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FHN dynamics

$$\dot{x}_i = \frac{1}{\epsilon}(x_i - x_i^3/3 - y_i) + \sum_{j \neq i} g_{ij} A_{ij} h(x_i, x_j) + \eta_i$$

$$\dot{y}_i = x_i + \alpha$$

Function to find peaks

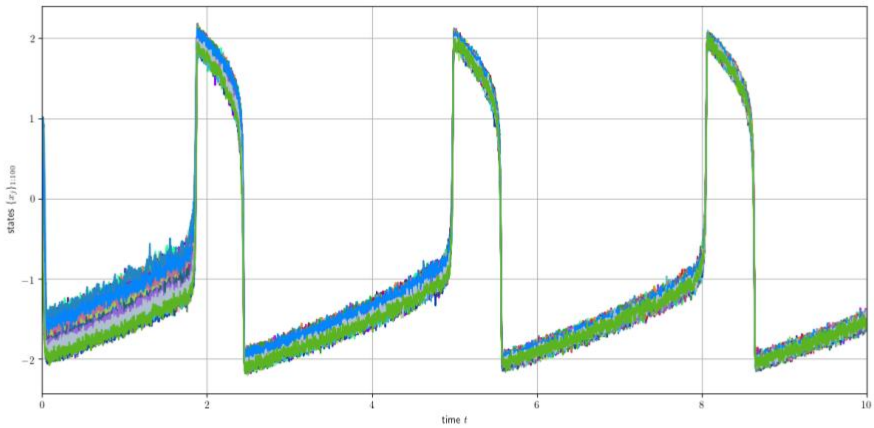
- **https://docs.scipy.org/doc/scipy/reference/generated/scipy.signal.find_peaks.html**

Diffusive FHN model

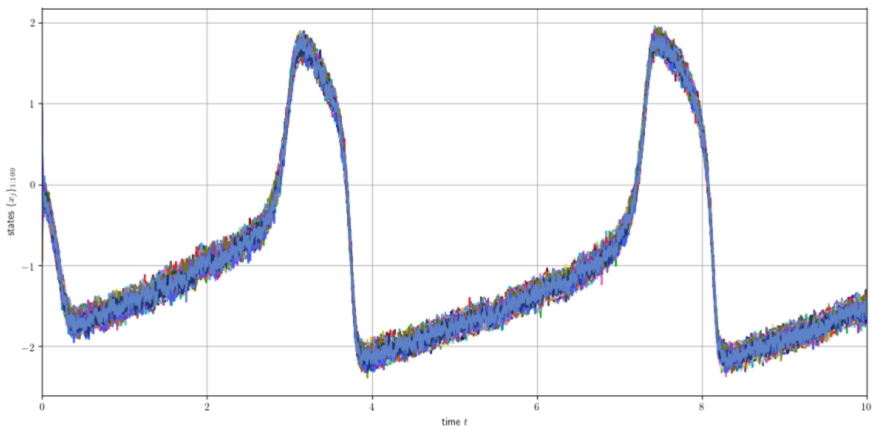
- **Playing around with FHN model**

- **Parameters**
  (a) Random directed weighted network
  (b) Size = 100, connection probability = 0.2, weights $\sim N(10,2)$, $\sigma_i = 1$
  (c) $(\boldsymbol{\epsilon = 0.01, 0.1, 1, \alpha = 0.95, 1, 1.5})$
  (d) Initial conditions $\mathrm{uniform}[-1,1]$

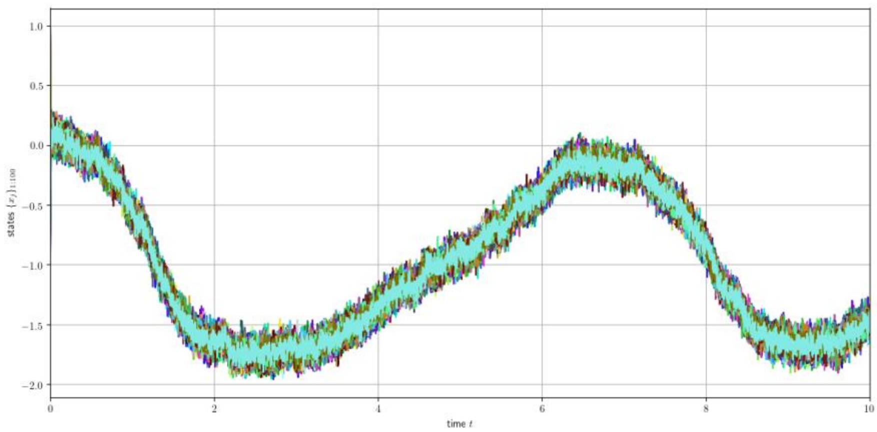
- $\boldsymbol{\epsilon = 0.01, \alpha = 0.95}$



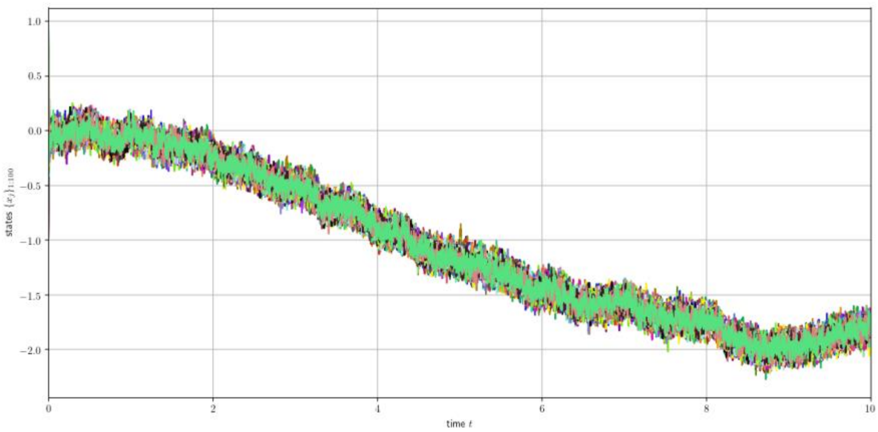
- $\boldsymbol{\epsilon = 0.1, \alpha = 0.95}$



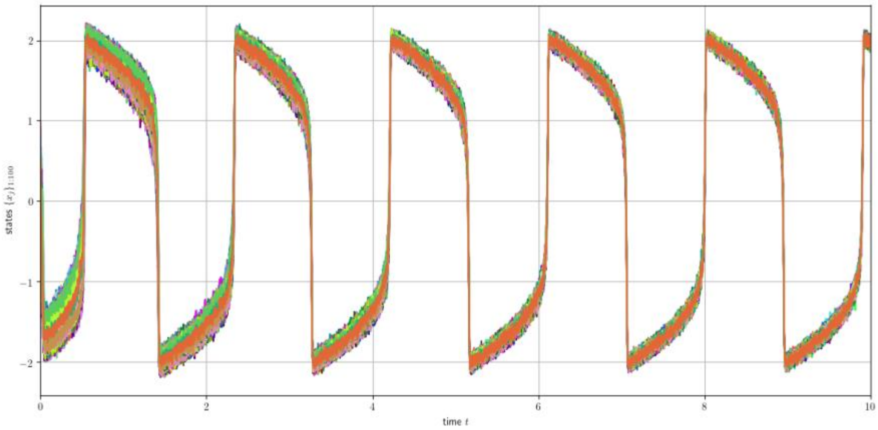
- $\boldsymbol{\epsilon = 1, \alpha = 0.95}$



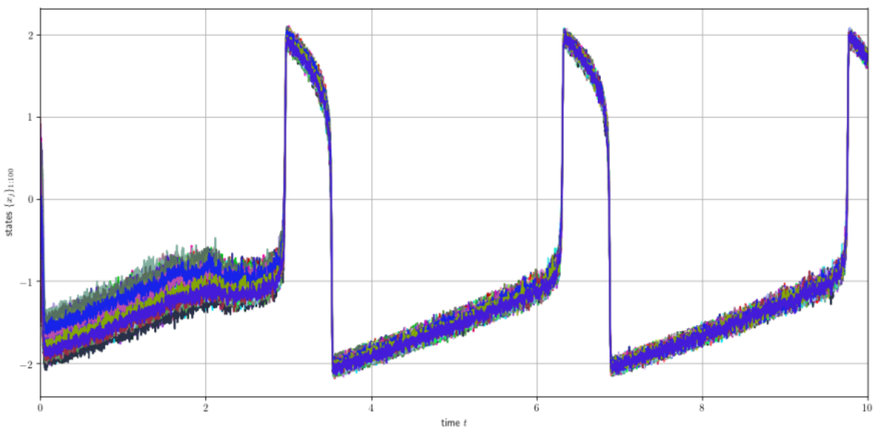
- $\epsilon = 10, \alpha = 0.95$



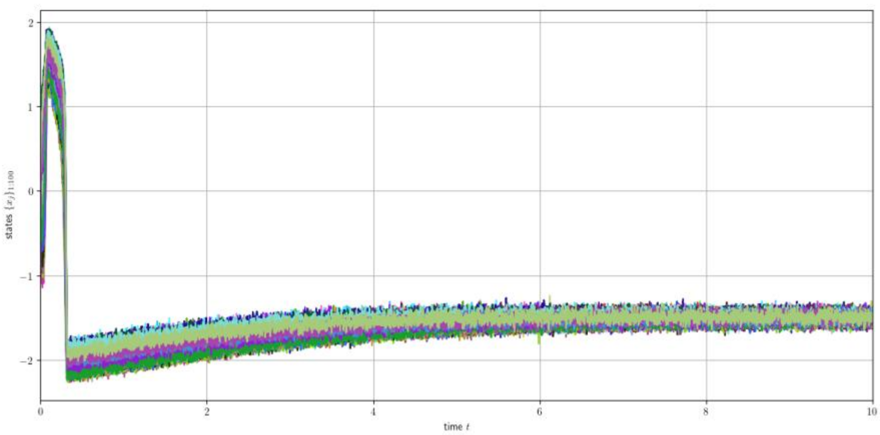
- $\epsilon = 0.01, \alpha = 0$



- $\epsilon = 0.01, \alpha = 1$



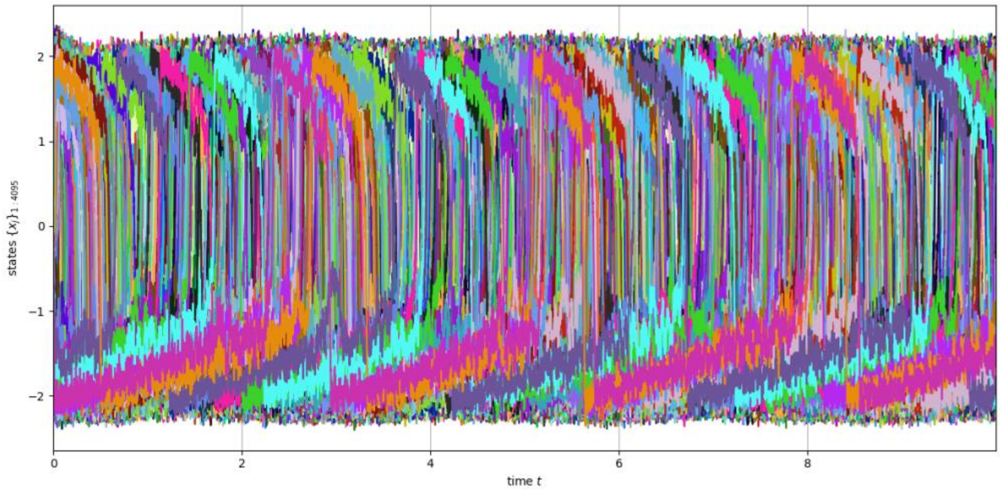
- $\epsilon = 0.01, \alpha = 1.5$



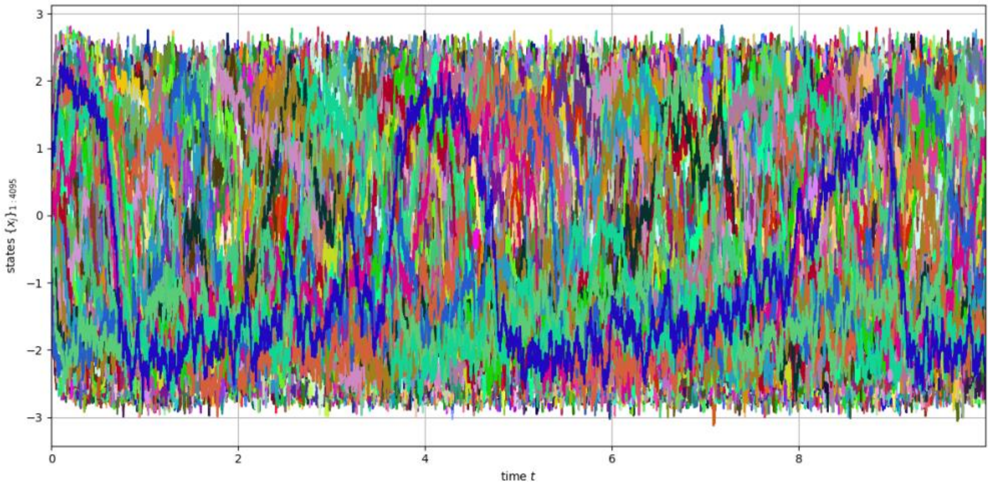
FHN model (DIV25_PREmethod, diffusive coupling function)

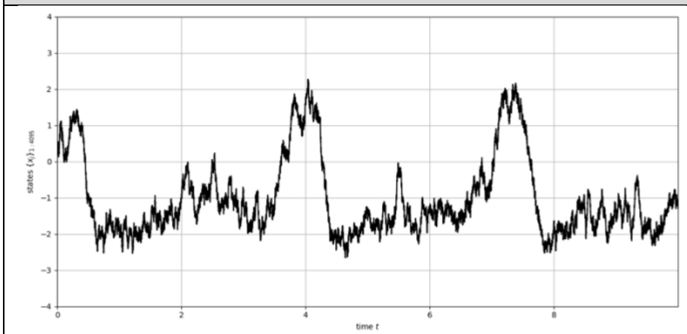
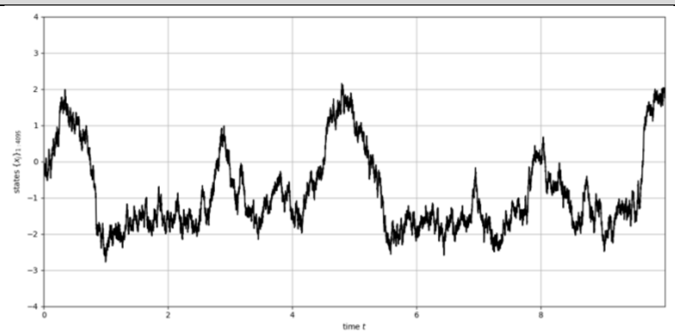
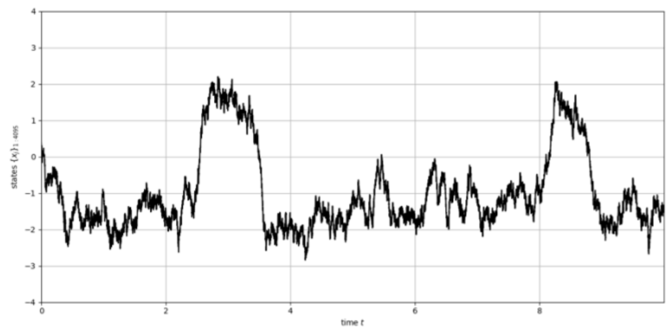
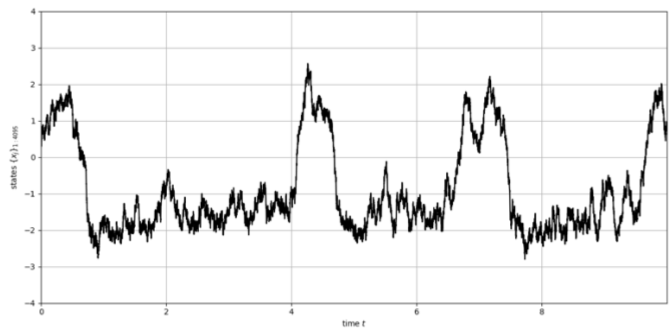
- **Using g_{ij} from "DIV25_PREmethod" (no multiplier)**

- $\epsilon = 0.01, \alpha = 0.95, \sigma_i = 2$



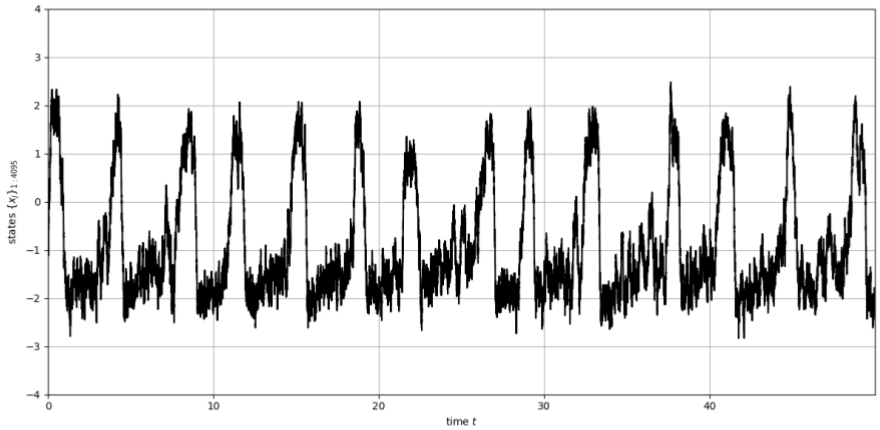
- $\epsilon = 0.1, \alpha = 0.95, \sigma_i = 2$ **(run for $t = 0$ to 10)**



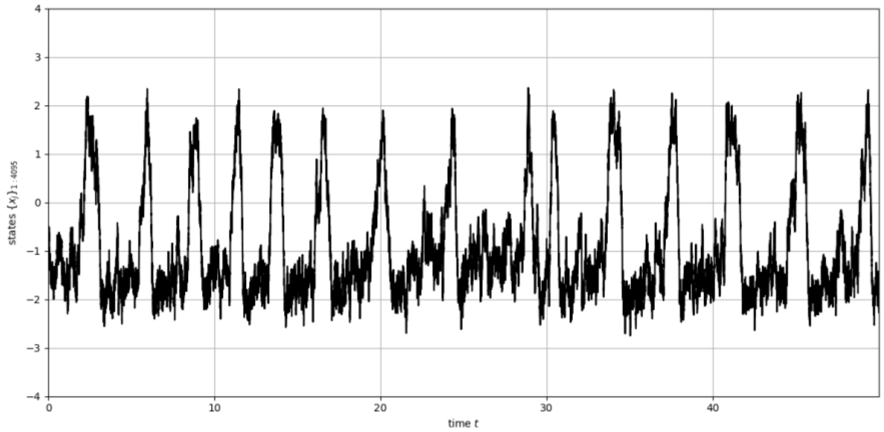
Node 0	Node 1
	
Node 2	**Node 3**
	

- $\epsilon = 0.1, \alpha = 0.95, \sigma_i = 2$ (run for $t = 0$ to 50)

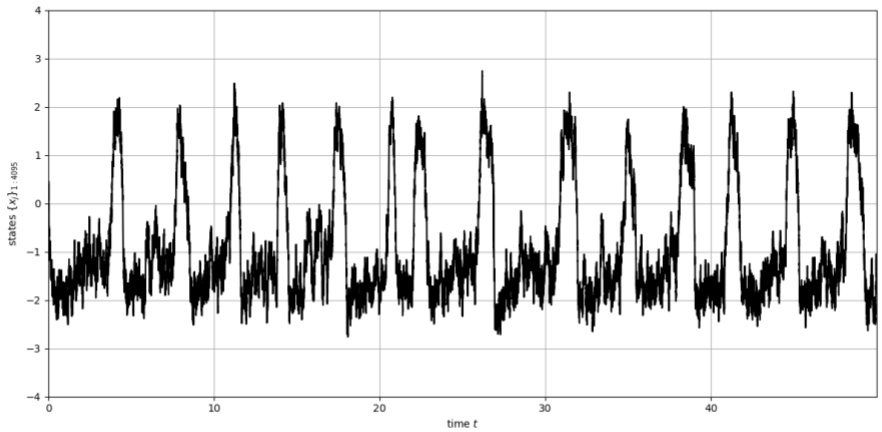
Node 0



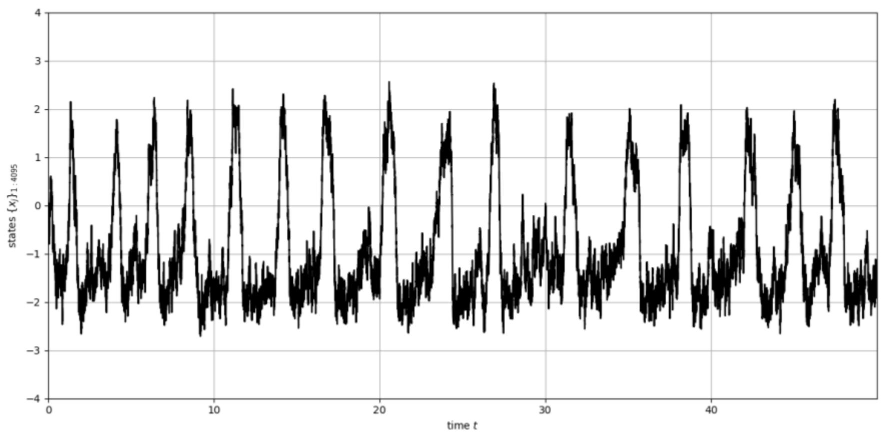
Node 1



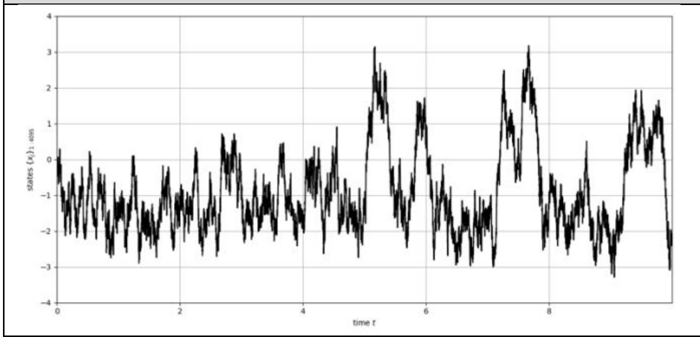
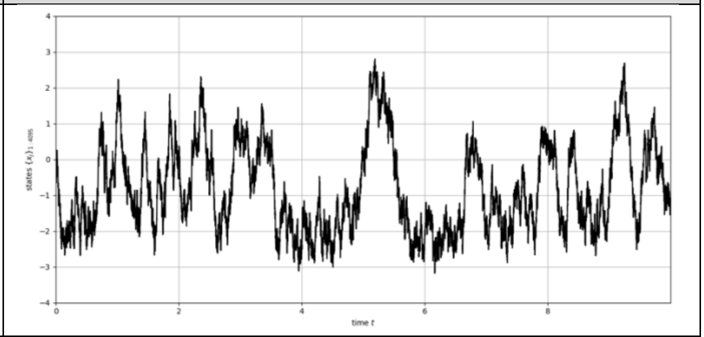
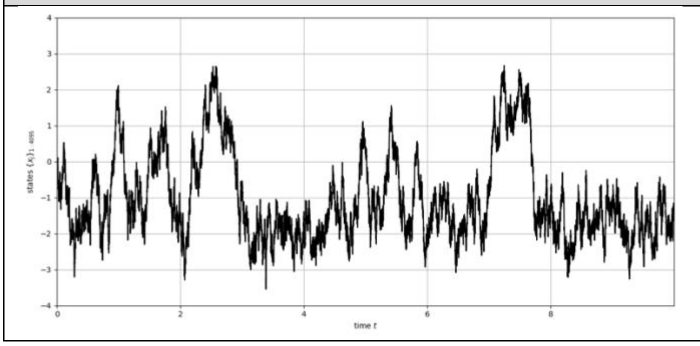
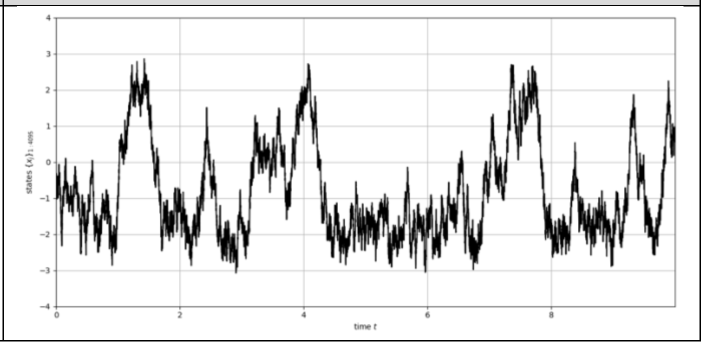
Node 2



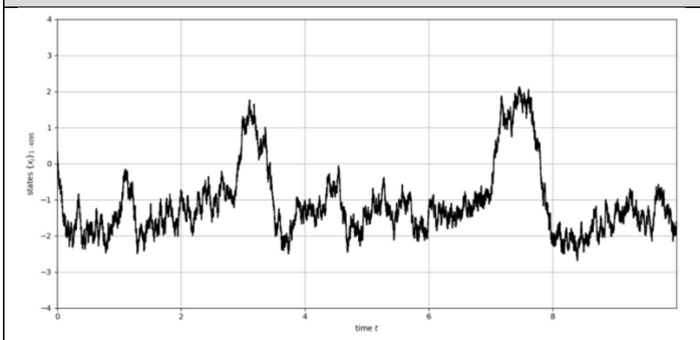
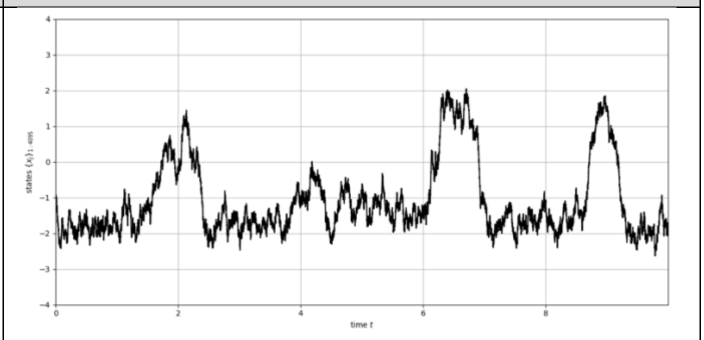
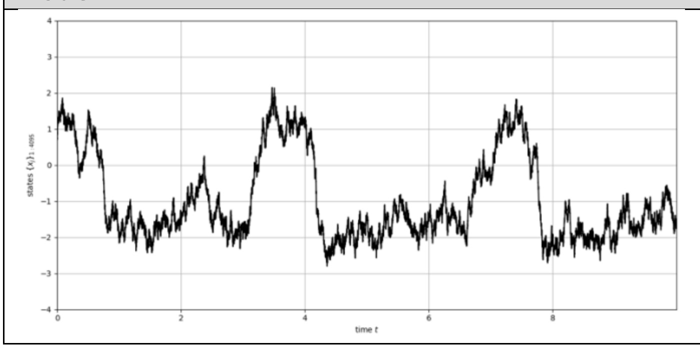
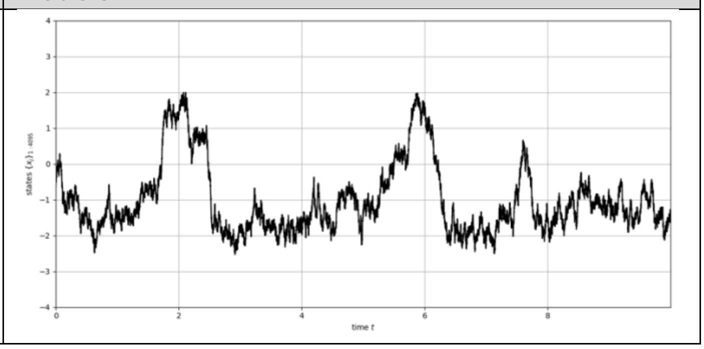
Node 3



- $\epsilon = 0.1, \alpha = 0.95, \sigma_i = 4$

Node 0	Node 1
	
Node 2	**Node 3**
	

- $\epsilon = 0.1, \alpha = 1, \sigma_i = 2$

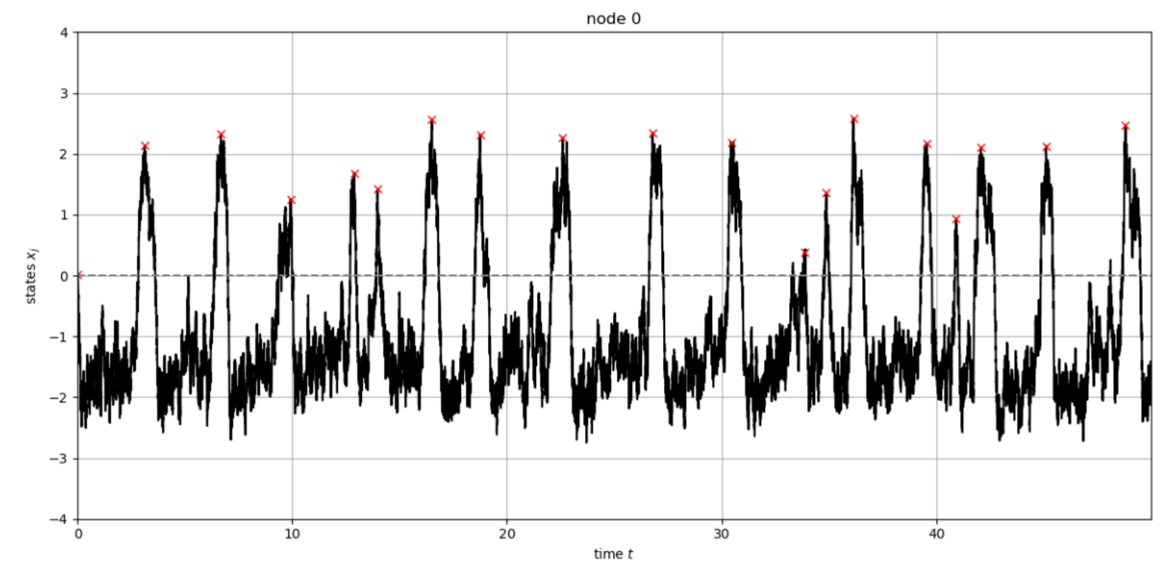
Node 0	Node 1
	
Node 2	**Node 3**
	

Spike analysis (peak distribution, peak vs strength plot)

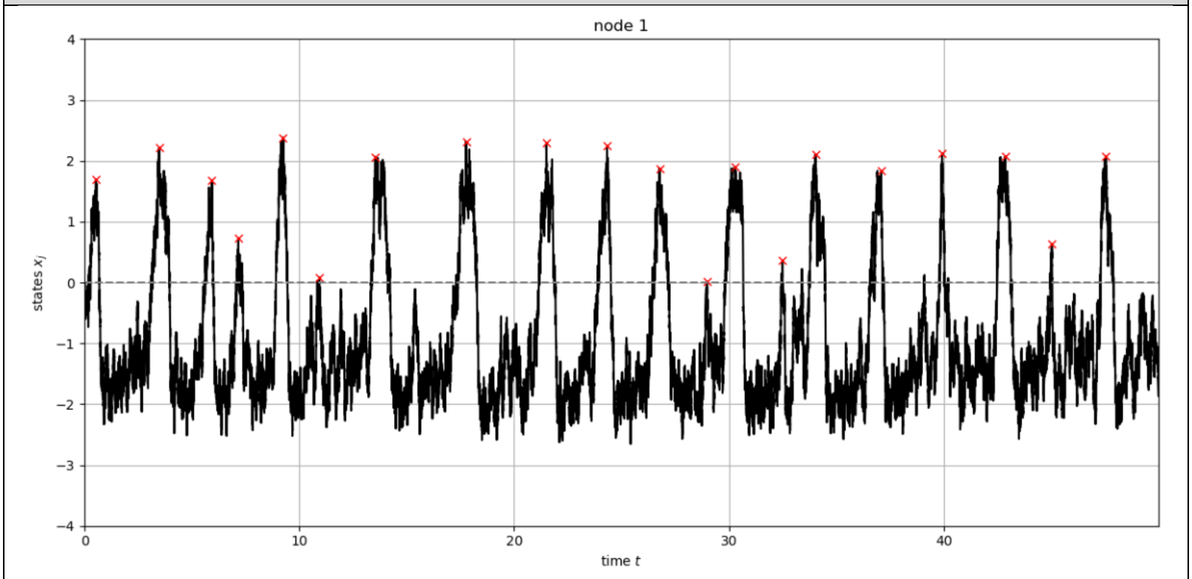
- **Using g_{ij} from "DIV25_PREmethod" (no multiplier)**
- **Parameters $\epsilon = 0.1, \alpha = 0.95, \sigma_i = 2$**

- **Examples of peaks (node 0 & 1)**
  - **Criteria: above 0; at least 1 unit of time apart**

Node 0

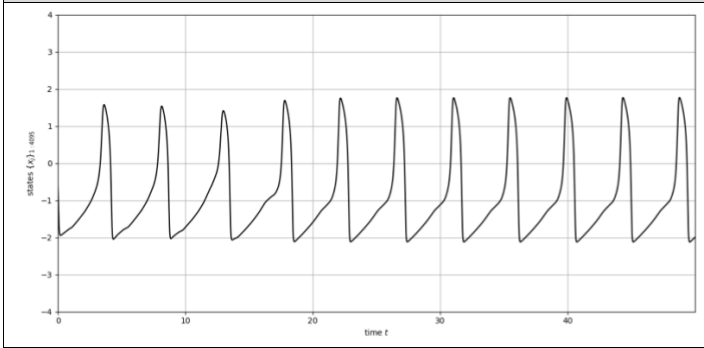


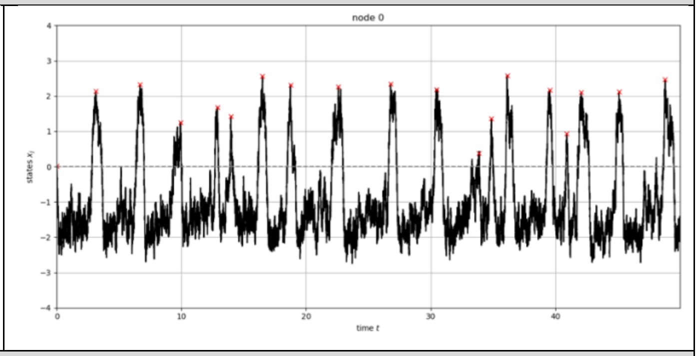
Node 1



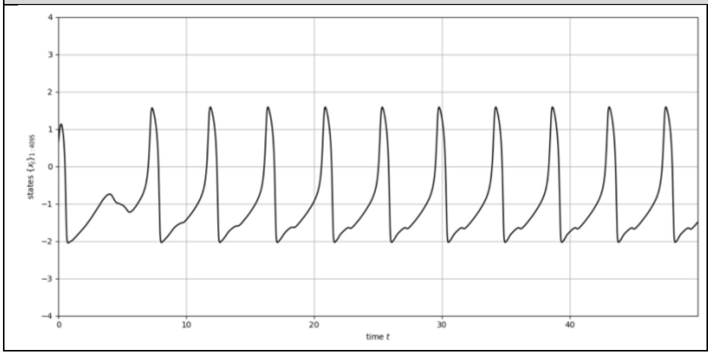
- **Noise-free time series as comparison**

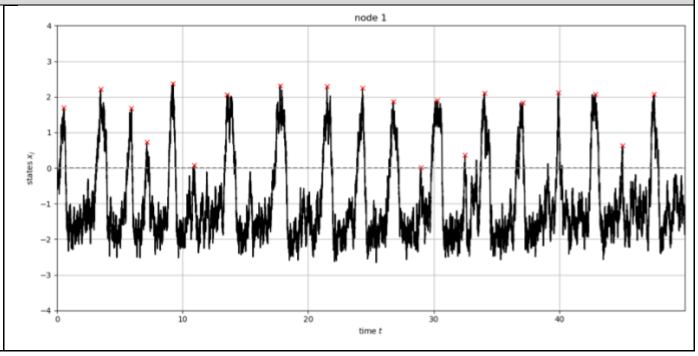
Node 0



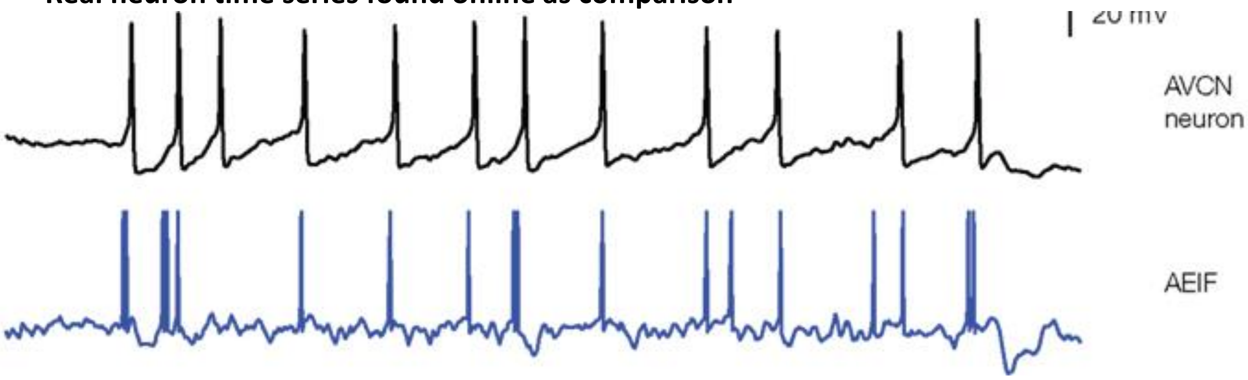


Node 1

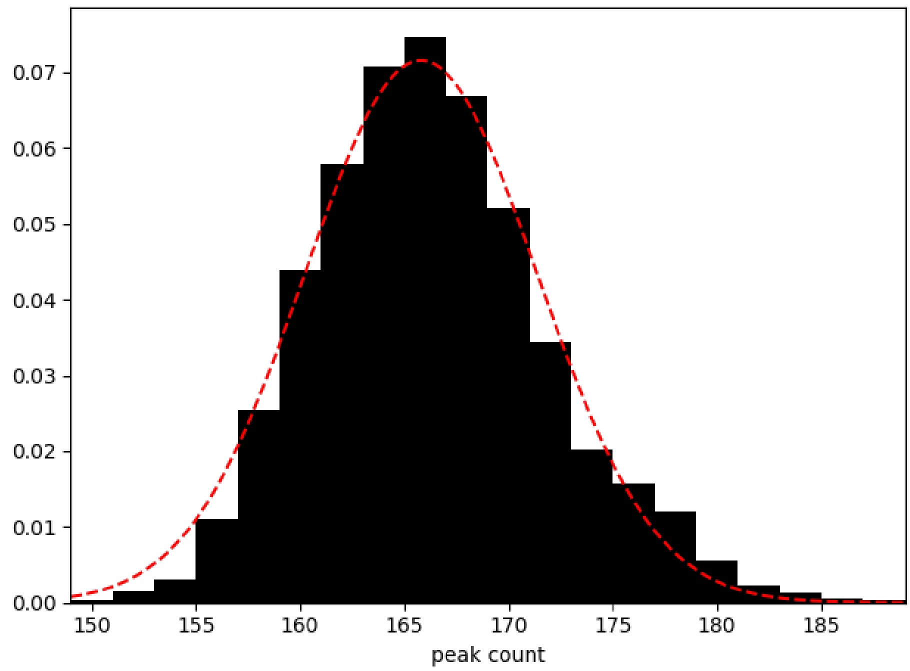




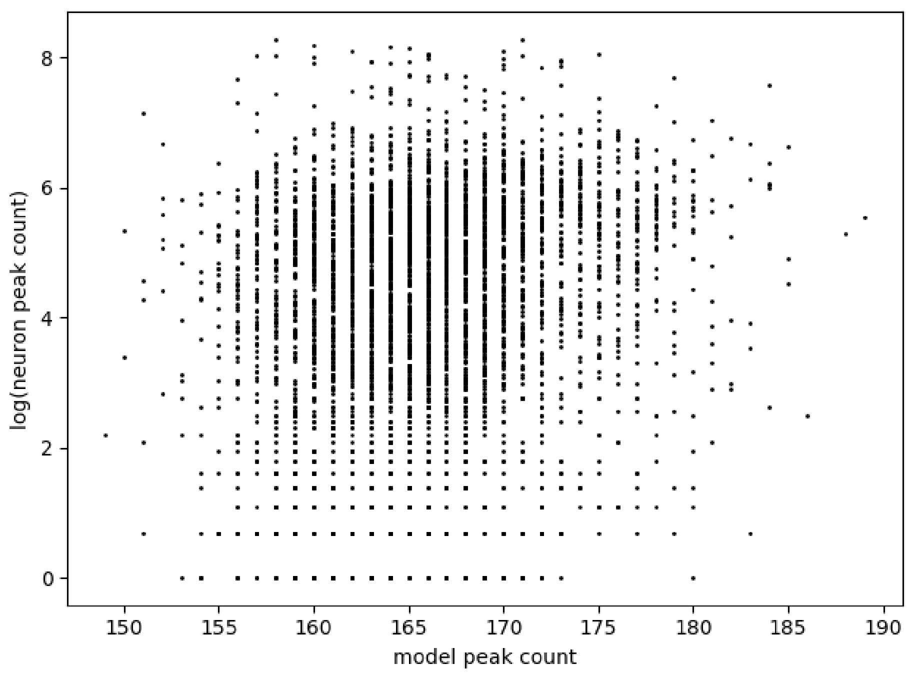
- **Real neuron time series found online as comparison**



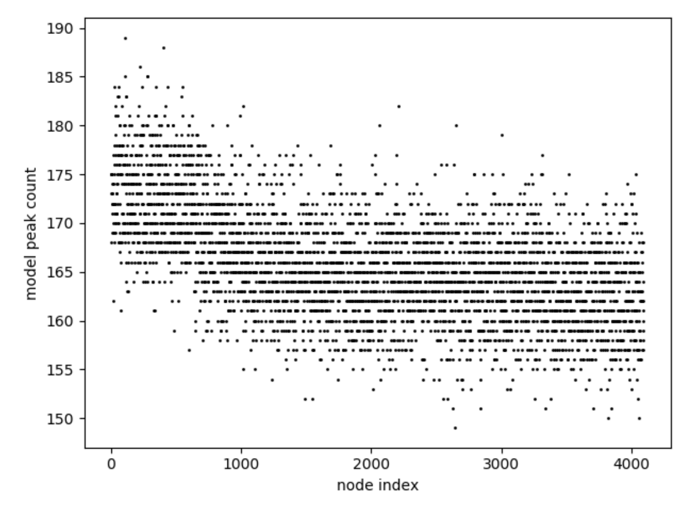
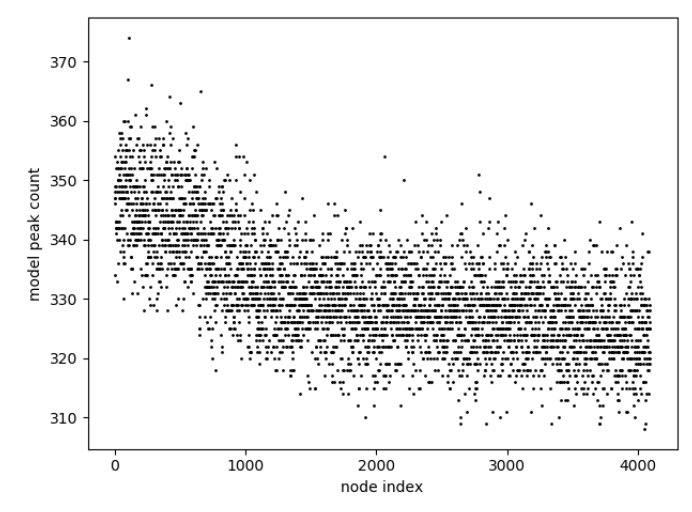
- Distribution of number of peaks (slightly heavy-tailed) [over 1e6 steps]
    - Median = 165, Min = 149, Max = 189 (Max-Median > Median-Min)
    - Mean = 165.7985 > Median
    - Skewness = 0.4002 (right-skewed)
    - (Excess) Kurtosis = 0.2204 (heavier tails than Gaussian)
    - Dotted line: Gaussian with same mean and s.d.



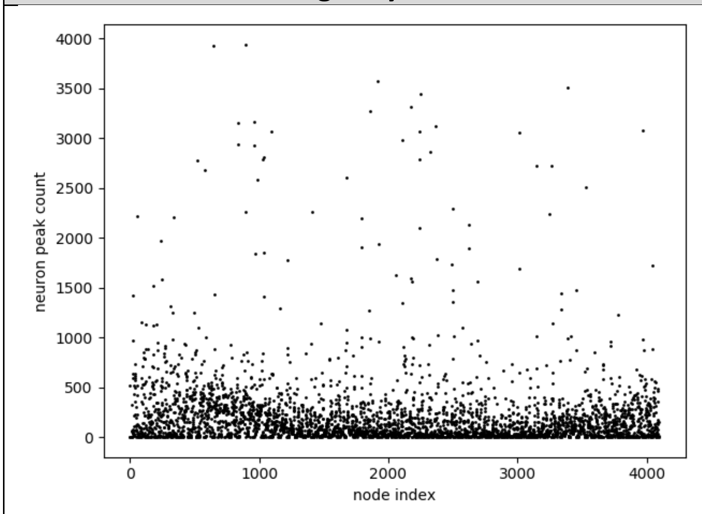
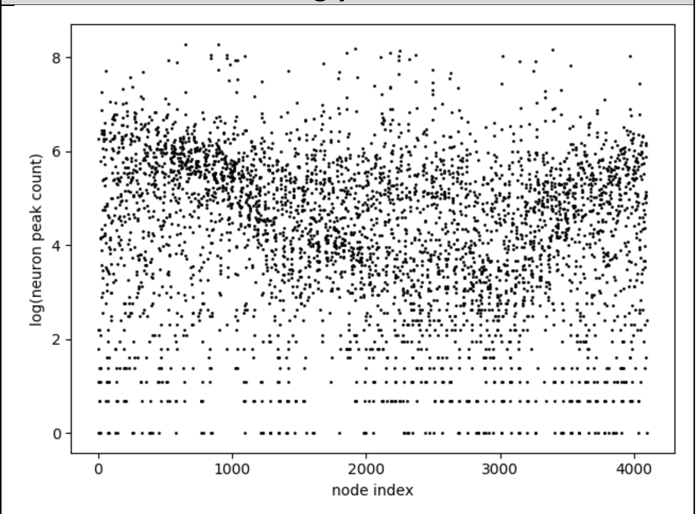
- Model peaks vs experimentally measured peaks (not similar)
    - Log scale for y-axis



- Model peaks vs node index
  - Larger peak counts for first 1000 nodes
  - Fairly uniform for other nodes
  - Does network connectivity (including in-degrees and in-strengths) cause this? [next two pages]

<table>
<tr><th>1e6 steps</th><th>2e6 steps</th></tr>
<tr><td></td><td></td></tr>
</table>

- Real peaks vs node index
  - First 1000 nodes generally also have larger peak counts
  - Log-y plot: for first 1000 nodes, quite a lot of points concentrate around y=6

<table>
<tr><th>No log for y-axis</th><th>Log y-axis</th></tr>
<tr><td></td><td></td></tr>
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- **Analysis of connectivity in adjacency matrix**
    - **(?) higher occupancy for first 1000 nodes causes the larger peak counts**

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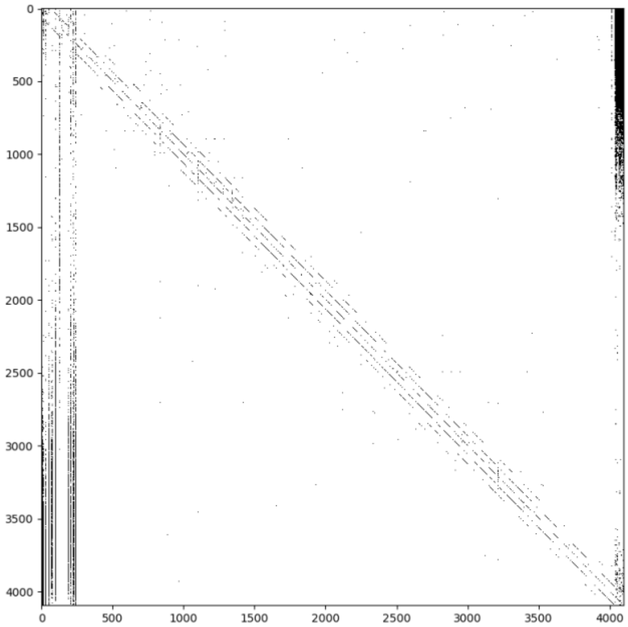
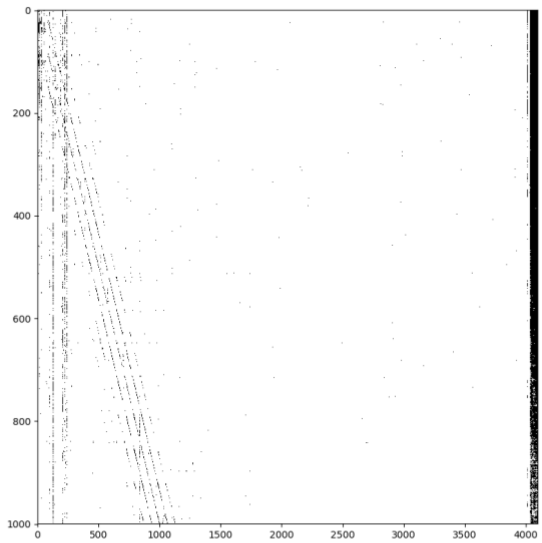
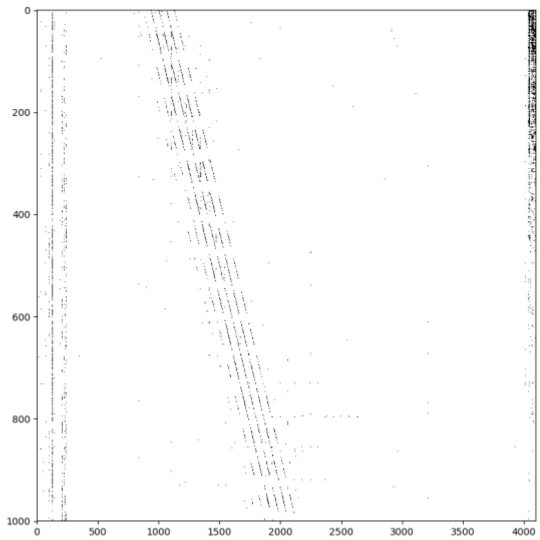
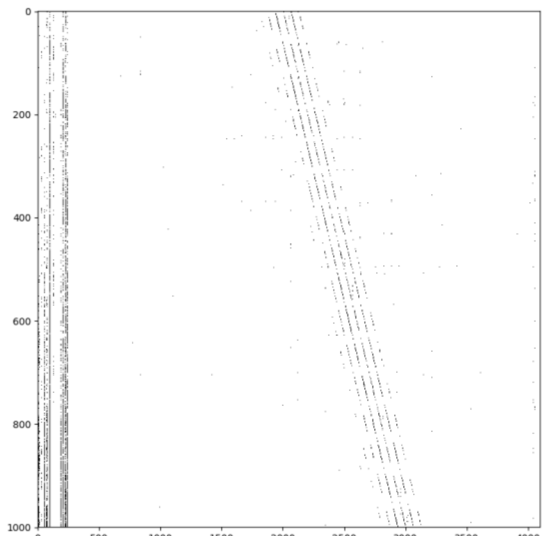
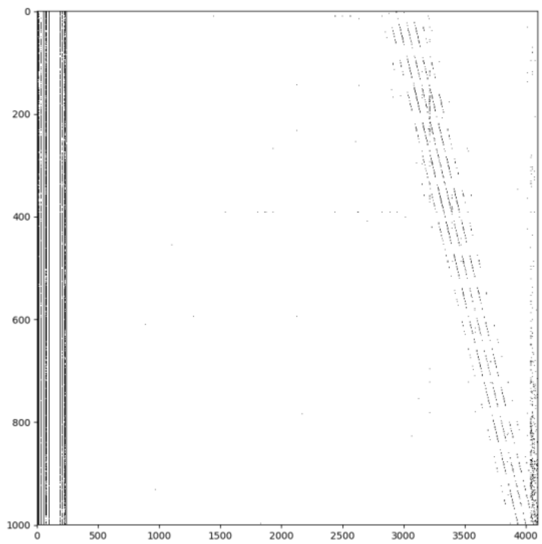
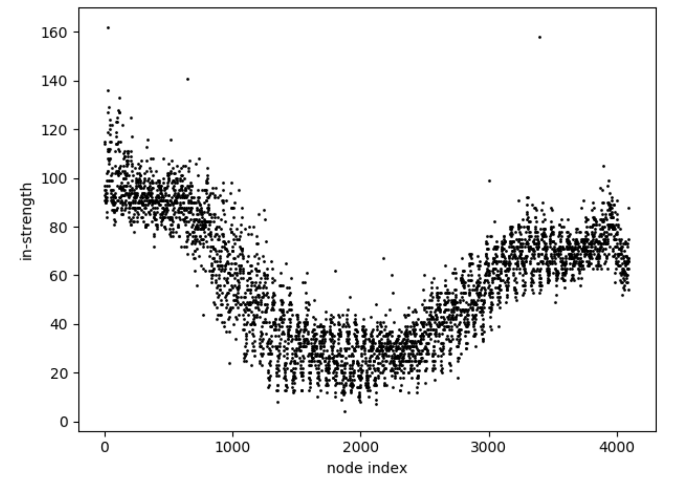
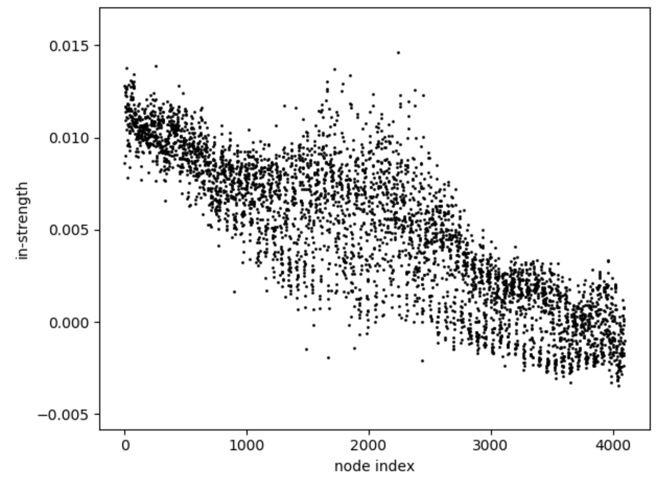
<tr><td colspan="2"></td></tr>
<tr><th>Node 0 to 1000 (2.14% occupied)</th><th>Node 1000 to 2000 (0.89% occupied)</th></tr>
<tr><td></td><td></td></tr>
<tr><th>Node 2000 to 3000 (0.91% occupied)</th><th>Node 3000 to 4000 (1.71% occupied)</th></tr>
<tr><td></td><td></td></tr>
</table>

