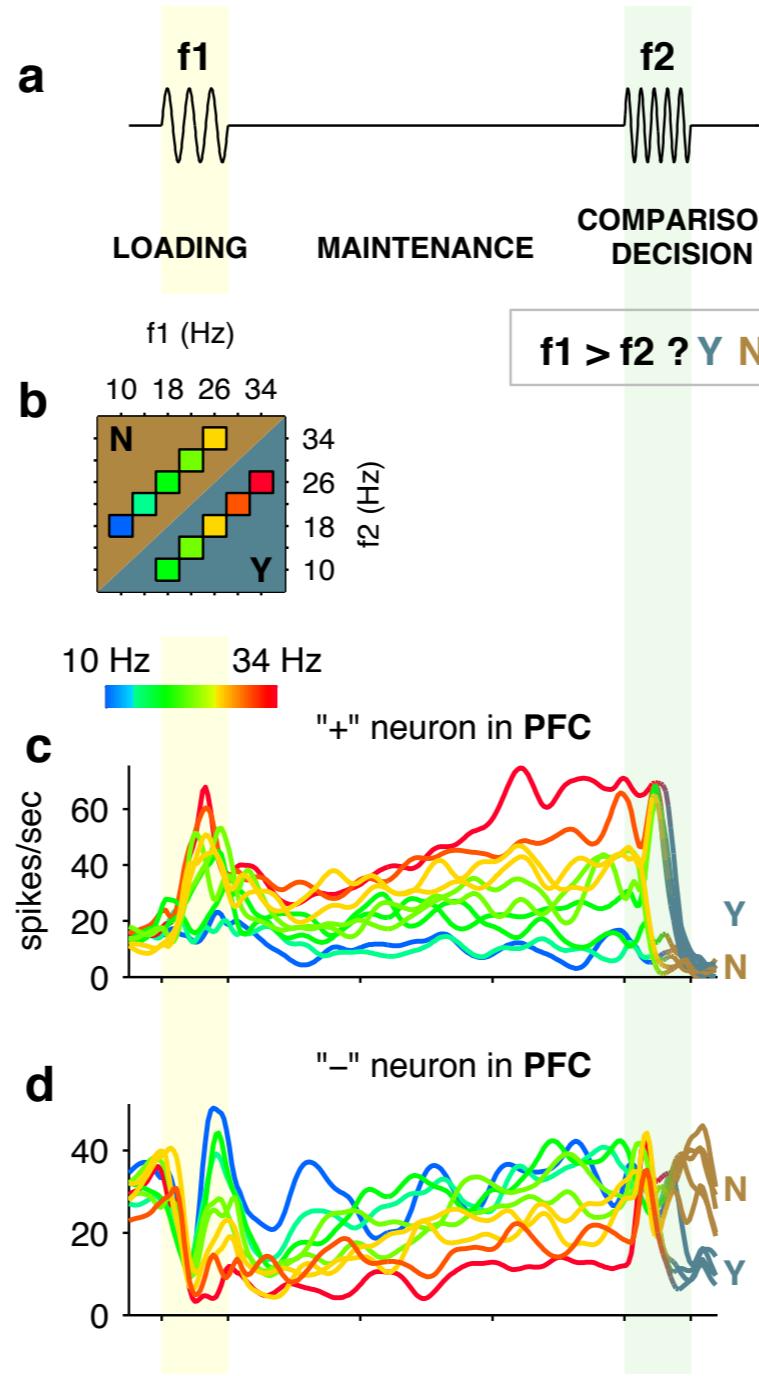


# Working Memory and attractor models

# A parametric