How the Higgs can be so light

Light Dilaton at Fixed Points and Ultra Light Scale SYM

Oleg Antipin

CP^3 - Origins

Particle Physics & Origin of Mass

VIIIth Rencontres du Vietnam, 2012

SOUTHERN DENMARK

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

(toy-model for electroweak symmetry breaking)

Infrared Destiny

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Perturbative 1-loop IR stable fixed point (a la Banks-Zaks)

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$$a_g = \frac{g^2 N_c}{(4\pi)^2}, a_H = \frac{y_H^2 N_c}{(4\pi)^2}$$

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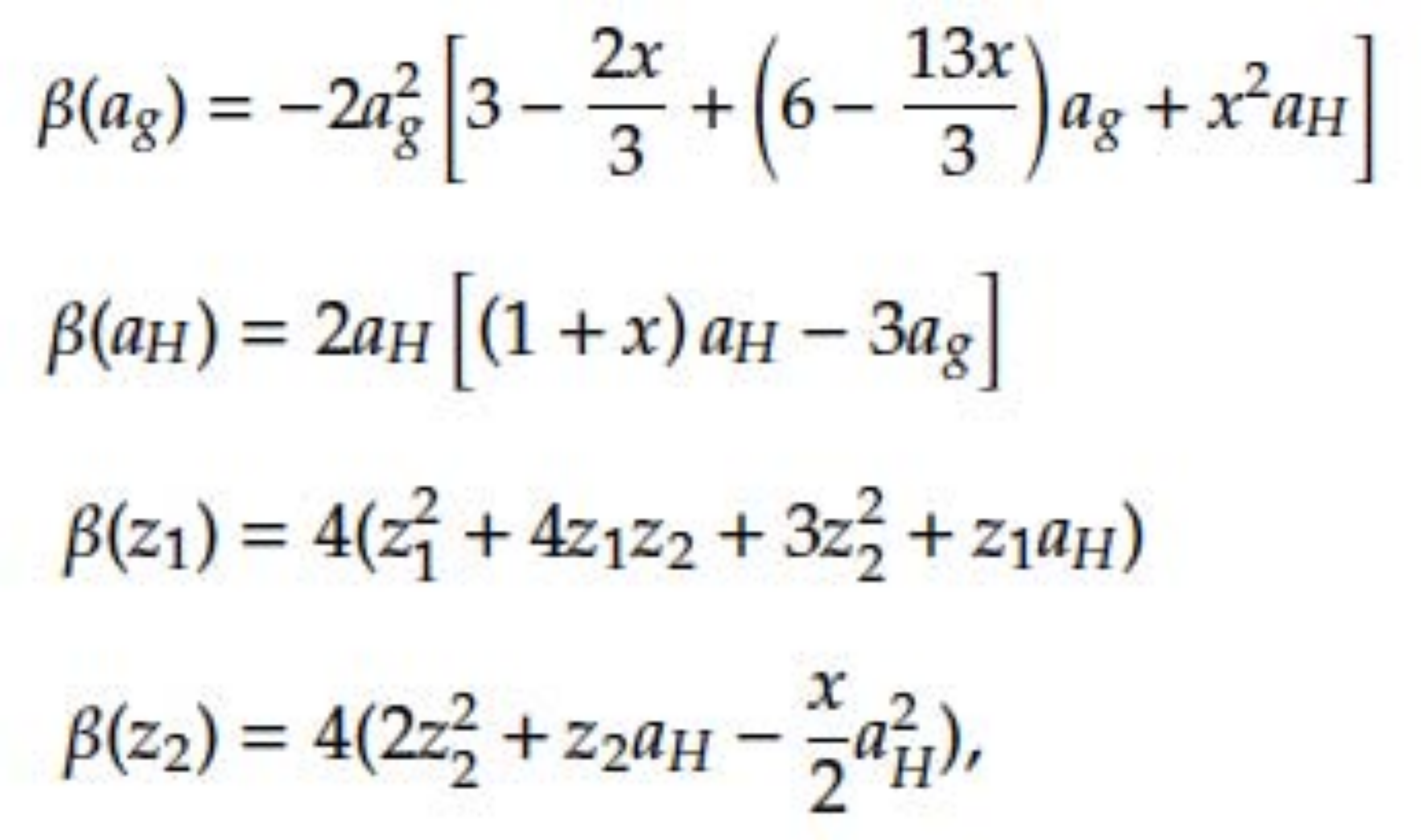
1-loop beta functions:



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

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

$$\beta(z_1) = 4(z_1^2 + 4z_1z_2 + 3z_2^2 + z_1 a_H)$$

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

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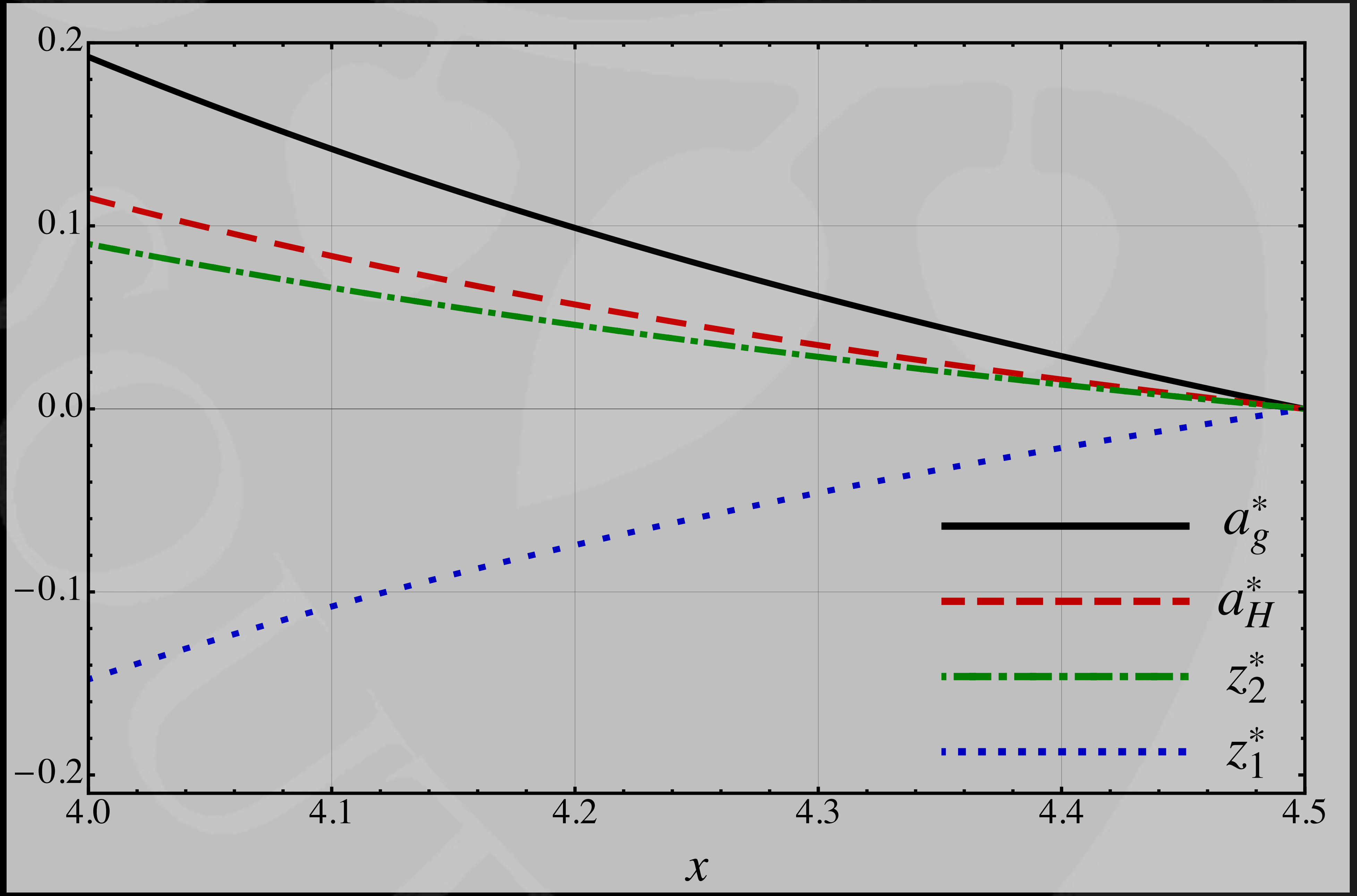

$$x \equiv \frac{9}{2}(1 - \epsilon)$$

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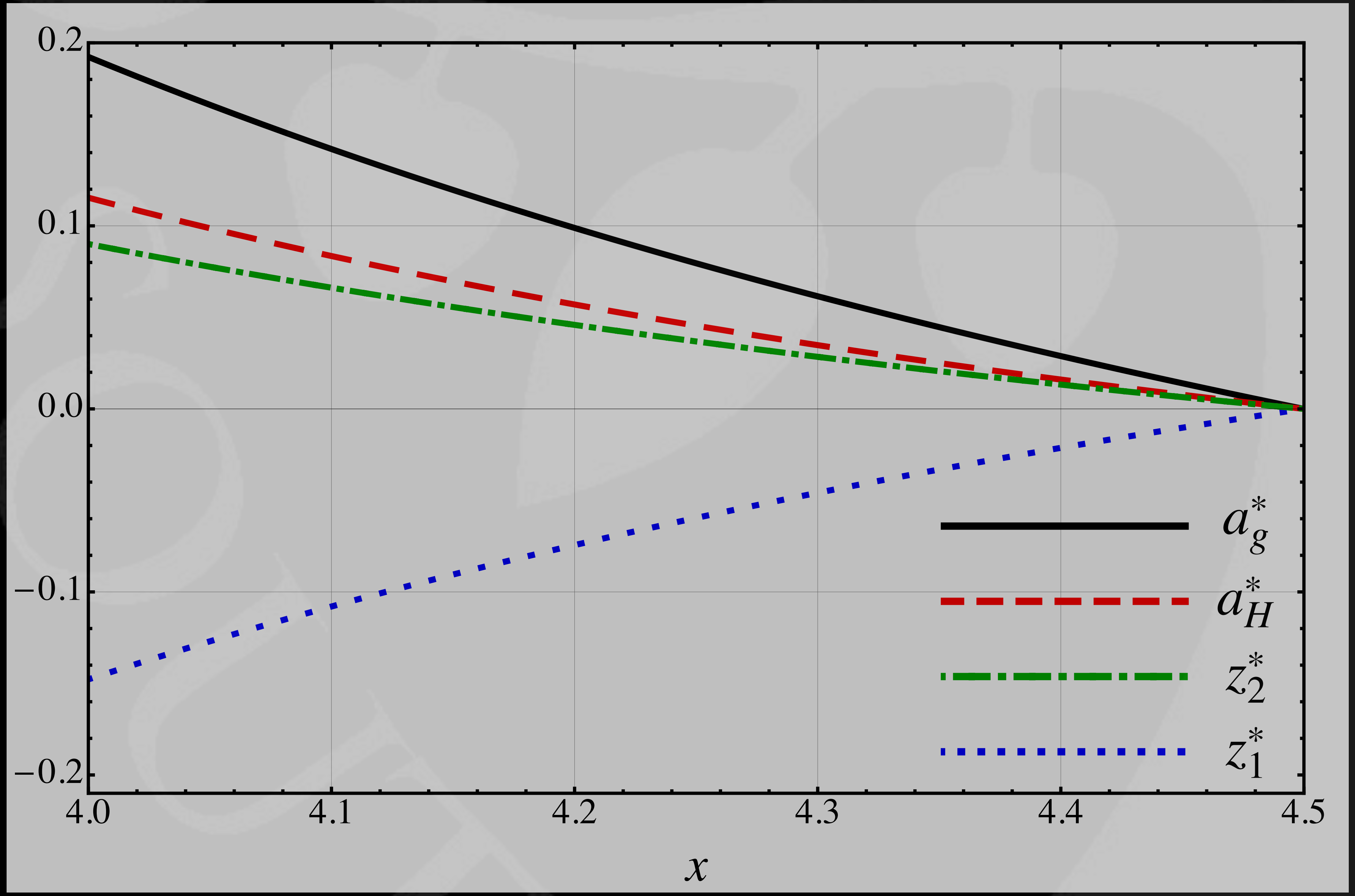

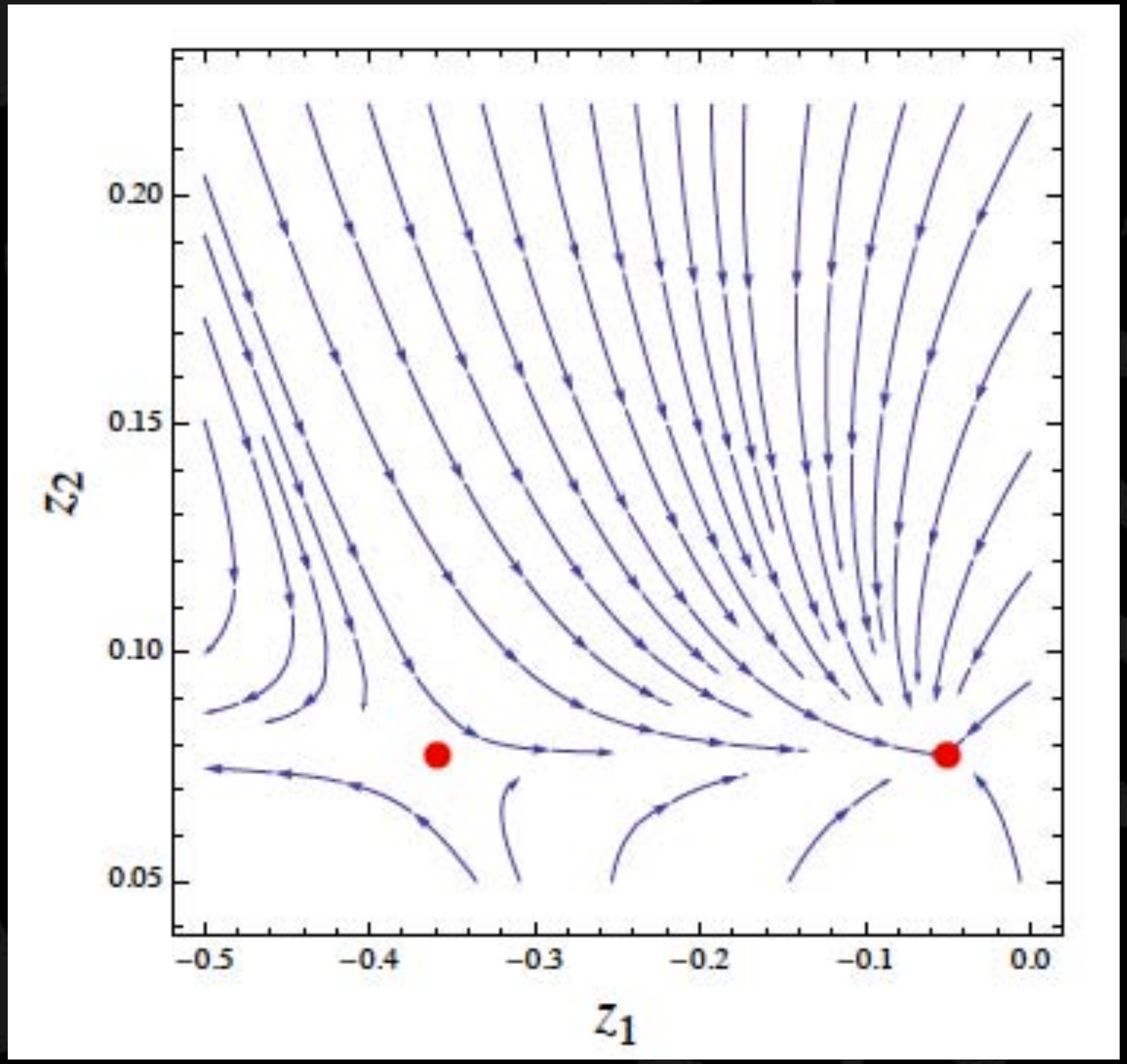

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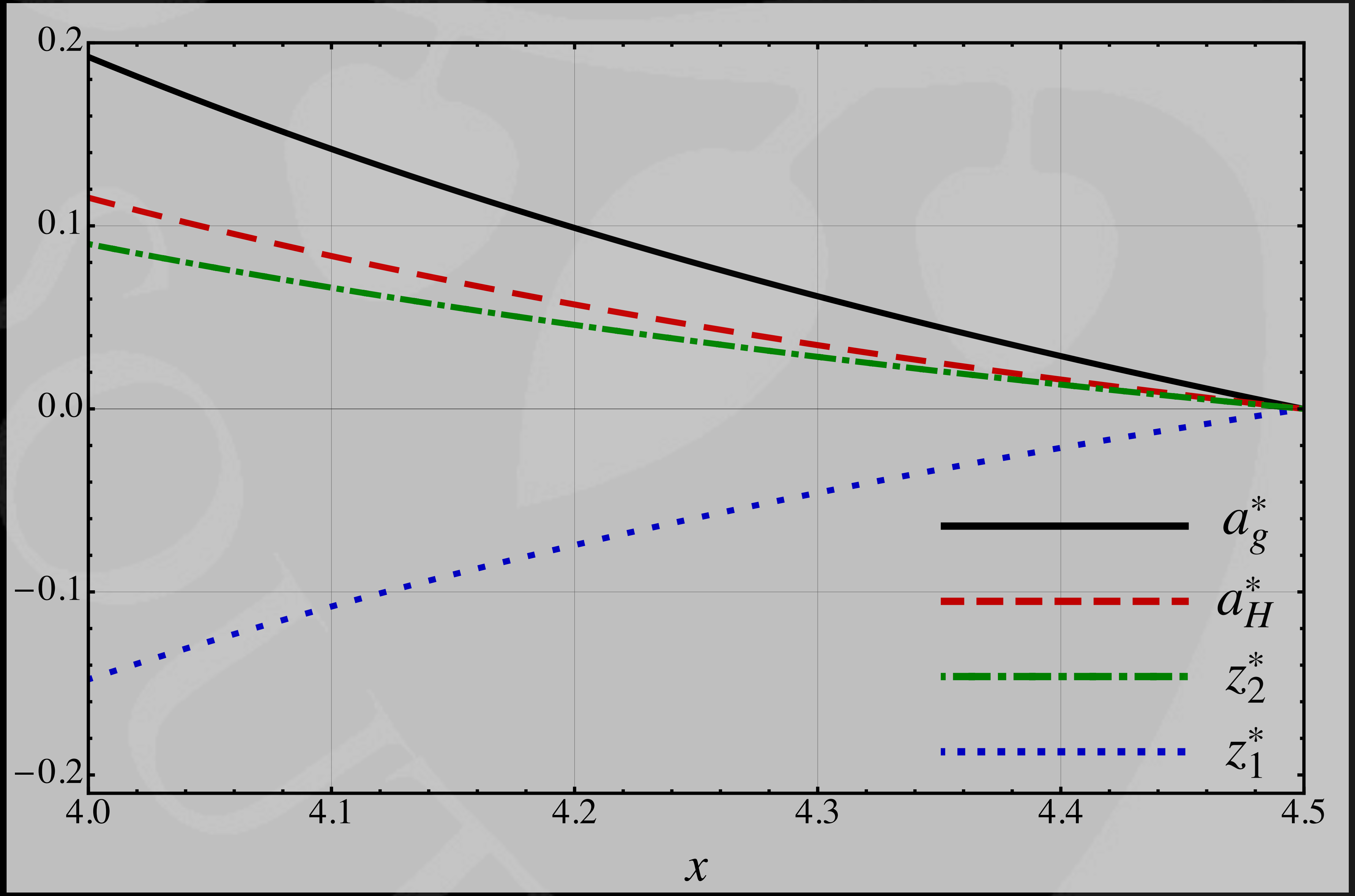

