

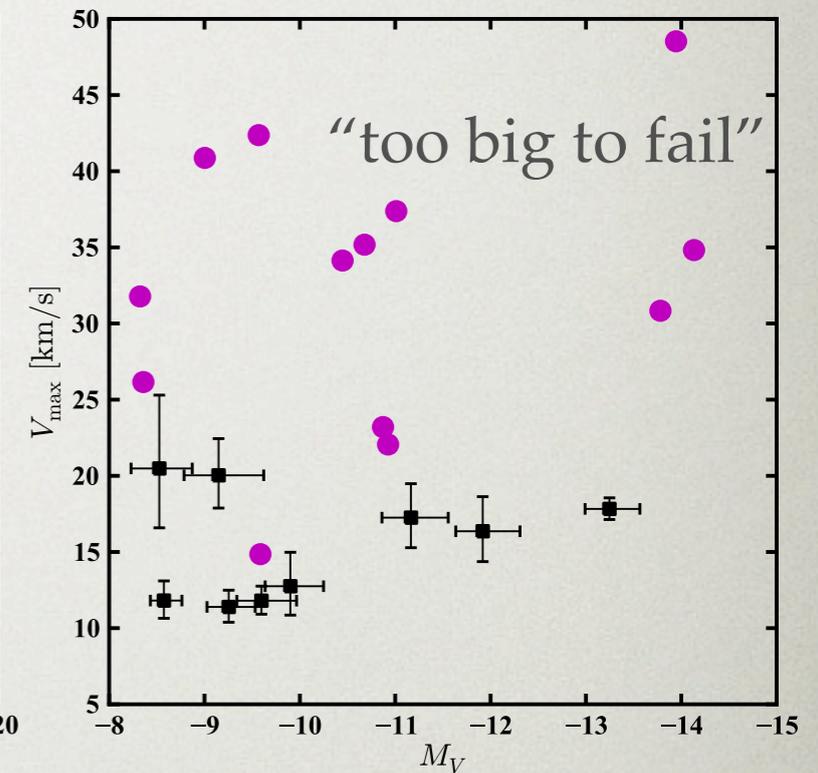
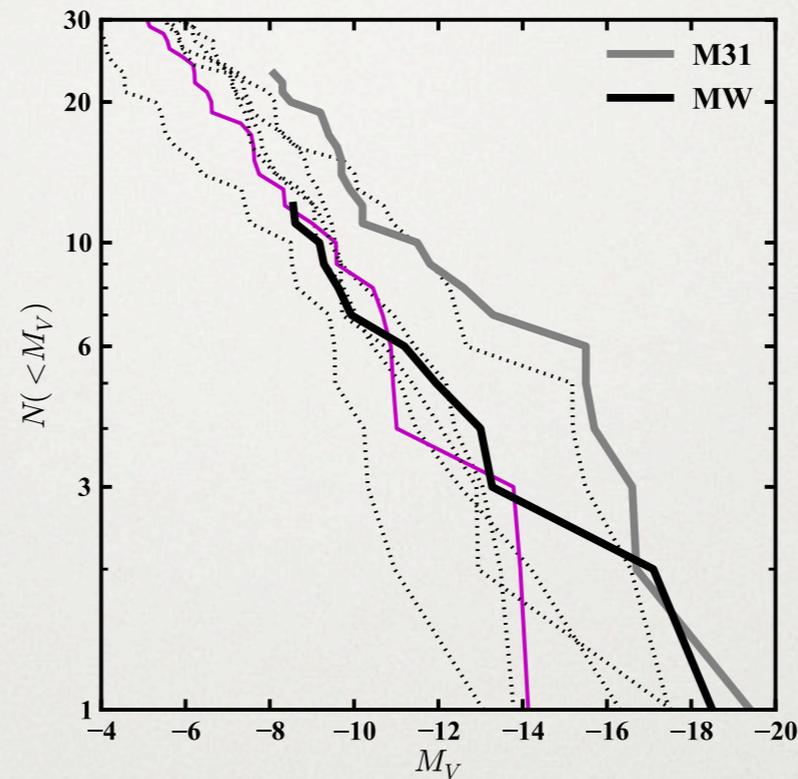
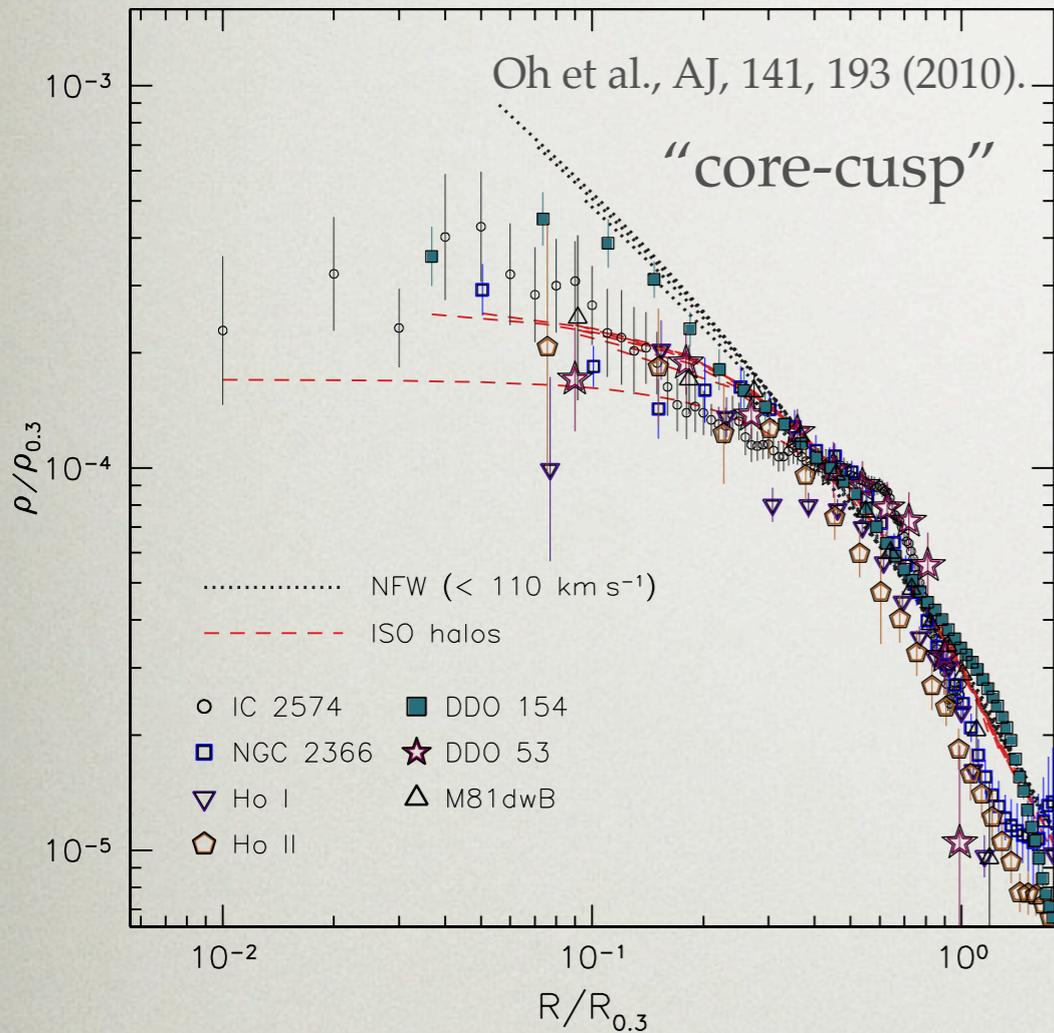
SELF-INTERACTING DARK MATTER IN A NON-ABELIAN HIDDEN SECTOR

