A Higgslike Dilaton and Conformal Phase Transition

Oleg Antipin

CP3 - Origins

Particle Physics & Origin of Mass

Corfu Summer Institute 2013

Goal

If electroweak symmetry is broken dynamically, need to explain

$$\frac{m_h}{4\pi v} = \frac{125GeV}{4\pi \times 246GeV} = 0.04 \ll 1$$

[In QCD: $\frac{m_\pi}{4\pi\Lambda_{QCD}} \sim 0.06$]

- Evidence of a "hidden" symmetry ?

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The higgs:
A dilaton

The Model

O. Antipin, M. Mojaza, F. Sannino - hep-ph/1107.2932

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$$\mathcal{L} = -\frac{1}{2}\mathrm{Tr}F^2 \quad + \sum_j^{N_f} i\overline{\psi}_j \not{D}\psi_j \quad + i\lambda^a \sigma^\mu D_\mu^{ab} \overline{\lambda}^b$$

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Higgs-sector

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U(N_f) x U(N_f) massless linear sigma model coupled to the fermions

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Notice that there is no mass term for the "H" field so that the model is classically conformal at the tree level

Infrared Destiny

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1-loop beta functions:

$$\beta(a_g) = -2a_g^2\left[3 - \frac{2x}{3} + \left(6 - \frac{13x}{3}\right)a_g + x^2 a_H\right]$$

$$\beta(a_H) = 2a_H\left[(1+x)\,a_H - 3a_g\right]$$

$$\beta(z_1) = 4(z_1^2 + 4z_1 z_2 + 3z_2^2 + z_1 a_H)$$

$$\beta(z_2) = 4(2z_2^2 + z_2 a_H - \frac{x}{2}a_H^2),$$

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Fixed point (simultaneous zero of the beta functions)

$$x \equiv \frac{N_f}{N_c} = \frac{9}{2}(1-\epsilon)$$

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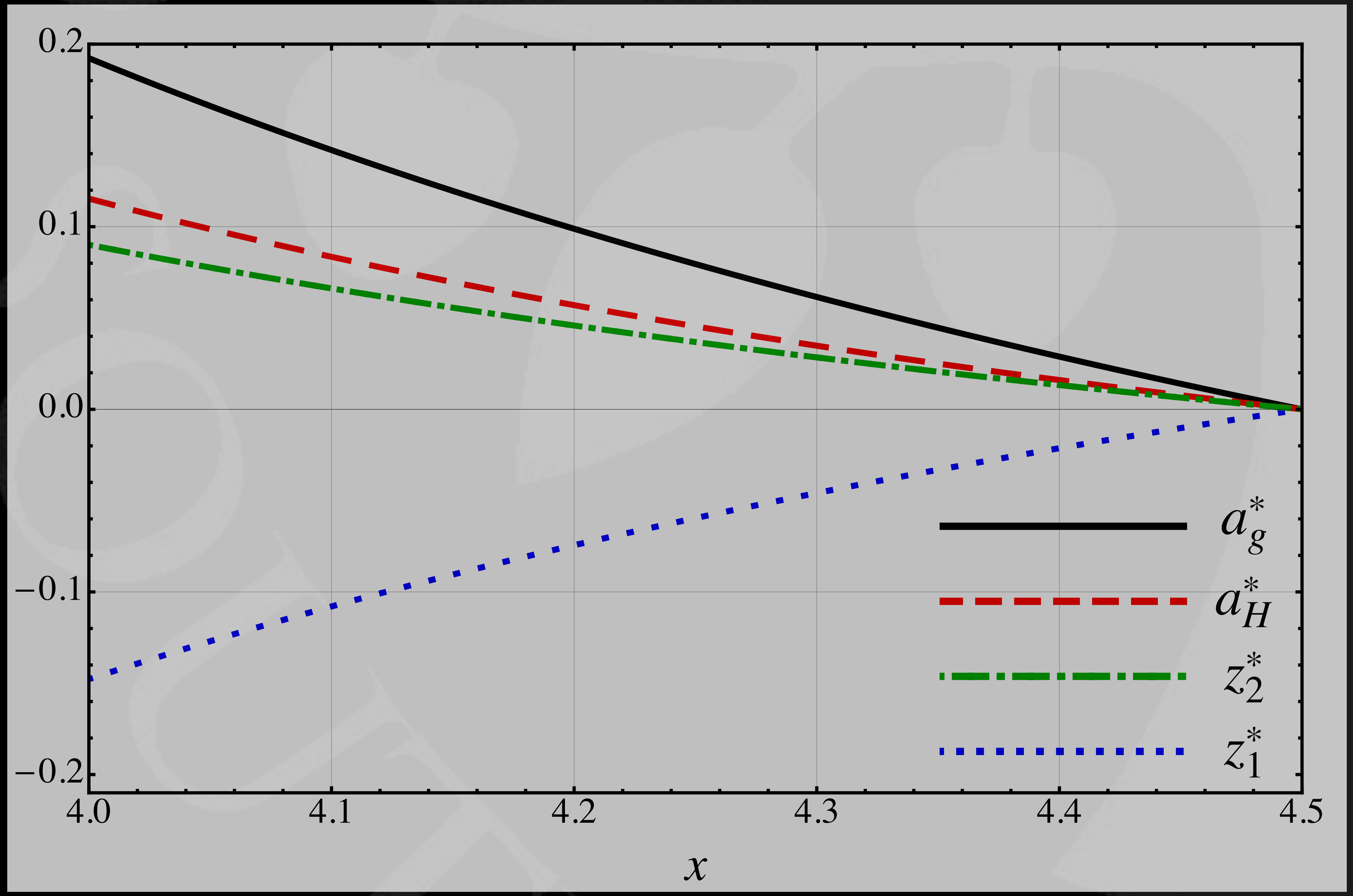

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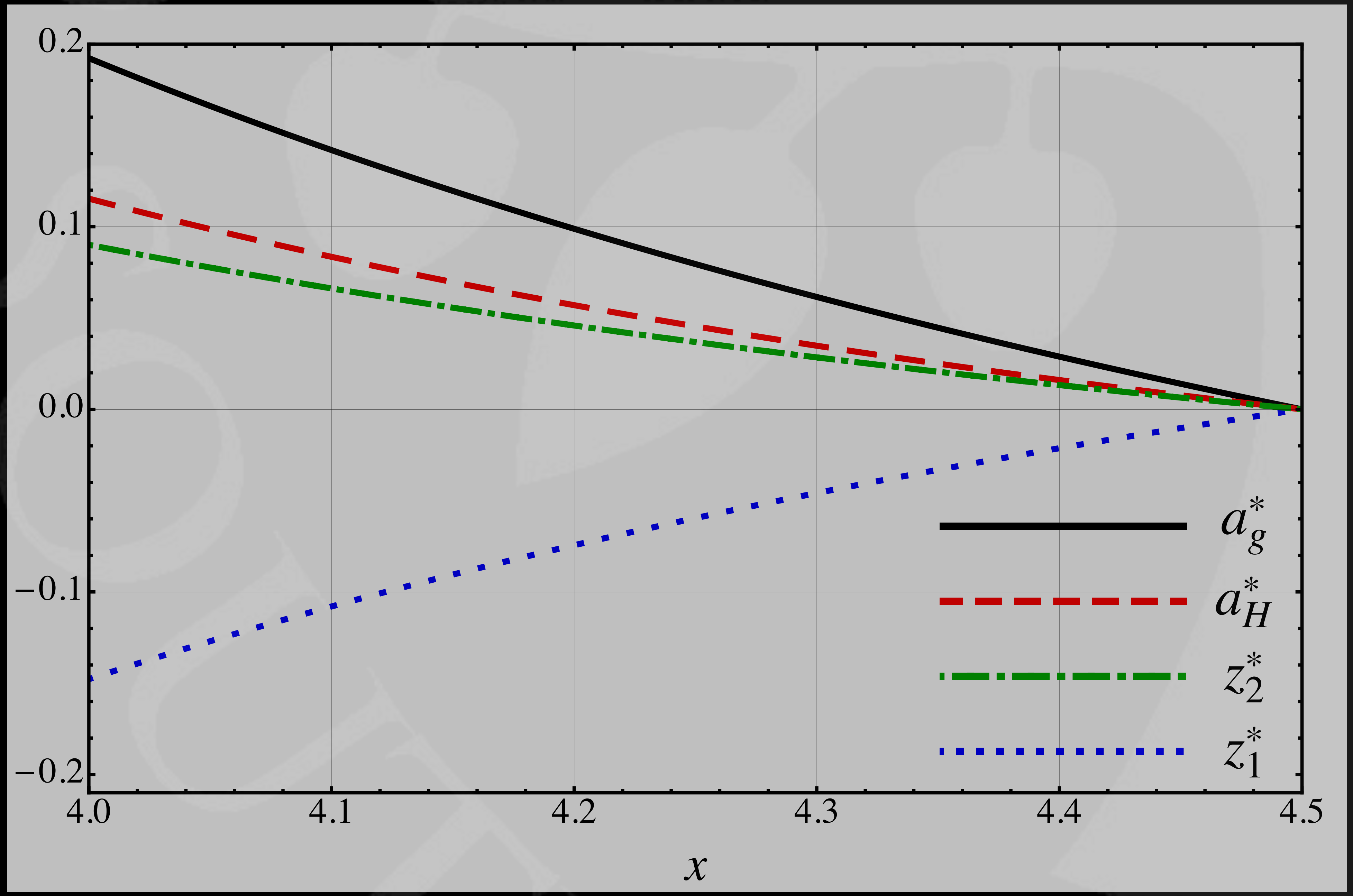

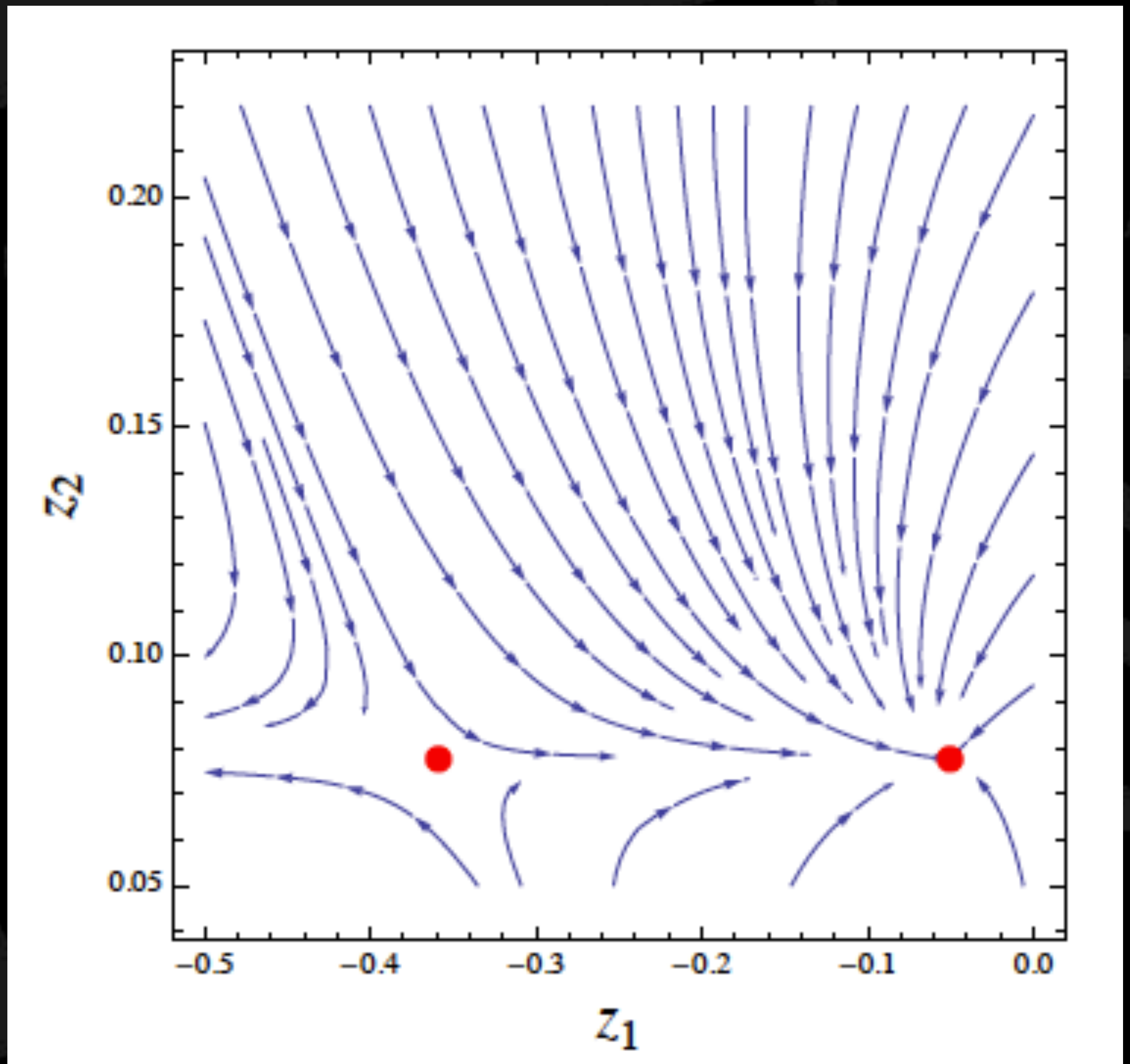

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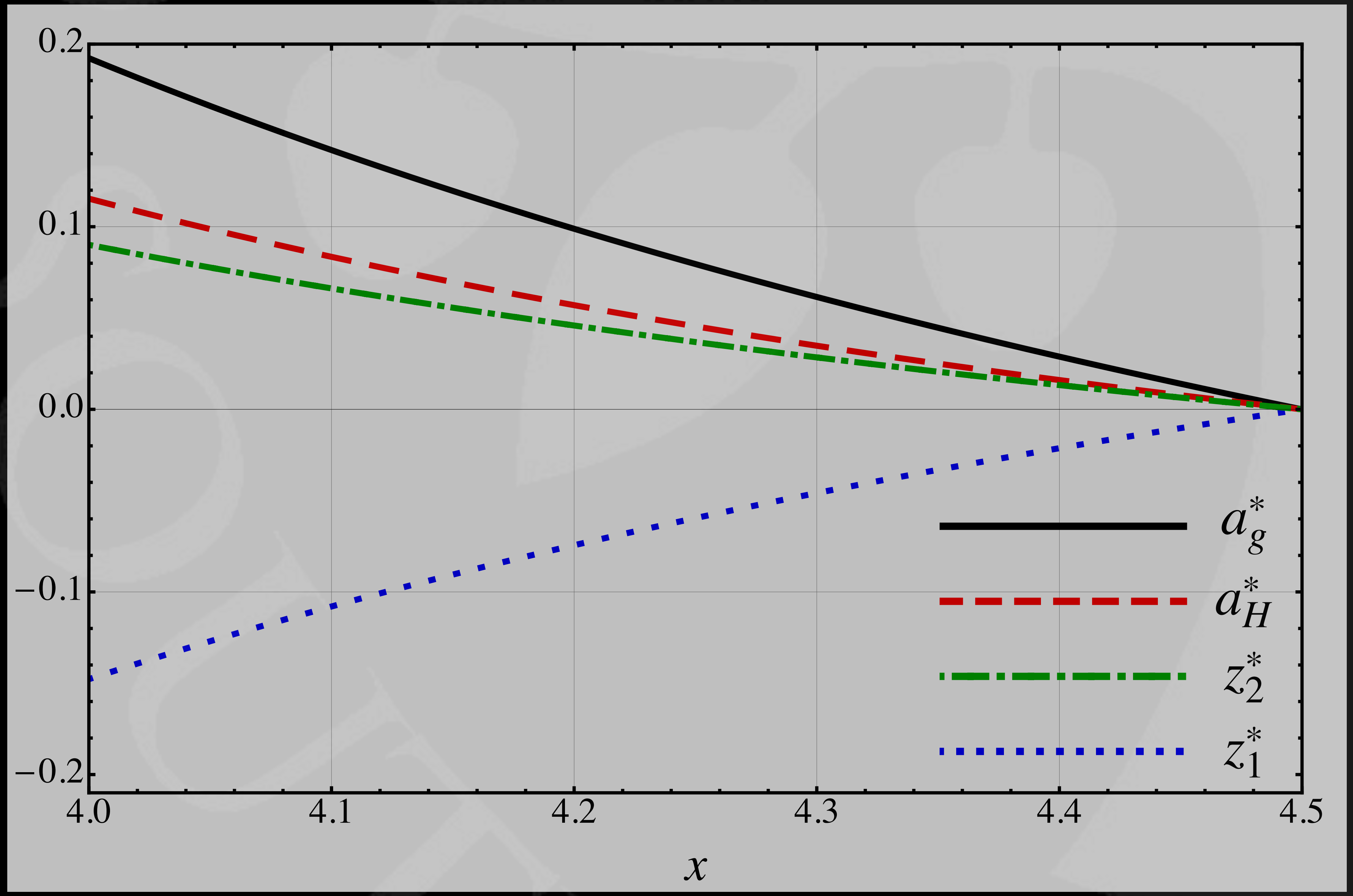

