Light Chiral Dark Sector

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Plan of Talk

- Introduction
- Set up of our model
- Experimental constraints
- Smoking-gun signature

Introduction

Basic questions about DM

- Mass scale
- Stability

Mass scale

$$m_{DM} \ll M_{\rm fundamental}(= M_{\rm pl}, M_{\rm GUT}, M_{\rm st})$$

$$m_{DM}/M_{\rm fundamental} \ll 1$$

Why do we have such a small parameter?

"Hierarchy problem"

(Although the smallness can be technically natural)

Stability

Why is it stable/long-lived?

Setup of our model

Overview

- Assume chiral gauge symmetry
- Chiral gauge symmetry forbids any mass terms
- Strong dynamics generate mass gap
- One of the composite particle is accidentally stable due to the gauge symmetry

Matter contents

	Ψ_1	Ψ_2	$\overline{\Psi}_1$	$\overline{\Psi}_2$
$SU(N)$	N	N	$\bar{N}$	$\bar{N}$
$U(1)_D$	1	-1	-a	a

chiral

$a \neq 1$ → Mass terms forbidden

approximate Symmetry

	Ψ_1	Ψ_2	$\overline{\Psi}_1$	$\overline{\Psi}_2$
$SU(N)$	N	N	$\bar{N}$	$\bar{N}$
$U(1)_D$	1	-1	-a	a
$U(1)_P$	1	-1	-1	1

$$SU(2)_L \times SU(2)_R$$

↓ gauging $U(1)_D$

$$U(1)_D \times U(1)_P$$

Chiral symmetry breaking

$$< \Psi_1 \bar{\Psi}_1 > = < \Psi_2 \bar{\Psi}_2 > \neq 0$$

$SU(2)_L \times SU(2)_R$ → $SU(2)_V$

$U(1)_D \times U(1)_P$ → $U(1)_P$

gauging U(1)D: $SU(2)_V$ → $U(1)_P$

one would-be NGB

+

two pseudo NGB

Dark pion

	Ψ_1	Ψ_2	$\bar{\Psi}_1$	$\bar{\Psi}_2$
$SU(N)$	N	N	$\bar{N}$	$\bar{N}$
$U(1)_D$	1	-1	-a	a

two pseudo-NGB form a complex scalar charged under

ϕ $\quad U(1)_D \times U(1)_P$

$$\Psi_1 \overline{\Psi}_2, \Psi_2 \overline{\Psi}_1$$

The accidental, unbroken $U(1)_P$ guarantees
the stability of the dark pion

c.f. O(10-100) TeV dynamical scale —> baryon DM

Dark photon/pion mass

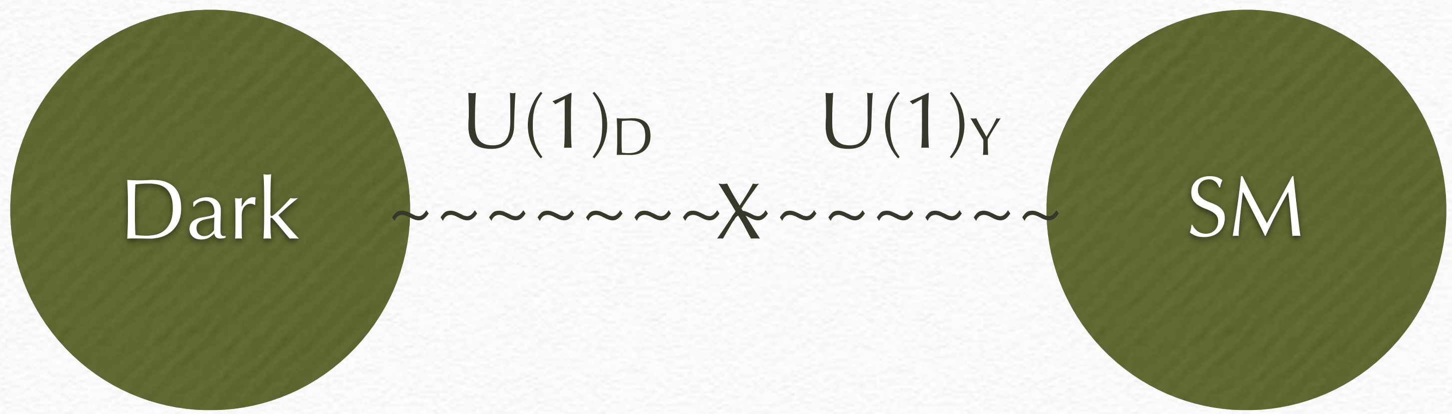
	Ψ_1	Ψ_2	$\bar{\Psi}_1$	$\bar{\Psi}_2$
$SU(N)$	N	N	$\bar{N}$	$\bar{N}$
$U(1)_D$	1	-1	-a	a