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IN COLLABORATION WITH J. FENG, M. KAPLINGHAT, T. TAIT

PROBLEMS WITH COLLISIONLESS CDM



Boylan-Kolchin et al., MNRAS, 422, 1203 (2012).

SIDM solves these issues on scales
from dwarfs to clusters

Need $0.1 \text{ cm}^2/\text{g} \lesssim \frac{\sigma}{m} \lesssim 1.0 \text{ cm}^2/\text{g}$

UCI: constant cross sections

Rocha et al., MNRAS, 430, 81 (2013).

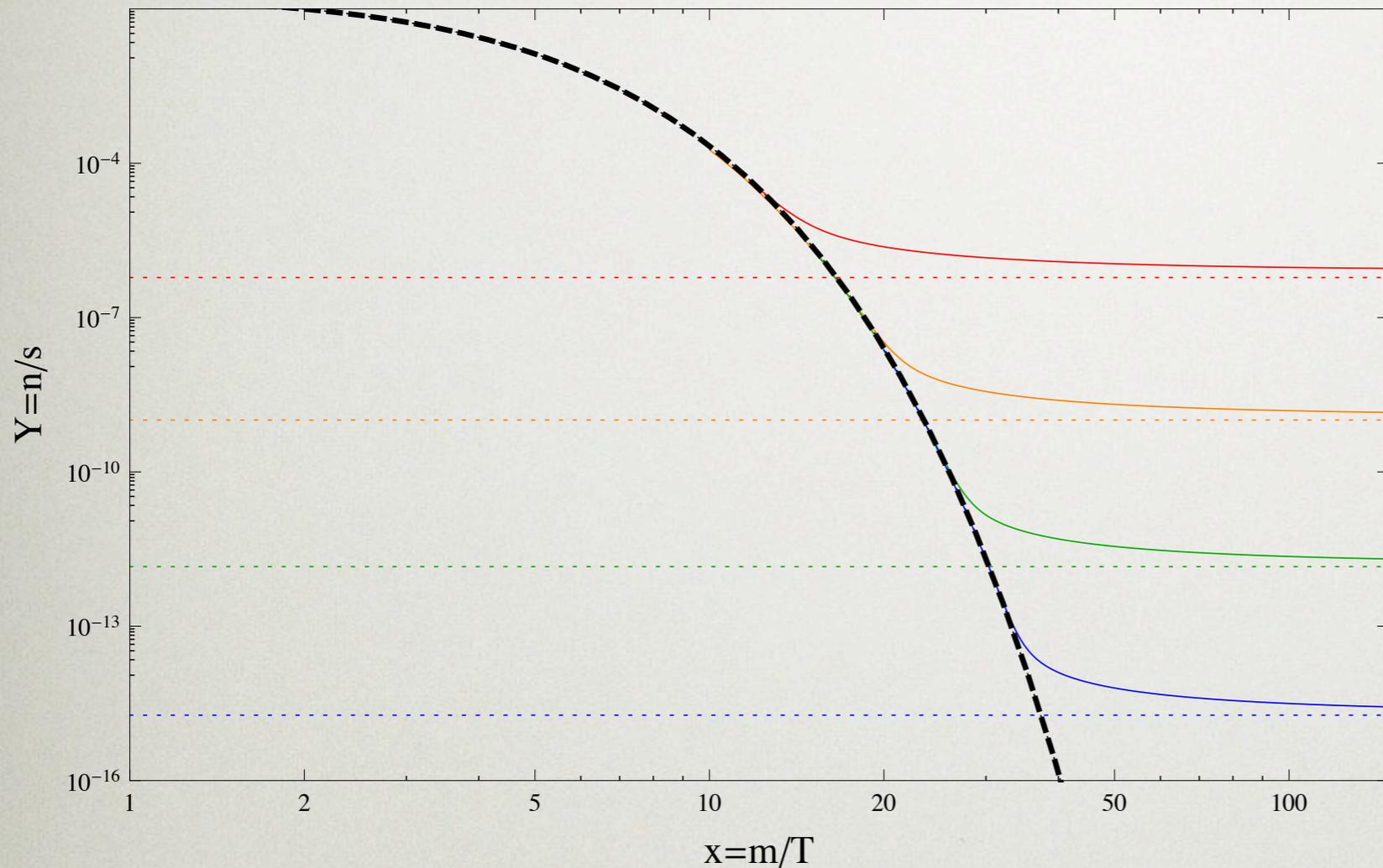
Peter et al., arXiv 1208.3026 [astro-ph.CO].

Harvard: velocity-dependent cross sections

Vogelsberger et al., MNRAS 423, 3740 (2012).

Zavala et al., 1211.6426 [astro-ph.CO].

COLD DARK MATTER



WIMP miracle

$$\Omega_{\text{CDM}} \simeq 0.23 \frac{\xi_f}{k} \left[\frac{0.025 m}{\alpha \text{ TeV}} \right]^2$$

WIMPless miracle

$$\Omega_{\text{CDM}} \sim \frac{1}{\langle \sigma v \rangle} \sim \frac{m^2}{\alpha^2}$$

Feng and Kumar, PRL, 101, 231301 (2008).

Do not need to be restricted to weak-scale particles

Hidden sector may have dark forces and different temperature

$$\xi \equiv \frac{T^h}{T}$$

s-wave annihilation:

$$\sigma v = k\pi \frac{\alpha^2}{m^2} \approx 3 \times 10^{-27} \text{ cm}^3/\text{s}$$

AMSB WITH SU(N) HIDDEN GAUGE

- AMSB naturally sets correct abundance $\frac{m_X}{g_X^2} \sim \frac{m_{3/2}}{16\pi^2} \sim \frac{m_\nu}{g_\nu^2}$
- SU(N) pure hidden sector (gluinos, gluons)
- Hidden gluinos are early-universe dark matter, hLSP

