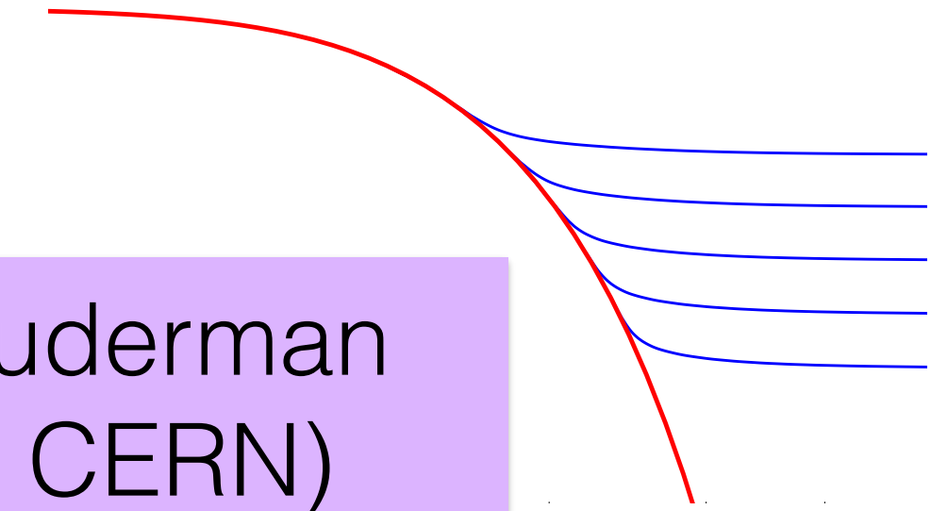
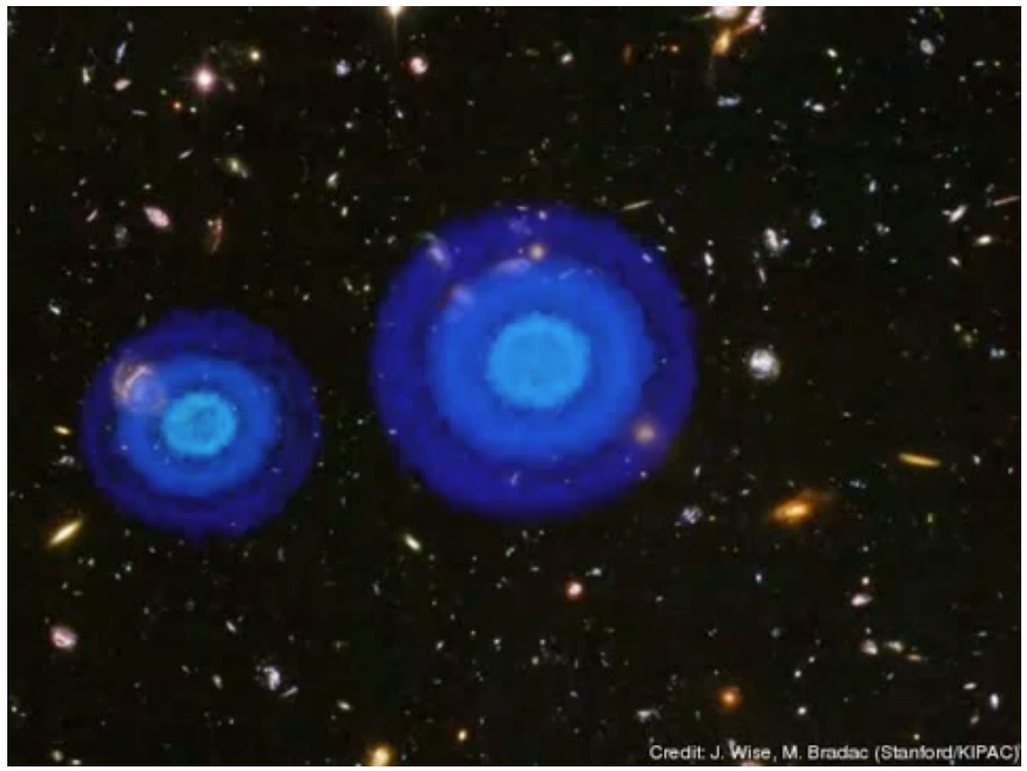
NYU

Center for Cosmology and Particle Physics

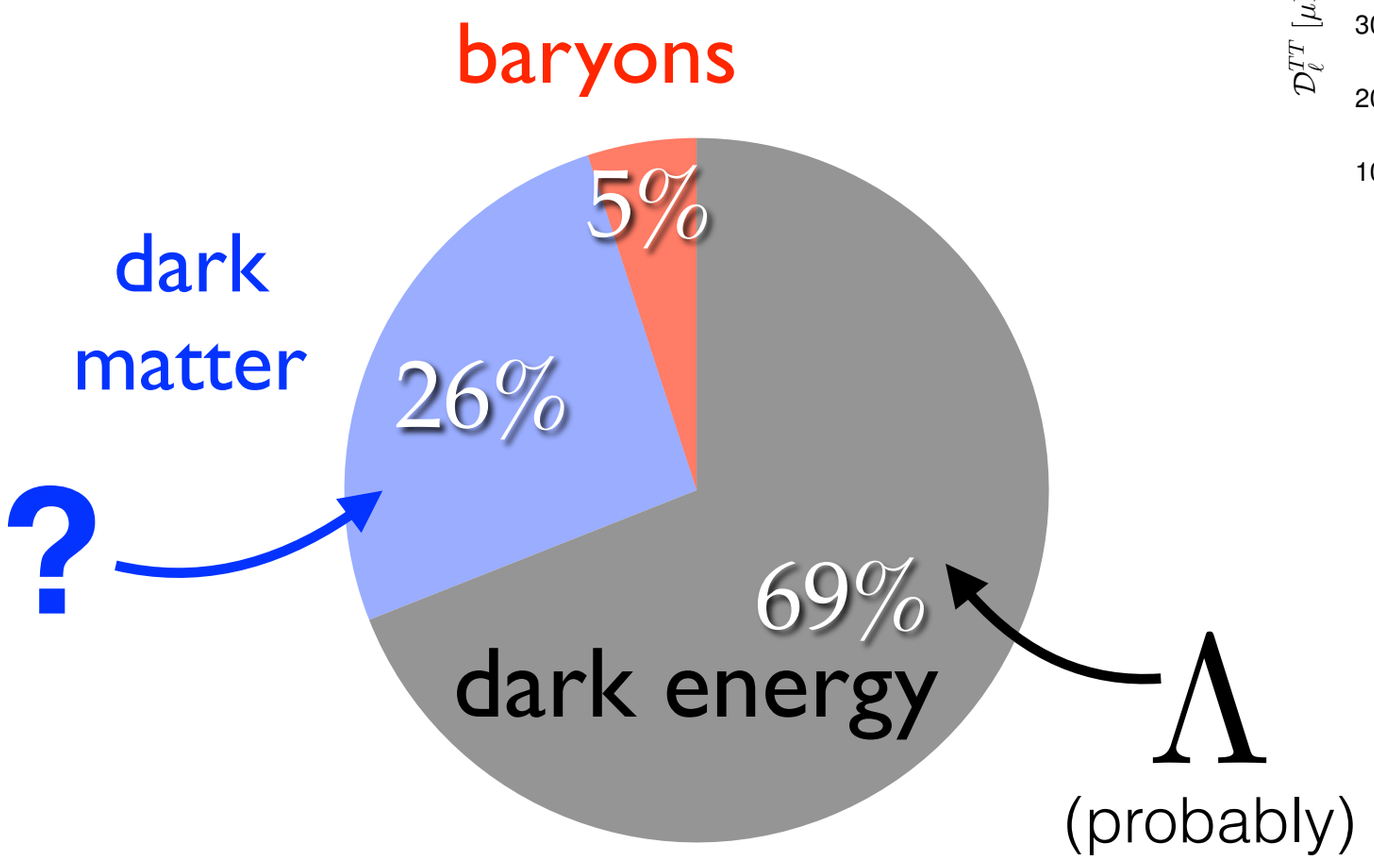
Thermal Relic Exceptions

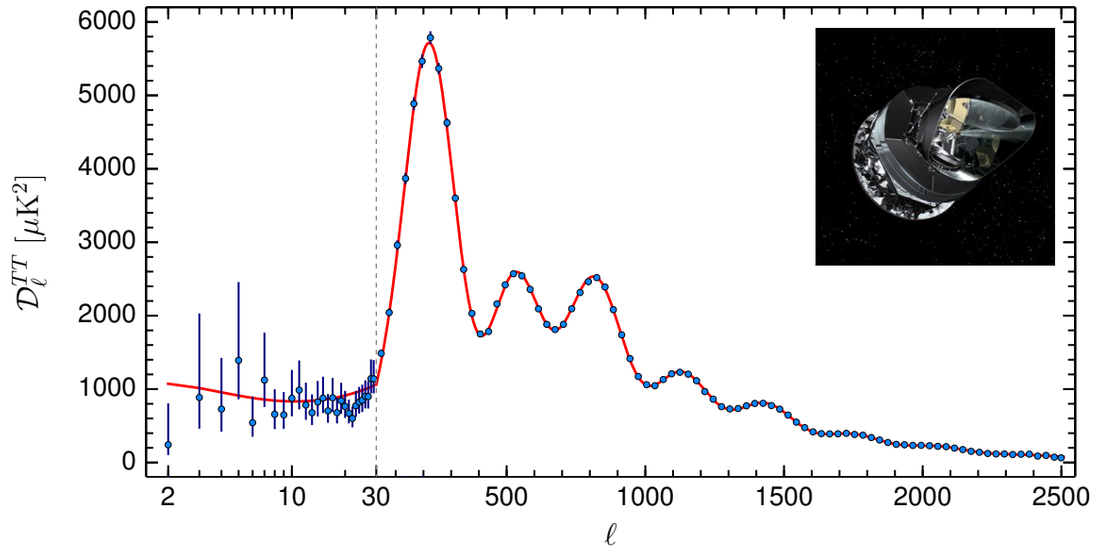
Josh Ruderman
(NYU, CERN)
@IFAE, 6/8/2018

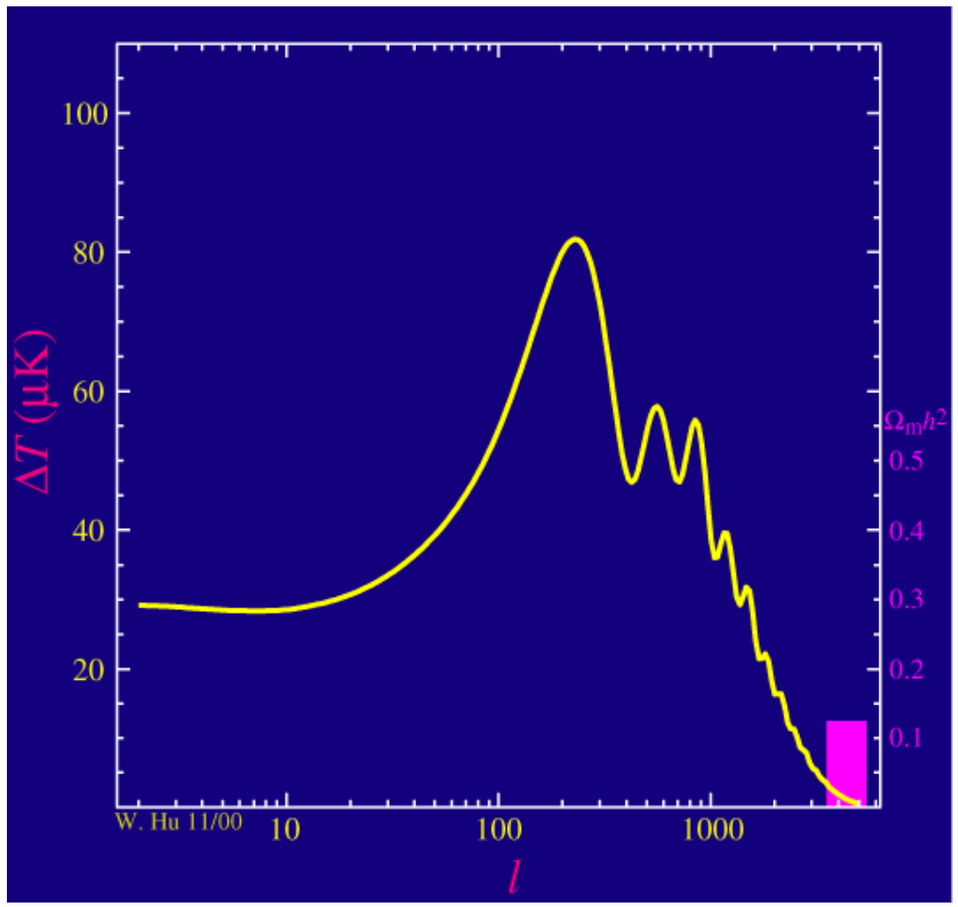




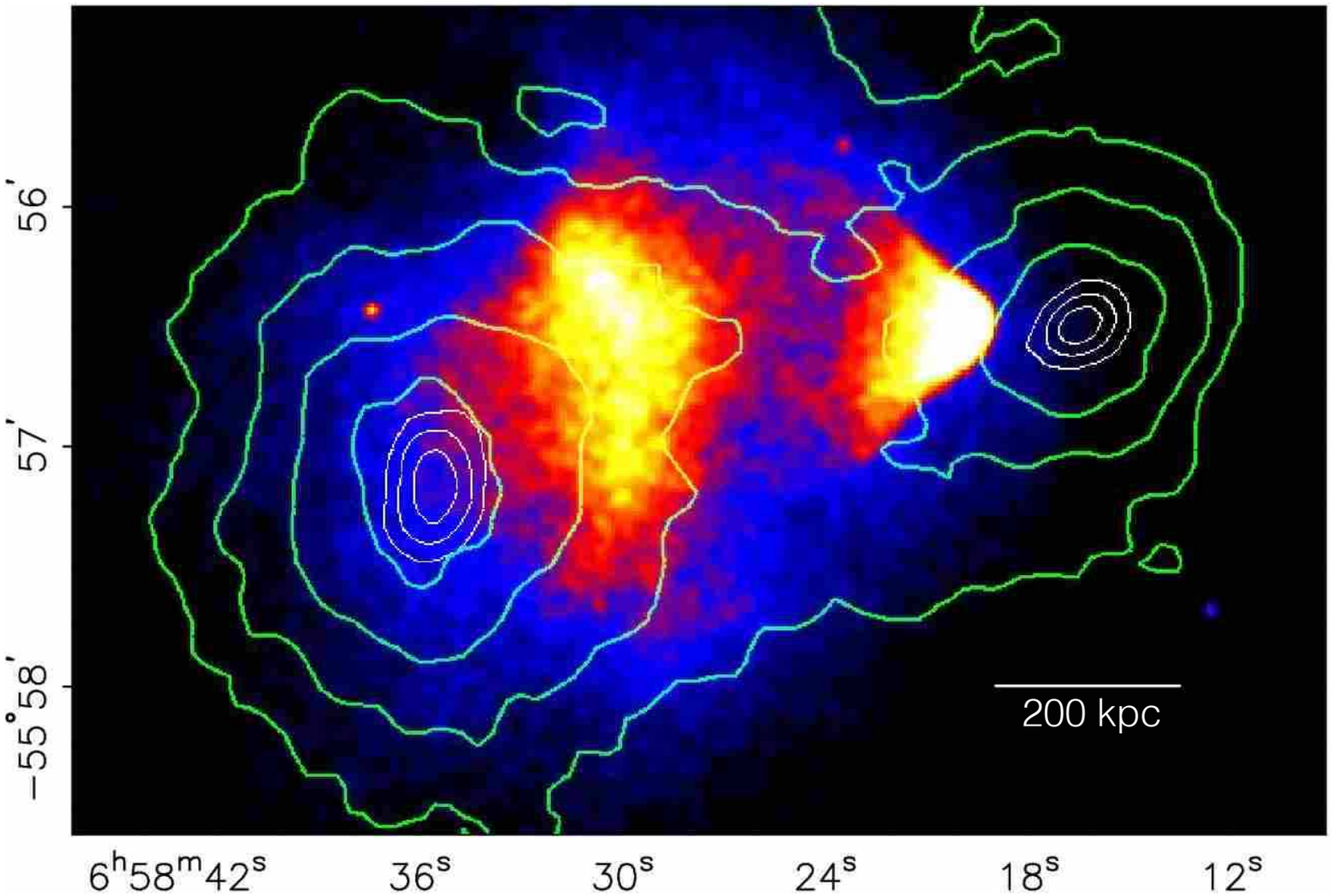
Energy Budget



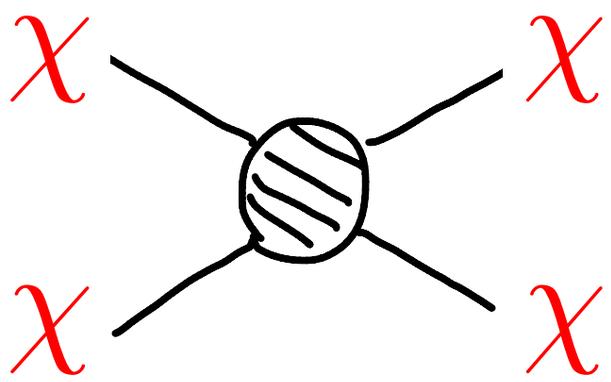




Bullet Cluster



self-interactions:



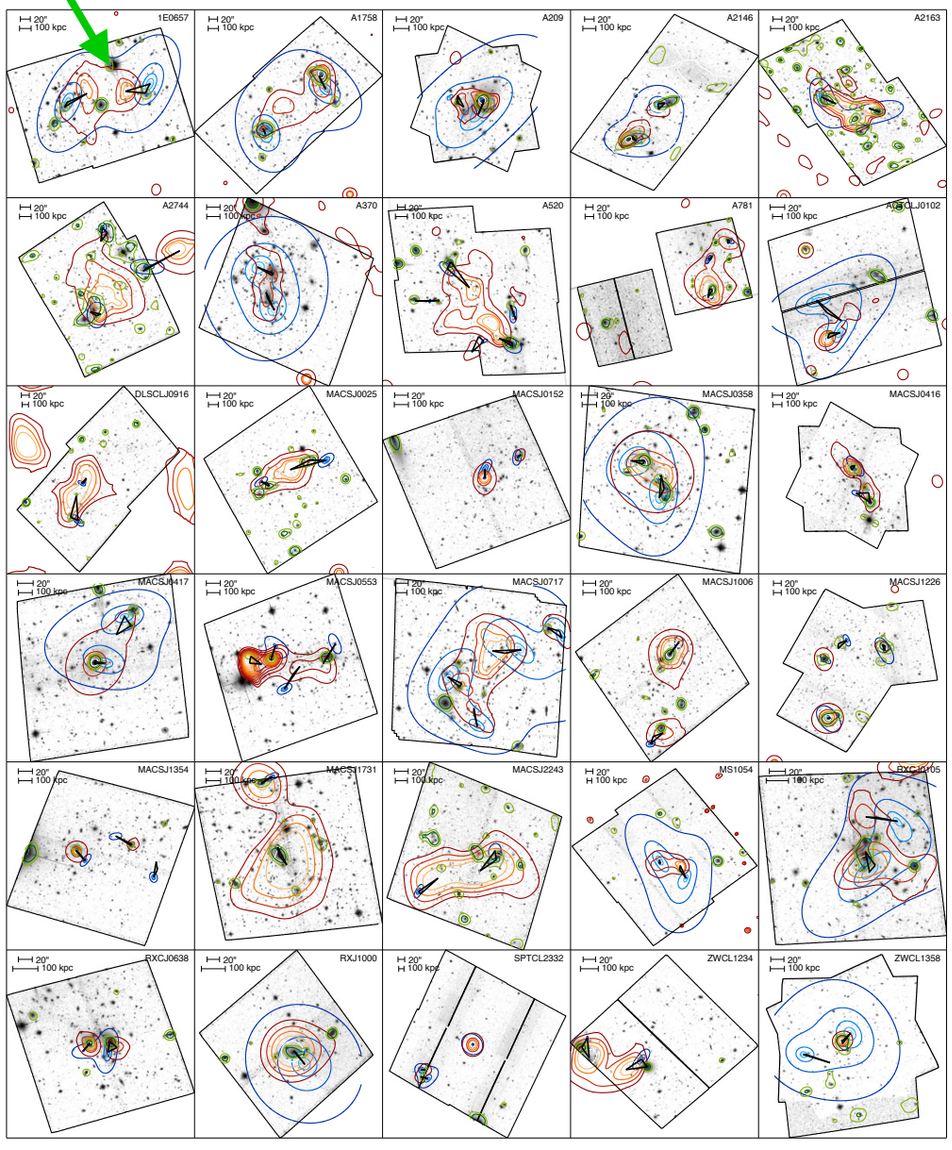
$$\frac{\sigma_{SI}}{m_\chi} \lesssim 1 \text{ cm}^2/\text{g}$$

