Neutrinalino DM search with micrOMEGAs

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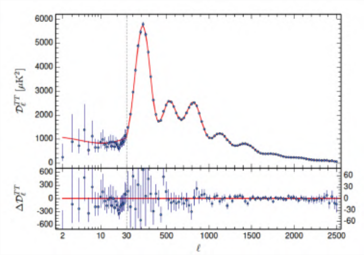
Introduction

Hocus Pocus?



6000
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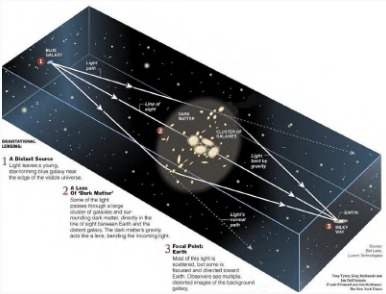
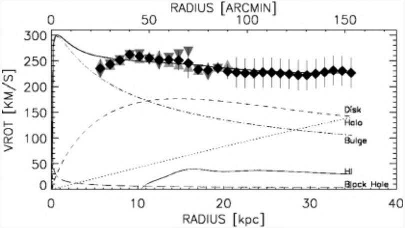


BLUE GALAXY
Light path
Line of sight
DARK MATTER
CLUSTER OF GALAXIES
Light bent by gravity
Light's normal path
EARTH
MILKY WAY
GRAVITATIONAL LENSING:
1 A Distant Source
Light leaves a young, star-forming blue galaxy near the edge of the visible universe.
2 A Lens Of 'Dark Matter'
Some of the light passes through a large cluster of galaxies and surrounding dark matter, directly in the line of sight between Earth and the distant galaxy. The dark matter's gravity acts like a lens, bending the incoming light.
3 Focal Point: Earth
Most of this light is scattered, but some is focused and directed toward Earth. Observers see multiple, distorted images of the background galaxy.



RADIUS [ARCMIN]
0
50
100
150
300
250
200
150
100
50
0
VROT [KM/S]
Disk
Halo
Bulge
HI
Black Hole
0
10
20
30
40
RADIUS [kpc]

What is Dark Matter?

- Dark Matter (DM) is widely considered to be a form of matter that comprises approximately 85 % of the total mass and 27 % of the mass-energy content in the universe.
- It explains Galaxy rotation curves, velocity dispersions of galaxies, gravitational lensing, CMB power spectrum, etc.
- However, despite its phenomenological success, we still do not know what it is nor how it interacts.
- Since we don't know (virtually) anything about it, this means that there are a lot of phenomenological models that describe it.

Dark Matter Detection

- Direct Detection: Scattering off of SM particles
- Indirect Detection: DM annihilation $\rightarrow$ excess signal
- Collider Search: Produces DM $\rightarrow$ missing momentum

Model to Detection

To compute the DM abundance predicted by any model:

- Write down your Lagrangian.
- Extract all vertices.
- Figure out which processes are relevant for dark matter production/depletion.
- Compute all the cross-sections.
- Write down the relevant Boltzmann equations.
- Code all these expressions and numerically solve your Boltzmann equations.

Taken from ISAAP School presentation by A. Goudelis

Computers: Help Make Your Life Easier!

- In order to obtain predictions from the phenomenological models and compare them with experiments using different detection methods, researchers resort to different kinds of coding tools (Neutdriver, DarkSUSY, etc.).
- Many of these software are focused on supersymmetric models with the neutralino as dark matter candidate.
- The first coding tool for dark matter studies to allow for the computation of dark matter predictions for generic dark matter models is micrOMEGAs.

micrOMEGAs

What is micrOMEGAs?

To compute the DM abundance predicted by any model:

- Write down your Lagrangian.
- Extract all vertices.

MicrOMEGAs

- Figure out which processes are relevant for dark matter production/depletion.
- Compute all the cross-sections.
- Write down the relevant Boltzmann equations.
- Code all these expressions and numerically solve your Boltzmann equations.

Taken from ISAAP School presentation by A. Goudelis

What does micrOMEGAs do?

