Systematic Uncertainties from Halo Asphericity in Dark Matter Searches

Based on:
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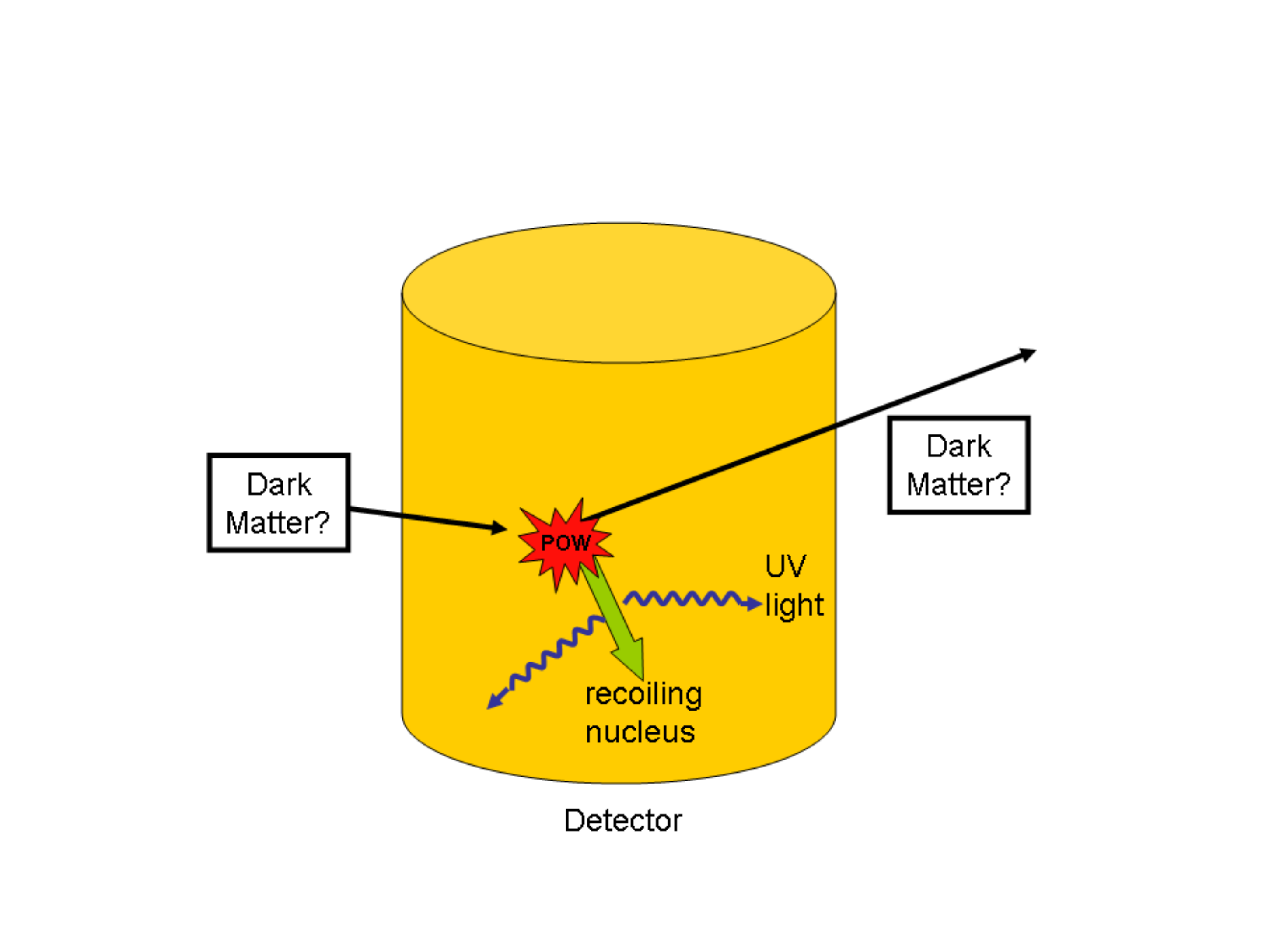
Outline

- Direct and Indirect Searches
- N-body simulations: Bolshoi
- Impact of halo Asphericity
- Results

