HoloQuark2018

QUANTUM CRITICALITY GIVES ME BUTTERFLIES

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THE GANG

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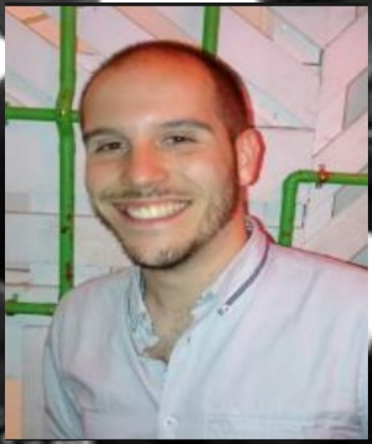

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Bikash Padhi
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Chandan Setty
(University of Illinois)

REFERENCES

arXiv:1802.08650

arXiv:1805.01470

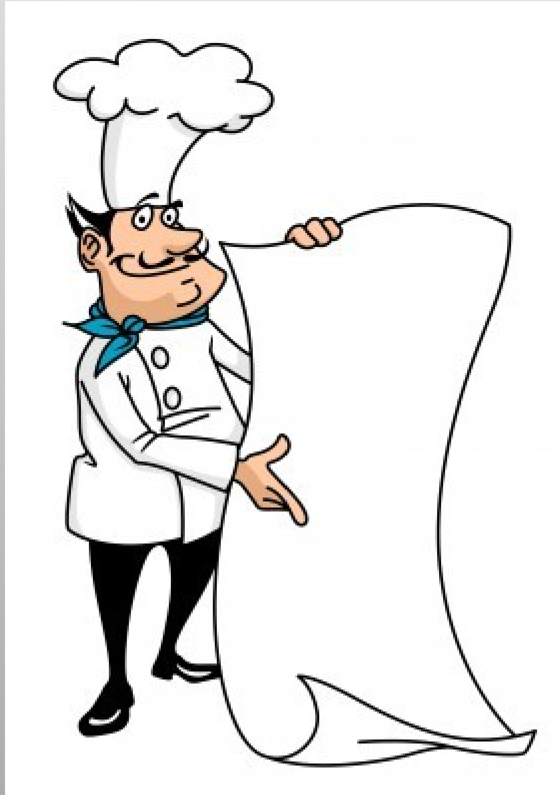
arXiv:1407.7526

arXiv:1508.04435

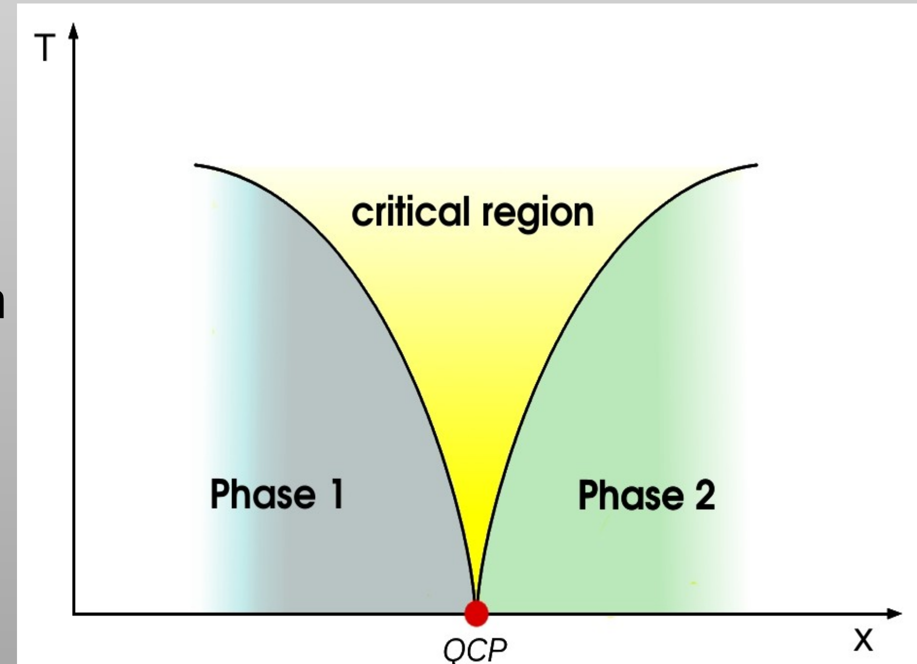
arXiv:1708.05691

arXiv:1708.07243

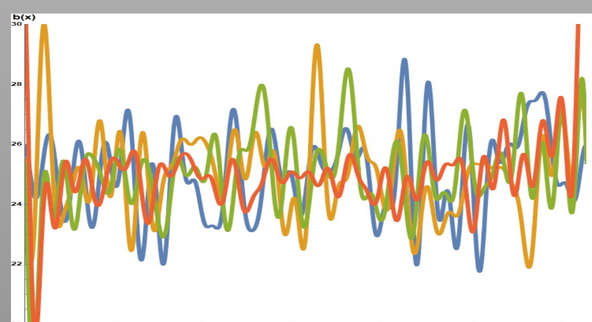
DISH OF THE DAY



1) Take your
   favorite quantum
   phase transition

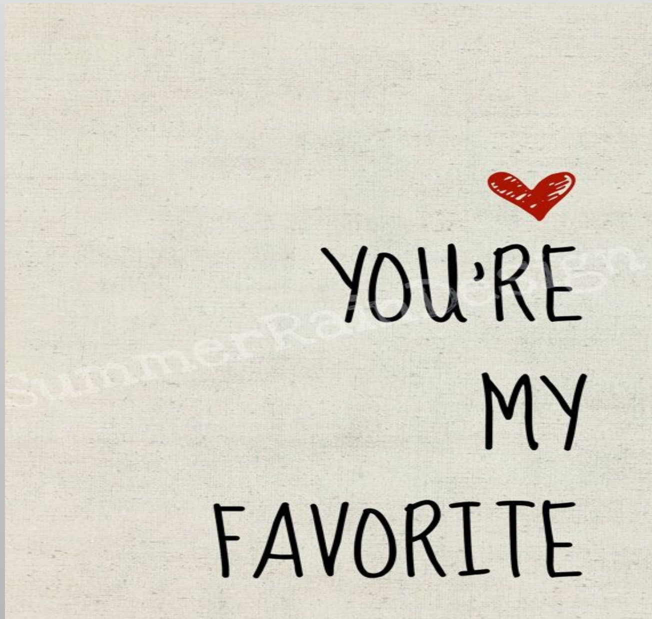


2) Add disorder



3) Garnish it
   with butterflies

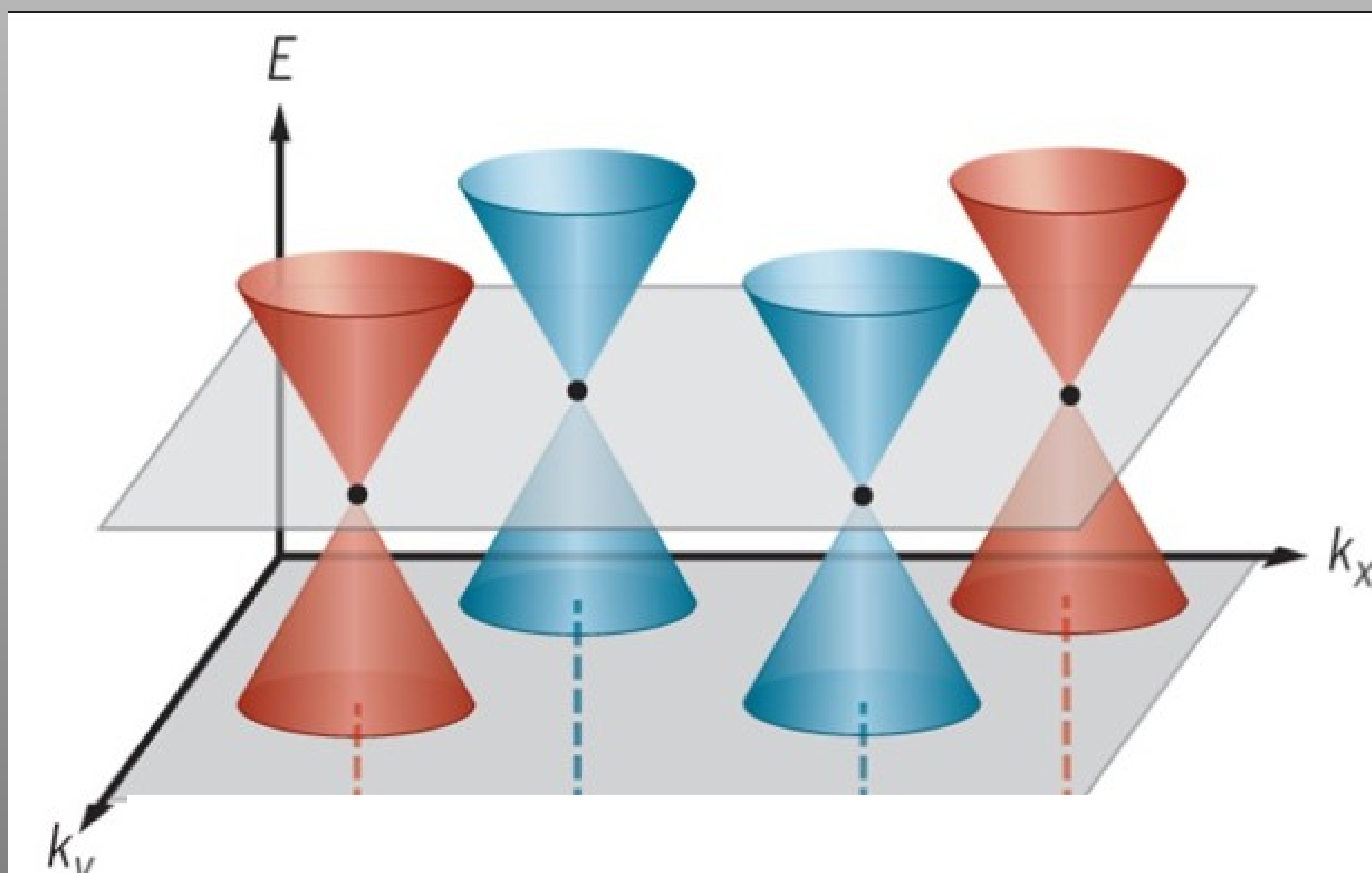
4) Enjoy it !!
   (and publish it)



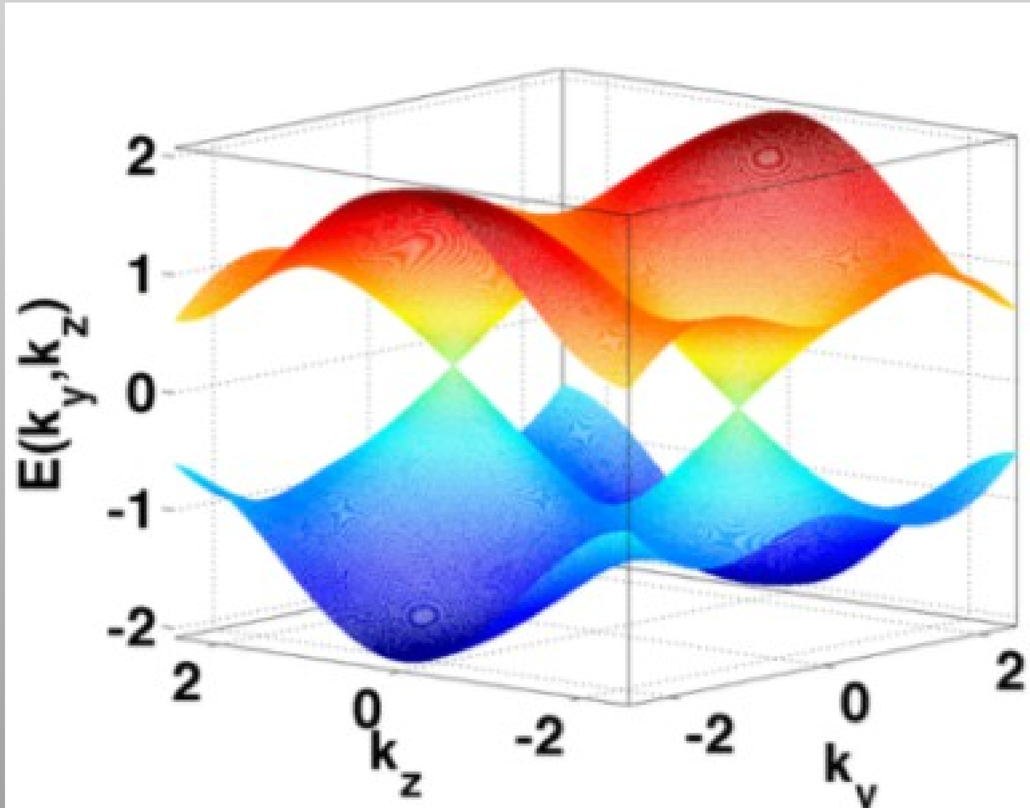
WEYL SEMIMETAL

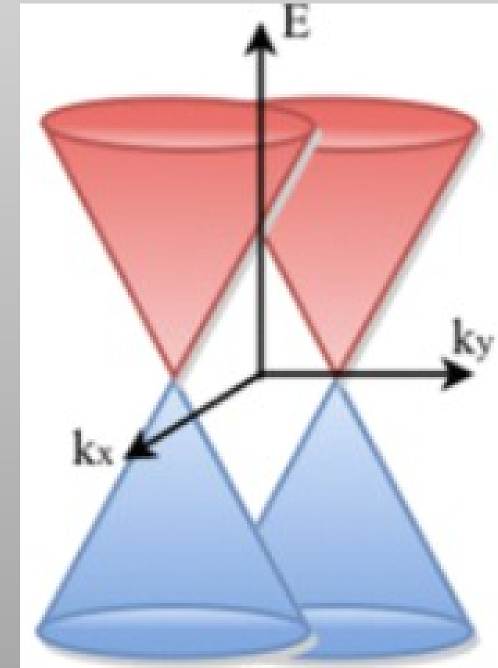
↕

INSULATOR



WEYL SEMIMETALS





Weyl semimetals are materials featuring crossing of bands at isolated, non degenerate points, *i.e.* Weyl nodes, in the Brillouin zone at the Fermi level