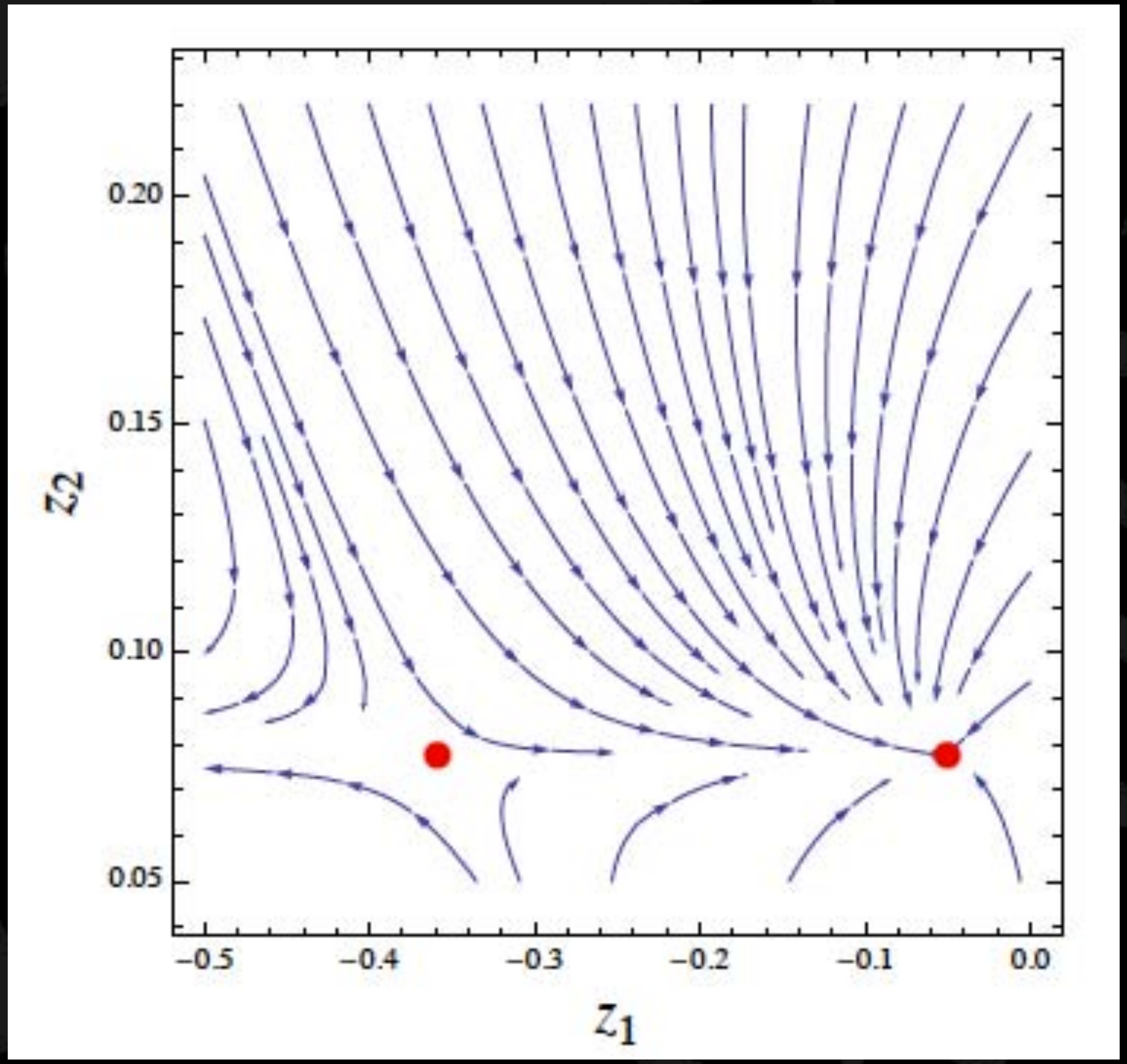

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This FP can become "hidden" by spontaneous symmetry breaking from radiative corrections (Coleman-Weinberg mechanism)

Spontaneous Symmetry Breaking

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Coleman-Weinberg mechanism solely controlled by beta functions

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$$\frac{dV_{\mathrm{eff}}^{\mathrm{RG}}}{d\mu} = \left(\mu\frac{\partial}{\partial\mu} + \sum_i \beta(g_i)\frac{\partial}{\partial g_i} + \gamma_\phi\phi_c\frac{\partial}{\partial\phi_c}\right)V_{\mathrm{eff}}^{\mathrm{RG}} = 0$$

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

Phase Transition

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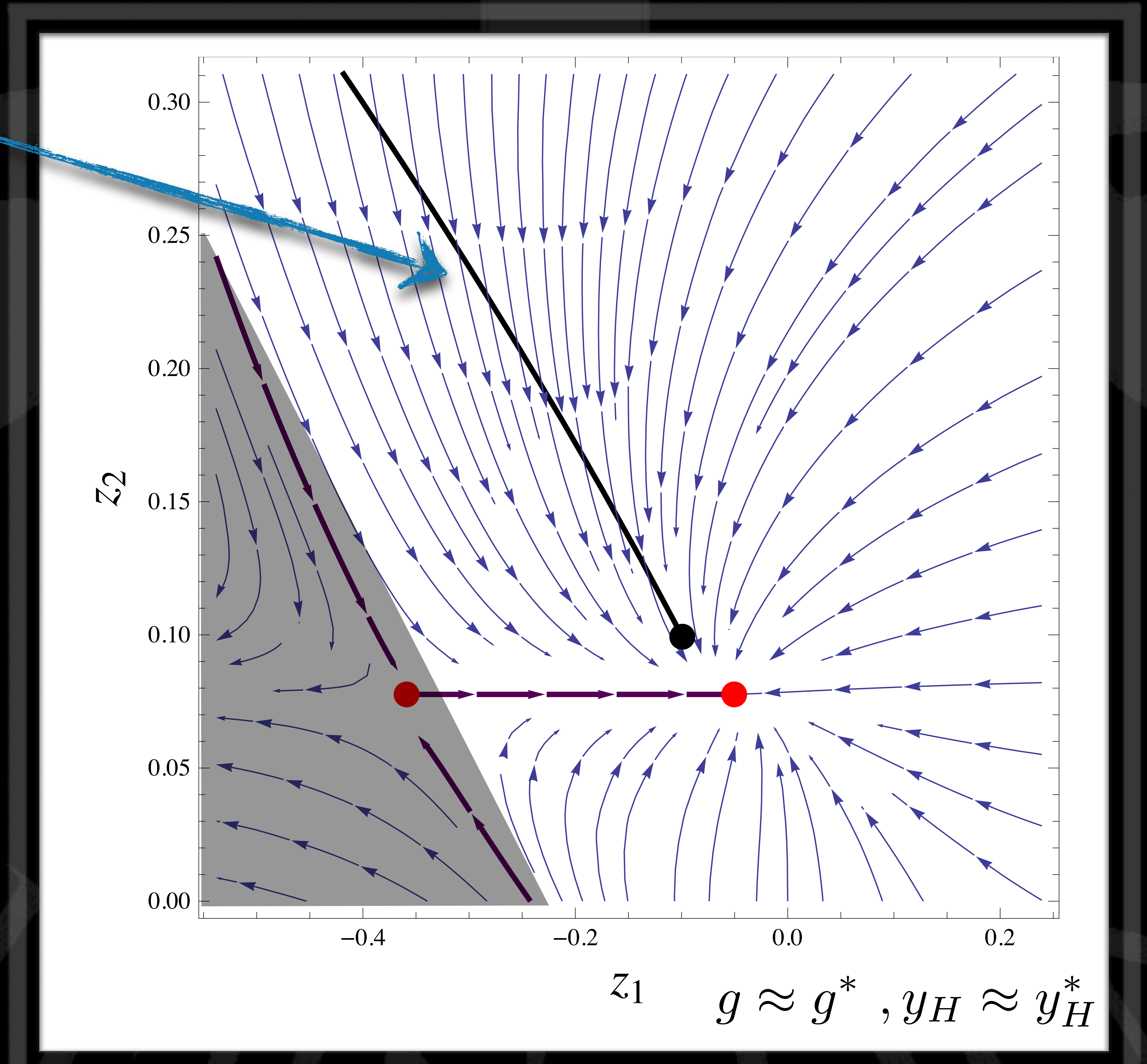

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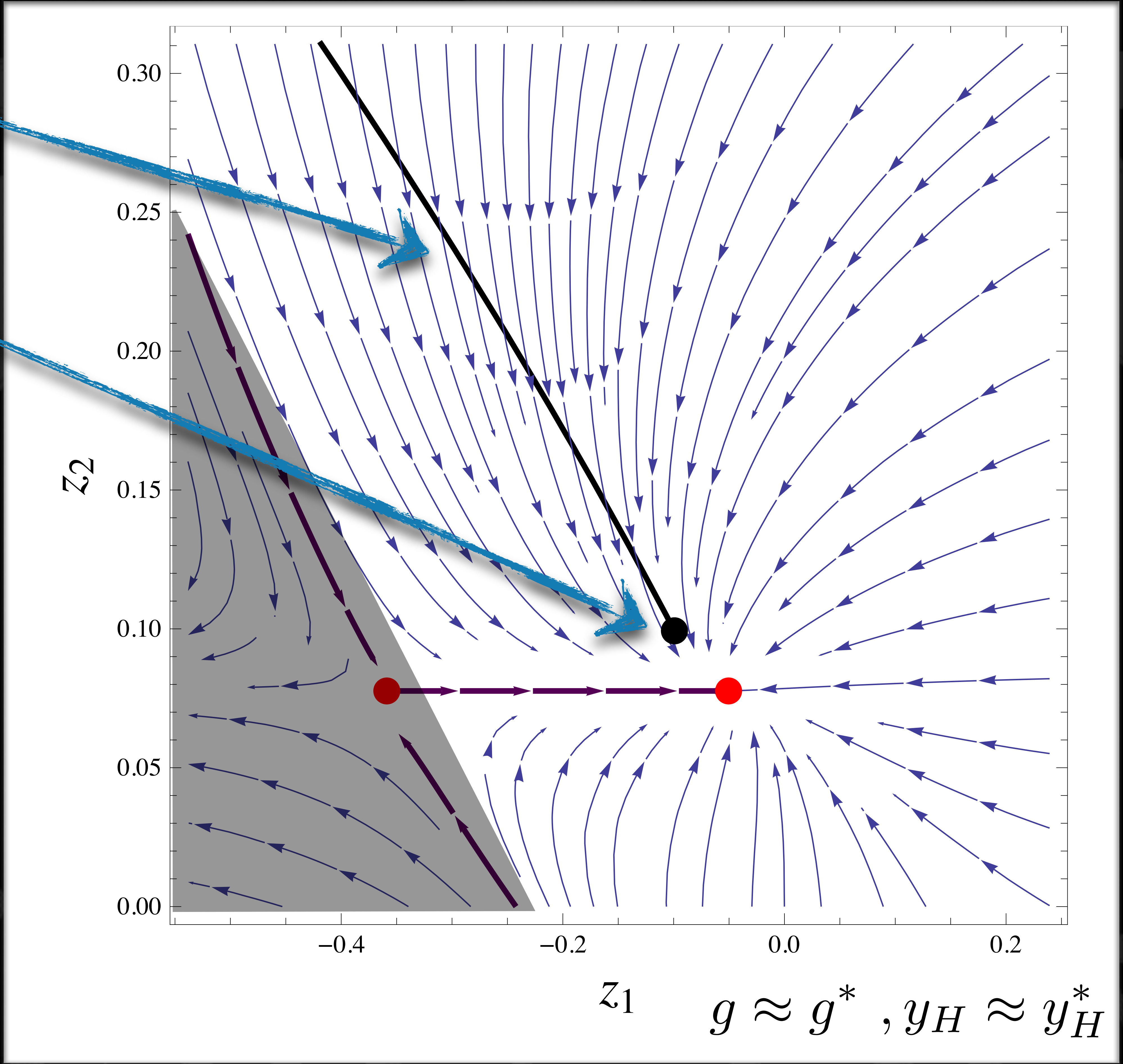

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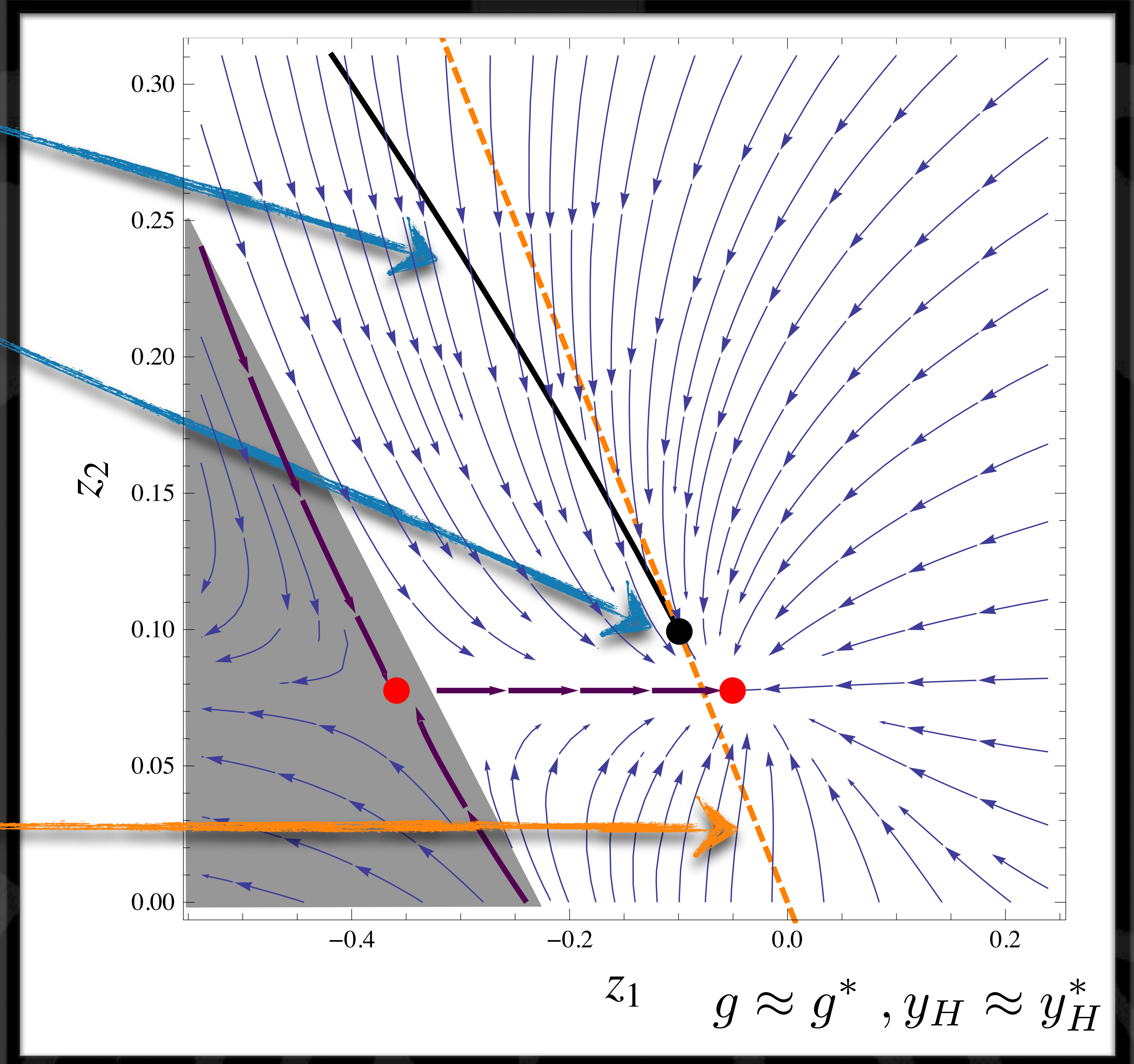

