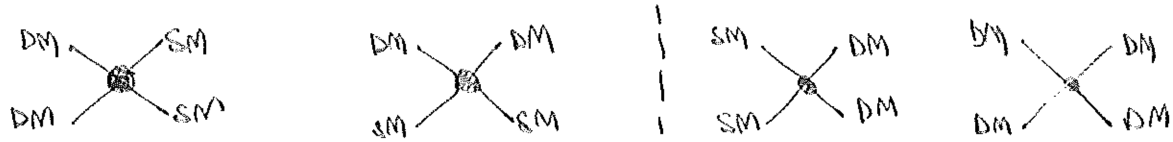
3 exceptions to Relic Abundance

BASED ON: Griest + Seckel PHYS REV D 43 (1991) 3191

main idea: $\xrightarrow{t}$



RELIC ABUNDANCE → ∃ target value for ✗ [also indirect det]

DIRECT DETECTION sets UPPER BOUND on ✗

COLLIDER | SELF-INT. ↳ not in this talk

∃ Tension! (esp. for simplest WIMP Models)

there are ways out by building more complicated Models BUT THOSE TEND TO BE PRETTY UGLY.

What's the main difference btwn "RELIC ABUNDANCE" & "DIRECT DETECTION" diagrams? KINEMATICS.

STANDARD RELIC ABUNDANCE

EARLY UNIVERSE: ASSUME UNIVERSE IS IN THERMAL EQUILIBRIUM
↑ reasonable assumption, but can consider alternatives eg "FREEZE IN" Models, out-of-equilibrium init cond.

for $T \gg m_\chi$, PAIR PRODUCTION FROM 'PLASMA' (whatever it is)
$T \ll m_\chi$ ↳ $n_{eq} \sim e^{-m_\chi/T}$

COLD RELIC (my usual assumption... Maybe astro people can convince me to relax this?)

n tracks n_{eq} UNTIL interactions not strong/frequent/"long ranged" enough to maintain equilibrium → EXPANSION RATE > INT. RATE (ANN.)

$$H = \frac{\dot a}{a} > \Gamma \sim \langle \sigma v \rangle n$$
(1/TIME)

formally: $\dot n = -3Hn - \langle \sigma v \rangle [n^2 - n_{eq}^2]$

BOLTZMANN EQ. ↑ from & $a^3(t)$ ↑ relative velocity

RULE OF THUMB: freeze out when $\boxed{\frac{m}{T} \approx 25}$

$\uparrow x_{\$}$ $\uparrow x_f$

more useful parameterization

$$Y = \frac{n}{T^3} \sim \frac{n}{s} \qquad \text{DIMENSIONLESS}$$

$$\dot{Y} = T^3 \langle \sigma v \rangle \left(Y_{EQ}^2 - Y^2 \right)$$

use $\dot{x} = Hx$

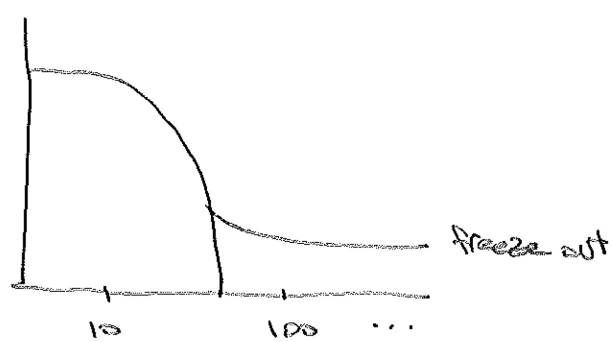
$$\frac{dY}{dx} = -\frac{m^3 \langle \sigma v \rangle}{H(m)\, x^2} \left(Y^2 - Y_{EQ}^2 \right)$$

RAD. ERA: $\varepsilon \sim T^4$, $H = H(m)/x^2$

↑ tiny @ late times
IGNORE THEN PATCH SOLUTION

note: $\langle \sigma v \rangle$ also has $x = m/T$ dependence
common to expand ↳ $\sigma v = a + b v^2 + \ldots$
SWAVE + P WAVE + ...
then do velocity avg.

