

# Modelling computation in V1

Andrew Davison

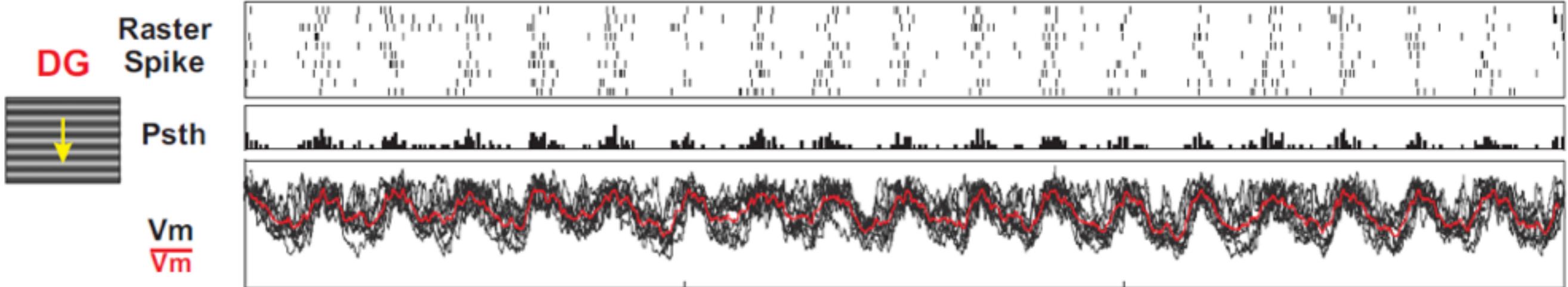
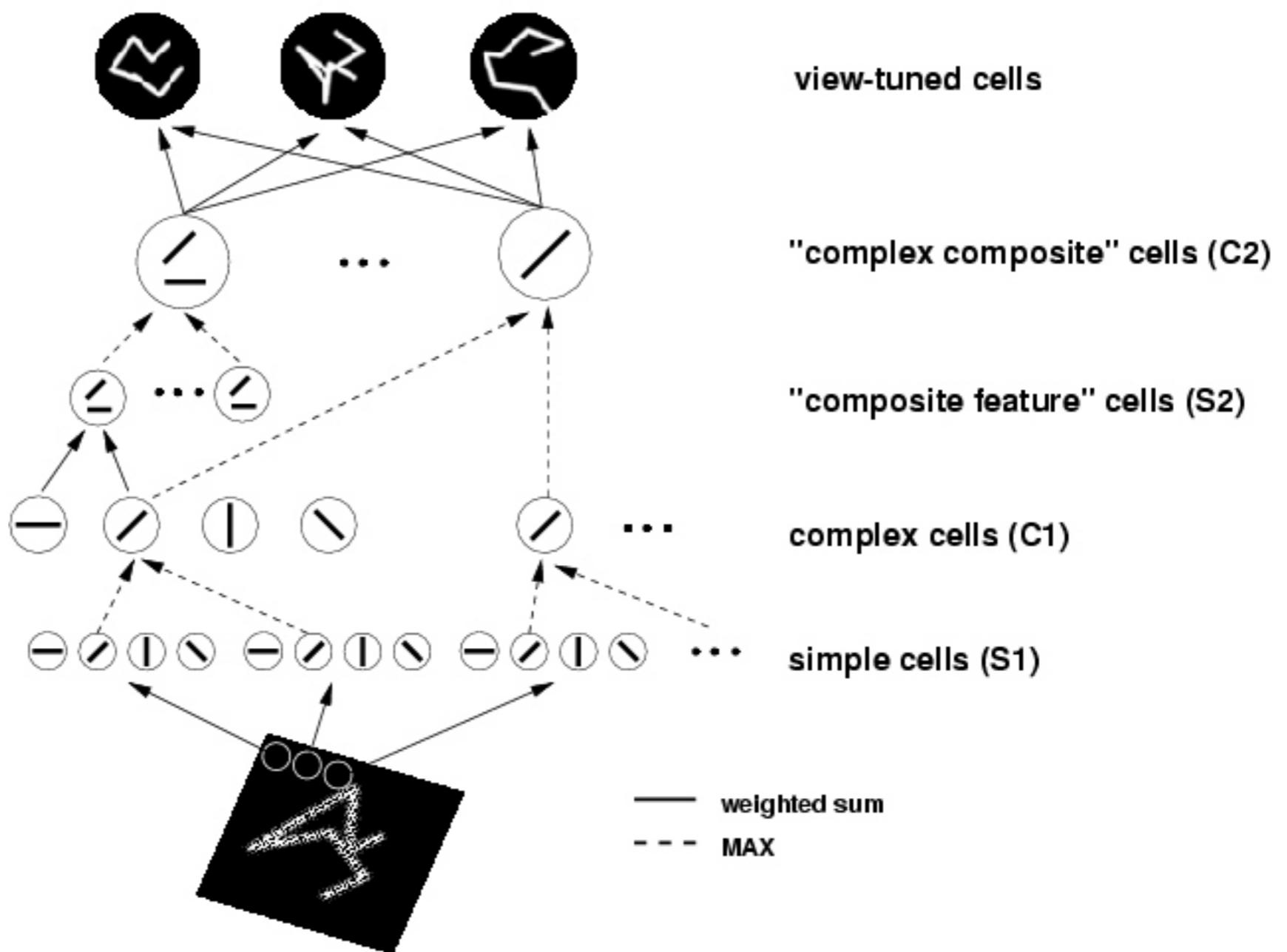
Unité de Neurosciences, Information et Complexité (UNIC),  
CNRS FRE 3293 (Dir. Y Frégnac)  
Gif sur Yvette

