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# Locating the Source of Forced Oscillations in Transmission Power Grids

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## People



Andrey Lokhov (LANL)



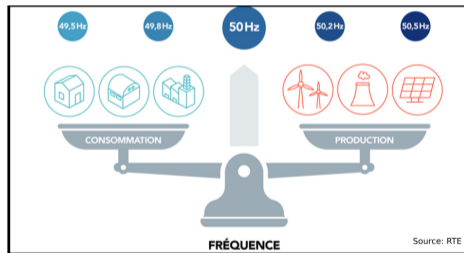
Melvyn Tyloo (LANL)



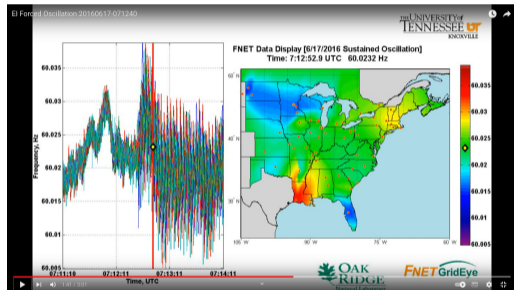
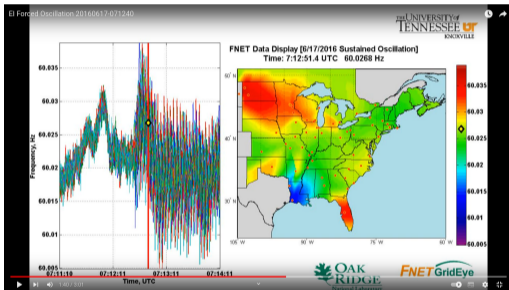
Marc Vuffray (LANL)

## Power grid dynamics

$$m_j \ddot{\theta}_j + d_j \dot{\theta}_j = P_{m,j} - P_{e,j} = P_j - \sum_k B_{jk} \sin(\theta_j - \theta_k)$$

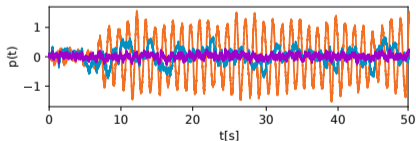
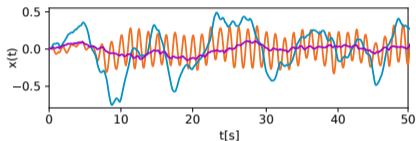
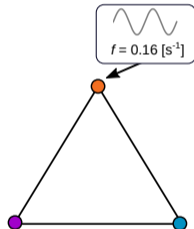


# Forced oscillations

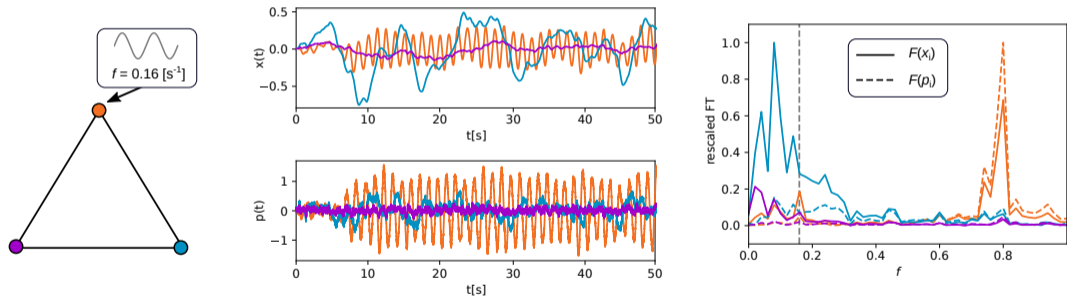


<https://www.youtube.com/watch?v=1vuxZJitEJg>

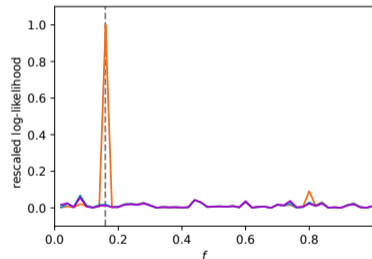
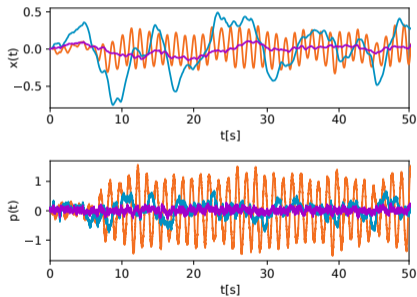
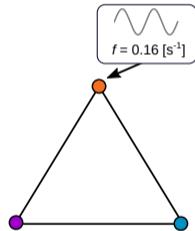
## Intuitive (but a bit naive) approach: ...



