The ongoing growth of the M87 halo through accretion events

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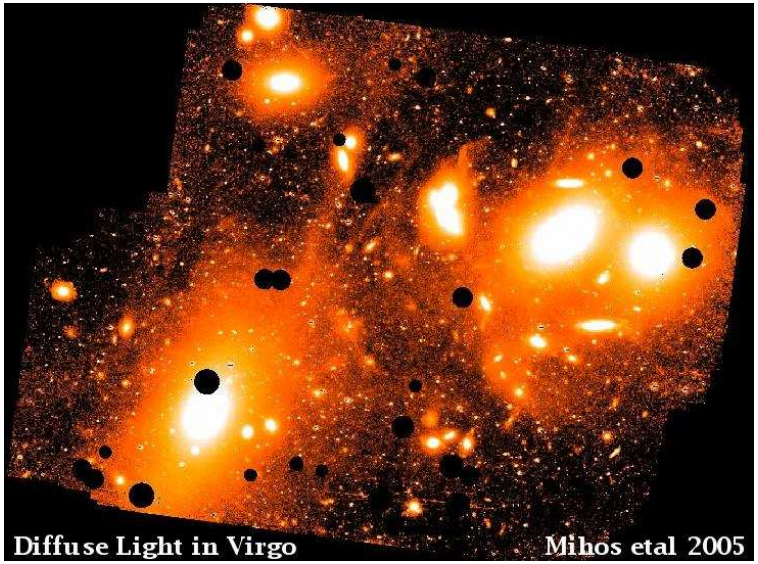
Outer regions of galaxies and structure formation

- Formation extended halos around BCGs closely related to the morphological transformation of galaxies in clusters (Murante+07,Puchwein+10)
- Two-phase formation scenario predicts that outer halos of massive ellipticals are assembled as consequence of accretion events (Naab+09,Van Dokkum+10,Oser+10). In BCGs the majority of stars are acrreted (Cooper+14)
- Outer regions of galaxies preserve fossil records of the accretion events that characterise the hierarchical assembly of galaxies (William+04,Rudick+09)
- Therefore, from the study of the physical properties and kinematics of galaxy halos we get information on the evolution of galaxies and hosting clusters

