Two-component scalar dark matter in Z_{2n} scenarios

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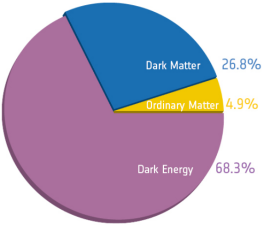
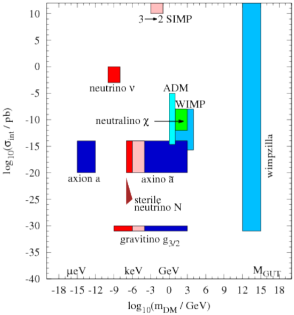
Evidence for dark matter is abundant and compelling

- Galactic rotation curves
- Bullet cluster
- Weak lensing
- Cluster and supernova data
- Big bang nucleosynthesis
- CMB anisotropies

Particle DM:

- ☐ Massive, non baryonic, elec. neutral.
- ☐ Non relativistic at decoupling.
- ☐ Stable or longlived
- ☐ $\Omega_{DM} \sim 1/4$.





It is usually assumed that the DM is entirely explained by one single candidate ($\tilde{\chi}_1^0$, N_S, a, S, etc).

Multicomponent DM

• It may be that the DM is actually composed of several species (as the visible sector): $\Omega_{DM} = \Omega_1 + \Omega_2 + ...$

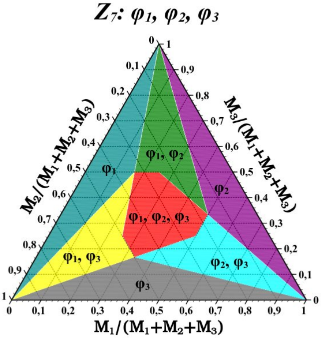
• These scenarios not only are perfectly consistent with observations but often lead to testable predictions in current and future DM exps.

What is the symmetry behind the stability of these distinct particles?

Z_N multicomponent scenarios

It seems that a single Z_N is the simplest way to simultaneously stabilize several DM particles. Batel 2010, Belanger et al 2014, Yaguna & OZ 2019.

- Models featuring scalar fields are particularly appealing.
- For k DM particles, they require k complex scalar fields that are SM singlets but have different charges under a Z_N ($N \geq 2k$).
- The Z_N could be a remnant of a spontaneously broken $U(1)$ gauge symmetry and thus be related to gauge extensions of the SM.

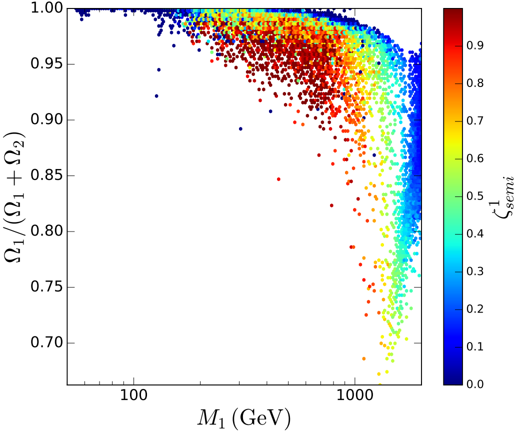


Yaguna & OZ 2019.

Models with two complex DM fields: Z_5 as a prototype

Belanger, Pukhov, Yaguna & OZ JHEP2020.

1. Models with sizeable trilinear couplings (semiannihilations) become viable over the entire range of DM masses.
2. The lighter DM particle accounts for most of Ω_{DM}.



Models with one complex ϕ_A and one real ϕ_B: Z_{2n}

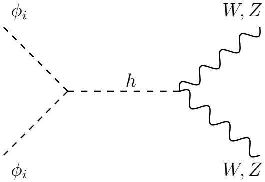
$\phi_{A,B}$ singlets under $\mathcal{G}_{SM}$ ($v_{A,B} = 0$); SM is singlet under Z_{2n}.

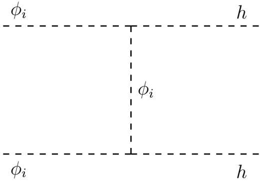
$$\phi_A \to \omega_{2n}^m, (m < n); \qquad \phi_B \to \omega_{2n}^n = -1; \qquad \omega_{2n} = \exp(i\pi/n).$$

$$\mathcal{V}_{Z_{2n}}(\phi_A, \phi_B) = \mathcal{V}_1 + \mathcal{V}_2.$$

$$\mathcal{V}_1 \equiv \mu_A^2|\phi_A|^2 + \lambda_{4A}|\phi_A|^4 + \frac{1}{2}\mu_B^2\phi_B^2 + \lambda_{4B}\phi_B^4 + \lambda_{4AB}|\phi_A|^2\phi_B^2 + \lambda_{SA}|H|^2|\phi_A|^2 + \frac{1}{2}\lambda_{SB}|H|^2\phi_B^2,$$

$\mathcal{V}_2$ accommodates the invariant terms associated to the specific Z_{2n} symmetry; it does not include any quadratic terms on ϕ_i.



