Quantum systems and non-equilibrium noise

T. Giamarchi

http://dpmc.unige.ch/gr_giamarchi/

UNIVERSITÉ DE GENÈVE

FNSNF
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E. Dalla Torre (Weizmann)

E. Altman (Weizmann)

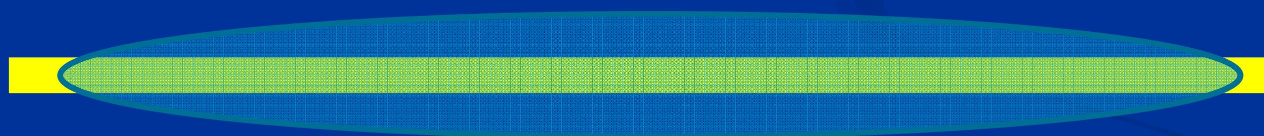
E. Demler (Harvard)

E. Dalla Torre, E. Demler,TG, E. Altman, Arxiv/0908.3345, Nat. Physics (2010)

Quantum physics with a bath

- Reasonable (?) understanding of isolated systems

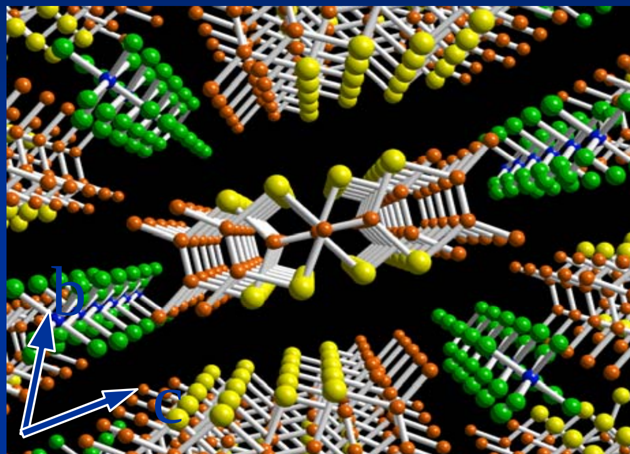
- Many systems are subjected to an external bath



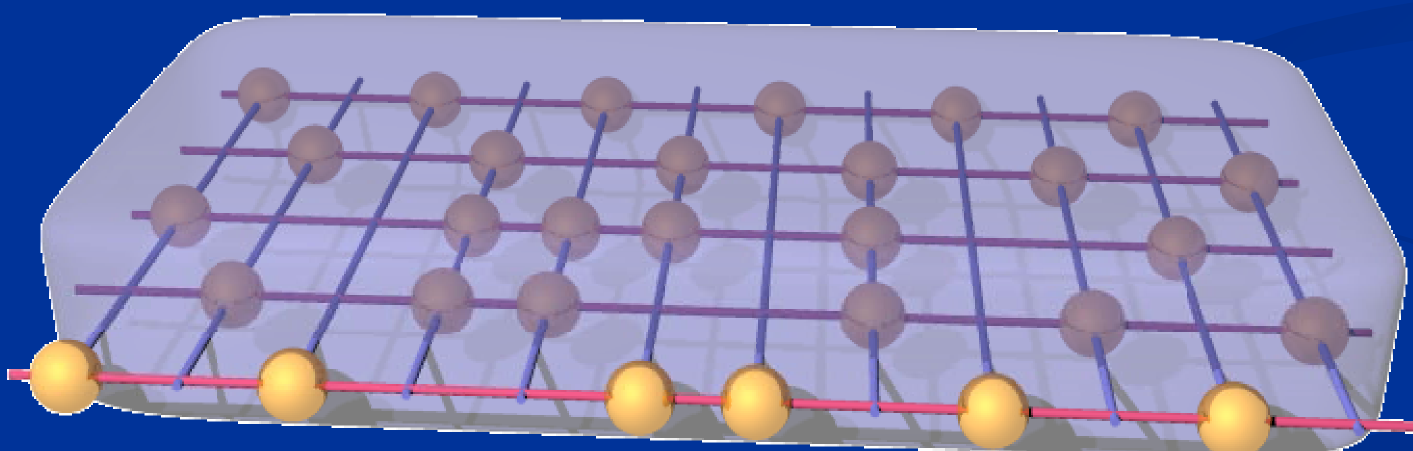
- How is the physics modified ?