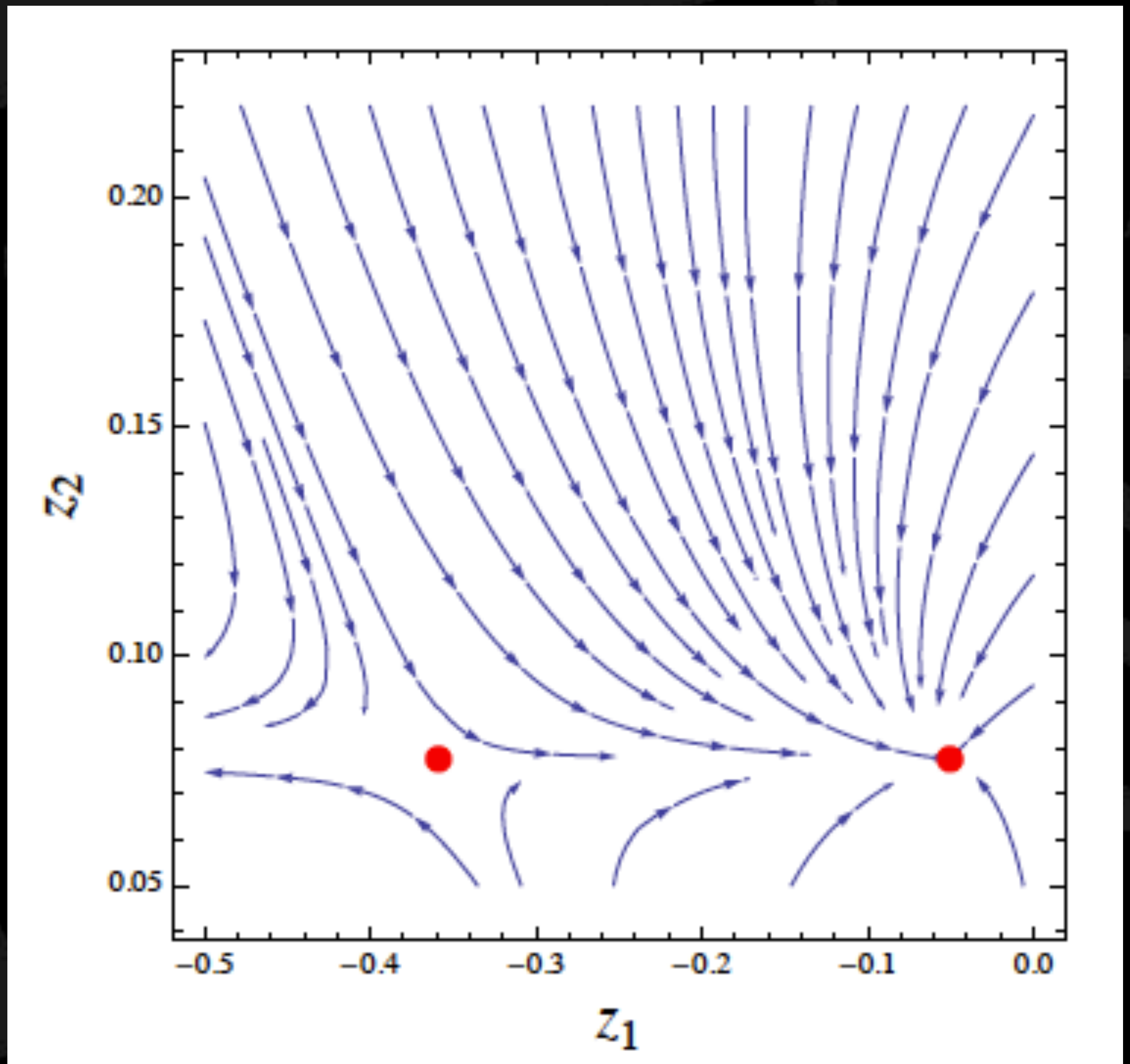

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This FP can become "hidden" by spontaneous symmetry breaking from radiative corrections (Coleman-Weinberg mechanism)

Spontaneous Symmetry Breaking

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Stability of the scalar potential is not encoded in the perturbative RG flow

Idea: Minimize tree-level potential so that 1-loop correction will dominate and test stability

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Stability of global minimum (flat direction)

$$U(N_f)_L \times U(N_f)_R$$

$$H' = U_L H U_R = diag(h_1, \ldots, h_{N_f})$$

$$U(N_f) \times U(N_f) \to U(N_f)$$

A. If $z_2(\mu) > 0$ and $z_1(\mu) + z_2(\mu) \leq 0 \Rightarrow V|_{\text{min}} = V(h_1, \ldots, h_1)$,

Classical background field:

$$H^c_{ij} = \langle 0|H_{ij}|0\rangle = \phi_c \delta_{ij}$$

$$H_{ij} \approx \frac{1}{\sqrt{2N_f}}(\phi_c + \phi + i\pi^0)\delta_{ij} + h_{ij} + i\pi_{ij}$$

NGB's

pNGB of broken scale-invariance

Now, we have to test that ϕ_c actually obtains a vev from 1-loop corrections to potential...

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Coleman-Weinberg mechanism solely controlled by beta functions

H. Yamagishi, 1980

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Tree-level potential: $V_{\mathrm{eff}}^{RG} \sim [z_1(t) + z_2(t)]\phi_c^4$ $\qquad \frac{d\bar{g}_i}{dt} \equiv \frac{\beta_i(g_i)}{1-\gamma_\phi(g_i)}, \qquad t \equiv \ln\frac{\phi_c}{\mu}$

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Region of SSB: $V_{\mathrm{eff}}^{\mathrm{RG}}(\phi_c) < 0 \quad \text{and} \quad V_{\mathrm{eff}}^{\mathrm{RG}\prime\prime}(\phi_c) = {m_\phi^{(1)}}^2 \propto 4z_2^2 - x a_H > 0$

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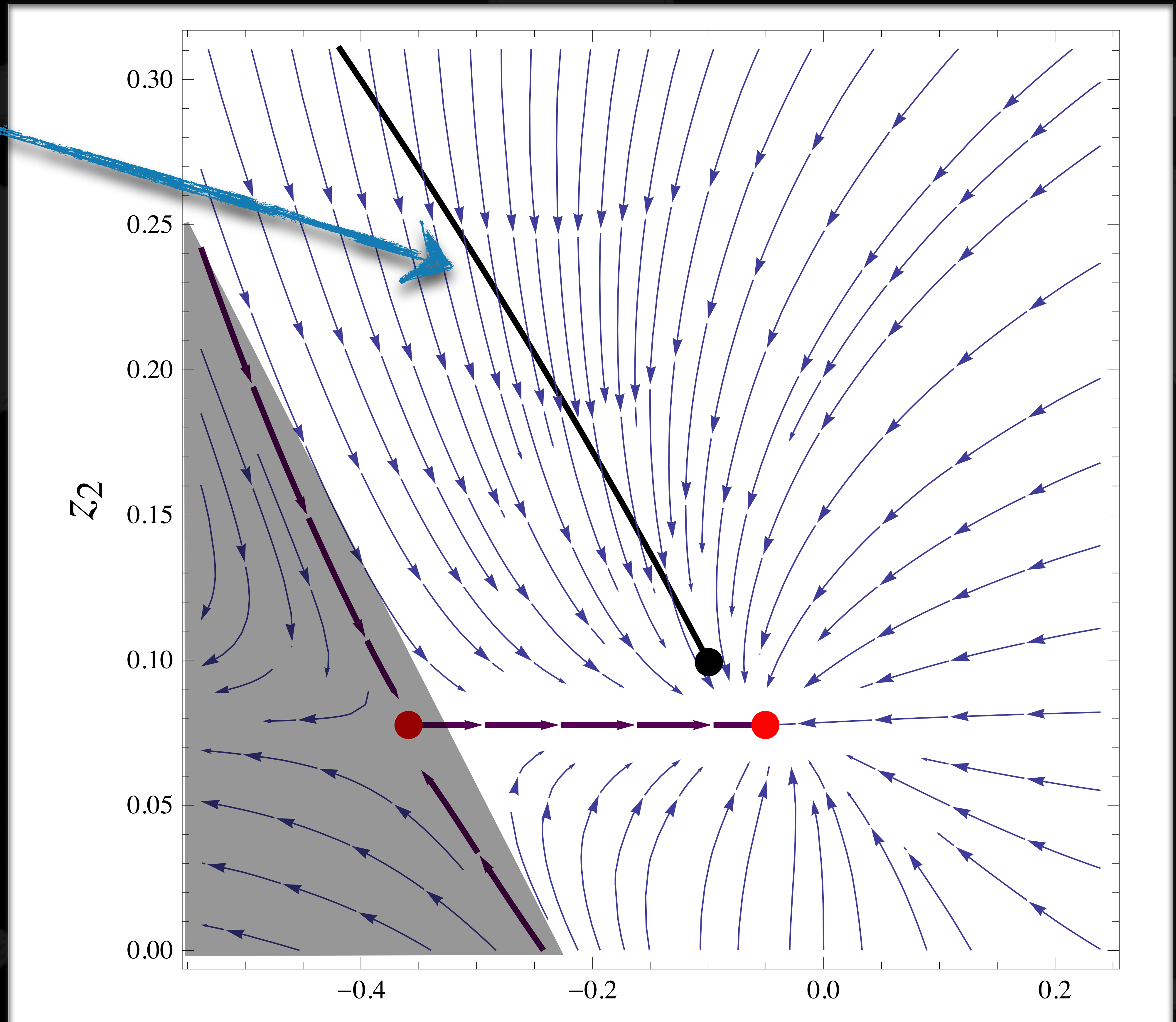

$g \approx g^*\ , y_H \approx y_H^*$

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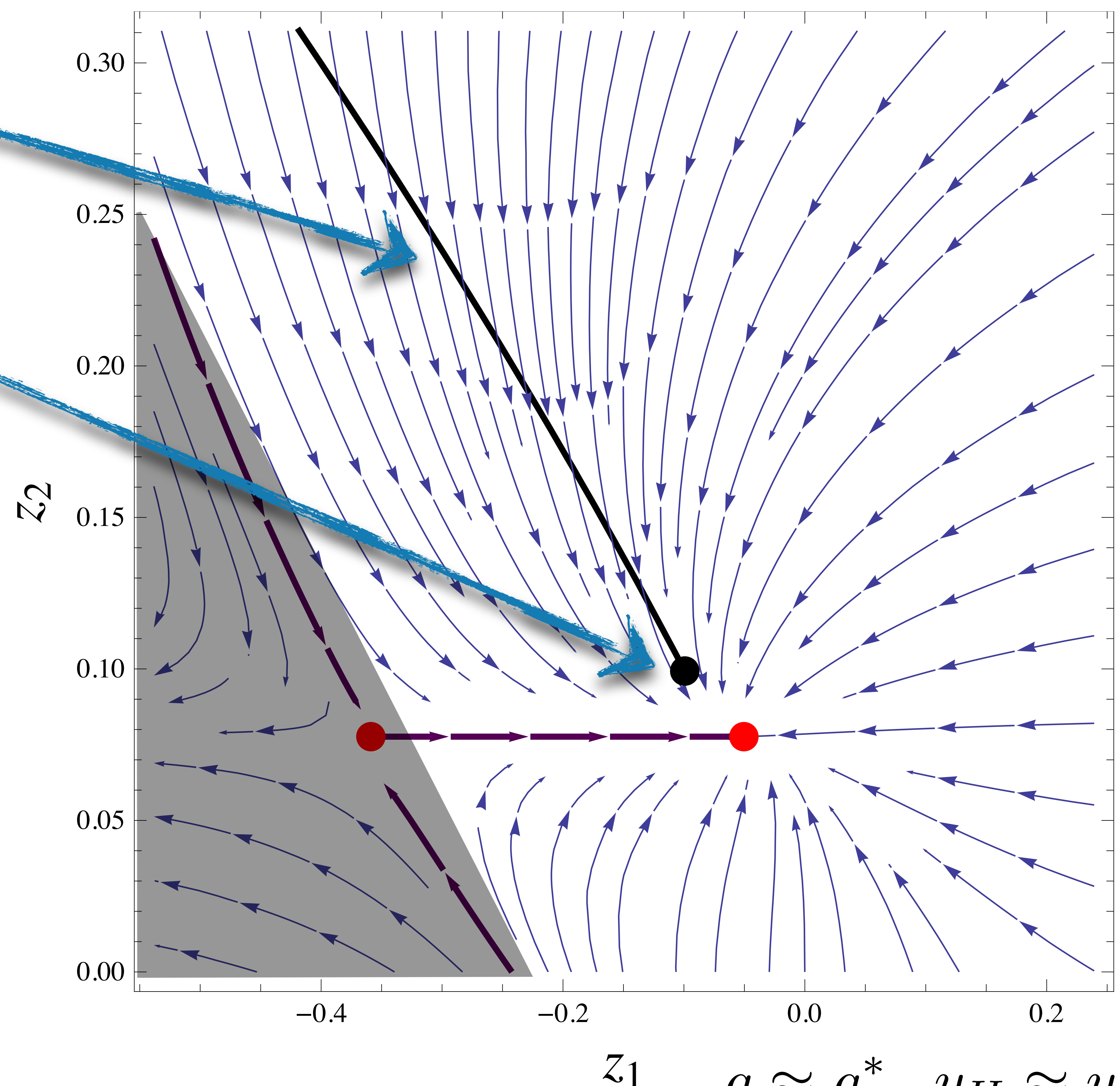

$g \approx g^*$, $y_H \approx y_H^*$

Phase Transition

O. Antipin, M. Mojaza, F. Sannino - hep-ph/1107.2932

$$\mathcal{L} = \mathcal{L}_K(F_{\mu\nu}, \lambda, \psi, H; g) + \sqrt{\frac{a_H}{N_f}}\bar{\psi}H\psi - \frac{z_1}{N_f^2}\left(\mathrm{Tr}H^\dagger H\right)^2 - \frac{z_2}{N_f}\mathrm{Tr}\left(H^\dagger H\right)^2$$

