Systematic uncertainties from halo asphericity in dark matter searches

based on NB, Jaime Forero-Romero,
Raghuveer Garani & Sergio Palomares-Ruiz

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Nicolás BERNAL
ICTP – SAIFR

ICTP
SAIFR
International Centre for Theoretical Physics
South American Institute for Fundamental Research

unesp
UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"

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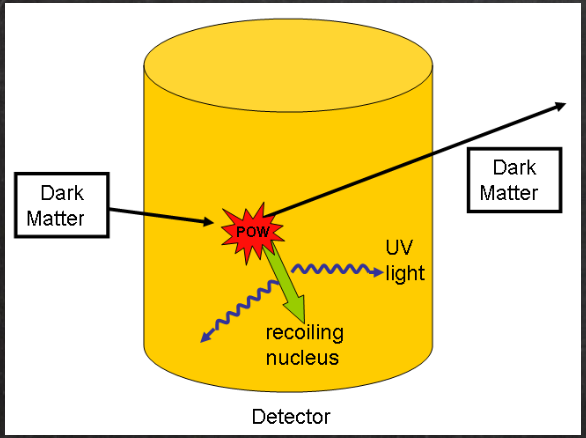
Direct and indirect DM searches

Several observations indicate existence of non-luminous Dark Matter (missing force) at very different scales! —» WIMPs

* Direct detection

DM particles streaming through the Earth could scatter with the nuclei of the detector



$$R \approx \frac{\rho_\odot \sigma \langle v \rangle}{m_\chi \, m_A}$$

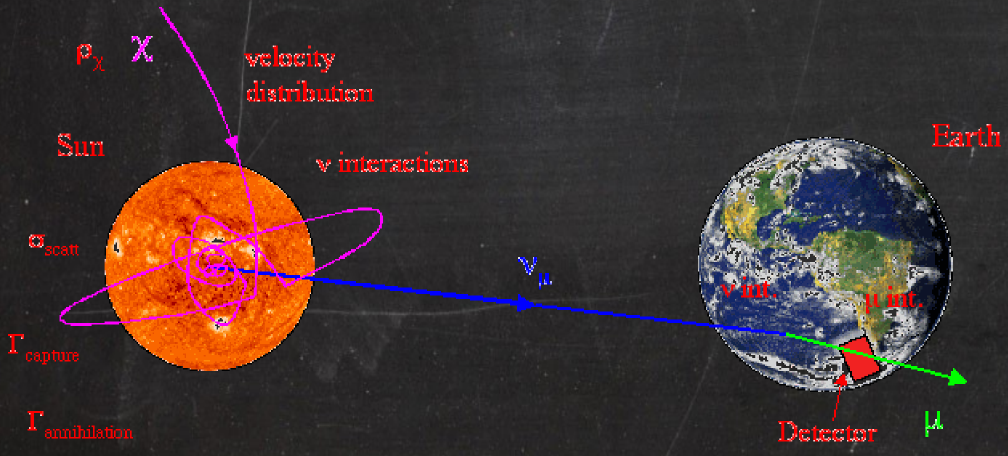
Direct and indirect DM searches

Several observations indicate existence of non-luminous Dark Matter (missing force) at very different scales! —» WIMPs

*** Direct detection**

*** Direct/Indirect detection**

Flux of neutrinos α Sun's capture rate
α DM particles through the Sun α local DM density



$$\dot{N}_\chi(t) = C_\odot - A_\odot\, N_\chi^2(t) - E_\odot\, N_\chi(t)$$

$$C^\odot \approx 1.3\times 10^{21}\,\mathrm{sec}^{-1}\left(\frac{\rho_{\mathrm{local}}}{0.3\,\mathrm{GeV/cm}^3}\right)\left(\frac{270\,\mathrm{km/s}}{\bar{v}_{\mathrm{local}}}\right) \times\left(\frac{100\,\mathrm{GeV}}{m_\chi}\right)\sum_i\left(\frac{A_i\,(\sigma_{\chi i,\mathrm{SD}}+\sigma_{\chi i,\mathrm{SI}})\,S(m_\chi/m_i)}{10^{-6}\,\mathrm{pb}}\right),$$

Direct and indirect DM searches

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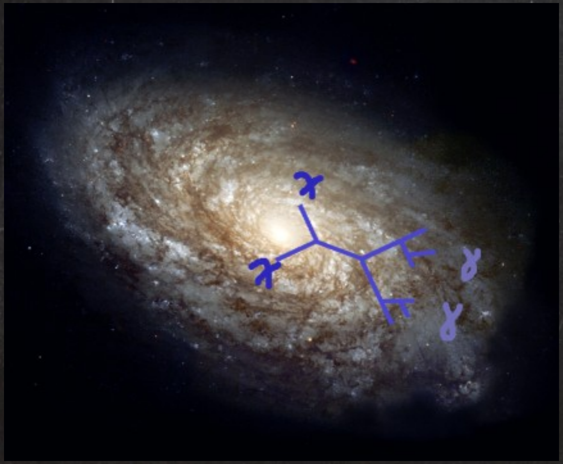
Dark Matter (missing force) at very different scales! —» WIMPs

* **Direct detection**

* **Direct/Indirect detection**

* **Indirect detection**

Not only the local normalization is important but the also the shape of the halo!



