Revisiting and Modeling Power-Law Distributions in Empirical Outage Data of Power Systems

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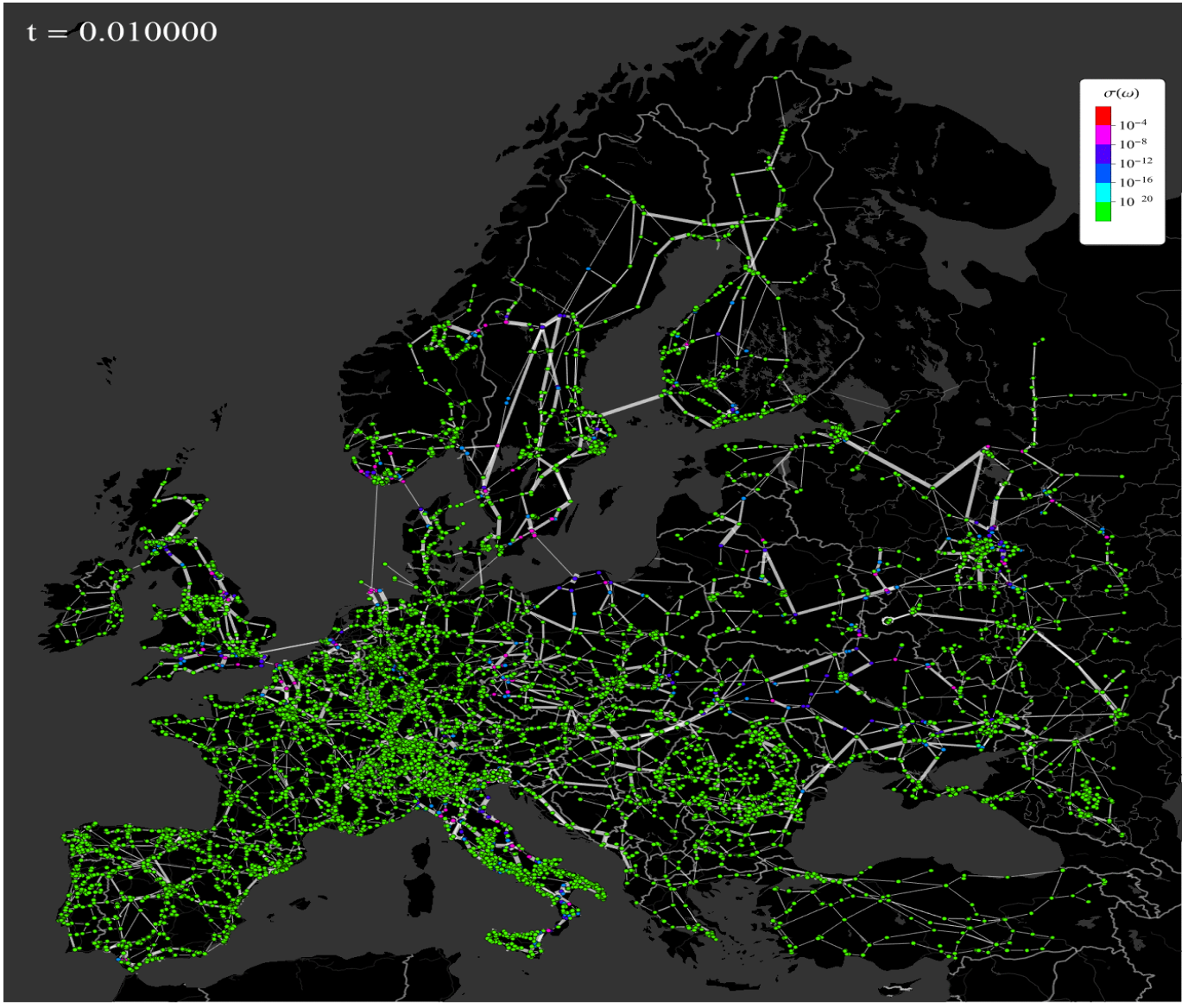

Blackout cascades
Known to exhibit PL distributions due to Self Organized Criticality (SOC)

Local frequency synchronizations of power-grids*:*
Deng and Ódor
Chaos 2024

We Guest Edit a Special issue on Synchronization Universality

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Outage durations with PL tails

