THE DARK MATTER/BARYOGENESIS CONNECTION

OR

ASYMMETRIC DARK MATTER

PARTICLE PHYSICS AND COSMOLOGY 2011
CERN

STEPHEN WEST
OUTLINE

- INTRODUCTION
- CHARACTERISTICS OF ASYMMETRIC DM
- MODELS OF ASYMMETRIC DM
- SIGNALS/EXPERIMENTAL CONSEQUENCES
- CONCLUSIONS
COMPOSITION OF THE UNIVERSE:

\[
\frac{\Omega_{dm}}{\Omega_b} \sim 5
\]

USUALLY THESE TWO NUMBERS ARE DETERMINED BY INDEPENDENT DYNAMICS

\[\Omega_{dm}\] BY WIMPS

\[\Omega_{b}\] BY BARYOGENESIS/LEPTOGENESIS
INTRODUCTION

□ COMPOSITION OF THE UNIVERSE:

- Dark Energy: 74%
- Dark Matter: 22%
- Atoms: 4%

\[
\frac{\Omega_{dm}}{\Omega_b} \sim 5
\]

□ USUALLY THESE TWO NUMBERS ARE DETERMINED BY INDEPENDENT DYNAMICS

- \(\Omega_{dm}\) by WIMPS
- \(\Omega_b\) by Baryogenesis/Leptogenesis

□ TAKE SERIOUSLY THE CLOSENESS OF THESE VALUES - INVESTIGATE DYNAMICS THAT LINK THE TWO...

...LEADS TO IDEAS OF ASYMMETRIC DM
INTRODUCE AN ASYMMETRY IN DM NUMBER DENSITY

\[ n_{dm} - \bar{n}_{dm} \neq 0 \]
INTRODUCE AN ASYMMETRY IN DM NUMBER DENSITY

\[ n_{dm} - \bar{n}_{dm} \neq 0 \]

USE DYNAMICS TO RELATE THIS ASYMMETRY IN DM TO THAT IN BARYONS

\[ n_{dm} - \bar{n}_{dm} \propto n_b - \bar{n}_b \]

LEADING TO

\[ \frac{\Omega_{dm}}{\Omega_b} \sim \frac{(n_{dm} - \bar{n}_{dm}) m_{dm}}{(n_b - \bar{n}_b) m_b} \sim C \frac{m_{dm}}{m_b} \]

THE VALUE OF \( C \) DEPENDS ON THE DETAILS OF THE DYNAMICS CONNECTING DM AND BARYONS...SEE LATER
ASYMMETRIC DARK MATTER BASICS

Candidates: Complex scalars and Dirac fermions (+ usual requirements for DM, no EM or colour charge etc) - cannot use Majorana

Need a shared quantum number, e.g. a charge associated with a global U(1)
ASYMMETRIC DARK MATTER BASICS

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**Toy Example:**

Baryons have charge $q$, dark matter has charge $Q$
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- Need a shared quantum number, e.g. a charge associated with a global $U(1)$

Toy Example:

Baryons have charge $q$, dark matter has charge $Q$

Conservation of global charge implies $Q(n_{dm} - \bar{n}_{dm}) = q(n_b - \bar{n}_b)$
ASYMMETRIC DARK MATTER BASICS

- CANDIDATES: COMPLEX SCALARS AND DIRAC FERMIONS (+ USUAL REQUIREMENTS FOR DM, NO EM OR COLOUR CHARGE ETC) - CANNOT USE MAJORANA

- NEED A SHARED QUANTUM NUMBER, E.G. A CHARGE ASSOCIATED WITH A GLOBAL U(1)

TOY EXAMPLE:

BARYONS HAVE CHARGE $q$, DARK MATTER HAS CHARGE $Q$

CONSERVATION OF GLOBAL CHARGE IMPLIES $Q(n_{dm} - \bar{n}_{dm}) = q(n_b - \bar{n}_b)$