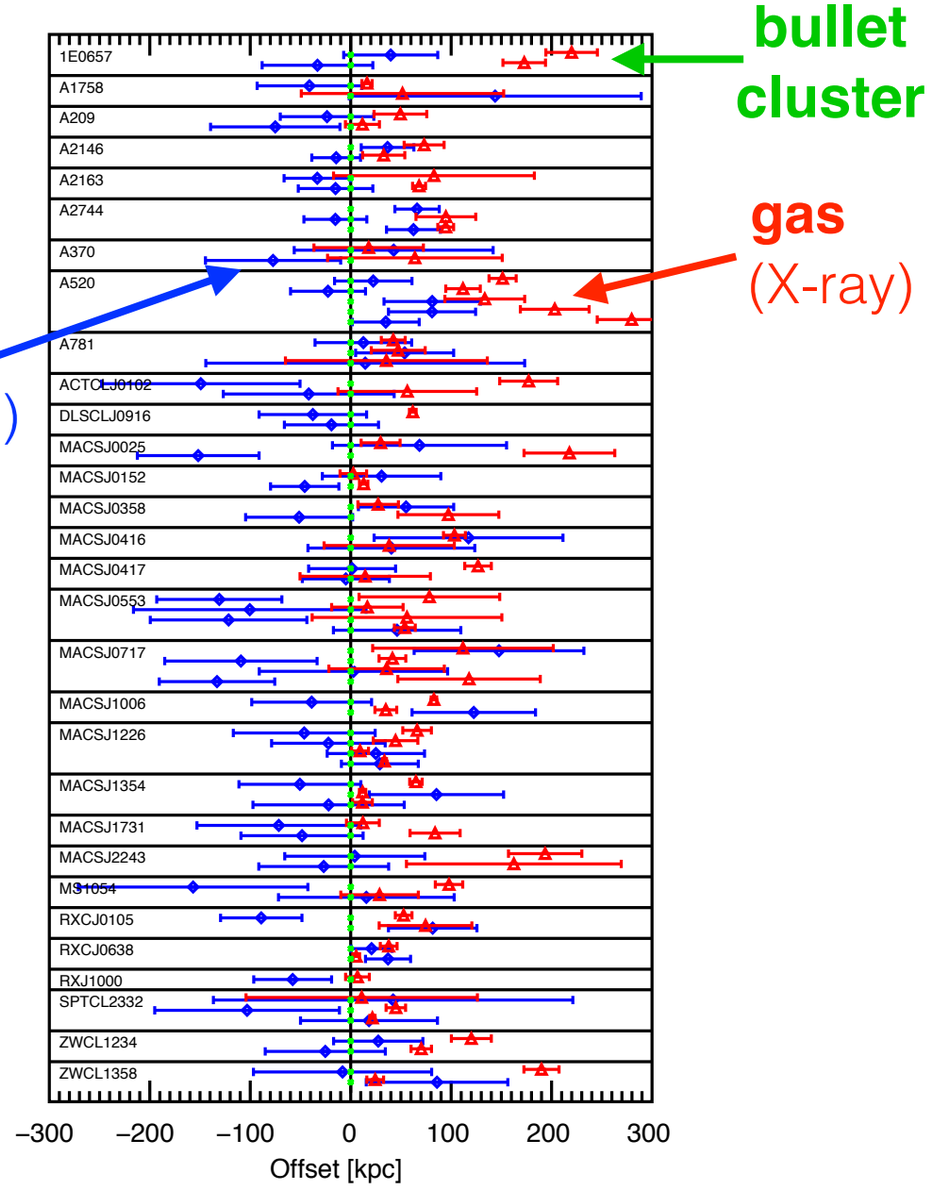
$$\sim 2 \text{ barn/GeV}$$

- Clowe *et al.*, **astro-ph/0608407**
- Randall *et al.*, **0704.0261**

Cluster Merger Zoo

bullet cluster

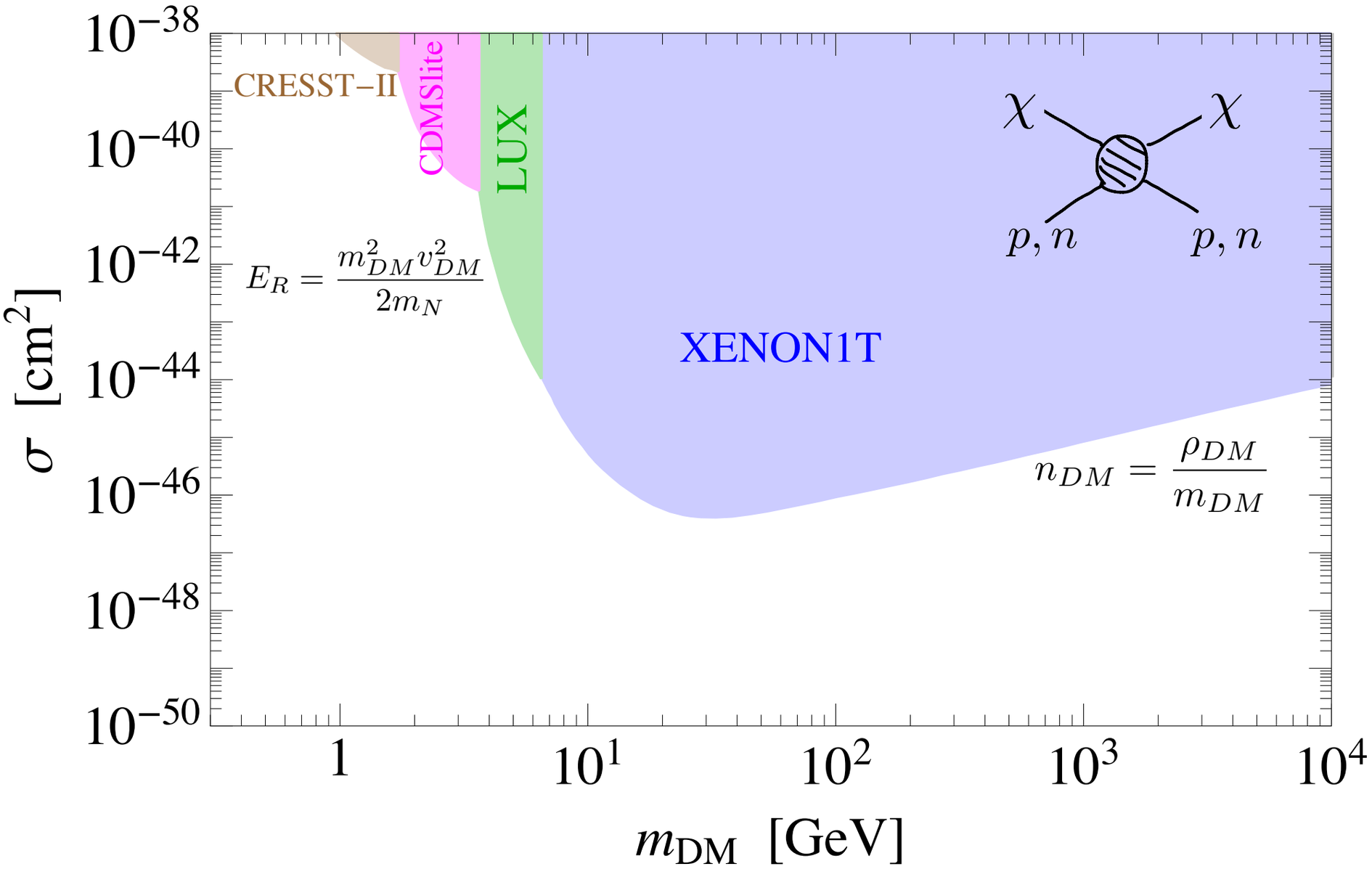




- Harvey *et al.*, **1503.07675**

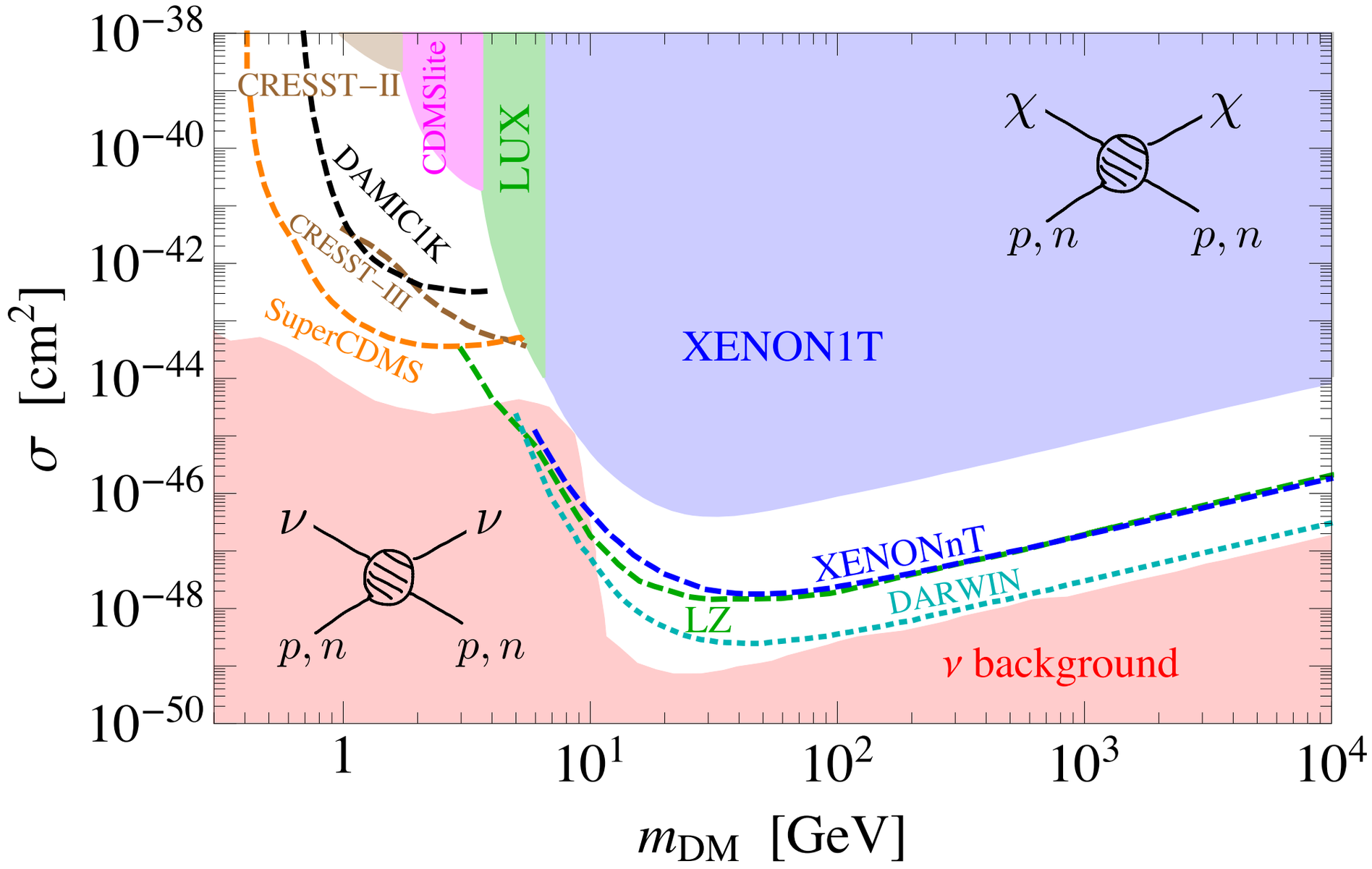
$$\frac{\sigma_{SI}}{m_\chi} \lesssim 1\ \mathrm{cm}^2/\mathrm{g}$$

Direct Detection vs. Dark Matter



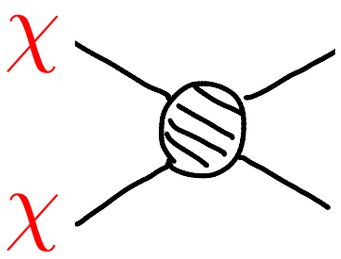
- CRESST-II, **1509.01515**
- SuperCDMS, **1509.02448**
- LUX, **1512.03506**
- XENON1T, Monday talks

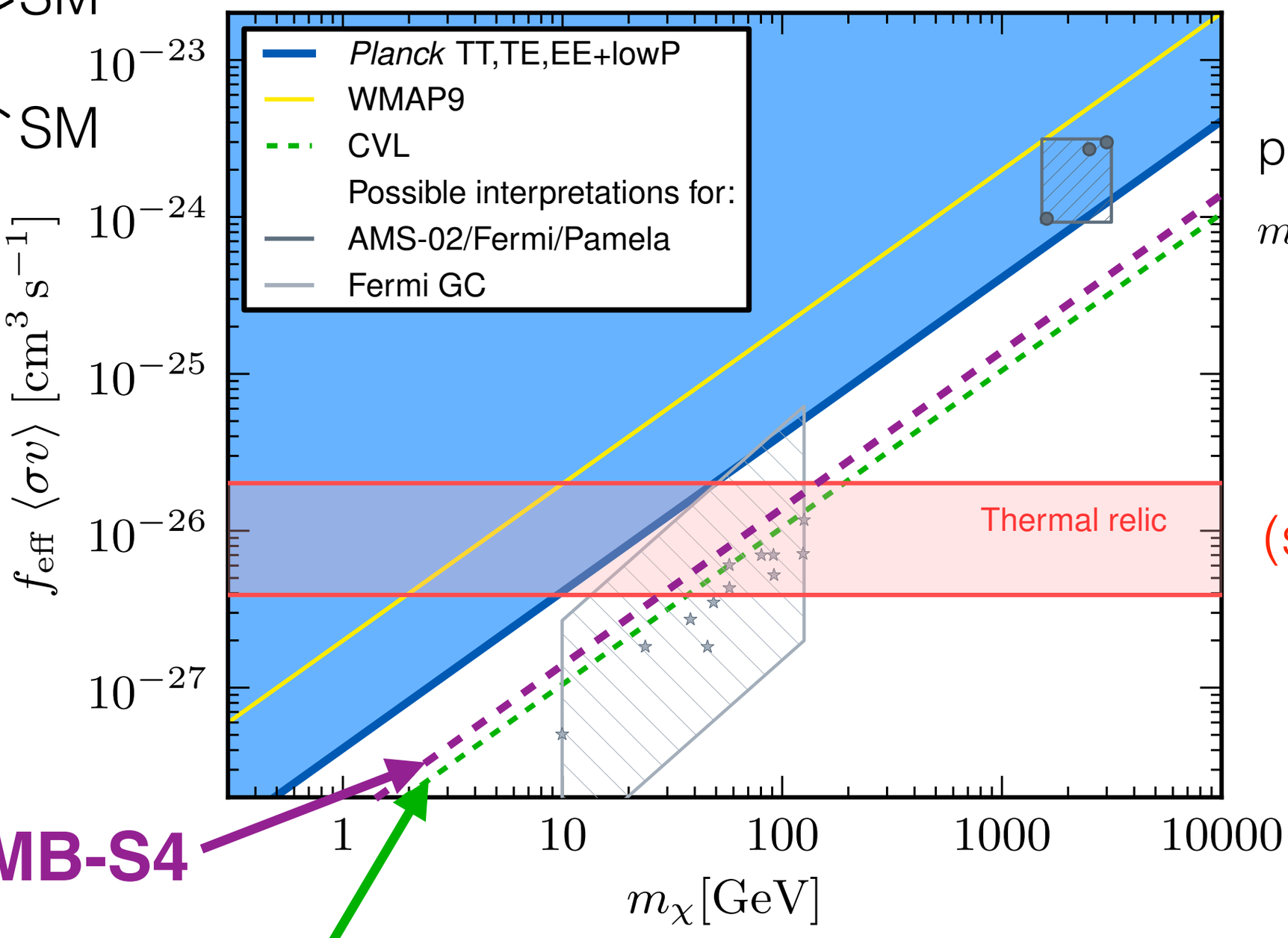
Direct Detection vs. Dark Matter



- CRESST-III, **1503.08065**
- DAMIC1K, **1707.04591**
- SuperCDMS, **1610.00006**
- XENONnT, **1512.07501**
- LZ, **1703.09144**
- DARWIN, **1606.07001**

CMB vs. Dark Matter





power:

$$m_{DM}\, n_{DM}^2 \propto \frac{1}{m_{DM}}$$

(s-wave)

CMB-S4

cosmic variance

- Planck, **1502.01589**
- CMS-S4, **1610.02743**

plan

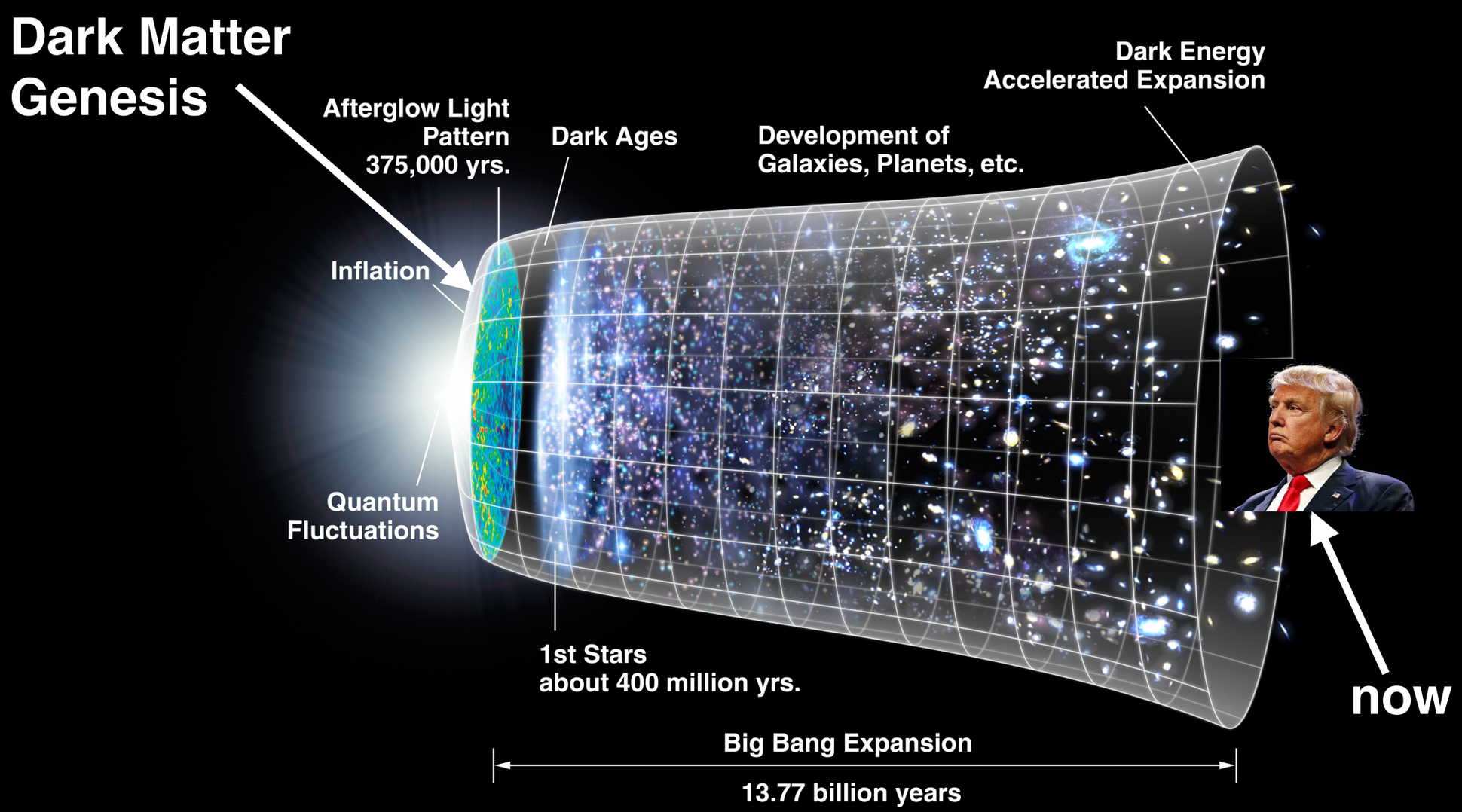
I. WIMP Warmup

II. Forbidden DM

III. Light DM from Coannihilation

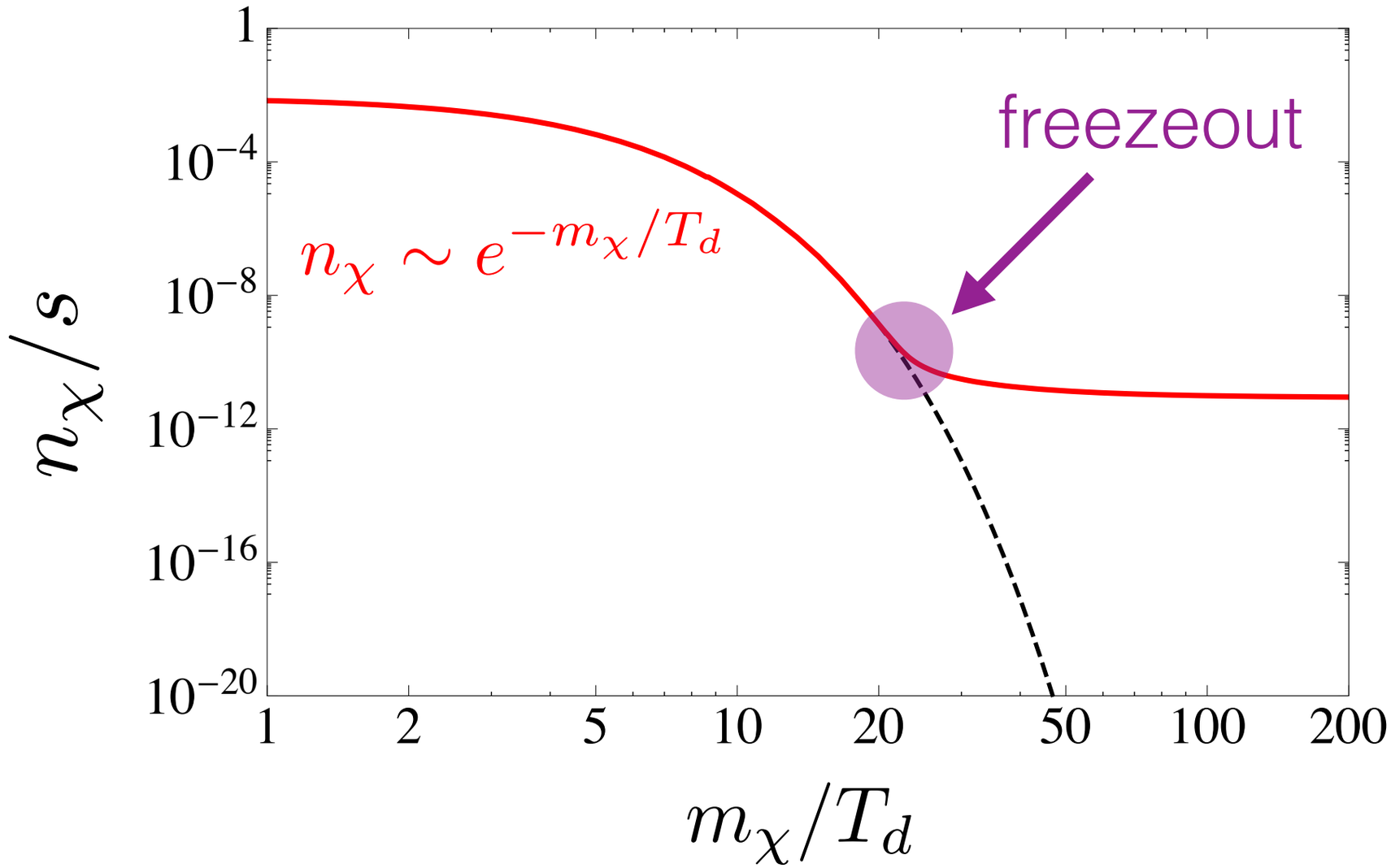
IV. Coscattering

I. WIMP Warmup

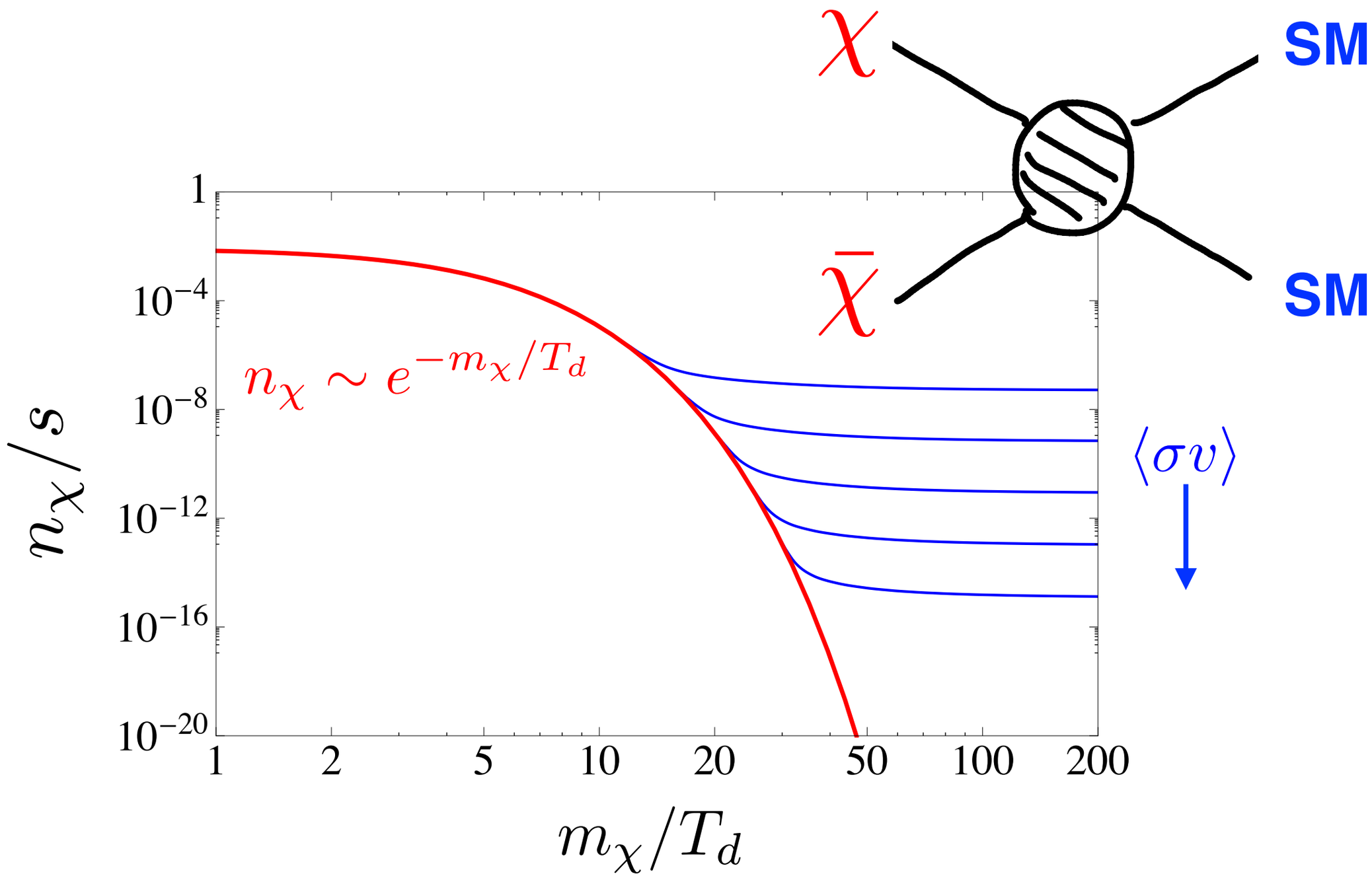


Thermal Relic Dark Matter

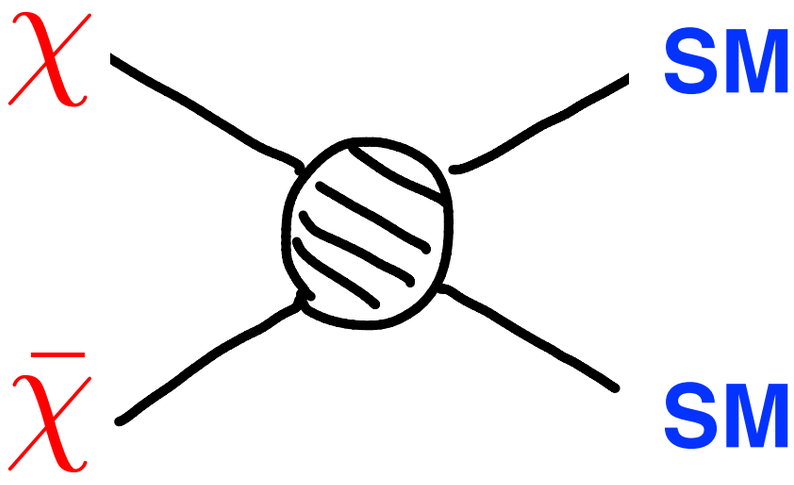
- thermal relic: $T_d \gtrsim m_\chi$



WIMP


χ
SM
$\bar{\chi}$
SM
$n_\chi \sim e^{-m_\chi/T_d}$
$\langle \sigma v \rangle$
n_χ / s
m_χ / T_d
1
10^{-4}
10^{-8}
10^{-12}
10^{-16}
10^{-20}
1
2
5
10
20
50
100
200

WIMP "Miracle"



- freezeout: $n_\chi \langle \sigma v \rangle \sim H$

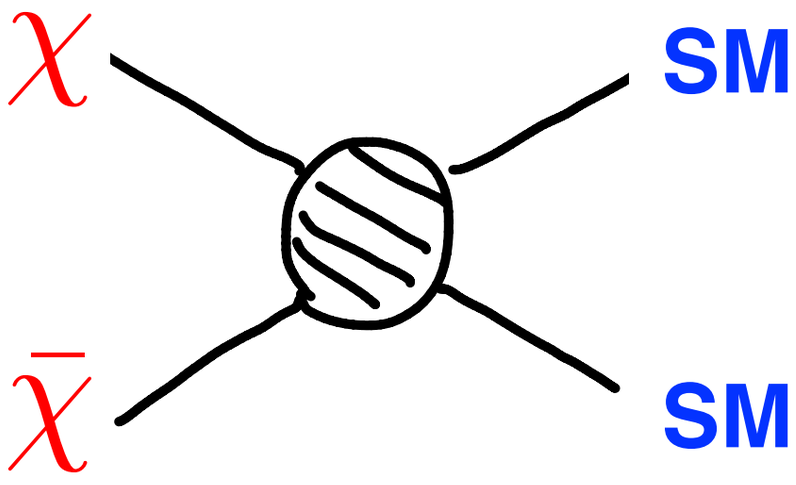
- abundance:

$$\Omega_\chi h^2 \sim \frac{m_\chi n_\chi}{s\, T_{eq}} \sim \frac{m_\chi H}{\langle \sigma v \rangle\, s\, T_{eq}} \sim \frac{1}{\langle \sigma v \rangle\, T_{eq} M_{pl}}$$

