SOCIÉTÉ FRANÇAISE D'ASTRONOMIE & D'ASTROPHYSIQUE

Observatoire astronomique de Strasbourg

The Sagittarius tidal stream as a gravitationnal experiment in the Milky Way

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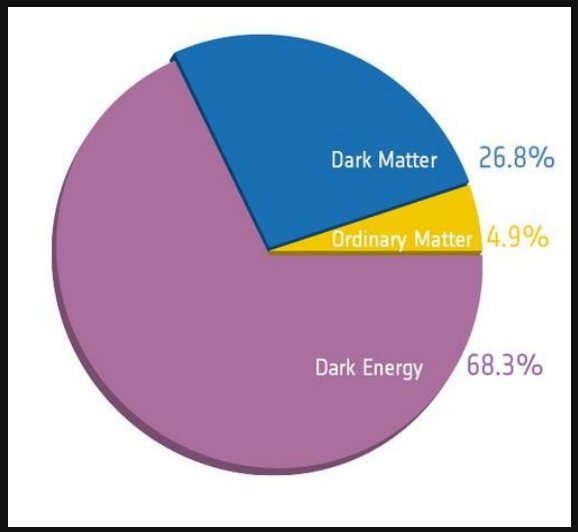
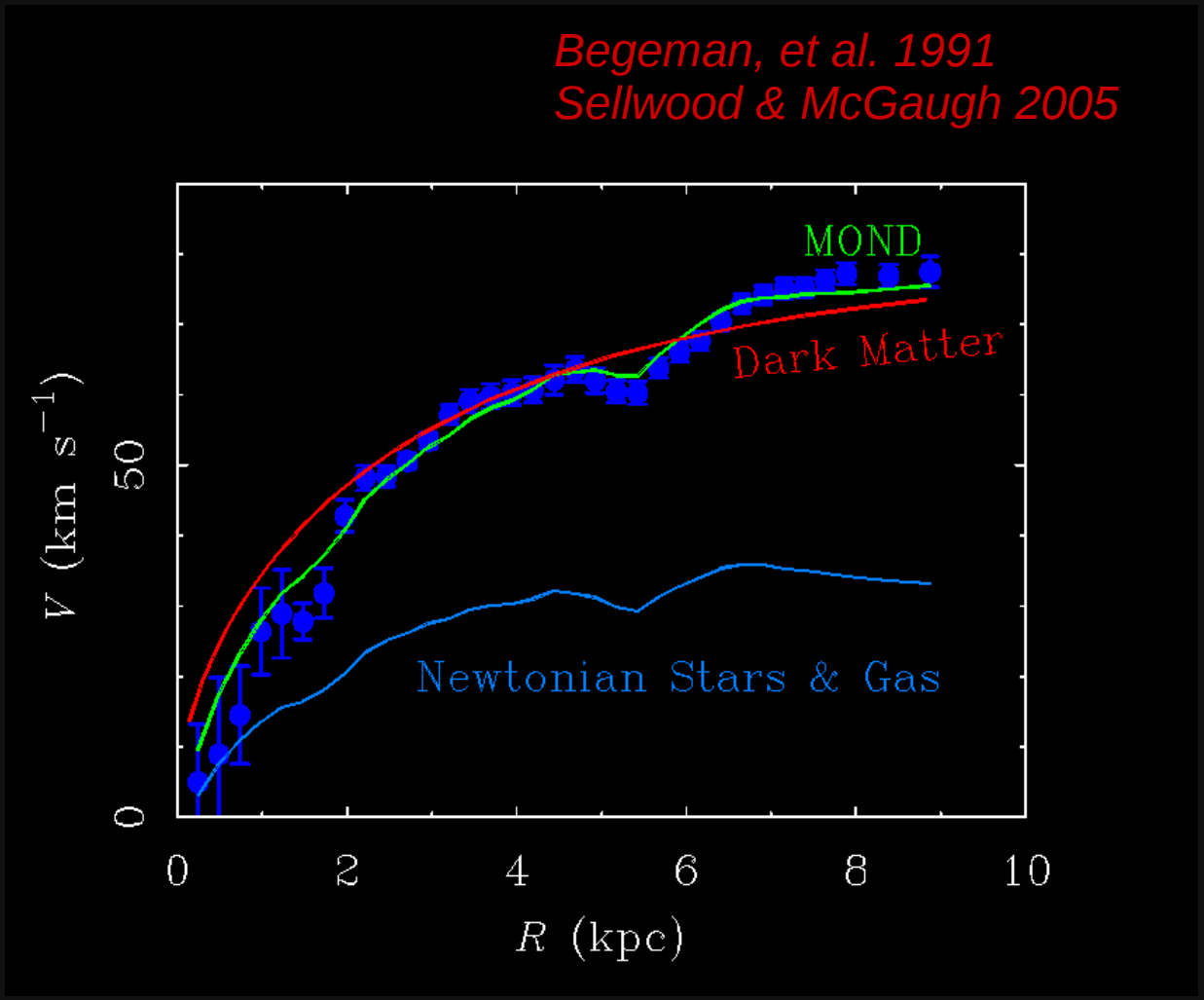
Dark matter or modified gravity ?

