NGC 1399 and MOND

Tom Richtler(1), Ylva Schuberth, (1,2) Aaron Romanowsky (1)

(1) Universidad de Concepcion; (2) Universitaet Bonn

Introduction

NGC 1399, the central galaxy of the Fornax cluster, is a very attractive target for studying globular cluster dynamics (Richtler et al. 2004, Schuberth et al., this conference). These studies reveal a huge dark halo, confirming by stellar dynamical means what has been found earlier by X-rays. In this poster, we keep a neutral position regarding the Cold Dark Matter paradigm and ask for the performance of MOND in the Fornax cluster.

M. Milgrom invented Modified Newtonian Dynamics (MOND) originally to explain the Tully-Fisher relation and the constancy of rotation curves of spiral galaxies (Milgrom 1983). In its simple version, the Newtonian acceleration $\mathbf{g_N}$ has to be replaced by the MOND acceleration in the case of small accelerations $\mathbf{g}$ through the relation

$$\mathbf{g_N} = \mu(g/a_0) \cdot \mathbf{g} \,,$$

with

$$\mathrm{a}_0 \approx 1.2 \cdot 10^{-8} cm \cdot s^{-2}$$

being a universal constant and $\mu(g/a_0)$ an unspecified function interpolating between the Newtonian and the MOND regime. This was meant to provide an alternative to the Cold Dark Matter (CDM) scenario.

Later on, MOND proved to have an impressive predictive power (e.g. Sanders & McGaugh 2002, see also the MOND pages of S. McGaugh). Many arguments have been raised against MOND, including its apparent arbitrariness, but until now no convincing case has been found which would disprove MOND. Meanwhile, MOND also has a theoretical foundation in the work of Bekenstein (2004).

Perhaps the most serious objection is that **MOND does not remove the need for dark matter on cluster scales** (Sanders 2003, Pointecouteau & Silk 2005). In this context, it is interesting to look at the Fornax cluster. For NGC 1399, a large number of globular cluster velocities out to 80 kpc of galactocentric radius are available (Richtler et al. 2004, Schuberth et al., this conference) probing deep into the halo of NGC 1399.