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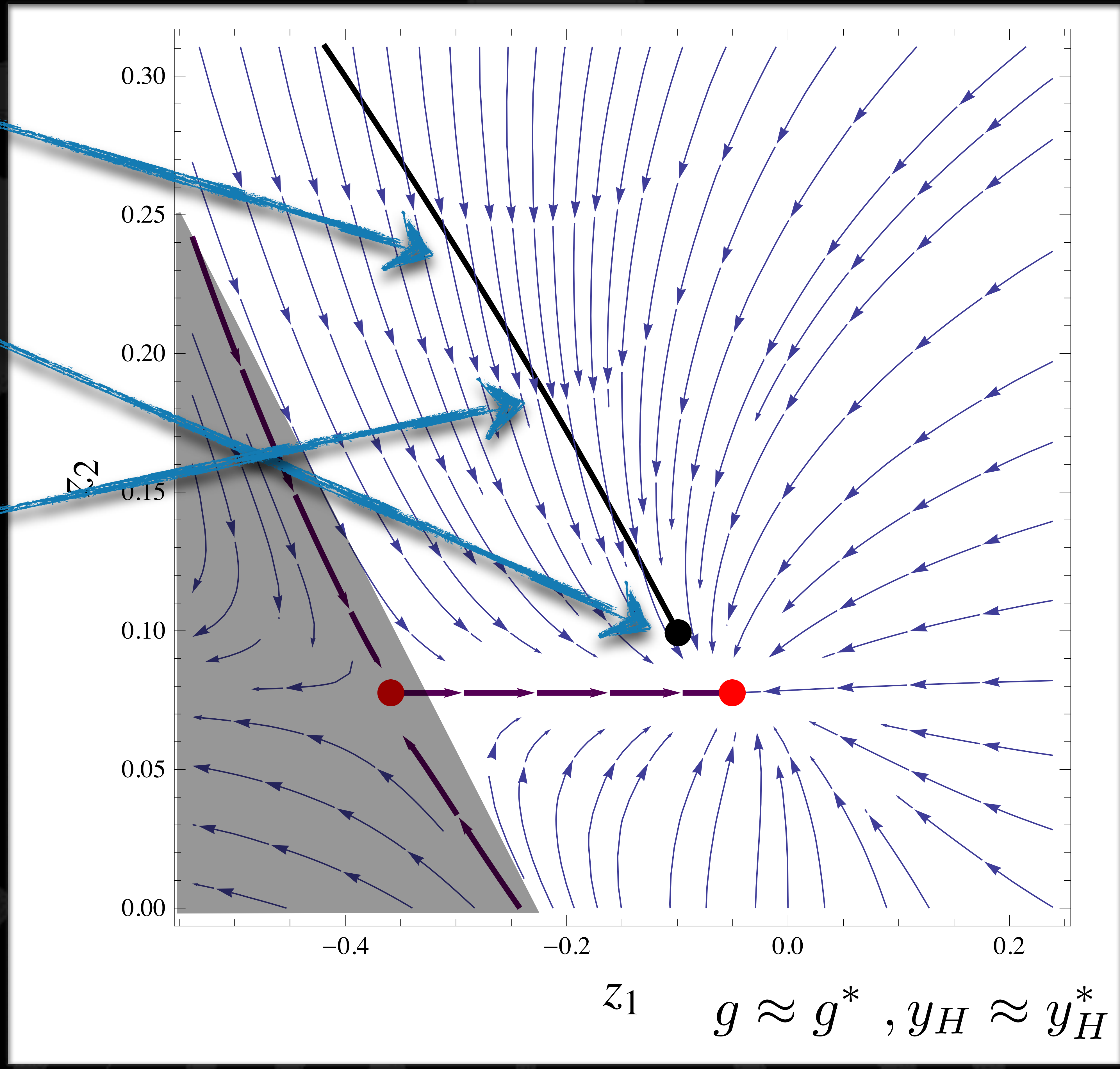

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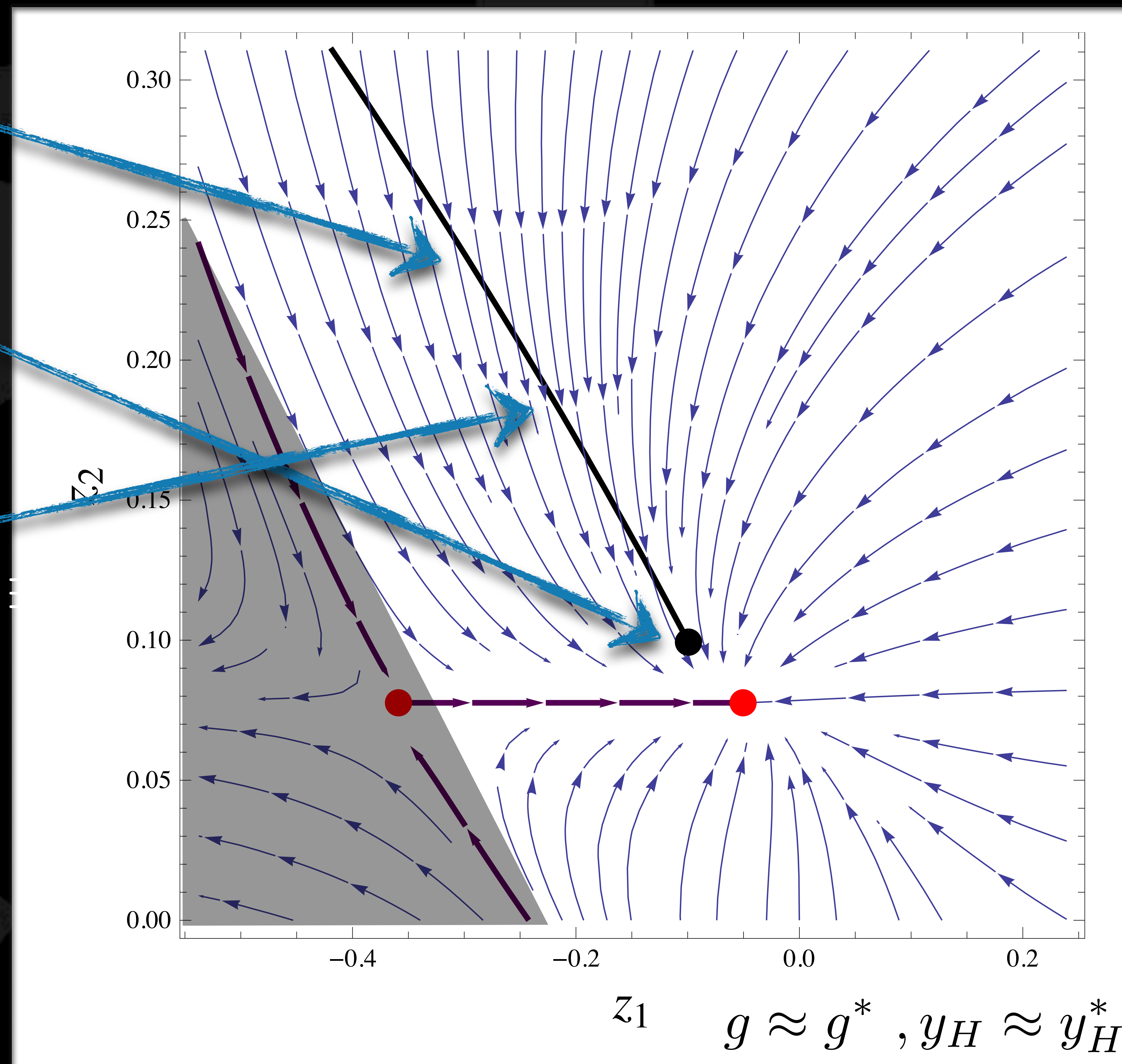

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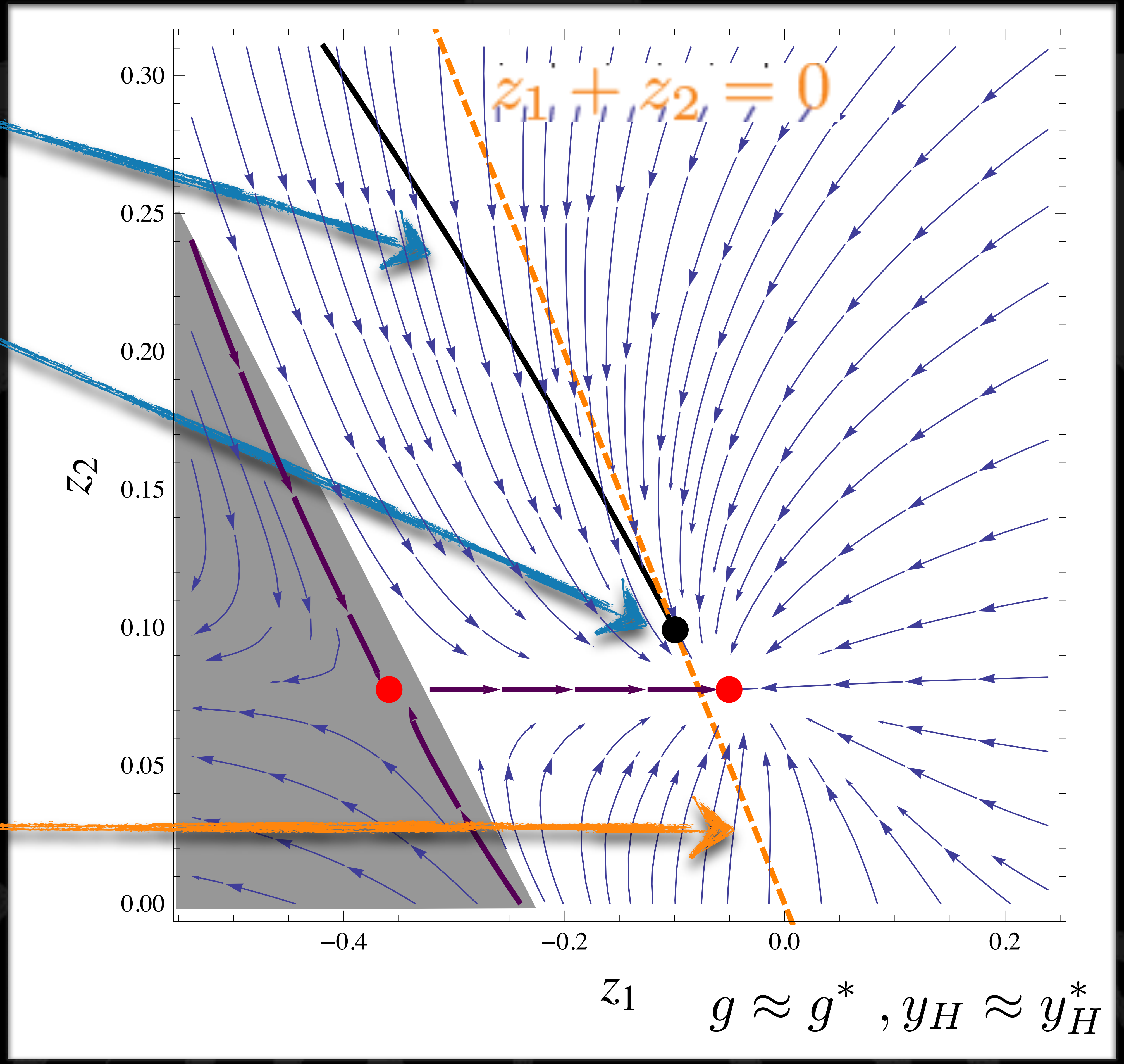

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The Light Dilaton

O. Antipin, M. Mojaza, F. Sannino - hep-ph/1107.2932

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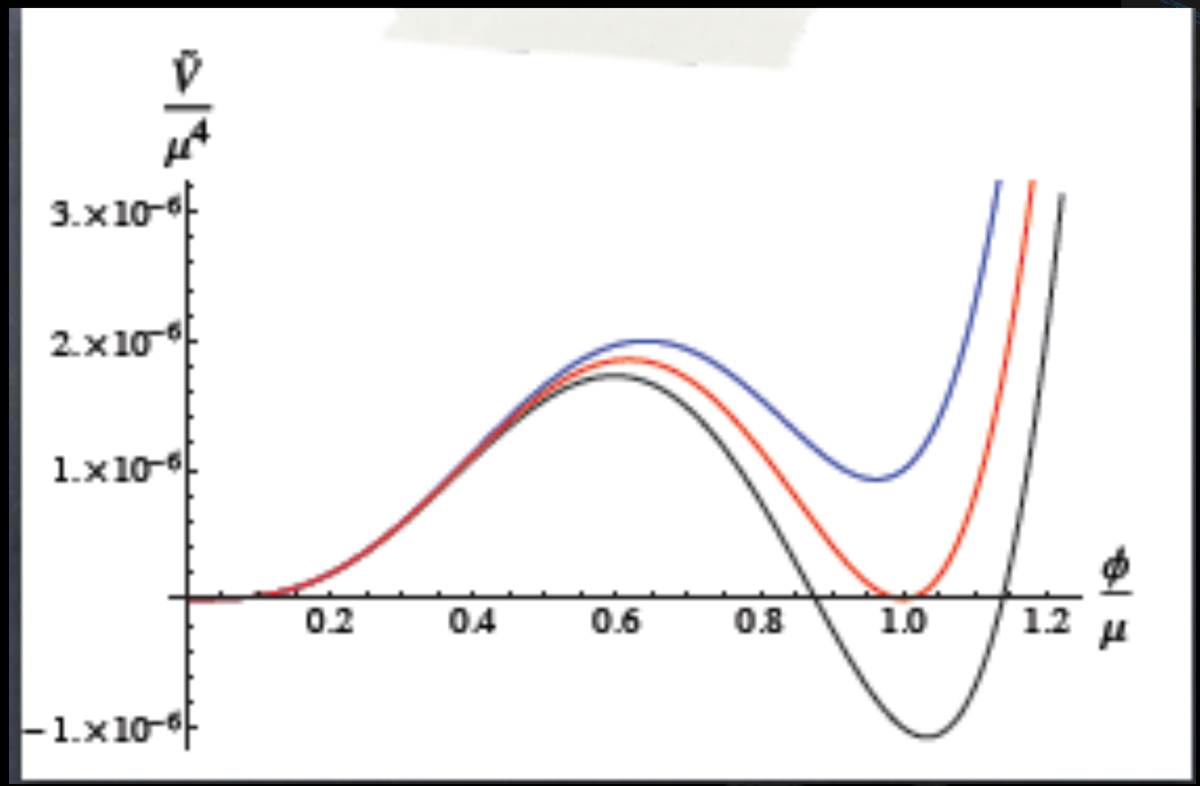

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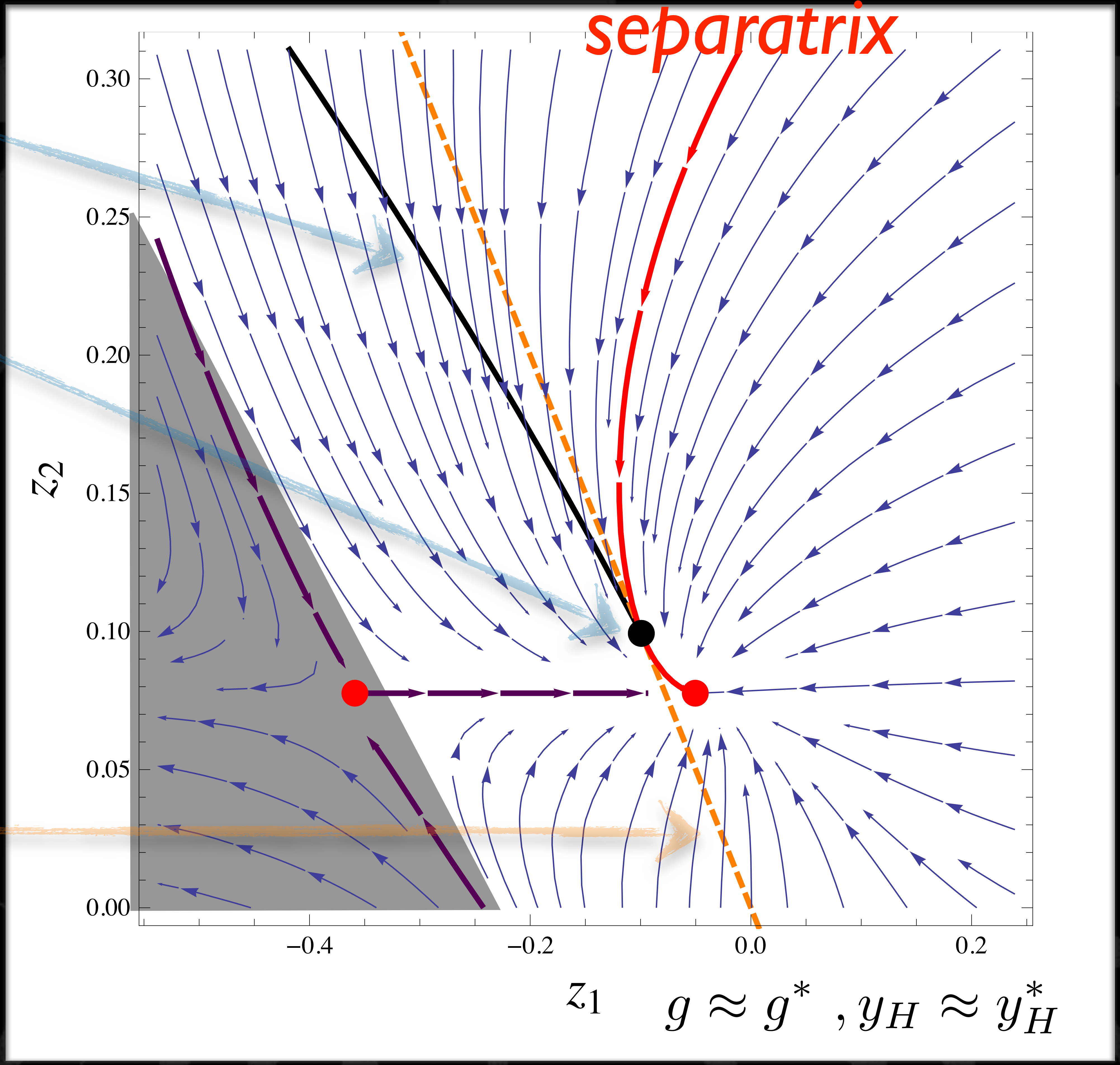

