Understanding the complexity of frequency and phase angle fluctuations in power grids

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aleable.github.io

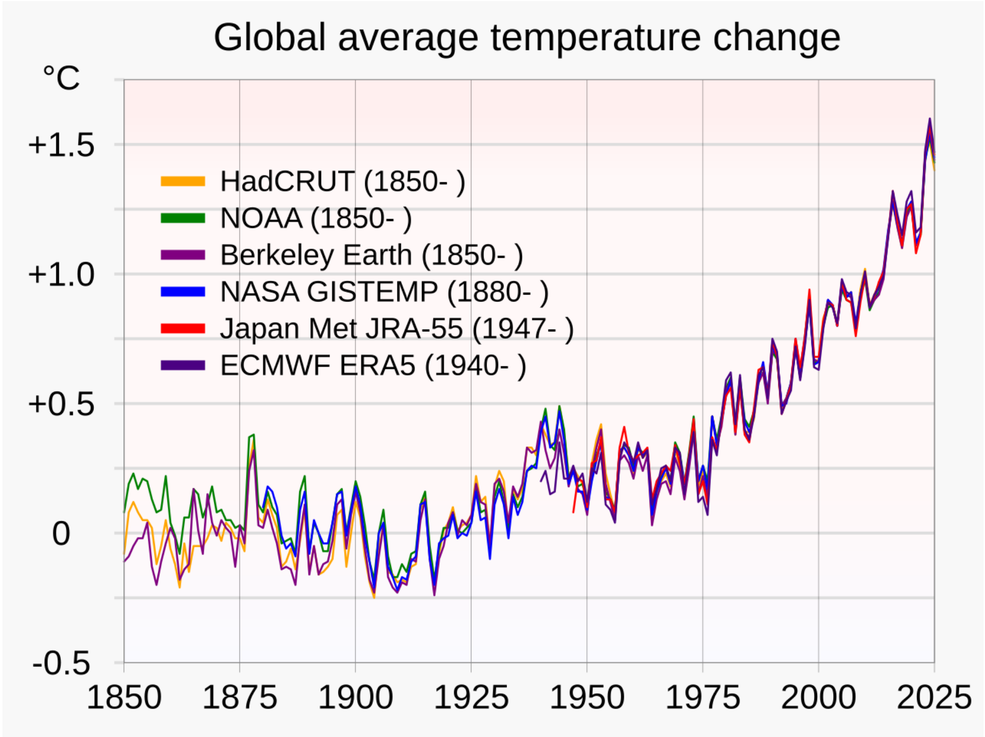
That is to say…

Statistical physics is a helpful tool for describing the emergent properties of power grids

Why does it matter?

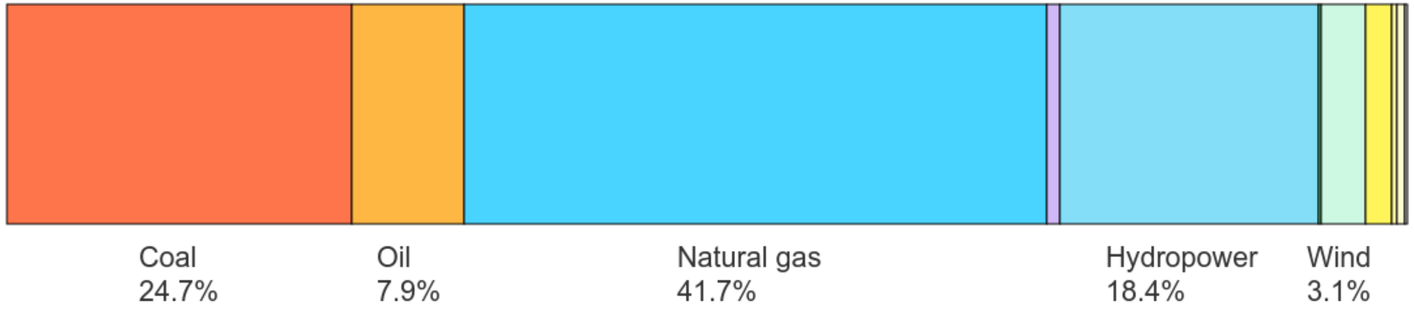
Increasing grid investment [helps] [...] holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C.