M87 in Virgo Cluster

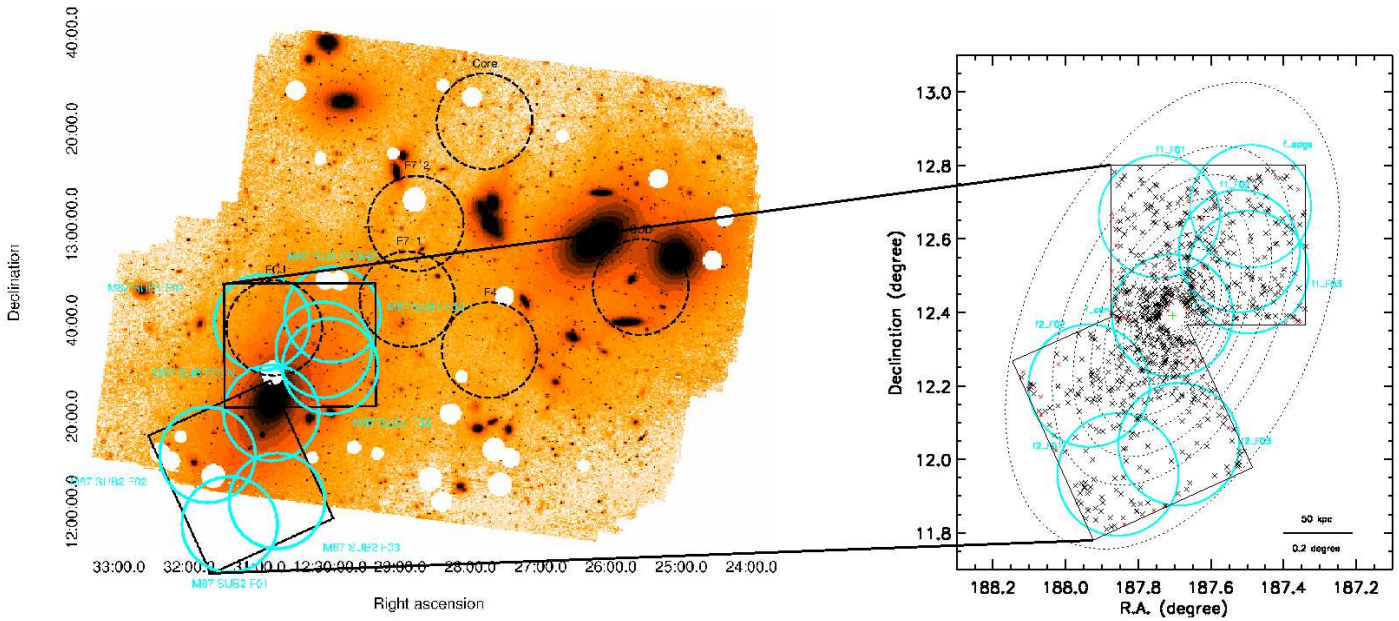


Ultra-deep wide field ($1.5^\circ \times 1.5^\circ$) image of the Virgo cluster core (Mihos et al. 2005)

- At the centre of the subcluster A in the Virgo cluster (Binggelli et al. 1987)
- Extended stellar halo down to $\mu_V \sim 27.0$ mag arcsec^{-2} (Kormendy+09)
- Observed gradients in colour and inferred age and metallicity gradients support the hierachical scenario (Rudick+10,Montes+14)
- Complex network of extended tidal features in the outer regions (Mihos+05)

PN Photometric and Spectroscopic Surveys with Suprime-Cam and FLAMES

Surveyed Area $\sim 0.5 \mathrm{deg}^2$



Suprime-Cam@Subaru Two fields covering the halo of M87 out to 150 kpc (FOV 34'×27') Fields observed through the NB503 narrow-band ([OIII] 5029 Å 74 Å) and broad-band V filter (Longobardi+13)

FLAMES@VLT

high-resolution grism HR08

$\lambda_c = 5048\text{Å}$

spectral resolution of 22 500

FWHM=0.29 Å (17 km/s)

λ_{err}= 0.0025 Å (150 m/s)

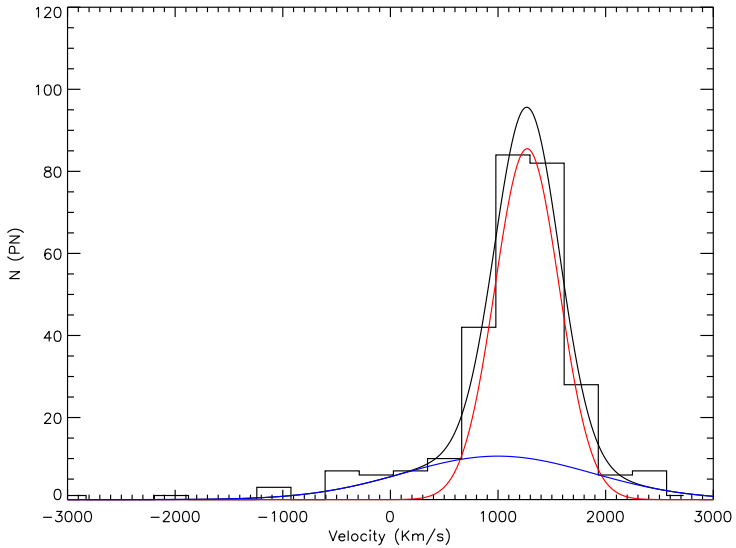
(Longobardi+15a)

