Astrophysical parameters and their impact on dark matter searches

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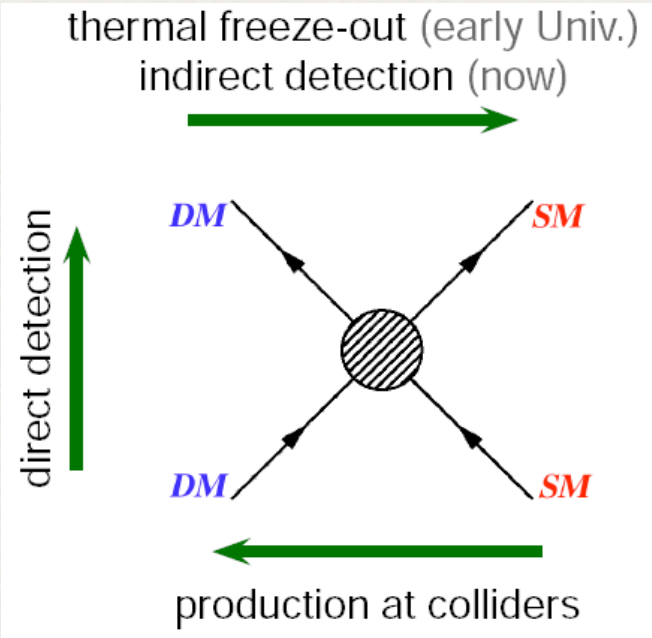
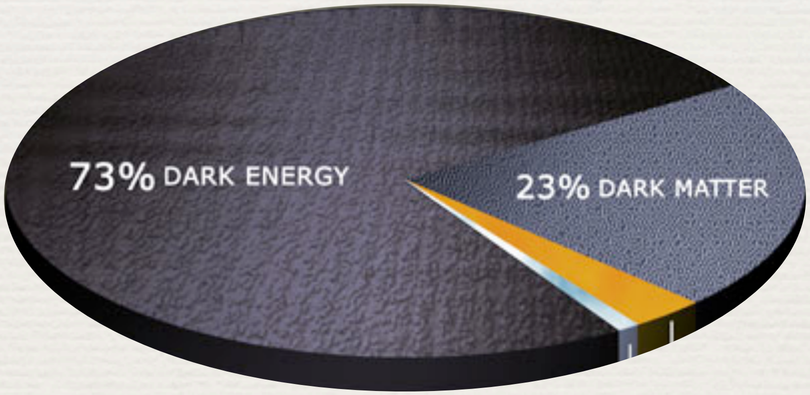
UC Davis Dark Matter in Collision 4/12/12

Particle Dark Matter

Weakly Interacting Massive Particles (WIMPs) in equilibrium in early Universe, may freeze-out with significant relic abundance

$$\sigma v \sim 3 \times 10^{-26}\ \mathrm{cm}^3/\mathrm{s}$$





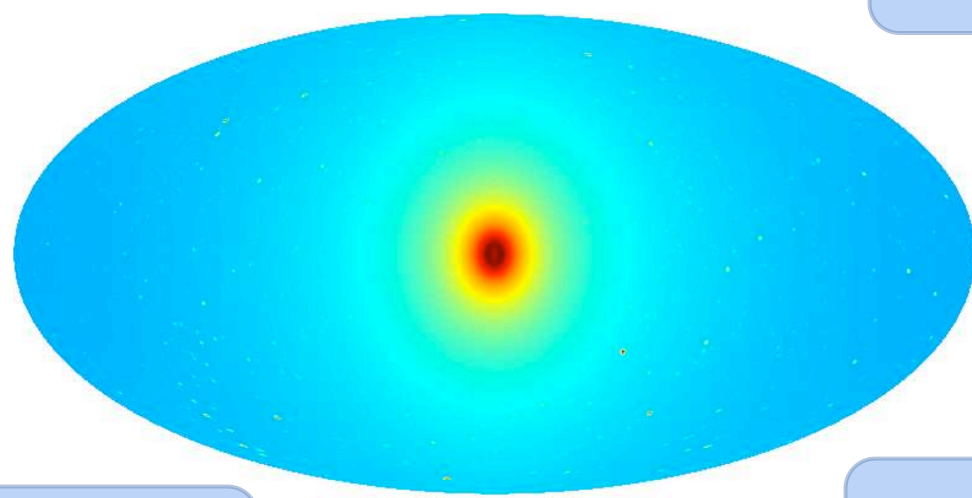
$$\sigma v = a + bv^2 = [\sigma v]_0 \left(1 + \frac{b}{a} v^2\right)$$

WIMP annihilation:Search Strategies

Satellites: Low bkgd, good source id, low statistics

Galactic center: Good statistics, source confusion/ diffuse backgrounds

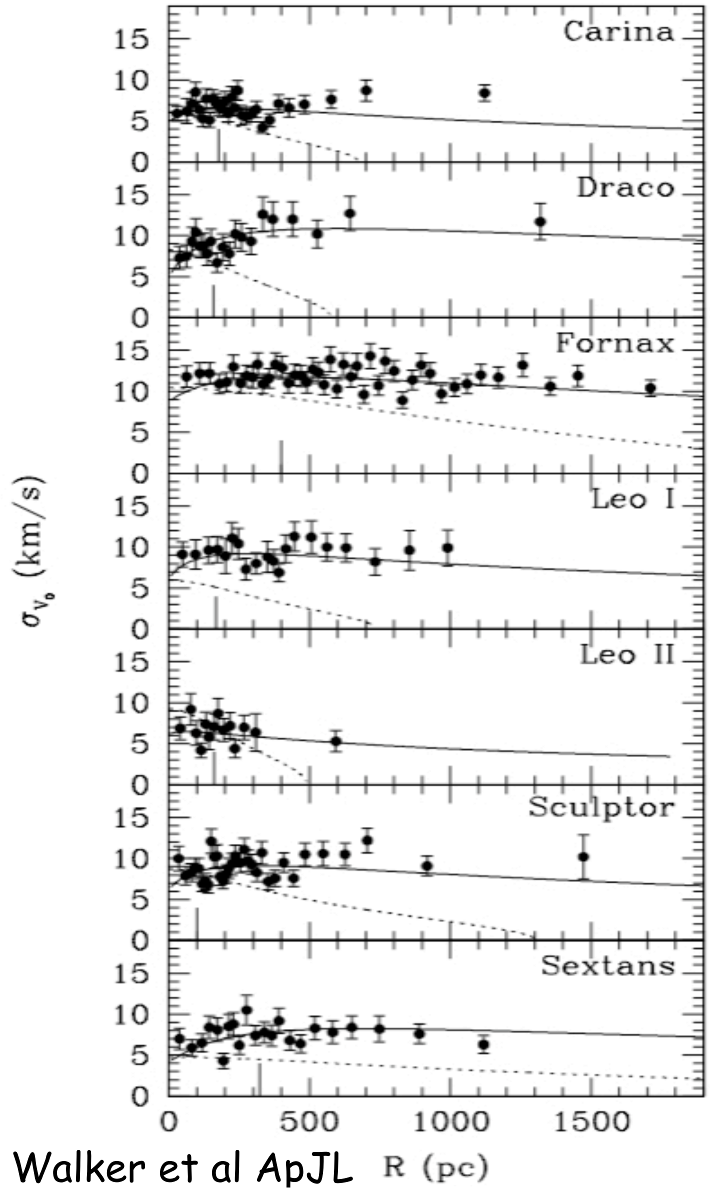
Halo: Good statistics but diffuse backgrounds

