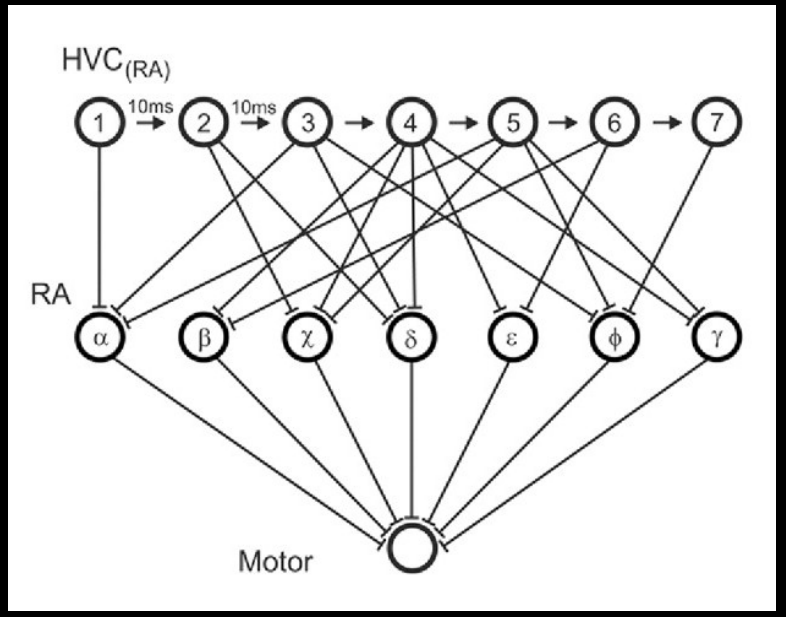
How Do Songbirds Produce Precise Vocalizations?