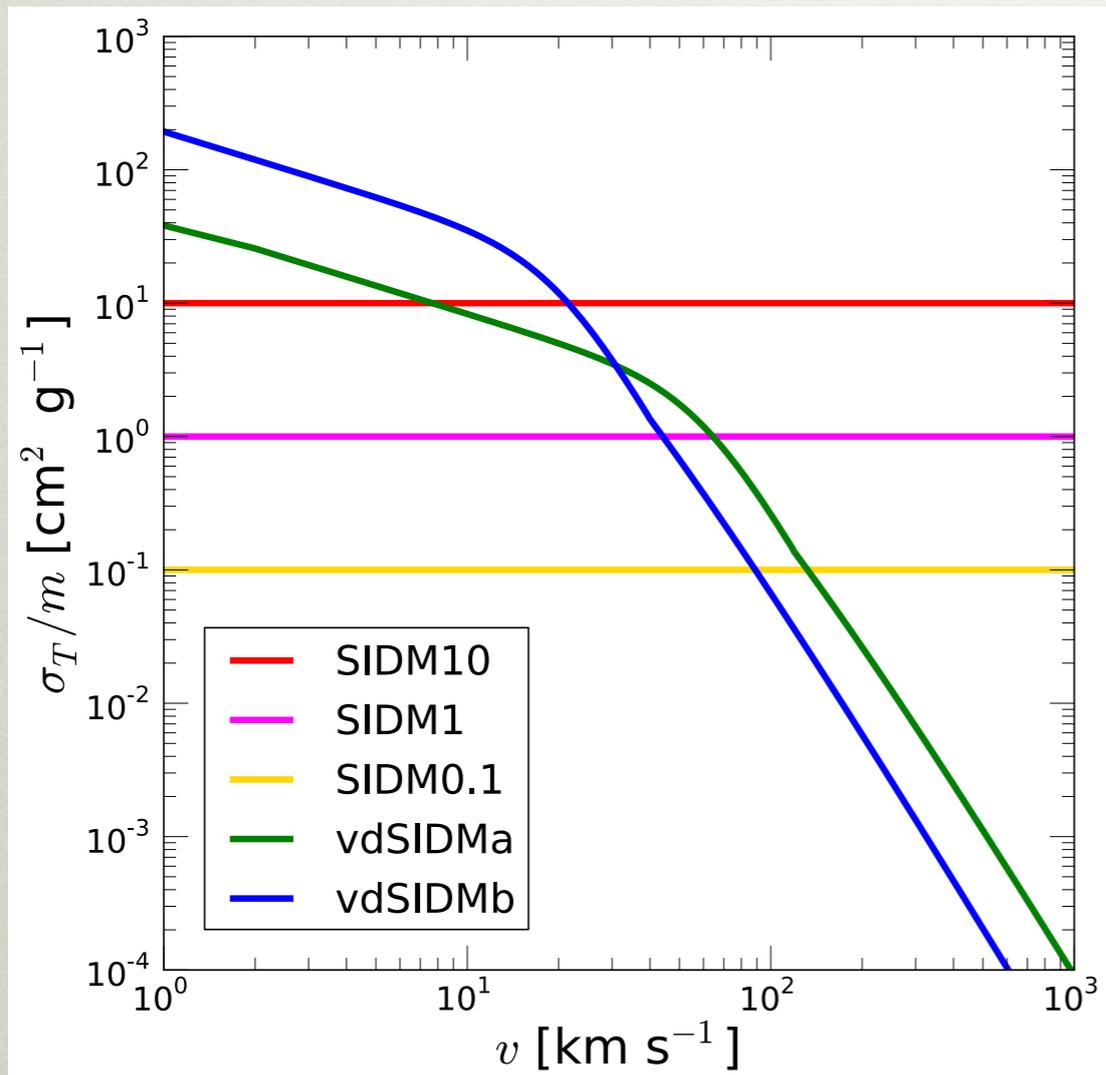
$$m_X = 3N \frac{\alpha_X}{4\pi} m_{3/2}$$

- Stable hLSP (R-parity) without MSSM connectors
- Confinement scale $\Lambda \sim m_X e^{-9m_{3/2}/22m_X}$
- Composite particles with “strong” interactions
 - Hidden glueballs ($g^h g^h$) with mass Λ
 - Hidden glueballinos ($\tilde{g}^h g^h$) with mass m_X
- Scattering via exchange of hidden glueballs

