The active electric sense of weakly electric fish: from electric organ discharge to sensory processing and behaviour

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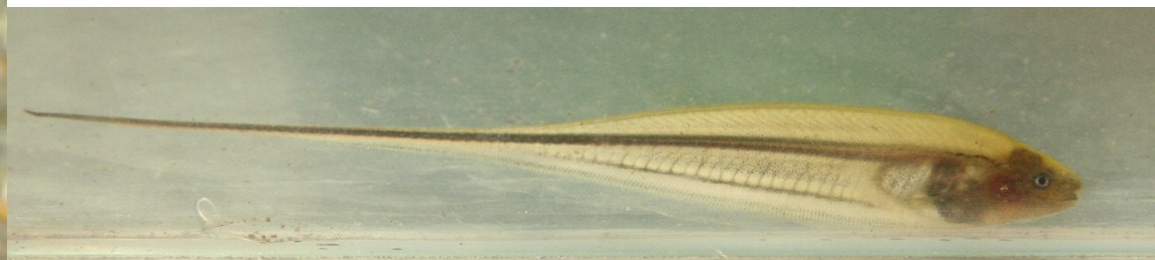
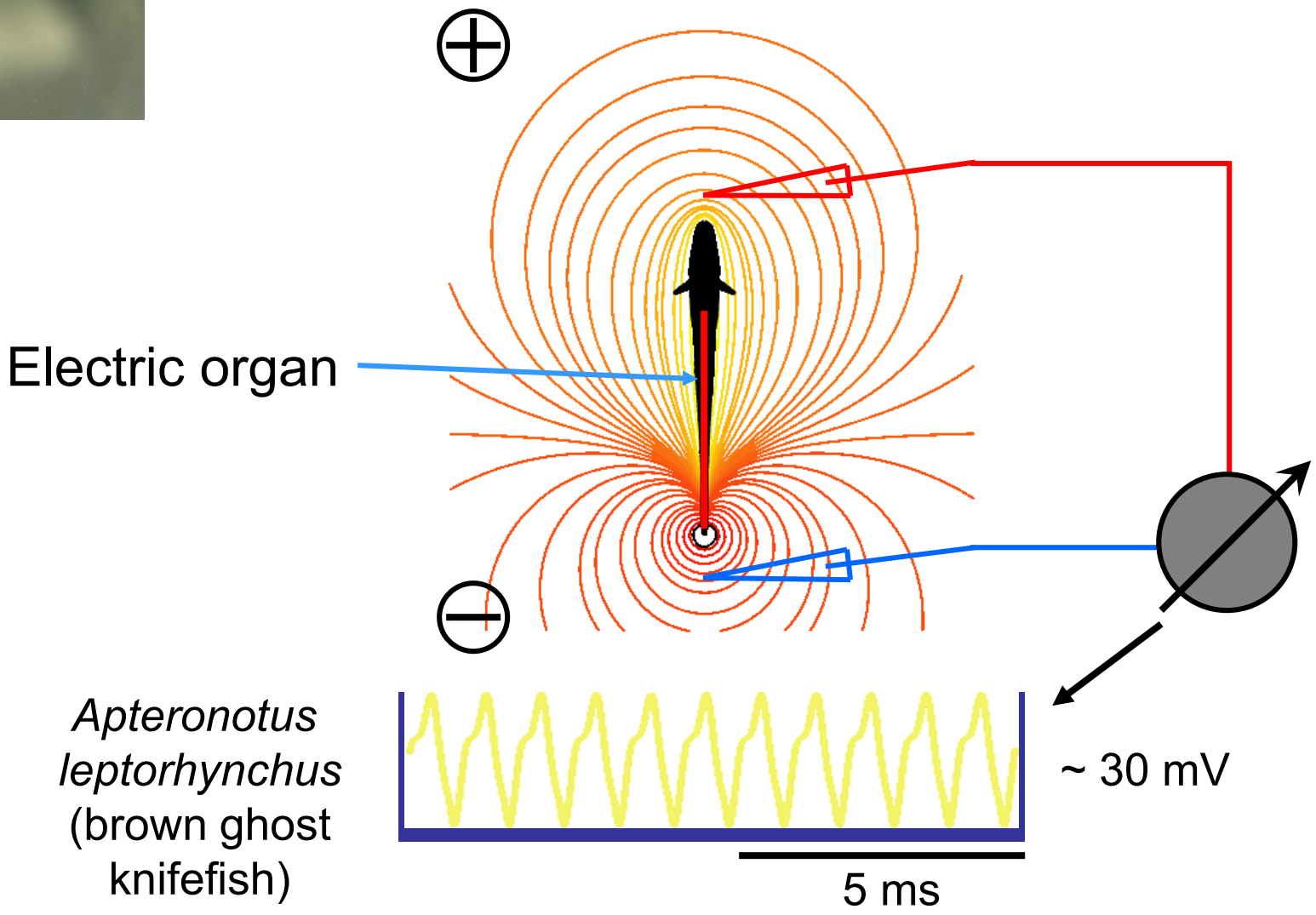
Outline

- **An electric fish primer**
- Sensory processing with multiple topographic maps
- Quantification of the properties of natural sensory stimuli: from the lab to the field and back

