UDLAP

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Theory meets Experiment
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UPAEP

Comparative Study Between MSSM & NMSSM as SUSY Candidate Models for Dark Matter

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Objectives

Explore the Parameter Space between the MSSM and NMSSM.

Analyze the Annihilation Photon Flux and Cosmological properties.

Obtain in both scenarios a resulting bino-like lightest neutralino in the $M_{\chi_1^0} \in [1, 5]$ TeV range.

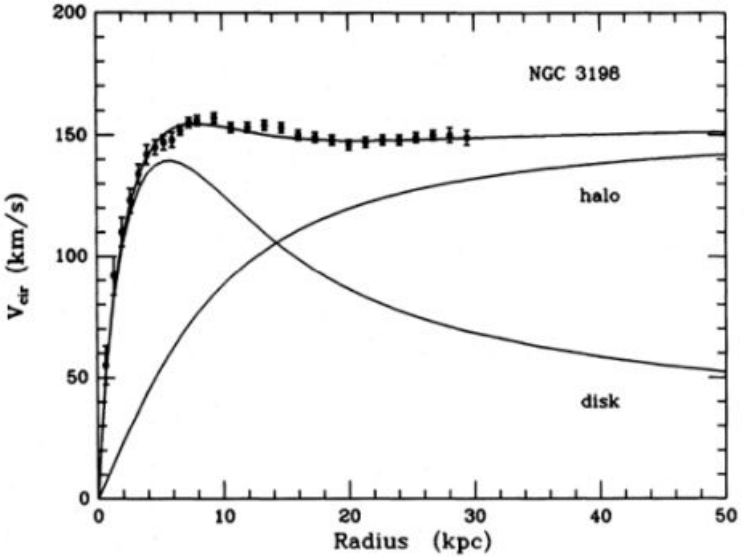
Introduction

WIMP-like particles can annihilate into SM particles producing gamma-rays through loop processes.

Dwarf Spheroidal Galaxies (dSphs) Good Candidates for DM Search.

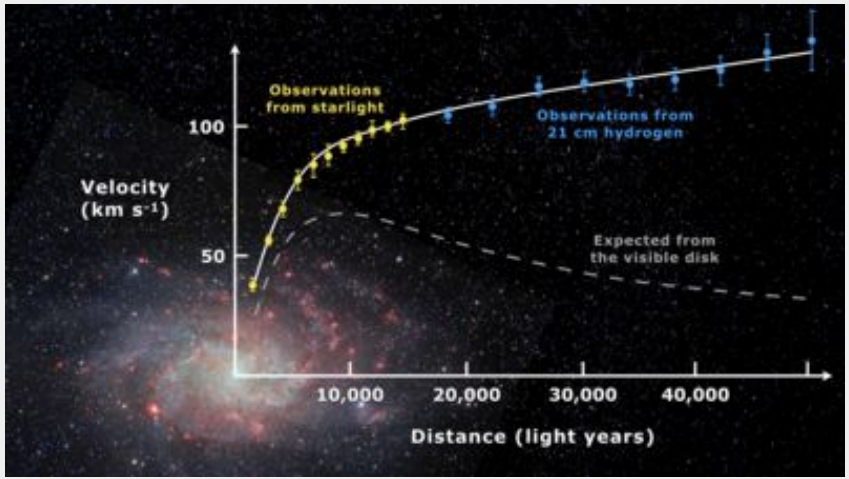
dSphs expected to be extremely DM rich, very low luminosity galaxies

Evidence



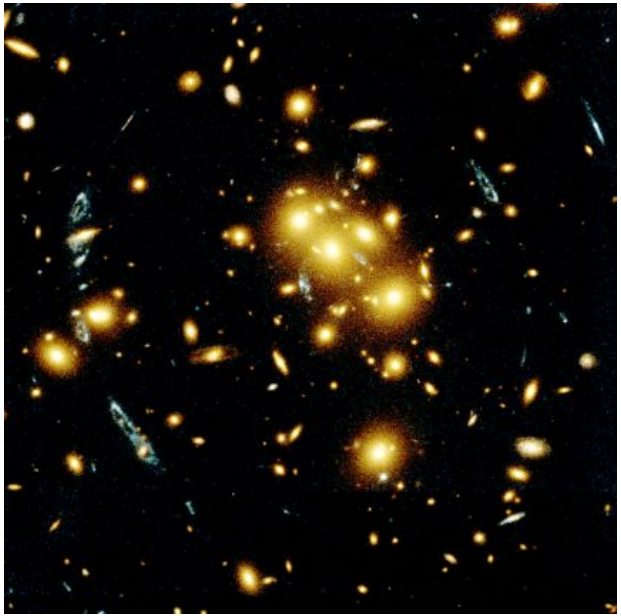
NGC 3198 galaxy [Rubin, 1983]

