New Priors in Hidden Physics

Neal Weiner Cosmic Visions Workshop March 23, 2017

The era of strong priors 199x~2016

- Hierarchy problem
- Weak scale DM
- Questions of the SM (unification, neutrino mass, strong CP...)

Dark matter in the era of strong priors

Hierarchy problem -

Thermal relics

weak scale DM

"WIMP" miracle made (and makes) a motivating case

breaking down priors

rapid progress in WIMP search



slide from J Feng



No sign of WIMPs so far

Plot from Josh Ruderman

LHC - no sign of weak scale BSM

ATLAS Preliminary

ATLAS SUSY Searches* - 95% CL Lower Limits

St	atus: March 2017							$\sqrt{s} = 7, 8, 13 \text{ TeV}$
	Model	e, μ, τ, γ	′ Jets	E ^{miss} T	∫ <i>L dt</i> [fb	⁻¹] Mass limit	\sqrt{s} = 7, 8 TeV \sqrt{s} = 13 TeV	Reference
Inclusive Searches	$\begin{array}{l} MSUGRA/CMSSM \\ \tilde{q}\tilde{q}, \ \tilde{q} \rightarrow q \tilde{\chi}_{1}^{0} \\ \tilde{q}\tilde{q}, \ \tilde{q} \rightarrow q \tilde{\chi}_{1}^{0} \ (\text{compressed}) \\ \tilde{g}\tilde{g}, \ \tilde{g} \rightarrow q \tilde{q} \tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \ \tilde{g} \rightarrow q q \tilde{\chi}_{1}^{1} \rightarrow q q W^{\pm} \tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \ \tilde{g} \rightarrow q q \tilde{\chi}_{1}^{\pm} \rightarrow q q W^{\pm} \tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \ \tilde{g} \rightarrow q q \mathcal{W}_{1}^{\pm} \rightarrow q q W^{\pm} \tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \ \tilde{g} \rightarrow q q \mathcal{W}_{1}^{2} \mathcal{W}_{1}^{0} \\ \tilde{g}\tilde{g}, \ \tilde{g} \rightarrow q q W Z \tilde{\chi}_{1}^{0} \\ GMSB (\tilde{\ell} \text{ NLSP}) \\ GGM (\text{bino NLSP}) \\ GGM (\text{higgsino-bino NLSP}) \\ GGM (\text{higgsino-bino NLSP}) \\ GGM (\text{higgsino NLSP}) \\ GGM (\text{higgsino NLSP}) \\ Gravitino LSP \end{array}$	$\begin{array}{c} 0\text{-}3 \ e, \mu/1\text{-}2 \ \tau \\ 0 \\ \text{mono-jet} \\ 0 \\ 3 \ e, \mu \\ 2 \ e, \mu \ (\text{SS}) \\ 1\text{-}2 \ \tau + 0\text{-}1 \\ 2 \ \gamma \\ \gamma \\ 2 \ e, \mu \ (Z) \\ 0 \end{array}$	2-10 jets/3 b 2-6 jets 1-3 jets 2-6 jets 2-6 jets 4 jets 0-3 jets ℓ 0-2 jets 1 b 2 jets 2 jets mono-jet	Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes	20.3 36.1 36.1 36.1 13.2 13.2 3.2 3.2 20.3 13.3 20.3 20.3		$\begin{array}{c c c c c c c c c c c c c c c c c c c $	1507.05525 ATLAS-CONF-2017-022 1604.07773 ATLAS-CONF-2017-022 ATLAS-CONF-2017-022 ATLAS-CONF-2016-037 ATLAS-CONF-2016-037 1607.05979 1606.09150 1507.05493 ATLAS-CONF-2016-066 1503.03290 1502.01518
3 rd gen. ẽ med.	$ \begin{array}{l} \tilde{g}\tilde{g}, \ \tilde{g} \rightarrow b\bar{b}\tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \ \tilde{g} \rightarrow t\bar{t}\tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \ \tilde{g} \rightarrow b\bar{t}\tilde{\chi}_{1}^{+} \end{array} $	0 0-1 <i>e</i> ,μ 0-1 <i>e</i> ,μ	3 b 3 b 3 b	Yes Yes Yes	36.1 36.1 20.1	ğ ğ ğ	$\begin{array}{c c} \textbf{1.92 TeV} & m(\tilde{\chi}_1^0) {<} 600 \ \text{GeV} \\ \hline \textbf{1.97 TeV} & m(\tilde{\chi}_1^0) {<} 200 \ \text{GeV} \\ \hline \textbf{1.37 TeV} & m(\tilde{\chi}_1^0) {<} 300 \ \text{GeV} \end{array}$	ATLAS-CONF-2017-021 ATLAS-CONF-2017-021 1407.0600