$$m_\phi \simeq \frac{e_D}{4\pi} m_{\rho_D} \times \sqrt{6a\ln 2}$$

$$m_{A_D} \simeq \frac{e_D}{4\pi} m_{\rho_D} \times \sqrt{N}(1-a)$$

Of the same order

Coupling to SM



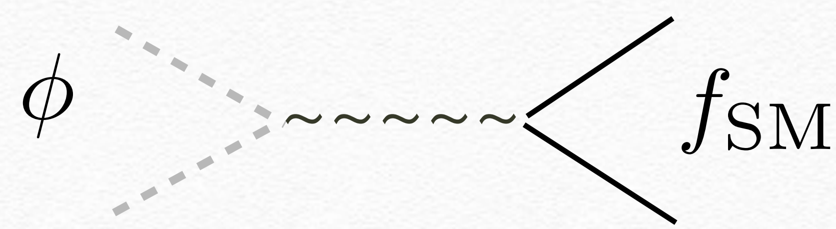
$$\mathcal{L} \supset \frac{\epsilon}{2\cos\theta_W} B_{\mu\nu} A_D^{\mu\nu}$$

Fayet (2007)

Pospelov, Ritz and Voloshin (2007)

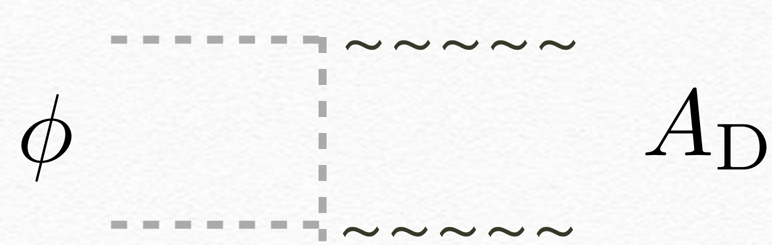
Thermal abundance

$m_\phi < m_{A_D}/2$ $\qquad$ $m_{A_D}/2 < m_\phi < m_{A_D}$



p-wave

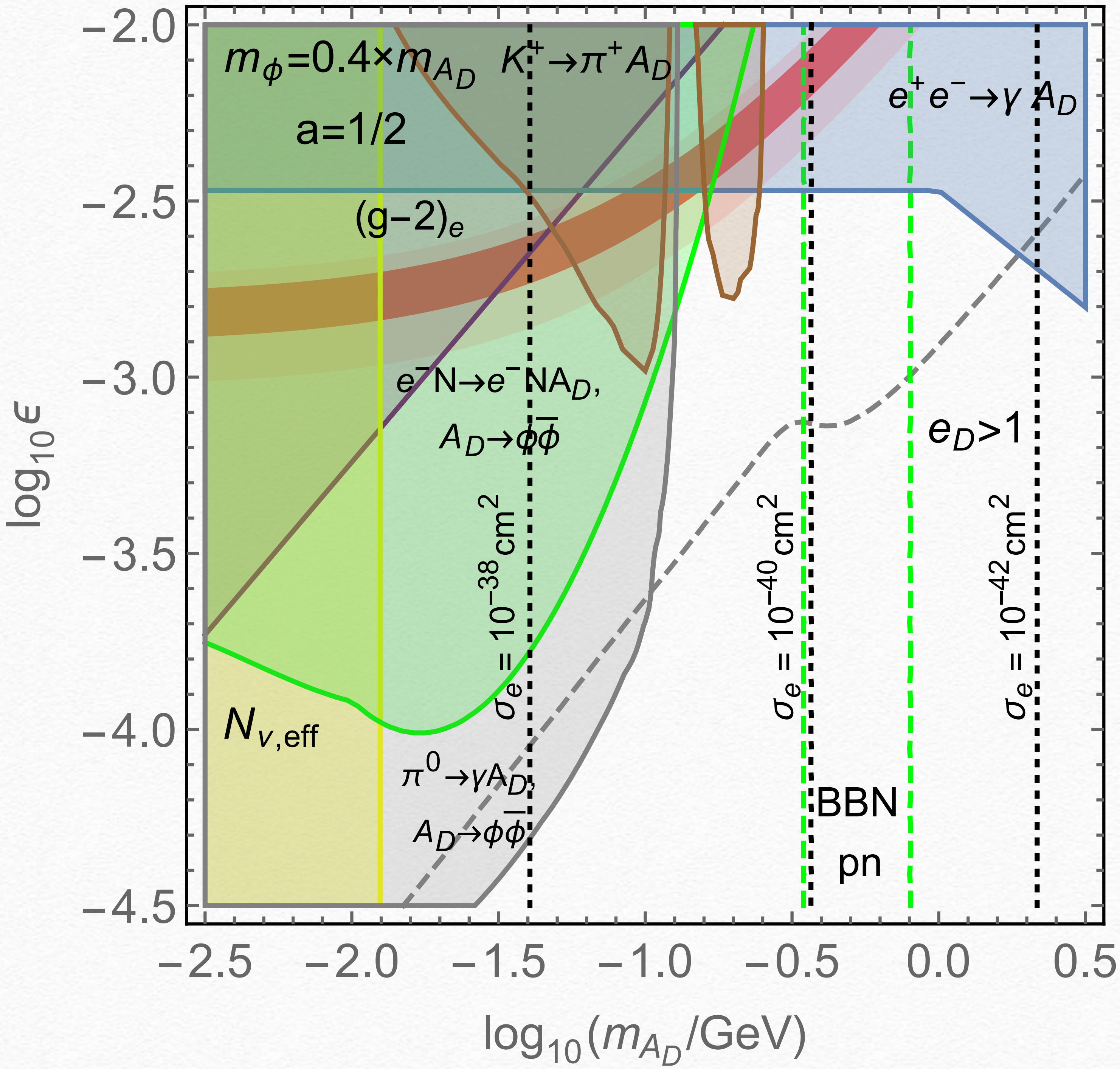
$m_\phi > m_{A_D}$



s-wave

