Synchronization and coherence in biological systems

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Plus ratio quam vis

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Research: biological applications of

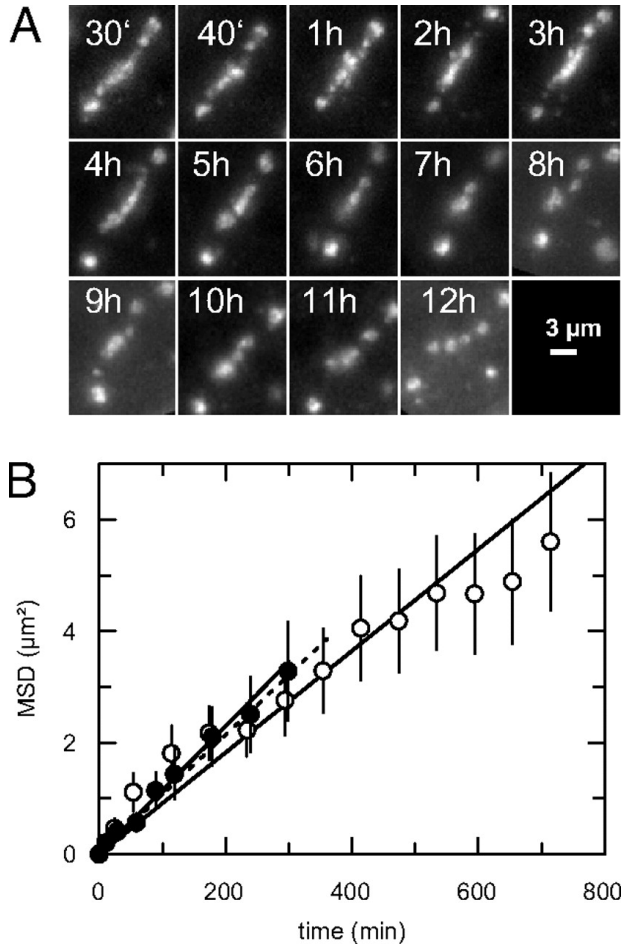
- Stochastic dynamic systems
- Response to stable (Lévy-like) noises
- Fine tuning by noise (stochastic resonance, resonant activation, synchronous response)
- CTRW asymptotics, anomalous and **paradoxical** diffusion

Motivation

Lévy noises (in general, non-Gaussian!) and **Lévy noise**-driven nonequilibrium systems manifest unusual physical properties; have been addressed in various realms...

- gating kinetics of biological channels
- transmission of biochemical signals in cells
- self-diffusion in micelle systems
- exciton and charge transport in (random) polymers under conformational motion
- incoherent atomic radiation trapping
- motion in optimal search strategies
- **transport in dendrites**

Signaling transport: movement of radiation-induced DSBs



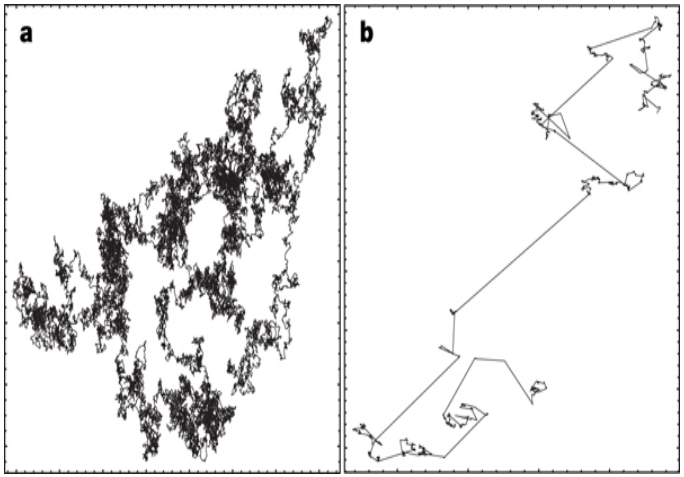
B. Jacob, J. Splintera, M. Durante, G. Taucher-Scholz, PNAS, **106** 3172 (2009)