Fig.1
Newtonian acceleration in NGC 1399

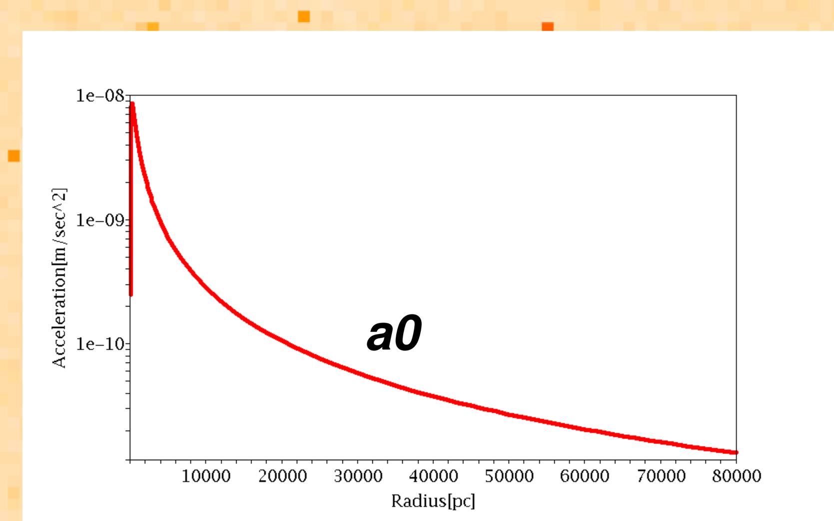
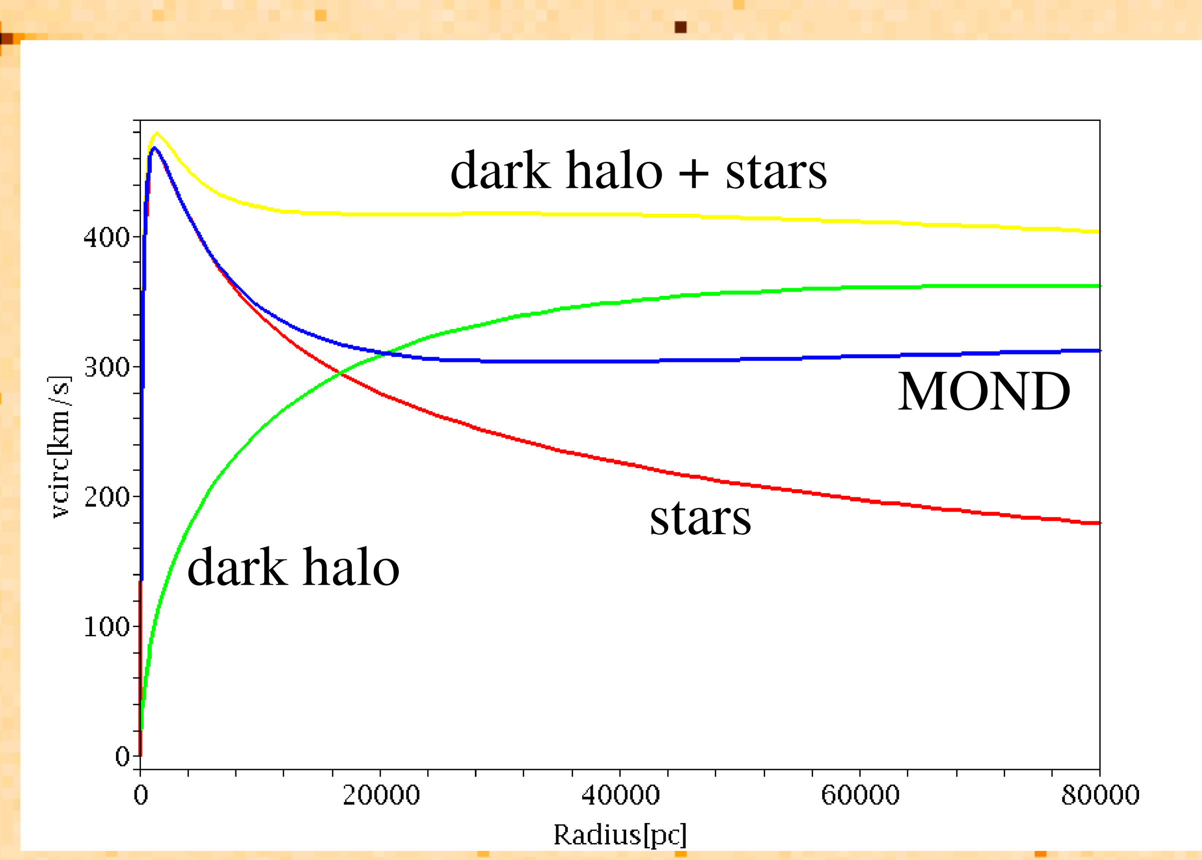


Fig.2
circular velocities for different components



From Newtonian to MONDian

Fig. 1 shows the Newtonian acceleration vs. galactocentric radius. We deprojected the large scale photometry of Dirsch et al. (2003) and assigned $\mathrm{M}/L_R = 5.5$ to the stellar population.

The inner 50 kpc are not yet MOND dominated, therefore the interpolation function $\mu(g/a_0)$ plays an important role. However, this function is mainly constrained empirically. According to Pointecouteau & Binney (2005) $\mu = x/(1-x)$ fits the Galactic rotation curve much better than the usual $\mu = x/\sqrt{1-x^2}$. Adopting the former function leads to a rather slow transition into the MONDian regime. The circular velocity curve then reads