ASSUME ANNIHILATIONS OF DM ANTI-DM EFFICIENT $n_{dm} \gg \bar{n}_{dm}$

THEN, $n_{dm} = Cn_b$ WHERE $C = q/Q$

$\Rightarrow \frac{\Omega_{dm}}{\Omega_b} \sim C \frac{m_{dm}}{m_b}$

ASYMMETRIC DARK MATTER
A (PARTIAL) HISTORY

80'S AND 90'S

COSMIONS AS ~5 GEV ADM: GELMINI, HALL, LIN (1987); GIUDICE, RABY (1990)

WEAK SCALE ADM: NUSSINOV (1985); BARR, CHIVUKULA, FARHI (1990), BARR (1991); DB KAPLAN (1992); THOMAS (1995);
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00'S


MANY RECENT DEVELOPMENTS - SORRY IF I MISS SOME NAMES

MURAYAMA, RATZ, KAPLAN (DE), LUTY, ZUREK, COHEN, CAI, FRANDSEN, SARKAR, SCHMIDT-HOBERG, PHALEN, SANNINO, DAVOUDIASL, MORRISSEY, SIGURDSEN, TULIN, HABA, MATSUMOTO, BUCKLEY, RANDALL, CHUN, GU, LINDNER, SARKAR, ZHANG, BLENNOW, DASGUPTA, FERNANDEZ-MARTINEZ, MCDONALD, GRAESSER, SHOEMAKER, VECCHIE, IMINNIYAZ, DREEZE, CHEN, HALL, MARCH-RUSSELL, SMW...MANY MORE

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GENERATING THE ASYMMETRY: CO-GENESIS VS SHARING

☐ CO-GENESIS

☐ ASYMMETRIES IN DM AND BARYONS GENERATED SIMULTANEOUSLY

☐ DM GENESIS/BARYOGENESIS ALL WRAPPED UP IN ONE MECHANISM

☐ POTENTIAL TO TEST BOTH DM GENESIS AND BARYOGENESIS
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☐ POTENTIAL TO TEST BOTH DM GENESIS AND BARYOGENESIS

☐ TRANSFERRING PRIMORDIAL ASYMMETRY

☐ ASSUME PRE-EXISTING ASYMMETRY (EITHER IN BARYONS OR DM)

☐ ASYMMETRY TRANSFERRED AND SHARED BETWEEN SECTORS

☐ OPERATORS FOR TRANSFER COULD BE TESTABLE

☐ GENERALLY HARD TO TEST GENERATION OF INITIAL ASYMMETRY

☐ MAY LOOSE THE LINK BETWEEN GENERATION OF BARYONS AND DM
E-WEAK BARYOGENESIS (EWB)  

- Extra $U(1)_{DM}$ symmetry with weak anomaly
- Stable particles charged under $U(1)_{DM}$ will be produced in EWB with baryons
- DM states charged under $SU(2)_L$
- Must also have light masses (sub 45 GeV)

⇒ Simple model ruled out by couplings to Z (direct detection and invisible Z-width)
CO-GENESIS EXAMPLES - MAKING AN ASYMMETRY IN B AND DM

- E-WEAK BARYOGENESIS (EWB) \textsuperscript{KAPLAN DB (1992)}
  - EXTRA $U(1)_{\text{DM}}$ SYMMETRY WITH WEAK ANOMALY
  - STABLE PARTICLES CHARGED UNDER $U(1)_{\text{DM}}$ WILL BE PRODUCED IN EWB WITH BARYONS
  - DM STATES CHARGED UNDER $SU(2)_L$
  - MUST ALSO HAVE LIGHT MASSES (SUB 45GEV)

  ⇒ SIMPLE MODEL RULED OUT BY COUPLINGS TO Z
  (DIRECT DETECTION AND INVISIBLE Z-WIDTH)

- OUT OF EQUILIBRIUM DECAYS
  - DECAYS OF PARTICLES OR SUSY FLAT DIRECTION
  - DECAYS VIOLATE CP AND PRODUCE ASYMMETRY IN DM AND LEPTON/BARYON NUMBER

