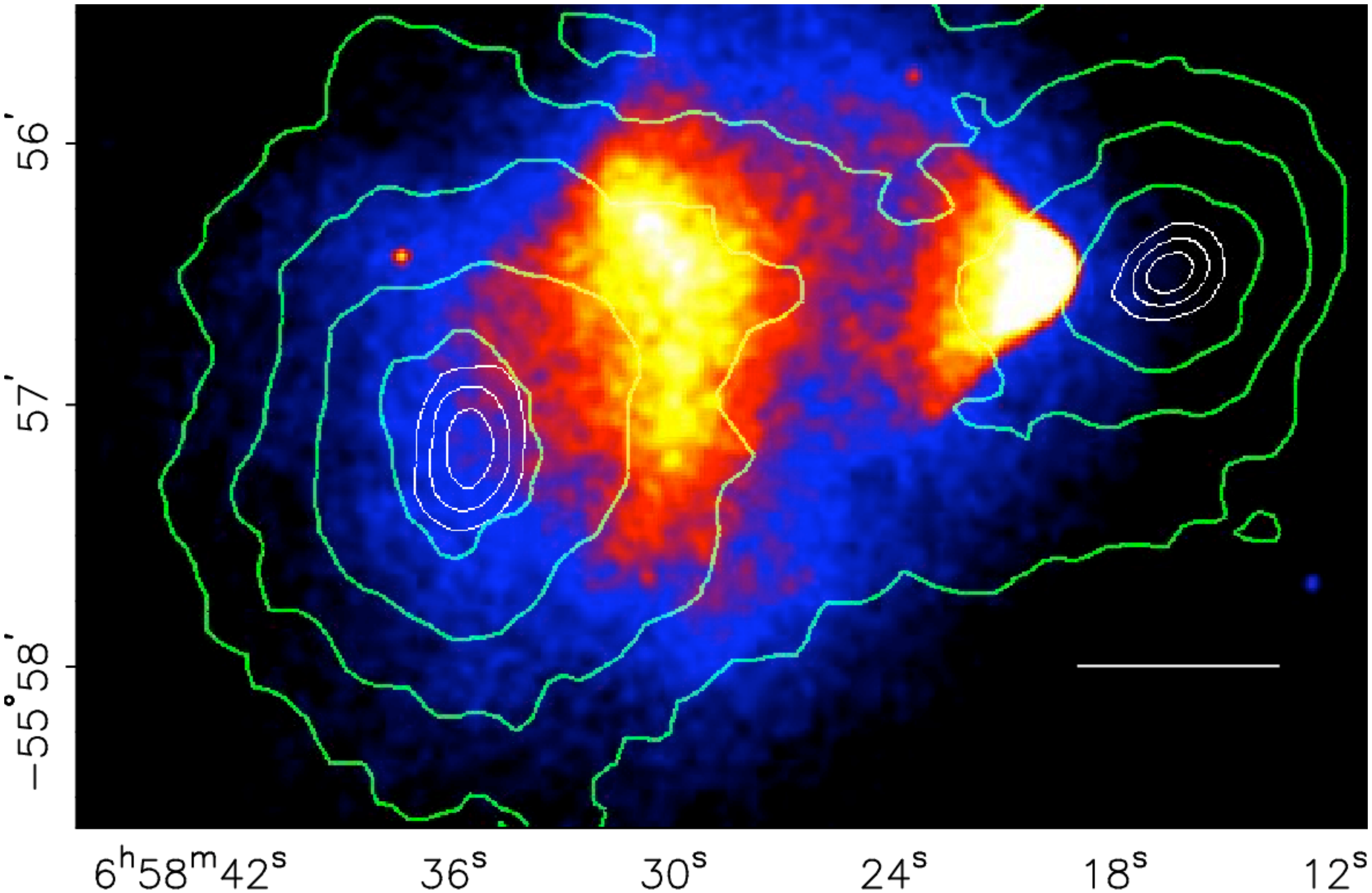
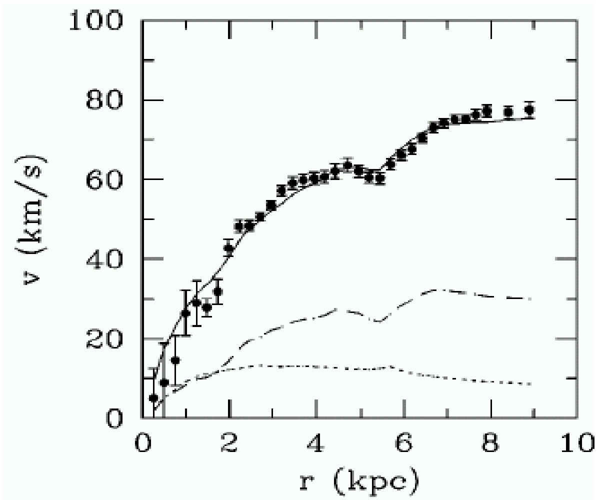
MOND and baryonic dark matter

