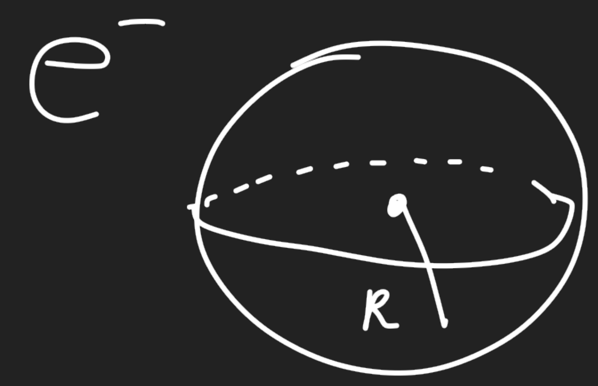
AD POLOSA

VIS. TEOR. 1

NEW PHYSICS AT ~1 MEV



(EM. CONTRIBUTION TO THE MASS OF e) $\quad E_{st} \lesssim \frac{e \cdot e}{R} \lesssim mc^2$ (self-energy)

$$R \gtrsim \frac{e^2}{mc^2} = \hbar c \frac{\alpha}{0.5\,\text{MeV}} \simeq 3\,\text{fm}$$

AS BIG AS A NUCLEUS WITH $A = 27$

MAYBE IN THE QUANTUM THEORY CANCELLATIONS ARE AT WORK AS $R \to 0$.

NEW PHYSICS AT ~1 MEV

IF ONE ELECTRON ALONE IS PRESENT, THE PROB. OF FINDING A CHARGE DENSITY AT TWO DIFFERENT POINTS SIMULTANEOUSLY (DISTANT BY $|\vec{\xi}|$) IS ZERO.

$$\left\langle \int \rho(\vec{r}+\vec{\xi}/2)\,\rho(\vec{r}-\vec{\xi}/2)\,d^3r \right\rangle \propto \delta^3(\vec{\xi})$$

THUS

$$E_{st} \to \infty$$

NEW PHYSICS AT ~1 MEV

BELOW SOME 'CUT-OFF' DISTANCE λ THE 'POSITRON THEORY' HAS TO BE USED.

(EM. CONTRIBUTION TO THE MASS OF e)

$$E_{st} = \lim_{R \to 0} \alpha \, mc^2 \ln\left(\frac{\lambda_c}{R}\right)$$

(Weisskopf '39)

THIS DISTANCE IS SET AT $\approx \lambda_c \approx \frac{1}{m_e c}$

— THE MASS OF THE POSITRON, THE NEW PARTICLE OF QED

NEW PHYSICS AT ~1 MEV

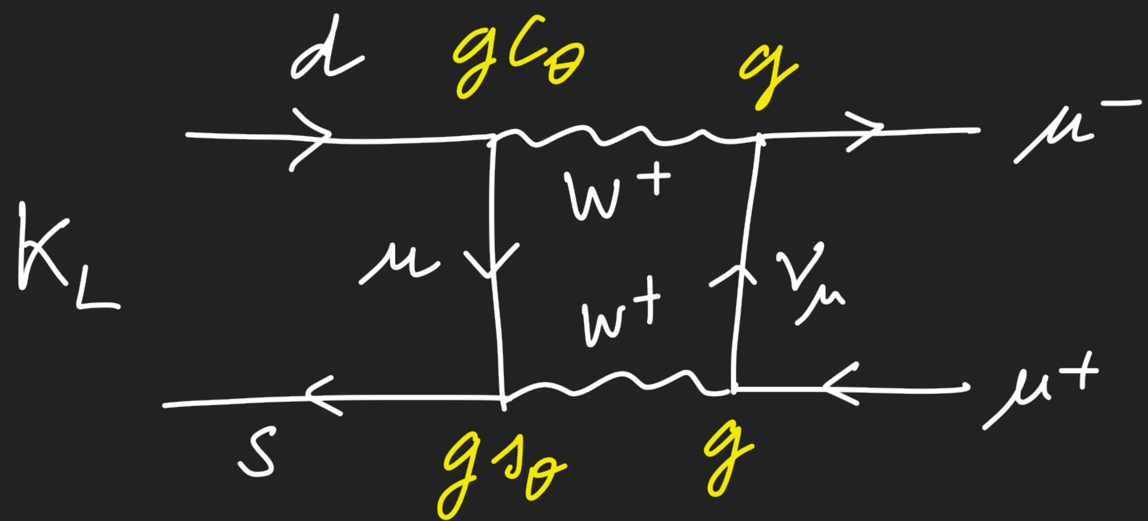
$$\alpha mc^2 \ln\left(\frac{\lambda_c}{R}\right) \lesssim mc^2$$

