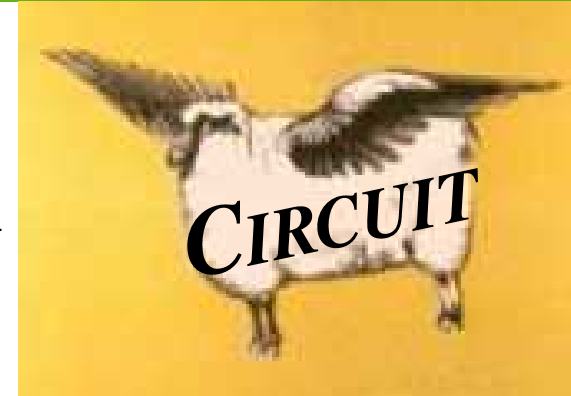


# *It's: MONTY PYTHON'S FLYING*

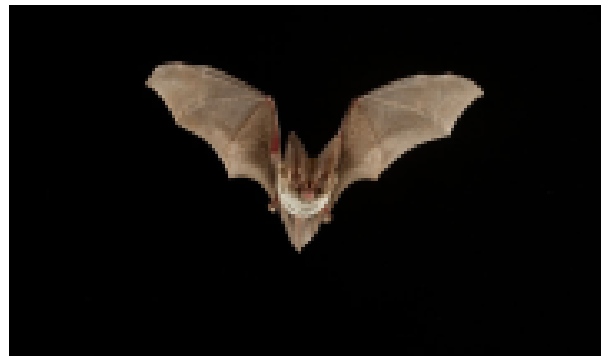


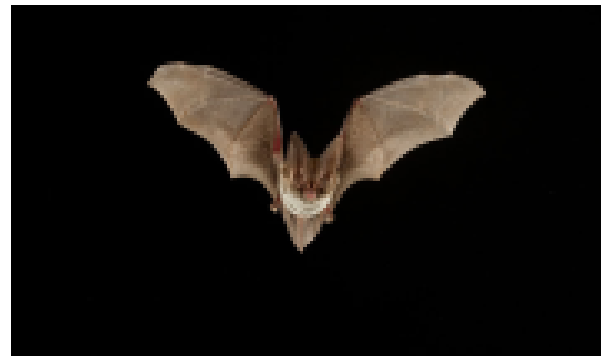
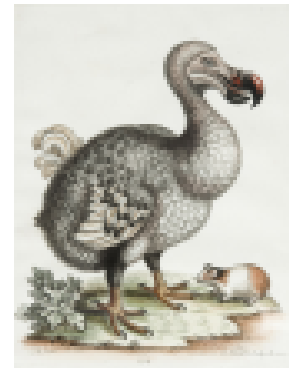
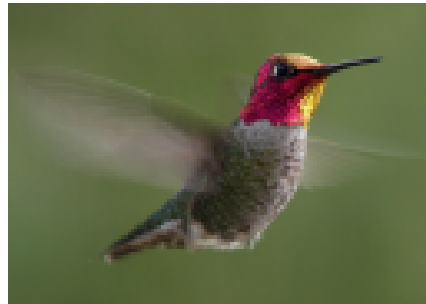
Johann Gambolputty  
Computational Neurophysiology  
Institute for Theoretical Biology

13.03.2018 A.D.



# To fly



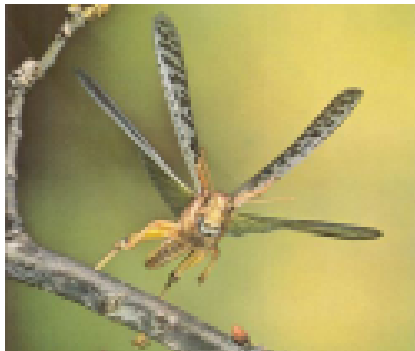


# Flying $\neq$ Flying



# Asynchronous flight in Insects (evolved 7-10 times)

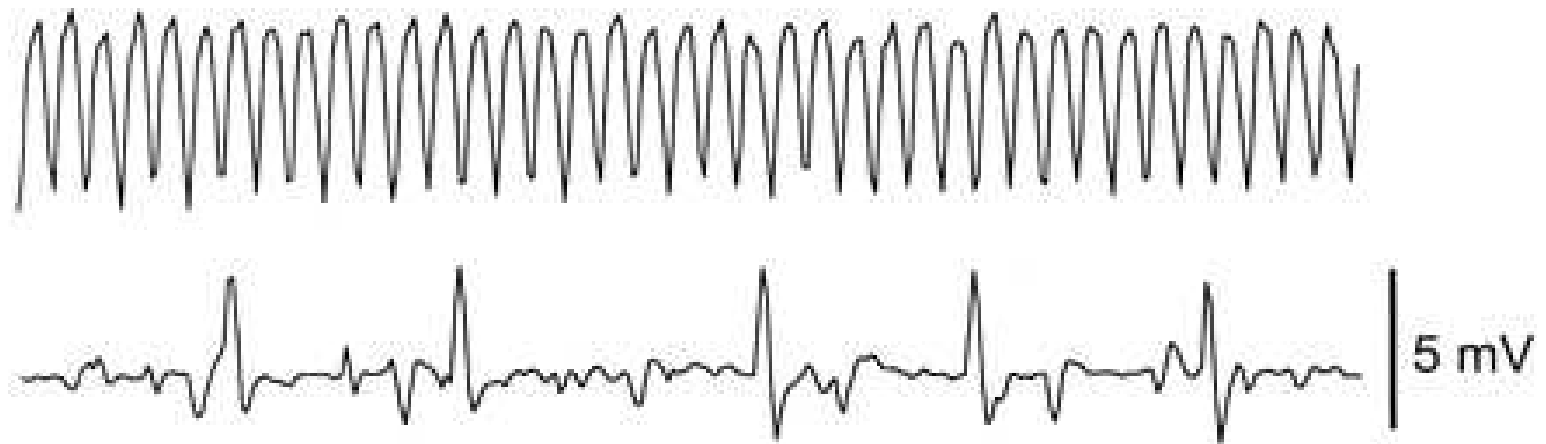
Flying insects are around since  
500-350 million years



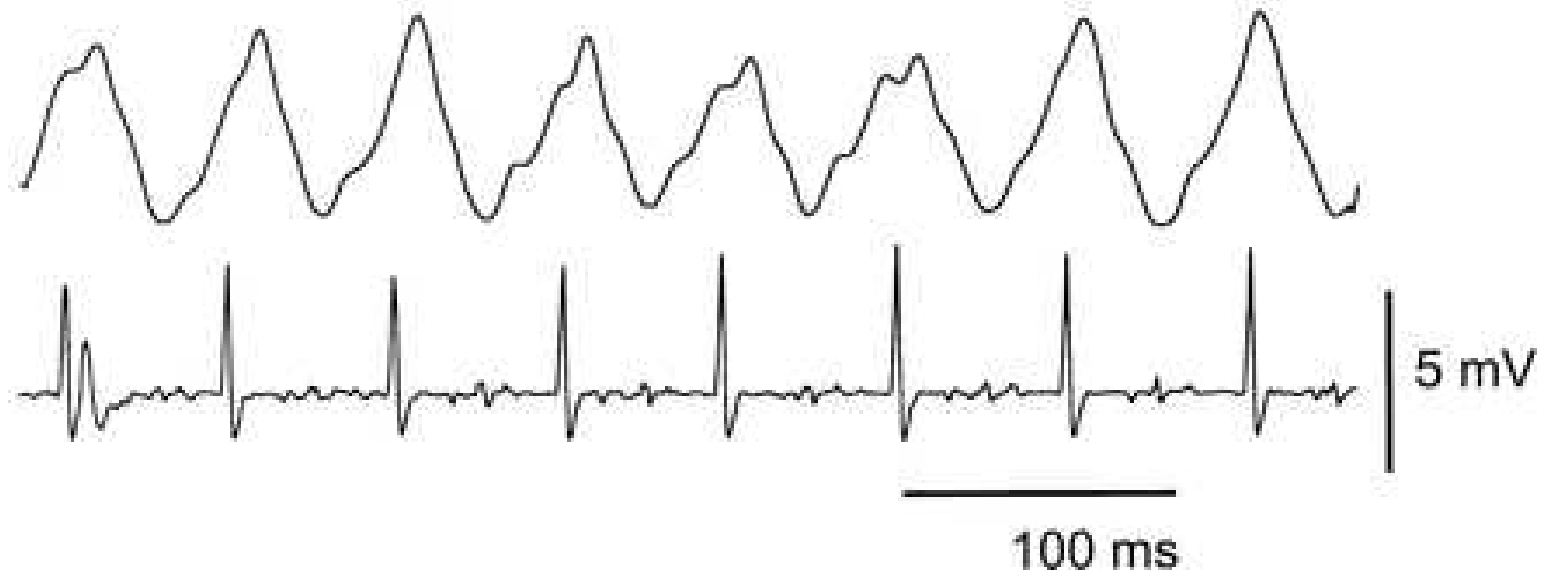
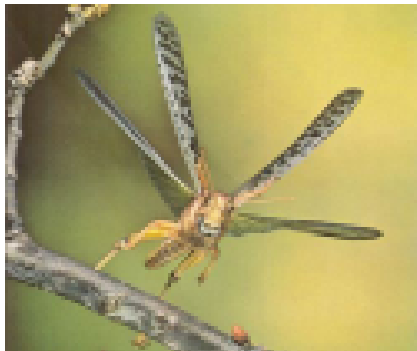
	Speed/mph	Beats/s
Honeybee	5.7	250
Housefly	4.4	190
Bumblebee	6.4	130
Syrphid hoverfly	7.8	120
Hornet	12.8	100
Horsefly	8.8	96
Hummingbird hawkmoth	11.1	85
Dragonfly	15.6	38
Scorpionfly	1.1	28
Damselfly	3.3	16
Large white butterfly	-	12

