Dark matter halos

See e.g arxiv:1004.0005, Agertz, Teyssier, Moore

review : arxiv:0801.1023, Dolag et al

links between N-body simulations and dark matter detection

Direct detection (arxiv:0909.2028)

Gamma indirect detection (arxiv:0801.4673)

Cosmic rays (arxiv:0808.0332)

Collaboration with L. Athanassoula, J. Lavalle, F.-S. Ling, R. Teyssier

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From neutrino to multimessenger astronomy, Marseille. 4 April 2011

Outline

- **N-body simulations : basics**
- **Features of dark matter halos**
- **Consequences for dark matter detection**

Introduction

Hierarchical structure formation scenario

- Comological parameters : $\Omega_\Lambda, \Omega_M, \Omega_b, \sigma_8, H_0, h.$

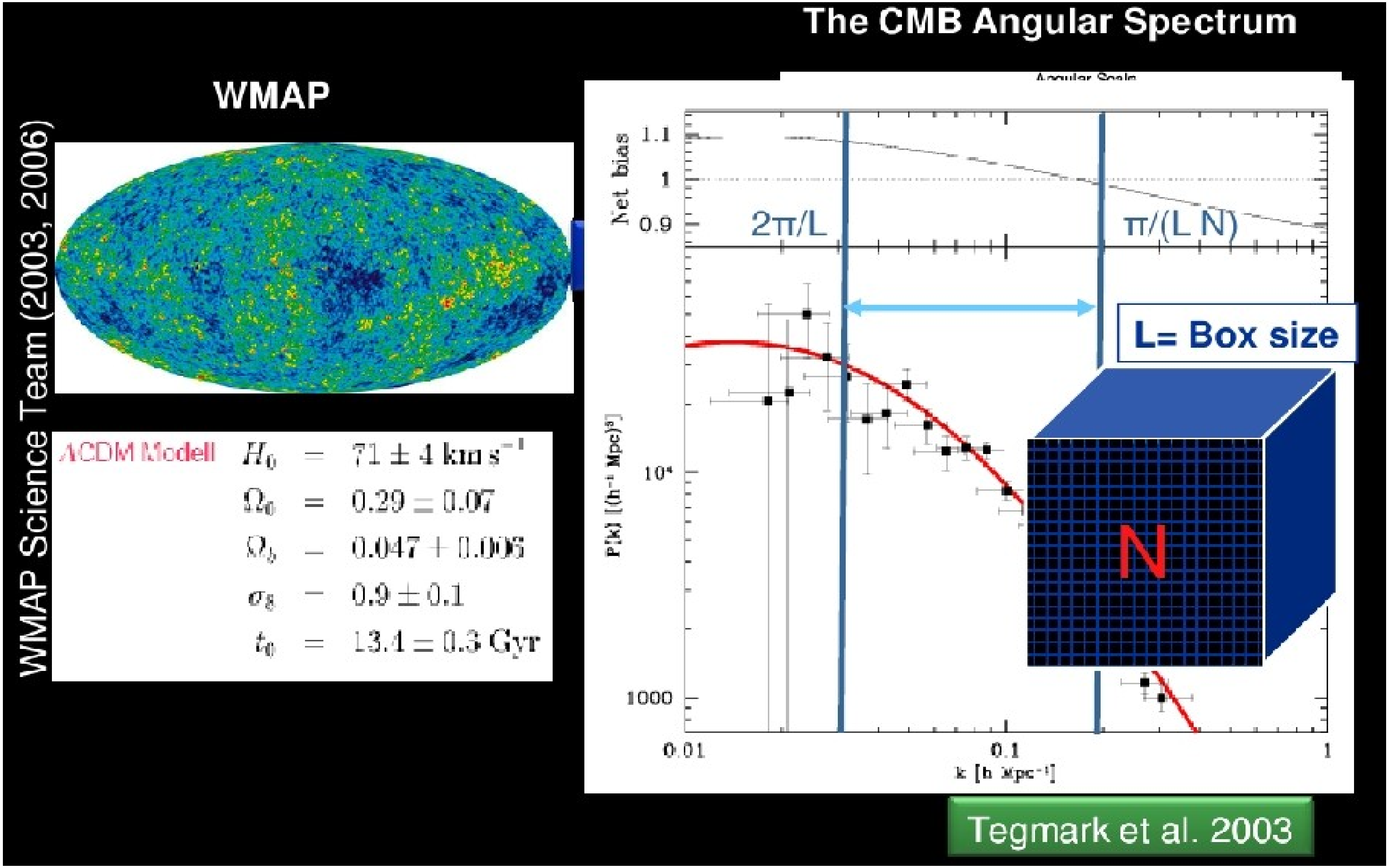
- Size of the box

- Computer capacity $\Rightarrow$ Nb of particles

$\Rightarrow$ Mass of dark matter particles $\sim 10^{3-5} M_\odot$

Introduction

Initial conditions given by CMB power spectrum : WMAP



Physics

DARK MATTER (and STARS)