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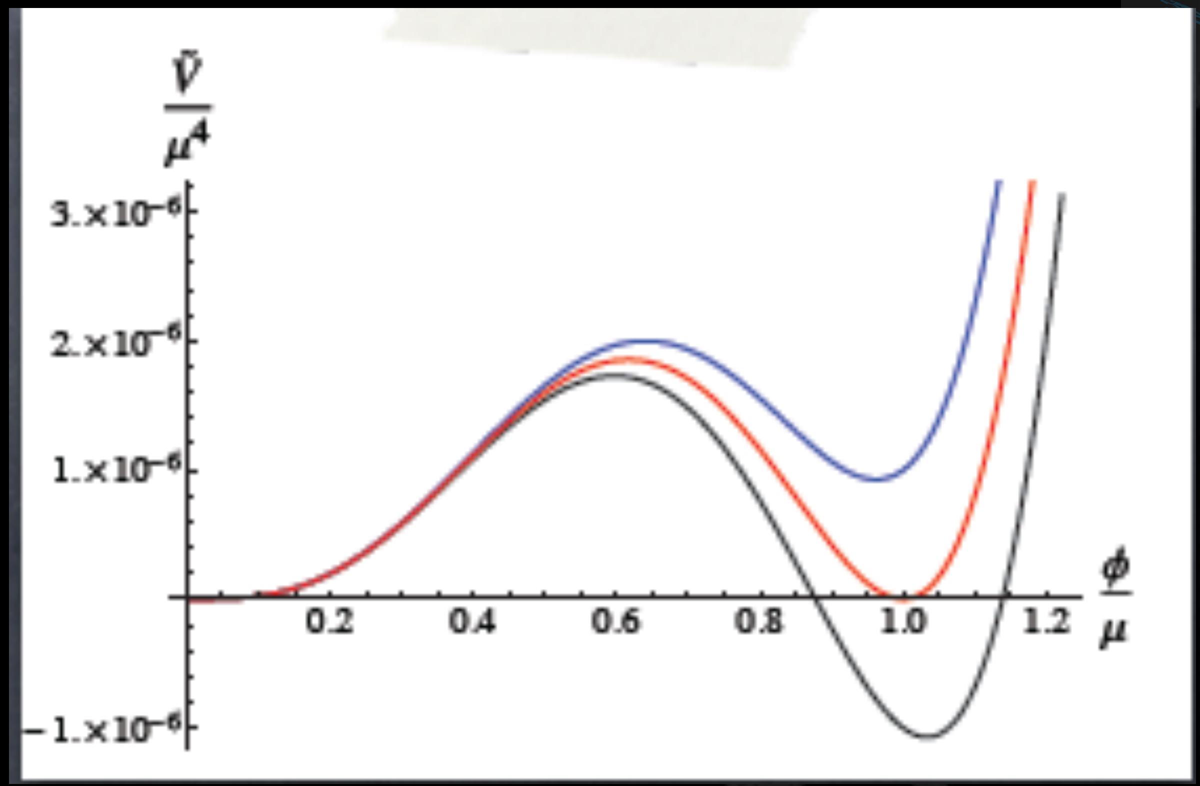

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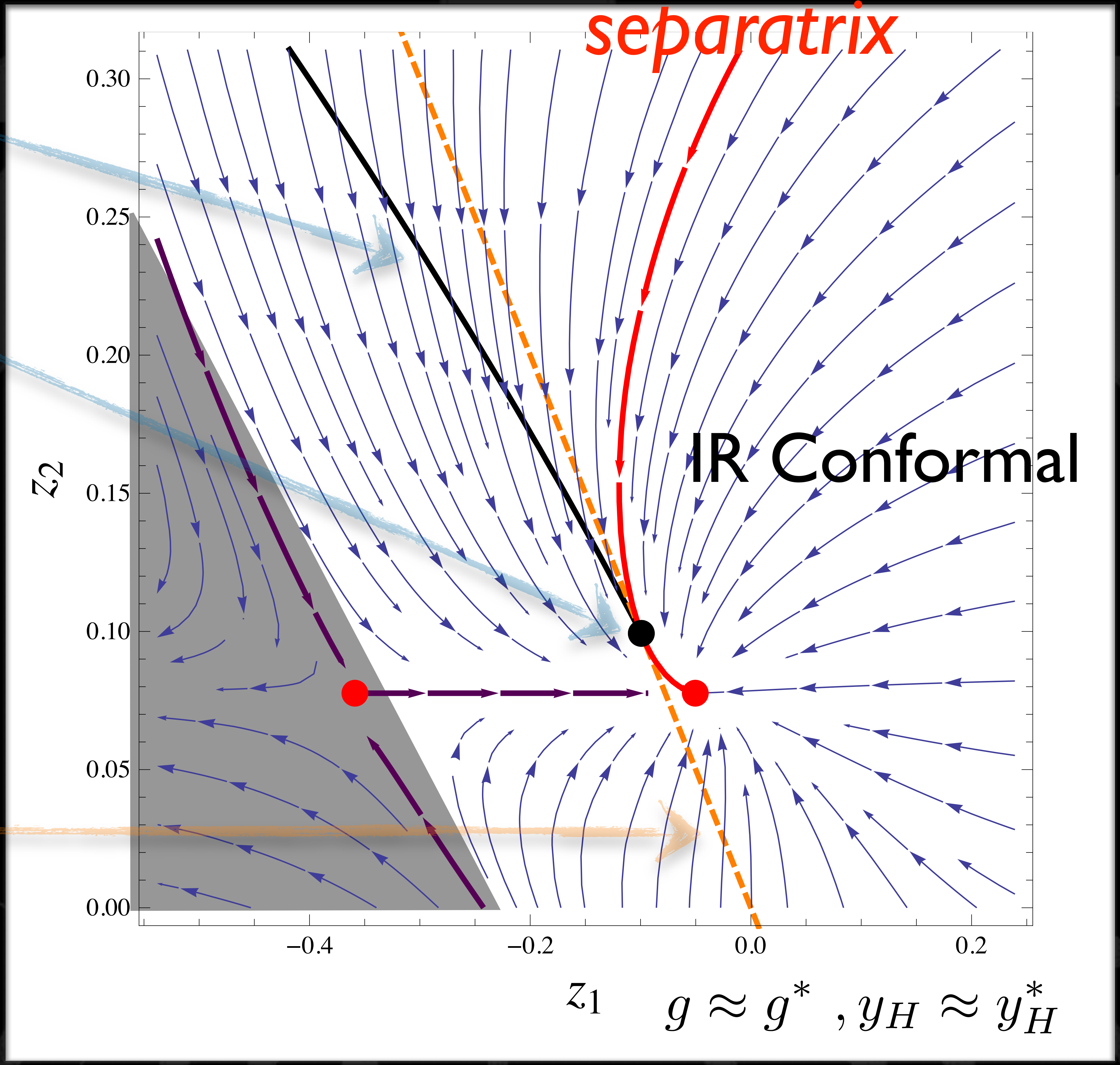

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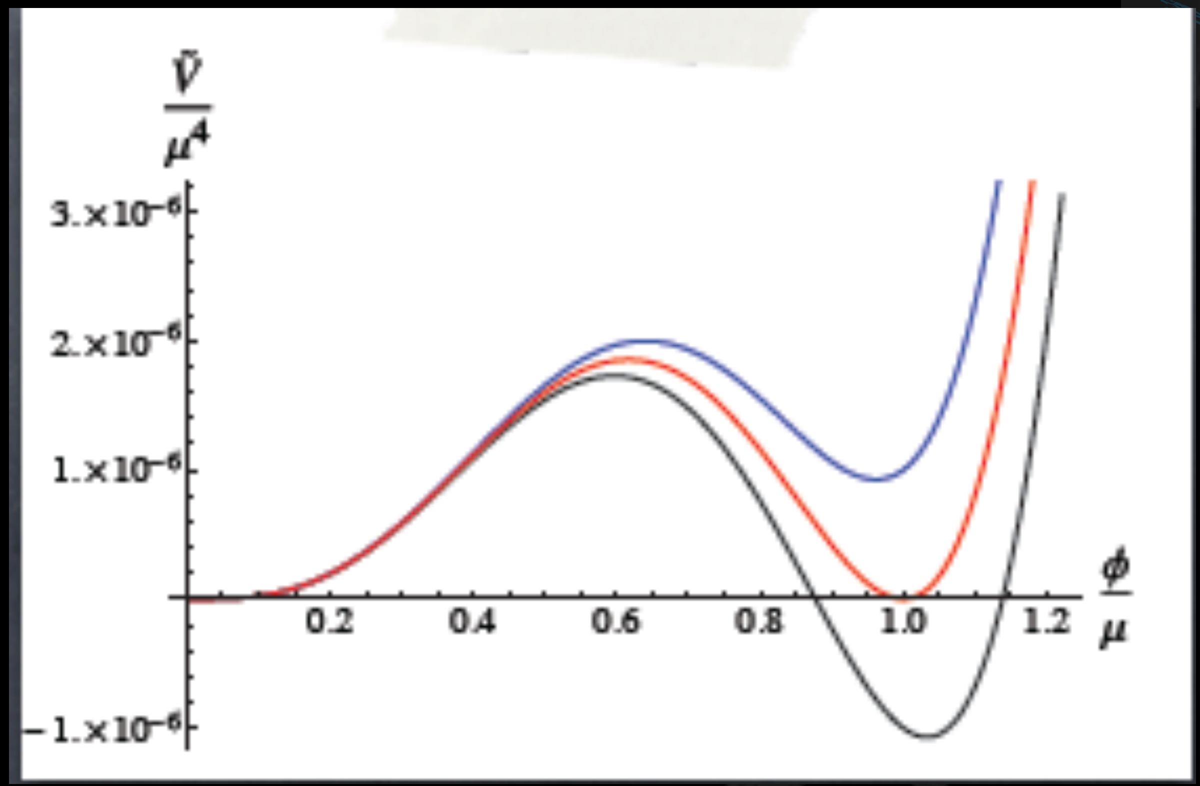

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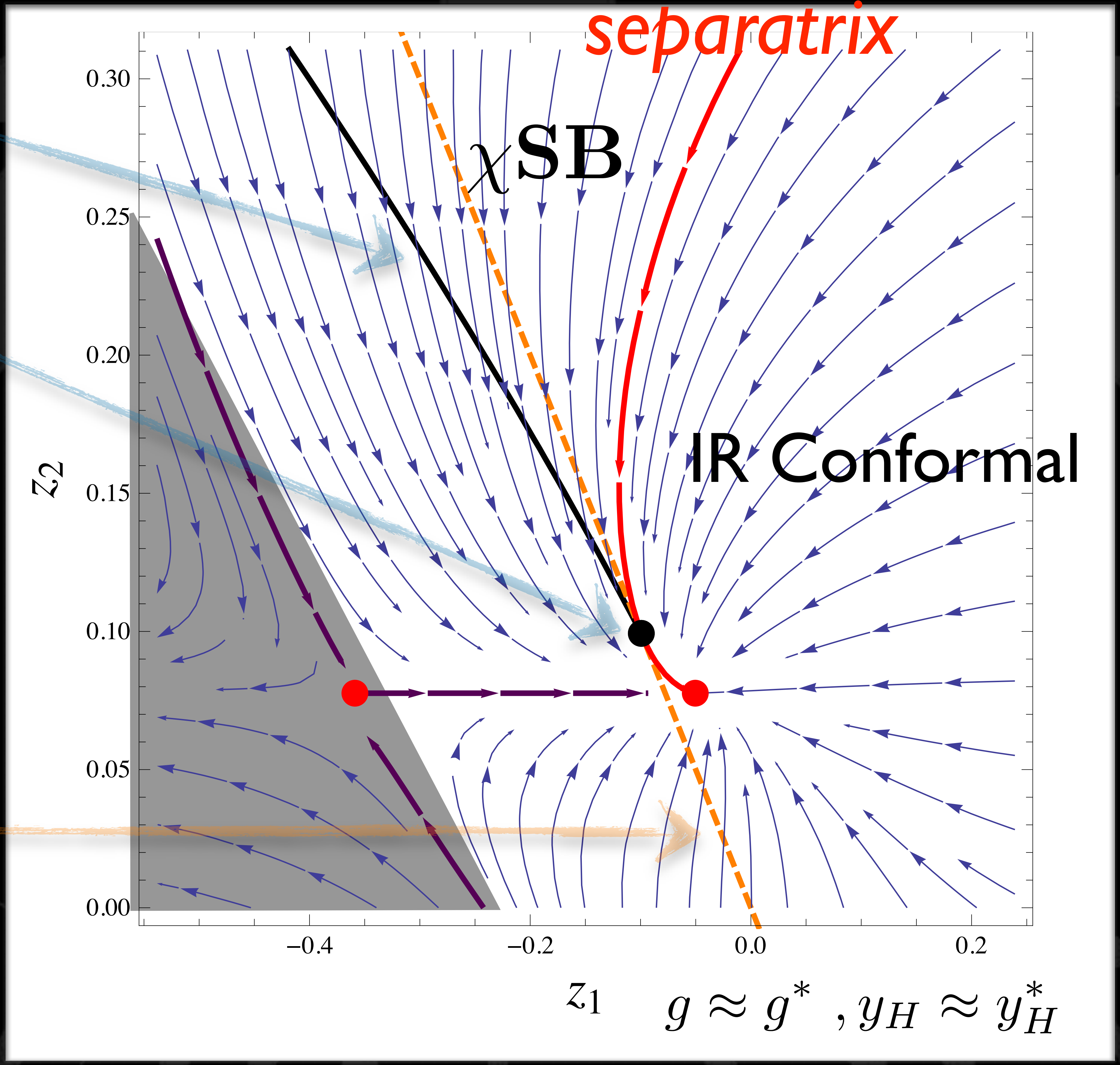