Direct DM Searches

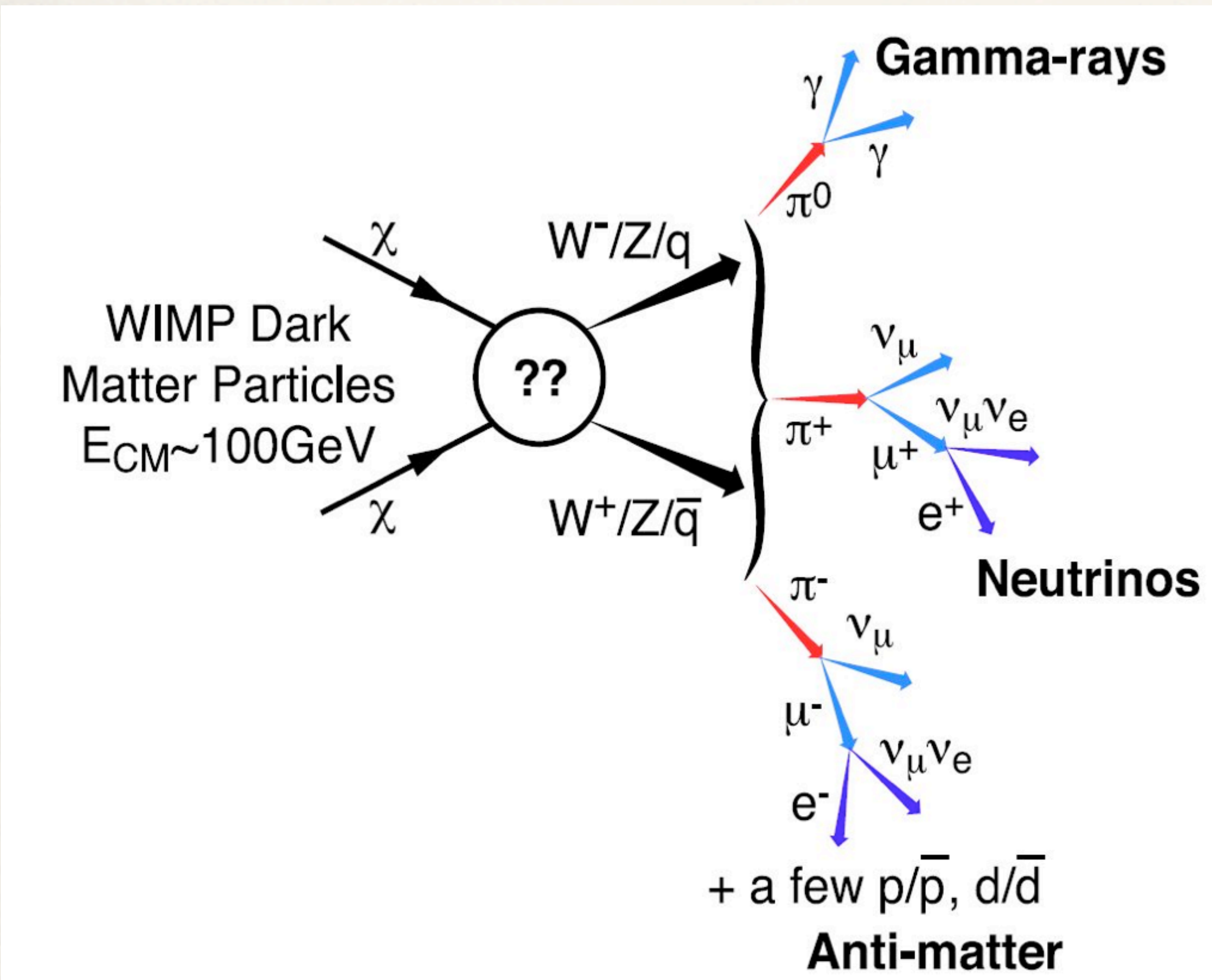


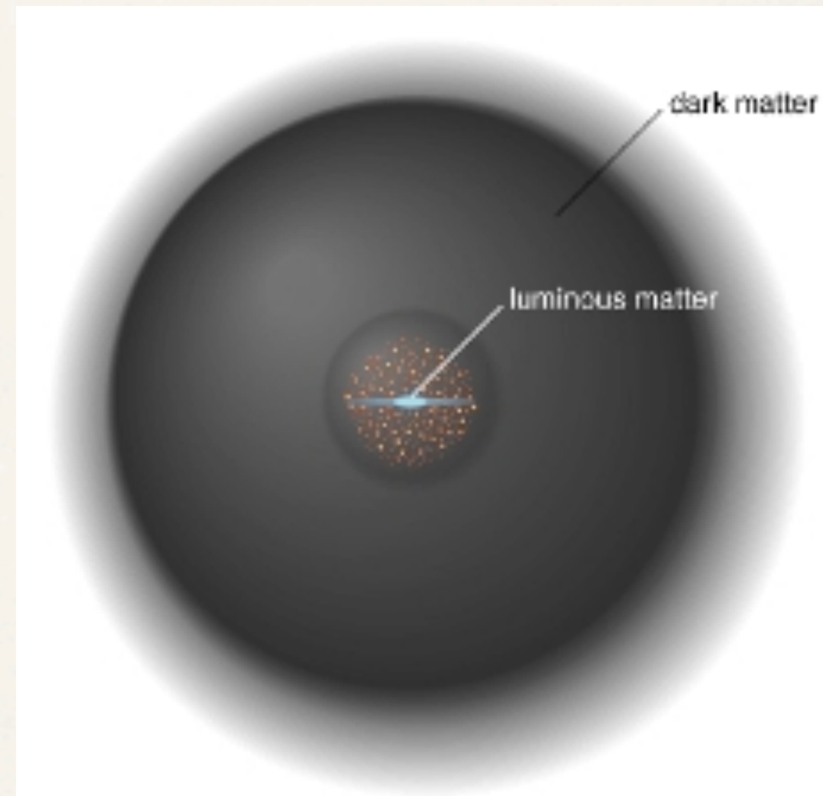
$$R \approx \frac{n_\chi \sigma \langle \nu \rangle}{m_N}$$

$$n_\chi = \rho_\odot / m_\chi$$

LUX, Xenon,CDMS and many more

Indirect DM Searches





$$N = \Phi \cdot \mathrm{A}_{eff} \cdot \mathrm{T}_{exp}$$

Fermi-LAT, Ice-Cube, AMS and many more

Indirect DM Searches

$$\frac{d\Phi_{\rm dec}}{dE}(E,\Delta\Omega) = \frac{1}{m_\chi\,\tau_\chi}\sum_i {\rm BR}_i\,\frac{dN^i_{\rm dec}}{dE}\,\bar{J}_{\rm dec}(\Omega)\,\frac{\Delta\Omega}{4\,\pi}$$

$$\frac{d\Phi_{\rm ann}}{dE}(E,\Delta\Omega) = \frac{\langle\sigma v\rangle}{2\,m_\chi^2}\sum_i {\rm BR}_i\,\frac{dN^i_{\rm ann}}{dE}\,\bar{J}_{\rm ann}(\Omega)\,\frac{\Delta\Omega}{4\,\pi}$$

$$\bar{J}_{\rm ann}(\Omega) = \frac{1}{\Delta\Omega}\int_{\Delta\Omega} d\Omega \int_{\rm los} \rho\big(r(s,\Omega)\big)^2\, ds$$

$$\bar{J}_{\rm dec}(\Omega) = \frac{1}{\Delta\Omega}\int_{\Delta\Omega} d\Omega \int_{\rm los} \rho\big(r(s,\Omega)\big)\, ds$$

- What is the impact of aspherical Halos?

