

Understanding inhibition in retinal circuits

Stephen A. Baccus

Stanford University School of Medicine, Department of Neurobiology

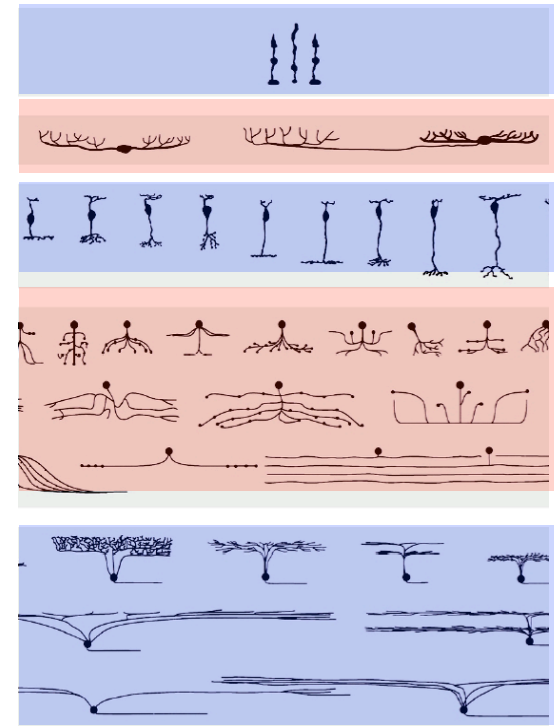
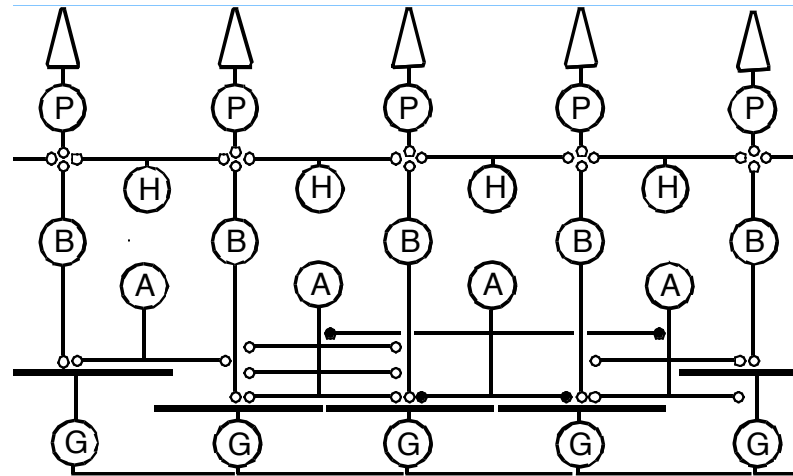
Photoreceptors

Horizontal cells

Bipolar cells

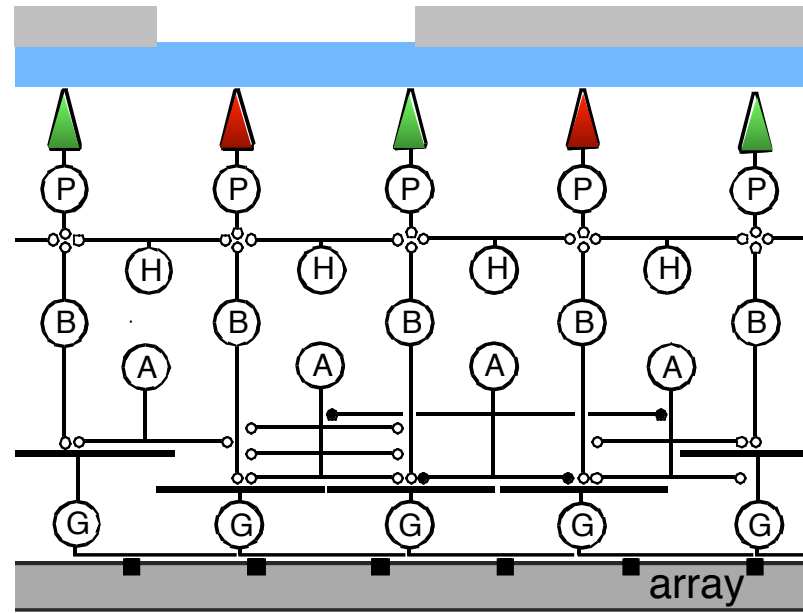
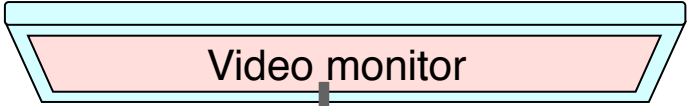
Amacrine cells

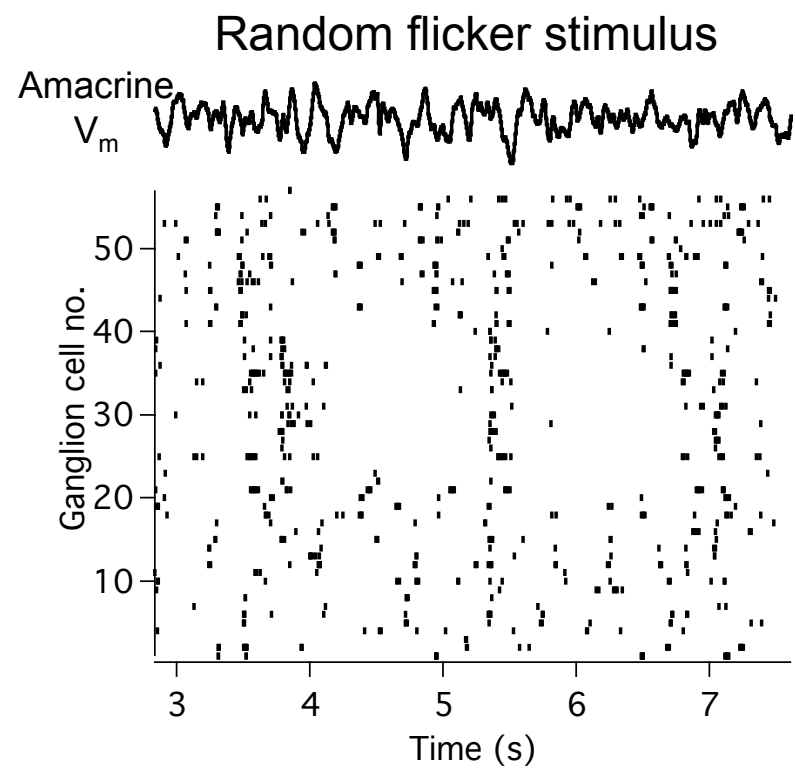
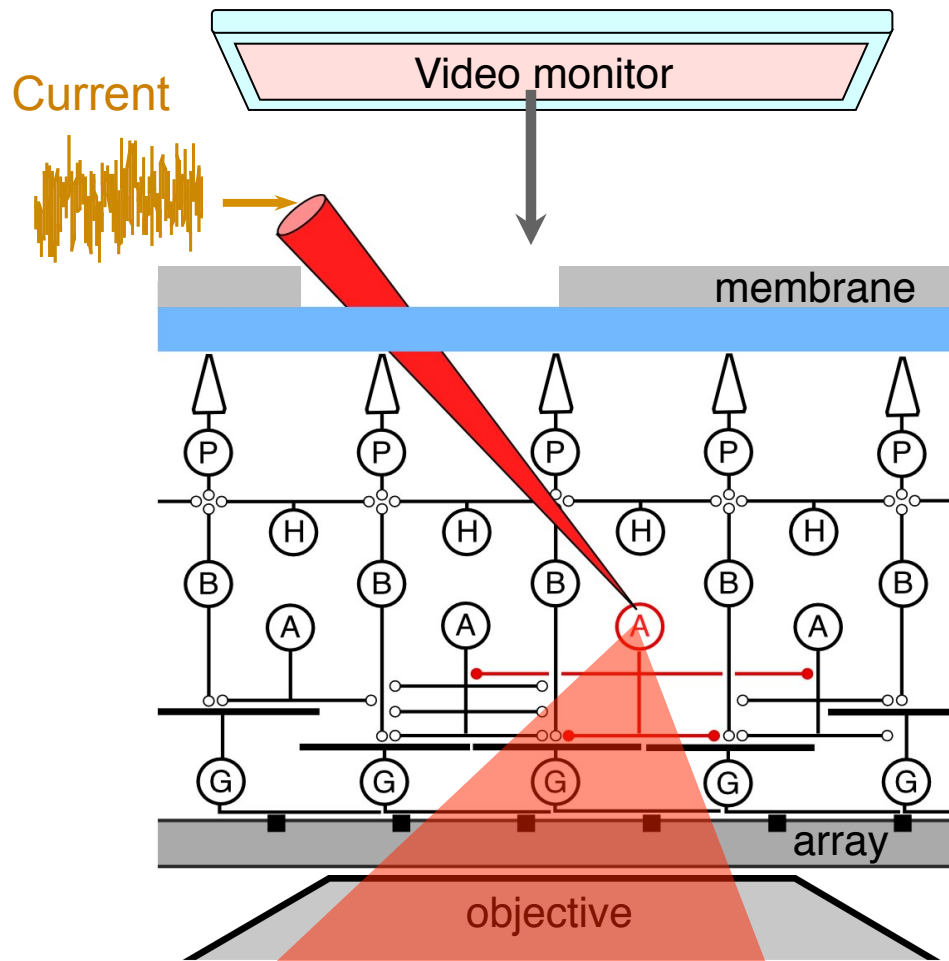
Ganglion cells



Masland (2001)

- Diversity of interneurons
- Synchrony
- Layered organization
- Different temporal channels
- Efficient use of wiring
- Noise
- Limited dynamic range

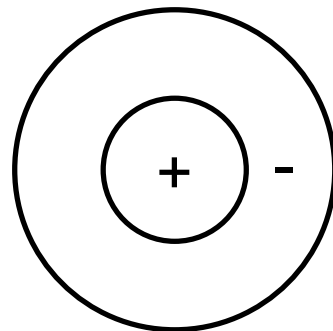




- The contribution of inhibitory interneurons to the linear receptive field
- Inhibition to generate a complex feature
- A new form of retinal short-term plasticity
- Using optical imaging and electrical recording together

Linear receptive field of retinal ganglion cells

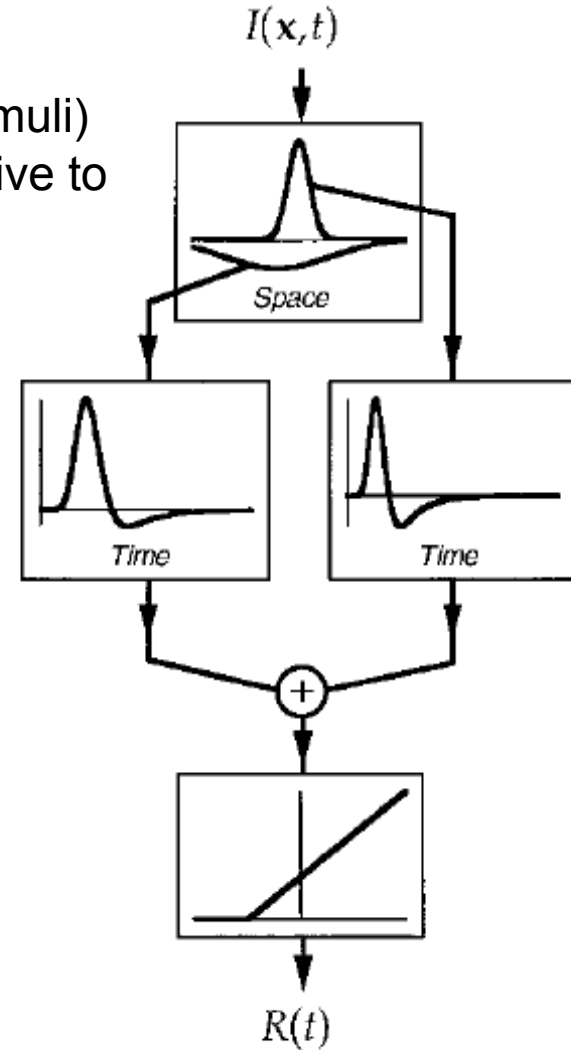
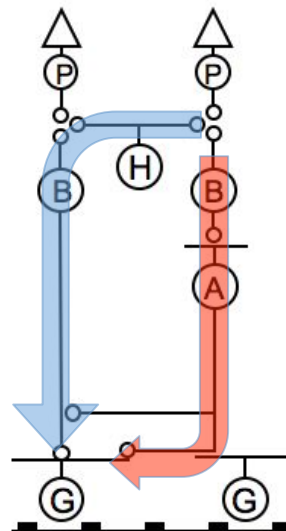
- Average feature preceding a spike (for white noise stimuli)
- Visual feature, on average, that the cell is most sensitive to



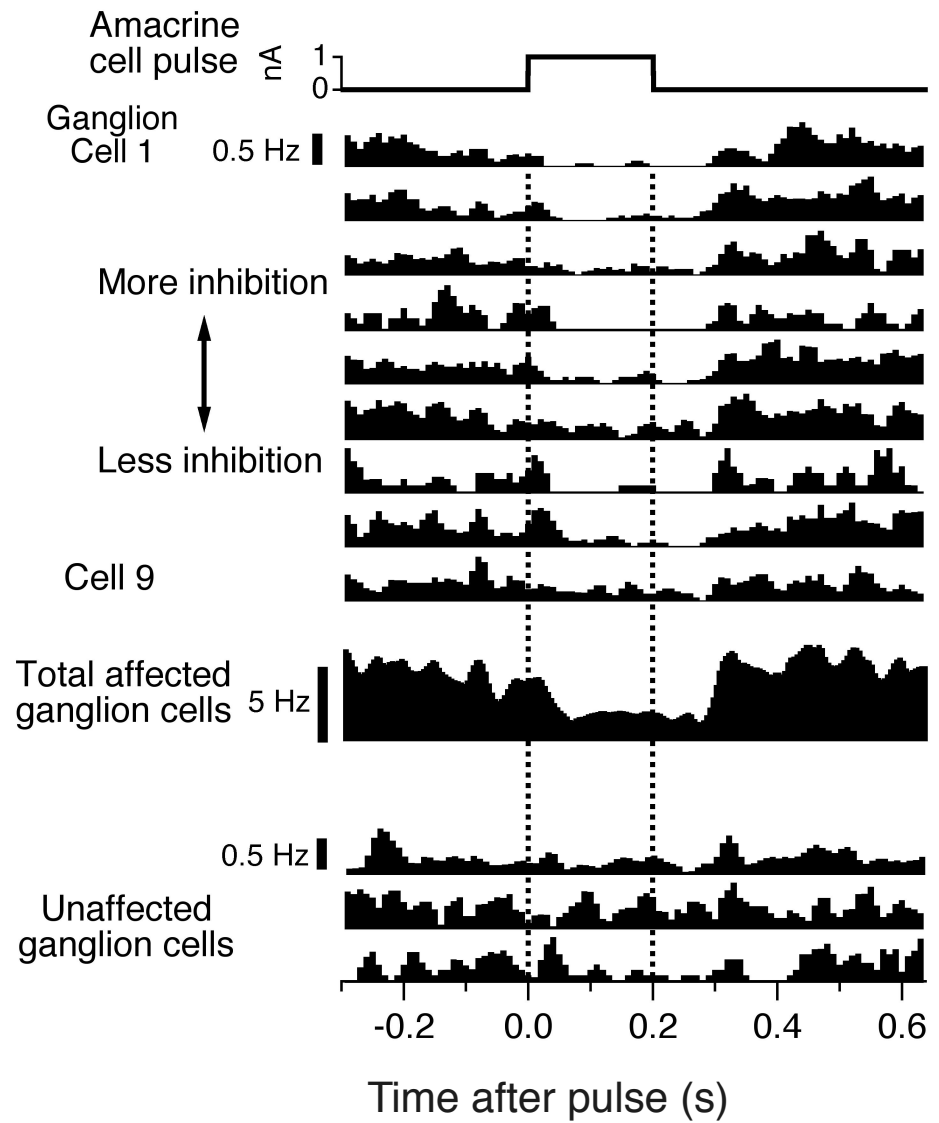
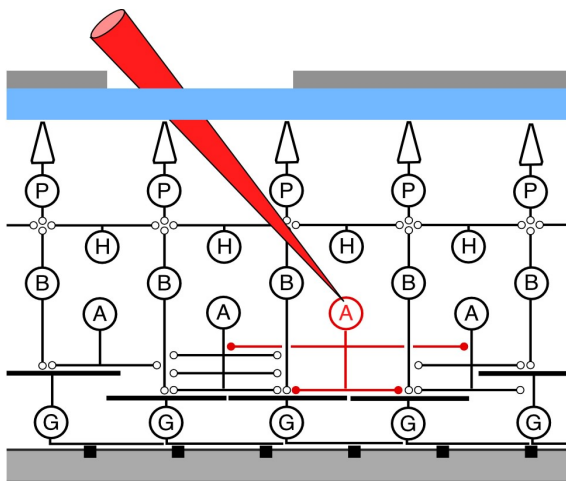
Kuffler, 1953

