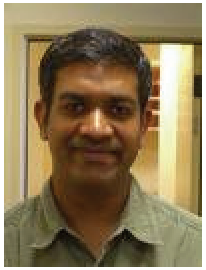
THE WIMPLESS MIRACLE

Jonathan Feng, UC Irvine

6 June 2008, Anticipating the LHC, KITP Santa Barbara

Based on Feng and Kumar, arXiv:0803.4196, and work in progress with



Jason Kumar

Louie Strigari

Huitzu Tu

Haibo Yu

LHC EXPECTATIONS

2 reasons to anticipate something rather than nothing (beyond the Higgs):

- Gauge hierarchy problem
- Dark matter
  - Qualitative: Ockham's razor
  - Quantitative: WIMPs give the right thermal relic density
  - Less robust: Other production mechanisms, candidates possible
  - More robust: Independent of notions of naturalness

WIMPs motivate many experimental searches

- Colliders: missing energy
- Dark matter searches: focused on masses around m_W ~ 100 GeV

Xerxes Tata's talk

START OVER

- What do we really know about dark matter?
  - All solid evidence is gravitational
  - Also solid evidence *against* strong and EM interactions
- A reasonable 1^{st} guess: dark matter has no SM gauge interactions, i.e., it is *hidden*
  - Hidden sectors: distinguished history and recent interest

Lee, Yang (1956); Gross, Harvey, Martinec, Rohm (1985)
Schabinger, Wells (2005); Patt, Wilczek (2006); Strassler, Zurek (2006); Georgi (2007); Kang, Luty (2008)
March-Russell, West, Cumberbatch, Hooper (2008); McDonald, Sahu (2008); Kim, Lee, Shin (2008); Krolikowski (2008); Foot (2008); many others

- What one (seemingly) loses
  - The WIMP miracle
  - Predictivity
  - Non-gravitational signals

THE WIMP MIRACLE

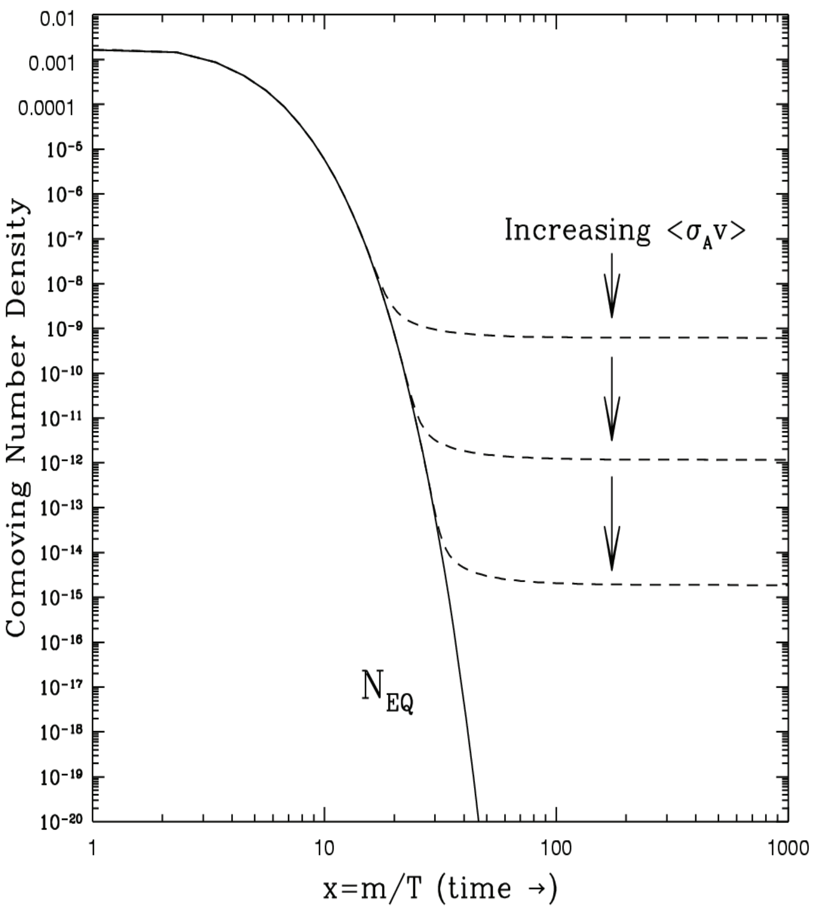
- WIMPs naturally freeze out with the desired relic density