DARK MATTER SCATTERING

Yukawa potential

$$V(r) = -\frac{\alpha}{r} \exp(-\Lambda r)$$

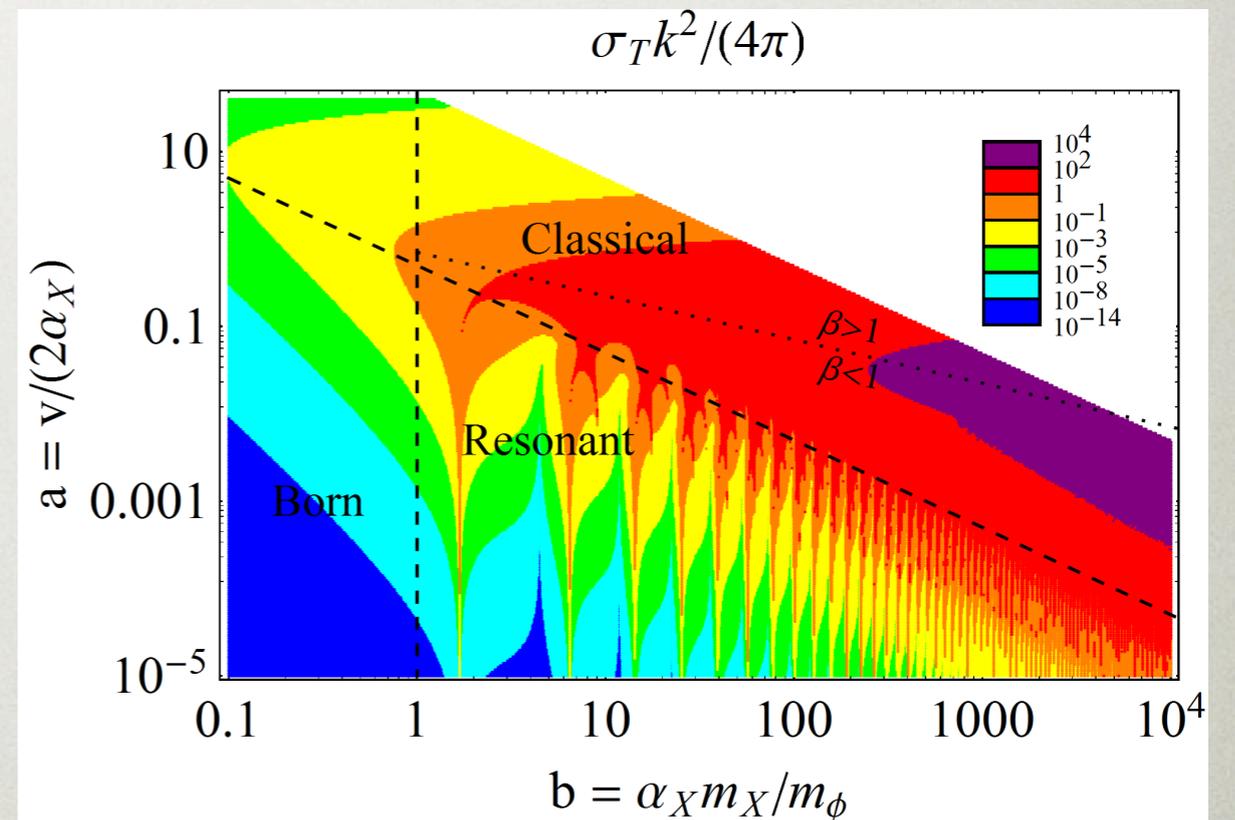


Vogelsberger and Zavala, MNRAS 430, 1722 (2013).

Transfer cross section:

$$\sigma_T = \int d\Omega (1 - \cos \theta) \frac{d\sigma}{d\Omega}$$

$$\sigma_T = \frac{4\pi}{k^2} \sum_{l=0}^{\infty} (l+1) \sin^2(\delta_{l+1} - \delta_l)$$



Tulin et al., arXiv:1302.3898 [hep-ph].