Professor Henry Greenside
Department of Physics, Duke University

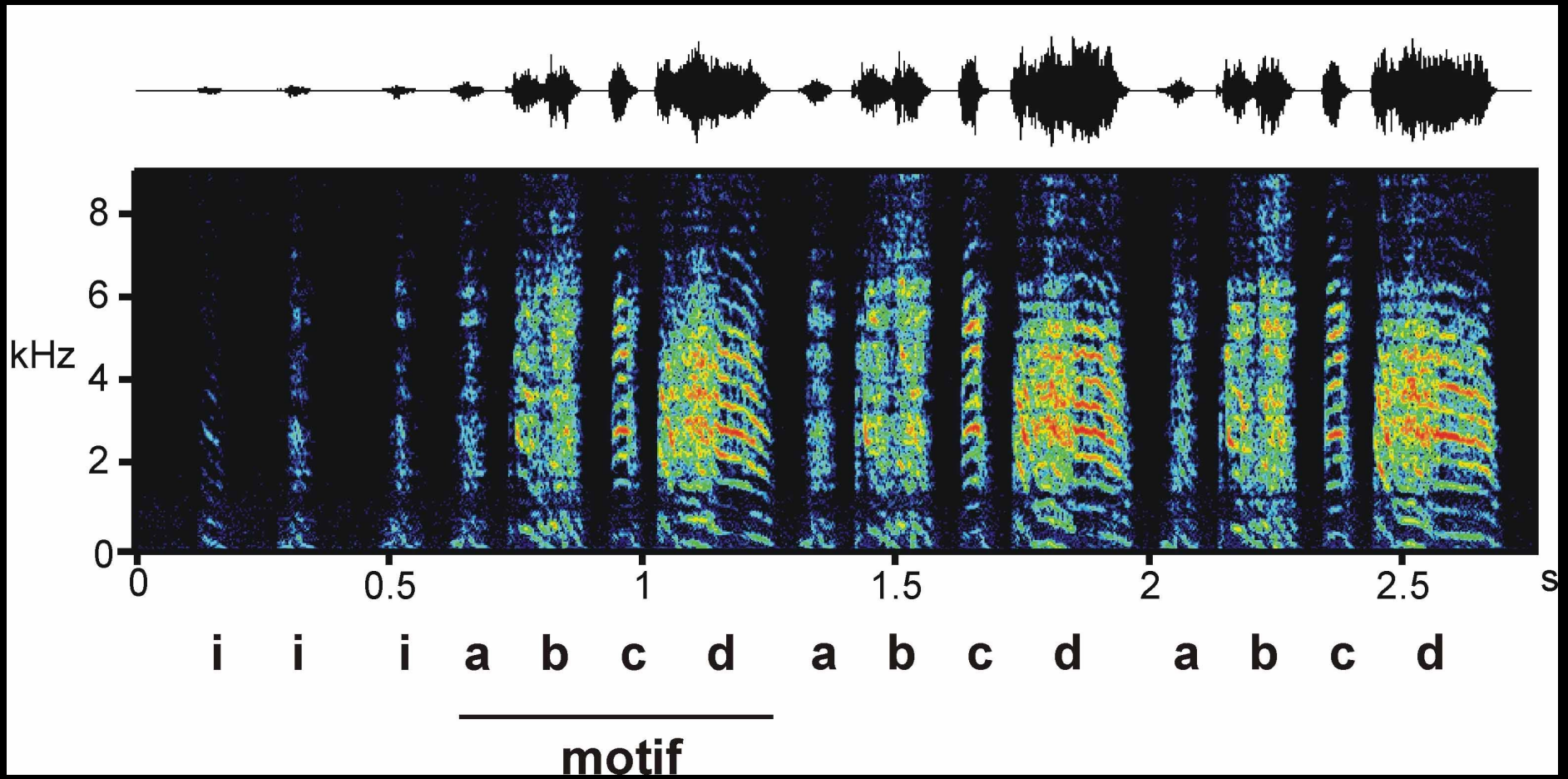


October 21, 2011

How Brains Process Information: A Great Unsolved Scientific Question

Discuss some of the ways physicists are contributing to this question in the context of sequence generation of songbirds.

Birdsong is the "Behavior" of Interest: Has Hierarchy: Notes, Syllables, and Motifs

