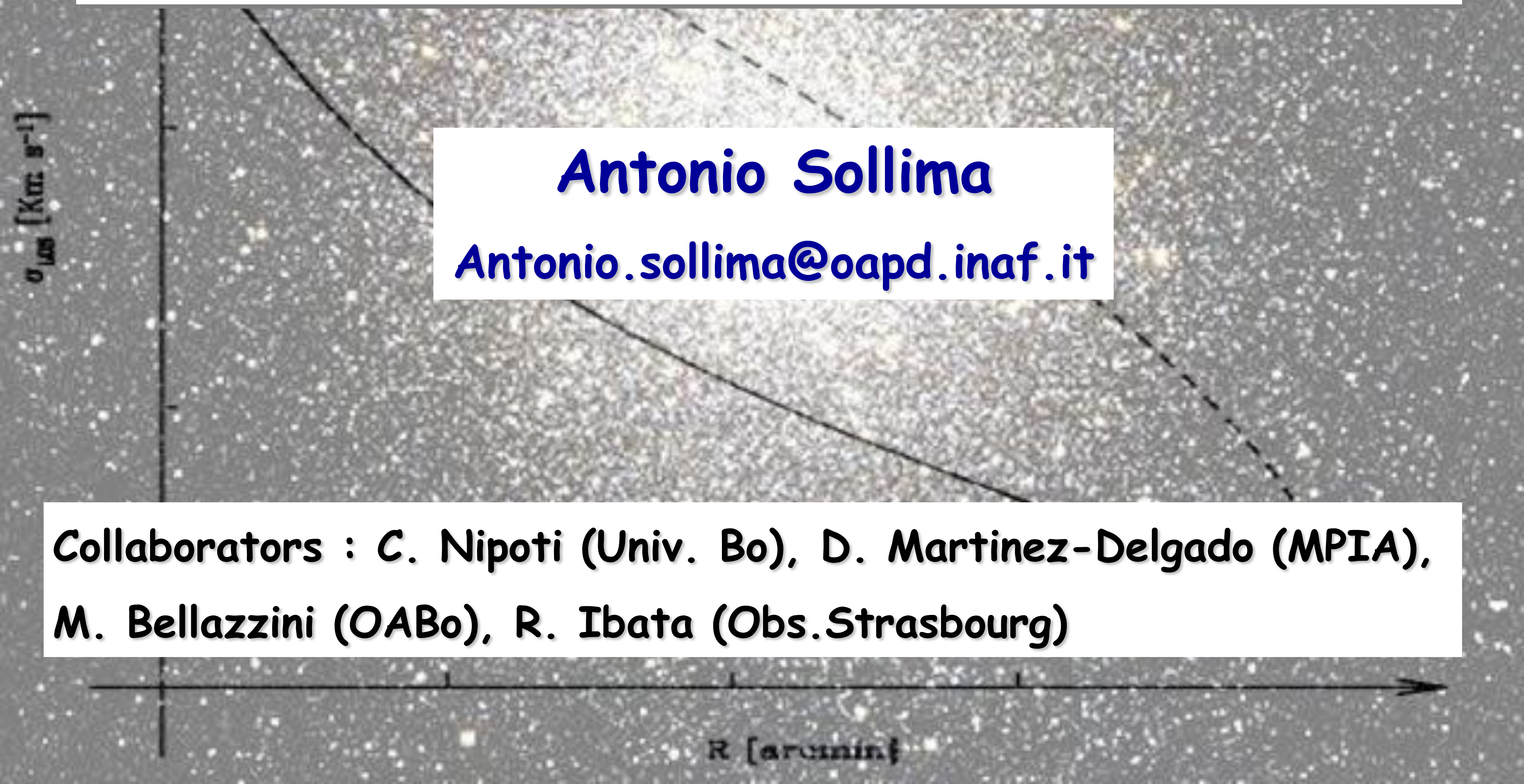
The structure and internal kinematics of globular clusters: tides and gravity



Antonio Sollima

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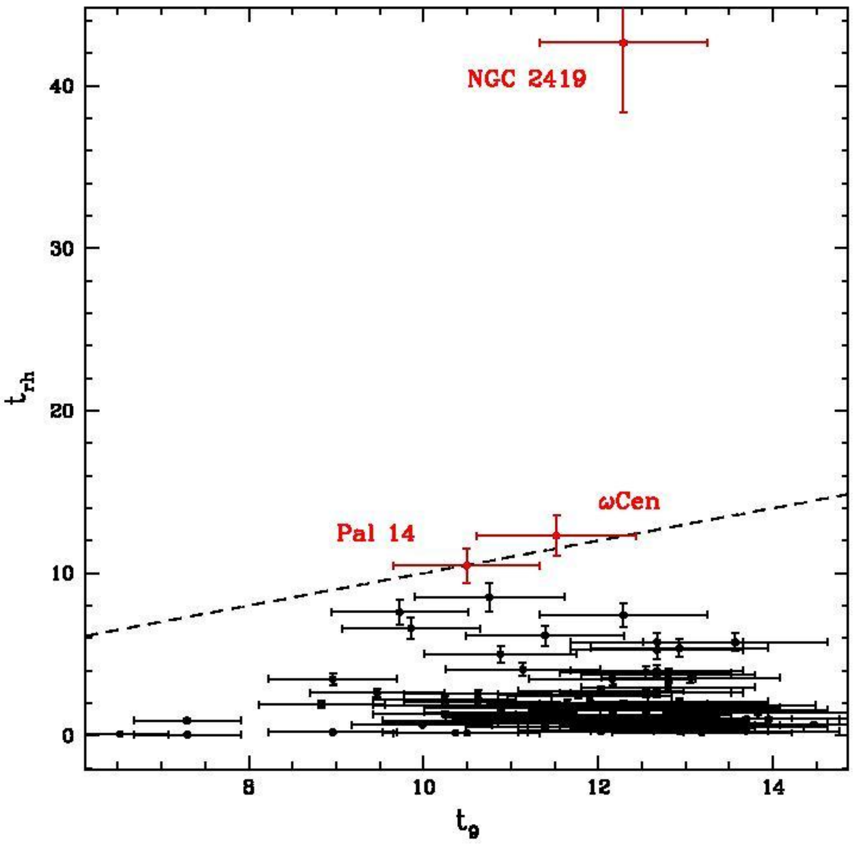
Collaborators : C. Nipoti (Univ. Bo), D. Martinez-Delgado (MPIA), M. Bellazzini (OABo), R. Ibata (Obs.Strasbourg)

Galactic Globular Clusters

Non-collisional GCs are ideal targets since:

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

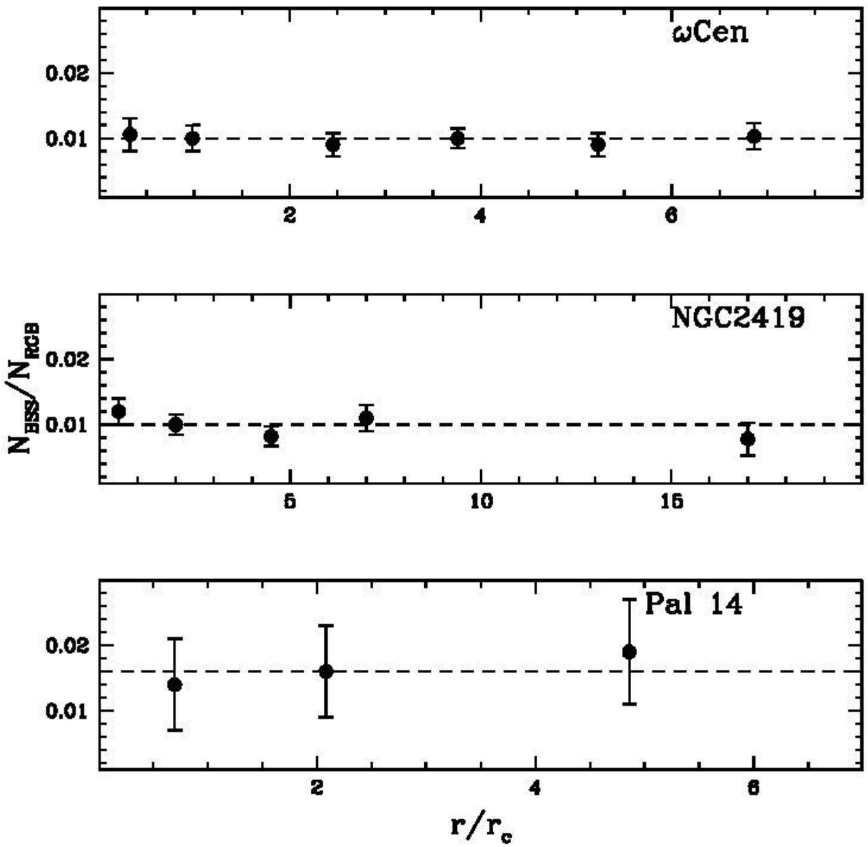


Galactic Globular Clusters

Ferraro et al. (2006)

Dalessandro et al. (2009)

