

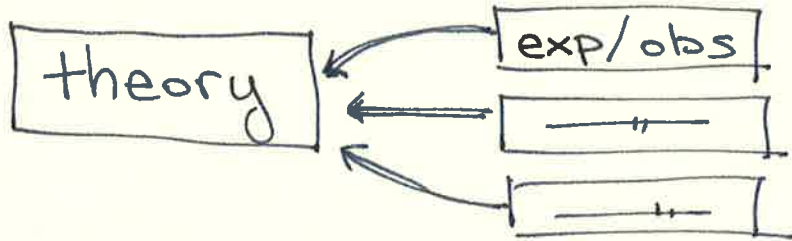
Revisiting Dark Matter Complementarity

↳ A DISCUSSION (FLIP TANELLO)

COMPLEMENTARITY

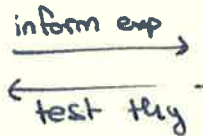
CAVEAT: mostly colly-level, broad strokes, won't carve out every counterex.

I.

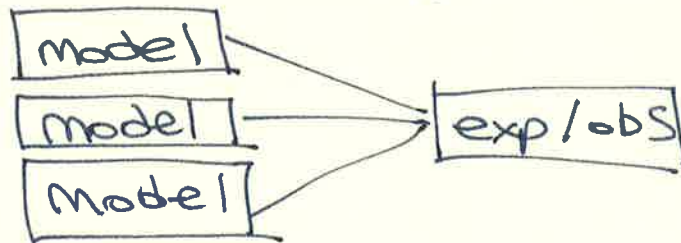


how different kinds of experiments & observations can inform us about a model of DM

search
constrain
exclude
...

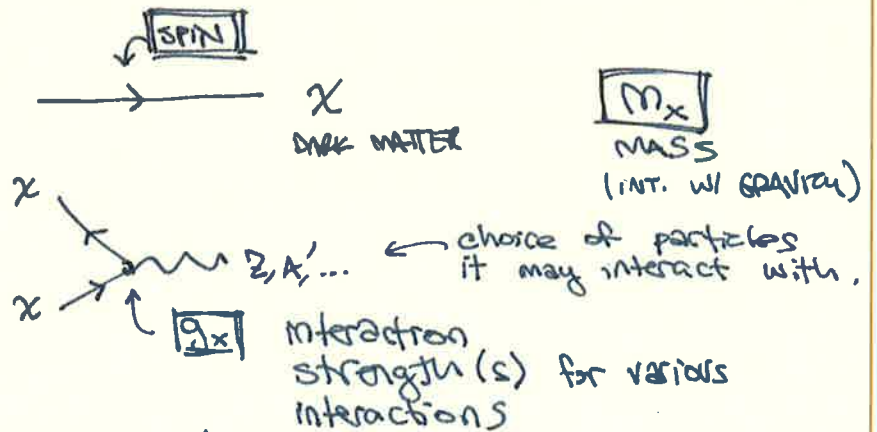


II.



how different models have distinguishable experimental signatures

particle physics:



"give me a Lagrangian"

↳ then can work out implications (particle physics)

IN A GLIB WAY: this is basically parameter fitting
(exclusion is when no value fits)

the way that we do this $th \leftrightarrow exp/obs$
is informed by

- ① the types of exp/obs we can make
(TOOLS WE HAVE & RANGE OF DM BEHAVIORS THAT CAN BE SEEN)
- ② theory biases / preferences
← "PRIORS"

I'D LIKE TO TALK ABOUT HOW WE GOT HERE
& WHERE WE MAY BE GOING.

Caveat: MANDELA EFFECT
Collective mis-remembering of history

opinion, not nec. fact! → ie this may be historical fiction, but it's a narrative that I think is useful
SEE HOOPER & BERTONE
↑ if only to highlight psychology of particle people.

EARLY DAYS: biggest question in PARTICLE PHYS

→ Higgs?

- does it exist? (turns out: yes.)
- why is it light?
NEEDED NEW PARTICLE(S) @ \approx TeV BECAUSE OF W^+W^- SCATTERING

"Naturalness" / "Hierarchy Problem"
toolkit: invoke new symmetry.
("snowball's chance in hell")

FAVORITE ANSWER : SUPERSYMMETRY ← similar story for other answers
SUSY version of Standard Model (MSSM) came with tons of new particles

some charged, some not ... most decay.
↑ DM? @ this stage, maybe don't even care...