## Intuitive (but a bit naive) approach: the Fourier Transform



# Using the SALO algorithm



# SALO: System-Agnostic Location of Oscillations

$$\text{Dynamics: } M\dot{\mathbf{p}} = D\mathbf{p} + B\mathbf{x} + \gamma\mathbf{e}_\ell \cos(2\pi ft + \phi) + \boldsymbol{\xi}.$$



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Discretized:  $\Delta_{t_j} = A\mathbf{X}_{t_j} + \gamma\mathbf{e}_\ell \cos(2\pi kt_j/T + \phi) + \boldsymbol{\xi}_j$ .

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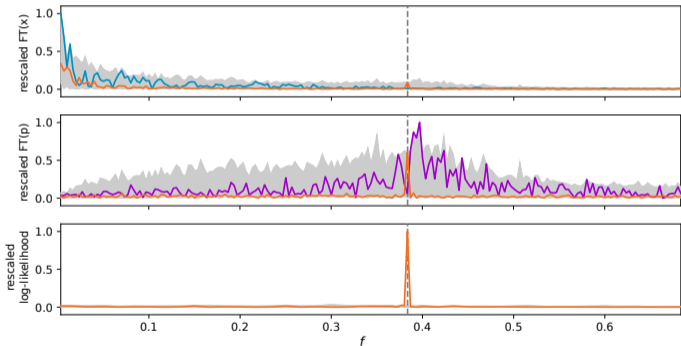
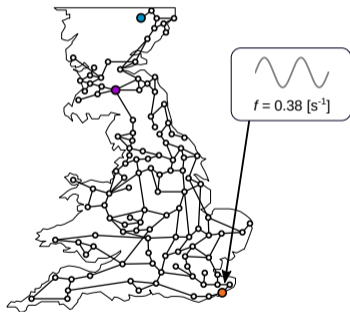
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Least square error:

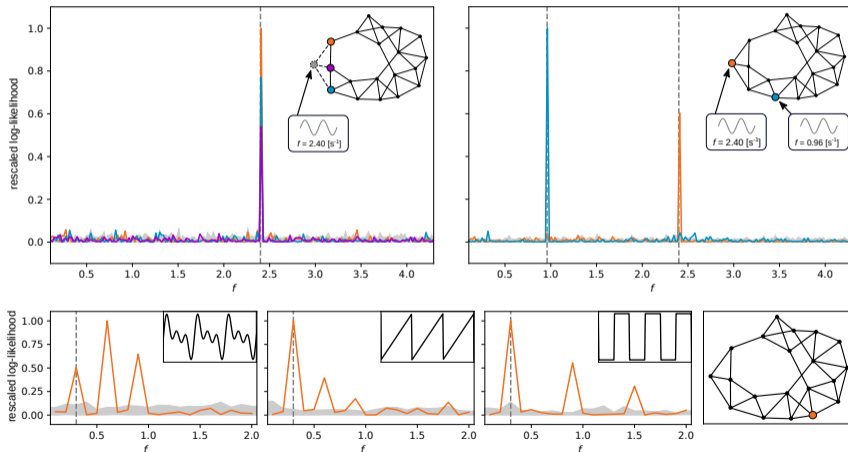
$$\text{SALO: } \arg \min_{A, \gamma, k, \ell, \phi} \sum_{j=0}^{T-1} \left\| \Delta_{t_j} - A\mathbf{X}_{t_j} - \gamma\mathbf{e}_\ell \cos(2\pi kt_j/T + \phi) \right\|^2.$$

... and a bit of work.

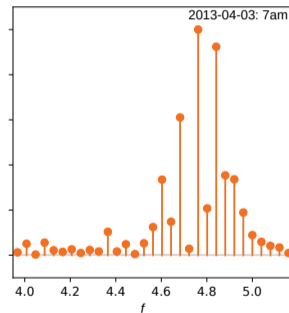
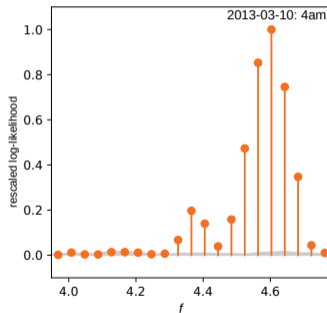
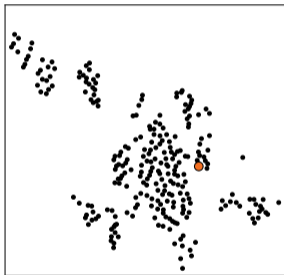
# Synthetic data



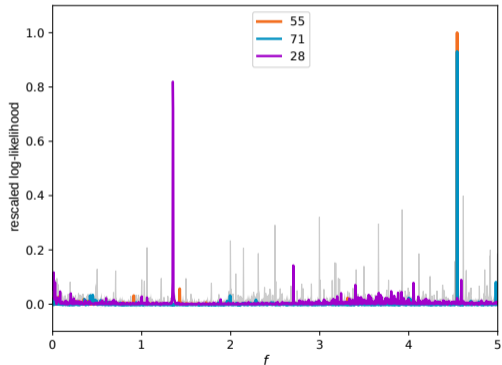
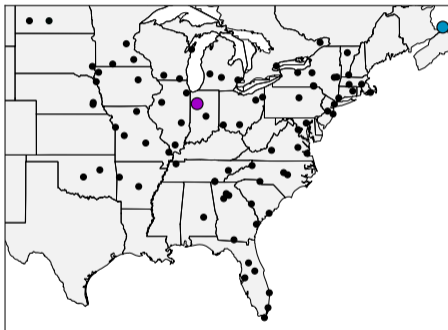
## Multiple or hidden sources



