Dark matter halos

N-body :

See e.g : Maccio et al arXiv:1111.5620
Keres et al arXiv:1109.4638
Agertz, Teyssier, Moore arxiv:1004.0005
Governato et al arxiv:0911.2237, arxiv:1106.0499
Pedrosa et al : arxiv:0902.2100

review : arxiv:0801.1023, Dolag et al

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Workshop Dark matter
CPPM 12 october 2011

Outline

- **N-body simulations : some basics**

- **Features of dark matter halos and disk galaxies**

Introduction

Hierarchical structure formation scenario

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

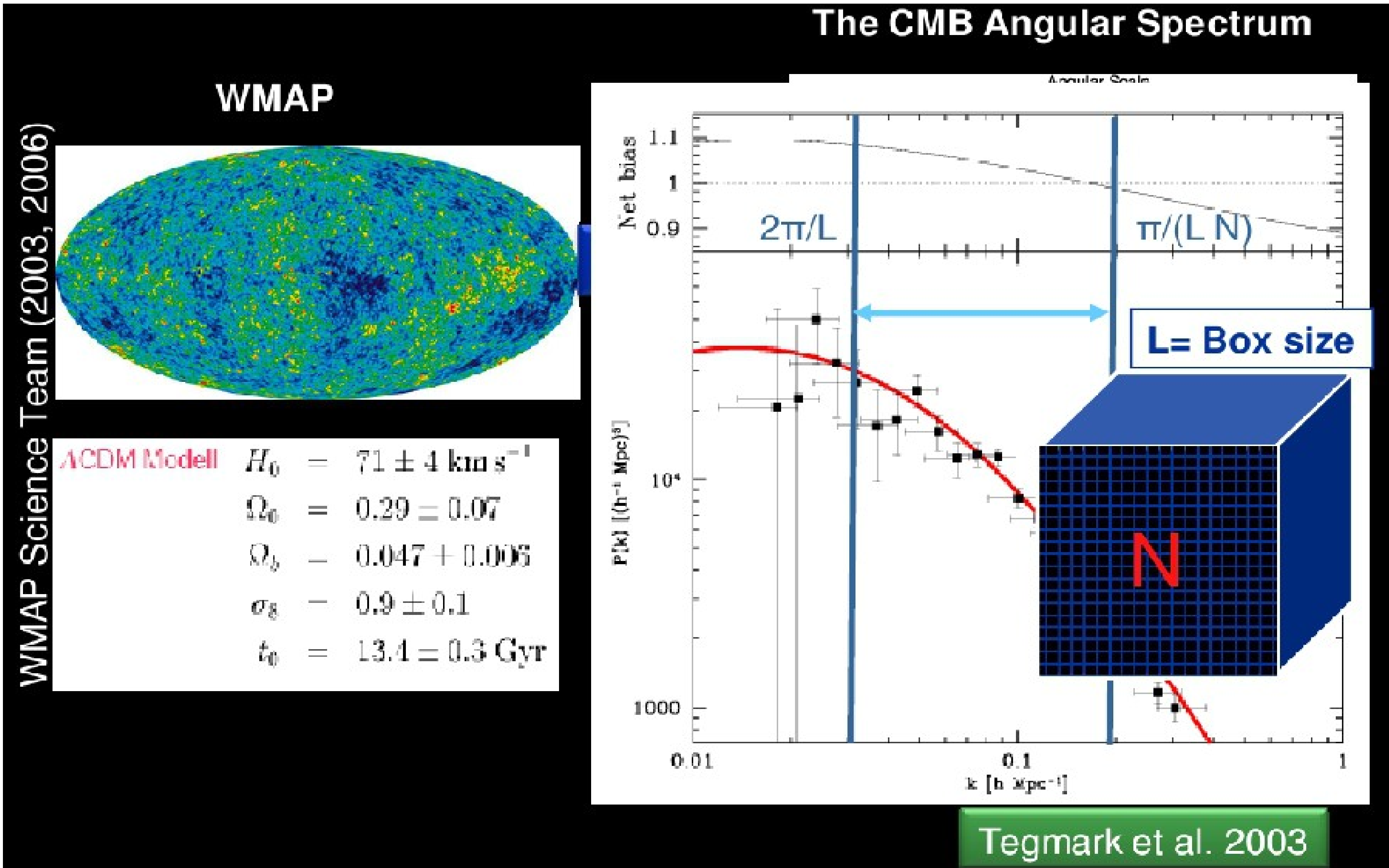
- Size of the box

- 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)

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

- **Gravity : Vlasov and Poisson equations**

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 :

- **Lagrangian : fluid=particles (SPH)**
  GADGET code (V.Springel)
- **Eulerian : fluid=grid (AMR)**
  RAMSES code (R.Teyssier)
- **"Hybrid"**
  AREPO (V.Springel)

