A DARK MATTER STUDY THROUGH THE HIGGS PORTAL

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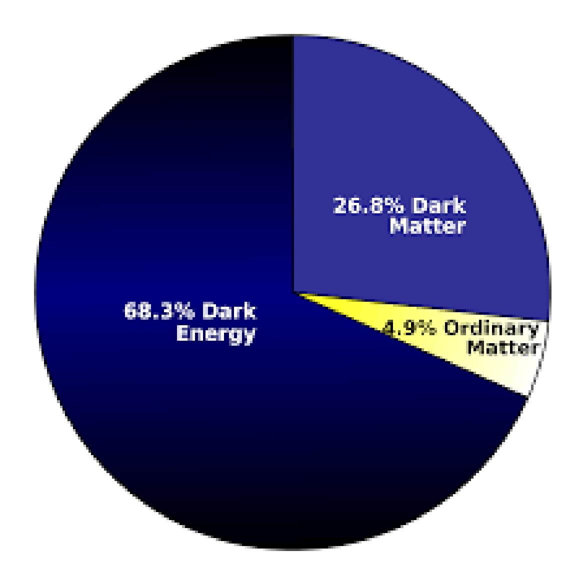
WHAT IS DARK MATTER AND HOW DO WE KNOW IT EXISTS?



Dark Matter (DM) is a form of mass-energy

- Electrically neutral
- Transparent
- Makes up 27% of universe
- May be a new type of particle

Evidence from:

- Galaxy rotation curves
- Gravitational Lensing Measurements

What are WIMPs?

- WIMPs are Weakly Interacting Massive Particles
- Typically 1 GeV-10,000 GeV (mass of proton)
- Proposed new DM particle of this size range
- Ultralight and ultraheavy particles have their own theories

