N-body Simulations with Baryons: Implications for Direct Detection.

Fu-Sin Ling

GDR Terascale – Heidelberg, 15 october 2009

FSL, E. Nezri, E. Athanassoula, R. Teyssier 2009, arXiv:0909.2028

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Outline

- Description of the simulation
- Velocity distributions
- Dark disk
- Direct detection
- Summary

Description of the simulation

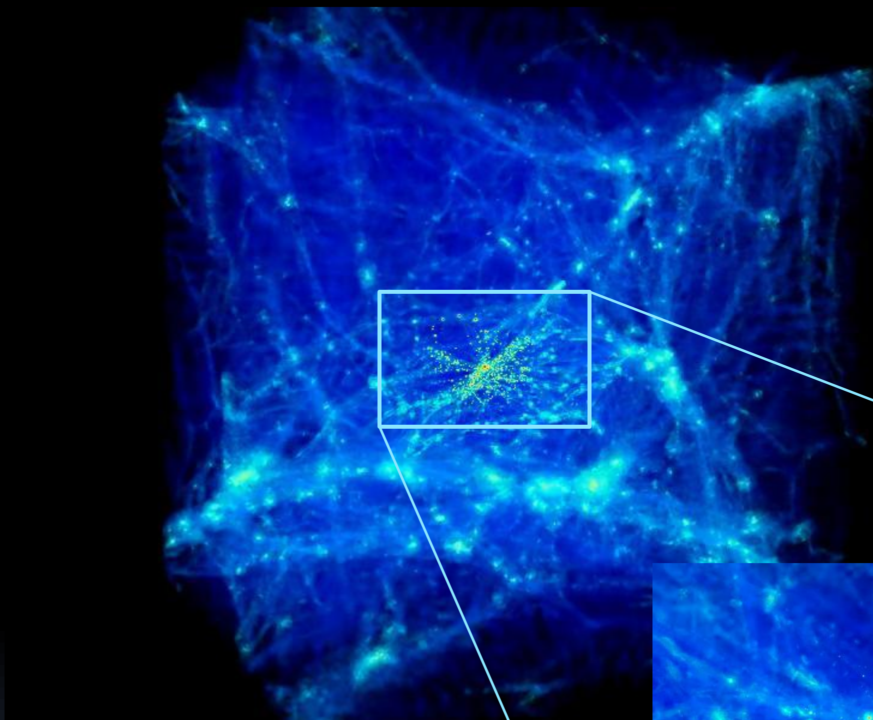
Cosmological parameters :

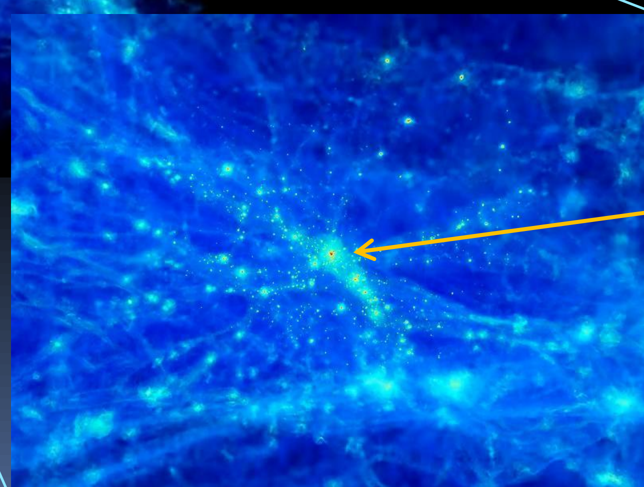
$\Omega_b = 4.5\ \%$; $\Omega_m = 30\ \%$; $\Omega_\Lambda = 70\ \%$

Includes DM, stars & gas. Full hydro with :

- gas radiative cooling
- star formation
- SN feedback
- chemistry

code : AMR Ramses (R. Teyssier)

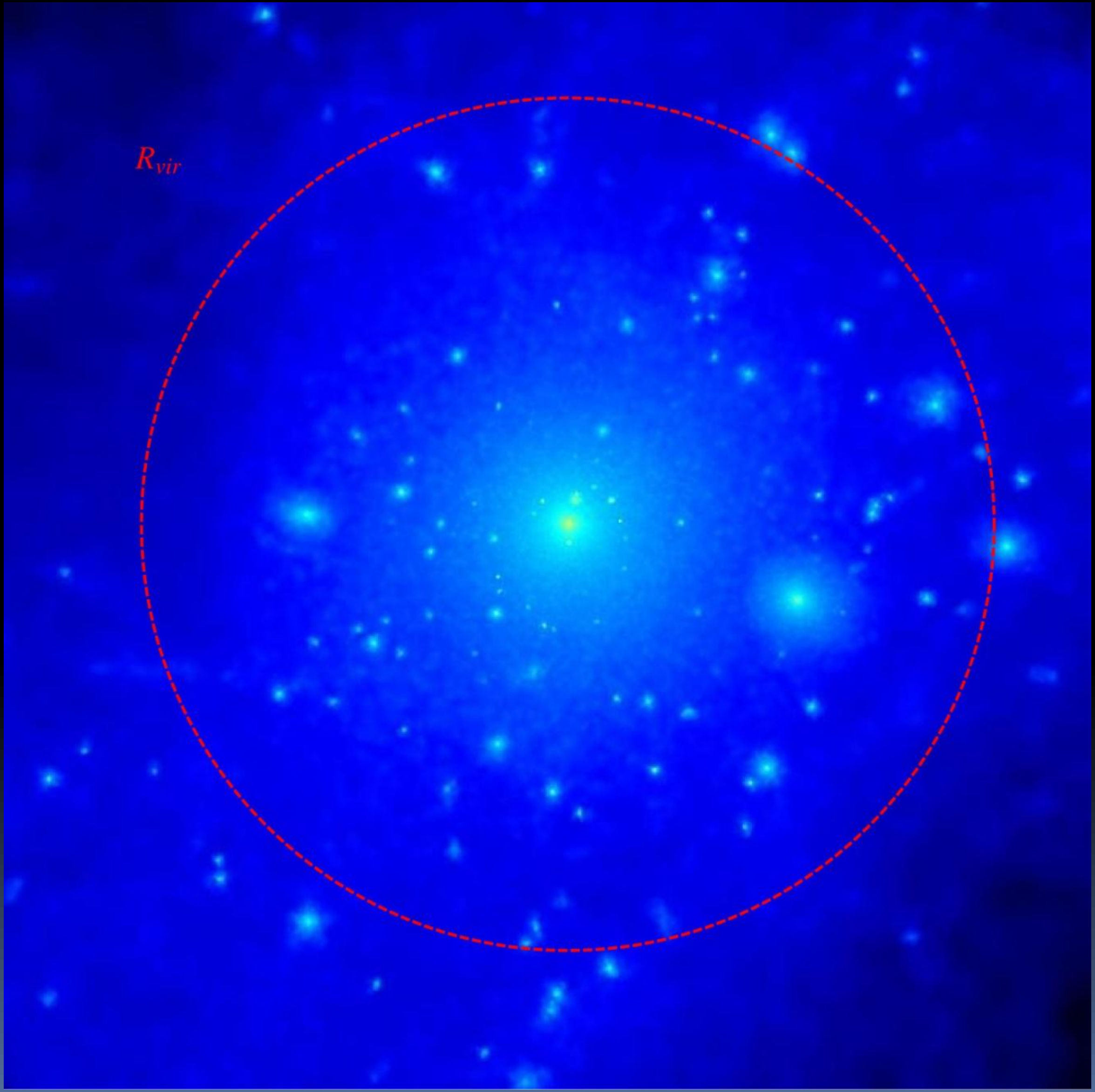




L_{box} = 20 Mpc/h

N = 1024^3 elements

Galactic DM halo



R_{vir} = 264 kpc

N_{DM} = 843 000

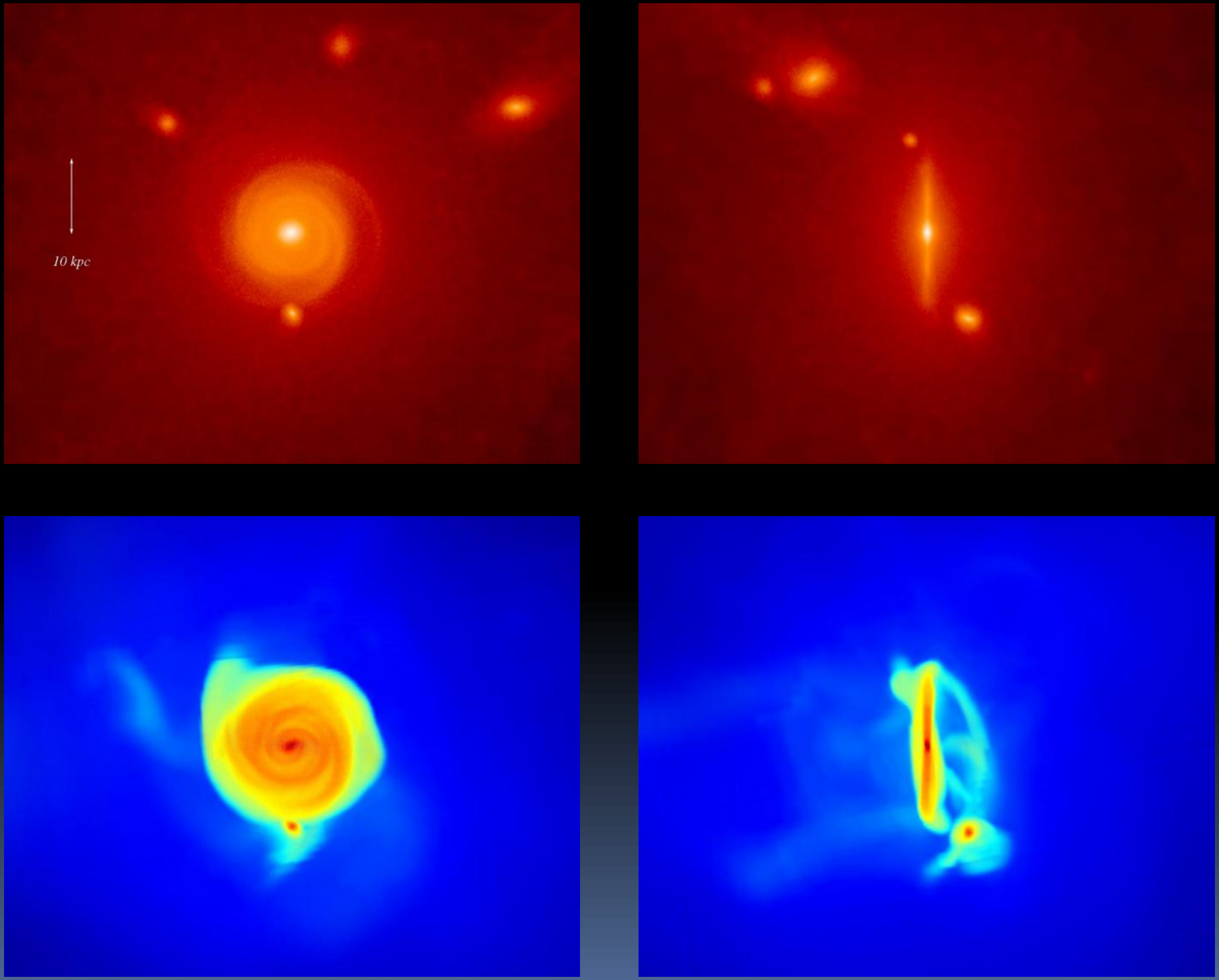
$M_{vir} = 6.3 \times 10^{11}\ M_{sun}$

δl = 200 pc

Galactic disc and bulge

Stars

Gas



Comparison with Milky Way

	Milky Way	Simu
DM halo mass	$2.35 \times 10^{12}\ M_{sun}$	$6.3 \times 10^{11}\ M_{sun}$
Bulge mass	$1.8 \times 10^{10}\ M_{sun}$	$4.0 \times 10^{10}\ M_{sun}$
Disc mass	$6.5 \times 10^{10}\ M_{sun}$	$4.0 \times 10^{10}\ M_{sun}$
Disc scale radius	3.5 kpc	1.9 kpc