- More explicitly:

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$

$(g_X, m_X) \sim (g_W, m_W) \rightarrow \Omega_X \sim \Omega_{DM}$

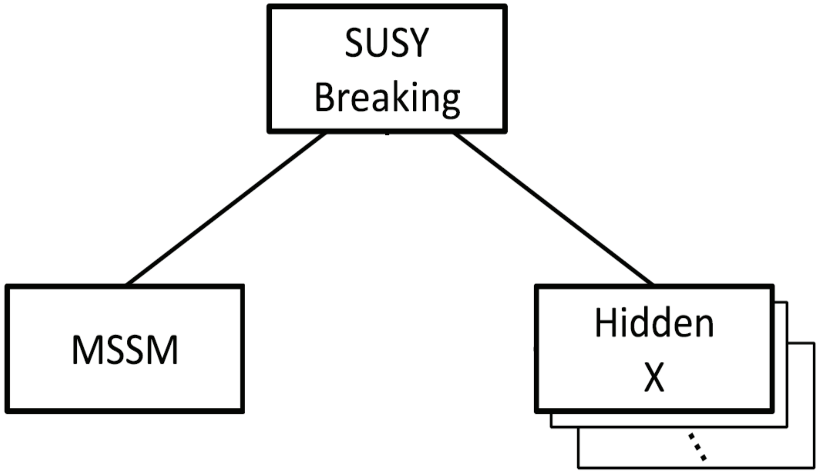
- Note: Ω_X , not n_X, appears above; m_X enters through σ and dimensional analysis



Kolb, Turner (1990)

HIDDEN SECTORS

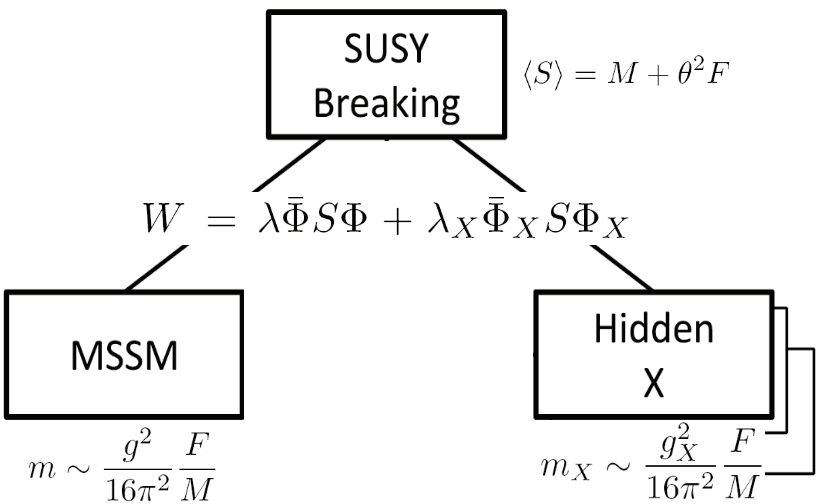
- Can we obtain something like the WIMP miracle, but with hidden DM? Need some structure.
- Consider standard GMSB with one or more hidden sectors
- Each hidden sector has its own gauge groups and couplings



THE WIMPLESS MIRACLE

Feng, Kumar (2008)

- Particle Physics



Superpartner masses, interaction strengths depend on gauge couplings

- Cosmology

$$\frac{m_X}{g_X^2} \sim \frac{m}{g^2} \sim \frac{F}{16\pi^2 M}$$

Ω depends only on the SUSY Breaking sector:

$$\Omega_X \sim \Omega_{WIMP} \sim \Omega_{DM}$$

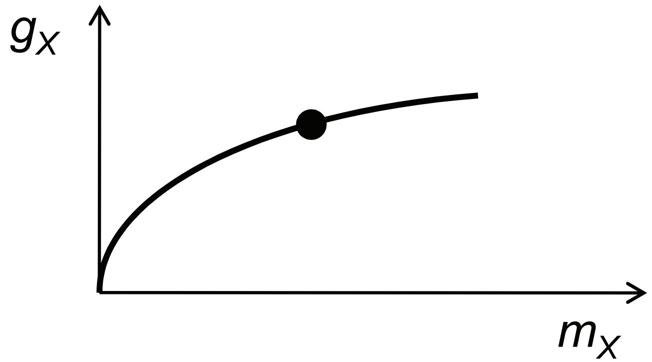
Any hidden particle with mass ~ m_X will have the right thermal relic density (for *any* m_X)