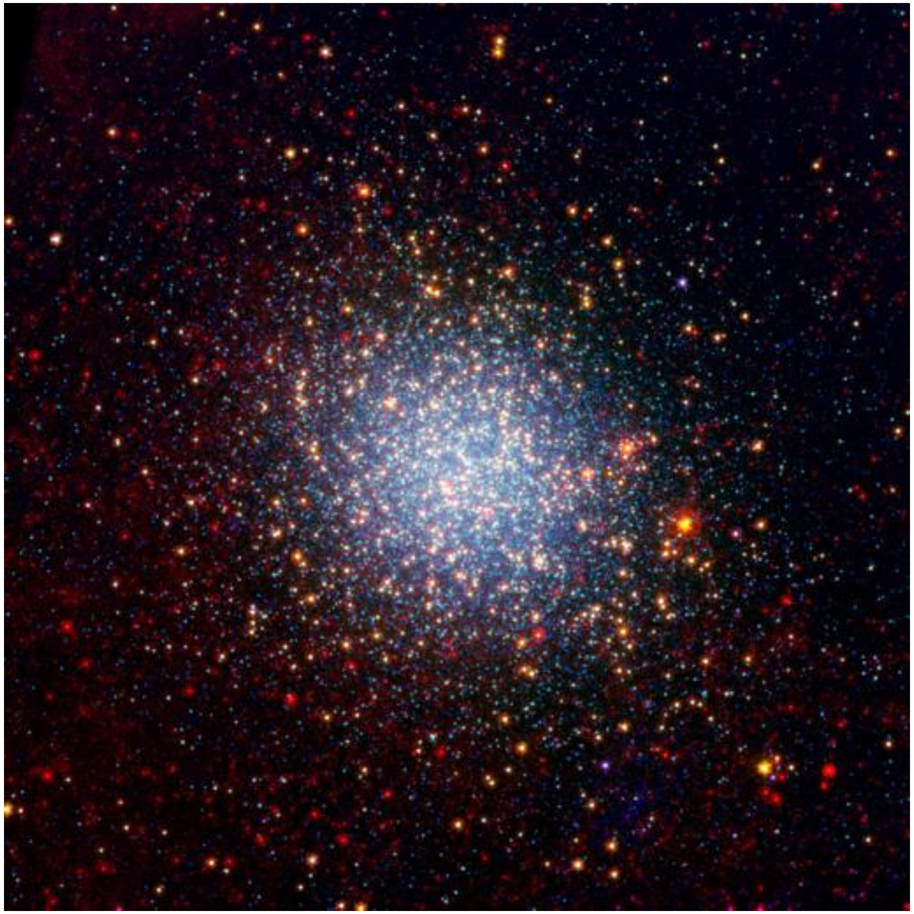
Beccari et al. (2011, in preparation)



Lack of relaxation confirmed confirmed by the flat BSS radial distribution

ω Centauri

The most massive and luminous GC of the Milky Way

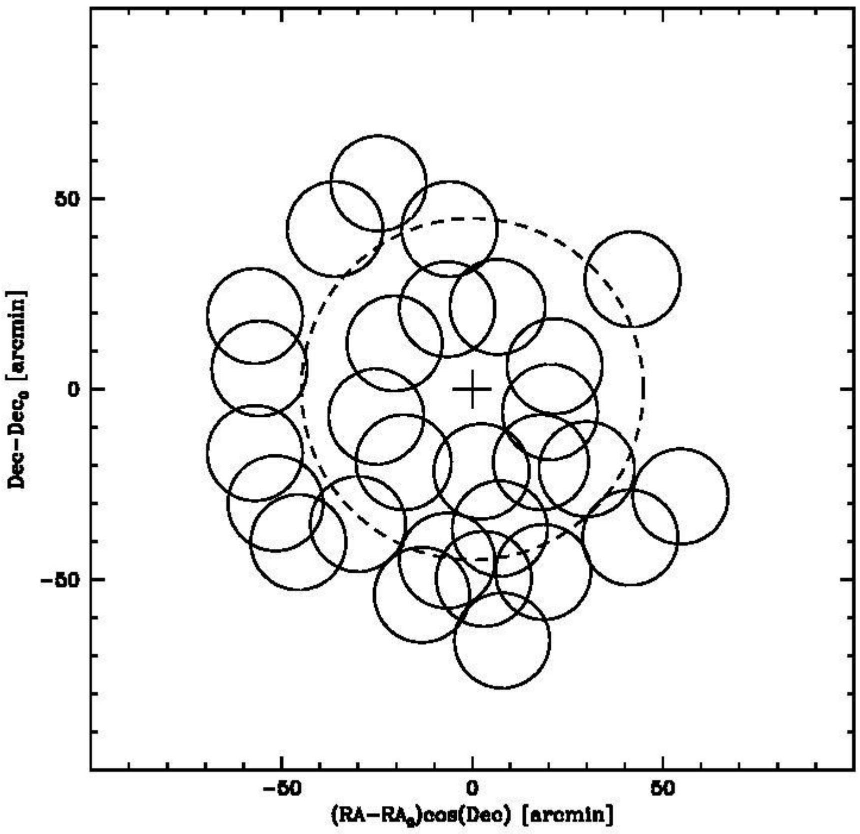


d ~ 5.4 kpc

$M \sim 3 \cdot 10^6\ M_{@}$

ω Centauri

- 3185 stars with FLAMES@VLT
- 28 pointings
- d<80'
- R~22,500
- δ_v~0.5 km/s



Sollima et al. (2009)

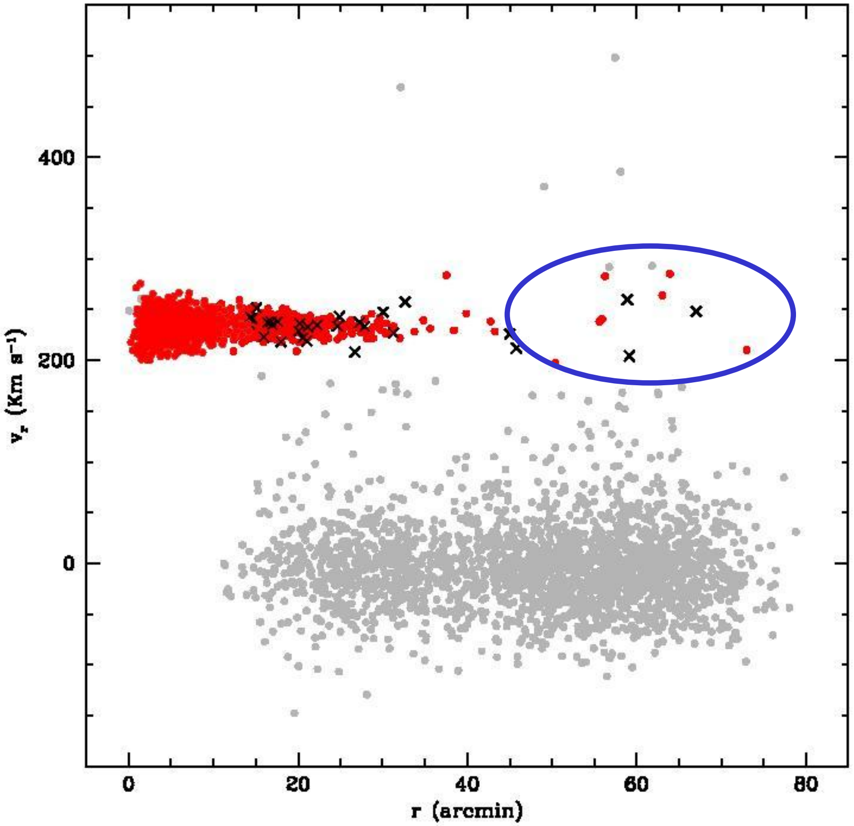
ω Centauri

•946 bona-fide cluster members

but uncertain membership at $r \sim r_t$

•$V_{rot} \sim 10.4$ km/s

•Good fit with Wilson (1975) model



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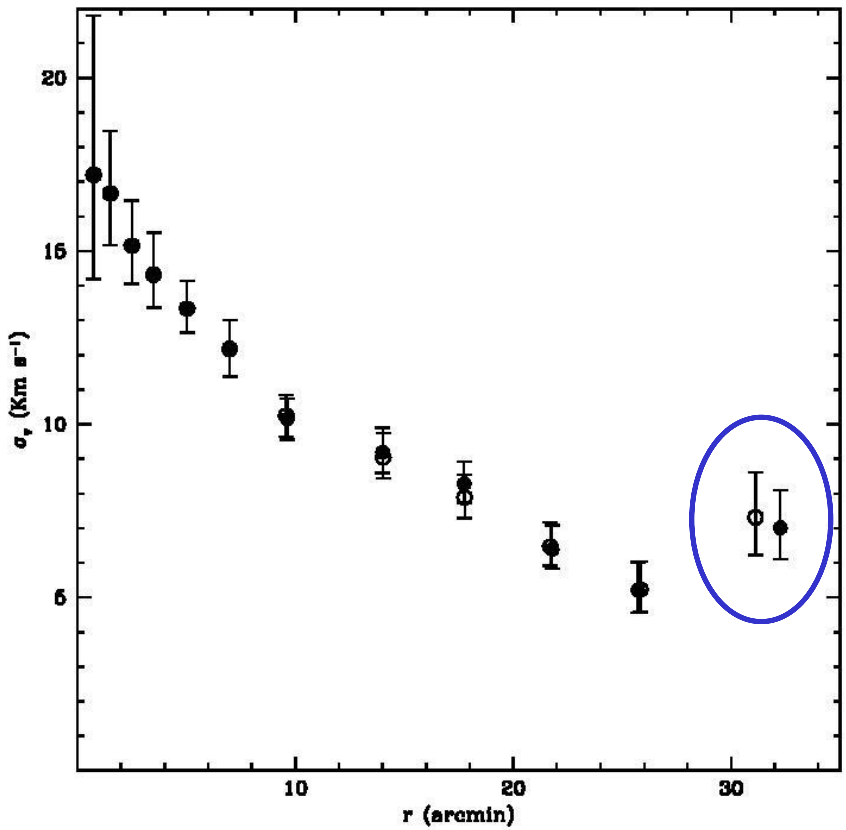