Rotation Curves at Galactic Scale

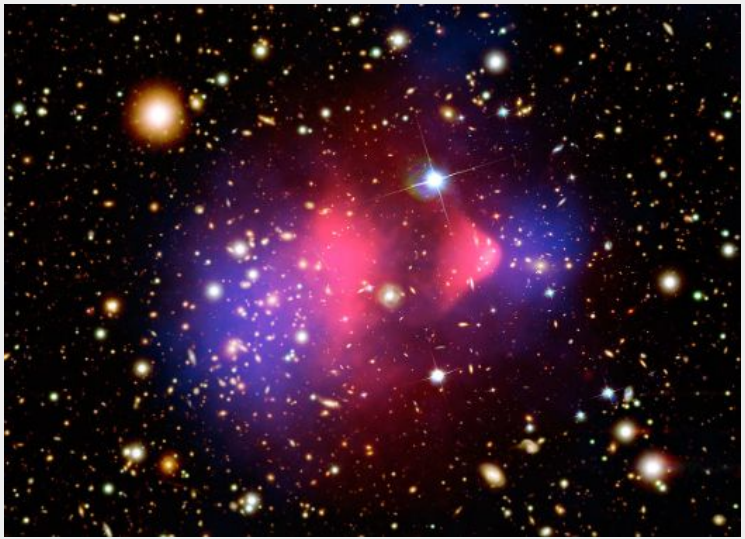


Evidence

Clusters & Large Clusters

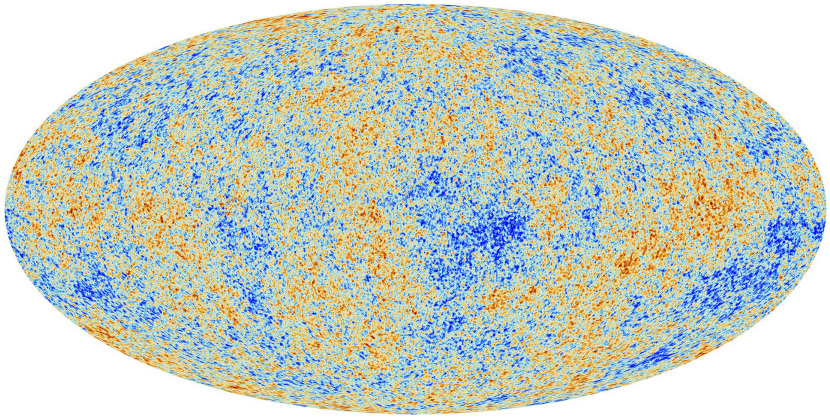


CL0024+1654 Cluster [ESA Hubble, 2021]



Bullet Cluster [ESA Hubble, 2021]

Evidence



CMB [Penzias & Wilson, 1965]

CMB Anisotropies

$$\Omega_b h^2 = 0.02264 \pm 0.00050$$

$$\Omega_m h^2 = 0.273 \pm 0.049$$

Relic Density

$$\Omega_{\mathrm{DM}} h^2 = 0.1138 \pm 0.0045$$

9 Year WMAP [Hinshaw, 2013]

Relic Density

$$W(s) = \sum_{ij} \frac{\lambda(s, m_i^2, m_j^2)}{2\sqrt{\lambda(s, m_\chi^2, m_\chi^2)}} g_i g_j \sigma_{ij}$$

$$A = \frac{T}{16\pi^4} \int_{4m_\chi^2}^{\infty} ds \sqrt{s - 4m_\chi^2} K_1\left(\frac{\sqrt{s}}{T}\right) W(s)$$

$$n_{\mathrm{eq}} = \frac{T}{2\pi^2} \sum_i g_i m_i^2 K_2\left(\frac{m_i}{T}\right)$$

