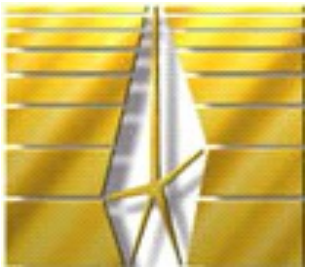
Bistability and noise inhibition of Purkinje cells

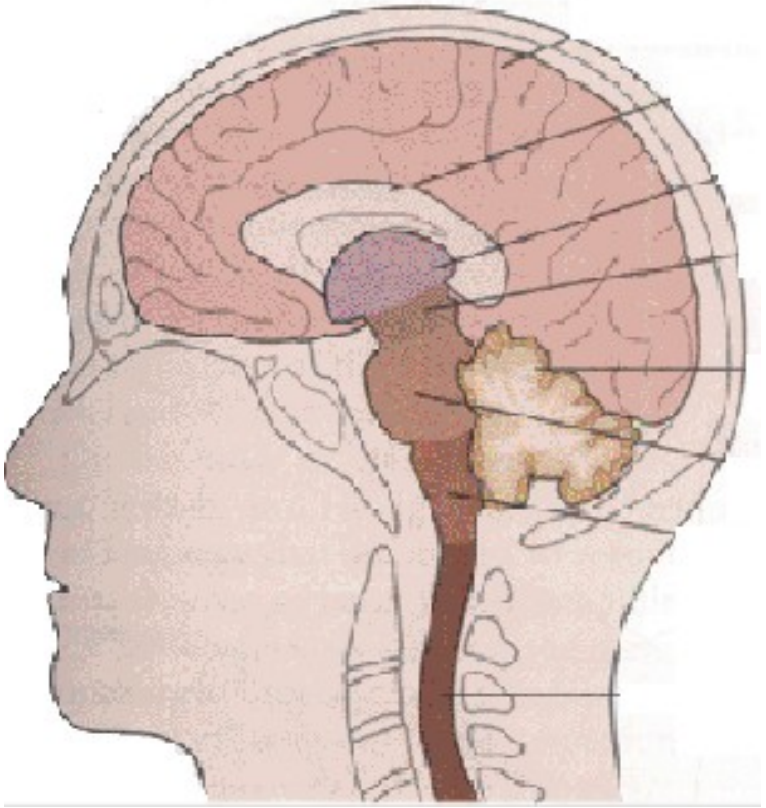
- Ioffe Physical Technical Institute,
  St.-Petersburg
  Anatoly Buchin

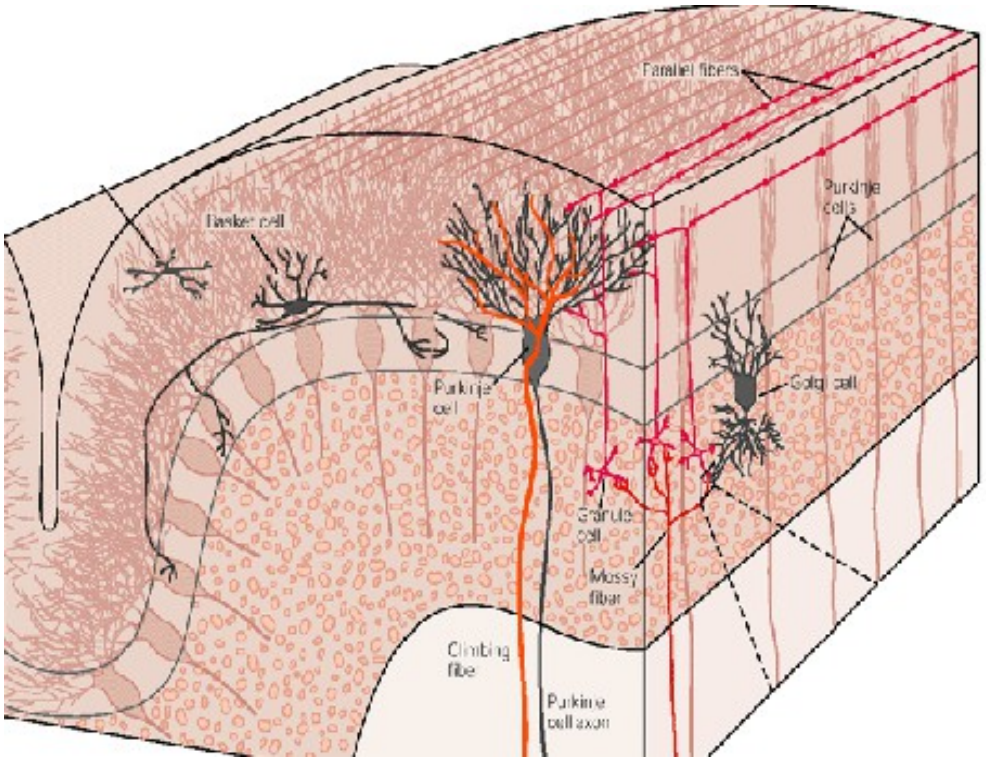


- The Group of Neural Theory,
  Paris, Ecole Normale Superiure
  Boris Gutkin

- University College London,
  Wolfson Institute of Biomedical Research
  Sarah Rieubland and Arnd Roth

