# Mixed axion-neutralino cold dark matter

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Mixed axion/neutralino cold dark matter in supersymmetric models (with A. Lessa, S. Rajagopalan and W. Sreethawong), JCAP**1106** (2011) 031.

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), JHEP**1106** (2011) 027.

Coupled Boltzmann calculation of mixed axion/neutralino cold dark matter production in the early universe (with A. Lessa and W. Sreethawong), JCAP**1201** (2012) 036.

Dark Radiation Constraints on Mixed Axion/Neutralino Dark Matter (with K. J. Bae and A. Lessa) JCAP**1304** (2013) 041.

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

- Consequence: nearly invisible ~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(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(axino)~m(saxion)~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-> SUSY: augment LSPs

- saxion->aa (model dependent): dark radiation

- saxion-> SM particles: entropy dilution of all relics present at time of decay

- details depend on KSVZ/DFSZ as well as SUSY spectra

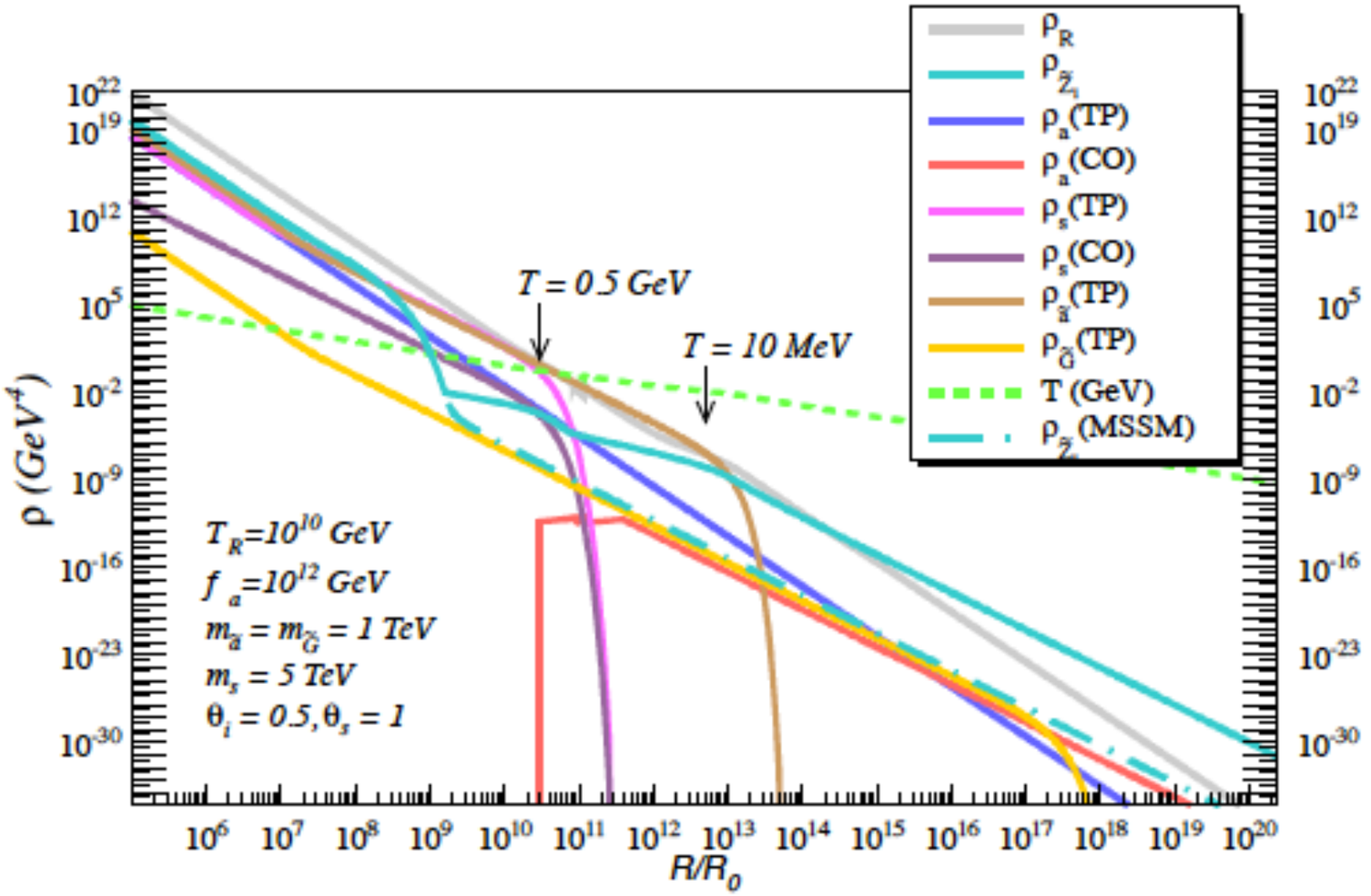
- neutralinos: produced thermally as usual
- produced via axino/saxion decays
- if axino or saxion temporarily dominates universe, then may lead to neutralino injection/re-annihilation at lower temperatures: augment
- neutralinos may be diluted by entropy dumping

