# Tackling astrophysical uncertainties in dark matter direct detection experiments

Bradley J. Kavanagh
ppxbk2@nottingham.ac.uk

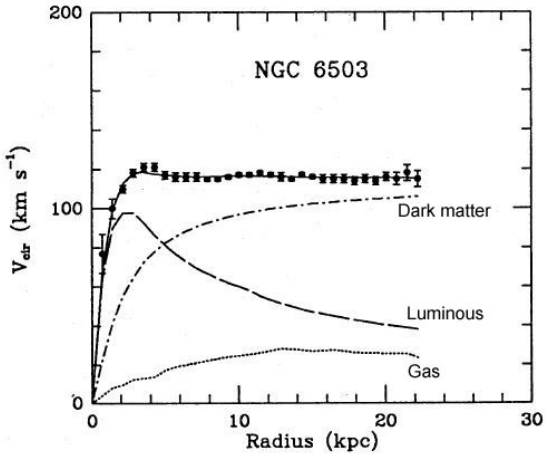
Particle Theory Group
University of Nottingham

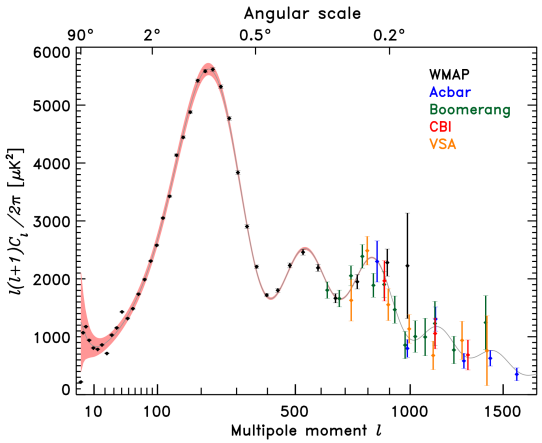
UKCosmo, 12 March 2013

[arXiv:1207.2039] (BJK, AM Green)
[arXiv:1303.XXXX] (BJK, AM Green)

# The Search for Dark Matter (DM)

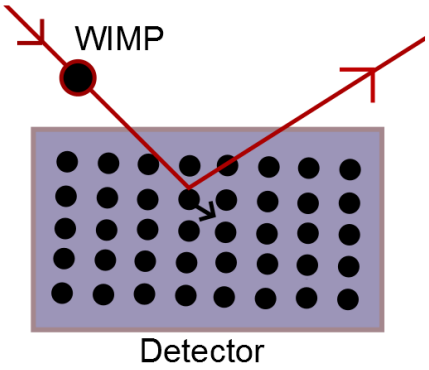
- Overwhelming evidence for DM on all scales




- Weakly Interacting Massive Particle (WIMP) is a well-motivated and popular candidate
- Many experiments aiming to detect WIMP-nucleus interactions in the lab - Direct Detection
- Detection would allow us to probe DM astrophysics, as well as particle physics beyond the Standard Model

# DM Direct Detection




- Aim to measure recoil energies ($O(\mathrm{keV})$) caused by DM-nucleus interactions in dedicated low background detectors

- Rate of nuclear recoils $R$ per unit recoil energy $E_R$ given by:

$$\frac{\mathrm{d}R}{\mathrm{d}E_R} = \underbrace{\frac{\sigma_p}{2m_\chi \mu_{\chi p}^2}}_{\text{Particle physics}} \times \underbrace{A^2 F^2(E_R)}_{\text{Nuclear physics}} \times \underbrace{\rho_0 \eta(v_{\min})}_{\text{Astrophysics}}$$

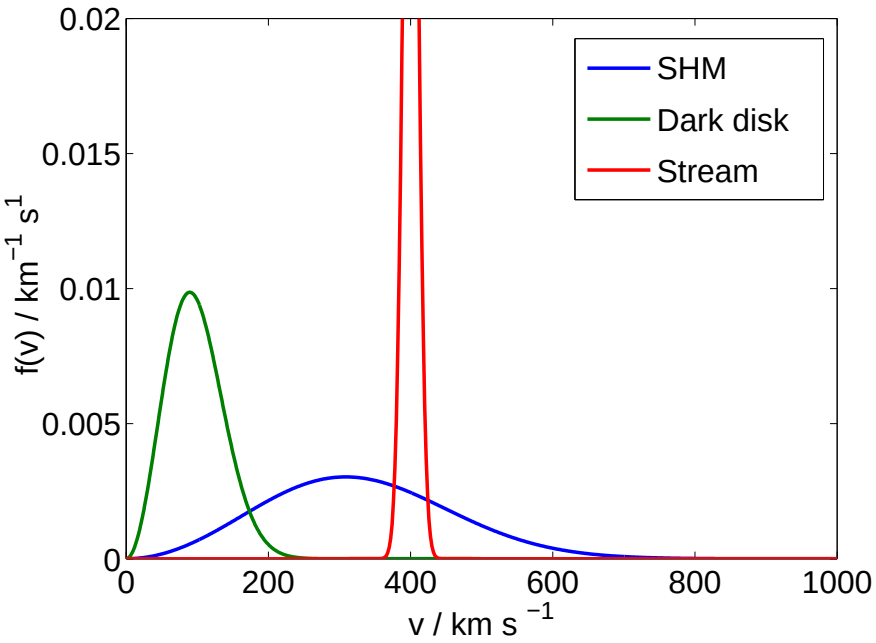
- DM speed distribution $f(v)$ enters in

