Title: Signals of asymmetric dark matter from galactic center pulsar implosions

Date: Jan 20, 2015 01:00 PM

URL: http://pirsa.org/15010116

Abstract: <p>If dark matter is asymmetric, fermionic, and self-interacting, it may form black holes in pulsars at the galactic center. In this case, a measurable maximum attainable pulsar age would track the density of the dark matter halo, with the oldest pulsars being allowed in the least dense parts of the halo. This could explain a recent observation, that there are not as many pulsars in the galactic center as expected.</p>

Detecting dark matter with imploding pulsars in the galactic center

Joseph Bramante

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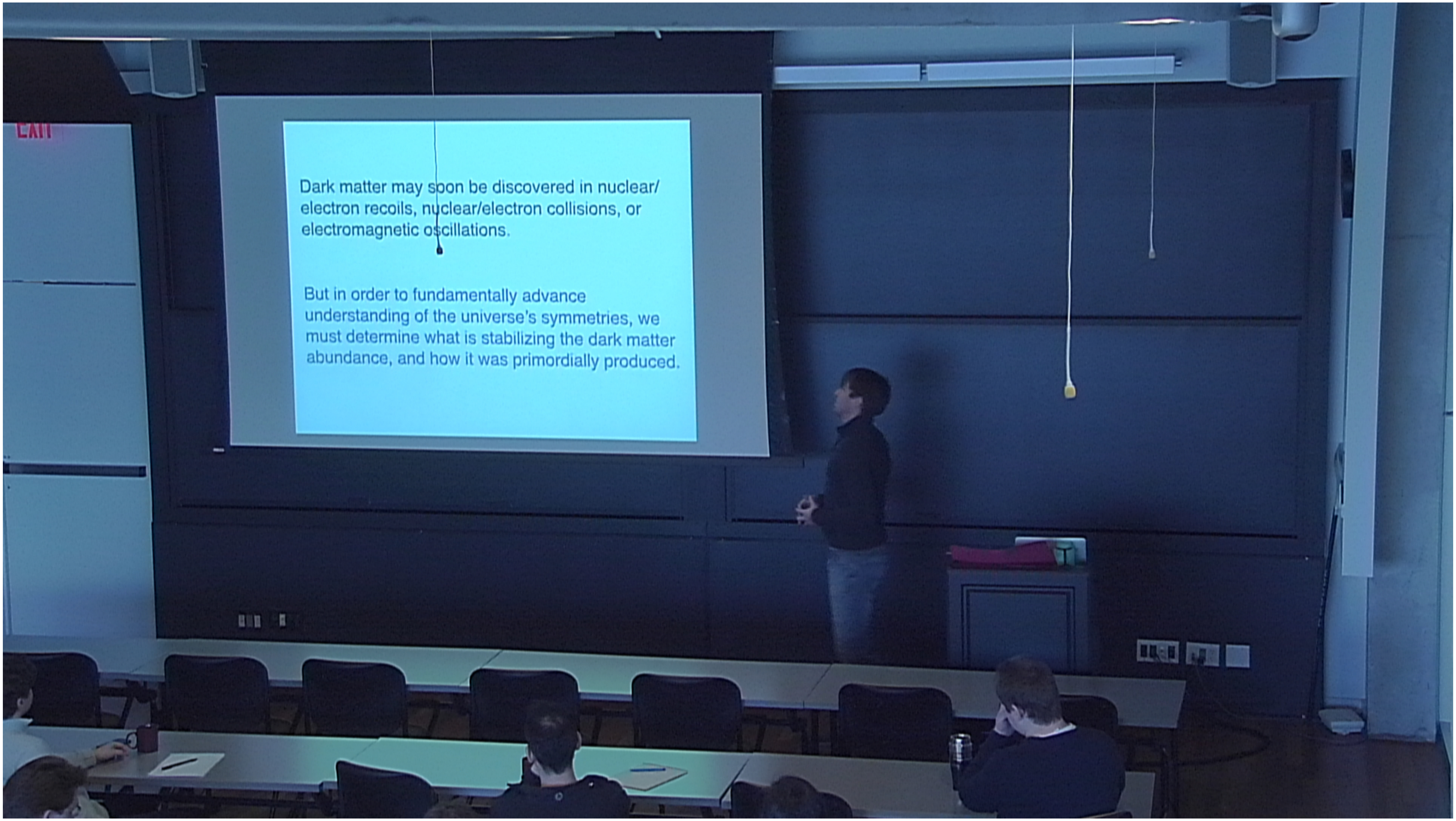
But in order to fundamentally advance understanding of the universe's symmetries, we must determine what is stabilizing the dark matter abundance, and how it was primordially produced.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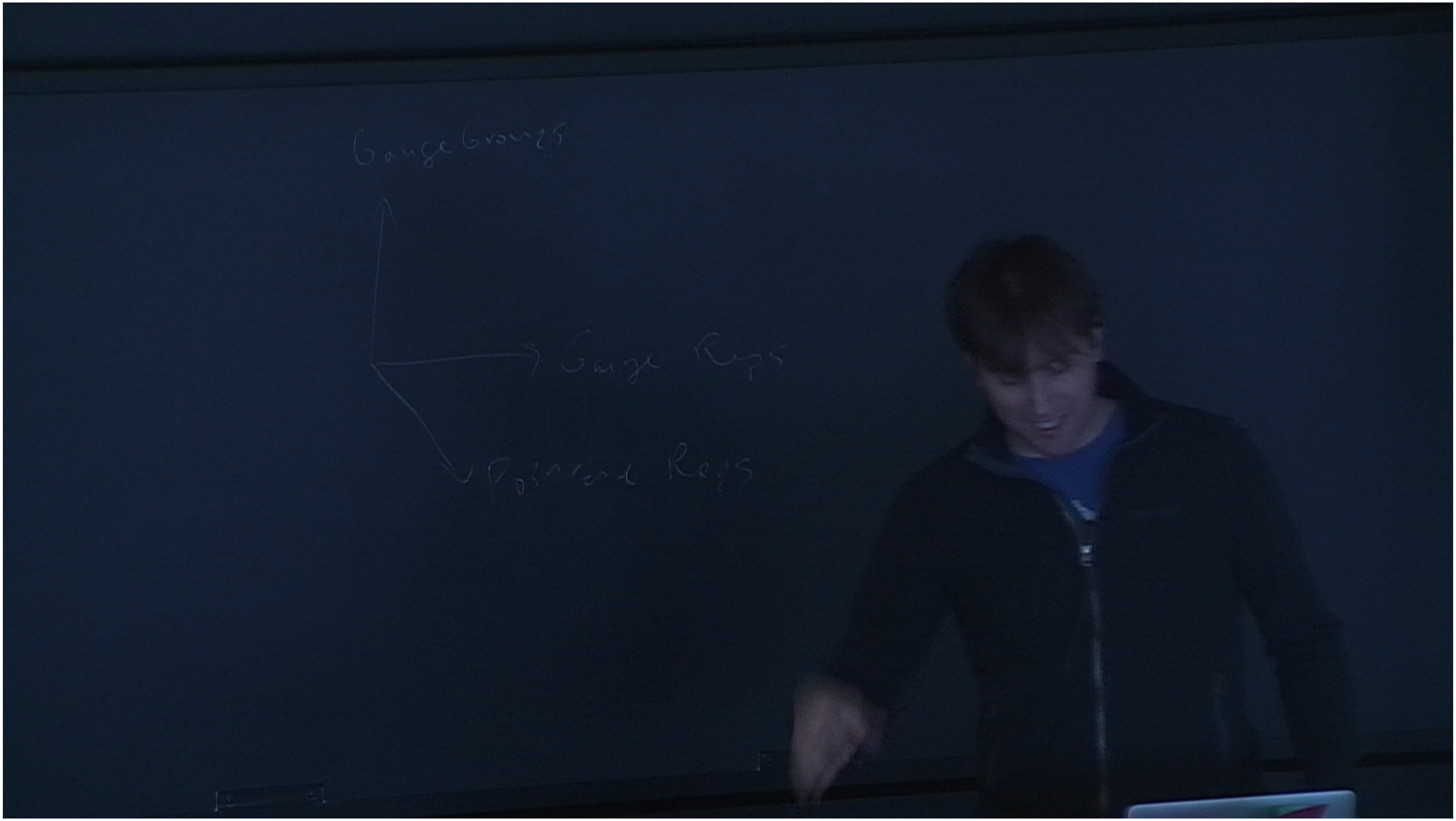
Gauge Groups
Gauge Reps
Poincaré Reps

The hardest task will be to identify and categorize the interactions dark matter may have with other dark particles. There are many possible handles on this — the collision of galaxies in bullet clusters, the inferred velocity dispersion of dwarf, spiral, and elliptic halos, and acoustic oscillations in and the normalization of the primordial power spectrum.

Asymmetric dark matter models suppose that dark matter in the halo, like ordinary matter in the halo, is composed of particles and *not antiparticles* charged under a continuous symmetry. This asymmetric abundance precludes X-X (as opposed to X*-X) annihilations.

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In a very futuristic setting, the interactions (C,CP violating) that lead to a dark asymmetry might be revealed through something like a pulsed collider + kamioka program.

In this talk I will show that, on a much shorter timescale, old pulsars in the galactic center imploding into black holes could be a signal of asymmetric dark matter. This signal relies on the fact that annihilating dark matter cannot copiously collect in pulsars to form black holes.

A neutron star is a ball of fermions formed from the supernova of a 10 solar mass progenitor star.

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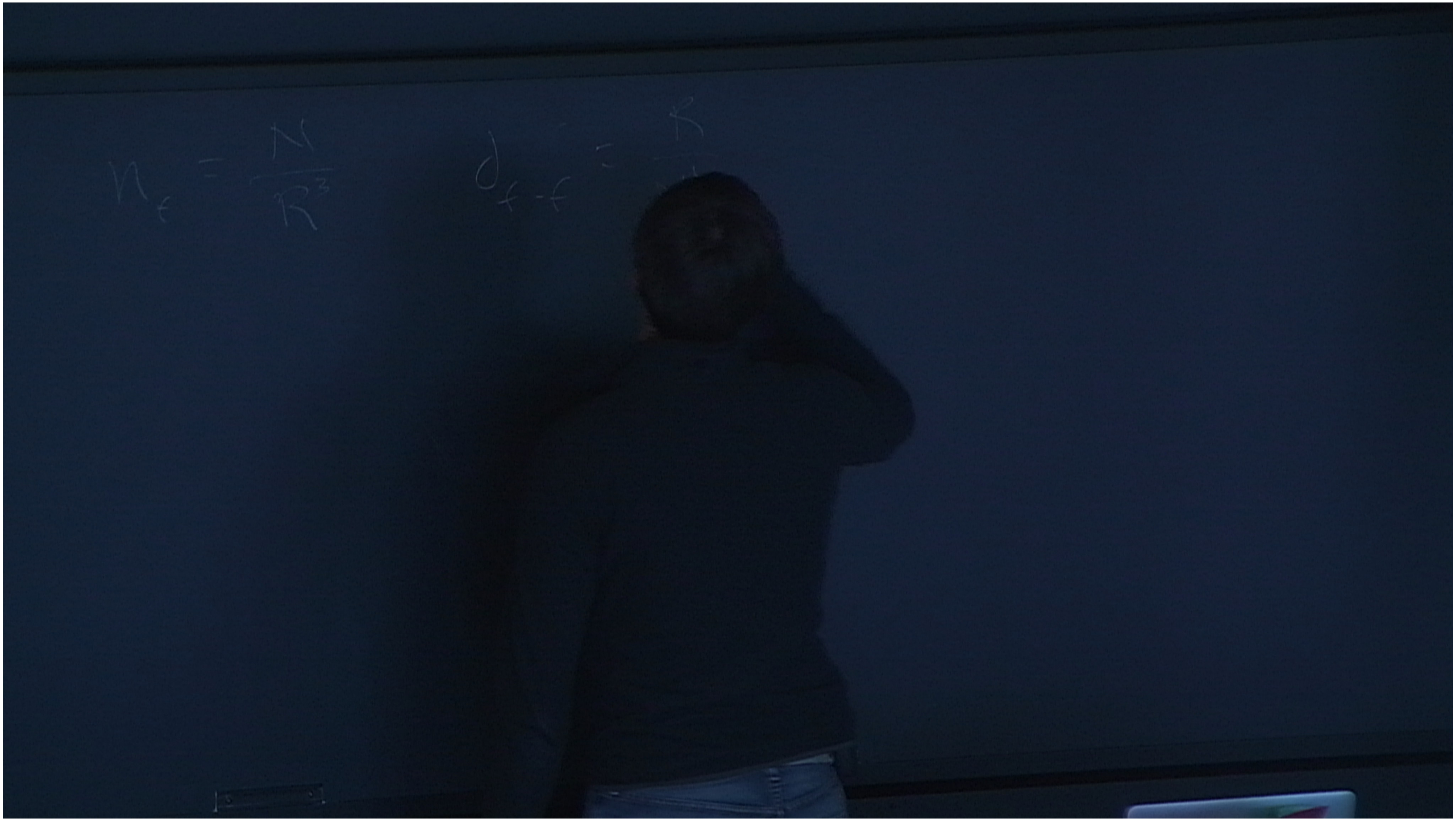
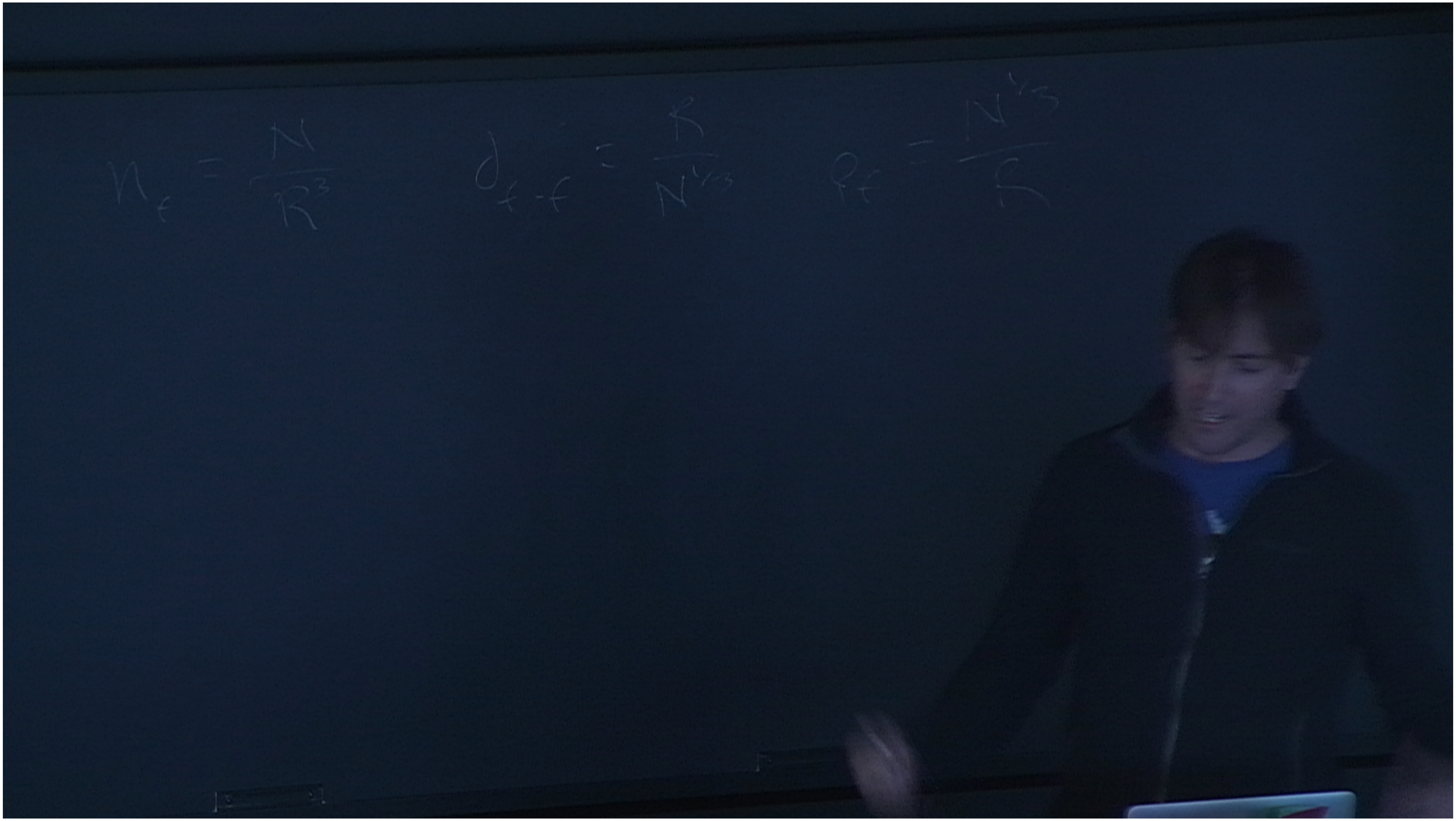
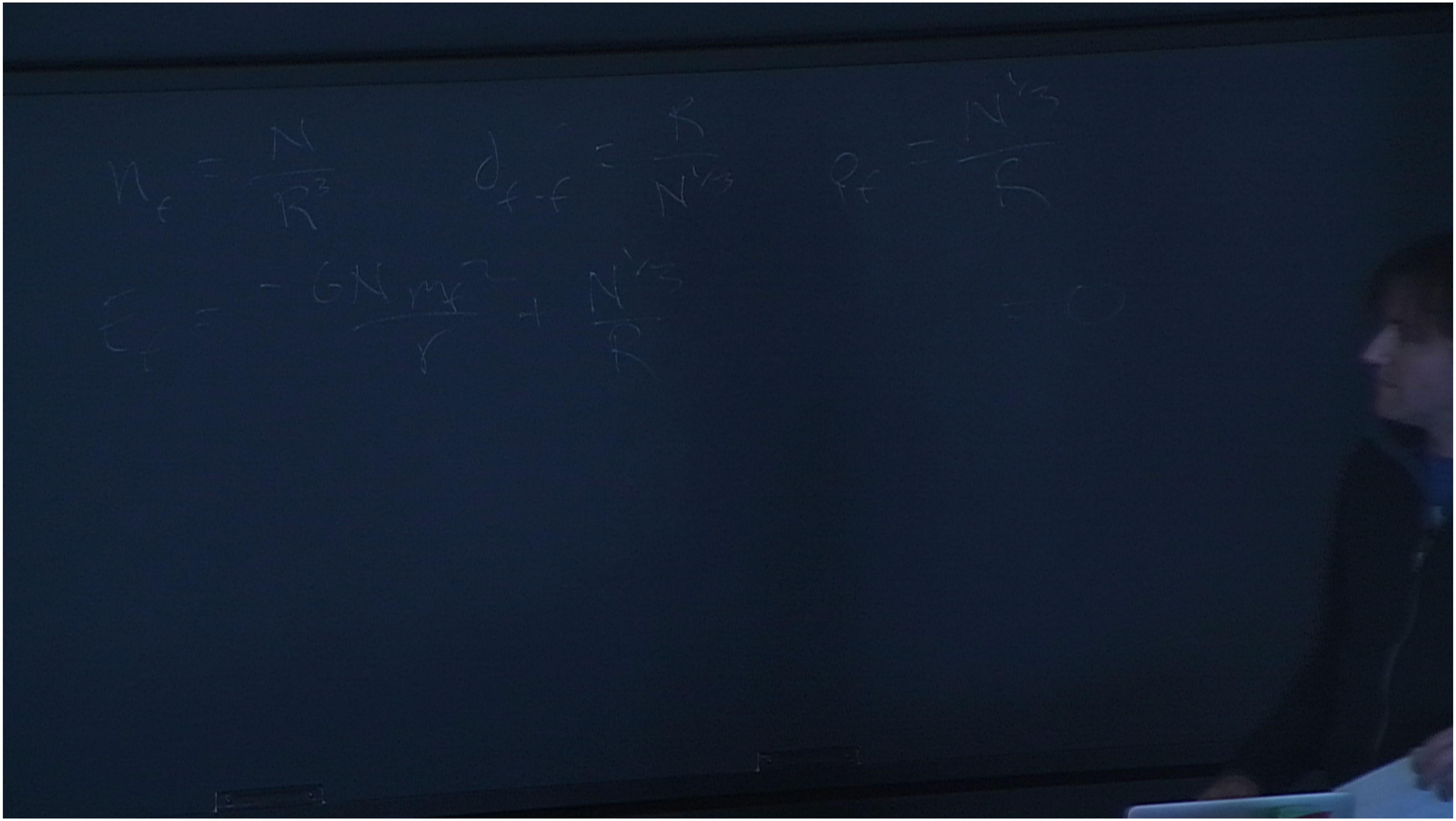

