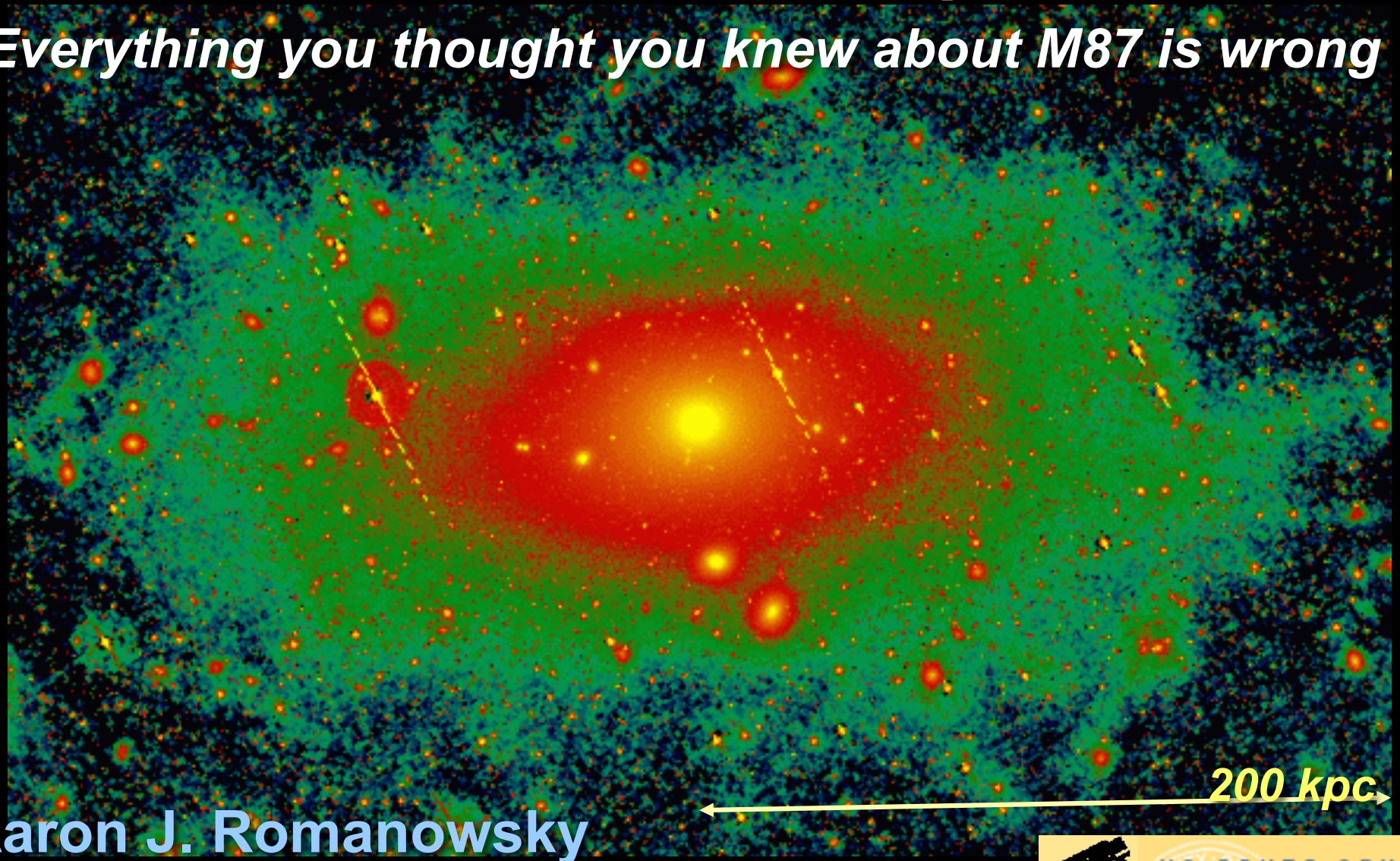
The origins of GCs and UCDs around massive ellipticals

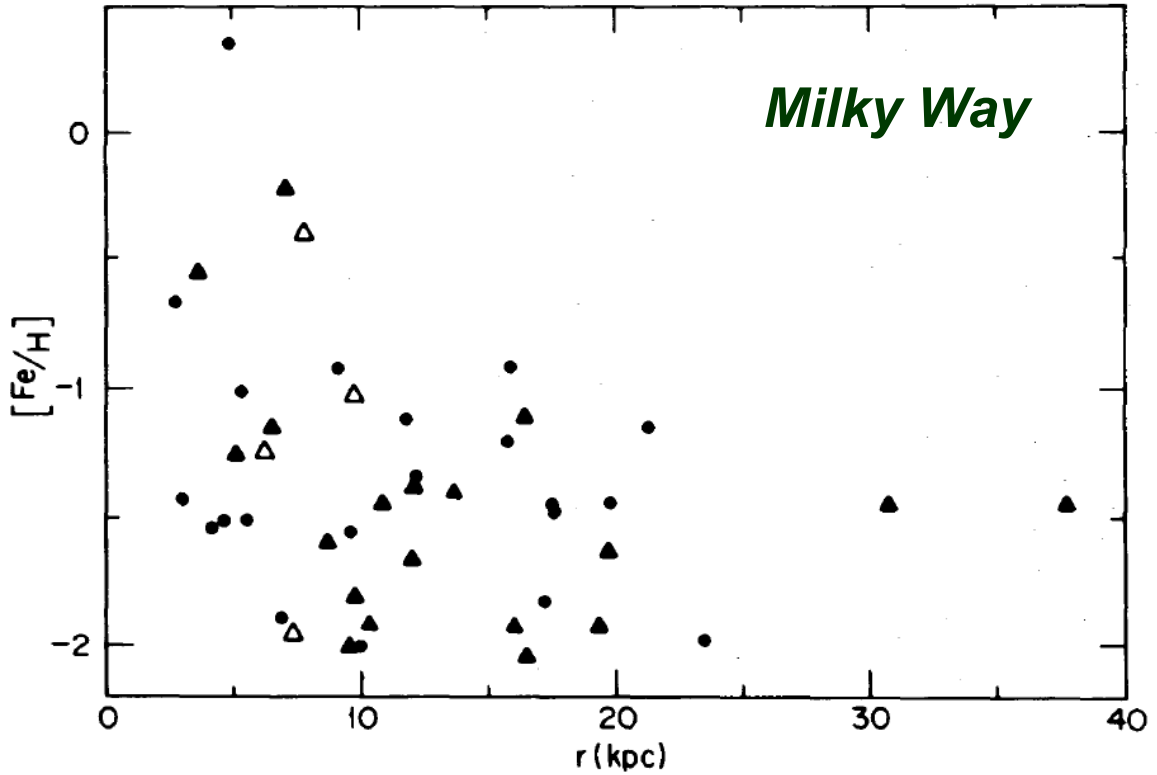
Everything you thought you knew about M87 is wrong