ALSO CAME w/ PROBLEM: proton decay

↳ simple fix : more symmetry.

R-parity : ~~prevents~~ prohibits some interactions, inc. those that catalyze proton decay.

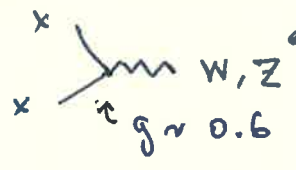
(other non-susy models have their own versions: KK-parity, T-parity, etc.)

BONUS ← viewed as icing on the cake
: R-parity stabilizes lightest new particle
↳ dark matter ^{CANDIDATE} for free
~~BUT DOES IT WALK THE WALK?~~

~~Neutralinos~~
Neutralinos the #2 WIMP template (#1 is heavy neutrino)

nb. there is ambiguity in what falls under the WIMP umbrella

• "WEAK" COUPLINGS in technical sense
← depends on model details



BUT COULD BE HEAVIER

"Weak Scale"

• MASS is assumed ~ few 100 GeV
→ HIGHER MASS — more unnatural (less natural)

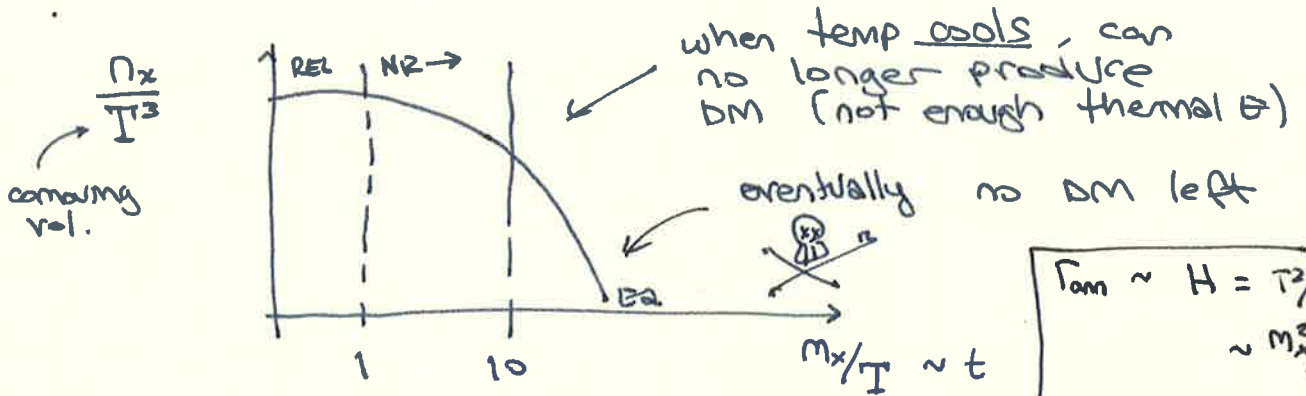
Does it walk the walk?

How much DM is there?

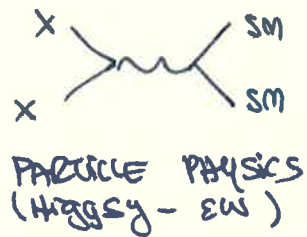
↳ we know Ω_x , have to hit this target.
 answer: freeze out.

$x + x \rightarrow \mu z \Rightarrow$ DM starts in EARLY UNIVERSE
 in thermal equilibrium w/ visible matter
 hot mess