working memory task



# Persistent activity in neurons encoding eye position

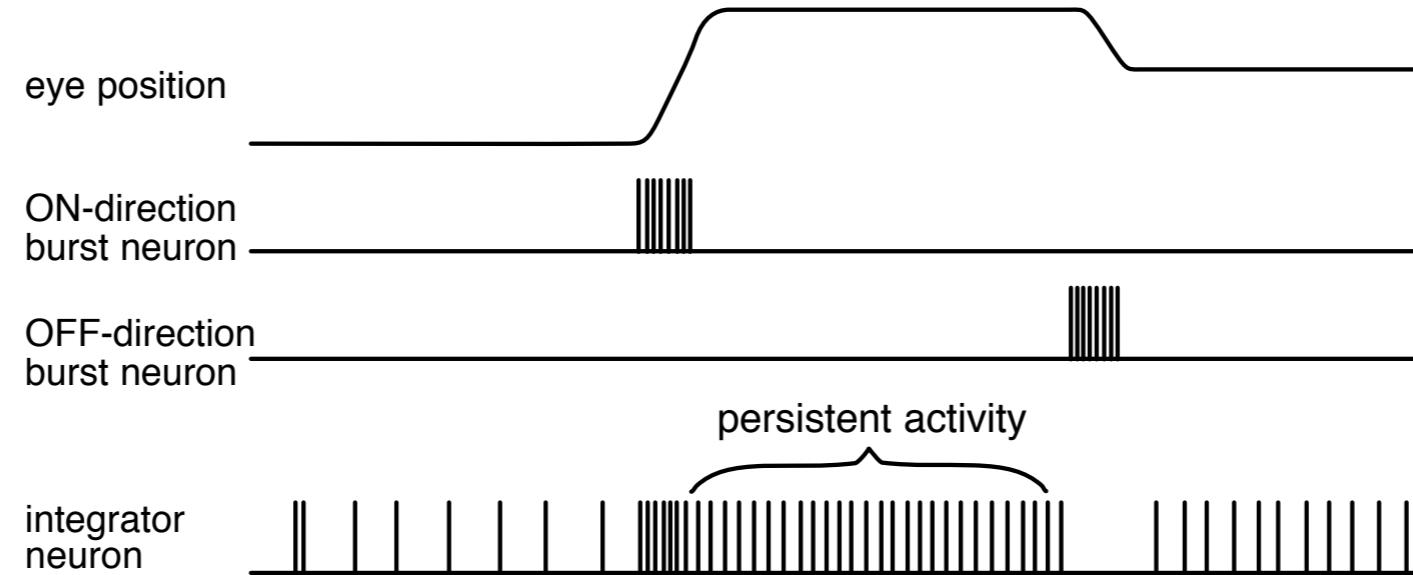