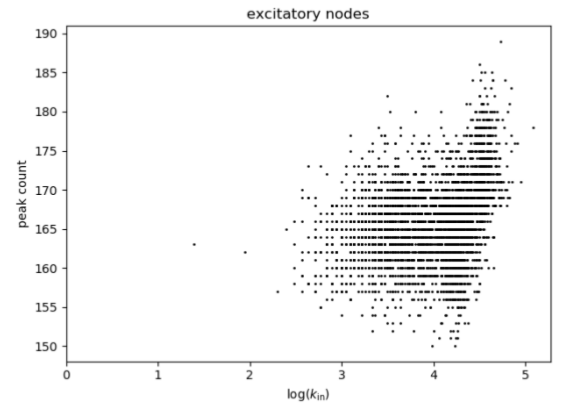
- **Analysis of in-degrees and in-strengths (vs node index)**
    - **First 1000 nodes have relatively more in-degrees and stronger in-strengths than the other nodes**
    - **(?) higher model peak counts for first 1000 nodes could be a reflection of such feature**

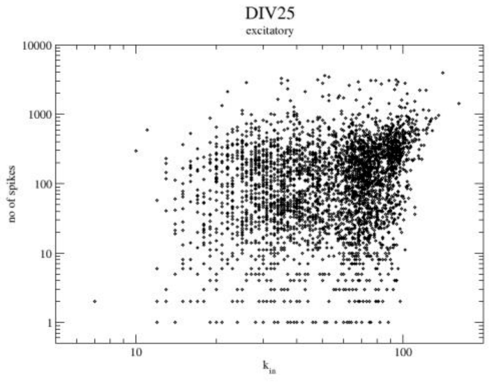
In-degrees	In-strengths
	

Peak count vs network features

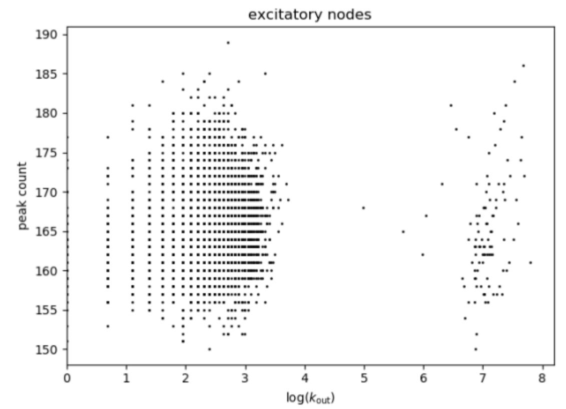
- Excitatory nodes

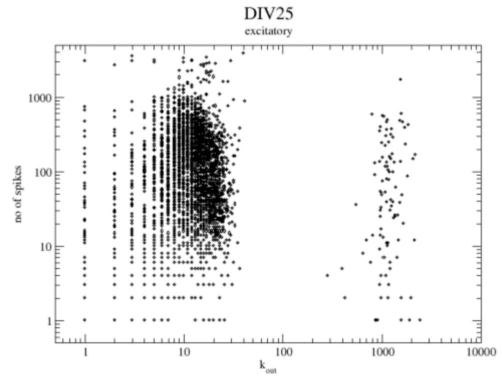
Peak count vs log k_in



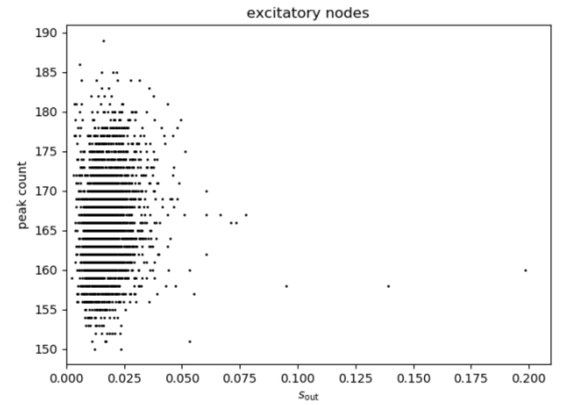


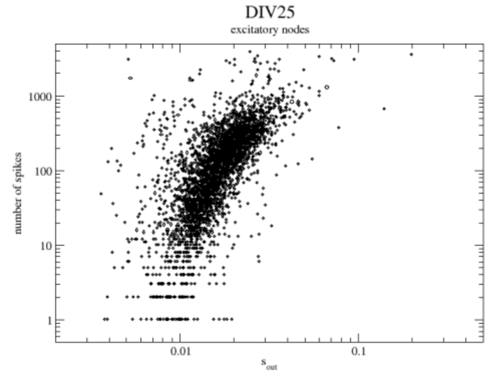
Peak count vs log k_out



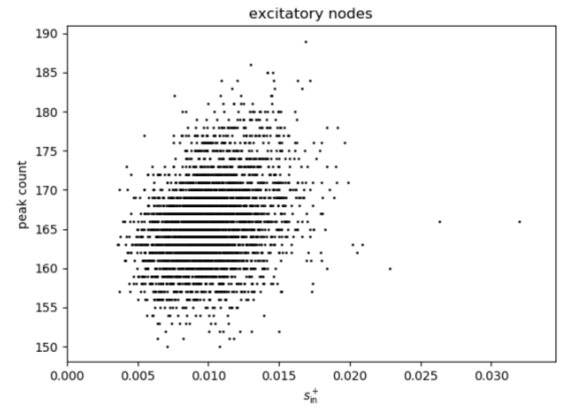


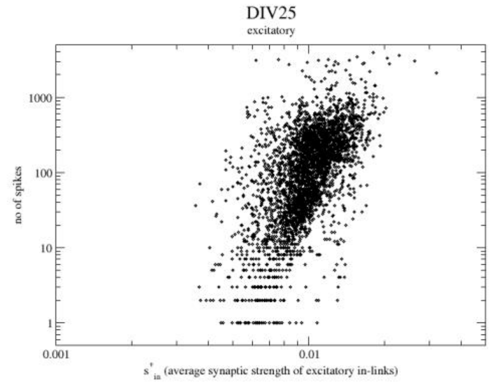
Peak count vs s_out





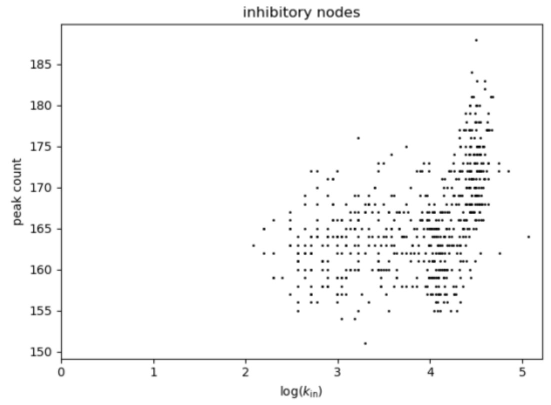
Peak count vs s^+_in

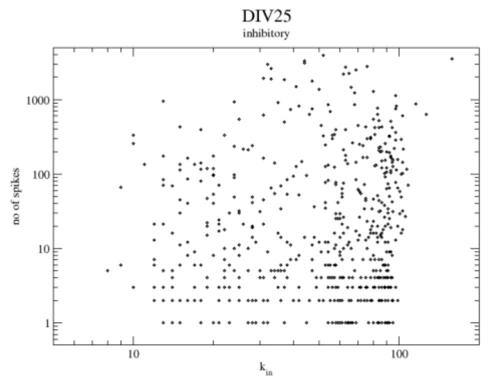




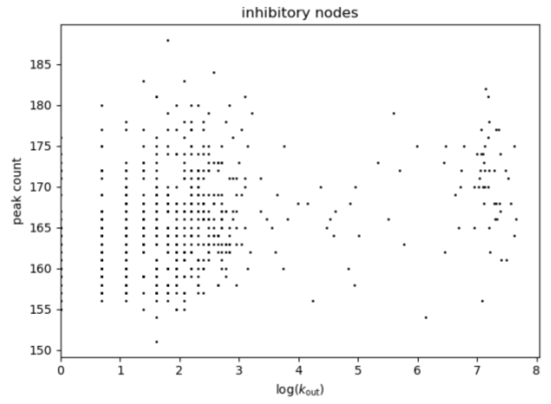
- **Inhibitory nodes**

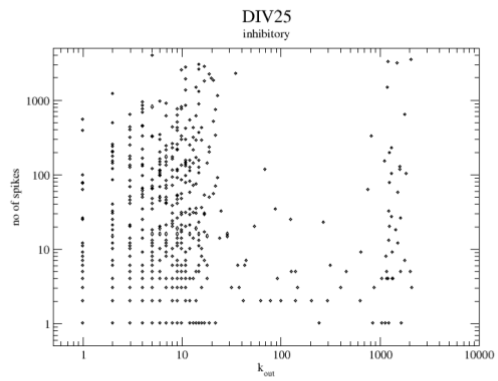
Peak count vs log k_in



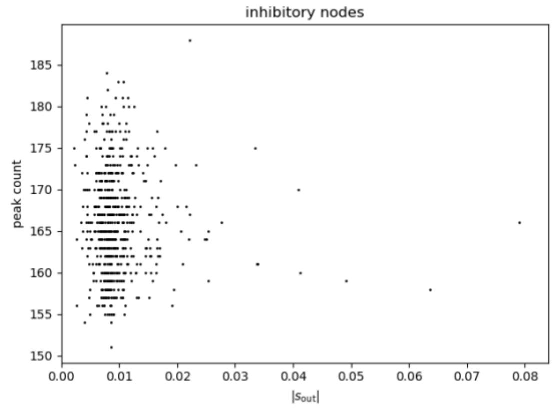


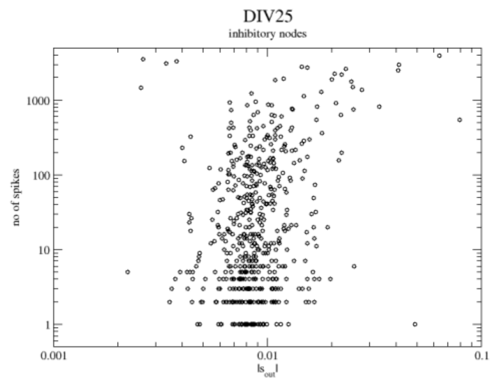
Peak count vs log k_out



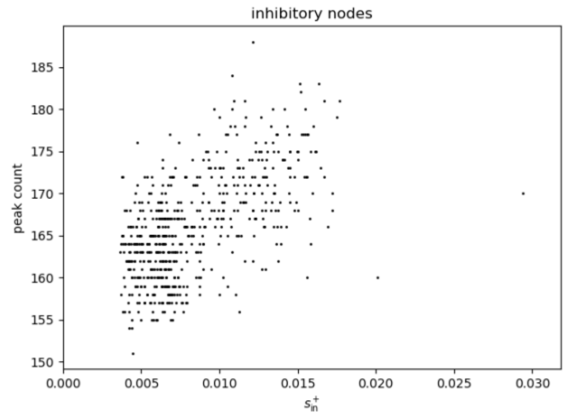


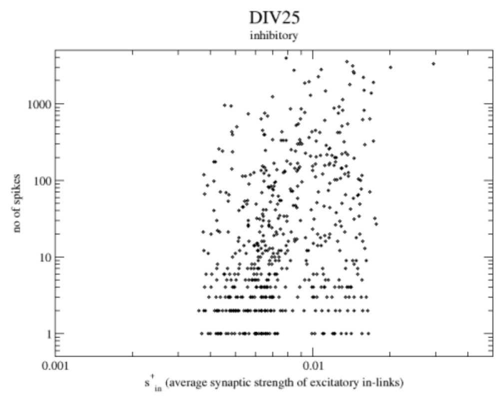
Peak count vs |s_out|





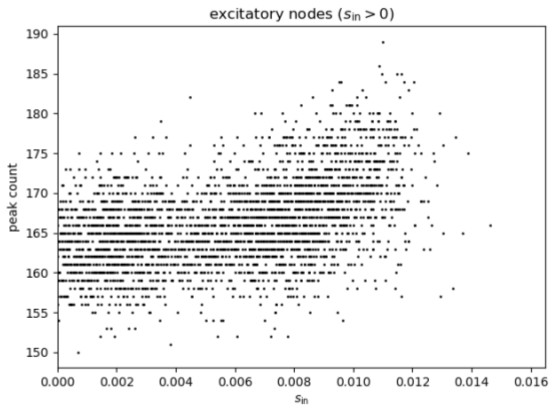
Peak count vs s^+_in

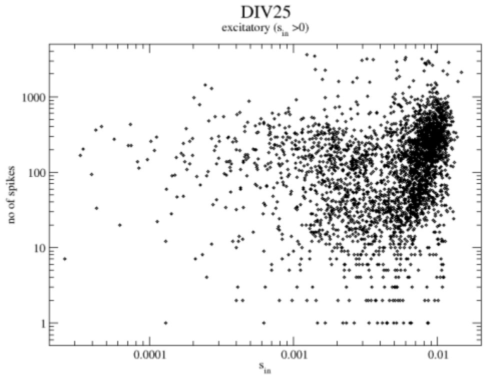




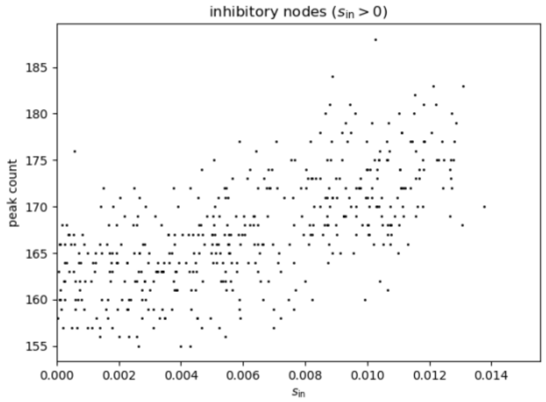
- **Mixed (x-axis: s_in or |s_in|)**

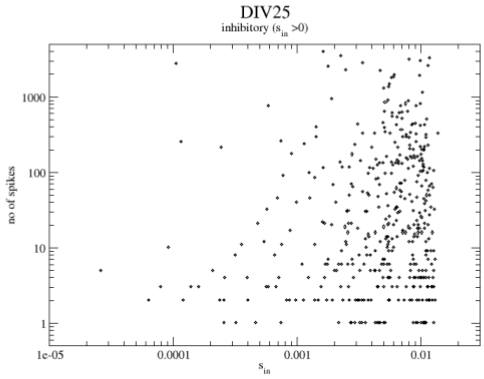
s_in > 0 & s_out > 0



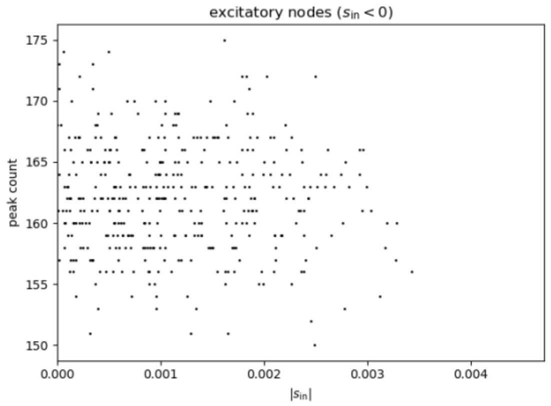


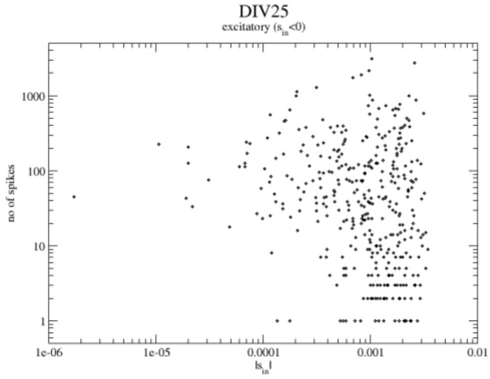
s_in > 0 & s_out < 0



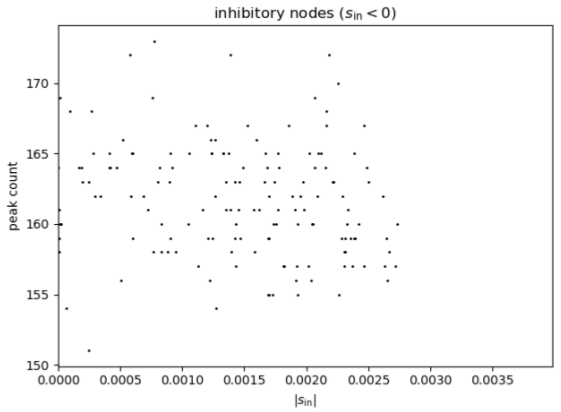


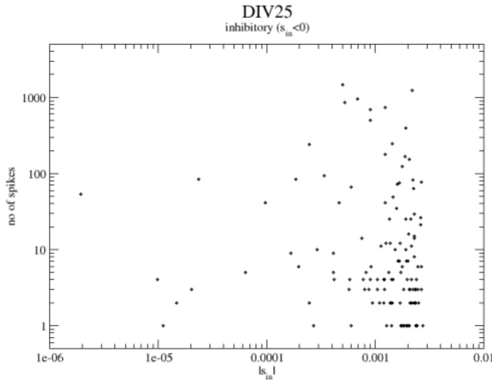
s_in < 0 & s_out > 0



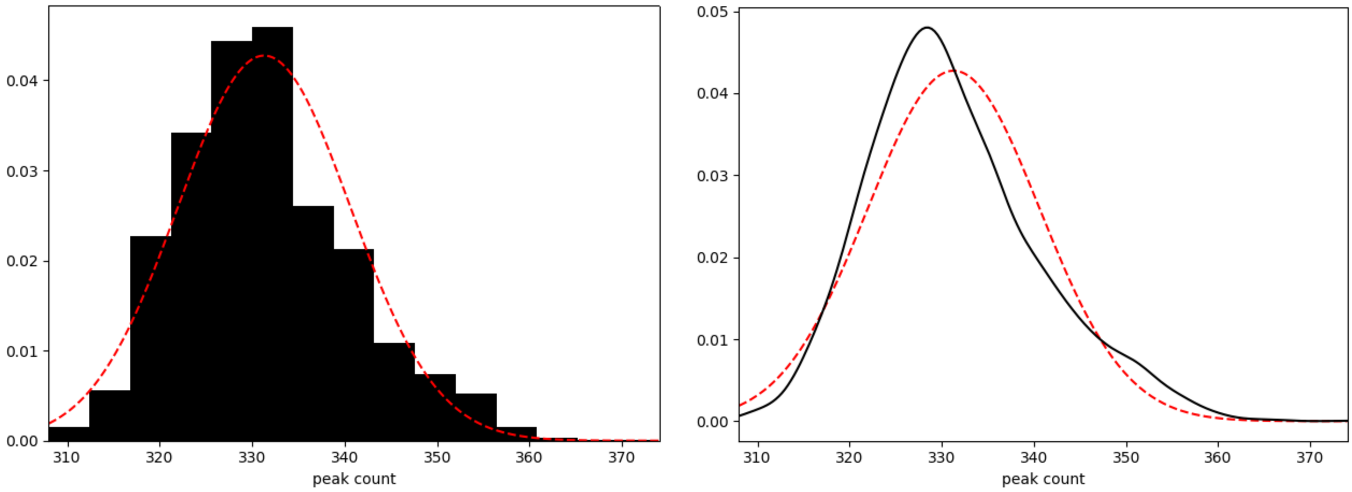


s_in < 0 & s_out < 0

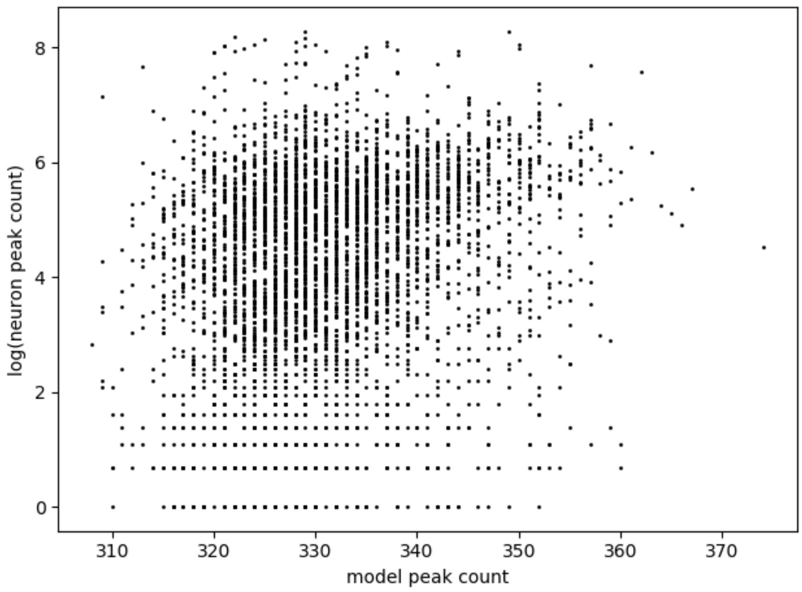




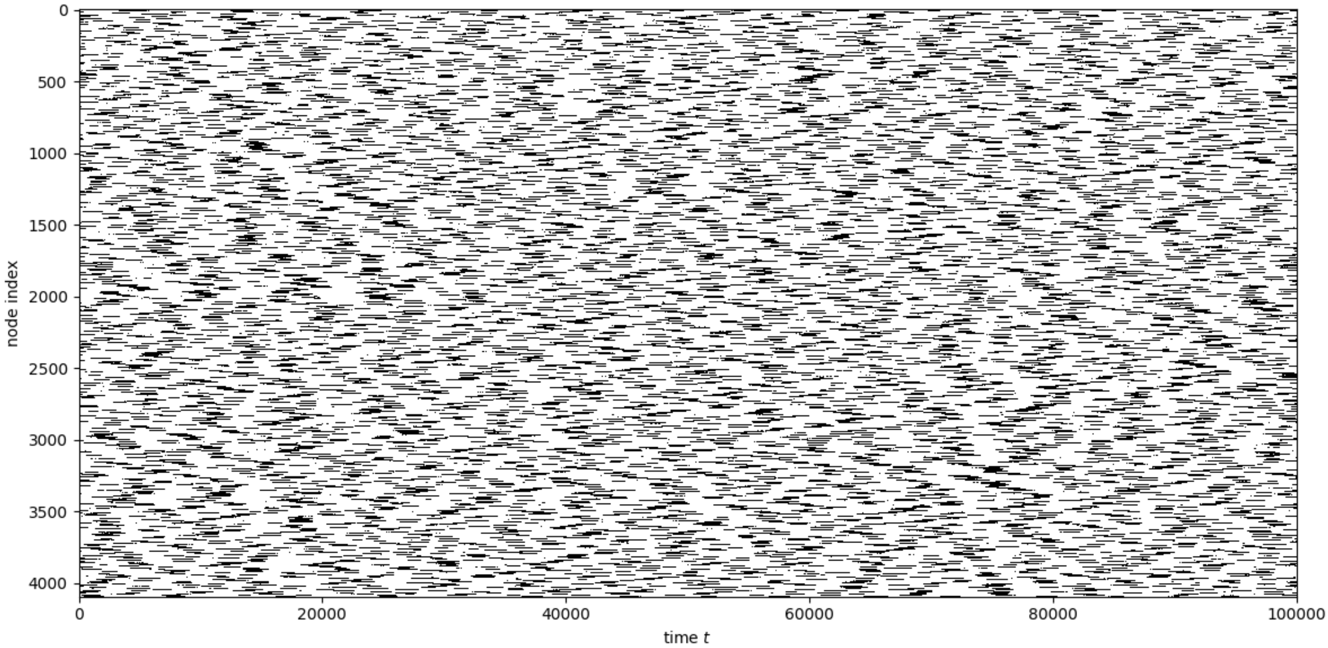
- **Distribution of number of peaks (slightly heavy-tailed) [over 2e6 steps]**
    - **Median = 330, Min = 308, Max = 374 (Max-Median > Median-Min)**
    - **Mean = 331.2886 > Median**
    - **Skewness = 0.5945 (right-skewed)**
    - **(Excess) Kurtosis = 0.2684 (heavier tails than Gaussian)**
    - **Dotted line: Gaussian with same mean and s.d.**



- **Model peaks vs experimentally measured peaks (not similar)**
    - **Log scale for y-axis**



- **Raster plot [1e5 steps]**

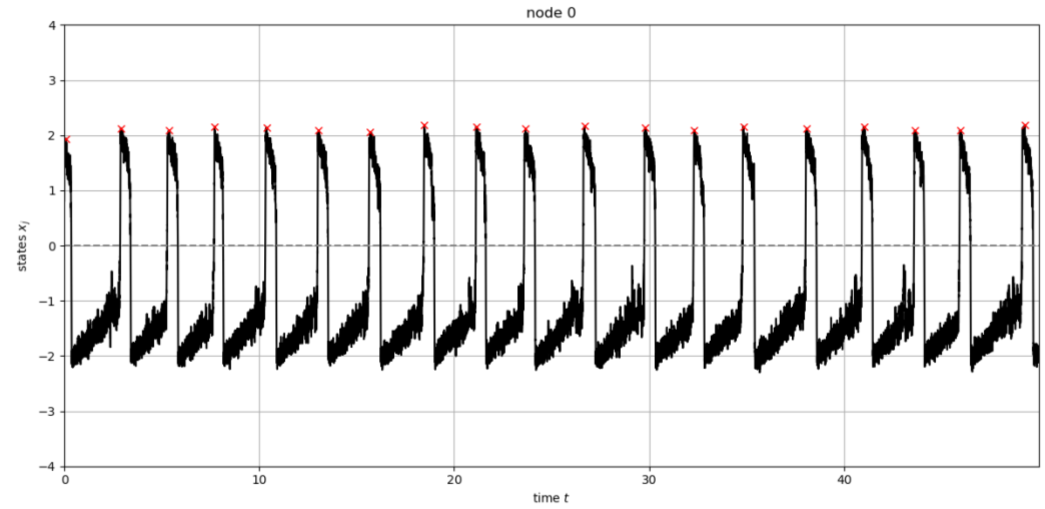


More spike analysis (other parameters)

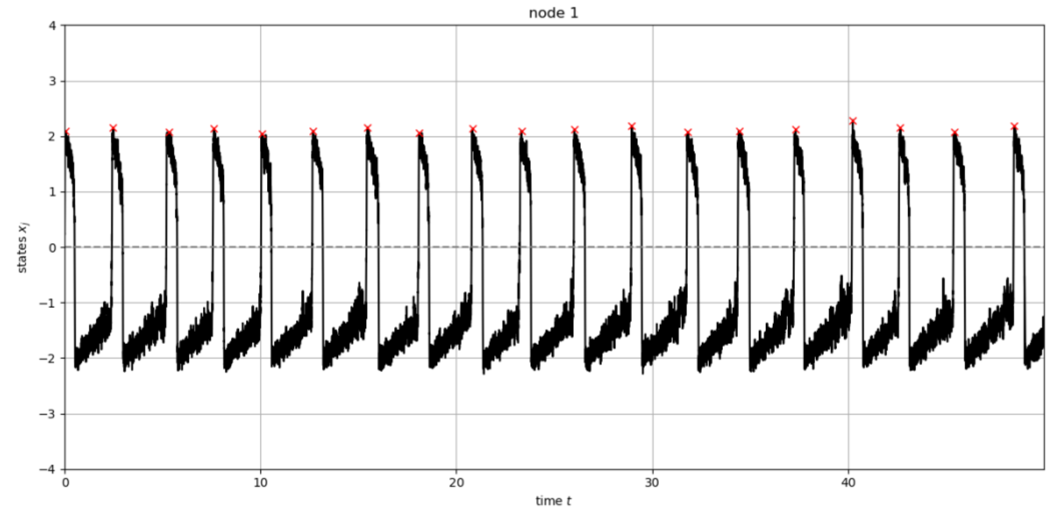
- Using g_{ij} from "DIV25_PREmethod" (no multiplier)
- Parameters $\epsilon = 0.01, \alpha = 0.95, \sigma_i = 2$

- Examples of peaks (node 0 & 1)
  - Criteria: above 0; at least 1 unit of time apart

Node 0

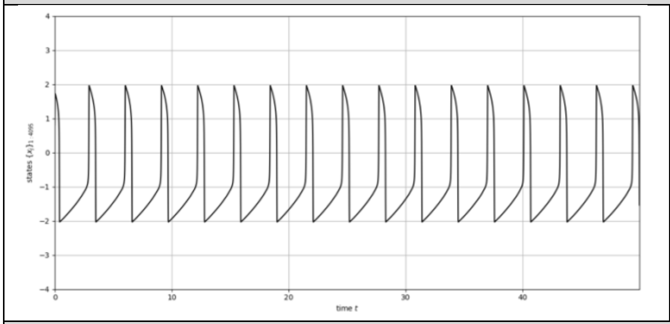


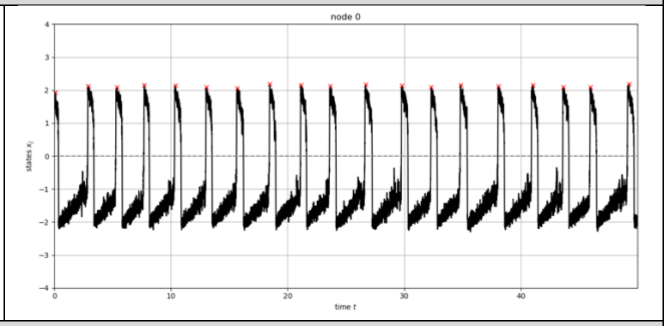
Node 1



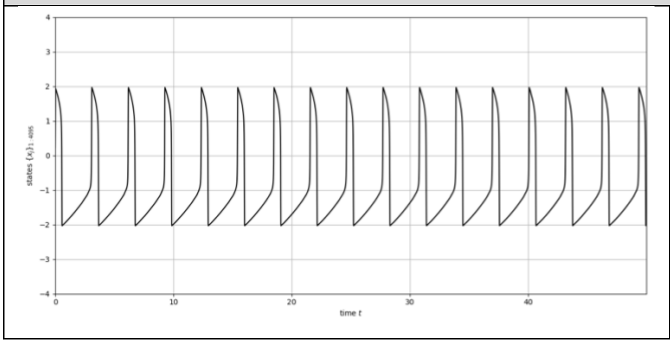
- **Noise-free time series as comparison (near periodic)**

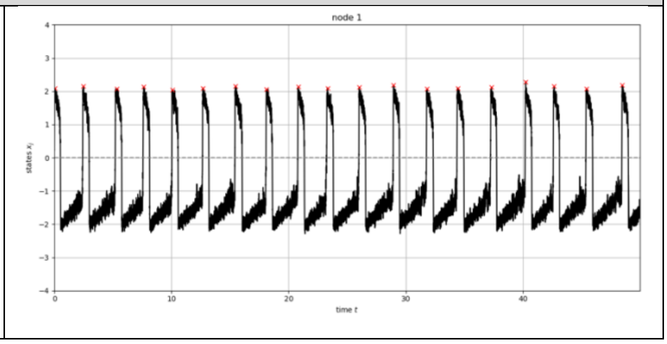
Node 0



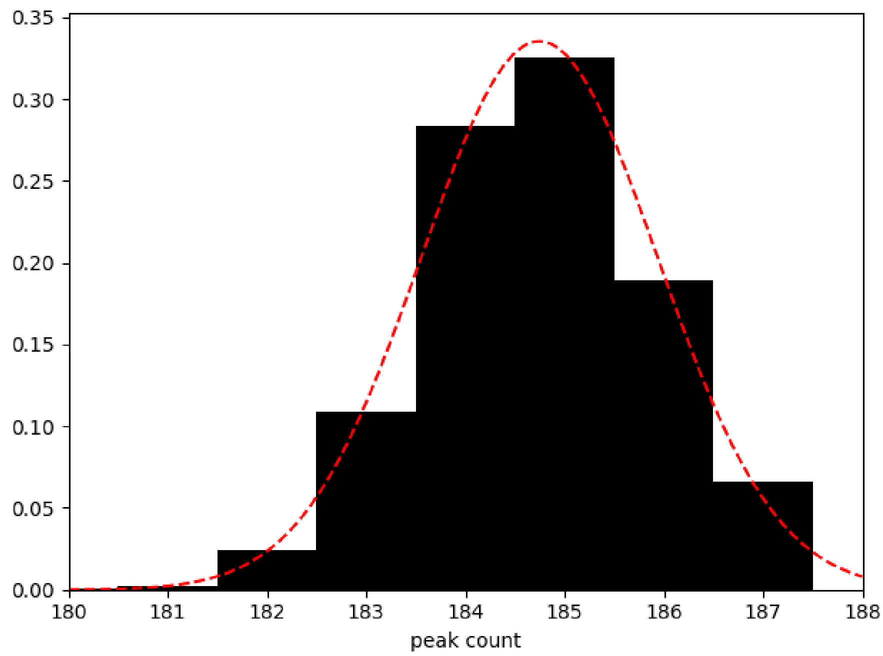


Node 1

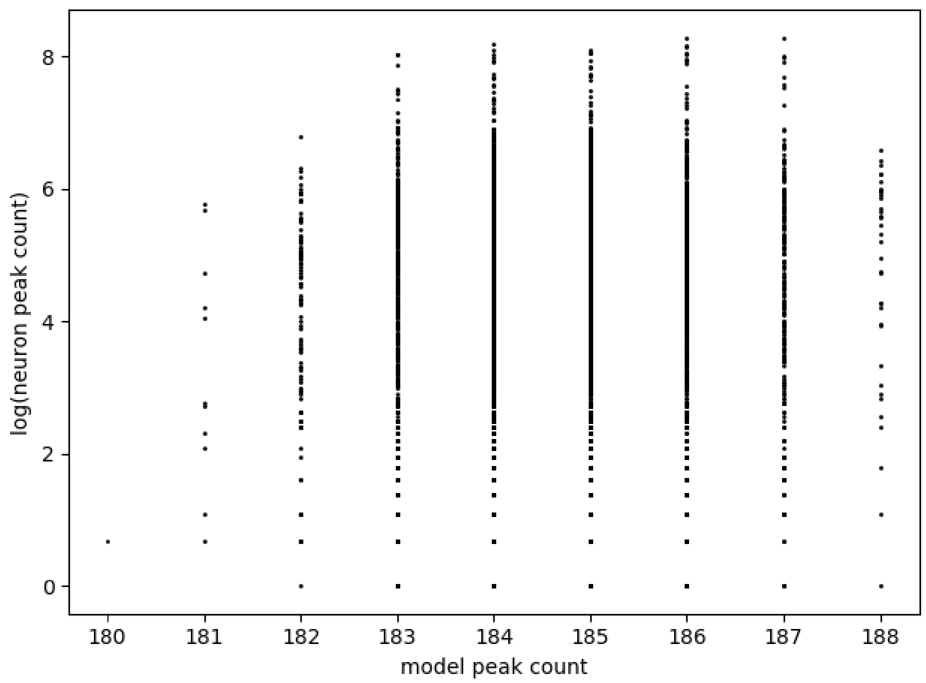




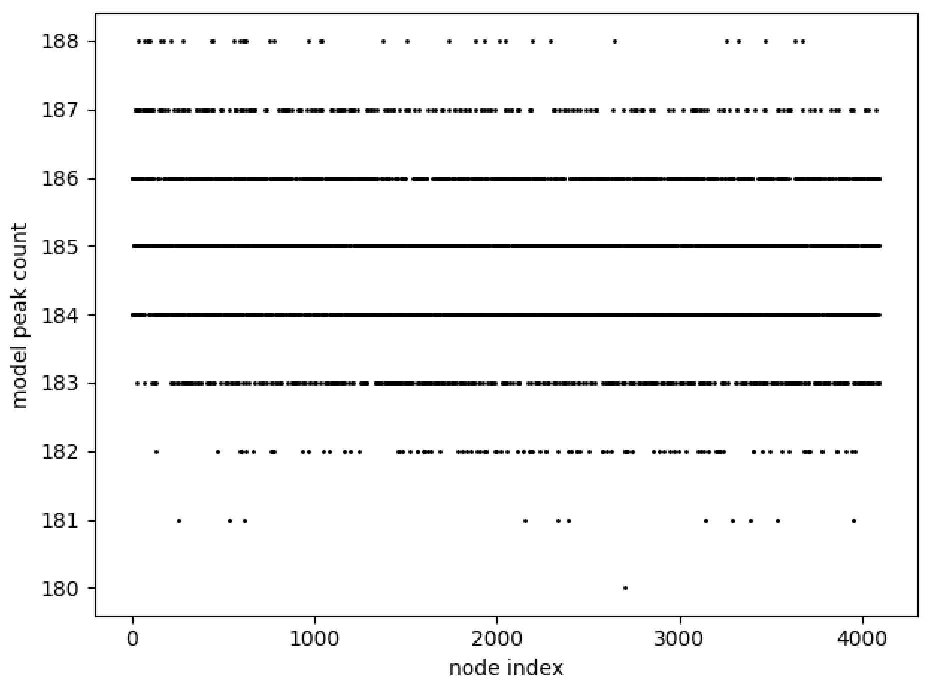
- **Distribution of number of peaks (near normal) [over 1e6 steps]**
  - **Median = 185, Min = 180, Max = 188**
  - **Mean = 184.7443 < Median**
  - **Skewness = -0.0100**
  - **(Excess) Kurtosis = 0.0148**
  - **Dotted line: Gaussian with same mean and s.d.**



- **Model peaks vs experimentally measured peaks (not similar)**
    - **Log scale for y-axis**



- **Model peaks vs node index**

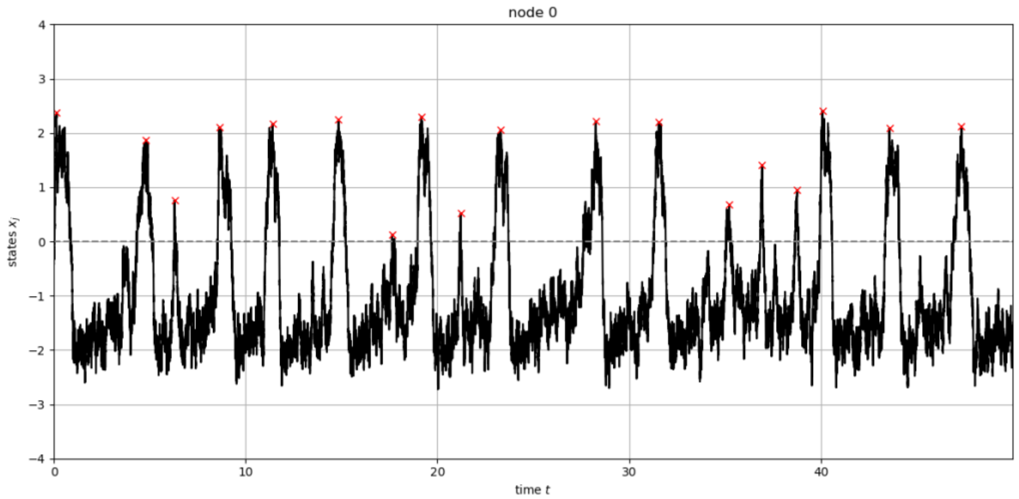


More spike analysis (other parameters)

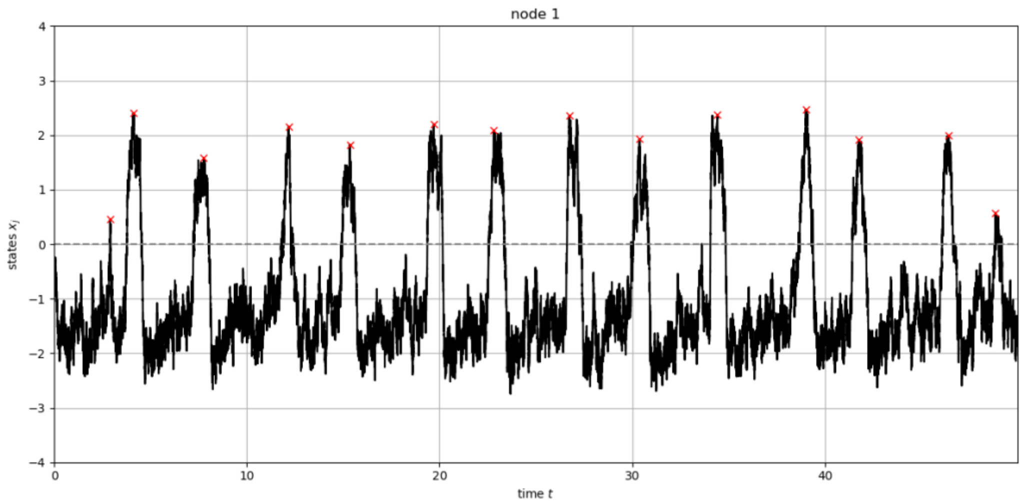
- **Using g_{ij} from "DIV25_PREmethod" (no multiplier)**
- **Parameters $\epsilon = 0.1, \alpha = 1, \sigma_i = 2$**

- **Examples of peaks (node 0 & 1)**
  - **Criteria: above 0; at least 1 unit of time apart**

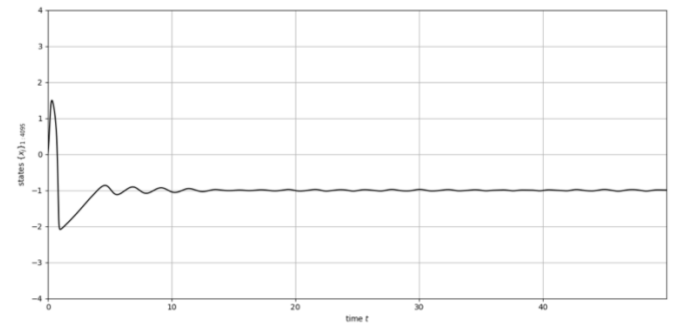
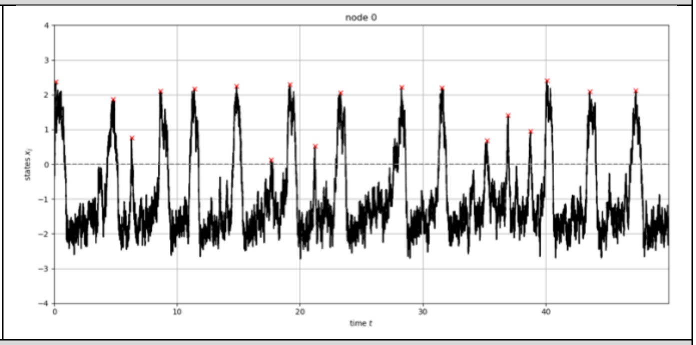
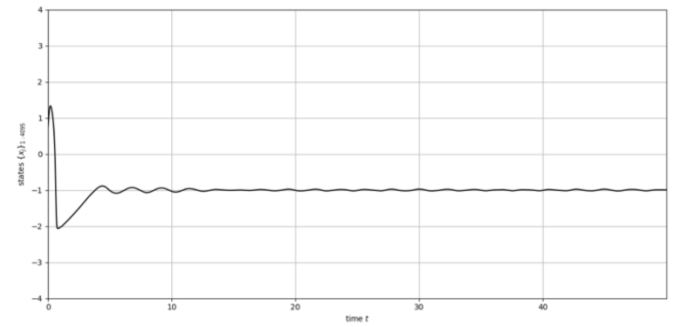
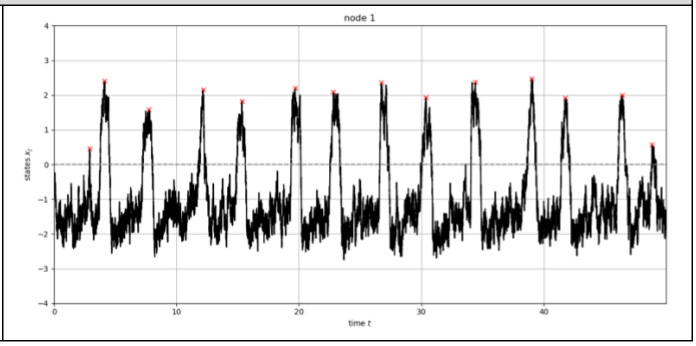
Node 0



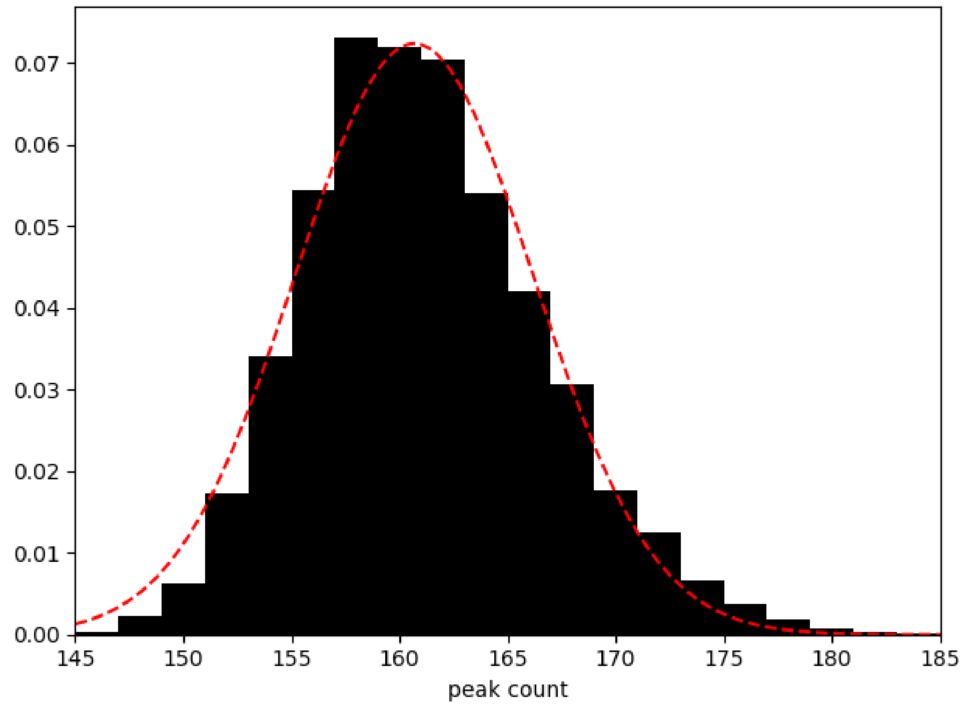
Node 1



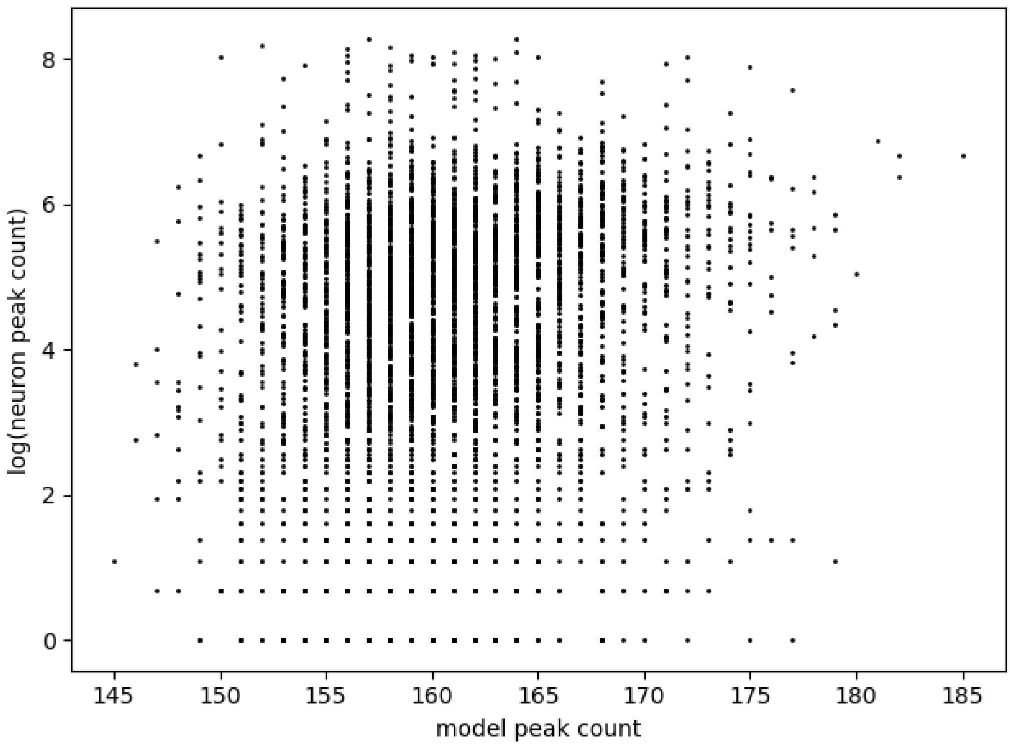
- **Noise-free time series as comparison**

Node 0	
	
Node 1	
	

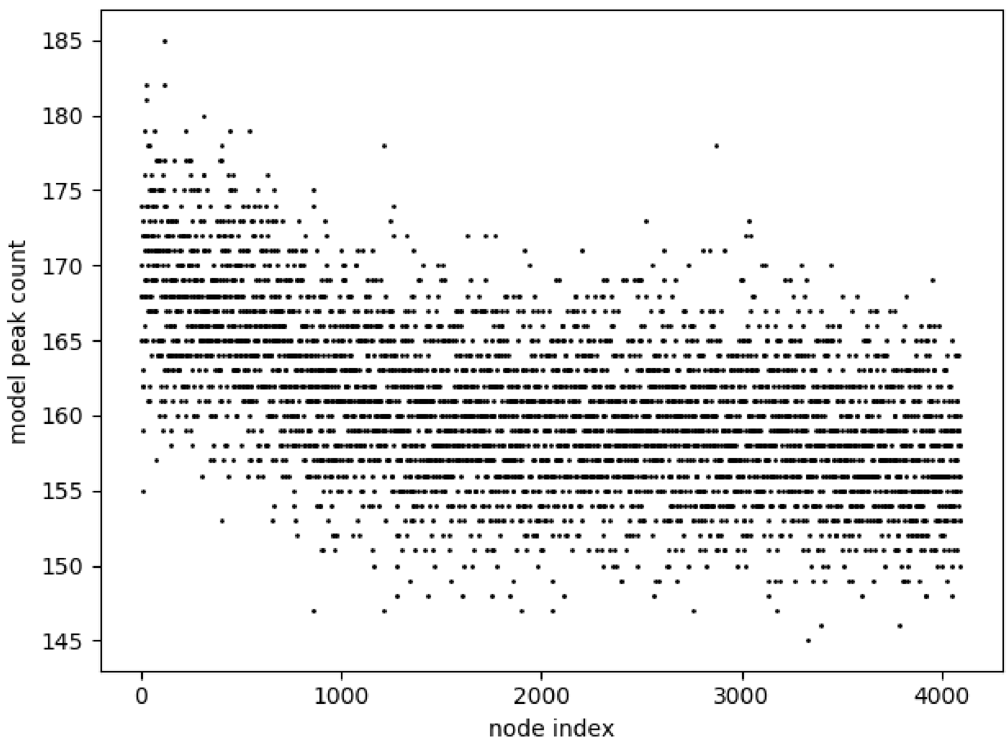
- **Distribution of number of peaks (slightly heavy-tailed) [over 1e6 steps]**
  - **Median = 160, Min = 145, Max = 185 (Max-Median > Median-Min)**
  - **Mean = 160.6794 > Median**
  - **Skewness = 0.4302 (right-skewed)**
  - **(Excess) Kurtosis = 0.2224 (heavier tails than Gaussian)**
  - **Dotted line: Gaussian with same mean and s.d.**



- **Model peaks vs experimentally measured peaks (not similar)**
  - **Log scale for y-axis**



- **Model peaks vs node index**

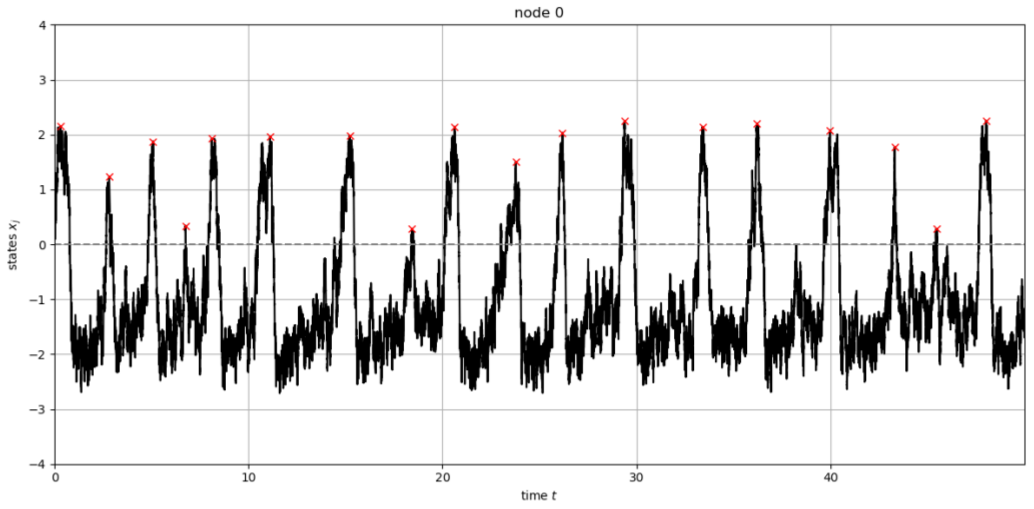


More spike analysis (other parameters)

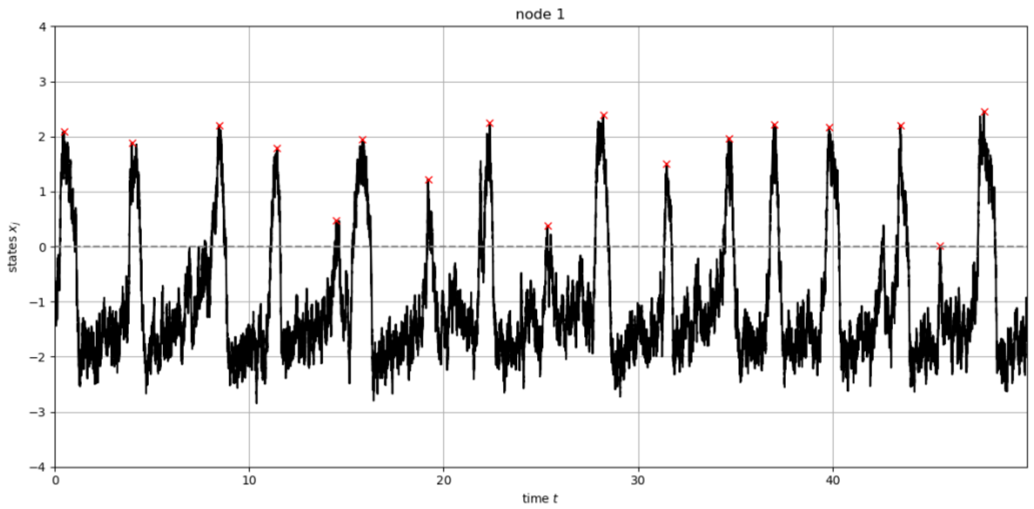
- Using g_{ij} from “DIV25_PREmethod” (no multiplier)
- Parameters $\epsilon = 0.1, \alpha = 1.05, \sigma_i = 2$

