# Direct detection and the dark matter distribution

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- WIMP direct detection basics
- The dark matter distribution
- Sub-milli-pc structure?

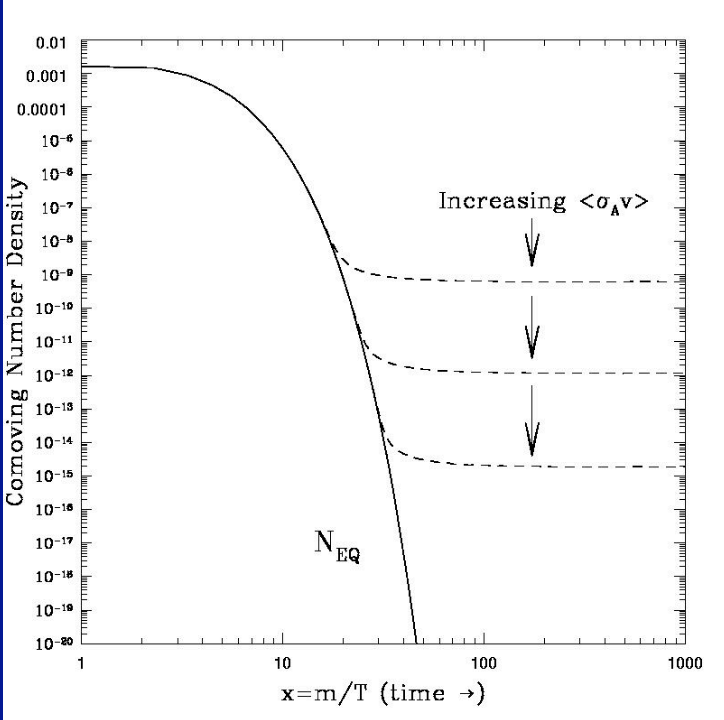
*Including work in collaboration with Ben Morgan, Stefan Hofmann & Dominik Schwarz and Daniele Fantin & Mike Merrifield.*

# WIMP direct detection basics

**W**eakly **I**nteracting **M**assive **P**articles are a good cold dark matter candidate because:

i) Any stable, Weakly Interacting Massive Particle in thermal equilibrium in the early Universe will have roughly the right density today.