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The Light Dilaton

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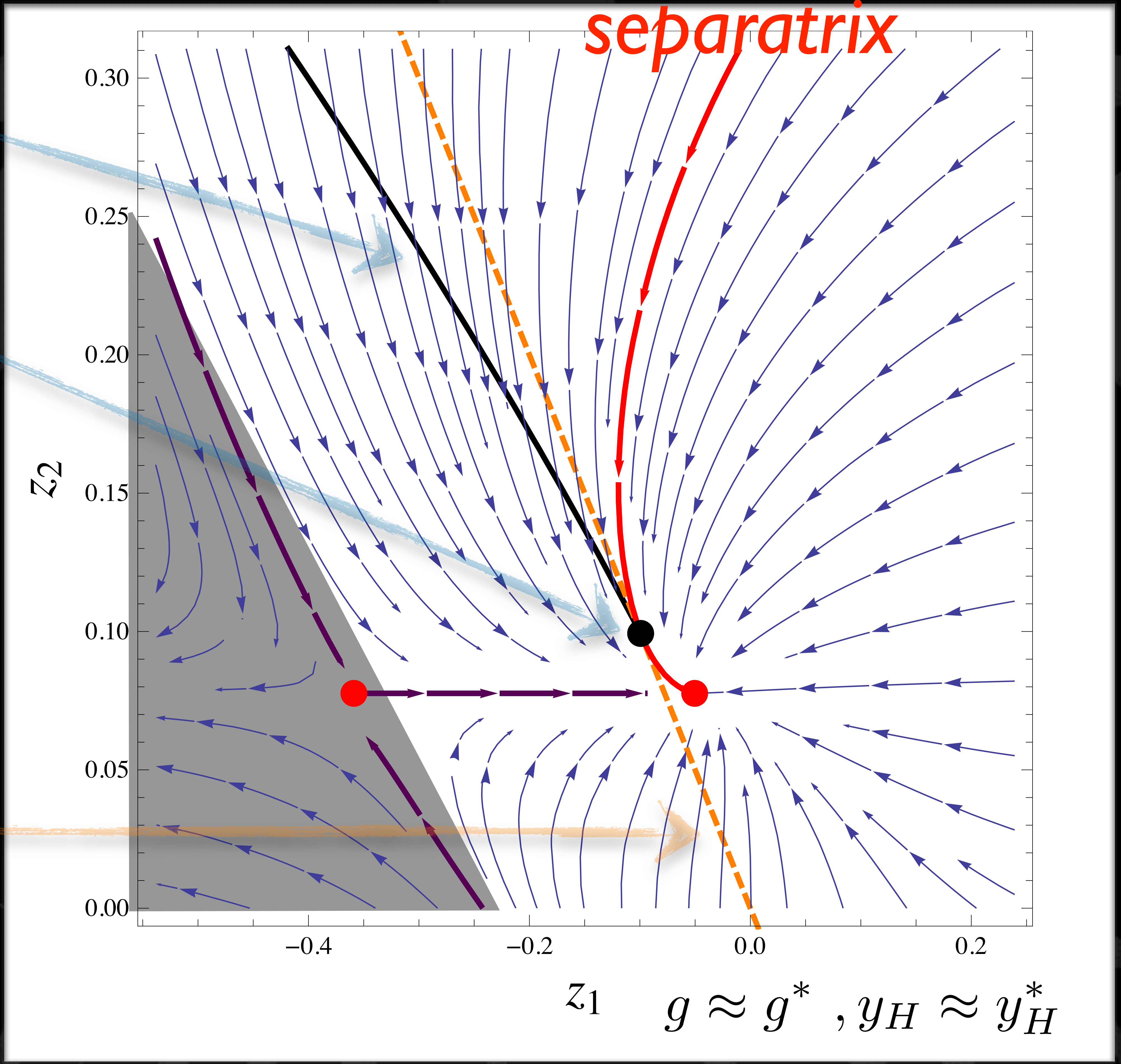

The Light Dilaton

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

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

$$V_{\text{eff}}^{\text{RG}\prime}(\phi_c) = 0$$

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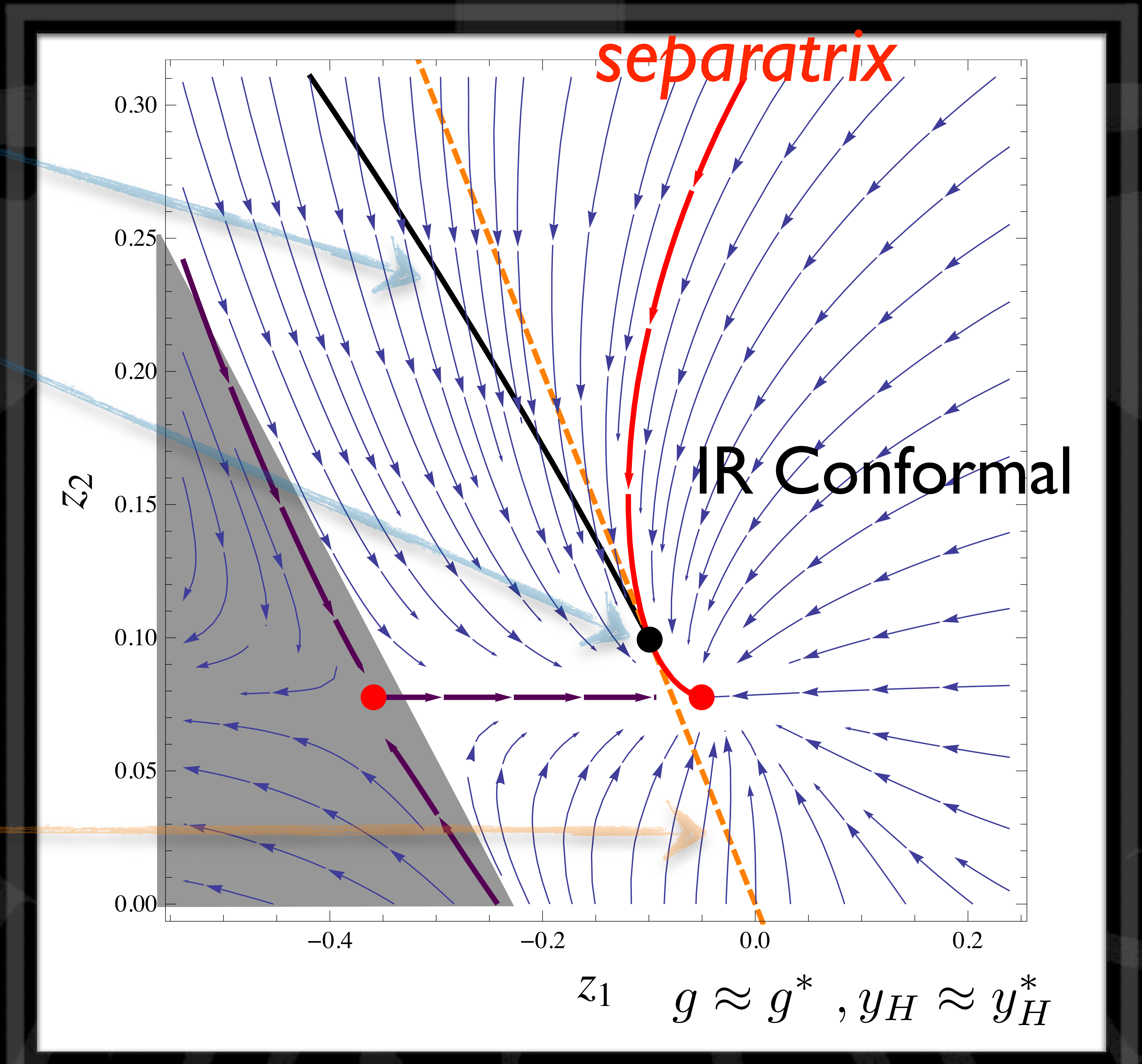

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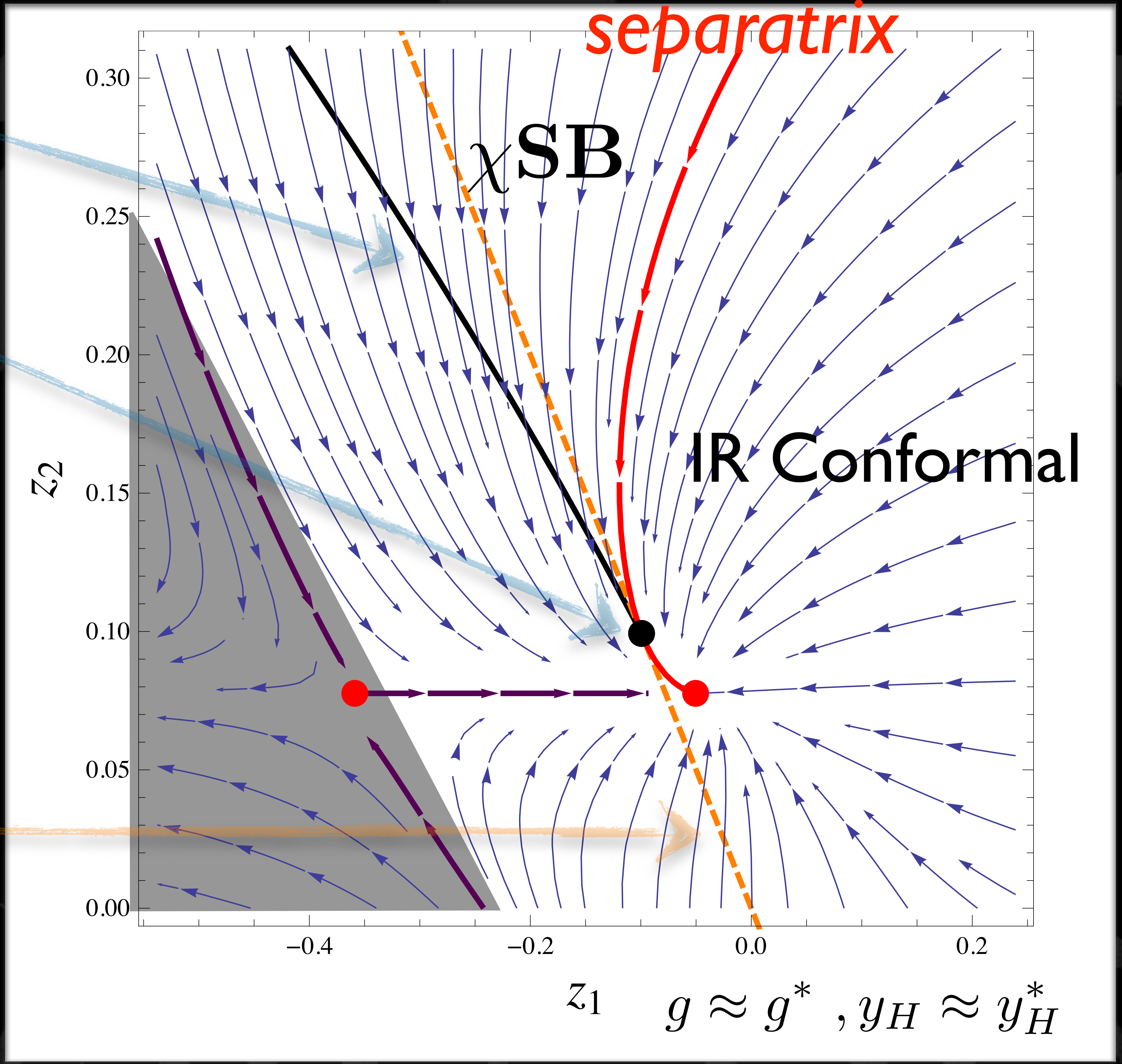

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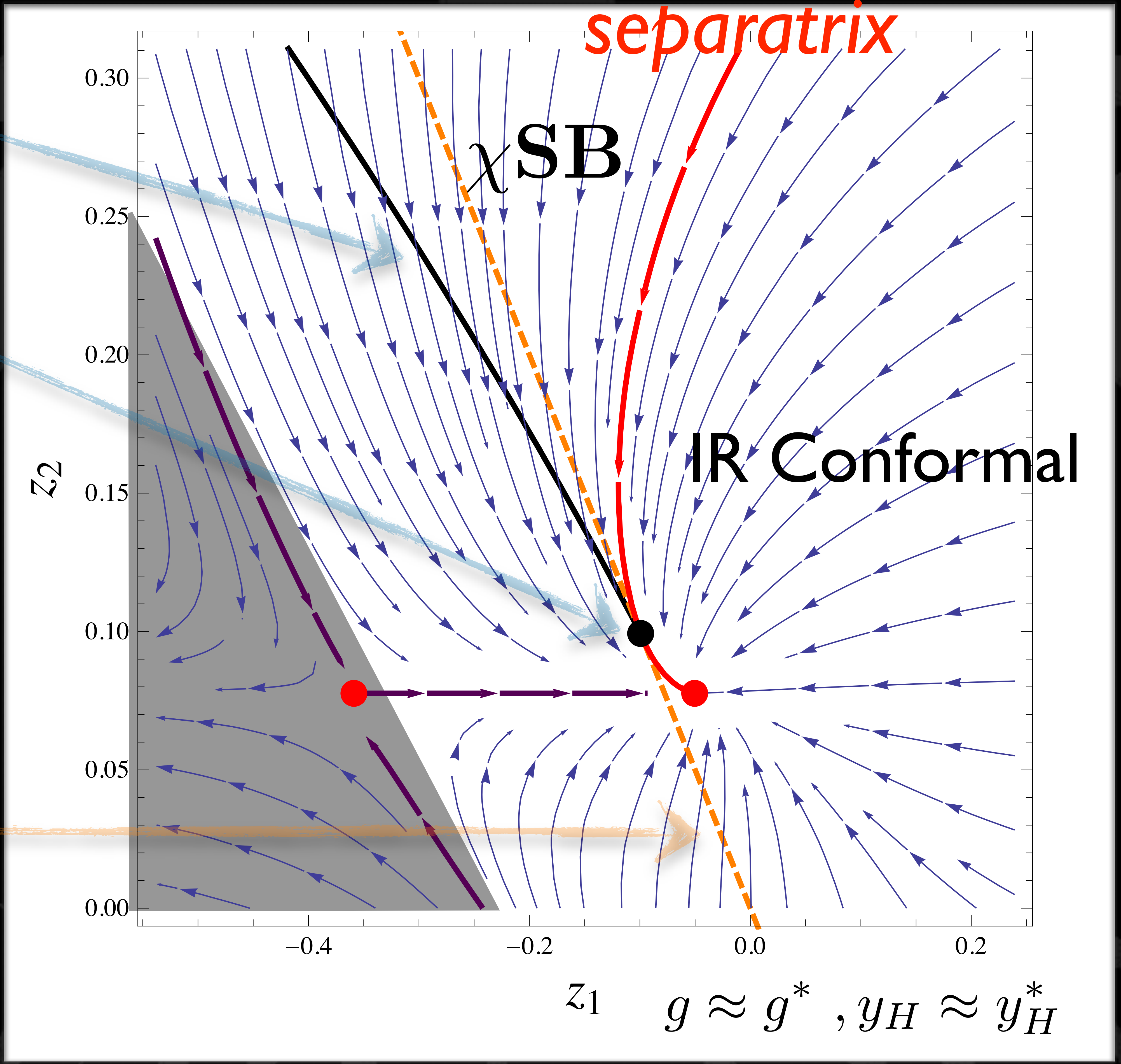

Scale generation by *dimensional transmutation.*

The Light Dilaton

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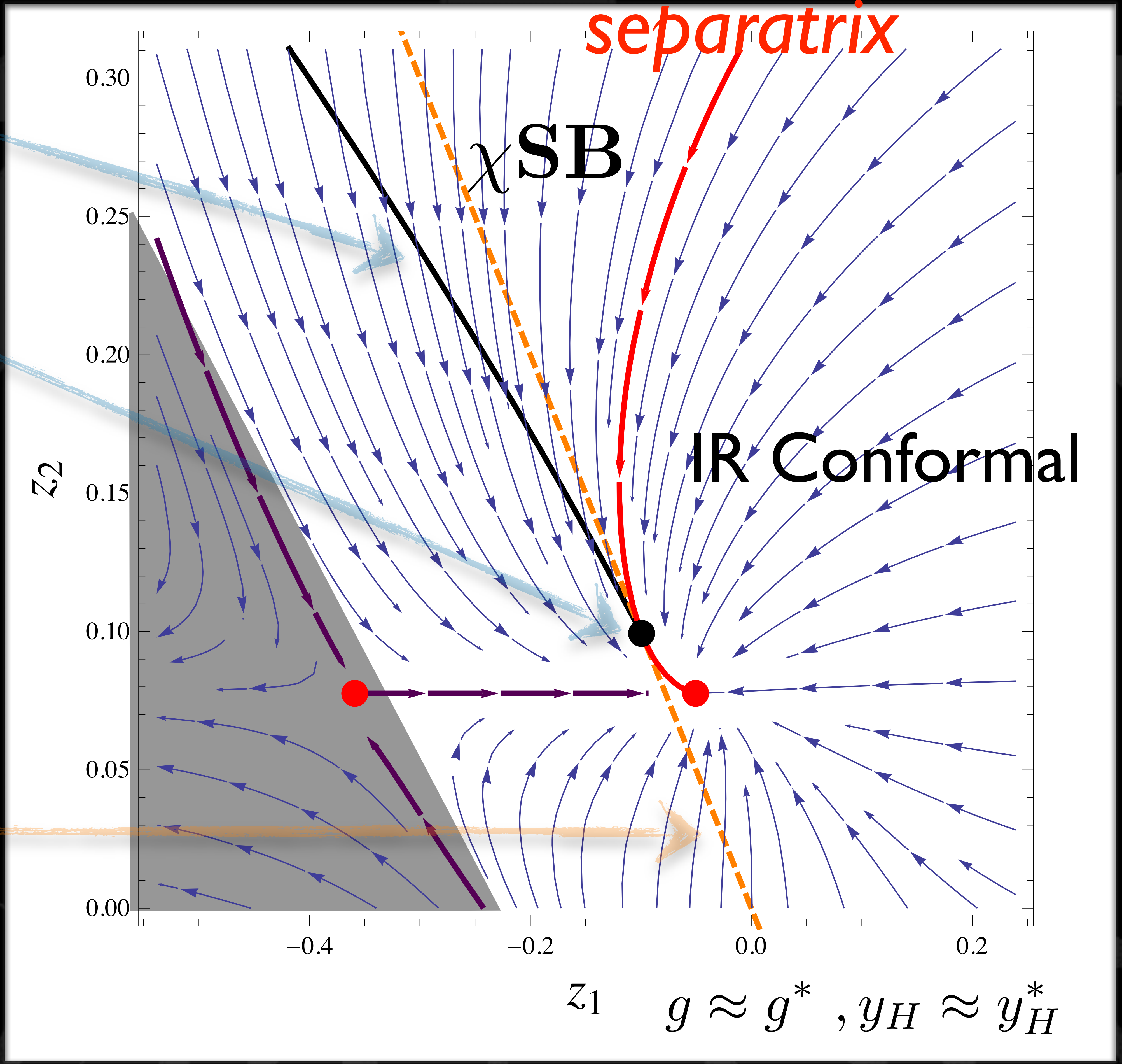

Scale generation by *dimensional transmutation.*

Near conformal symmetry spont. broken.