Equilibrium baths

Quasi-one dimensional systems



Chemical Review
104 5037 (2004)



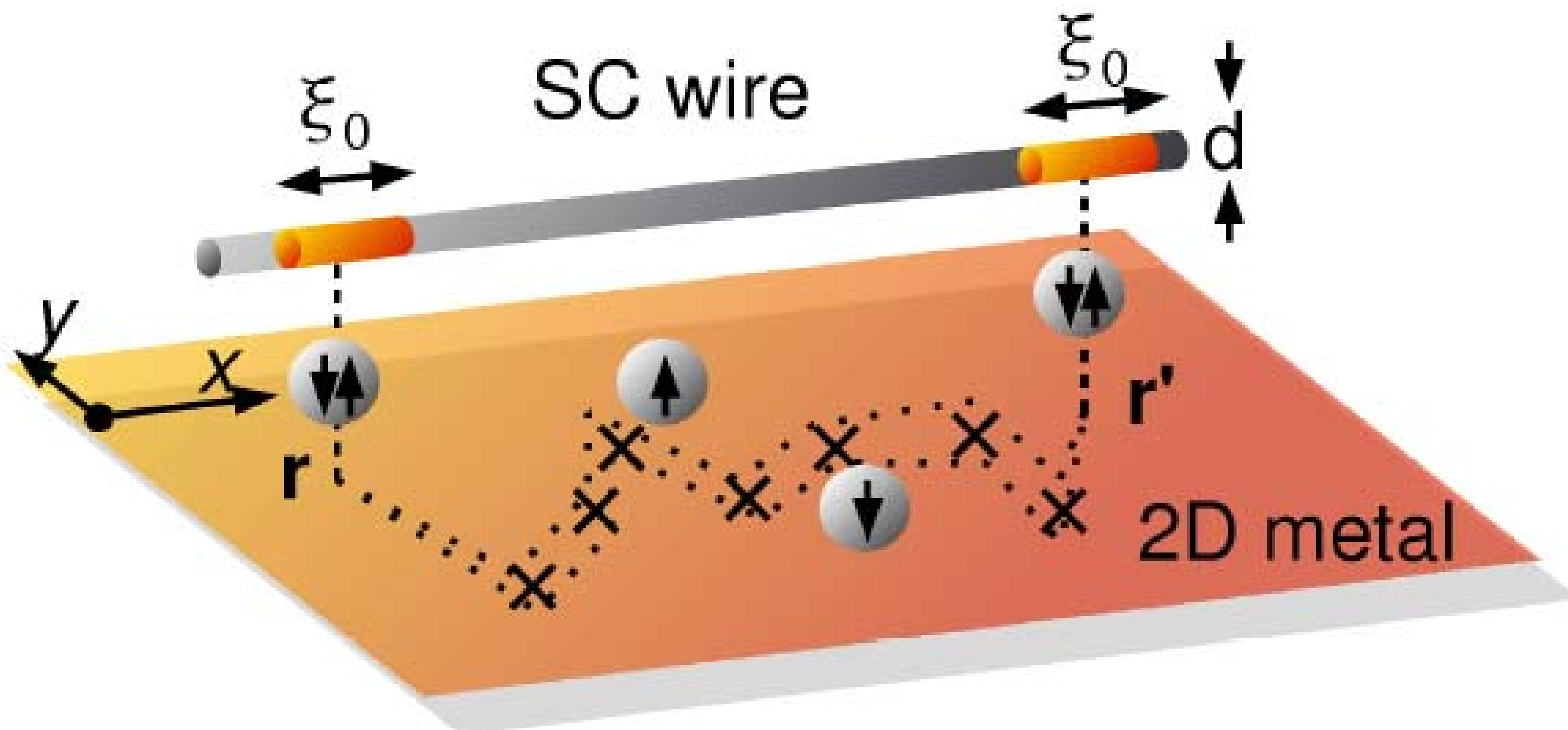
Ch-DMFT

1D Luttinger liquid + (self consistent) bath

S. Biermann, A. Georges, A. Lichtenstein, TG, PRL 87 276405 (2001)
C. Berthod et al. PRL 97, 136401 (2006)