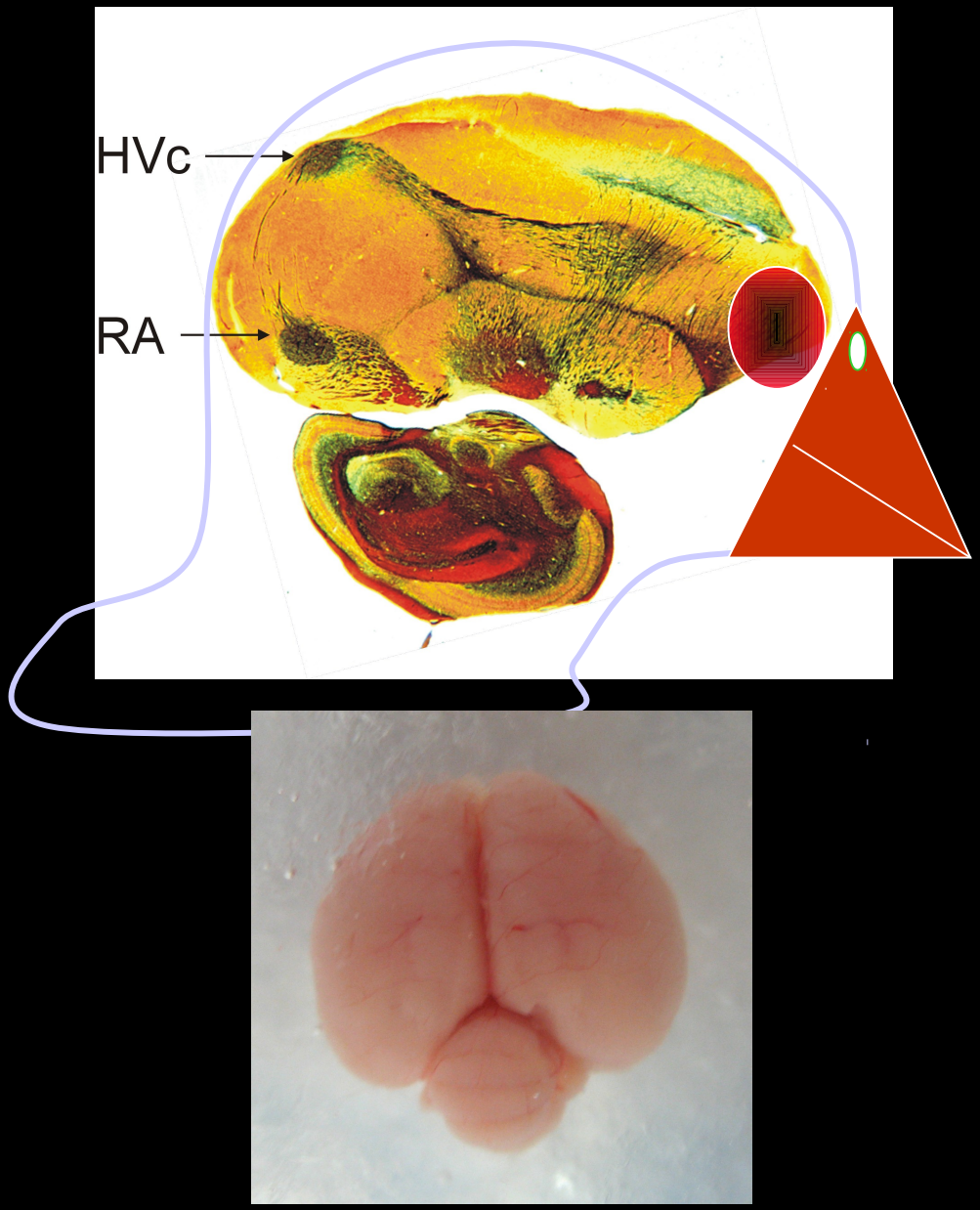


Key Questions: Generation and Hierarchy

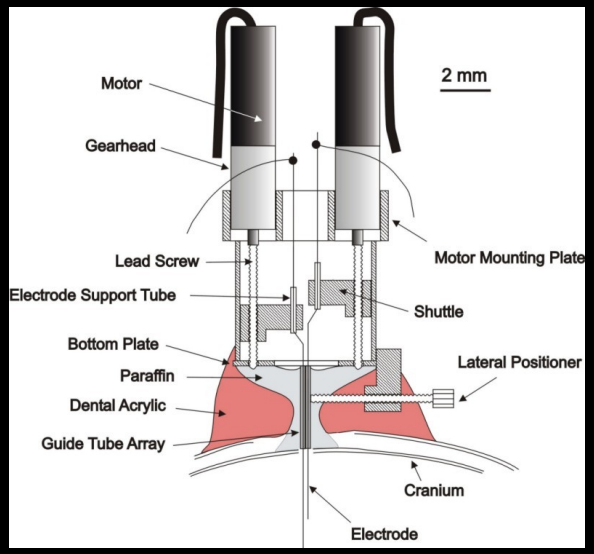
- How does a network of neurons dynamically generate precise commands that coordinate many muscles?

- For birdsong, do different brain regions handle different time scales of the song? If so, how does the brain coordinate the regions?

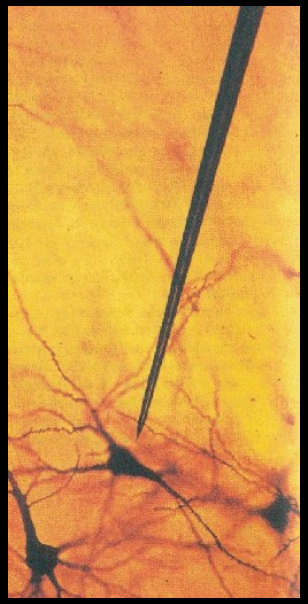
Birds Have Specialized Brain Areas for Singing



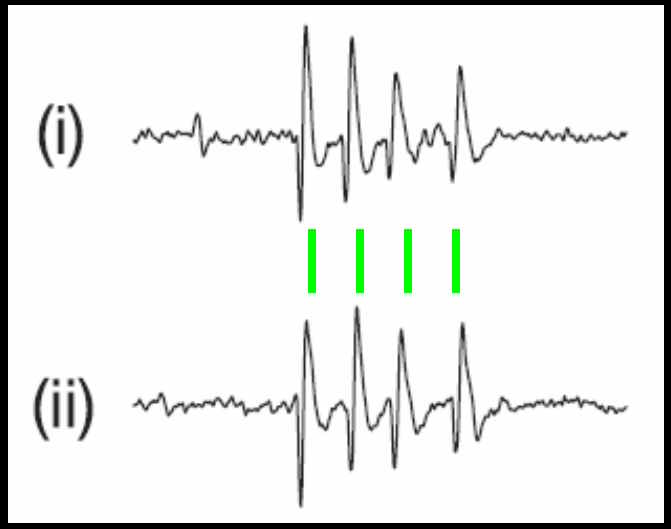
Activity of Neurons During Singing?
Device Physics Helps Neuroscience



