Antideuterons and Dark Matter

TUI-3 Workshop (KITP) 2015
June 25, 2015

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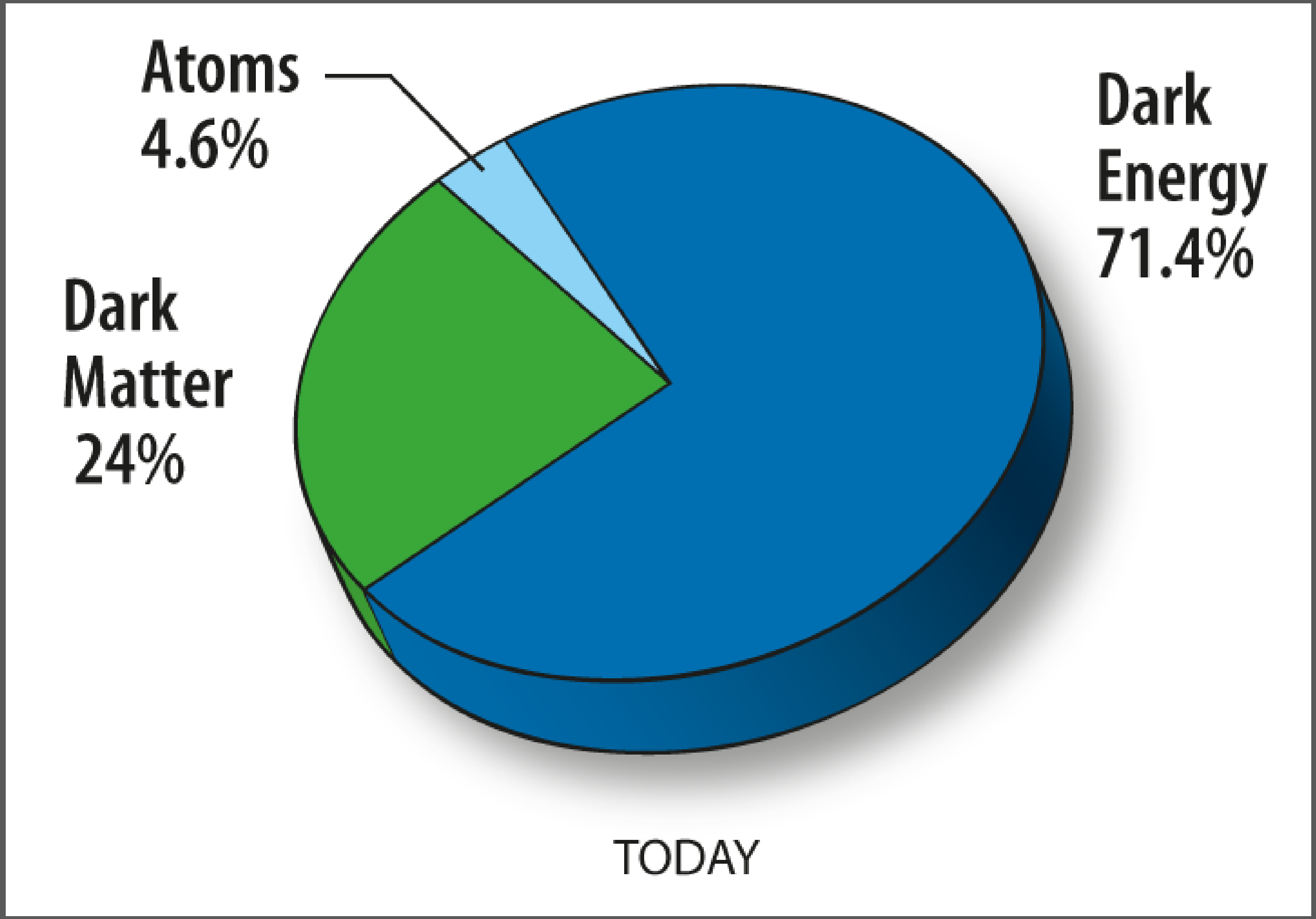
WESTERN STATE COLORADO UNIVERSITY
Learning. Elevated.

Y. Cui, JM, L. Randall: arXiv:1006.0983 (also in PRD)

The Composition of the Universe (Today)



Dark Matter

Evidence

10 kpc： Rotation Curves/ Gravitational Lensing

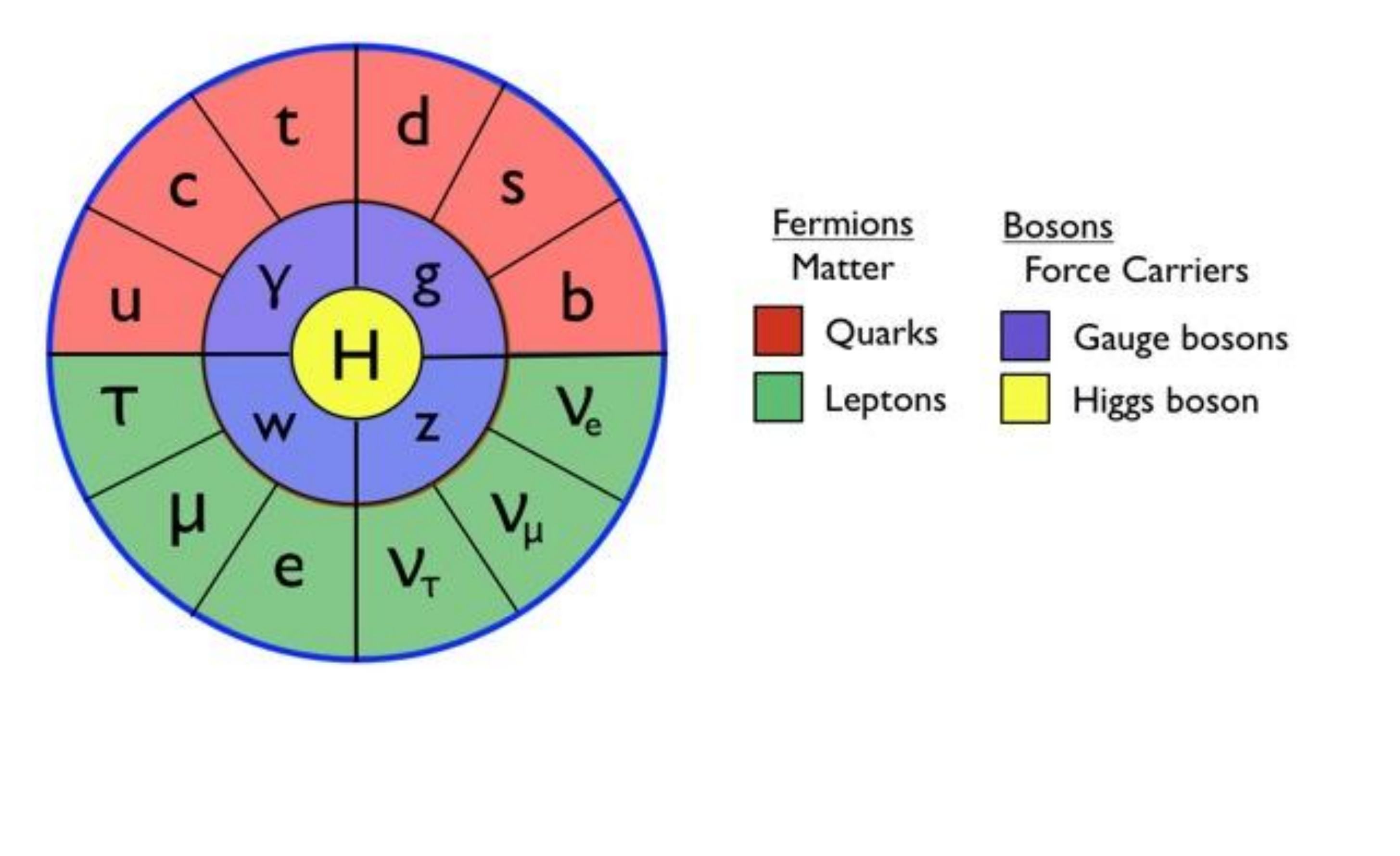
10 Mpc： Galaxy Cluster masses/Gravitational Lensing

$100\text{-}10^4$ Mpc： CMB and high-z supernovae

All of this evidence comes from gravitational interactions

What the Dark Matter is can only be answered by understanding its non-gravitational interactions