end up w/ plots like



$\langle \sigma v \rangle$ ⟶ **INCREASE**
$\uparrow$ PARTICLE PHYSICS

χ HAS LARGER X-SEC
FINDS EACH OTHER "MORE EASILY"
IN THERMAL EQUILIBRIUM LONGER
FREEZES OUT TO SMALLER RELIC DENSITY

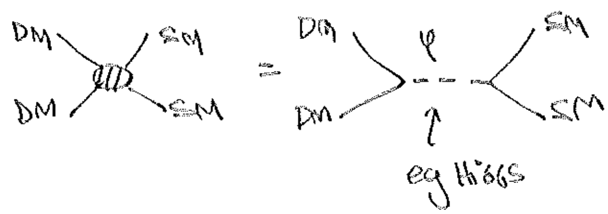
GENERICALLY,
Direct detection pushes us to smaller interaction strengths.
↳ want to boost $\langle \sigma v \rangle$

DECREASE (eg bc DM DM → SM SM)
smaller x-sec
won't find each other as easily
falls out of eq. sooner.
freezes out to LARGER RELIC DENS.

TRick #1 : Resonant Annihilation

in some sense, kind of the dumbest thing you can do.

SUPPOSE



if $M_\varphi \approx 2 M_{DM}$, then this process is resonant.

FOR THOSE W/ EFT BACKGROUND:

$$\varphi \text{ propagator} = \frac{i}{p^2 - M_\varphi^2 + i\varepsilon}$$

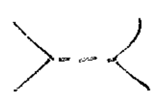
← has pole in σ

$p \sim 2(M_{DM}, \vec{0})$

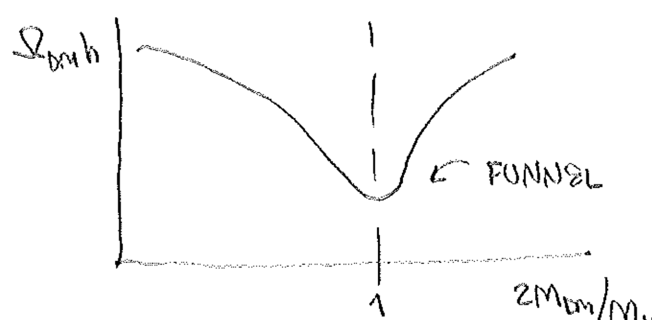
$\varepsilon \sim \Gamma$ WIDTH

SETS PHYSICAL VALUE

FOR THOSE W/O EFT: like resonant circuit

then:  $\sim \frac{1}{\Gamma}$ ← can be made small, DEPENDS ON DECAYS

 more/stronger decays → larger Γ



What about DD?

Kind of a shitty solution unless you can explain $2M_{DM} = M_\varphi$

Q. What about Direct Detection?

if 

is s-channel ↪ 

then 

is t-channel 

& the propagator is $\frac{i}{(P_{DM} + P_{SM})^2 - M_\varphi^2}$

$\uparrow$
$\neq M_\varphi^2 \rightarrow$ no resonance.

~~Coanni~~ <u>Trick #2</u> : <u>Coannihilation</u>

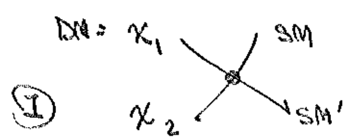
We implicitly assumed that DM freezeout is unaffected by <u>other particles</u>

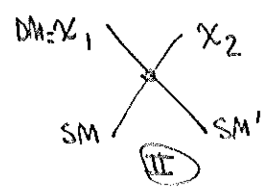
↳ either froze out long before or won't freeze out until long after.

suppose that in addition to DM χ, $\exists$ other particles w/ <u>similar mass</u>, χ_2

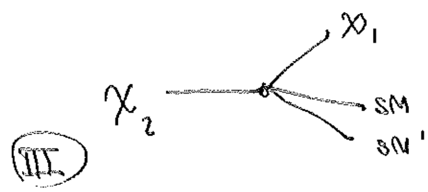
↳ slightly greater.

then: these can affect χ_1 ABUNDANCE.





s.t. kinematic. allowed eg $M_{SM'} < M_{SM}$



$$\frac{dn_1}{dt} = -3Hn_1 - \sum_{SM,SM'} \Big\{ \langle \sigma_{12} v \rangle (n_1 n_2 - n_1^{eq} n_2^{eq}) \quad \text{(I)}$$

$$- \big[\langle \sigma'_{12} v \rangle n_1 n_x - \langle \sigma'_{21} \rangle n_2 n_{x'} \big] \quad \text{(II)}$$

$$- \Gamma_{12} (n_1 - n_1^{eq}) \Big\} \quad \text{(III)}$$

ASSUME that all χ_2 EVENTUALLY GO TO $\chi_1 = DM$
SO SUFFICIENT TO CONSIDER

$$n = n_1 + n_2 \quad \rightarrow \quad \dot{n} = -3Hn - \sum_{i,j} \langle \sigma_{ij} v \rangle (n_i n_j - \bar{n}_i \bar{n}_j)$$