- There is **non visible matter**
  → Adding a Dark Matter halo



Begeman, et al. 1991
Sellwood & McGaugh 2005

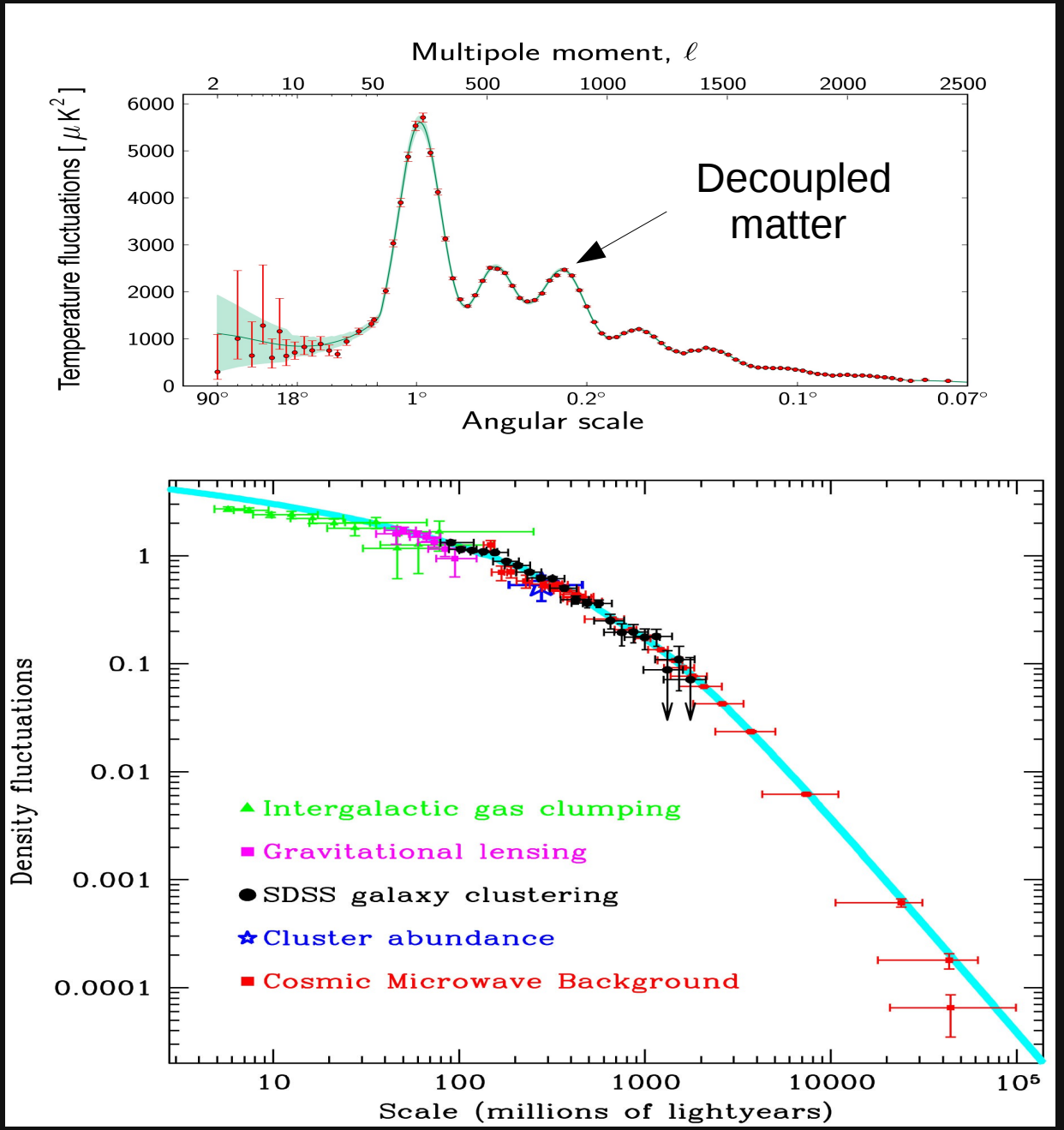


- Gravitational law is incomplete
  → **Modifing the gravitational law**

Standard Cosmological Model ΛCDM

Works well

- CMB - LSS



Works less well

ESA, the Planck Collaboration & SDSS

