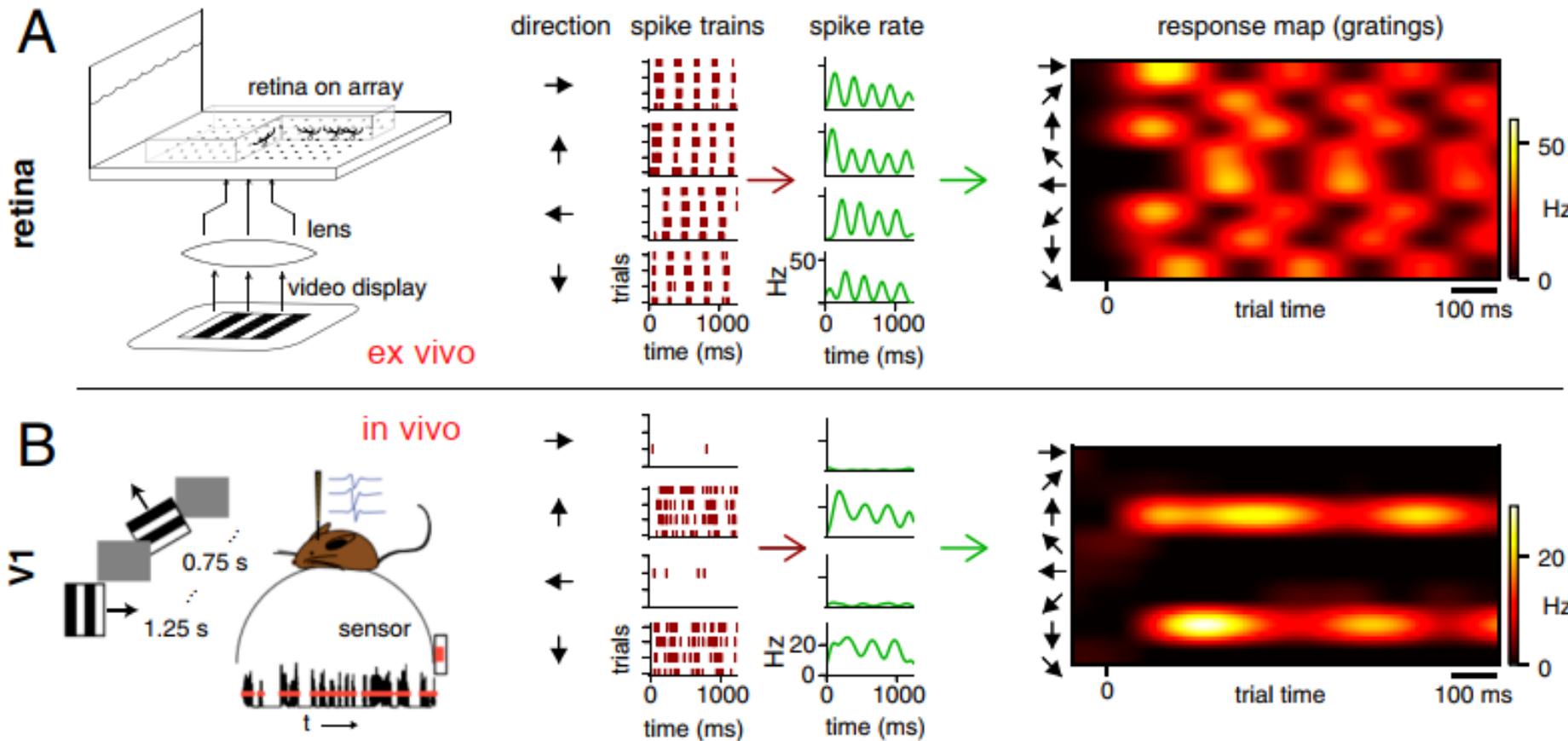


Embedding Analysis of Neuron/Bouton Responses under Various Stimuli in dLGN

Huimiao Chen
Sep 5, 2025

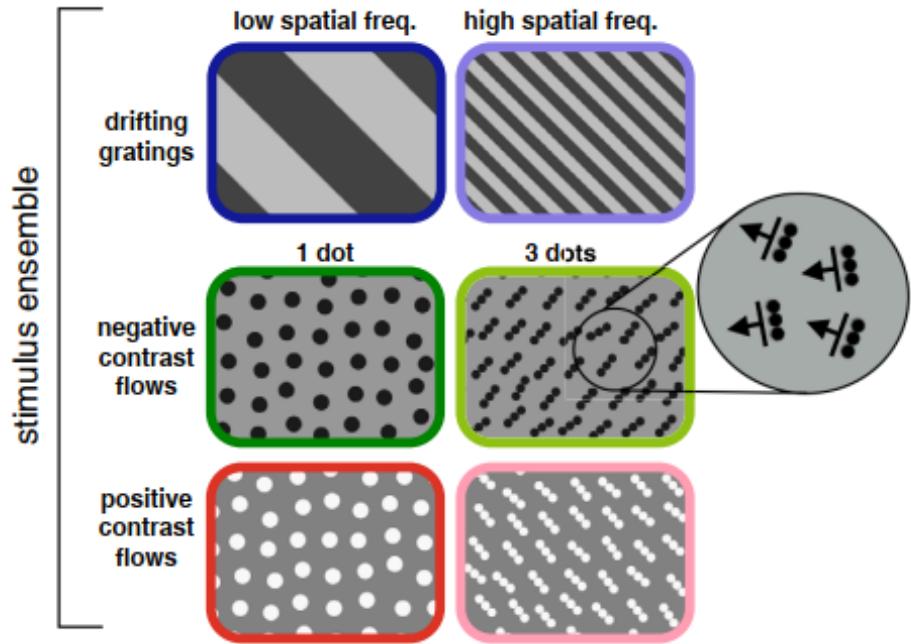
Background

Retinal and cortical population encodings differ



- Multi-electrode array (MEA) recordings
- Retina (*ex vivo*) and V1 (*in vivo*)
- Data: spike trains → firing rates → response maps

Retinal and cortical population encodings differ

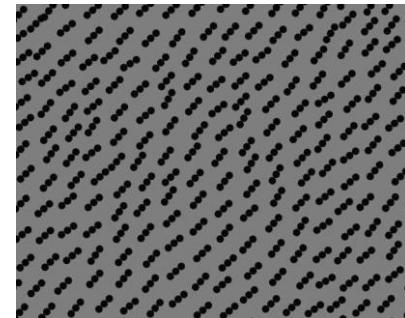


Stimuli and Data

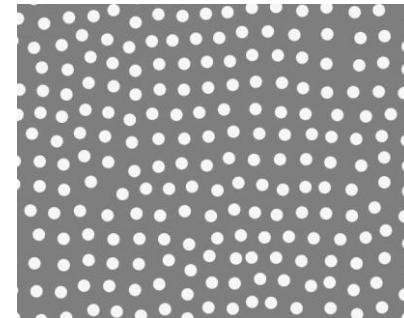
dir: 0, 45, 90, 135, 180, 225, 270

Low Freq Gratings
High Freq Gratings
Neg 1-dot Flows
Neg 3-dot Flows
Pos 1-dot Flows
Pos 3-dot Flows

In total, $6 * 8 = 48$ stimuli



neg_3flows_315

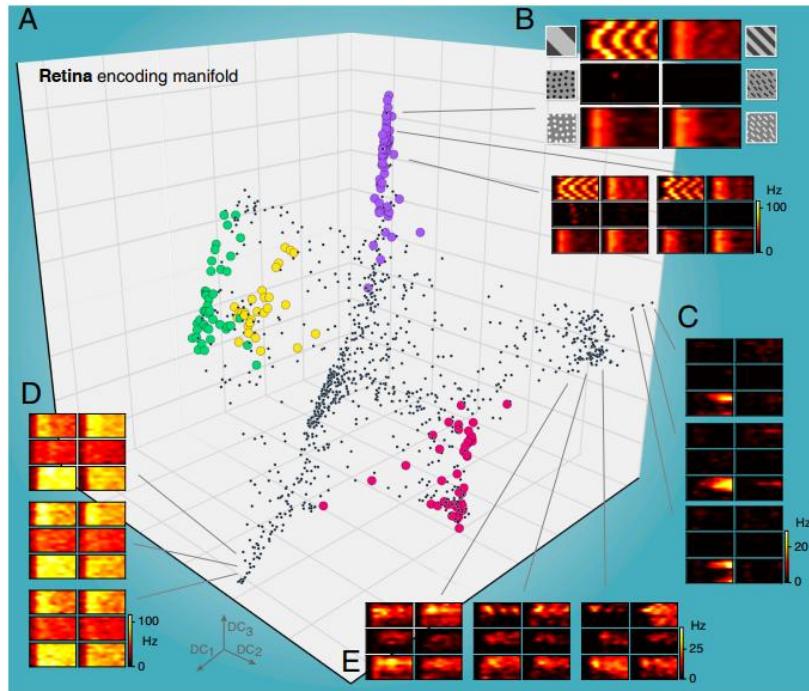


pos_1flows_225



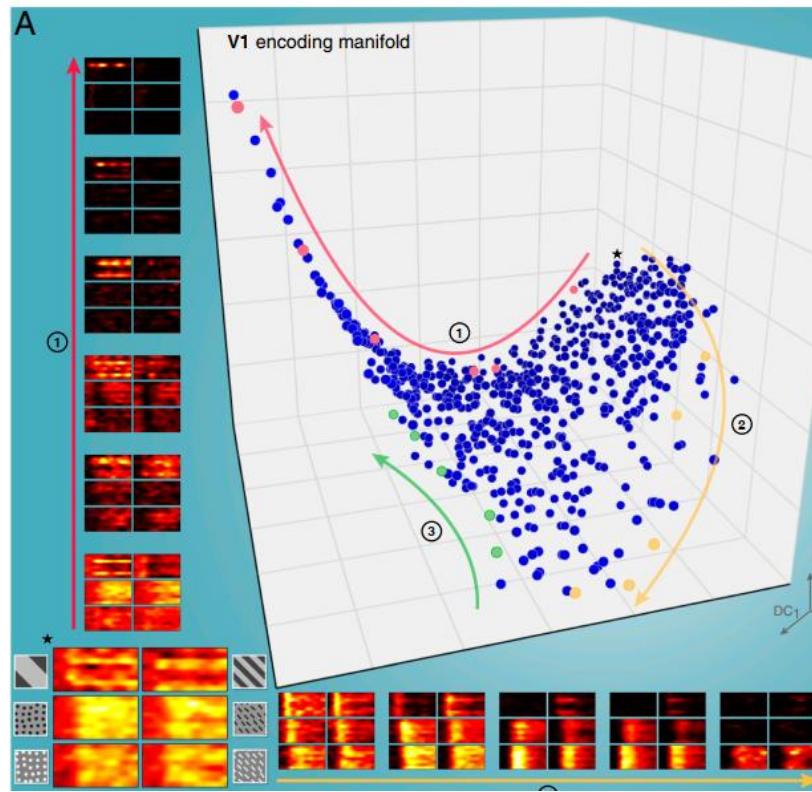
gratings_lf_45

Retina: Discrete clusters; V1: Continuous encoding

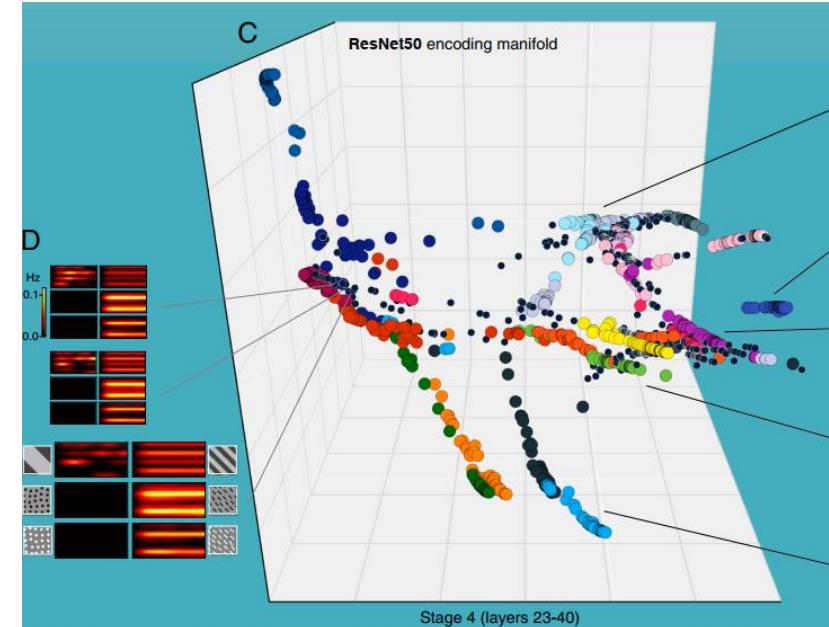


Retinal neurons' encoding manifold showing **discrete clusters**: each cluster corresponding to a specific functional type.

V1 neurons' encoding manifold showing a **continuous distribution**: feature selectivity and response dynamics varying smoothly across the manifold.

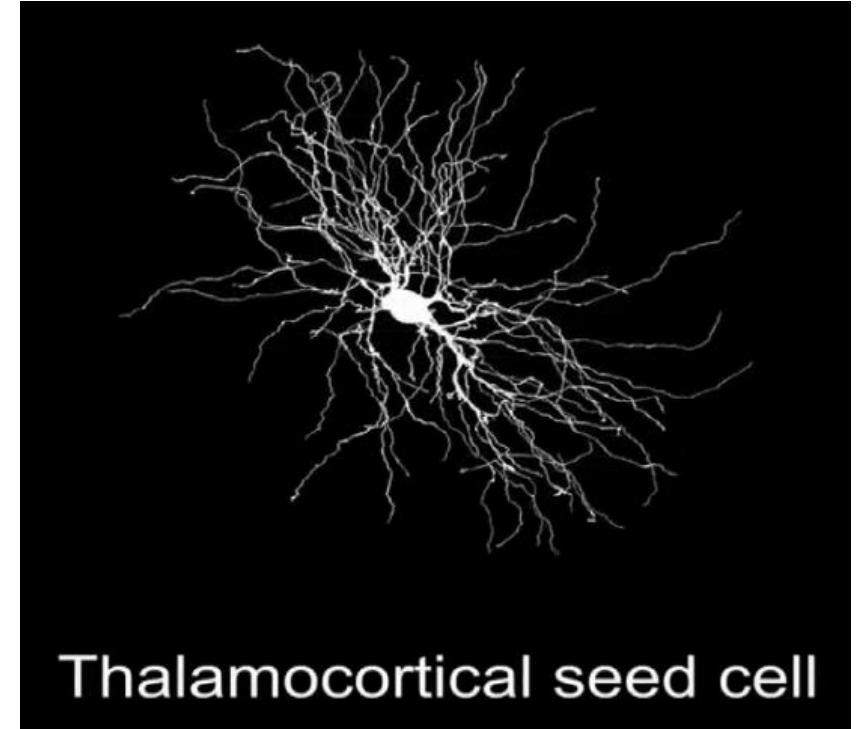
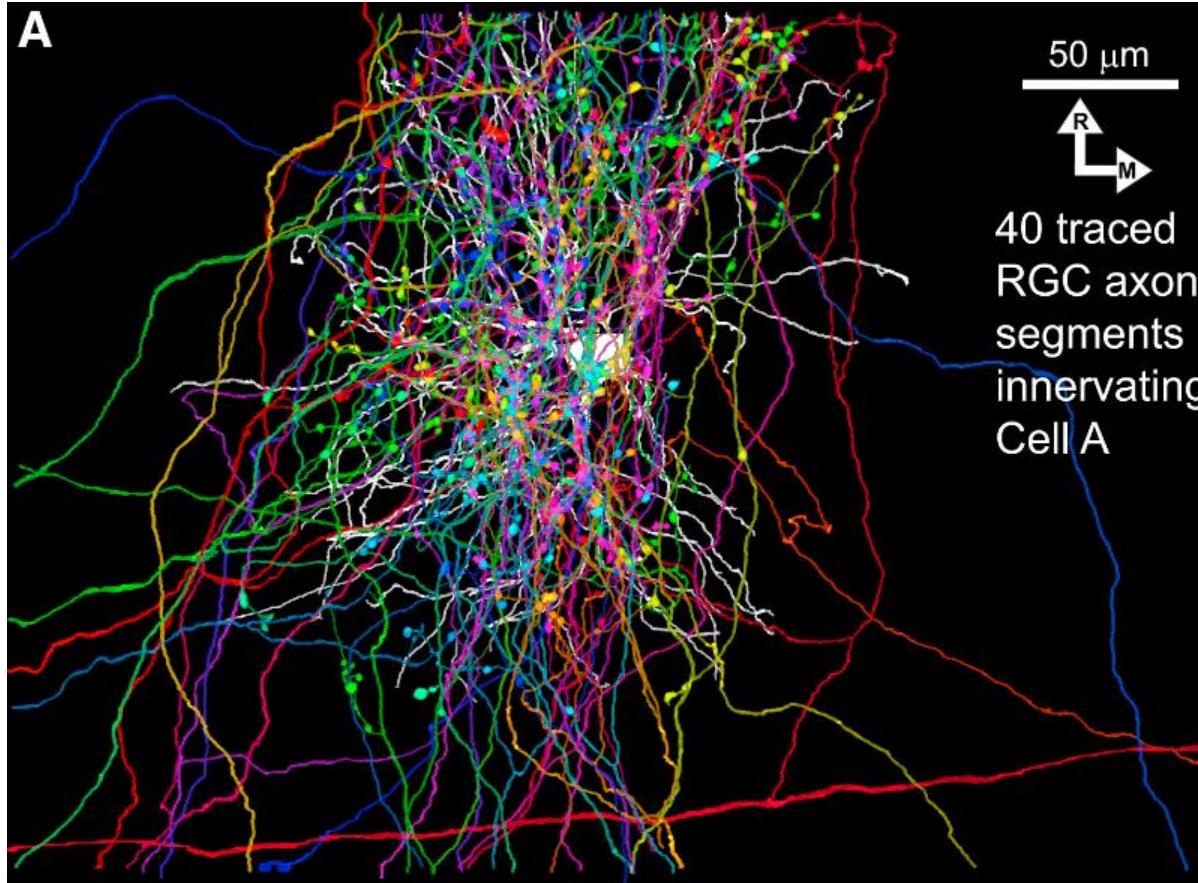


The encoding manifold was constructed using non-negative tensor factorization (NMF) and diffusion maps, showing how neurons are organized in stimulus–response space.



ResNet50 (CNN) network's encoding manifold showing **strong clustering**: more discrete than the retina, and unlike V1.