- **Gravity : Vlasov and Poisson equations**

$$\nabla^2 \Phi = 4\pi G \left[\rho + (n-2)\rho_X \right]$$

GAS

- **Hydrodynamics : Euler equations**
- **+ Gravity**

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0,$$

$$\frac{\partial \boldsymbol{u}}{\partial t} + (\boldsymbol{u} \cdot \nabla) \boldsymbol{u} = -\nabla \Phi - \frac{\nabla p}{\rho},$$

$$\frac{\partial \varepsilon}{\partial t} + \boldsymbol{u} \cdot \nabla \varepsilon = -\frac{p}{\rho} \nabla \cdot \boldsymbol{u},$$

Physics

DARK MATTER (and STARS)

- **Gravity : Vlasov and Poisson equations**

Solved by N-body techniques :
i.e "particles"

GAS

- **Hydrodynamics : Euler equations**
- **+ Gravity**

2 approaches :

- **Eulerian : fluid=grid (AMR)**
  e.g RAMSES code, R. Teyssier
- **Lagrangian : fluid=particles (SPH)**
  e.g GADGET code, V. Spingel

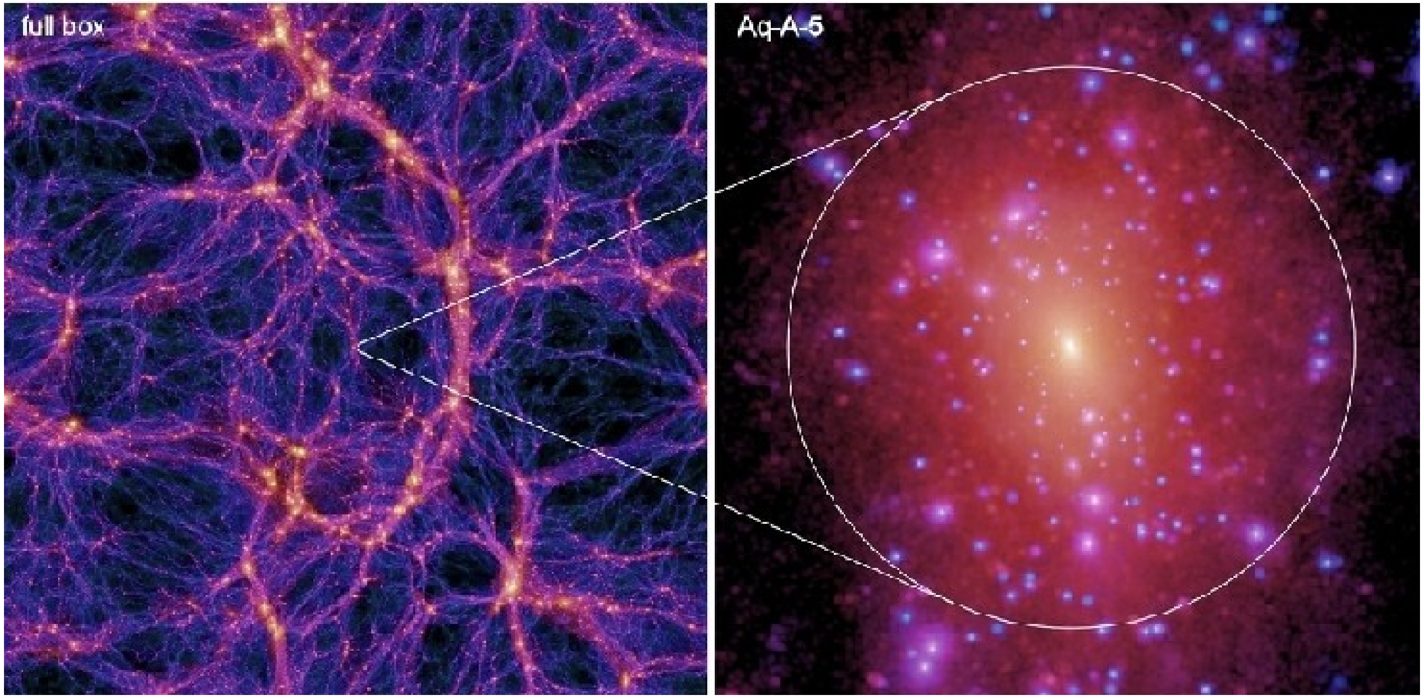
Some results

- **NFW, VIA LACTEA I&II, AQUARIUS, GHALO, HORIZON, CLUES ...**

DARK MATTER only simulations :