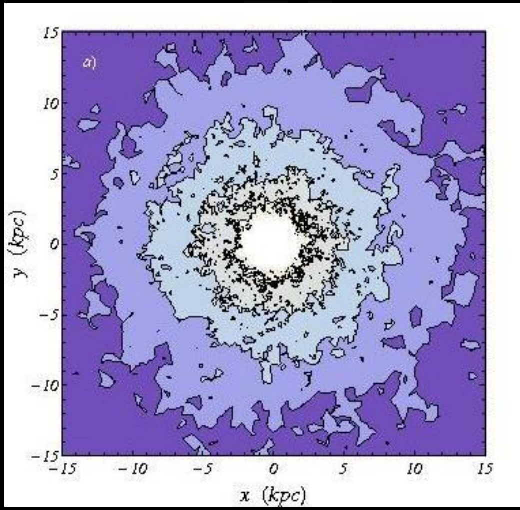
Sofue, Honma, Omodaka 2008, arXiv:0811.0859

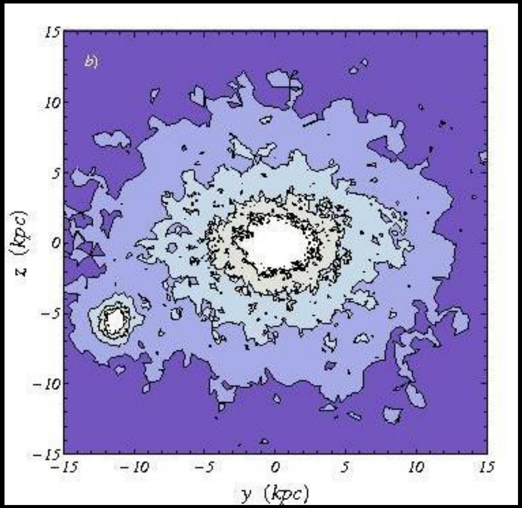
- Low mass halo
- Bulge too fat
- Disc too small

→ generic problems of simulations with baryons

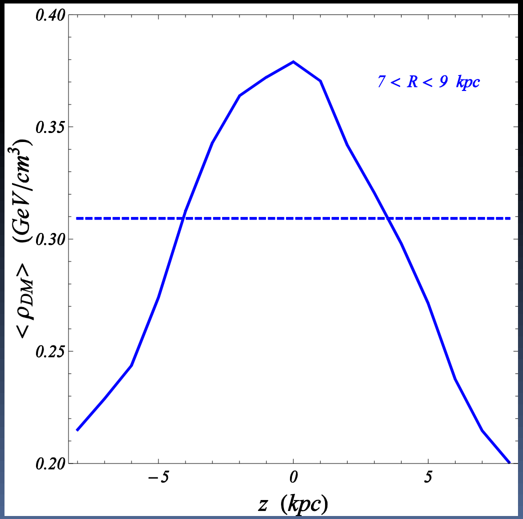
Dark Matter density

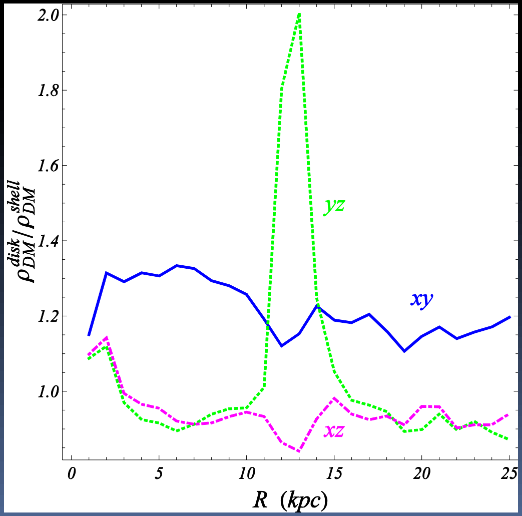
Pxy
(galactic plane)





Pyz



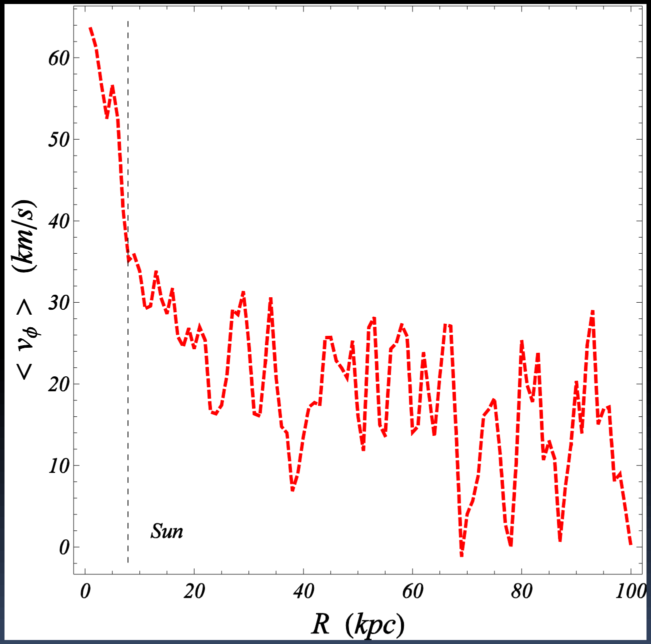


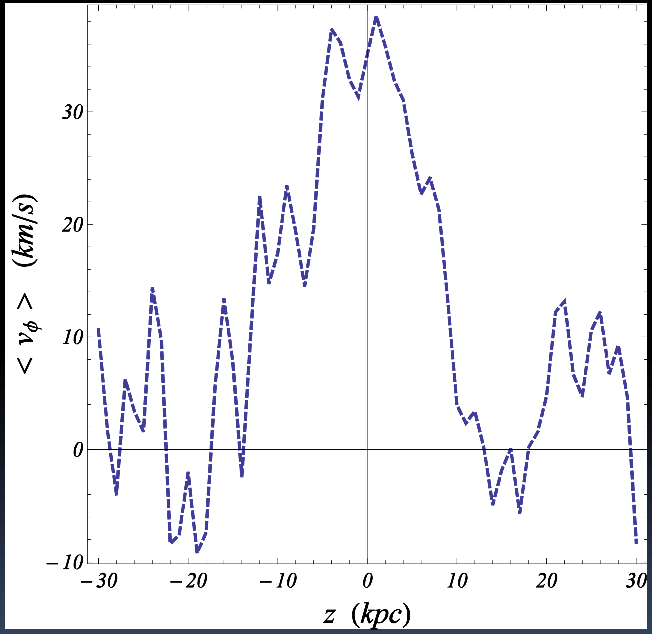
Q1 : Is there a dark disk in the Milky Way ?

Q2 : Does the dark disk affect DM signals ?

Dark Disk

- New DM component found (?) in cosmological N-body simulations : thick disk of DM co-rotating with the galactic disc of stars





Dark Disk

- New DM component found (?) in cosmological N-body simulations :
  thick disk of DM co-rotating with the galactic disc of stars

- Origin of dark disc and rotation :
  Accreted DM from mergers, preferential drag towards galactic plane

- Characteristics depend on merger history and correlate with those of accreted stars

  $\rho_{DD} = 0.25 \ldots 1.5\ \rho_H$

  $v_{lag} = 0 \ldots 150\ km/s$

- Velocity dispersion : - small in controlled simulations $\sigma \sim 50\ km/s$

  - large in full hydro simulations $\sigma > 100\ km/s$

Implications for searches

- Direct detection : - Enhanced signal @ low energy recoil

  - Enhanced annual modulation

  - Modulation phase : maximum occurs earlier

- Indirect detection : - Enhanced capture in the Sun

  - Enhanced capture in the Earth

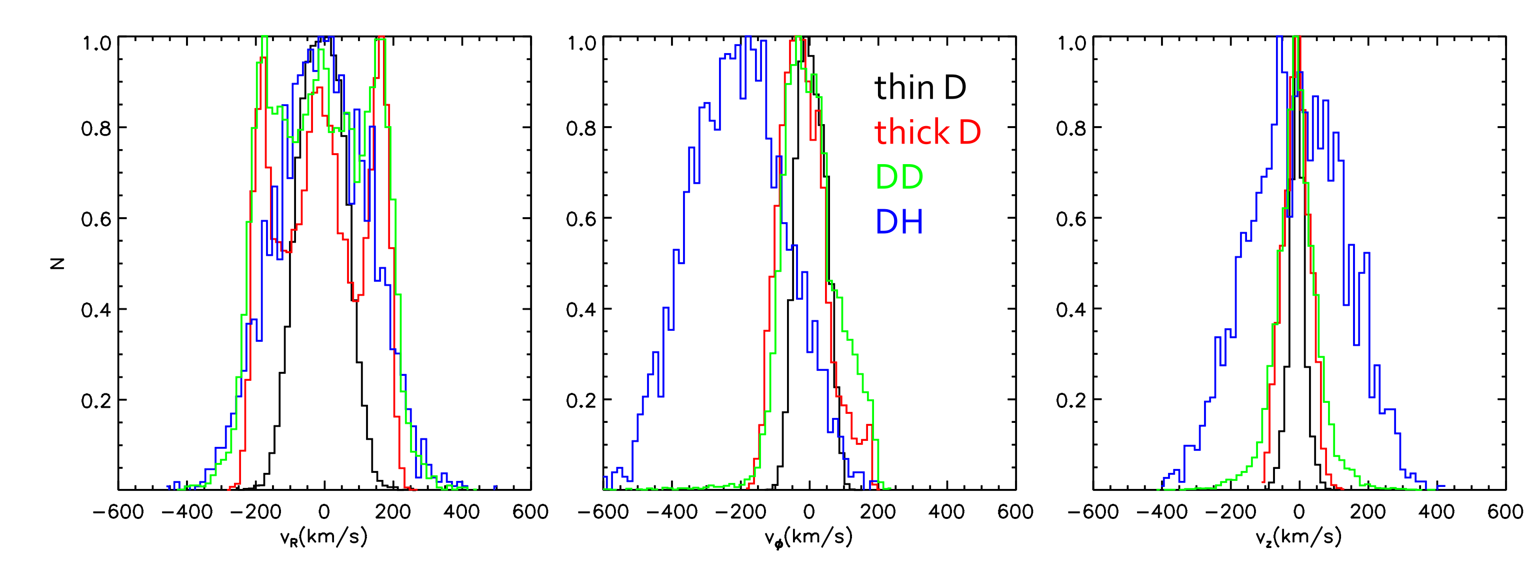
  → Larger muon neutrino flux

Growth of galactic disk

- DM halos & galactic disks grow dominently by mergers with

  $M_{sat} : M_{host} = 1 : 10$ Purcell et al. 2008, arXiv:0810.2785

- Dark disk : low inclination merger leads to a thick disk of DM



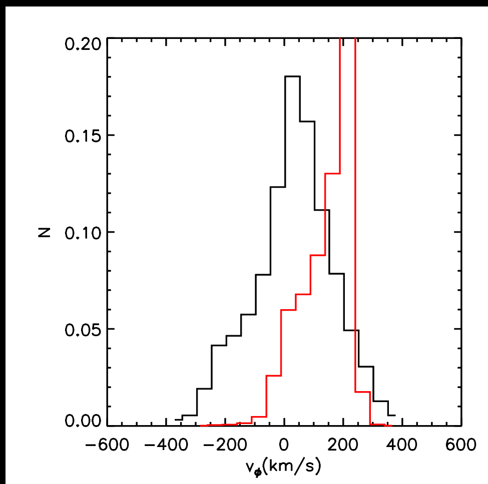
→ Controlled simulations Read et al. 2008, arXiv:0803.2714

