WIMPs and superWIMPs

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Dark Matter

- The dawn (mid-morning?) of precision cosmology:

$$\Omega_{DM} = 0.23 \pm 0.04$$

$$\Omega_{total} = 1.02 \pm 0.02$$
$$\Omega_{baryon} = 0.044 \pm 0.004$$
$$t_0 = 13.7 \pm 0.2 \text{ Gyr}$$

WMAP (2003)

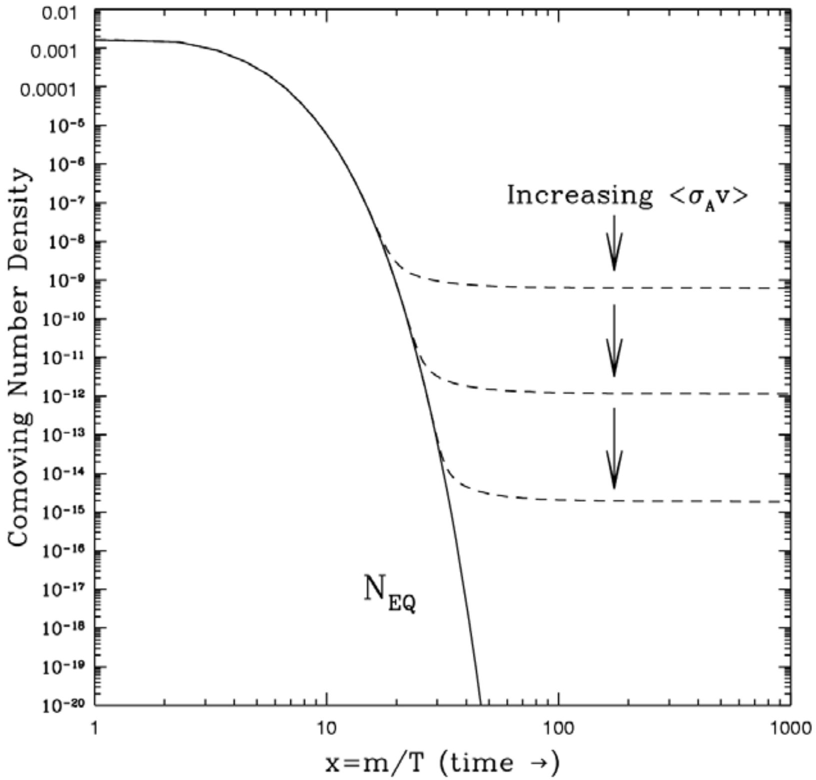
- We live in interesting times:
  We know how much dark matter there is
  We have no idea what it is

- Our best evidence for new particle physics

WIMPs

- Weakly-interacting particles with weak-scale masses decouple with $\Omega_{DM} \sim 0.1$; this is remarkable
  [Cf. quarks with natural $\Omega_B \sim 10^{-11}$]

- Either
  – a devious coincidence,
    or
  – a strong, fundamental, and completely cosmological motivation for new physics at the electroweak scale



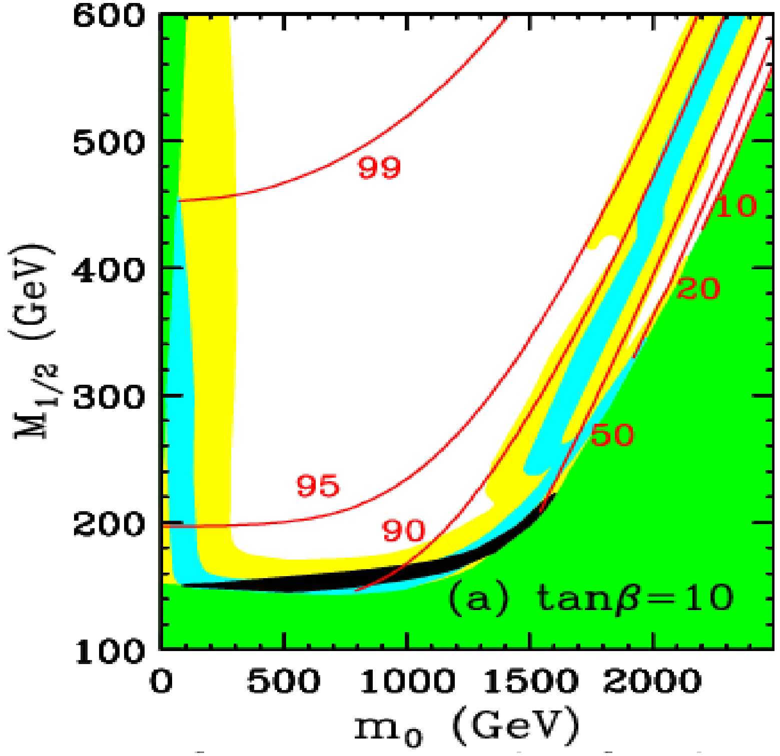
Jungman, Kamionkowski, Griest (1995)