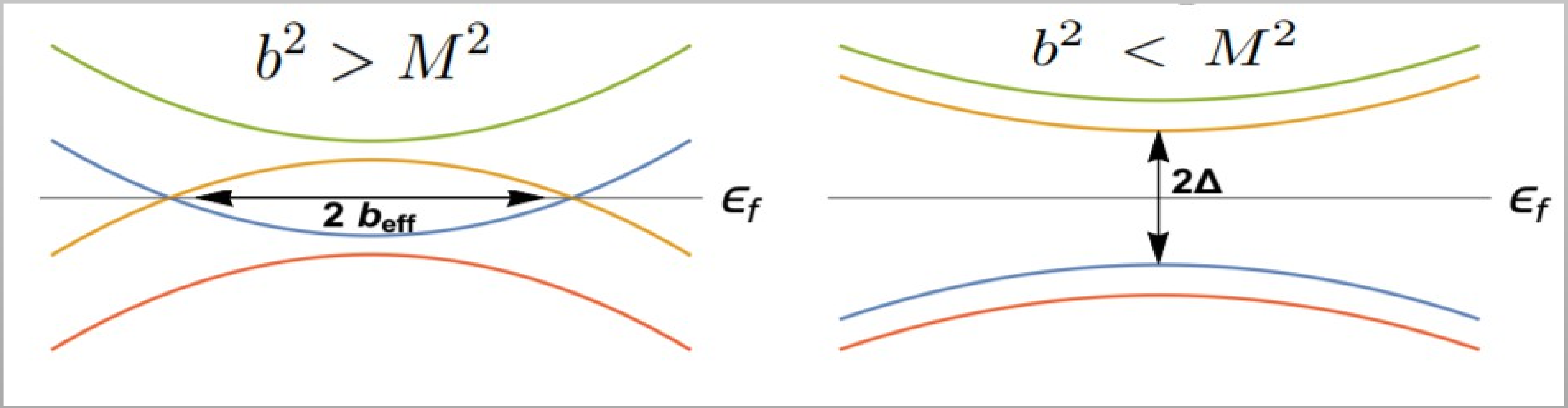
WEYL FERMIONS + **ANOMALOUS TRANSPORT**

See Karl's talk and review !

EFT for the Weyl QPT

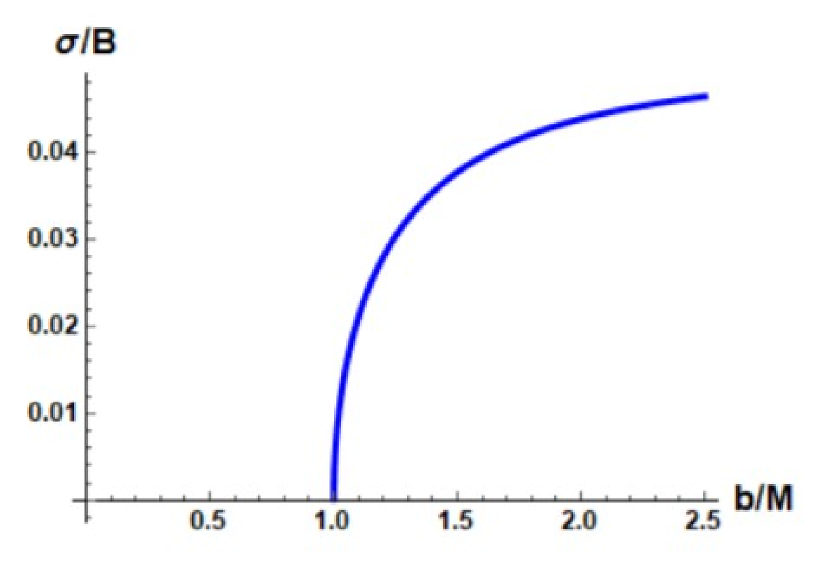
$$\left(i\,\partial\!\!\!/ - M + \gamma_5\,\gamma_z b\right)\,\Psi = 0\,.$$

b: time reversal breaking parameter



WEYL NODES $b_{\rm eff} = \sqrt{b^2 - M^2}.$

GAP $\Delta = \sqrt{M^2 - b^2}$



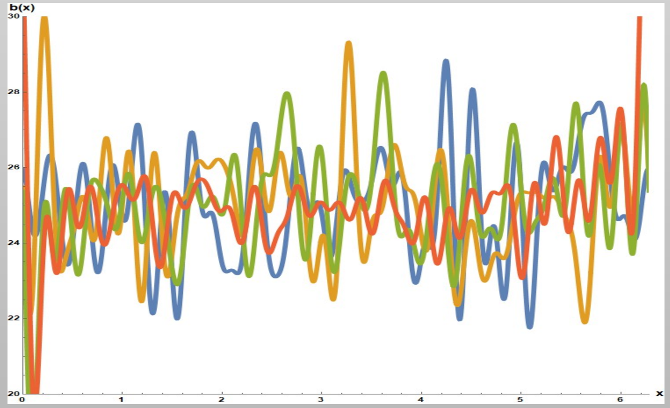
Order parameter:
ANOMALOUS HALL CONDUCTIVITY

$$\sigma_{xy}(B=0) = \frac{b^2 - M^2}{2\,\pi^2}\,\Theta\left(|b| - |M|\right)\,.$$

WE CHOOSED OUR FAVORITE QPT…

NOW …

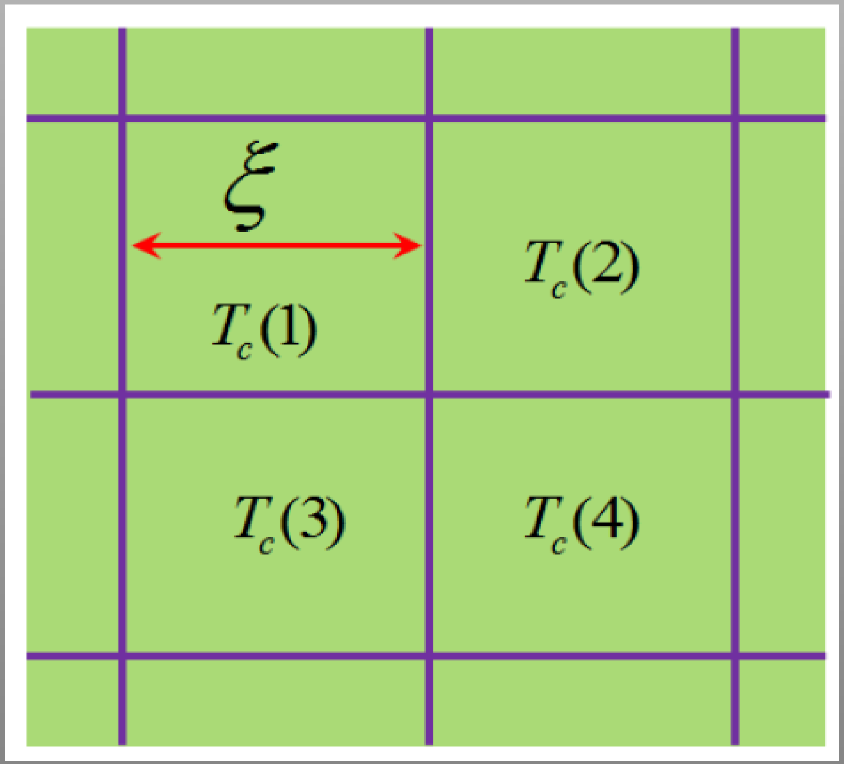
DISORDER AND HARRIS CRITERION



$$\mathcal{S} = \mathcal{S}_0 + \int d^d x \, g_i(x) \, \mathcal{O}_i(x)$$

HARRIS CRITERION :

$$\delta T_c < T - T_c$$



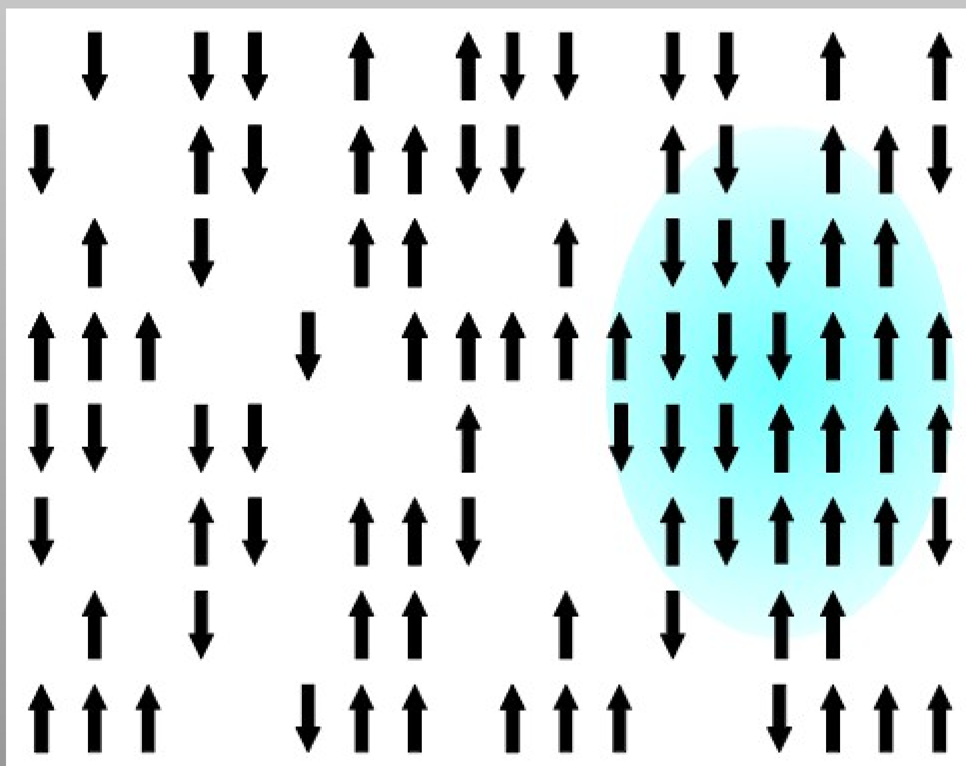
Fluctuations : $\delta T_c \propto \xi^{-d/2}$

Distance from Tc : $T - T_c \propto \xi^{-1/\nu}$

$\longrightarrow$ $d\nu > 2$

IS THAT ALL ?? RARE REGIONS!

The Harris criterion deals with averaged disorder and coarse graining...
What about local effects ??



Local regions which are in
A different phase with
Respect to the global one

On quantum phase transitions
They can have a strong impact !

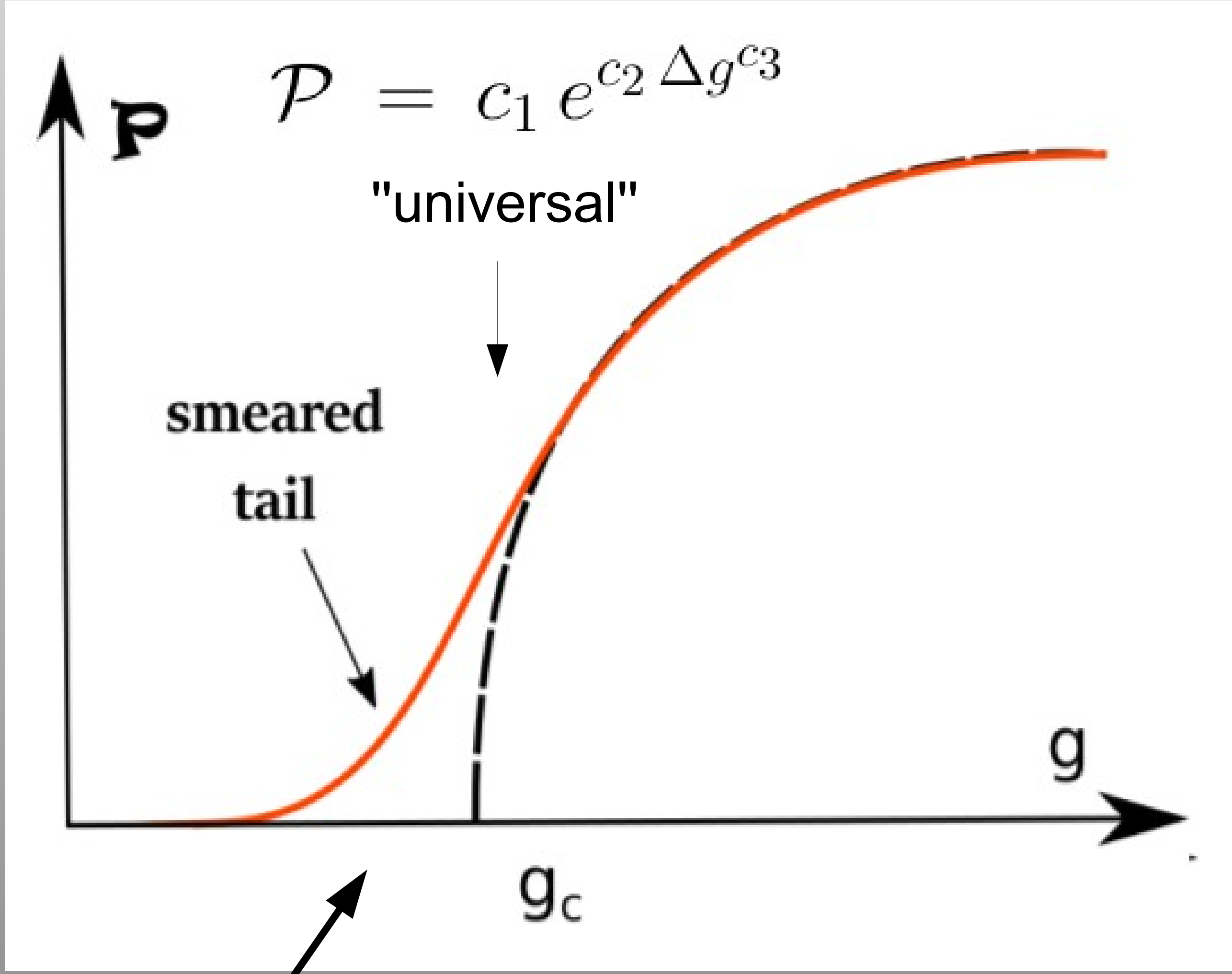
SMEARING

MONOPOLIUM

[Vojta + ...]