Superconducting wire + gate

A. M. Lobos *et al.*, PRB **80**, 214515 (2009)



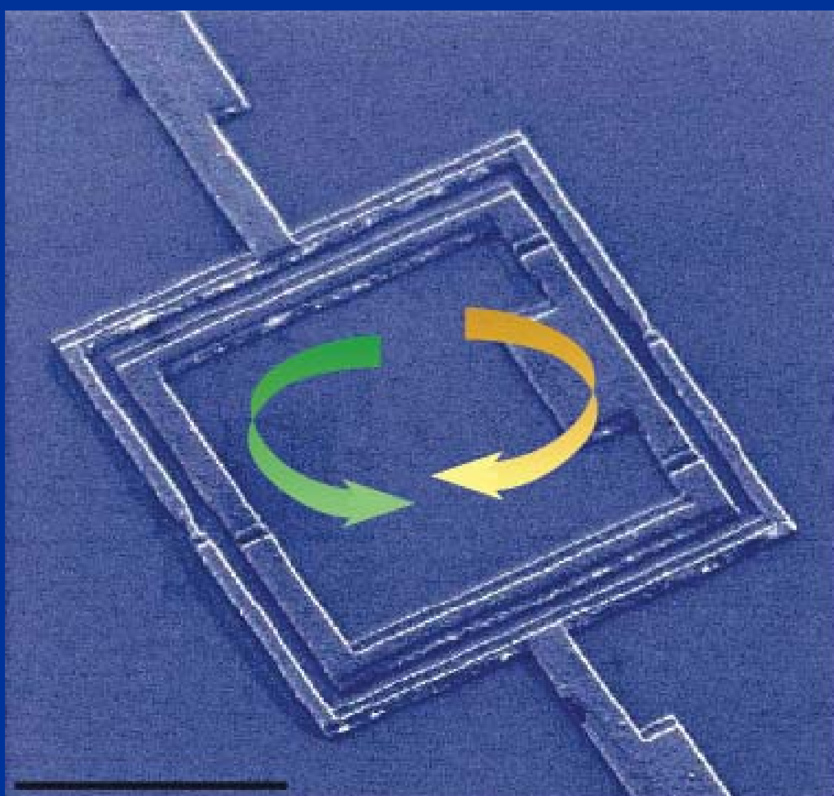
Out of equilibrium baths

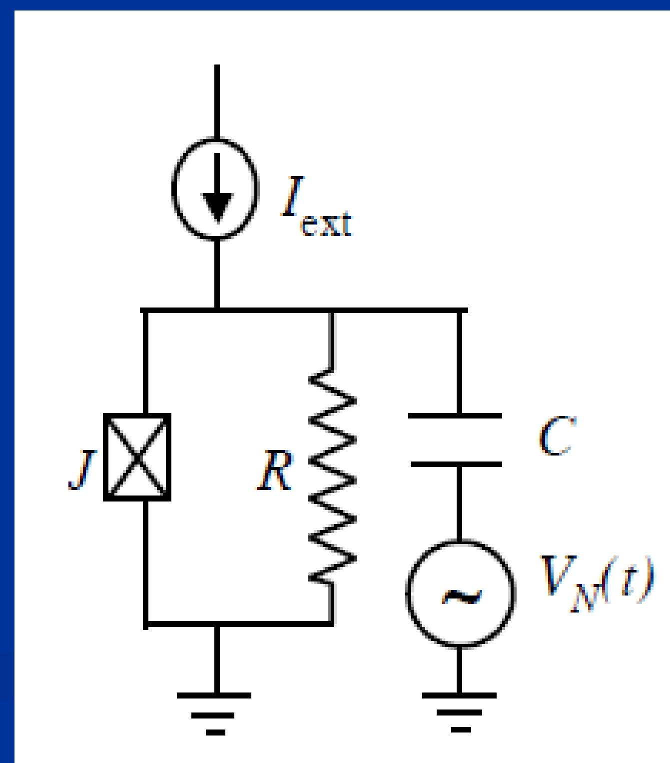
Noisy Josephson junction

Superconducting quantum bits

John Clarke[1,2] & Frank K. Wilhelm[3]