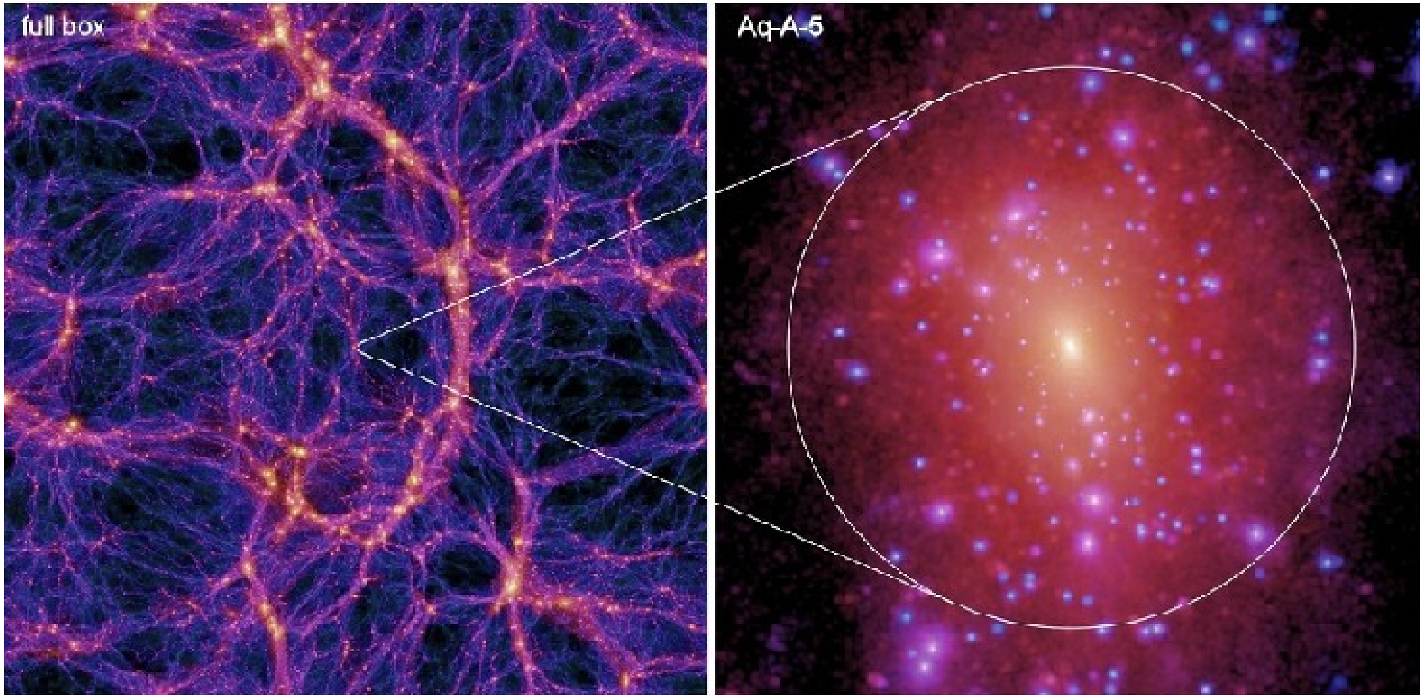
Some results

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

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, Sheth-Tormen)**

= CLUMPS



AQUARIUS, Springel et al 2008

Some results

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

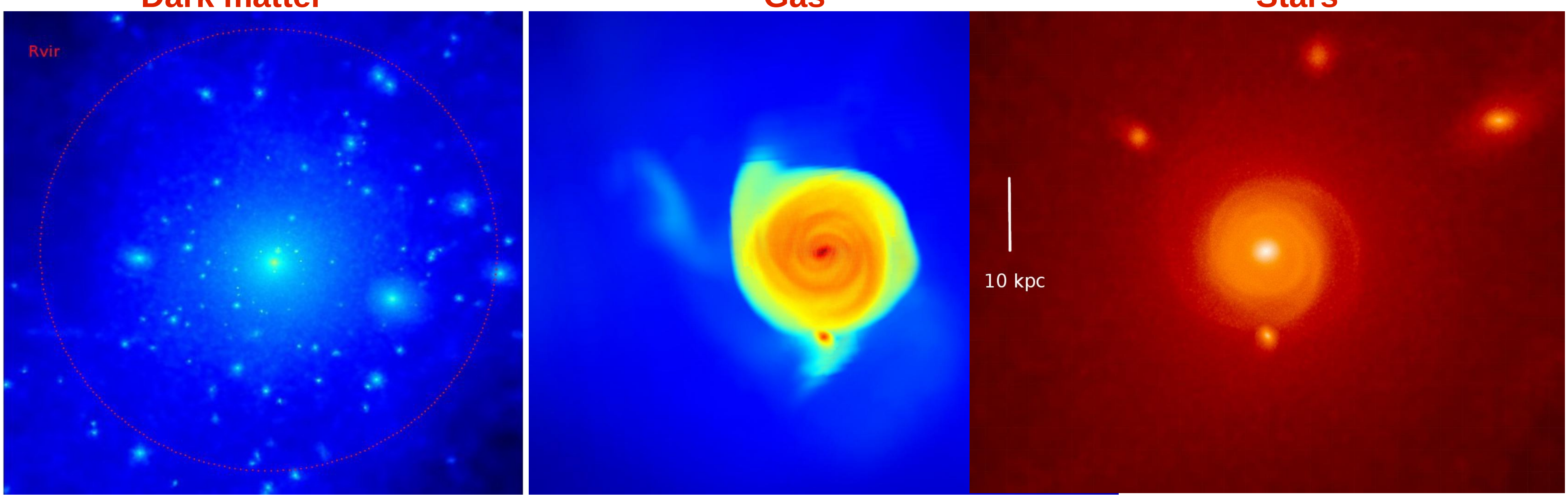
Simulations including gas :