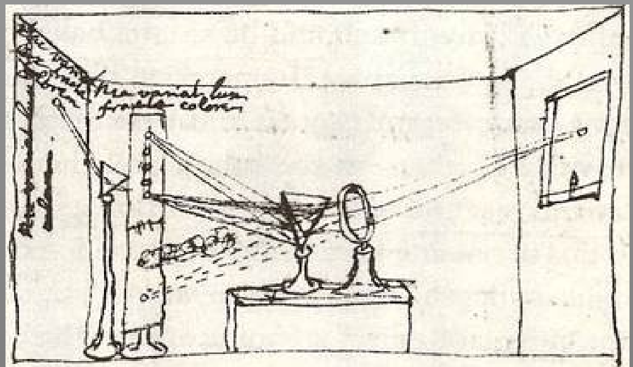
Temperature: "similar" effects

SMEARING THE QPT

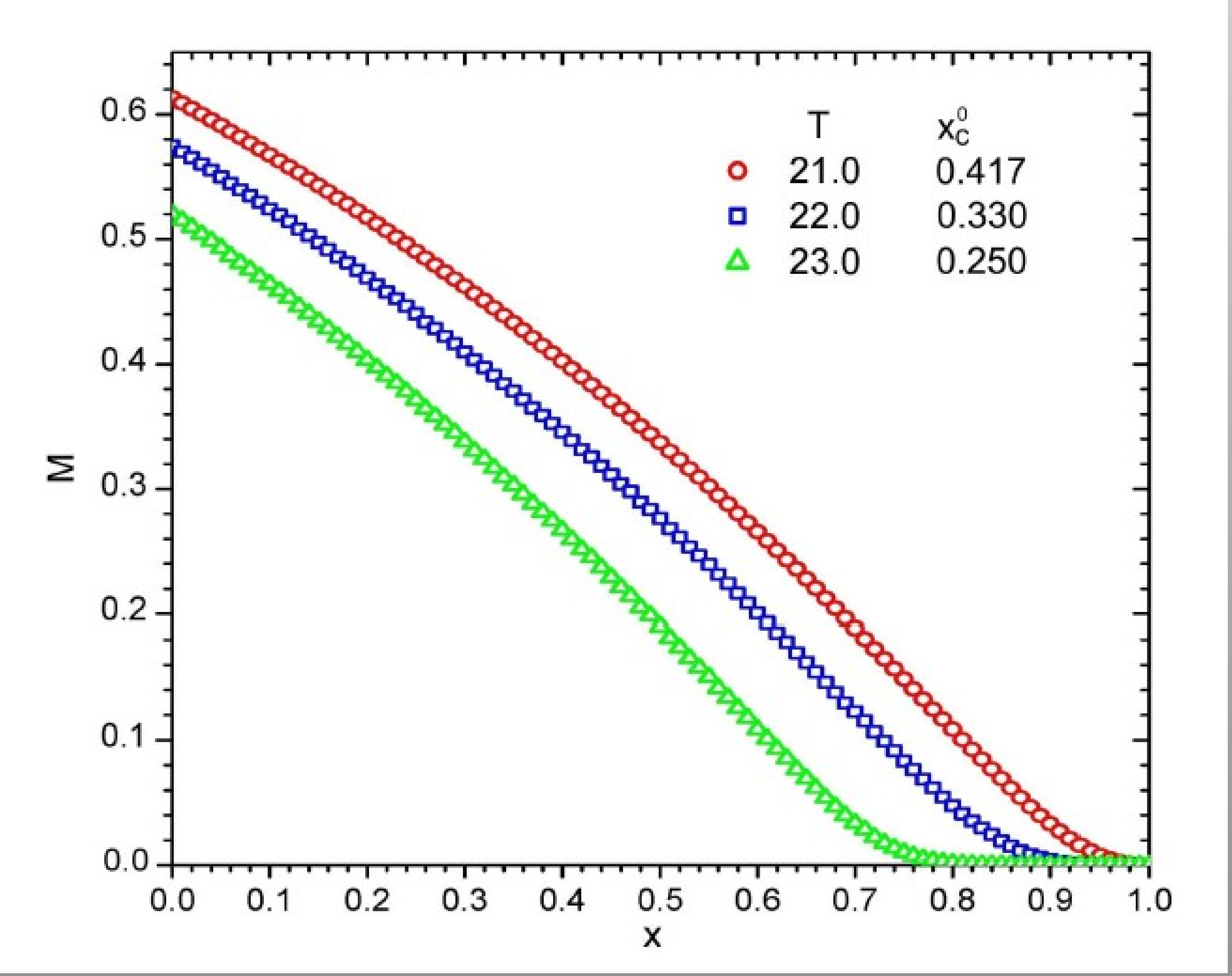


Rare regions effects !!

Observed in many QPTs



AN EXAMPLE



$$M \sim \exp\left[-C\frac{(x - x_c^0)^{2-d/\phi}}{x(1-x)}\right]$$

arXiv:1103.5439

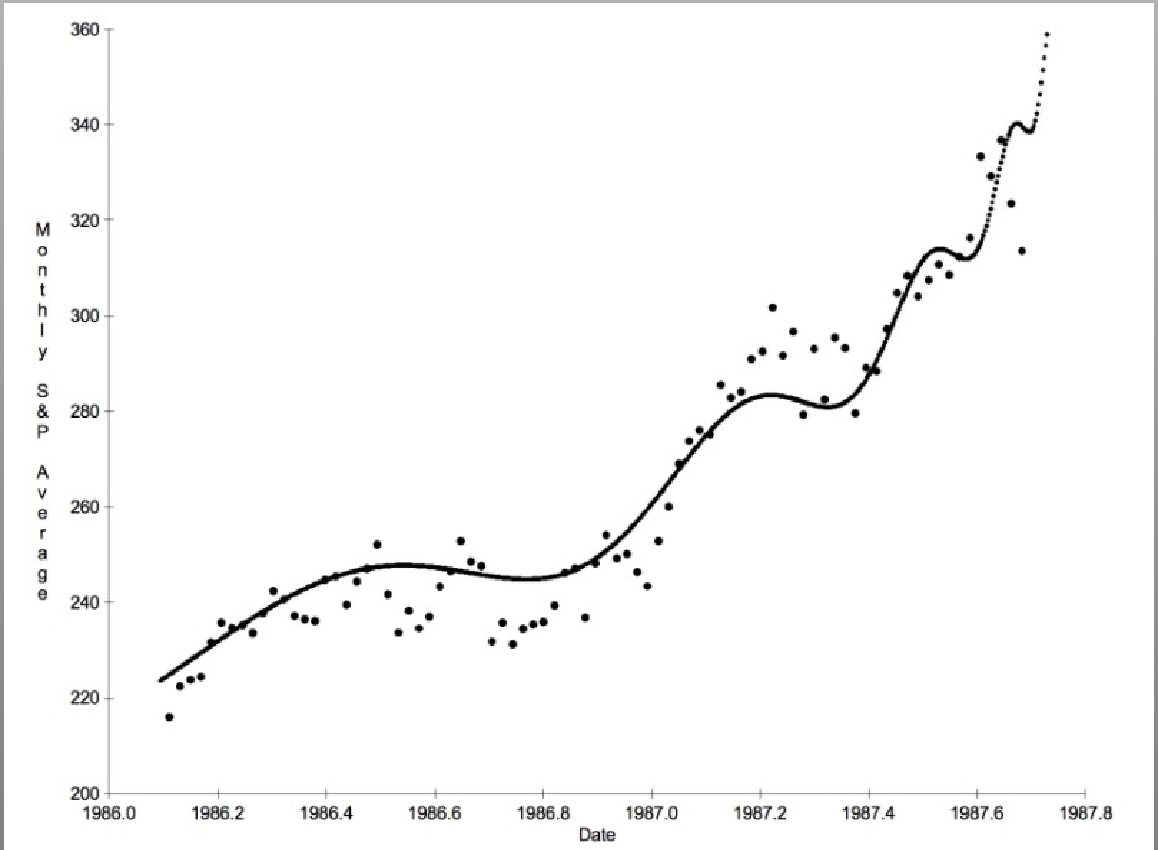
DISCRETE SCALE INVARIANCE

DISORDER → **DSI**

WHAT ARE THE SIGNATURES OF DSI?

Log-periodicity and complex exponents

$$\mathcal{O}_{DSI}(x) \propto x^{\alpha}, \quad \alpha = -\frac{\log \mu}{\log \lambda_0} + i\frac{2\pi n}{\log \lambda_0}, \quad n \in \mathbb{Z}.$$



[Sornette + ...]

$$\mathcal{O}_{DSI}(x) = \mu(\lambda_0)\mathcal{O}_{DSI}(\lambda_0 x)$$

Fractals, stock markets, earthquakes

And of course

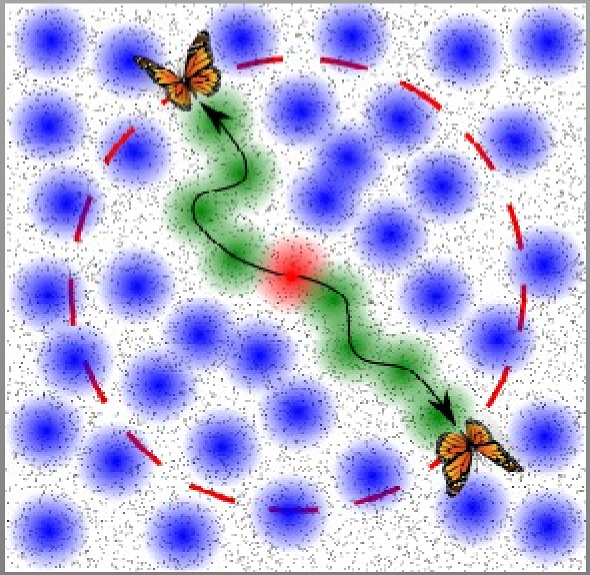
PHYSICS!

QUANTUM CHAOS

$$\langle [\mathcal{V}(x,t)\mathcal{W}(0,0)]^2 \rangle_\beta \sim e^{\lambda_L (t-t^* - |x|/v_B)},$$

OUT-OF-TIME CORRELATOR

classical chaos $\equiv$ *exponential dependence on the initial conditions,*



Holographic probe :