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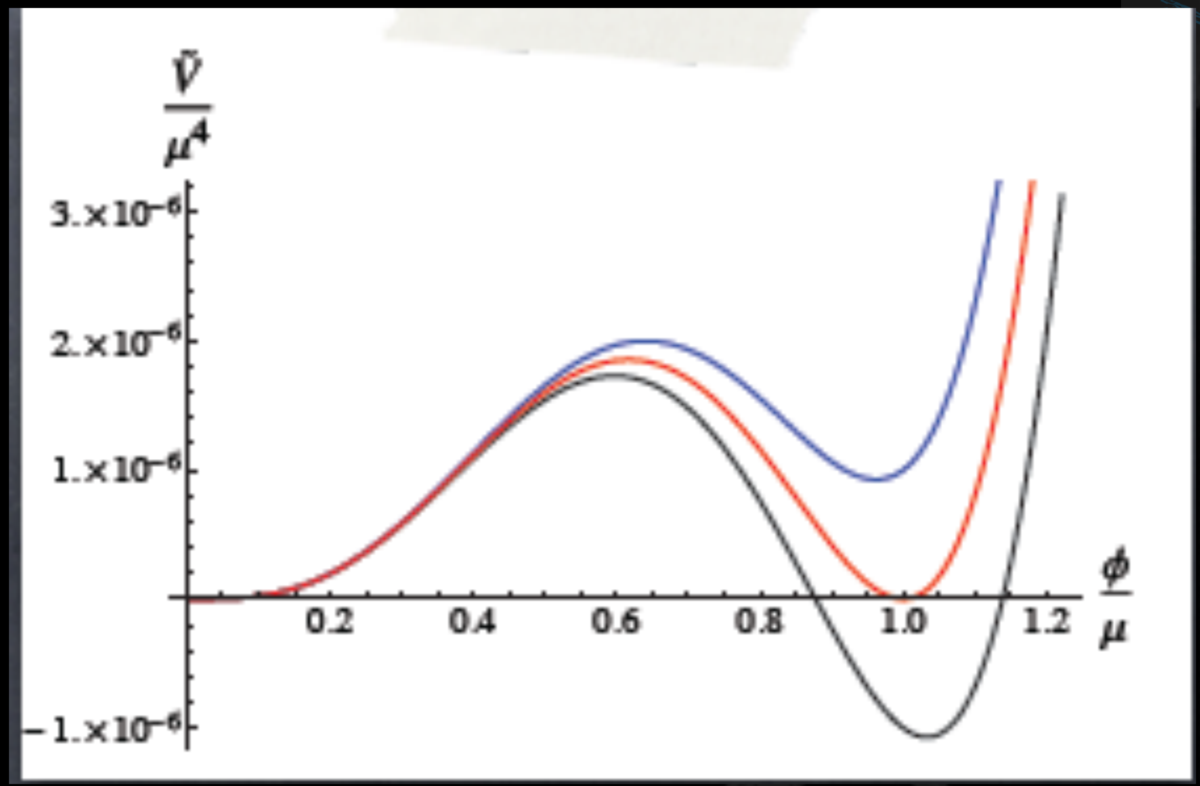

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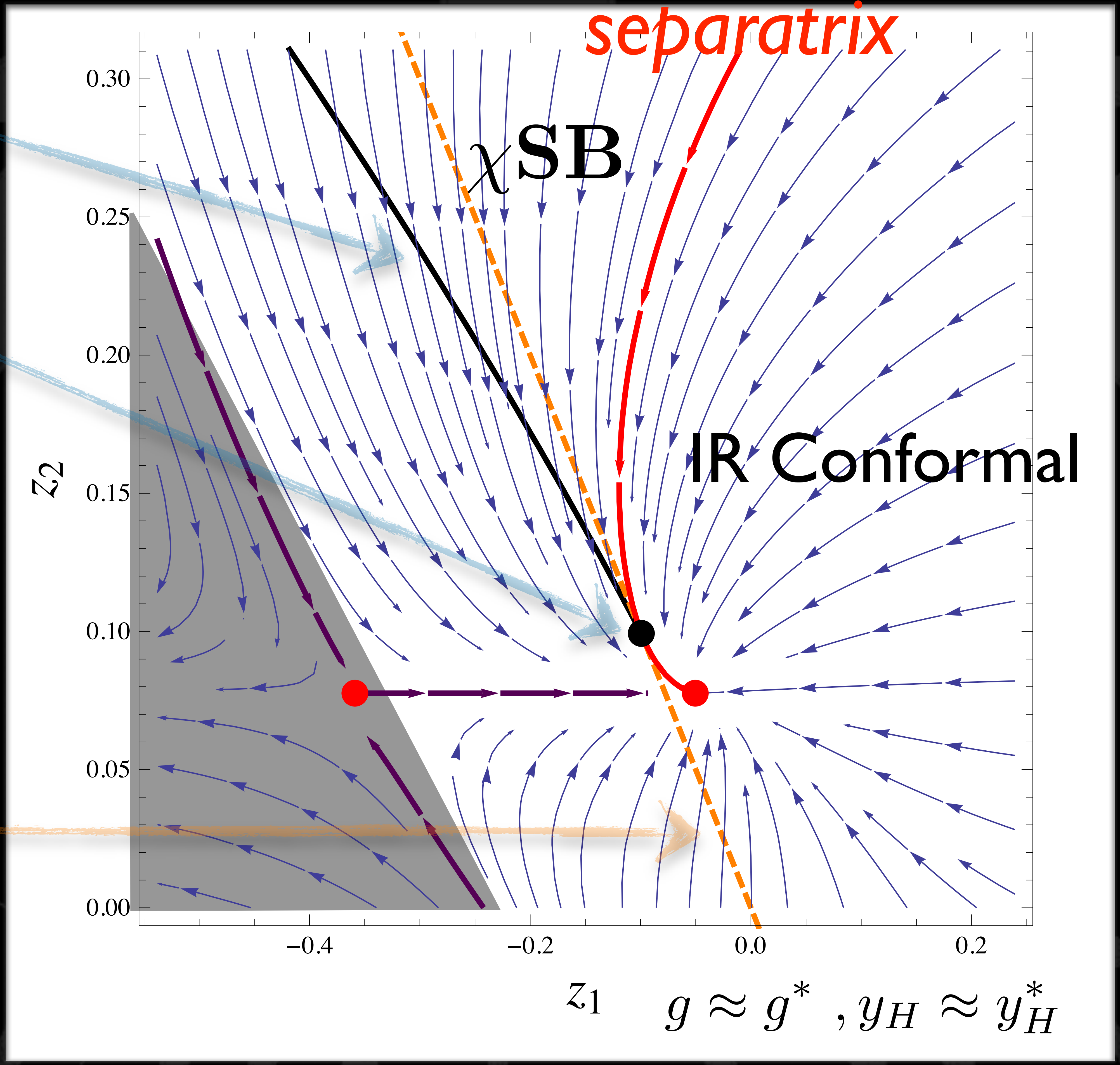

Scale generation by *dimensional transmutation.*

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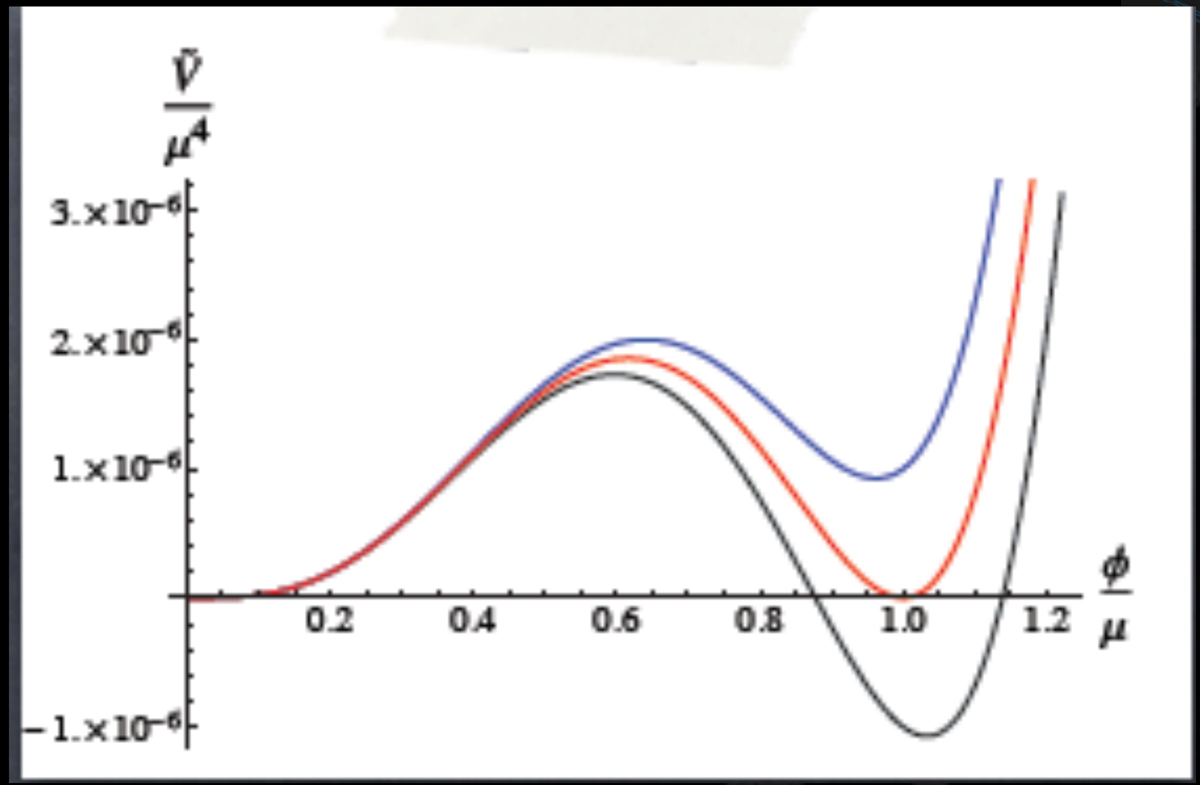

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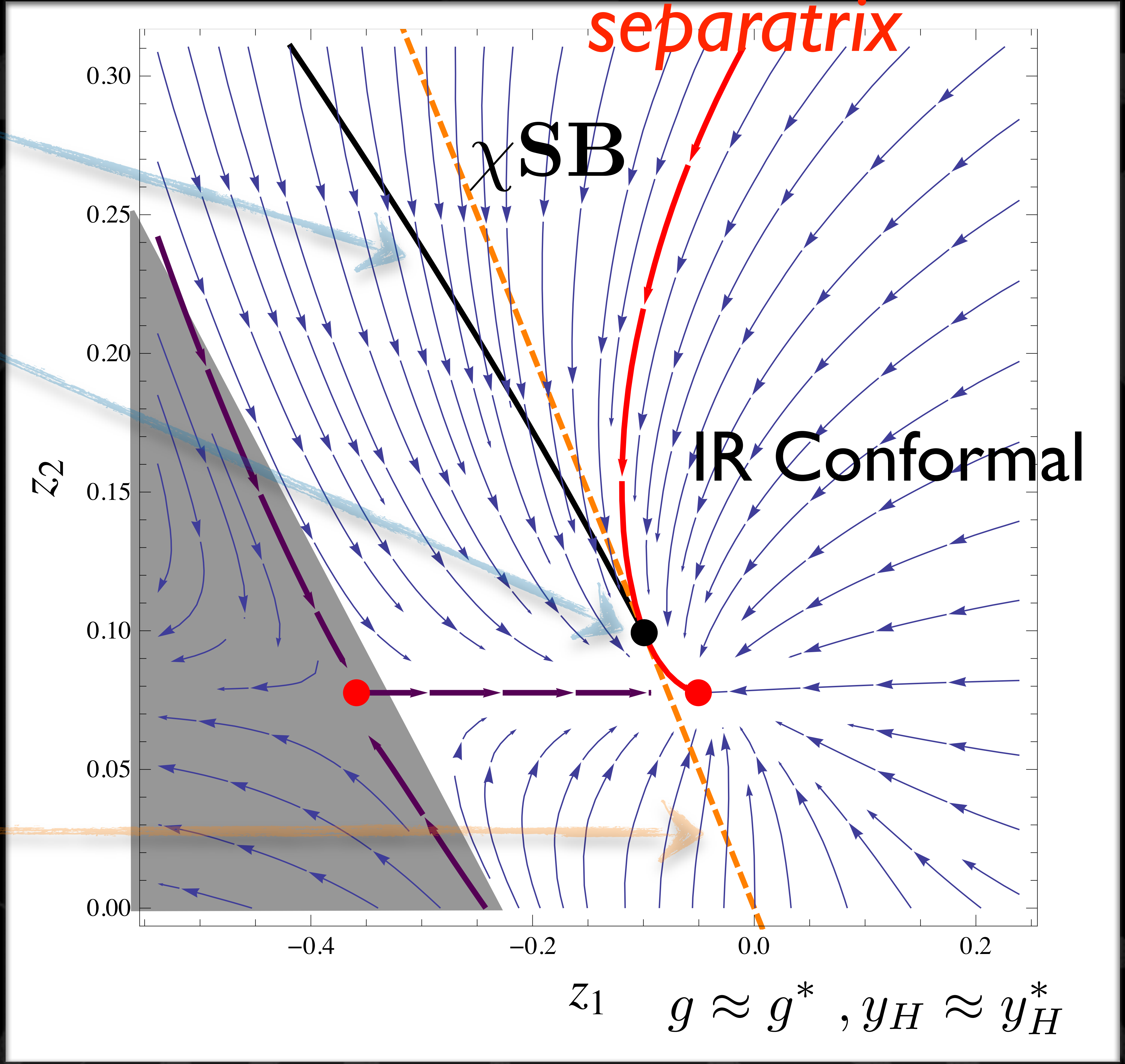

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Near conformal symmetry spont. broken.

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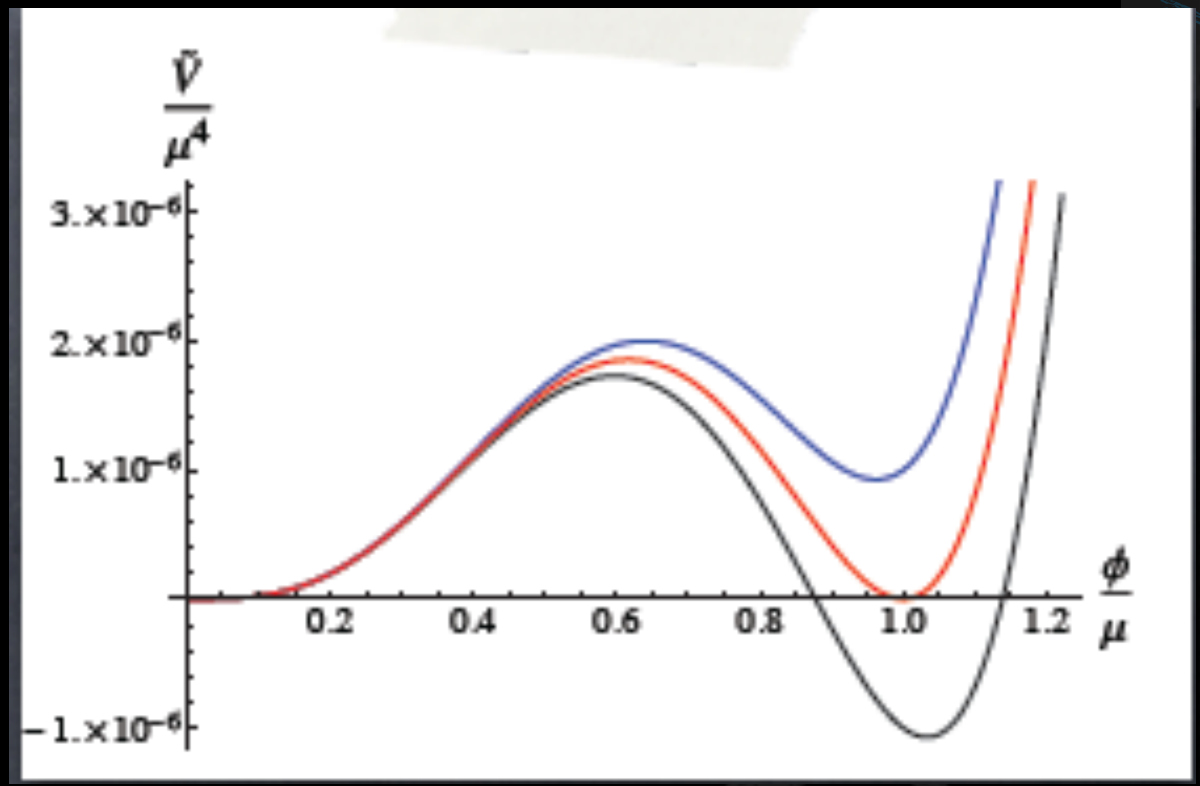