\text{SUBSET OF RELATED: THOMAS, DAVOUDIASL, MORRISSEY, SIGURDSON, TULIN, HALL, MARCH-RUSSELL, SMW, CHUN, BLENNOW, ALLAHVERDI, FALKOWSKI, RUDERMAN, VOLANSKY, ZUREK, CHEUNG}
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- **ASYMMETRIC FREEZE-IN...MORE LATER**

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IMPORTANT ASIDE ON THE ELECTROWEAK ANOMALY/SPHALERONS

- **B+L Violating Process, Conserves B-L Efficiently Operate**
  - At $T_C \sim 100\,\text{GeV}$ (Below this temp exponentially suppressed)

- Can effectively be thought of as multi-particle vertex involving $\text{SU}(2)_L$ charged states

*Diagram of Sphaleron process* 

Taken from Buchmuller, HEP-PH/0204288
IMPORTANT ASIDE ON THE ELECTROWEAK ANOMALY/SPHALERONS

- B+L VIOLATING PROCESS, CONSERVES B-L EFFICIENTLY OPERATE AT $T_C \sim 100$ GeV (BELOW THIS TEMP EXPONENTIALLY SUPPRESSED)

- CAN EFFECTIVELY BE THOUGHT OF AS MULTI-PARTICLE VERTEX INVOLVING SU(2)$_L$ CHARGED STATES

- MUST HAVE ASYMMETRY IN B-L NUMBER BEFORE SPHALERONS REPROCESS ASYMMETRY

- E.g. IF $L \neq 0$, $B=0$ SPHALERONS WILL REPROCESS L ASYMMETRY INTO B NUMBER

- IF $B \neq 0$, $L \neq 0$ BUT B-L=0, E-WEEK ANOMALY WILL WASH OUT THE ASYMMETRY

TAKEN FROM BUCHMULLER, HEP-PH/0204288

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TRANSFER OF PRE-EXISTING ASYMMETRY

- PRE-EXISTING ASYMMETRY IN BARYON OR DM SECTOR

- ASYMMETRY NEEDS TO BE TRANSFERRED (ASSUMING NOT CHARGED UNDER SU(2)\textsubscript{L})

SEE E.G. KAPLAN, LUTY, ZUREK (2009)
TRANSFER OF PRE-EXISTING ASYMMETRY

- PRE-EXISTING ASYMMETRY IN BARYON OR DM SECTOR

- ASYMMETRY NEEDS TO BE TRANSFERRED (ASSUMING NOT CHARGED UNDER SU(2)\textsubscript{L})

- REQUIRE OPERATORS THAT LEAD TO INTERACTIONS CAPABLE OF TRANSFERRING ASYMMETRY

E.G.

\[ \mathcal{L} \sim \frac{1}{M^{d-4}} O_{dm} O_{sm} \]

\( d \) = DIMENSION OF COMBINED OPERATOR

\( O_{sm} \) AND \( O_{dm} \) INDIVIDUALLY CHARGED UNDER GLOBAL U(1), BUT COMBINED OPERATOR IS IN Variant UNDER U(1)

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  \( d = \)DIMENSION OF COMBINED OPERATOR

  \( O_{sm} \) AND \( O_{dm} \) INDIVIDUALLY CHARGED UNDER GLOBAL U(1), BUT COMBINED OPERATOR IS INVARIANT UNDER U(1)

- IF ASYMMETRY EXISTS IN EITHER SM OR DM SECTOR, THESE OPERATORS WILL SHARE THIS WITH THE OTHER SECTOR

- OPERATORS MUST BE IN THERMAL EQUILIBRIUM ABOVE \( T = m_{dm} \)

- HOWEVER, THEY MUST DROP OUT OF THERMAL EQUILIBRIUM ABOVE DM FREEZE-OUT OTHERWISE THEY WILL WASH OUT THE ASYMMETRY

SEE E.G. KAPLAN, LUTY, ZUREK (2009)
GLOBAL SYMMETRY USED IS $U(1)_{B-L}$

AT HIGH $T$, A $B-L$ ASYMMETRY IS GENERATED

TRANSFER OPERATORS PRESERVE $B-L$, E.G.

