Lattice QCD enlightens Dark Matter

Progress report

Laurent Lellouch for the collaboration

Started early 2013
First hire Nov. 2013

CPT Marseille
CNRS & Aix-Marseille U.

Context:

- a new generation of direct DM detection experiments is coming on line (LUX, CRESST-II, SuperCDMS, ...) and more are planned (Xenon 1T, Dark Side, LZ, ...)

  $\Rightarrow$ $x100$ increase in sensitivity expected in the year(s) to come

  $\Rightarrow$ within next 10-15 years should be able to find or exclude WIMP DM all the way down to the neutrino coherent scattering bound

- large theoretical uncertainties and unknown correlations in local DM phase-space distributions and in couplings of WIMPs to nucleons (that compose the detectors)

  $\rightarrow$ uncontrolled uncertainties in interpretation of experimental results in terms of WIMP-nucleon cross sections and particle physics WIMP models

Main objectives:

- design a fully integrated approach for the prediction and interpretation of WIMP signals in direct (and indirect) DM detection experiments
- account for all astrophysical, cosmological and particle physics uncertainties in a fully correlated and self-consistent manner
- implement this approach into a direct DM detection analysis tool
- use this tool to make direct DM event prediction rates and possible interpretations of signals in combinations of present and upcoming experiments
- $>$ 2015 extend the study to the complementarity between direct and indirect searches

Methods and milestones:

- coordinate expertise of:
  - LUPM in direct/indirect DM detection phenomenology and astroparticle physics
  - LAM in cosmological simulations and DM phenomenology
  - CPT in nonperturbative QCD and particle physics phenomenology

  $\Rightarrow$ truly interdisciplinary project

- consistent description of local DM density and velocity distributions, correctly accounting for the uncertainties and correlations between the various astrophysical parameters (e.g $\rho_\odot$, v_c, $v_{\rm esc}$, ...) needed for DM rate calculations, which arise from assumptions made in measuring these parameters (e.g. Milky Way mass model)
- cosmological hydrodynamic simulations of MW-like galaxies to test assumptions made in determining local DM phase-space distributions and help assess uncertainties and correlation
- *Ab-initio* lattice QCD simulations to determine WIMP couplings to ordinary matter (nucleons) with fully controlled and significantly uncertainties, as required for interpreting experimental direct detection constraints or signal in terms of particle physics WIMP models

People:

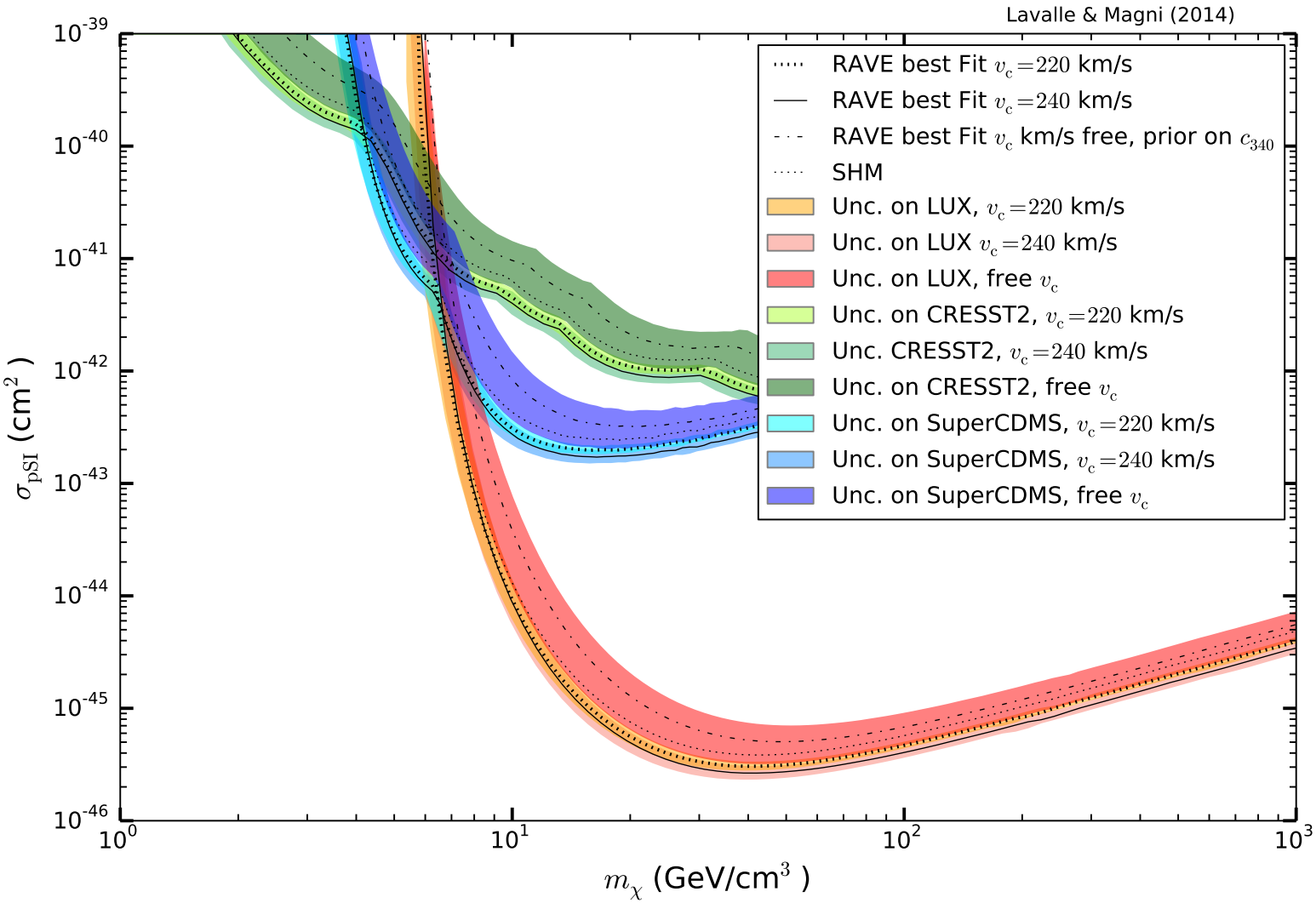
- CPT: L Lellouch (coord.), C Torrero (OCEVU PD, since Nov. 2013), Th Métivet (PhD, CEA Saclay, since Oct. 2012)
- LAM: E Nezri, P Mollitor (partly OCEVU funded PhD, until Dec. 2014)
- LUPM: J Lavalle, S Magni (PhD, since Oct. 2012), ?? (new OCEVU PhD, from Oct. 2014)

OCEVU funding:

- 1 PD from Nov. 2013 to Oct. 2016
- 1 PhD from fall 2015 to fall 2018
- 9.5 k€/year for internal meetings, longer work visits and conference attendance
- 5 k€ in 2014 for server dedicated to lattice QCD post-simulation analysis and DM predictions and signal interpretations

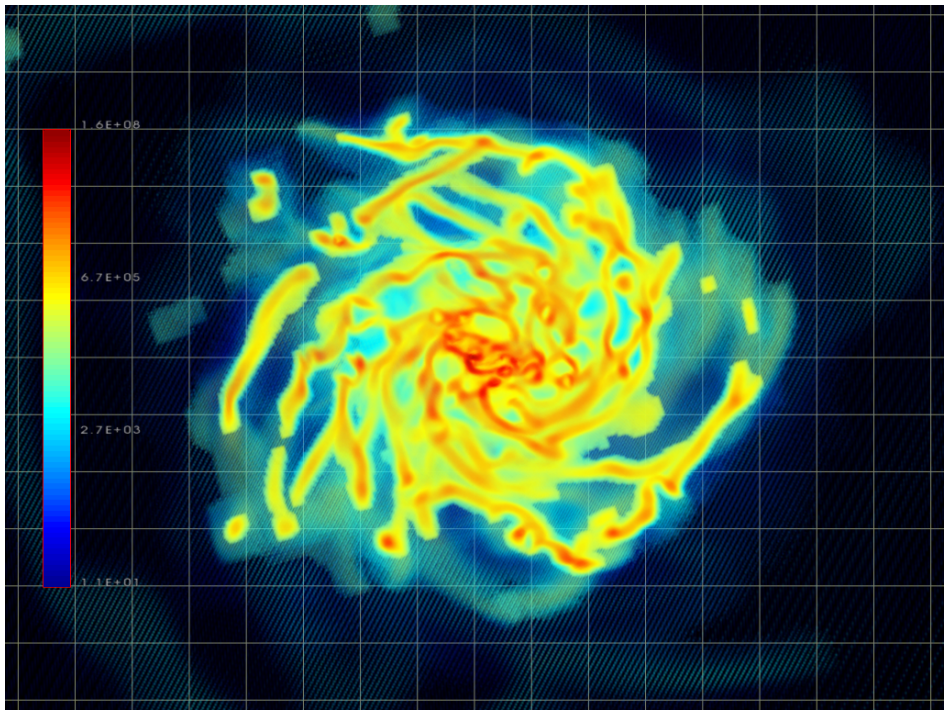
DD exclusion curves w/ fully correlated uncertainties