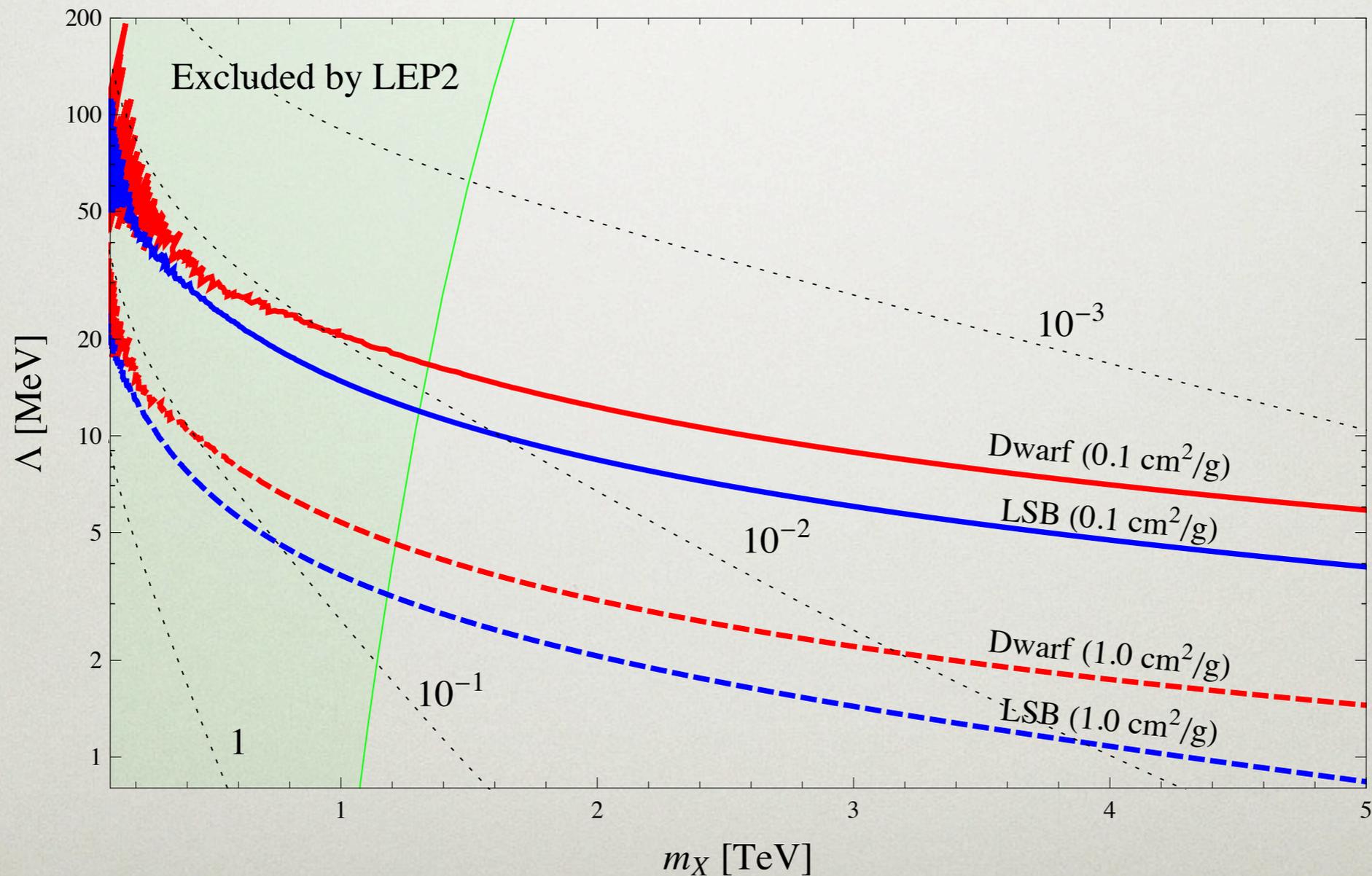
DARK MATTER SCATTERING

$$\langle \sigma_T \rangle = \int_0^{2\sqrt{2}v_0} \frac{d^3v}{(2\pi v_0^2)^{3/2}} e^{-v^2/2v_0^2} \sigma_T(v)$$

$v_0(\text{dwarf}) \sim 40 \text{ km/s}$

$v_0(\text{LSB}) \sim 100 \text{ km/s}$

$v_0(\text{cluster}) \sim 1000 \text{ km/s}$



AVOID OVER-CLOSURE

- Both glueballinos and glueballs contribute to CDM relic density

$$\Omega_{\text{gb}} \sim \frac{Y_{\infty} s_0 \Lambda}{\rho_{c0}}$$