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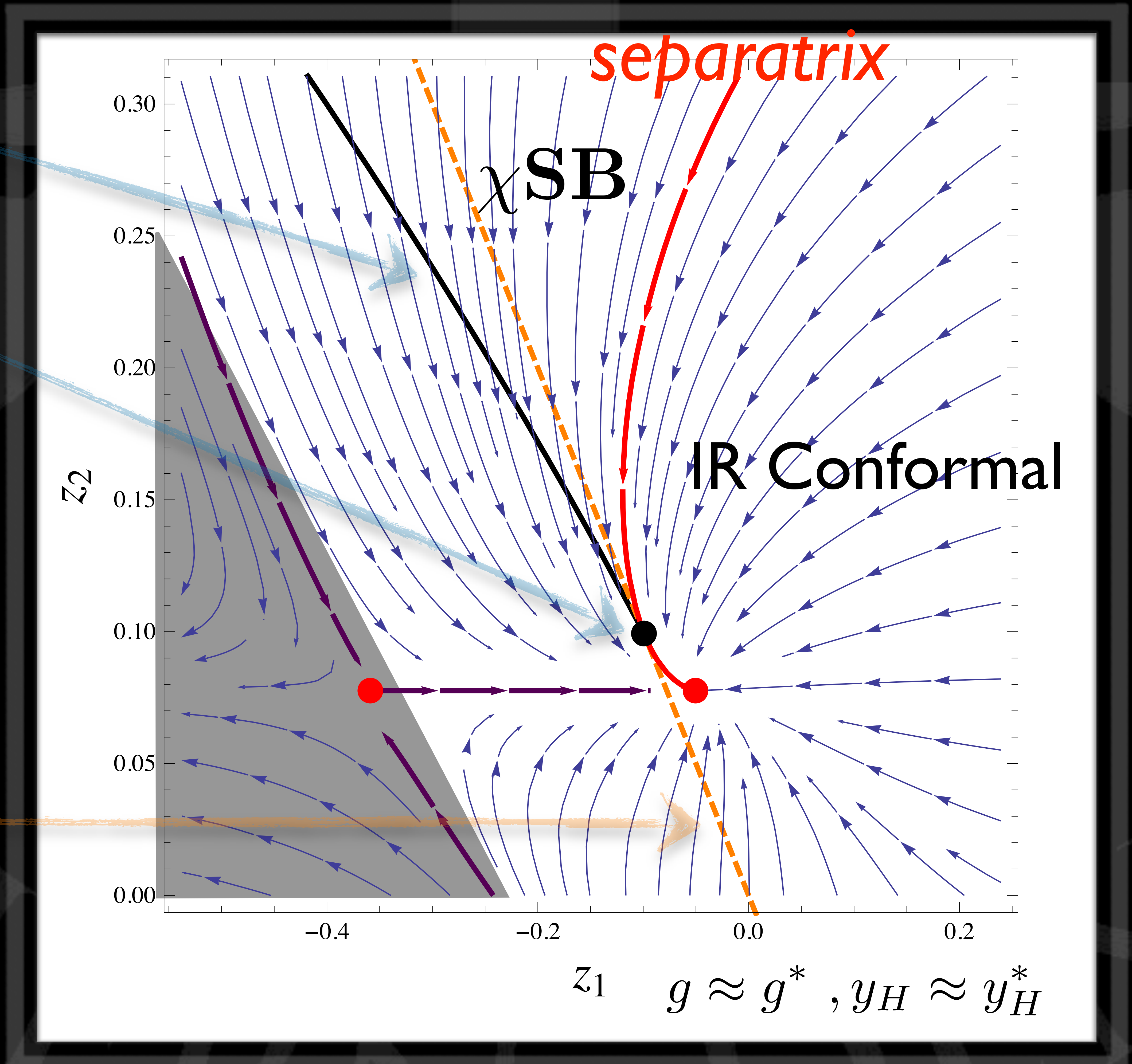

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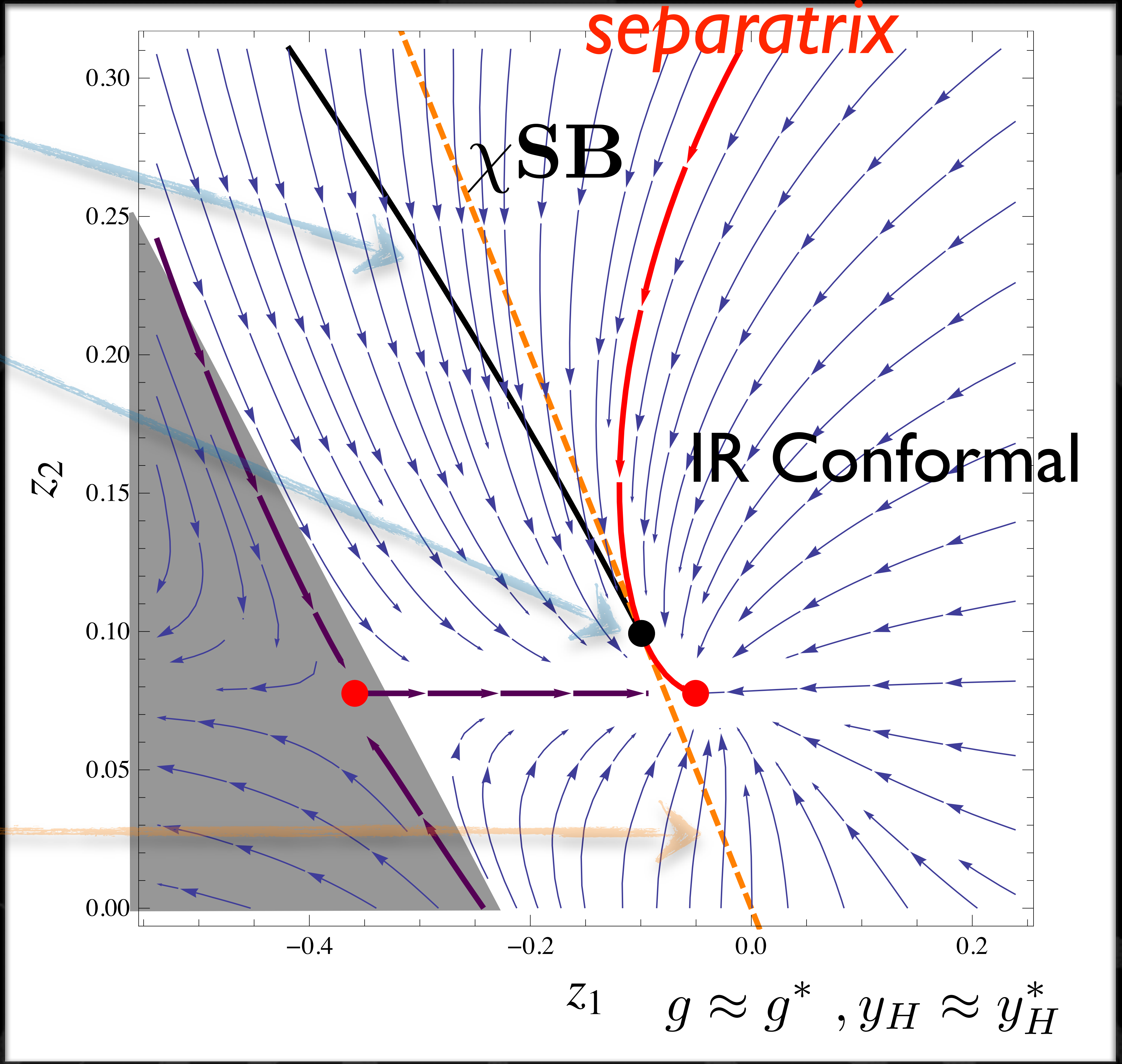

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Arbitrarily light by tuning:

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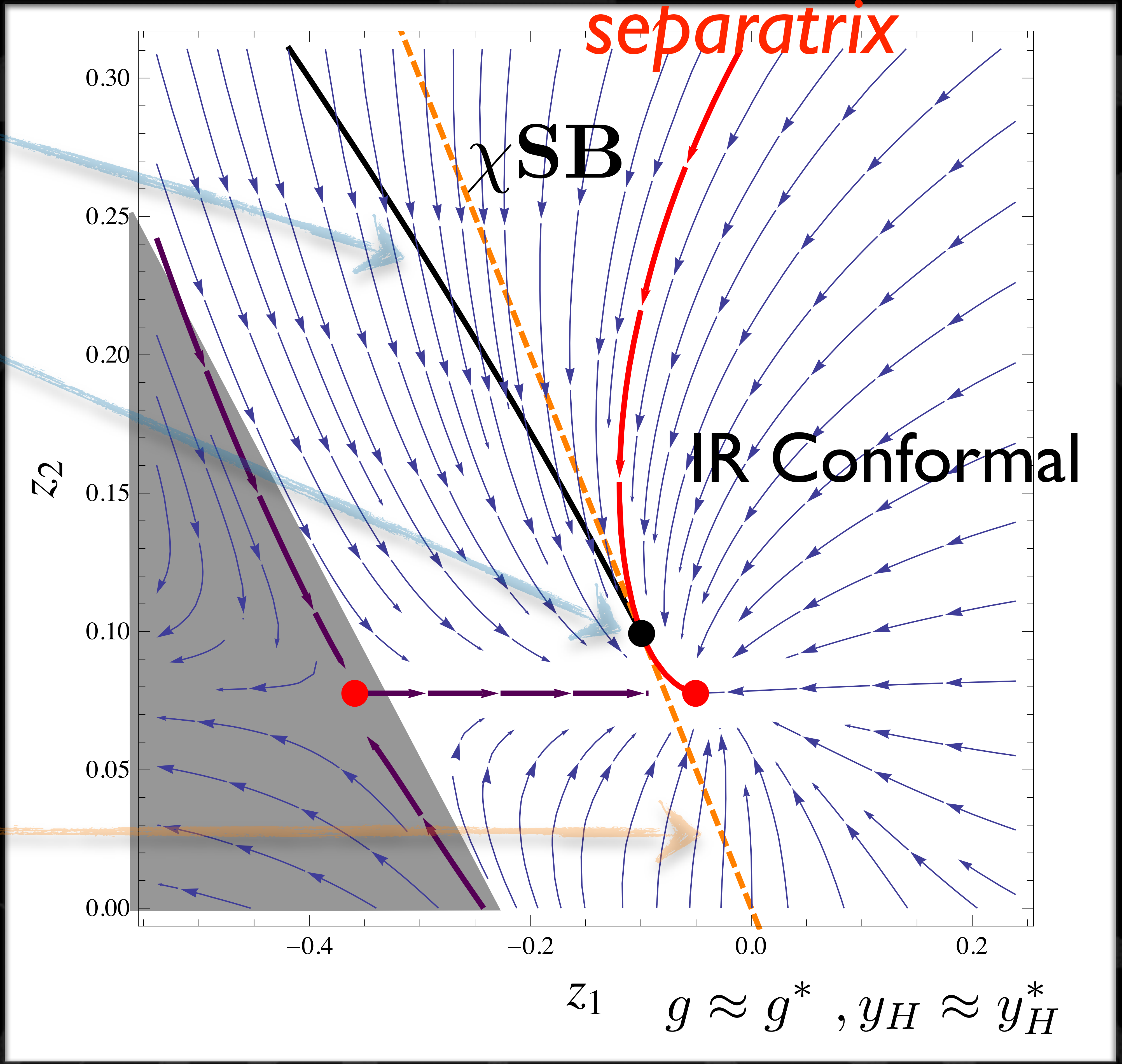

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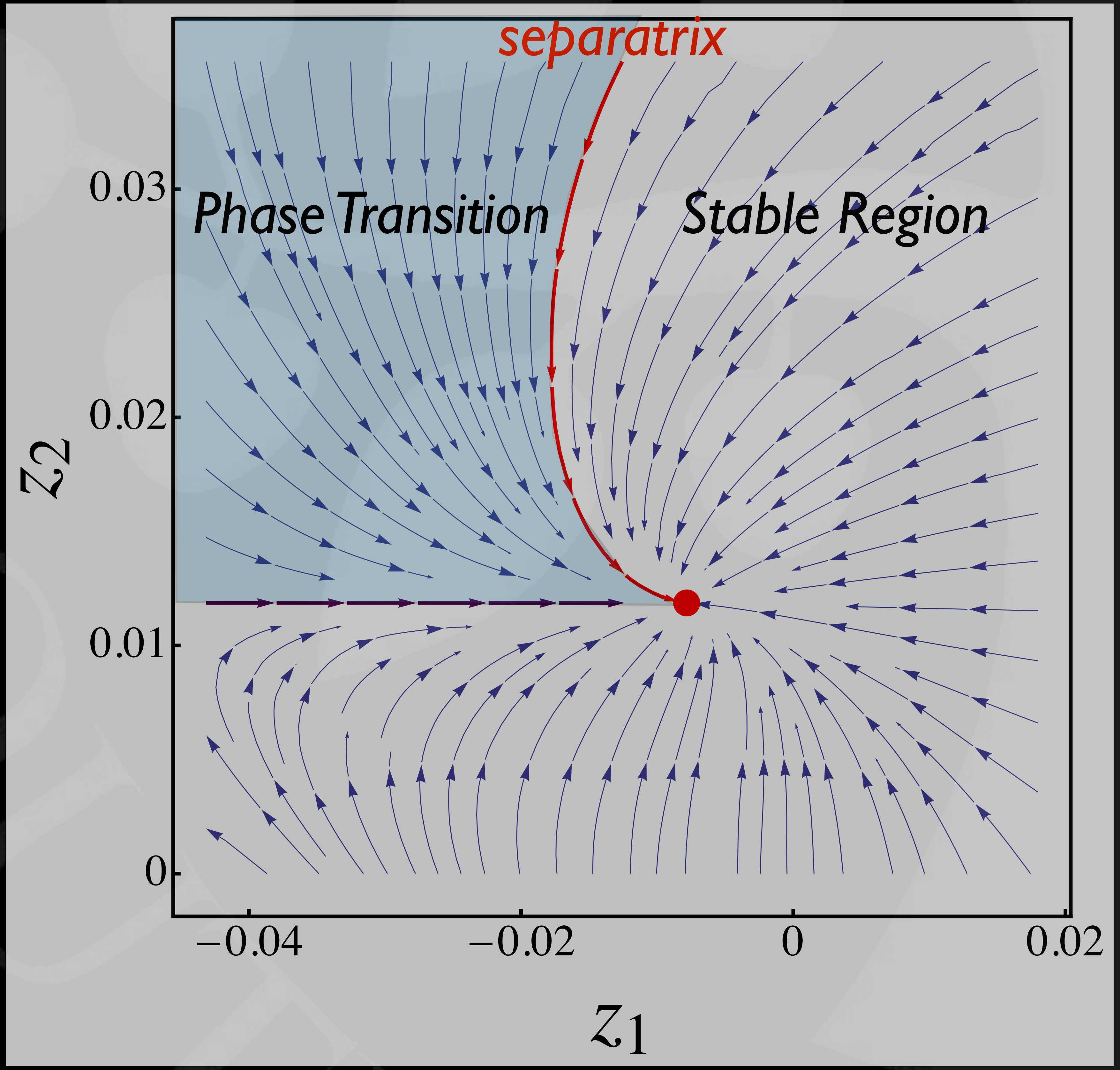
$$m_h^2 = (4z_2^2 - x a_H^2)\phi_c^2 \equiv \delta\phi_c^2$$

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 Dilaton

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The Dilaton

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At the Quantum level

The Dilaton

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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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The Dilaton

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- The dilaton mass is defined by the matrix element

$$\langle D|\partial_\mu D^\mu|0\rangle = -f_D m_D^2$$

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The Dilaton

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- Lightest spinless state that couples strongest to the EM-tensor

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

The Complete Picture

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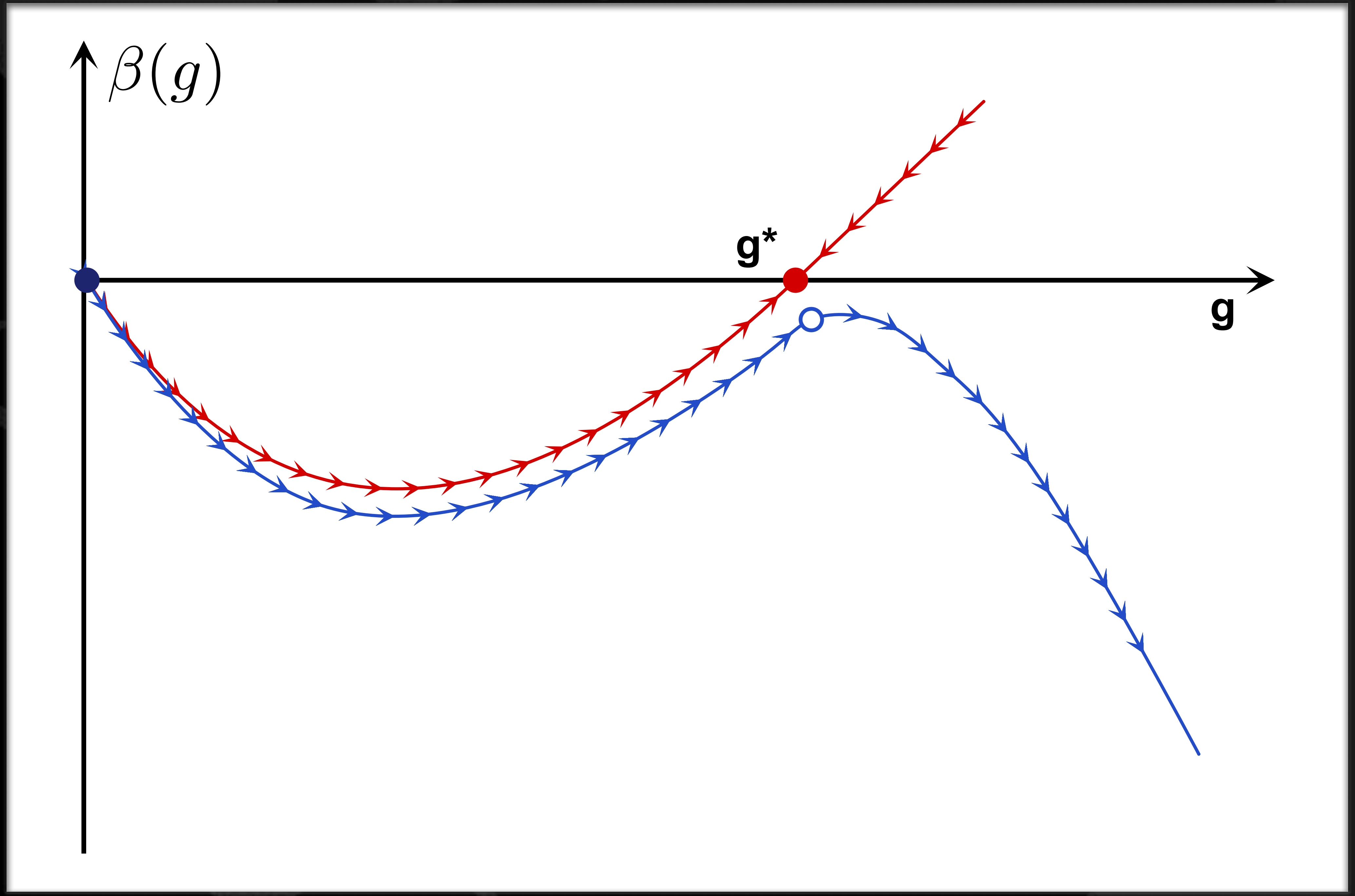
$$\mathcal{L} = \mathcal{L}_K(F_{\mu\nu}, \lambda, \psi\,, H; g) + y_H \bar{\psi} H \psi + \text{h.c.} - u_1 \left(\text{Tr} H^\dagger H\right)^2 - u_2 \text{Tr}\left(H^\dagger H\right)^2$$



