Halo Globular Clusters and Dark Matter (Sub)Halos

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Goal of talk

- Observational evidence that ~10% of MW halo globular clusters are at the center of local dark matter halos
 - Old (first Gyr), metal poor, clusters
 - Distinct from "disk" clusters, which are younger and more metal rich
- There may be another ~20% with eroded DM halos
- These likely formed at/near centers of ~10⁹ M_sun halos

M54-Sgr low surface brightness dwarf +/- 100 pc nucleated dwarf vs GC M54 mostly an old GC

Messier 1778 Ibata et al 1994 Sgr 25.4 mag/sq" at center Sgr: M/L~20 Ibata, Wyse et al 1997 orbit



M54-Sgr color-mag selection

more metal rich/younger than M54. There are more metal poor stars



Density and radial velocity dispersion profiles



Jeans mass analysis:
$$M(< r) = -\frac{r\sigma_r^2}{G} \left[\frac{d\ln\nu}{d\ln r} + \frac{d\ln\sigma_r^2}{d\ln r} + 2\beta(r) \right]$$

- σ_r : Radial velocity dispersion
- v : volume density of tracer population (fairly sampled)
- β : velocity anisotropy 1- σ_t^2 / σ_r^2 where σ_t is tangential
- Our projected 2D measurements approximate 3D in Jeans equation
 - No clear gradient of σ_r
 - Density gradient is approximated as either -2 for green & red, -5 to -1 for blue
 - Velocity ellipsoid isotropic, β =0, beyond 100 pc, blue β = 0.25-0.5 -0



Jeans equation mass & mean interior mass density wide radial bins. Lines are nbody dark matter halos



Globular clusters and dark halos

- 10(20)% (±?)of globular clusters remain at the centers of dark matter sub-halos consistent with current data.
- Many others started at centers, but DM eroded to none measurable.
- M54 is in a ~few x 10⁸ M_sun halo with a <50pc/no core
- Worries: interlopers (data rapidly improving)

Implications:

- DM halo increases escape velocity from cluster (x3, x10 in energy)
 - Helps retain black hole binaries
 - Helps retain gas
- DM density profiles consistent with cold, collisionless, dark matter



Clusters started at sub-halo centers eroded to varying degrees. 1kpc postage stamps.



Cluster velocity dispersion profile rises beyond 3 half-mass radii if there is a local dark halo



Globular clusters at centers of dark halos

- Formation sites:
 - Likely a range of radii in star forming disks
 - likely vary with redshift (more central formation at high z?)
- At high redshift dynamical friction inspiral more effective
 - Dynamical friction timescale ~ σ^3 / ρ much shorter at high redshift
 - $\sigma^3 \sim Mass of halo, typically ~10^9 at z~10$
 - $\rho \sim (1+z)^3$ factor of 1000 at redshift 9
 - Drags clusters (or their gassy precursors) to halo centers
 - Or, tidally disrupts lower mass clusters



But, outer velocity anomalies

N= 10⁵, Kroupa IMF, low mass depleted, stellar evolution, no tides **~10% of GCs have large radius velocity dispersion anomalies** NGC2808 r_h=3.9pc/80 arcsec





Gaia kinematics for 25 Metal poor halo GCs within 20 kpc

- 19 of the 25 have good data to 5 half-mass radii or more
- Background suppressed by ~10,000 by color-mag and velocity cuts

Most (11/19) have declining velocity dispersion to tidal radius



NGC 6752 (perigalacticon 3.23 kpc) velocity outliers



NGC 6205 (M13: perigalacticon 1.55 kpc, apogalacticon 8.3 kpc)



Summary of Metal poor GCs within 20 kpc

- 19 of the 25 have good data to 5 half-mass radii
- 11 of the 19 show no evidence for local dark matter
- 6 of the 19 are flat or falling: ambiguous
- 2 of the 19 are rising
 - Have pericenters of 1.55 and 3.23 kpc
 - Tidal pumping not a problem
 - Background interlopers? Low probability, but...
 - Local dark matter

Could the outer rise be due to tidal heating for NGC6205? Very unlikely. Nbody: Stars gain +vr at peri, then drift away at apo, pulled off at peri. Post apo is least disturbed velocity field.







Summary

- M54 is undoubtedly a dense star cluster in a dark matter halo
 - Dark matter contribution small within 3 half mass radii (20 pc)
 - Dark matter profile is essentially a standard CDM sub-halo, ~3x10⁸, eroded from a much later initial halo.
 - Could have formed anywhere within the central 500pc and would have spiralled down to center in a ~Gyr. At larger radii would have been lost to tidal tail
- Evidence for dark matter around other halo globular clusters is suggestive in ~10-25% of cases, but not yet compelling.