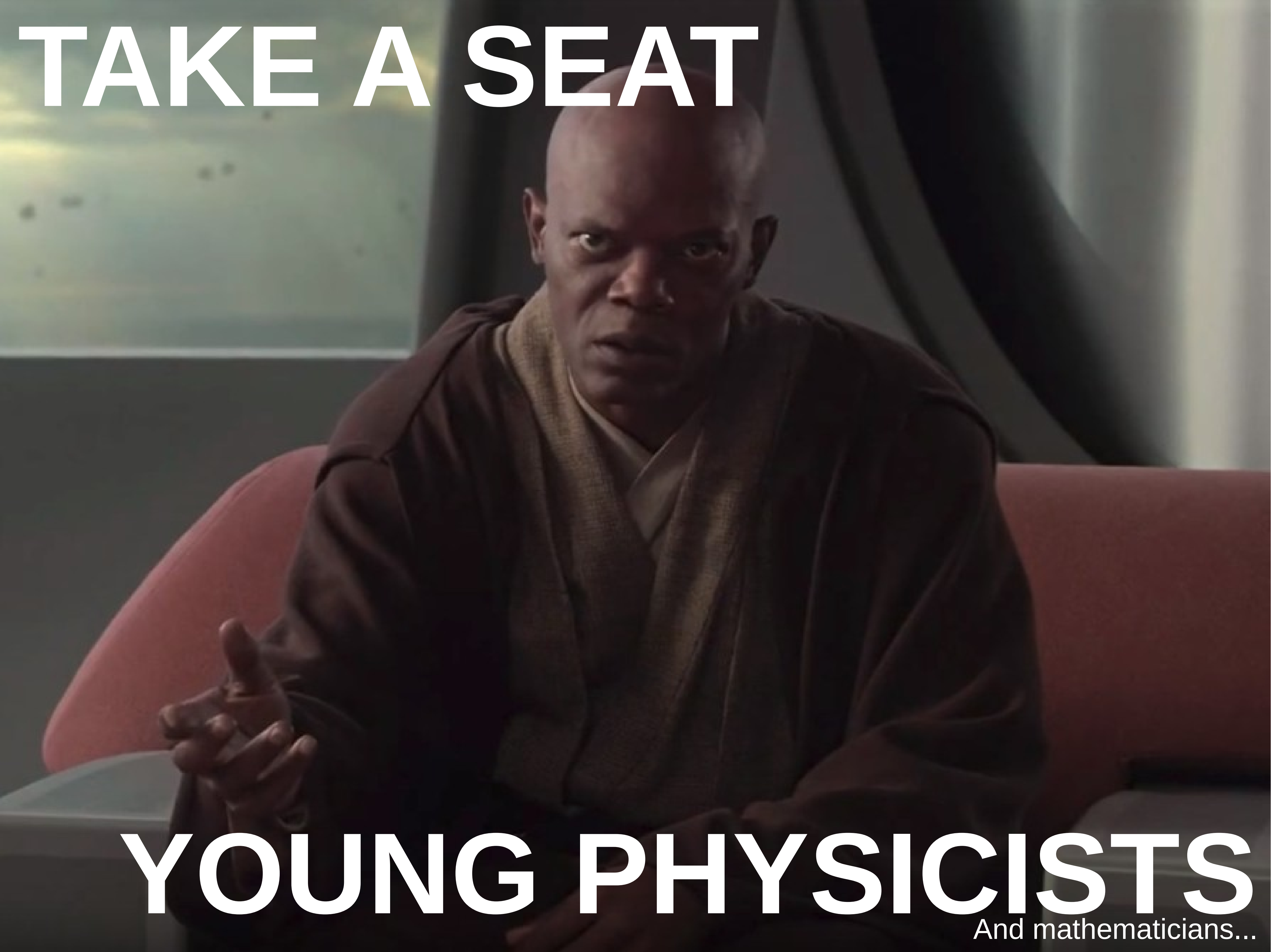
TAKE A SEAT
YOUNG PHYSICISTS
And mathematicians...

An Introduction to Higgsplosion

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An Introduction to Higgsplosion

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Split talk into three parts:

1) What is Higgsplosion?

2) Effect on RG running, with phi4 example (1709.08655)

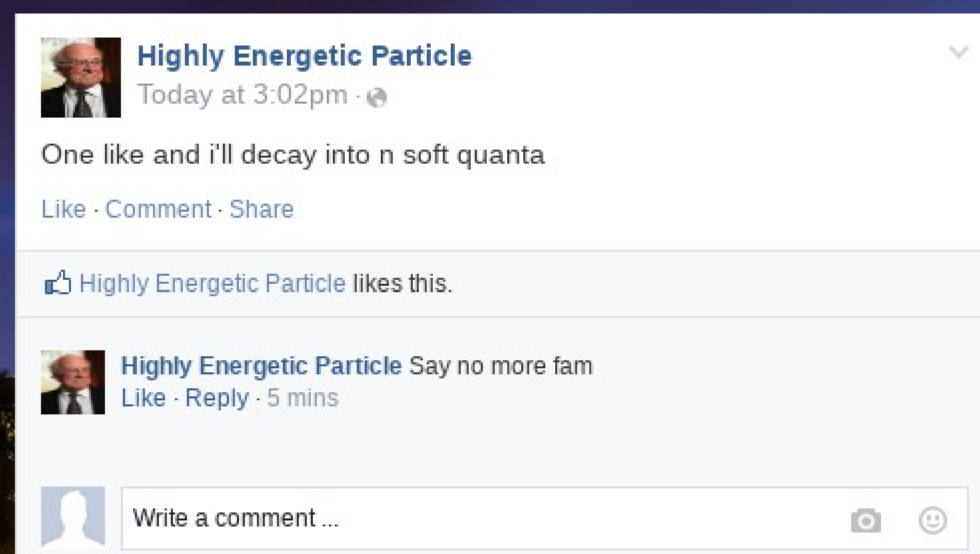
3) Higgsploding DM?