- axions produced as usual via coherent oscillations

- also produced thermally esp. at low f_a

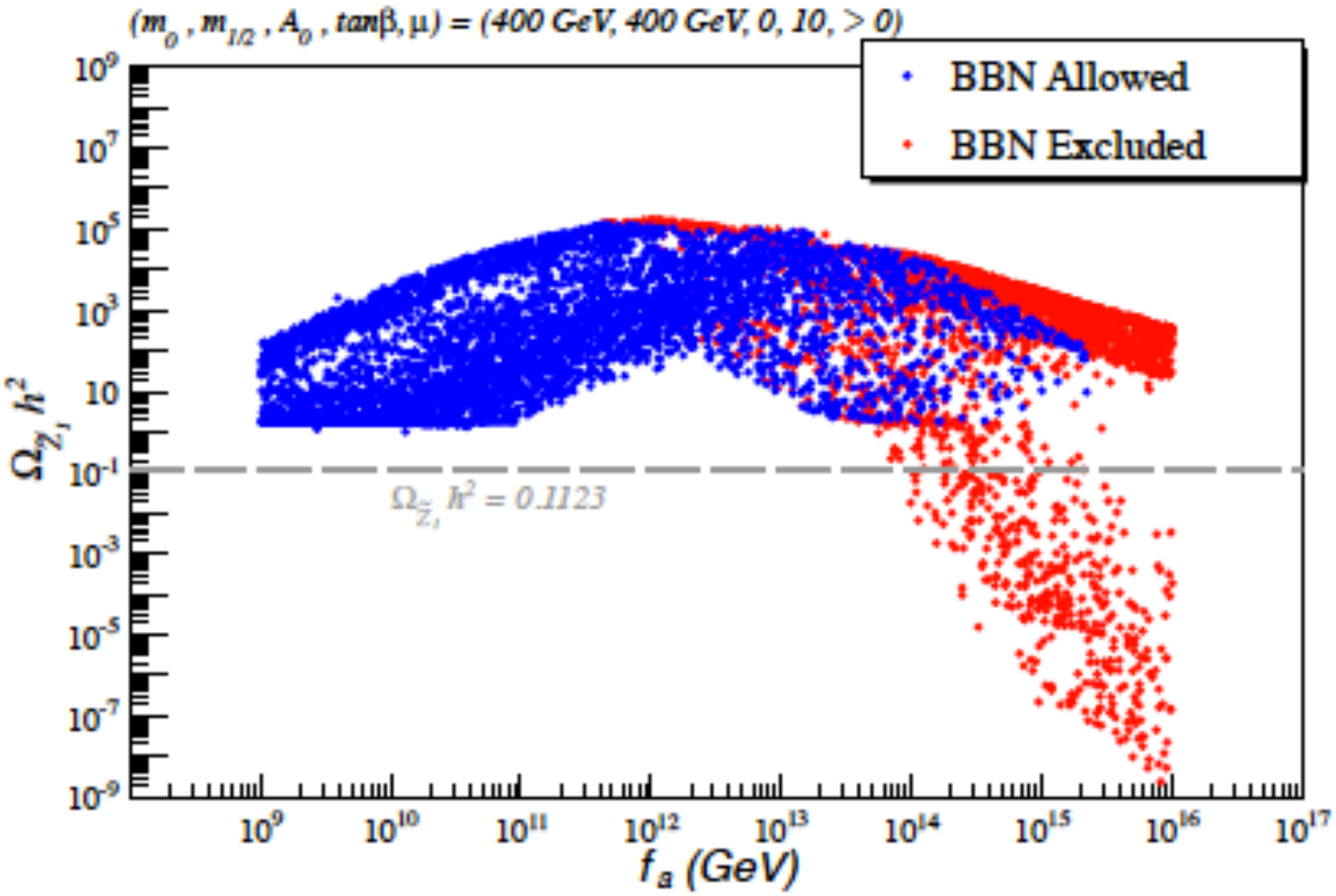
- also produced via s-> aa: dark rad.