Dark Matter and the Standard Model



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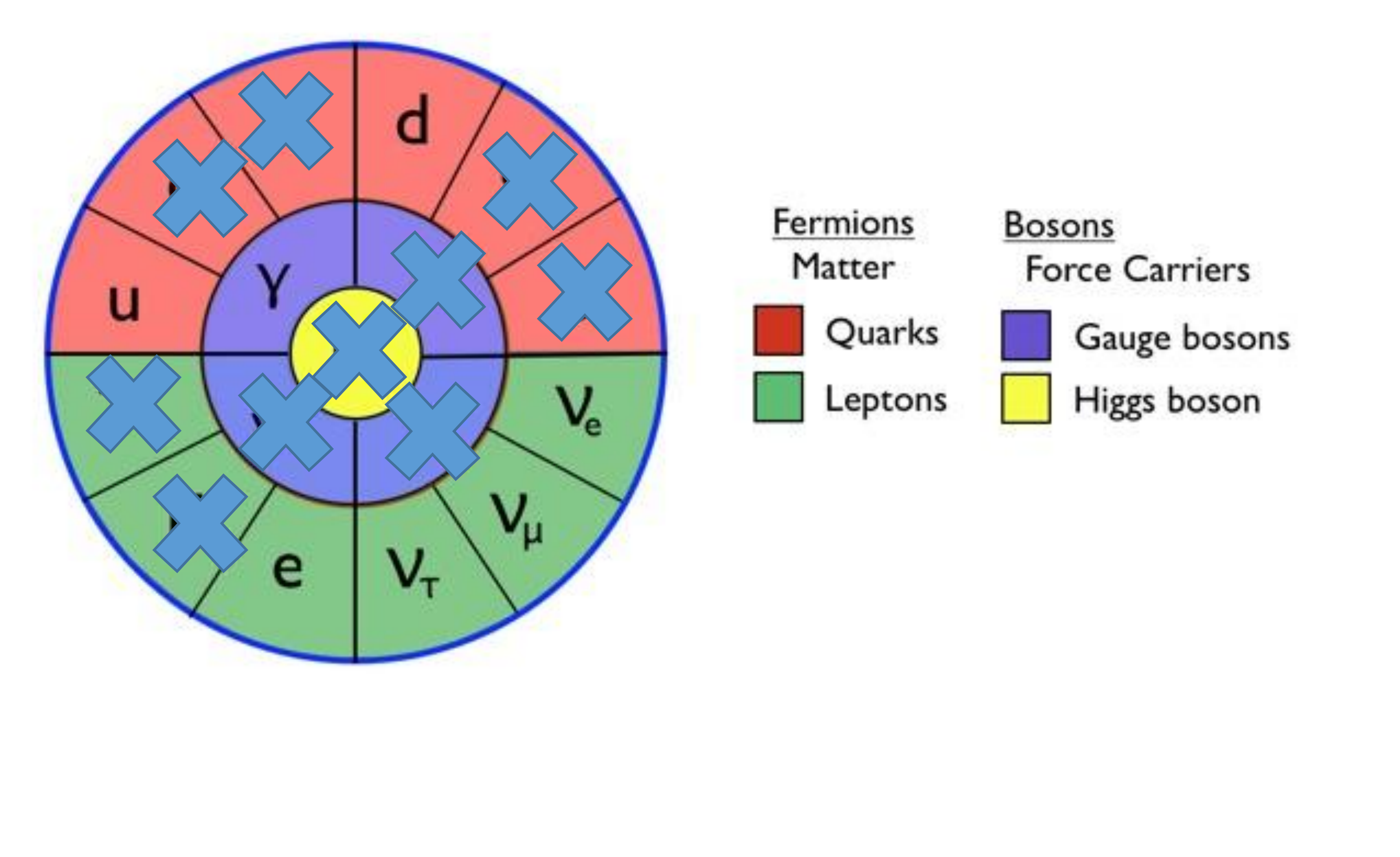

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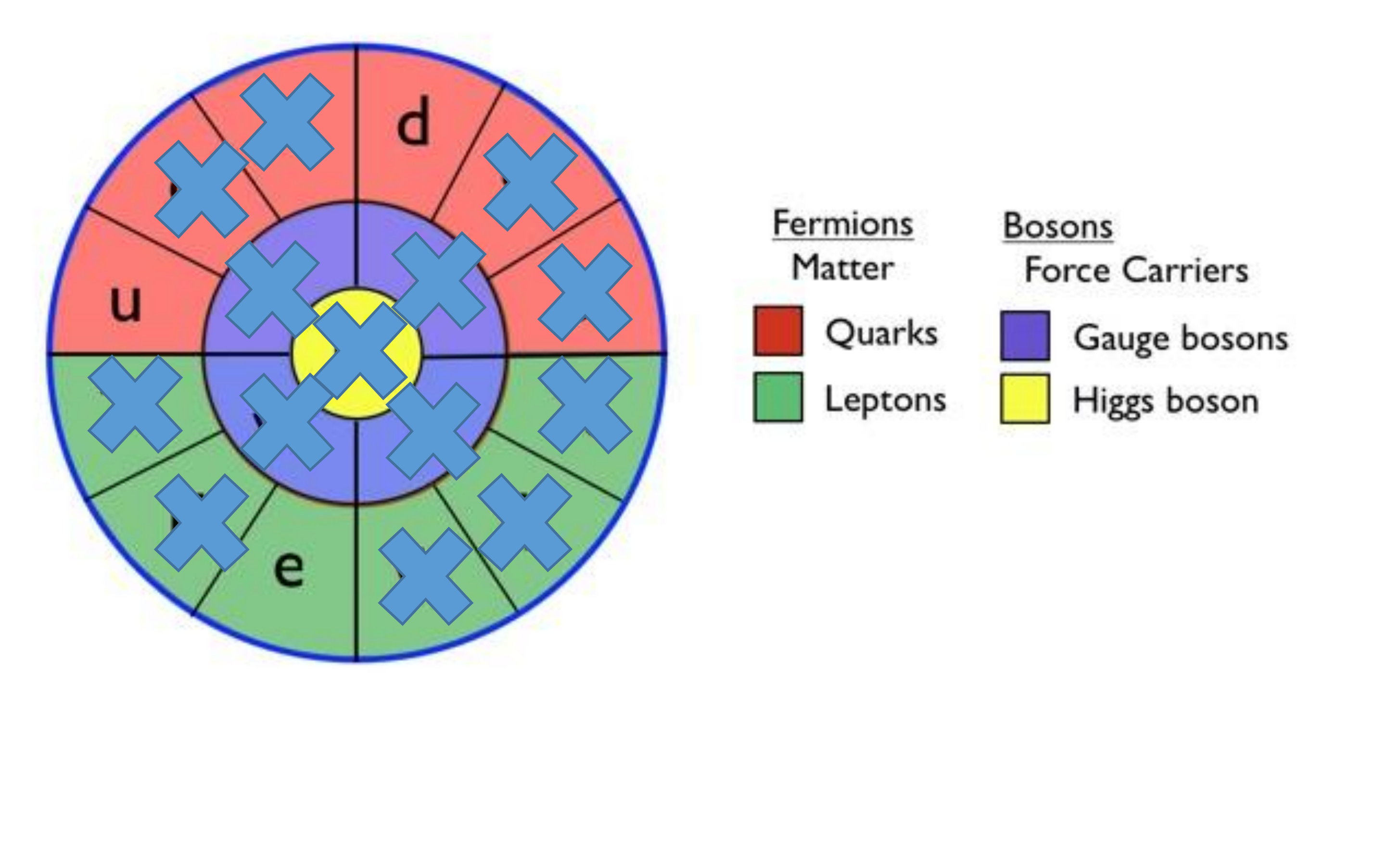