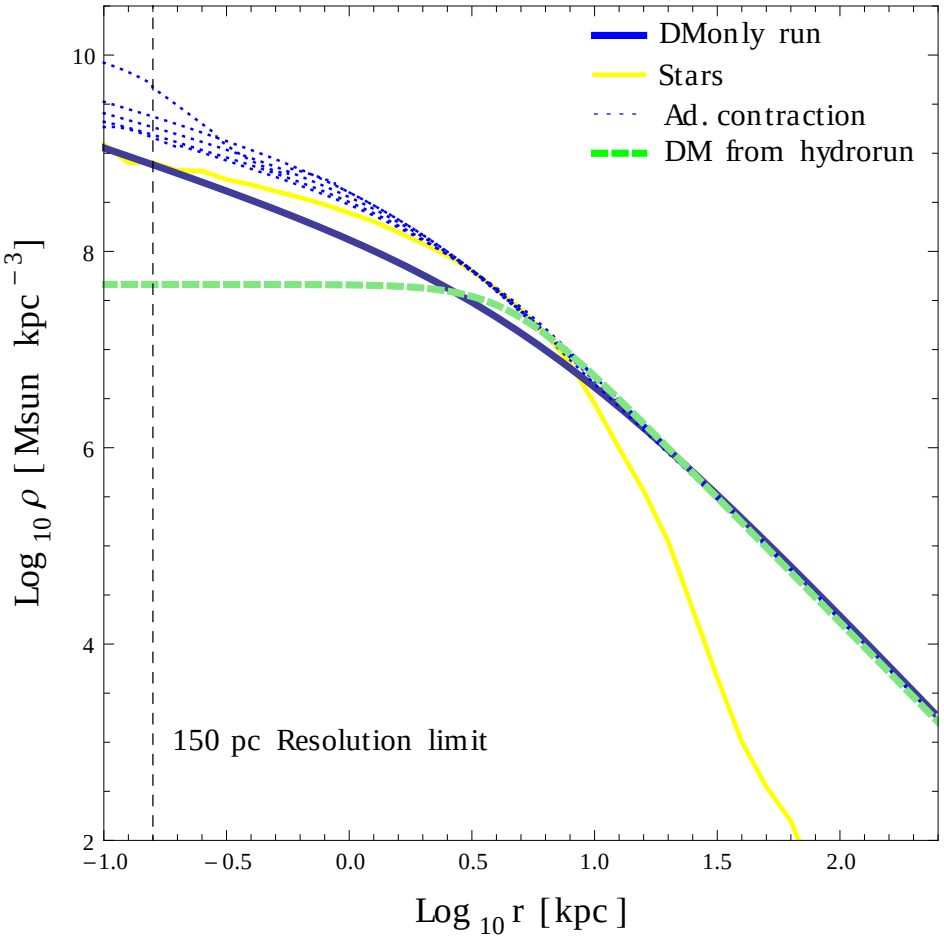
Lavalle & Magni, arXiv:1411.1325



Baryonic and DM distribution in cosmological simulations

Mollitor, Nezri & Teyssier, arXiv:1405.4318



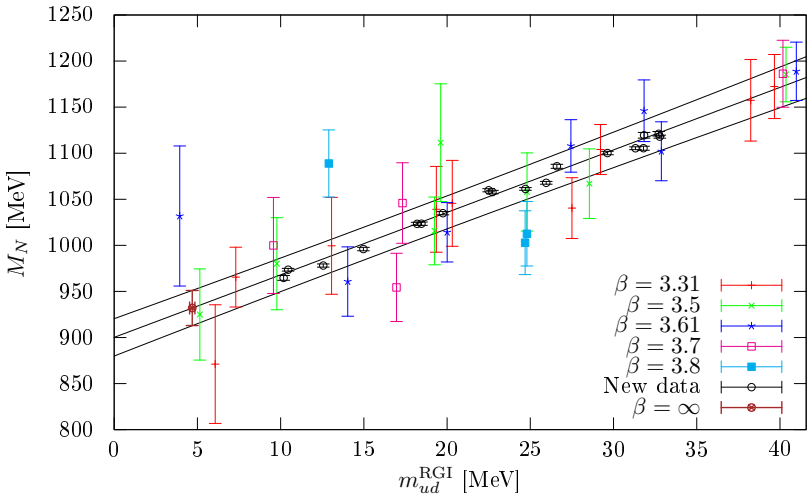


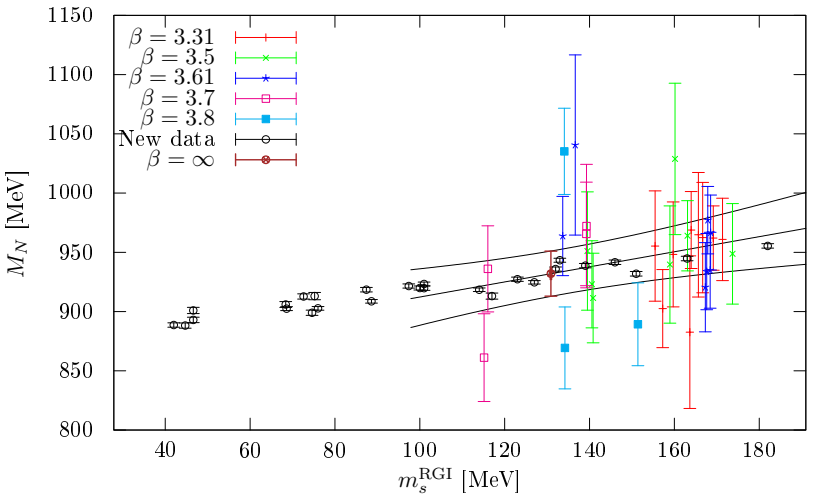
Ab-initio calculation of SI WIMP-nucleon couplings

Lellouch, Torrero et al, arXiv:1411.2459 and in progress

Spin-independent (SI) couplings of WIMP to ordinary matter proportional to square of quark contents:

$$f_{udN} = \frac{m_{ud}}{M_N}\frac{\partial M_N}{\partial m_{ud}}\bigg|_{\text{phys}}, \qquad f_{sN} = \frac{m_s}{M_N}\frac{\partial M_N}{\partial m_s}\bigg|_{\text{phys}},$$





- Have reached fully controlled $\sim 50\%$ uncertainties on f_{udN} and f_{sN}
- Worked hard to improve methods and performing completely new simulations to reduce uncertainties $\leq 5\%$

Publications:

- J. Lavalle and S. Magni, “Making sense of the local escape speed estimate in direct dark matter detection”, arXiv:1411.1325 [astro-ph.CO].