3 rd gen. squarks direct production	$\begin{split} \tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_1^0 \\ \tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow t \tilde{\chi}_1^{\pm} \\ \tilde{r}_1 \tilde{r}_1, \tilde{r}_1 \rightarrow b \tilde{\chi}_1^{\pm} \\ \tilde{r}_1 \tilde{r}_1, \tilde{r}_1 \rightarrow W b \tilde{\chi}_1^0 \text{ or } t \tilde{\chi}_1^0 \\ \tilde{r}_1 \tilde{r}_1, \tilde{r}_1 \rightarrow C \tilde{\chi}_1^0 \\ \tilde{r}_1 \tilde{r}_1 (\text{natural GMSB}) \\ \tilde{r}_2 \tilde{r}_2, \tilde{r}_2 \rightarrow \tilde{r}_1 + Z \\ \tilde{r}_2 \tilde{r}_2, \tilde{r}_2 \rightarrow \tilde{r}_1 + h \end{split}$	$\begin{array}{c} 0 \\ 2 \ e, \mu \ (\text{SS}) \\ 0 \ -2 \ e, \mu \\ 0 \ -2 \ e, \mu \\ 0 \\ 2 \ e, \mu \ (Z) \\ 3 \ e, \mu \ (Z) \\ 1 \ -2 \ e, \mu \end{array}$	2 b 1 b 1-2 b 0-2 jets/1-2 b mono-jet 1 b 1 b 4 b	Yes Yes Yes Yes Yes Yes Yes Yes	3.2 13.2 4.7/13.3 20.3 3.2 20.3 36.1 36.1	$ \begin{array}{c c c c c c c c } & & & & & & & & & & & & & & & & & & &$	$\begin{split} & m(\tilde{\chi}_{1}^{0}) < 100 \mathrm{GeV} \\ & m(\tilde{\chi}_{1}^{0}) < 150 \mathrm{GeV}, m(\tilde{\chi}_{1}^{\pm}) = m(\tilde{\chi}_{1}^{0}) + 100 \mathrm{GeV} \\ & m(\tilde{\chi}_{1}^{\pm}) = 2m(\tilde{\chi}_{1}^{0}), m(\tilde{\chi}_{1}^{0}) = 55 \mathrm{GeV} \\ & m(\tilde{\chi}_{1}^{0}) = 1 \mathrm{GeV} \\ & m(\tilde{\chi}_{1}^{0}) = 5 \mathrm{GeV} \\ & m(\tilde{\chi}_{1}^{0}) > 150 \mathrm{GeV} \\ & m(\tilde{\chi}_{1}^{0}) = 0 \mathrm{GeV} \\ & m(\tilde{\chi}_{1}^{0}) = 0 \mathrm{GeV} \\ & m(\tilde{\chi}_{1}^{0}) = 0 \mathrm{GeV} \end{split}$	1606.08772 ATLAS-CONF-2016-037 1209.2102, ATLAS-CONF-2016-077 1506.08616, ATLAS-CONF-2017-020 1604.07773 1403.5222 ATLAS-CONF-2017-019 ATLAS-CONF-2017-019
EW direct	$ \begin{array}{l} \tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell} \rightarrow \ell \tilde{\chi}_{1}^{0} \\ \tilde{\chi}_{1}^{+}\tilde{\chi}_{1}^{-}, \tilde{\chi}_{1}^{+} \rightarrow \tilde{\ell}\nu(\ell\tilde{\nu}) \\ \tilde{\chi}_{1}^{+}\tilde{\chi}_{1}^{-}, \tilde{\chi}_{1}^{+} \rightarrow \tilde{\ell}\nu(\ell\tilde{\nu}) \\ \tilde{\chi}_{1}^{+}\tilde{\chi}_{2}^{0} \rightarrow \tilde{\ell}_{L}\nu\tilde{\ell}_{L}\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_{L}\ell(\tilde{\nu}\nu) \\ \tilde{\chi}_{1}^{+}\tilde{\chi}_{2}^{0} \rightarrow W\tilde{\chi}_{1}^{0}Z\tilde{\chi}_{1}^{0} \\ \tilde{\chi}_{1}^{+}\tilde{\chi}_{2}^{0} \rightarrow W\tilde{\chi}_{1}^{0}h\tilde{\chi}_{1}^{0}, h \rightarrow b\bar{b}/WW/\pi \\ \tilde{\chi}_{2}^{0}\tilde{\chi}_{3}^{0}, \tilde{\chi}_{2,3}^{0} \rightarrow \tilde{\ell}_{R}\ell \\ GGM (wino NLSP) weak prod GGM (bino NLSP) weak prod$	$\begin{array}{c} 2 \ e, \mu \\ 2 \ e, \mu \\ 2 \ \tau \\ 3 \ e, \mu \\ 2 - 3 \ e, \mu \\ 2 - 3 \ e, \mu \\ e - \tau / \gamma \gamma e, \mu, \gamma \\ 4 \ e, \mu \\ 1 \ e, \mu + \gamma \\ 2 \ \gamma \end{array}$	0 0 0-2 jets 0-2 <i>b</i> 0 	Yes Yes Yes Yes Yes Yes Yes Yes	20.3 13.3 14.8 13.3 20.3 20.3 20.3 20.3 20.3 20.3	$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{split} & m(\tilde{\chi}_{1}^{0}) {=} 0 \ GeV \\ & m(\tilde{\chi}_{1}^{0}) {=} 0 \ GeV, m(\tilde{\ell}, \tilde{\nu}) {=} 0.5(m(\tilde{\chi}_{1}^{\pm}) {+} m(\tilde{\chi}_{1}^{0})) \\ & m(\tilde{\chi}_{1}^{0}) {=} 0 \ GeV, m(\tilde{\tau}, \tilde{\nu}) {=} 0.5(m(\tilde{\chi}_{1}^{\pm}) {+} m(\tilde{\chi}_{1}^{0})) \\ & m(\tilde{\chi}_{1}^{\pm}) {=} m(\tilde{\chi}_{2}^{0}), m(\tilde{\chi}_{1}^{0}) {=} 0, m(\tilde{\ell}, \tilde{\nu}) {=} 0.5(m(\tilde{\chi}_{1}^{\pm}) {+} m(\tilde{\chi}_{1}^{0})) \\ & m(\tilde{\chi}_{1}^{\pm}) {=} m(\tilde{\chi}_{2}^{0}), m(\tilde{\chi}_{1}^{0}) {=} 0, \tilde{\ell} \ decoupled \\ & m(\tilde{\chi}_{1}^{\pm}) {=} m(\tilde{\chi}_{2}^{0}), m(\tilde{\chi}_{1}^{0}) {=} 0, \tilde{\ell} \ decoupled \\ & m(\tilde{\chi}_{2}^{0}) {=} m(\tilde{\chi}_{3}^{0}), m(\tilde{\chi}_{1}^{0}) {=} 0, m(\tilde{\ell}, \tilde{\nu}) {=} 0.5(m(\tilde{\chi}_{2}^{0}) {+} m(\tilde{\chi}_{1}^{0})) \\ & c\tau {<} 1 \ mm \\ & c\tau {<} 1 \ mm \end{split}$	1403.5294 ATLAS-CONF-2016-096 ATLAS-CONF-2016-093 ATLAS-CONF-2016-096 1403.5294, 1402.7029 1501.07110 1405.5086 1507.05493 1507.05493
Long-lived particles	Direct $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^- \tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^-$ Direct $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_2^-$ Stable, stopped \tilde{g} R-hadron Stable \tilde{g} R-hadron Metastable \tilde{g} R-hadron GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0 \rightarrow \tilde{\tau}(\tilde{e}, \tilde{\mu}) + \tilde{\tau}(\tilde{e}, \tilde{\mu}$	$\tilde{\ell}_1^{\pm}$ Disapp. trk $\tilde{\ell}_1^{\pm}$ dE/dx trk 0 trk dE/dx trk $e(e,\mu)$ 1-2 μ 2 γ displ. $ee/e\mu//$ displ. vtx + je	x 1 jet - 1-5 jets - - - - μμ - ets -	Yes Yes - - Yes - Yes	36.1 18.4 27.9 3.2 3.2 19.1 20.3 20.3 20.3	$\tilde{\chi}_1^{\pm}$ 430 GeV $\tilde{\chi}_1^{\pm}$ 495 GeV \tilde{g} 850 GeV \tilde{g} 850 GeV $\tilde{\chi}_1^0$ 537 GeV $\tilde{\chi}_1^0$ 440 GeV $\tilde{\chi}_1^0$ 1.0 TeV $\tilde{\chi}_1^0$ 1.0 TeV	$ \begin{array}{c} m(\tilde{\chi}_{1}^{\pm})\text{-}m(\tilde{\chi}_{1}^{0})\text{-}160 \; MeV, \; \tau(\tilde{\chi}_{1}^{\pm})\text{=}0.2 \; ns \\ m(\tilde{\chi}_{1}^{\pm})\text{-}m(\tilde{\chi}_{1}^{0})\text{-}160 \; MeV, \; \tau(\tilde{\chi}_{1}^{\pm})\text{<}15 \; ns \\ m(\tilde{\chi}_{1}^{0})\text{=}100 \; GeV, \; 10 \; \mus < \tau(\tilde{g})\text{<}1000 \; s \\ \hline \mathbf{1.57 \; TeV} \\ \mathbf{1.57 \; TeV} \\ m(\tilde{\chi}_{1}^{0})\text{=}100 \; GeV, \; \tau\text{>}10 \; ns \\ 10\text{<}tan\beta\text{<}50 \\ 1\text{<}\tau(\tilde{\chi}_{1}^{0})\text{<}3 \; ns, \; SPS8 \; model \\ 7 \; < c\tau(\tilde{\chi}_{1}^{0})\text{<} 740 \; mm, \; m(\tilde{g})\text{=}1.3 \; TeV \\ 6 \; < c\tau(\tilde{\chi}_{1}^{0})\text{<} 480 \; mm, \; m(\tilde{g})\text{=}1.1 \; TeV \\ \end{array} $	ATLAS-CONF-2017-017 1506.05332 1310.6584 1606.05129 1604.04520 1411.6795 1409.5542 1504.05162 1504.05162
