

Particle Dark Matter Constraints: The Effect of Galactic Uncertainties

Based on:

arXiv: 1612.02010

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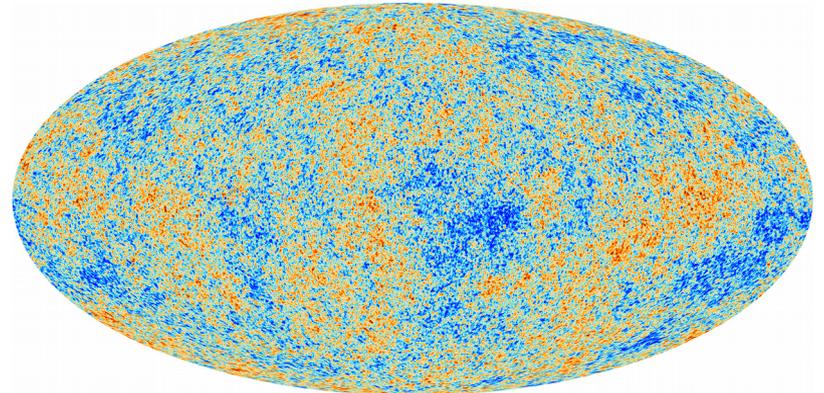
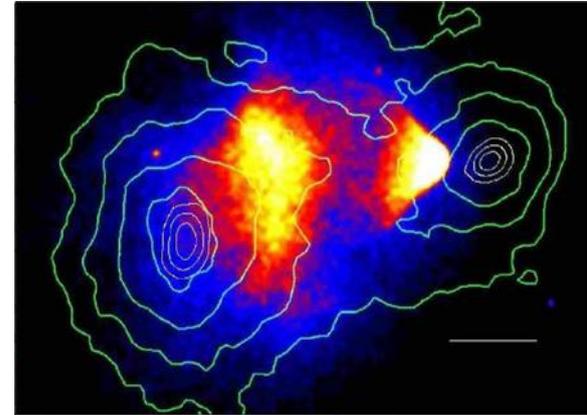
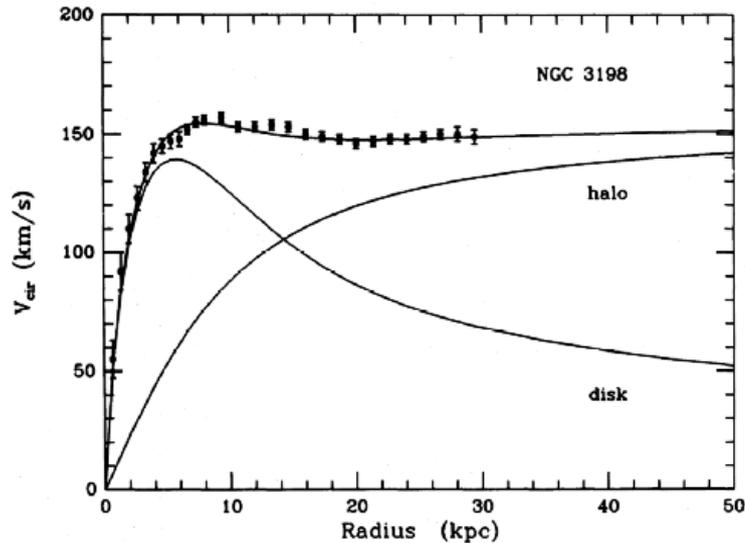
June 28th, 2017

Evidences for Dark Matter

Several observations indicate existence of non-luminous Dark Matter (missing force) at very different scales!

- * Galactic rotation curves
- * Clusters of galaxies
- * CMB anisotropies

DISTRIBUTION OF DARK MATTER IN NGC 3198



Direct Detection

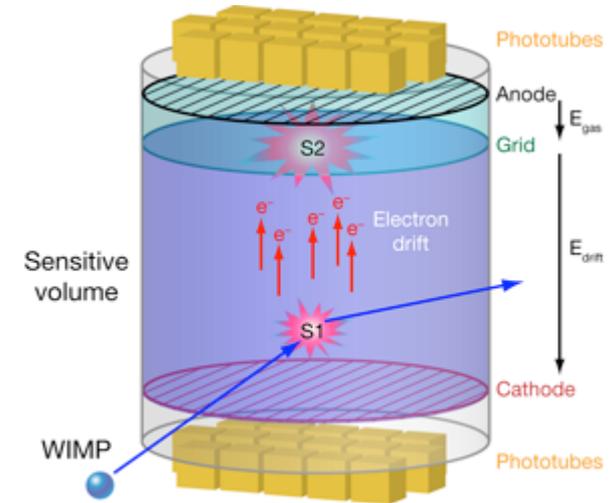
Direct detection experiments aim to measure the recoil energy of a nucleus in a detector after the collision with a DM from the halo of the MW.