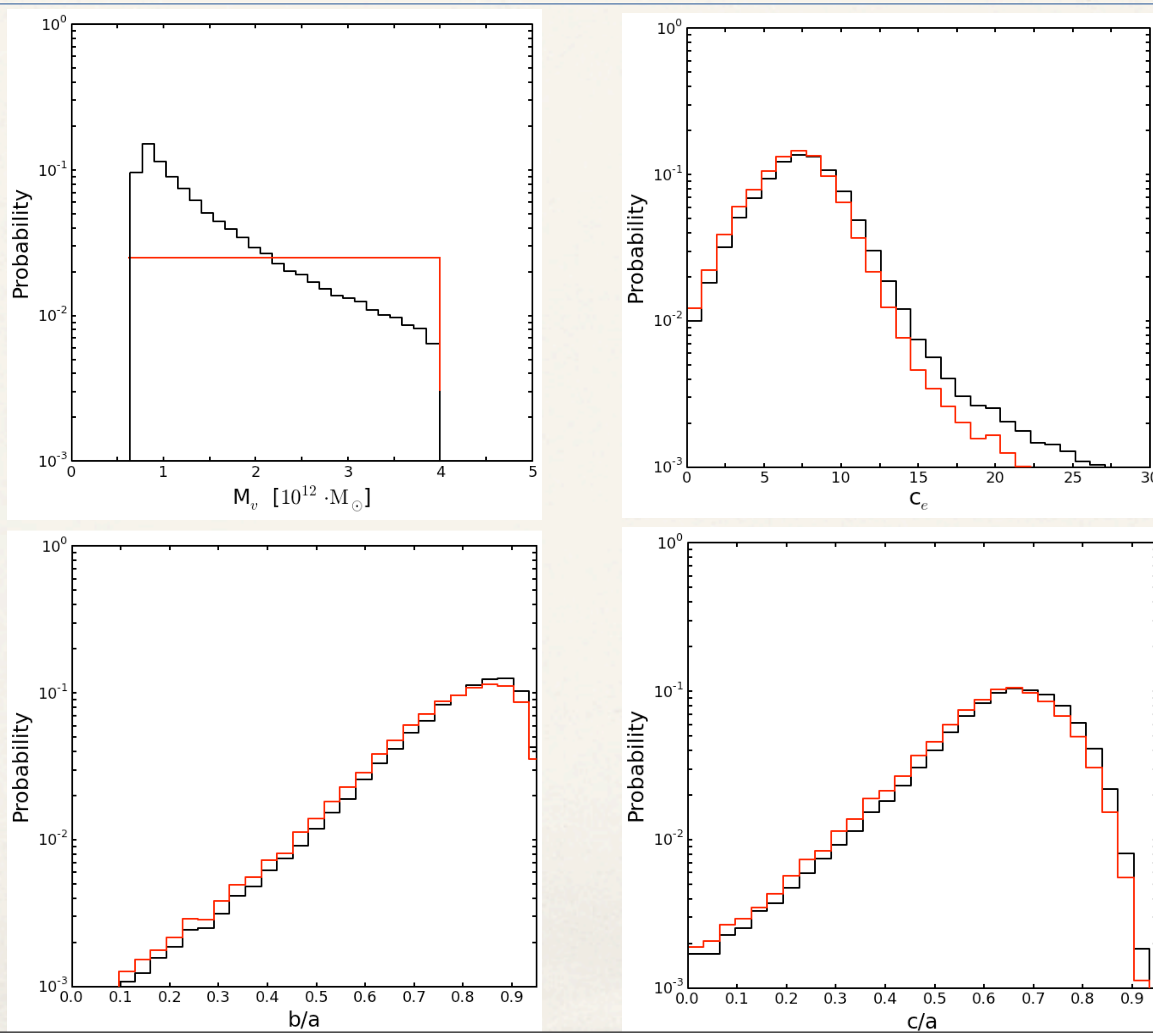
N-Body Simulations: Bolshoi

Klypin et.al '11

Parameter	PLANCK	WMAP7	Bolshoi	Description
h	0.671	0.71	0.70	Hubble parameter
Ω_Λ	0.6825	0.734	0.73	density parameter for dark energy
Ω_m	0.3175	0.2669	0.27	density parameter for matter (dark matter+baryons)
Ω_b	0.0489	0.0449	0.0469	density parameter for baryonic matter
n	0.9624	0.963	0.95	slope of the power spectrum
σ_8	0.8344	0.801	0.82	normalization of the power spectrum

- The density distribution in Bolshoi is best fit by NFW profile.
- Halo parameters such as the virial mass, radius and shape parameters are extracted.

Simulation Results:
Halo Parameters



10^5 *halos*

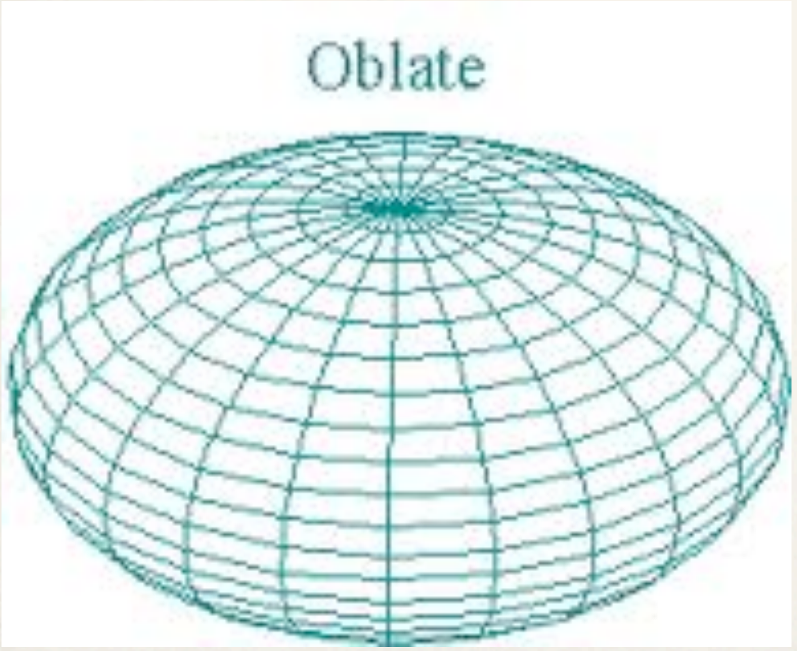
Bolshoi Simulation
Halo shape

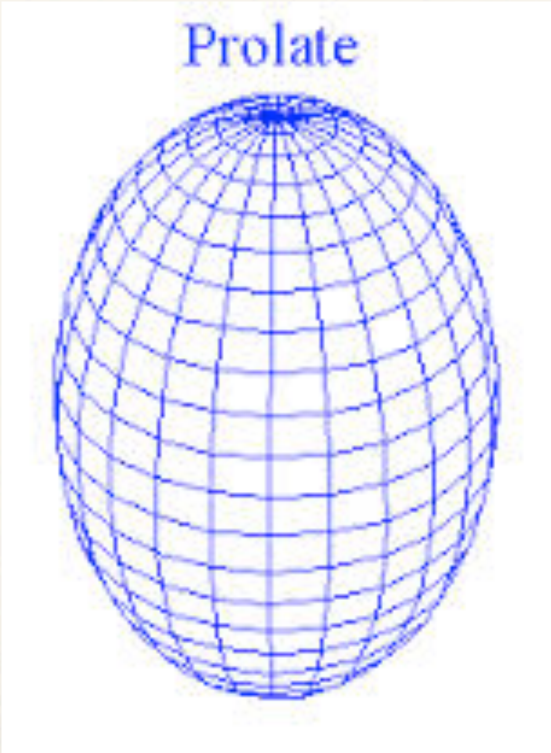
$$T_{jk} = \sum_i \frac{x_{ij}x_{ik}}{r_i^2}$$

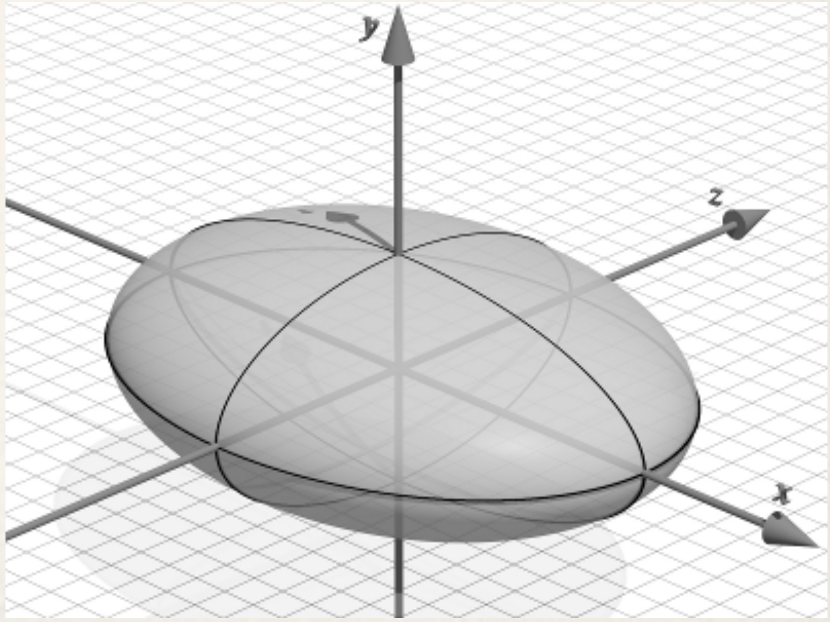
Define axes ratios:

$$b/a = T_b/T_a$$

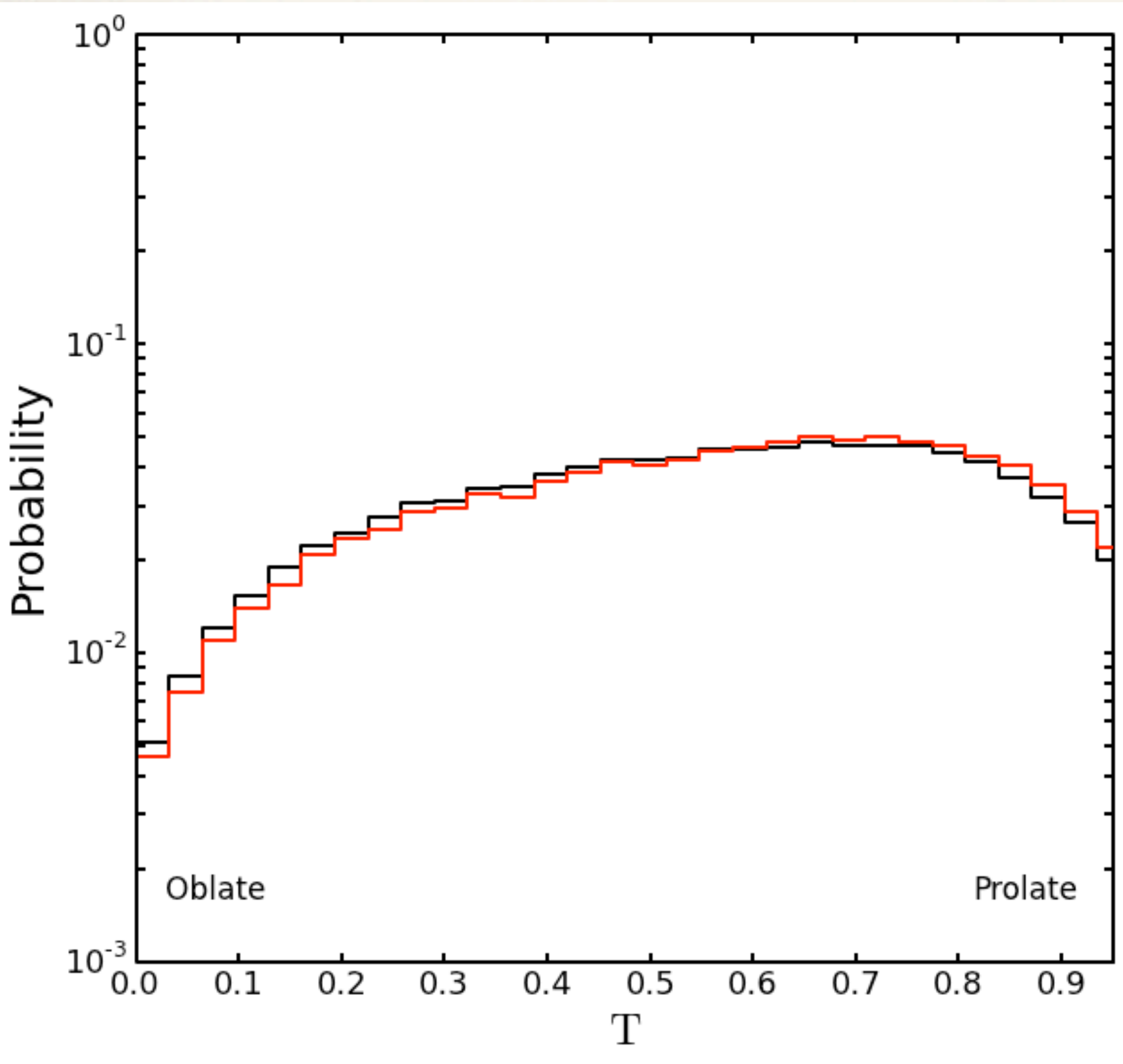
$$c/a = T_c/T_a$$







Simulation Results:
Shapes



Spherical halos are in fact very rare!

Parameterize shape with Triaxiality parameter (T):