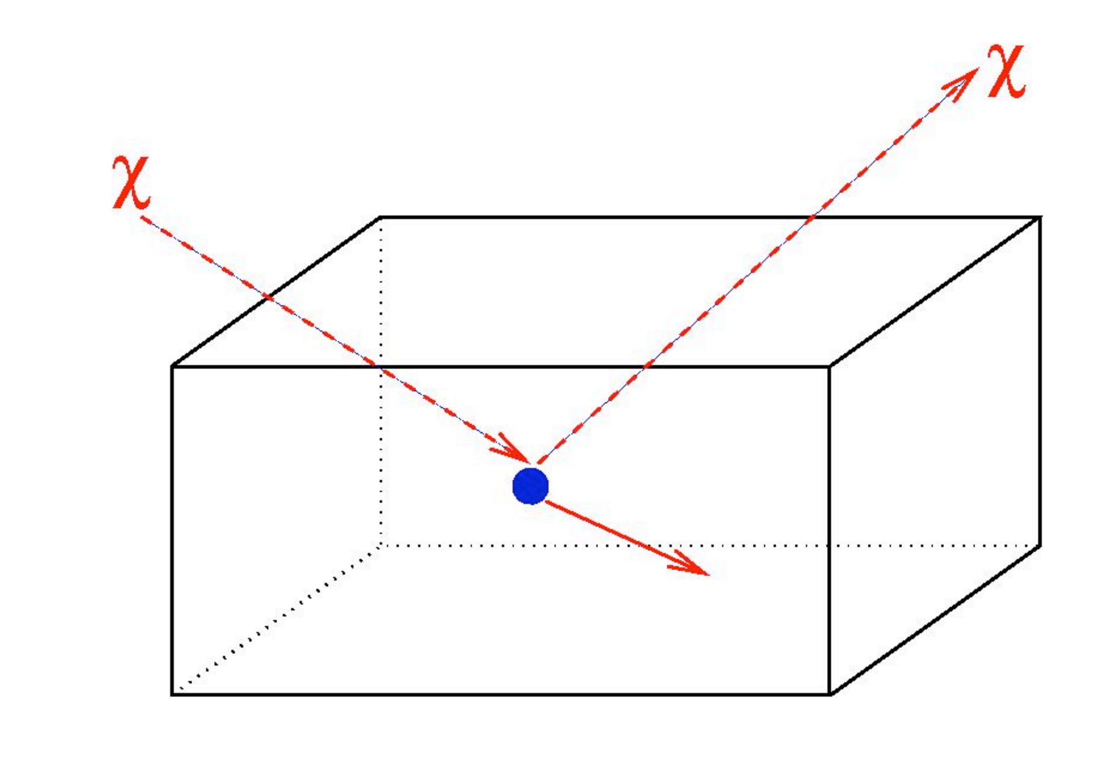
$$\chi+\chi \Leftrightarrow X+\bar{X}$$




ii) **Supersymmetry** (favoured extension of the standard model of particle physics, *solves the hierarchy problem, unifies coupling constants and is required in string theory*) provides us with a concrete, well motivated WIMP candidate-the **lightest supersymmetric particle**.

WIMPs can be directly detected in the lab via elastic scattering off of target nuclei.

$$\chi + N \rightarrow \chi + N$$




For details of how this is done in practice see talks this afternoon.

# Event rate:

(assuming spin-independent coupling)

$$\frac{dR}{dE} = \frac{(m_p + m_\chi)^2}{m_p^2 m_\chi^3} \sigma_p \rho_\chi A^2 F^2(E) \int_{v_{min}}^{\infty} \frac{f^E(v)}{v} dv$$

local WIMP density

target form factor

WIMP speed distribution in rest frame of detector

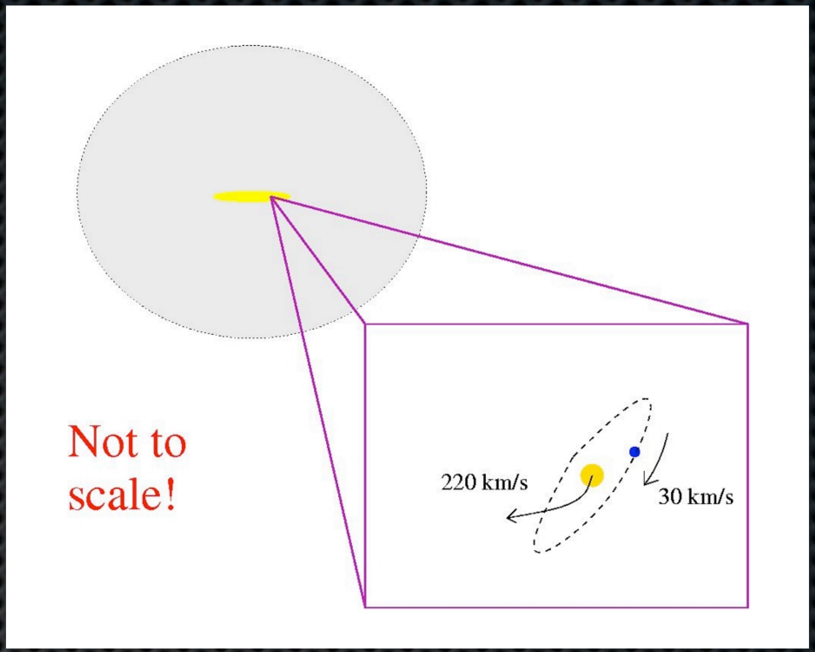
WIMP scattering cross-section on proton

target mass number

minimum WIMP speed which can cause a recoil of energy E.

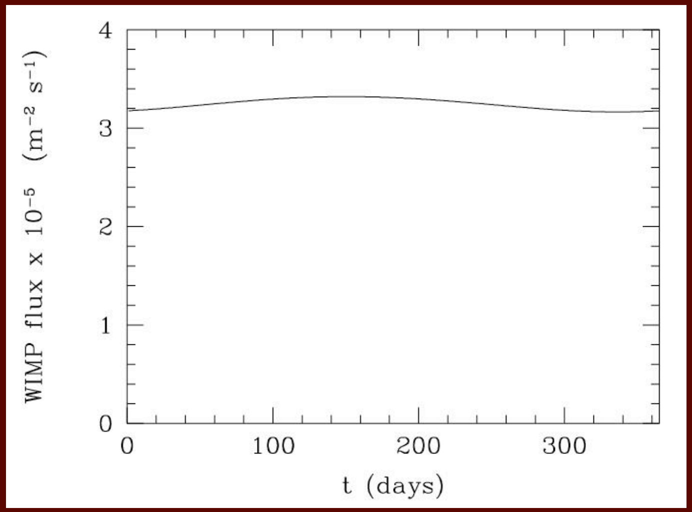
$$v_{min} = \left( \frac{E(m_A + m_\chi)^2}{m_A m_\chi^2} \right)^{1/2}$$