$n_\chi \langle \sigma v \rangle \sim H$

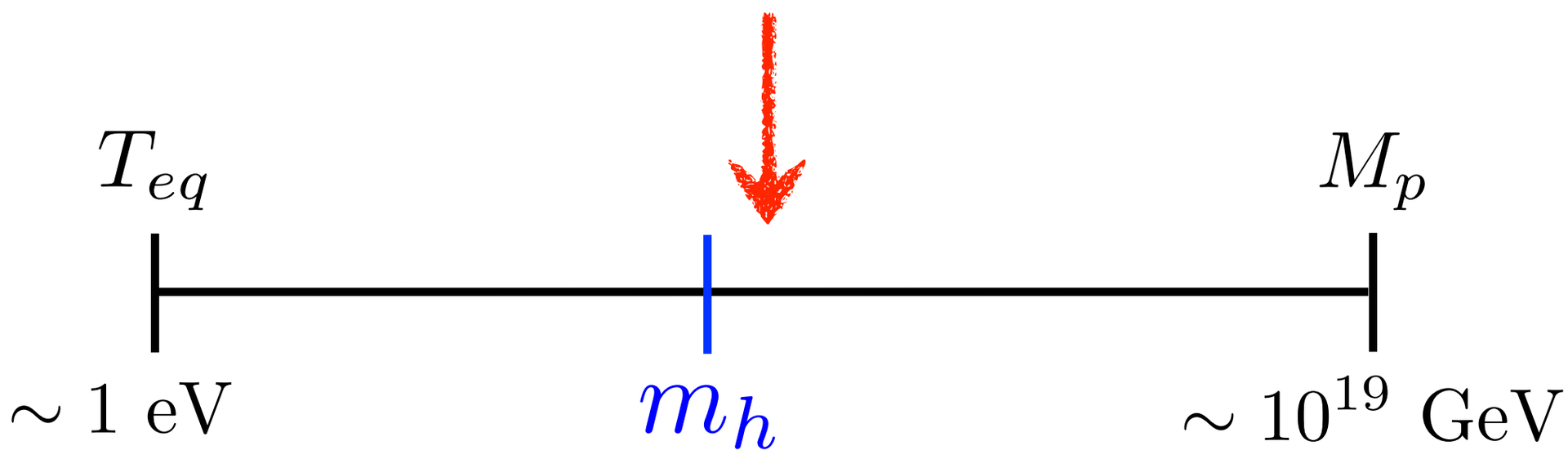
$H \sim T^2/M_{pl}$
$s \sim T^3$
$T \sim m$

WIMP "Miracle"

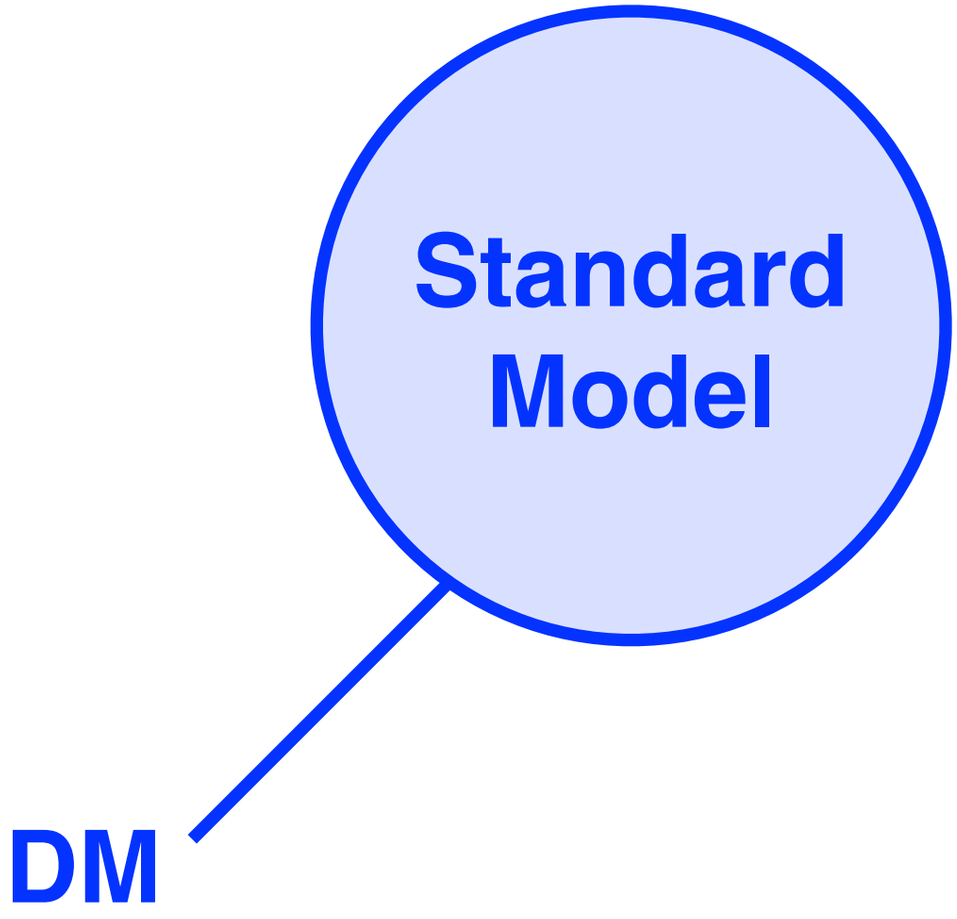


$$\langle \sigma v \rangle \sim \frac{\alpha_W^2}{m_\chi^2} \sim \frac{1}{T_{eq} M_{pl}}$$

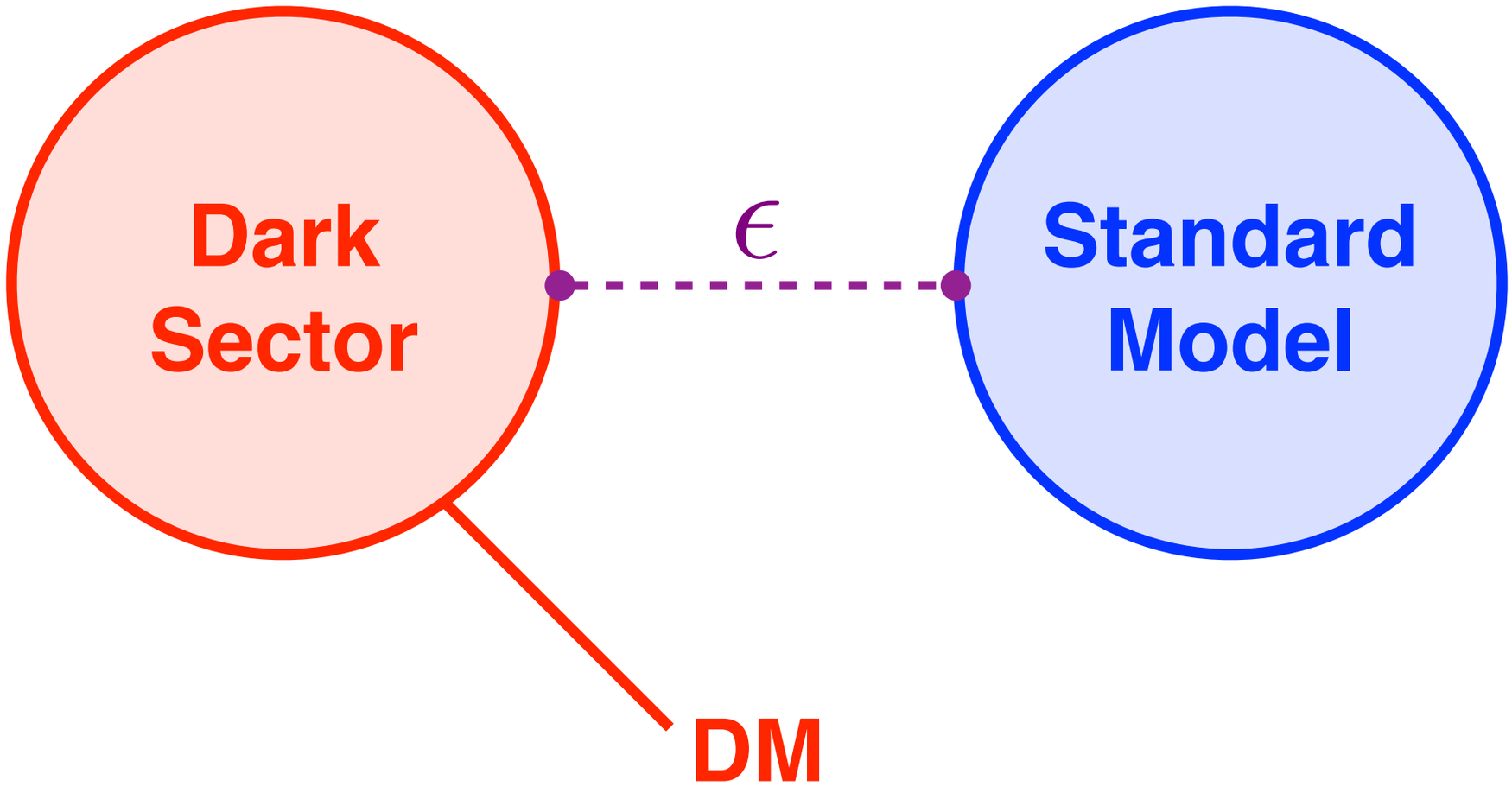
$$m_\chi \sim \alpha_W \sqrt{T_{eq} M_{pl}}$$



WIMP



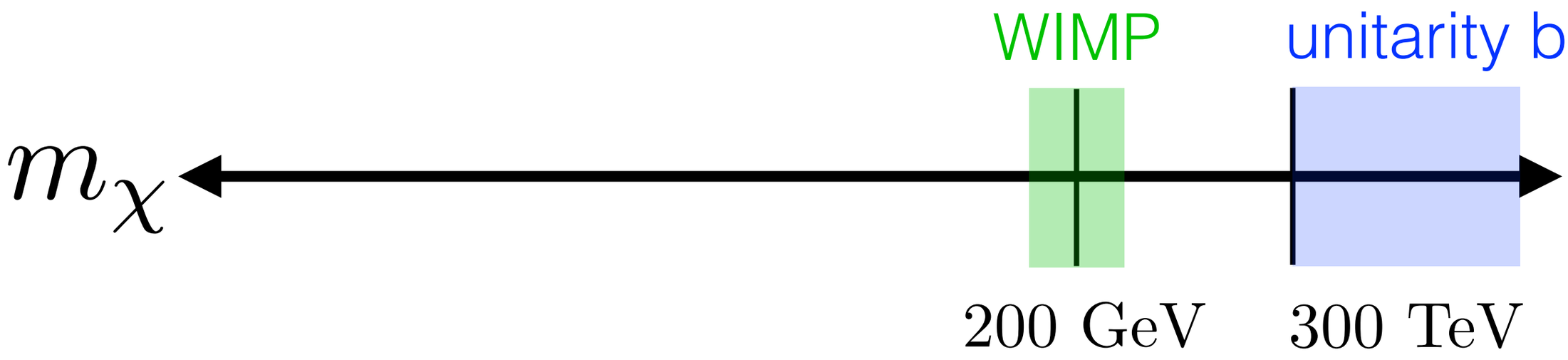
Hidden Sector Dark Matter



What are the possible cosmologies for thermal relics in hidden sectors?

- Goldberg, Hall, **1986**
- Strassler, Zurek, **hep-ph/0604261**
- Arkani-Hamed, Finkbeiner, Slatyer, Weiner, **0810.0713**

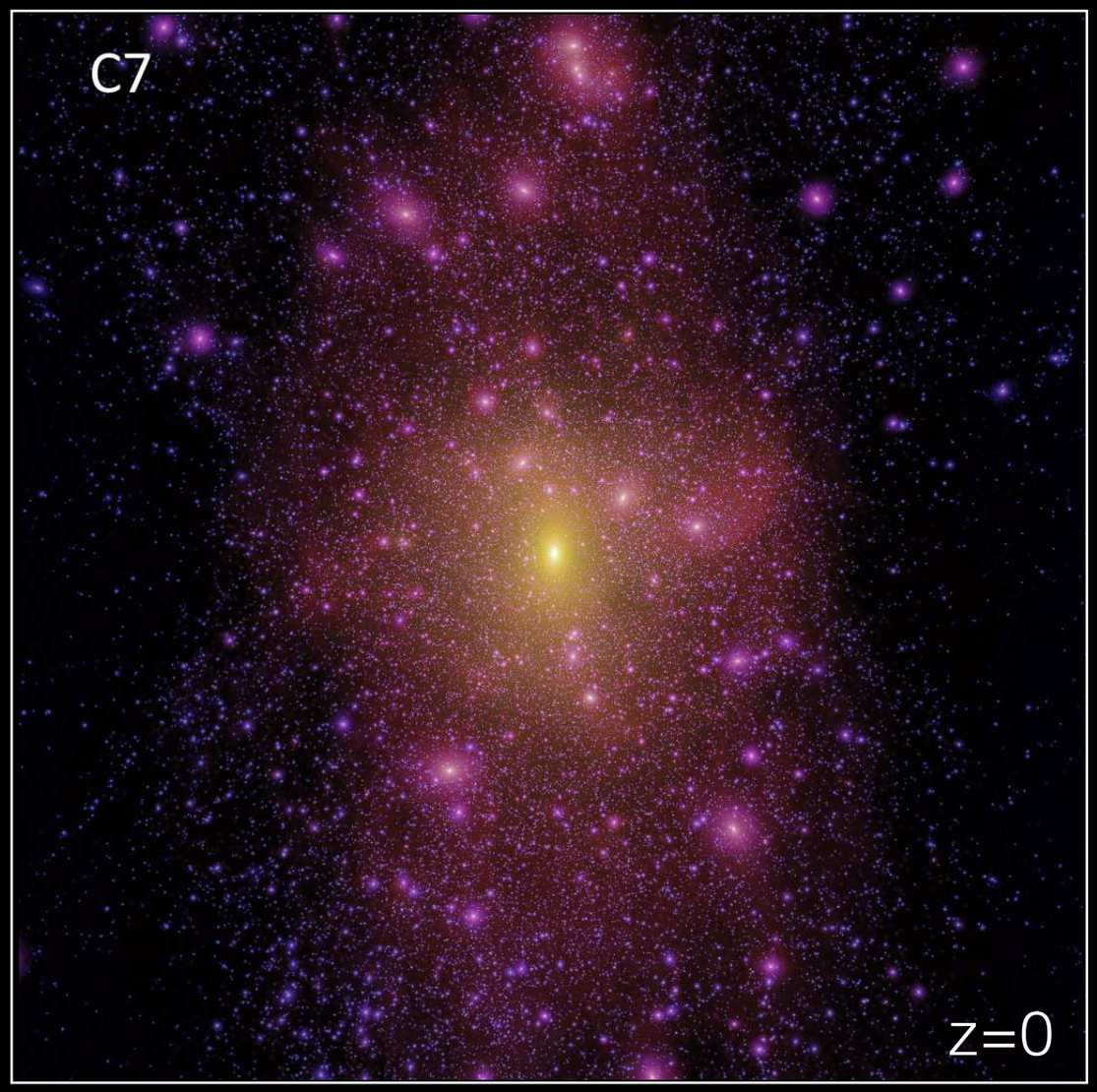
Thermal Relic Spectrum



- Griest, Kamionkowski, Phys. Rev. Lett. **64**, 615 (1990).

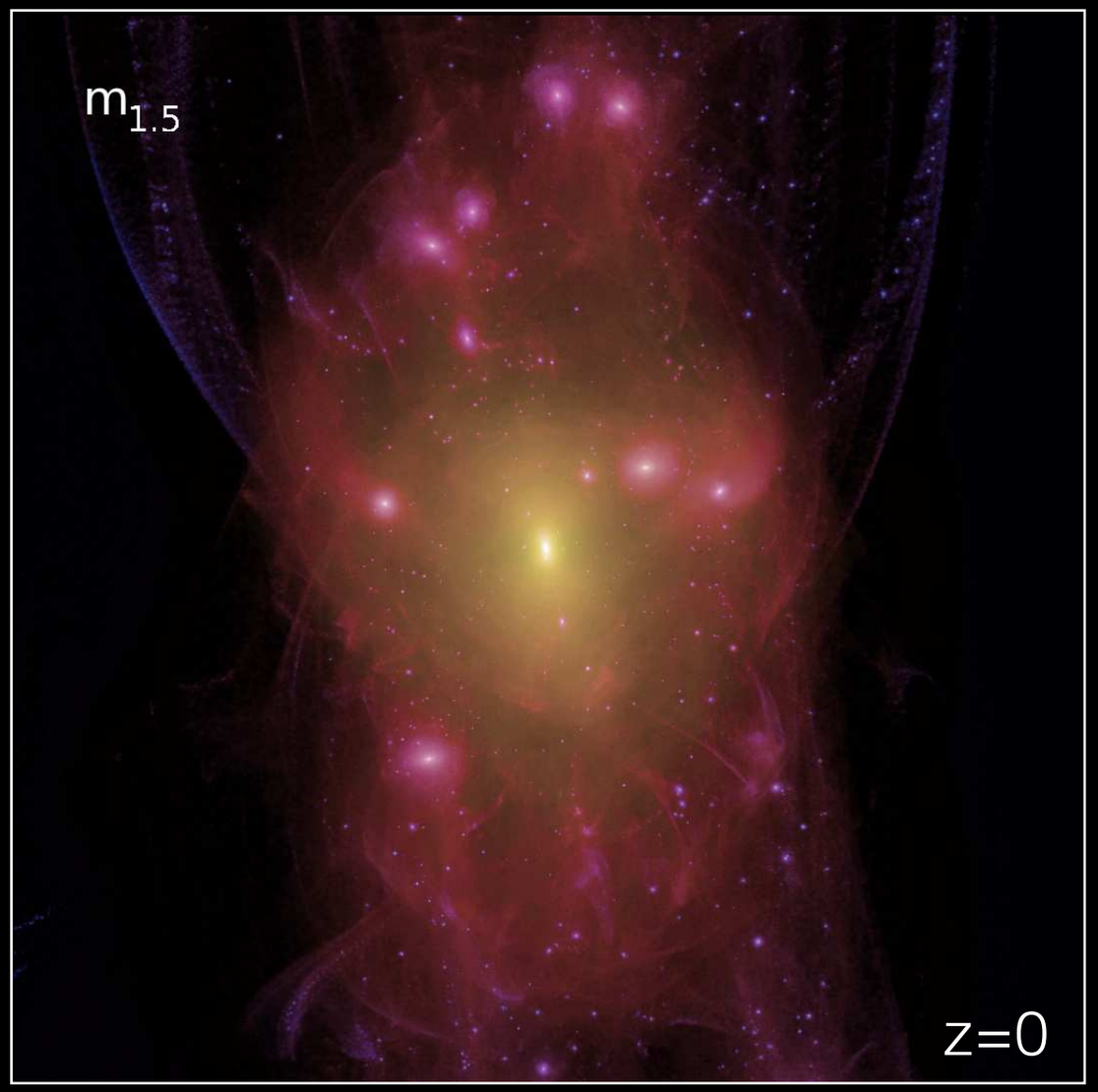
Cold vs. Warm Dark Matter

Cold: $m_{DM} \gg 1$ keV



1.5 Mpc

Warm: $m_{DM} = 1.5$ keV



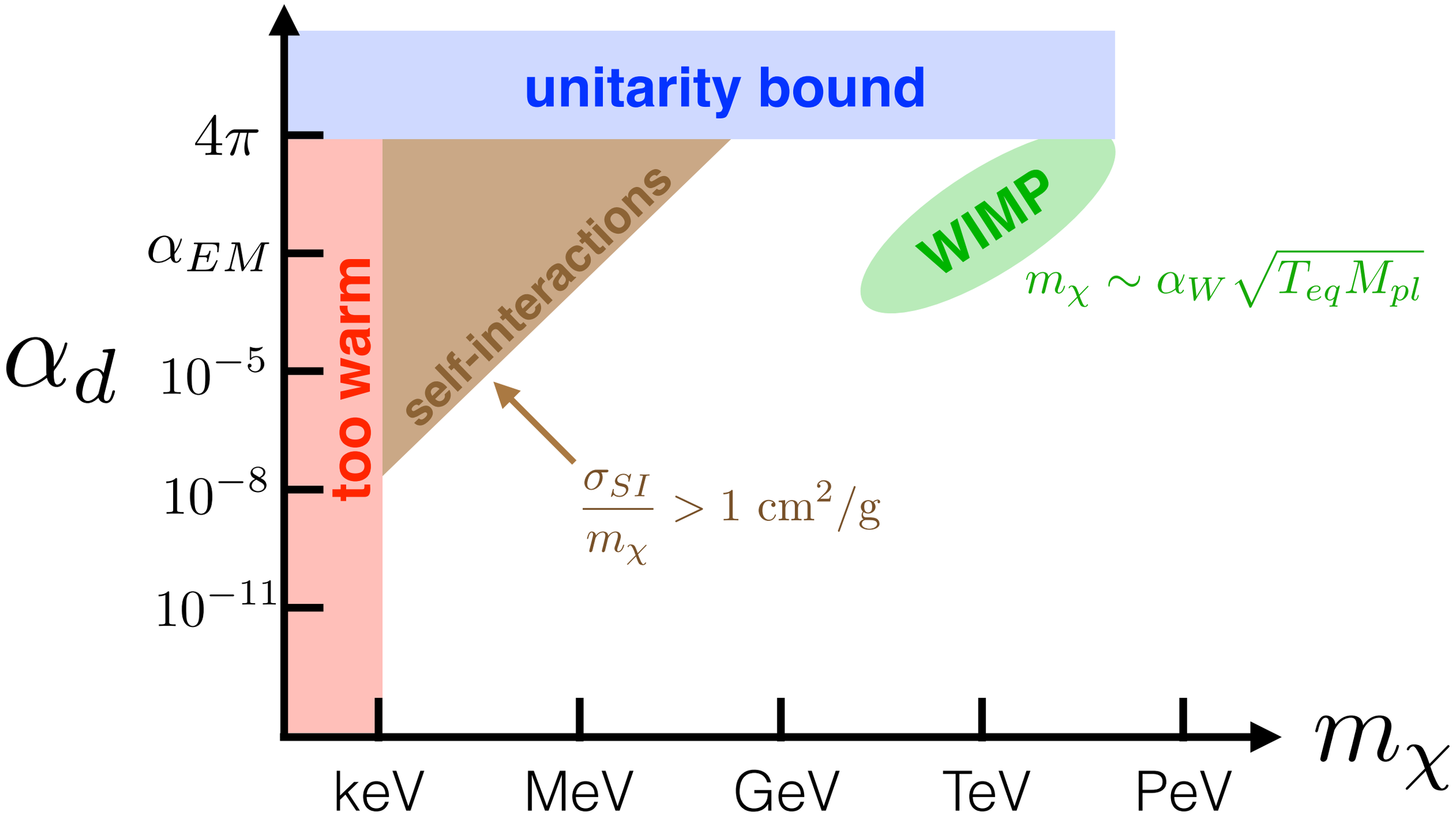
1.5 Mpc

- Lovell *et al.*, **1308.1399**

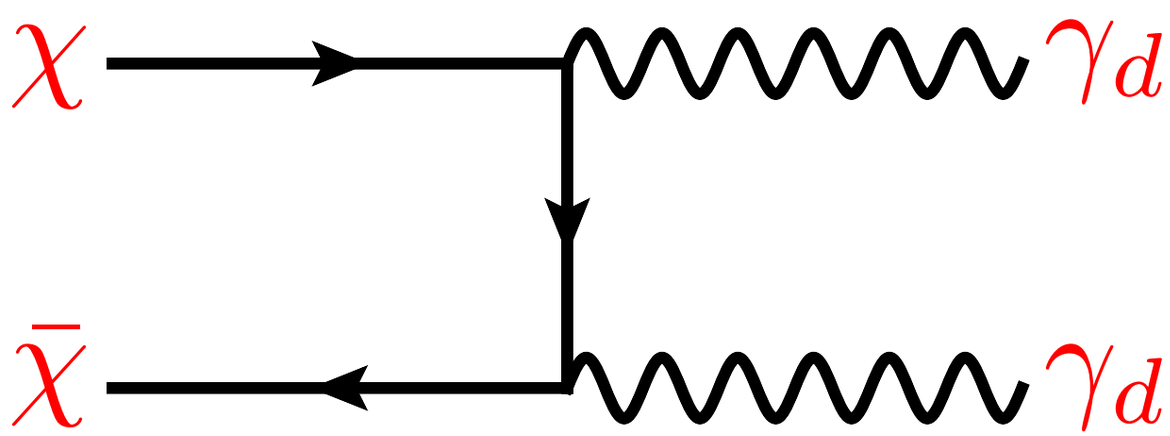
Thermal Relic Spectrum

- Lovell *et al.*, **1308.1399**
- Irsic *et al.*, **1702.01764**
- Griest, Kamionkowski, Phys. Rev. Lett. **64**, 615 (1990).