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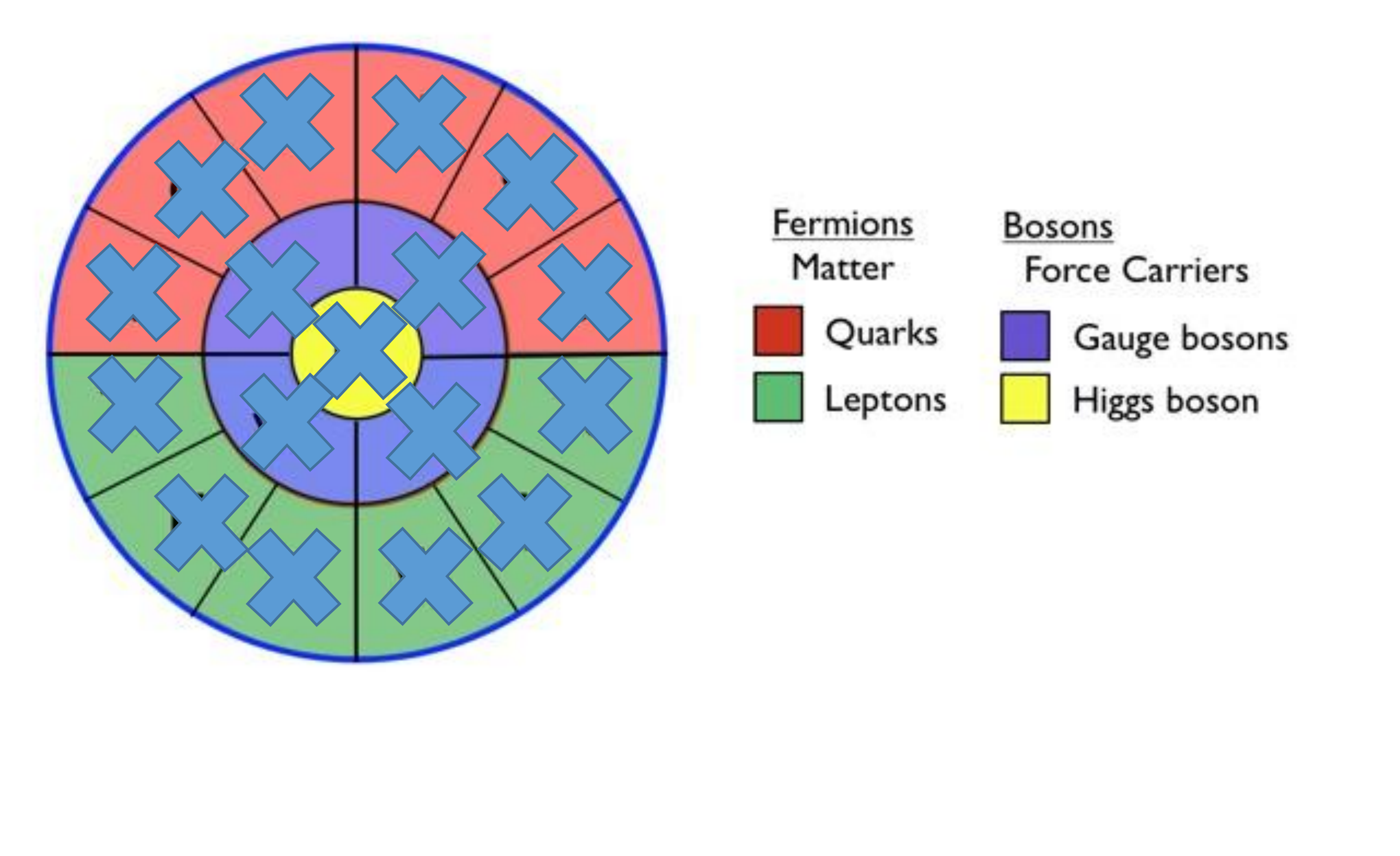

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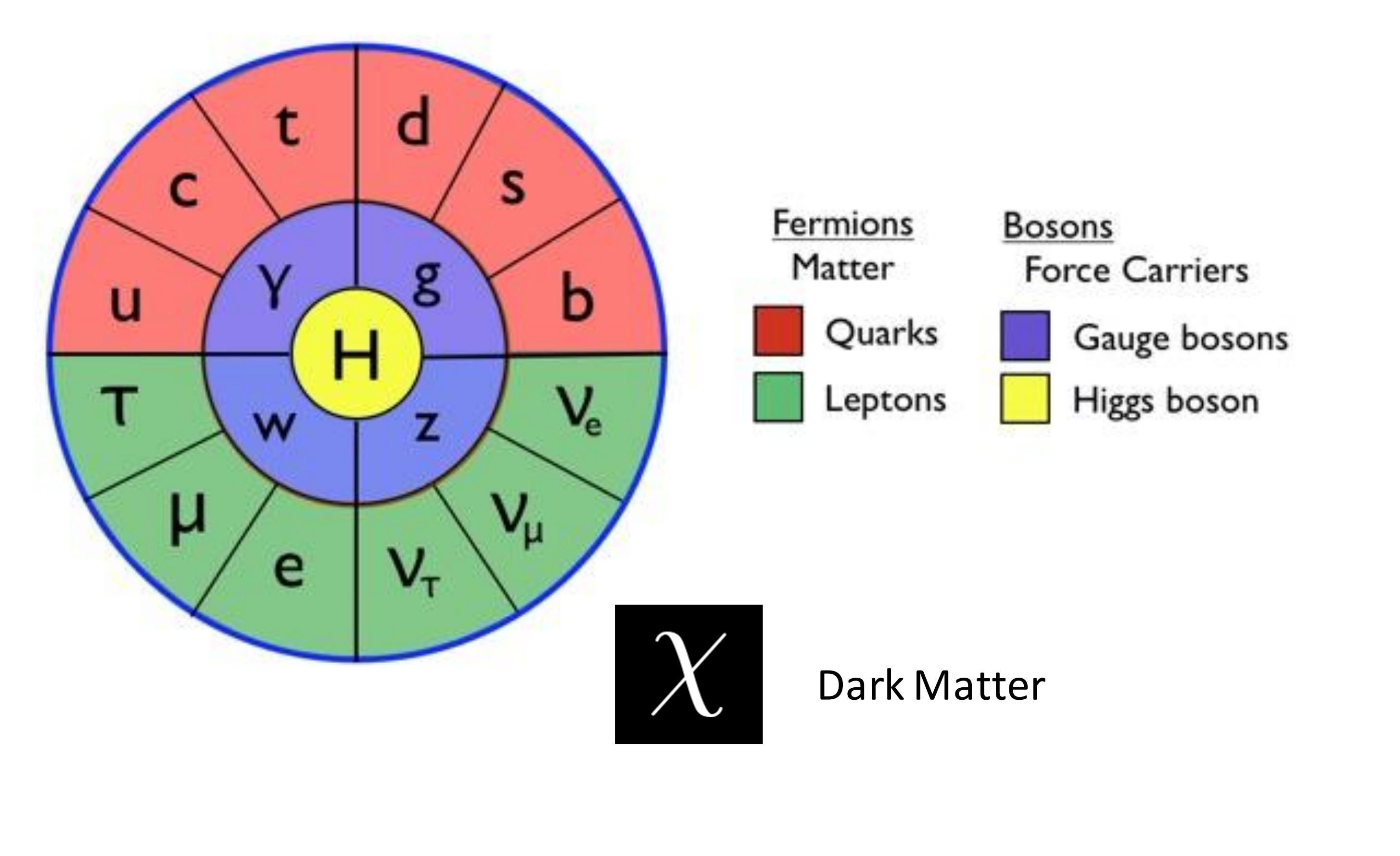
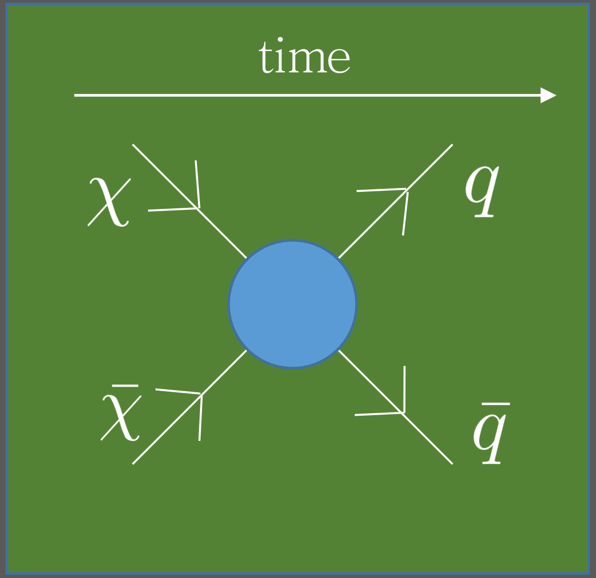


