Dark Matter in the Giant Elliptical Galaxies NGC 1399 and NGC 4636?

Ylva Schuberth (AIIfA/U. de Concepción)
Tom Richtler (U. de Concepción)
Michael Hilker (ESO)
Dynamical Studies in Giant Ellipticals

- Far away (~15 – 20 Mpc)
- (almost) no HI
- Stellar kinematics: difficult because the surface brightness falls off rapidly
- X-rays, kinematics of globular clusters and planetary nebulae
- Giant ellipticals have rich GC Systems
  - large samples of tracers
  - also at large radii where DM is thought to dominate
Spherical Jeans Models

GCs: test-particles moving in the underlying potential of the galaxy

Jeans-Equation (non-rotating):

\[ v_c^2 = \frac{G \cdot M(r)}{r} = -\sigma_r^2 \cdot \left( \frac{d \ln(\rho)}{d \ln(r)} + \frac{d \ln(\sigma_r^2)}{d \ln(r)} + 2\beta \right) ; \quad \beta \equiv 1 - \frac{\sigma_\theta^2}{\sigma_r^2} \]

- \( v_c \) circular velocity
- \( r \) radial distance from the center
- \( \sigma_r \) radial velocity dispersion
- \( \rho \) spatial density of the test-particles
- \( \beta \) anisotropy parameter
The Data …

- Washington photometry (Dirsch et al. 2003, 2005 & Bassino et al. 2006)

- Medium resolution spectra FORS 2/ MXU and Gemini-S/GMOS. GC radial velocities determined via cross-correlation:
  - NGC 1399: 670 GCs
  - NGC 4636: 440 GCs
Washington Photometry

- CTIO MOSAIC wide-field photometry
  - candidate identification
  - colours -> subpopulations
  - spatial distribution of GCs

Bimodal colour distribution (NGC 1399)
Red GCs more concentrated towards host galaxy

Modified Hubble Law

Deprojection Integral has analytical solution
NGC 1399 – at the Centre of Fornax

670 GC velocities

$v_{\text{sys}} = 1441 \text{ km/s}$

80 kpc

NGC 1387

NGC 1404

$(v = 1947 \text{ km/s})$
Disentangle NGC 1399 & NGC 1404 GCs

Distance from NGC 1404

exclude all GCs within 3' (17 kpc) of NGC 1404
Velocity Dispersion Profiles
Velocity Dispersion Profiles

- red GCs
- blue GCs

Graph showing velocity dispersion profiles with data points and error bars.
Velocity Dispersion Profiles

Moving bin
Modelling the Red GCs

add NFW halo, $r_s = 10, 20... 80$ kpc
adjust $\rho_s$

$r_s = 30$ kpc $\rho_s = 0.015$ M$_\text{sun}$/pc$^3$
Going to larger radii...

Radial velocities from Bergond et al. '07

Colours from MOSAIC photometry

(Schuberth et al. A&A Letter, in press)
NGC 1399 - Results

- red clusters: declining velocity dispersion

- blue clusters: possibly 'contaminated' by GCs stripped off neighbouring galaxies

- The centre of Fornax is a complex environment but our model describes the GC dynamics out to about 150 kpc
NGC 4636 – in the outskirts of Virgo

10° from M87

D = 15 Mpc

$v_{\text{sys}}$ = 906 km/s

$\sim 440$ GC velocities

blue GCs

30 kpc
NGC 4636 - All GCs ($\Delta v<50$ km/s)

- $\sigma(R)$ vs $R$ [kpc]
- $v(R)$ vs $R$ [kpc]

348 GCs
NGC 4636 - Red GCs ($\Delta v<50$ km/s)

![Graphs showing the distribution of GCs and their radial velocities with respect to the radius in kpc.](image)
NGC 4636 - Blue GCs ($\Delta v < 50$ km/s)

\begin{figure}
\centering
\begin{minipage}{0.8\textwidth}
\centering
\includegraphics[width=\textwidth]{ngc4636_blue_gcs}
\end{minipage}
\end{figure}

173 GCs
NGC 4636 Jeans Models using the blue GCs

\[ \beta = 0 \]

\begin{align*}
& \text{line-of-sight dispersion} \\
\text{radial} & \beta = 0.5 \\
\text{tangential} & \beta = -0.5, -2
\end{align*}

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\[ \sigma(R) \text{ [km s}^{-1}] \]

\[ R \text{ [kpc]} \]

\[ \sigma(R) \text{ [km s}^{-1}] \]

\[ R \text{ [kpc]} \]

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\[ \text{stars } M/L_R = 6.8 \]
NGC 4636 Jeans Models using the blue GCs

at 30 kpc (∼4 \( R_{\text{eff}} \)):

\[
\begin{align*}
\beta = 0.5 & \quad M_{\text{dark}}/M_{\text{tot}} = 52 \% \\
\beta = 0 & \quad M_{\text{dark}}/M_{\text{tot}} = 48 \% \\
\beta = -0.5 & \quad M_{\text{dark}}/M_{\text{tot}} = 43 \% \\
\beta = -2 & \quad M_{\text{dark}}/M_{\text{tot}} = 37 \%
\end{align*}
\]

\( r_s = 30 \text{ kpc} \quad \rho_s = 0.003 \text{ M}_{\odot}/\text{pc}^3 \)
MOND?
NGC 4636 and MOND:

Bekenstein (2004)

Famaey & Binney (2005)

Schuberth et al. (2006)
NGC 1399 and MOND

Additional dark matter needed. Probably not neutrinos.
NGC 4636: GC dynamics consistent with MOND.

NGC 1399: Probably small scale variant of the finding that MOND fails in galaxy clusters unless one invokes a dark matter component.
Thank You!
Extended GCs around NGC 4636?

- Some radial velocity-confirmed GCs not in point-source catalogue!
- FORS 2 Pre-imaging/ Acquisition Images with very good seeing (0.5"-0.8") but short (~90 sec) exposure times
- Can we distinguish between GCs and foreground stars? ISHAPE (Larsen 2002) software to detect 'resolved' sources...

--> first preliminary results:
NGC 4636 - Extended GCs?
NGC 4636 - Extended GCs?
Outlook

NGC 4697: GC dynamics (GMOS-S)  
(PI: A. Romanowsky)

~100 GCs in 4 GMOS masks

Hubble Type: E6
Spherical Jeans Models

Assumptions:
- spherical symmetry (GC System + host galaxy)
- no rotation
- anisotropy $\beta$ constant with radius

Input:
- 3D GC number density (deprojected photometry)
- cumulative stellar mass:
  (deprojected photometry + stellar M/L-ratio)
- GC line-of-sight velocity dispersion (spectroscopy)

Approach: Find the NFW dark halo ($r_{\text{dark}}, \rho_0$) needed to reproduce the observed dispersion!
NGC 1399
Centre of Fornax
#GCs~6500, $S_n = 5.1$
GCS Extent: ~250 kpc
(Bassino et al. 2006)

NGC 4636
Outskirts of Virgo
#GCs~3700, $S_n = 5.9$
GCS Extent: ~50 kpc
(sharp drop @ 35-40 kpc)

very X-ray luminous:
dark matter dominated!?

e.g. Matsushita et al. (1998),
Loewenstein et al. (2003)
NGC 1399
Centre of Fornax
#GCs~6500, $S_n = 5.1$
GCS Extent: ~250 kpc
(Bassino et al. 2006)

NGC 4636
Outskirts of Virgo
#GCs~3700, $S_n = 5.9$
GCS Extent: ~50 kpc
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**BUT:**

disturbed X-ray morphology

~5 kpc (Jones et al. 2002)