McMahon, Packer & Dacey (2004)
Primate surround primarily horizontal cells

Ichinose & Lukasiewicz (2005)
Salamander surround both horizontal and amacrine cells

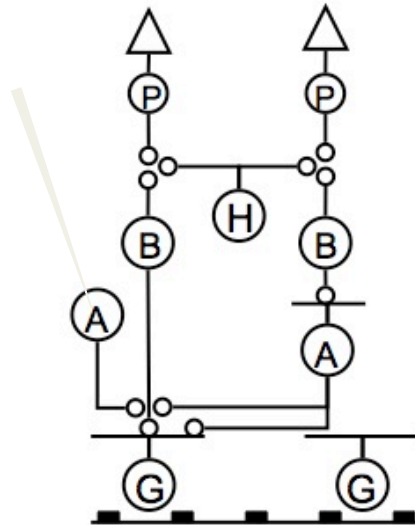


Rodieck, 1965
Enroth-Cugell et al., 1983
Meister & Berry, 1999



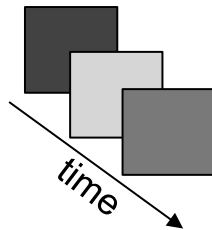
White noise analysis

Video monitor

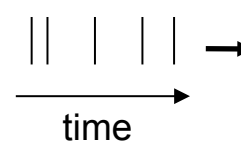


Multielectrode array

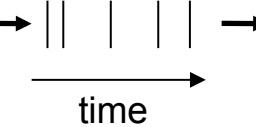
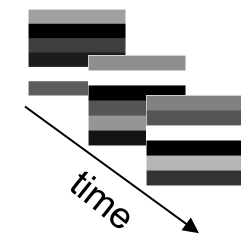
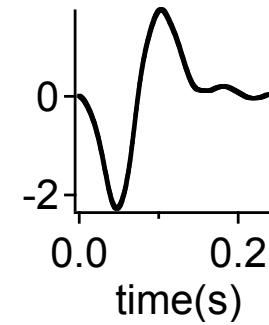
Visual stimulus



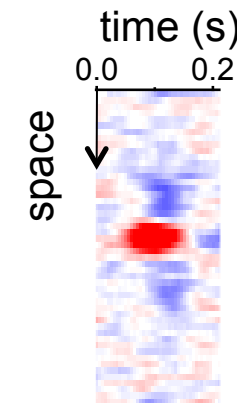
Spike train



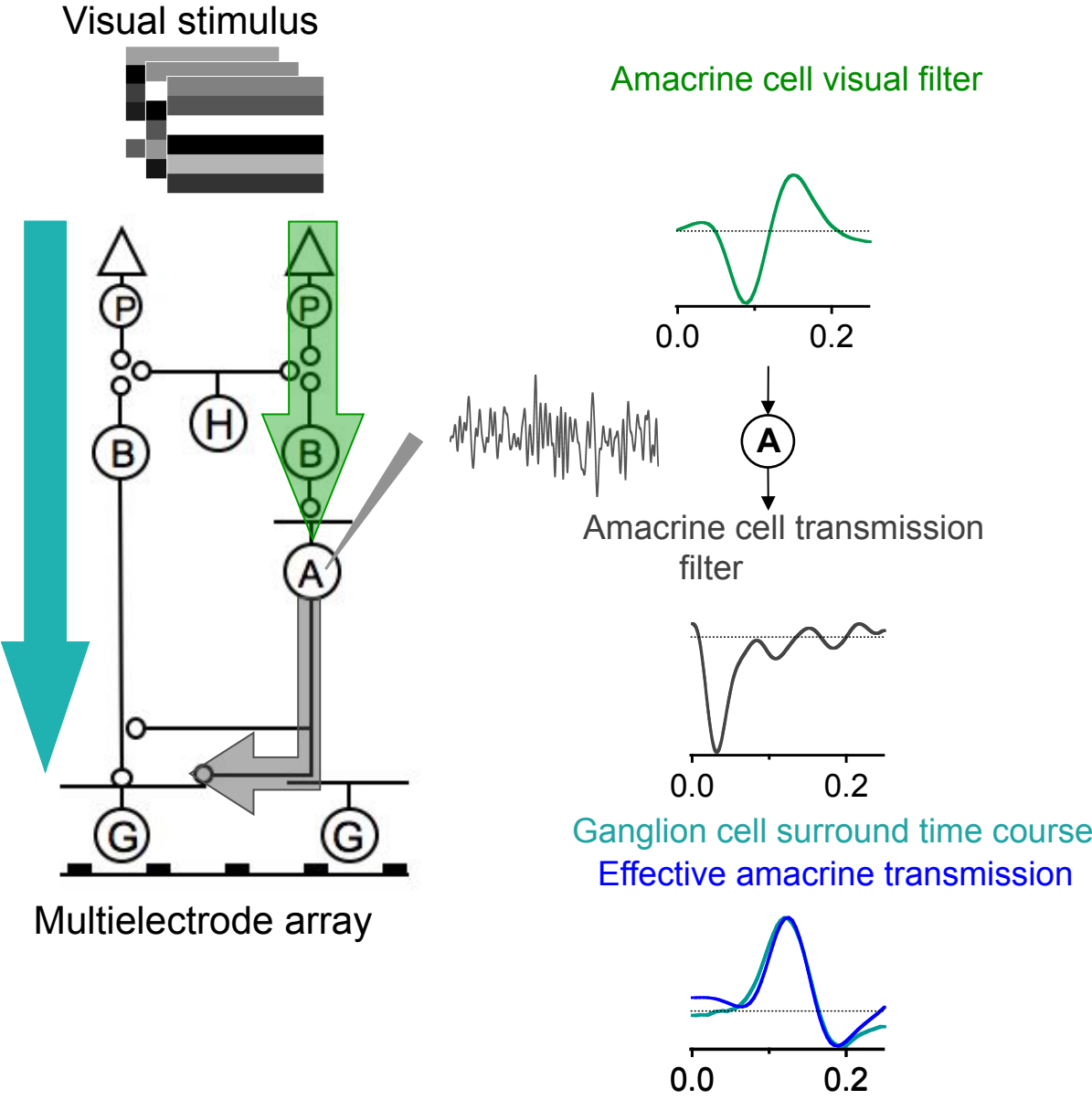
Temporal receptive field



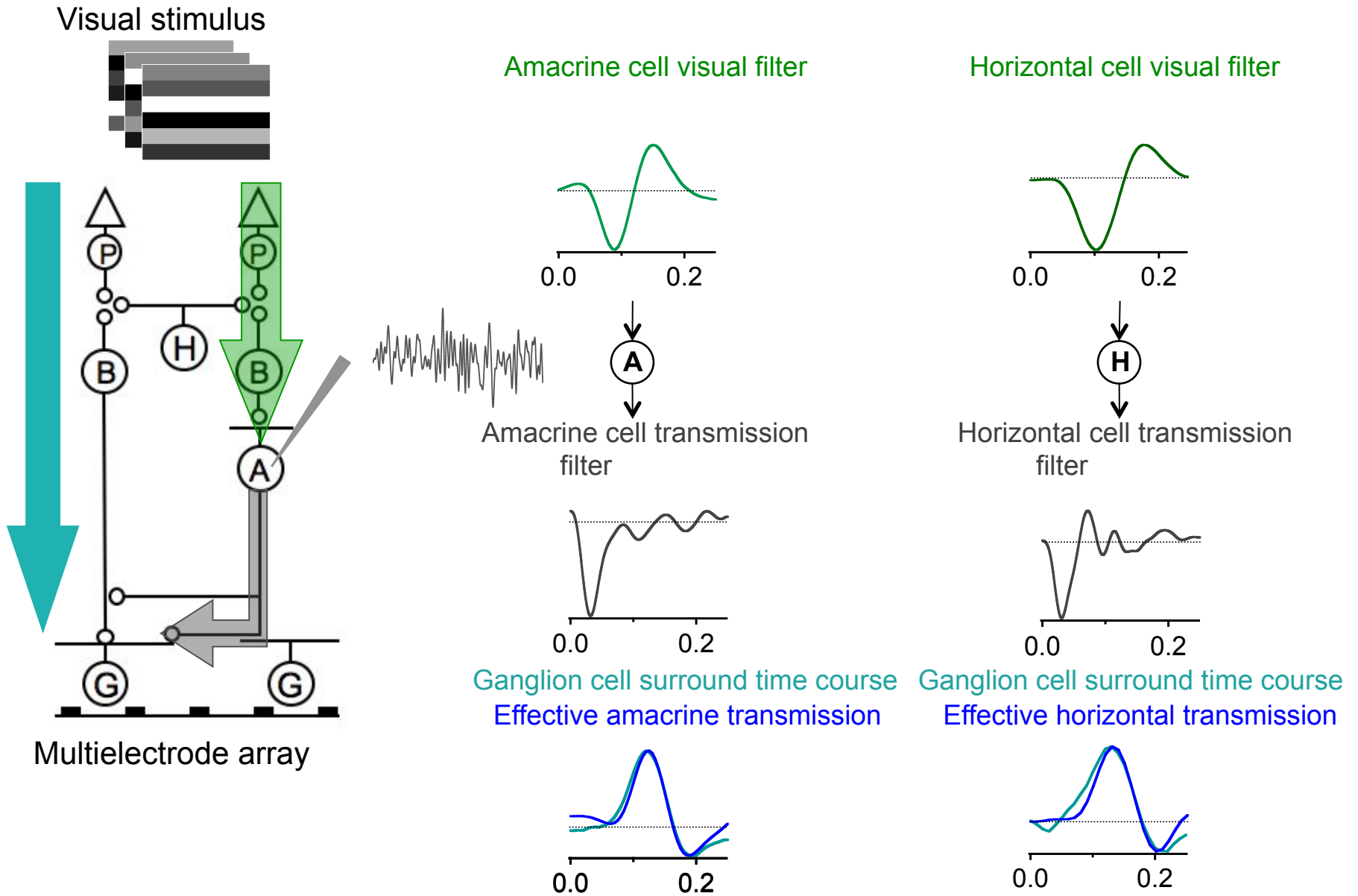
Spatio-temporal receptive field



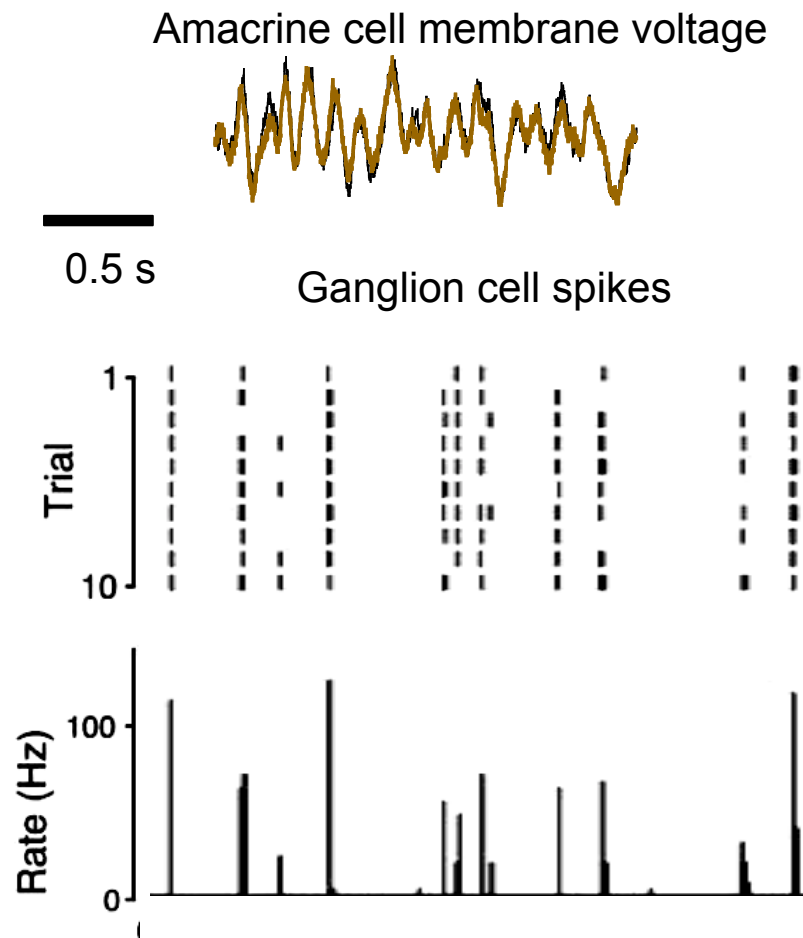
Amacrine cell transmission matches the ganglion cell linear surround