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

- **Gas accreted in DM potential**

  → Disk and stars formation

Dark matter **Gas** **Stars**



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**
- **ρ0 threshold density**
- **ε_{ff} drive star formation rate**

→ Transform gas into star particles

Supernovae feedback

- **Type II SN, relevant for stellar masses ~** $8-40\ M_\odot$
- **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** $E_{\rm SNII} = 10^{51}\,{\rm erg}$

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

(Cuspy ?) Dark matter Halos

Fit of N-body results :

- **Cusps**

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

- **Einasto (AQUARIUS)**

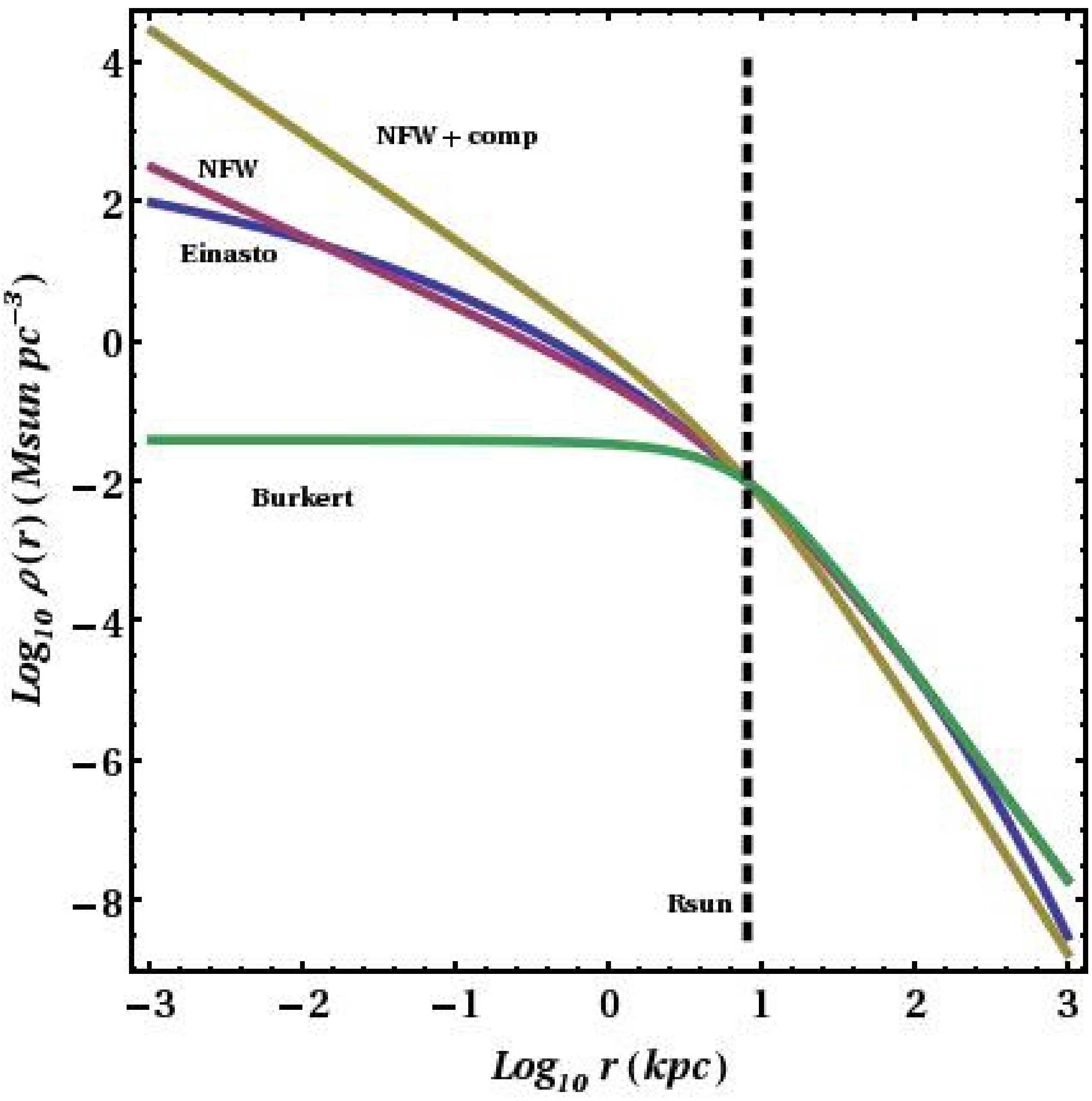
$$\rho_D M(r) = \rho_{-2} e^{-\frac{2}{\alpha}[(r/r_{-2})^\alpha - 1]}$$

