

Scalar potential analysis of the \mathbb{Z}_5 multi-component dark matter model

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The model

The most general and renormalizable scalar potential of the model is given by

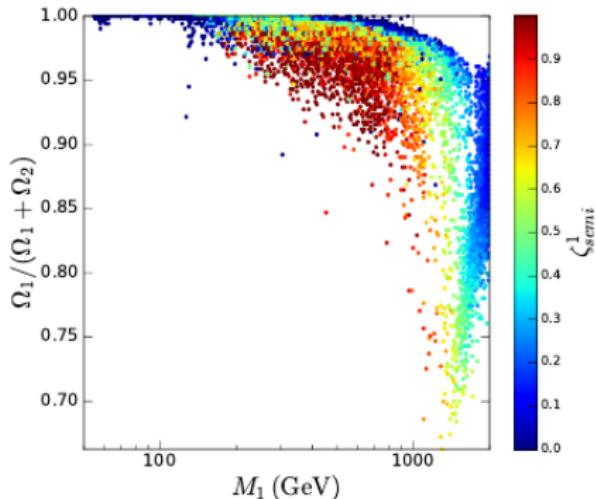
$$\begin{aligned} \mathcal{V}_{\mathbb{Z}_5} = & -\mu_H^2 |H|^2 + \lambda_H |H|^4 + \mu_1^2 |\phi_1|^2 + \lambda_{S1} |H|^2 |\phi_1|^2 + \lambda_{41} |\phi_1|^4 \\ & + \mu_2^2 |\phi_2|^2 + \lambda_{42} |\phi_2|^4 + \lambda_{S2} |H|^2 |\phi_2|^2 + \lambda_{412} |\phi_1|^2 |\phi_2|^2 \\ & + \frac{1}{2} (\mu_{S1} \phi_1^2 \phi_2^* + \mu_{S2} \phi_2^2 \phi_1 + \lambda_{31} \phi_1^3 \phi_2 + \lambda_{32} \phi_1 \phi_2^{*3} + \text{h.c.}). \end{aligned} \quad (1)$$

Two new complex scalar fields,

$$\phi_1 \sim \omega_5, \quad \phi_2 \sim \omega_5^2; \quad \omega_5 = e^{i2\pi/5}$$

$\phi_{1,2}$ do not acquire VEV and $M_1 < M_2 < 2M_1$ so that both are stable. They are singlets under the gauge group of the SM and the SM particles are singlets under \mathbb{Z}_5 .

The model



$$\begin{aligned}40 \text{ GeV} &\leq M_1 \leq 2 \text{ TeV}, \\M_1 &< M_2 < 2M_1, \\10^{-4} &\leq |\lambda_{S1}| \leq 1, \\10^{-3} &\leq |\lambda_{S2}| \leq 1.\end{aligned}$$

Figure: Bélanger et al. (2020). *The \mathbb{Z}_5 model of two-component dark matter.*

arXiv: 2006.14922

The model

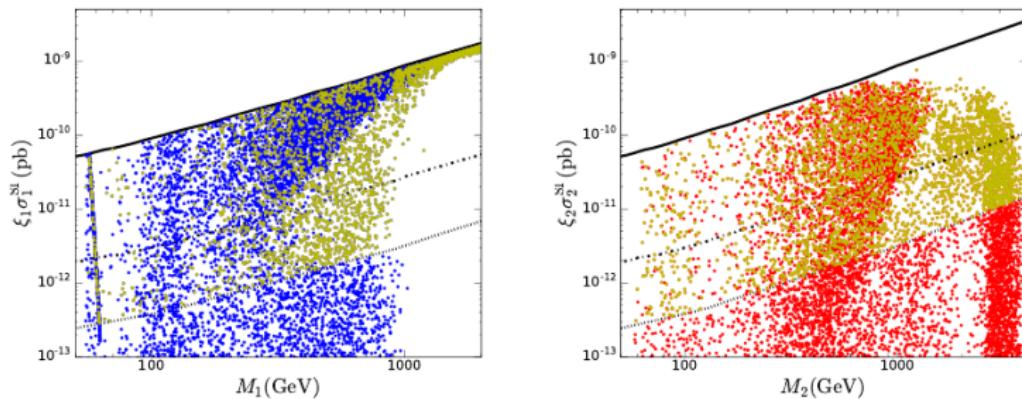


Figure: Bélanger et al. (2020). *The \mathbb{Z}_5 model of two-component dark matter.*
arXiv: 2006.14922

Constraints over the parameter space

Set of free parameters

$$M_i, \lambda_{4i}, \lambda_{Si}, \lambda_{412}, \mu_{Si}, \lambda_{3i}. \quad (2)$$

We have then seven dimensionless parameters and four dimensionful parameters, which have to be restricted.

