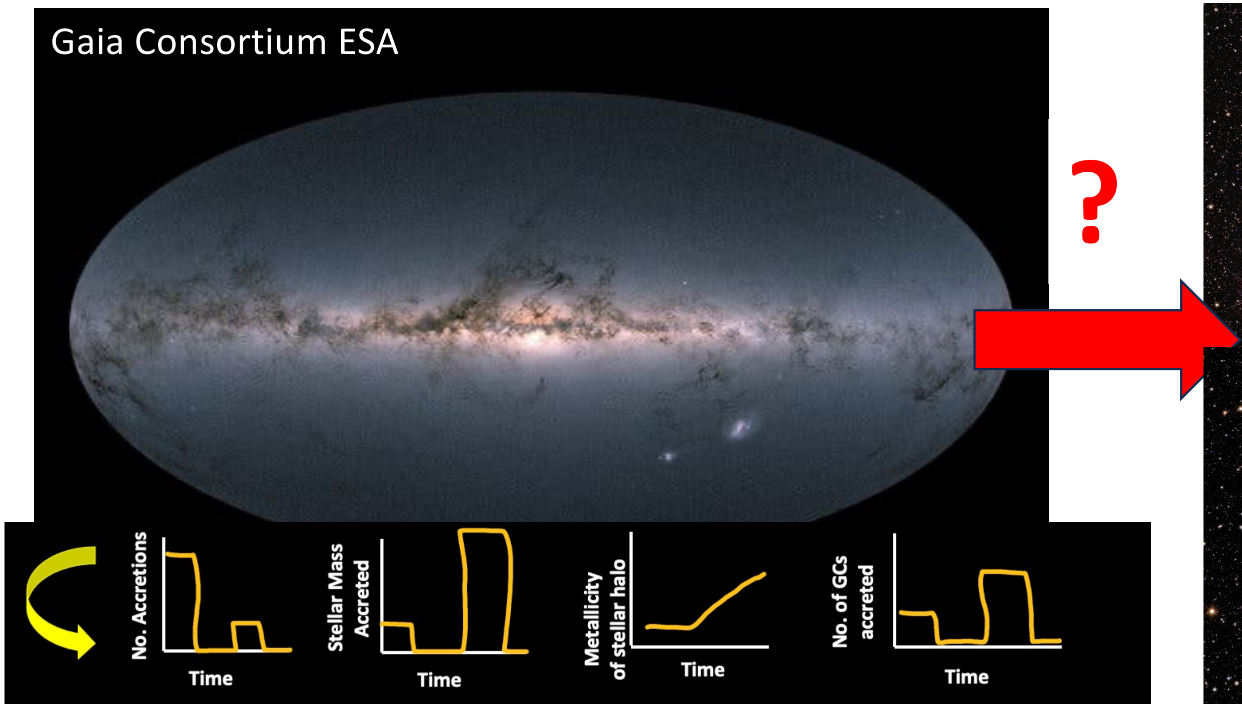
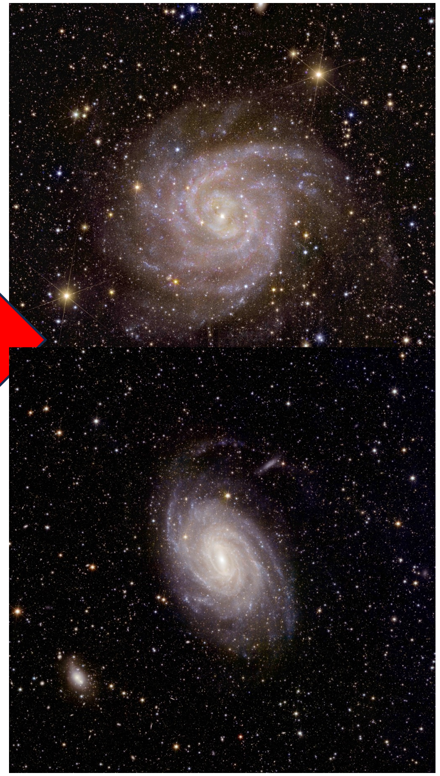
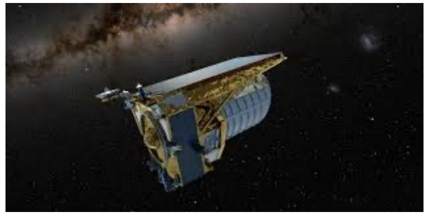
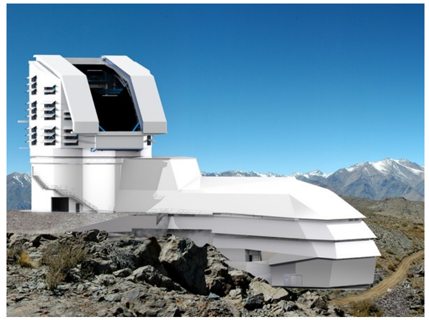
Insights into the Assembly History of M31 from its Halo Globular Clusters

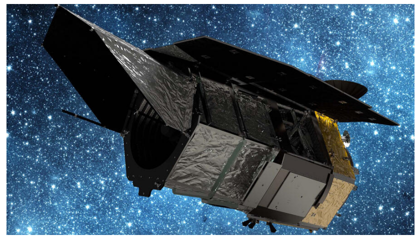
Annette Ferguson - University of Edinburgh











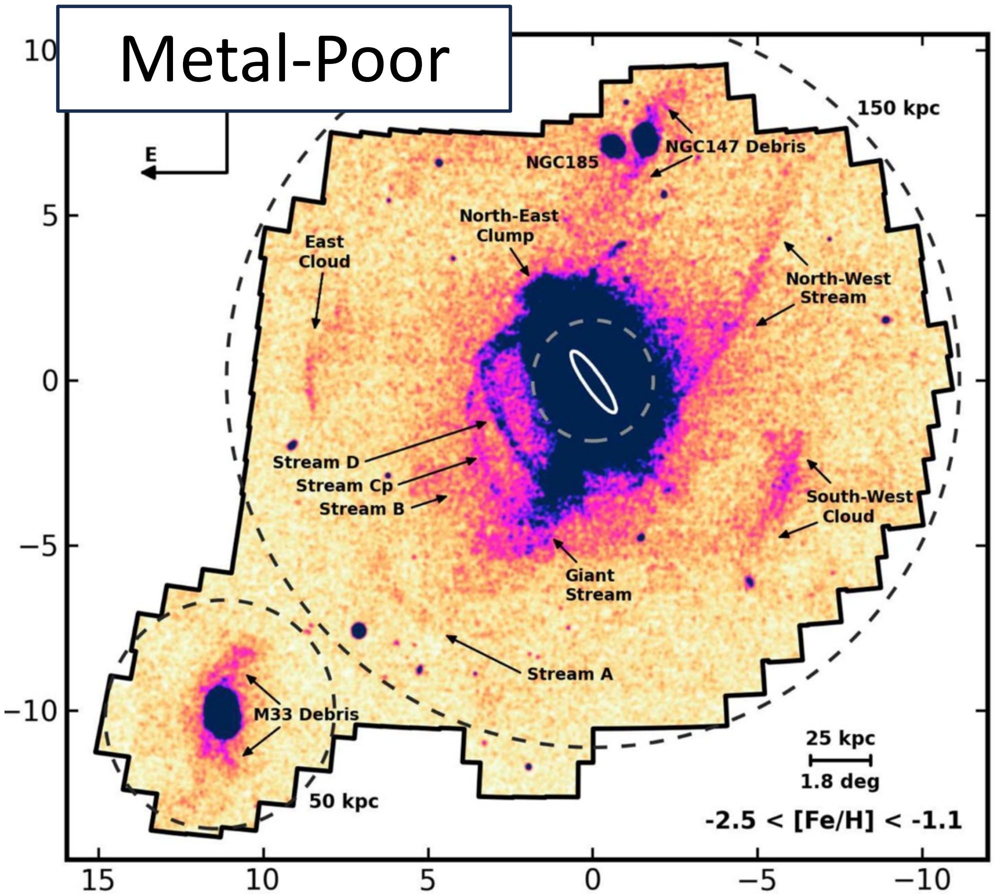
Property	MW	M31
Total Mass	~.7-1.5x10^{12} $M_\odot$	~1-3x10^{12} $M_\odot$
Stellar Mass	~5x10^{10} $M_\odot$	~1.2x10^{11} $M_\odot$
Stellar Halo Mass	~1.4x10^{9} $M_\odot$	~10^{10} $M_\odot$
R_d	2-2.6 kpc	~5.5 kpc
N_{GC} (R_{proj}>25 kpc)	~160 (24*)	>500 (92)
N_{dwarf}	~80, with 2 having M_V<-15	~40, with 7 having M_V<-15