Halo and ICL in Virgo: Kinematical separation

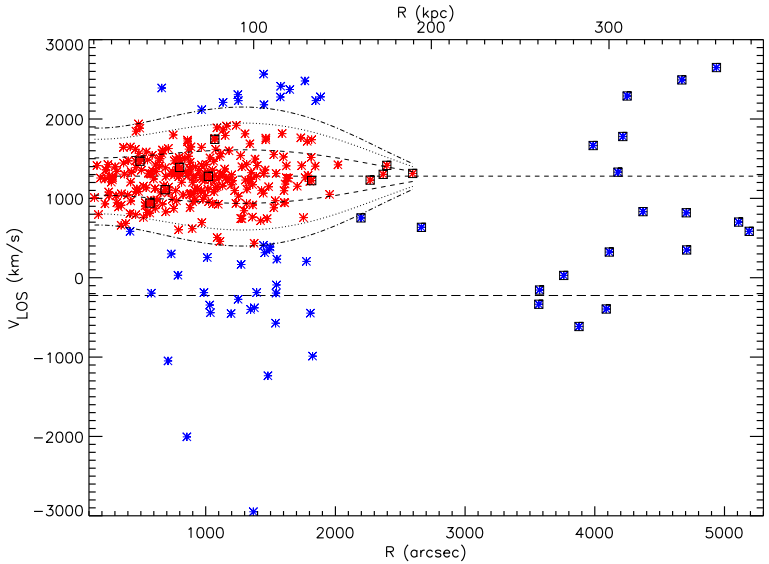
Sample of ∼ 300 spectroscopically confirmed PNe out to 200 kpc

Red: halo PNe (bound)

Blue: intracluster PNe (unbound) Black squares: PN data from Doherty+09



PN LOSVD for halo (red) and IC (blue) components (Longobardi+15a)

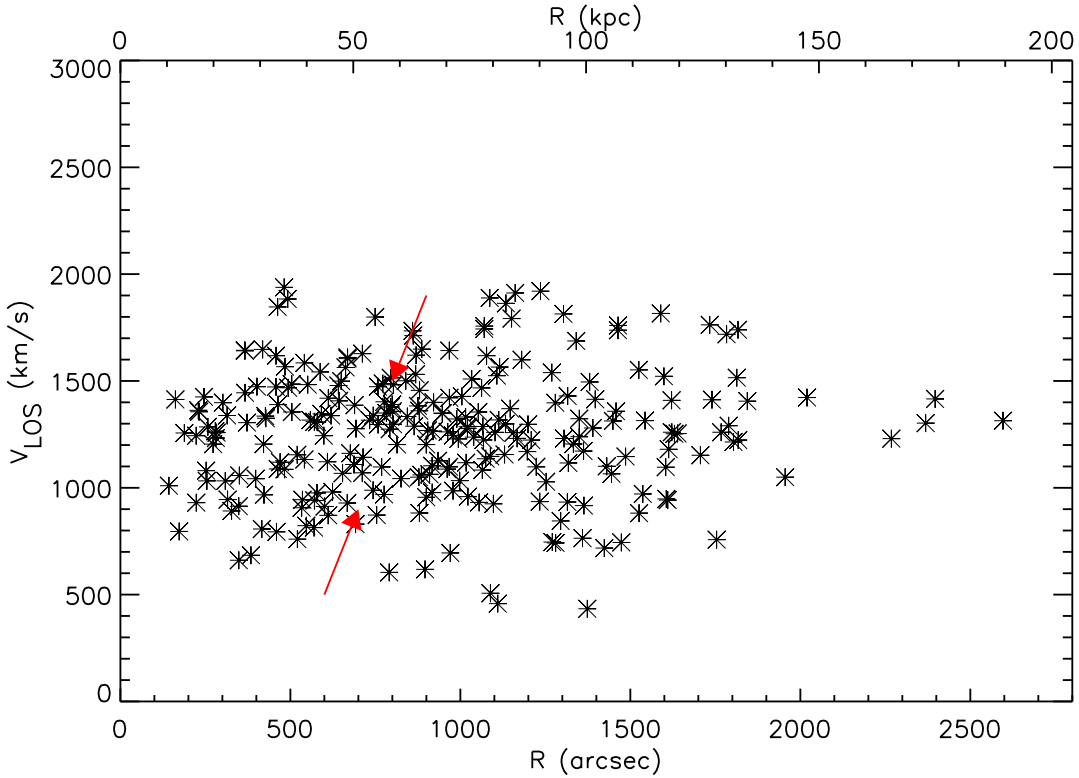


V_{LOS} vs major axis distance (Longobardi+15a)

- M87 halo and Virgo ICL are dynamically distinct components with different density profiles
- Different PN specific numbers: $\alpha_{\rm halo} = 1.06 \times 10^{-8}$ $N_{PN} L^{-1}_{\odot,bol}$ and $\alpha_{\rm ICL} = 2.72 \times 10^{-8}$ $N_{PN} L^{-1}_{\odot,bol}$
- Different shapes of the PNLFs

