The kinematics of the extreme outer halo of M87 as revealed by Planetary Nebulae

A.Longobardi
M.Arnaboldi
O.Gerhard

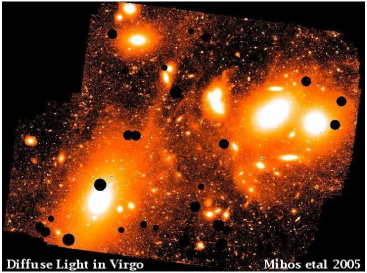
Max-Planck-Institut für extraterrestrische Physik

Garching 2015, 26th Feb.

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

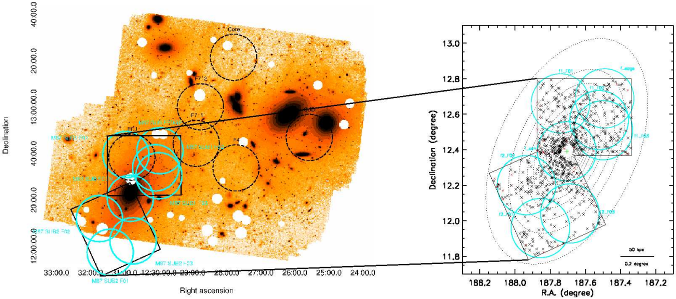


Ultra-deep wide field ($1.5^\circ \times 1.5^\circ$) image of the Virgo cluster core (Mihos et al. 2005)

- 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)

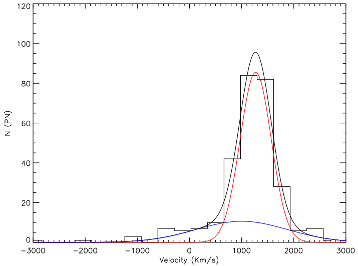
FLAMES@VLT
high-resolution grism HR08
$\lambda_c = 5048$Å
spectral resolution of 22 500
FWHM=0.29 Å (17 km/s)
λ_{err}= 0.0025 Å (150 m/s)
(Longobardi+15a)

Halo and ICL in Virgo: Kinematical separation

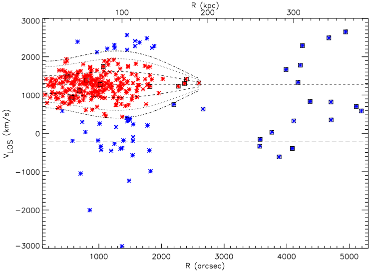
Sample of ~ 300 spectroscopically confirmed PNe out to 200 kpc

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)

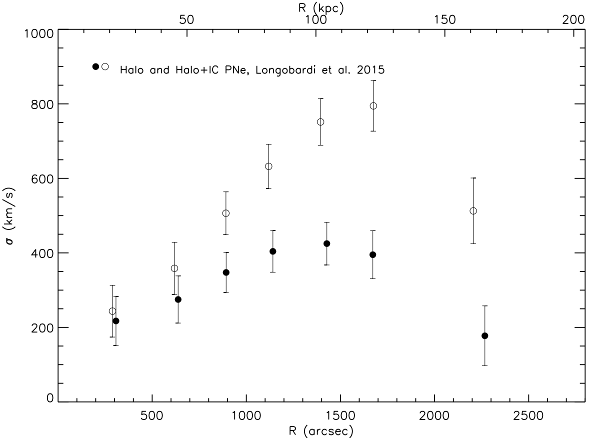


V_{LOS} vs major axis distance (Longobardi+15a)

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

see talk by M.Arnaboldi

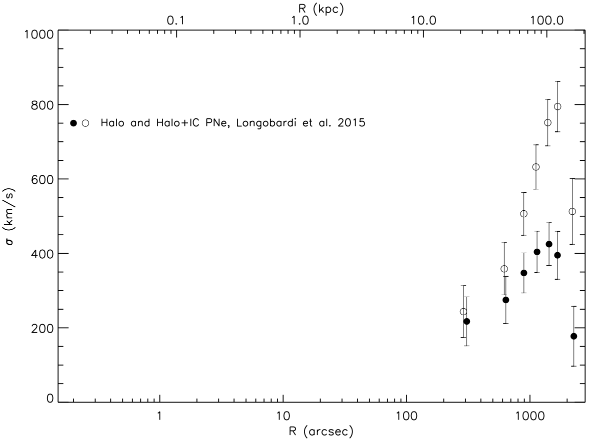
M87 velocity dispersion profile: PN data



