The Emergent Complexity of Contagion

Correlated heterogeneity in simple contagions mimics complex contagions

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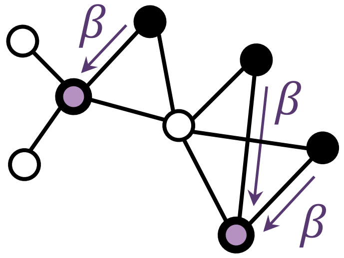
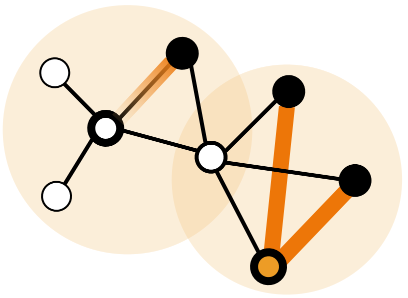
NetSci 2026, June 5

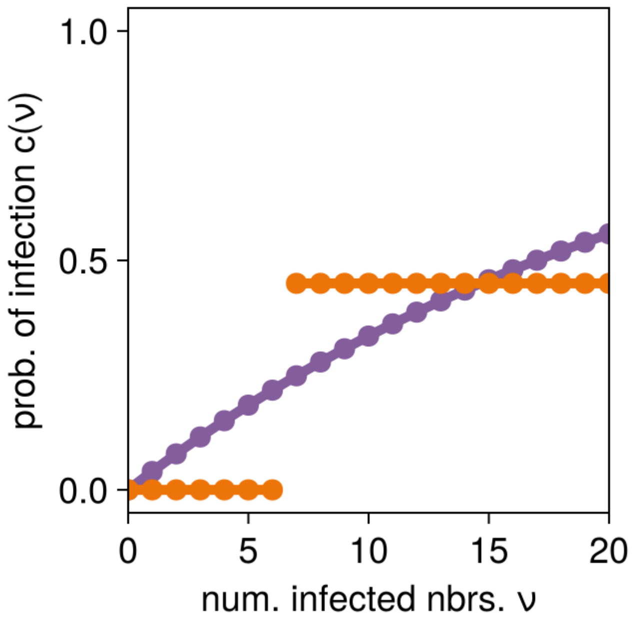
Simple vs. complex contagions

Simple contagion assumes each exposure independently influences a node's infection probability.



Complex contagion assumes multiple exposures are required for infection.





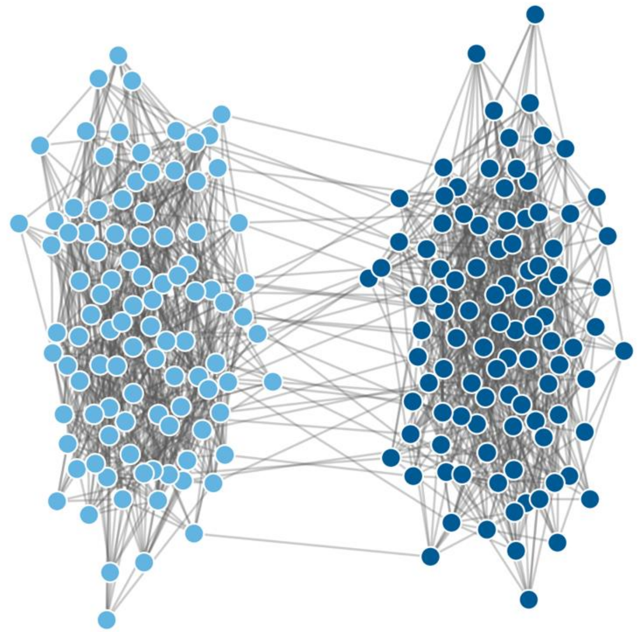
Contagion kernel unifies these paradigms, maps number of exposures to probability of transmission.
Landry et al. '24, Cencetti et al. '23, Andres et al. '25 develop methods for kernel inference.