1er colloque du GDR BioComp  
7th October 2015      St Paul de Vence

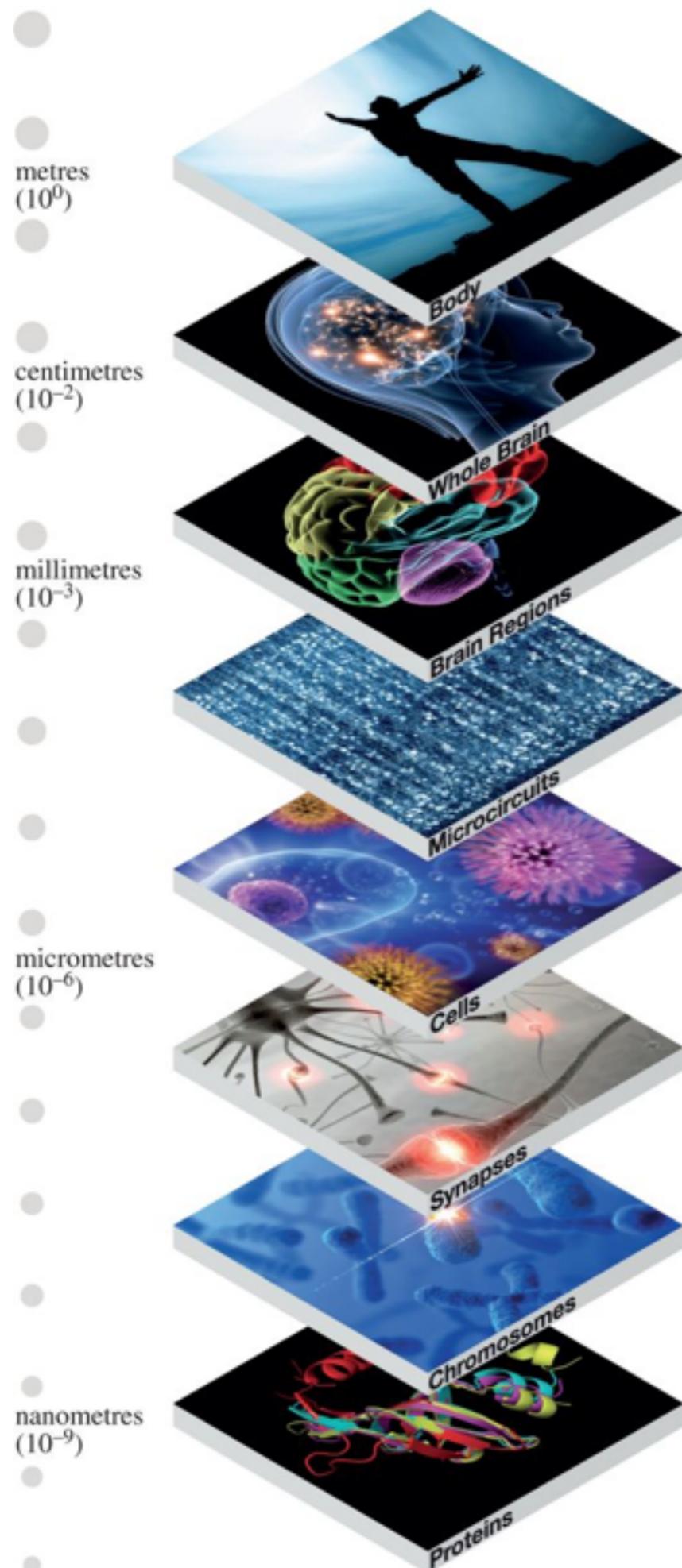


Biological computation

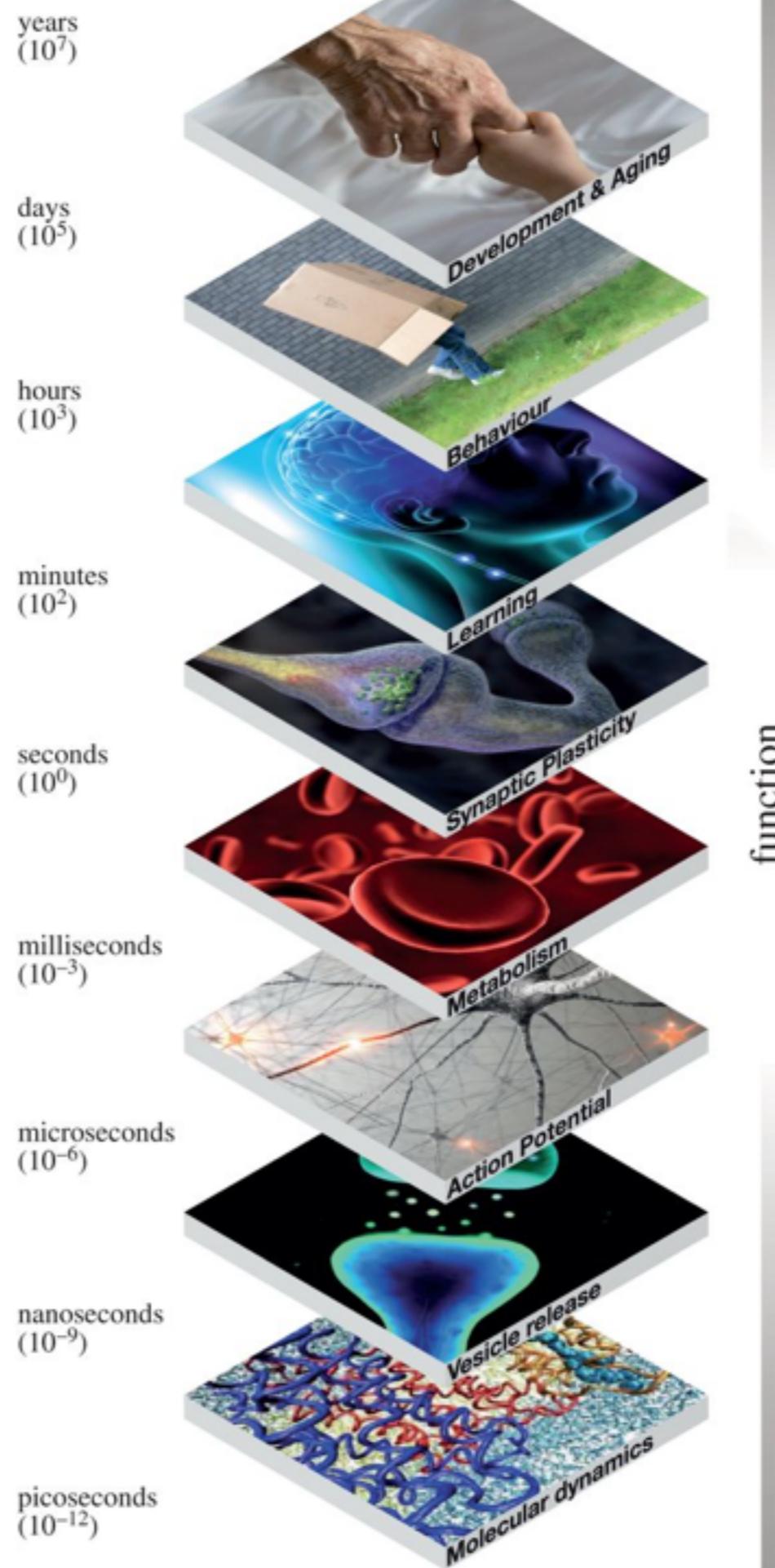
Biology-inspired computation



spatial scales



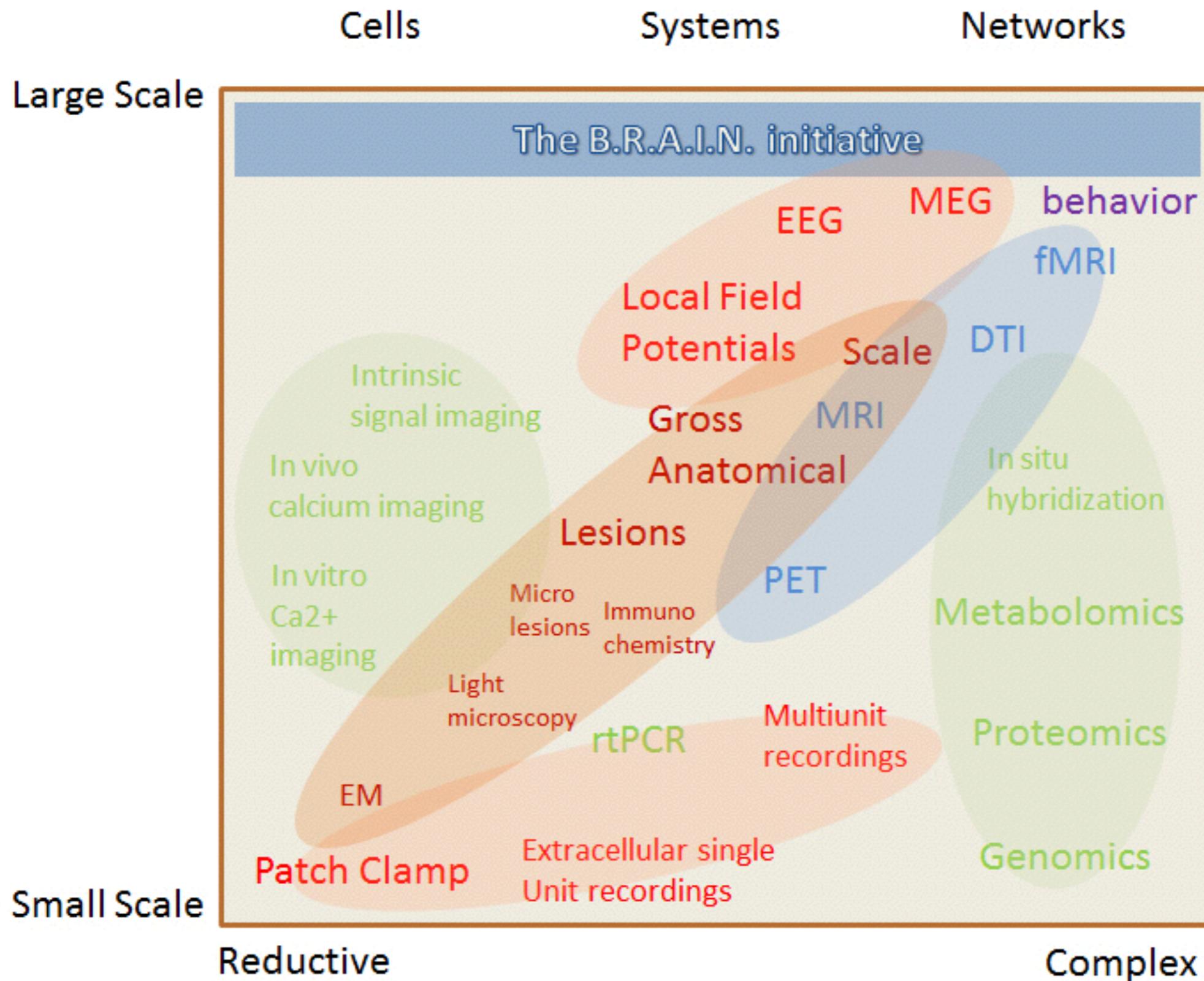
time scales



structure

function

# Neuroscience Techniques



# Fine-scale, detailed modelling

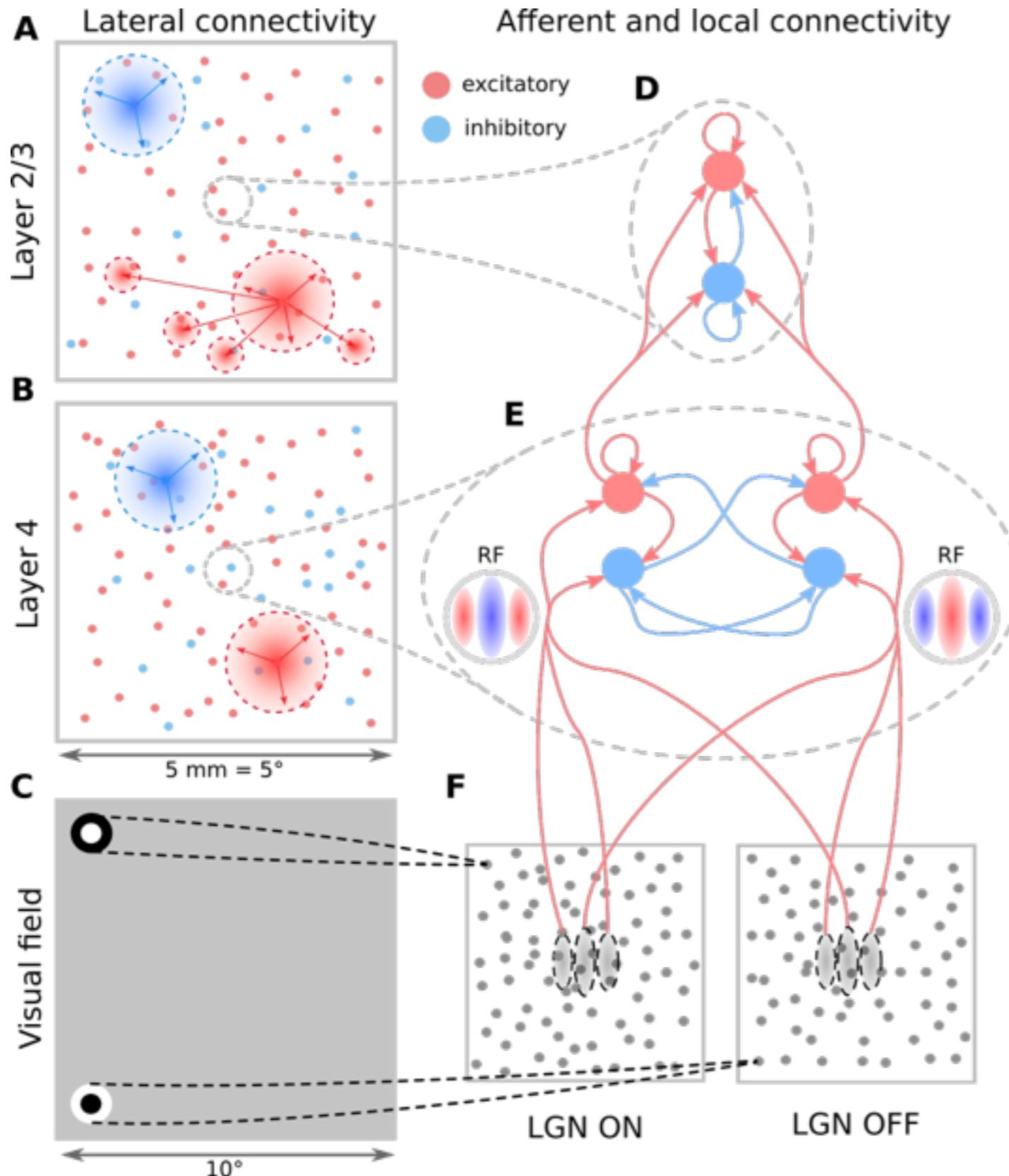
## Advantages

- few free parameters (values obtained from experiments)
- more constrained by data:
  - direct relationship to fine-scale data (electrode recordings, anatomy)
  - relationship to coarse-scale data by forward, mechanistic modelling

## Disadvantages

- complex, difficult to understand, interpret
- missing data —> more free parameters to be fitted

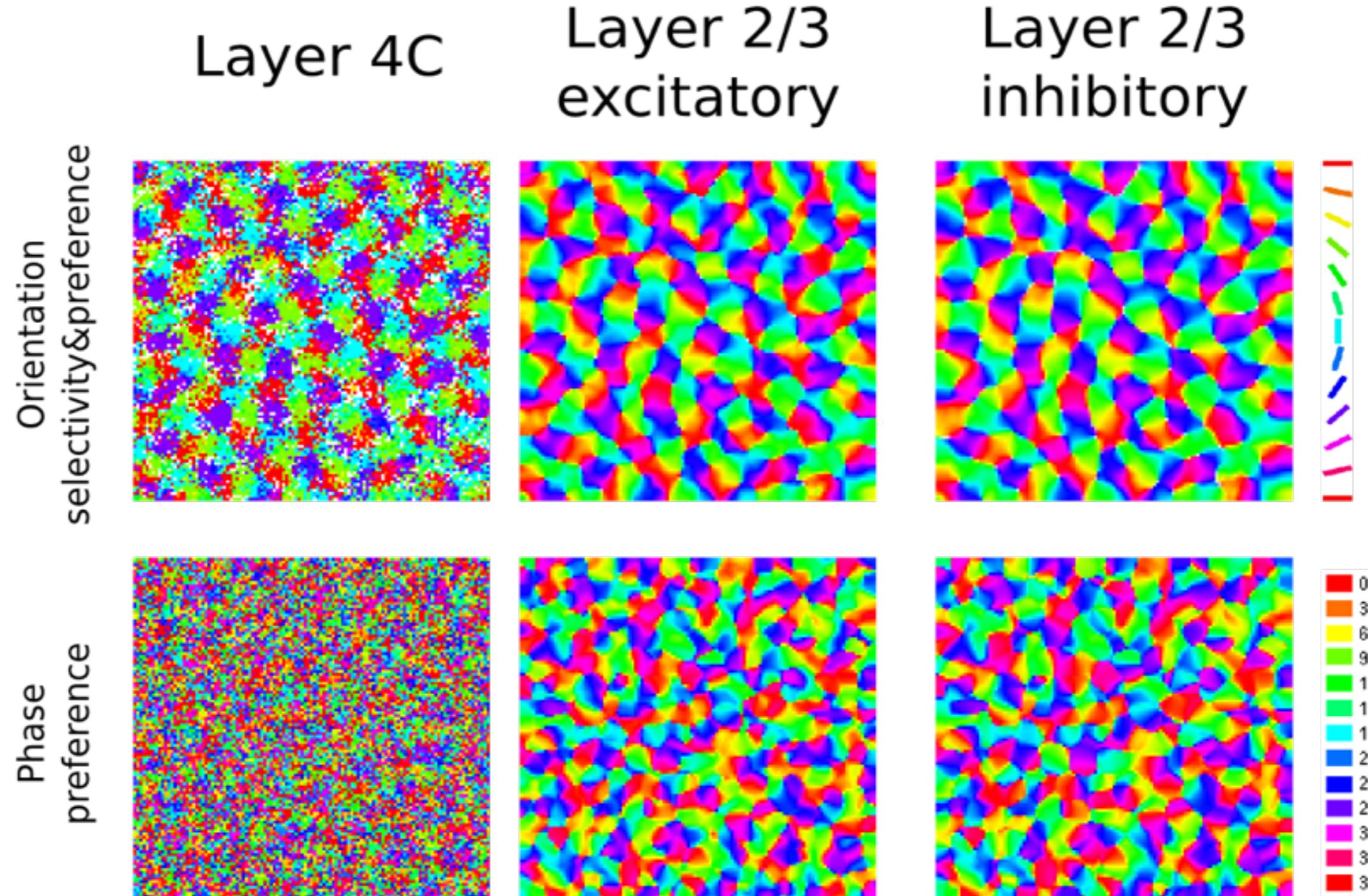
# A detailed model of cat primary visual cortex



- 5x5 deg patch of parafoveal V1, Layers 2/3, 4
- 90000 neurons, 29 million synapses (downsampling)
- 4:1 ratio of excitatory:inhibitory neurons
- thalamocortical synapses <5% of synaptic input in layer 4
- AdExp neuron model

Ján Antolík



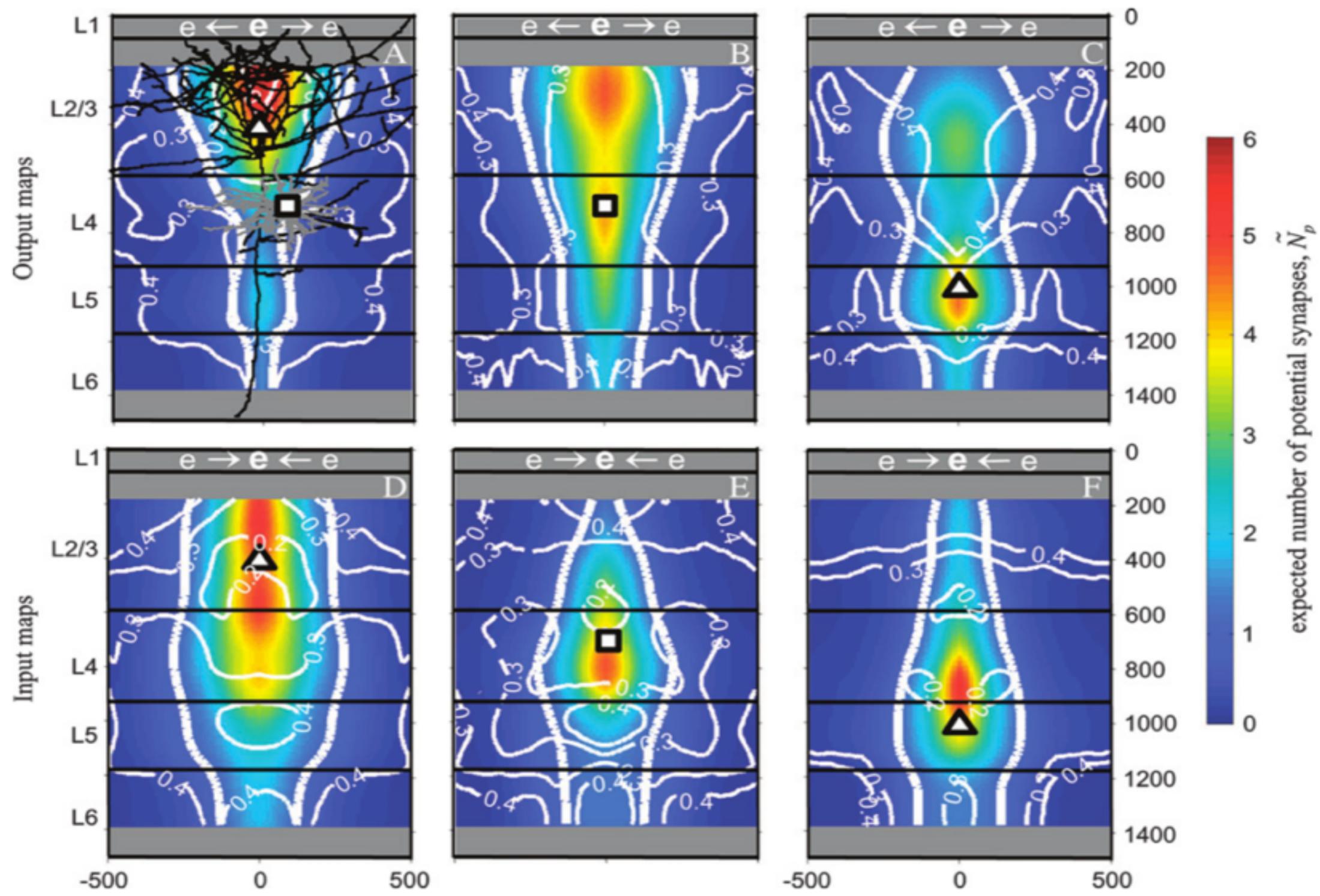


CCLISSOM model  
Antolik & Bednar (2012), Front. Comput. Neurosci

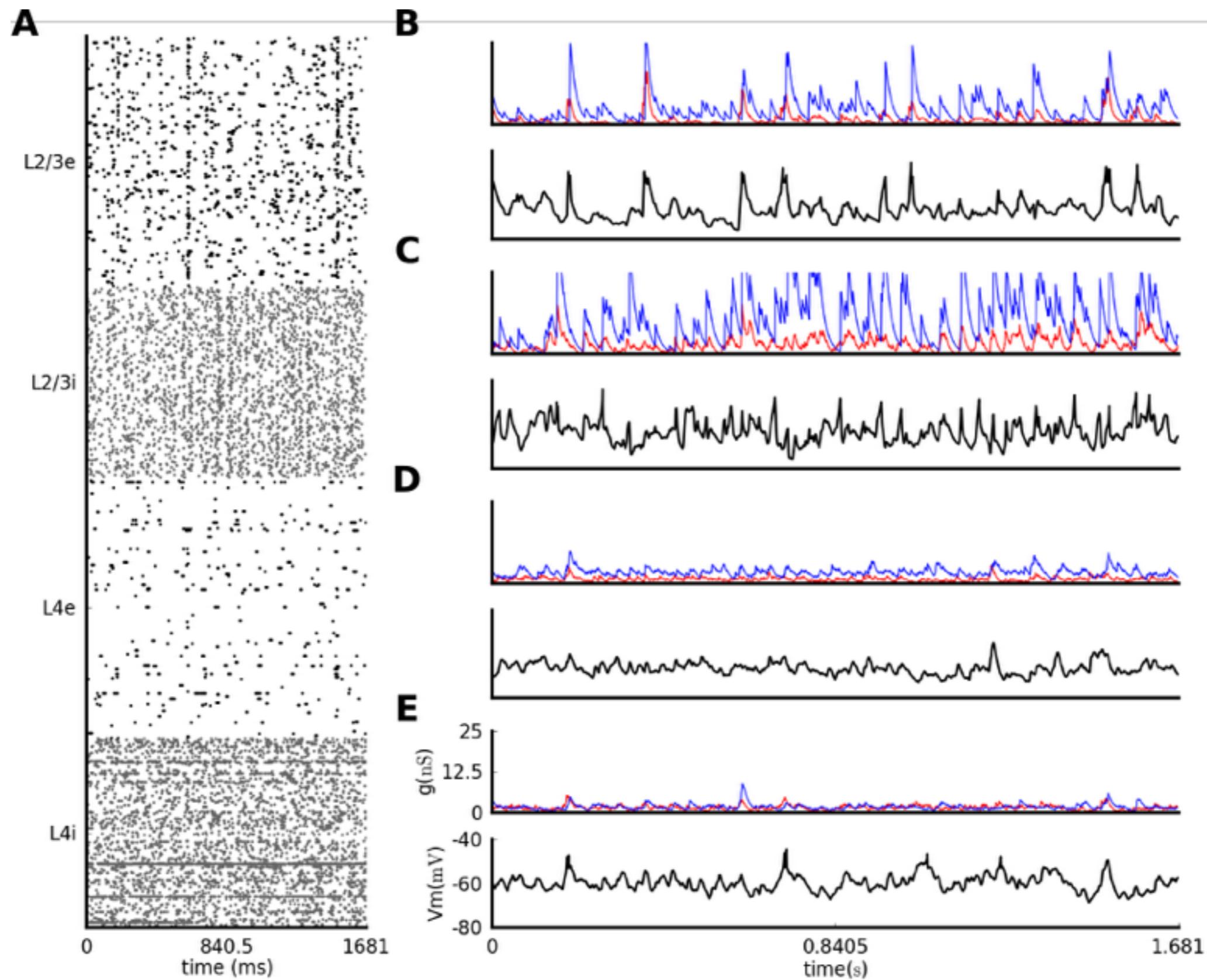
# Data sources for model construction

- spatial and temporal parameters of LGN receptive field - Allen & Freeman (2006)
- luminance and contrast saturation of LGN relay neurons - Papaioannou & White (1972), Bonin *et al.* (2005)
- variability of LGN responses - Troyer, Krukowski *et al.* (1998)
- neuron parameters (resting potential, membrane time constant, membrane resistance, threshold potential, refractory period, sub-threshold adaptation, spike-triggered adaptation) - Monier *et al.* (2008) McCormick *et al.* (1985), Jolivet *et al.* (2008)
- lateral axonal propagation delays - Bringuier *et al.* (1999), Chavane *et al.* (2011)
- synaptic depression
  - at thalamocortical synapses - Banitt *et al.* (2007), Kremkow *et al.* (2011)
  - at corticocortical synapses - Markram *et al.* (1998)
- average weights of corticocortical synapses by type - Hoffmann *et al.* (2015), Cruikshank *et al.* (2007)
- statistics of synaptic connections - Rockland *et al.* (2013), Stepanyants *et al.* (2009), Boucsein *et al.* (2011), da Costa & Martin (2011)
- failure rates in cortico-cortical synapses - Stratford *et al.* (1996), Allen & Stevens (1994)
- weak functional bias of V1 connectivity - Buzás *et al.* (2006), Ko *et al.* (2011)
- spatial extent of local intra-cortical connectivity - Stepanyants *et al.* (2008), Angelucci *et al.* (2002), Budd & Kisvárdy (2001)
- no clustering of spatial phase in cat V1 - Ziskind (2013)
- size and shape of V1 receptive fields - Jones & Palmer (1987)