n_f = N / R^3


$n_f = \frac{N}{R^3}$
$d_{f-f} = \frac{R}{N^{1/3}}$
$\rho_f = \frac{N^{1/3}}{R}$


n_f = N / R^3
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ρ_f = N^{1/3} / R
E_f = - G N m_f^2 / r + N^{1/3} / R = 0

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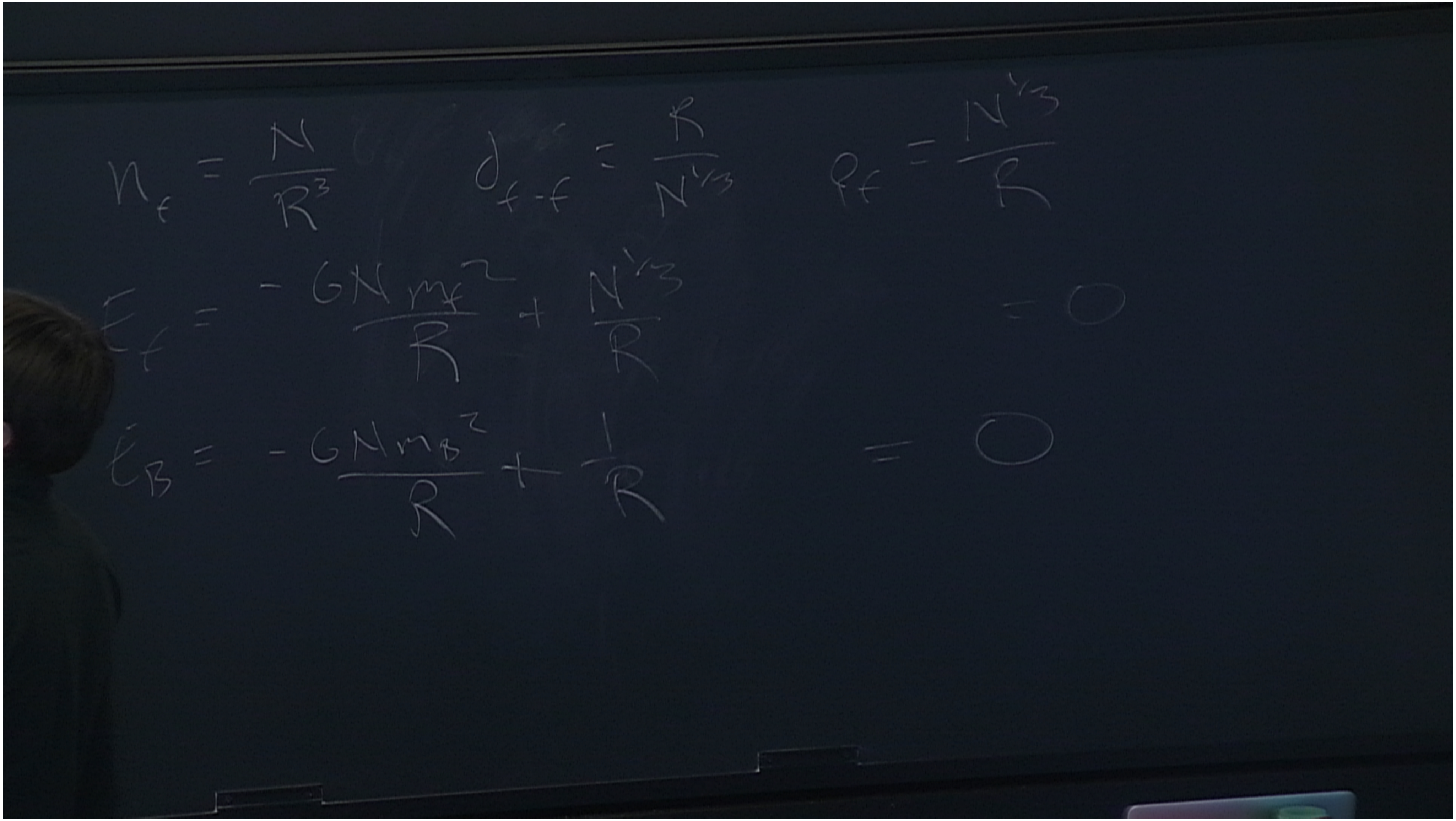
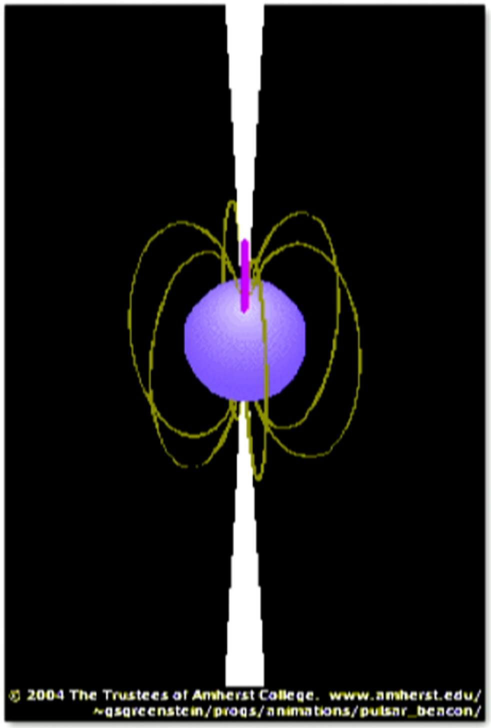
The bound above can be compared to the same limit on a ball of bosons.

$$N_b = \frac{m_{pl}^2}{m_X^2}$$


$n_f = \frac{N}{R^3}$ $d_{f-f} = \frac{R}{N^{1/3}}$ $p_f = \frac{N^{1/3}}{R}$
$E_f = -\frac{G N m_f^2}{R} + \frac{N^{1/3}}{R} = 0$
$E_B = -\frac{G N m_B^2}{R} + \frac{1}{R} = 0$

A pulsar is a spinning neutron star, observed as a regularly radiating revolving magnetic dipole.



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How old is it?

P

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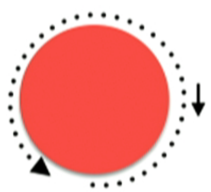

$\dot{P}$

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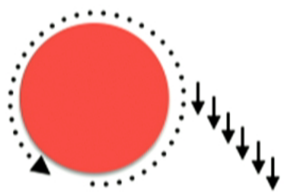

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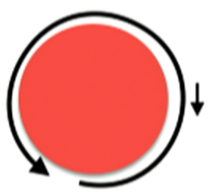

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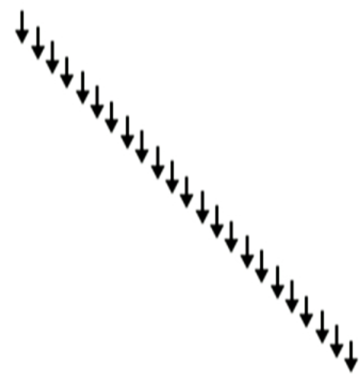

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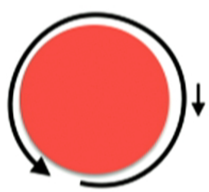
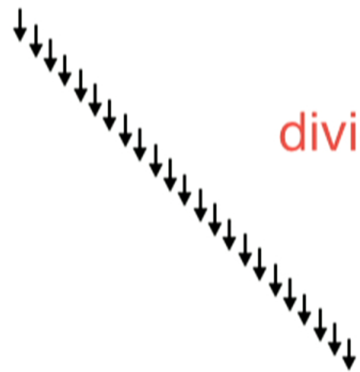
$$t_{NS} = \frac{\mathrm{P}}{2\dot{\mathrm{P}}}$$



$\dot{\mathrm{P}}$



divided by 

Now we know how old pulsars are, and that either Heisenberg or Fermi pressure stabilizes compact matter.

We can now discuss pulsar-destroying black holes formed from dark matter collected in pulsars.

1] DM captured

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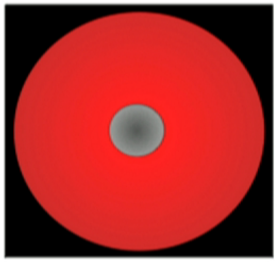
$$C_X \propto \frac{\rho_X}{\bar{v}} \sigma_{nX}$$

1] DM captured

2] DM thermalizes



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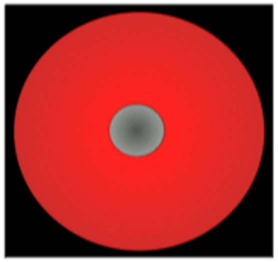

Bertoni, Nelson, Reddy 1309.1721

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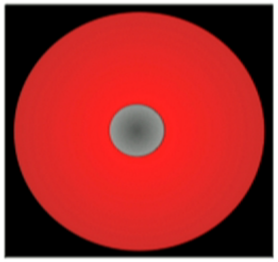

3] DM **collapses**

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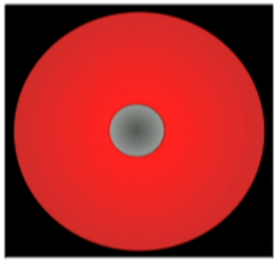

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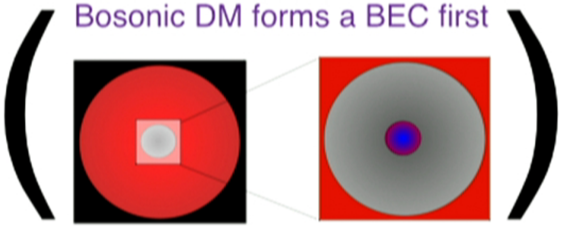
(Bosonic DM forms a BEC first)