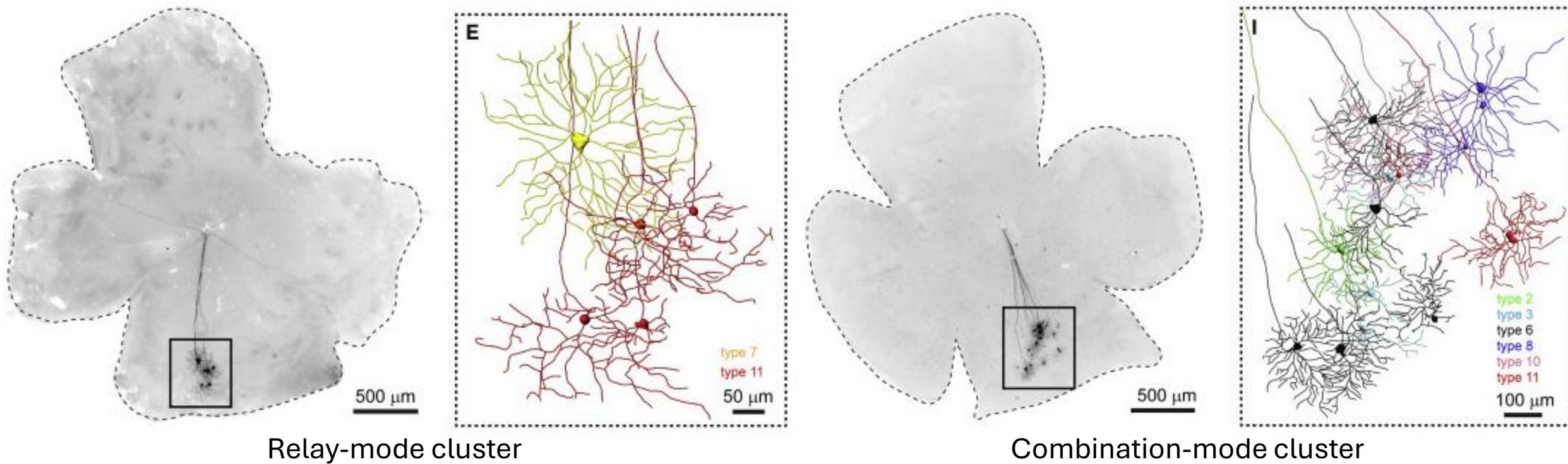
Tens of RGCs can converge to a single dLGN neuron



A single dLGN neuron (white) receives input from ~40 RGC axon segments (different colors).

Retrograde tracing shows inputs from multiple morphologically distinct RGC types.

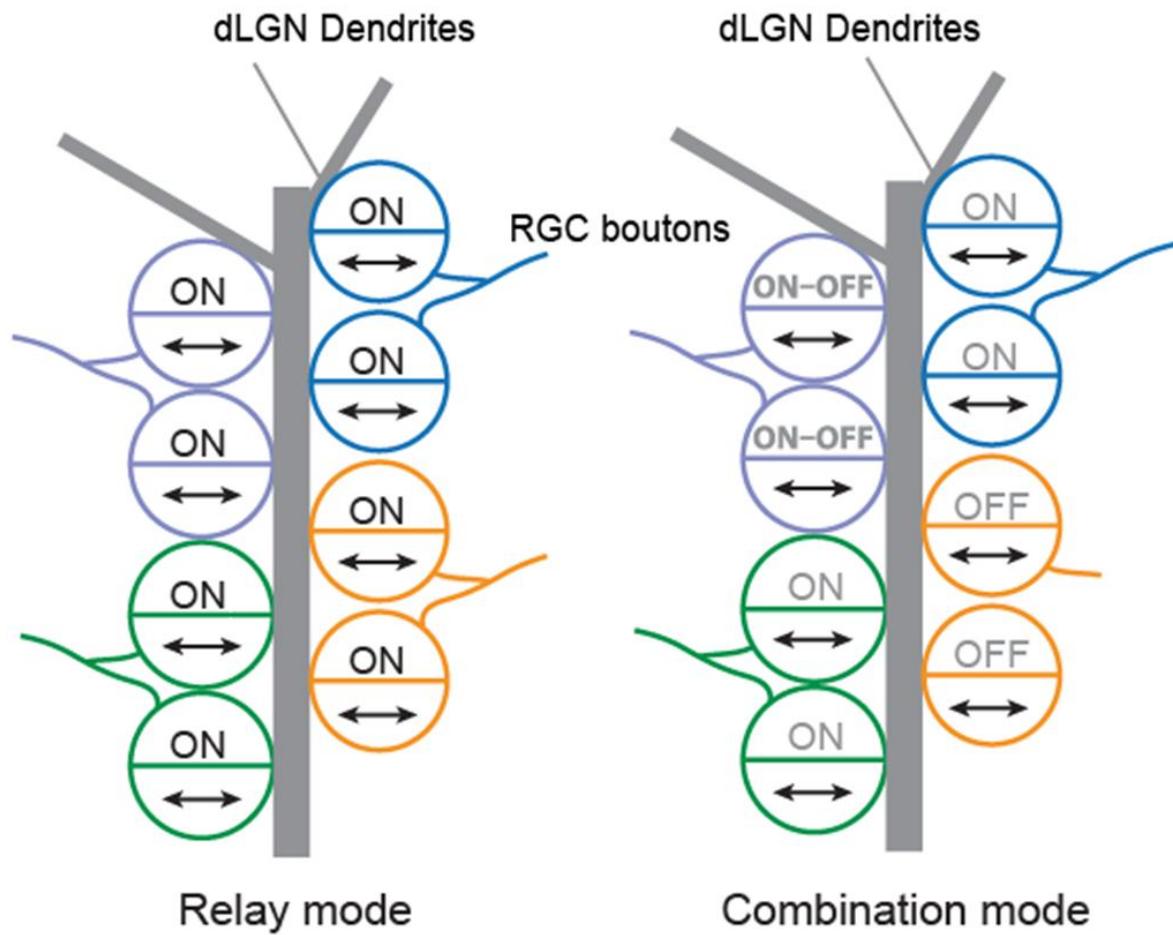
dLGN cells integrate retinal inputs in relay and combination mode



In addition to labeled-line connections (single RGC type), combination-mode connections (multiple RGC types) were observed.

More monocular LGN cells (8/15) received inputs from 2–6 different RGC types.

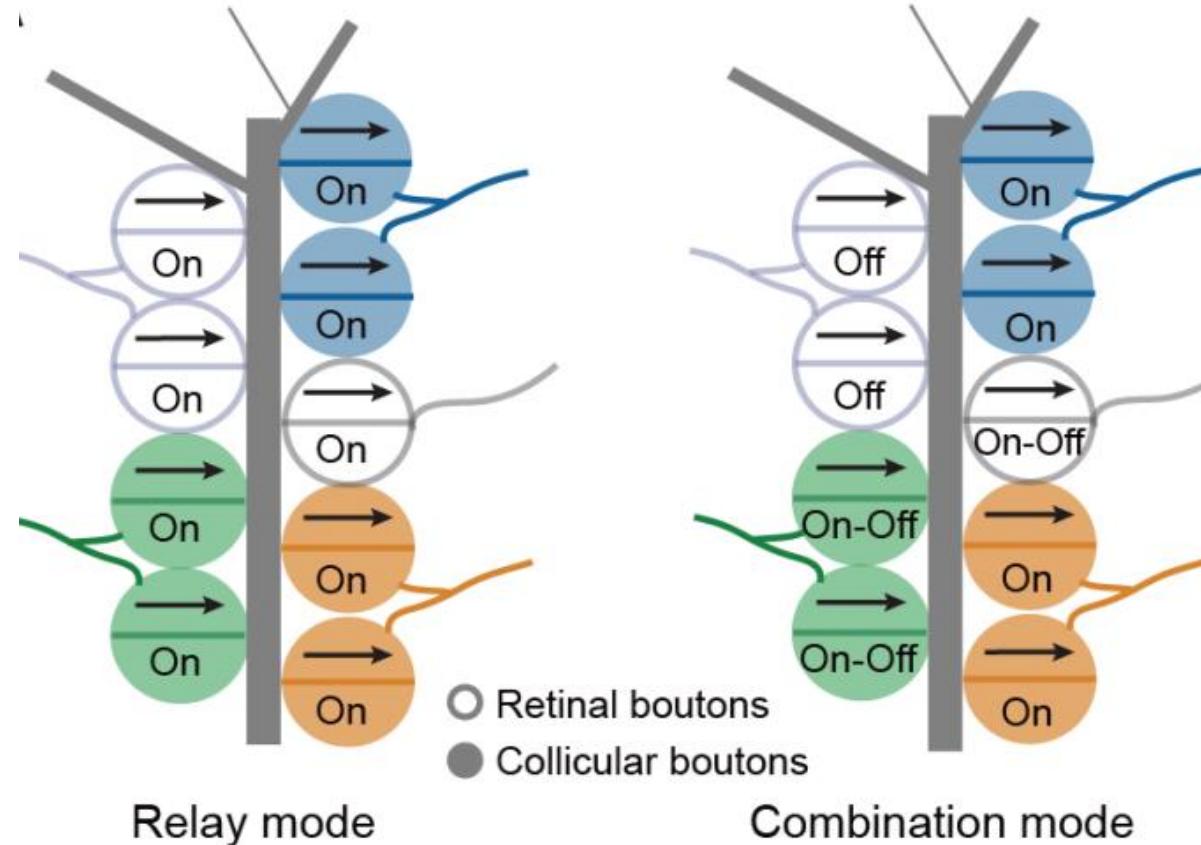
Nearby RGC boutons share one or several similar visual feature preference



Visual responses of RGC boutons in dLGN show local clustering by feature preference.

Nearby boutons tend to prefer similar visual features, beyond coarse retinotopy.

Relay- and Combination-mode Convergence of Nearby Retinal and Collicular Boutons

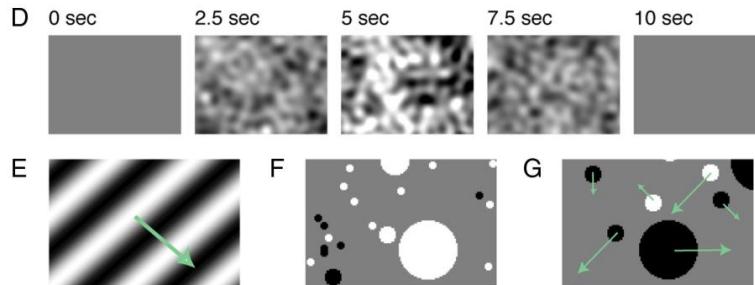


Relay mode: nearby boutons share preferences for a single feature

Combination mode: nearby boutons exhibit similar preferences for multiple features

between retinal and collicular boutons.

Functional Diversity of dLGN Neurons



Four stimulus sets used.

D, Contrast modulated band-limited noise.

E, Drifting sinusoidal gratings.

F, Flashing spots.

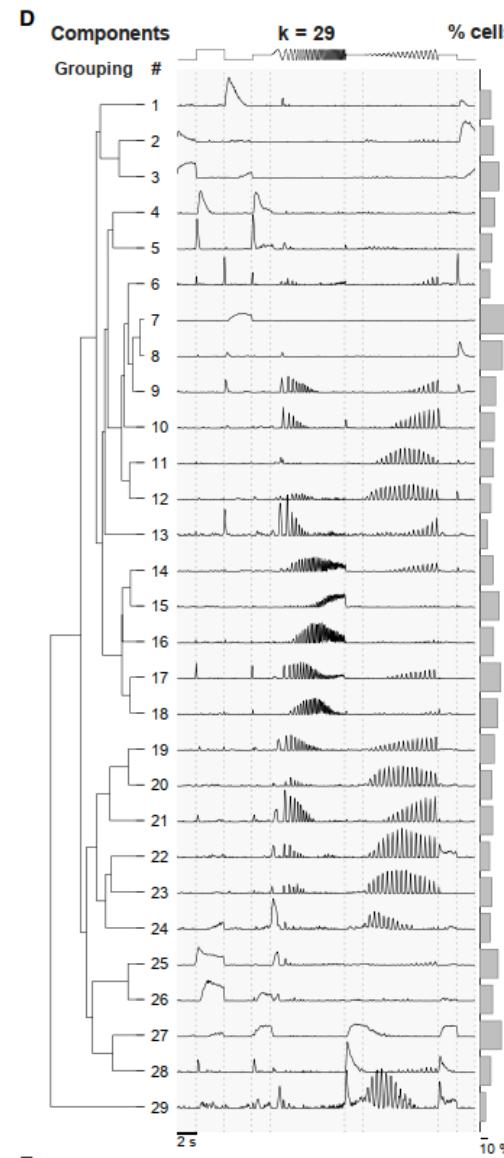
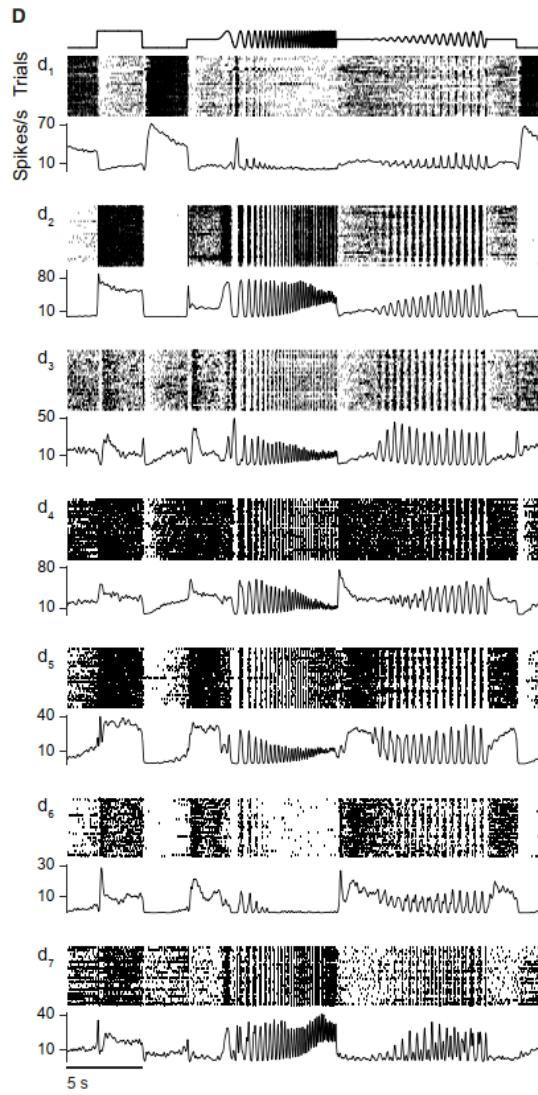
G, Moving spots.

Unsupervised clustering (k-means) based on responses to flashes, drifting gratings, and noise movies.

7 Discrete Cell Types Identified:

Cluster	Abbreviation	Key response property	n (cells)	% of total
Sustained ON	sON	Persistent response to light onset	64	25%
Sustained OFF	sOFF	Persistent response to light offset	28	11%
Transient OFF	tOFF	Brief response to light offset	42	16%
Direction/Orientation selective	DS/OS	Selectivity for motion direction or orientation	28	11%
Suppressed-by-contrast	–	Reduced firing to most stimuli (contrast suppression)	14	5%
Slow / W-like	–	Longer latency, respond to slow stimuli	38	15%
Non-responsive	–	Did not respond enough for clustering (not part of 6 main groups)	~18%	–

Limited Convergence, Rich Responses in dLGN



Full-field chirp stimulus
(step, frequency sweep, contrast sweep)

Each dLGN neuron typically integrates signals **from about 5 types, with 2 having dominant influence.**

Despite this limited convergence, the dLGN shows rich response diversity, suggesting both feature-specific input selection and functional integration.

Non-negative matrix factorization (NMF) was used to reveal around 29 distinct response components .

Hypothesis on dLGN Cell Type Organization

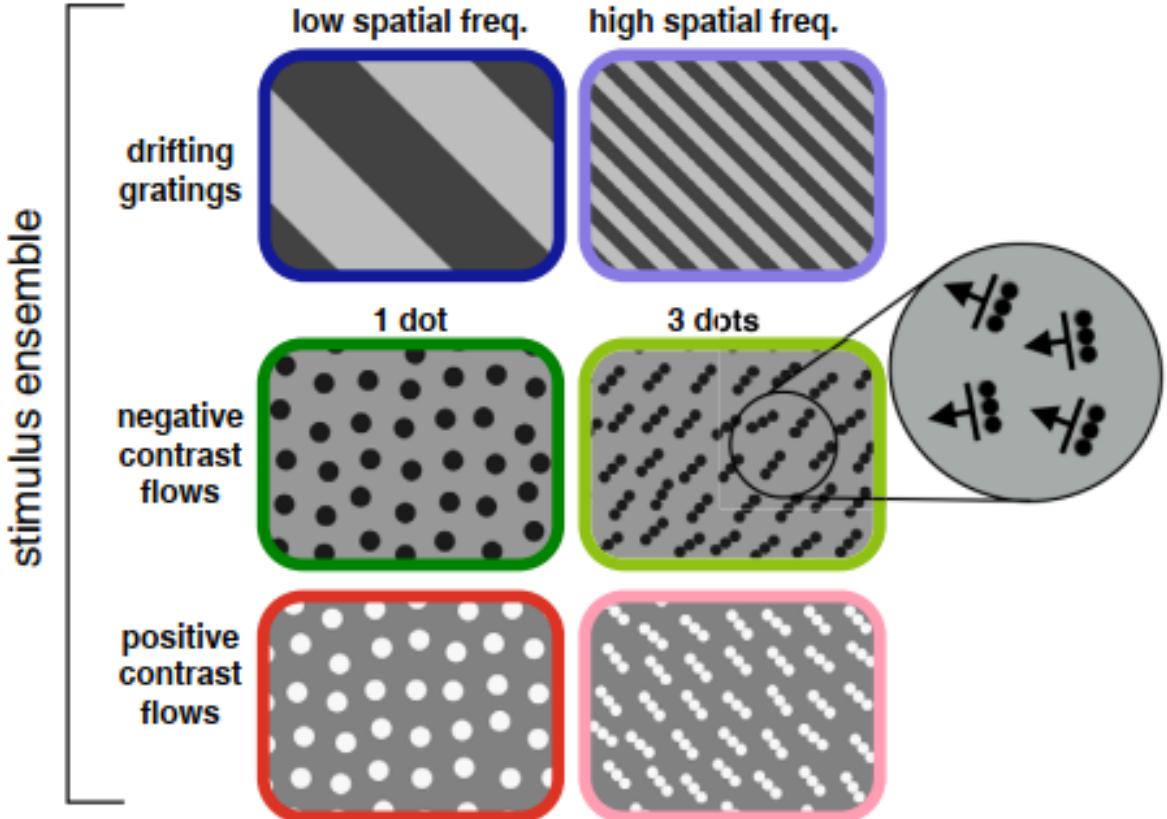
We hypothesize that dLGN neurons are not as discretely organized into cell types as RGCs.

Instead, dLGN may exhibit a more continuous distribution of response properties, resembling an intermediate stage between the discrete organization in the retina and the continuous representations in V1.

Also, we want to compare the analysis of dLGN and RGC to study how to model the dLGN cells based on RGC bouton responses, which may also provide insights on the labeled-line connections and combination-mode connections.

