$\not\!\!E_T$ signatures and dark matter connection

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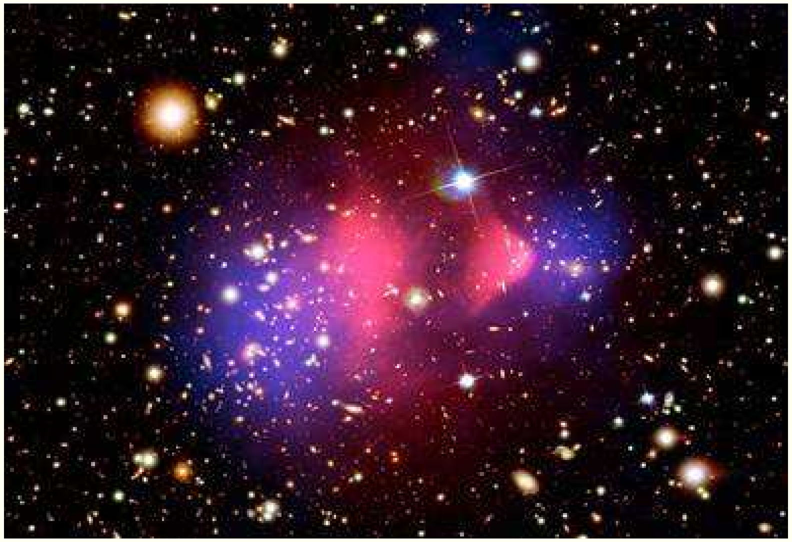
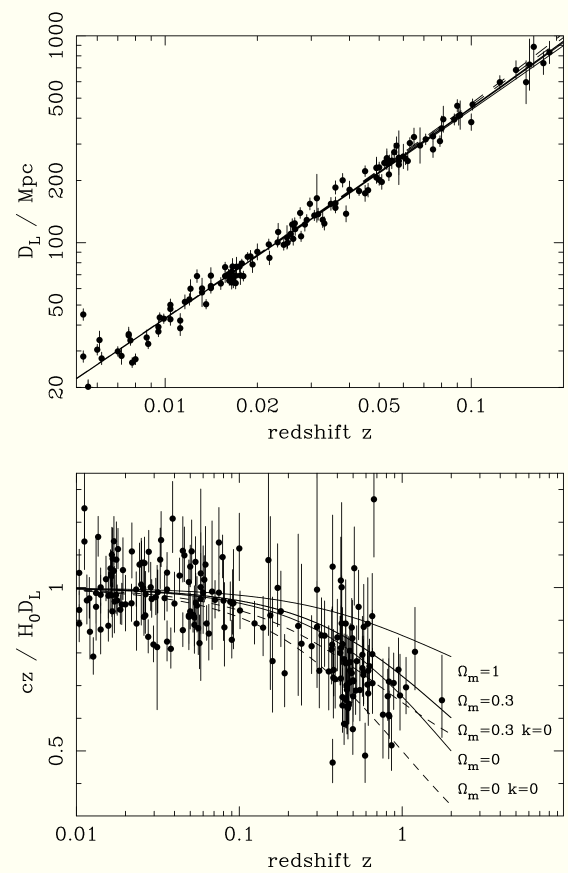
Florida State/ Oklahoma

- ⋆ Evidence for CDM
- ⋆ Candidates for CDM
- ⋆ Neutralino CDM
  - • Relic density
  - • Direct and indirect detection of DM
- ⋆ NUSUGRA models
- ⋆ The gravitino problem
- ⋆ Gravitino CDM
- ⋆ Axino CDM



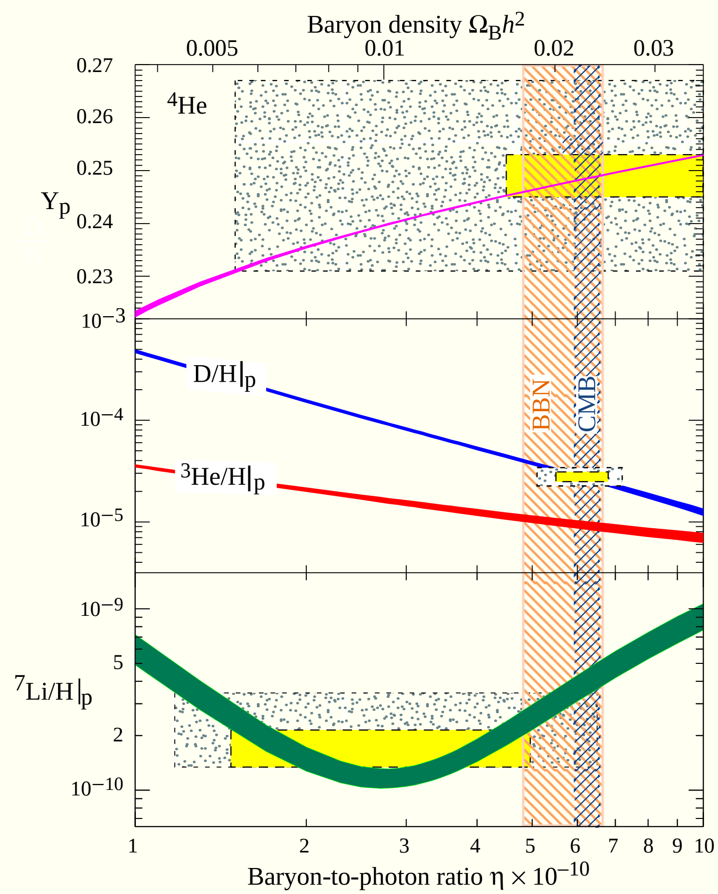
Pillars of Big Bang cosmology: Hubble expansion

- ⋆ Theory: FRW universe
- ⋆ Hubble expansion
  - HST key project
  - type Ia supernovae probe
- ⋆ $H_0 d_L = z + \frac{1}{2}(1-q_0)z^2 + \cdots$
- ⋆ $H_0 = 72$ km/sec/Mpc$\pm 10\%$
- ⋆ evidence for $\Lambda > 0$!
- ⋆ age of universe: ~ 13.7 Gyrs



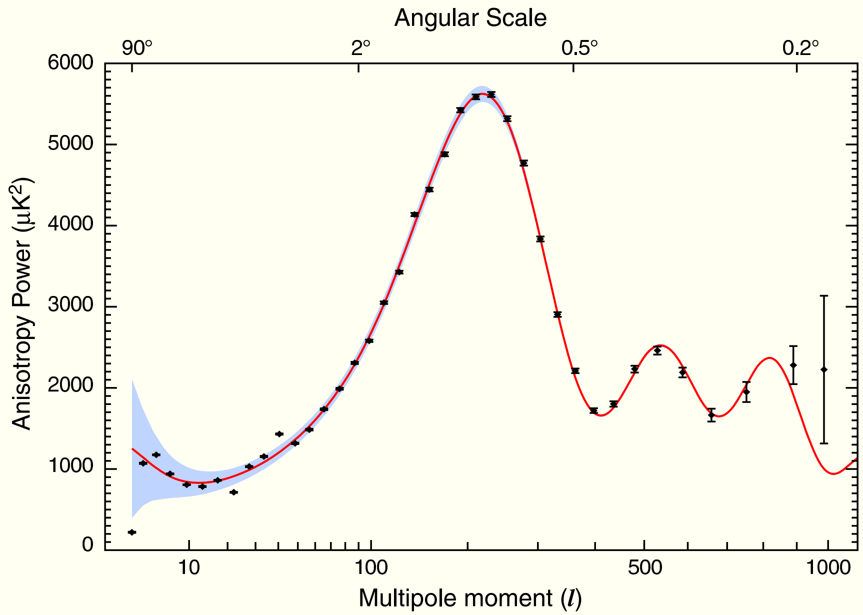
Big Bang nucleosynthesis (BBN)

- ⋆ Thermal history of universe:
- ⋆ Can compute light element abundances: ^4He, D, ^3He, ^7Li
  - match to data:
  - $\eta_B \equiv \frac{n_B}{n_\gamma} \simeq 6 \times 10^{-10}$
  - η_B from BBN consistent with CMB results



Cosmic microwave background (CMB)

- ⋆ COBE/WMAP/WMAP3, $\cdots$
- ⋆ anisotropies $\sim 10^{-5}$
- ⋆ can extract numerous cosm. param's from power spectrum
  - flat $(k = 0)$ universe: $\rho = \rho_c$ as in inflation models
  - contents of universe
    - $\Omega_\Lambda \sim 0.7$
    - $\Omega_{baryons} \sim 0.04$
    - $\Omega_{CDM} \sim 0.25$
    - $\Omega_\nu \sim tiny$



Baryogenesis: explaining η_B

★ SM electroweak baryogenesis: only if $m_{H_{SM}} \lesssim 50$ GeV

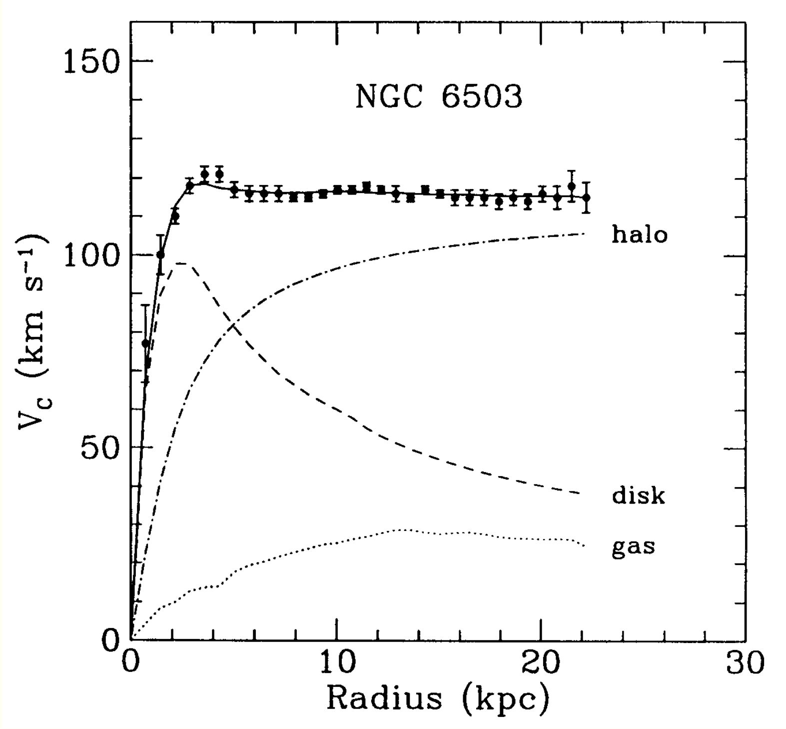
★ MSSM: many more possibilities

- EW baryogenesis: need $m_{\tilde{t}_1} < m_t$; $m_h \lesssim 120$ GeV (Carena et al.)
- Affleck-Dine: decay of flat directions: baryo- or leptogenesis
- thermal leptogenesis: (Fukugita, Yanagida; Buchmueller, Plumacher, ...)
  - ∗ natural link to physics of massive neutrinos
  - ∗ due to decay of heavy N states: $N \to H\ell \neq N \to H^\dagger\bar{\ell}$
  - ∗ lepton asymmetry converted to baryon asymmetry via sphaleron effects
  - ∗ get $\eta_B \sim 6 \times 10^{-10}$ if $M_N \sim 10^{10}$ GeV
  - ∗ need reheat temp $T_R \sim 10^{10}$ GeV
  - ∗ overproduction of gravitinos if $.1 \lesssim m_{\tilde{G}} \lesssim 10$ TeV
- leptogenesis via inflaton decay

★ can be constrained by ν/sparticle measurements

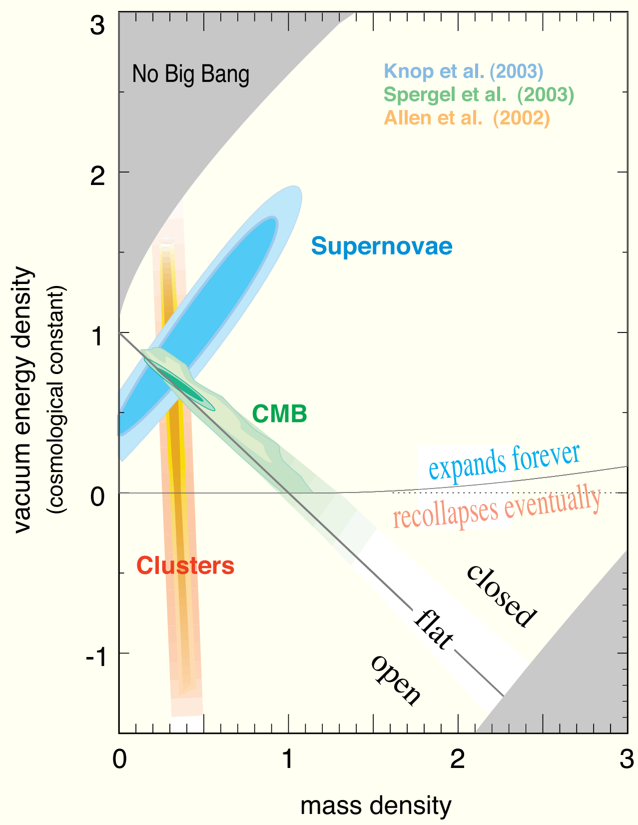
Dark Matter in the universe

- ⋆ Binding of clusters
- ⋆ Galactic rotation curves
- ⋆ Gravitational lensing
- ⋆ Hot gas in clusters
- ⋆ CMB fluctuations
- ⋆ Large scale structure
- ⋆ flatness/BBN