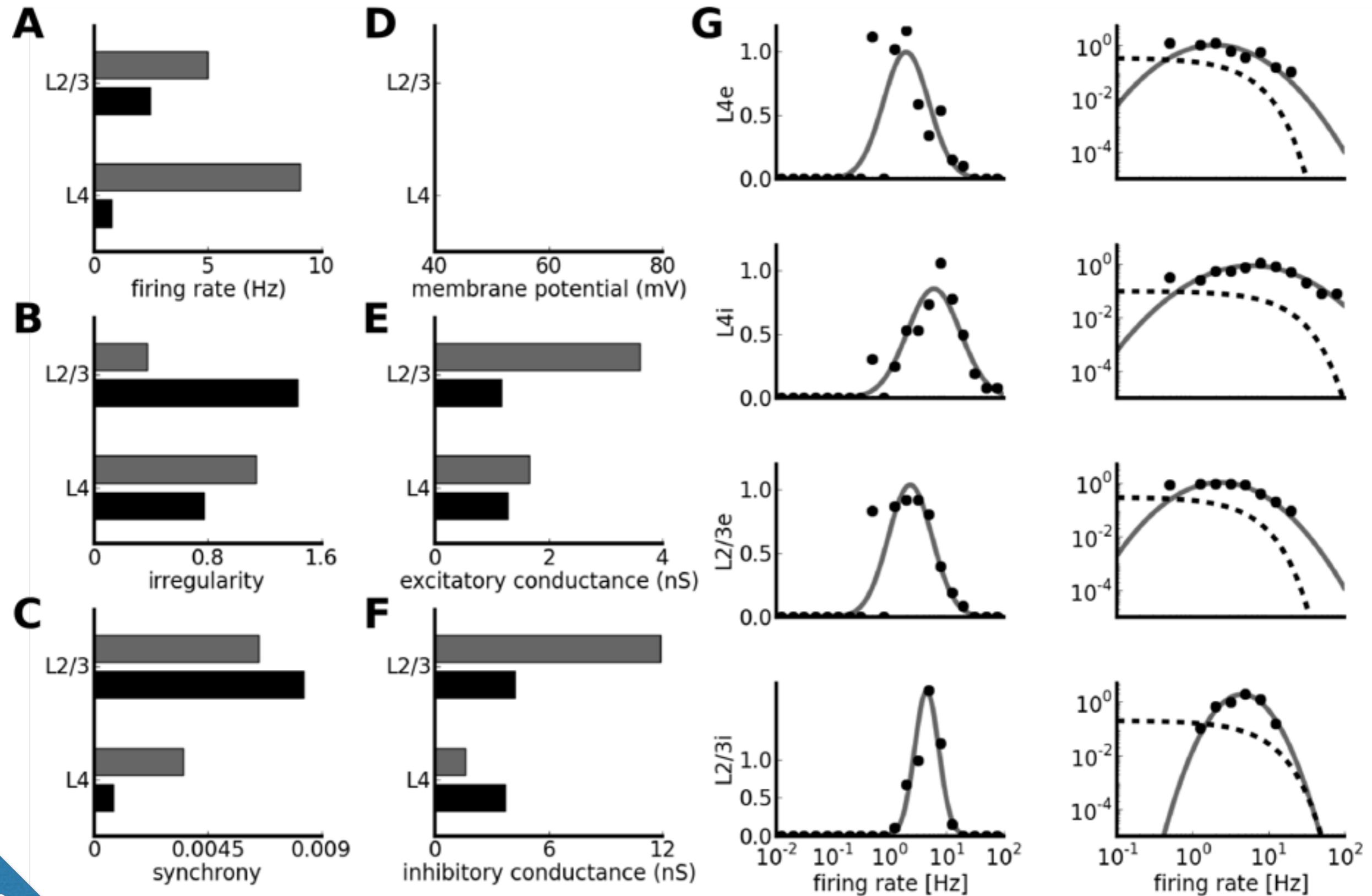
# Data sources for model construction



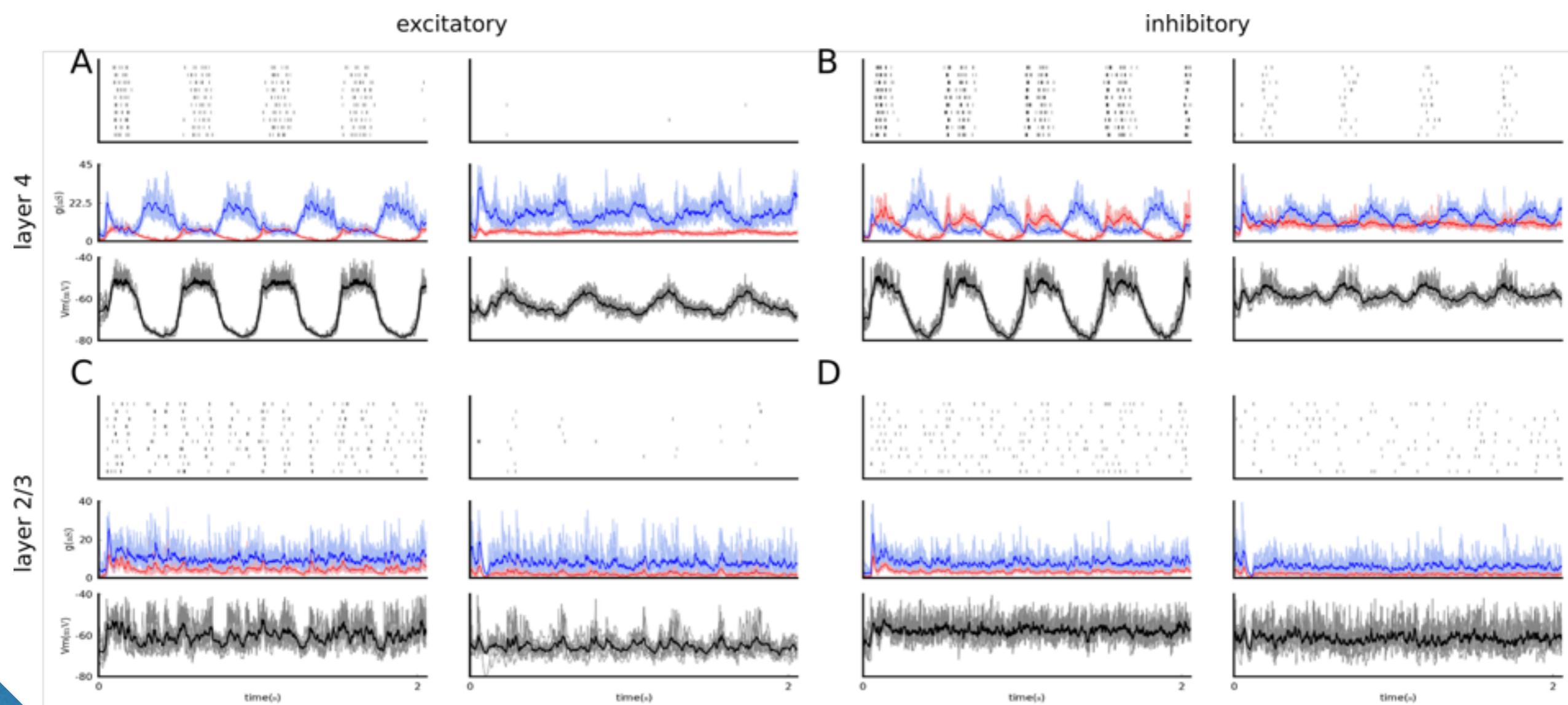
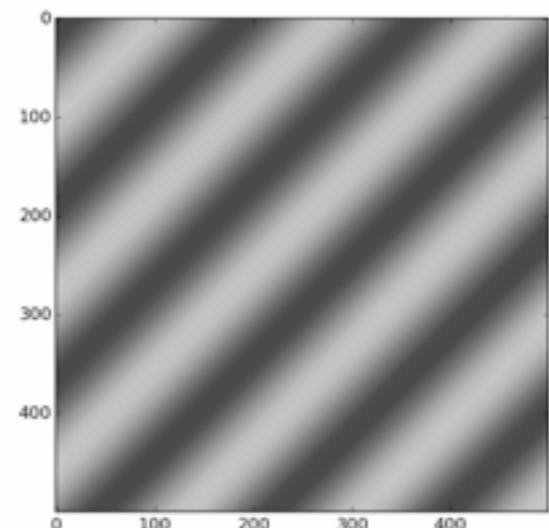
# Model validation: spontaneous activity



# Model validation: spontaneous activity

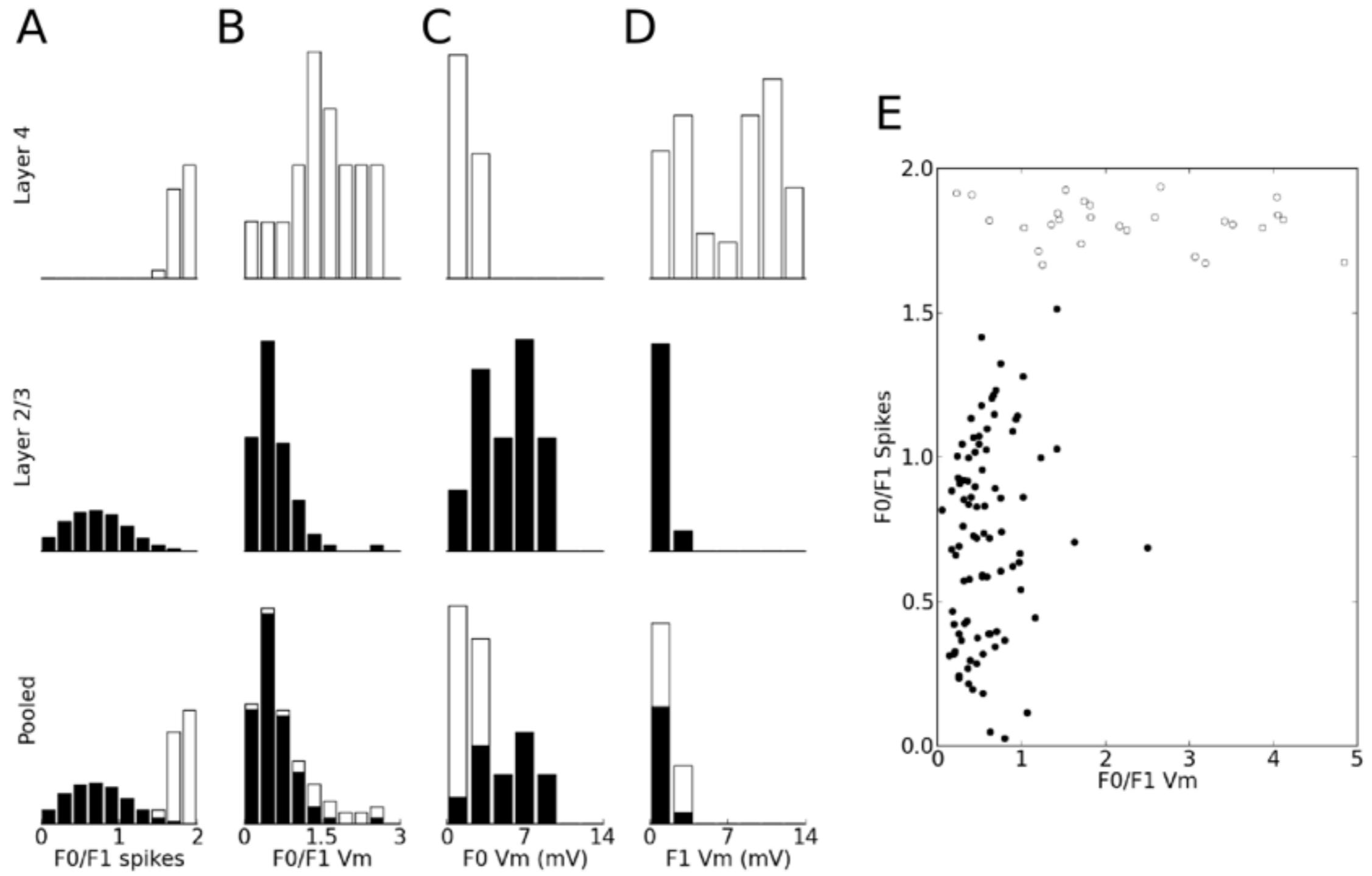


# Model validation: drifting gratings

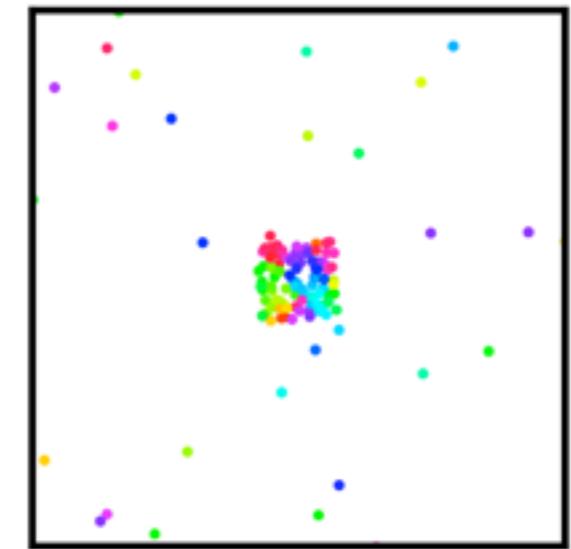
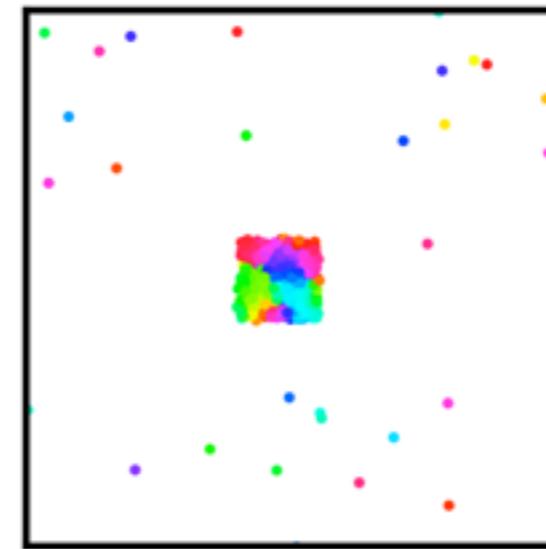
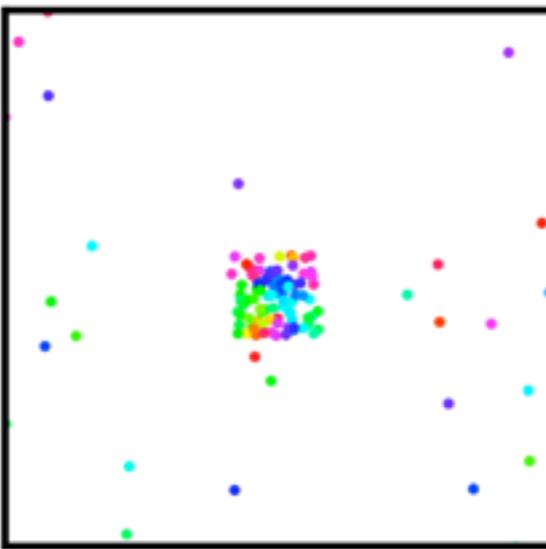
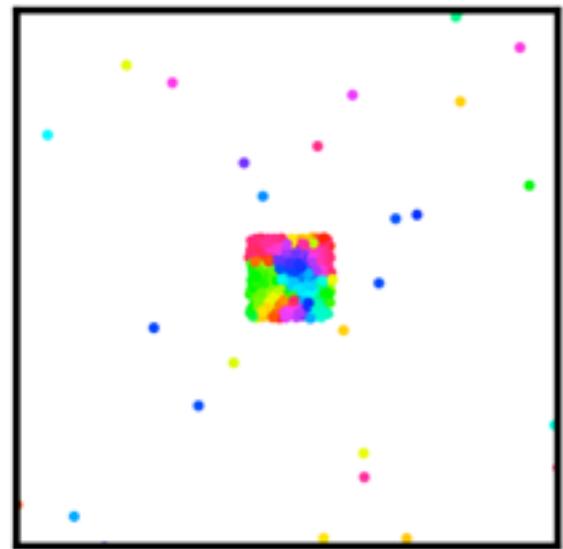
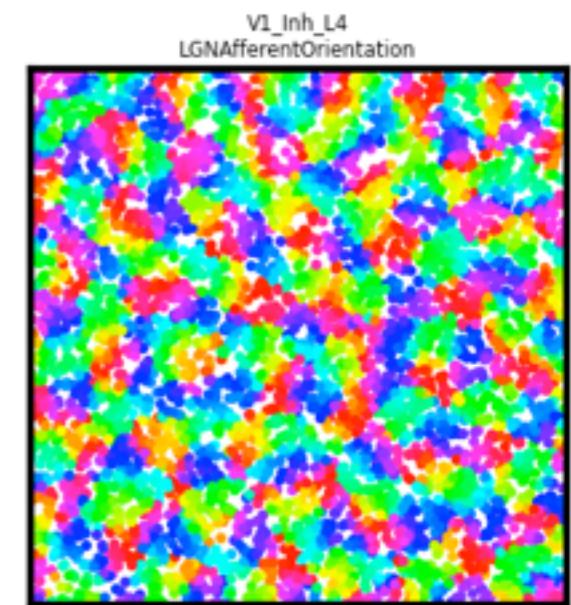
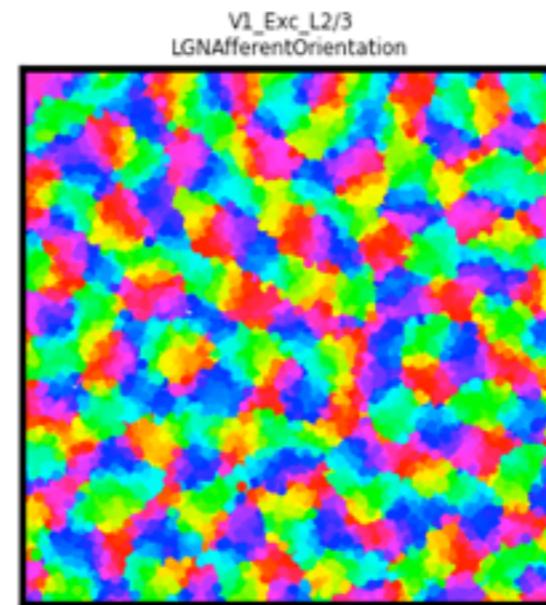
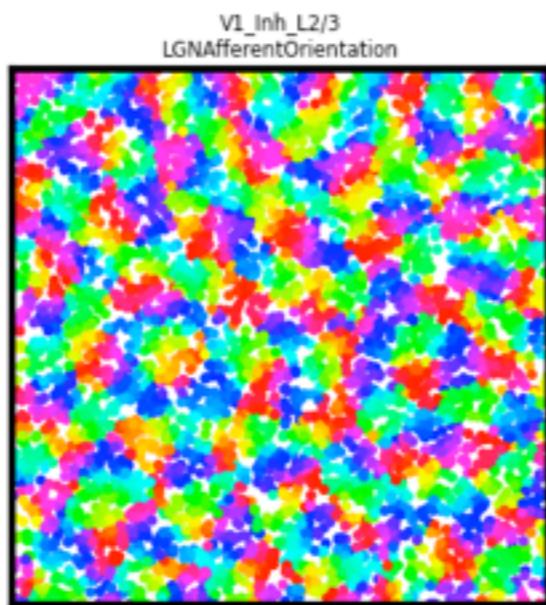
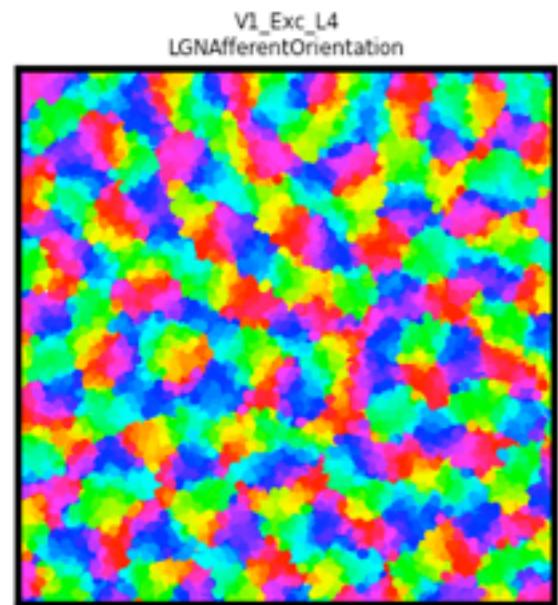