SUSY WIMPs

- Neutralinos:
  - Depends on composition, but generally $\Omega_{DM} \sim 0.1$ in much of parameter space
- Requirements:
  - high supersymmetry breaking scale (supergravity)
  - *R*-parity conservation

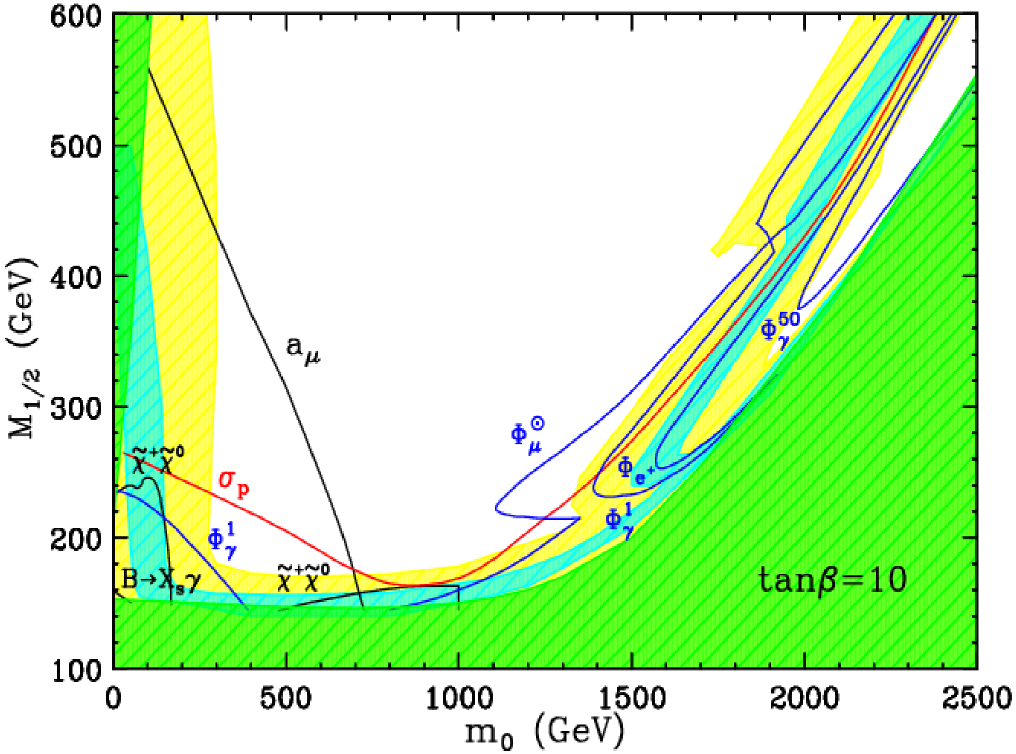
Relic density regions (blue $0.1 < \Omega_\chi h^2 < 0.3$)

and gaugino-ness (%)



Feng, Matchev, Wilczek (2000)

SUSY WIMP Detection



Observable	Type	Sensitivity	Experiment(s)
$\tilde\chi^\pm\tilde\chi^0$	Collider	See Ref. [5]	Tevatron: CDF, D0
$B \to X_s\gamma$	Low energy	$\lvert\Delta B(B \to X_s\gamma)\rvert < 1.2 \times 10^{-4}$	BaBar, BELLE
Muon MDM	Low energy	$\lvert a_\mu^{\rm SUSY}\rvert < 8 \times 10^{-10}$	Brookhaven E821
$\sigma_{\rm proton}$	Direct DM	$\sim 10^{-8}$ pb (See Ref. [5])	CDMS, CRESST, GENIUS
ν from Earth	Indirect DM	$\Phi_\mu^\oplus < 100$ km^{-2} yr^{-1}	Amanda, Nestor, Antares
ν from Sun	Indirect DM	$\Phi_\mu^\odot < 100$ km^{-2} yr^{-1}	Amanda, Nestor, Antares
γ (gal. center)	Indirect DM	$\Phi_\gamma(1) < 1.5 \times 10^{-10}$ cm^{-2} s^{-1}	GLAST
γ (gal. center)	Indirect DM	$\Phi_\gamma(50) < 7 \times 10^{-12}$ cm^{-2} s^{-1}	MAGIC
e^+ cosmic rays	Indirect DM	$(S/B)_{\rm max} < 0.01$	AMS-02