Differential event rate

$$\frac{dR}{dE} = \frac{\rho_0}{m_\chi} \frac{1}{m_N} \int d^3v \frac{d\sigma}{dE} v f(v)$$

Particle physics: m_χ and σ

Astrophysics: ρ_0 and $f(v)$



Indirect Detection

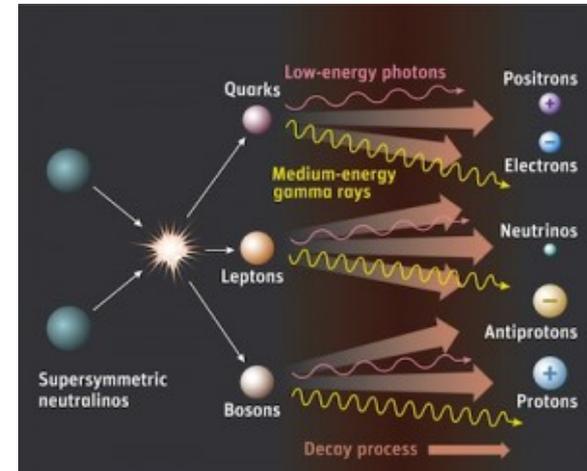
Indirect detection aims at detecting the flux of final stable particles produced by DM annihilation or decay.

Differential event rate

$$\frac{dN}{dA dt d\Omega dE} = \frac{\langle\sigma v\rangle}{2 m_\chi^2} \frac{dN}{dE} \frac{1}{4\pi} \int_{\text{los}} \rho_\chi^2 dl$$

Particle physics: m_χ , $\langle\sigma v\rangle$ and the ann. channel

Astrophysics: $\rho_\chi(l, \Omega)$



Our Aim

- The determination of Particle Physics quantities is highly affected by *astrophysical uncertainties*
- The latter, especially those for our own MW, are ill-known, and often not fully accounted for when analyzing the pheno of particle physics models
- Systematic analysis of how the uncertainties on the DM structure in our Galaxy affect the determination of New Physics
- Estimate the effects of the Galactic Uncertainties in the *particle physics parameter space*, by varying different sources of uncertainty one at a time
- Treat uncertainties (direct & indirect) in a self-consistent way

Galactic Dynamics

- Dynamical Method:
 Rotation curves track *total* gravitational potential compared to the expected velocity due to visible matter
 Mismatch → fit DM density profile
- Compilation of observed RC data (Iocco, Pato & Bertone '15)
 Milky Way morphology: 70 baryonic models
 Stellar bulge + Stellar disk + Gaseous disk (Pato, Iocco & Bertone '15)

- gNFW DM density profile:
$$\rho_\chi = \rho_0 \left(\frac{R_0}{R} \right)^\gamma \left(\frac{R_s + R_0}{R_s + R} \right)^{3-\gamma}$$

- Fit → (ρ_0, γ)
 $R_s = 20 \text{ kpc}$

$$\chi^2 = \sum_{i=1}^N d_i^2 \equiv \sum_{i=1}^N \left[\frac{(y_i - y_{t,i})^2}{\sigma_{y,i}^2 + \sigma_{b,i}^2} + \frac{(x_i - x_{t,i})^2}{\sigma_{x,i}^2} \right]$$

Galactic Dynamics

- **Reference** Morphology of the baryonic component (BjX)
 $R_0 = 8 \text{ kpc}$ and $v_0 = 230 \text{ km/s}$
→ $\gamma = 1.11$ and $\rho_0 = 0.466 \text{ GeV/cm}^3$

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$$R_0 = 8 \text{ kpc} \quad \text{and} \quad v_0 = 230 \text{ km/s}$$

$$\rightarrow \gamma = 1.11 \quad \text{and} \quad \rho_0 = 0.466 \text{ GeV/cm}^3$$