NATURE|Vol 453|19 June 2008|doi:10.1038/nature07128



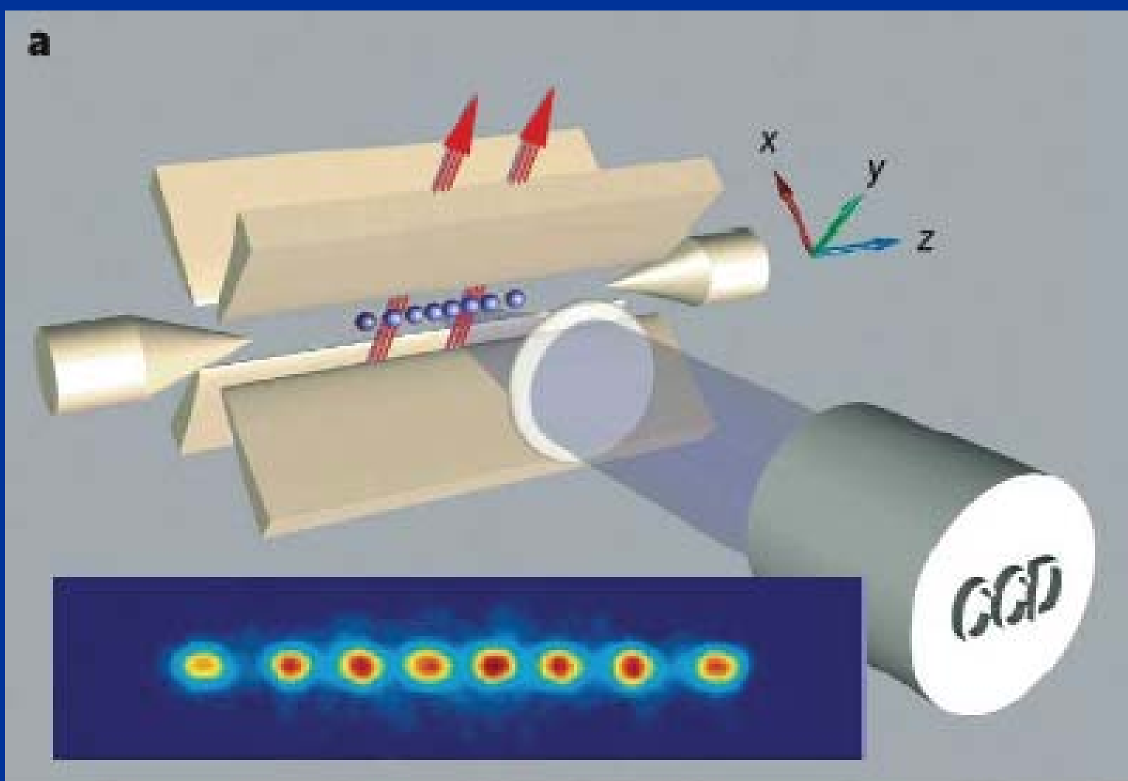


Trapped ions

Entangled states of trapped atomic ions

Rainer Blatt[1,2] & David Wineland[3]

NATURE|Vol 453|19 June 2008|doi:10.1038/nature07125



Noise on the electrodes: 1/f noise

Disspative bath: laser cooling

Polar molecules

A High Phase-Space-Density Gas of Polar Molecules

K.-K. Ni,[1]* S. Ospelkaus,[1]* M. H. G. de Miranda,[1] A. Pe'er,[1] B. Neyenhuis,[1] J. J. Zirbel,[1] S. Kotochigova,[2] P. S. Julienne,[3] D. S. Jin,[1]† J. Ye[1]†