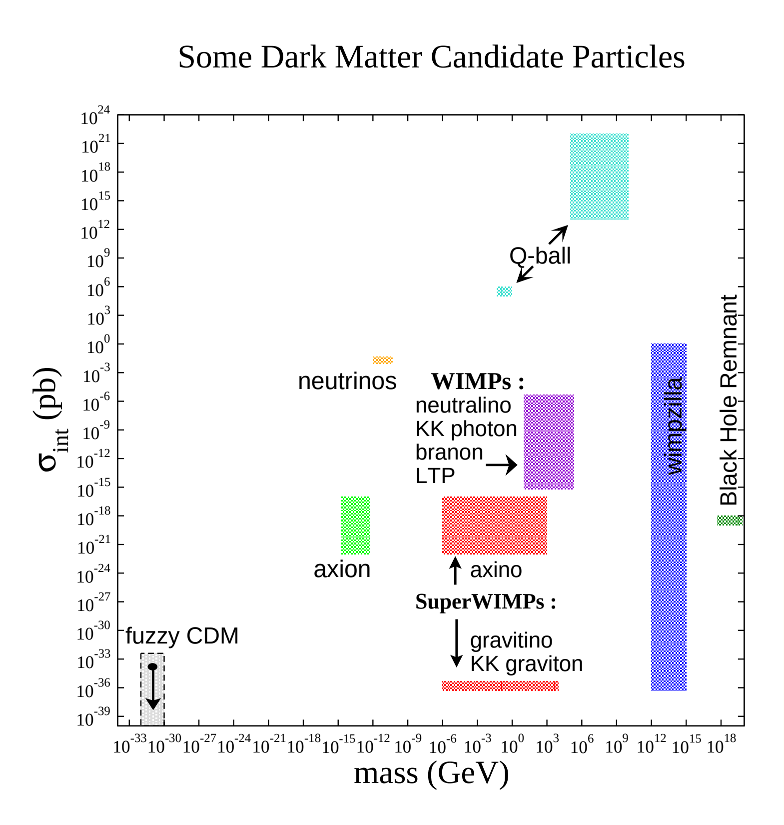
Best fit cosmology: concordance (ΛCDM) model

- $\Omega_B h^2 = 0.022 \pm 0.001$
- $\Omega_\nu h^2 < 0.007 \;\; 95\% \; CL$
- $\Omega_\Lambda h^2 \sim 0.38 \pm 0.03$
- $\Omega_{CDM} h^2 = 0.105 \pm 0.01$



Candidates for Dark Matter

- ⋆ unseen baryons, e.g. BHs, brown dwarves, stellar remnants
  - – inconsistent with BBN element abundance calc'n
  - – limits from MACHO, EROS, OGL
- ⋆ light neutrinos ($= HDM$)
- ⋆ axions/axinos
- ⋆ WIMPS
- ⋆ superWIMPS
- ⋆ Q-balls
- ⋆ primordial BHs

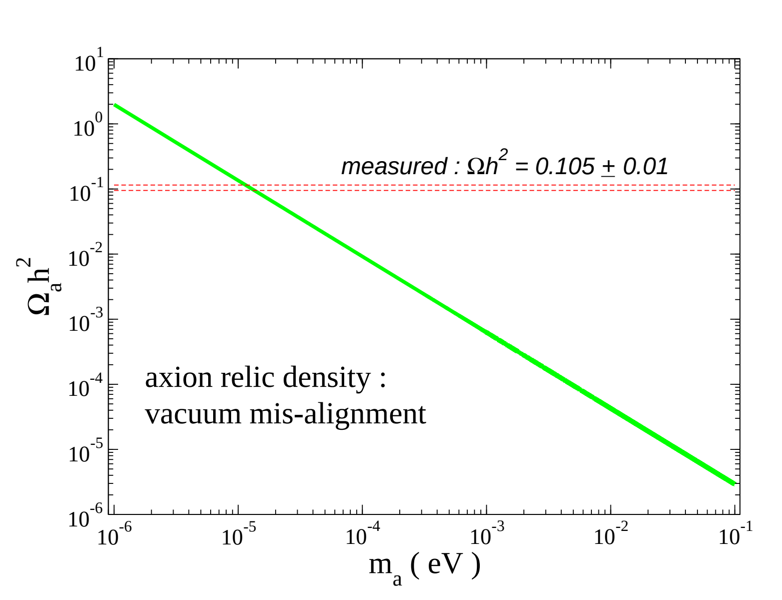


Axions

★ PQ solution to strong CP problem in QCD

★ pseudo-Goldstone boson from PQ breaking at scale f_a

★ non-thermally produced via vacuum mis-alignment

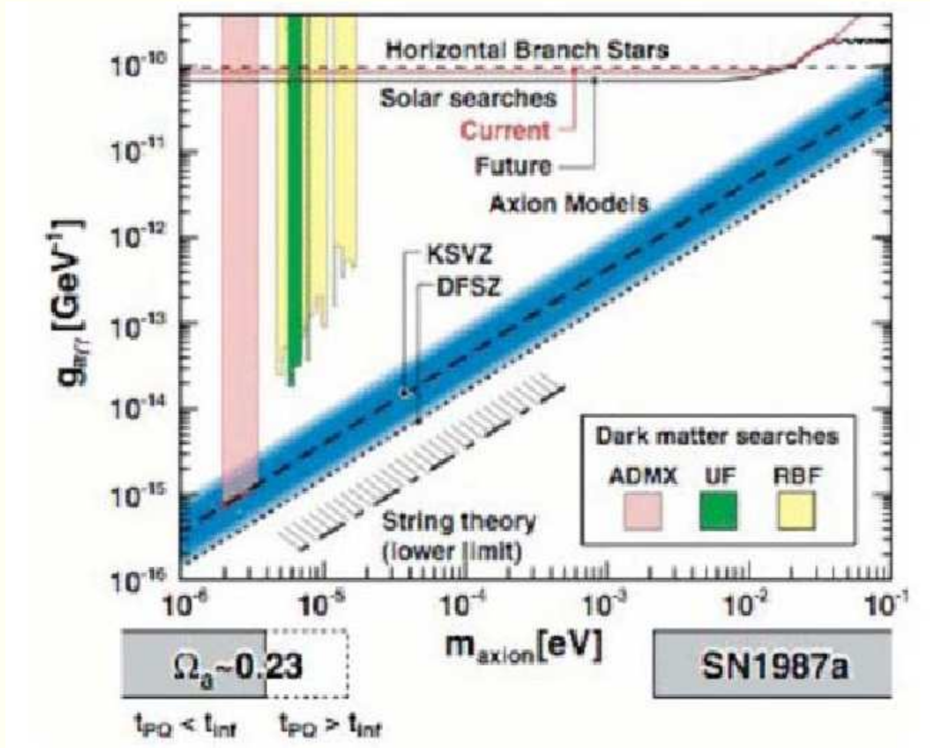


- $m_a \sim \Lambda_{QCD}^2/f_a \sim 10^{-6} - 10^{-1} eV$
- $\Omega_a h^2 \sim \frac{1}{2}\left[\frac{6\times 10^{-6} eV}{m_a}\right]^{7/6} h^2$
- astro bound: stellar cooling $\Rightarrow m_a < 10^{-1} eV$
- a couples to EM field: $a-\gamma-\gamma$ coupling (Sikivie)
- axion microwave cavity searches

Axion microwave cavity searches

⋆ ongoing searches: ADMX experiment

- Livermore⇒ U Wash.
- Phase I: probe KSVZ for $m_a \sim 10^{-6} - 10^{-5}\ eV$
- Phase II: probe DFSZ for $m_a \sim 10^{-6} - 10^{-5}\ eV$
- beyond Phase II: probe higher values m_a

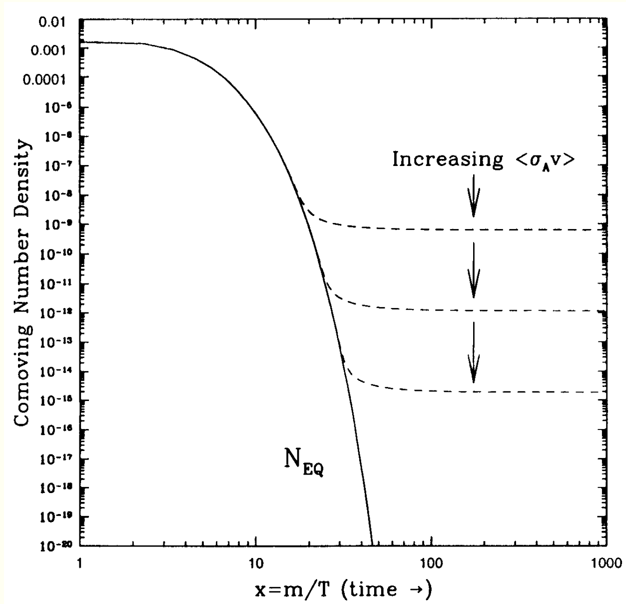


WIMPs: the WIMP miracle!

- Weakly Interacting Massive Particles
- assume in thermal equil'n in early universe
- Boltzman eq'n:

$$-\ dn/dt = -3Hn - \langle \sigma v_{rel} \rangle (n^2 - n_0^2)$$

- $\Omega h^2 = \frac{s_0}{\rho_c/h^2} \left(\frac{45}{\pi g_*} \right)^{1/2} \frac{x_f}{M_{Pl}} \frac{1}{\langle \sigma v \rangle}$
- $\sim \frac{0.1\ pb}{\langle \sigma v \rangle} \sim 0.1 \left(\frac{m_{wimp}}{100\ GeV} \right)^2$
- thermal relic $\Rightarrow$ new physics at M_{weak}!