only need that

$$R \gtrsim \lambda_c e^{-137} \quad (\text{instead of } R \gtrsim 3\,fm)$$

QED RESTORES UNNATURALNESS:
NO MISTERIOUS 'CANCELLATIONS' BUT A
NEW PHYSICS W/ e^-, e^+ & γ.

NEW PHYSICS AT ~1 GEV



(Ioffe & Shabalin)
'68

$$\int^{\Lambda} \frac{\left(\frac{k^\mu k^\nu}{m_W^2}\right)^2}{(k^2-m_W)^2}\cdot\frac{\not{k}+m}{(k^2-m^2)}\cdot\frac{\not{k}}{k^2}\, d^4k \sim \Lambda^2$$

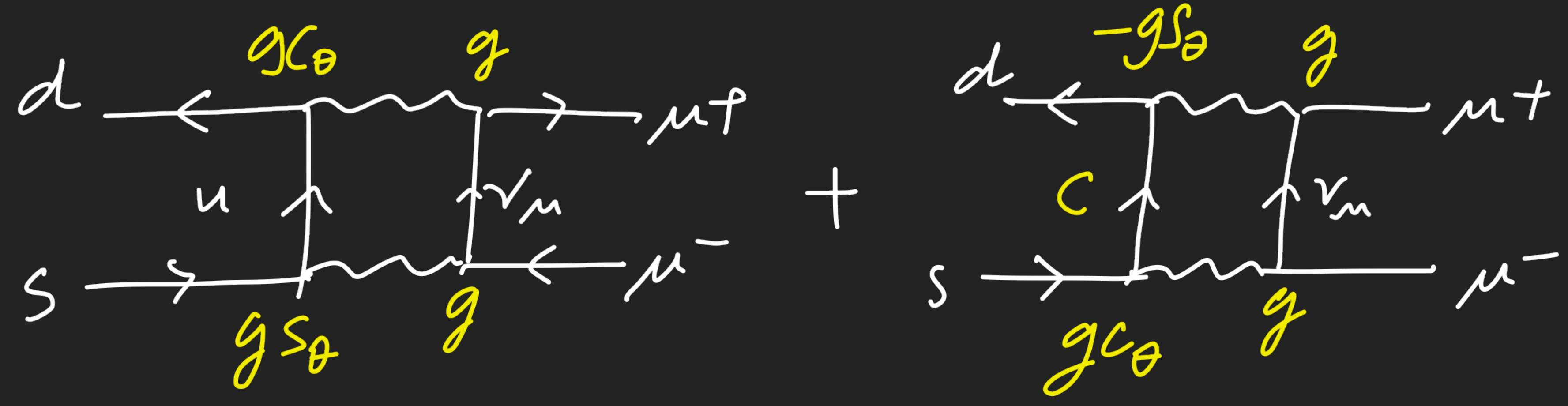
POWER COUNTING $\sim G_F^2\Lambda^2$

CFR W/ $\mathcal{B}(K_L\to\mu^+\mu^-)\sim 7\times 10^{-9}$

$$\boxed{\Lambda \lesssim 3\ \mathrm{GeV}}$$

Does this 'cutoff' also correspond to the existence of a new part?