Benoit Famaey (Brussels, ULB)



CDM: the cusp problem and the « conspiration » problem

- Simulations of clustering CDM halos (e.g. Diemand et al.) predict a central cusp $\rho \propto r^{-\gamma}$, with $\gamma > 1$, observed neither in the MW (e.g. Famaey & Binney 2005), neither in HSB nor in LSB (No present-day satisfactory solution)
- Baryonic Tully-Fisher relation
  $V_\infty^4 \propto M_{bar}$ (tight->triaxiality of halo?)
- Tidal Dwarf Galaxies with DM?
  (Gentile et al. **arXiv:0706.1976**)
- What is more: wiggles of rotation curves follow wiggles of baryons in many HSB and in some LSB



Modified Newtonian Dynamics

- Correlation summarized by the MOND formula in galaxies (Milgrom 1983) :
  $\mu\,(|g|/a_0)\,\mathbf{g} = \mathbf{g}_{N\ baryons}$ where $a_0 \sim cH_0$
  with $\mu(x) = x$ for $x \ll 1$ (MONDian regime) => $V_c^2/r \sim 1/r$ => $V_c \sim$cst + **BTF**
  $\mu(x) = 1$ for $x \gg 1$ (Newtonian regime)
- Why does it work in CDM **and** CDM-free galaxies?
- If fundamental: a) fundamental property DM ?
  b) modification of gravity ?

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

- 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)

MOND cosmology

- Can we form structure without dark matter in relativistic MOND?
- Perturbations in the vector field

  $U^{\nu} = (1+\alpha_0, \boldsymbol{\alpha})$

  In modified Poisson equation: term depending on the spatial part $\boldsymbol{\alpha}$ of the vector field **(zero in static systems)**

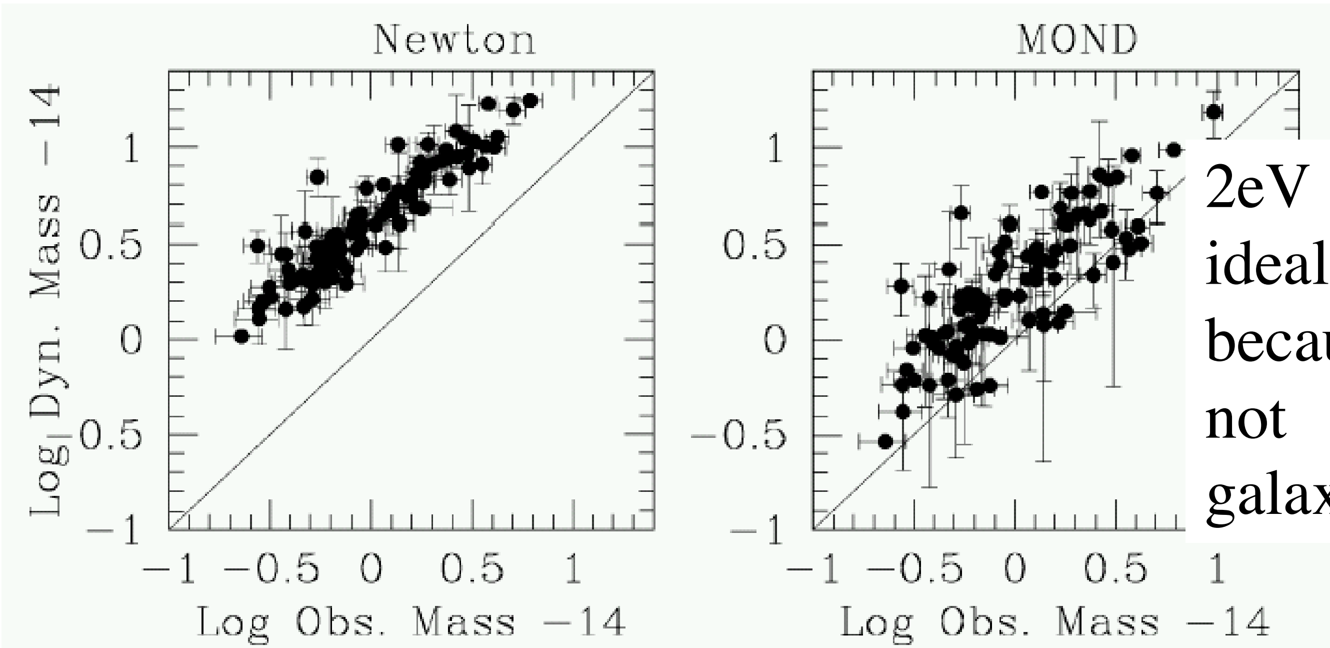
  Acts as as a source term => plays the role of dark matter!