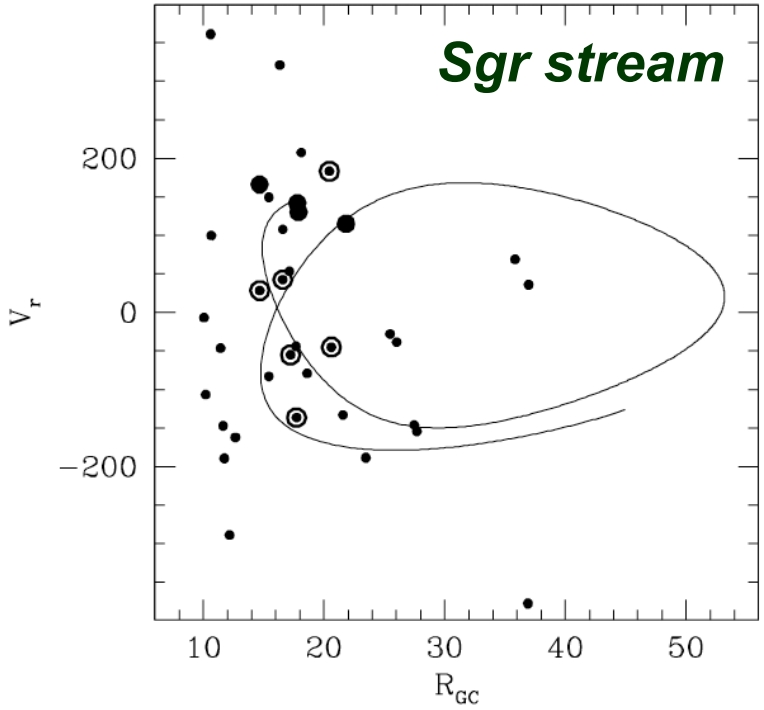
Aaron J. Romanowsky
Univ. California Observatories

UC SANTA CRUZ

GC chemodynamics as tracer of galaxy halo assembly



(Searle & Zinn 1978 → Forbes & Bridges 2010)



(Bellazzini+2003)

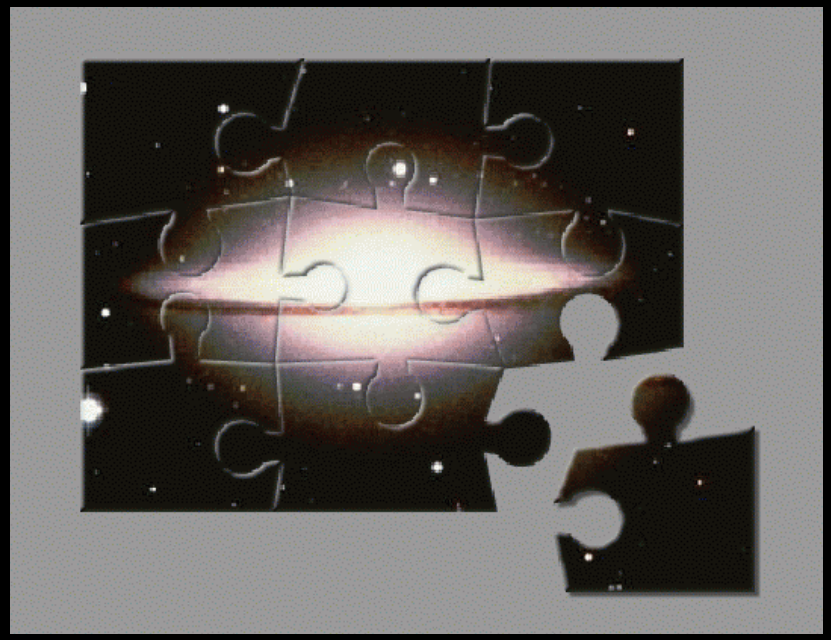
Second stage of Milky Way halo assembly established from GC positions, velocities, metallicities *jointly*

Precursor to today's full phase-space studies of stars

GCs still unique accretion tracer beyond Local Group

(Forte+1982; Côté+1998, 2003; Peng+2002; Woodley & Harris 2011)

Fossil clues of early-type galaxy formation at z~0…



SAGES Legacy Unifying Globulars and Galaxies Survey

Spectroscopic Mapping of Early-type Galaxies to their Outer Limits

J. Brodie, A. Romanowsky, D. Forbes, J. Strader, V. Pota, C. Usher

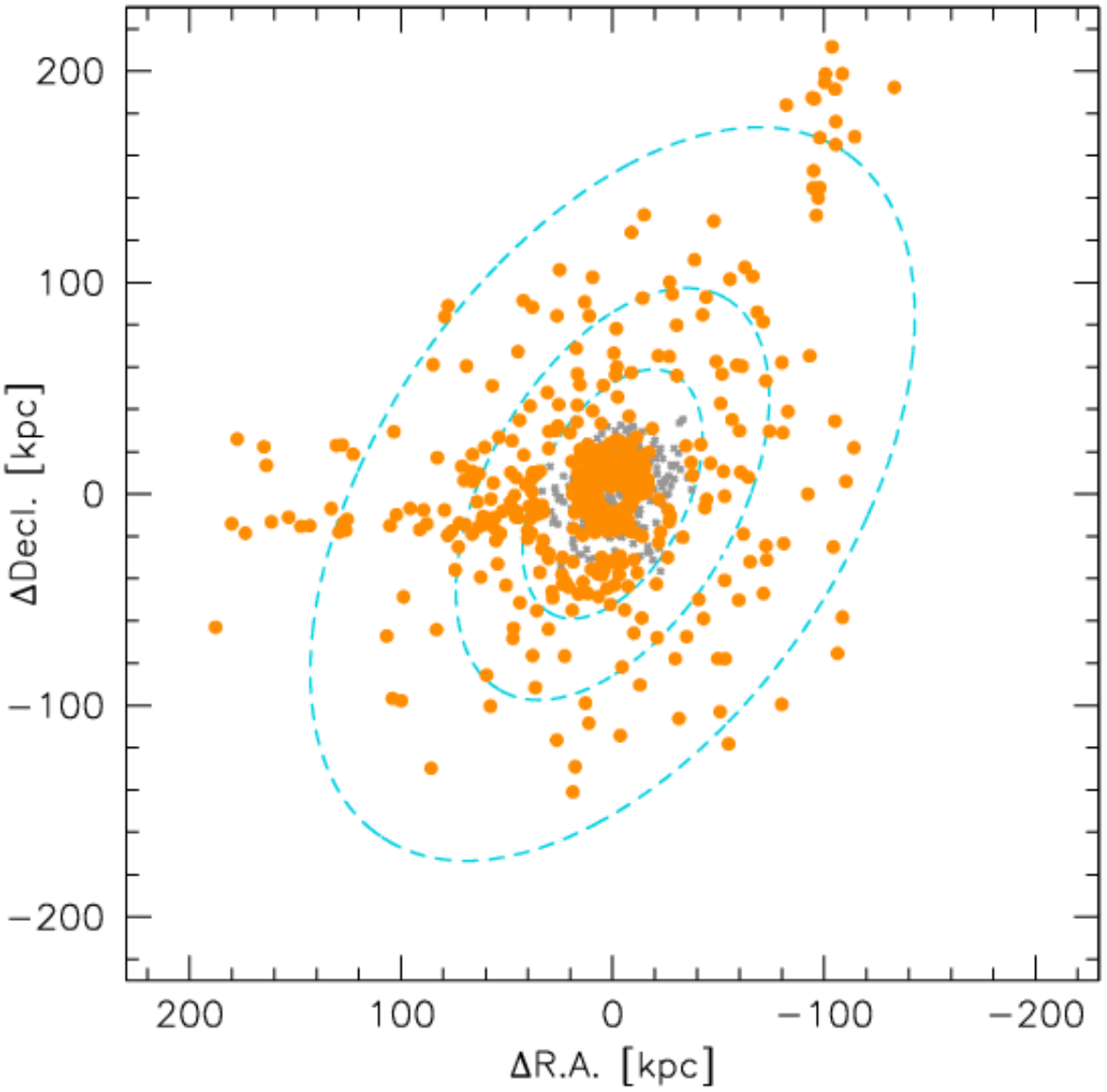
J. Arnold, L. Spitler, C. Foster, C. Blom