Higgsplosion a nutshell:

- Predict that highly energetic particles coupled to higgs develop exponentially growing decay rates for virtualities $p^2 > E^2_H$
- Just an expected consequence of scalar QFTs
- Nothing added to SM!

Basic Consequences:

- Distinct new phase of the theory: state of large number of soft quanta
- Loop integrals are cut off, regulating UV divs
- Sets a minimum resolvable distance $1/E_H$



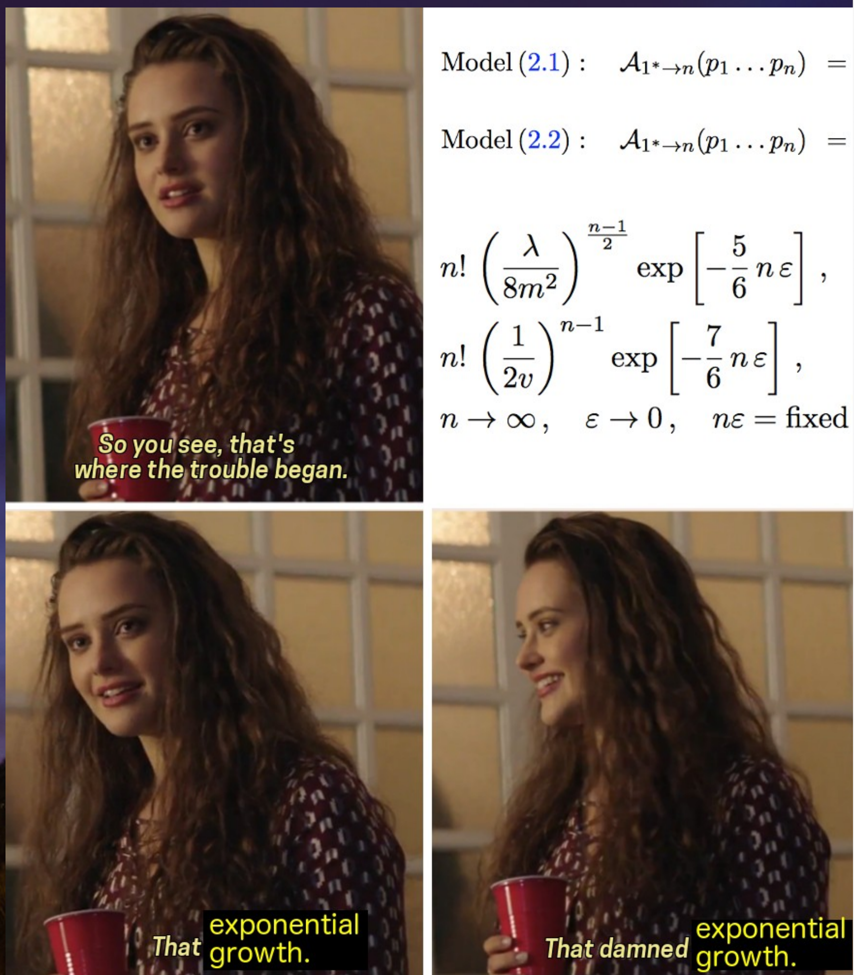
Which means…

- Theory is UV finite: couplings freeze at scale E_H
- No Landau poles, asymptotically safe
- Hierarchy problem enormously reduced
- Easier to add heavy species


This is where the fun begins.

Scalars be crazy…

- In 90s, found that scalar QFTs such as phi4 theory have exponentially growing amplitudes for 1→n threshold process
- Factorial growth of diagrams
- No destructive interference



The higgs boson is a scalar...

- Expect h→ nh to have a large amplitude

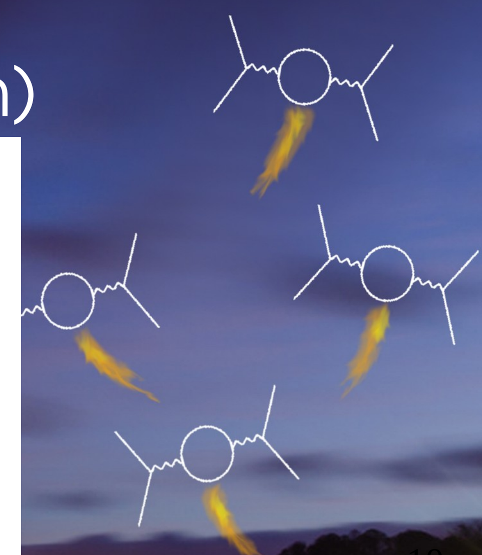
- Decay rate grows exponentially

$$\Gamma_n(s) \propto \mathcal{R}(\lambda; n, \varepsilon) = \exp\left[n \left(\log \frac{\lambda n}{4} + \frac{3}{2} \log \frac{\varepsilon}{3\pi} + \frac{1}{2} - \frac{25}{12}\varepsilon + Q(\lambda n, \varepsilon) \right) \right] .$$

- For real processes, intermediate higgs is dressed → preserve unitarity (Higgspersion)

$$\sigma^{\Delta}_{gg\to n\times h} \sim y_t^2 m_t^2 \log^4 \left(\frac{m_t}{\sqrt{p^2}} \right) \times \frac{1}{p^4 + m_h^4 \mathcal{R}^2} \times \mathcal{R}_n \,,$$

$$\sigma_{gg\to n\times h} \sim \begin{cases} \mathcal{R} & : \text{ for } \sqrt{s} \le E_* \text{ where } \mathcal{R} \lesssim 1 \\ 1/\mathcal{R} \to 0 & : \text{ for } \sqrt{s} \ge E_* \text{ where } \mathcal{R} \gg 1 \end{cases} .$$