Constraints

- Perturbative unitarity.
- Positivity.
- Global minimum SM.

All of the above, at different energy scales.

$$40 \text{ GeV} \leq M_1 \leq 2 \text{ TeV},$$

$$M_1 < M_2 < 2M_1,$$

$$10^{-4} \leq \lambda_{4i}, |\lambda_{412,Si,3i}| \leq \sqrt{4\pi},$$

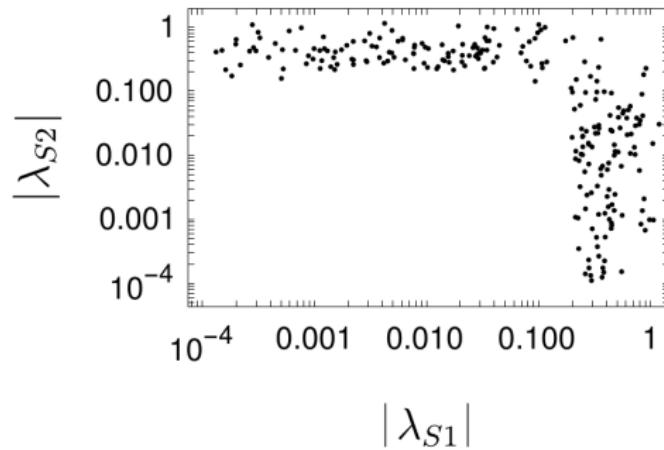
$$100 \text{ GeV} \leq |\mu_{Si}| \leq 10 \text{ TeV}.$$

Results: positivity bounds

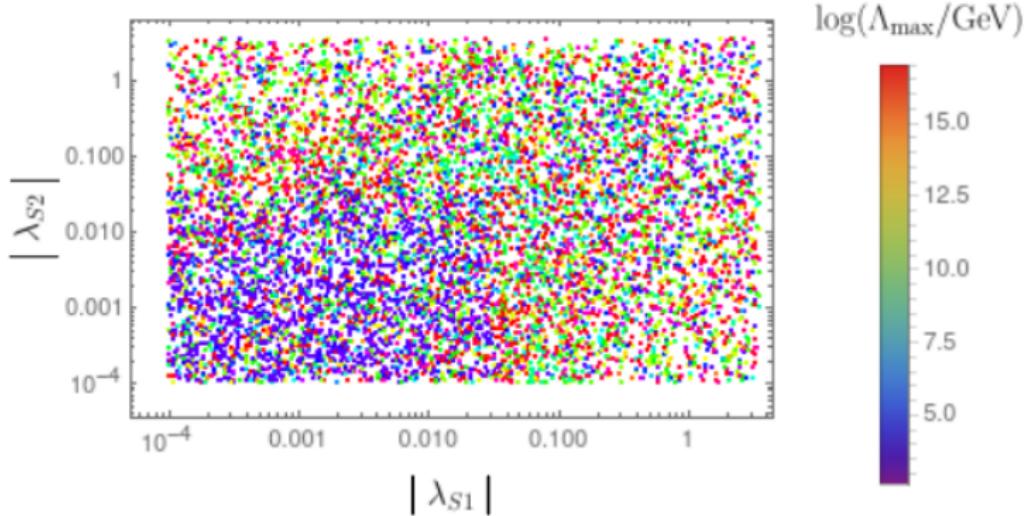
There are three main cases for the analysis:

- $\lambda_{Si} > 0$
- $\lambda_{Si} < 0$
- $\lambda_{S1}\lambda_{S2} < 0$

The positivity of the scalar potential impose higher constraints over the dimensionless couplings.