- **Burkert :**

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

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

(Cuspy ?) Dark matter Halos



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,Pontzen& Governato arxiv:1106.0499

- Stellar formation rate could help to solve angular momentum problem
(=bulges too dominant, discs not extended enough)
-> more realistic (larger) disk. Agertz, Teyssier, Moore arxiv:1004.0005

- Higher feedback could erase the cusp even in massive spirals. Maccio et al arxiv:1111.5620

Still debated ...

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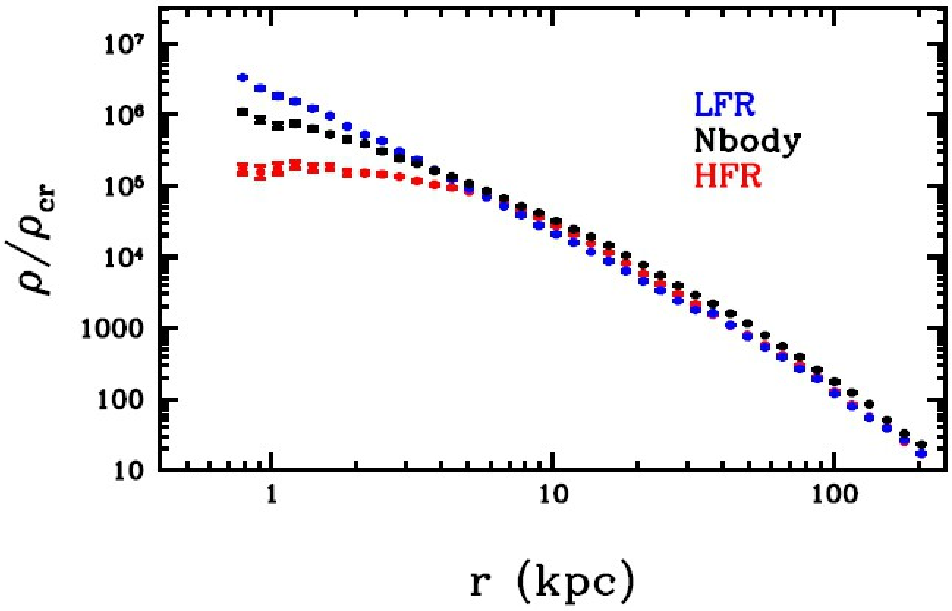
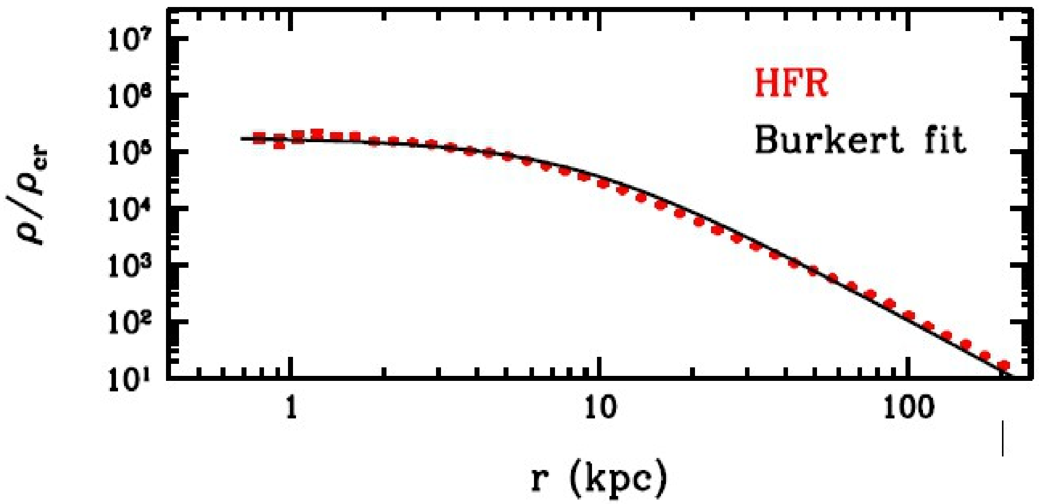




Still debated ...