- **Statistical** Uncertainties (Reference morphology)

$$R_0 = 8 \text{ kpc} \quad \text{and} \quad v_0 = 230 \text{ km/s}$$

$$\rightarrow \gamma = 1.11 \pm 0.03 \quad \text{and} \quad \rho_0 = 0.466 \pm 0.010 \text{ GeV/cm}^3$$

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- Uncertainties on **Galactic Parameters** R_0 and v_0 (Reference morphology)
 $R_0 = [7.5, 8.5] \text{ kpc}$ and $v_0 = [200 \pm 20, 279 \pm 33] \text{ km/s}$

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 $R_0 = [7.5, 8.5] \text{ kpc}$ and $v_0 = [200 \pm 20, 279 \pm 33] \text{ km/s}$
- Uncertainties on the **Morphology** of the baryonic component ($R_0 = 8 \text{ kpc}$ and $v_0 = 230 \text{ km/s}$)
Different morphologies in order to minimize/maximize γ and ρ_0

Galactic Dynamics

**Reference
morphology**



Morphology	R_0 (kpc)	v_0 (km/s)	M_* ($\times 10^{10} M_\odot$)	γ	ρ_0 (GeV/cm ³)	χ^2/dof
BjX	8	230	2.4 ± 0.5	1.11	0.466	1.22

Galactic Dynamics

**Statistical
uncertainties**

**Reference
morphology**

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Galactic Dynamics

Statistical uncertainties

Reference morphology

Galactic parameters

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BjX	8	230	2.4 ± 0.5	$1.11^{+0.04}_{-0.03}$	0.466 ± 0.010	1.22
BjX	7.5	312	1.52 ± 0.19	$0.633^{+0.019}_{-0.020}$	1.762 ± 0.017	1.35
BjX	8.5	180	2.4 ± 0.5	2.02 ± 0.07	0.055 ± 0.004	0.90