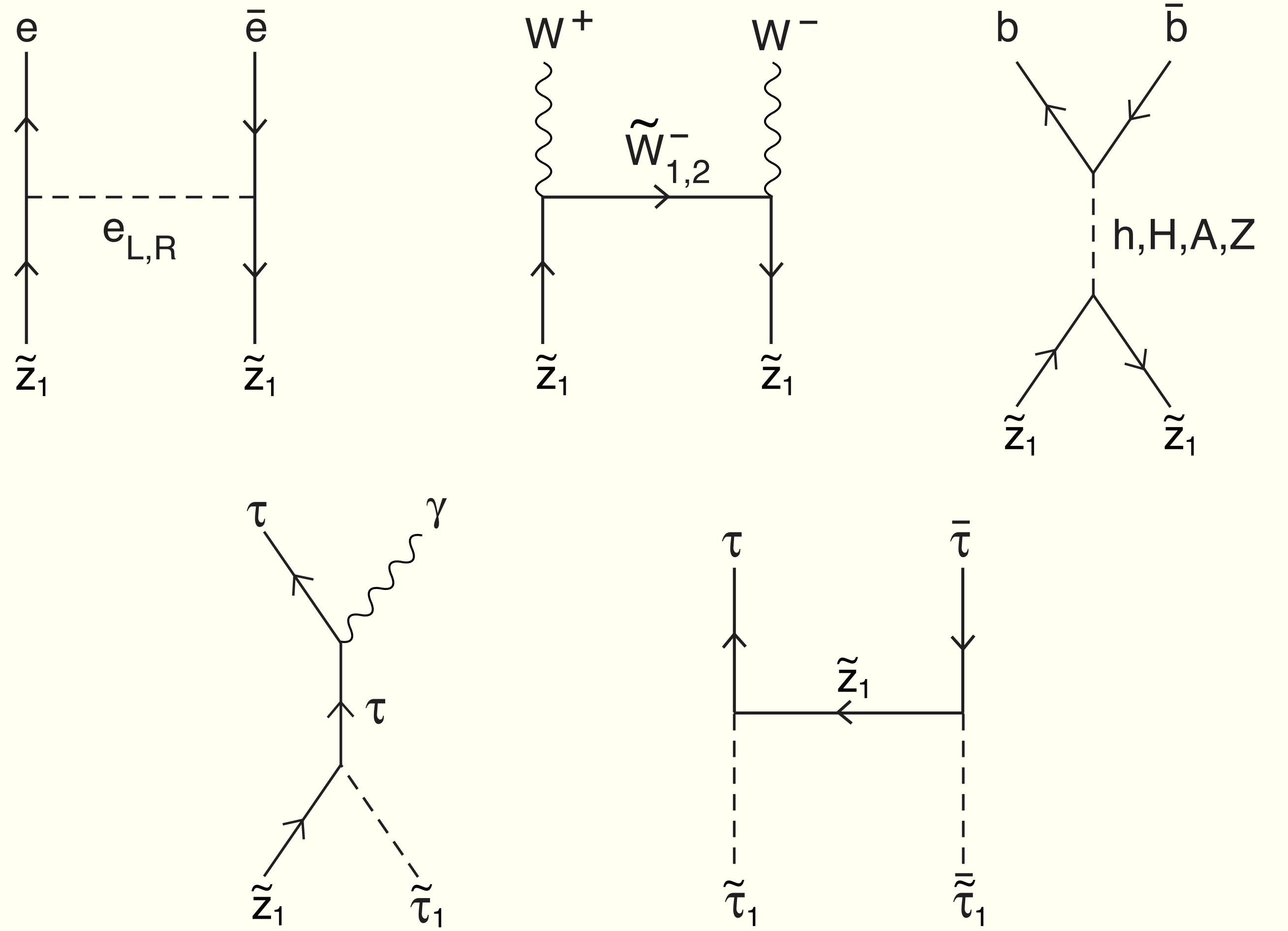
Some WIMP candidates

- ⋆ 4th gen. Dirac ν (excluded)
- ⋆ SUSY neutralino (χ or $\widetilde{Z}_1$)
- ⋆ UED excited photon B^1_μ
- ⋆ little Higgs photon B_H
- ⋆ little Higgs (theory space) N_1 (scalar)
- ⋆ warped GUTS: LZP KK fermion
- ⋆ branons
- ⋆ $\cdots$

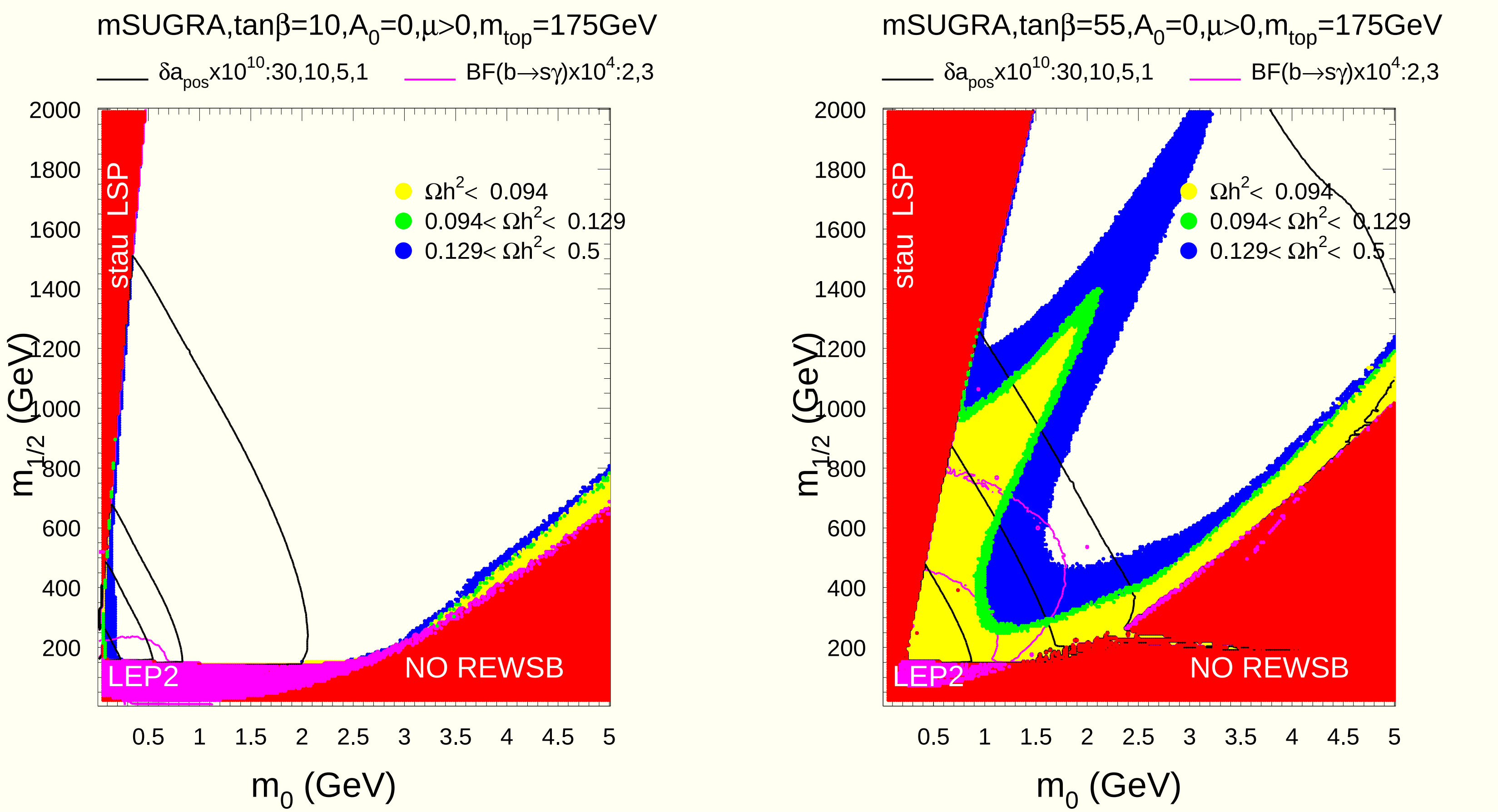
Neutralino dark matter

- ⋆ Why R-parity? natural in $SO(10)$ SUSYGUTS if properly broken, or broken via compactification (Mohapatra, Martin, Kawamura, $\cdots$)
- ⋆ In thermal equilibrium in early universe
- ⋆ As universe expands and cools, freeze out
- ⋆ Number density obtained from Boltzmann eq'n
  - $dn/dt = -3Hn - \langle \sigma v_{rel} \rangle (n^2 - n_0^2)$
  - depends critically on thermally averaged annihilation cross section times velocity
- ⋆ many thousands of annihilation/co-annihilation diagrams
- ⋆ several computer codes available
  - DarkSUSY, Micromegas, IsaReD (part of Isajet)

Some neutralino (co)annihilation processes



Relic density in minimal SUGRA model



HB, A. Belyaev, T. Krupovnickas and A. Mustafayev

Main mSUGRA regions consistent with WMAP

- ⋆ bulk region (low m_0, low $m_{1/2}$)
- ⋆ stau co-annihilation region ($m_{\tilde{\tau}_1} \simeq m_{\widetilde{Z}_1}$)
- ⋆ HB/FP region (large m_0 where $|\mu| \to small$)
- ⋆ A-funnel ($2m_{\widetilde{Z}_1} \simeq m_A,\ m_H$)
- ⋆ h corridor ($2m_{\widetilde{Z}_1} \simeq m_h$)
- ⋆ stop co-annihilation region (particular A_0 values $m_{\tilde{t}_1} \simeq m_{\widetilde{Z}_1}$)

Constraints on SUSY models

★ LEP2:

- $m_h > 114.4$ GeV for SM-like h
- $m_{\widetilde{W}_1} > 103.5$ GeV
- $m_{\tilde{e}_{L,R}} > 99$ GeV for $m_{\tilde{\ell}} - m_{\widetilde{Z}_1} > 10$ GeV

★ $BF(b \to s\gamma) = (3.55 \pm 0.26) \times 10^{-4}$ (BELLE, CLEO, ALEPH)

- SM theory: $BF(b \to s\gamma) \simeq (3.0 - 3.7) \times 10^{-4}$

★ $a_\mu = (g-2)_\mu/2$ (Muon $g-2$ collaboration)

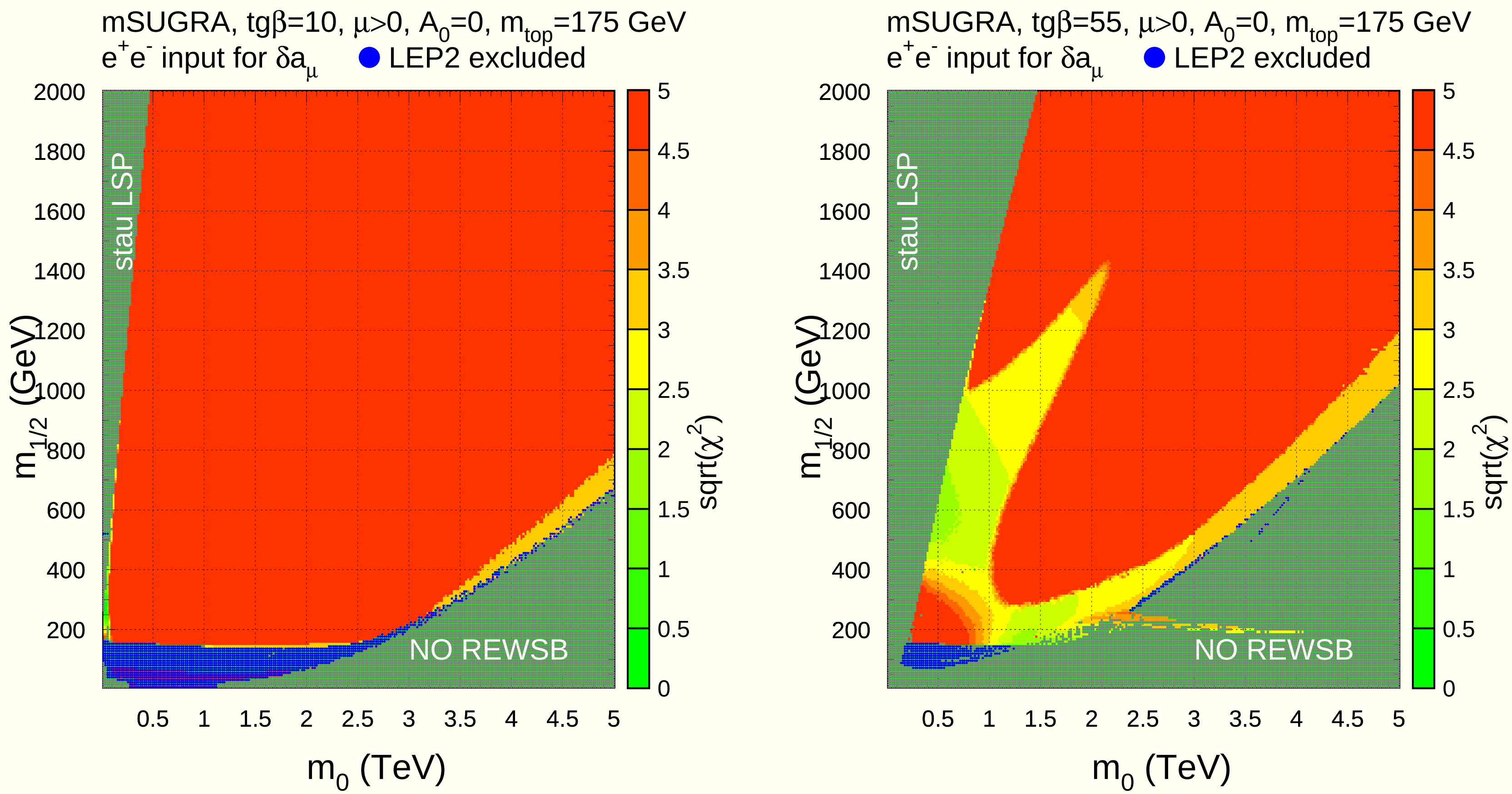
- $\Delta a_\mu = (22 \pm 10) \times 10^{-10}$ (PDG value e^+e^-)
- $\Delta a_\mu^{SUSY} \propto \frac{m_\mu^2 \mu M_i \tan\beta}{M_{SUSY}^4}$

★ $BF(B_s \to \mu^+\mu^-) < 1.5 \times 10^{-7}$ (CDF)