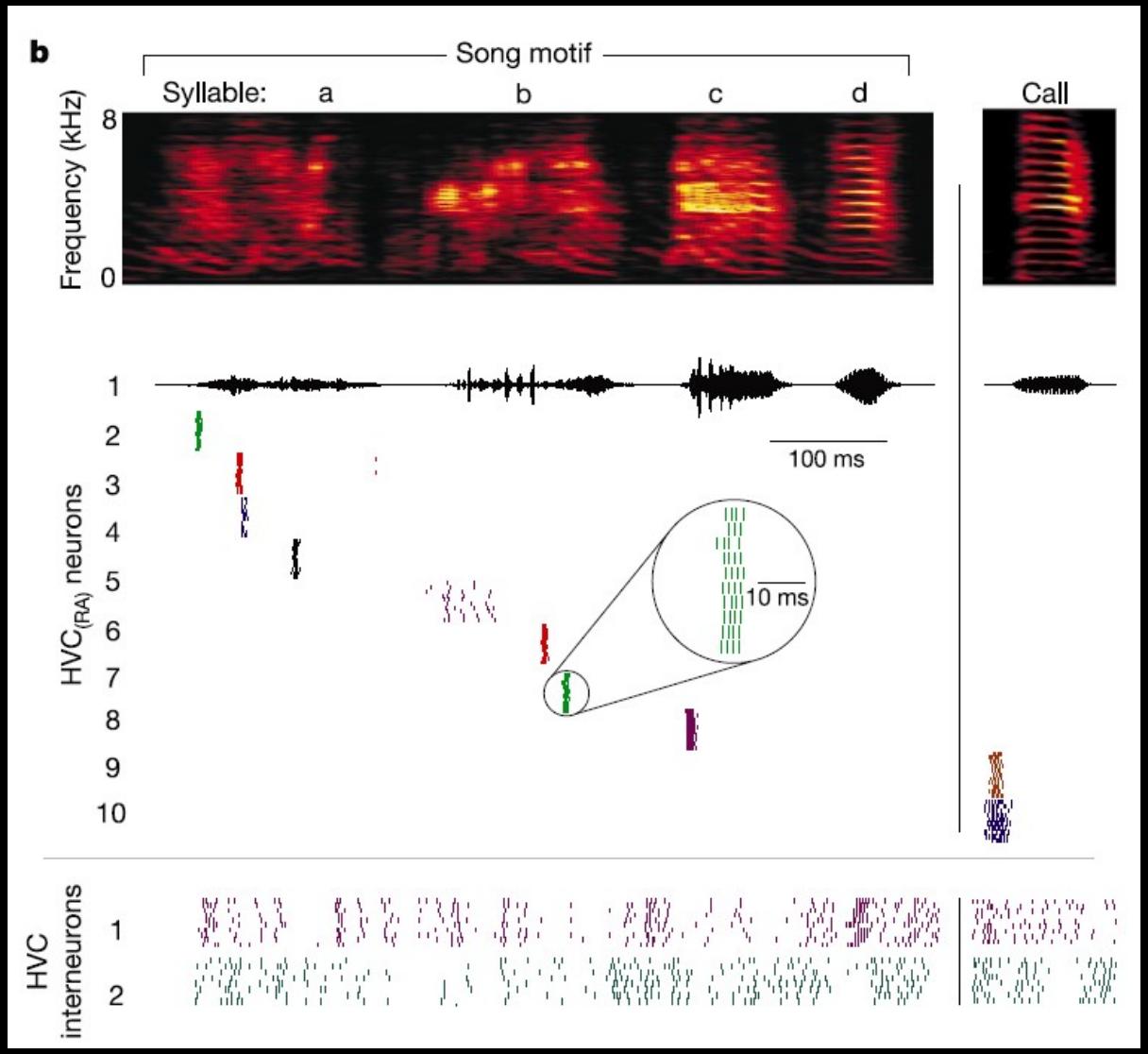
Michale Fee, MIT



Dr. Jon Prather, Duke



Ultra-sparse Bursting of HVC_{RA} Neurons During Singing



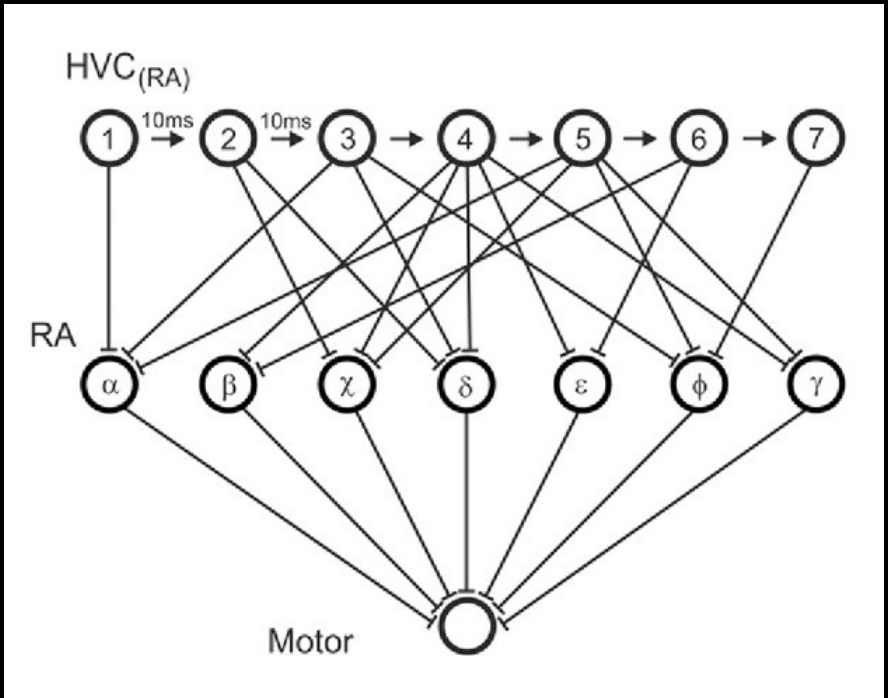
sparse

precise

robust