- **Describe well large scale structure formation : filaments**
- **Give non smooth dark matter distribution : presence of virialized (sub)structures (agreement with Press-Schester theory)**

= CLUMPS



AQUARIUS, Springel et al 2008

Some results

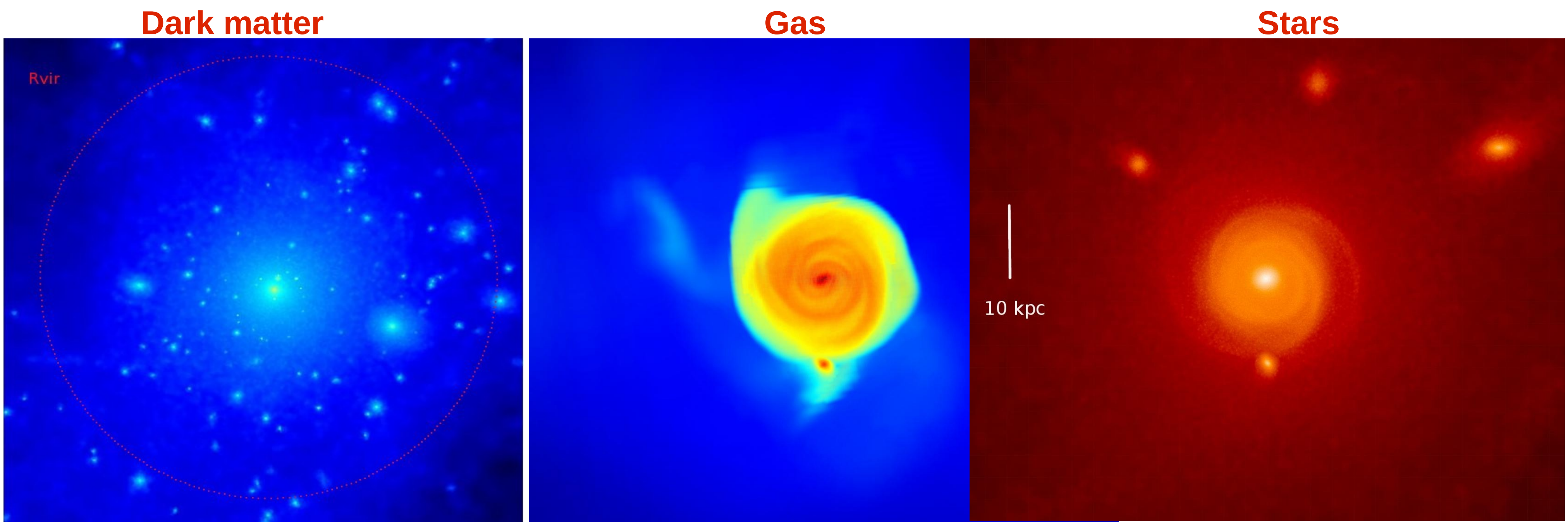
- **NFW, VIA LACTEA I&II, AQUARIUS, GHALO, HORIZON, CLUES ...**

Simulations including gas :

- **Filaments**
- **CLUMPS**

- **Gas accreted in DM potential**

  → Disk and stars formation



HORIZON project simulation by R.Teyssier

Pictures with Glnemo viewer (Jean-Charles.Lambert@oamp.fr)

Star formation : recipe

- **Infall of cold gas → stars**

- **Model the gas conversion into stars by a Schmidt law**

$$\dot{\rho}_g = -\epsilon_{\rm ff} \frac{\rho_{\rm g}}{t_{\rm ff}} \text{ for } \rho > \rho_0$$

- **t_{ff} free-fall time**
- **$\rho 0$ threshold density**

- **ε_{ff} drive star formation rate**

→ Transform gas into star particles

Supernovae feedback

- **Type II SN, relevant for stellar masses ~** $8-40\ \mathrm{M}_{\odot}$
- **Represents ~ 10 % of the mass of a stellar population**
- **Short lived stars**
- **~ 10-20 Myr after the star (particle) creation : explosion**
- **~ 10 % of the star (particle) mass is re-injected into the gas**
- **Energy per explosion** $E_{\mathrm{SNII}} = 10^{51}\ \mathrm{erg}$

→ **reheat the gas, regulate star formation rate**

Clumpy dark matter halos

- **Dark matter distribution not smooth : clump spectrum**

$$\frac{dN_{cl}}{dM} \propto \left(\frac{M}{M_H}\right)^n$$

typically $n \sim -1.8 - 2$

Problem :

Number of satellites > observations … new dwarf galaxies to be discovered ? … in progress
satellites whitout gas and stars ?