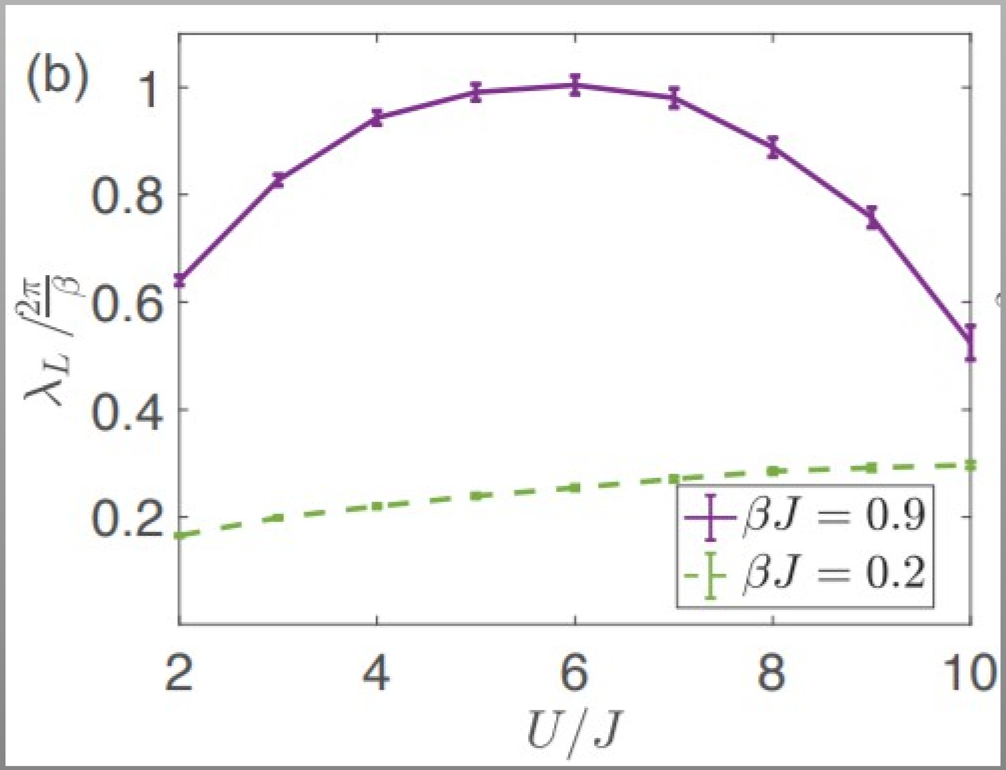
bulk shockwave

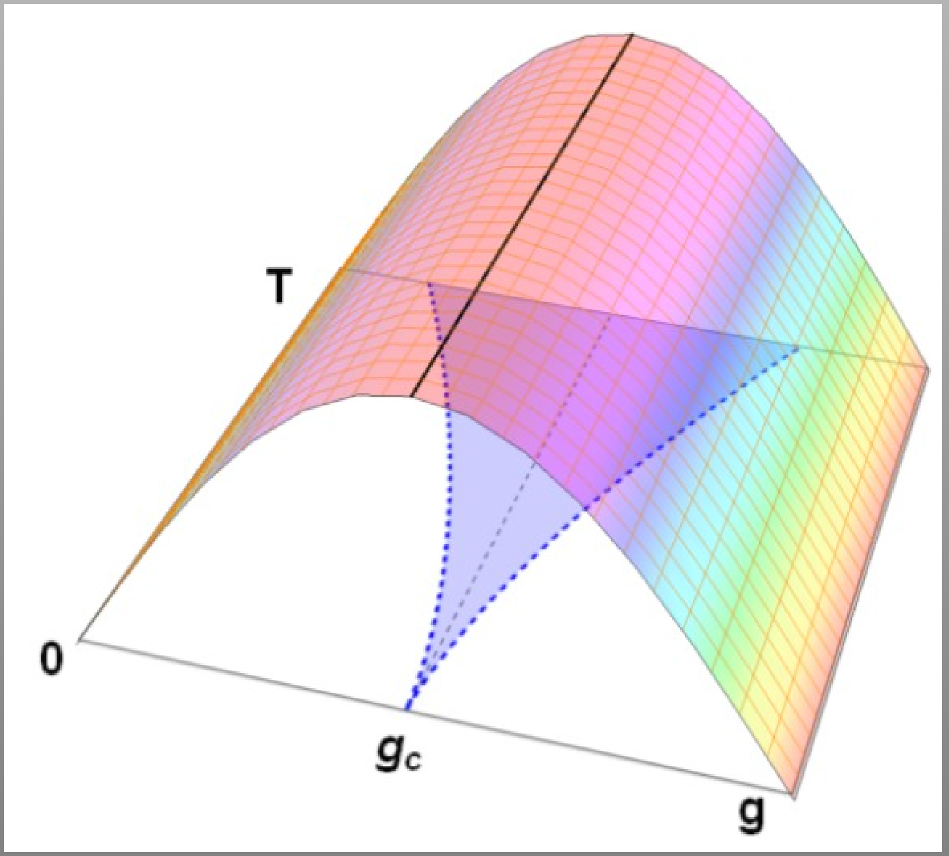
[Shenker, Stanford, Susskind, Swingle, Maldacena, Roberts, Douglas, ...]

CHAOTIC QPTs

arXiv:1608.02438

" The Liapunov exponent
displays a peak in the quantum critical region "





A MODEL FOR AN HOLOGRAPHIC QPT

$$\mathcal{L} = -\frac{1}{4}H^{ab}H_{ab} - \frac{1}{4}F^{ab}F_{ab} + (D_a\Phi)^*(D^a\Phi) - \mathcal{V}(\Phi) + \frac{\kappa}{3}\epsilon^{abcde}A_a\left(F_{bc}F_{de} + 3H_{bc}H_{de}\right),$$

[Landsteiner, Liu, Sun]

$$D_a \equiv \partial_a - iqA_a,\ F = dA,\ H = dV$$

$$\mathcal{V}(\Phi) = m^2|\Phi|^2$$

$$A_z(x,\rho) \sim b(x)\,\rho^0 + \dots,$$

$$\phi(x,\rho) \sim M(x)\,\rho^1 + \dots$$

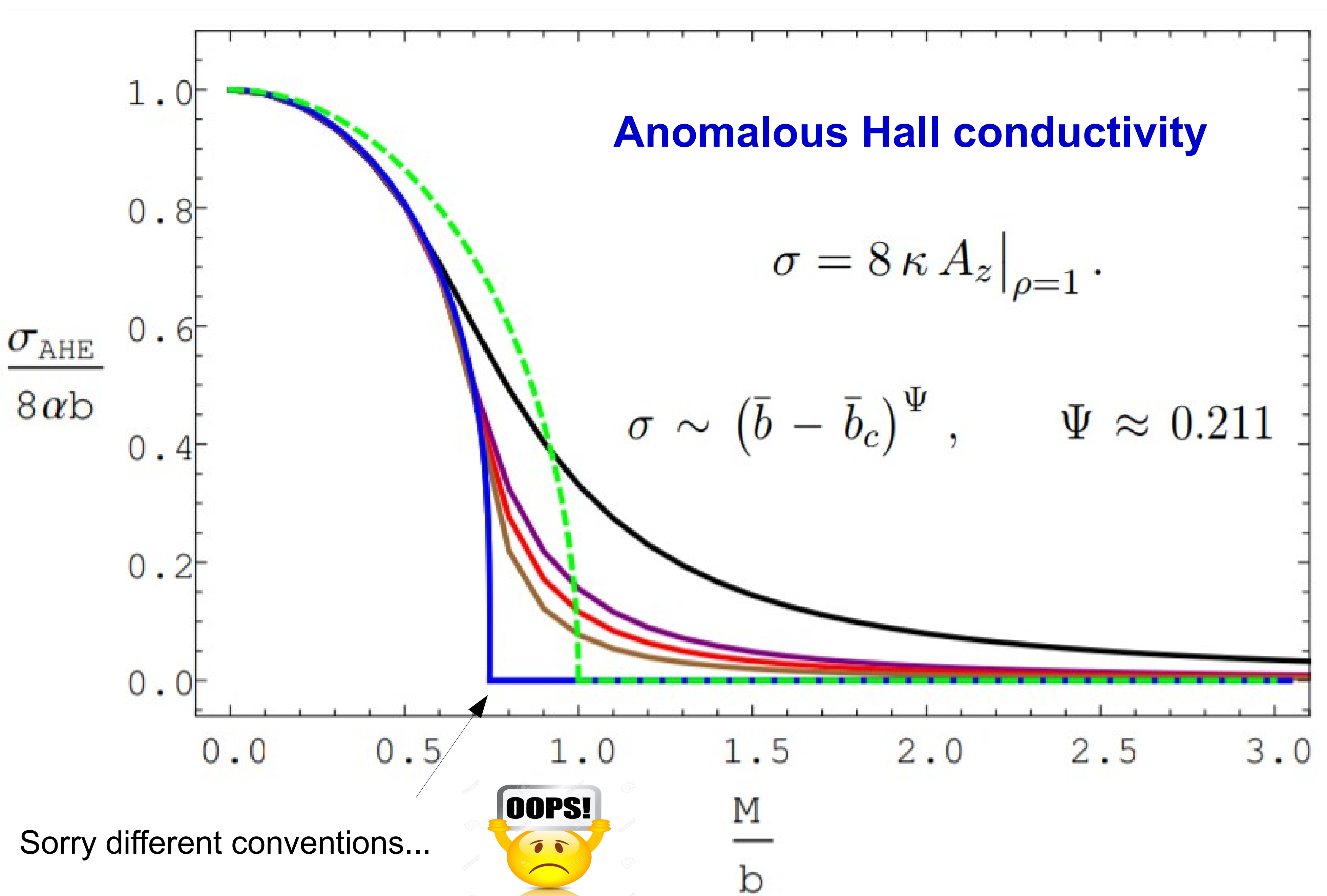
Time reversal Breaking parameter

In the homogeneous case:

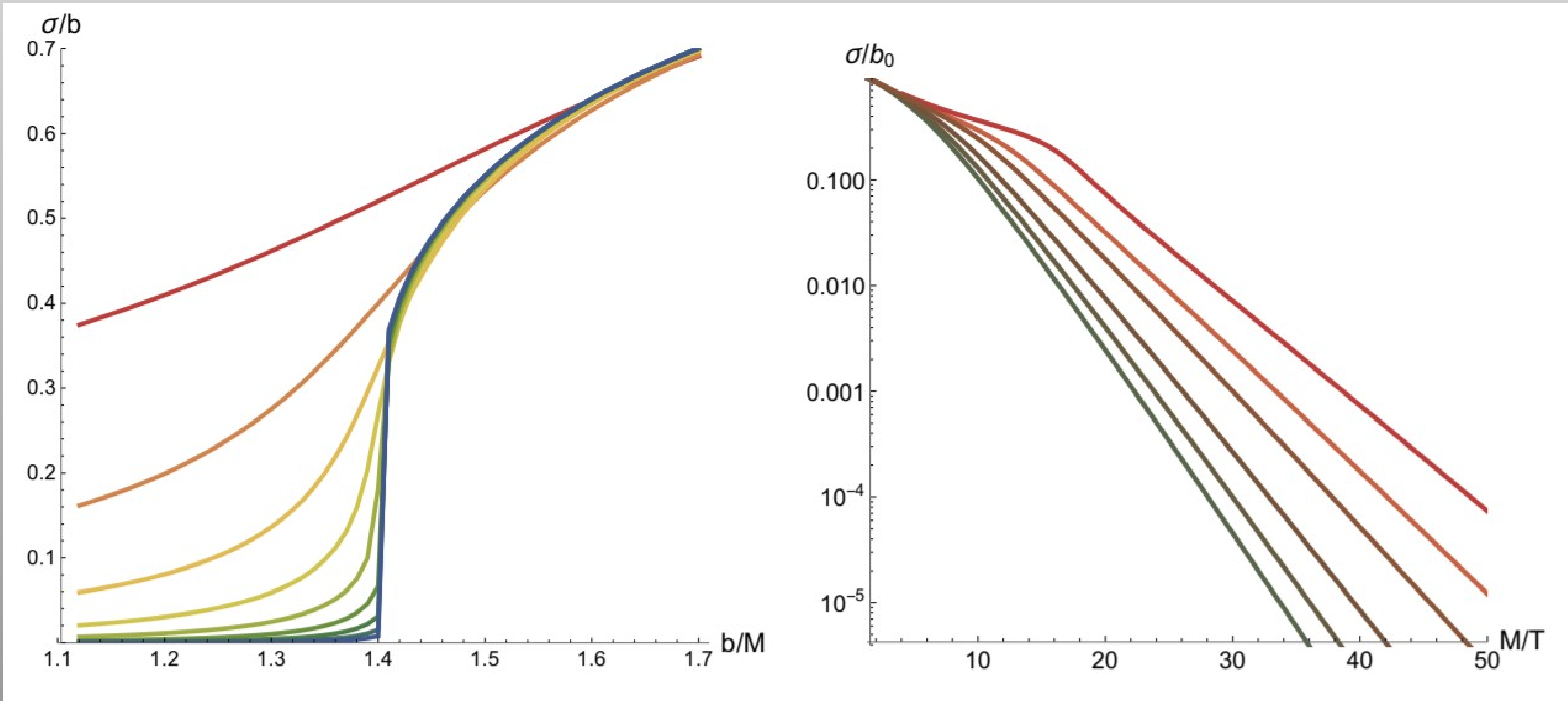
$$b/M \approx 1.40$$ → **QPT**

" Weyl nodes separation "