- Matter power spectrum ok without DM (Dodelson & Liguori 2006), but IN THE PRESENT MODEL needs DM in the form of e.g. 2eV neutrinos to fit the angular power spectrum of the CMB, in order not to change the angular-distance relation by having too much acceleration (Skordis et al. 2006)

MOND in galaxy clusters

- The purpose of MOND is to explain the conspiracies between observed baryons and the gravitational field in galaxies, not necessarily to get rid of dark matter
- In X-ray emitting rich galaxy clusters:

$g(r) = -kT(r)/r\langle m\rangle \, [d\ln\rho_x/d\ln r + d\ln T/d\ln r]$



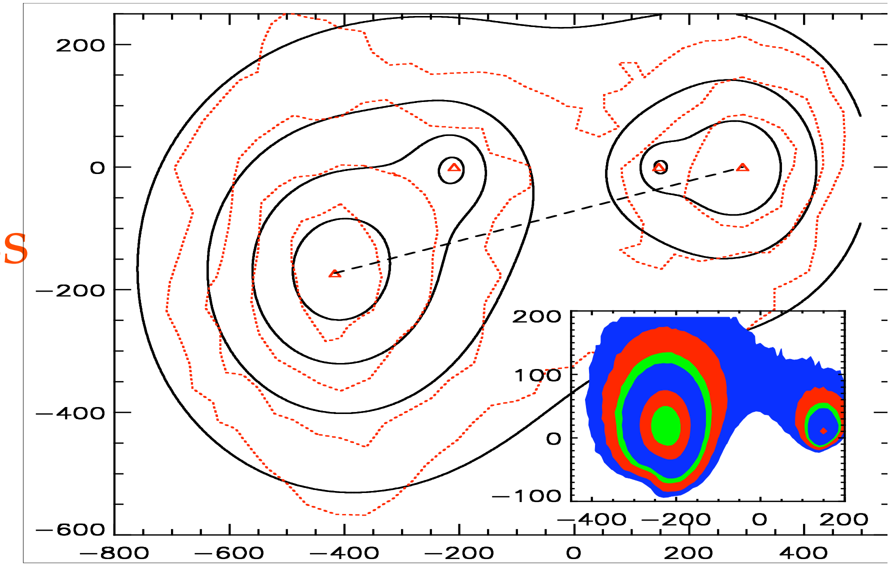
2eV neutrinos ideal candidates because they do not cluster on galaxy scales

The Bullet Cluster:

Angus, Shan, Zhao & Famaey (2007, ApJ 654 L13)