(Cuspy ?) Dark matter Halos

Fit of N-body results :

- **Cusps**

$$\rho_{DM}(r) = \frac{\rho_s}{(r/r_s)^{\gamma}[1+(r/r_s)^{\alpha}]^{(\beta-\gamma)/\alpha}} \qquad \rho_{DM}(r) \propto r^{-\gamma} \text{ (small } r\text{)}$$

⋆ NFW 1997 : $\gamma = 1$

⋆ Moore et al 1999 : $\gamma = 1.5$

⋆ VIA LACTEA (I and II), Diemand et al 2006-2008 : $\gamma = 1.2$

- **Einasto (AQUARIUS)** $\rho_D M(r) = \rho_{-2} e^{-\frac{2}{\alpha}[(r/r_{-2})^{\alpha}-1]}$

But : Observations suggest cored profiles, i.e $\gamma = 0$

Baryon impacts on dark matter halo

Dark matter profile steepened or flattened by baryon processes

- **Adiabatic compression : Blumenthal et al 1986**

Angular momentum and mass conservation : $M_i(r_i)r_i = [M_b(r_f) + M_{DM}(r_f)]r_f$

★ $M_i(r)$: mass profile of the galactic halo before the cooling of the baryons

★ $M_b(r)$: the baryonic composition of the Milky Way observed now

★ $M_{DM}(r)$: the dark matter component of the halo today (determined iteratively)

$$\text{NFW} : \rho_{DM}(r) \propto r^{-1} \rightarrow r^{-1.5}$$

- **ISM physics : stellar formation, SN feedback …**

- The response of the DM halo is driven by the history of assembly of baryons into a galaxy : *Pedrosa et al* : arxiv:0902.2100

- ISM carefull treatment could lead to shallow profiles on dwarf scale *Governato et al* arxiv:0911.2237

- **Dark disc : clump accretion by stellar and star disc … *Read et al* 0902.0009**

→ enhancement of capture rates in the Sun ? *Bruch et al 2009 vs Ling 2010*

Still debated ...

Cosmological simulations

Disc Galaxy formation works well qualitatively :

Need carefull treatement and improvement of ISM physics … in progress

Realistic and consistent Milky-Way like framework for astroparticle calculations ...

Gamma/neutrino indirect detection

$$\frac{d\Phi_{\gamma,\nu}}{d\Omega} = \frac{1}{4\pi} \underbrace{\frac{1}{\delta}\frac{\langle\sigma v\rangle}{m_{DM}^2} \int_{E_{min}^{\gamma,\nu}}^{E_{max}^{\gamma,\nu}} \sum_i \frac{dN_{\gamma,\nu}^i}{dE_{\gamma,\nu}} BR_i}_{\doteq HEP_{\gamma,\nu}} \underbrace{\int_{l(\vec{\Omega})} \rho_{DM}^2 \, dl}_{\doteq ASTRO} \, ,$$