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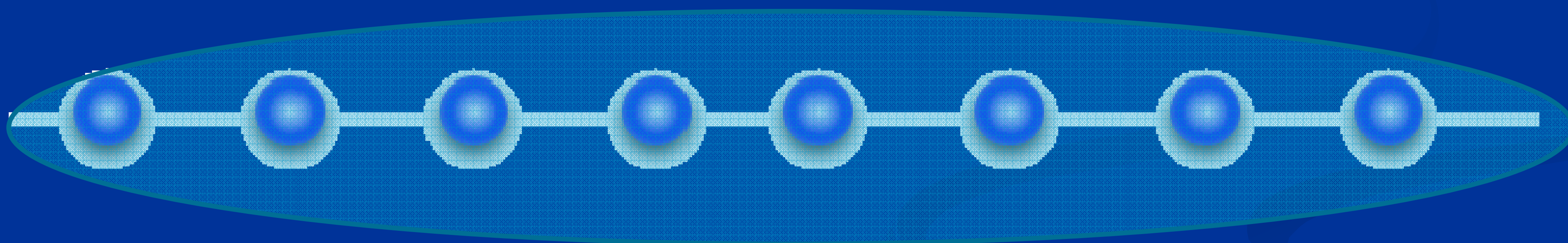
2008



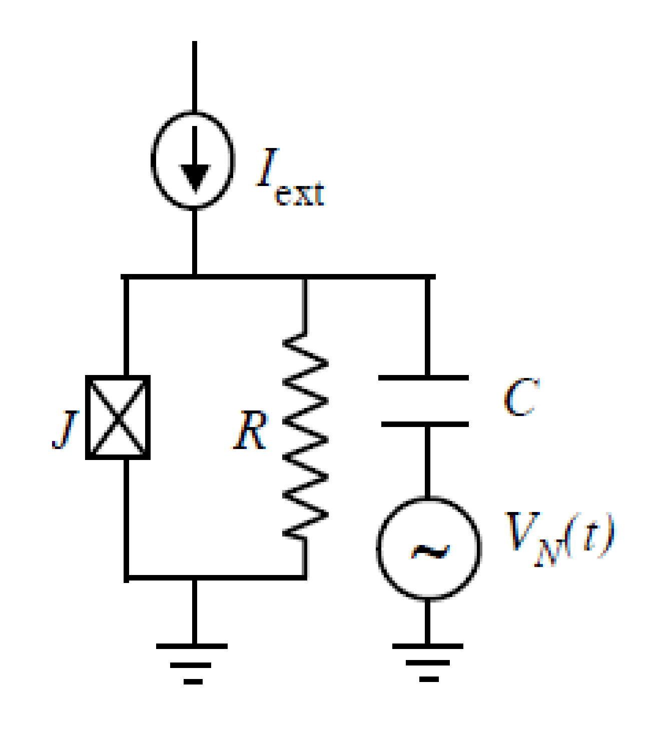
Noise: EM waves

Bath ? : [immersion in a condensate]

Questions

- Time dependent noise: out of equilibrium bath
- Does the bath acts as a “simple” temperature ?
- Can critical states be preserved ?
- Can phase transitions be preserved ?
- Physical consequences of out of equ. Physics ?

Noisy Josephson junction



Offset charge: 1/f noise

$$V_N(t) = eN_0(t)/C.$$

$$\langle\, N(\omega)\, N^*(\omega)\, \rangle = F_0 / |\omega|$$

Resistance : ohmic bath

$$\frac{1}{2}c\ddot{\theta} + \eta\dot{\theta} = \zeta(t) + \frac{1}{2}\dot{N}_0(t).$$

$$c = \hbar C/2e^2$$

$$\eta = (1/2\pi)R_Q/R.$$

$$\langle \zeta^\star_\omega \zeta_\omega \rangle = \eta|\omega|$$

Equilibrium bath (T → 0)

No dissipation for N : No FDT theorem !

$$\langle \cos\left[\theta_{cl}(t) - \theta_{cl}(0)\right]\rangle \sim t^{-(1+F_0/\eta)/\pi\eta}$$

Noise keep a scale invariant state !