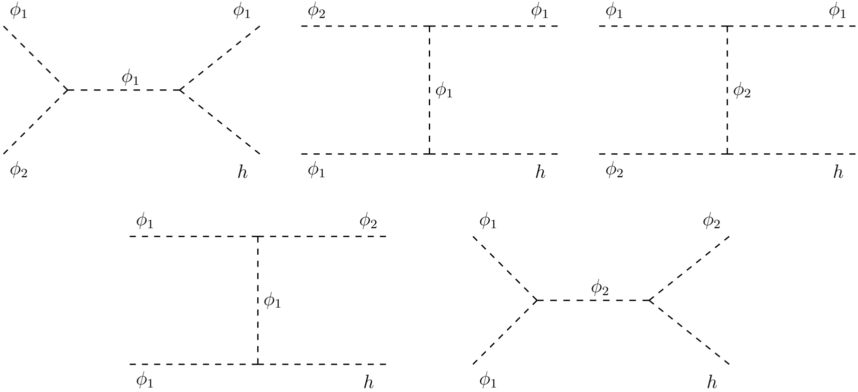


Z_4 model

$\phi_1 \sim \omega_4, \;\; \phi_2 \sim \omega_4^2.$

$$\mathcal{V}_2^{Z_4}(\phi_1, \phi_2) = \frac{1}{2}\left[\mu_{S1}\phi_1^2\phi_2 + \lambda_{51}\phi_1^4 + \text{h.c.}\right].$$

$M_{\phi_2} < 2M_{\phi_1}$ so that ϕ_2 remains stable.

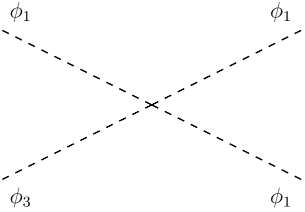


$Z_6(13)$ model

$\phi_1 \sim \omega_6, \;\; \phi_3 \sim \omega_6^3.$

$$\mathcal{V}_2^{Z_6}(\phi_1, \phi_3) = \frac{1}{3}\lambda'_{41}\phi_1^3\phi_3 + \text{h.c.}.$$

$M_{\phi_3} < 3M_{\phi_1}$ to render ϕ_3 stable (ϕ_1 is absolutely stable).

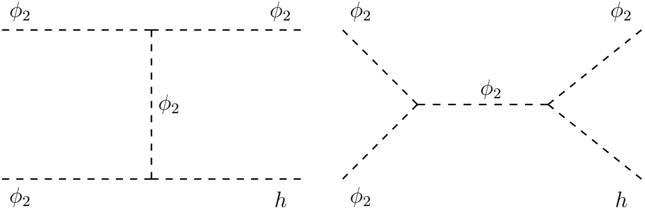


$Z_6(23)$ model

$\phi_2 \sim \omega_6^2, \ \ \phi_3 \sim \omega_6^3.$

$$\mathcal{V}_2^{Z_6}(\phi_2, \phi_3) = \frac{1}{3}\mu_{32}\phi_2^3 + \text{h.c.}.$$

ϕ_2 and ϕ_3 are both stable independently of their masses.



Viable parameter space

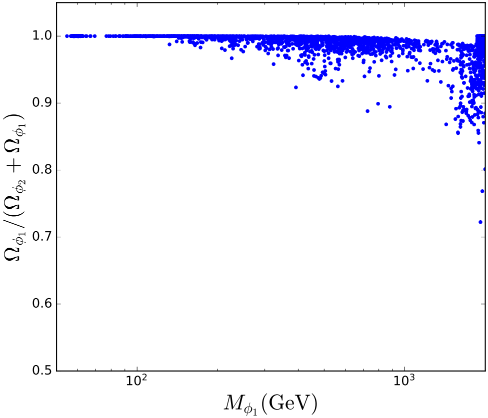
$$40\,\text{GeV} \leq M_{A,B} \leq 2\,\text{TeV},$$
$$10^{-4} \leq |\lambda_{Si}|, |\lambda_X| \leq 1,$$
$$100\,\text{GeV} \leq \mu_X \leq 10\,\text{TeV}.$$

$$\Omega_{\phi_A} + \Omega_{\phi_B} = \Omega_{\text{DM}}. \qquad \Omega_{\text{DM}} h^2 = 0.1198 \pm 0.0012.$$