THE HOLOGRAPHIC WEYL SEMIMETAL



LET'S MAKE IT HOT



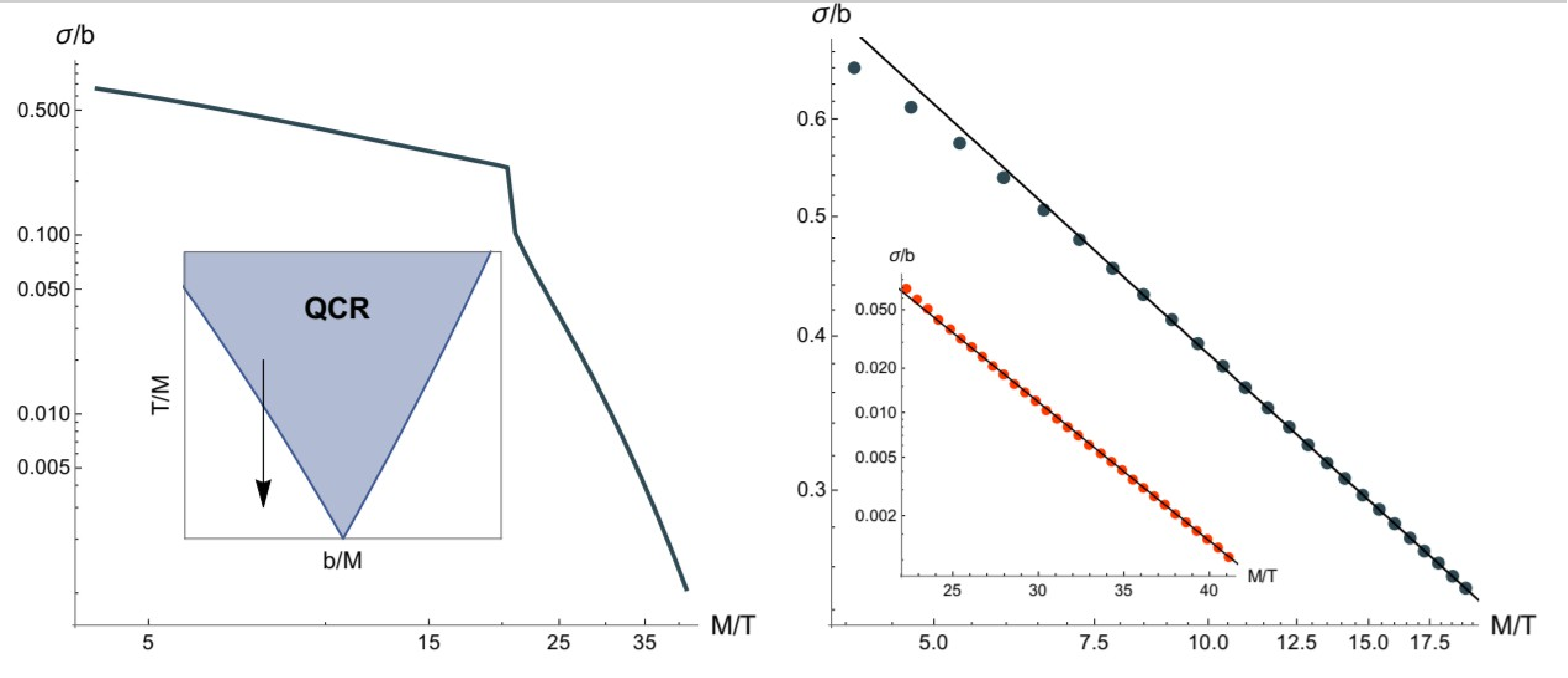
Finite temperature

QPT → **CROSSOVER**

$$\sigma \sim e^{-cM/T}$$

Outside the quantum Critical region

LET'S MAKE IT HOT : PART II



$$\sigma \sim \left(\frac{M}{T}\right)^{-\nu}$$

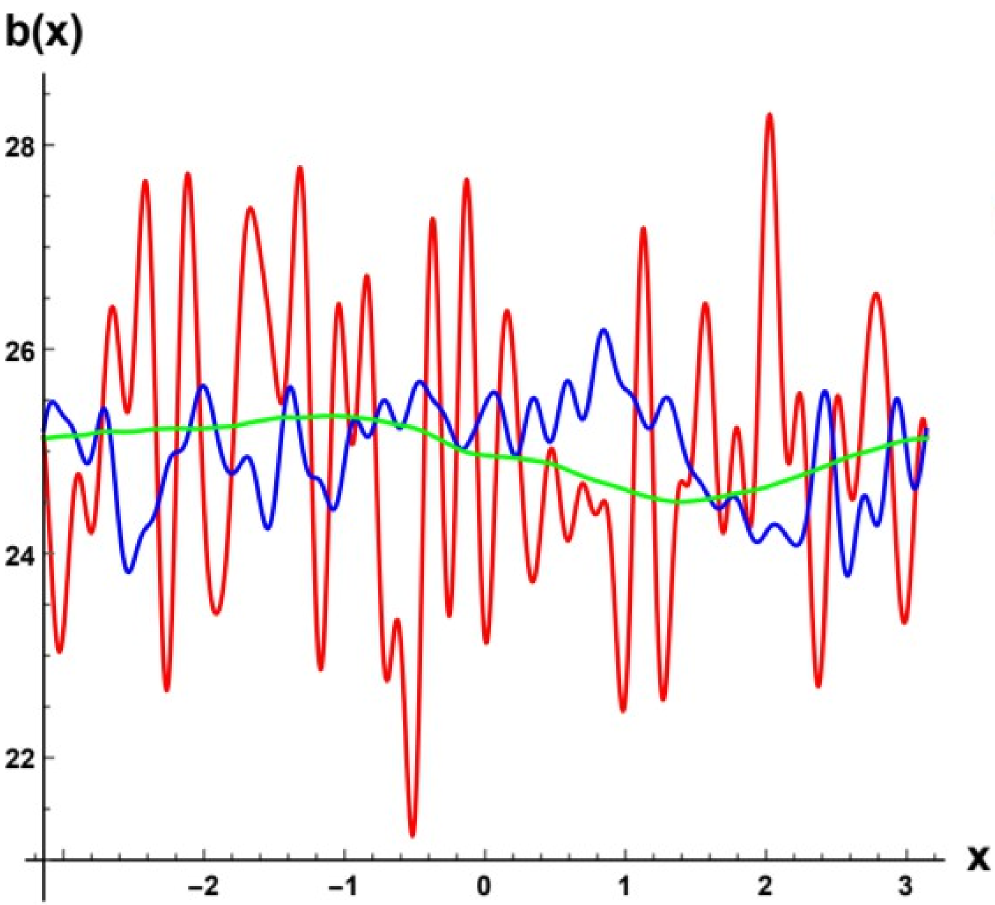
Inside the critical region

Power law, scale invariance

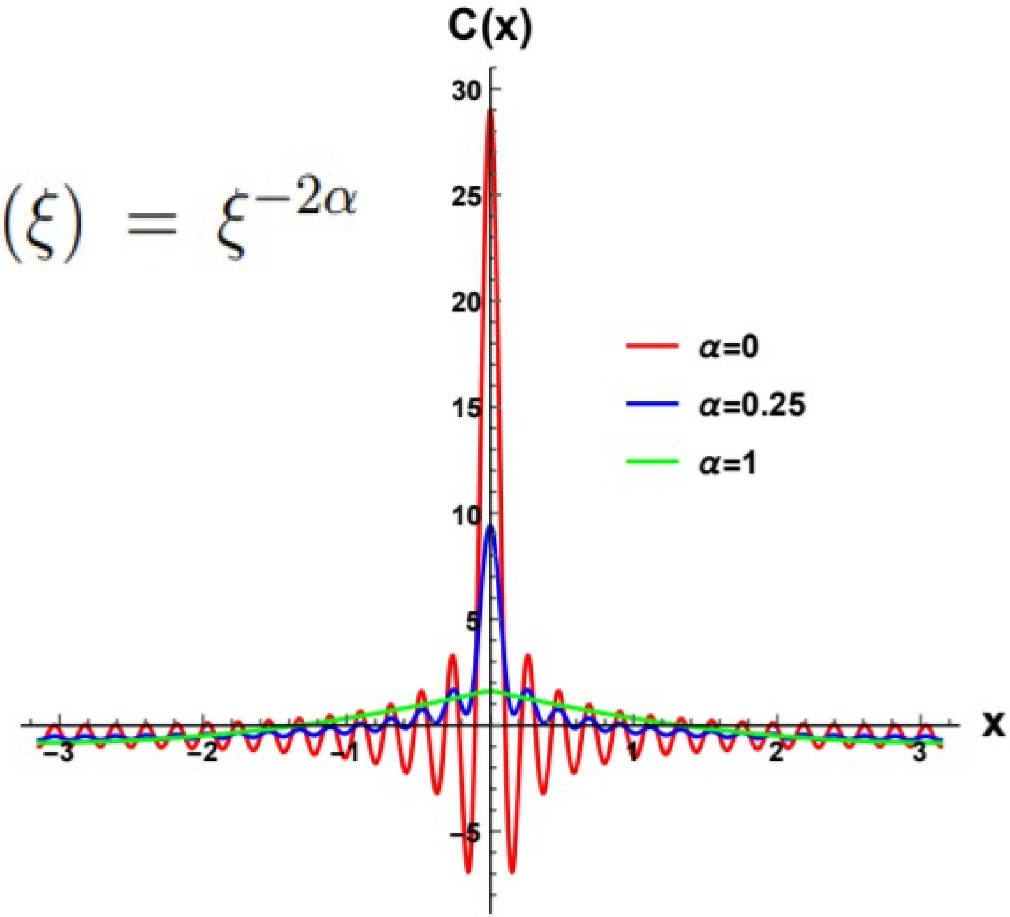
LET'S MAKE IT DIRTY

Spectral representation

$$b(x) = b_0 + 2\,\gamma \sum_{i=1}^{N-1} \sqrt{S(k_i)}\,\sqrt{\Delta k}\,\cos\left(k_i\,x + \delta_i\right)$$