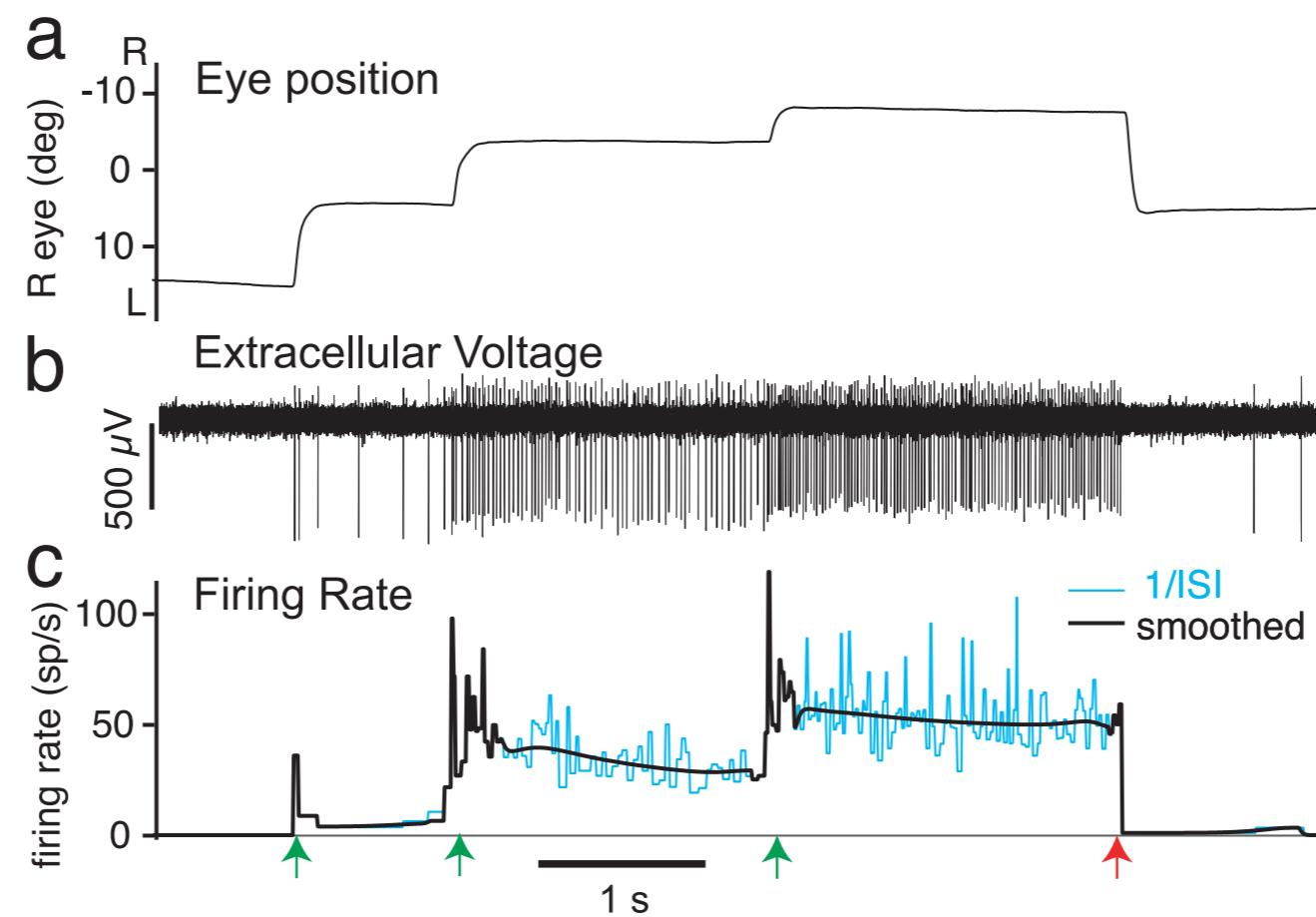
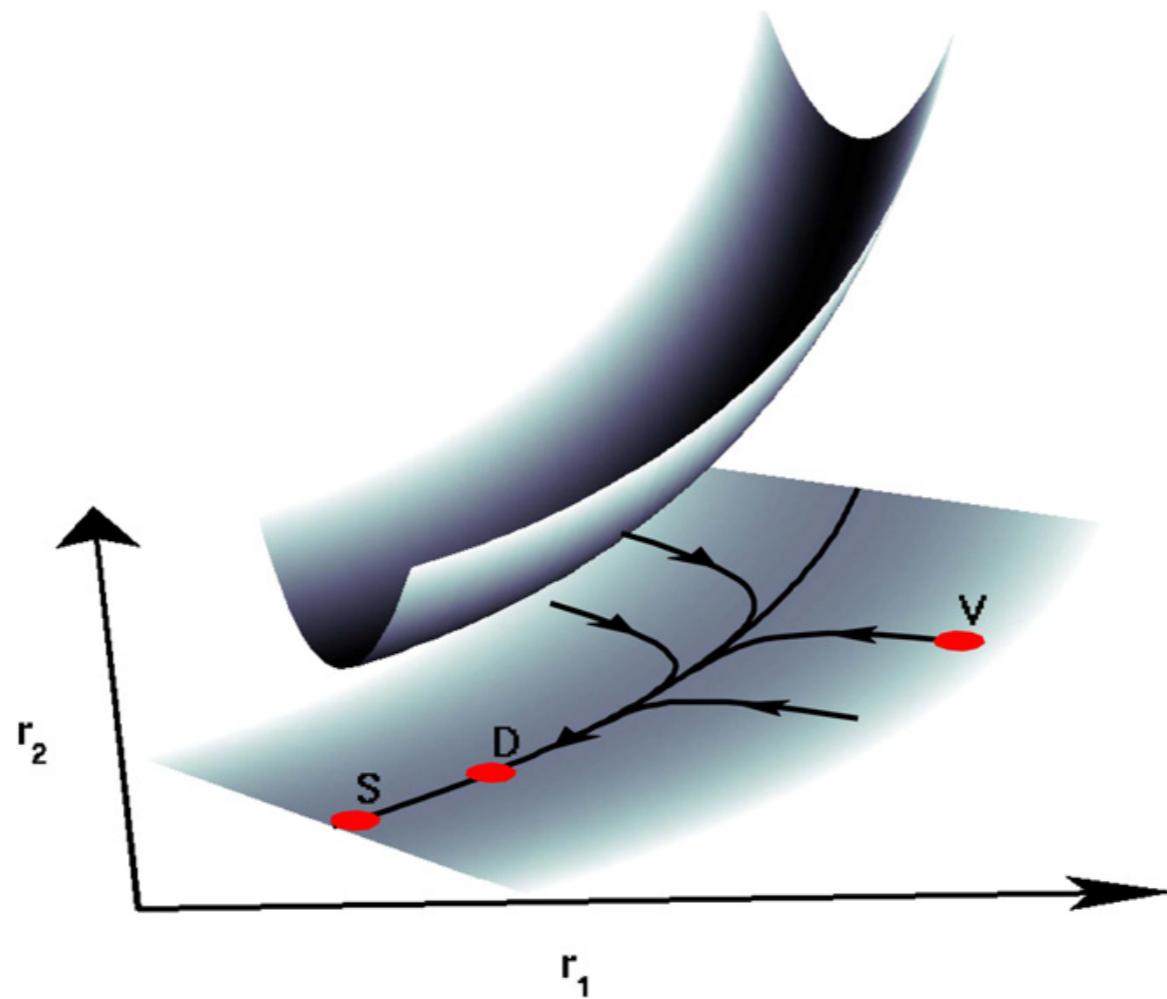