- Calculates relic densities according to freeze-in and freeze-out picture.
- Calculates direct detection observables.
- Calculates indirect detection observables.
- Calculates decay widths and cross-sections.
- Plots useful quantities.
- Many other utilities (compute $b \to s\gamma$, interfaces with other useful Software, etc.).
- Available models: MSSM, NMSSM, Little Higgs Model (LSM), Inert Doublet Model (IDM), etc.
  (You can make your own!)

How does micrOMEGAs work?

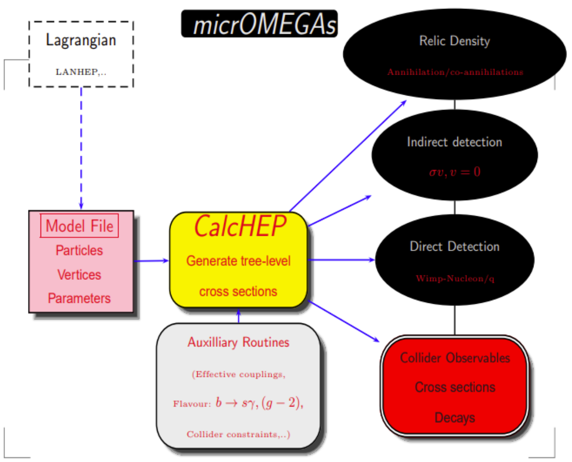


Figure 1: The flowchart of micrOMEGAs.

From arXiv:1402.0787

The Recipe

- Install and compile micrOMEGAs.
- Create CalcHEP Model files (you can use LanHEP, FeynRules, etc.).
- Put them in the *work/models* folder of your working directory in micrOMEGAs.
- Edit two files:
    - main.c file: code in C (tells microMEGAs what we want it to do).
    - data.par file: parameter names and values (adjusts external parameter values).
- Have fun!

Model

Dark Matter from the viewpoint of the (MS)SM

- The Standard Model (SM) is undoubtedly the most successful scientific theory in human kinds history. Despite that, there are a few reasons to suspect it doesn't tell the full story:
  - **Landau Pole:** QED has a Landau pole at $E \sim 10^{286}$ eV, which means that the theory becomes invalid after that point.
  - **Hierarchy Problem:** In the SM, the Higgss mass is an input parameter. If we view it as an EFT of a GUT, then an extreme fine tuning is required for it to have the value we observe.
  - **Dark Matter:** None of the SM particles are viable DM candidates.
- The Minimal Supersymmetric Standard Model (MSSM , minimal SUSY + SM) ameliorates the last two problems.

MSSM Basics

- SUSY extends the Poincare algebra of the SM into the "Super" Poincare Algebra,

$$\{Q_\alpha, \bar{Q}_{\dot{\alpha}}\} = 2\sigma^m_{\alpha,\dot{\alpha}} P_m, \tag{1}$$

with P_m being the generators of the Poincare algebra and Q_α the generators of the SUSY transformation:

$$Q_\alpha |B\rangle = |F\rangle \ , \ Q_\alpha |F\rangle = |B\rangle \,. \tag{2}$$

Each SM boson and fermion get a superpartner.

- SUSY can be viewed as a translation in Superspace:

$$z = z(x^\mu, \theta, \bar{\theta}). \tag{3}$$

MSSM Basics

- In order to respect Baryon and Lepton Conservation, SUSY must be equipped with an extra parity symmetry (R symmetry).
- SM particles are even and their Superpartners are odd under it.
- This has a profound consequence: if R-parity is exact, the Lightest Superpartner (LSP) is stable $\implies$ viable DM candidate!
- On this work we will focus on such a DM candidate. Namely, we shall investigate the neutralino.

Neutralino

- The Neutralino is made up from the superpartners of the gauge bosons (gauginos) and the Higgs (Higgsino),

$$\tilde{\chi} = \alpha_1 \tilde{W}^0 + \alpha_2 \tilde{B}^0 + \alpha_3 \tilde{H}_u^0 + \alpha_4 \tilde{H}_d^0. \tag{4}$$

- The couplings of the Neutralino to the MSSM particles are shown below:

Couplings

$$\tilde{\chi} Z \;,\; \tilde{\chi} \gamma \;,\; \tilde{\chi} H \;,\; \tilde{\chi} F \tilde{F}$$

Signatures

- There are two observational signatures we are (mainly) interested at:
    - **Relic Density:** Since the neutralino constitutes the DM, we can find its relic density by using the Boltzmann equation to calculate the freeze-out temperature and their number density.
    - **Nucleon Ampltitudes:** The aforementioned interaction vertices can be used to construct an EFT for χpp and χnn scattering. Depending on whether we have scalar of Vector-Axial (VA) interactions, the amplitudes can either be Spin Independent (SI) or Spin Dependent (SD), respectively.