$$\left(\frac{d\Phi_{\mathrm{ann}}}{dE}\right)(E,\Delta\Omega) = \frac{\langle\sigma v\rangle}{2\,m_\chi^2}\sum_i \mathrm{BR}_i\,\frac{dN^i_{\mathrm{ann}}}{dE}\,J_{\mathrm{ann}}(\Omega)\,\frac{\Delta\Omega}{4\,\pi}$$

$$\left(\frac{d\Phi_{\mathrm{dec}}}{dE}\right)(E,\Delta\Omega) = \frac{1}{m_\chi\,\tau_\chi}\sum_i \mathrm{BR}_i\,\frac{dN^i_{\mathrm{dec}}}{dE}\,J_{\mathrm{dec}}(\Omega)\,\frac{\Delta\Omega}{4\,\pi}$$

$$J_{\mathrm{ann}}(\Omega)\Delta\Omega = \int_{\Delta\Omega}\mathrm{d}\Omega\int_{\mathrm{los}}\rho(r(s,\Omega))^2\,\mathrm{d}s$$

$$J_{\mathrm{dec}}(\Omega)\Delta\Omega = \int_{\Delta\Omega}\mathrm{d}\Omega\int_{\mathrm{los}}\rho(r(s,\Omega))\,\mathrm{d}s$$

Direct and indirect DM searches

Several observations indicate existence of non-luminous Dark Matter (missing force) at very different scales! —» WIMPs

*** Direct detection**

*** Direct/Indirect detection**

*** Indirect detection**

In order to extract particle physics parameters (m_x, σ, $<\sigma v>$, τ_{dec} ...) from DM experiments, the astrophysics (ρ_0, $J \cdot \Delta\Omega$) has to be under control —» DM halo

DM: spherical halos?

N-body simulations favour Einasto and Navarro-Frenk-White profiles.

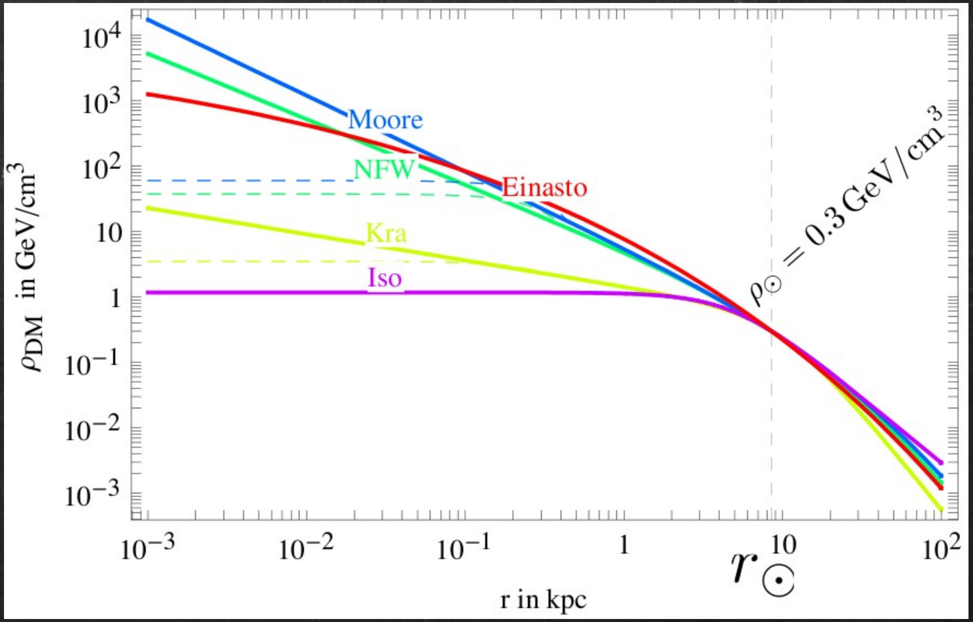
NFW
$$\rho(r) = \frac{4\rho_s}{r/r_s\,(1+r/r_s)^2}$$

Einasto
$$\rho(r) = \rho_\odot \exp\left[-\frac{2}{\alpha}\left(\left(\frac{r}{r_s}\right)^\alpha - \left(\frac{R_\odot}{r_s}\right)^\alpha\right)\right]$$

ρ_0 = 0.3 GeV / cm^3

r_s = 20 kpc

α = 0.38



DM: triaxial halos!

N-body simulations favour Einasto and Navarro-Frenk-White profiles.

Halos are found to be non-spherical.
In fact, spherical halos are rare!

Baryons prefer to lay in one of the 3 symmetry planes

NFW

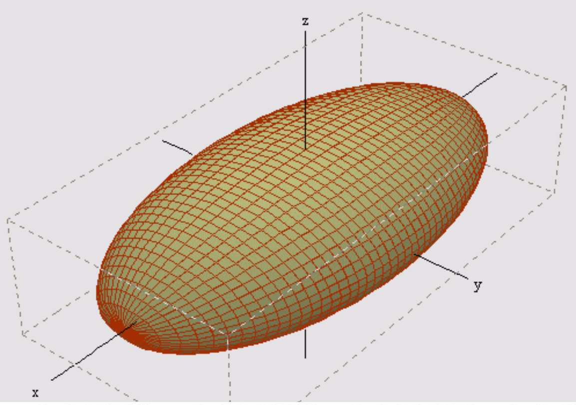
$$\rho(r) = \frac{4\rho_s}{r/r_s\,(1+r/r_s)^2}$$