Particle probes
Direct DM detection
Indirect DM detection

- Astrophysical and particle searches are promising: many possible DM signals before 2007
- This is generally true of WIMPs: undetectable → weak interactions → weak annihilation → too much relic density

superWIMPs

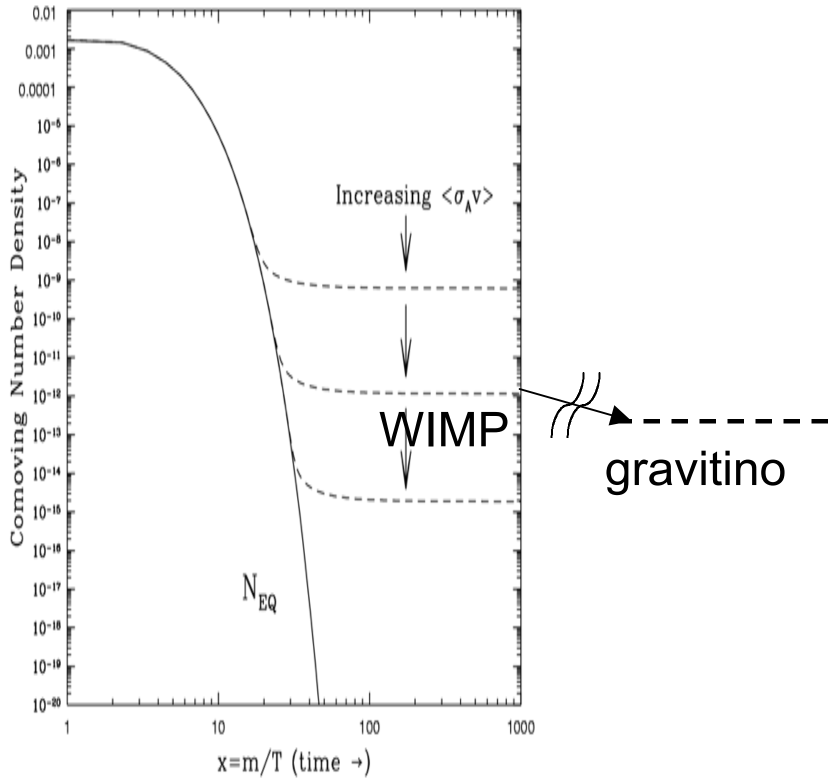
- Are neutralinos the only viable SUSY DM candidates? In SUGRA,

  $m_{3/2} \sim m_0 \sim M_{1/2} \sim \langle F \rangle / M_{Pl}$,

  unknown $O(1)$ coefficients determine ordering. Gravitino LSPs may be *cold* dark matter.

- If NLSP is a WIMP, the WIMP freezes out with the desired Ω, then decays much later via WIMP → gravitino.

- Gravitino inherits the desired Ω, retains all WIMP virtues.



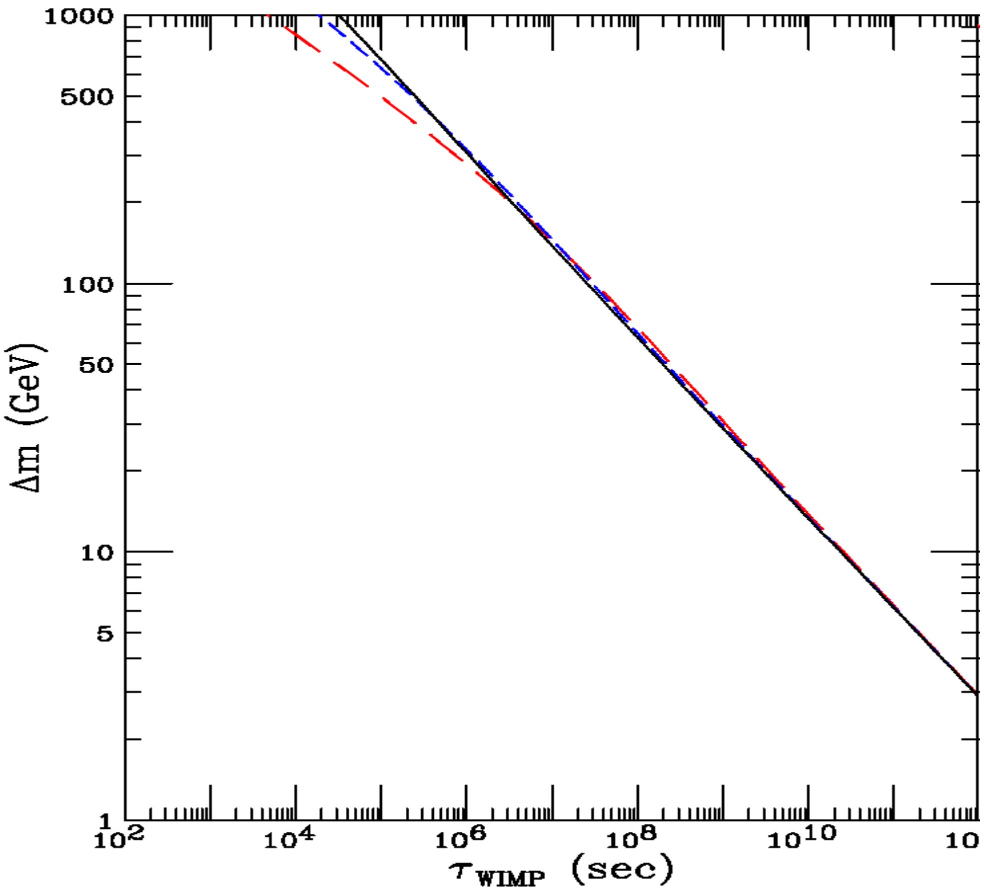
- BUT: Gravitino is superweakly-interacting, undetectable by *all* DM searches. Gravitino = *superWIMP* (also KK gravitons in UED,...)