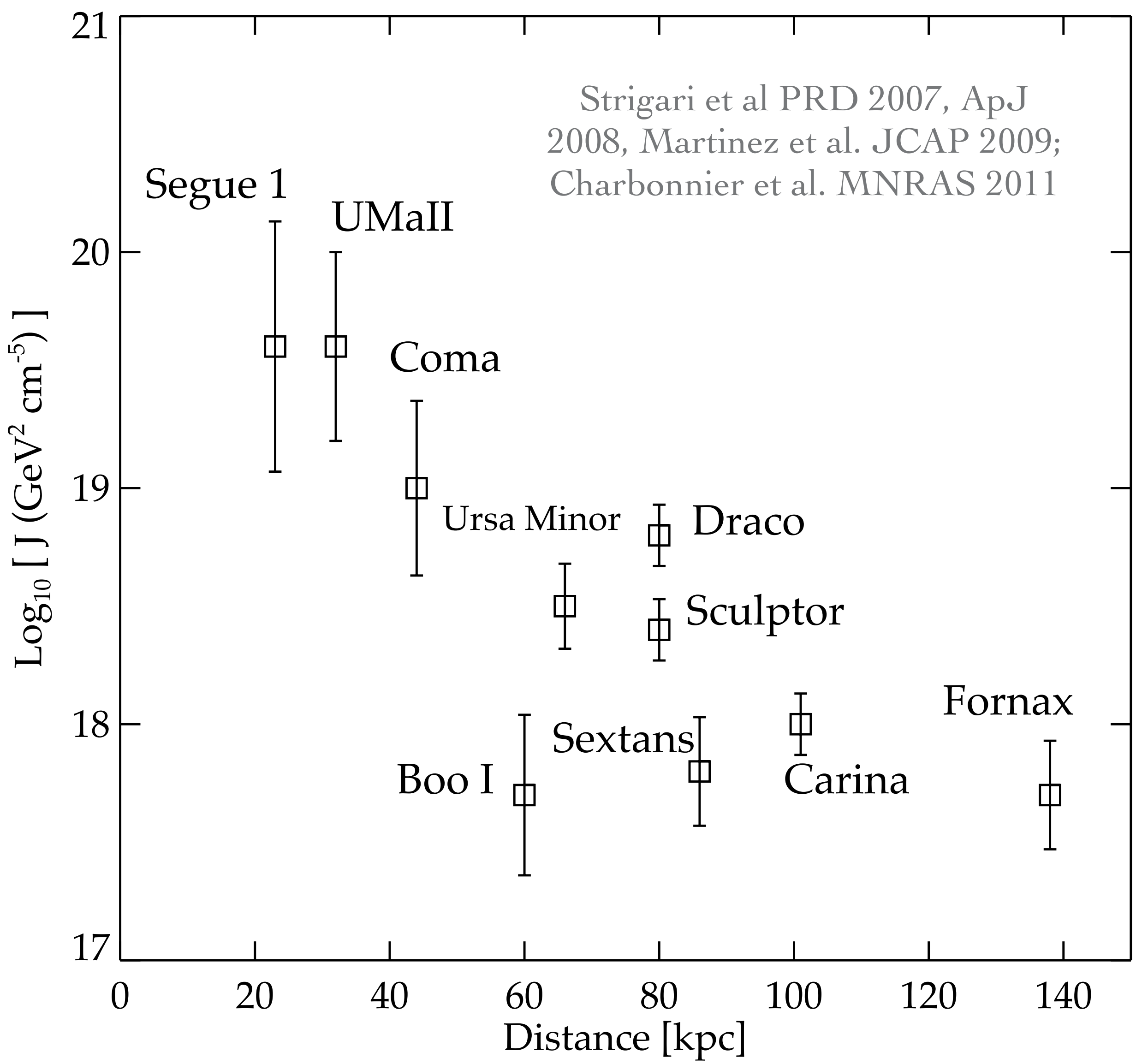


Spectral lines: Good source id, low statistics

Extragalactic: Good statistics, diffuse bkgds and astrophysics

Galaxy clusters: Low backgrounds but low statistics

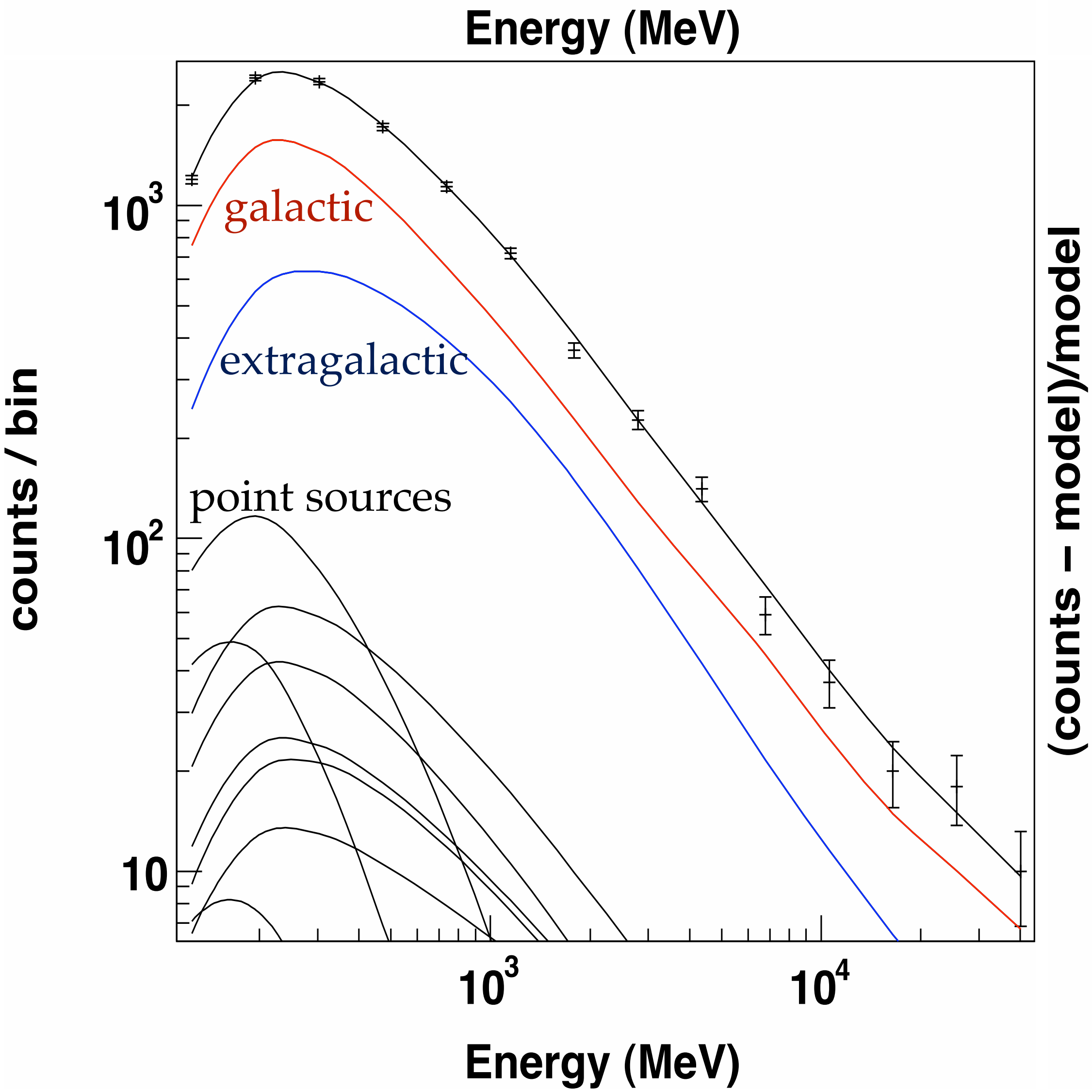




$$\left\{\int_{E_{\rm th}}^{M_\chi} \sum_i \frac{dN_{\gamma,i}}{dE} \frac{\langle \sigma v \rangle_i}{M_\chi^2}\, dE\right\} \left\{\int_0^{\Delta\Omega} \left\{\int_{\rm LOS} \rho^2[r(\theta, \mathcal{D}, s)]\, ds\right\} d\Omega\right\}$$