Our Results

Motion Stimuli



dir: 0, 45, 90, 135, 180, 225, 270

Low Freq Gratings

High Freq Gratings

Neg 1-dot Flows

Neg 3-dot Flows

Pos 1-dot Flows

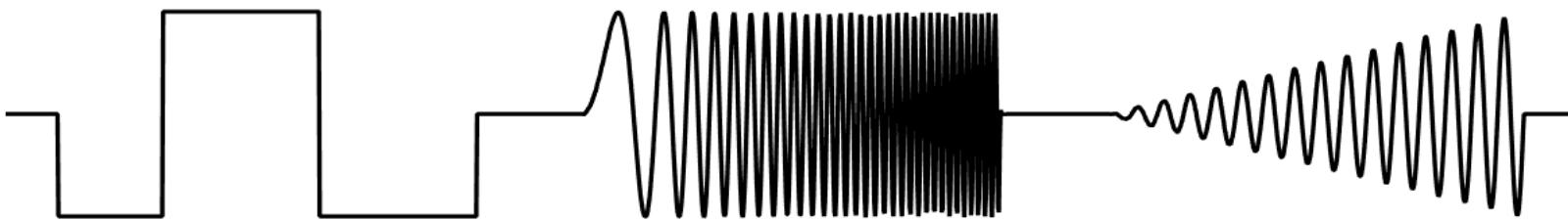
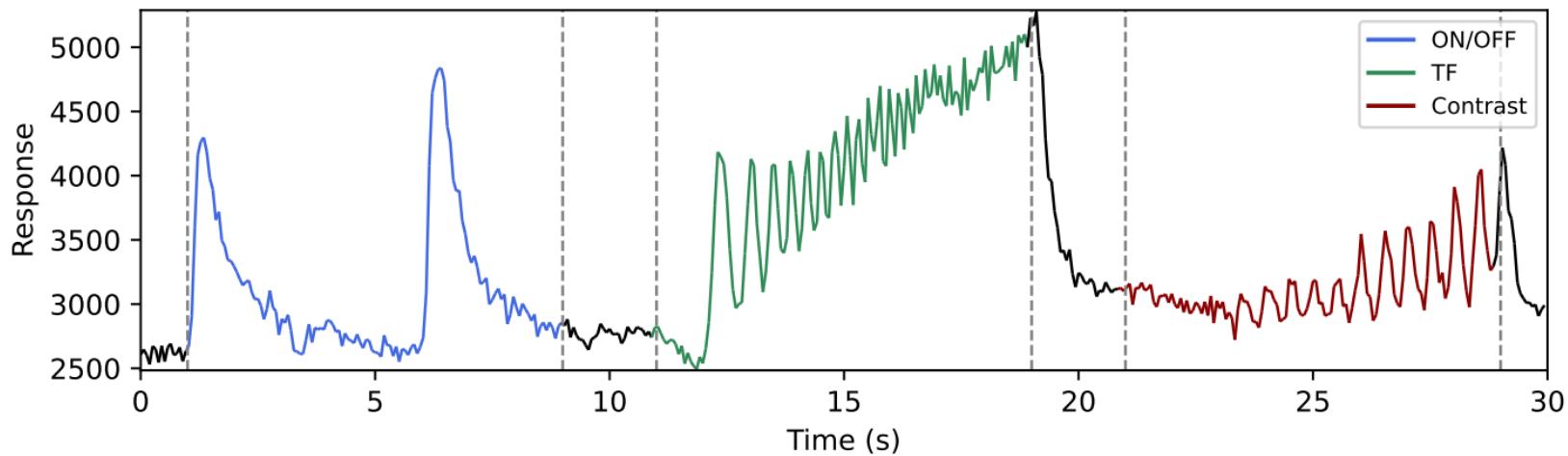
Pos 3-dot Flows

In total, $6 * 8 = 48$ stimuli

Flow stimuli were chosen because they mimic certain features of naturalistic stimuli, and previous work has shown that they engage nonlinearities in V1 that are not predicted based on the responses to gratings.

Luciano et al., 2018

Chirp Stimuli

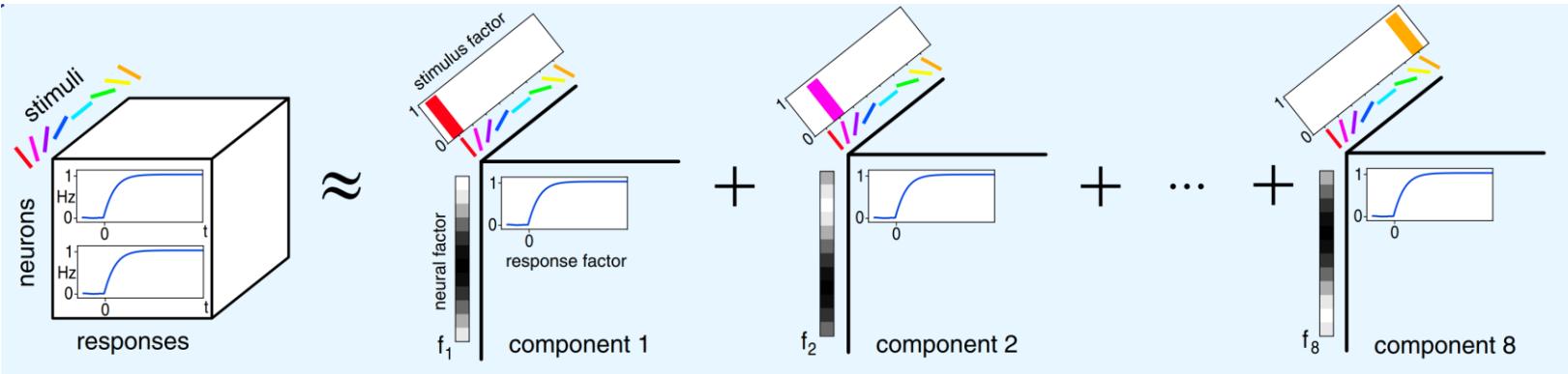


Data collected by Yue Fei

**801 significant dLGN neurons
(out of 1137)**

Manifold Embedding

Tensor Decomposition



Data here is a 3-D tensor (traces):
Neurons, Stimuli, Responses.

Neural factors: How each neuron responds to different stimuli.

Stimulus factors: The components of the stimuli that drive the neural responses.

Response factors: The temporal dynamics of the neural responses.

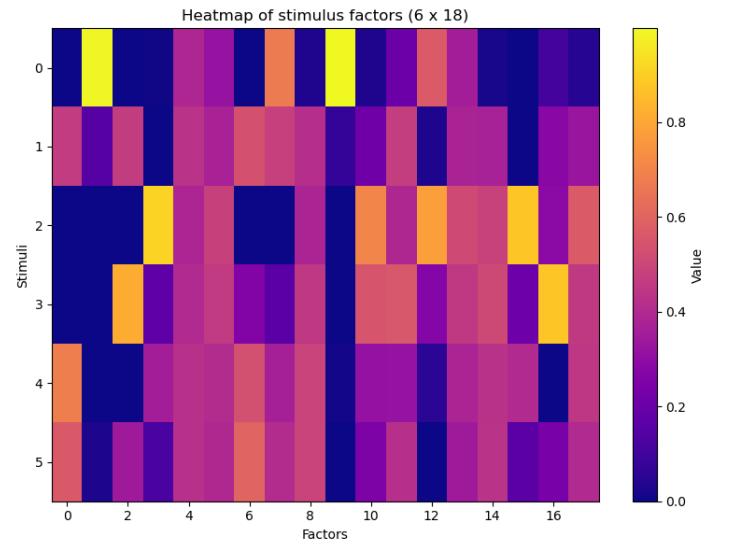
L. Dyballa et al 2024

- **Neuron factor matrix** $N \in \mathbb{R}^{I \times R}$,
- **Stimulus factor matrix** $S \in \mathbb{R}^{J \times R}$,
- **Response factor matrix** $R \in \mathbb{R}^{K \times R}$,

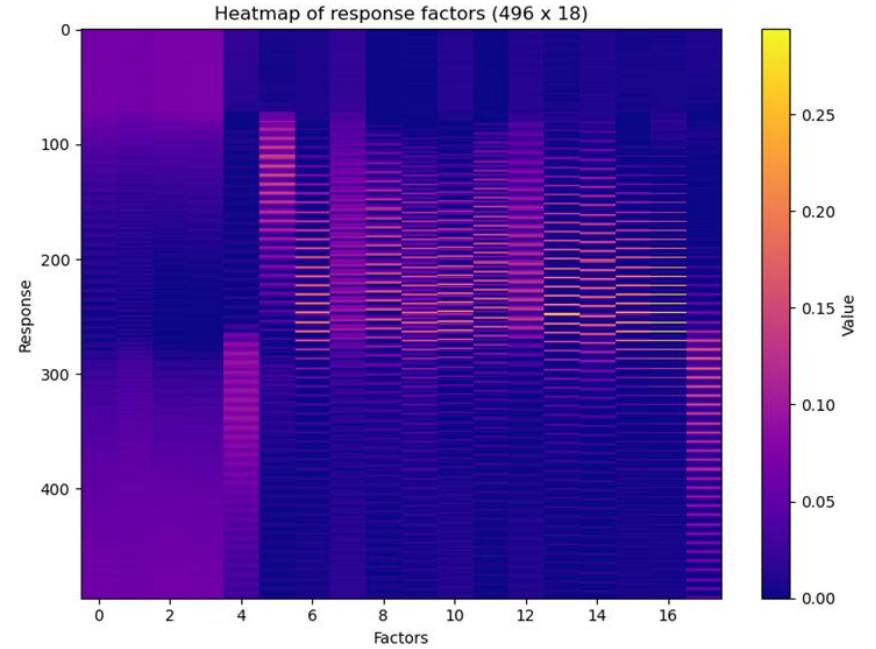
where R is the rank of the decomposition (i.e., the number of hidden components), and the number of columns R represents the number of latent factors.

$$\min_{N,S,R} \frac{1}{2} \|T - \sum_{r=1}^R N(:, r) \circ S(:, r) \circ R(:, r)\|_F^2$$

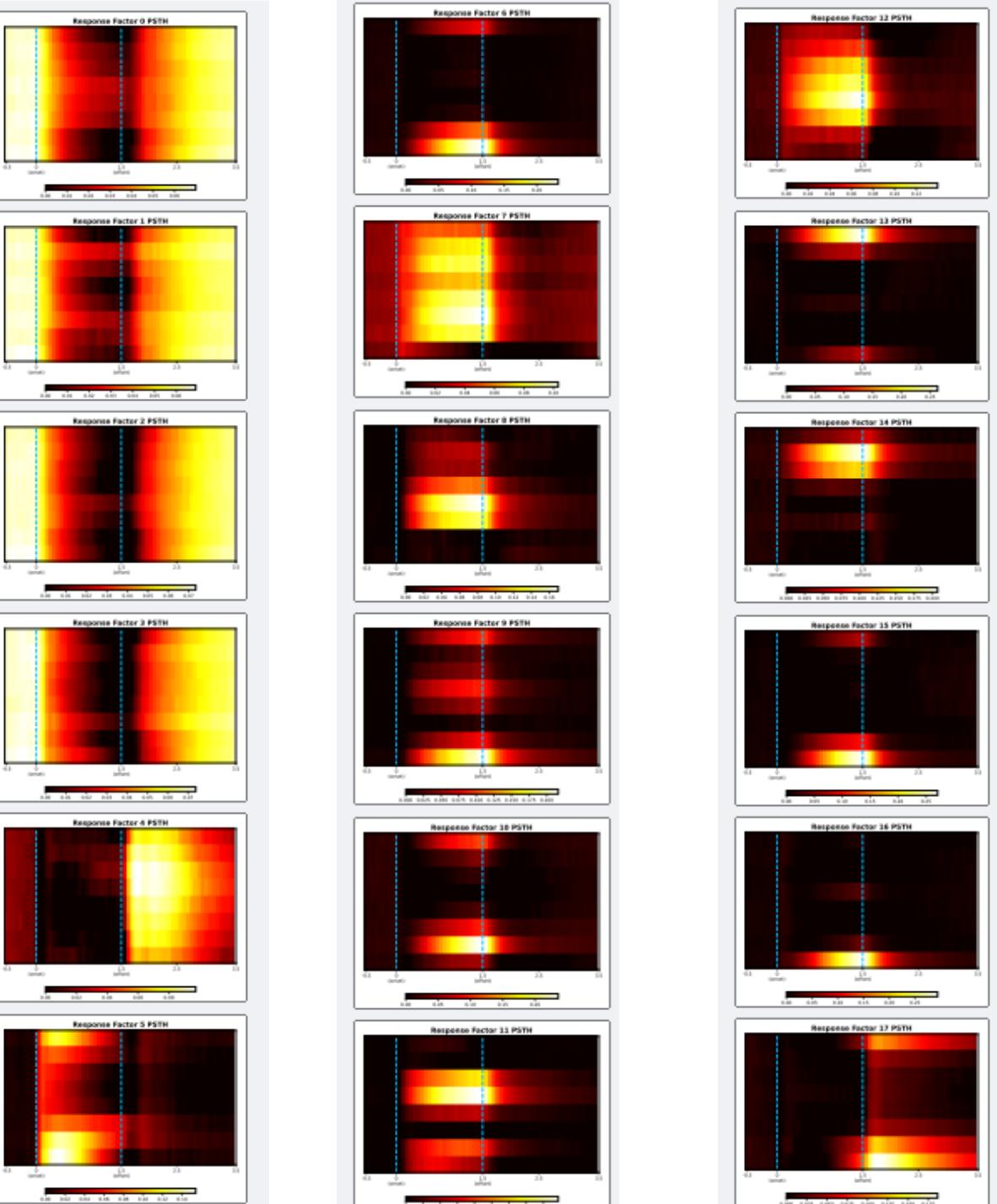
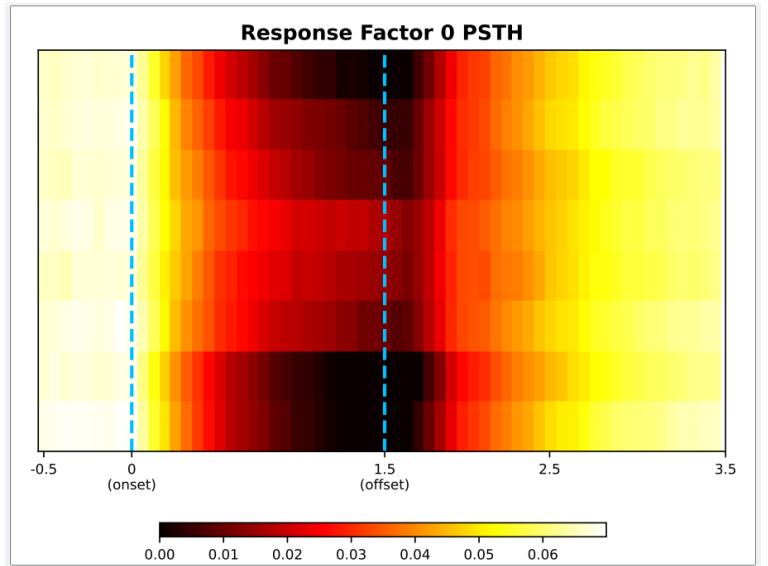
Stimulus Factors



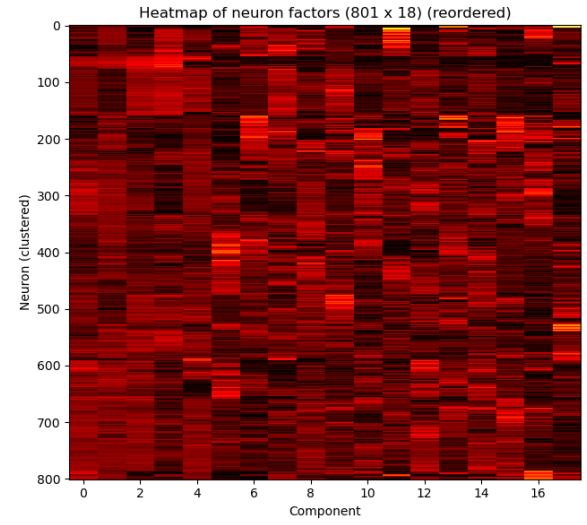
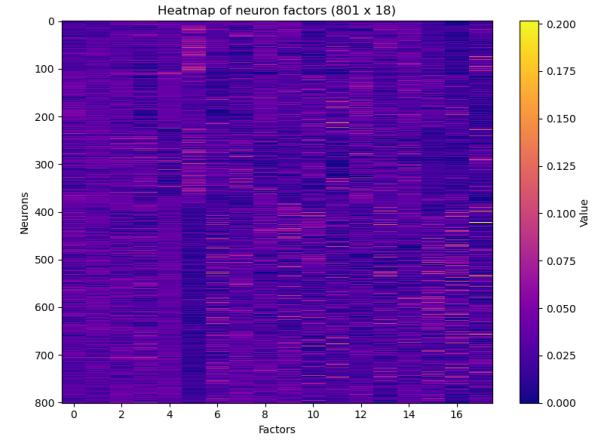
Response Factors



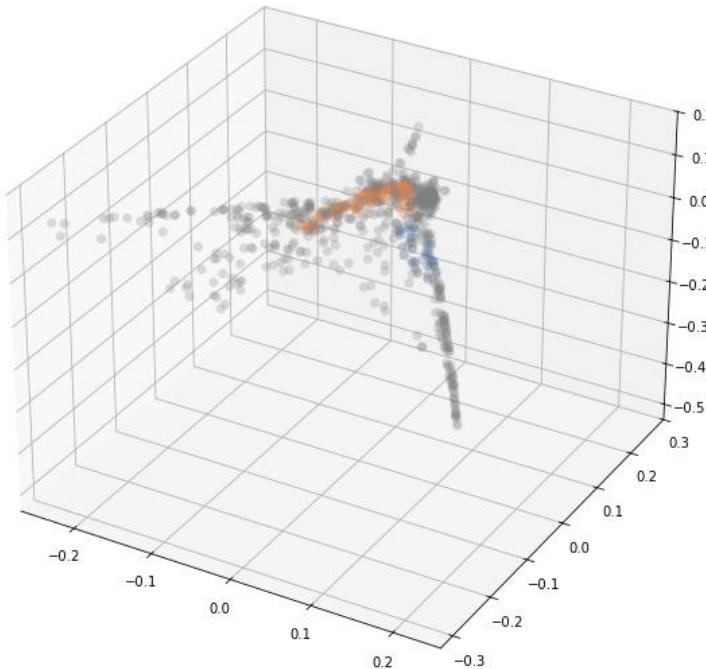
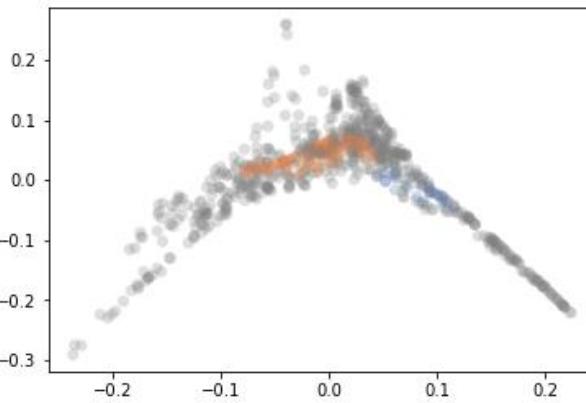
Direction