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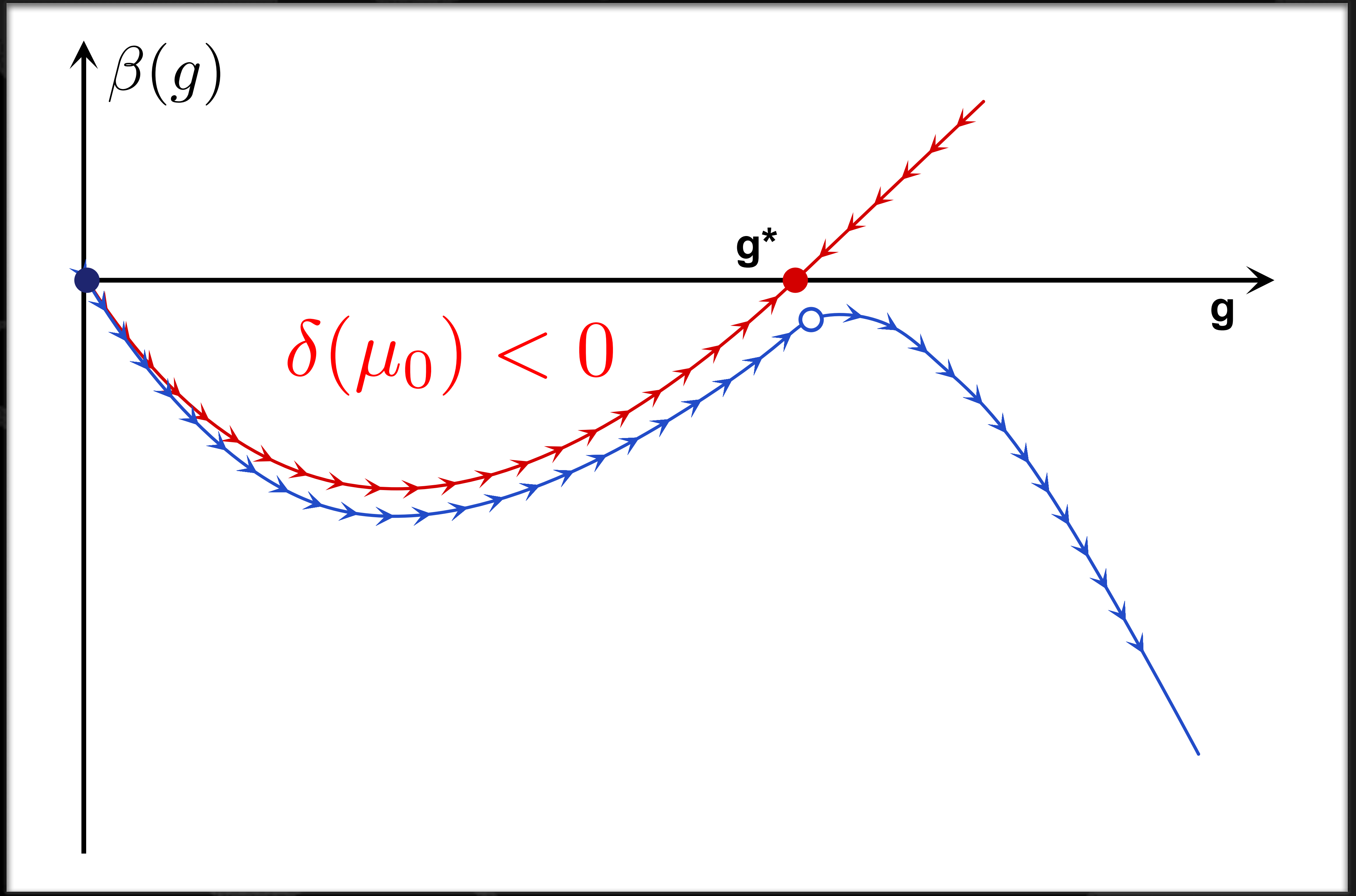

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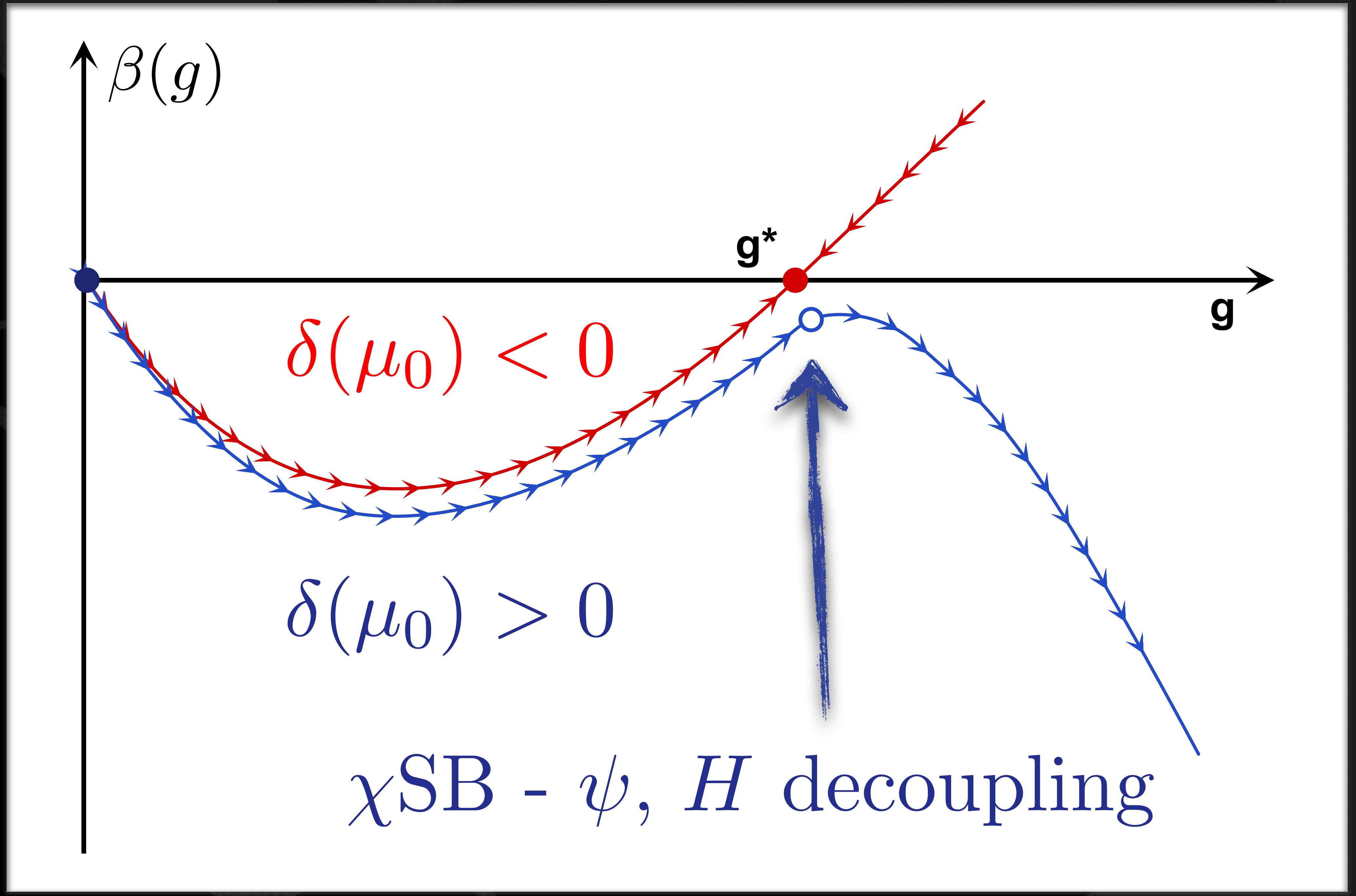

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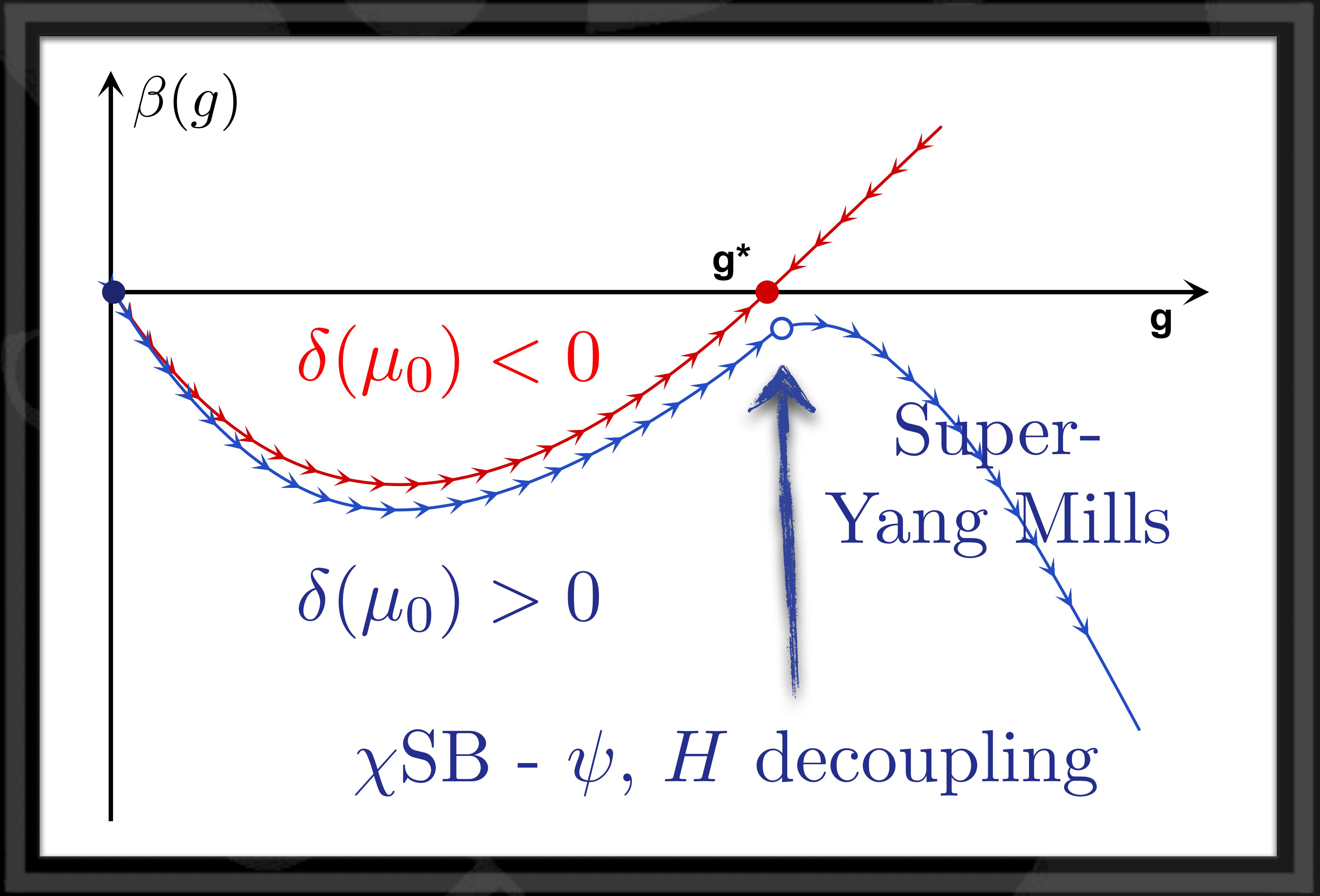

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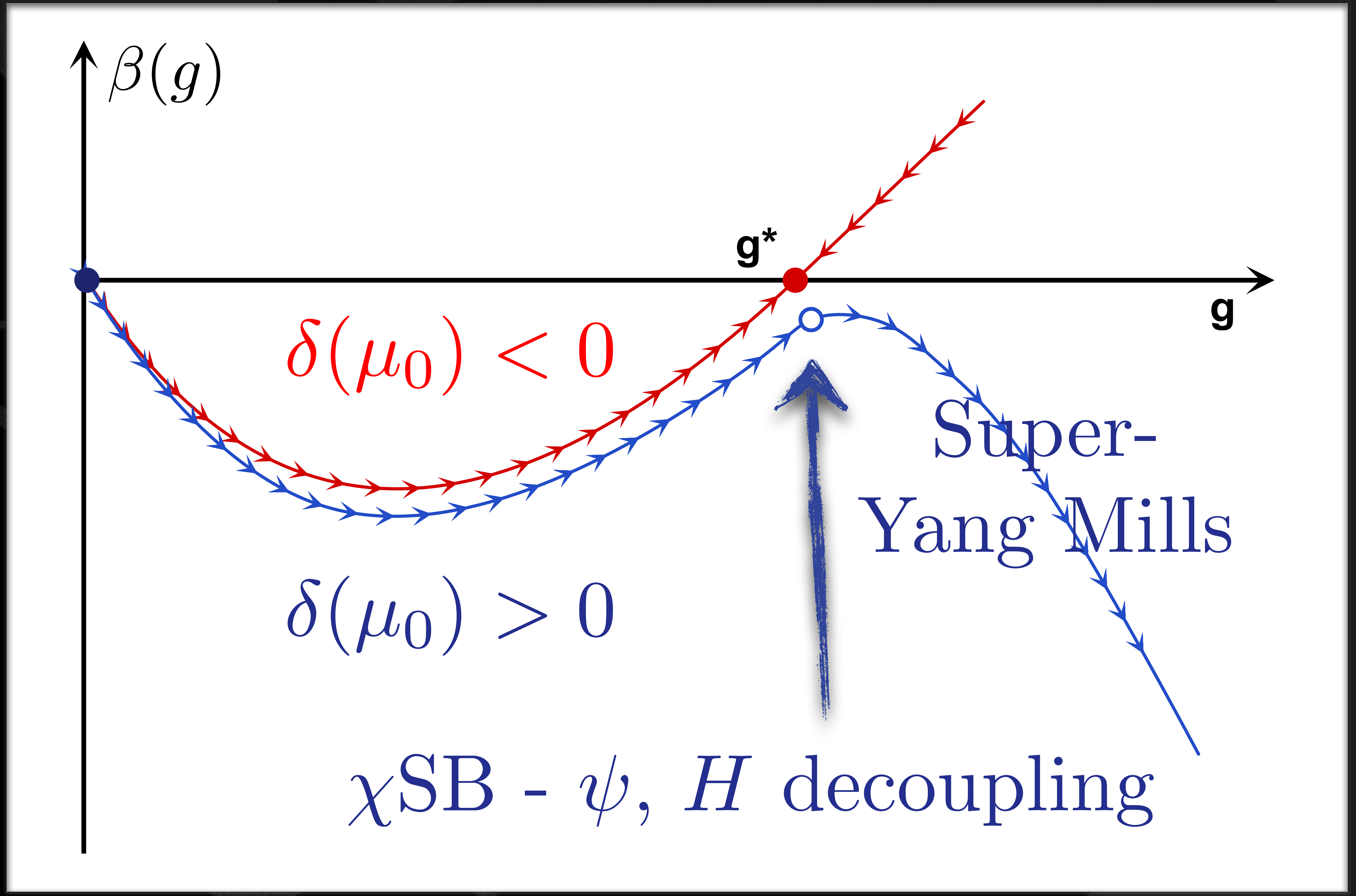

