Dynamics of the Local Group

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Content of this talk

- Local Group
- Working hypothesis
- NEMO
- MOdified Newtonian Dynamics
- N-MODY
- Next steps
Local Group members:

- Milky Way
- M31
- LMC
- SMC
- M33
- +36 more known dwarf galaxies
A plane of galaxies

- Most galaxies in the local group are distributed in a thin plane (see Sawa & Fujimoto 2005).
- This plane doesn’t correspond to a galactic plane of the spirals.
Sawa & Fujimoto  My own results

- Normal vector in galactic coordinates
  - $l=206^\circ$, $b=-11^\circ$ (Milky Way on plane)
  - $l=200^\circ$, $b=-20^\circ$ (A)
  - $l=203^\circ$, $b=-27^\circ$ (2$\sigma$-clipping)
  - $l=200^\circ$, $b=-20^\circ$ (Milky Way and M31 on plane) (B)

- Thickness of the Local Group plane
  - About 50-100 kpc
  - 21 galaxies within 100kpc (A)
  - 28 galaxies within 100kpc (B)

Results basically similar but no perfect match
Origin of the Local Groups satellites

- Cosmological dark matter sub-halos
  - Problem: expected distribution would be spherical symmetric

- Infall and scattering of a filament
  - Problem: expected plane would be too thick

- Early interaction of extended gas-rich discs of Milky Way and M31
  - reproduces observed distribution very well
  - Problem: missing satellite problem, except in MOND, because no dark matter
Most dwarf galaxies have been formed by an encounter of the gaseous discs of Milky Way and M31 more than 10 Billion years ago.

Scattered across the Local Group.

Orbits dominated by the two main galaxies.

Dwarfs are located now near the movement plane of Milky Way and Andromeda-galaxy.
My model

- Milky Way and M31 on an elliptical orbit
- LMC, SMC and M33 are also massive
- All other dwarf galaxies are test particles
- Simulation starts about 10 Gyr in the past
- Test particles are located in the interacting outer edges of the two main spirals
NEMO

- Stellar Dynamics Toolbox by Teuben P.J.
- Contains many different models and codes
- Tools for analyzing and plotting results
- Easy input with Shell-commands
MOdified Newtonian Dynamics

- Alternative theory to explain observed rotations curves of galaxies
- Avoids dark matter (on galactic scales)
- First suggested by Milgrom in 1983
- Relativistic extension by Bekenstein in 2004
How does MOND work?

- Changes the law of gravitation for small accelerations.
- Introduces a new fundamental constant $a_0$
- By fitting of rotation curves
  
  $$a_0 \sim 1.2 \times 10^{-10} \text{ m/s}^2 \sim 1/6 \text{ c } H_0$$
- Non-linear differential equations
- **Modified Poisson-equation**

\[
\vec{\nabla} \left( \mu \left( \frac{a}{a_0} \right) \vec{\nabla} \Phi (\vec{r}) \right) = 4\pi G \rho (\vec{r})
\]

- **Interpolating function \( \mu(x) \)**

\[
\mu(x) = \frac{x}{\sqrt{1 + x^2}} \quad \text{alternative:} \quad \mu(x) = \frac{x}{1 + x}
\]

- **No longer superposition of accelerations possible**

- **Force on particle depends on absolute acceleration**
\[ F = m \mu \left( \frac{a}{a_0} \right) a \]

\[ \frac{G M}{r^2} = \mu \left( \frac{a}{a_0} \right) a \]

**central potential**

\[ a \gg a_0 \quad \rightarrow \mu \sim 1 \]

\[ a \ll a_0 \quad \rightarrow \mu \sim \frac{a}{a_0} \]

\[ a = \frac{\sqrt{G M a_0}}{r} \]

**Deep-MOND limit**

**Newtonian limit**

\[ a = \frac{G M}{r^2} \]
Problems

- merging is less likely in MOND but it also takes much longer → observed merging rate?

- Needs a new theory of general relativity (TeVeS), violation of strong equivalence principle → Lyman α forest problem

- Requires (hot) dark matter on cluster scale

- Bullet cluster
N-MODY

- Stellar dynamic n-body code for MOND written by Londrillo P. and Nipoti C.
- in Fortran 90
- (modified) Poisson-solver
- parallelized code (but also scalar version)
N-MODY uses a particle-mesh scheme

- it creates a grid-based density-field from a given particle distribution

- calculates the MONDian acceleration on the grid and interpolates

- advances particles using a leap-frog scheme

- Output of particle-phase-space position, grid-data, potential-data and system parameters
Problems with N-MODY

- Output and input in strange binary-format
  - translator program written √

- Only equal mass particles allowed
  - code modified √

- Maximal 100 output-files
  - code extended √
More problems

Kuijken & Dubinski 95 model (without halo) showed strange behavior of the disc in N-MODY
A BIG 2BODY-PROBLEM!!!

Newton with NEMO

MOND with N-MODY
Newton ↑ MOND out of center ↓ MOND centered ↑ MOND out of center ↓
next steps

- Find an alternative to N-MODY = do it yourself method
- Finish setup of my model
- Run simulations (Dark Matter and MOND)
- Analysis of results and writing everything down