Model

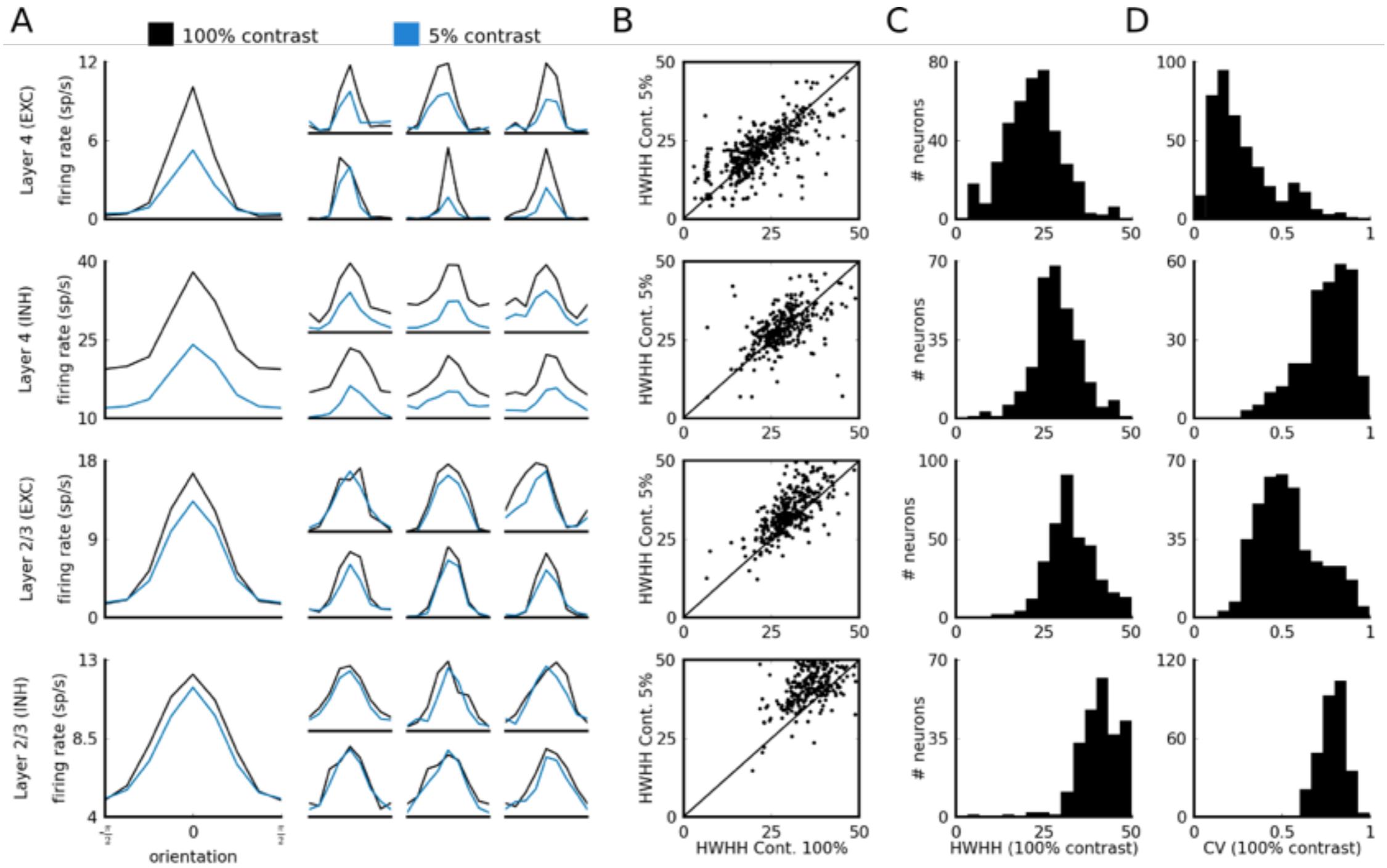
# Model validation: drifting gratings



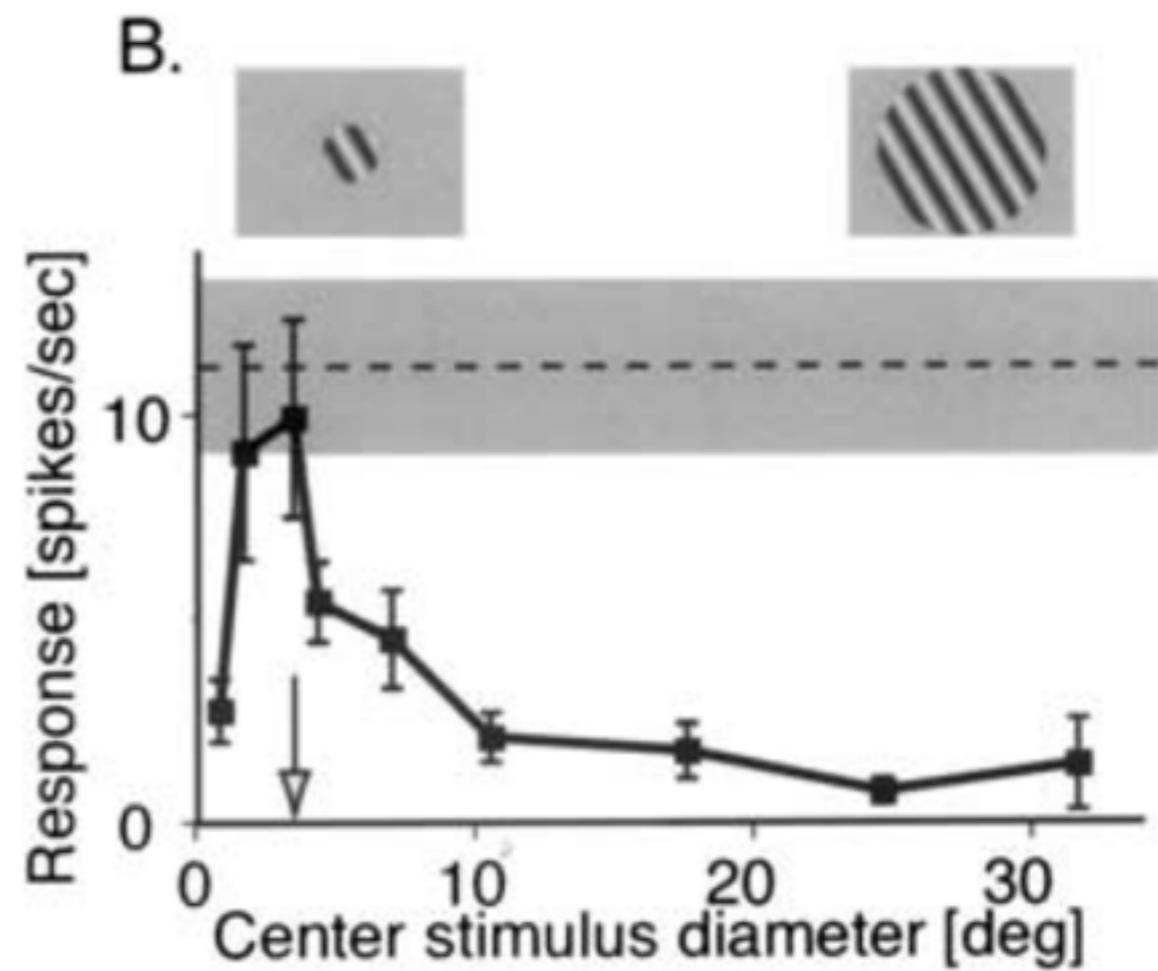
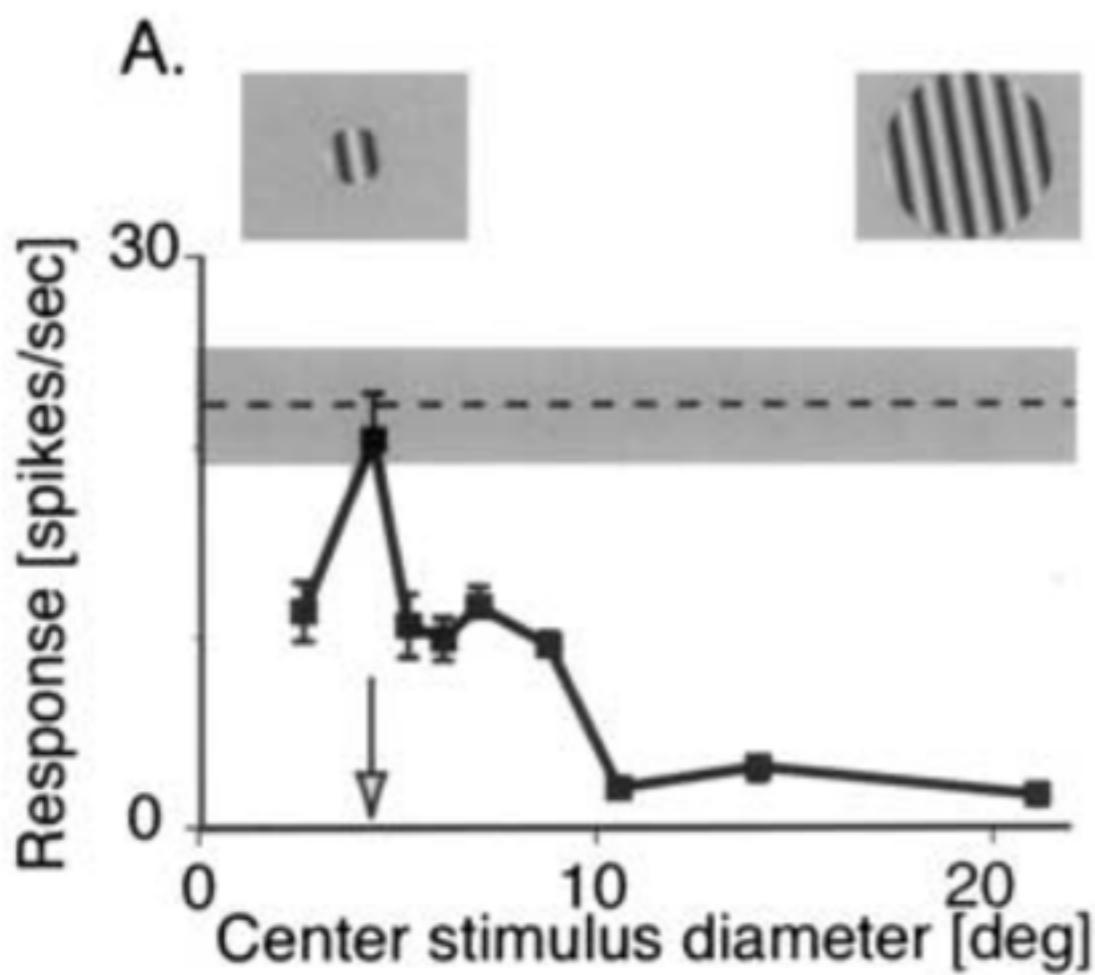
# Model validation: nominal and measured orientation preference maps



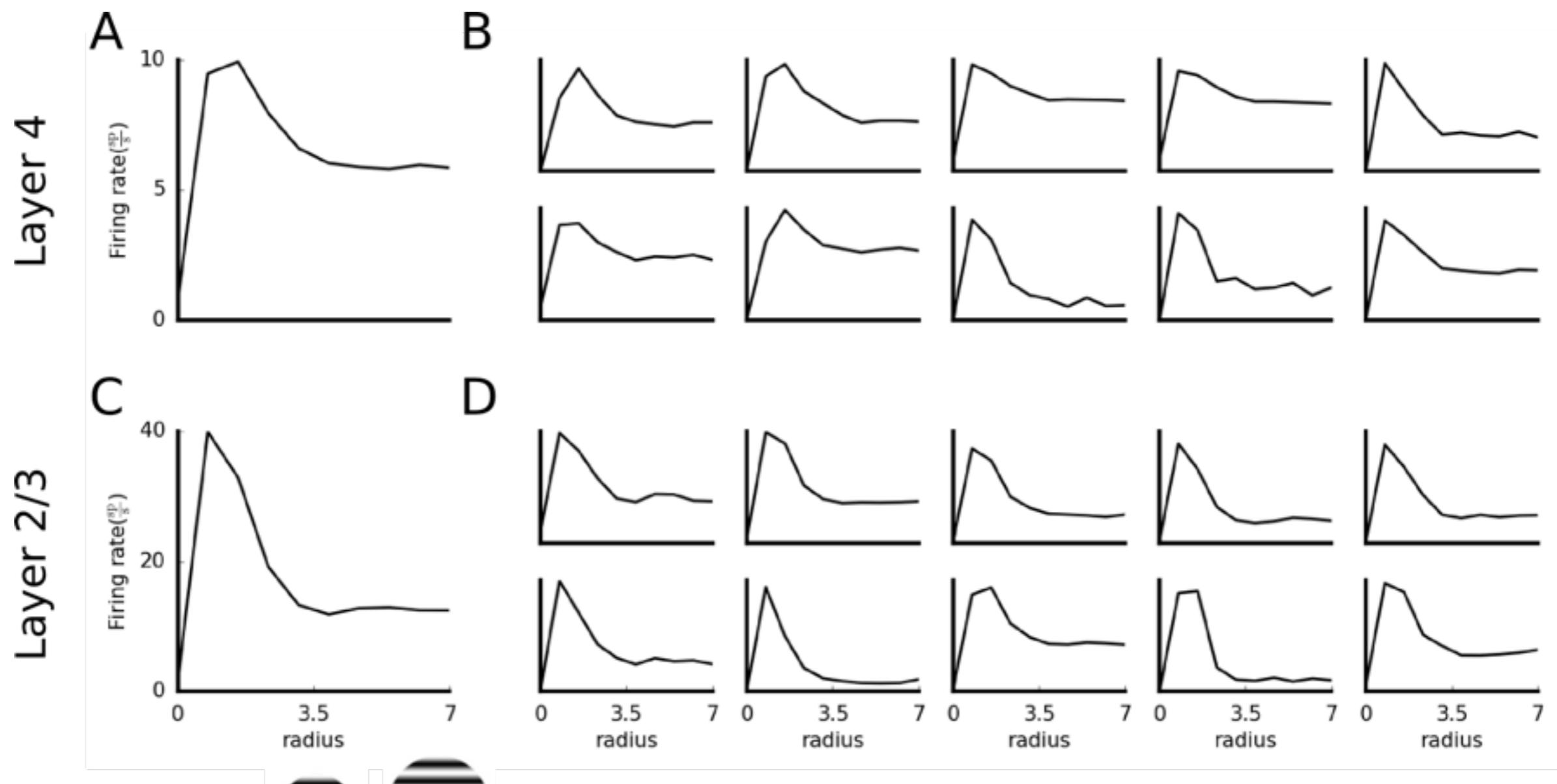
# Model validation: contrast-independent orientation tuning