Loop integrals and propagator:

- Can treat Γ as a going from 0 → inf at $p^2=E_H^{\ 2}$
  → propagator has a heaviside factor $\Theta(p^2-E_H^{\ 2})$
  → closing loop introduces p integral which is cut-off

$$\Delta_R(x,x) = \int_{p^2 \leq E_*^2} \frac{d^4p}{(2\pi)^4} \frac{1}{p^2+m^2} .$$

$$\Delta(x) := \langle 0|T(\phi(x)\,\phi(0))|0\rangle \sim \begin{cases} m^2\, e^{-m|x|} & : \ \text{for } |x| \gg 1/m \\ 1/|x|^2 & : \ \text{for } 1/E_* \ll |x| \ll 1/m \\ E_*^2 & : \ \text{for } |x| \lesssim 1/E_* \end{cases}$$

Higgsplosion scale:

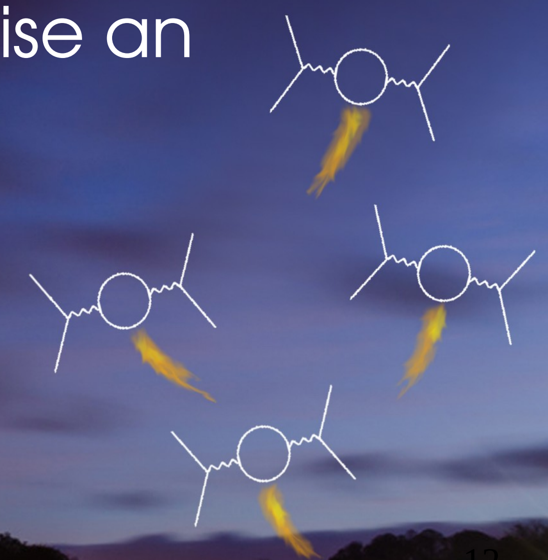
- By dimensional grounds:

$$E_* = \frac{m_h}{f(\lambda)}\,, \qquad \text{where} \quad f(\lambda)|_{\lambda\to 0} \to 0\,.$$

- Similar to sphaleron where: $M_{\rm sph} = \text{const}\,\frac{m_W}{\alpha_w}\,.$

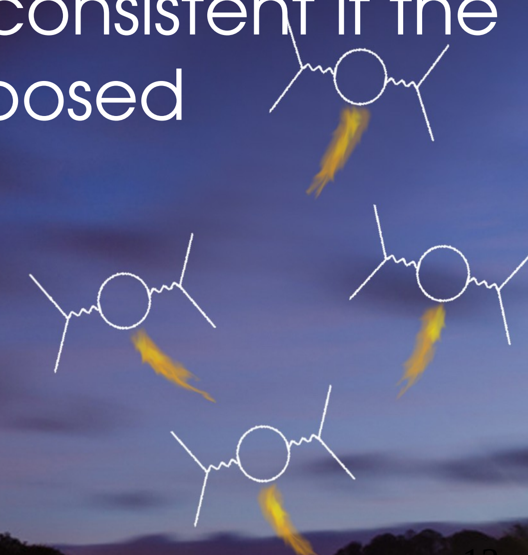
- Both non-perturbative and semiclassical in nature

- Not in Lagrangian, but rather characterise an energy scale for a transition



Aim for this next part:

- Based on parts of (1709.08655)
- The exponential stuff done in 90s from a maths perspective: an interesting feature of scalar QFTs
- Now we have a scalar – can we apply to SM?
- Need to check if their 90s calcs are still consistent if the propagators/loops are affected as proposed



Review of Brown's method (1/2):

- Scalar phi4 with source, LSZ reduction:

$$\mathcal{L} = -|\partial\phi|^2/2 - m^2\phi^2/2 - \lambda\phi^4/4! + \rho\phi$$

$$\langle n|\phi(x)|0\rangle = \prod_{a=1}^{n} \int (d^4x_a) e^{-ip_a x_a} (p_a^2 + m^2) \frac{\delta}{\delta\rho(x_a)} \langle 0+|\phi(x)|0-\rangle^{\rho} |_{\rho=0}$$

- For tree level, generating function is classical solution: $\langle 0+|\phi(x)|0-\rangle^{\rho} \rightarrow \phi_{cl}(x)$

Review of Brown's method (2/2):

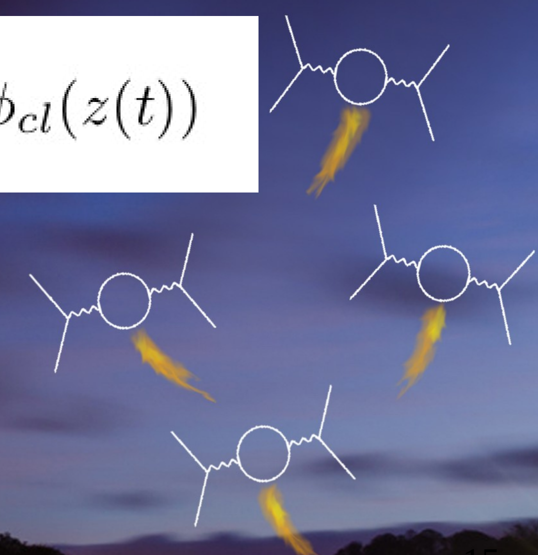
- Momenta vanish on threshold

- Can impose spatial uniformity in this limit:

$$\vec{p}_a = 0, \text{ so } \rho(x), \phi_{cl}(x) \to \rho(t) \equiv \rho_0 e^{i\omega t}, \phi_{cl}(t)$$