$$\Delta W = \frac{1}{M} \overline{X}^2 LH_u$$

THE $X$ FIELD HAS $L = \frac{1}{2}$
GLOBAL SYMMETRY USED IS $U(1)_{B-L}$

AT HIGH T, A B-L ASYMMETRY IS GENERATED

TRANSFER OPERATORS PRESERVE B-L, E.G.

$$\Delta W = \frac{1}{M} \overline{X}^2 LH_u$$  \hspace{1cm} \text{THE X FIELD HAS} \hspace{1cm} L = \frac{1}{2}$$

WHEN IN EQUILIBRIUM, THIS OPERATOR TRANSFERS AN L ASYMMETRY INTO THE DM X SECTOR, THIS LEADS TO

$$2(n_X - \overline{n}_X) \approx (n_L - \overline{n}_L)$$
Assuming transfer process drops out of thermal equilibrium above e-weak phase transition

$X$ asymmetry can be calculated in terms of $B-L$

$$X = -\frac{11}{79}(B - L)$$
Assuming transfer process drops out of thermal equilibrium above e-weak phase transition

\[ X = -\frac{11}{79}(B - L) \]

Asymmetry can be calculated in terms of B-L

Through the e-weak anomaly B-L is transferred into B

\[ B \approx 0.31(B - L) \]
Assuming transfer process drops out of thermal equilibrium above E-weak phase transition.

\[ X = -\frac{11}{79} (B - L) \]

Through the E-weak anomaly B-L is transferred into B.

\[ B \approx 0.31 (B - L) \]

Finally by inverting \( \frac{\Omega_X}{\Omega_b} \sim \frac{X m_X}{B m_b} \), a prediction for

\[ m_X \approx \frac{B \Omega_X}{X \Omega_b} \approx 11 \text{ GeV} \]
POSSIBLE MASSES

SIMPLEST CASES, THERE ARE TWO MASS REGIONS

\[ m_{dm} \sim 5 \text{ GeV} \text{ AND } m_{dm} \sim 1 \text{ TeV} \]
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☐ IF THE DM IS NOT CHARGED UNDER SU(2)_L WE GET THE LOW MASS REGION CORRESPONDING TO THE CASE ALREADY DESCRIBED

\[ \Rightarrow \frac{\Omega_{dm}}{\Omega_b} \approx \frac{m_{dm}}{m_b} \rightarrow m_{dm} \sim 5 \text{ GeV} \]
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☐ IF THE DM IS CHARGED UNDER SU(2)\(_L\) IT WILL INTERACT VIA SPHALERONS AND WE GET TWO POSSIBILITIES

▷ IF \( m_{dm} \leq T_c \) THEN WE AGAIN FIND ABOVE RESULT - \( m_{dm} \sim 5 \text{ GeV} \)
POSSIBLE MASSES

SIMPLEST CASES, THERE ARE TWO MASS REGIONS

\[ m_{dm} \sim 5 \text{ GeV} \quad \text{AND} \quad m_{dm} \sim 1 \text{ TeV} \]

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\( \square \) IF THE DM IS CHARGED UNDER SU(2)_L IT WILL INTERACT VIA SPHALERONS AND WE GET TWO POSSIBILITIES

\( \triangleright \) IF \( m_{dm} \lesssim T_c \) THEN WE AGAIN FIND ABOVE RESULT - \( m_{dm} \sim 5 \text{ GeV} \)

\( \triangleright \) IF \( m_{dm} \gtrsim T_c \) (I.E. DM STARTS TO BECOME NON-RELATIVISTIC, DROPPING OUT OF T.E.) WE GET NUSSINOV (1985)

\[ \frac{\Omega_{dm}}{\Omega_b} \approx \frac{m_{dm}}{m_b} x^{3/2} e^{-x} \quad \text{WITH} \quad x = \frac{m_{dm}}{T_c} \]
POSSIBLE MASSES