WIMPLESS DARK MATTER

- The thermal relic density constrains only one combination of g_X and m_X

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$

- These models map out the remaining degree of freedom



- This framework decouples the WIMP miracle from WIMPs, gives a new class of candidates with WIMP pedigree, but with a range of masses/couplings, e.g.:

$$10^{-3} \lesssim \; g_X \; \lesssim 3$$
$$10 \text{ MeV} \lesssim m_X \lesssim 10 \text{ TeV}$$

STABILITY

- This requires that an m_X particle be stable. Can one be?

MSSM		Flavor-free MSSM O(1) Yukawas	
m_X	sparticles, W, Z, t q, l	m_X	sparticles, W, Z, q, l, $\tilde{\tau}$ (or τ)
0	p, e, γ, ν, $\tilde{G}$	0	g, γ, ν, $\tilde{G}$

- If the hidden sector is a flavor-free MSSM, a natural NLSP candidate, the stau (or tau), would be stabilized by charge conservation. No bounds from hidden sea water, etc.

AN ASIDE: SUSY FLAVOR AND DARK MATTER

- Generically in SUSY there is tension between flavor and dark matter solutions
  - Flavor: small gravity effects → light gravitino
  - DM: neutralino LSP → heavy gravitino

- The standard thermal gravitino is no longer viable
  - $\Omega_{\tilde{G}} h^2 \approx 1.2 \, (m_{\tilde{G}} / \text{keV})$
  - $m_{\tilde{G}} > 2$ keV; DM can't be too hot

Pagels, Primack (1982)

Viel et al.; Seljak et al. (2006)

- WIMPless DM provides one resolution (there are others)

Han, Hempfling (1997); Baltz, Murayama (2003); Ibe, Kitano (2006); Feng, Smith, Takayama (2007)

CONCRETE MODELS

Feng, Tu, Yu (2008)

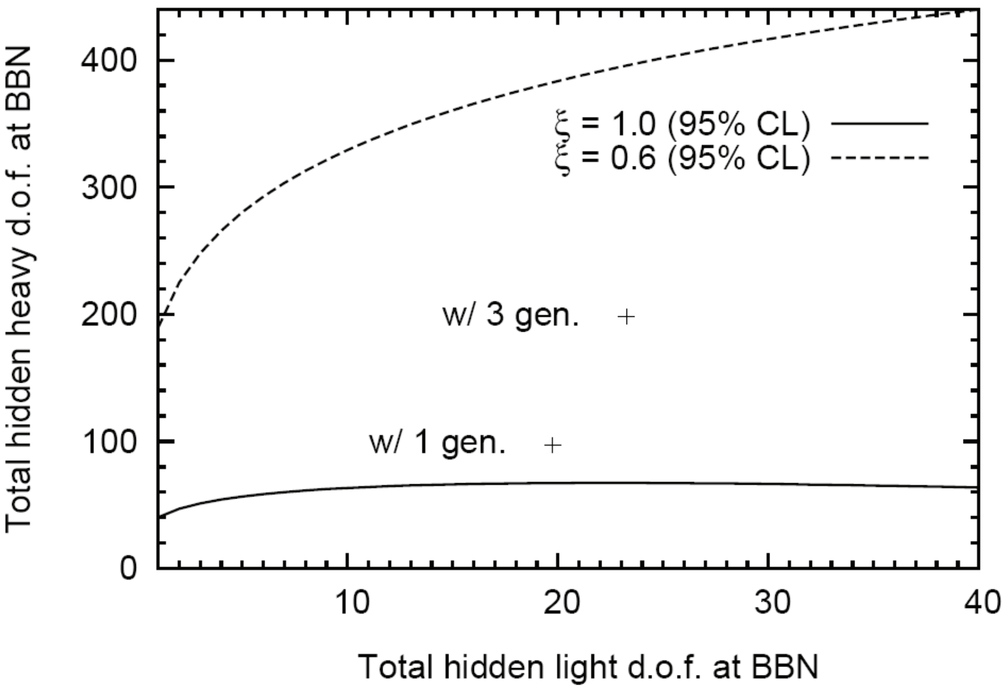
- Does all of this hold up under closer scrutiny?