3 WAYS OF DETECTING DARK MATTER

1. Direct Detection:
Wait for WIMPs to hit nuclei; measure recoil of nucleus

2. Indirect Detection:
Look for Standard Model (SM) particles left behind from WIMP self-annihilation

3. Collider Experiments:
Treat WIMPs produced as missing energy and momentum; use conservation laws

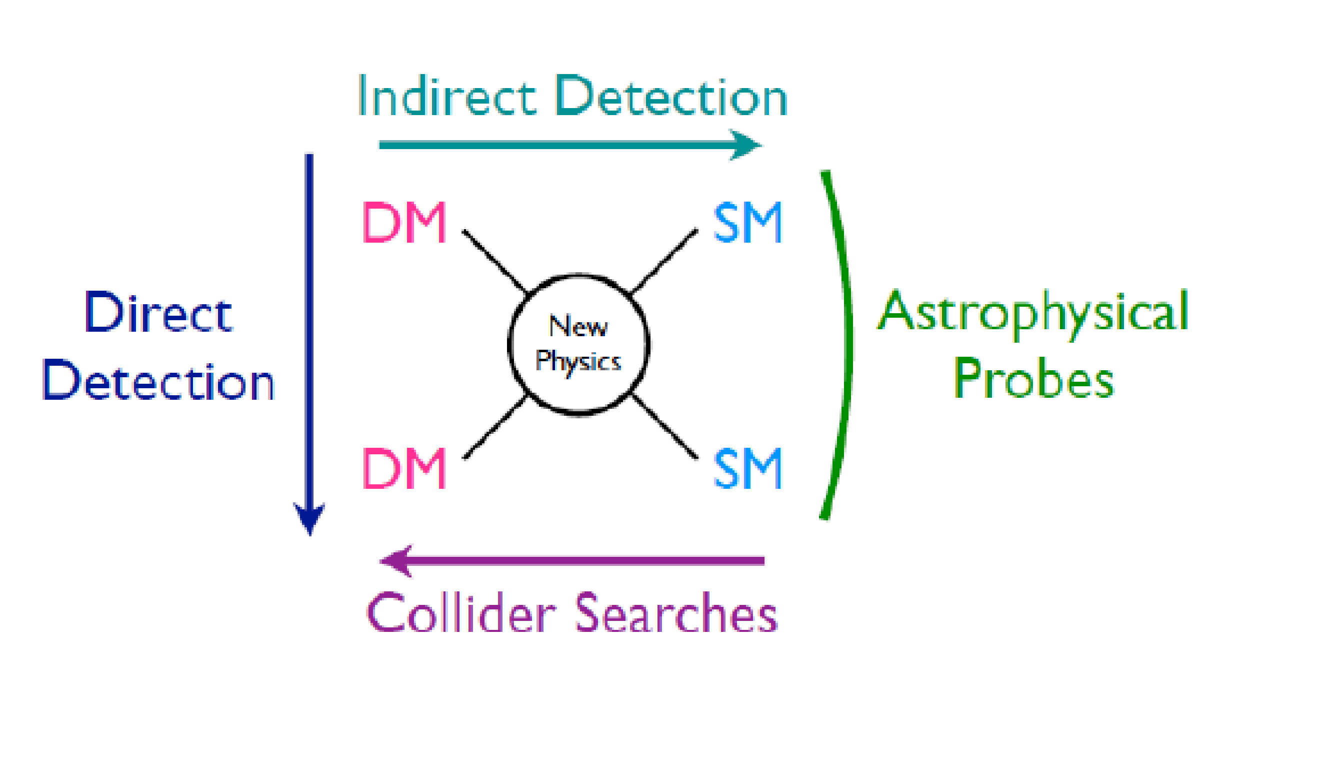


Figure from Dr. Kuver Sinha, 2017

THEORY AND EXPERIMENT

- The XENON1T Experiment
- Constraints on DM parameters
- To the left: too lightweight to measure recoil energy
- To the right: fixed number density, fewer particles if all are this massive
- Start with model; calculations based on WIMPs interaction with SM particles

