Immediate recapture in the trapping-detrapping process of a single charge carrier

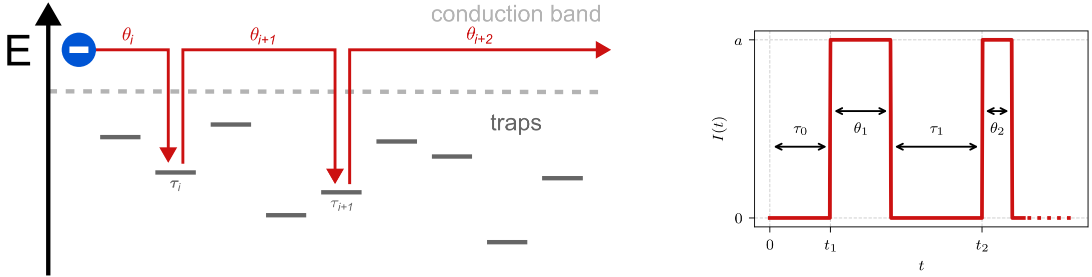
Aleksejus Kononovicius*, Bronislovas Kaulakys

Institute of Theoretical Physics and Astronomy, Vilnius University

aleksejus.kononovicius@tfai.vu.lt

kononovicius.lt, rf.mokslasplius.lt

Trapping-detrapping process



Signal with non-overlapping rectangular pulses is observed.

Power spectral density formula

In general for non-overlapping pulses:

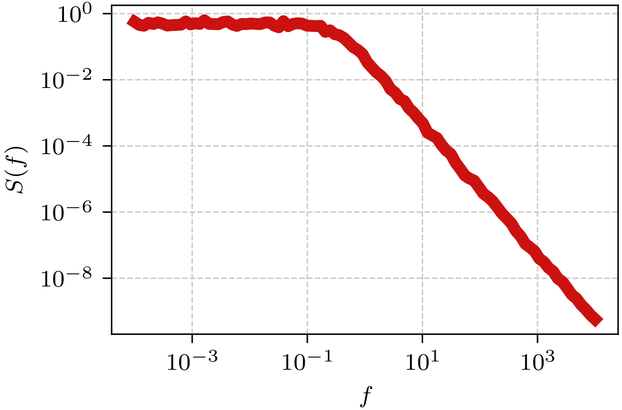
$$S(f) = \lim_{T \to \infty} \left\langle \frac{2}{T} \left| \int_0^T I(t)\, e^{-2\pi \mathrm{i} f t}\, \mathrm{d}t \right|^2 \right\rangle = \lim_{T \to \infty} \left\langle \frac{2}{T} \left| \sum_k e^{-2\pi \mathrm{i} f t_k} F_k(f) \right|^2 \right\rangle .$$

For rectangular pulses:

$$F_k(f) = \frac{\mathrm{i} a}{2\pi f} \left(e^{-2\pi \mathrm{i} f \theta_k} - 1 \right), \qquad \boxed{S(f) = \frac{a^2 \bar{\nu}}{\pi^2 f^2} \operatorname{Re}\left[\frac{(1 - \chi_\theta(f))(1 - \chi_\tau(f))}{1 - \chi_\theta(f)\chi_\tau(f)} \right]}.$$

[Kononovicius & Kaulakys (PRE, 2023)]

Lorentzian PSD



- Identical Poissonian traps:

$$\tau_i \sim \mathrm{Exp}\left(\gamma_\tau\right).$$

- Uniformly distributed traps:

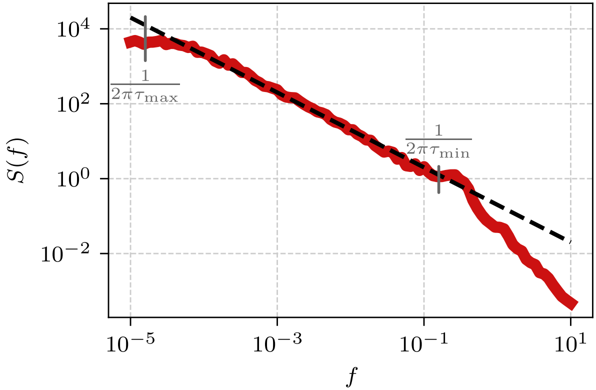
$$\theta_i \sim \mathrm{Exp}\left(\gamma_\theta\right).$$

Power-law trapping and detrapping time distributions

$$\tau_i \sim \text{Pareto}\left(\alpha \approx 1, \tau_{\text{min}}, \tau_{\text{max}}\right),$$

$$\theta_i \sim \text{Pareto}\left(\alpha \approx 1, \theta_{\text{min}}, \theta_{\text{max}}\right),$$

yields $S(f) \propto 1/f$.