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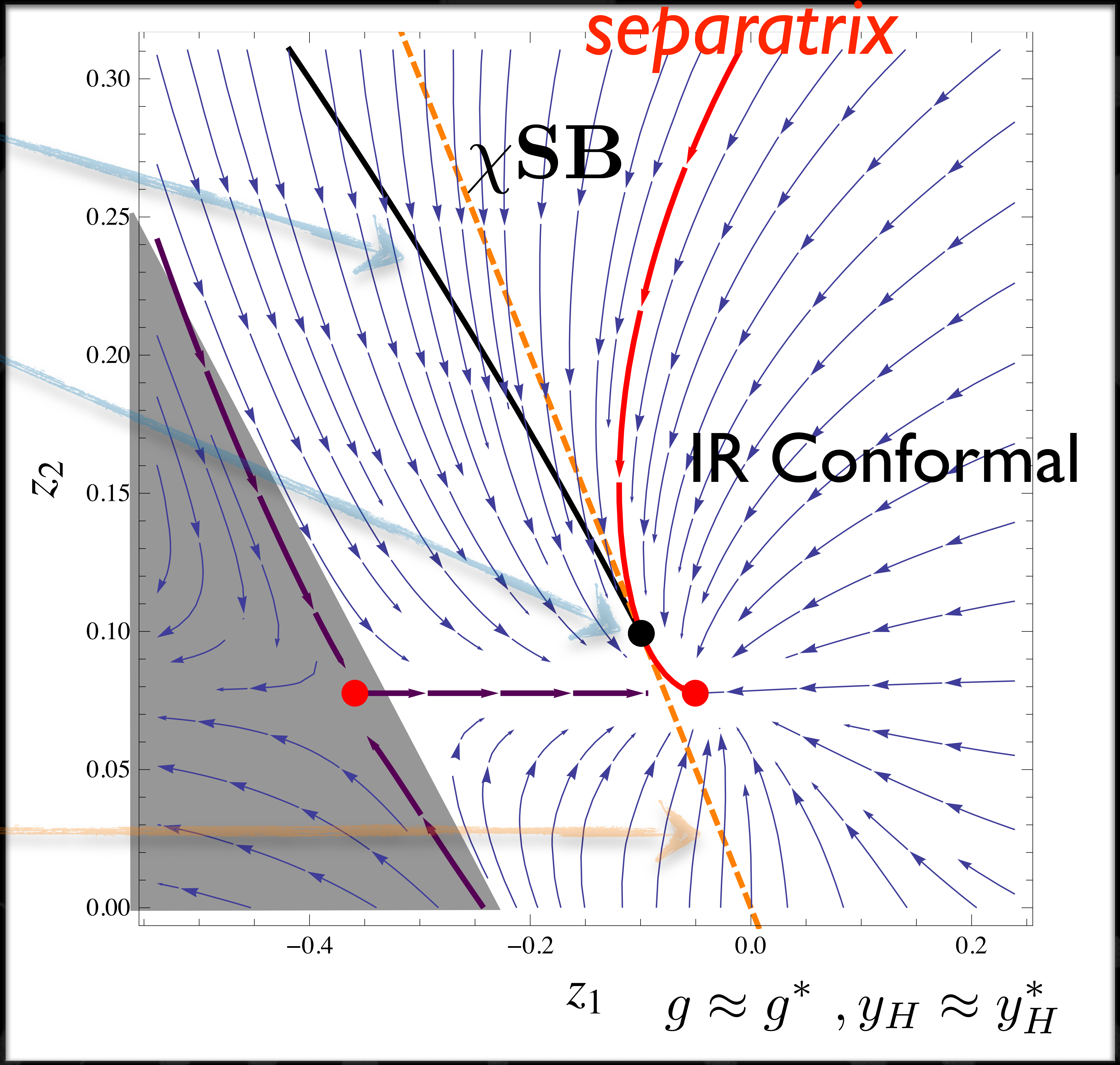

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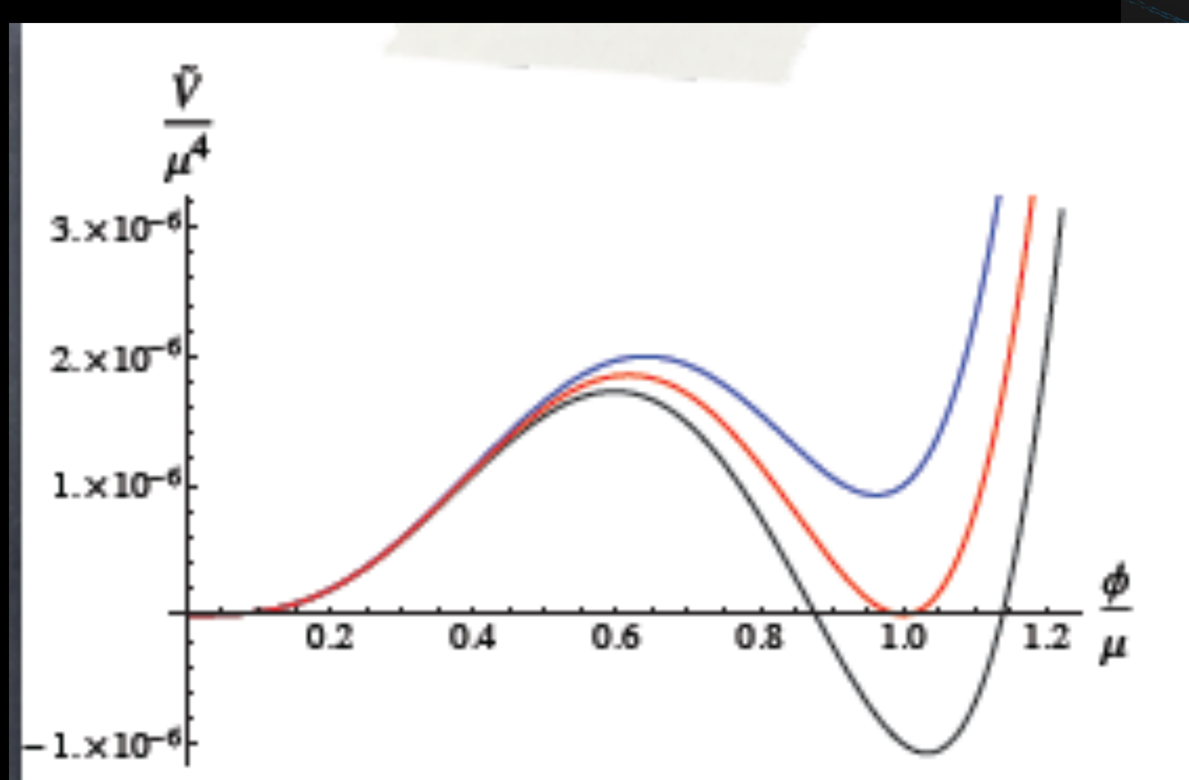

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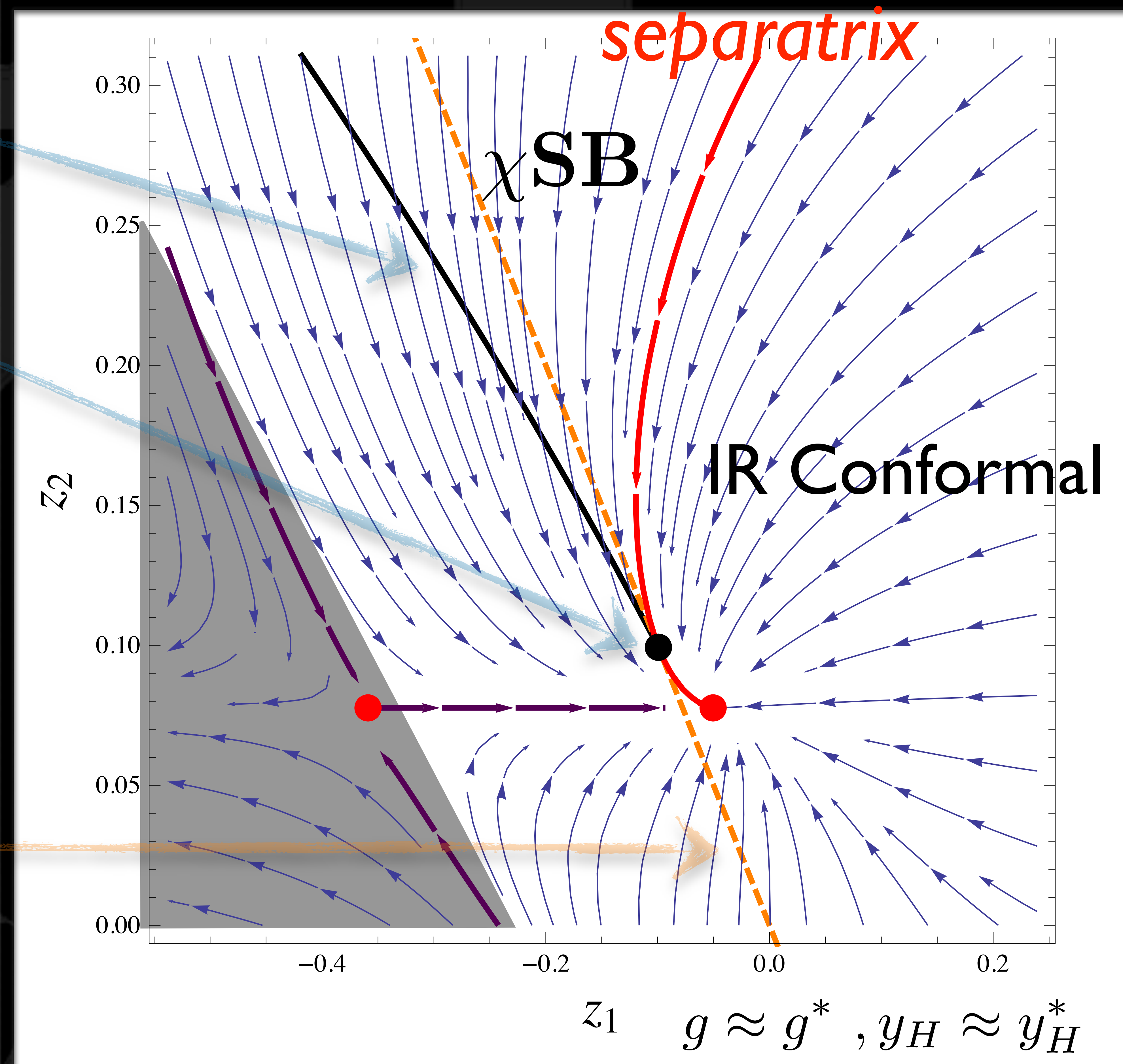

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Arbitrarily light by tuning:

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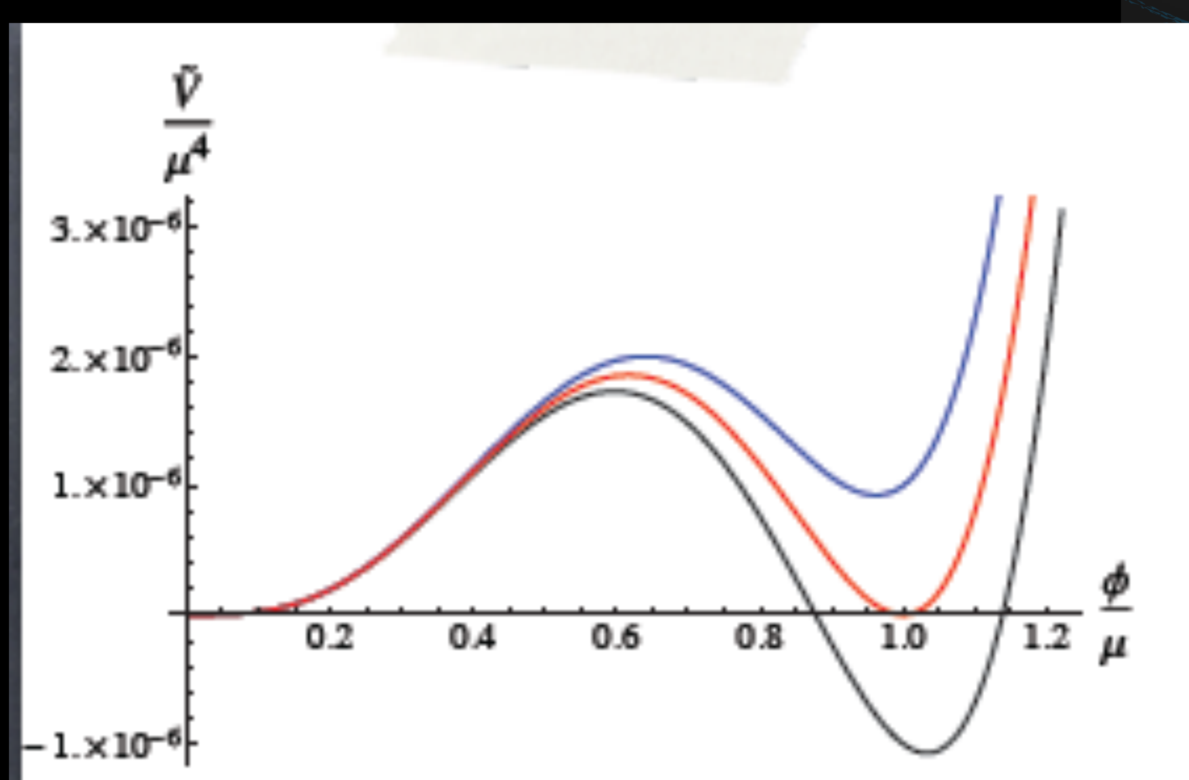

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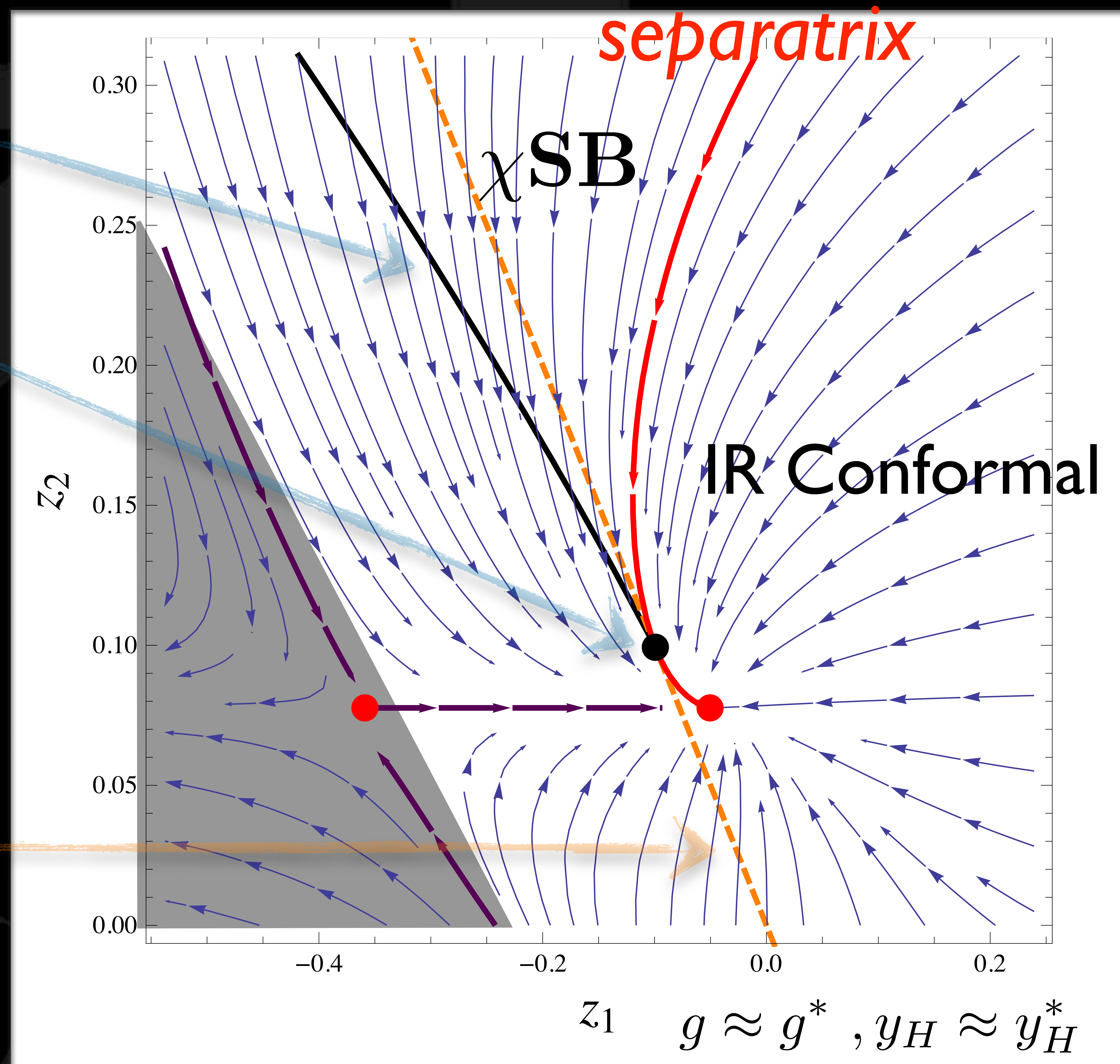