- Examples of peaks (node 0 & 1)
  - Criteria: above 0; at least 1 unit of time apart

Node 0

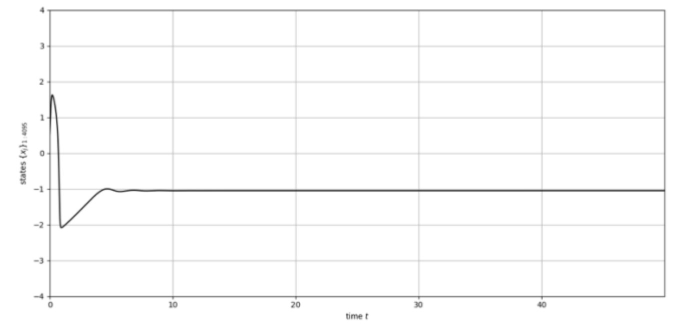


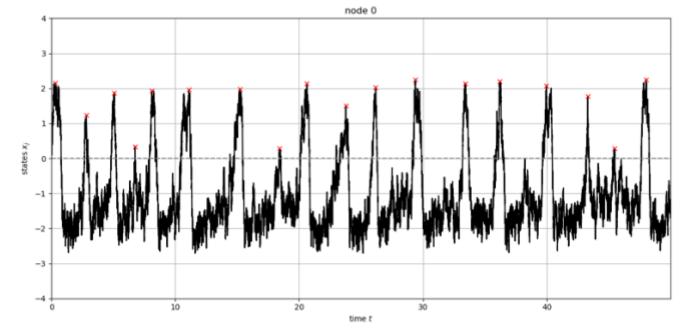
Node 1



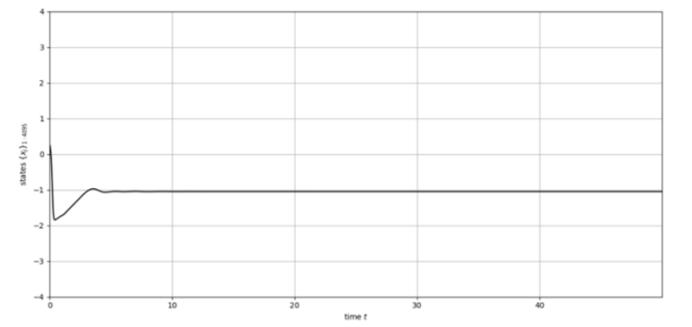
- **Noise-free time series as comparison**

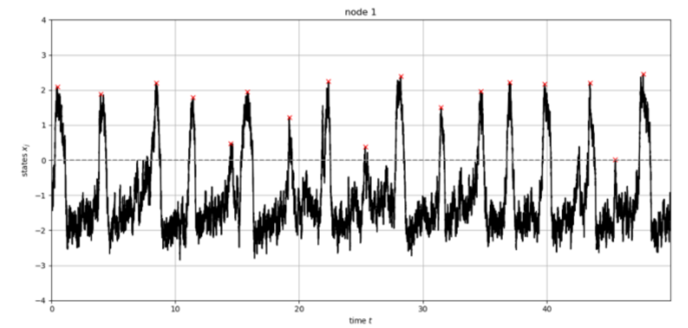
Node 0



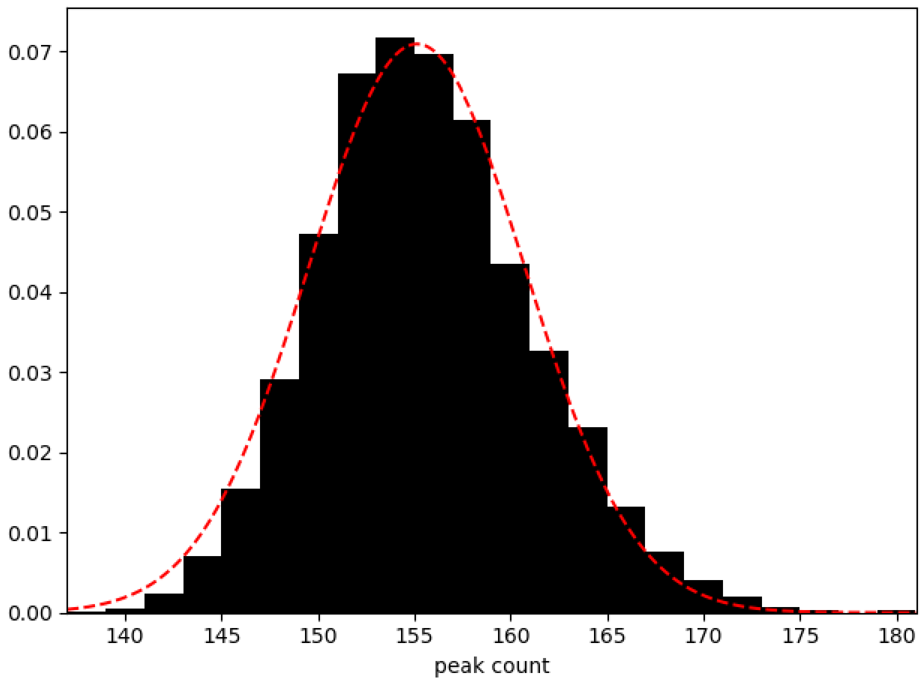


Node 1

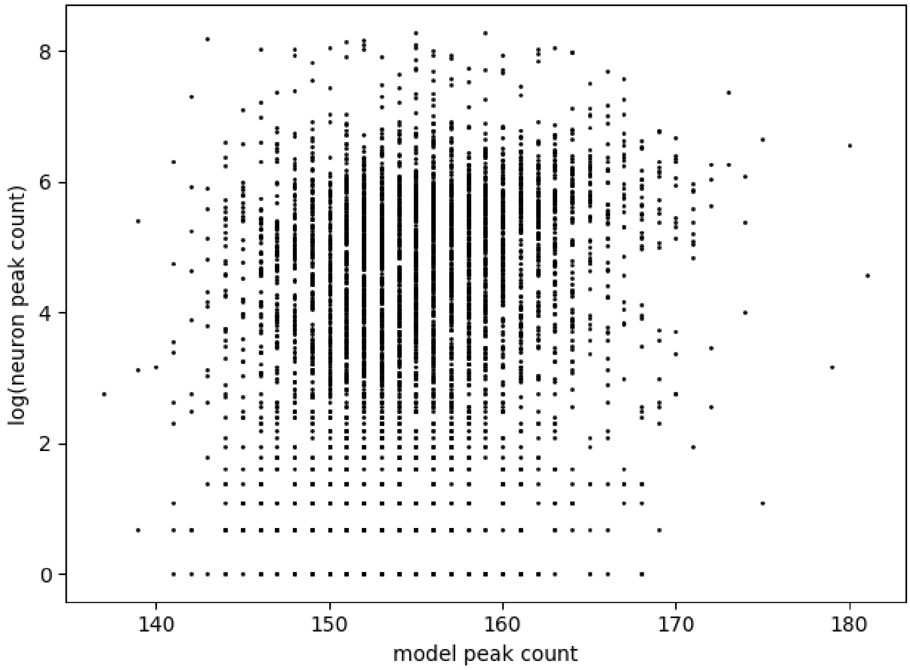




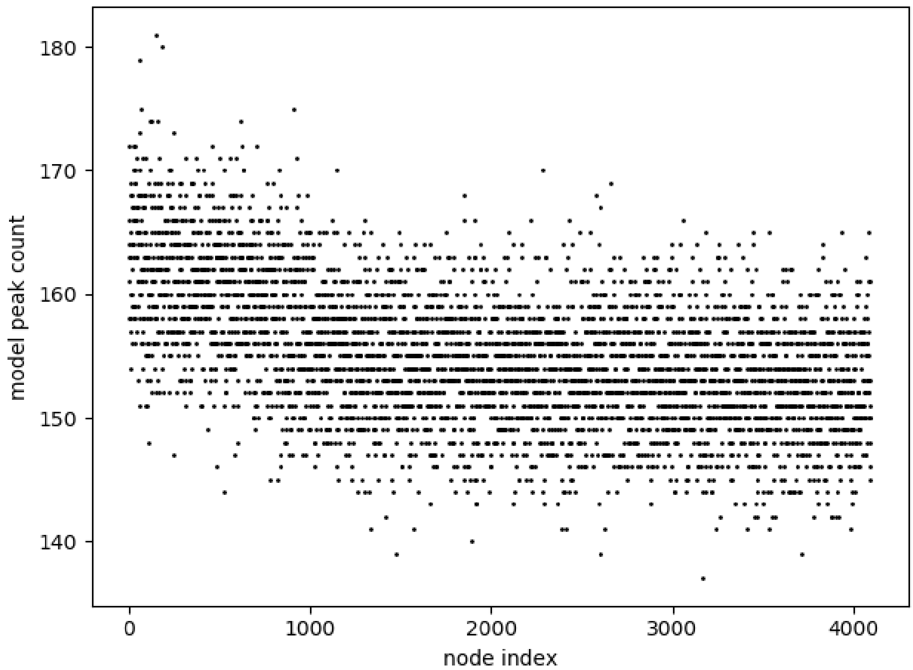
- **Distribution of number of peaks (slightly heavy-tailed) [over 1e6 steps]**
  - **Median = 155, Min = 137, Max = 181 (Max-Median > Median-Min)**
  - **Mean = 155.1231 > Median**
  - **Skewness = 0.3537 (right-skewed)**
  - **(Excess) Kurtosis = 0.2562 (heavier tails than Gaussian)**
  - **Dotted line: Gaussian with same mean and s.d.**



- **Model peaks vs experimentally measured peaks (not similar)**
  - **Log scale for y-axis**

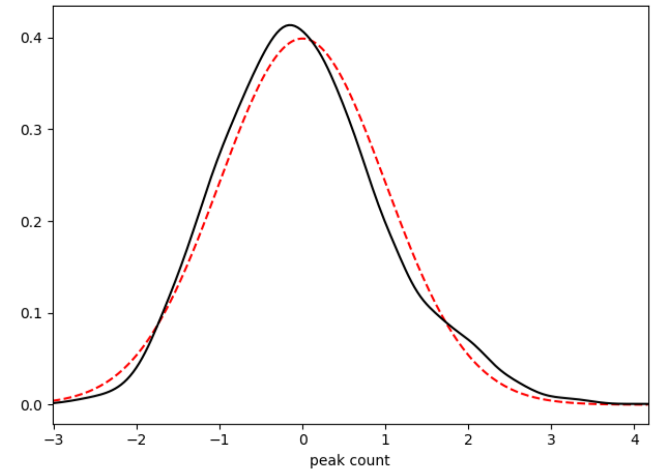


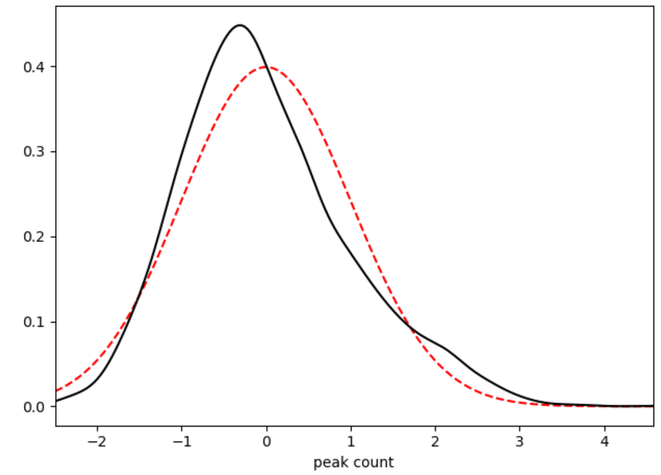
- **Model peaks vs node index**

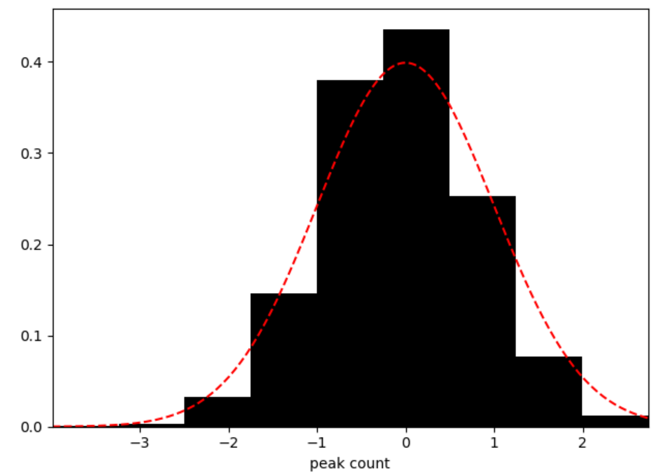


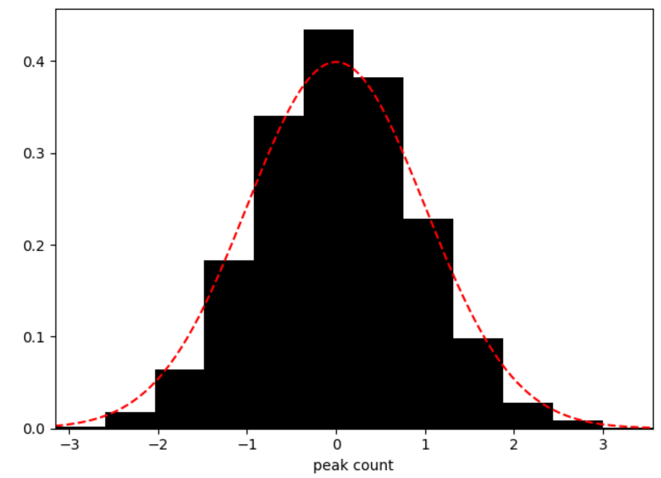
Standardized peak distributions

x-axis: leftmost = min, rightmost = max

<table>
<tr><th>1e6 steps</th><th>2e6 steps</th></tr>
<tr><td colspan="2">Case 1: $\epsilon = 0.1, \alpha = 0.95, \sigma_i = 2$</td></tr>
<tr><td>


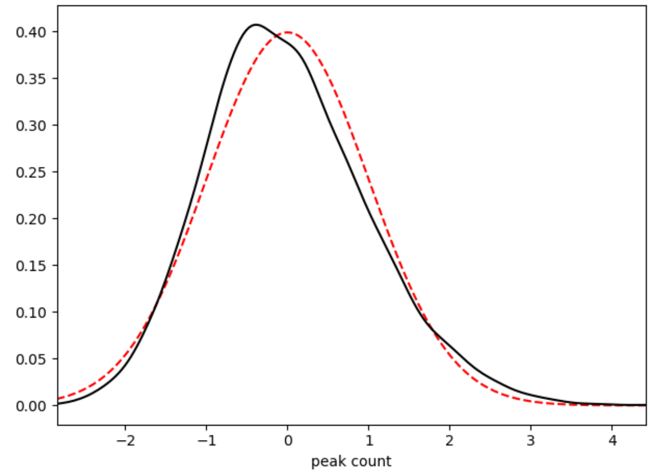
- Median = 165, Min = 149, Max = 189
- Mean = 165.7985
- Skewness = 0.4002 (right-skewed)
- (Excess) Kurtosis = 0.2204 (heavier tails than Gaussian)
</td><td>


- Median = 330, Min = 308, Max = 374
- Mean = 331.2886
- Skewness = 0.5945 (right-skewed)
- (Excess) Kurtosis = 0.2684 (heavier tails than Gaussian)
- *This is the most right-skewed among the other sets of params*
- *Max = 4 s.d. from mean*
</td></tr>
<tr><td colspan="2">Case 2: $\epsilon = 0.01, \alpha = 0.95, \sigma_i = 2$</td></tr>
<tr><td>


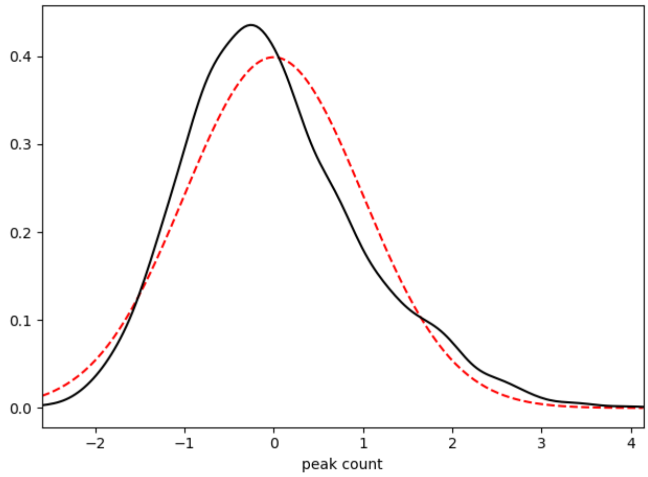
- Median = 185, Min = 180, Max = 188
- Mean = 184.7443
- Skewness = -0.0100
- (Excess) Kurtosis = 0.0148
- Can't properly fit a curve as there are too few data points so I still use histogram
</td><td>


- Median = 369, Min = 364, Max = 375
- Mean = 369.1739
- Skewness = 0.0519
- (Excess) Kurtosis = 0.0033
- Can't properly fit a curve as there are too few data points so I still use histogram
</td></tr>
</table>

Case 3: $\epsilon = 0.1, \alpha = 1, \sigma_i = 2$

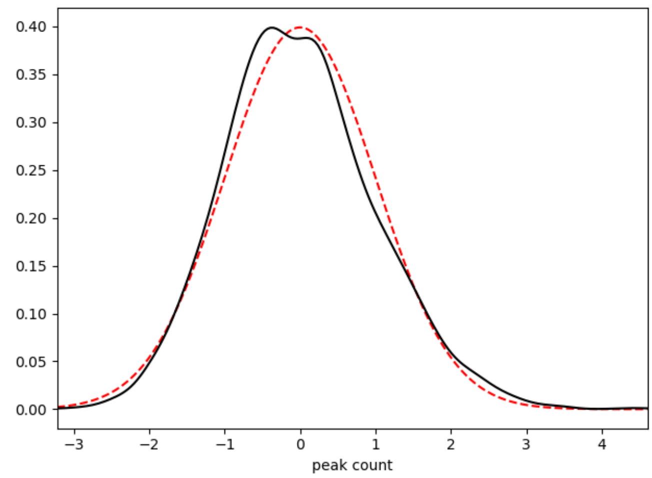


- Median = 160, Min = 145, Max = 185
- Mean = 160.6794
- Skewness = 0.4302 (right-skewed)
- (Excess) Kurtosis = 0.2224 (heavier tails than Gaussian)

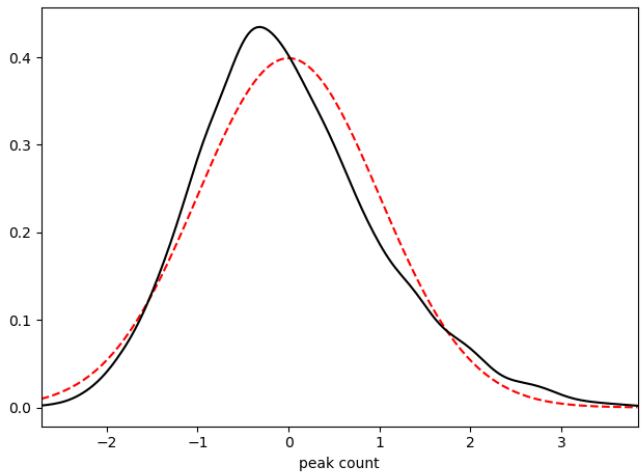


- Median = 320, Min = 297, Max = 359
- Mean = 320.9031
- Skewness = 0.5982 (right-skewed)
- (Excess) Kurtosis = 0.3511 (heavier tails than Gaussian)

Case 4: $\epsilon = 0.1, \alpha = 1.05, \sigma_i = 2$

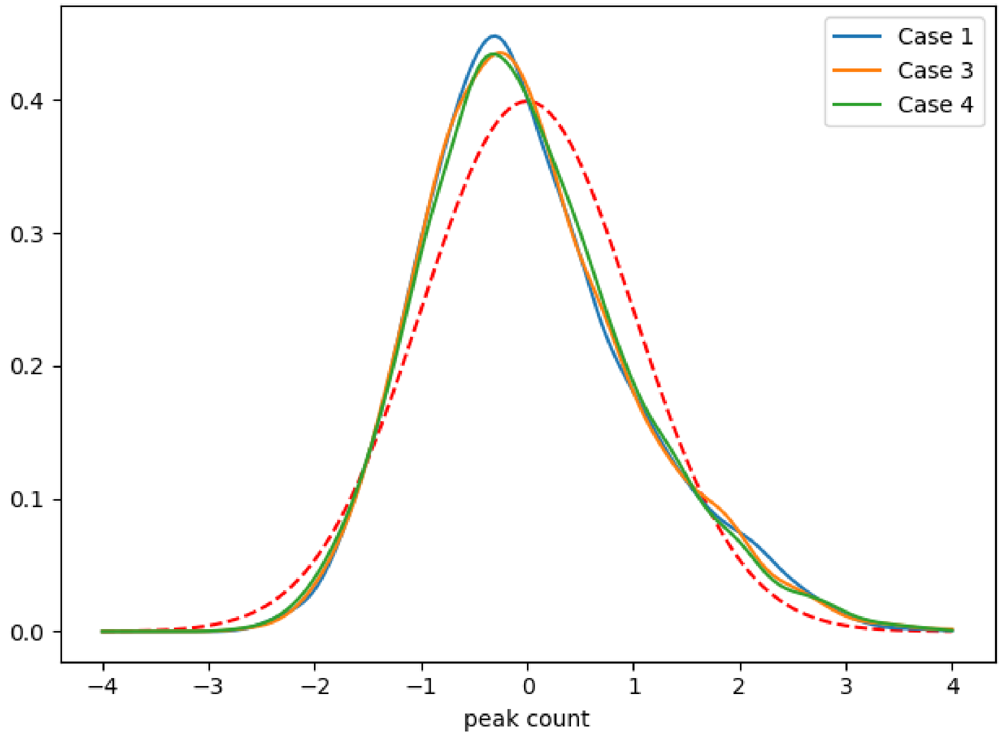


- Median = 155, Min = 137, Max = 181
- Mean = 155.1231
- Skewness = 0.3537 (right-skewed)
- (Excess) Kurtosis = 0.2562 (heavier tails than Gaussian)



- Median = 309, Min = 285, Max = 345
- Mean = 309.8799
- Skewness = 0.5384 (right-skewed)
- (Excess) Kurtosis = 0.3200 (heavier tails than Gaussian)

Case 1,3,4 combined

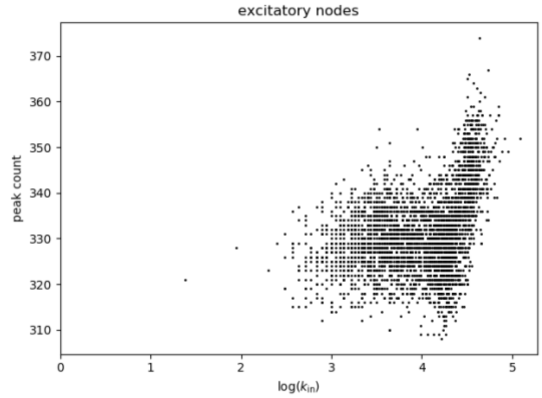


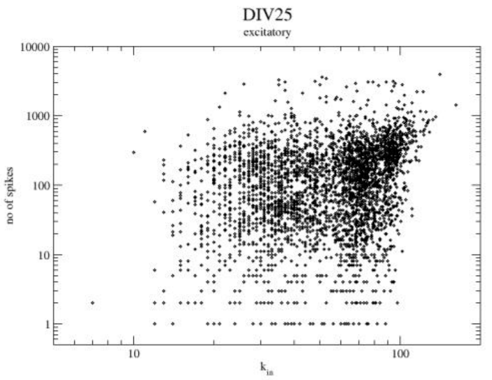
Peak count vs network features (2e6 steps)