Local dark matter

Capture rate :

- Local dark matter density

- Velocity distribution

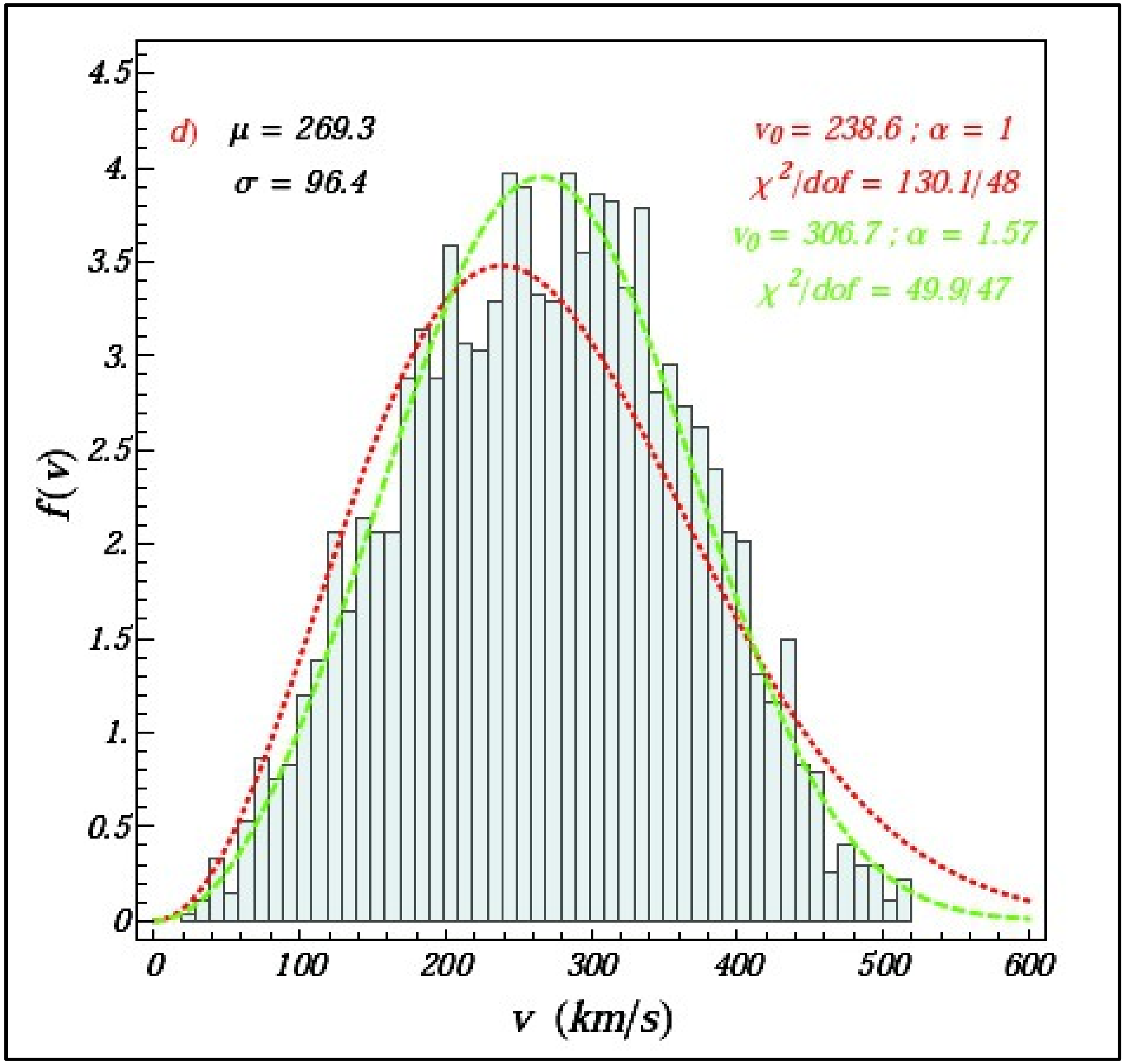
$$\eta = \int d^3\vec{v}\, \frac{f(\vec{v})}{\left|\vec{v} - \vec{v}_{\oplus,G}\right|}$$

Features ≠ Maxwellian ?
Dark disk ?
Corotation ?