- axion abundance may be diluted by entropy dumping as well



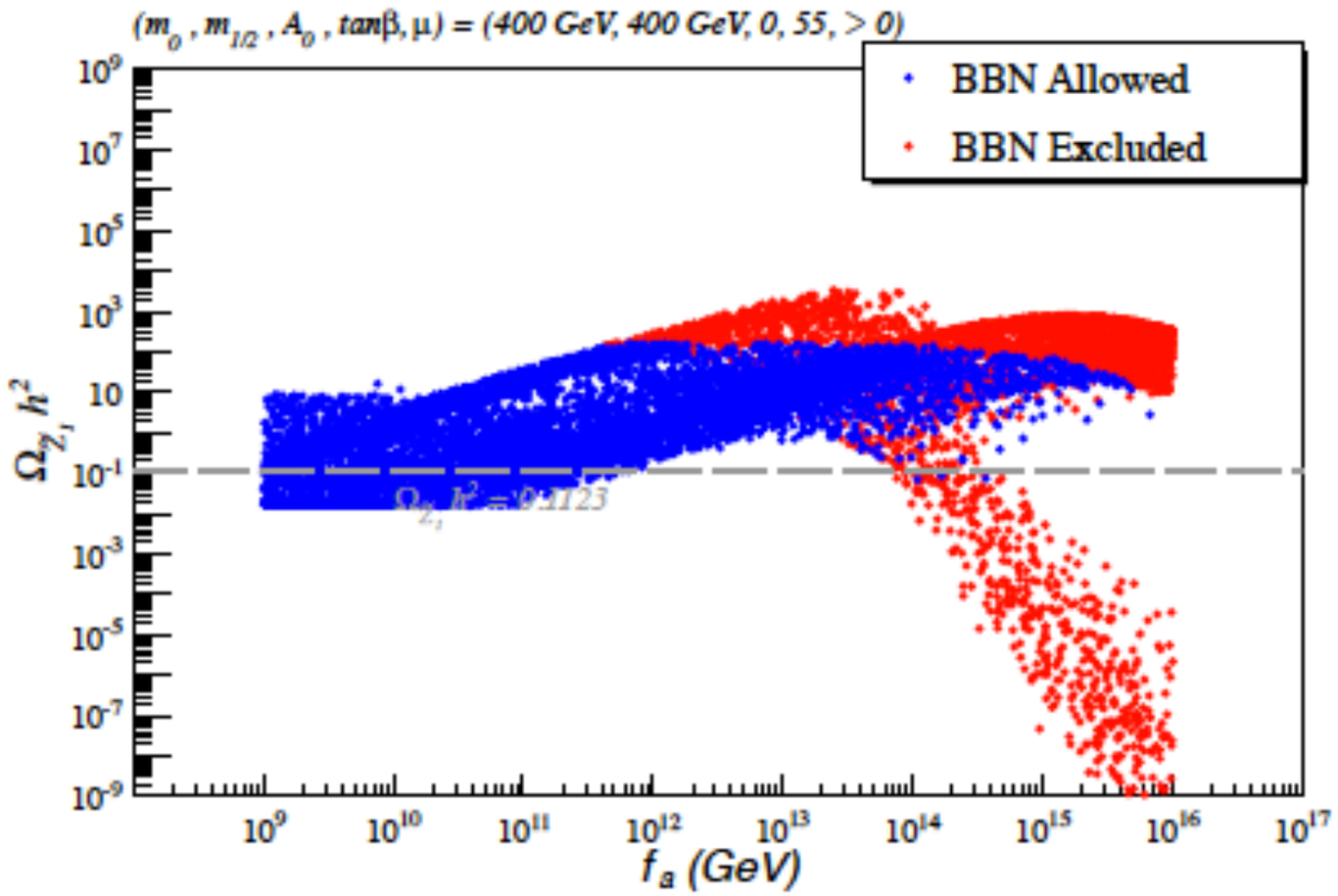

coupled Boltzmann calculation of axion/neutralino abundance in KSVZ model with xi=0
(no s->aa decays)