J value

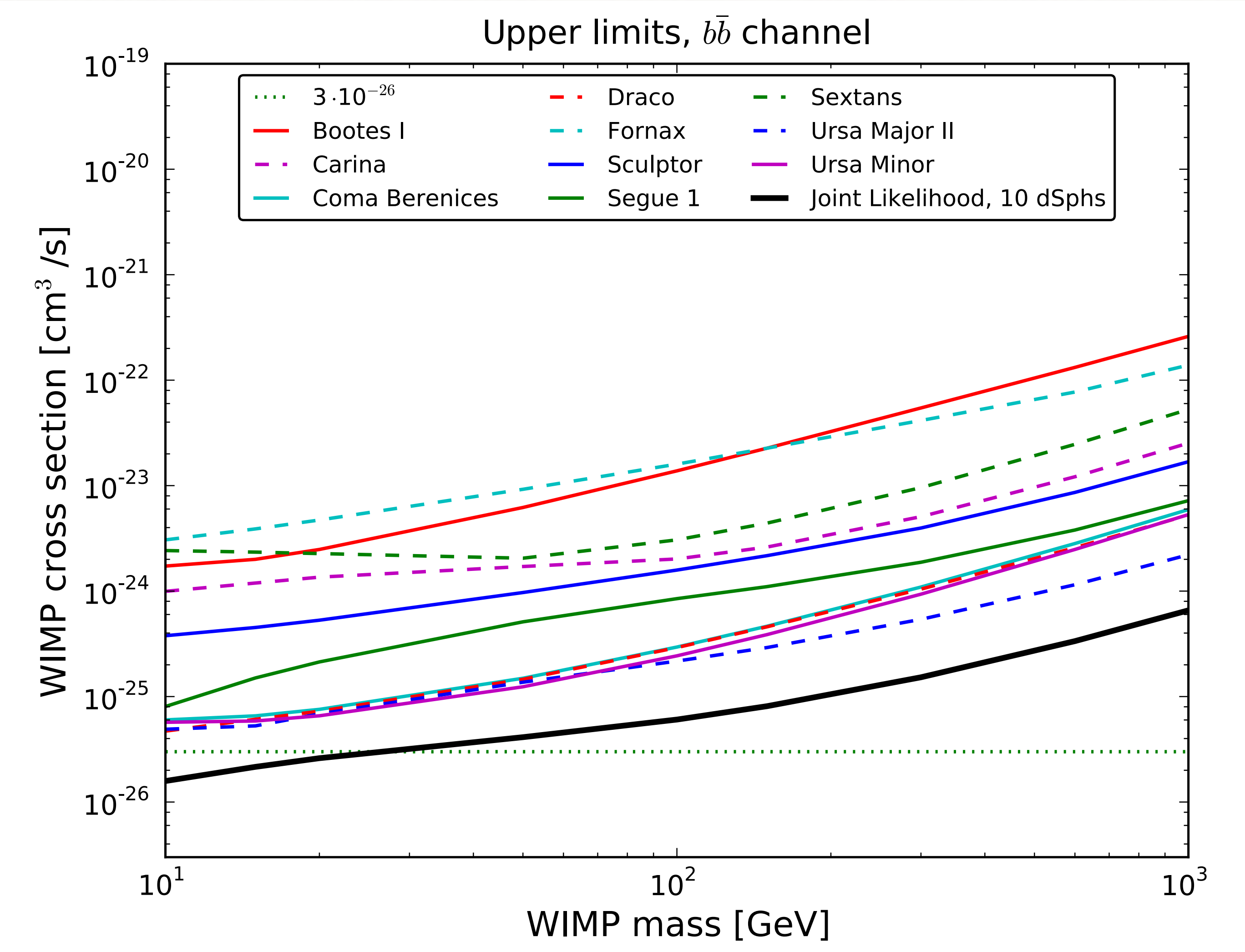
Fermi-LAT Collaboration, ApJ 2010



Constraining Dark Matter Models from a Combined Analysis of Milky Way Satellites with the Fermi Large Area Telescope

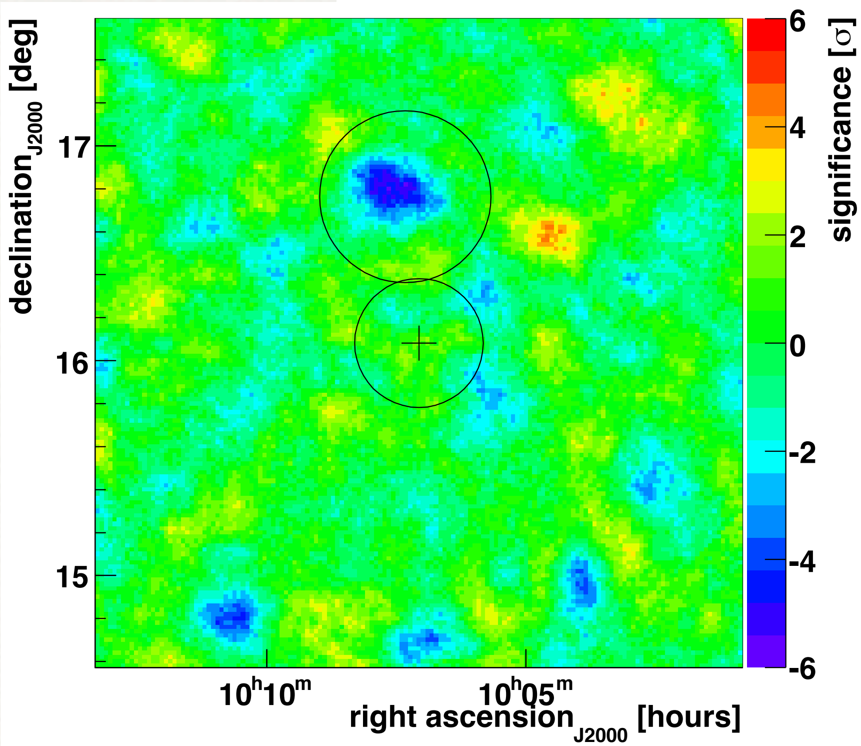
Fermi-LAT Collaboration, PRL 2011

$$L(D|\mathbf{pw},\{\mathbf{p}\}_i) = \prod_i L_i^{\mathrm{LAT}}(D|\mathbf{pw},\mathbf{p}_i) \times \frac{1}{\ln(10)\, J_i \sqrt{2\pi}\sigma_i} e^{-\left[\log_{10}(J_i) - \overline{\log_{10}(J_i)}\right]^2/2\sigma_i^2}$$