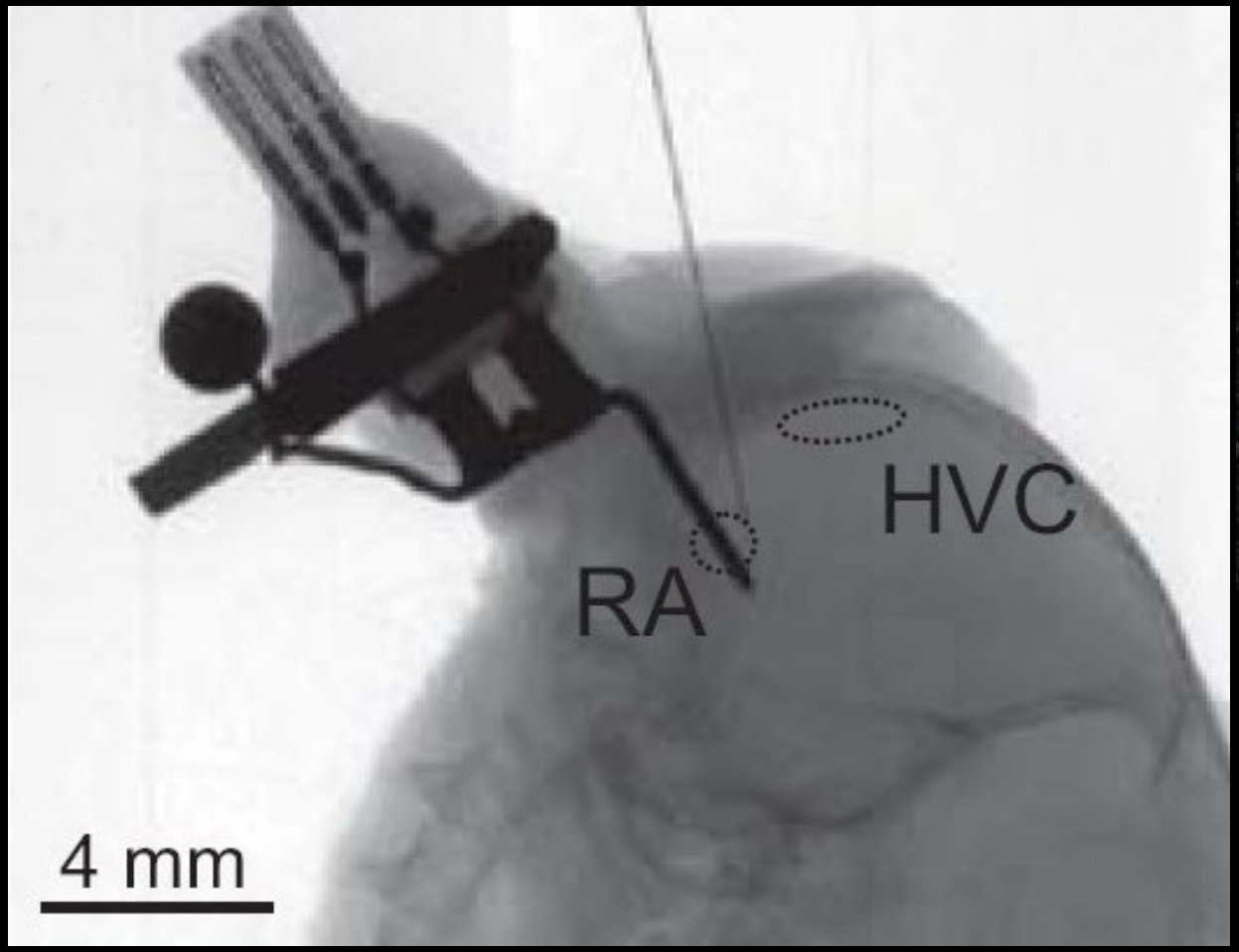
R. Hahnloser, A. Kozhevnikov, M. Fee Nature **419**:65-70 (2002)

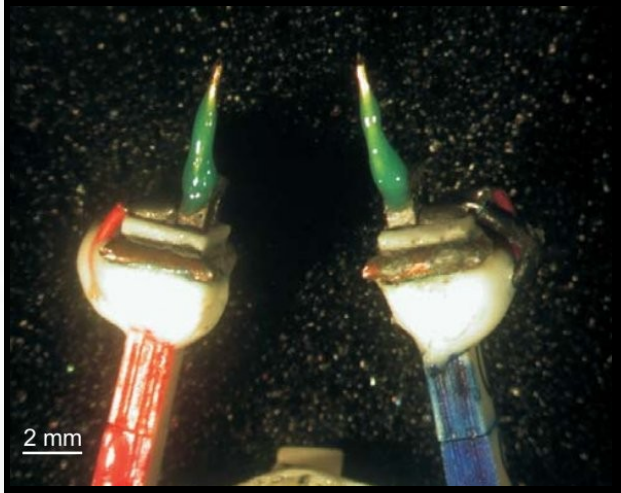
Hypothesis for Sparseness: HVC_{RA} Neurons Form a Feedforward Chain That Acts Like A Digital Clock!



