The Epistemology of Model-Independence: A case study with Dark Matter Detection

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ENS | PSL

Experimental and Theoretical definitions

The annual-modulation effect measured in DAMA experiments is model-independent. In other words, the annual modulation of the event rate is an experimentally established fact, independent on theoretical interpretations of the identity of dark matter and specifics of its interactions. (p.1 Addazi *et. al.*, 2015)

As regards comparisons, we recall that no direct model independent comparison is possible in the field when different target materials and/or approaches are used; the same is for the strongly model dependent indirect searches. (p.2, Bernabei *et al.* 2017)

The second feature of our method is a decomposition of the distribution function in moments of a model independent basis, with minimal reliance on the ansatz for its functional form….. One of the main goals of this paper is to provide a parameterization of the [distribution function] that is as generic as possible. (Alvis *et al.*, 2012)

Differential Event Rate

$$\frac{\mathrm{d}R}{\mathrm{d}E} = \frac{\rho_0}{2m_\chi \mu_{\chi A}^2}[\sigma^{\mathrm{SI}} F_{\mathrm{SI}}^2(E) + \sigma^{\mathrm{SD}} F_{\mathrm{SD}}^2(E)]\, g(v_{\mathrm{min}}),$$

$$g(v_{\mathrm{min}}) = \int_{v > v_{\mathrm{min}}}^{\infty} \frac{f_{\mathrm{lab}}(\mathbf{v})}{v}\, \mathrm{d}^3\mathbf{v}.$$

$\sigma^{SI/SD}$ = Spin independent/dependent WIMP-nucleus scattering cross-section
ρ_0 = local WIMP density
m_χ = WIMP mass
f($\mathbf{v}$) = WIMP velocity distribution function

$\mu_{\chi A}$ = WIMP nucleus reduced mass = $(m_A m_\chi)/(m_A+m_\chi)$
F(E) = Form factor
E = Recoil energy
v_{min} = minimum velocity that can cause recoil = $(Em_A/2\mu_{A\chi})^{½}$

(Green 2017)

The different models

Standard Halo Model (SHM)

v_{lag} = 230 km s^{-1} σ_v = 123 km s^{-1}

Dark Matter Stream

v_{lag} = 400 km s^{-1} σ_v = 10 km s^{-1}

SHM with 50% admixture dark disk

v_{lag} = 50 km s^{-1} σ_v = 50 km s^{-1}

Fix:

m_χ = 50 GeV σ^{SI} = 2 x 10^{-45} cm^2 ρ_0 = 0.3 GeV cm^{-3}

$$f_1(v) = v^2 \exp\left\{-\sum_{k=0}^{N} a_k \tilde{P}_k\left(\frac{v}{v_{\max}}\right)\right\},$$

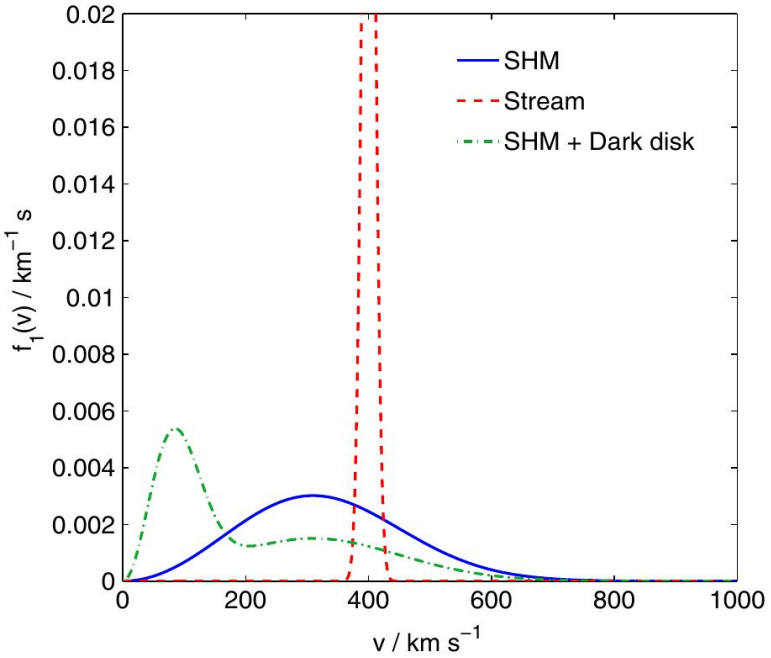


FIG. 1 (color online). The speed distribution for the three benchmark models defined in the text: SHM (solid blue line), SHM + DD (dot-dashed green line), and stream (dashed red line).