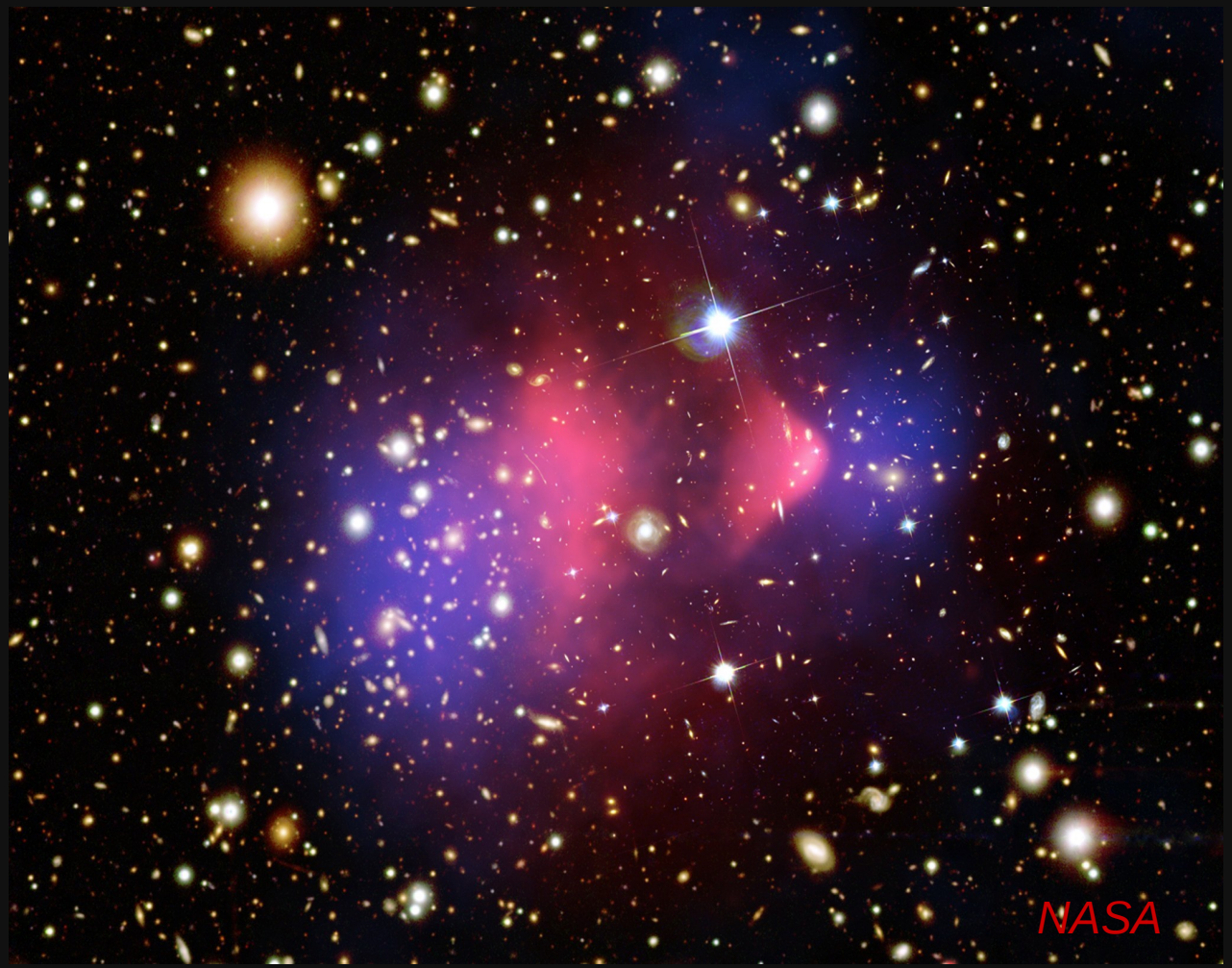
Standard Cosmological Model ΛCDM

Works well

- CMB - LSS
- Galaxy clusters

Works less well

Bullet Cluster



Standard Cosmological Model ΛCDM

Works well

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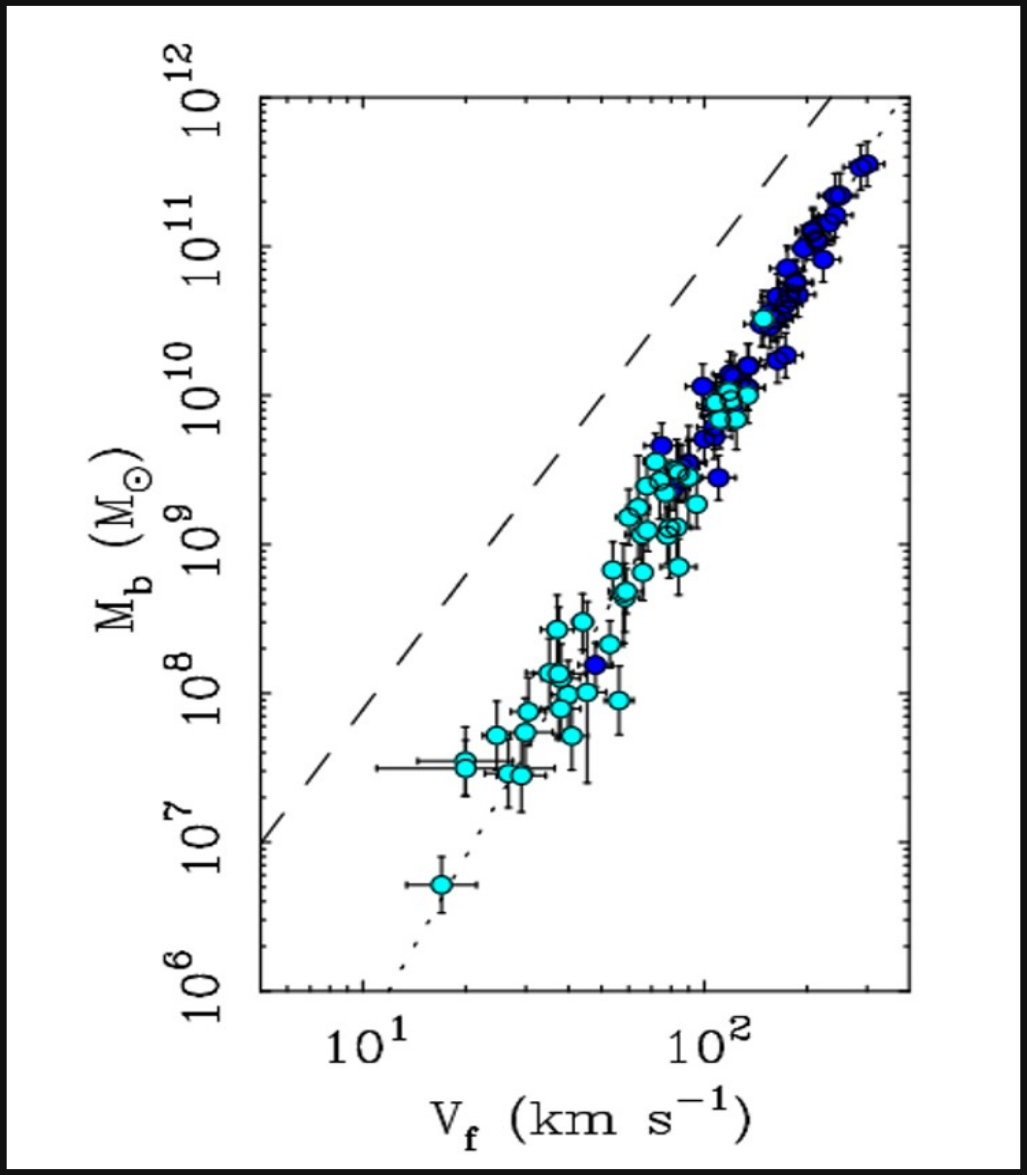
Works less well