Josephson coupling (Keldysh + duality)

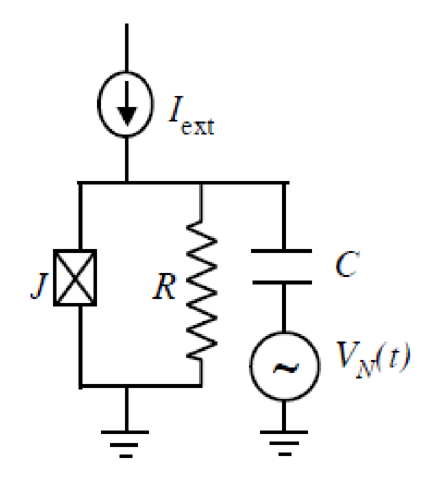
- Weak coupling ($E_J \ll E_C$)

Josephson coupling term : $\cos(\theta)$

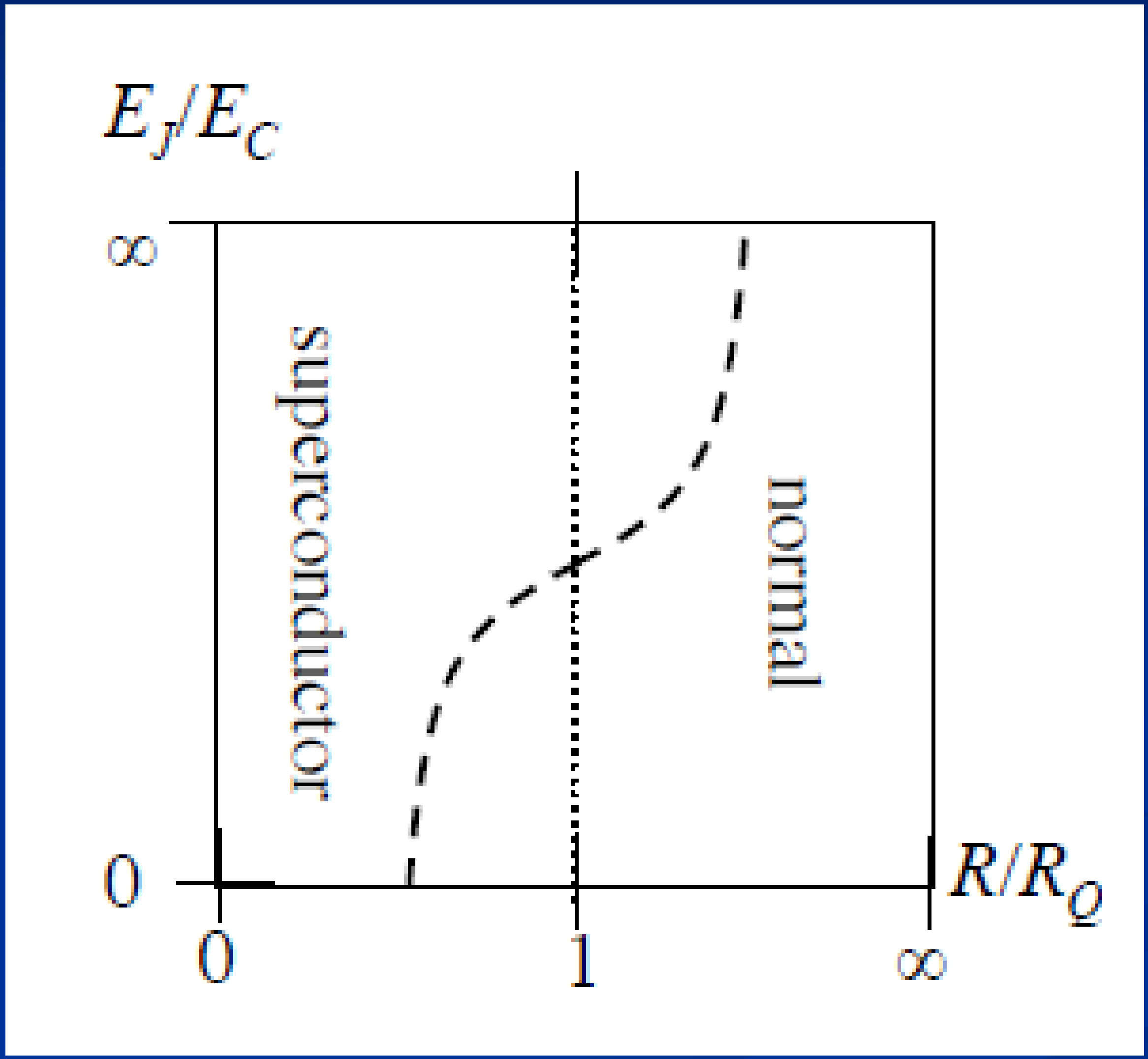
Relevant when $1- (1+F_0/´)/2\pi´ > 0$

- Strong coupling ($E_C \ll E_J$)