$$c_S(\upsilon) = 1 - (1-\beta)^{\upsilon}$$

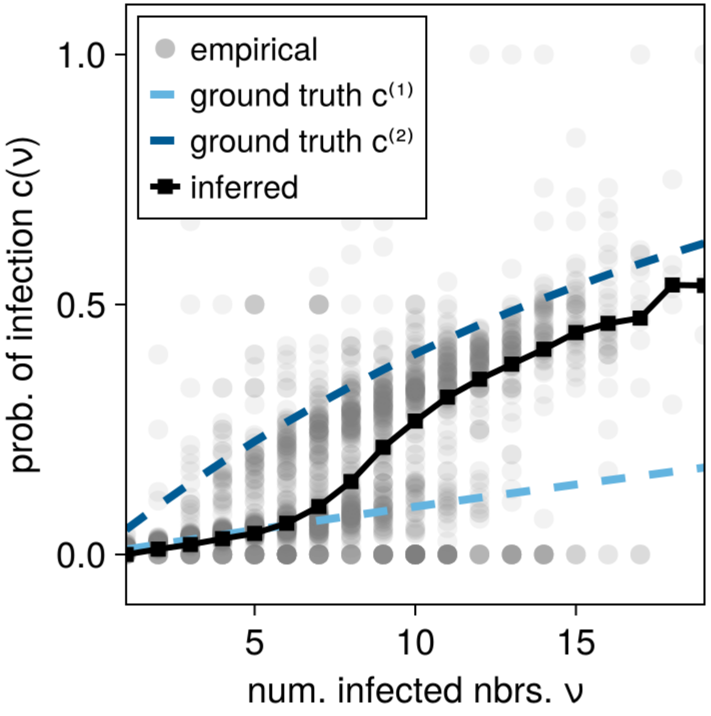
$$c_C(\upsilon) = \beta \mathbb{I}[\upsilon \geq \tau]$$

Contagion kernel inference ≠ mechanism selection!

Emergent complexity



$\beta_1 = 0.01 \qquad \beta_2 = 0.05$

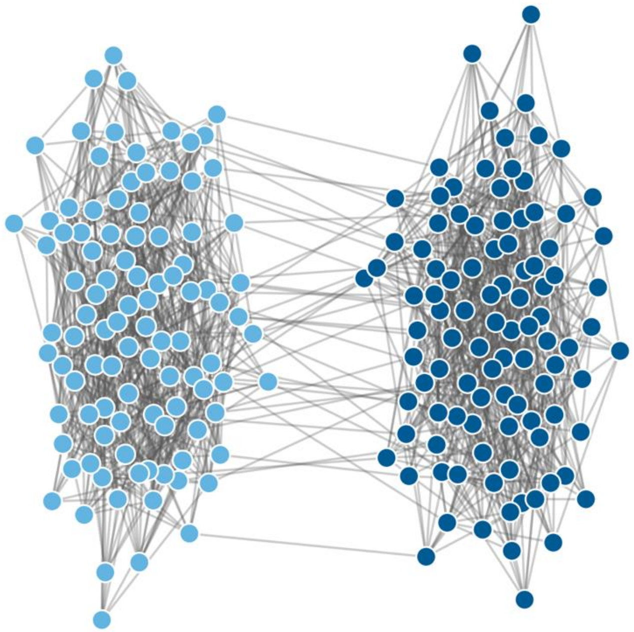


Contagion process appears complex, even when every node follows simple contagion rules.

This is **emergent complexity**, arises from, e.g.,

- heterogeneous parameters (St-Onge et al. ’24)
- synergistic contagions (Hébert-Dufresne et al. ’20)
- uncertain contact topology (Landry et al. ’24)

Emergent complexity



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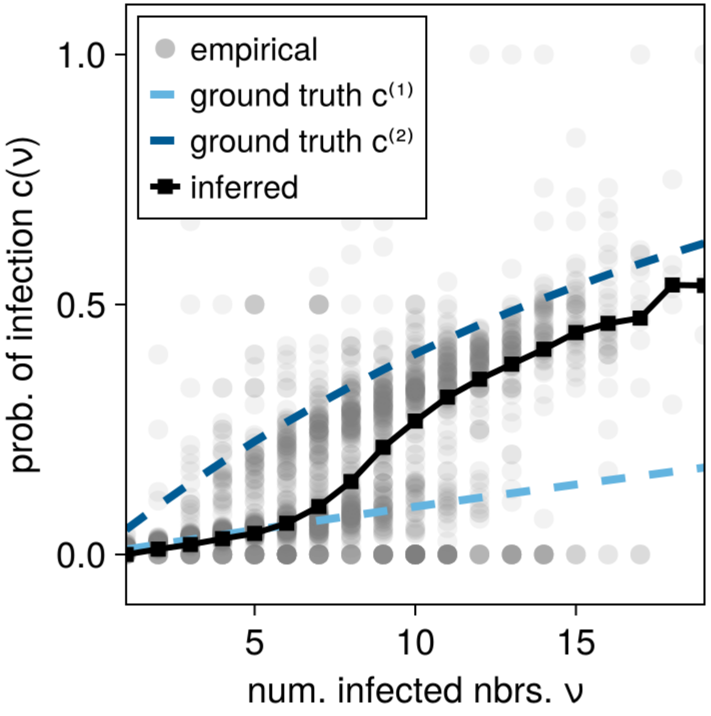