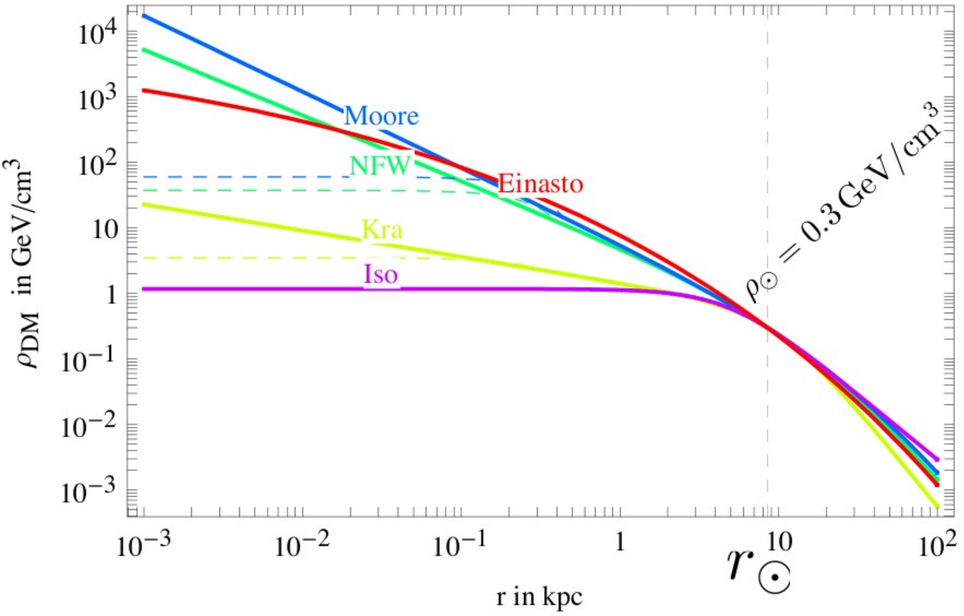
Einasto

$$\rho(r) = \rho_\odot \exp\left[-\frac{2}{\alpha}\left(\left(\frac{r}{r_s}\right)^\alpha - \left(\frac{R_\odot}{r_s}\right)^\alpha\right)\right]$$

$$r_e^2 = x^2 + \left(\frac{y}{b/a}\right)^2 + \left(\frac{z}{c/a}\right)^2$$

a > b > c





Bolshoi simulation

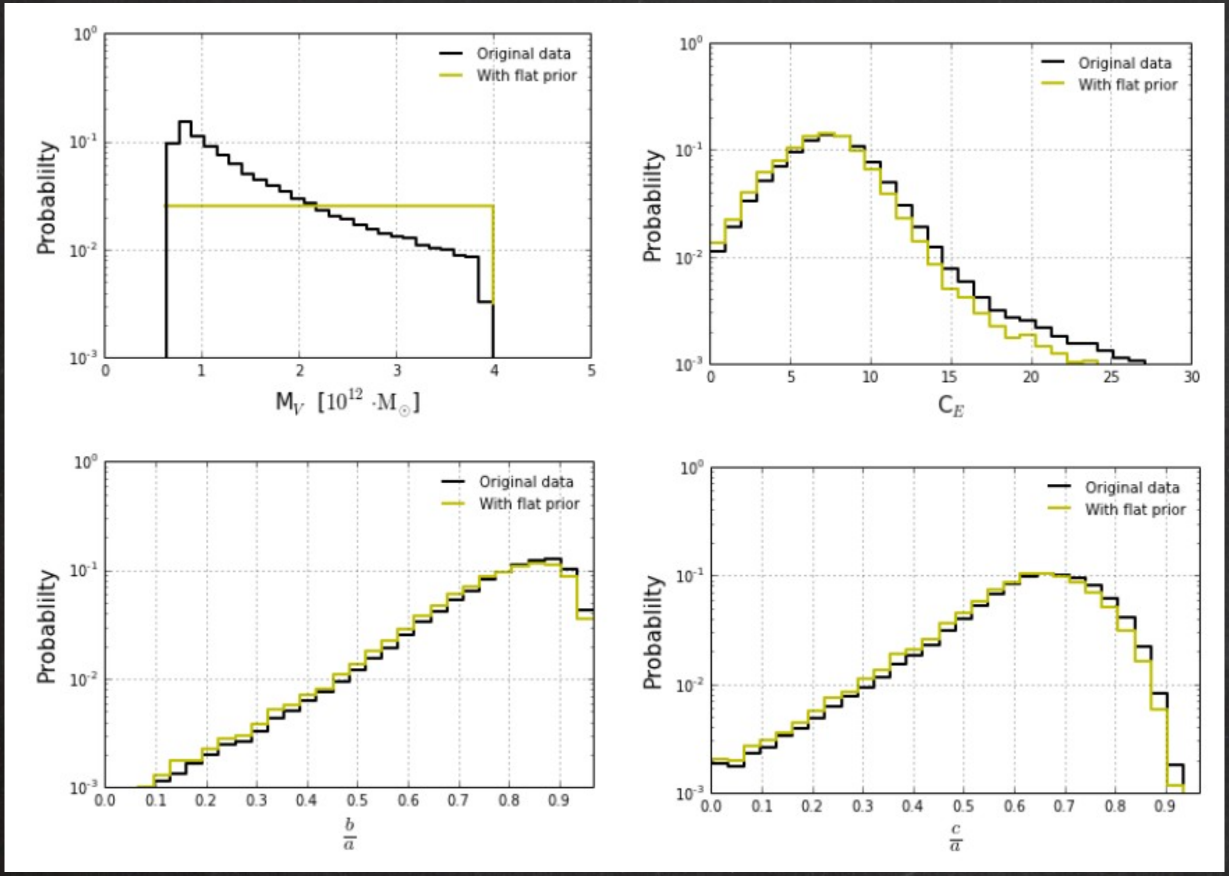
Bolshoi A. Klypin, S. Trujillo-Gómez & J. Primack '10
Publicly available through the MultiDark Database K. Riebe et al. '11
Cubic volume 250 h^{-1} Mpc, sampled with 2048^3 particles
Mass of a simulation particle $1.4 \cdot 10^8\ h^{-1}\ M_*$

Cosmological parameters compatible with WMAP9
  $\Omega_m=0.27$, $\Omega_\Lambda=0.73$, $n_s=0.95$, $h=0.70$, $\sigma_8=0.82$

  DM only
  DM halos fitted using NFW profile
  Effects due to substructure (clumps) captured