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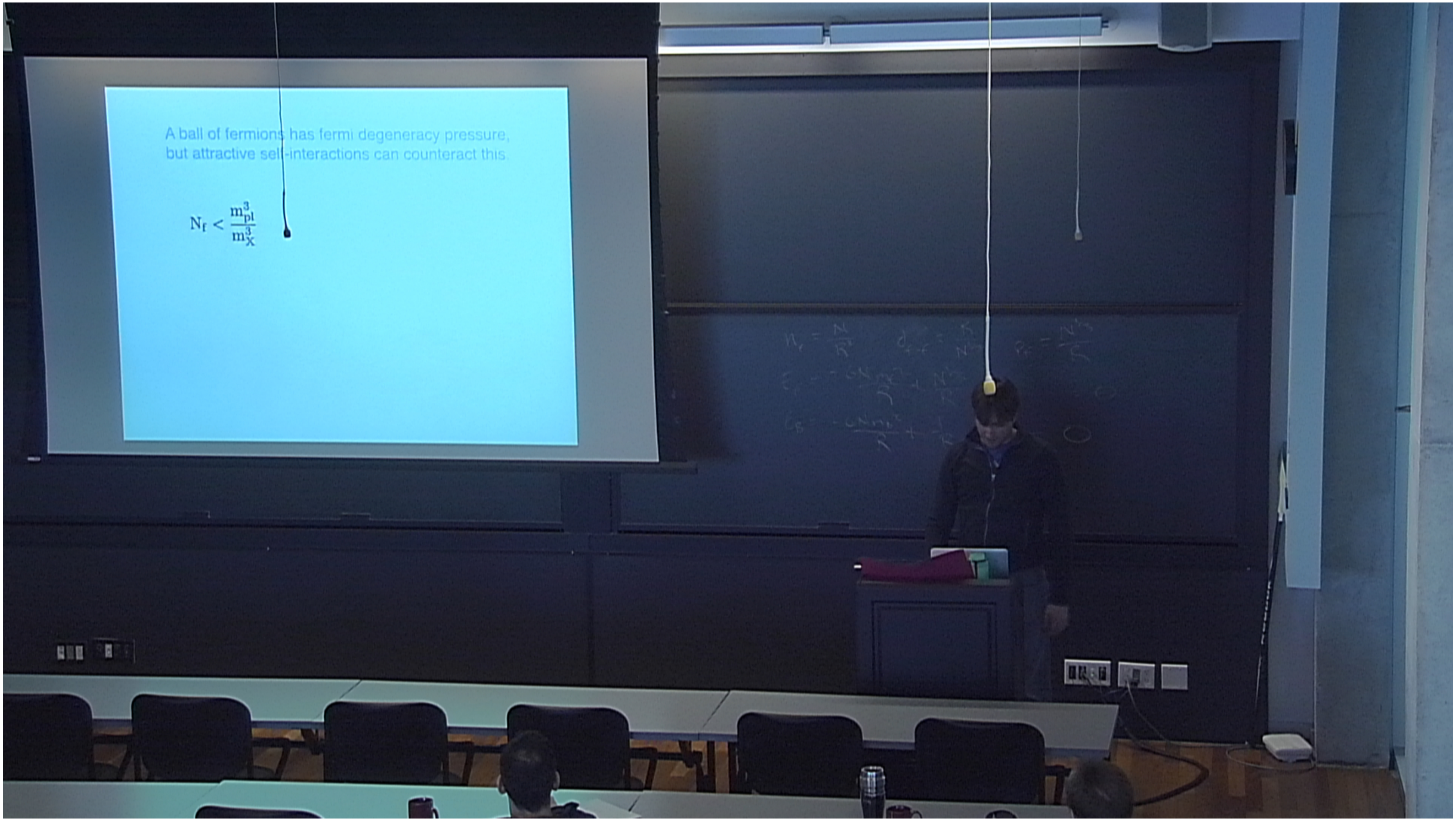
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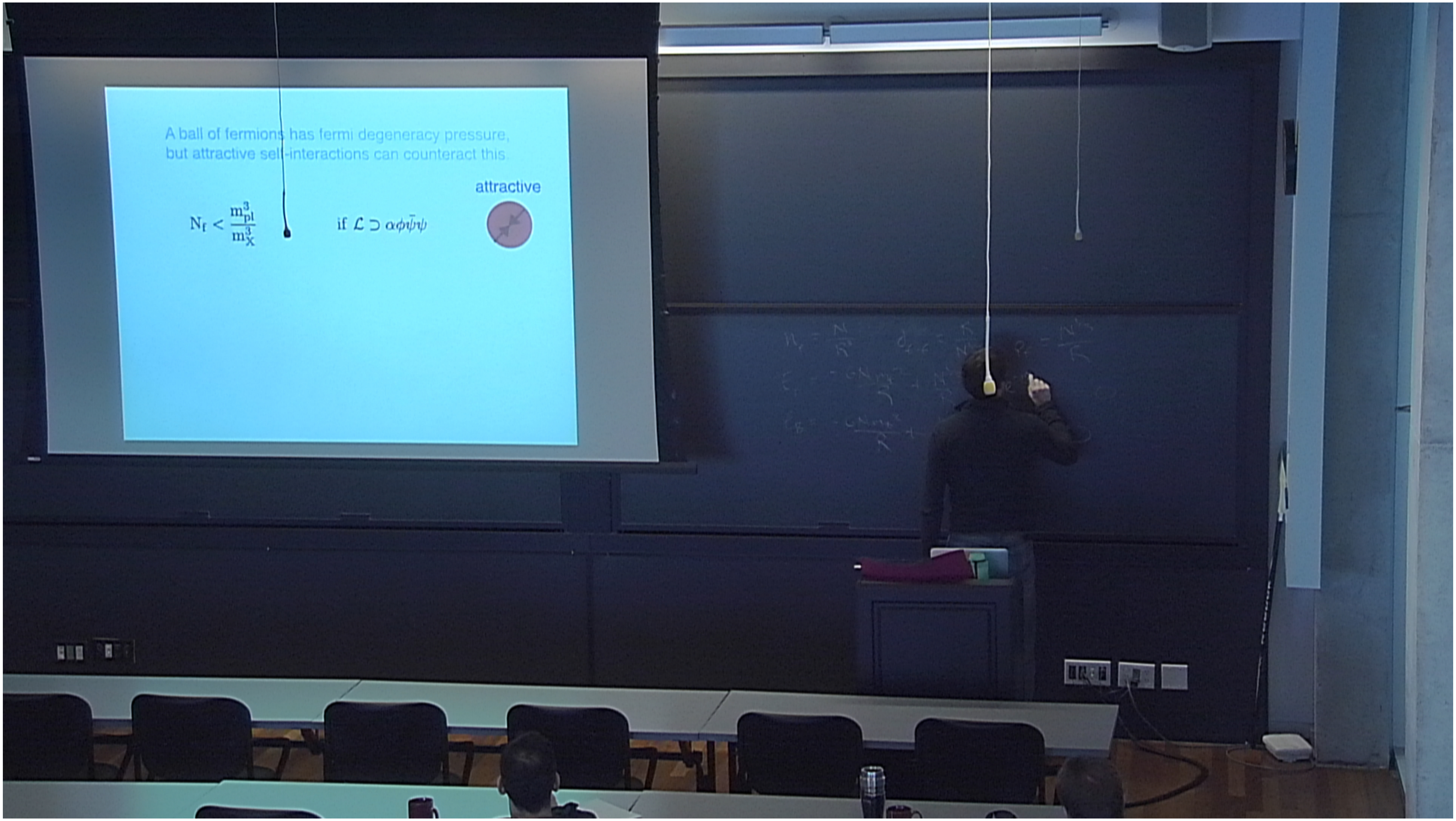
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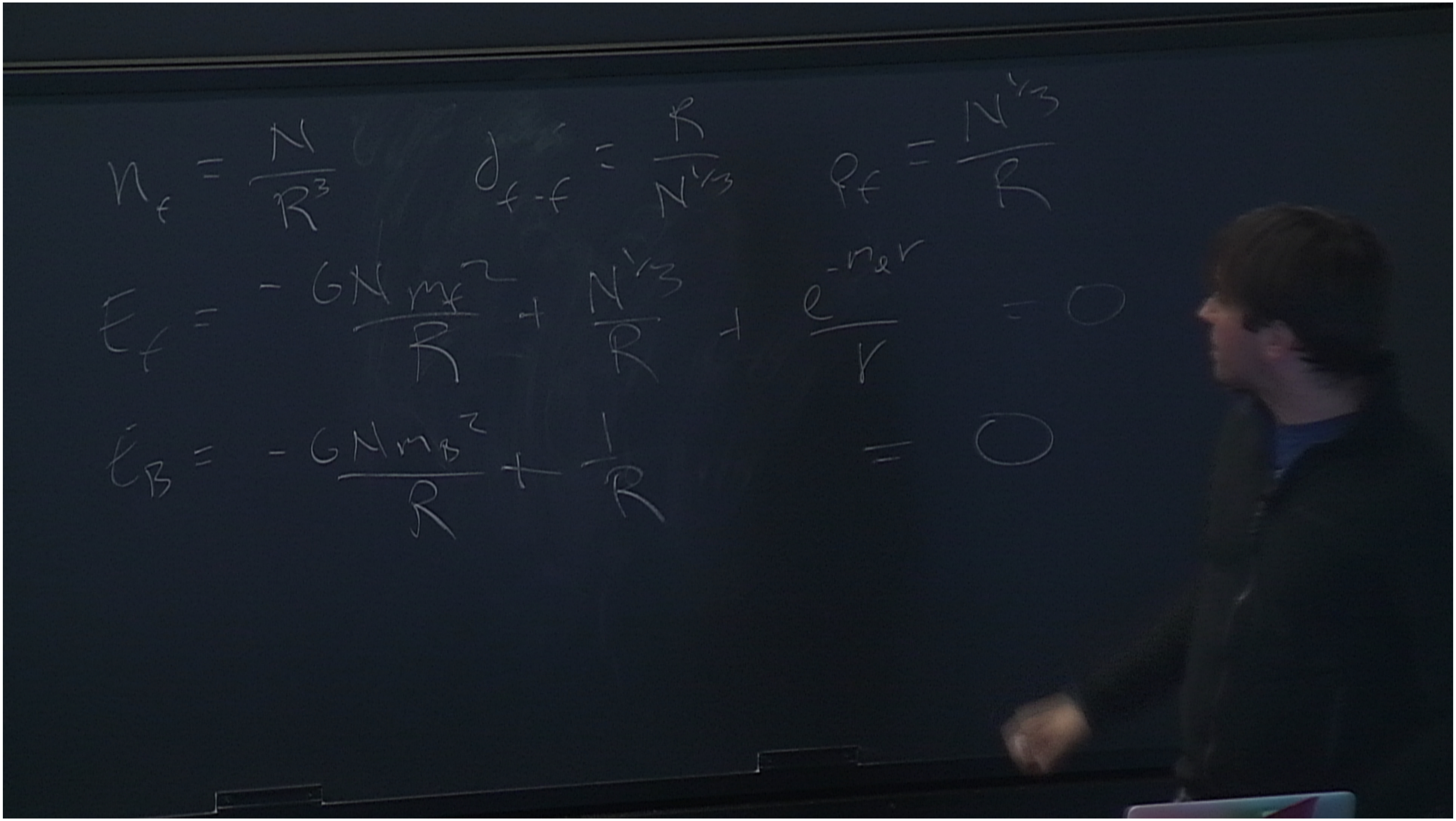
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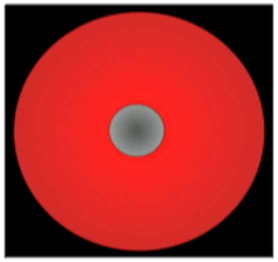

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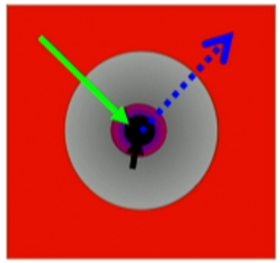
4] BH accretes, radiates



if it grows rapidly, then

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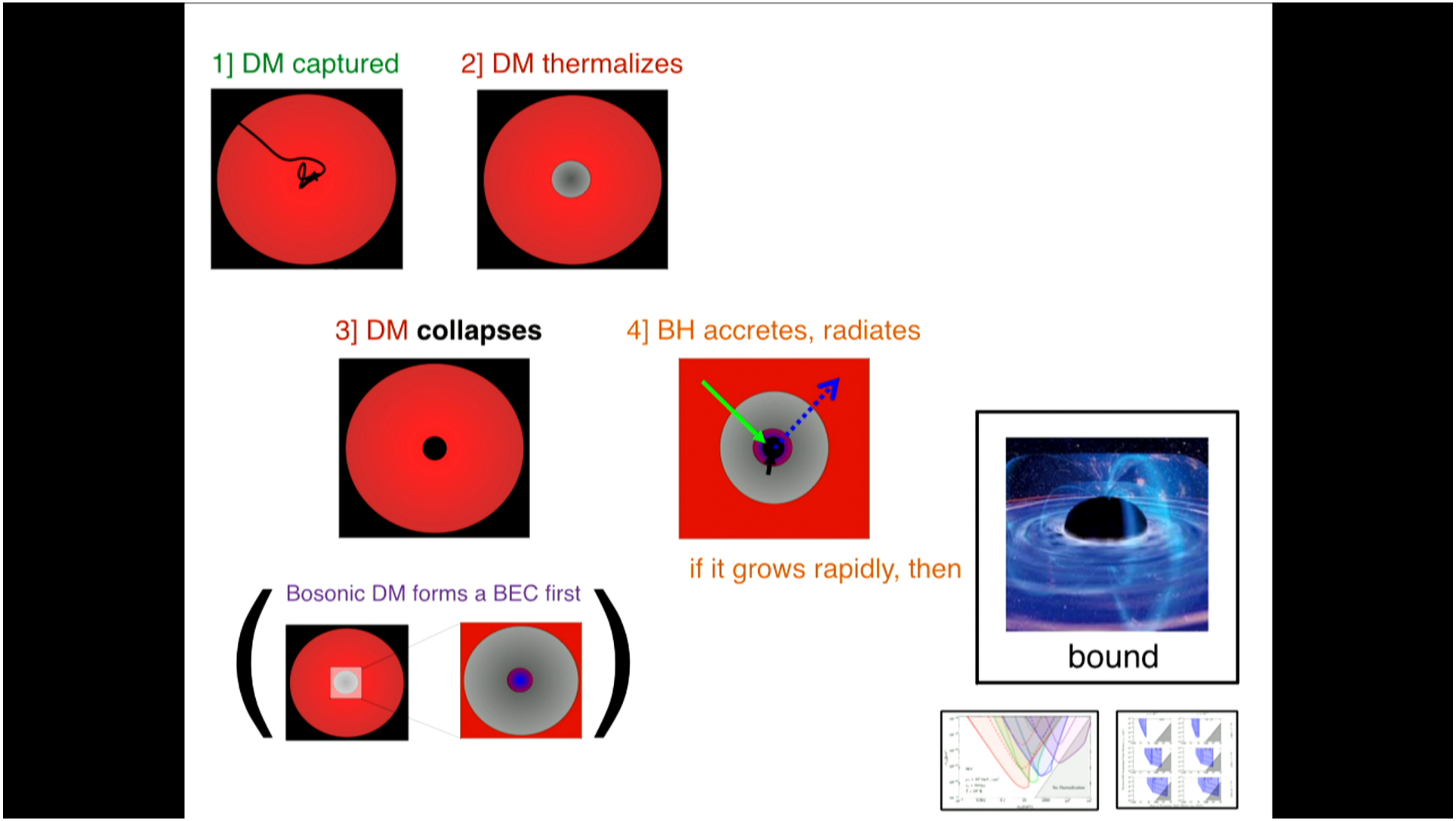
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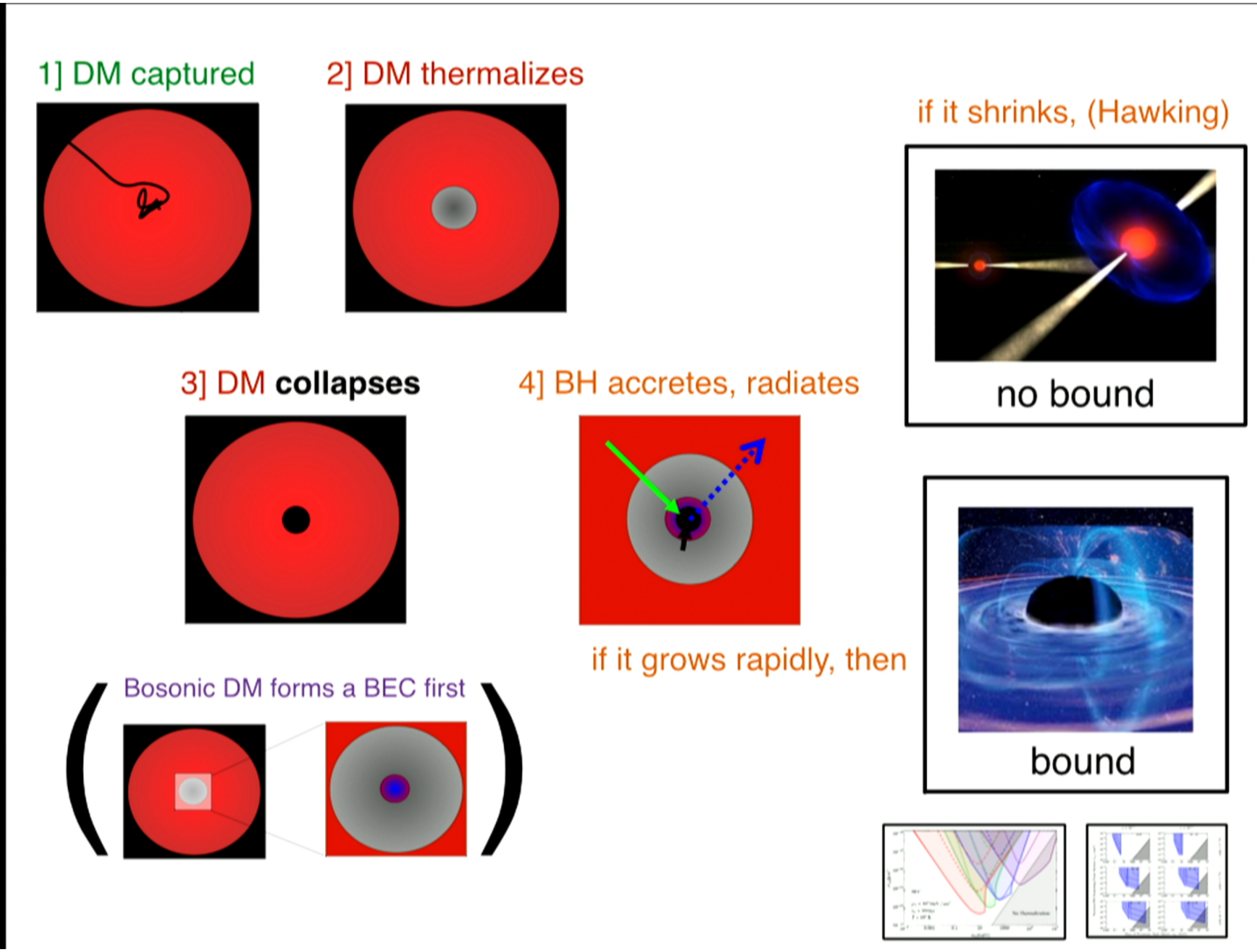
1] DM captured
2] DM thermalizes
if it shrinks, (Hawking)
no bound
3] DM collapses
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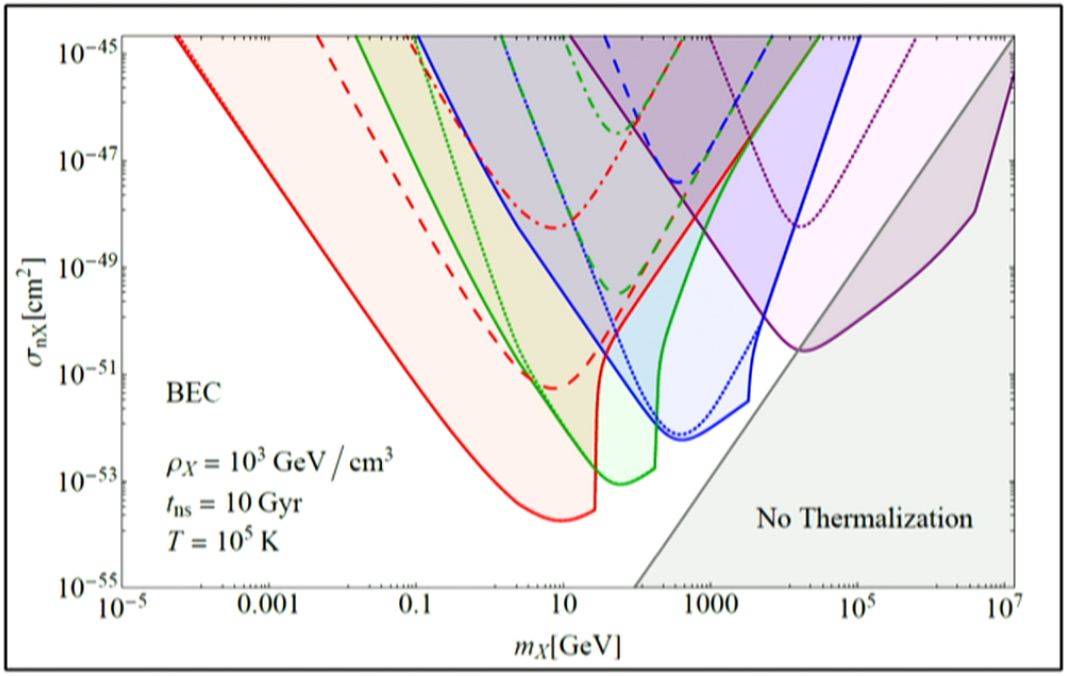
bound
if it grows rapidly, then
(Bosonic DM forms a BEC first)