# Asynchronous flight in Insects (evolved 7-10 times)

Beetle (asynchronous) Coleoptera

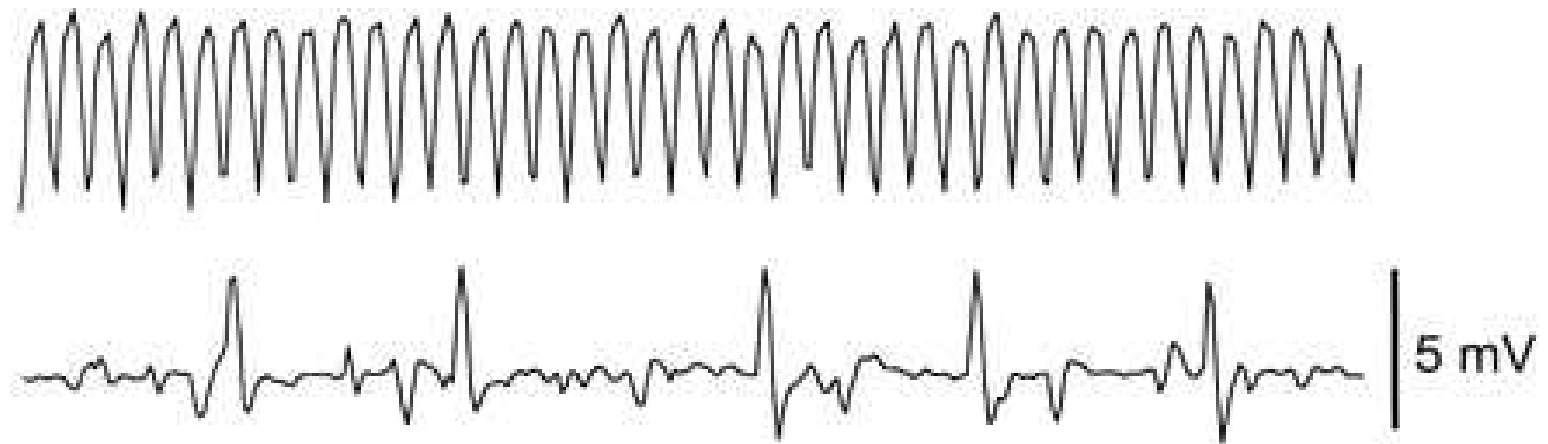


Locust (synchronous) Orthoptera

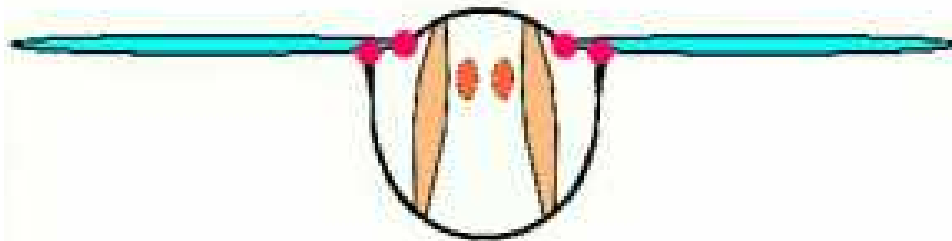


# Asynchronous flight in Insects (evolved 7-10 times)

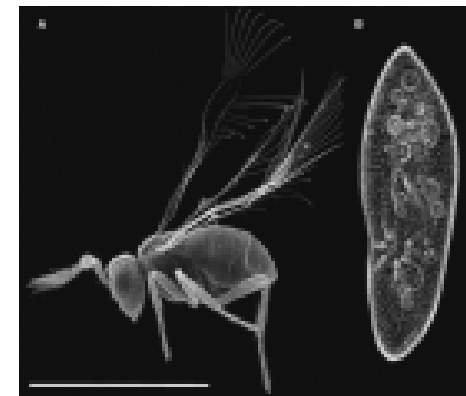
Beetle (asynchronous)



Requires sustained  $\text{Ca}^{2+}$  level in at least one of the muscle fibres



Use few neurons (<135000 in *D. melanogaster*)?



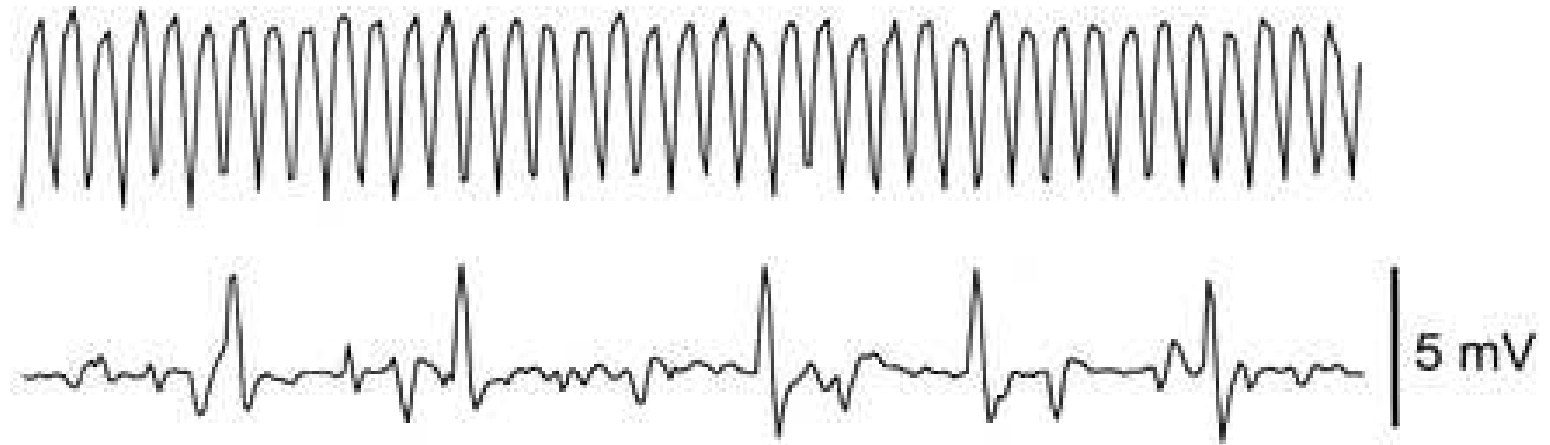
200  $\mu\text{m}$

*Megaphragma mymaripenne* (parasitic wasp)