Neutralino Relic Density
[Gondolo, 1997]

Thermally Averaged Annihilation Cross Section

$$\langle \sigma_{\mathrm{eff}} v \rangle = \frac{A}{n_{\mathrm{eq}}^2}$$

Relic Density

$$\frac{\mathrm{d}n}{\mathrm{d}t} = -3Hn - \langle \sigma_{eff} v \rangle (n^2 - n_{eq}^2)$$

Photon Flux

$$J = \int_{\text{source}} d\Omega \int dx \rho^2(r(\theta, x))$$

$$D = \int_{\text{source}} d\Omega \int dx \rho(r_{\text{gal}}(\theta, x))$$

Neutralino Relic Density
[Gondolo, 1997]

Annihilation Photon Flux

$$\frac{dF}{dE}_{\text{annihilation}} = \frac{\langle \sigma_A v \rangle}{8\pi M_\chi^2} \frac{dN_\gamma}{dE} J$$

Decay Photon Flux

$$\frac{dF}{dE}_{\text{decay}} = \frac{1}{4\pi\tau M_\chi} \frac{dN_\gamma}{dE} D$$

MSSM

Higgs Doublets

$$\Phi_u = \begin{pmatrix} \phi_u^+ \\ \phi_u^0 \end{pmatrix} \qquad \Phi_d = \begin{pmatrix} \phi_d^0 \\ \phi_d^- \end{pmatrix}$$

Superpotential

$$W_{\text{MSSM}} = \bar{u}\mathbf{y_u}Q\mathbf{\Phi_u} - \bar{d}\mathbf{y_d}Q\mathbf{\Phi_d} - \bar{e}\mathbf{y_e}L\mathbf{\Phi_d} + \mu\mathbf{\Phi_u}\mathbf{\Phi_d}$$

Neutralino Mass Matrix

$$\mathcal{M}_N = \begin{pmatrix} M_1 & 0 & -M_Z \sin\theta_W \cos\beta & M_Z \sin\theta_W \sin\beta \\ 0 & M_2 & M_Z \cos\theta_W \cos\beta & -M_Z \cos\theta_W \sin\beta \\ -M_Z \sin\theta_W \cos\beta & M_Z \cos\theta_W \cos\beta & 0 & -\mu \\ M_Z \sin\theta_W \sin\beta & -M_Z \cos\theta_W \sin\beta & -\mu & 0 \end{pmatrix}.$$

MSSM [Kuroda, 2005]

- Additional Higgs Supermultiplet

- 5 Higgs States
- 4 neutralinos

Neutralinos	Higgs States
χ_1^0	h^0
χ_2^0	H^0
χ_3^0	H^+
χ_4^0	H^-
	A^0

NMSSM

Higgs Doublets + Singlet

$$H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}, \qquad H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}, \qquad S$$

Superpotential

$$W = \tilde{u}_R^* y_u (\tilde{Q}^{\mathrm{T}} \epsilon H_u) - \tilde{d}_R^* y_d (\tilde{Q}^{\mathrm{T}} \epsilon H_d) - \tilde{e}_R^* y_e (\tilde{L}^{\mathrm{T}} \epsilon H_d) + \lambda S (H_u^{\mathrm{T}} \epsilon H_d) + \frac{1}{3} \kappa S^3$$

Neutralino Mass Matrix

$$M_{\tilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -c_\beta s_W m_Z & s_\beta s_W m_Z & 0 \\ 0 & M_2 & c_\beta c_W m_Z & -s_\beta c_W m_Z & 0 \\ -c_\beta s_W m_Z & c_\beta c_W m_Z & 0 & -\lambda v_s/\sqrt{2} & -\lambda v_u/\sqrt{2} \\ s_\beta s_W m_Z & -s_\beta c_W m_Z & -\lambda v_s/\sqrt{2} & 0 & -\lambda v_d/\sqrt{2} \\ 0 & 0 & -\lambda v_u/\sqrt{2} & -\lambda v_d/\sqrt{2} & \sqrt{2}\kappa v_s \end{pmatrix}$$

NMSSM [Maniatis, 2010]