Collection of $\mathcal{O}(10^5)$ halos characterised by
  Virial mass M_V (and/or virial radius)
  Triaxial parameters b/a & c/a
  Concentration parameter C_E

Data set

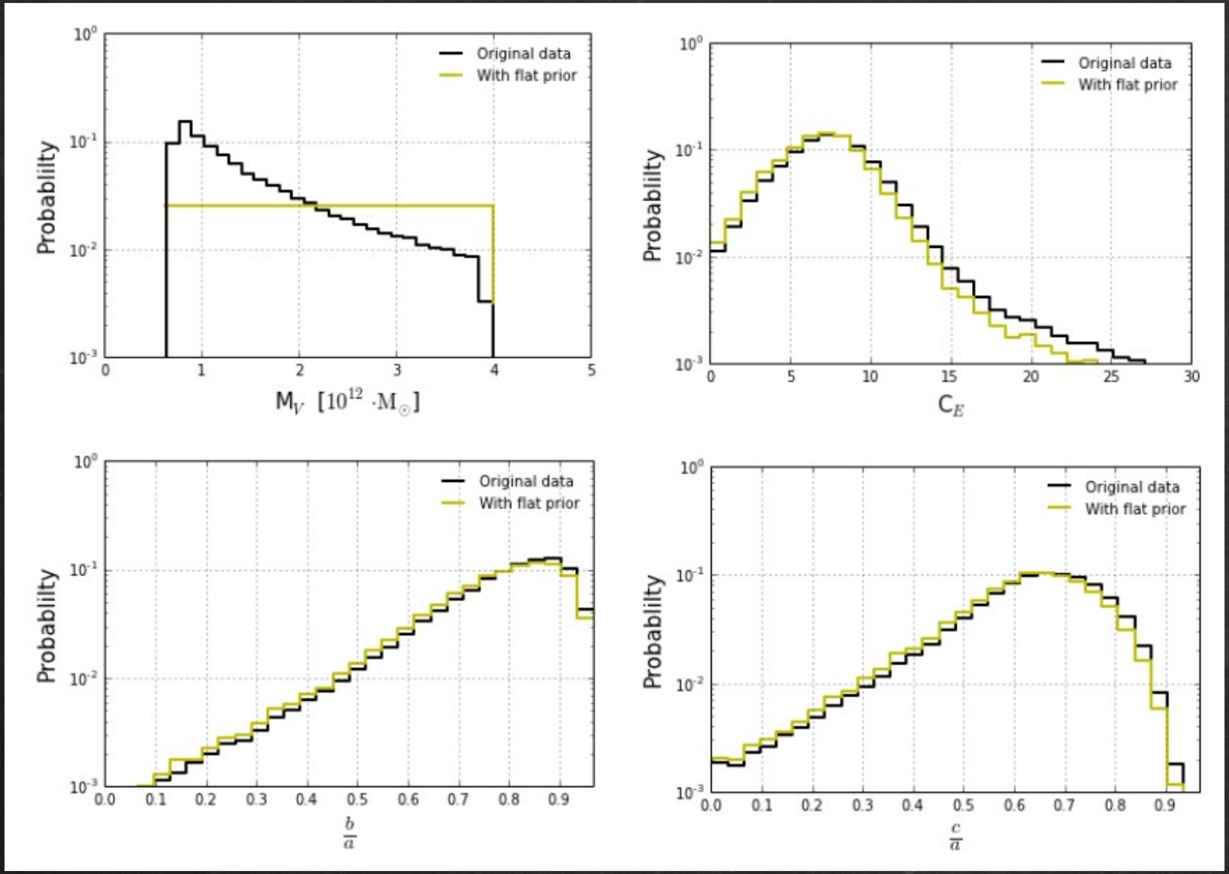


~10^5 DM only halos

- $\langle M_V \rangle \sim 1.5 \cdot 10^{12}\ M_*$
- $\langle C \rangle \sim 8.9$
- $\langle b/a \rangle \sim 0.81$
- $\langle c/a \rangle \sim 0.66$

Flat prior on M_V in order to avoid cosmological bias

Data set



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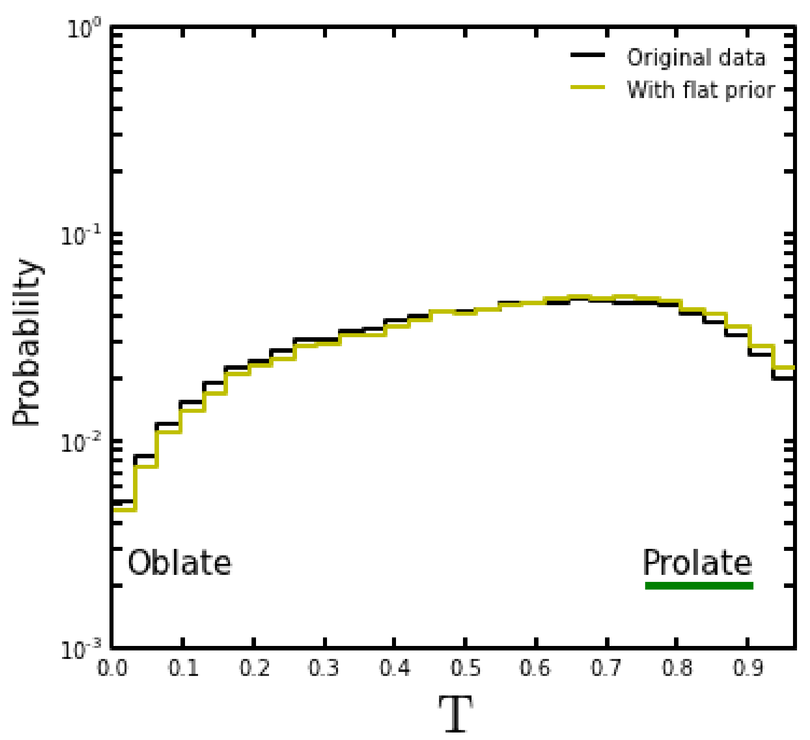
Triaxiality parameter