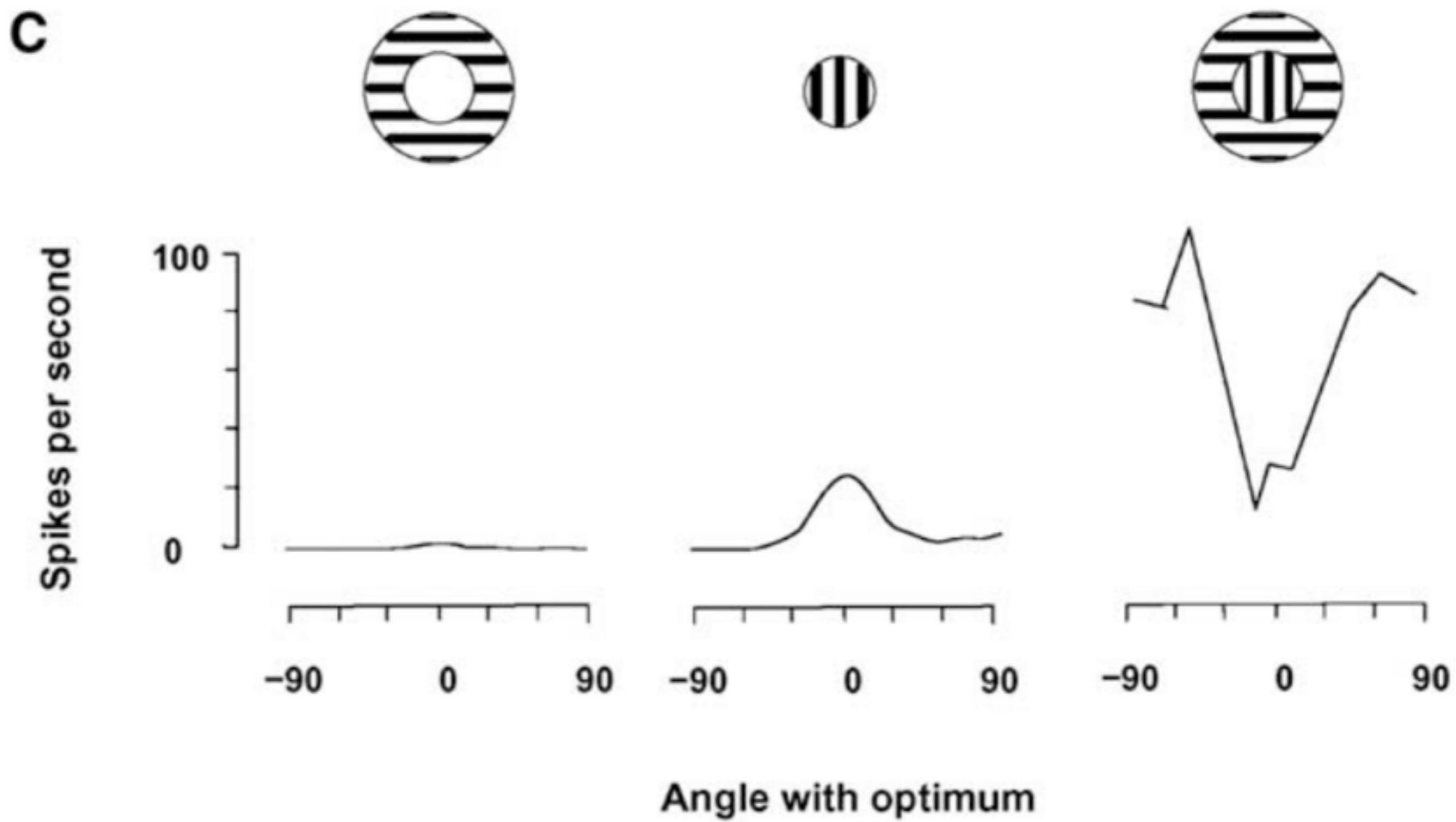
# Model validation: size tuning



# Model validation: size tuning

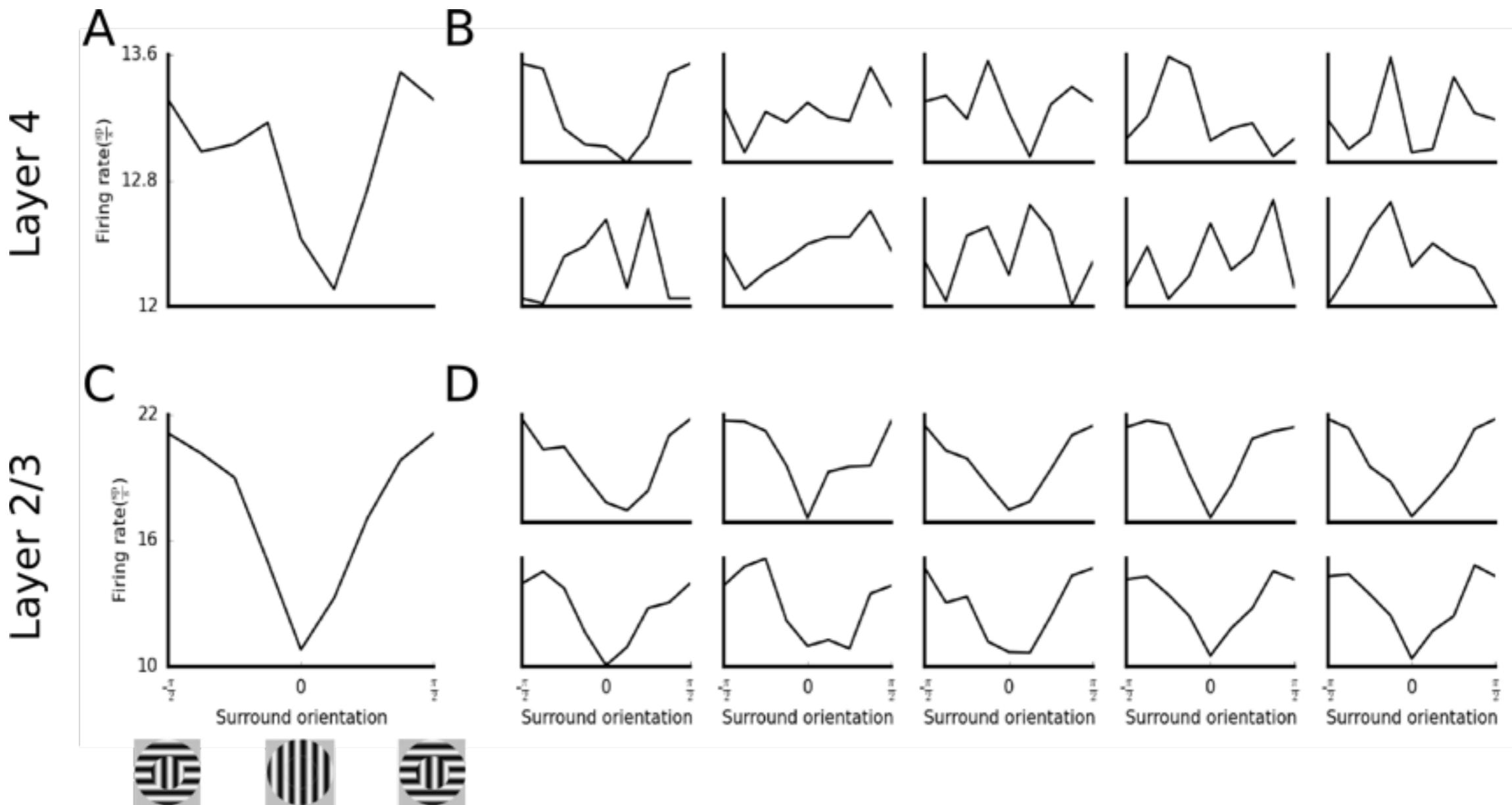


# Model validation: orientation contrast tuning



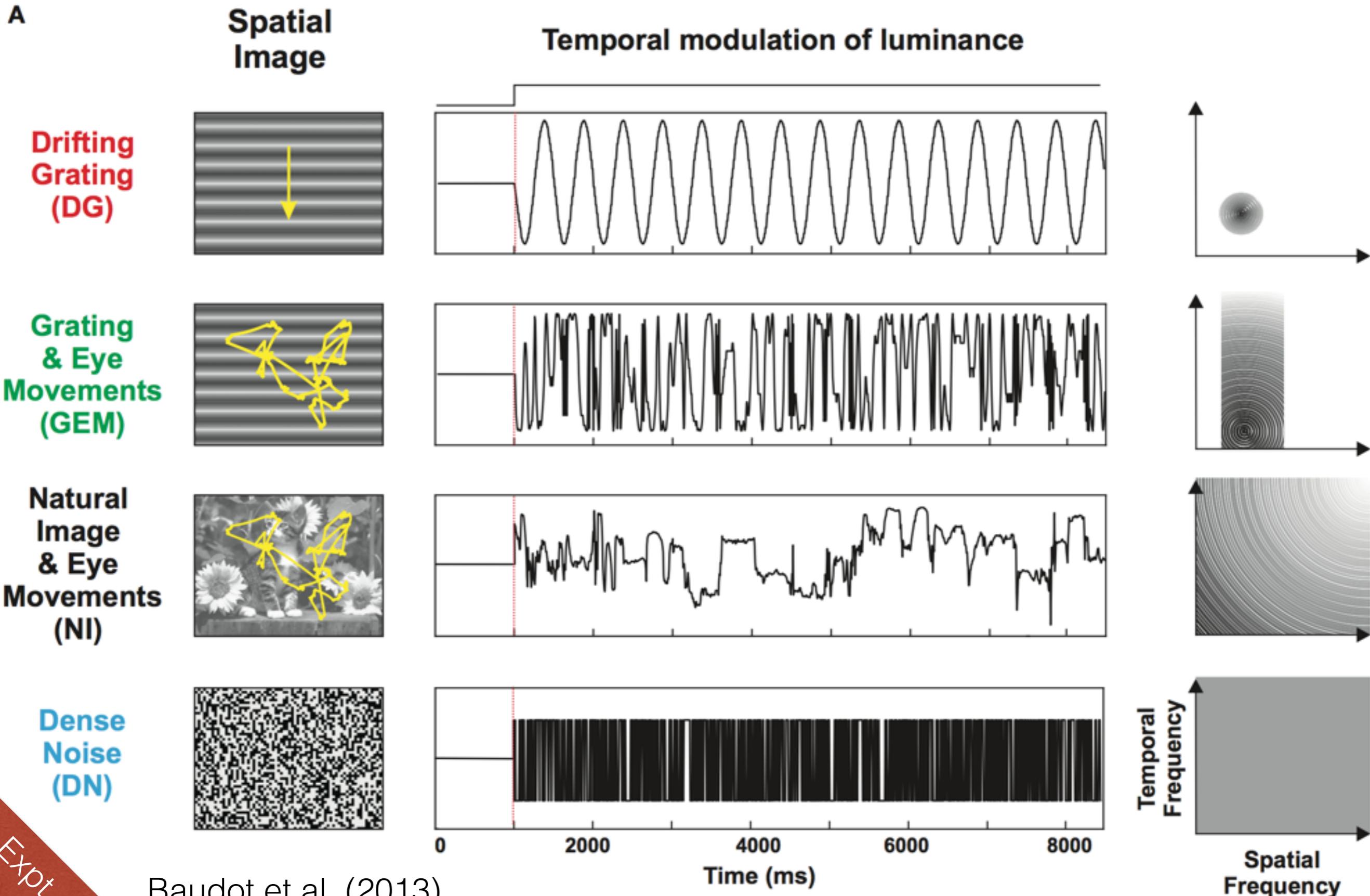
Sillito and Jones 1996

# Model validation: orientation contrast tuning

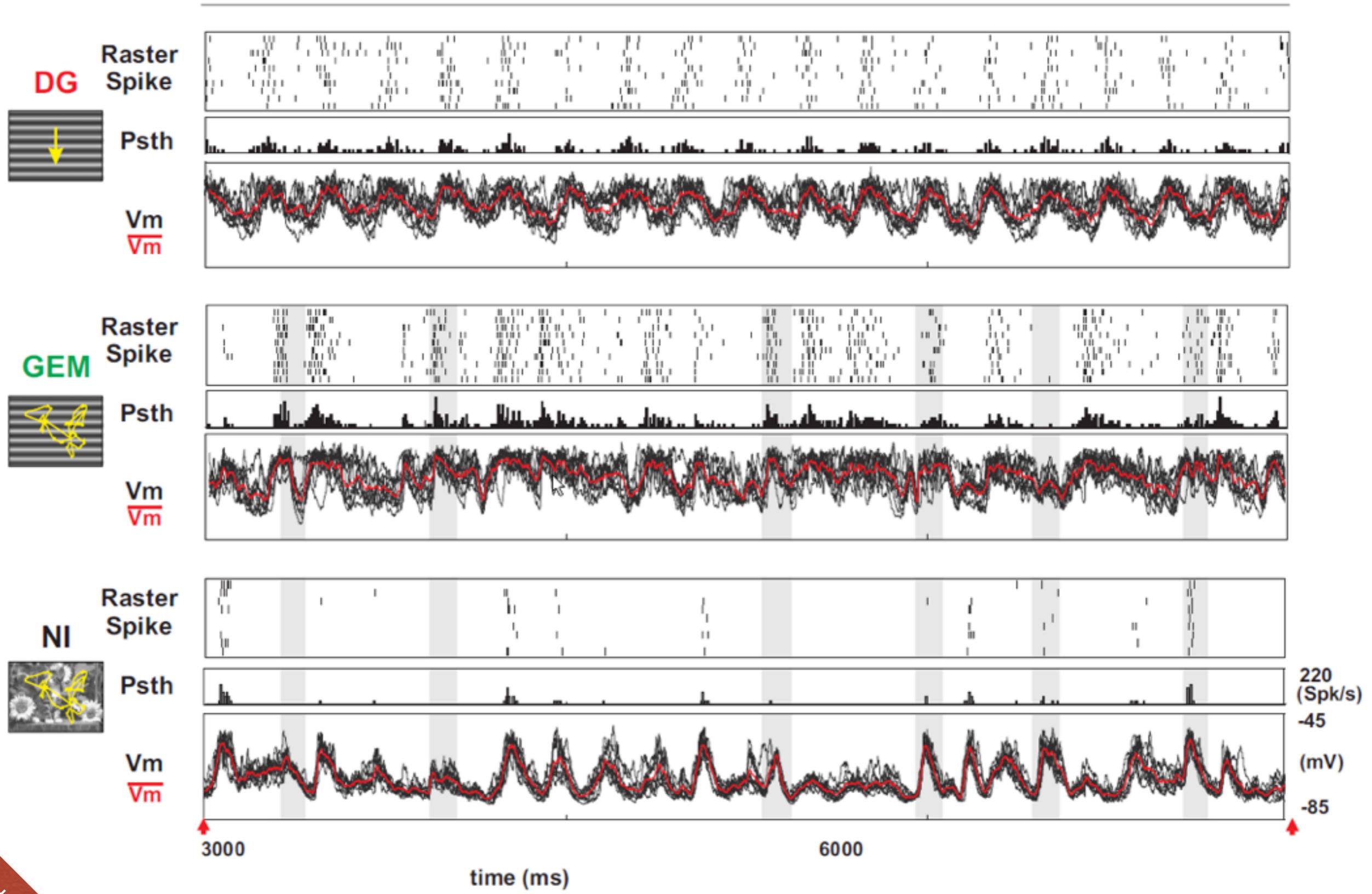


# Model validation: responses to natural stimuli

A

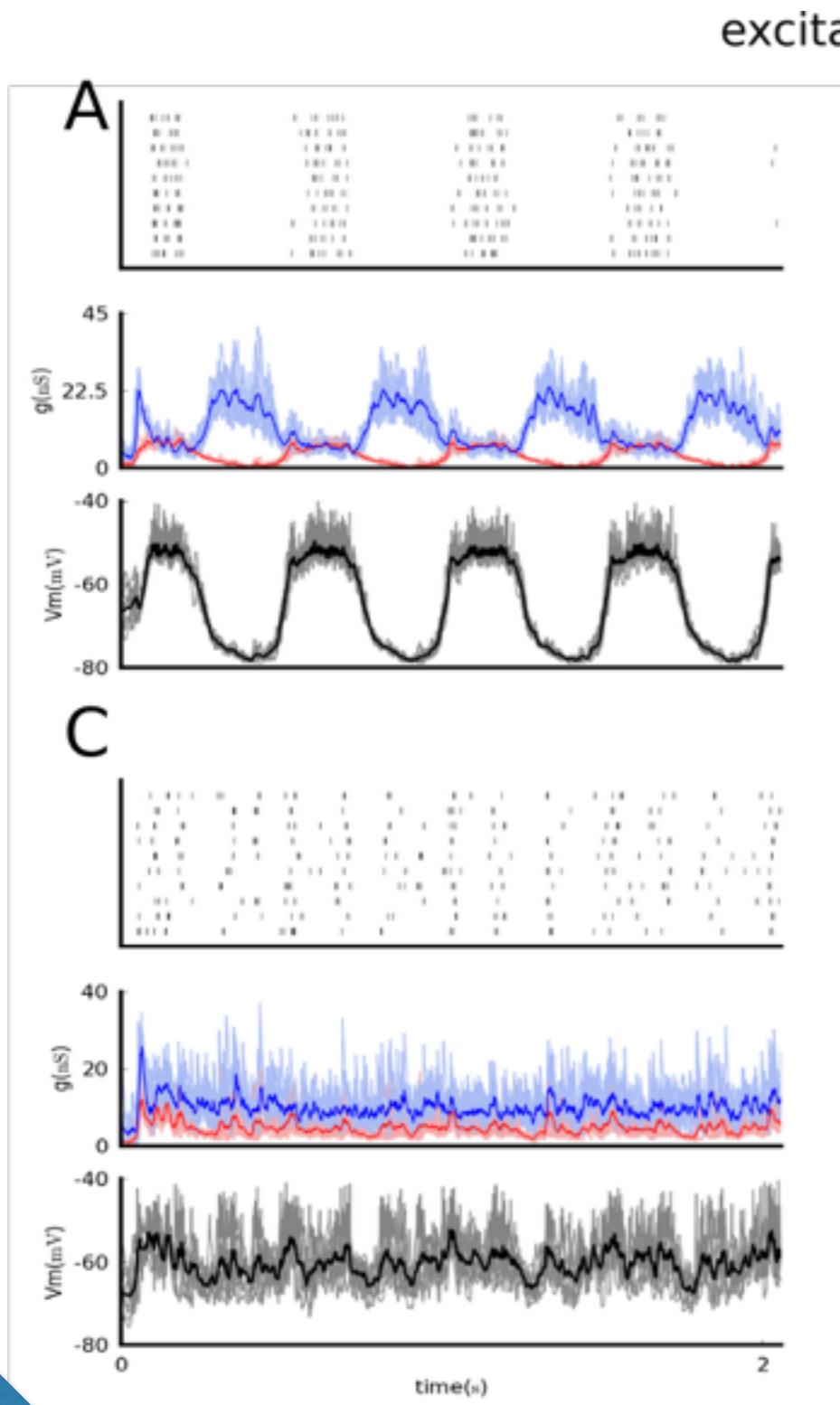


# Model validation: responses to natural stimuli

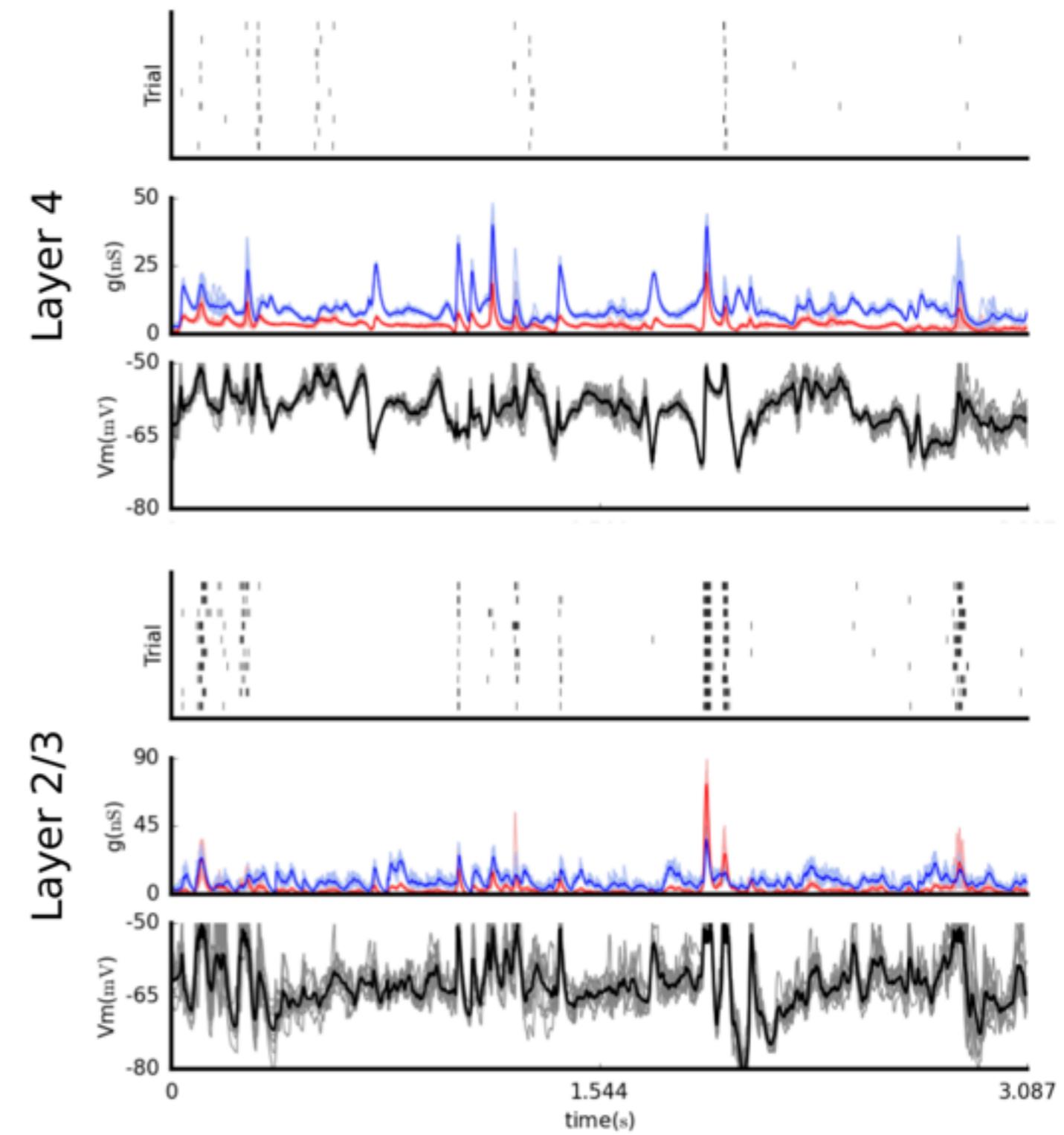


# Model validation: responses to natural stimuli

layer 4



Model



|   |  |
|---|--|
| <b>Anatomical properties</b>              | <p>Two types of neurons exc/inh<br/>LGN, layer 4C and layer 2/3</p> <p>Layer 4C neurons have small number of thalamic inputs<br/>Layer 4C cells have Gabor-like RFs</p> <p>Push-pull connectivity among layer 4C neurons<br/>Functionally specific connectivity in layer 2/3</p> <p>Realistic distance dependent connectivity<br/>Realistic distance dependent delays</p> <p>Feedback from L2/3 to L4C<br/>Thalamic and cortical synaptic depression</p> |
| <b>Mean rate based measures</b>           | <p>Both cortical layers contain matching orientation preference maps<br/>Layer 4C has randomly distributed phase preference</p> <p>Bias towards simple cells in L4C and complex cells in L2/3<br/>Realistic orientation tuning (width, maximum rates etc.)</p> <p>Contrast invariant orientation tuning<br/>Dependence of orientation tuning sharpness on map location</p> <p>Size tuning properties<br/>Orientation-contrast properties</p>             |