- constrains at very large $\tan\beta \gtrsim 50$

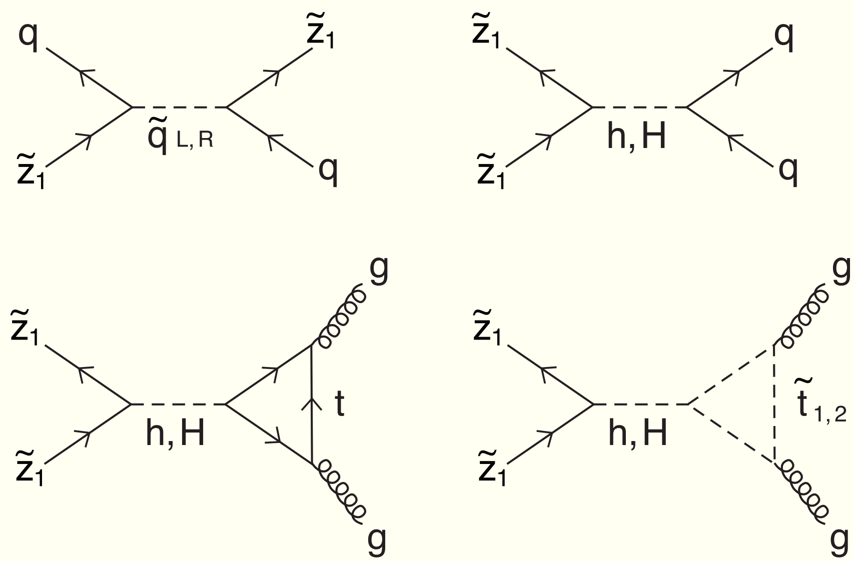
★ $\Omega_{CDM} h^2 = 0.11 \pm 0.01$ (WMAP)

Constraints as χ^2 on mSUGRA model

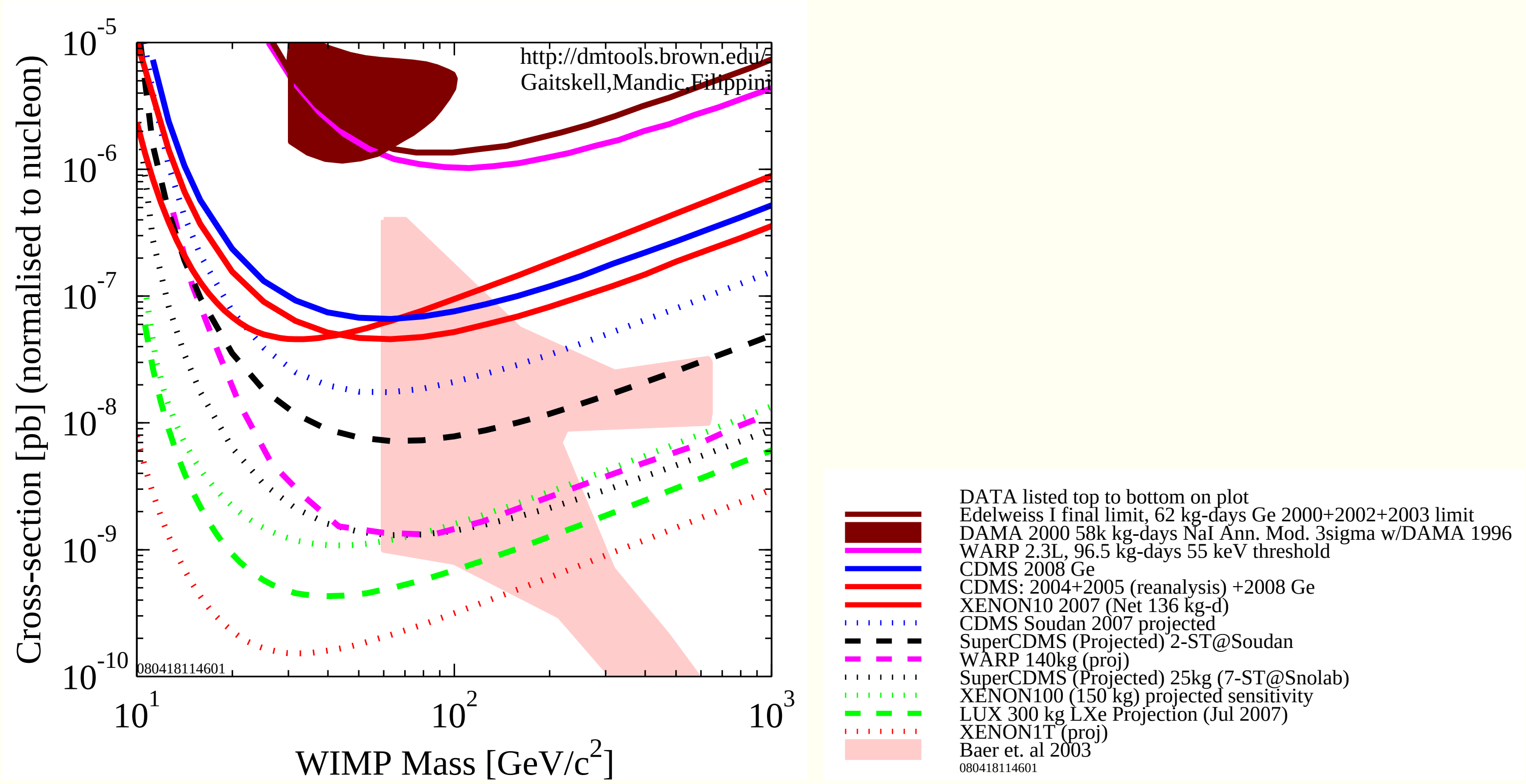


Direct detection of SUSY DM

- ⋆ Calculate neutralino-nucleus scattering
  - • calculate $\widetilde{Z}_1 - q$ or $\widetilde{Z}_1 - g$ scattering: take $v \to 0$ limit
    - ∗ spin-dependent cross section couples to spin of nucleus: cancel
    - ∗ spin-independent cross section $\propto A^2$: add
    - ∗ results usually quoted in terms of $\sigma_{SI}(\widetilde{Z}_1 p)$ so results from different target nuclei can be compared



Current best limit: Xenon-10/CDMS results!

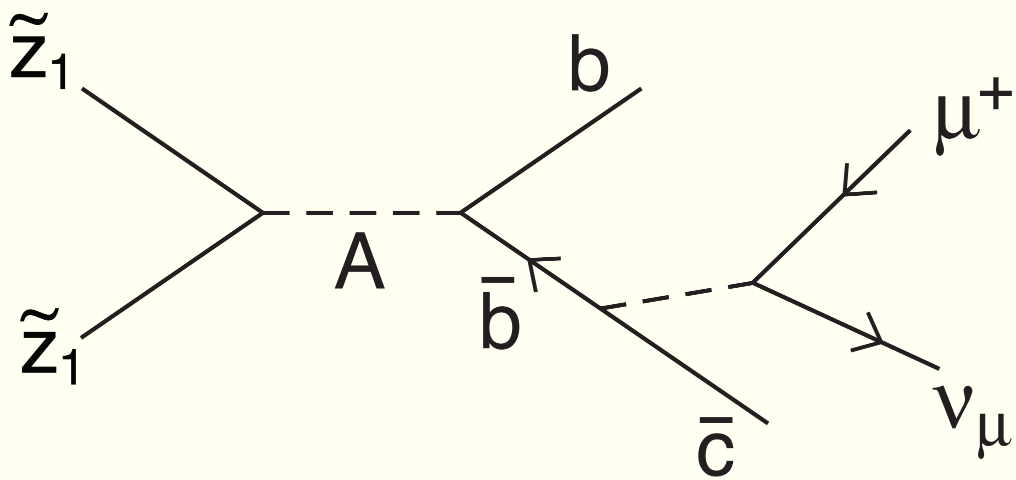


Indirect detection (ID) of SUSY DM: ν-telescopes

★ $\tilde{Z}_1\tilde{Z}_1 \to b\bar{b}, etc.$ in core of sun (or earth): $\Rightarrow \nu_\mu \to \mu$ in ν telescopes

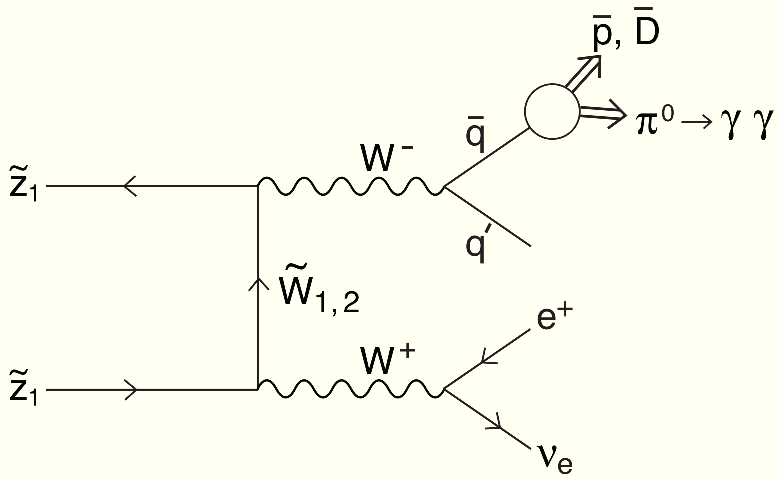
★ flux is largest when $\sigma(\widetilde{Z}_1 p)$ is largest

- $e.g.$ low $m_{\tilde{q}}$ or HB/FP region for mSUGRA
- experiments: Amanda, Icecube, Antares

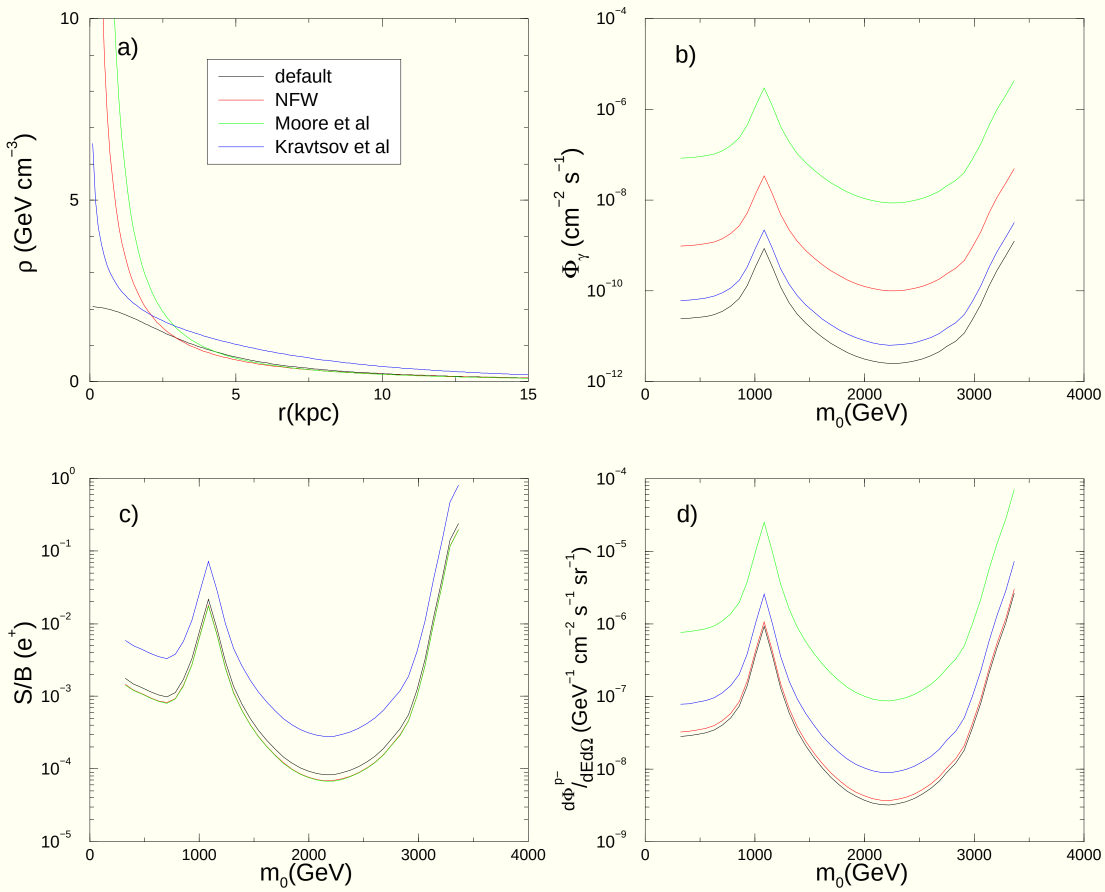


ID of SUSY DM: γ and anti-matter searches

- $\tilde{Z}_1\tilde{Z}_1 \to q\bar{q}, etc. \to \gamma$ in galactic core or halo
- $\tilde{Z}_1\tilde{Z}_1 \to q\bar{q}, etc. \to e^+$ in galactic halo
- $\tilde{Z}_1\tilde{Z}_1 \to q\bar{q}, etc. \to \bar{p}$ in galactic halo
- $\tilde{Z}_1\tilde{Z}_1 \to q\bar{q}, etc. \to \bar{D}$ in galactic halo