- Baryonic Tully-Fisher Relation

$$\log M_b = 4 \log (V_f) - \log (G a_0)$$



Famaey & McGaugh, 2012

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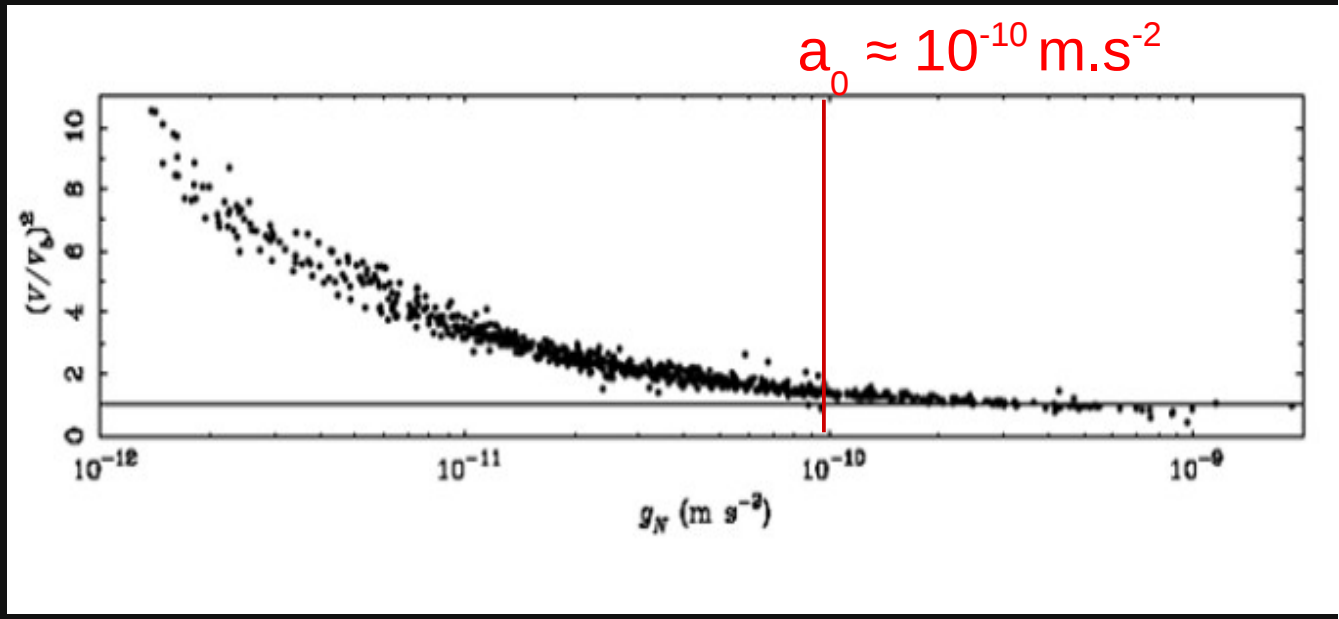


Famaey & McGaugh, 2012

Works less well

- Baryonic Tully-Fisher Relation

$$\log M_b = 4 \log(V_f) - \log(G a_0)$$

- Mass discrepancy – acceleration relation

MOdified Newtonian Dynamics

- Proposed in 1983 by Mordelai Milgrom

$$g = g_N \quad \text{if } g \gg a_0$$
$$g = (g_N\, a_0)^{1/2} \quad \text{if } g \ll a_0$$

- **QuMOND** : *Quasi – linear formulation of MOND*
  - Mondian Poisson equation : $\nabla^2 \Phi = 4\pi G(\rho_b + \rho_{ph})$
  - Phantom dark matter : $\rho_{ph} = \nabla\left[\tilde{\nu}\left(\frac{|\nabla \Phi_N|}{a_0}\right)\cdot \nabla \Phi_N\right]$
- Relativistic formulations exist : *BIMOND, RAQUAL, TeVeS ...*
  but problem with the CMB and clusters