Dark Freezeout Map



Ultraweakly Coupled Dark Matter

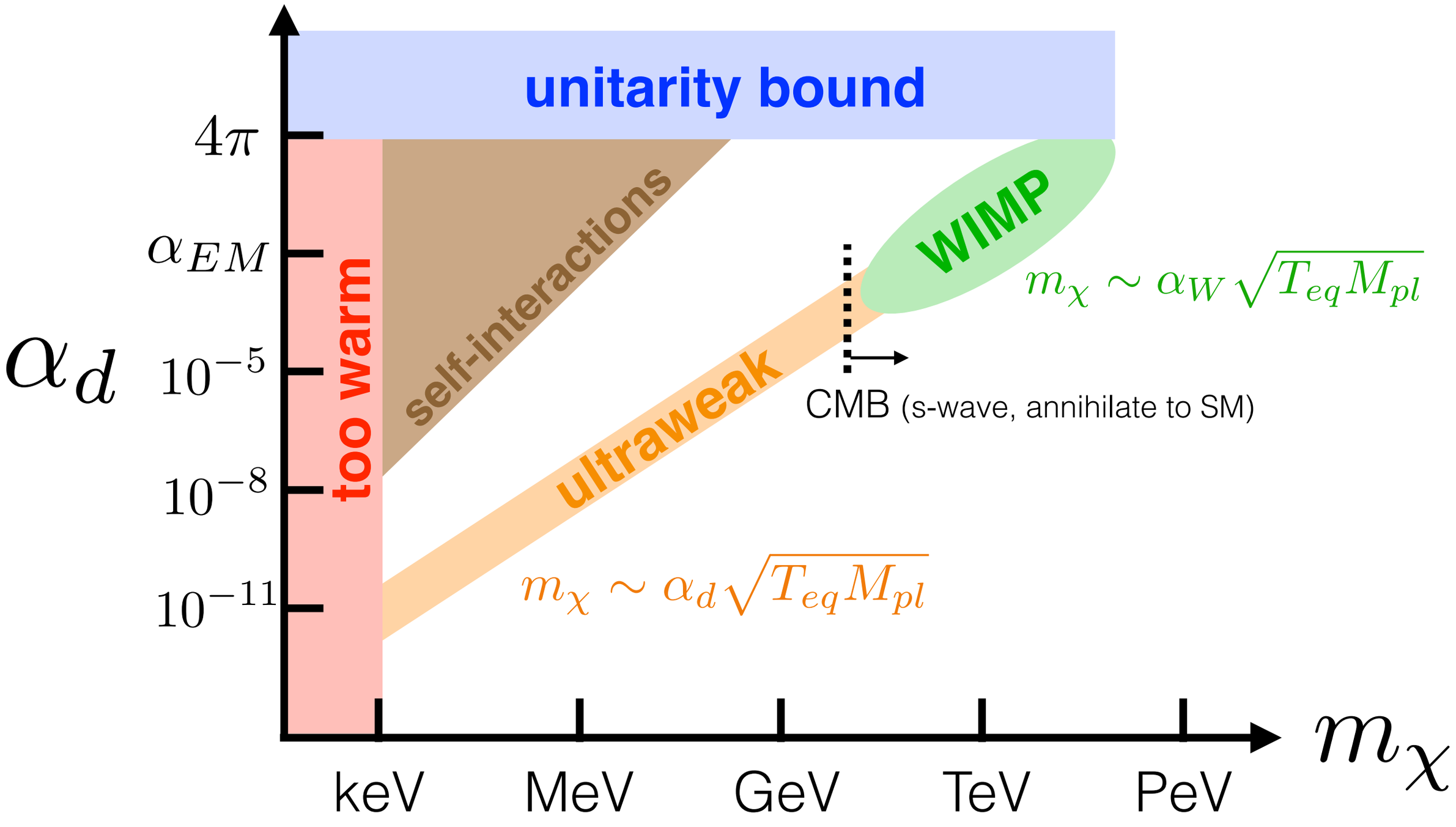


$$\langle \sigma v \rangle \sim \frac{\alpha_d^2}{m_\chi^2}$$

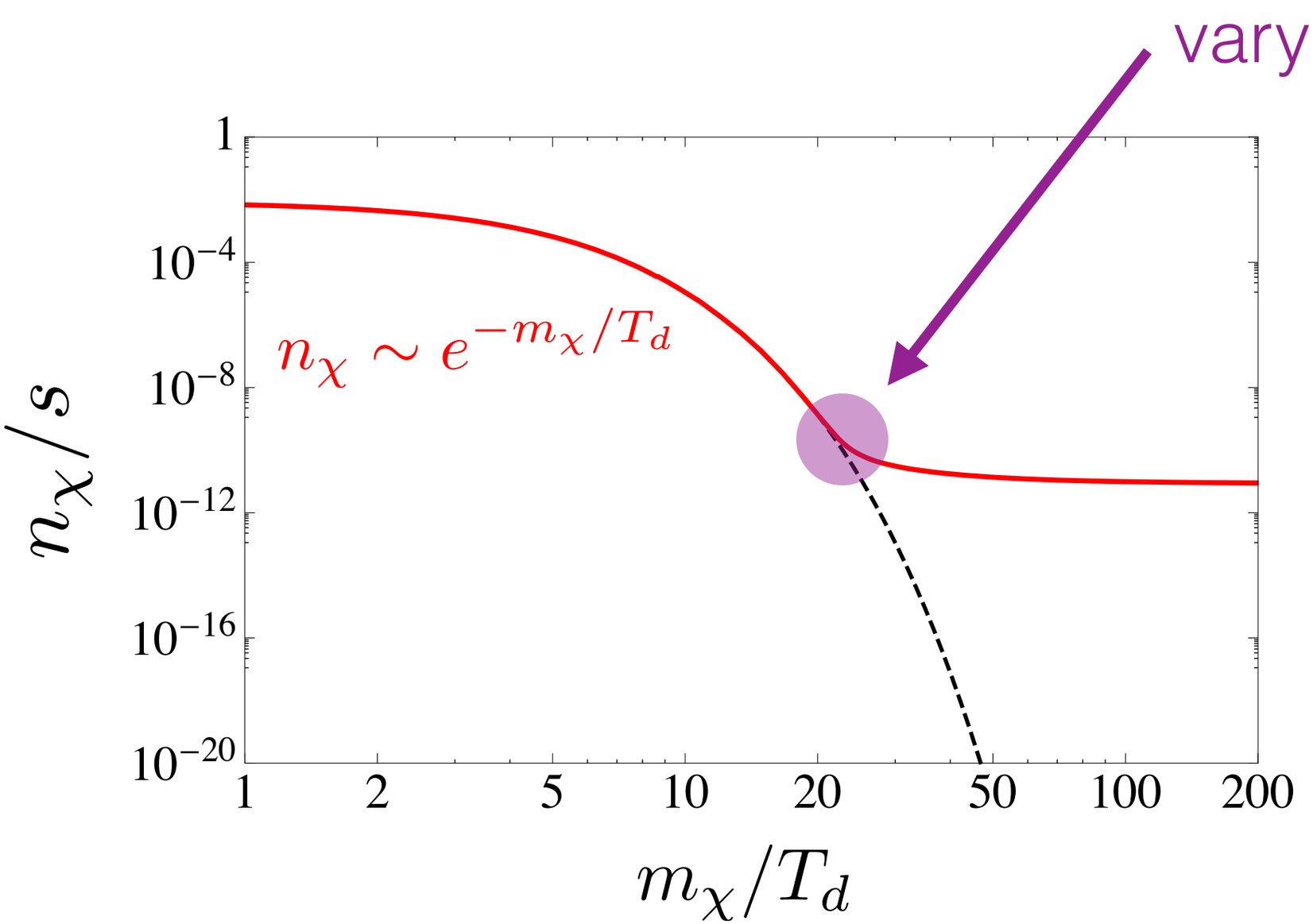
$$m_\chi \sim \alpha_d \sqrt{T_{eq} M_{pl}} \sim \left(\frac{\alpha_d}{\alpha_W} \right) \times 1 \text{ TeV}$$

- Boehm, Fayet, **hep-ph/0305261**
- Finkbeiner, Weiner, **astro-ph/0702587**
- Pospelov, Ritz, Voloshin, **0711.4866**
- Feng, Kumar **0803.4196**

Dark Freezeout Map



Thermal Relics Beyond the WIMP



WIMP-like Assumptions

- thermal relic with:

A) $2 \leftrightarrow 2$ annihilations*

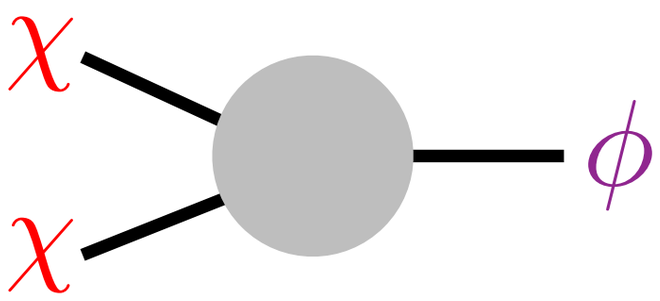
B) $T_d \sim T_\gamma$

C) no entropy dump

*Z_2, symmetric

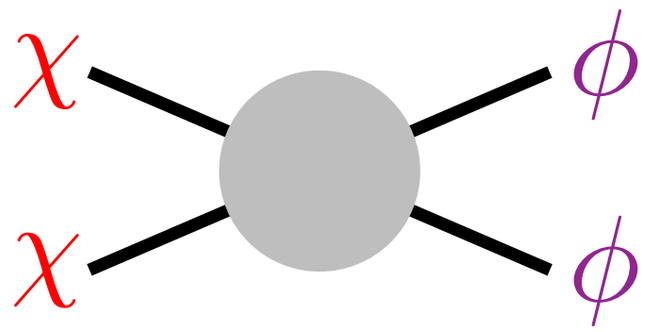
Dark Exceptions

1) pole



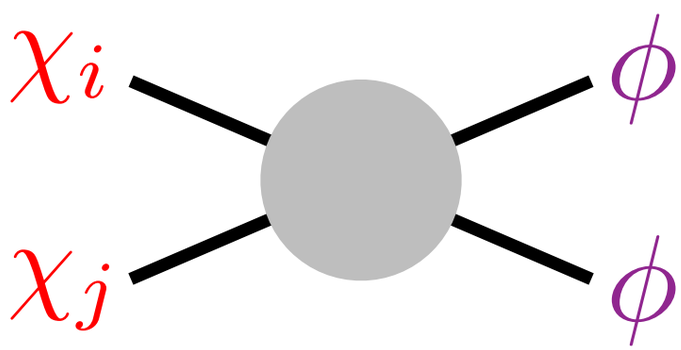
$2m_\chi \approx m_\phi$

2) forbidden channels

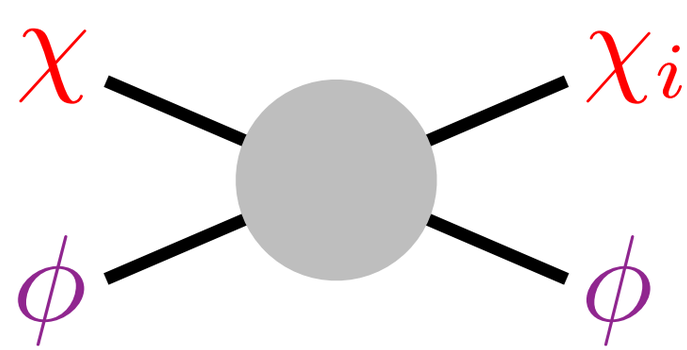


$m_\chi < m_\phi$

3) coannihilations

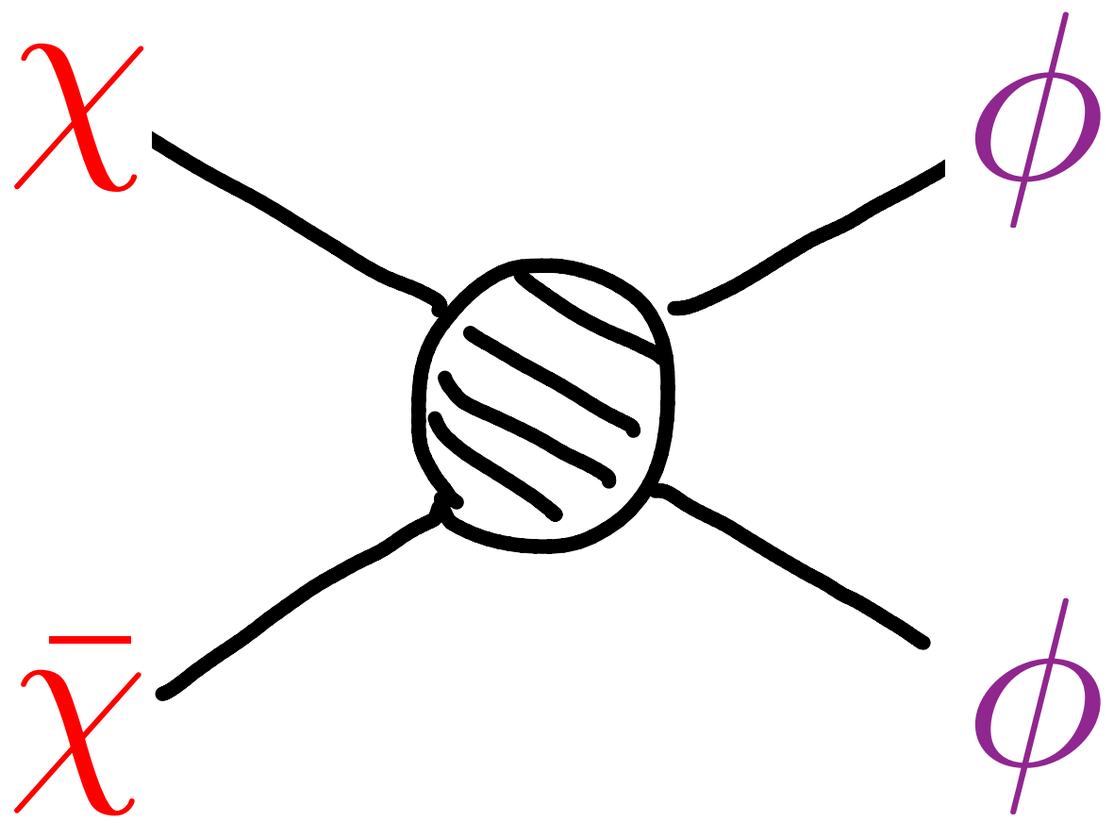


4) coscattering



- Griest, Seckel, **1991**
- D'Agnolo, Pappadopulo, JTR, **1705.08450**

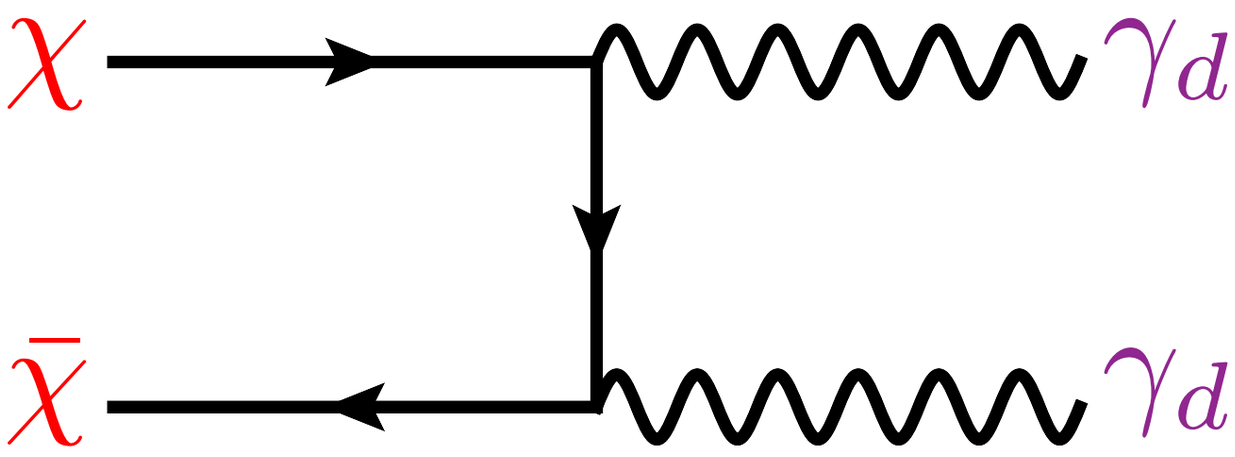
II. Forbidden Dark Matter

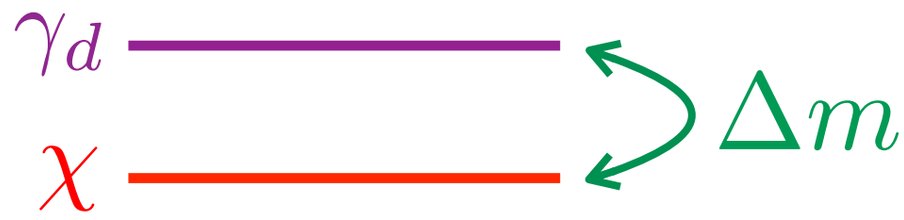


$$m_\chi < m_\phi$$

- Raffaele D'Agnolo, JTR, **1505.07107** (PRL)

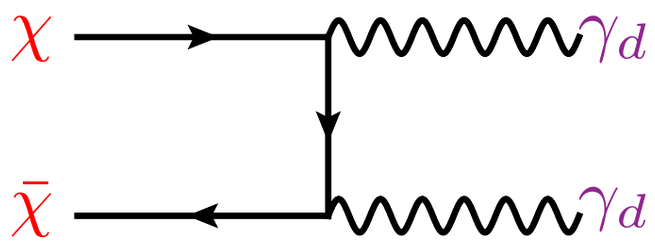
Forbidden Dark Matter

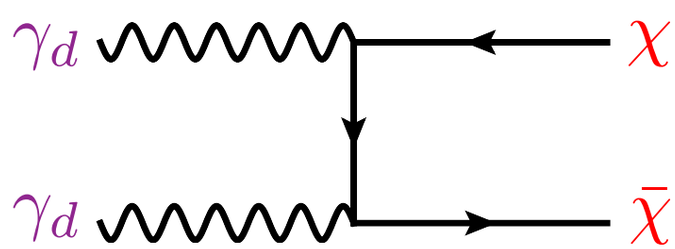




$\langle \sigma v \rangle_{\chi\bar{\chi}}$

- detailed balance:

$(n_\chi^{eq})^2 \times$ 

$=$ $(n_{\gamma_d}^{eq})^2 \times$ 

$\sim \dfrac{\alpha_d^2}{m_\chi^2}$

- thermally averaged cross:

$$\langle \sigma v \rangle_{\chi\bar{\chi}} = \frac{(n_{\gamma_d}^{eq})^2}{(n_\chi^{eq})^2} \langle \sigma v \rangle_{\gamma_d\gamma_d} \sim \frac{\alpha_d^2}{m_\chi^2} e^{-2\Delta m/T_{FO}} \sim \frac{1}{T_{eq} M_{pl}}$$

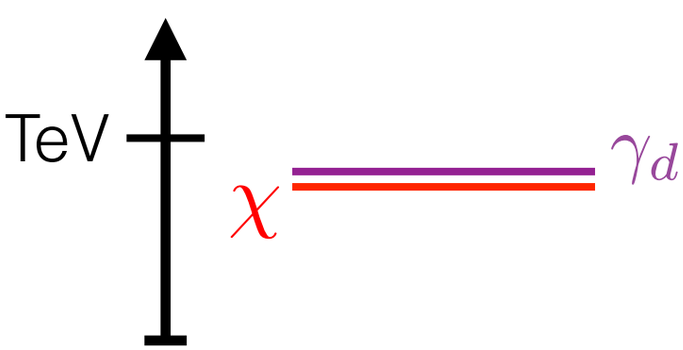
Forbidden Mass Spectrum

$$m_\chi \sim e^{-\Delta m/T_{FO}}\, \alpha_d \sqrt{T_{eq} M_{pl}}$$

Griest, Seckel, 1991

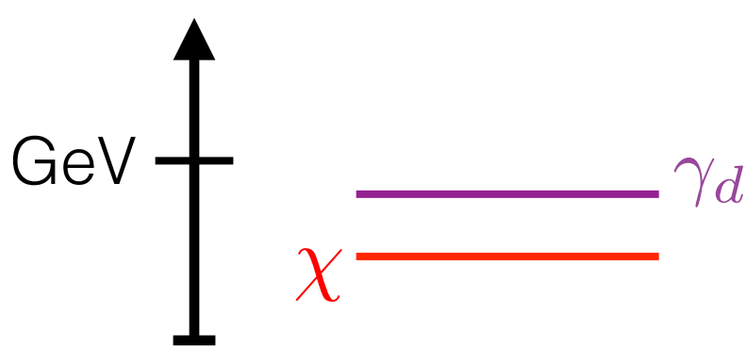
- assume: $m_\chi \sim \mathrm{TeV}$
- forbidden relevant when:

$$\frac{\Delta m}{m_\chi} \lesssim 0.1$$



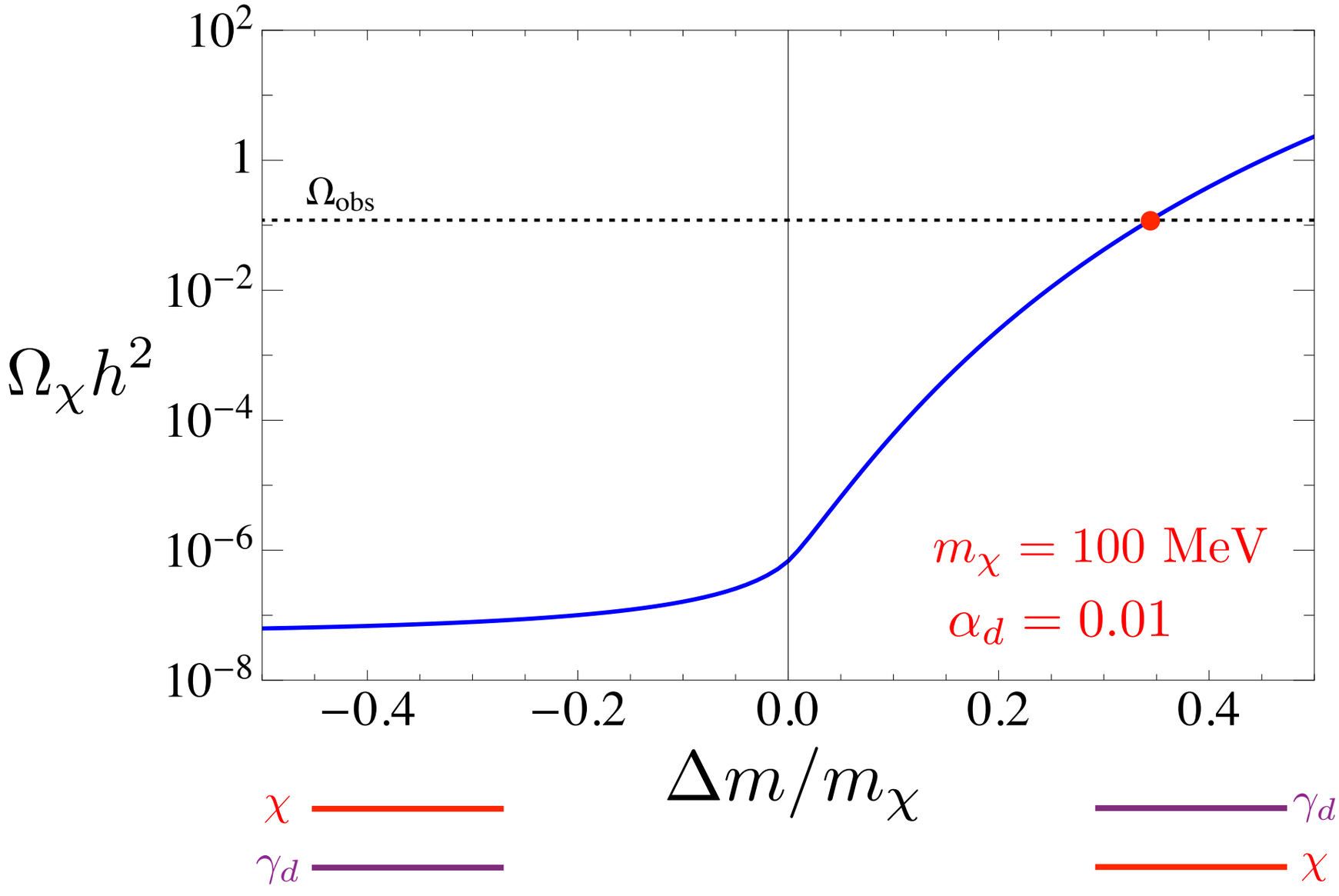
us

- allow: $\dfrac{\Delta m}{m_\chi} \sim \mathcal{O}(1)$
- predict: $m_\chi \ll \mathrm{TeV}$
- evades CMB: $\Delta m \gg T_{\mathrm{rec}}$



Forbidden Relic Density

$$\Omega_\chi h^2 \sim \frac{m_\chi^2}{\alpha_d^2 T_{eq} M_{pl}} e^{2\Delta m/T_{FO}}$$



Relic Density with Exponential Sensitivity

WIMP

$$\Omega_\chi h^2 \sim \frac{m_\chi^2}{\alpha_d^2 T_{eq} M_{pl}}$$

forbidden

$$\Omega_\chi h^2 \sim \frac{m_\chi^2}{\alpha_d^2 T_{eq} M_{pl}} e^{2\Delta m/T_{FO}}$$

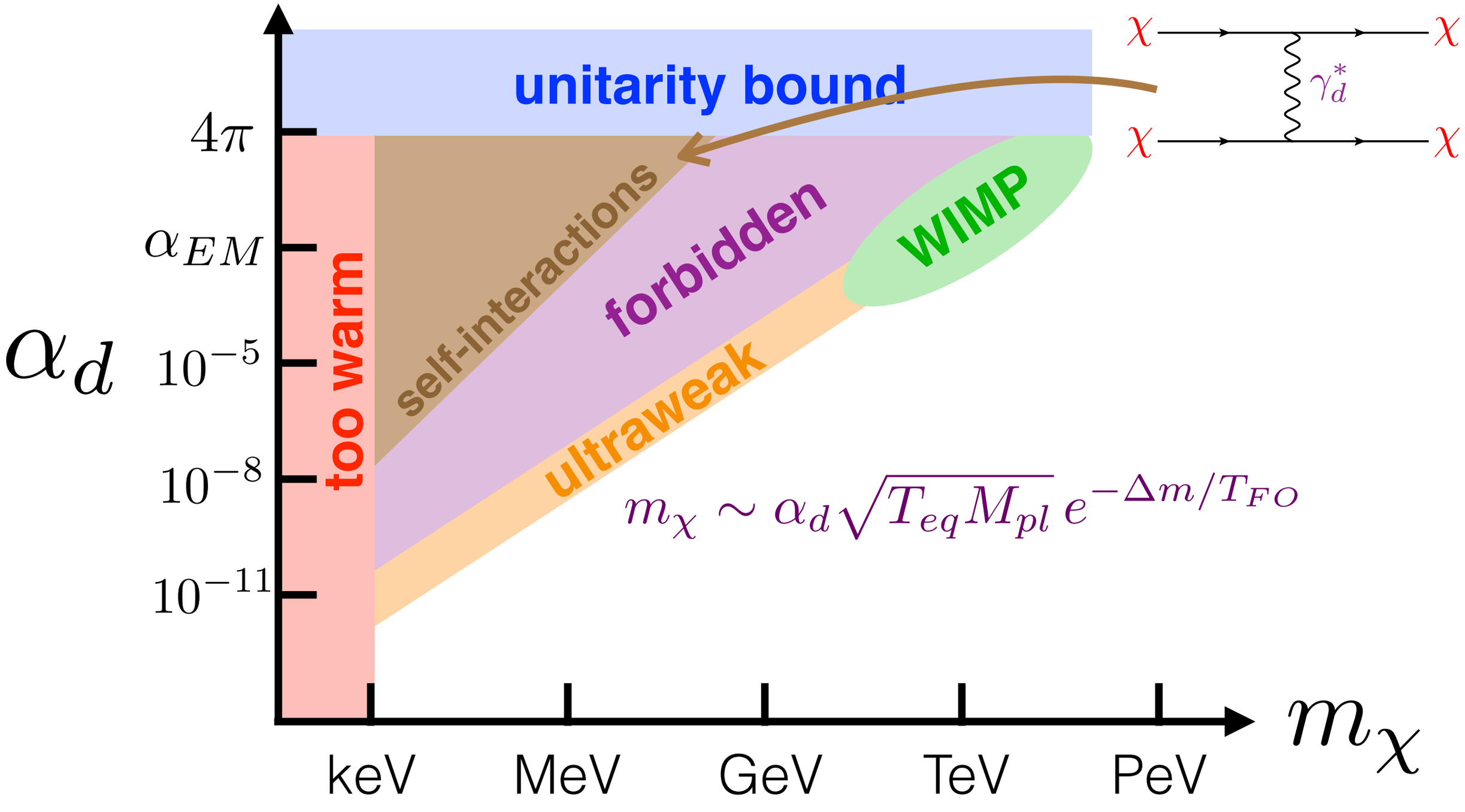
is this bad?