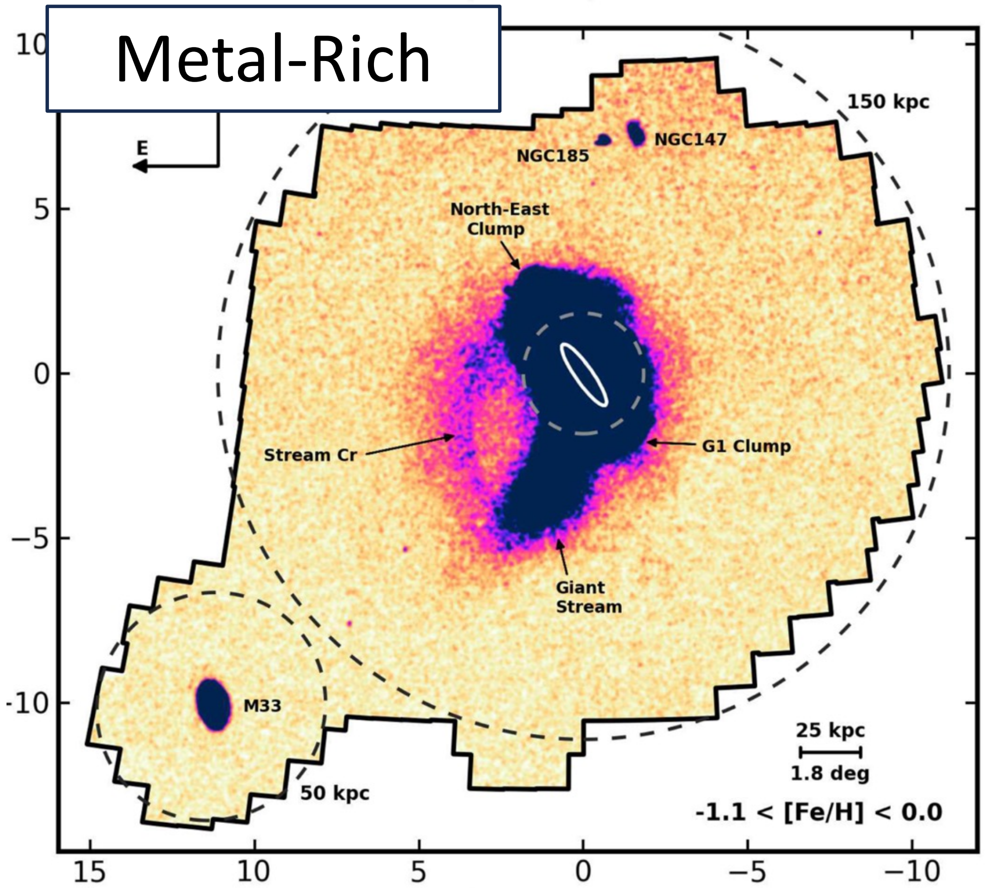
…. even bulk properties of M31 suggest a more vigorous history of mergers and accretions compared to the Milky Way

Sources: MW - Bland-Hawthorn & Gerhard 2016, M31 – Veljanoski et al. 2014, Courteau et al. 2011, Tamm et al. 2012, Callingham et al. 2020, Patel and Mandel 2023

The Outer Stellar Halo of M31

PAndAS Survey, Mackey, Ferguson et al. 2019

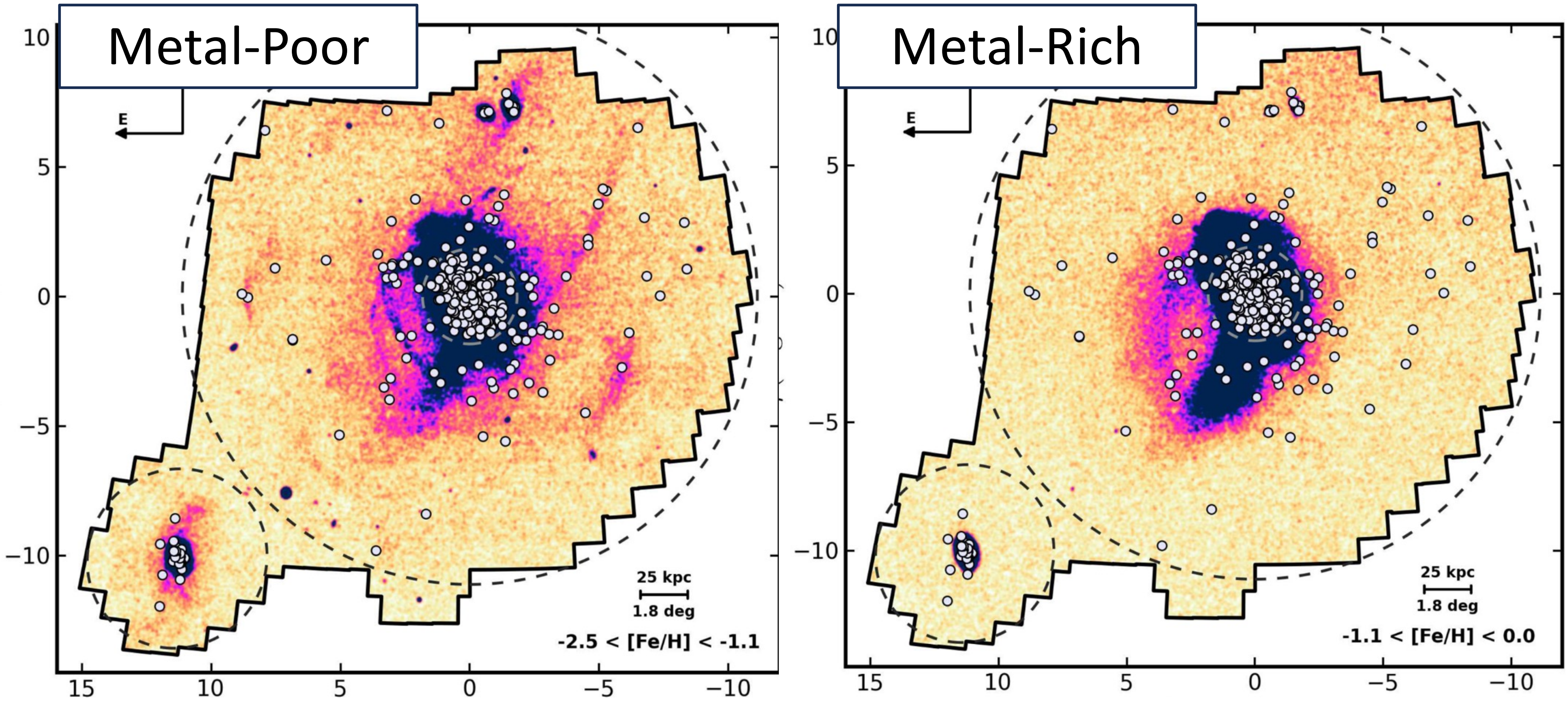




Faint features are 30-32 mag/sq. arcsec!