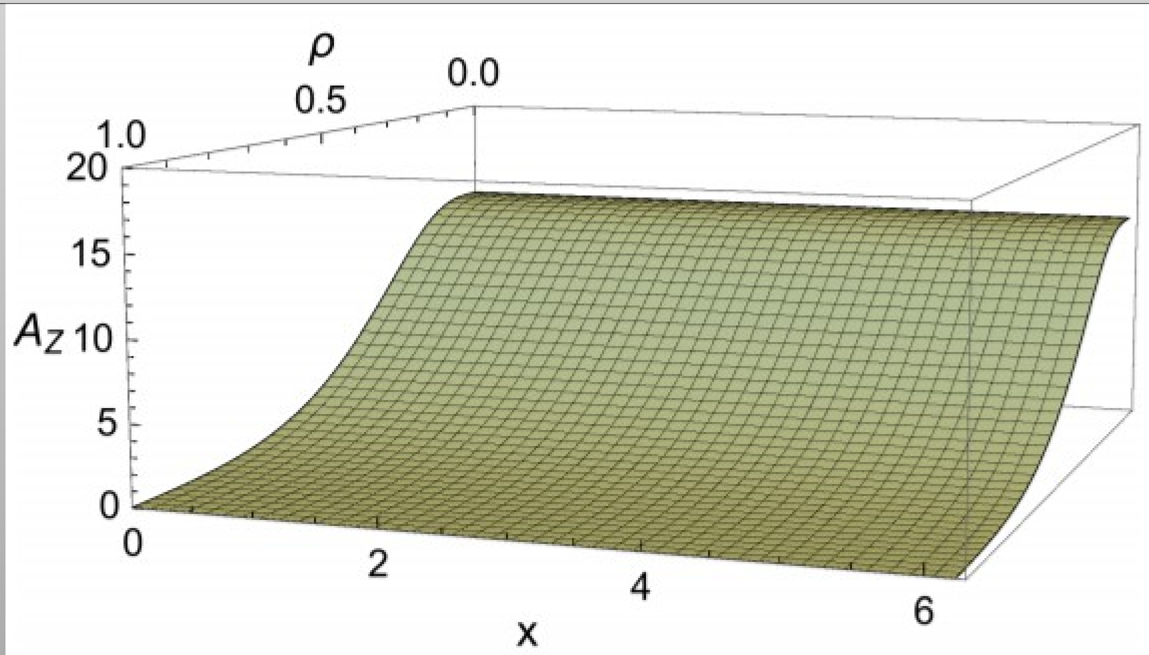


$$S(\xi) = \xi^{-2\alpha}$$



$\alpha = 0$ and $N \to \infty$ → **GAUSSIAN DISORDER**

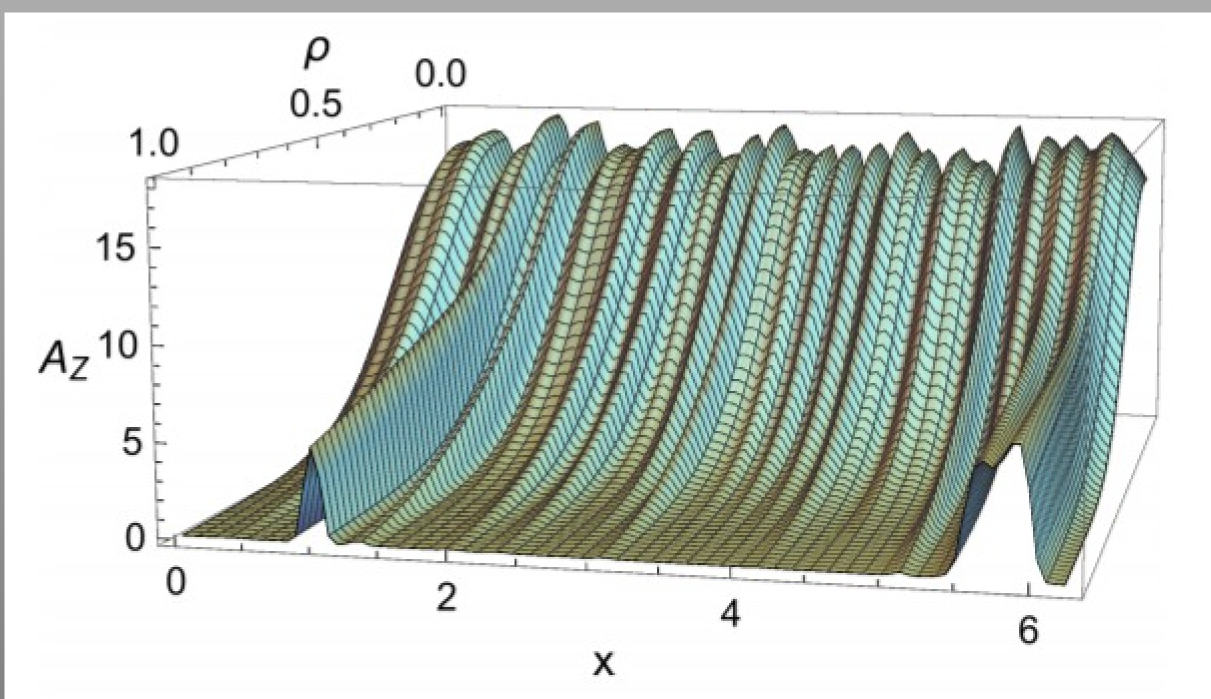
DISORDERED BULK FIELDS



Constant source

↓

Nothing happens

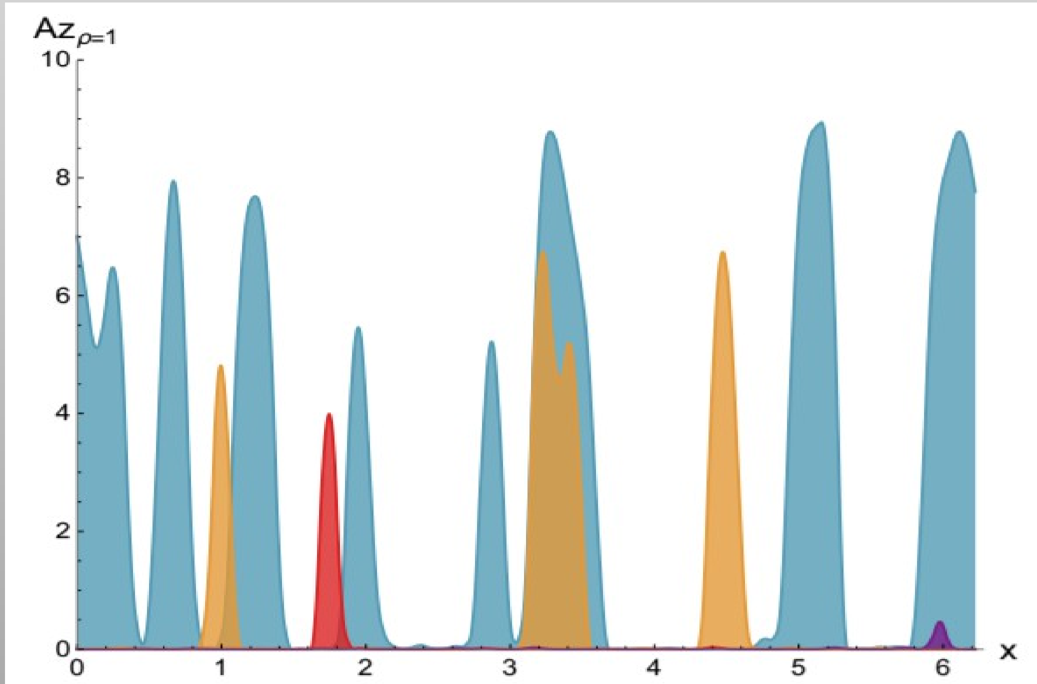


Disordered source

↓

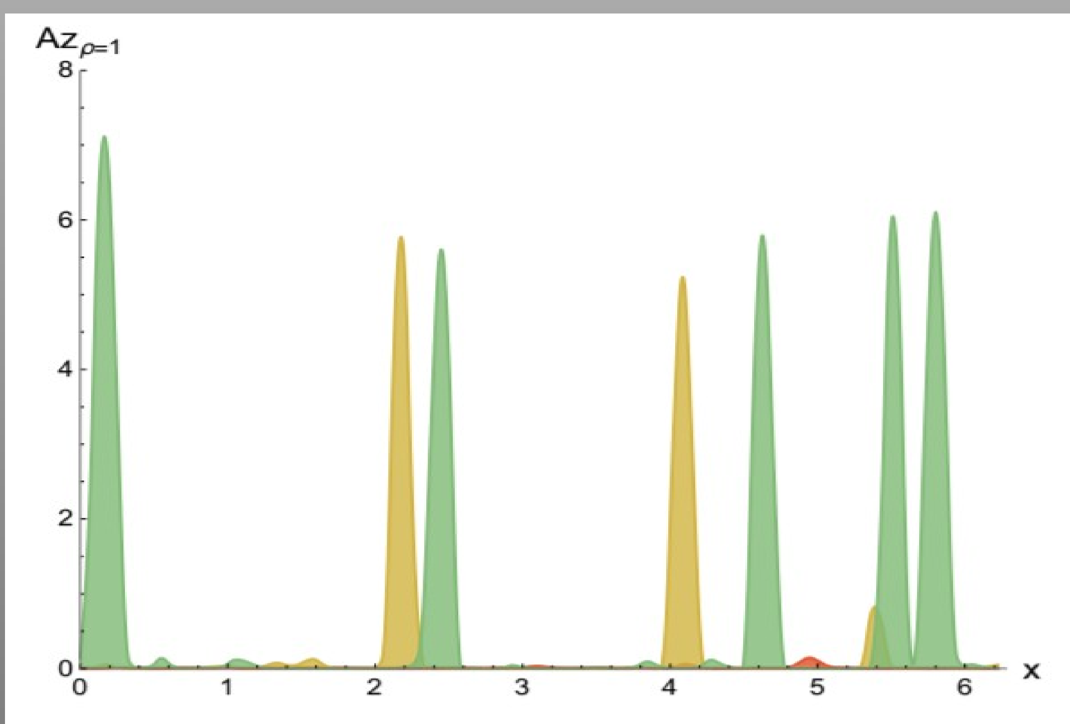
Features at the Horizon ...

RARE REGIONS



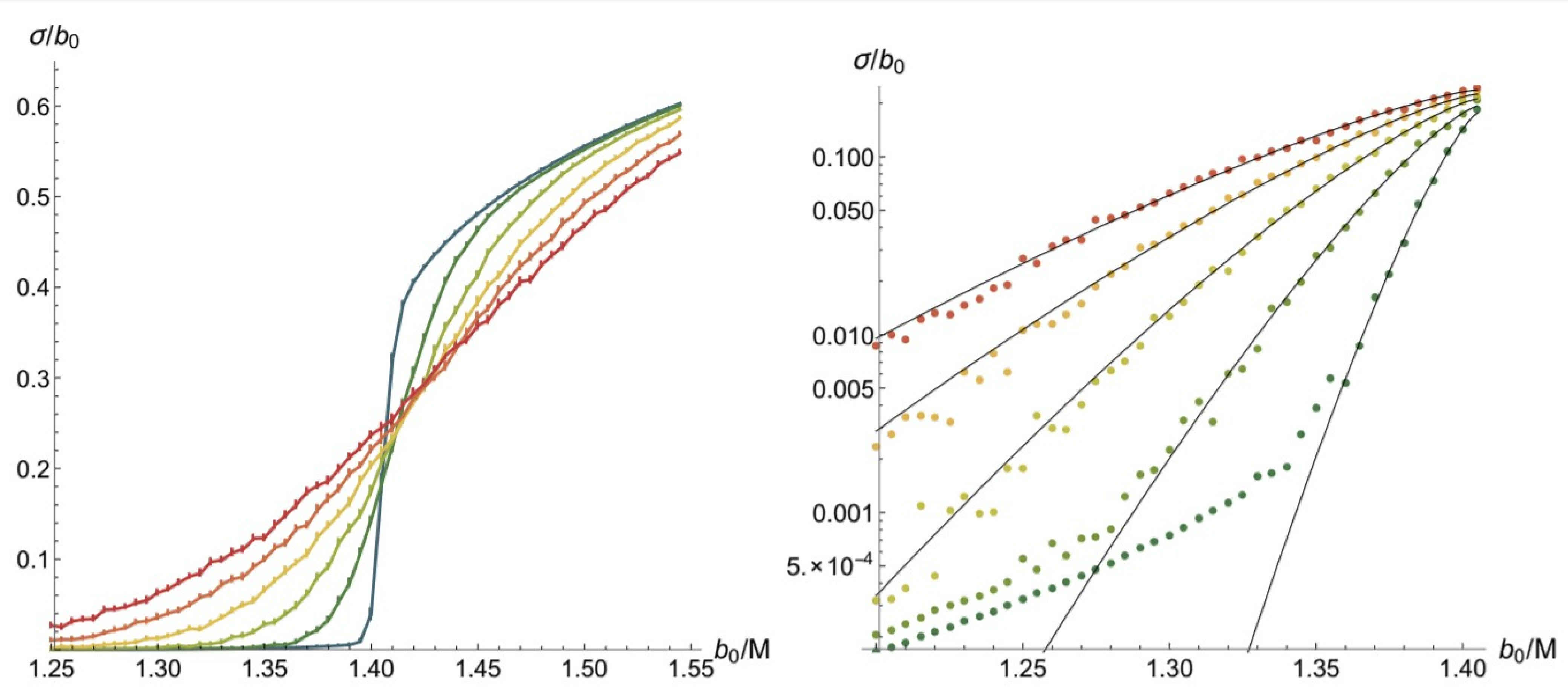
They become less rare and larger
Close to the quantum
Critical point

SMEARING !



They become less rare and larger
Increasing the disorder
Strength !!!

SMEARED QPT



$$\sigma_{xy} \sim c_1\, e^{c_2(1.4023-\bar{b}_0)^{c_3}}$$

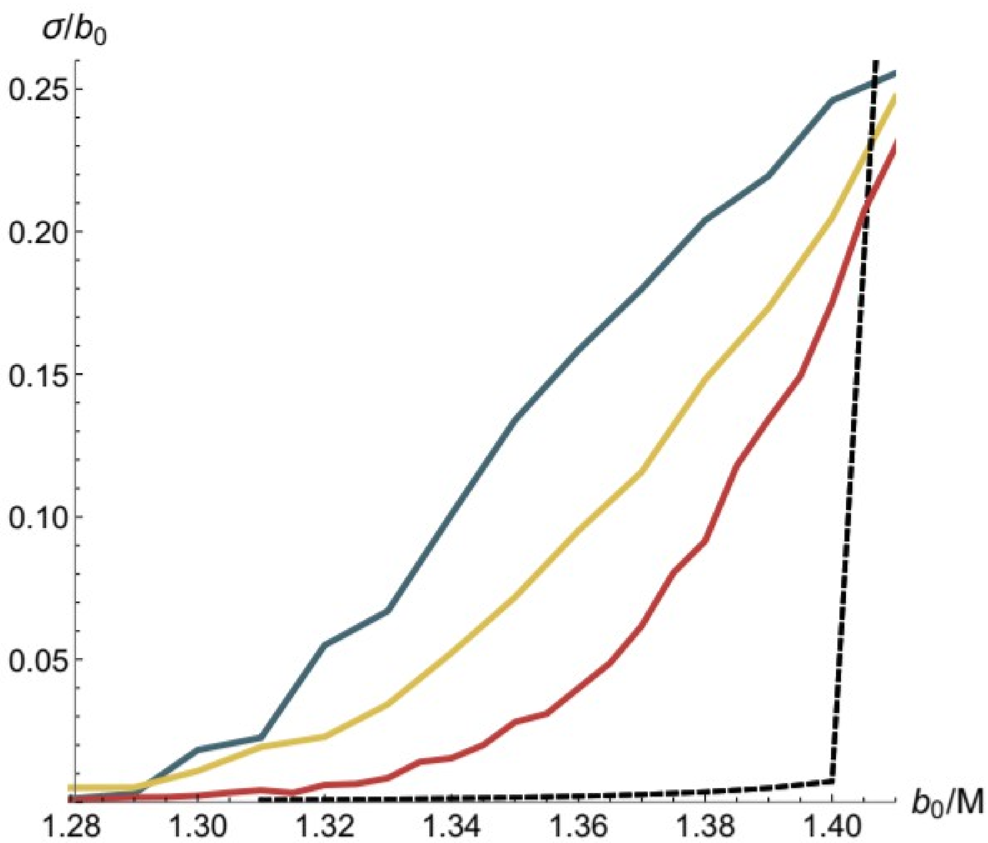
→ Independent of disorder strength

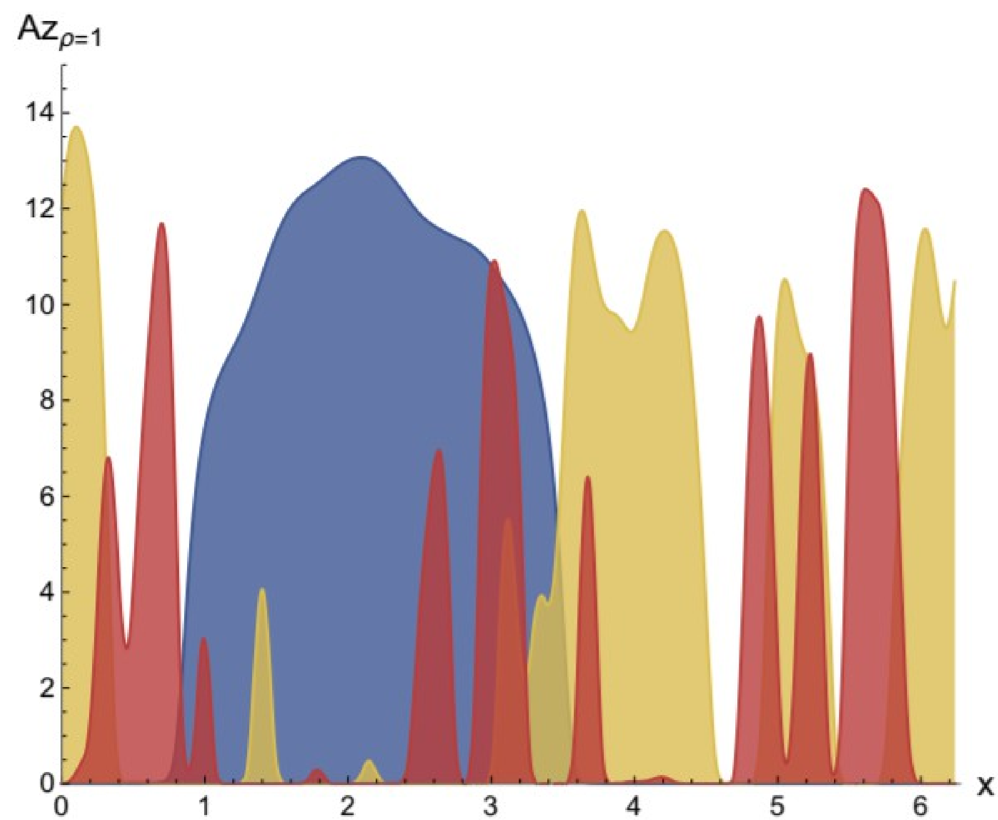
In agreement with CM expectations, e.g.