QCD

$$\Lambda_{QCD} \approx \Lambda_{UV} e^{-\frac{2\pi}{b_3 \alpha_3(\Lambda_{UV})}} \qquad m_p, \Omega_b h^2 \propto e^{-2\pi/(b_3 \alpha_3(\Lambda_{UV}))}$$

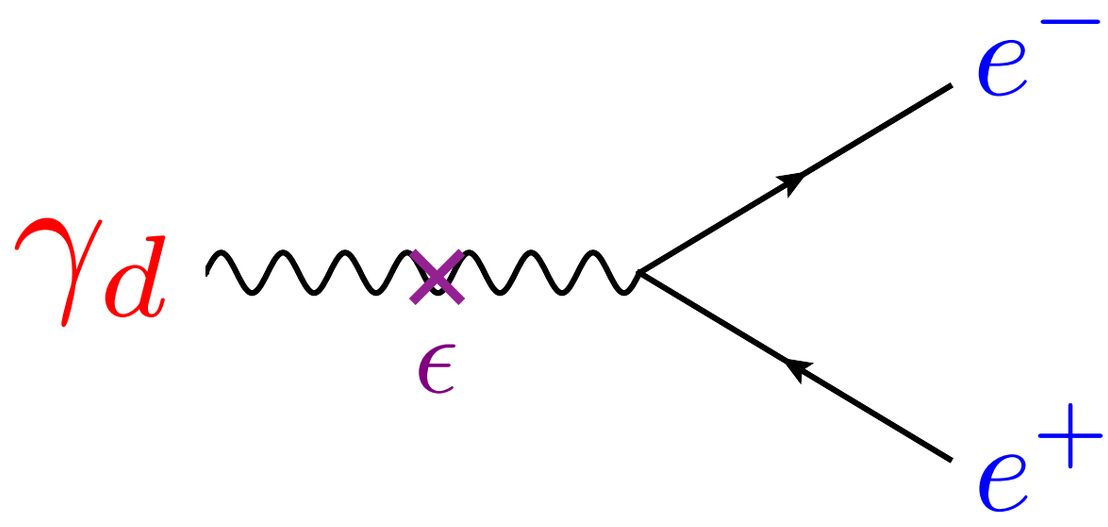
- Anderson, Castano **hep-ph/9409419**

Dark Freezeout Map



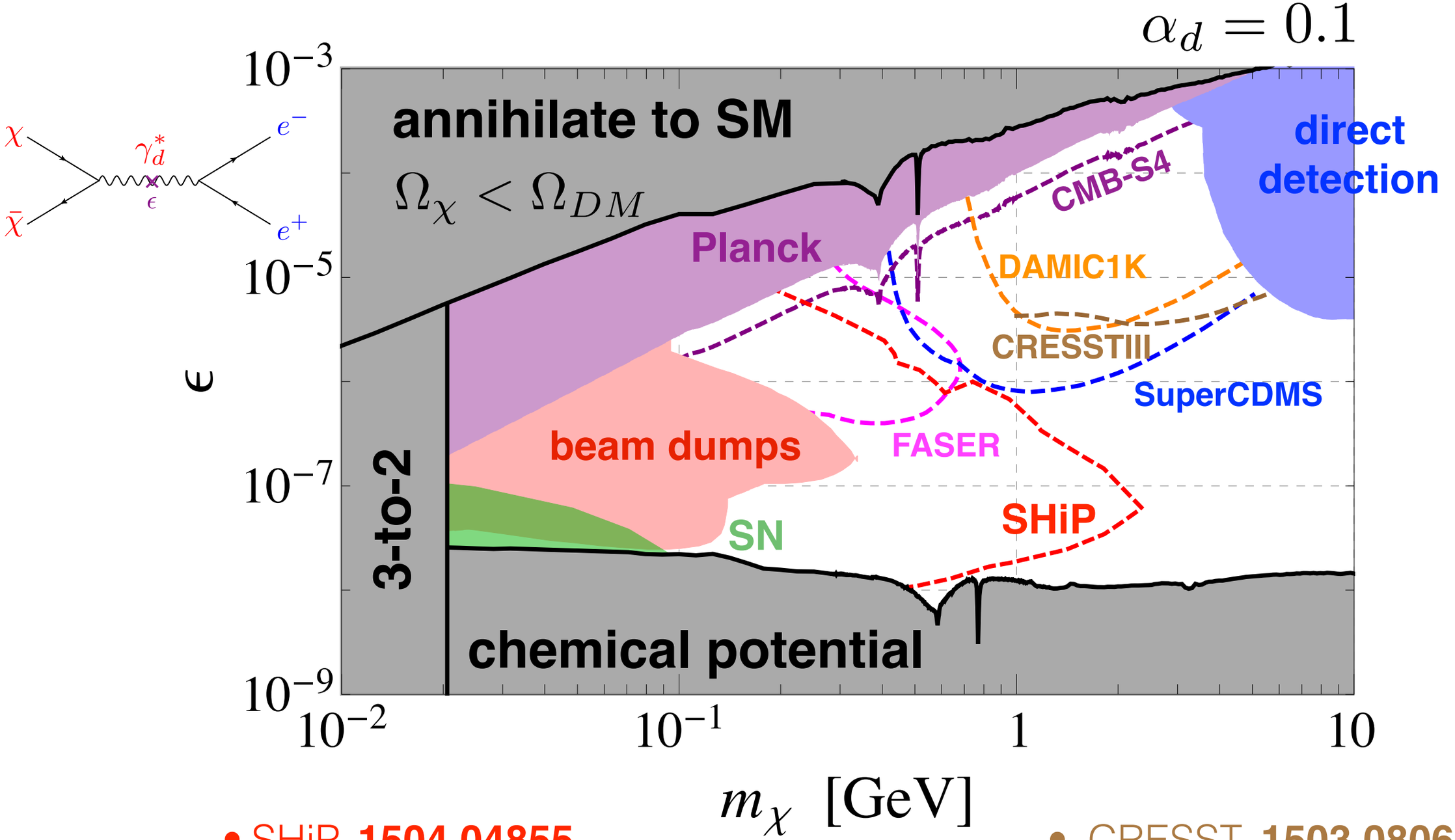
Forbidden DM with Kinetic Mixing Portal

$$\mathcal{L} \supset \frac{\epsilon}{2} F^d_{\mu\nu} F^{\mu\nu}$$



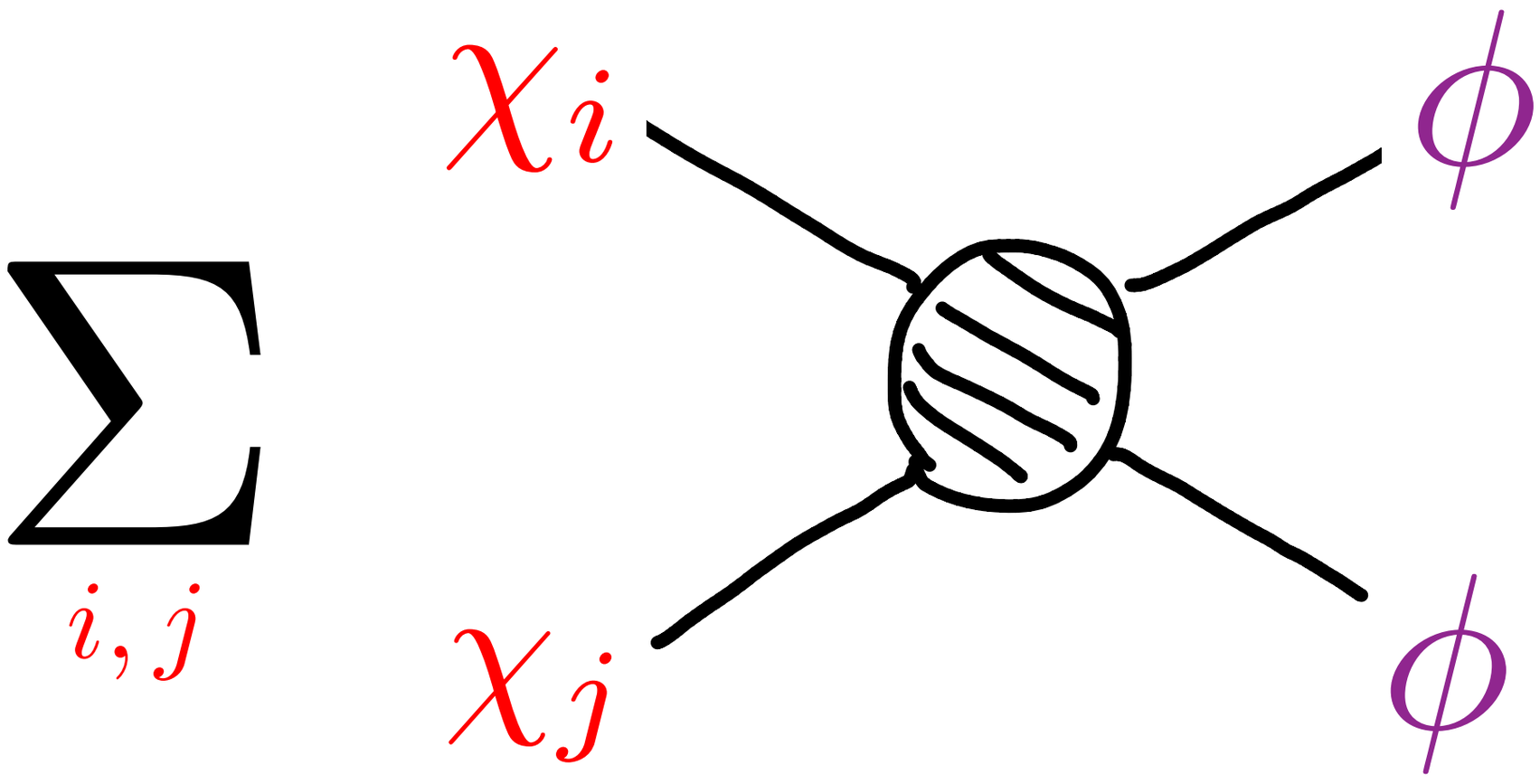
- Holdom, **1986**

Forbidden Parameter Space



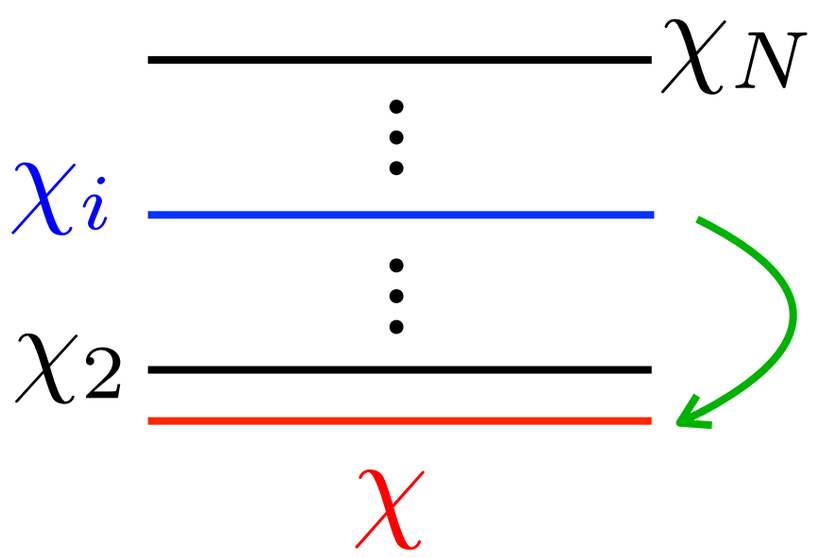
- SHiP, **1504.04855**
- CMB-S4, **1610.02743**
- FASER, **1708.09389**
- CRESST, **1503.08065**
- SuperCDMS, **1610.00006**
- DAMIC1K, **1707.04591**

III. Light DM from Coannihilation



- Raffaele D'Agnolo, Cristina Mondino, JTR, Po-Jen Wang, **1803.02901**

Coannihilation



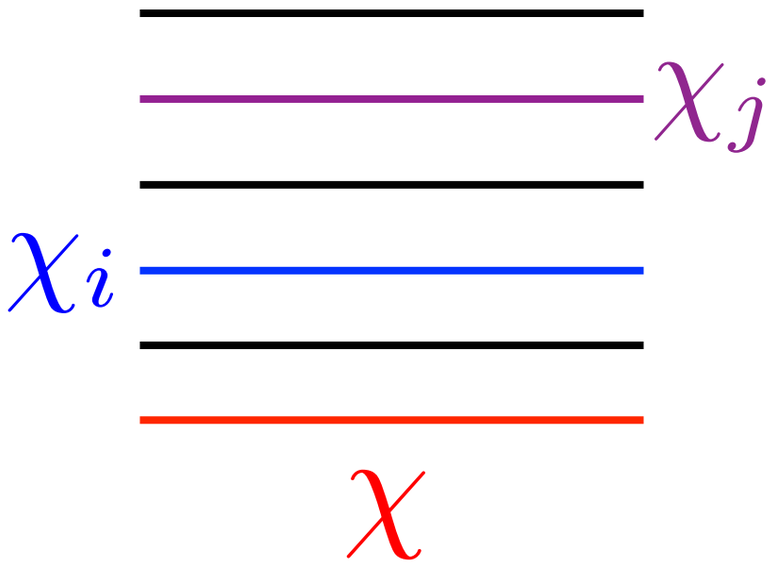
- heavier states decay to dark matter at late times

- *assume* equilibrium among dark states: $\chi \leftrightarrow \chi_i$

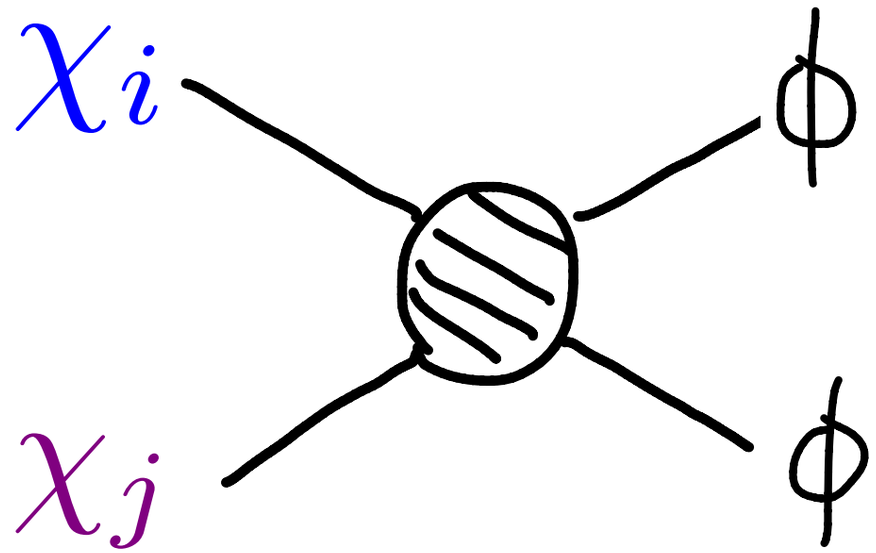
(foreshadowing)

- Griest, Seckel, **1991**

Coannihilation



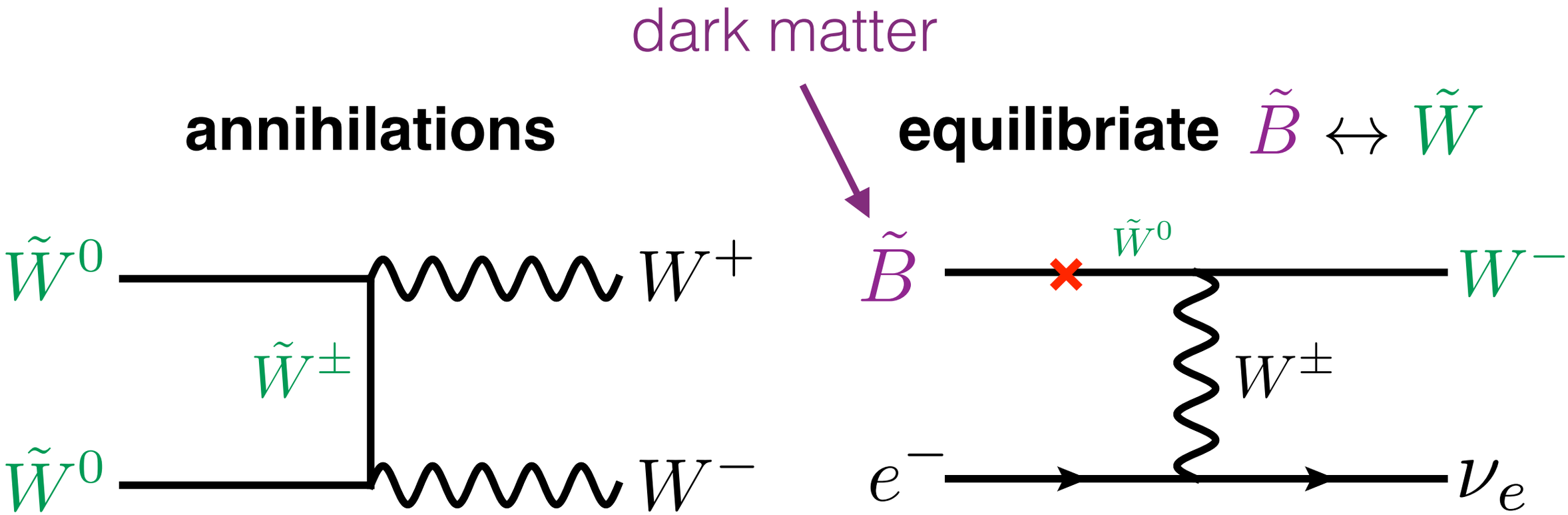
$\sum_{ij}$



$$\Omega_\chi h^2 \sim \frac{1}{\langle \sigma v \rangle_{eff} T_{eq} M_{pl}} \qquad \langle \sigma v \rangle_{eff} = \sum_{i,j} \frac{n_i^{eq} n_j^{eq}}{(n_\chi^{eq})^2} \langle \sigma_{ij} v \rangle$$

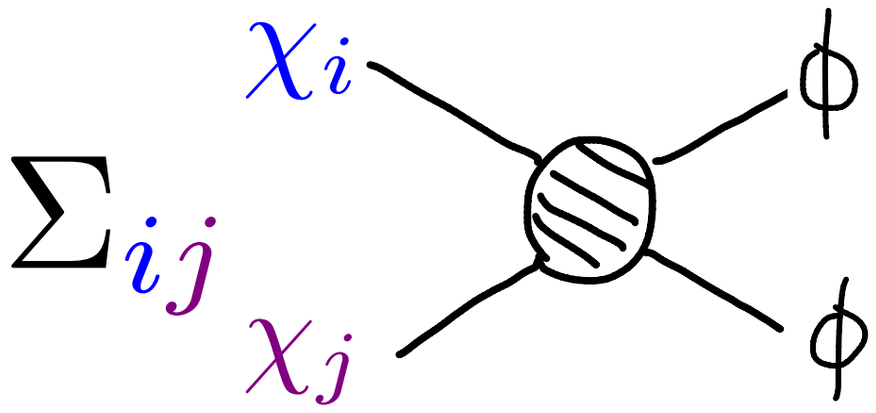
- Griest, Seckel, **1991**

ex) Well-Tempered Neutralino

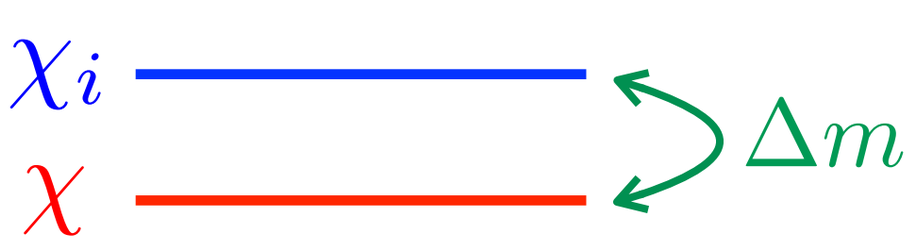


- Arkani-Hamed, Delgado, Giudice **hep-ph/0601041**
- Cheung, Hall, Pinner, JTR **1211.4873**

Degenerate Coannihilations



$$\langle \sigma v \rangle_{eff} = \sum_{i,j} \frac{n_i^{eq} n_j^{eq}}{(n_\chi^{eq})^2} \langle \sigma_{ij} v \rangle$$