- Additional Higgs Supermultiplet and Singlet Field
- effective mu term
- 7 Higgs States
- 5 neutralinos

Neutralinos	Higgs States
χ_1^0	H_1
χ_2^0	H_2
χ_3^0	H_3
χ_4^0	H^+
χ_5^0	H^-
	A_1
	A_2

NMSSM

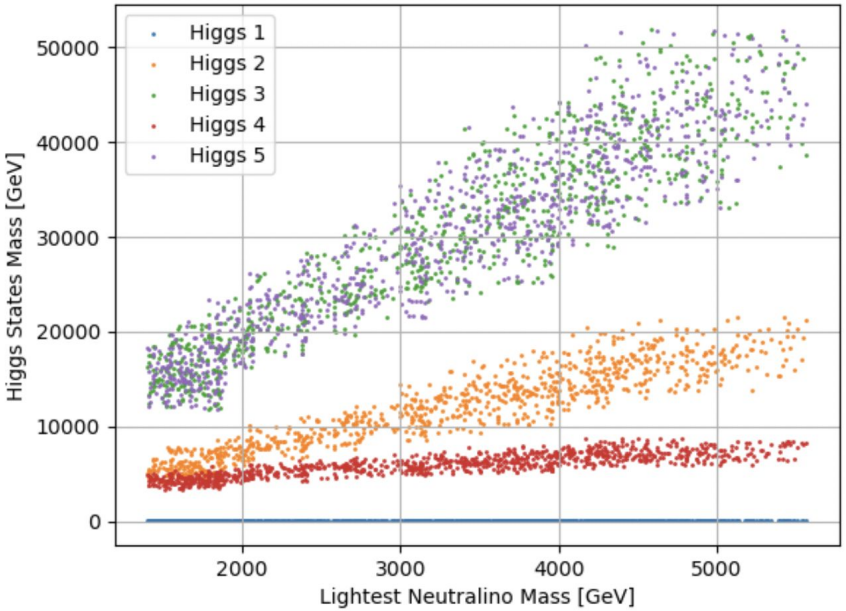
$$1000 < \mu < 10000$$
$$1000 < M_1 < 5000$$
$$M_2 \sim 5000$$
$$1000 < M_3 < 3000$$
$$\lambda = 0.1$$
$$\kappa = 0.1$$

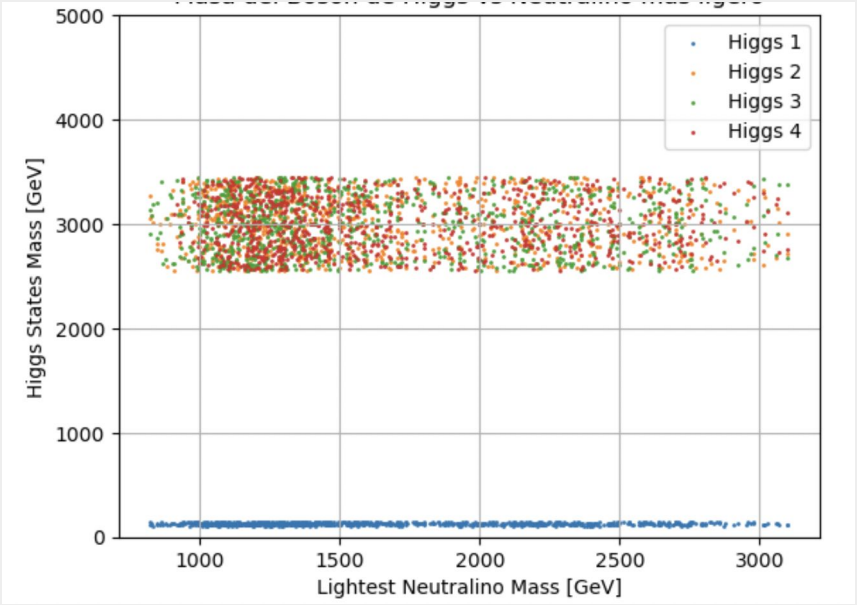
MSSM

$$1000 < \mu < 4000$$
$$1000 < M_1 < 3000$$
$$2000 < M_2 < 6000$$
$$1000 < M_3 < 3000$$
$$\tan\beta = 20$$