- Find that $\phi_{cl}(t) = \phi_{cl}(z(t))$ and therefore LSZ reduces to ODE:

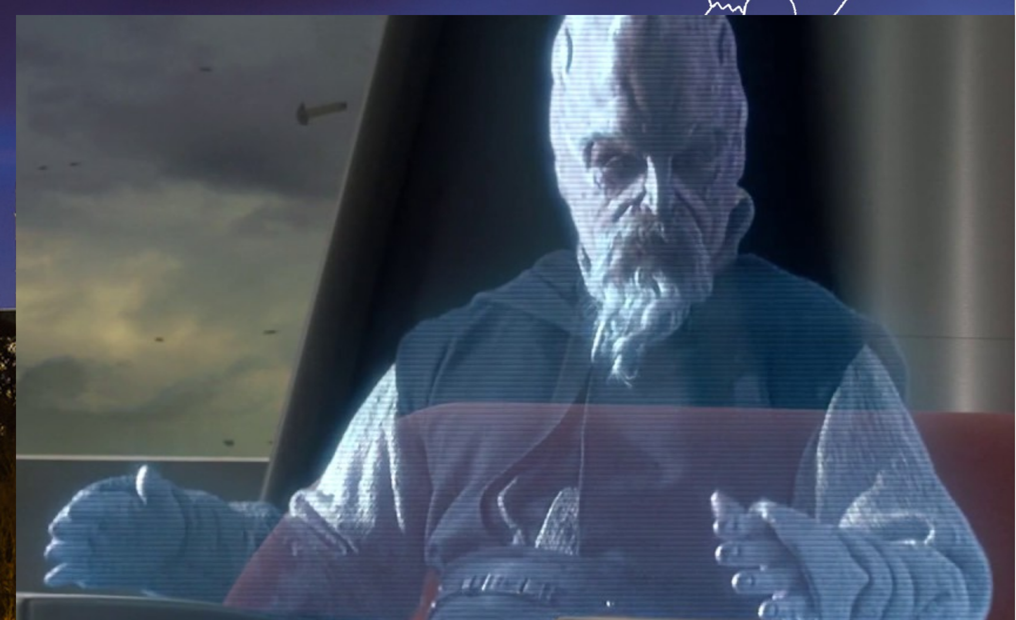
$$\int (d^4 x_a) e^{-ip_a x_a} (p_a^2 + m^2) \frac{\delta}{\delta \rho(x_a)} \phi_{cl}(t; [\rho]) = \frac{\partial}{\partial z_0} \phi_{cl}(z(t))$$



$$\langle n|\phi(0)|0\rangle^{tree}_{threshold} = \left(\frac{\partial}{\partial z}\right)^n \phi_{cl}|_{z=0}$$

Comments on Brown:

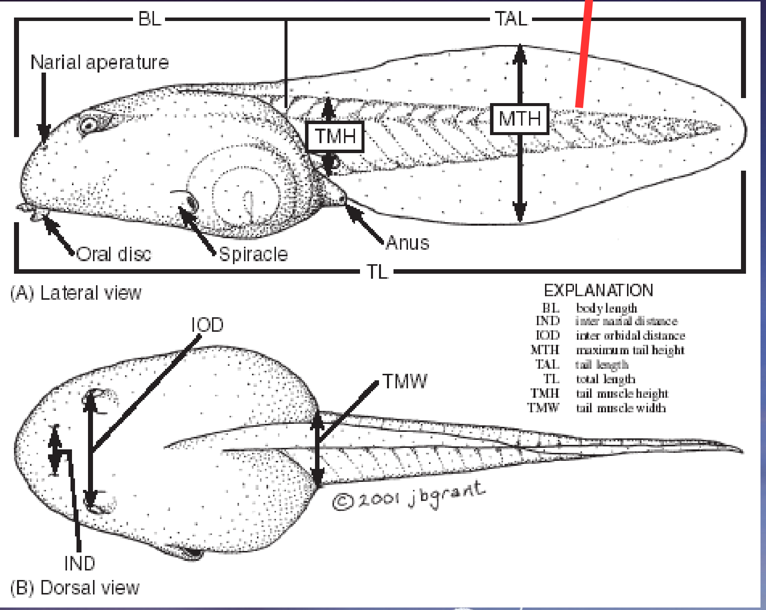
- Only tree level
- Higgsplosion boils down to cutting off loop momenta integrals → no effect on tree level
- Only for simple scalar sector… what about the fermions' effect on the decay rate?
- Threshold PS is zero



“Oh I'm not brave enough for 1-loop calculations...”

Brief summary of Voloshin:

- Expand QM corrections around classical $\langle \phi \rangle = \phi_0 + \langle \phi_q \rangle$
- Use mixed space rep
$$\langle n|\phi|0\rangle = \left(\frac{\partial}{\partial z_0}\right)^n (\phi_0 + \langle \phi_q \rangle)\,\Big|_{z_0=0}\,.$$
- Clever time shift and rotation to make it look like a known QM example…
- Lots of dry maths



Enter Higgsplosion:

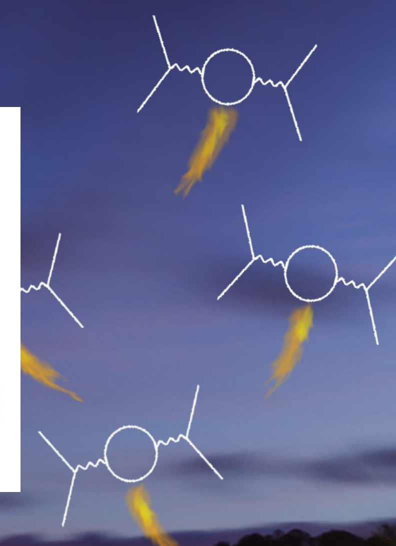
- Ultimately Voloshin finds:

$$G(x,x) = \frac{1}{16\pi^2}\left(E_*^2 - m^2 \log\frac{E_*^2}{m^2}\right) - \frac{1}{2\pi^2}\frac{3\lambda\phi_0^2}{8}\left(\log\frac{E_*^2}{m^2}+1\right) - \frac{3\lambda^2\phi_0^4}{32}F\,.$$

