Mixed axion-neutralino cold dark matter

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Some necessary conditions for allowing the PQ scale as high as $M_{GUT}$ in SUSY models with an axino or neutralino LSP (with A. Lessa), JHEP1106 (2011) 027.


• After 35 years, PQWW solution to strong CP problem still elegant, compelling

• Consequence: nearly invisible \(\sim\) micro-eV mass axion

• Any theory of dark matter which doesn’t account for axion is likely misguided....
• New scalar Higgs-like boson discovered recently at LHC with $m=125$ GeV

• Hard to comprehend existence of fundamental scalar without SUSY: cure quadratic divergences

• gauge coupling unification

• $m(\text{top})$ seeds breakdown of EW symmetry

• $m(h)$ lies within narrow band predicted by SUSY

• seem to need PQ+SUSY: PQMSSM
• Introduce axion superfield: contains spin-1/2 axino and spin-0 saxion

• $m(\text{axino}) \sim m(\text{saxion}) \sim m_{3/2}$ in gravity mediation: expect around TeV scale

• then lightest SUSY particle likely lightest neutralino (WIMP)

• R-parity conserved (stable proton)

• expect mixed axion-neutralino CDM: two DM particles!
• dark matter production much more intricate than in axion-only or neutralino-only cosmology

• axinos produced thermally in early universe; undergo late decays; decay (possibly via cascade) to LSP, thus augmenting relic abundance

• production rate/decay modes model-dependent: SUSY KSVZ or SUSY DFSZ
• saxions can be produced thermally at low $f_a$ and/or via coherent oscillations at high $f_a$

• saxion-$\rightarrow$ SUSY: augment LSPs

• saxion-$\rightarrow$aa (model dependent): dark radiation

• saxion-$\rightarrow$ SM particles: entropy dilution of all relics present at time of decay

• details depend on KSVZ/DFSZ as well as SUSY spectra
• neutralinos: produced thermally as usual

• produced via axino/saxion decays

• if axino or saxion temporarily dominates universe, then may lead to neutralino injection/re-annihilation at lower temperatures: augment

• neutralinos may be diluted by entropy dumping
• axions produced as usual via coherent oscillations

• also produced thermally esp. at low $f_a$

• also produced via $s \rightarrow aa$: dark rad.

• axion abundance may be diluted by entropy dumping as well
coupled Boltzmann calculation of axion/neutralino abundance in KSVZ model with $\xi=0$
(no s-$\rightarrow$aa decays)

track gravitino abundance as well: BBN constraints
neutralino abundance in KSVZ $\chi_i=0$
Standard Overabundance case (SOA): all excluded
neutralino abundance in KSVZ \( \xi = 0 \) SUA case:

disjoint range of \( f_a \) allowed;

very large \( f_a \) may be allowed by entropy dump

\[ \text{Oh}^2(\text{axion}) = 0.12 - \text{Oh}^2(z1) \]

can always adjust \theta_i so this works
abundances in KSVZ $\xi=1$ case with SUA: radiatively-driven natural SUSY with higgsino-like WIMP: barely allowed by dark radiation
neutralino abundance in KSVZ $\chi=1$ SUA case: RNS model

low and high $f_a$ allowed
• present work: SUSY DFSZ model

• compelling in that provides solution to SUSY mu problem: PQ scale related to SUSY breaking scale~$10^{12}$ GeV (Kim-Nilles)

• fits well with RNS model: natural SUSY needs light higgsinos (mu)

• mu term forbidden by PQ symmetry:

• generated by SUSY breaking effects so $\mu \sim m_{3/2}$
• direct coupling of axino-higgs-higgsino

• direct coupling saxion-higgs-higgs

• for given $f_a$, much quicker decay: usually decay before neutralino freezeout unless $f_a$ very large

• then expect standard neutralino abundance

• for light higgsino case: $\chi_1$ makes 5-10% CDM

• axion makes 90-95% of CDM
DFSZ $\xi=0$ case: axions dominate until at high $f_a$ axino decay increases
RNS model with DFSZ $\xi=1$; also axion domination out to high $f_a$
Lessons:

- mixed axion-neutralino dark matter: both can be present: PQ+SUSY= <3 (heart)
- relative abundances model dependent
- favors SUSY with underabundance but overabundance can work in cases of entropy dump which avoid BBN
- RNS favors SUSY DFSZ: expect axion domination over most lower $f_a$ range
- may detect both WIMP and axion!