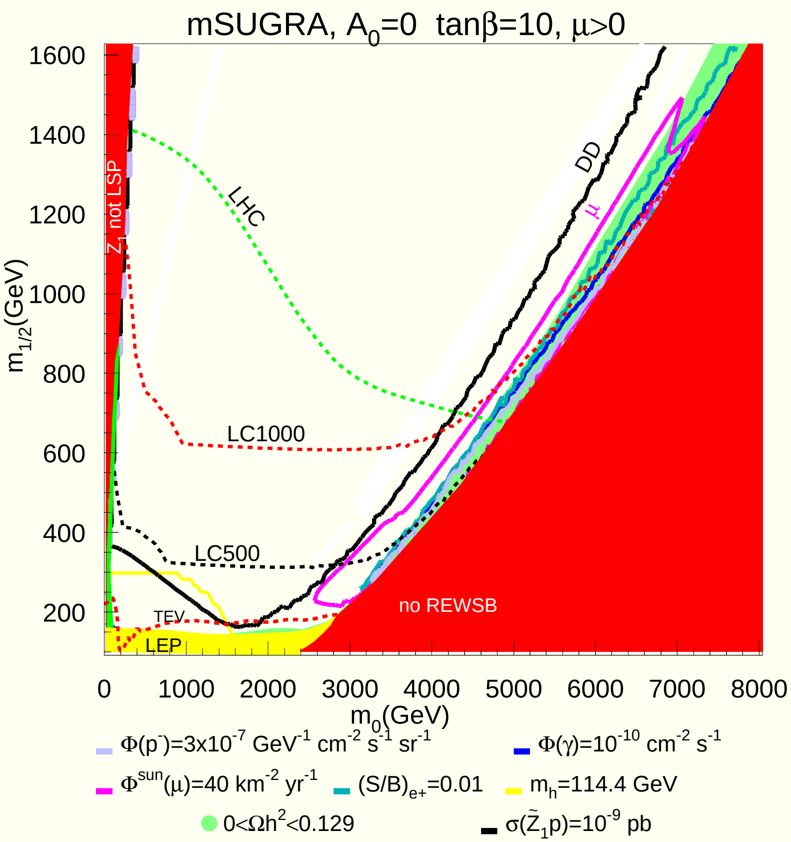


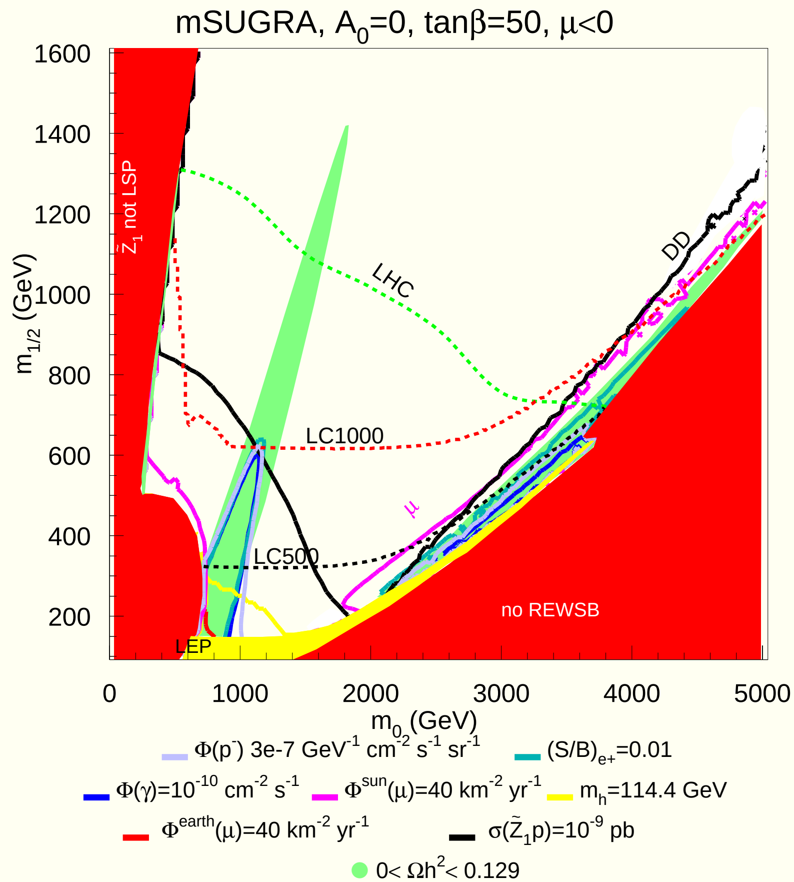
Rates for γs, e^+s, $\bar{p}$s vs. m_0 for fixed $m_{1/2} = 550$ GeV, $\tan\beta = 50$



- rates enhanced in A-funnel and HB/FP region (MHDM)

Direct and indirect detection of neutralino DM

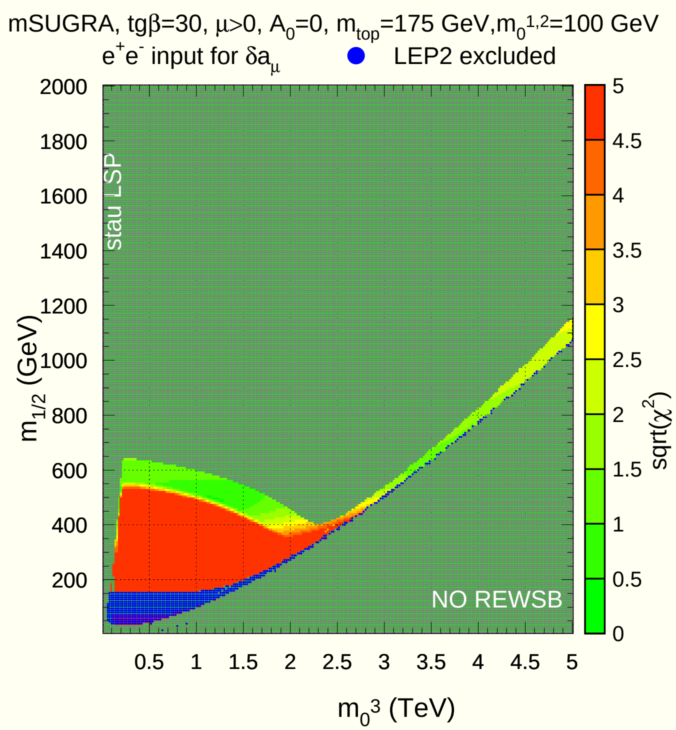




HB, Belyaev, Krupovnickas, O'Farrill

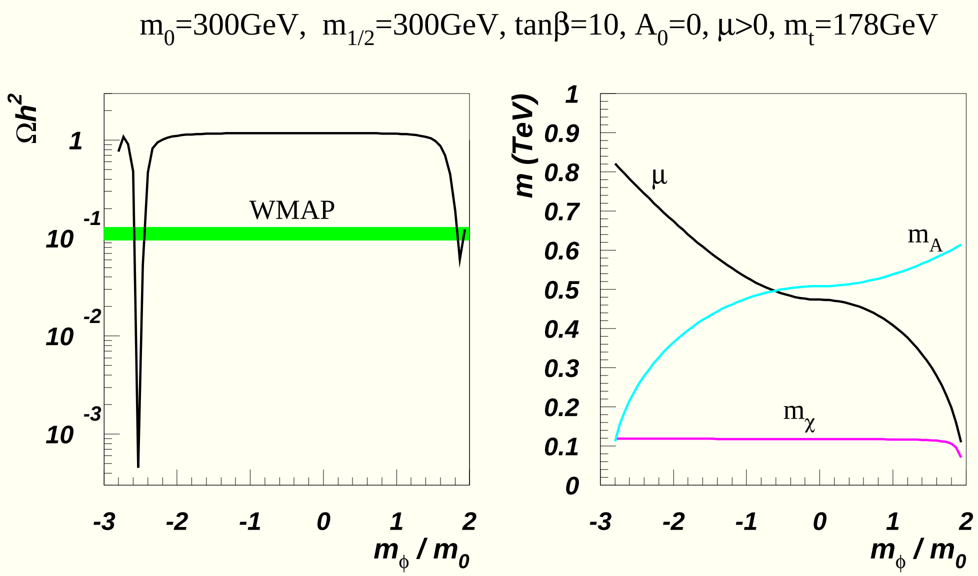
SUGRA models with non-universal scalars

- Normal scalar mass hierarchy NMH: HB, Belyaev, Krupovnickas, Mustafayev
- $m_0(1) \simeq m_0(2) \ll m_0(3)$ (preserve FCNC bounds)
- motivation: reconcile $BF(b \to s\gamma)$ with $(g-2)_\mu$ anomaly



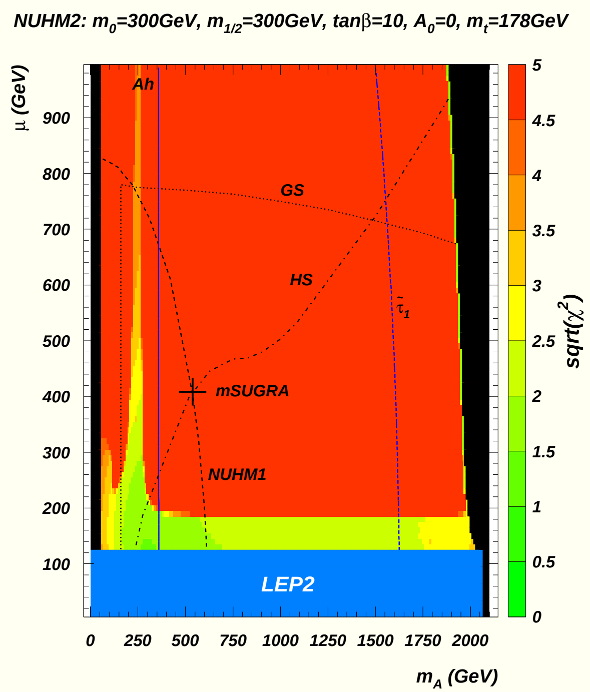
SUGRA models with non-universal Higgs mass (NUHM1)

- $m_{H_u}^2 = m_{H_d}^2 \equiv m_\phi^2 \neq m_0$: HB, Belyaev, Mustafayev, Profumo, Tata
- motivation: $SO(10)$ SUSYGUTs where $\hat{H}_{u,d} \in \phi(10)$ while matter $\in \psi(16)$
- $m_\phi^2 \gg m_0 \Rightarrow$higgsino DM for any $m_0,\ m_{1/2}$
- $m_\phi^2 < 0 \Rightarrow$ can have A-funnel for any $\tan\beta$



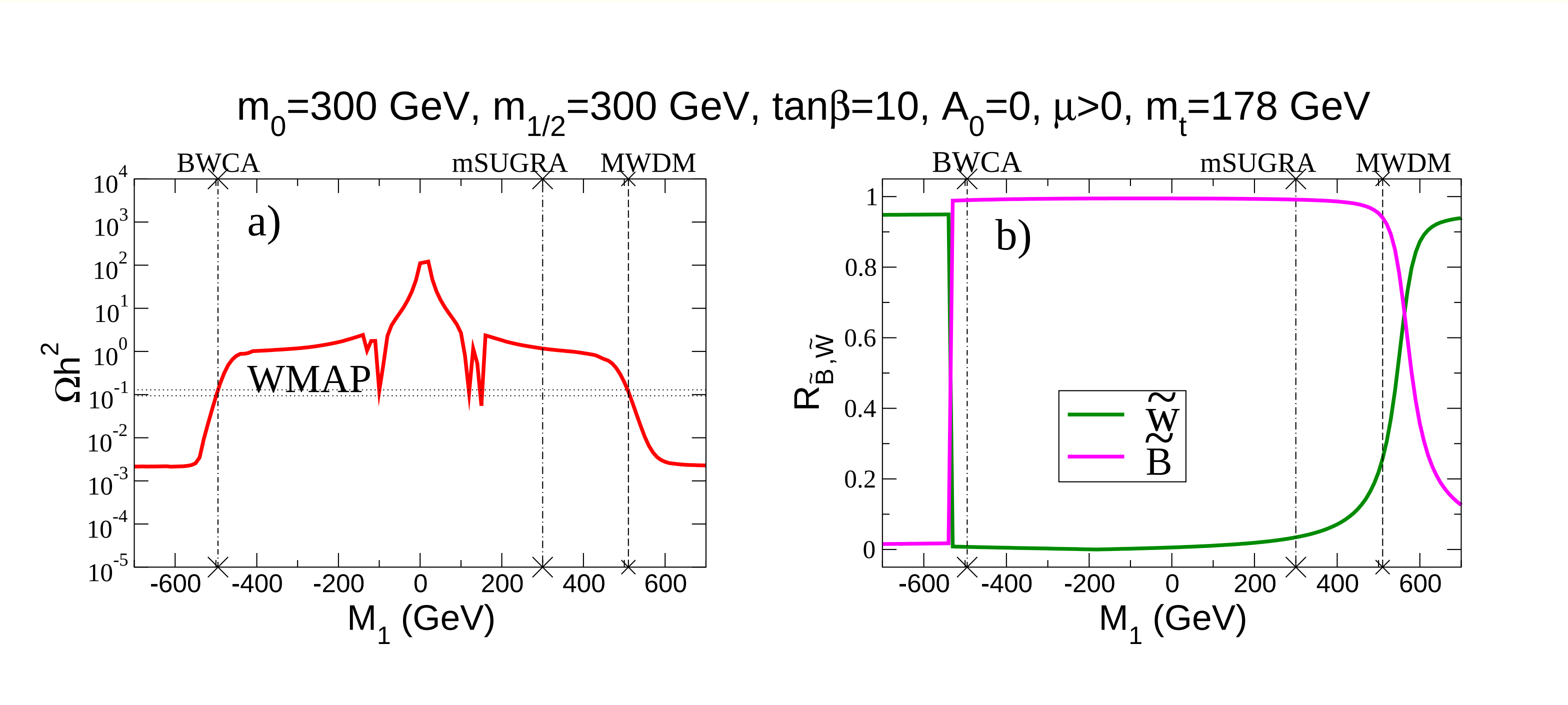
NUHM2 (2-parameter case)