RPV	LFV $pp \rightarrow \tilde{v}_{\tau} + X, \tilde{v}_{\tau} \rightarrow e\mu/e\tau/\mu\tau$ Bilinear RPV CMSSM $\tilde{\chi}_{1}^{+}\tilde{\chi}_{1}^{-}, \tilde{\chi}_{1}^{+} \rightarrow W \tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow eev, e\mu v,$ $\tilde{\chi}_{1}^{+}\tilde{\chi}_{1}^{-}, \tilde{\chi}_{1}^{+} \rightarrow W \tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow \tau \tau v_{e}, e\tau v$ $\tilde{g}\tilde{g}, \tilde{g} \rightarrow qqq$ $\tilde{g}\tilde{g}, \tilde{g} \rightarrow qq\bar{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow qqq$ $\tilde{g}\tilde{g}, \tilde{g} \rightarrow t t \tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow qqq$ $\tilde{g}\tilde{g}, \tilde{g} \rightarrow \tilde{t}_{1}t, \tilde{t}_{1} \rightarrow bs$ $\tilde{t}_{1}\tilde{t}_{1}, \tilde{t}_{1} \rightarrow b\ell$	$ \begin{array}{rccc} & e\mu, e\tau, \mu\tau \\ & 2 e, \mu (SS) \\ \mu\mu\nu & 4 e, \mu \\ \gamma_{\tau} & 3 e, \mu + \tau \\ & 0 & 4 \\ & 1 e, \mu & 4 \\ & 1 e, \mu & 4 \\ & 0 \\ & 2 e, \mu \\ \end{array} $	- 0-3 <i>b</i> - 1-5 large- <i>R</i> je 8-10 jets/0-4 8-10 jets/0-4 2 jets + 2 <i>b</i> 2 <i>b</i>	- Yes Yes ts - ts - b - b - -	3.2 20.3 13.3 20.3 14.8 14.8 36.1 36.1 15.4 20.3	\tilde{v}_{r} \tilde{q}, \tilde{g} \tilde{x}_{1}^{\pm} \tilde{x}_{1}^{\pm} \tilde{x}_{1}^{\pm} \tilde{x}_{1}^{\pm} \tilde{g} \tilde{g} \tilde{g} \tilde{g} \tilde{g} \tilde{t}_{1} 410 GeV 450-510 GeV \tilde{t}_{1} 0.4-1.0 TeV	$\begin{array}{c c} \textbf{1.9 TeV} & \lambda_{311}'=0.11, \lambda_{132/133/233}=0.07 \\ \textbf{1.45 TeV} & \textbf{m}(\tilde{q})=\textbf{m}(\tilde{g}), c\tau_{LSP}<1 \text{ mm} \\ \textbf{TeV} & \textbf{m}(\tilde{\chi}_1^0)>400 \text{GeV}, \lambda_{12k}\neq0 \ (k=1,2) \\ \textbf{m}(\tilde{\chi}_1^0)>0.2\times\textbf{m}(\tilde{\chi}_1^{\pm}), \lambda_{133}\neq0 \\ \textbf{eV} & \text{BR}(t)=\text{BR}(b)=\text{BR}(c)=0\% \\ \textbf{1.55 TeV} & \textbf{m}(\tilde{\chi}_1^0)=800 \text{ GeV} \\ \textbf{2.1 TeV} & \textbf{m}(\tilde{\chi}_1^0)=1 \text{ TeV}, \lambda_{112}\neq0 \\ \textbf{m}(\tilde{\chi}_1^0)=1 \text{ TeV}, \lambda_{323}\neq0 \\ \textbf{BR}(\tilde{t}_1\rightarrow be/\mu)>20\% \end{array}$	1607.08079 1404.2500 ATLAS-CONF-2016-075 1405.5086 ATLAS-CONF-2016-057 ATLAS-CONF-2016-057 ATLAS-CONF-2017-013 ATLAS-CONF-2017-013 ATLAS-CONF-2016-022, ATLAS-CONF-2016-084 ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c} \rightarrow c \tilde{\chi}_1^0$	0	2 <i>c</i>	Yes	20.3	<i>č</i> 510 GeV	m($\tilde{\chi}_{1}^{0}$)<200 GeV	1501.01325
*Only a phen	a selection of the availabl	e mass limits f the limits ar	on new si e based o	tates c n	or 1	D^{-1}	1 Mass scale [TeV]	,