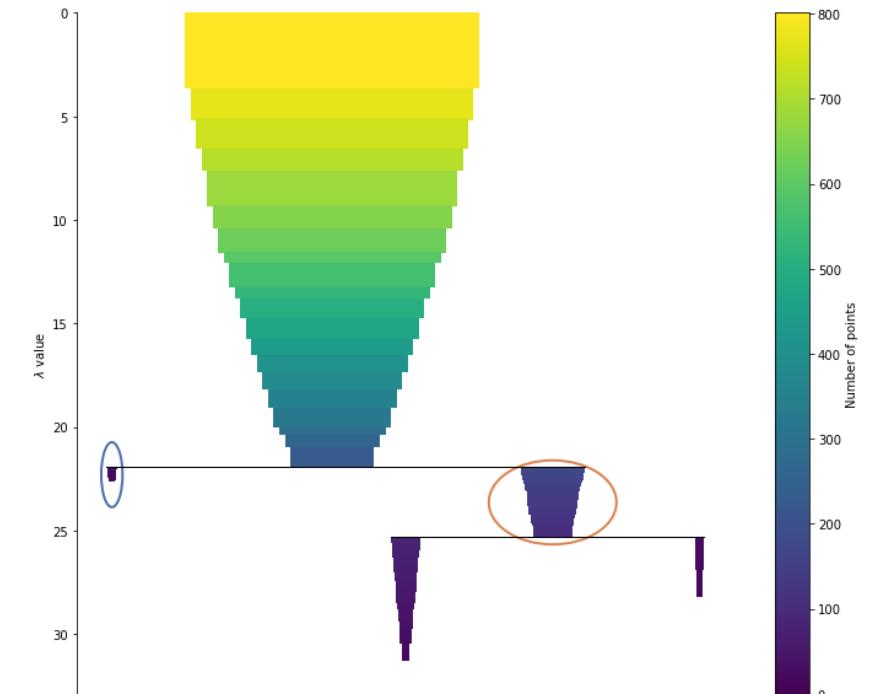
Neural Factors



Manifolds



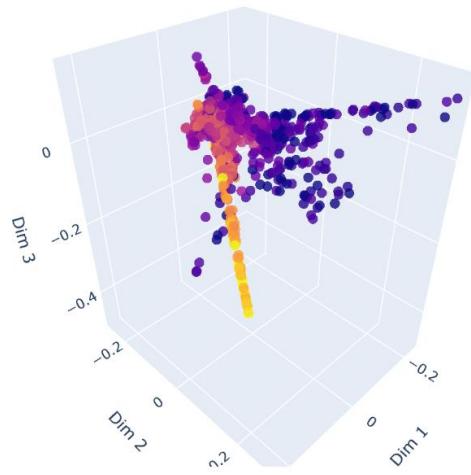
HDBSCAN clustering



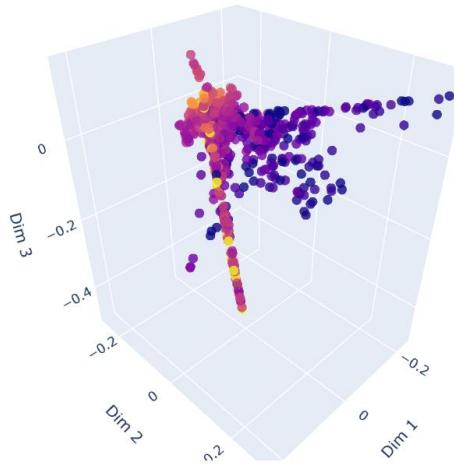
Min cluster size = 15

Manifolds labeled with different indices

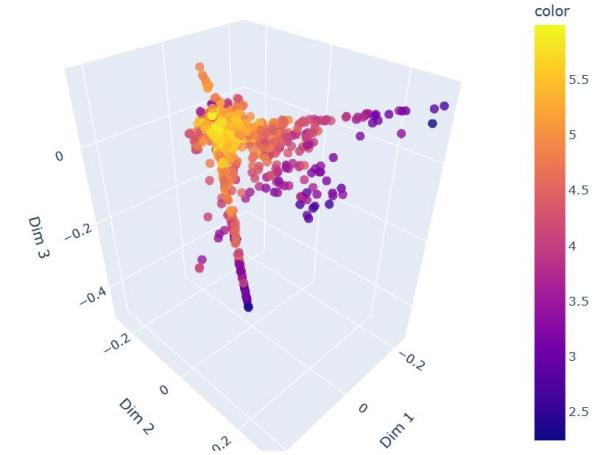
Neuron Diffusion Map (Grating Selectivity Index)



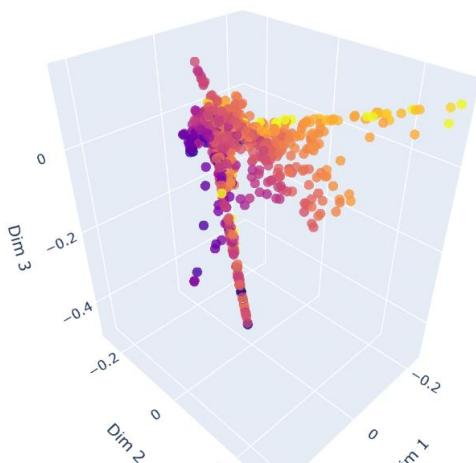
Neuron Diffusion Map (Flow Polarity Index)



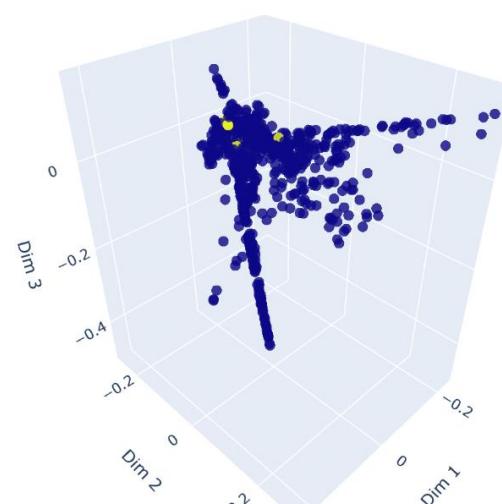
Neuron Diffusion Map (Stimulus Entropy Index)



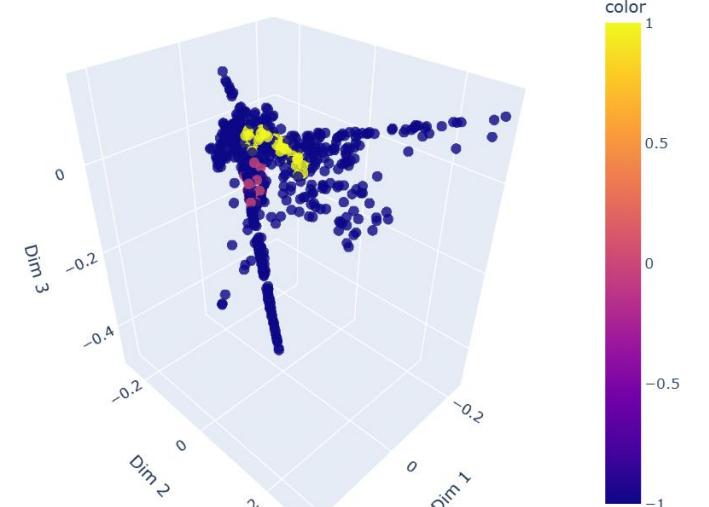
Neuron Diffusion Map (Dot Selectivity Index)



Neuron Diffusion Map (Negative Response Index)

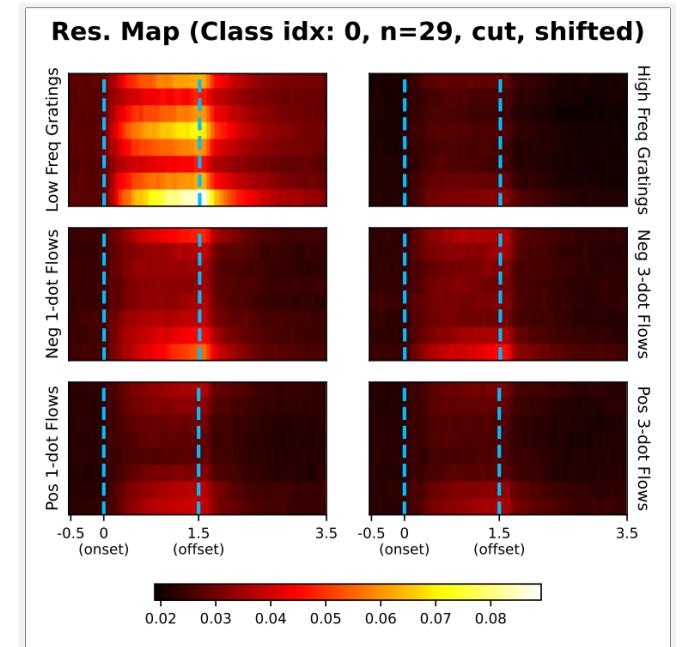
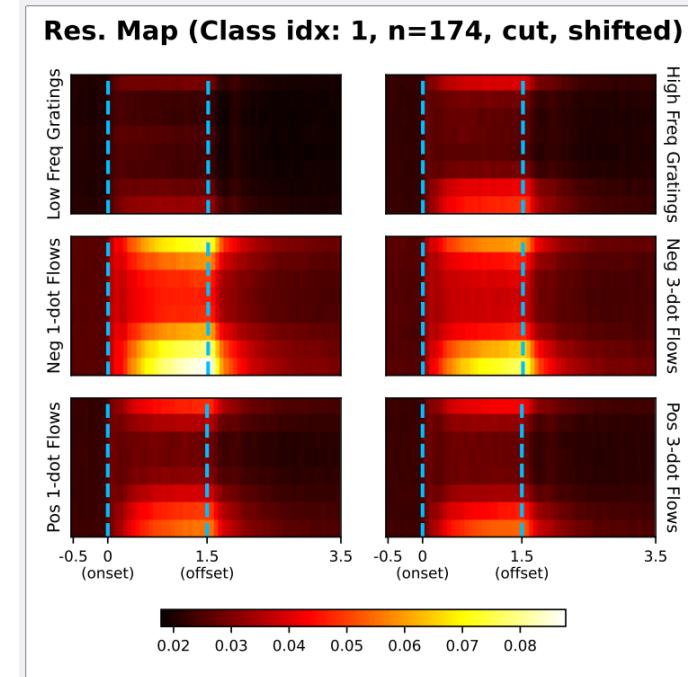
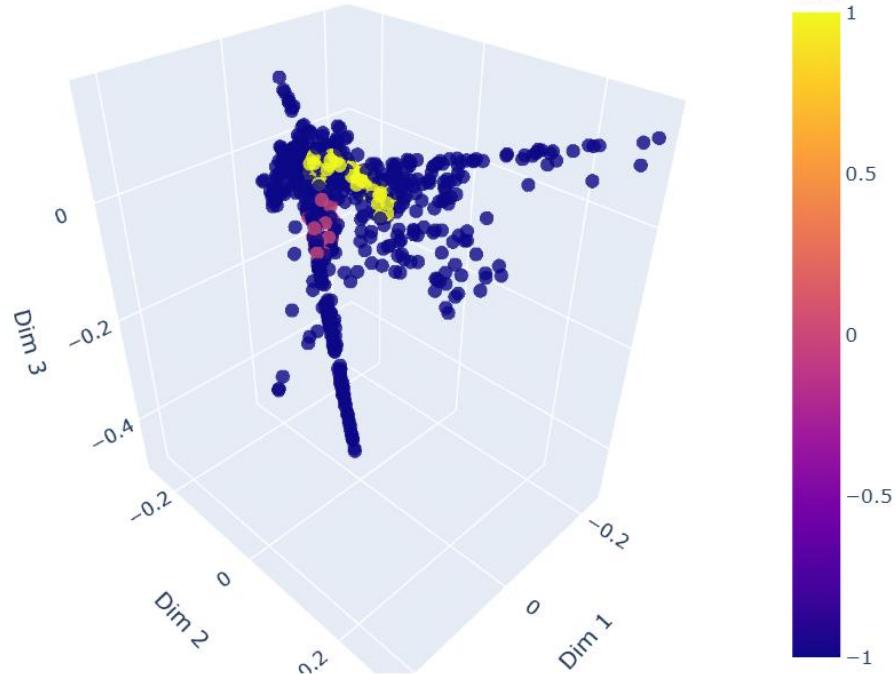


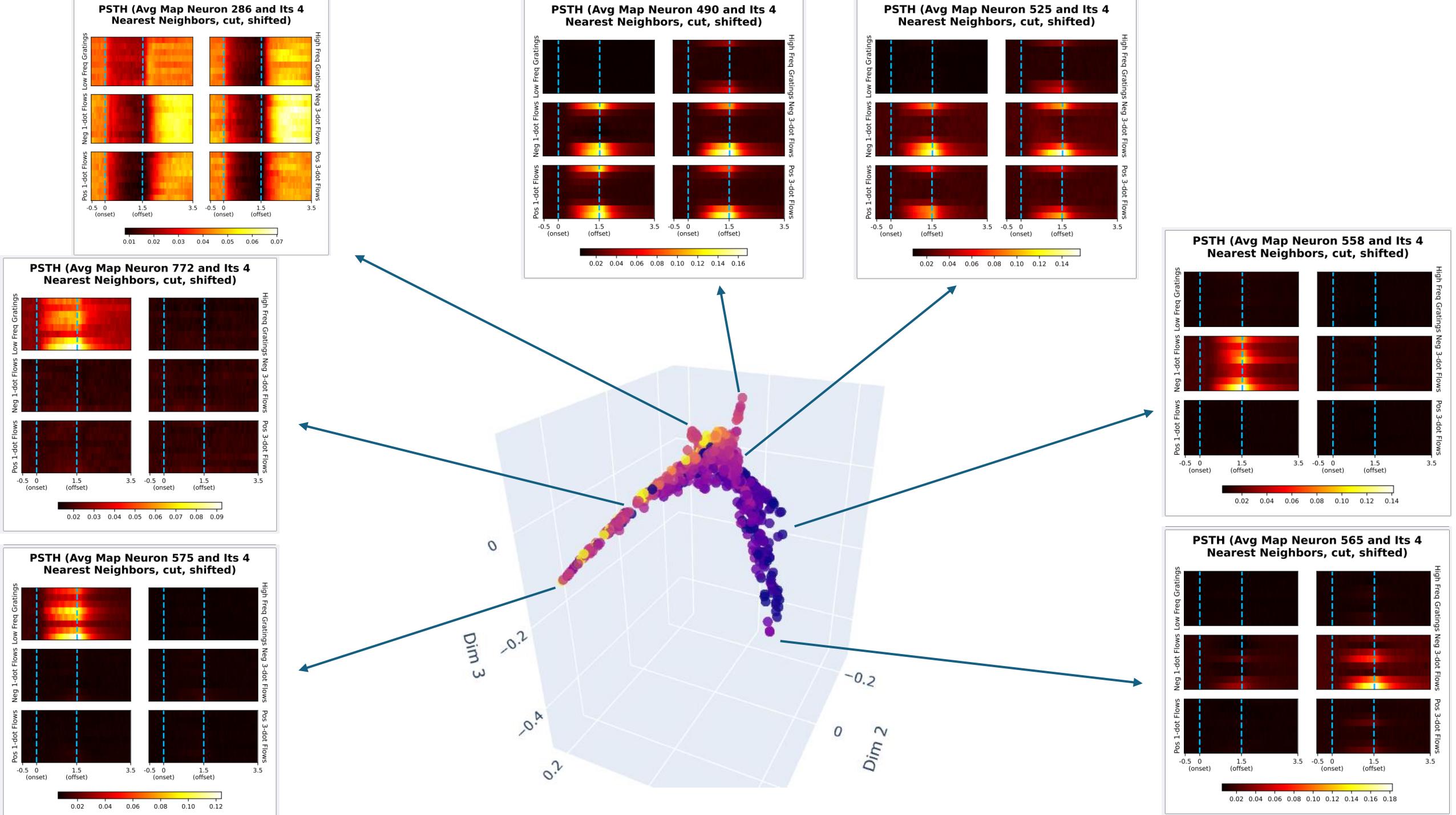
Neuron Diffusion Map (HDBSCAN Cluster Index)



Two clusters' avg response

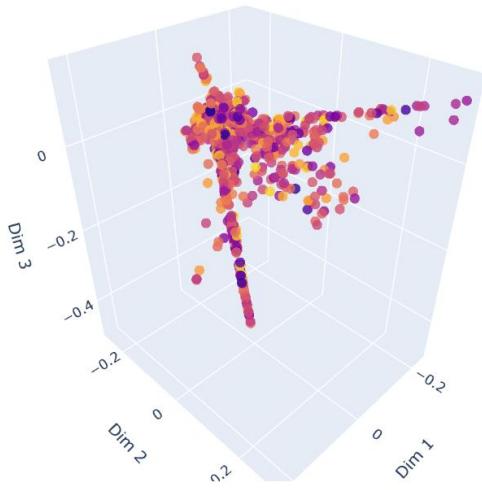
Neuron Diffusion Map (HDBSCAN Cluster Index)





Manifolds labeled with different chirp indices

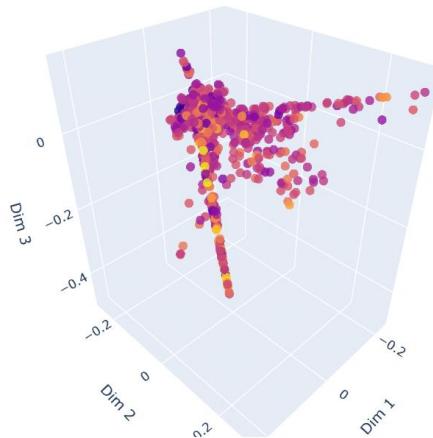
Neuron Diffusion Map (ON-OFF Preference Index)



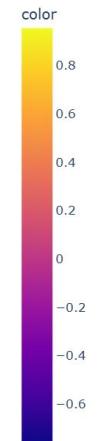
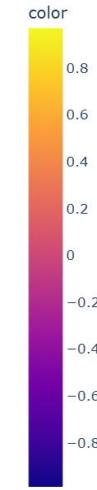
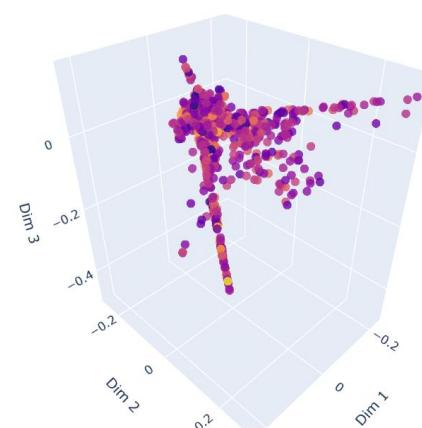
Neuron Diffusion Map (ON-OFF Sustain Index)