- 26 representative galaxies: *full range of* L, σ, v/σ, ε, γ, a_4, ρ_{env}
- using Keck+DEIMOS, Subaru+Suprime-Cam
- field stars, globular clusters to ~ 3-10 R_{eff} : photometry, kinematics, metallicities

→ *probing for mass, angular momentum, orbital dynamics, substructure…*

Ultra-wide-field kinematics of M87 globular clusters

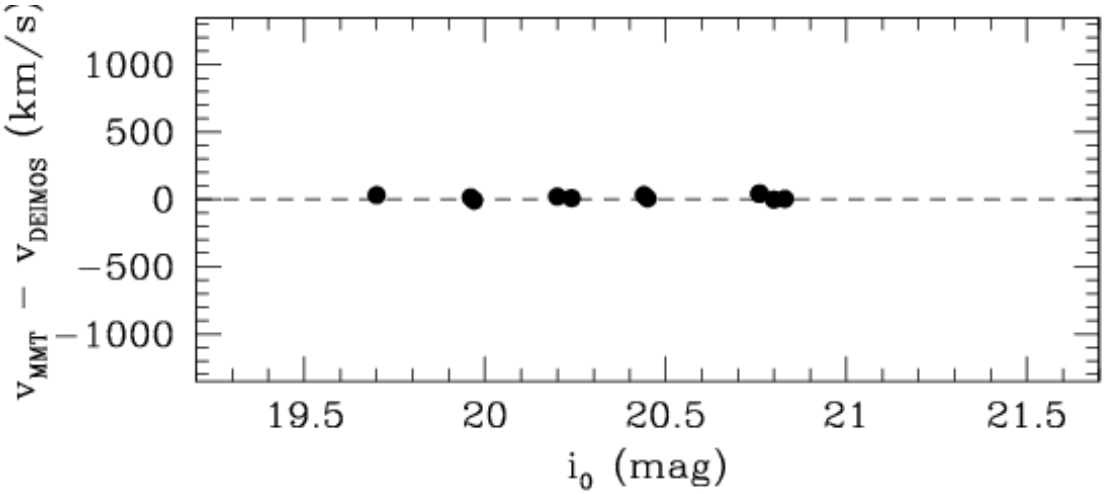
Virgo cluster central galaxy



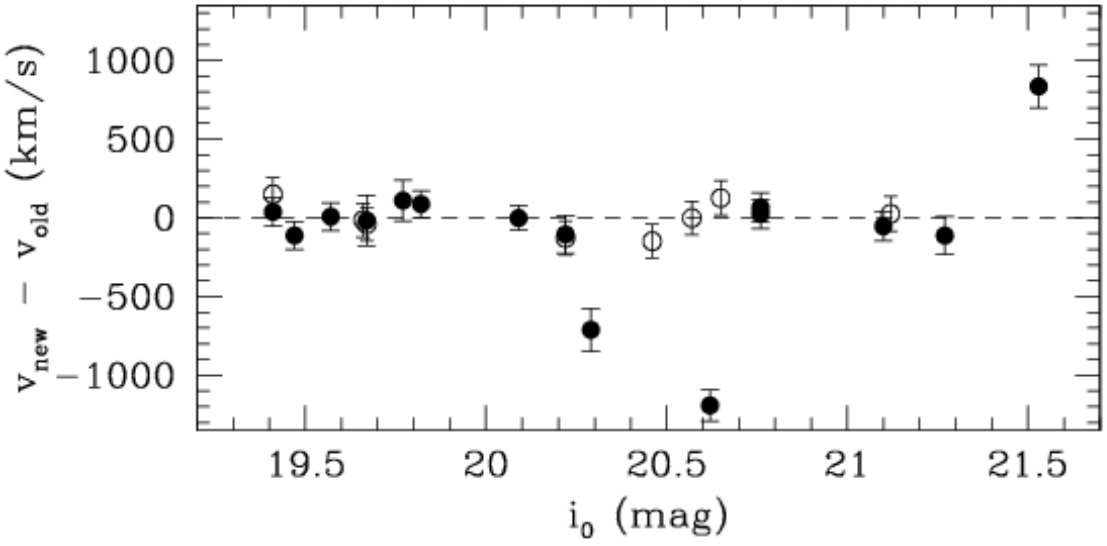
Old data: Hale, MMT, Keck/LRIS, CFHT/MOS (Mould+1987,1990; Huchra & Brodie 1987; Cohen & Ryzhov 1997; Cohen 2000; Hanes+2001)
288 velocities
to $i \sim 21$, $R \sim 50$ kpc,
typical $\Delta v \sim 110$ km s^{-1}

New: Keck/DEIMOS, LRIS, MMT/Hectospec (Strader+2011)
487 velocities (737 total)
to $i \sim 22.5$, $R \sim 200$ kpc,
typical $\Delta v \sim 18$ km s^{-1}
344 *HST* size measurements

Velocity reliability



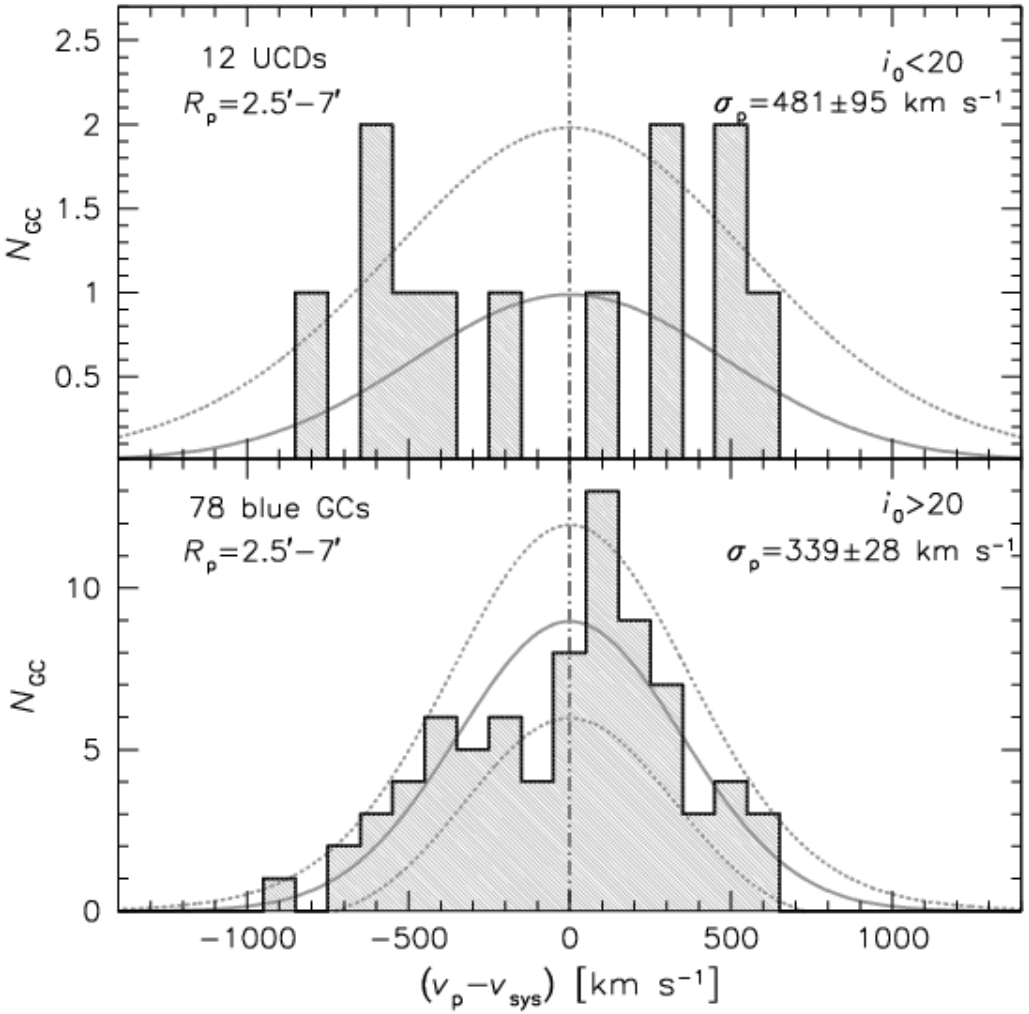
Duplicate objects:
Hectospec versus DEIMOS:
consistent with
$\Delta v \sim 18$ km s^{-1}