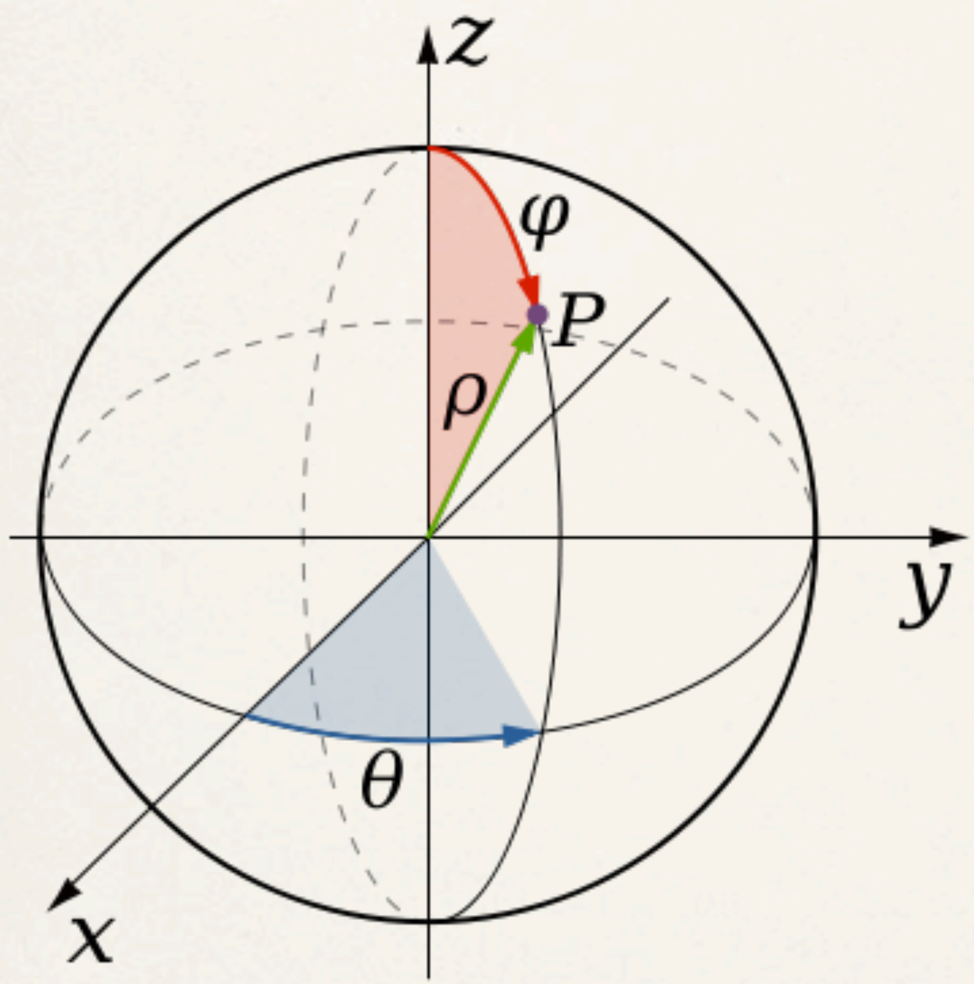
$$T = \frac{1-(b/a)^2}{1-(c/a)^2}$$

Prolate (Sausage shaped)
$a \gg b \approx c(1 > T > 2/3)$

Triaxial $a > b > c \ (2/3 > T > 1/3)$

Oblate (Pancake shaped)
$a \approx b \gg c \ (1/3 > T > 0)$

Impact of Halo Asphericity

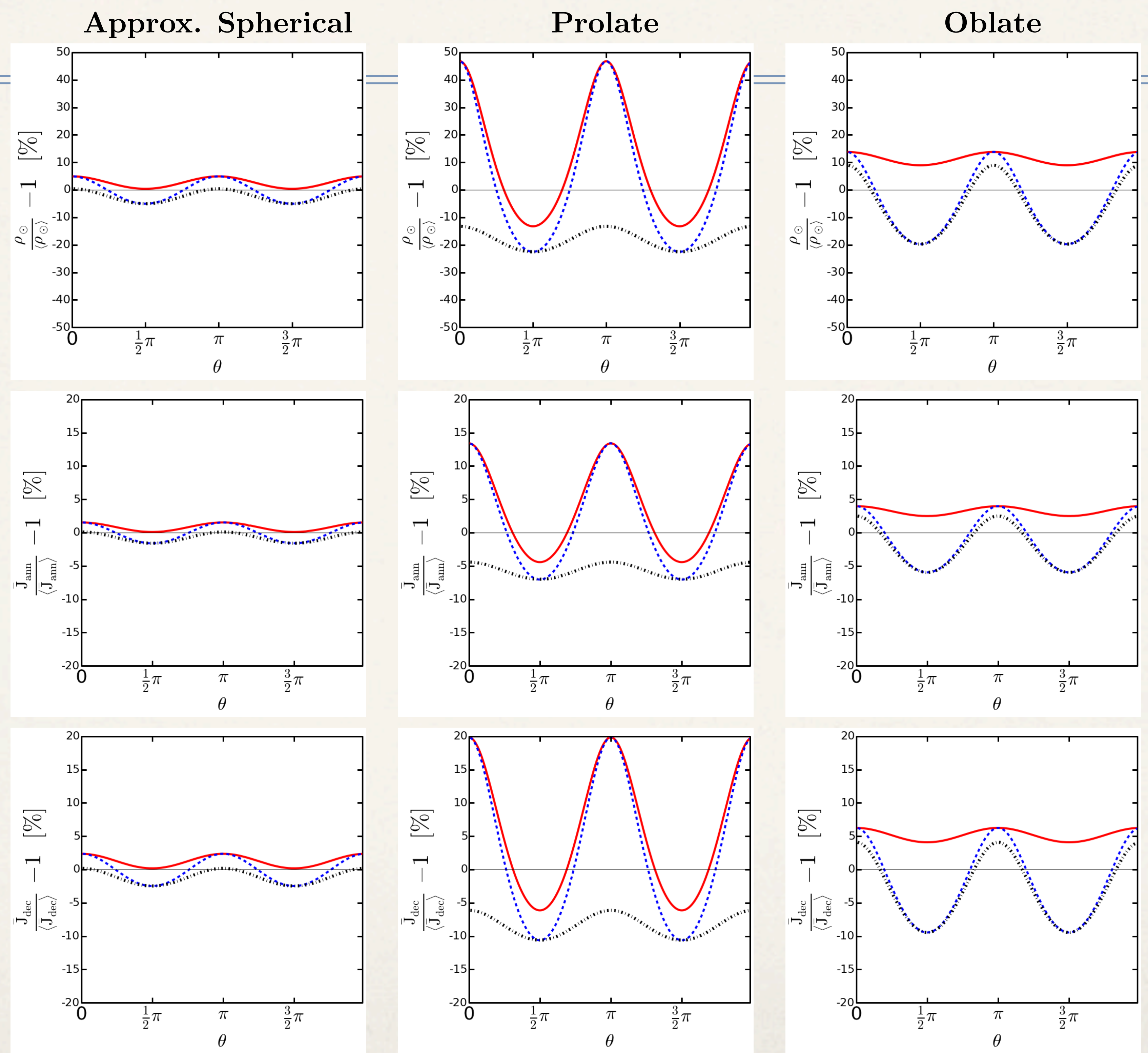


$$\rho(r) = \frac{N}{(r/r_s)\left[1 + (r/r_s)\right]^2}$$

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

Halo Type	M_v [10^{12} $M_\odot$]	R_v [kpc]	c_e	b/a	c/a
Approx. Spherical	3.8	242	9.73	0.97	0.91
Prolate	3.6	404	5.33	0.58	0.48
Oblate	2.0	419	9.79	0.97	0.77

Impact of Halo Asphericity



Observational Priors

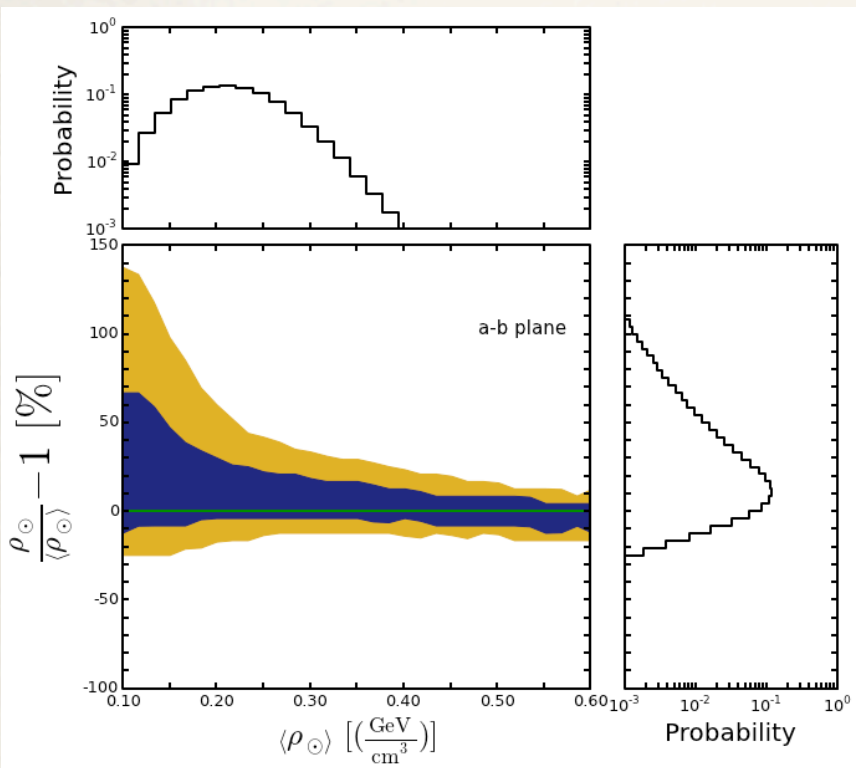
	Gaussian priors		Flat priors	
	Central value	1σ error	Lower cut	Upper cut
Virial mass $[10^{12}\,\mathrm{M}_\odot]$	–	–	$M_v^{\min} = 0.7$	$M_v^{\max} = 4.0$
DM mass within 60 kpc $[10^{11}\,\mathrm{M}_\odot]$	$M_{60}^{\mathrm{DM}} = 4.0$	$\sigma_{60} = 0.7$	–	–
Local DM surface density $[\mathrm{M}_\odot\,\mathrm{pc}^{-2}]$	$\Sigma_{1.1}^{\mathrm{DM}} = 17$	$\sigma_\Sigma = 6$	–	–
Sun's galactocentric distance [kpc]	–	–	$\mathrm{R}_\odot{}^{\min} = 7.5$	$\mathrm{R}_\odot{}^{\max} = 9$