- What hidden sectors are viable?

  BBN: $N_\nu = 3.24 \pm 1.2$

  Cyburt et al. (2004)

$T_H = \xi\, T_{MSSM}$



- Possible resolutions
  - Model building: $g_{*H} < g_{*MSSM}$
  - Cosmology: Hidden = MSSM or similar, but hidden sector reheats to lower temperature

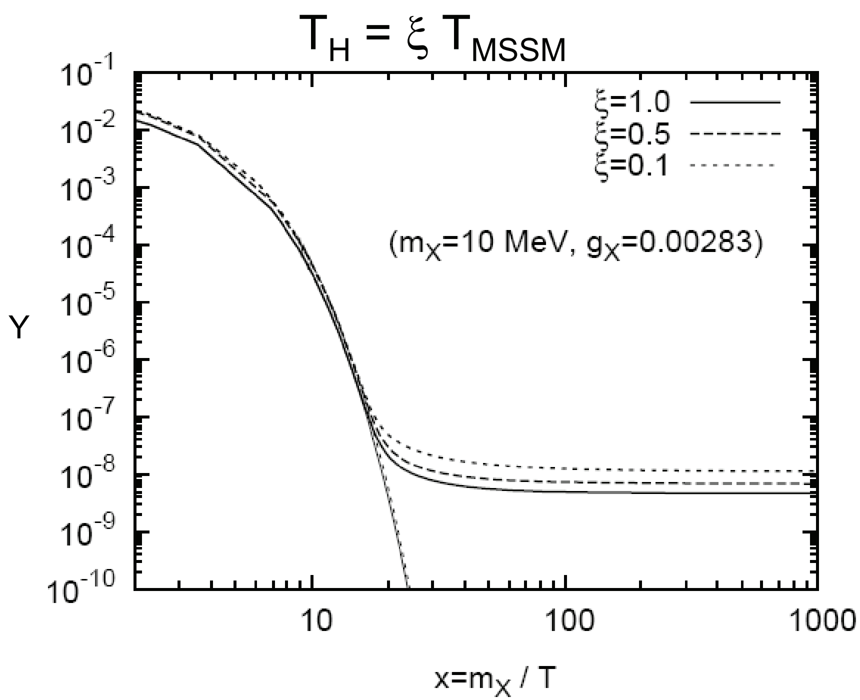
RELIC DENSITIES IN COLDER HIDDEN SECTORS

- The hidden Boltzmann equation:

$$\frac{dn}{dt} = -3Hn - \langle \sigma v \rangle \left[n^2 - n_{\rm eq}^2 \right]$$

  – All sectors contribute to H
  – $\langle\sigma v\rangle$ thermally-averaged over T_H

- Consider a hidden sector with
  – flavor-free MSSM
  – 1 generation
  – $\tilde{\tau}$ WIMPless candidate
  – $\tilde{\tau}\,\tilde{\tau} \rightarrow \gamma\gamma, \gamma Z$ (all are hidden particles)