Case 1: $\epsilon = 0.1, \alpha = 0.95, \sigma_i = 2$

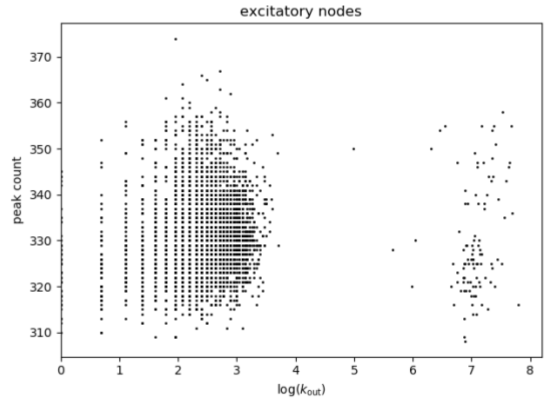
- **Excitatory nodes**

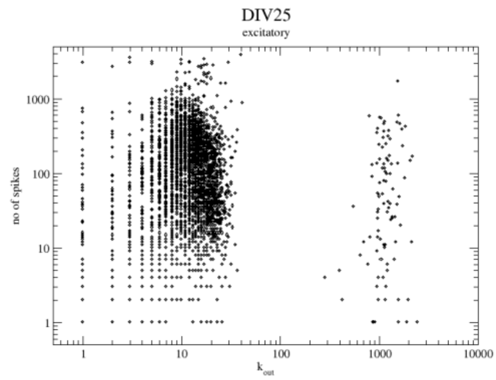
Peak count vs log k_in



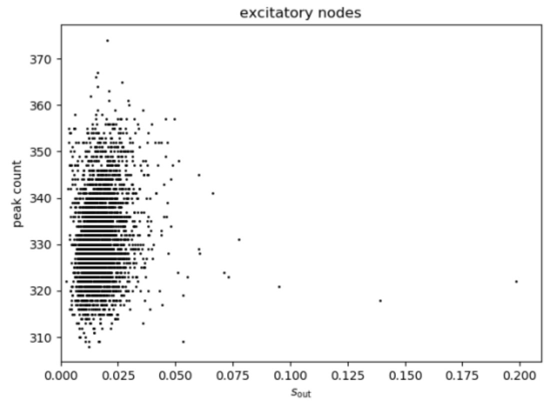


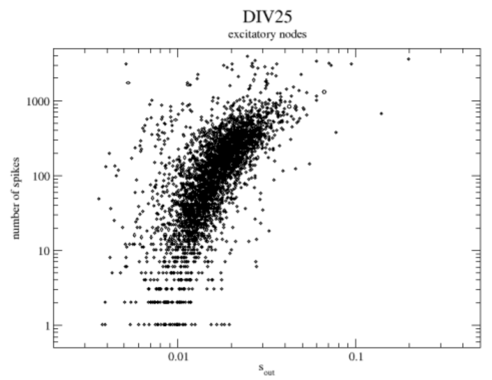
Peak count vs log k_out



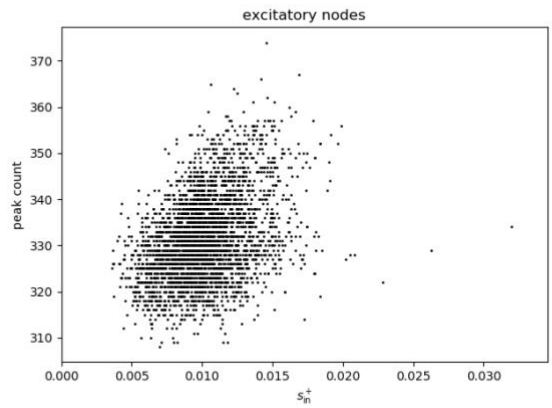


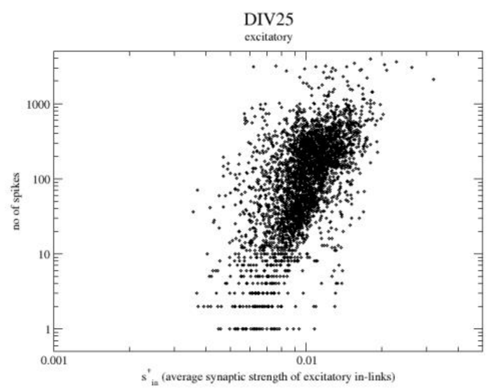
Peak count vs s_out





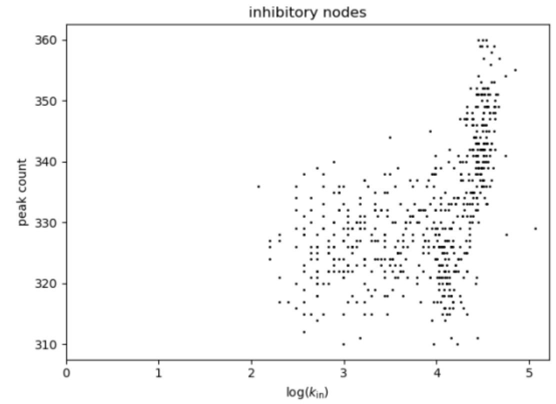
Peak count vs s^+_in

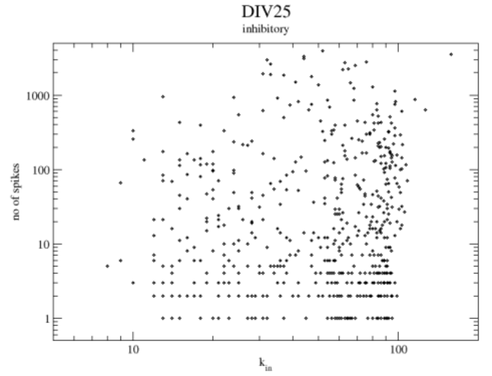




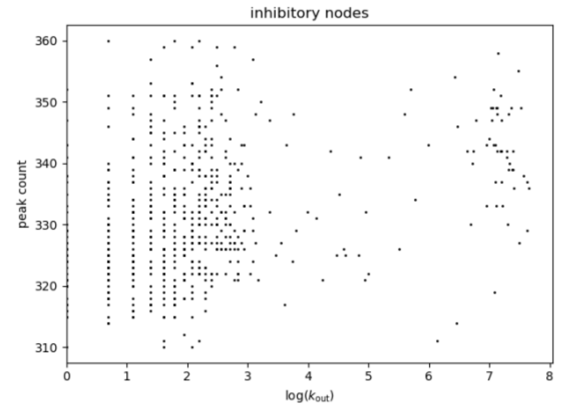
- **Inhibitory nodes**

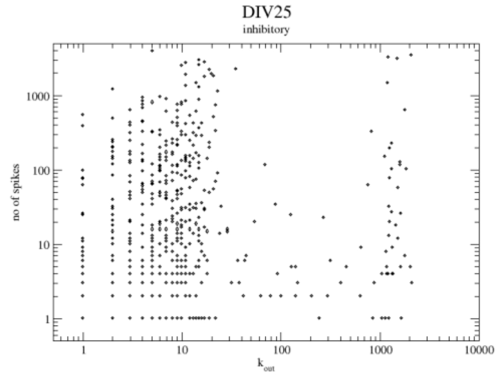
Peak count vs log k_in



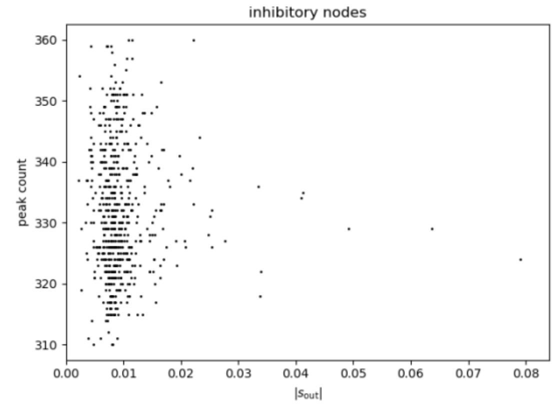


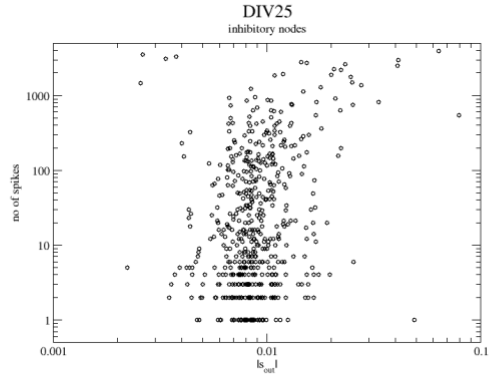
Peak count vs log k_out



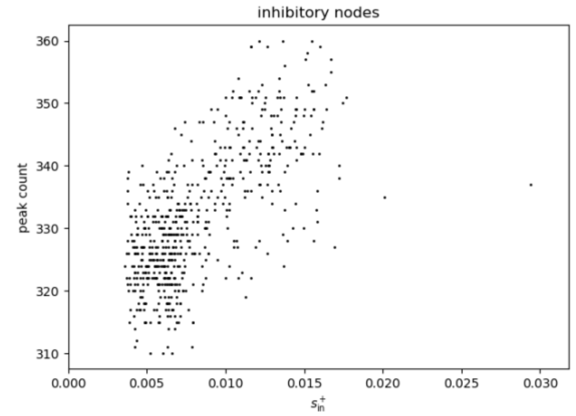


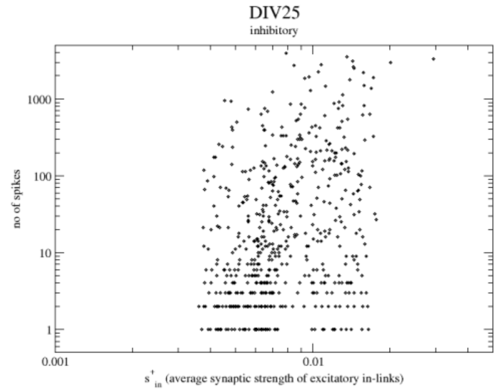
Peak count vs |s_out|





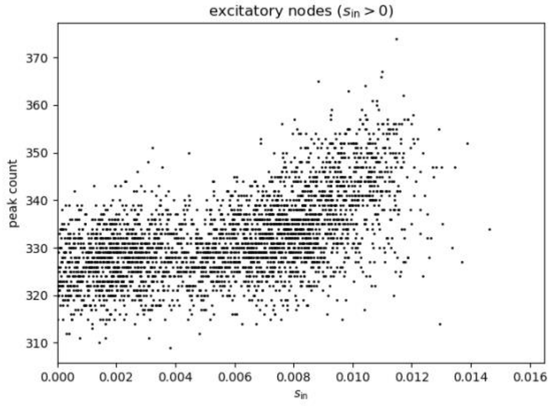
Peak count vs s^+_in

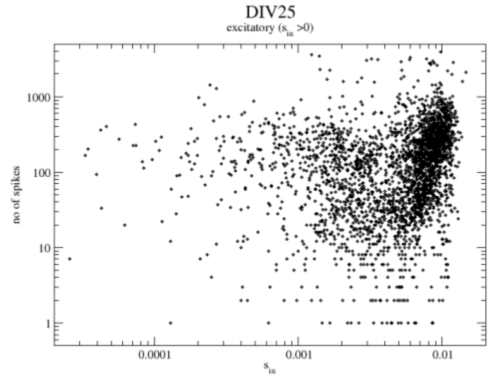




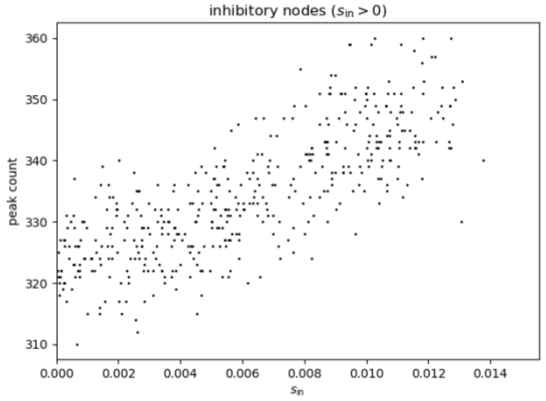
- **Mixed (x-axis: s_in or |s_in|)**

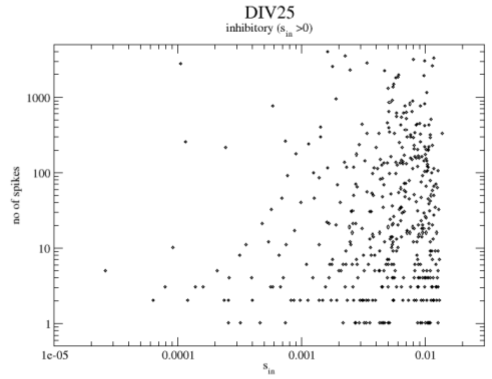
s_in > 0 & s_out > 0



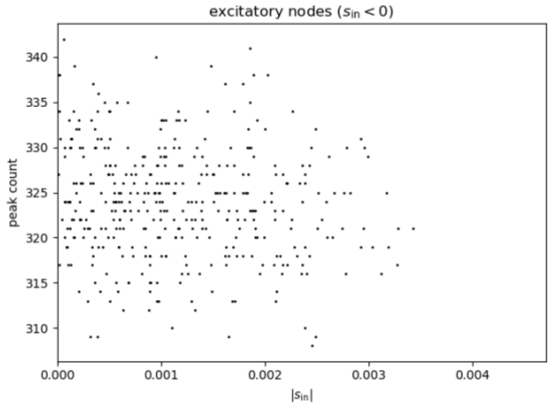


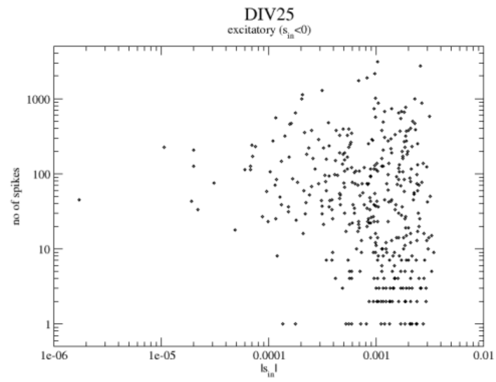
s_in > 0 & s_out < 0



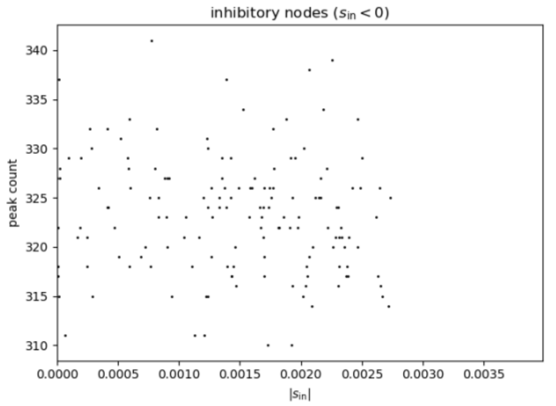


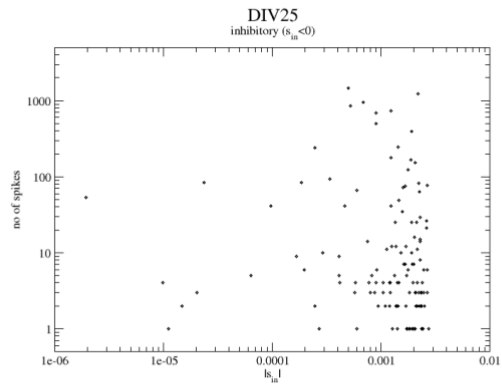
s_in < 0 & s_out > 0





s_in < 0 & s_out < 0

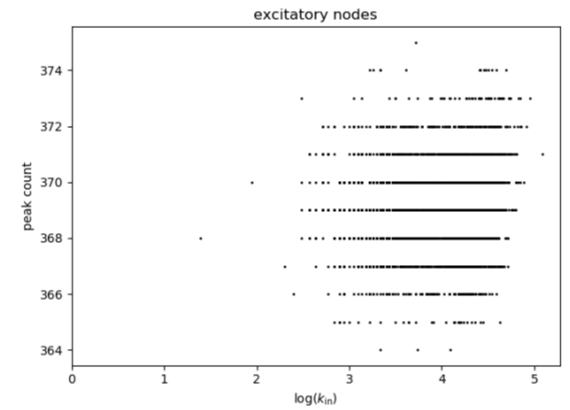


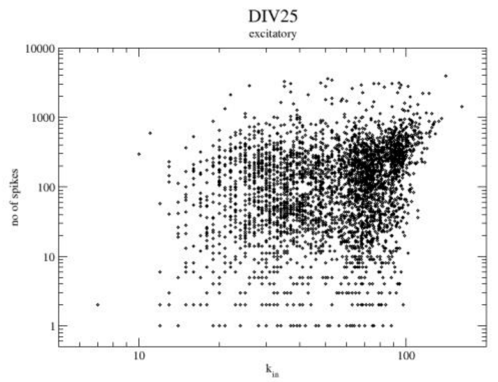


Case 1: $\epsilon = 0.01, \alpha = 0.95, \sigma_i = 2$

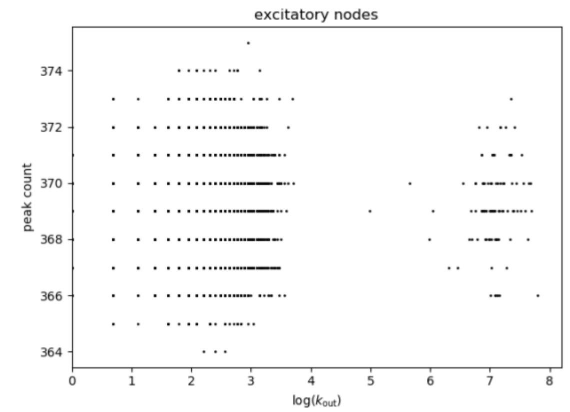
- **Excitatory nodes**

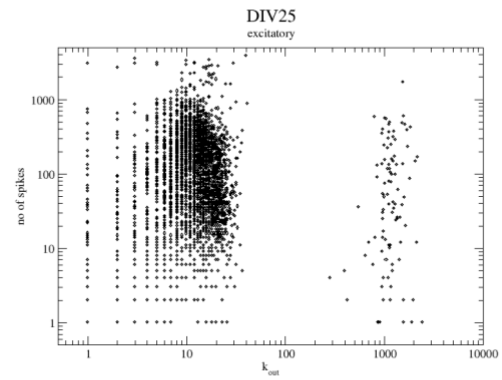
Peak count vs log k_in



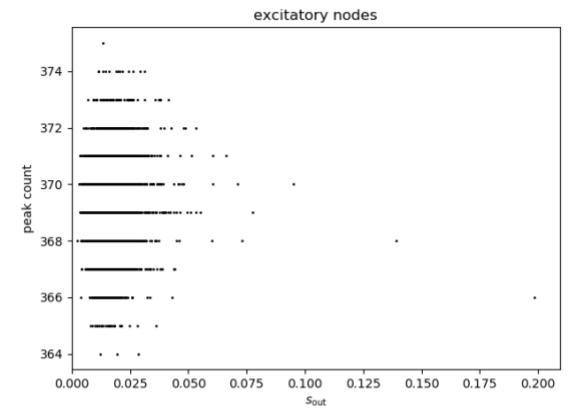


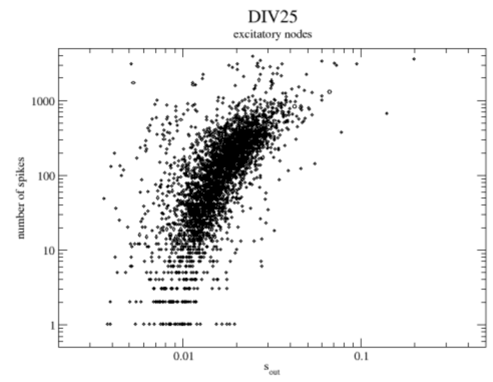
Peak count vs log k_out



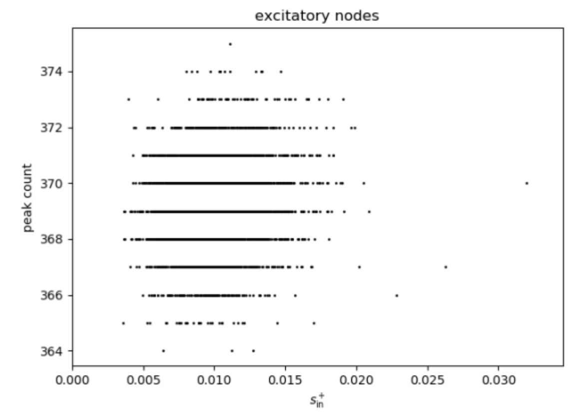


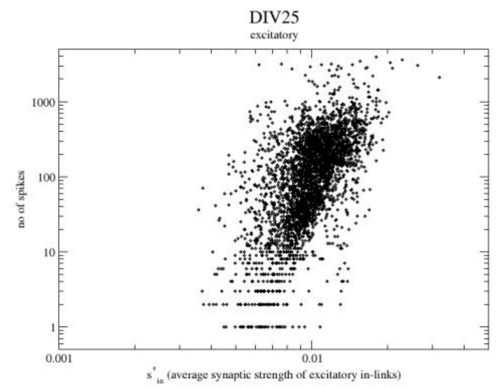
Peak count vs s_out





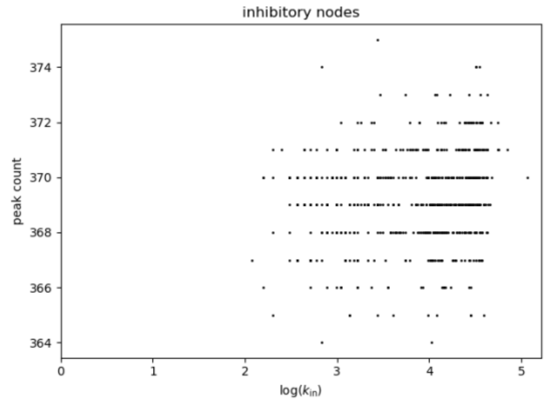
Peak count vs s^+_in

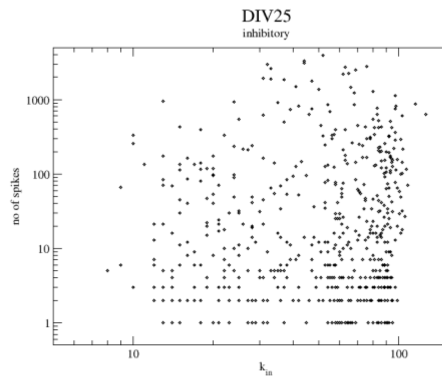




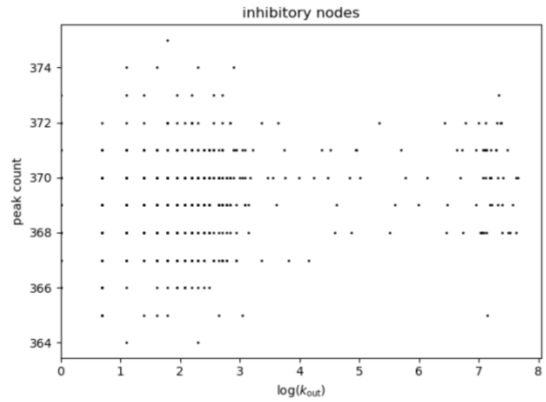
- **Inhibitory nodes**

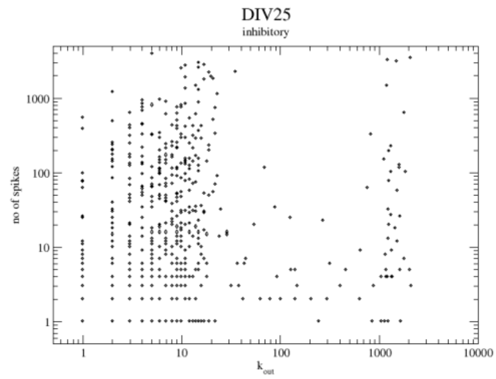
Peak count vs log k_in



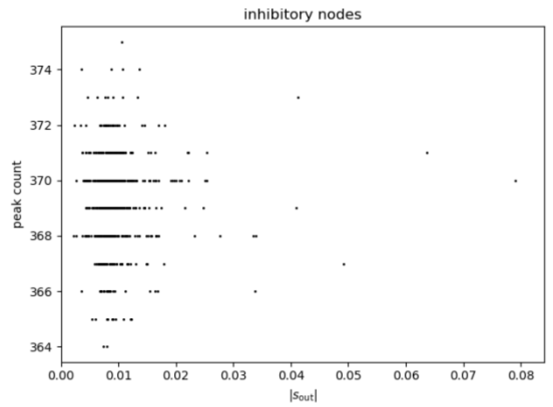


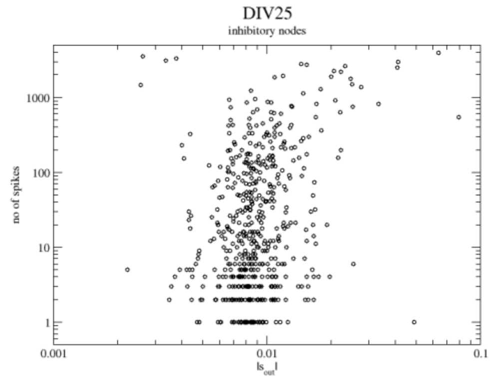
Peak count vs log k_out



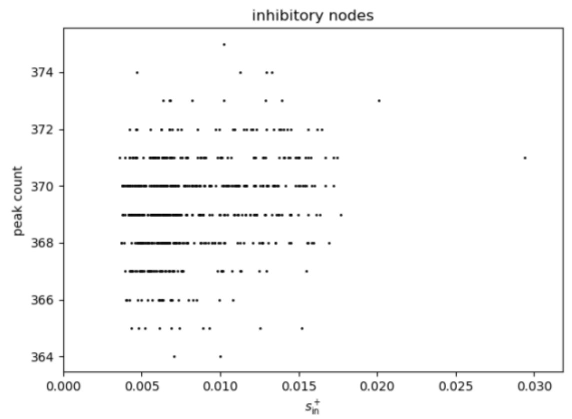


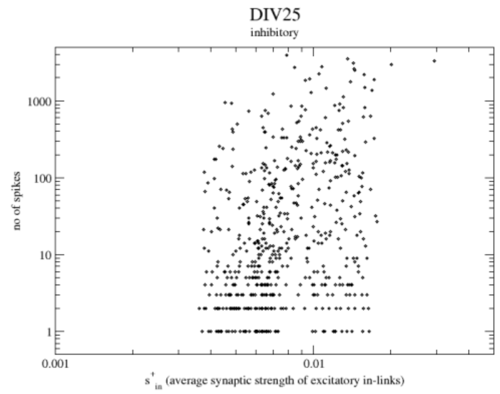
Peak count vs |s_out|





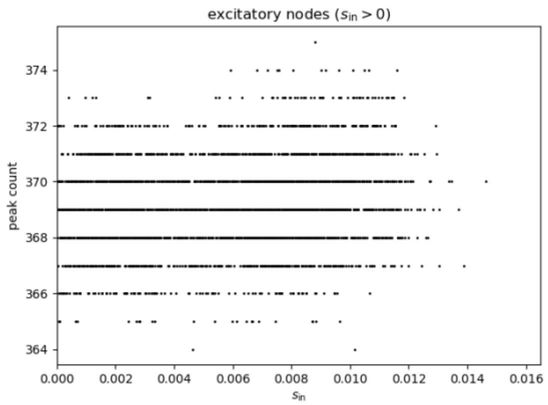
Peak count vs s^+_in

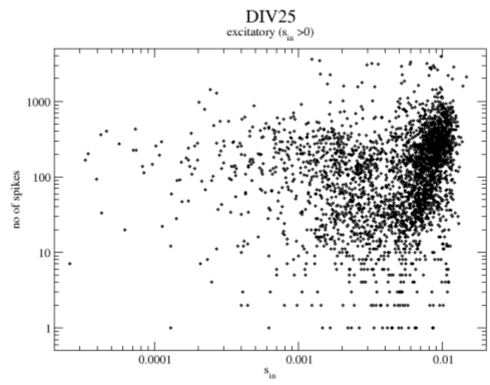




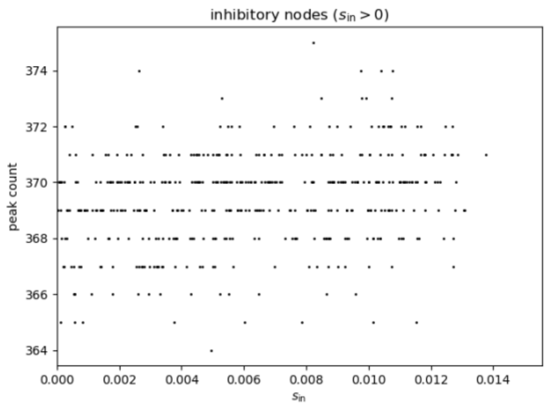
- **Mixed (x-axis: s_in or |s_in|)**

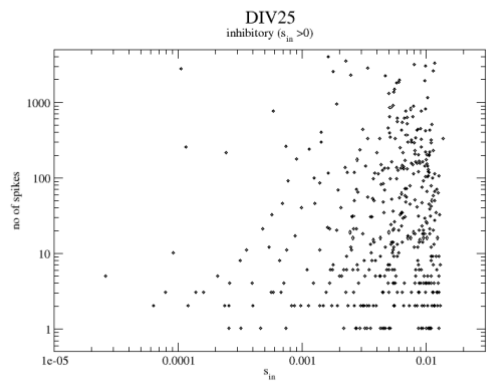
s_in > 0 & s_out > 0



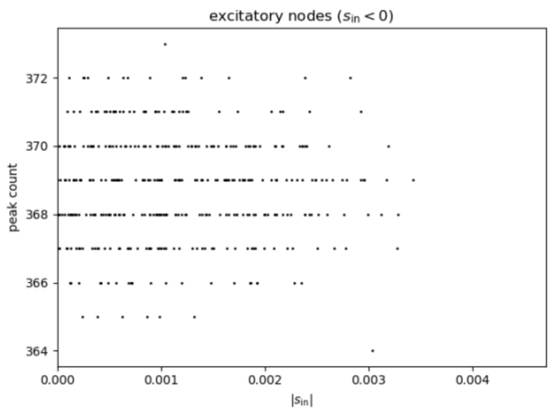


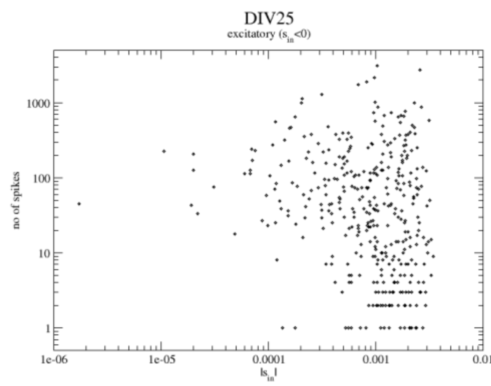
s_in > 0 & s_out < 0



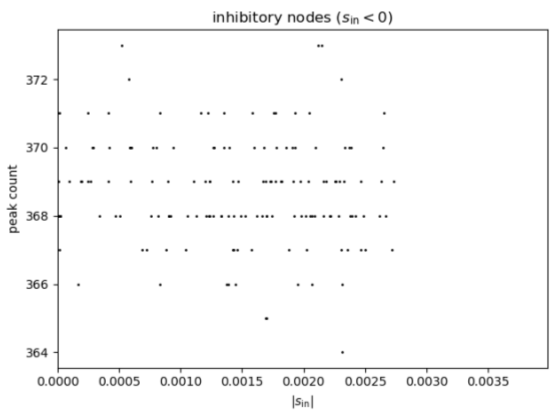


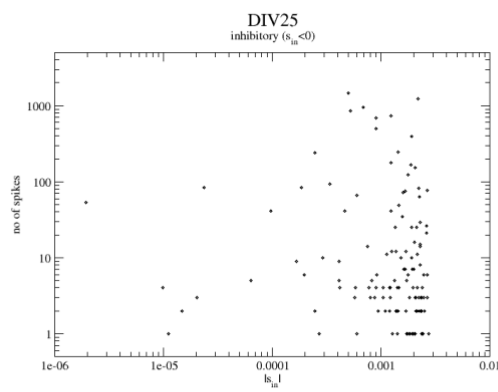
s_in < 0 & s_out > 0





s_in < 0 & s_out < 0

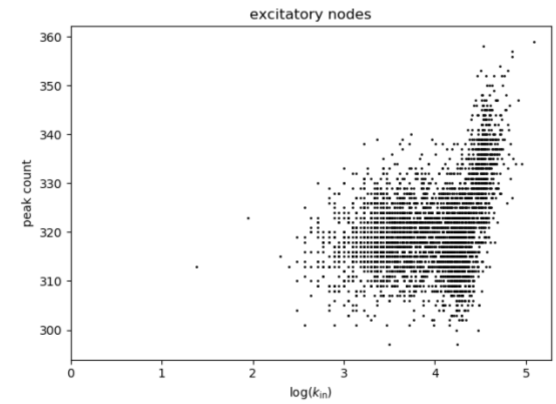


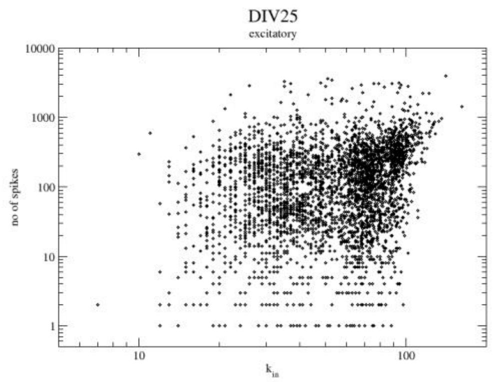


Case 1: $\epsilon = 0.1, \alpha = 1, \sigma_i = 2$

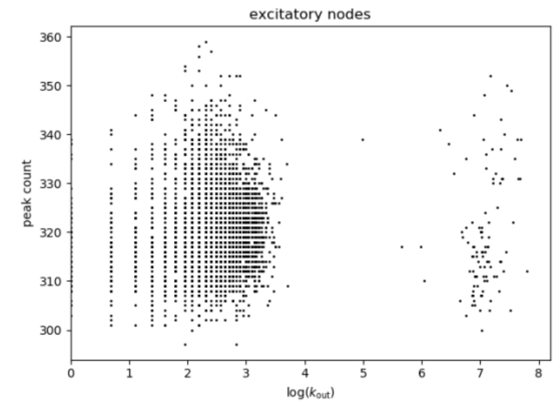
- **Excitatory nodes**

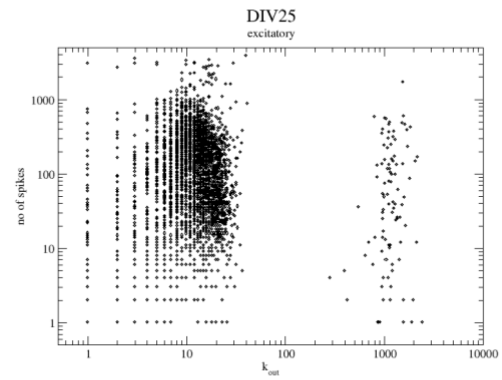
Peak count vs log k_in



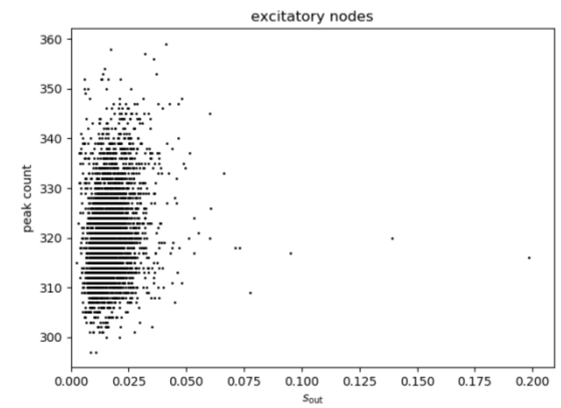


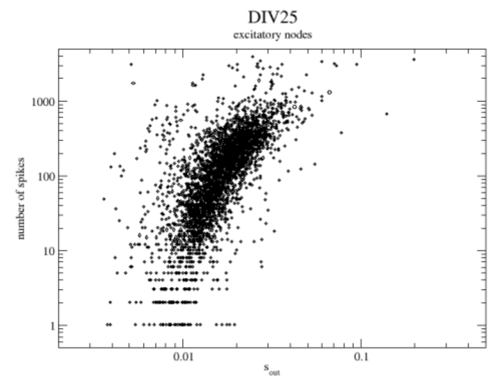
Peak count vs log k_out



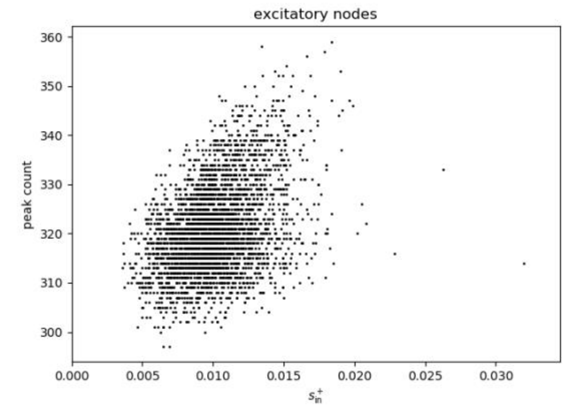


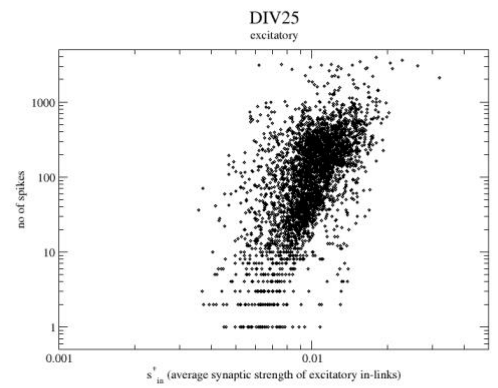
Peak count vs s_out





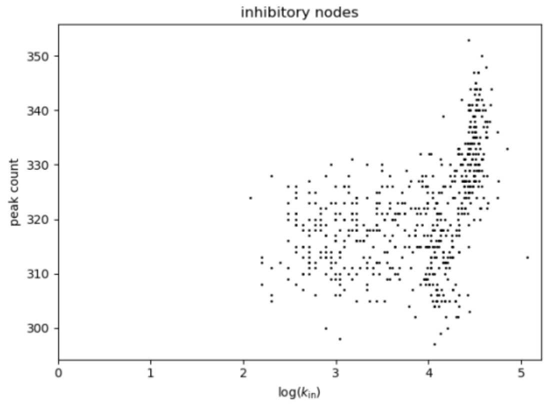
Peak count vs s^+_in

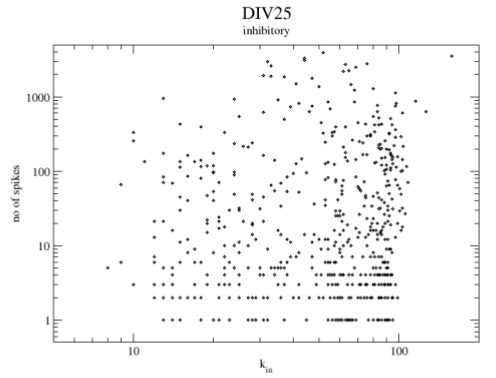




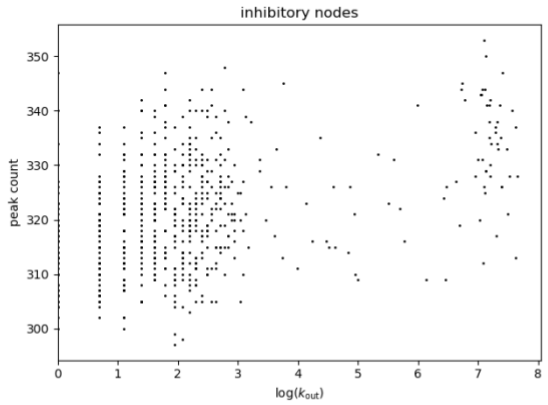
- **Inhibitory nodes**

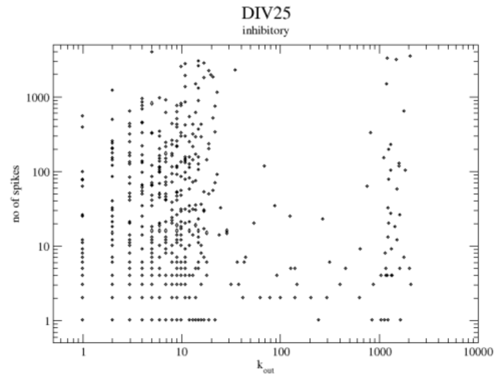
Peak count vs log k_in



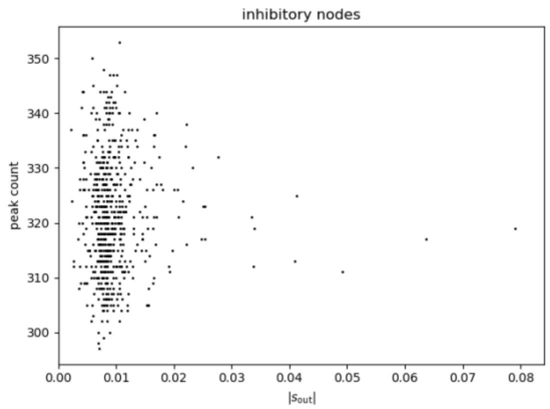


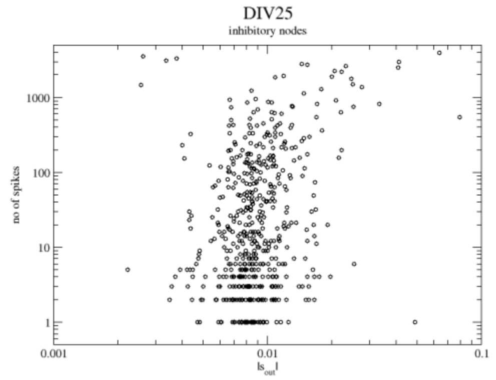
Peak count vs log k_out



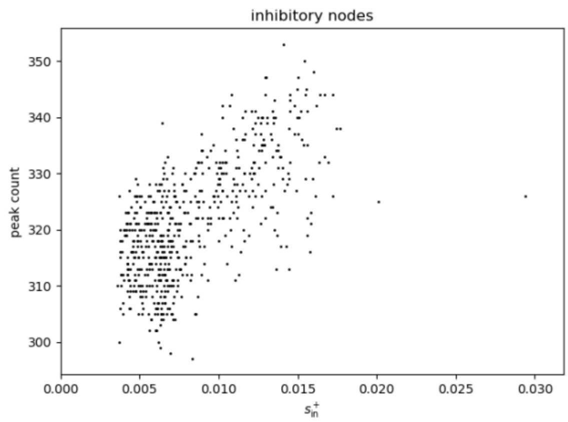


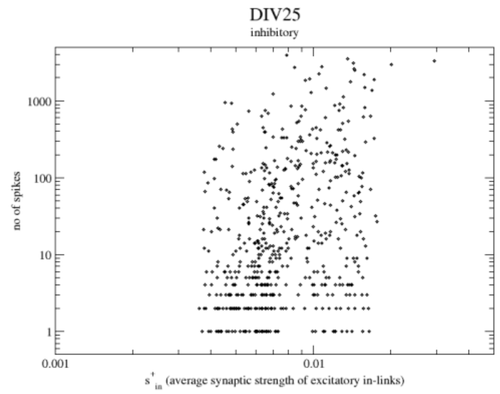
Peak count vs |s_out|





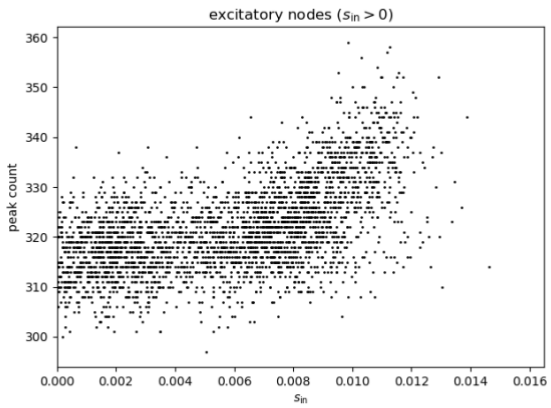
Peak count vs s^+_in

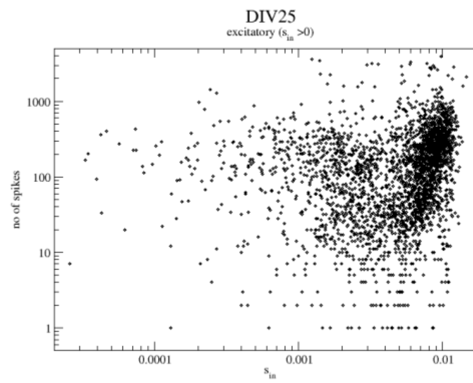




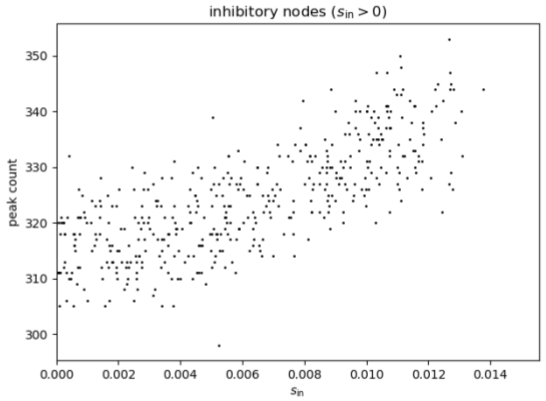
- **Mixed (x-axis: s_in or |s_in|)**

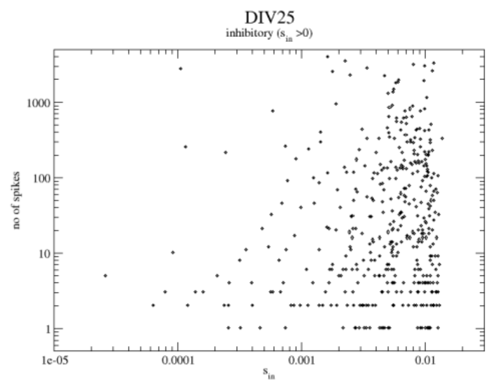
s_in > 0 & s_out > 0



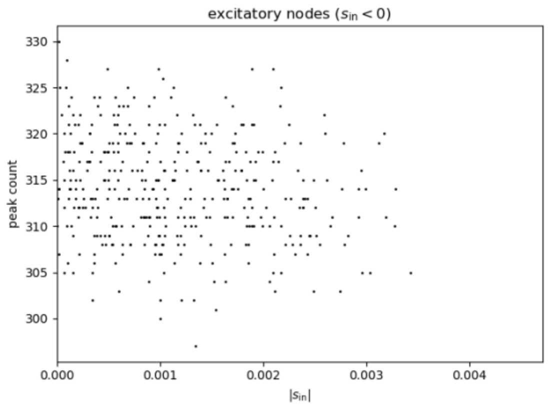


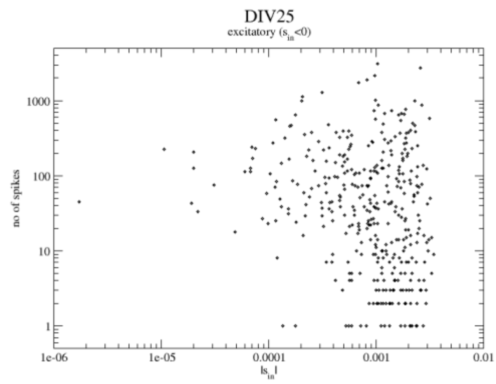
s_in > 0 & s_out < 0



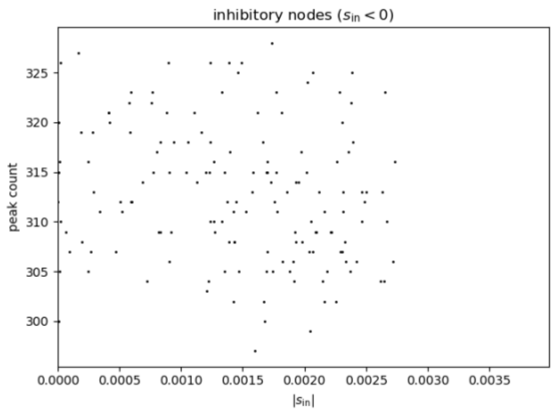


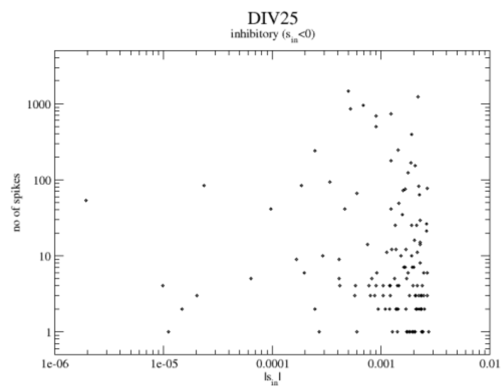
s_in < 0 & s_out > 0





s_in < 0 & s_out < 0

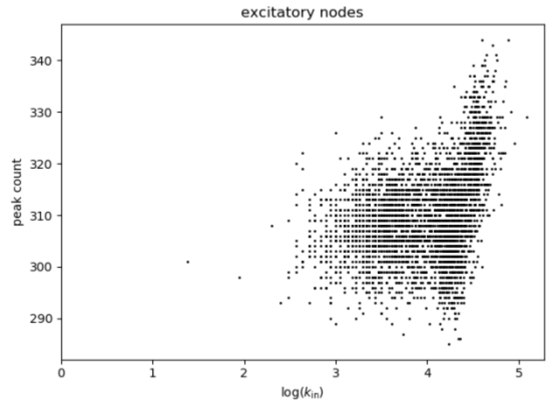


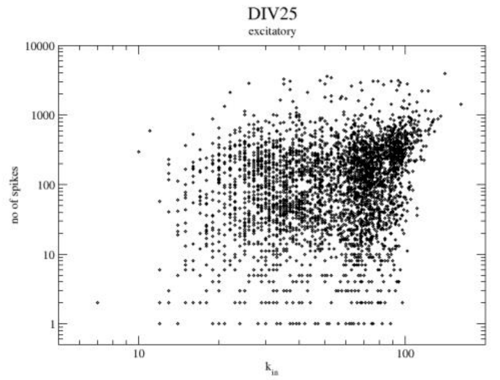


Case 1: $\epsilon = 0.1, \alpha = 1.05, \sigma_i = 2$

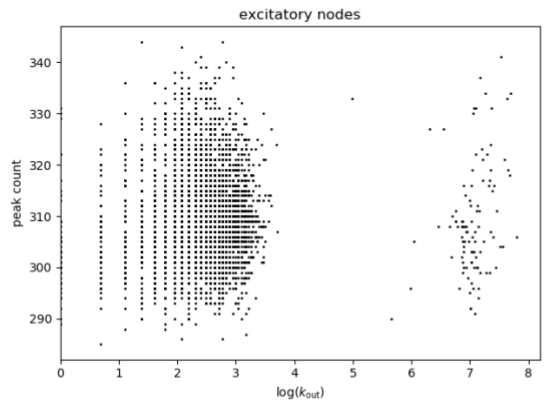
- **Excitatory nodes**

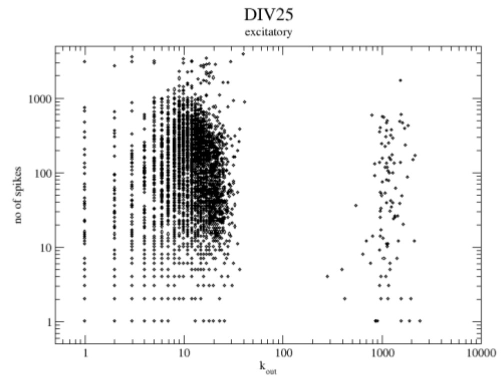
Peak count vs log k_in



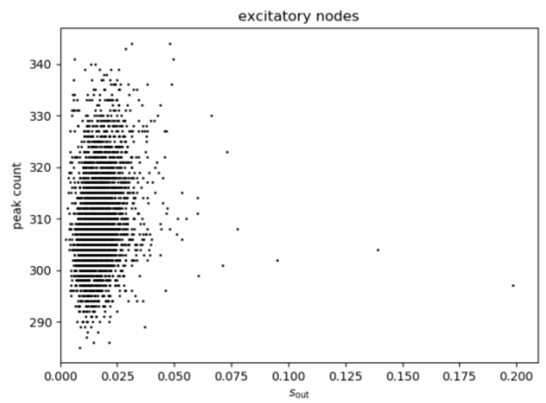


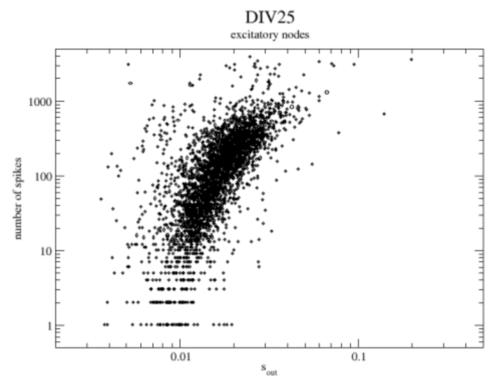
Peak count vs log k_out



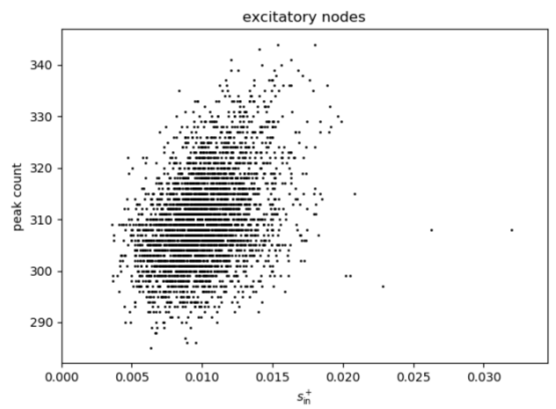


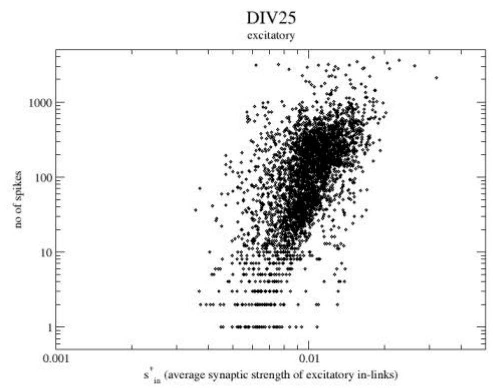
Peak count vs s_out





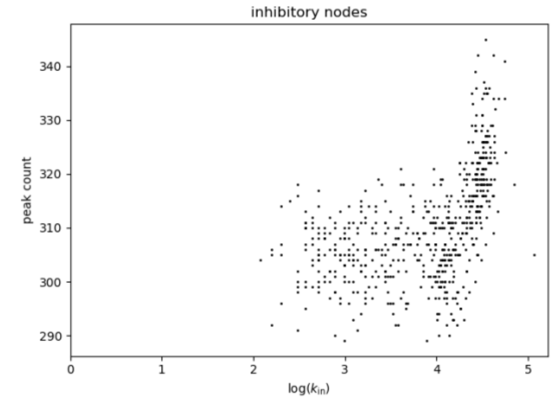
Peak count vs s^+_in

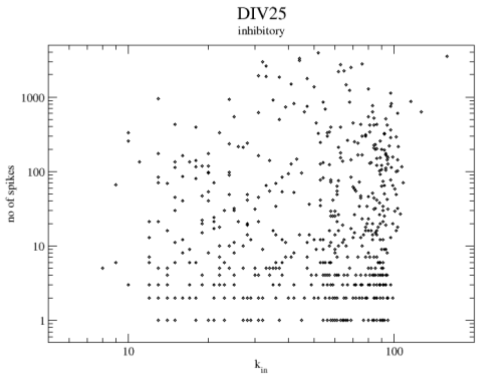




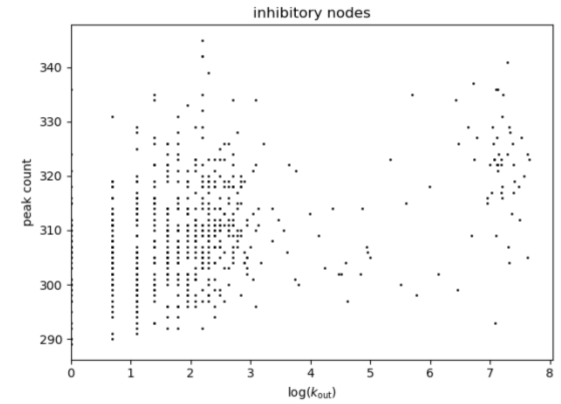
- **Inhibitory nodes**

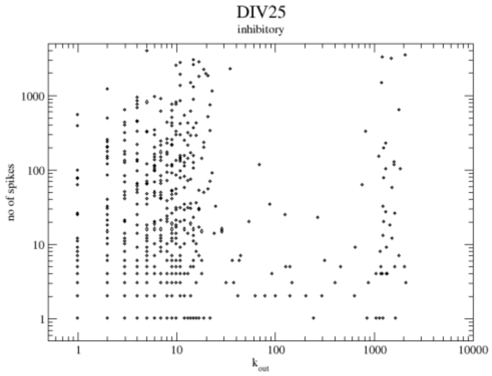
Peak count vs log k_in



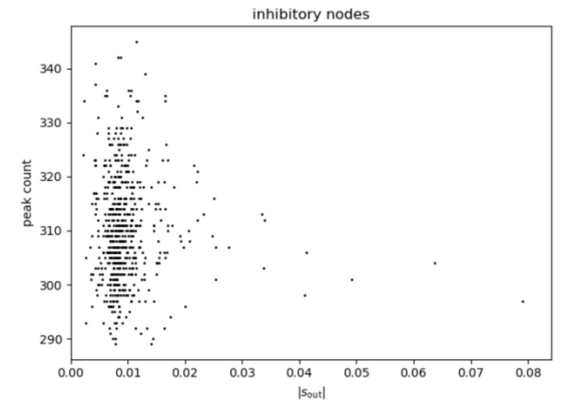


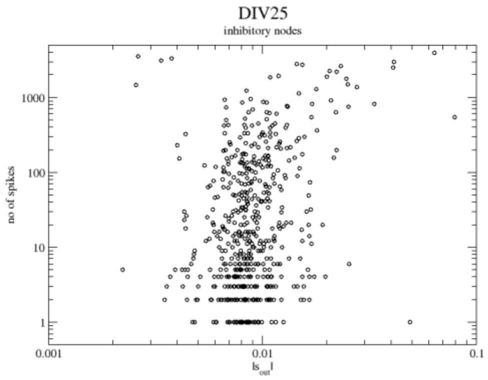
Peak count vs log k_out



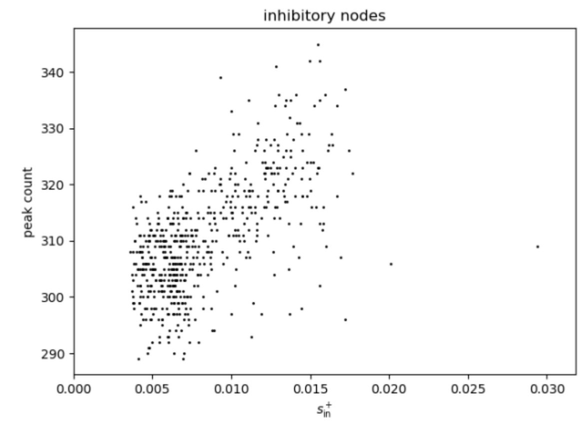


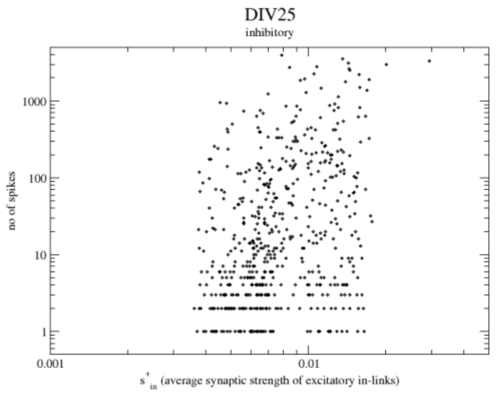
Peak count vs |s_out|





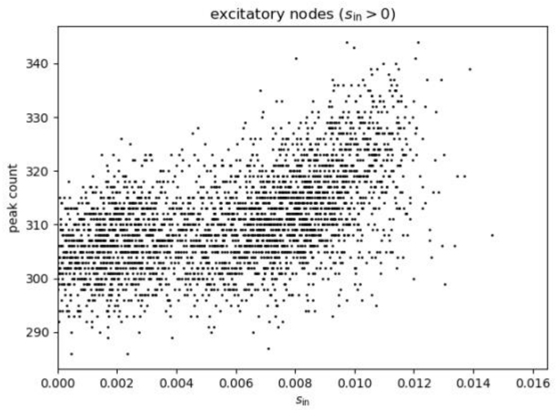
Peak count vs s^+_in

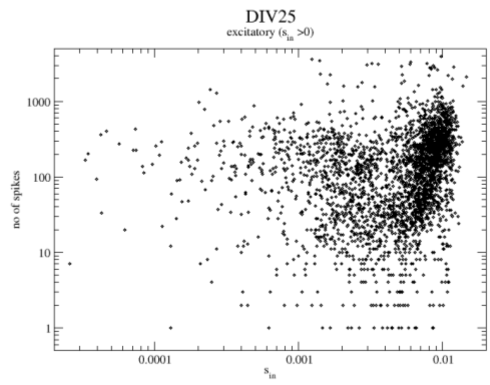




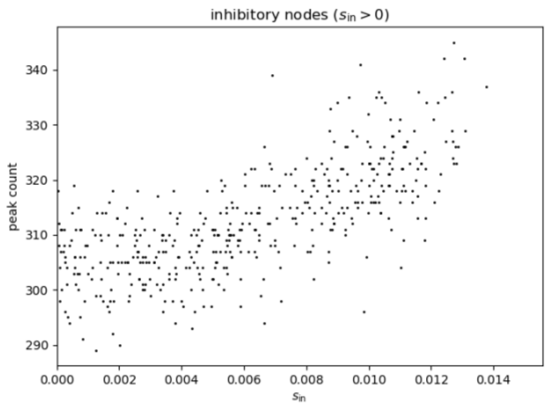
- **Mixed (x-axis: s_in or |s_in|)**

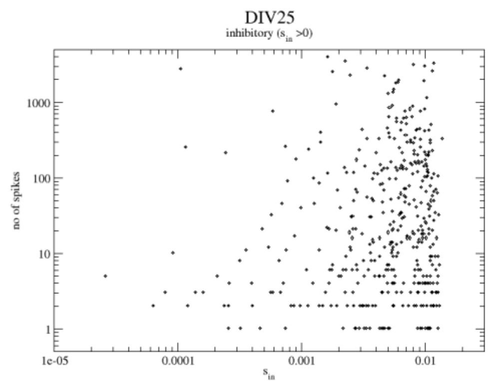
s_in > 0 & s_out > 0



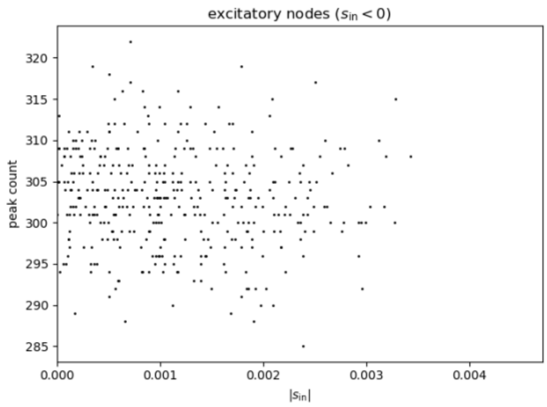


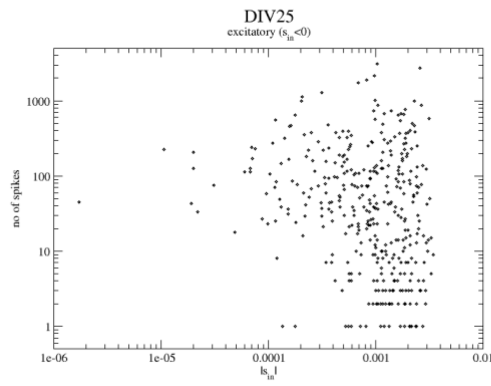
s_in > 0 & s_out < 0



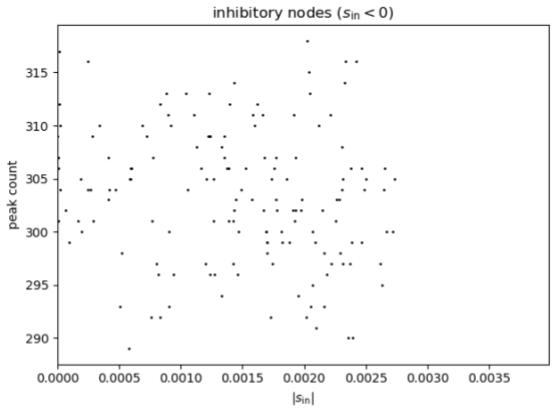


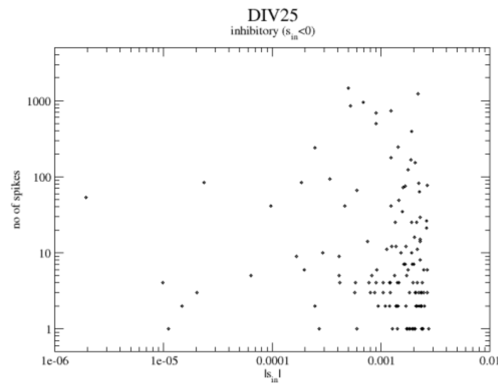
s_in < 0 & s_out > 0





s_in < 0 & s_out < 0

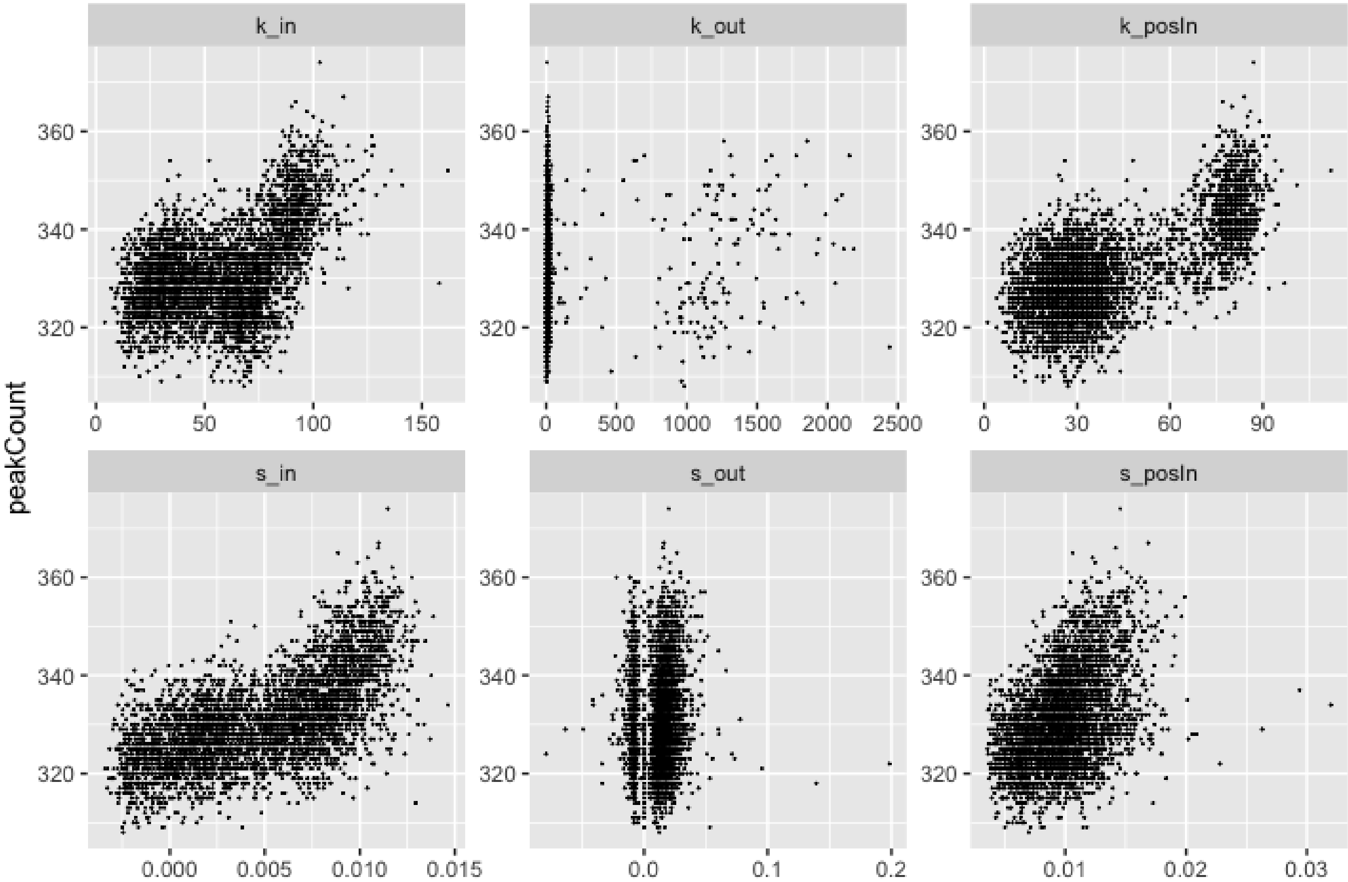




More analysis on Case 1

- **Case 1: $\epsilon = 0.1, \alpha = 0.95, \sigma_i = 2$**

- **Exploratory analysis**



- **Regression**
  - **Model 1: peak count vs all explanatory variables (i.e. k_in, k_out, …)**
    All coefficients are significant except for k_out's (|t-statistic|<2)

```
Residuals:
    Min      1Q  Median      3Q     Max
-20.111  -4.280  -0.209   4.191  28.313

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.187e+02  3.889e-01 819.403  < 2e-16 ***
k_in        -8.728e-02  2.647e-02  -3.297 0.000986 ***
k_out       -3.017e-04  4.199e-04  -0.719 0.472432
k_posIn      2.995e-01  3.398e-02   8.813  < 2e-16 ***
s_in         3.611e+02  1.255e+02   2.877 0.004036 **
s_out       -5.089e+01  9.049e+00  -5.623  2.0e-08 ***
s_posIn      4.670e+02  9.571e+01   4.879  1.1e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 6.286 on 4088 degrees of freedom
Multiple R-squared:  0.5472,    Adjusted R-squared:  0.5465
F-statistic: 823.3 on 6 and 4088 DF,  p-value: < 2.2e-16
```

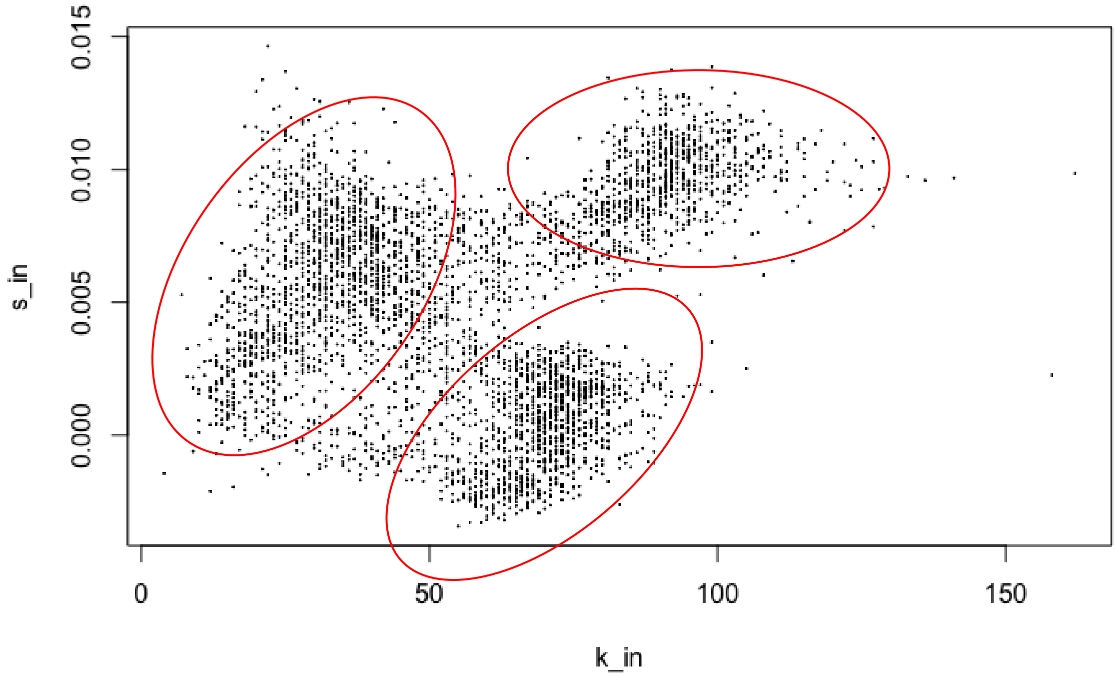
  - **Model 2: peak count vs all explanatory variables except k_out**

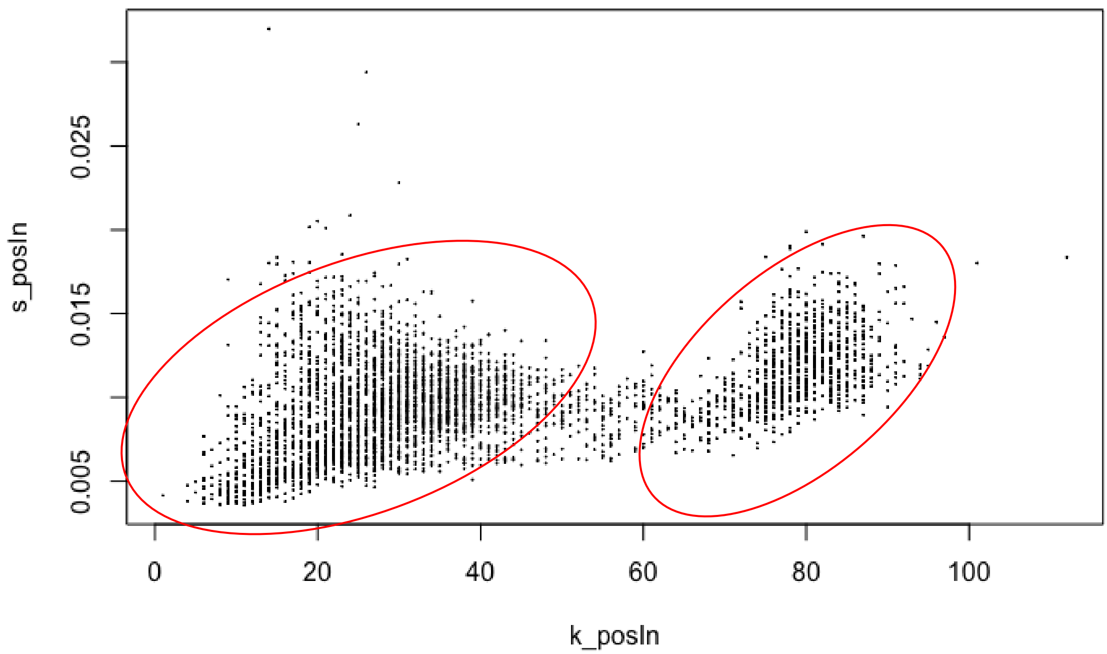
```
Residuals:
     Min       1Q   Median       3Q      Max
-20.0890  -4.2830  -0.1967   4.2044  28.3507

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 318.74129    0.38589 825.989  < 2e-16 ***
k_in         -0.08758    0.02647  -3.309 0.000944 ***
k_posIn       0.29942    0.03398   8.811  < 2e-16 ***
s_in        363.29479  125.48484   2.895 0.003810 **
s_out       -49.41719    8.81455  -5.606 2.20e-08 ***
s_posIn     460.75478   95.31020   4.834 1.39e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 6.286 on 4089 degrees of freedom
Multiple R-squared:  0.5471,    Adjusted R-squared:  0.5466
F-statistic:   988 on 5 and 4089 DF,  p-value: < 2.2e-16
```

- **Possibly classify nodes in degree-strength space?**
  May use machine learning kNN algorithm



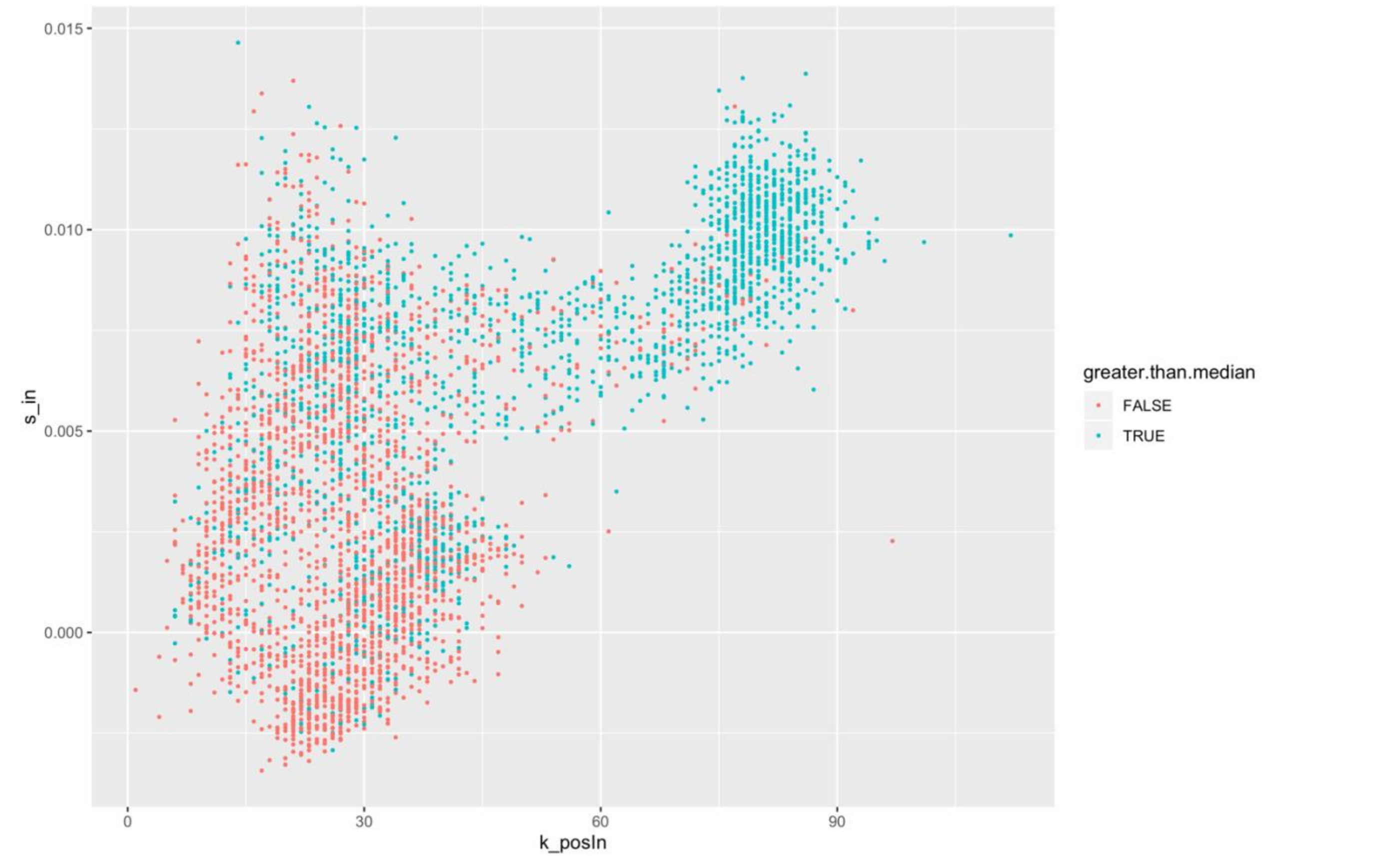


- **Peak count in degree-strength space (median as threshold)**

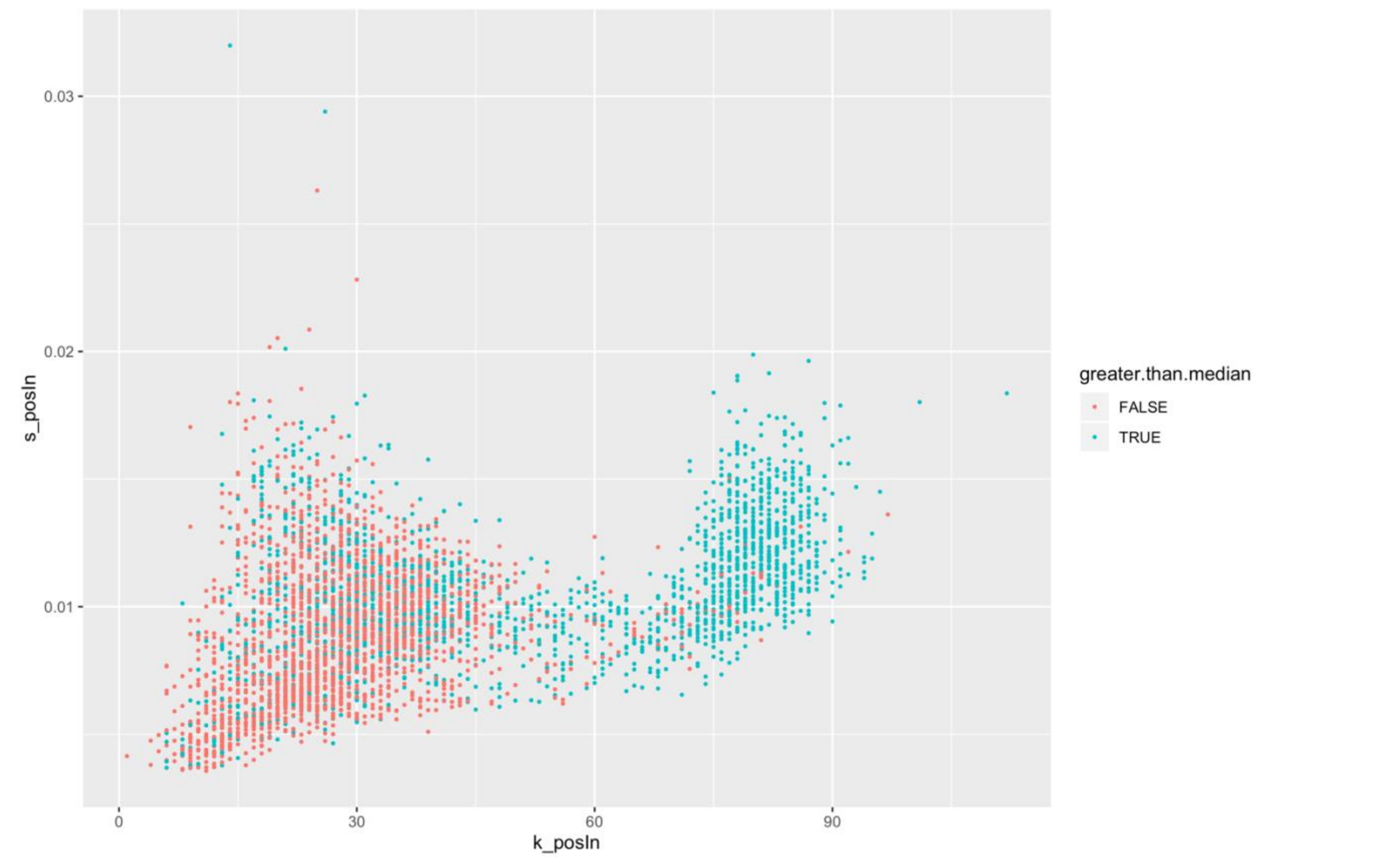
s_in vs k_in

s^+_in vs k_in


s_in vs k^+_in

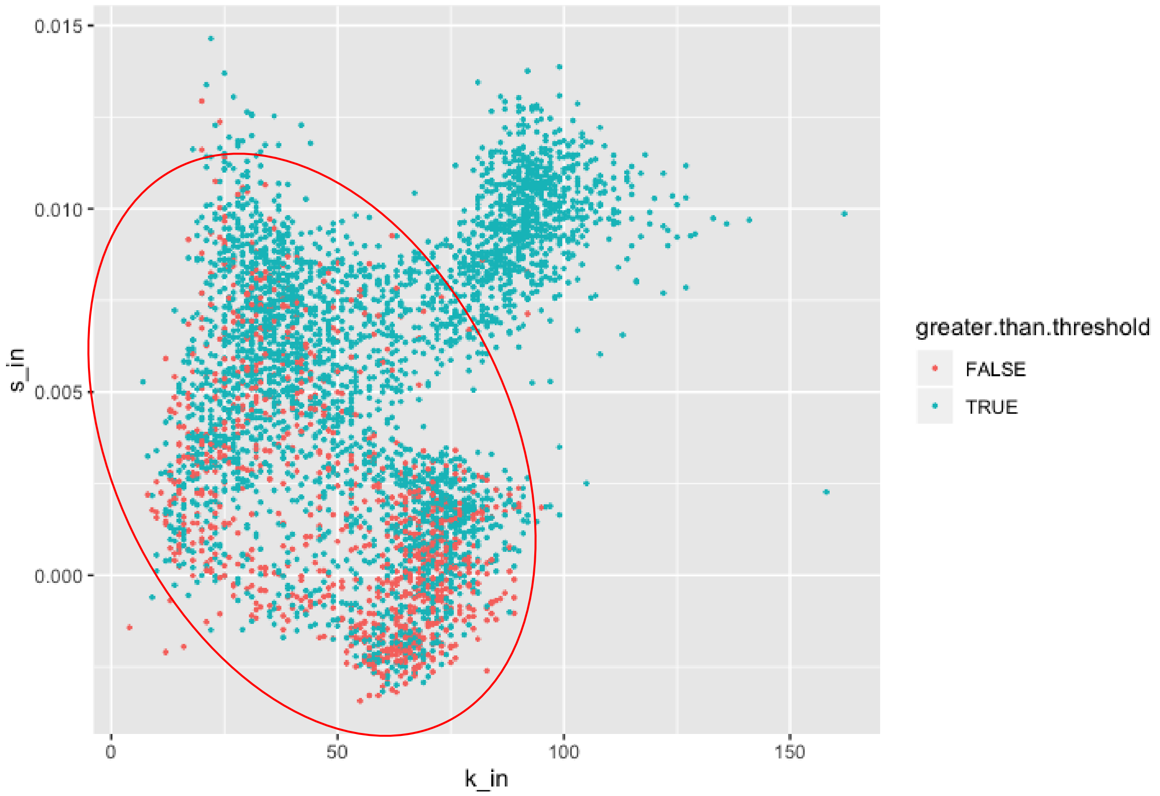


s^+_in vs k^+_in

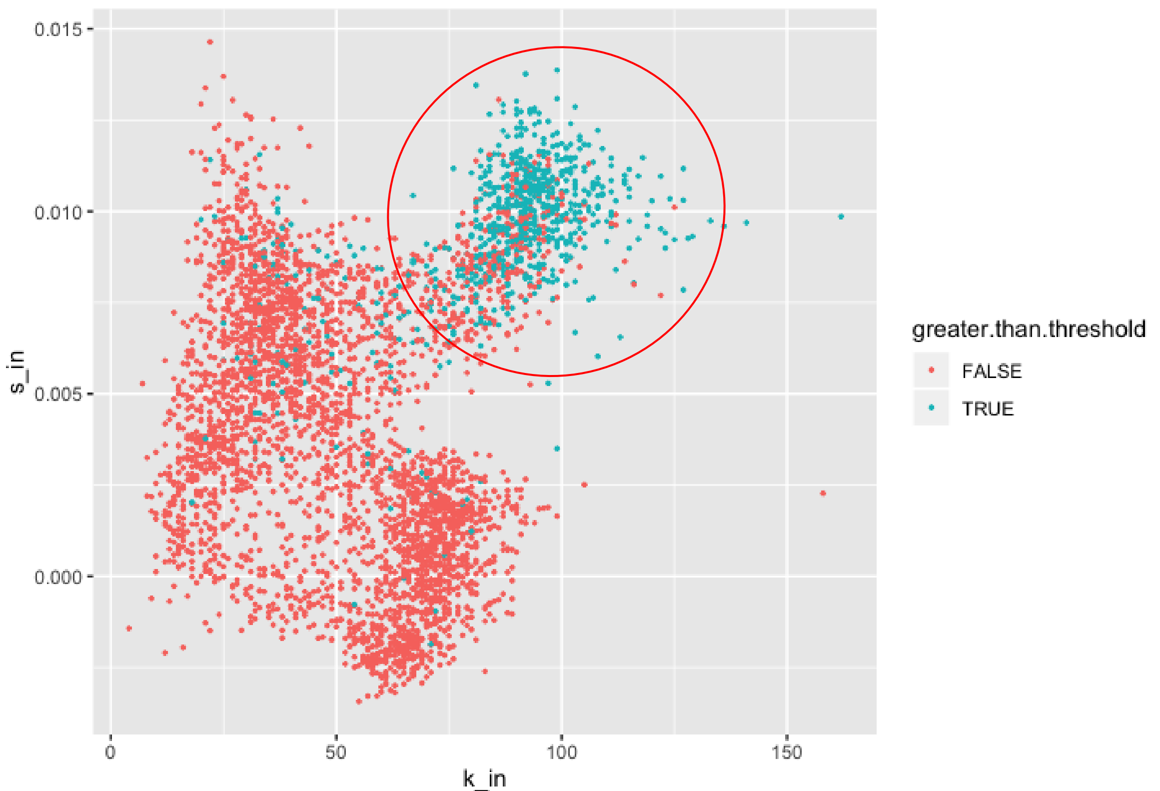


- **Peak count in degree-strength space (other thresholds)**

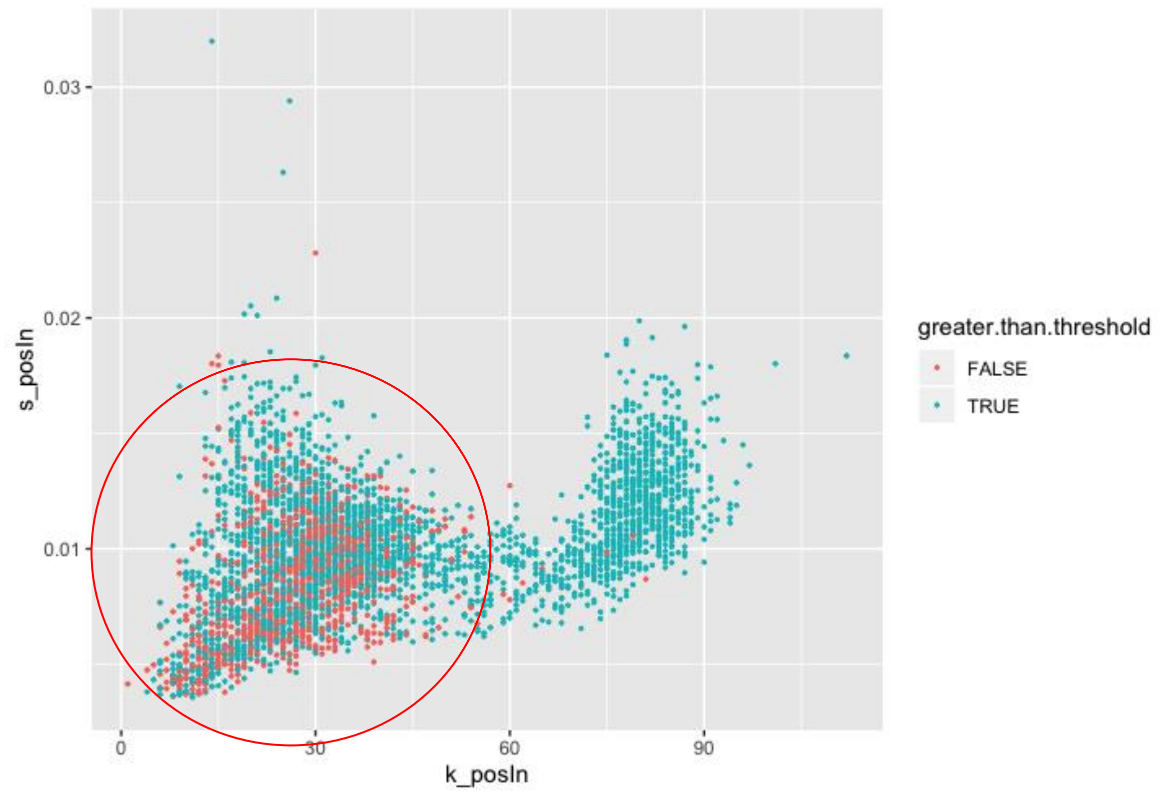
s_in vs k_in (20th percentile threshold)