E. Gudowska-Nowak et al. , Eur. Phys. J. E **30** 317 (2009)

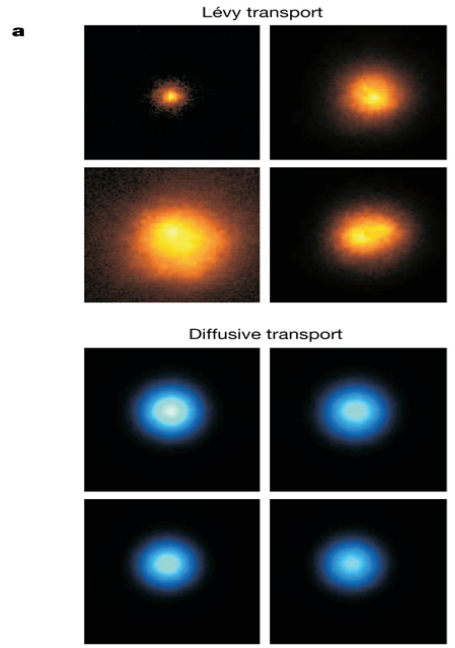
Light transmission in polidispersive media...

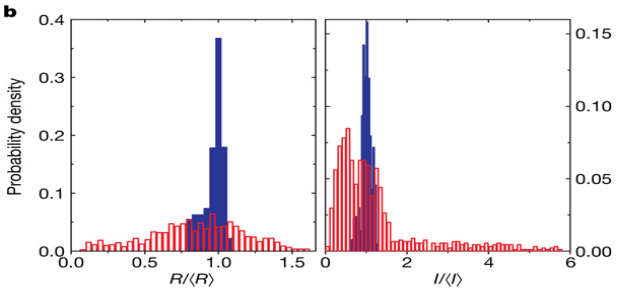
$$\left\langle x^2(t) \right\rangle \propto t^{\gamma}$$

Wiersma et al., *Nature*, **453**, 494, (2008)

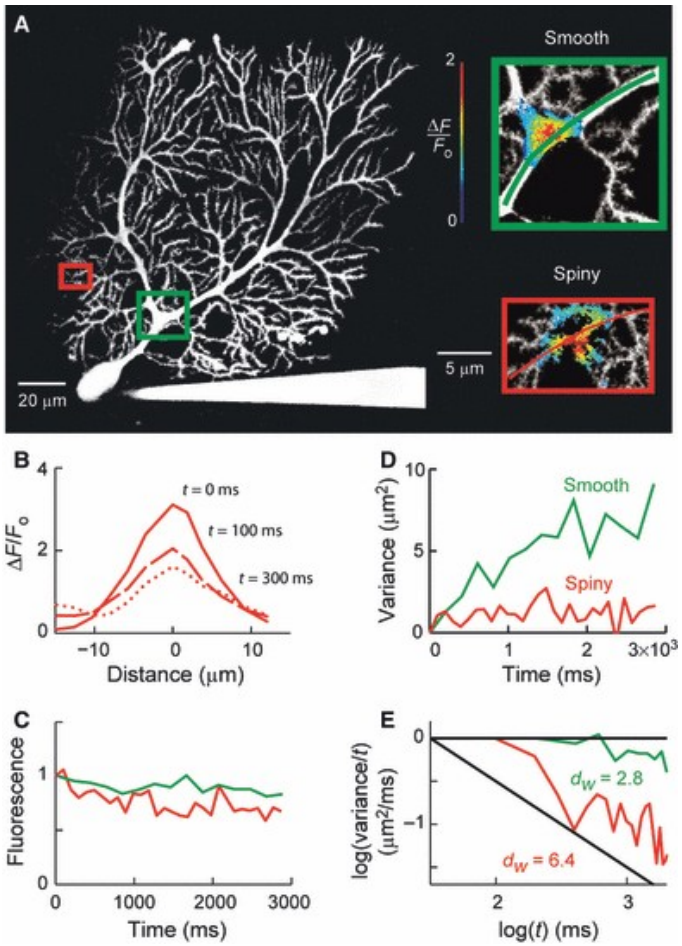


Trajectories: Wiener process (a) and Lévy walk (b) ($p(x) \propto x^{-(1+\alpha)}, \alpha < 2$)