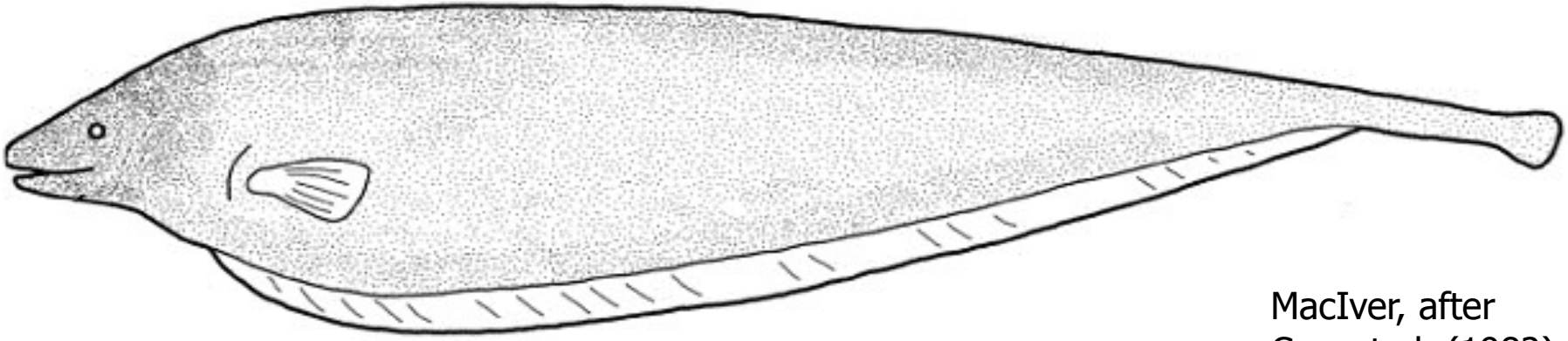


The electric organ discharge (EOD)

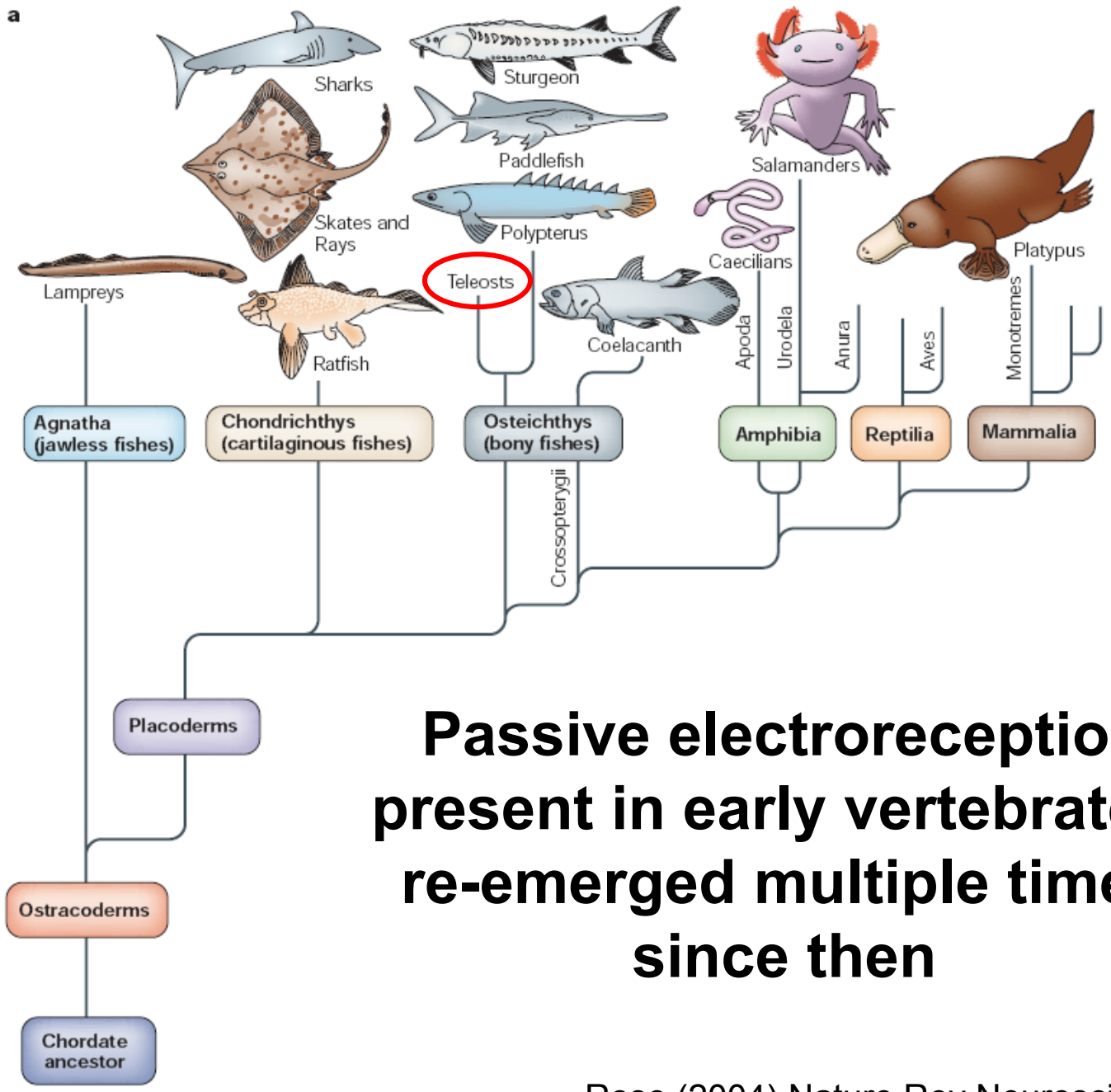


Apteronotus leptorhynchus (brown ghost knifefish)