<u>NOTE</u>: (I) is <u>small</u>: SUPPRESSED BY ADDITIONAL n_i

$$\text{(I)} \sim e^{-(m_1+m_2)/T}$$

$$\text{(II)}, \text{(III)} \sim e^{-m_i/T} \times \underbrace{e^{-m_{SM}/T}}$$

m_{SM} can be $\ll m_1$

anyway — then you can calculate relic abundances.

OUR GOAL ISN'T TO GO THROUGH THE CALCULATIONS (UNLESS THEY'RE ENJOYING) → see DARKSUSY

↳ Griest & Seckel give an example w/ increase in abundance by ~(?)

how'd they get such a large #?

[DM] ⟵ FAIRLY CONSTRAINED ⟶ [NEUTRAL]
LSP (or LTP, LKP, ...)

COANNIHILATION IS ALL ABOUT <u>N</u>LSP

↑ next lightest NP
ALL BETS OFF! CAN BE EVEN CHARGED!

INDEED: you can even get interesting sommerfeld effects

$\tilde{t} = \chi_2$
$\tilde{t}^* = \chi_2$

0705.4027
+ ORIGINAL HISANO

(stop NLSP also nice for NATURALNESS

TRICK #3 : FORBIDDEN CHANNELS

basically the same game

IDEA:

MAYBE SM, BUT ASSUME NOT RELEVANT IN DIRECT DET.

↑ **LARGE** CROSS SECTION (eg MUCH LARGER THAN DM DM → $q\bar{q}$ which crosses to give DIRECT DET.)

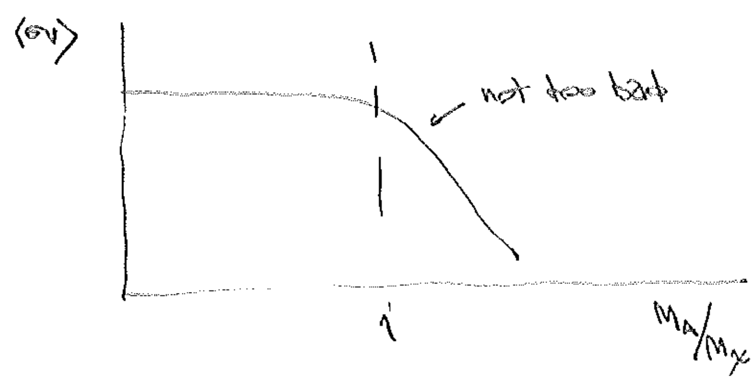
but: $2M_\chi \lesssim M_A + M_{A'}$

so naively: KINEMATICALLY NOT ALLOWED!

BUT: FREEZE OUT WHEN $x = \frac{m_\chi}{T} = 25$

Thermal distribution of DM can permit some χ to have enough KINETIC ENERGY TO MAKE DM DM → A A' HAPPEN

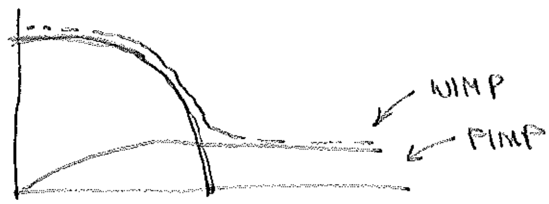
↪ can balance it s.t. this dominates the small DM DM → $q\bar{q}$ cross sec (DM DM → $q\bar{q}$ constr. by D.D.)



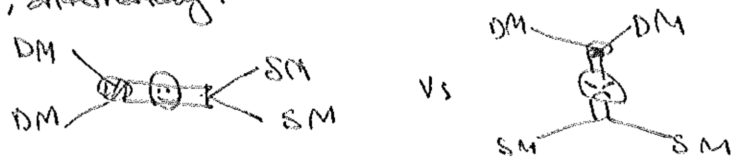
* other ways out.

break out of the FREEZE OUT PARADIGM

eg. 1. SUPERWIMP / FREEZE IN



2. or, alternately:



construct model w/ different mediator sectors.

3. Different dynamics lead to relic density

eg. ASYM. DM where relic comes from same/similar mechanism as BARYON #.