- Absorb divergences in renormalisation

- Higgsplosion scale enters as the cut-off to these divergences

$$\bar{\lambda}_* = \lambda - \frac{9\lambda^2}{8\pi^2}\left(\log\frac{E_*}{m}+\frac{1}{2}\right),$$
$$\bar{m}_*^2 = m^2 + \frac{3\lambda}{16\pi^2}\left(E_*^2 - m^2\log\frac{E_*^2}{m^2}\right),$$

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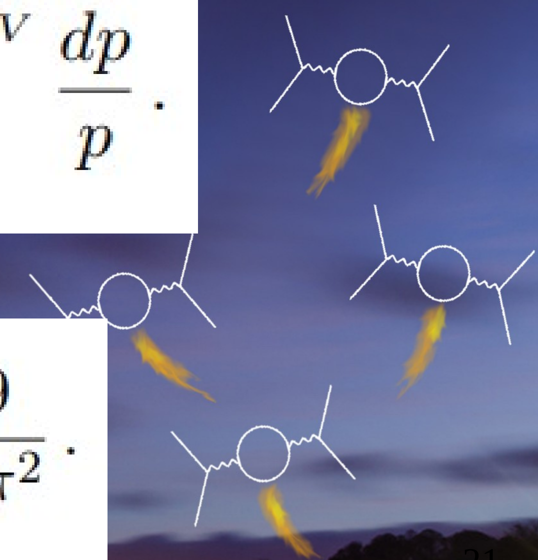
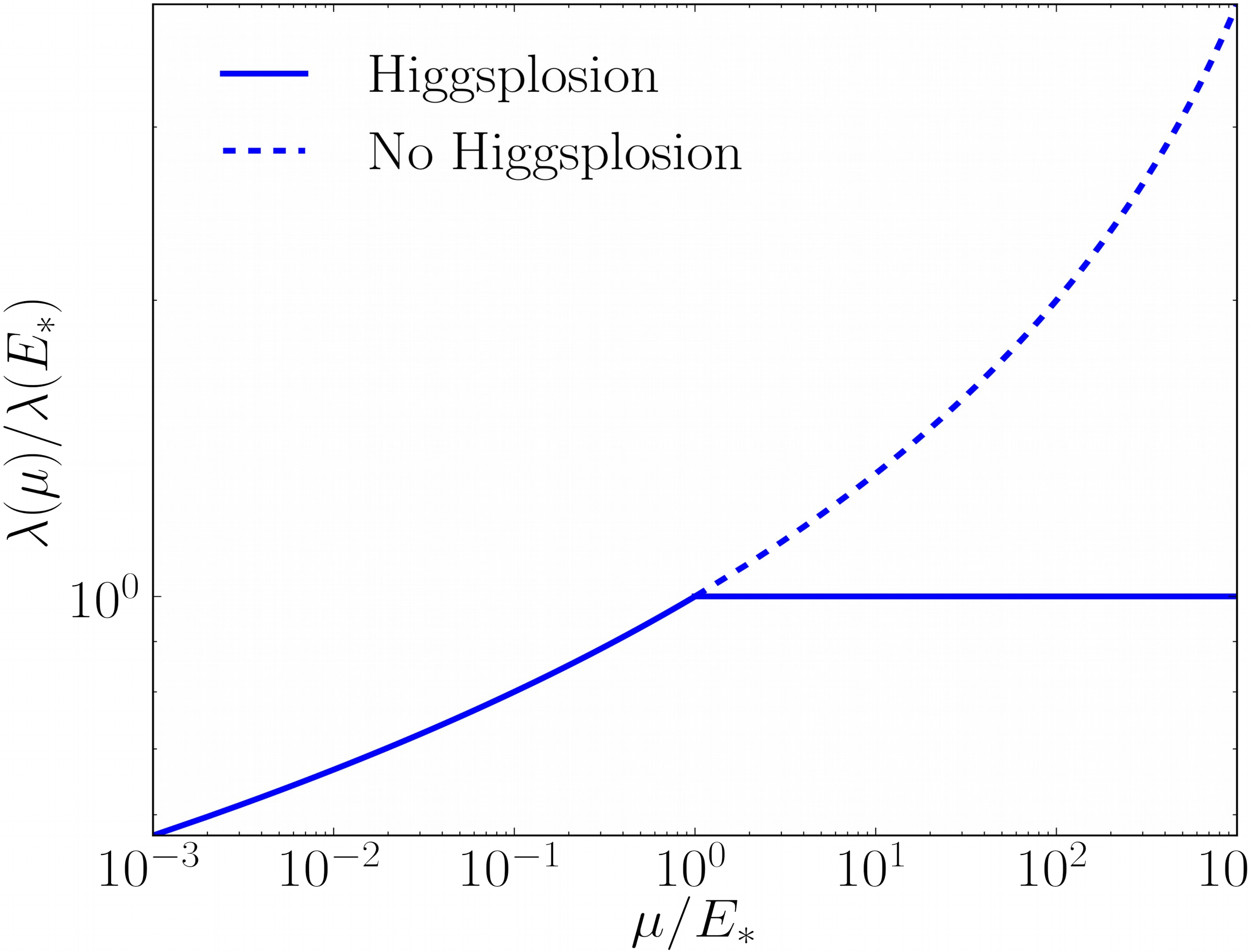
Running of coupling:

- Cut-off is now physically significant!
- Any corrections to finite terms sub-leading
- In RG, Higgsplosion freezes evolution at E_H

$$1/\lambda(\mu) = 1/\lambda(\Lambda_{UV}) + \frac{9}{8\pi^2}\int_{\mu}^{\Lambda_{UV}} \frac{dp}{p} .$$

$$\lambda(\mu) = \frac{1}{\beta_0 \log\left(\frac{\Lambda_{LP}}{\mu}\right)} \quad , \quad \beta_0 = \frac{9}{8\pi^2} .$$




Higgsplosion
No Higgsplosion
$\lambda(\mu)/\lambda(E_*)$
10^0
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
μ/E_*

A surprise, to be sure, but a welcome one:

- Fixed UV point, conformal symmetry
- No Landau poles, asymptotic safety
- Probably not great for GUTs...