- Take parametric logarithmic potential $\Phi(r)$

$$\Phi_i(r) = 1/2\ v_i^2 \ln[1+(r/r_i)^2]$$



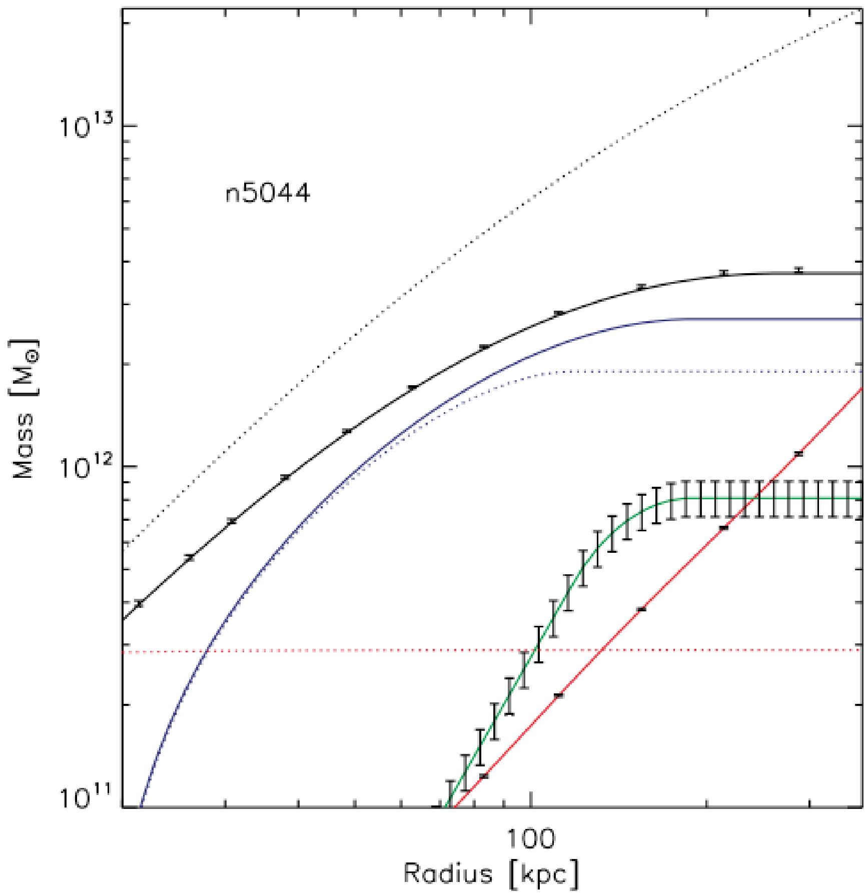
- Use Φ_1, Φ_2, Φ_3, Φ_4 for the 4 mass components of the bullet cluster

$\Rightarrow$ Parametric convergence $\kappa(R)$

- χ^2 fitting the 8 parameters on 233 points of the original convergence map

Cenral densities of the collisionless matter in MOND are compatible with the maximum density of 2eV neutrinos! (~ 10^{-3} M_{sun}/pc^3 in the bullet cluster for T=9 keV ~ 10^8 K)

Angus, Famaey &
Buote 2007
arXiv:0709.0108



- Tremaine-Gunn limit for neutrinos:

  ρ_ν (max) $\propto T^{3/2}$

=> Problem for X-ray emitting **groups** with T<2 keV

Conclusions

=> **Ordinary neutrinos** of 2eV are **not enough** to explain the MOND discrepancy in X-ray groups

=> Maybe another fermionic dark **HDM** particle?
(hot light sterile neutrinos with $m_\nu \sim 10eV$?)

BUT note that $\Omega_{bvisible}$ (=0.02) < Ω_b (=0.04) at z=0

50% missing baryons => baryonic « dark matter »

How many baryons in WHIM? 30%?

The total discrepancy in clusters and groups is only about 2-3 meaning there is about as much BDM as X-ray gas, meaning 10-20% of missing baryons is enough, even without neutrinos (but then, new MOND cosmology?)

BUT bullet => collisionless => BDM in the form of **e.g.** dense clumps of cold gas (Pfenniger & Combes 1994), present only in galaxy clusters? (but then, microlensing? X-ray emission from cloud-cloud annihilation?)

+ Why only in clusters and groups?

BUT what about Abell 520? (Mahdavi et al. 2007) Effect of intercluster filaments on gravitational lensing in MOND? (Xu et al. 2007 arXiv:0710.4935)

Central convergence κ=0.02 compared to 0.4 in the bullet