Composition-tuned smeared phase transitions

Fawaz Hrahsheh, David Nozadze, Thomas Vojta

DISORDER CORRELATION

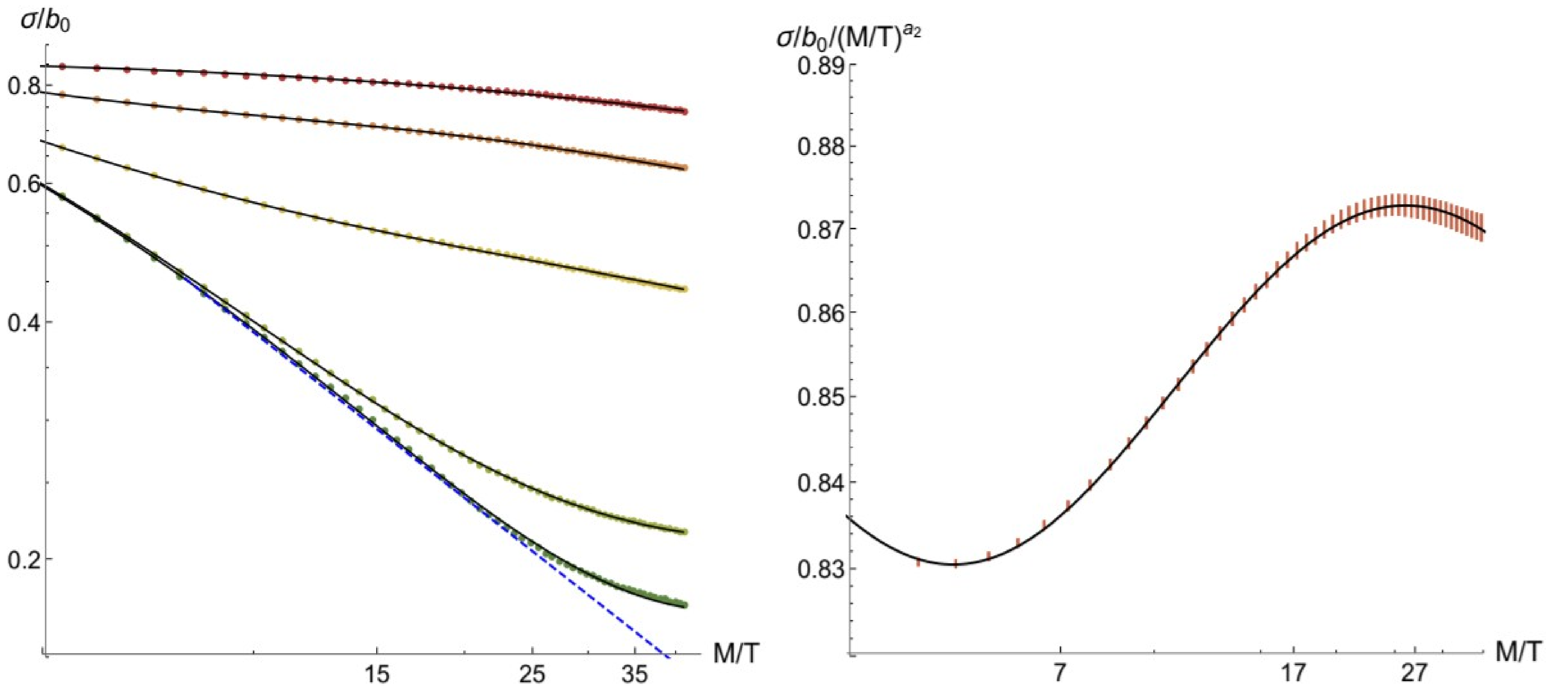




Positive correlation increases the smearing
We see indeed broader and less rare regions
that have undergone the phase transition

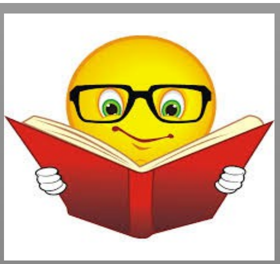
cond-mat > arXiv:1109.4290

DISCRETE SCALE INVARIANCE



Appearance of Log-Oscillatory structures

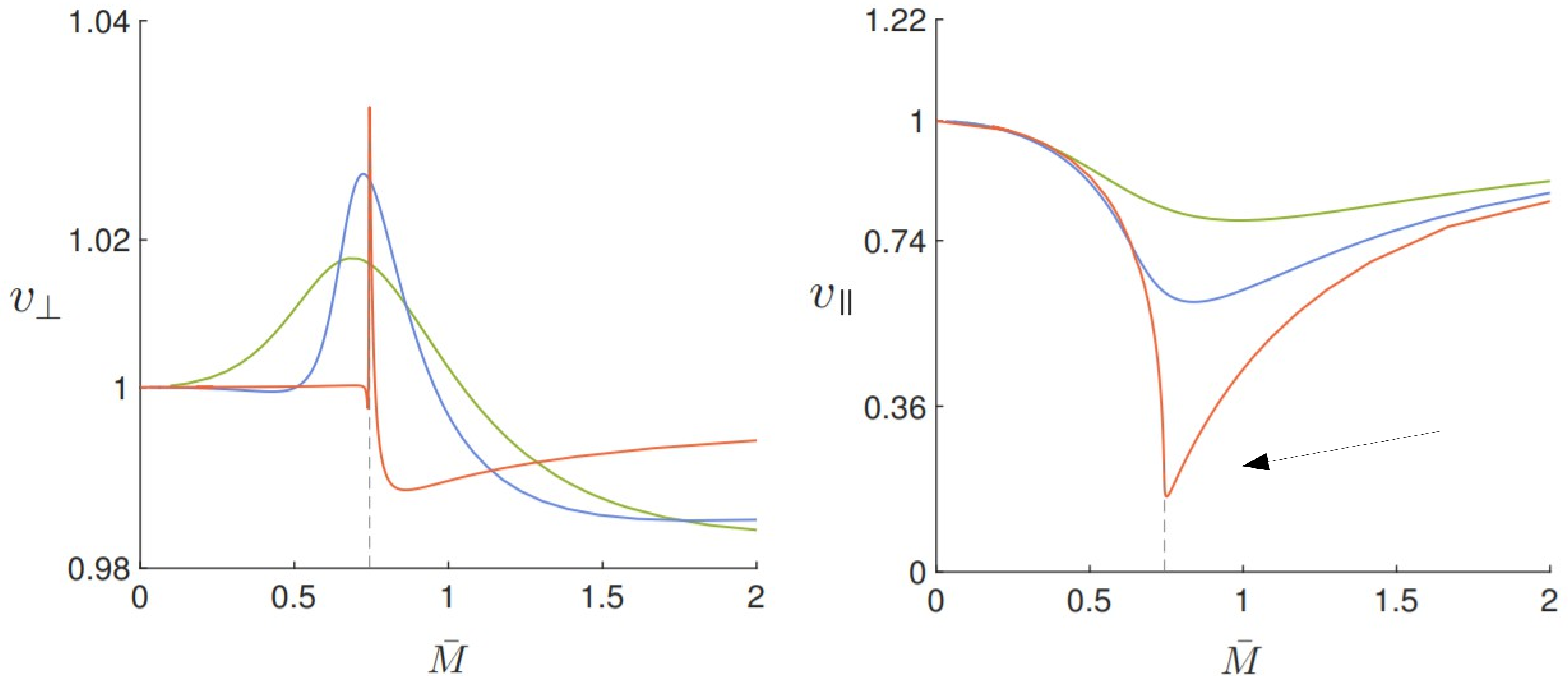
DISORDER ----> DISCRETE SCALE INVARIANCE



cond-mat > arXiv:cond-mat/9707012

BUTTERFLY VELOCITIES

$$ds^2 = -g_{tt}(r)\,dt^2 + g_{rr}(r)\,dr^2 + h_\perp(r)\,d\vec{x}_\perp^2 + + h_{||}(r)\,d\vec{x}_{||}^2,$$