Motion of the Earth (w.r.t Galactic rest frame) provides us with two potential WIMP 'smoking guns'.




## Annual modulation

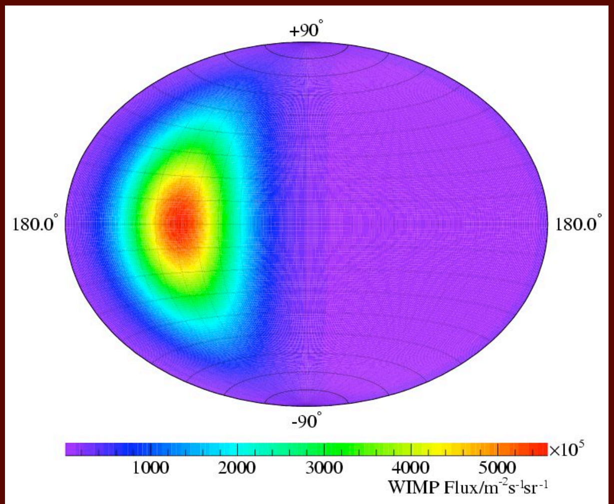
[Drukier, Freese, Spergel]




Signal small, need many events.
Could be mimiced by systematics?

## Direction dependence

[Spergel]




Only O(10) events needed *in principle*.

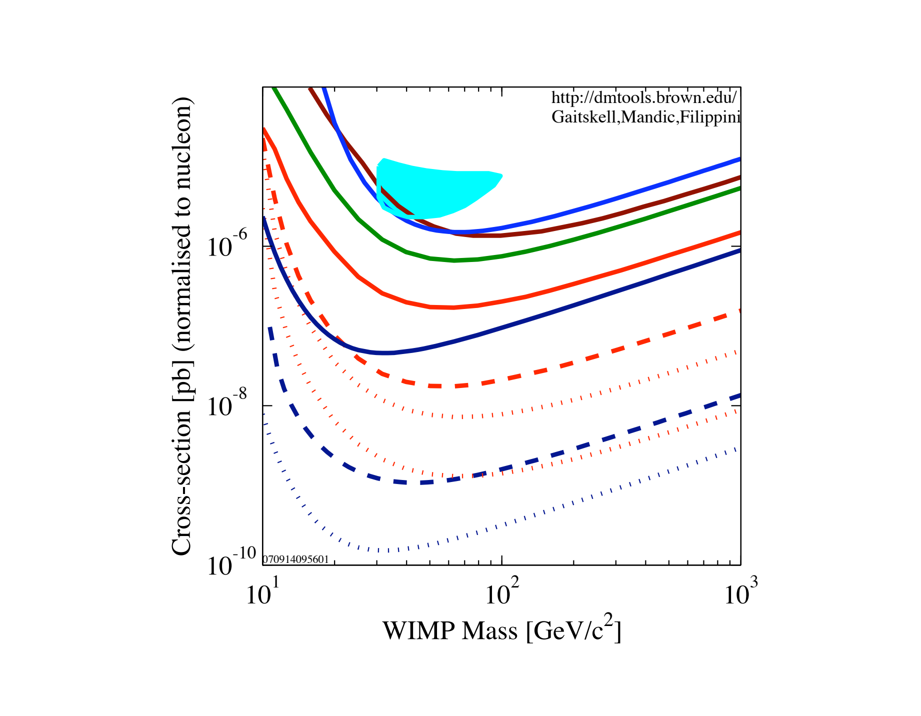
(see Ben Morgan's talk)

Requires a detector capable of detecting directions of recoils.

(see Neil Spooner's talk)

Experiments constrain (or measure...) dR/dE.

Results usually presented in terms of limits on *(or allowed values of)* WIMP mass and cross-section.