Many Standard Model Extensions couple Dark Matter to Standard Model particles:

$$\mathcal{L} \supset (\bar{\chi}\chi)(\bar{q}q)$$

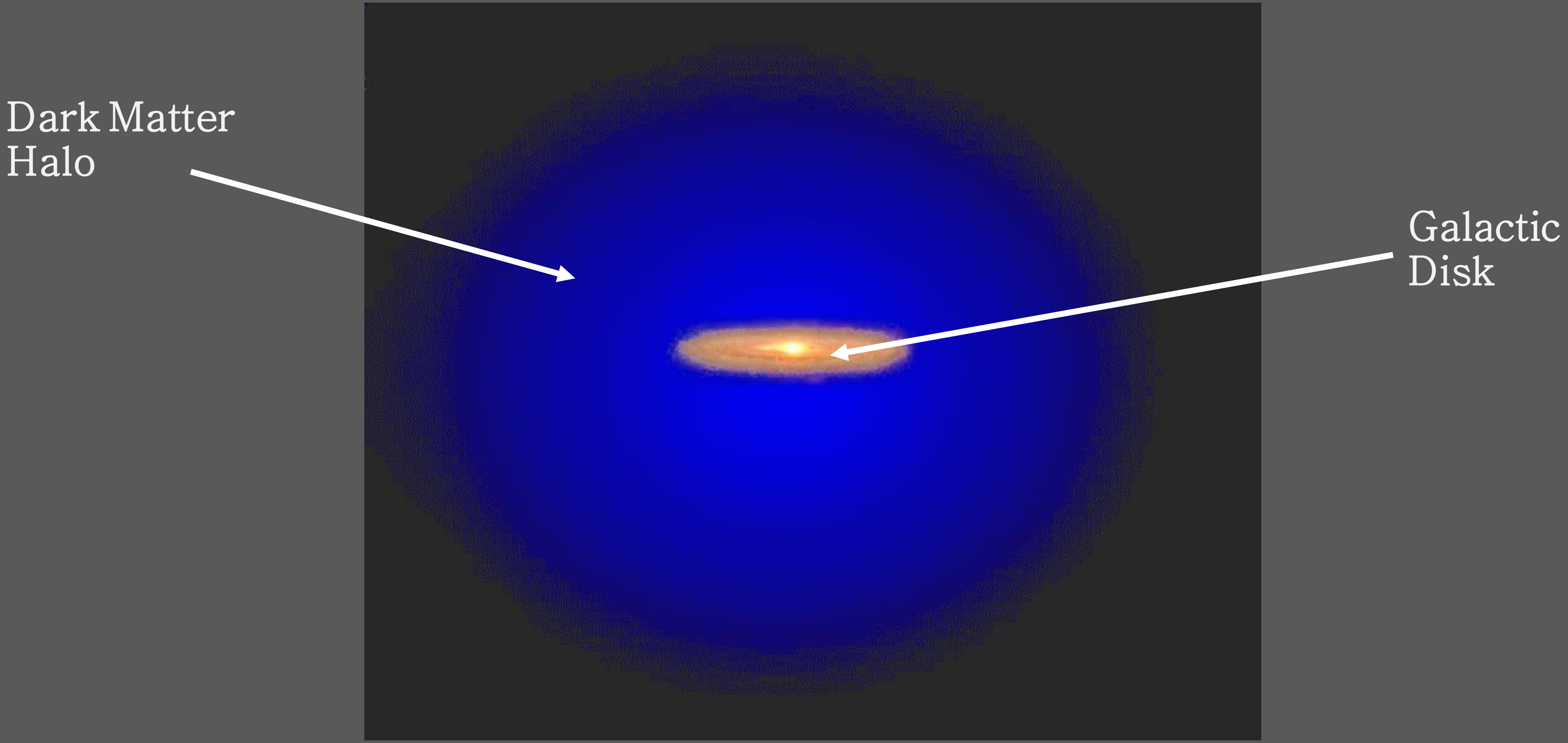
These interactions gives rise to the following reaction:



$$\bar{\chi}\chi \to \bar{q}q$$

Dark Matter
"Annihilation"

Our Galaxy with Dark Matter



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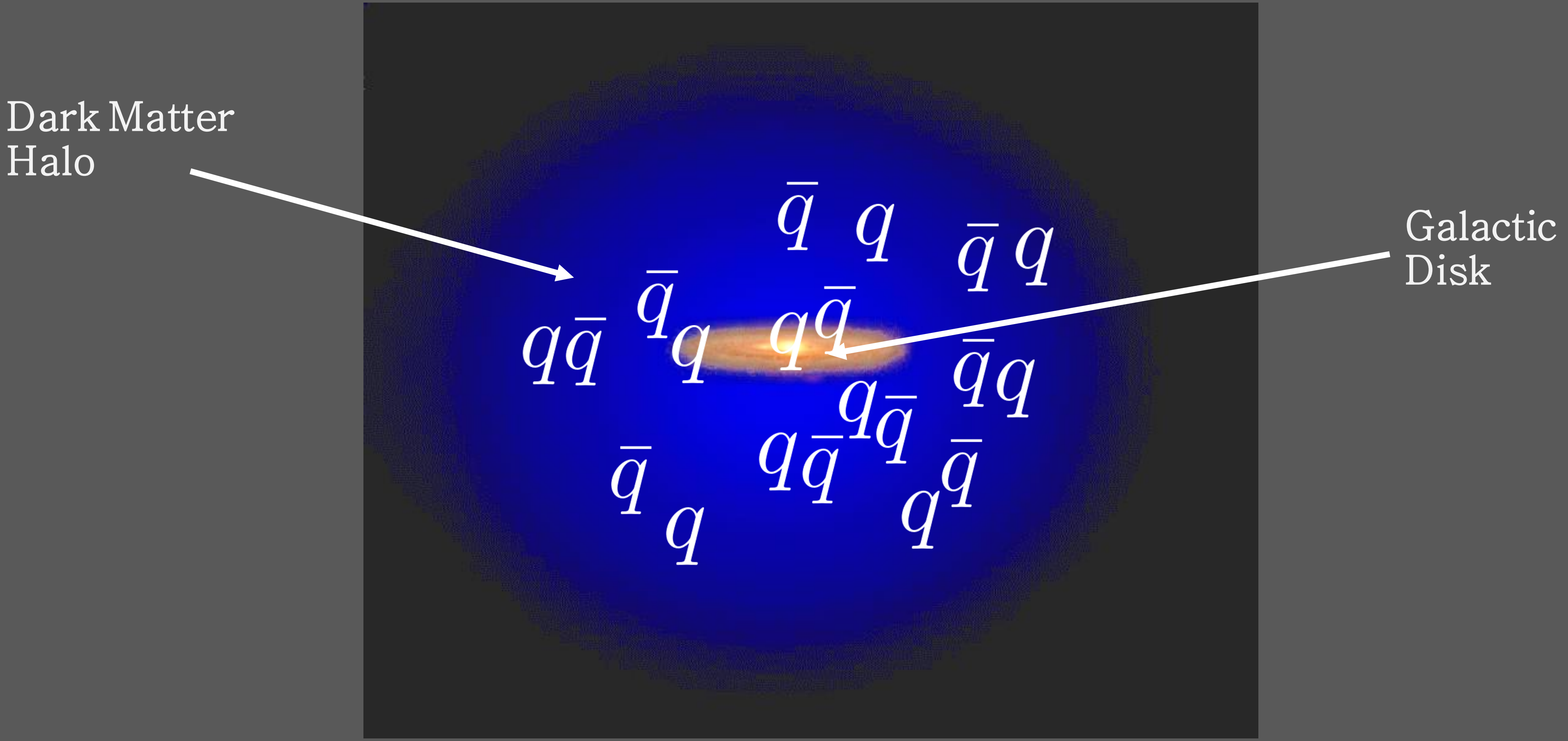