superWIMP Lifetime

- The WIMP decay width depends only on the WIMP and gravitino massses
- For $\Delta m \ll m$, $\tau \sim (\Delta m)^{-3}$ and is independent of the overall mass scale
- For Bino NLSP,

$$\Gamma(\tilde{B} \to \tilde{G}\gamma) = \frac{\cos^2\theta_W}{48\pi M_*^2} \frac{m_{\tilde{B}}^5}{m_{\tilde{G}}^2} \left[1 - \frac{m_{\tilde{G}}^2}{m_{\tilde{B}}^2}\right]^3 \left[1 + 3\frac{m_{\tilde{G}}^2}{m_{\tilde{B}}^2}\right]$$

m_{sWIMP} = 0.1, 0.3, 1 TeV (from below)



Feng, Rajaraman, Takayama (2003)

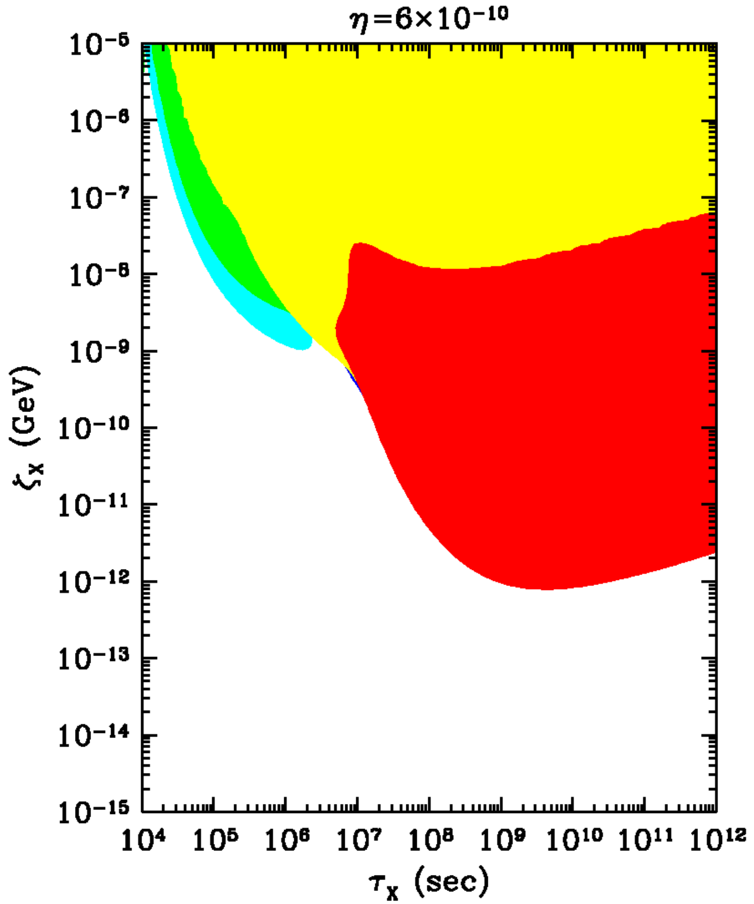
BBN

- Late decays may destroy BBN light element abundance predictions

- γ typically quickly thermalize, BBN constrains total energy release $\zeta_X = \varepsilon_\gamma \, n_{SWIMP} / n_{BG}$

- Constraints are weak for early decays: universe is hot, $\gamma \gamma_{BG} \rightarrow e^+e^-$ suppresses spectrum at energies above nuclear thresholds

Excluded Regions (shaded)



Cyburt, Ellis, Fields, Olive (2002)