To do this you have to make assumptions about the local WIMP velocity distribution and density.

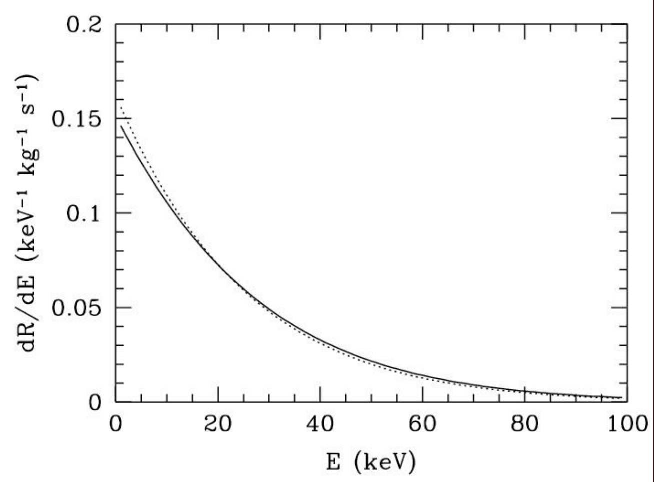
'Standard halo model':

isotropic, isothermal sphere

$$f(v) = N[\exp(-v^2/v_c^2) - \exp(-v_{esc}^2/v_c^2)] \qquad v < v_{esc}$$

$$v_c = 220\,km\,s^{-1} \qquad v_{esc} = 540\,km\,s^{-1} \qquad \rho_\chi = 0.3\,GeV\,cm^{-3}$$

Uncertainty? ~10% ~10% ~x2



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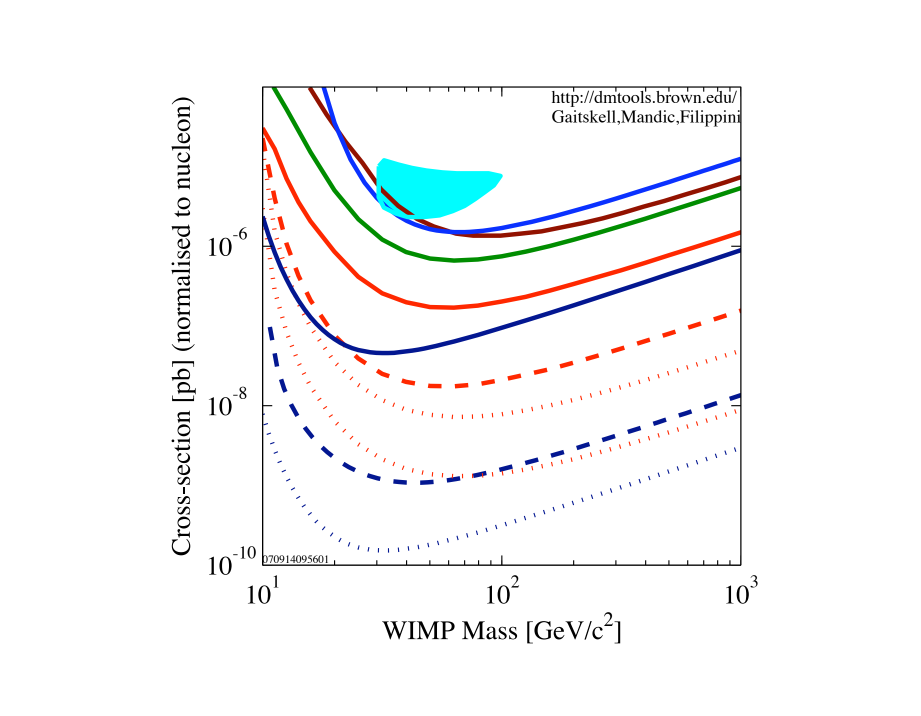


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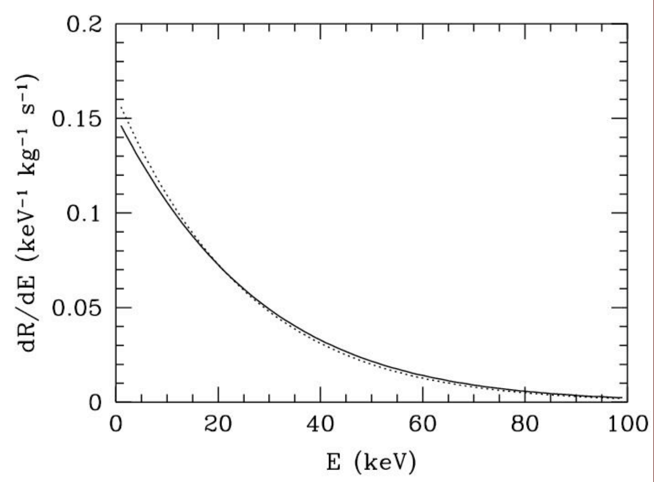