New vs old data:
Mostly consistent with Δv
but several "catastrophic" discrepancies:
up to 12 σ, 1200 km s^{-1}

Even 1 such outlier out of 500 can wreak havoc on kinematical and dynamical analyses

Luminosity/size - kinematics connections



Line-of-sight velocity distribution of central bright/extended objects

Very non-Gaussian, avoid systemic velocity

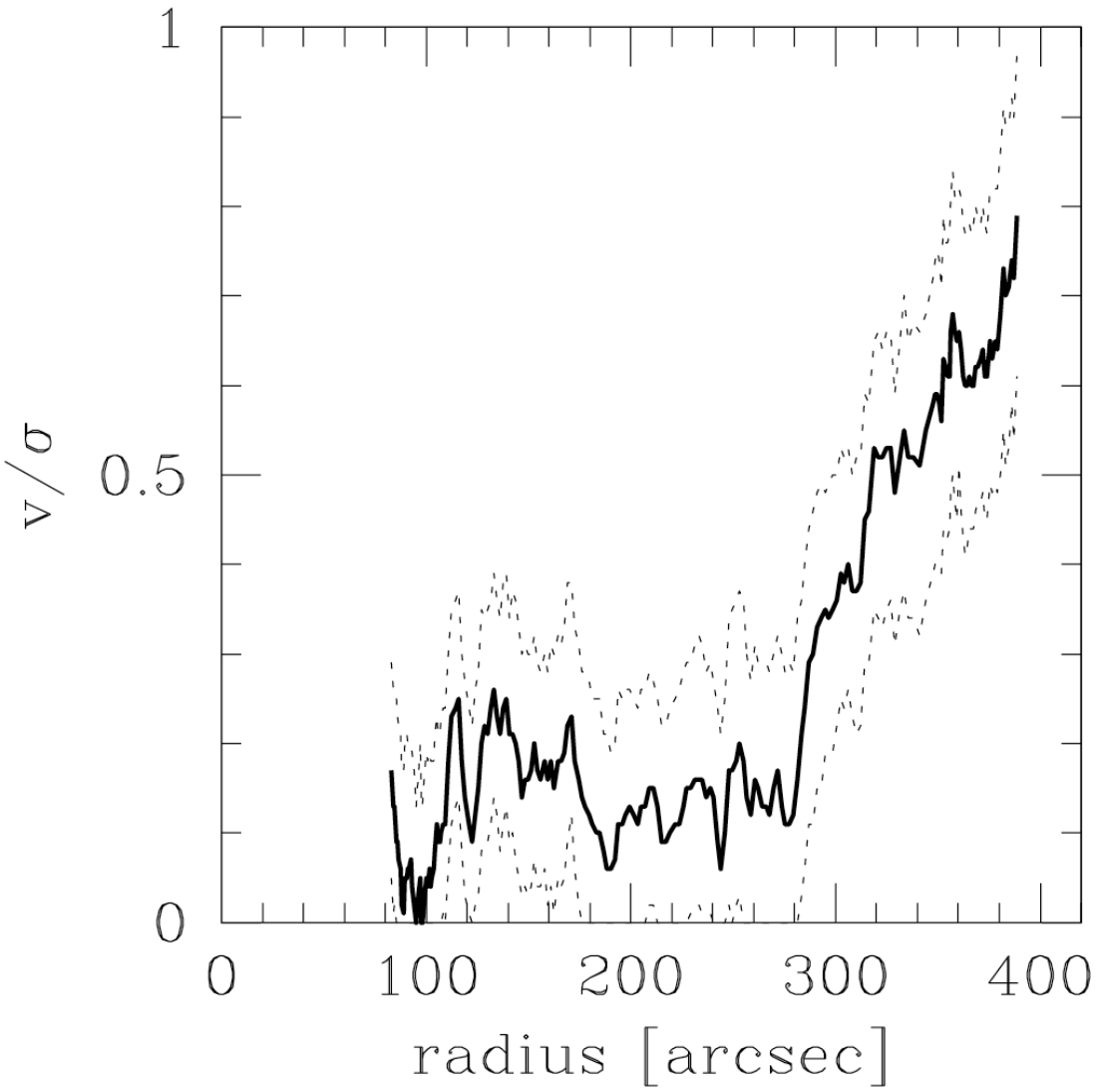
Reminiscent of other galaxies with kinematic transition at M_V ~ –10.5

(Romanowsky+2009; Schuberth+2010; Woodley+2010)

- ***Most "GC" studies really probing UCDs w/distinct kinematics?***
- ***Need clearer predictions for kinematical and dynamical properties of UCDs*** *(radial = dwarfs; circular = star clusters?)*

(cf. Bekki+2003; Goerdt+2008)