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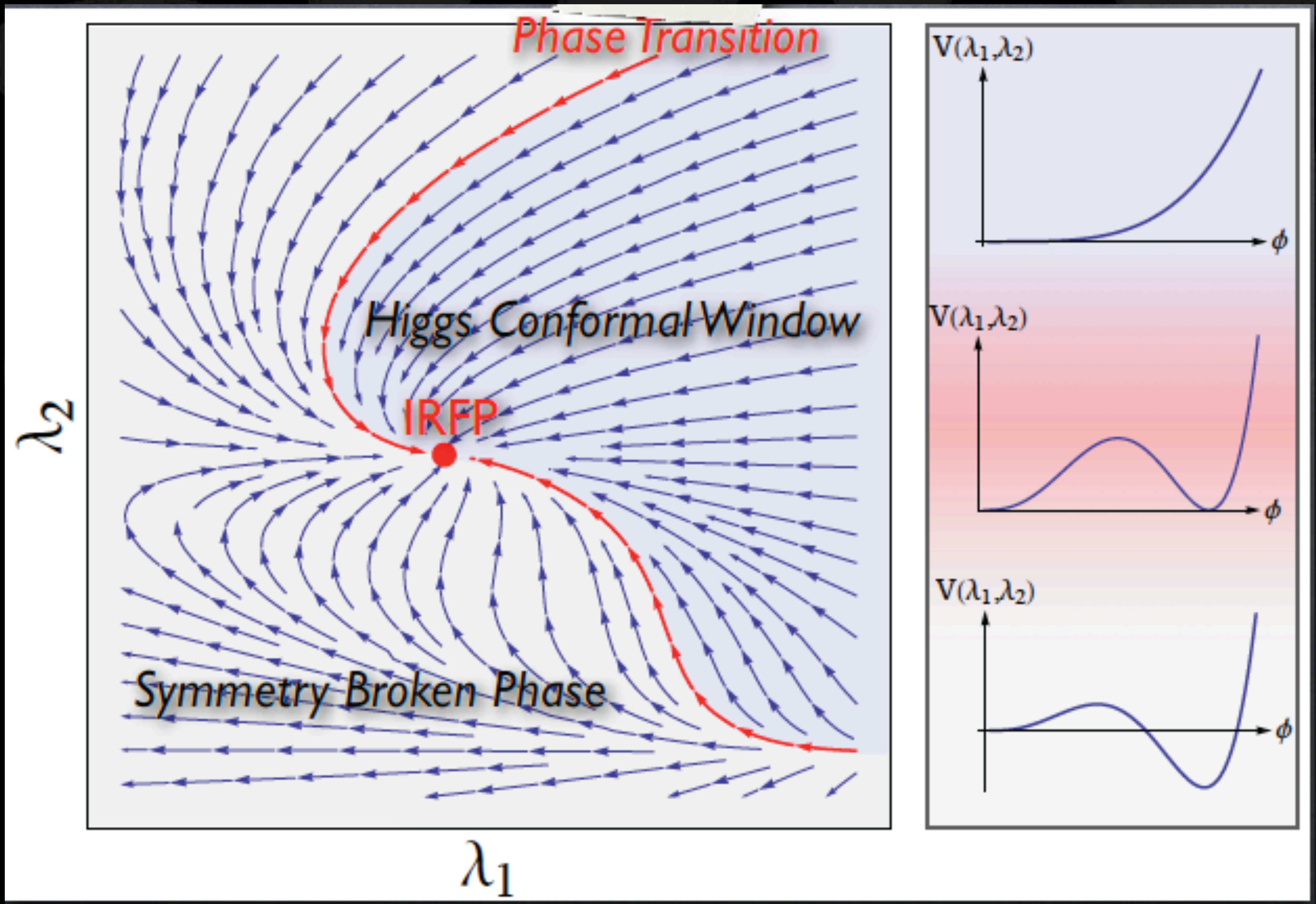
$$m_h^2 = (4z_2^2 - x a_H^2)\phi_c^2 \equiv \delta \phi_c^2$$

The Light Dilaton



$$U(N_f) \times U(N_f) \to U(N_f)$$

Conformal symmetry broken by scalar condensation (Coleman-Weinberg phenomenon).

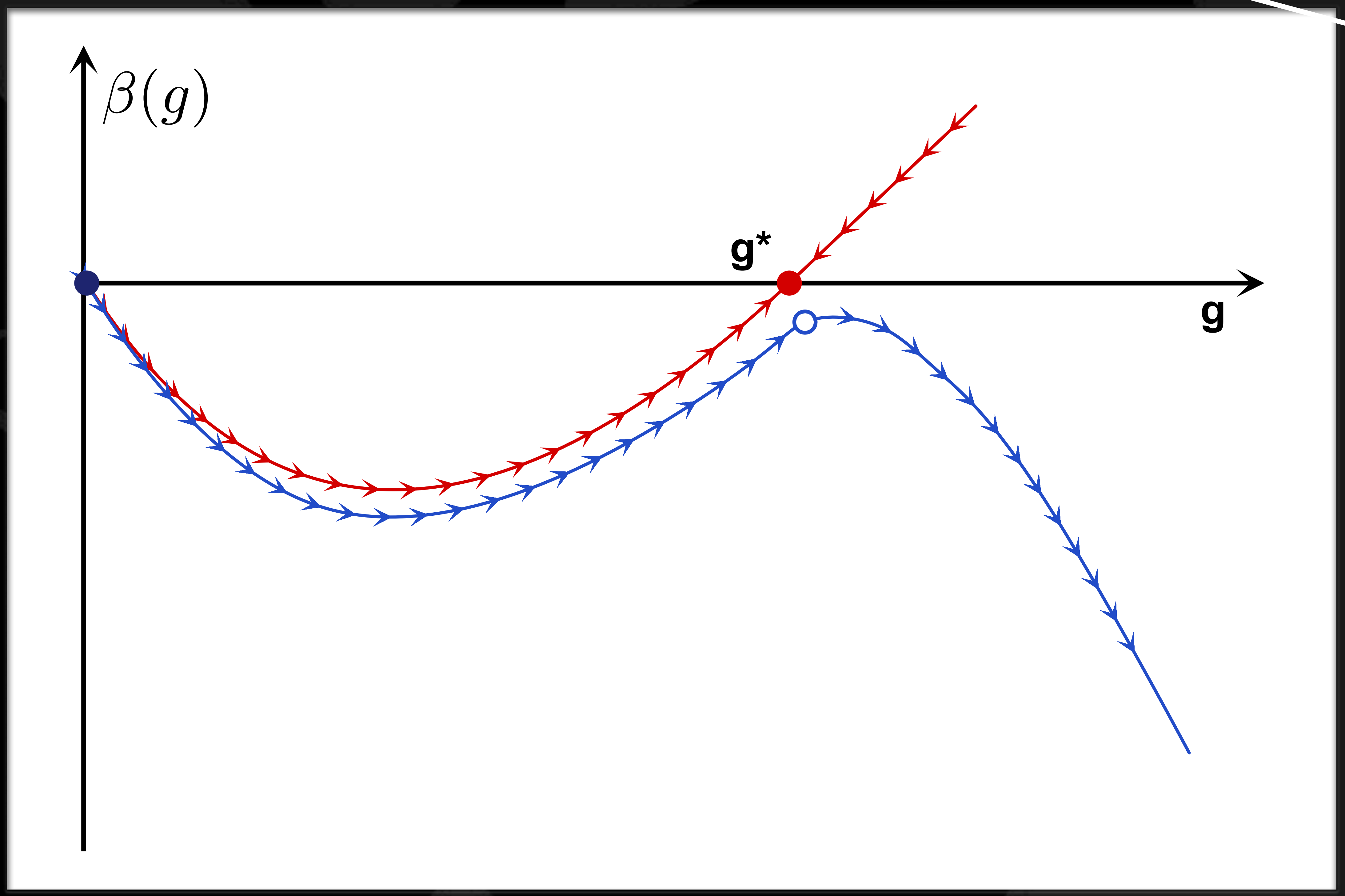
This generates a massive dilaton.

$$\frac{m_h^2}{v^2} = \frac{m_h^2}{\phi_c^2} \sim 4z_2^2 - xa_H^2$$

The Complete Picture

O. Antipin, M. Mojaza, F. Sannino - hep-ph/1107.2932

$$\mathcal{L} = \mathcal{L}_K(F_{\mu\nu}, \lambda, \psi, H; g) + y_H \bar{\psi} H \psi + \text{h.c.} - u_1 \left(\text{Tr} H^\dagger H\right)^2 - u_2 \text{Tr}\left(H^\dagger H\right)^2$$



Quarks get mass from Yukawa interactions.
The remaining massless adjoint fermion and gluons survive to low energies and form sypersymmetric spectrum

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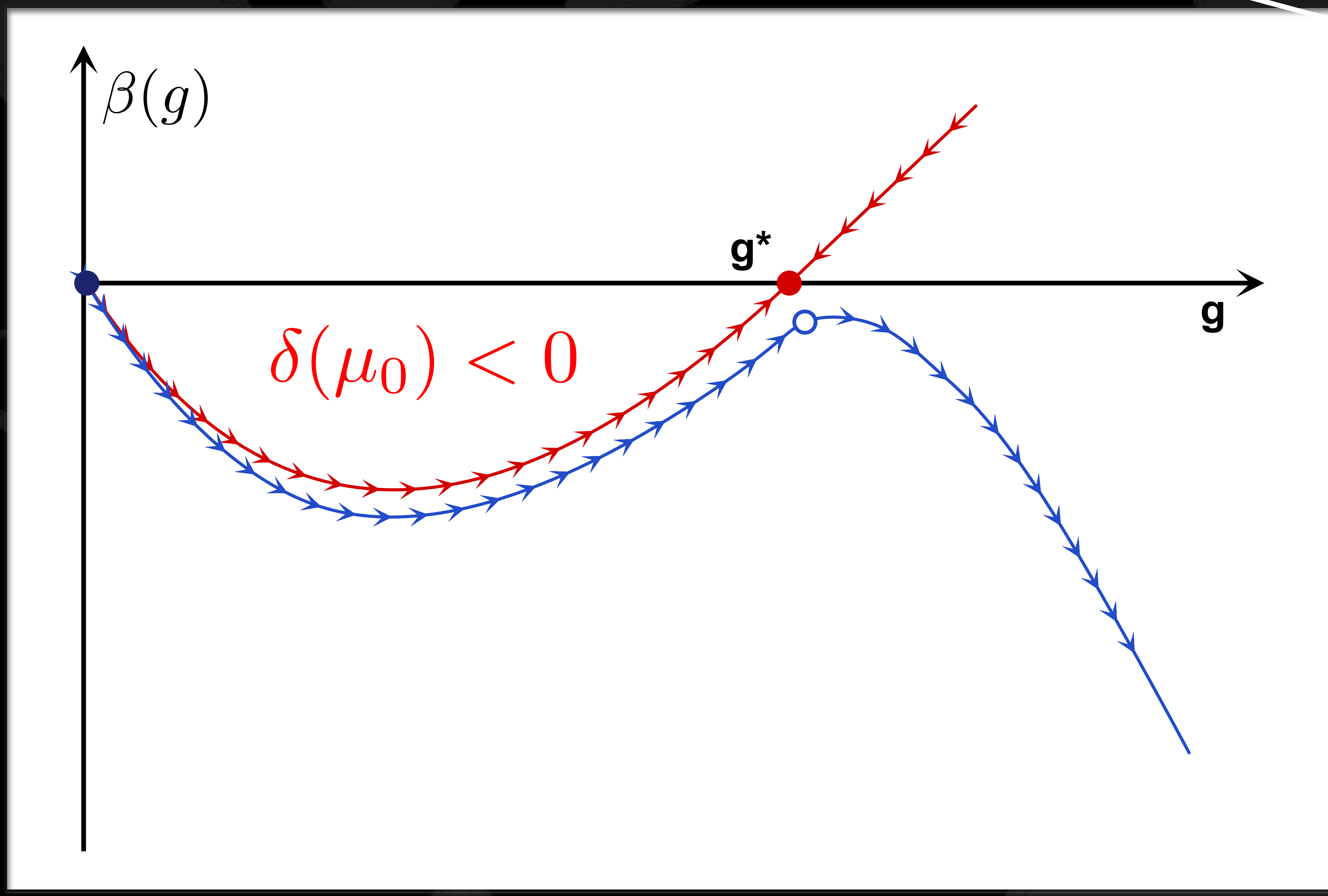

Quarks get mass from Yukawa interactions.

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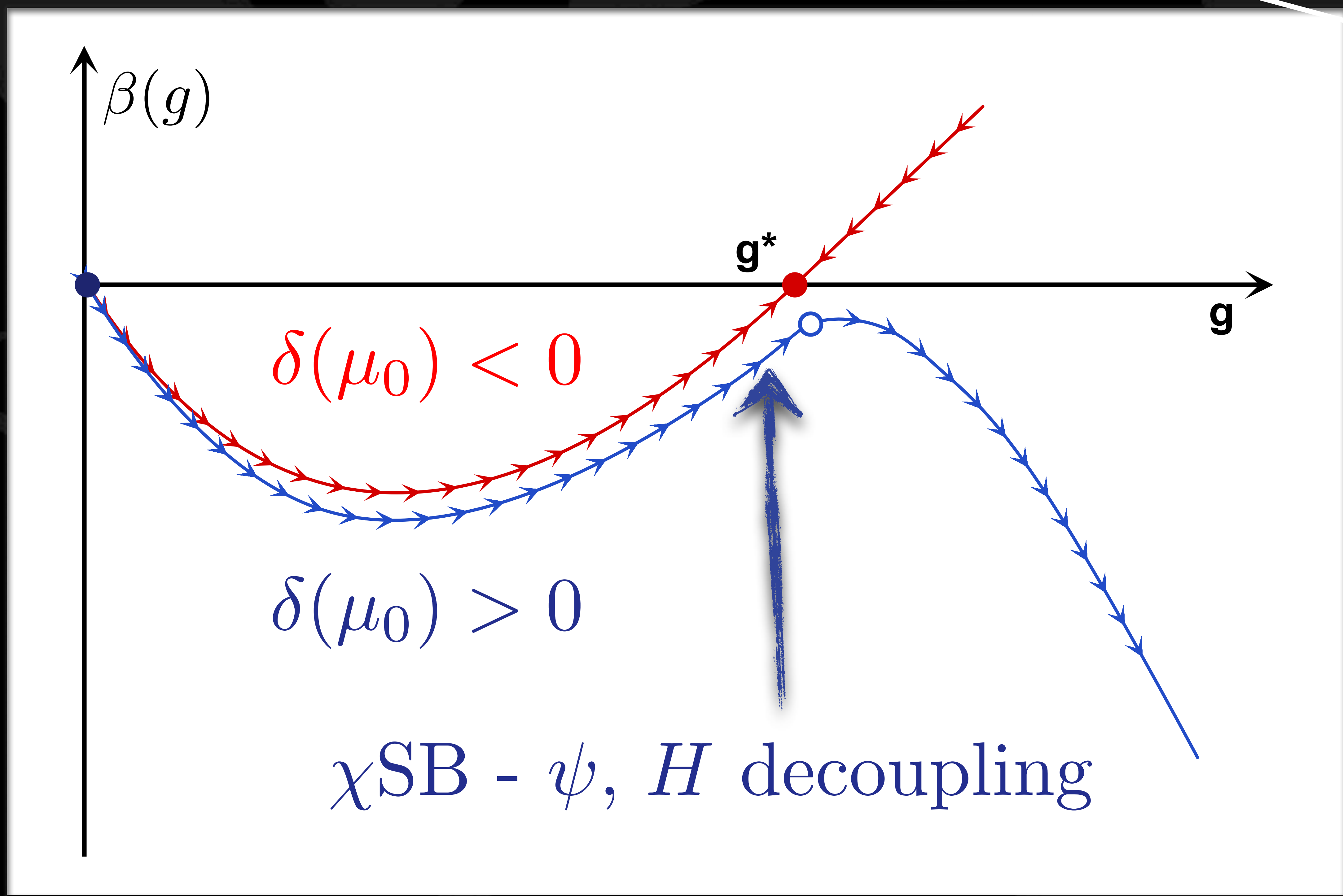