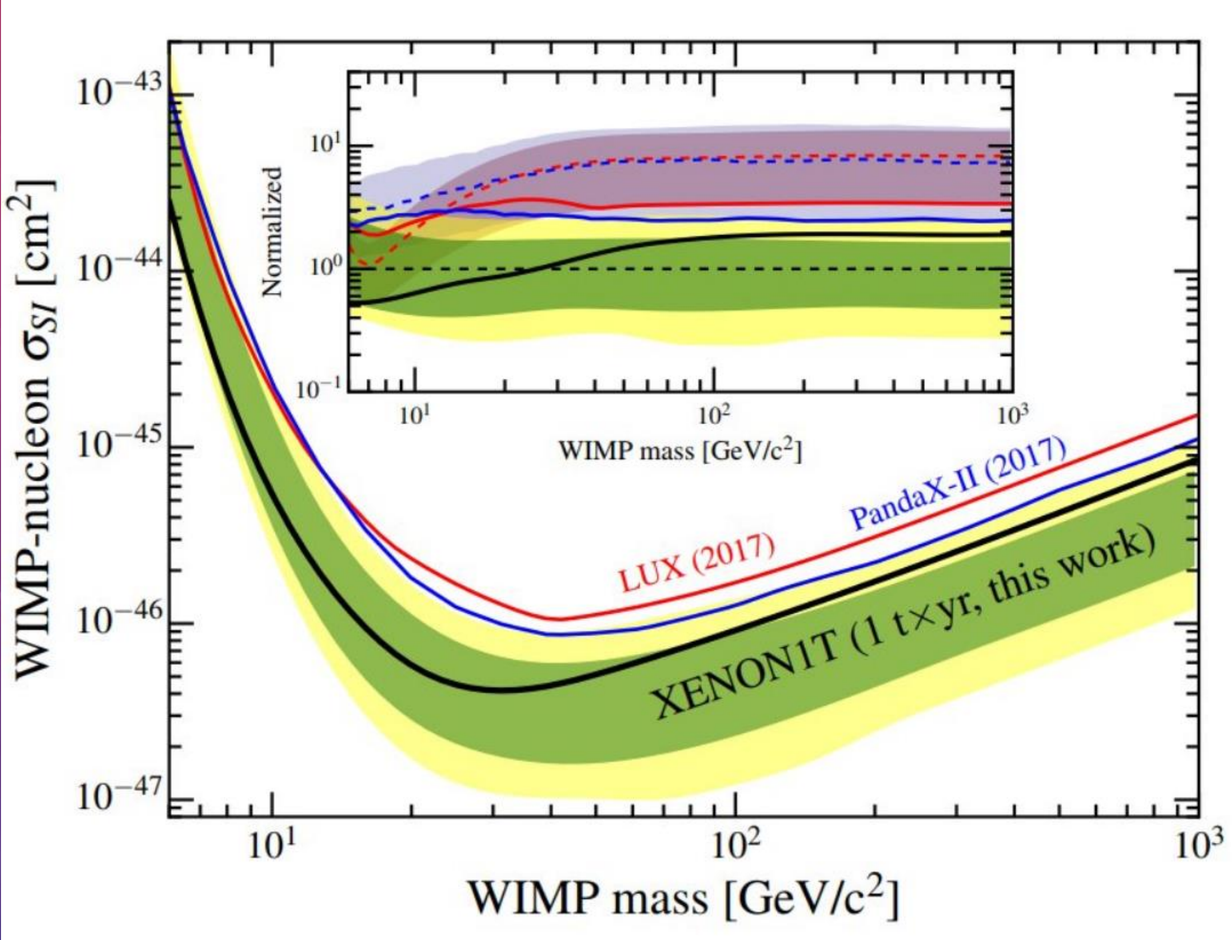
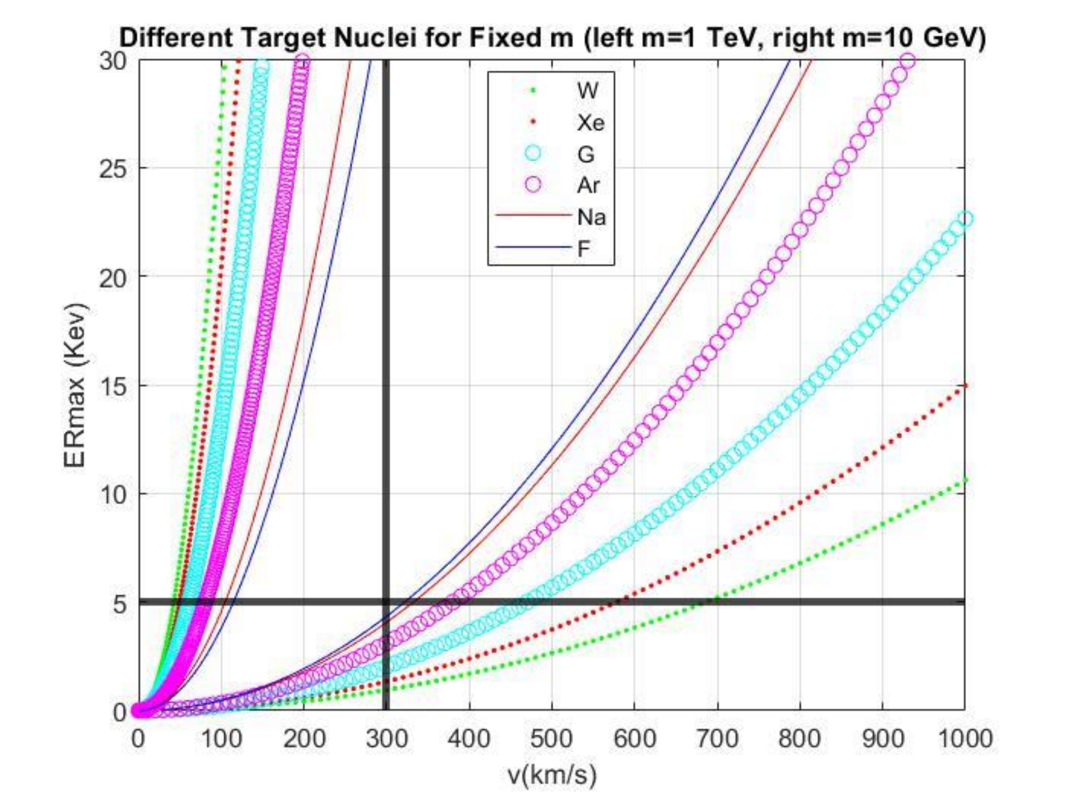