Globular Clusters in the Outer Stellar Halo of M31

PAndAS Survey, Mackey, Ferguson et al. 2019

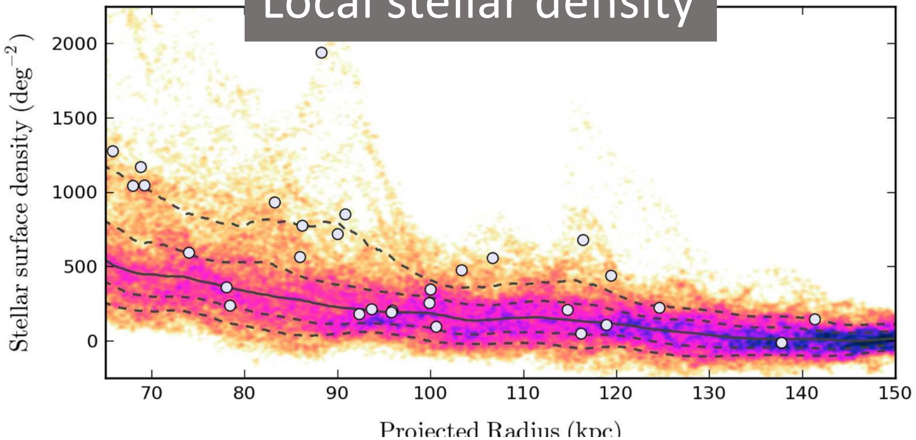


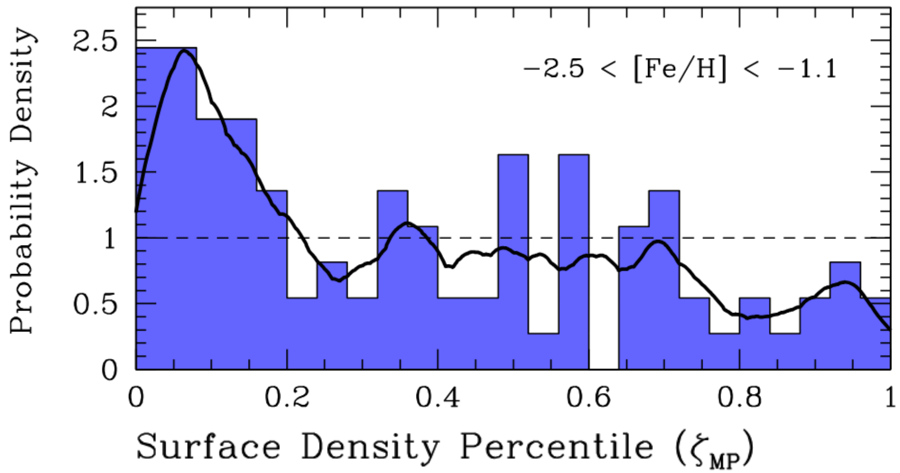
Faint features are 30-32 mag/sq. arcsec!

Quantifying the Association of GCs and Substructure

Mackey, Ferguson et al. 2019

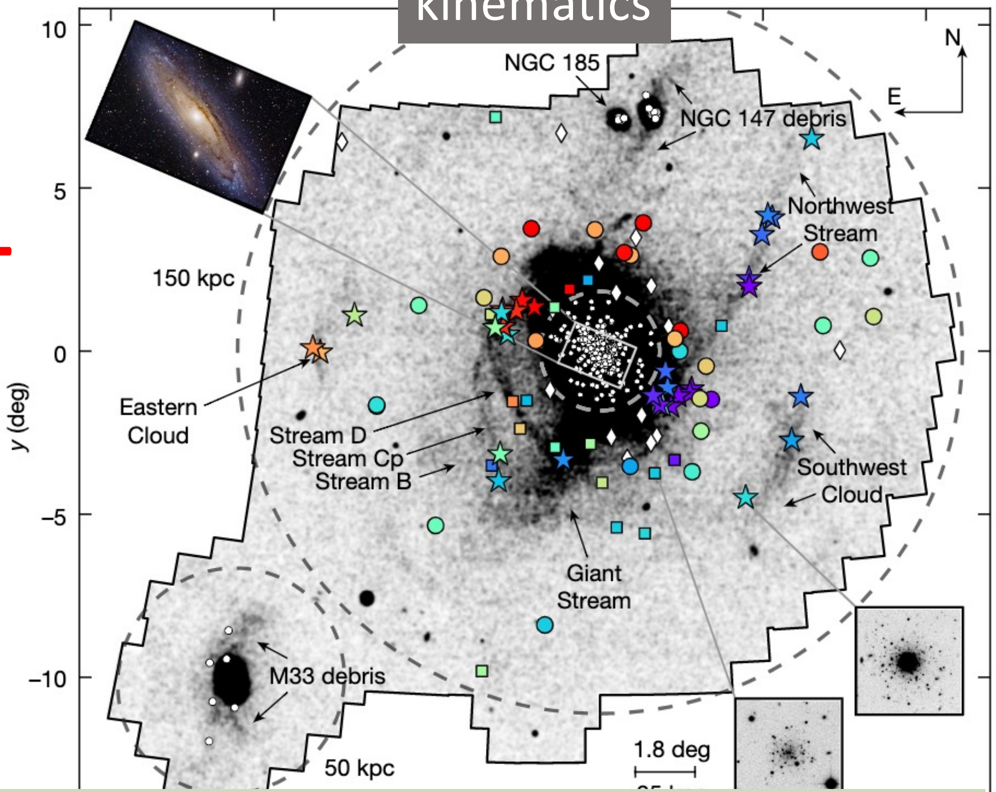
Local stellar density





+

kinematics



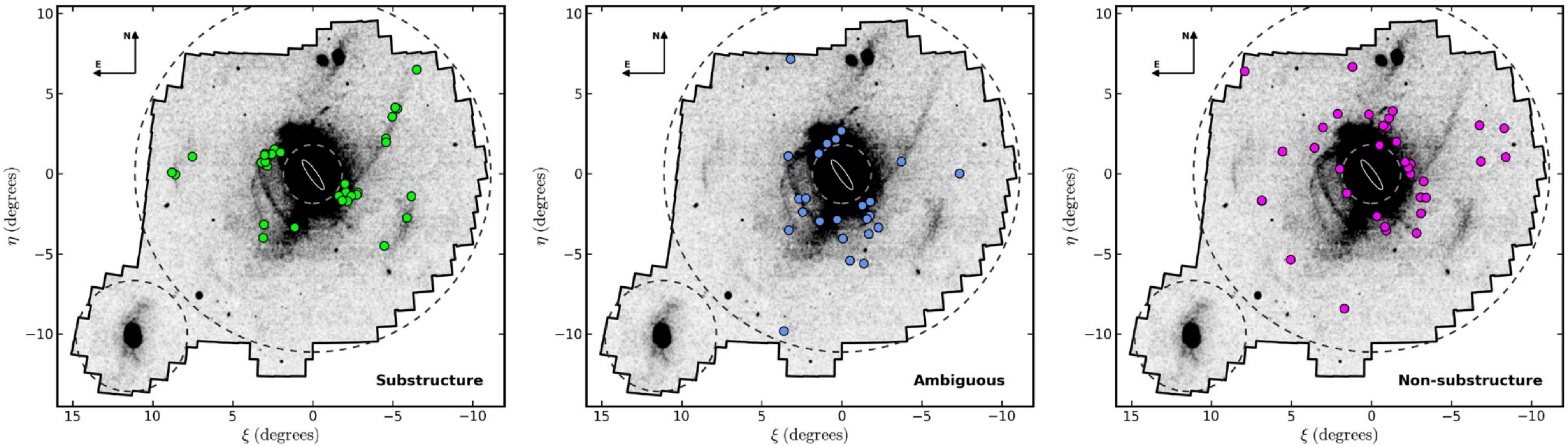
Focus on the 92 GCs at R > 25 kpc, 77 of which have measured RVs