| <b>Variance based measures</b>            | <p>Self-sustained spontaneous activity<br/>Realistic changes of <math>V_m</math> variance at different orientations and contrasts</p> <p>Realistic variance of <math>V_m</math> and conductance in no stimulus condition<br/>Colored ongoing synaptic activity (rather than a white noise source)</p>  |
| <b>Stimulus dependence of neural code</b> | <p>Realistic conductance regimes in spontaneous and stimulus evoked conditions<br/>Increase in sparsity and precision between gratings and natural stimuli</p> <p>Increase in sparsity between optimal and full-field gratings<br/>Spontaneous cortical waves</p>  |

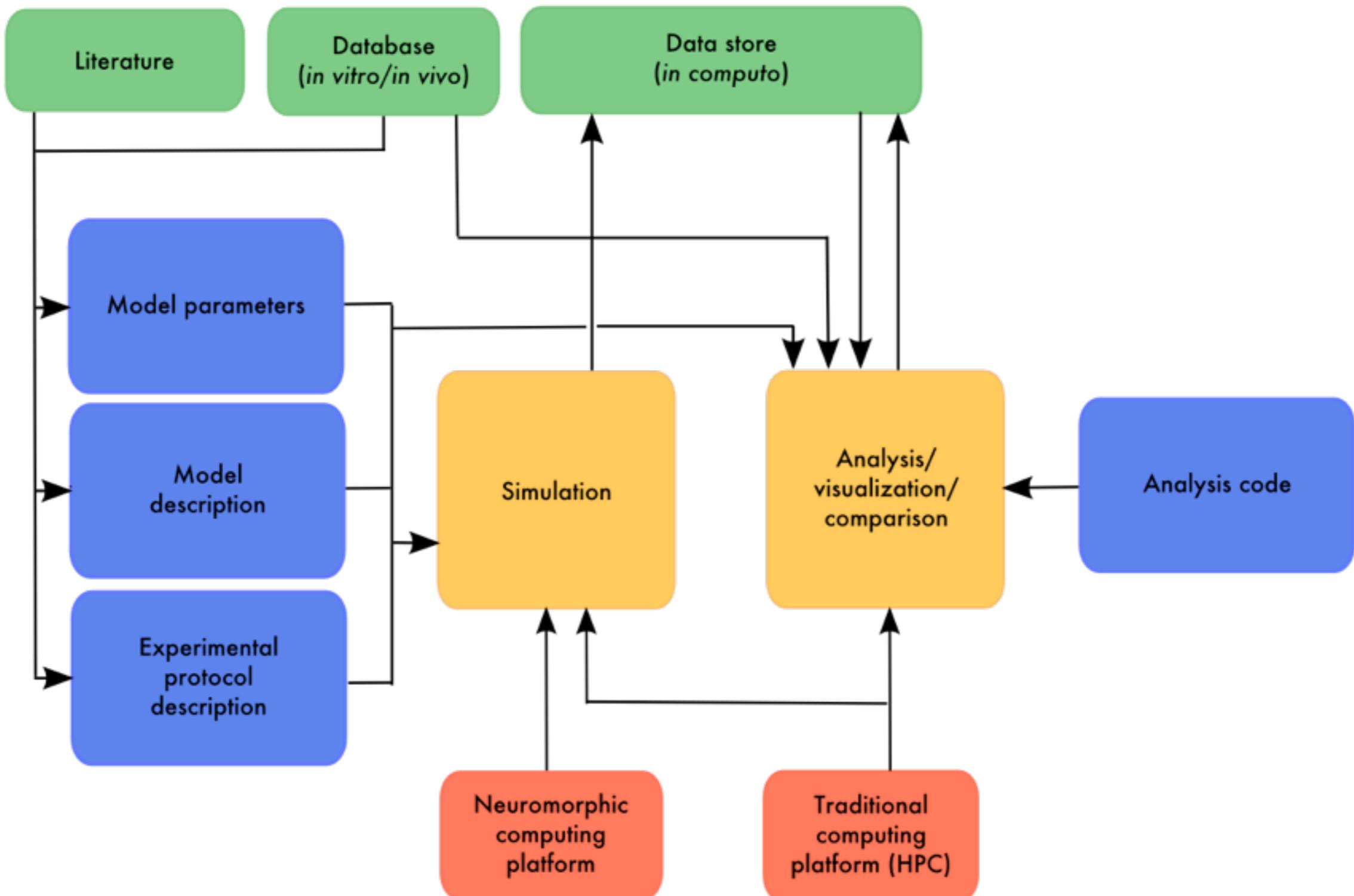
# Approximations and simplifications

- combined retina-LGN model
- no corticothalamic feedback
- only layers 2/3 and 4C
- integrate-and-fire neurons
- only two cell types per layer
- no NMDA receptors
- ...

# Summary

1. The brain is complex, and multiplexes many activities in the same circuit
2. Modelling as a tool for data integration:
  - one model to explain all the data, not one model for each phenomenon

# Model implementation



# Model and experiment description

- Python script using the PyNN API
- PyNN allows same model to be simulated on NEST, NEURON, Brian and the HBP neuromorphic computing systems



```
import pyNN.nest as simulator
import pyNN.neuron as simulator
import pyNN.nmpm1 as simulator
import pyNN.spiNNaker as simulator
```



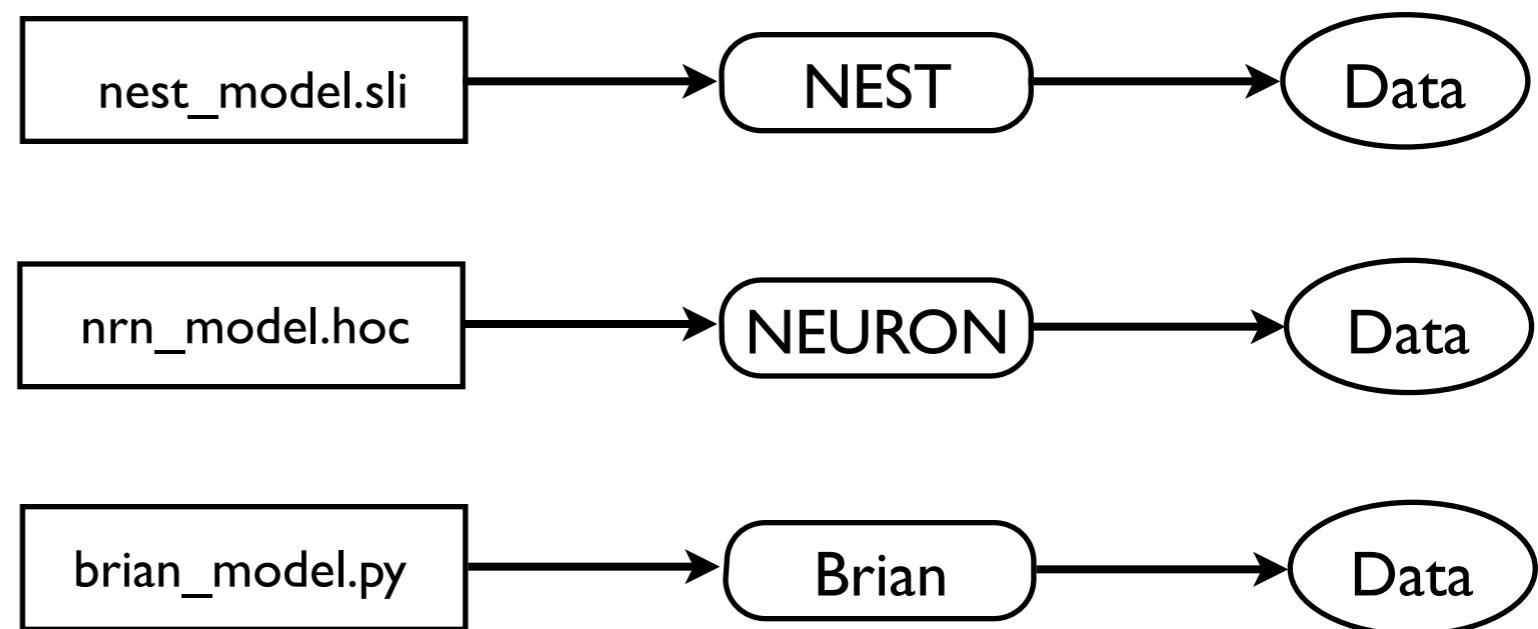
# Verification, cross-checking and model sharing

A single researcher or single lab  
cannot hope to model everything of  
interest.

Need to build on previous work:  
re-use and extend existing models.

But almost all models only run on a  
single simulator, and translation is  
challenging and time consuming.

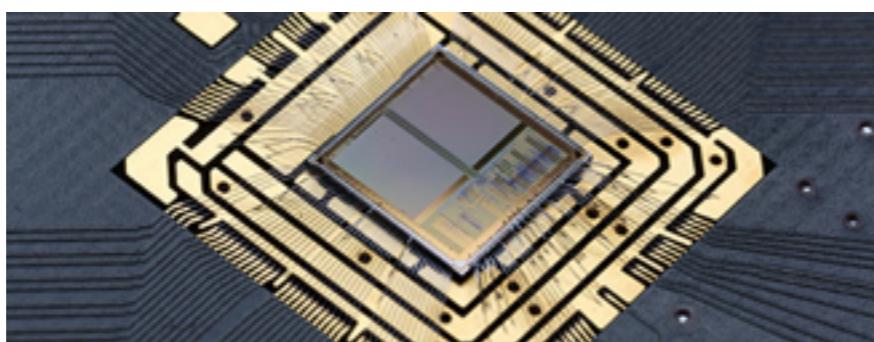
Hence not reusable or testable.