Both Scenarios are considered with heavy squarks and sleptons that dont contribute to DM, so are equaled to 5000 GeV

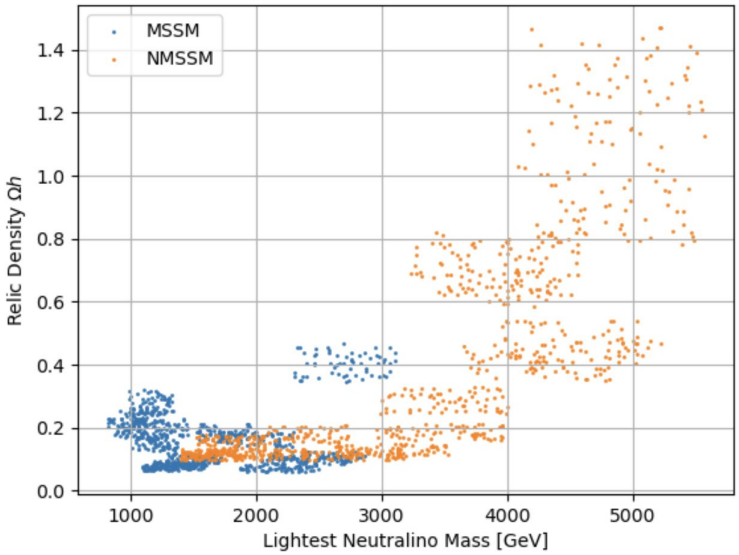
Higgs Sector



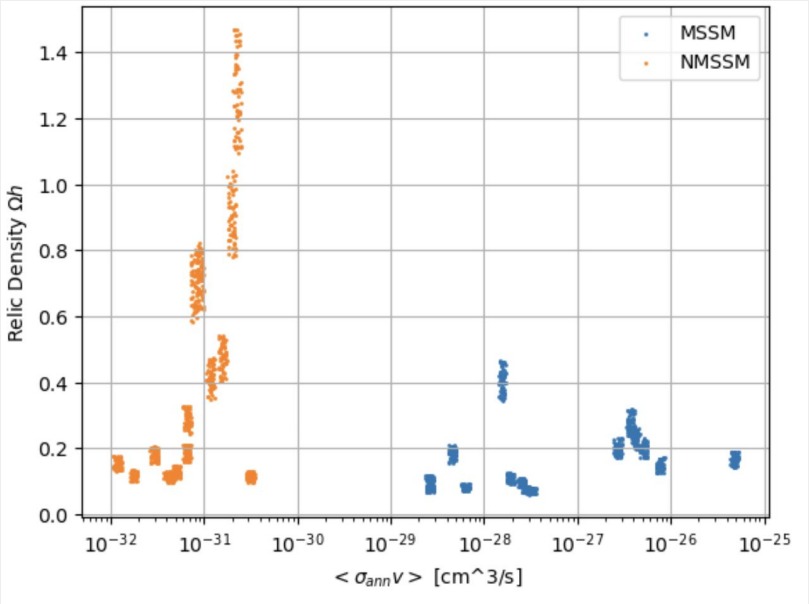


Relic Density

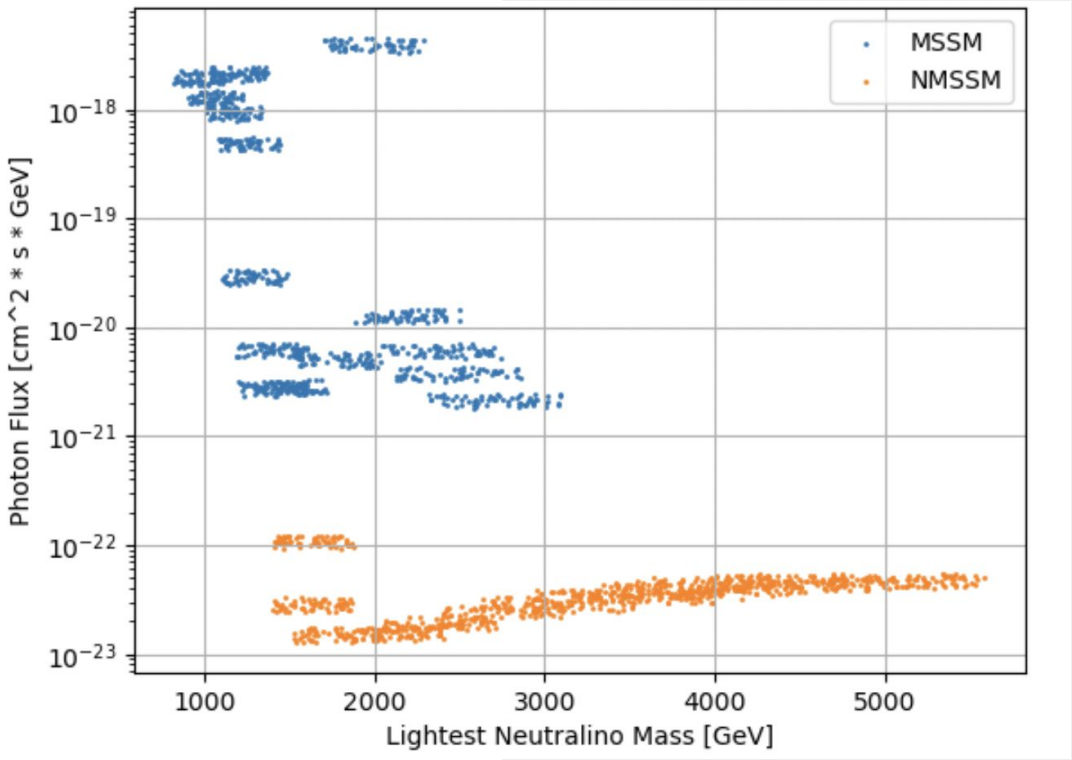
vs LSP



vs Thermally Averaged Annihilation Cross Section

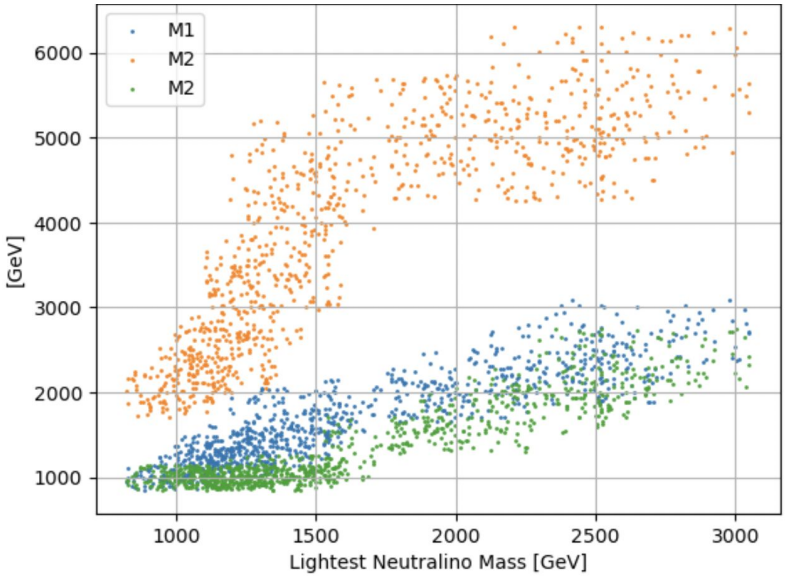


Photon Flux