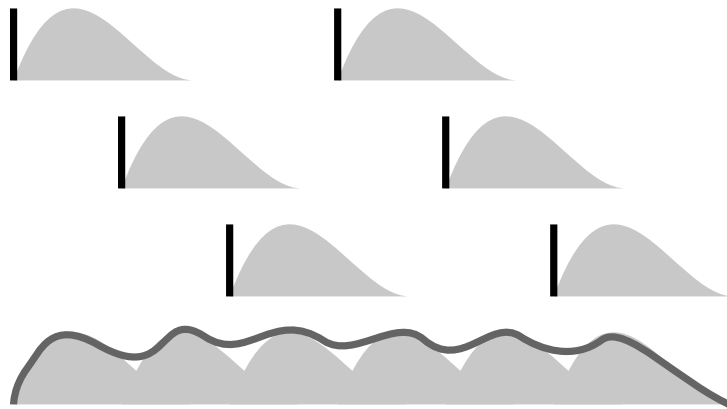
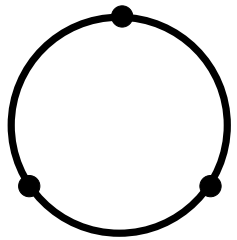
*Paramecium caudatum* (protozoan)

# Asynchronous flight in Insects (evolved 7-10 times)

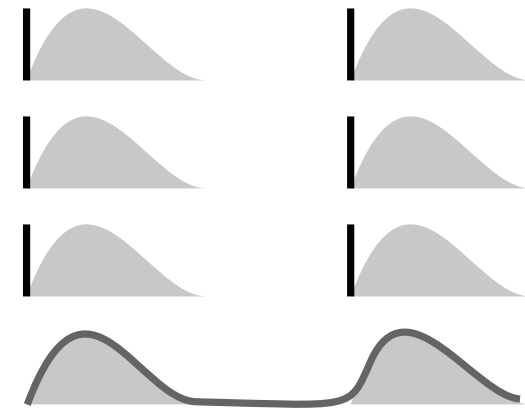
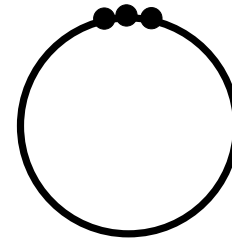
Beetle (asynchronous)



splayed



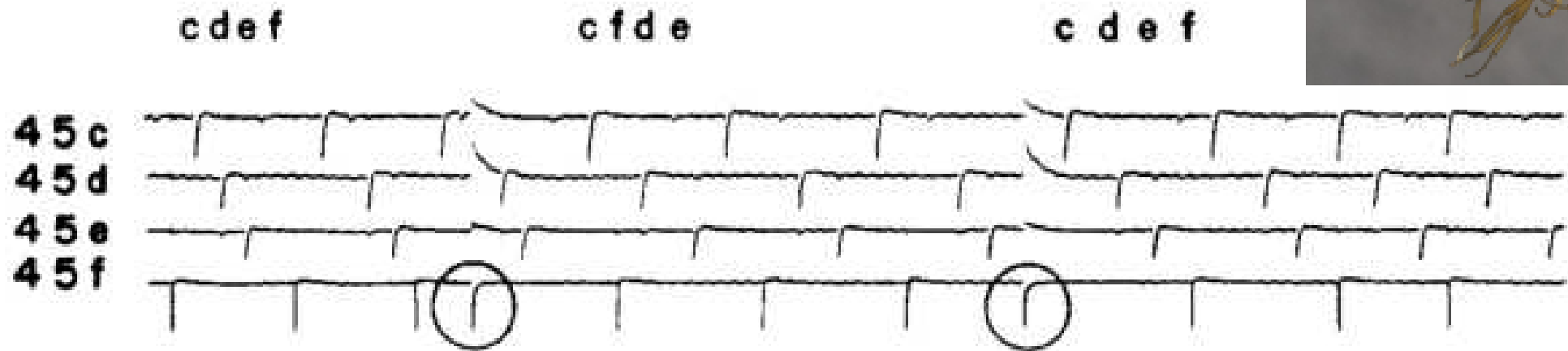
sync





# *Drosophila* MN1-4 activity during flight

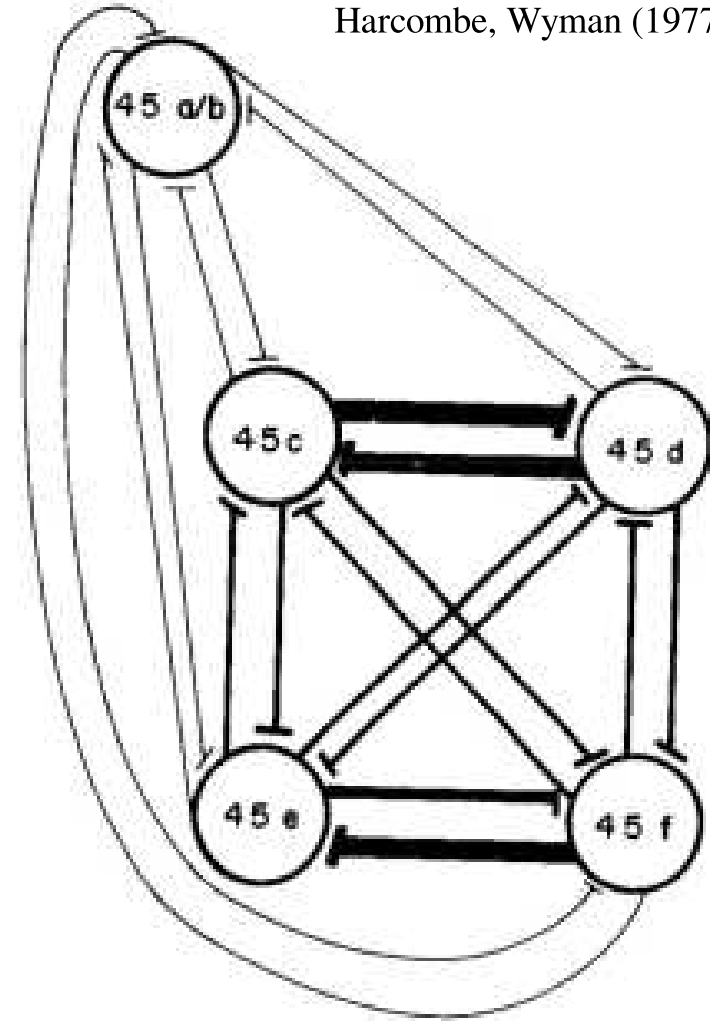
5 Motoneurons enervating the wing depressor muscle



How are the motoneurons connected?

# Connectivity of *Drosophila*'s Flying Circuit

Harcombe, Wyman (1977)