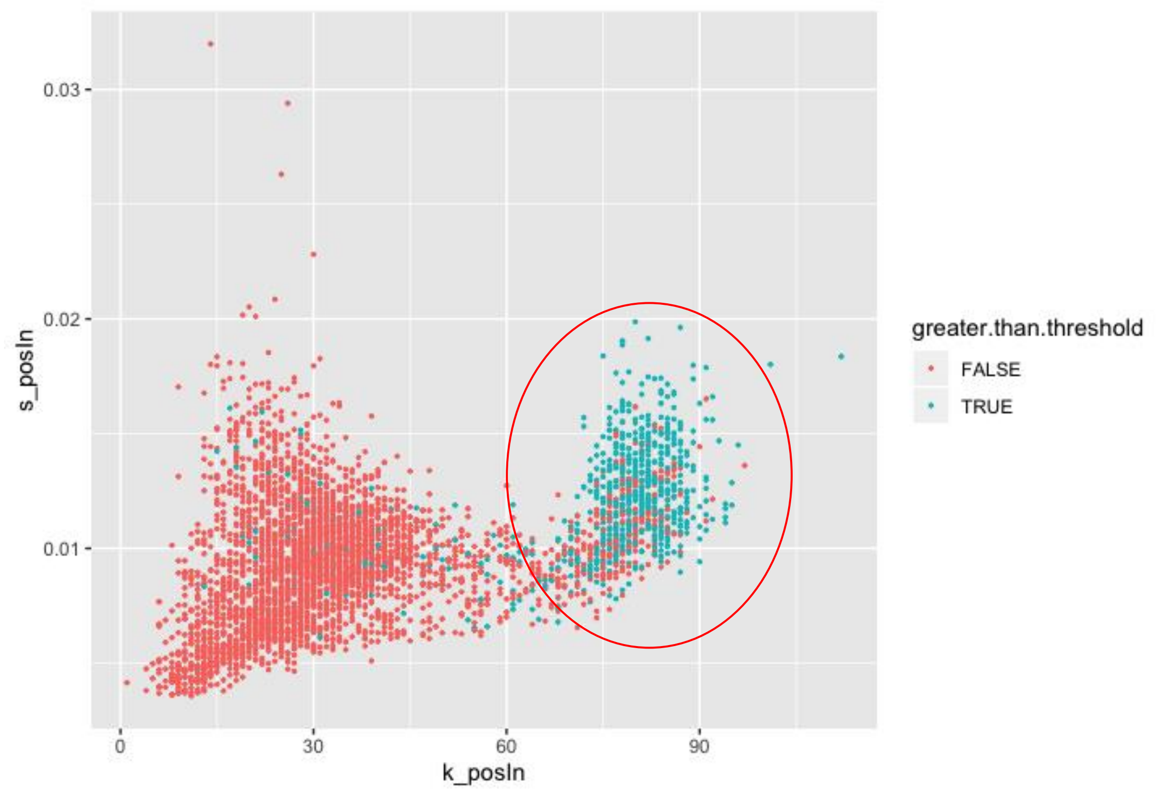
s_in vs k_in (80th percentile threshold)



s^+_in vs k^+_in (20th percentile threshold)



s^+_in vs k^+_in (80th percentile threshold)



Analysis on reference networks

(a) reference network 1: keep Aij but replace nonzero gij by values taken from a Gaussian distribution of same mean and standard deviation (this time we do not separately consider positive and negative gij's). This network has same k_in and k_out but different s_in and s_out

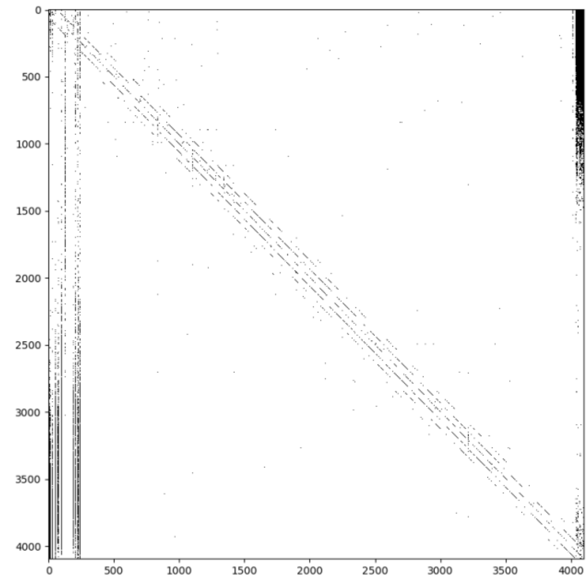
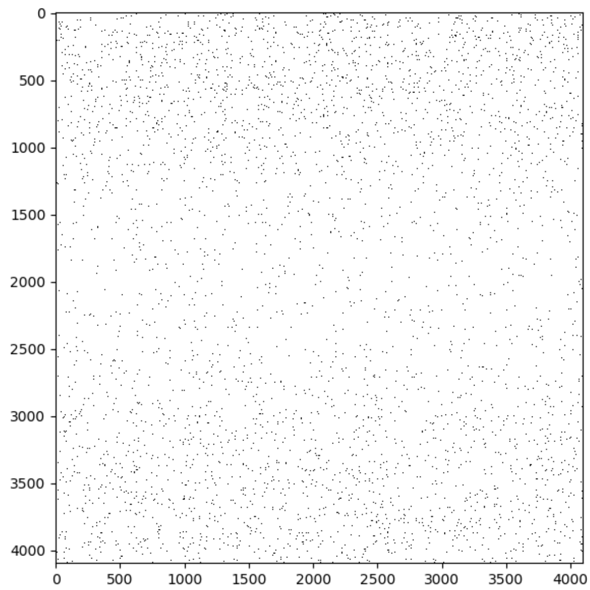
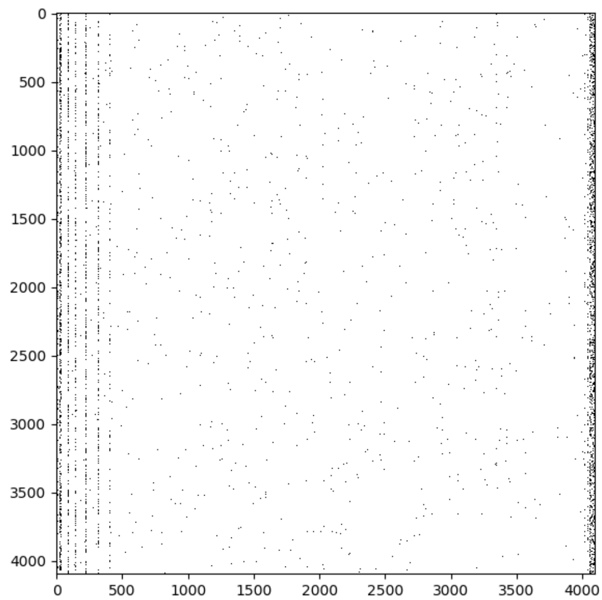
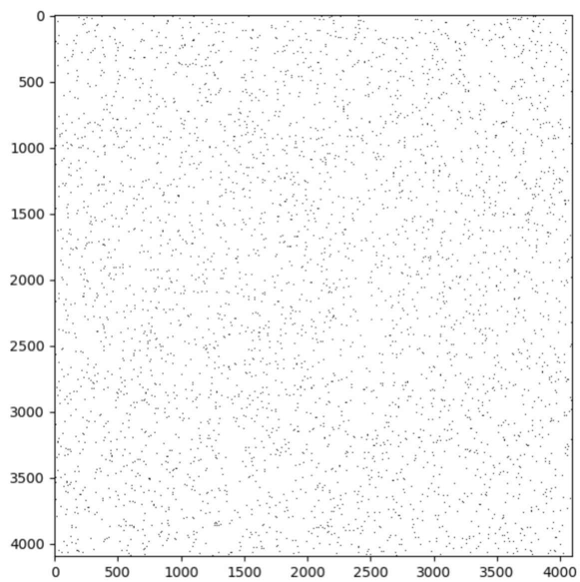
(b) reference network 2: shuffle gij for fixed i; this has same k_in and s_in but different k_out and s_out

(c) reference network 3: shuffle gij for fixed j; this has same k_out and s_out but different k_in and s_in

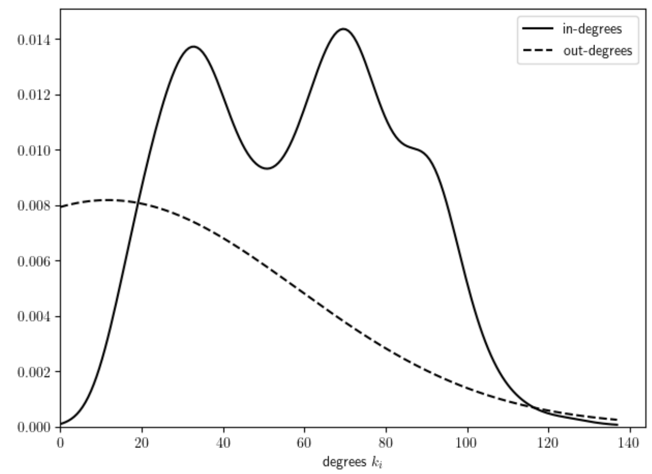
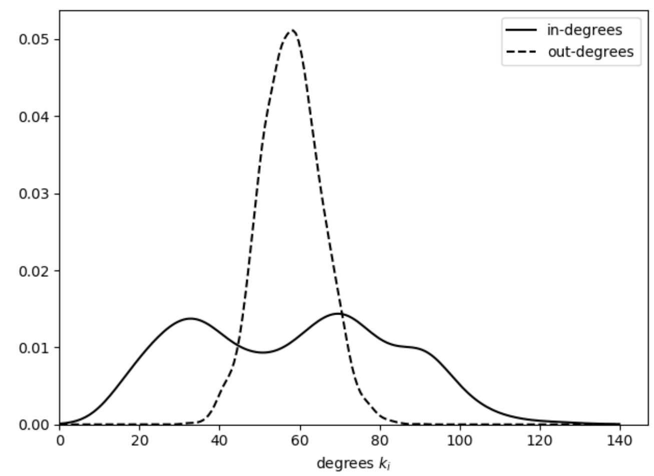
(d) reference network 4: random directed network with same connection probability p and gij from a Gaussian distribution of same mean and standard deviation

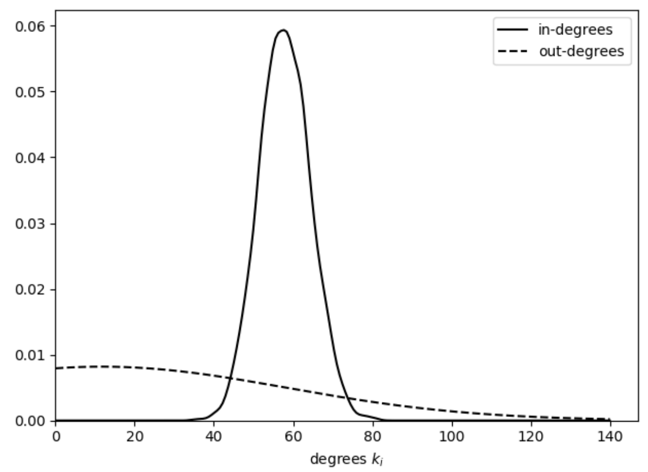
(e) reference network 5: keep Aij but shuffle non-zero gij

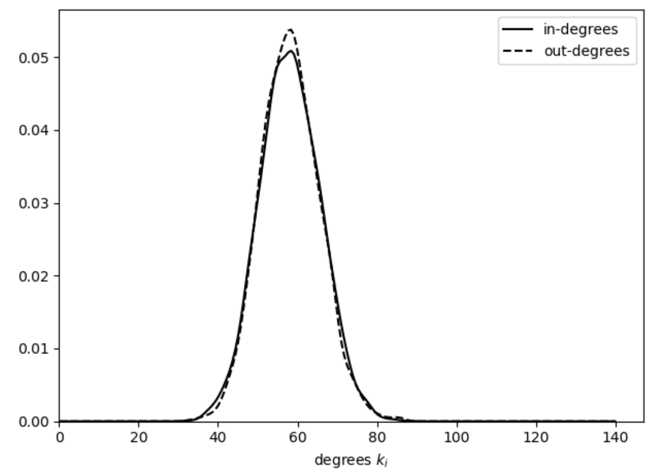
Adjacency matrix

Original Network	Ref. Network 1 (non-zero gij Gaussian)
	(same as the original adjacency matrix)
Ref. Network 2 (row gij shuffled)	**Ref. Network 3 (col gij shuffled)**
	
Ref. Network 4 (random)	**Ref. Network 5 (non-zero gij shuffled)**
	(same as the original adjacency matrix)

Degree distribution

<table>
<tr><th>Original Network</th><th>Ref. Network 1 (non-zero gij Gaussian)</th></tr>
<tr><td>
</td><td>(same as the original degree distribution)</td></tr>
<tr><th>Ref. Network 2 (row gij shuffled)</th><th>Ref. Network 3 (col gij shuffled)</th></tr>
<tr><td>

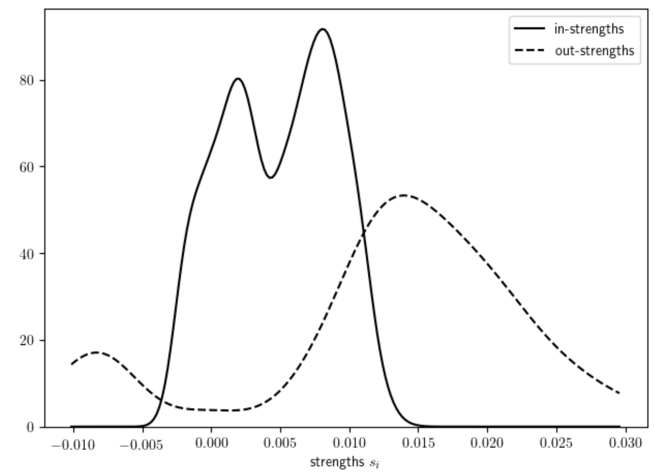
- In-degrees identical to original</td><td>

- Out-degrees identical to original</td></tr>
<tr><th>Ref. Network 4 (random)</th><th>Ref. Network 5 (non-zero gij shuffled)</th></tr>
<tr><td>

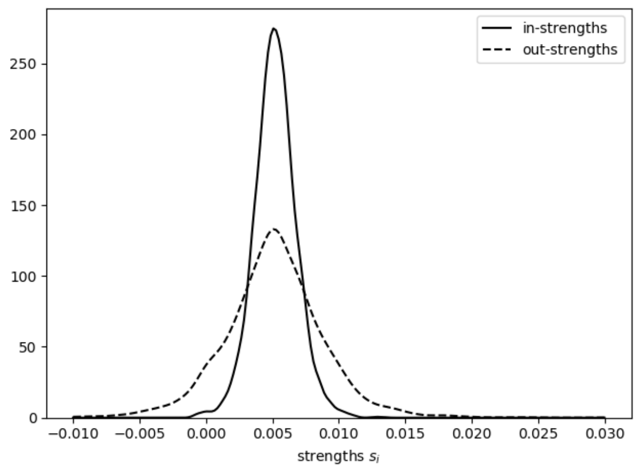
- In-degrees & out-degrees have same distribution</td><td>(same as the original degree distribution)</td></tr>
</table>

Strength distribution

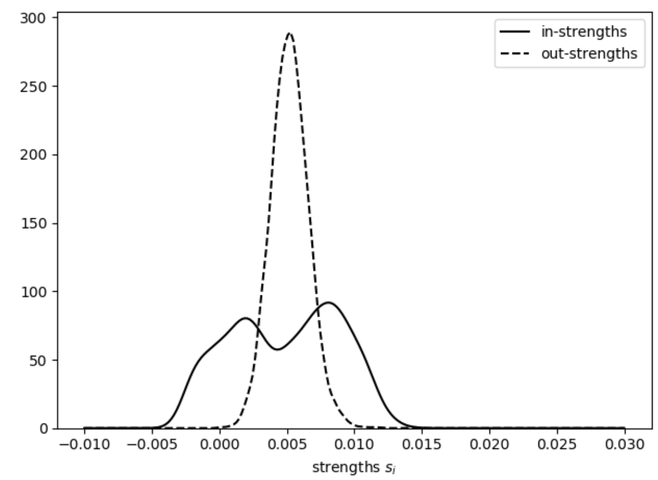
Original Network



Ref. Network 1 (non-zero gij Gaussian)

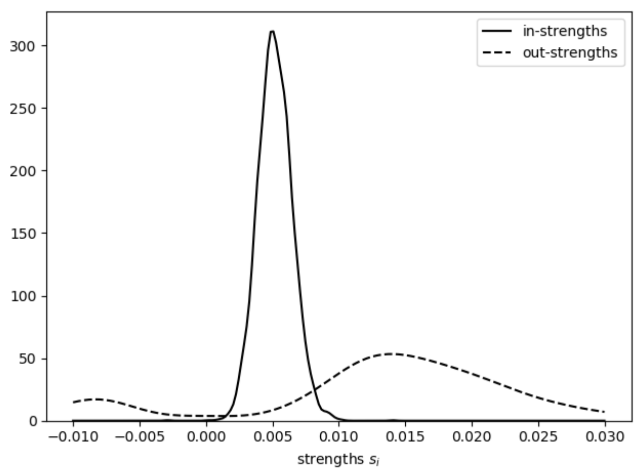


Ref. Network 2 (row gij shuffled)



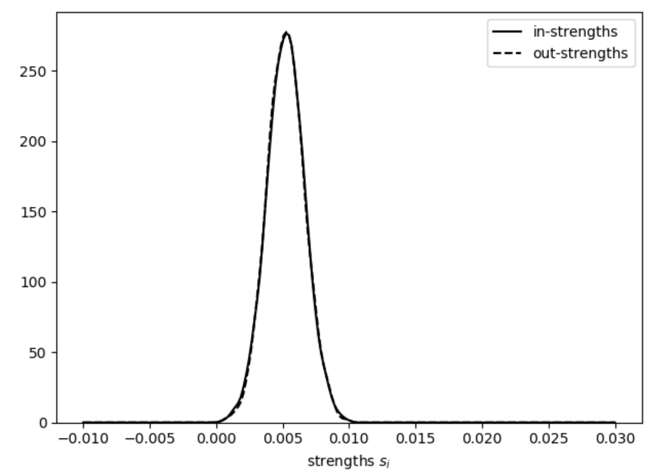
- **In-strengths identical to original**

Ref. Network 3 (col gij shuffled)



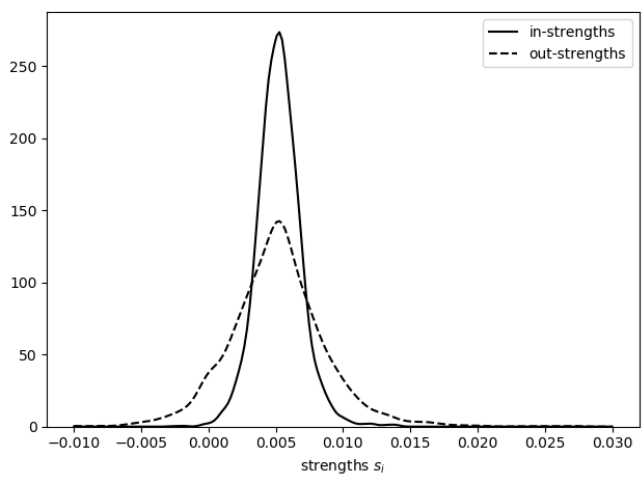
- **Out-strengths identical to original**

Ref. Network 4 (random)



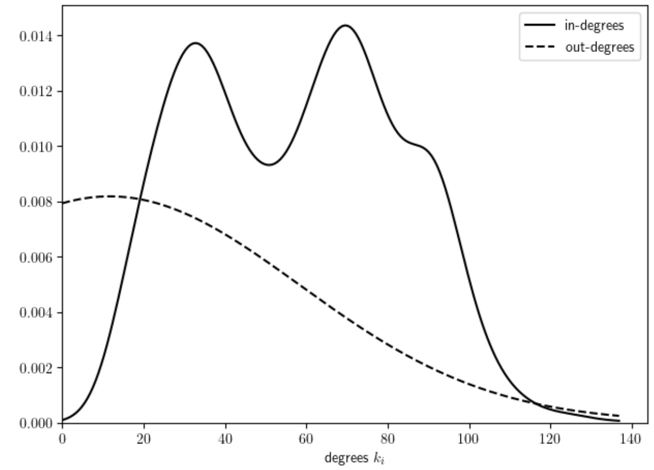
- **In-strengths & out-strengths have same distribution**

Ref. Network 5 (non-zero gij shuffled)



Degree distribution (standardized)
Red dotted = standard Gaussian

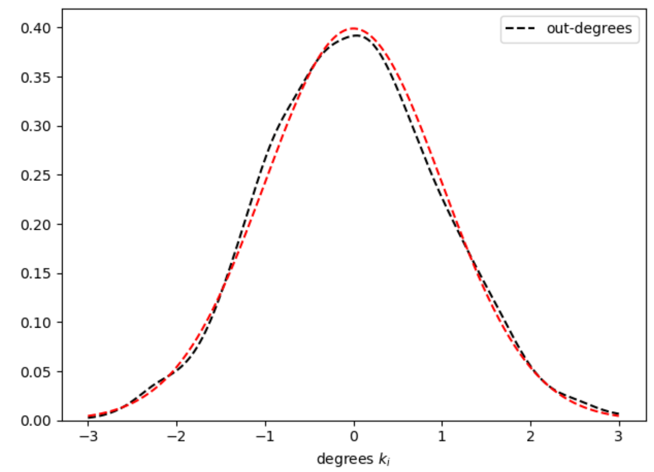
Original Network



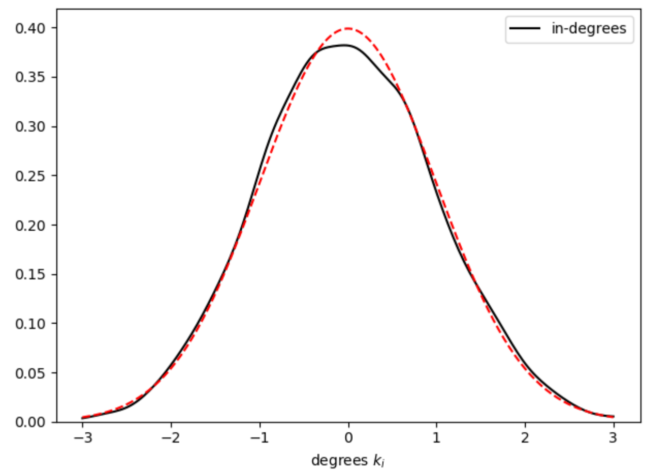
Ref. Network 1 (non-zero gij Gaussian)

(same as the original degree distribution)

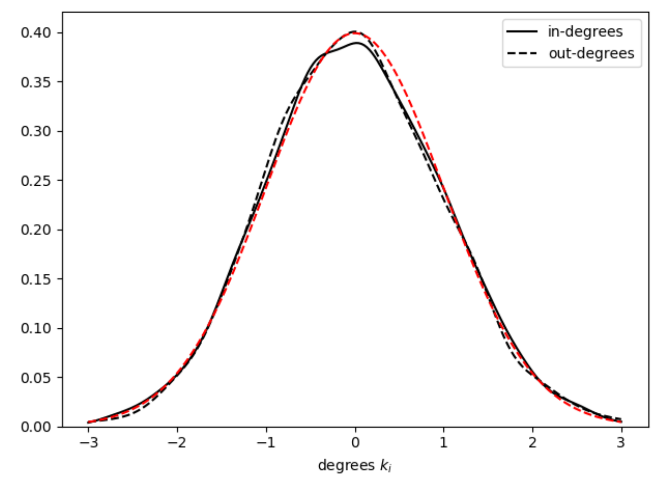
Ref. Network 2 (row gij shuffled)



Ref. Network 3 (col gij shuffled)



Ref. Network 4 (random)

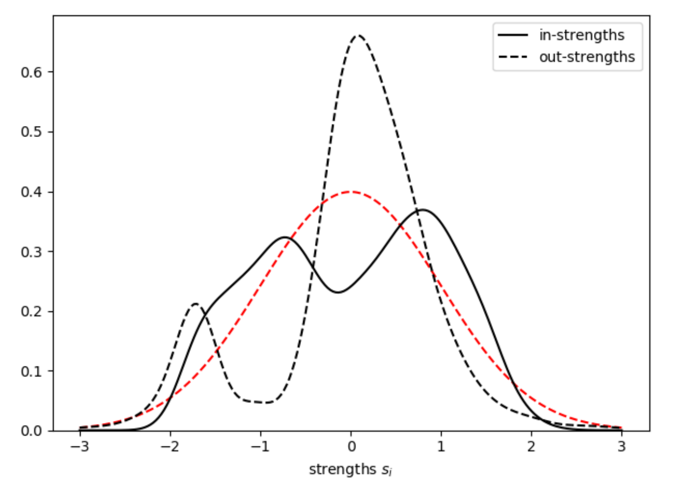


Ref. Network 5 (non-zero gij shuffled)

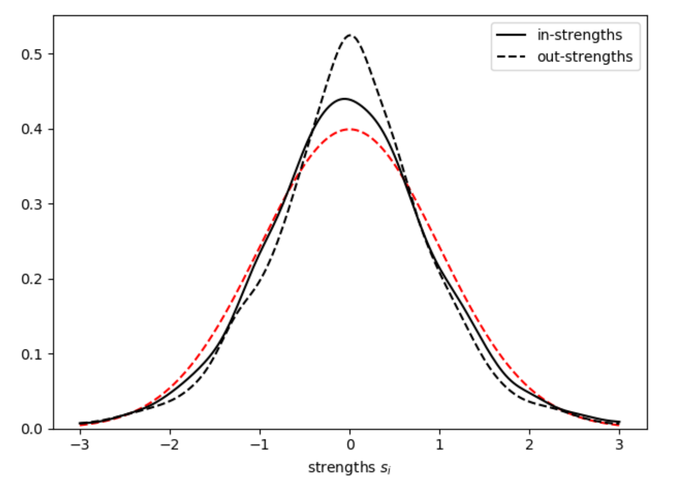
(same as the original degree distribution)

Strength distribution (standardized)
Red dotted = standard Gaussian

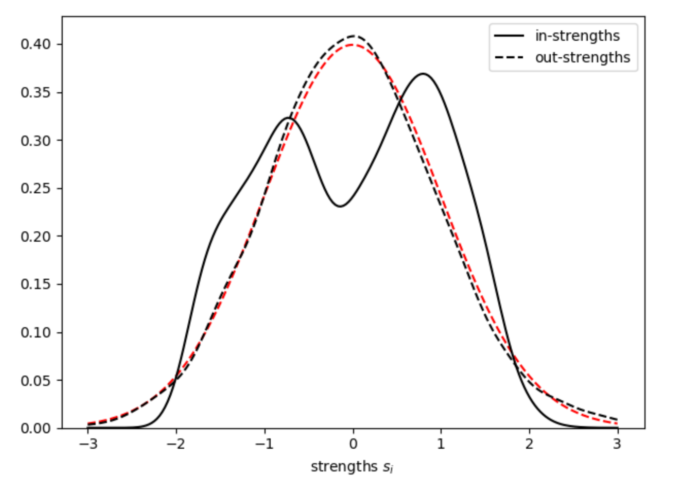
Original Network



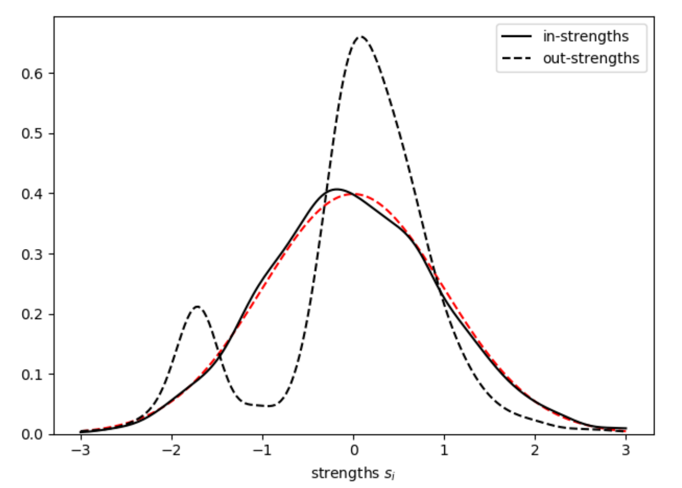
Ref. Network 1 (non-zero gij Gaussian)



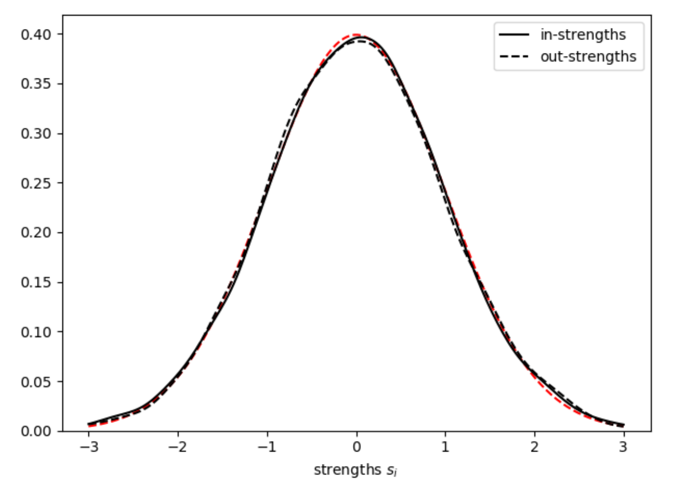
Ref. Network 2 (row gij shuffled)



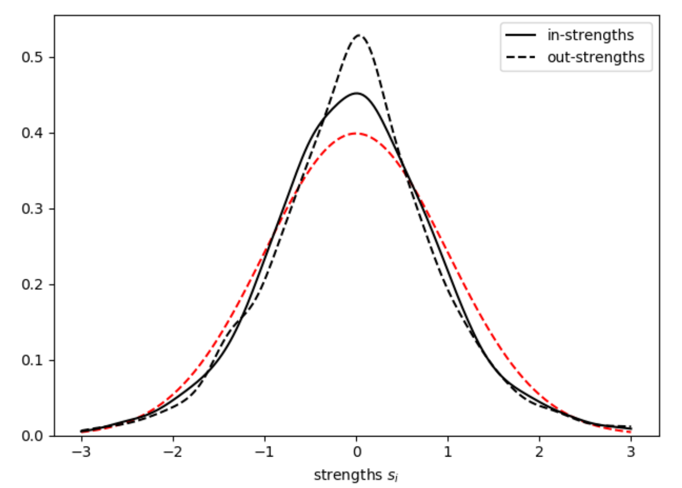
Ref. Network 3 (col gij shuffled)

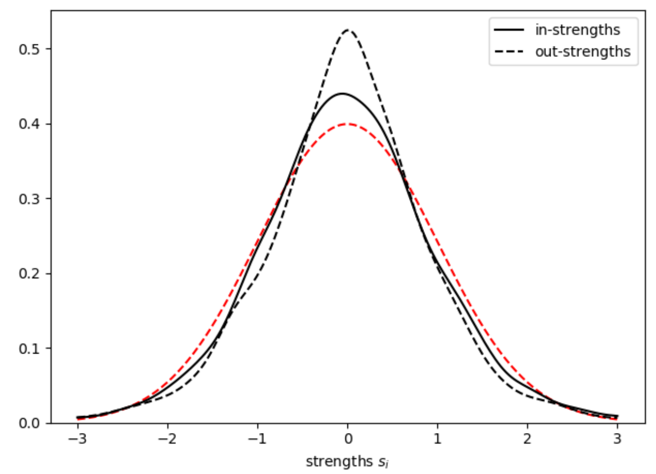
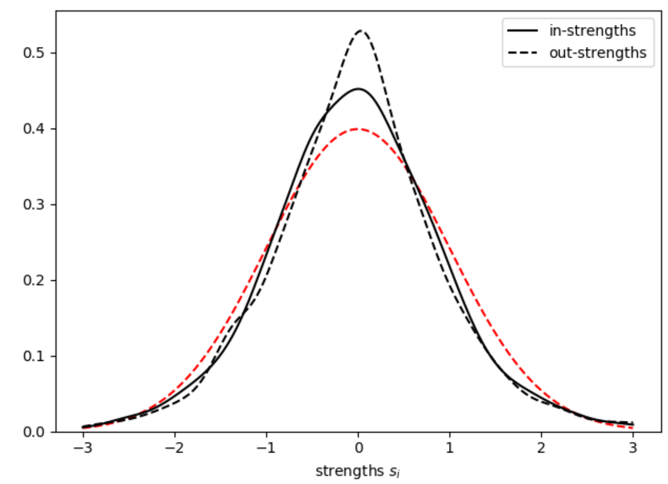


Ref. Network 4 (random)



Ref. Network 5 (non-zero gij shuffled)



<table>
<tr><th>Ref. Network 1 (non-zero gij Gaussian)</th><th>Ref. Network 5 (non-zero gij shuffled)</th></tr>
<tr><th colspan="2">Strength distribution (standardized)</th></tr>
<tr><td>
</td><td>
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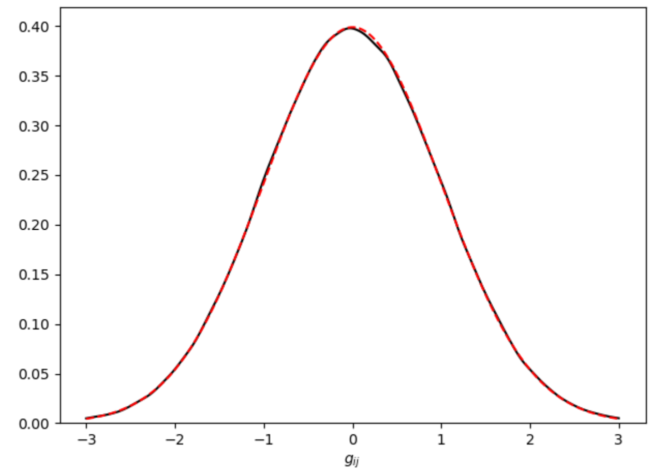
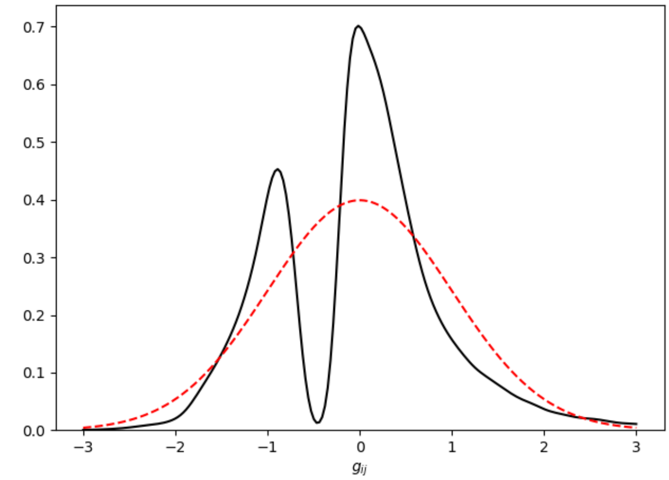
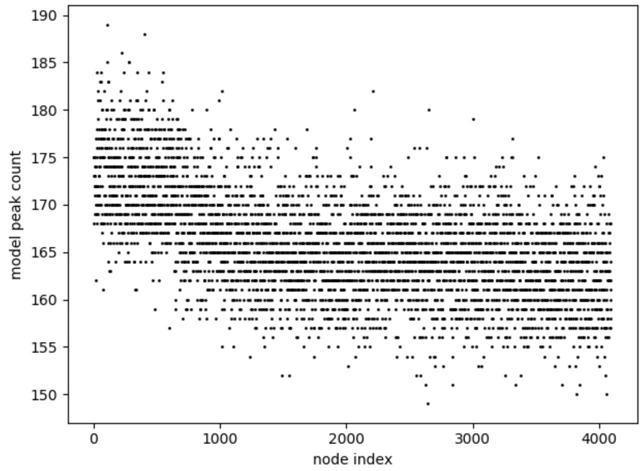
<tr><th colspan="2">gij distribution (standardized)</th></tr>
<tr><td>
</td><td>

(same as original network’s)</td></tr>
</table>

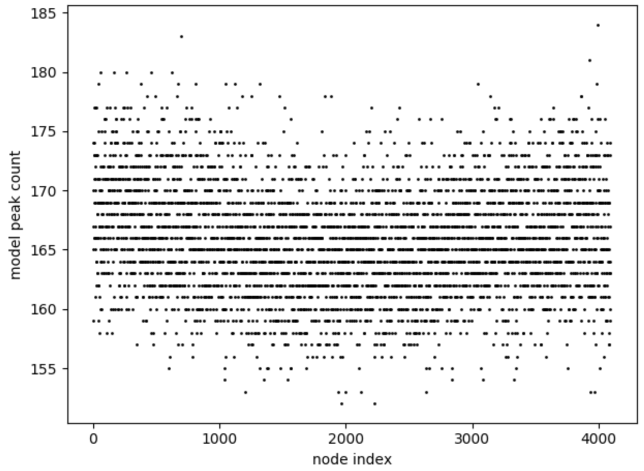
Peak count vs index (1e6 steps)

Case 1: $\epsilon = 0.1, \alpha = 0.95, \sigma_i = 2$

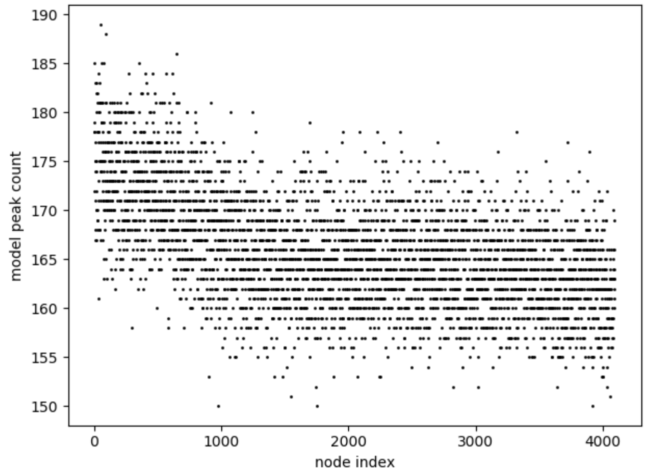
Original Network



Ref. Network 1 (non-zero gij Gaussian)

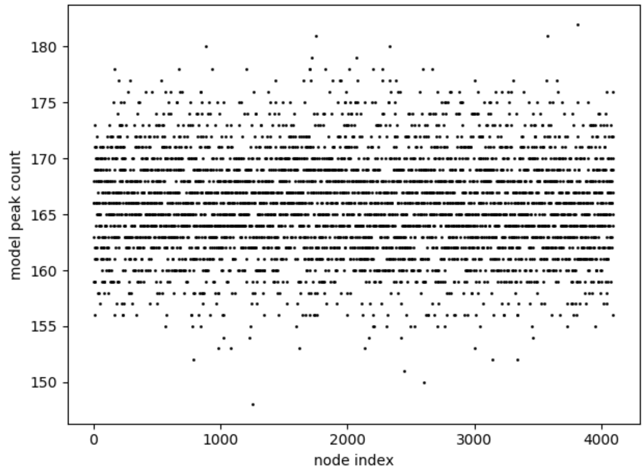


Ref. Network 2 (row gij shuffled)



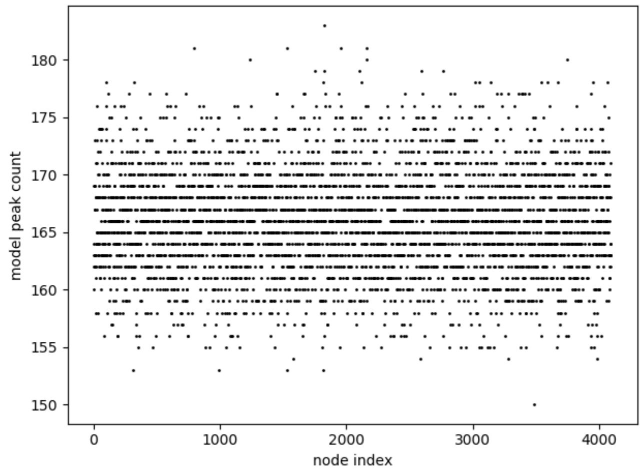
- Very similar to original; similar range
- Could imply k_in and s_in are important factors for peak counts

Ref. Network 3 (col gij shuffled)

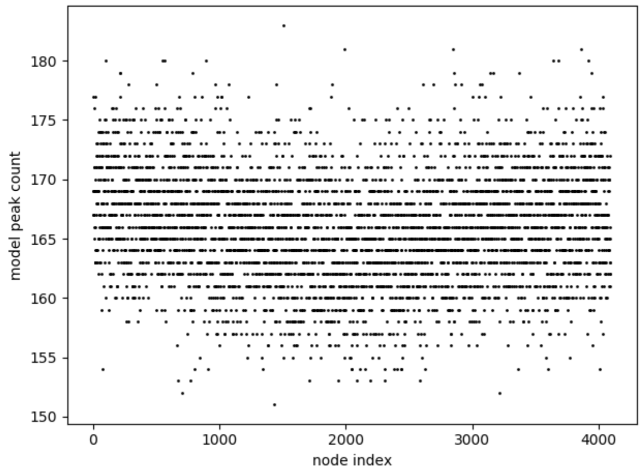


- Different from original; narrower range
- Could imply k_out and s_out are not important factors for peak counts

Ref. Network 4 (random)



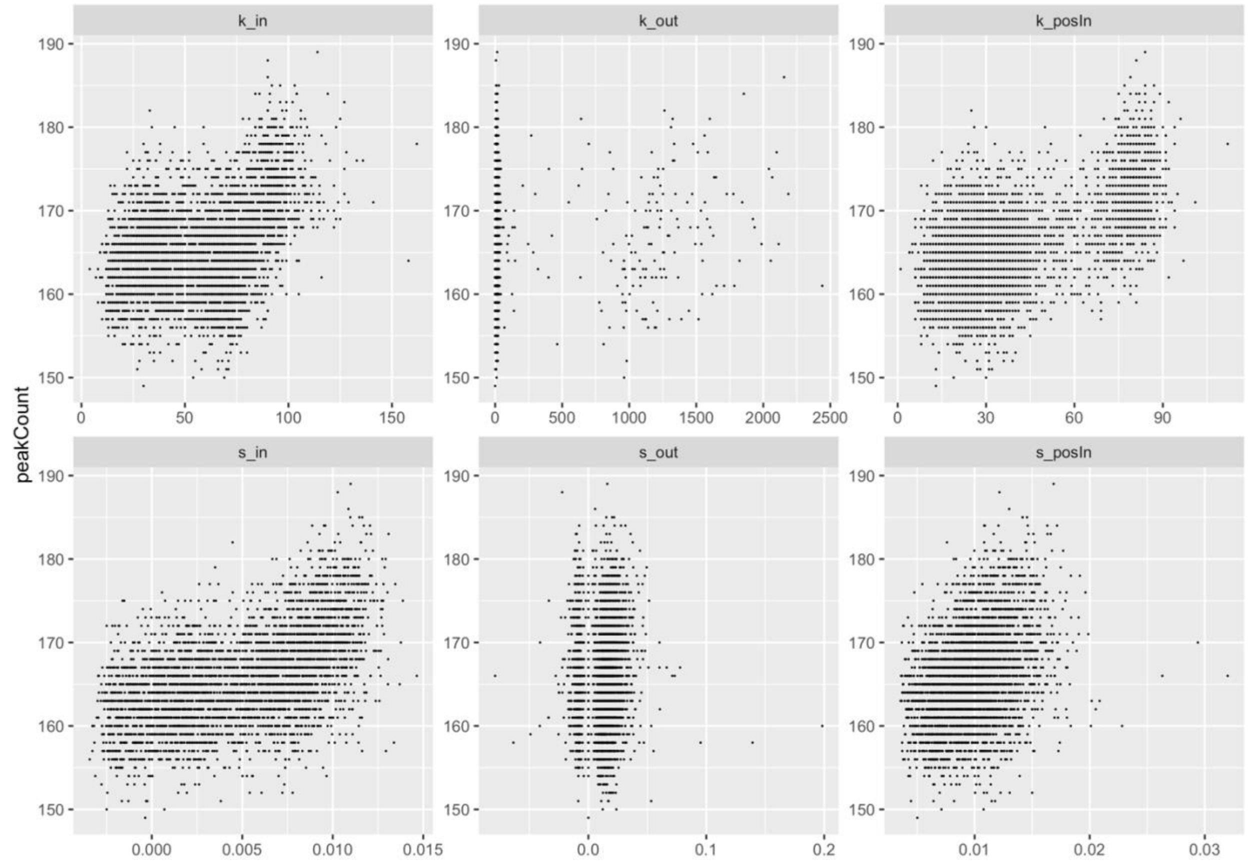
Ref. Network 5 (non-zero gij shuffled)



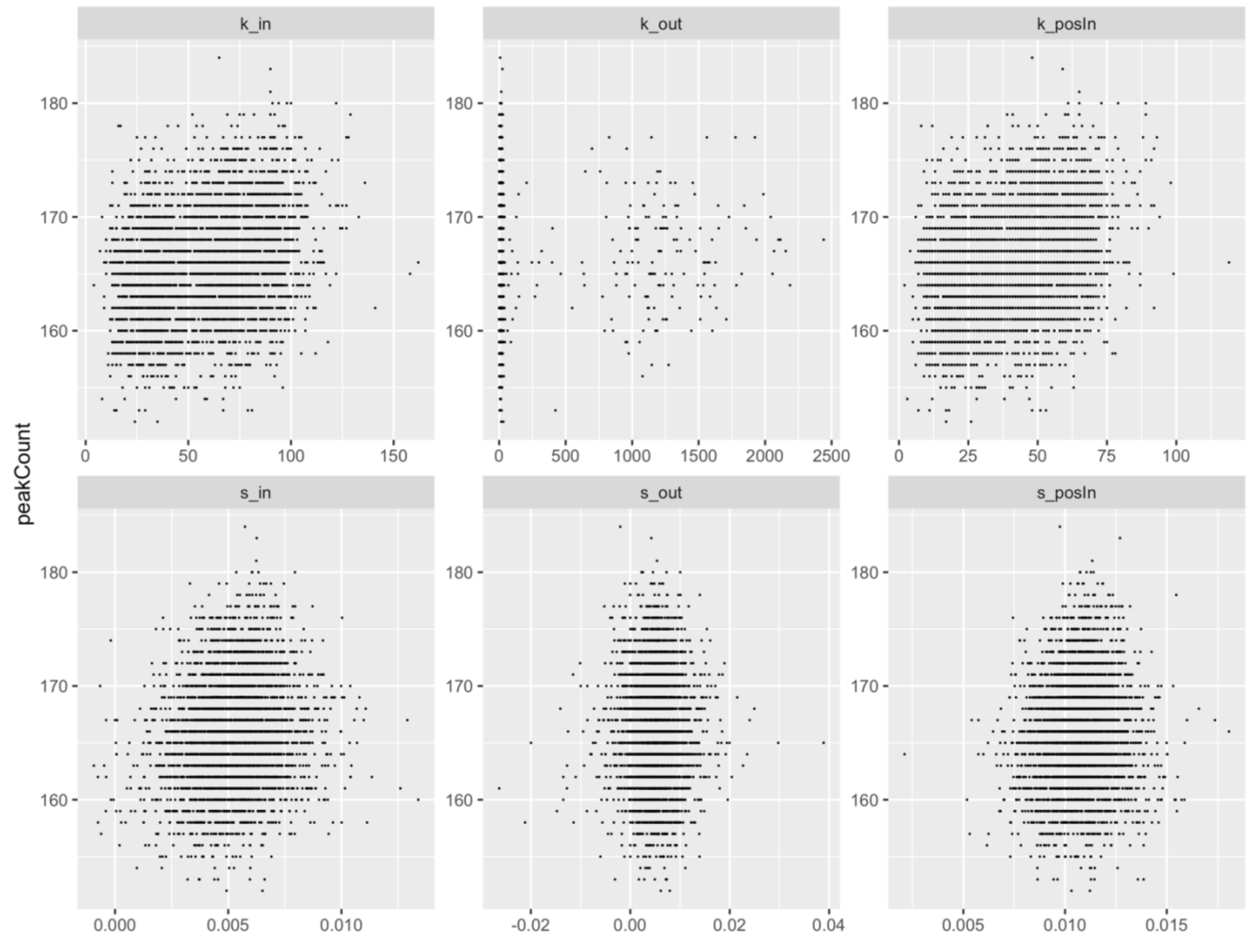
- Similar to ref. network 1

Exploratory analysis (1e6 steps)