Quantifying the Association of GCs and Substructure

- 32 GCs clearly associated with substructure
- 35 GCs clearly unassociated with substructure
- 25 GCs with “ambiguous associations”

35-62% show evidence of being accreted

Mackey, Ferguson et al. 2019

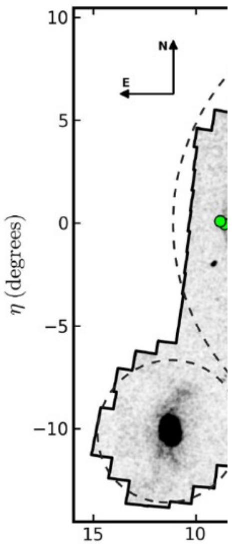


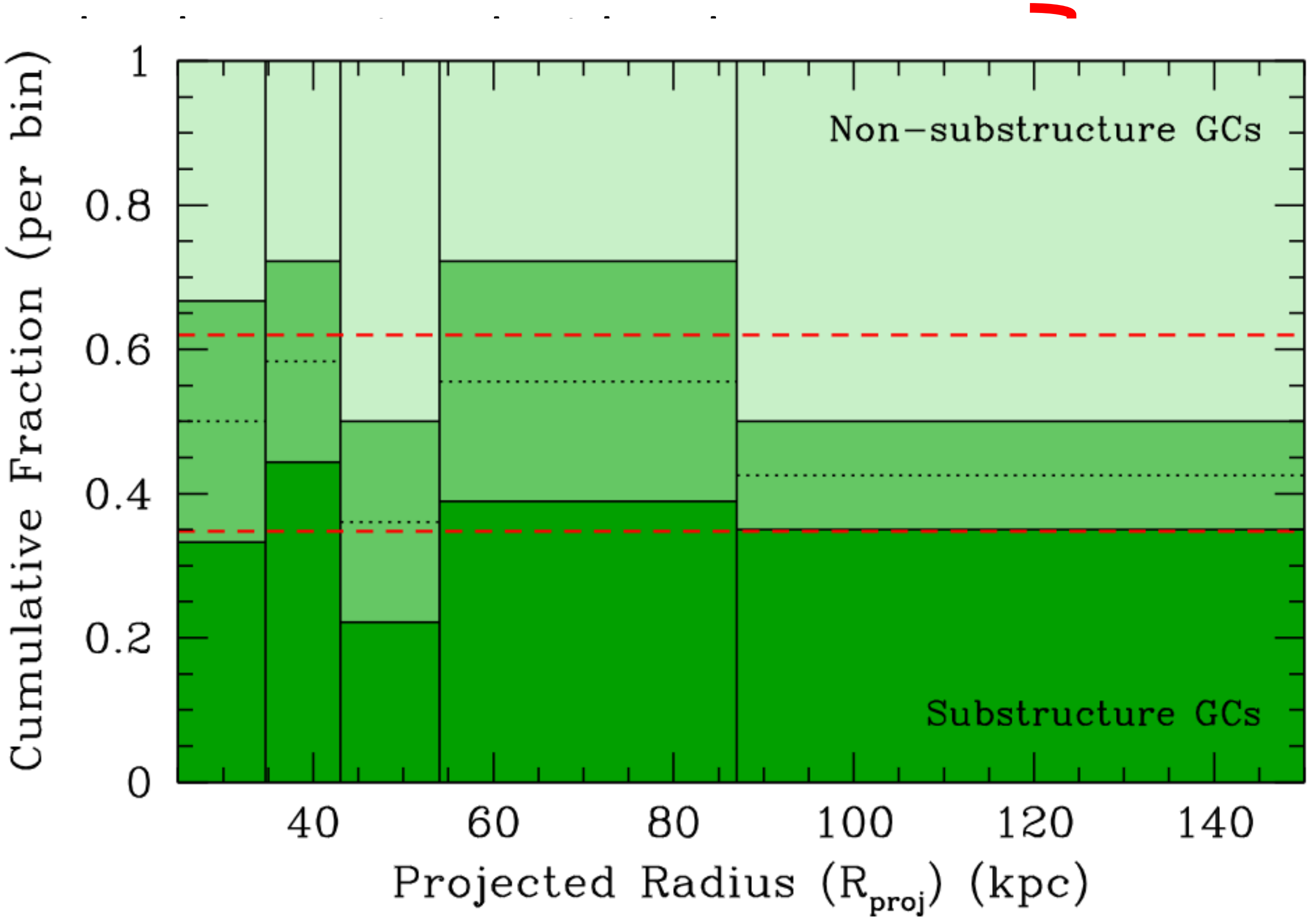
Quantifying the Association of GCs and Substructure