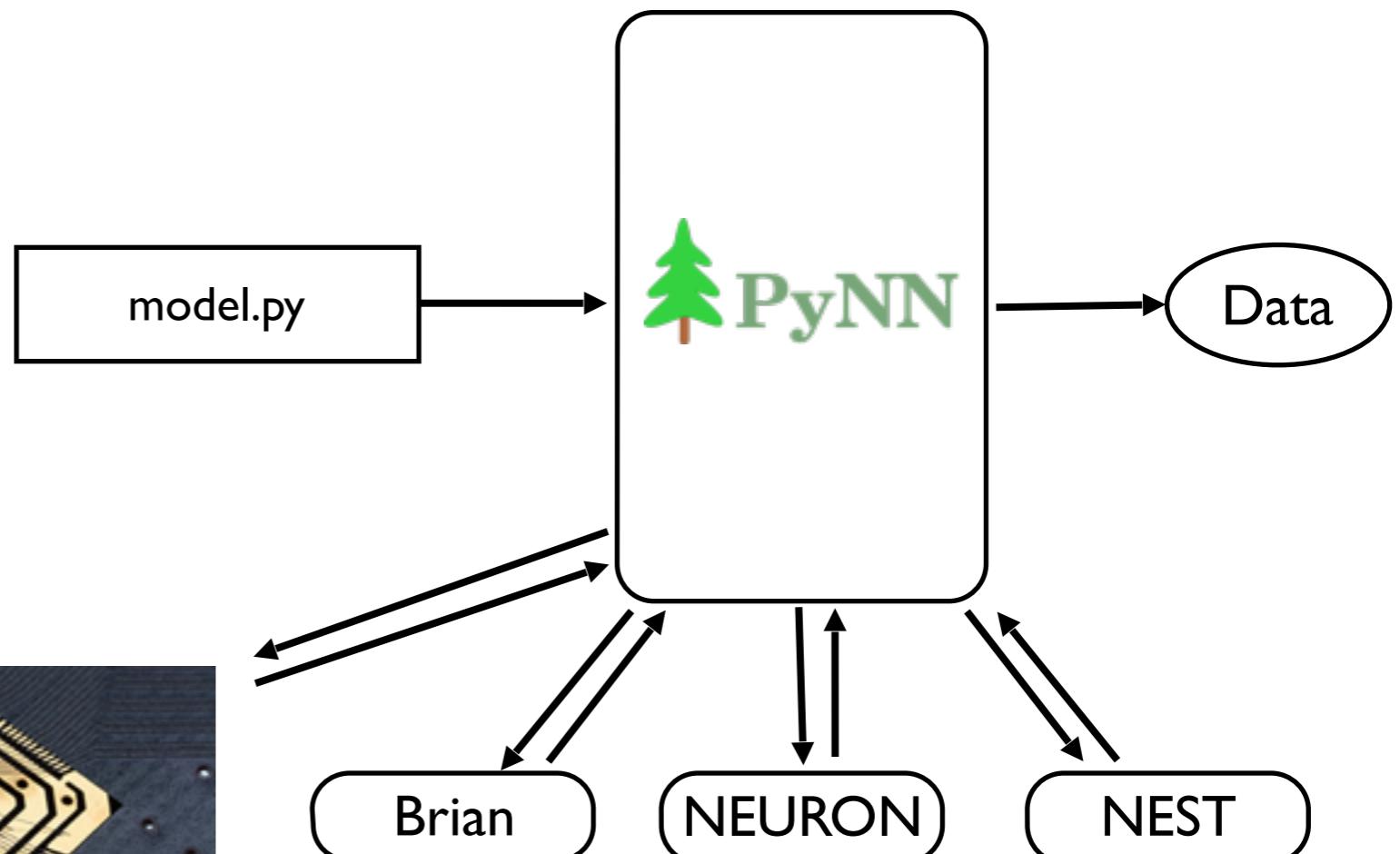
# A common API for neuronal network modelling

## Goals:

- facilitate model sharing and reuse
- simplify validation of simulation results
- provide a common platform on which to build other tools (stimulation, analysis, visualization, GUIs)
- provide a more powerful API for neuronal network modelling (save scientist time)
- hide complexity of parallelization from user (increased computational efficiency without decreased scientist efficiency)



neuromorphic hardware



# Neuron types

```
parameter_space = {
    'tau_m': RandomDistribution('uniform', (10.0, 15.0)),
    'cm': 0.85,
    'v_rest': lambda i: np.cos(i*pi*10/n),
    'v_reset': np.linspace(-75.0, -65.0, num=n) }

cell_type = IF_cond_exp(**parameter_space)
```

# Populations and assemblies

```
structure = RandomStructure(boundary=Sphere(radius=200.0))

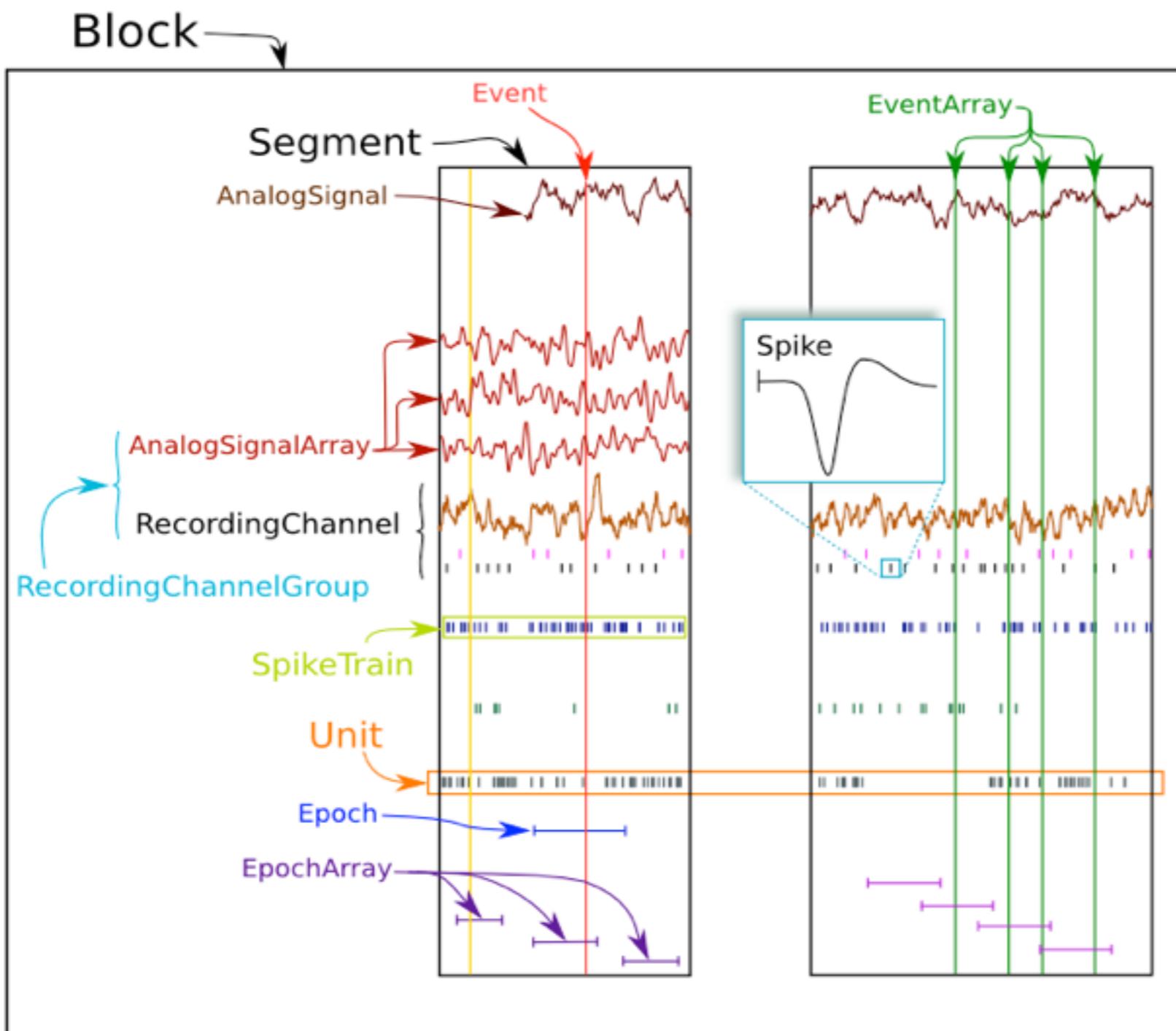
cells = Population(100, thalamocortical_relay_neuron,
                   structure=structure,
                   initial_values={'v': RandomDistribution('uniform', (-75, -55)),
                                   'label': "Thalamocortical neurons")}

view = cells[:80]          # the first eighty neurons
view = cells[::2]           # every second neuron
view = cells[45, 91, 7]     # a specific set of neurons
view = cells.sample(50)      # 50 neurons at random

...
layer4 = spiny_stellates + 14_interneurons # an Assembly
```

# Connectivity

# Data handling



neo

# V1 model on neuromorphic hardware

- preliminary work to adapt model to Heidelberg hardware
  1. simplified version - single column, Layer 4 only, 4000 neurons, additional background noise
  2. adapt parameters to be within ranges compatible with the hardware, run on NEST simulator

# Adapt parameters to be within ranges compatible with the hardware

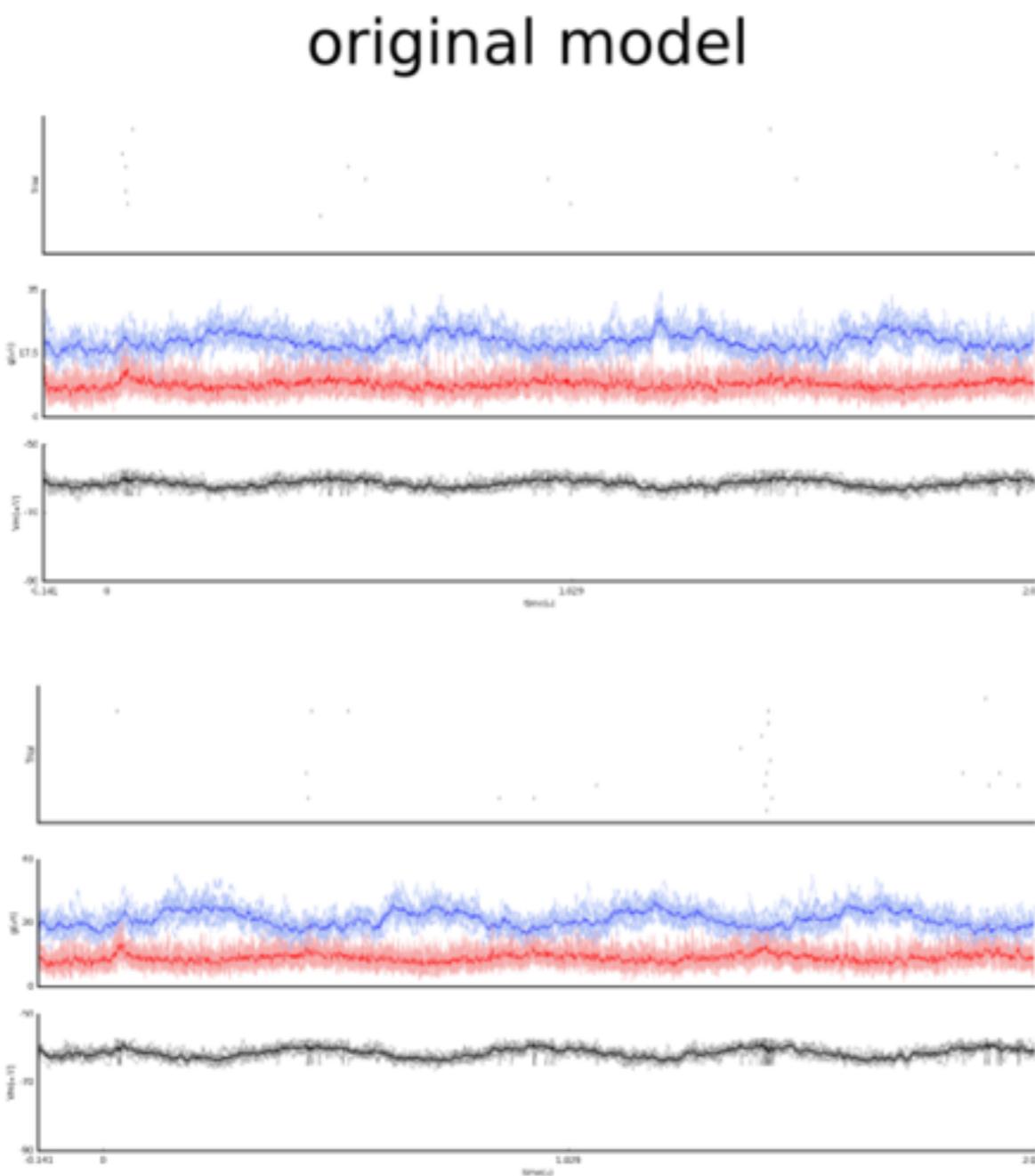
## 1. Excitatory neurons

- (a) spike threshold: -57 mV to -50 mV.
- (b) post-spike voltage reset: -65 to -70 mV.
- (c) membrane capacitance: 0.29 to 0.2 nF.
- (d) time-constant of excitatory synapses: 1.5 to 2.5 ms.
- (e) excitatory background synaptic input: 3000 to 1500 Hz.
- (f) inhibitory background synaptic input: 2000 to 1500 Hz.
- (g) thalamo-cortical synapses: 1nS to 2nS

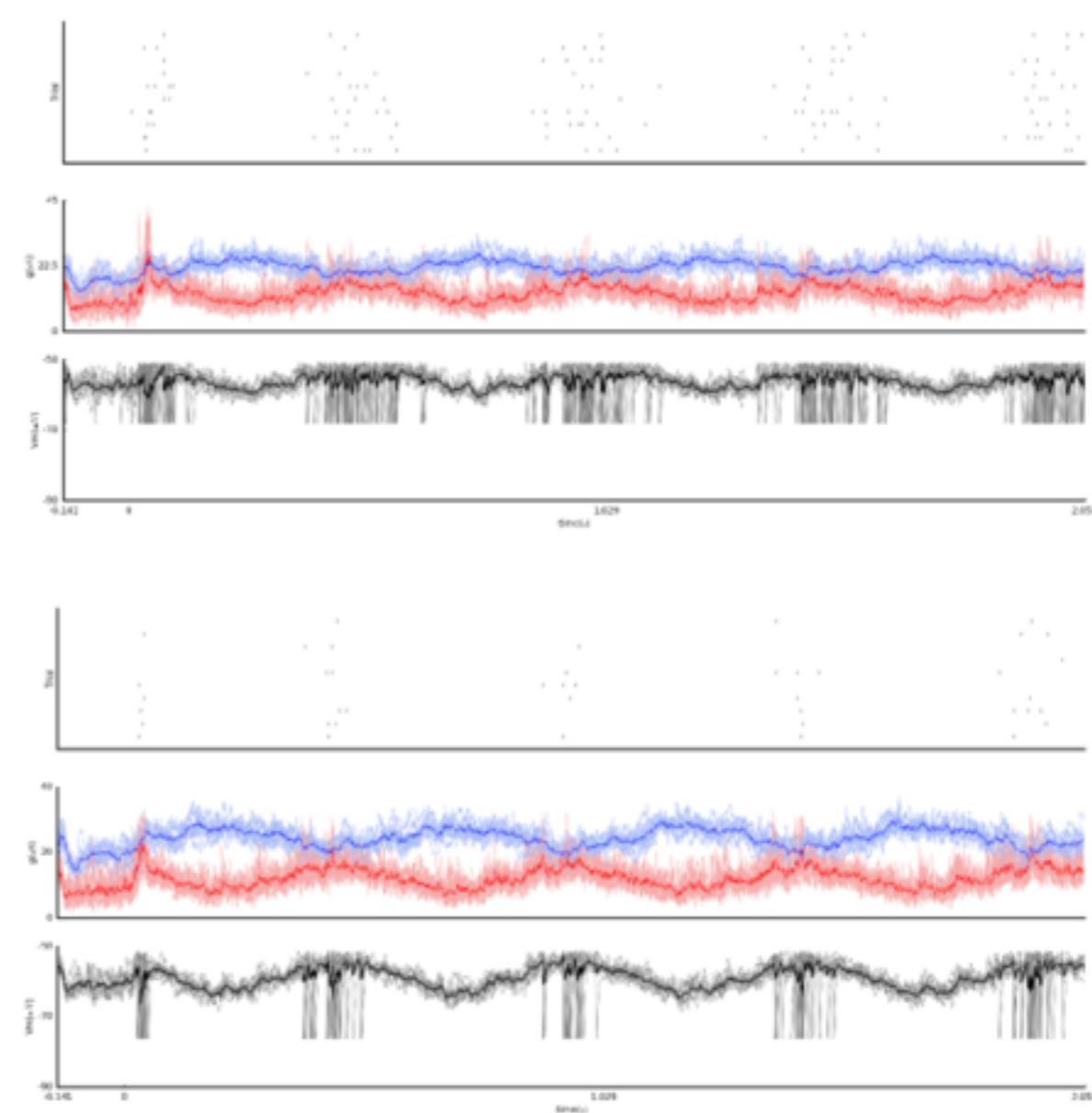
## 2. Inhibitory neurons

- (a) spike threshold: -57 mV to -50 mV.
- (b) post-spike voltage reset: -65 to -70 mV.
- (c) membrane capacitance: 0.141 to 0.2 nF.
- (d) membrane time-constant: 7.5 to 6.4 nF.
- (e) time-constant of excitatory synapses: 1.5 to 2.5 ms.
- (f) excitatory background synaptic input: 2000 to 1500 Hz.
- (g) inhibitory background synaptic input: 2000 to 1500 Hz.
- (h) thalamo-cortical synapses: 2nS to 10nS