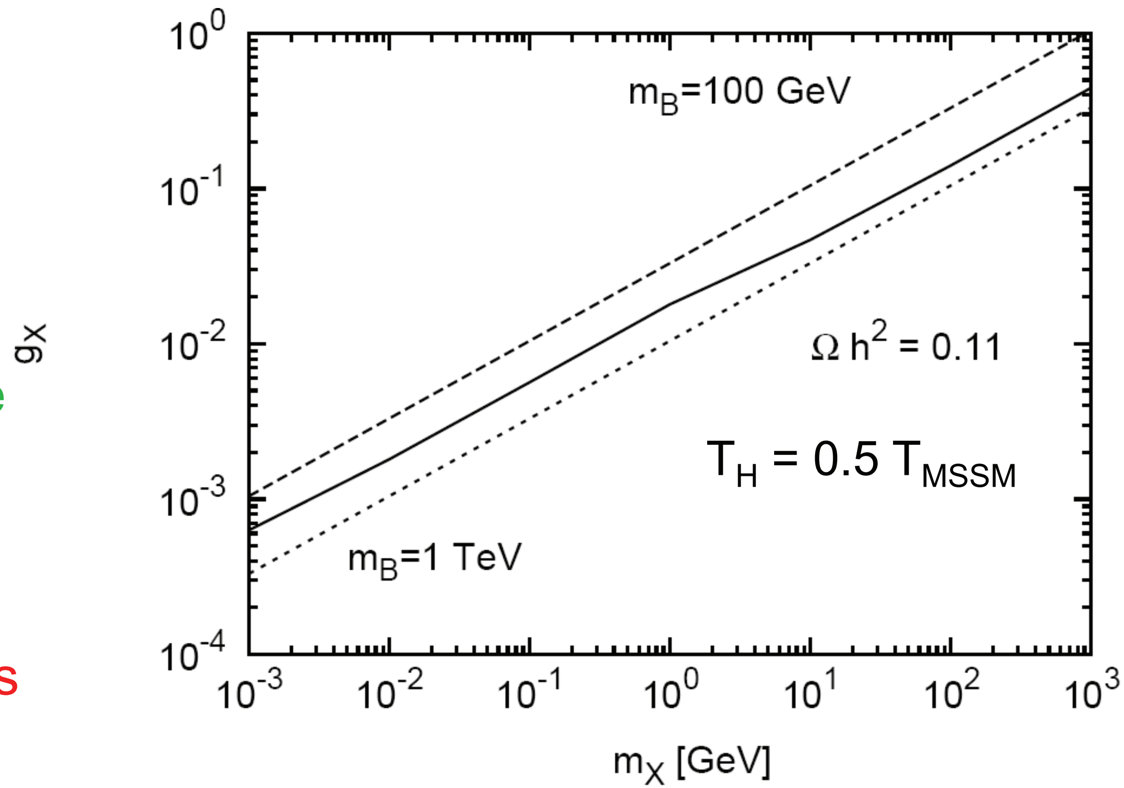


Feng, Tu, Yu (2008)

- Minimal impact : $\langle\sigma v\rangle = \sigma_0 + \sigma_1 v^2 + \ldots$, low T only suppresses sub-dominant P-wave contributions

RELIC DENSITIES IN COLDER HIDDEN SECTORS

- Numerically solve hidden Boltzmann equation for various (g_X, m_X)
- The parameters that give the correct relic density are also those that give weak-scale MSSM masses.
- The dimensional analysis is confirmed in this concrete example

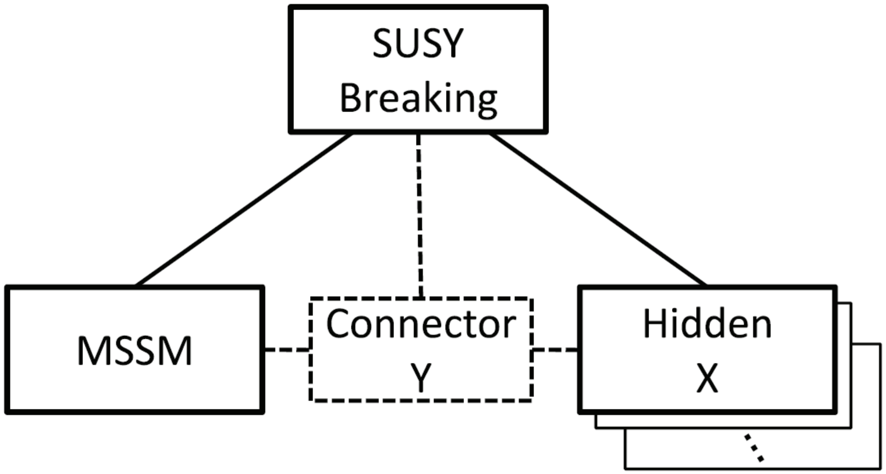


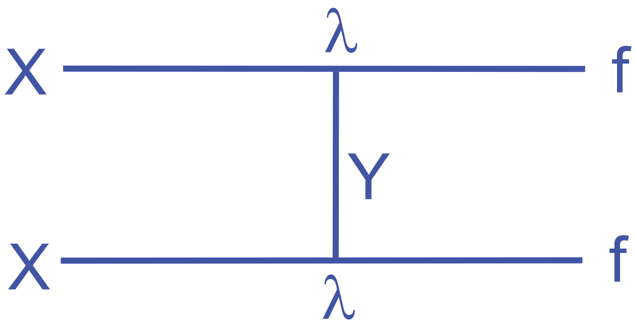
Feng, Tu, Yu (2008)

DETECTION

Feng, Kumar, Strigari (2008)