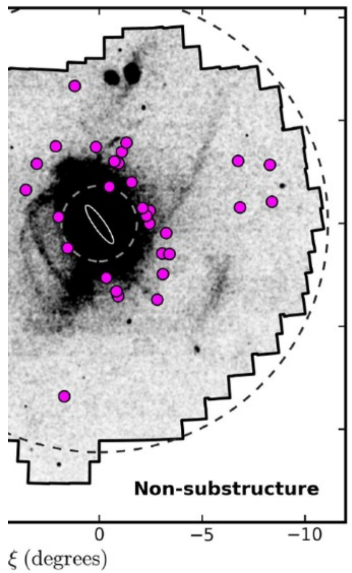
- 32
- 35
- 25

ow evidence
ccreted

Mackey, Ferguson et al. 2019

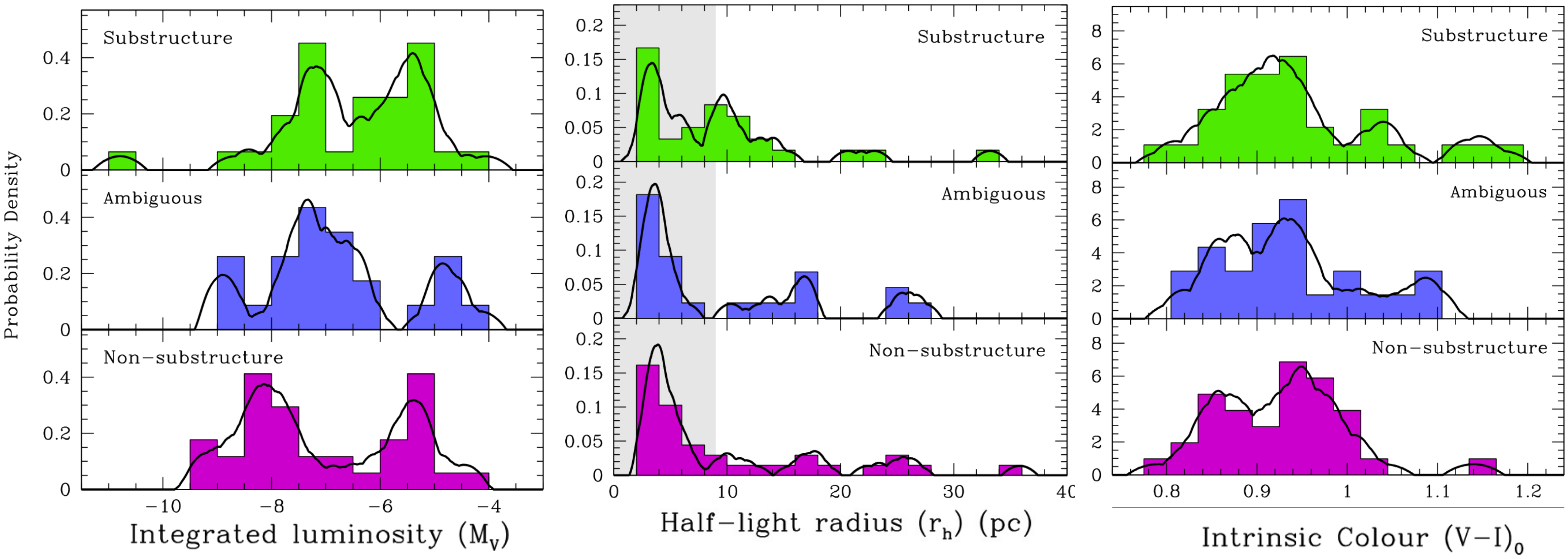






Photometric Properties of GC Classes

Mackey, Ferguson et al. 2019



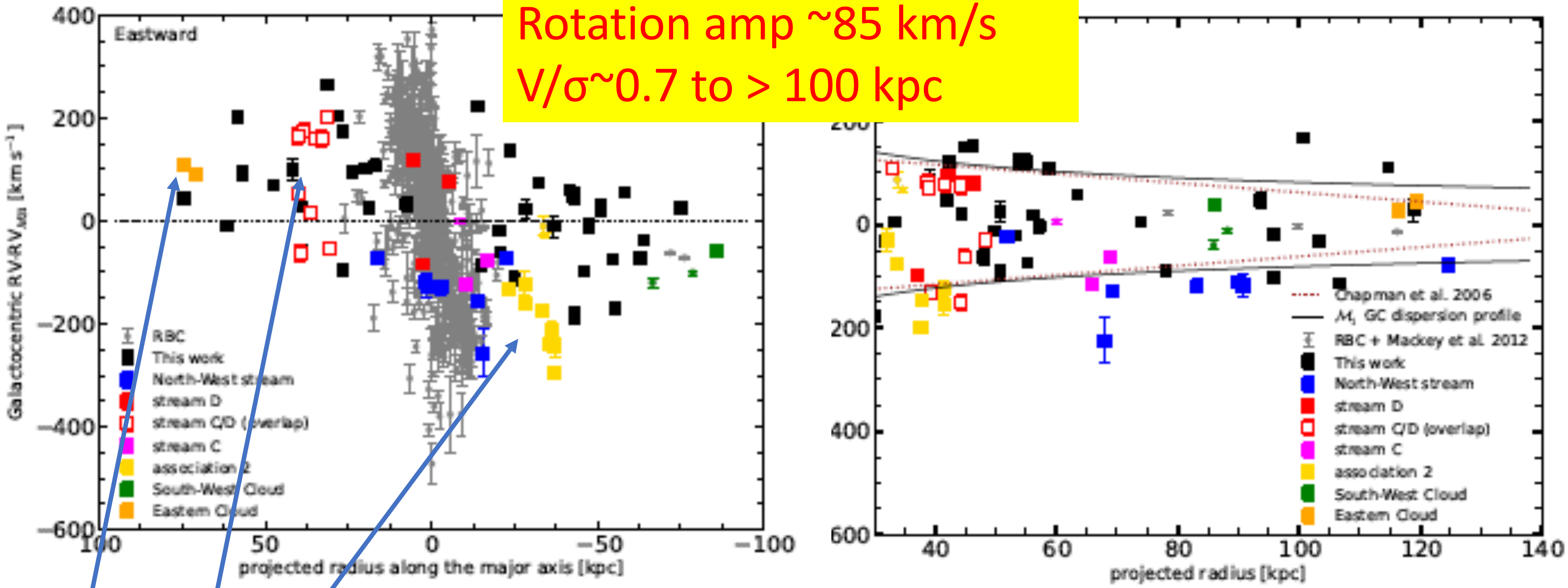
Bimodal LFs + Varying bright peak

Extended GCs

Excess red substructure GCs?

Kinematical Properties of Overall GC Population

Rotation amp ~85 km/s
V/σ~0.7 to > 100 kpc



Cold kinematic features

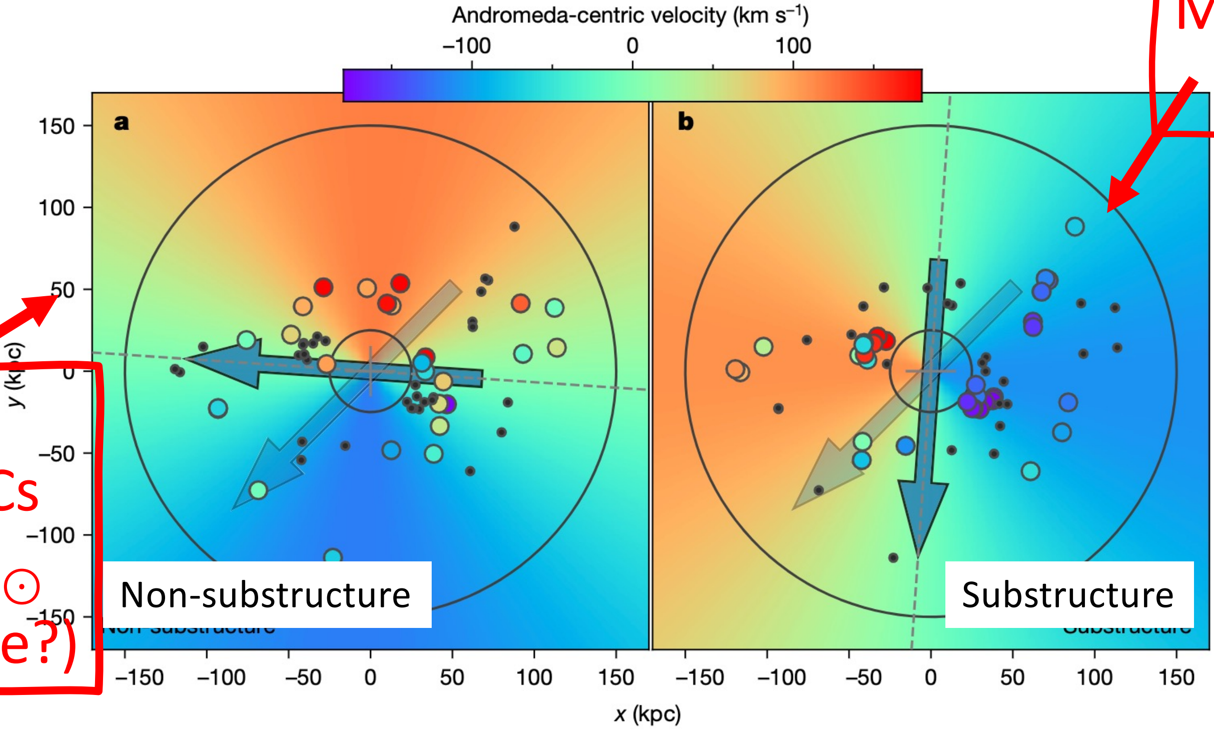
Veljanoski et al. 2014

Kinematical Properties of GC Classes

Two major accretion epochs in M31 from two distinct populations of globular clusters