Adapted, United Nations Climate Change Conference, COP29 Global Energy Storage and Grids Pledge (2024)



https://climate.metoffice.cloud/temperature.html

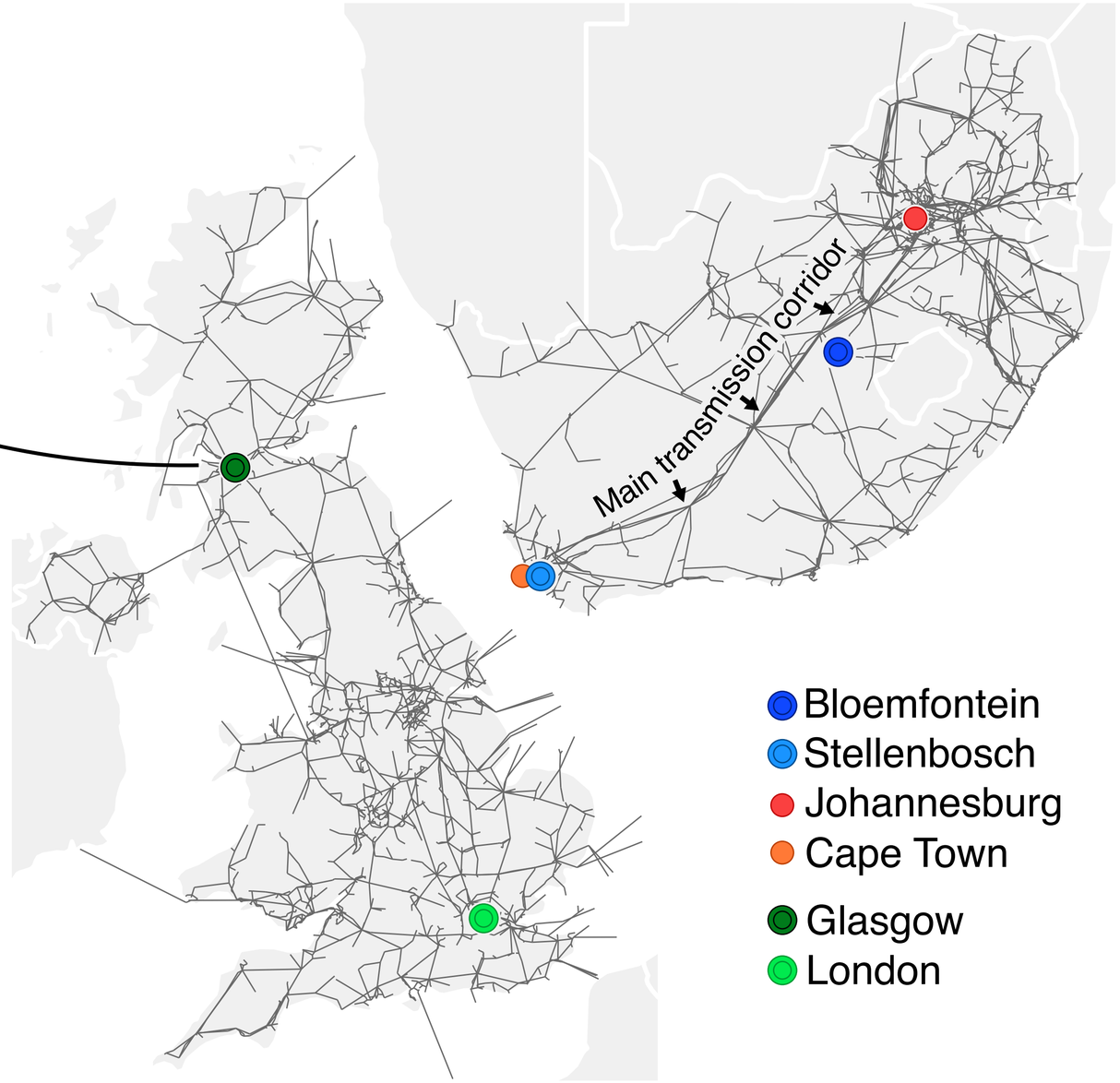
Electricity generation by source, Africa, 2023



Power grids (as a complex system)