$$\Omega_X + \Omega_{\text{gb}} = \Omega_{\text{CDM}}$$

$$Y_{\infty} = \frac{45\zeta(3)}{2\pi^4} \xi_f^3 \frac{g_{\text{eff}}(t_f)}{g_{*S}(t_f)}$$

- Need Ω_X to be dominant contribution
- For $N=2$, $\Lambda \sim 0.1$ MeV

$$\xi_f < 0.07$$

$$T_{\Lambda} > 3 \text{ MeV}$$

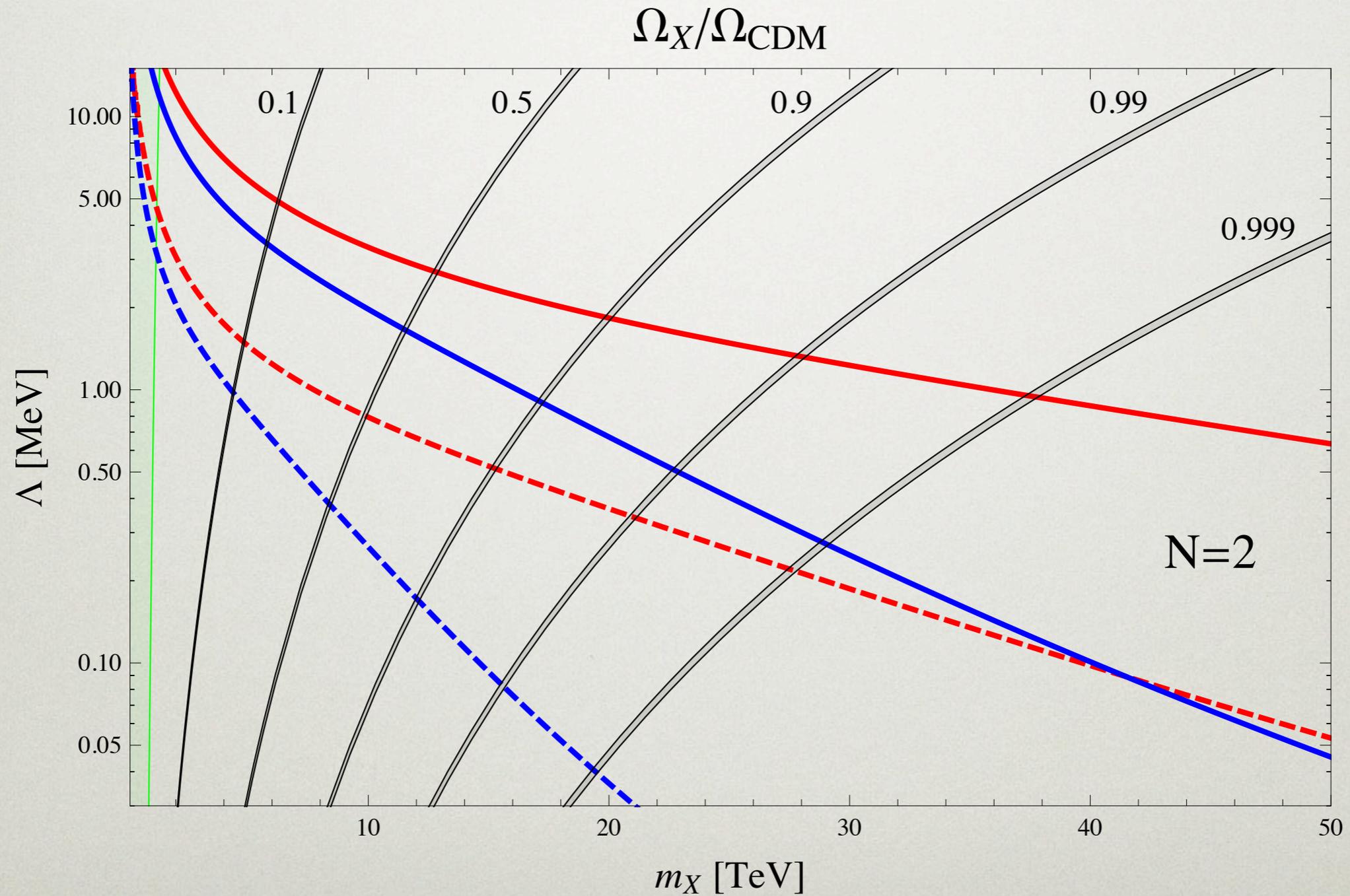
$$N_{\text{eff}} = 3.30 \pm 0.27$$

Planck 2013 results,
arXiv:1303.5076 [astro-ph.CO]