Dougal Mackey[1]*, Geraint F. Lewis[2], Brendon J. Brewer[3], Annette M. N. Ferguson[4], Jovan Veljanoski[5], Avon P. Huxor[6], Michelle L. M. Collins[7], Patrick Côté[8], Rodrigo A. Ibata[9], Mike J. Irwin[10], Nicolas Martin[9,11], Alan W. McConnachie[8], Jorge Peñarrubia[4], Nial Tanvir[12] & Zhen Wan[2]

Mackey et al. 2019b



Recent accretion event, 43 GCs

$M_{halo} > 1.9 \times 10^{11} M_\odot$

($\gtrsim$1:10)

Ancient Accretion, 34 GCs

$M_{halo} > 1.5 \times 10^{11} M_\odot$

(~1:2-3 at the time?)

$$\frac{M_{GC}}{M_{halo}} \approx 2.9\times10^{-5}$$

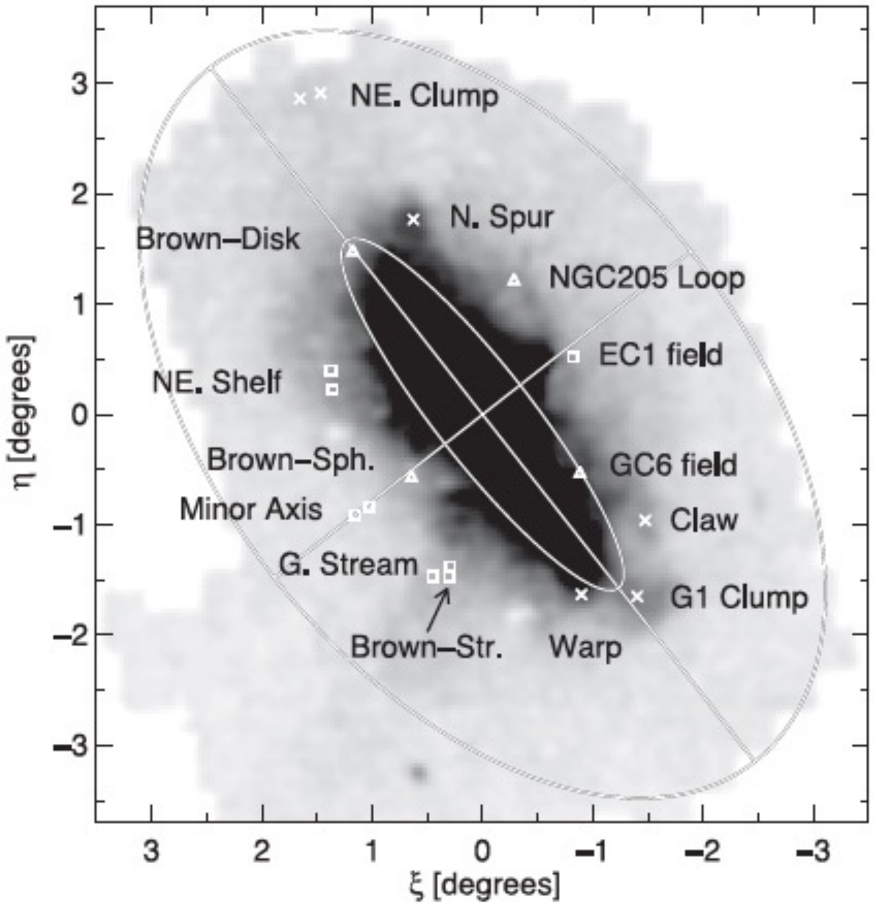
Harris et al 2017, holds over 5 orders of magnitude in M_{halo}

Further Evidence for a Significant Recent Accretion Event

Deep HST CMDs for 14 inner halo fields in M31, spanning projected radii of 13-45 kpc.

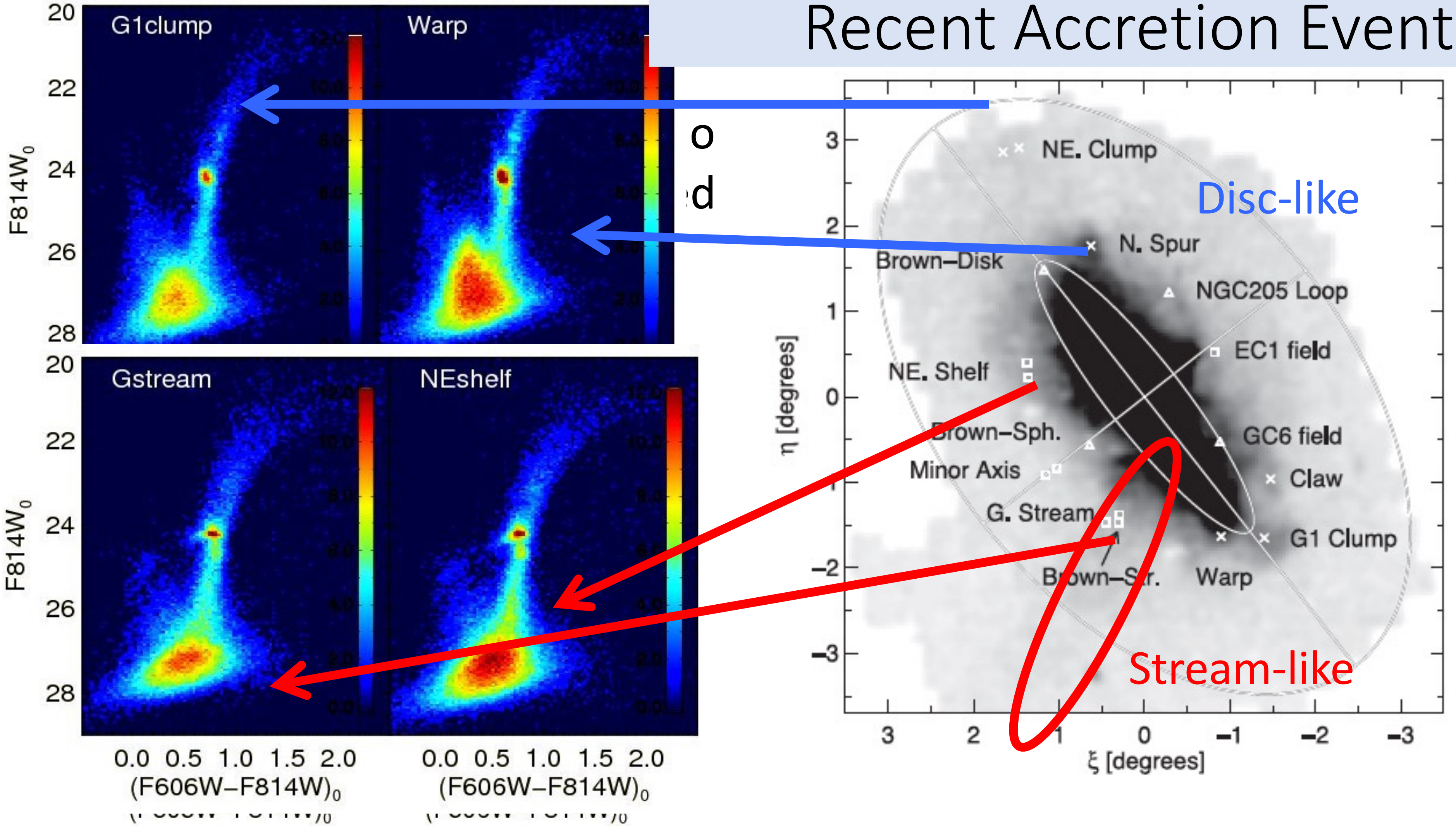
The fields target coherent substructures, with a variety of complex morphologies.

