The structure and internal kinematics of globular clusters: tides and gravity

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Non-collisional GCs are ideal targets since:

- No mass segregation
- Tides affect equally all stars
- No collisional effects
- No interactions with binaries
Galactic Globular Clusters

Ferraro et al. (2006)

Dalessandro et al. (2009)

Beccari et al. (2011, in preparation)

Lack of relaxation confirmed by the flat BSS radial distribution
ω Centauri

The most massive and luminous GC of the Milky Way

d \sim 5.4 \text{ kpc}

M \sim 3 \cdot 10^6 \, M_\odot
ω Centauri

- 3185 stars with FLAMES@VLT
- 28 pointings
- $d<80'$
- $R \sim 22,500$
- $\delta_v \sim 0.5$ km/s

*Sollima et al. (2009)*
\( \omega \) Centauri

- 946 bona-fide cluster members but uncertain membership at \( r \sim r_\ast \)
  
- \( V_{\text{rot}} \sim 10.4 \) km/s
  
- Good fit with Wilson (1975) model

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Sollima et al. (2009)
Tidal tails?

Detected by Leon et al. (2000) ...

...questioned by Law et al. (2003)
Tidal tails?

N-body simulation with Momentum-conserving tree code NEMO

50,000 particles immersed in the Milky Way tidal field Following the cluster orbit
Tidal tails?

Tides produce the outer power-law density profile
And the flat velocity dispersion profile
Tidal tails?

Only 0.4% of former cluster stars are expected between $1 < r/r_t < 2$

$\mu_V < 30$ mag arcsec$^{-2}$

Outermost stars seem to be aligned with the cluster orbit

Sollima et al. (2009)
NGC 2419

The second GC of the Milky Way in terms of mass after ω Centauri

$M \approx 1.0 \cdot 10^6 \, M_\odot$

Populates the outer Galactic halo at $d \approx 87$ kpc
NGC 2419

178 stars with DEIMOS@KeckII

$R \sim 6,500$

$\delta_v \sim 2.2 \text{ km/s}$

*Ibata et al. (2011, in preparation)*
NGC 2419

- 151 bona-fide cluster members
- $V_{rot} < 3 \text{ km/s}$
NGC 2419

- 151 bona-fide cluster members
- $V_{\text{rot}} < 3$ km/s
Comparison with NGC 2419

Ibata et al. (2011, in preparation)
Comparison with NGC 2419

Ibata et al. (2011, in preparation)
Comparison with NGC 2419

MOND models seem to not reproduce the velocity dispersion profile of NGC2419.
Palomar 14

- Faint low-mass GC
- $M \sim 1.2 \cdot 10^4 \, M_\odot$
- Populates the outer Galactic halo at $d \sim 72 \, \text{kpc}$
Palomar 14

- MegaCam@CFHT imaging
- $1^\circ \times 1^\circ$ FoV
- Massive tidal tail
- $r_h \sim 46.1$ pc
- $r_{\text{Roche}} < r_t$

Sollima et al. (2011)
Palomar 14

- MegaCam@CFHT imaging
- $1^\circ \times 1^\circ$ FoV
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Sollima et al. (2011)
Palomar 14

- MegaCam@CFHT imaging
- 1° x 1° FoV
- Massive tidal tail
- $r_{h} \sim 46.1$ pc
- $r_{\text{Roche}} < r_{\text{t}}$

*Sollima et al. (2011)*
Kinematics in Palomar 14

- 19 stars with UVES@VLT and HIRES@Keck I
- $R \approx 45,000$
- $\delta_v \sim 0.2$ km/s
- $\sigma_v \sim 0.39 \pm 0.12$ km/s
- A deep freeze? (Kupper & Kroupa 2010)

_Jordi et al. (2009)_
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Test of MOND in Palomar 14

Jordi et al. (2009)

... but see Gentile et al. (2010)
Test of MOND in Palomar 14

Also Pal 14 has an overall velocity dispersion which is not compatible with MOND
Test of MOND in Palomar 14

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Test Newton in Palomar 14

Fractions of binaries up to ~30% are still compatible with the data

$M/L = 1.885$

$f_b = 20\%$
Fractions of binaries up to \(~30\%) are still compatible with the data.
Conclusions

• No need of DM and/or non-canonical physics

• Significant effect of tidal heating in the outskirts of ω Cen and Pal 14

• Pal 14 can be classified as an extended “fuzzy” cluster like those observed in M31 (Mackey et al. 2010)

• MOND models predicts velocity dispersions that are not compatible with those observed in NGC 2419 and Pal 14

• Flat velocity dispersion profiles can be produced by many processes (tidal heating, non-standard DF, binaries, ellipticity, rotation, field contamination, small statistics, etc.)