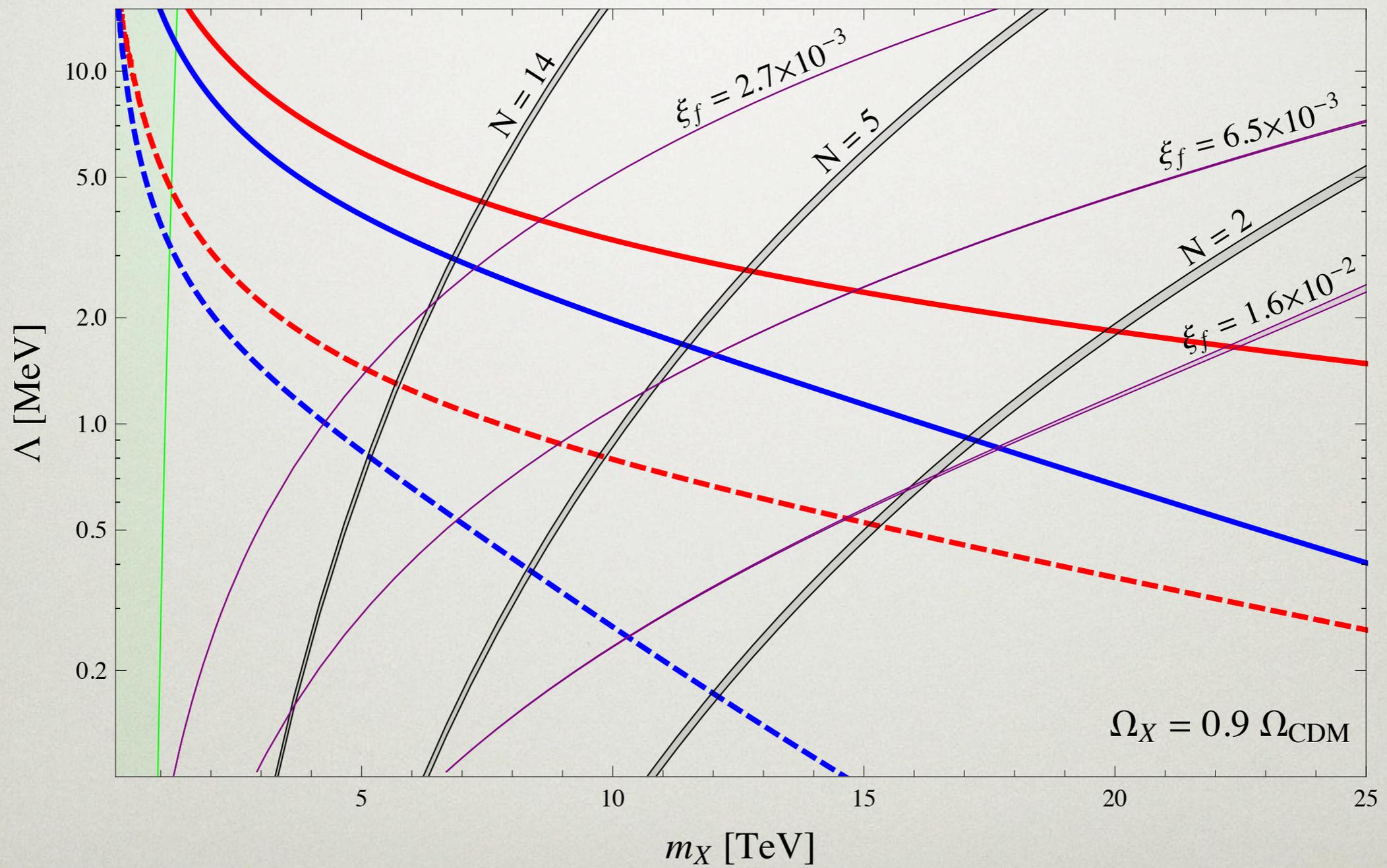
Hidden sector contributes

$$g_*^h \xi^4 = 2(N^2 - 1)\xi^4$$

RELIC ABUNDANCE: PURE SU(N)