Asymmetric Boson DM Bounds



JB,Kumar,Fukushima (2013)

$$\langle \sigma_a v \rangle = 0 \quad 10^{-50} \quad 10^{-45} \quad 10^{-42} \ \mathrm{cm^3/s}$$

Why consider fermionic asymmetric dark matter?

Resonant Self-Interacting Fermionic DM

Bullet clusters (1000 km/s) and spiral galaxies (200 km/s) constrain the cross-section of dark matter with itself to

$\sigma/m < 1\ \mathrm{cm^2/g}$, $\sigma/m < 1\ \mathrm{cm^2/g}$

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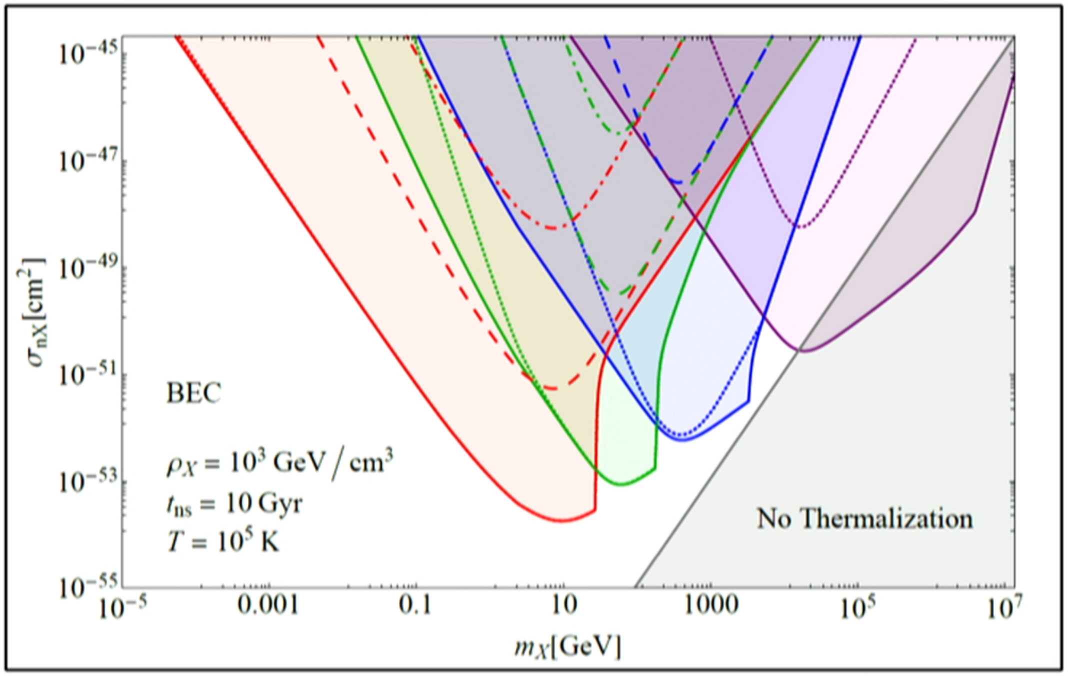

$$\lambda = \boxed{0}\ \boxed{10^{-30}}\ \boxed{10^{-25}}\ \boxed{10^{-15}}\ [\sigma_{xx} \sim 0,\ 10^{-118}, 10^{-98}, 10^{-58}\ \mathrm{cm}^2]$$

$$\langle \sigma_a v \rangle = \boxed{0}\ \boxed{10^{-50}}\ \boxed{10^{-45}}\ \boxed{10^{-42}}\ \mathrm{cm}^3/\mathrm{s}$$

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But the preferred cross-section to core the dwarf halo (10 km/s) is

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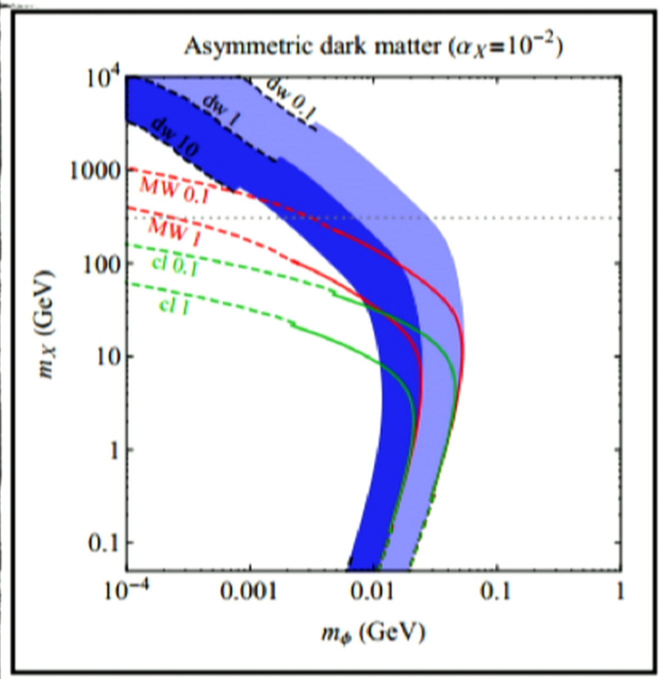
Answer: velocity dependent cross-section provided by light mediator.



Tulin, Yu, Zurek
1210.0900

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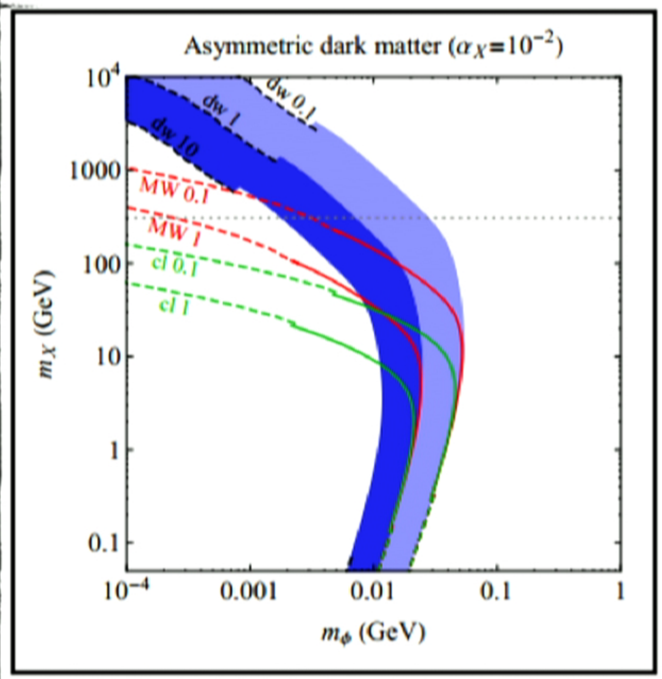

Tulin, Yu, Zurek
1210.0900

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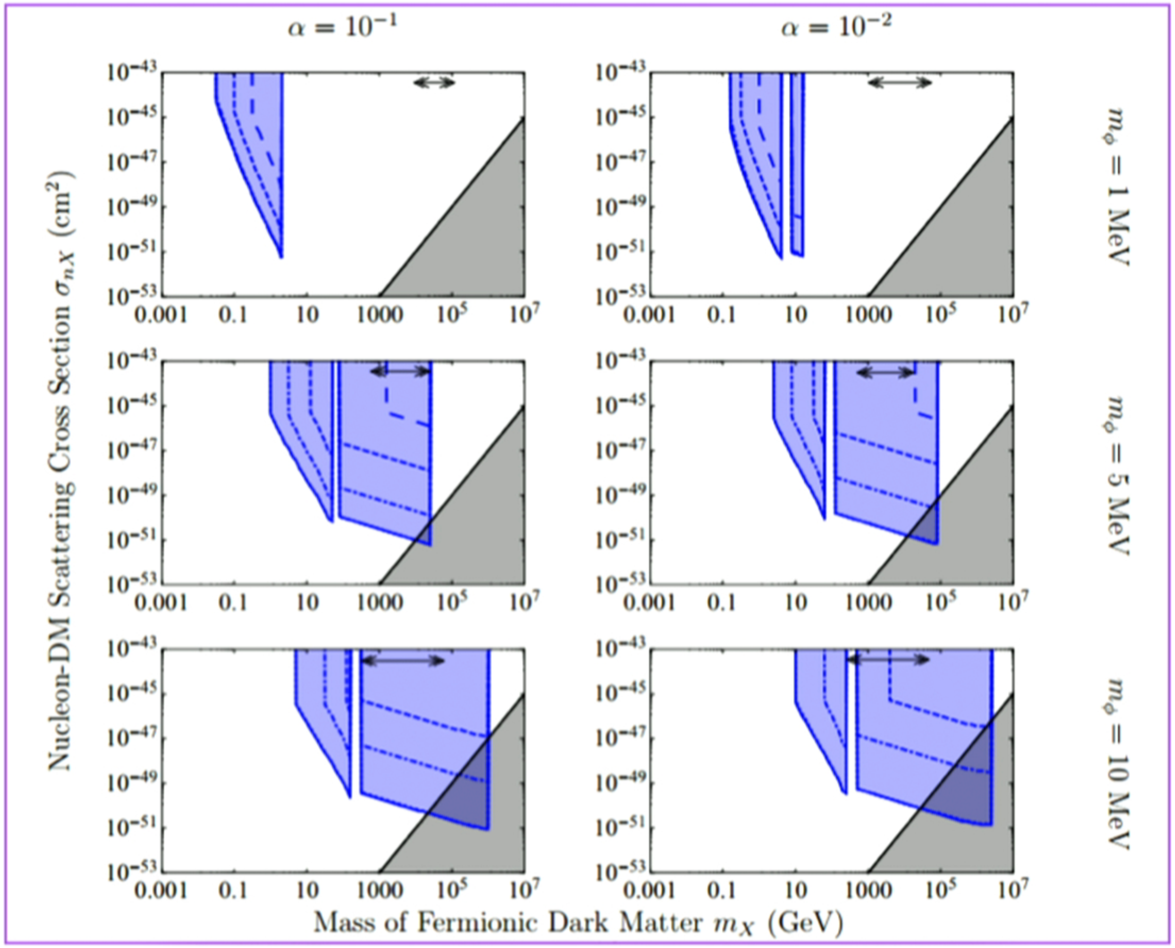
Bounds on SIDM Fermions



$<\sigma_a v> =$ 0 | 10^{-47} | 10^{-45} | 10^{-43} cm^3/s

JB, Kumar, Fukushima, Stopnitzky (2013)

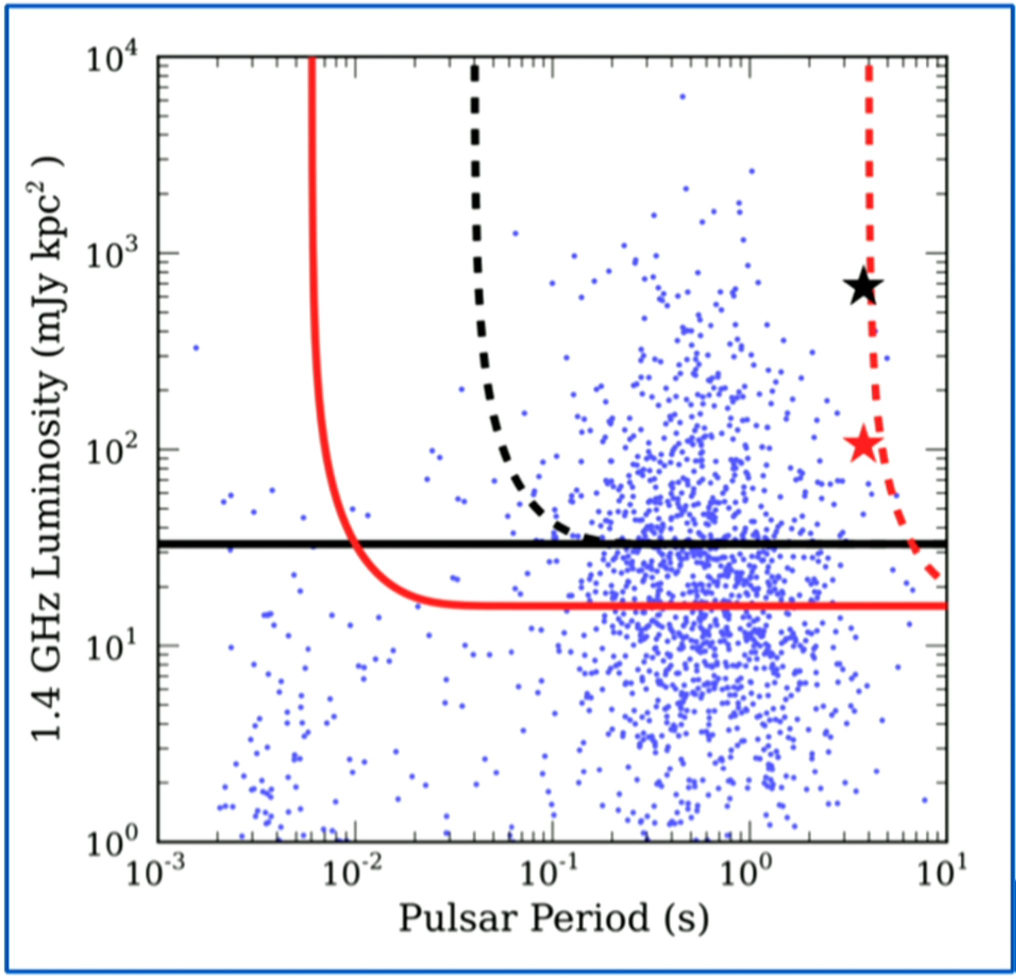
The missing pulsar problem

Prior to the detection of a very luminous magnetar one tenth of a parsec away from the ($10^8 \odot$ mass) black hole at the galactic center, it was assumed that pulsars had not been detected there, because a charged screen of material at the galactic center was broadening pulse signals. Pulsars are expected because of a large population of high mass progenitor stars and X-ray binary systems.

