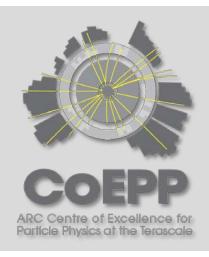
# Axion/axino dark matter in Peccei-Quinn extended minimal supergravity

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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

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

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Good news: Yes!

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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

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 :  $\{M_0, M_{1/2}\} = \{2,2\} \text{ TeV}$ 

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<sub>o</sub> common scalar mass
  - $M_{1/2}$  common gaugino mass
  - A<sub>0</sub> common tri-linear coupling tanβ 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  $m_a \approx (5 \times 10^6 \text{ GeV/}\Lambda_{PO}) \text{ eV}$
- nEDM and mSuGra place limits on  $\Lambda_{PQ}$   $1 \times 10^9 \, \text{GeV} < \Lambda_{PQ} < 5 \times 10^{11} \, \text{GeV}$
- PQmSuGra: additional parameters  $\Lambda_{PQ}$  and  $\lambda_{HuHd}$

# Bayesian inference

• weather forecast:

$$P(rain) = 0.5$$

prior

a look out of the window:

$$P(blue sky) = 1$$

evidence

observational input:

likelihood

probability inversion:

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

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

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

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

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

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

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

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

#### Structure of the odds

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

Posterior odds = Bayes factor × Prior odds

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

$$B(data) = B(precision) \times B(LHC) \times B(PLANCK)$$

#### Structure of the odds

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# Experimental data

We calculate P(data | DM) using

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

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:  $m_{y+}$ , ...
- precision observables:  $g_{\mu}$ -2, Br(b $\rightarrow$ 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.