- $m^2_{H_u} \neq m^2_{H_d} \neq m_0$: HB, Belyaev, Mustafayev, Profumo, Tata
- motivation: $SU(5)$ SUSYGUTs where $\hat{H}_u \in \phi(5)$, $\hat{H}_d \in \phi(\bar{5})$
- can re-parametrize $m^2_{H_u},\ m^2_{H_d} \leftrightarrow \mu,\ m_A$ (Ellis, Olive, Santoso)
- large S term in RGEs $\Rightarrow$ light $\tilde{u}_R,\ \tilde{c}_R$ squarks, $m_{\tilde{e}_L} < m_{\tilde{e}_R}$



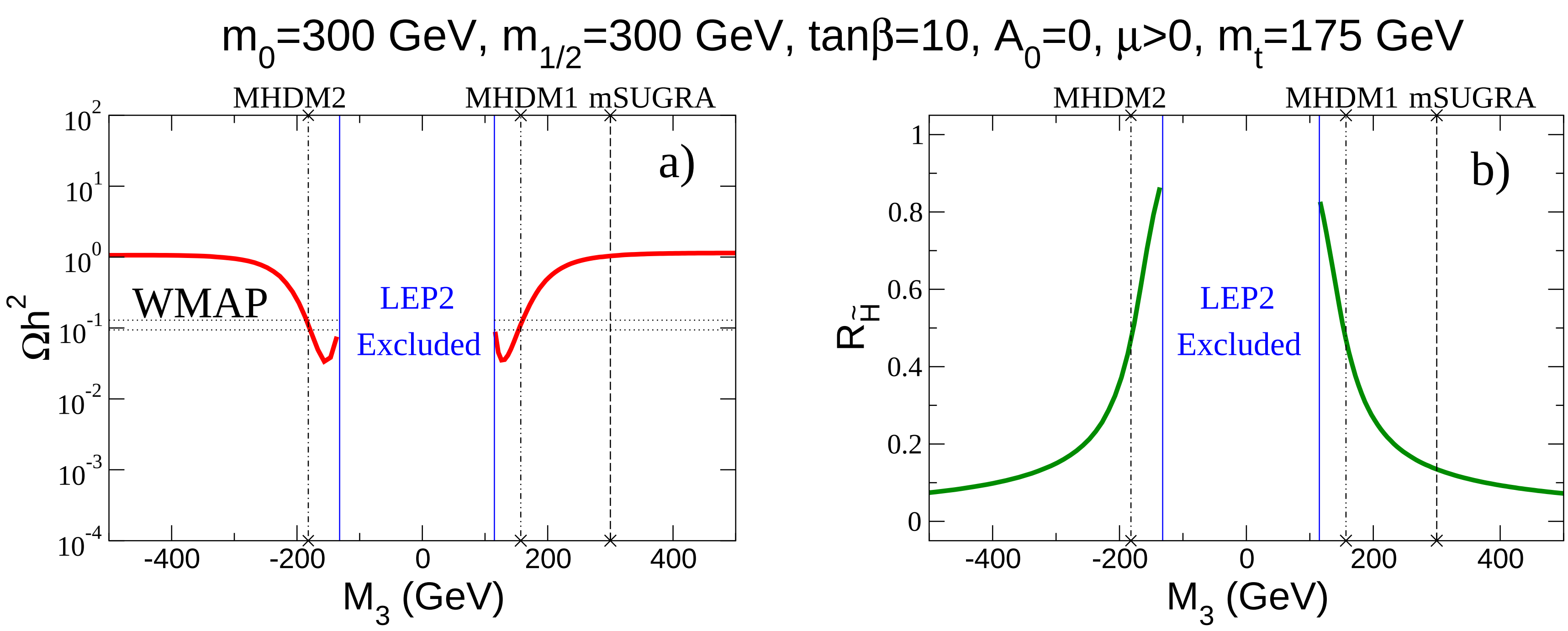
Gaugino mass non-universality

- $M_1 \neq M_2 \neq M_3$: HB, TK, AM, EP, SP, XT
- motivation: SUSYGUTs where gauge kinetic function transforms non-trivially
- $M_2 \sim M_1$ at M_{GUT}: mixed wino dark matter (MWDM)
- $M_2 \simeq -M_1$ at M_{GUT}: bino-wino co-annihilation (BWCA)

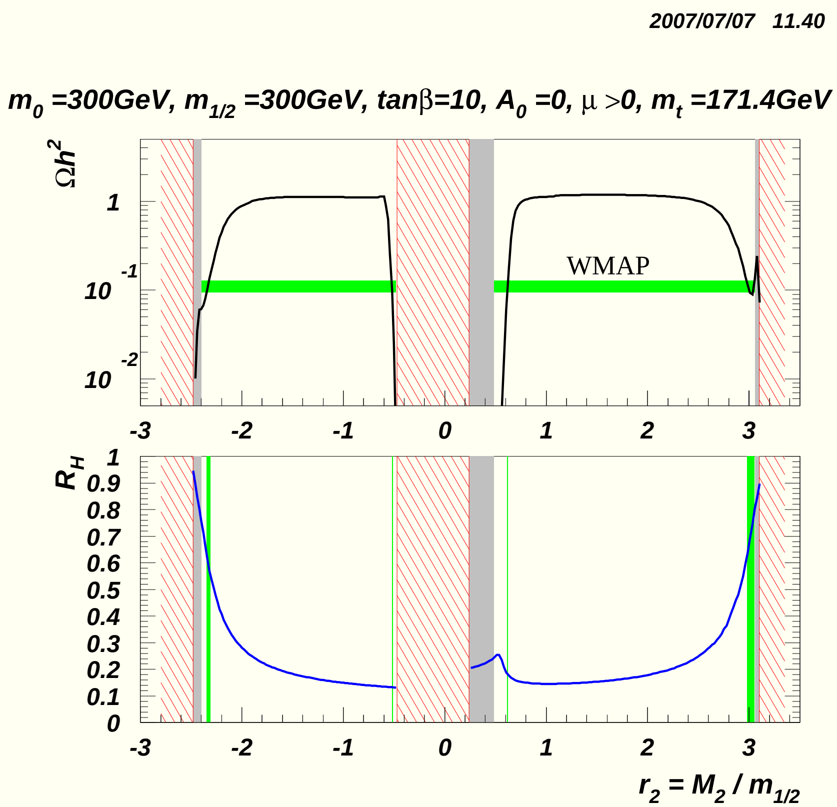


Gaugino mass non-universality: low M_3 case

- $M_3 < M_1 \sim M_2$: HB, TK, AM, EP, SP, XT
- motivation: mixed-moduli AMSB models
- lower $M_3 \to$ low $m_{\tilde{q}} \to$ low $\mu \to$ mixed higgsino DM

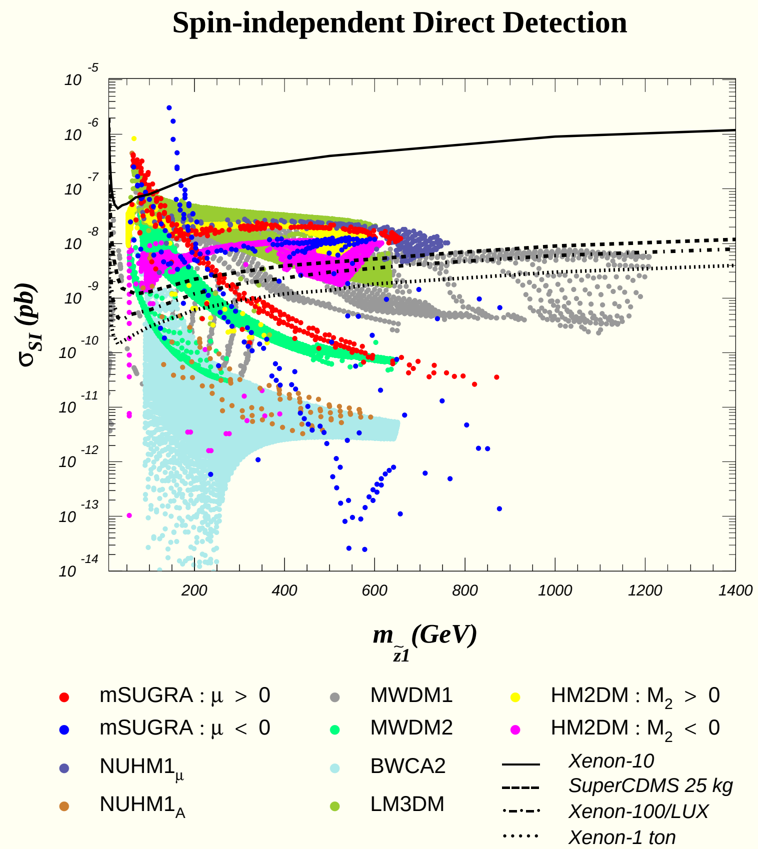


Mixed higgsino DM from a high M_2 (HM2DM)



- high $M_2 \Rightarrow$ low $|\mu|$ so get mixed higgsino DM but high $m_{\tilde{q}_L}$
- HB, Mustafayev, Summy, Tata

Direct DM detection: well-tempered $\widetilde{Z}_1$ models



- well-tempered $\widetilde{Z}_1$ models asymptote at $\sigma(\widetilde{Z}_1 p) \sim 10^{-8}$ pb!