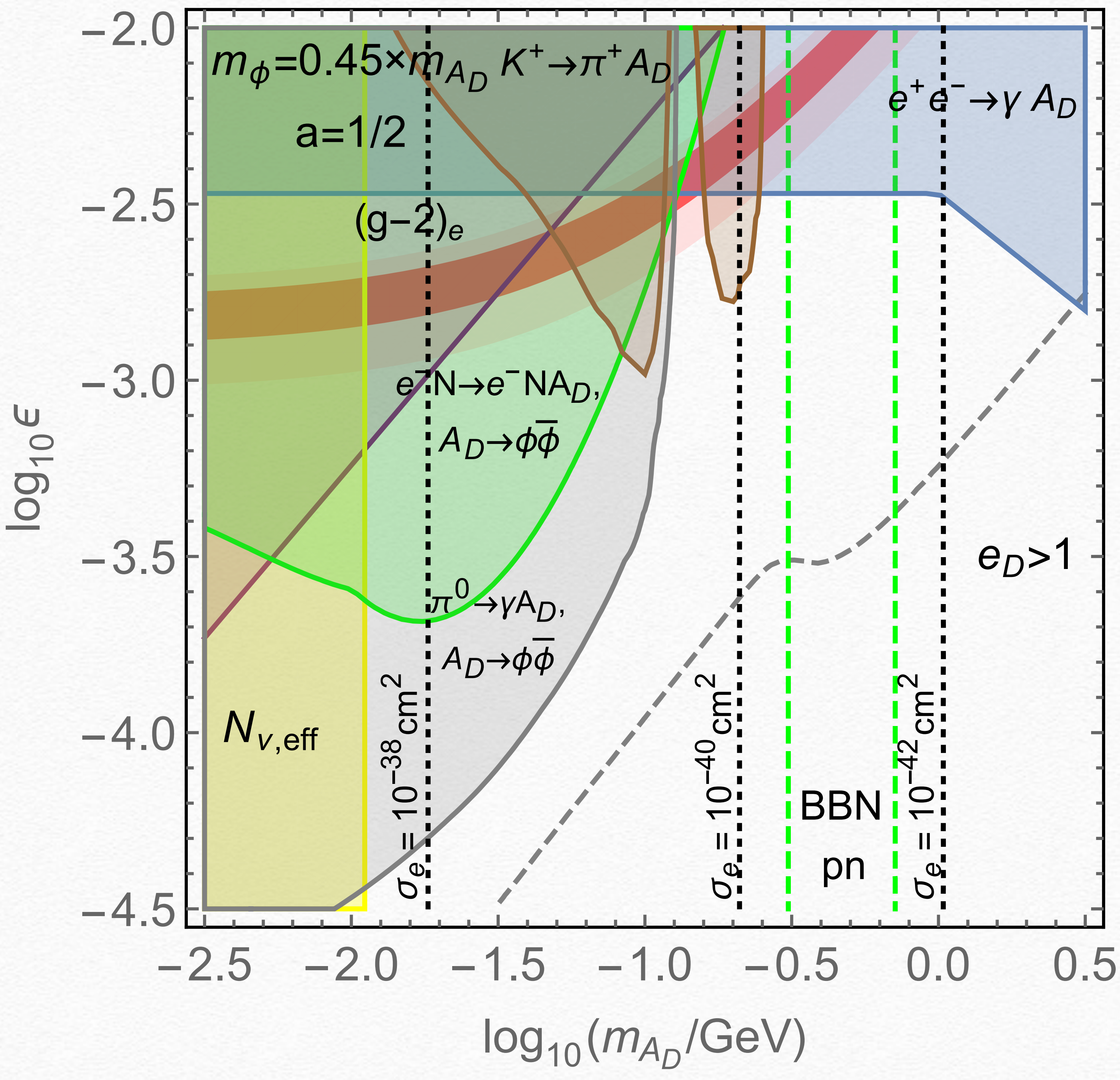
Experimental constraints

$$m_\phi < m_{A_D}/2$$



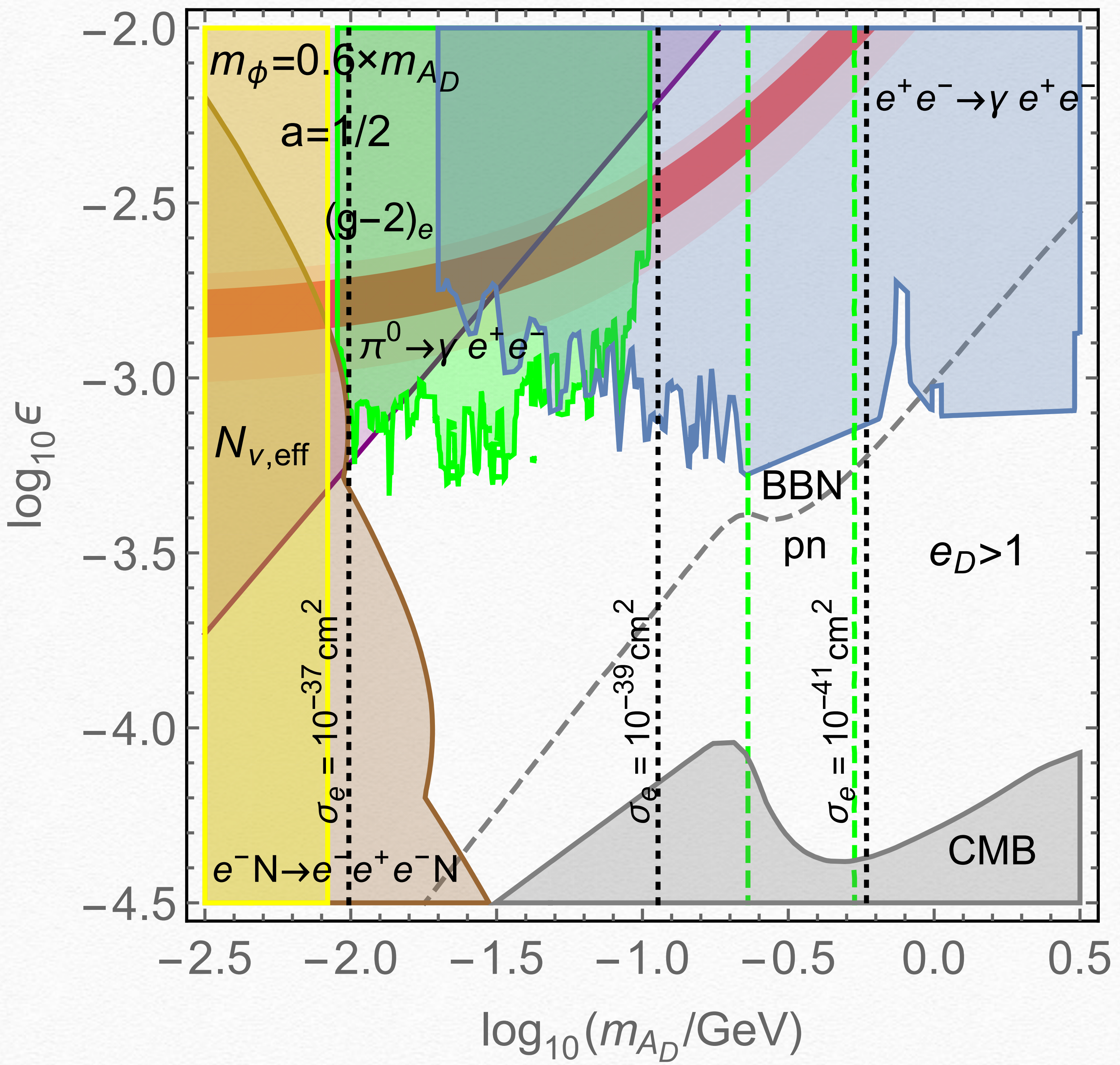
m_ϕ=0.4×m_{A_D}
a=1/2
$K^+\to\pi^+ A_D$
$e^+e^-\to\gamma A_D$
(g−2)$_e$
$e^-N\to e^-NA_D$,
$A_D\to\phi\bar{\phi}$
e_D>1
$\sigma_e = 10^{-38}$cm^2
$\sigma_e = 10^{-40}$cm^2
$\sigma_e = 10^{-42}$cm^2
$N_{\nu,\mathrm{eff}}$
$\pi^0\to\gamma A_D$,
$A_D\to\phi\bar{\phi}$
BBN
pn
−2.0
−2.5
−3.0
−3.5
−4.0
−4.5
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
$\log_{10}\epsilon$
$\log_{10}(m_{A_D}$/GeV)

Muon g-2?