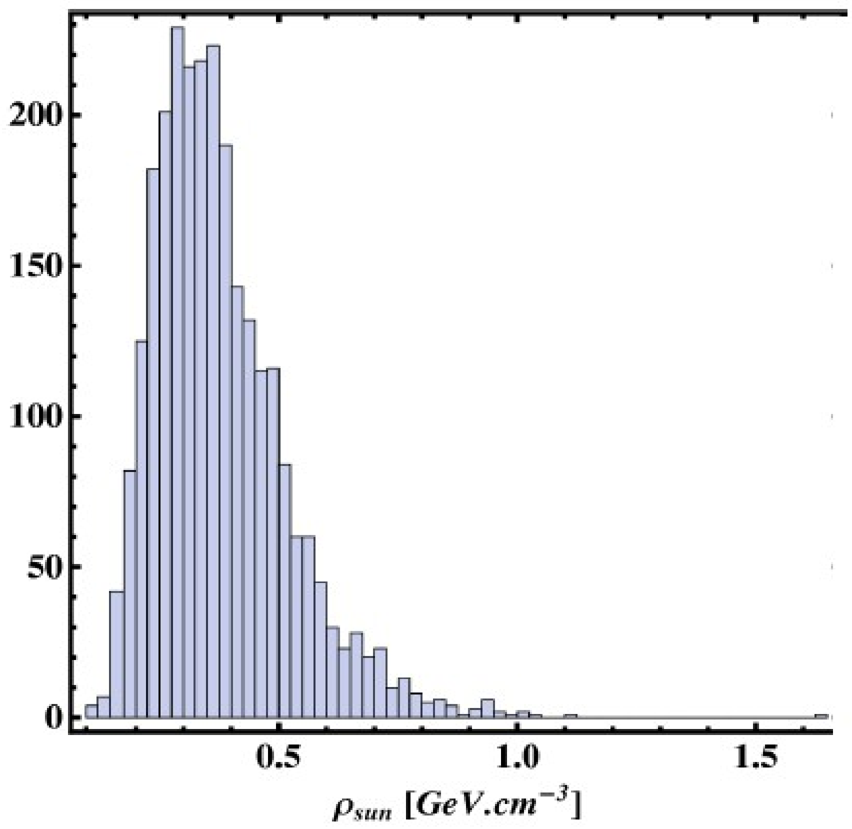
Dark disc : clump accretion by stellar and star disc … *Read et al* 0902.0009

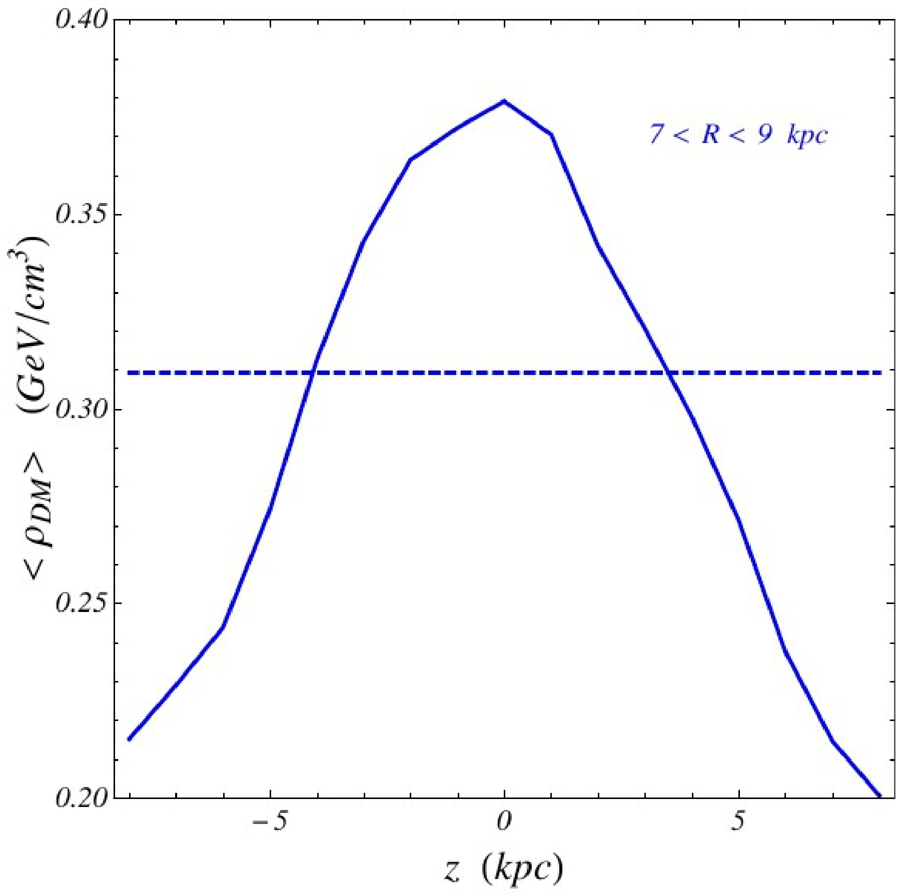
→ enhancement of DD and neutrino telescope signal ?
capture rates in the Sun ? *Bruch et al 2009 vs Ling 2010*

Simulation : Dark matter velocity distribution



Cosmological simulation : Local DM density, Dark disk ?