**Is this a good approximation to the real, local, structure of the Milky Way?**

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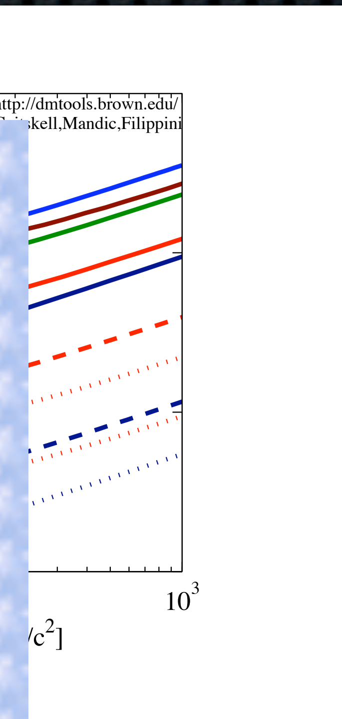


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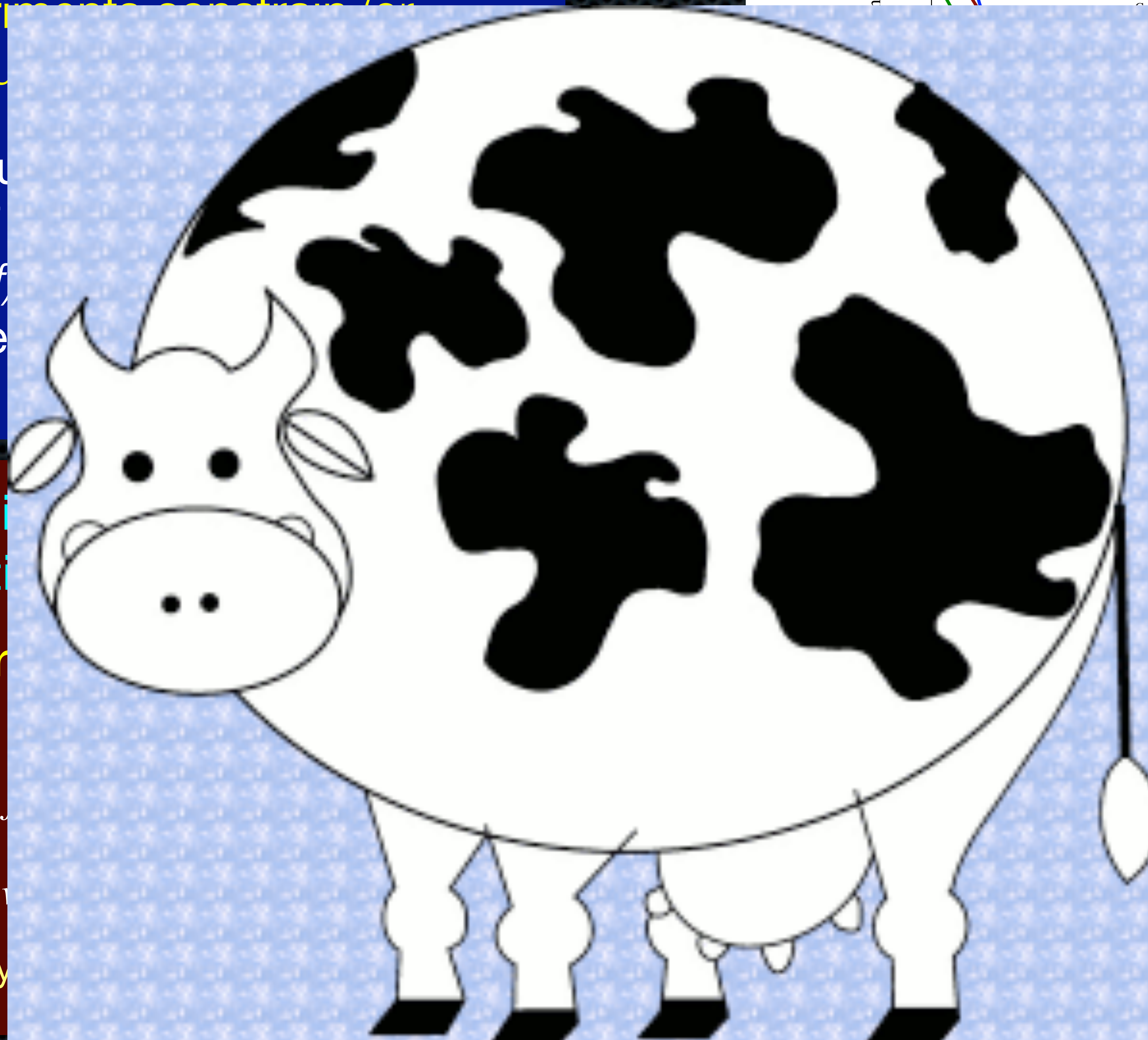