Indirect Dark Matter Detection

Anti-matter is rare in our Universe

- Made by pp collisions in the Galactic Disk (background)

$$p \longrightarrow p \;\Rightarrow\; p \; p \; \bar{p} \; p$$

- Anti-matter could also arise from Dark Matter annihilations

$$\chi \;\; \bar{\chi} \;\Rightarrow\; p \;\; \bar{p}$$

- Measured Anti-protons Cosmic rays are more-or-less predicted by background

Giesen et. al.
arXiv:1504.04276

Antideuterons

- Antideuterons are a bound state of an antiproton and an antineutron

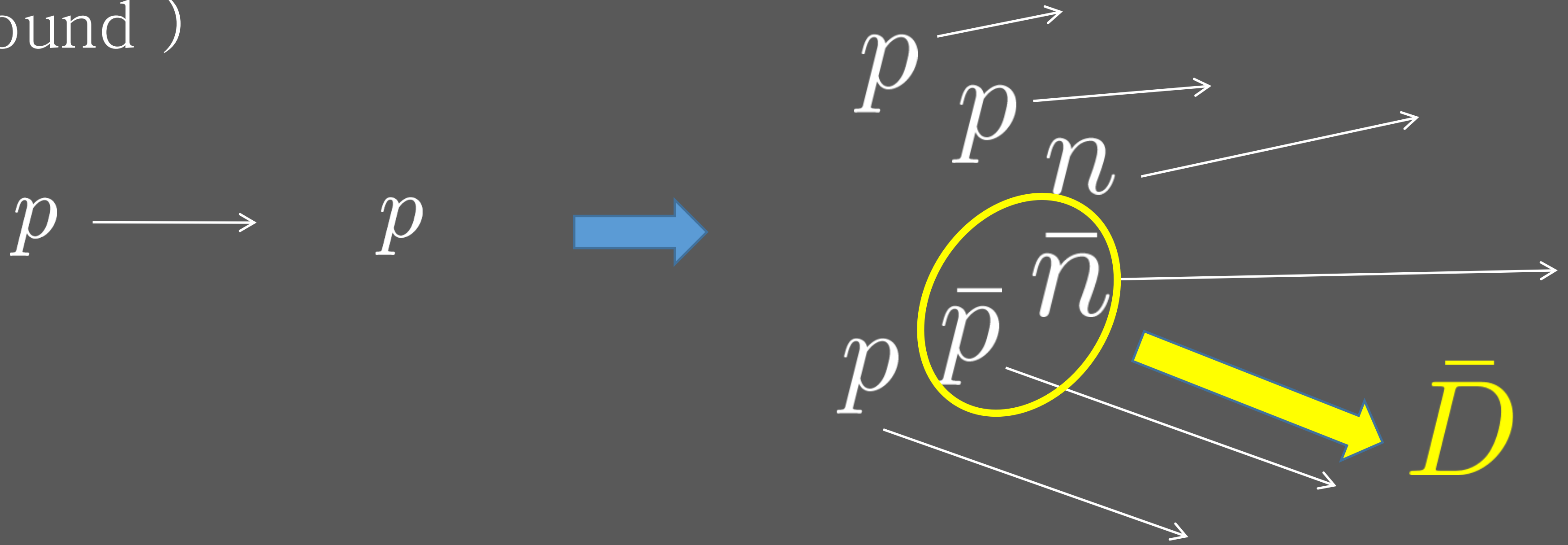
$$\bar{D} = \bar{p}\ \bar{n}$$

- Binding Energy B = 2.2 MeV, but mass is M = 2,000 MeV.

- Antideuterons can’t slow down via elastic scattering.

Astrophysical Antideuterons

- Made by pp collisions in the Galactic Disk （background ）



- Threshold energy of this process is very large: $E_p^{(th)} = 17 m_p$

- Astrophysical $\bar{D}$ move fast: $\gamma = 3$

Antideuterons from Dark Matter

- Dark Matter annihilation produces antideuterons

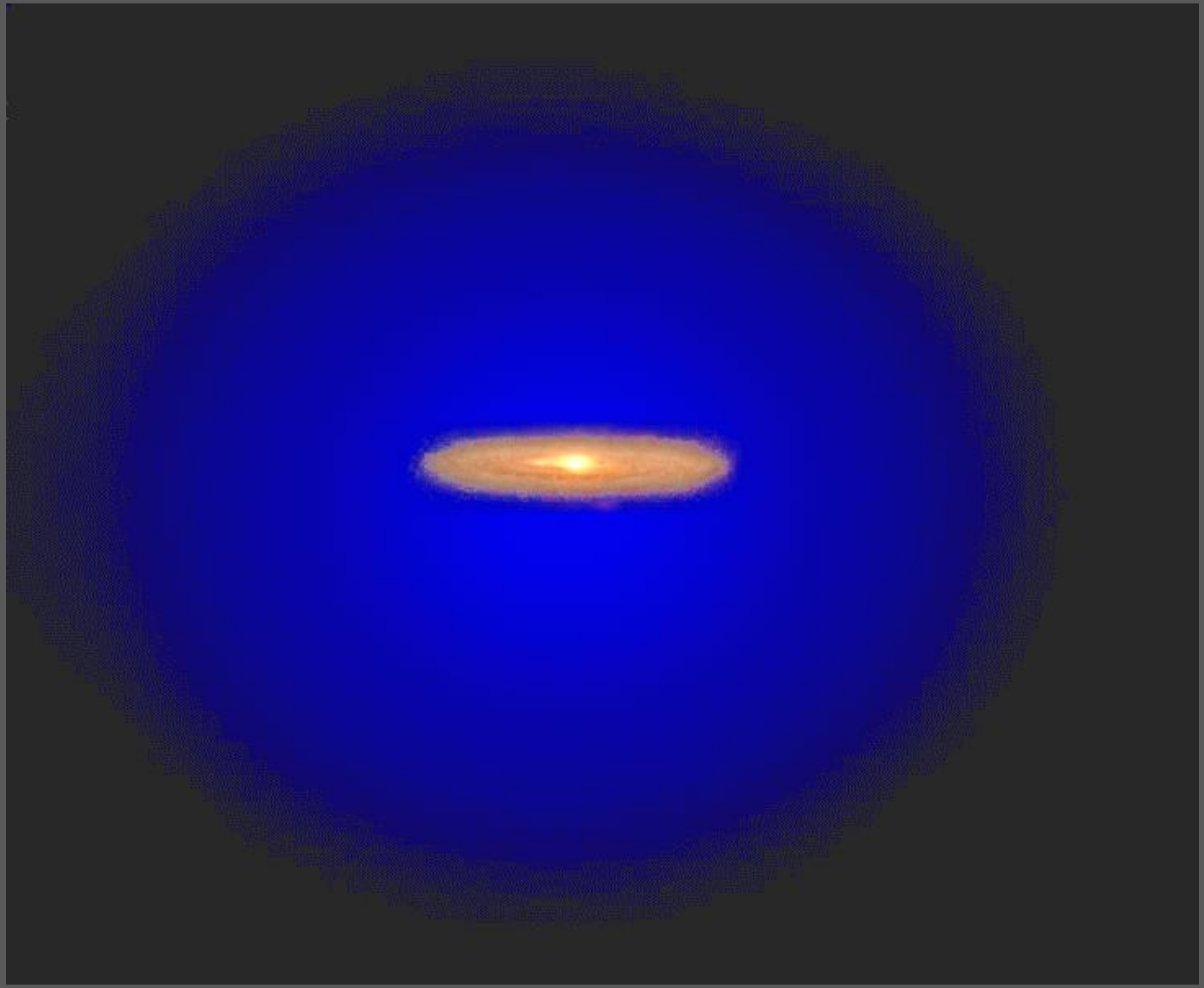
$$\chi \ \bar{\chi} \rightarrow n \ p \ \bar{n} \ \bar{p} \ \bar{D}$$

- Dark Matter sourced antideuterons move slowly (non-relativistic) !

Low energy antideuteron cosmic rays can be produced by Dark Matter and have essentially no conventional Astrophyiscal source.