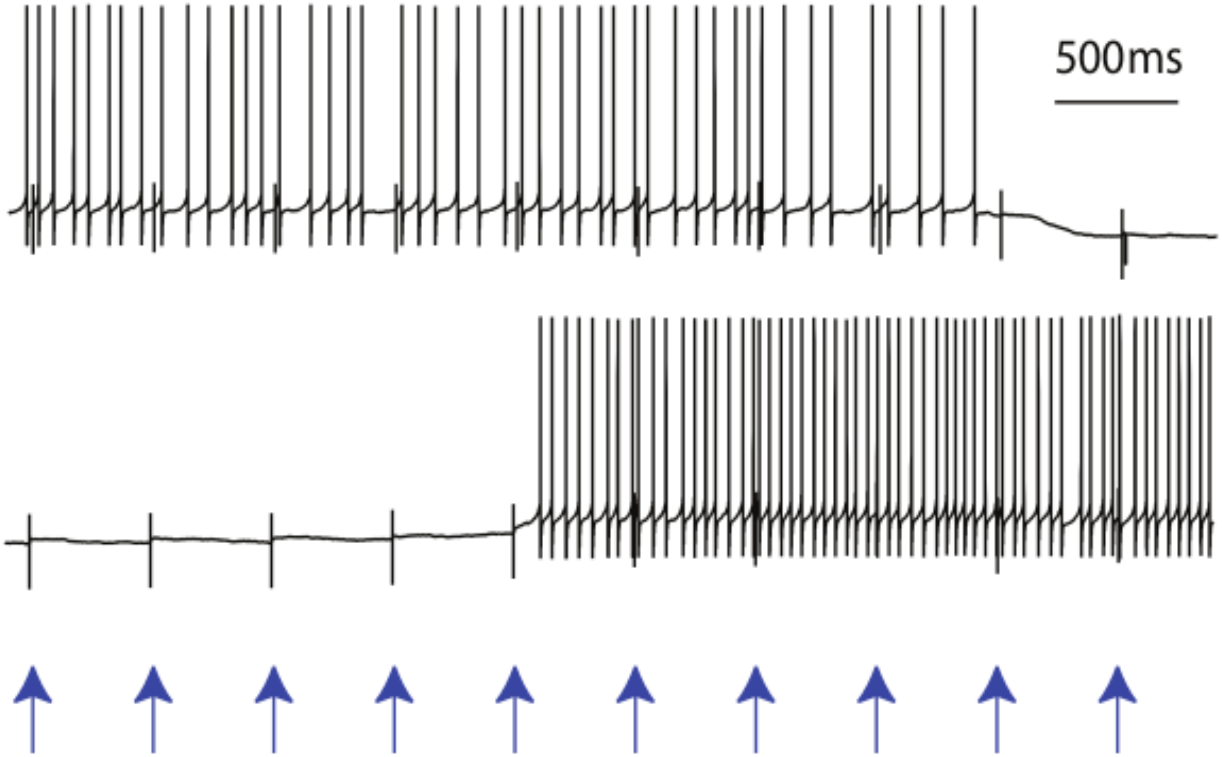
Introduction



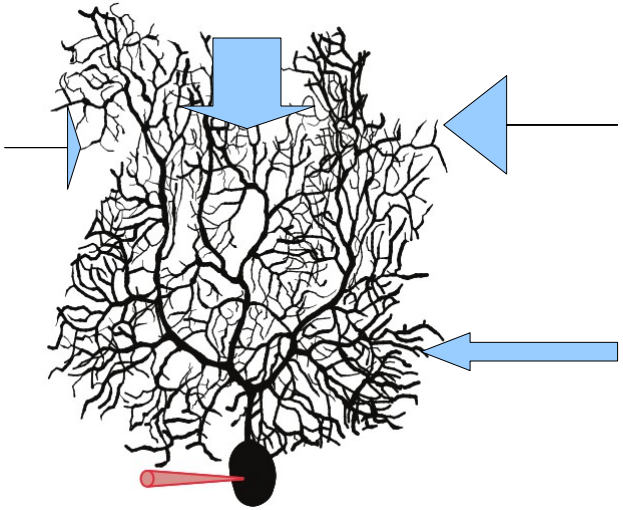


[E. Kandel, Principles of Neural Science 2004]