Electroreceptor organs are distributed over the surface of weakly electric fish



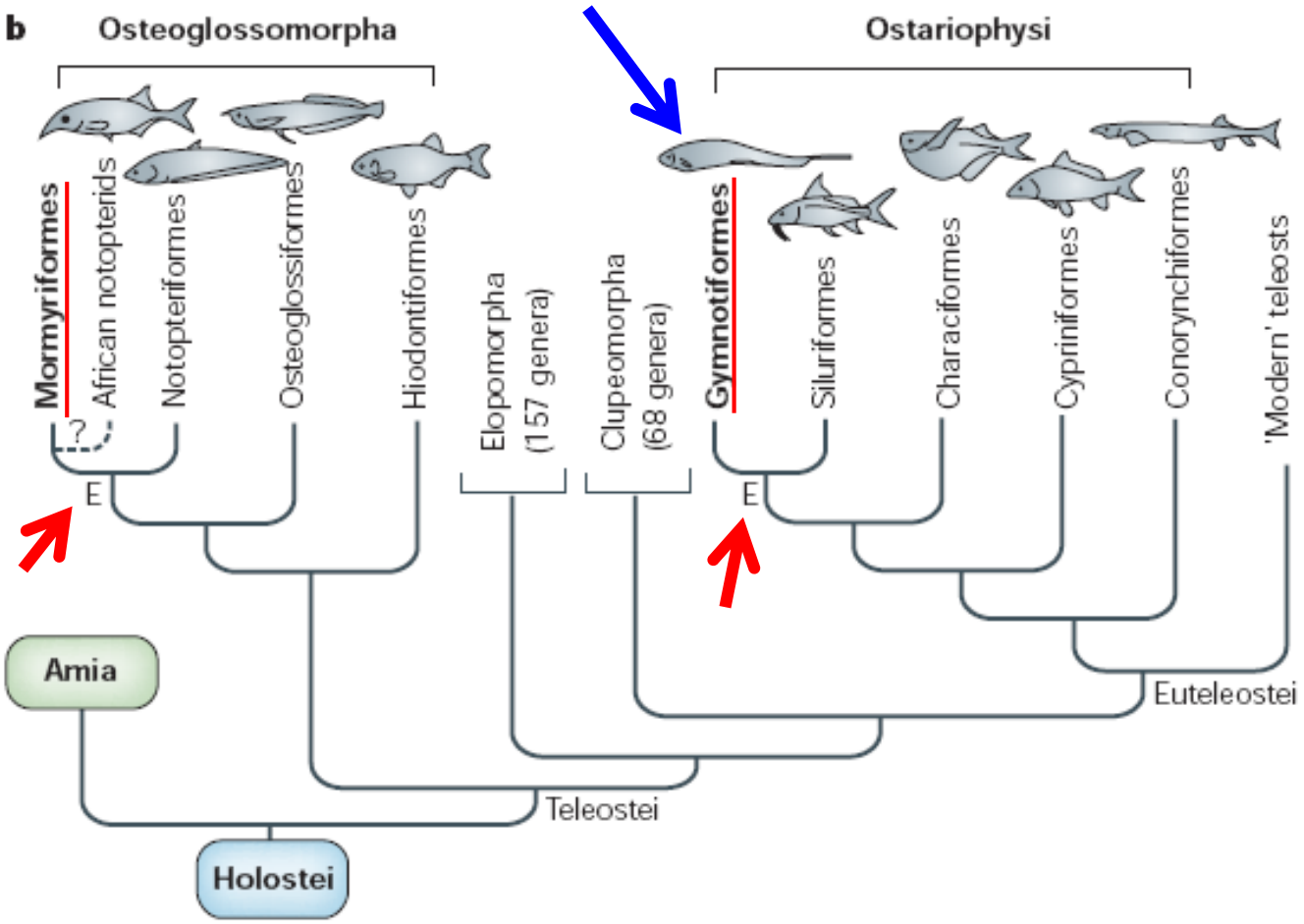
MacIver, after
Carr et al. (1982)
J Comp Neurol
211:139-153



Passive electroreception present in early vertebrates; re-emerged multiple times since then

Rose (2004) Nature Rev Neurosci 5:943-951

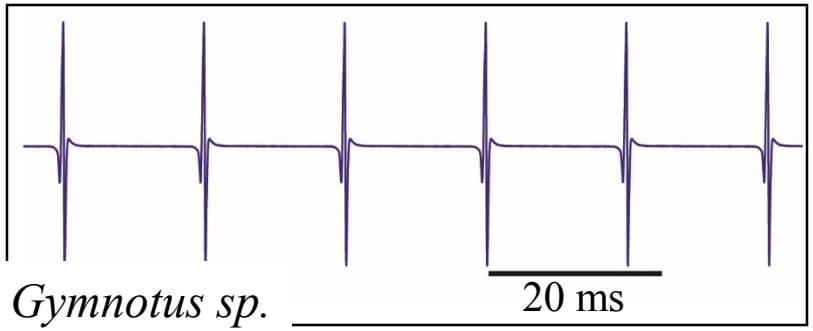
Two groups of teleosts independently evolved electrosensation and some of those evolved active electrosensation

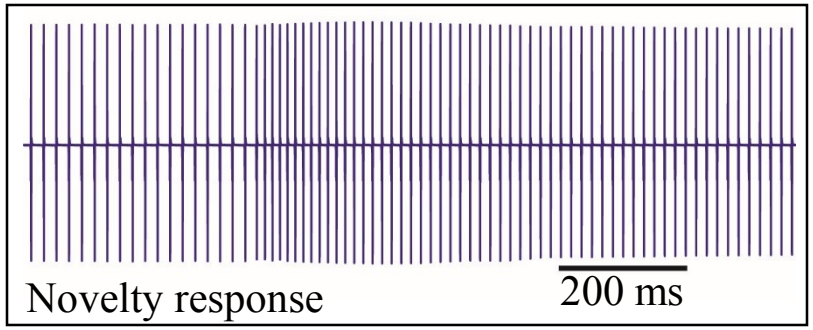


Rose (2004) Nature Rev Neurosci 5:943-951

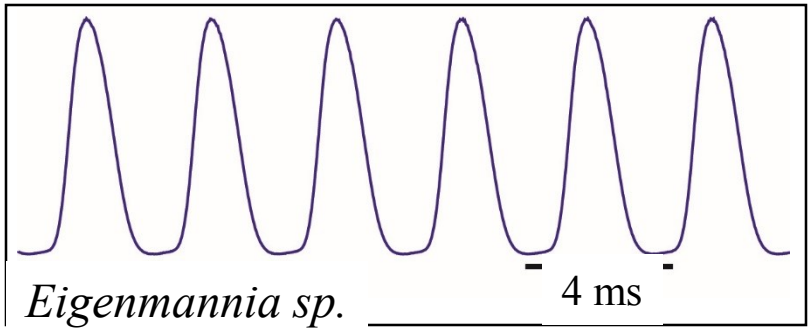
Electric organ discharge types and frequency

