Gaia and Galactic kinematics: dark matter or modified gravity?

SF2A 2009, AS GAIA

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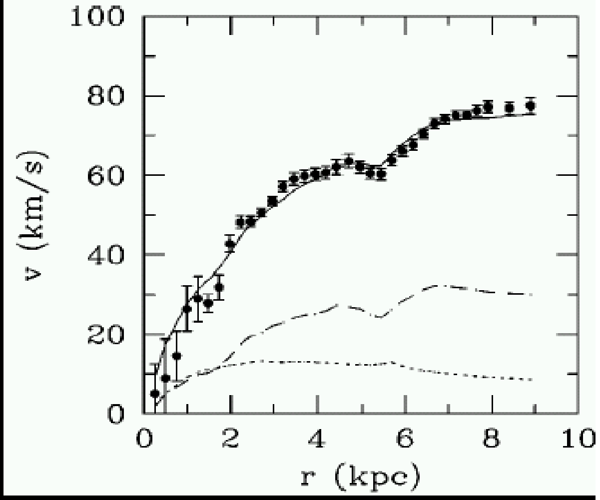
Gaia: long-term objective

- Choose potential, write Hamiltonian, write closest integrable Hamiltonian, find distribution function F(*J*), adjust potential…

- On shorter term: can we answer the crucial question of the existence of galactic dark matter by excluding (or at least constraining) a modified gravity approach?

Dark matter problems in external galaxies

- Simulations of clustering CDM halos (e.g. Diemand et al.) predict a central cusp $\rho \propto r^{-\gamma}$, with $\gamma > 1$, observed in no single galaxy (No present-day solution)
- Baryonic Tully-Fisher relation $V_\infty^4 \propto M_{bar}$ (tight -> triaxiality of halo?)
- Wiggles of rotation curves follow wiggles of baryons (Renzo's rule)
- Tidal Dwarf Galaxies with DM in NGC 5291?



- Correlation summarized by formula of Milgrom:

$\mu(|g|/a_0)\, g = g_{N\ baryons}$ where $a_0 \sim cH_0 \sim 10^{-10}$ m s^{-2}

with $\mu(x) = x$ for $x \ll 1$ => $V_c^2/r \sim 1/r$ => $V_c \sim$cst + **BTF**

$\mu(x) = 1$ for $x \gg 1$

Does not work for galaxy clusters!!

Modified Newtonian Dynamics

- Milfrom's formula works in CDM **and** CDM-free galaxies (but not in galaxy clusters)
- If fundamental: a) fundamental property DM ?
  b) non-local modification of « inertia »?
  c) modification of gravity ?
  (+DM in clusters)

$$\nabla . [\mu (|\nabla\Phi| / a_0) \nabla\Phi] = 4 \pi G \rho$$

- Modifying GR to obtain MOND in static weak-field limit: dynamical 4-vector field $U^\alpha U_\alpha = -1$, with free function in the action playing the role of μ (Bekenstein 2004; Zlosnik, Ferreira & Starkman 2007)

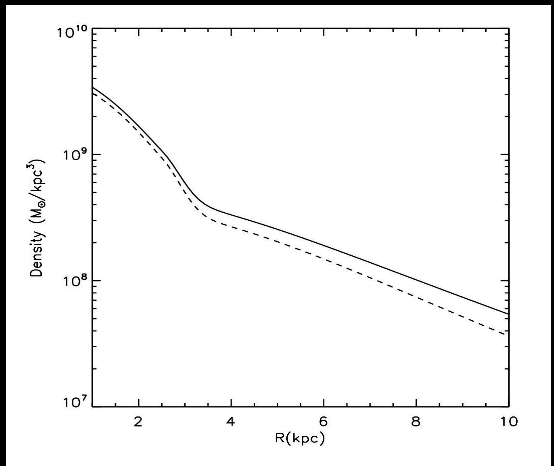
Testing modif. gravity in the MW

- Only one version of MOND
- Only the relation between the potential and the matter source is altered, so one can constrain the potential in the usual way
- Crucially depends on our knowledge of the baryonic distribution
- Depends on the exact choice for μ
- Then, the theory makes a unique and falsifiable prediction for the galactic potential

=> as an example let us use $\mu(x)=x/(1+x)$ and the Besançon model based on the synthesis approach

The « dark disk » from the Besançon model in MOND

- With $\mu(x)=x/(1+x)$, at the solar position one has Σ_{eff} = 78 $M_{*}pc^{-2}$ within z=1.1 kpc to compare with present constraints Σ_{dyn} = 74+-6 $M_{*}pc^{-2}$
- The effective radial density distribution in the disk has a scale-length enhanced by 25% (along the sun-GC axis, since model is non-axisymmetric)