Donato et. al. arXix:hep-ph/0004481

A Model of our Galaxy with Dark Matter



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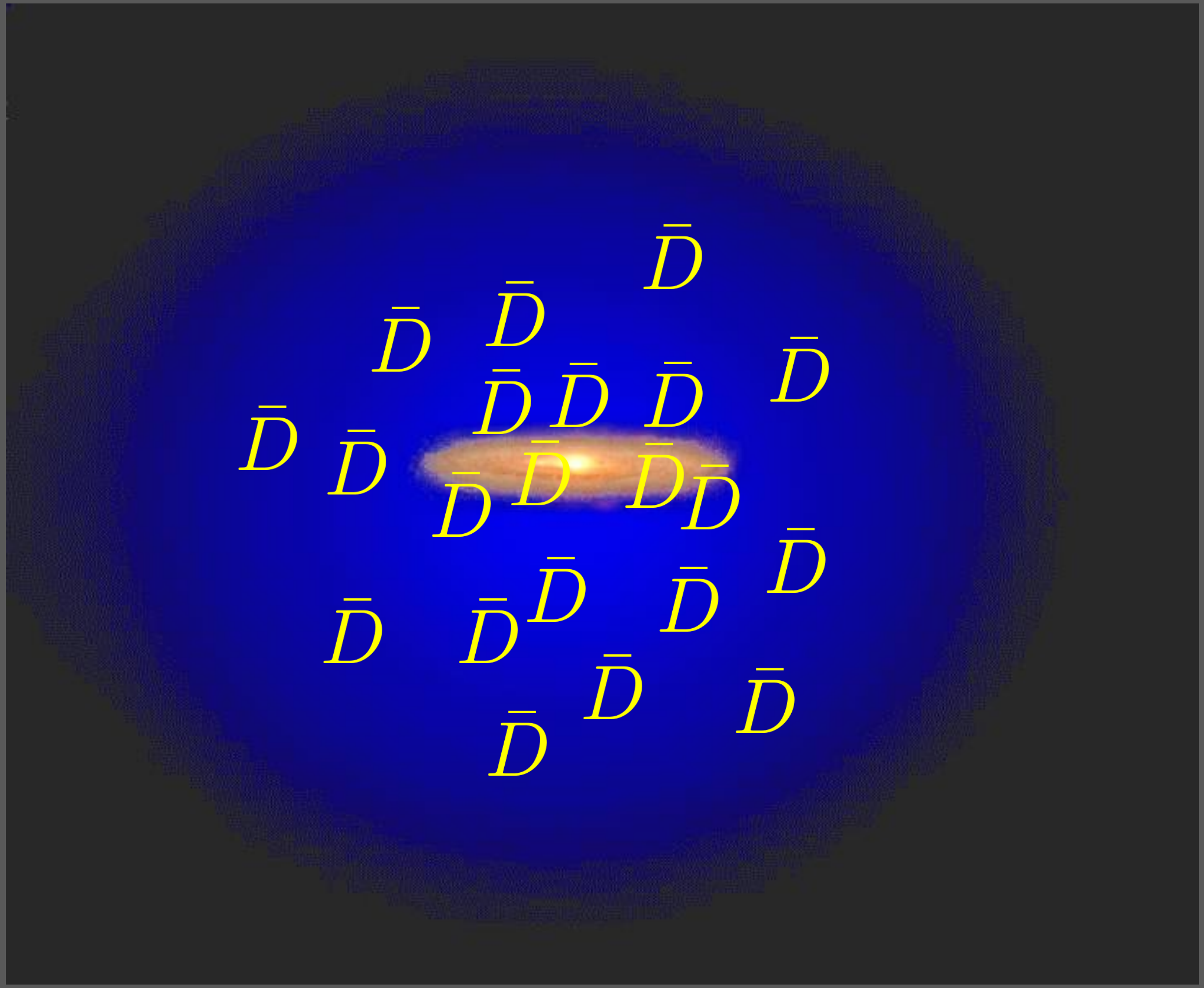
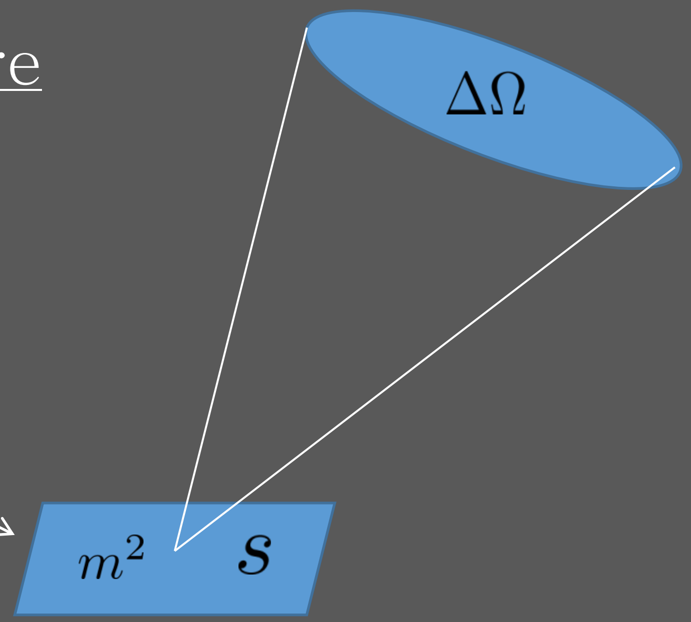


Define the Cosmic Ray "Flux"

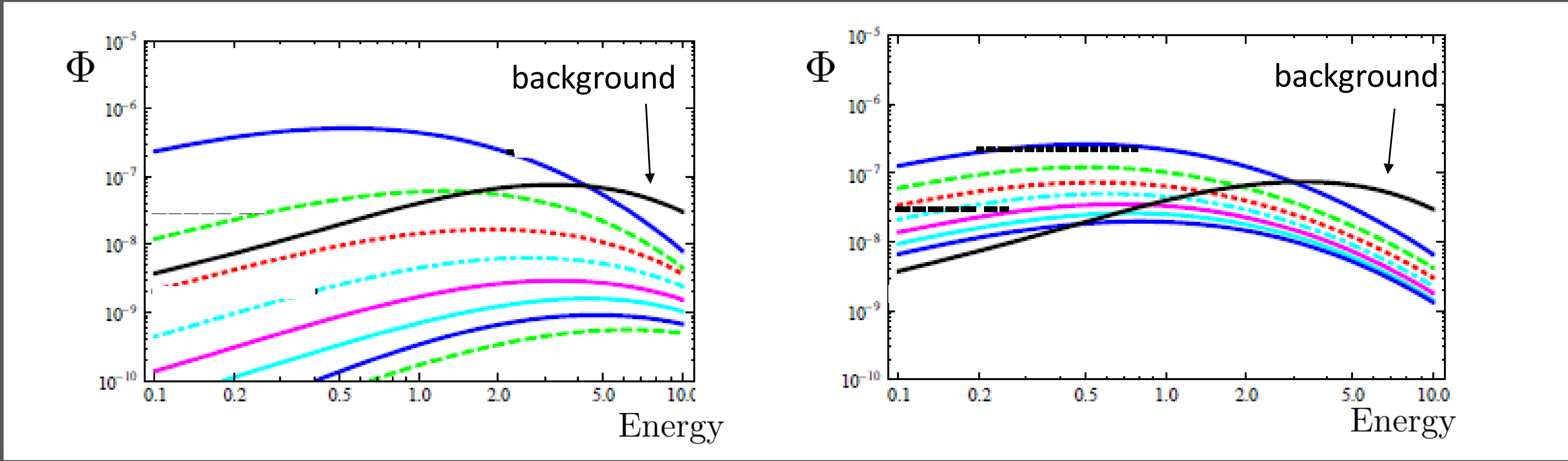
$$\Phi = \frac{Number}{m^2 \ sr \ s \ Gev}$$

Experiments measure this:

- BESS
- ATIC
- PAMELA
- FERMI
- AMS-02
- GAPS



Astrophysical Antideuterons vs. Dark Matter Antideuterons



WW

tt

$$m_{DM} = (\text{thresh}, \ldots, 1000\ \text{GeV})$$

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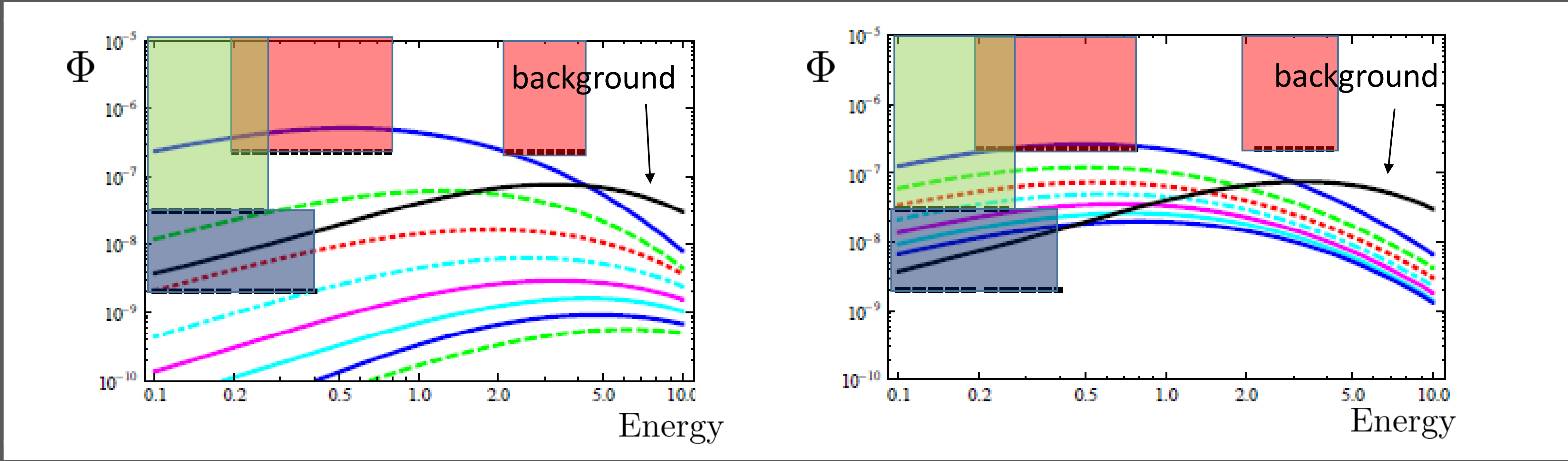