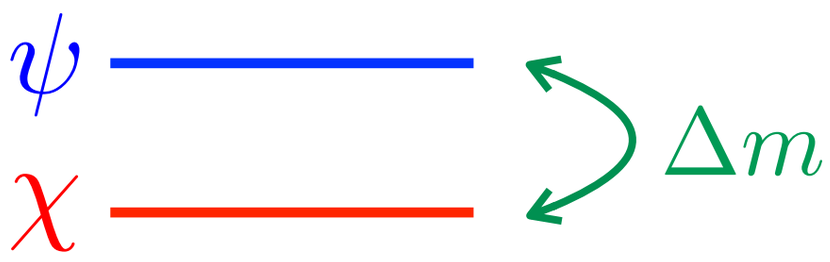


$$\frac{n_i^{eq}}{n_\chi^{eq}} \sim e^{-\Delta m/T}$$

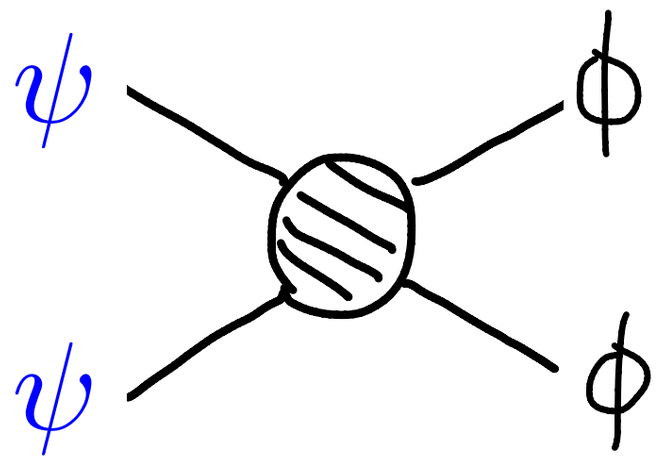
- lore: coannihilations is only relevant for degenerate states

$$\frac{\Delta m}{m_\chi} \lesssim 0.1$$

Non-Degenerate Coannihilations



dominate annihilation:



$$\langle \sigma v \rangle \sim \frac{\alpha_d^2}{m_\psi^2}$$

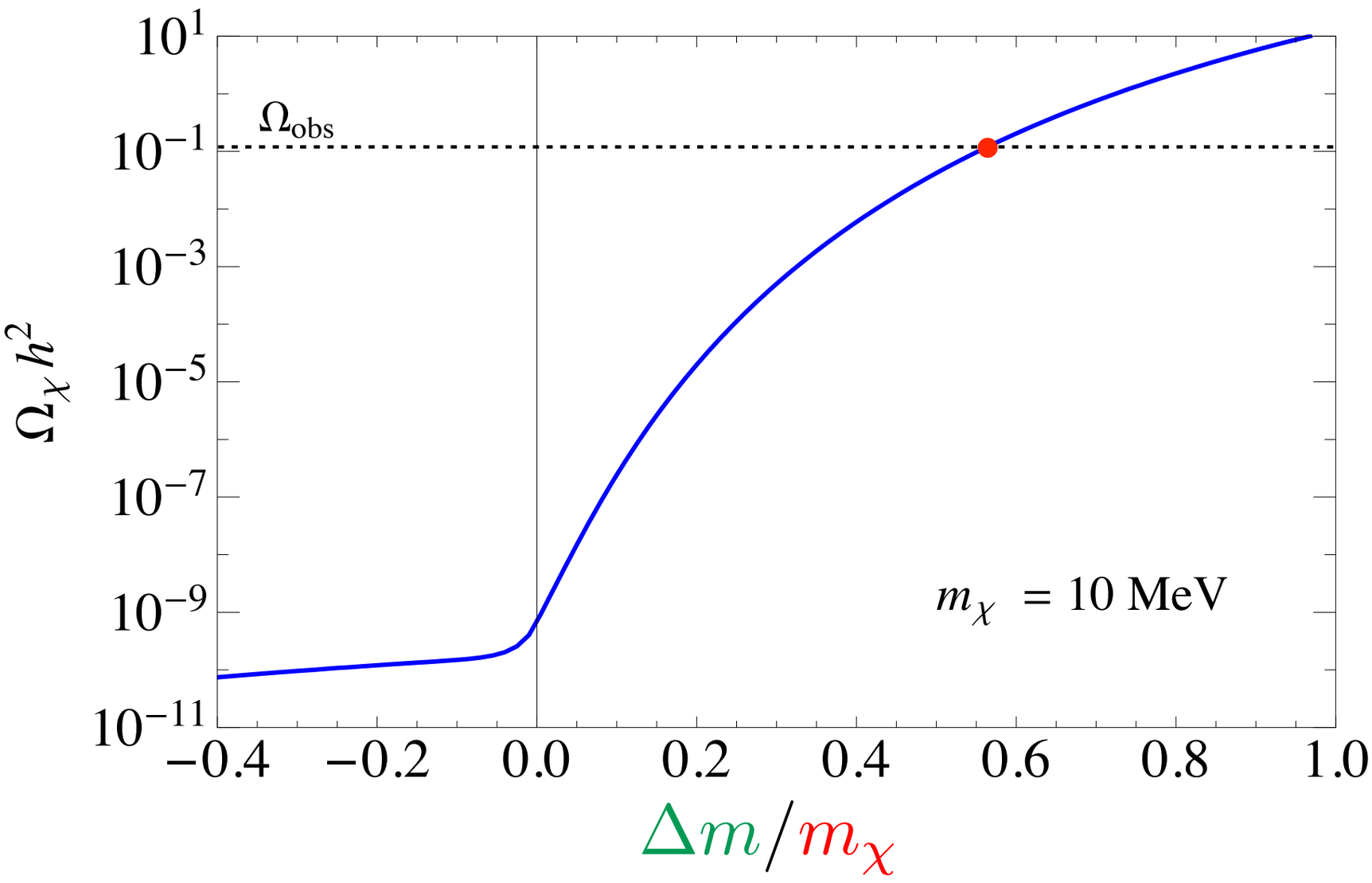
$$\langle \sigma v \rangle_{eff} \sim \frac{\alpha_d^2}{m_\psi^2} e^{-2\Delta m/T}$$

- DM mass: $m_\chi \sim \alpha_d \sqrt{T_{eq} M_{pl}}\, e^{-2\Delta m/T_{FO}}$

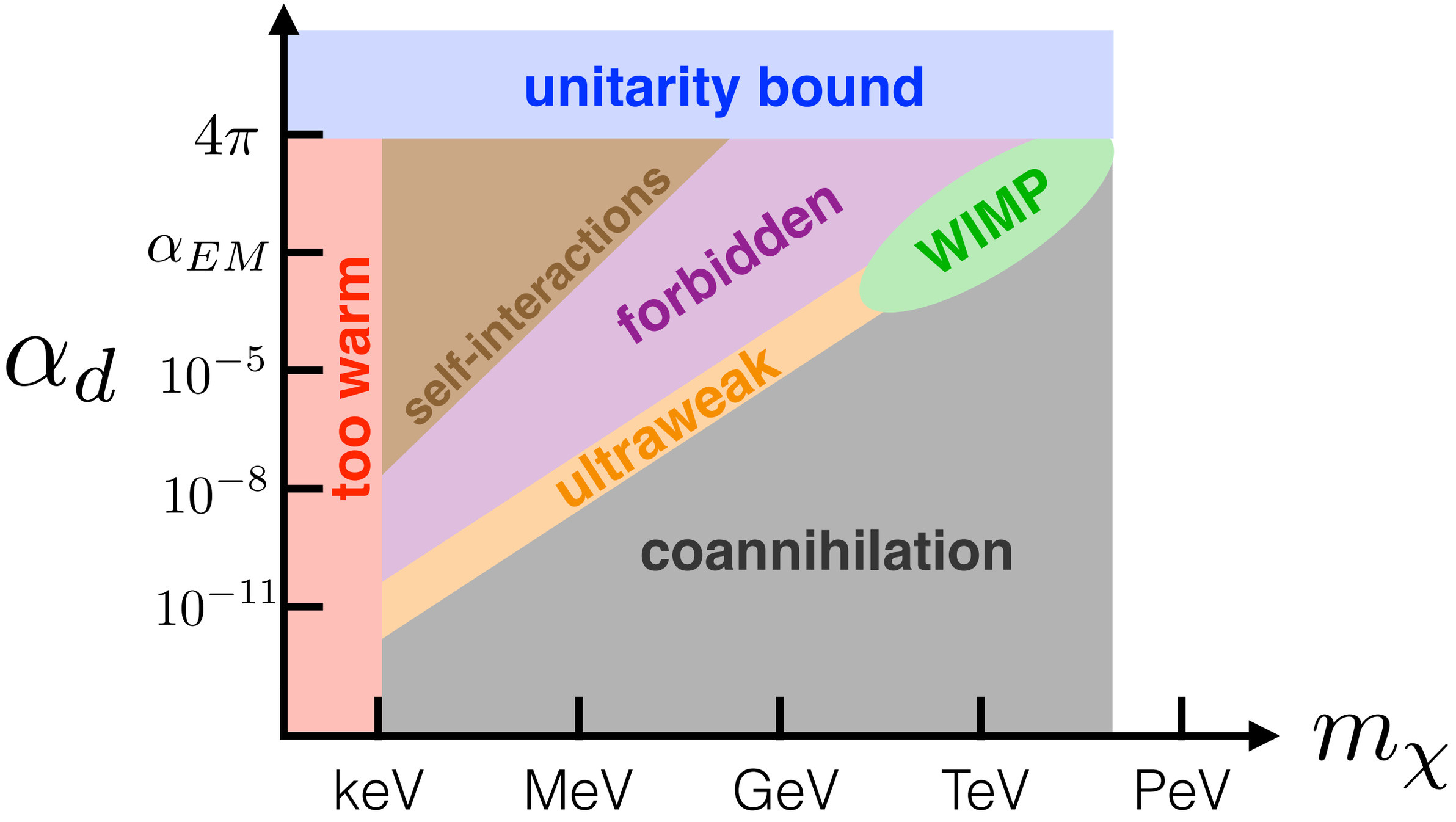
- evades CMB: $\sigma_{\chi\chi} \ll \sigma_{\psi\psi}$

Non-Degenerate Coannihilations

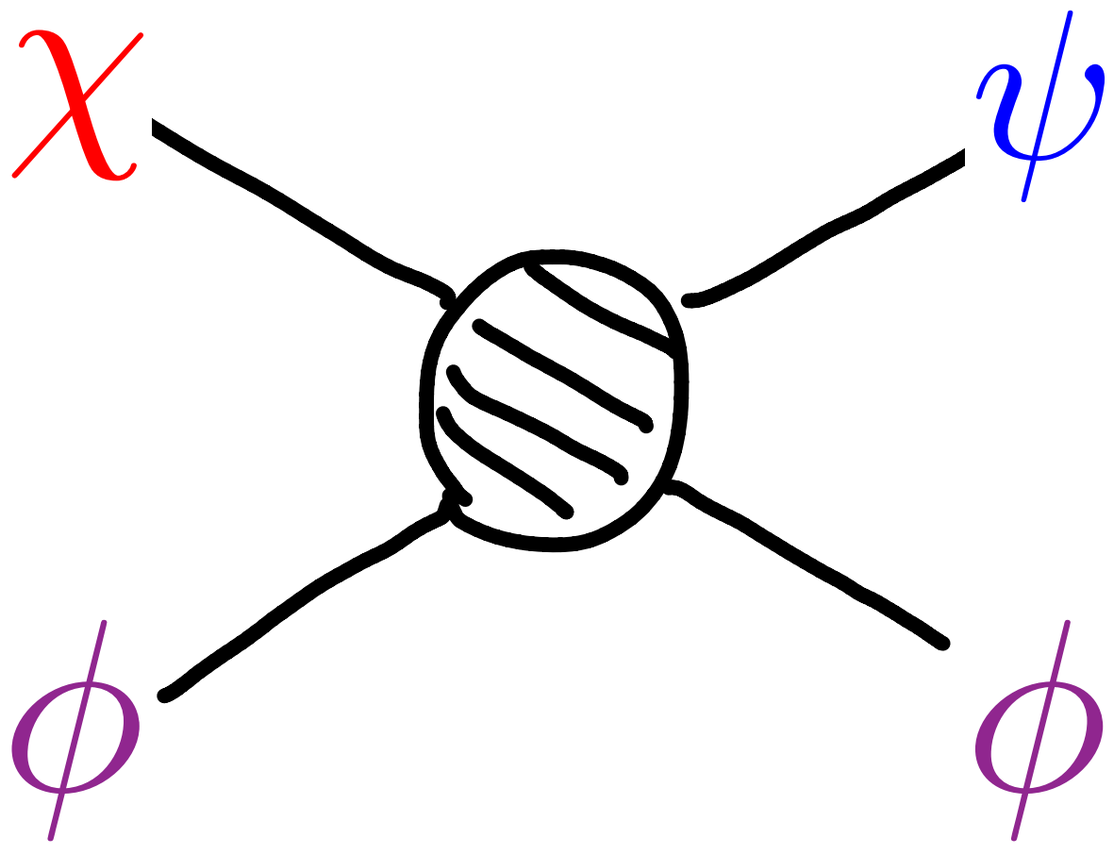
$$\Omega_\chi h^2 \sim \frac{m_\chi^2}{\alpha_d^2 T_{eq} M_{pl}} e^{2\Delta m/T_{FO}}$$



Dark Freezeout Map

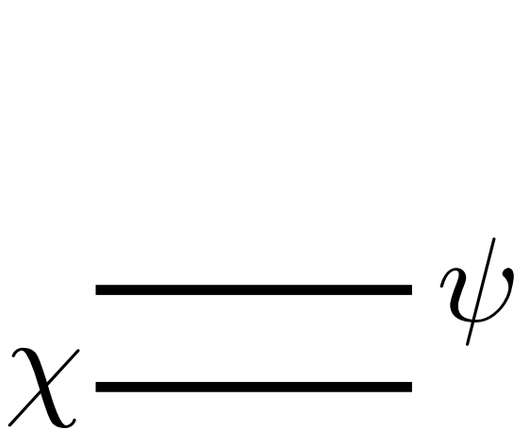


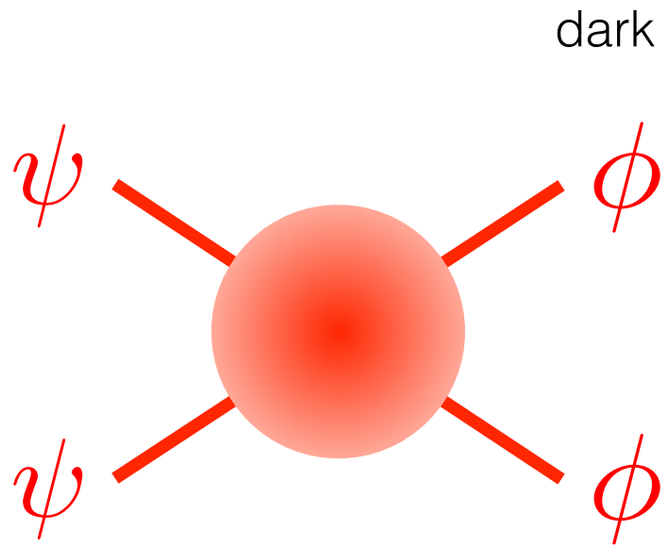
IV. Coscattering

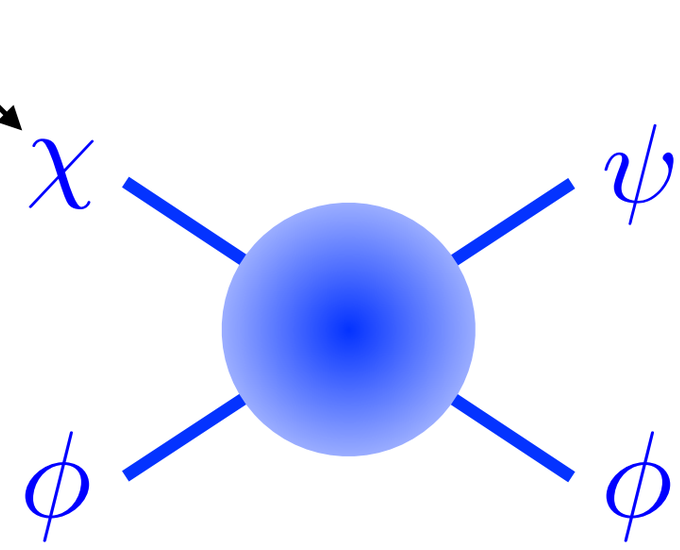


- Raffaele D'Agnolo, Duccio Pappadopulo, JTR, **1705.08450** (PRL)

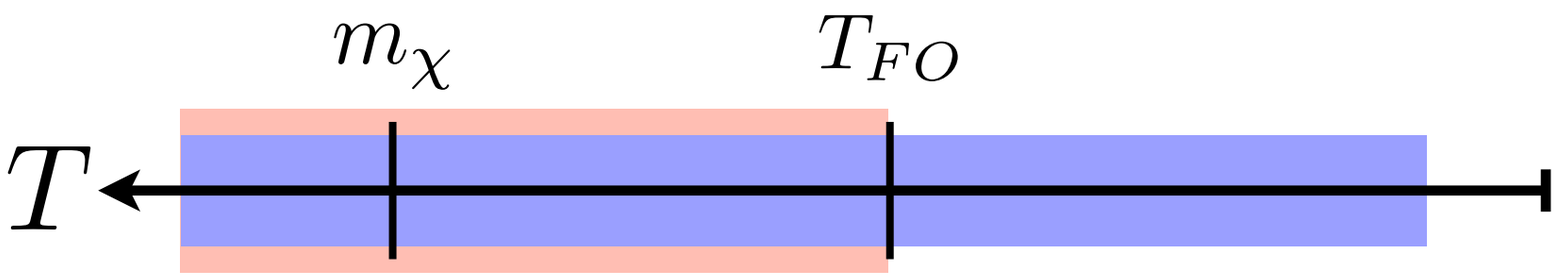
Coannihilation vs. Coscattering



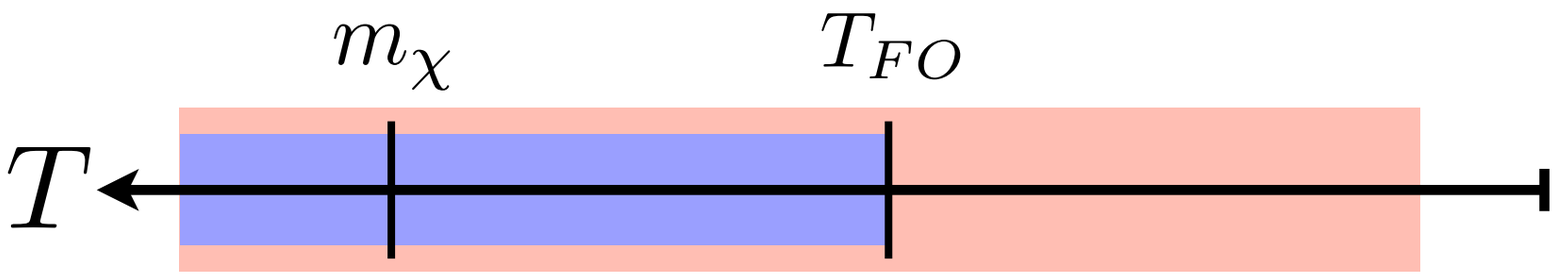




- coannihilation



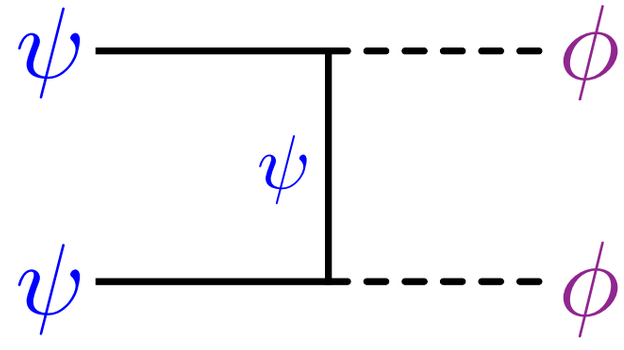
- coscattering



Mix-In Dark Matter

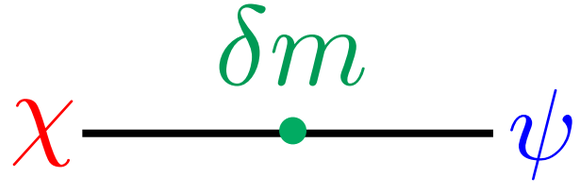
- active state

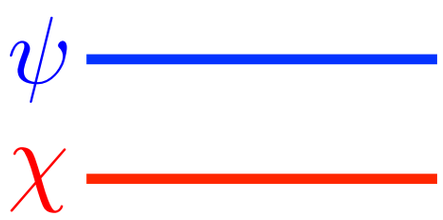
$$\frac{y}{2}\phi\psi^2$$



- sterile state (DM)

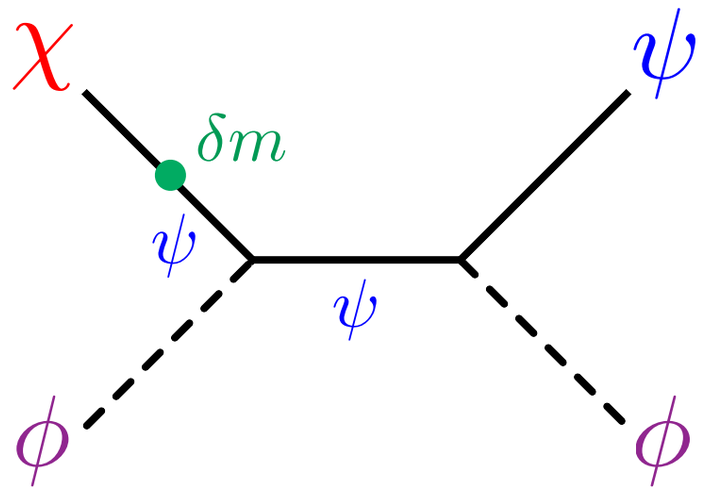
$$\delta m \chi \psi$$





$$\delta m \ll m_\chi$$

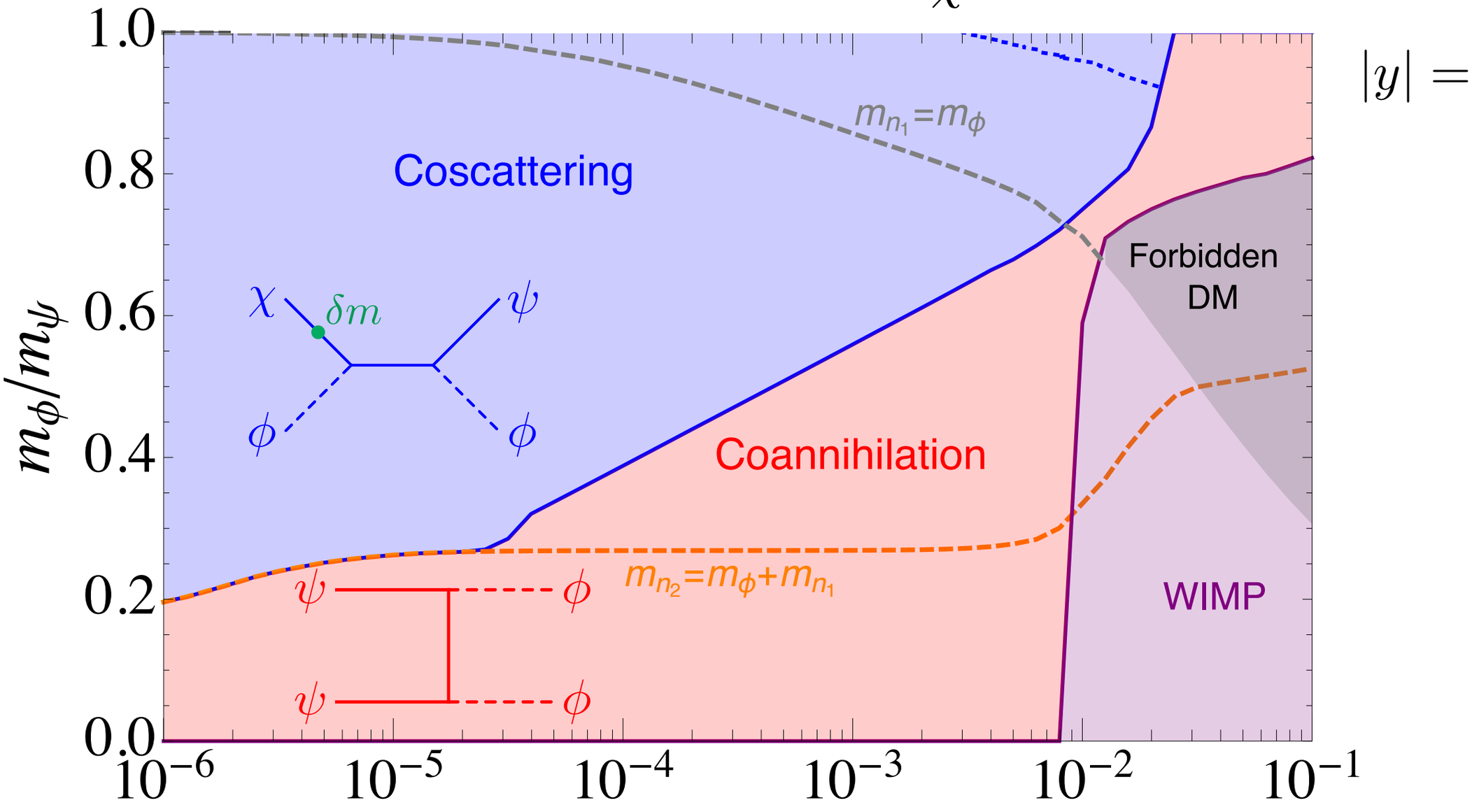
- equilibriate: $\chi \leftrightarrow \psi$