Results

Particle of Interest

- We pick light Wino-like Neutralino for our DM candidate.
- Parameters for Wino-like Neutralino:
  - Wino mass should be lesser than Bino mass and Higgsino mass parameter: $M_{\widetilde{W}^0} < M_{\widetilde{B}}$ & $M_{\widetilde{W}^0} < \mu$.
  - $\tan\beta$ parameter should be small.
- Parameters we picked:

Parameters

$$M_{\widetilde{W}^0} = [5, 190]\, GeV$$
$$M_{\widetilde{B}} = 2000\, GeV \;,\; \mu = 2000\, GeV$$
$$\tan\beta = \frac{v_{H_u}}{v_{H_d}} = 2$$

Neutralino Mass Calculation

- Let's pick a Wino mass of $M_{\widetilde{W}^0} = 106\,GeV$.
- Neutralino is found to be:

$$\tilde{\chi} = -0.999\tilde{W}^0 + 0.001\tilde{B}^0 + 0.036\tilde{H}_u^0 - 0.020\tilde{H}_d^0$$

- Neutralino was found to be of $M_{\widetilde{\chi}_1^0} = 110\,GeV$.

```
Dark matter candidate is '~o1' with spin=1/2  mass=1.10E+02

~o1 = 0.001*bino -0.999*wino +0.036*higgsino1 -0.020*higgsino2
```

Calculation of Masses & Widths

```
=== MASSES OF HIGGS AND SUSY PARTICLES: ===
Higgs masses and widths
      h   101.14 2.74E-03
      H   704.70 7.86E+00
     H3   700.00 9.00E+00
     H+   704.70 9.10E+00

Masses of odd sector Particles:
~o1      : MNE1    = 109.781 || ~1+      : MC1     = 109.782 || ~l1      : MSl1    = 197.301
~eR      : MSeR    = 202.754 || ~mR      : MSmR    = 202.754 || ~ne      : MSne    = 497.697
~nm      : MSnm    = 497.697 || ~nl      : MSnl    = 497.697 || ~eL      : MSeL    = 501.187
~mL      : MSmL    = 501.187 || ~l2      : MSl2    = 501.399 || ~t1      : MSt1    = 1306.804
~b1      : MSb1    = 1553.366 || ~uL      : MSuL    = 1557.689 || ~cL      : MScL    = 1557.689
~uR      : MSuR    = 1557.958 || ~cR      : MScR    = 1557.958 || ~dR      : MSdR    = 1558.321
~sR      : MSsR    = 1558.321 || ~dL      : MSdL    = 1558.832 || ~sL      : MSsL    = 1558.832
~b2      : MSb2    = 1563.772 || ~t2      : MSt2    = 1686.462 || ~g       : MSG     = 1842.142
~o2      : MNE2    = 1934.187 || ~o3      : MNE3    = 1981.212 || ~2+      : MC2     = 1984.164
~o4      : MNE4    = 2019.726 ||
```

Relic Density Calculation

$$X_f = \frac{M_{\widetilde{\chi}}}{T_f} = 30.8 \ , \ \Omega_\chi h^2 = 3.26 \times 10^{-4}$$