M. Fee, A. Kozhevnikov, R. Hahnloser
Annals of the New York Academy of Science
1016: 153–170 (2004).

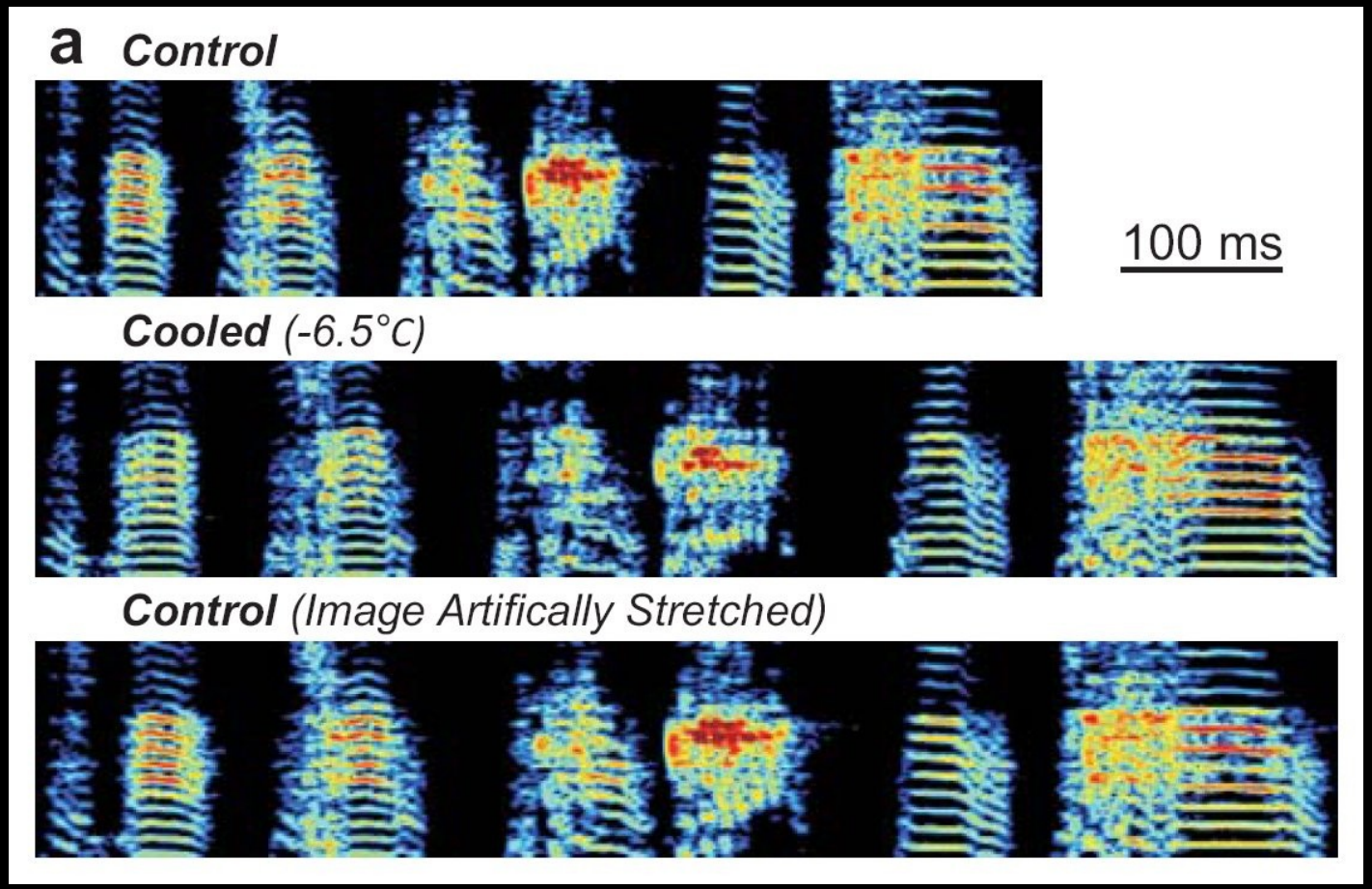
Test Chain Theory:
Cool HVC Bilaterally with Peltier Device





M. Long and M. Fee, Nature **456**:189-194 (2008)

Cooling Slows Down All Timescales: One Brain Region Controls All Timescales



M. Long and M. Fee, Nature **456**:189-194 (2008)

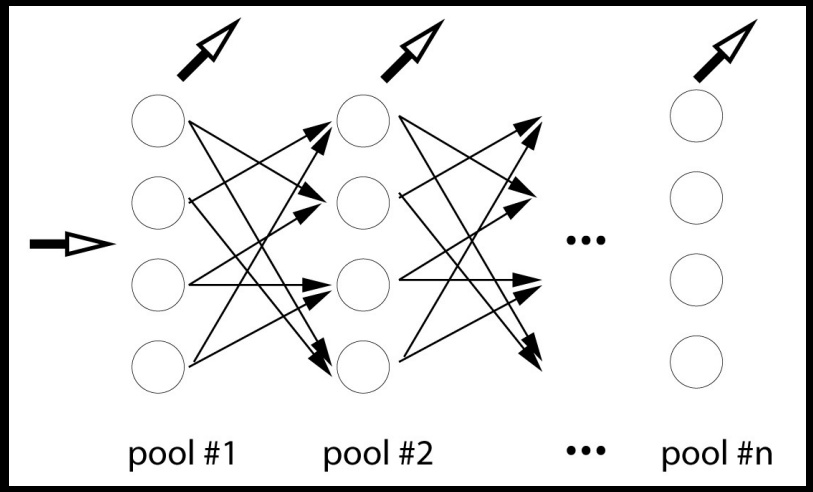
Theory: Multiple Cross-Connected Chains Are Needed for Robustness and Precision