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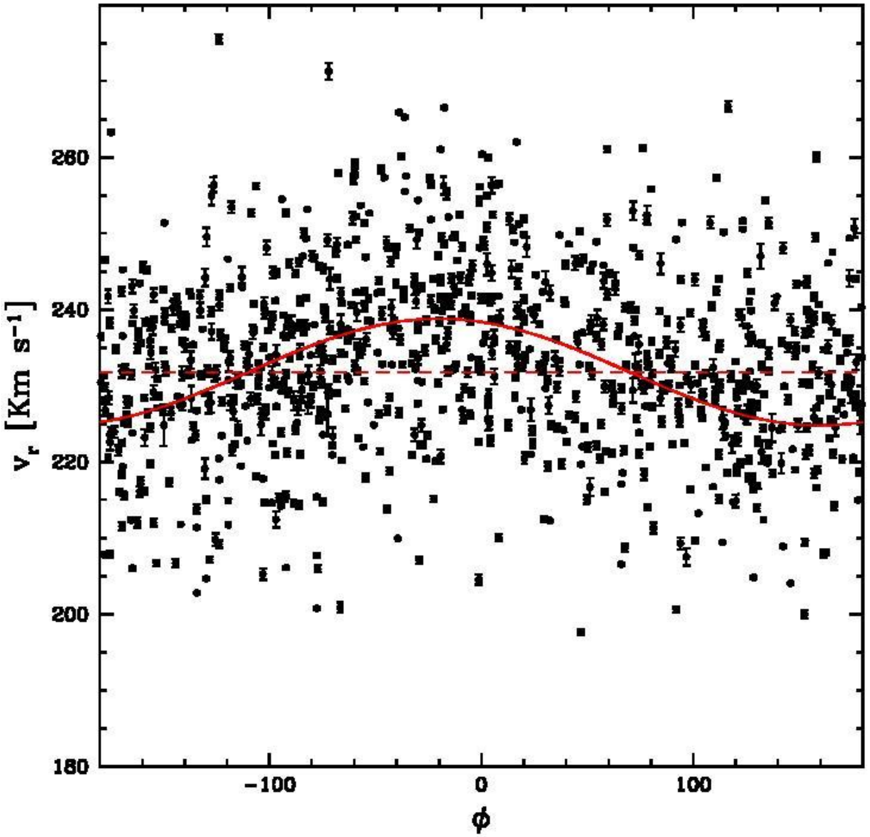

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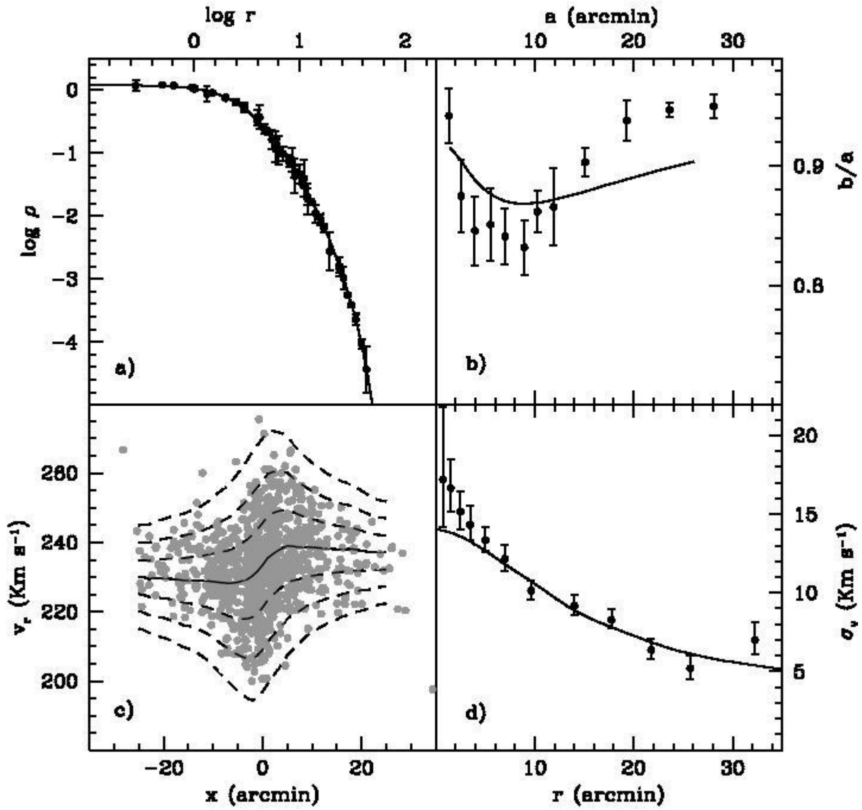
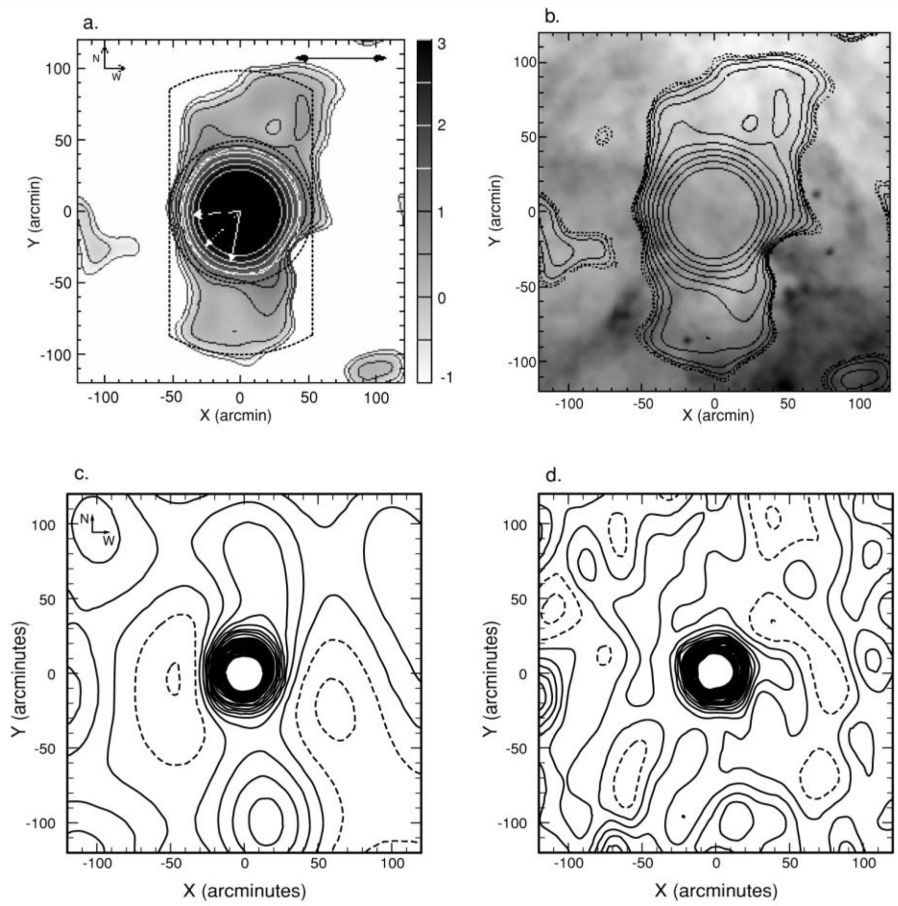


Sollima et al. (2009)

Tidal tails?

Detected by Leon et al. (2000) …

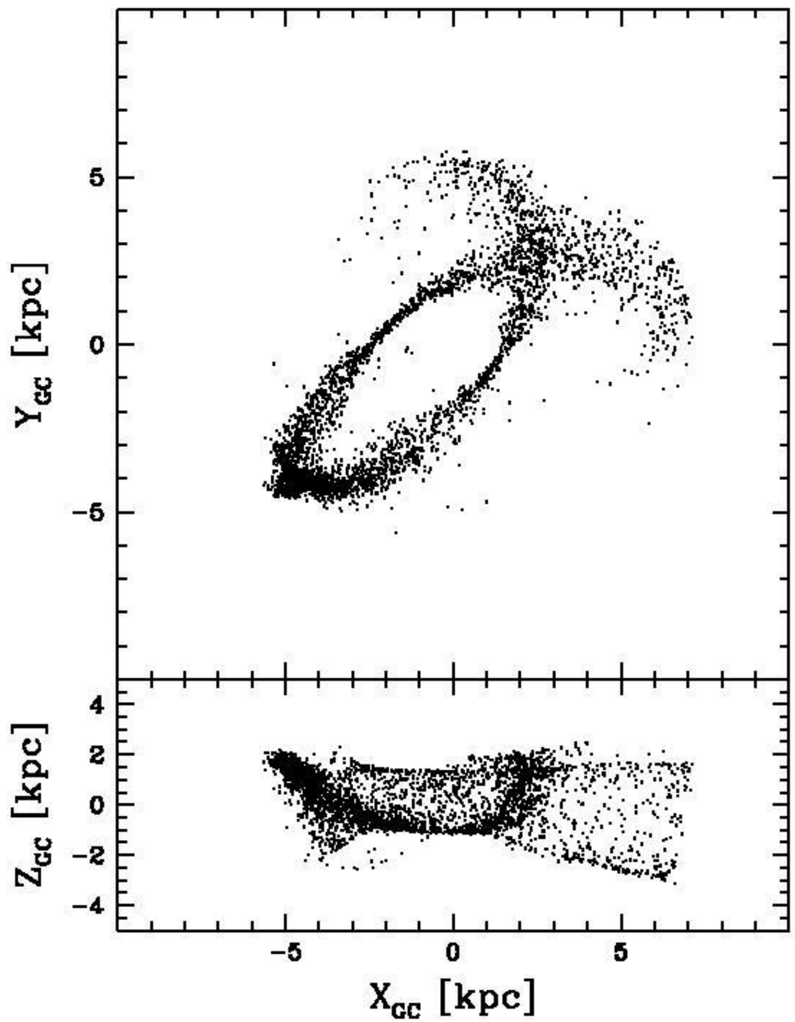
…questioned by Law et al. (2003)