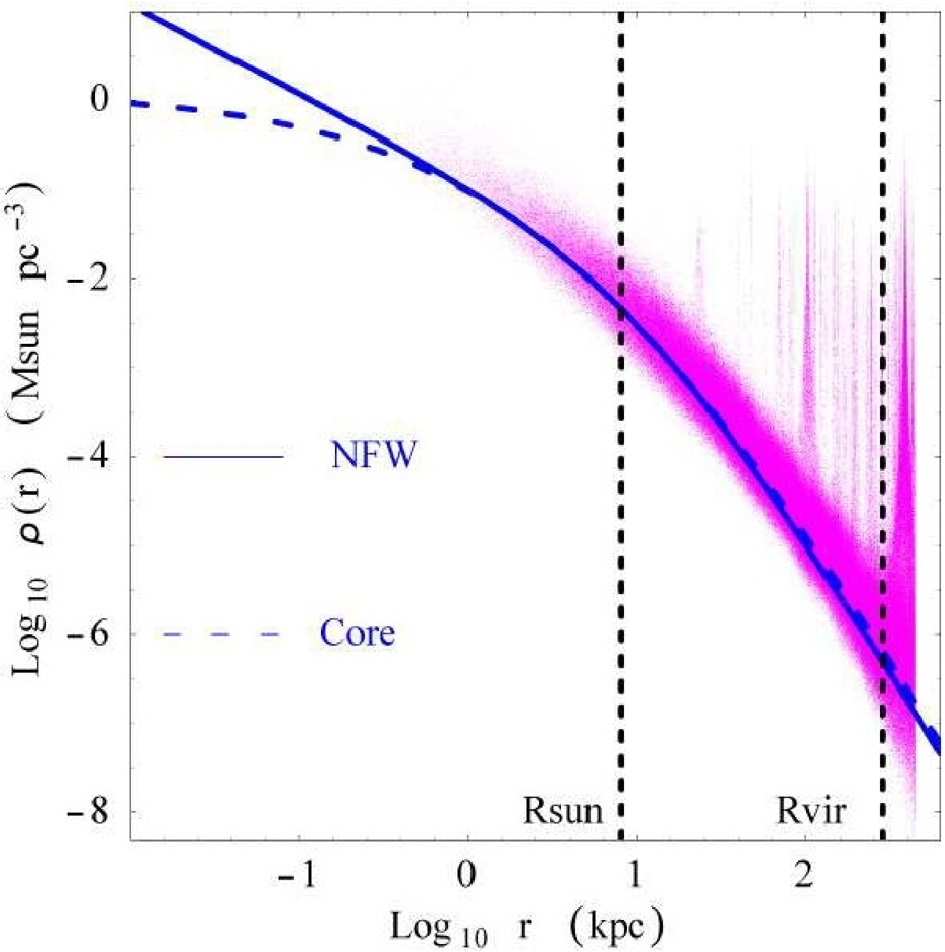
Particle physics **Astrophysics**

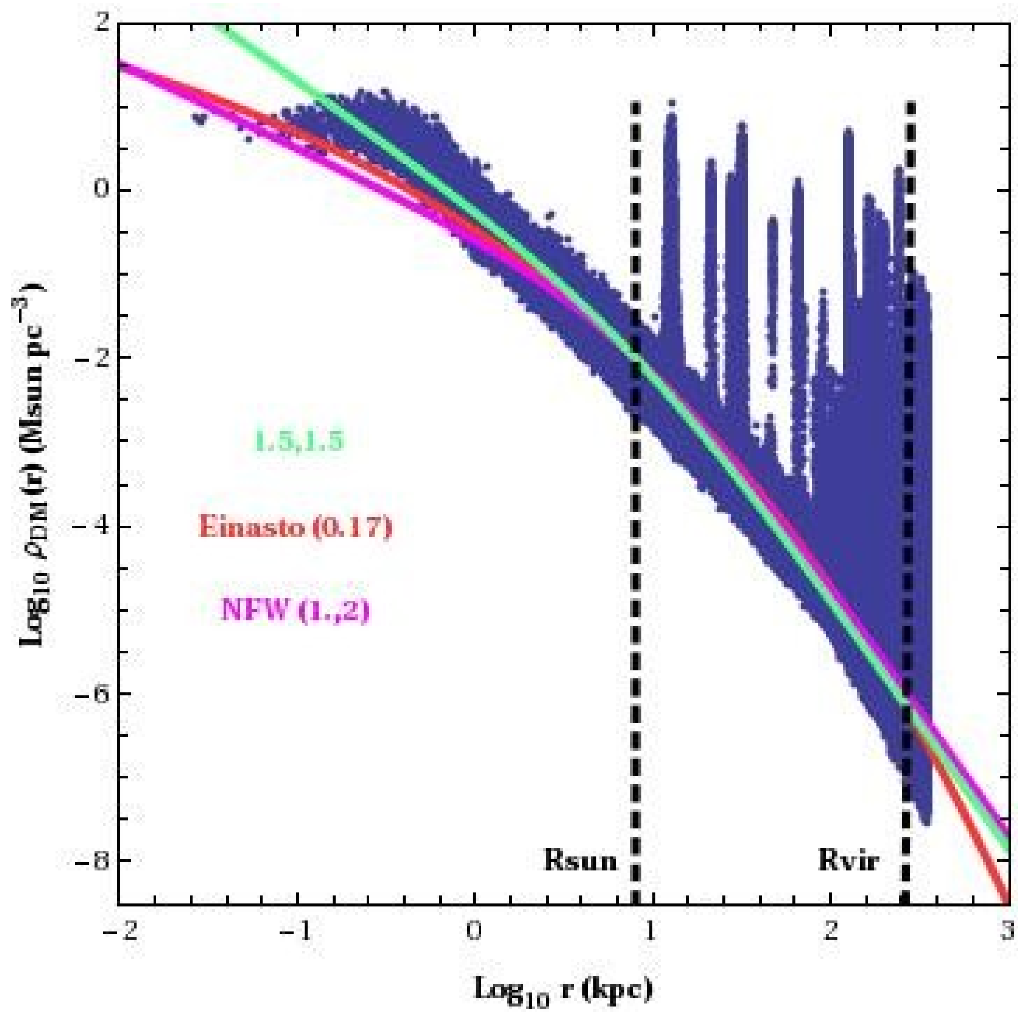
Annihilation cross section
Dark matter mass
Annihilation induced spectra

DM distribution:

Features ?
Cusp ?
Clump features ?
Baryons ? (compression ?)
Feedback ?