$$\eta(v_{\min}) = \int_{v_{\min}}^{\infty} \frac{f(v)}{v}\,\mathrm{d}v$$

where $v_{\min} = v_{\min}(E_R, m_\chi)$ is the minimum WIMP speed required to excite a recoil of energy $E_R$

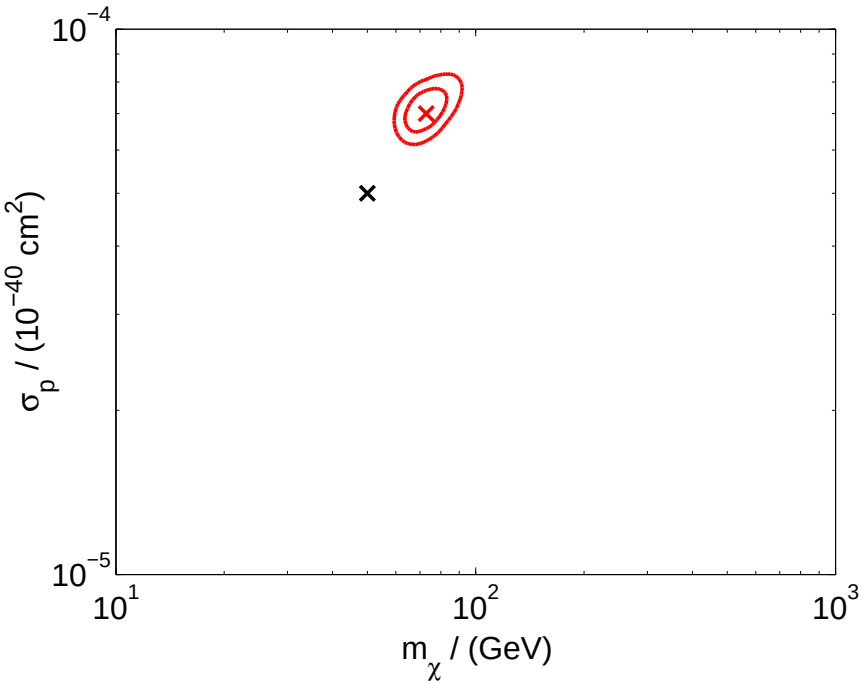
# DM Speed Distribution

- Fraction of DM particles with speed $v \to v + \mathrm{d}v$ in the lab frame
- Depends on growth history of Milky Way Halo
- Typically assume equilibrated Maxwell-Boltzmann distribution (Standard Halo Model)
- However, could be dominated by tidal stream, dark disk, debris flow, ...



# Parameter Reconstruction

- Pick values for $m_\chi$, $\sigma_p$ and choose a form for $f(v)$
- Generate mock data for a set of proposed experiments
- Attempt to reconstruct parameters by exploring the posterior likelihood using MultiNest
- Here we generate data using a stream distribution but *assume* a Standard Halo Model in the reconstruction:



# Previous Work

- Many attempts at dealing with these astrophysical uncertainties, usually by parametrising $f(v)$ and including these parameters in the fit, e.g.
  - parametrise in terms of galactic parameters (scale radius, inner slope ...) [Pato et al. - arXiv:1211.7063]
  - parametrise as a series of constant bins in speed [Peter - arXiv:1103.5145]...
  - ...or as a series of constant bins in momentum [BJK & Green - arXiv:1207.2039]
  - and others...
- So far attempts at a model independent approach have either been too narrow or have failed