$$\omega(t) = 2\pi\,(f(t) - f_{\mathrm{R}})$$

$$\theta_i(t) \in [0,2\pi)$$



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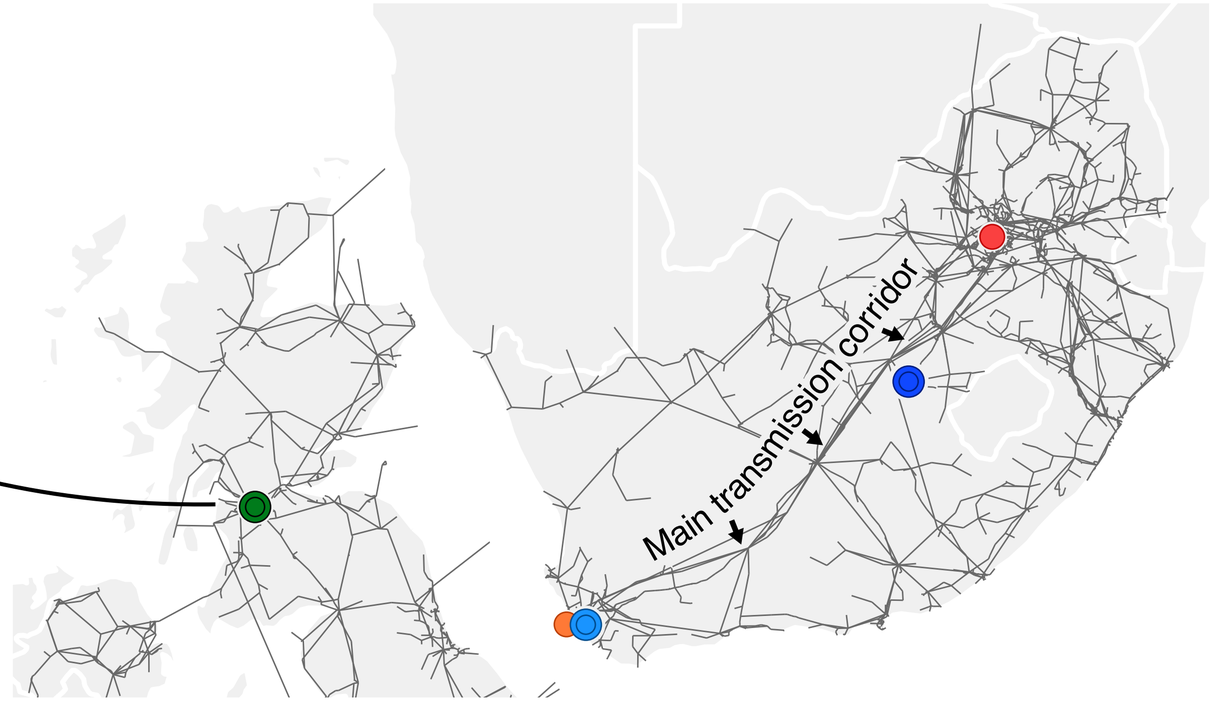
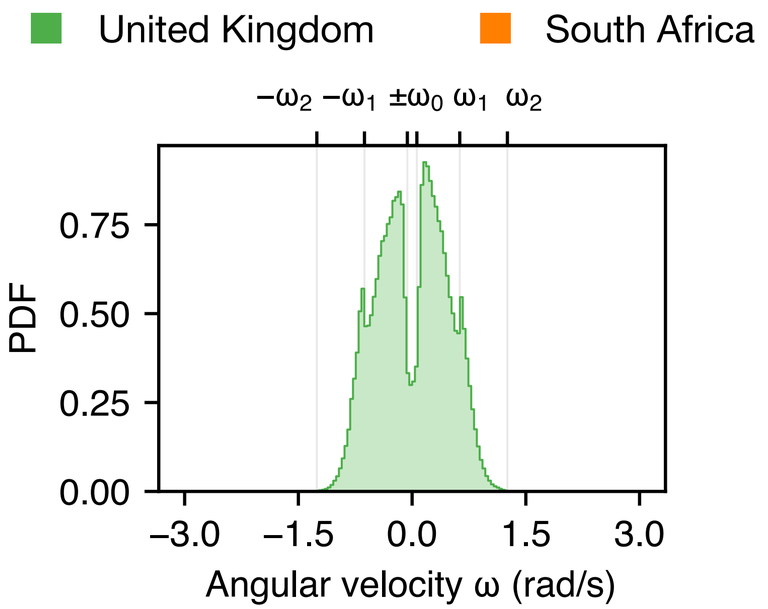
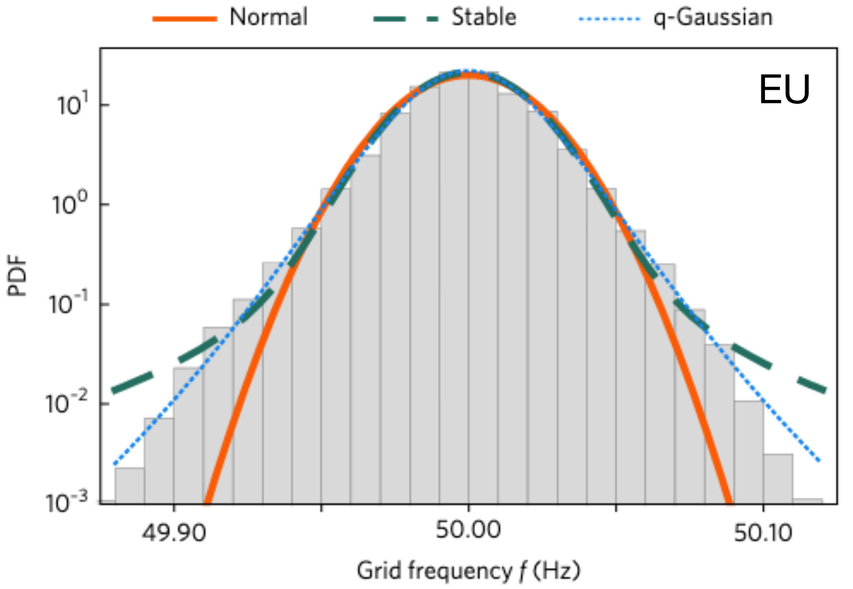