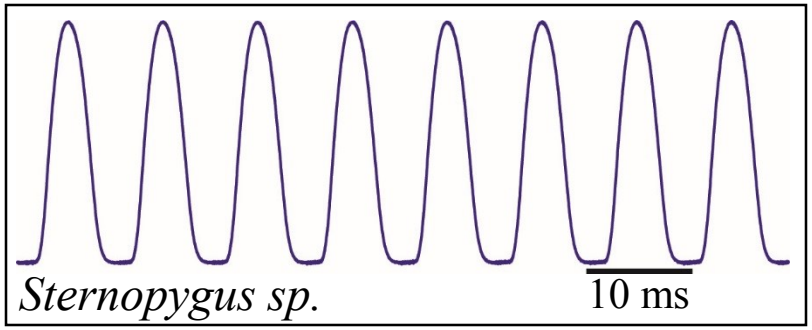
Pulse-type EOD/fish

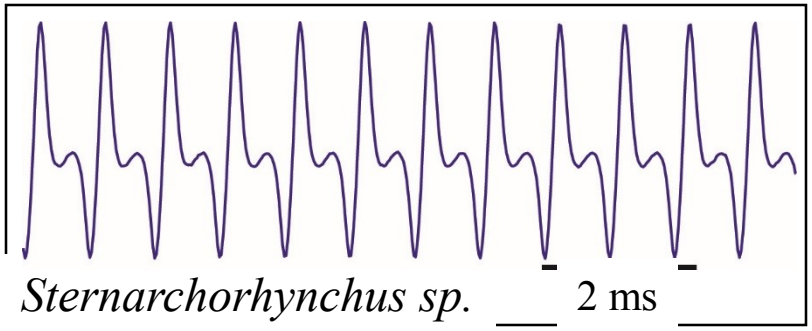




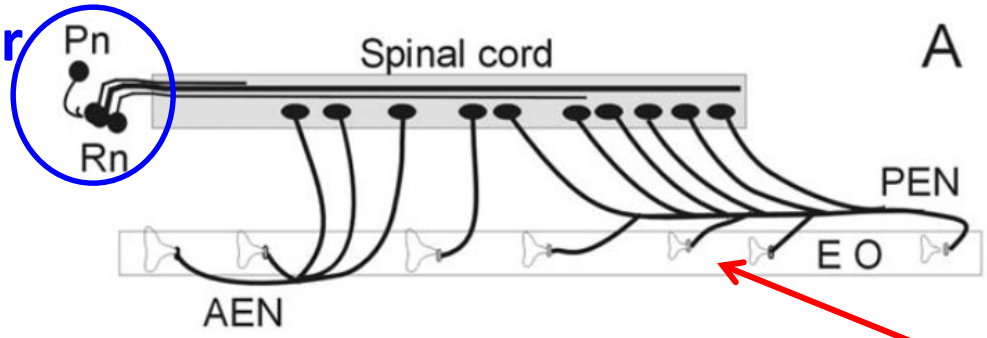
Wave-type EOD/fish







Pacemaker nucleus

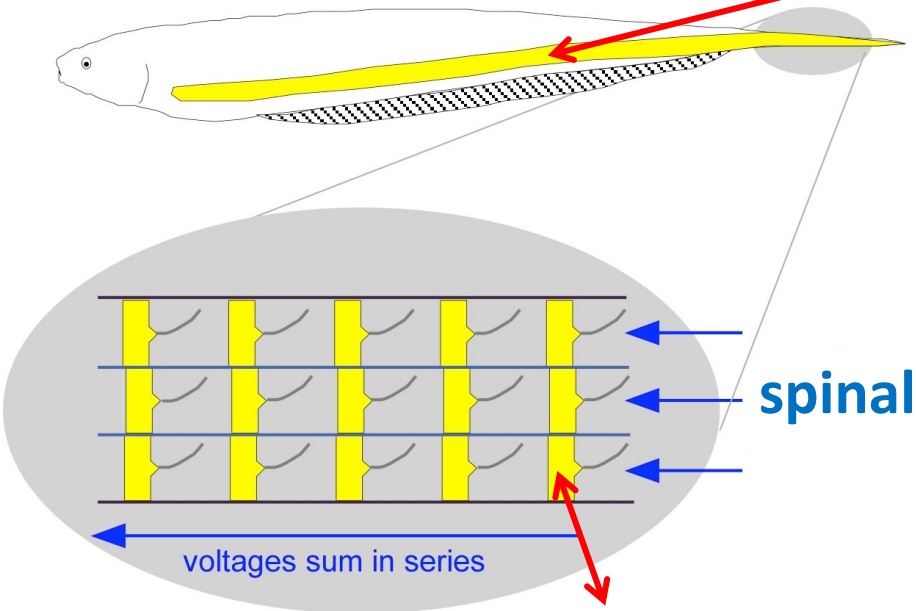


Caputi et al. (2005) In: Electroreception (Bullock, T. H. et al., eds), pp 410-451 New York: Springer

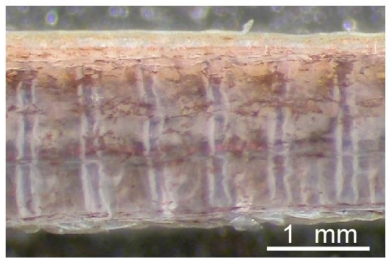
electric organ

How is the EOD generated?