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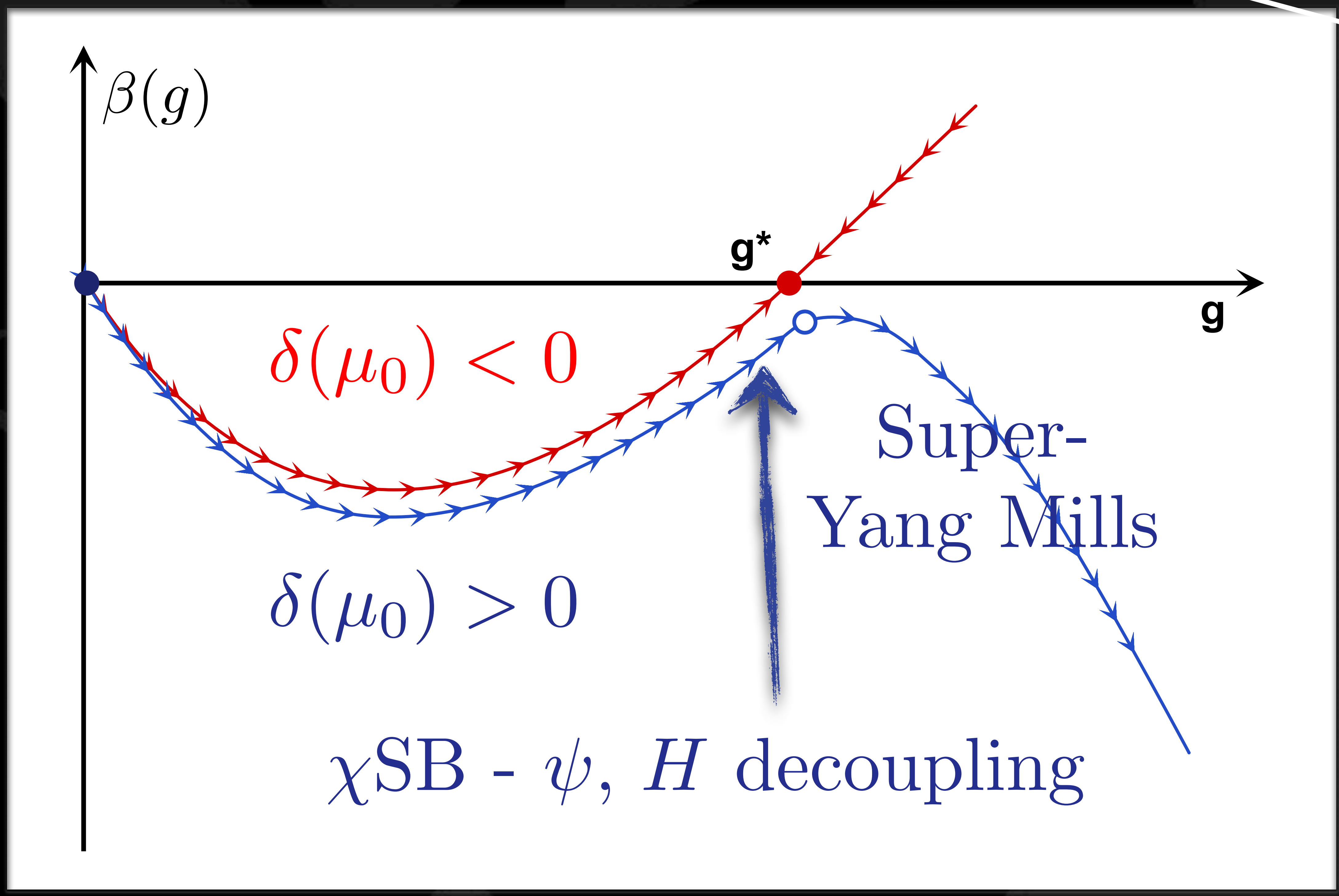

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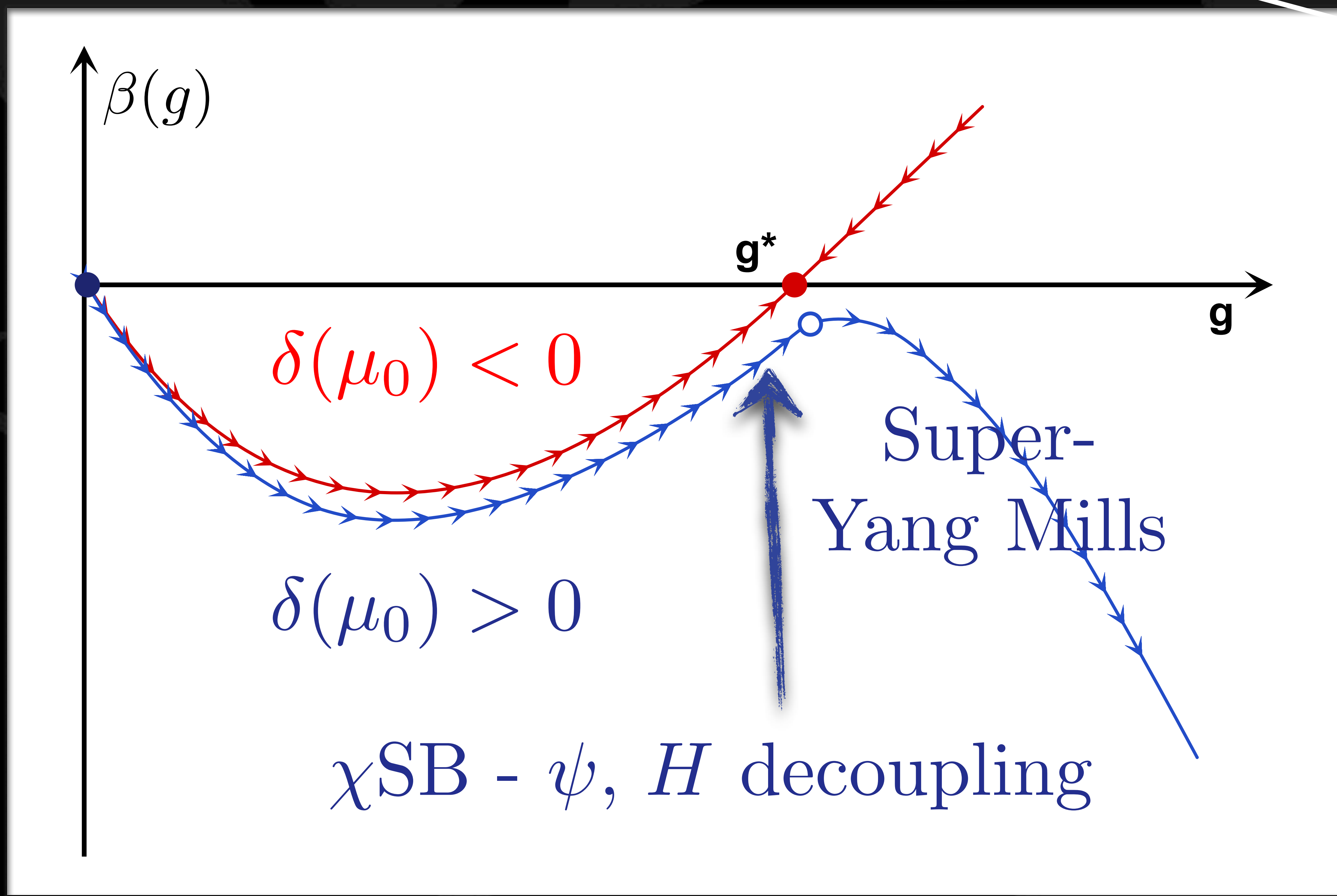

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$$\langle \lambda\lambda \rangle = -\frac{9}{32\pi^2} \Lambda^3_{SYM}$$

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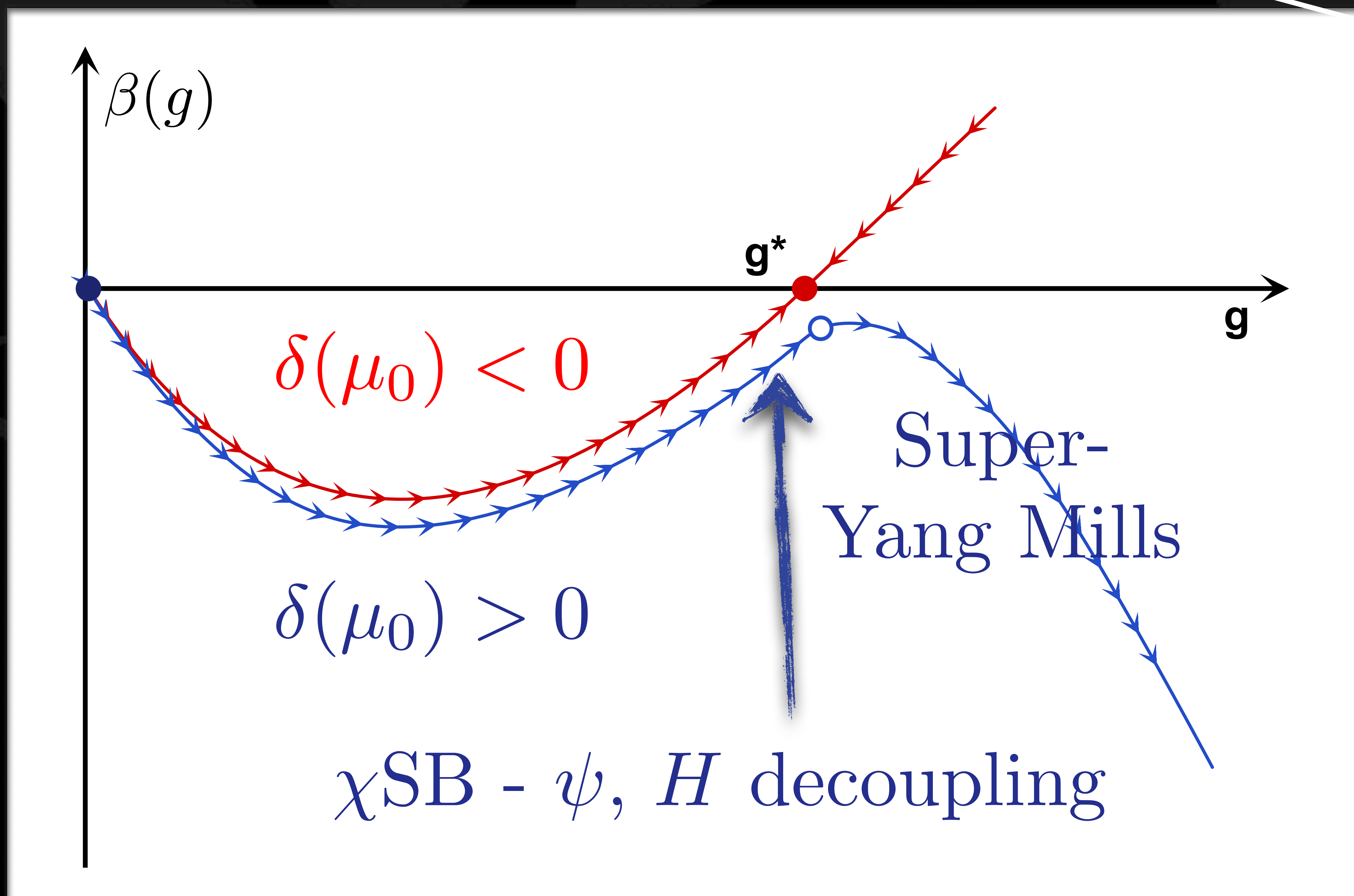

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$$\langle \lambda\lambda \rangle = -\frac{9}{32\pi^2}\Lambda^3_{SYM} \qquad \Lambda^2_{\text{SYM}} = v^2 \left(\frac{3}{11\epsilon}\right)^{2/3} \exp\left(-\frac{6}{22\epsilon}\right).$$

Full Spectrum in Broken Phase

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Mass eigenstates of quarks and mesons

$$H_{ij} \approx (\phi_c + \phi + i\pi^0)\delta_{ij} + h^a T^a_{ij} + i\pi^a T^a_{ij}, \qquad a = 1, \ldots N_{\rm f}^2 - 1$$

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Scale μ:

$m^2_{\rm NGB} = 0$	$m^2_{\rm SYM} \sim e^{-1/\epsilon}$	$m^2_d \sim \delta\epsilon$	$m^2_\psi \sim m^2_h \sim \epsilon$
N_f^2	$4(N_c^2 - 1)$	1	$4N_f N_c + (N_f^2 - 1)$

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Toy Model

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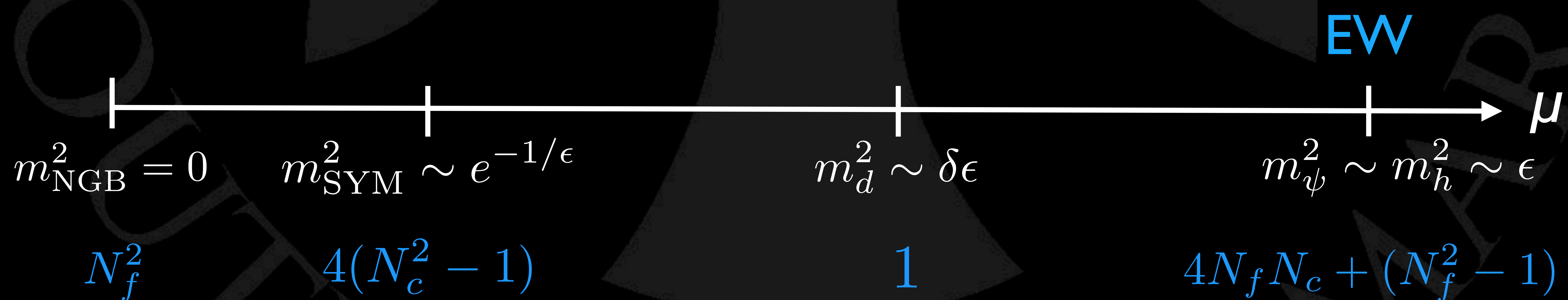

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DM | Higgs | EW | μ

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N_f^2 | $4(N_c^2 - 1)$ | 1 | $4 N_f N_c + (N_f^2 - 1)$

Toy Model

Full Spectrum in Broken Phase

O. Antipin, M. Mojaza, F. Sannino - hep-ph/1107.2932

$$\mathcal{L} = \mathcal{L}_K(F_{\mu\nu}, \lambda, \psi, H; g) + y_H \bar{\psi} H \psi + \text{h.c.} - u_1 \left(\text{Tr} H^\dagger H\right)^2 - u_2 \text{Tr} \left(H^\dagger H\right)^2$$

Mass eigenstates of quarks and mesons

$$H_{ij} \approx (\phi_c + \phi + i\pi^0)\delta_{ij} + h^a T^a_{ij} + i\pi^a T^a_{ij}, \qquad a = 1, \dots N_{\rm f}^2 - 1$$

?	DM	Higgs	EW
$m^2_{\rm NGB} = 0$	$m^2_{\rm SYM} \sim e^{-1/\epsilon}$	$m^2_d \sim \delta\epsilon$	$m^2_\psi \sim m^2_h \sim \epsilon$
N_f^2	$4(N_c^2 - 1)$	1	$4N_f N_c + (N_f^2 - 1)$

(scale axis: μ)

Toy Model

THANK YOU!

The Dilaton

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The Dilaton

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At the Quantum level

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At the Quantum level

- Scale invariance is already broken by the *Trace Anomaly* of the EM-tensor

$$\partial_\mu D^\mu = \Theta^\mu_\mu = \sum_i \beta(g_i) \frac{\partial \mathcal{L}}{\partial g_i}$$

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$$\Theta^\mu_\mu \propto (\beta_1 + \beta_2)\phi + \cdots \qquad \text{since } \beta(g), \beta(y_H) \approx 0 \text{ at } \mu_0$$