track gravitino abundance as well: BBN constraints



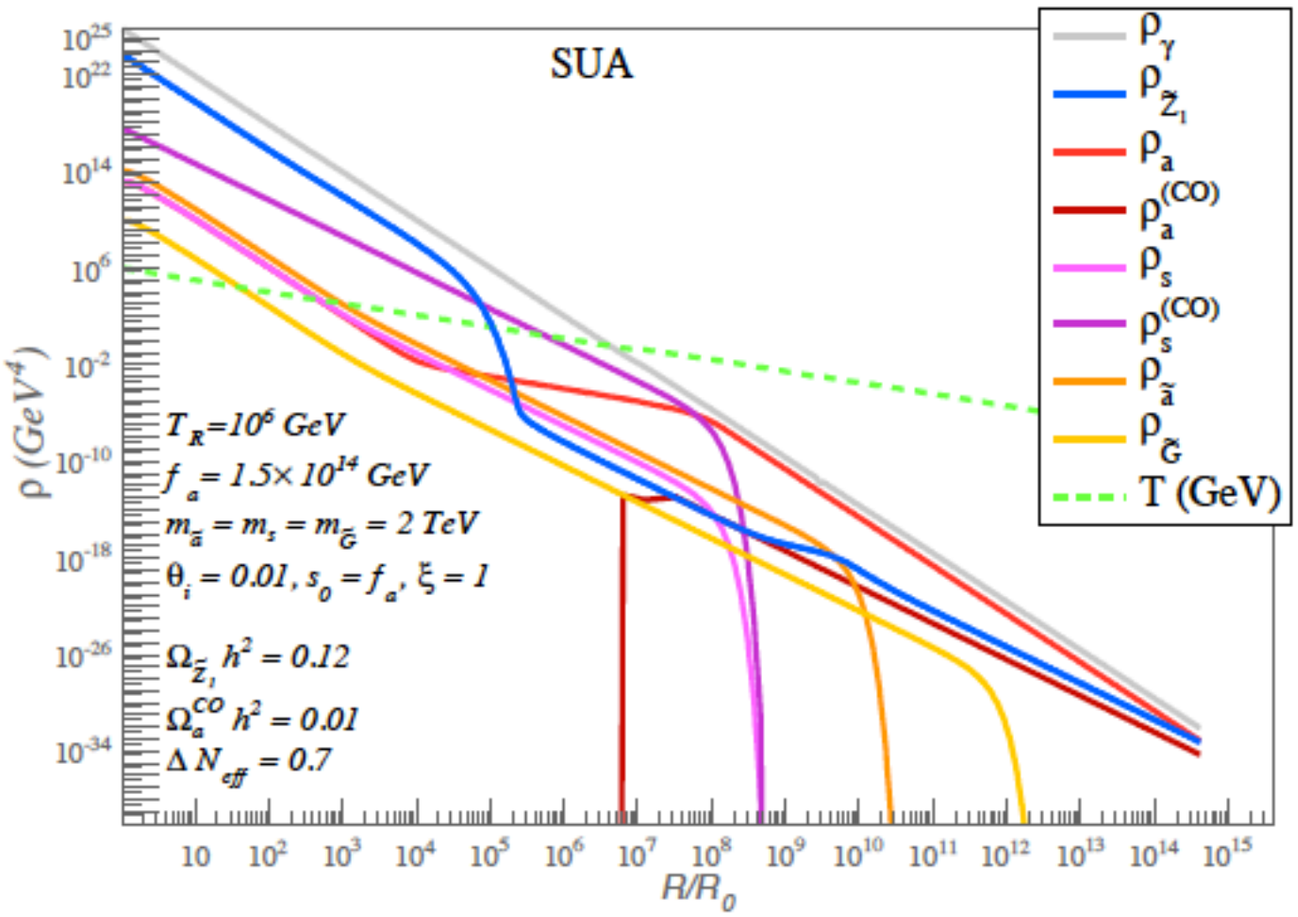

neutralino abundance in KSVZ xi=0

Standard Overabundance case (SOA): all excluded

