



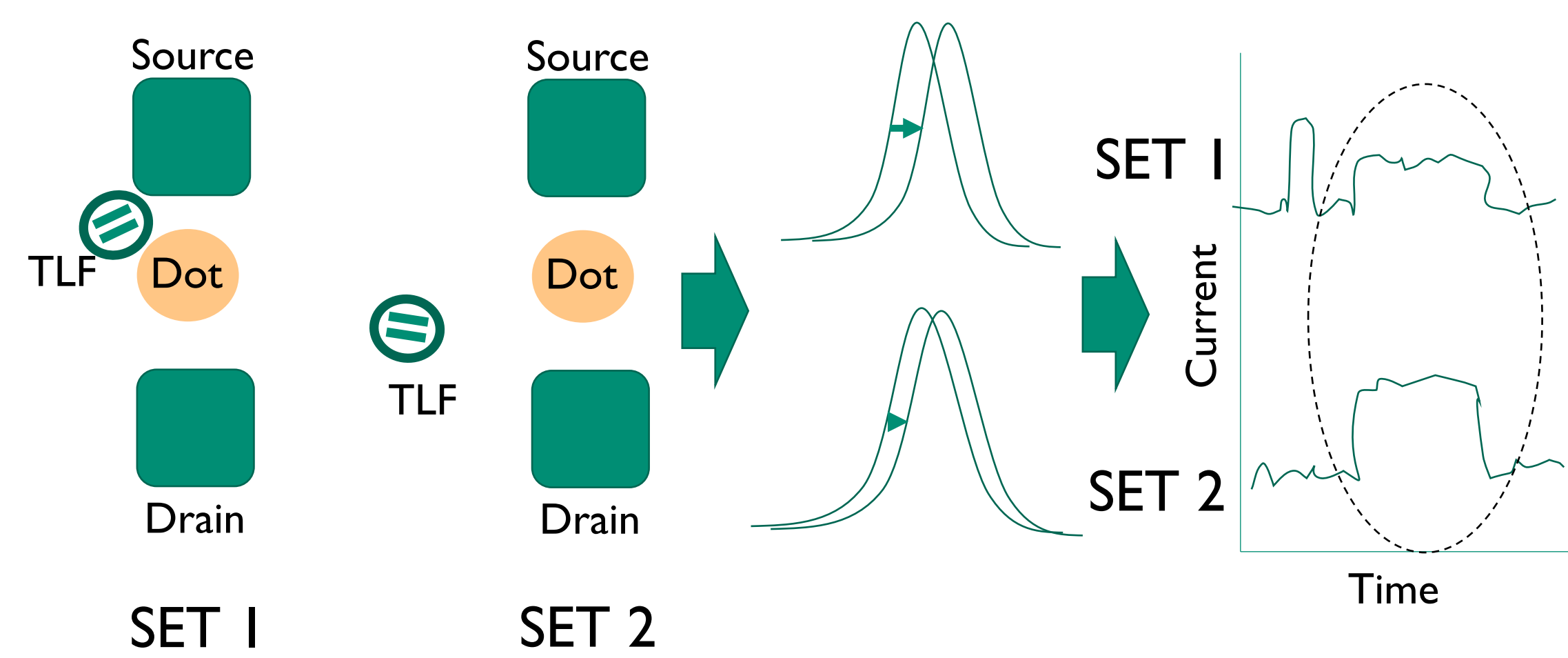
NoMoPy: Noise Modeling in Python

A Python package for detailed modeling of time series data.

Dylan Albrecht and Toby Jacobson (PI)

Motivation

Silicon quantum dot devices are subject to two-level (or more) fluctuators (TLFs), typically stemming from charge traps. Directly modeling these noise signals can provide rich information.