Intracellular recordings of Purkinje cell when stimulating by parallel fibers

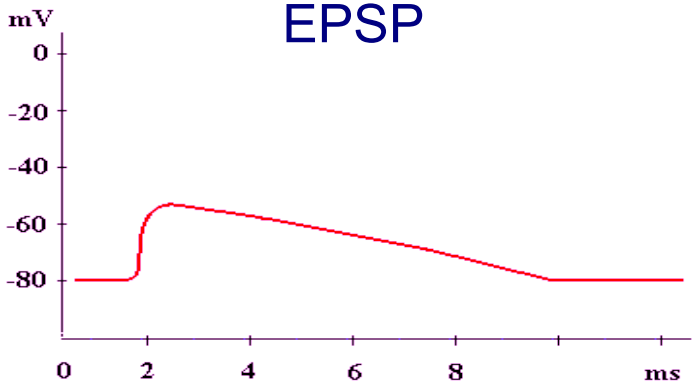


The model of synaptic input

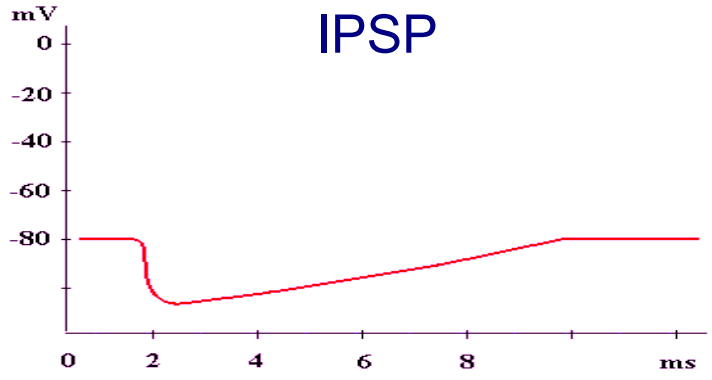


$$\tau_S \frac{dI}{dt} = -I + \tau_S \sigma \xi(t)$$

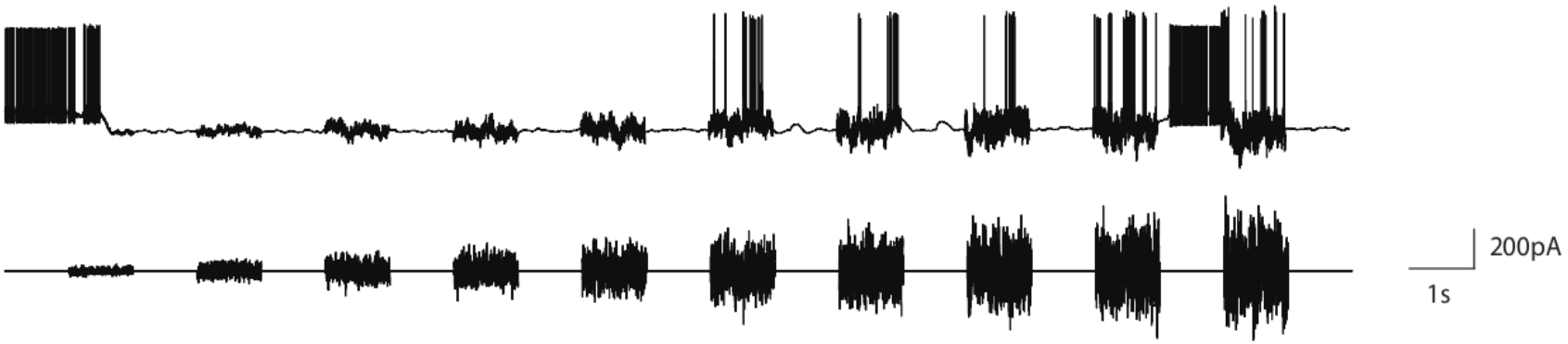
EPSP



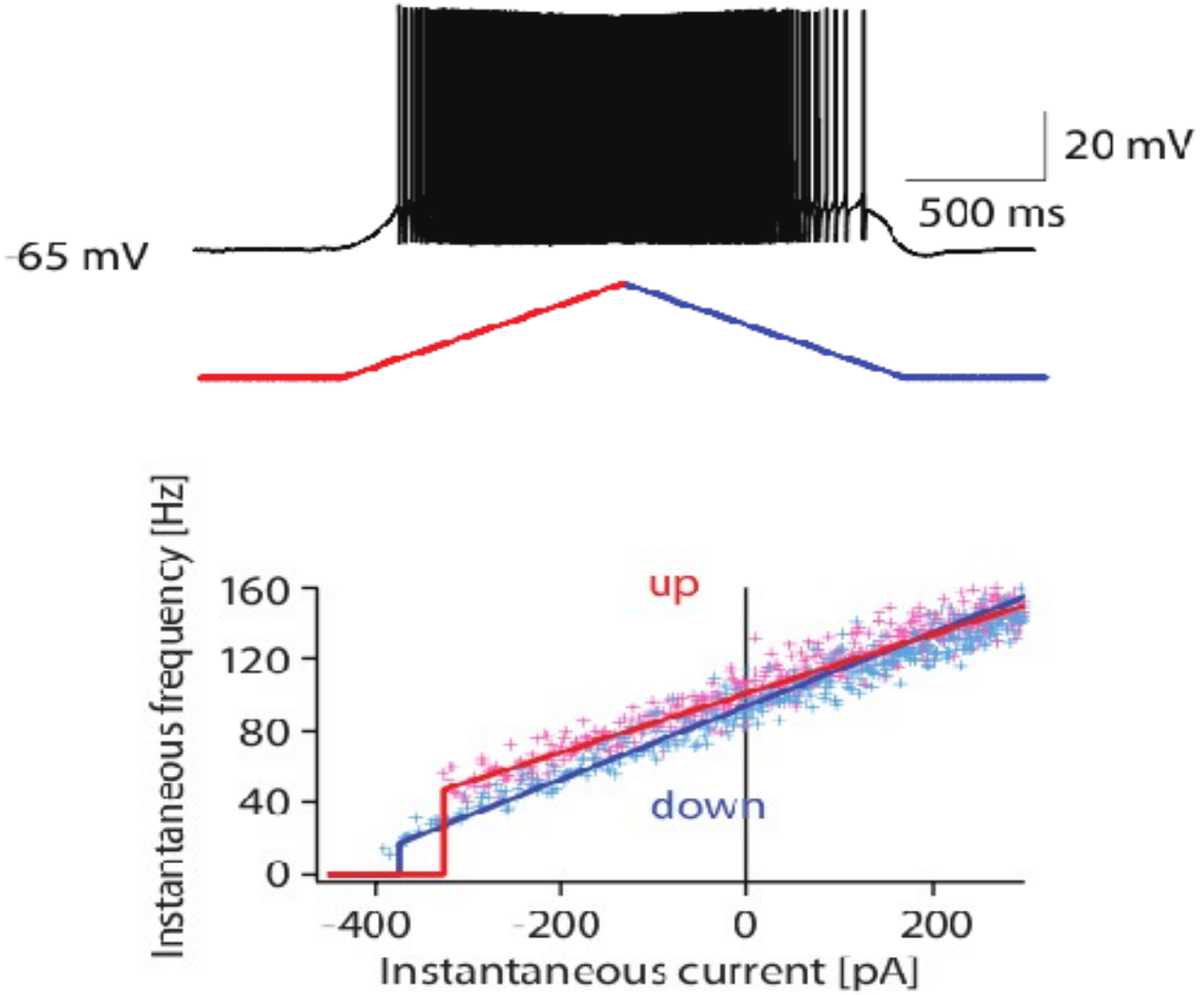
IPSP



Experiment: inhibition of Purkinje cell by current noise injection