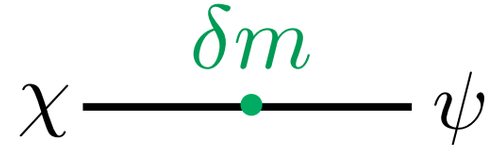


Freeze-Out Phase Diagram

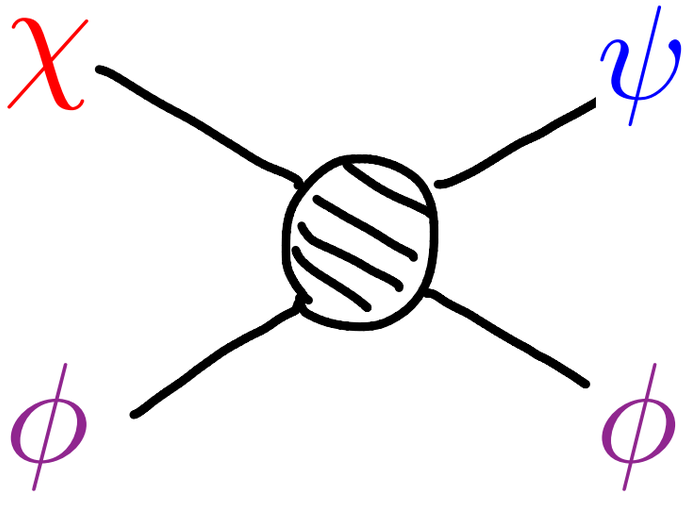
$m_\chi = 100$ MeV

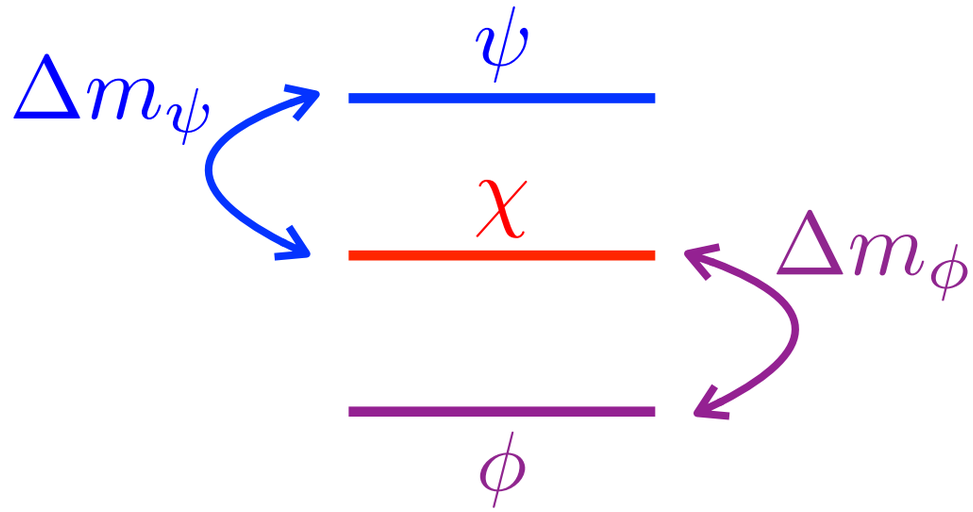
$|y| = 0.5$





Coscattering Abundance





$$n_\phi^{eq} \langle \sigma v \rangle = H$$

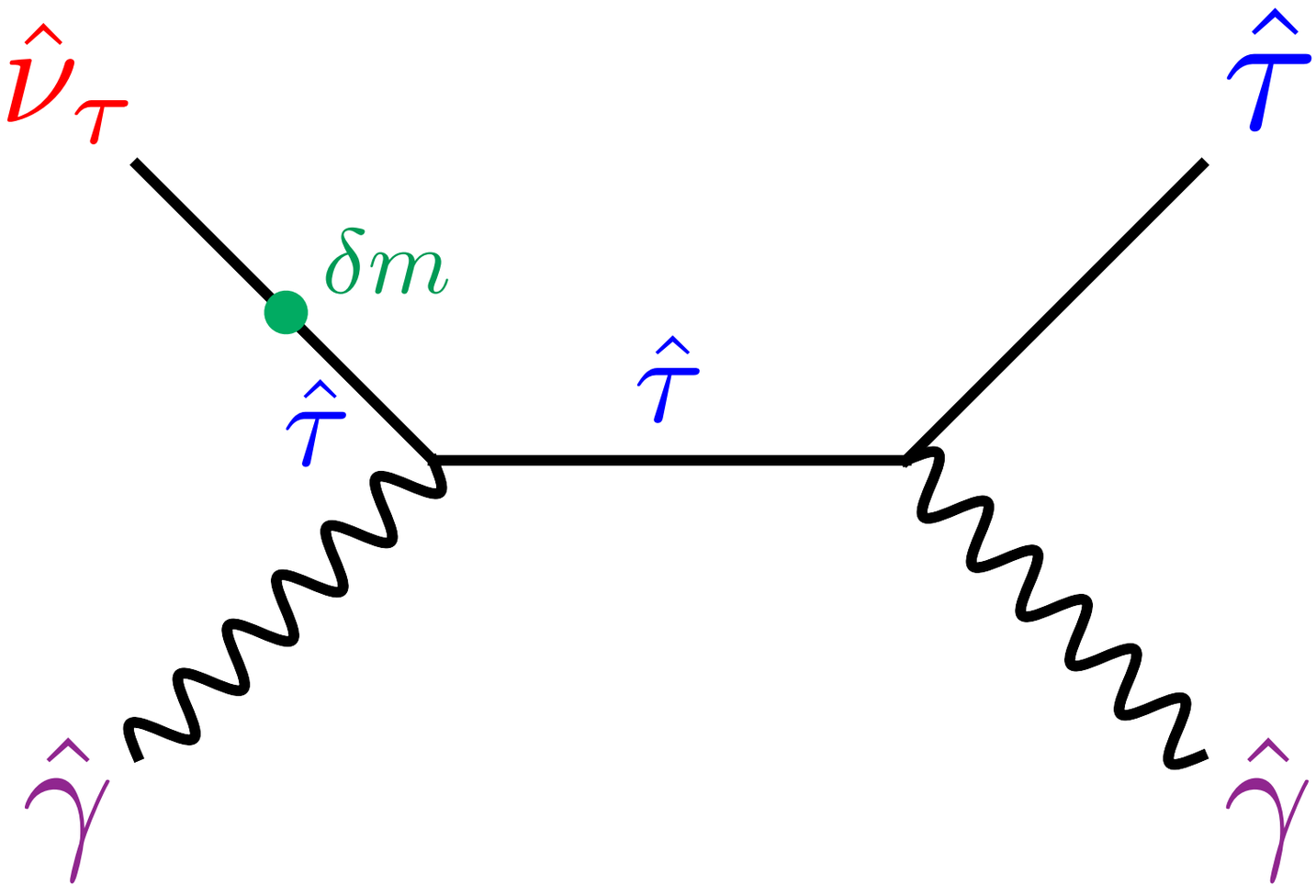
freeze-out

$$m_\chi \sim \alpha_d \sqrt{T_{eq} M_{pl}}\, e^{-(\Delta m_\psi - \Delta m_\phi)/2T_{FO}}$$

thermal average

$$\langle \sigma v \rangle \sim \frac{\alpha_d^2}{m_\chi^2} e^{-\Delta m_\psi / T}$$

Coscattering in Fraternal Twin Higgs



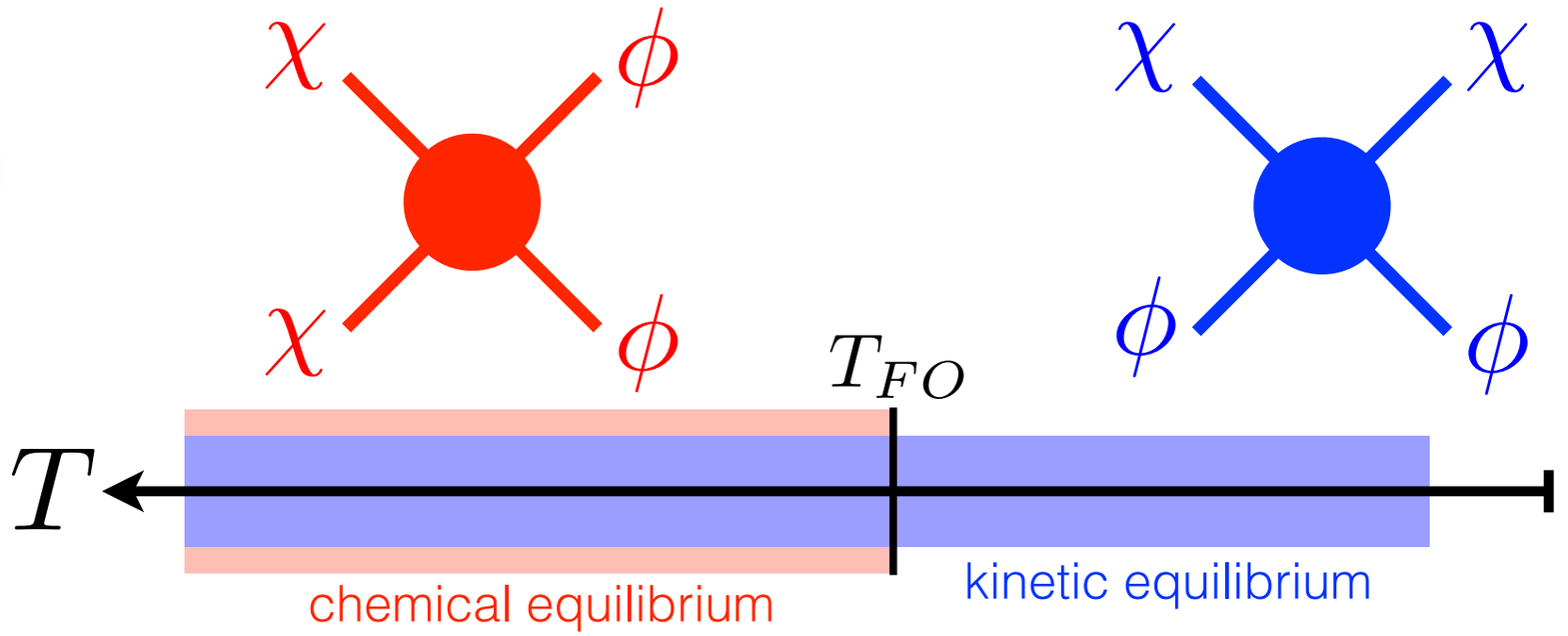
$$m_{\hat{\gamma}}, m_{\hat{\nu}_\tau}, m_{\hat{\tau}} \sim 0.1 - 10\,\mathrm{GeV}$$

Cheng, Li, Zheng, **1805.12139**

Chemical vs. Kinetic Decoupling

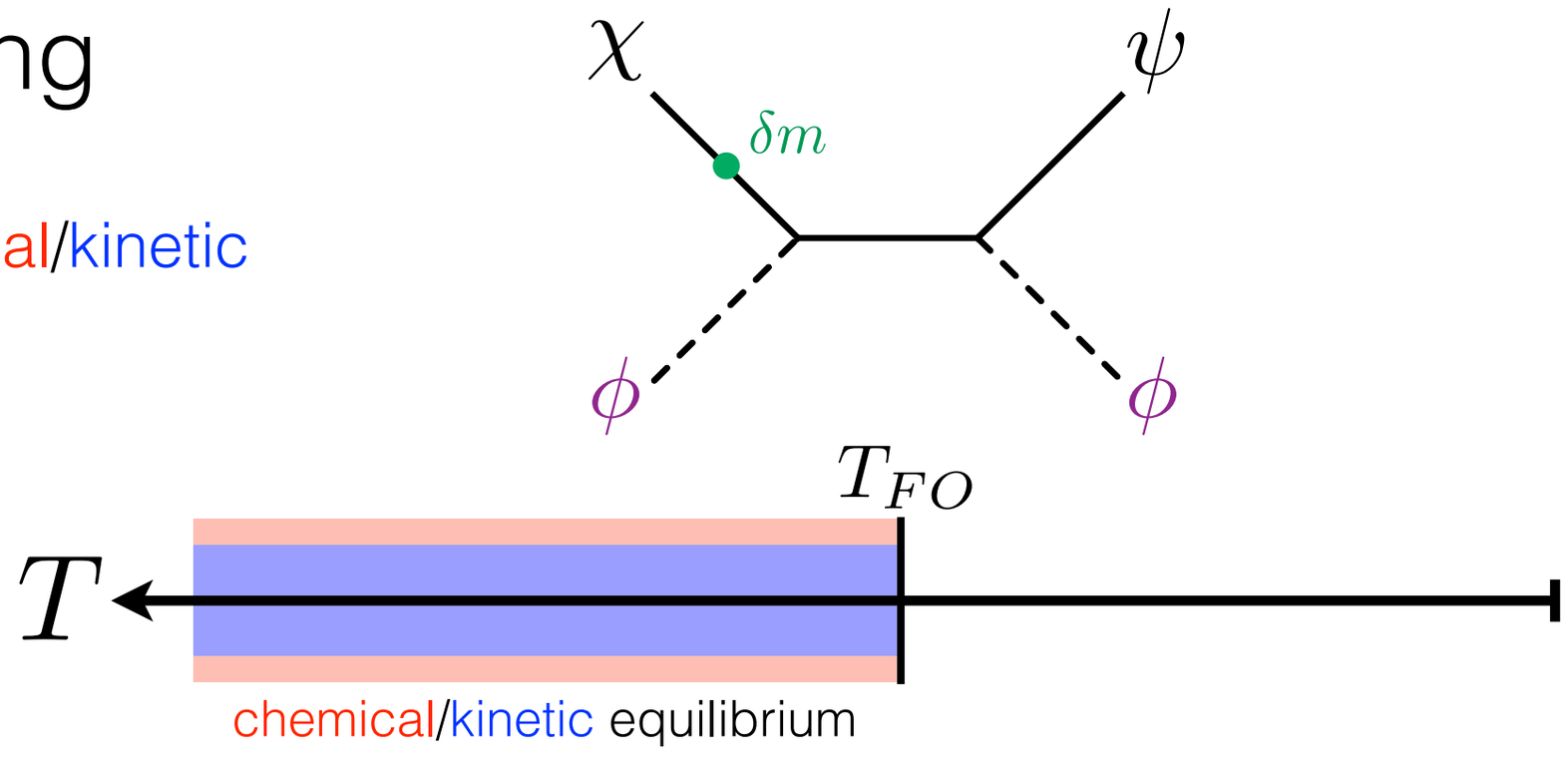
- WIMP/forbidden/coannihilations

chemical decoupling
before kinetic



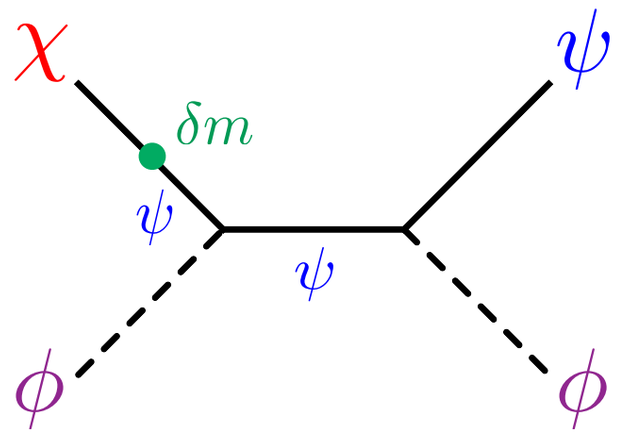
- coscattering

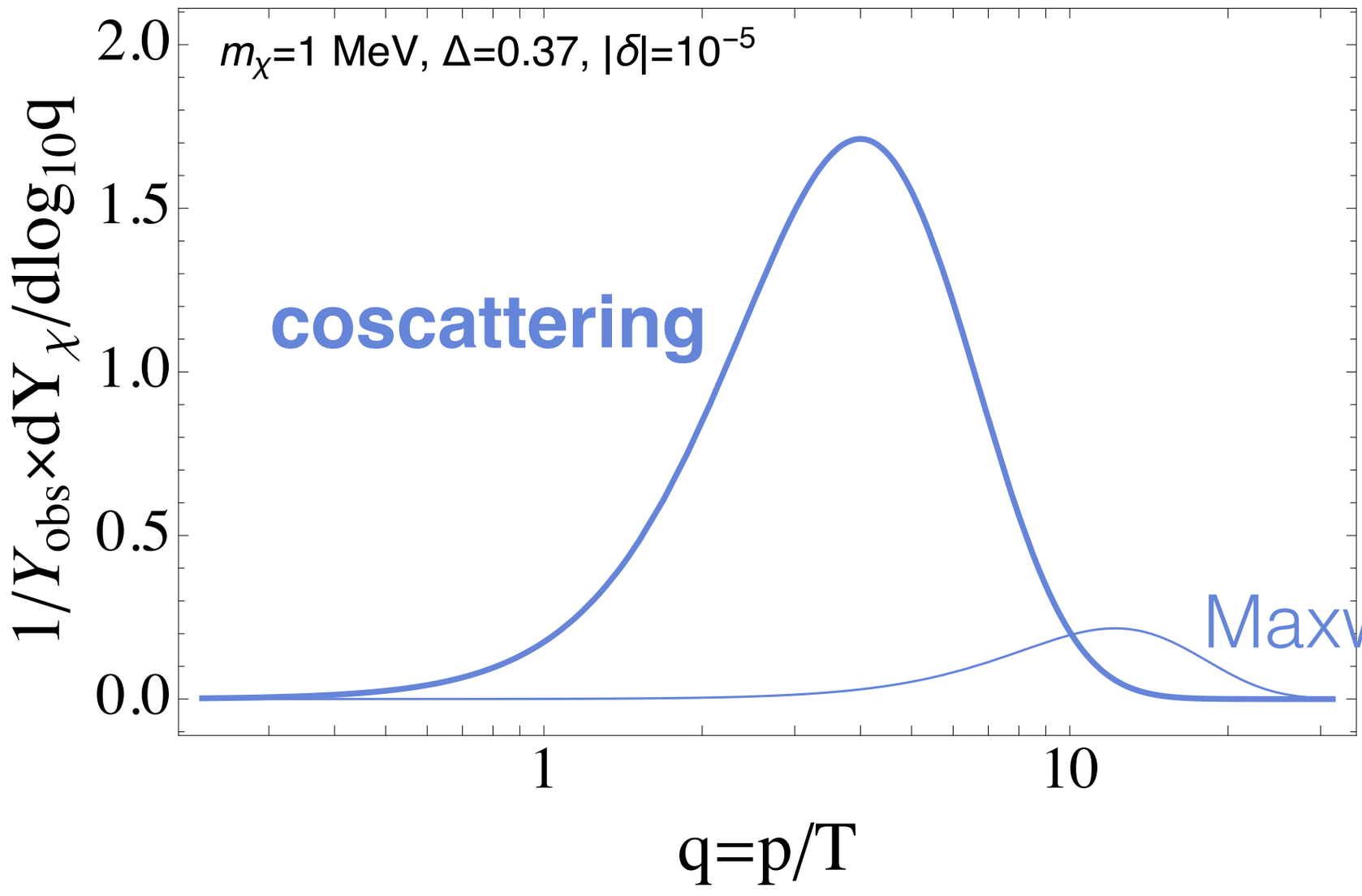
simultaneous chemical/kinetic
decoupling



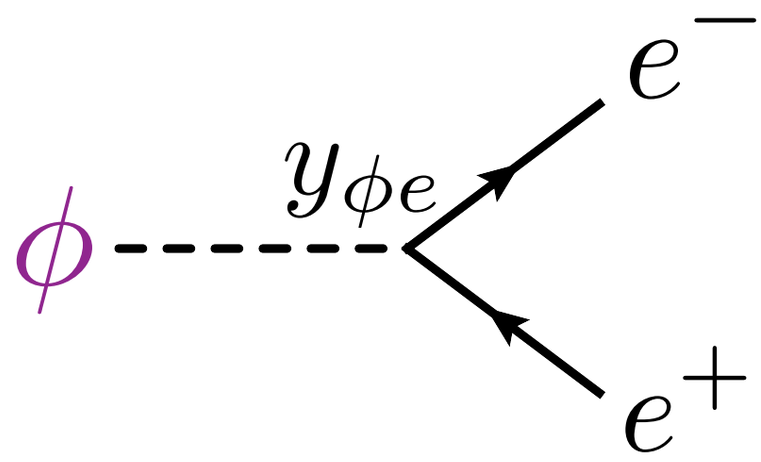
Distorted Dark Matter Phase Space

low-momentum modes decouple
before high-momentum modes

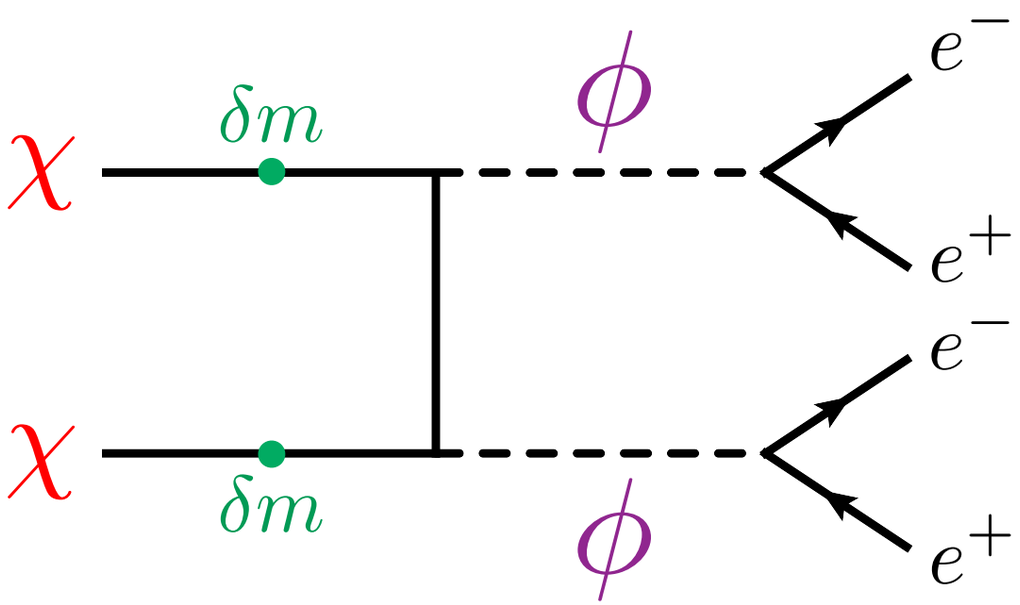




Coscattering Coupled to SM

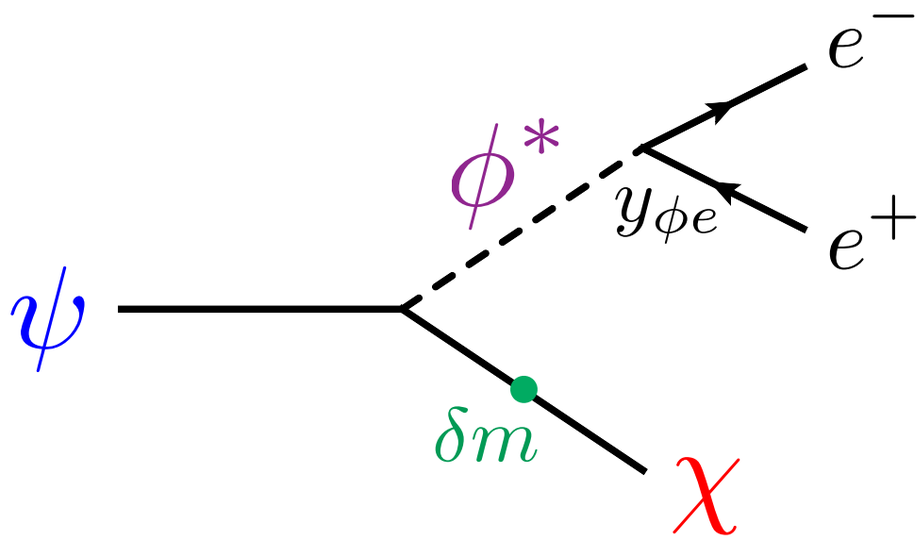


annihilations

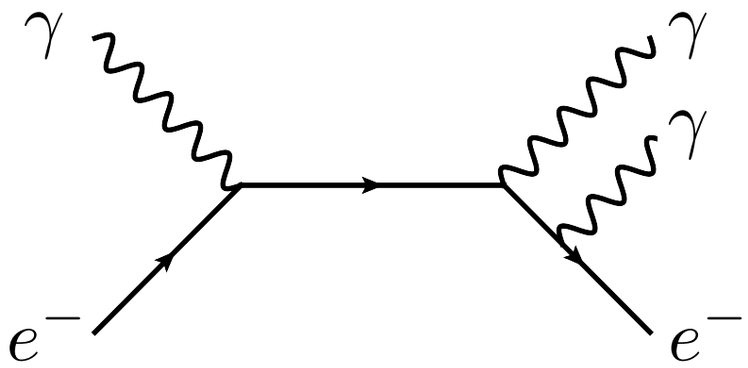


$$\langle \sigma v \rangle_{\chi\chi} \ll \langle \sigma v \rangle_{\rm WIMP} \sim \frac{1}{T_{eq} M_{pl}}$$