CMB

- Late decays may also destroy black-body spectrum of CMB

- Again get weak constraints for early decays, when

  $e^- \gamma \rightarrow e^- \gamma$

  $e^- X \rightarrow e^- X \gamma$

  $e^- \gamma \rightarrow e^- \gamma \gamma$

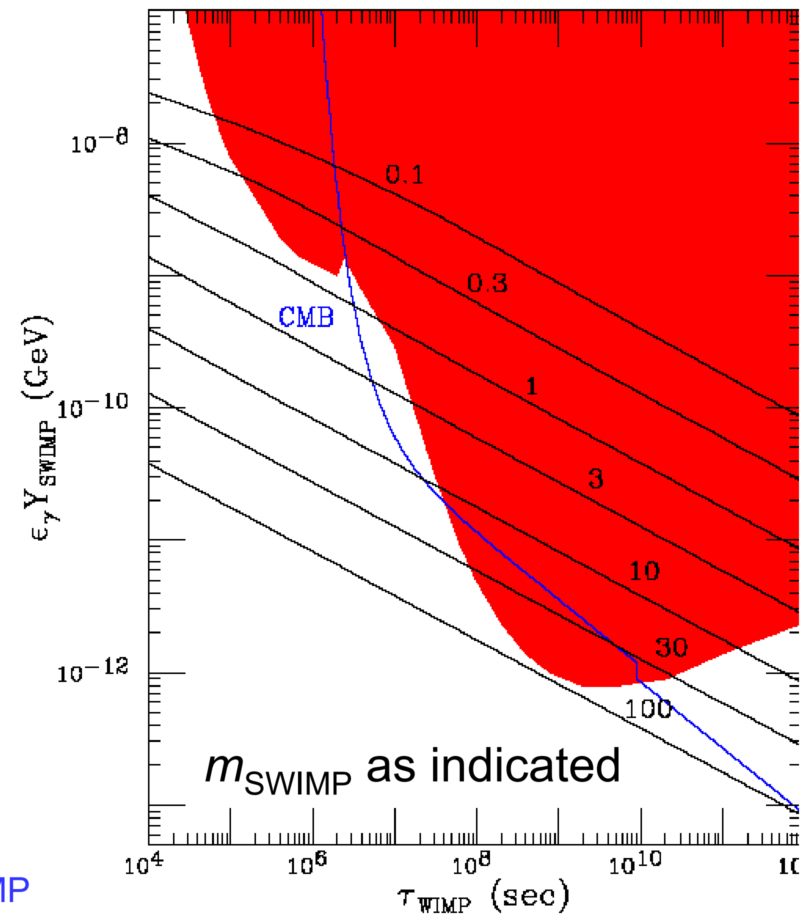
  are all effective

- superWIMP DM:

  $m_{\mathrm{WIMP}}, m_{\mathrm{SWIMP}} \rightarrow \tau, \varepsilon_\gamma$

  $\Omega_{\mathrm{SWIMP}} = \Omega_{\mathrm{DM}} \rightarrow$ abundance Y_{SWIMP}

Excluded regions (above CMB contours)



Feng, Rajaraman, Takayama (2003)