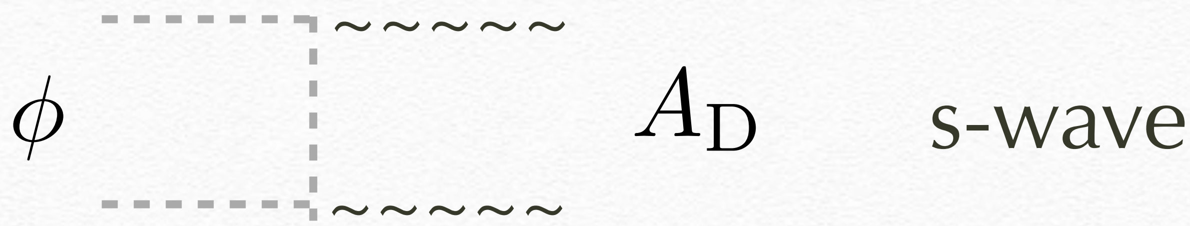
m_ϕ=0.45×m_{A_D}
$K^+\to\pi^+ A_D$
a=1/2
(g−2)$_e$
$e^+e^-\to\gamma A_D$
$e^-N\to e^-NA_D$,
$A_D\to\phi\bar{\phi}$
$\pi^0\to\gamma A_D$,
$A_D\to\phi\bar{\phi}$
e_D>1
$N_{\nu,\mathrm{eff}}$
σ_e = 10^{-38}cm^2
σ_e = 10^{-40}cm^2
σ_e = 10^{-42}cm^2
BBN
pn
$\log_{10}\epsilon$
$\log_{10}(m_{A_D}/\mathrm{GeV})$
−2.0
−2.5
−3.0
−3.5
−4.0
−4.5
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5

$$m_{A_D}/2 < m_\phi < m_{A_D}$$



$\phi\phi^* \to A_D f f^*$

$$m_\phi > m_{A_D}$$



Annihilante effectively around the recombination era
Excluded by CMB observations

Smoking-gun signature

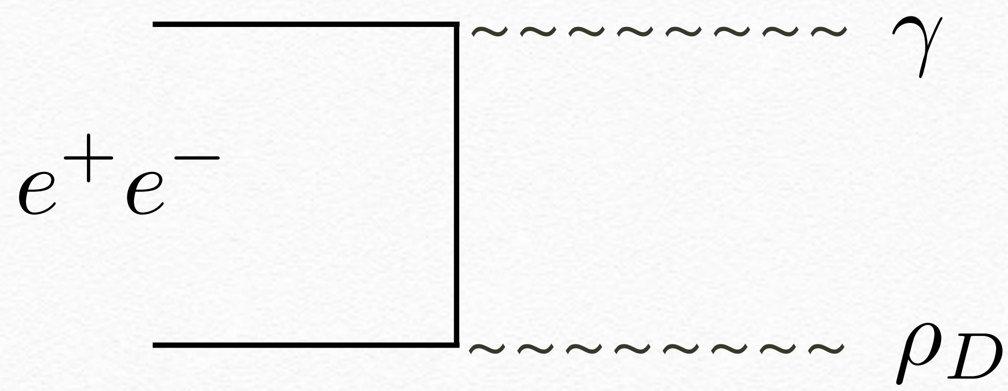
Higher resonances

rho mesons
baryons
etc.

Ex. Dark rho meson

rho meson mixies with dark photon

$$\epsilon' \rho_D^\mu J_\mu^{\mathrm{em}} \qquad \epsilon' \sim \frac{\sqrt{N}}{4\pi} e_D \epsilon$$