$$T = \frac{1-(b/a)^2}{1-(c/a)^2}$$

$\langle T \rangle \sim 0.58$



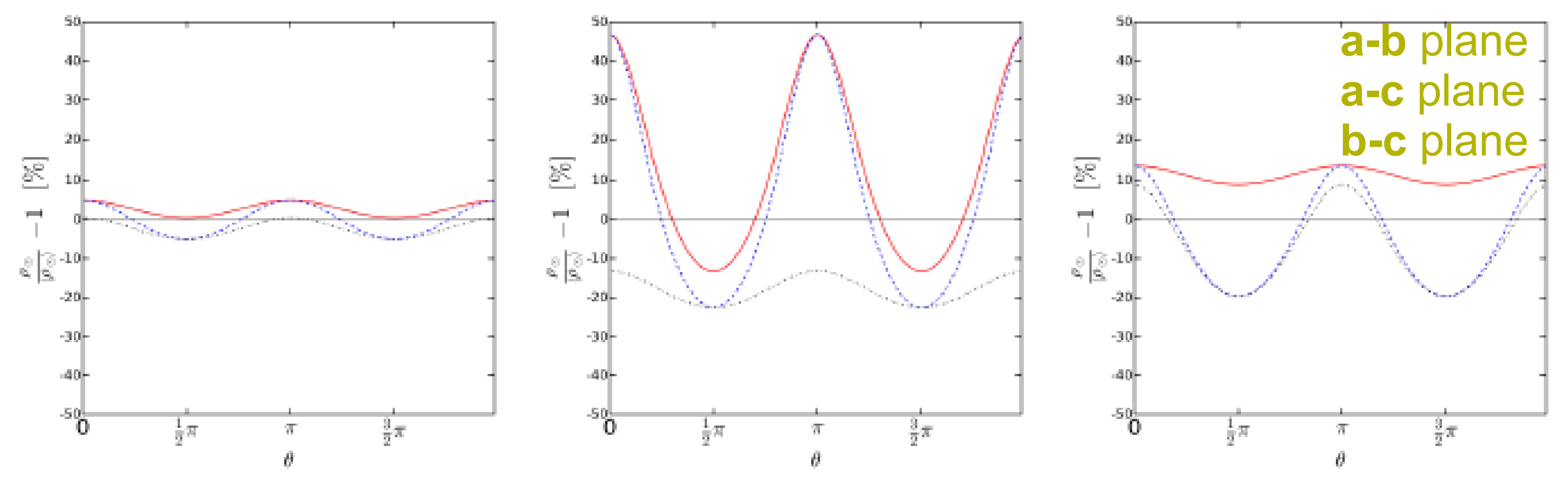
Impact of halo asphericity

~spherical
b/a=0.96
c/a=0.92

prolate
b/a=0.58
c/a=0.48

oblate
b/a=0.97
c/a=0.77

ρ/<ρ> - 1
[%]



$\rho_0(\theta)$: Local DM density at a given angle θ

$\langle\rho_0\rangle$: Spherically averaged local DM density

$\rho_0 / \langle\rho_0\rangle$ -1: Uncertainty induced by **triaxiality**

Impact of halo asphericity

~spherical
b/a=0.96
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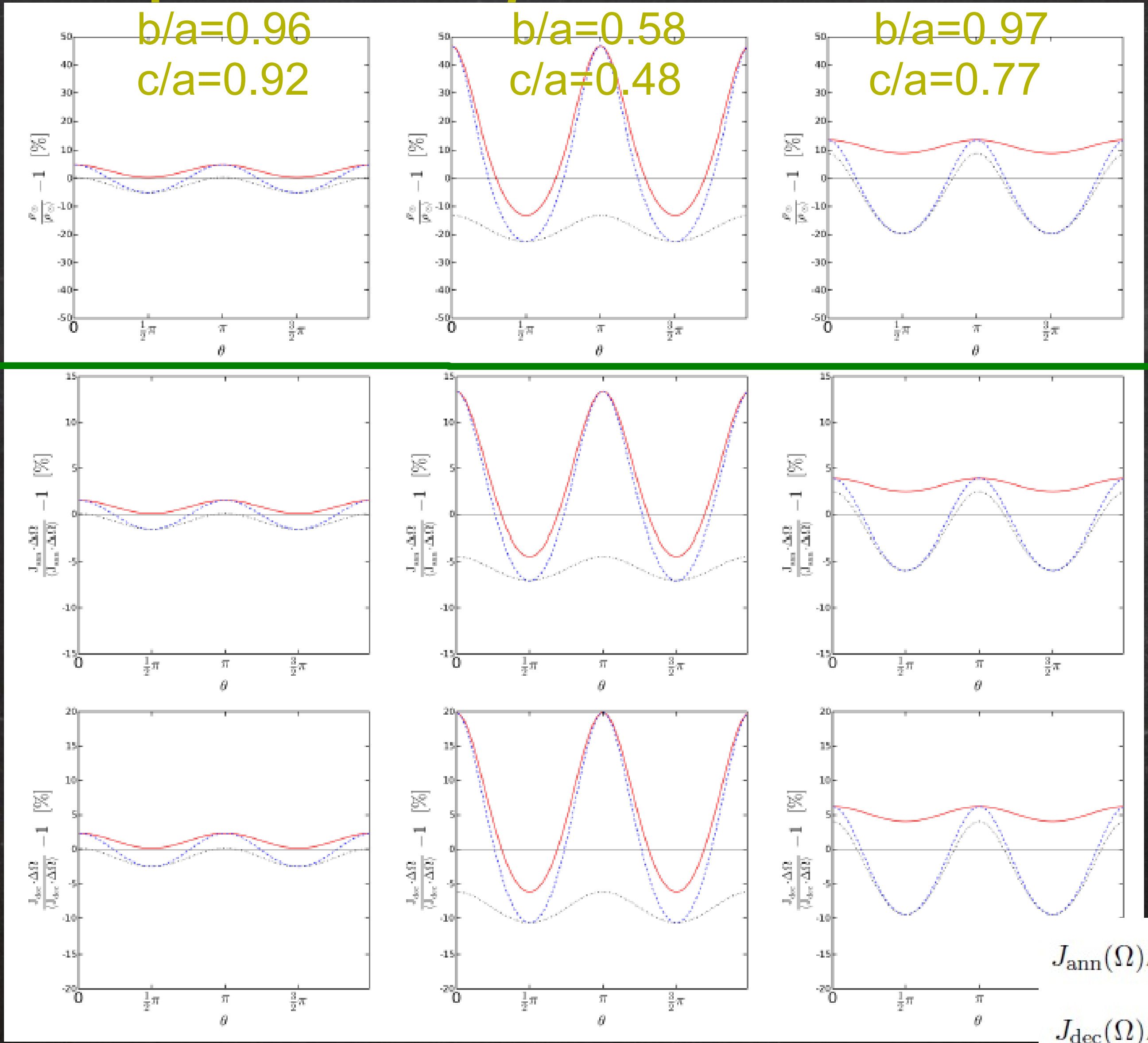