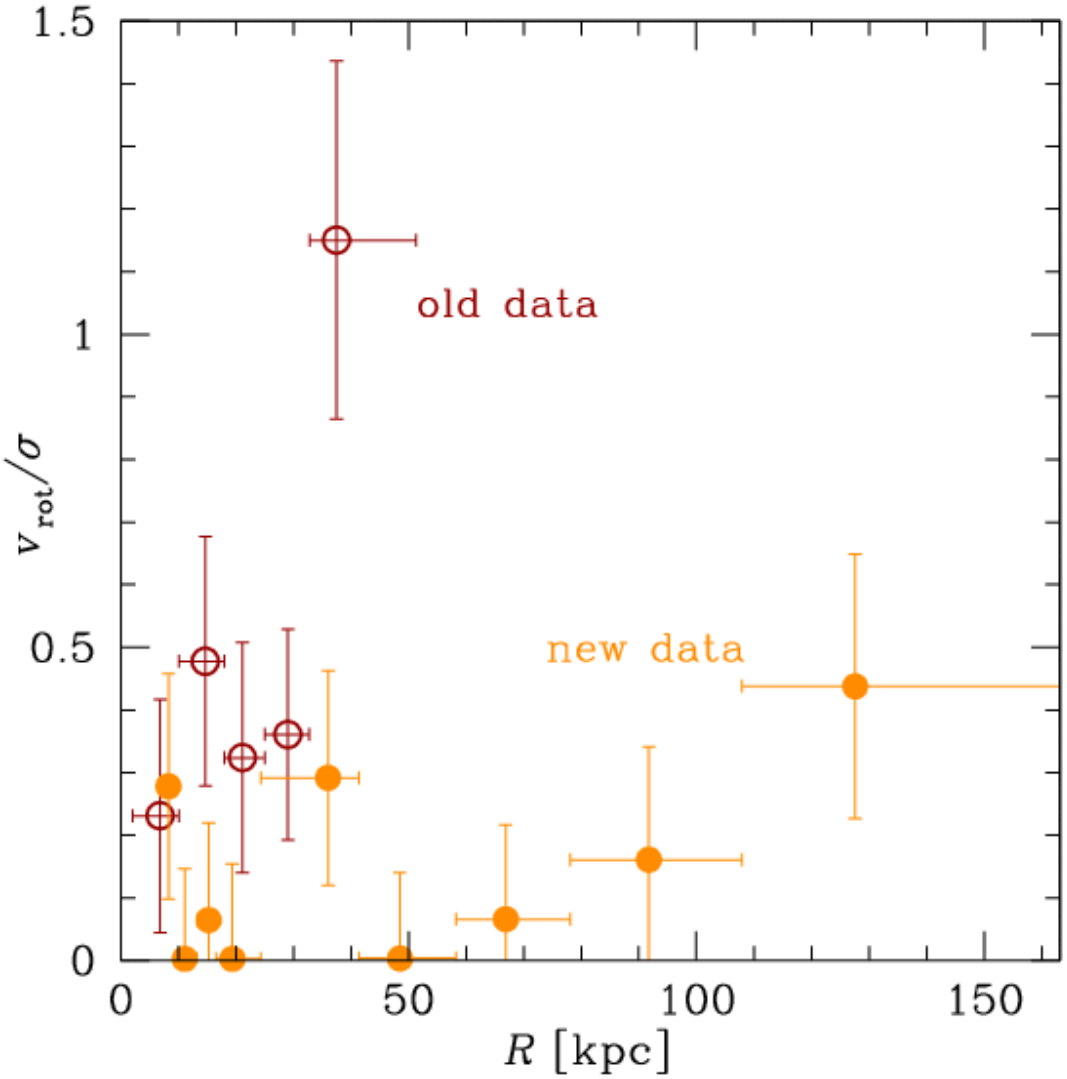
M87 halo rotation



(Kissler-Patig & Gebhardt 1999;
Côté+2001;
Vitvitska+2002)

High outer GCS rotation interpreted as spin-up from major merger; or shear from Virgo infall

M87: halo rotation?



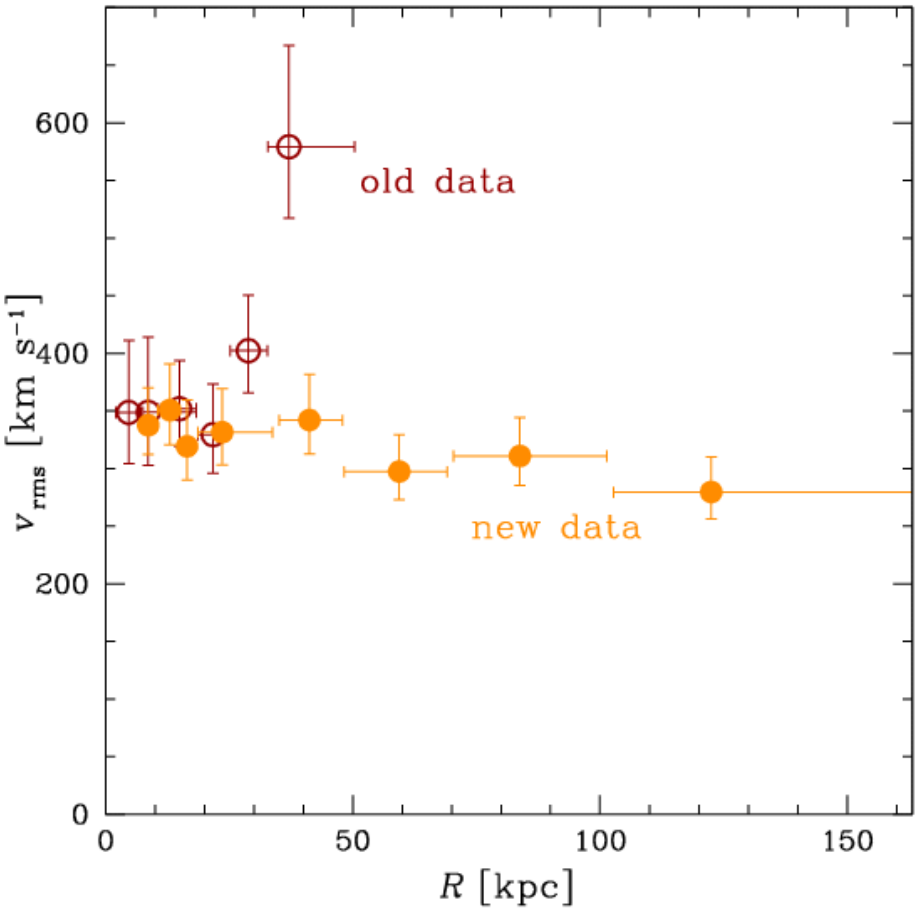
Much lower rotation, typically ~20 km s^{-1}

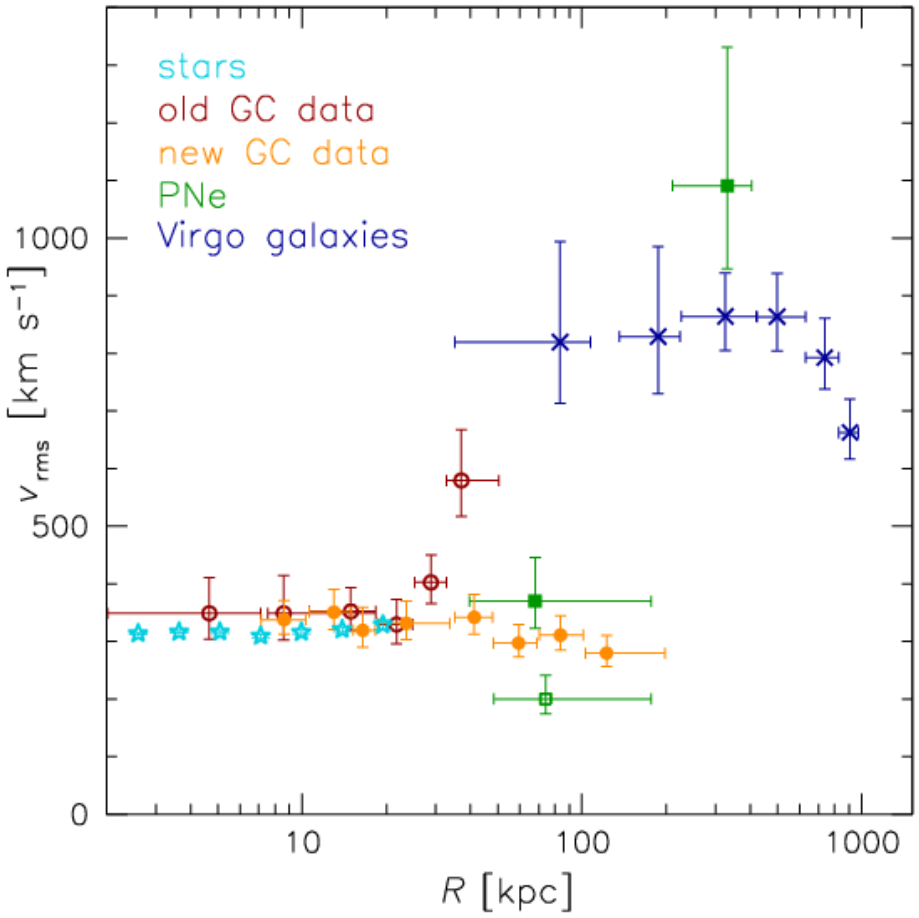
Suggests halo assembly by many minor mergers with little net angular momentum