The missing pulsar problem

However, measurements of radio pulses from the newly discovered galactic center magnetar indicate a much cleaner path for radio pulses than was supposed. In addition, measurements of the radio pulses' angular broadening match those of SgA*. This is evidence that the scattering screen is homogeneous.

The missing pulsar problem



Dexter, O'Leary
1310.7022

Could Asymmetric Dark Matter Have Imploded the Missing Pulsars?

The capture rate for dark matter on pulsars scales inversely with velocity dispersion and linearly with the local dark matter density.

$$C_X \propto \frac{\rho_X}{\bar{v}} \sigma_{nX}$$

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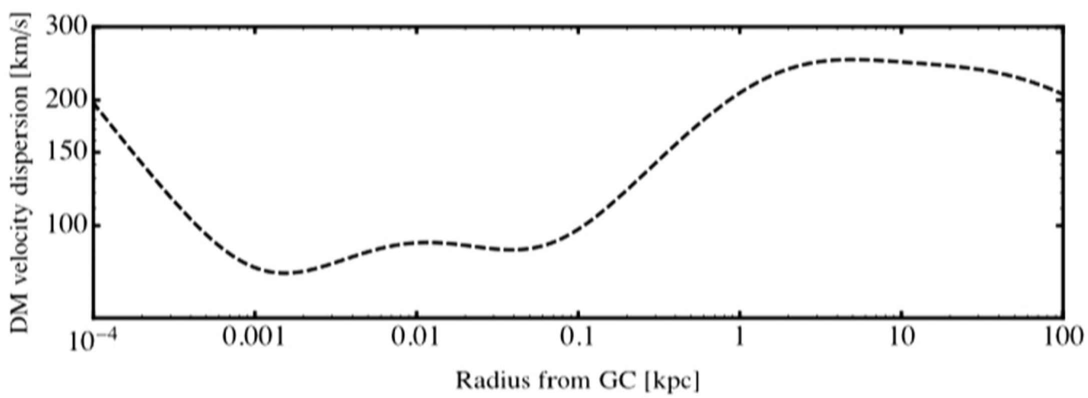
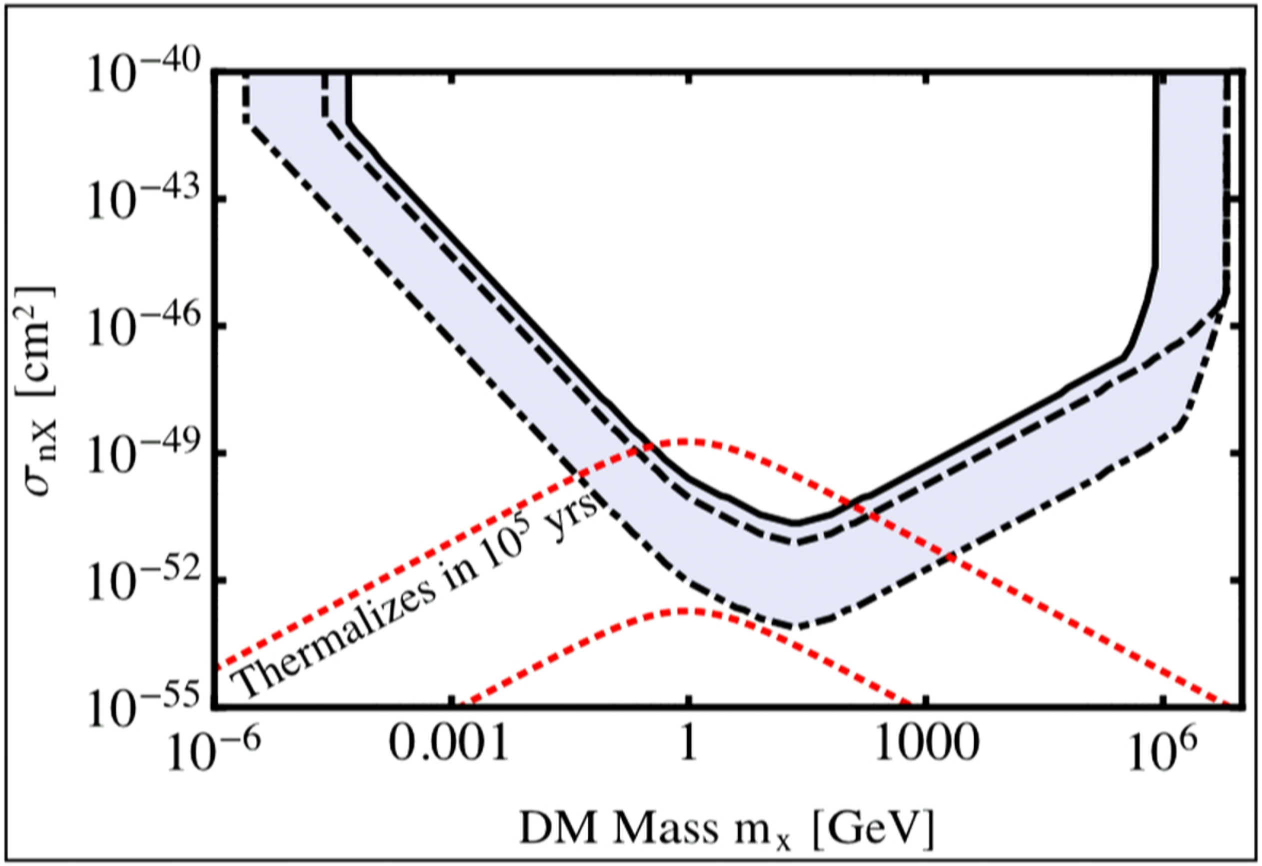
Model our galaxy's dark matter profile using disc and galactic center star velocity measurements (NFW).

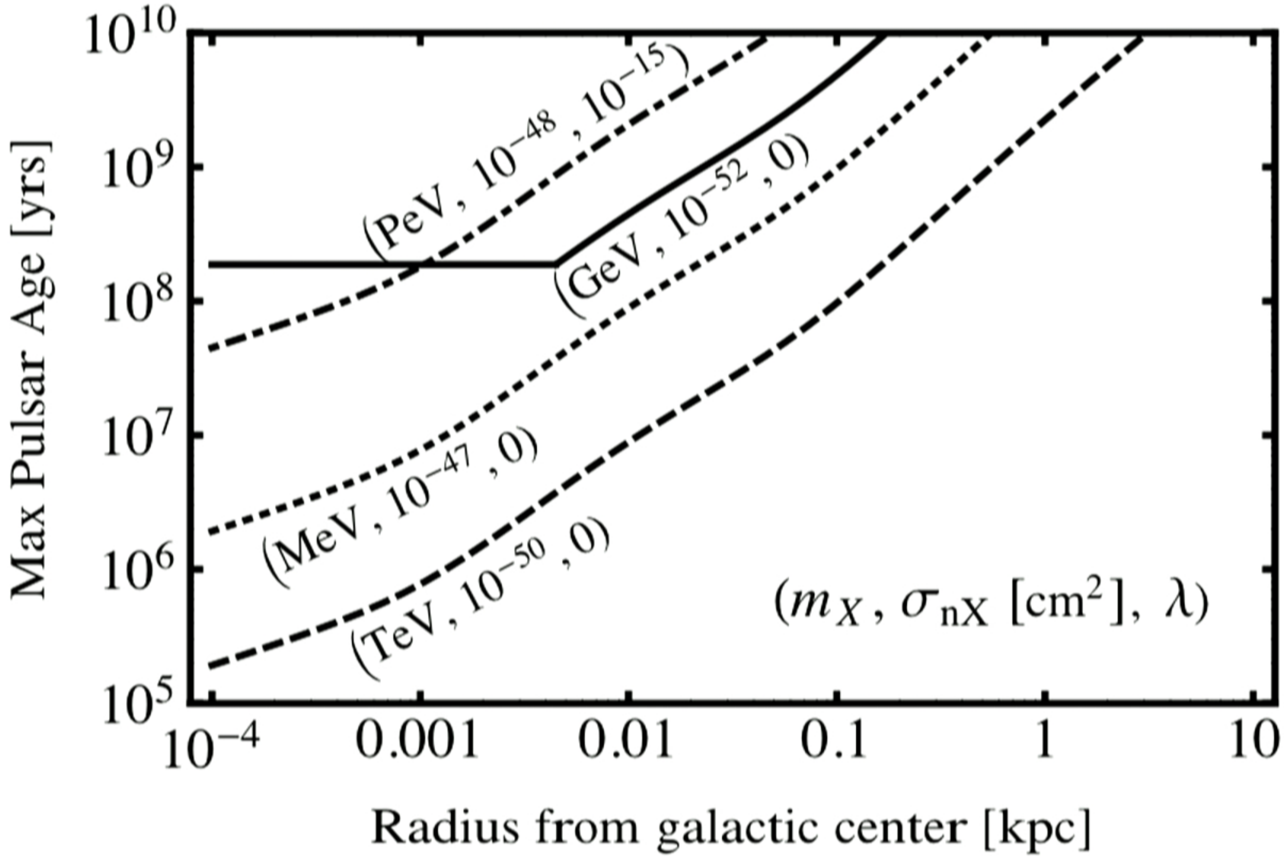


DM Bosons Collapsing Pulsars



JB,Linden (2014)

Prediction of Pulsar Age Curves



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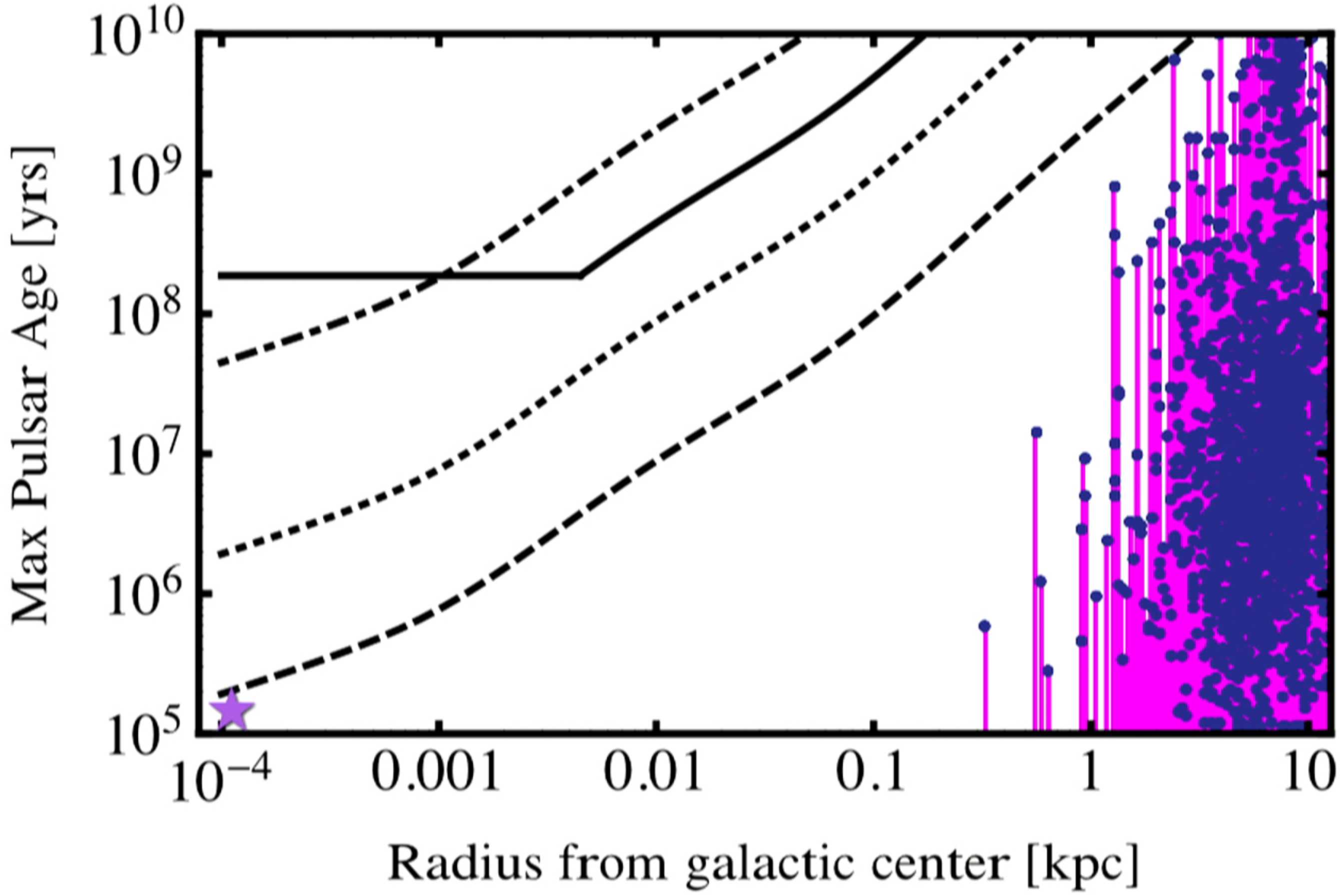
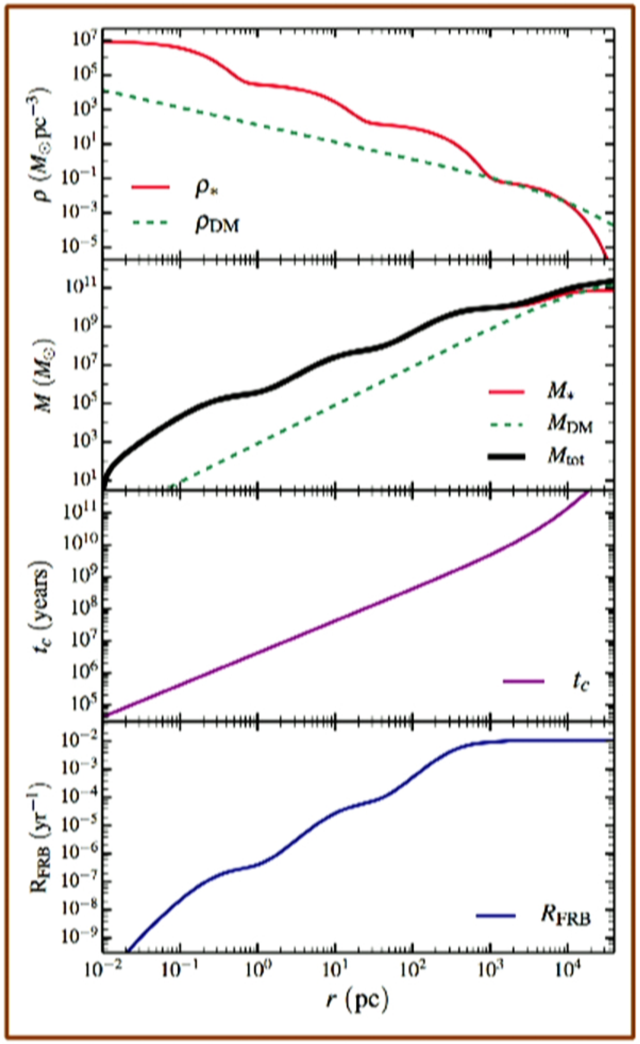