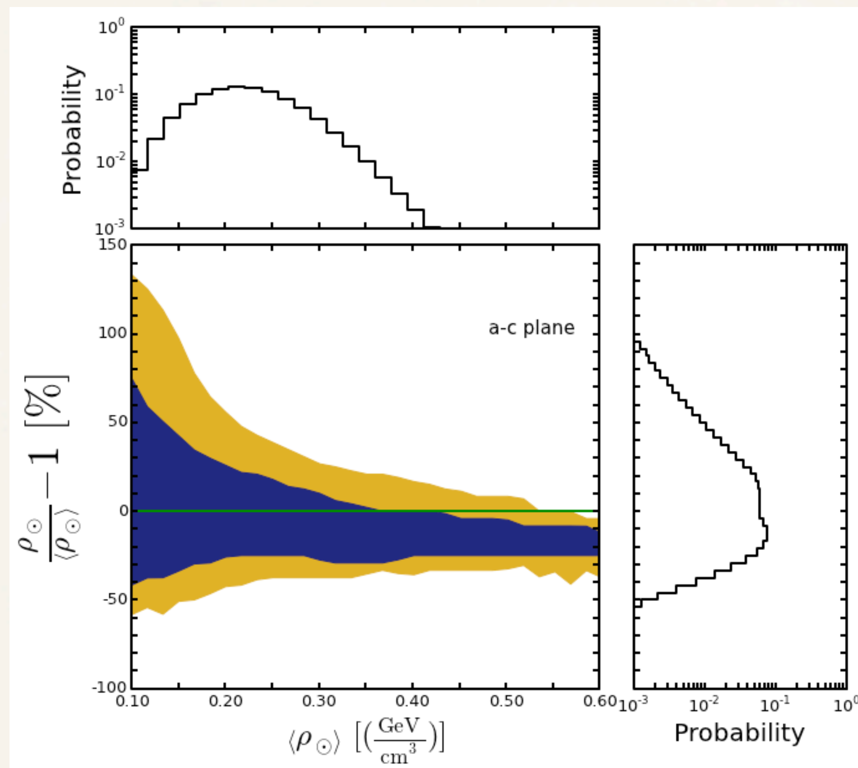
SDSS

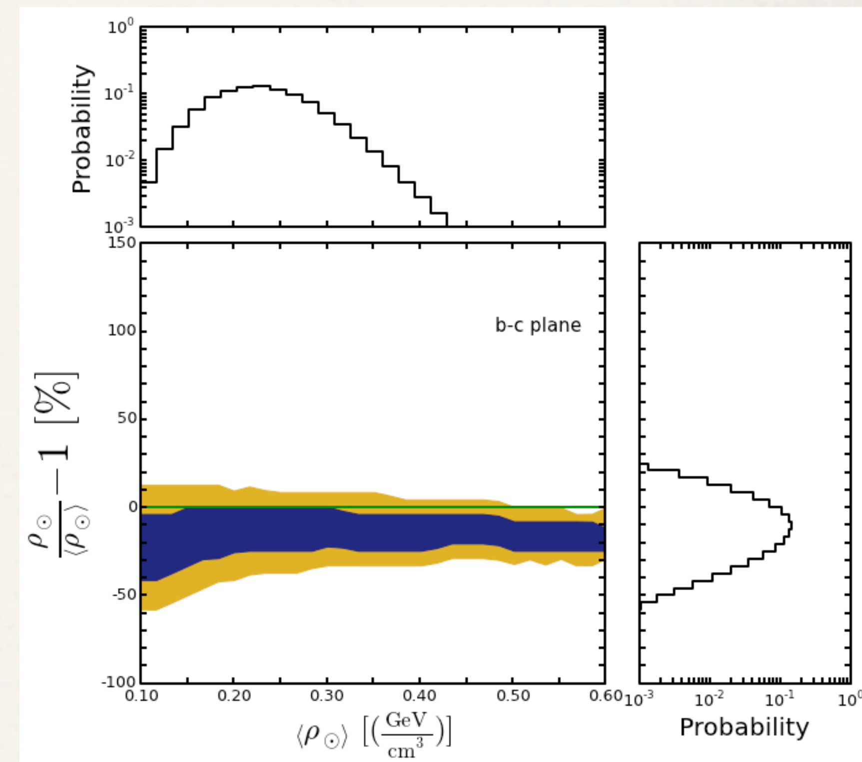
Bovy and Rix

$$\mathrm{PDF}^p_{\mathrm{prior}}(\vec{\omega}) = C\,\frac{\mathrm{PDF}(\vec{\omega})}{\mathrm{PDF}(M_v)} \times \theta(M_v - M_v^{\min})\,\theta(M_v^{\max} - M_v) \times \int_{\mathrm{R}_\odot{}^{\min}}^{\mathrm{R}_\odot{}^{\max}} \mathrm{dR}_\odot \exp\left[-\frac{(M_{60}^{\mathrm{DM}} - M_{60})^2}{2\,\sigma_{60}^2}\right] \times \int_0^{2\pi} \mathrm{d}\psi \exp\left[-\frac{(\Sigma_{1.1}^{\mathrm{DM}} - \Sigma_{1.1}^p(\mathrm{R}_\odot,\psi))^2}{2\,\sigma_\Sigma^2}\right],$$