(e.g., Vitvitska+2002; Abadi+2006; Bournaud+2007)

Pattern of low halo rotation now seen in most giant ellipticals, suggesting **two-phase assembly**
(see talks by Jean Brodie and Vincenzo Pota)

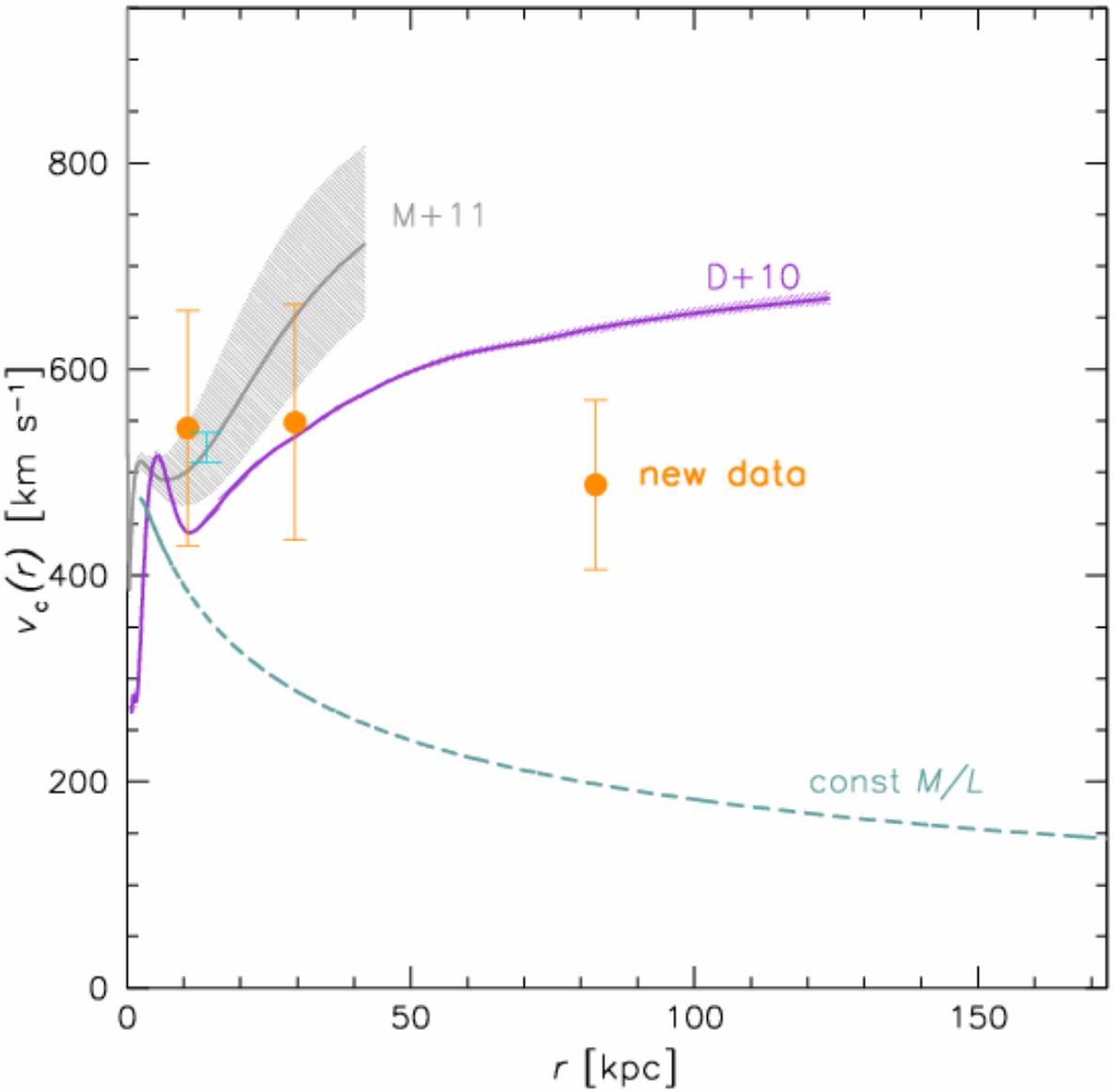
M87: halo velocity dispersion





- **No more steep dispersion increase nor truncation**
  (cf. Côté+2001; Doherty+2009)
- **M87 decoupled from greater Virgo Cluster**

M87: mass profile



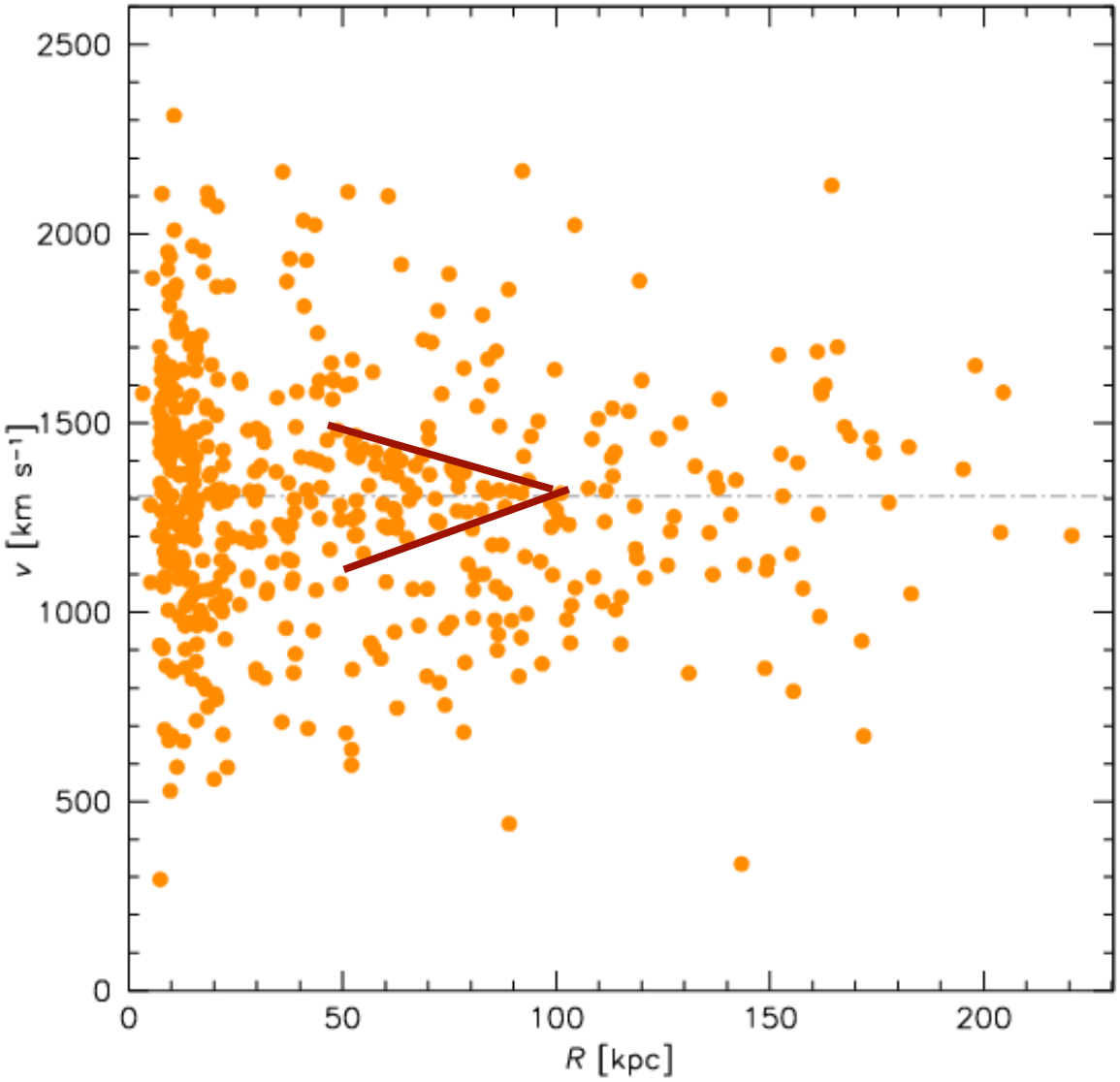
Dynamical modeling with high dispersion gave **steep mass profile** in disagreement with **X-ray profile**