simplified models, c.f. refs. for the assumptions made.

Neutrinos/GUTs

- Neutrino mass guess: few x 10⁻³
- Neutrino mixing guess: small (CKM)
- Proton decay?





We have pursued scenarios under very strong assumptions

• Where do we go from here?

Moving beyond the era of strong priors

- No priors?
- Weak priors?
- New priors?

We know there is physics beyond the standard model (DM)!

Example: axion

- weak priors: EFT of scalars and pseudoscalars coupling to SM
- moderate priors: QCD axion
- strong priors: QCD axion + standard cosmology

weaker C

theory priors

stronger weaker

cosmo priors





weaker

theory priors

stronger weaker

EFT couplings to new physics

cosmo priors stronger



weaker

theory priors

stronger weaker

EFT couplings to new physics



thermal and quasi
thermal relics,
scalars from EUPT

weaker

theory priors

weaker stronger

EFT couplings to new physics

QCD axions w/o cosmology; scale-free DM



thermal and quasi thermal relics, scalars from EUPT



weaker

theory priors

weaker stronger

EFT couplings to ne physics

QCD axions w/o cosmology; scale-free DM



2	۱۸/	
)	VV	

thermal and quasi thermal relics, scalars from EUPT



WIMPs; "classic" PQ axions

BSM in the era of moderate priors

- Opportunity to ask broader questions
- Can't simply be fishing expedition (although IMHO a certain amount of cost effective fishing is important)
- Take one step back on some prior axis and find target regions
 - e.g., consider a thermally connected particle
 - a broader class of axion like particles



