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Fixed Points of Simple Gauge-Yukawa Theories

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Motivation

- Standard Model is flawed: Landau poles, no gravity, flavour anomalies (?) …
- extension is necessary – valid to highest energies
- no infinities in couplings – controlled by UV fixed point

Asymptotic Freedom: couplings vanish at fixed point

Asymptotic Safety: couplings run into finite values

- AS is a generalization of AF, extends parameter space
- new opportunities for model building !

Historic Development

- Asymptotic Freedom in Abelian gauge theories [Gross, Wilczek, Politzer (1973)]
- IR fixed point of gauge theories [Caswell (1974), Banks & Zaks (1982)]
- Asymptotic Safety as a paradigm for Quantum Gravity [Weinberg (1979)]
- UV fixed point in Einstein-Hilbert Gravity [Reuter (1996)]
- exact UV fixed point gauge-Yukawa theory [Litim, Sannino (2014)]

Progress with Gauge-Yukawa Theory

Yukawa interactions are vital for interacting UV fixed point:
[Bond, Litim, PRD 2018 & arXiv:1801.08527]

- Systematic analysis [Bond, Litim, EPJ 2017]
- Extension to semi-simple gauge groups [Bond, Litim, PRD 2018]
- UV conformal window [Bond, Litim, Medina, TS, PRD 2018]
- Phenomenological study of SM extension
  [Bond, Hiller, Kowalska, Litim, JHEP 2017]
  [Pellagi, Plascencia, Salvio, Sannino, Smirnov, Strumia, PRD 2018]
- supersymmetric model [Bond, Litim, PRL 2017]

What is left to be done?

➔ Study of alternative Yukawa sectors – building block for BSM!
➔ Influence of scalar quartic sector? Not technically natural!

Models

- SU(N) gauge theory, both fermionic and scalar matter in various representations
- single Yukawa coupling, number of quartics depends on scalar representations $\mathcal{L}_{\text{int}} = -y\,\text{Tr}\left[\chi\,\varphi\,\psi + \text{h.c.}\right] - V\left(\varphi\right)$
- models should allow for Veneziano limit (large-N in gauge & flavour symmetry)

uncharged scalar (quark-like fermions)

- ► scalar flavour singlet $\chi_{i\alpha}\,\varphi\,\psi_{i\alpha} + \text{h.c.}$
- ► meson-like scalar $\chi_{i\alpha}\,\varphi_{ij}\,\psi_{j\alpha} + \text{h.c.}$

charged scalar (fl. singlet / matrix)

- ► chiral model $\chi_\alpha\,\phi_\alpha\,\psi + \text{h.c.}$
- ► adjoint scalar $\chi_\alpha\,t^a_{\alpha\beta}\,\phi^a\,\psi_\beta + \text{h.c.}$
- ► adjoint fermion $\chi_\alpha\,t^a_{\alpha\beta}\,\phi_\beta\,\psi^a + \text{h.c.}$
- ► reducible rep $\chi_\alpha\,\varphi_{\alpha\beta}\,\psi_\beta + \text{h.c.}$

Renormalization Group

absorb loop factor in couplings: $\alpha_g = \left(\frac{g}{4\pi}\right)^2 \,, \quad \alpha_y = \left(\frac{y}{4\pi}\right)^2 \,, \quad \alpha_i = \frac{\lambda_i}{(4\pi)^2}$

perturbative expansion, leading non-trivial order [Bond, Litim, EPJ 2017 | Bond, Litim, Medina, TS, PRD 2018]:

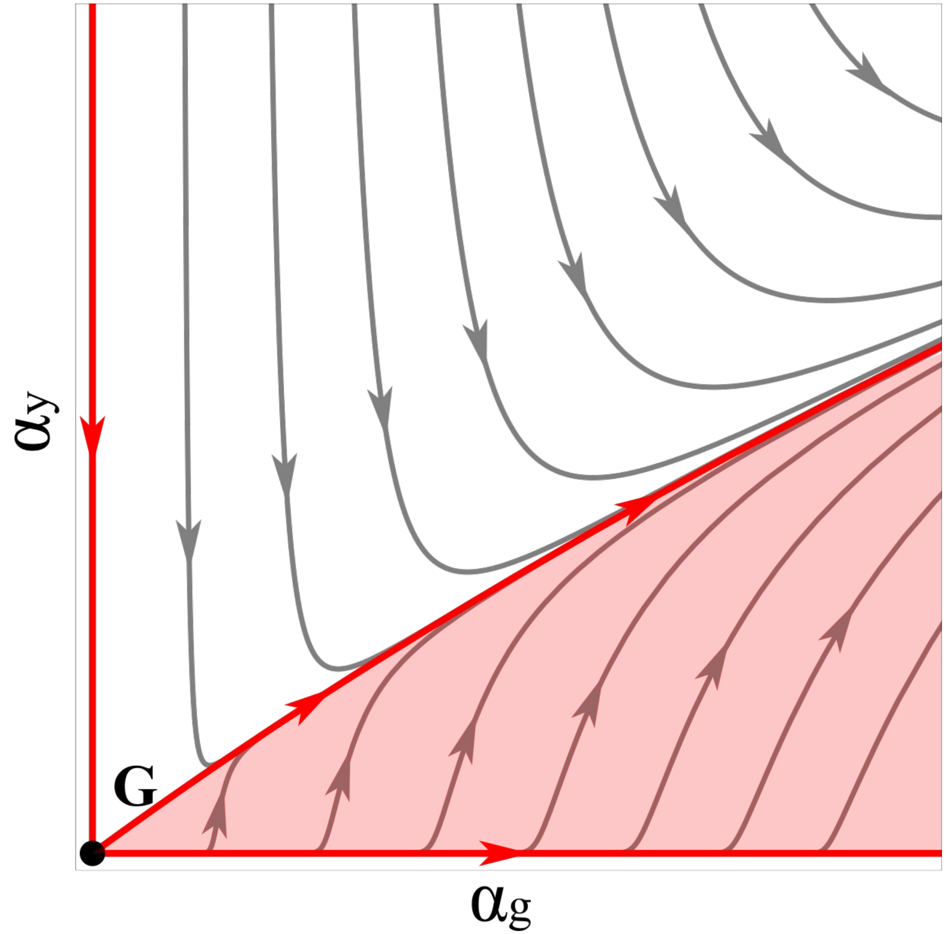
$$\beta_g = -B\,\alpha_g^2 + C\,\alpha_g^3 - D\,\alpha_y\,\alpha_g^2$$
$$\beta_y = E\,\alpha_y^2 - F\,\alpha_g\,\alpha_y$$
$$\beta_i = H^{ijk}\,\alpha_j\,\alpha_k + I^{ijy}\,\alpha_i\,\alpha_y - I^{ijg}\,\alpha_i\,\alpha_g - J^{iy}\,\alpha_y^2 + J^{ig}\,\alpha_g^2$$

- D, E, F, H, I, J positive (semi-definite); sign of B, C depend on matter content
- gauge-Yukawa subsystem may be solved independently
- quartic RGEs are quadratic equation: unphysical solutions are complex or vacuum unstable
- fixed points of gauge-Yukawa system might be invalidated by quartic subsector

NOW: phase diagrams and discussion of results

Asypmtotic Freedom

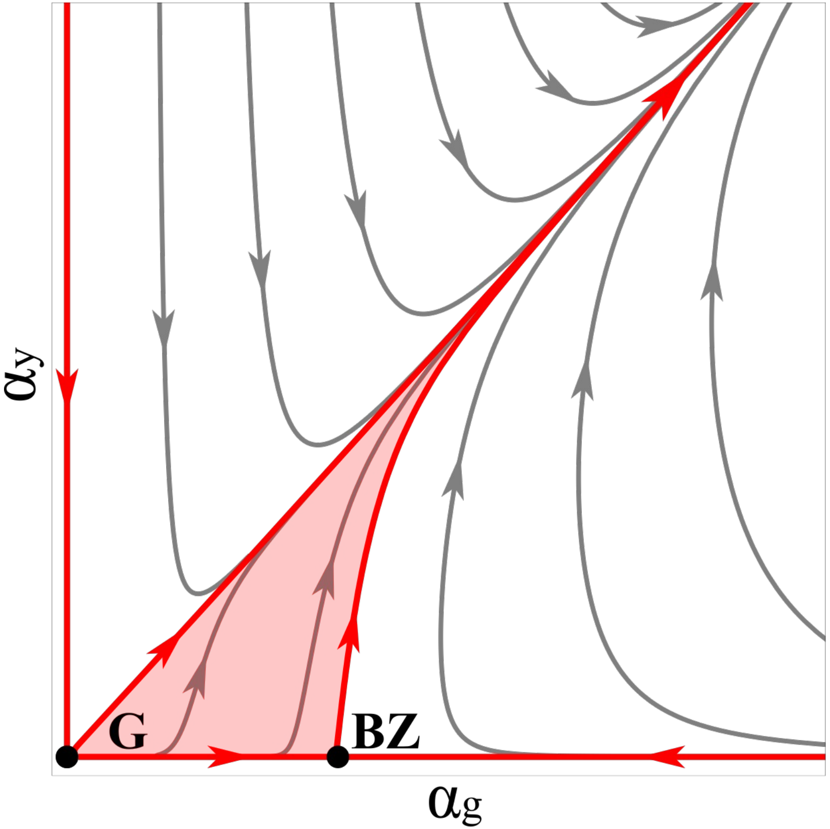
weakly coupled theory: only Gaussian UV fixed point