(Murphy+2011; Das+2010)

Simple Jeans analysis of new data alleviates discrepancy

M87/Virgo dark matter profile is poorly known

M87: phase-space substructure



Romanowsky, Strader, Brodie, Mihos, Spitler, Forbes, Foster, *Science*, submitted

High velocity precision reveals cold kinematic structure in halo

Chevron morphology is classic signature of accretion shell

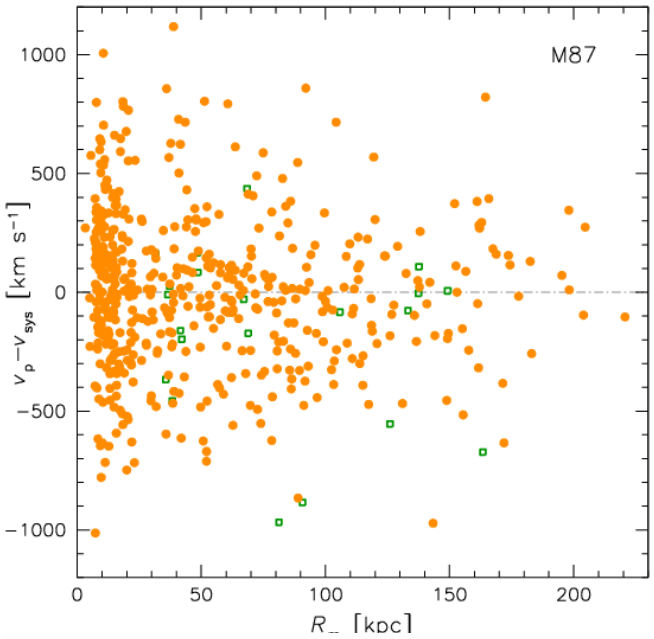
(e.g., Hernquist & Quinn 1988; Fardal+2007)

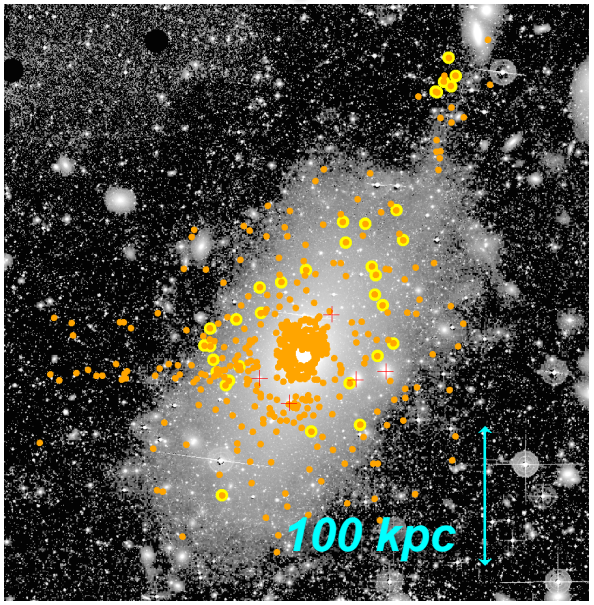
~L^* galaxy bringing in ~1000 GCs within past ~1 Gyr

Supports ΛCDM prediction of recent assembly of BCGs

(e.g., De Lucia & Blaizot 2007)