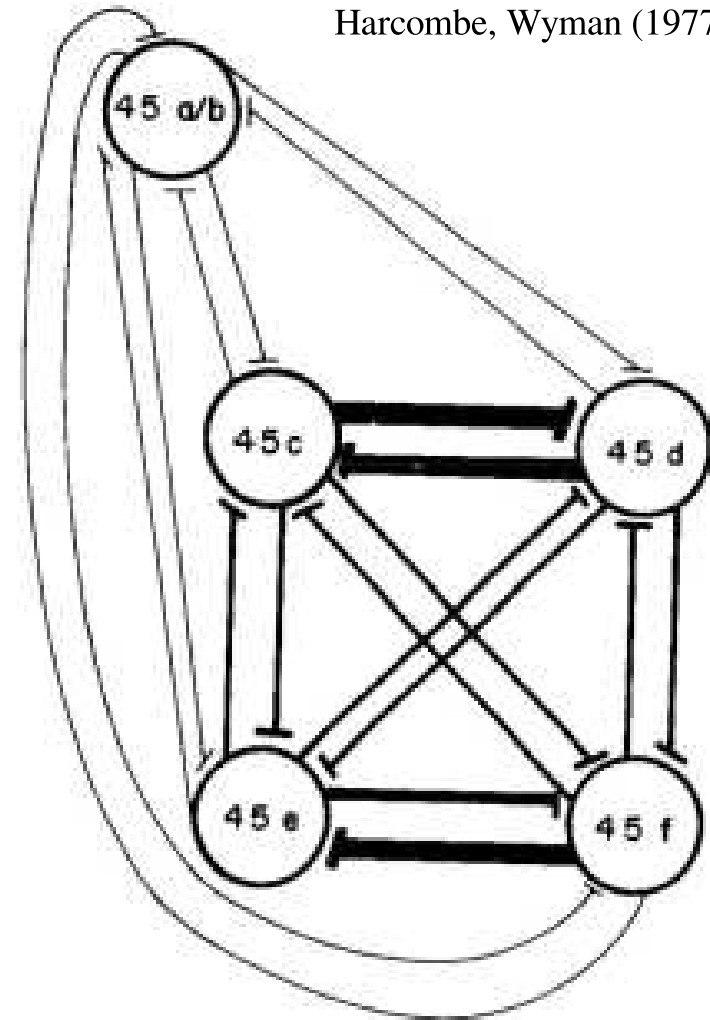


Winfree model

$$\dot{\phi}_j = f_j - Z_j(\phi_j) \sum_{k=1}^N g_{jk} \delta(\phi_k)$$

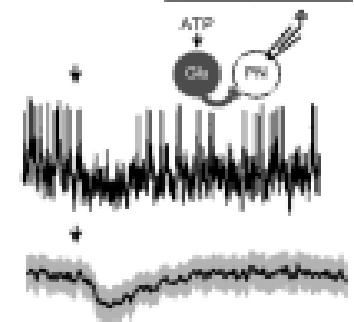
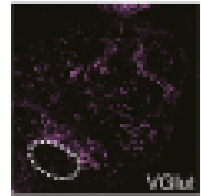
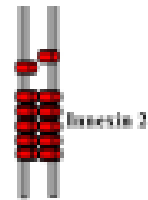
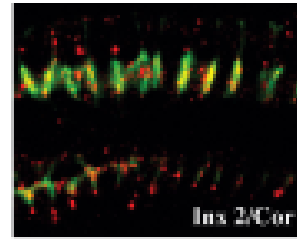
# Connectivity of *Drosophila*'s Flying Circuit

Harcombe, Wyman (1977)



- molecular evidence for gap-junctions:  
ShakB (innexin8)

- fast inhibitory (Cl<sup>-</sup>) coupling  
puffing glutamate experiments



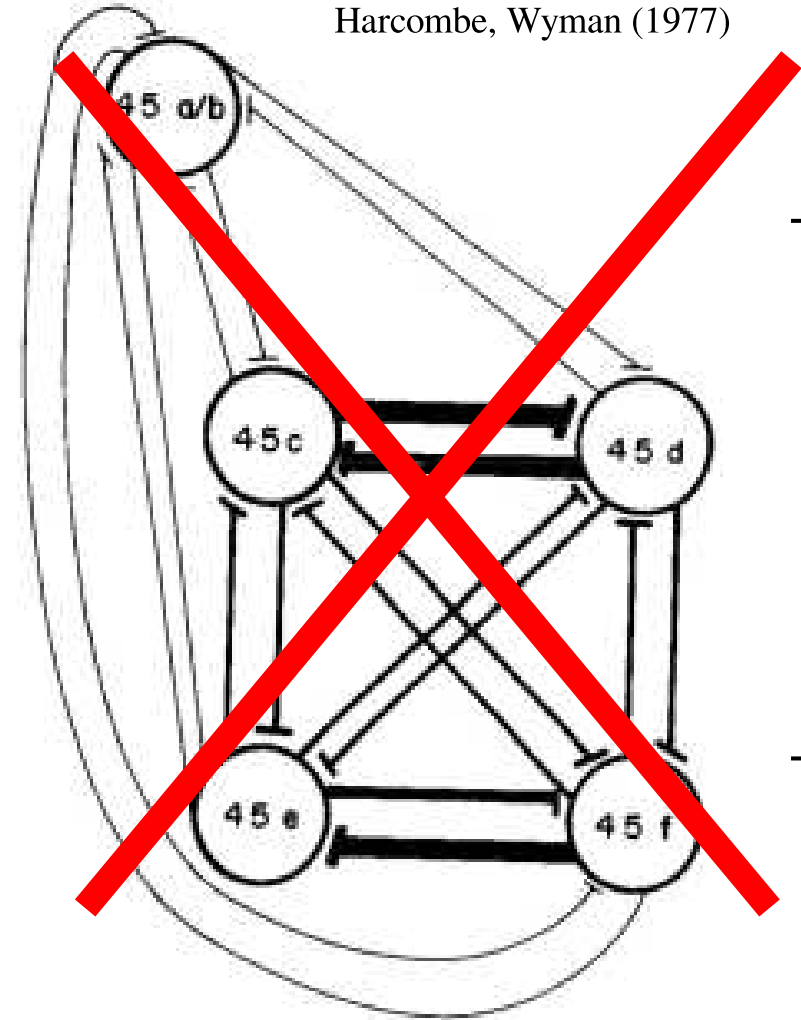
Winfree model

$$\dot{\phi}_j = f + Z(\phi_j) \sum_{k=1}^N g_{jk}^{\text{gap}} \left( \delta(\phi_k) - \delta(\phi_j) \right)$$

Bauer et al (2005)

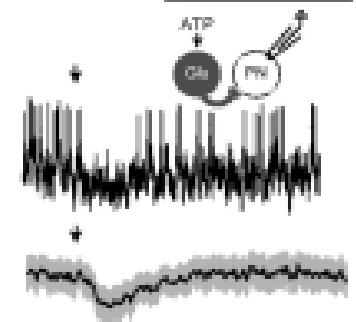
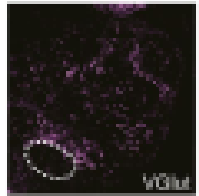
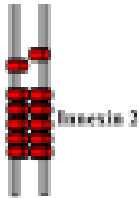
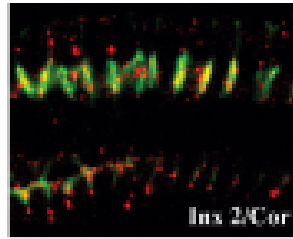
# Connectivity of *Drosophila*'s Flying Circuit

Harcombe, Wyman (1977)



- molecular evidence for gap-junctions:  
ShakB (innexin8)  
Duch 2018: Are functional!

- fast inhibitory (Cl<sup>-</sup>) coupling  
puffing glutamate experiments



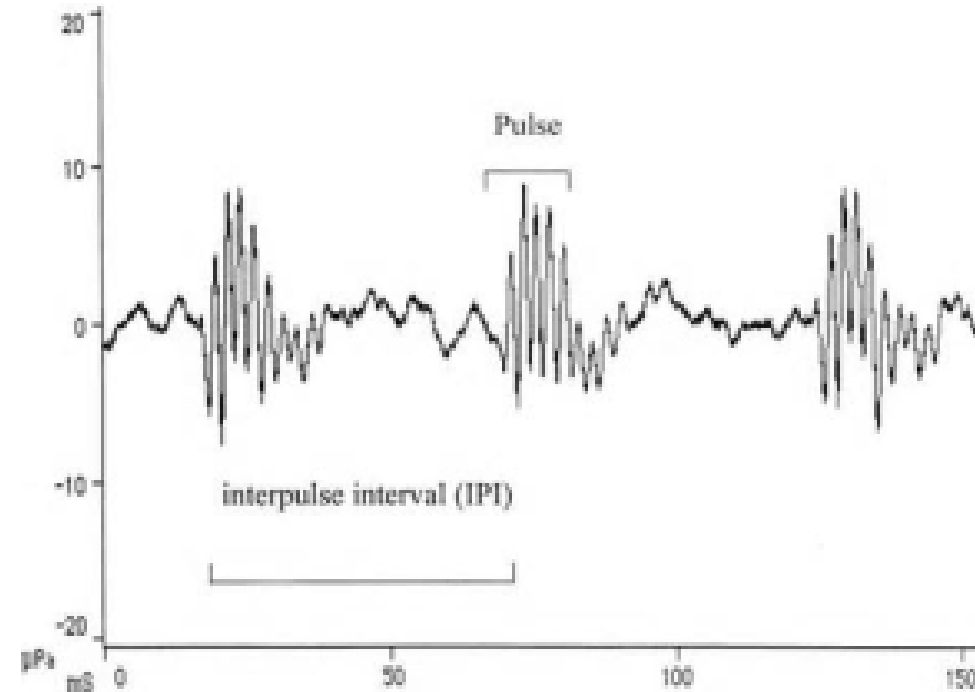
Winfree model

$$\dot{\phi}_j = f + Z(\phi_j) \sum_{k=1}^N g_{jk}^{\text{gap}} \left( \delta(\phi_k) - \delta(\phi_j) \right)$$

Duch et al (2018)