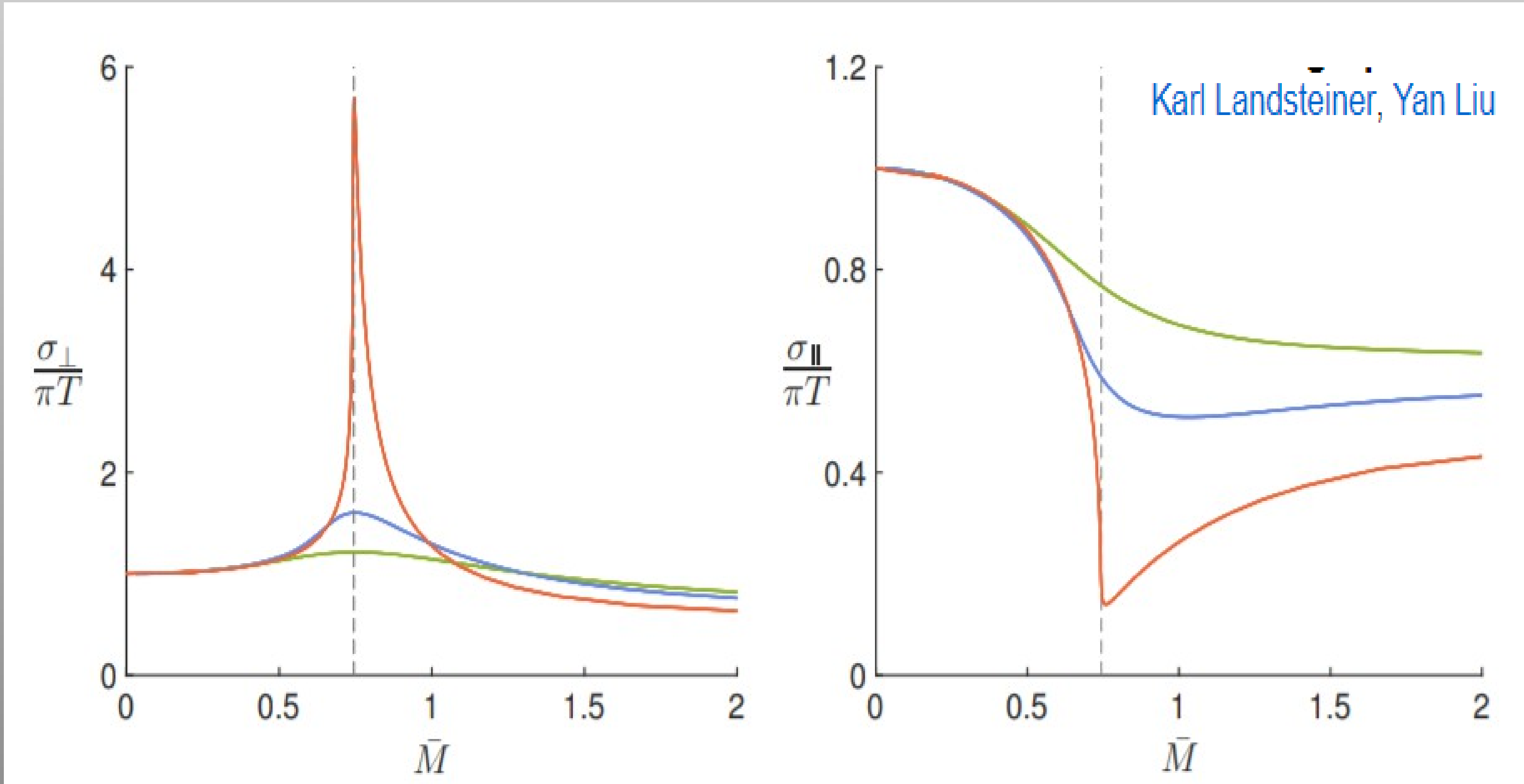


Similar results In anisotropic backgrounds

arXiv:1708.05691

arXiv:1708.07243

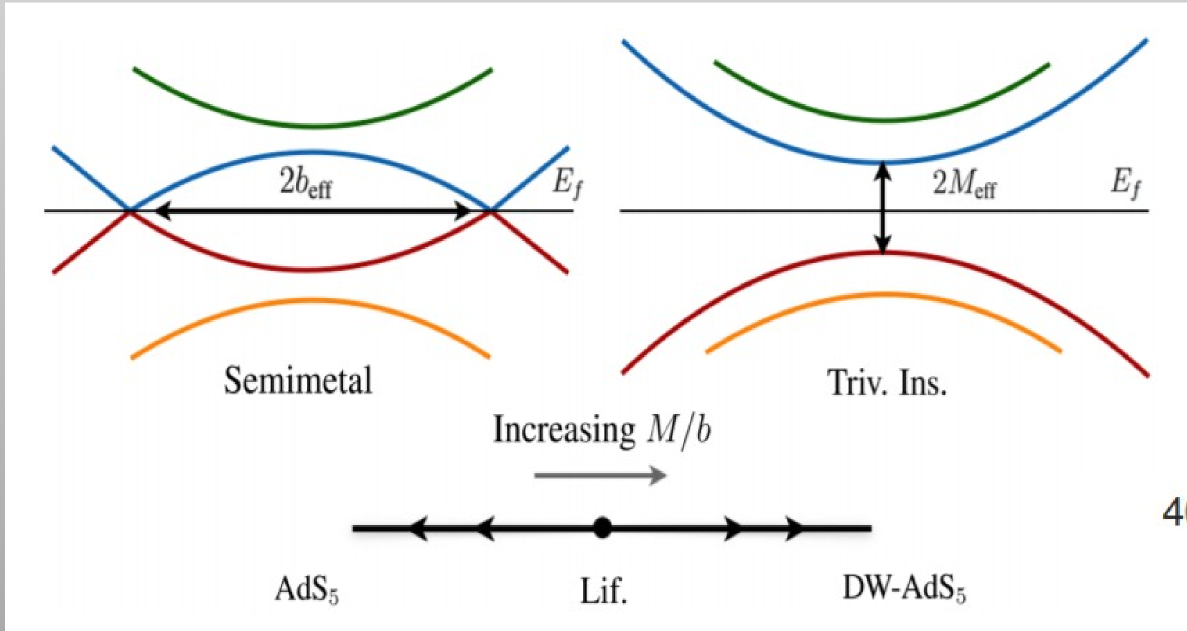
OTHER OBSERVABLES



Same behaviour in the Viscosities

VIOLATION OF KSS

ANISOTROPY

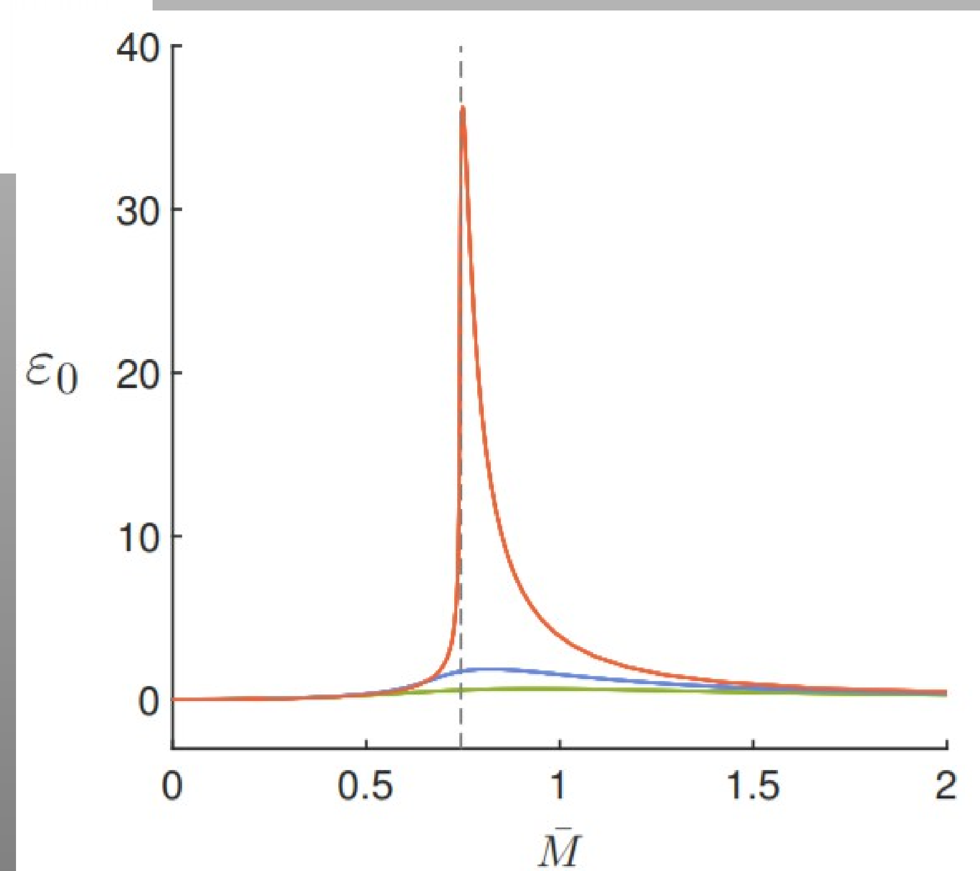


Measure of anisotropy

$$\varepsilon_0 \equiv \frac{h(r_0)}{g(r_0)} - 1$$

$$\frac{v_\perp^2}{v_\parallel^2} = \frac{\sigma_\perp}{\sigma_\parallel} = \frac{\eta_\perp}{\eta_\parallel} = 1 + \varepsilon_0 \,.$$

$$\frac{h(r_0)}{g(r_0)} \sim r_0^{2(\beta_0 - 1)},$$



THE IDEA

$$ds^2 = -g_{tt}(r)\,dt^2 + g_{rr}(r)\,dr^2 + h_\perp(r)\,d\vec{x}_\perp^2 + +h_{||}(r)\,d\vec{x}_{||}^2,$$

vB is affected by anisotropy via h(r)

$$v_B^{(\zeta)} = \frac{\lambda_L}{\mu\sqrt{h_{(\zeta)}(r_0)}} \quad , \quad \mu^2 = 2\pi T \sum_\eta \frac{d_\eta}{2} \frac{h'_{(\eta)}(r)}{h_{(\eta)}(r)}\Big|_{r_0} .$$

that is the reason of the minimum (= KSS)

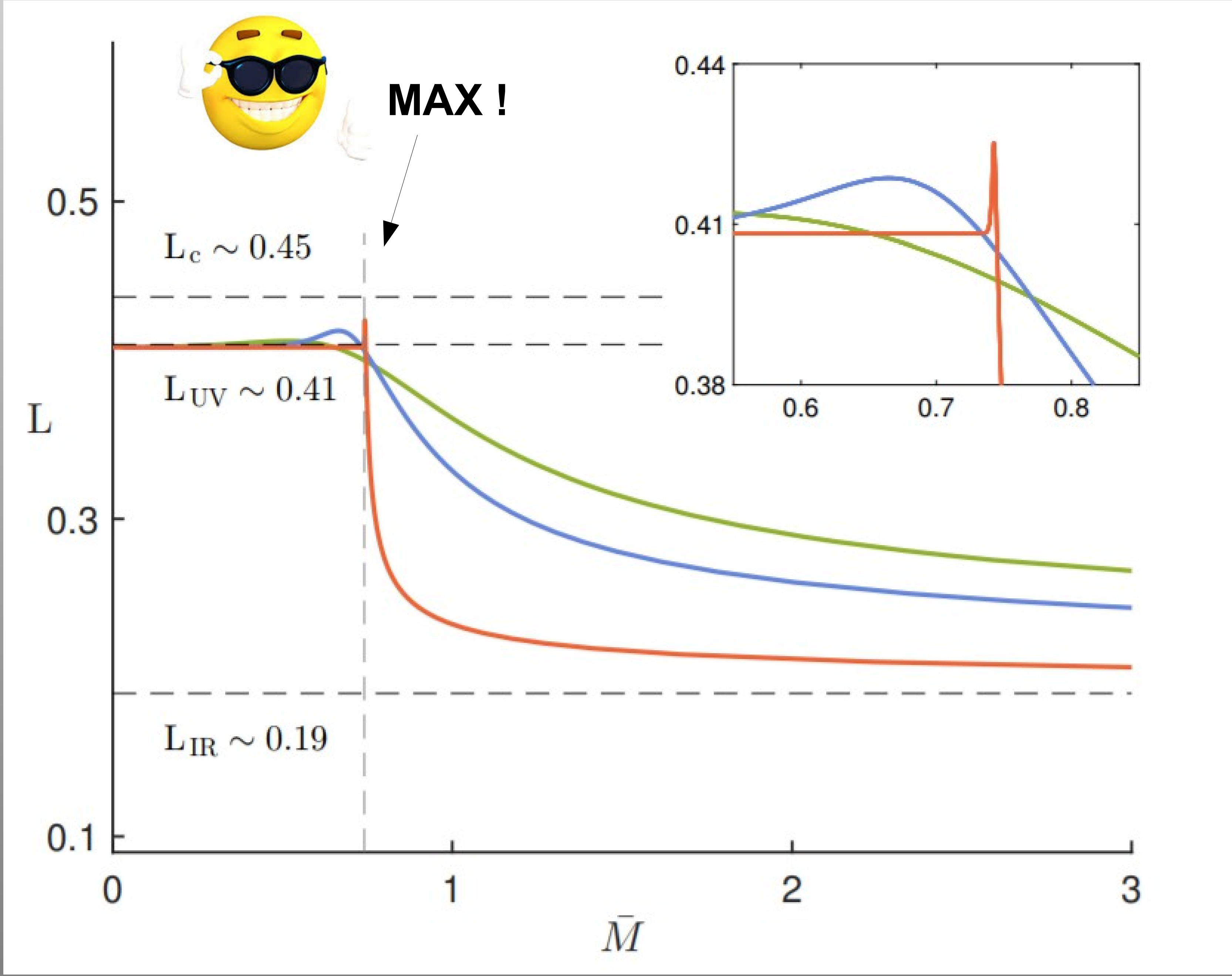
dimensionless information screening length L,

$$\mu^2 = \kappa \frac{\partial}{\partial r} \log \mathcal{A}\Big|_{r=r_0}$$

$$\mathrm{L} \equiv 1/\mu,$$

Curious form …. (c/a theorem ??)

THE RESULTS



MAX !
0.5
0.3
0.1
L
$L_c \sim 0.45$
$L_{UV} \sim 0.41$
$L_{IR} \sim 0.19$
0
1
2
3
$\bar{M}$
0.44
0.41
0.38
0.6
0.7
0.8

A CONJECTURE

Assume an anisotropy of the form (our case) $h(r) = h_0 r^{2\beta_0}$

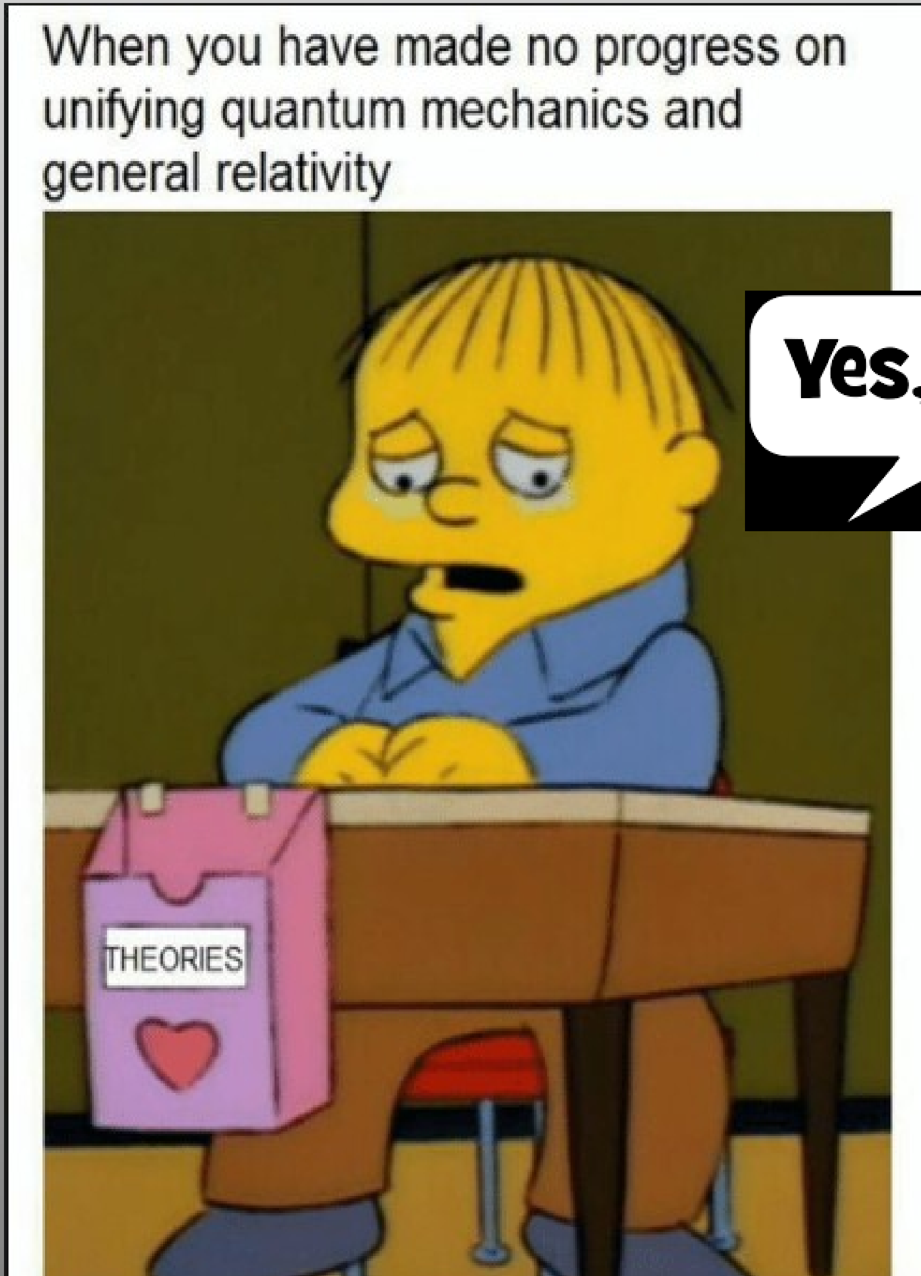
$$2\text{L} \leq \frac{1}{D_\perp + \beta_0 D_{||}} .$$

AND MAXIMUM AT THE QUANTUM CRITICAL POINT !!!

NEC forces $\beta_0 < 1.$ → **MAX AT THE CRITICAL POINT**

Dependence on the IR near-horizon geometry ...

CONCLUSIONS



Discrete scale invariance

Disorder backreaction

Connection with c/a theorems ??

QCP with emergent isotropy ??

Definition of L from field theory ??

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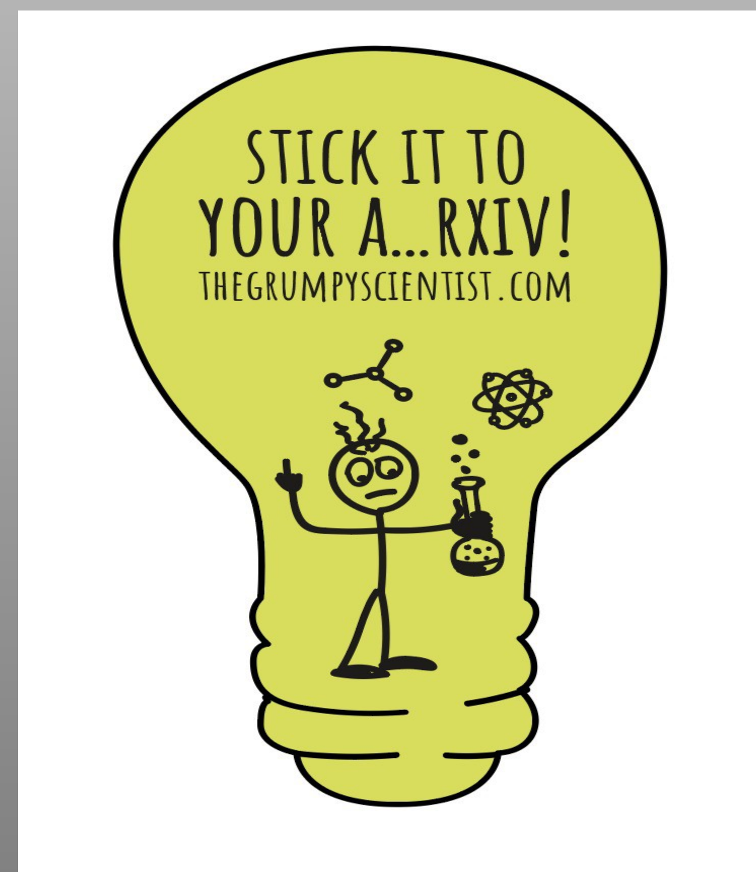
STAY GRUMPY, STAY SCIENTIST

The grumpy scientist



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