SIMPLEST CASES, THERE ARE TWO MASS REGIONS

\[ m_{dm} \sim 5 \text{ GeV} \quad \text{AND} \quad m_{dm} \sim 1 \text{ TeV} \]

\[ \begin{align*}
\Rightarrow \quad \frac{\Omega_{dm}}{\Omega_b} & \approx \frac{m_{dm}}{m_b} \\
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\end{align*} \]

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(ACTUALLY ONLY REALLY CORRECT FOR \( m_{dm} \gg T_c \))

NUSSINOV (1985)

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POSSIBLE MASSES

SIMPLEST CASES, THERE ARE TWO MASS REGIONS

\[ m_{dm} \sim 5 \text{ GeV} \quad \text{AND} \quad m_{dm} \sim 1 \text{ TeV} \]

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IF THE DM IS NOT CHARGED UNDER SU(2)_L, WE GET THE LOW MASS REGION CORRESPONDING TO THE CASE ALREADY DESCRIBED.

IF THE DM IS CHARGED UNDER SU(2)_L, IT WILL INTERACT VIA SPHALERONS AND WE GET TWO POSSIBILITIES.

\[ m_{dm} \lesssim T_c \quad \text{THEN WE AGAIN FIND ABOVE RESULT} - \quad m_{dm} \sim 5 \text{ GeV} \]

\[ m_{dm} \gtrsim T_c \quad (\text{I.E. DM STARTS TO BECOME NON-RELATIVISTIC, DROPPING OUT OF T.E.}) \quad \text{WE GET} \quad \text{NUSSINOV (1985)} \]

\[ \frac{\Omega_{dm}}{\Omega_b} \approx \frac{m_{dm}}{m_b} \frac{x^{3/2}}{e^{-x}} \quad \text{WITH} \quad x = \frac{m_{dm}}{T_c} \]

(Actually only really correct for \( m_{dm} \gg T_c \))

CORRECT RATIO FOR \( m_{dm} \sim 1 \text{ TeV} \)
ASYMMETRIC FREEZE-OUT

In all these models a large abundance of symmetric DM must be annihilated away.

Freeze-out operates as usual via annihilations but now the DM has an asymmetry - this changes the freeze-out details.

For more details see Imniniyaz, Dreess, Chen (1104.5548); Graesser, Shoemaker, Vecchi, (1103.2771)
ASYMMETRIC FREEZE-OUT

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Freeze-out operates as usual via annihilations but now the DM has an asymmetry - this changes the freeze-out details.

Asymmetric and symmetric DM freeze-out, with the same annihilation rate and mass.

Anti-particles annihilate efficiently.

Particles are depleted less than symmetric case.

Actually need larger annihilation rate, approx factor of 2-3 larger.

For more details see Imniniyaz, Drees, Chen (1104.5548); Graesser, Shoemaker, Vecchi, (1103.2771)

\[ \eta = 0.88 \times 10^{-10} \]
AN ASIDE ON FREEZE-IN

Freeze-in is relevant for particles that are feebly coupled to the thermal bath, call them FIMPS (FEEBLY INTERACTING MASSIVE PARTICLES).

Operators generating coupling can be renormalisable or non-renormalisable.
AN ASIDE ON FREEZE-IN

Freeze-in is relevant for particles that are feebly coupled to the thermal bath, call them FIMPS (feebly interacting massive particles)

Operators generating coupling can be renormalisable or non-renormalisable.

Simple picture for a renormalisable feebly coupling

Production is IR dominated

Function of couplings and masses
Consider FIMP $X$ coupled to two bath fermions

$$L_Y = \lambda \psi_1 \psi_2 X \quad m_{\psi_1} > m_X + m_{\psi_2}$$
Aside on Freeze-in Cont...