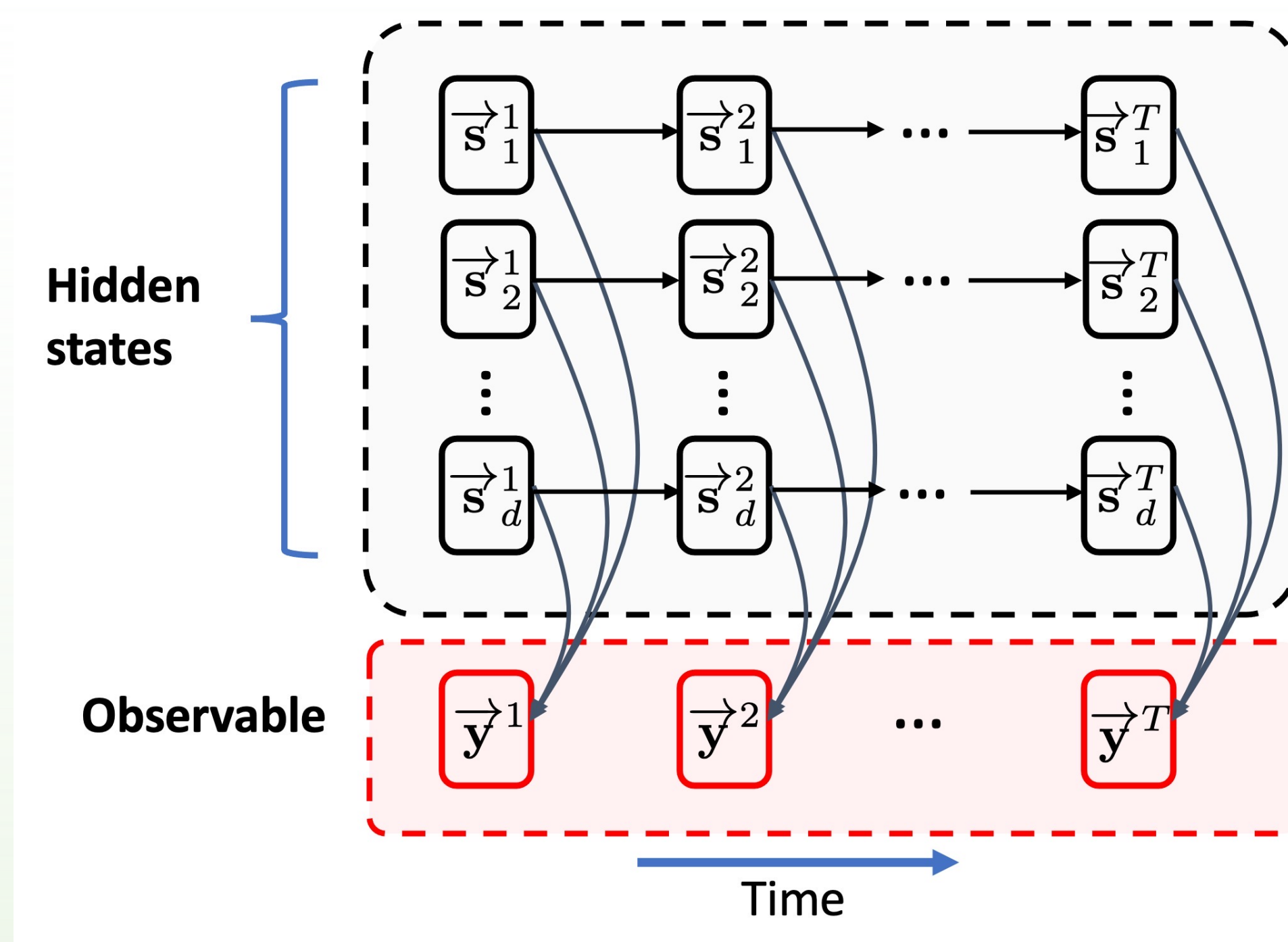


Two sensor currents affected by TLFs, showing one shared TLF.

Estimating the number of TLFs, transition rates, and dipole weights may allow:

- Triangulating TLFs, for characterization/fab implications.
- Modeling correlated noise.
- Detailing noise temperature (or other) dependence.

FHMMs



Probabilistic graphical model representation.

A factorial hidden Markov model (FHMM) [0] is a generalization of the hidden Markov model,

- d independent k -level systems.
- Weights W_{ok}^d log transition probabilities A_{kk}^d
- Observable time series vector $\vec{y}^t$ with covariance C

$$\vec{y}^t \sim \mathcal{N}(\sum_{i=1}^d W_i^t \cdot \vec{s}_i^t, C)$$

Markov condition on graph:

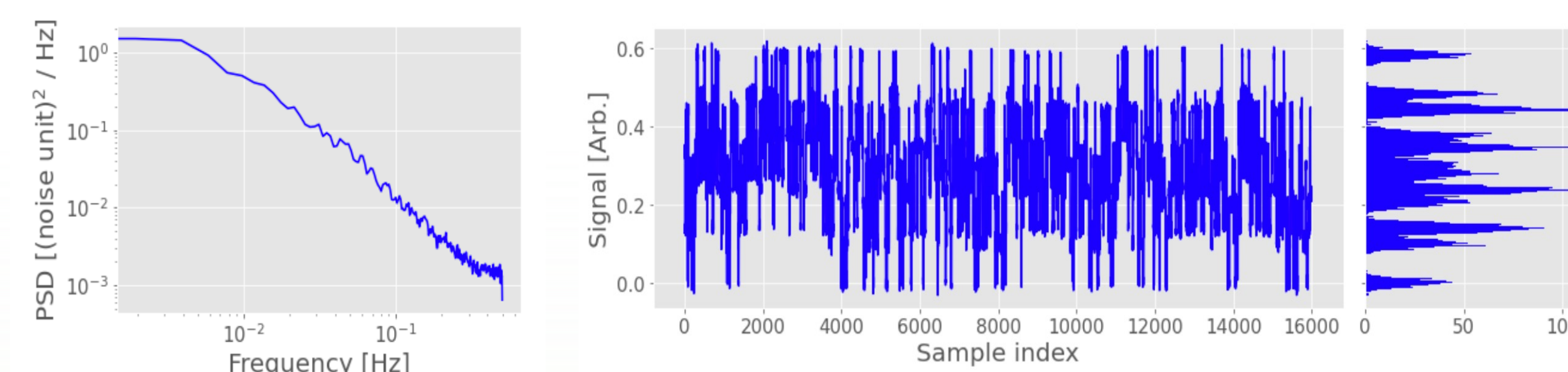
$$P(\vec{s}_i^t | \{s\}, \{y\}; \theta) = P(\vec{s}_i^t | \vec{s}_i^{t-1}; \theta)$$

Model fit: Expectation-Maximization (EM) algorithm for maximum likelihood estimation (MLE).