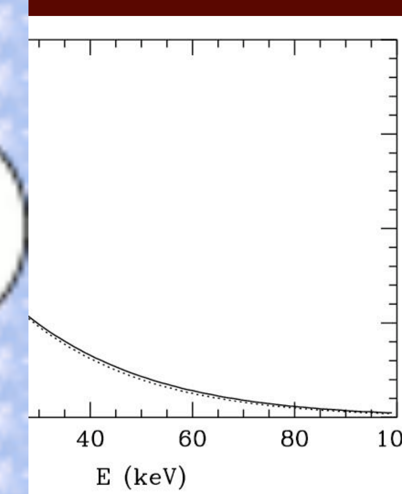


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# The dark matter distribution

## Properties of dark matter halos

### Observations:

Of other galaxies: $b/a > 0.8$ $0.2 < c/a < 1.0$

Milky Way:

Upper limit on flattening from kinematics of Sgr stream?
Contains moderate numbers of satellite galaxies

### Simulations:

Triaxiality and anisotropy vary significantly between halos and also as a function of radius.

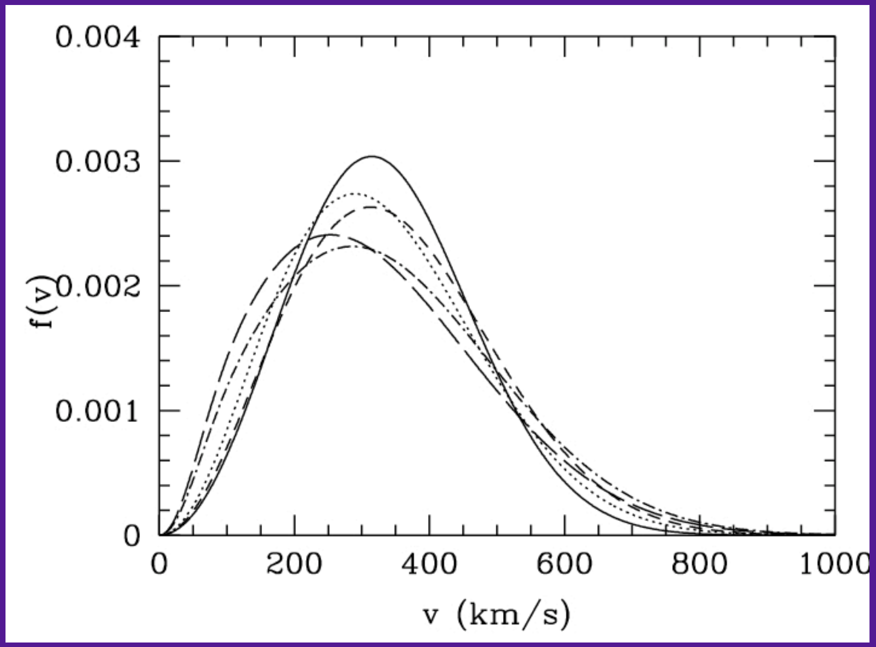
Contain large amounts of substructure.

Halo modeling: use analytic models which are solutions of the collisionless Boltzmann equation (i.e. assume the phase space distribution function has reached a steady state).