Asypmtotic Freedom and Safety

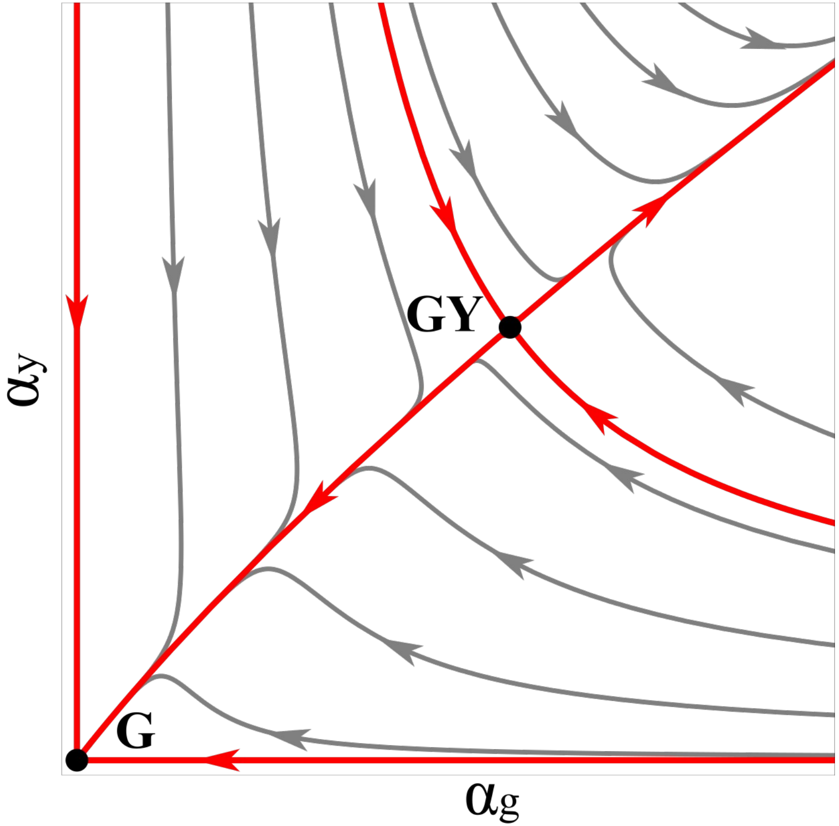
Asymptotic Freedom

- Gaussian (G) UV fixed point
- Banks-Zaks (BZ) IR fixed point

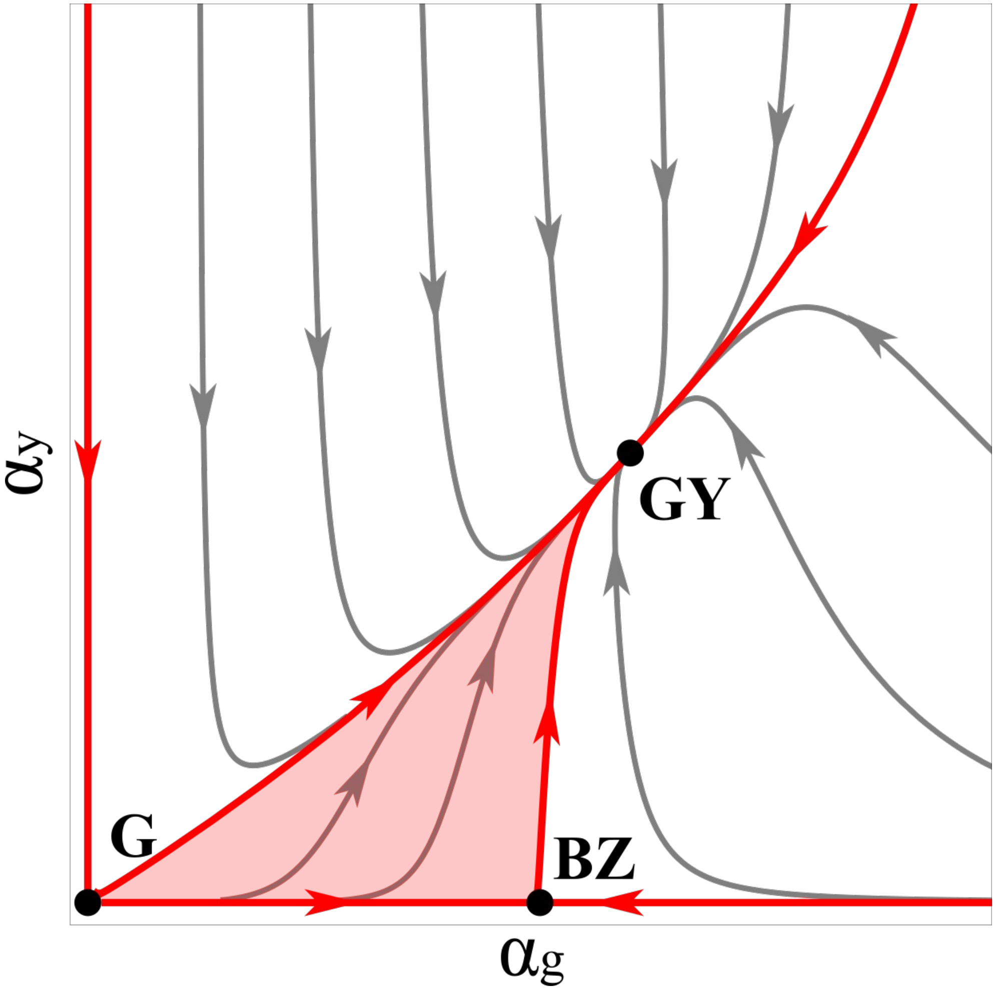


Asymptotic Safety

- Gaussian (G) IR fixed point
- Gauge-Yukawa (GY) UV fixed point



Asypmtotic Freedom + IR fixed points



- Gaussian (G) UV fixed point
- Banks-Zaks (BZ) IR fixed point
- Gauge-Yukawa (GY) IR fixed point
- scalar quartic sector may invalidate interacting fixed points

Conclusions

- no other theories than the Litim-Sannino type models were detected to achieve AS
- constraints from quartic sector mild for uncharged scalars
- some or all IR fixed points invalidated for charged scalars
- asymptotic freedom is lost in the Veneziano limit for theories without interacting fixed points
- Motivation for supersymmetry ?

Backup I

$$\beta_g = -B\,\alpha_g^2 + C\,\alpha_g^3 - D\,\alpha_y\,\alpha_g^2$$

$$\beta_y = E\,\alpha_y^2 - F\,\alpha_g\,\alpha_y$$

$$\beta_i = H^{ijk}\,\alpha_j\,\alpha_k + I^{ijy}\,\alpha_i\,\alpha_y - I^{ijg}\,\alpha_i\,\alpha_g - J^{iy}\,\alpha_y^2 + J^{ig}\,\alpha_g^2$$

Fixed Point	Type	Condition	α_g^*	α_y^*
Gaussian (G)	UV [IR]	$B > 0\ [B < 0]$	0	0
Banks-Zaks (BZ)	IR	$B,\, C > 0$	$\frac{B}{C}$	0