Experiment: firing-rate hysteresis of Purkinje cell



Adaptive Exponential Integrate-and-fire model of a neuron (aEIF)

$$C\frac{dV}{dt} = -g_l(V - V_l) + g_l\Delta\, e^{\left(\frac{V - V^T}{\Delta}\right)} - w + I$$

$$\tau_w \frac{dw}{dt} = a(V - V_l) - w$$

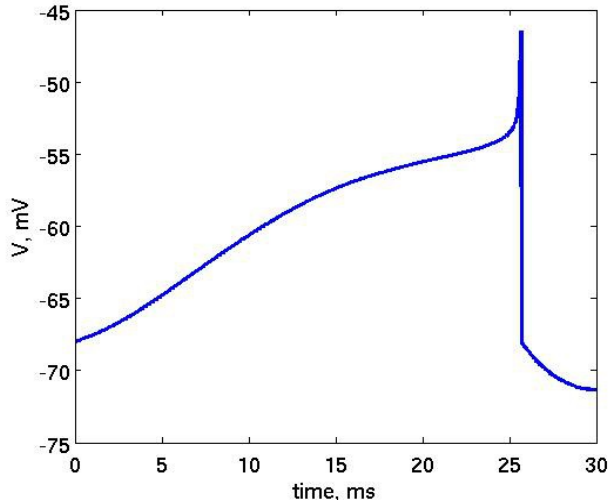
$$if\ V > V_{spike}\quad then\quad V = V_{reset}$$
$$w = w + b$$

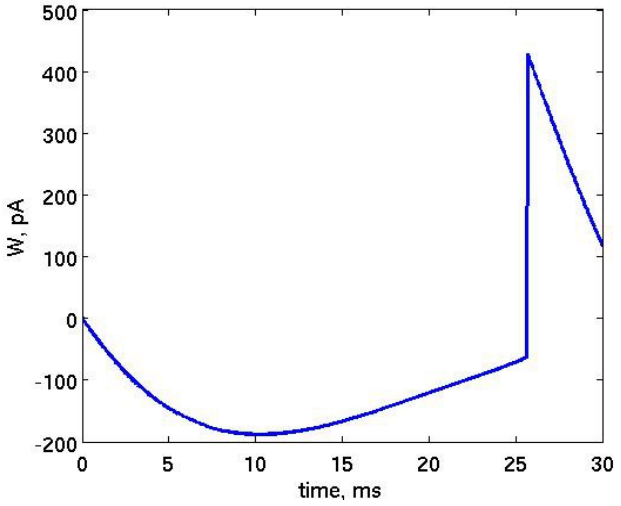
$C = 217\ pF$ $\quad gl = 12.8\ mS$ $\quad b = 495\ pA$