M87: shell dynamics

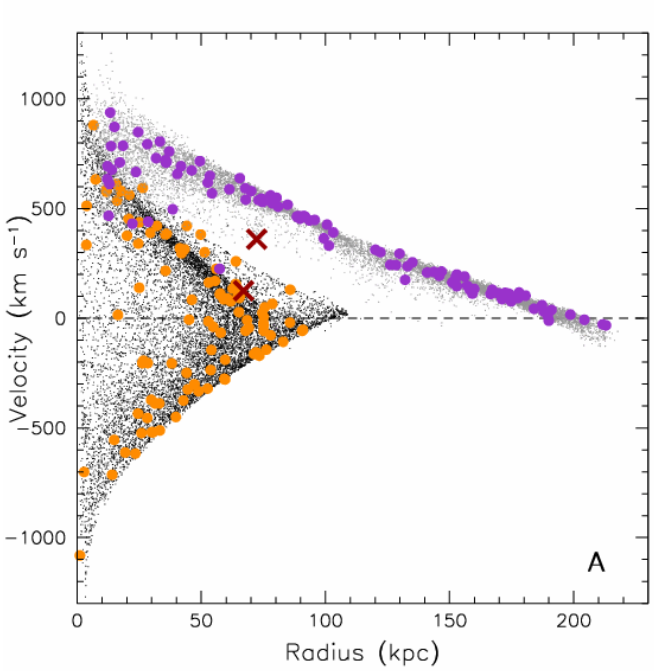


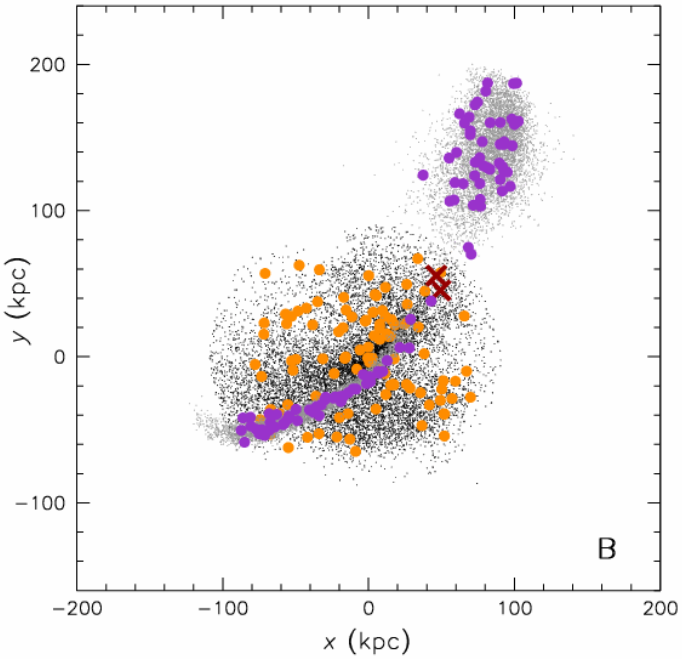


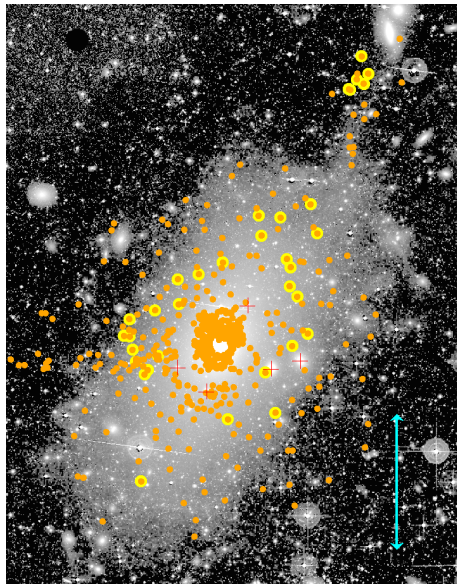
Simple N-body accretion models reproduce broad shell features

But σ ~ 20 km s^{-1} suggests dE accretion not *L

Also ~1:3–1:6 merger ratio might produce more halo rotation







Epochal survey of GC kinematics : M87

- *~500 wide-field, high-precision velocities*
- *Data in 2011A raise total to ~1000*

Bright GC / UCD kinematics

- *Double-peaked LOSVD*
- *Needs theoretical interpretation*

Low halo rotation

Suggests halo assembly by accretion not major merger

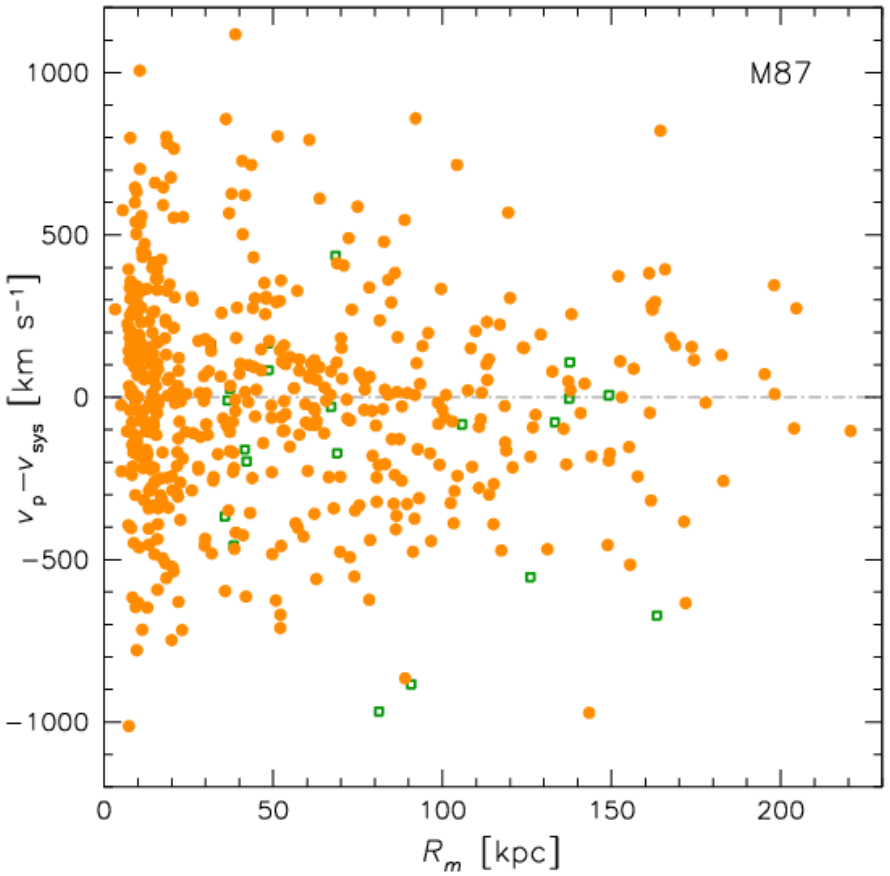
Constant halo velocity dispersion

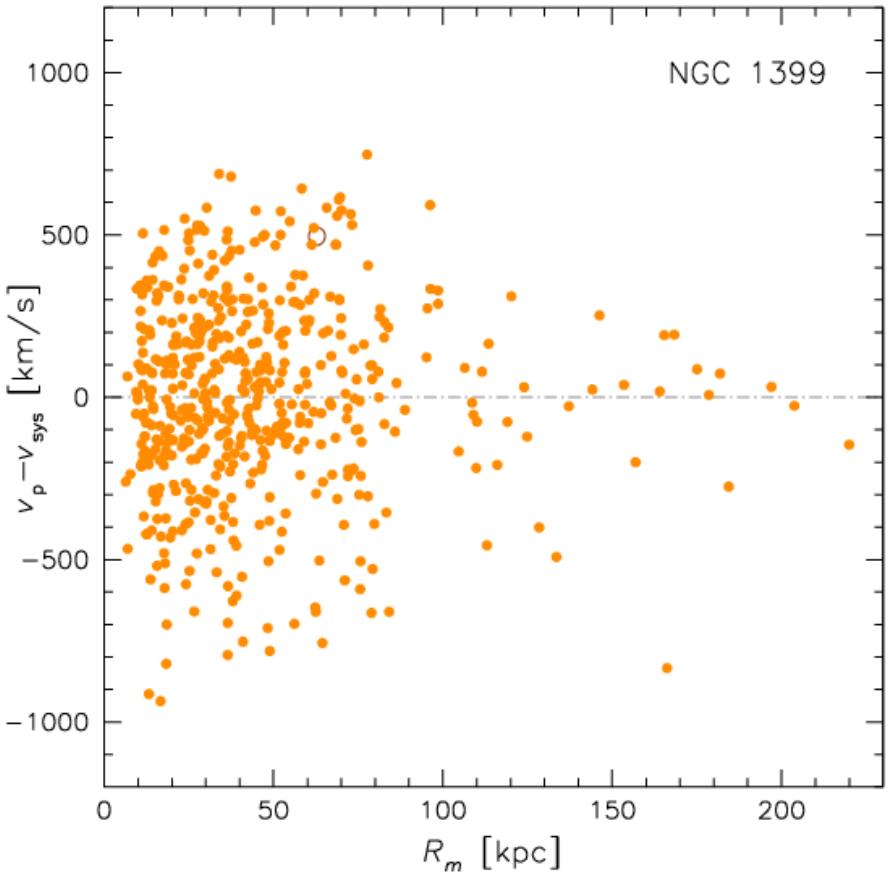
- *M87 decoupled from Virgo*
- *Reduces tension with X-ray mass profile*

Enormous shell in phase-space

- *Recent massive accretion event*
- *Puzzling dynamics*

M87 vs NGC 1399





Comparable data sets in many respects (e.g., Schuberth+2010)

- ***Neither shows transition to hot cluster kinematics***
- ***N1399 has velocity asymmetry of unclear origin***

(cf. McNeil+2010)

- ***Where are the intracluster GCs?*** (extending out to ~±1500 km s^{-1})