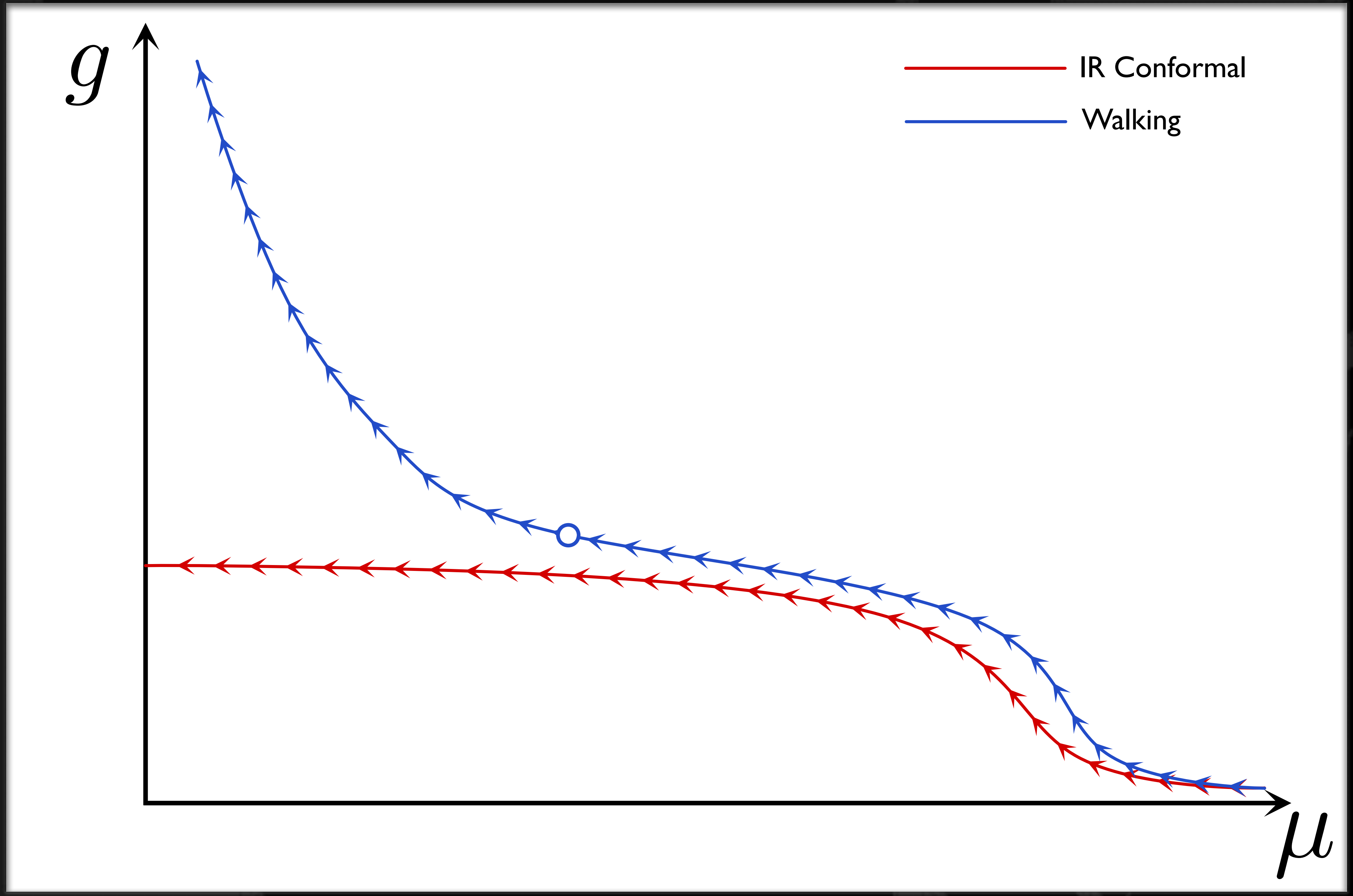

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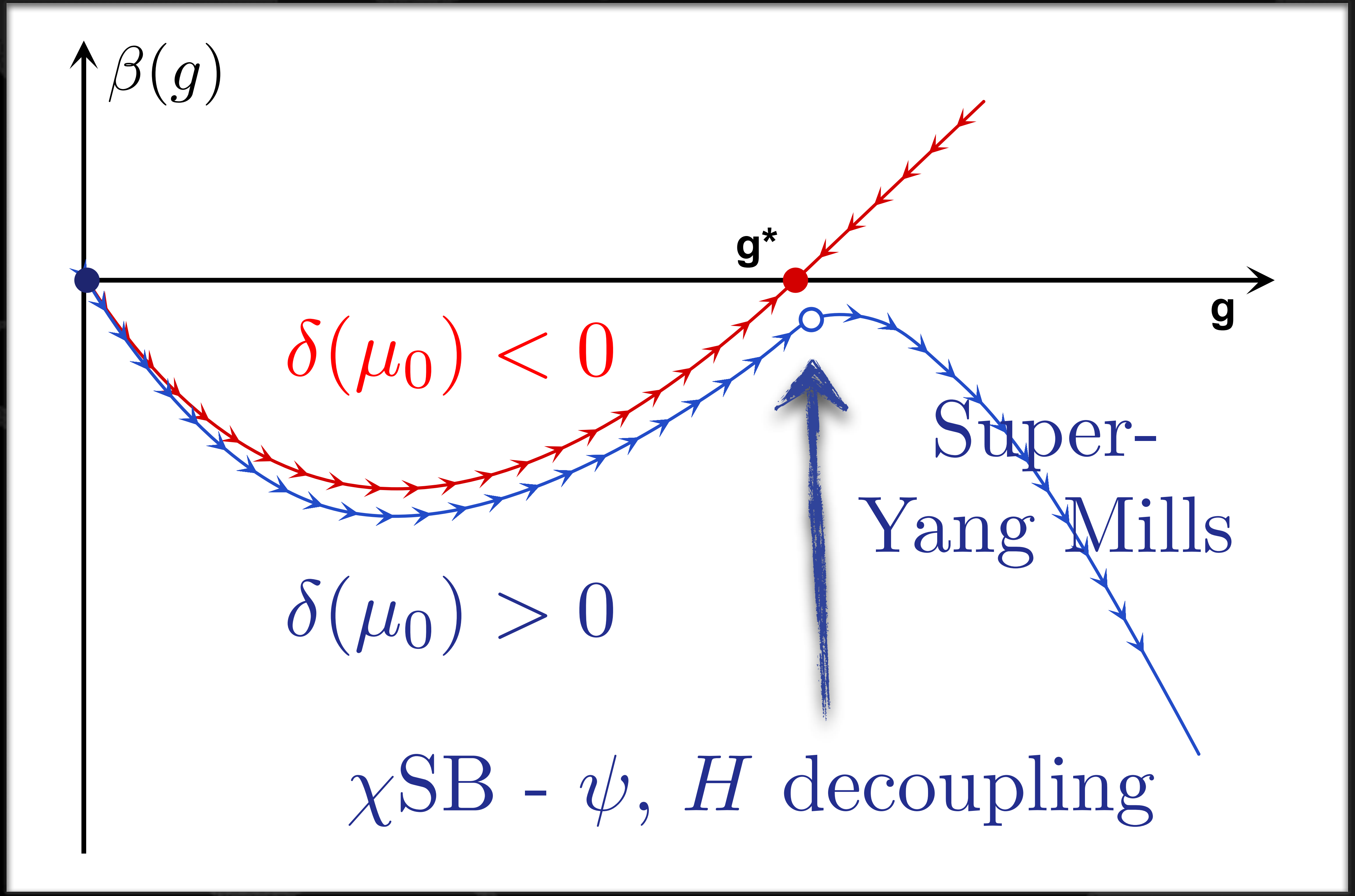

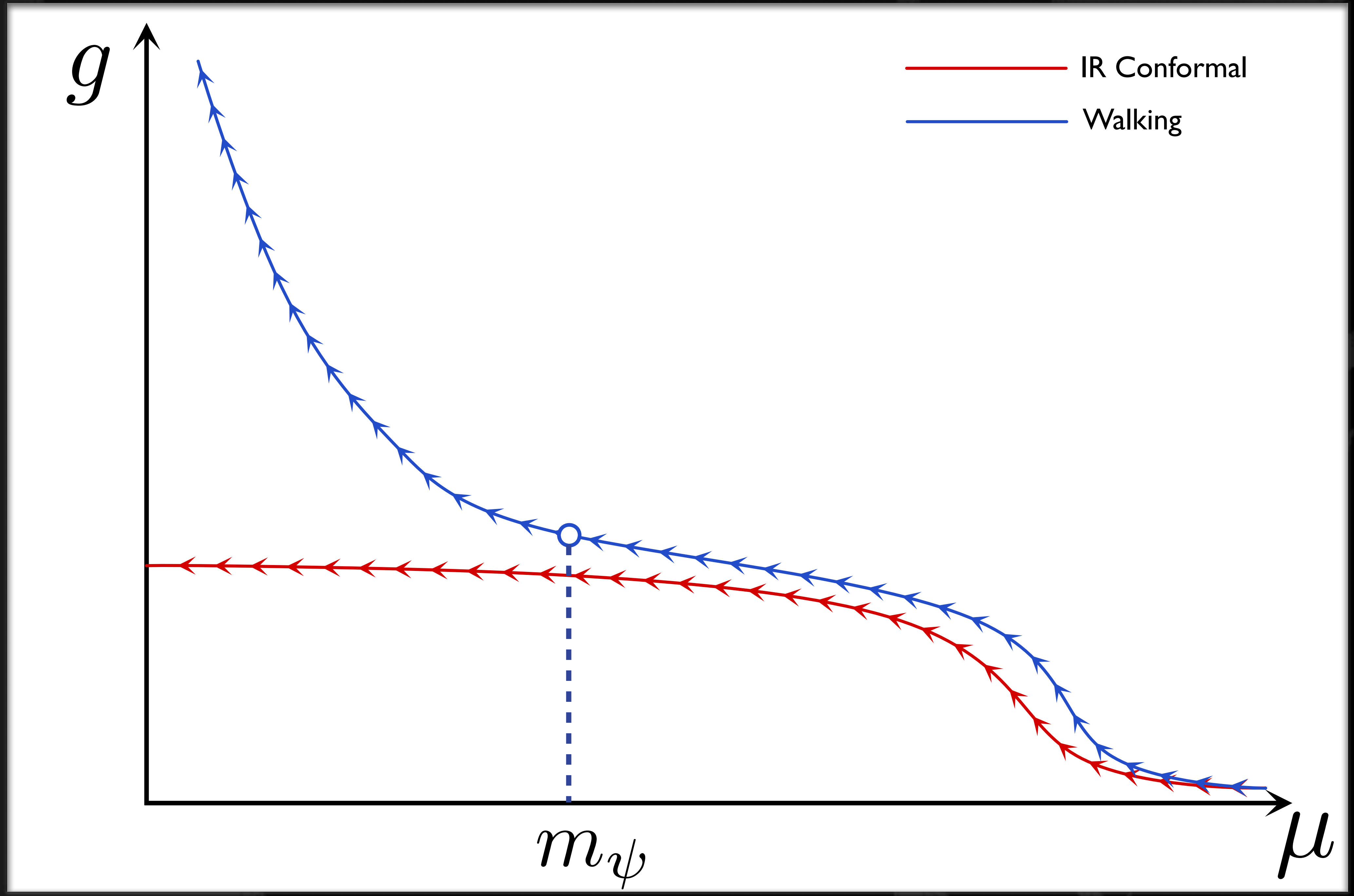

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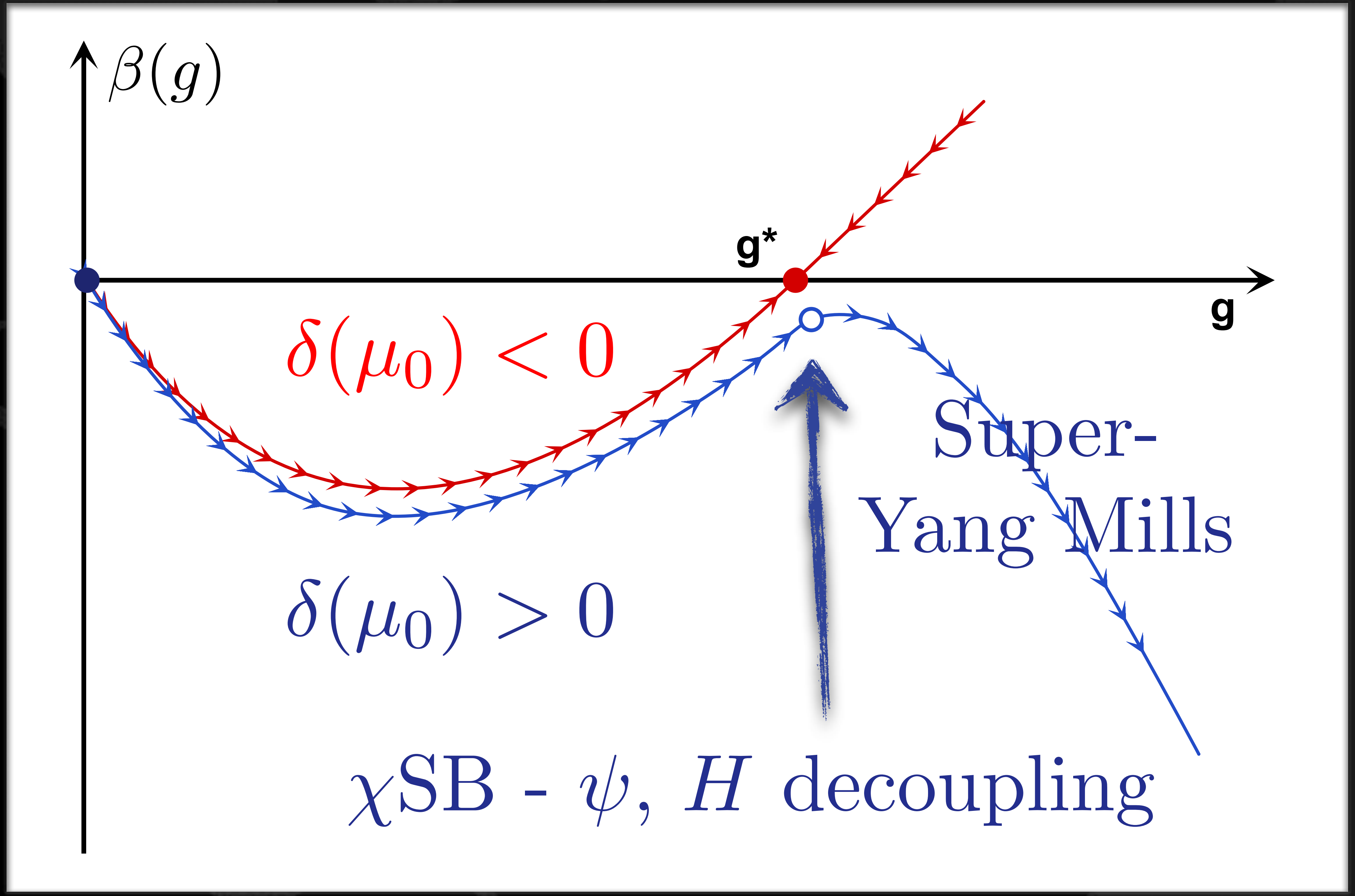

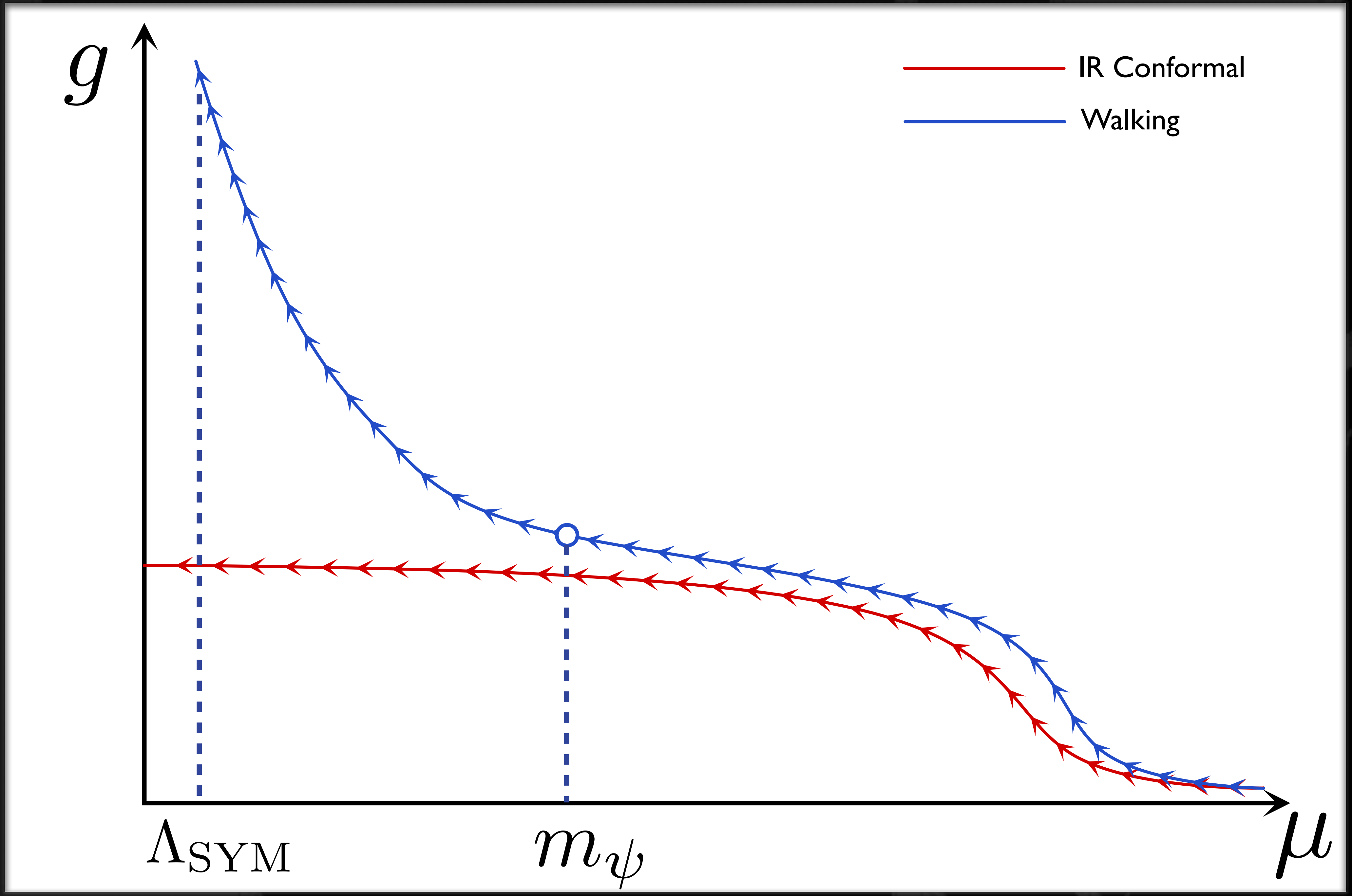

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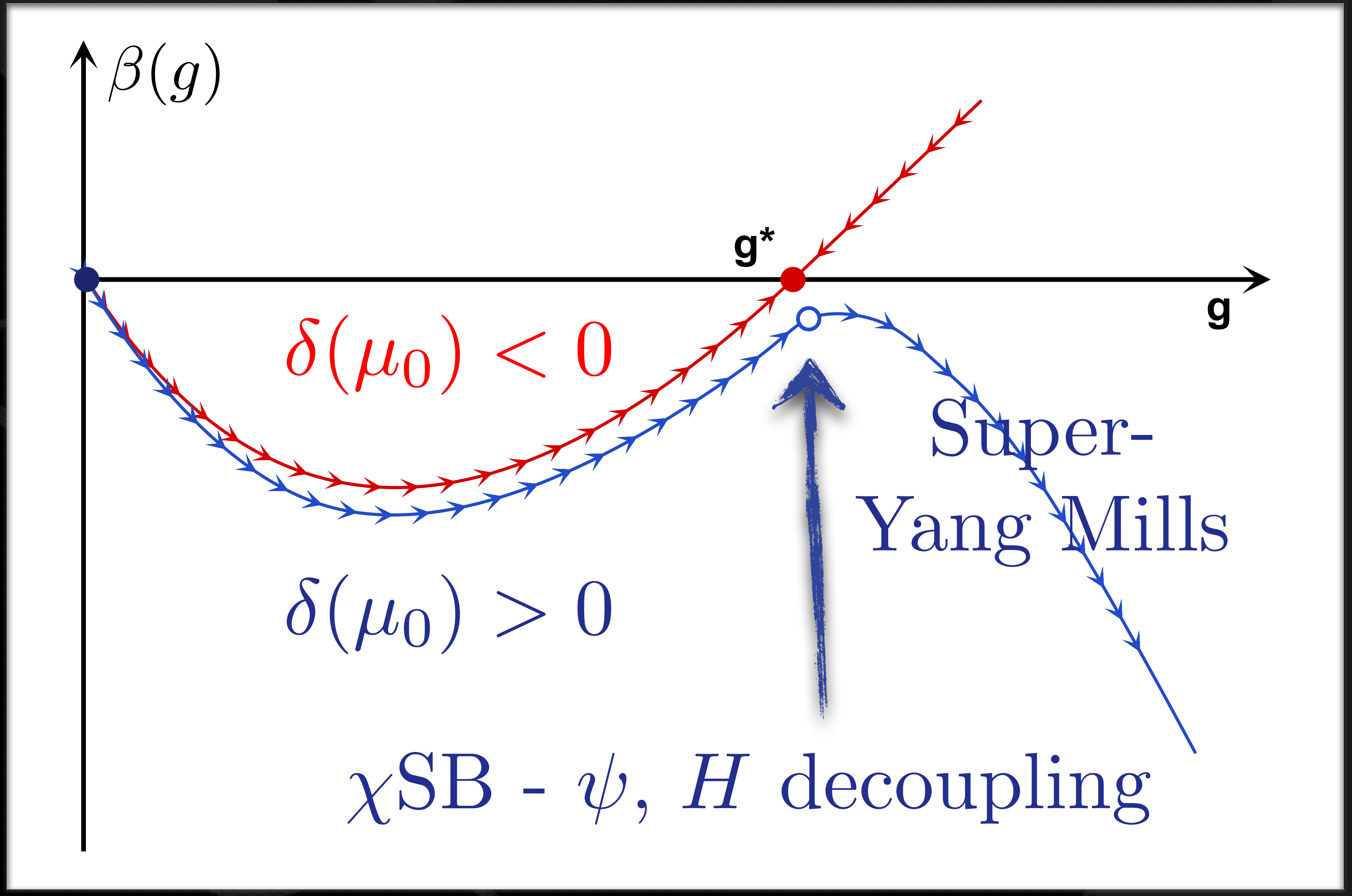