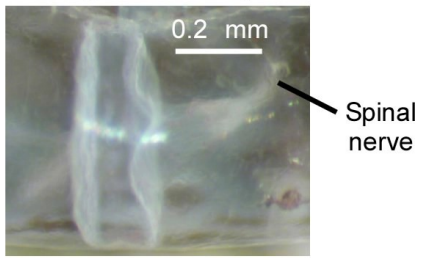
Gymnotiformes



Electric organ

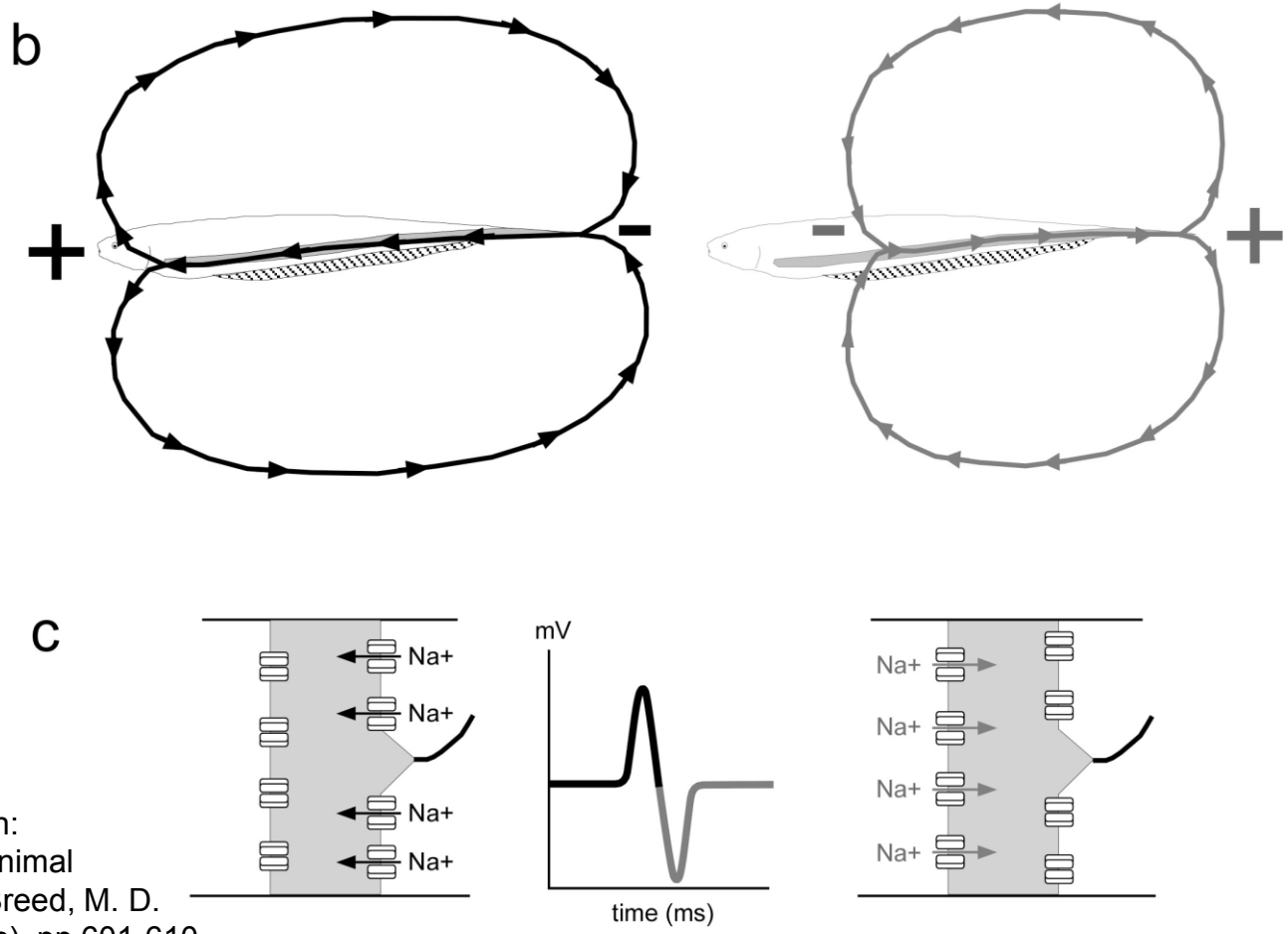


Single electrocyte



Stoddard (2010) In: Encyclopedia of Animal Behavior, vol. 1 (Breed, M. D. and Moore, J., eds), pp 601-610 Oxford: Academic Press

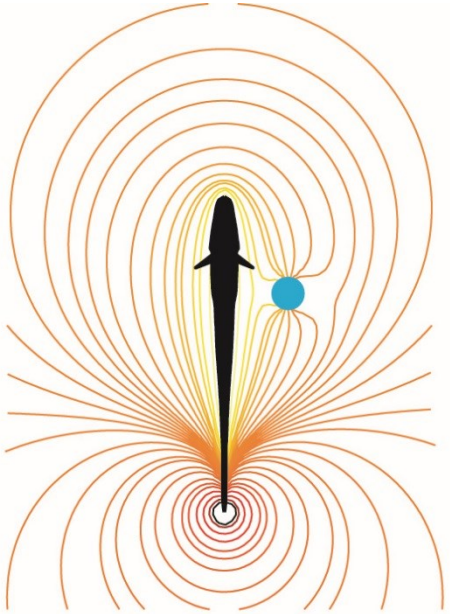
Current flow and the shape of the waveform of the EOD

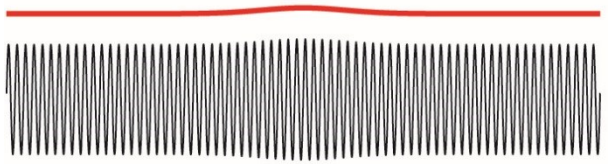


Stoddard (2010) In: Encyclopedia of Animal Behavior, vol. 1 (Breed, M. D. and Moore, J., eds), pp 601-610 Oxford: Academic Press

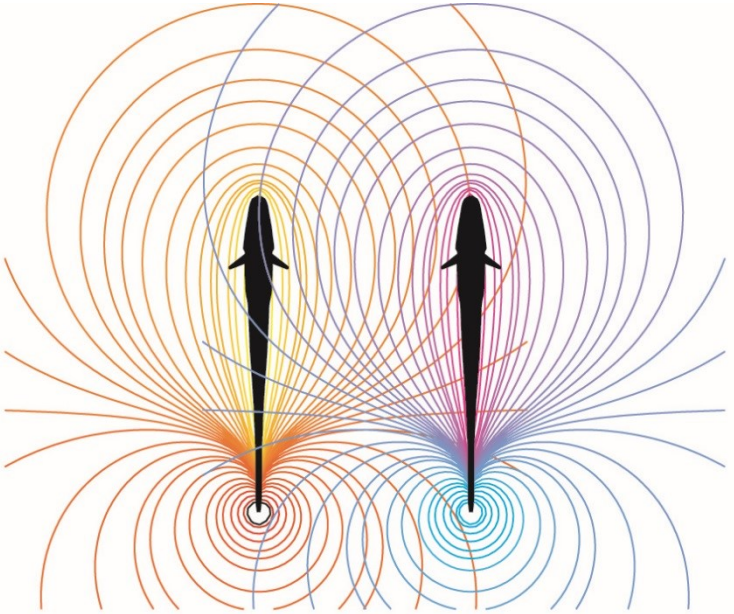
“Active sensing” enables electric fish to forage and communicate at night and in turbid water

local (object, prey)