ρ/<ρ> - 1
[%]

ann.

J/<J> - 1
[%]

dec.

ROI = 20°x20°

$$J_{\rm ann}(\Omega)\Delta\Omega = \int_{\Delta\Omega} \mathrm{d}\Omega \int_{\rm los} \rho(r(s,\Omega))^2\,\mathrm{d}s$$

$$J_{\rm dec}(\Omega)\Delta\Omega = \int_{\Delta\Omega} \mathrm{d}\Omega \int_{\rm los} \rho(r(s,\Omega))\,\mathrm{d}s$$

Observational priors

Virial mass

Different methods like gravitational lensing, rotation curves, escape velocity, velocity dispersion profiles of some tracers...

Estimates based on stellar kinematics tend to yield $\leq 10^{12}\ M_*$
distant tracers tend to yield $\geq 10^{12}\ M_*$

M_V is expected to lie within $\mathbf{0.7 \cdot 10^{12}\ M_* < M_V < 4 \cdot 10^{12}\ M_*}$

Observational priors

Virial mass

Mass at 60 kpc

Total mass in the innermost 60 kpc

Sloan Digital Sky Survey '08

$$M(<60\ \text{kpc}) = (4.0 \pm 0.7) \cdot 10^{11}\ M_{*}$$

Observational priors

Virial mass

Mass at 60 kpc

Local DM surface density

$$\Sigma_{z_0}(\mathrm{R}_\odot) \equiv \Sigma(\mathrm{R}_\odot, |z| < z_0) = \int_{-z_0}^{+z_0} \rho\,(\mathrm{R}_\odot, z))\, \mathrm{d}z$$

$\Sigma(|z|<1.1\ \mathrm{kpc}) = (17\pm6)\ \mathrm{M}_*\ \mathrm{pc}^{-2}$ J. Bovy & HW. Rix '13