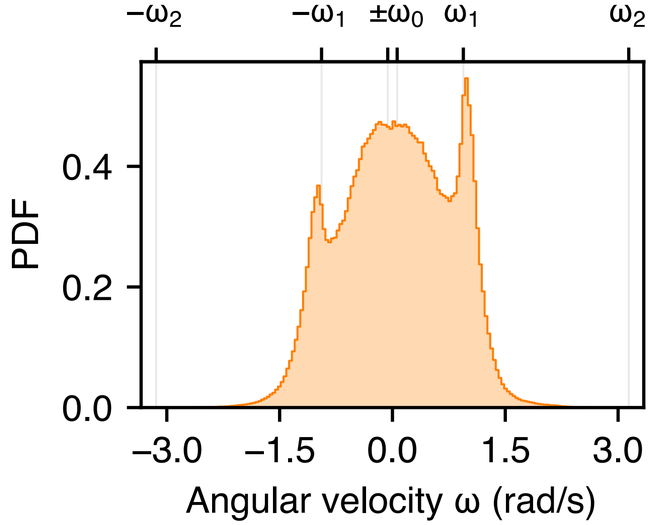
Frequency

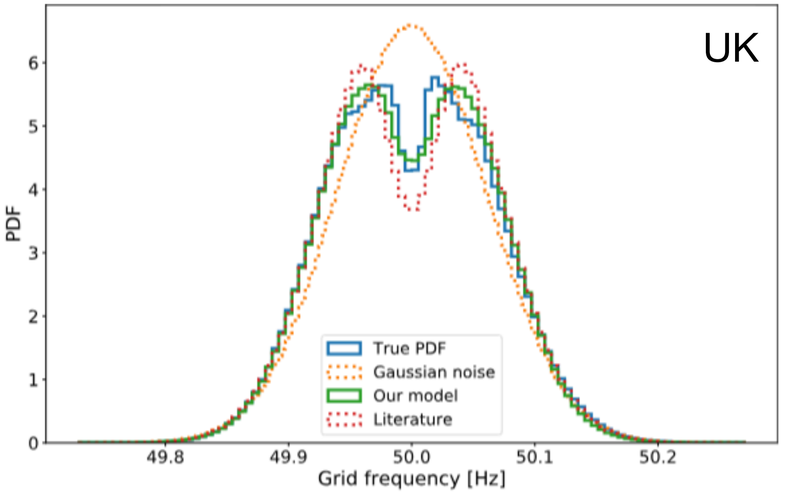
New data





B. Schäfer et al. *Nature Energy* (2018)

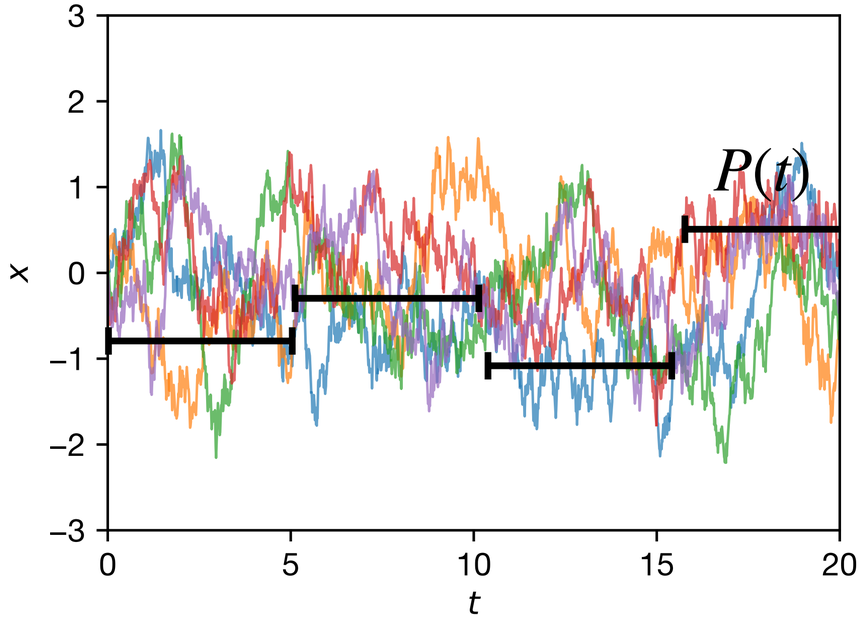


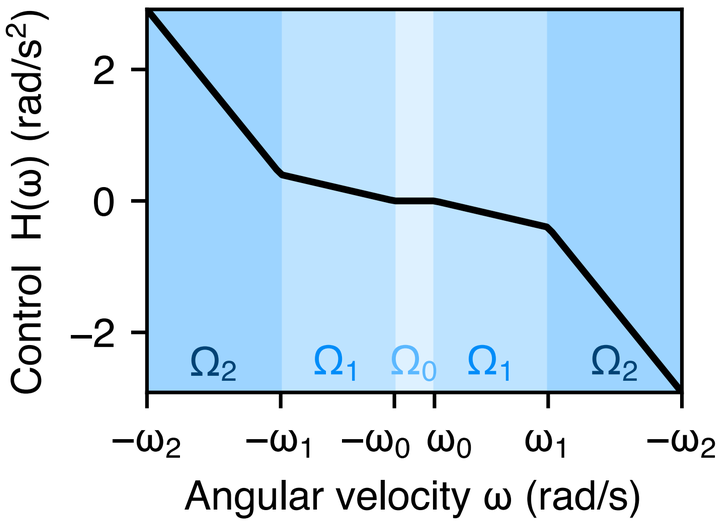


D. Kraljic *IEEE Transactions on Power Systems* (2023)

A new kind of superstatistics