Excluded mass range in the singlet scalar Z_2 model:

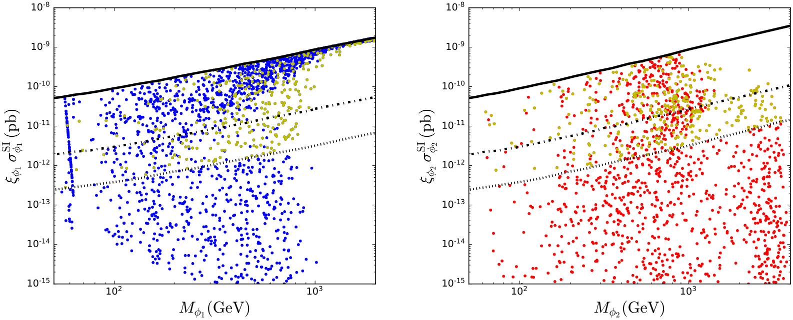
- Real case: $M_W \lesssim M_S \lesssim 950$ GeV.
- Complex case: $M_W \lesssim M_S \lesssim 1850$ GeV.

Z_4 model: $M_{\phi_1} < M_{\phi_2}$



• ϕ_1 always gives the dominant contribution accounting for more than 90% of Ω_{DM}.

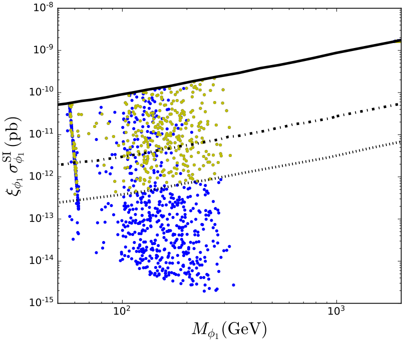
Z_4 model: $M_{\phi_1} < M_{\phi_2}$

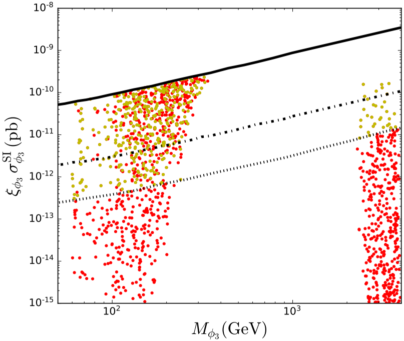


- Either DM particle may be observed in future DD experiments.
- The small Ω_2 can be compensated by a large λ_{S2}.
- Yellow points indicate that both DM particles lay within DARWIN.

$Z_6(13)$ model: $M_{\phi_1} < M_{\phi_3}$

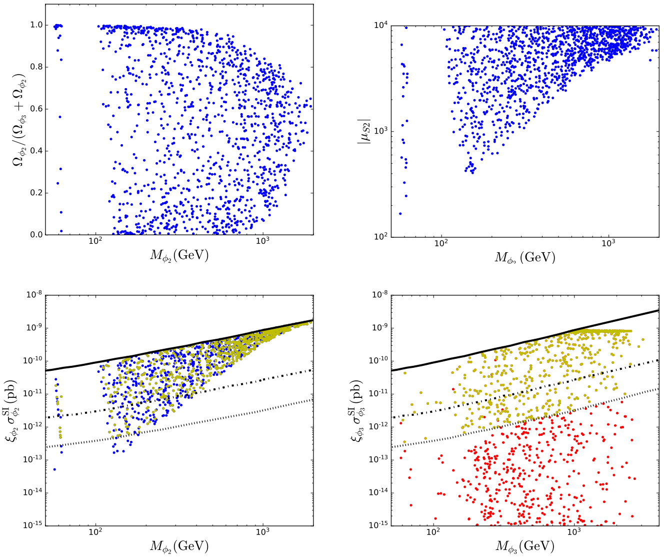
For $M_W \lesssim M_{\phi_1} \lesssim 1.8$ TeV ϕ_1 always gives the dominant contribution accounting for more than 98% of Ω_{DM}.





- $M_{\phi_3} < M_{\phi_1}$: no viable points between $M_W \lesssim M_{\phi_3} \lesssim 1.8$ TeV.

$Z_6(23)$ model: $M_{\phi_2} < M_{\phi_3}$



Summary

1. In the Z_4 and $Z_6(23)$ models it is possible to satisfy $\Omega \approx 0.25$ and current DD limits over the entire range of DM masses considered.

2. Remarkably in the $Z_6(23)$ model Ω_{DM} can be dominated by the heavier dark matter particle.

3. DD experiments offer great prospects to test these models, including the possibility of observing signals from *both* dark matter particles.

Besides being simple and well-motivated, Z_N models are consistent and testable frameworks for two-component dark matter.