Mean(ρ_{sun}) > 0.3 GeV.cm3

Local dark matter

Iocco et al : arxiv:1107.5810
Microlensing and dynamical constraints
-> constraint on density profile and local dark matter 0.20-0.56 Gev/cm3

Catena and Ullio
arxiv:0907.0018 : use dynamical observables
(circular velocity, total mass,surface mass ...) to constrain the galaxy model
-> higher local dark matter density ~ 0.39 Gev/cm3

arxiv:1111.3556 : Eddington's formula
Link dark matter profile with phase-space distribution
-> different from Maxwell distribution (higher DD rates)

Sallucci et al arxiv:1003.3101
Relies on the local centrifugal equilibrium
Inpedendent of uncertainties concerning halo proofile, bulge/disk/halo mass decomposition,
Whole galaxy modelling
-> 0.43(11)(10) GeV/cm3

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

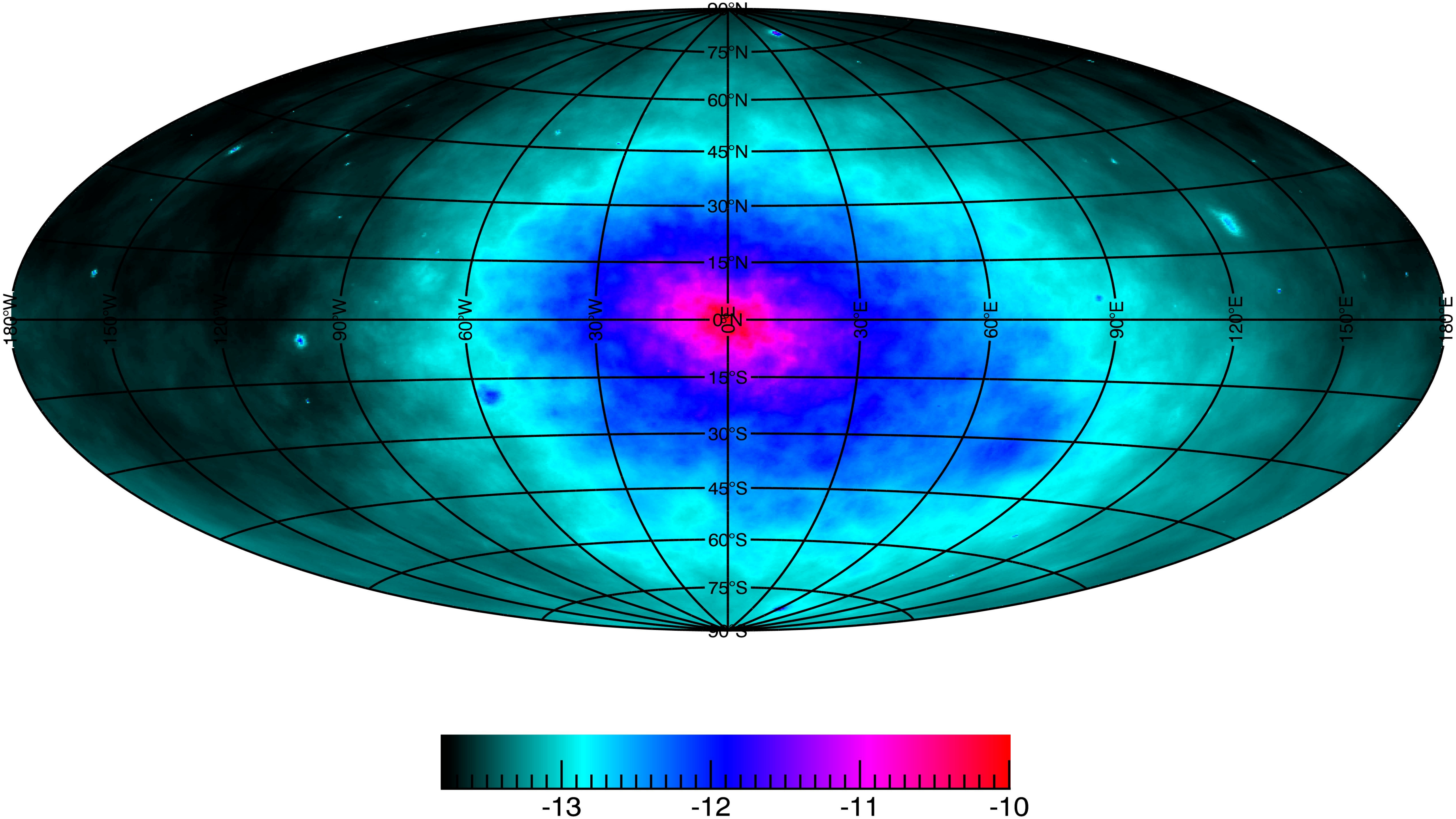
Annihilation cross section
Dark matter mass
Annihilation induced spectra