(Kavanagh and Green 2013)

Kavanagh and Green (2013) Distribution function parameterisation

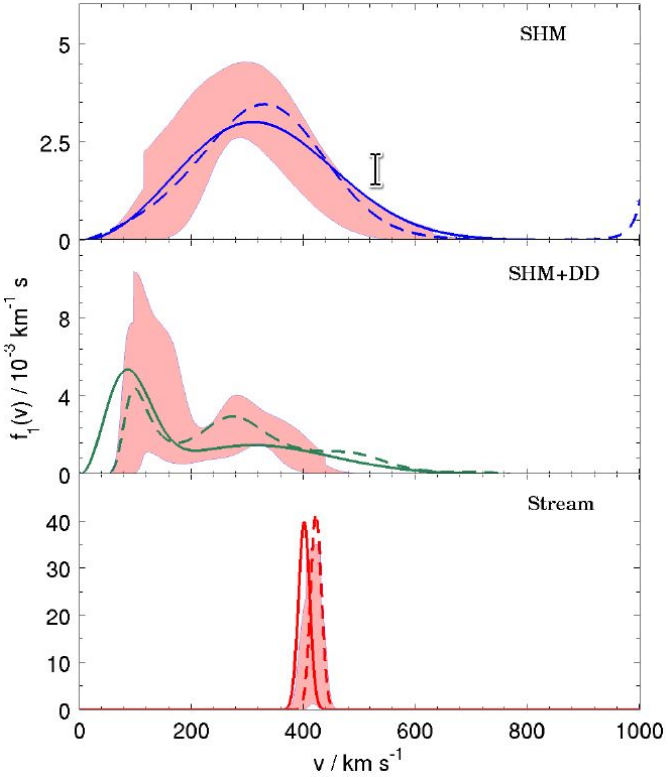
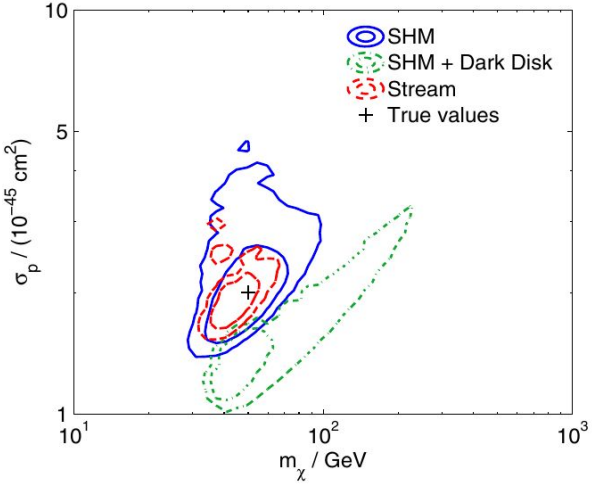


FIG. 3 (color online). Reconstructed speed distributions for the SHM (top panel), SHM + DD (middle panel), and stream (bottom panel) benchmarks. The true distribution is shown as a solid curve, while the best fit reconstructed value is shown as a dashed curve. Also shown are the marginalized 68% credible intervals (shaded pink).



Speed distribution	Reconstructed mass (GeV)
SHM	$50.0^{+12.6}_{-9.2}$
SHM + DD	$44.2^{+8.1}_{-3.7}$
Stream	$44.7^{+6.9}_{-3.6}$