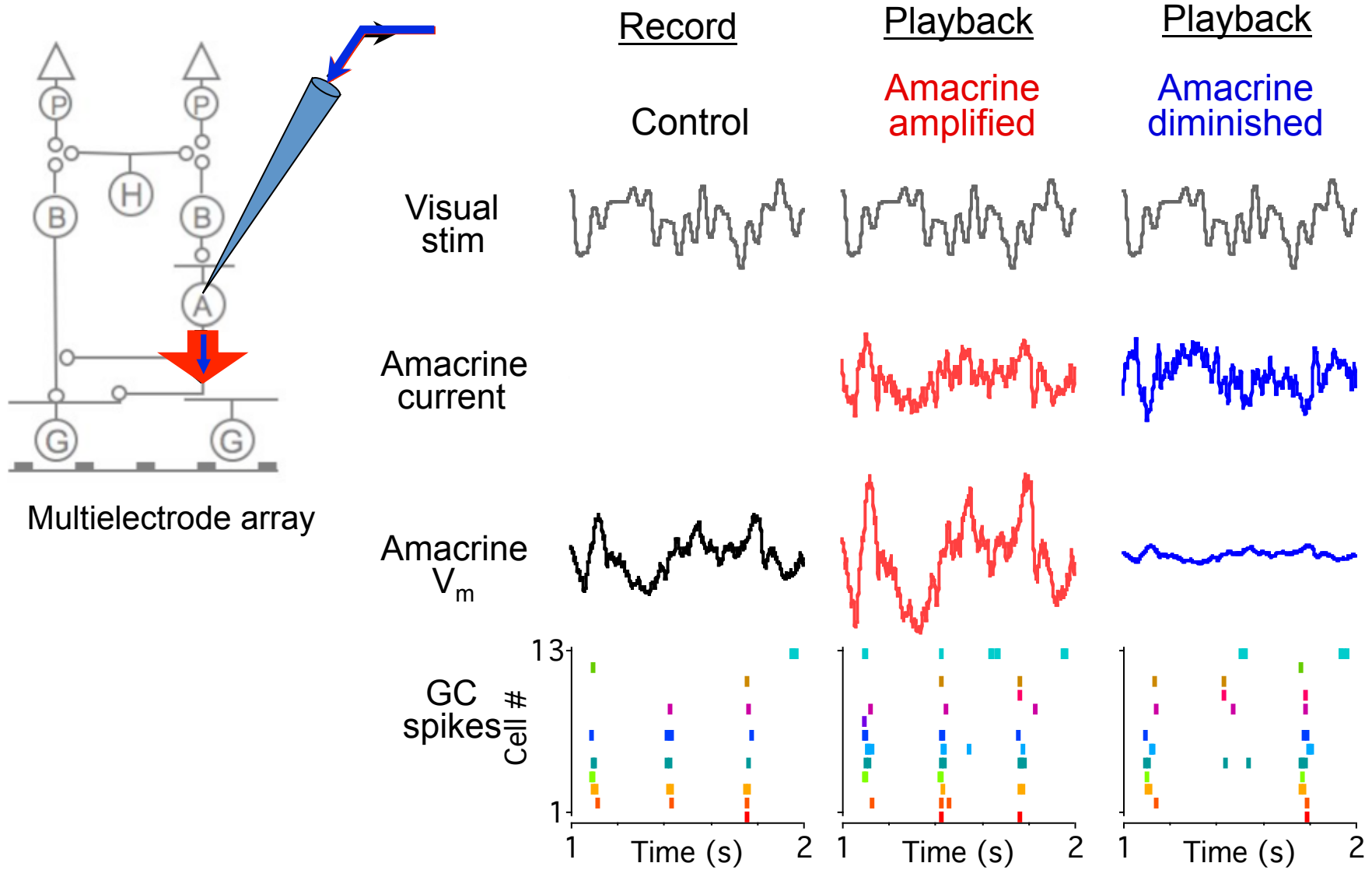
Amacrine and Horizontal cells contribute to the ganglion cell linear surround



Retinal responses are highly reproducible

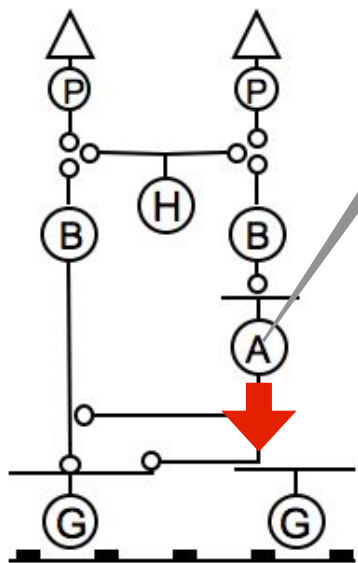


Measuring how an amacrine cell changes the ganglion cell receptive field

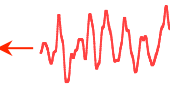


Measuring how an amacrine cell changes the ganglion cell receptive field - Record and Playback

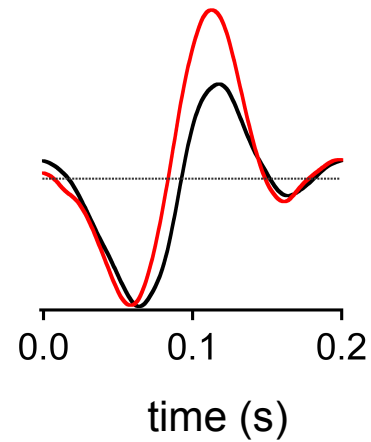
Video monitor



Amacrine cell amplified



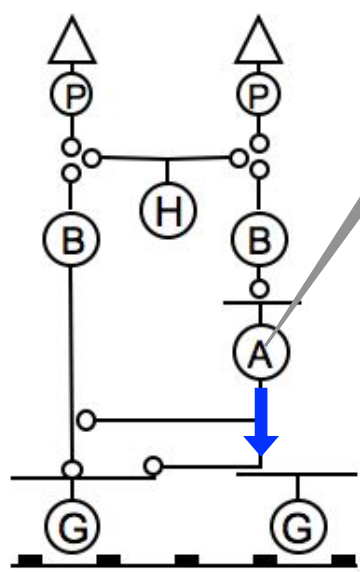
Ganglion cell visual filter



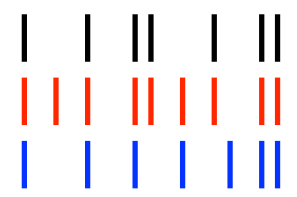
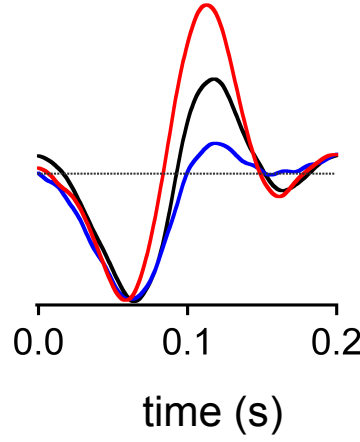
Measuring how an amacrine cell changes the ganglion cell receptive field - Record and Playback

Video monitor

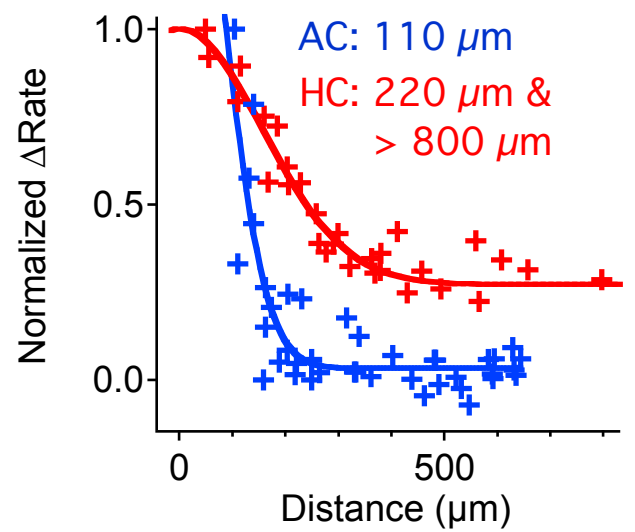
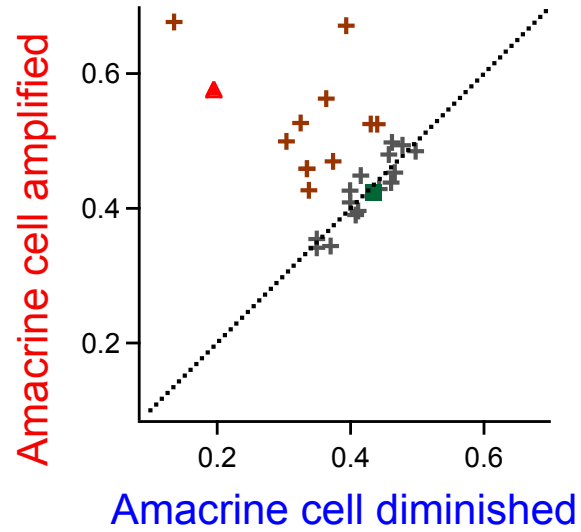
Ganglion cell visual filter



Amacrine cell amplified
Amacrine cell diminished

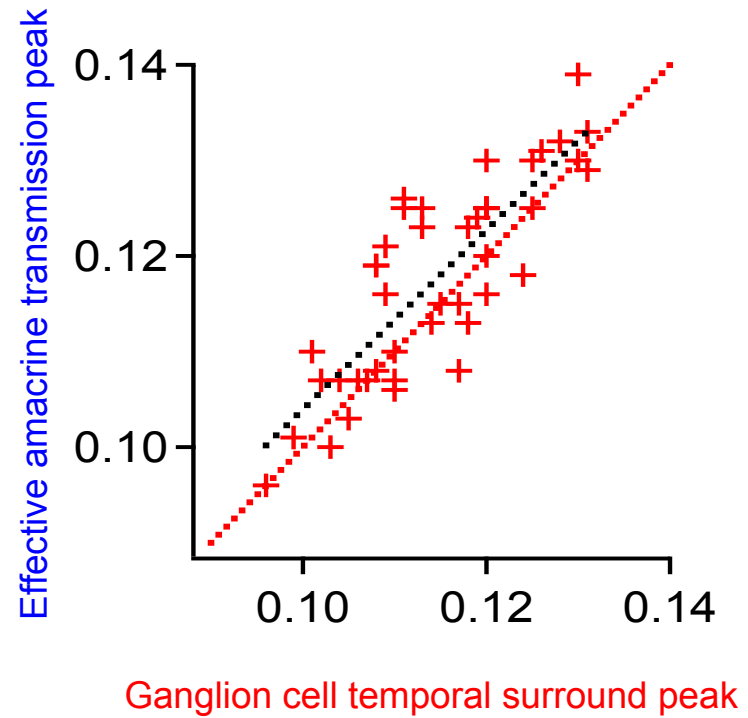
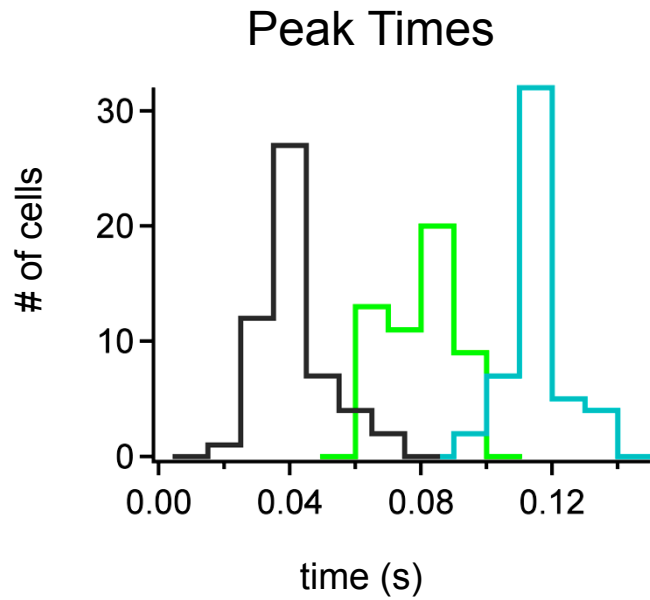


Normalized surround amplitude

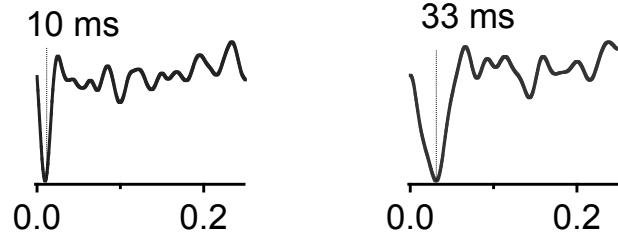


Transmission of diverse amacrine cells is matched to the ganglion cell surround

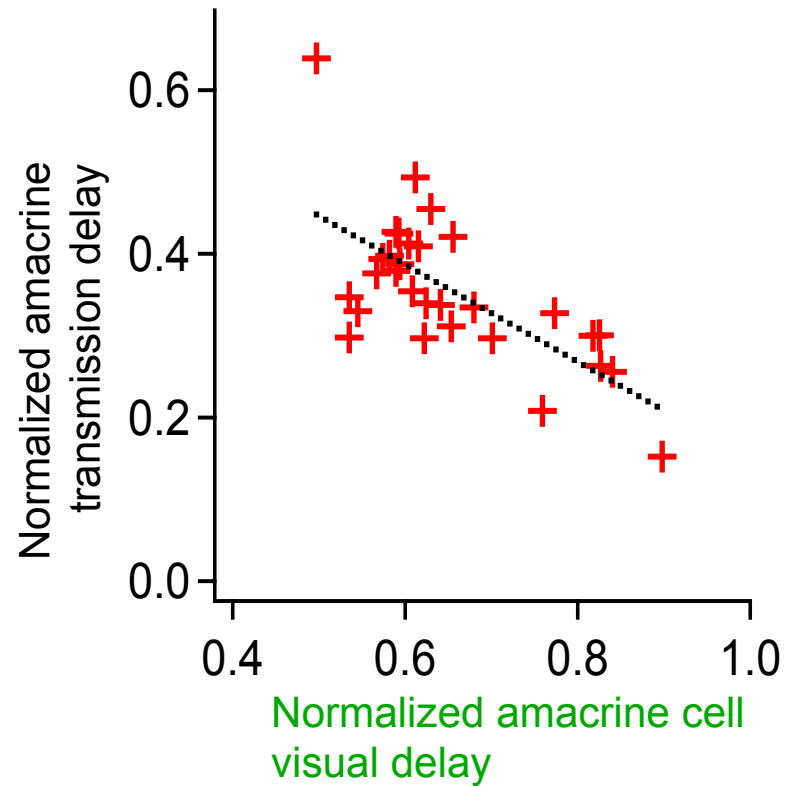
Amacrine visual filter
Transmission filter
Ganglion cell surround



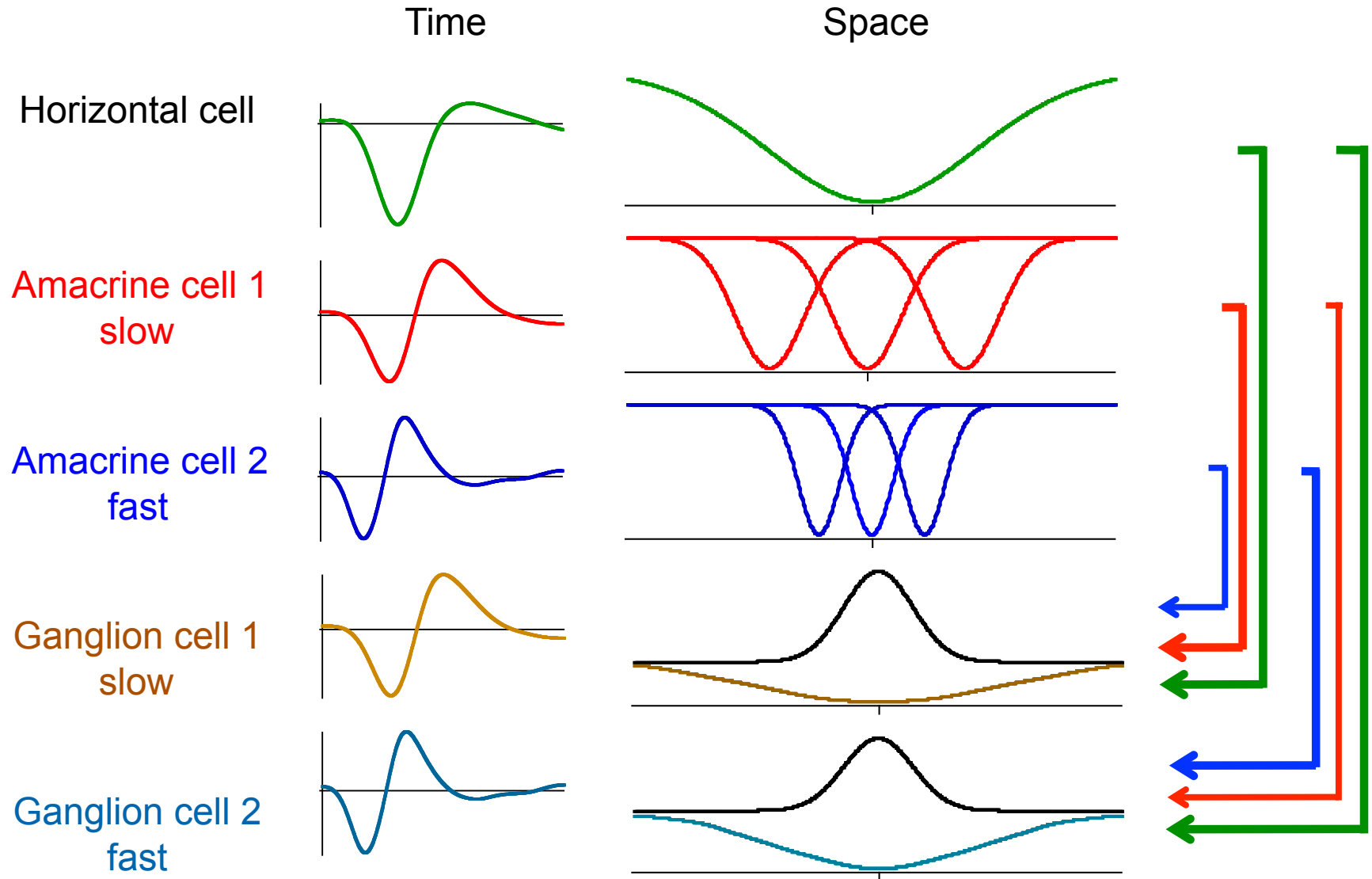
Slow and fast transmission filters



Transmission from amacrine cells with different kinetics is matched to ganglion cells with similar kinetics