Galactic Dynamics

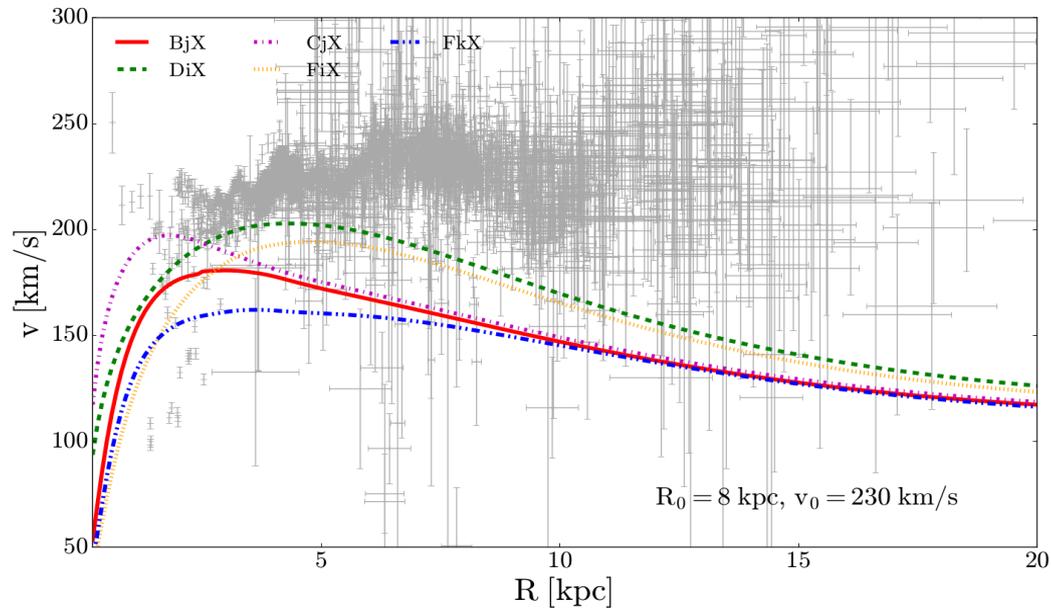
Statistical
uncertainties

Reference
morphology

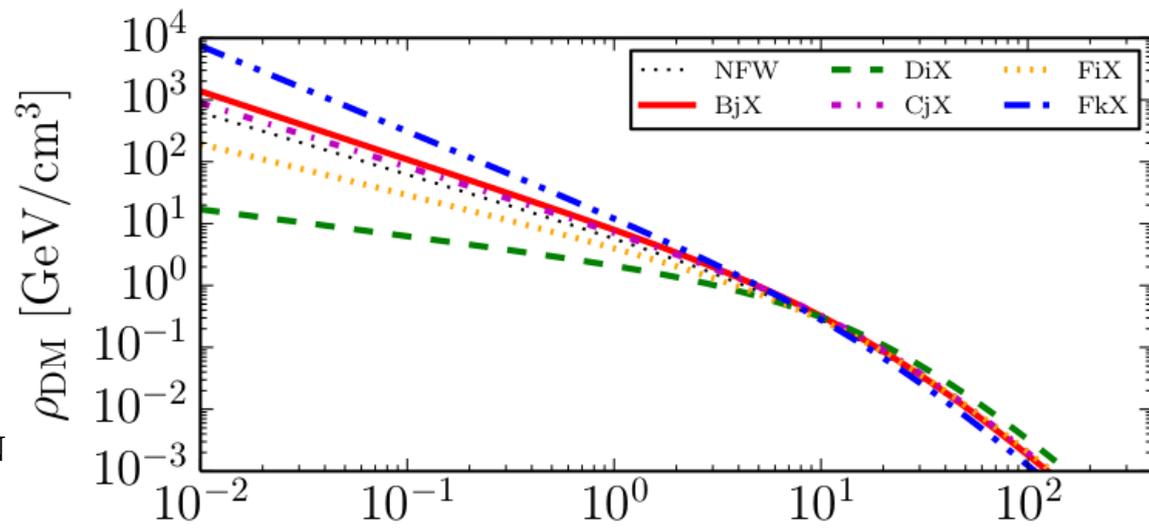
Galactic
parameters

Morphology
variation

Morphology	R_0 (kpc)	v_0 (km/s)	M_* ($\times 10^{10} M_\odot$)	γ	ρ_0 (GeV/cm ³)	χ^2/dof
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BjX	8.5	180	2.4 ± 0.5	2.02 ± 0.07	0.055 ± 0.004	0.90
FkX	8	230	2.0 ± 0.4	$1.38^{+0.03}_{-0.02}$	$0.427^{+0.007}_{-0.008}$	1.05