# And now for some singing ...

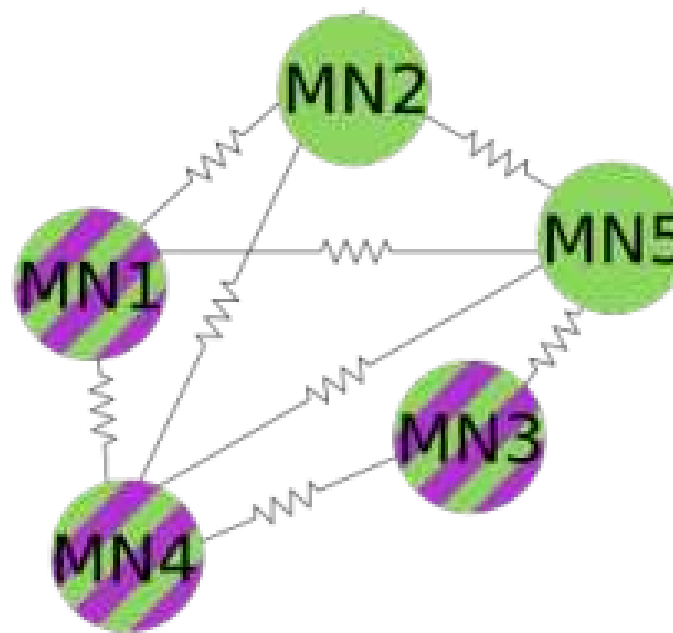
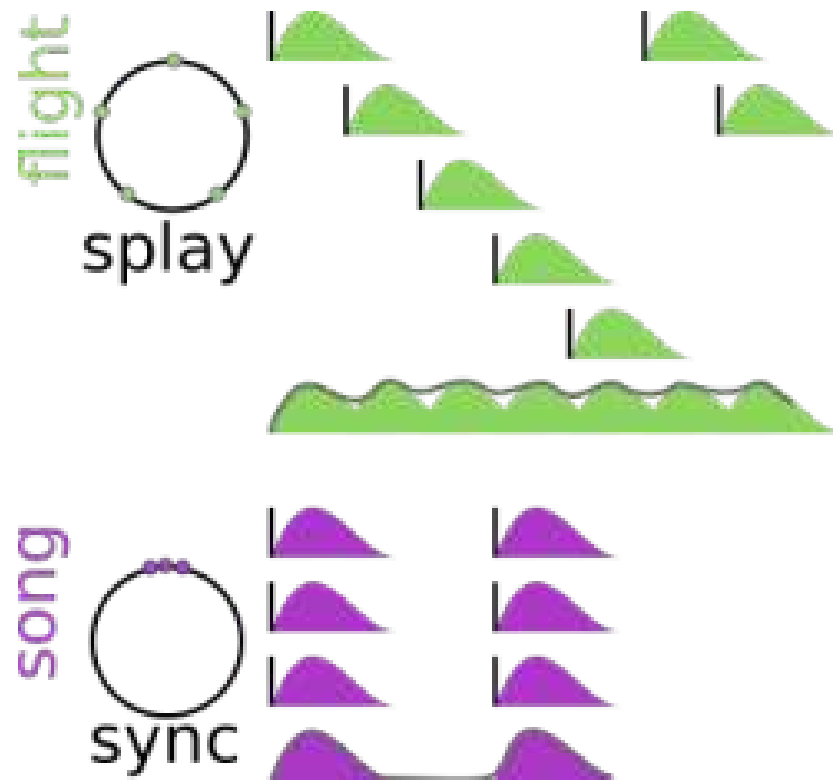
Same circuit  $\Rightarrow$  different motor pattern  
 $\Rightarrow$  different function



# And now for some singing ...

Same circuit  $\Rightarrow$  different motor pattern

Maybe a subpopulation of MN1-5

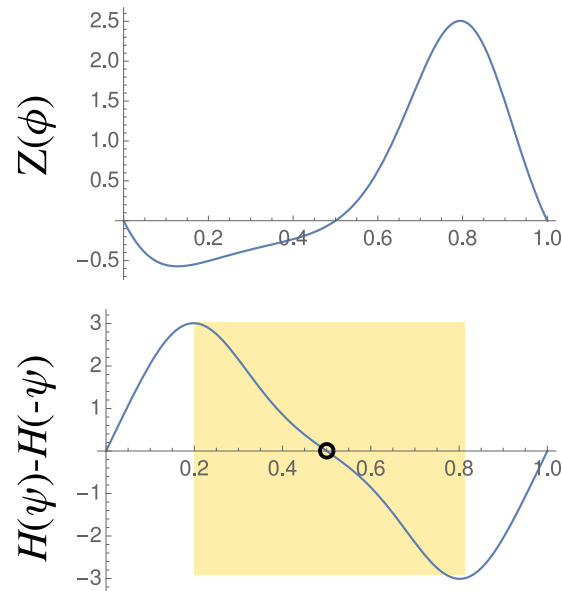


# And now for some singing ...

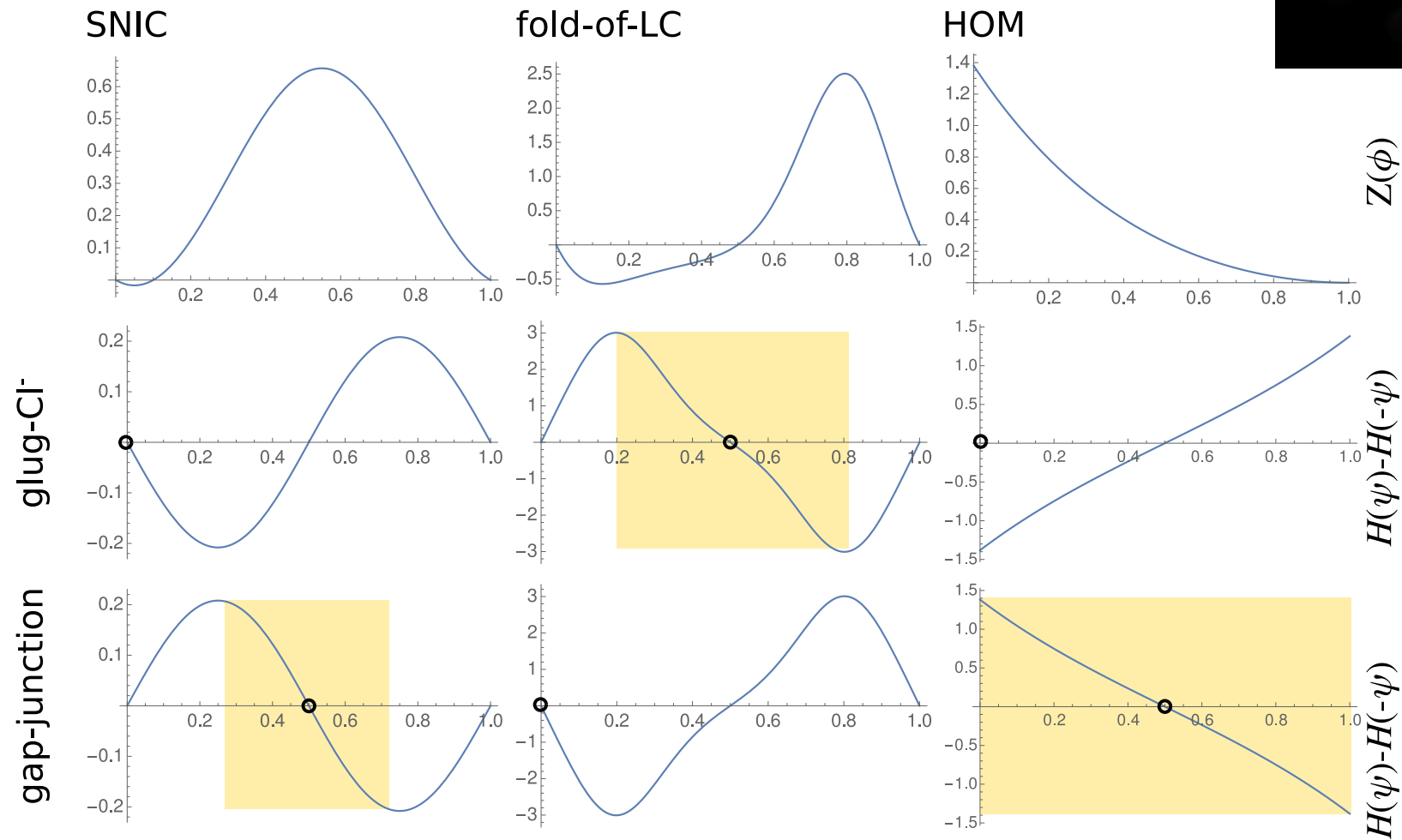
Phase difference  $\psi = \phi_1 - \phi_2$