Summary & exponentiation

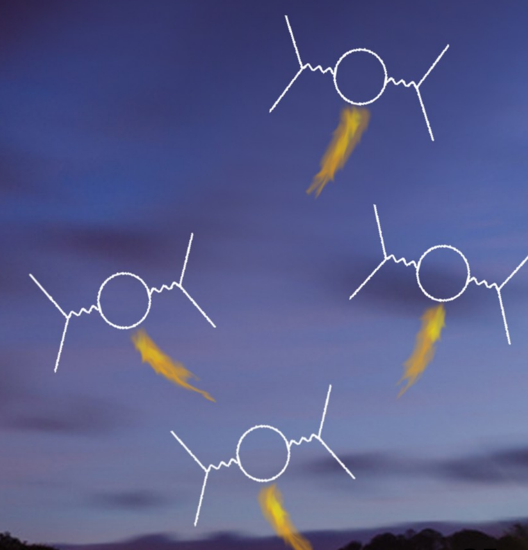
- Finite terms more-or-less unaffected in 1-loop correction

  → Libanov's 1994 exponentiation still valid
  → important for using **semi-classical** methods in non-perturbative regime

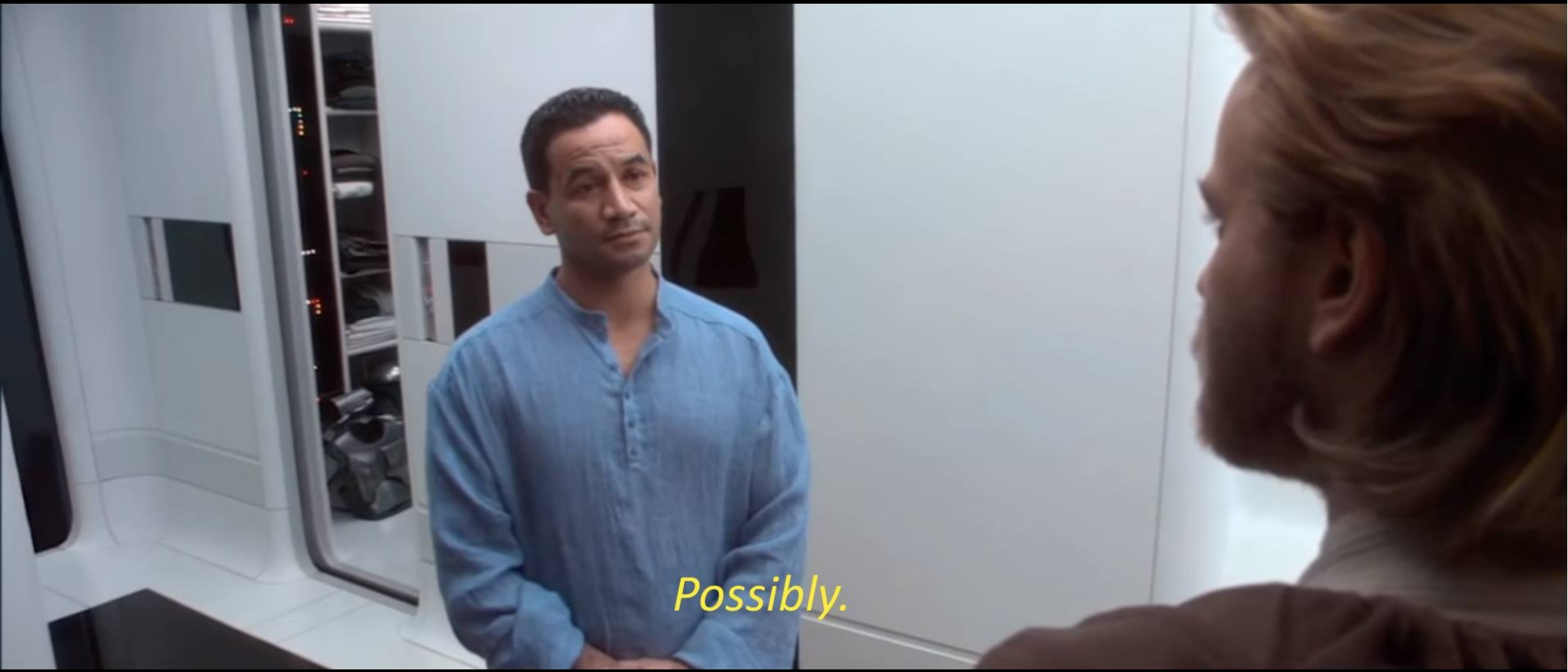
- This is just phi4, need to add vector & top loops etc

- But looks alright so far

Can we have a singlet scalar DM that higgsplodes?




Yep


Possibly.