GIM ('70) INTRODUCES A DYNAMICAL MECH. TO SUPPRESS $K_L \to \mu^+ \mu^-$



THE DIFFERENCE IN MASS $m_c - m_u$ MAKES THE CANCELLATION <u>INCOMPLETE</u>.

$$Amp(K_L \to \mu^+ \mu^-) \propto G^2 s_\theta c_\theta \left(m_c^2 - m_u^2 \right)$$

A CONVERGENT RESULT

$$m_c \simeq 2-3\,GeV$$

NEW PHYSICS AT ~1 TEV

$$\begin{pmatrix}\text{EW. CONTRIBUTION} \\ \text{TO THE HIGGS MASS}\end{pmatrix}^2 \propto G_F\, f(m_W, m_Z, m_t, m_H)\,\Lambda^2 \lesssim m_H^2$$

(the constant is $3/4\pi^2\sqrt{2}$, $f = 4m_t^2 - m_Z^2 - 2m_W^2 - m_H^2$)

THIS REQUIRES $\Lambda \lesssim 0.5$ TeV

Does this 'cutoff' ALSO CORRESPOND TO THE EXISTENCE OF A NEW PARTICLE / NEW PHYSICS @ 1TeV ?

NEW PHYSICS AT ~1 TEV

HIGGS MASS $m_H \sim G_F^{-1/2}$ SHOULD BE CLOSE TO THE MAX. ENERGY ALLOWED BY THEORY $M_{PL} \sim G_N^{-1/2}$

$$M_{PL} = \sqrt{\frac{\hbar c}{G_N}}$$

$$\frac{G_N}{\hbar c} = 6.7 \times 10^{-39} \left(\frac{GeV}{c^2} \right)^{-2}$$

$$\frac{G_F}{(\hbar c)^3} = 1.16 \times 10^{-5}\ GeV^{-2}$$

&

$$\frac{G_N}{G_F} \frac{\hbar^2}{c^2} = 5.7 \times 10^{-34} \neq 1 \ !!$$

IN THE VAST MAJORITY OF UNIVERSES

$$G_F/G_N \sim 1$$

BUT THOSE HAVE NOT THE RIGHT PROPERTIES

TO DEVELOP **OBSERVERS**.

WIMPS

$$\chi\bar{\chi} \rightleftarrows SM$$

$n(t) =$ number density of χ

Rate of decrease in the number of LEFT-OVER PARTICLES IN A "COMOVING" VOLUME

$$\underbrace{n(t)\,a^3(t)}_{\#(t)\,cm^{-3}} \times \underbrace{n(t)\,\langle v\sigma\rangle_T}_{sec^{-1}} =$$

$$= n^2(t)\,a^3(t)\,\langle v\sigma\rangle_T$$

AT EQUILIBRIUM

$$= n_{EQ}^2\,a^3(t)\,\langle v\sigma\rangle_T$$

WIMPS

$$\frac{d}{dt}\left(n(t)\,a^3(t)\right) = -\left(n^2(t) - n_{EQ}^2\right) a^3(t) \langle v\sigma \rangle_T$$

$$\frac{d}{dt}(n a^3) = \left(\frac{dn}{dt}\right) a^3 + n\, 3a^2 \cdot \dot{a}$$

$$\boxed{\frac{dn}{dt} = \underbrace{-3Hn}_{\text{dilution from expanding universe}} - \left(n^2 - n_{EQ}^2\right) \langle v\sigma \rangle_T}$$

$$H(t) = \frac{\dot{a}(t)}{a(t)}$$

$$H(\text{today}) = H_0 = 100\, h\, \frac{\text{km}}{\text{Mpc}}\, \text{sec}^{-1} \quad \& \quad h \simeq 0.72$$

WIMPS AND FREEZE-OUT

$$\boxed{\frac{dn}{dt} = \underbrace{-3Hn}_{\text{dilution from expanding universe}} - (n^2 - n_{EQ}^2)\langle v\sigma\rangle_T}$$