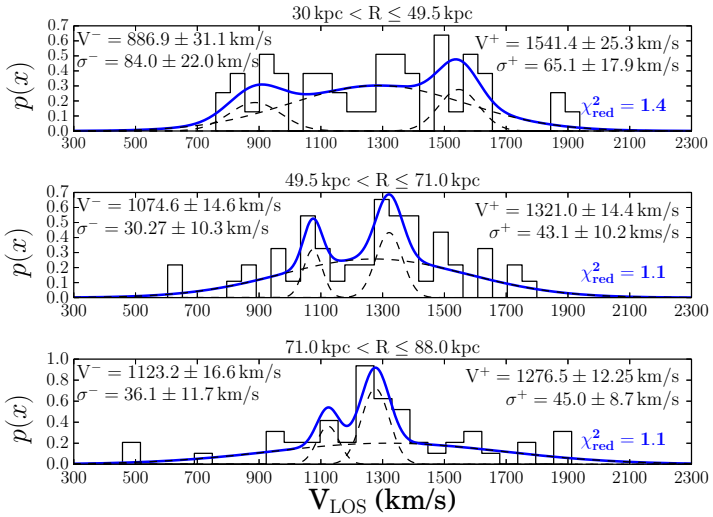
see talk Sp16

M87 Halo Phase-space

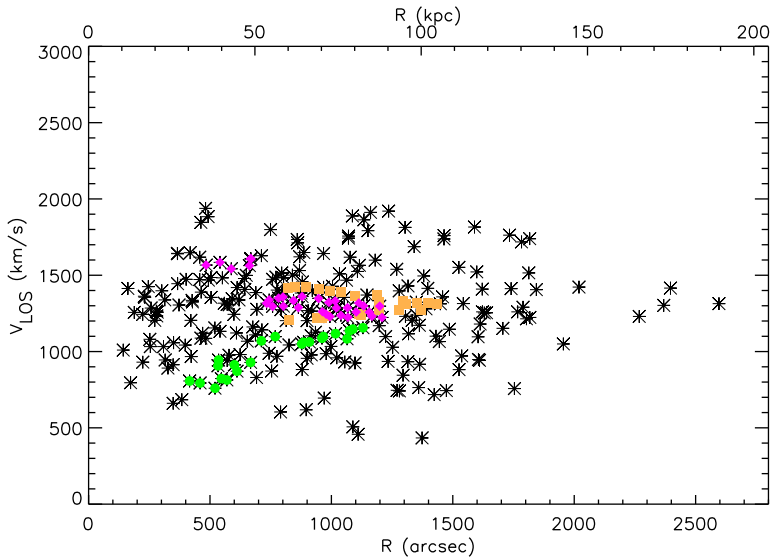


- The Halo phase-space shows a non uniform distribution of points
- Chevron-like substructure