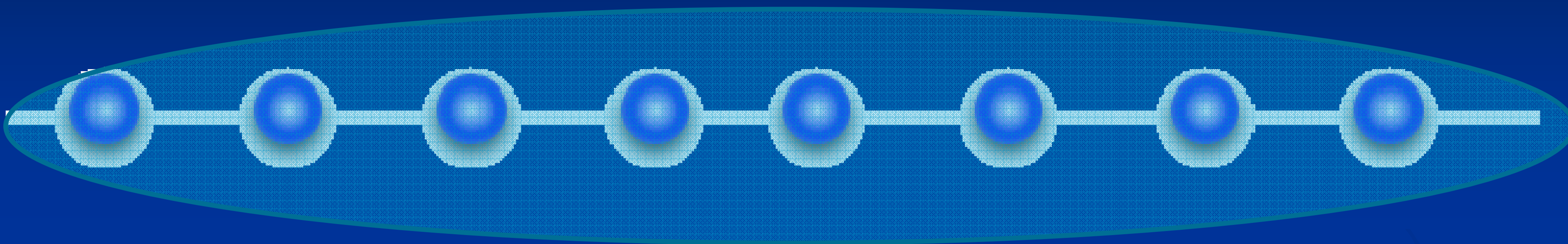
Phase slip term: $\cos(\phi)$



Phase transition with 1/f noise



One dimension chain of molecules/ions



Without noise: Luttinger liquid

$$H = \frac{\hbar}{2\pi}\int dx\left[\frac{uK}{\hbar^2}(\pi\Pi(x))^2 + \frac{u}{K}(\nabla\phi(x))^2\right]$$

$$\pi\Pi = \nabla\theta$$

$$\hat{O}_{DW} = \rho_0 \cos(2\pi\rho_0 x + 2\phi(x,t))$$

Powerlaw decay of correlations (K)

Noise

Long wavelength $-f(x,t)\pi^{-1}\partial_x\phi(x,t)$

$$F(q,\omega) = \langle f(q,\omega) f(-q,-\omega) \rangle$$

$$F(q,\omega) = F_0/|\omega|$$

- Dissipative bath needed   Time scale 1/´

- Limit $F_0 \to 0$, ´ $\to 0$, F_0/´ =Cste

Correlations

$$\langle \cos(2\phi_{cl}(x)) \cos(2\phi_{cl}(0)) \rangle \sim x^{-2K(1+\pi^{-2}F_0/\eta)}$$