DiX	8	230	3.0 ± 0.6	$0.43^{+0.07}_{-0.06}$	0.405 ± 0.011	0.99
CjX	8	230	2.5 ± 0.6	1.03 ± 0.04	$0.471^{+0.010}_{-0.011}$	1.13
FiX	8	230	2.6 ± 0.4	0.82 ± 0.05	0.387 ± 0.010	1.16



Galkin
 (Pato & Iocco '17)



Impact on Particle Physics Models

Singlet Scalar DM

McDonald '07

S is a scalar singlet, protected by a Z_2

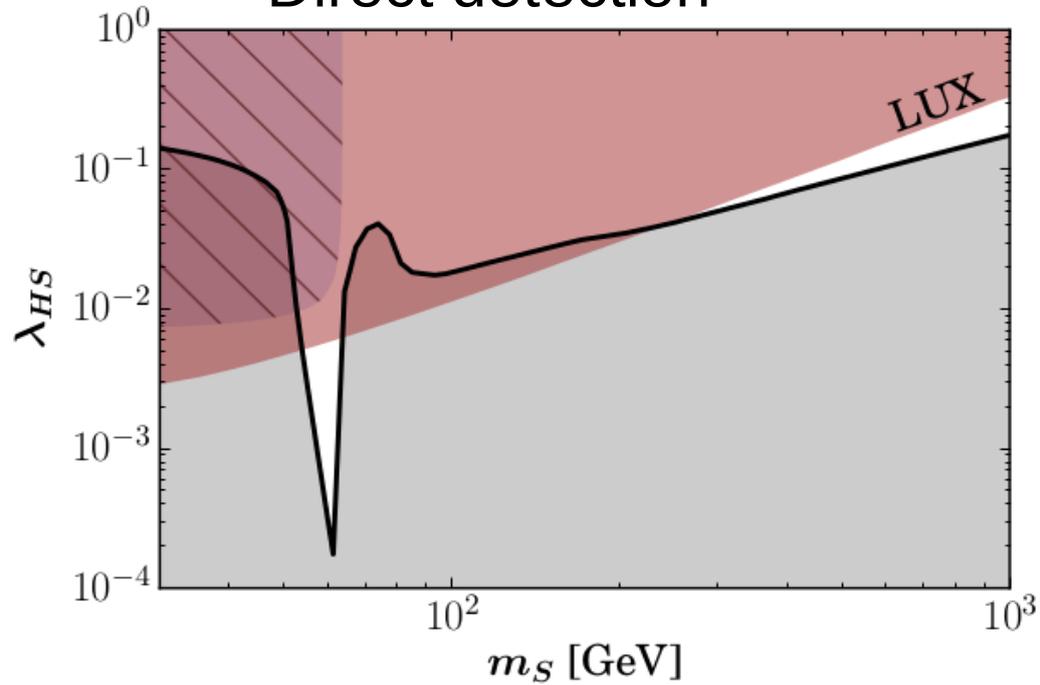
$$V \supset \mu_S^2 S^2 + \lambda_S S^4 + \lambda_{HS} |H|^2 S^2$$