Longobardi+15b

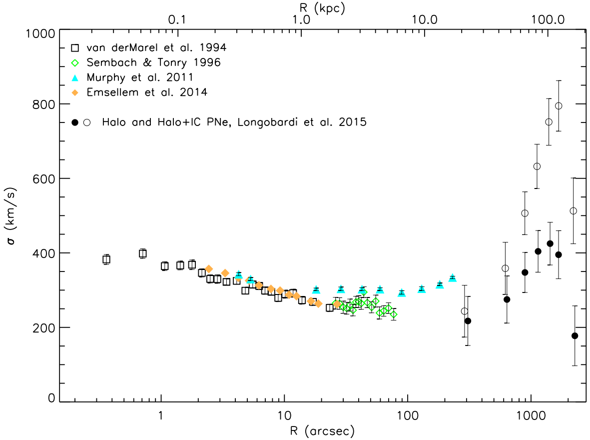
- IC stars increase velocity dispersion

M87 velocity dispersion profile: PN data



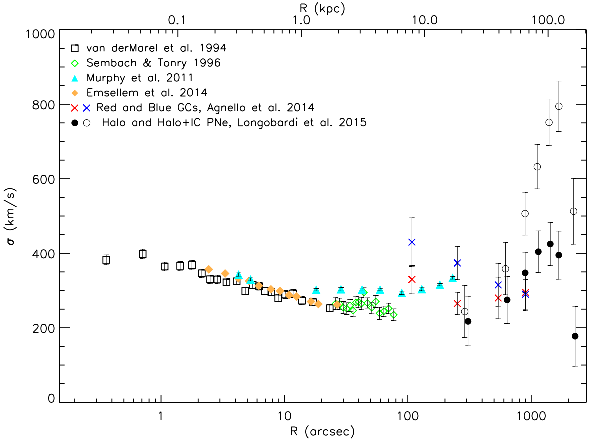
σ profile on a log scale

M87 velocity dispersion profile: PN data plus absorption line data



- M87 σ profile consistent with halo PNe
- ICL may impact IFU kinematics

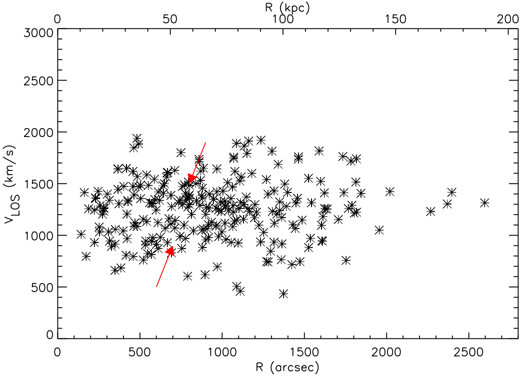
M87 velocity dispersion profile: PN data plus absorption line data and GC data



Longobardi+15b

- Kinematics of red GCs closer to halo stars. Blue GCs discrepant

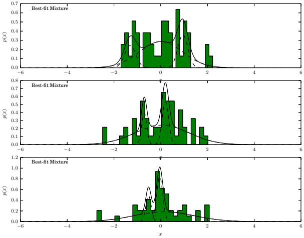
M87 Halo Phase-space



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

Different to GC substructure (Romanowsky+12); see later

PN tagging: Gaussian Mixture Models



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

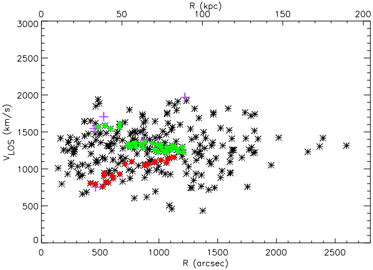
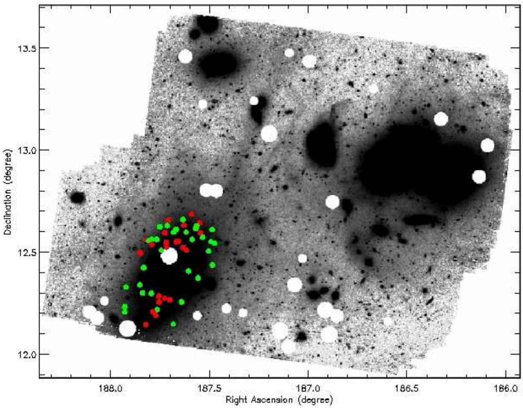


Figure : (Longobardi+15c)

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

Chevron Spatial distribution

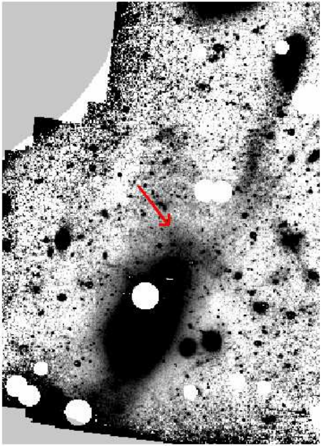


Longobardi+15c. Image from Mihos+05

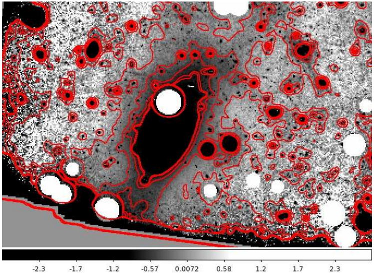
Suggestion the PNe trace tidal debris

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

PN overdensity associated to a substructure in Surface brightness



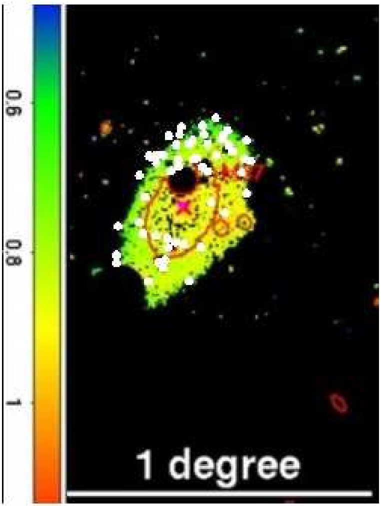
Masked Image that amplifies the high-frequency components.