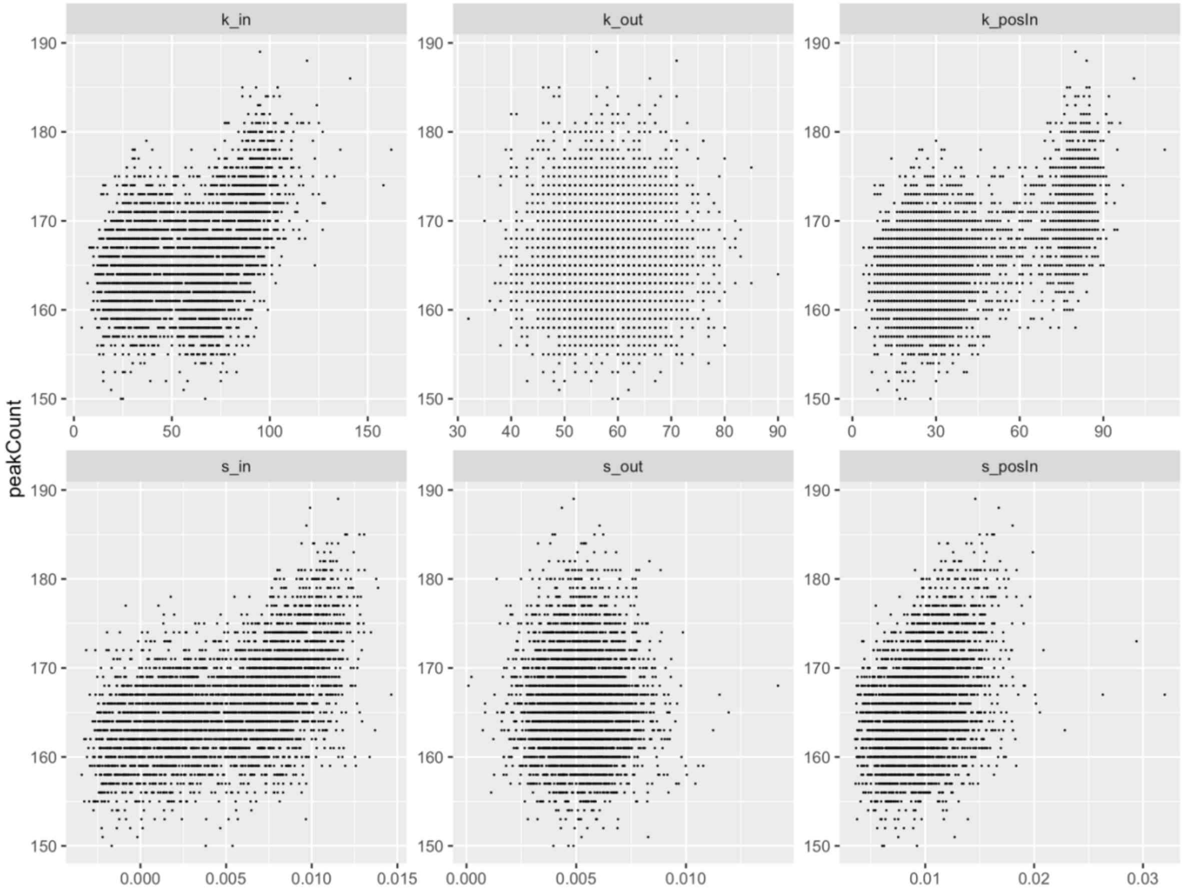
Original Network



Ref. Network 1 (non-zero gij Gaussian)

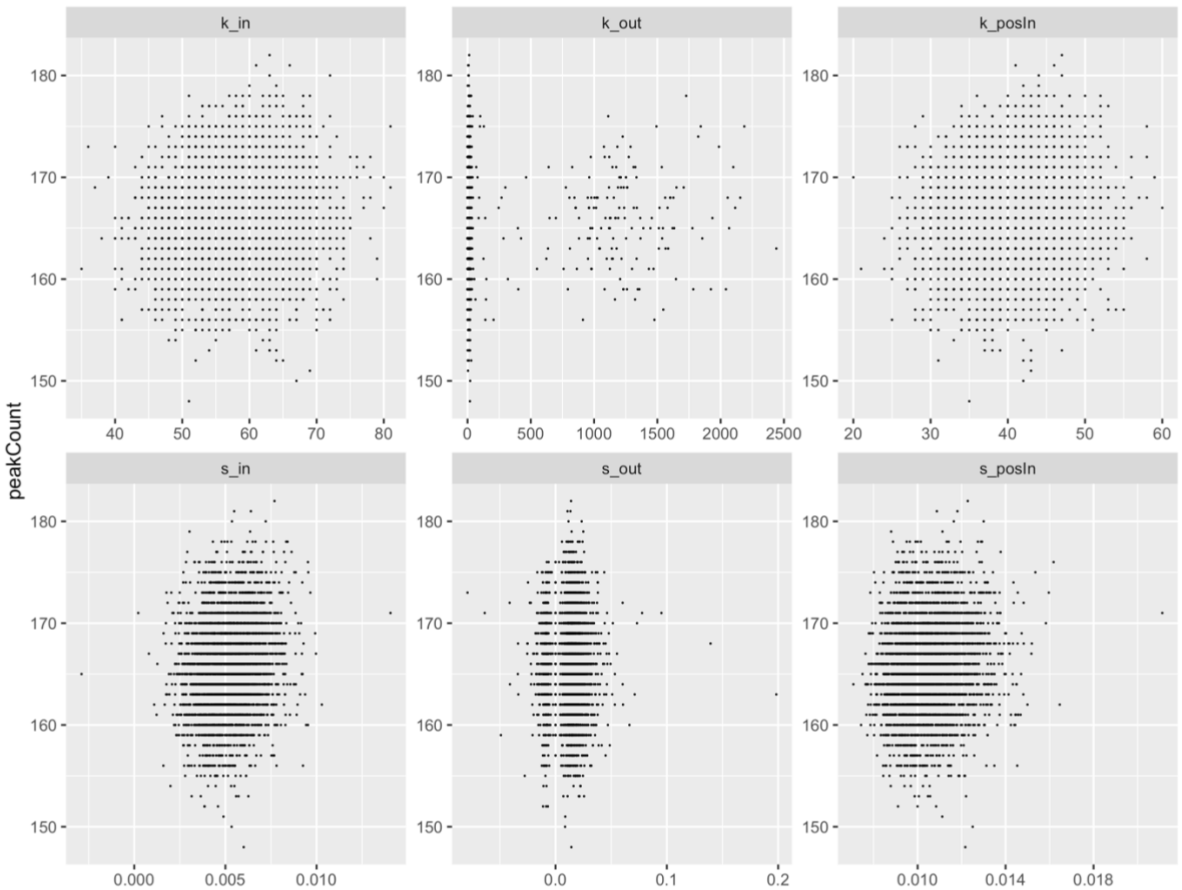


Ref. Network 2 (row gij shuffled)

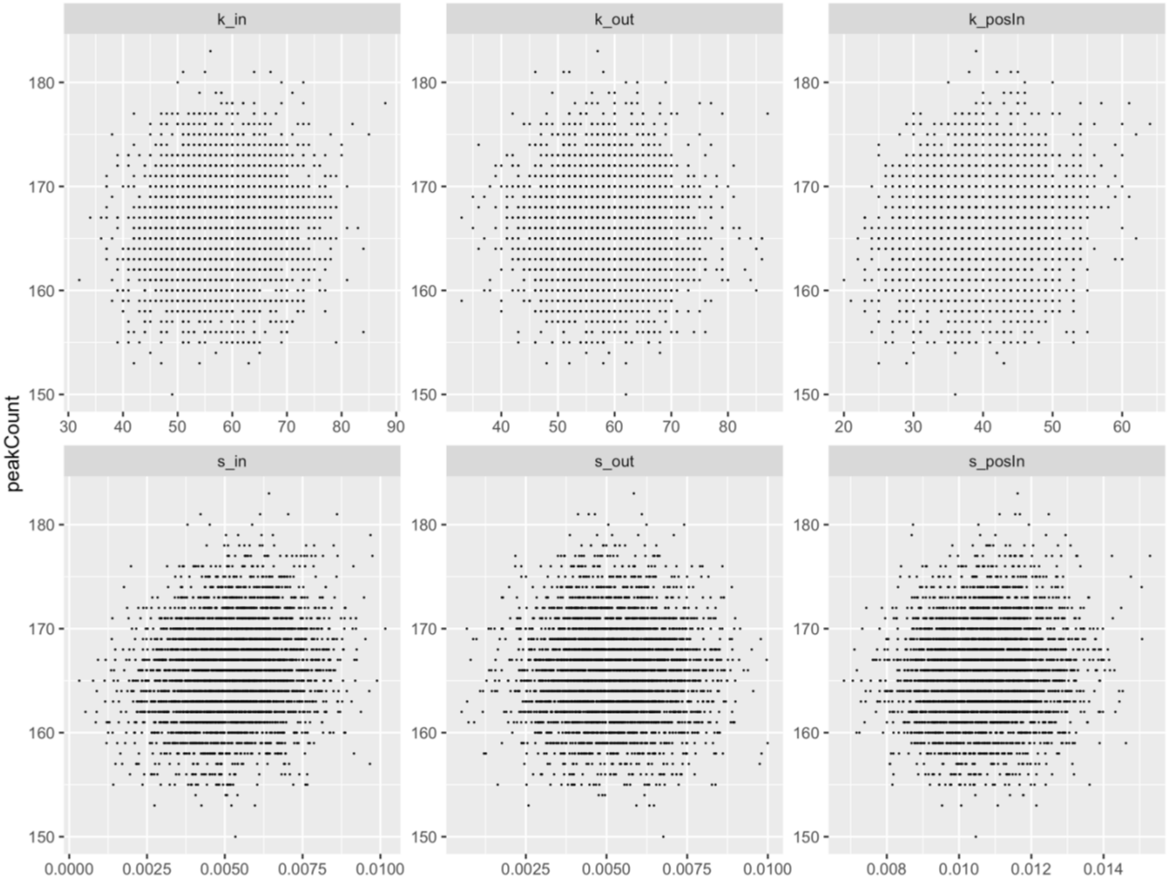


- **Very similar to original**

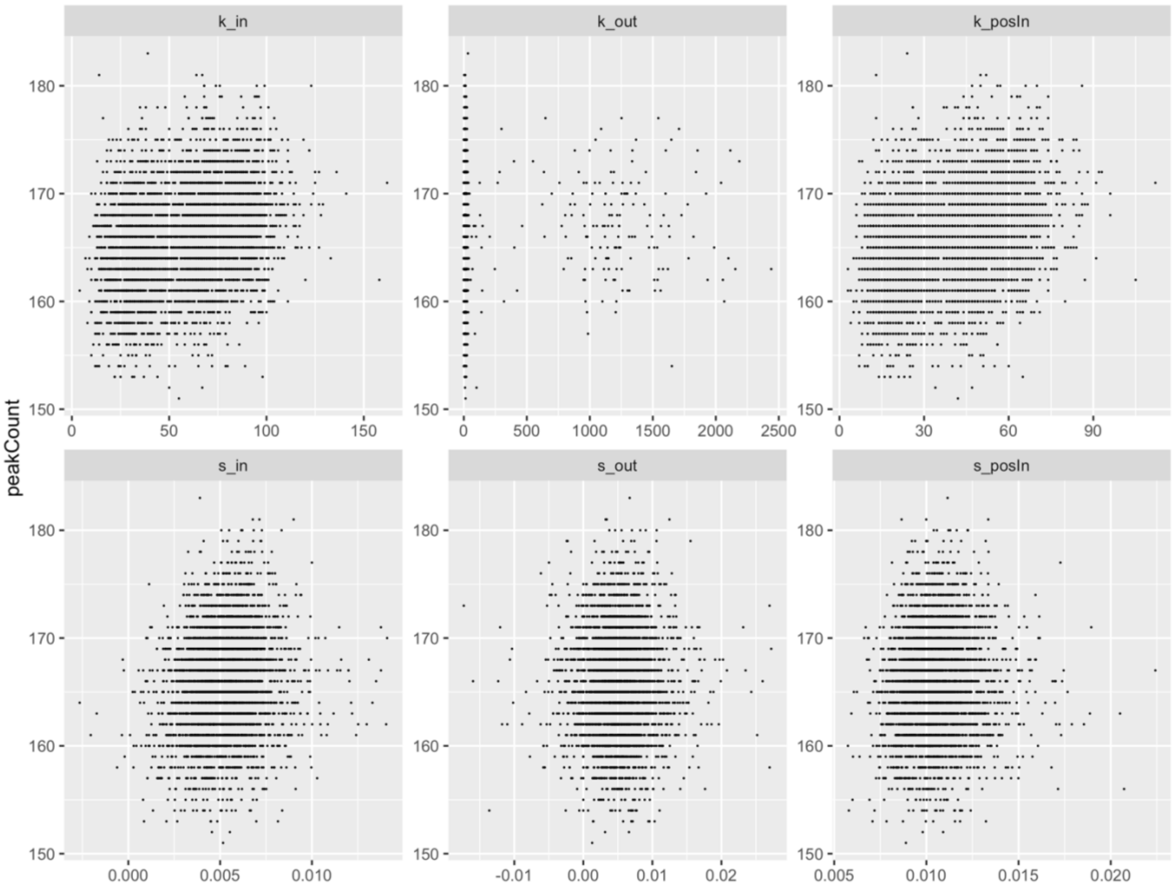
Ref. Network 3 (col gij shuffled)



Ref. Network 4 (random)



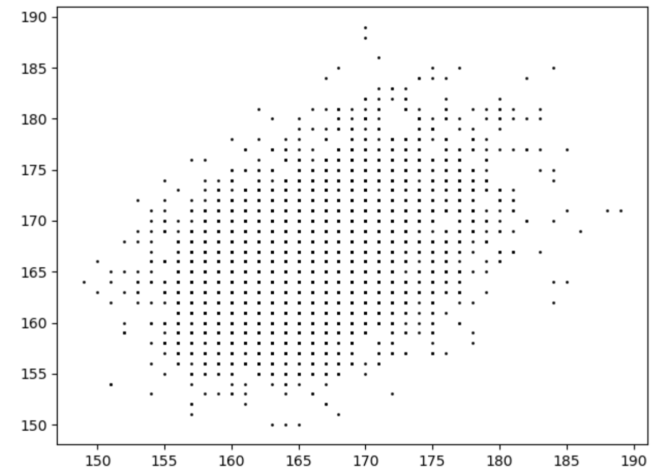
Ref. Network 5 (non-zero gij shuffled)



Peak count distribution comparison

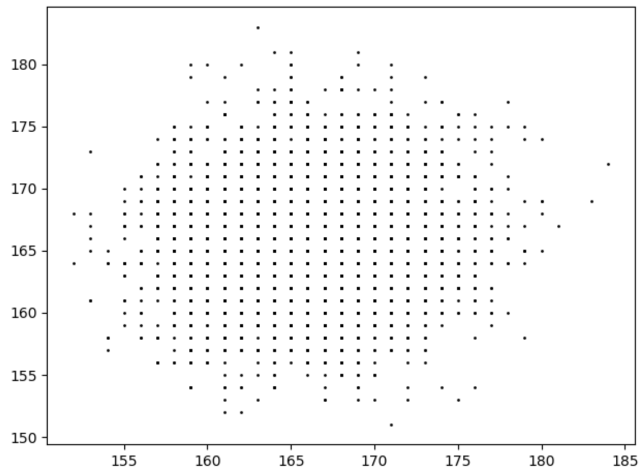
- **A vs B -> x-axis = A, y-axis = B**
- **Only networks with similar peak count vs index plots are compared**

Original Network vs Ref. Network 2



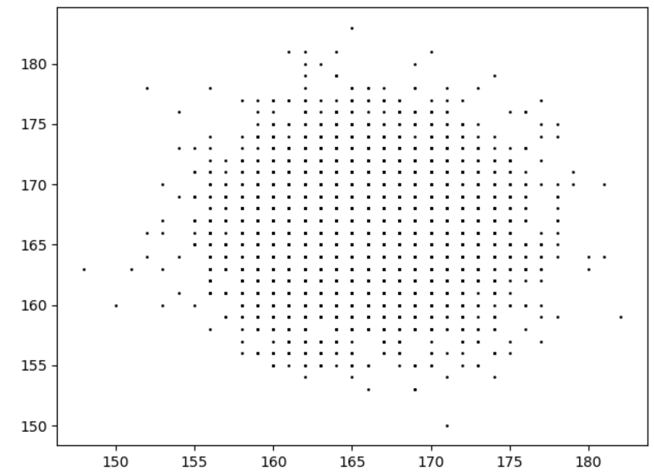
- **Correlation 0.3958**

Ref. Network 1 vs Ref. Network 5



- **Correlation 0.0638**

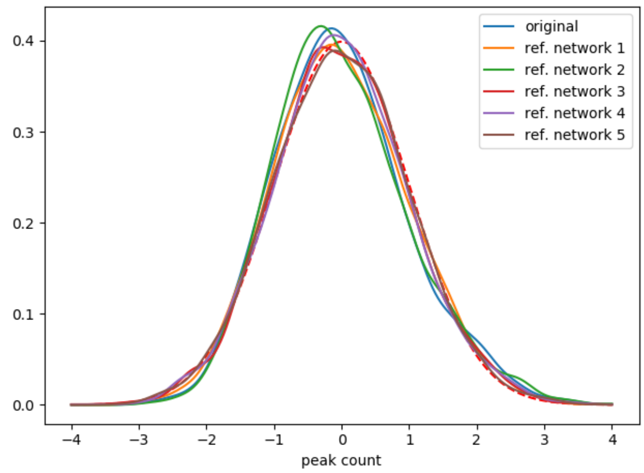
Ref. Network 3 vs Ref. Network 4

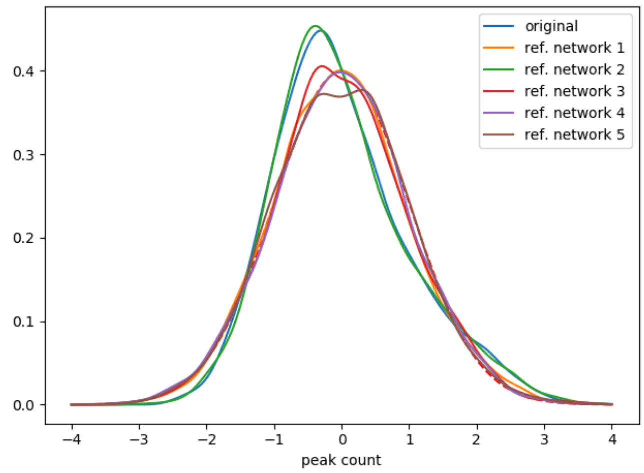


- **Correlation 0.0061**

- **May do a line fit and check F-statistic (later)**

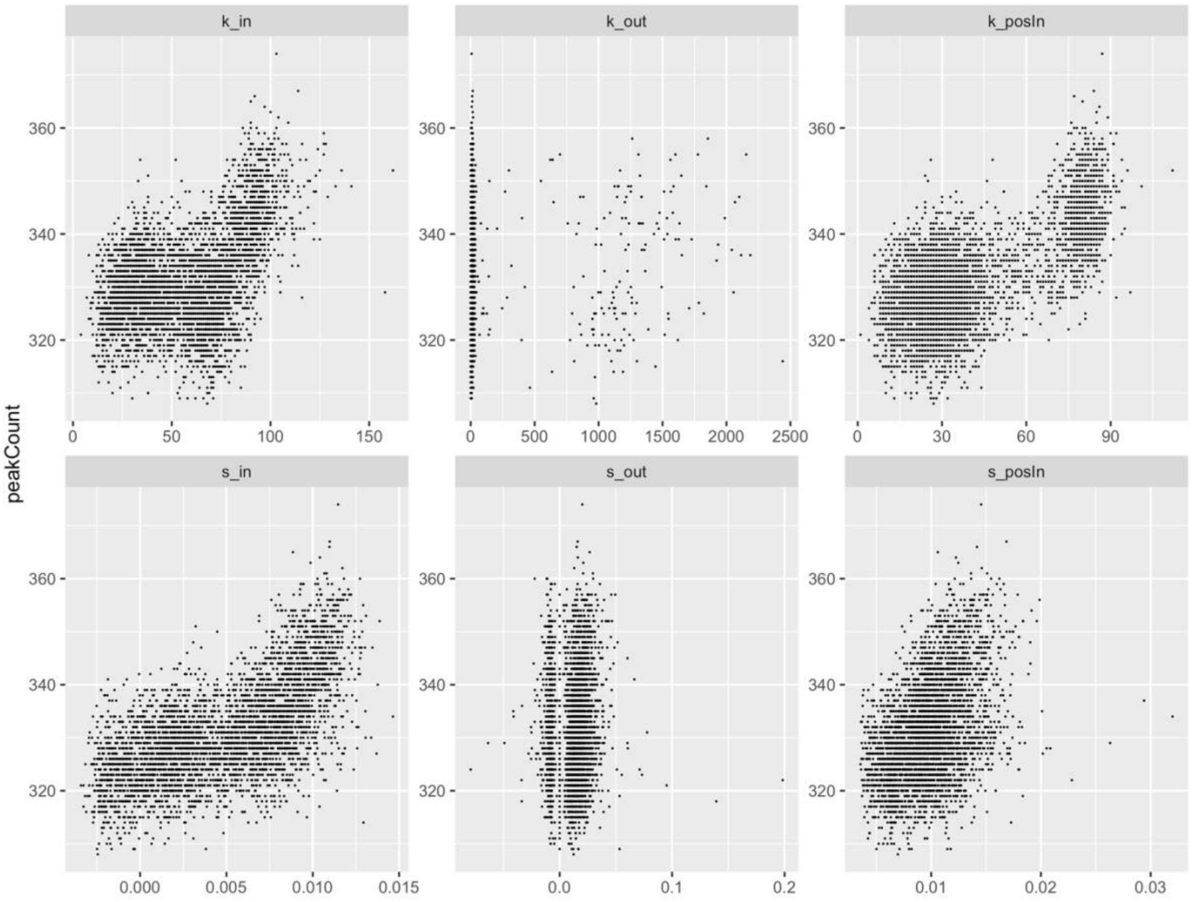
Peak count distribution comparison (2e6 steps)

<table>
<tr><th colspan="2">Distributions of original & 5 ref. networks combined</th></tr>
<tr><th>1e6 steps</th><th>2e6 steps</th></tr>
<tr><td>

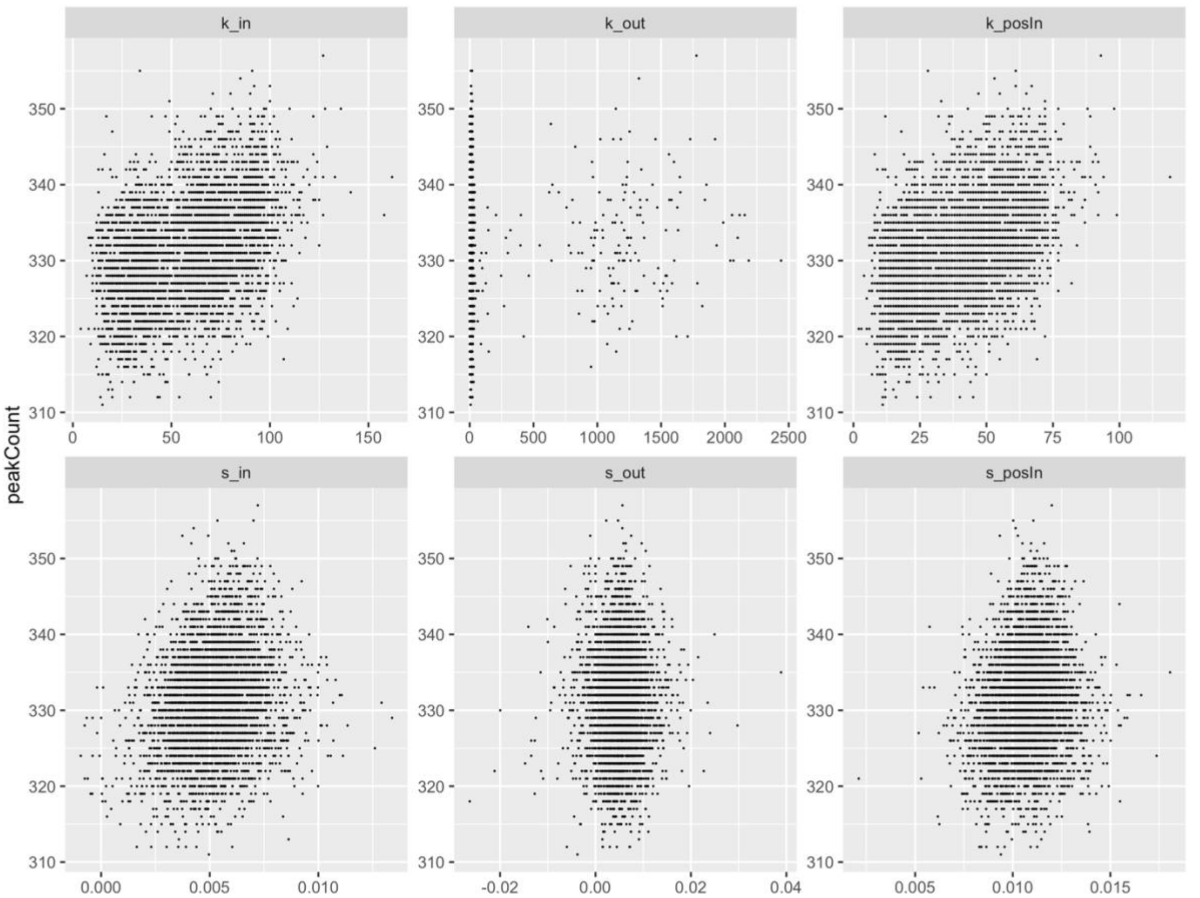
- Original & ref. network 2 are the most skewed
- Their peak count vs index plots are also similar</td><td>
</td></tr>
</table>

Exploratory analysis (2e6 steps)

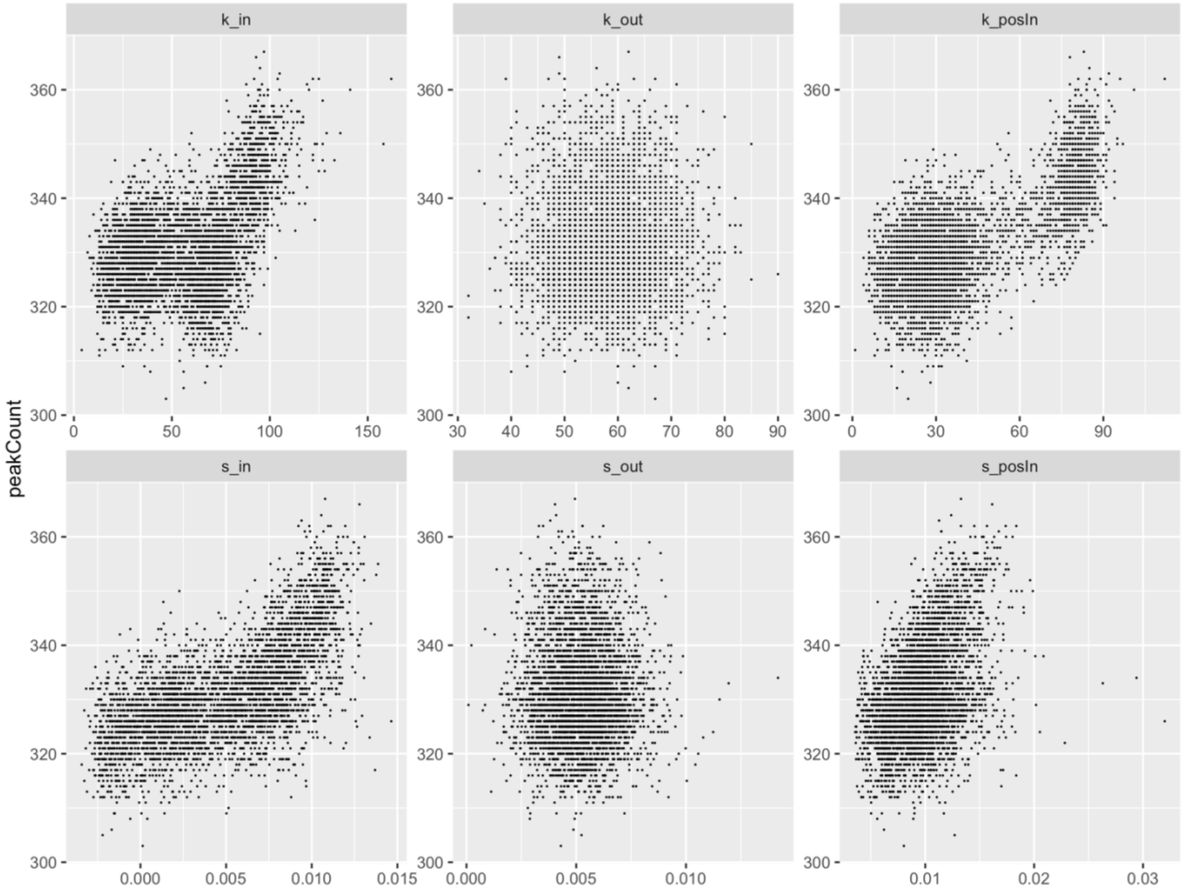
Original Network



Ref. Network 1 (non-zero gij Gaussian)

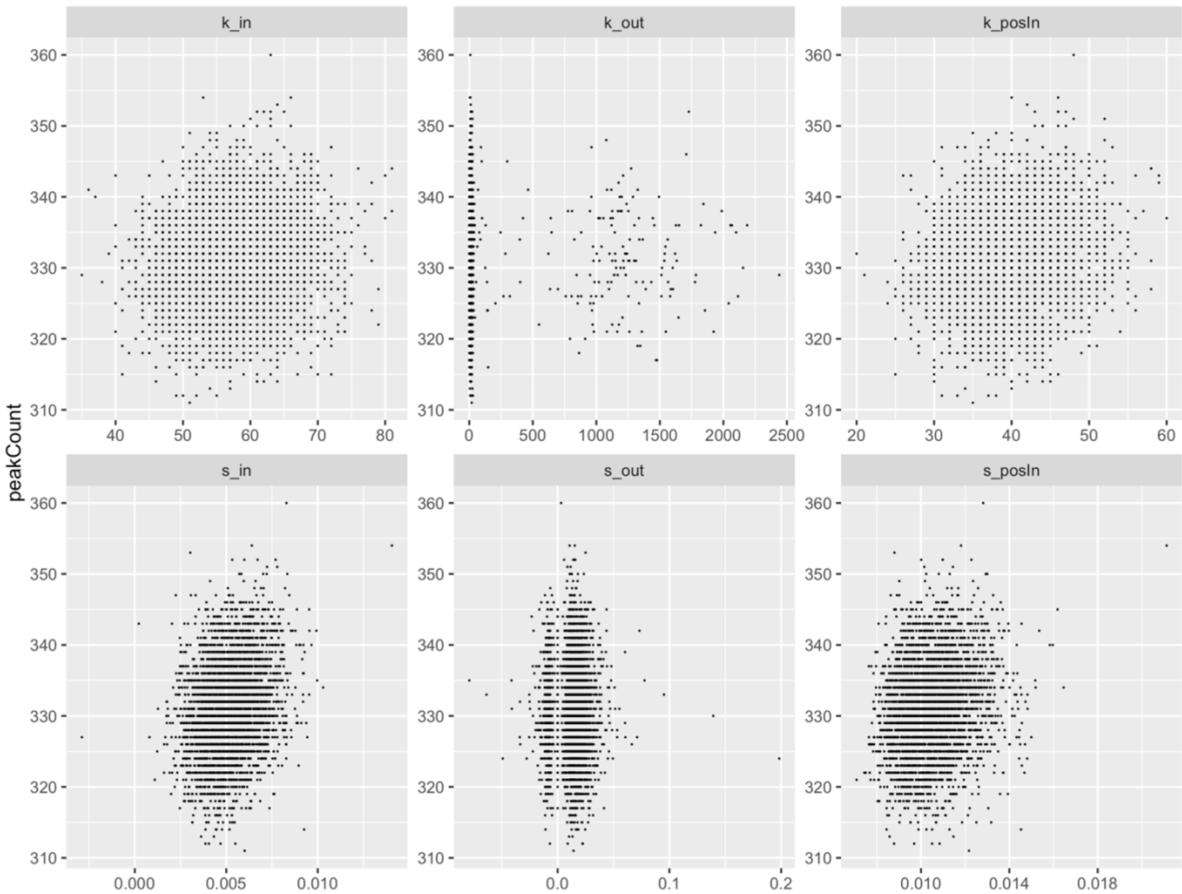


Ref. Network 2 (row gij shuffled)

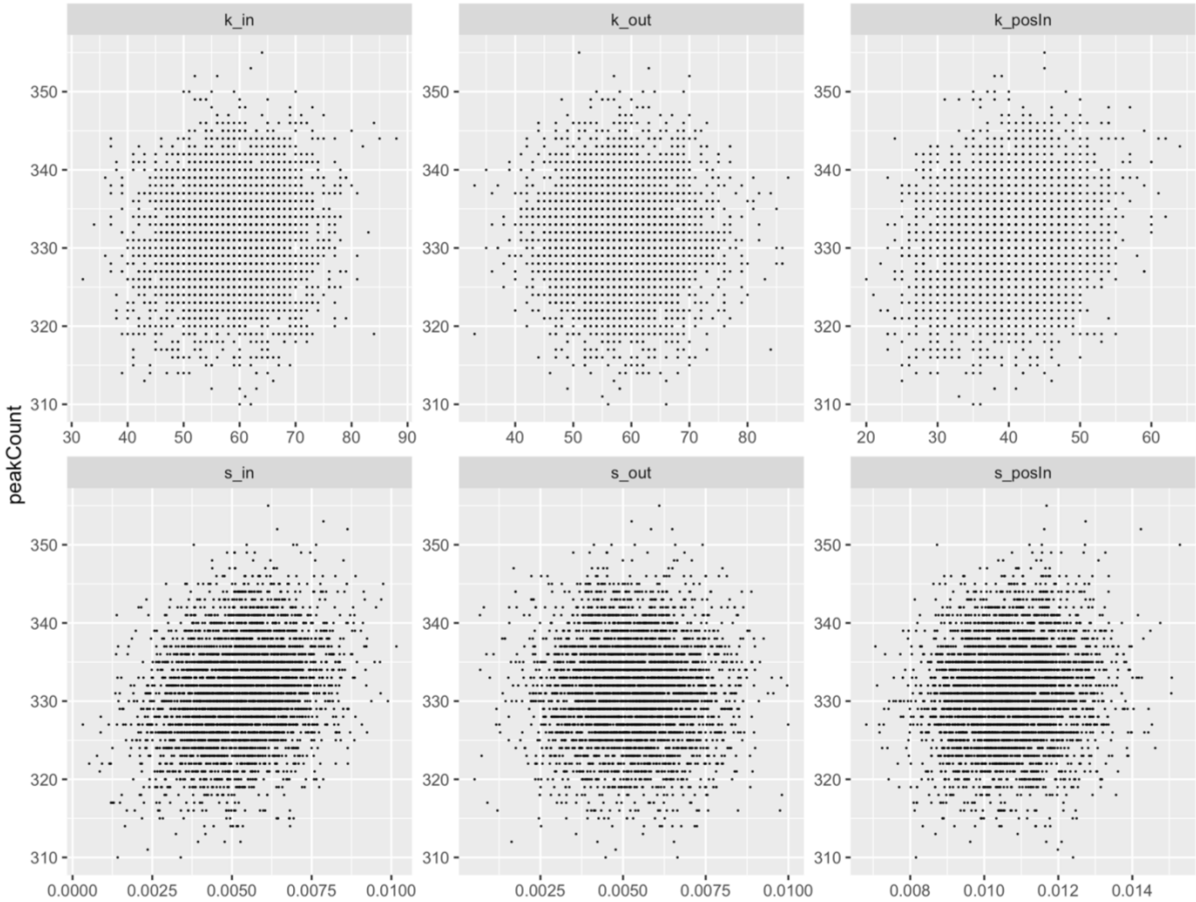


- **Very similar to original**

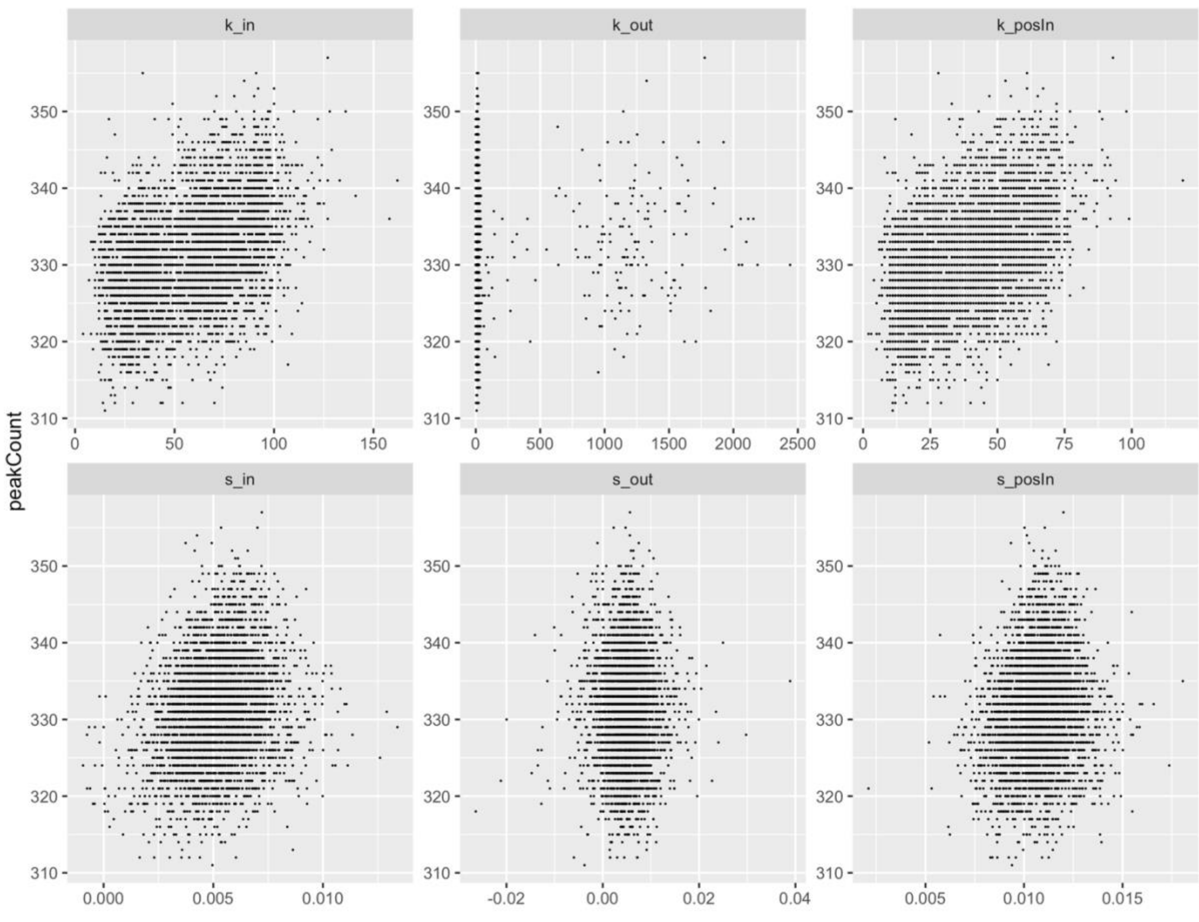
Ref. Network 3 (col gij shuffled)



Ref. Network 4 (random)

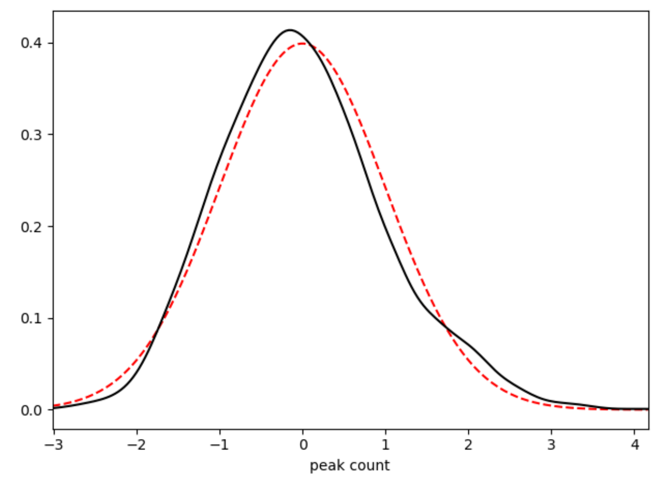
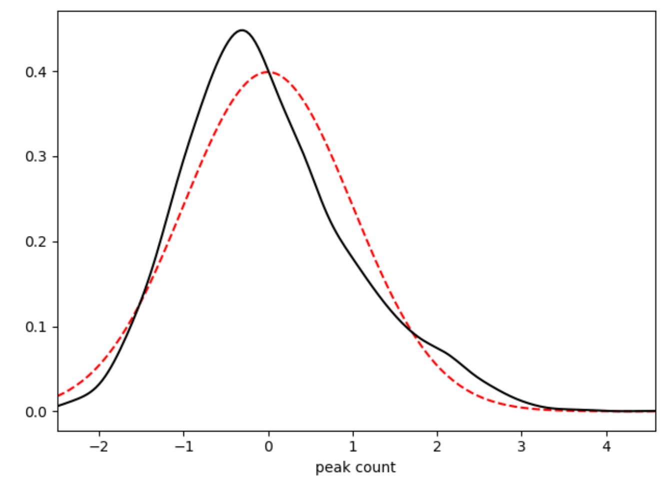
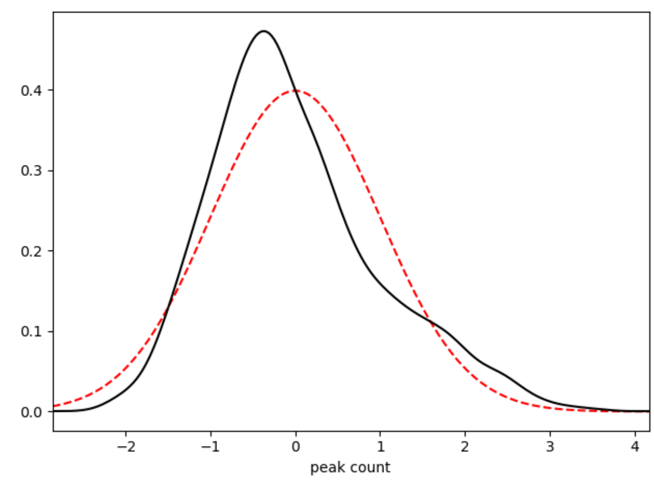
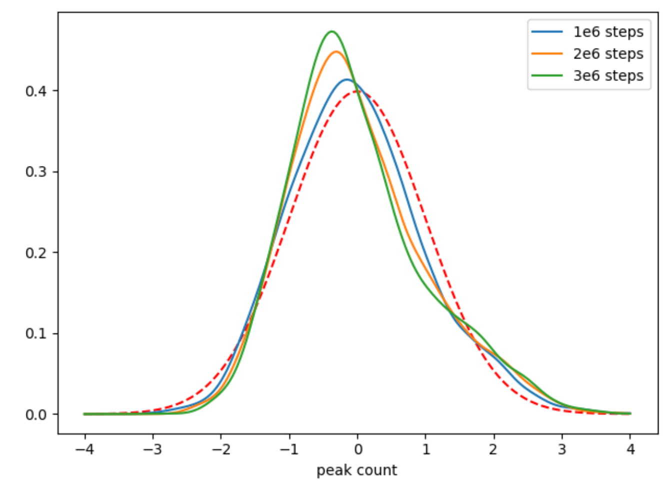


Ref. Network 5 (non-zero gij shuffled)



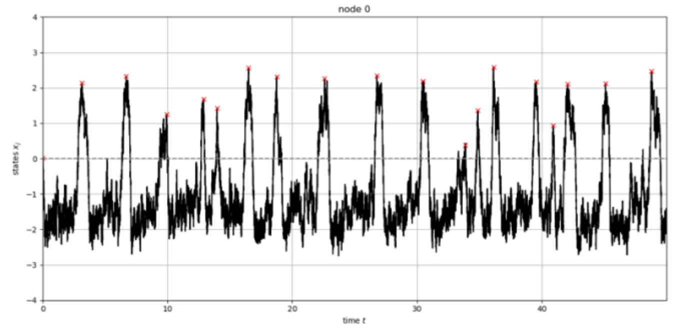
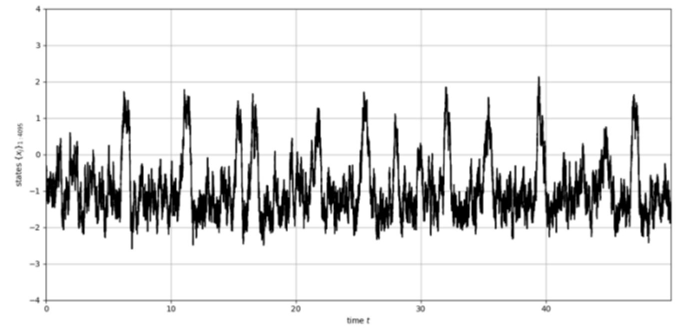
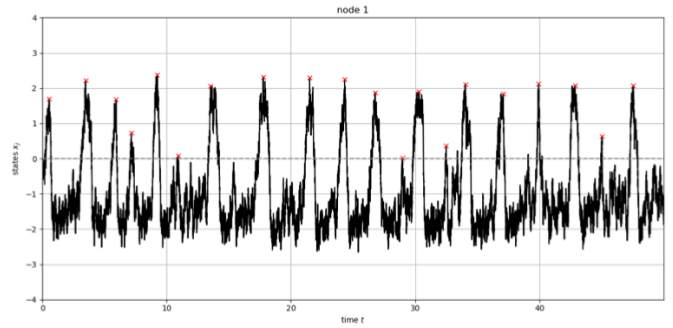
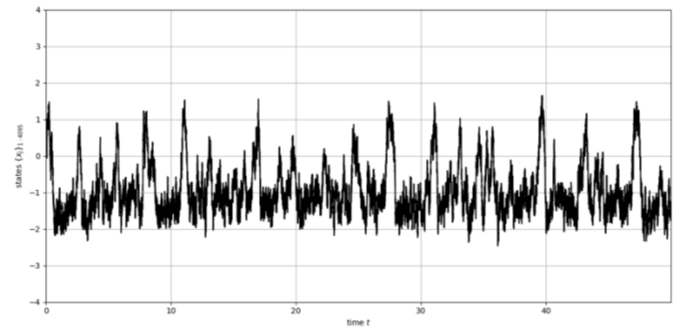
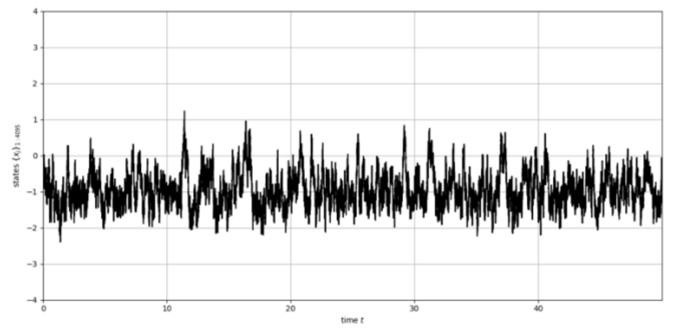
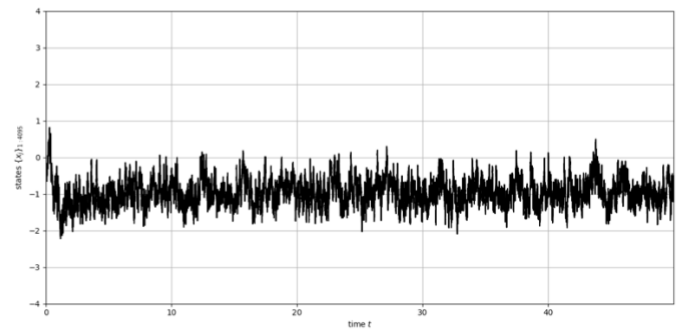
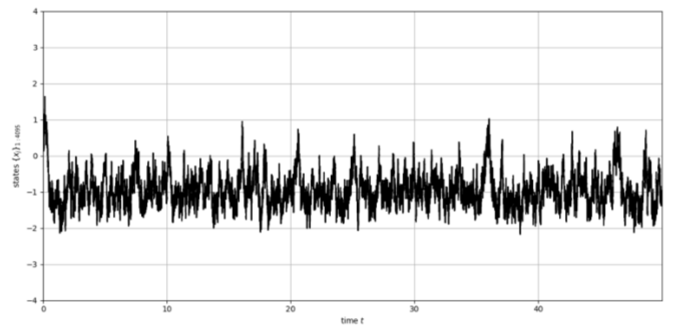
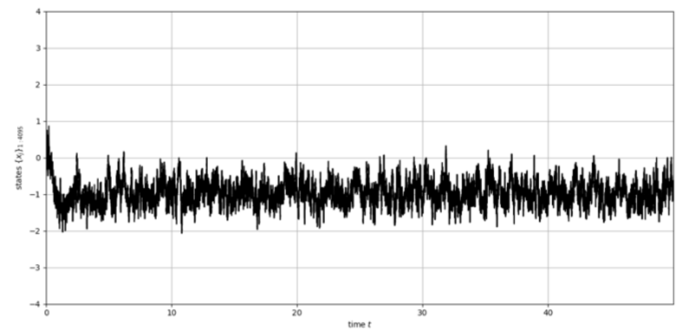
Peak count distribution comparison of Original Network (3e6 steps)

- **To check if peak count distribution is stationary**

<table>
<tr><th>1e6 steps</th><th>2e6 steps</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>3e6 steps</th><th>All three</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