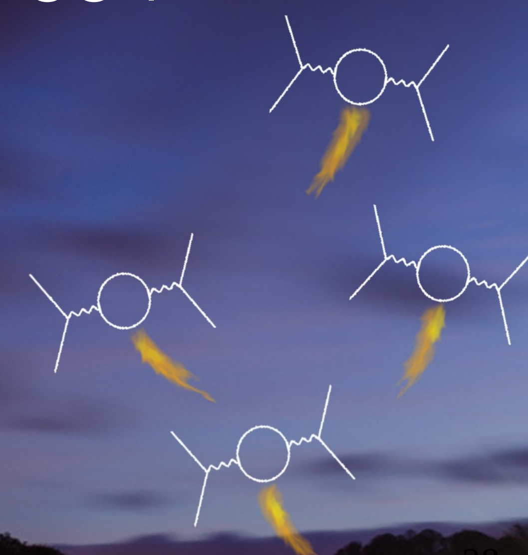
Just a singlet scalar & higgs portal…

- Keep it simple

$$\mathcal{L} = \mathcal{L}_{SM} + \partial_\mu X^\dagger \partial^\mu X - m_0^2 X^\dagger X - \frac{\lambda_X}{4}\left(X^\dagger X\right)^2 - \lambda_{HX}\left(X^\dagger X\right)\left(H^\dagger H\right).$$

- Assume $\lambda_X << \lambda_{HX}$ and m^2_0 small so that m_X is dominated by higgs bubble diagram $m_X \approx \sqrt{\lambda_{HX}}\frac{E_H}{4\pi}.$

- So now DM mass, portal coupling and Higgsplosion scale linked - only 2 free paramaters!



Standard freeze out stuff:

- Follow the standard recipe

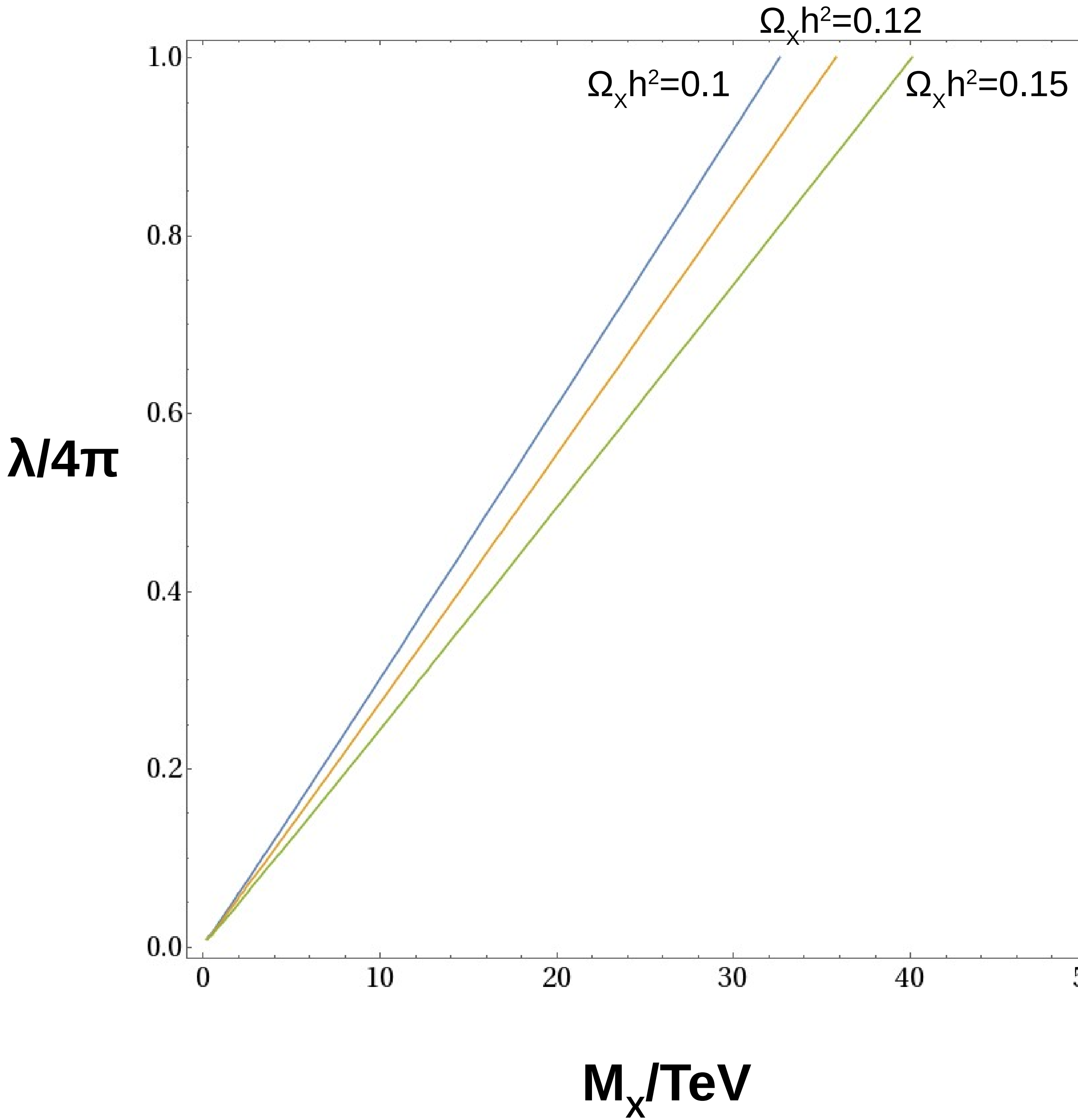
$$\Omega_X h^2 = \frac{(1.07 \times 10^9) x_f}{\sqrt{g_*} M_{PL} \mathrm{GeV} \langle \sigma_{ann} v_{rel} \rangle},$$

$$x_f \simeq \ln \left[\frac{0.038 M_{PL} m_X \langle \sigma_{ann} v_{rel} \rangle}{\sqrt{g_* x_f}} \right].$$