$\tau_m = 4.5$ $\quad V^T = -56.252\ mV$ $\quad \tau_w = 11.12\ ms$

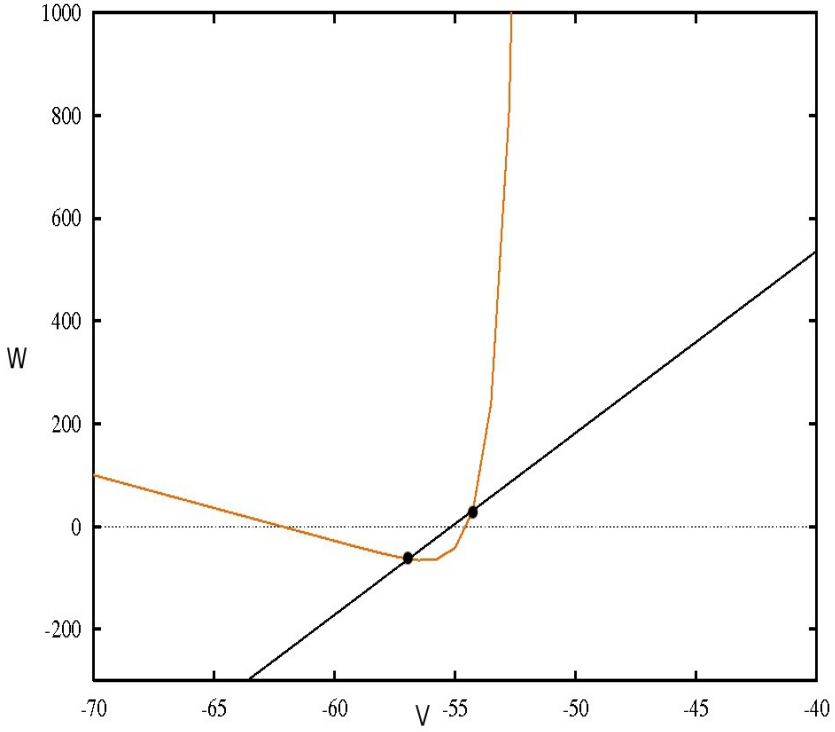
$El = 55.144\ mV$ $\quad \Delta = 0.77\ mV$

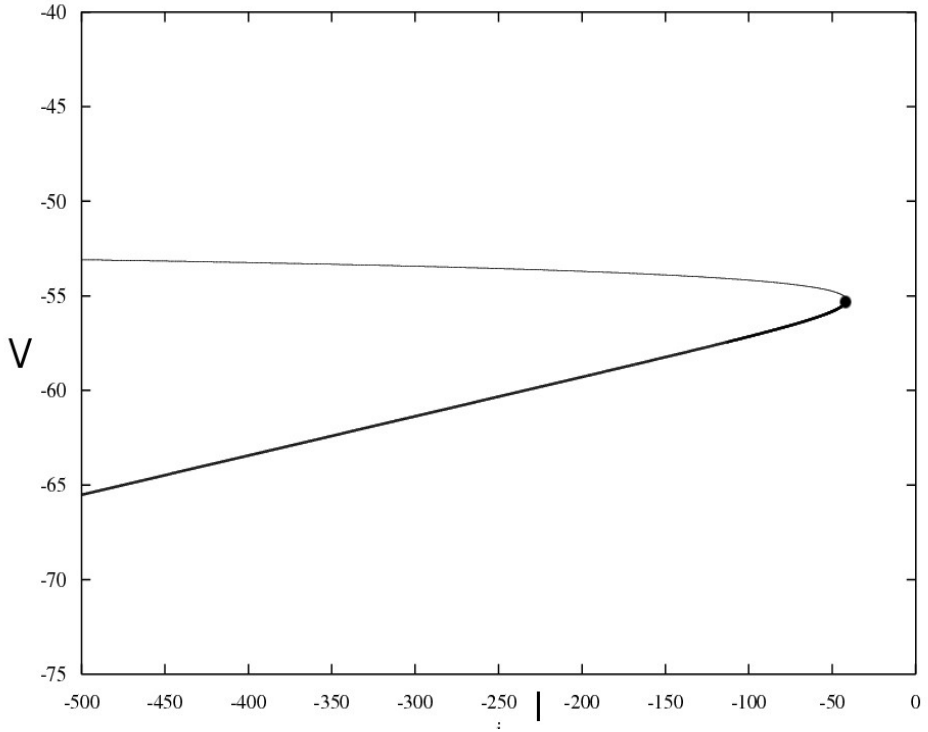
$V_{reset} = -68\ mV$ $\quad a = 35.4\ nS$