MOdified Newtonian Dynamics

- Interpolation functions :
  - **Simple**

$$\tilde{\nu}(y)=\frac{\left(1+4\,y^{-1}\right)^{(1/2)}-1}{2}$$

  - **Standard**

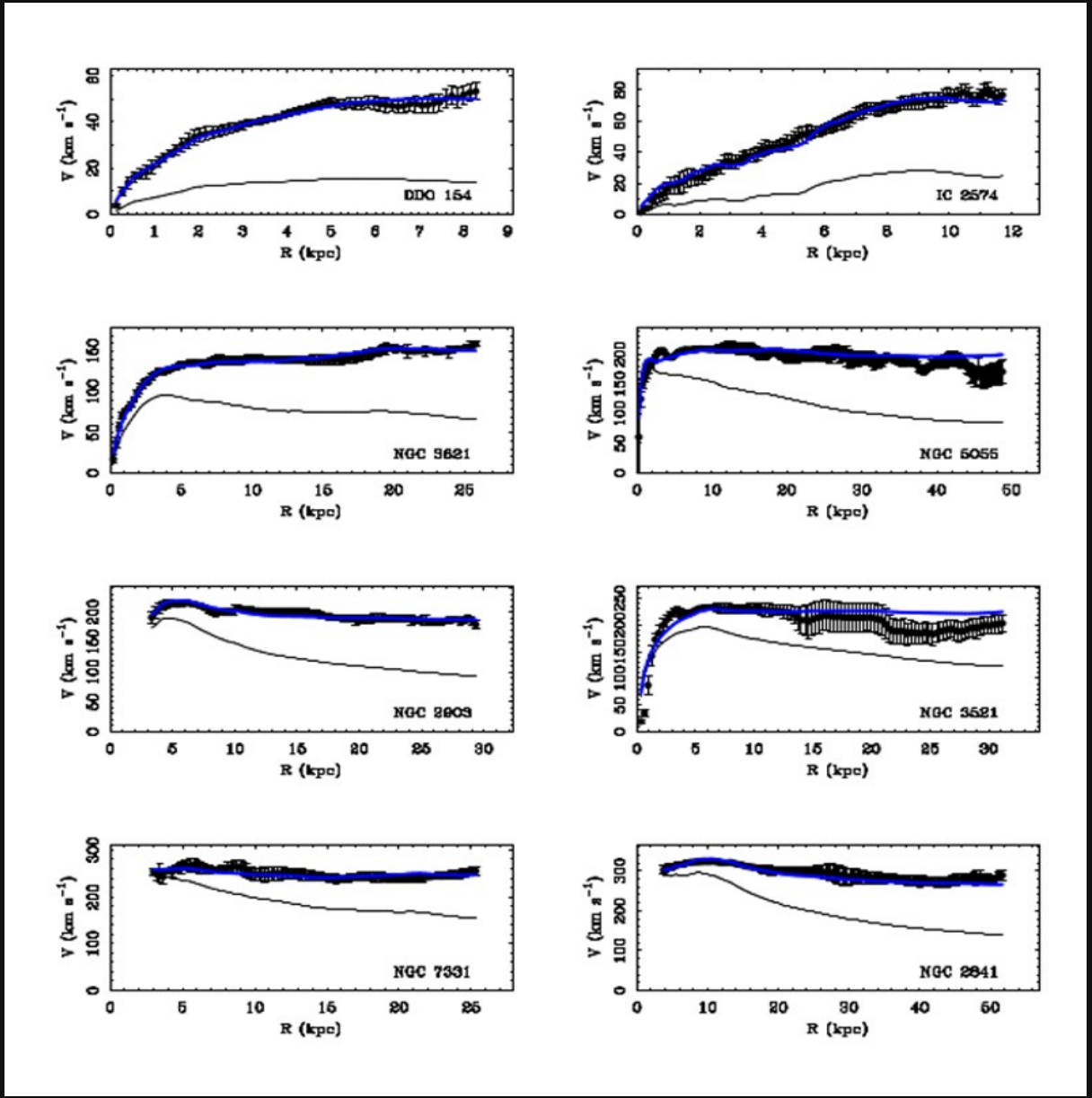
$$\tilde{\nu}(y)=\left[\frac{1+\sqrt{1+4\,y^{-2}}}{2}\right]^{1/2}-1$$

  - **Exponantial**

$$\tilde{\nu}(y)=\left(1-e^{-y^2}\right)^{-1/4}+\frac{3e^{-y^2}}{4}-1$$

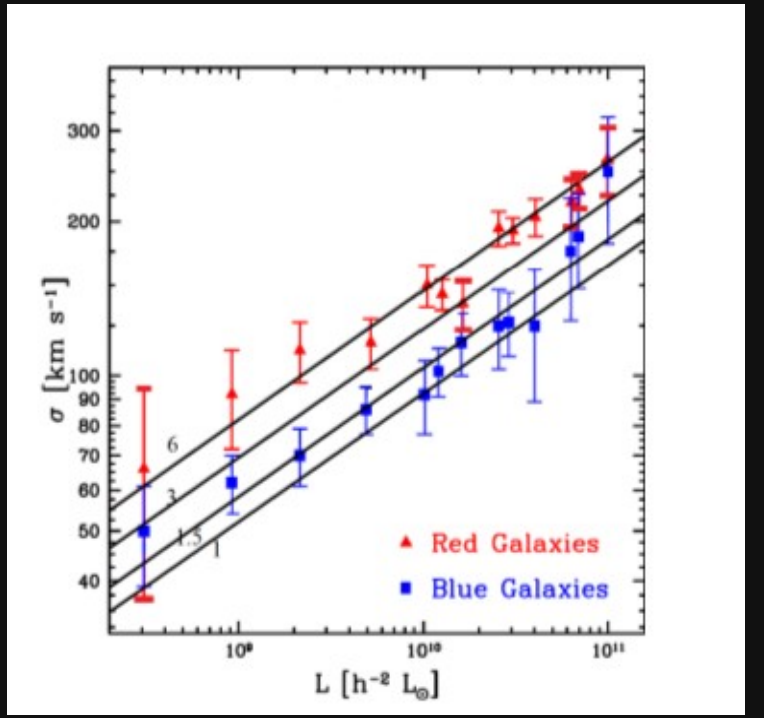
In agreement in the solar system

Success of MOND



Famaey & McGaugh, 2012

- **Rotation curves** of spirals galaxies well reproduced
- Also for **LSB** galaxies
- Explain the galaxy **Gravitational Lensing**