Observational priors

Virial mass

Mass at 60 kpc

Local DM surface density

Sun's galactocentric distance

$R_* = [7.5, 8.7]$ kpc

Observational priors

Virial mass

Mass at 60 kpc

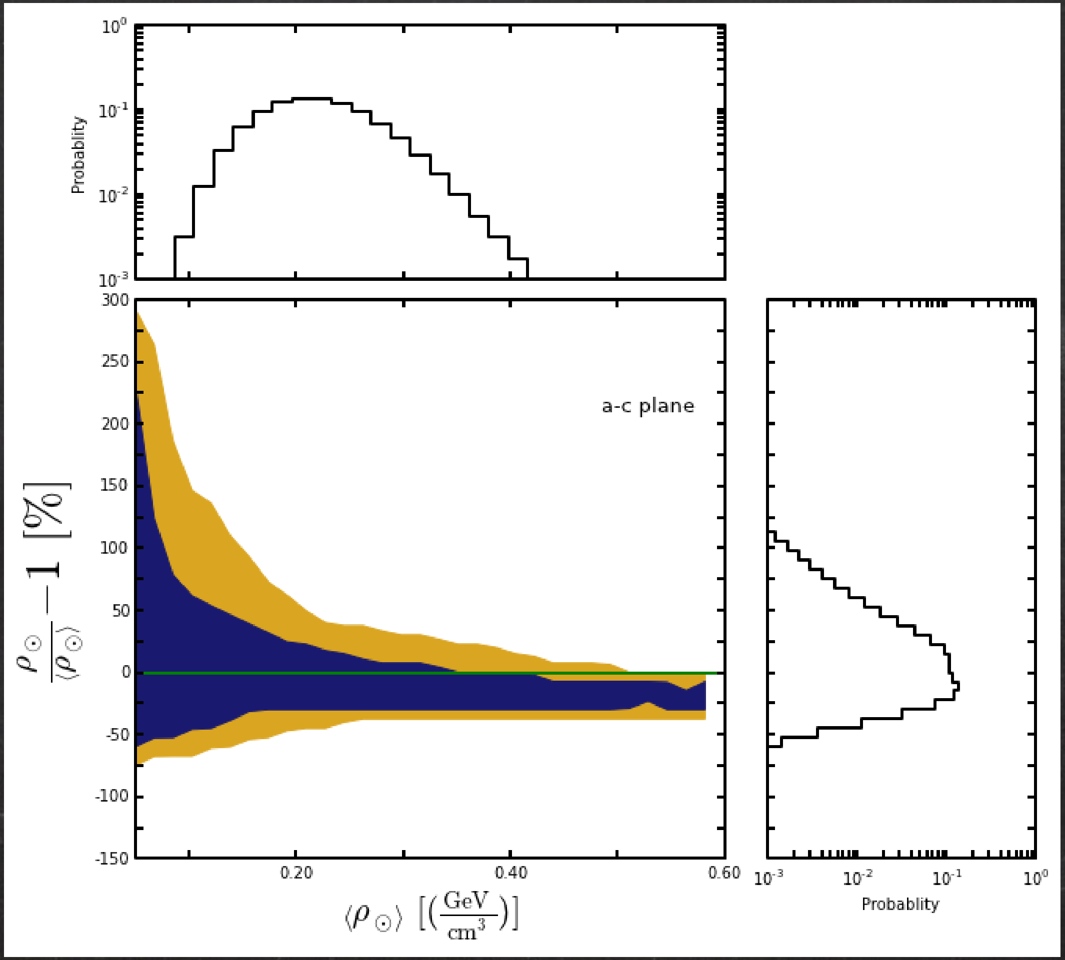
Local DM surface density

Sun's galactocentric distance

Other dynamical constraints for the Milky Way:
Terminal velocities,
velocity dispersions in a tracer population,
local circular velocities...
need a detailed **mass model for baryons in** the MW