Anomalous transport in crowded environments



F. Santamaria et al. , *Eur. J. Neurosci.* **34** 561-568 (2011)

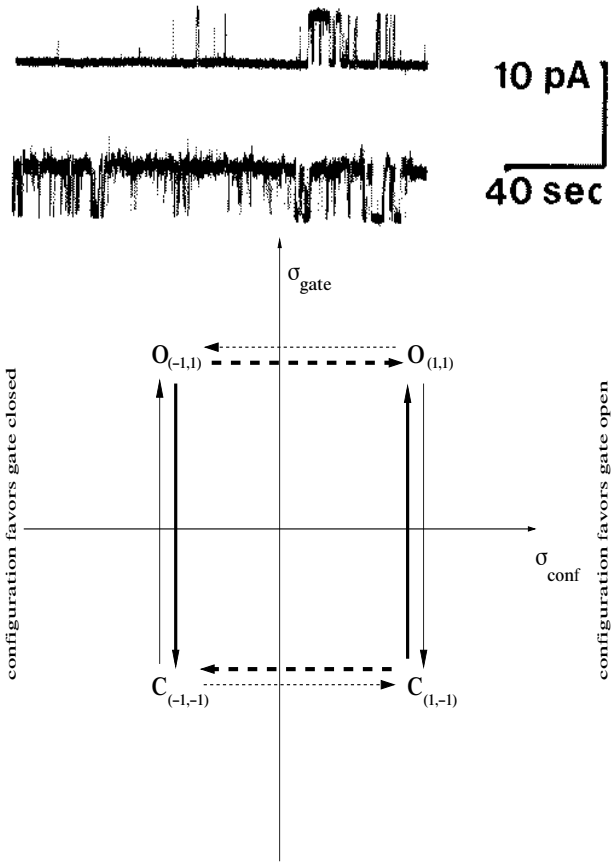
Motion on rough surfaces

- energy distribution
  $\Pi(E) = E_0^{-1} \exp(-E/E_0)$
- reaction/escape times

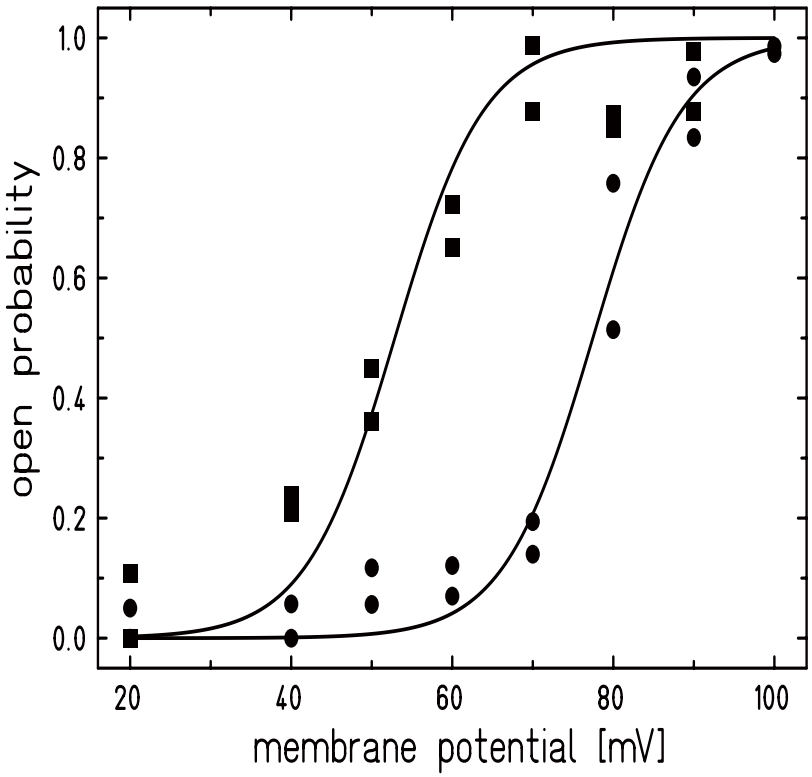
$$\tau = \tau_0 \exp(E/k_B T)$$

- $\Pi(E)dE = g(\tau)d\tau \Rightarrow g(\tau) = \frac{k_B T}{E_0} \frac{\tau_0^\mu}{\tau^{1+\mu}}, \mu = k_B T/E_0$