Bienaymé, Famaey et al. 2009, A&A in press

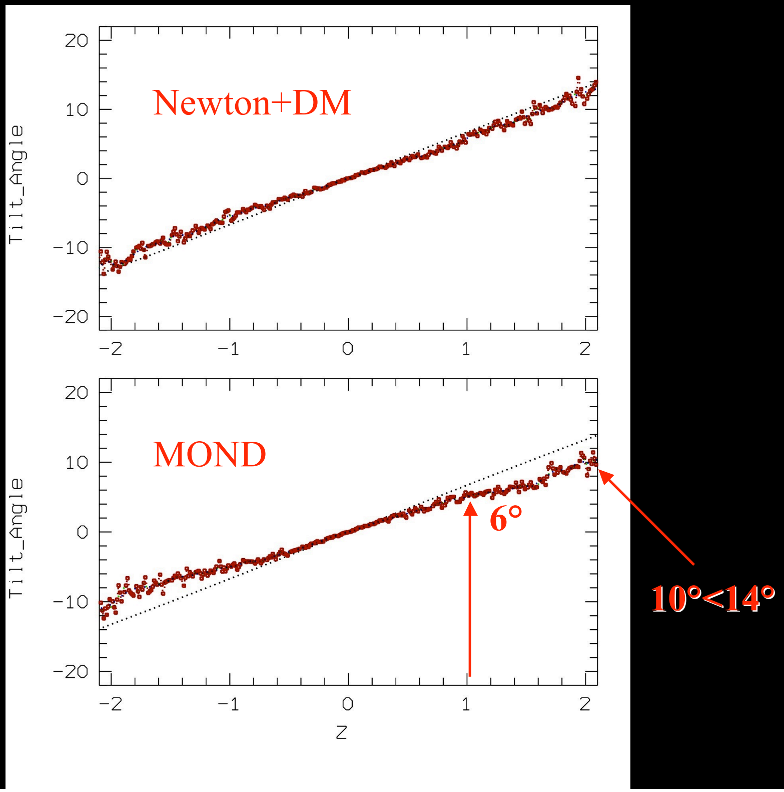
=> measuring dynamically the disk surface density as a function of R with GAIA (but problem of extinction, maybe JASMINE too) should allow to constrain μ or even exclude MOND as modified gravity

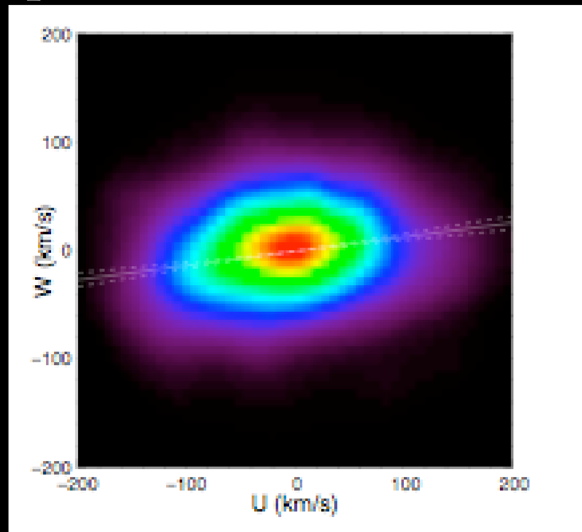
=> quick way to exploit GAIA data

The vertical tilt of the velocity ellipsoid

- Angle $\delta = \text{arctg}[2\sigma^2_{UW} / (\sigma^2_U - \sigma^2_W)]/2$ is linked to the disk scale-legnth and dark halo flattening (Bienaymé 2009)

=> compute orbits in axisymmetric Besançon model to measure the tilt as a function of z at solar position





RAVE data Siebert et al. 2008

$\delta(z=1\text{kpc}) = 7.3° \pm 1.8°$

(!streams and resonances!)

Conclusion

- MOND as a phenomenology *might* be telling us something about the nature of DM or about gravity
- We presented 3 quick tests to test MOND as modified gravity in the Milky Way with GAIA-like quality data
- This should allow to constrain μ or even exclude MOND as modified gravity
- Testing gravity crucially depends on our knowledge of the baryonic distribution (even more than when determining the DM distribution) => importance of :

  - star counts, stellar population synthesis

  - gaseous content (including molecular gas)

  - inhomogeneities (clusters, gas clouds)