If $T < m_\chi$, creation term is Gibbs suppressed and at

$$n\langle v\sigma\rangle = H$$

we have

$$\frac{dn}{dt} \propto -Hn$$

$$\ln n \propto -Ht$$

$$n(t) \propto e^{-Ht}$$ FREEZE-OUT

WIMPS

$$\frac{d}{dt}\left(n(t)\,a^3(t)\right) = -\left(n^2(t) - n_{EQ}^2\right) a^3(t) \langle v\sigma\rangle_T$$

$$\Big\downarrow \; t \to T$$

$$\frac{d}{dx}\,u(x) = B\left[u^2(x) - u_{eq}^2(x)\right]$$

$$x = T/m_\chi\,, \quad u = n/T^3\,, \quad B = \#\,\langle v\sigma\rangle_T\, m_\chi$$

$$\langle v\sigma\rangle_T \sim G_F^2\, m_\chi^2\, \mathcal{F}$$

SUPPOSE DM HAS WEAK INTERACTIONS

$$\frac{d}{dx} n(x) = B\left[n^2(x) - n^2_{eq}(x)\right]$$

THE PRESENT ENERGY DENSITY OF LEFT-OVER PARTS. IS

$$m_\chi n(0) T_0^3 = \rho_\chi$$

REQUIRE

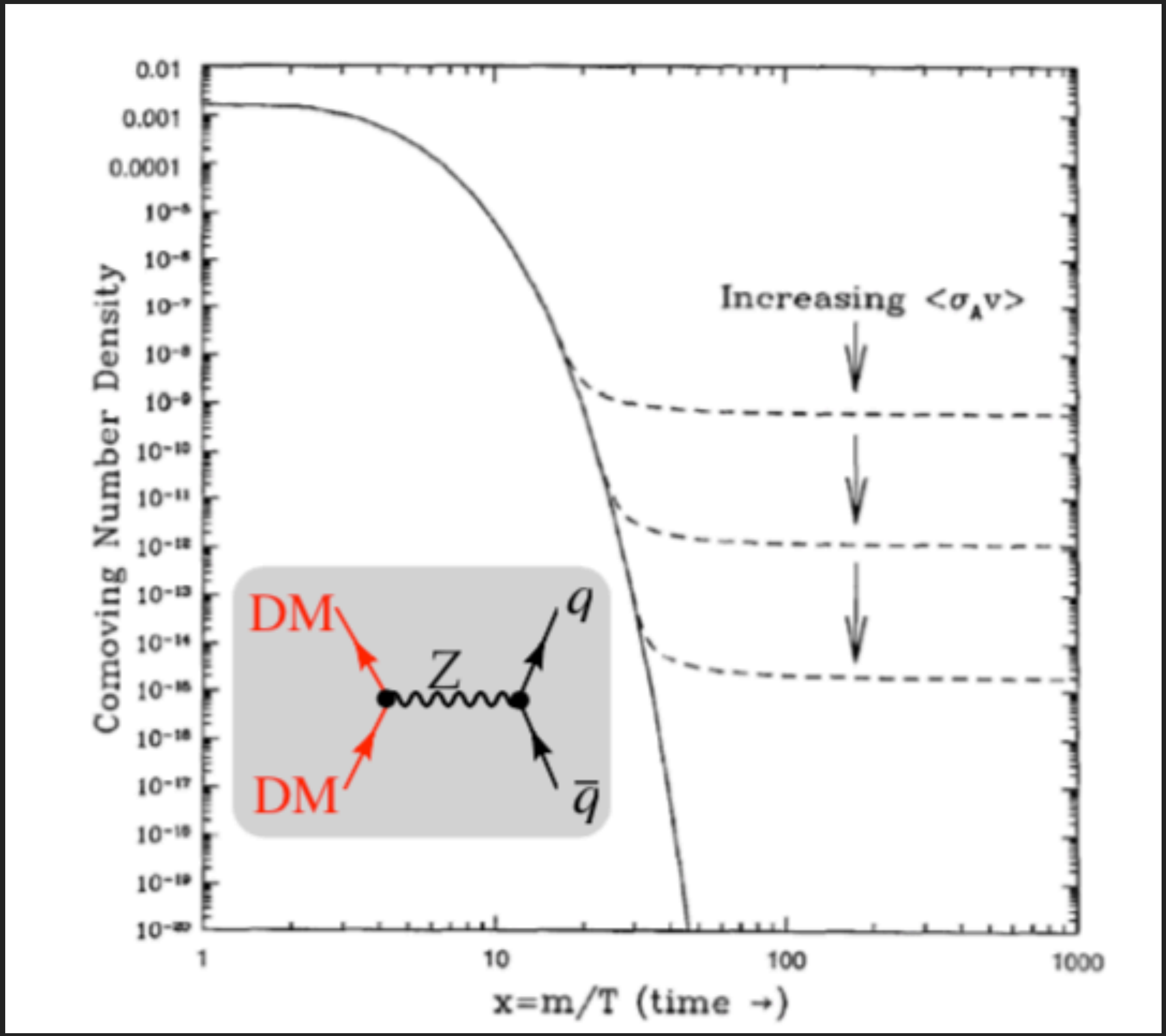
1) $\Omega_\chi = \dfrac{8\pi G_N \rho_\chi}{3H_0^2} \approx \Omega_M$