Compressed SUSY (Steve Martin)

- in models with low M_3 and $A_0 \sim -M_1$, the $\tilde{t}_1$ becomes quite light
- Martin finds that if
  - $m_t < m_{\widetilde{Z}_1} \lesssim m_t + 100$ GeV and
  - $m_{\widetilde{Z}_1} + 25\ \mathrm{GeV} \lesssim m_{\tilde{t}_1} \lesssim m_{\widetilde{Z}_1} + 100$ GeV, then
- $\widetilde{Z}_1\widetilde{Z}_1 \to t\bar{t}$ is dominant dark matter annihilation mechanism in early Universe!
- implications for LHC, DD, IDD: (HB, Box, Park, Tata)
  - light $m_{\tilde{g}}$ with $\tilde{t}_1 = NLSP$
  - collider signatures depend on whether $\tilde{t}_1 \to c\widetilde{Z}_1$ or $bW\widetilde{Z}_1$
  - if $\tilde{t}_1 \to c\widetilde{Z}_1$, then large $\not{E}_T + jets$, but very low isolated lepton rates
  - IDD halo annihilation signals enhanced since $\widetilde{Z}_1\widetilde{Z}_1 \to t\bar{t} \to \gamma$s, anti-matter

Mixed modulus-AMSB models

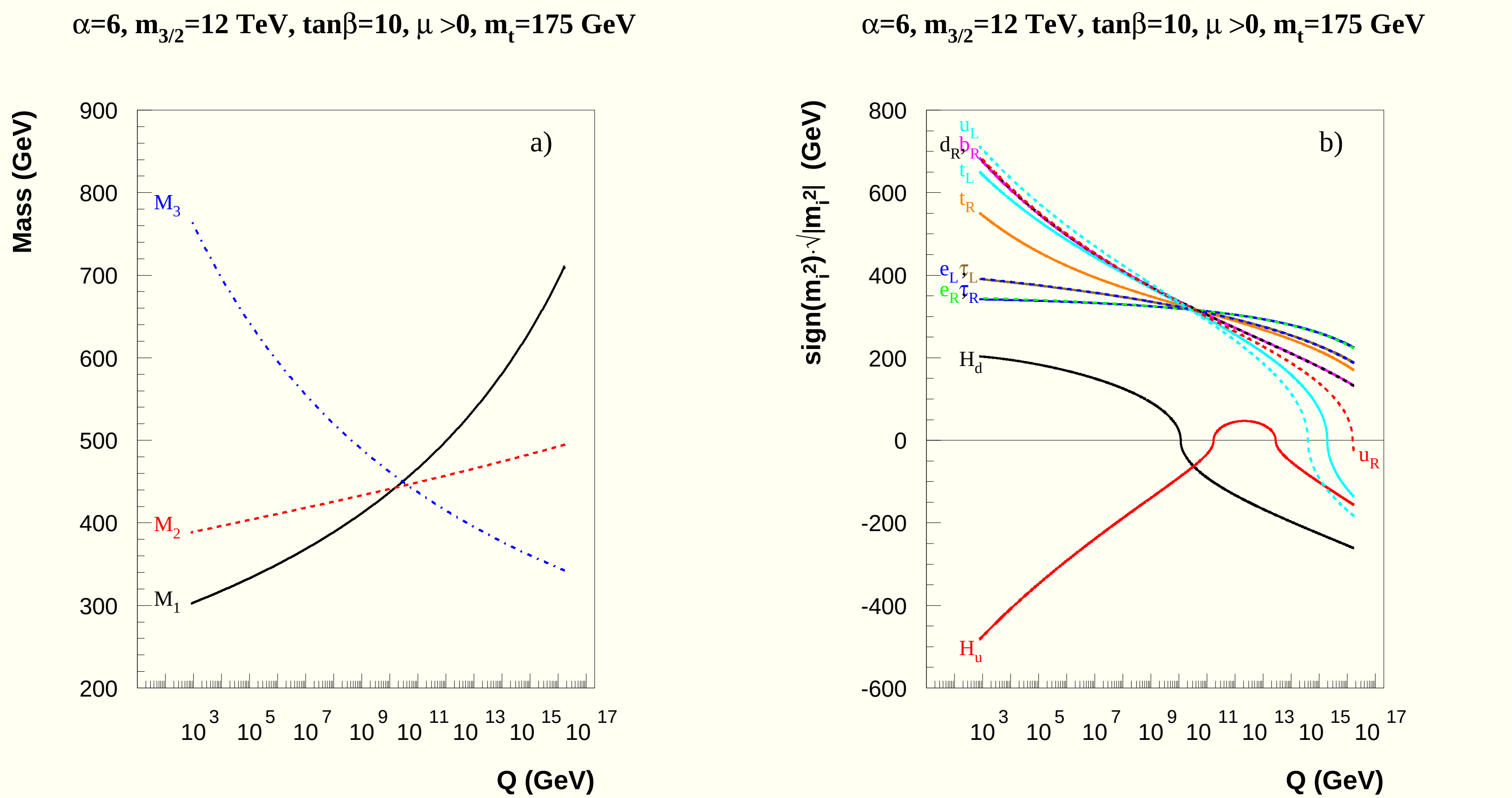
★ KKLT model: type IIB superstring compactification with fluxes

- stabilize moduli/dilaton via fluxes and e.g. gaugino condensation on $D7$ brane
- introduce anti-$D3$ brane (uplifting potential; de Sitter universe with $\Lambda > 0$
- small SUSY breaking due to $\overline{D3}$ brane
- mass hierarchy: $m_{moduli} \gg m_{3/2} \gg m_{SUSY}$

★ MSSM soft terms calculated by Choi, Falkowski, Nilles, Olechowski, Pokorski

★ phenomenology: Choi, Jeong, Okumura; Falkowski, Lebedev, Mambrini; Kitano, Nomura

★ see also: HB, E. Park, X. Tata, T. Wang, JHEP**0608**, 041 (2006); PL**B641**, 447 (2006); JHEP**0706**, 033 (2007);



- GUT scale AMSB splitting of soft terms cancelled by RGE running: soft terms unify at "mirage" unification scale
- MM-AMSB contains BWCA, MWDM, LM3DM scenarios!

$SO(10)$ SUSYGUTs: motivation

⋆ In all the excitement of new models, it is easy to neglect the really good ideas from the past:

⋆ SUSYGUTs with $SO(10) \to SU(5) \to SU(3)_C \times SU(2)_L \times U(1)_Y$:

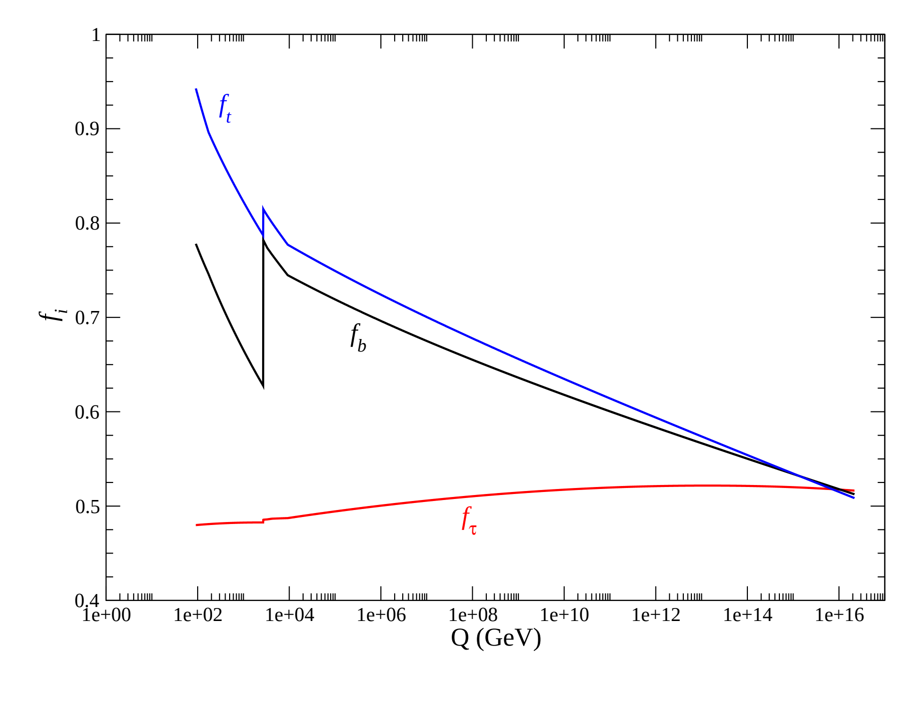
- unification of forces
- $SO(10)$ naturally anomaly free
- explain ad-hoc SM hypercharge assignments (charge relations: *e.g.* why $m(proton) = -m_e$
- unification of matter in $SO(10)$: $matter \in \psi(16)$, $higgs \in \phi(10)$ (simplest models)
- The 16-dim'l spinor rep of $SO(10)$ contains *all* the matter in a single generation of the SM, plus a right-handed neutrino state.
- break $SO(10)$: get see-saw νs!
- simplest models: $t - b - \tau$ Yukawa unification

YU requires precision calculation of SUSY spectrum:

Hall, Rattazzi, Sarid; Pierce *et al.* (PBMZ)

- need full 2-loop RGE running
- RG-improved 1-loop effective potential evaluated at optimized scale
- t, b, τ threshold effects
- full set of 1-loop sparticle/Higgs mass corrections
- use Isajet/Isasugra 7.75 spectrum generator

Running of Yukawa couplings: $m_{16} = 10$ TeV

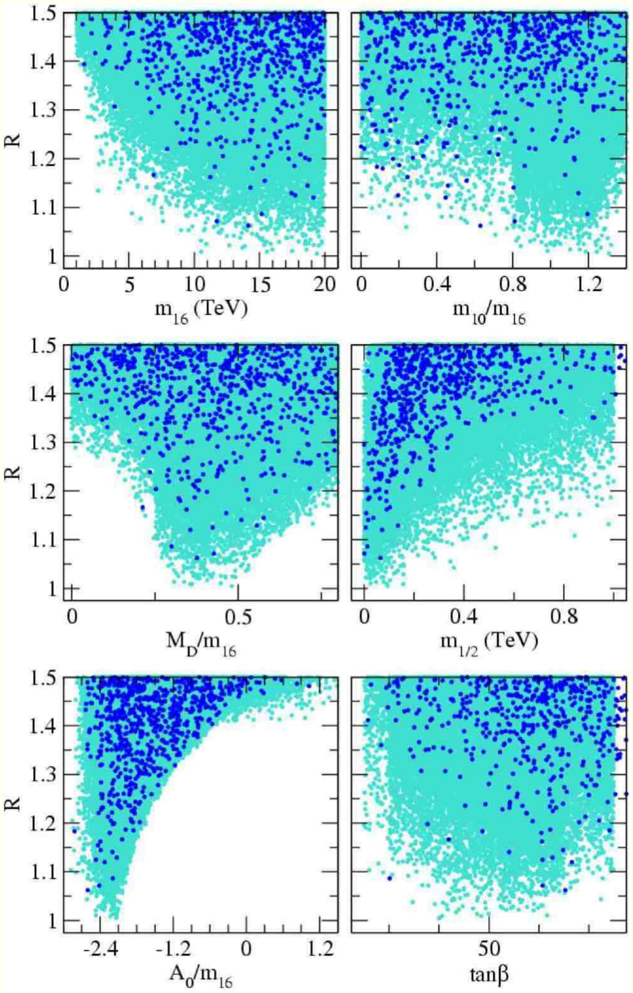


- note shifts at $Q = M_{SUSY}$!

$t - b - \tau$ Yukawa unification in HS model!

- need $m_{16} \sim 5 - 20$ TeV
- need $m_{10} \simeq \sqrt{2} m_{16}$
- $A_0 \simeq -2m_{16}$
- $\tan\beta \simeq 50$
- $m_{1/2} \ll m_{16}$
  - inverted scalar mass hierarchy: Bagger et al.
- split Higgs needed for EWSB: $m_{H_u}^2 < m_{H_d}^2$
- Auto, HB, Balazs, Belyaev, Ferrandis, Tata
- HB, Kraml, Sekmen, Summy
- related work: Blazek, Dermisek, Raby (BDR); DRRR uses 1-loop SSB RGEs and scalar pot'l minimization at $Q = M_Z$

Scan for $R \simeq 1$ in HS model with $\mu > 0$

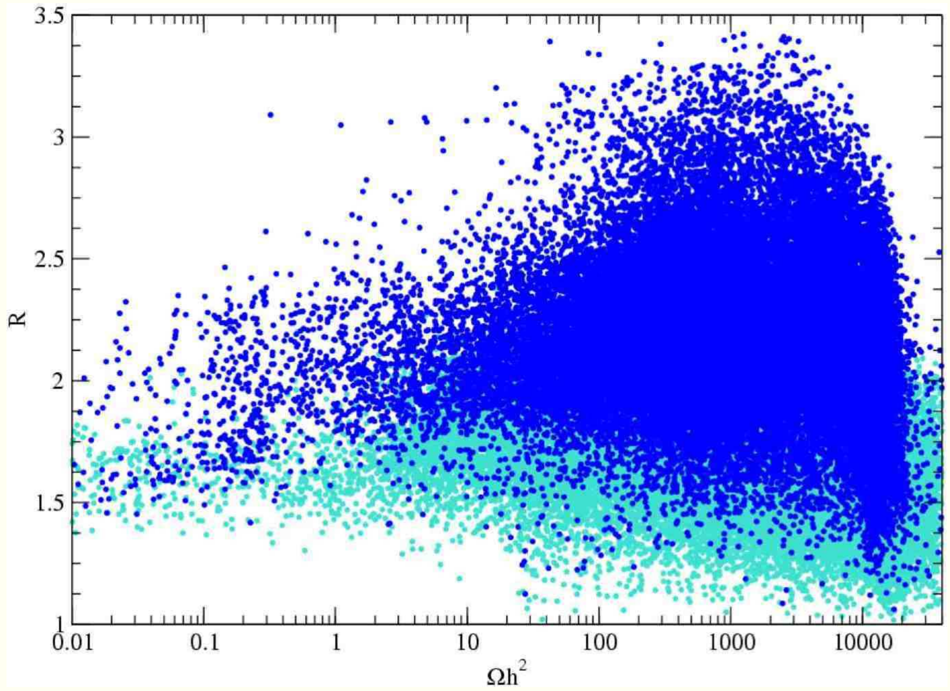


- $R = max(f_t, f_b, f_\tau)/min(f_t f_b, f_\tau)$

Special SUSY spectrum from Yukawa unified models

- first/second gen. squarks/sleptons $\sim 5 - 20$ TeV
- third gen. scalars, μ, $m_A \sim 1 - 2$ TeV
- gluinos $\sim 350 - 500$ GeV
- charginos $\sim 100 - 160$ GeV
- $\widetilde{Z}_1$ or $\tilde{\chi}_1 \sim 50 - 80$ GeV