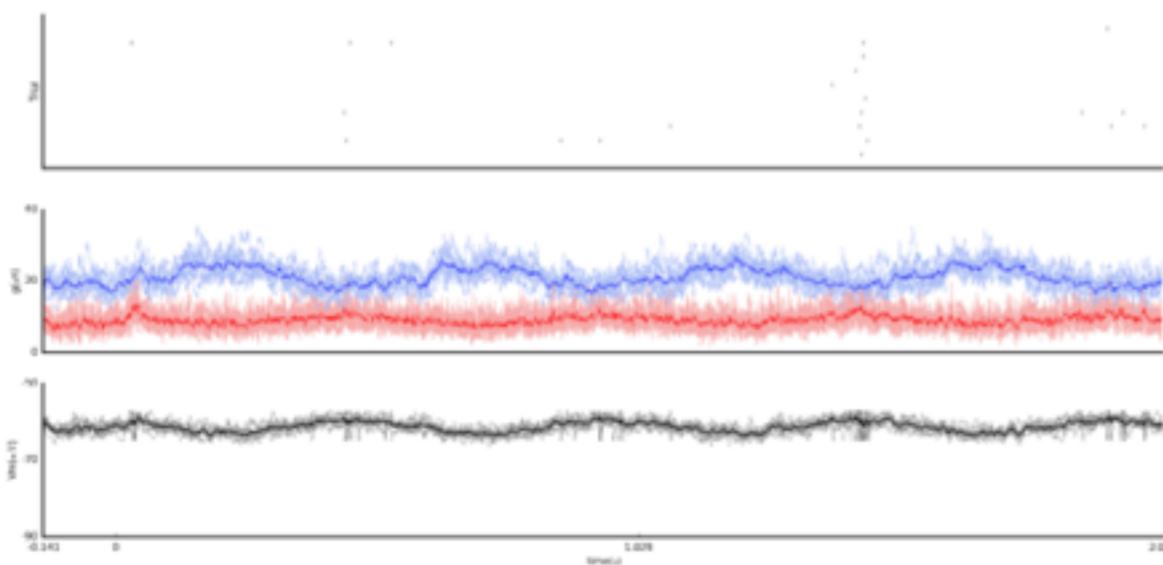
# original model



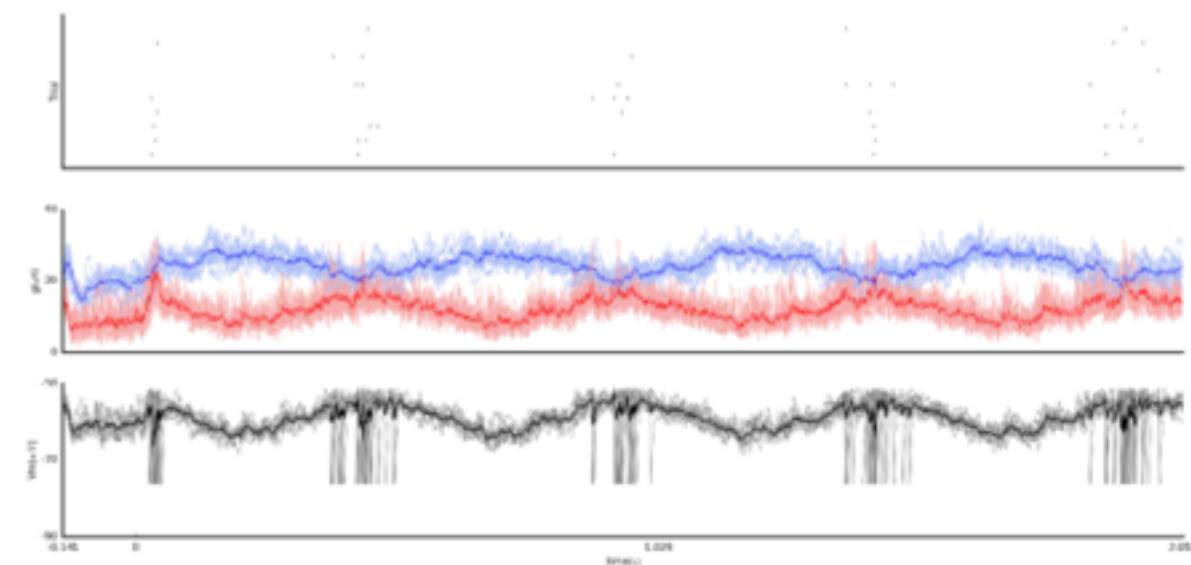
# hardware parametrization



# original model

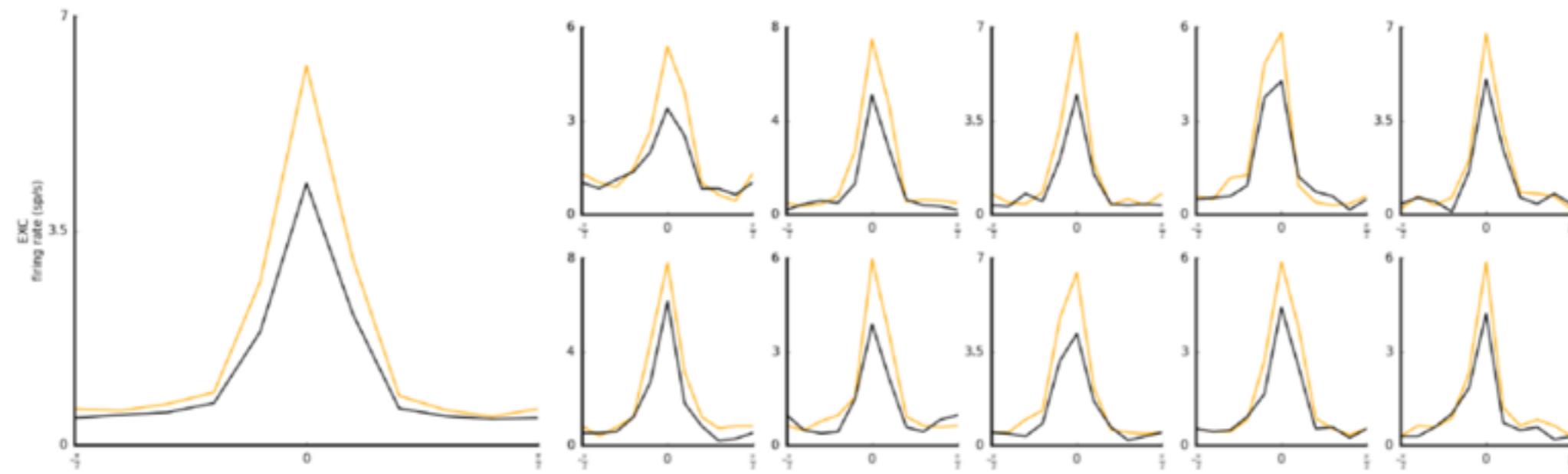


# hardware parametrization

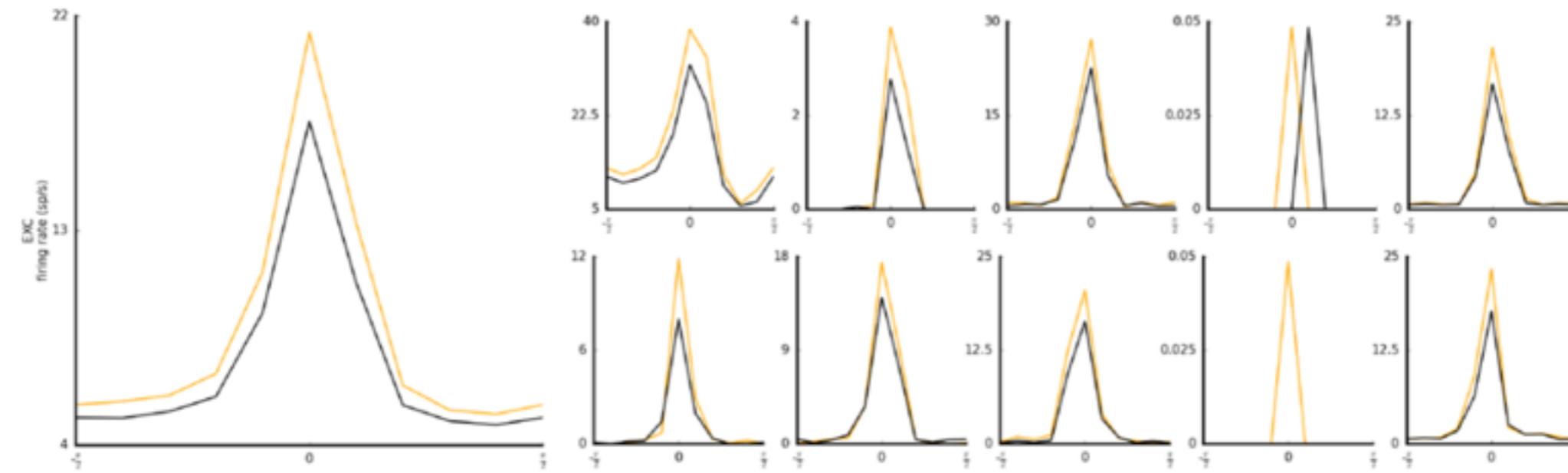


■ 100% contrast  
■ 30% contrast

## Original model



## Hardware parameters



# V1 model on neuromorphic hardware

- Adapting model to Heidelberg hardware:
  1. simplified version - single column, Layer 4 only, 4000 neurons, additional background noise
  2. adapt parameters to be within ranges compatible with the hardware, run on NEST simulator
  3. run on hardware simulator (“ESS”)
    - bandwidth limitations due to background noise
    - current strategy - use noise-generating networks on the wafer instead of external Poisson noise
    - full model does not require such high levels of injected noise
  4. run on hardware (not yet attempted)

# Human Brain Project: Neuromorphic Computing Platform

Navigation

- Overview
- Team
- Job Manager**
- Guidebook
- Settings

Workspace

Job Manager

Neuromorphic Computing Platform

| ID    | Status   | Project | URL   | Test | Date                | User     |
|-------|----------|---------|---|------|---------------------|----------|
| 13005 | finished | NM-PM1  | <a href="https://github.com/electronicvisions/hbp_platform_...">https://github.com/electronicvisions/hbp_platform_...</a> | test | 2015-09-22 17:07:51 | emuller  |
| 13006 | finished | ESS     | <a href="https://github.com/electronicvisions/hbp_platform_...">https://github.com/electronicvisions/hbp_platform_...</a> | test | 2015-09-22 17:08:50 | emuller  |
| 13007 | error    | NM-PM1  | <a href="https://www.hbpneuromorphic.eu/app/index.html#/que...">https://www.hbpneuromorphic.eu/app/index.html#/que...</a> | test | 2015-09-22 17:09:00 | emuller  |
| 13008 | finished | NM-PM1  | <a href="https://github.com/electronicvisions/hbp_platform_...">https://github.com/electronicvisions/hbp_platform_...</a> | test | 2015-09-22 17:14:41 | emuller  |
| 13009 | running  | NM-PM1  | <a href="https://github.com/electronicvisions/hbp_platform_...">https://github.com/electronicvisions/hbp_platform_...</a> | test | 2015-09-22 17:15:22 | emuller  |
| 13010 | running  | NM-PM1  | <a href="https://github.com/electronicvisions/hbp_platform_...">https://github.com/electronicvisions/hbp_platform_...</a> | test | 2015-09-22 17:20:40 | emuller  |
| 13011 | finished | NM-PM1  | <a href="https://github.com/electronicvisions/hbp_platform_...">https://github.com/electronicvisions/hbp_platform_...</a> | test | 2015-09-22 17:22:31 | emuller  |
| 13050 | finished | NM-MC1  | import pyNN   | test | 2015-09-24 08:19:01 | adavison |

Collaboration

AR DG EM DL C8 This is the very beginning of the current collab's chat. Start using it to collaborate with your team!

Yesterday

<https://bbpcode.epfl.ch/code/#/admin/projects/platform/JSLibOidcClient>

18:08

this is the JS OIDC library git repo

18:09

Send a message

Activity

Provenance

Public release April 2016



# The HBP Physical Model System (Heidelberg Site)



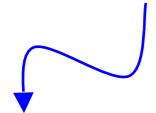
4M Adex Neurons, 1B conductance based synapses  
10000x acceleration beyond real-time



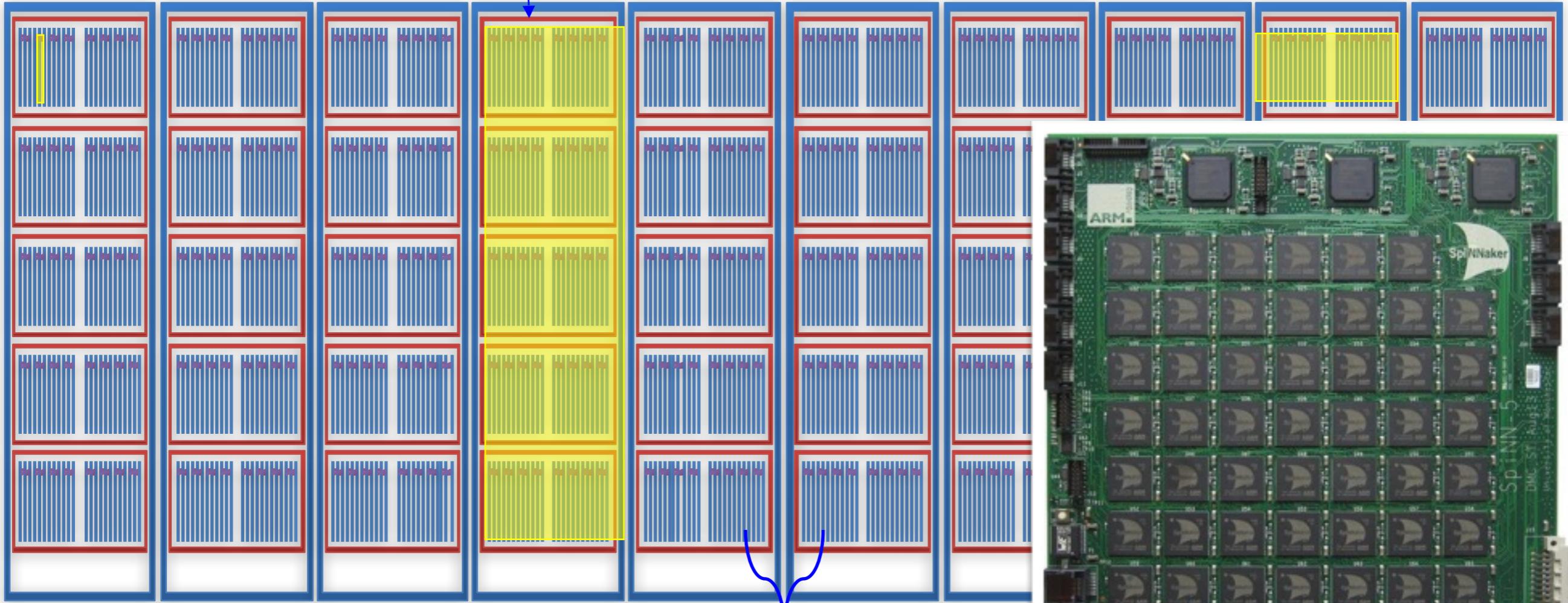


# The HBP Many-Core System (Manchester Site)

103 machine: 864 cores, 1 PCB, 75W



105 machine: 103,680 cores, 1 cabinet, 9kW



104 machine: 10,368 cores, 1 rack, 900W  
(NB 12 PCBs for operation without aircon)



106 machine: 1M cores, 10 cabinets, 90kW

# Submitting a job

## Create Job

Project

Hardware Platform

Description

Hardware Config

Input File

# Python client

## IP[y]: Notebook HBP Neuromorphic Platform demo (autosaved)

File Edit View Insert Cell Kernel Help



```
In [1]: import nmpi
```

```
In [3]: c = nmpi.Client(username="adavison", password="*****")
```

```
In [4]: job_id = c.submit_job(source="https://github.com/electronicvisions/hbp_platf
platform="Spikey",
project="Synfire chain demo")
```

Job submitted

# Acknowledgements

- Yves Frégnac
- Cyril Monier
- Ján Antolík
- Domenico Guarino



FACETS



Human Brain Project