Multiple inhibitory interneurons generate the linear surround



Combining measured input and output in a model gives an estimate of the cell's functional contribution

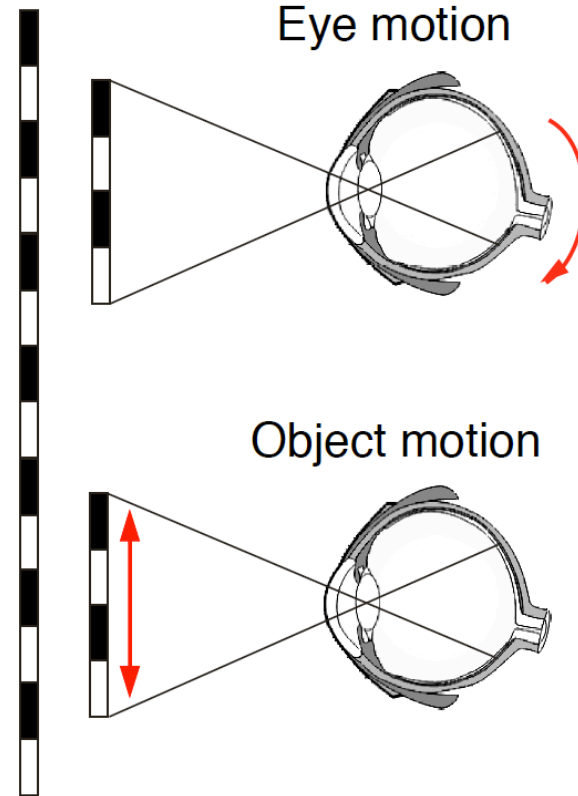
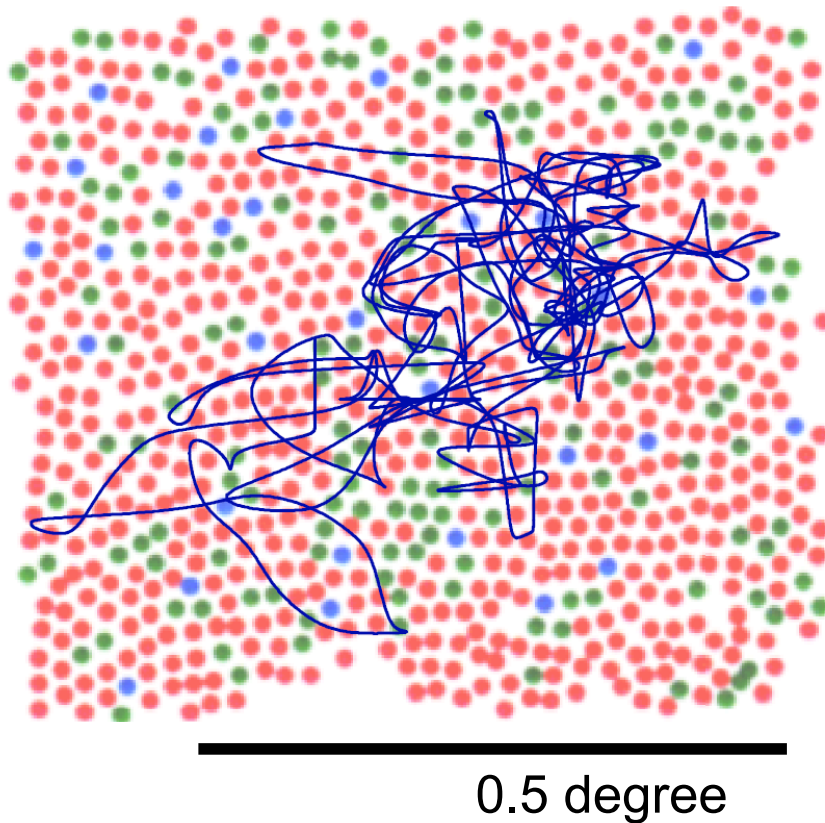
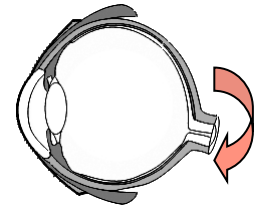
Playback of interneuron responses allows a causal measurement of the cell's functional role

Horizontal cells and diverse amacrine cells contribute to the salamander ganglion cell linear surround

Diverse amacrine cell inputs may allow the linear surround to be flexible, efficient and adaptive

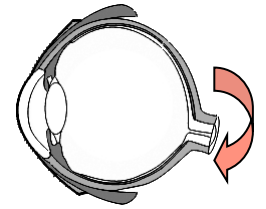
What's moving: the eye or the object?

The Real World + Fixational Eye - movements = Retinal Image

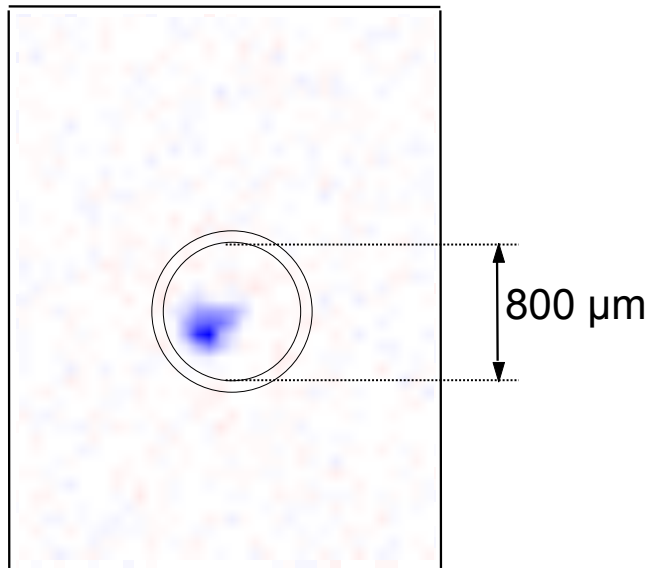


What's moving: the eye or the object?

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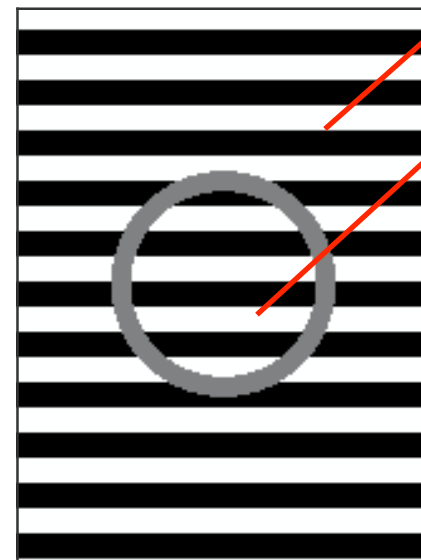


Ganglion cell receptive field

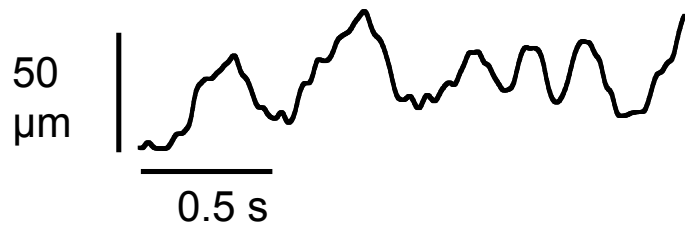


Background

Object



Rabbit fixational eye movements



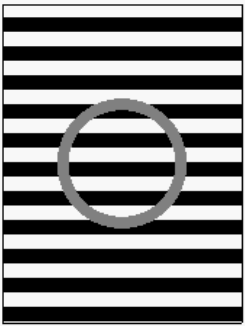
Random walk



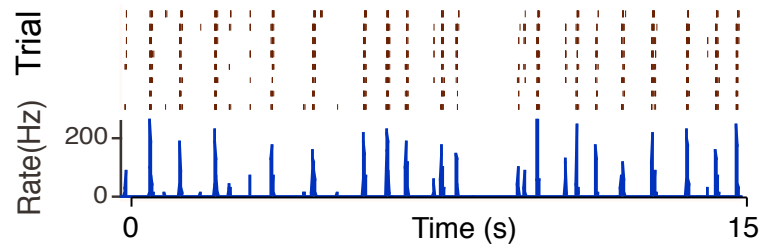
Ölveczky, Baccus & Meister (2003)

Object motion sensitive ganglion cells

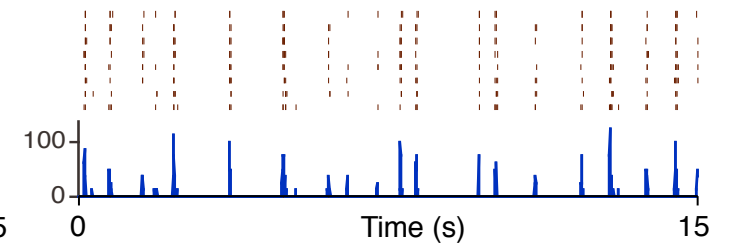
Differential motion
(Object + Eye)



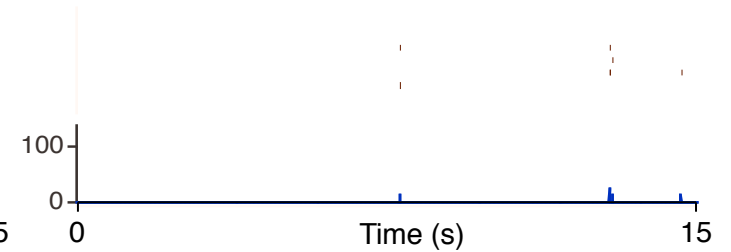
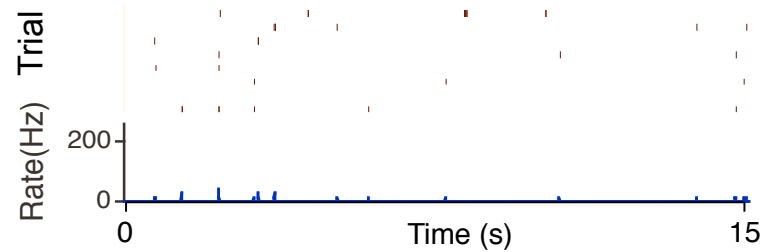
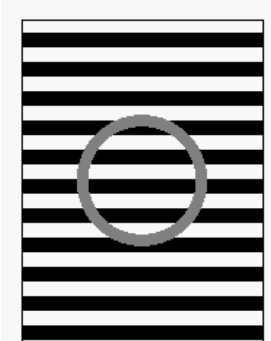
Rabbit "ON Brisk Transient"

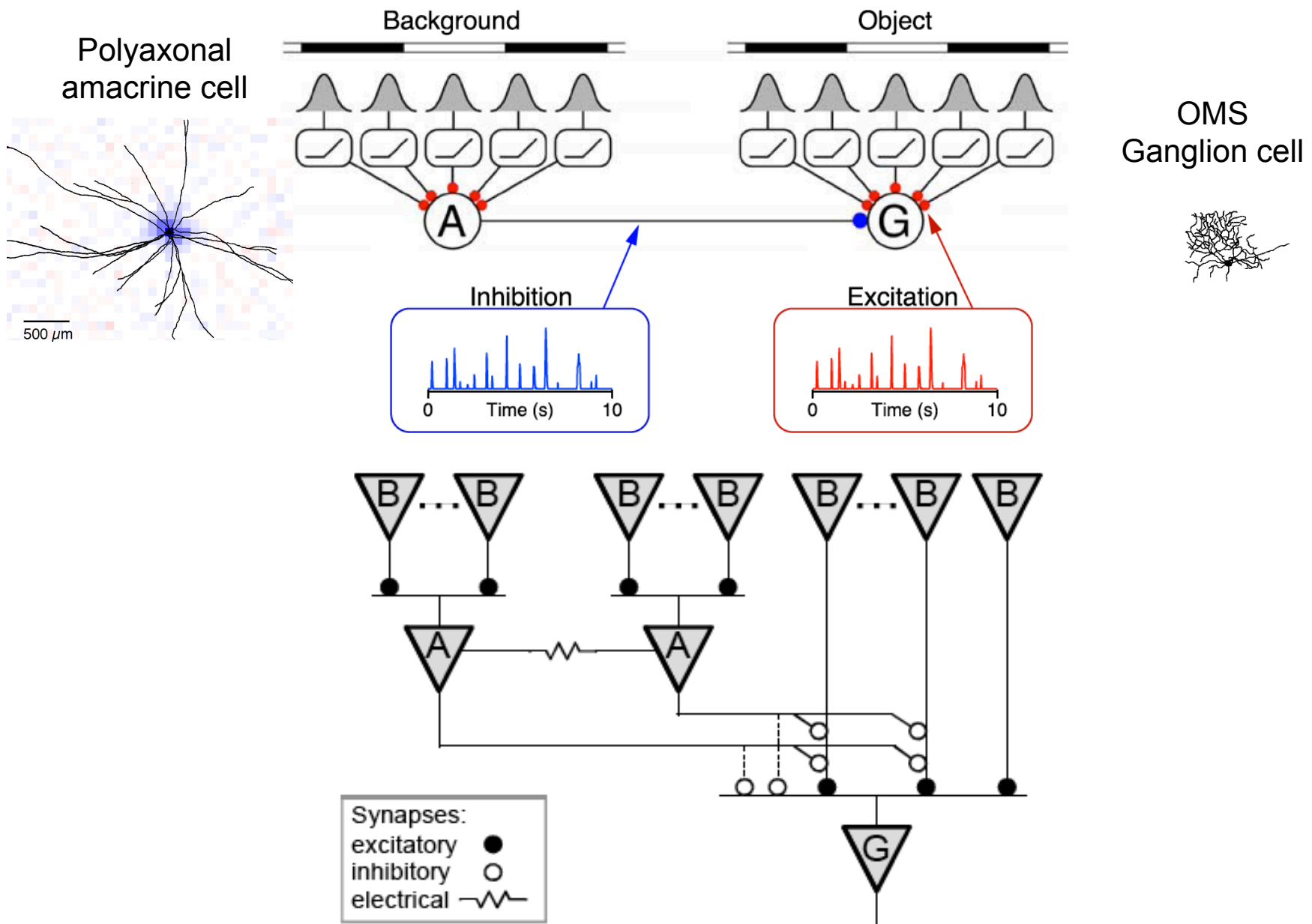


Salamander "Fast OFF"