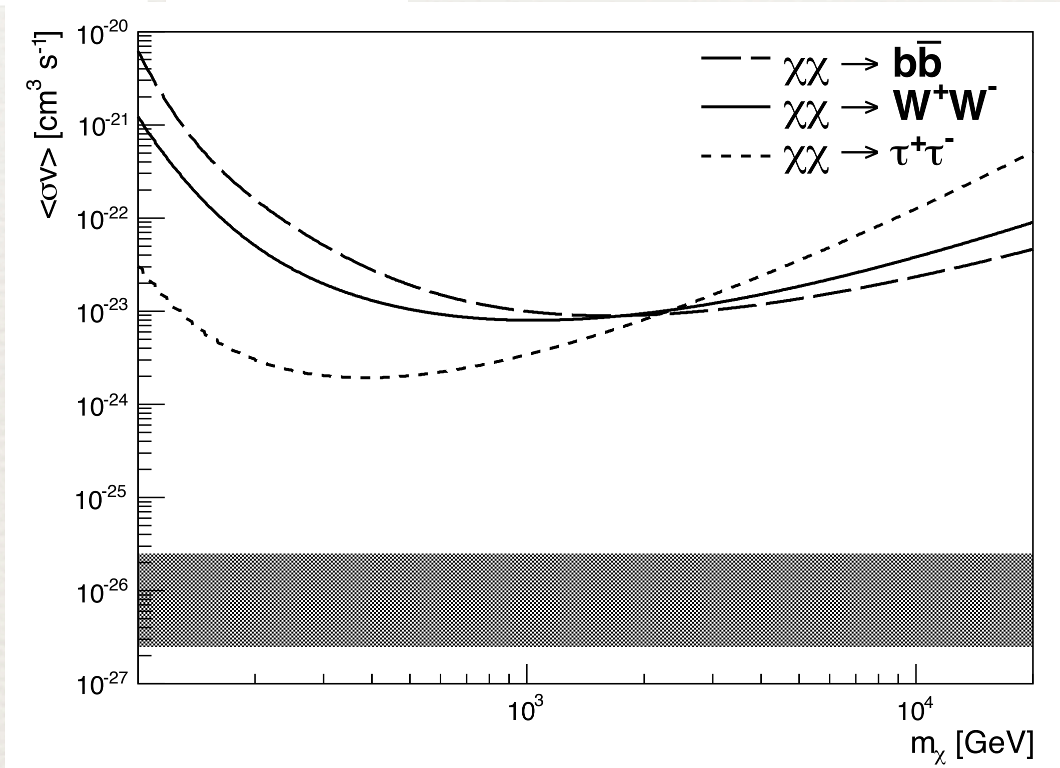


ACT limits at higher energies

Veritas, arXiv:1202.2144



Segue 1



CTA expected to reach thermal relic scale (2017)

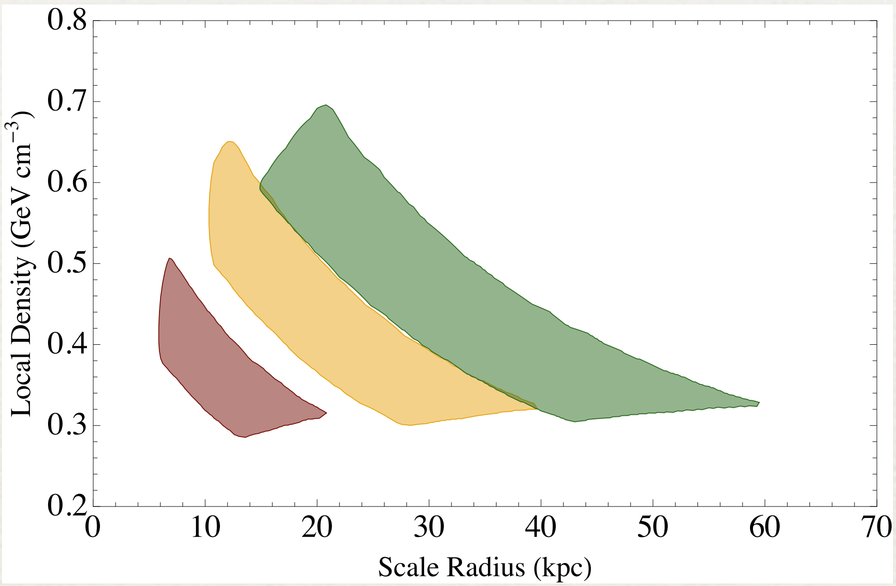
Overview of direct detection

- Frequent claims of DM ‘detections’ or at least ‘anomalies’
- What do we make of these?
- Experimental issues
- Extracting new physics
- How `vanilla’ is the astrophysics?
    - Often the last issue brought up
    - Astrophysics can be `messy’: how is this an issue?

Local inventory

- Local mass density in disk is ~ 0.1 M_{sun}/pc^3 [Holmberg & Flynn 2000, 2004]
- Stars, molecular/atomic gas, cold/warm/hot components
- Surface mass density out to 1.1 kpc is 74 +- 6 M_{sun}/pc^2, 56 +- 6 from disk. Agreement with visible material
- No significant DM disk component [Moni Bidin et al. ApJ 2010]

Estimates of Local DM density



Lisanti, LS, Wacker, Wechsler PRD 2011

- rho_DM = 0.389 +- 0.025 GeV/cm^3 [Catena & Ullio JCAP 2010]
- rho_DM = $0.11^{+0.34}_{-0.27}$ GeV/cm^3 [Garbari et al. MNRAS 2011]
- Uncertainties in MW scale radius

Conservatively, probably fair to say still about a factor of 2 uncertainty, at least

Estimates of velocity distribution

We of course only measures velocities of stars, not DM

\`Standard Halo Model' is:

$$f(\mathbf{v}) = \begin{cases} N\left[\exp\left(-\frac{3|\mathbf{v}|^2}{2\sigma^2}\right)\exp\left(-\frac{3v_{\rm esc}^2}{2\sigma^2}\right)\right], & |\mathbf{v}| < v_{\rm esc} \\ 0\,, & |\mathbf{v}| \geq v_{\rm esc} \end{cases}$$

Escape velocity estimates from tail of stellar distribution

$$f(|\mathbf{v}|) \propto \begin{cases} (v_{\rm esc}^2 - |\mathbf{v}|^2)^k = [(v_{\rm esc} - |\mathbf{v}|)(v_{\rm esc} + |\mathbf{v}|)]^k\,, & |\mathbf{v}| < v_{\rm esc} \\ 0\,, & |\mathbf{v}| \geq v_{\rm esc} \end{cases}$$

Typically, k = 2.7-4.7 [Smith et al. MRNAS 2006 (RAVE)]

Phenomenological Prescriptions

Double power law:

$$f(\boldsymbol{v}) = \begin{cases} \frac{1}{N}\left[\exp\left(\frac{v_{\rm esc}^2 - v^2}{k v_0^2}\right) - 1\right]^k, & |\boldsymbol{v}| < v_{\rm esc} \\ 0, & |\boldsymbol{v}| \geq v_{\rm esc} \end{cases}$$

Tsallis model:

$$f(\boldsymbol{v}) = \begin{cases} \frac{1}{N}\left[1 - (1-q)\,\frac{\boldsymbol{v}^2}{v_0^2}\right]^{1/(1-q)}, & |\boldsymbol{v}| < v_{\rm esc} \\ 0, & |\boldsymbol{v}| \geq v_{\rm esc} \end{cases}$$