PN tagging: Gaussian Mixture Models



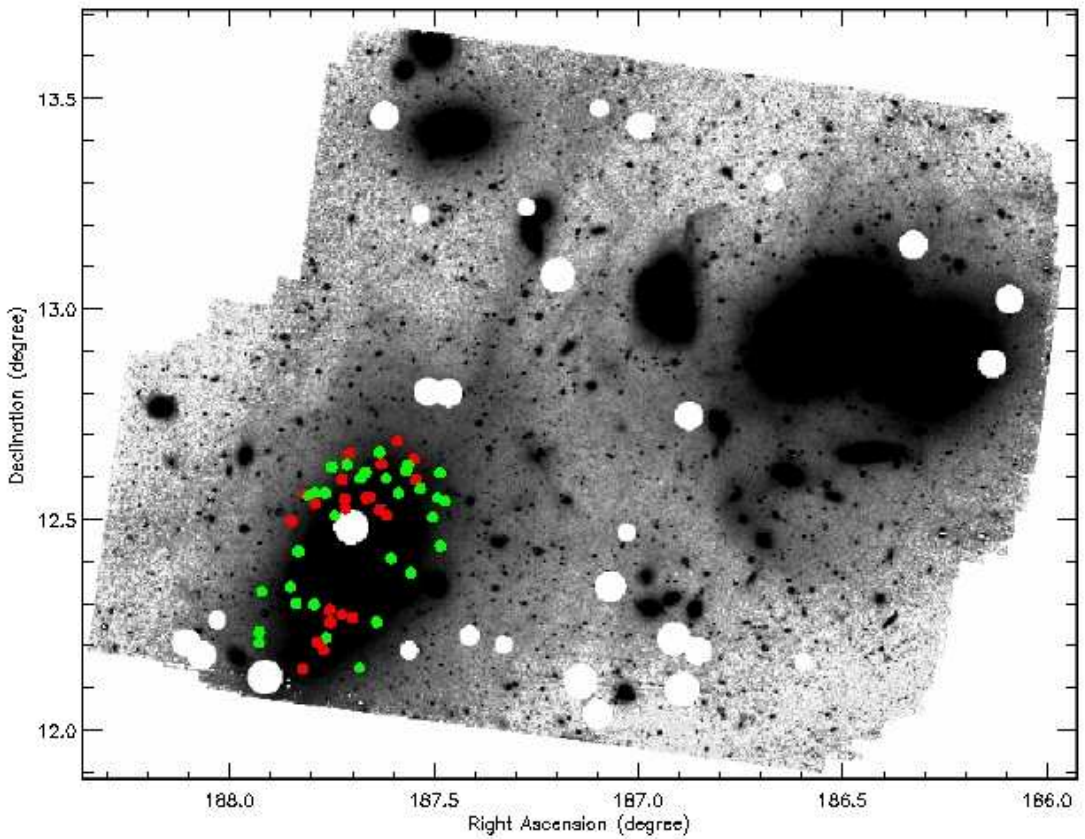
GMM assigns the contribution of each particle to the total (mixture) probability distribution



Chevron PNe (magenta, and green points; Longobardi+15c). Orange sqaures: GC substructure (Romanowsky+12)

- Chevron substructure extends over 700” along the major axis
- Asymmetry in number of PNe in the substructure

