Dark Matter Halo History
and
Tidal Streams
Good Vibrations

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Fully Dynamical Globular Clusters in a Cosmological Simulation

• Stellar dynamical models
  • Insert King model star clusters
  • Distributed in a rotating exponential disk
  • Within a Dark Matter Halo
  • Soften, but add collisional heating with an MC approach

• The Dark Matter is a fully cosmological Milky Way sub-region
  • The Via Lactae II simulation
  • (Sub-) halo catalog
Conclusions

• GC tidal dissolution during the hierarchical assembly of a Milky-Way like halo can be followed in an Nbody code.

• A GC thin stream normally is imbedded in a wider “cocoon”, a consequence of hierarchical assembly
  • Broad stream width indicates size of orbit in initial halo(s).

• Stream stars should have velocities perpendicular to the stream of 10’s of km/sec, a consequence of collisionless halo vibrations.
  • SIDM DM reduces the velocities
  • Requires a large sample of streams.
N=1M, m* ~ 0.44 M_sun
SFB881 model
Jongsuk Hong
Jeremy Webb

Top View***
We see edge on generally
Rhalf/Rtide vs Mass
MW>8kpc left,
sims right
M>10^5 underfill tidal surface
±20x180 degree. Grey scale emphasizes low density regions. Stream is saturated.
Two stage Tidal Stream structure:
Thin stream and cocoon

• Dwarf galaxy stage:
  • Stream wraps around in a 1-2 kpc size orbit
  • Accretes into main halo

• Main halo stage:
  • Early stage stream is now a stream 1-2 kpc wide
  • Newly released stars give the thin (100pc) stream

• Small angular width streams usually near pericenter.

• **Cocoons should be almost universal if progenitor clusters are created in pregalactic sub-halos (dwarfs).**
(Age, [FeH]) = (12.5 Gyr, −2.0 dex)

GD - 1

L_z [km s^{-1} kpc]
L_z and L_perp calculated for stream rotated into instantaneous orbital plane of progenitor. The L values will not in general be conserved quantities.
Incommensurate Stream Velocities

• In the simplest case, stream velocities are oriented along the stream.
• Perpendicular velocities should be small
• In a static potential.
Orphan kinematics

Fardal, van der Marel, Sohn, Molina
LMC wake:

Garavito-Carmargo, Laporte, Johnston, Gomez & Watkins
Orphan Stream Koposov, Belokurov, et al

Velocities perpendicular to the stream
Distribution of stream perpendicular velocities in simulation

Dashed lines are $\text{Exp}[-v/s]$ with $s$ of 10 and 20 km/sec.
Forces perpendicular to stream
Halo major axis at ~20-30 kpc constant
Halo 2\textsuperscript{nd} and 3\textsuperscript{rd} axes with time, vibrating, possible erratic rotation
Perpendicular quadrupole force fluctuations

Q matrix largest eigenvalue at 20-30 kpc

The fluctuations about mean are the interesting part.

\[ Vc^2/r \sim 10^4 \]

\[ \Delta Qr \sim 50 \]
Indicative tangential velocities (zero mean) integral of $\frac{3}{2}Q*r \, dt$ (no orbit)
With SIDM
Self-interacting Dark Matter damping
Cross-section in cm$^2$ gm$^{-1}$

\[ \Delta v = \frac{3}{2} \int Q \rho \, dt \]

Indicative velocity. Not an orbit.

Red line is a collisionless halo
Increasing SIDM cross-section

Viscosity \sim mfp \times velocity dispersion
Mean free path \sim 1/cross-section

SIDM 0.1-1 very effective at suppressing vibrations
Caveats and Concerns, Conclusions

• Streams are a powerful probe of DM and its history.

• Star cluster mass loss started in sub-galactic fragments (dwarf galx)
  • All thin star streams should have accompanying “cocoons”
  • Evidence for a cocoon for GD-1

• Galactic halos continue to gain mass and have potential fluctuations
  • Collisionless halos “ring” or “vibrate”. Monopole nearly constant
  • Quadrupole force fluctuations a few percent,
  • at frequencies that couple to orbits
  • Streams should have ~20 km/sec perpendicular velocities
  • Orphan (LMC surely plays a role as well)