- So far, WIMPless DM has no observable consequences (other than gravitational)
- But we can add connectors with both MSSM and hidden charges; e.g., bifundamentals motivated by intersecting brane models
- Y particles mediate both annihilation to and scattering with MSSM particles





EXAMPLE

- Suppose the connectors are chiral Y multiplets, interacting through

$$\mathcal{L} = \lambda_f X \bar{Y}_{f_L} f_L + \lambda_f X \bar{Y}_{f_R} f_R + m_{Y_f} \bar{Y}_{f_L} Y_{f_R}$$

- *Y* particles get mass from both MSSM and hidden gauge-mediation, so

$m_Y \sim \max(m_W, m_X)$

- Does annihilation through Y's destroy the relic density properties?
  No, annihilation to MSSM is subdominant, as long as $\lambda_f < g_W$.

- Y's are subject to 4th generation constraints from collider direct searches, precision electroweak, Yukawa perturbativity. For 4th generation quarks,

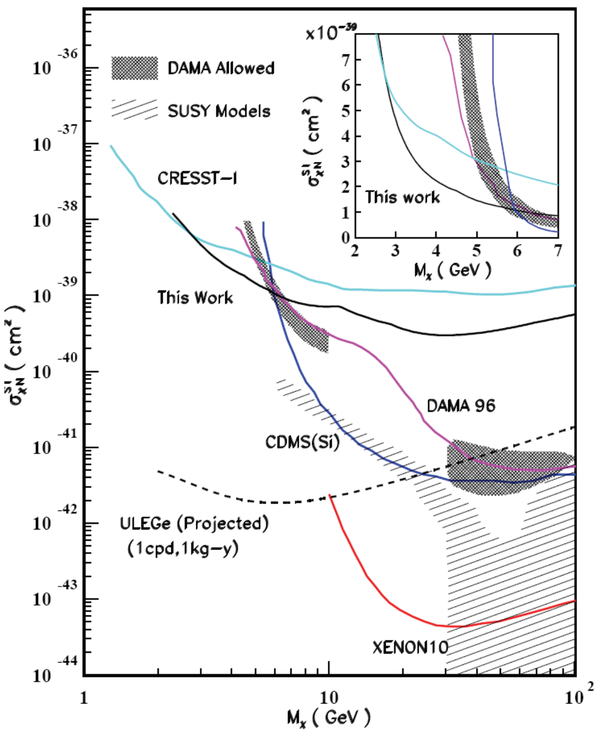
$250 \text{ GeV} < m_Y < 500 \text{ GeV}$

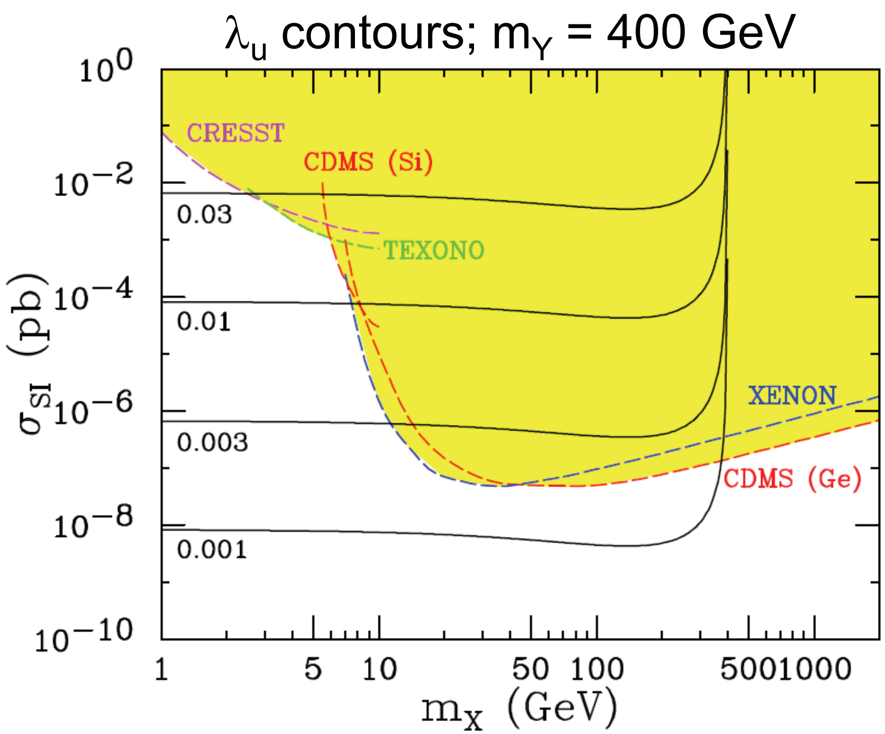
Kribs, Plehn, Spannowsky, Tait (2007); Fok, Kribs (2008)