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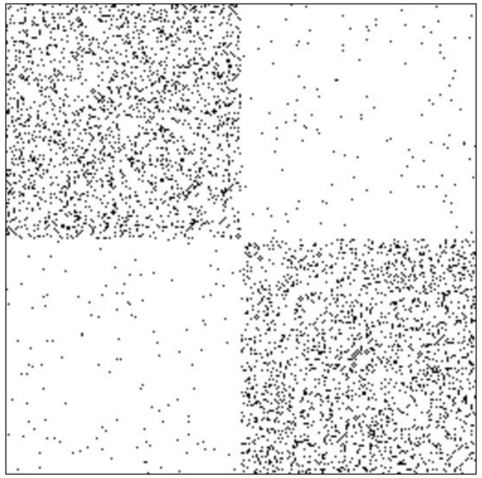
Our contributions

- Measure and map emergent complexity across structure and heterogeneity.
- Use mixture model to disentangle apparent from mechanistic complexity.

Emergent complexity & correlated heterogeneity



Two-block SBM experiment with $n = 256, \langle k \rangle = 18.$

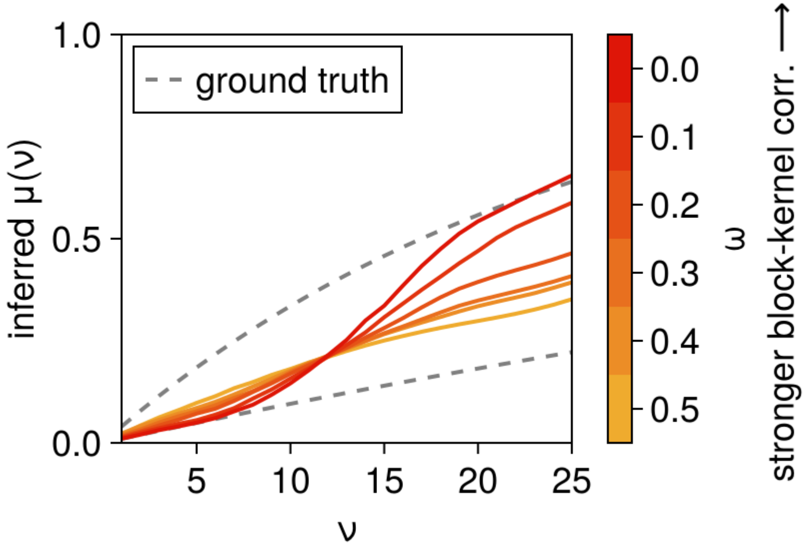
Block 1 node assigned simple kernel $c^{(1)}$ with probability $1 - \omega$, $c^{(2)}$ with probability ω. Opposite for block 2 node.

Observing SIS contagion process yields exposure-outcome tuples (υ, num. infections, num. failed infections) for each node.

$$\text{logit}\, \boxed{c_i(\nu)} \sim \text{Normal}(\boxed{\tilde{\mu}(\nu)}, \sigma)$$