Results: Local density







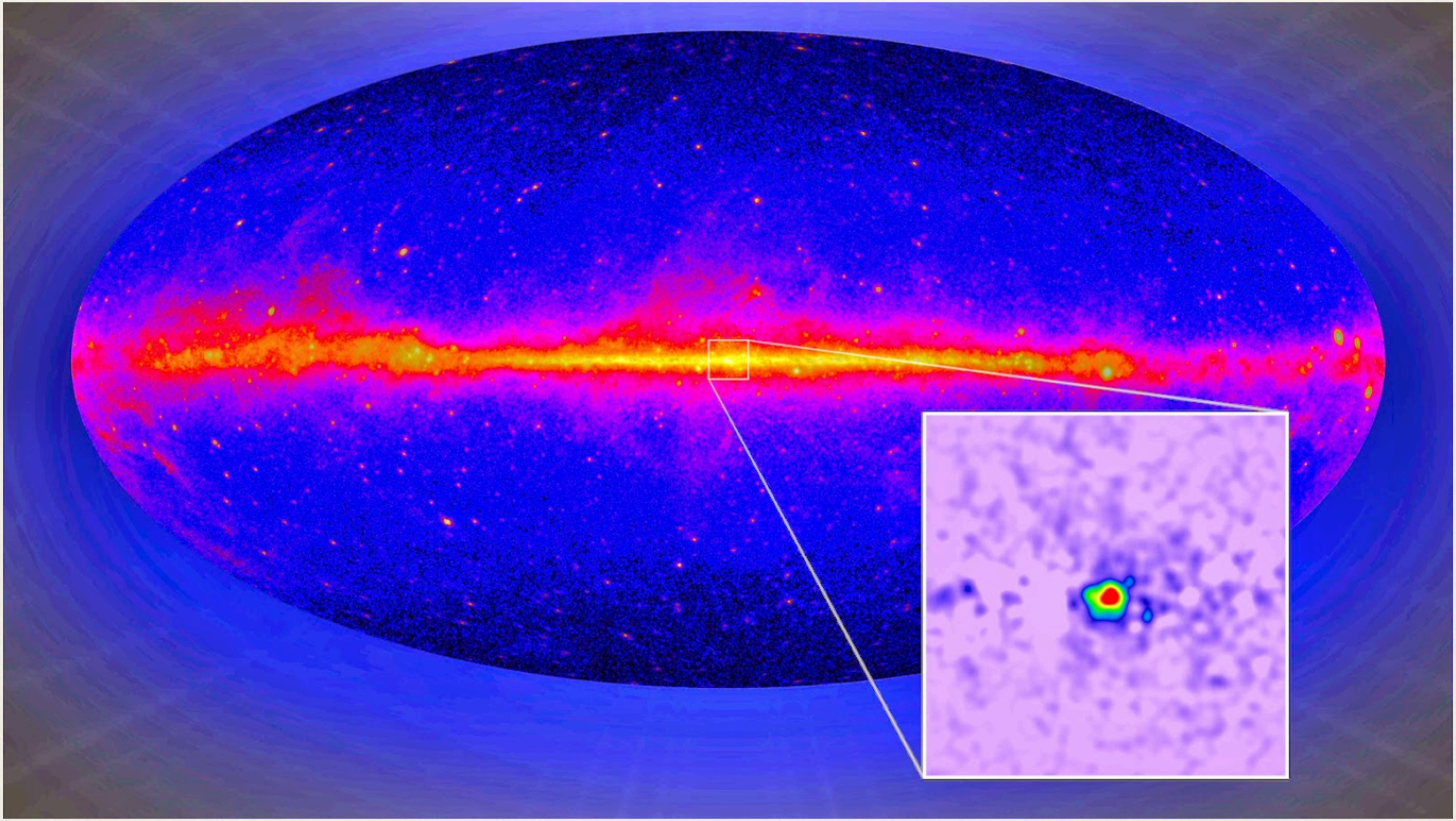
Note that the deviations are of the order of 10 - 40 %

a-b plane: $^{+20\%}_{-5\%}\left(^{+40\%}_{-15\%}\right)$

a-c plane: $^{+15\%}_{-30\%}\left(^{+35\%}_{-40\%}\right)$

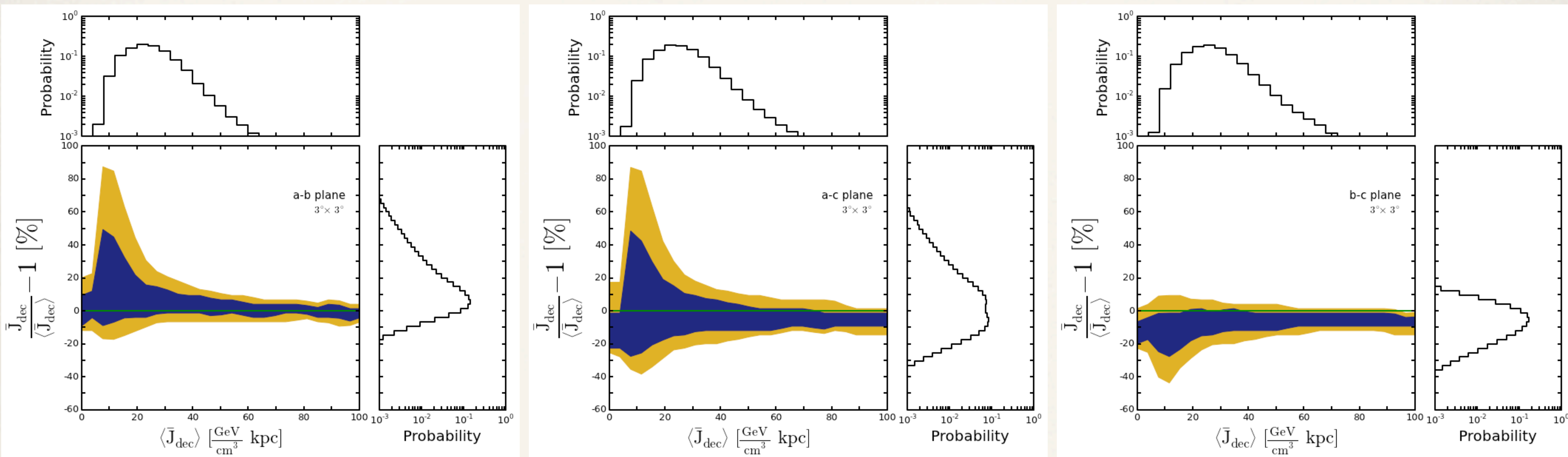
b-c plane: $^{+0\%}_{-30\%}\left(^{+10\%}_{-35\%}\right)$