Systematic uncertainties in ρ_0

a-c plane

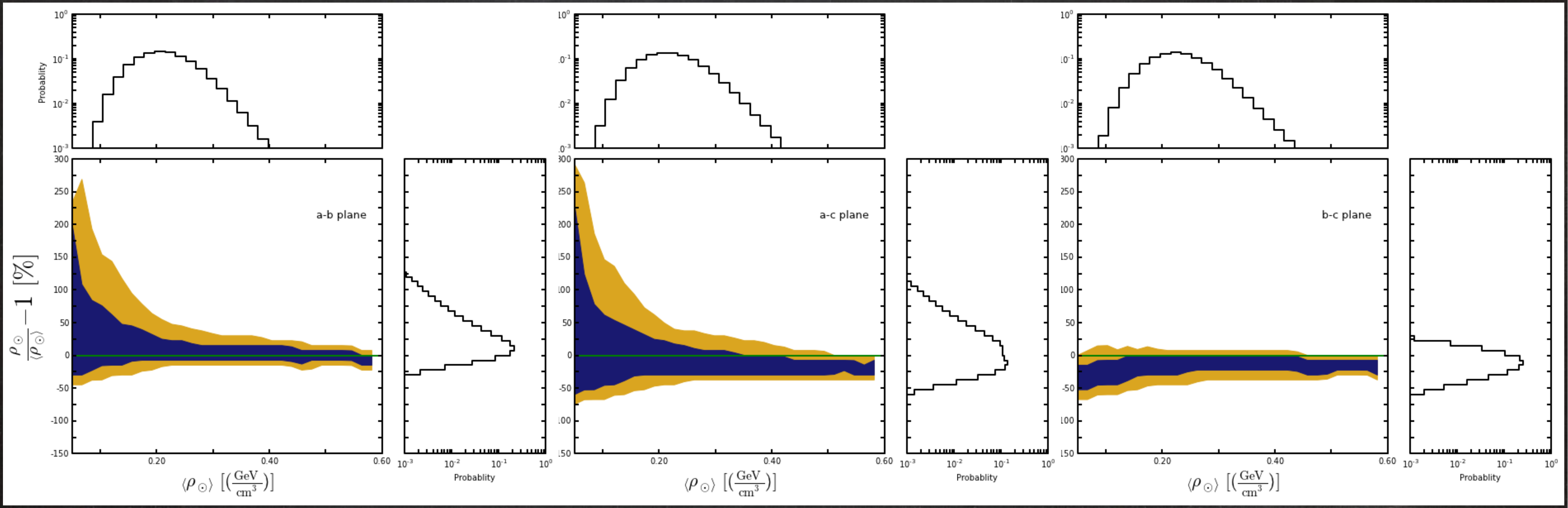


$\langle\rho_0\rangle$: Spherically averaged DM local density

$\rho_0 / \langle\rho_0\rangle - 1$: Uncertainty induced by triaxiality

Systematic uncertainties in ρ_0

a-b plane　　a-c plane　　b-c plane



If $\langle\rho_0\rangle \sim 0.3$ GeV/cm^3　　the uncertainty ~40% @ 95% CL

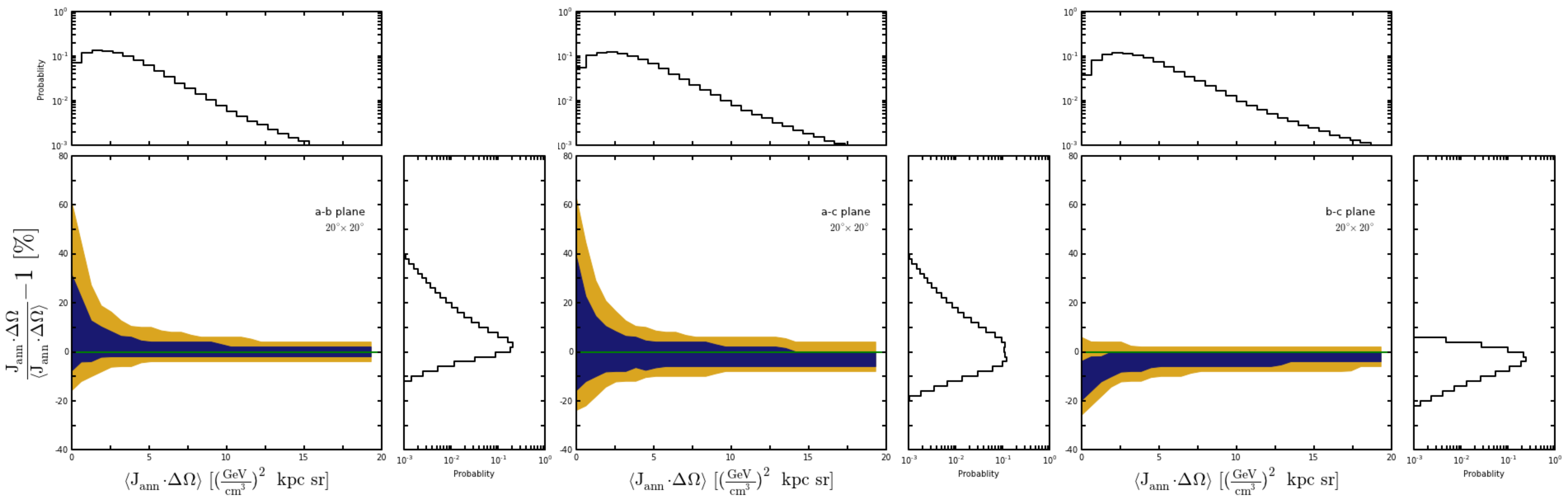
Systematic uncertainties in $J\cdot\Delta\Omega$

Annihilation

a-b plane

a-c plane

b-c plane



$\langle J_{ann}\cdot\Delta\Omega\rangle \sim 14\ (\mathrm{GeV/cm}^3)^2$ kpc sr

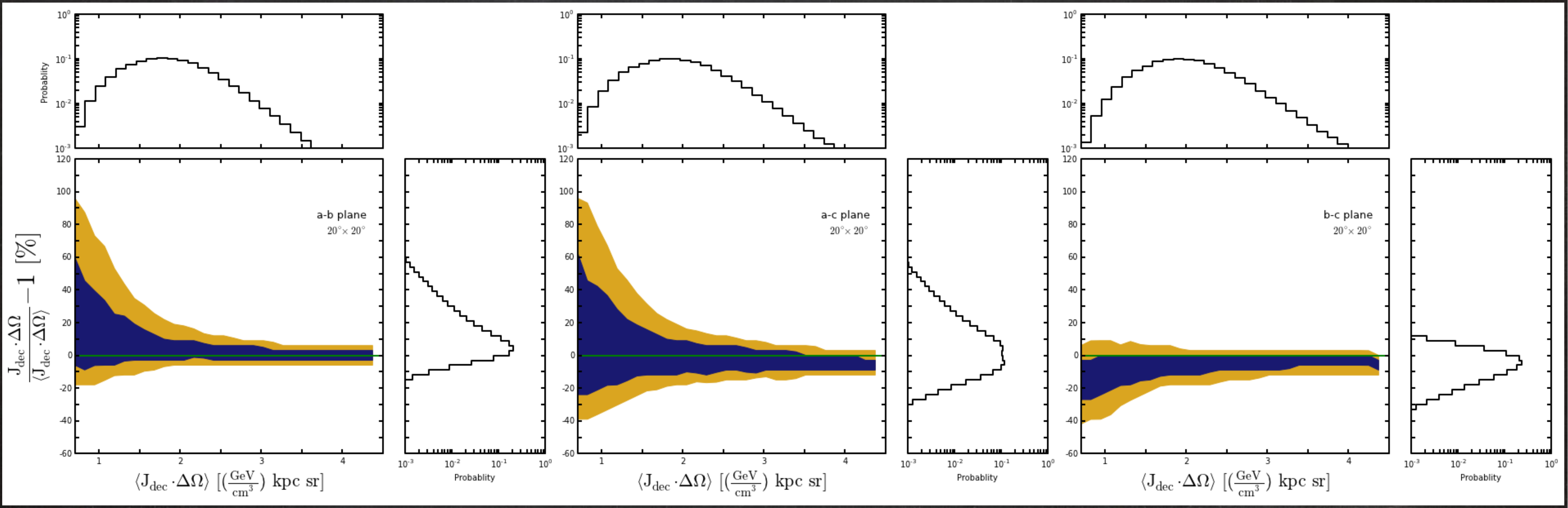
uncertainty ~9% @ 95% CL

ROI = 20° x 20° around the GC

Systematic uncertainties in J·ΔΩ

Decay

a-b plane a-c plane b-c plane



$<J_{dec}\cdot\Delta\Omega>$ ~ 3.5 GeV/cm^3 kpc sr

ROI = 20° x 20° around the GC

uncertainty ~15% @ 95% CL

Conclusions

* In order to extract particle physics parameters (m_x, σ, <σv>) from DM experiments, the astrophysics has to be under control.

* N-body simulations predicts triaxial DM halos. Spherical halos are rare!

* Using the DM only N-body simulation *Bolshoi* we studied the systematic uncertainties in ρ_0 and J·ΔΩ due to the halo asphericity.

* We took into account observational priors (M_V, M_{60}, SD...) in order to make the halos more Milky way like.

*** For a standard NFW, deviations for ρ_0 ~ 0.3-0.4 GeV/cm^3: ~40%.**

J_{ann}·ΔΩ ~ 9% (annihilation)
J_{dec}·ΔΩ ~ 15% (decay) @95% CL ROI = 20° x 20° around the GC

* Non negligible effect for DM detection!

* For J-factors, uncertainty on the different profiles!