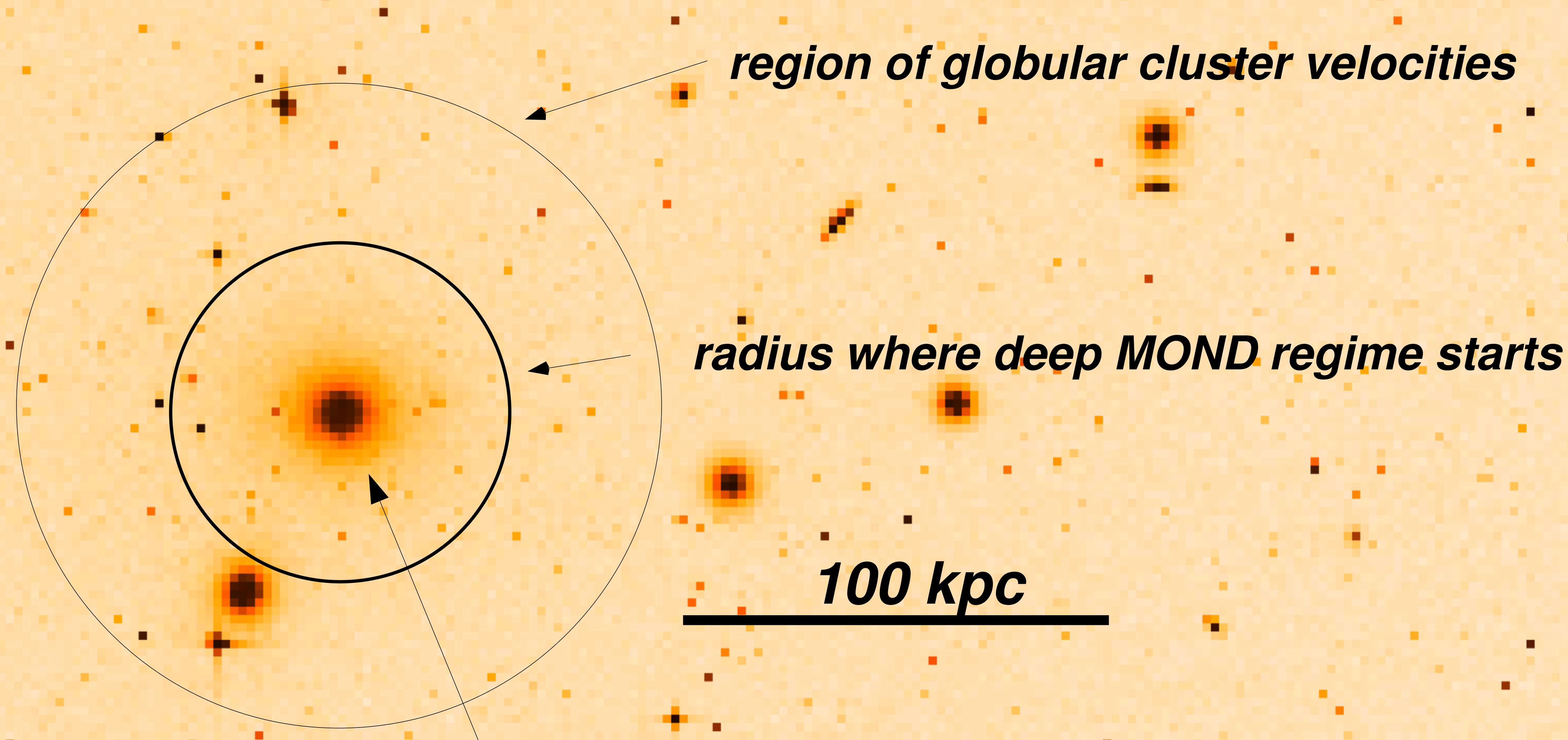
$$\mathrm{V}^2_{circ,MOND} = \frac{V^2_{circ,N}}{2} + \sqrt{\frac{V^4_{circ,N}}{4} + V^2_{circ,N} \cdot a_0 \cdot r}$$

where $\mathrm{V}_{circ,N}$ is the Newtonian circular velocity. Fig. 2 shows the circular velocity curves for different components: the stellar population, the MOND circular velocity, **refering only to the stellar population**, and the circular velocity curve of the sum of the stellar mass and a dark halo with a mass density profile like

$$\rho(r) = \rho_0 \cdot \frac{r}{r_0}^{-1} (1 + \frac{r}{r_0})^{-2}$$

with $\rho_0 = 0.01 M_\odot/pc^3$ and $\mathrm{r}_0 = 33.5kpc$. Disregarding MOND, this dark halo is necessary to account for the observed velocity dispersion of globular clusters (Schuberth et al., this conference).

It is evident that the MOND rotation curve resulting solely from the stellar population cannot replace the dark halo. While the dark halo is calculated for isotropy, even a strong radial anisotropy of globular clusters would not change this conclusion, so dark matter would be needed.



