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

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• 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 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
M87 in Virgo Cluster

Introduction

- 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)

Summary

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

- M87 as revealed by Planetary Nebulae
- Alessia Longobardi
Suprime-Cam@Subaru Two fields covering the halo of M87 out to 150 kpc (FOV 34'x27') 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) $\lambda_{err} = 0.0025\text{Å}$ (150 m/s) (Longobardi+15a)
Sample of \( \sim 300 \) 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)

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

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

see talk by M.Arnaboldi
IC stars increase velocity dispersion
M87 velocity dispersion profile: PN data

σ profile on a log scale

σ (km/s)

R (arcsec)

0.1 1.0 10.0 100.0

0 200 400 600 800 1000

Halo and Halo+IC PNe, Longobardi et al. 2015
M87 velocity dispersion profile: PN data plus absorption line data

- M87 $\sigma$ profile consistent with halo PNe
- ICL may impact IFU kinematics
M87 as revealed by Planetary Nebulae

Alessia Longobardi

Introduction

PN Surveys

PNe as tracers of light and stellar population

Simulations of optical shells in ellipticals

Summary

- 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

- 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
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
Correspondence to blue colours: \((B-V)=0.75\) as inferred for the IC component (Rudick+10)

By adopting the specific PN number 

\[ \alpha_{ICL} = 2.72 \times 10^{-8} \frac{N_{PN}}{L_{\odot}} \]

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)
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By adopting the specific PN number \(\alpha_{ICL} = 2.72 \times 10^{-8} N_{PN} L_{\odot}^{-1}\), 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

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.
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