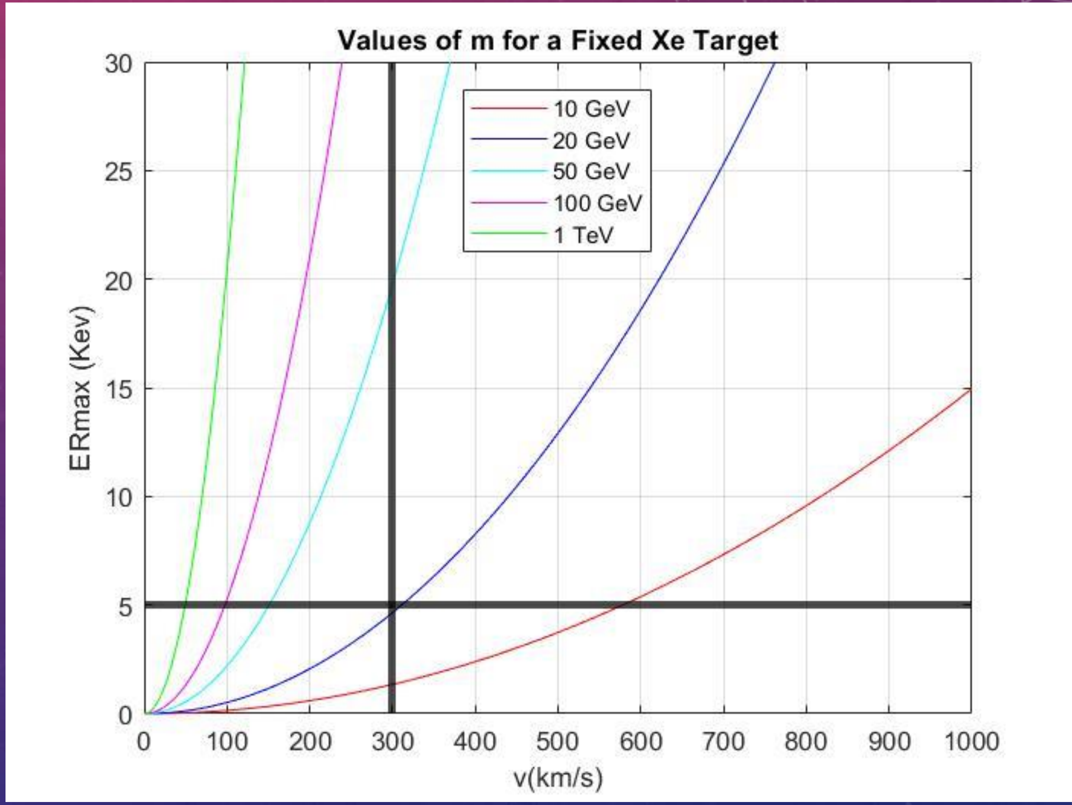