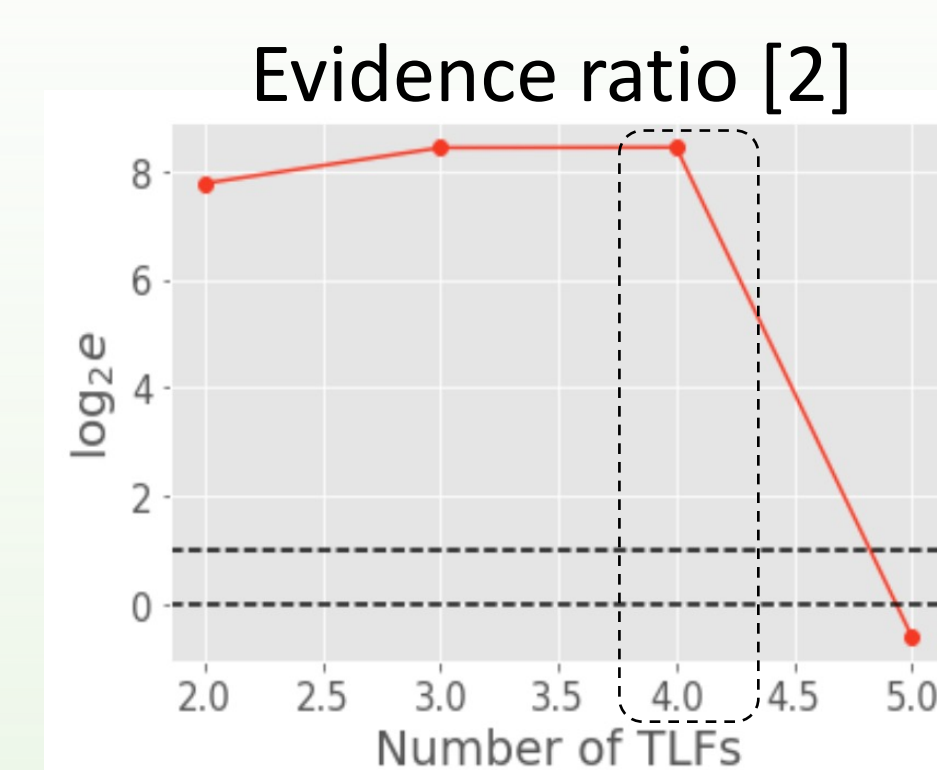
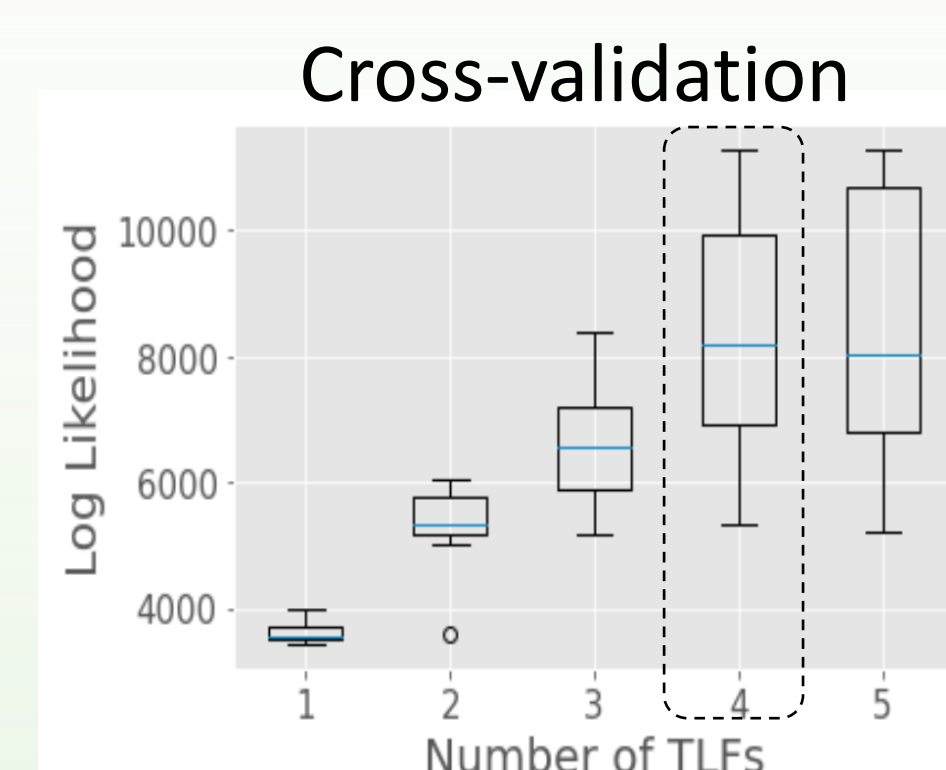
- Exact and approximate E-steps.
- Analytic M-step.
- Local optimum guaranteed.

Simulation

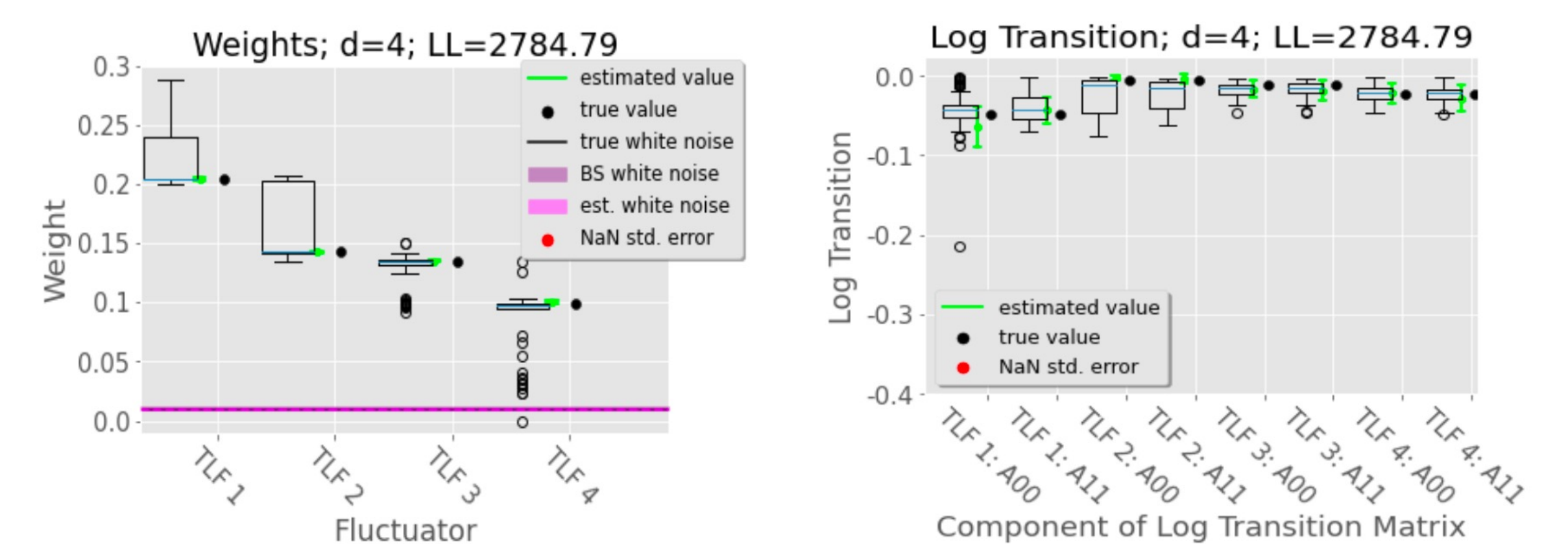
Simulated example: blind source separation (BSS), separating a single signal into four separate signals.