Dark matter density :





Dark matter only

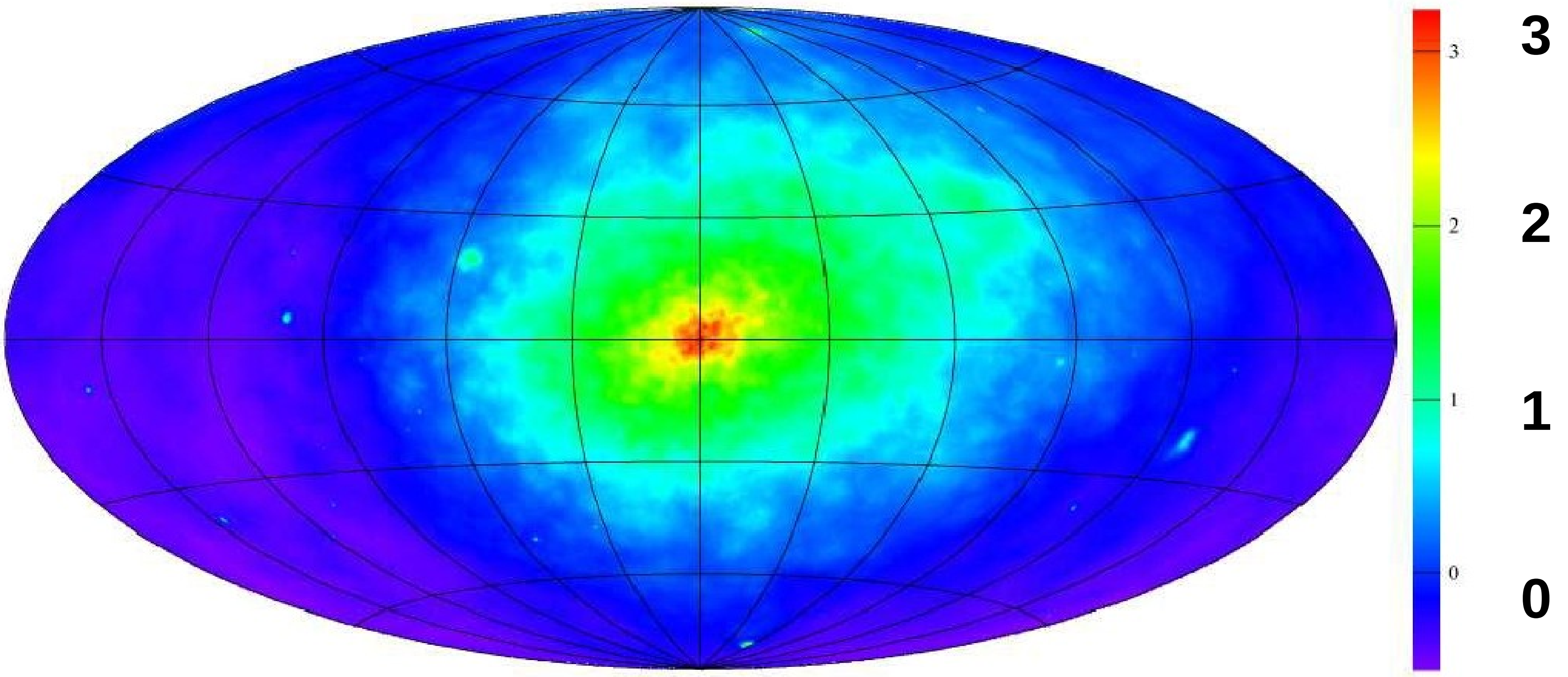
Dark matter+ baryons

Adiabatic compression

(too?) Strong cusp

Simulations from the HORIZON project,
AMR RAMSES code (R. Teyssier)