Figure from Xenon1T.org, 2018

ENERGY RECOIL PLOTS FOR ELASTIC DM SCATTERING





Nuclear Recoil Threshold Info from
10.1103/PhysRevLett.126.091301

Based on plots and equations from
arXiv:2104.12785

THE HIGGS PORTAL MODEL

- Higgs portal is a model for mediation between SM and DM
- "The Minimal Model of Nonbaryonic Dark Matter: A Singlet Scalar," C. P. Burgess et al.
- Model varies with Higgs mass (from 2001)

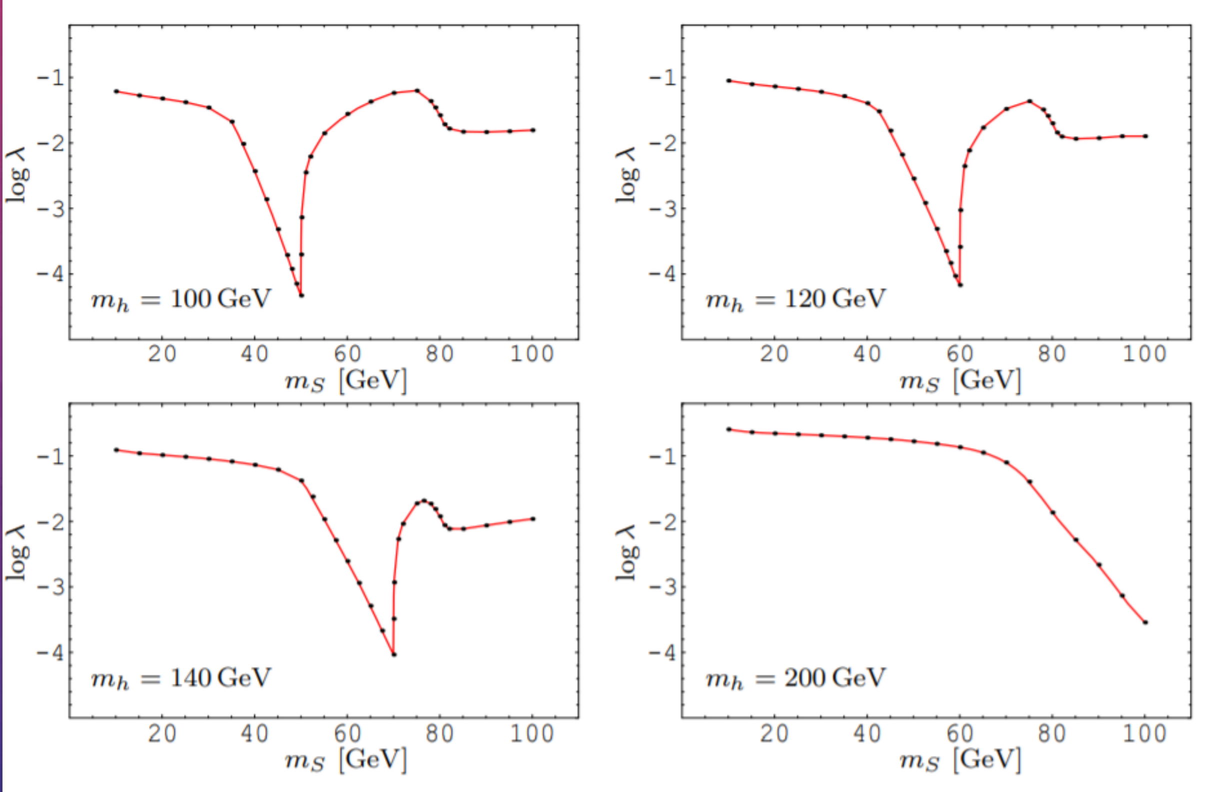


Figure from C. P. Burgess et al.

LAGRANGIANS

What are Lagrangians and why do we care?

- VERY important, lot of time spent studying theory
- Classically: defines a system in terms of position coordinates and their derivatives with respect to time, L=T-V, Lagrange's equations give motion of system
- Particle physics: defines system in terms of fields and their derivatives
- Lagrangian IS theory of how DM particles interact with the SM

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{2}\partial_\mu S\,\partial^\mu S - \frac{m_0^2}{2}\,S^2 - \frac{\lambda_s}{4}\,S^4 - \lambda\,S^2\,H^\dagger H$$

$$V = \frac{1}{2}\left(m_0^2 + \lambda\,v_{EW}^2\right)S^2 + \frac{\lambda_s}{4}\,S^4 + \lambda v_{EW}\,S^2\,h + \frac{\lambda}{2}\,S^2\,h^2$$

Equations from C. P. Burgess et al.

MICROMEGAS

- Useful because already contains SM Lagrangian
- Input variables and use LANHEP to create specific Lagrangians
- Contains MANY different models
- Calculates relic density and cross sections

MicrOMEGAs: a code for the calculation of Dark Matter Properties
including the **relic density**, direct and **indirect rates**
in a general supersymmetric model
and other models of New Physics