SIGNATURES

- DM is under investigation in ~100 experiments around the world. Many hints of DM have been reported
  - DAMA
  - HEAT
  - HESS
  - INTEGRAL
  - WMAP haze
  - …
- Most are not naturally explained by WIMPs. What about WIMPless DM?

DIRECT DETECTION



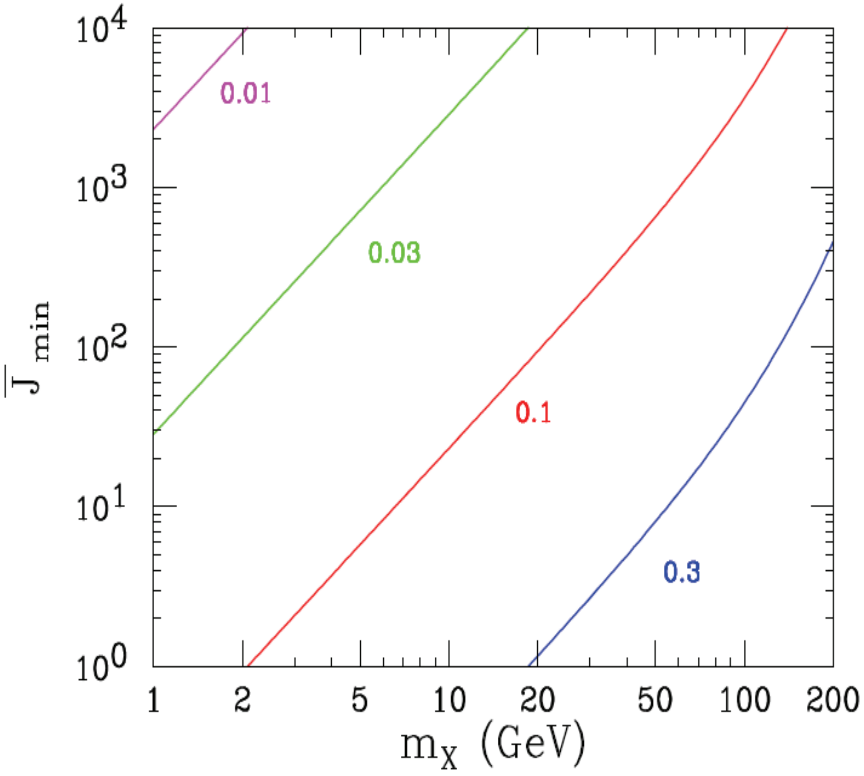


Gelmini, Gondolo (2005); TEXONO (2007)

- WIMPless DM can have very large cross sections, and masses from MeV to 10 TeV, explain DAMA

INDIRECT DETECTION

- WIMPless DM predicts constant Ω for all m
- But n ~ 1/m, and so indirect rates ~ n^2 are greatly enhanced for light DM (annihilation cross sections are determined by λ, not g)
- GLAST will be sensitive to ~GeV to 10 GeV WIMPless DM, even for smooth halos with $\bar{J}$ ~ 1 (not so for WIMPs)



LHC SIGNALS

- The WIMPless DM scenario motivates unusual LHC phenomenology of GMSB + 4th generation. Many effects:
  - Conventional GMSB spectrum with GMSB signals (prompt photon, multi-leptons, etc.)
  - But also pair production YY → XX f f, "gravity-mediated" missing energy signal
  - Higgs mass as high as 300 GeV
  - gg → h enhanced by ~ 10 from 4th generation in loop
  - Higgs portal
  - Enhanced, viable electroweak baryogenesis

Kribs, Plehn, Spannowsky, Tait (2007); Fok, Kribs (2008)

SUMMARY

- Early days
- WIMPless dark matter
  - Relic density: $\Omega \sim 0.1$
  - Mass: MeV to 10 TeV
  - Hidden gauge couplings: 10^{-3} to 1
- WIMP pedigree with potential for new signals
  - Direct detection
  - Indirect detection
  - LHC
  - Cosmology