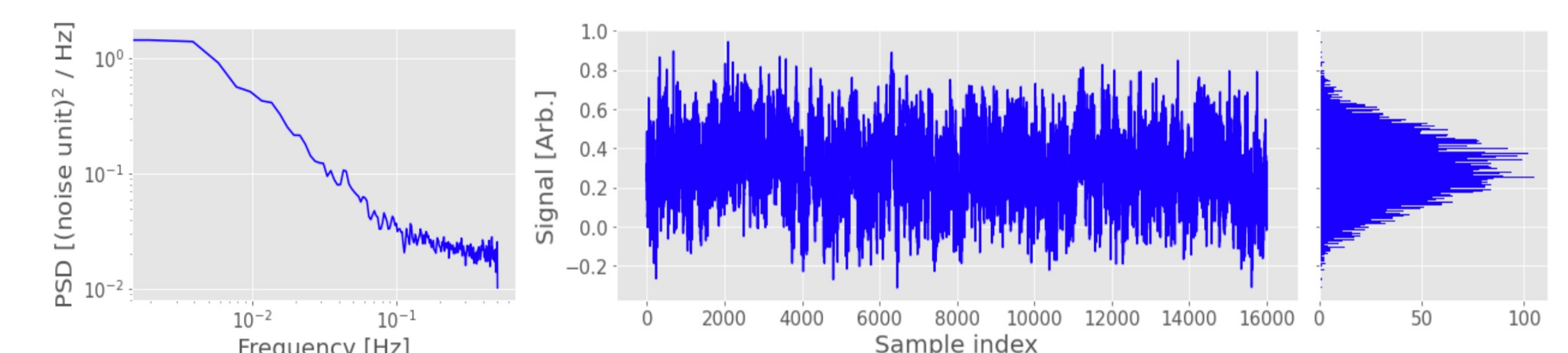
The simulated data has a $1/f^\alpha$ PSD, while the histogram contains discrete levels. Fitting a FHMM indicates a 4 TLF model.



The fit also lines up well with the true values (up to reordering).



Approaching the limit of fit feasibility:



The weights are on the order of the Gaussian white noise level. We can capture 3 of the 4 TLFs [2].

Summary

- Disentangle M signals into N shared, discrete (hidden) fluctuators.
- Extract correlated noise.
- Potentially track fits as temperature (or other parameter) changes.
- Compute Hessian and bootstrapped error bars.
- Run optimized computations, scaled to HPC resources.
- Open source software (release pending sponsor approval).

References

- [0] Ghahramani, Z. and Jordan, M. I. (1997). Factorial hidden Markov models. *Machine Learning*, 29(245).
- [1] Rudinger, K., Hogle, C. W., Naik, R. K., Hashim, A., Lobser, D., Santiago, D. I., Grace, M. D., Nielsen, E., Proctor, T., Seritan, S., Clark, S. M., Blume-Kohout, R., Siddiqi, I., and Young, K. C. (2021). PRX Quantum, 2:040338.
- [2] Albrecht, D. and Jacobson, N. T. NoMoPy: Noise Modeling in Python. *Publication forthcoming*.