DM distribution:

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

Gamma/Neutrino skymap : Dark matter contribution

N-body simulation : dark matter only

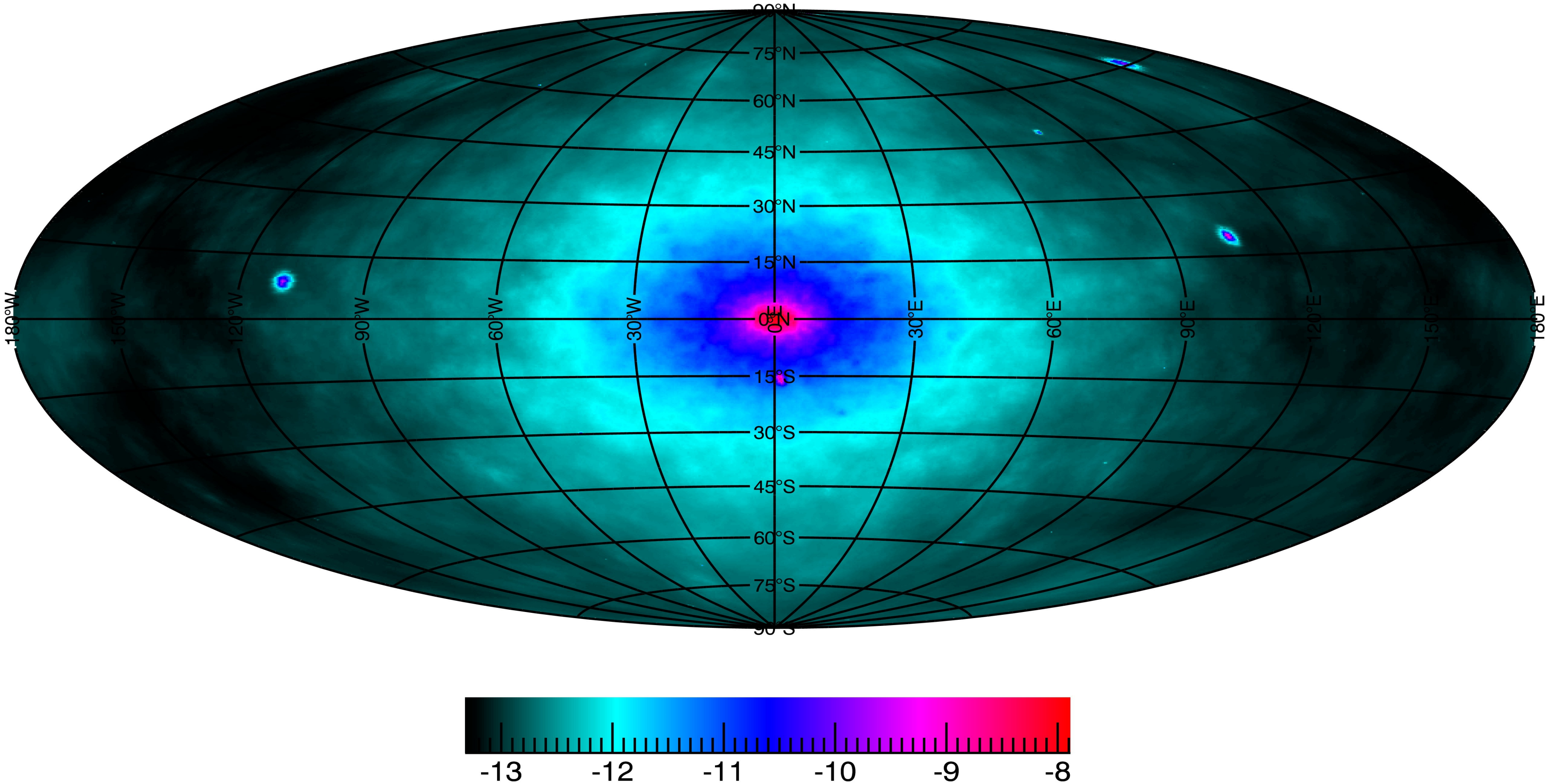


+ standard thermal (HEP+cosmo) scenario
Gammas : FERMI,HESS ~ -10
Neutrinos : KM3Net GC ~ -9

arxiv:0801.4673

Gamma/Neutrino skymap : Dark matter contribution

N-body simulation : dark matter + baryons



~ 2 orders of magnitude higher fluxes in central region

Very high astrophysics contribution → HEP scenarios

Possible conflict with observations FERMI, HESS ...

Depend on background …

Nezri, Lavalle, Teyssier … in prep

Thanks