Consider FIMP $X$ coupled to two bath fermions:

\[ L_Y = \lambda \psi_1 \psi_2 X \]

\[ m_{\psi_1} > m_X + m_{\psi_2} \]

Correct abundance for $m_X \sim m_{\psi_1}$

\[ \Omega_X h^2 \sim 10^{24} \frac{m_X \Gamma_{\psi_1}}{m_{\psi_1}^2} \]

Abundance goes as $\lambda^2$

$\Rightarrow \lambda \sim 10^{-11}$
Aside on Freeze-In Cont...

Consider FIMP $X$ coupled to two bath fermions

$$L_Y = \lambda \psi_1 \psi_2 X \quad m_{\psi_1} > m_X + m_{\psi_2}$$

Interesting possibilities for new DM genesis mechanism

Gives long lived decays at LHC, implications for BBN

What about asymmetric DM in this scenario?

Correct abundance

For $m_X \sim m_{\psi_1}$

$\Rightarrow \lambda \sim 10^{-11}$
ASYMMETRIC FREEZE-IN

- Freeze-in processes could be CP- and B-L number violating.

- These processes already contain out-of-equilibrium processes - FIMP is not in thermal equilibrium.

- Asymmetry could be produced through interference of tree and loop-level processes.

Hall, March-Russell, SMW, ArXiV:1010:0245
ASYMMETRIC FREEZE-IN

- FREEZE-IN PROCESSES COULD BE CP- AND B-L NUMBER VIOLATING

- THESE PROCESSES ALREADY CONTAIN OUT-OF-EQUILIBRIUM PROCESSES - FIMP IS NOT IN THERMAL EQUILIBRIUM

- ASYMMETRY COULD BE PRODUCED THROUGH INTERFERENCE OF TREE AND LOOP-LEVEL PROCESSES

- INITIALLY IT WAS THOUGHT THAT AN ASYMMETRY AT $\lambda^2$ COULD BE GENERATED. TURNS OUT, LOWEST ORDER IS $\lambda^3$.

HALL, MARCH-RUSSELL, SMW, ARXIV:1010:0245

DEPENDING ON THE MODEL, ASYMMETRIC FREEZE-IN MAY ALLOW “FULL” PROBE OF BARYOGENESIS - DM CONNECTION

HALL, MARCH-RUSSELL, SMW, ARXIV:1010:0245

Hook, Arxiv:1105:3728

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EXPERIMENTAL SIGNATURES FOR ADM

☐ LHC SIGNALS

☐ INDIRECT DETECTION SIGNALS

☐ IMPLICATIONS FOR BBN AND BEYOND

☐ CONSTRAINTS FROM THE SUN

☐ DIRECT DETECTION
LHC SIGNALS

- MANY ASYMMETRY TRANSFER OPERATORS CAN LEAD TO LONG LIVED PARTICLES AT THE LHC.

- FOR EXAMPLE, IN SUSY MODELS THE LOSP CAN BE LONG LIVED IF IT HAS A SMALL DECAY WIDTH TO THE DM STATE THROUGH A CONNECTOR OPERATOR.

\[ \Delta W = \lambda L H_u X \]

\[ \chi^- \rightarrow l^- X \]
LHC SIGNALS

- Many asymmetry transfer operators can lead to long lived particles at the LHC.
- For example, in SUSY models the LOSP can be long lived if it has a small decay width to the DM state through a connector operator.

\[
\Delta W = \lambda L H_u X
\]

\[
\chi^- \rightarrow l^- X
\]

- LOSP in this simple example is a chargino.
- Gives charged track plus lepton plus missing.
- Note: Each SUSY event will end in this decay - overall event is two leptons plus missing (with two charge tracks).
- Decay length of the chargino depends on scenario, but could be \( cT \sim \) primary vertex - many meters.
INDIRECT SIGNALS

- Traditional indirect signals will be suppressed...Any others?

- Large symmetric abundance of DM needs to annihilate away
INDIRECT SIGNALS

Traditional indirect signals will be suppressed... any others?