- Dark disk characteristics depend on merger history

Read et al. 2009, arXiv:0902.0009

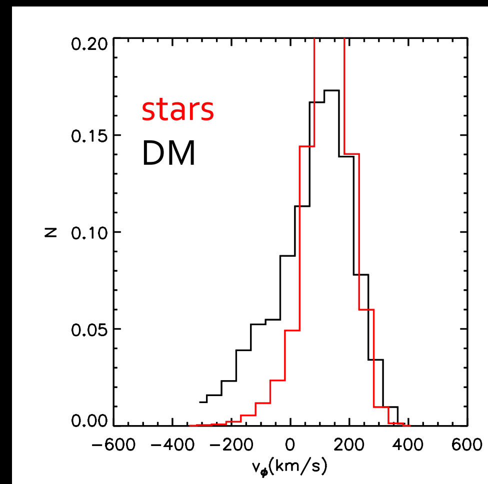
→ Fully consistent cosmological hydrodynamics simulations

MW1



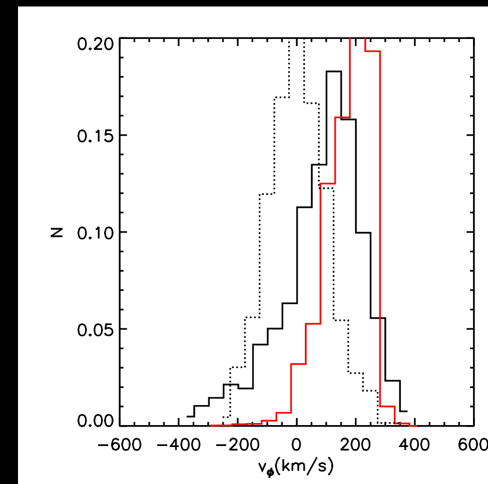
no significant merger
after z = 2

H204

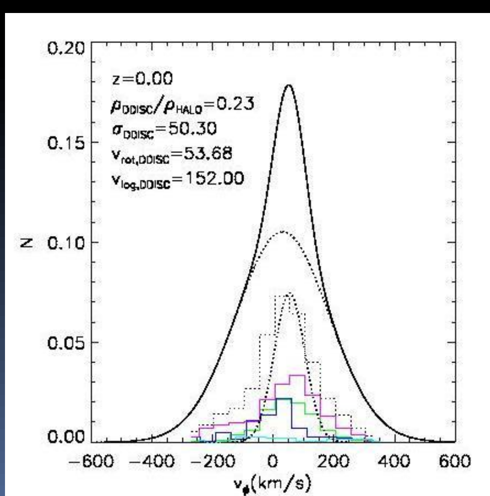


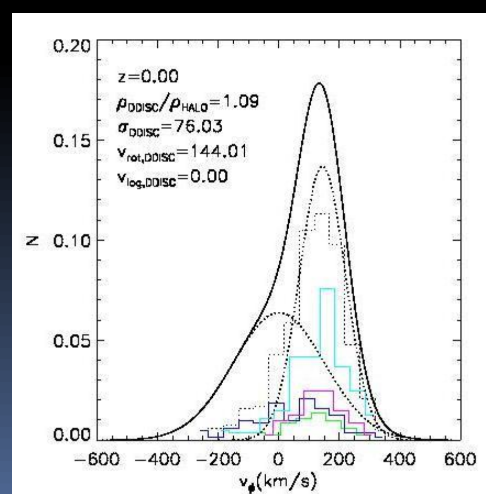
several massive merger
after z = 1

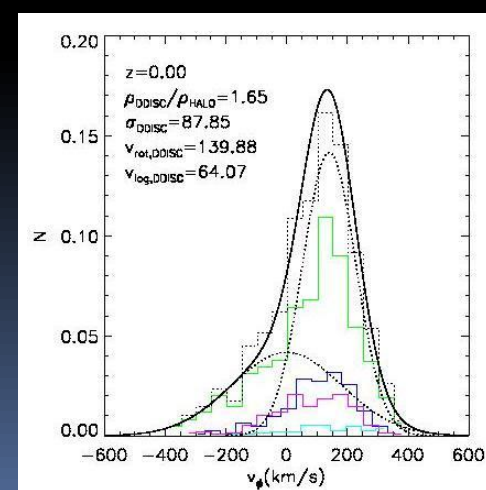
H258



very massive merger 1 : 1
at z = 1

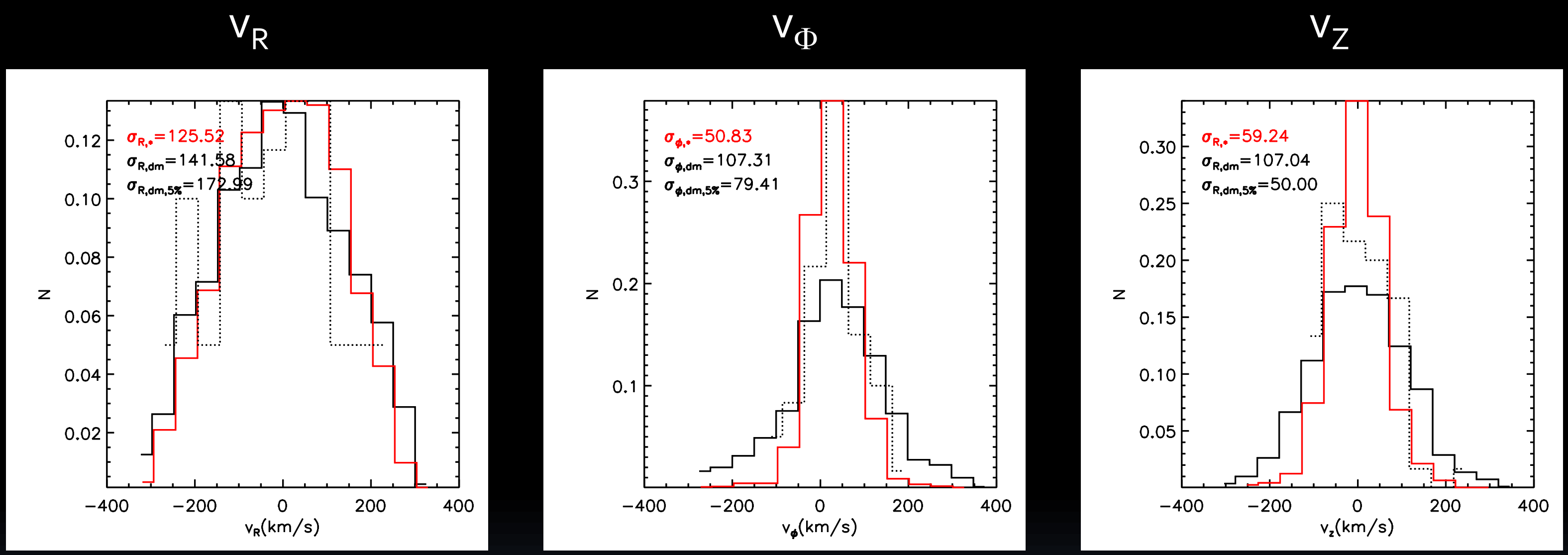






- Thick disk : stars from the satellite halo settle in a thick disk of the host halo
- Comparison between accreted DM and accreted stars