## Measurement data



## Measurement data (bis)



## Refinements to SALO

- ▶ Relaxation of the amplitude vector:

$$\text{SALO-relax: } \arg \min_{A, \gamma, k, \phi} \sum_{j=0}^{T-1} \left\| \Delta_{t_j} - A \mathbf{X}_{t_j} - \gamma \cos(2\pi k t_j / T + \phi) \right\|^2 .$$

- ▶ Use of prior information.

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- ▶ Use of prior information.
- 

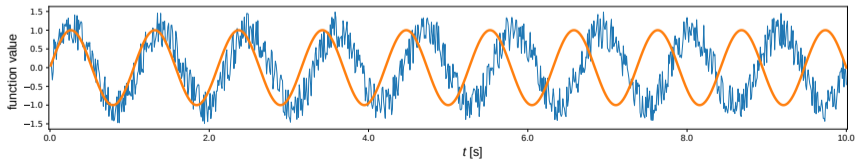
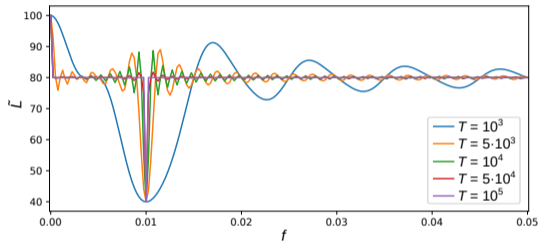
Thank you!

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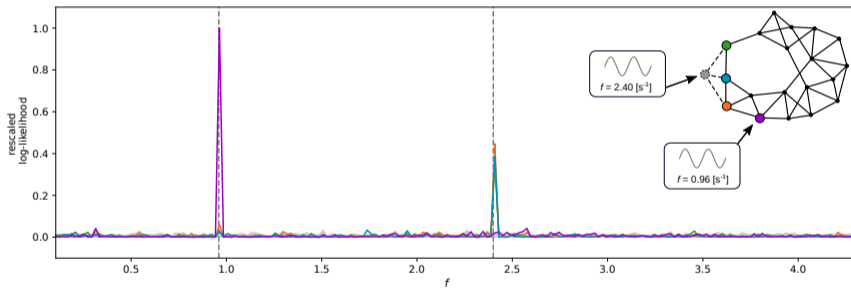
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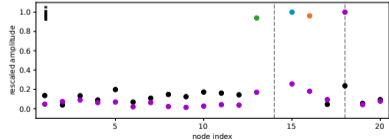
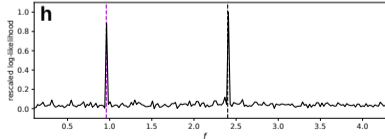
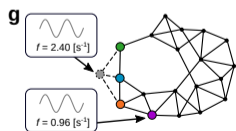
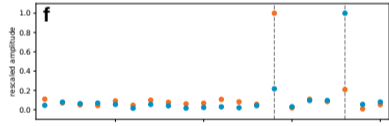
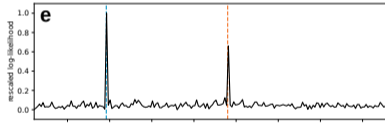
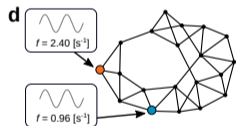
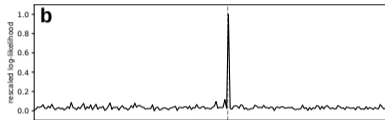
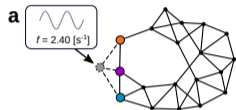
# Optimization landscape



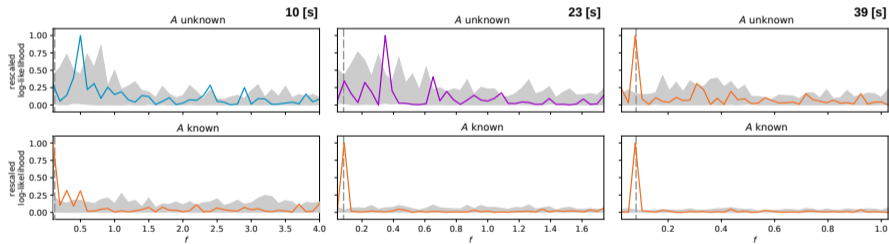
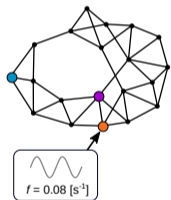
## Complex cases



# Complex cases



# Informed SALO



# Informed SALO-relax