Effect of memory and dynamic hysteresis

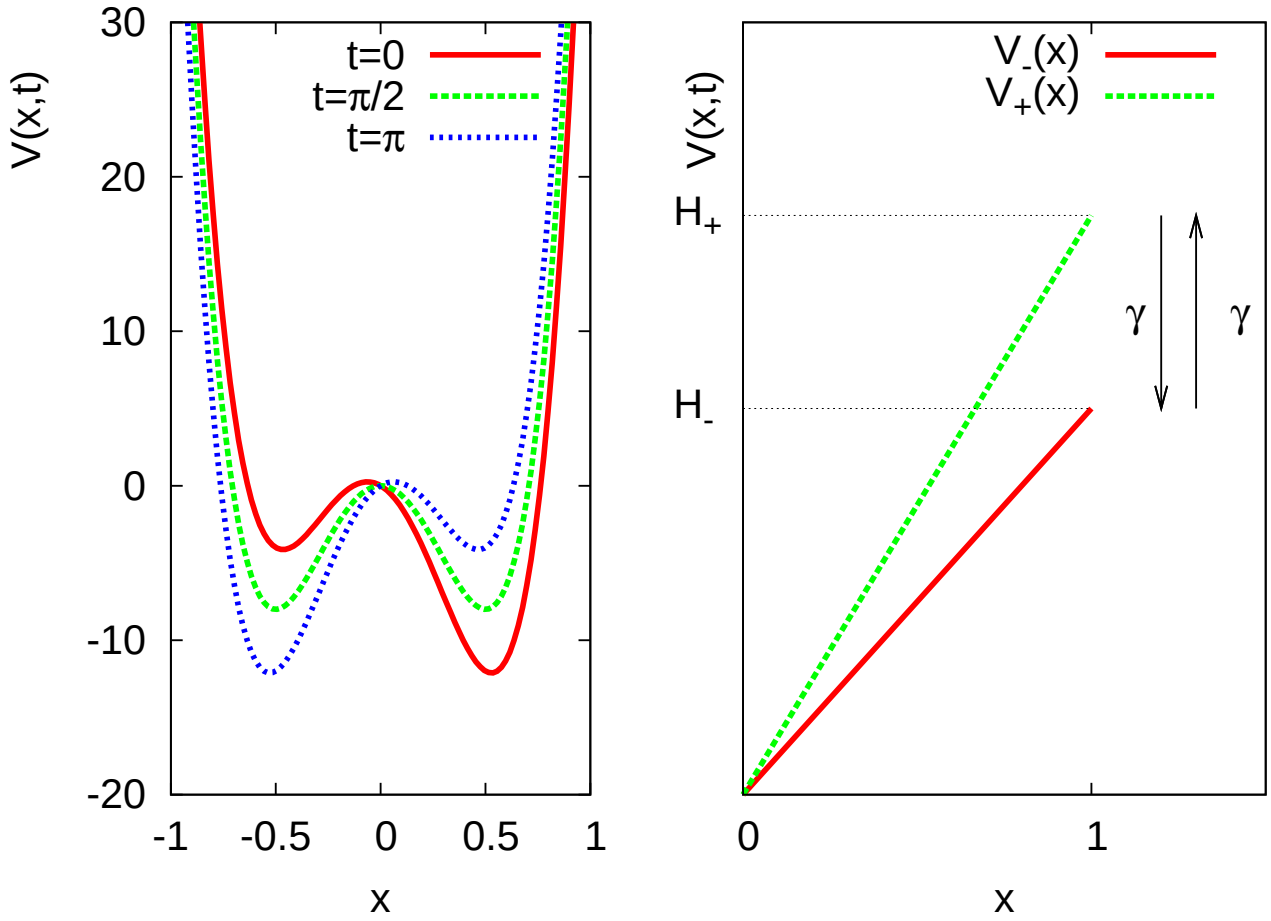


Response to periodic voltage $V(t)$



Measure of synchrononization stochastic resonance
Detection of sub-threshold signals

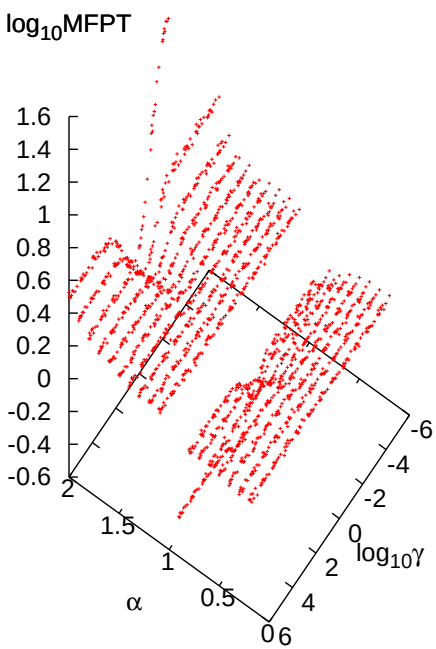
Stochastic resonance – two-state (on-off) models