Phase portrait and bifurcation in the model of aEIF neuron

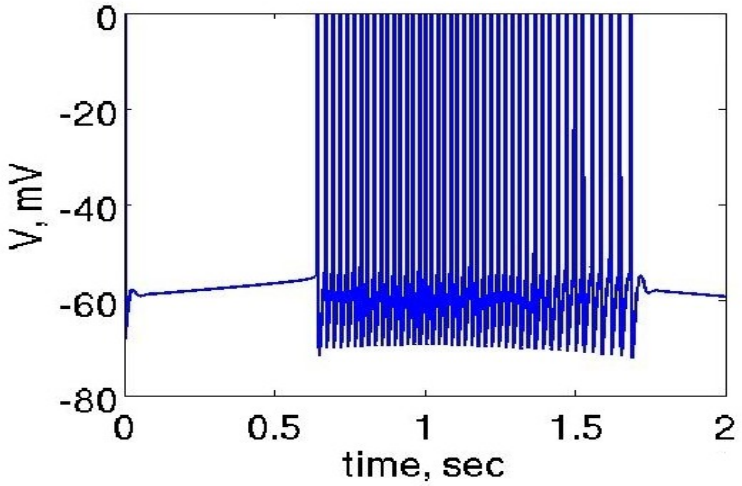


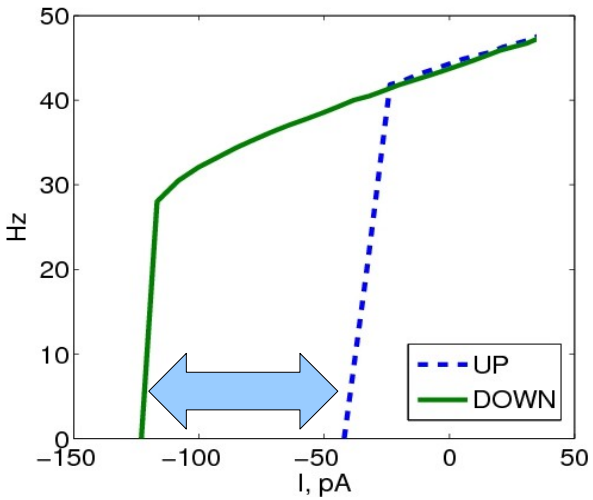


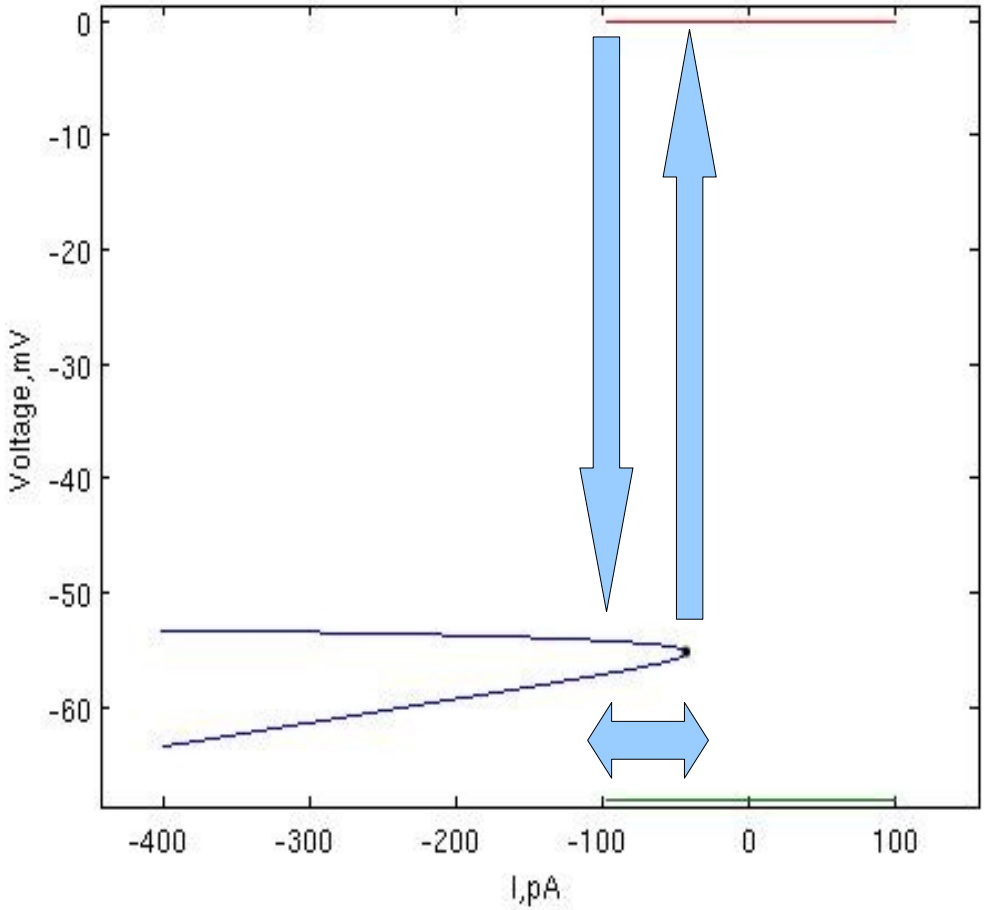
$$w = -g_L(V - E_L) + g_L \Delta_T \exp\left(\frac{V - V_T}{\Delta_T}\right) + I \quad \textit{(V-nullcline)}$$