$$C_m \frac{dv_i^k}{dt} = \sum_{m=1}^{5} g_m(t, v_i^k)\left(v_m - v_i^k\right) + I_{i,e}^k(t) + I_{i,S}^k(t) + \xi_i^k(t).$$

$$I_{i,S}^k(t) = \sum_{j=1}^{W} M_{ij}^{k,k-1} I_s(t - t_j^{k-1}; v_i^k).$$

$$I_s(t; v) = g_s C(t/\tau_s) e^{-t/\tau_s}\left(v_s - v\right).$$

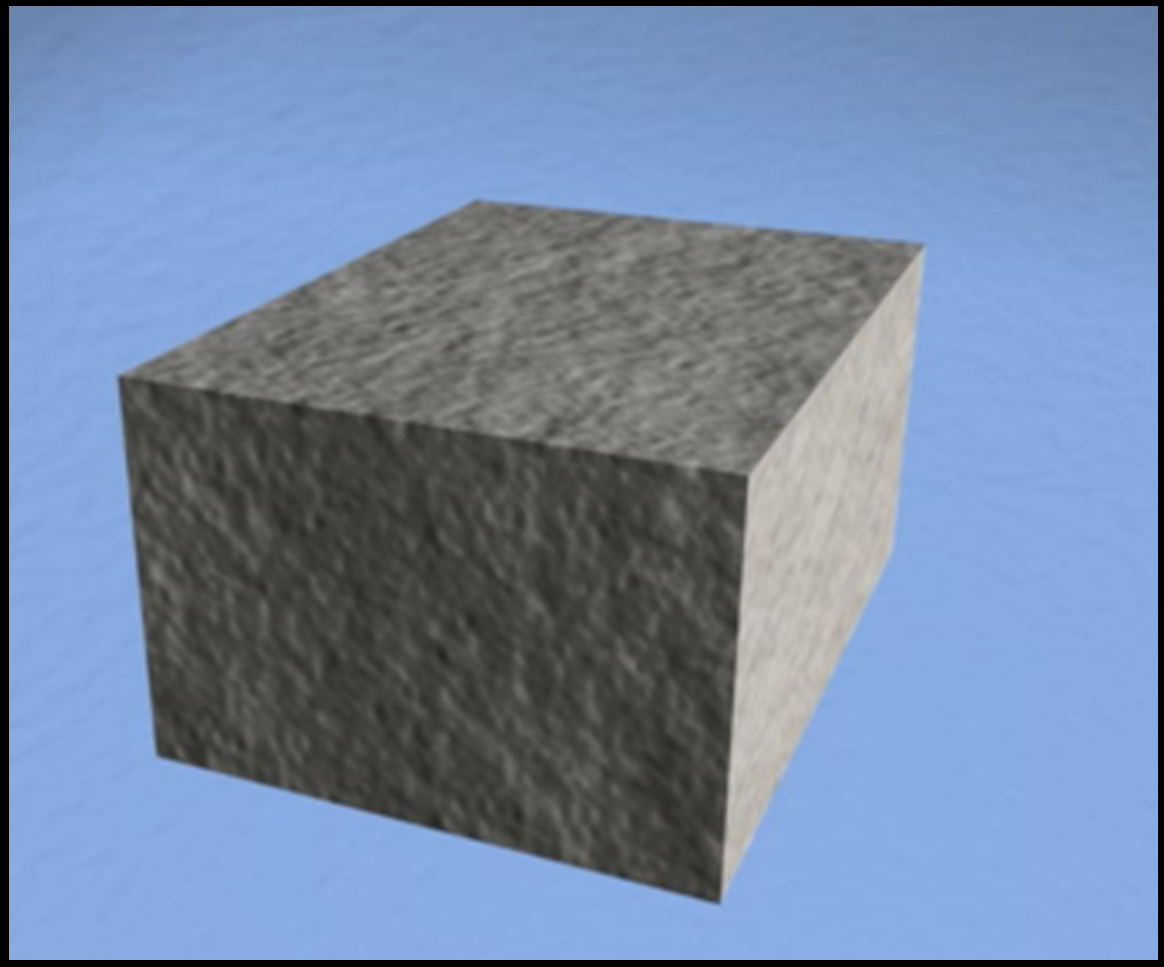
$$\begin{aligned} g_m(t, v) &= \bar{g}_m x_1^u(t) x_2^v(t) \\ \tau(v)\frac{dx}{dt} &= x_\infty(v) - x \\ x_\infty(v) &= \left(1 + e^{-(v - v_0)/v_1}\right)^{-1} \\ \tau(v) &= t_2 + t_1\left(1 + e^{-((v - v_2)/v_3)}\right)^{-1} \end{aligned}$$