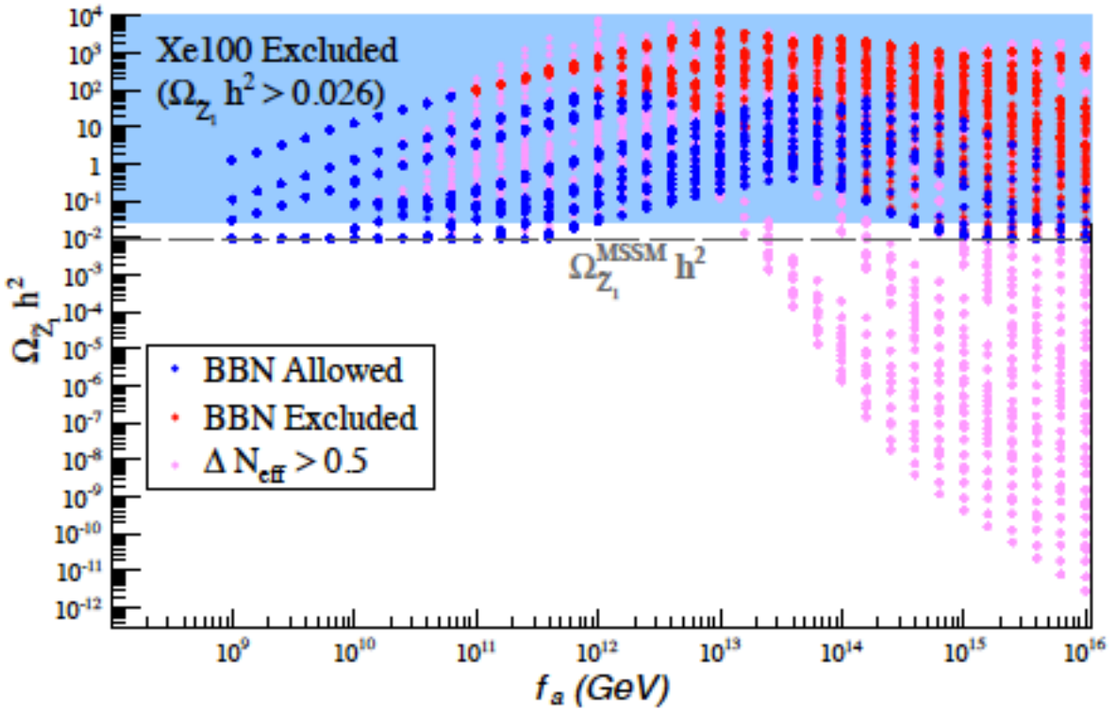



neutralino abundance in KSVZ xi=0 SUA case:
disjoint range of f_a allowed;
very large f_a may be allowed by entropy dump