Global motion
(Eye Only)

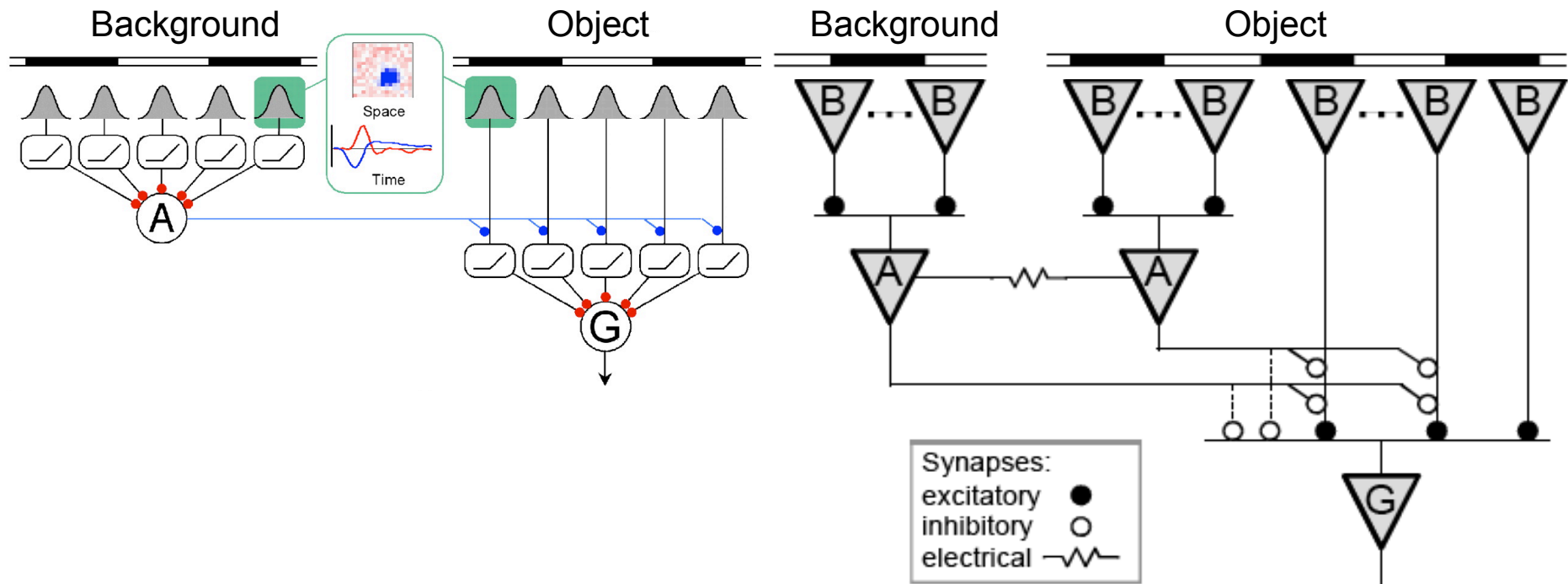




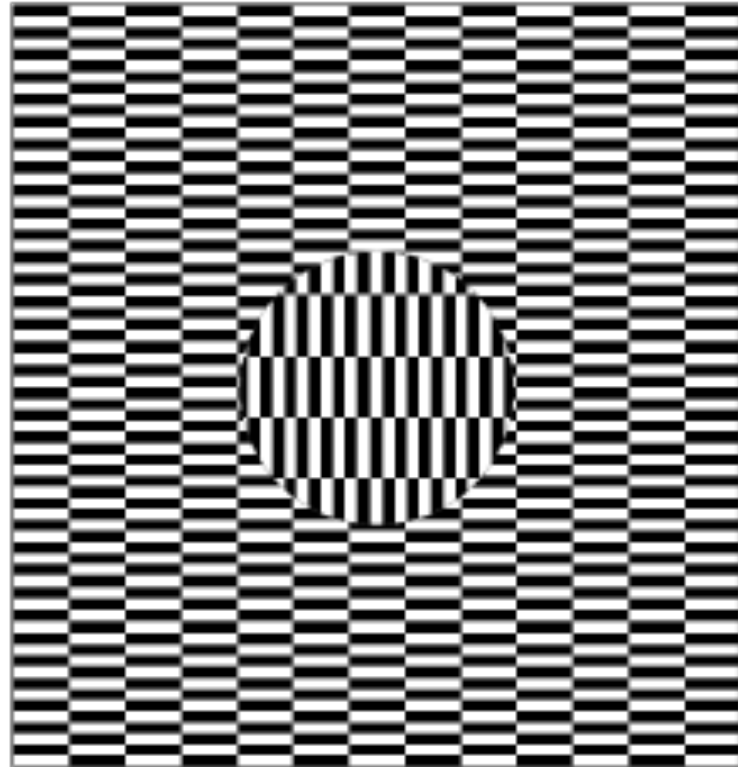
Object motion sensitive circuit and model

Selectivity for object motion can be explained by a circuit containing:

- Fast Off Bipolar cells as nonlinear subunits
- Nonlinear polyaxonal amacrine cells with large projective fields
- Nonlinear ganglion cells
- Amacrine and ganglion cells that receive synchronous input during background motion
- Amacrine cells that inhibit the synaptic inputs to OMS ganglion cells



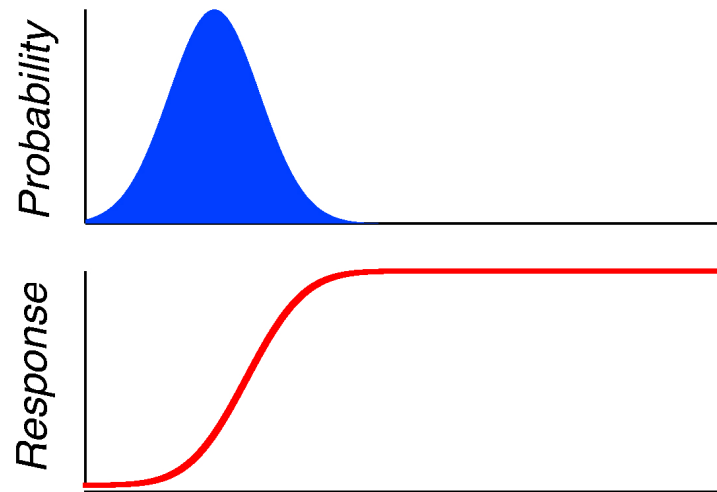
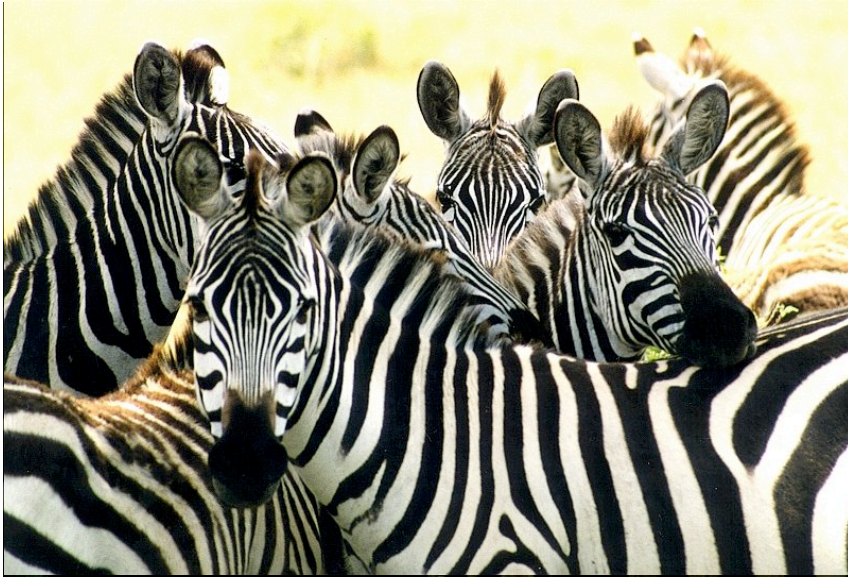
Apparent motion percept reflecting eye movements



Ouchi

Stimulate center with horizontal eye movements, surround with vertical eye movements

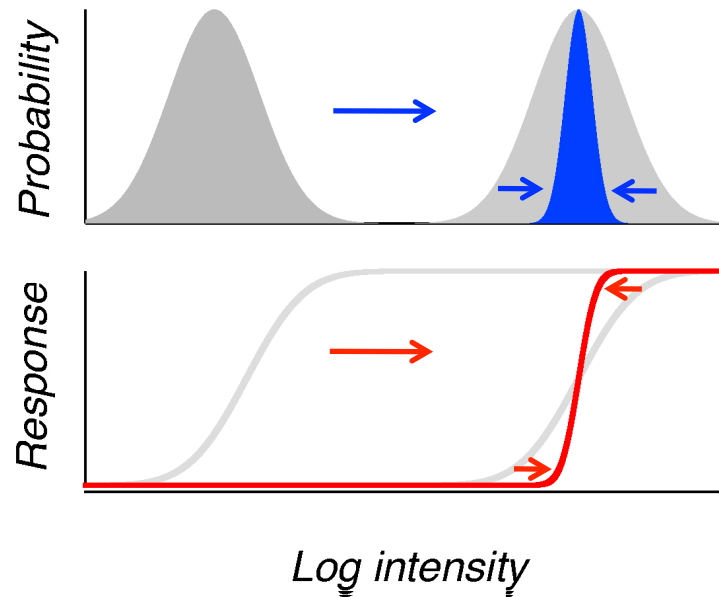
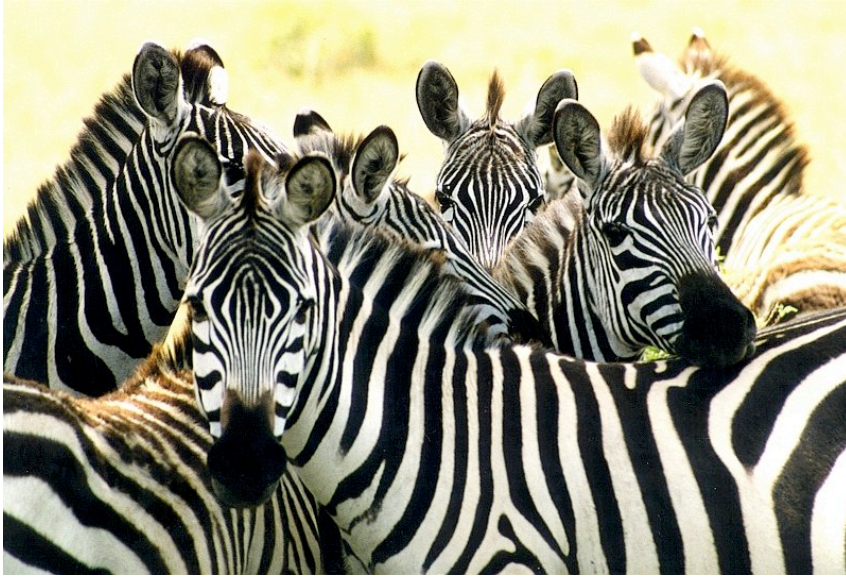
Adaptation in a changing environment