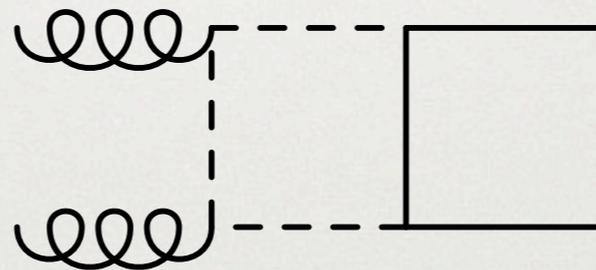


RELIC ABUNDANCE: PURE SU(N)

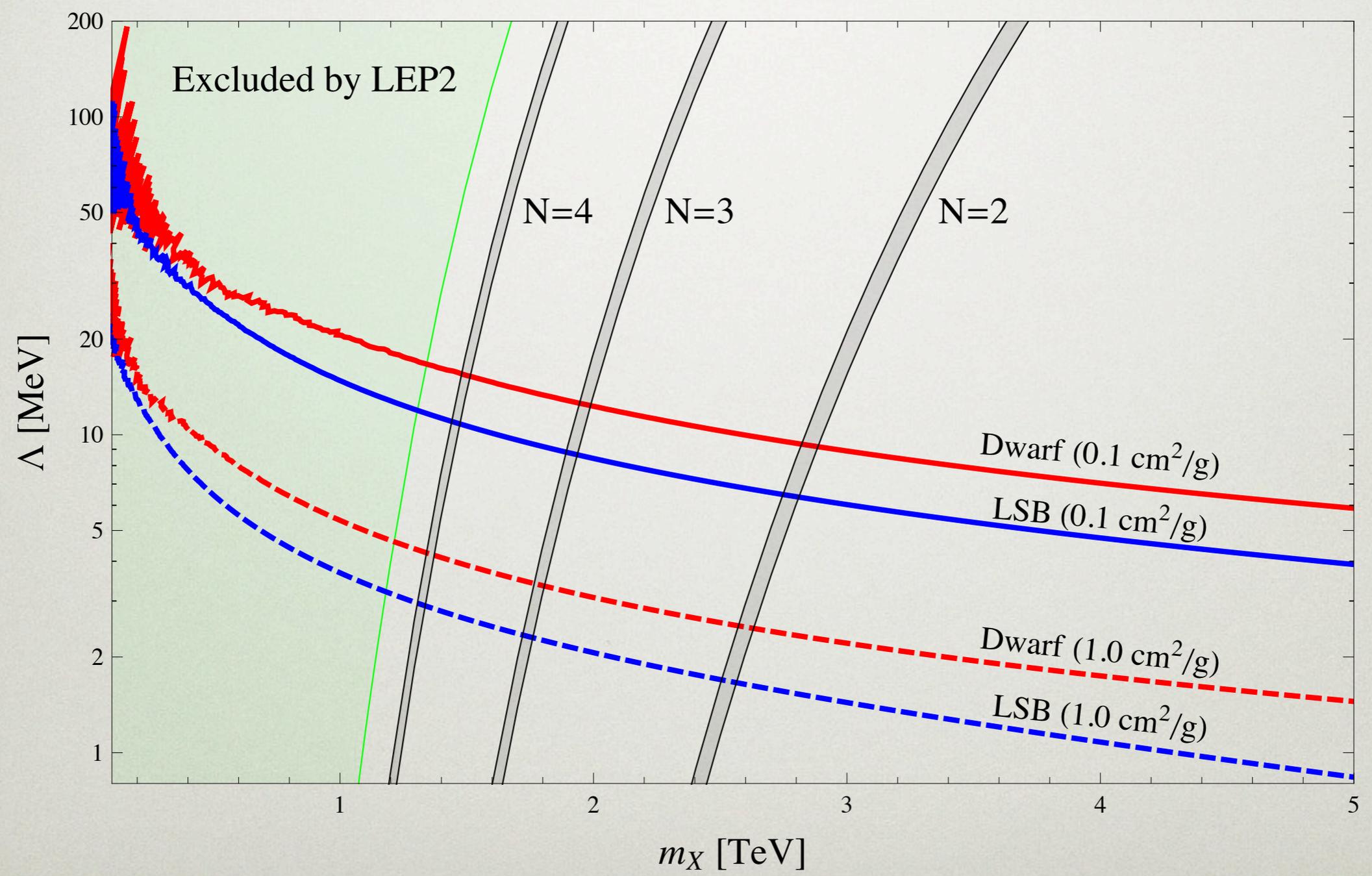


PURE SU(N) WITH CONNECTORS

- Consider connector fields to SM
- Allow hidden glueballs to decay
 - electrons
 - photons
 - neutrinos
- Visible and hidden sectors might not decouple prior to confinement $\xi_f = 1$
- Confinement temperature is $T_\Lambda = \Lambda$



RELIC ABUNDANCE: PURE SU(N) WITH CONNECTORS



SUMMARY

- Λ CDM is insufficient on small scales
- SIDM provides an appealing solution from dwarf to cluster scales, while preserving large-scale structure
- Use WIMPless miracle and AMSB framework to set correct dark matter relic abundance
- SU(N) composite particles allow for interactions with large scattering cross sections
- Solve astrophysical anomalies on dwarf and LSB scales
- Consistent with bounds from cluster mergers
- Decays to SM particles -- work in progress