Large symmetric abundance of DM needs to annihilate away

Two options to do this:

- Use further connector operators in annihilations directly, these must not transfer an asymmetry [Buckley, 1104.1429]

\[ \Delta L = \frac{m_q}{\Lambda^2} X^* X \bar{q}q \]

Constraints from direct detection, colliders etc
INDIRECT SIGNALS

- Traditional indirect signals will be suppressed... any others?

- Large symmetric abundance of DM needs to annihilate away

- Two options to do this:

  ▶ Use further connector operators in annihilations directly, these must not transfer an asymmetry

  E.g. \[ \Delta \mathcal{L} = \frac{m_q}{\Lambda^2} X^* X \bar{q}q \]

  Constraints from direct detection, colliders etc

  Buckley, 1104.1429

  ▶ Use additional states in dark sector - freeze-out in this sector to some very light or unstable state, which decays back to SM sector

  E.g. Hall, March-Russell, SMW, ArXiv:1010:0245

- Possibly very interesting scenario - constraints coming from BBN and CMBR depending on lifetime of unstable state
CONSTRAINTS FROM THE SUN

- If DM has large spin-dependent scattering cross section or self-interacting, DM can accumulate in the Sun.

- Old idea to solve solar neutrino problem - cosmions/low mass DM in the Sun transports energy away from core.

- DM with an asymmetry needed so that abundance built up.

- Changes temp profile, which affects the neutrino fluxes — of course now solved by oscillations.
CONSTRAINTS FROM THE SUN

☐ IF DM HAS LARGE SPIN-DEPENDENT SCATTERING CROSS SECTION OR SELF INTERACTING, DM CAN ACCUMULATE IN THE SUN

☐ OLD IDEA TO SOLVE SOLAR NEUTRINO PROBLEM - COSMIONS/LOW MASS DM IN THE SUN TRANSPORTS ENERGY AWAY FROM CORE

☐ DM WITH AN ASYMMETRY NEEDED SO THAT ABUNDANCE BUILT UP

☐ CHANGES TEMP PROFILE, WHICH AFFECTS THE NEUTRINO FLUXES -- OF COURSE NOW SOLVED BY OSCILLATIONS

☐ IN NEW MODELS OF ADM, THE COSMION CONDITIONS COULD BE REPRODUCED

☐ CAPTURE OF ADM BY THE SUN, COULD THEN BE CONSTRAINED BY THE PROPERTIES OF THE SUN OR MAY EVEN ALLEVIATE POTENTIAL ISSUES WITH THE STANDARD SOLAR MODEL

ADM/COSMION PAPERS: FAULKNER, GILLILAND (1985); SPERGEL, PRESS (1985); GILLILAND, FAULKNER, PRESS, SPERGEL (1986); GELMINI, HALL, LIN (1987); GIUDICE, RABY (1990); LOPES, SILK, HANSEN, BERTONE (2002) FRANDSEN, SARKAR (2010); CUMBERBATCH, GUZIK, SILK, WATSON, SMW (2010); TAOSO, IOCCO, MEYNET, BERTONE, EGGENBERGER (2010)

SERENLLI, BASU, FERGUSON (2009), ASPLUND, GREVESSE, SAUVALL (2004, 2009)
CONCLUSIONS

ADM IS AN INTERESTING AND WELL MOTIVATED DM SCENARIO TO EXPLAIN

\[
\frac{\Omega_{dm}}{\Omega_b} \approx 5
\]

REQUIRE A **SHARED (GLOBAL) QUANTUM NUMBER** BETWEEN DM AND SM

TWO MAIN SCENARIOS, **CO-GENESIS** (DM AND B ASYMMETRY GENERATED SIMULTANEOUSLY) AND **SHARING** WHERE A PRE-EXISTING ASYMMETRY IS TRANSFERRED BETWEEN DM AND SM SECTORS

**RICH PHENOMENOLOGY** POSSIBLE AT COLLIDERS, IN DIRECT AND INDIRECT DM SIGNALS, IMPLICATIONS FOR BBN AND EVEN THE SUN.

LOTS MORE TO INVESTIGATE...

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