Figure 7.7: Cartoon of burst and integrator neurons involved in horizontal eye positioning. The upper trace represents horizontal eye position during two saccadic eye movements. Motion of the eye is driven by burst neurons that move the eyes in opposite directions (second and third traces from top). The steady-state firing rate (labeled persistent activity) of the integrator neuron is proportional to the time integral of the burst rates, integrated positively for the ON-direction burst neuron and negatively for the OFF-direction burst neuron, and thus provides a memory trace of the maintained eye position. (Adapted from Seung et al., 2000.)

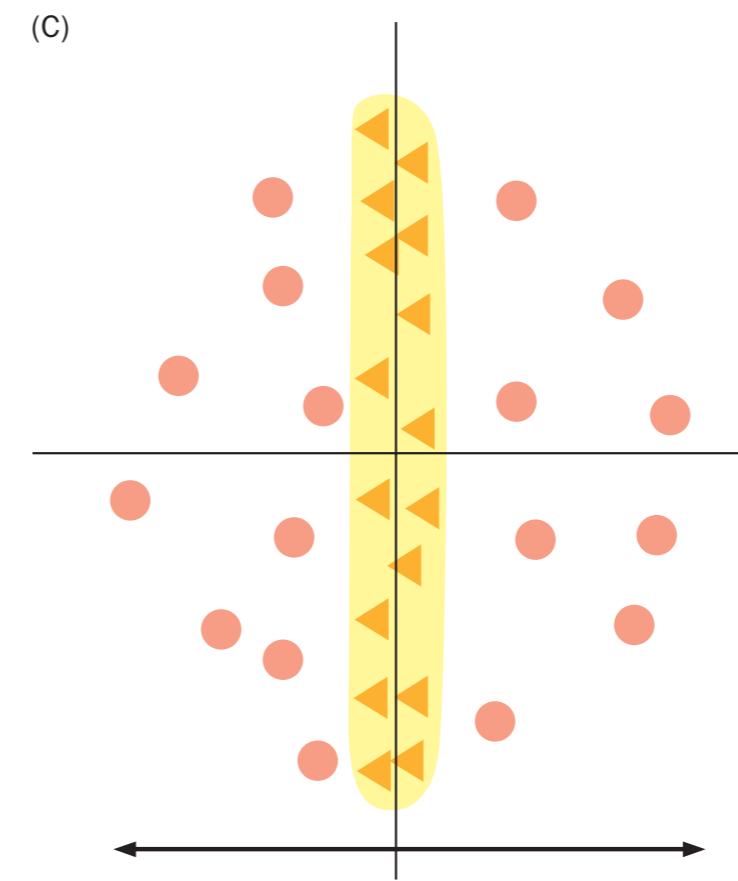
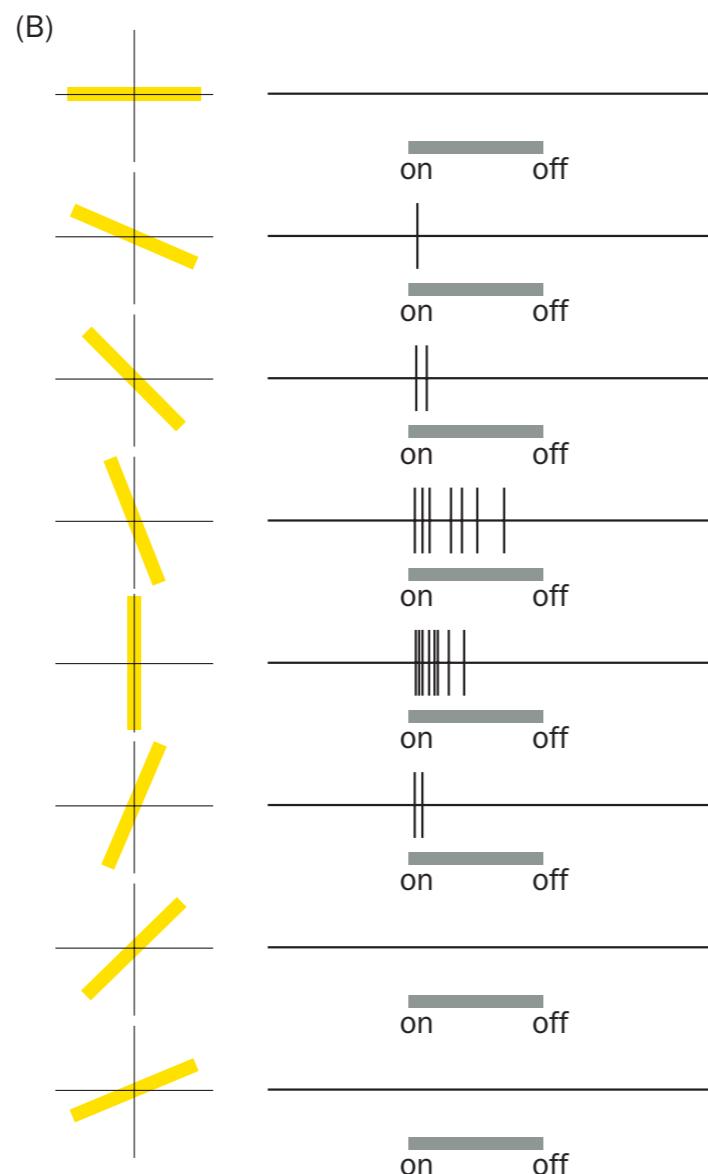
# Persistent activity in neurons encoding eye position