$$w = a(V - E_L) \quad \textit{(w-nullcline)}$$

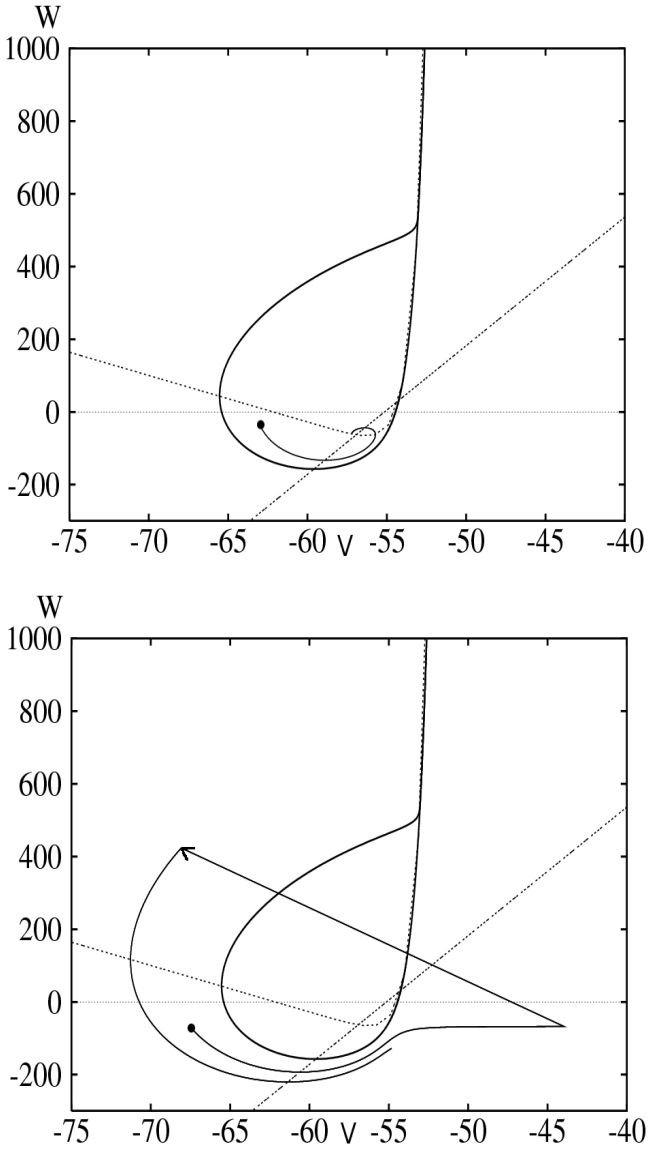
Model of firing-rate hysteresis

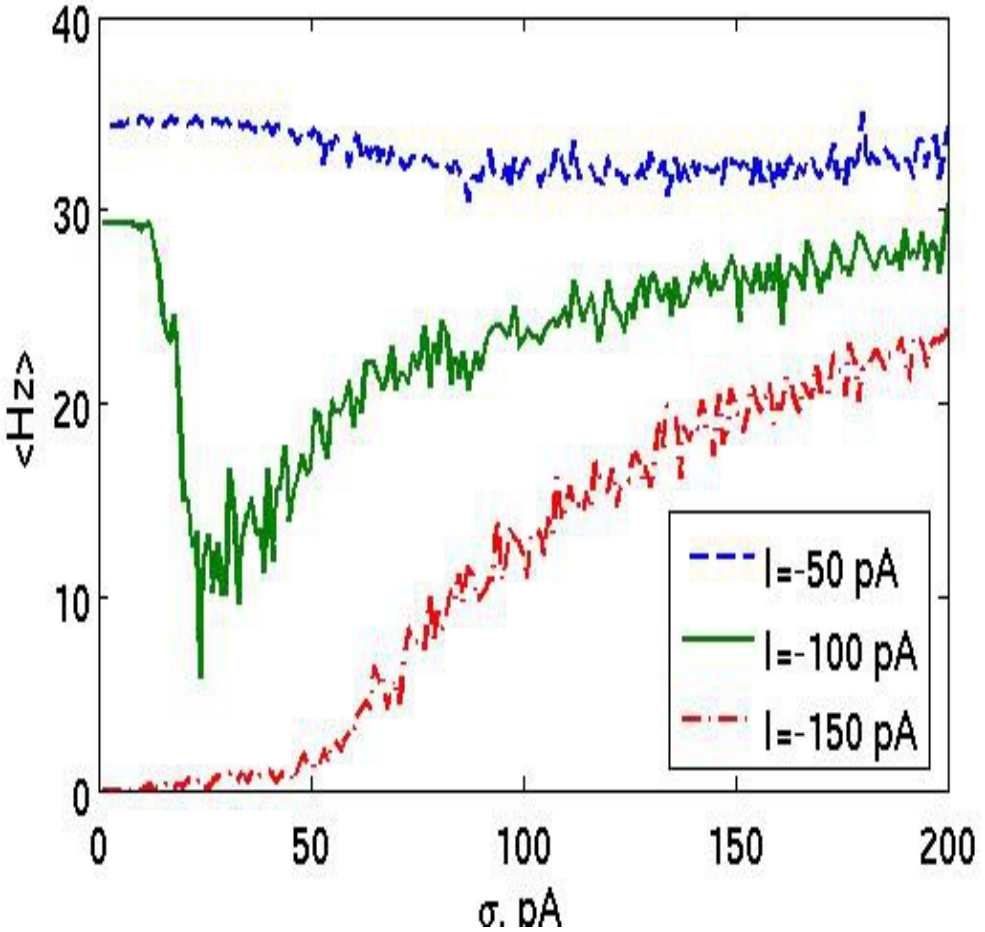




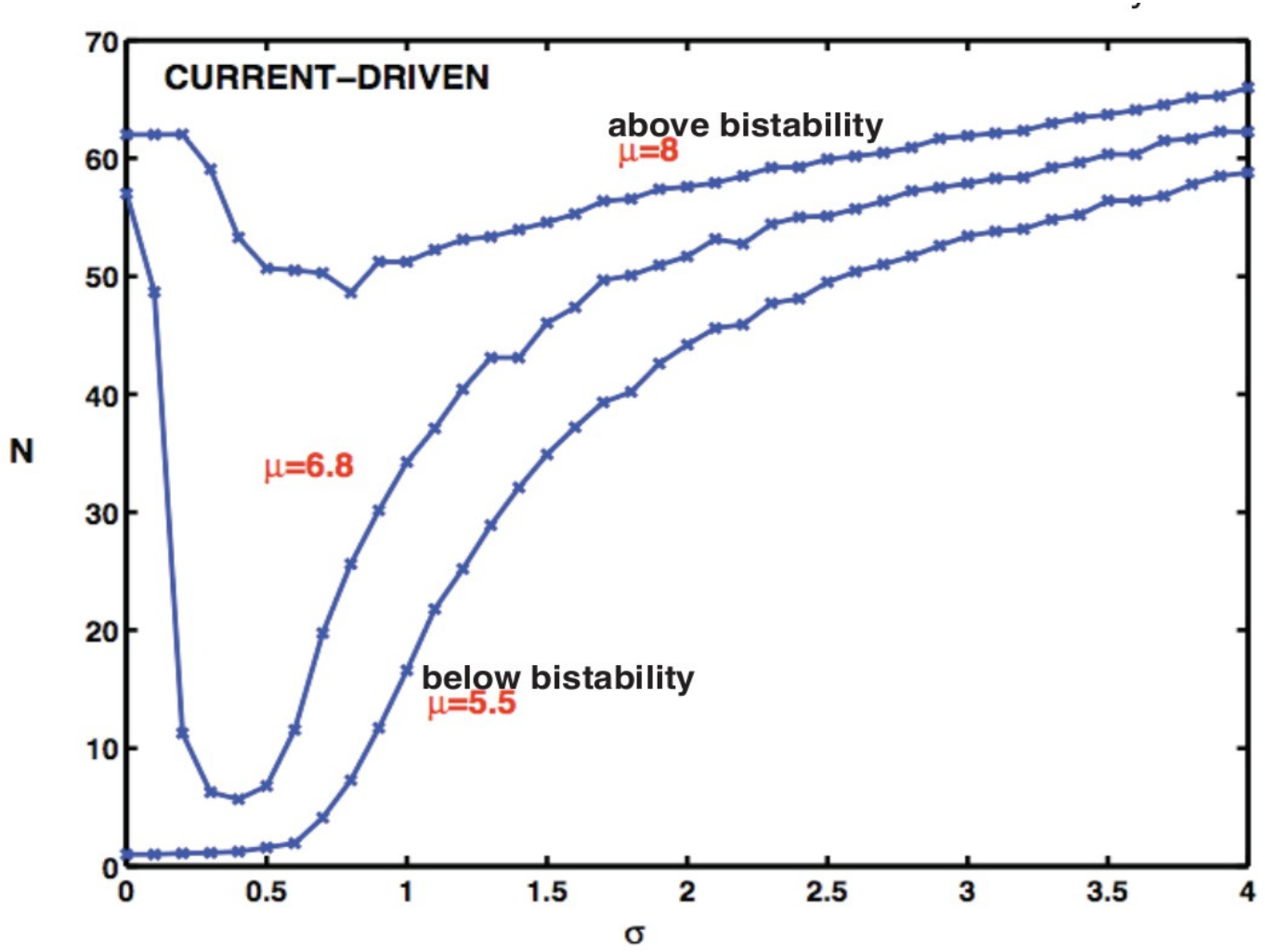


Model of noise inhibition





Inhibition by noise in Hodjkin-Huxley model



[Gutkin BS, Jost J, Tuckwell HC 2009]

Conclusions

- Experimentally fitted aEIF model explains quiescent and spiking state of a Purkinje cell.
- Inhibition by noise and firing-rate hysteresis is based on switching between these two states.
- This directly supports the idea of Purkinje cell bistability *in vivo*.