Gravity safe, electroweak natural axionic solution to
strong CP and SUSY $\mu$ problems in the LHC era with
determination of the PQ scale

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Abstract
Particle physics models with Peccei-Quinn (PQ) symmetry breaking as a consequence of
supersymmetry (SUSY) breaking are attractive in that they solve the strong CP problem
with a SUSY DFSZ-like axion, link the SUSY breaking and PQ breaking intermediate mass
scales and can resolve the SUSY $\mu$ problem with a naturalness-required weak scale $\mu$ term
whilst soft SUSY breaking terms inhabit the multi-TeV regime as required by LHC sparsity
particle mass limits and the Higgs mass measurement. In spite of so many advantages these
models have a major disadvantage in that global symmetries are incompatible with gravity
and hence suffer a generic gravity spoliation problem. We present two models based on the
discrete R-symmetry $\mathbb{Z}_{24}^R$-which may emerge from compactification of 10-d Lorentzian space-
time in string theory-where the $\mu$ term and dangerous proton decay and R-parity violating
operators are either suppressed or forbidden while a gravity-safe PQ symmetry emerges as
an accidental approximate global symmetry leading to a solution to the strong CP problem
and a weak-scale/natural value for the $\mu$ term. Though there are many other solutions to
the $\mu$ problem, the models based on discrete R-symmetry $\mathbb{Z}_{24}^R$ seem highly motivated. A
general consideration of string theory landscape imply a mild statistical draw towards large
soft SUSY breaking terms. We can extend this reasoning to the models considered here in
which PQ symmetry is broken by a large negative quartic soft term. The pull towards large
soft terms also pulls the PQ scale as large as possible. Unless this is tempered by rather
severe (unknown) cosmological or anthropic bounds on the density of dark matter, then we
would expect a far greater abundance of dark matter than is observed. This conclusion
cannot be negated by adopting a tiny axion misalignment angle $\theta_i$ because WIMPs are also
overproduced at large $f_a$. Hence, we conclude that setting the PQ scale via anthropics is
highly unlikely. Instead, requiring soft SUSY breaking terms of order the gravity-mediation
scale $m_{3/2} \sim 10-100$ TeV places the mixed axion-neutralino dark matter abundance into the
intermediate scale sweet zone where $f_a \sim 10^{11-10^{12}}$ GeV. We compare our analysis to the
more general case of a generic SUSY DFSZ axion model with uniform selection on $\theta_i$ but
leading to the measured dark matter abundance: this approach leads to a preference for $f_a
\sim 10^{12}$ GeV.