Change of the exponent

Not just a shift of K; no duality K → 1/K

Phase correlations suppressed too

$$(1 + F_0/\eta)/2K$$

Response

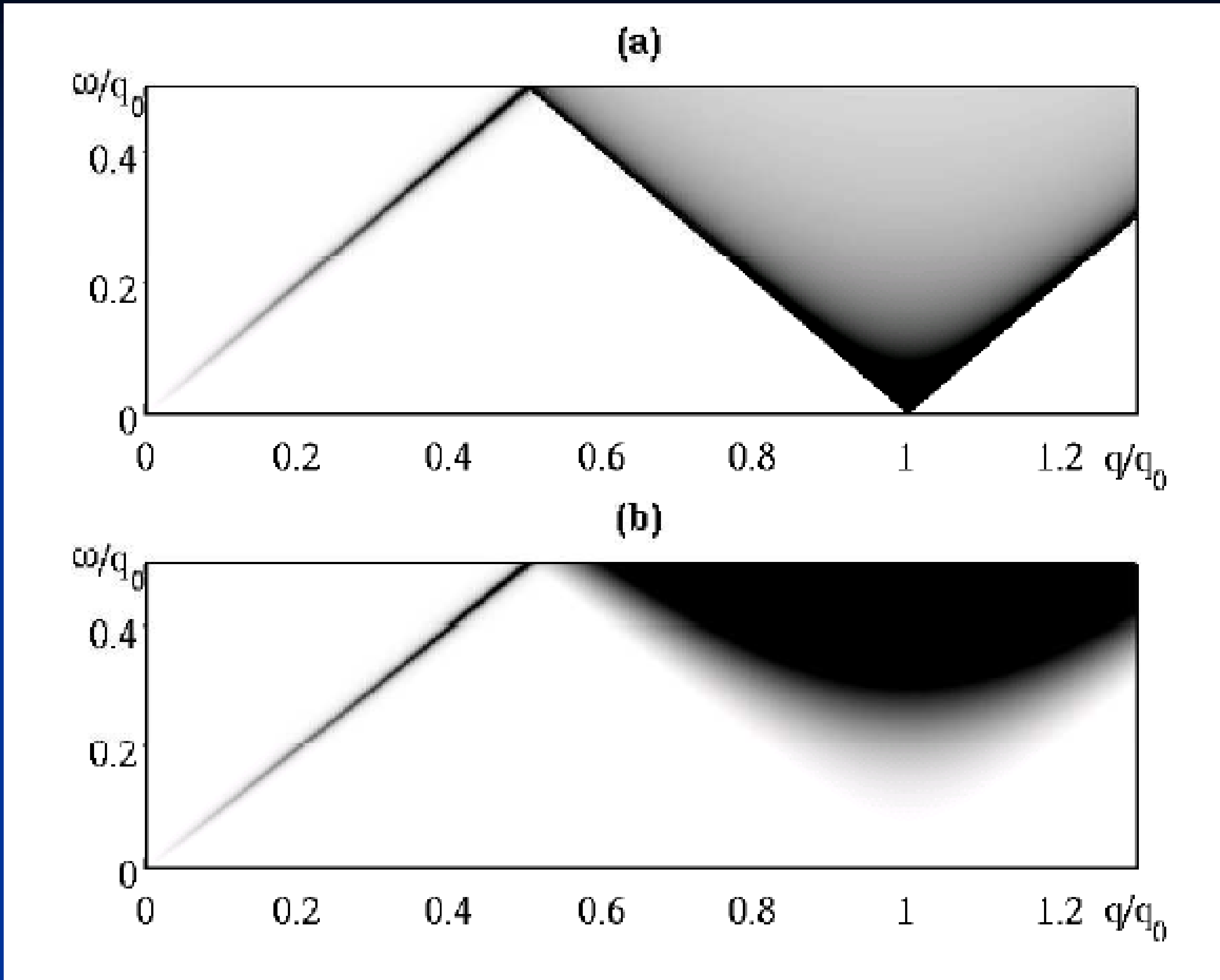
Bragg spectroscopy (coupling to density)

$$\chi''(q,\omega) \;=\; C\,(K,K_\star)\,(\omega^2-\delta q^2)^{K_\star-1}\Theta(\omega^2-\delta q^2)$$

$$C(K,K_\star) \;=\; \frac{1}{4\Gamma^2(K_\star)}\frac{\sin(\pi K)}{\sin(\pi K_\star)}$$

$\pm$ q =
q – $2\pi\ \rho_o$

$$K_\star \equiv K(1+\pi^{-2}F_0/\eta)$$



$$F_0/´ = 4\,\pi^2$$

Out of equilibrium

$$\chi''(q,\omega) \; = \; C\,(K,K_\star)\,(\omega^2 - \delta q^2)^{K_\star - 1}\Theta(\omega^2 - \delta q^2)$$

$$C(K,K_\star) \; = \; \frac{1}{4\Gamma^2(K_\star)}\frac{\sin(\pi K)}{\sin(\pi K_\star)}$$

$$K_\star \equiv K(1 + \pi^{-2}F_0/\eta)$$

Im $\chi < 0$!! ; negative energy dissipated !

1/f noise plays the role of a pump

Non-equ. phase transitions

Periodic potential (Mott transition)

$$S_g = g \int dx dt \ \cos(2\phi(x,t))$$

Equilibrium : transition at $K_c = 2$

Out of equilibrium:

$$F_0/\eta < \pi^2(2K^{-1} - 1)$$

Conclusions

- Quantum systems in presence of 1/f noise
- Noise does not act a simple temperature
- Modification of the exponents
- Phase transitions in the presence of an out of equilibrium noise
- Experimental test in trapped ions