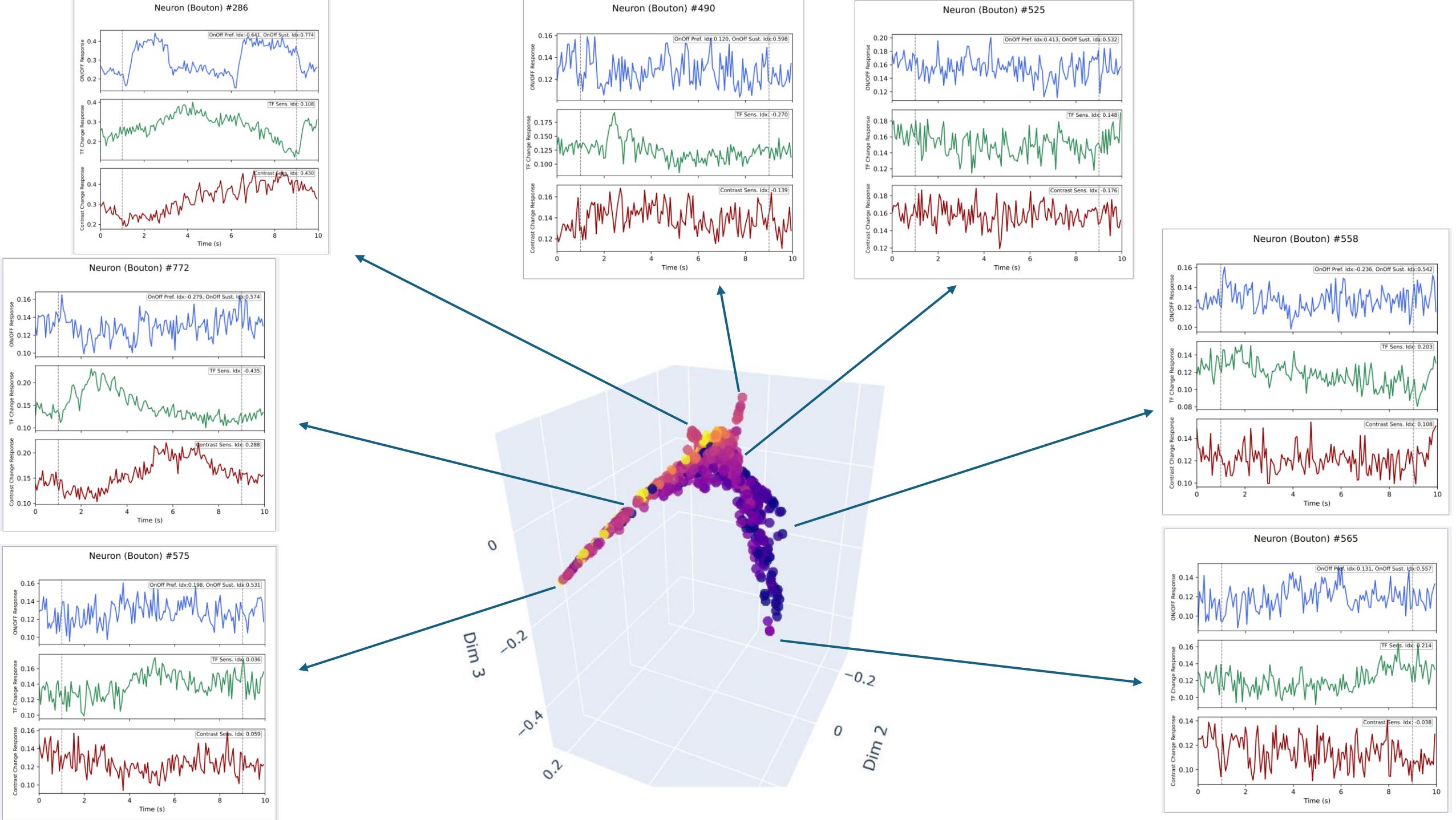


Neuron Diffusion Map (Temporal Frequency Index)

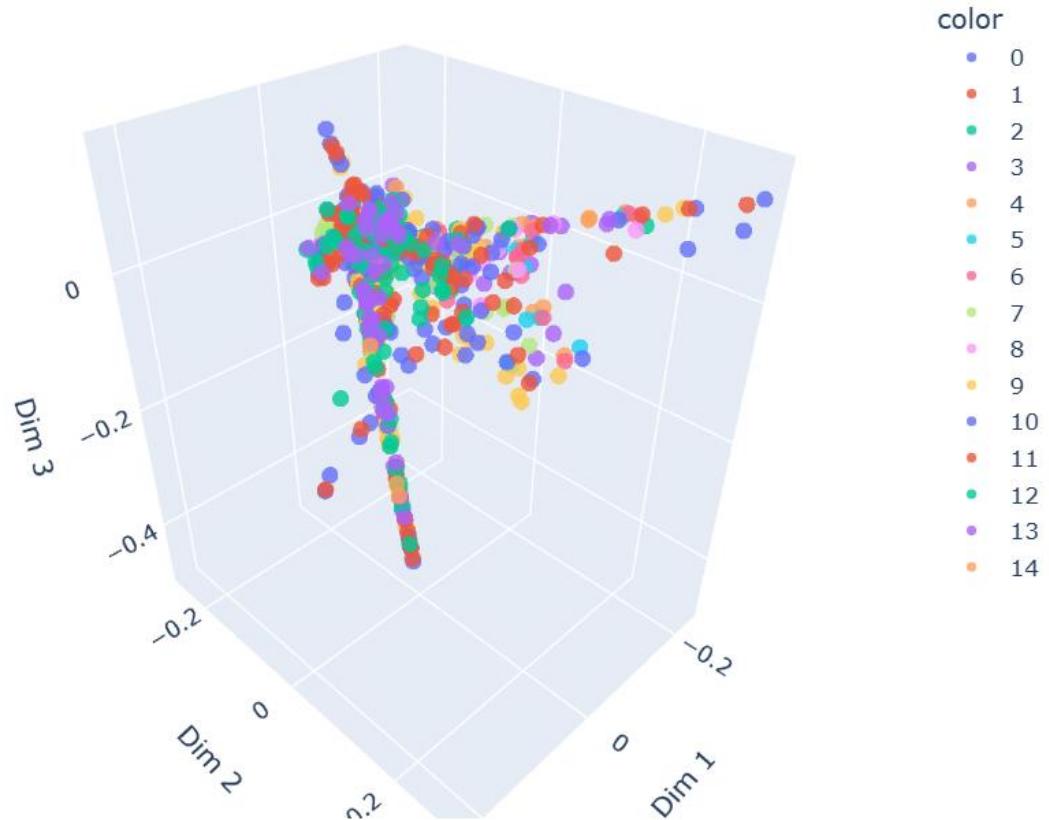


Neuron Diffusion Map (Contrast Index)



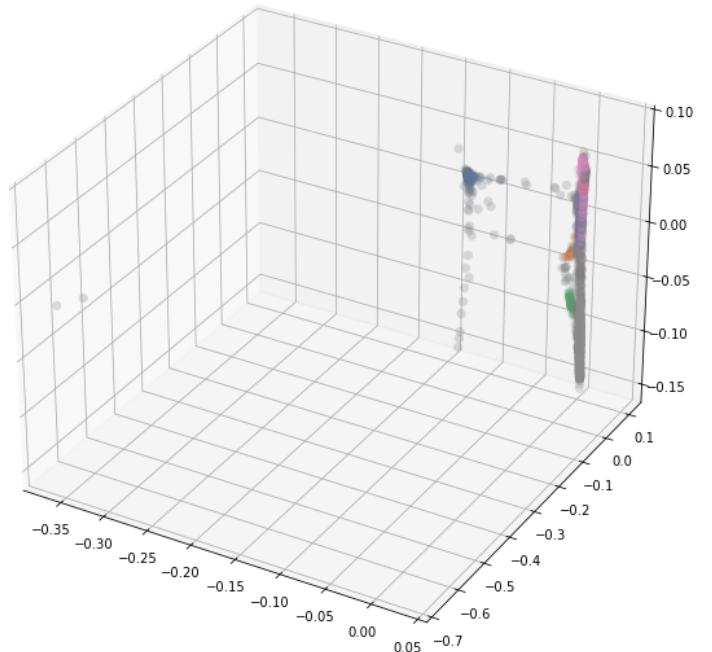
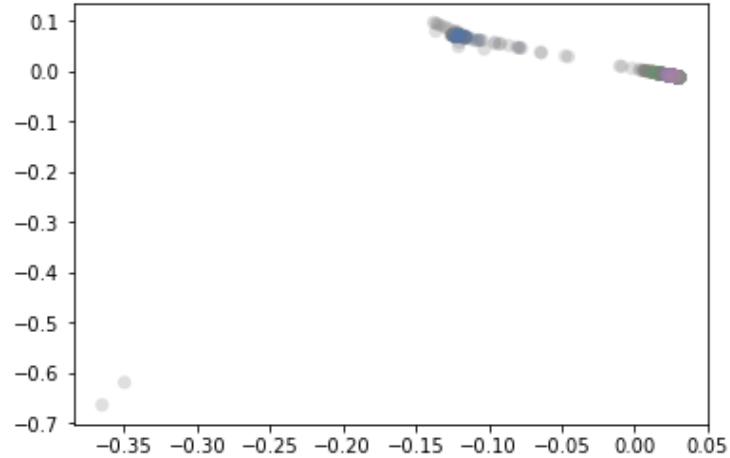


Neuron Diffusion Map (FOV labels)

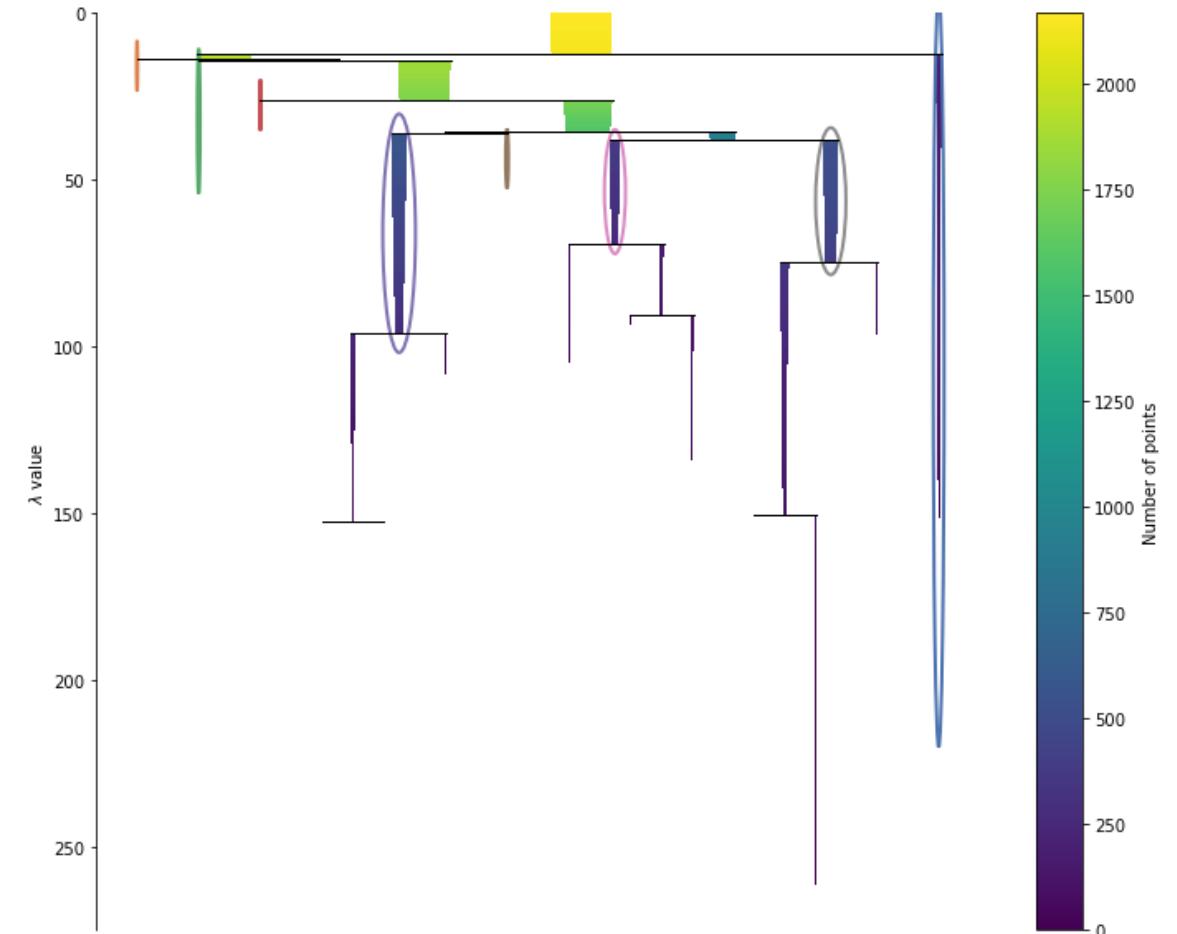


**2166 significant RGC boutons
(out of 4902)**

Manifolds



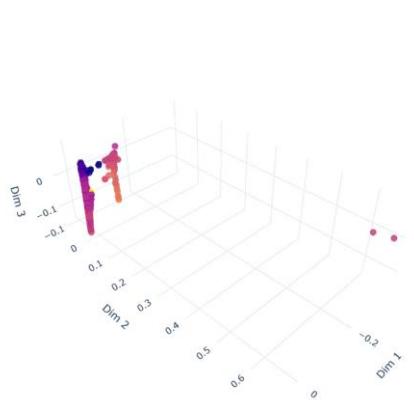
HDBSCAN clustering



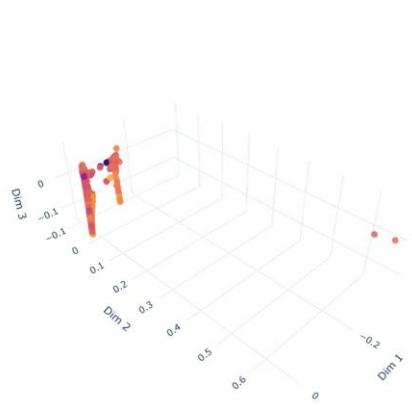
8 clusters. Min cluster size = 15

Manifolds labeled with different indices

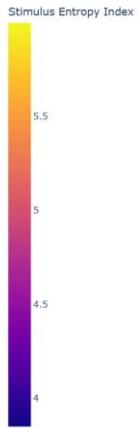
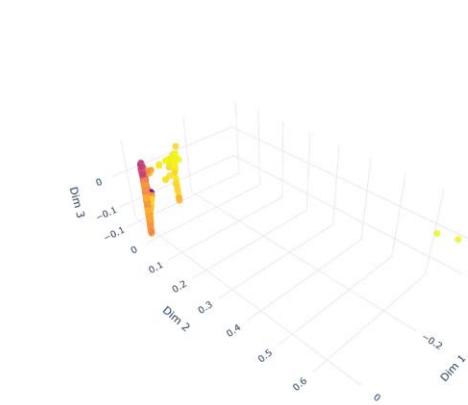
Neuron Diffusion Map (Grating Selectivity Index)



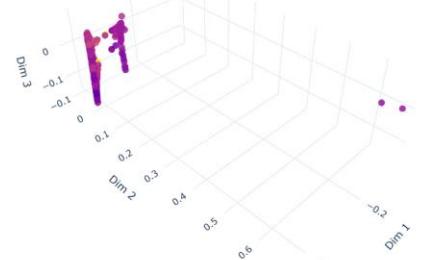
Neuron Diffusion Map (Flow Polarity Index)



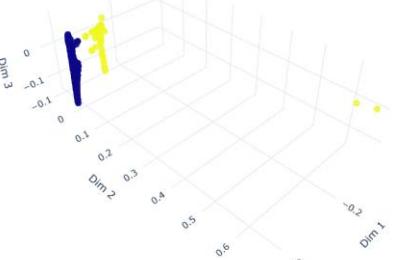
Neuron Diffusion Map (Stimulus Entropy Index)



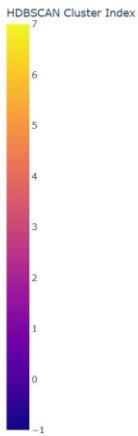
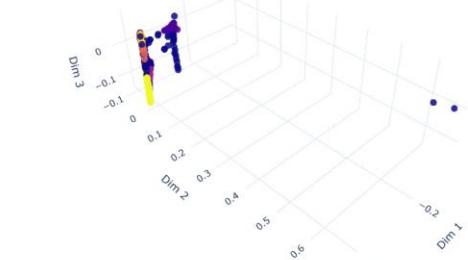
Neuron Diffusion Map (Dot Selectivity Index)



Neuron Diffusion Map (Negative Response Index)



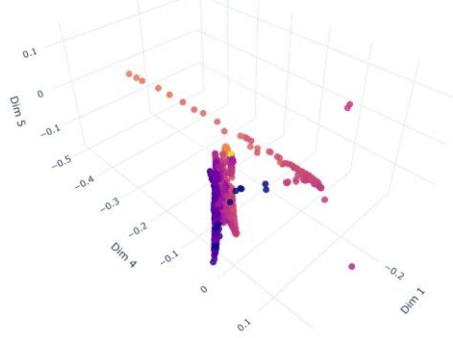
Neuron Diffusion Map (HDBSCAN Cluster Index)



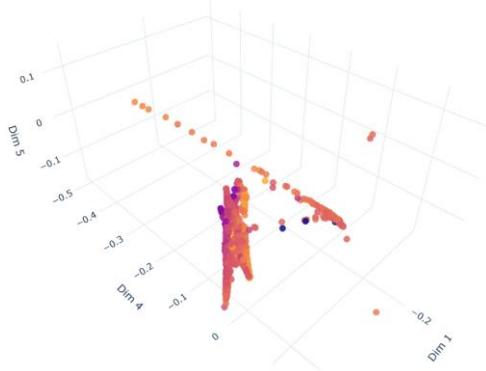
Dimensions 1 2 3

Manifolds labeled with different indices

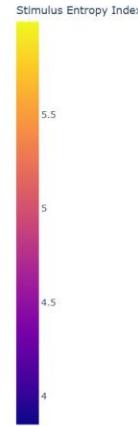
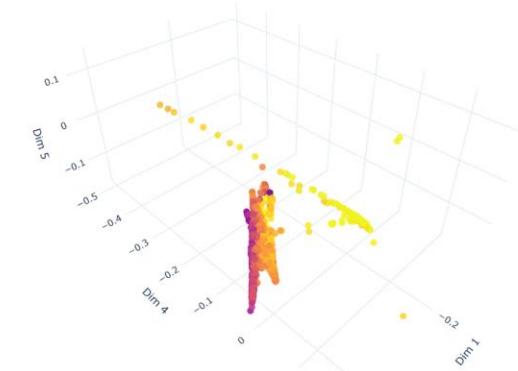
Neuron Diffusion Map (Grating Selectivity Index)