# One dimensional dynamics

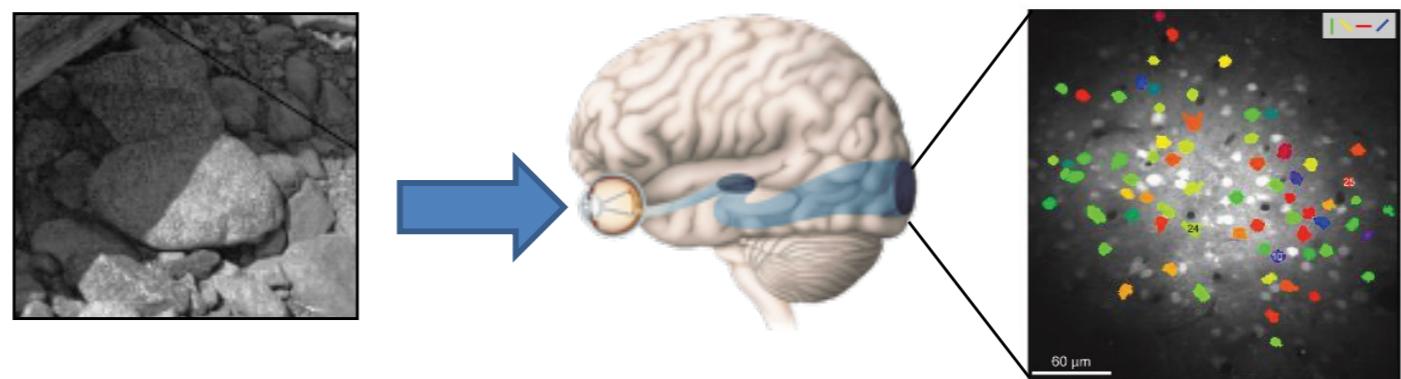


# Simple cell receptive field in the cat primary visual cortex

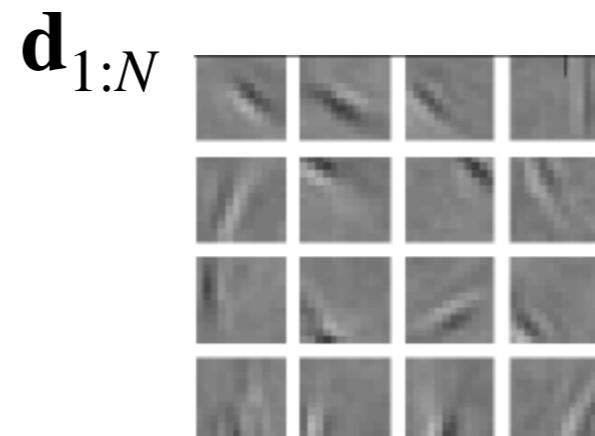


Hubel and Wiesel, 1959 Journal of Physiology

# Working memory and sensory representation



$$\mathbf{s} \approx \sum_{i=1}^N r_i(t) \mathbf{d}_i$$



## Fixed points and stability

Global stability: starting from **any** initial condition

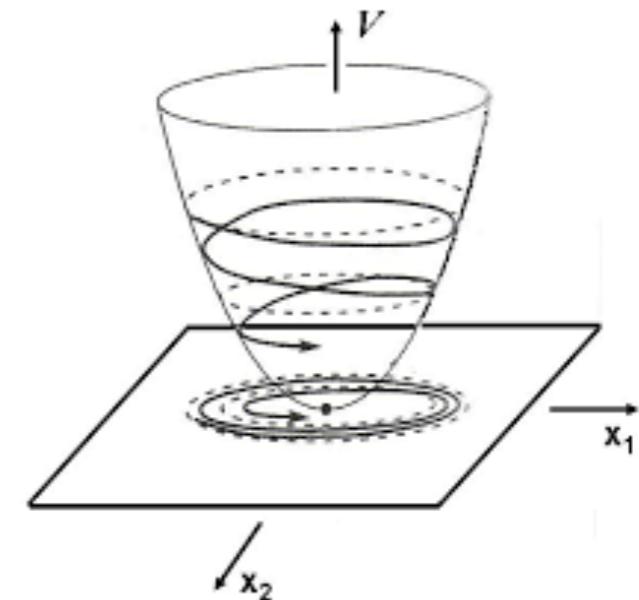
$$\frac{d\mathbf{u}}{dt} = \mathbf{f}(\mathbf{u})$$

Lyapunov function  $V(u)$