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



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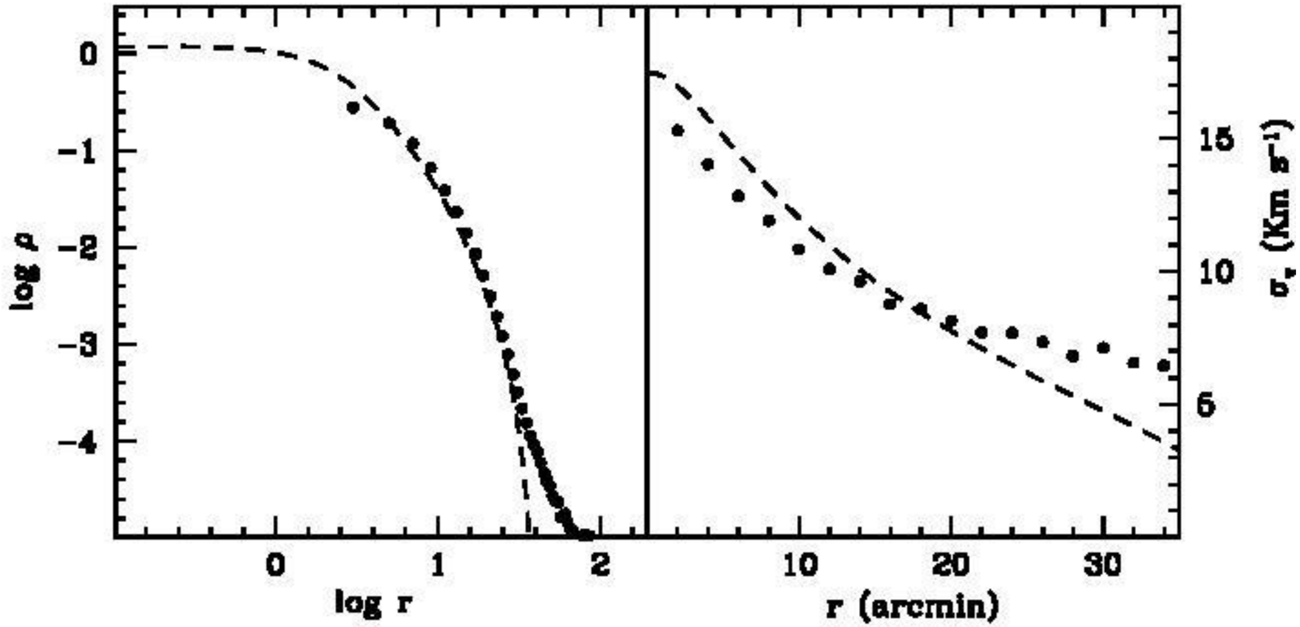


Tides produce the outer power-law density profile

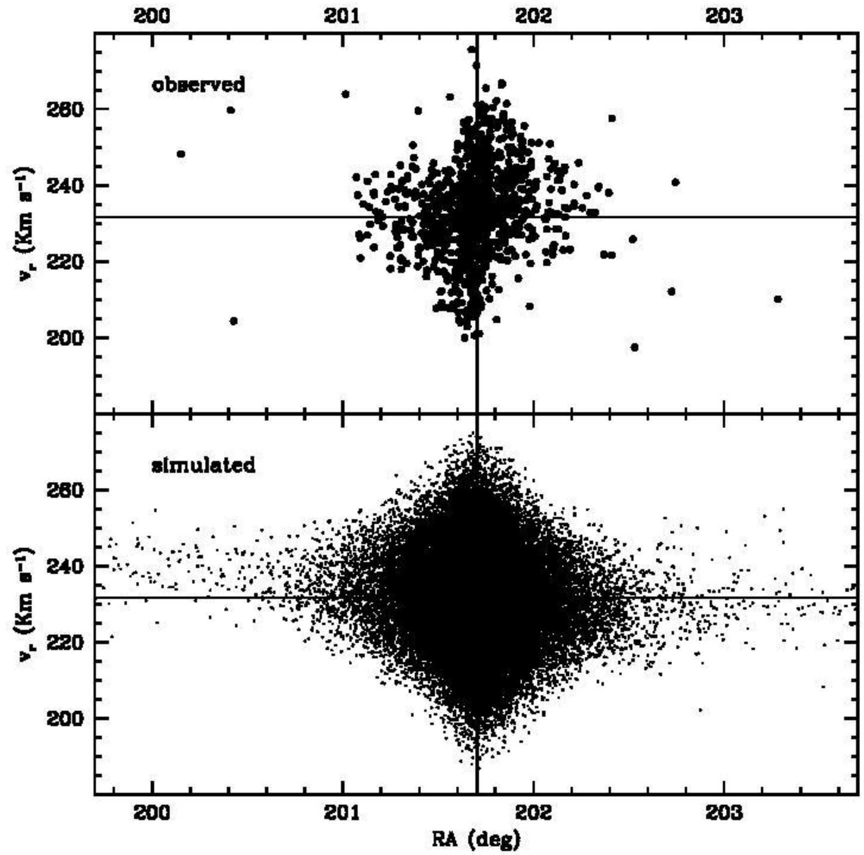
And the flat velocity dispersion profile

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 seeems to be aligned with the cluster orbit



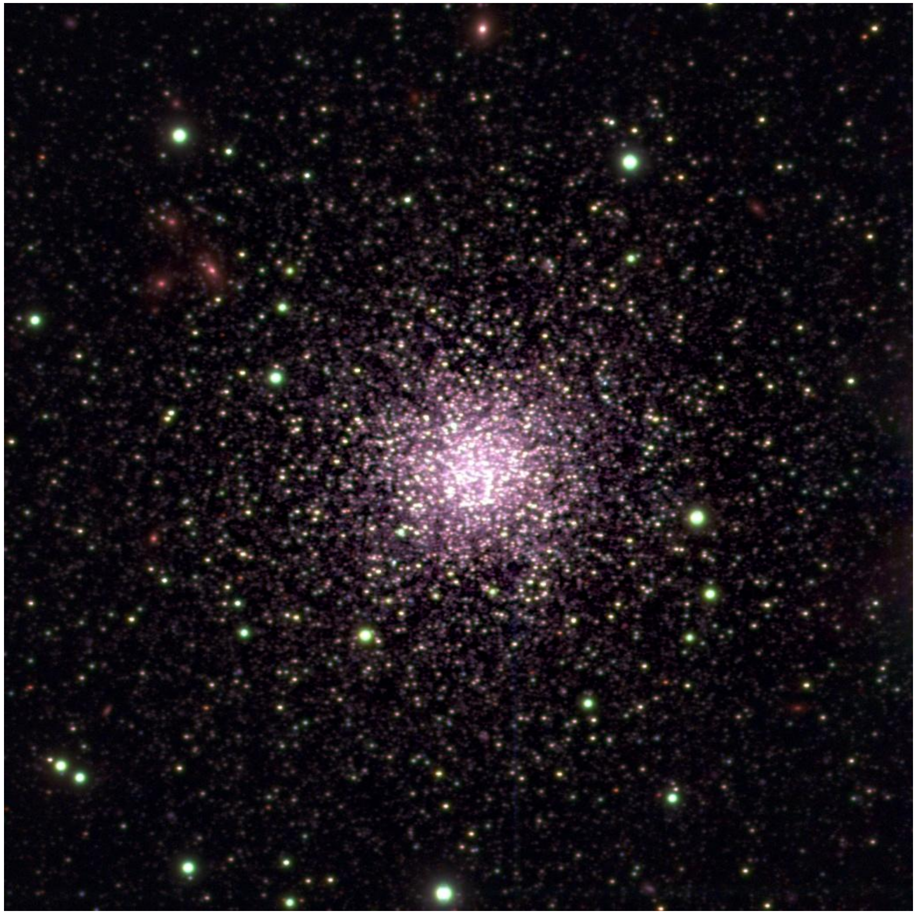
Sollima et al. (2009)