Gauge-Yukawa (GY)	IR [UV]	$B,\, C' > 0\ \left[B,\, C' < 0\right]$	$\frac{B}{C'}$	$\frac{F\,B}{E\,C'}$

$$C' = C - DF/E$$

Backup II

Model	Global symmetry	Number of Quartics	Fermion χ		Fermion ψ		Scalar φ		
			Gauge	Global	Gauge	Global	Gauge	Global	R/C
A	$U(N_F)$	1	$\overline{N_C}$	$\overline{N_F}$	N_C	N_F	1	1	R
B	$U(N_F)$	1	$\overline{N_C}$	$\overline{N_F}$	N_C	N_F	1	1	C
C	$O(N_F) \times O(N_F)$	2	$\overline{N_C}$	$N_F \times 1$	N_C	$1 \times N_F$	1	$N_F \times N_F$	R
D	$U(N_F) \times U(N_F)$	2	$\overline{N_C}$	$N_F \times 1$	N_C	$1 \times N_F$	1	$N_F \times N_F$	C
E	$U(N_F)$	1	$\overline{N_C}$	$\overline{N_F}$	1	N_F	N_C	1	C
F	$U(N_L) \times U(N_R)$	3	$\overline{N_C}$	$N_L \times 1$	1	$1 \times N_R$	N_C	$\overline{N_L} \times \overline{N_R}$	C
G	$U(N_F)$	2	$\overline{N_C}$	$\overline{N_F}$	N_C	N_F	$N_C^2 - 1$	1	R
H	$U(N_F)$	2	$\overline{N_C}$	$\overline{N_F}$	$N_C^2 - 1$	1	N_C	N_F	C
I	$U(N_F)$	8	$\overline{N_C}$	$\overline{N_F}$	N_C	N_F	$N_C \times \overline{N_C}$	1	C

Model	Phase Diagrams	BZ+scalar fixed points			GY+scalar fixed points		
		physical	unstable	complex	physical	unstable	complex
A	①, ③	1	0	0	1	0	0
B	①, ③	1	0	0	1	0	0
C	①, ③	1	0	0	1	3	0
D	①, ②, ④	1	0	0	1	3	0
E	①, ③ with pGY	2	0	0	0	0	2
F	no complete AF	0	0	8	0	0	8
G	①, ③ with pGY	2	2	0	0	0	4
H	①, ③ with pBZ	0	0	4	1	3	0
I	no complete AF	0	0	16	0	0	16