Problem: $\Omega_{\widetilde{Z}_1} h^2 \sim 10^3 - 10^5 \times$ WMAP



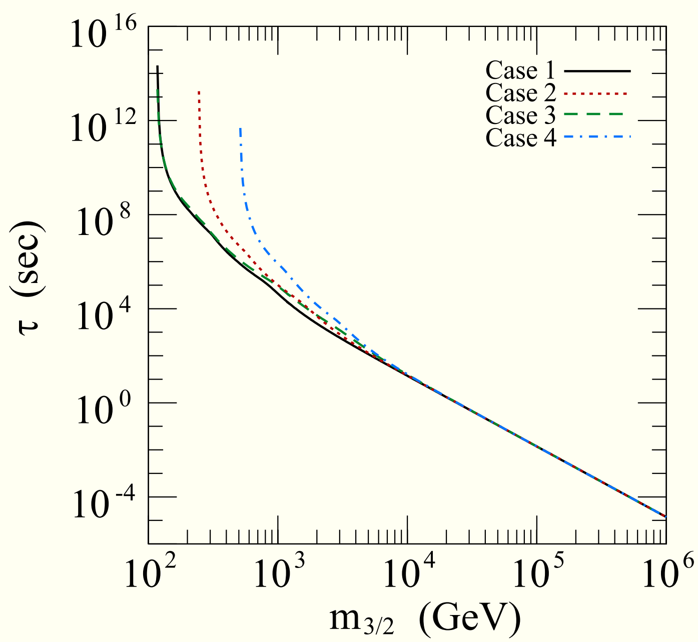
- for $R \simeq 1$, then $\Omega_{\widetilde{Z}_1} h^2 \gtrsim 10^2$!
- higher than measured value by $10^3 - 10^5$
- Does this rule out Yukawa-unified SUSY?

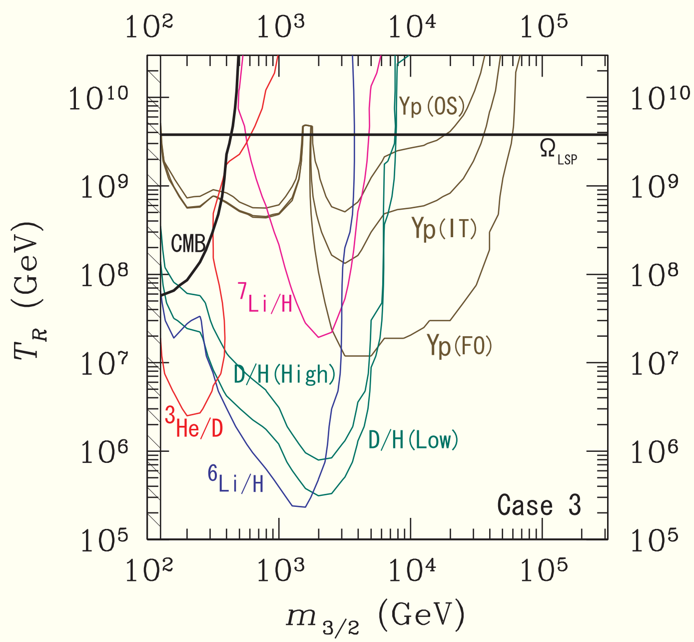
Solution: axino $\tilde{a}$ dark matter

- invoke axion solution to strong CP problem
- axino is spin $\frac{1}{2}$ element of saxion/axion/axino supermultiplet
- $10^{-6}\ eV < m_a < 10^{-2}\ eV$
- $100\ keV < m_{\tilde{a}} <\sim 10\ GeV$
- for our case, $\widetilde{Z}_1 \to \tilde{a}\gamma$ with $\tau_{\widetilde{Z}_1} \sim 0.03$ sec
- can shed large factors of relic density:
- $\Omega_{\tilde{a}} h^2 \sim \frac{m_{\tilde{a}}}{m_{\widetilde{Z}_1}} \Omega_{\widetilde{Z}_1} h^2$: $\Rightarrow$ warm DM for $m_{\tilde{a}} < 1 - 10$ GeV (JLM)
- also generate thermal component for axino DM depending on T_R: $\Rightarrow$ CDM

Consistent cosmology for SUSY $SO(10)$: gravitino problem

- gravitino problem in generic SUGRA models: overproduction of $\tilde{G}$ followed by late $\tilde{G}$ decay can destroy successful BBN predictons: upper bound on T_R





(see Kohri, Moroi, Yotsuyanagi; Cybert, Ellis, Fields, Olive)

Leptogenesis via inflaton decay

- Upper bound on T_R from BBN is below that for successful thermal leptogenesis: need $T_R \gtrsim 10^{10}$ GeV (Buchmuller, Plumacher)
- Alternatively, one may have non-thermal leptogenesis where inflaton $\phi \to N_i N_i$ decay (Lazarides,Shafi; Kumekawa, Moroi, Yanagida)
- additional source of N_i in early universe allows lower T_R:

$$\frac{n_B}{s} \simeq 8.2 \times 10^{-11} \times \left(\frac{T_R}{10^6 \text{ GeV}}\right)\left(\frac{2m_{N_1}}{m_\phi}\right)\left(\frac{m_{\nu_3}}{0.05 \text{ eV}}\right)\delta_{eff} \qquad (1)$$

- WMAP observation: $n_b/s \sim 0.9 \times 10^{-10} \Rightarrow T_R \gtrsim 10^6$ GeV

Cold and warm axino DM in the universe

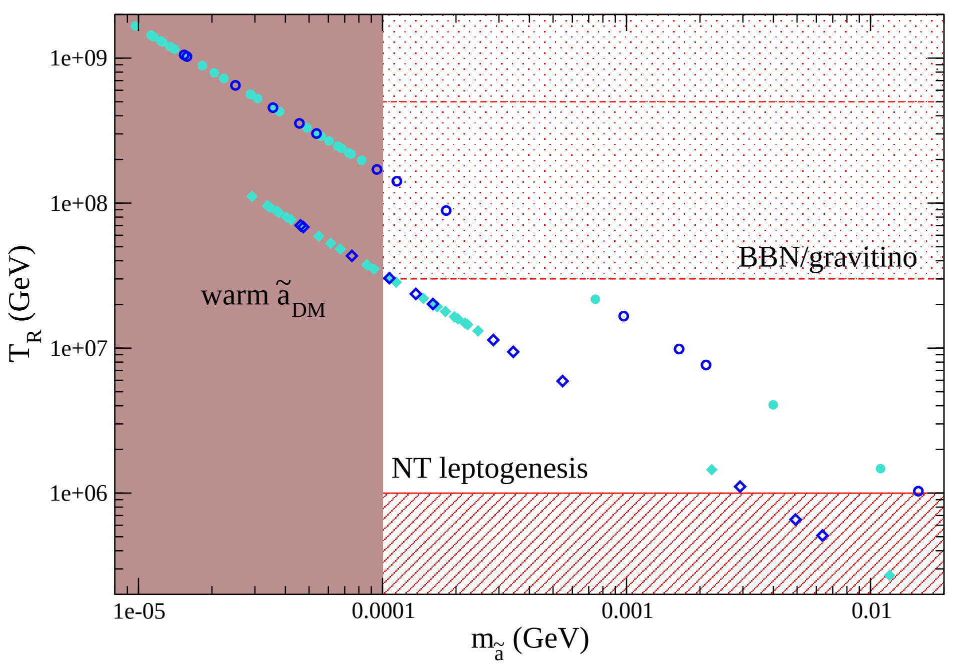
- Non-thermal axino production via $\widetilde{Z}_1 \to \tilde{a}\gamma$ decay:
  $\Rightarrow$ warm DM for $m_{\tilde{a}} \lesssim 1$ GeV (Jedamzik, Lemoine, Moultaka)
- thermal production of $\tilde{a}$: *cold* DM for $m_{\tilde{a}} > .1$ MeV
  (Brandenberg, Steffen)

$$\Omega_{\tilde{a}}^{TP} h^2 \simeq 5.5 g_s^6 \ln\left(\frac{1.108}{g_s}\right)\left(\frac{10^{11}\ \mathrm{GeV}}{f_a/N}\right)^2\left(\frac{m_{\tilde{a}}}{0.1\ \mathrm{GeV}}\right)\left(\frac{T_R}{10^4\ \mathrm{GeV}}\right) \qquad (2)$$

- with $0.1 \simeq \Omega_{\tilde{a}} h^2 = \Omega_{\tilde{a}}^{TP} h^2 + \frac{m_{\tilde{a}}}{m_{\widetilde{Z}_1}} \Omega_{\widetilde{Z}} h^2$, can calculate value of T_R needed given a PQ breaking scale $f_a/N \sim 10^{11}$ GeV

Consistent cosmology for $SO(10)$ SUSY GUTs with $\tilde{a}$ DM

- Happily, T_R falls into the right range to give *cold* axino DM with a small admixture of warm axino DM, preserve BBN predictions (solving the gravitino problem) and have non-thermal leptogenesis!
- See HB and H. Summy, arXiv:0803.0510 (2008)



SuperWIMPs (e.g. $\tilde{G}$ in SUGRA or G in UED)

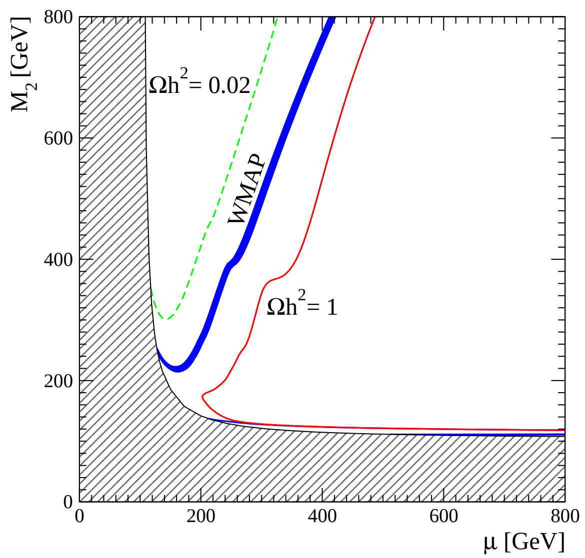
★ $m_{\tilde{G}} = F/\sqrt{3}M_* \sim$ TeV in Supergravity models

- usually $\tilde{G}$ decouples (but see Moroi et al. for BBN constraints)
- if $\tilde{G}$ is LSP, then calculate NLSP abundance as a thermal relic: $\Omega_{NLSP}h^2$
- $\widetilde{Z}_1 \to h\tilde{G},\ Z\tilde{G},\ \gamma\tilde{G}$ or $\tilde{\tau}_1 \to \tau\tilde{G}$ possible
  - lifetime $\tau_{NLSP} \sim 10^4 - 10^8$ sec
  - constraints from BBN, CMB not too severe
  - DM relic density is then $\Omega_{\tilde{G}} = \frac{m_{\tilde{G}}}{m_{NLSP}}\Omega_{NLSP} + \Omega_{\tilde{G}}^{TP}(T_R)$
  - Feng, Rajaraman, Su, Takayama; Ellis et al; Buchmuller et al.
- $\tilde{G}$ undetectable via direct/indirect DM searches
- unique collider signatures:
  - $\tilde{\tau}_1$=NLSP: stable charged tracks
  - can collect NLSPs in e.g. water (slepton trapping)
  - monitor for $NLSP \to \tilde{G}$ decays

SUGRA models beyond MSSM: NMSSM

⋆ Add extra singlet SF $\hat{S}$

- motivation: introduce μ parameter via SUSY breaking
- 3 neutral scalar higgs, 2 pseudoscalars and 5 neutralinos



Belanger, Boudjema, Hugonie, Pukhov, Semenov

Conclusions

- ⋆ Overwhelming evidence for CDM in the universe
- ⋆ Numerous candidate CDM particles
  - Axions: searches ongoing (ADMX group)
- ⋆ SUSY LSP: thermal relic from Big Bang
- ⋆ Various regions ⇒ distinct collider/DM signatures
- ⋆ Direct/ indirect DM detection prospects
- ⋆ Detection at colliders: Tevatron, LHC, ILC
- ⋆ Beyond mSUGRA:
  - NMH, NUHM1, NUHM2, MWDM, BWCA, low M_3, high M_2, comp. SUSY, $SO(10)$
  - axino $\tilde{a}$ or gravitino $\tilde{G}$ as dark matter
  - NMSSM