$V(u) \geq V_0$ , has a lower bound

$$\frac{d}{dt}V(u(t)) \leq 0$$

$$\frac{d}{dt}V(u(t)) = 0 \Rightarrow \nabla V(u) = 0$$



**Theorem:** If there exists a Lyapunov function, the system is (globally) stable where the trajectory will converge to one of the extrema of  $V(u)$ .

## An example

$$\frac{dx}{dt} = -x + 4y$$

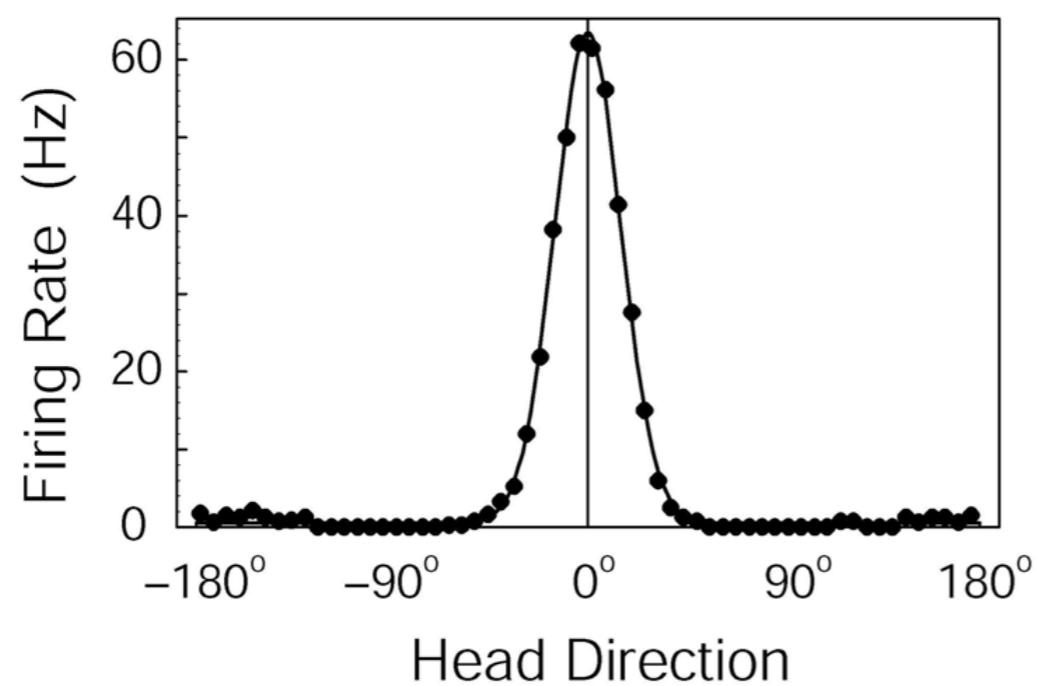
$$\frac{dy}{dt} = -x - y^3$$

Consider  $V(x, y) = x^2 + \alpha y^2$

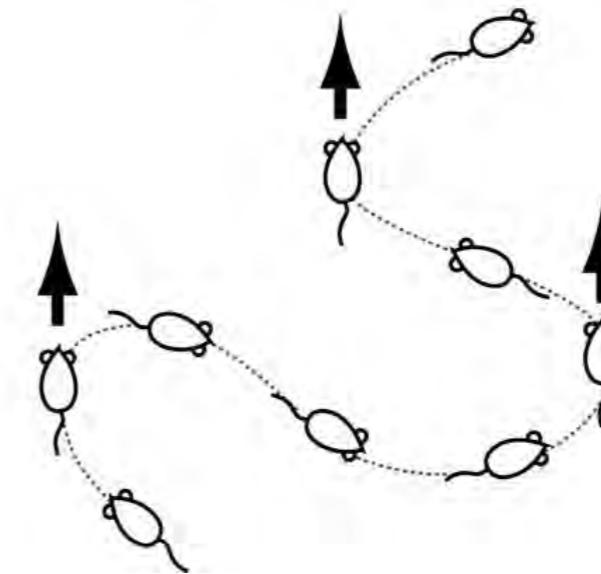
$$\dot{V} = 2x\dot{x} + 2\alpha y\dot{y} = 2x(-x + 4y) + 2\alpha y(-x - y^3)$$