Monophoton e.g. at Belle II

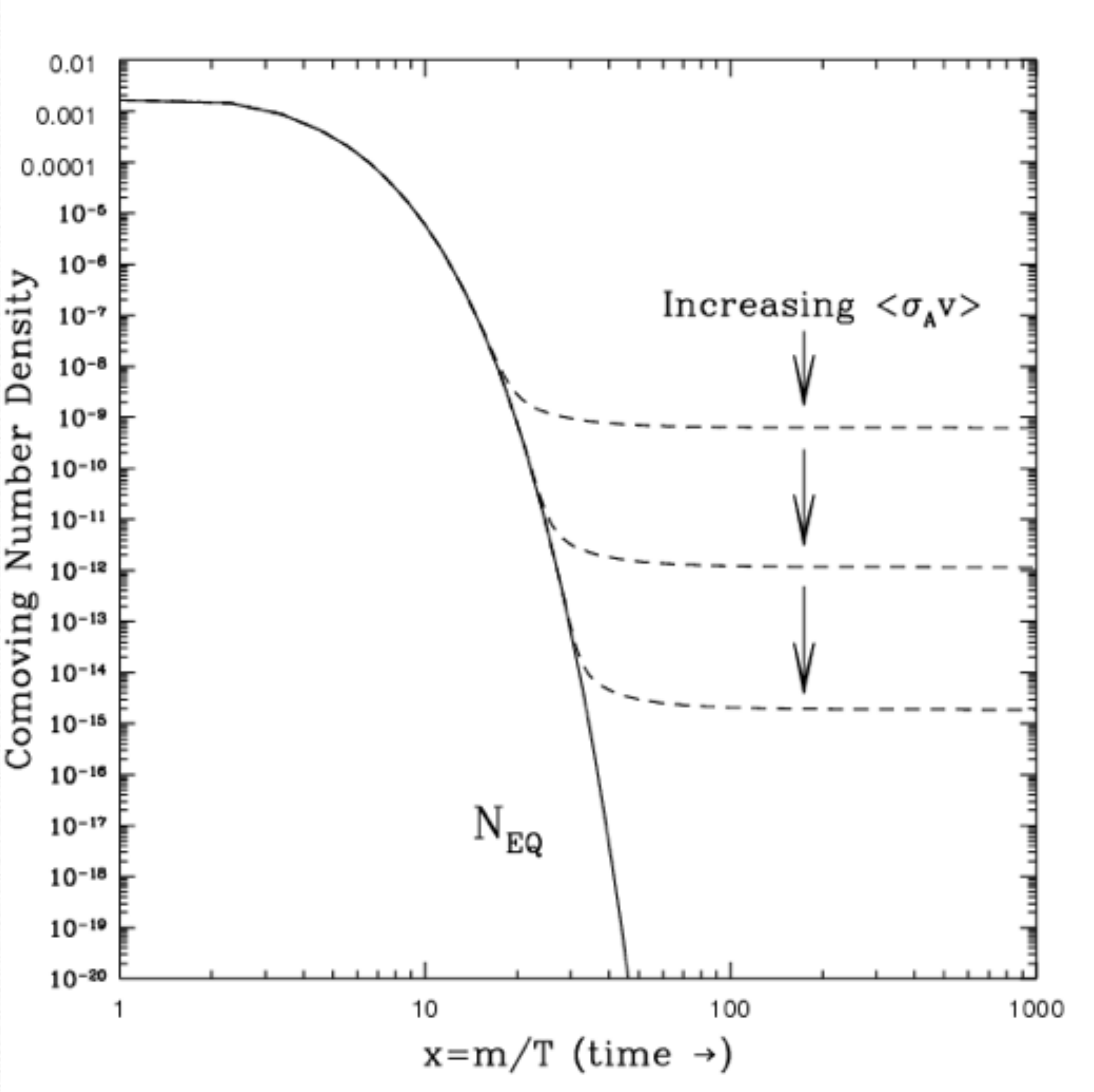
see Hochberg, Kuflik and Murayama (2015)
for more rigorous discussion

Summary

- Mass of dark matter and the stability of dark matter are understood in our model
- Smoking-gun signature from higher resonances

Dark matter from thermal bath

Lee and Weinberg



"Particle Dark Matter"