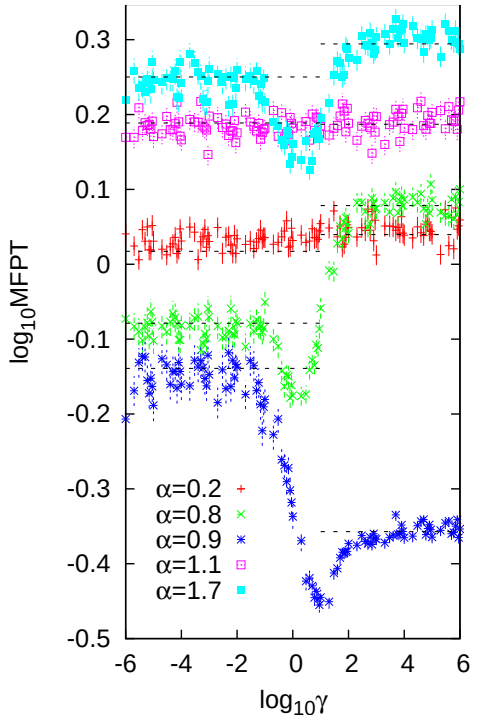


$$V(x,t) = -\frac{a}{2}x^2 + \frac{b}{4}x^4 + A_0 x \cos\Omega t \quad \text{with} \quad a = 128,\ b = 512,\ A_0 = 8.$$

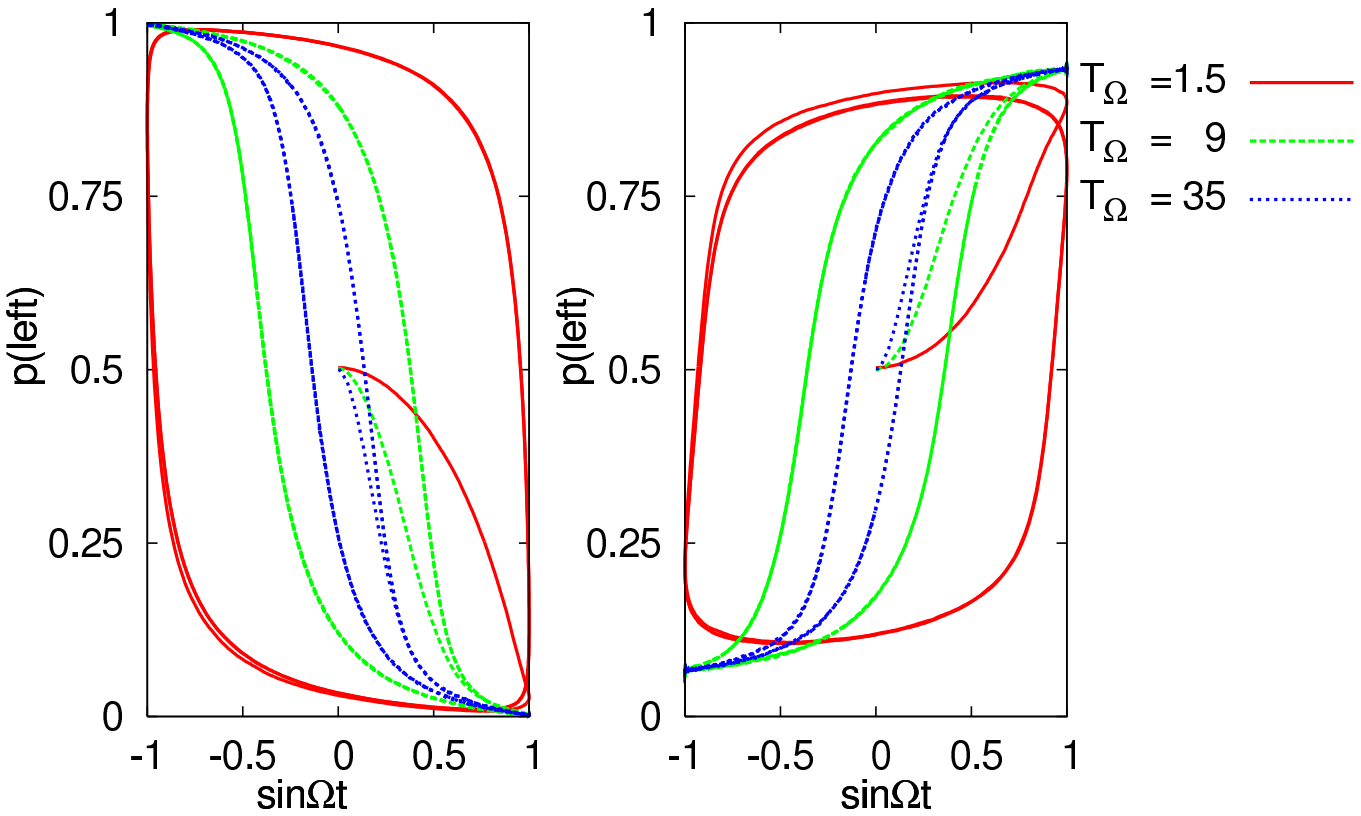
Resonant activation: fine tuning to noise