NGC 2419

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

$M \sim 1.0 \cdot 10^6\ M_{@}$

Populates the outer Galactic halo at d~87 kpc

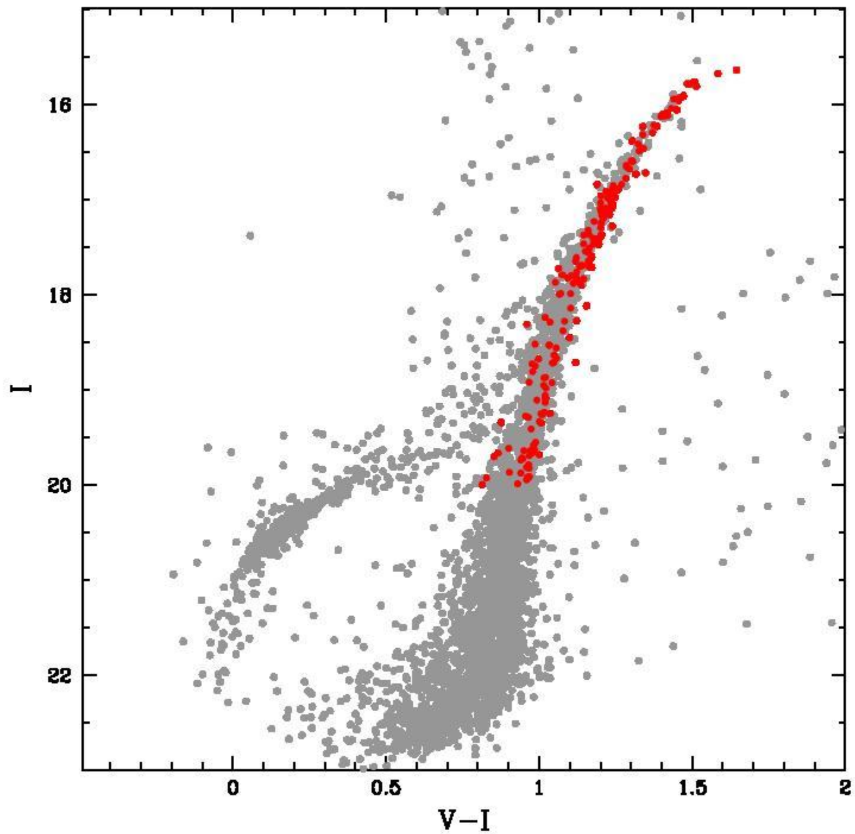


NGC 2419

178 stars with DEIMOS@KeckII

R~6,500

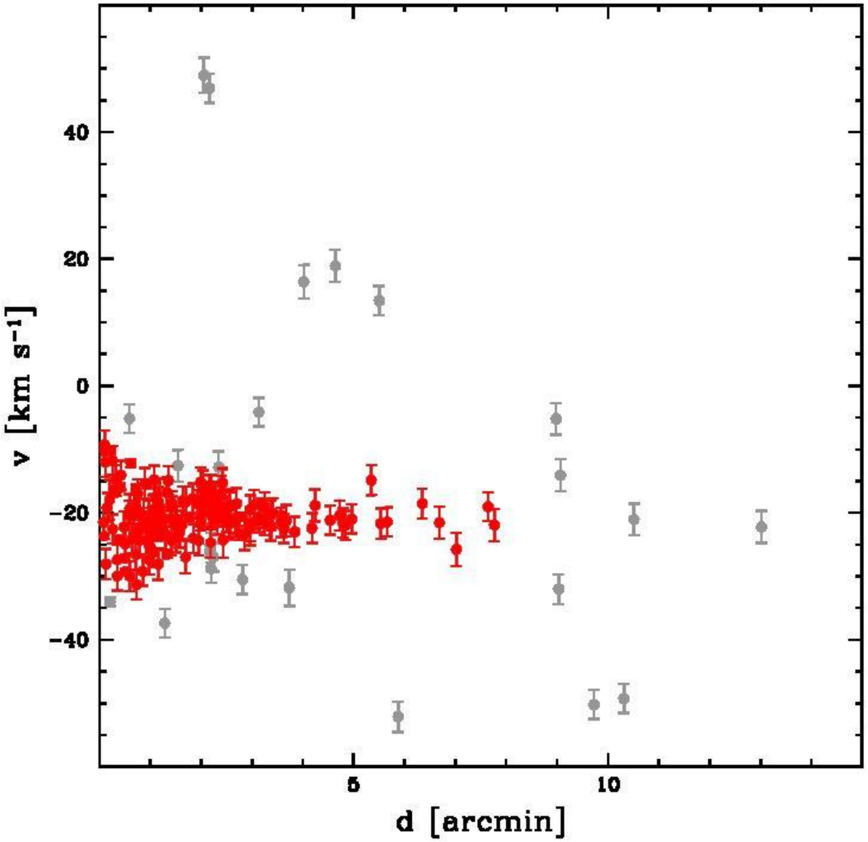
δ_v~2.2 km/s



Ibata et al. (2011, in preparation)

NGC 2419

- 151 bona-fide cluster members

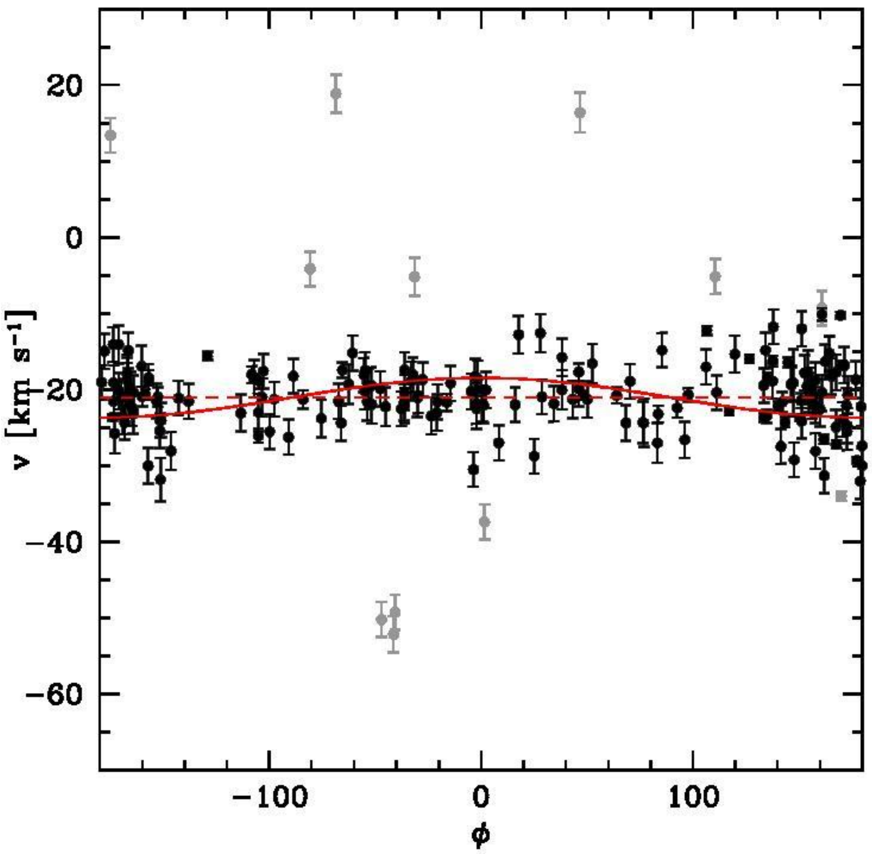


- $V_{rot} < 3$ km/s

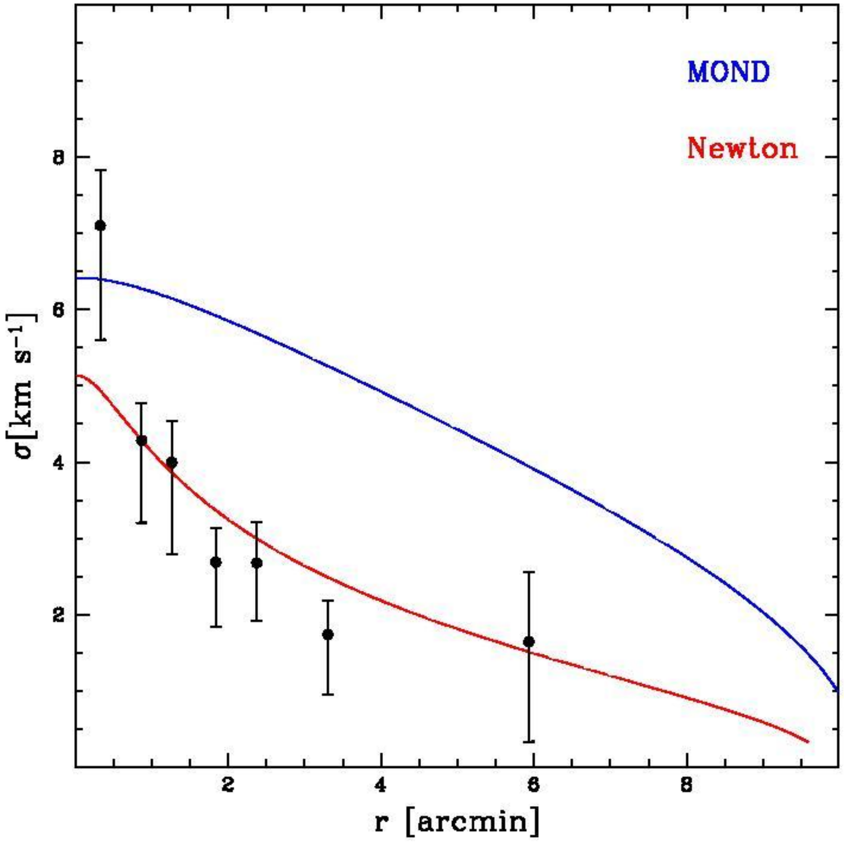
NGC 2419

•151 bona-fide cluster members

•V_{rot}<3 km/s



Comparison with NGC 2419



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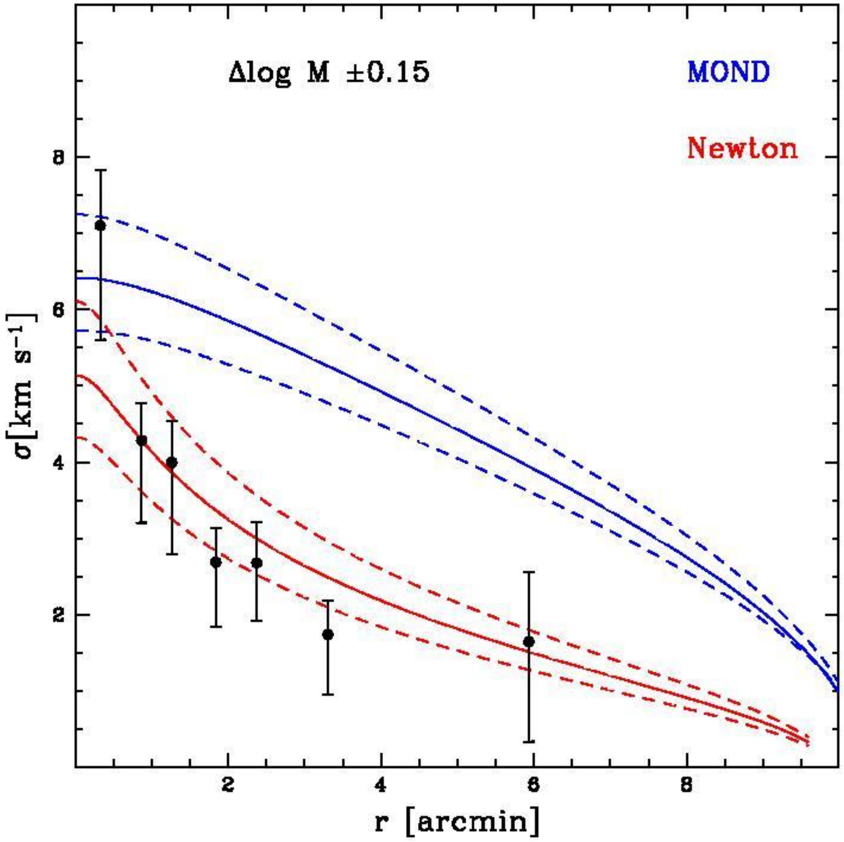