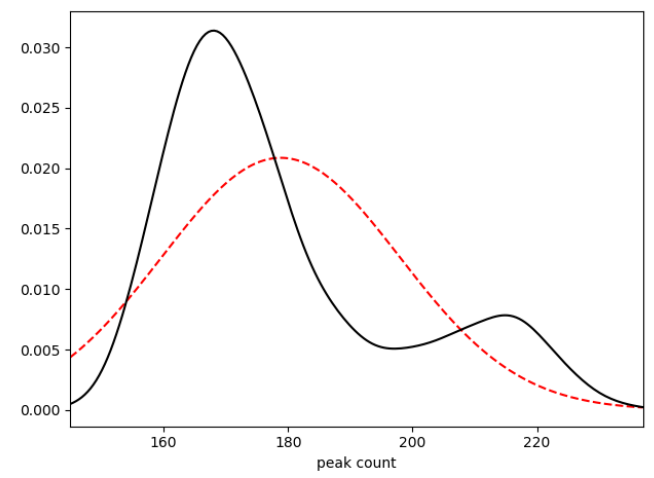
Model with scaled gij

- Parameters $\epsilon = 0.1, \alpha = 0.95, \sigma_i = 2$

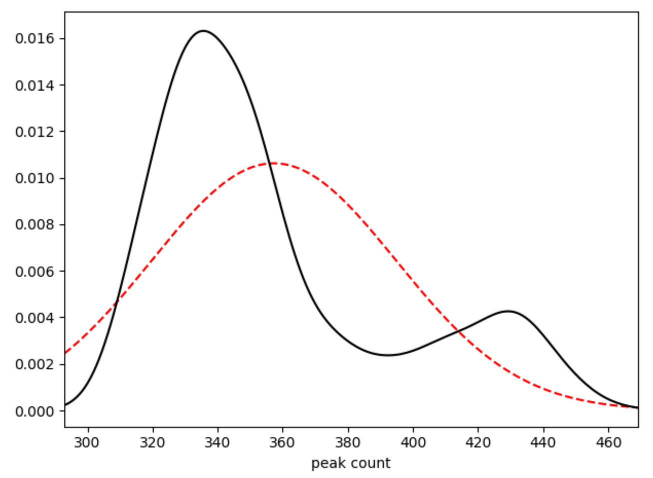
gij not scaled	gij * 5
Node 0	Node 0
	
Node 1	Node 1
	
gij * 10	gij *20
Node 0	Node 0
	
Node 1	Node 1
	

Peak count distribution of gij * 5 network

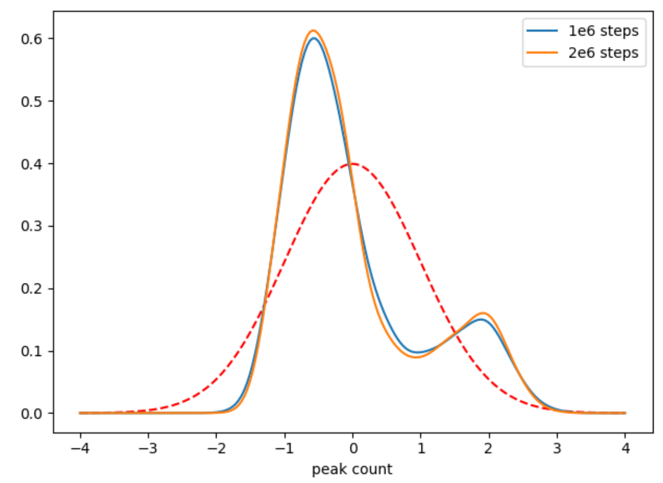
1e6 steps



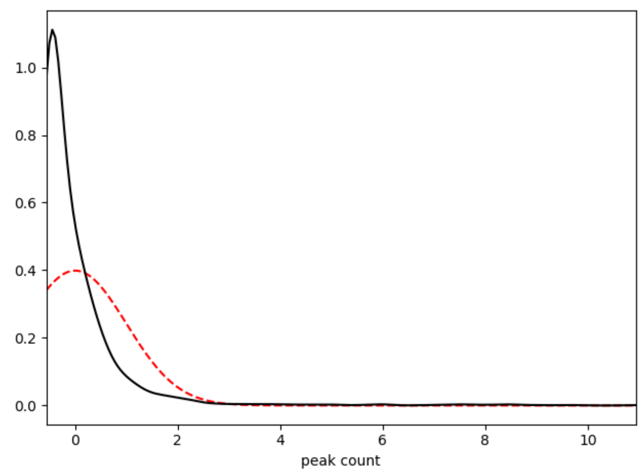
2e6 steps



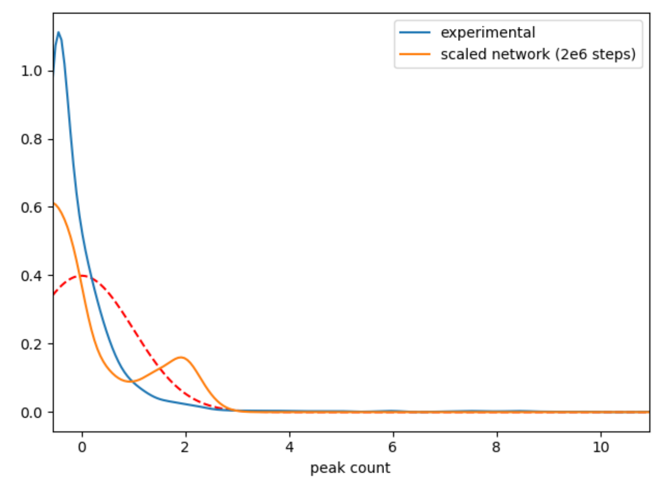
1e6 & 2e6



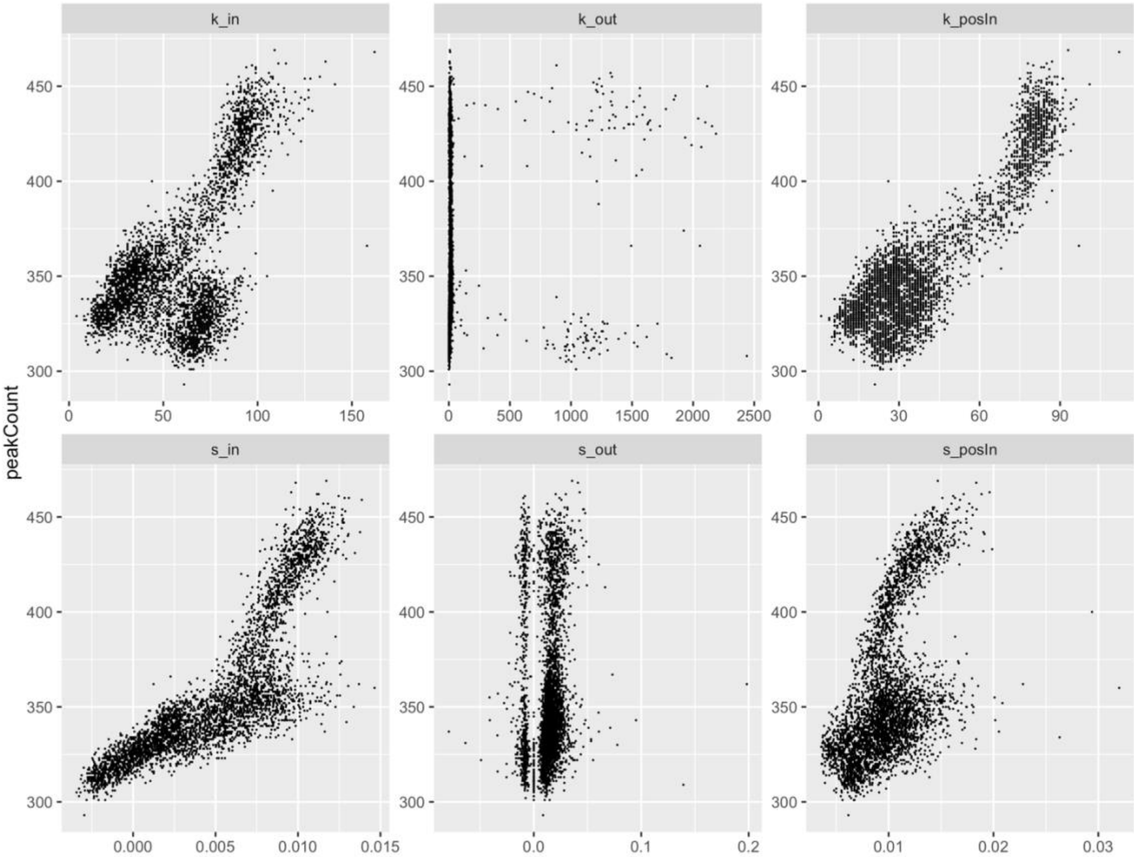
Experimental



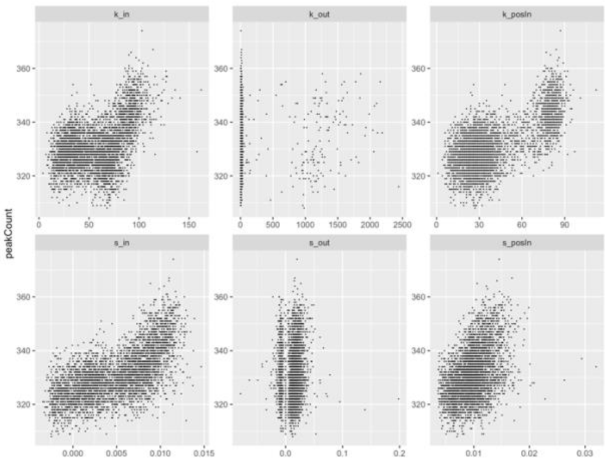
Comparison



Exploratory analysis (2e6 steps)



Original network without scaling gij (P59)



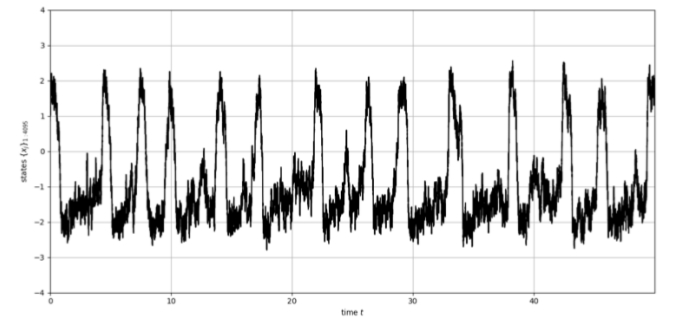
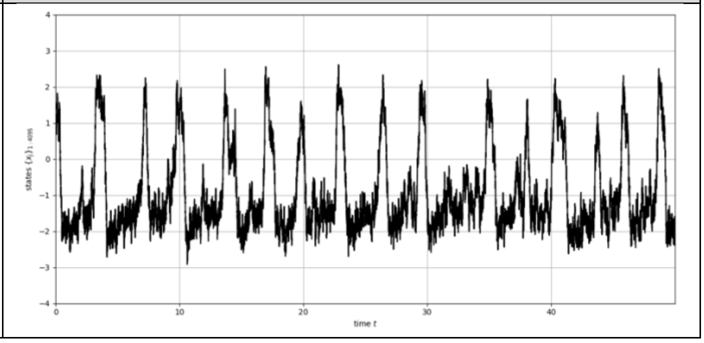
Scaled gij makes patterns more obvious and more "exaggerated"

Synaptic FHN model

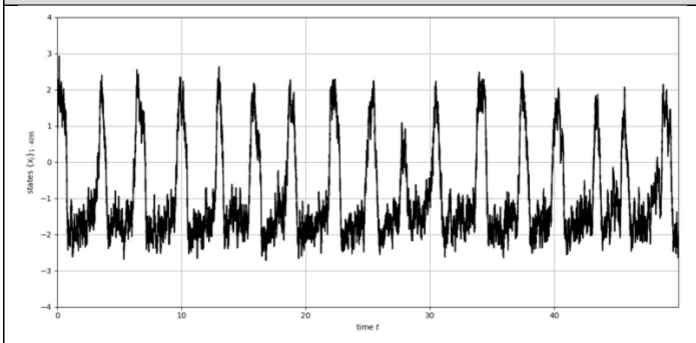
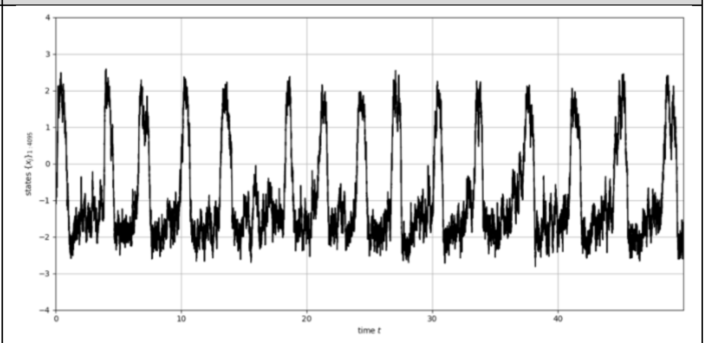
- **Play around with different parameters**

$$h^{\mathrm{syn}}(x,y) = (1/\beta_1)\{1+\tanh[\beta_2(y-y_0)]\}.$$

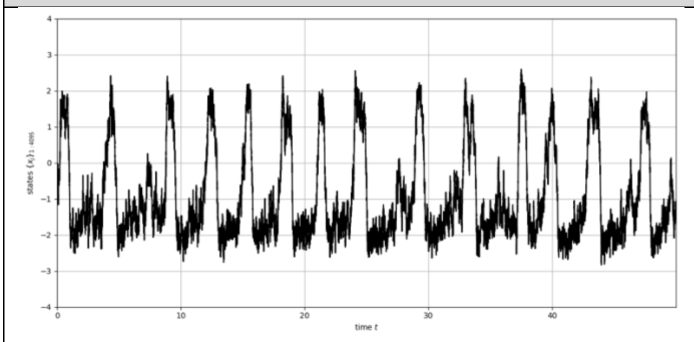
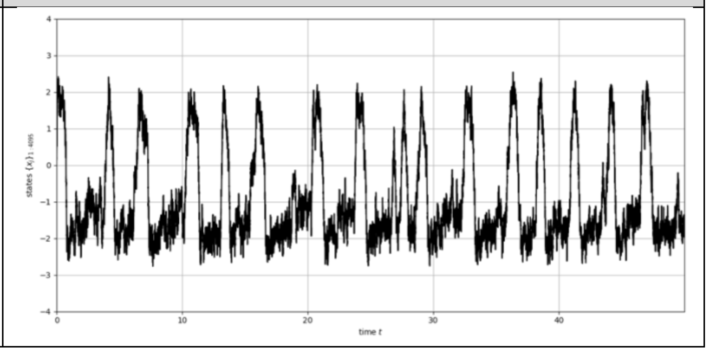
- $(\boldsymbol{\beta_1}, \boldsymbol{\beta_2}, \boldsymbol{y_0}) = (\mathbf{0.5}, \mathbf{1}, \mathbf{1})$

Node 0	Node 1
	

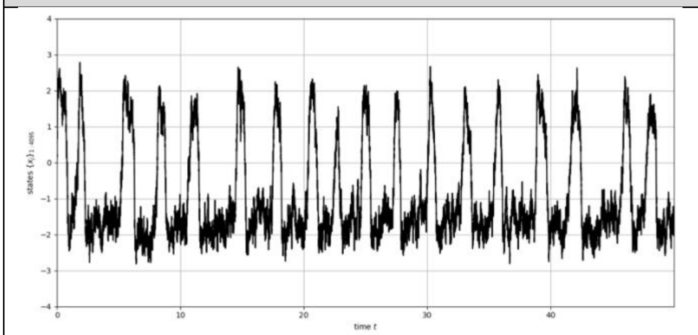
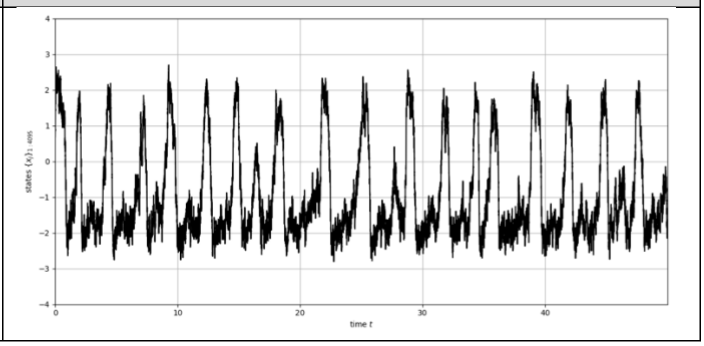
- $(\boldsymbol{\beta_1}, \boldsymbol{\beta_2}, \boldsymbol{y_0}) = (\mathbf{0.1}, \mathbf{1}, \mathbf{1})$

Node 0	Node 1
	

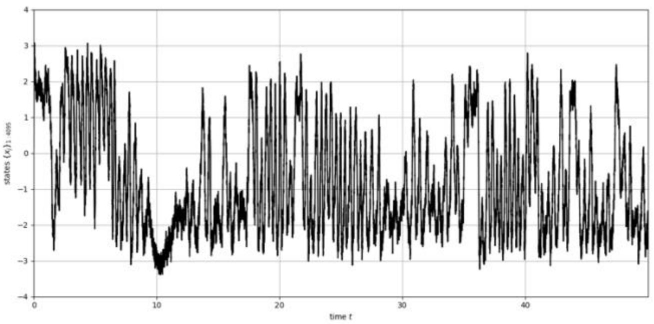
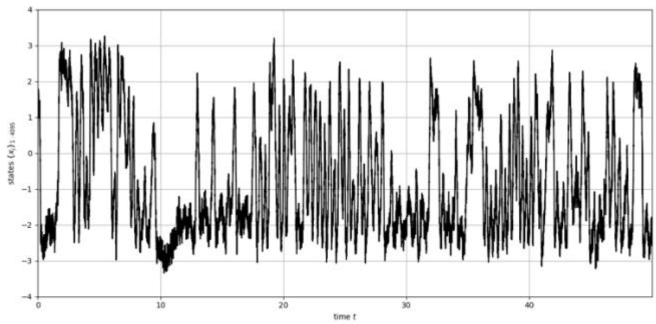
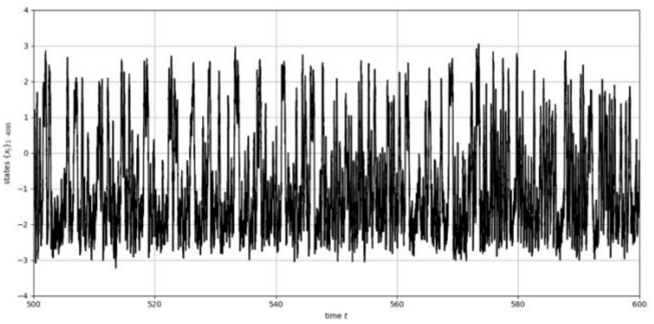
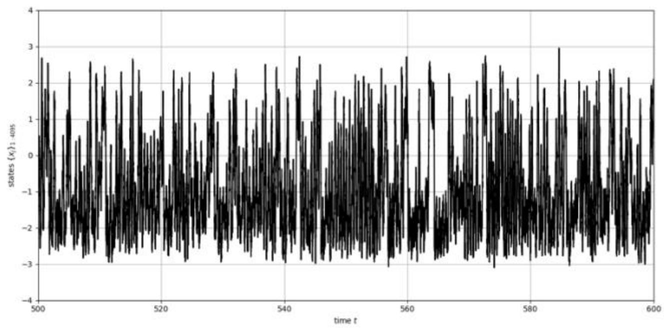
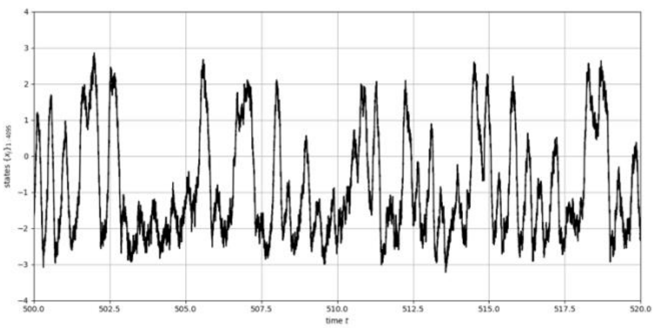
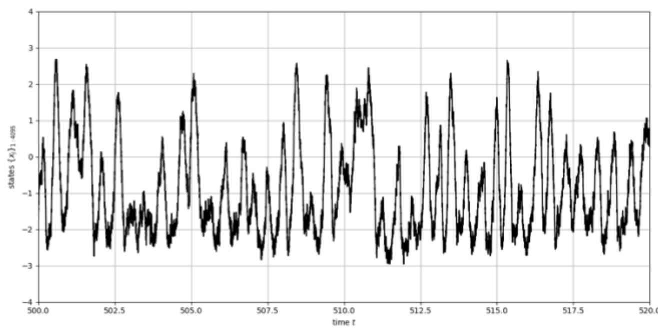
- $(\boldsymbol{\beta_1}, \boldsymbol{\beta_2}, \boldsymbol{y_0}) = (\mathbf{0.1}, \mathbf{1}, \mathbf{0})$

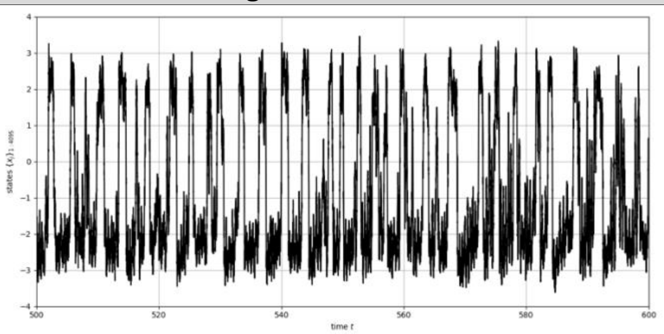
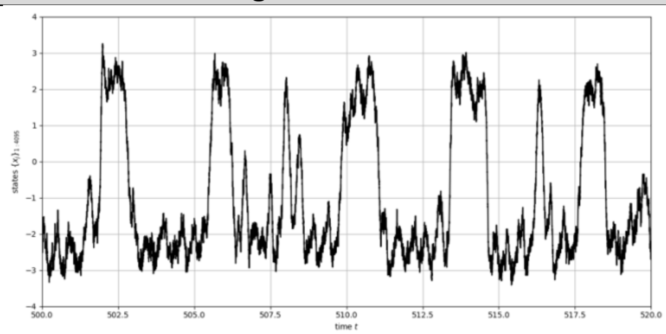
Node 0	Node 1
	

- $(\boldsymbol{\beta_1}, \boldsymbol{\beta_2}, \boldsymbol{y_0}) = (\mathbf{0.05}, \mathbf{1}, \mathbf{0})$

Node 0	Node 1
	

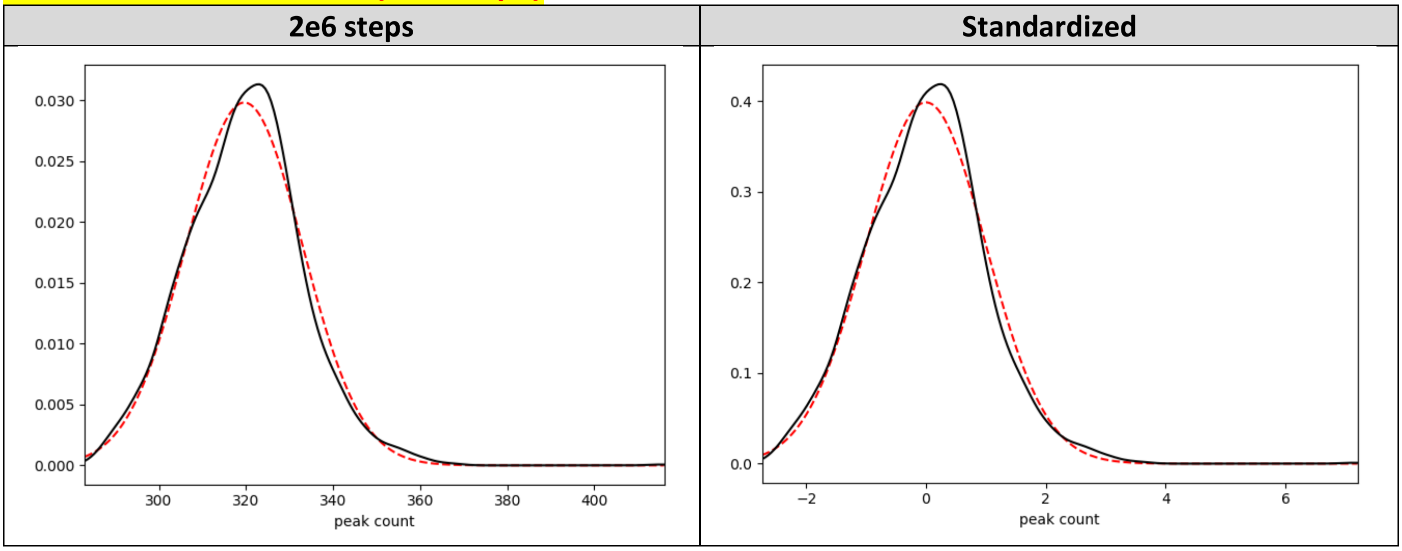
- $(\boldsymbol{\beta_1}, \boldsymbol{\beta_2}, \boldsymbol{y_0}) = (\mathbf{0.01}, \mathbf{1}, \mathbf{0})$

Starting from t=0 to 50	
Node 0	Node 1
	
Starting from t=500 to 600	
Node 0	**Node 1**
	
Starting from t=500 to 520	
Node 0	**Node 1**
	

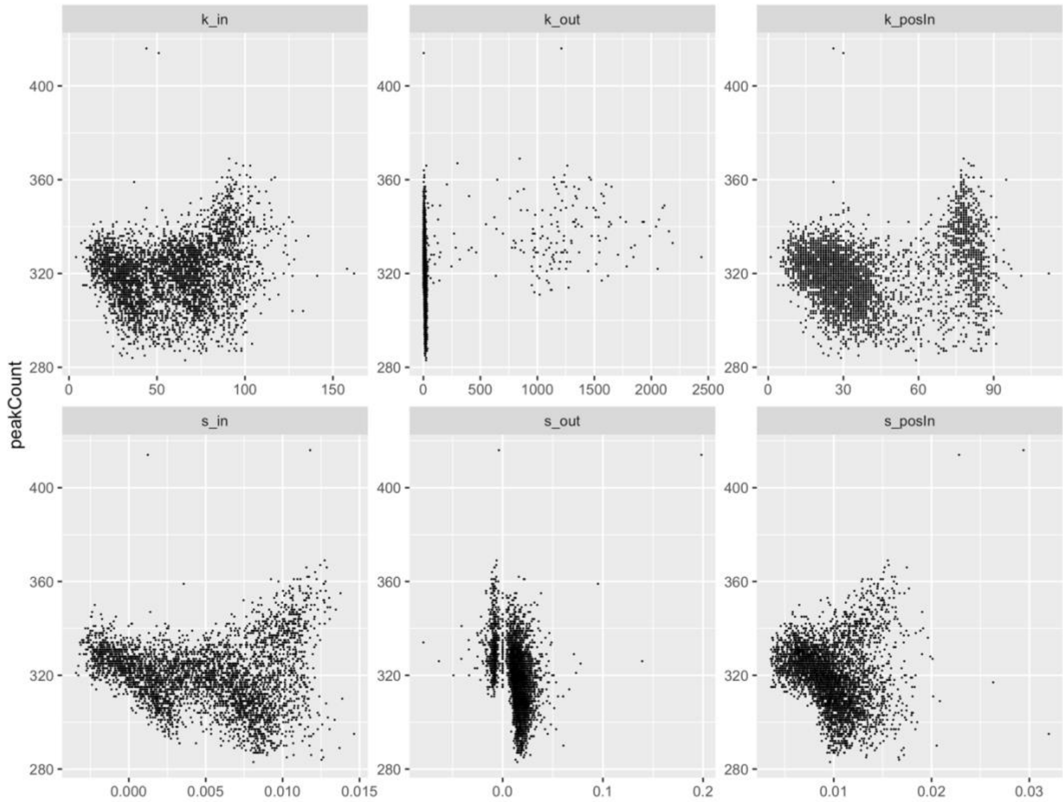
Node 40	
Starting from t=500 to 600	Starting from t=500 to 520
	

$(\beta_1, \beta_2, y_0) = (0.05, 1, 0)$; $\epsilon = 0.1, \alpha = 0.95$

Peak count distribution (2e6 steps)



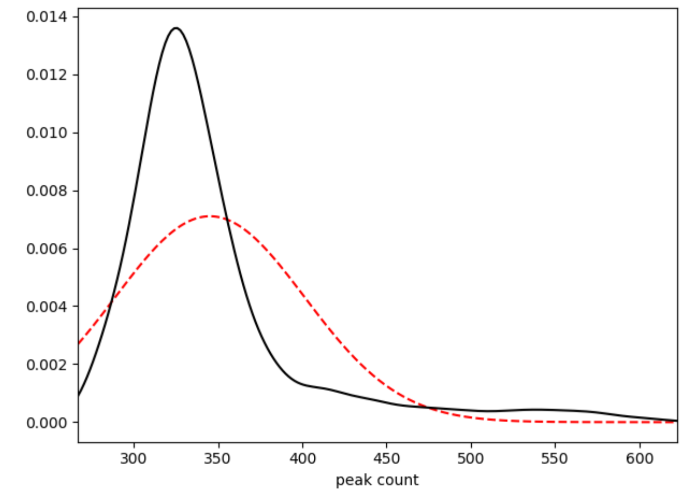
Exploratory analysis (2e6 steps)



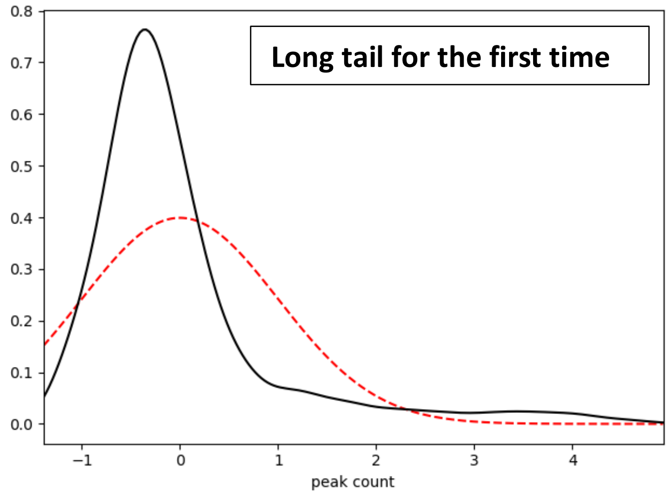
$(\boldsymbol{\beta_1}, \boldsymbol{\beta_2}, \boldsymbol{y_0}) = (\mathbf{0.01}, \mathbf{1}, \mathbf{0})$; $\boldsymbol{\epsilon} = \mathbf{0.1}, \boldsymbol{\alpha} = \mathbf{0.95}$

Peak count distribution (2e6 steps)

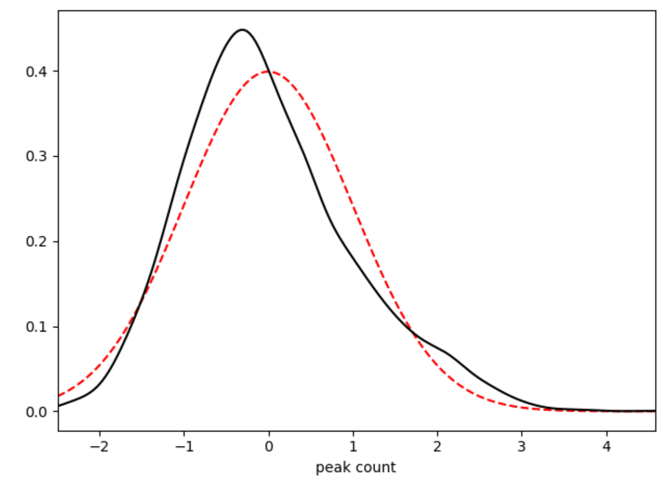
2e6 steps



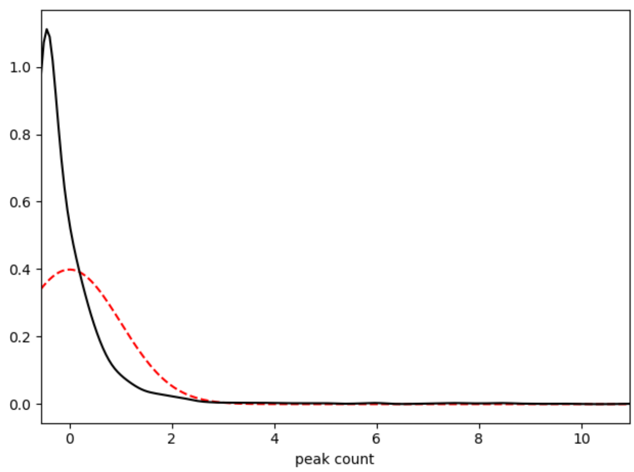
Standardized



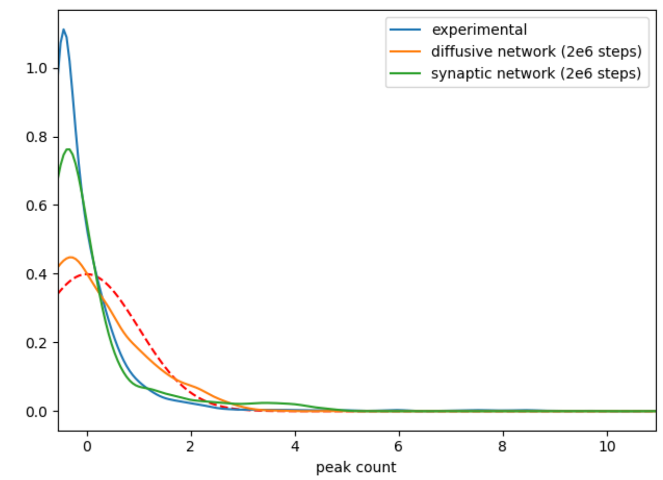
Diffusive coupling ("Original network")



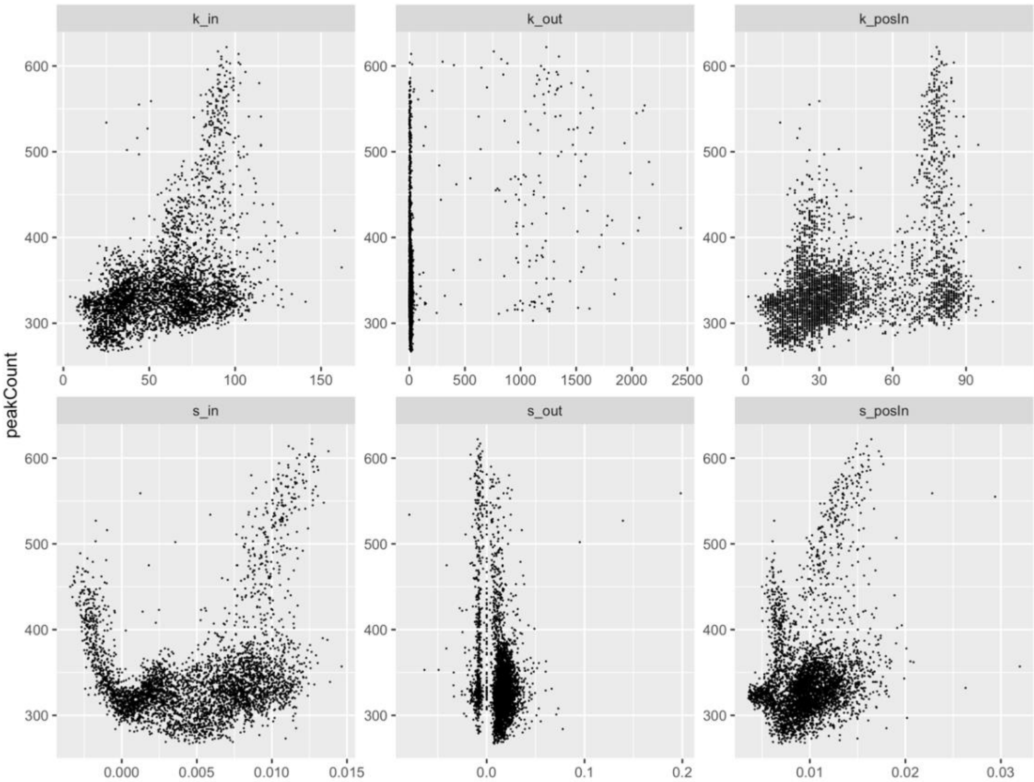
Experimental

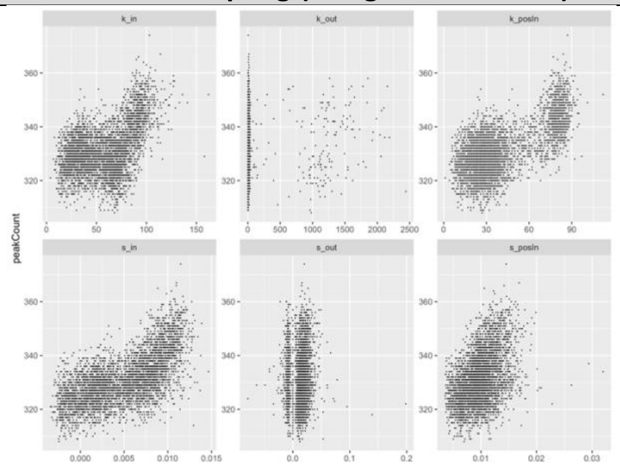
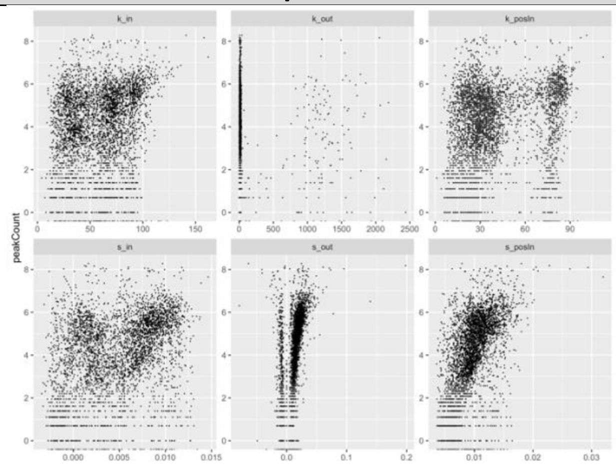


Comparison

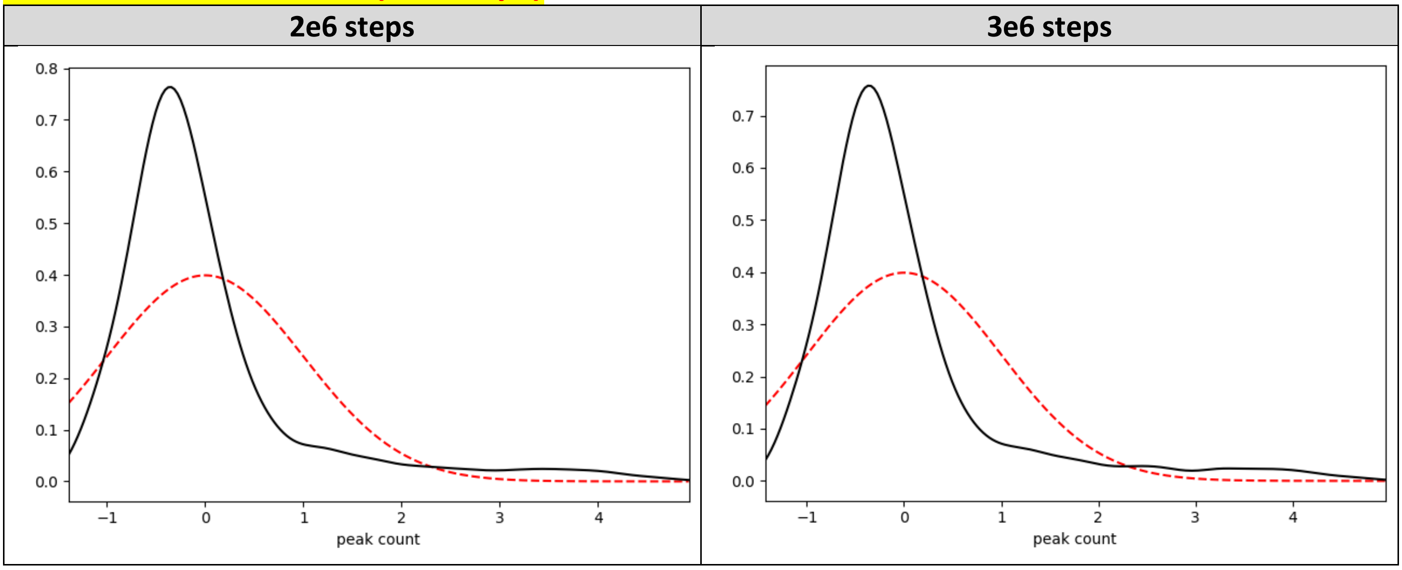


Exploratory analysis (2e6 steps)

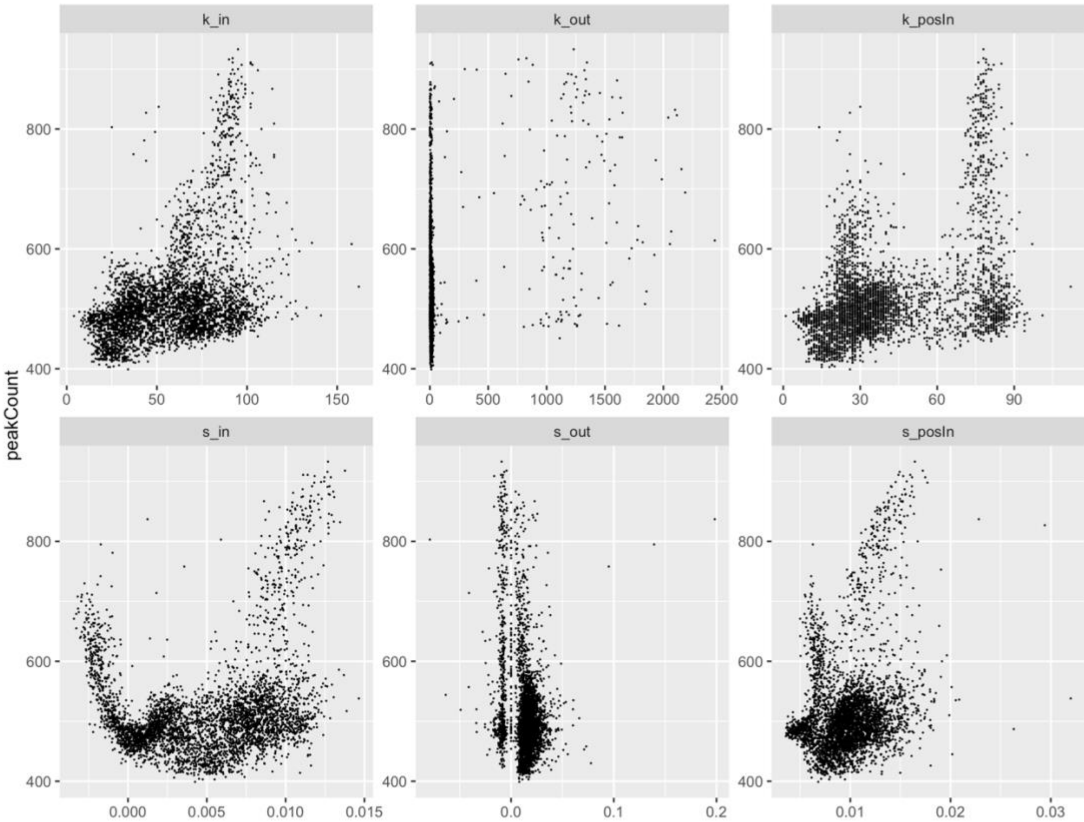


Diffusive coupling ("Original network")	Experimental
	

Peak count distribution (3e6 steps)



Exploratory analysis (3e6 steps)



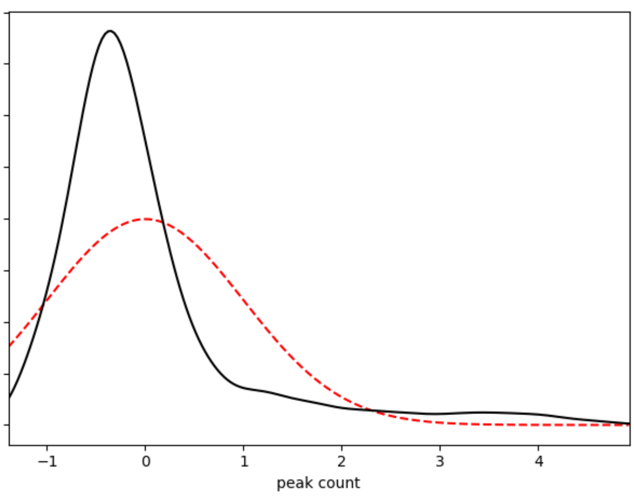
Analysis on reference networks

- $(\beta_1, \beta_2, y_0) = (0.01, 1, 0); \epsilon = 0.1, \alpha = 0.95$

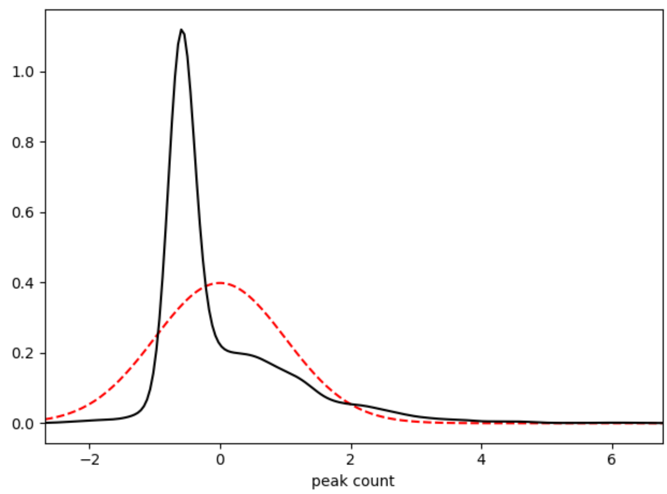
(a) reference network 1: keep Aij but replace nonzero gij by values taken from a Gaussian distribution of same mean and standard deviation (this time we do not separately consider positive and negative gij's). This network has same k_in and k_out but different s_in and s_out
(b) reference network 2: shuffle gij for fixed i; this has same k_in and s_in but different k_out and s_out
(c) reference network 3: shuffle gij for fixed j; this has same k_out and s_out but different k_in and s_in
(d) reference network 4: random directed network with same connection probability p and gij from a Gaussian distribution of same mean and standard deviation
(e) reference network 5: keep Aij but shuffle non-zero gij

Peak count distribution comparison (2e6 steps)

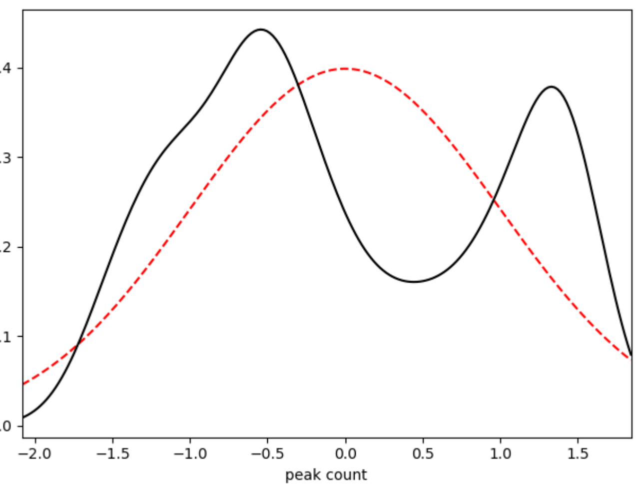
Original Network



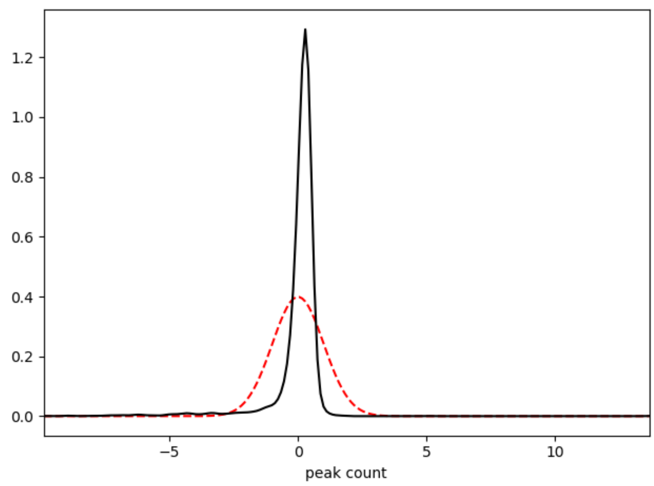
Ref. Network 1 (non-zero gij Gaussian)



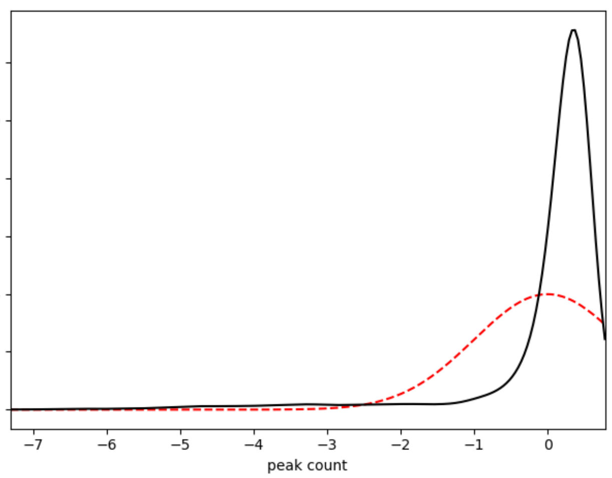
Ref. Network 2 (row gij shuffled)



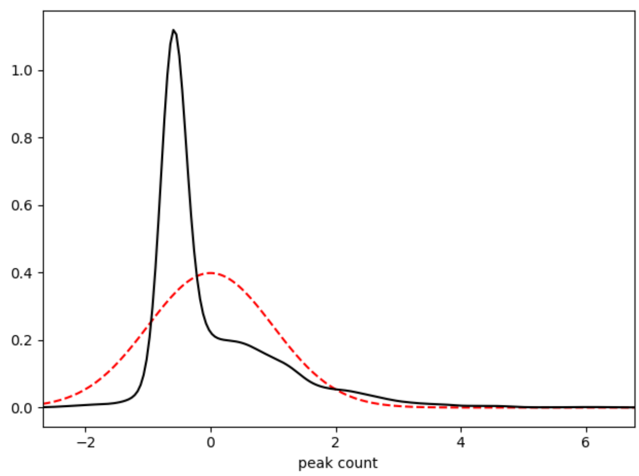
Ref. Network 3 (col gij shuffled)



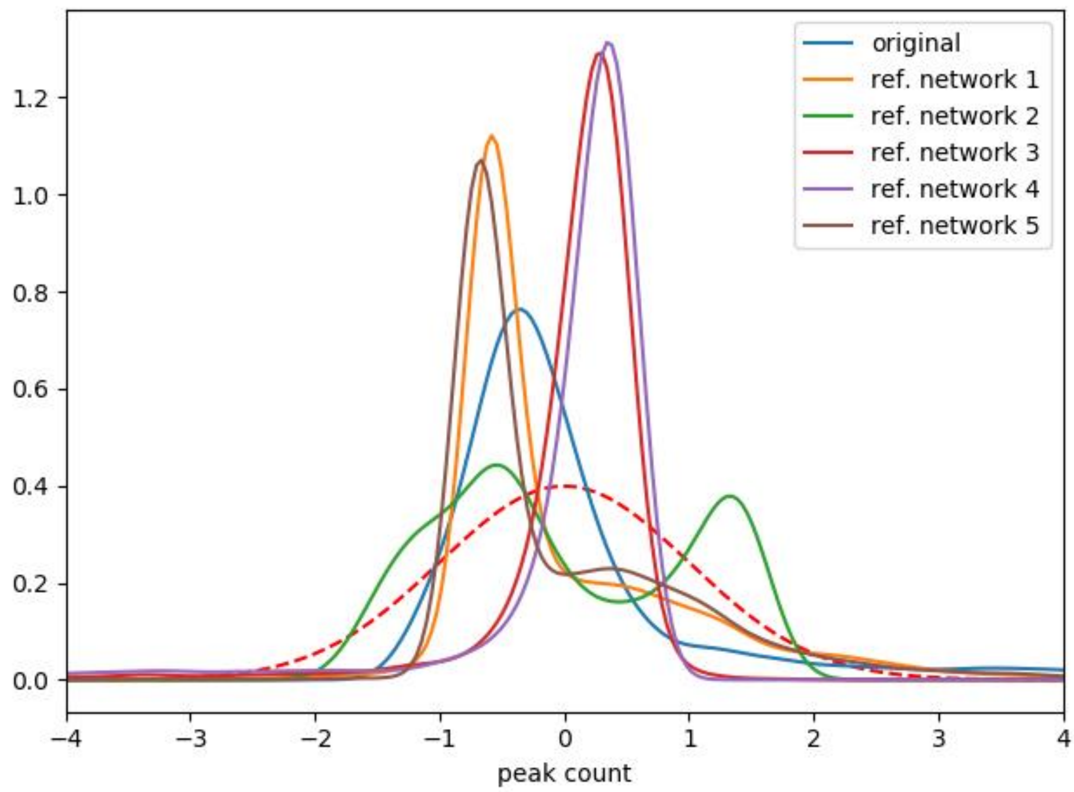
Ref. Network 4 (random)



Ref. Network 5 (non-zero gij shuffled)



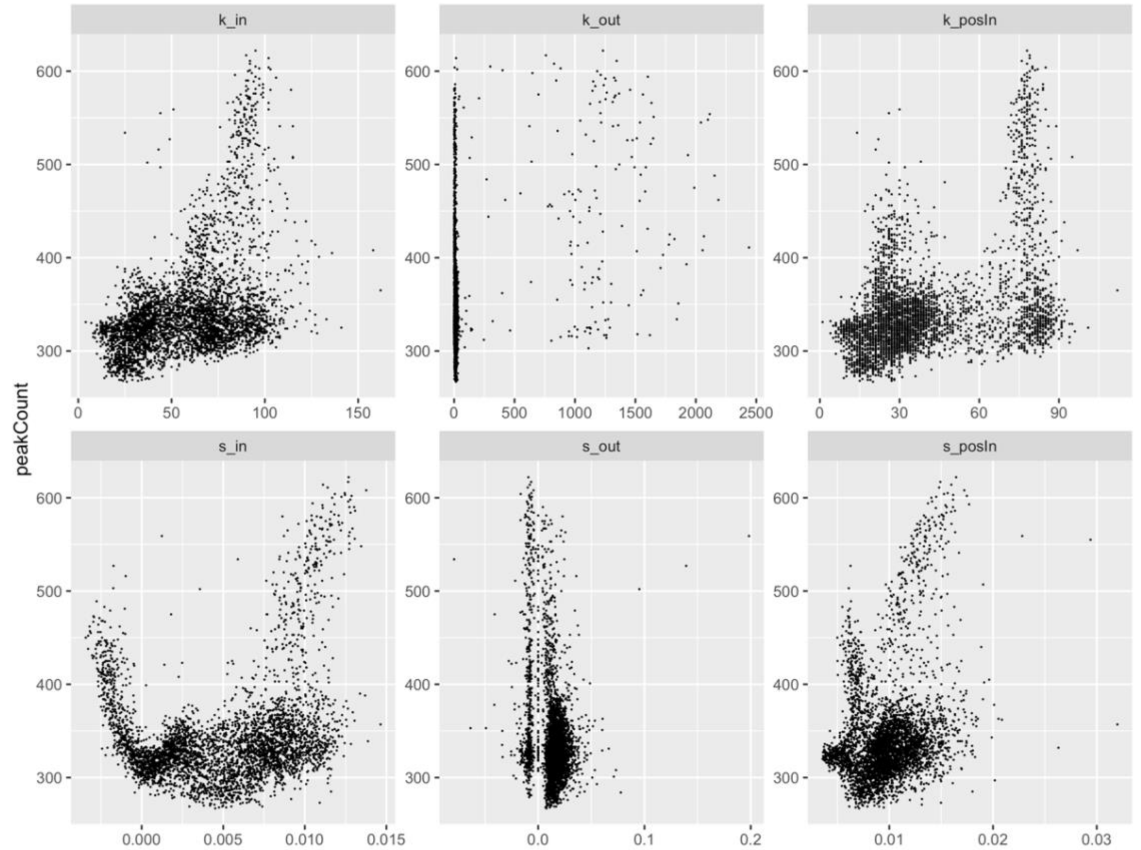
Combined



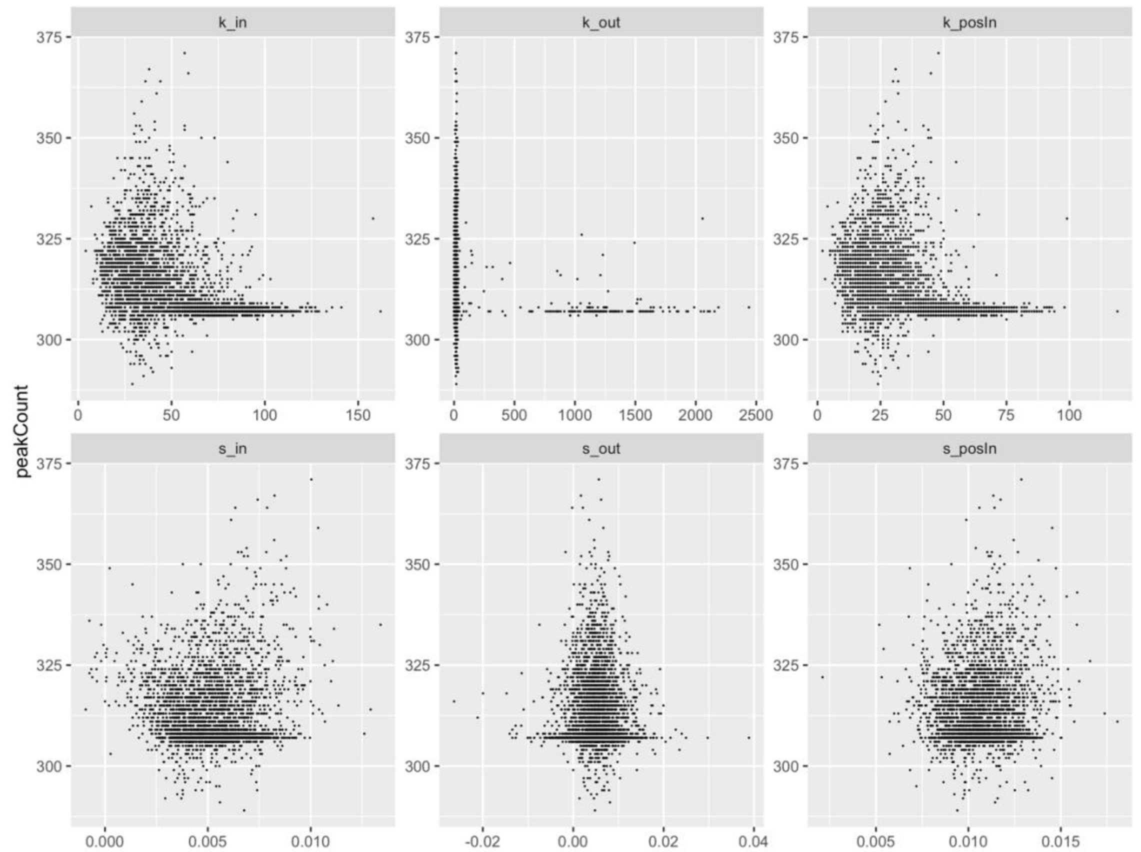
original
ref. network 1
ref. network 2
ref. network 3
ref. network 4
ref. network 5
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−4
−3
−2
−1
0
1
2
3
4
peak count