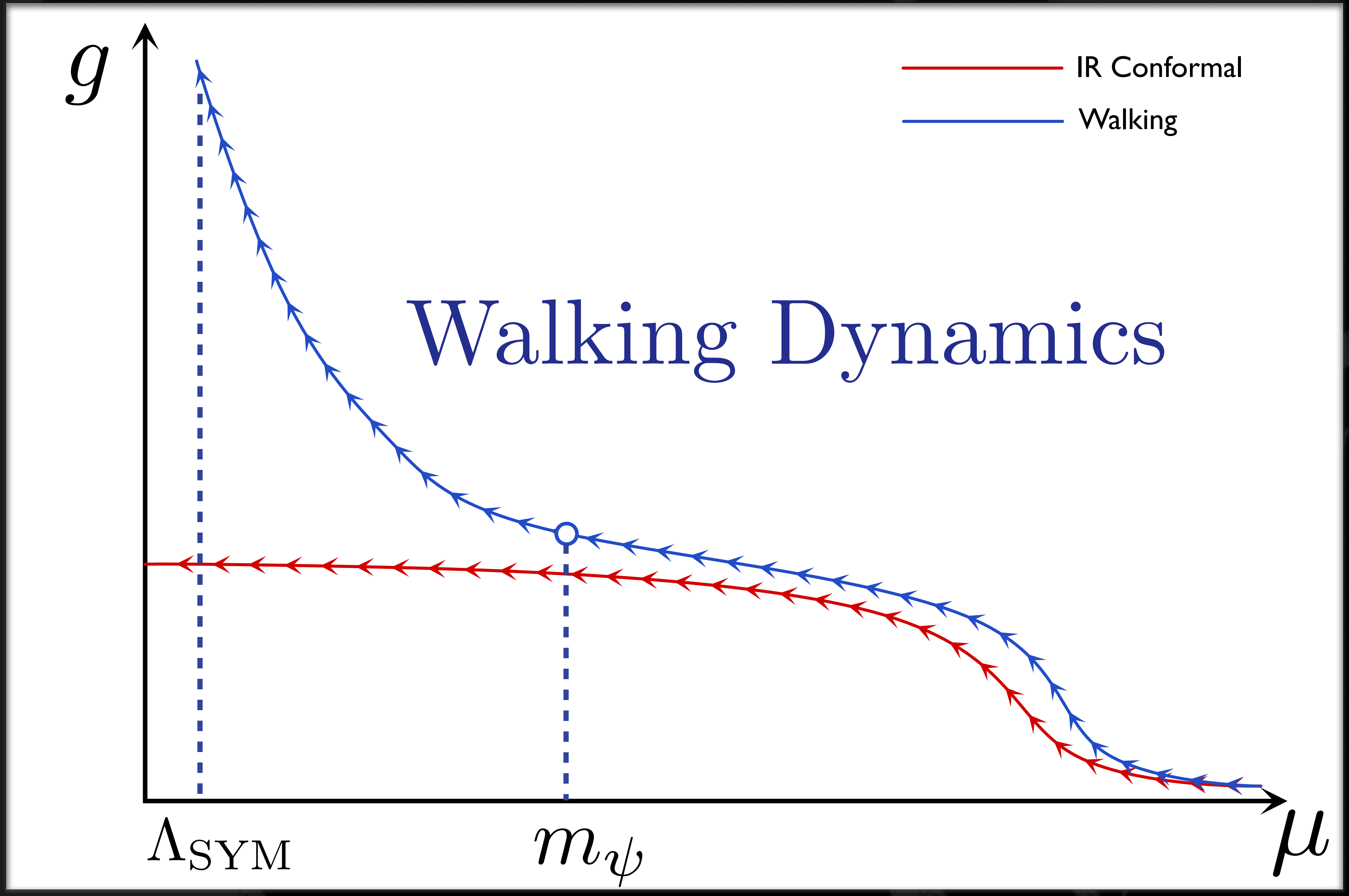

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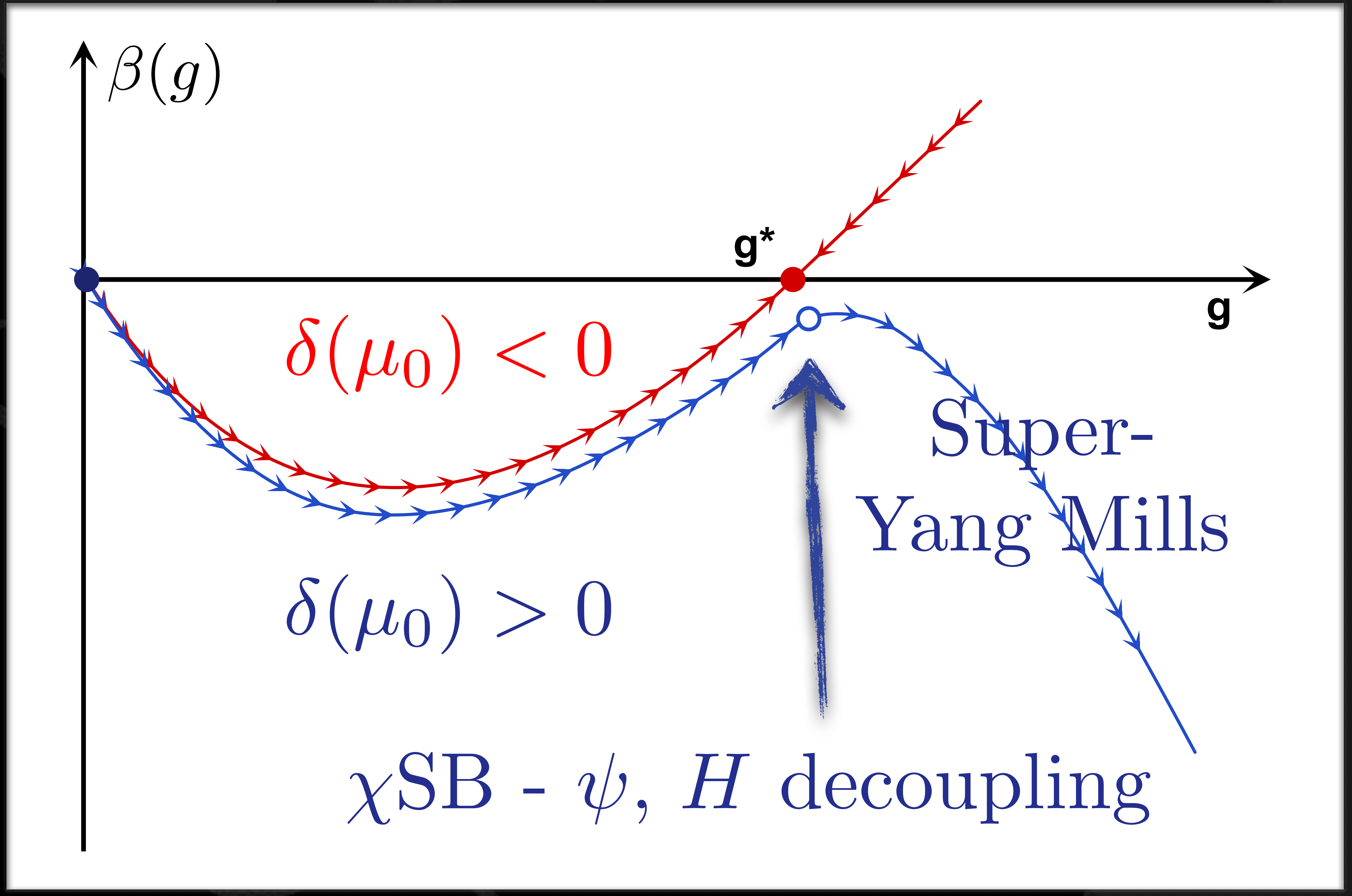

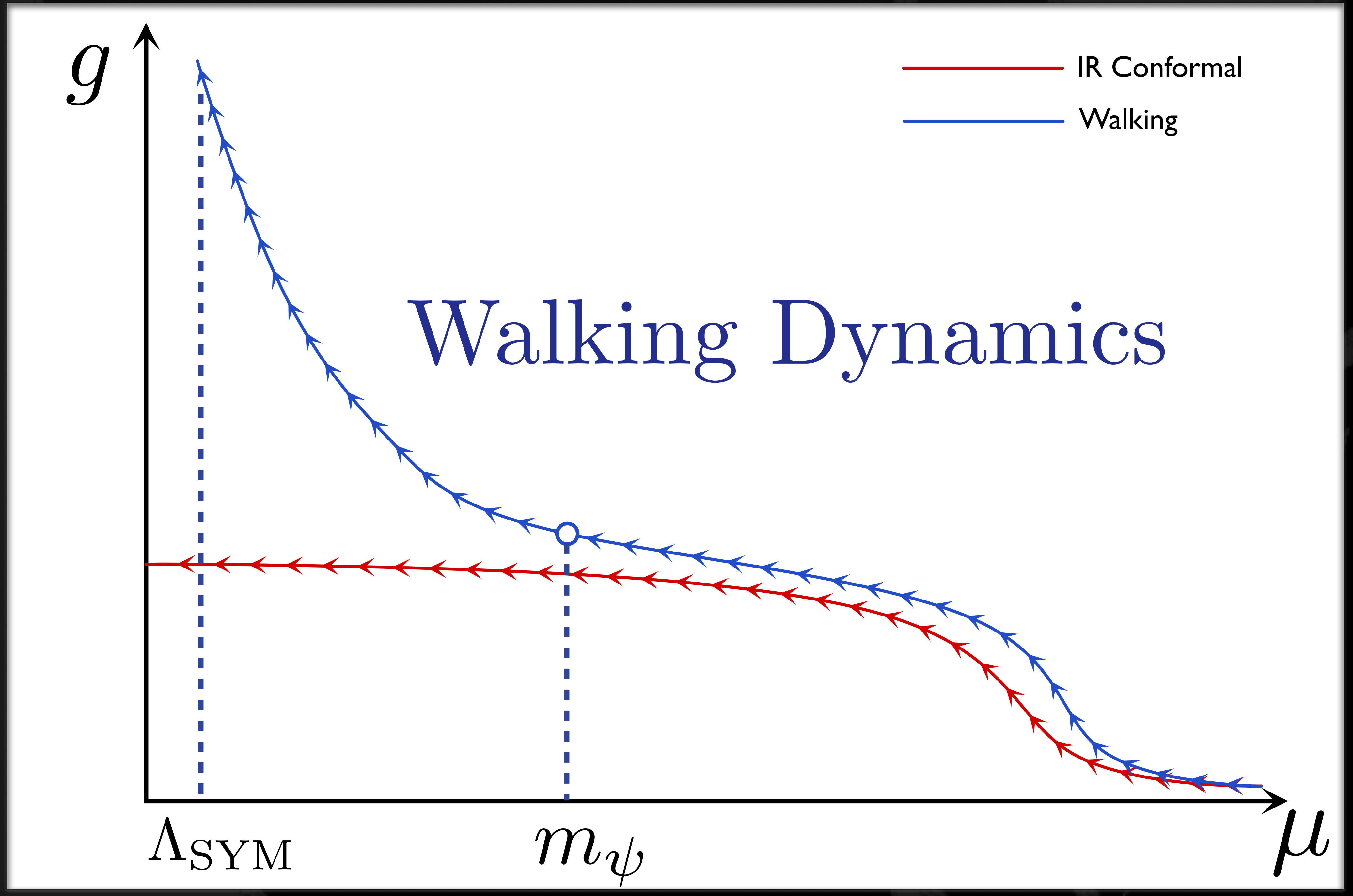

$$\langle \lambda\lambda \rangle = -\frac{9}{32\pi^2} \Lambda_{SYM}^3$$

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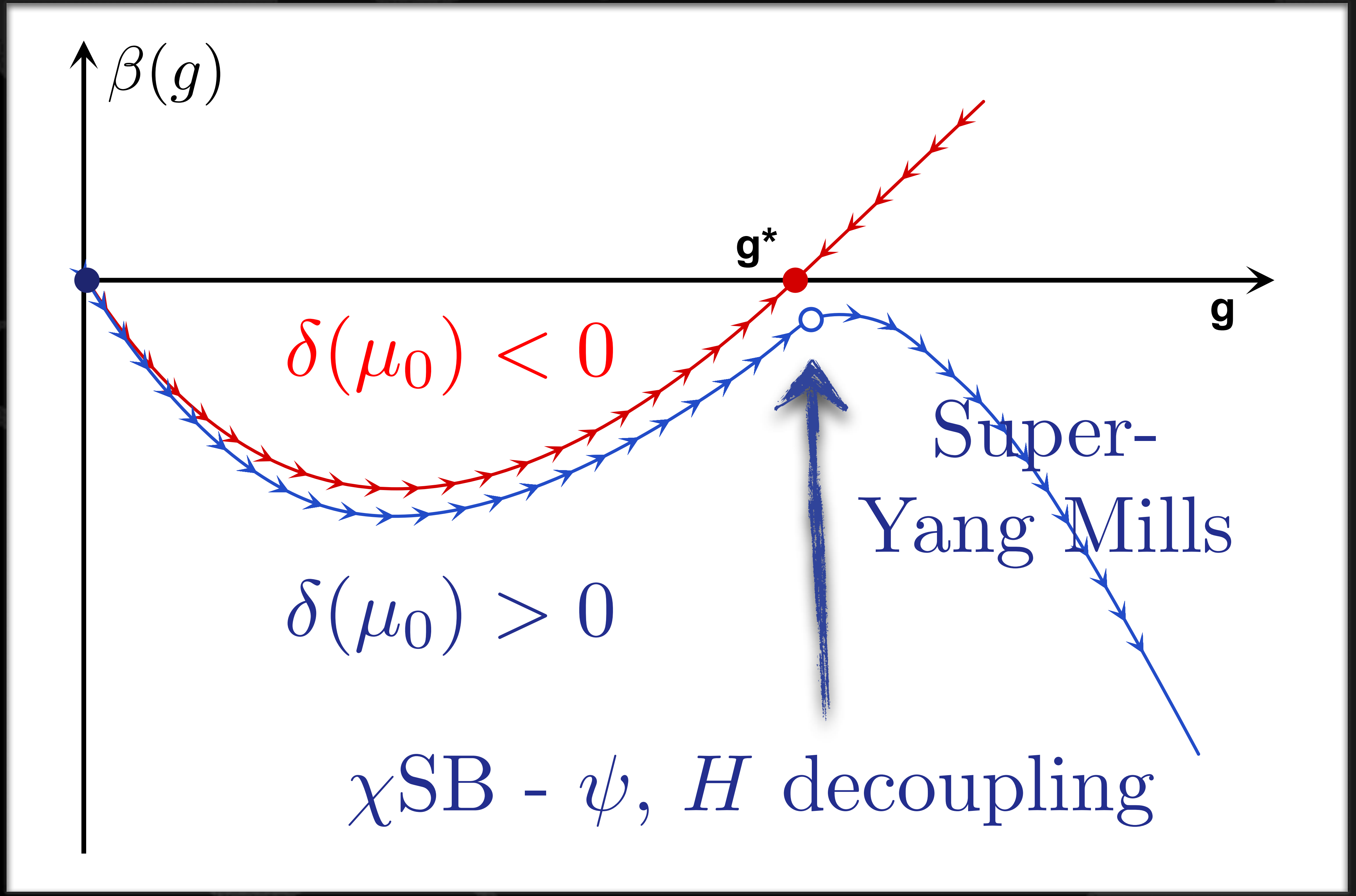

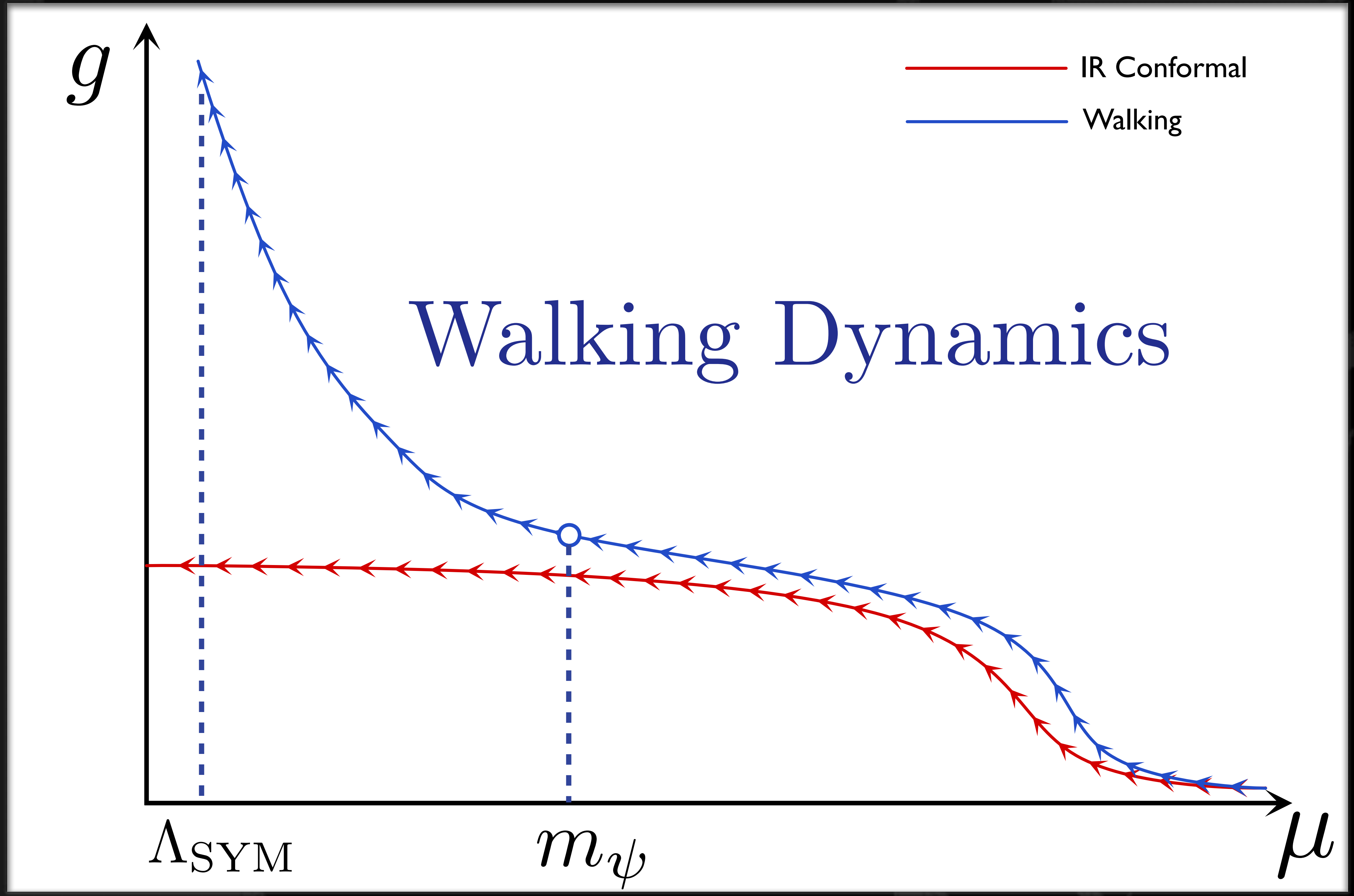

$$\langle \lambda\lambda \rangle = -\frac{9}{32\pi^2} \Lambda^3_{SYM} \qquad \Lambda^2_{\text{SYM}} = v^2 \left(\frac{3}{11\epsilon}\right)^{2/3} \exp\left(-\frac{6}{22\epsilon}\right).$$