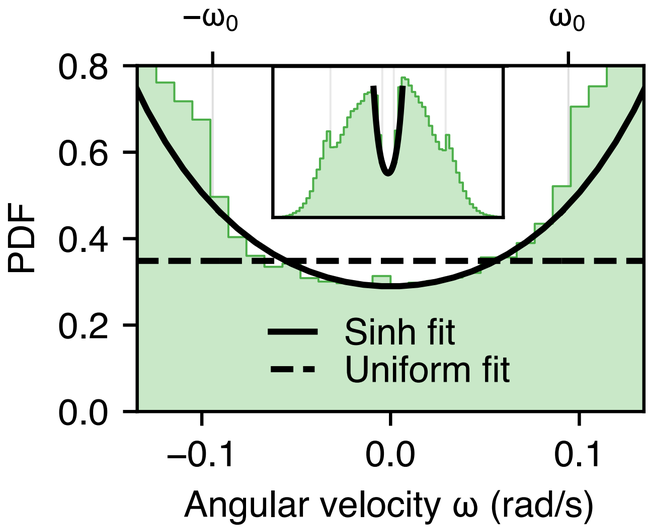
$$\frac{\mathrm{d}\omega}{\mathrm{d}t} = H(\omega) + P(t) + \epsilon\xi \qquad P(t) \text{ slow}$$



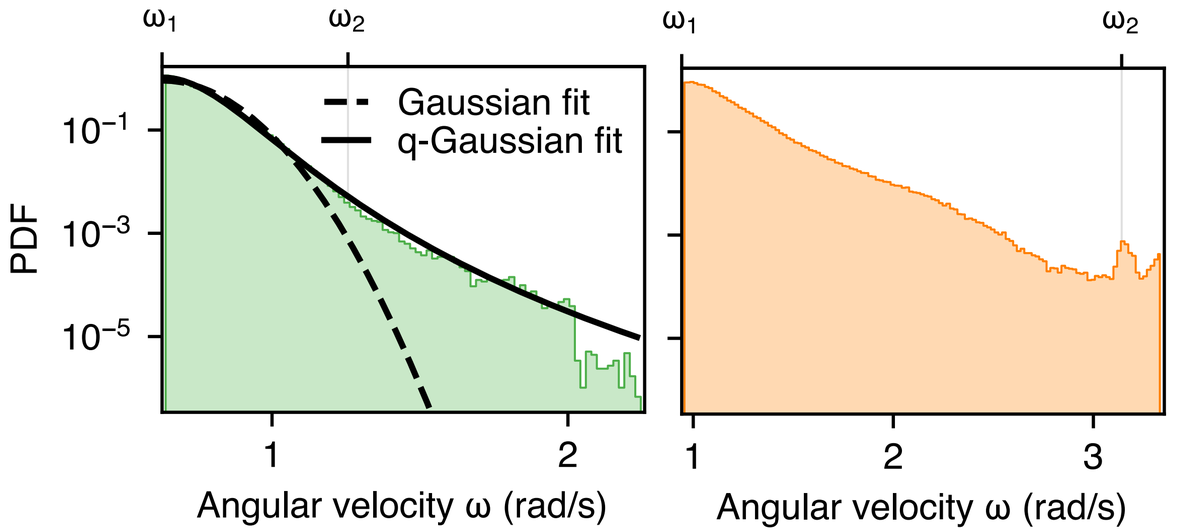


C. Beck *Physical Review Letters* 2001
C. Beck, E. G. D. Cohen *Physica A: Statistical Mechanics and its Applications* 2003