Synfire chain

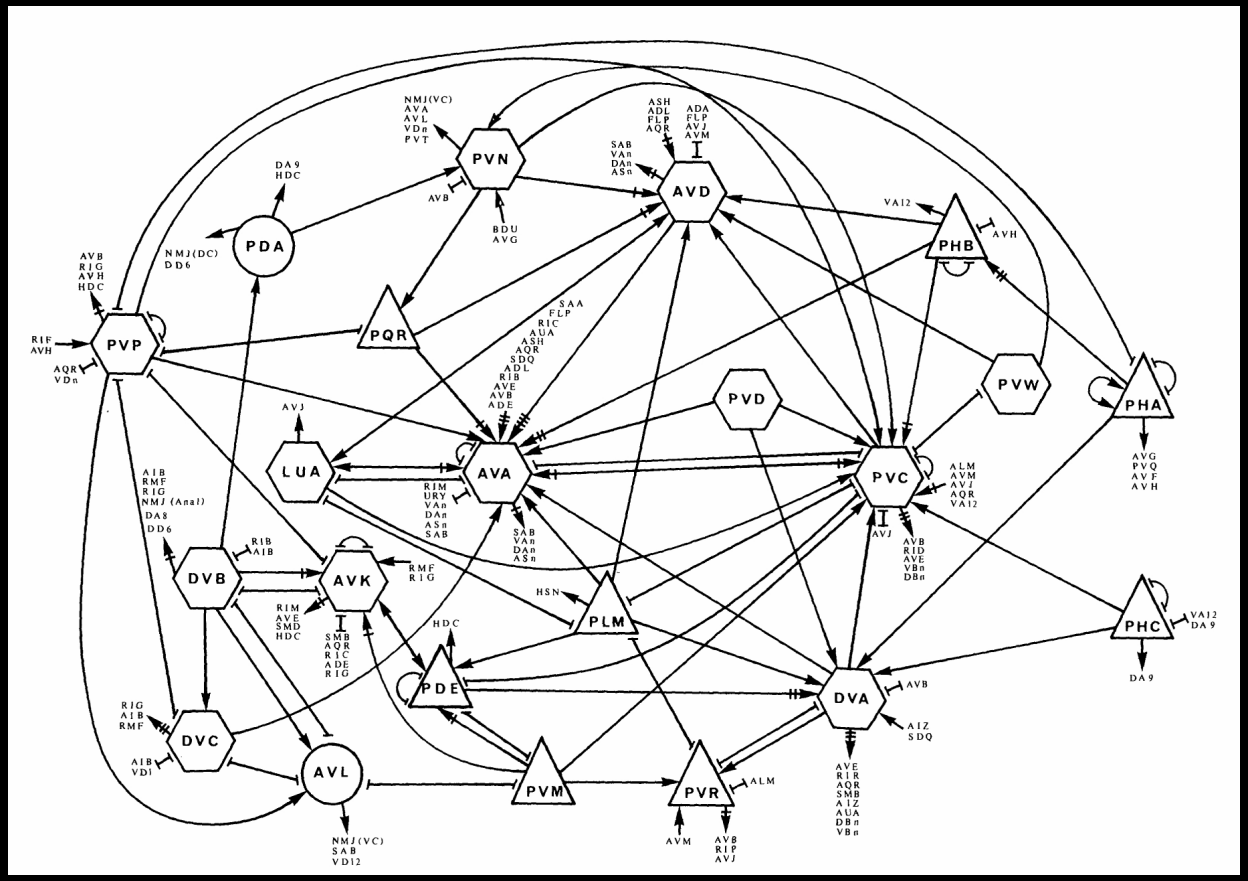
M. Li and H. Greenside, Physical Review E**74**:**011918** (2006)
D. Jin et al, J. Comput. Neuroscience **23**:283-289 (2007).

Direct Test of HVC Wiring By Connectomics?



Movie courtesy of Mitya Chklovskii at Janelia Farm Research Center

Connectivity Does Not Determine Functionality



White, J. G.; Southgate, E.; Thomson, J. N.; Brenner, S. (1986). "The Structure of the Nervous System of the Nematode Caenorhabditis elegans". Philosophical Transactions of the Royal Society B: Biological Sciences **314**(1165): 1–340

http://www.wormatlas.org

Conclusions

1. Discussed several ways that physicists are contributing to brain science: device physics, quantitative measurements, and theory.
2. Neuroscience young science, many open questions, many opportunities for physicists.