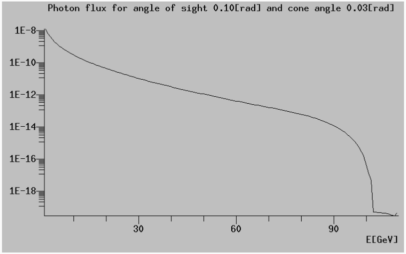
```
==== Calculation of relic density =====
Xf=3.08e+01 Omega=3.26e-04 err=0
# Channels which contribute to 1/(omega) more than 1%.
# Relative contributions in % are displayed
   15% ~1+ ~o1 ->u D
   15% ~1+ ~o1 ->S c
    6% ~1+ ~o1 ->Z W+
    5% ~o1 ~o1 ->W+ W-
    5% ~1+ ~1+ ->W+ W+
    4% ~1+ ~o1 ->ne E
    4% ~1+ ~o1 ->nm M
    4% ~1+ ~o1 ->nl L
    4% ~1+ ~1- ->W+ W-
    4% ~1+ ~1- ->s S
    4% ~1+ ~1- ->d D
    4% ~1+ ~1- ->b B
    4% ~1+ ~1- ->u U
    4% ~1+ ~1- ->c C
    3% ~1+ ~o1 ->t B
    2% ~1+ ~1- ->A Z
    2% ~1+ ~1- ->Z Z
    2% ~1+ ~o1 ->W+ h
    2% ~1+ ~o1 ->A W+
    1% ~1+ ~1- ->ne Ne
    1% ~1+ ~1- ->nm Nm
    1% ~1+ ~1- ->nl Nl
    1% ~1+ ~1- ->Z h
```

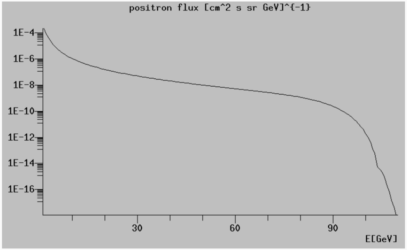
Indirect Detection Calculation

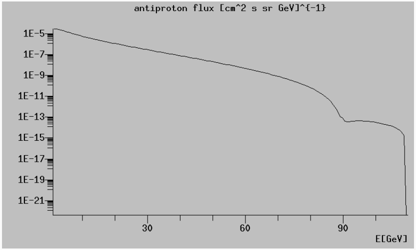
$$< \sigma v > = 4.22 \times 10^{-24} \, cm^3/s$$

```
==== Indirect detection =======
    Channel          vcs[cm^3/s]
==================================
 annihilation cross section 4.22E-24 cm^3/s
 contribution of processes
  ~o1,~o1 -> W+ W-                 1.00E+00
  ~o1,~o1 -> l L                   1.35E-07
  ~o1,~o1 -> b B                   8.40E-08
  ~o1,~o1 -> Z h                   2.33E-09
  ~o1,~o1 -> G G                   1.77E-09
  ~o1,~o1 -> c C                   6.75E-10
  ~o1,~o1 -> ne Ne                 2.27E-10
  ~o1,~o1 -> nm Nm                 2.27E-10
  ~o1,~o1 -> nl Nl                 2.27E-10
  ~o1,~o1 -> e E                   2.15E-10
  ~o1,~o1 -> m M                   2.15E-10
  ~o1,~o1 -> h h                   1.58E-10
  ~o1,~o1 -> Z Z                   6.45E-11
  ~o1,~o1 -> d D                   3.14E-11
  ~o1,~o1 -> s S                   3.14E-11
  ~o1,~o1 -> u U                   1.21E-11
  ~o1,~o1 -> A A                   5.53E-12

Photon flux  for angle of sight f=0.10[rad]
and spherical region described by cone with angle 0.0349[rad]
Photon flux = 6.80E-13[cm^2 s GeV]^{-1} for E=54.9[GeV]

Positron flux  =  7.10E-09[cm^2 sr s GeV]^{-1} for E=54.9[GeV]

Antiproton flux  =  9.60E-09[cm^2 sr s GeV]^{-1} for E=54.9[GeV]
```