# Head direction cell

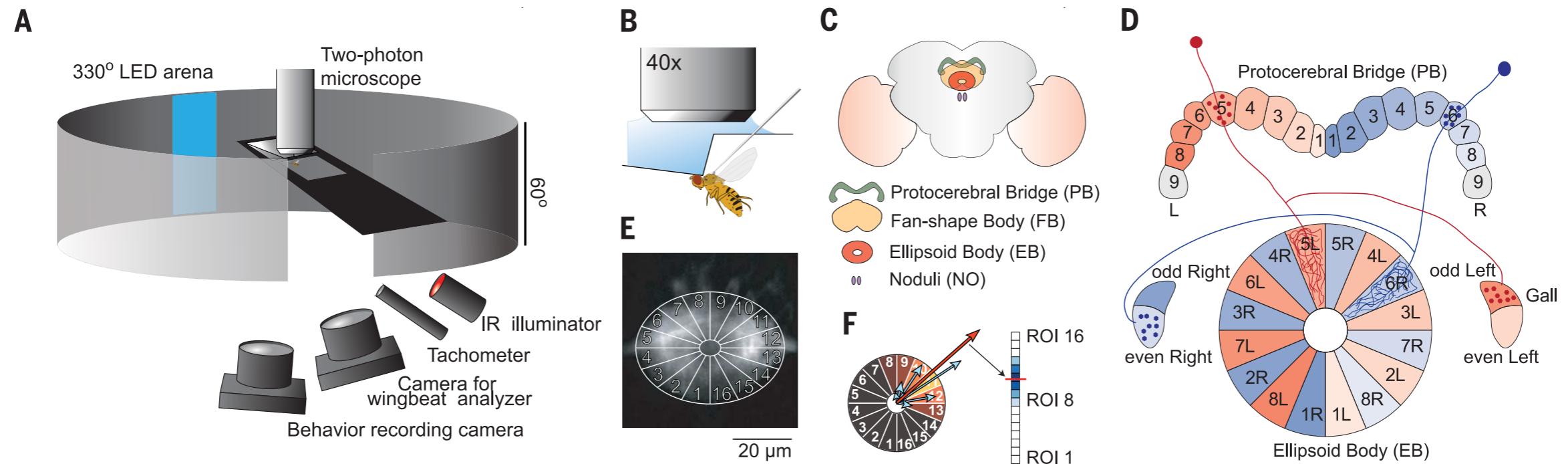
Tuning Curve of a Head-Direction Cell



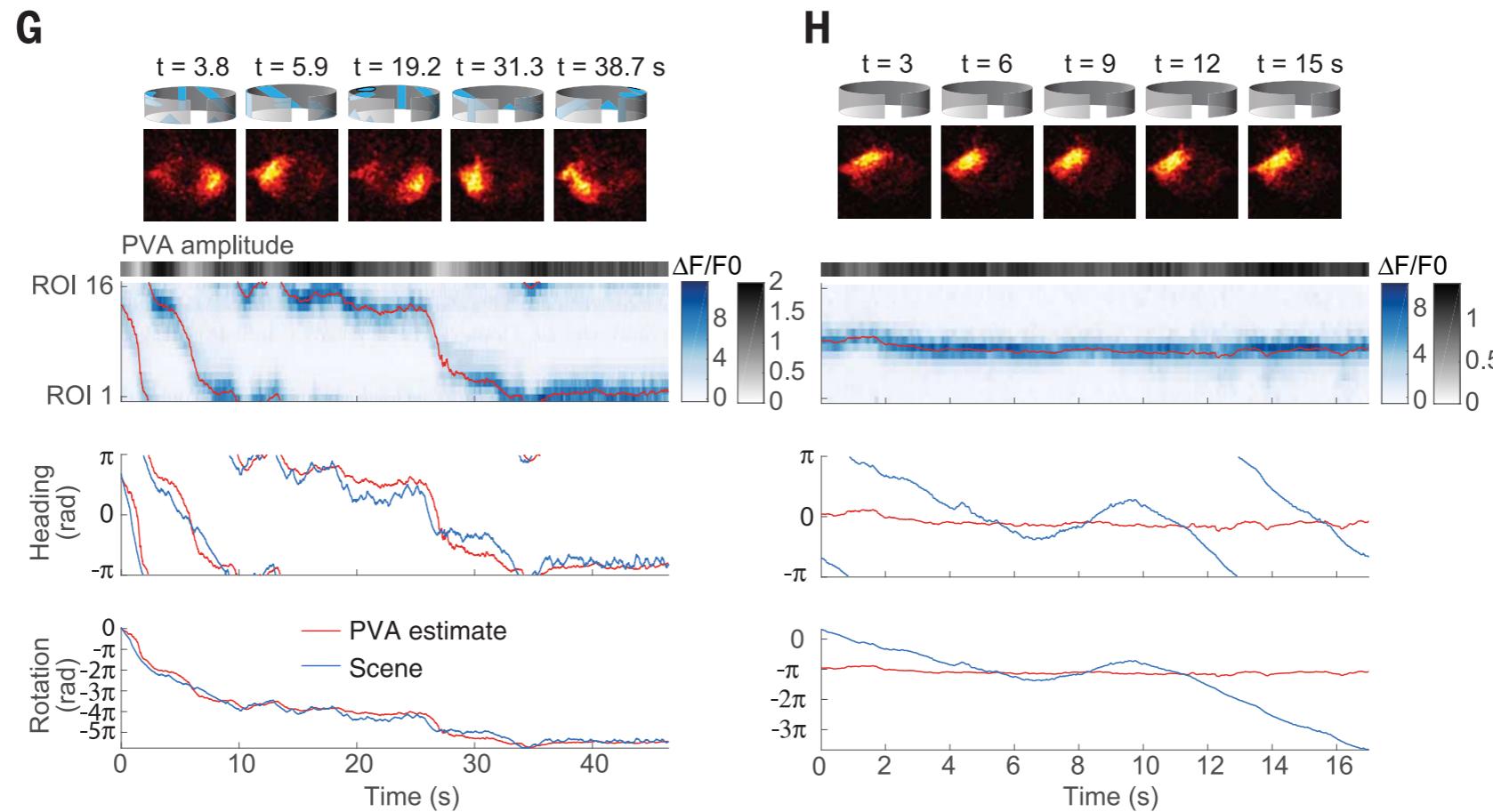
Preferred Direction of a Single Head-Direction Cell