Noise-induced shortest transition time, most effective kinetics





Dynamical hysteresis – periodically modulated noisy input



$$V(x) = \frac{x^4}{4} \text{ and } \beta = \beta_{\max} \sin[\Omega t] = \beta_{\max} \sin\left[\frac{2\pi}{T_\Omega} t\right].$$

Anomalous diffusion as a CTRW asymptotics

Power law jump length distribution ($0 < \alpha \leqslant 2$)

$$w(x) \propto |x|^{-(1+\alpha)}.$$

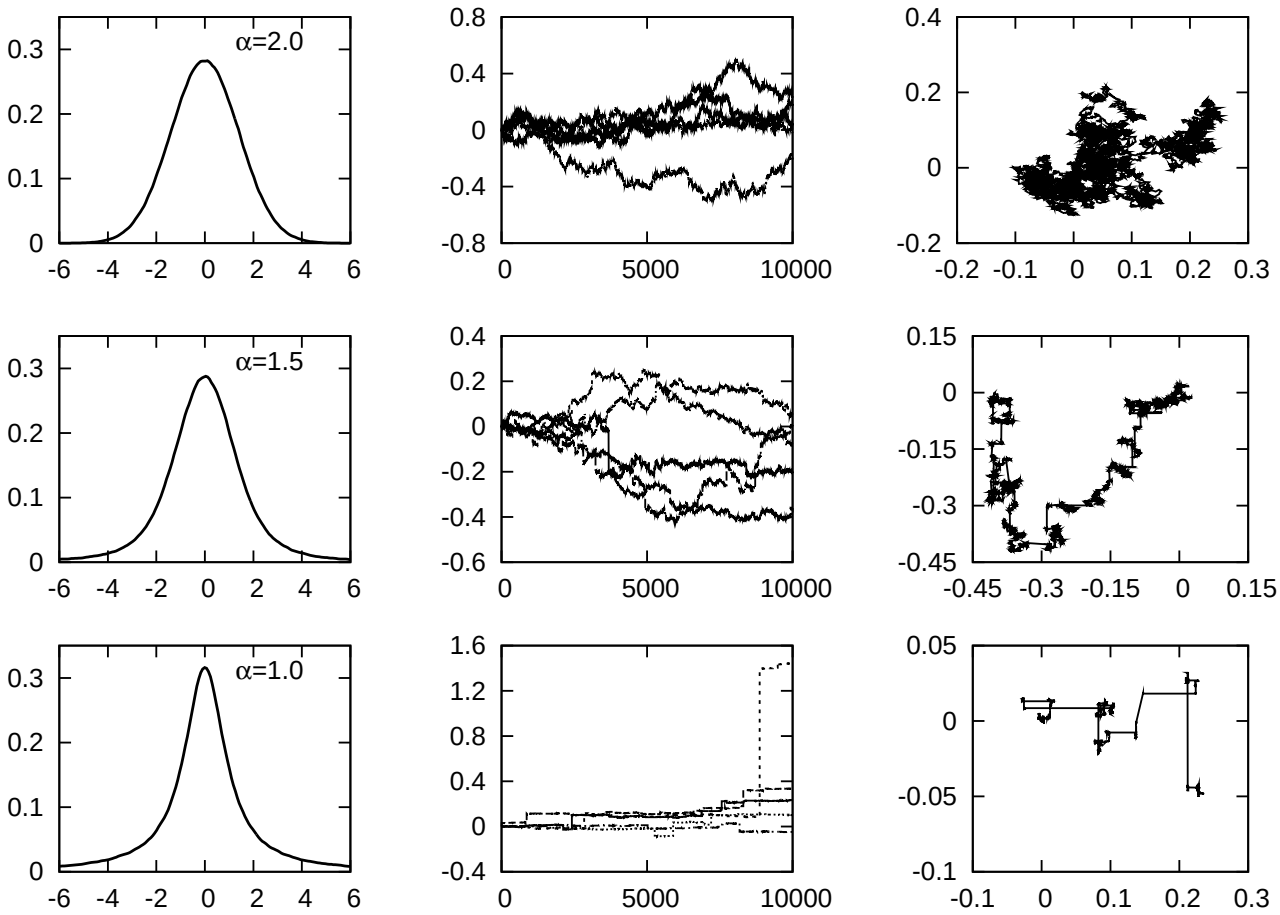
Power law waiting time distribution ($0 < \nu \leqslant 1$)