Deadband



Heavy tails



United Kingdom South Africa

Phase angles

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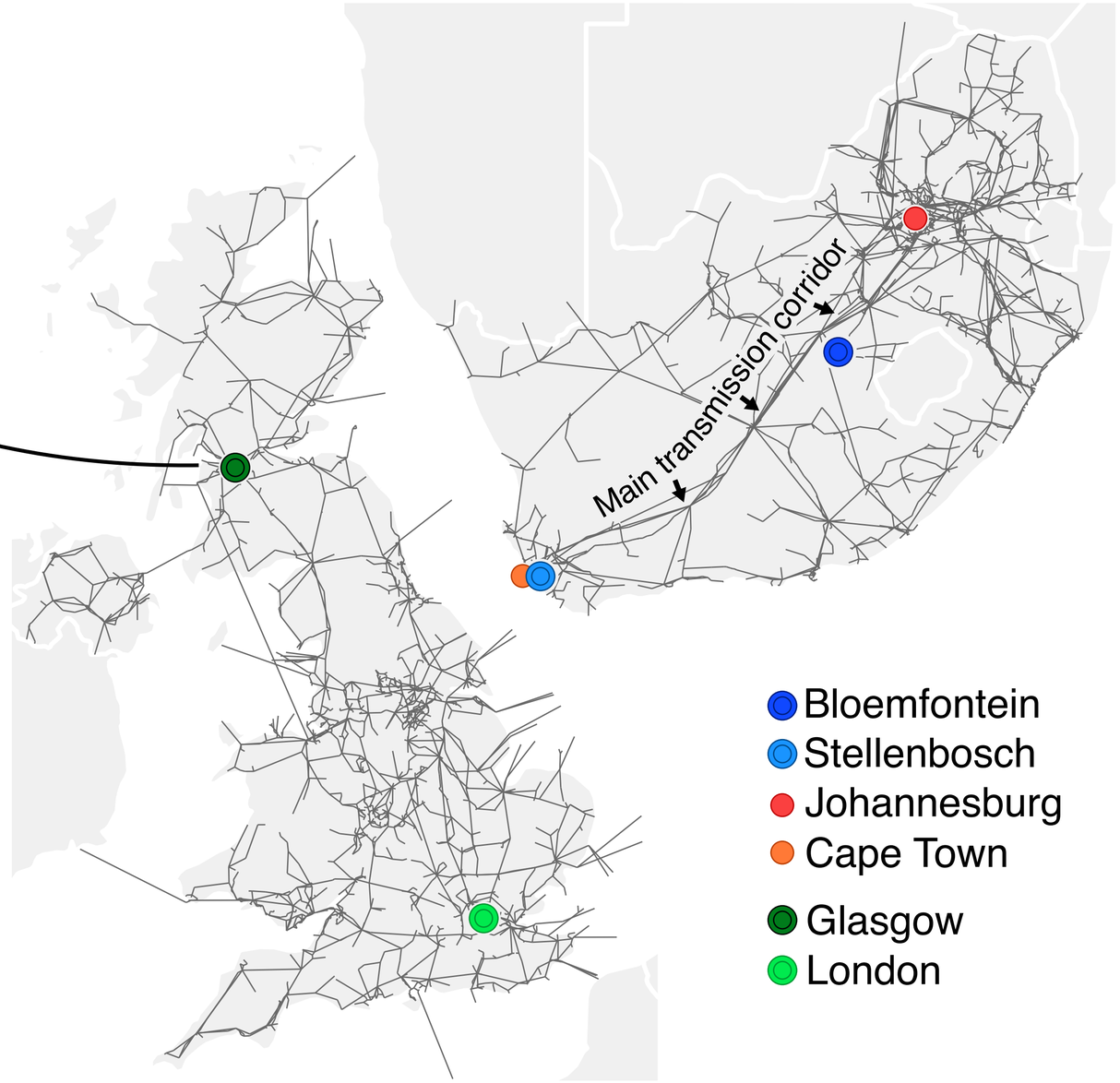
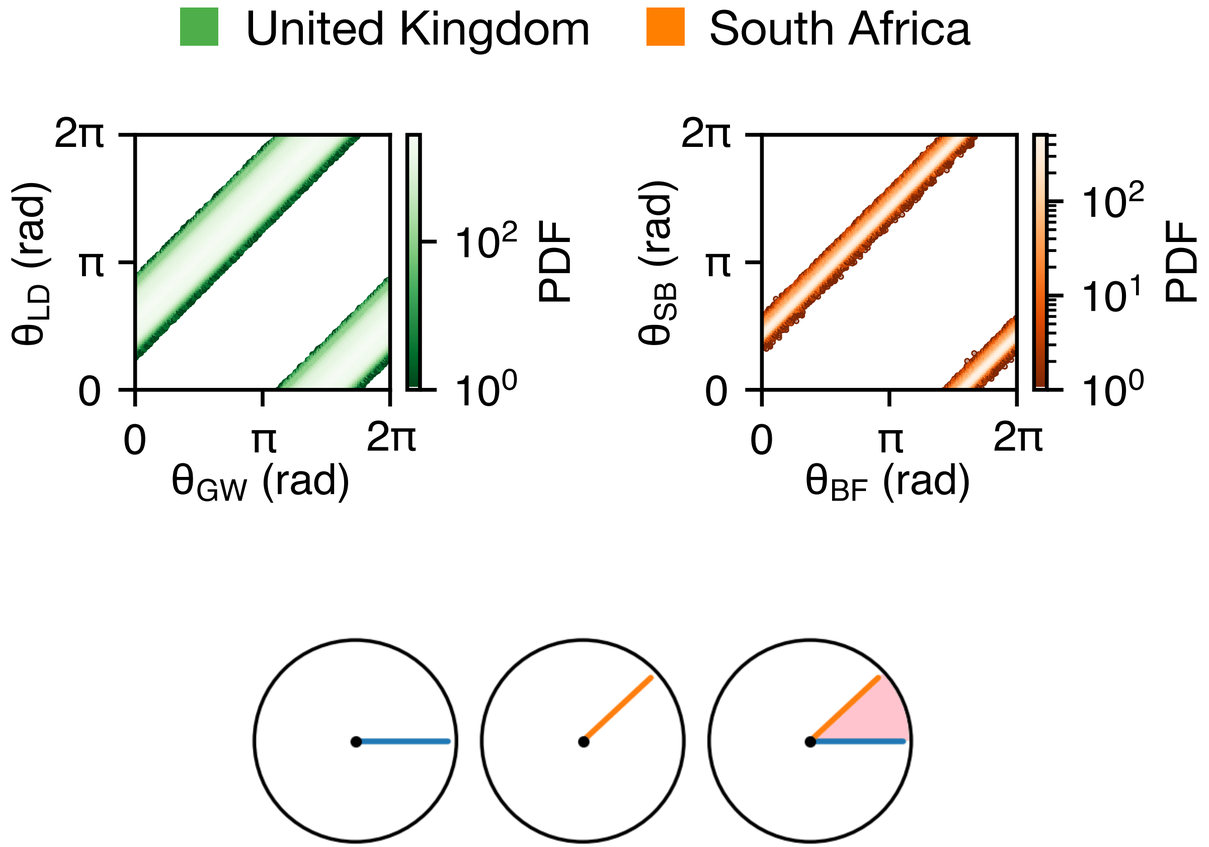
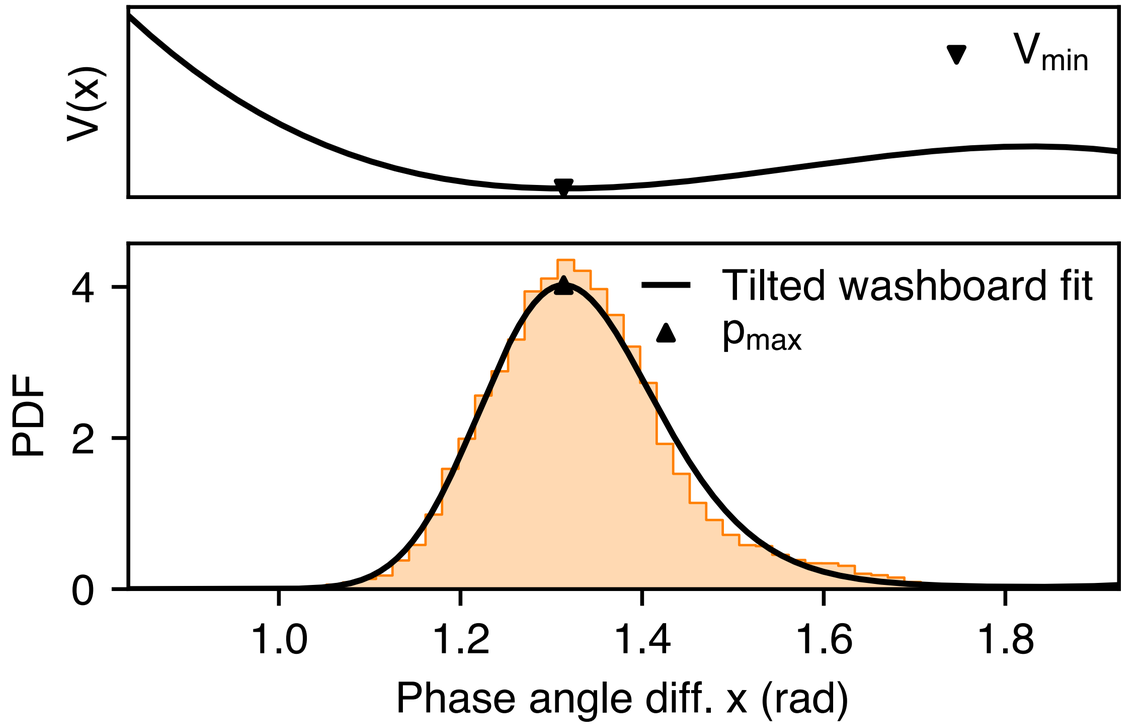