- At $m_X > m_{SM}$, annihilation dominated by $hh, W_L W_L, Z_L Z_L \rightarrow$ just $h_{1,2,3,4}$

$$\langle \sigma_{ann} v_{rel} \rangle \approx \frac{\lambda_{HX}^2}{16 \pi m_X^2}.$$

- Demand Planck relic denisty $\Omega_X h^2 = 0.12$, reducing to 1 free parameter: m_X



$\Omega_X h^2$=0.12
$\Omega_X h^2$=0.1
$\Omega_X h^2$=0.15
λ/4π
M_X/TeV

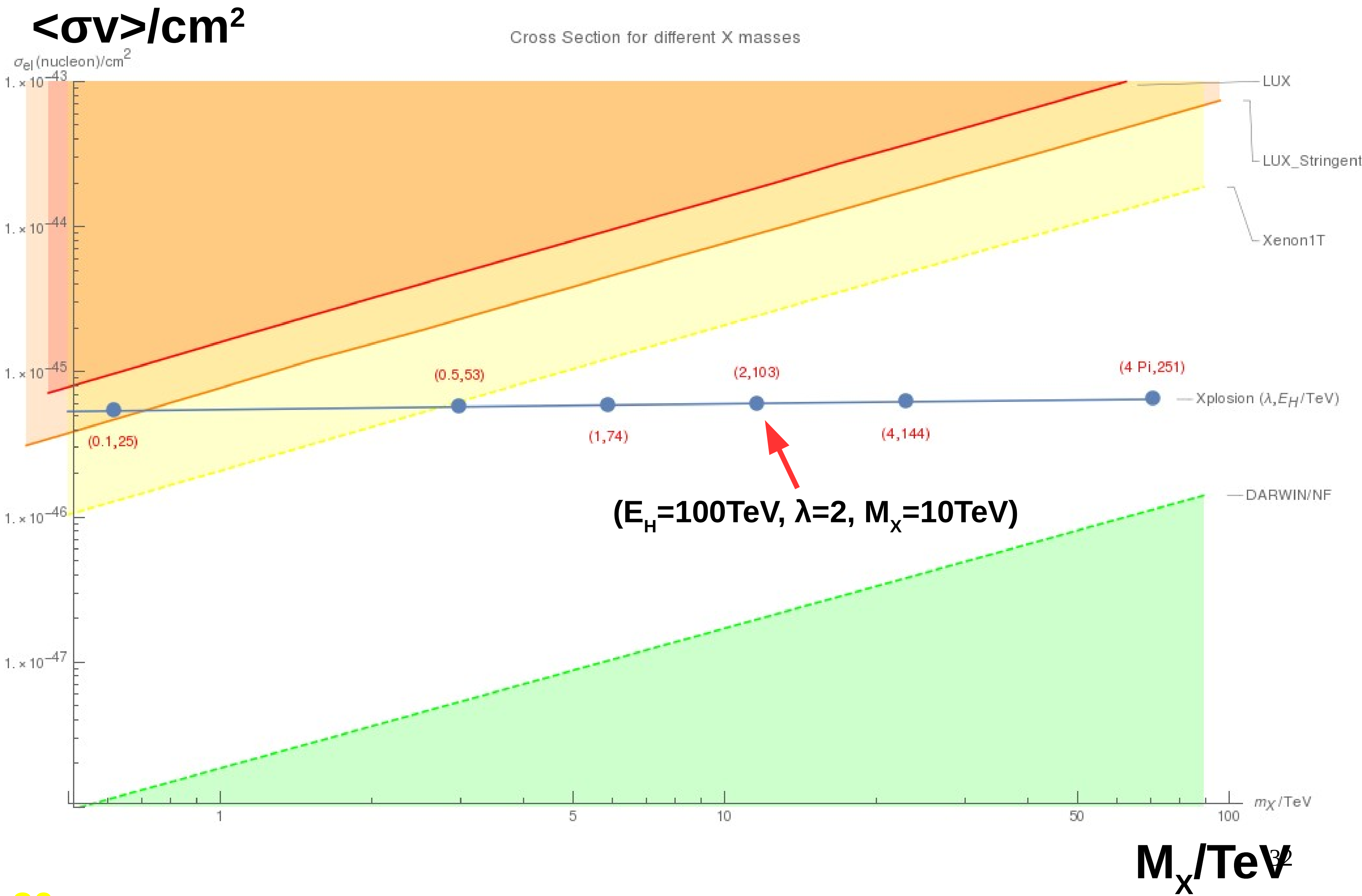
Direct detection:

- Elastic collision via higgs exchange:

$$\sigma_{el} = 4\lambda_{HX}^2 \left(\frac{100\text{GeV}}{m_h = 125\text{GeV}} = 0.8 \right)^4 \left(\frac{50\text{GeV}}{m_X} \right)^2 (20 \times 10^{-42}\text{cm}^2).$$

- Demand 'perturbative' coupling, limiting solutions to a line segment!

- Plot with present and projected constraints from LUX, XENON-1T and DARWIN


<σv>/cm²
Cross Section for different X masses
σel (nucleon)/cm2
1. × 10−43
1. × 10−44
1. × 10−45
1. × 10−46
1. × 10−47
LUX
LUX_Stringent
Xenon1T
(0.5,53)
(2,103)
(4 Pi,251)
Xplosion (λ,EH/TeV)
(0.1,25)
(1,74)
(4,144)
(EH=100TeV, λ=2, MX=10TeV)
DARWIN/NF
1
5
10
50
100
mX/TeV
MX/TeV

I don't like indirect detection…

Summary:

- Higgsploding DM can be fine, even at most primitive level
- In this case, still have small hierarchy problem
- Interesting to see: adding fermions, relaxing coupling assumption → introducing important direct X self interactions

It's time for the talk to end...