2) Solve finding $n(0) \simeq 6B^{-1}$

$$m_\chi \left(\frac{J}{\sqrt{N}}\right)^{1/2} \simeq 3.7 \left(\underbrace{\Omega_M h^2}_{0.15}\right)^{-1/2} \mathrm{GeV}$$

WIMPS & FREEZE-OUT

Larger cross section, later freeze-out, LOWER number density (today)



Correct DM density for $$\langle v\sigma\rangle \simeq 3\times 10^{-26}\,\frac{\mathrm{cm}^3}{\mathrm{sec}} \simeq \frac{1}{(20\ \mathrm{TeV})^2}$$

Dark sector interactions & mass close to the weak scale

UNNATURAL HIGGS & WIMPS

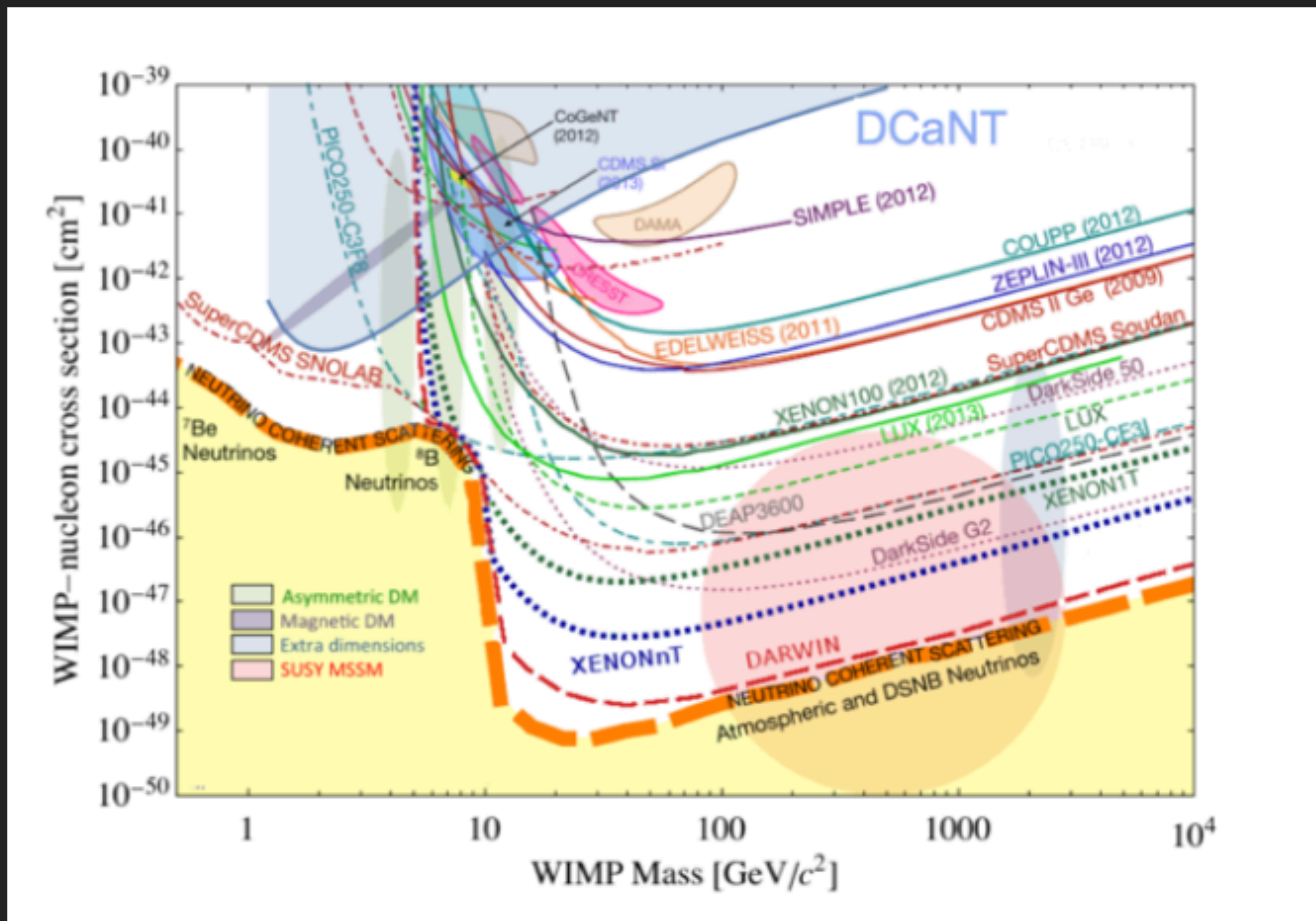
WIMPS COULD (HAVE BEEN?) BE UNDERSTOOD WITH THE SAME PHYSICS NEEDED TO CURE THE "UNNATURAL HIGGS"