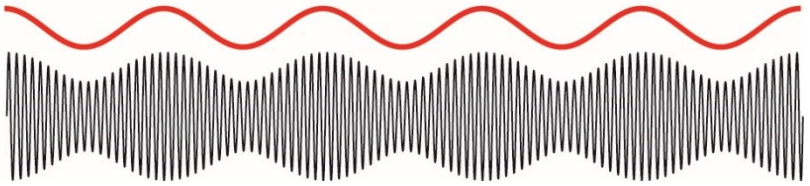


global (communication)



AM

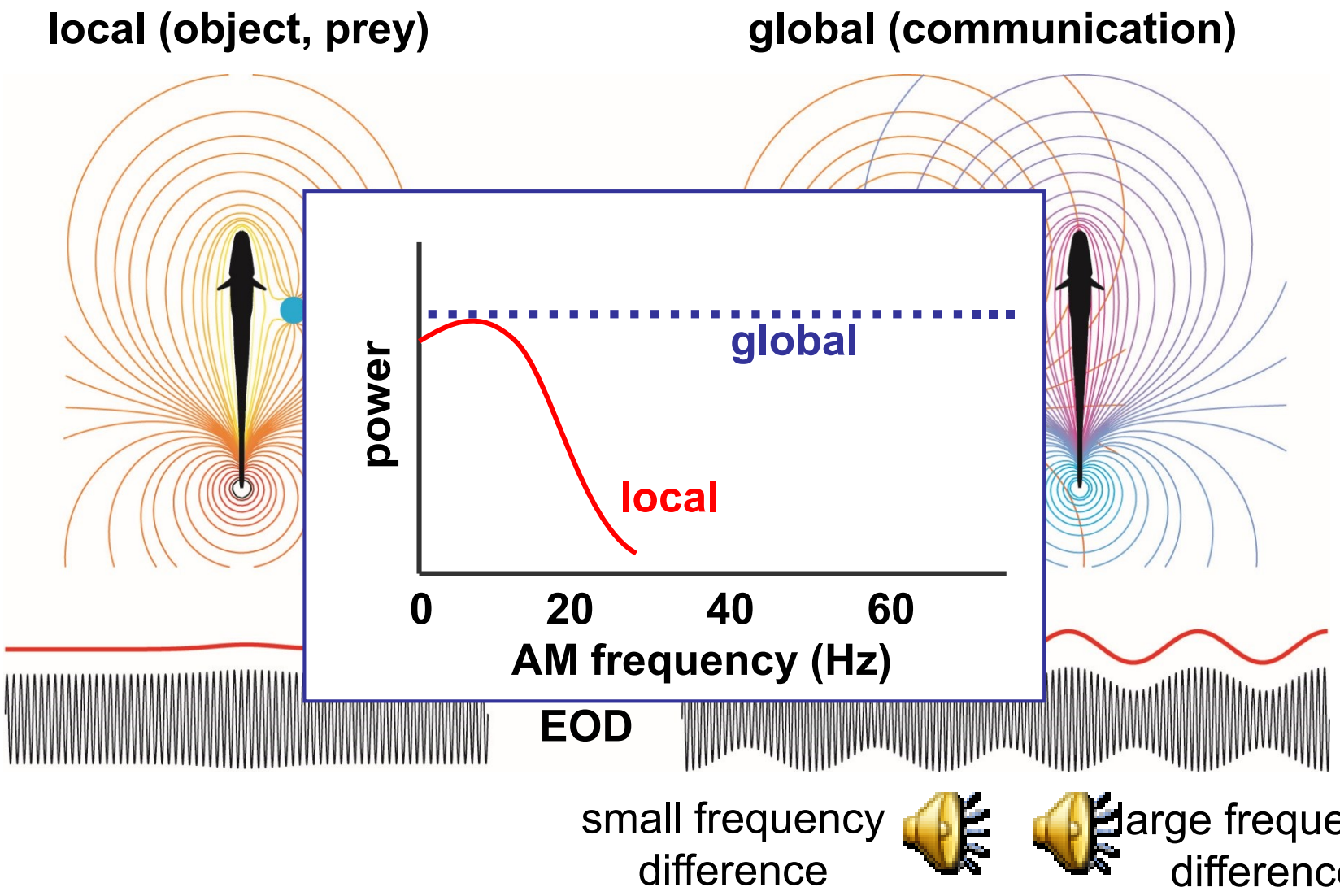
EOD



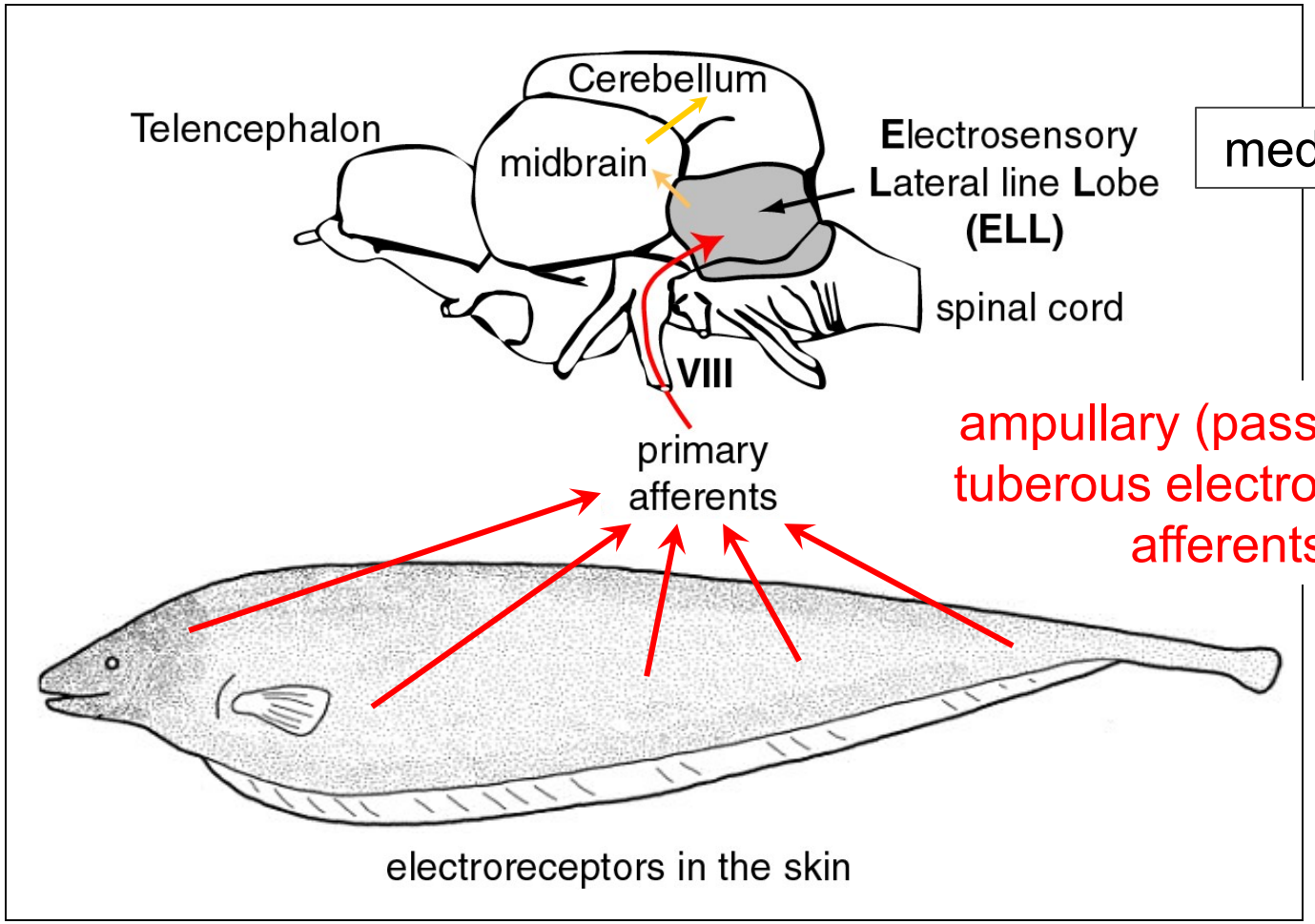
small frequency difference

large frequency difference

Local stimuli contain only low AM frequencies; Global stimuli can be of high or low frequency