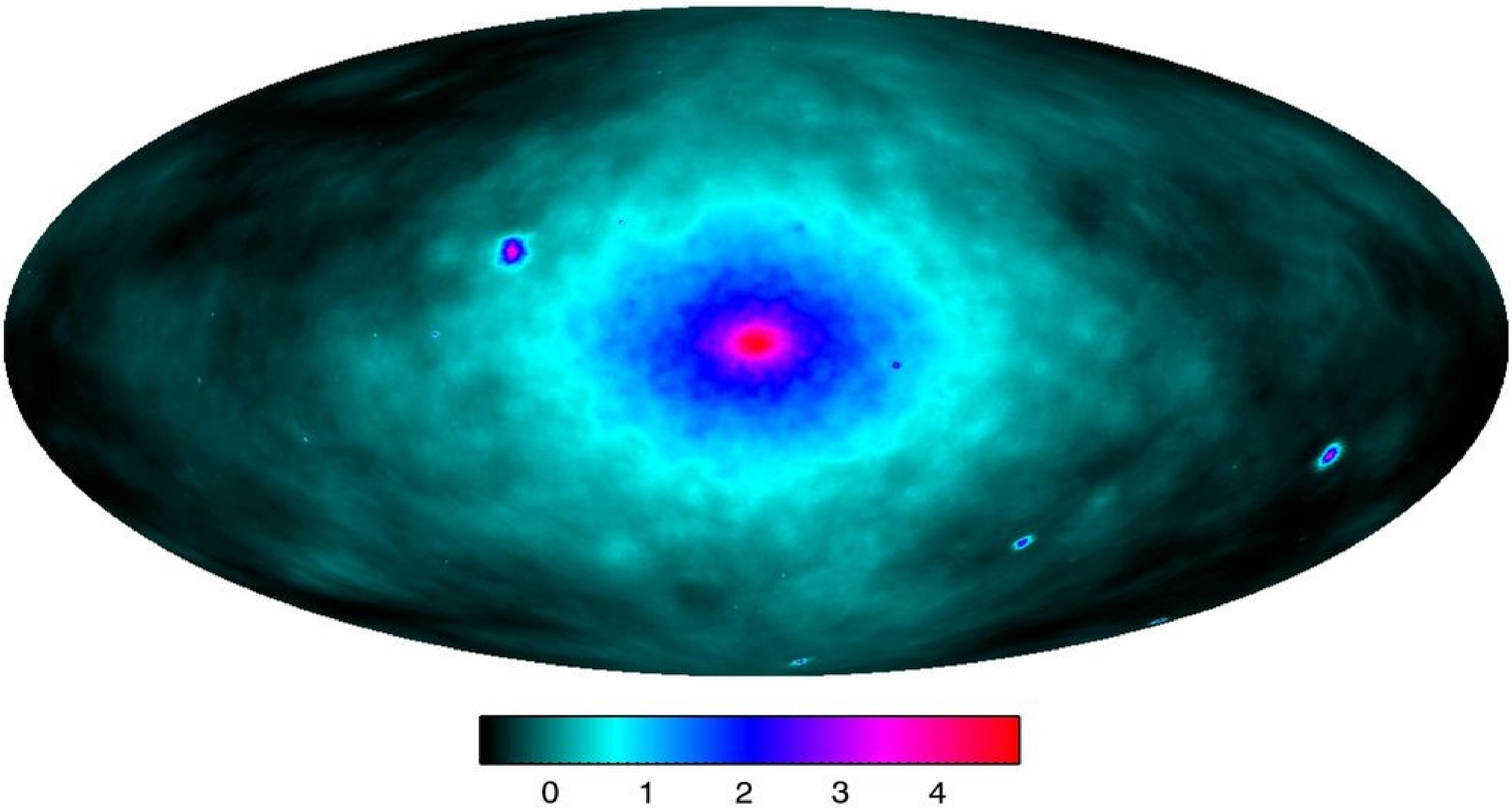
Dark matter : Gamma skymap
N-body simulation : dark matter only



Gammas : FERMI,HESS+standard thermal (HEP+cosmo) scenario ~ 3
Neutrinos : KM3Net GC + ” ~4

arxiv:0801.4673

Dark matter : Gamma skymap
N-body simulation : dark matter + baryons



Dark matter only simulations : GC ~ 2 orders of magnitude lower fluxes at GC
Gammas : FERMI,HESS+standard thermal (HEP+cosmo) scenario ~ 3
Neutrinos : KM3Net+   ”   ~4

Very high astrophysics contribution → HEP scenarios
Possible conflict with observations FERMI, HESS ...
Depend on background …

Nezri, Lavalle, Teyssier … soon on arxiv

Summary-Conclusion

- **Cosmological N-body simulations with gaz : successful tool for galaxy formation**