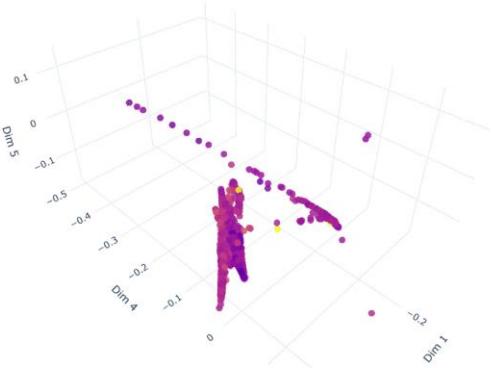
Neuron Diffusion Map (Flow Polarity Index)



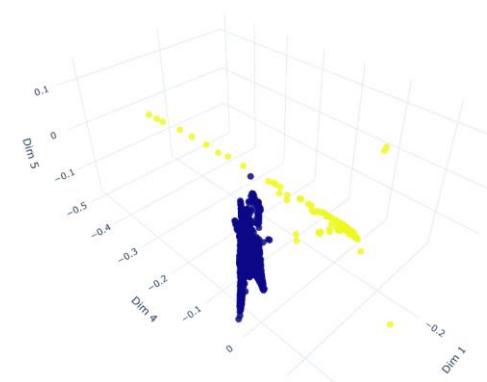
Neuron Diffusion Map (Stimulus Entropy Index)



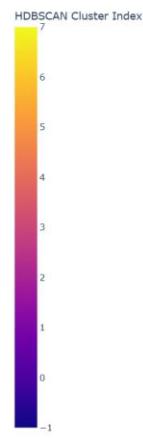
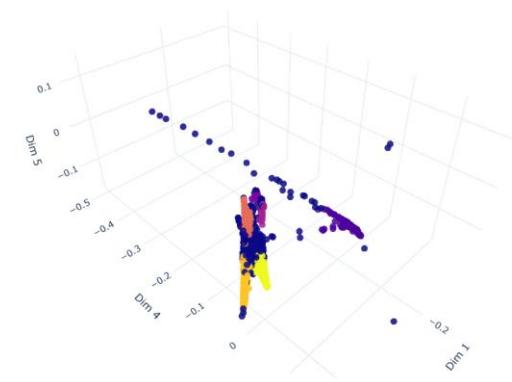
Neuron Diffusion Map (Dot Selectivity Index)



Neuron Diffusion Map (Negative Response Index)



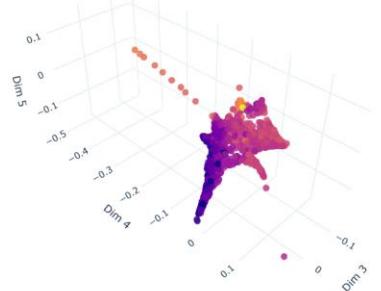
Neuron Diffusion Map (HDBSCAN Cluster Index)



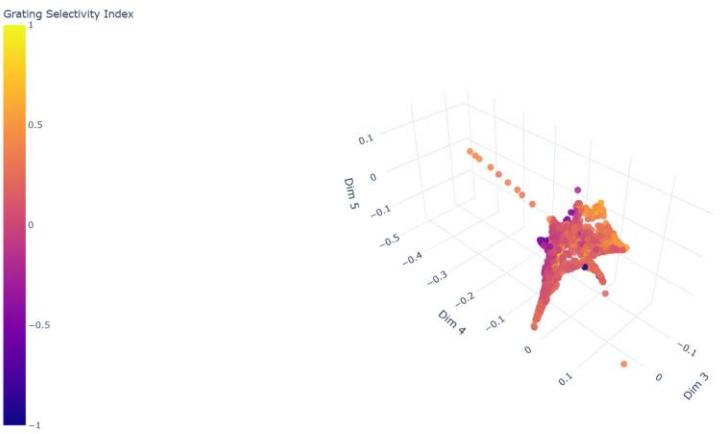
Dimensions 1 4 5

Manifolds labeled with different indices

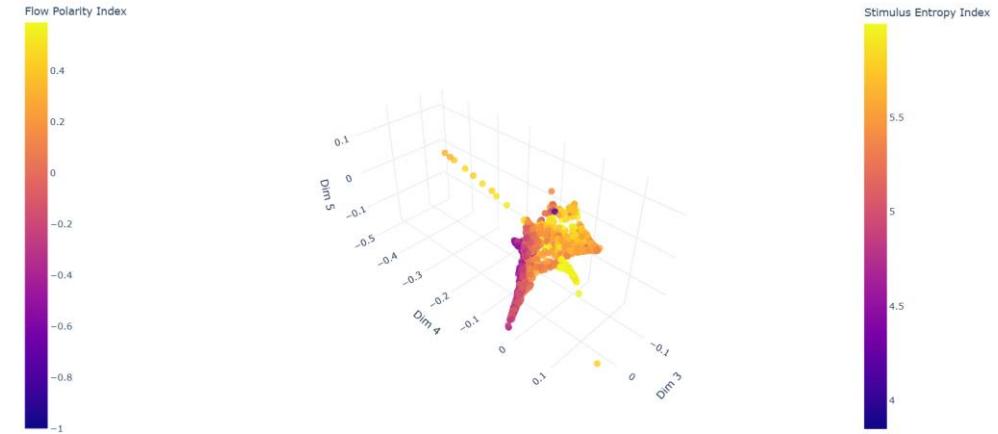
Neuron Diffusion Map (Grating Selectivity Index)



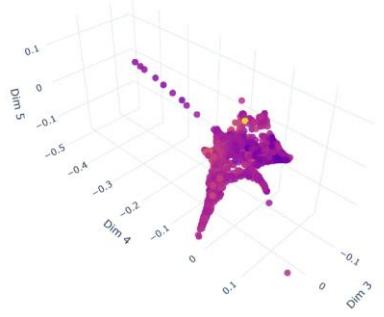
Neuron Diffusion Map (Flow Polarity Index)



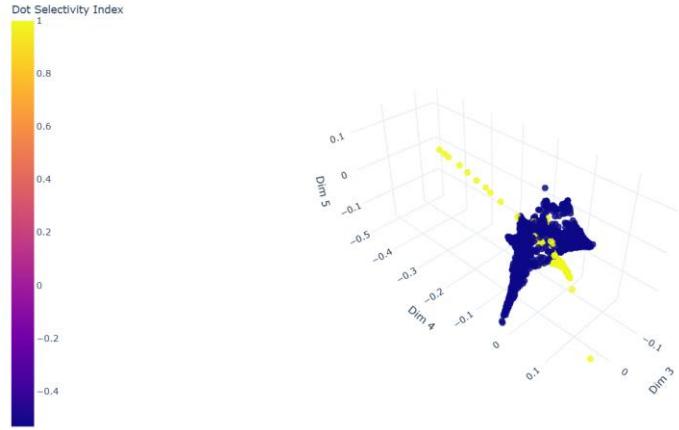
Neuron Diffusion Map (Stimulus Entropy Index)



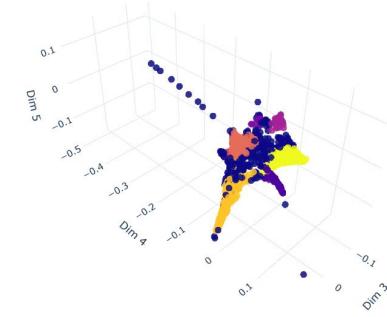
Neuron Diffusion Map (Dot Selectivity Index)



Neuron Diffusion Map (Negative Response Index)

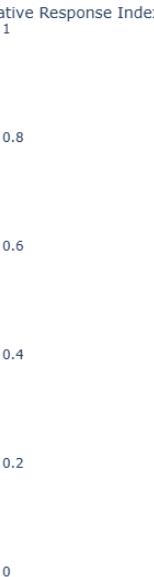
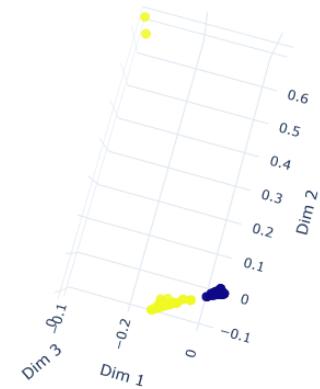


Neuron Diffusion Map (HDBSCAN Cluster Index)

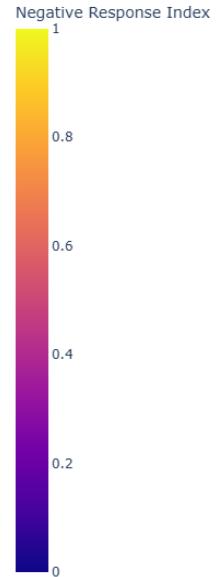
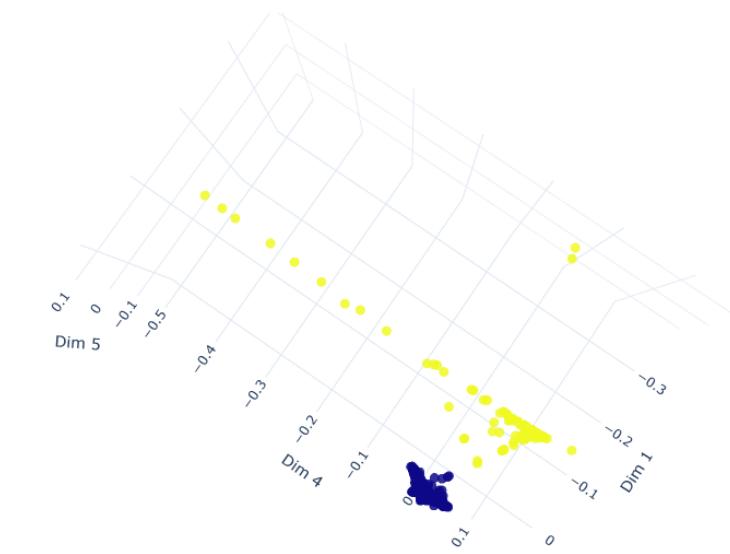


Dimensions 3 4 5

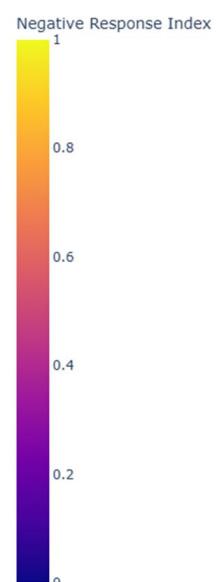
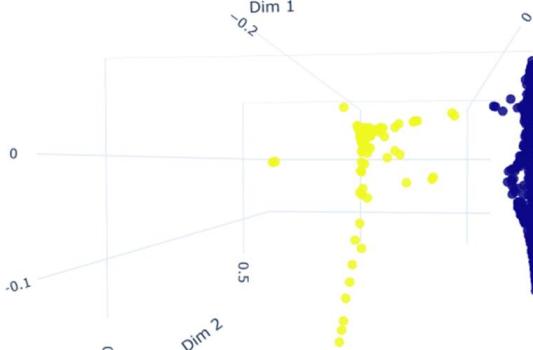
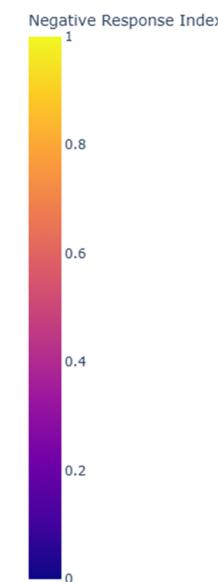
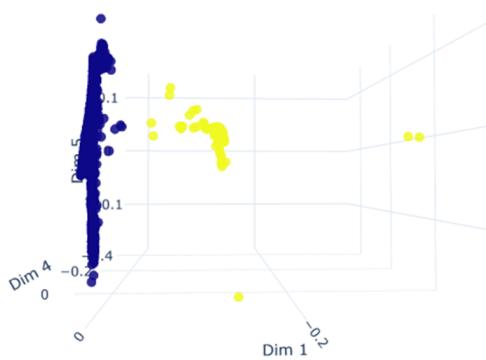
Neuron Diffusion Map (Negative Response Index)



Neuron Diffusion Map (Negative Response Index)

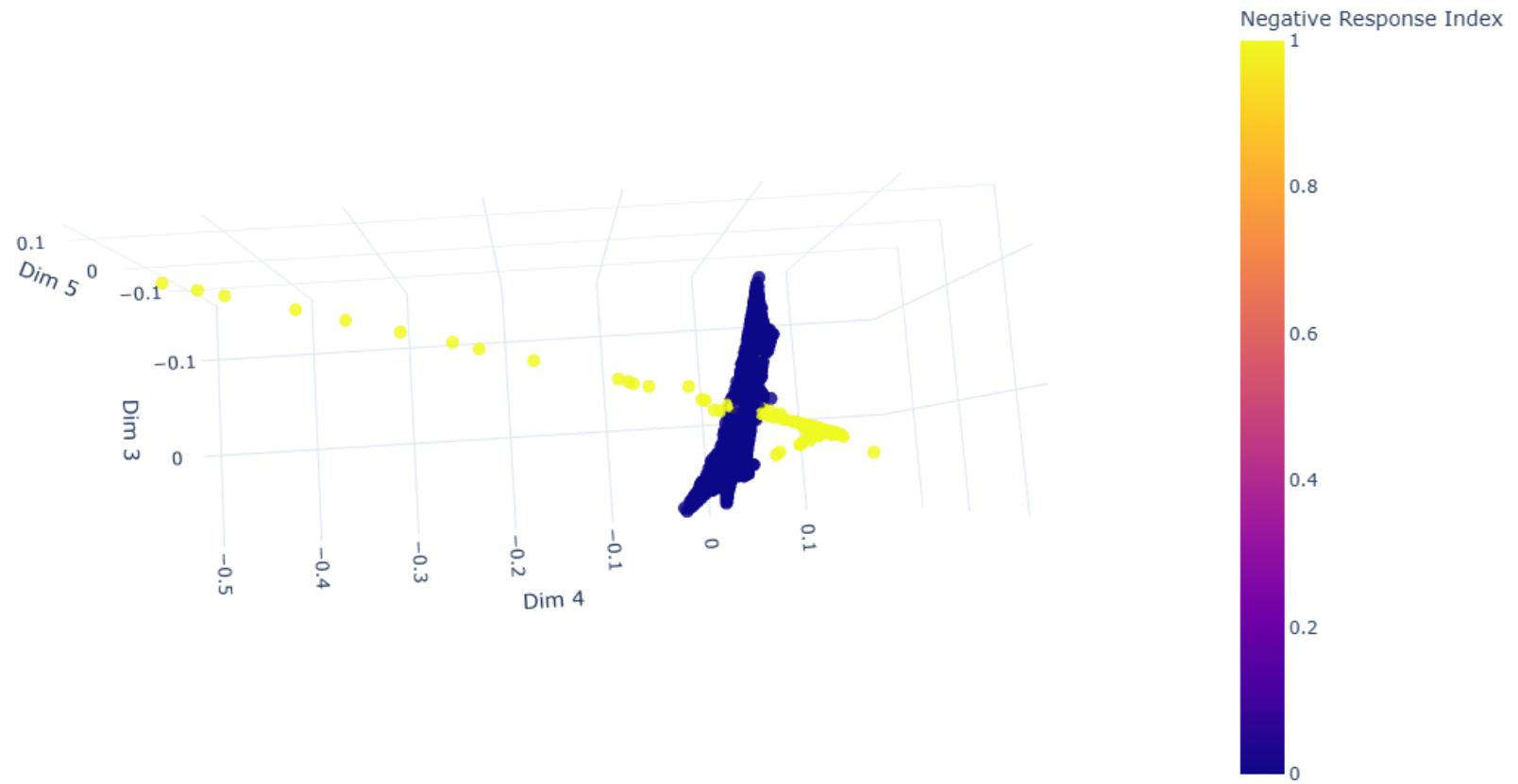


Neuron Diffusion Map (Negative Response Index)



Dimension 1 can well distinguish the suppressed-by-contrast boutons.