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

Longobardi+15c

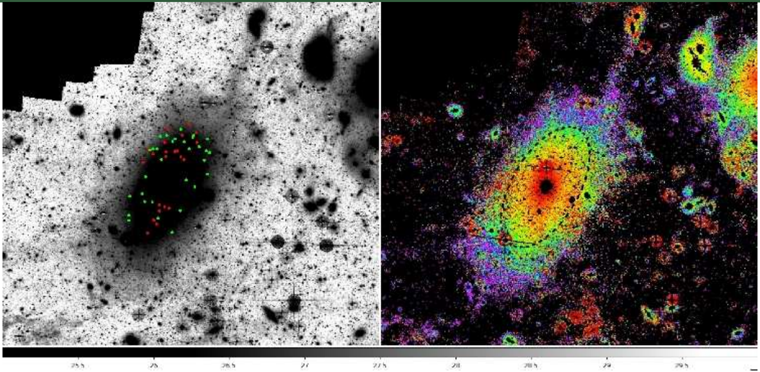
Chevron Spatial distribution and M87 colour



M87 Colours (Rudick+10) with Chevron PN overplotted (white dots)

- Correspondence to blue colours: (B-V)=0.75 as inferred for the IC component (Rudick+10)
- By adopting the specific PN number $\alpha_{\mathrm{ICL}} = 2.72 \times 10^{-8}\ \mathrm{N_{PN}L^{-1}_{\odot,bol}}$ this substructure is consistent with an accretion event involving a system with luminosity $\mathrm{L_V} \sim 1. \times 10^{9}\mathrm{L_{\odot}}$, similar to LMC (Longobardi+15c)

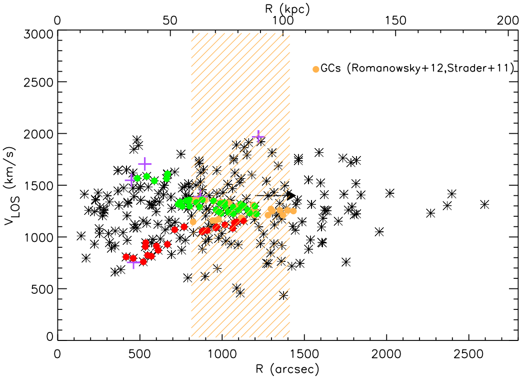
Chevron Spatial distribution and M87 colour



Deep M87 image and Colour map (Mihos+15) with Chevron PN overplotted

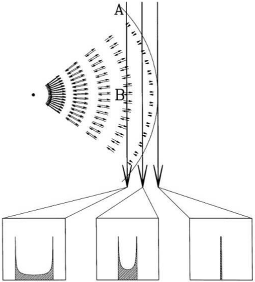
- Correspondence to blue colours: (B-V)=0.75 as inferred for the IC component (Rudick+10)
- By adopting the specific PN number $\alpha_{\rm ICL} = 2.72 \times 10^{-8}$ $N_{PN}L^{-1}_{\odot,bol}$ this substructure is consistent with an accretion event involving a system with luminosity $L_V \sim 1. \times 10^9 L_\odot$, similar to LMC (Longobardi+15c)

Halo Phase-space: Comparison with Globular clusters

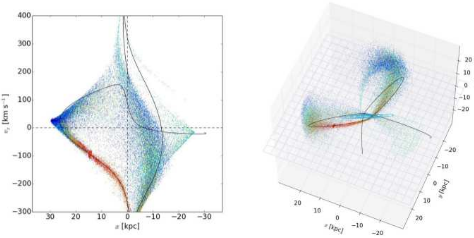


- Chevron for GCs (Romanowsky+12) ends at larger major axis distances.
- Tidally disrupted earlier?

Simulations of shells features in ellipticals



Schematic diagram of the star velocities in a spherical shell system with LOSVD down three cuts of LOS (Merrifield&Kuijken98)



Position and velocity phase-space for N-body model of a shell stream (Foster+14)

- Since ’70s attention to the existence of shell-like structures shown to be the result of a radial collision of an elliptical galaxy and a cold disk galaxy (Quinn84).
- In position velocity phase-space tracers are distributed on a chevron-like substructure (Quinn84)

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 ICL component if not taken into account would result in an overestimation of the velocity dispersion.
- The PN phase-space shows signatures of a chevron-like substructure that can be seen in both surface brightness and colour maps.
- The substructure is in region where the colour becomes bluer ((B-V)=0.8). Similar values have been attributed to the ICL.
- The number of PNe associated to the substructure implies an accretion event of a LMC-like system.
- PNe and stars on the chevron substructure appear to be on lower energy orbits than GCs
- M87 is still growing by accreting satellite galaxies.