3 free parameters:

- * m_S DM mass
- * λ_{HS} Higgs portal
- * λ_S DM quartic coupling

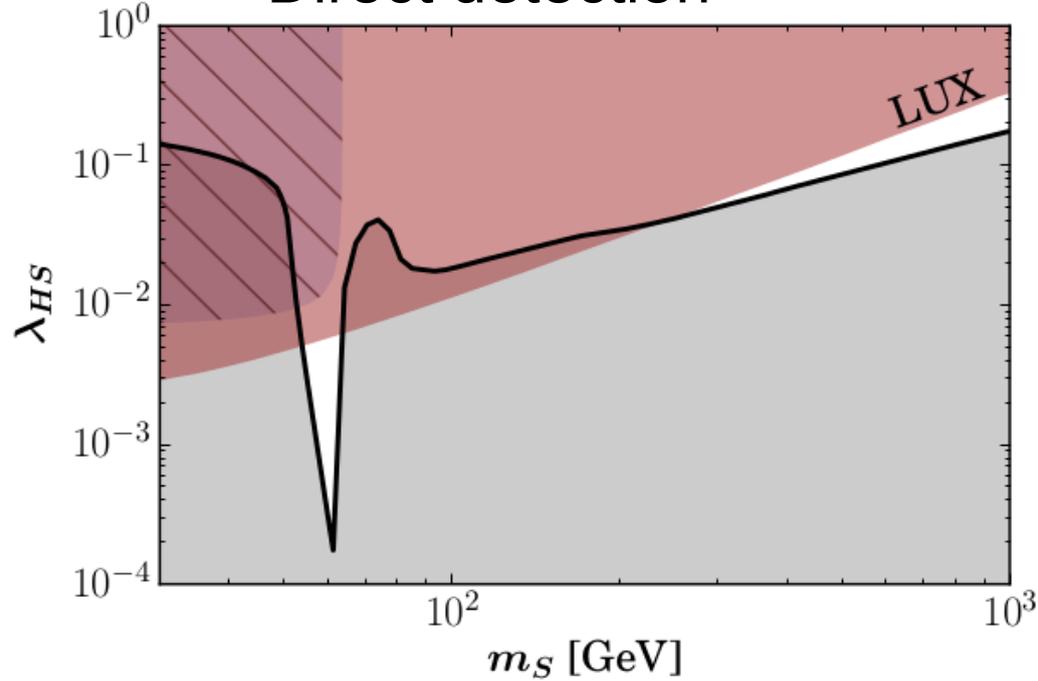
Singlet Scalar DM: Reference morphology

Direct detection

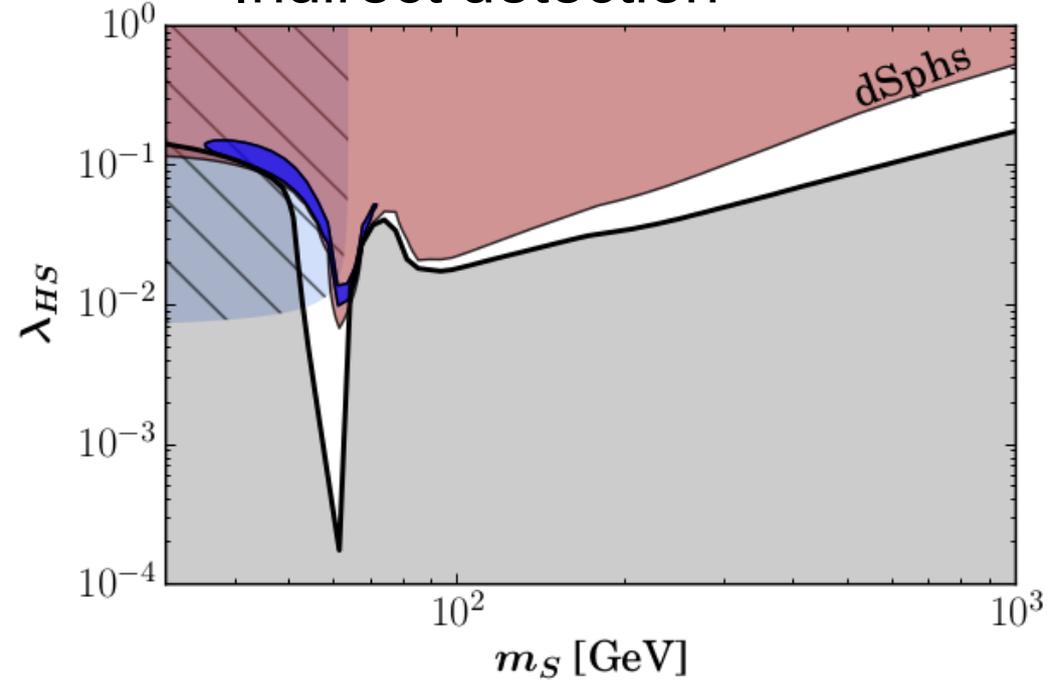


Singlet Scalar DM: Reference morphology

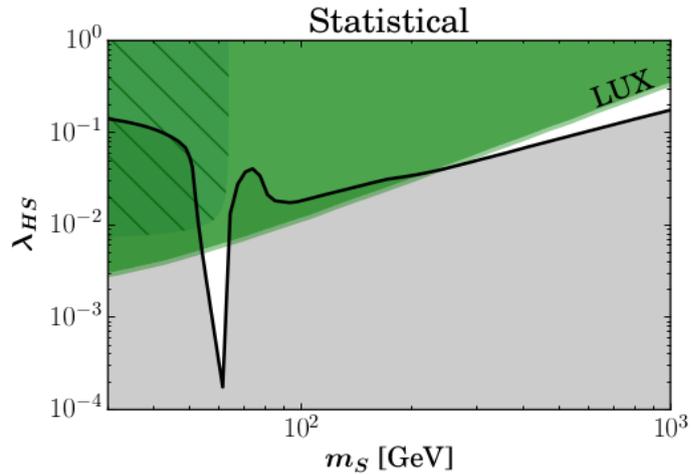
Direct detection



Indirect detection

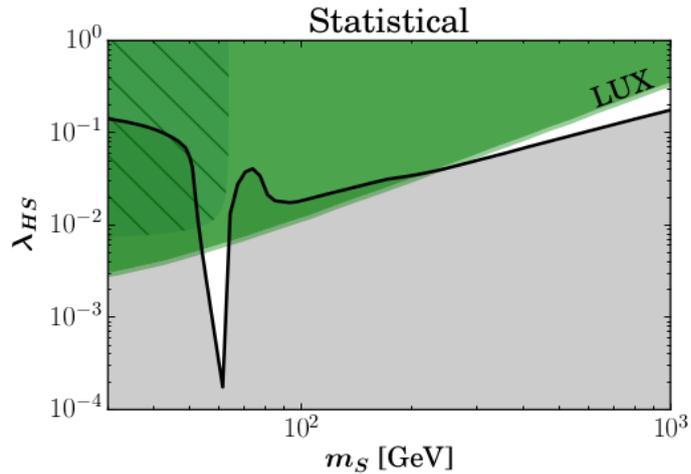


