The Virgo cD galaxy M87 and its environment as revealed by Planetary Nebulae

A. Longobardi
M. Arnaboldi
O. Gerhard
C. J. Mihos

Max-Planck-Institut für extraterrestrische Physik

IAU XXIX GA 2015 – Division J
• Formation of intracluster light (ICL) and extended halos around BCGs closely related to the morphological transformation of galaxies in clusters (Murante+07,Puchwein+10)

• Simulations show that mergers and accretion are driving mechanisms for galaxy characteristics at the current epoch (Naab+09,Van Dokkum+10,Oser+10).

At the centre of cluster the majority of stars are accreted (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
BCG and ICL single entity or discrete components?

**Introduction**

PNe as tracers of light and stellar population

**Summary**

Two distinct dynamical components with different parent stellar systems in terms of spatial distribution, age and metallicity (Cui+14, Dolag+2010)

**Single entity consisting** of all stars not bound to any subhalos (Zibetti+05, D’Souza+14, Cooper+14)

Alessia Longobardi

M87 as revealed by Planetary Nebulae
Ultra-deep wide field (1.5° × 1.5°) 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 hierarchical scenario (Rudick+10,Montes+14)
- Complex network of extended tidal features in the outer regions (Mihos+05)
M87 as revealed by Planetary Nebulae

Alessia Longobardi

Introduction

PN Surveys

PNe as tracers of light and stellar population

Summary

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)

Surveyed Area ~ 0.5deg²

FLAMES@VLT high-resolution grism HR08 λc = 5048Å spectral resolution of 22 500 FWHM=0.29 Å (17 km/s) λerr = 0.0025 Å (150 m/s) (Longobardi+15a)
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)

VLOS vs major axis distance (Longobardi+15a)

- M87 halo and Virgo ICL are dynamically distinct components
The halo component is more centrally concentrated and less extended than the ICL.
Two component photometric model

\[
\Sigma(R) = \alpha_{2.5,\text{halo}} \left[ I(R)_{K09} + \left( \frac{\alpha_{2.5,ICL}}{\alpha_{2.5,\text{halo}}} - 1 \right) I_{\text{ICL}} \right]
\]

\[
\alpha_{2.5,\text{halo}} = (1.07 \pm 0.12) \times 10^{-8} \text{PNL}_\odot^{-1}
\]

\[
\alpha_{2.5,ICL}/\alpha_{2.5,\text{halo}} \sim 2.5
\]

\[
\alpha_{2.5,ICL} = (2.72 \pm 0.63) \times 10^{-8} \text{PNL}_\odot^{-1}
\]

\[
I_{\text{ICL}} \propto R^\gamma
\]

M87 azimuthally averaged colour profile becomes bluer at larger radii (Rudick+10) in the same regions where we observe the \( \alpha \) parameter increment. If the stars in the M87 halo have a higher metallicity than the ICL, we might expect a variation of the luminosity specific PN number in the region of radii where the M87 stellar halo and the ICL are superposed along the LOS.
Red: halo PNLF  
Blue: ICL PNLF  
cyan triangles: M33 PNLF

- Halo PNLF has steeper slope at fainter magnitude than ICPNLF  
- Dip in the ICPNLF as observed for PN populations in star forming galaxies
The Halo phase-space shows a non uniform distribution of points

Chevron-like substructure
M87 as revealed by Planetary Nebulae

Alessia Longobardi

Introduction

PN Surveys

PNe as tracers of light and stellar population

Summary

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

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

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

Longobardi+15c. Image from Mihos+05

Suggestion the PNe trace tidal debris
PN overdensity associated to a substructure in Surface brightness

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

Longobardi+15c

Masked Image that amplifies the high-frequency components.
M87 as revealed by Planetary Nebulae

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

- Correspondence to blue colours: (B-V) = 0.76 ± 0.05
- \[ \alpha = 1.8 \pm 0.7 \times 10^{-8} \, N_{\text{PN}} L_{\odot, \text{bol}}^{-1}, \quad L_V = 2.8 \pm 1 \times 10^9 L_{\odot, V}, \quad M = 6.4 \pm 2.3 \times 10^9 M_{\odot} \]

(Longobardi+15c)
M87 velocity dispersion profile: PN data plus absorption line data and GC data

- M87 $\sigma$ profile consistent with halo PNe
- ICL may impact IFU kinematics
- Kinematics of red GCs closer to halo stars. Blue GCs discrepant
M87 velocity dispersion profile shows the dynamical complexity of a still assembling system
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 observed properties of the halo and IC PN population, such as the $\alpha$-parameter and the shape of the PNLF show that the M87 stellar halo is redder and more metal rich than the diffuse ICL.
- The halo 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 variance 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.