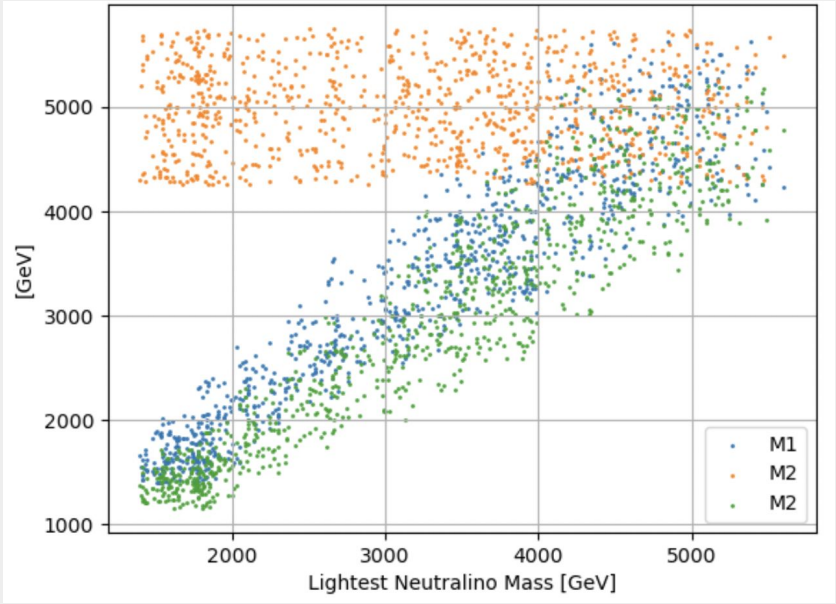

MSSM
NMSSM
Photon Flux [cm^2 * s * GeV]
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
1000
2000
3000
4000
5000
Lightest Neutralino Mass [GeV]

Gaugino Sector

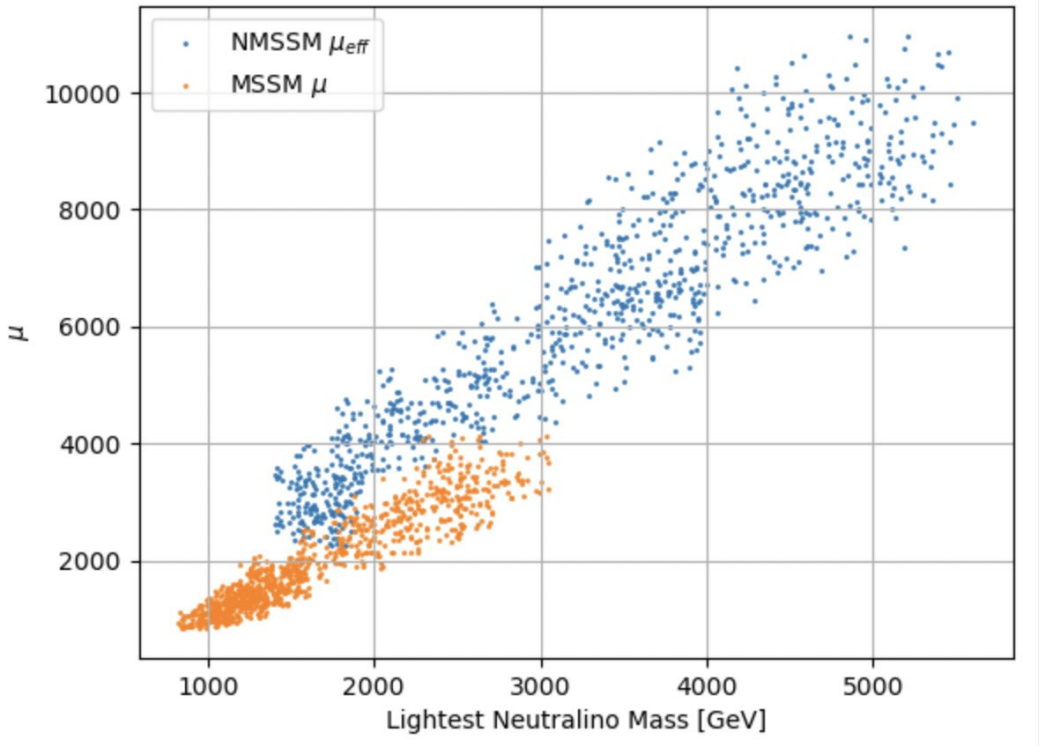
NMSSM



MSSM



Couplings


NMSSM μ_{eff}
MSSM μ
10000
8000
6000
4000
2000
μ
1000
2000
3000
4000
5000
Lightest Neutralino Mass [GeV]

Conclusions

We have two viable DM Candidates with studied input SUSY parameters.

Both have consistencies with Cosmological measured properties such as the Relic Density.

Both have a Higgs state consistent with the Higgs Boson measured at 125 GeV

Next Steps

Study an ALP scenario with same methodology

Wait for the HAWC 500 days probe on dSphs to analyze model viability

Perform an analysis on the decay branches for each DM

Thank You