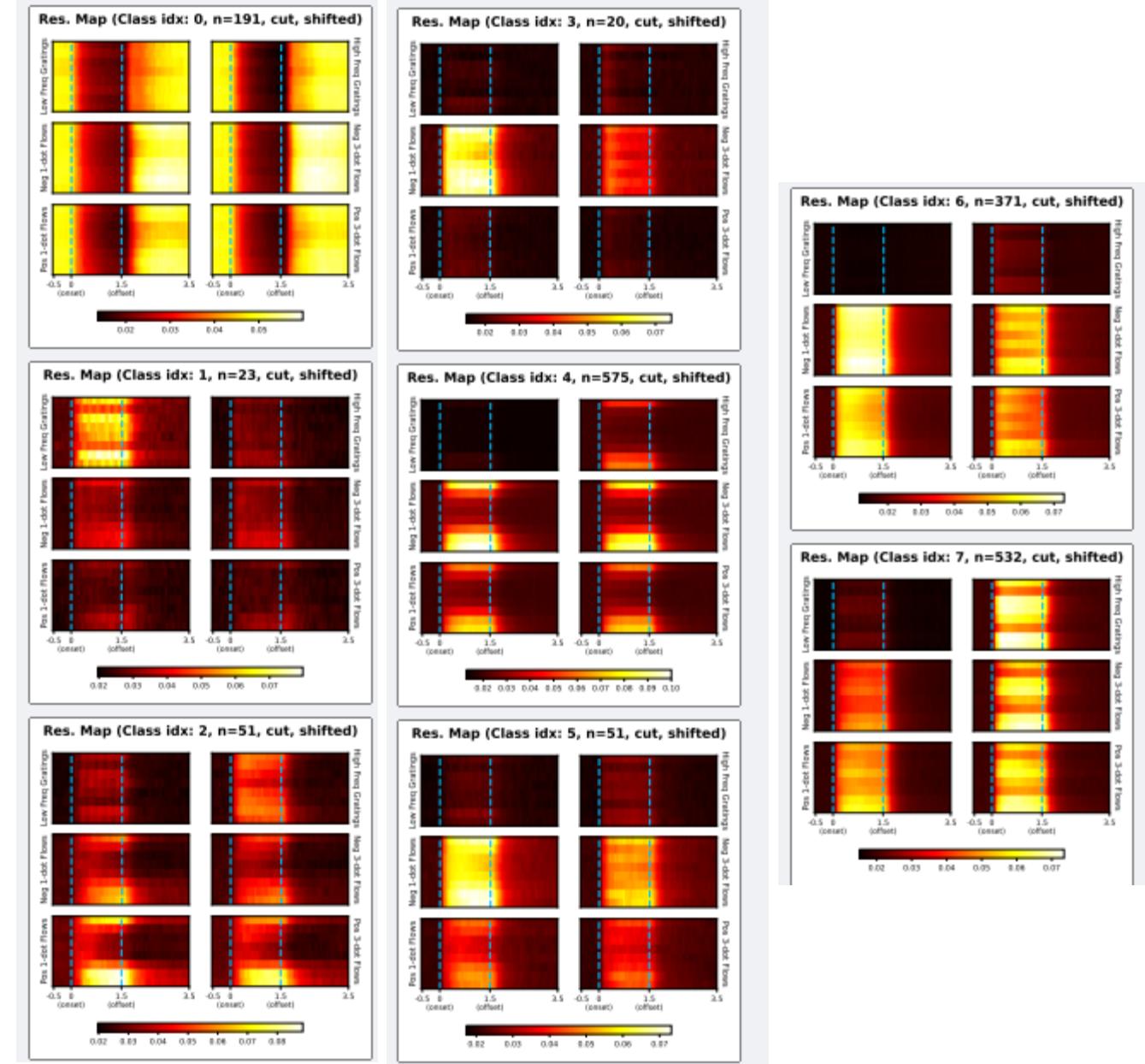
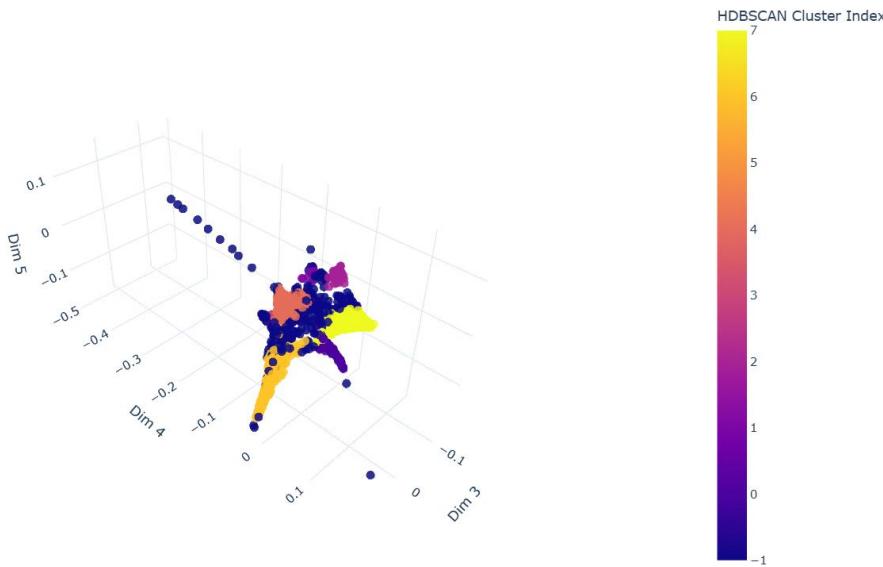
Neuron Diffusion Map (Negative Response Index)



We may also distinguish suppressed-by-contrast boutons by dimensions 3 and 4.

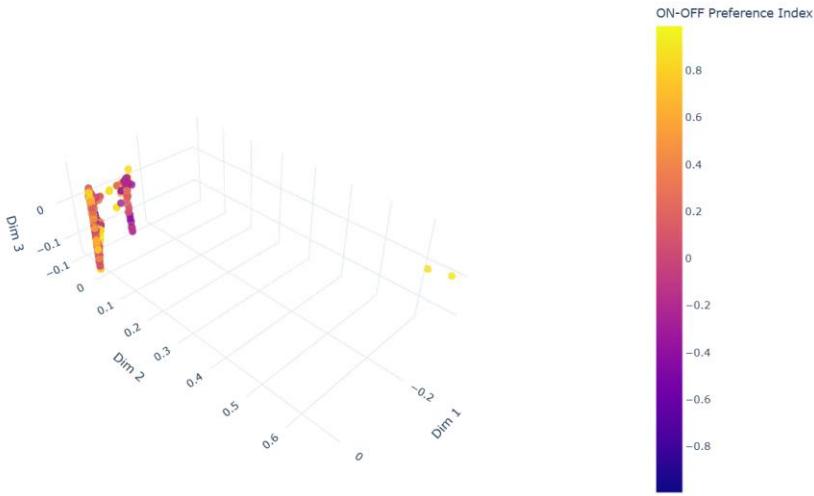
8 clusters' avg response

Neuron Diffusion Map (HDBSCAN Cluster Index)

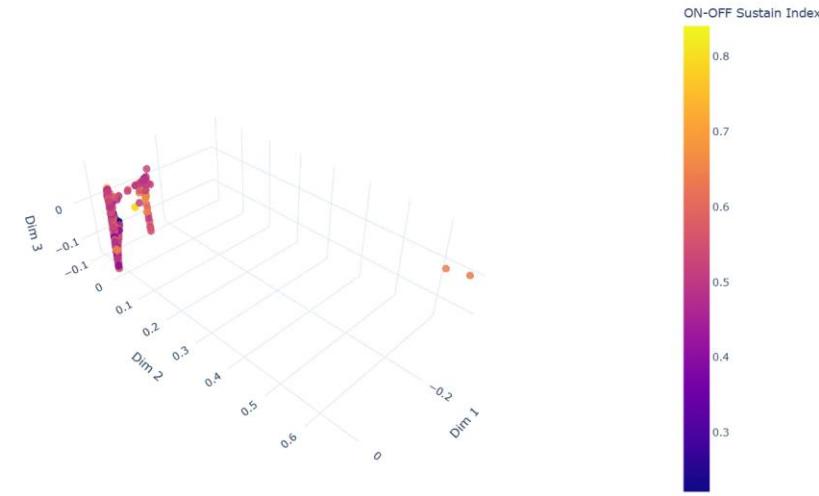


Manifolds labeled with different chirp indices

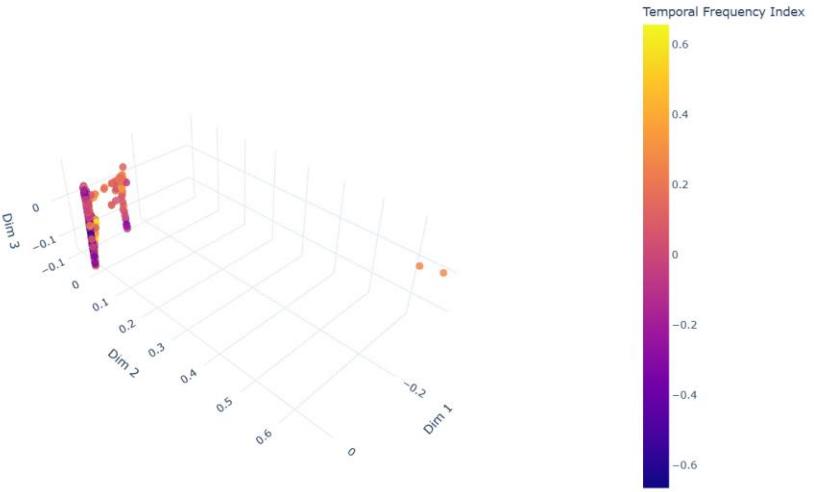
Neuron Diffusion Map (ON-OFF Preference Index)



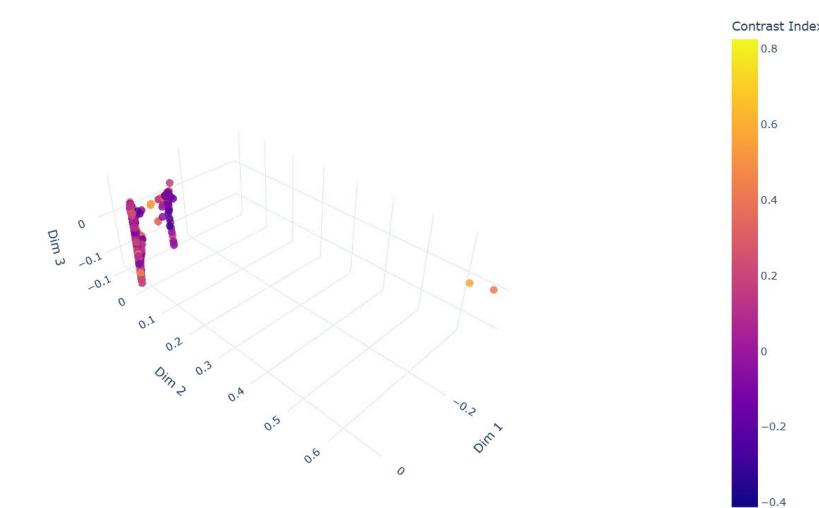
Neuron Diffusion Map (ON-OFF Sustain Index)



Neuron Diffusion Map (Temporal Frequency Index)



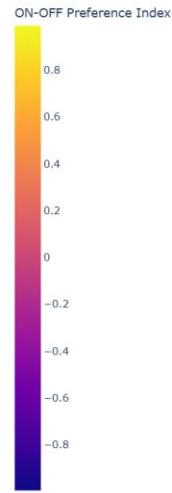
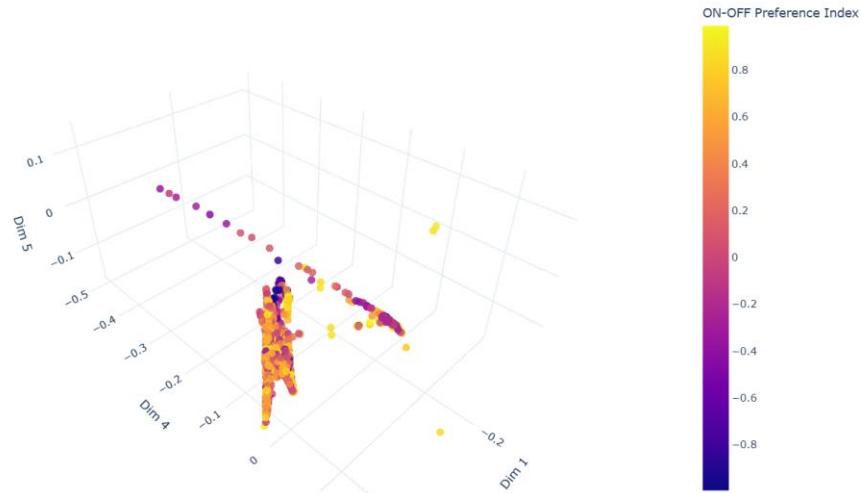
Neuron Diffusion Map (Contrast Index)



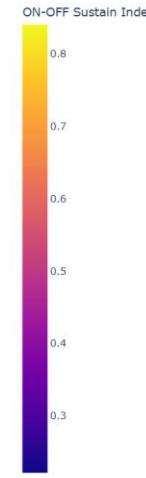
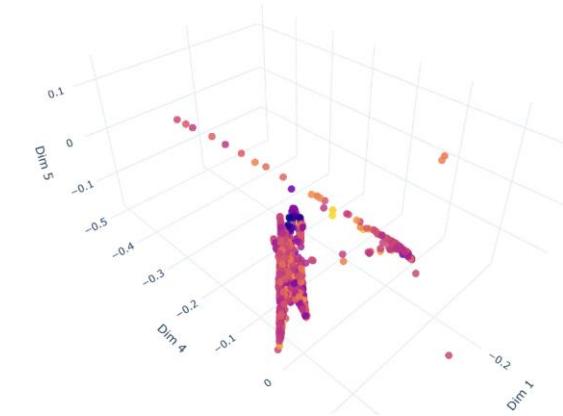
Dimensions 1 2 3

Manifolds labeled with different chirp indices

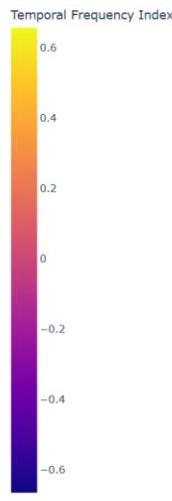
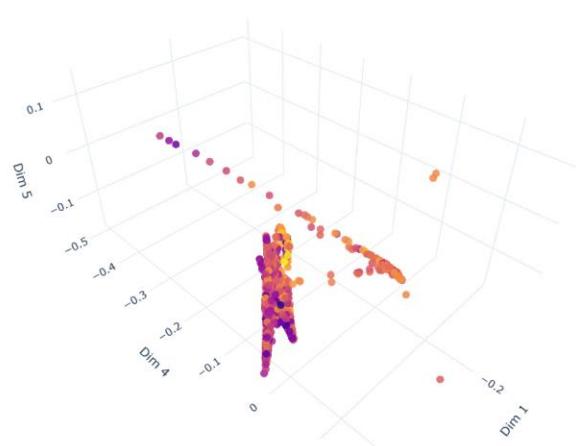
Neuron Diffusion Map (ON-OFF Preference Index)



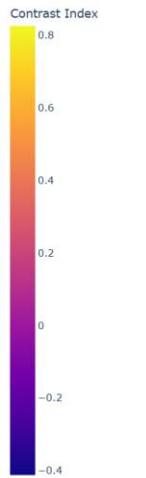
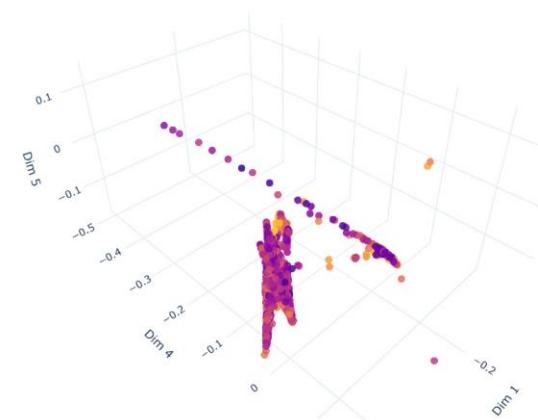
Neuron Diffusion Map (ON-OFF Sustain Index)



Neuron Diffusion Map (Temporal Frequency Index)



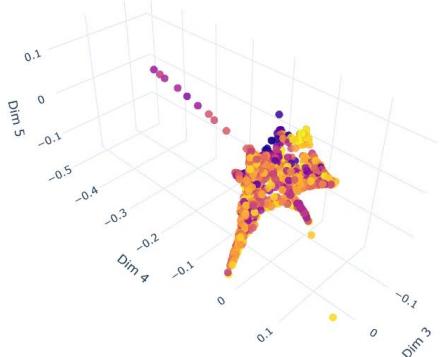
Neuron Diffusion Map (Contrast Index)



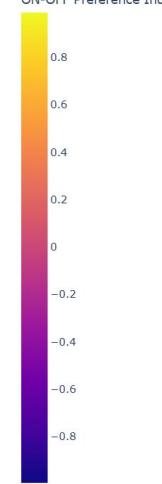
Dimensions 1 4 5

Manifolds labeled with different chirp indices

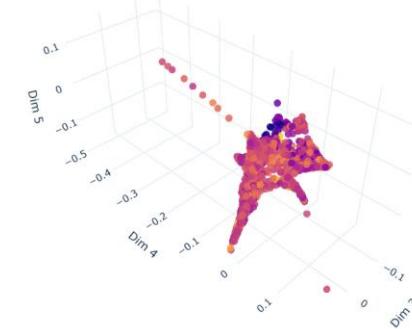
Neuron Diffusion Map (ON-OFF Preference Index)



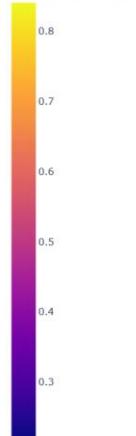
ON-OFF Preference Index



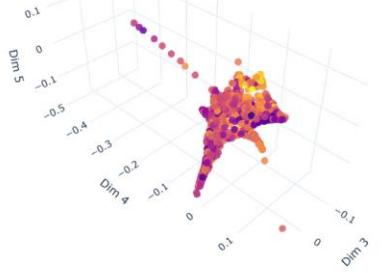
Neuron Diffusion Map (ON-OFF Sustain Index)



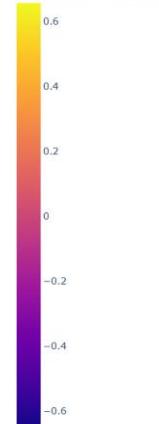
ON-OFF Sustain Index



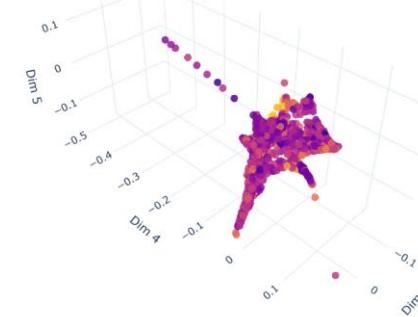
Neuron Diffusion Map (Temporal Frequency Index)



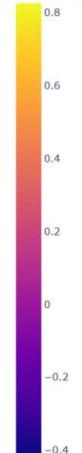
Temporal Frequency Index



Neuron Diffusion Map (Contrast Index)