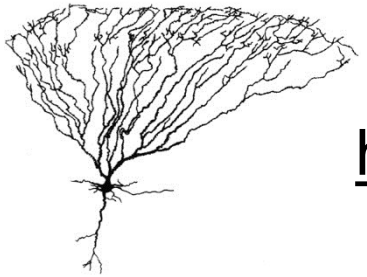


The electrosensory pathway

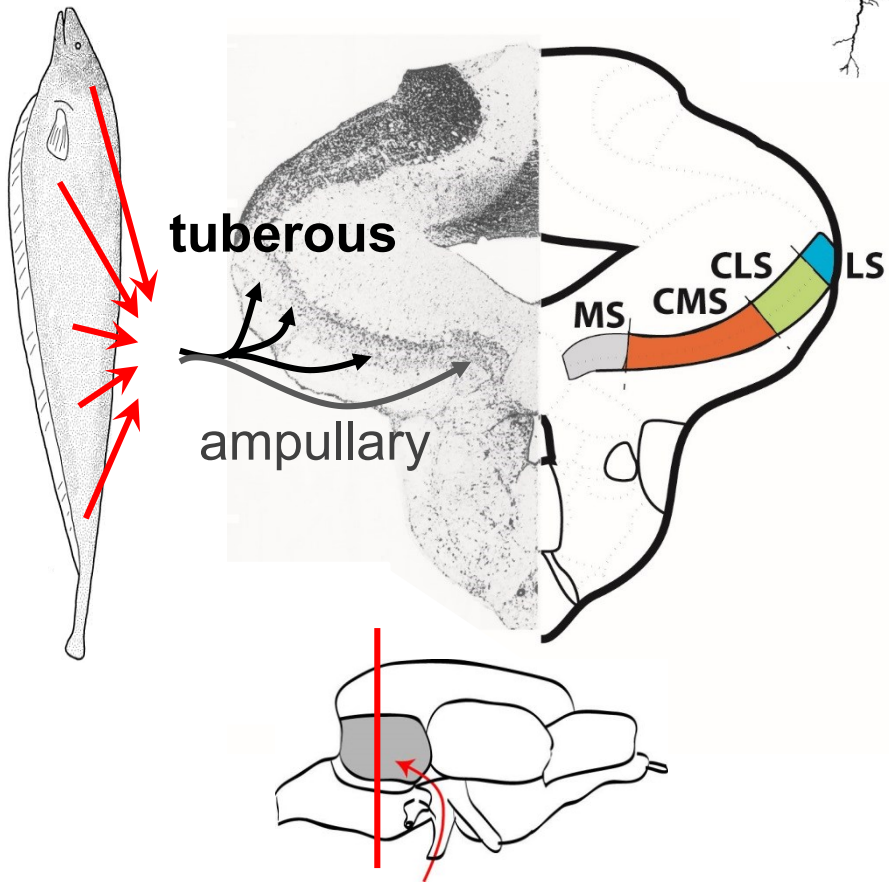


Three topographic maps of the body surface receive identical afferent input (+ one ampullary map), all via 8th nerve