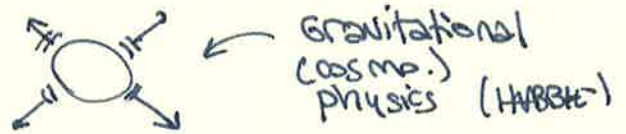
PRODUCTION \leftrightarrow ANNIHILATION



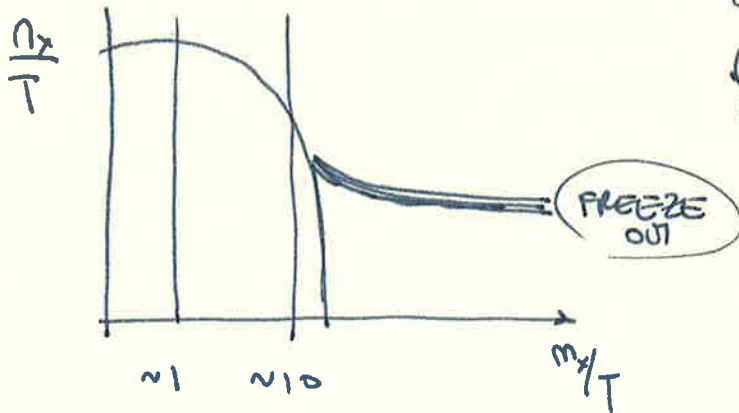
but: universe is expanding



vs



↳ makes it harder for DM to find itself to annihilate



(comparing) number density FREEZES OUT from its equilibrium value

MIRACLE

Weak scale coupling
 \uparrow mass give correct Ω_x

↳ w/in θ mag or so

MIRACLE : HIGGS MYSTERY → new particles
 w/ fixed-ish coupling
 & preferred mass

proton stability → stabilizing parity

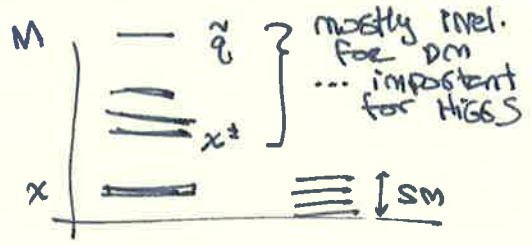
⇓

FOR FREE : Ω_{χ}
 non-trivial benefit!

what a win for (susy)! this had to be it!
 ↳ WIMP MIRACLE (specific meaning of WIMP)

~~WIMP MIRACLE~~

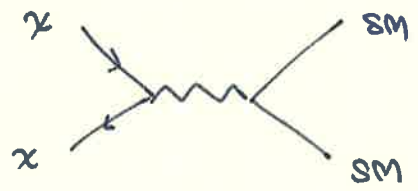
So we have our theory.



eg susy : some params in DARK sector... but really had a sense of m_{χ}, g_{χ}

comes w/ BUNCH OF COLLIDER PREDICTIONS FOR OTHER NEW PARTICLES (more model dep w/ many params)

HOW TO TEST ?

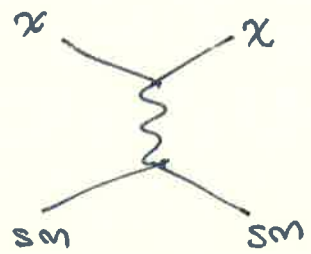


ANNIHILATION

in the past: controls freeze out (WIMP MIRACLE)

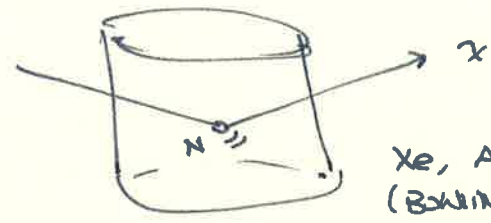
today: indirect det
 DM annihilates in regions of high density.
 look for visible matter remnants

BUT YOU CAN AUTOMATICALLY DRAW OTHER PROCESSES:



$$X (SM) \rightarrow X (SM)$$

DIRECT DETECTION
 ↳ obs. DM bouncing off ordinary matter



Xe, Ar, Si, Ge
 (BUBBLE BALL MATHS)

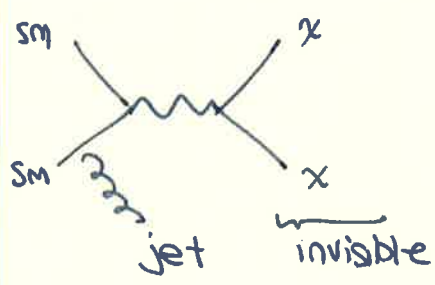
FUTURE: other types of materials
 (SUPER/SEMI CONDUCTORS)

phen: different kinds of responses based on details of interaction

... turns out it really kills the simplest, nicest, most generic SUSY WIMPS

(all of it? no...)

to zeroth order, D.P. BEATS THIS FOR NEUTRALINO



PRODUCTION OF WIMPS
 = g @ COLLIDERS (2015)

around the same time, COLLIDERS EXCLUDE A LOT OF THE OTHER PARTICLES PREDICTED BY SUSY

in other words: we found HIGGS, but failed to find promised new particles that explained why so light!