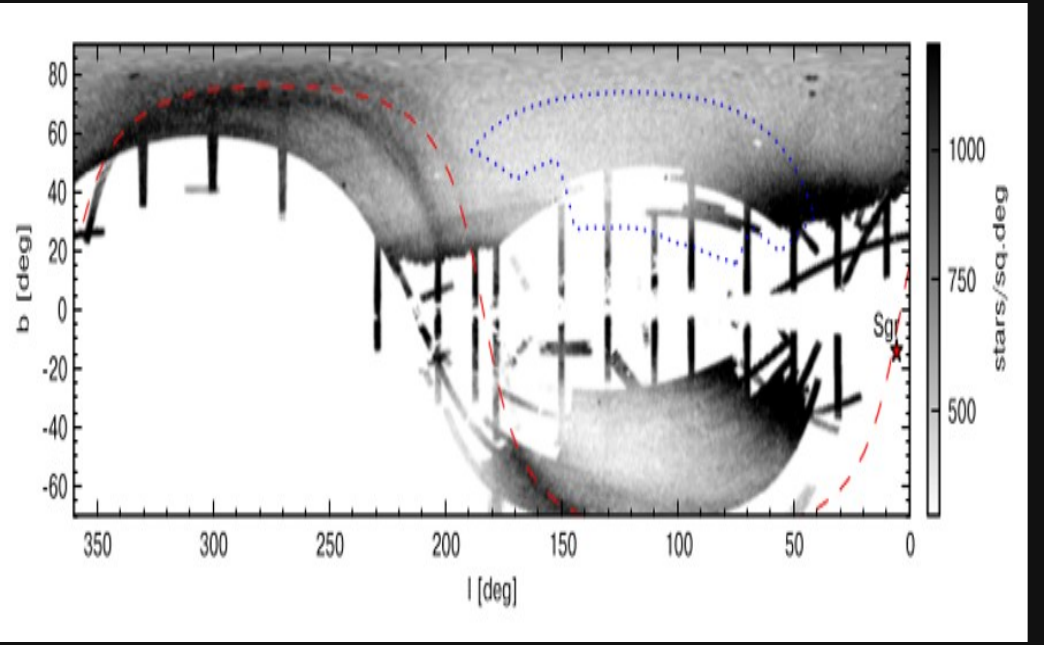
Milgrom et al, 2013

New test of MOND : Streams

- Stream formed by **merger** of a **dSph** with a host galaxy
- Stream are important to trace the shape of the potential outside of the plane
- **No dynamical friction** in MOND
- Role of the **External Field Effect** (EFE)

Sagittarius Dwarf Spheroidal (dSph Sgr)

- Discovered in 1994 by R. IBATA
- $M_* = 2.1\ 10^7\ M_\odot$
- $r_h = 2.587$ kpc
- $D_{sun} \sim 25$ kpc
- Long stream well visible