$$\dot{\psi} = H(\psi) - H(-\psi)$$

$$H(\psi) = \int Z(\psi + \phi) s(\phi) d\phi$$



# And now for some singing ...





# Stop! That's enough singing for now.



c d e f

c f d e

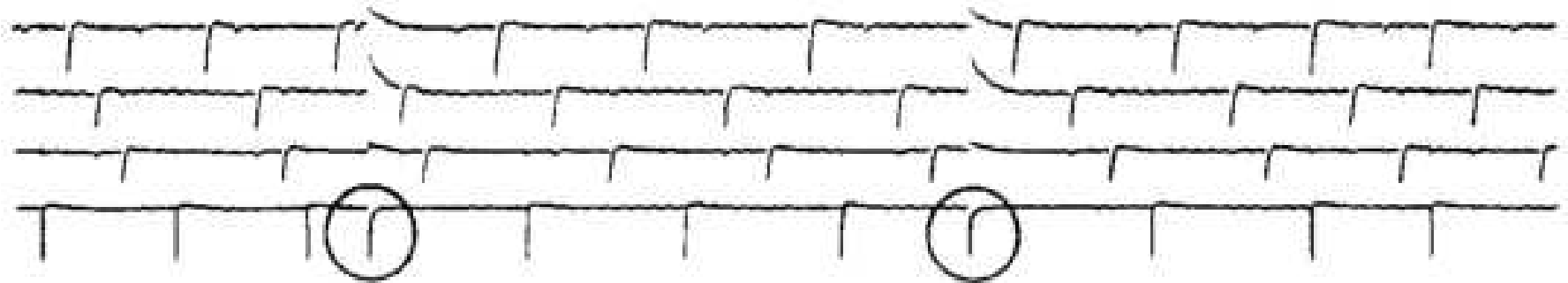
c d e f

45 c

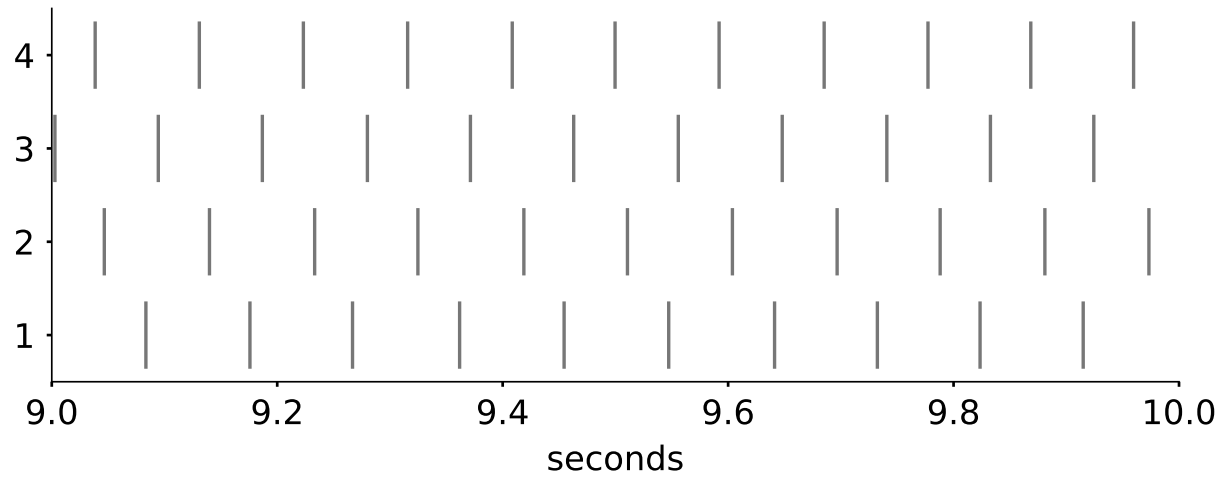
45 d

45 e

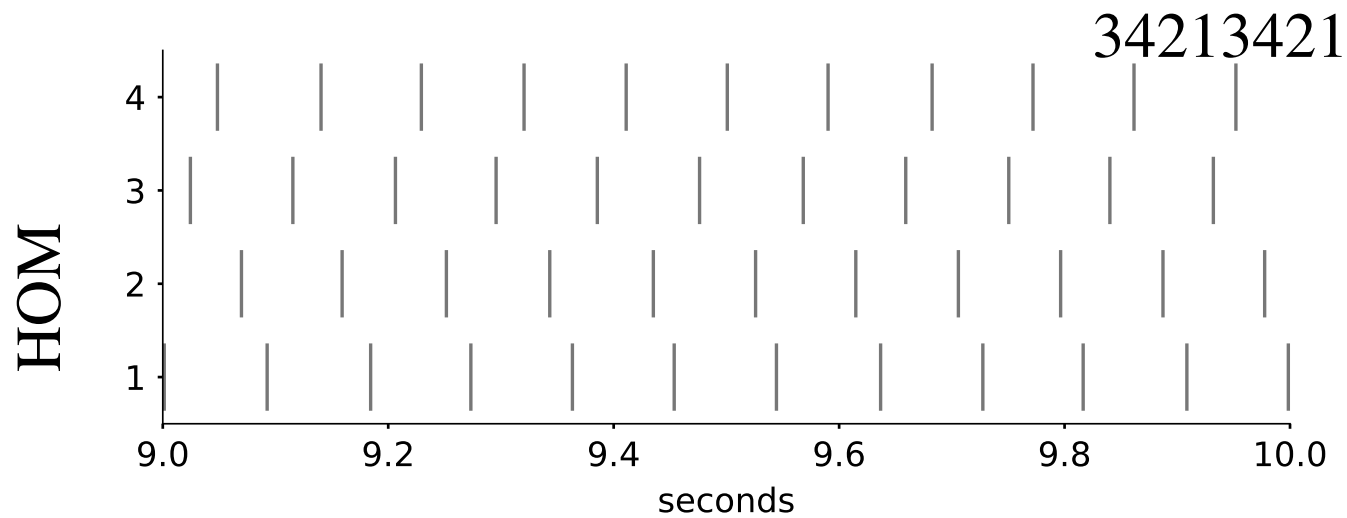
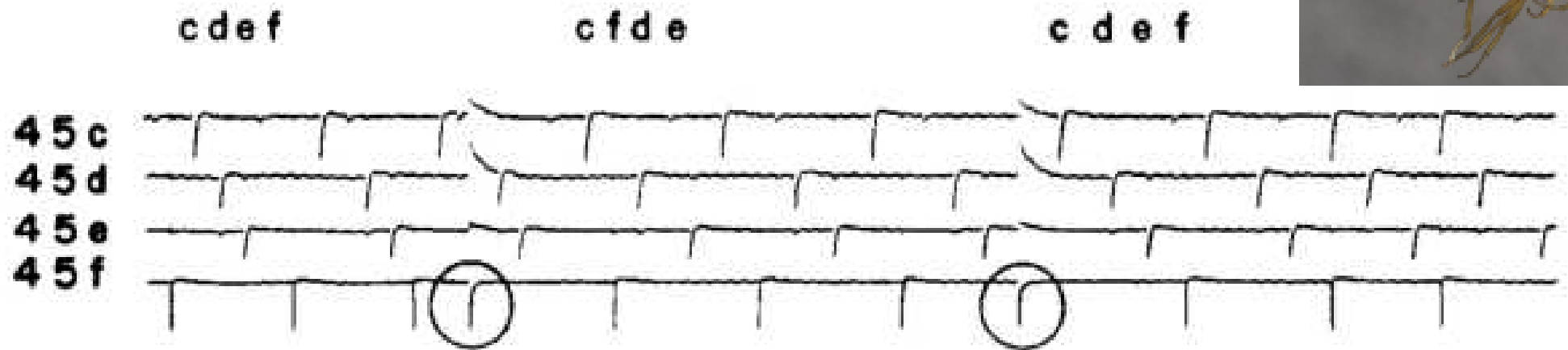
45 f