Chevron Spatial distribution

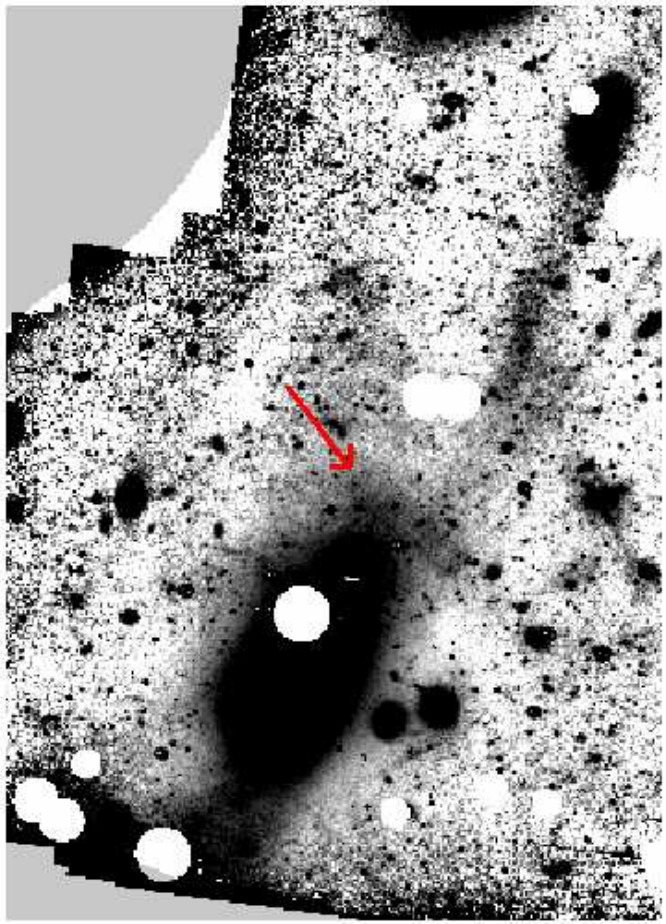


Longobardi+15c. Image from Mihos+05

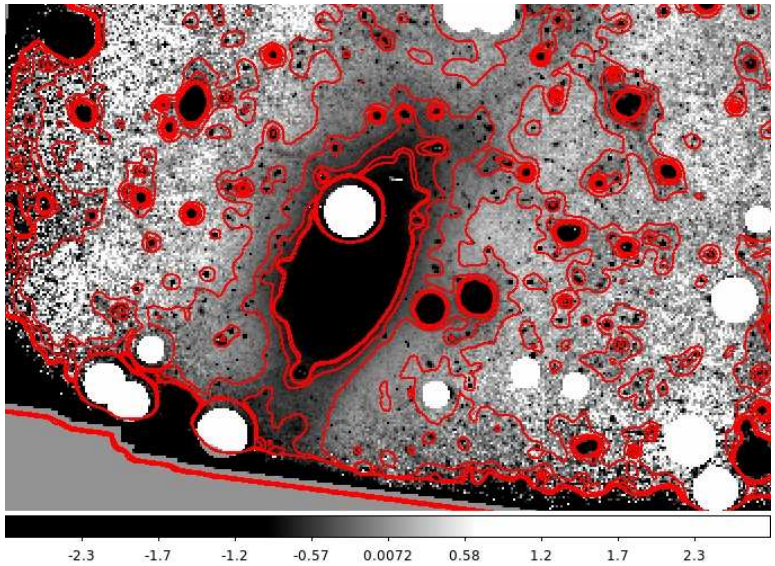
Suggestion the PNe trace tidal debris

Chevron Spatial distribution and M87 surface brightness: The Crown of M87

PN overdensity associated to a substructure in Surface brightness



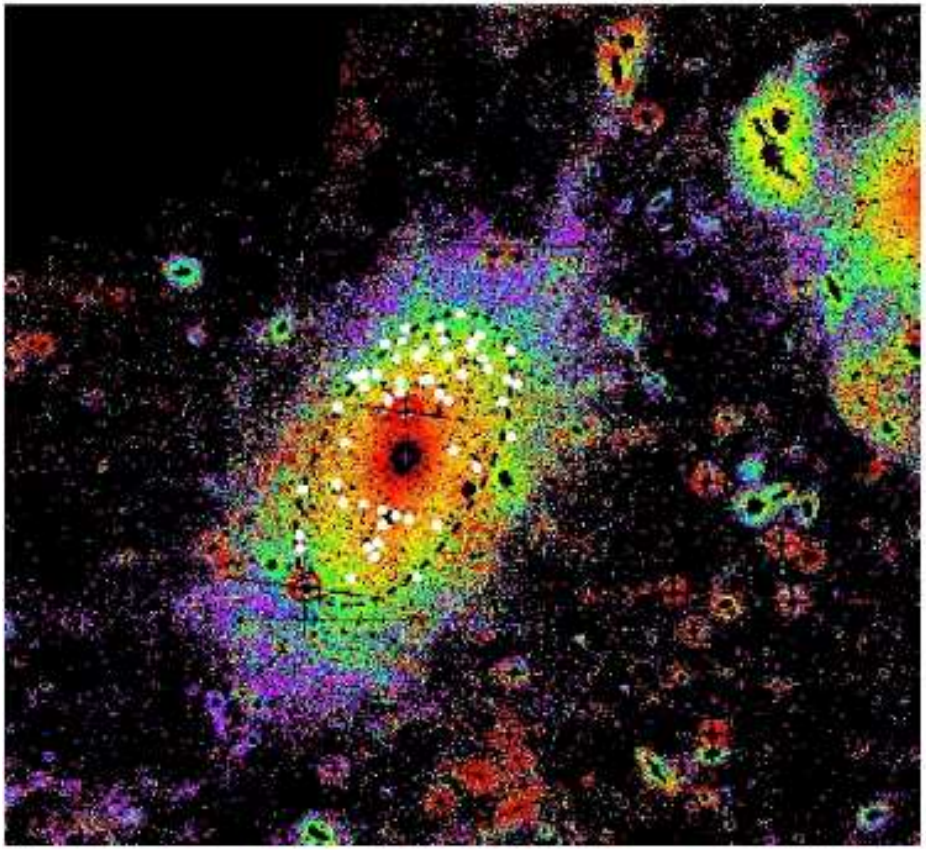
Masked Image that amplifies the high-frequency components.