Electrical outages ≠ Blackout cascades, still they show PL duration

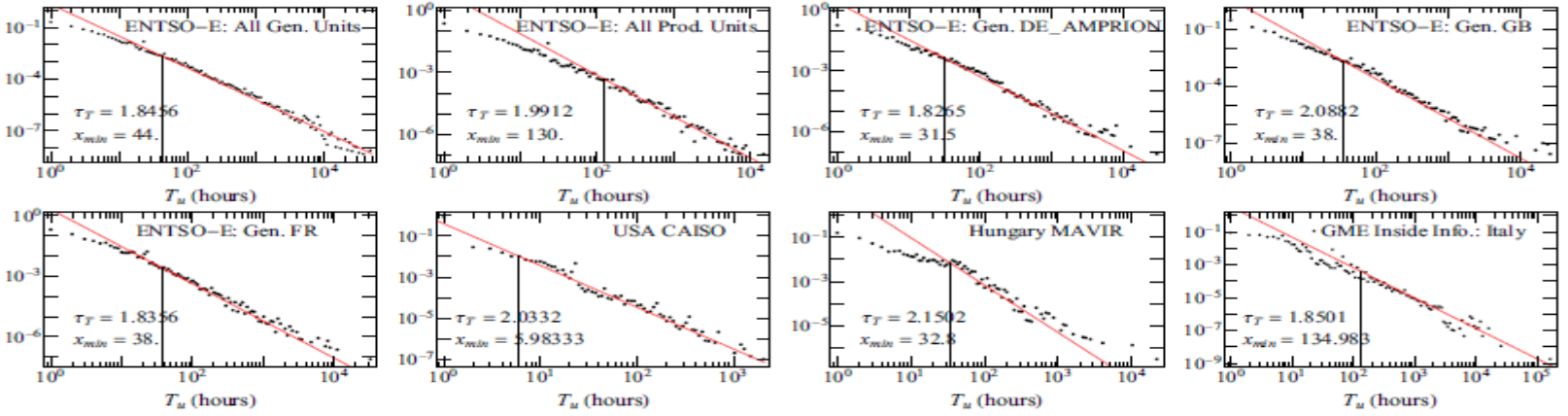

Figure 3: Probability distributions (black dots) of generation outages measured in terms of the unavailable duration.

Universality of the PL tail exponents for different power-grids

Generation	τ_E	τ_T	$\tau_{T_{\leq 24}}$	$\tau_{T_{>24}}$	Transmission	τ_T	$\tau_{T_{>24}}$
ENTSO-E All Gen.	1.86	1.85	1.43	1.86	BPA Transmission	1.85	1.72
ENTSO-E All Prod.	1.82	1.99	1.34	2.24	BPA Transformer	1.09	1.17
ENTSO-E DE_AMPRION	1.57	1.83	1.40	1.90	AESO	2.37	2.37
ENTSO-E GB	1.54	2.09	1.49	2.02	ENTSO-E All Transmission	1.54	1.54
ENTSO-E FR	1.62	1.84	1.50	1.84	ENTSO-E DE_50HZ-PL_CZ	1.07	1.01
USA CAISO	2.01	2.03	1.47	2.20	ENTSO-E NO-SE	1.12	1.12
Hungary MAVIR	1.34	2.15	1.08	2.14	ENTSO-E PT-ES	1.25	1.25
GME Italy	1.86	1.85	1.54	1.85	ENTSO-E SE-DK_CA	1.00	0.97

Table: Summary of various exponents obtained for energy outages (τ_E) and for outage duration (τ_T), with available τ_T for $T_u \leq 24$ hours and $T_u > 24$ hours also displayed.

Models

Hihghly
Optimized
Tolerance

- For outage events, if power-law tails emerge: SOC or HOT?