SNIC



# Stability of the *splay state*



# Stability of the *splay state*

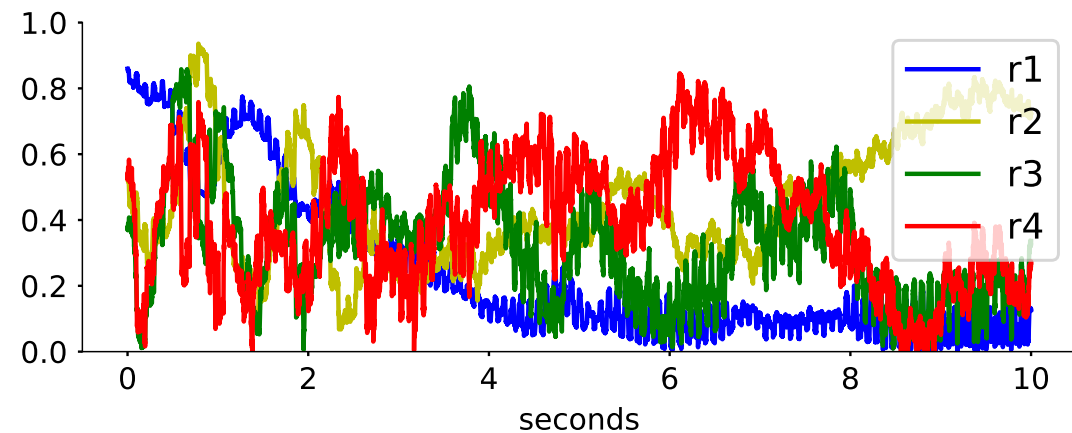
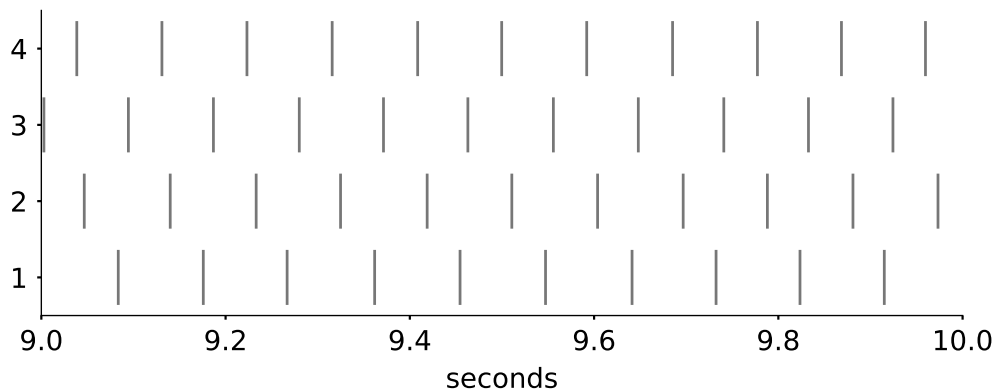
Generalised Order Parameter

$$r_n(t) = \frac{1}{N} \sum_{k=1}^N e^{in\phi_k(t)}$$

Splay state in the rotational frame  $\psi_j = j/N$



SNIC



# Stability of the *splay state*

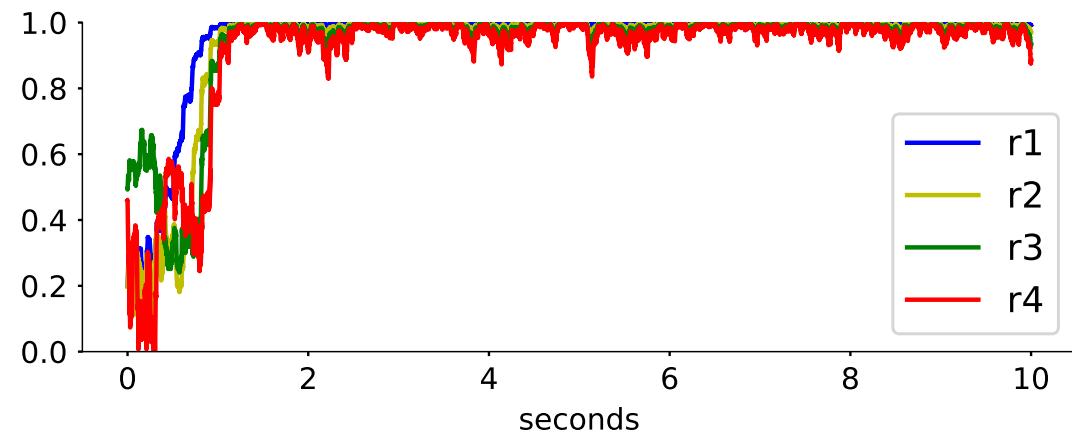
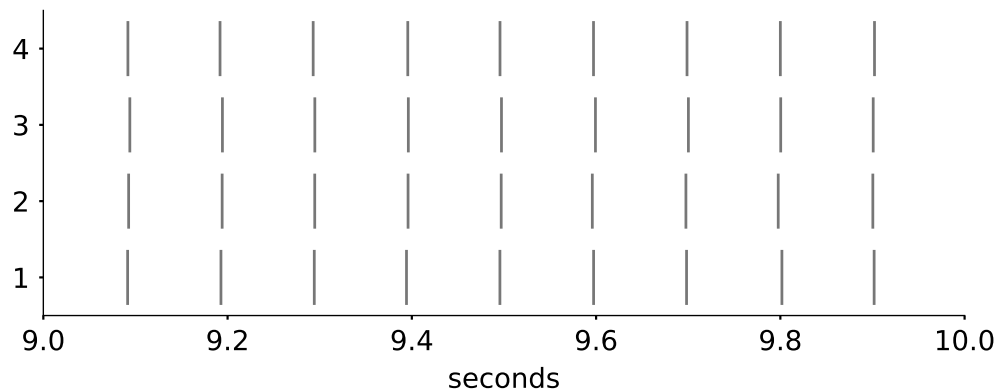
Generalised Order Parameter