$$\psi(t) \propto t^{-(1+\nu)}.$$

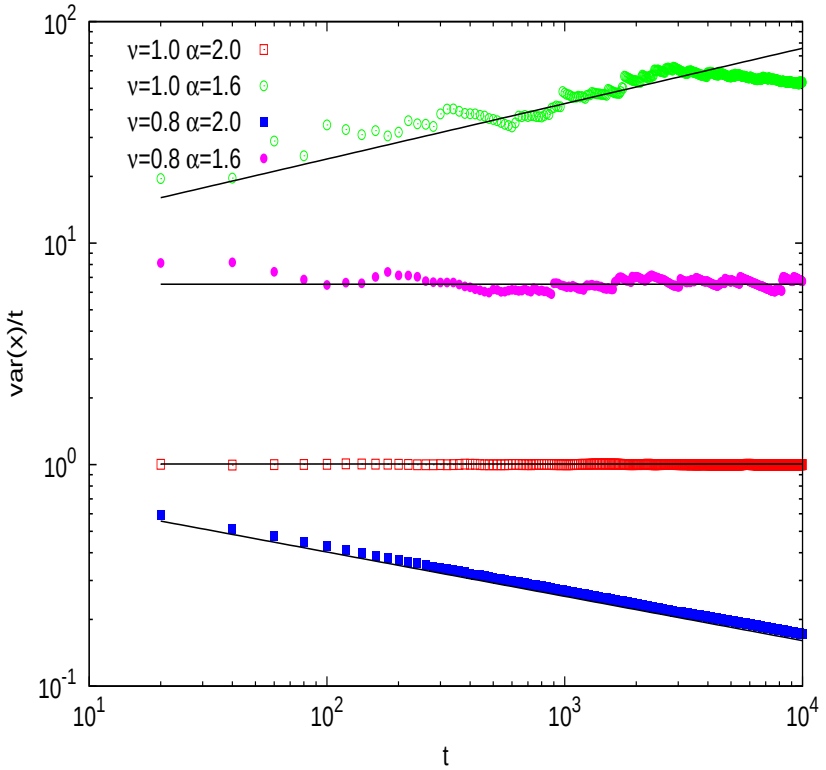
$X_N = \sum_i^N \Delta x_i \propto N^{1/\alpha}$ and $T_N = \sum_i^N \Delta t_i \propto N^{1/\nu}$