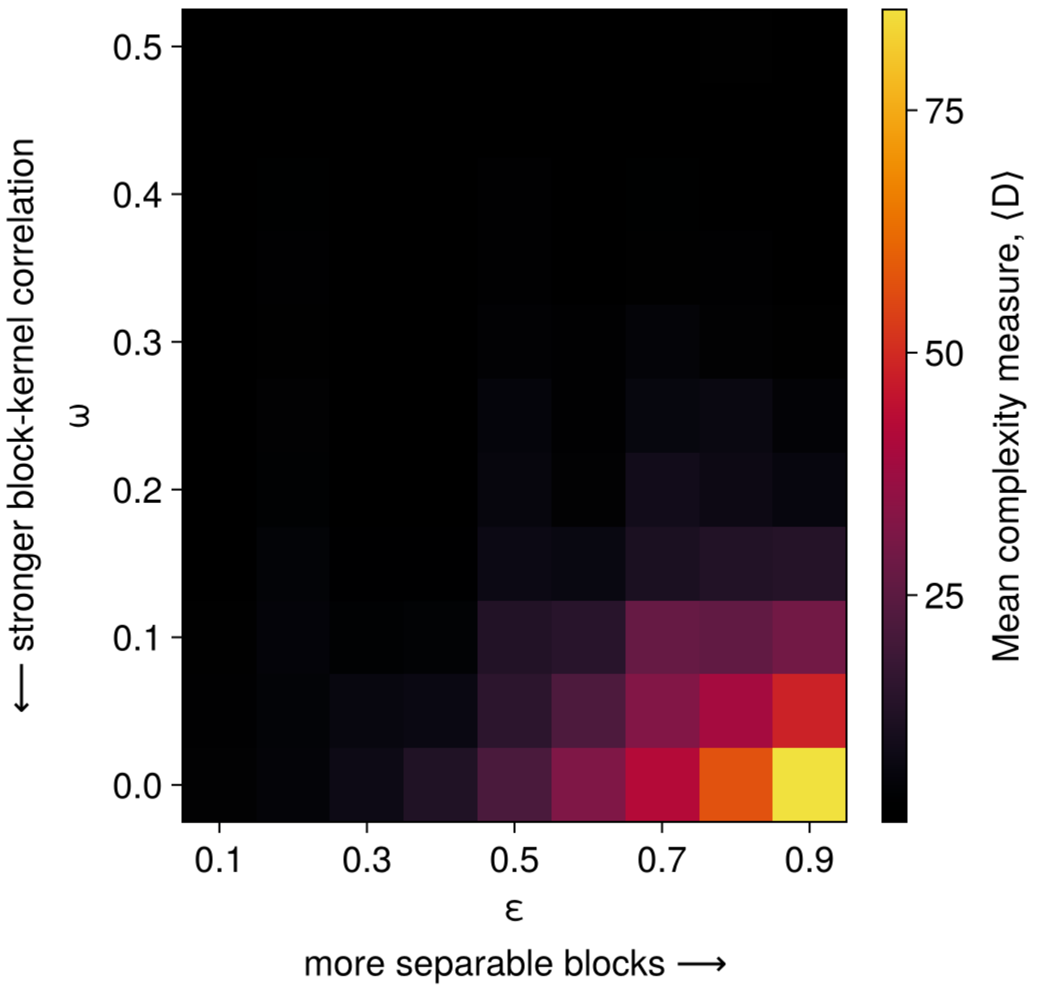
node i's contagion kernel

kernel mode (global)



Takeaway: correlated heterogeneity sufficient to see emergent complexity

Emergent complexity & correlated heterogeneity



Complexity of kernel mode $\tilde{\boldsymbol{\mu}}$ is:

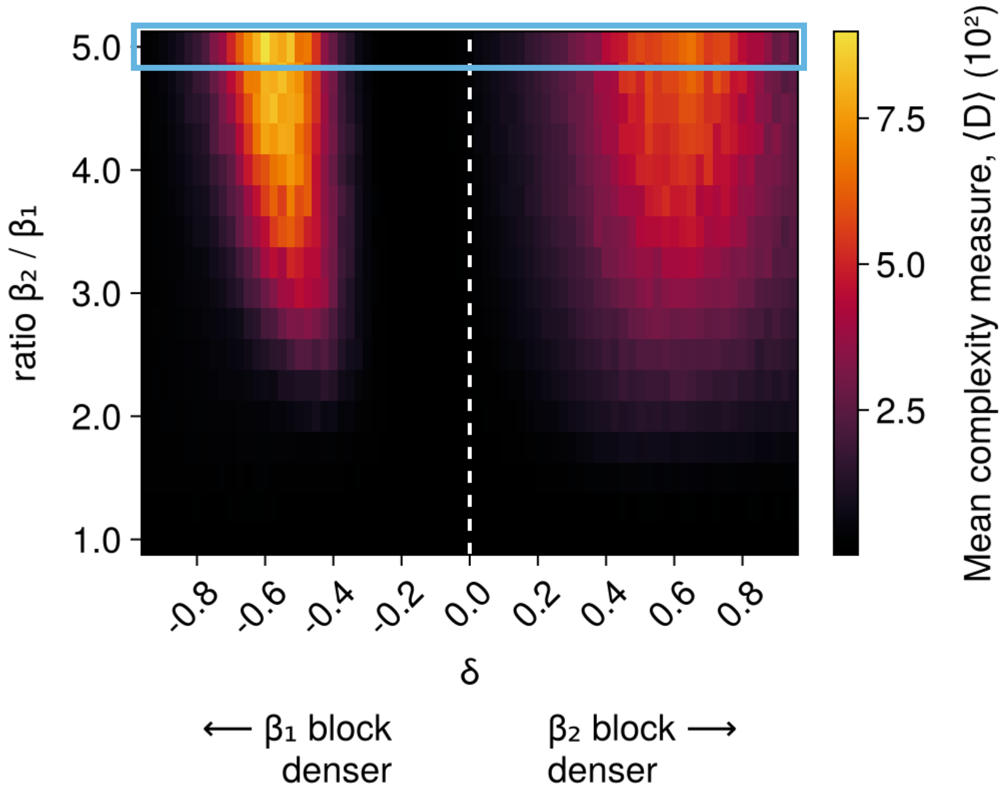
best-fit simple kernel

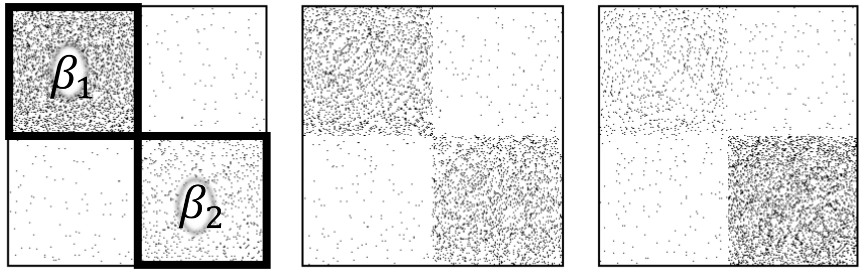
posterior covariance

$$D = \frac{(\tilde{\boldsymbol{\mu}} - \boxed{\tilde{\boldsymbol{\mu}}_{\mathrm{sm}}})^\top \boxed{\boldsymbol{\Sigma}}^{-1} (\tilde{\boldsymbol{\mu}} - \tilde{\boldsymbol{\mu}}_{\mathrm{sm}})}{\boxed{\mathrm{erank}(\boldsymbol{\Sigma}^{-1})}}$$

effective rank normalization — gives **“per-informative dimension” distance from simple kernel** (Roy & Vetterli ’07)

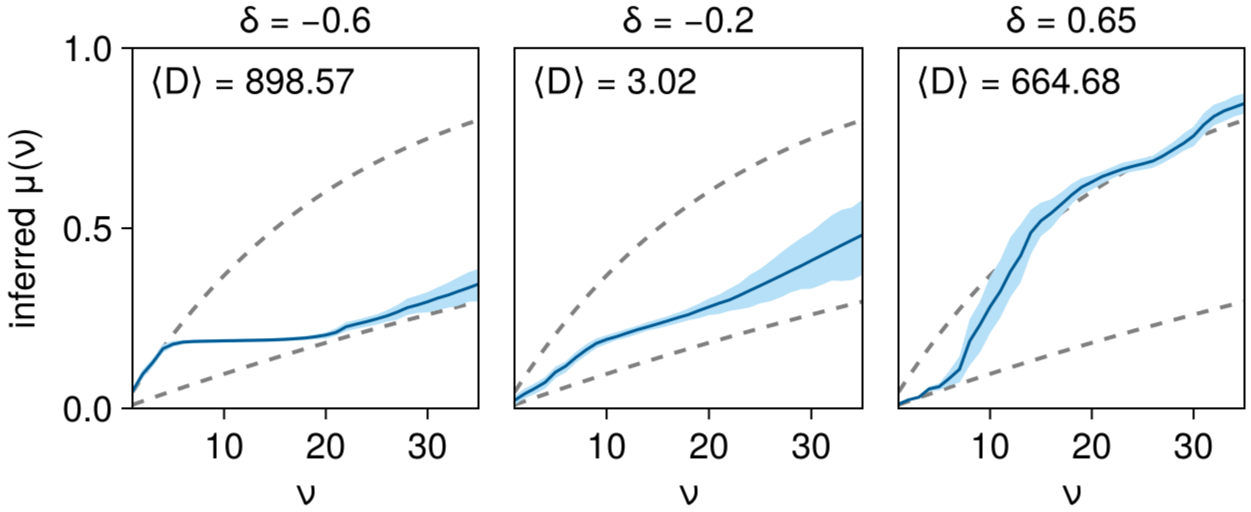
Structural effects on emergent complexity