Phase-locked states

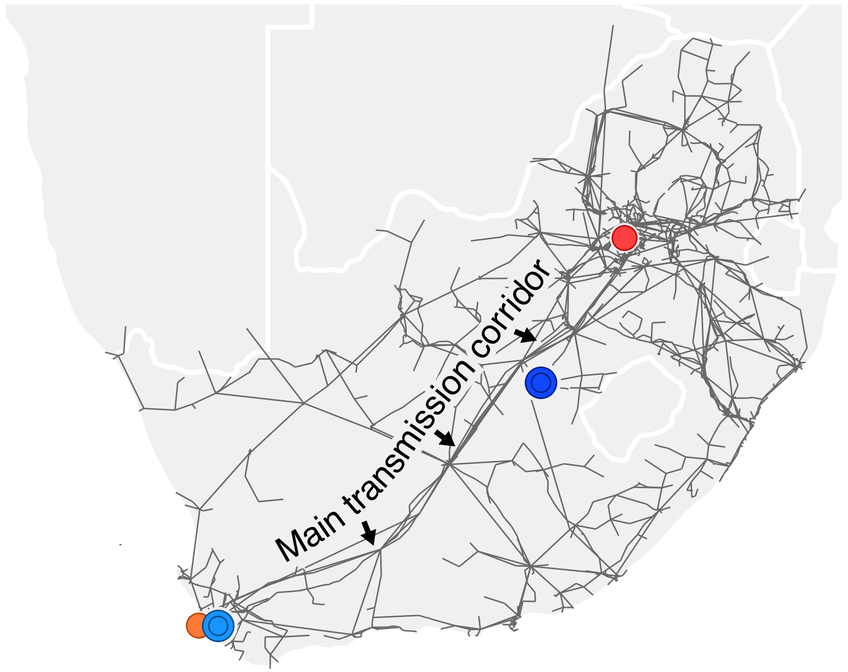


Two nodes only

$$p(x) \propto e^{-\gamma V(x)/\epsilon^2} \qquad V(x) = -\delta x - 2\kappa \cos x$$



South Africa



Bloemfontein
Stellenbosch
Johannesburg
Cape Town

Take home message

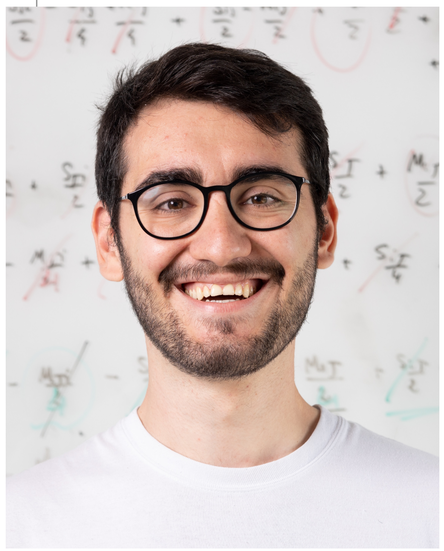
Statistical physics is a helpful tool for describing the emergent properties of power grids

Networks 

Understanding the complexity of frequency and phase angle fluctuations in power grids

Alessandro Lonardi,[1] Jacques M. Maritz,[2] Leonardo Rydin Gorjão,[3,4] and Christian Beck[1]

Preprint	arXiv:2604.03133
Code (GitHub)	aleable/power-grid-complexity
Data (Zenodo)	10.5281/zenodo.19397526
Slides	aleable.github.io/talks.html



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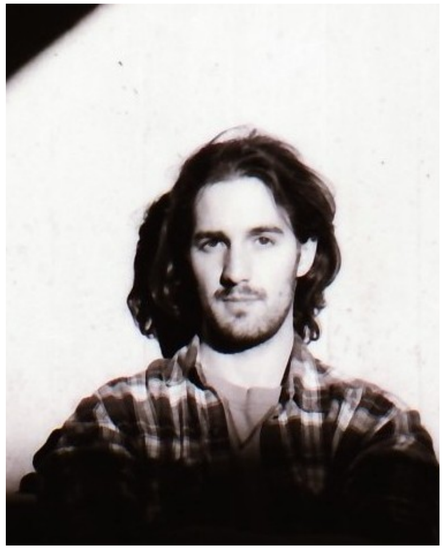
Jacques Maritz
UFS



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Thank you!