MW1

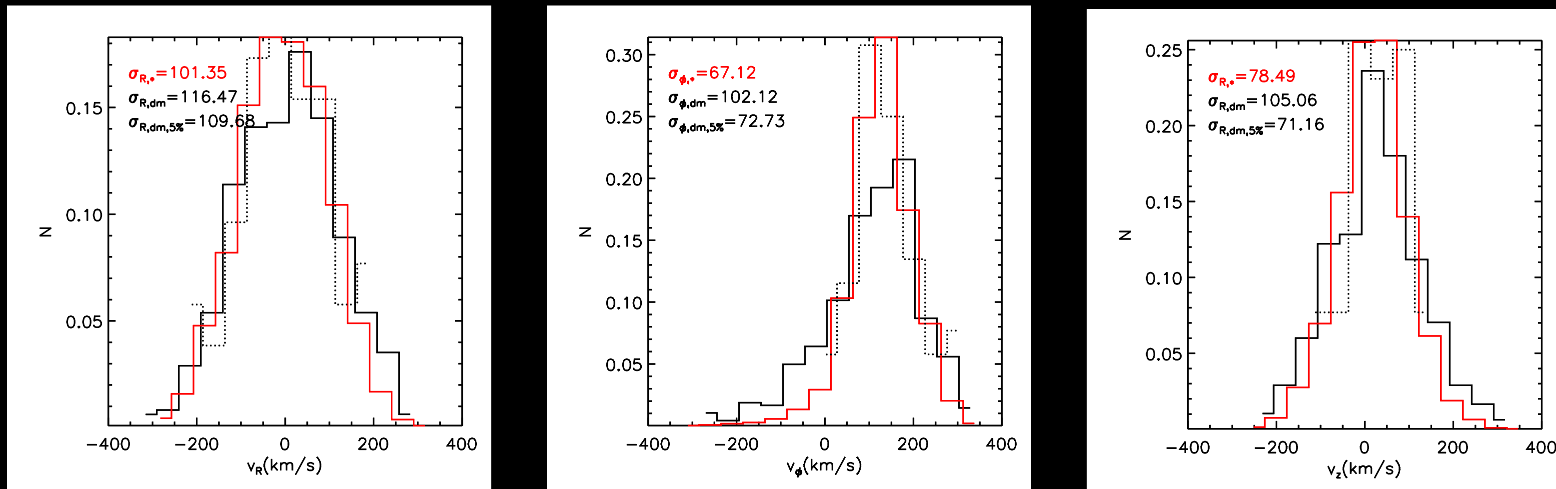


→ *σ ~ 120 km/s*

Read et al. 2009, arXiv:0902.0009

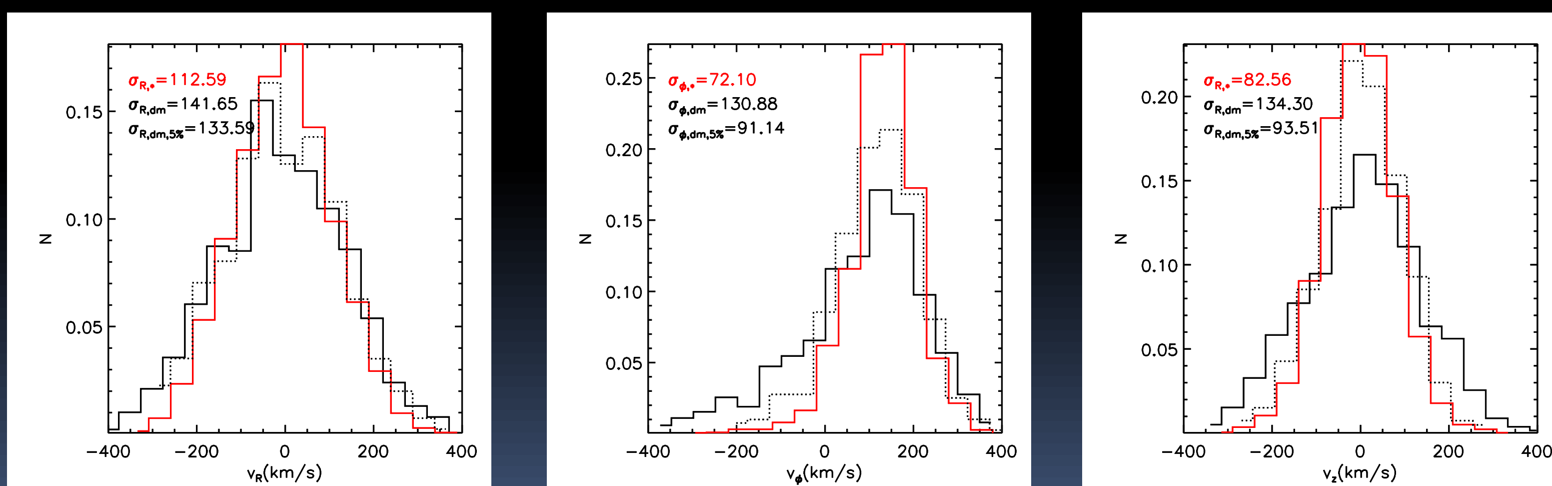
v_R v_Φ v_Z

H204



→ *σ ~ 108 km/s*

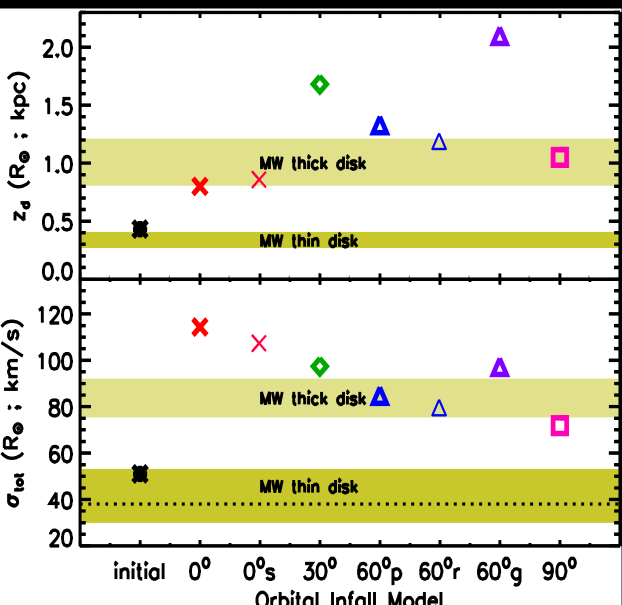
H258

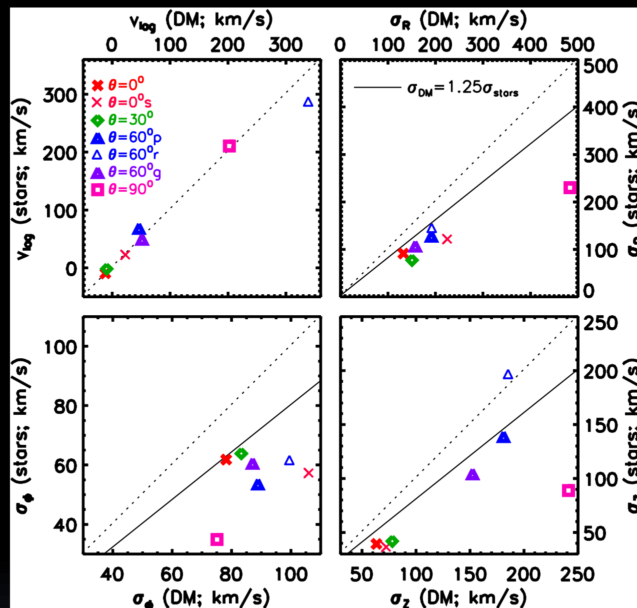


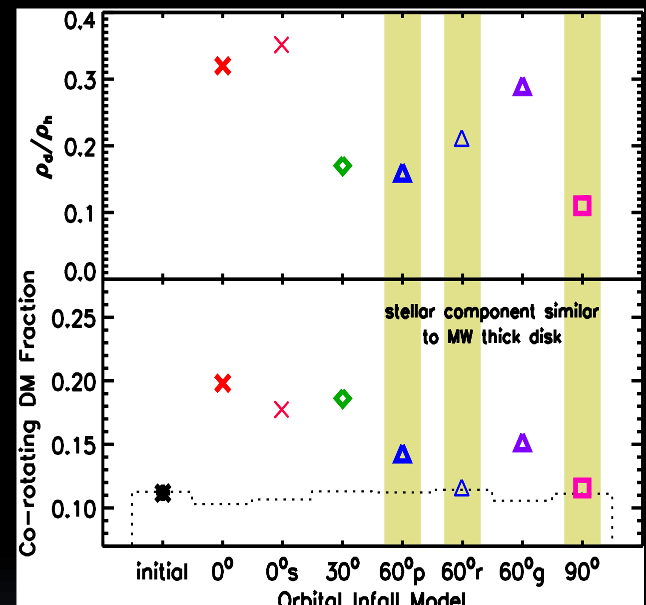
→ *σ ~ 135 km/s*

Comparison with Milky Way

→ Controlled simulations







→ MW merger history must have been unusually quiescent

→ Dark disk contribution small (<20% host halo density at Sun's location)

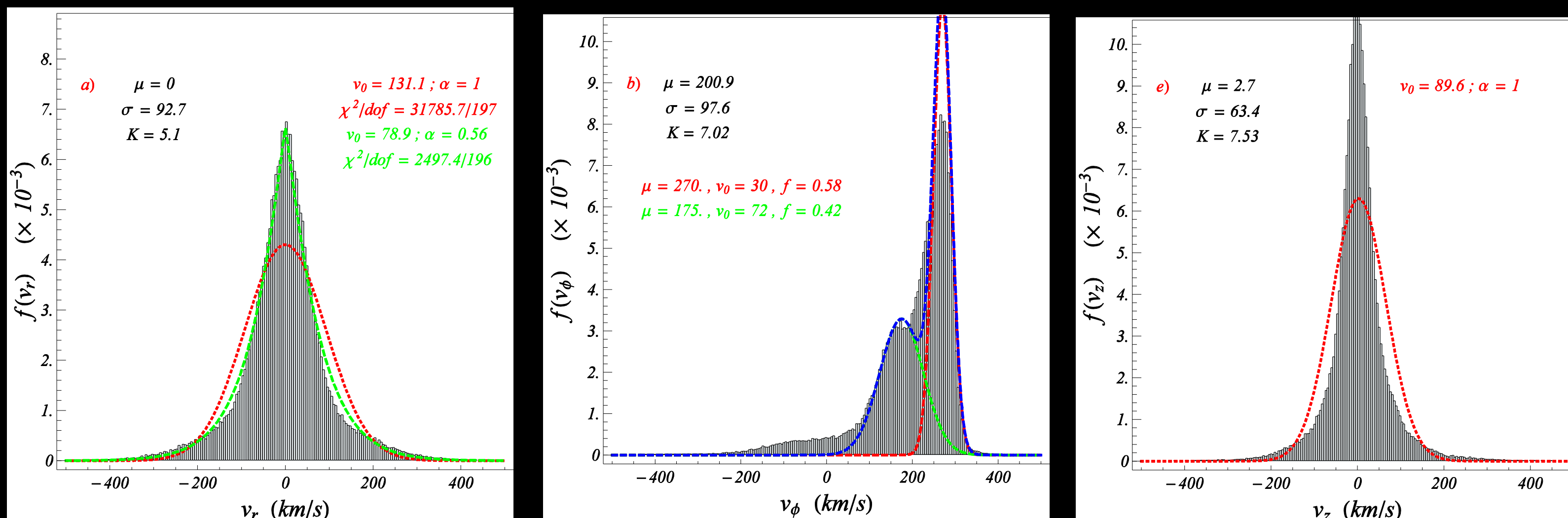
→ Velocity dispersion of accreted stars ≠ final thick disk stars velocity dispersion