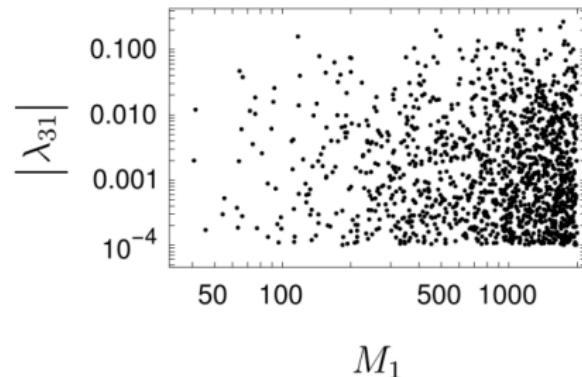
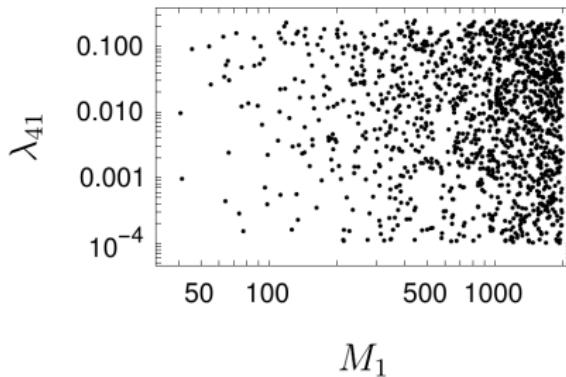
Results: positivity bounds



$$\lambda_{42}\lambda_{S1}^2 - \lambda_{412}\lambda_{S1}\lambda_{S2} + \lambda_{41}\lambda_{S2}^2 + \sqrt{-\lambda_{S1}\lambda_{S2}}(|\lambda_{32}||\lambda_{S1}| + |\lambda_{31}||\lambda_{S2}|) \geq 0$$

Results: perturbative unitarity bounds

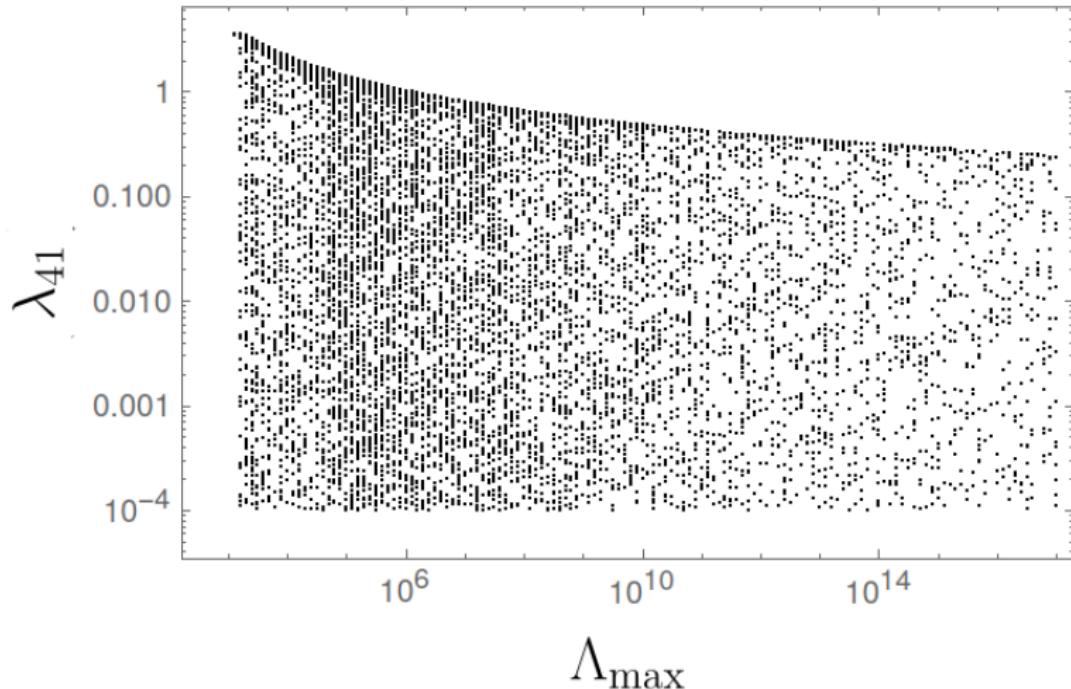
The unitarity of S-Matrix mainly restrict the self-couplings of the model.