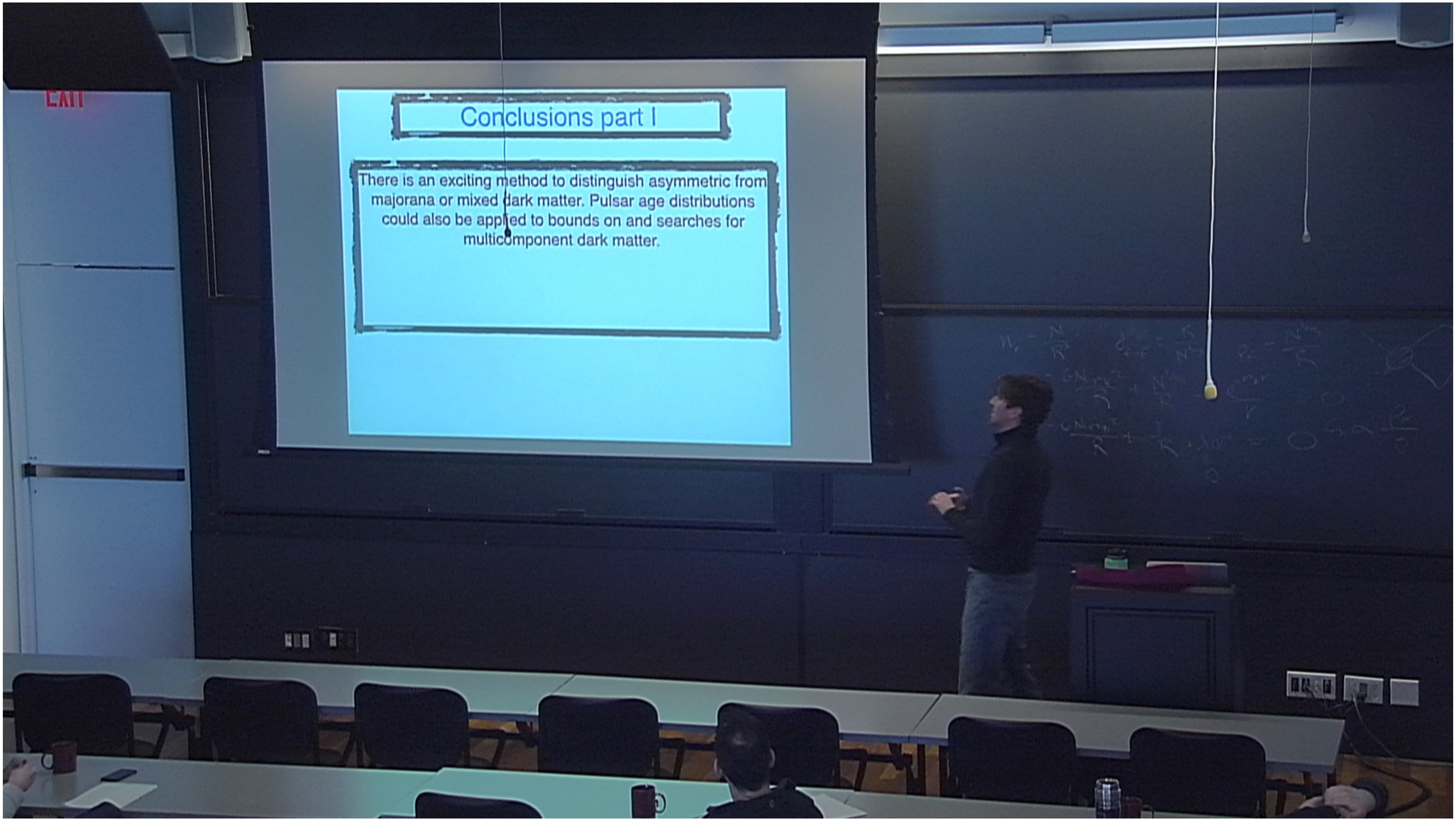


FRB Explanation

Fuller and Ott 1412.6119

$$R_{\rm FRB} \sim 5 \times 10^{-5}\,{\rm Mpc}^{-3}\,{\rm yr}^{-1}$$

$$R_{\rm obs} \sim 10^{-4}\,{\rm Mpc}^{-3}\,{\rm yr}^{-1}\left(\frac{D}{2\,{\rm Gpc}}\right)^{-3}$$


Conclusions part I
There is an exciting method to distinguish asymmetric from majorana or mixed dark matter. Pulsar age distributions could also be applied to bounds on and searches for multicomponent dark matter.

Proton Annihilation

Simple exercise: begin with $U(1)_B$ x $U(1)_L$ x $U(1)_{B-L}$, then break it to discrete symmetries and see what nucleons do.

JB, Kumar, Learned
1412.2140

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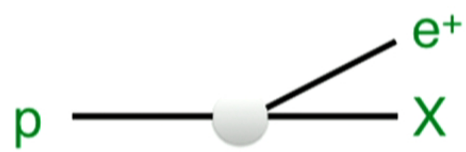

symmetries	proton decay	alternative signature
$U(1)_{B-L} \times Z_2^{B+L}$	$p \to e^+ X$	—

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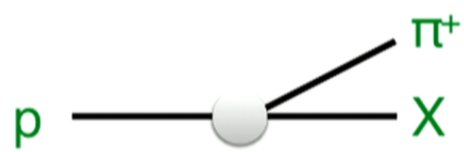

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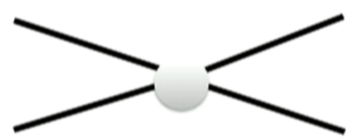

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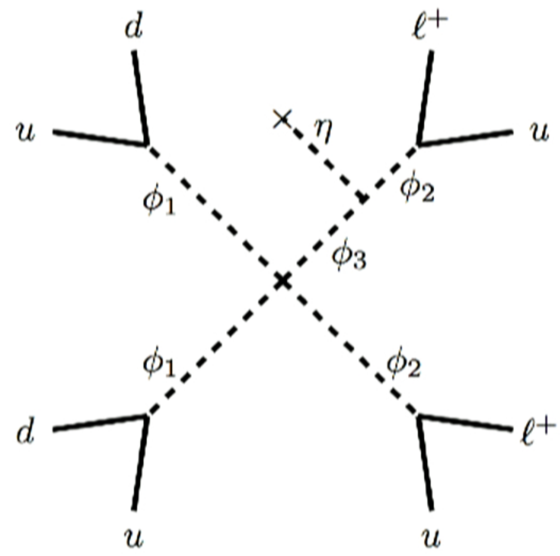
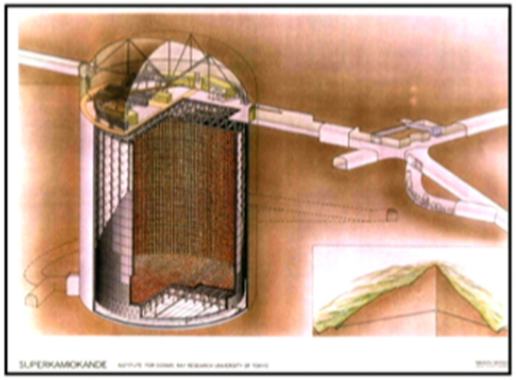
$U(1)_L$	$p \to \pi^+ X$	—
$Z_2^B \times U(1)_L$	—	$n - \bar{n}$ oscillation; $pp \to \pi^+\pi^+, K^+K^+$
$Z_4^{B+L} \times U(1)_{B-L}$	—	$pp \to l^+l^+$



$(\mathrm{SU}(3)_c, \mathrm{U}(1)_Y, \mathrm{U}(1)_B, \mathrm{U}(1)_L)$ charges
$\eta \in (1, 0, 2, 2)$
ϕ scalar fields
$\phi_1 \in (3, -\frac{1}{3}, -\frac{2}{3}, 0)$
$\phi_2 \in (\bar{3}, \frac{1}{3}, -\frac{1}{3}, -1)$
$\phi_3 \in (\bar{3}, \frac{1}{3}, \frac{5}{3}, 1)$

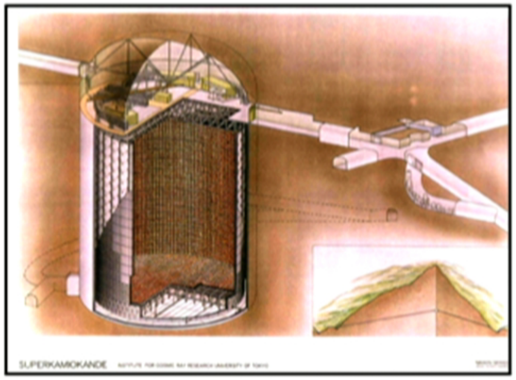
$$\mathcal{O}_{Q1} = \frac{1}{\Lambda_{Q1}^8}(\bar{Q}^c P_L Q)^2(\bar{Q}^c P_L l)(\bar{l}^c P_L Q)$$

High Luminosity



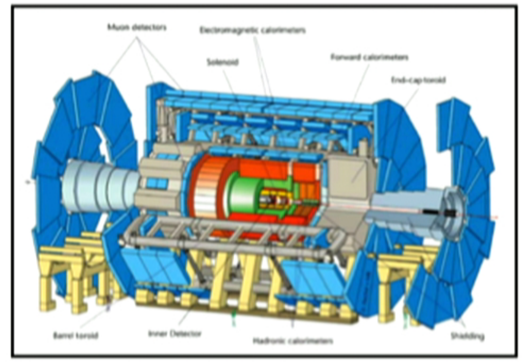
$$\mathcal{O}_{Q1} = \frac{1}{\Lambda_{Q1}^8} (\bar{Q}^c P_L Q)^2 (\bar{Q}^c P_L l)(\bar{l}^c P_L Q)$$

High Luminosity



$$N \propto \frac{\mathcal{L}}{E^2} \left(\frac{E}{\Lambda_Q} \right)^{16}$$

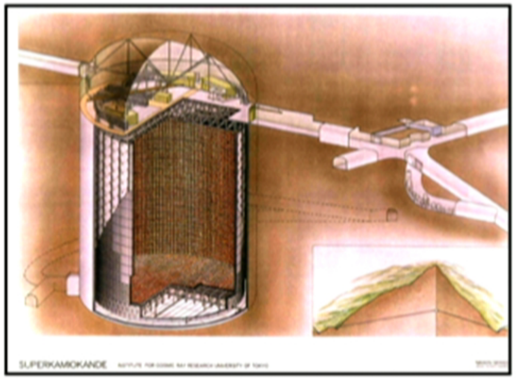
High Energy



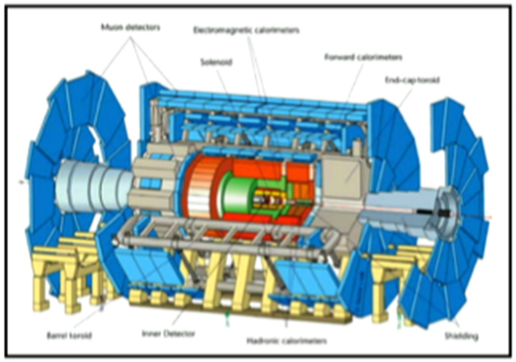
$$\mathcal{O}_{Q1} = \frac{1}{\Lambda_{Q1}^8}(\bar{Q}^c P_L Q)^2(\bar{Q}^c P_L l)(\bar{l}^c P_L Q)$$

High Luminosity

High Energy



$$N \propto \frac{\mathcal{L}}{E^2}\left(\frac{E}{\Lambda_Q}\right)^{16}$$



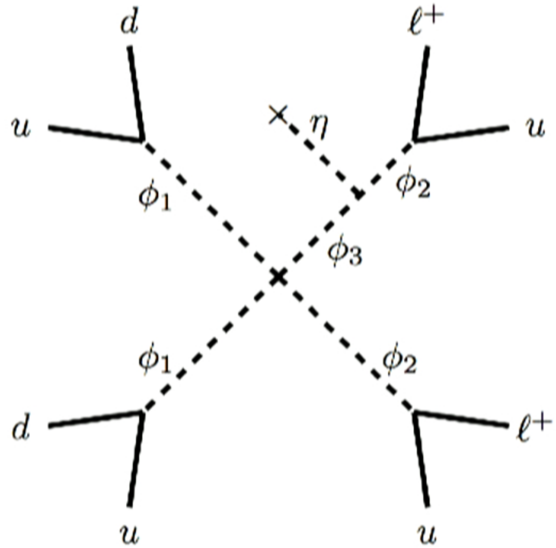
Current Bound :

Super-K $pe^- \to \bar{p}e^+$

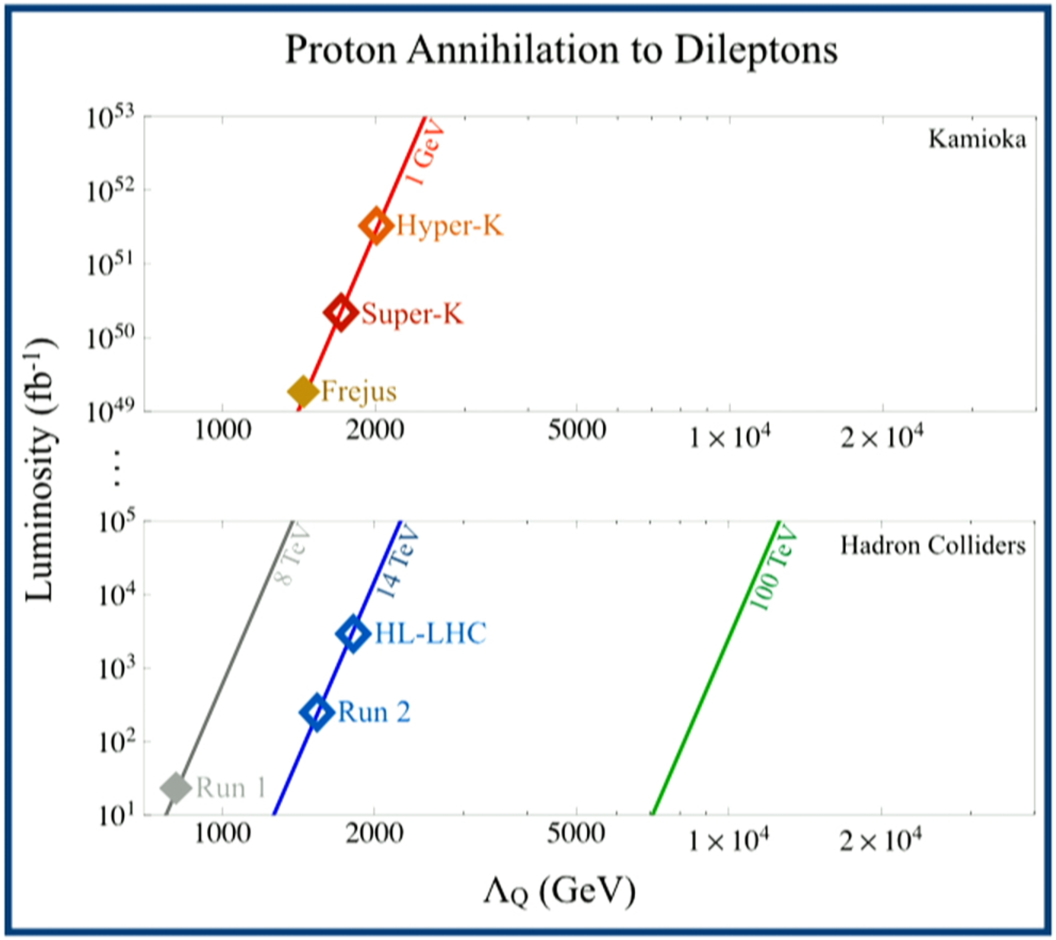
LHC 8 TeV 20 fb^{-1}

Super-K $pp \to e^+e^+$

$\Lambda_Q/\text{GeV} =$ 10^2 10^3 10^4



$(\mathrm{SU}(3)_c, \mathrm{U}(1)_Y, \mathrm{U}(1)_B, \mathrm{U}(1)_L)$ charges
$\eta \in (1, 0, 2, 2)$
ϕ scalar fields



Proton Annihilation to Dileptons
Luminosity (fb^{-1})
10^{53}
10^{52}
10^{51}
10^{50}
10^{49}
1 GeV
Hyper-K
Super-K
Frejus
Kamioka
1000
2000
5000
1×10^4
2×10^4
10^5
10^4
10^3
10^2
10^1
8 TeV
14 TeV
100 TeV
HL-LHC
Run 2
Run 1
Hadron Colliders
Λ_Q (GeV)

Conclusions part II

There is an exciting method to distinguish asymmetric from majorana or mixed dark matter. Pulsar age distributions could also be applied to bounds on and searches for multicomponent dark matter.