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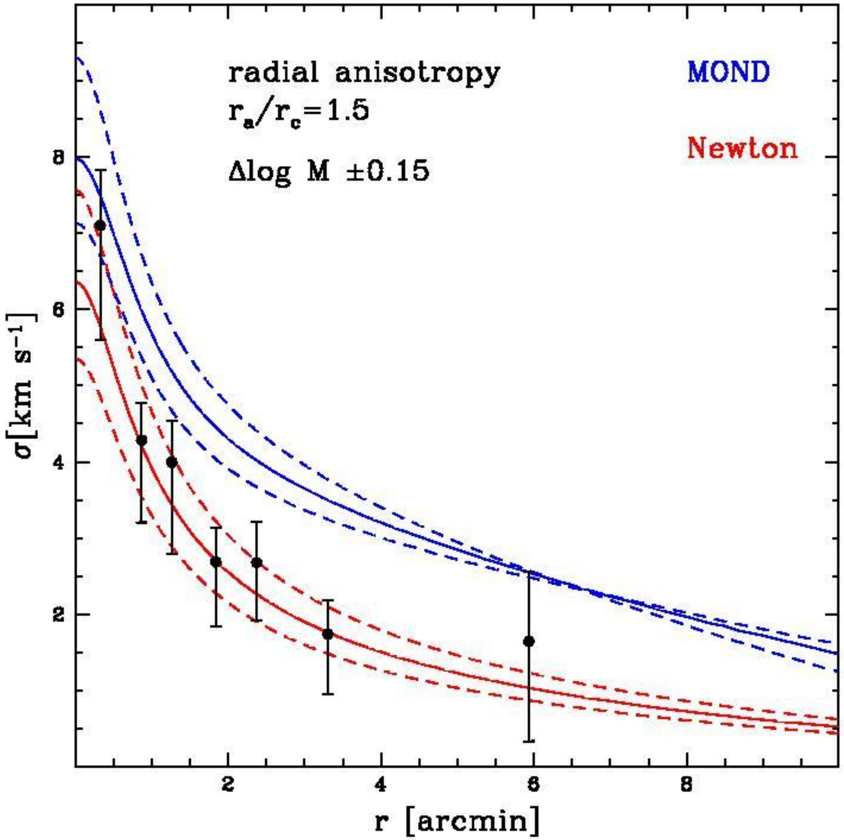


MOND models seems to not reproduce the velocity dispersion profile of NGC2419

Palomar 14

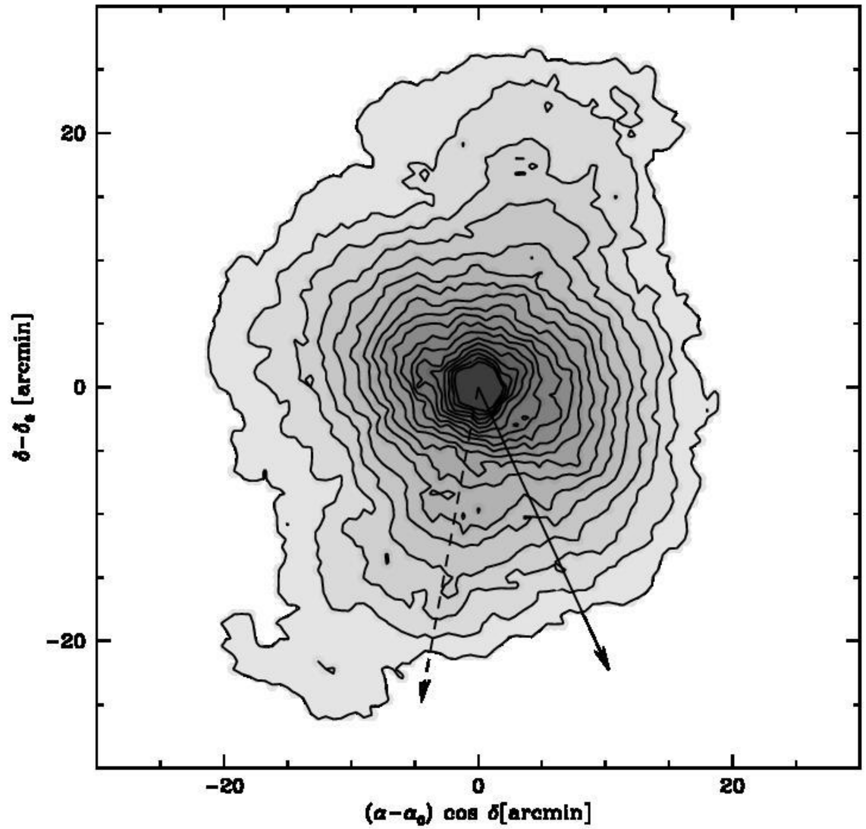
- Faint low-mass GC

- $M \sim 1.2 \cdot 10^4\ M_{@}$

- Populates the outer Galactic halo at d~72 kpc

Palomar 14

- MegaCam@CFHT imaging
- 1°x1° FoV
- Massive tidal tail
- r_h~46.1 pc
- $r_{Roche} < r_t$



Sollima et al. (2011)

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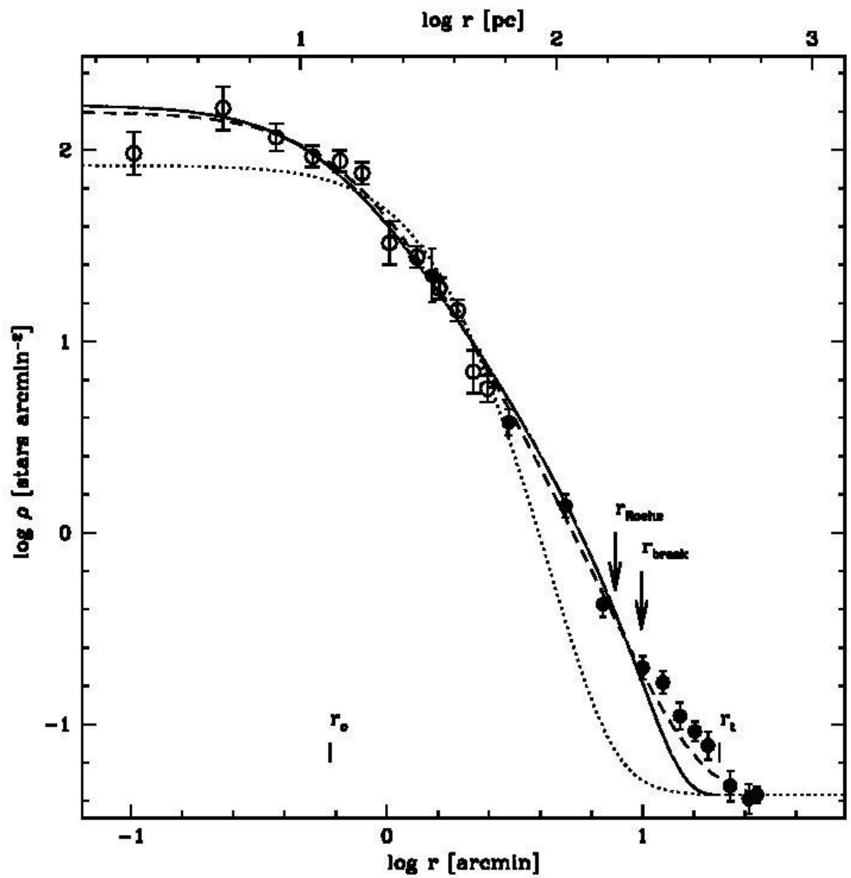

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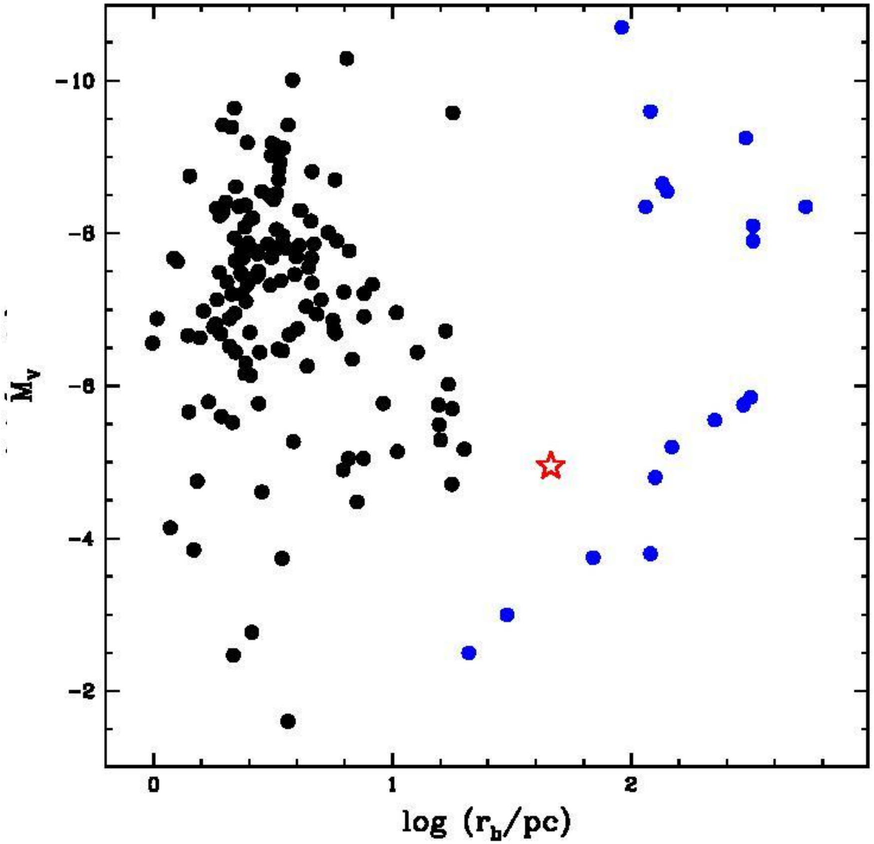
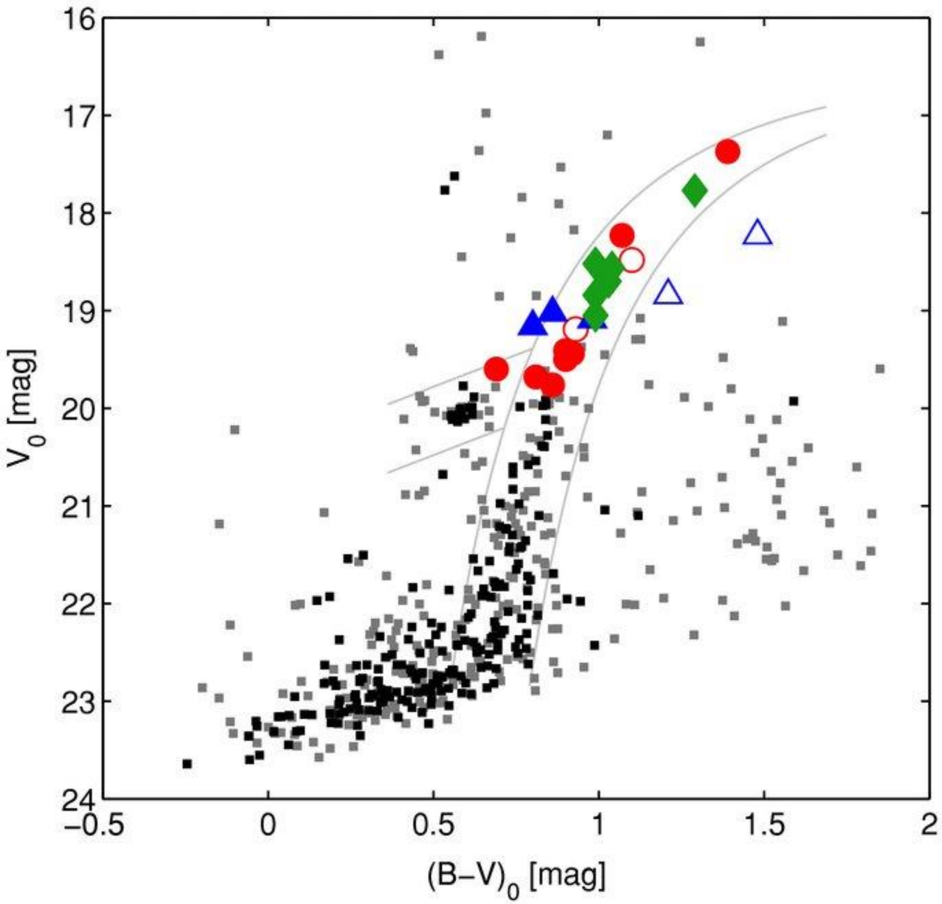