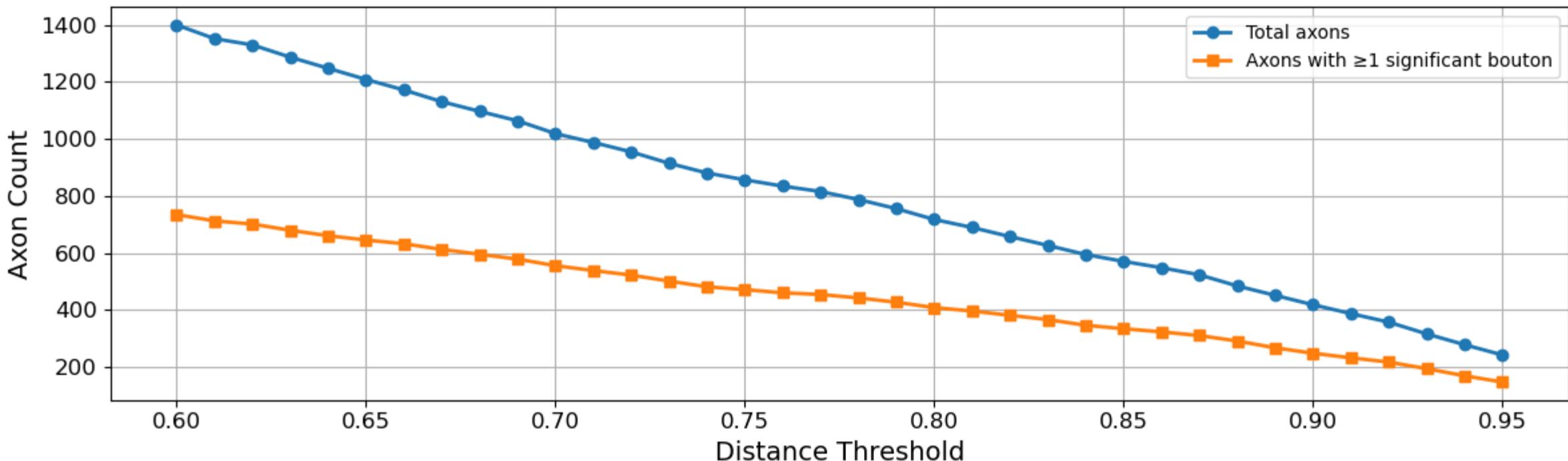
Contrast Index



Dimensions 3 4 5

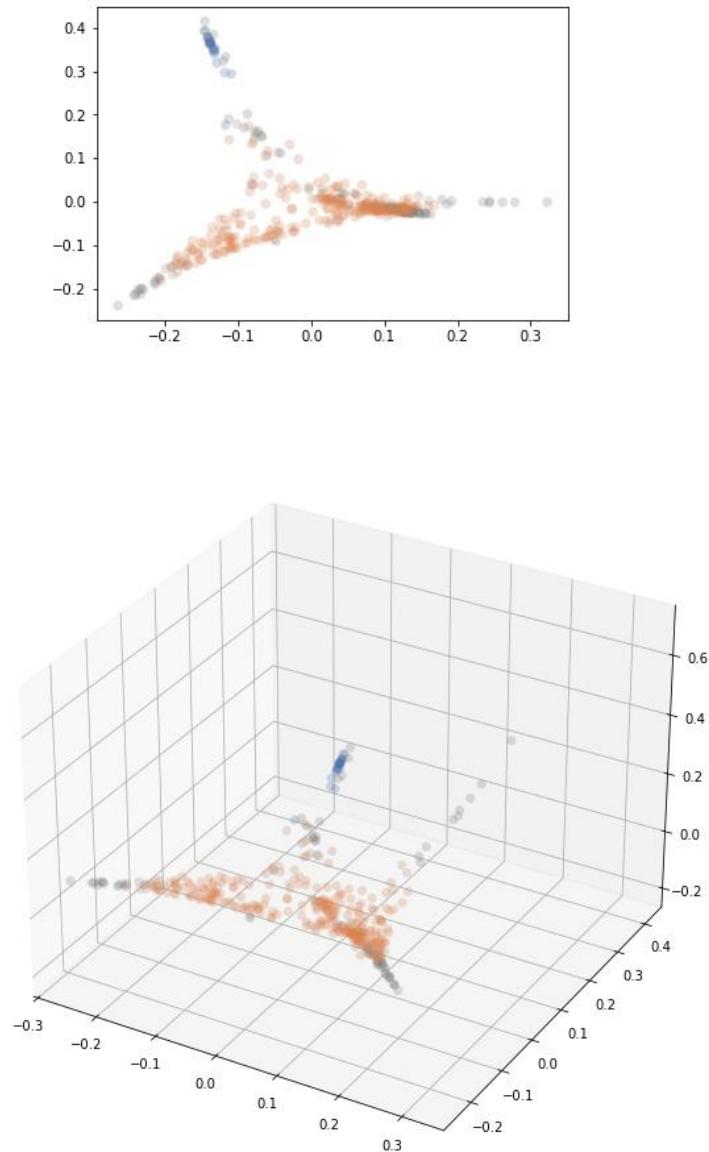
**409 significant RGC boutons
with only one bouton per axon
out of 2166 significant boutons
(out of 4902)**

Axon Counts vs Distance Threshold

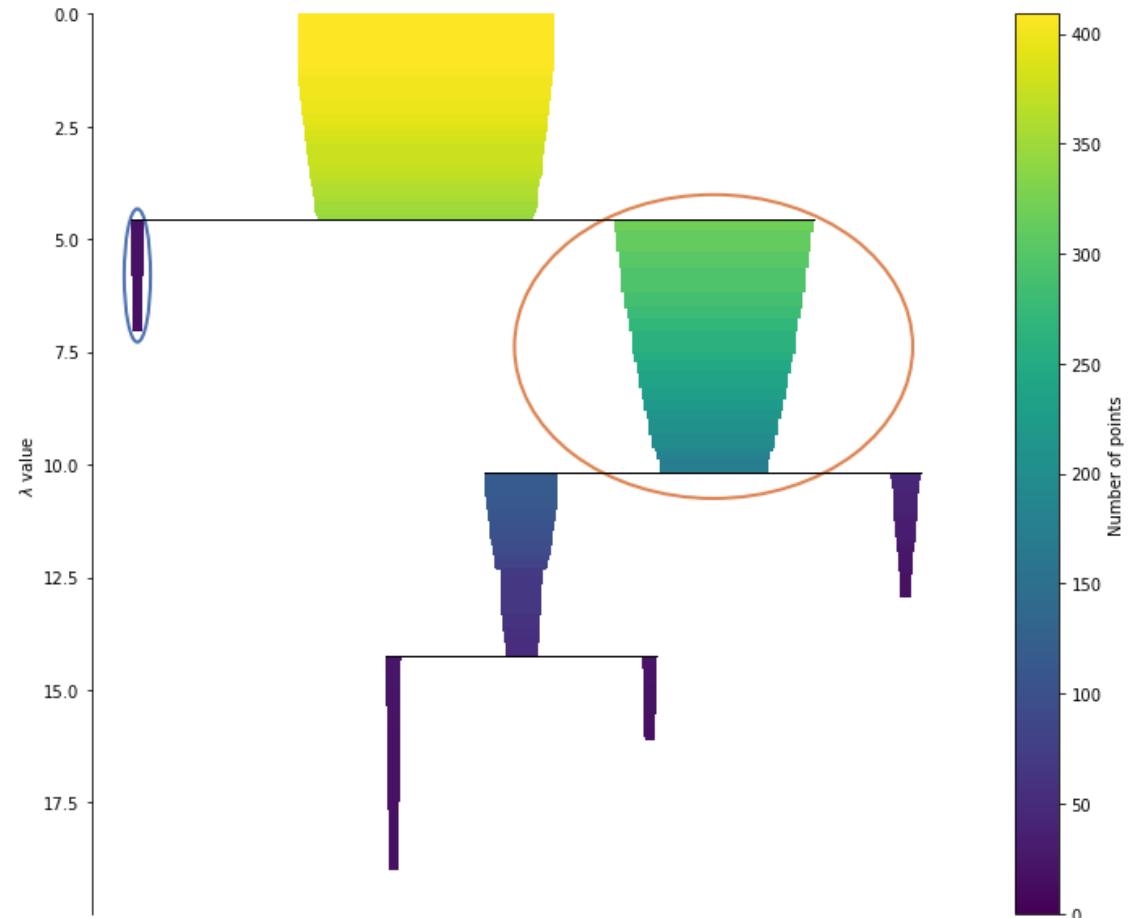


v_threshold = 0.60, total axons = 1400, sig axons = 735
v_threshold = 0.65, total axons = 1209, sig axons = 646
v_threshold = 0.70, total axons = 1019, sig axons = 556
v_threshold = 0.75, total axons = 857, sig axons = 472
v_threshold = 0.80, total axons = 718, sig axons = 409
v_threshold = 0.85, total axons = 571, sig axons = 335
v_threshold = 0.90, total axons = 419, sig axons = 249
v_threshold = 0.95, total axons = 243, sig axons = 148

Manifolds



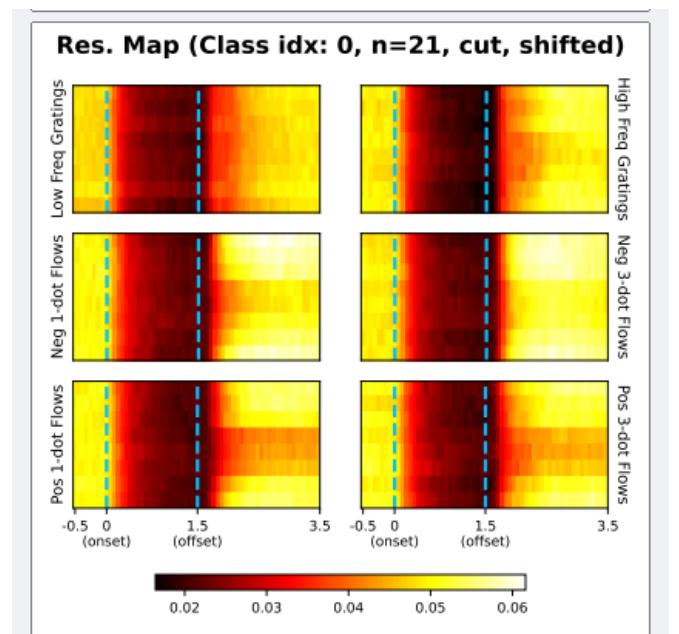
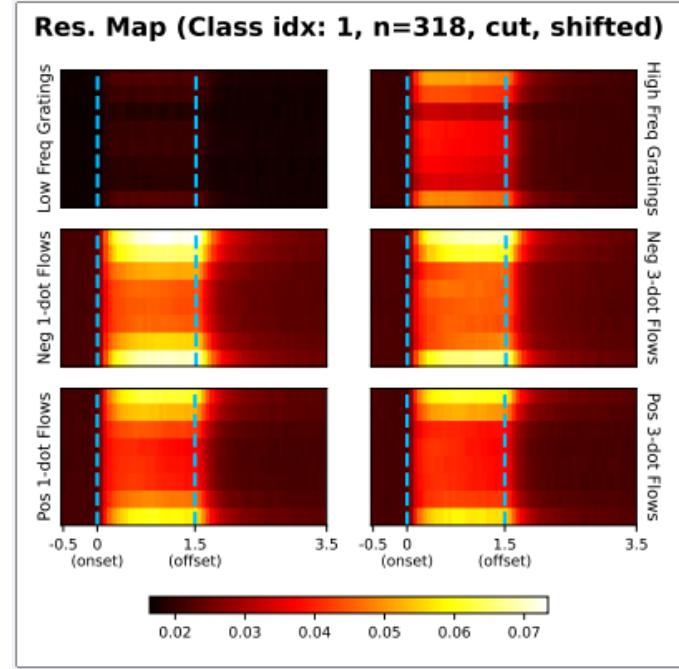
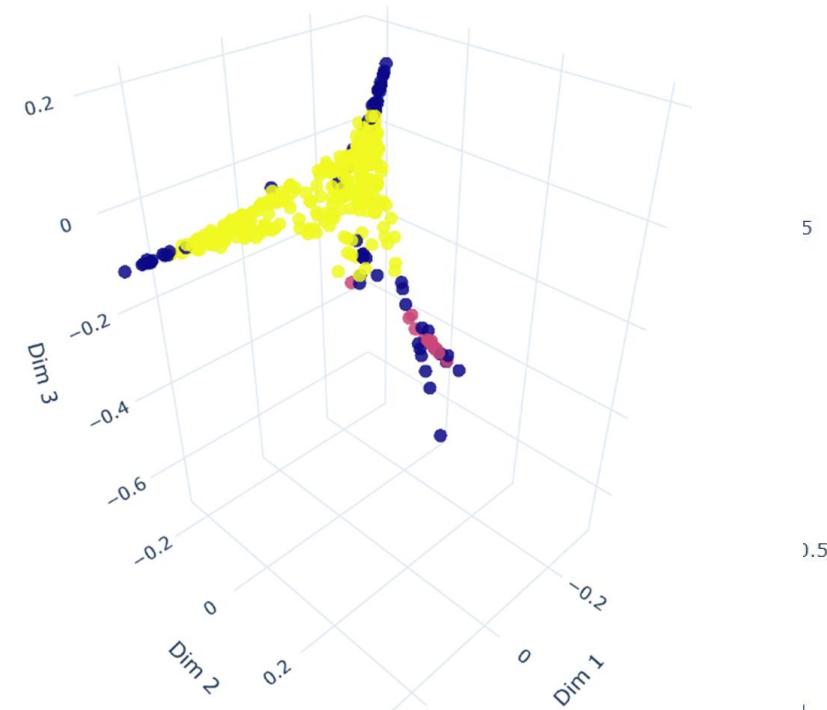
HDBSCAN clustering



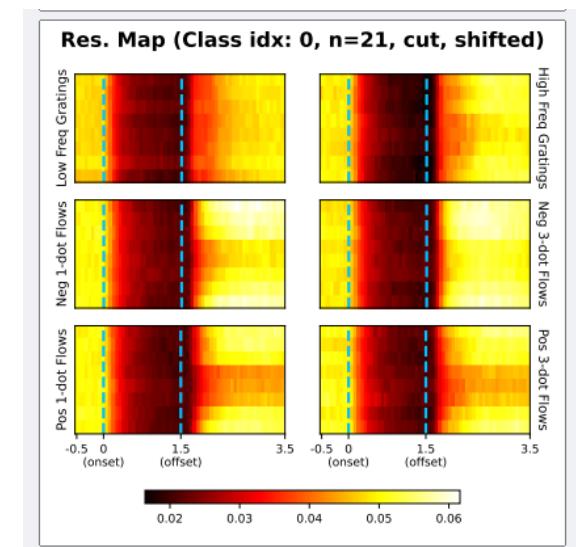
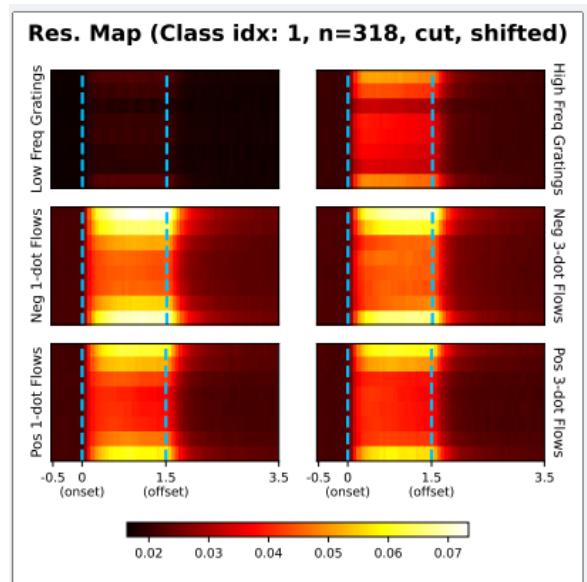
2 clusters. Min cluster size = 15 (13 clusters if min cluster size = 5)

Two clusters' avg response

N_c Neuron Diffusion Map (HDBSCAN Cluster Index)

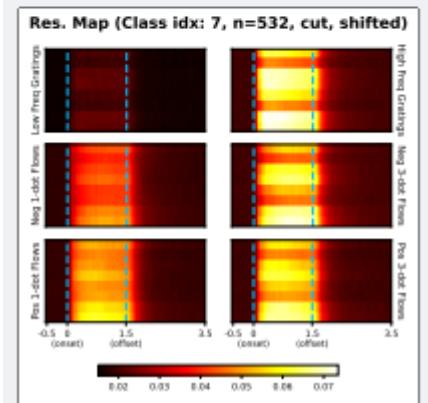
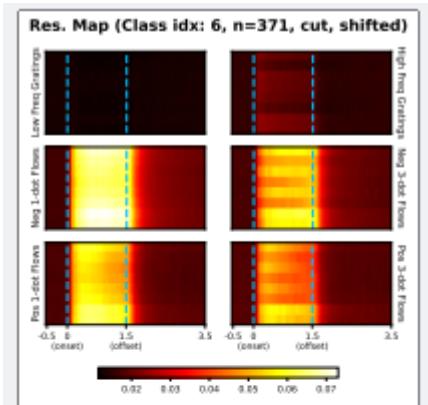
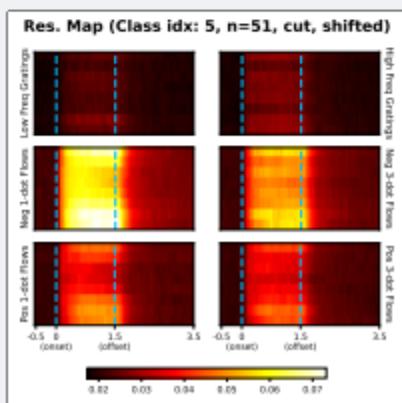
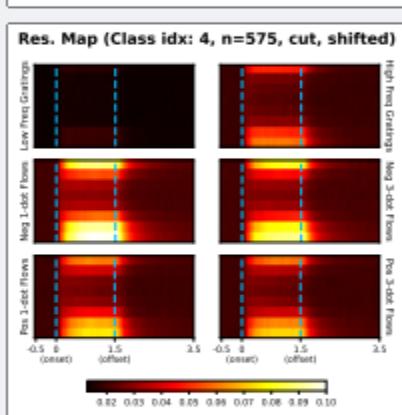
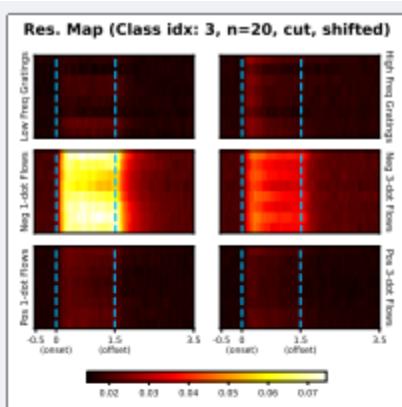
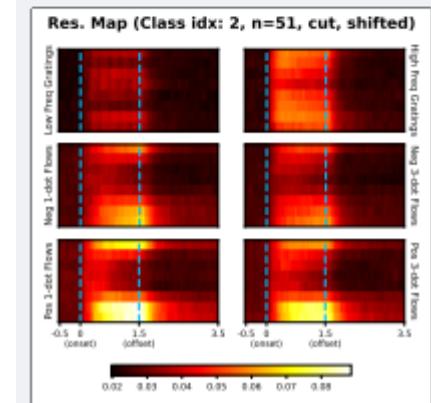
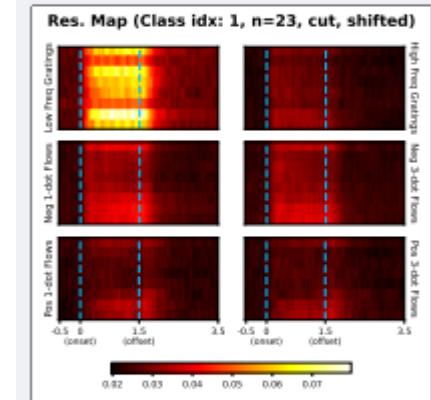
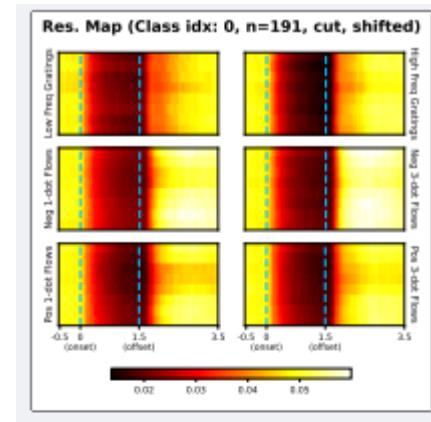


Two clusters of 409



VS

8 clusters of 2166



Thank you!