A high energy collider program could be a necessity in order to further probe primordial lepton/baryon/dark matter asymmetries — contrary to prior experience.

Conclusions part II

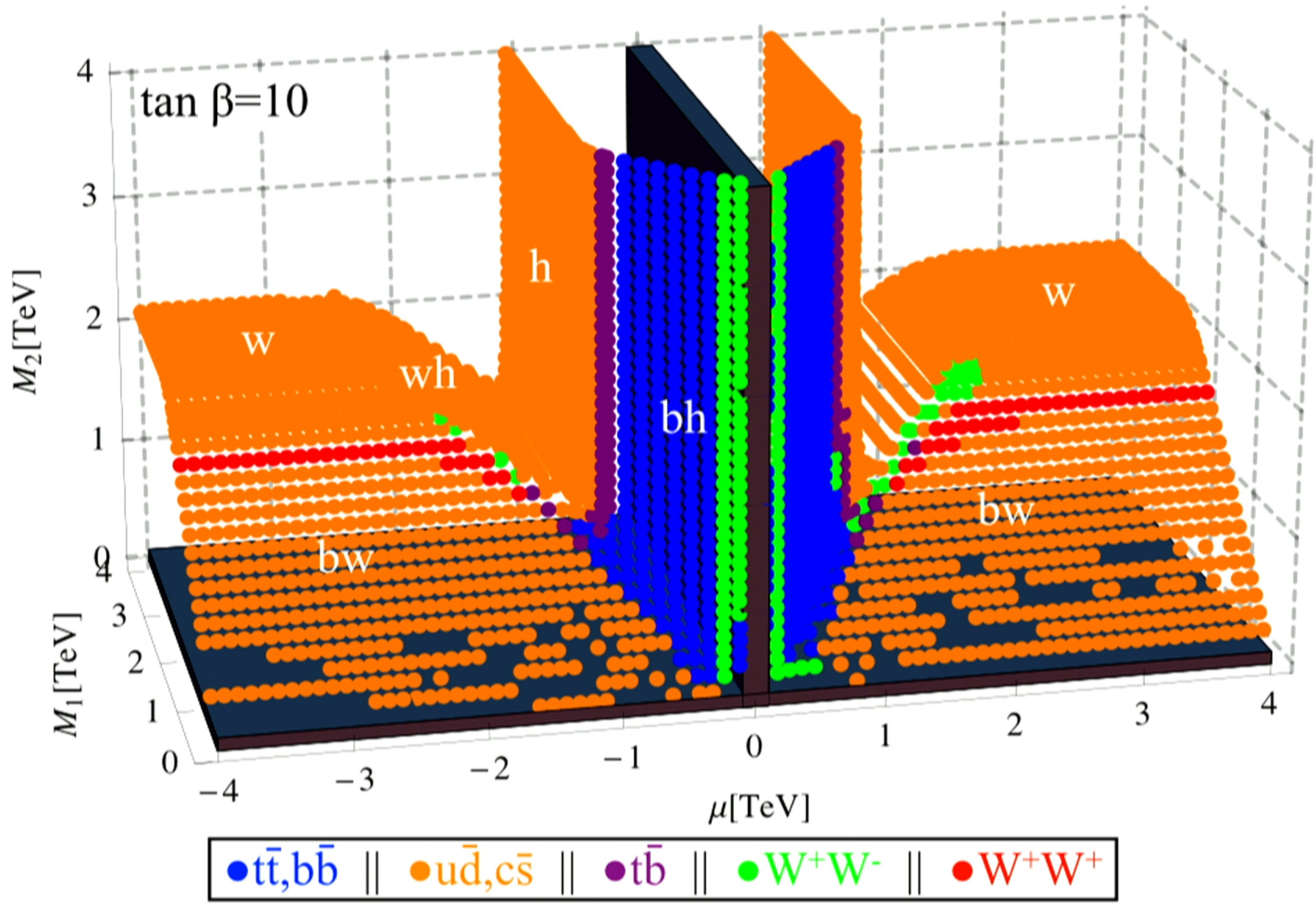
There is an exciting method to distinguish asymmetric from majorana or mixed dark matter. Pulsar age distributions could also be applied to bounds on and searches for multicomponent dark matter.

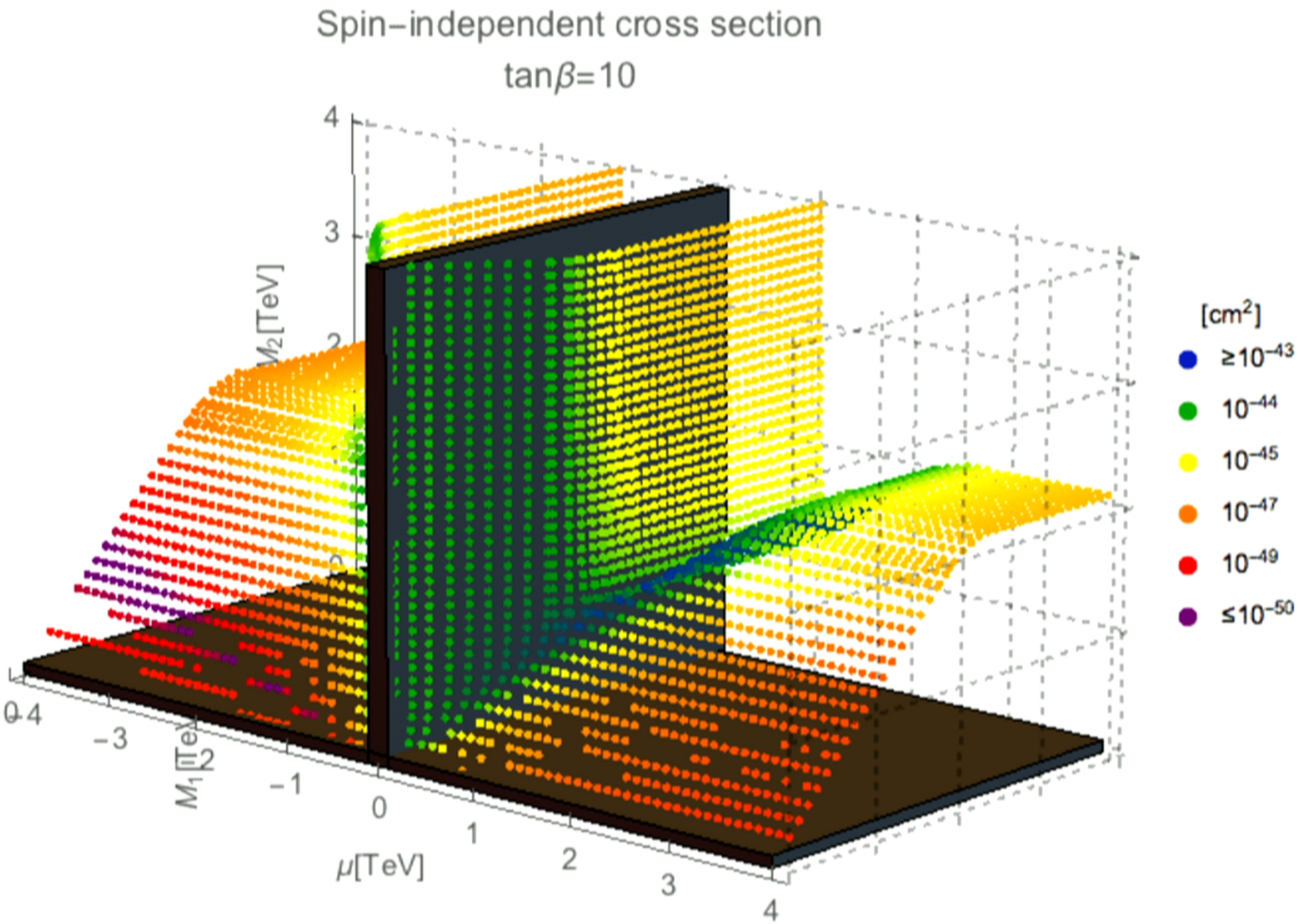
A high energy collider program could be a necessity in order to further probe primordial lepton/baryon/dark matter asymmetries — contrary to prior experience.

Consider a "supersymmetric" spectrum with all scalar sparticles and the gluino decoupled. The result is a low-scale spectrum with bino, higgsinos, and winos [singlet, doublet, triplet reps of SU(2)].

Require that these particles freeze out to the correct relic abundance only through coupling to SM states. [This is well-tempering except for the pure states.]

JB, Fox, Martin, Ostdiek, Plehn, Schell, Takeuchi 1412.4789





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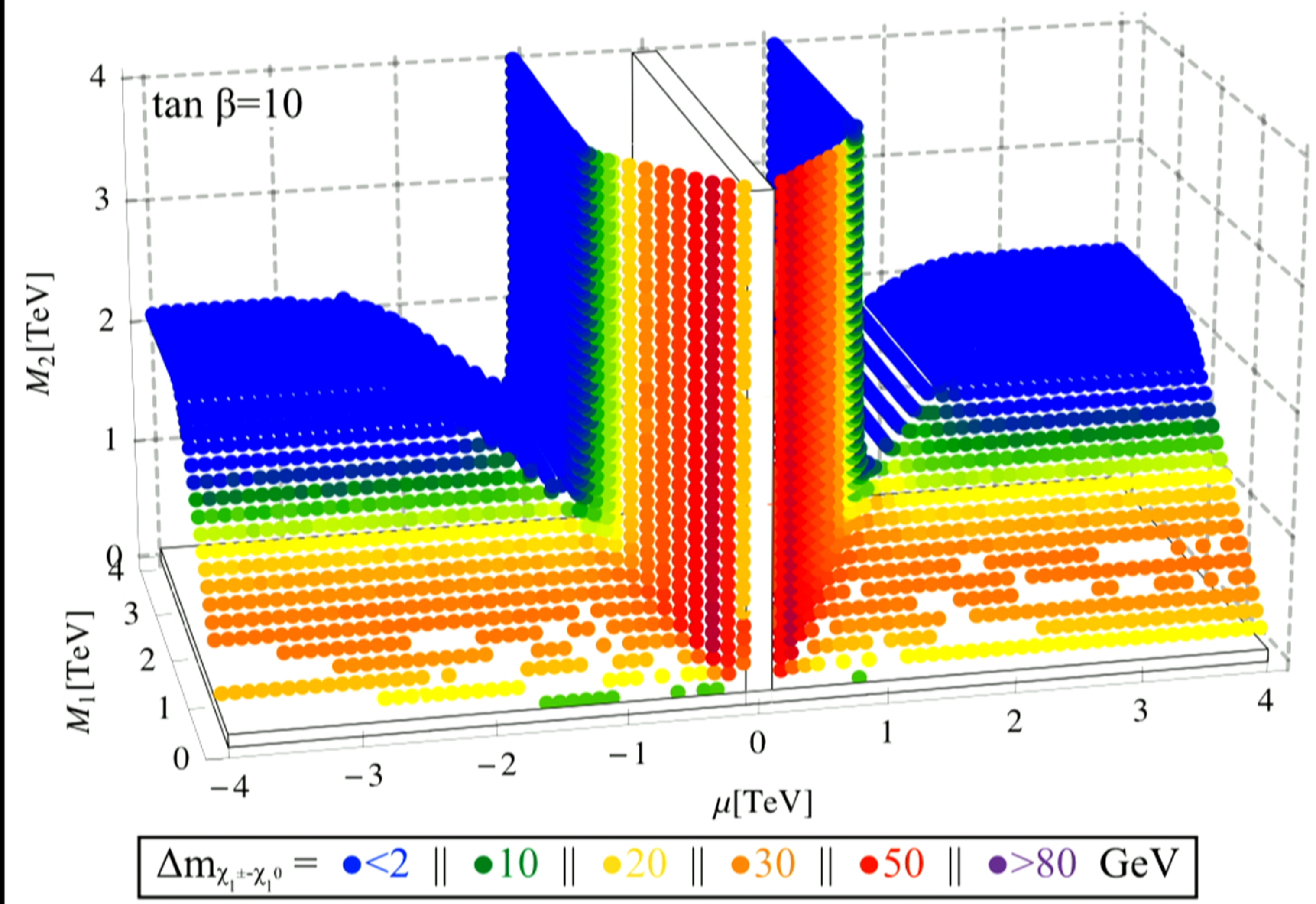
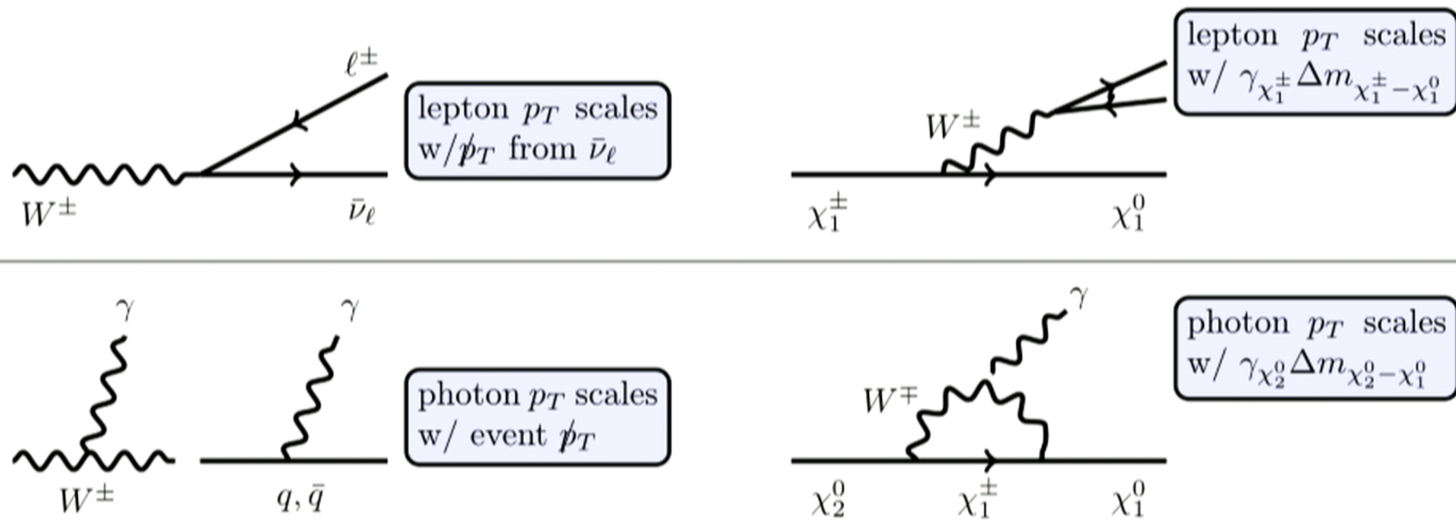
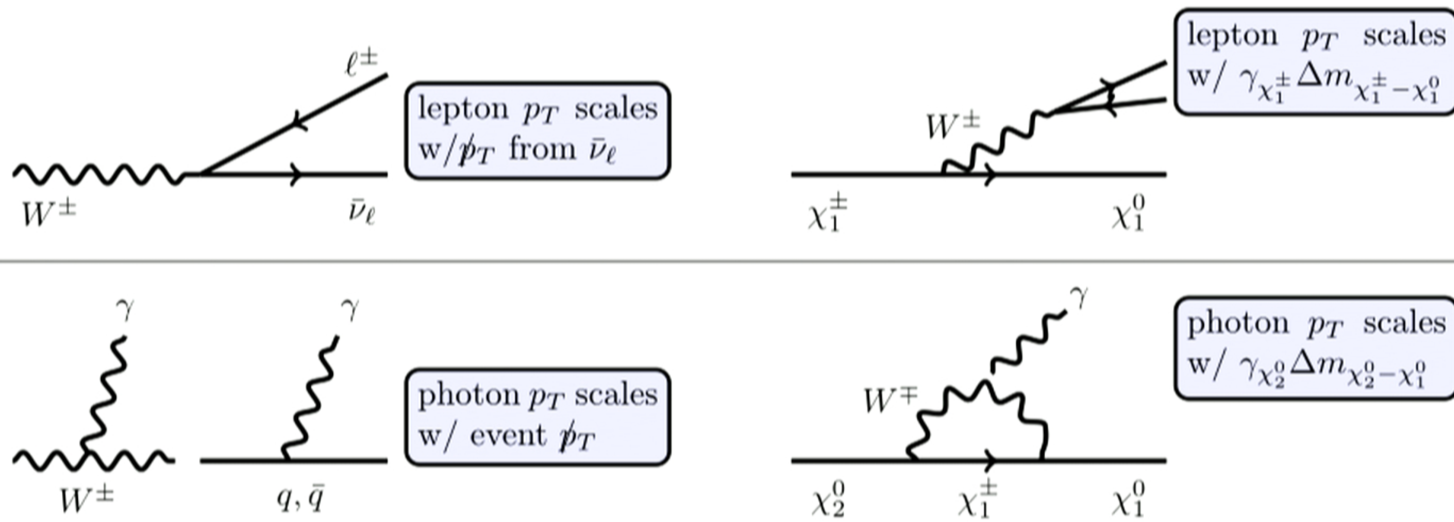