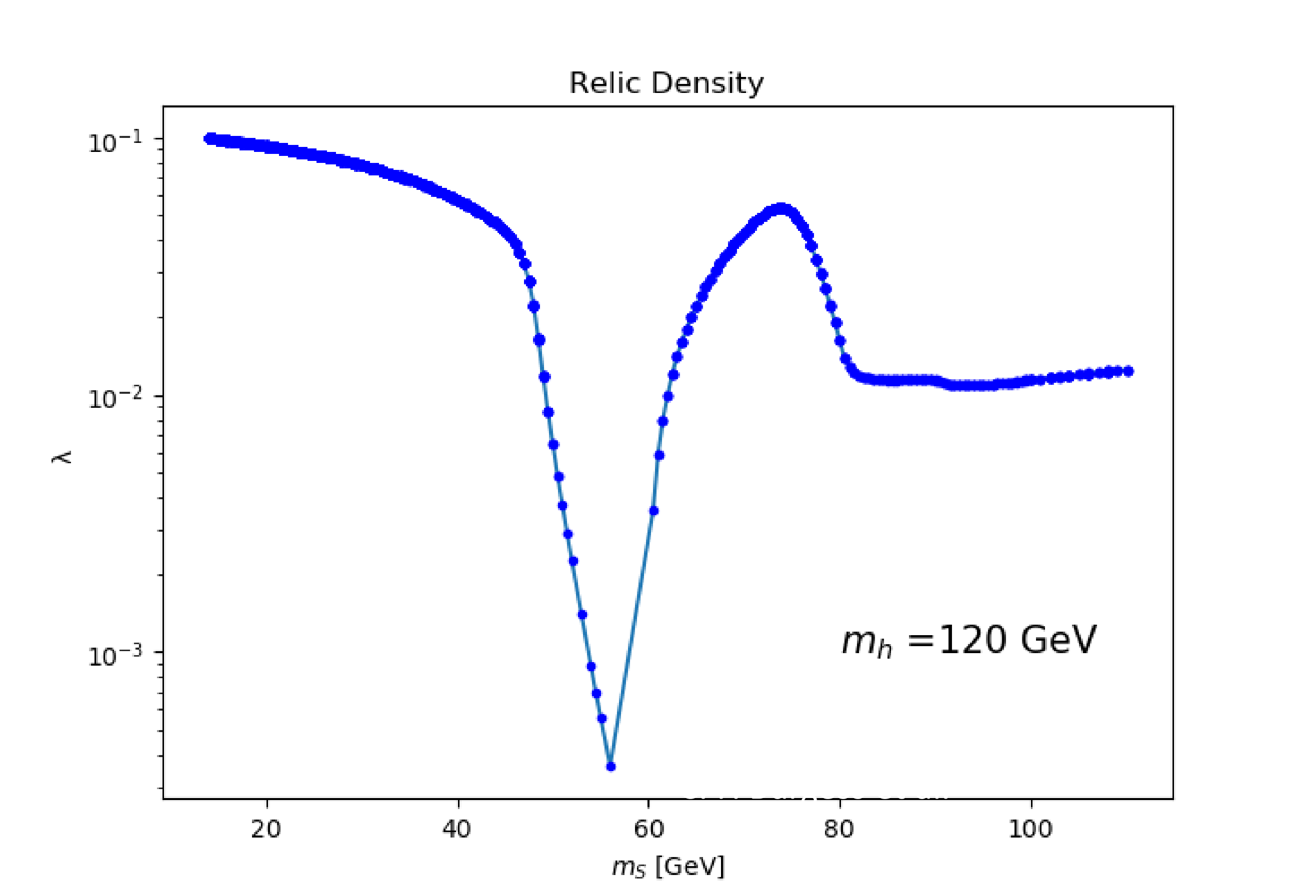
RELIC DENSITY

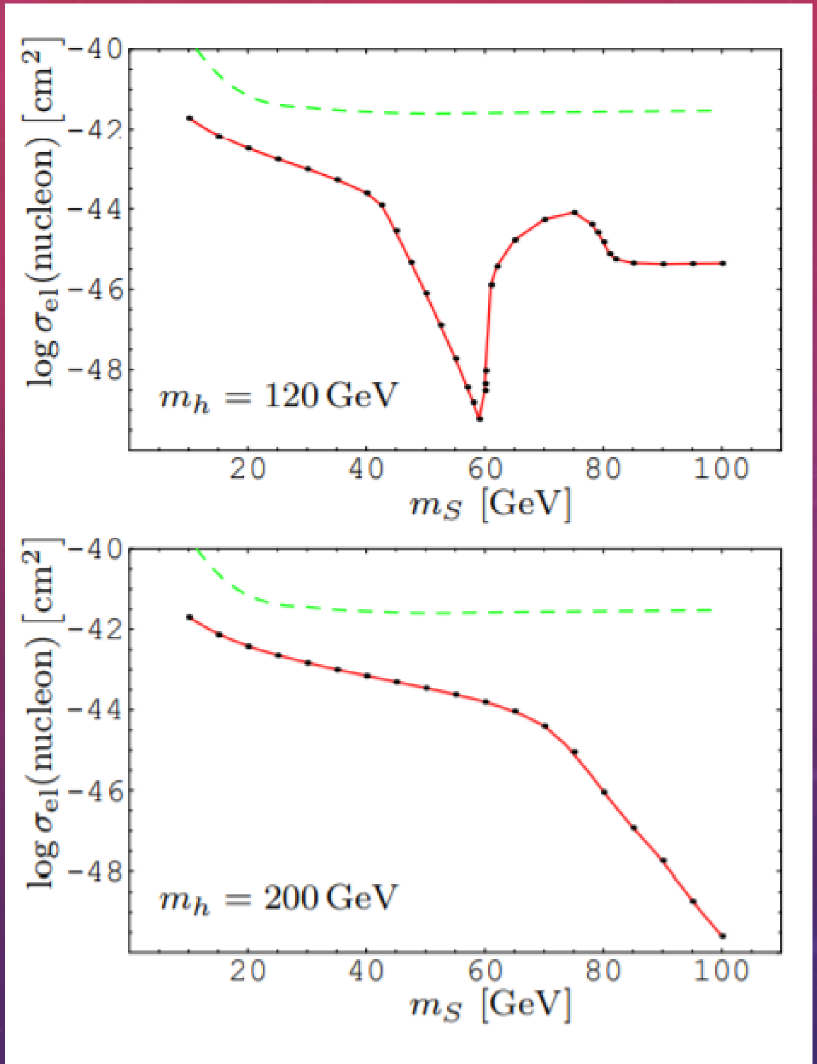
- Density of DM left after freeze out
- 0.3 at the time of paper
- Calculated assuming mass of Higgs = 120 GeV