Log intensity

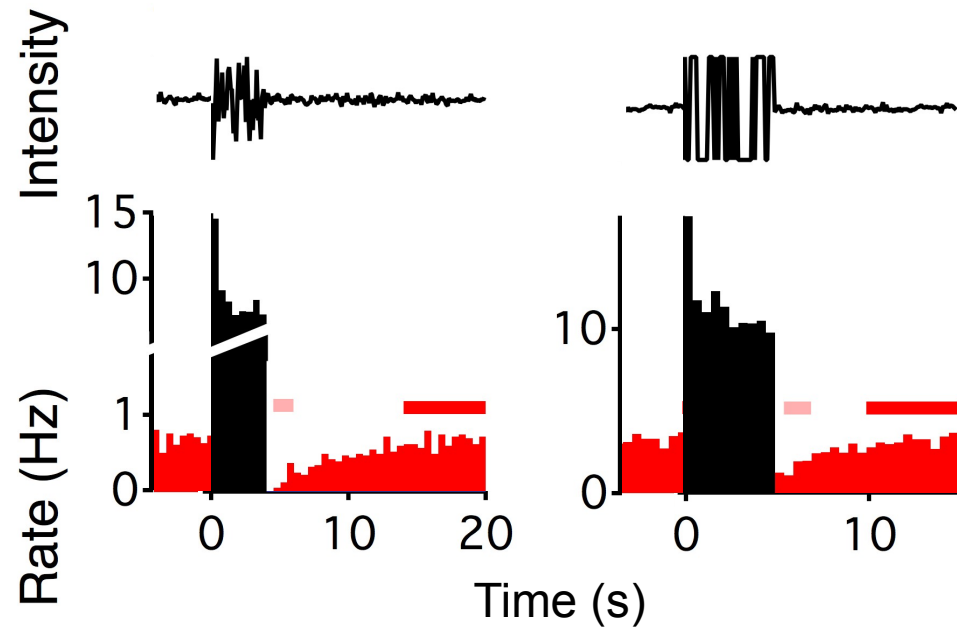
Laughlin, 1981

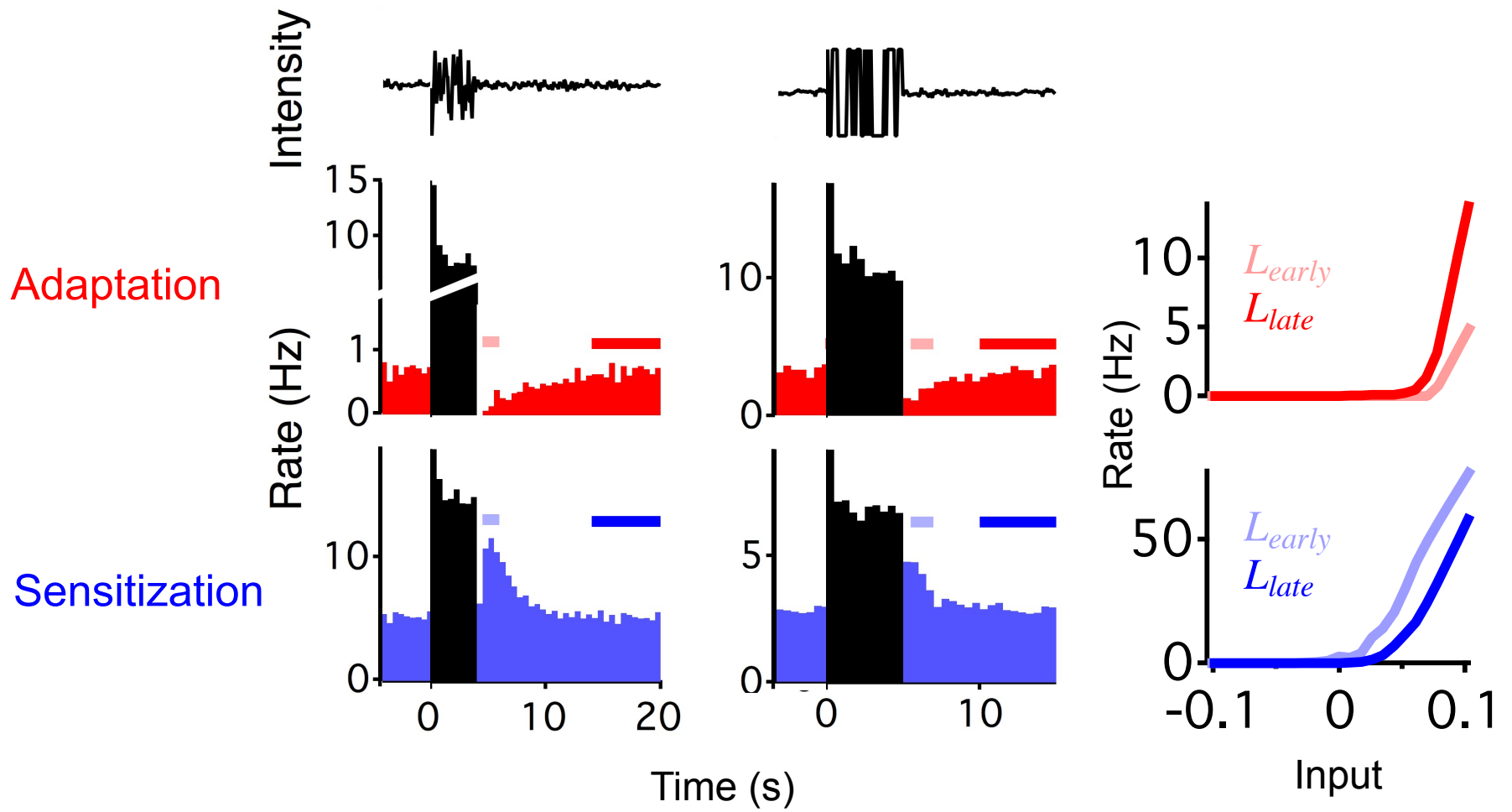
Adaptation in a changing environment



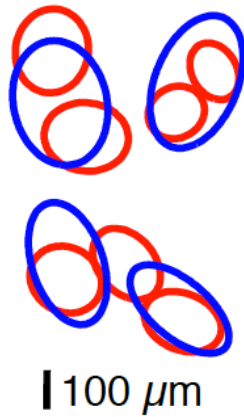
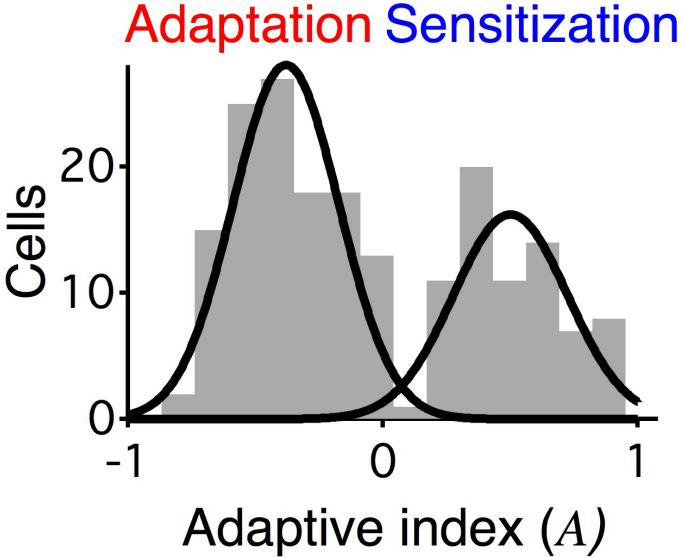
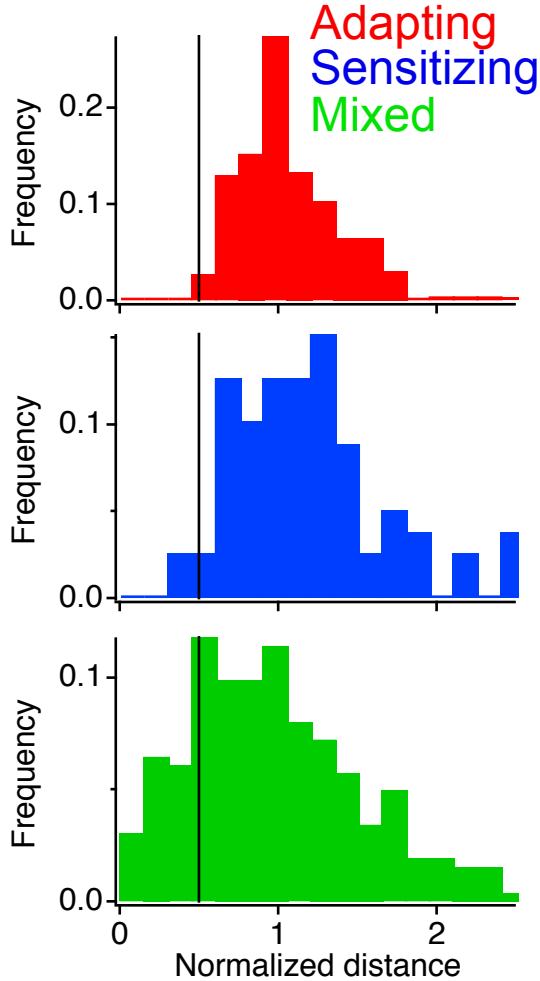
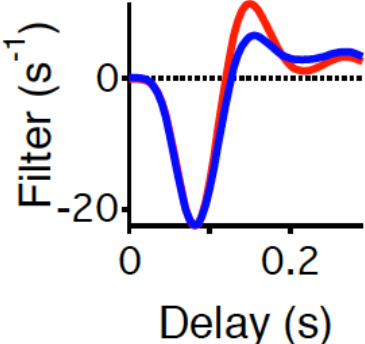
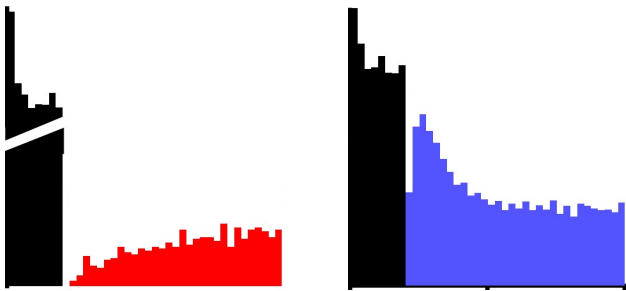
Blakemore & Campbell, 1969
Shapley & Victor, 1979
Smirnakis et al., 1997

Adaptation



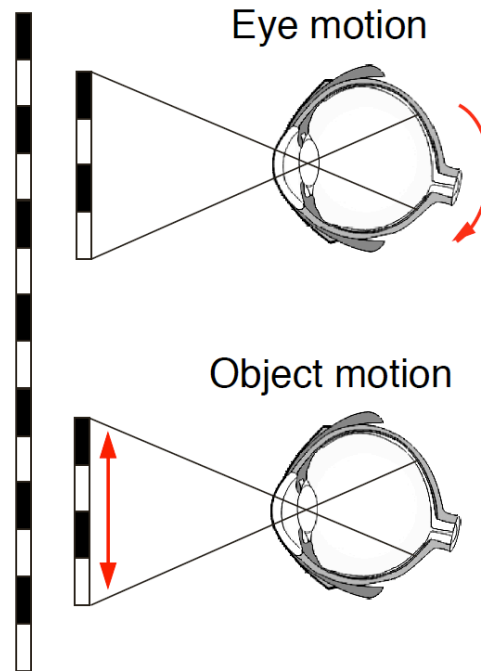
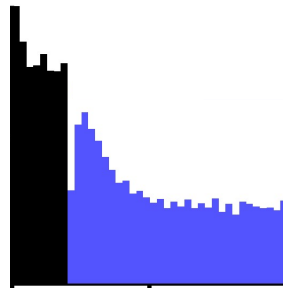


Adaptation and sensitization are distinct forms of short-term plasticity



Changing spatio-temporal contrast from different sources of motion

Sensitization



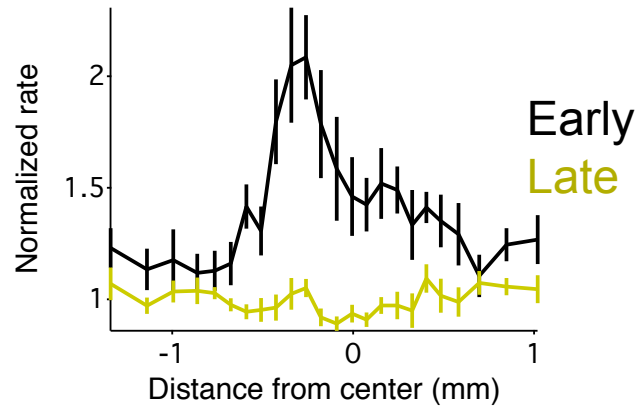
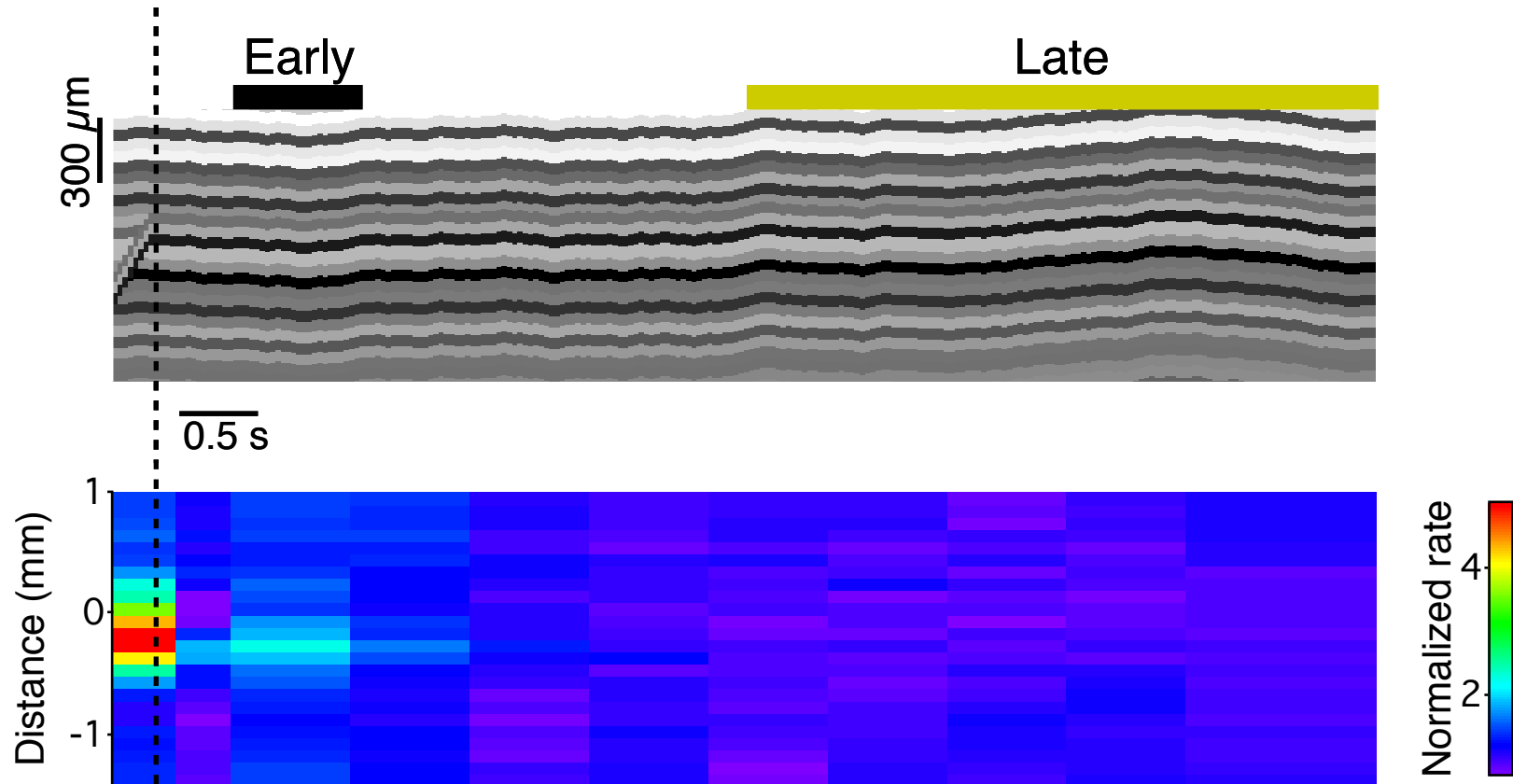
Camouflage as changing spatio-temporal contrast



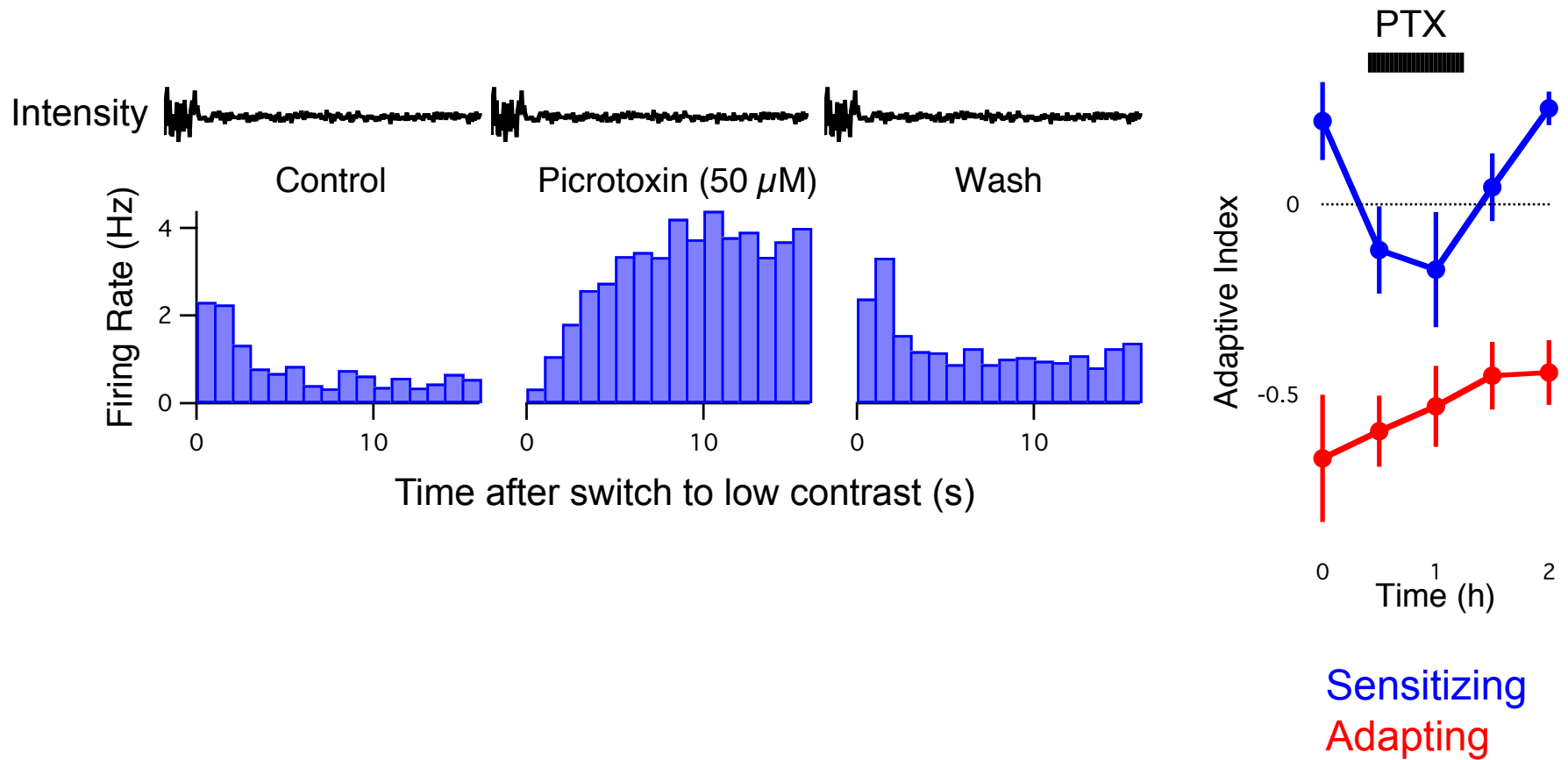
Stimulus representing camouflaged object