Fluxes in Indirect Detection



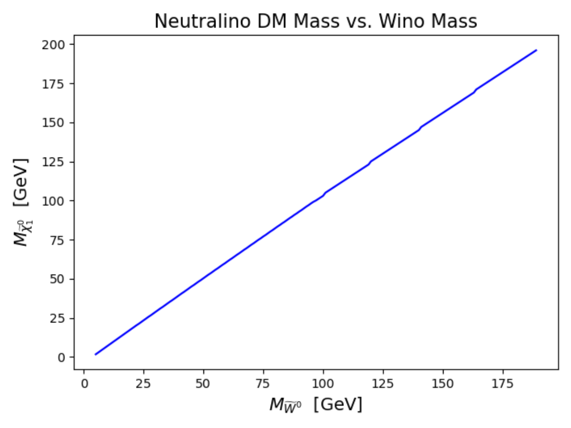




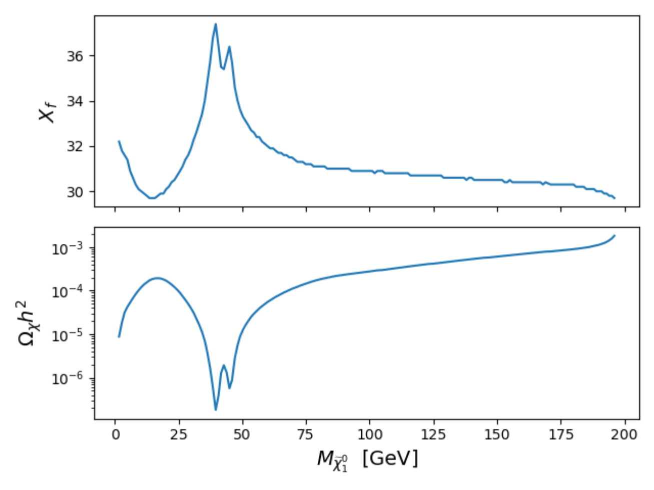
Direct Detection Calculations

```
==== Calculation of CDM-nucleons amplitudes  =====
~o1-nucleon micrOMEGAs amplitudes:
proton:  SI  -1.320E-09  SD  -1.370E-09
neutron: SI  -1.336E-09  SD  8.077E-09

==== ~o1-nucleon cross sections[pb] ====
 proton  SI 7.490E-10  SD 2.419E-09
 neutron SI 7.665E-10  SD 8.411E-08
Excluded by LZ5Tmedian [CDM_NUCLEON] 100.0%

===== Direct detection exclusion:======
Excluded by LZ5Tmedian [CDM_NUCLEUS]  100.0%
pval=2.748723e-26 experiment=LZ5Tmedian
```

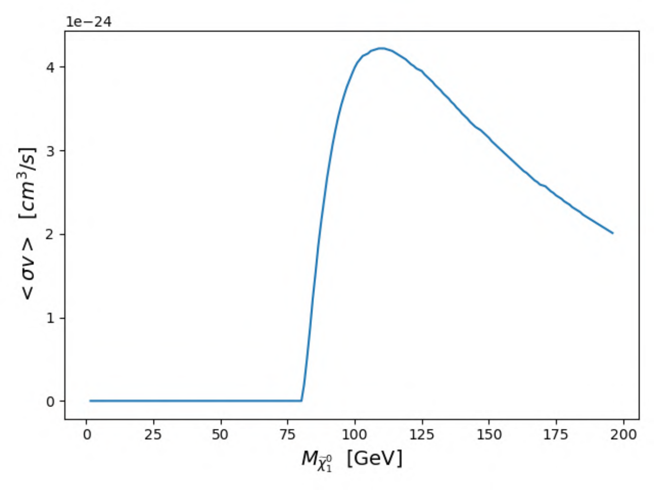
Neutralino Masses for a Range of Light Wino Mass



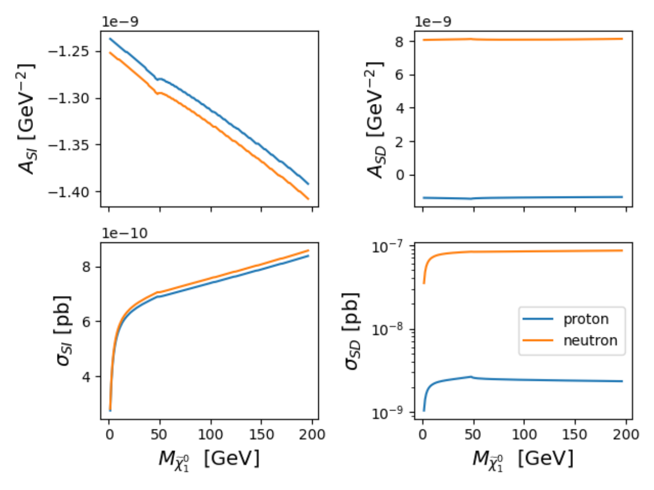
Relic Densities and Freeze-out Parameters



Indirect Detection: Annihilation Cross-sections



Direct Detection: Amplitudes & Scattering Cross-sections



Questions?