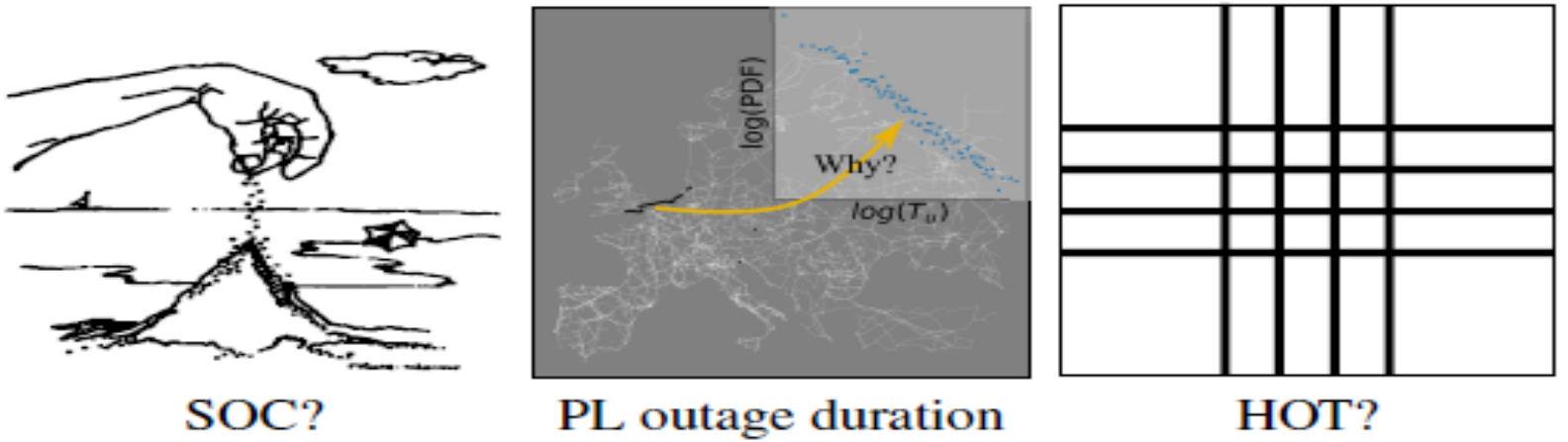

Figure 1: Power-law distribution for unavailable duration in outage events can be observed, but a consensus on the underlying mechanism has not yet been reached.

SOC: competition of supply and demand of repairing capacity

0: functioning units; **A**: faulty (active) ones; **B**: repairing teams.

$$0 \to A, \quad A + 0 \to A + A, \quad A + B \to 0 + B$$

Duration exponents fit well with that of a 2d critical Mannna universality class!!

SOC: 1/f spectra, HOT: constant

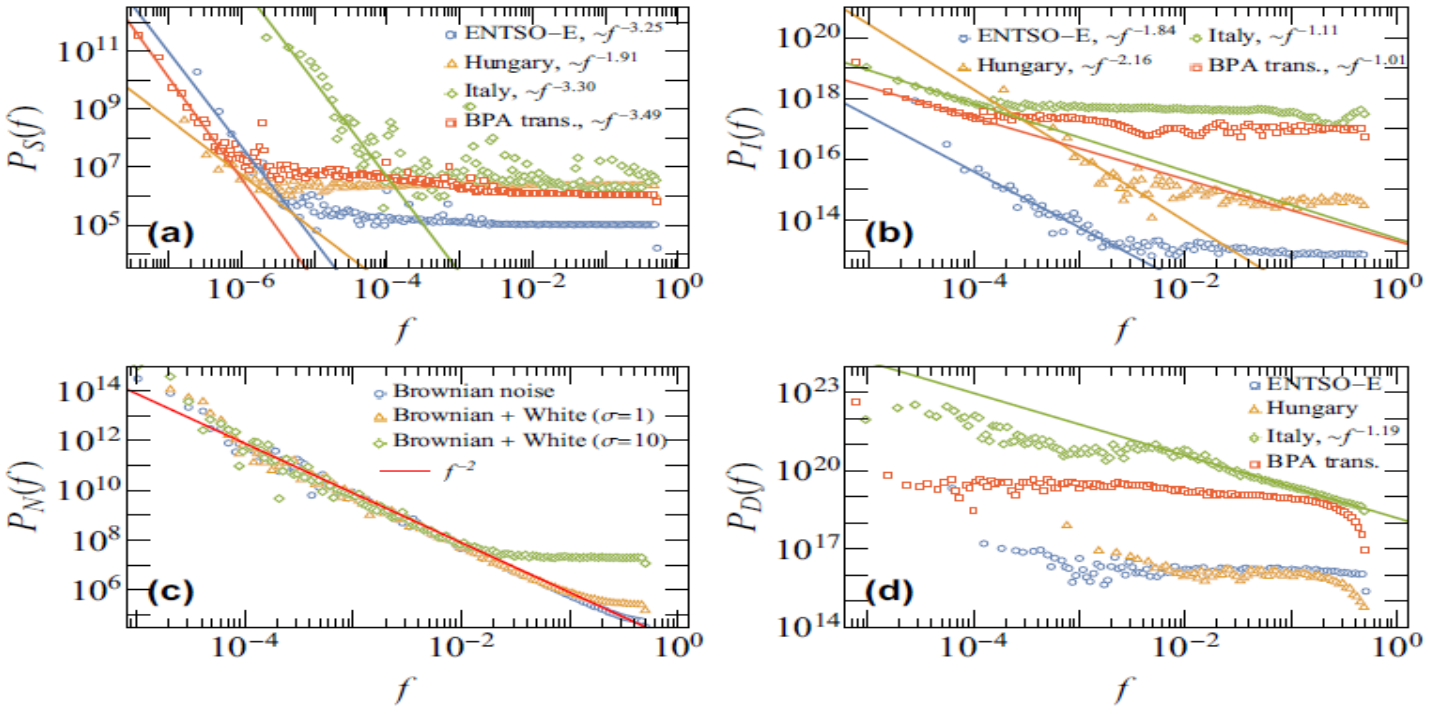

Figure 4: Power spectra of the time series for $S(t)$, $I(t)$, $N(t)$, and $D(t)$.

Power spectra suggest composite events:

SOC cascades + HOT like individual events