Axion/axino dark matter in Peccei-Quinn extended minimal supergravity

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Summary

In the framework of the simplest supergravity model, a wide collection of present experimental data prefers axion/axino dark matter over the lightest neutralino.

Outline

- Minimal supergravity & Peccei-Quinn mSuGra
- Bayesian inference: PQmSuGra vs. mSuGra
- Results: PQmSuGra is preferred by data

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Pop quiz

After LHC7/8 SUSY is

(a) alive, well and kicking

(b) not so attractive

(c) dead, cold

(d) none of the above

SUSY after LHC7

Can we ***quantify*** the status of SUSY dark matter after LHC7/8?

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Good news: Yes!

Bad news: presently only…

- for a specific model
- for a part of its parameter space
- relative to another specific model

SUSY after LHC7

Can we ***quantify*** the status of SUSY dark matter after LHC7/8?

Good news: Yes!

In this talk

- specific model : PQmSuGra
- part of para space : $\{M_0, M_{1/2}\} = \{2,2\}$ TeV
- the other model : mSuGra

Minimal supergravity

- MSSM: supersymmetric SM with
  SM fields elevated to superfields
- mSuGra: MSSM + SUSY breaking via (super)gravity
- Universal boundary conditions at GUT scale:
  - M_0 common scalar mass
  - $M_{1/2}$ common gaugino mass
  - A_0 common tri-linear coupling
  - $\tan\beta$ ratio of the two Higgs doublet vev.s
- Only 4 parameters → high predictivity

Peccei-Quinn minimal supergravity

- Supersymmetric PQ models: new chiral superfield

$$\hat{\Phi}_a = \frac{s + ia}{\sqrt{2}} + \theta\tilde{a} + \theta\bar{\theta}F_a$$

- The axion couplings are standard
- The axion mass is related to the PQ breaking scale

$$m_a \approx (5 \times 10^6 \text{ GeV}/\Lambda_{PQ}) \text{ eV}$$

- nEDM and mSuGra place limits on Λ_{PQ}

$$1 \times 10^9 \text{ GeV} < \Lambda_{PQ} < 5 \times 10^{11} \text{ GeV}$$

- PQmSuGra: additional parameters Λ_{PQ} and λ_{HuHd}

Bayesian inference

- weather forecast:

  P(rain) = 0.5 — prior

- a look out of the window:

  P(blue sky) = 1 — evidence

- observational input:

  P(blue sky|rain) = 0 — likelihood

- probability inversion:

$$P(\text{rain}|\text{blue sky}) = P(\text{blue sky}|\text{rain})\, P(\text{rain})/P(\text{blue sky})$$

$$= 0 \times 0.5/1 = 0$$

Bayesian inference

Can we perform ***probability inversion for neutralino or axion DM***?

P(rain|blue sky) = P(blue sky|rain) P(rain)/P(blue sky)

$P(\chi\ DM|data) = P(data|\chi\ DM)\ P(\chi\ DM)/P(data)$

P(a DM|data) = P(data|a DM) P(a DM)/P(data)

P(a DM) = ???, $P(\chi\ DM)$ = ???, P(data) = ???

Looks like we're stuck!

Model comparison

To get rid of P(data) we can form the ***odds***

$$P(a\ DM|data) = P(data|a\ DM)\ P(a\ DM)/P(data)$$

$$P(\chi\ DM|data) = P(data|\chi\ DM)\ P(\chi\ DM)/P(data)$$

Model comparison

To get rid of P(data) we can form the ***odds***

$$\frac{P(a\ DM|data)}{P(\chi\ DM|data)} = \frac{P(data|a\ DM)\ P(a\ DM)/P(data)}{P(data|\chi\ DM)\ P(\chi\ DM)/P(data)}$$

P(data) cancels out

Model comparison

To get rid of P(data) we can form the ***odds***

$$\frac{P(\text{a DM}|\text{data})}{P(\chi\text{ DM}|\text{data})} = \frac{P(\text{data}|\text{a DM})\, P(\text{a DM}) / \cancel{P(\text{data})}}{P(\text{data}|\chi\text{ DM})\, P(\chi\text{ DM}) / \cancel{P(\text{data})}}$$

The odds express how much the data favor axion compared to neutralino dark matter (within the context of mSuGra)

Model comparison

Structure of the odds

$$\frac{P(a\ DM|data)}{P(\chi\ DM|data)} = \frac{P(data|a\ DM)\ P(a\ DM)}{P(data|\chi\ DM)\ P(\chi\ DM)}$$

Posterior odds = Bayes factor × Prior odds

- Bayes factor ***updates*** the odds after data is learned
- Bayes factors ***factorize*** for independent data:

B(data) = B(precision) × B(LHC) × B(PLANCK)

Model comparison

Structure of the odds

$$\frac{P(a\ DM|data)}{P(\chi\ DM|data)} = \frac{P(data|a\ DM)}{P(data|\chi\ DM)} \times \frac{P(a\ DM)}{P(\chi\ DM)}$$

Posterior odds = Bayes factor × Prior odds

- Bayes factor ***updates*** the odds after data is learned
- Bayes factors ***factorize*** for independent data:

B(data) = B(precision) × B(LHC) × B(PLANCK)

Experimental data

We calculate P(data|DM) using

$$\mathcal{L}_i = \frac{1}{\sqrt{2\pi}\sigma_i} e^{-\chi_i^2/2} \qquad \chi_i^2 = \frac{\left(\mathcal{O}_i^{th.} - \mathcal{O}_i^{exp.}\right)^2}{\sigma_i^2}$$

which we integrate over the theory para-space, after we input the following data:

- LHC Higgs data: m_H, $R_{pp\to\gamma\gamma}$, $R_{pp\to 4l}$, $R_{pp\to 2l2\nu}$
- LHC sparticle limits: $m_{\chi+}$, …
- precision observables: g_μ-2, Br($b\to s\gamma$), $\delta\rho$, …
- PLANCK: dark matter abundance

Results

a DM : χ DM Bayes factors for various experiments

Experimental data	Bayes factor *a* DM : χ DM	Strength of preference
precision obs.	1.2 : 1	very weak
LHC Higgs	4.6 : 1	weak
PLANCK	9.0 : 1	moderate
Combined	50 : 1	strong

I haven't mentioned it…

… but our paper also discusses:

- mixed neutralino/axion/axino dark matter
- PQ contributions to Higgs mass & decay
- parameter priors
- LHC Higgs & sparticle limits
- effect of rare decays
- effect of g-2
- and more…

Conclusion

In the framework of the simplest supergravity model, a wide collection of present experimental data prefers axion/axino dark matter over the lightest neutralino.