$$r_n(t) = \frac{1}{N} \sum_{k=1}^N e^{in\phi_k(t)}$$

Splay state in the rotational frame  $\psi_j = j/N$



## Fold-of-LC



# Stability of the *splay* state

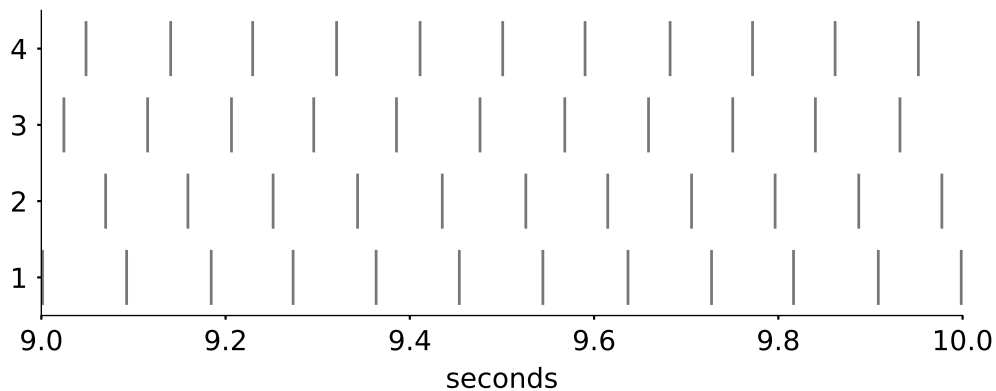
Generalised Order Parameter

$$r_n(t) = \frac{1}{N} \sum_{k=1}^N e^{in\phi_k(t)}$$

Splay state in the rotational frame  $\psi_j = j/N$

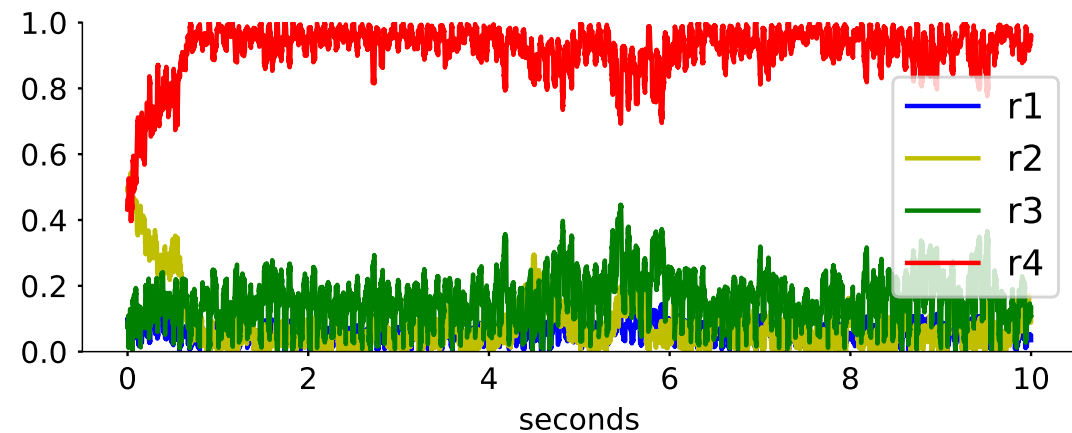


## HOM



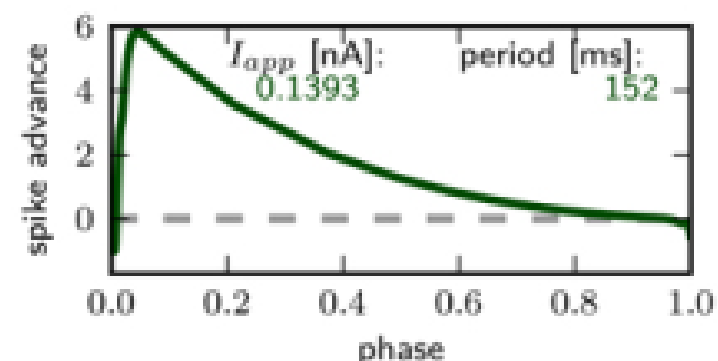
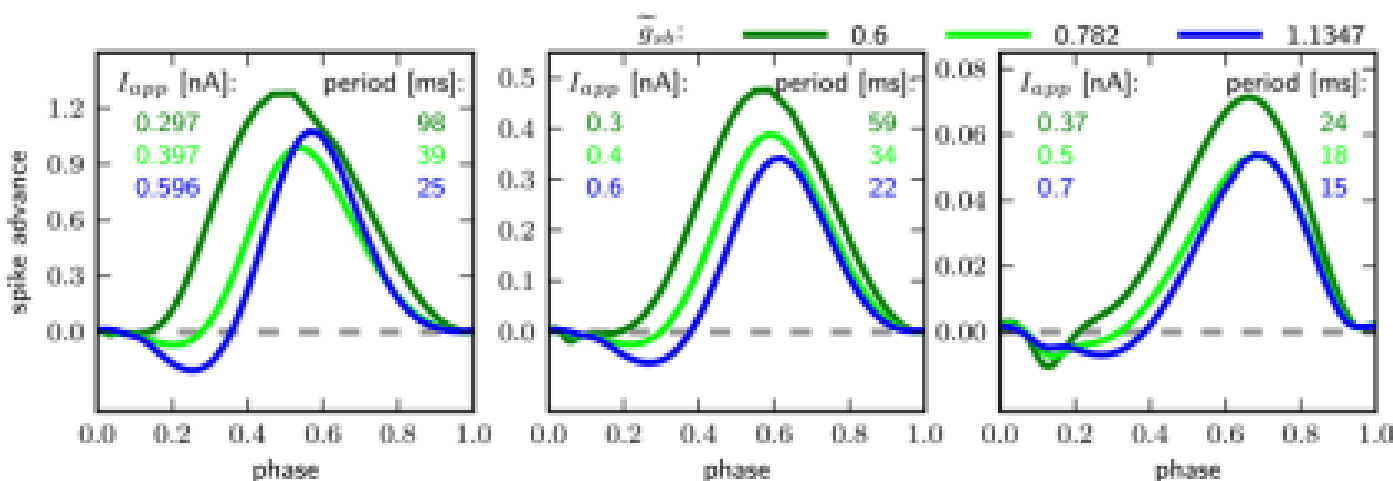
Generalised Order Parameter

$$\dot{r}_n(t) = in \left( \sum_k c_k r_k^* r_{n+k} - Z(0) r_n \right)$$



# Take-home message

- How does action selection work in the circuit?  
(Input, Neuromodulators, Heterogeneity)
- Patch-clamp data from MN5  
⇒ Conductance-based model
- Measure spike pattern during song
- How different are the neurons?  
(Development / Intrinsic Regulation)

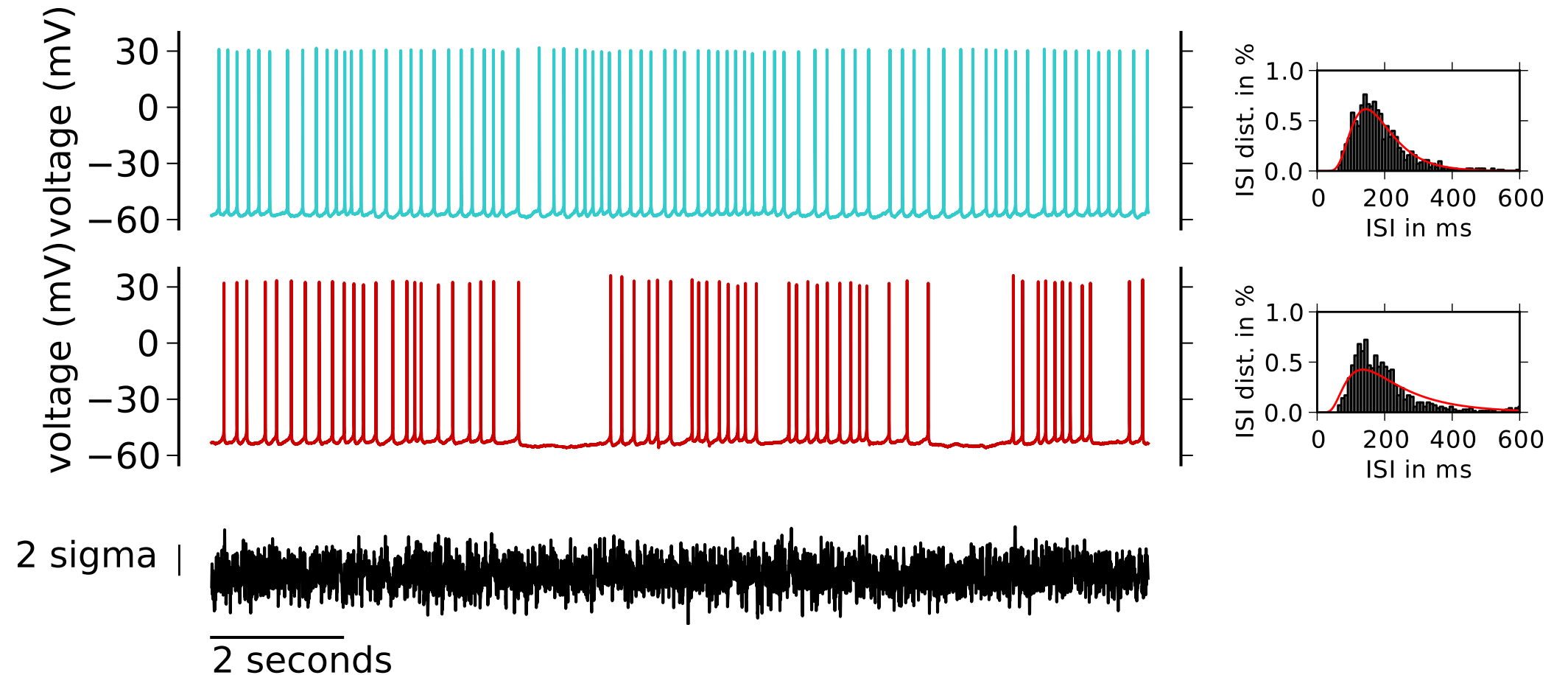


Berger *et al.* (2015)

# I didn't expect a kind of Spanish Inquisition



# Switch in spike statistics



$\dot{\phi} = f + \sigma \xi(t) \rightarrow$  Inverse Gaussian  
waiting time distribution

two temperatures  
no network  
similar firing rates  
same stimulus



# Unfolding of Saddle-Node Homoclinics