Purcell et al. 2009, arXiv:0906.5348

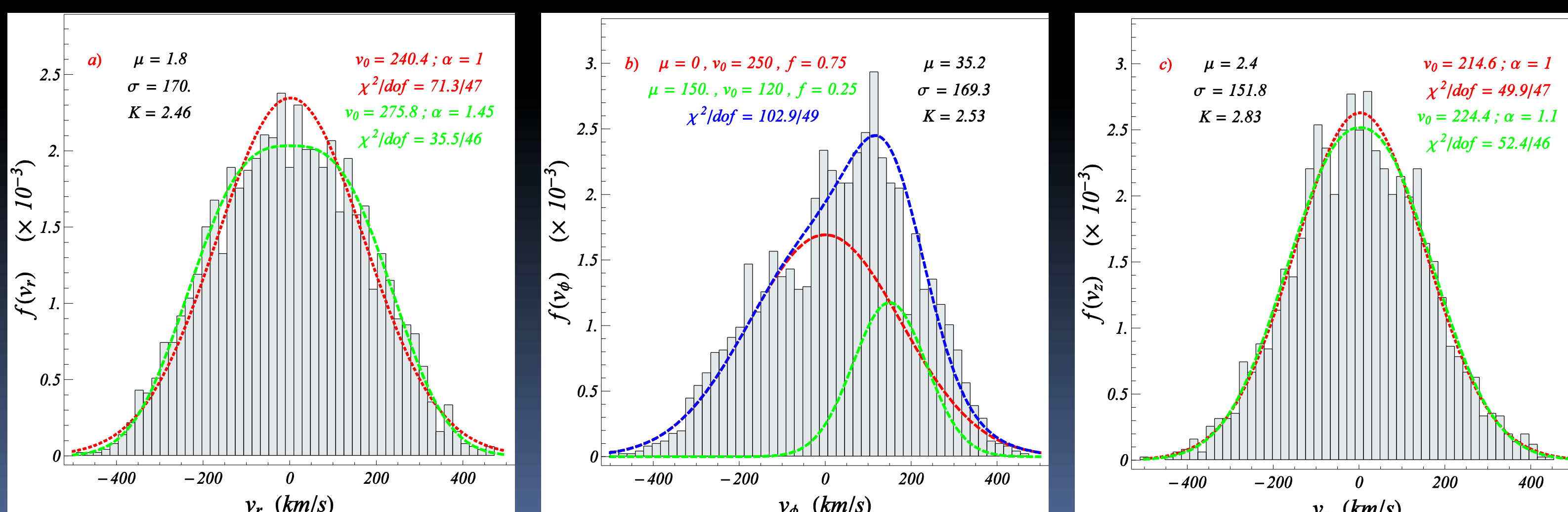
Velocity distributions

$N_{ring} = 2\,650$

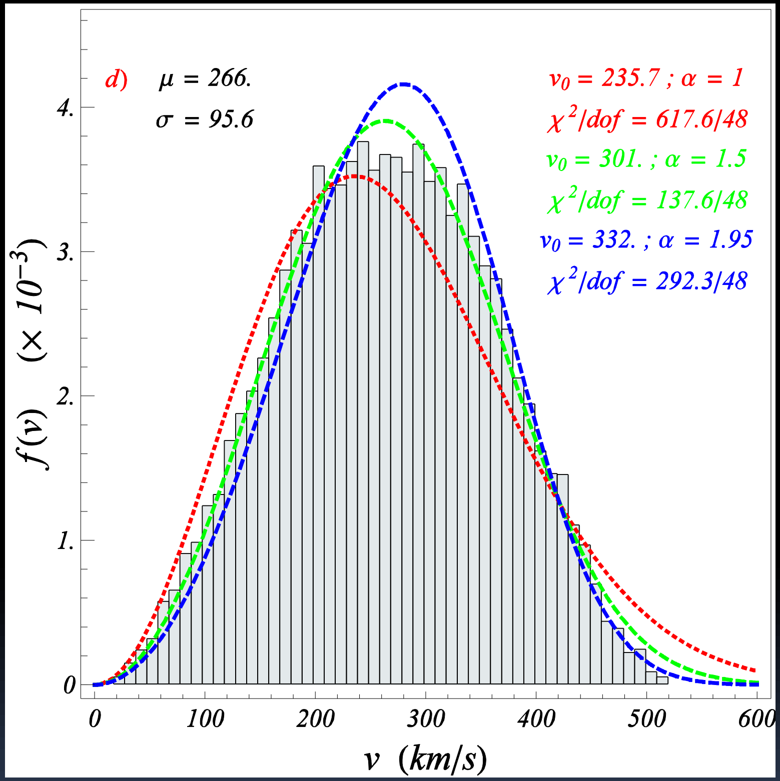
Stars



DM



Velocity wrt galactic center



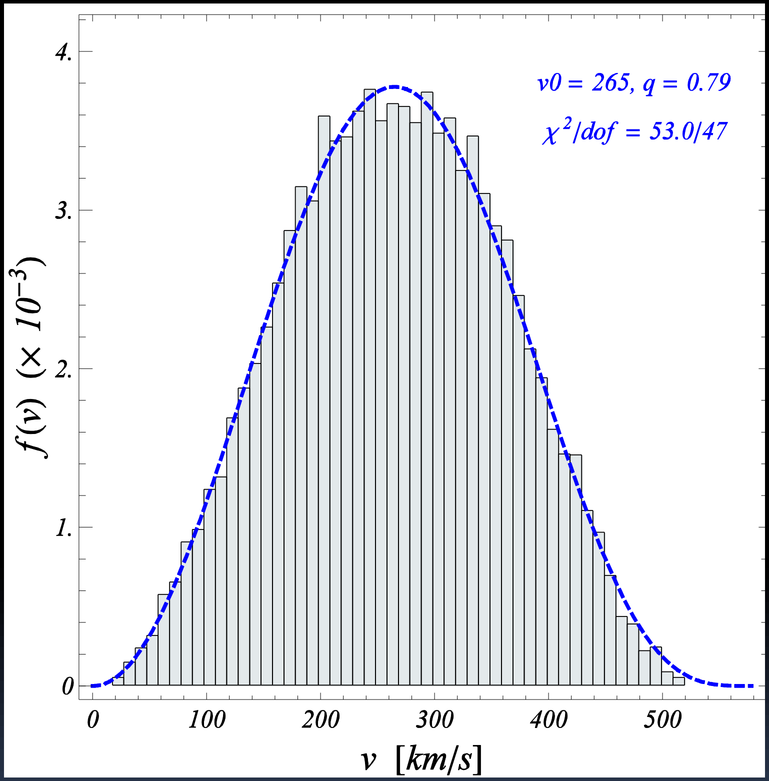
Generalized Gaussian and Maxwellian distributions

$$f(\vec{v}) \sim e^{-((v-\mu)^2/v_0^2)^\alpha}$$

$$f(\vec{v}) \sim v^2 e^{-((v-\mu)^2/v_0^2)^\alpha}$$

$N_{shell} = 16\,500$

Velocity wrt galactic center



Tsallis distribution

$$f(\vec{v}) \sim v^2 \left(1-(1-q)\frac{v^2}{v_0^2}\right)^{\frac{q}{1-q}}$$

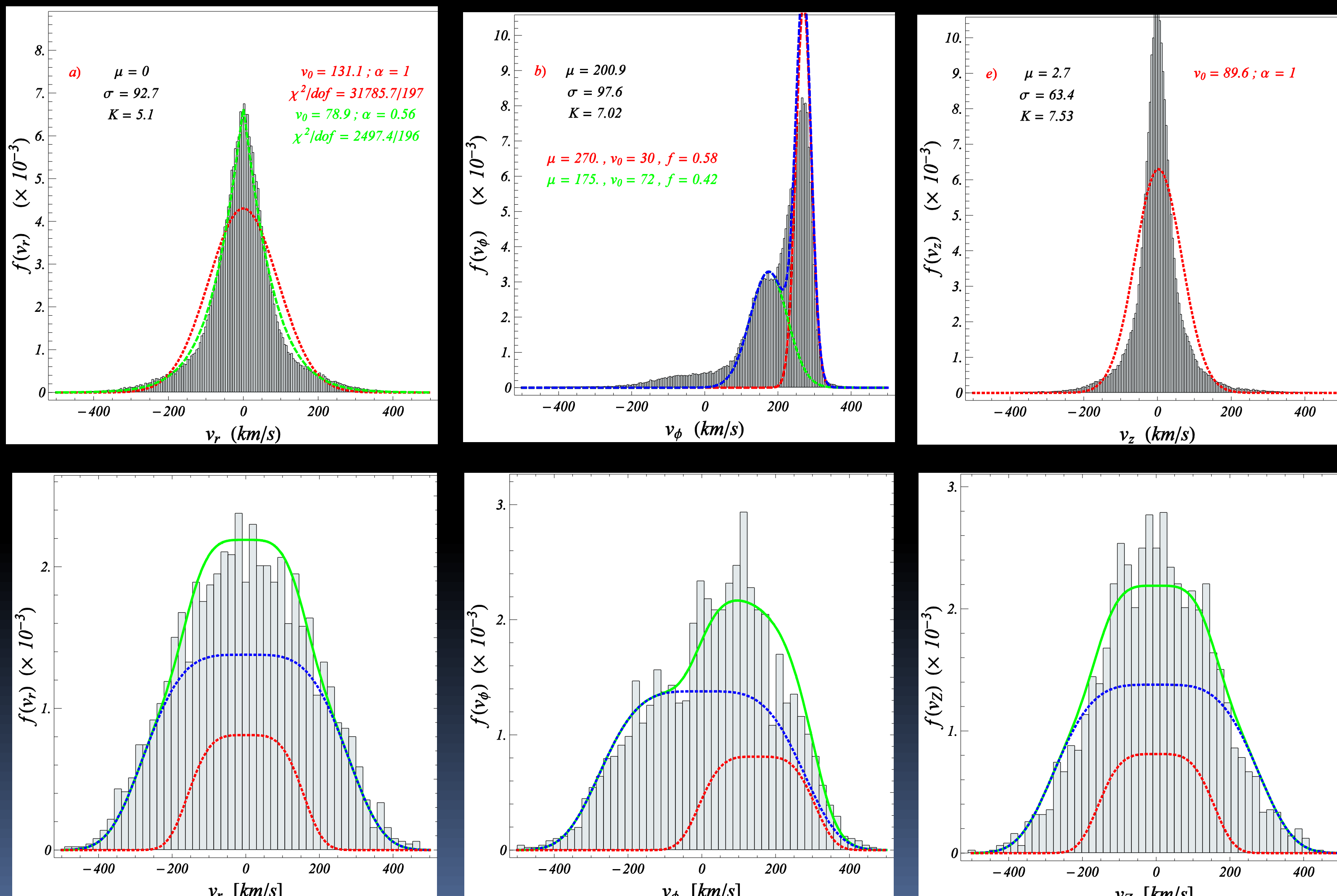
N_{shell} = 16 500

Velocity distributions

$N_{ring} = 2\,650$

Stars

DM



Is there a Dark Disk ?

- Resolution is not sufficient to clearly disentangle a rotating dark disk from a static halo
- Velocity distributions compatible with mild dark disc

$$\rho_{DD} = 0.25\,(\rho_H + \rho_{DD})$$

$$v_{lag} = 70\ km/s$$

- Velocity dispersion : $\sigma \sim 100\ km/s$

but platykurtic (K < 3) distributions in *r* and *z* !!

Velocity wrt the Sun

Standard Maxwellian Halo :

$v_o = 220$ km/s ; $\alpha = 1$
$\sigma x = \sigma y = \sigma z = 155$ km/s

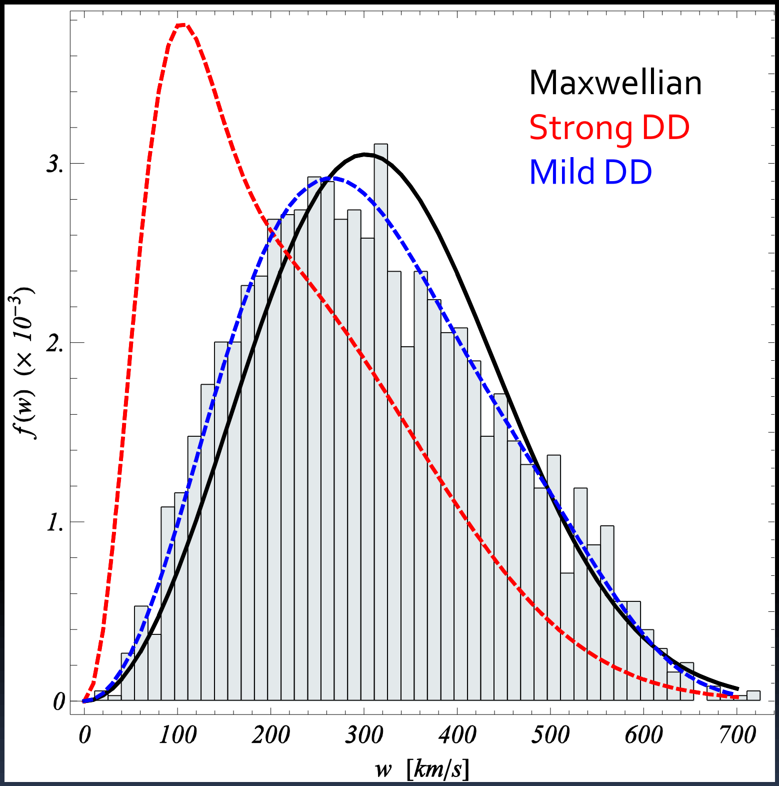
SH + Strong Dark Disk :

$v_{oDD} = 70$ km/s ; $\alpha_{DD} = 1$
$\sigma x_{DD} = \sigma y_{DD} = \sigma z_{DD} = 50$ km/s
vlag = 50 km/s
$\rho_{DD}/\rho_H = 1/1$

Mild Dark Disk :

$v_o = 300$ km/s ;
$\alpha x = \alpha y = \alpha z = 2$
→ $\sigma x = \sigma y = \sigma z = 175$ km/s

$v_{oDD} = 170$ km/s
$\alpha x_{DD} = \alpha y_{DD} = \alpha z_{DD} = 2$
→ $\sigma x_{DD} = \sigma y_{DD} = \sigma z_{DD} = 100$ km/s
vlag = 70 km/s
$\rho_{DD}/\rho_H = 1/3$



Velocity wrt the Sun

Standard Maxwellian Halo :