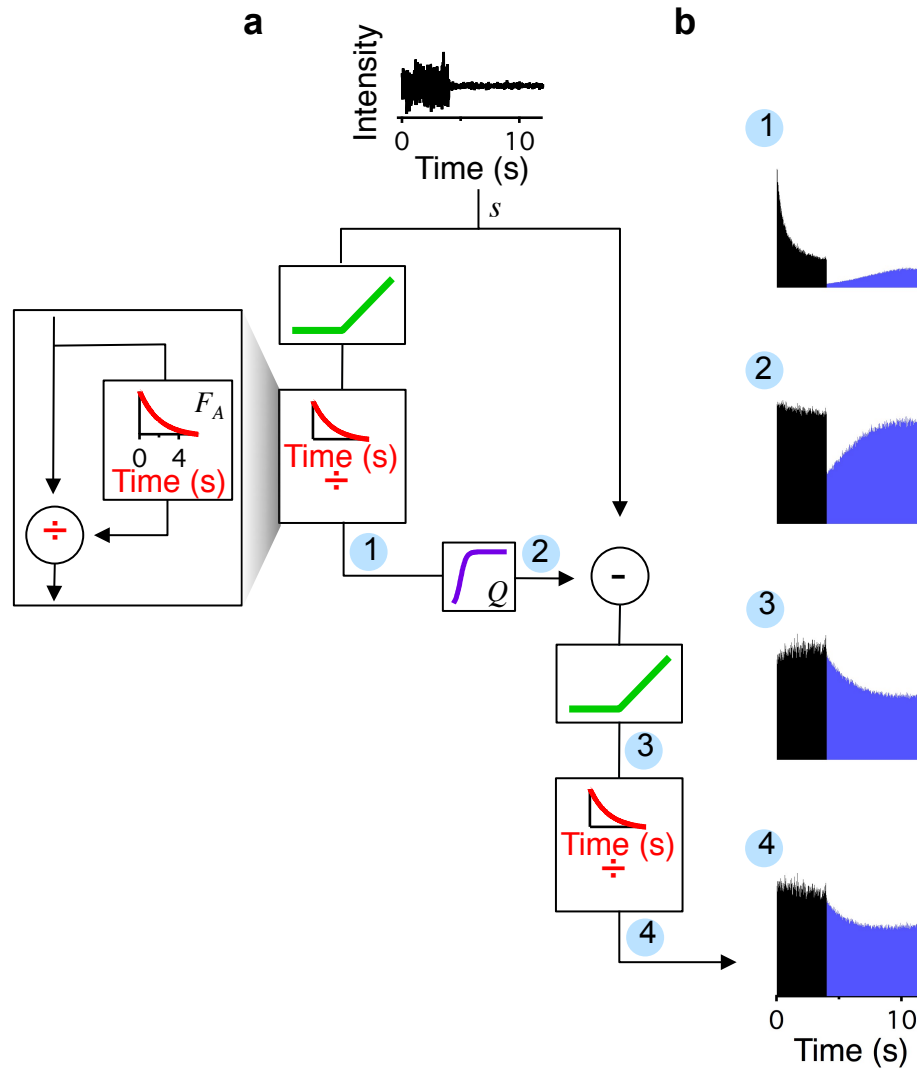
Retinal sensitization is a form of short term information storage



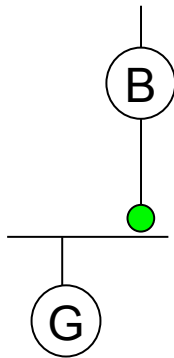
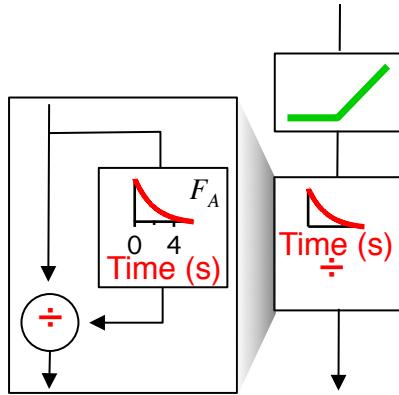
Sensitization requires GABAergic inhibitory transmission



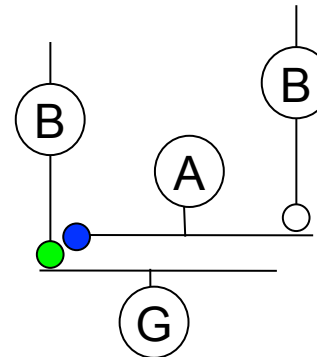
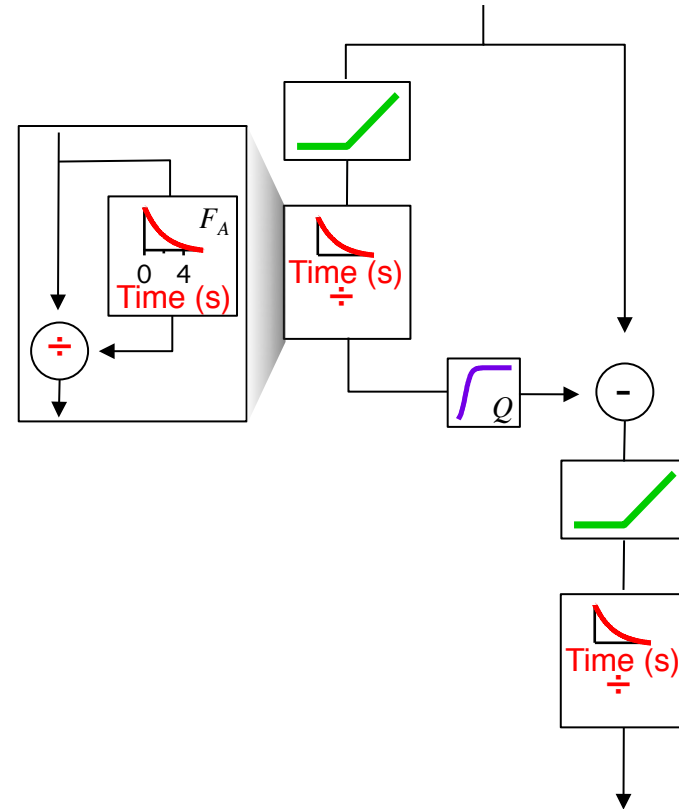
Sensitization can arise from adapting excitation and inhibition



Adapting



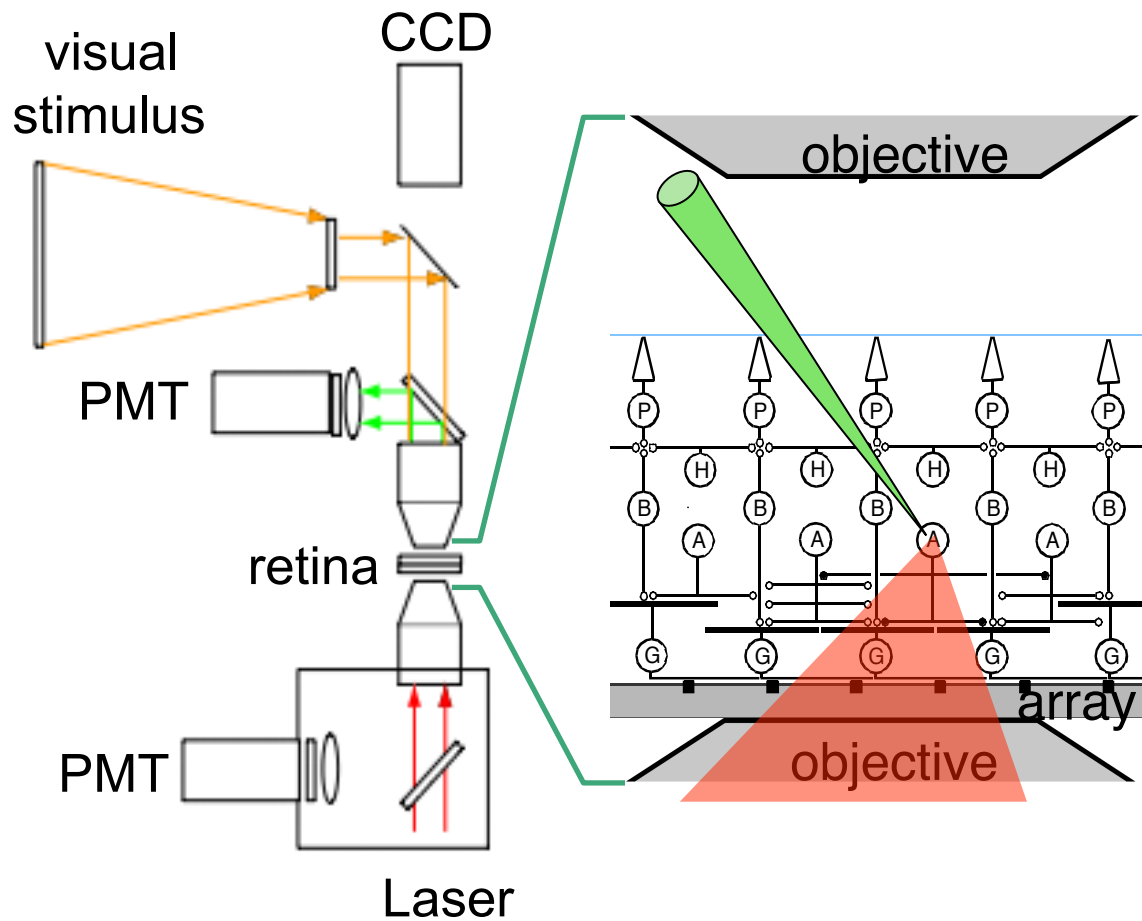
Sensitizing



Adapting synapses

- Excitatory
- Inhibitory

Simultaneous two-photon imaging and multielectrode recording of retina visual responses

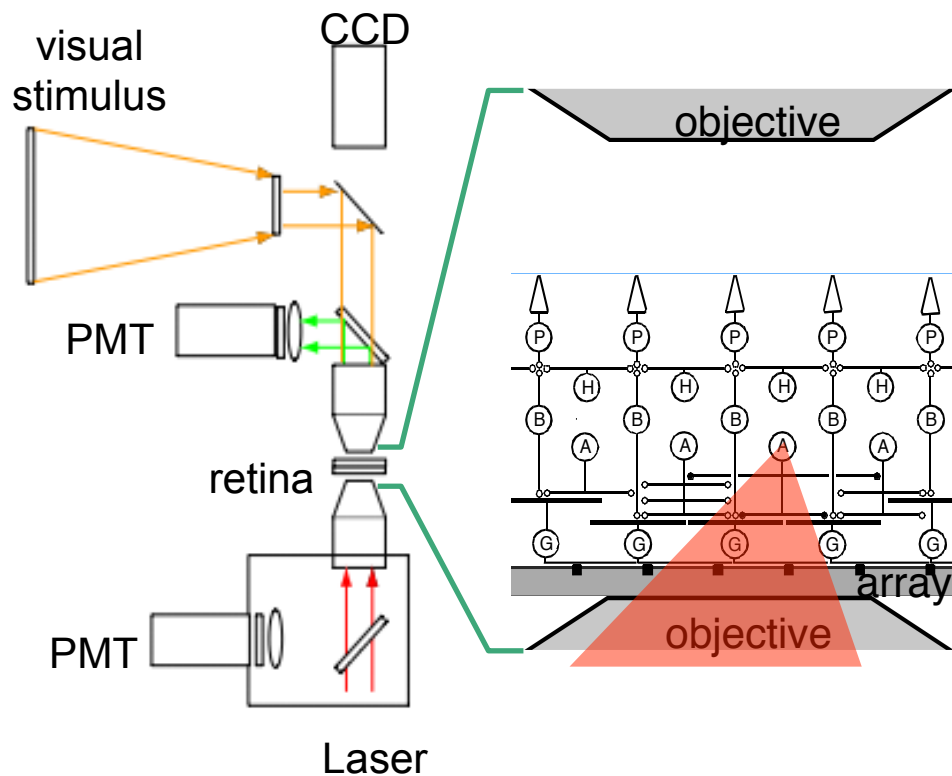


Goals

- Activate the photoreceptor population
- Record optically from the interneuron population
- Record electrically from the ganglion cell population

Interactions between Laser, Array, Retina, Imaging & Visual Stimulus

A problem in diplomacy



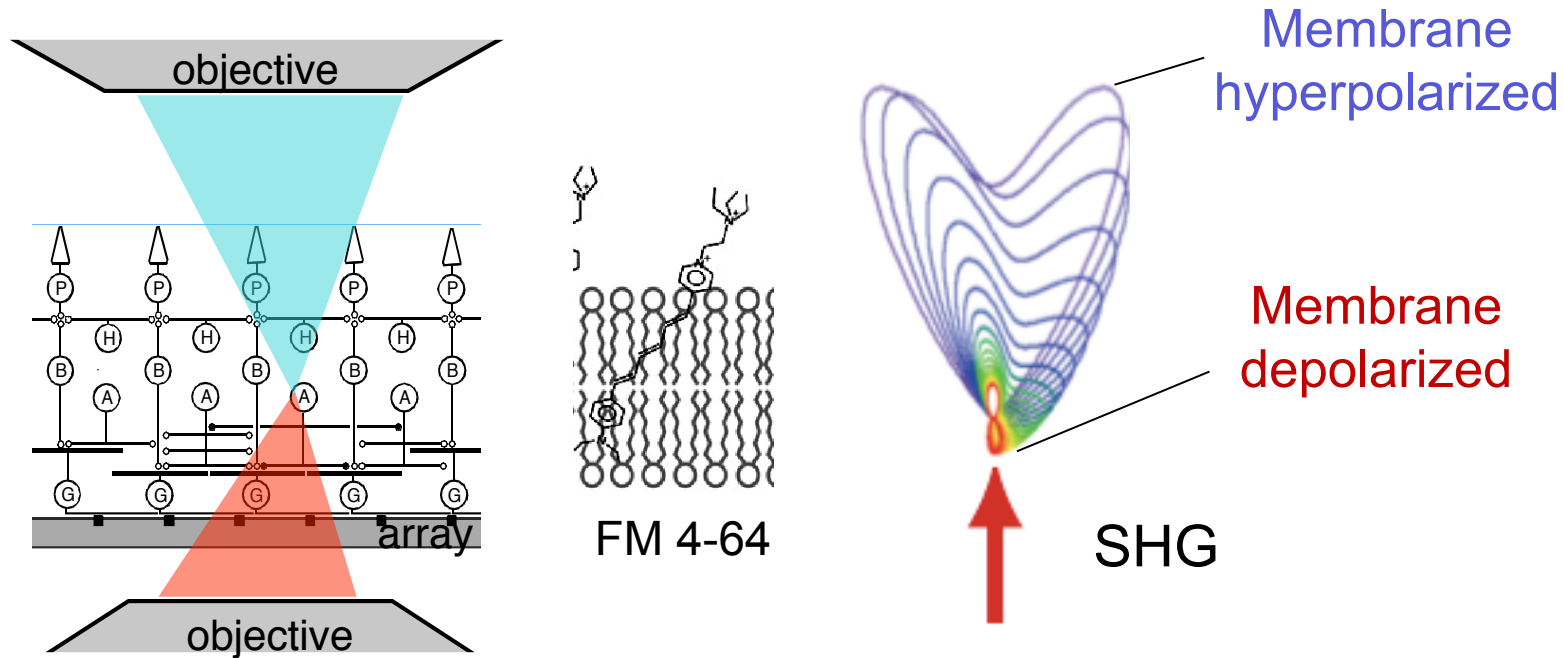
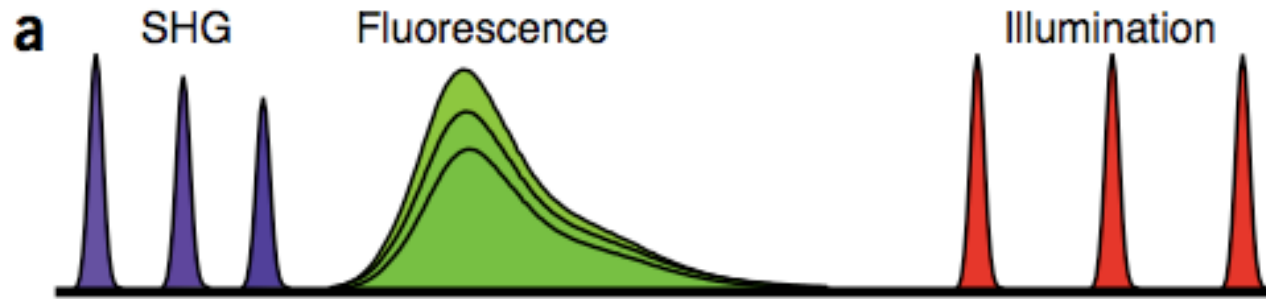
Electrode array → Two photon imaging
Effect of semitransparent array on imaging