# A New Parametrisation

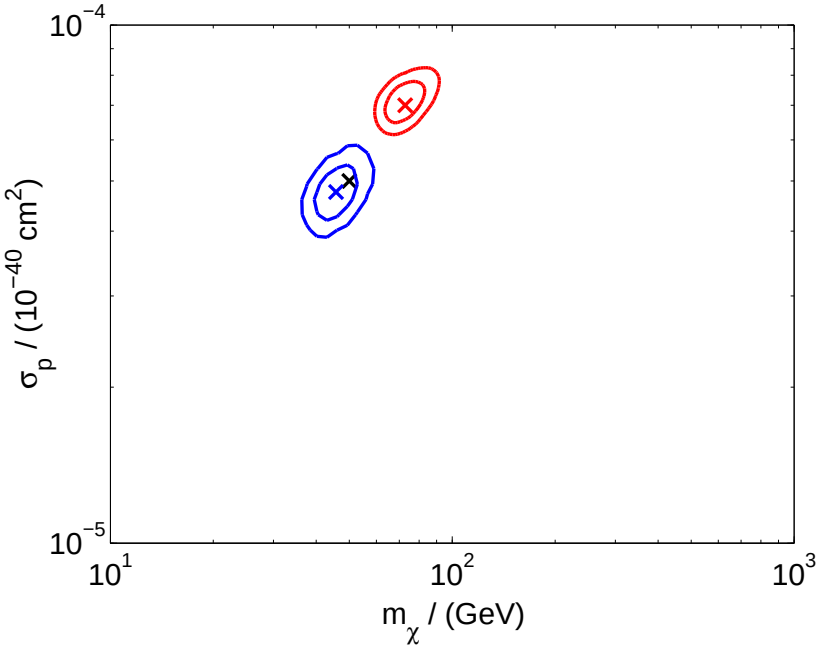
- Motivated to consider functions which are strictly positive and decay at large $v$
- Start with a 'Maxwell-Boltzmann'-type function, with corrections to the exponent - can fit many shapes of $f(v)$
- Write

$$f(v) = v^2 \exp\left(-a_0 - a_1 v - a_2 v^2 - ...\right)$$

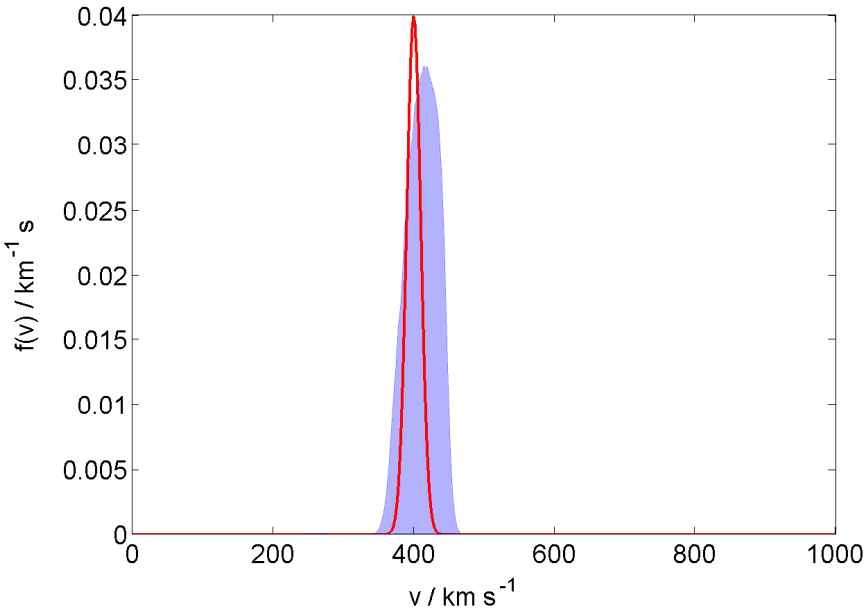
- With $O(100)$ events, only need a few $a_i$'s - say 5
- Fit $m_\chi$, $\sigma_p$ and set of $\{a_i\}$

# Results

Incorrect assumption
New method




True 'stream' distribution
Reconstructed 1-$\sigma$ interval




Works well for a range of masses, cross-sections and both simple and complex distribution functions (with only a few caveats)

# What does this mean?

- If a signal is observed in DM detectors - we can now reliably recover its mass
  - A new handle on structure formation (*hot* vs *cold*) and for probing BSM physics
- Making few assumptions, we can *measure* the DM distribution function - WIMP Astronomy
  - Probe DM distribution on scales inaccessible to N-body simulations or other methods
  - Probe growth and merger history of Milky Way halo
- What next? Extend the method to *directional* DM detection - can we measure the full 3-D velocity distribution?

Thank You