NGC 1399 – central galaxy of the Fornax cluster

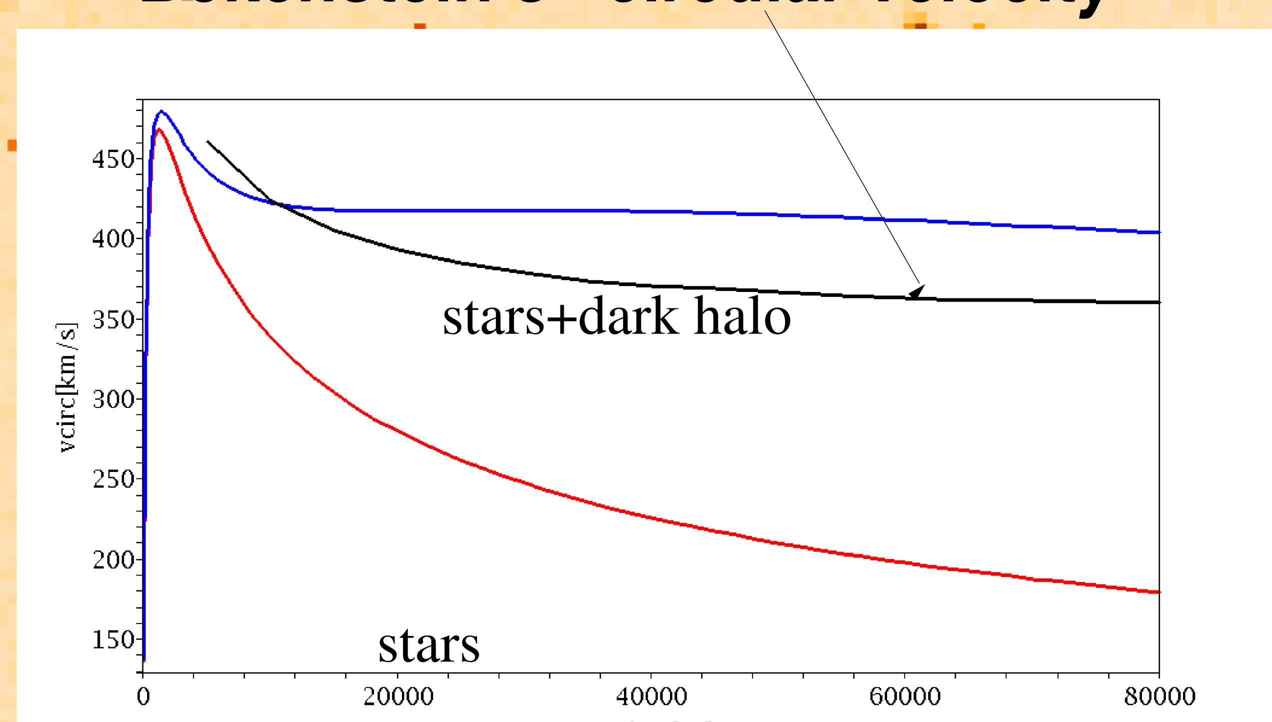
Bekenstein's interpolation

However, the symmetry difference between spiral galaxies and galaxy clusters is the difference between axisymmetric and spherical systems. MOND shows a highly nonlinear behaviour and there is no reason to assume that an interpolation function which works for spiral galaxies, is also applicable to spherical systems. Bekenstein (2004) develops in his relativistic TeVeS theory (which interprets MOND as modified gravity rather than modified inertia) for spherical symmetry the interpolation

$$\mu(x) = \frac{\sqrt{1+4x} - 1}{\sqrt{1+4x} + 1}$$

This interpolation provides an even smoother transition from the Newtonian to the MONDian regime. Applying this to NGC 1399 has a quite strong effect, which is shown in Fig. 3. The MONDian circular velocity still is lower, but the uncertainty of the NGC 1399 circular velocity may be around $\pm 30 km/s$. Allowing for some uncertainty also in a_0 **one may not longer insist on dark matter**, if Bekenstein's interpolation is used. Both Sanders (2003) and Pointecouteau & Silk (2005) adopt interpolations where the transition from Newtonian to MONDian is quite abrupt. It is beyond our scope to analyse whether MOND could explain the whole Fornax cluster dynamics. At present, there is the possibility that MOND's failure on the scale of galaxy clusters is a consequence of spherical rather than disk symmetry.

Fig.3
"Bekenstein's" circular velocity



Conclusions?

- **Bekenstein's interpolation does not leave much room for dark matter**
- **symmetry of mass distribution important for calculating MOND effects?**
- **new MOND view at galaxies, globular clusters, galaxy clusters?**

References

Bekenstein 2004, PhRvD 70,id. 083509
Dirsch et al. 2003, AJ 125, 1908
Famaey, Binney 2005, MNRAS 363, 603
Milgrom 1983, ApJ 270, 365
Pointecouteau, Silk 2005, MNRAS 364, 654
Richtler et al. 2004, AJ 127, 2094
Sanders 2003, MNRAS 342, 901
Sanders, McGaugh 2002, ARAA 40, 263