Singlet Scalar DM: Direct Detection

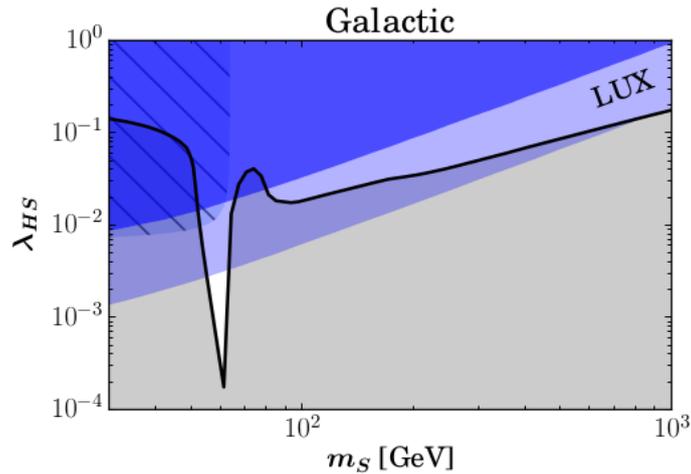


BjX with $R_0 = 8$ kpc and $v_0 = 230$ km/s
 $\gamma = 1.11 \pm 0.03$
 $\rho_0 = 0.466 \pm 0.01$ GeV/cm³

Singlet Scalar DM: Direct Detection

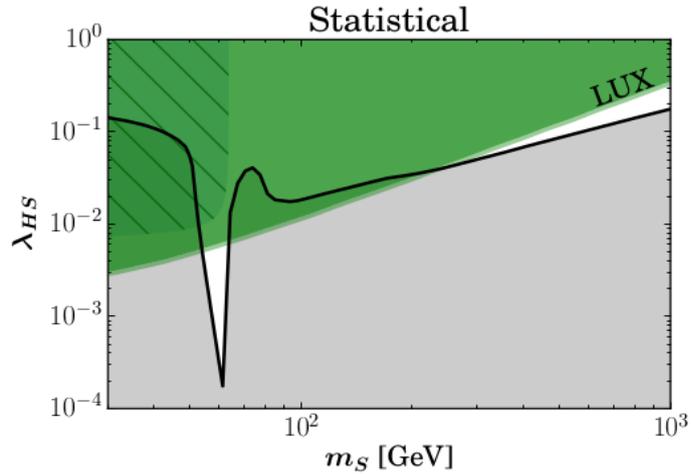


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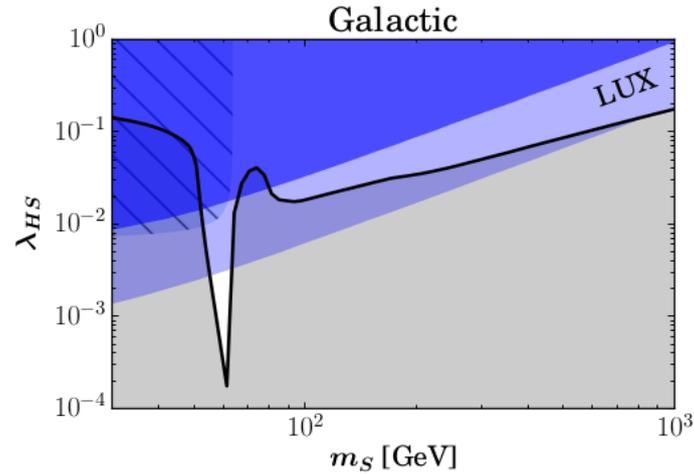