Exploratory analysis (2e6 steps)

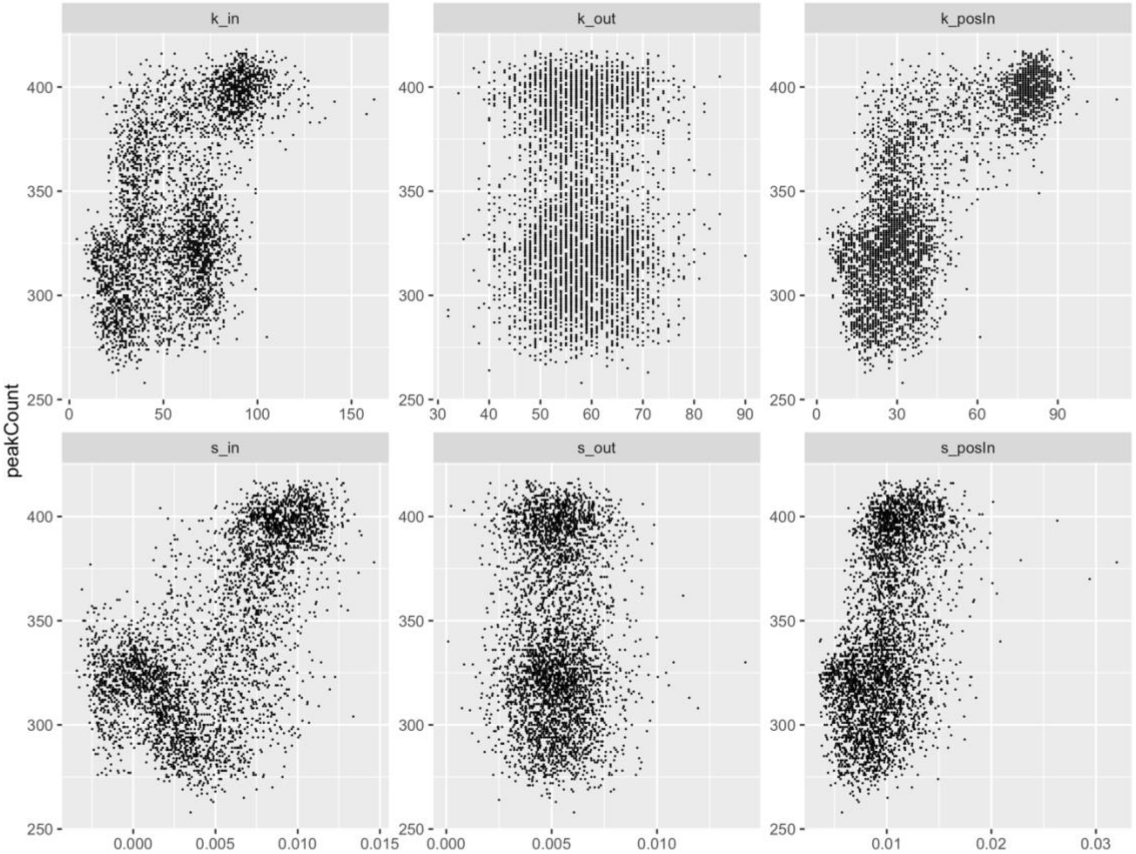
Original Network



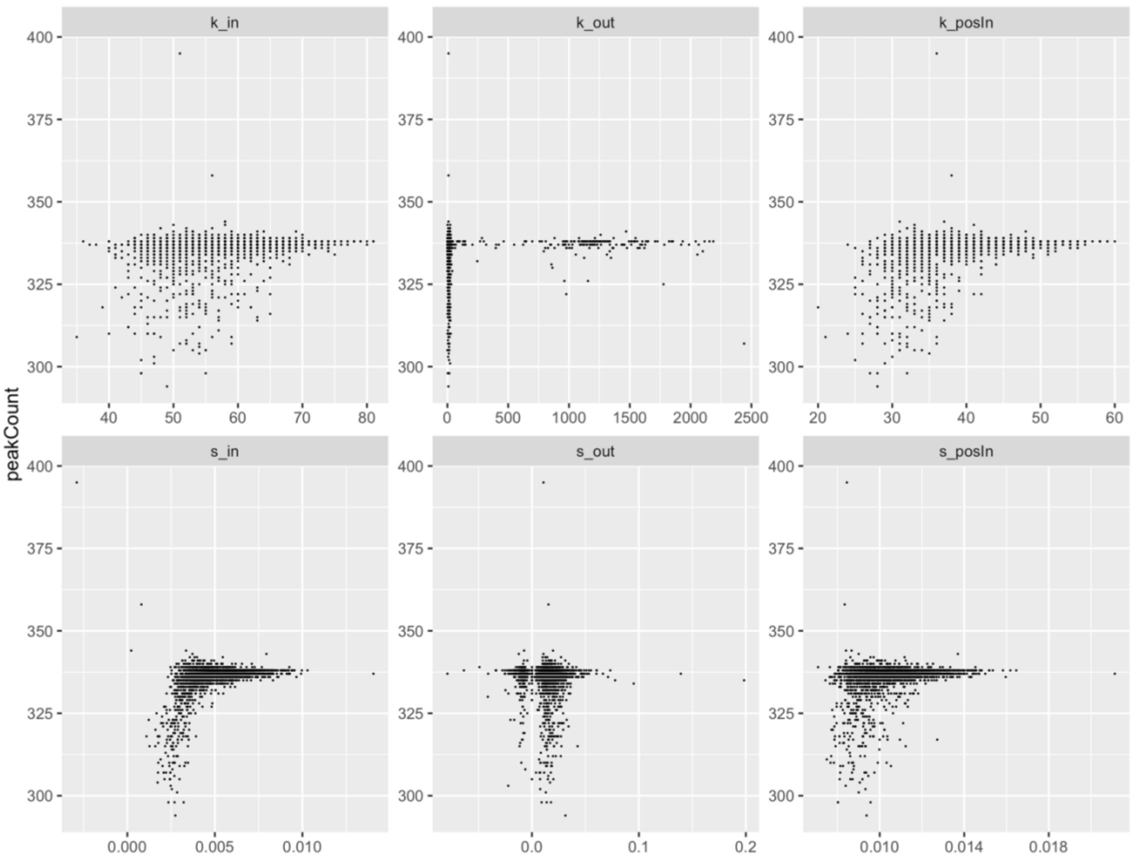
Ref. Network 1 (non-zero gij Gaussian)



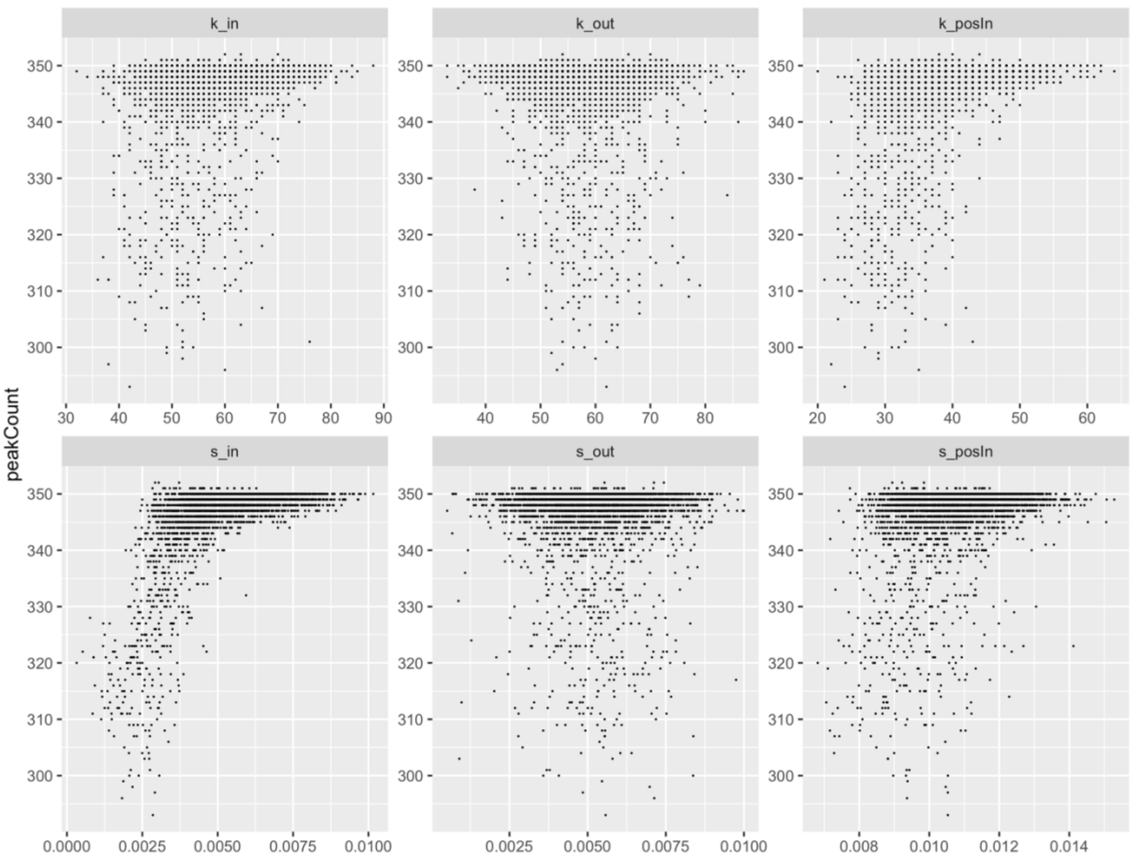
Ref. Network 2 (row gij shuffled)



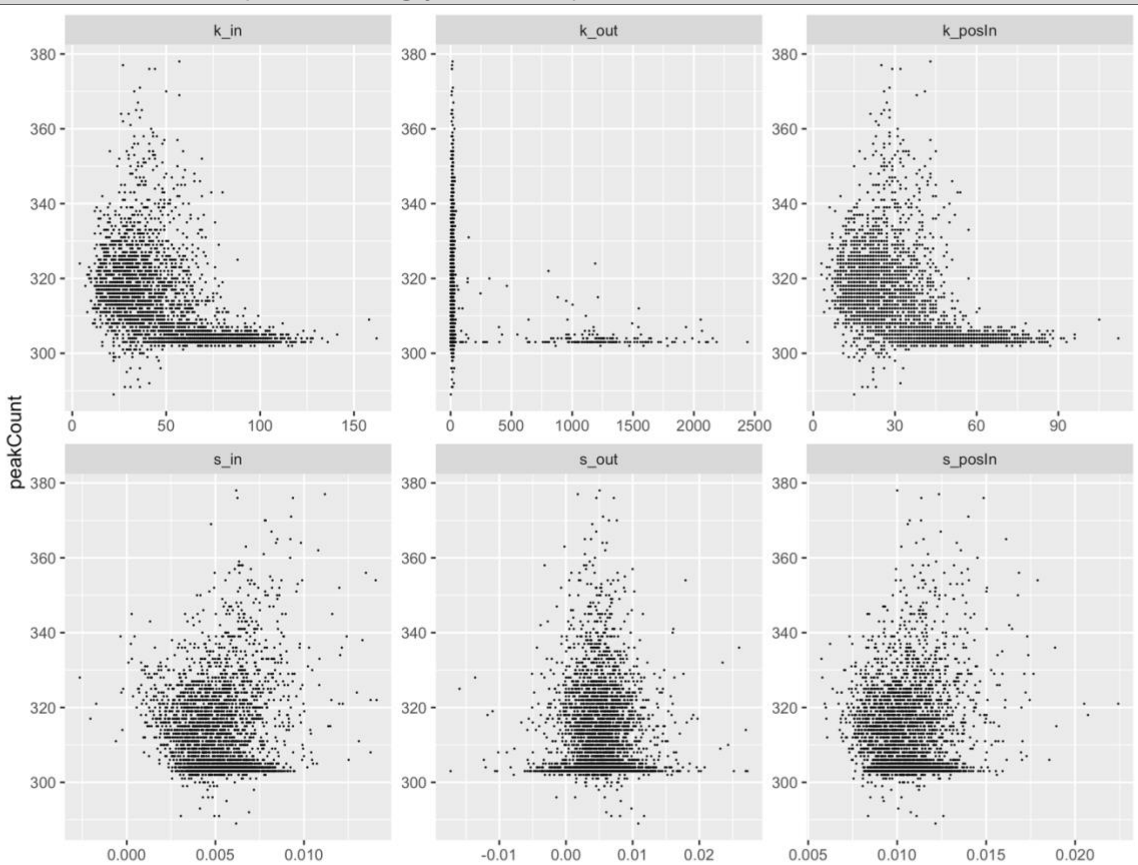
Ref. Network 3 (col gij shuffled)



Ref. Network 4 (random)

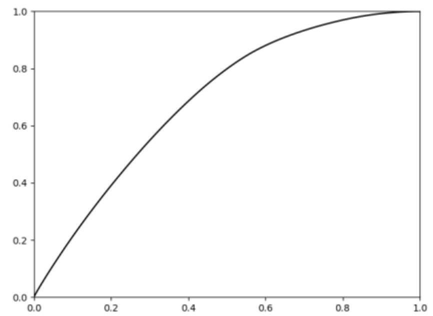
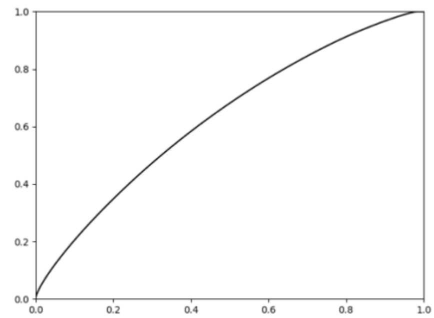
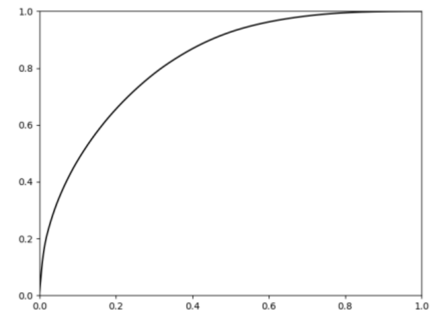
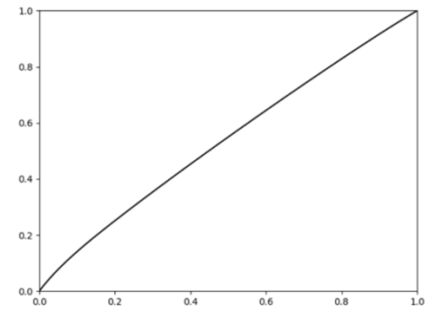
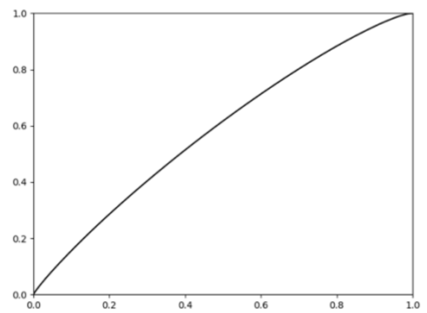
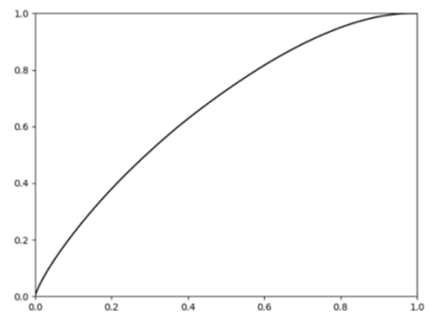
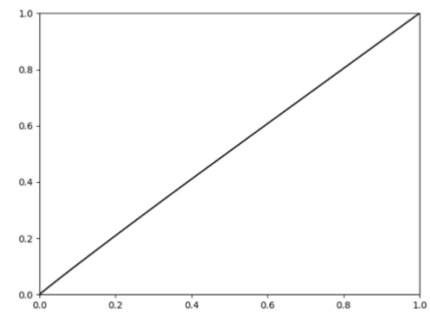
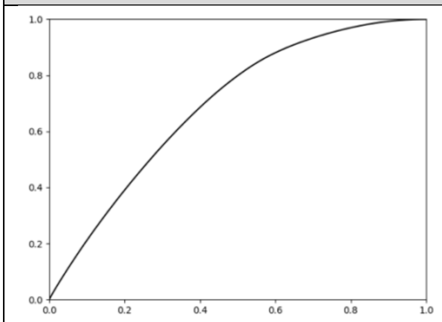
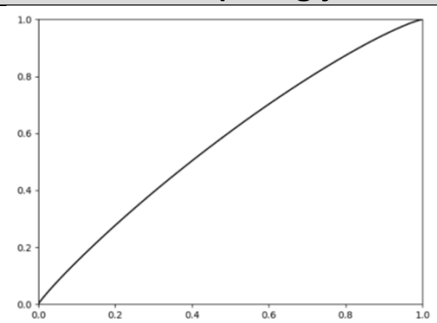
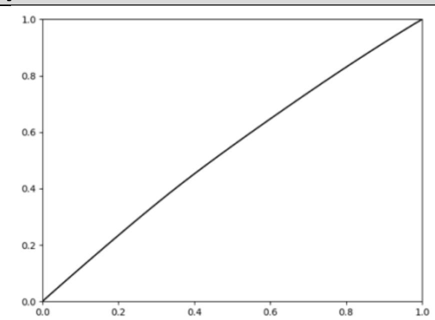


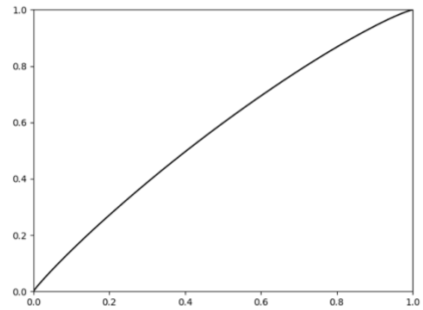
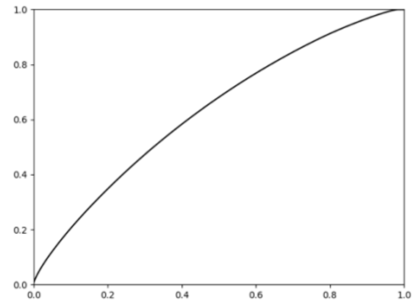
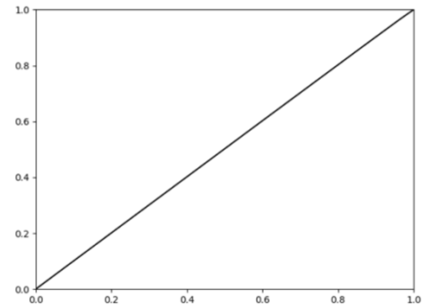
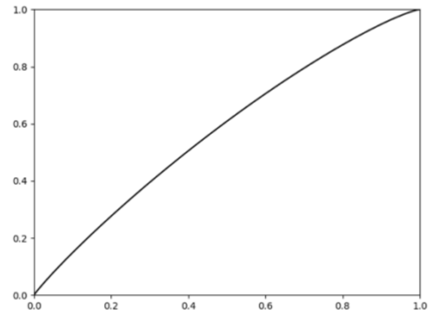
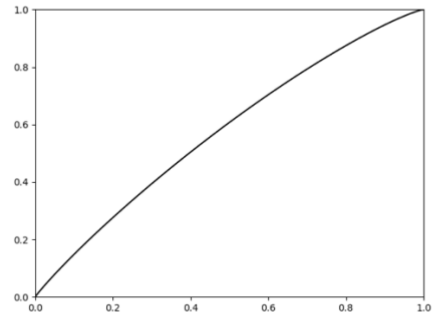
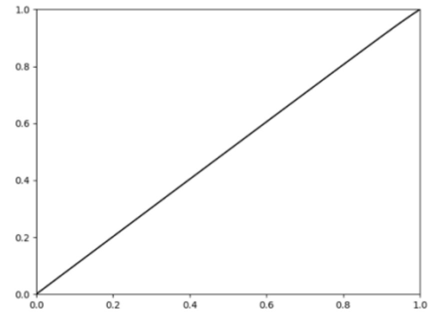
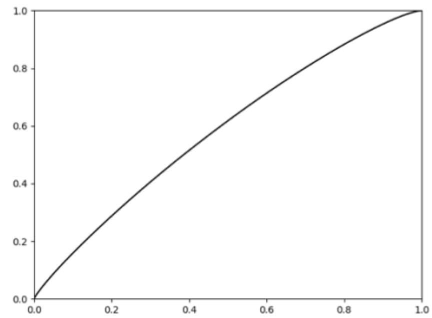
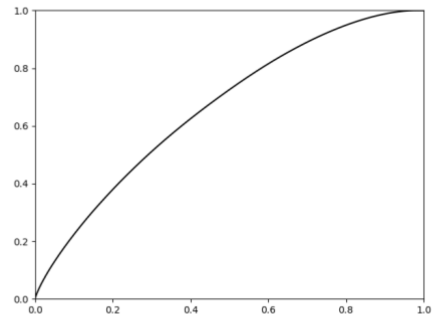
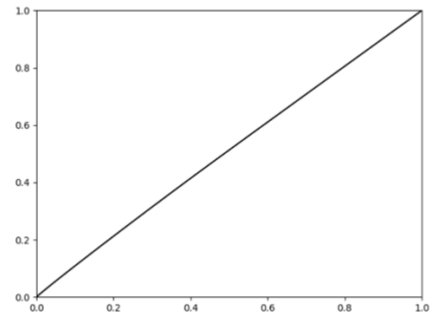
Ref. Network 5 (non-zero gij shuffled)

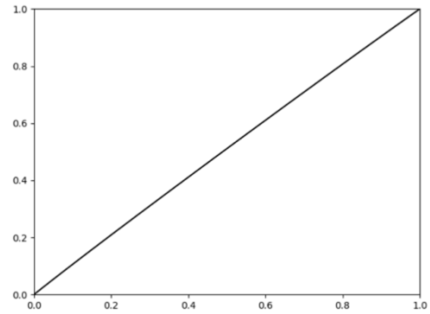
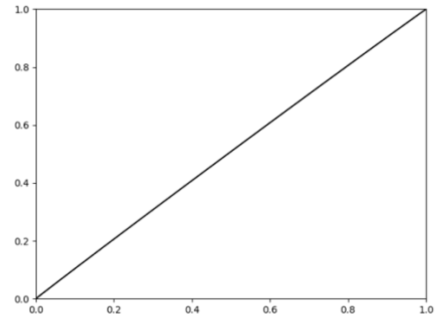
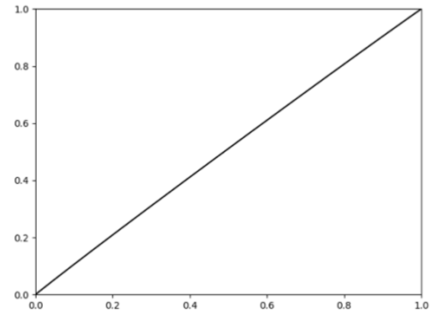
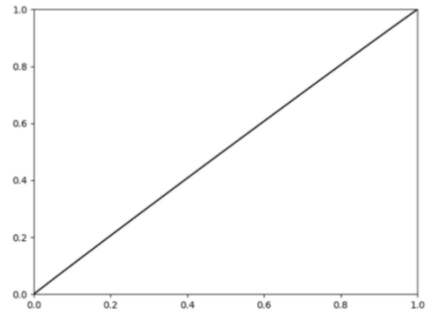
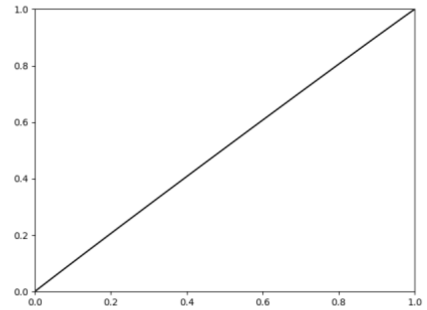
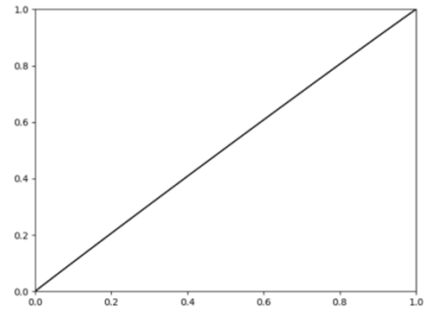


Analysis on peak counts

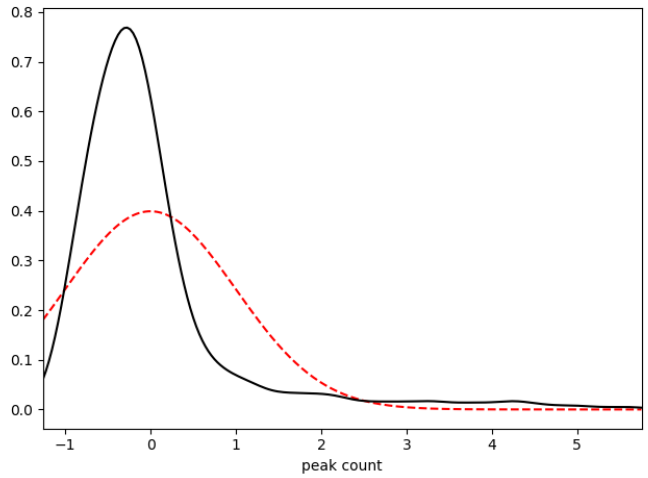
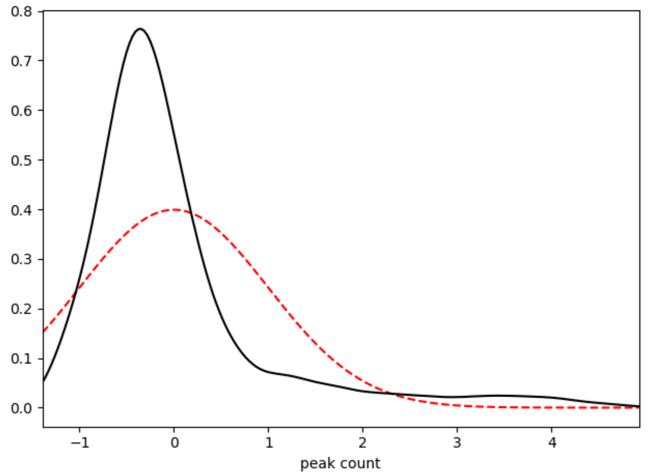
- **Fraction of total accounted for by the top quantiles**

In-strengths (Magnitude)	Out-strengths (Magnitude)	Peak counts
Experimental		
		 **(Very large curvature)**
Original Network (Synaptic)		
Same as above	**Same as above**	 **(Little curvature)**
Ref. Network 1 (non-zero gij Gaussian)		
		 **(Basically straight)**
Ref. Network 2 (row gij shuffled)		
		 **(Little curvature but most curved among all ref networks)**

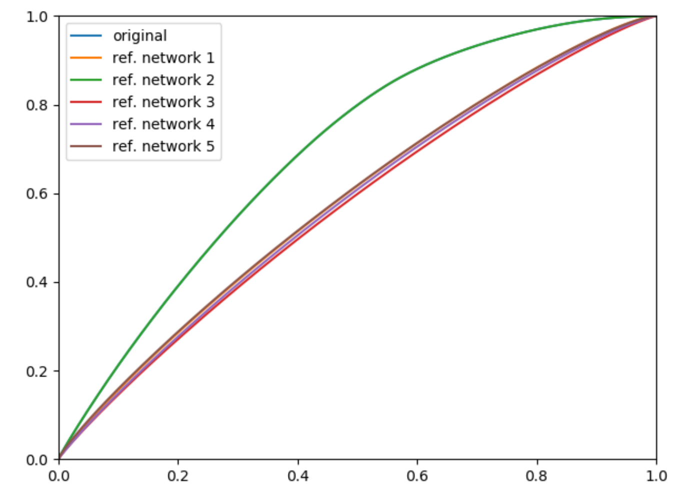
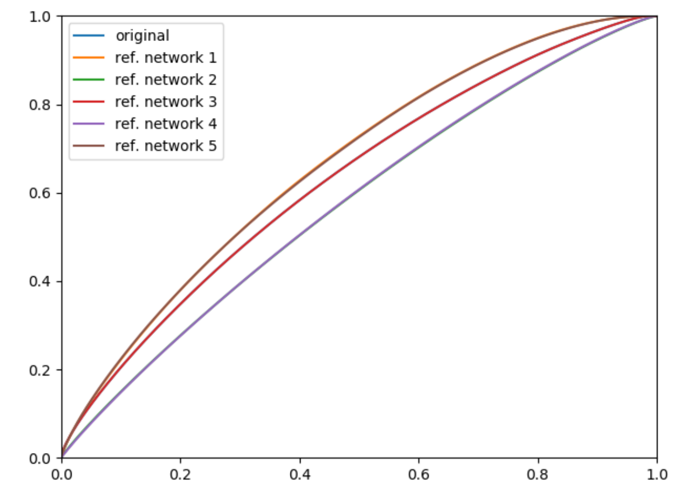
<table>
<tr><th colspan="3">Ref. Network 3 (col gij shuffled)</th></tr>
<tr><td></td><td></td><td>
(Basically straight)</td></tr>
<tr><th colspan="3">Ref. Network 4 (random)</th></tr>
<tr><td></td><td></td><td>
(Basically straight)</td></tr>
<tr><th colspan="3">Ref. Network 5 (non-zero gij shuffled)</th></tr>
<tr><td></td><td></td><td>
(Basically straight)</td></tr>
</table>

Diffusive (All basically straight)		
Original Network (Diffusive)	**Ref. Network 1 (non-zero gij Gaussian)**	**Ref. Network 2 (row gij shuffled)**
		
Ref. Network 3 (col gij shuffled)	**Ref. Network 4 (random)**	**Ref. Network 5 (non-zero gij shuffled)**
		

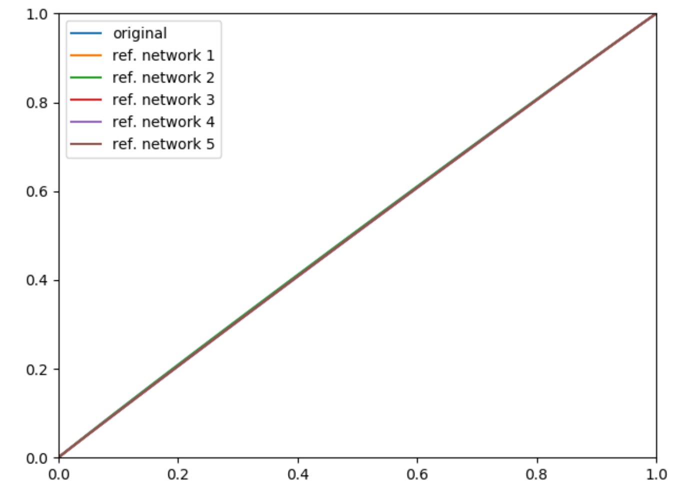
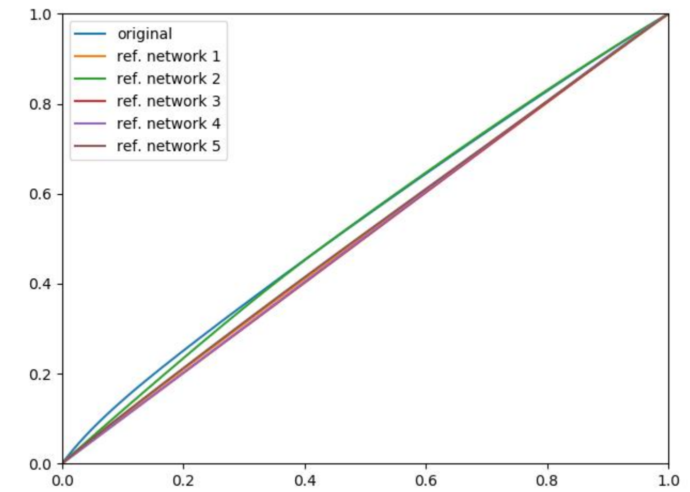
Peak detection method

Original Network (Synaptic)	
d=1000 time steps btw. peaks	**d=2000 time steps btw. peaks (previously used)**
	

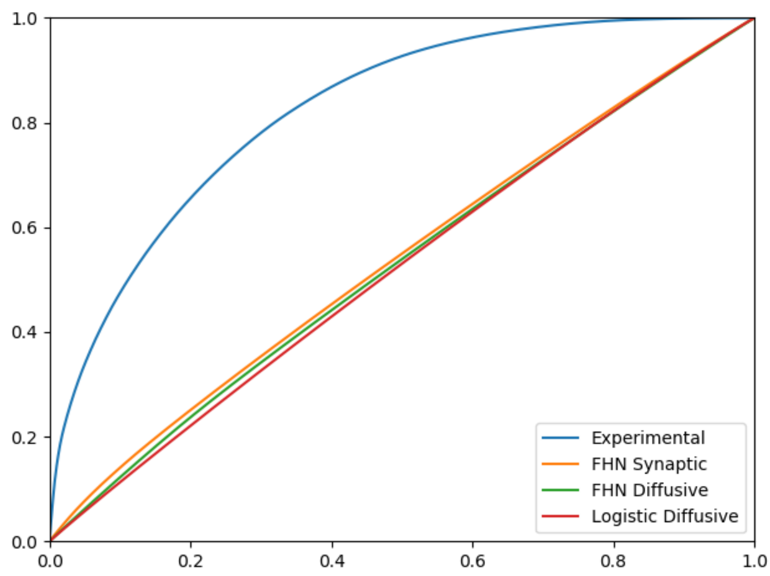
Dominance plot comparison

In-strengths (Magnitude)	Out-strengths (Magnitude)
	

FHN

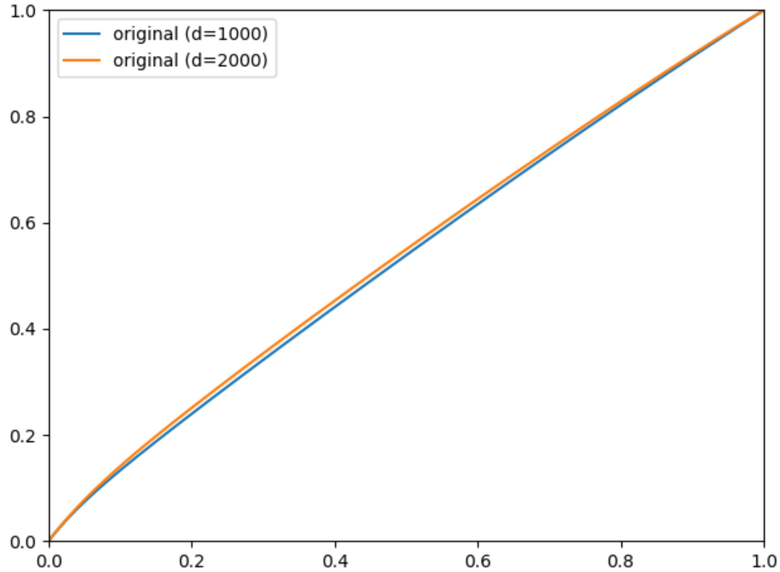
Diffusive	Synaptic
	

(Model comparison) Experimental, Logistic, FHN Diffusive (gij multiplied), FHN Synaptic

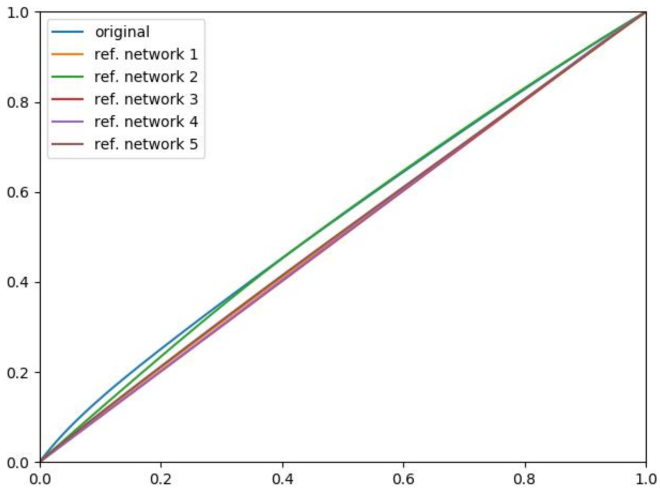


Effect of min sep d on peak counts

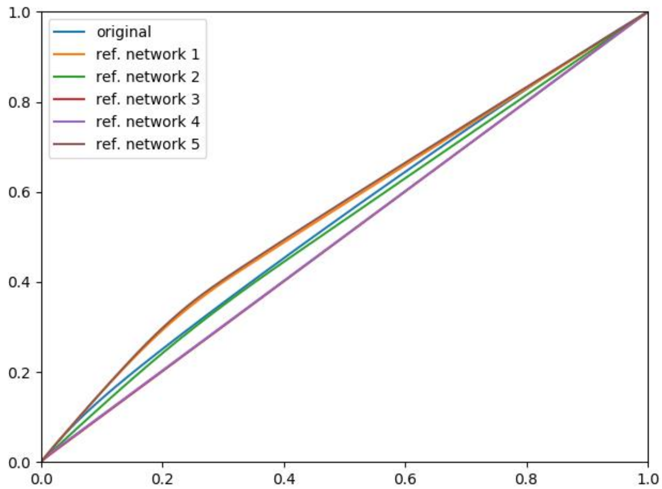
Original Network (d=1000 vs d=2000)



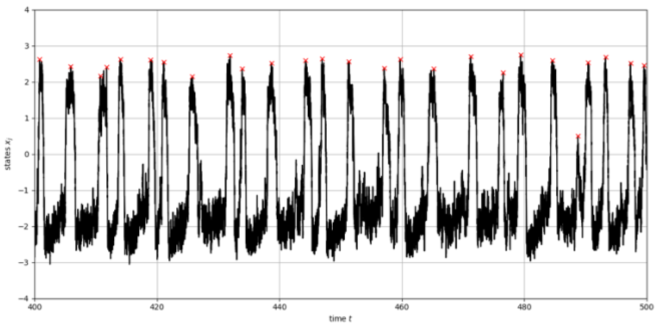
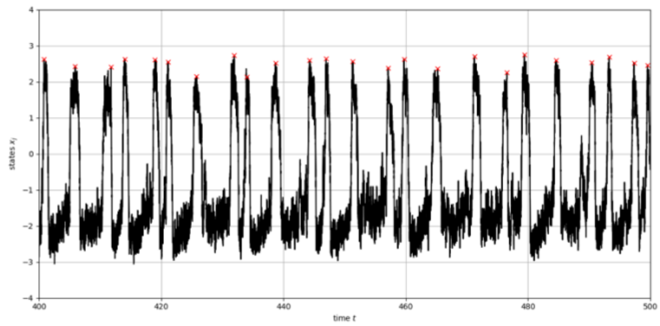
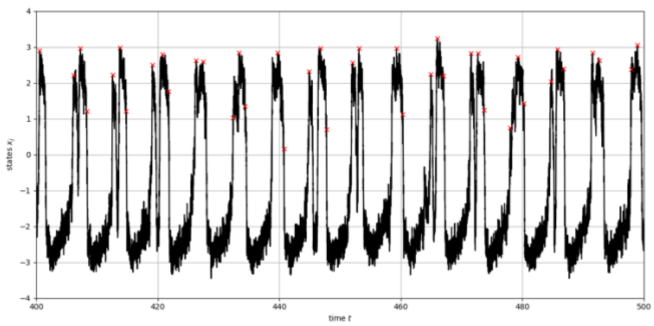
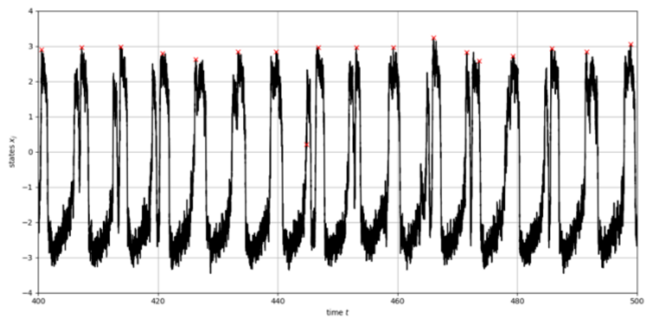
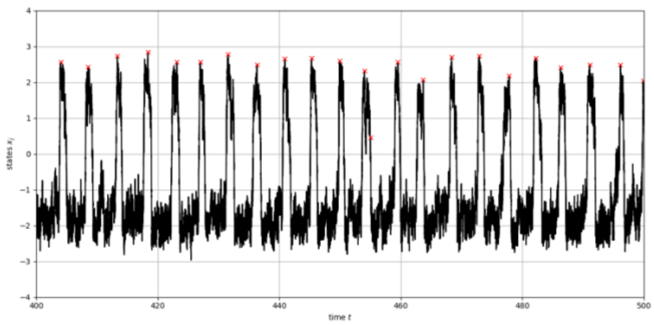
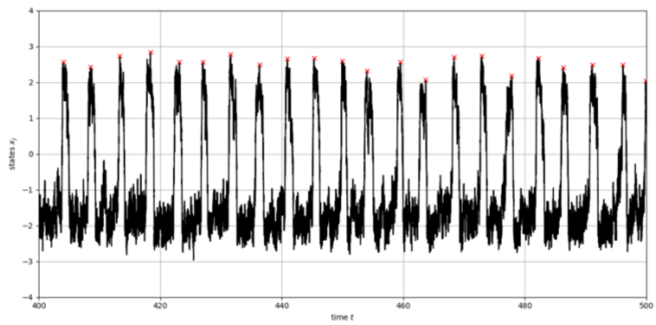
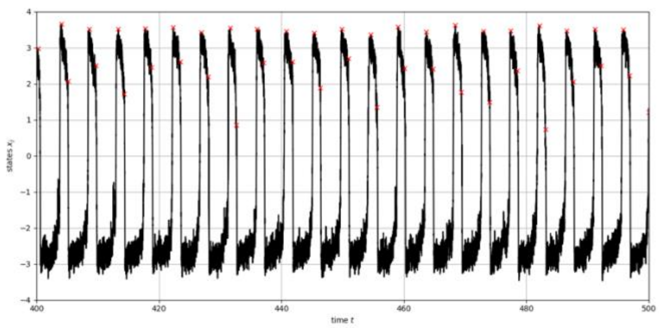
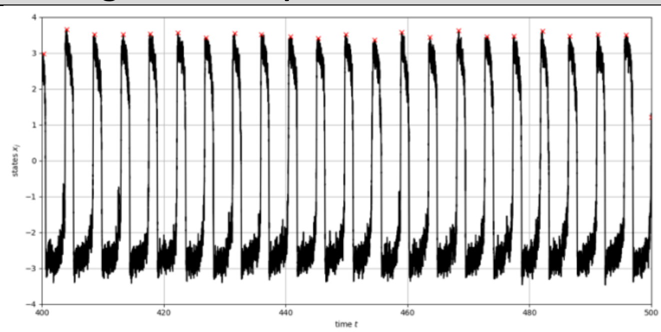
Ref. Network (d=2000)



Ref. Network (d=4000)



Refence network detected peaks

<table>
<tr><th>d=2000</th><th>d=4000</th></tr>
<tr><td colspan="2">Ref. Network 1 (non-zero gij Gaussian)</td></tr>
<tr><td colspan="2">Min peak counts (according to d=2000)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Max peak counts (according to d=2000)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Ref. Network 2 (row gij shuffled)</td></tr>
<tr><td colspan="2">Min peak counts (according to d=2000)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Max peak counts (according to d=2000)</td></tr>
<tr><td></td><td></td></tr>
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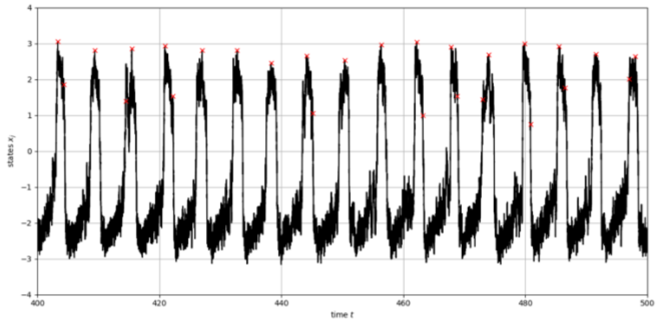
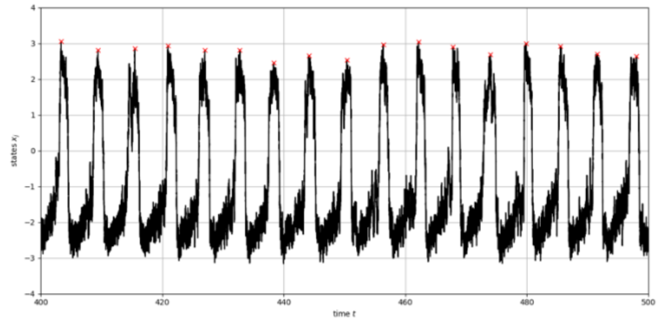
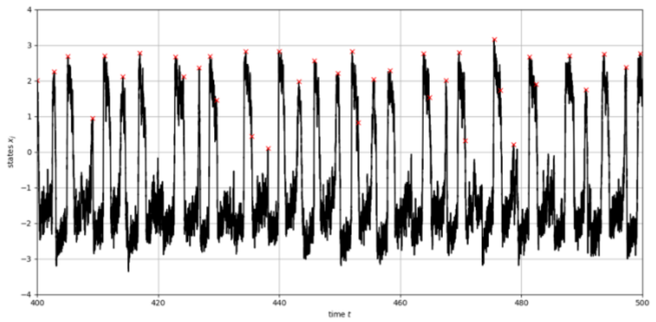
Ref. Network 3 (col gij shuffled)

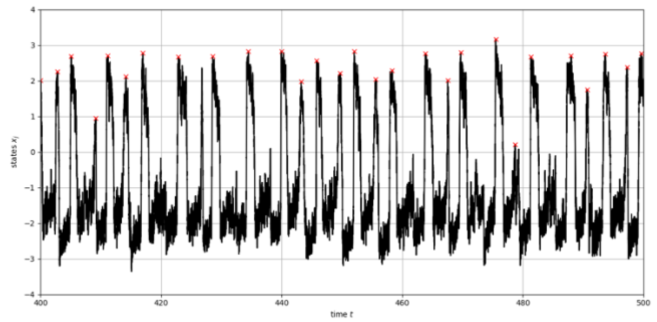
Min peak counts (according to d=2000)





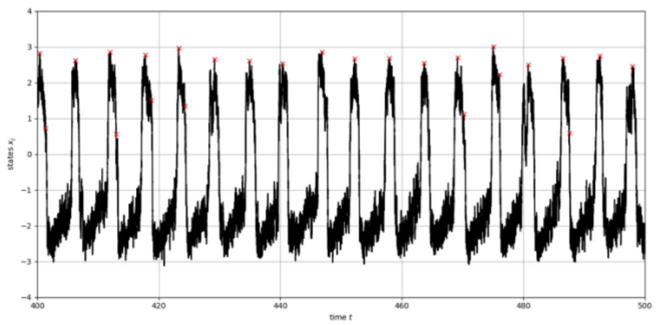
Max peak counts (according to d=2000)

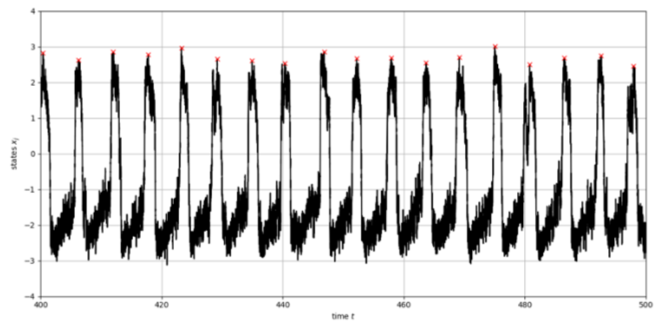




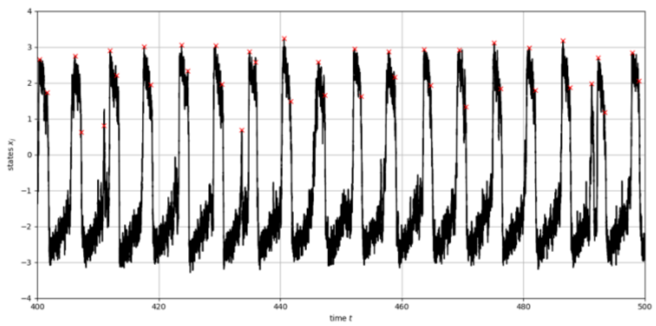
Ref. Network 4 (random)

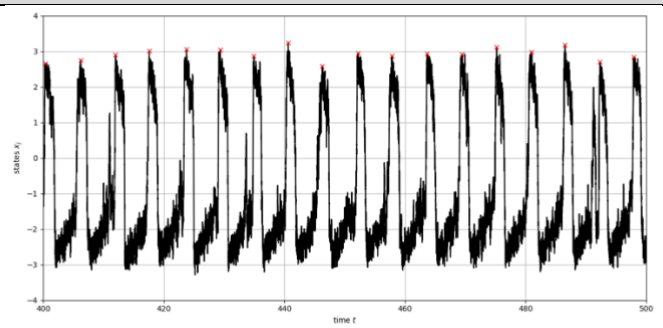
Min peak counts (according to d=2000)

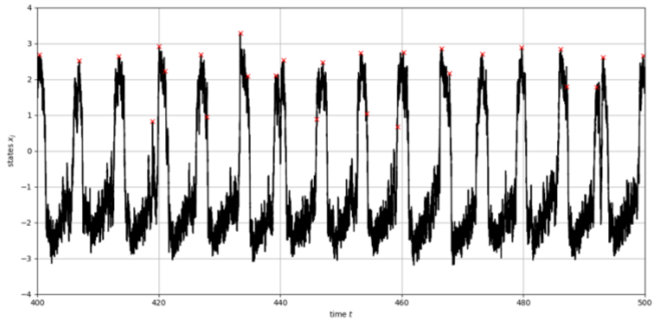
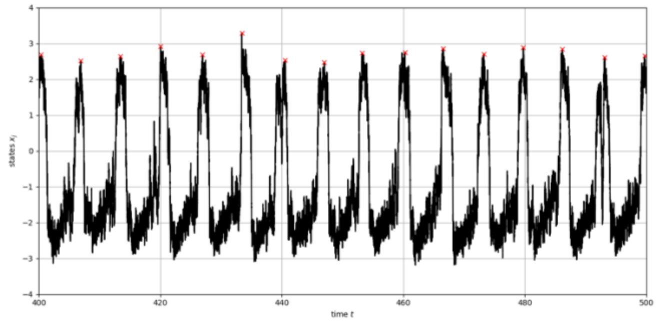
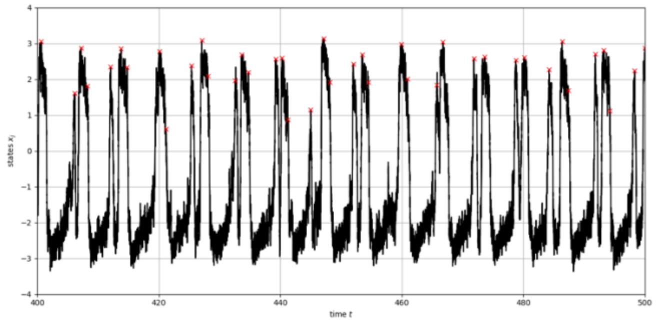
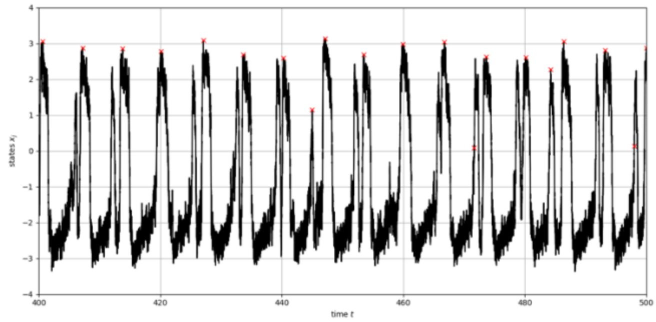




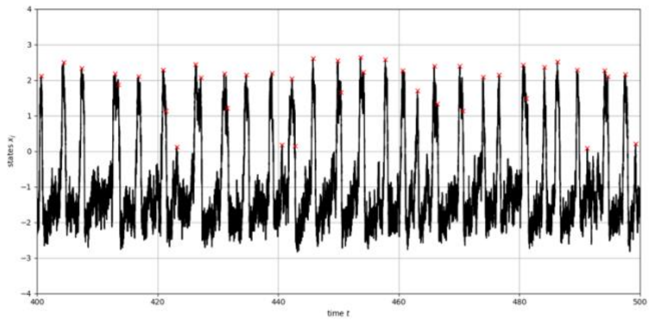
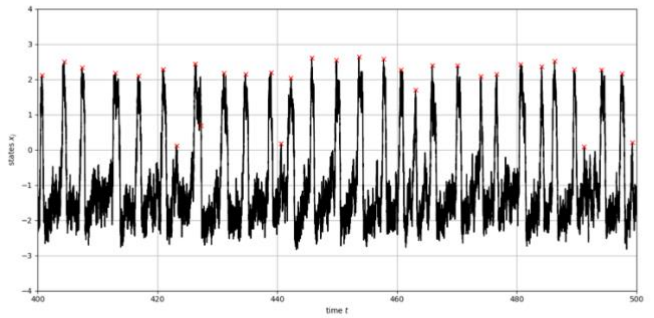
Max peak counts (according to d=2000)





Ref. Network 5 (non-zero gij shuffled)	
Min peak counts (according to d=2000)	
	
Max peak counts (according to d=2000)	
	

Original network detected peaks

d=1000	d=2000
Min peak counts (according to d=1000)	
	
Max peak counts (according to d=1000)