$X(t) \propto t^{\nu/\alpha}$ and $p(x,t) = t^{-\nu/\alpha} p(xt^{-\nu/\alpha})$

Anomalous diffusion – trajectories



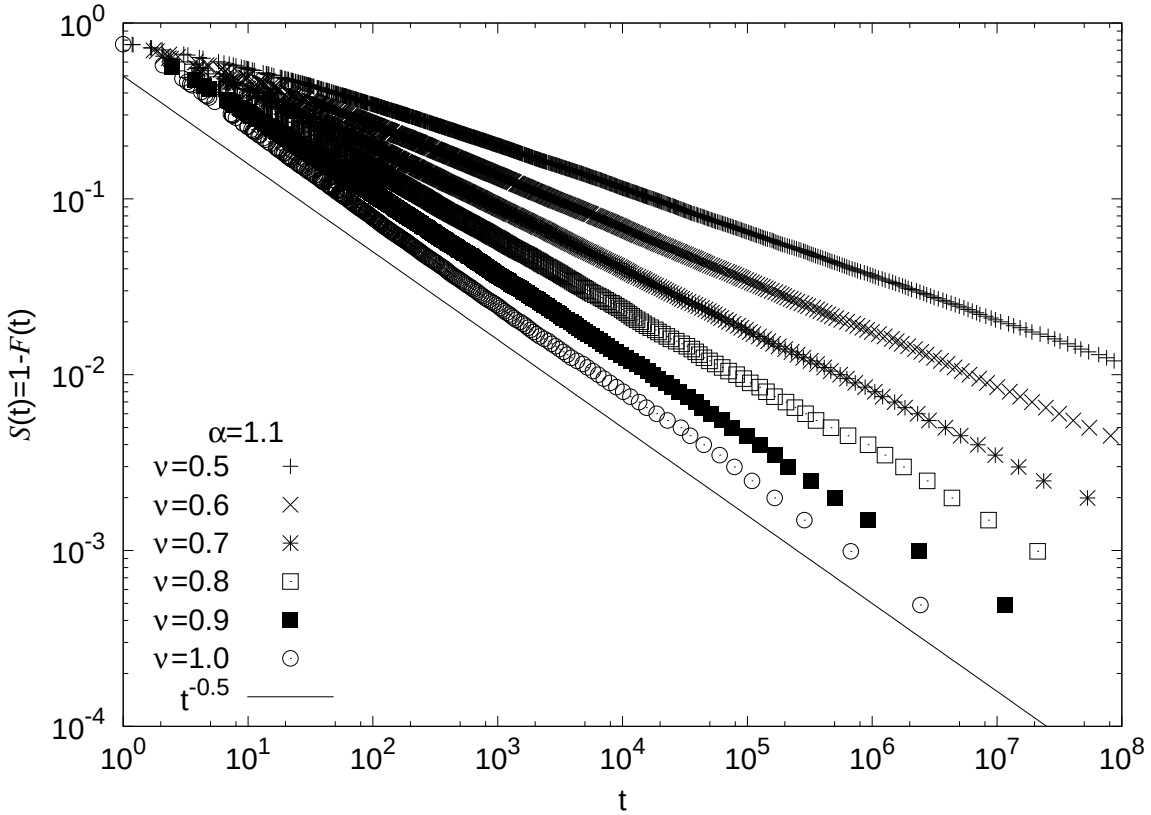
Anomalous looks normal $\nu/\alpha = 1/2$



Analysis of the mean-squared displacement (MSD) is insufficient to discriminate between normal and anomalous diffusion !

$$var(x)/t \propto t^{2\nu/\alpha-1}$$

Relaxation properties: Survival probability



B. Dybiec, J. Stat. Mech. P08025 (2009)

B. Dybiec, E. Gudowska-Nowak, Chaos, **20**, 043129 (2010)

$$S(t) = 1 - F(t) \propto t^b$$

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$b = -(0.54 \pm 0.01)\nu + (0.03 \pm 0.03)$
no α-dependence

Summary

Conclusions

- Constructive effects of noises (synchronization, resonant response) are robust and can be observed for non-Gaussian noises – crucial for signal detection and analysis
- Subdiffusive dynamics may be **non-ergodic** - a challenge for data analysis as ensemble/time averages yield different results

- B. Dybiec, E. Gudowska-Nowak *Paradoxical diffusion* Phys. Rev E **80** 061122 (2009).
- B. Dybiec, E. Gudowska-Nowak *Anomalous diffusion and Sparre-Andersen scaling* Europhys. Lett. **88** 10003 (2009).
- B.Dybiec, E. Gudowska-Nowak *Subordinated diffusion and CTRW asymptotics* Chaos, **20** 043129 (2010).