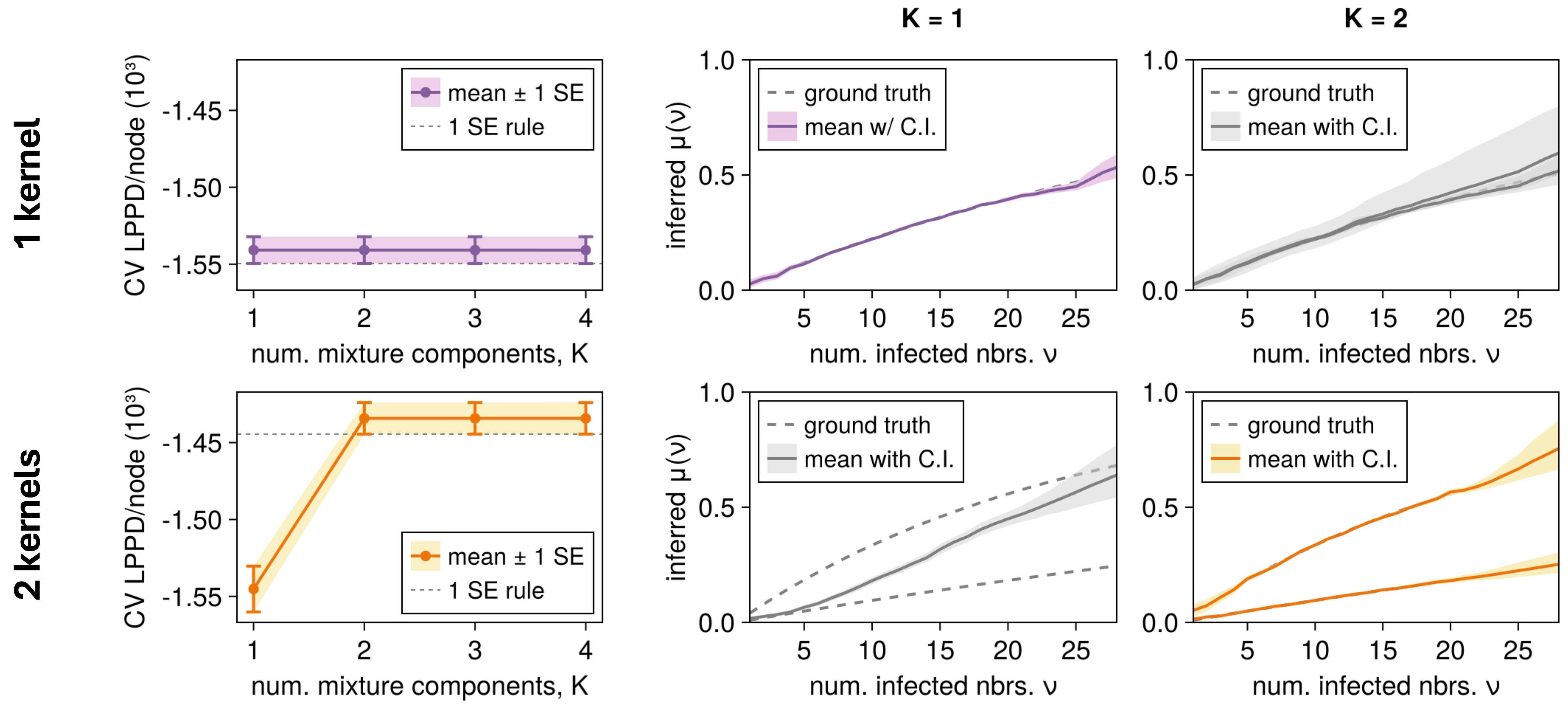
Two-block SBM experiment with imbalanced degree.

Now we **vary δ, relative imbalance of average degree** in each block, and **ratio of βs** in each block.



Disentangling mechanistic and emergent complexity

$$\tilde{c}_i(\nu) \sim \mathrm{Normal}(\tilde{\mu}_{z_i}(\nu), \sigma), \quad z_i \in \{1, \ldots, K\}$$



Thank you! Questions?

Katerina is happy to be infected
with postdoc opportunities!

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