Results: J factors



Fermi-LAT, Daylan et al. 2014

Results: J factors for decay

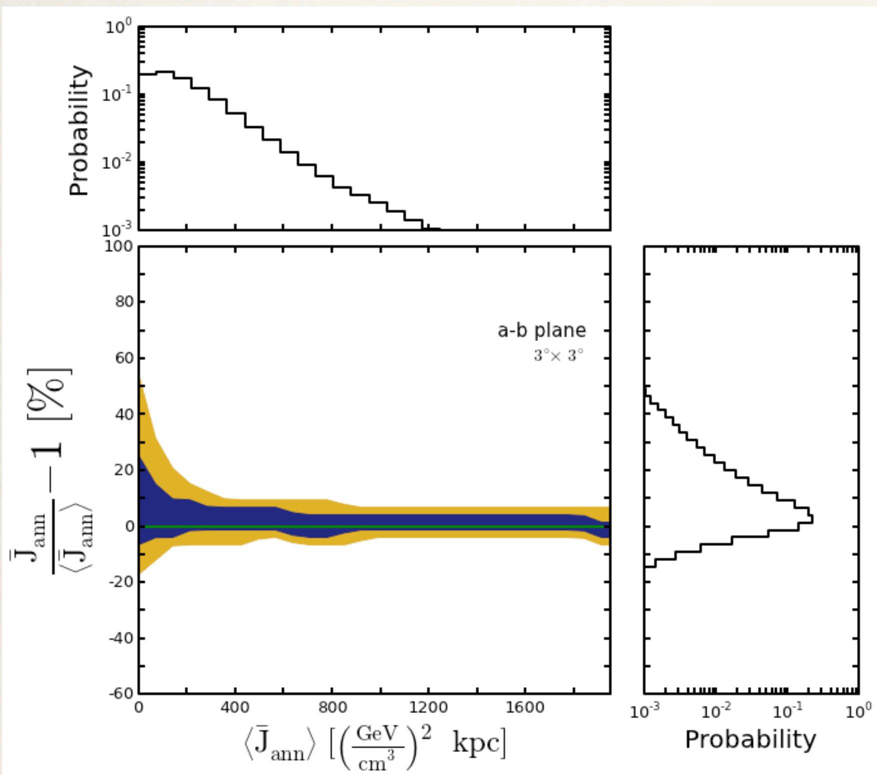


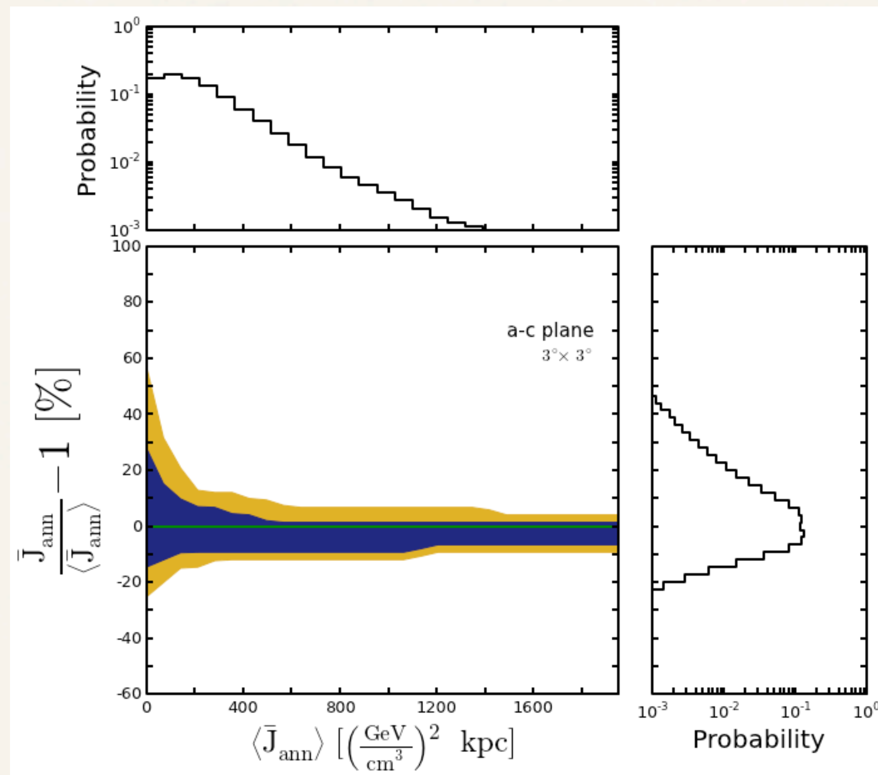
Deviations from
spherical average
are in the range 10 - 15 %

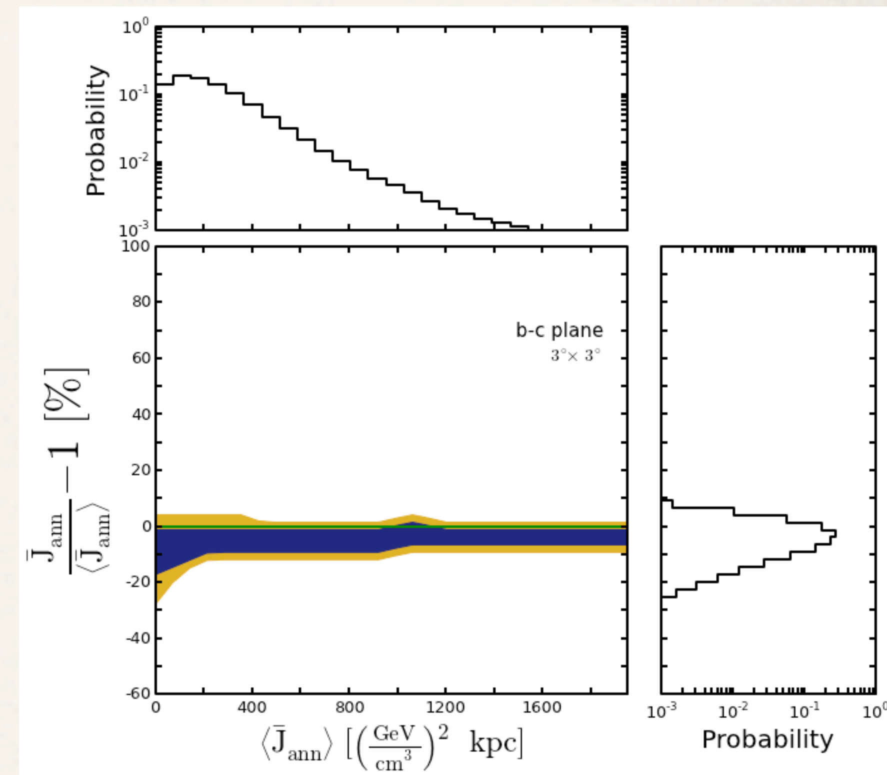
Typically
quoted value

$$\langle \bar{J}_{\rm dec} \rangle = 43 \left(GeV/cm^3 \right) kpc$$

Results: J factors for annihilations







Deviations from spherical average are in the range 5 - 10 %

Typically quoted value

$$\langle \bar{J}_{\rm ann} \rangle = 590 \left(GeV/cm^3 \right)^2 kpc$$

Conclusions

- Direct and Indirect DM searches crucially depend on Milky-Way DM halo properties, such as the local density and J factors.
- N-body simulation favor halos that are non-spherical. Spherical halos are rare.
- Using data from large N-body simulation Bolshoi, systematic uncertainties due to halo asphericity in DM searches are quantified.
- We find: $$\frac{\rho_\odot}{\langle \rho_\odot \rangle} = 0.83 - 1.35$$

$$\frac{\bar{J}_{\rm dec}}{\langle \bar{J}_{\rm dec} \rangle} = 0.93 - 1.13$$ and $$\frac{\bar{J}_{\rm ann}}{\langle \bar{J}_{\rm ann} \rangle} = 0.95 - 1.09$$