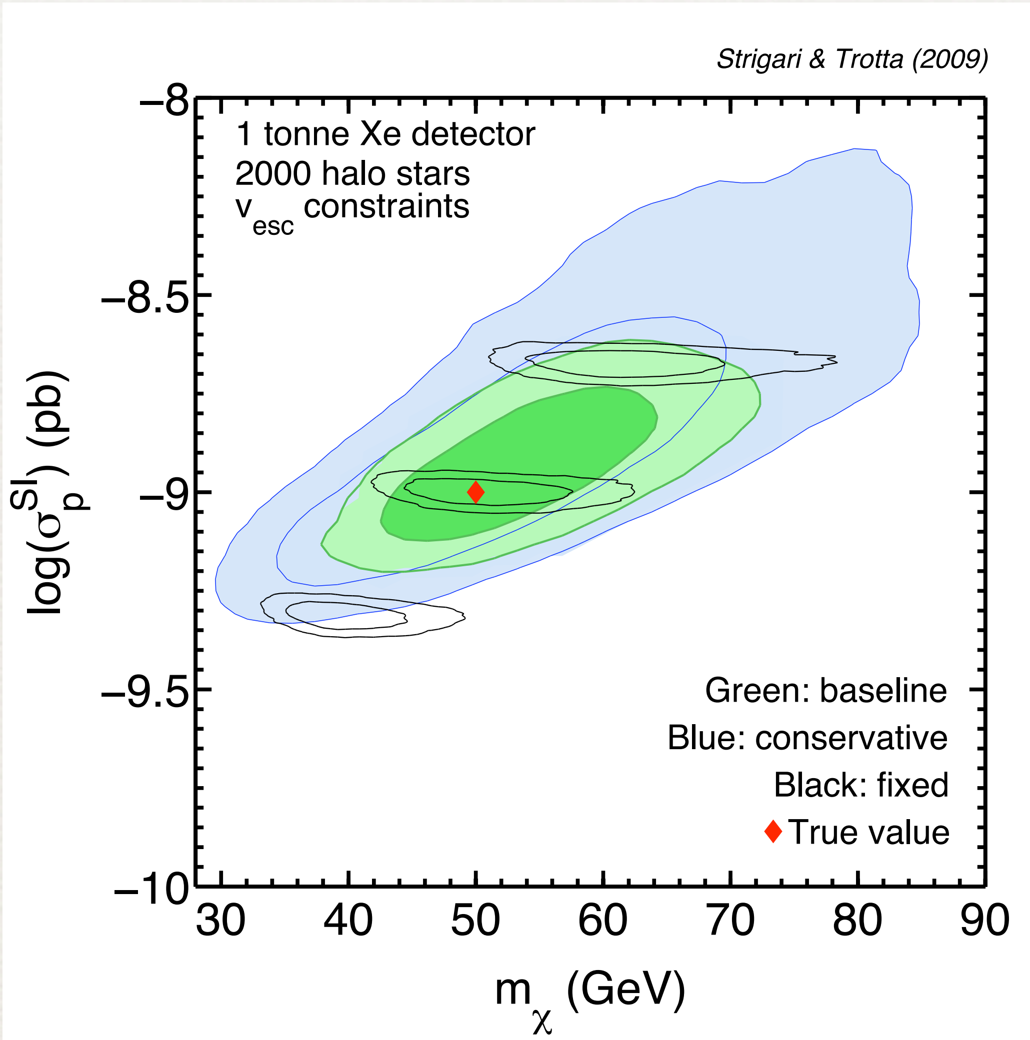
Anisotropic models:

$$f(\boldsymbol{v}) = \begin{cases} \frac{1}{N}\left[\exp\left(-(v_r^2/\overline{v}_r^2)^{\alpha_r}\right)\exp\left(-(v_t^2/\overline{v}_t^2)^{\alpha_t}\right)\right], & |\boldsymbol{v}| < v_{\rm esc} \\ 0, & |\boldsymbol{v}| \geq v_{\rm esc} \end{cases}$$

Log ellipsoidal model:

$$f(\boldsymbol{v}) = \begin{cases} \frac{1}{N}\left[\exp\left(-v_r^2/\overline{v}_r^2 - v_\phi^2/\overline{v}_\phi^2 - v_z^2/\overline{v}_z^2\right)\right], & |\boldsymbol{v}| < v_{\rm esc} \\ 0, & |\boldsymbol{v}| \geq v_{\rm esc} \end{cases}$$

Implications for WIMP reconstruction



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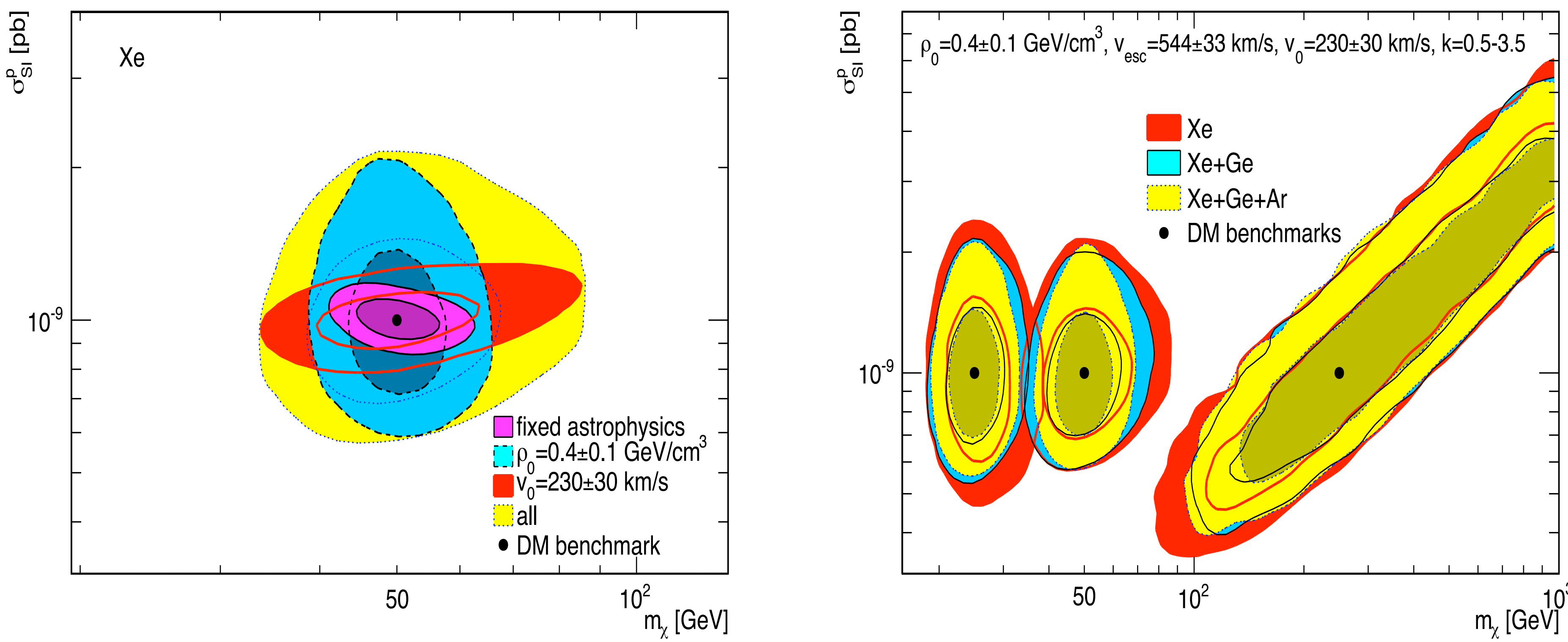


Pato, Baudis, Bertone, Ruiz de Austri, LS, Trotta, PRD 2011

Improved theoretical approach

- Previous methodology not necessarily `self-consistent'
- Velocity distribution does not follow from density model for the DM halo
- Possible to relate f(v) ↔ rho(r), under some simplifying assumptions
  - Isotropy (or mild anisotropy)
  - Spherical symmetry
- MCMC implementation computationally expensive

Improved theoretical approach

Isotropic orbits:

$$f(\mathcal{E}) = \frac{1}{\sqrt{8}\pi^2}\left[\int_0^{\mathcal{E}} \frac{\mathrm{d}^2\rho}{\mathrm{d}\Psi^2}\frac{\mathrm{d}\Psi}{\sqrt{\mathcal{E}-\Psi}} + \frac{1}{\mathcal{E}^{1/2}}\left(\frac{\mathrm{d}\rho}{\mathrm{d}\Psi}\right)_{\Psi=0}\right]$$

Constant Anisotropy:

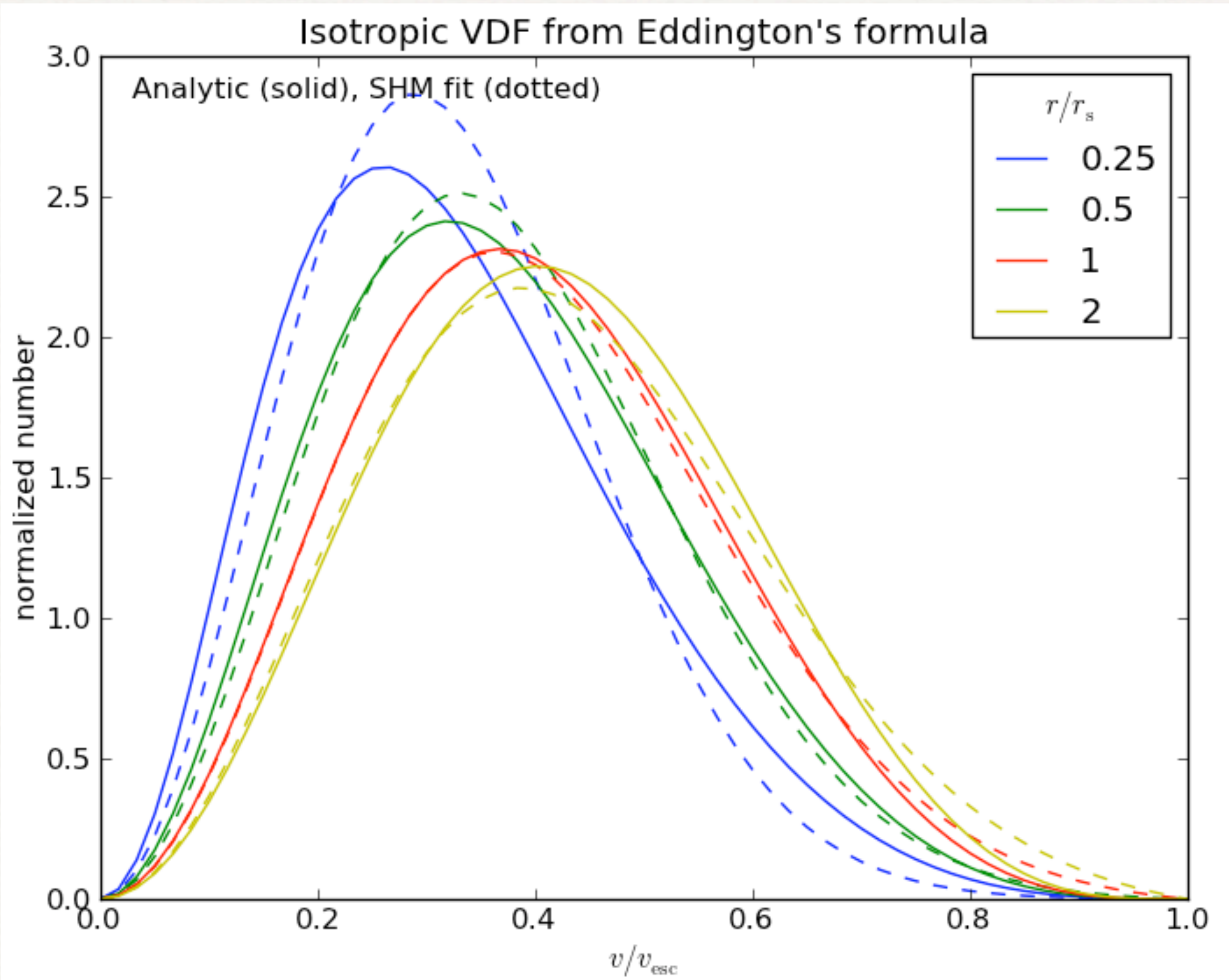
$$f(E,L) = L^{-2\beta} f_E(E)$$

Osipkov-Merritt:

$$\beta = 1 - \frac{\sigma_\theta^2 + \sigma_\phi^2}{2\sigma_r^2} = \frac{1}{1+(r_a/r)^2}$$

- Rich phenomenology
- WIMP event rate directly connected to the spatial model for the DM density profile

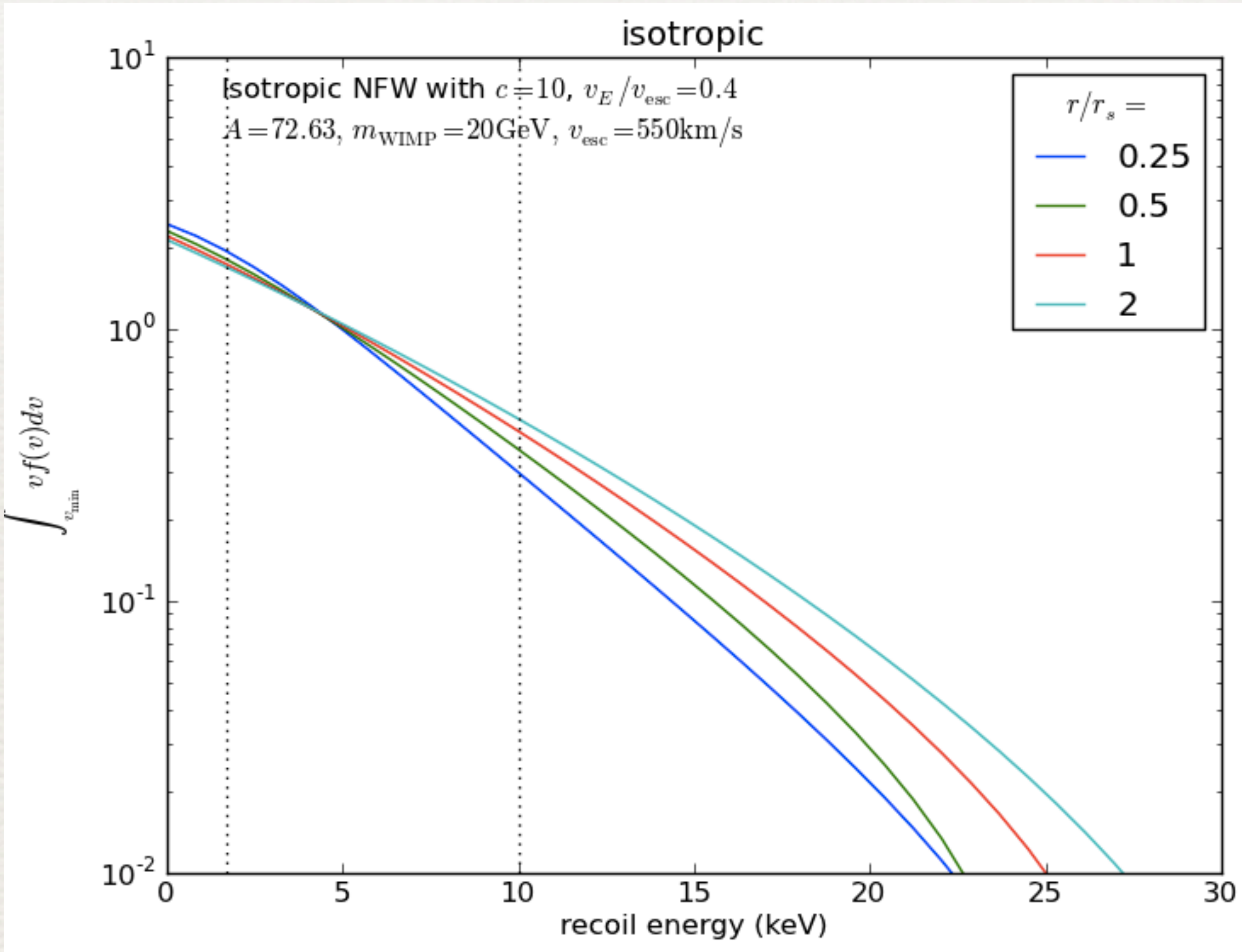
Improved theoretical approach



- Uncertainty on the scale radius of halo [typically taken to be about 20 kpc]
- Standard halo model not a good description
- New urgency for astrophysical data on MW