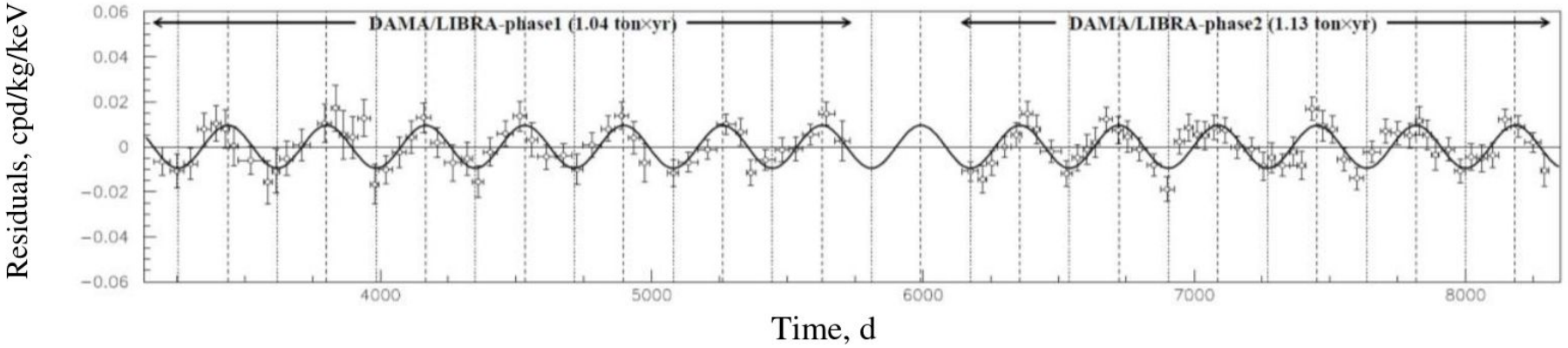
Generically then, it is not possible to reconstruct σ_p, and the bias in σ_p shown in Fig. 2 is a problem inherent to all model independent approaches … Nonetheless, this ignorance of the cross section does not preclude us from accurately reconstructing the DM mass, as we have seen. (p.4, Kavanagh and Green 2013)

Models on the way up

- Model-independence = generalisation of models' parameter?
  - Parameterisation that allows us to reconstruct models?
    - With lack of interpretation of experimental data, a model independent parameter P is tested against target model S which is itself tested against target system T
    - Approximation of 'true' distributions which are themselves idealisations
  - Loss of information: scattering cross section is dependent on mass.
    - It is another way to test if the mass is accurate
    - That method is no longer available with parameterisation
- Model-independence as fictional view of models
  - Model-independent parameter as a prop
  - Indirect view of representation as a connection between the models and the parameterisation

Final Question : Assuming we accept Kavanagh and Green's parameterisation, does the following constitute a detection of dark matter?

DAMA/LIBRA:
In the energy region between 2 and 6 keV … all these values are well in agreement with those expected for DM particles (p.1, Bernabei *et. al.*, 2019)



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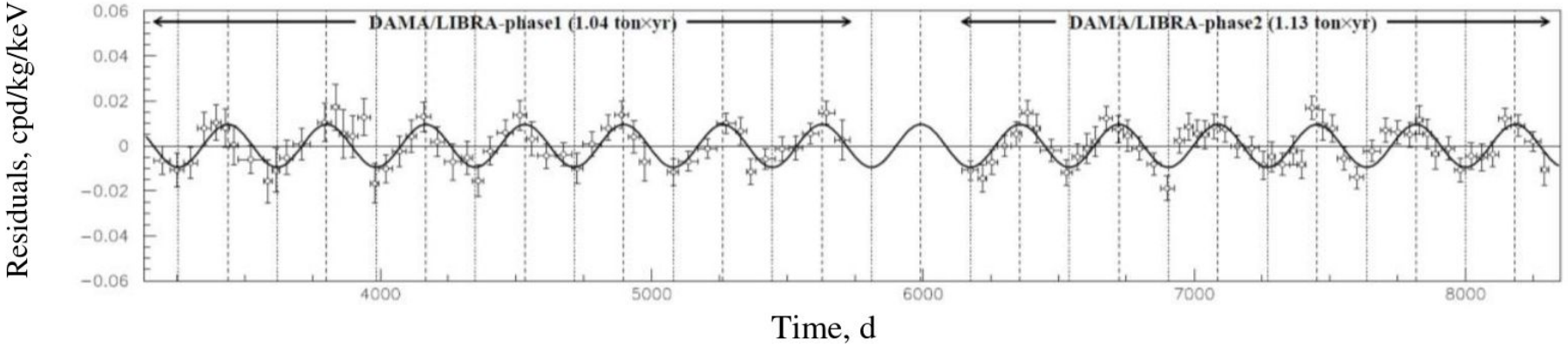

LUX:
With roughly fourfold improvement in sensitivity for high WIMP masses relative to our previous results, this search yields no evidence of WIMP nuclear recoils. (p.1 Akerbi *et. al.*, 2017)