SCORECARD

- ✓ MOTIVATED BY OTHER PHYSICS
- ✓ STABLE (but had to fix p^+ decay to get $h\nu$ s)
- ✓ Ω_x

- ✗ DIRECT DET.
- ✗ COLLIDER → MET, but also other particles.

[] ASTRO: CDM

WEAK ↔ $SU(2)_L$, very specific meaning

→ PROBLEM: WIMP VERTEX IS OVER CONSTRAINED.

is it dead?

technically no

linguistically no

M_x wriggle room

∫ hiding places
some are not even particularly perverse

"weak" can mean lots of things, not just the SM WEAK coupling. (see TIM'S talk)

... but then not related to the HIGGS.

~~personally~~

experimentally no

→ EXISTING PROGRAM OF DD / ID / COLLIDER MET CONTINUES TO CARVE OUT UNEXPLORED TERRITORY

emotionally/personally → yes.

→ "dead to me"

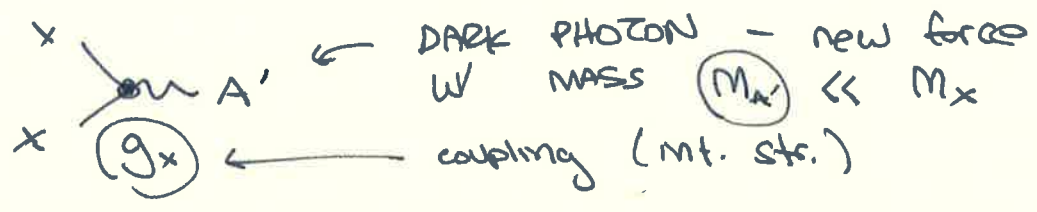
PHRASE ~~MEANS~~: not a funeral, but a break up.

↳ no longer emotionally invested ← in some way

WHY: ① biggest motivations "died" independently | ③ exp. / pheno prog. is nature. what to add?
② other possibilities, more general!

Next wave: SIMPLIFIED MODELS / DARK SECTOR
 DM + new force
 ("secluded dark matter")

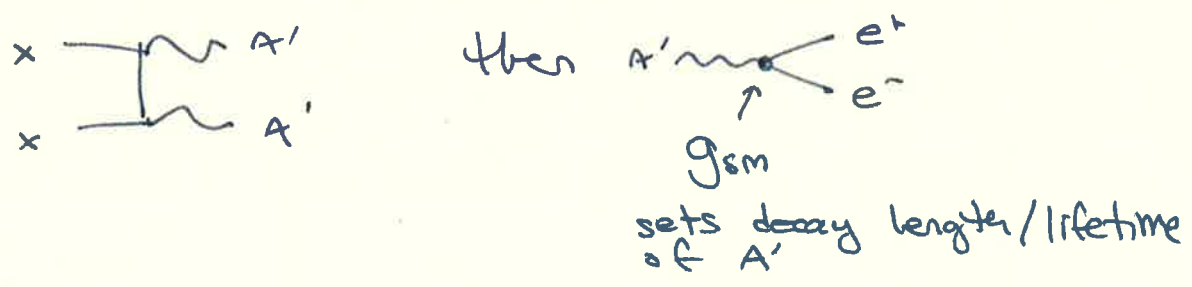
nicest thing: $\Omega_x \leftarrow$ in WIMP, it was a miracle
 NOW LET'S MAKE IT OUR FIRST TARGET



then: is the annih.
 [Fix] g_x to give Ω_x

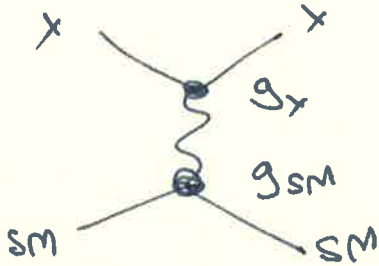
Nb: for WIMP, kinematically suppr.
 b/c $M_z \sim M_x$
 (not true for heavy M_x)

ANNIHILATION TO on-shell MEDIATORS

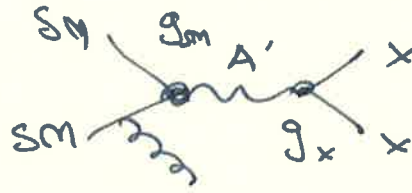


BUT: Annihil. of DM indep of g_{sm}
 ($g_{sm} \rightarrow 0$ limit is fine)

DIRECT DET



COLLIDER / PRODUCTION



both of these $\sim g_{SM}!$
so $m \rightarrow 0$ w/ g_X fixed limit,

you get: Annihilation $\leftrightarrow \Omega_X$ (not free, had to fix g param in theory)

no DD/collider bound.