tan β=10
M_2[TeV]
M_1[TeV]
μ[TeV]
$\Delta m_{\chi_1^\pm - \chi_1^0}$ = ●<2 || ●10 || ●20 || ●30 || ●50 || ●>80 GeV

Background, e.g. $W^{\pm}\gamma j$ Signal, e.g. $\chi_1^{\pm}\chi_2^0 j$



Background, e.g. $W^{\pm}\gamma j$

Signal, e.g. $\chi_1^{\pm}\chi_2^0 j$



Conclusions part III

There is an exciting method to distinguish asymmetric from majorana or mixed dark matter. Pulsar age distributions could also be applied to bounds on and searches for multicomponent dark matter.

A high energy collider program could be a necessity in order to further probe primordial lepton/baryon/dark matter asymmetries — contrary to prior experience.

The relic neutralino or split susy surface can be discovered with 100 TeV compressed dark matter collider searches.

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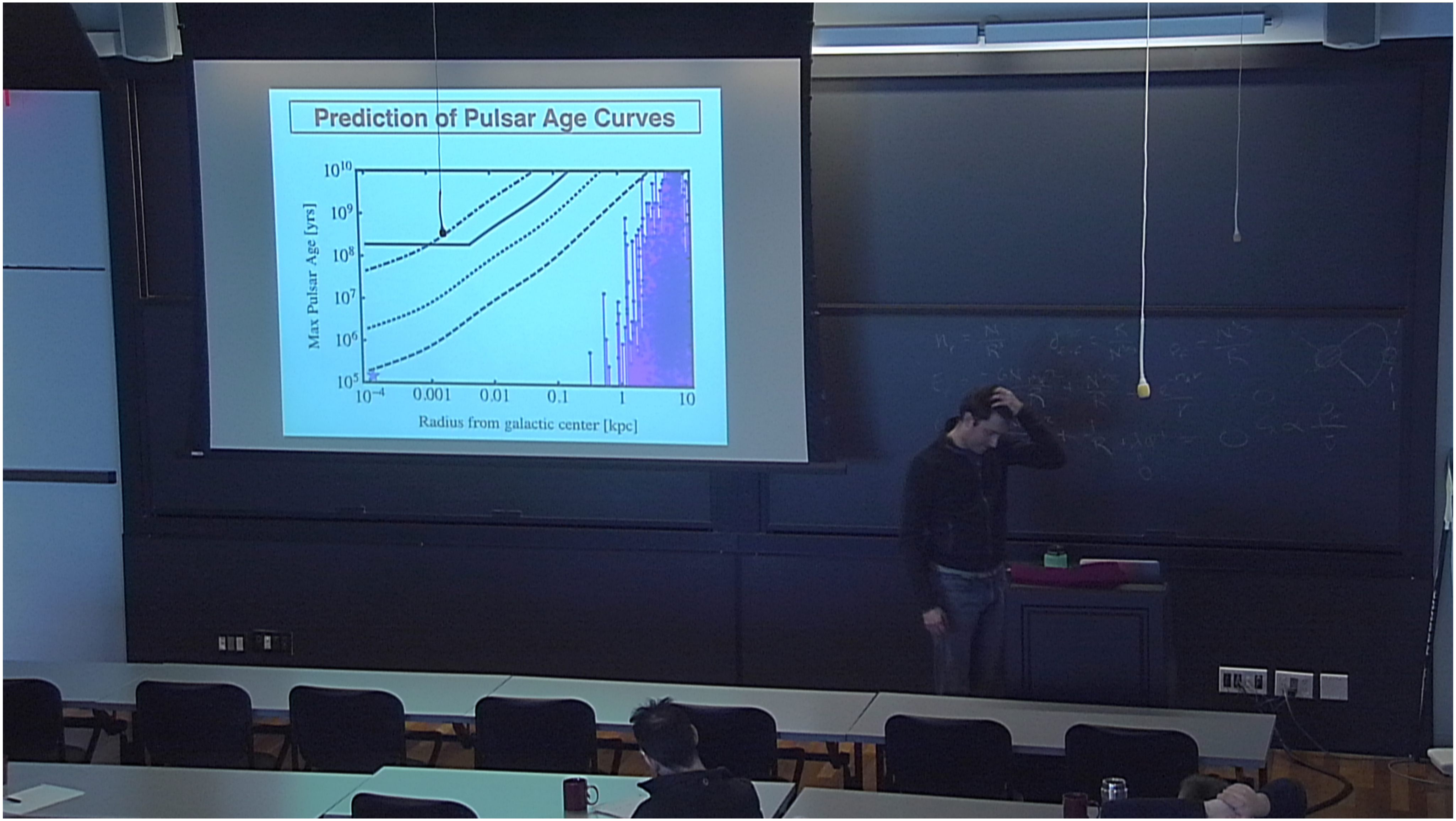
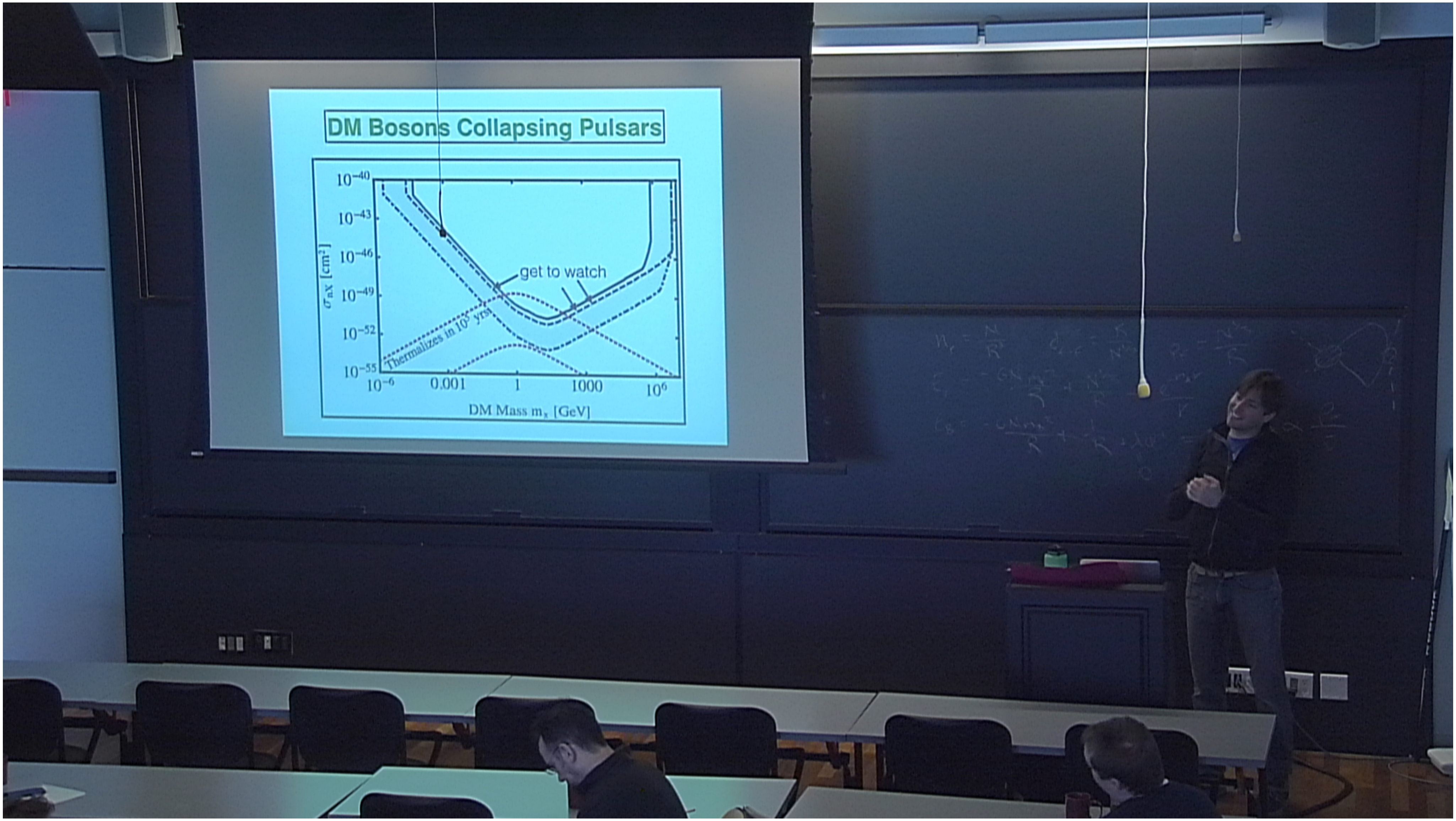
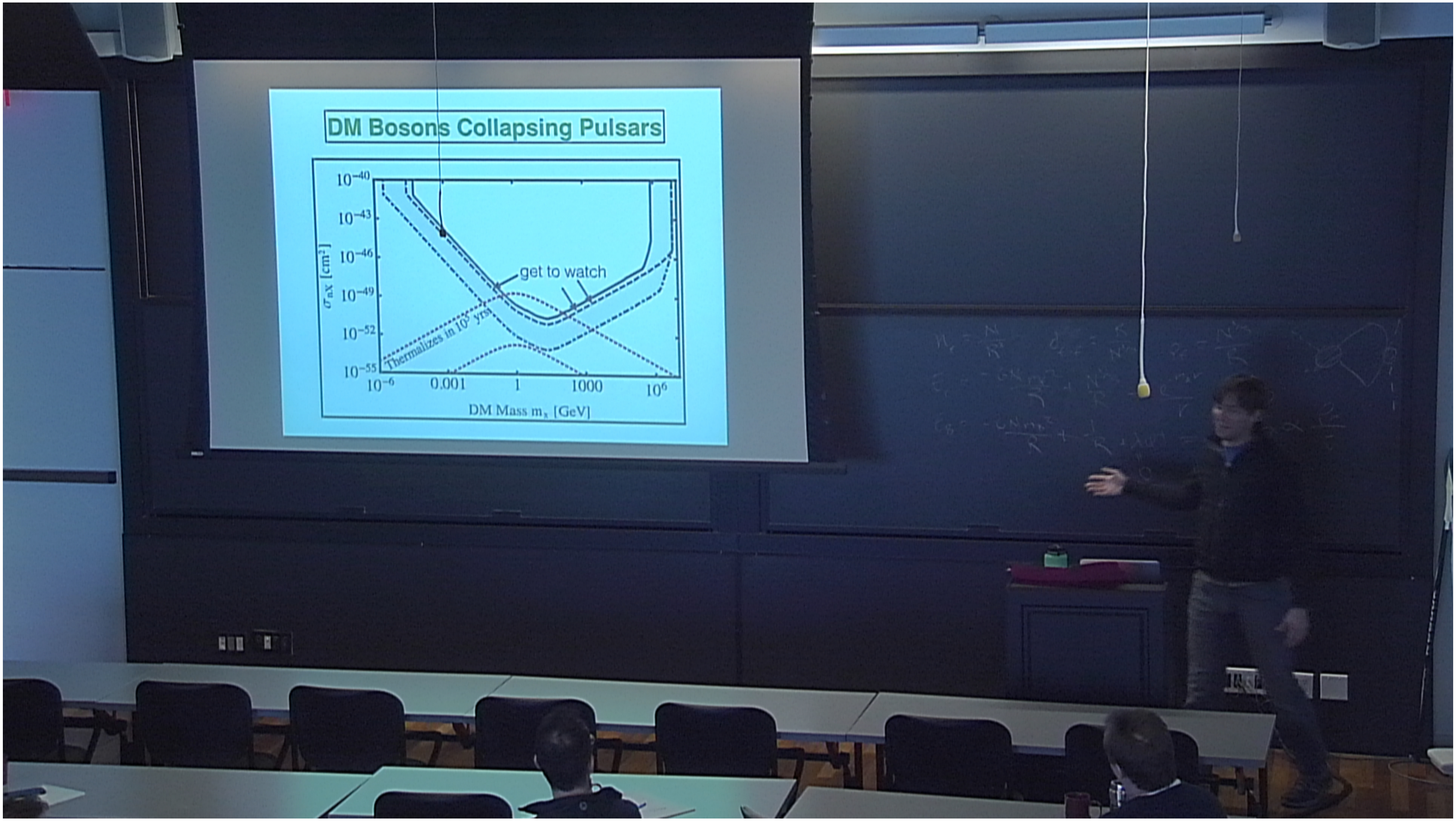


Prediction of Pulsar Age Curves
Max Pulsar Age [yrs]
Radius from galactic center [kpc]


DM Bosons Collapsing Pulsars
get to watch
Thermalizes in 10^5 yrs
σ_{nX} [cm^2]
DM Mass m_x [GeV]
10^{-40}
10^{-43}
10^{-46}
10^{-49}
10^{-52}
10^{-55}
10^{-6}
0.001
1
1000
10^6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