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vlag = 50 km/s
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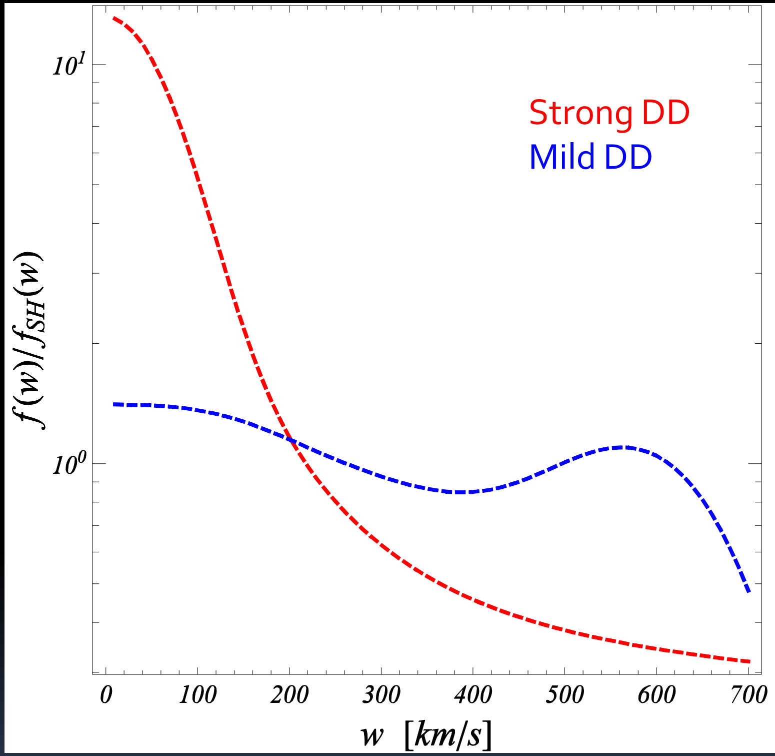
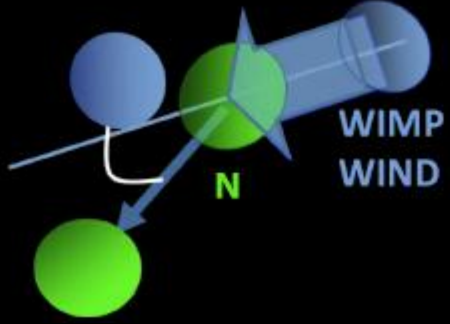


Direct Detection – Event rate



Differential rate

$$\frac{dR}{dE_R} = \frac{\rho_{DM}}{M_{DM}} \frac{d\sigma}{dE_R} \eta(E_R, t)$$

particle and nuclear physics

astrophysics

$$\frac{d\sigma}{dE_R} = \frac{M_N}{2\mu_n^2} \sigma_n^0 \frac{\left(f_p^2 Z + (A-Z) f_n^2\right)^2}{f_n^2} F^2(E_R)$$

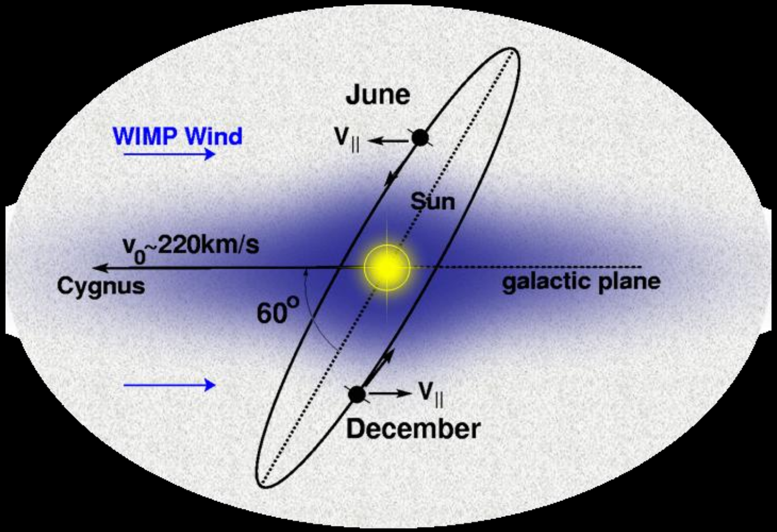
$$\eta = \int d^3\vec{v} \frac{1}{\left|\vec{v} - \vec{v}_{\oplus,G}\right|}$$

Total rate

$$R(t) = \int_{E_1}^{E_2} dE_R\, \varepsilon(E_R) \left(\frac{dR}{dE_R} * G(E_R, \sigma(E_R)) \right)$$

detector efficiency and energy resolution

Annual modulation



Modulation of the Earth velocity

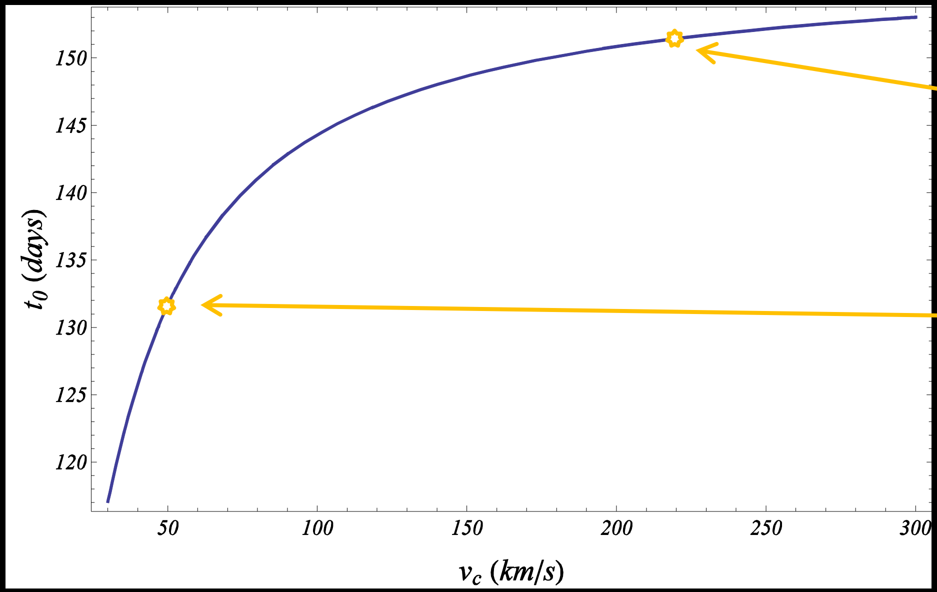
$$v_{\oplus,G} = v_S + v_{\oplus,S} \sin\gamma \cos\omega(t - t_0)$$

$$t_0 = t_1 + \frac{\pi}{2\omega} + \frac{1}{\omega}\arctan\frac{\vec{v}_S \cdot \vec{e}_2}{\vec{v}_S \cdot \vec{e}_1} \approx 151.5$$

Modulation of the differential event rate

$$\eta(E_R, t) = \eta_0(E_R) + \eta_1(E_R)\frac{v_{\oplus,S}}{v_S}\sin\gamma\cos\omega(t - t_0)$$

Annual modulation



Standard Halo

$t_o = 152.5$ → June 2nd

Fast rotating Dark Disk

$t_o = 131.5$ → May 11th

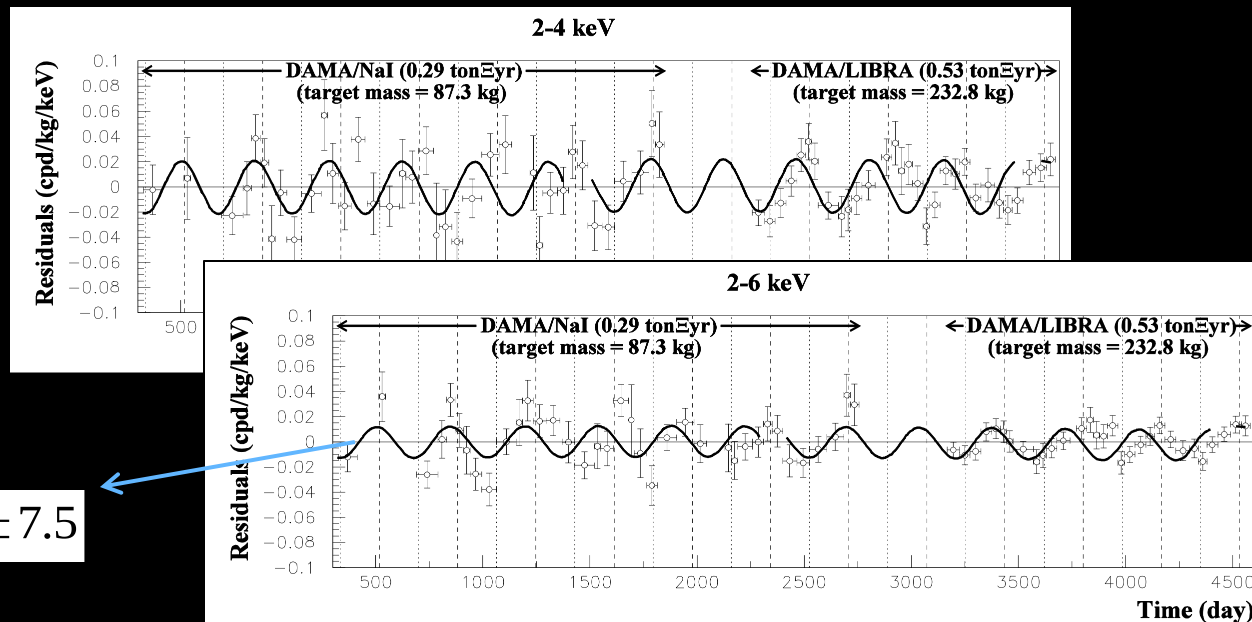
→ 3 weeks earlier

DAMA *(2 < Eee < 6 keV) :* $t_o = 144 \pm 7.5\ (1\sigma)$ → May 24th

DAMA signal

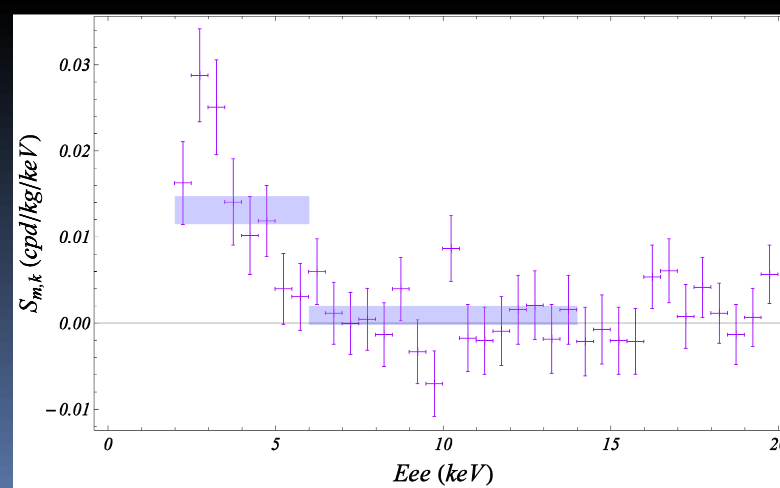
Eur. Phys. J. C56: 333-355(2008) arXiv:0804.2741