 $<\sigma v>_{ann}\approx 3$ pprox -

The story of the WIMP

For a thermal relic, you learn precisely one number, namely the annihilation cross section

$$\frac{3 \times 10^{-26} \text{cm}^3 \text{sec}^{-1}}{\alpha^2}}{(200 \text{GeV})^2}$$



For a thermal relic, you learn precisely one number, namely the annihilation cross section

 $<\sigma v>_{ann}\approx 3$ pprox -

The story of the WIMP

$$\frac{3 \times 10^{-26} \text{cm}^3 \text{sec}^{-1}}{\alpha^2}$$
$$\frac{\alpha^2}{(200 \text{GeV})^2}$$



For a thermal relic, you learn precisely one number, namely the annihilation cross section

 $<\sigma v>_{ann}\approx 3$ pprox -

The story of the WIMP

$$\frac{3 \times 10^{-26} \text{cm}^3 \text{sec}^{-1}}{\alpha^2}}{(200 \text{GeV})^2}$$

Broadening the scope



~MeV

structure "bound": DM not enough SSS if T_{DM} ~ T_{SM} BBN "bound" no new relativistic DOF at BBN if T_{DM} ~ T_{SM}

Huge range of possibilities from keV to GeV scale

~100 TeV WIMPs



WIMP complementarity





cosmic rays (indirect)

colliders (production)

Coupling and decoupling a light particle



Simple example a "dark photon" - can naturally be very weakly mixed Holdom; Boehm + Fayet

A light DM particle needs a new interaction to stay in equilibrium



SM Annihilation



Hidden Sector Annihilation



SM Annihilation

Hidden Sector Annihilation

Complementarity "Classic"

cosmic rays (indirect)



Limited final states so complementarity is more robust

Cosmology: already powerful



• CMB, LSS much more advanced than in 90's

• CMB constraints light relics more effectively



A signal from z = 1100

 E_{λ} $n_{x}^{2} < \sigma v > m_{x}$

- Need to turn off annihilation at recombination Annihilation is p-wave (velocity suppressed) [scalar]

 $\sim (\frac{1}{3} < \sigma v)$ m_{x}

Mass splitting between Majorana states [pseudo-Dirac fermion]

Direct detection



SM recoils (direct)

Not just nuclear anymore

The Thermal Target



Plot from Essig



"New" Complementarity



Parametrically linked tightly to thermal diagram



"New" Complementarity



DM self interaction? Anomalies like 8Be?



Parametrically linked more weakly to thermal diagram

Asking general questions

- This needn't be *the* DM to be interesting
- Are there any particles leftover from "late" (sub TeV) thermal contact?



Scaling of signals

 $p \sim \frac{1}{T}$ i.e. $p \sim p \cdot \frac{\sigma}{T}$ ht nov pour po. ov nost N² Jvn <u>n³ J²</u> J <u>l</u> de creeses fo-m³ J² J <u>large</u> J

Scaling arguments

direct signal stable

indirect signal decreases

The thermal target here is *more* robust





Scaling arguments

direct signal decreases

indirect signal decreases faster





Moving away from priors changes questions

- hidden physics would be profound
- may not be

• Looking for the DM is critical, but finding cosmologically "relevant"

A WIMP was motivated to be "the" DM, but hidden physics may or

 Broadening the question changes how we think about targets, how robust they are and changes the implications of complementarity

Generalizations of thermal history

- Freeze-in (signal arises later) •
- SIMPS (new "miracle" at 100 MeV)
- ELDERS •

- Forbidden DM •
- Dynamical DM

Still need labs for new ideas

Major theoretical advancement has been in rethinking "generic" thermal particles

Rebalancing our priorhedron