Diffuse Photon Flux

- For very late decays with small Δm, photons do not interact

- Photons produced at earlier times have larger initial

  $E\gamma \sim \Delta m$

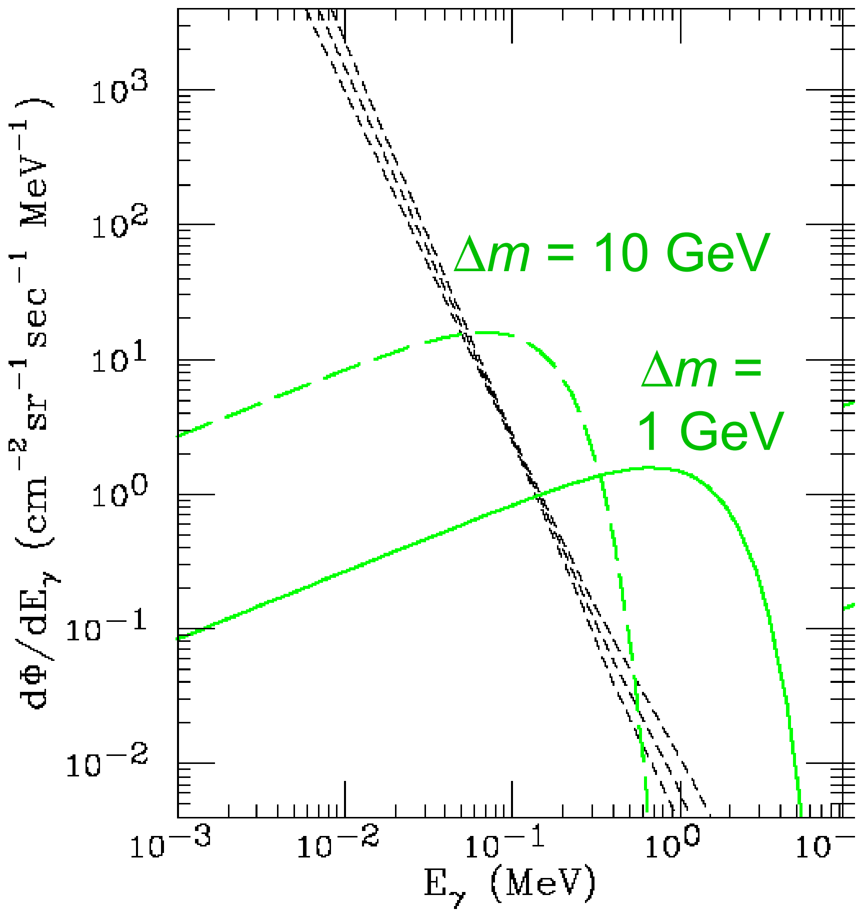
  but redshift by

  $1+z \sim \tau^{-2/3} \sim (\Delta m)^2$

  and so are now softer

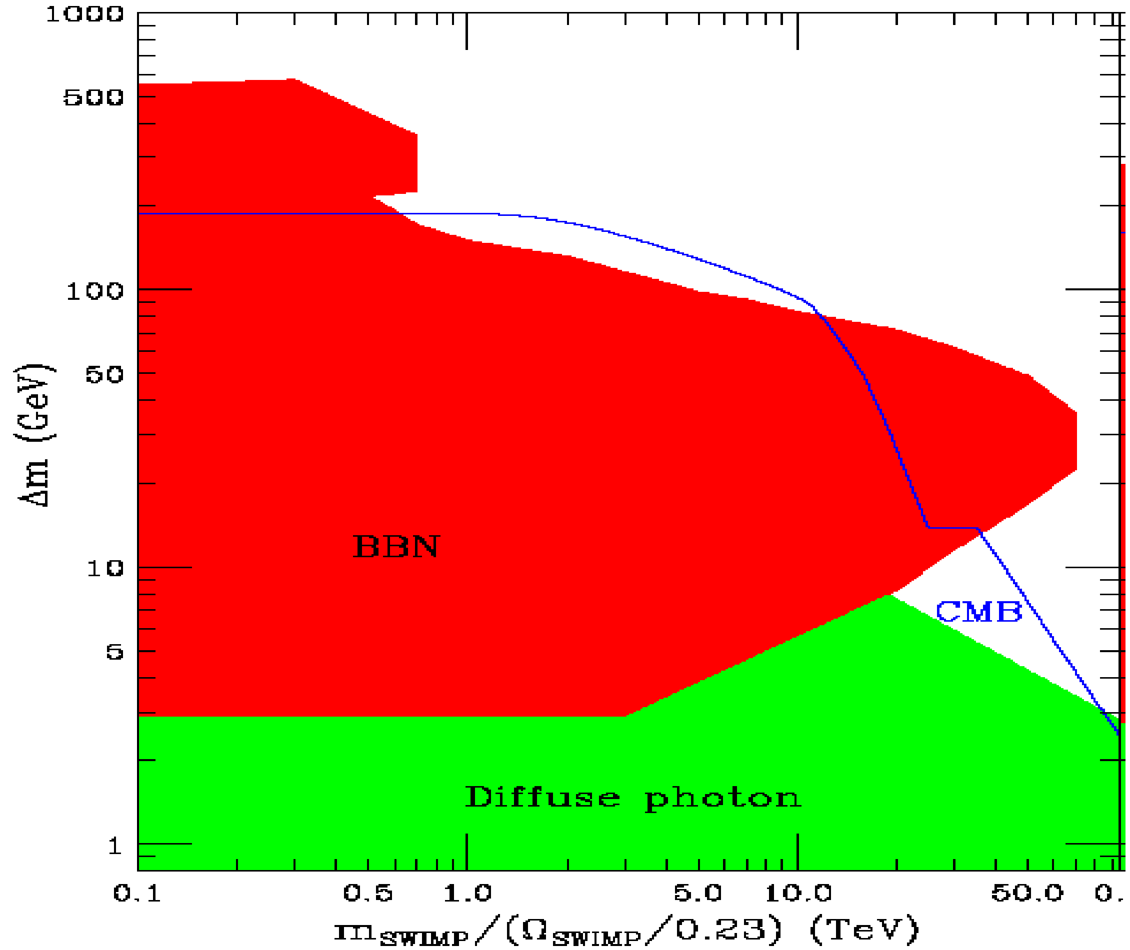
➔ stringent bounds on Δm < 10 GeV

m_{SWIMP} = 1 TeV



Feng, Rajaraman, Takayama (2003)