Time residuals



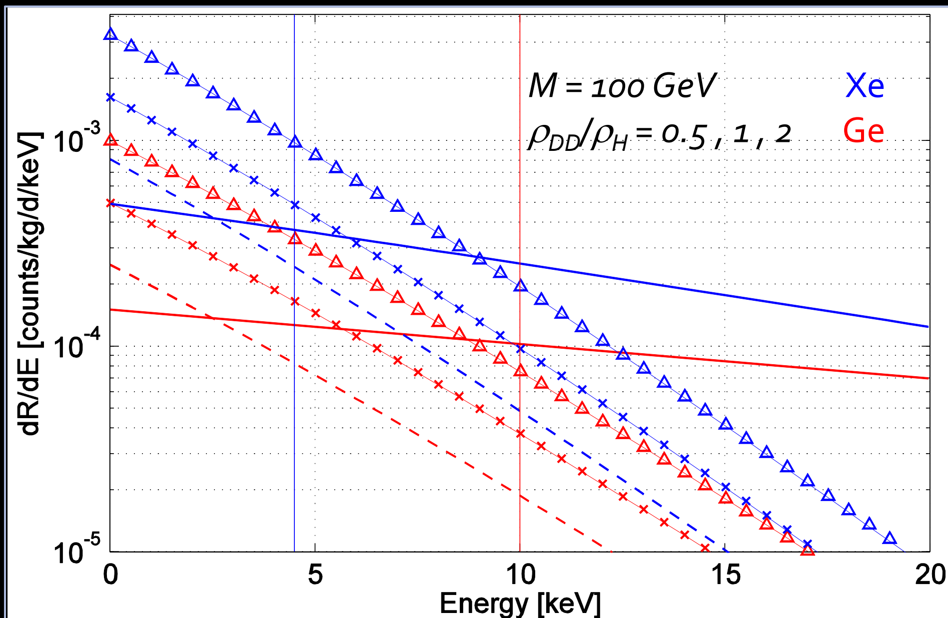
$$t_0 = 144.0 \pm 7.5$$

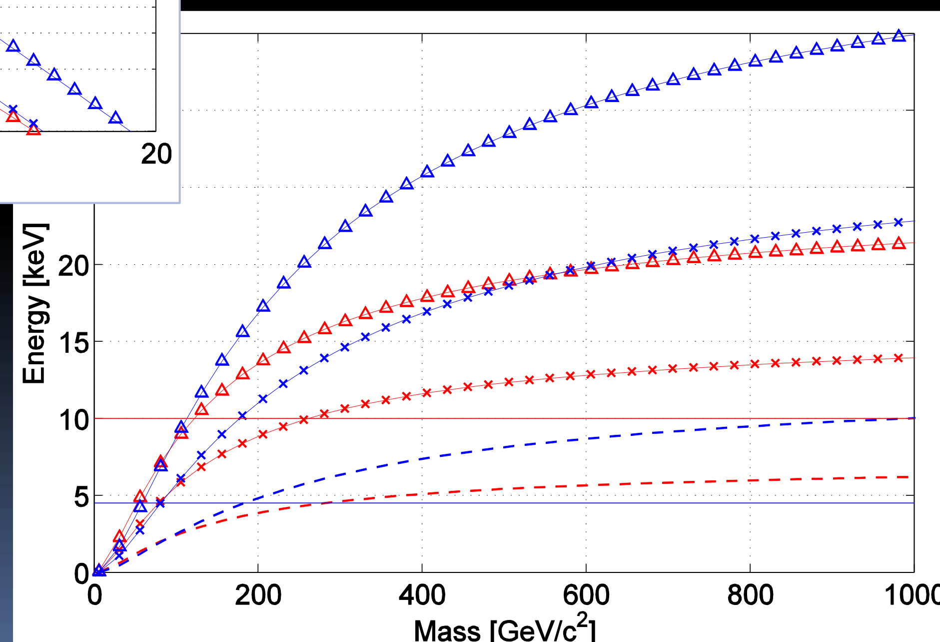
Modulation spectrum



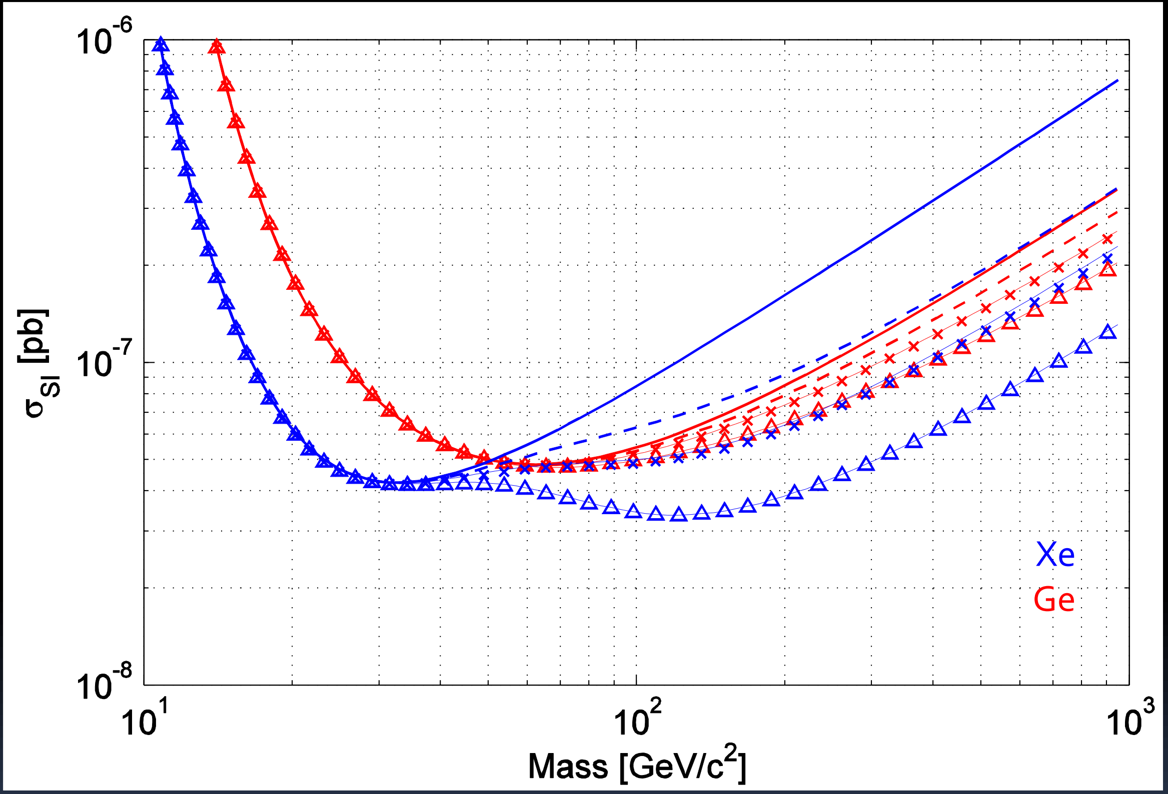
Direct detection

Bruch et al. 2008, arXiv:0804.2896



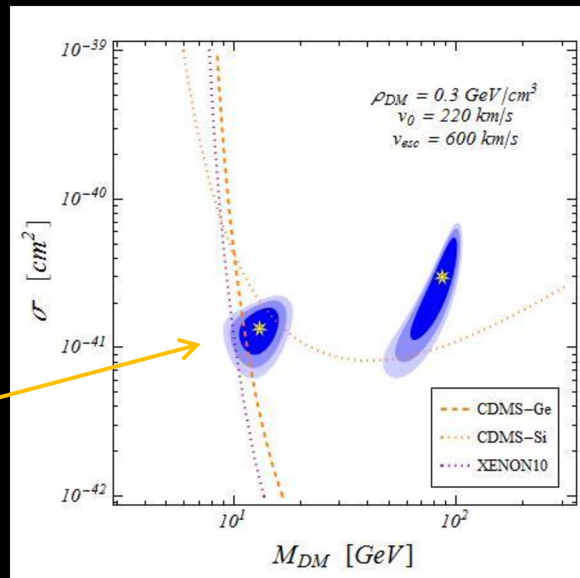


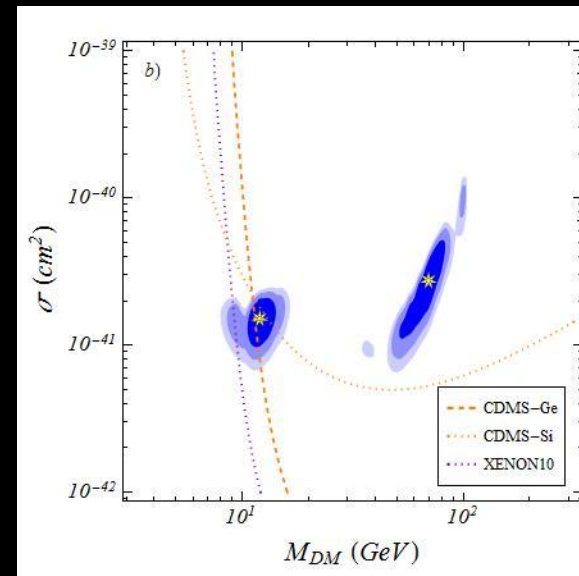
Exclusion limits



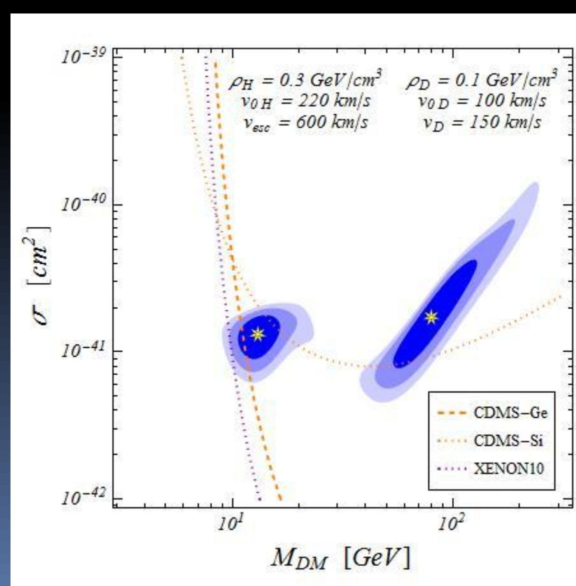
DAMA vs. Null experiments

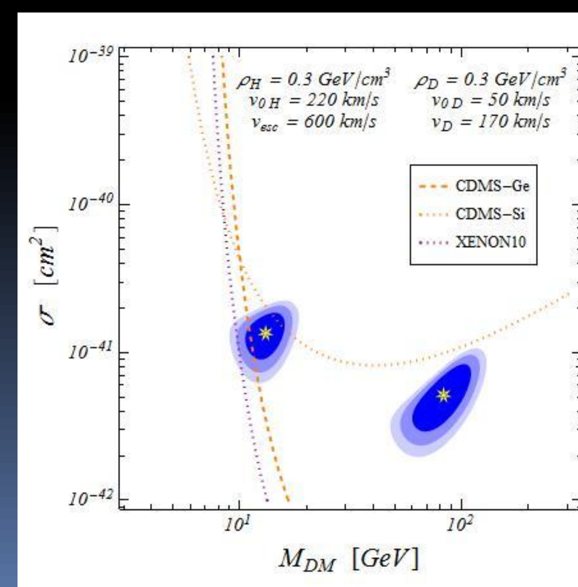
Elastic scenario





Channeling region little affected by Dark Disk

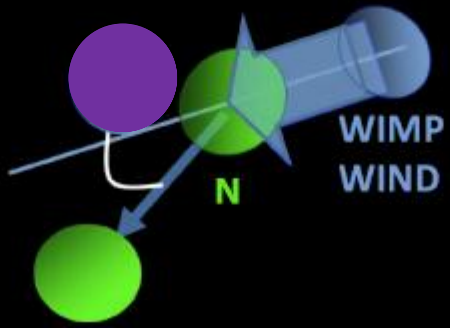




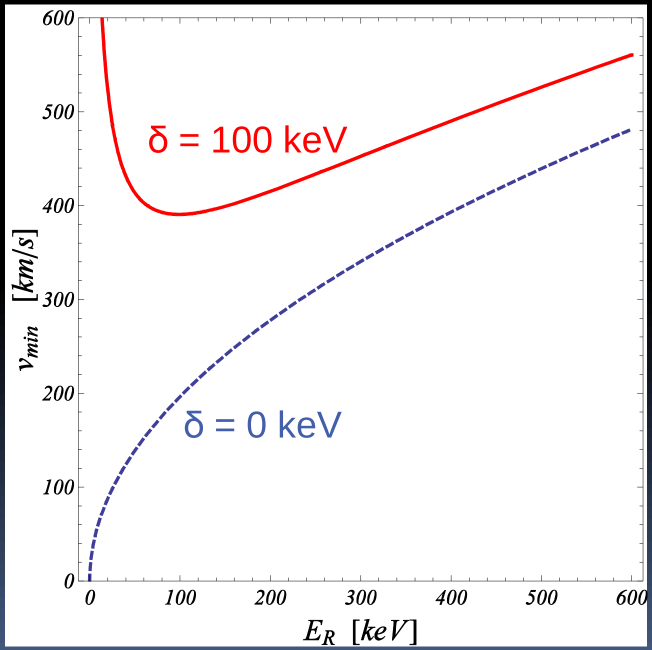
DAMA vs. other
→ no improvement in compatibility