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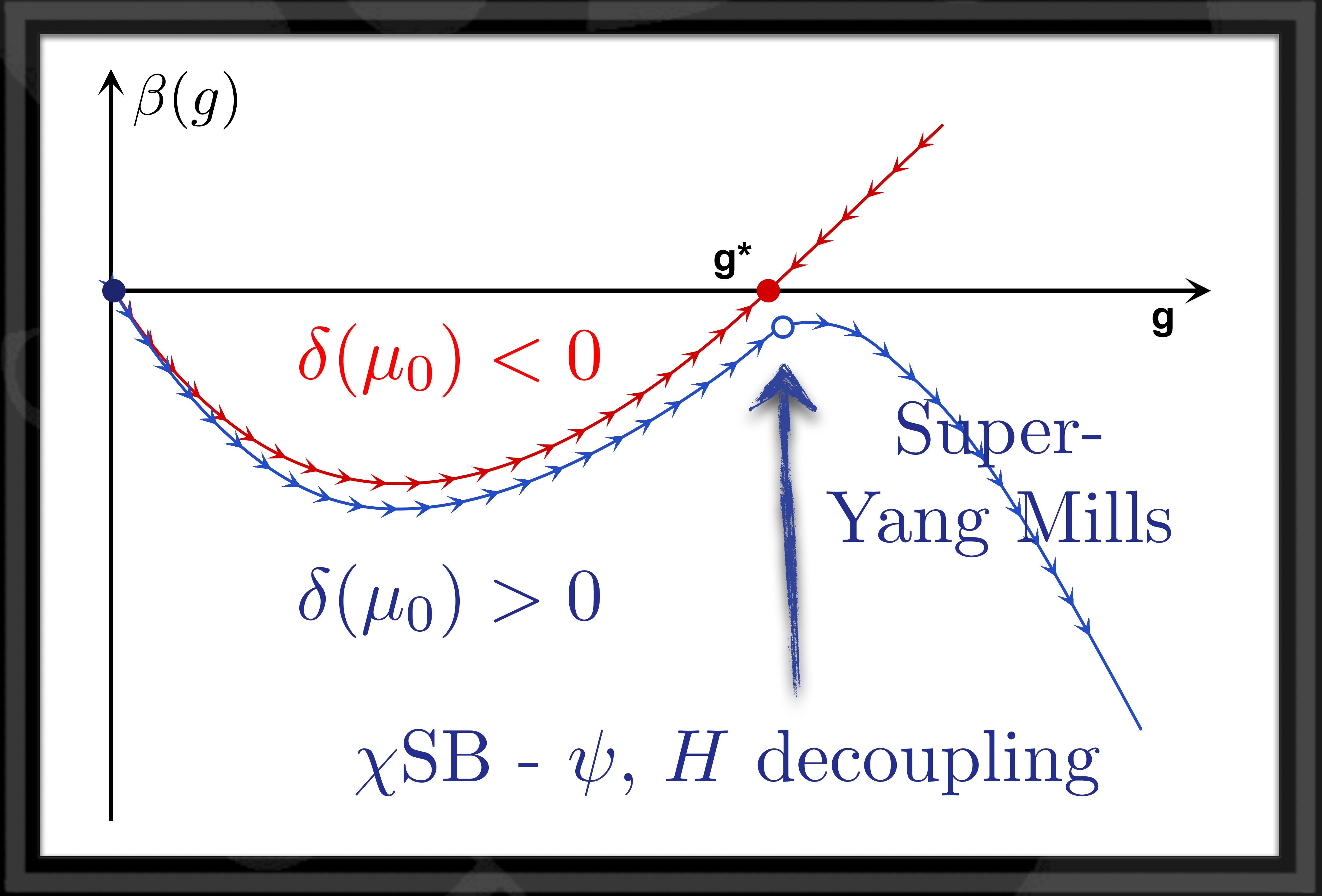

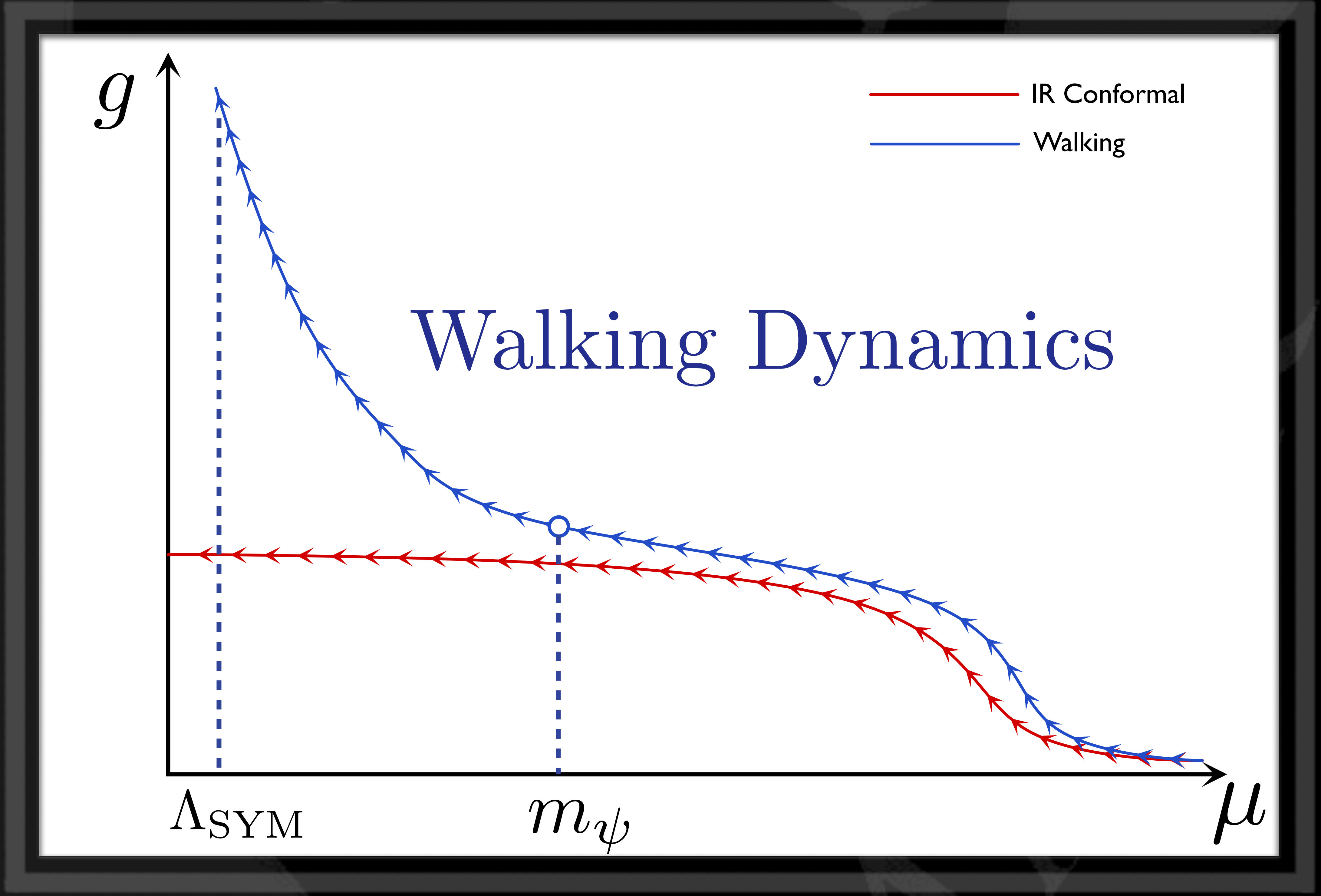

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Dilaton state unchanged at lower scale since $\Theta^\mu_\mu(\text{SYM}) = 0$

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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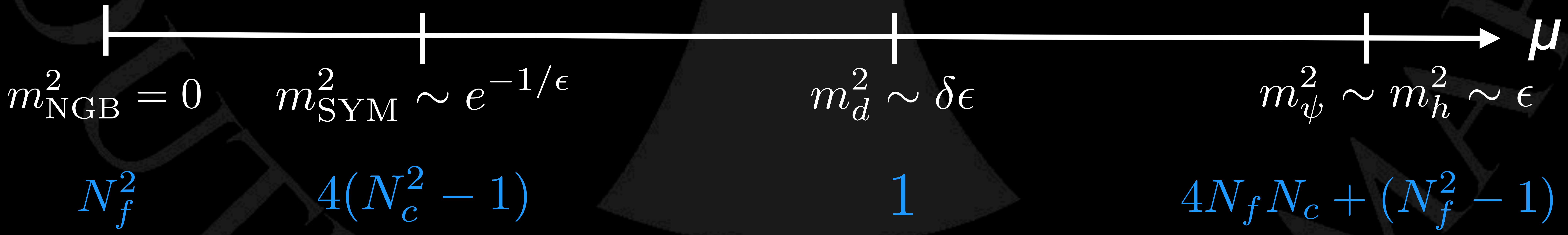

$m^2_{\text{NGB}} = 0$	$m^2_{\text{SYM}} \sim e^{-1/\epsilon}$	$m^2_d \sim \delta\epsilon$	$m^2_\psi \sim m^2_h \sim \epsilon$
N_f^2	$4(N_c^2 - 1)$	1	$4N_f N_c + (N_f^2 - 1)$

Full Spectrum in Broken Phase

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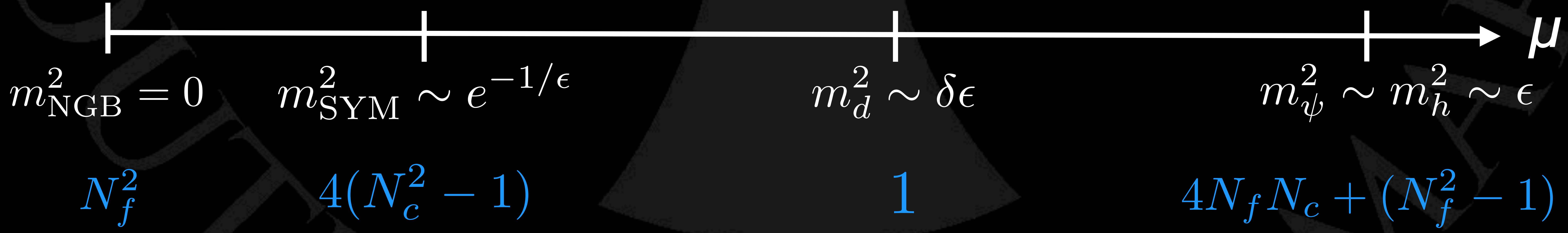

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N_f^2 $4(N_c^2 - 1)$ 1 $4N_f N_c + (N_f^2 - 1)$

Toy Model

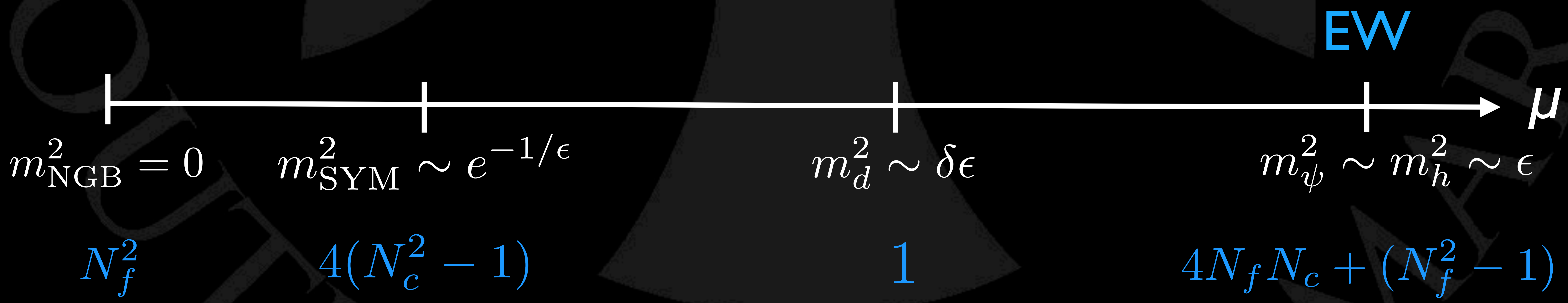
Full Spectrum in Broken Phase

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

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



EW

μ

$m^2_{\text{NGB}} = 0$ — N_f^2

$m^2_{\text{SYM}} \sim e^{-1/\epsilon}$ — $4(N_c^2 - 1)$

$m^2_d \sim \delta\epsilon$ — 1

$m^2_\psi \sim m^2_h \sim \epsilon$ — $4N_f N_c + (N_f^2 - 1)$

Toy Model

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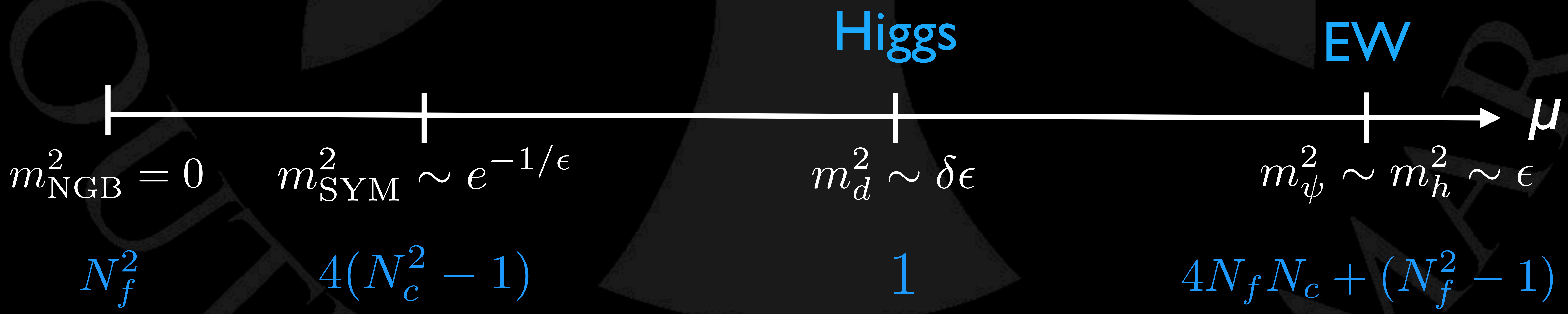

Higgs

EW

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N_f^2

$4(N_c^2 - 1)$

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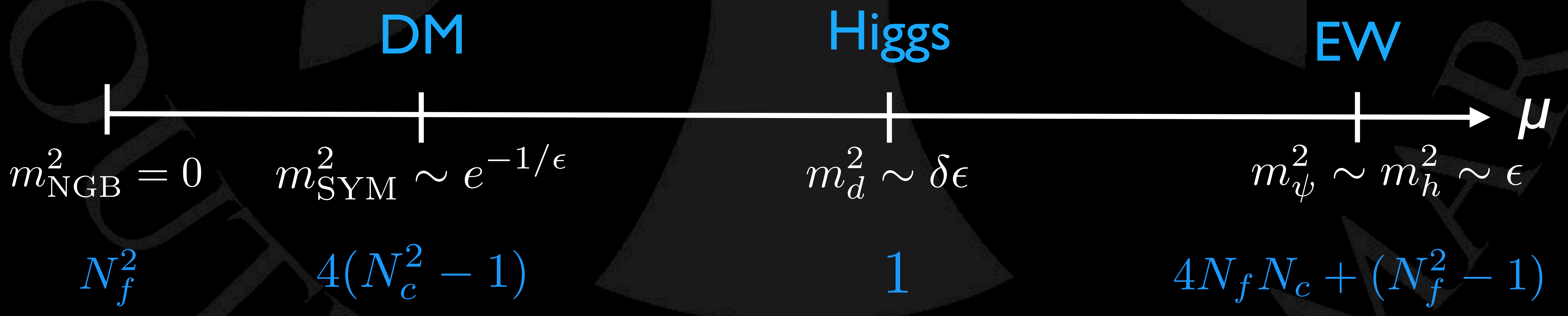

Toy Model

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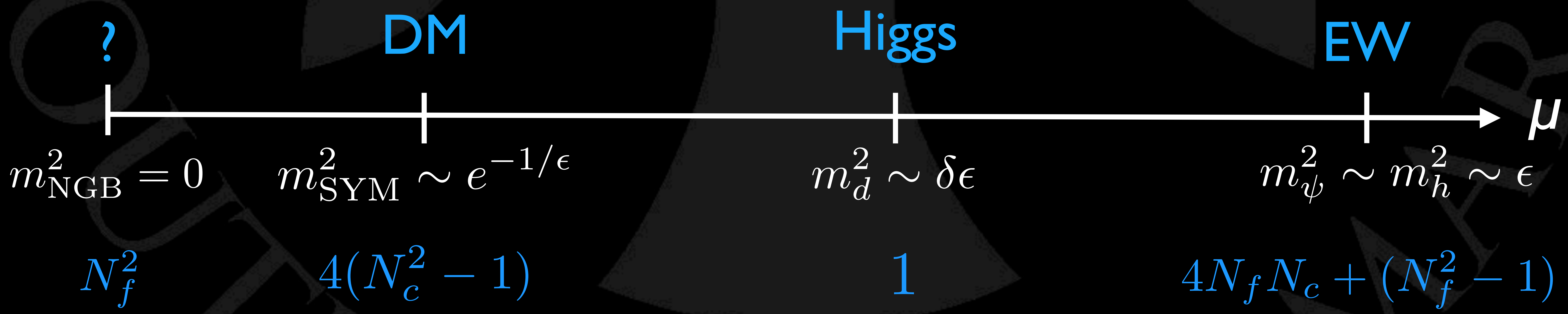

?

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Toy Model

THANK YOU!