Sollima et al. (2011)

Kinematics in Palomar 14

- 19 stars with UVES@VLT and HIRES@Keck I
- R~45,000
- δ_v~0.2 km/s
- σ_v~ 0.39 ± 0.12 km/s
- A deep freeze? (Kupper & Kroupa 2010)



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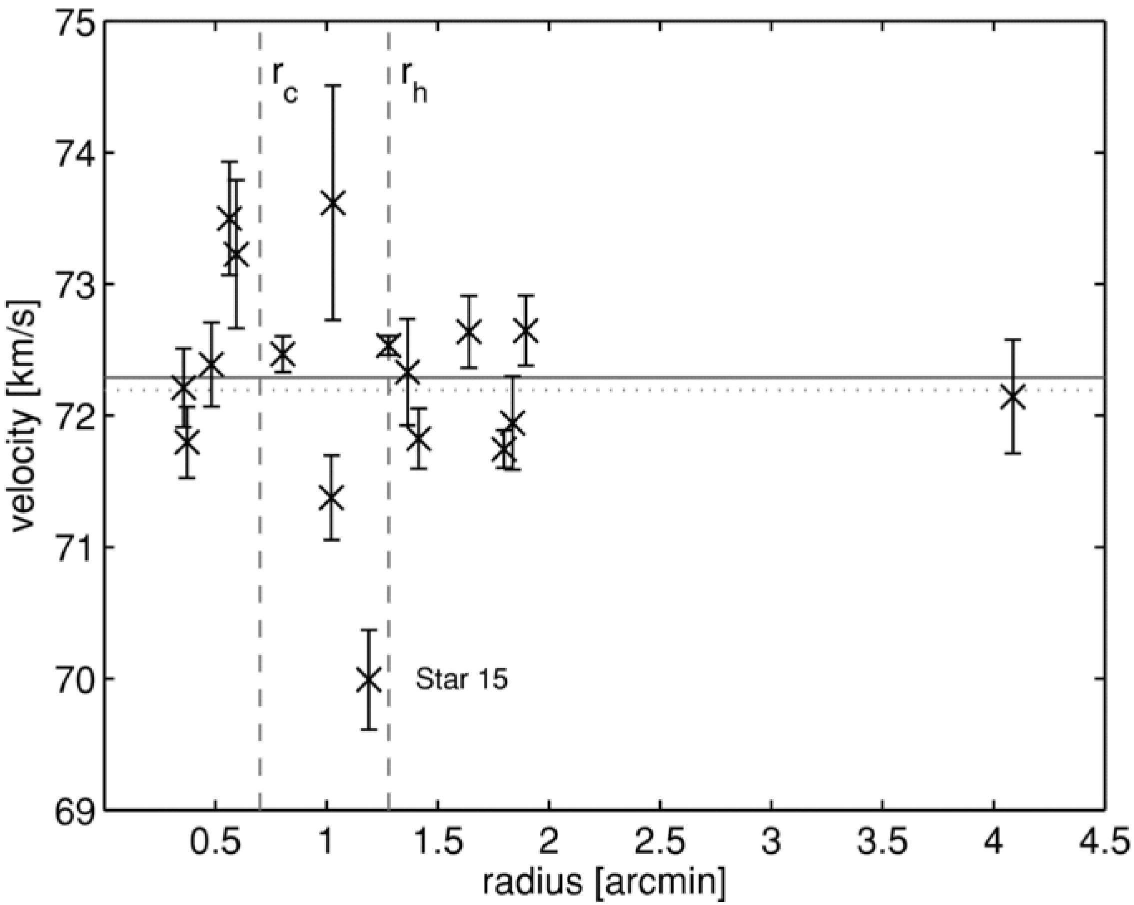

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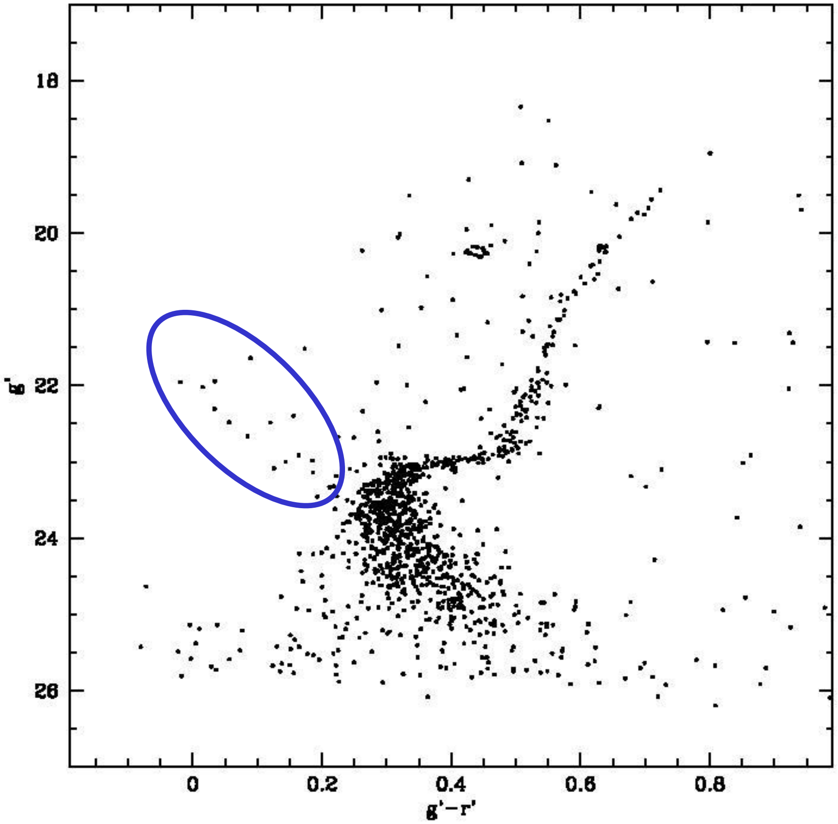
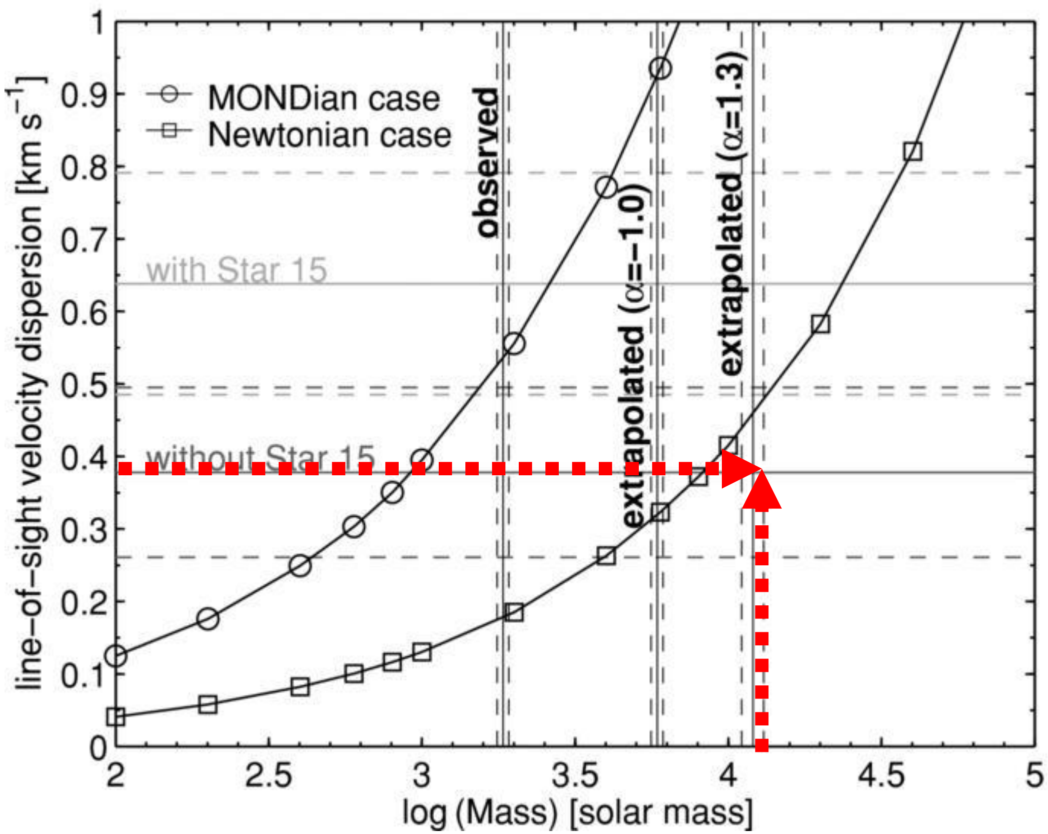