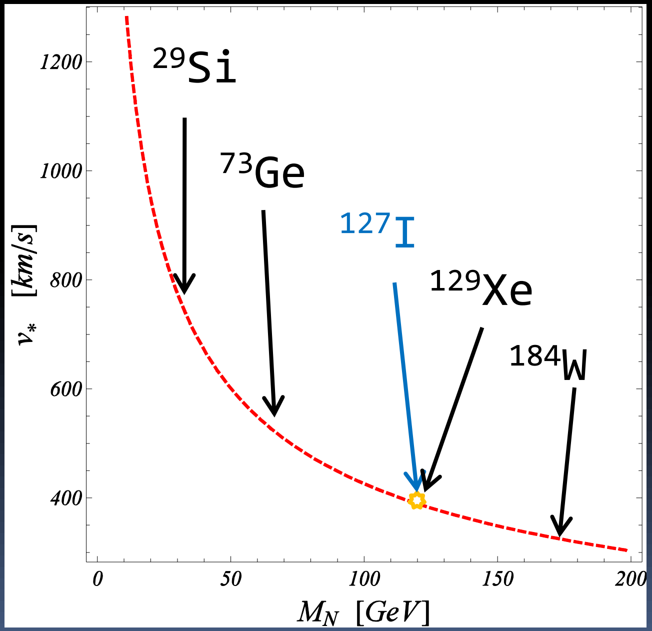
Inelastic Dark Matter

D. Tucker-Smith and N. Weiner, Phys. Rev. D64, 043502(2001), arXiv:hep-ph/0101138.



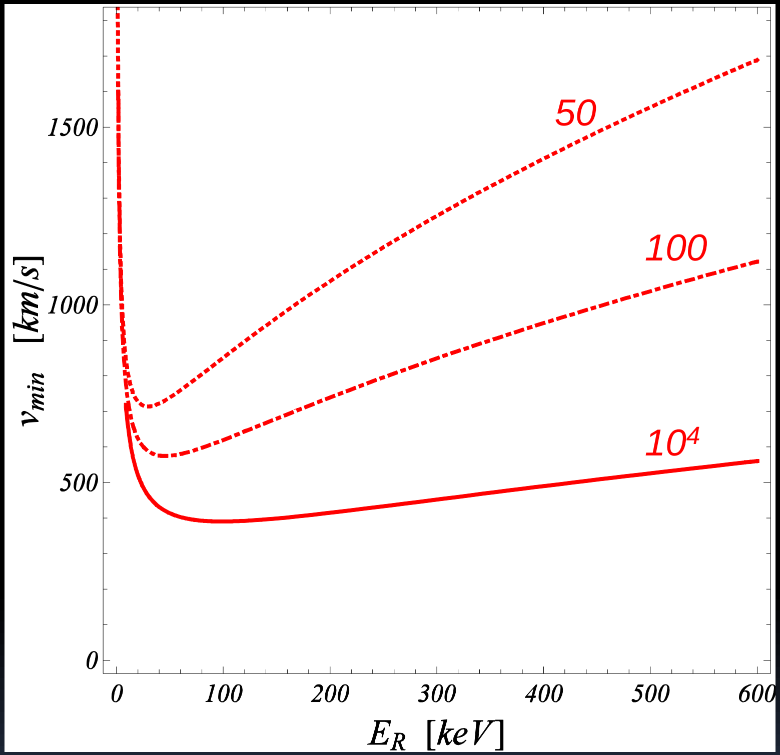
$$v_{\min} = \frac{1}{\sqrt{2M_N E_R}}\left(\frac{M_N E_R}{\mu} + \delta\right)$$

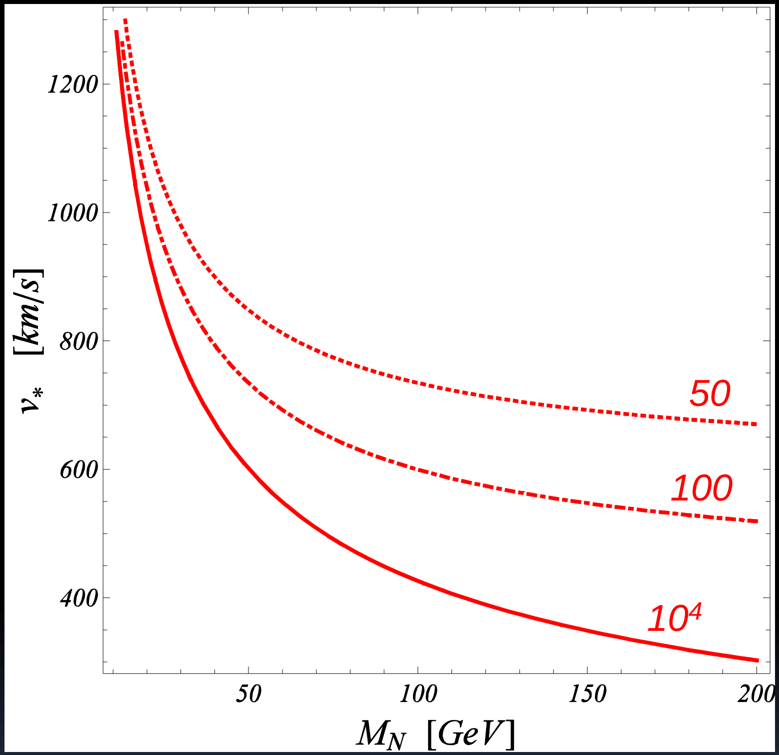




$M_{DM} = 10\ TeV$

M_{DM} = 50 Gev, 100 GeV, 10 TeV

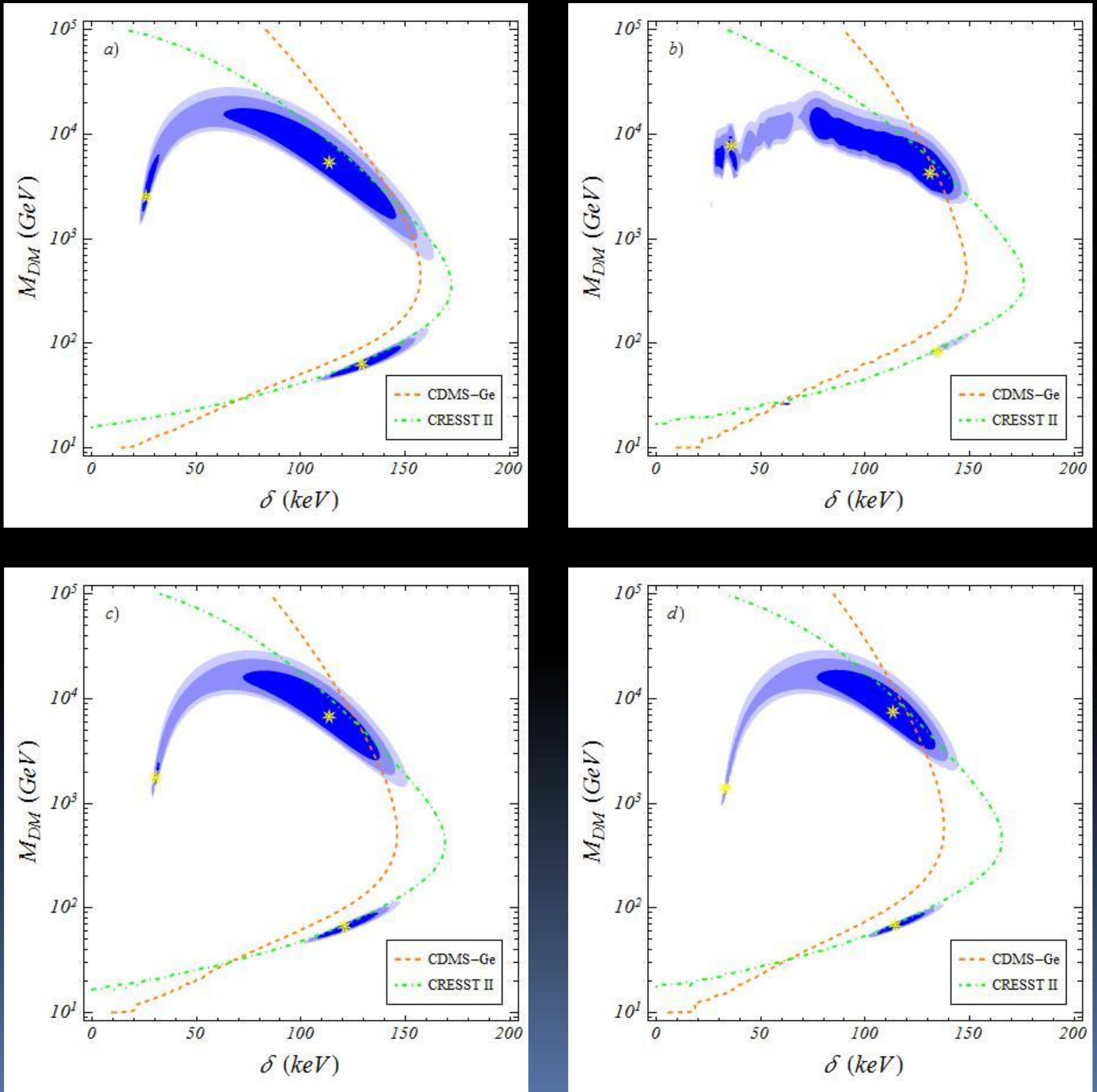




DAMA vs. Null experiments

Inelastic scenario

$\sigma = \sigma_Z$



Summary

- We have presented a recent cosmological hydrodynamics N-body simulation that contains DM, stars and gas. The central part contains a Milky-Way sized galaxy with a beautiful spiral disc. However, size and weight of galactic components (DM halo, disc & bulge) still differ from MW expected values.
- The DM halo is oblate and co-rotates with the galactic disc. Local DM density at the Sun's location is around *0.4 GeV/cm³*, compared to an average value of around *0.3 GeV/cm³* at a distance of *8 kpc* from the GC.
- Resolution is not sufficient to disentangle the possible dark disk component. Velocity distributions can be described as the sum of a static and fast rotating isotropic components. Non-gaussianities are important.
- Mild effect of dark disc : fraction of slow moving particles (wrt the Sun) is only slightly increased. Therefore, no strong boost in the event rate at low recoil energy (direct detection), and in the capture rate in Earth or Sun (indirect detection).
- Improvement of compatibility between DAMA and null experiments mainly due to non-gaussianities, which is most relevant in the inelastic scattering scenario.

Backup slides

Muon flux for $E_\mu > 1$ GeV

Bruch et al. 2009, arXiv:0902.4001

Sun

Earth