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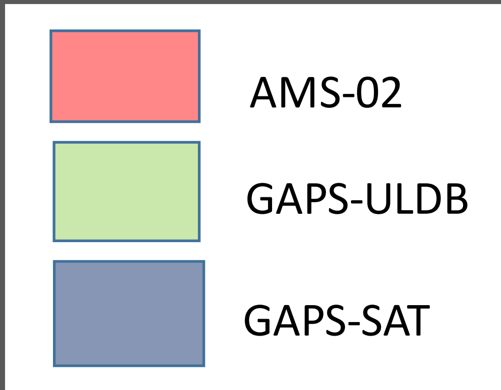

Experimental Status

Current Bound

$$\Phi_{\bar{D}} < 0.95 \times 10^{-4} [m^2 \; s \; sr \; \text{GeV}]^{-1} \quad 0.17 \leq T/n \leq 1.15 \text{ (GeV/n)} \quad \text{BESS}$$

Future Sensitivities 3–4 orders of magnitude improvement

$$\Phi_{\bar{D}} = 2.25 \times 10^{-7} [m^2 \; s \; sr \; \text{GeV}]^{-1} \quad 0.2 \leq T/n \leq 0.8 \text{ (GeV/n)} \quad \text{AMS} - 02,$$

$$\Phi_{\bar{D}} = 2.25 \times 10^{-7} [m^2 \; s \; sr \; \text{GeV}]^{-1} \quad 2.2 \leq T/n \leq 4.2 \text{ (GeV/n)} \quad \text{AMS} - 02,$$

$$\Phi_{\bar{D}} = 1.5 \times 10^{-7} [m^2 \; s \; sr \; \text{GeV}]^{-1} \quad 0.1 \leq T/n \leq 0.2 \text{ (GeV/n)} \quad \text{GAPS(LDB)}$$

$$\Phi_{\bar{D}} = 3.0 \times 10^{-8} [m^2 \; s \; sr \; \text{GeV}]^{-1} \quad 0.05 \leq T/n \leq 0.25 \text{ (GeV/n)} \quad \text{GAPS(ULDB)}$$

$$\Phi_{\bar{D}} \sim 2.6 \times 10^{-9} [m^2 \; s \; sr \; \text{GeV}]^{-1} \quad 0.1 \leq T/n \leq 0.4 \text{ (GeV/n)} \quad \text{GAPS(SAT)}.$$

Experimental Status

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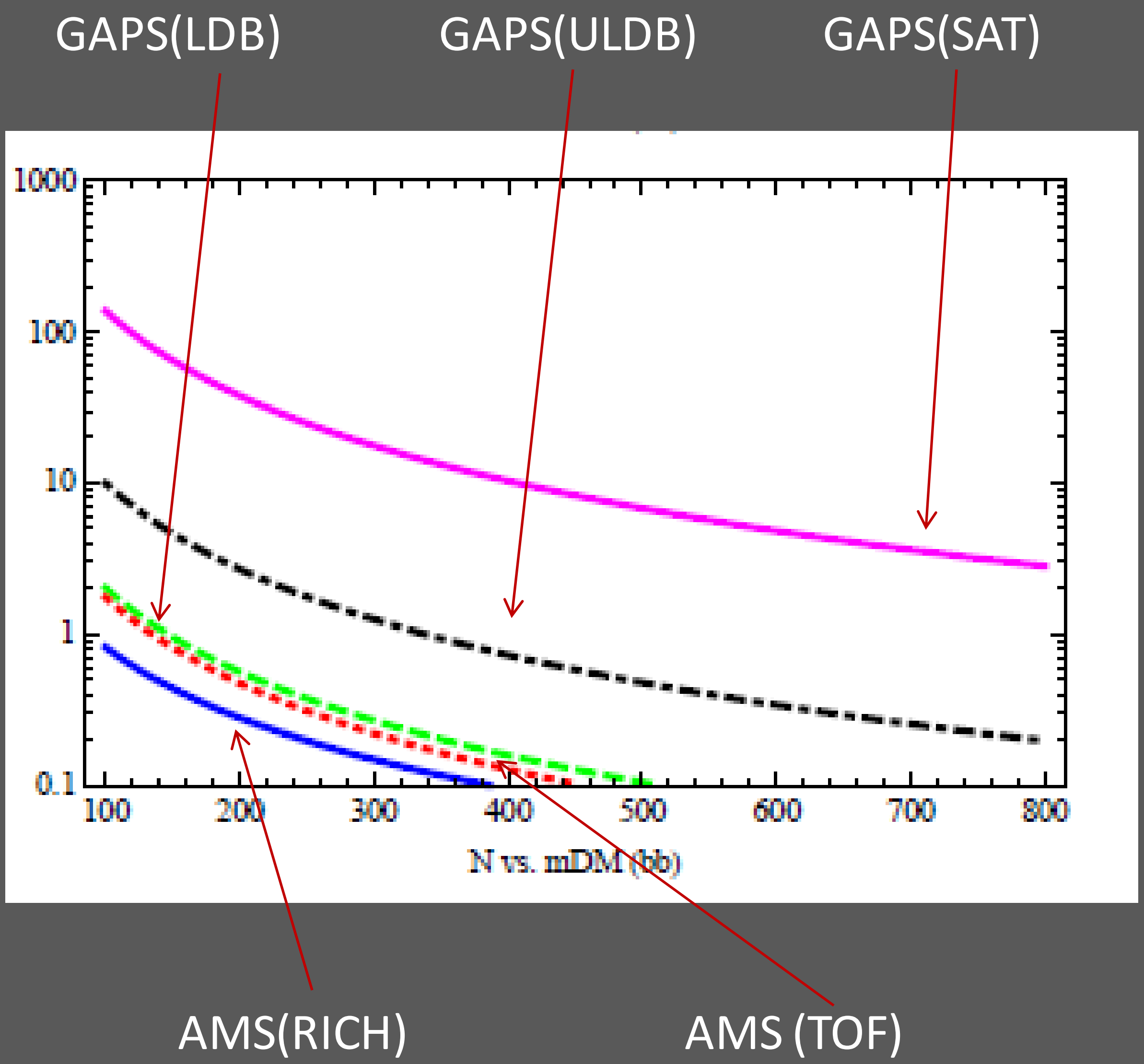


GAPS(LDB)
GAPS(ULDB)
GAPS(SAT)
1000
100
10
1
0.1
100
200
300
400
500
600
700
800
N vs. mDM (bb)
AMS(RICH)
AMS (TOF)