And things "filling" WIMP.

feature: this framework has more params.

some of them map on to all of "WIMP" space

... but also allows flexibility to other types of models

beyond WIMP

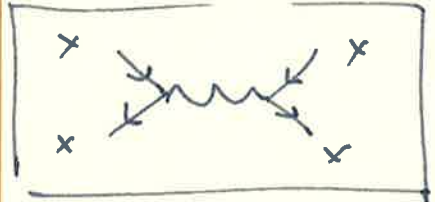
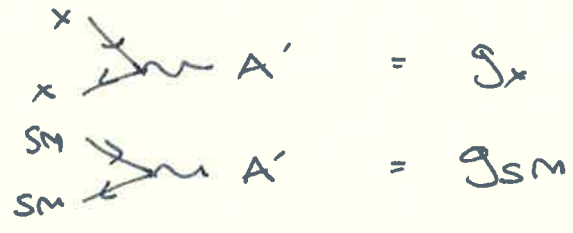
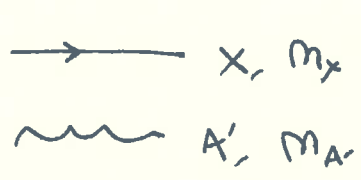
→ lose "Higgs" motivation... but arguably that was already lost from us!

→ new theories to explain dark sec.

either: ① map onto dark sector

② break it

NEW FEATURES of A DARK SECTOR :



DARK MATTER SELF-INTERACTIONS w/ LIGHT MEDIATOR

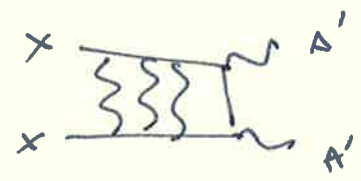
$$V(r) \sim \frac{e^{-m_{A'} r}}{r}$$

classical pot. btwn DM particles

DM self int \rightarrow halo shapes

indep of g_{SM} !

~~NEW~~ NEW FEATURE :



sommerfeld enhancement

of indirect detection @ low velocities

(rate of $\chi\chi \rightarrow A'A'$ bigger today than naively expect from Ω_χ)

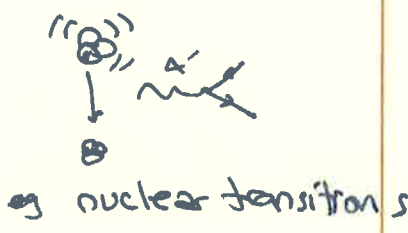
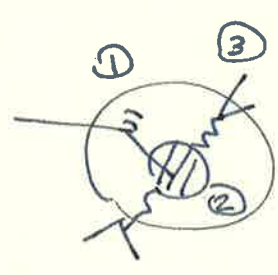
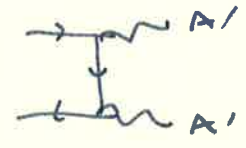
NEW FEATURE :

A' is a new, light, unstable particle
 \hookrightarrow cosmological imprint?

"PRODUCTION" :

not just MET, can look for light, very weakly coupled particles (like axion program)

WHERE THIS CAN TAKE US:

	<u>WIMP</u>	<u>DARK SECTOR</u>	<u>TWISTS</u>
<u>PRODUCTION</u>	MET search for xx	BEAM DUMP & RELATED (search for A')	 eg nuclear transitions
DIRECT DET <u>SCATTER</u>	DIRECT DET	(same)	<div style="border: 1px solid black; padding: 10px; width: fit-content; margin: auto;"> <p>EARTH CAPTURE STORY</p>  </div>
INDIRECT <u>ANNIHIL.</u>	INDIRECT DET		
<u>SELF</u>	n/a (med for heavy)	<div style="border: 1px solid black; border-radius: 50%; padding: 5px; display: inline-block;"> HAVO PROFILES </div> ↓ how to patch on to simulations	

Q: How do we better connect to obs/sim?
 Dark sectors are not favorite theory of nature, just flexible ROSETTA STONES BTWN thry & obs.

what about things not on this list?
 ↳ fuzzy/extended DM, axions/light DM, multi-mediators, nonpert. objects, ...