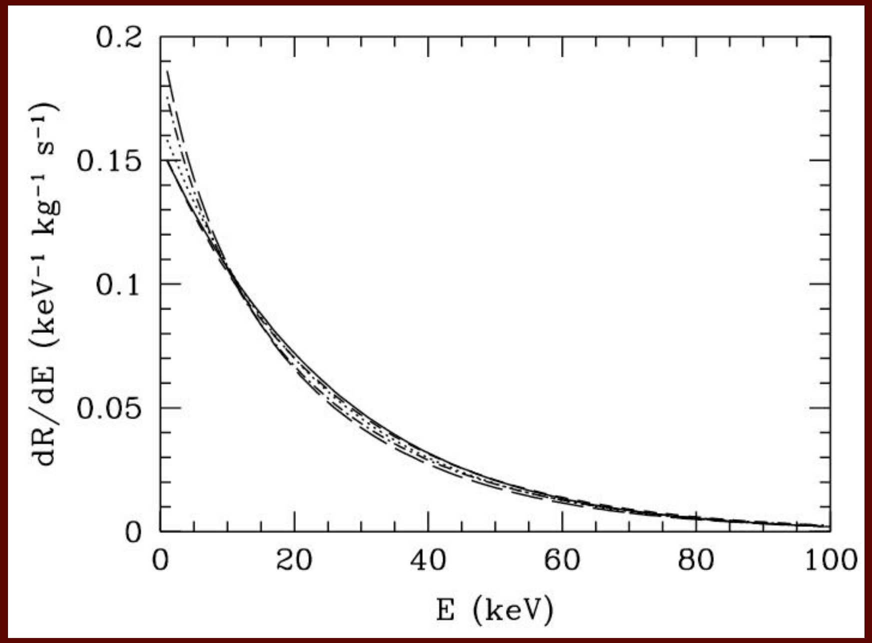
## An example:

the logarithmic ellipsoidal model [Evans, Carrollo & de Zeeuw]

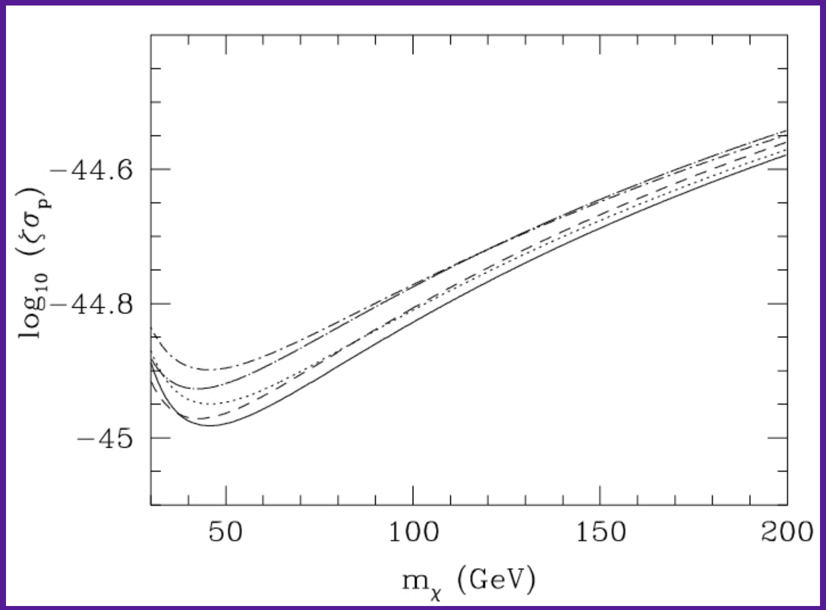
Simplest, triaxial generalisation of the isothermal sphere, f(v) is a multi-variate gaussian in conical co-ordinates. Triaxiality and anisotropy independent of radius.