- P. Mollitor, E. Nezri and R. Teyssier, “Baryonic and dark matter distribution in cosmological simulations of spiral galaxies,” arXiv:1405.4318 [astro-ph.GA].
- C. Torrero for the Budapest-Marseille-Wuppertal collaboration, “Computing the nucleon sigma terms at the physical point,” in proceeding of Lattice 2014, arXiv:1411.2459 [hep-lat].
- J. Lavalle, S. Magni, P. Mollitor and E. Nezri, “Revisiting the escape speed concept from zoom-in cosmological simulations: implications for direct dark matter detection,” in preparation
- J. Lavalle, L. Lellouch, S. Magni, P. Mollitor, E. Nezri, C. Torrero, “Theoretical uncertainties in direct Dark Matter searches,” planned 2015

Events and conference contributions:

- full collaboration meetings at least 2 times yearly . . .
- . . . and additional work visits
- Organization of and talks at:
  - “News from the Dark,” Monptellier 2013
  - “CosmoSamSim 2014”, Marseille 2014
- (Invited) talks at many conferences, including: “Origin of Mass 2014” (LL, Odense), “Lattice 2014” (CT, New York), “Astroparticle Physics 2014” (PM, Amsterdam), “Dark side of the universe 2014” (SM, PM, Cape Town)