Oh2(axion)=.12-Oh2(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

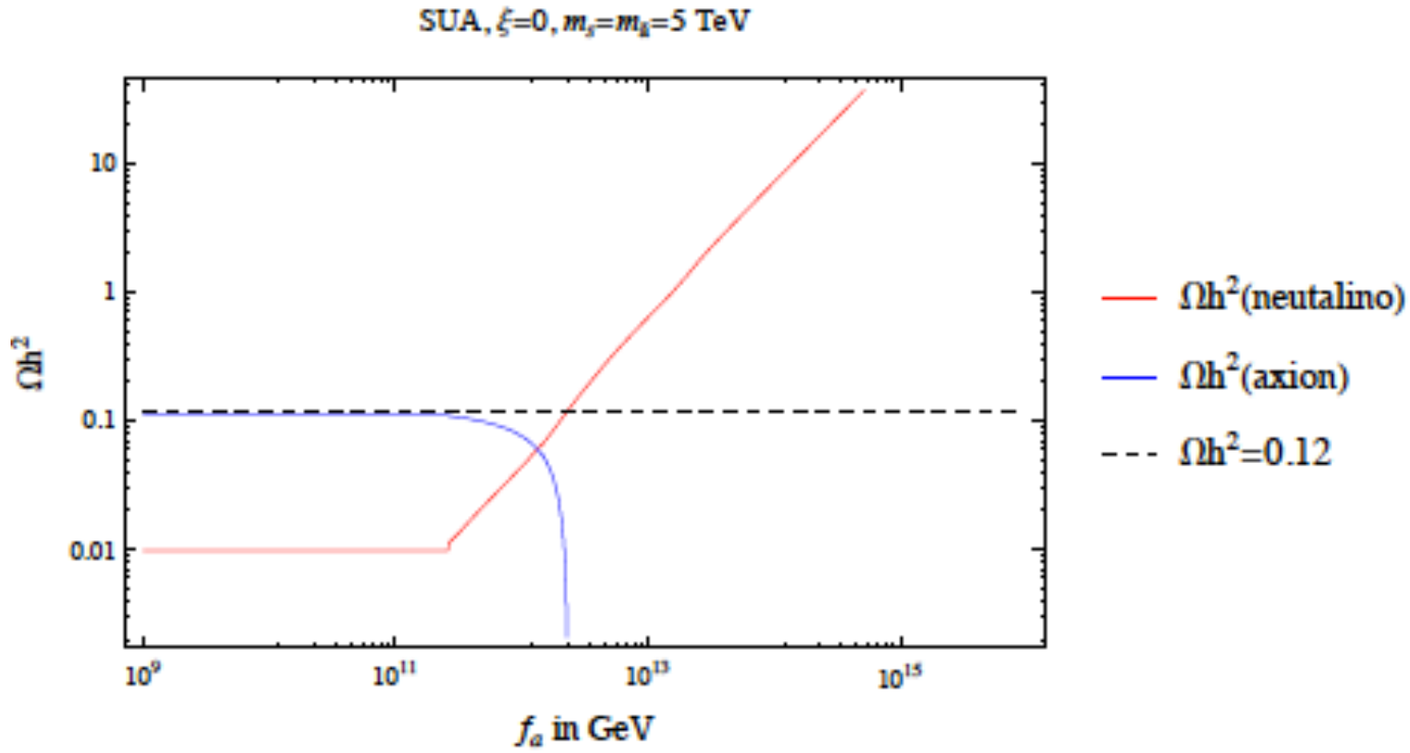


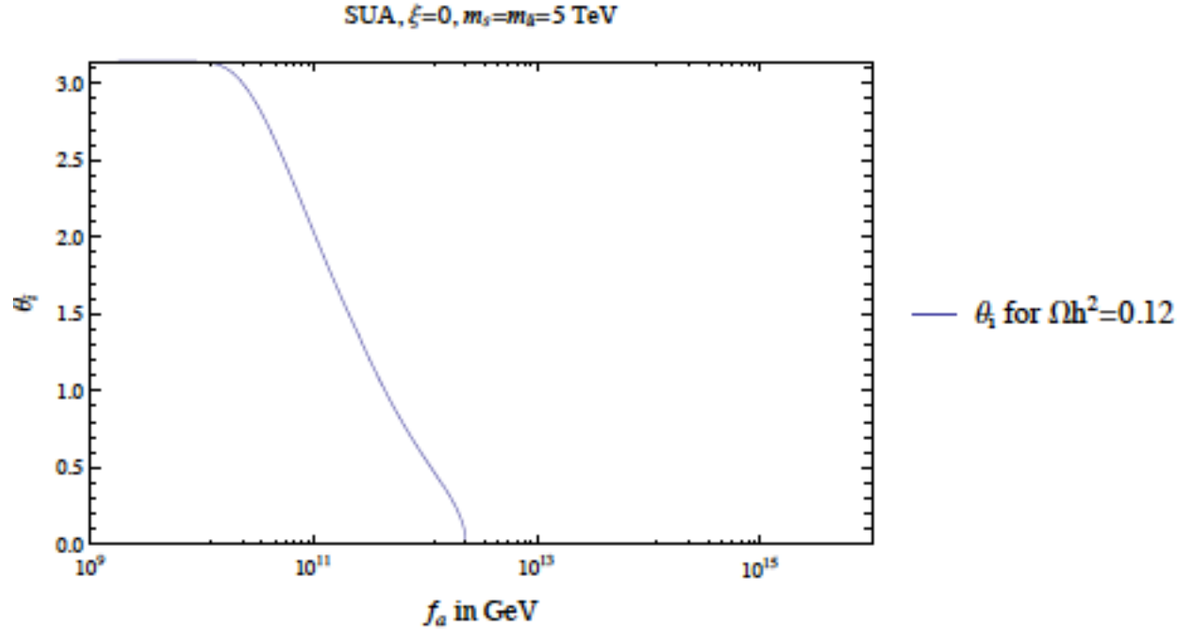

# neutralino abundance in KSVZ xi=1 SUA case: RNS model

low and high f_a allowed

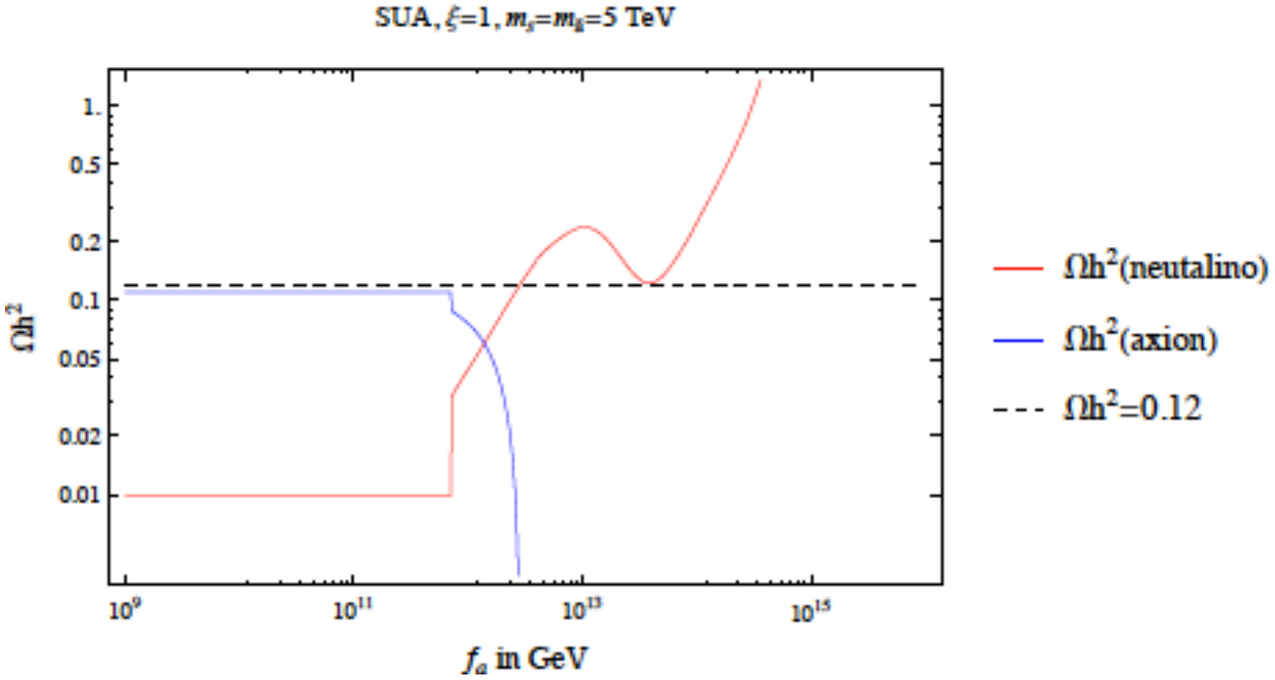
- present work: SUSY DFSZ model
- compelling in that provides solution to SUSY mu problem: PQ scale related to SUSY breaking scale~10^12 GeV (Kim-Nilles)
- fits well with RNS model: natural SUSY needs light higgsinos (mu)
- mu term forbidden by PQ symmetry:
- generated by SUSY breaking effects so mu~m_3/2