## Differential event rate

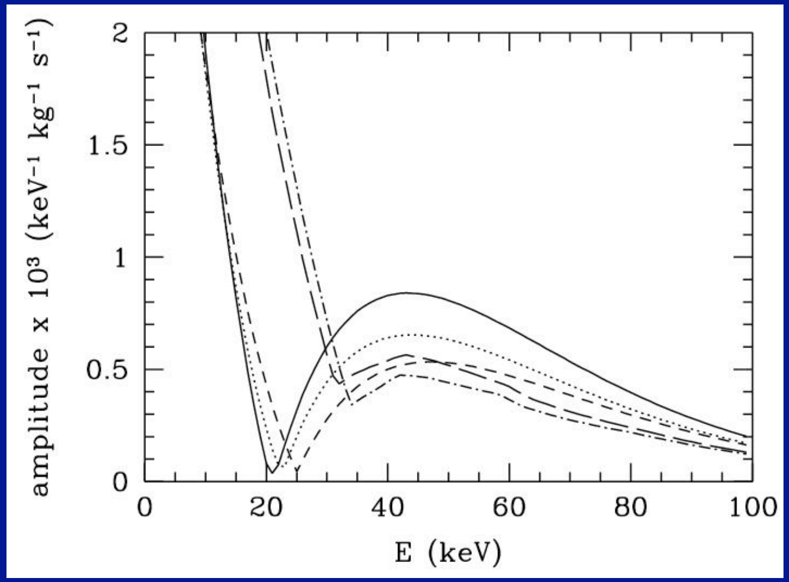



## Exclusion limit

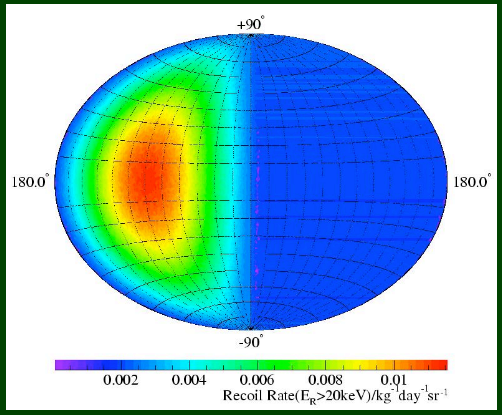



Uncertainty in density absorbed in cross-section.

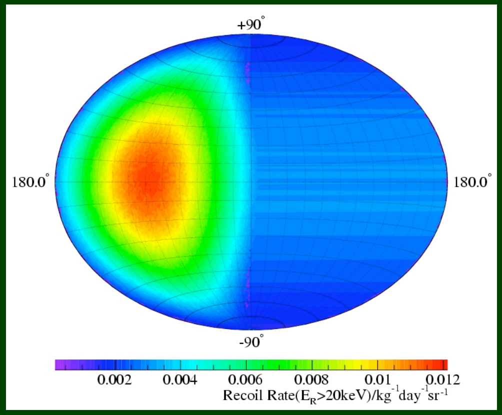
## Annual modulation amplitude




## Directional recoil rate




standard halo

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# sub-milli-pc stucture?

'non-standard halo models' use solutions of the collisionless Boltzmann equation.

Has the local (fine-grained) phase space distribution function reached a steady state?

In simulations DM dist in 'solar neighbourhood' mostly smooth, but resolution of simulations O(100 pc) >> O(0.1 mpc) scales probed by direct detection experiments.

Equivalently mass of smallest sub-halos resolved $O(10^5\ M_{sun})$ >> mass of smallest WIMP micro-halos $O(10^{-6}\ M_{sun})$. [Green, Hofmann & Schwarz]

No consensus yet on whether local DM distribution is smooth:

Stiff & Widrow: reverse simulations, finite number of streams in solar neighbourhood

Helmi, White & collaborators: $10^5$ streams in solar neighbourhood (from time dependence of density of a single stream)

ongoing work in collaboration with Fantin & Merrifield...

## Consequences for direct detection experiments if local DM dist is:

i) Dynamically well mixed and consists of thousands of overlapping streams

good news for direct detection experiments and toy halo models probably a good approximation

ii) Moderately mixed and consists of a small number of streams

probably OK for direct detection-could still detect WIMPs but would need multiple targets to be able to extract WIMP mass & cross-section

iii) Weakly mixed and local DM density is zero

disastrous for direct detection experiments

# Summary

WIMP direct detection signals depend on the local (sub-milli-pc) WIMP density and velocity distribution.

If the local WIMP distribution is smooth:

- Uncertainty in mean differential event rate (and hence exclusion limits) fairly small. *[main issue is factor of ~2 uncertainty in local density and hence constraints-on/measurements-of cross-section]*
- Phase and amplitude of annual modulation signal can vary significantly.
- Details of directional event rate can vary, but general properties of ‘rear-front’ asymmetry robust.

But we don’t yet know whether or not the local WIMP distribution is smooth......