SENSITIVITY

Directionality gives a better control on backgounds.

Z tree

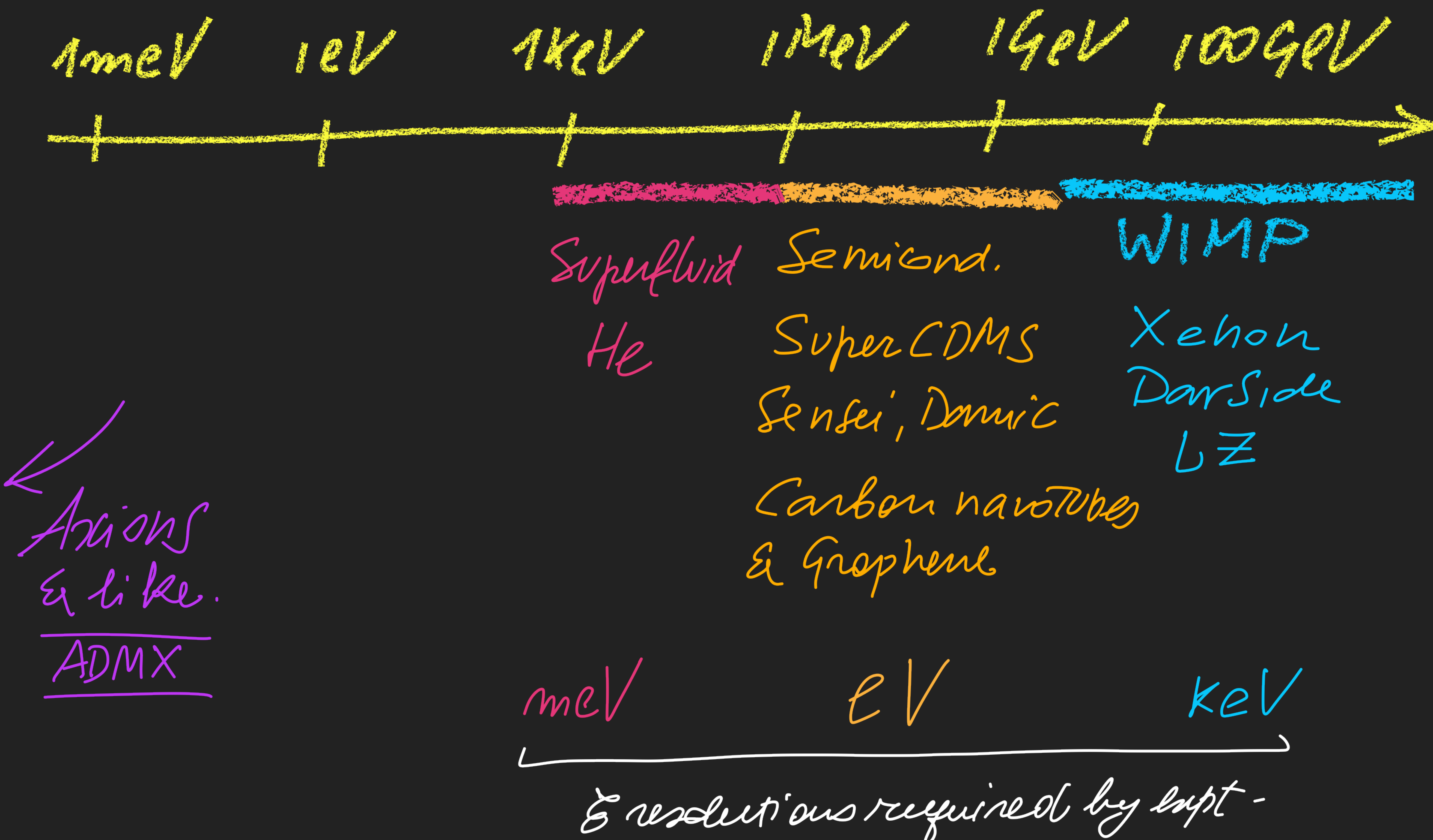
W loop



Exposure 0.4 * Kg * 1 year – output ions @ 1 keV

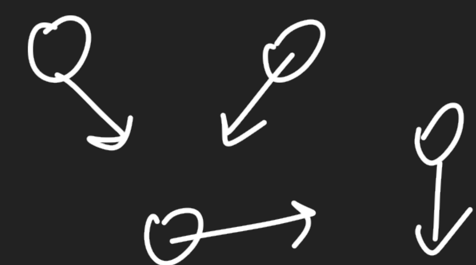
Capparelli et al. Phys. Dark Univ. 9-10 (2015) 24, ibid. Phys. Dark Univ. 11 (2016) 79;

DARK MATTER LANDSCAPE



DARK MATTER LANDSCAPE

WIMPS



(Scalars)