superWIMP Dark Matter

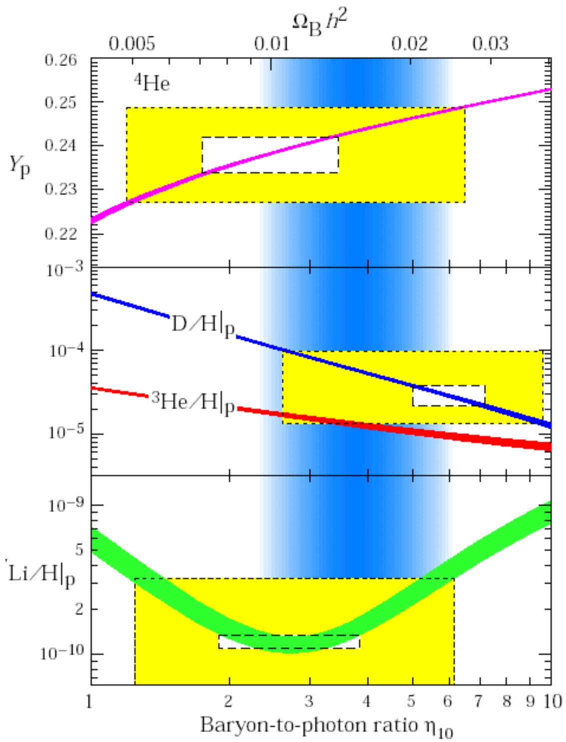


Feng, Rajaraman, Takayama (2003)

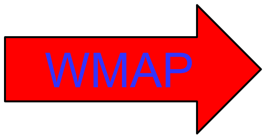
Weak-scale superWIMPs are viable CDM for natural parameters

Is it testable?

- BBN versus CMB baryometry is a powerful probe



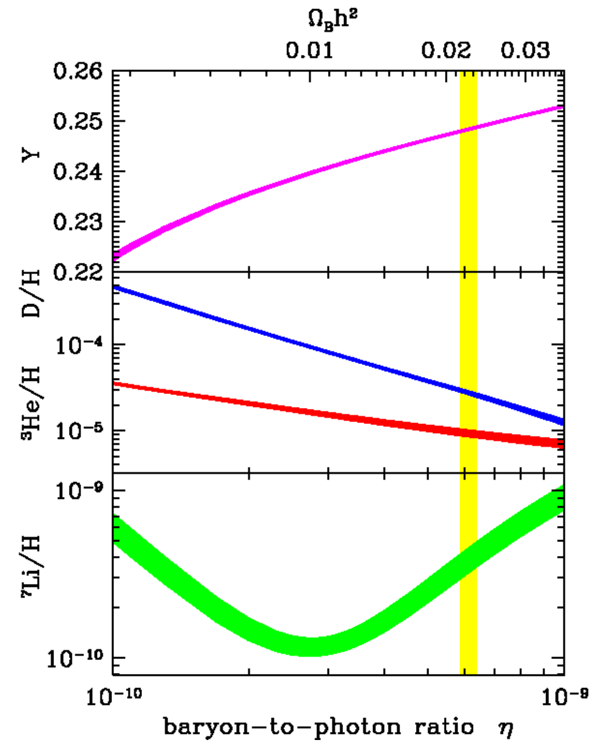
Fields, Sarkar, PDG (2002)