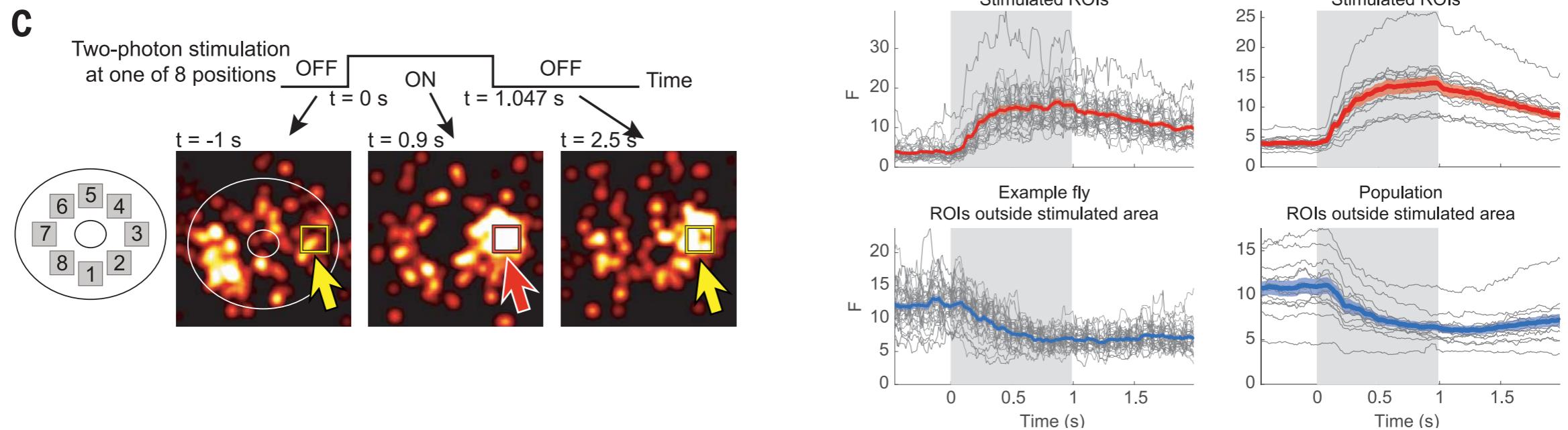
# Ring attractor dynamics in fly brain



# Ring attractor dynamics in fly brain



# Ring attractor dynamics in fly brain



# Contrast dependent receptive field