$$\sigma_{\text{ann}}\, v_{rel} \;=\; \frac{8\lambda^2 v_{EW}^2}{(4m_S^2 - m_h^2)^2 + m_h^2\Gamma_h^2}\, F_X$$

$$\Omega_s h^2 = \frac{(1.07 \cdot 10^9)\; x_f}{g_*^{1/2}\; M_{\text{Pl}}\; \text{GeV}\; \langle \sigma v_{\text{rel}} \rangle}.$$

Equations from C. P. Burgess et al.





CROSS SECTIONS

- Probability of interaction between DM and SM nucleus
- Calculated with values that gave correct relic density
- Their plots overlaid with exclusionary limit of their time
- ALL allowed

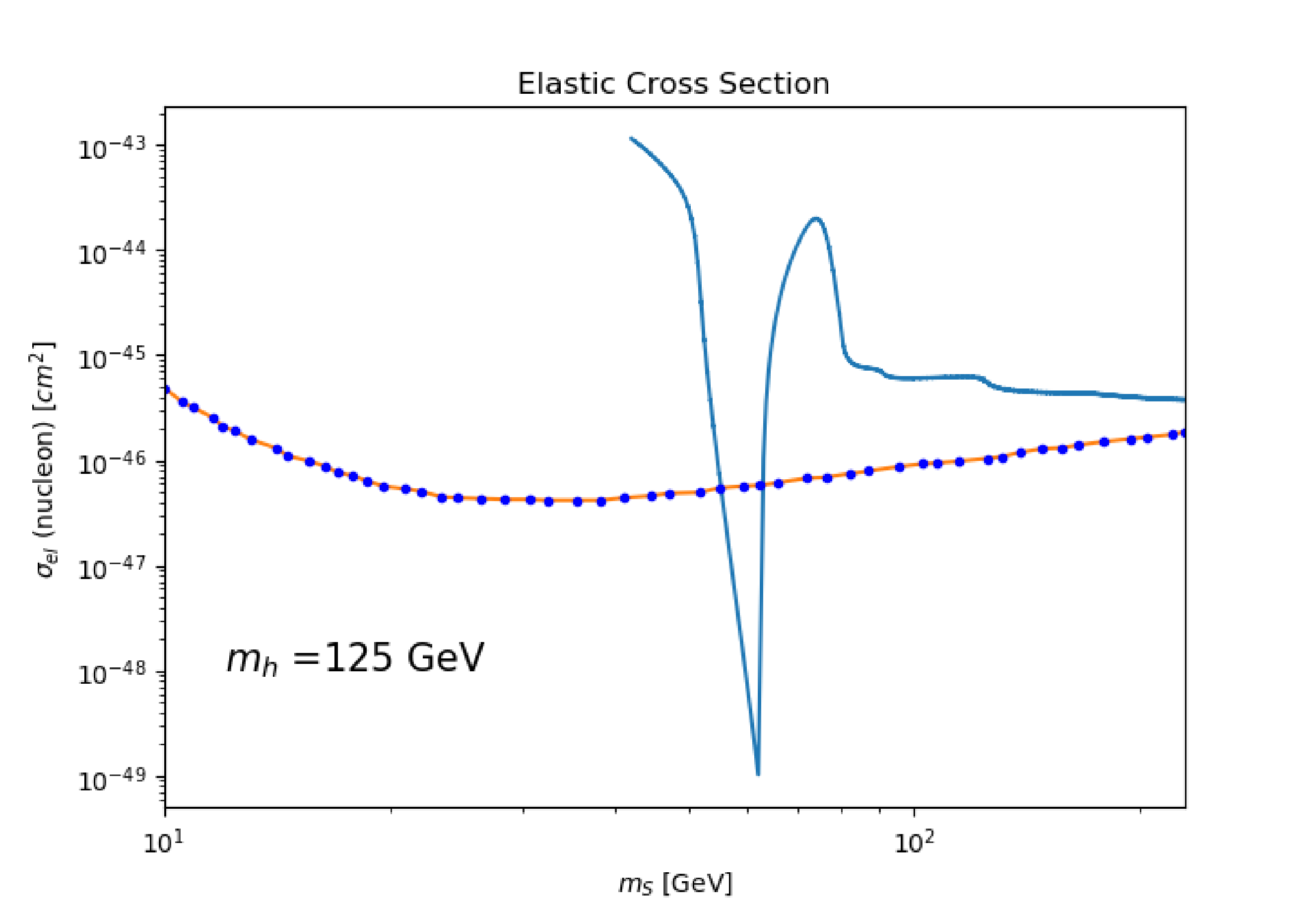
$$\sigma_{\rm el}(\text{nucleon}) = \lambda^2 \left(\frac{100 \text{ GeV}}{m_h}\right)^4 \left(\frac{50 \text{ GeV}}{m_S}\right)^2 \left(20 \times 10^{-42} \text{ cm}^2\right)$$