think in terms of waves

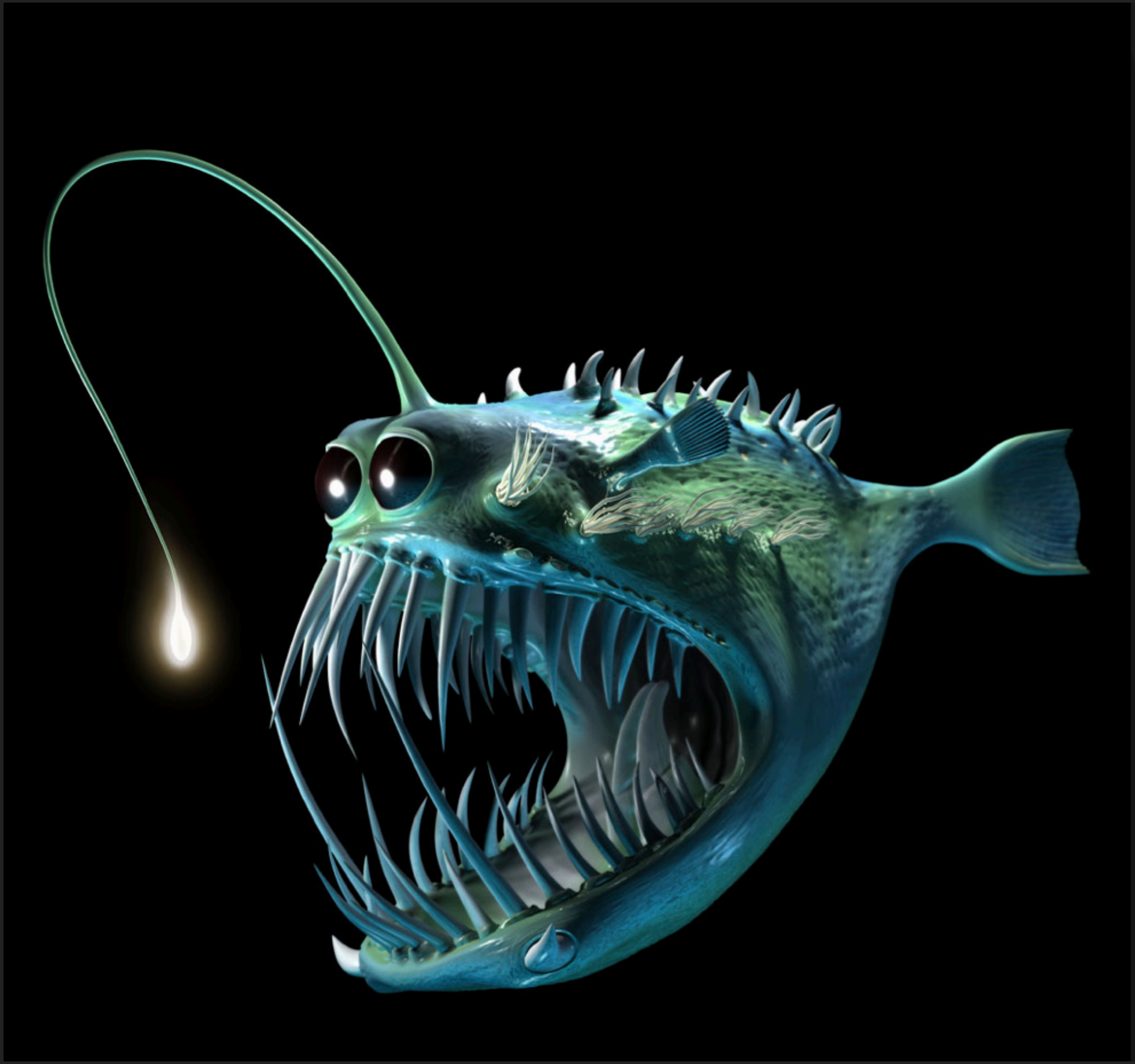
$$\lambda = \frac{\hbar}{m_\chi v}$$

decrease m_χ

(Scalar waves)

$$\phi(t) \simeq \phi_0 \cos \omega_\chi t$$

$$\omega_\chi \simeq \frac{m_\chi c^2}{\hbar} \, ; \quad \phi_0 = \sqrt{\rho_\chi} / m_\chi$$



BACKUP

WIMPS

$$\frac{d}{dt}\left(n(t)a^3(t)\right) = -\left(n^2(t) - n_{EQ}^2\right)a^3(t) \langle v\sigma\rangle_T$$

If $m_\chi \ll T$ the creation term is "on" and n_{EQ} is a solution of the eq. Thus

$$n_{EQ}\, a^3 \sim \text{const}$$

$$n_{EQ} \sim \frac{1}{a^3} \underbrace{\sim T^3}_{\substack{S(T)a^3 \sim \text{const.} \\ \text{ADIABATIC EXPANSION}}}$$

Indeed the number density in a rel. gas at thermal equilibrium is $\sim T^3$.

WIMPS

$$\frac{d}{dt}\left(n(t)\,a^3(t)\right) = -\left(n^2(t) - n_{EQ}^2\right) a^3(t) \langle v\sigma\rangle_T$$

WHEN T DROPS $T \ll m_\chi$, THE CREATION TERM IS "OFF" (GIBBS SUPPRESSED) AND WE HAVE

$$\frac{d}{dt} n a^3 = -\, n^2(t)\, a^3(t) \langle v\sigma\rangle_T$$

$$n(t)\,a^3(t) = \frac{n(t_1)\,a^3(t_1)}{1 + n(t_1)a^3(t_1)\int_{t_1}^{t} \frac{\langle v\sigma\rangle_T}{a^3(t')}\,dt'}$$

If the integral converges there are LEFT OVER PARTS.