$\eta_D = \eta_{CMB}$

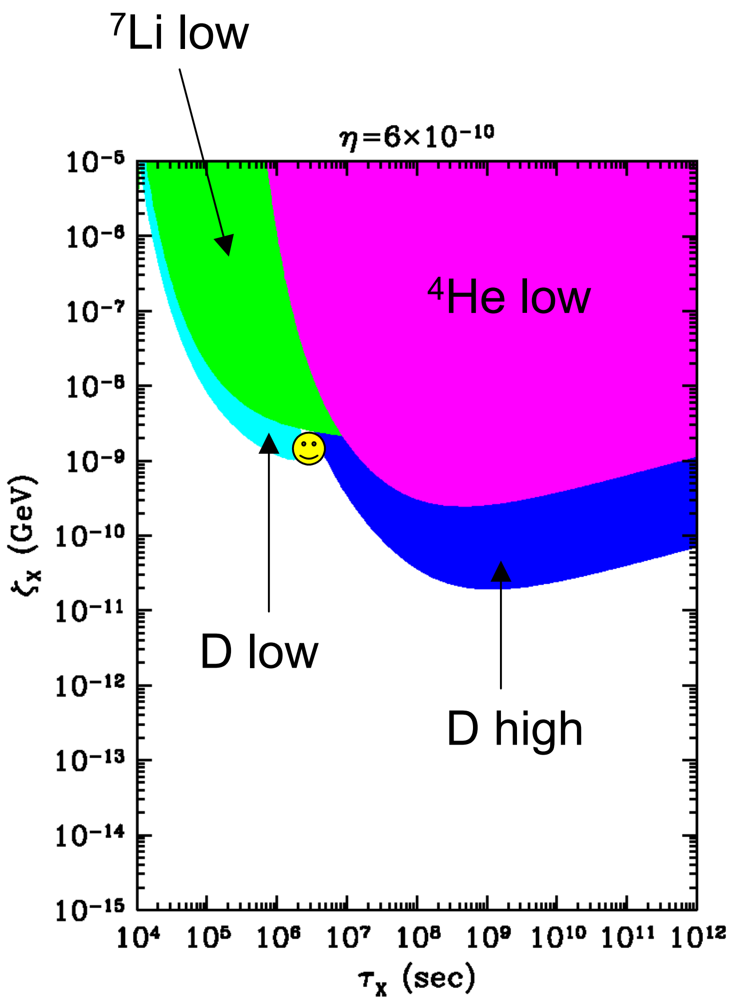
but

^{7}Li is low

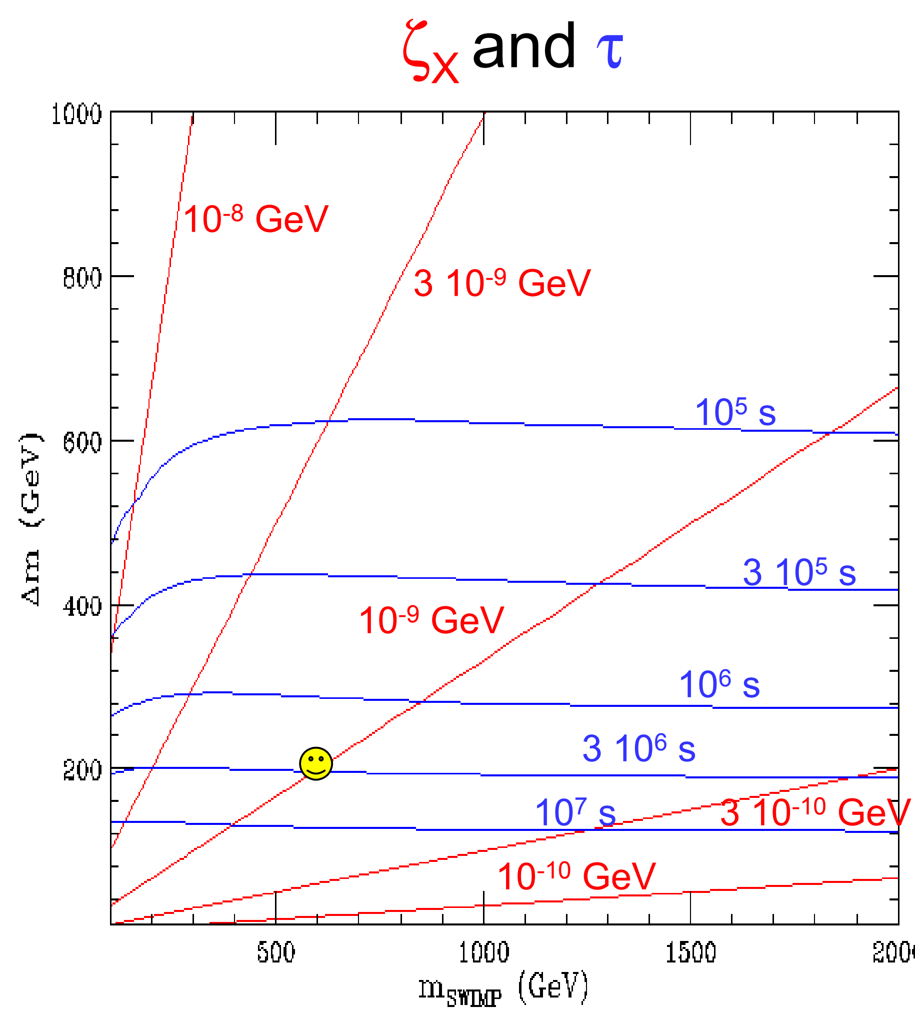


Cyburt, Fields, Olive (2003)

Gravitino superWIMPs: predicted lifetime and abundance are in the range to resolve BBN tensions



Cyburt, Ellis, Fields, Olive (2002)



Feng, Rajaraman, Takayama (2003)

Conclusions

- DM guiding principles:
  - well-motivated particle physics
  - naturally correct Ω_{DM}
- superWIMPs: gravitinos naturally obtain desired thermal relic density, preserve all WIMP virtues but are inaccessible to all conventional searches
- Bino NLSP: BBN, CMB signals
- Many other NLSP candidates to investigate

  Escape from the tyranny of neutralino dark matter!