[Kononovicius & Kaulakys (PRE, 2023)]

Heterogeneous detrapping process

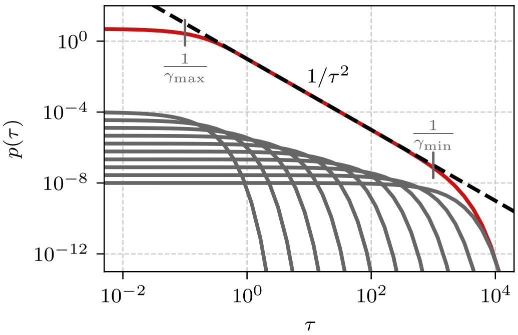
If traps are heterogeneous:

$$\gamma_i \sim \mathcal{U}\left(\gamma_{\text{min}}, \gamma_{\text{max}}\right),$$

$$\tau_i \sim \text{Exp}\left(\gamma_i\right),$$

then,

$$p(\tau) \propto \int_{\gamma_{\text{min}}}^{\gamma_{\text{max}}} \gamma_i \exp\left(-\gamma_i \tau\right) \mathrm{d}\,\gamma \propto \frac{1}{\tau^2}.$$



[Kononovicius & Kaulakys (arXiv:2306.07009)]

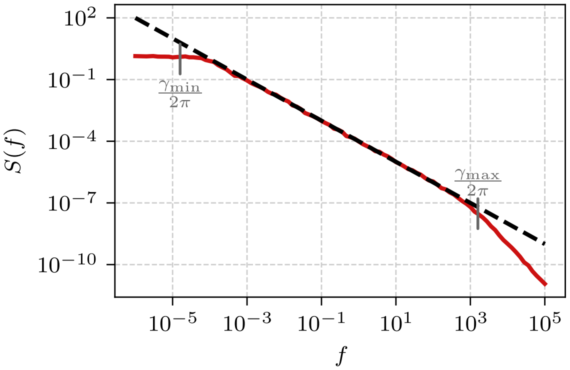
Homogeneous trapping process

Let traps be distributed uniformly:

$$\theta_i \sim \mathrm{Exp}\left(\gamma_\theta\right),$$

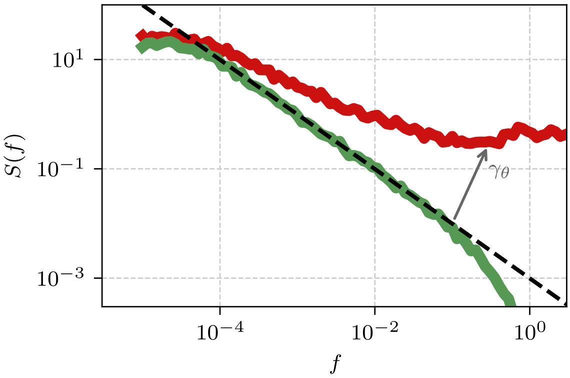
then, for long pulses ($\gamma_\theta \ll \gamma_{\max}$),

$$S(f) \approx \frac{a^2 \bar{\nu}}{\gamma_{\max}} \cdot \frac{1}{f}.$$



[Kononovicius & Kaulakys (arXiv:2306.07009)]

What if pulses are short?