Remarkably, only two distinct CMD morphologies are seen: ‘stream-like’ and ‘disc-like’.



Ferguson et al. 2005, Faria et al. 2007, Richardson et al. 2008, Bernard et al. 2015a

Further Evidence for a Significant Recent Accretion Event



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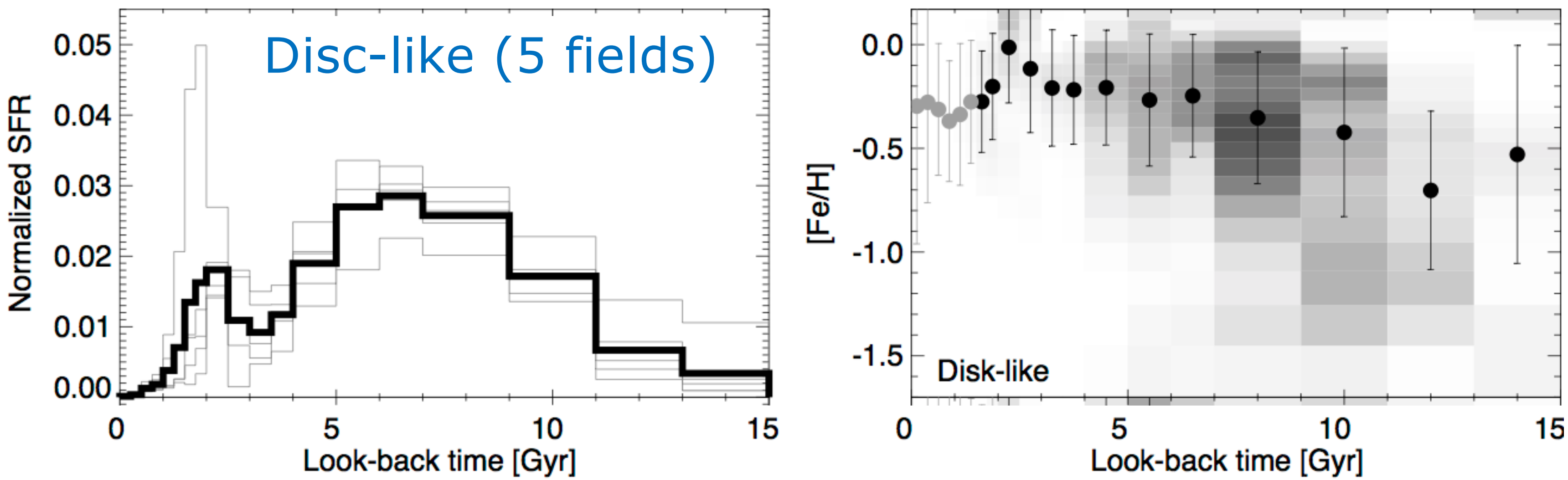
Further Evidence for a Significant Recent Event



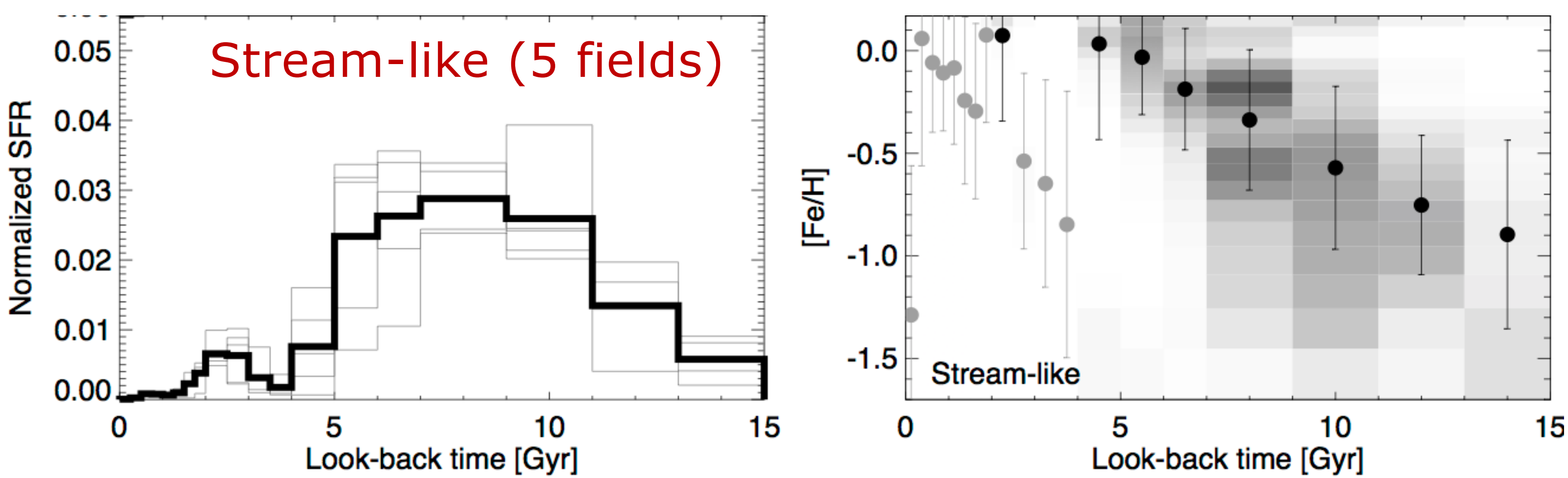
Bernard et al. 2015a; See also Dorman et al. 2013

Disc-like fields experienced nearly continuous star formation (note burst at 2Gyr seen throughout main disc) and slow chemical evolution

→ Consistent with a splashed/kicked up thin disc origin for this component

Nature of the Giant Stream Progenitor?

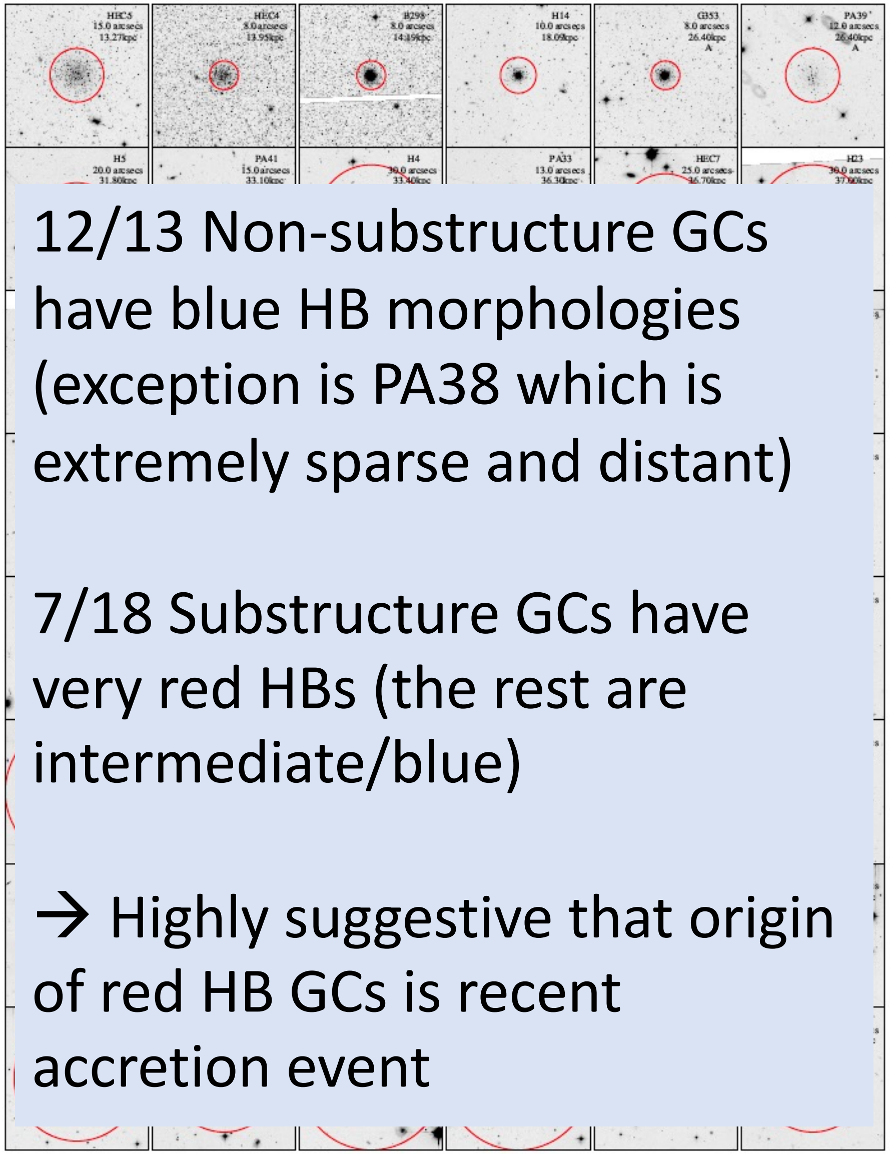
Bernard et al. 2015a; see also Brown et al. 2006