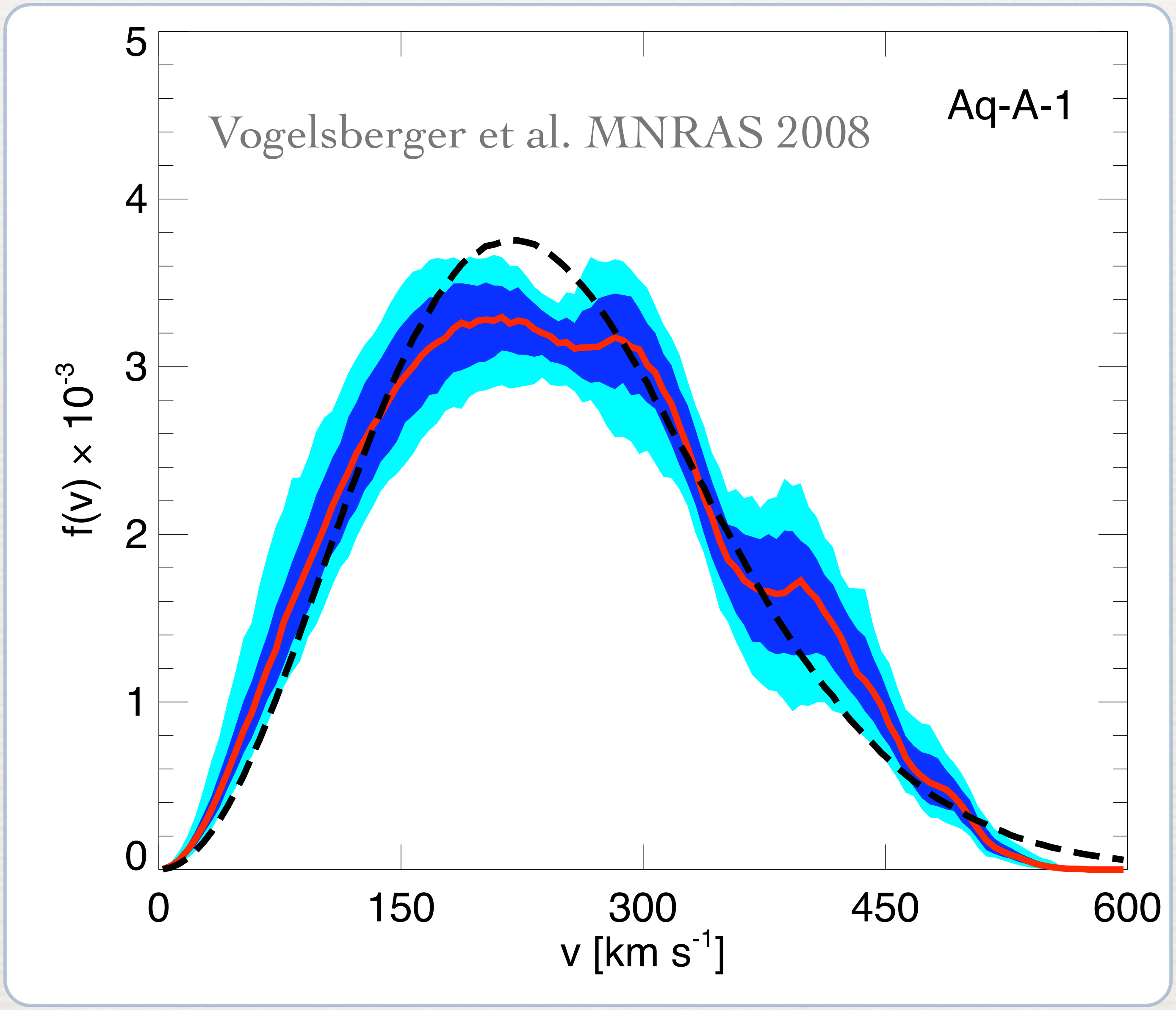
Mao, LS, Wechsler 2012 to appear

Improved theoretical approach

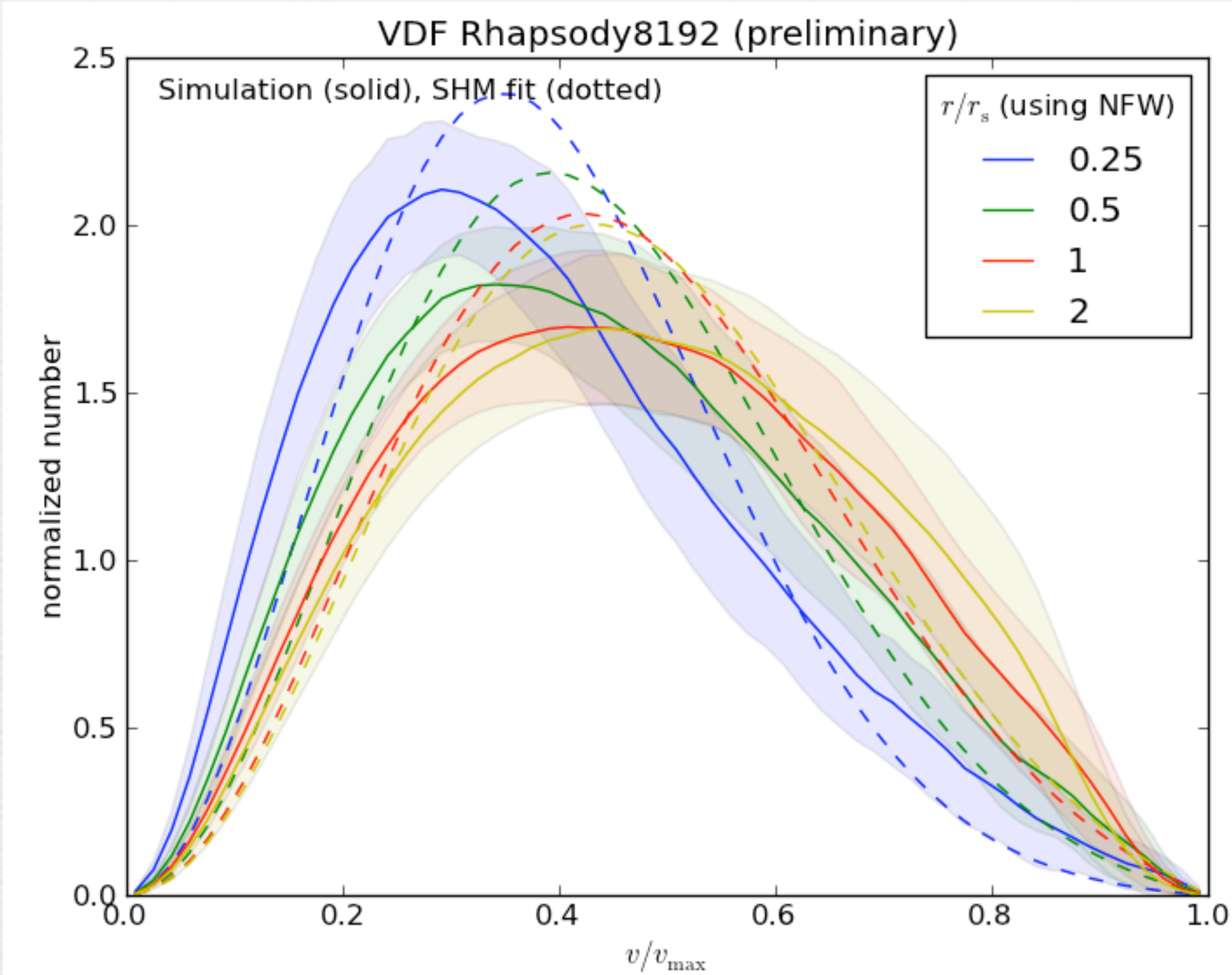


Mao, LS, Wechsler 2012 to appear

Simulations: in halo variance

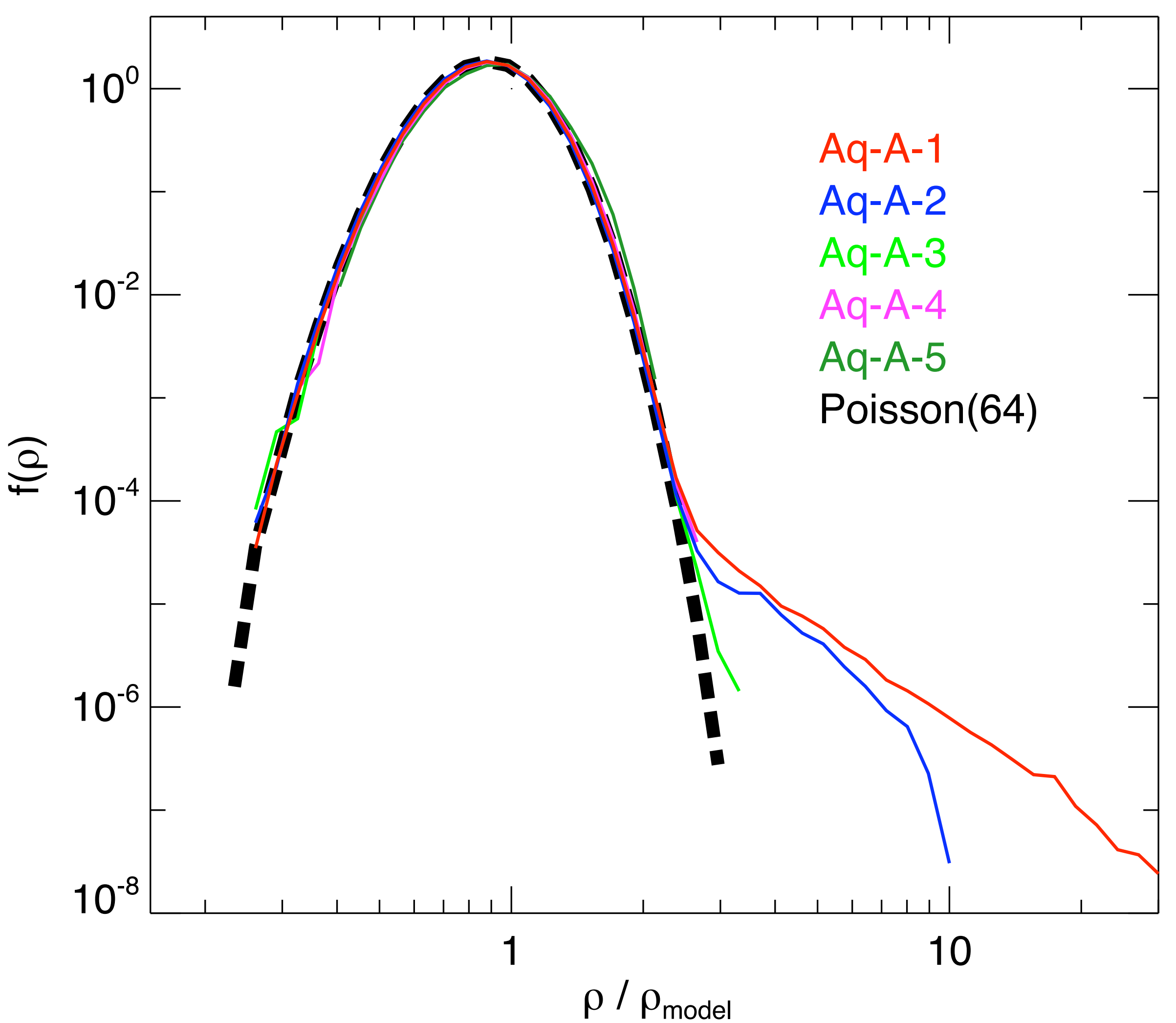


Simulations: cosmology variance



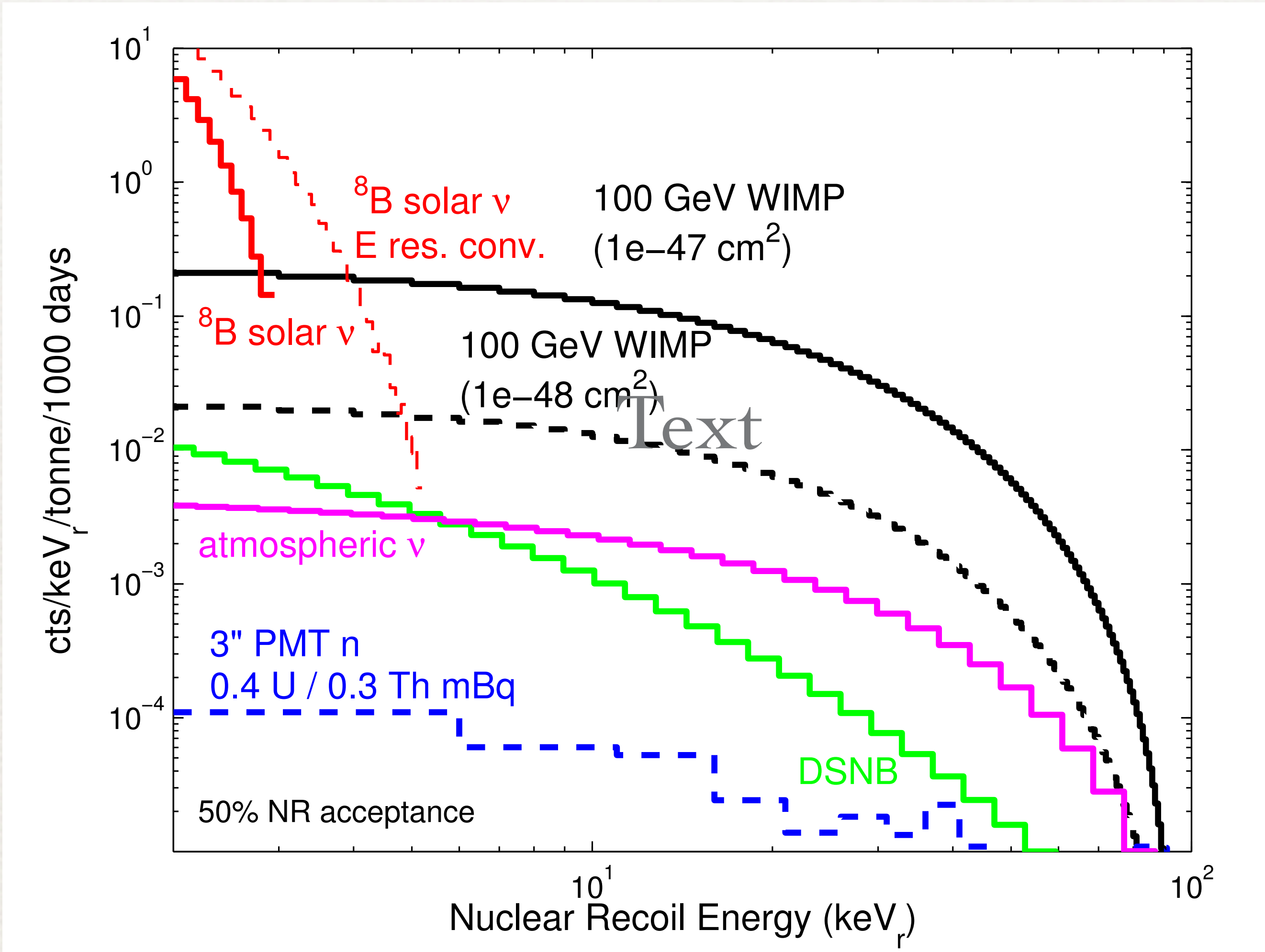
Mao, LS, Wechsler 2012 to appear

Clumps in the local DM distribution



Koushiappas & Kamionkowski PRD 2008;
Vogelsberger et al. MNRAS 2008

Neutrinos = end of direct detection?



Malling et al. 1110.0103

Conclusions

- Fermi-LAT now has important DM results for masses 10-25 GeV and annihlation to bbar and tau+/tau-
- More data and better understanding of systematics will improve results
- On longer timescales ACTs (CTA)
- How worried are we about ``astrophysics" in interpretation of direct detection limits? (From a practical perspective... interesting Galactic astronomy of course)
- Does it matter as long as in discovery mode? Variations in astrophysics don't yet reconcile ``hints" (Frandsen et al. 2011)
- Will theory (simulations, etc) be outpaced by experiments?