Contours map on the unsharped masked image.
Contours go from -0.1 to -0.8 in steps of 0.2

Longobardi+15c

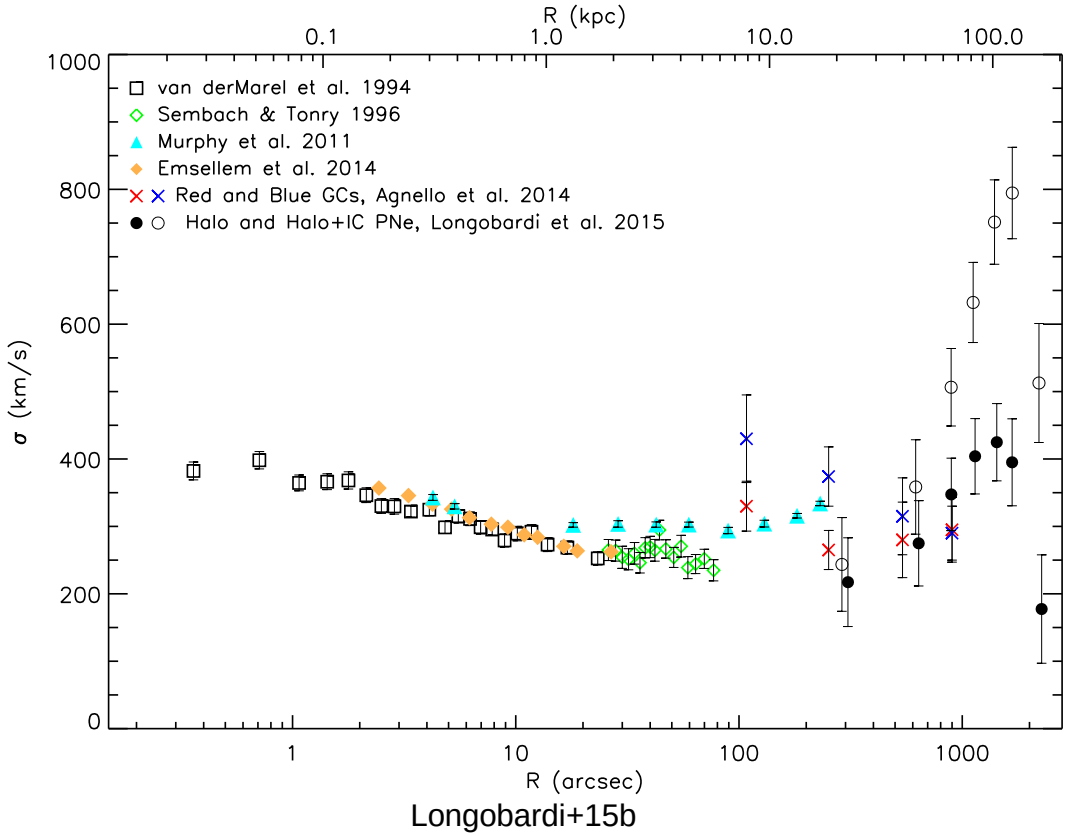
Chevron Spatial distribution and M87 colour



M87 (B-V) colour map (Mihos+15) with Chevron PN overplotted

- Correspondence to blue colours: (B-V)=0.76±0.05
- $\alpha = 1.8 \pm 0.7 \times 10^{-8}$ $N_{PN} L^{-1}_{\odot,bol}$, $L_V = 2.8 \pm 1 \times 10^9 L_{\odot,V}$, M= $6.4 \pm 2.3 \times 10^9 M_\odot$ (Longobardi+15c)

M87 velocity dispersion profile: PN data plus absorption line data and GC data



Longobardi+15b

- M87 σ profile consistent with halo PNe
- ICL may impact IFU kinematics
- Kinematics of red GCs closer to halo stars. Blue GCs discrepant

Summary

- We carried out a photometric and spectroscopic PN survey around the dominant Virgo elliptical galaxy M87 out to 150 kpc
- The BCG halo of M87 and the Virgo ICL are dynamically distinct components with different density profiles and velocity distributions and parent stellar populations.
- The PN phase-space shows signatures of a chevron-like substructure that can be seen in both surface brightness and colour maps.
- The substructure traces the azimuthal varience of the M87 colour
- The number of PNe associated to the substructure implies an accretion event of a LMC-like system.
- The M87 Kinematics as revealed by PNe supports the hierarchical scenario, consistent with a late build-up of its halo.
- M87 is still growing by accreting satellite galaxies.