Jordi et al. (2009)

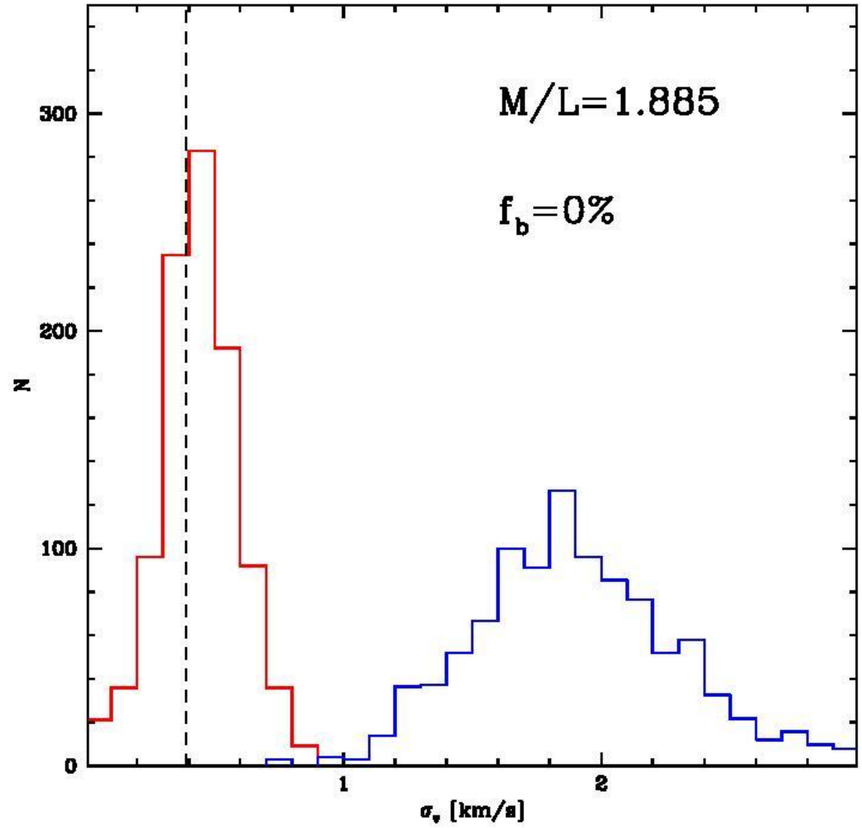
Test of MOND in Palomar 14



Jordi et al. (2009)

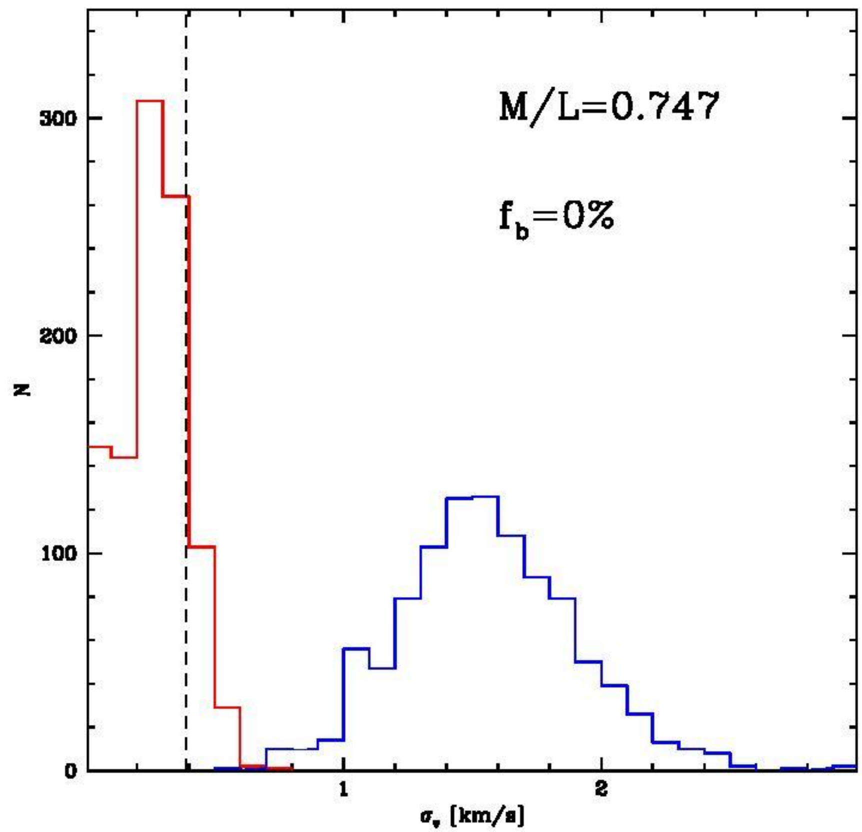
… but see Gentile et al. (2010)

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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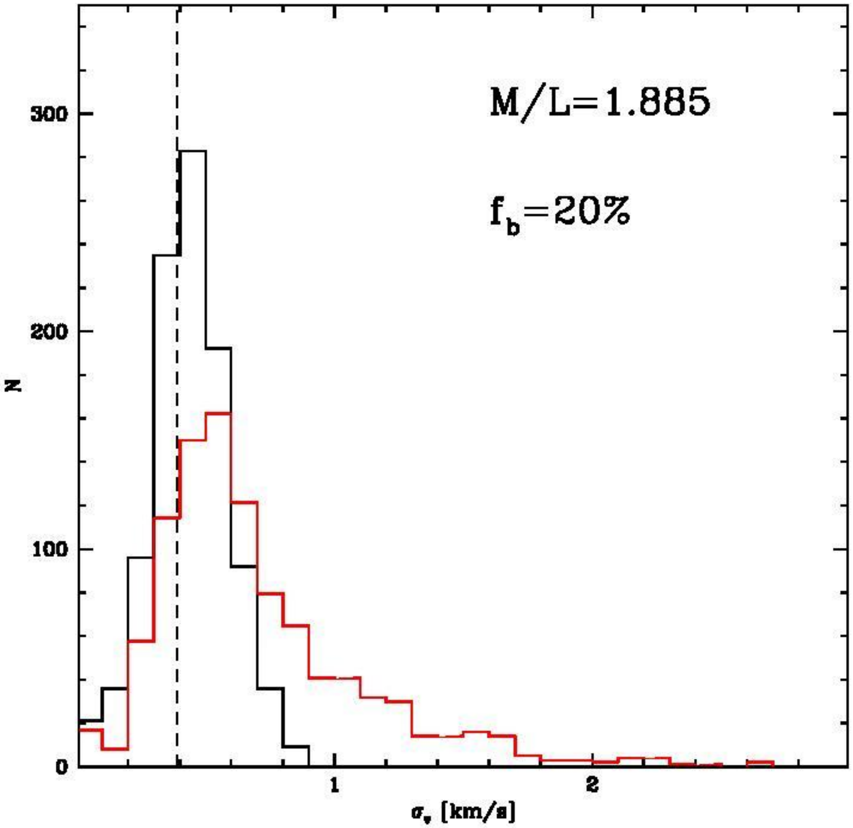

Fractions of binaries up to ~30% are still compatible with the data

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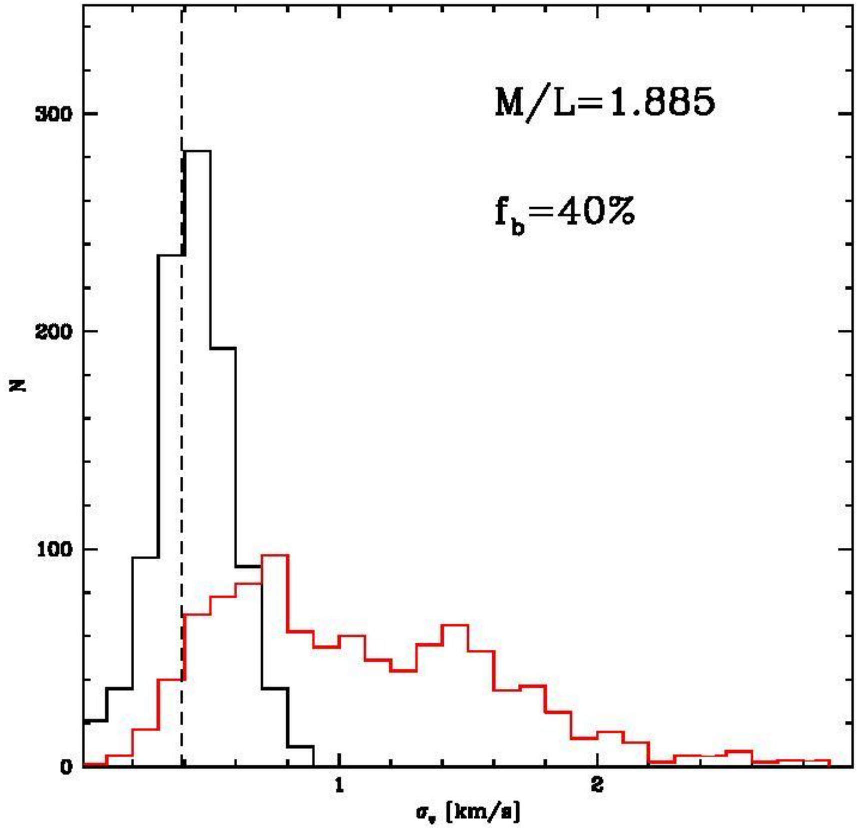

Fractions of binaries up to ~30% are still compatible with the data

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.)