Figure and equation from C. P. Burgess et al.

UPDATED ELASTIC CROSS SECTION PLOTS

How have these plots changed?

- [1]Current relic density is 0.12
- Higgs mass is 125 GeV
- [2]Exclusionary data is from XENON1T (earlier slide)



1. Planck, 2018
2. Xenon1T.org, 2018

WHAT'S NEXT?

- Higgs portal model is now highly constrained; great achievement!
- Know to concentrate on Higgs resonance (DM mass at 62.5 GeV)
- Area of current research for galactic center excess (arXiv:2010.15129)
- Other WIMP models less highly constrained
- Ultralight/ultraheavy theories being examined
- Exciting, lots left to learn and discover!

THANK YOU!
QUESTIONS?

BACKUP SLIDES

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{2}\partial_\mu S\,\partial^\mu S - \frac{m_0^2}{2}\,S^2 - \frac{\lambda_S}{4}\,S^4 - \lambda\,S^2\,H^\dagger H$$

S- DM particle field
H- SM Higgs doublet
Lambda- coupling constant
m- DM mass

$$V = \frac{1}{2}\left(m_0^2 + \lambda\,v_{EW}^2\right)S^2 + \frac{\lambda_S}{4}\,S^4 + \lambda v_{EW}\,S^2\,h + \frac{\lambda}{2}\,S^2\,h^2$$

Vew= vacuum electroweak value
Lambda S- self interaction of S field
h- Higgs particle field

$$\sigma_{\rm ann}\,v_{rel} \;=\; \frac{8\lambda^2 v_{EW}^2}{(4m_S^2 - m_h^2)^2 + m_h^2\Gamma_h^2}\,F_X$$

$$F_X \;:=\; \lim_{m_{\tilde{h}}\to 2m_S}\left(\frac{\Gamma_{\tilde{h}X}}{m_{\tilde{h}}}\right)$$

Mh=Higgs mass
Th=Higgs decay rate
Th in limit=partial decay,
Virtual Higgs

$$\Omega_s h^2 = \frac{(1.07\cdot 10^9)\,x_f}{g_*^{1/2}\;M_{\rm Pl}\;{\rm GeV}\;\langle\sigma v_{\rm rel}\rangle}.$$

Xf=inverse freeze out temperature
G=degrees of freedom at freeze out
Mpl= Planck mass=2.18e8 kg
sigma=annihilation cross section

$$\sigma_{\rm el}({\rm nucleon}) \;=\; \lambda^2\left(\frac{100\ {\rm GeV}}{m_h}\right)^4\left(\frac{50\ {\rm GeV}}{m_S}\right)^2\left(20\times 10^{-42}\ {\rm cm}^2\right)$$

Know: DM is moving 300 km/s
Weird bump is artifact of Micromegas