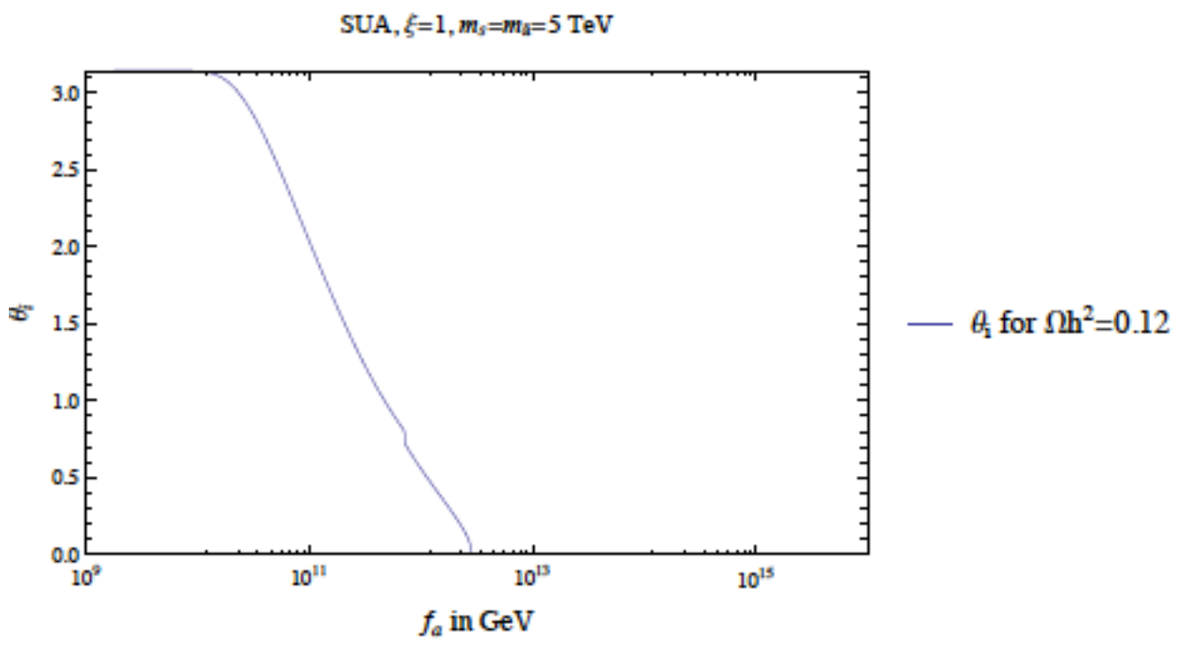
- direct coupling of axino-higgs-higgsino
- direct coupling saxion-higgs-higgs
- for given f_a, much quicker decay: usually decay before neutralino freezeout unless f_a very large
- then expect standard neutralino abundance
- for light higgsino case: z1 makes 5-10% CDM
- axion makes 90-95% of CDM




# 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!