SF in giant stream progenitor got underway early on, peaked 8-9 Gyr ago, and quenched 5-6 Gyr ago

~50% of the stellar mass in place by 9 Gyr ago and reached solar metallicity by 5 Gyr ago → a massive system.

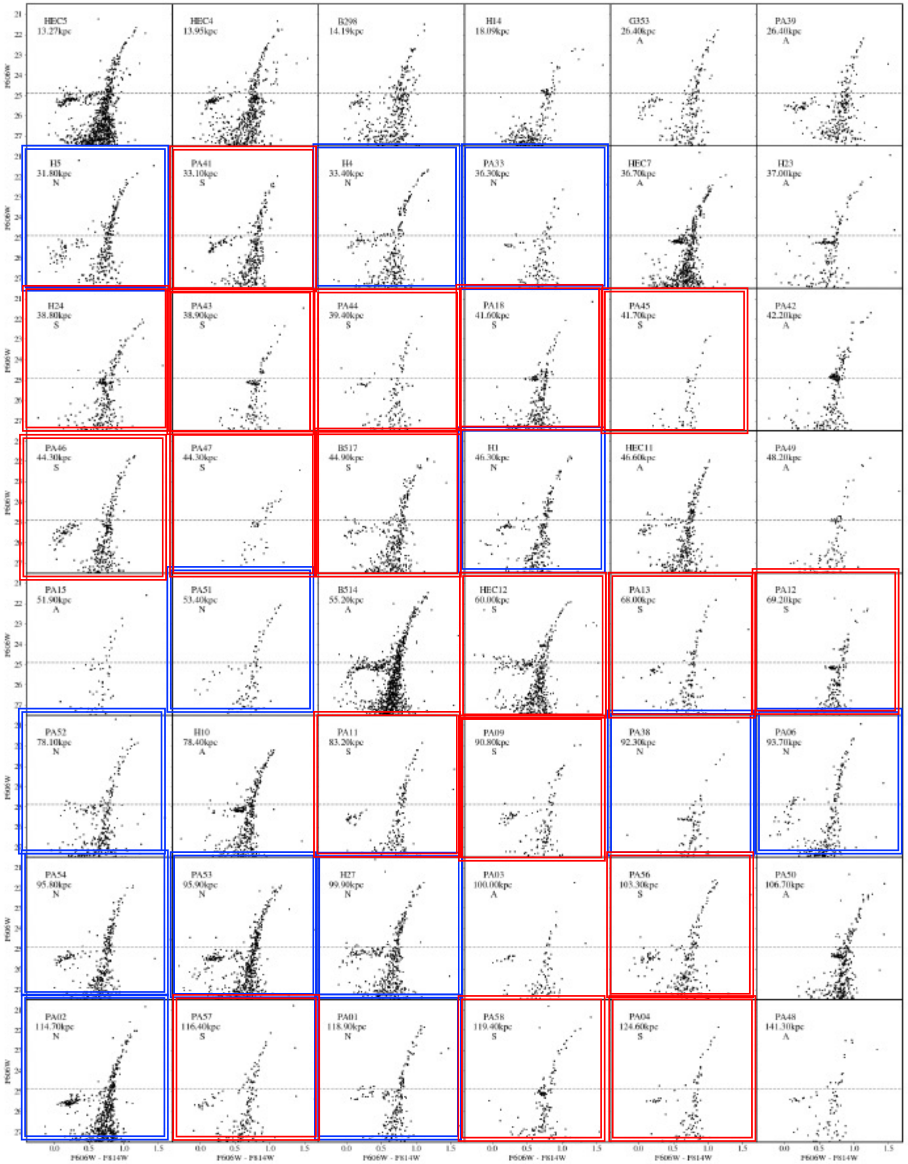
HST observations of 48 outer halo GCs:
18 S, 13 non-S and 17 A



12/13 Non-substructure GCs have blue HB morphologies (exception is PA38 which is extremely sparse and distant)

7/18 Substructure GCs have very red HBs (the rest are intermediate/blue)

→ Highly suggestive that origin of red HB GCs is recent accretion event



McGill et al. in prep

THE ASTROPHYSICAL JOURNAL, **225**:357–379, 1978 October 15

A Blast from the Past?!

COMPOSITIONS OF HALO CLUSTERS AND THE FORMATION OF THE GALACTIC HALO

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Received 1978 March 2; accepted 1978 April 21

ABSTRACT

A new method of abundance determination, based upon reddening-independent characteristics of low-resolution spectral scans, has been applied to 177 red giants in 19 globular clusters. Most of these clusters have galactocentric distances exceeding 8 kpc. We find that there is no radial abundance gradient in the cluster system of the outer halo. The distribution over abundance for these outer clusters appears to be independent of galactocentric distance and is nearly identical to that for halo subdwarfs in the solar neighborhood. This distribution is such that the density declines exponentially with increasing metal abundance. The clusters of the outer halo show a broad spread in the color distribution on the horizontal branch, and this property is uncorrelated with metal abundance. In contrast, more tightly bound clusters, in the same range of abundance, show very little dispersion in this property. These facts are all consistent with the hypothesis that the loosely bound clusters of the outer halo have a broader range of age than the more tightly bound clusters and originated in transient protogalactic fragments that continued to fall into dynamical equilibrium with the Galaxy for some time after the collapse of its central regions had been completed.

Subject headings: clusters: globular — galaxies: Milky Way — galaxies: structure — stars: abundances — stars: late-type

Summary

M31 has a very rich and extended halo GC system that exhibits a remarkable property – the spatial correlation of GCs and tidal streams. Late-time accretion can account for 35-62% of the outer halo GC population!

While accreted GCs do not have distinct photometric properties, they exhibit a striking kinematical pattern that suggests they arrived via a single massive recent accretion event → triggered the 2Gyr disc-wide burst of star formation and led to subsequent splashing of disc material throughout the inner halo?

Deep HST CMDs show that accreted GCs are the origin of (all/most?) very red (young?) HB GCs in the M31 halo, further supporting a merger with a galaxy that was forming stars until relatively recently.