Koposov et al, 2012

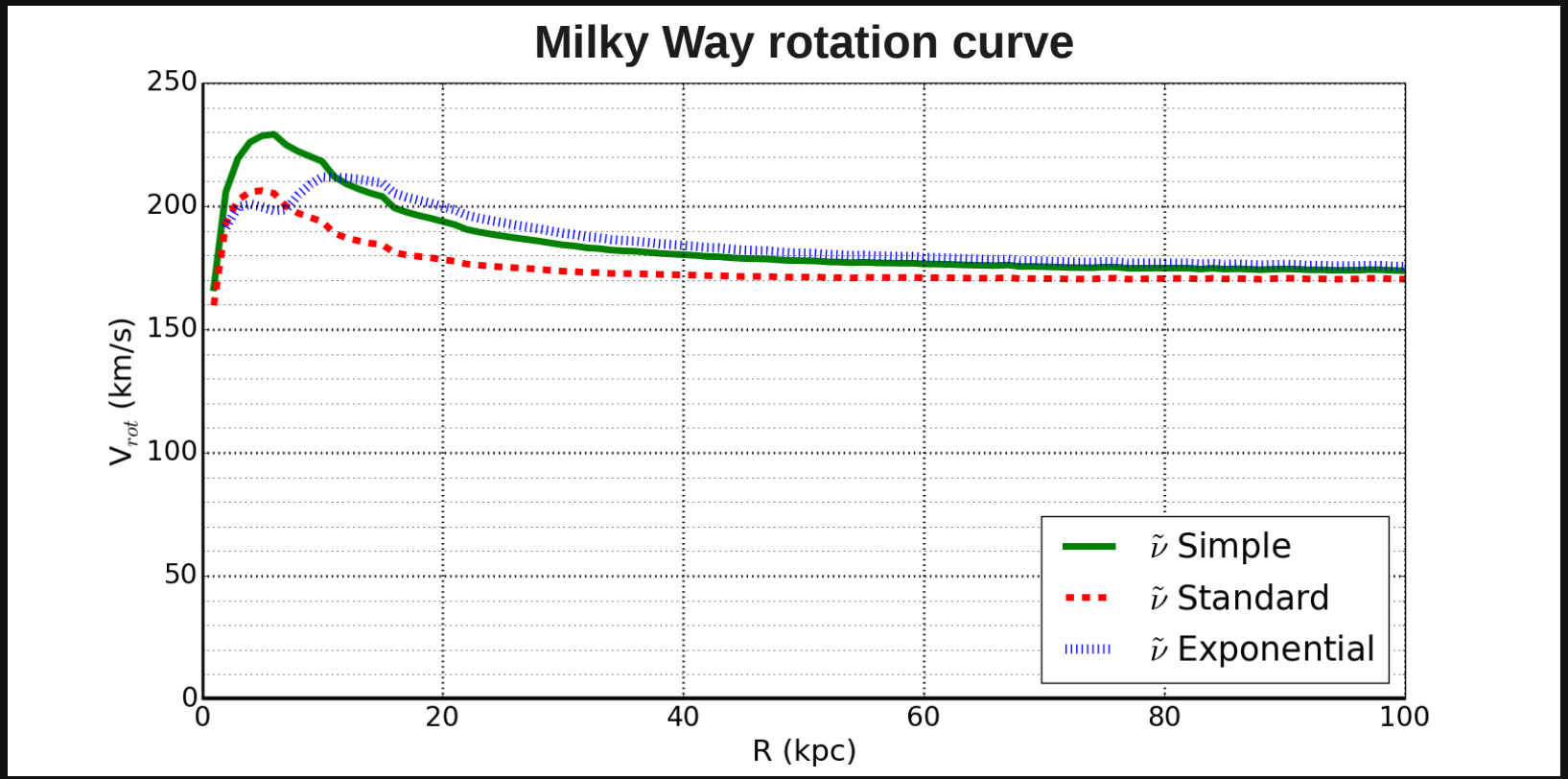
New test of MOND : Streams

Milky Way model

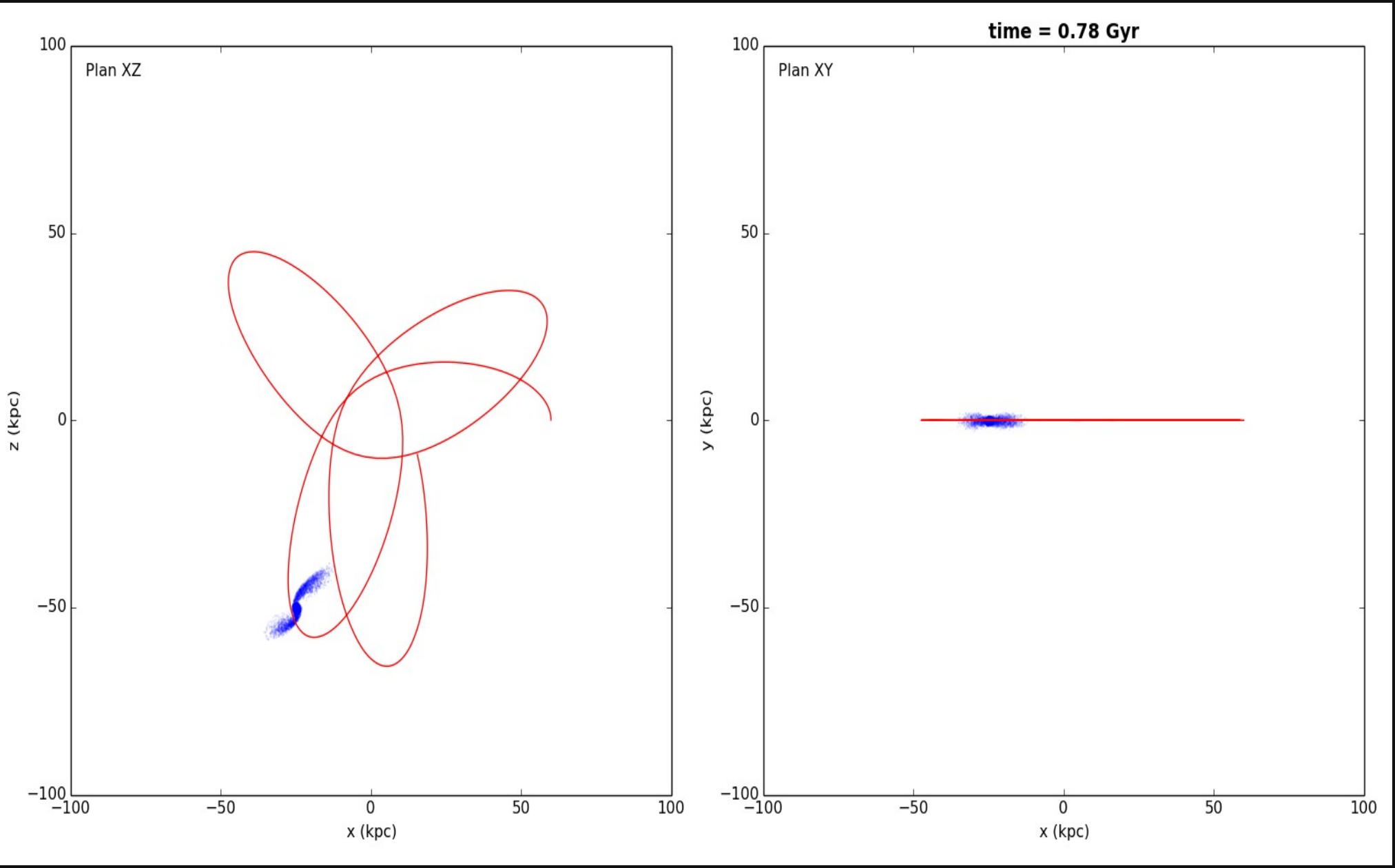
- Disk (Thin, thick, ISM)
- Bulge
- Without DM halo
- $M_{MW} = 5.64\ 10^{9}\ M_{\odot}$