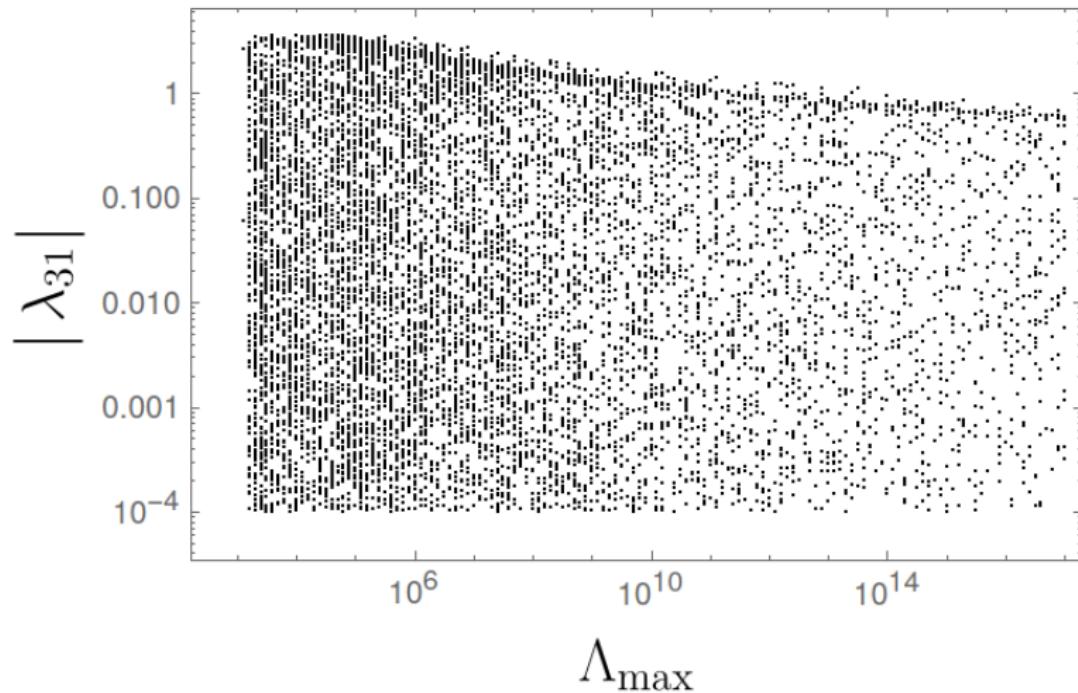
Therefore,

$$10^{-4} \leq |\lambda_{3i}|, \lambda_{4i} \lesssim 10^{-1}$$

Results: perturbative unitarity bounds

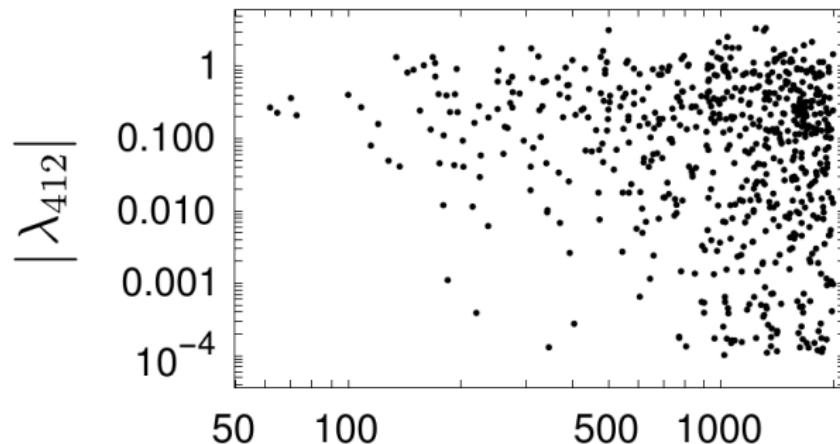


Results: perturbative unitarity bounds



Results: Global minimum bounds

The coupling among both dark matter particles is widely bounded by the imposition of the minimum of SM as the global minimum.



$$M_1$$

Conclusions

- The theoretical conditions for $\Lambda \leq 10^{17}$ GeV impose significant bounds over the dimensionless parameters of the model.
- In general, we have a scenario of weakly self-interacting dark matter.
- We must to perform more analysis of varying the energy in the CM frame for other values in the unitarity condition os S-Matrix.

Referencias

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- [3] Kristjan Kannike. “Vacuum stability of a general scalar potential of a few fields”. In: *The European Physical Journal C* 76.6 (2016). ISSN: 1434-6052. doi: [10.1140/epjc/s10052-016-4160-3](https://doi.org/10.1140/epjc/s10052-016-4160-3). URL: <http://dx.doi.org/10.1140/epjc/s10052-016-4160-3>.

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- [4] Kristjan Kannike. “Vacuum stability conditions from copositivity criteria”. In: *The European Physical Journal C* 72.7 (2012). ISSN: 1434-6052. doi: [10.1140/epjc/s10052-012-2093-z](https://doi.org/10.1140/epjc/s10052-012-2093-z). URL: <http://dx.doi.org/10.1140/epjc/s10052-012-2093-z>.

Thanks.