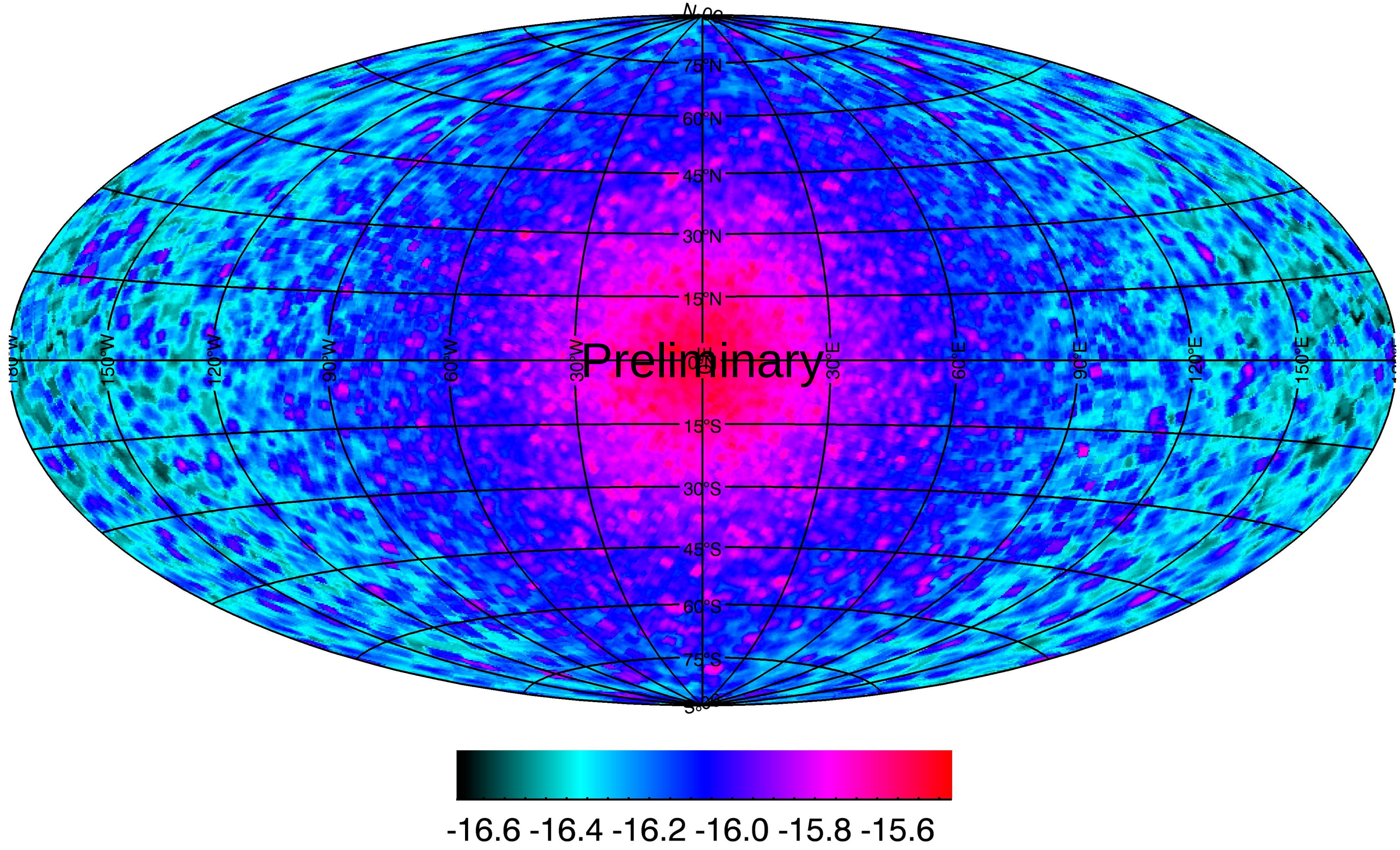
- **Nb of satellites**
- **Cusp/Core** (*Governato et al* arxiv:0911.2237)
- **Angular momentum problem** (Agertz, Teyssier, Moore arxiv:1004.0005)
(bulges too dominant, discs not extended enough)
- **Improvement of ISM physics treatment**

- **Very consistent framework for dark matter detection and astroparticle calculations**
- **Dark matter signals (gamma, neutrinos, CR)** arxiv:0801.4673, arxiv:0808.0332
- **Backgrounds from gas, stars and ISM physics**

Nezri, Lavalle, Teyssier soon on arxiv...

Thanks

Cosmic Ray map from a N-body simulation



Gamma background from a N-body simulation