Instead of

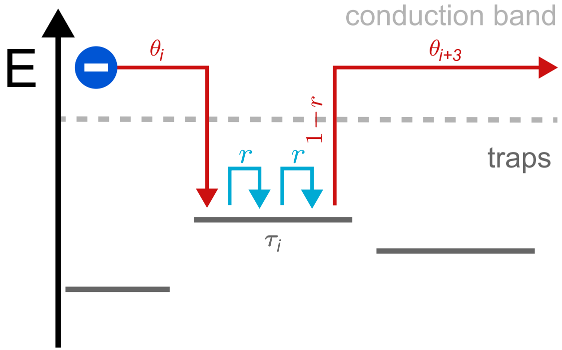
$$S(f) \propto \frac{1}{f}$$

we observe

$$S(f) \propto \frac{1}{f \cdot \ln(f)}.$$

[Kononovicius & Kaulakys (PRE, 2023)]

Let us allow $\theta = 0$ with probability r



Time spent trapped (assuming k_i recaptures):

$$\tau_i^{(k_i)} \sim \sum^{k_i} \text{Exp}(\gamma_i) \sim \text{Erlang}(\gamma_i, k_i).$$

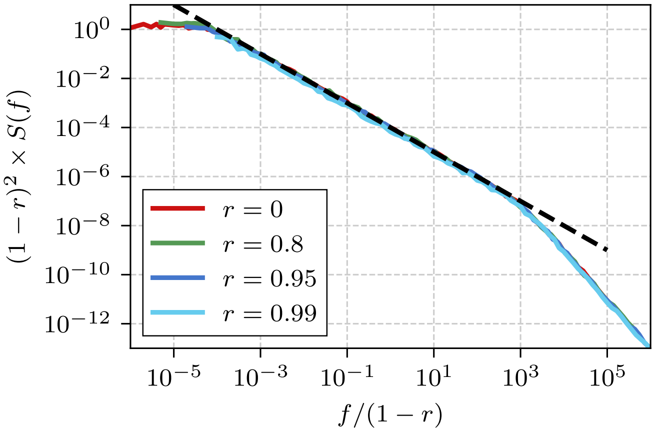
Number of recaptures:

$$k_i \sim \text{Geom}(r).$$

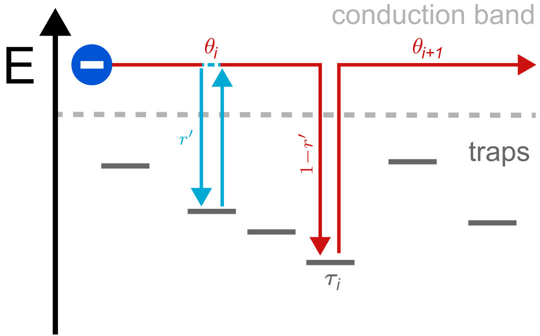
Then the time spent trapped:

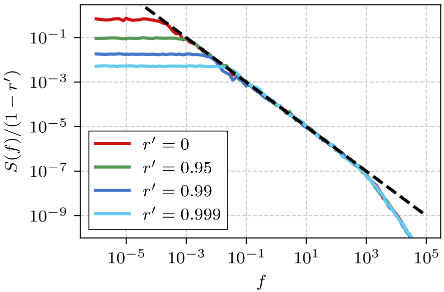
$$\tau_i \sim \text{Exp}\left[(1-r)\gamma_i\right].$$

Recapture mechanism still results in $1/f$ noise



Consider a mirror mechanism: immediate ejection





As

$$\theta_i \sim \mathrm{Exp}\left[(1 - r')\,\gamma_\theta\right],$$

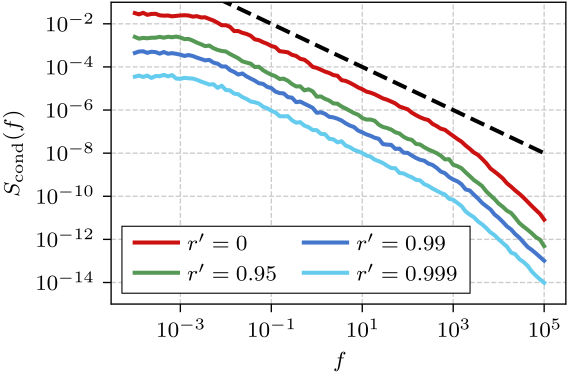
r' should not matter.

Low-frequency cutoff

Is caused by a **decreasing number of pulses** observed as $r' \to 1$.

Can also be caused by

- large γ_{min},
- too many pulses,
- $\ln(f)$ term.



[Leibovich & Barkai (PRE, 2017)], [Kononovicius & Kaulakys (PRE, 2023)] [Kononovicius & Kaulakys (arXiv:2306.07009)],

Thank you!

aleksejus.kononovicius@tfai.vu.lt
kononovicius.lt, rf.mokslasplius.lt