Mass Reach via Antideuteron Cosmic Rays

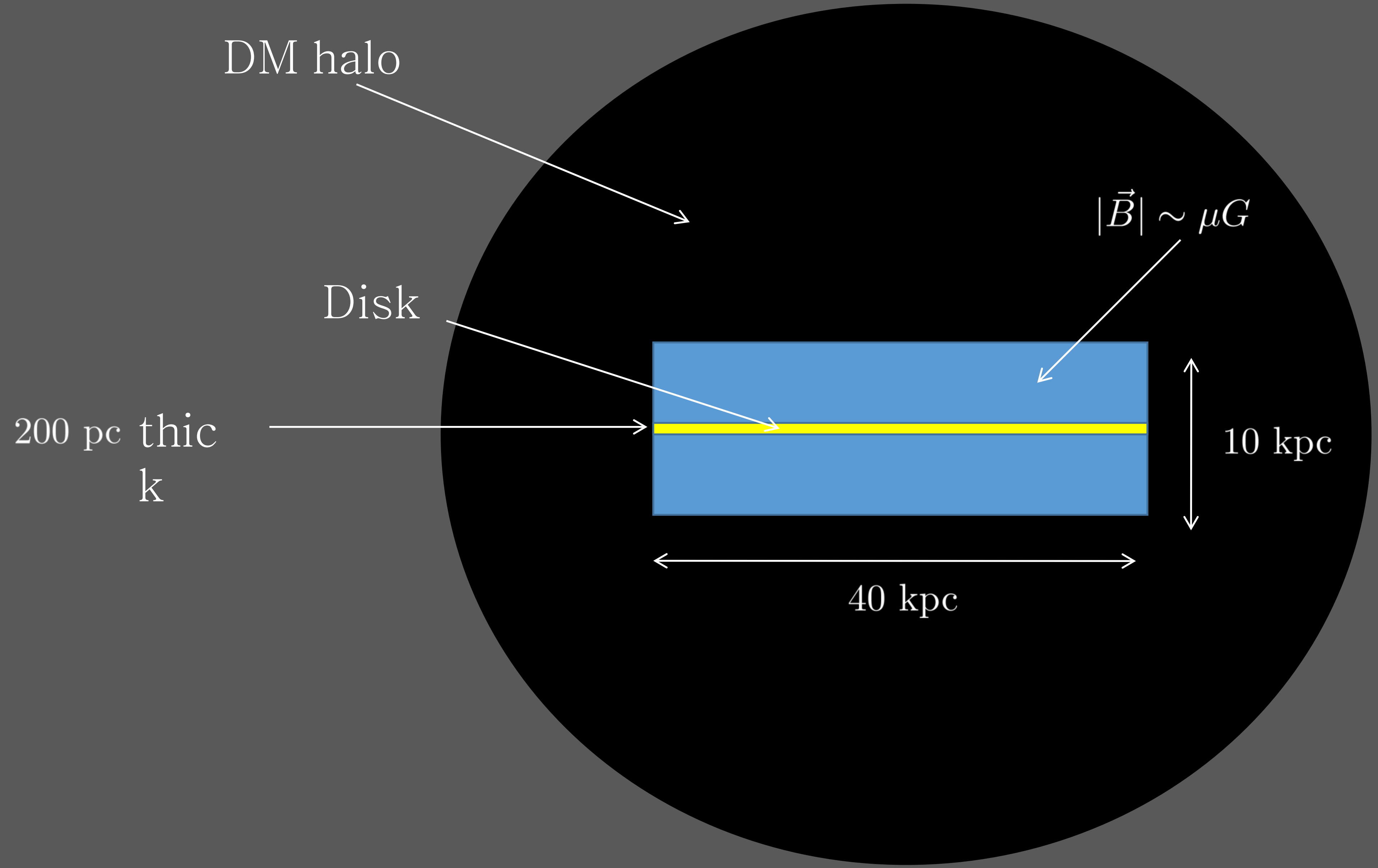
Experiment	$\bar{q}q$	$\bar{t}t$	h^0h^0	gg	W^+W^-	N_{crit}
AMS-02 high (3σ)	50	$< m_t$	$< m_h$	100	$< m_W$	3
AMS-02 low (3σ)	100	$< m_t$	$< m_h$	200	100	2
GAPS (LDB) (3σ)	140	200	140	300	120	1
GAPS (ULDB) (3σ)	250	400	250	500	160	2
GAPS (SAT) (3σ)	500	700	500	900	240	10
AMS-02 high (5σ)	30	$< m_t$	$< m_h$	60	$< m_W$	6
AMS-02 low (5σ)	70	$< m_t$	$< m_h$	140	$< m_W$	4
GAPS (LDB) (5σ)	75	$< m_t$	$< m_h$	150	$< m_W$	3
GAPS (ULDB) (5σ)	150	220	150	300	120	5
GAPS (SAT) (5σ)	360	550	300	670	200	16

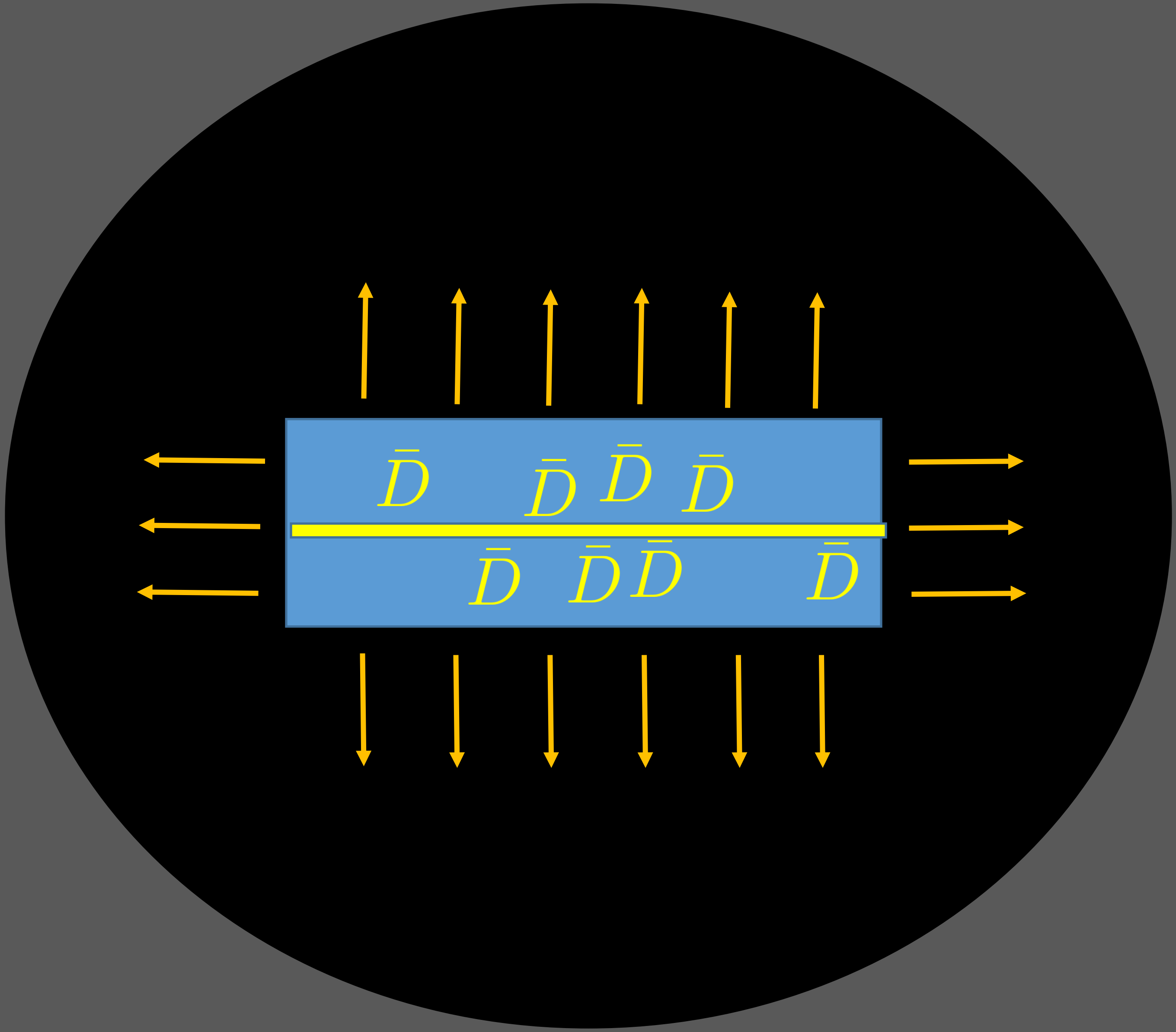
Summary of Antideuterons

- Antideuterons are the most sensitive indirect probe of DM annihilations to hadrons.
- AMS-02 and GAPS (ULDB) will make a giant leap in sensitivity to antideuteron cosmic rays and will have implications for Dark Matter up to 400 GeV mass scale
- GAPS (SAT) would be sensitive to Dark Matter masses of 500 GeV w/ significant antideuteron detection.

Thank You!

A Model of our Galaxy with Dark Matter





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