Sgr dSph model

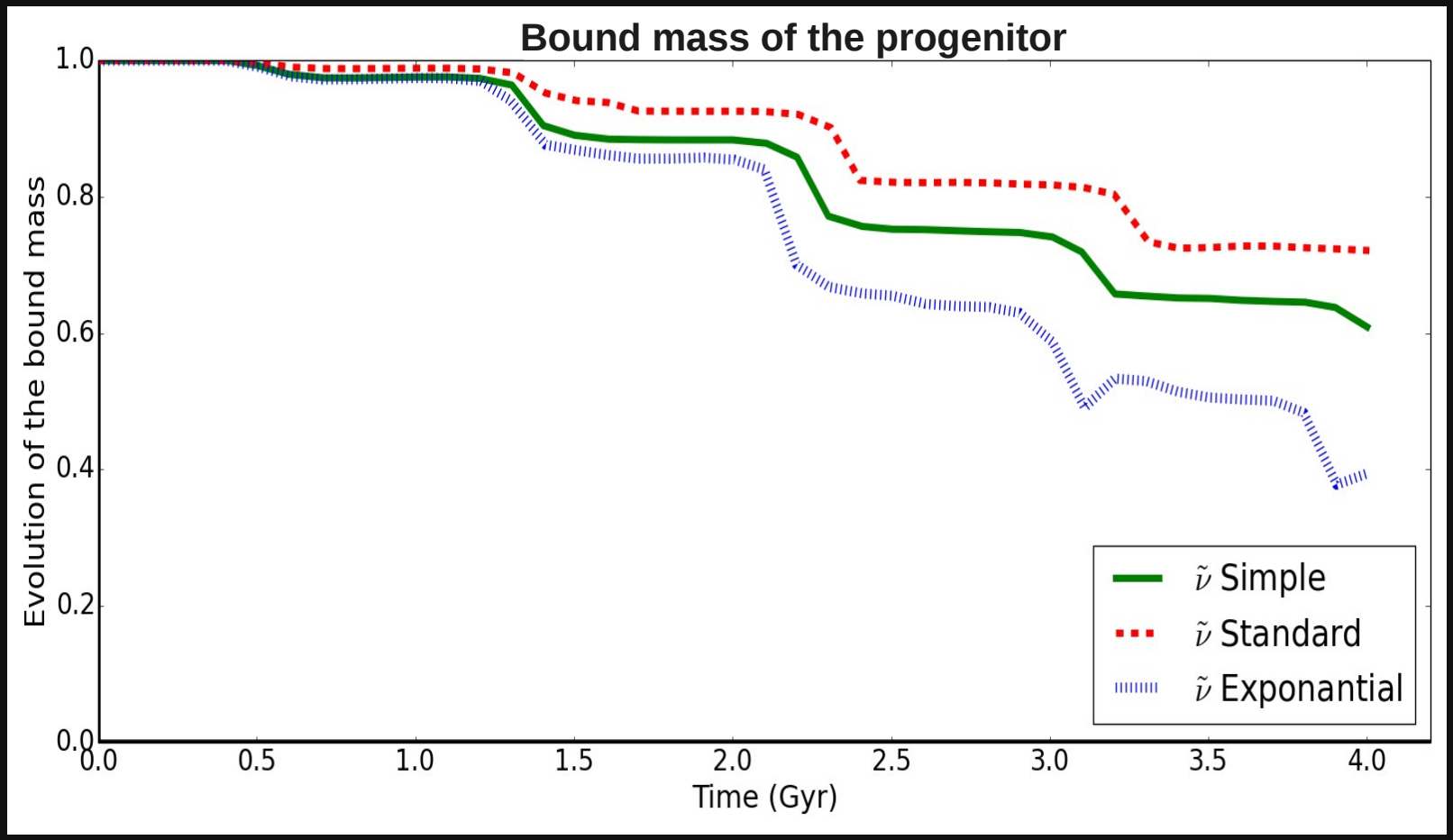
- King profile
- $M_{Sgr,dSph}(t=0\ Gyr) = 4.67\ 10^{7}\ M_{\odot}$
- $r_{t}(t=0\ Gyr) = 0.84$ kpc



New test of MOND : Streams



Conclusion



- Central dispersion $\sigma_{c(t=4Gyr)}$ ~ 11 km/s
- Mass of the remnants $M_{rem,(t=4Gyr)}$ ~ 2.2 - 2.8 10^7 $M_\odot$

Works well with dSph Sgr

Future projects

- Compare generically the simulations and the currents observations
- Simulate other streams in the Milky Way and in other galaxies (M 31, …)
- Make predictions and compare them with the future Gaia results

Thank You