BjX with
 $R_0 = [7.5, 8.5]$ kpc
 $v_0 = [180, 312]$ km/s

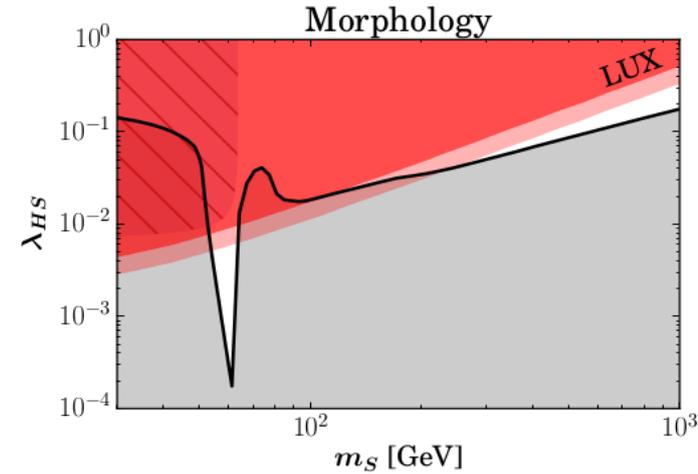
Singlet Scalar DM: Direct Detection



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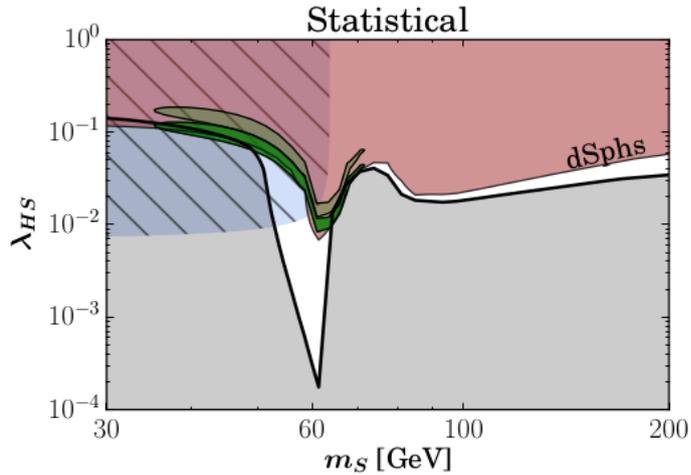


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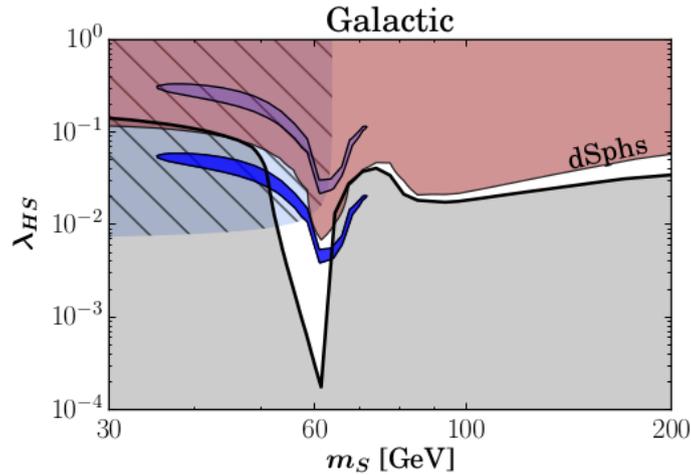


Different morphologies
for the baryons
 $R_0 = 8$ kpc and $v_0 = 230$ km/s

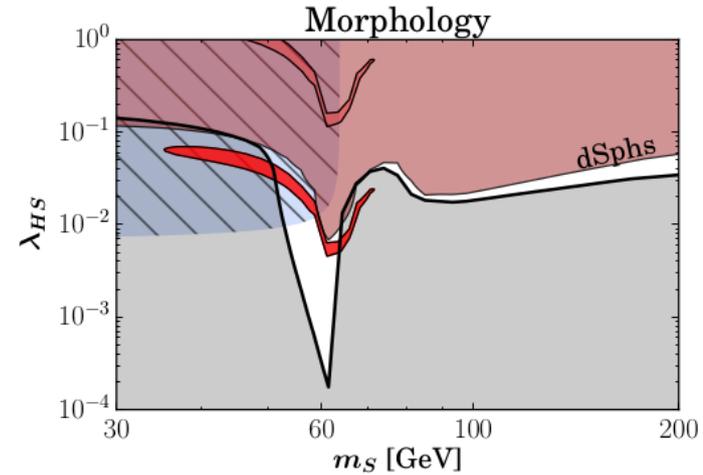
Singlet Scalar DM: Indirect Detection



BjX with $R_0 = 8$ kpc and $v_0 = 230$ km/s
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BjX with
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Different morphologies
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 $R_0 = 8$ kpc and $v_0 = 230$ km/s

Conclusions

- Galactic uncertainties affect the determination of the DM distribution and propagate when constraining New Physics
- Galactic uncertainties have to be under control in order to extract particle physics observables (m_χ , $\langle\sigma v\rangle$, σ , Br)
- Systematic scan of major sources of uncertainties:
 - * Statistical
 - * Galactic Parameters
 - * Baryonic Morphology
- Galactic uncertainties play a major role, but too often overlooked!
- Gaia mission expected to improve the determination of R_0 and ρ_0