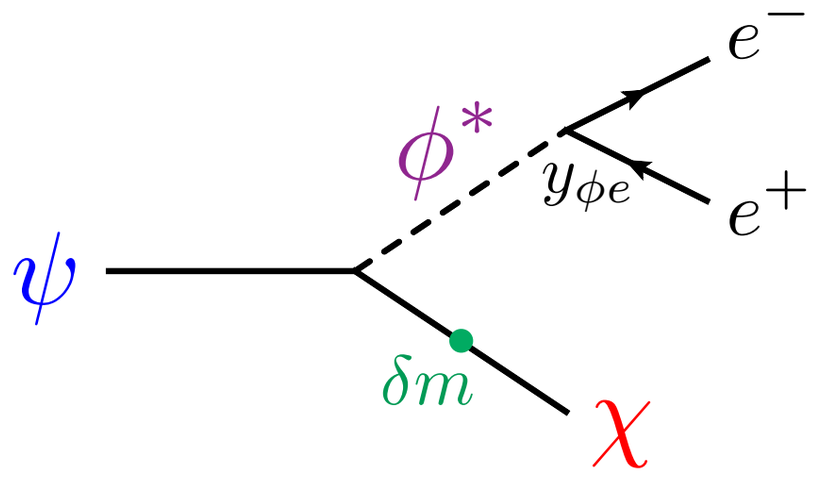
decay



Spectral Distortions from Coscattering



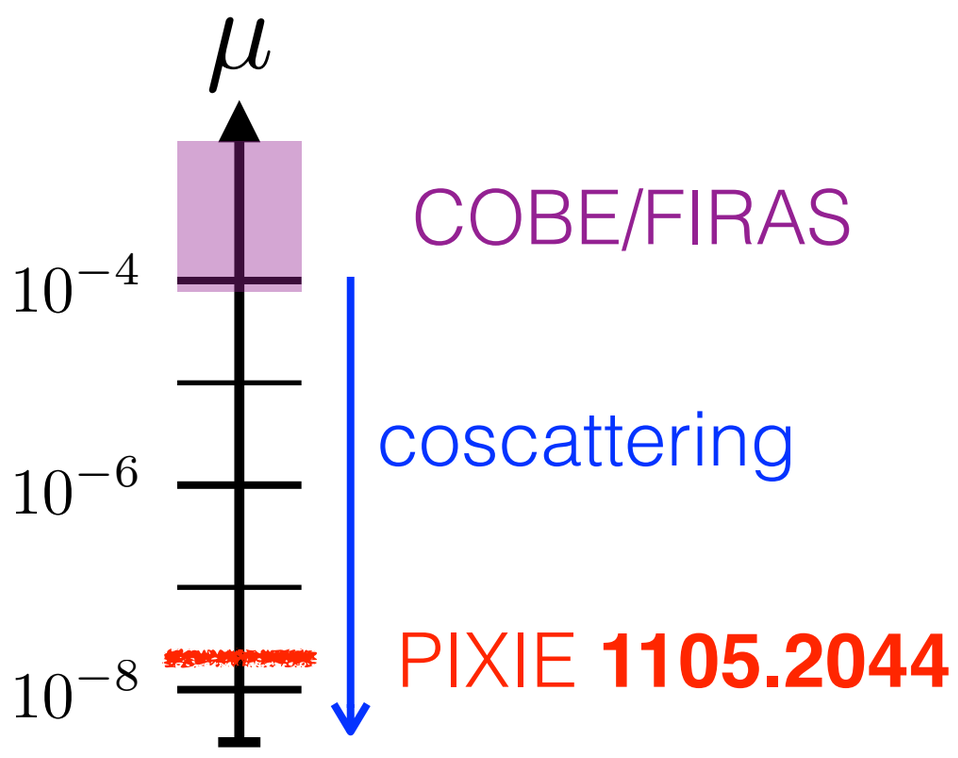
photon number changing



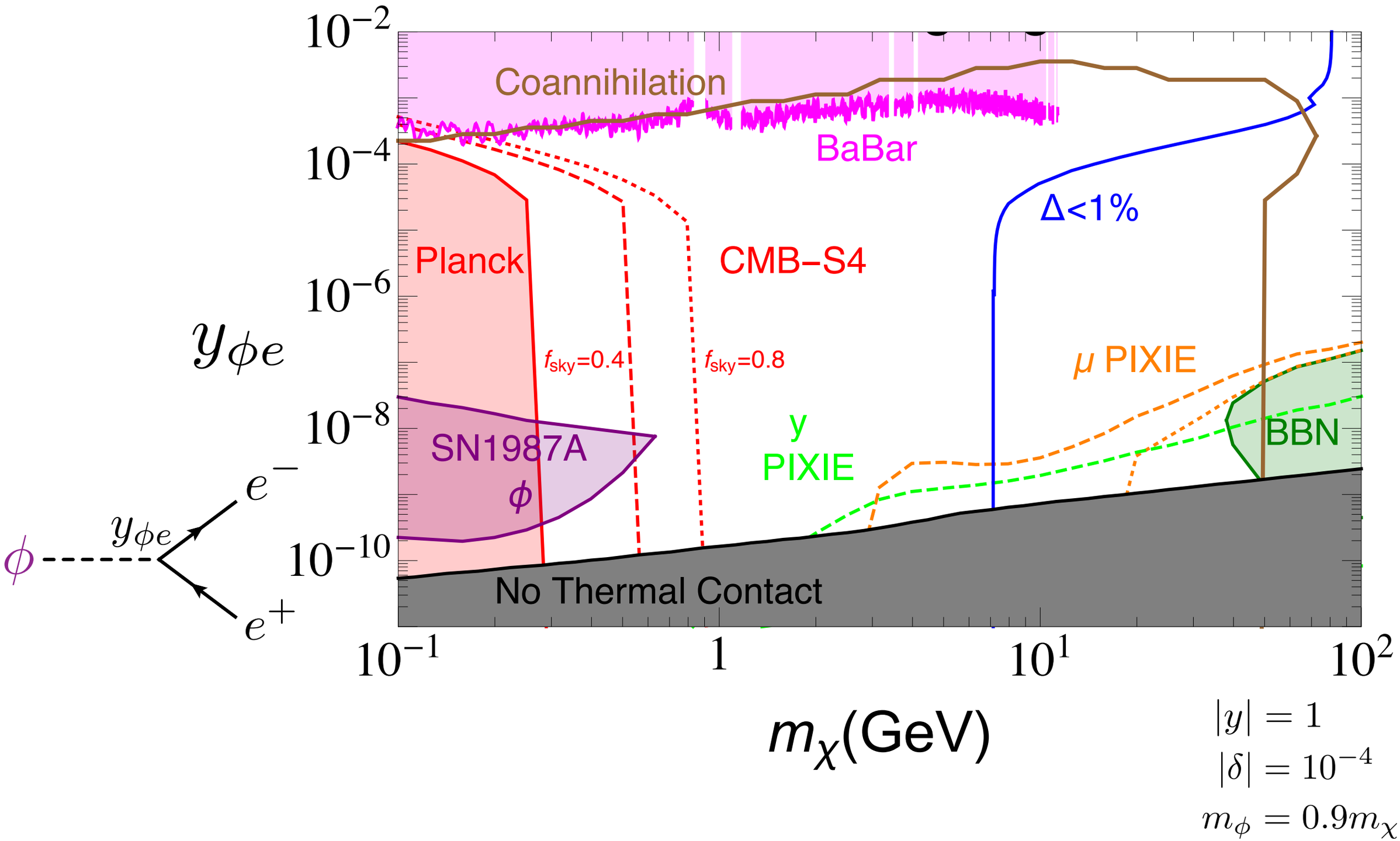
late decay

$\mu -$ distortion

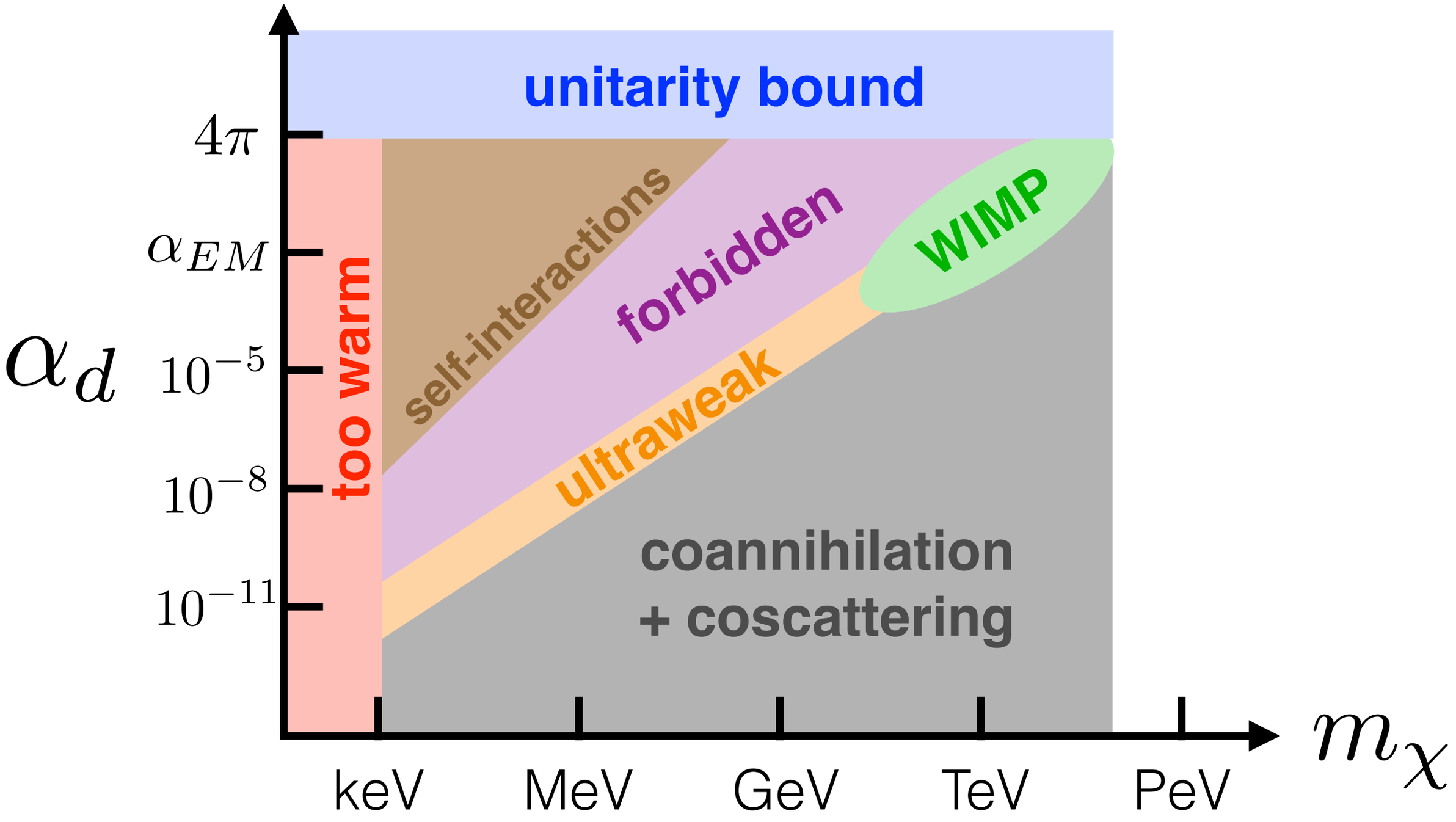
$$f_\gamma(E) = \frac{1}{e^{E/(kT)+\mu} - 1}$$

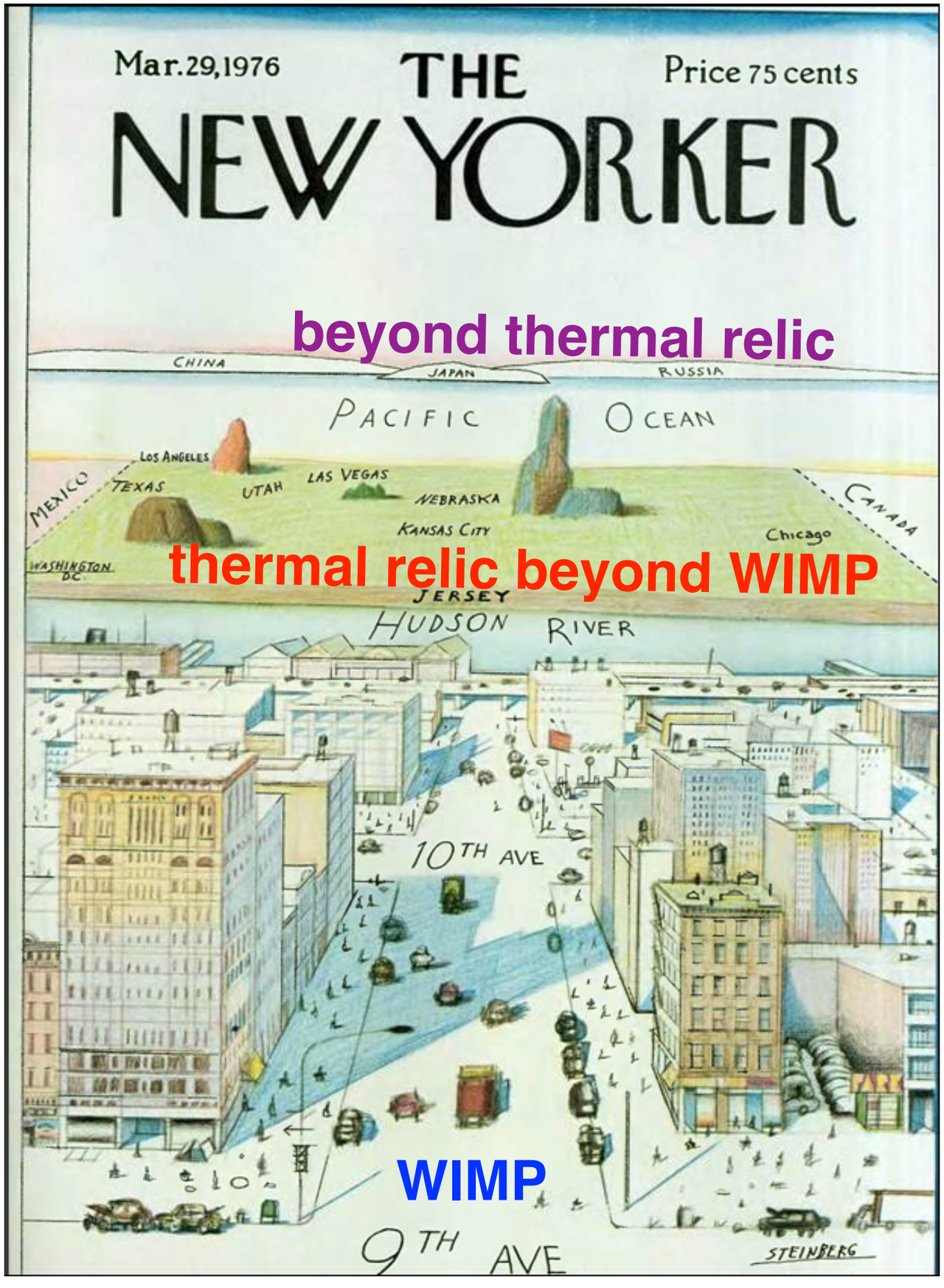


Coscattering Parameter Space



Dark Freezeout Map




Mar.29,1976
THE
NEW YORKER
Price 75 cents
beyond thermal relic
CHINA
JAPAN
RUSSIA
PACIFIC
OCEAN
LOS ANGELES
MEXICO
TEXAS
UTAH
LAS VEGAS
NEBRASKA
KANSAS CITY
Chicago
CANADA
WASHINGTON DC
thermal relic beyond WIMP
JERSEY
HUDSON
RIVER
10TH AVE
WIMP
9TH AVE
STEINBERG

this talk

dark matter

Dark Mechanism Flow

thermal

nonthermal

symmetric

asymmetric

inflaton decay

misalignment

3-to-2

2-to-2

thermal parent

$m_\chi \ll m_h$

WIMP

forbidden

freeze-in

superWIMP

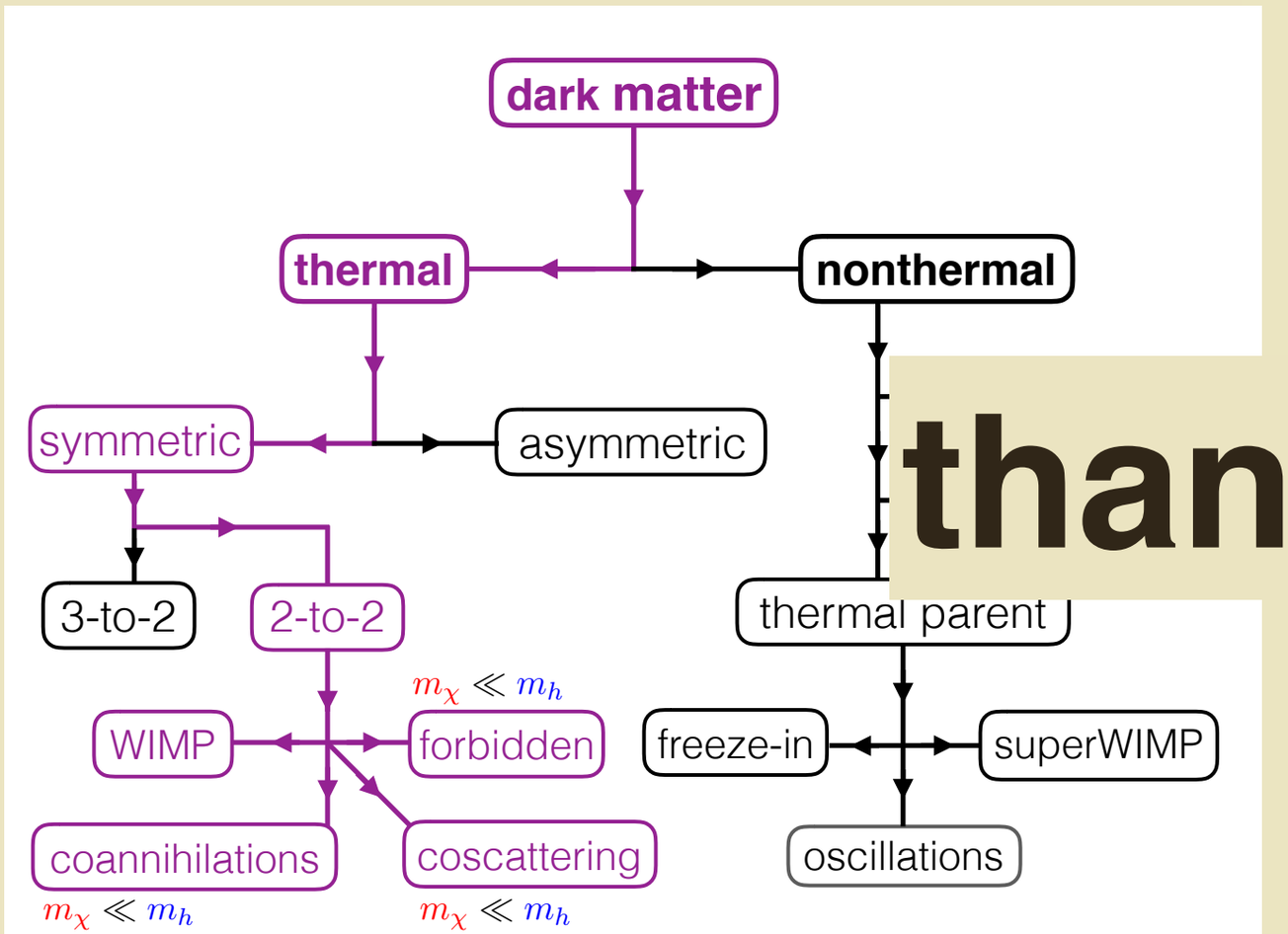
coannihilations

coscattering

oscillations

$m_\chi \ll m_h$

$m_\chi \ll m_h$


dark matter
thermal
nonthermal
symmetric
asymmetric
3-to-2
2-to-2
thermal parent
$m_\chi \ll m_h$
WIMP
forbidden
freeze-in
superWIMP
coannihilations
coscattering
oscillations
$m_\chi \ll m_h$
$m_\chi \ll m_h$

thanks!


ALE
LAGER
The Very, Very Many Varieties OF BEER
AMBER ALE
New Belgium Fat Tire
Trögs Hopback Amber Ale
Lost Coast Apricot Wheat
Three Floyds Gumballhead
AMERICAN WHEAT ALE
New Glarus Crack'd Wheat
Redhook Blonde Ale
BLONDE ALE
Rogue Oregon Blond Ale
AMERICAN PALE ALE
HeBrew Genesis Ale
Oskar Blues Dale's Pale Ale
Anchor Liberty Ale
Three Floyds Alpha King
Sierra Nevada Pale Ale
Newcastle Brown Ale
BROWN ALE
Abita Turbodog
PALE ALE
Smithwick's Ale
McSorley's Ale
IRISH ALE
Great Lakes Edmund Fitzgerald Porter
ENGLISH PALE ALE/ BITTER
Boddingtons Pub Ale
Smuttynose Robust Porter
AMERICAN PORTER
Deschutes Obsidian Stout
Sierra Nevada Stout
AMERICAN STOUT
Mackeson XXX Stout
STOUT/ PORTER
ENGLISH PORTER
Fuller's London Porter
Geary's London-Style Porter
Bass Ale
BURTON PALE ALE
PREMIUM BITTER/ ESB
Gritty McDuff's Best Bitter
Fuller's ESB
Wychwood Hobgoblin
IRISH STOUT
Murphy's Irish Stout
Guinness Draught
Beamish Stout
FOREIGN STOUT
Lion Stout
Reaper Ale Mortality Stout
Guinness Foreign Extra Stout
SWEET STOUT
Young's Double Chocolate Stout
OATMEAL STOUT
Iron Fist Brewing Velvet Glove
Samuel Smith's Oatmeal Stout
CREAM ALE
New Glarus Spotted Cow
Genny Cream Ale
CALIFORNIA COMMON
Steamworks Steam Engine Lager
Anchor Steam Beer
BALTIC PORTER
Zywiec Porter
Koff Porter
Victory Baltic Thunder
AMERICAN LAGER
Saranac Lager
Michelob
AMERICAN PALE LAGER
Moosehead Lager
AMERICAN DARK/AMBER LAGER
Coney Island Lager
Brooklyn Lager
Killian's Irish Red
AMERICAN ADJUNCT LAGER
Tsingtao
Budweiser
PBR
Presidente
Miller High Life
Corona Extra
JAPANESE RICE LAGER
Sapporo Premium Beer
Asahi Super Dry
ICE BEER
Natural Ice
Bud Ice
LIGHT BEER
Bud Light
Coors Light
Keystone Light
DRY BEER
Milwaukee's Best Dry
MALT LIQUOR
King Cobra
Olde English 800
Rogue Dad's Little Helper Malt Liquor
AMERICAN IMPERIAL PILSNER
Samuel Adams Hallertau Imperial Pilsner
Dogfish Head Golden Era
AMERICAN PILSNER
Rolling Rock Extra Pale
Labatt's Blue
Victory Prima Pils
Yuengling Premium Lager
PILSNER
GERMAN PILSENER
Beck's
St. Pauli Girl
Jever Pilsener
BOHEMIAN PILSNER
Pilsner Urquell
Carlsberg Elephant
Warka Strong
Lagunitas PILS
Budweiser Budvar
Moonlight Brewing Death & Taxes
Port Brewing Hot Rocks Lager
EUROPEAN LAGER
EUROPEAN STRONG LAGER
Baltika #9 Extra
EUROPEAN DARK LAGER
Leinenkugel's Creamy Dark
AMERICAN STRONG ALE
Rogue Double Dead Guy Ale
Mendocino Eye of the Hawk
Kuhnhenn Fourth Dementia Old Ale
Theakston Old Peculier
Terrapin Gamma Ray
WHEAT-WINE
Smuttynose Wheat Wine
Victory Old Horizontal
Brooklyn Monster Ale
Sierra Nevada Bigfoot
BARLEY WINE
AleSmith Wee Heavy Scotch Ale
OLD ALE
Fuller's 1845
ENGLISH STRONG ALE
Ridgway Insanely Bad Elf
Avery Old Jubilation Ale
WINTER WARMER
Dogfish Head Shelter Pale Ale
Pyramid Snow Cap
STRONG PALE ALE
SCOTCH ALE
Founders Dirty Bastard Scotch Ale
McEwan's Scotch Ale
DOUBLE IPA
Dogfish Head 120 Minute IPA
Flying Dog Double Dog Double Pale Ale
BrewDog Sink the Bismarck
INDIA PALE ALE
Harpoon IPA
Victory HopDevil
Stone IPA
Bear Republic Racer 5
Morland Old Speckled Hen
BLACK IPA
Laughing Dog DogZilla Black IPA
Southern Tier Iniquity
Goose Island Honker's Ale
LIGHT ALE
Goachers Fine Light Ale
Courage Light Ale
MILD ALE
Motor City Ghettoblaster
Brains Dark
PUMPKIN ALE
Southern Tier Imperial Pumking
Post Road Pumpkin Ale
Russian River Consecration
AMERICAN WILD ALE
Jolly Pumpkin La Roja
SAHTI
Dogfish Head Sah'tea
Allagash White
Unibroue Blanche de Chambly
WITBIER
Blue Moon Belgian White
Hoegaarden Original White Ale
FARO
Girardin Faro
Boon Faro Perotale
LAMBIC
GUEUZE
Boon Oude Gueuze Mariage Parfait
Drie Fonteinen Oude Gueuze
FRUIT
Kriek De Ranke
Lindemans Framboise
UNBLENDED
Cantillon Iris
OUD BRUIN
Petrus Oud Bruin
Deschutes The Dissident
SAISON
De Cam Lambiek
Saison Dupont
Ommegang Hennepin
BIERE DE GARDE
Lost Abbey Avant Garde
St. Sylvestre 3 Monts
BIERE DE CHAMPAGNE
Malheur Biere Brut
BELGIAN/ FRENCH ALE
New Belgium Lips of Faith Sahti
FLANDERS RED ALE
Rodenbach Grand Cru
Duchesse de Bourgogne
BELGIAN DARK ALE
Ommegang Rare Vos
Bink Bruin
Gulden Draak
BELGIAN STRONG DARK ALE
Trögs Mad Elf
DUBBEL
St. Bernardus Prior 8
Goose Island Pere Jacques
BELGIAN PALE ALE
Leffe Blonde
Orval Trappist Ale
BELGIAN STRONG PALE ALE
Duvel
Delirium Tremens
Chimay Tripel
QUADRUPEL
Trappistes Rochefort 8
La Trappe Quadrupel
TRIPEL
Unibroue La Fin du Monde
Avery The Reverend
GERMAN ALE
ROGGENBIER
Thurn Und Taxis Roggen
HEFEWEIZEN
Paulaner Hefeweissbier
Kapuziner Weissbier
WEISSBIER
GOSE
Upright Brewing Gose
Bayerischer Bahnhof Original Leipziger Gose
BERLINER WEISSE
Berliner Kindl Weisse
KRISTALL-WEIZEN
Weihenstephan 1809
Tucher Kristall Weizen
DUNKEL-WEIZEN
Erdinger Weissbier Dunkel
WEIZENBOCK
Schneider Aventinus
Weihenstephaner Kristall Weissbier
Victory Moonglow Weizenbock
KÖLSCH
Reissdorf Kölsch
Pyramid Curve Ball Kölsch
ALTBIER
New Glarus Black Wheat
Uerige Doppelsticke
Alaskan Amber
MAIBOCK/ HELLES
Rogue Dead Guy Ale
Hofbräu Maibock
DORTMUNDER
Great Lakes Dortmunder Gold
Ayinger Jahrhundert Bier
BOCK
Spaten Optimator
DOPPEL-BOCK
Ayinger Celebrator Doppelbock
EISBOCK
Capital Brewery Eisphyre
Kulmbacher Reichelbrau Eisbock
GERMAN LAGER
KELLER BIER
Voodoo Pilzilla
St. Georgenbräu Keller Bier
DUNKLER BOCK
Samuel Adams Chocolate Bock
Einbecker Ur-Bock Dunkel
MÄRZEN
Spaten Oktoberfestbier Ur-Märzen
Paulaner Oktoberfest
RAUCHBIER
Spezial Rauchbier Lager
Aecht Schlenkerla Rauchbier Marzen
VIENNA LAGER
Great Lakes Eliot Ness
Samuel Adams Boston Lager
Dos Equis Amber Lager
SCHWARZ-BIER
Köstritzer Schwarzbier
Kelso Chocolate Lager
Samuel Adams Black Lager
MUNICH LAGER
MUNICH HELLES
Löwenbräu Original
Stoudt's Gold Lager
Warsteiner Premium Dunkel
EUROPEAN PALE LAGER
Harp Lager
Grolsch Premium Lager
Stella Artois
Kronenbourg 1664
Heineken Lager Beer
Peroni Nastro Azzuro
MUNICH DUNKEL
Weihenstephaner Original
Negra Modelo
Can
40 Oz. Bottle
Weizen
Pint
Pilsner
Tulip
Stein
Stange
Chalice
Snifter
Flute