Laser → Multielectrode recording
Photoelectric effect of laser on array
Laser damage of array

Laser → Retina
Laser activation of photoreceptors
(Detwiler & Denk)

Visual stimulus → Two photon imaging
Visual stimulus artifact

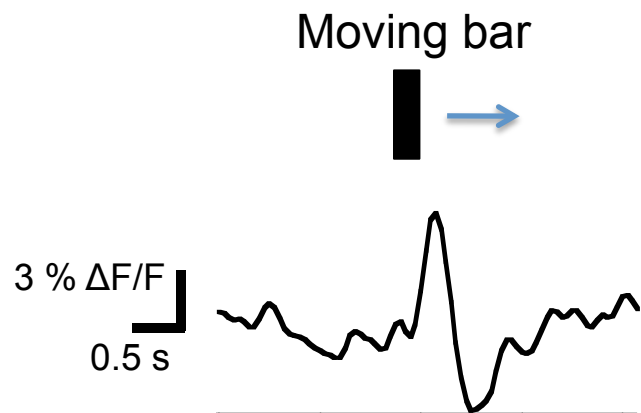
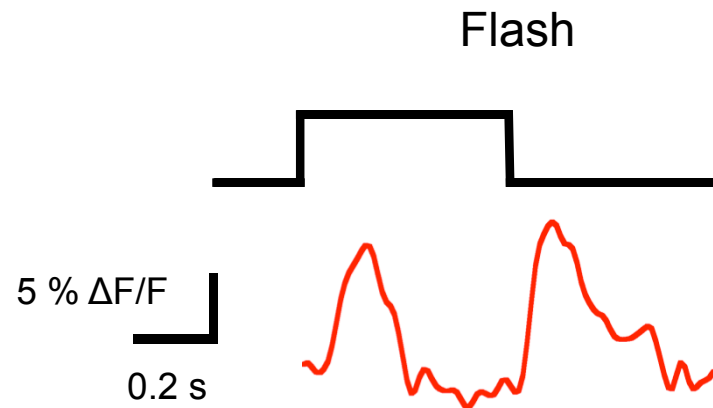
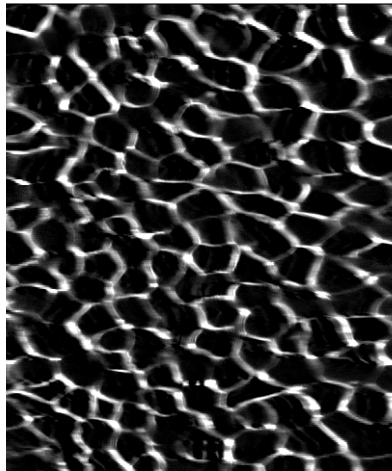
Imaging the interneuron population using second harmonic generation imaging



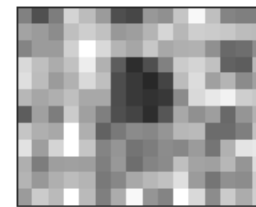
Dombeck, Blanchard-Desce & Webb W (2004)

Nuriya, Jiang, Nemet, Eisenthal & Yuste R. (2006)

Imaging the interneuron population using second harmonic generation imaging

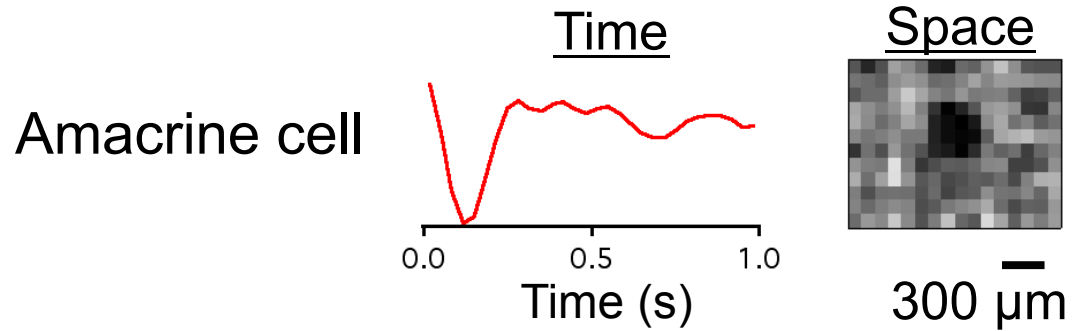


Receptive field

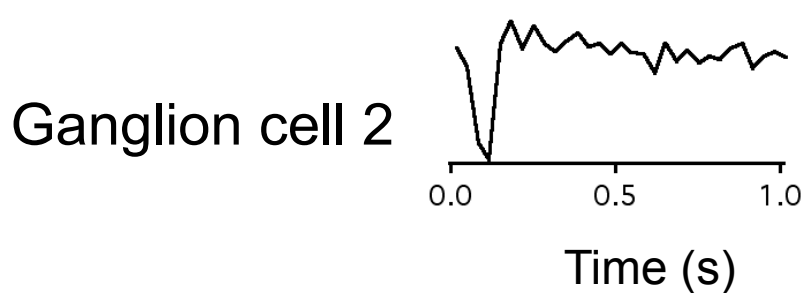
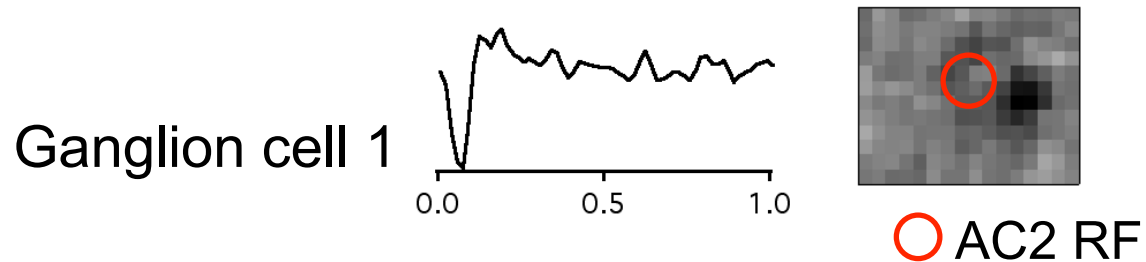


300 μm

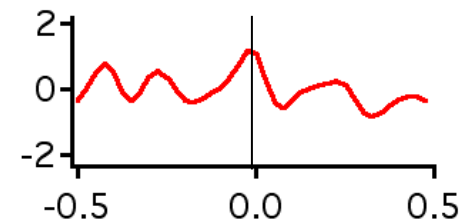
Amacrine cell recorded optically



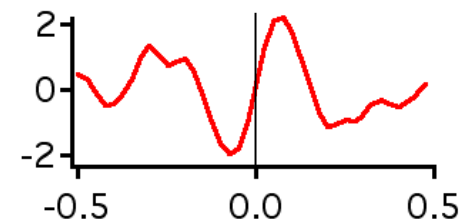
Ganglion cells recorded electrically



AC - GC1 correlation



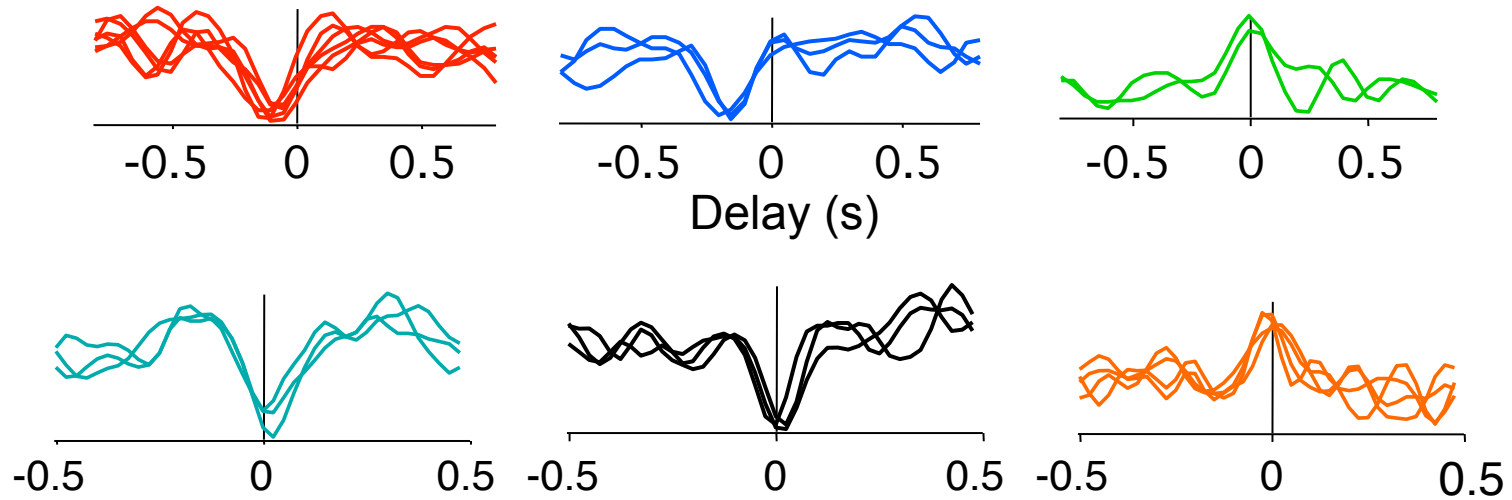
AC - GC2 correlation



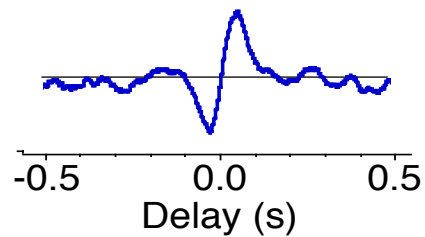
Time (s)

Correlations between amacrine cells (recorded optically)
and a ganglion cell (recorded electrically)

Optical recordings triggered on ganglion cell spike

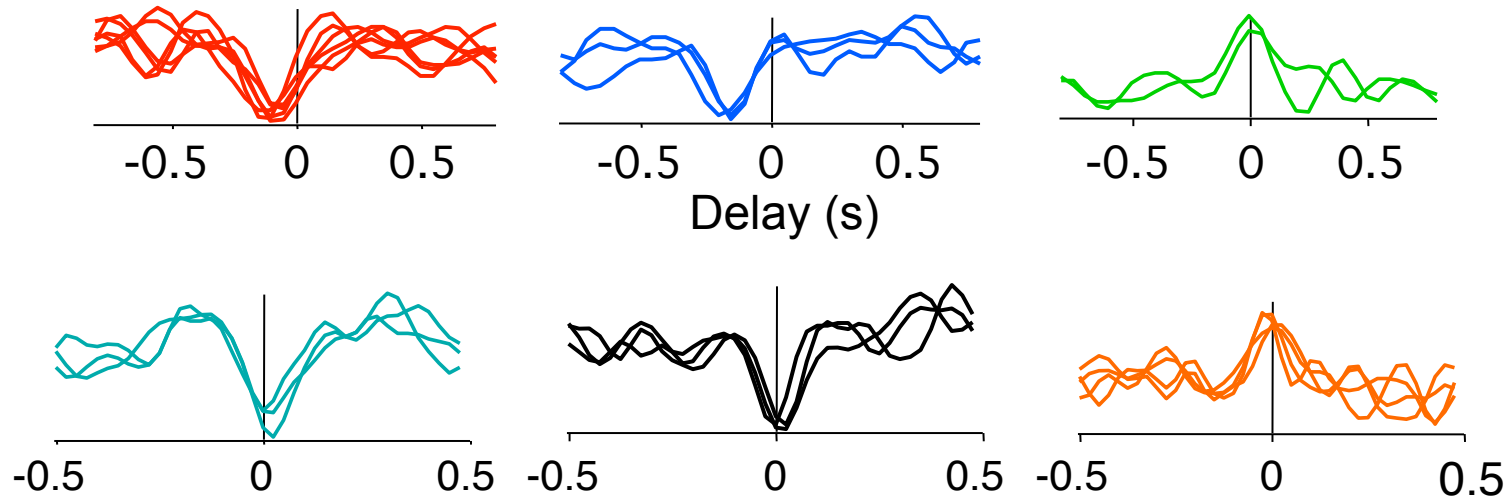


Electrical recording, different amacrine
and ganglion cell pair

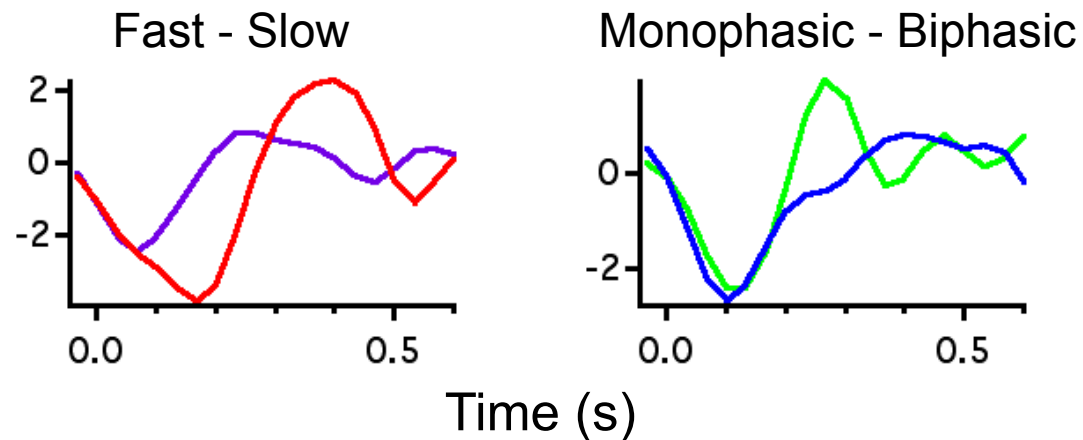


Correlations between amacrine cells (recorded optically)
and a ganglion cell (recorded electrically)

Optical recordings triggered on ganglion cell spike



Temporal filters of amacrine cells correlated with a single ganglion cell



Research Associate
Michael Menz

Postdoctoral Fellows
Citlali Trueta
Mihai Manu
Pablo Jadzinsky

Graduate Students
David Kastner
Yusuf Ozuysal
Neda Nategh

Undergraduate
David Brody

Markus Meister
Bence Ölveckzy

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