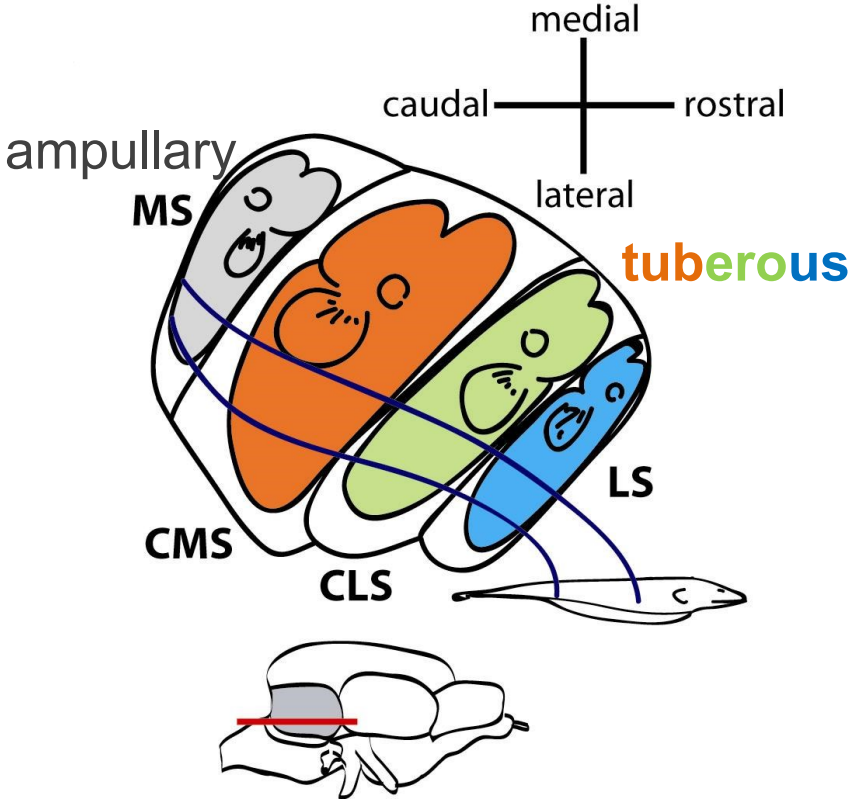
pyramidal cell



cross section



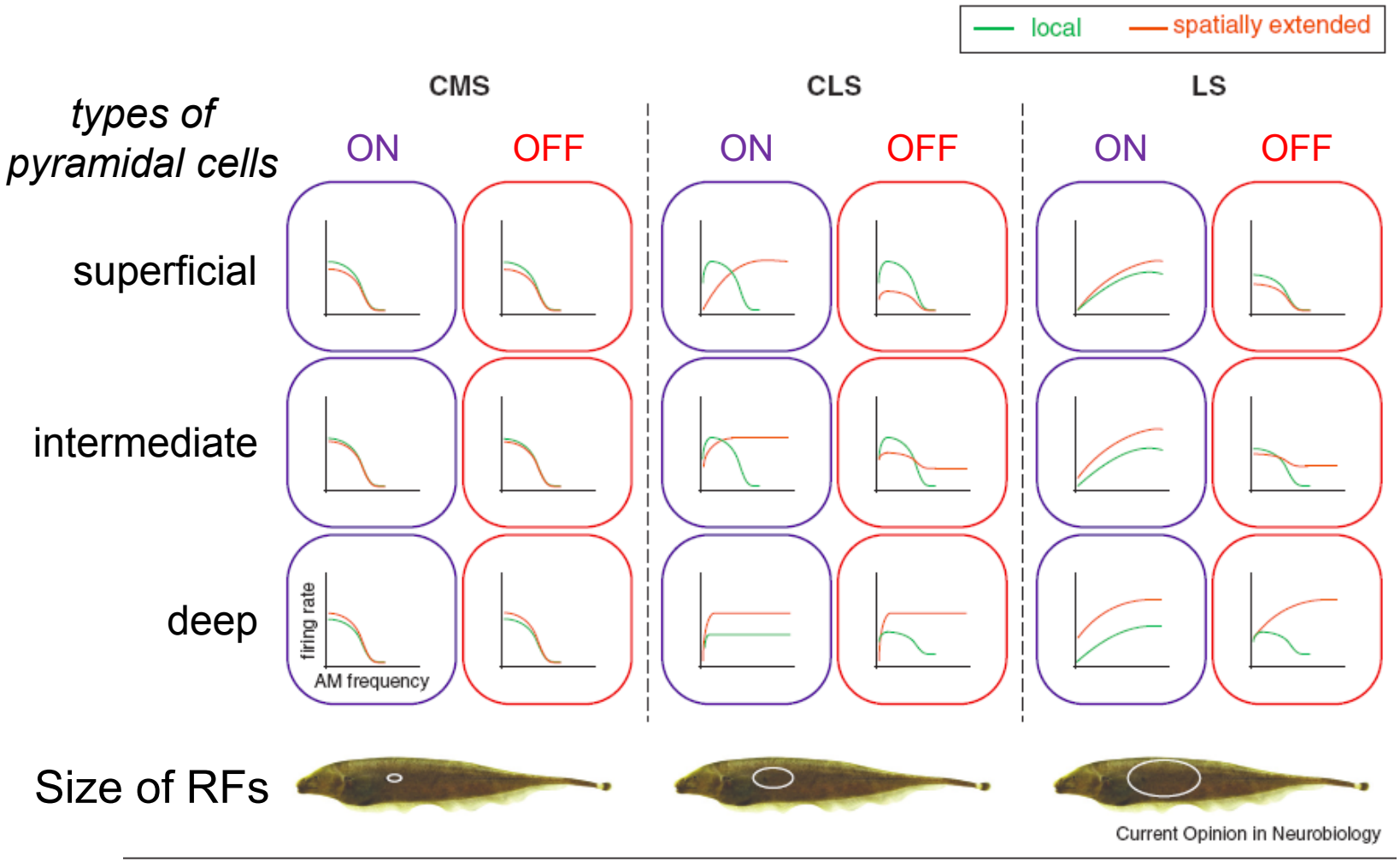
horizontal section



"Pisciculi" in the brain of the fish

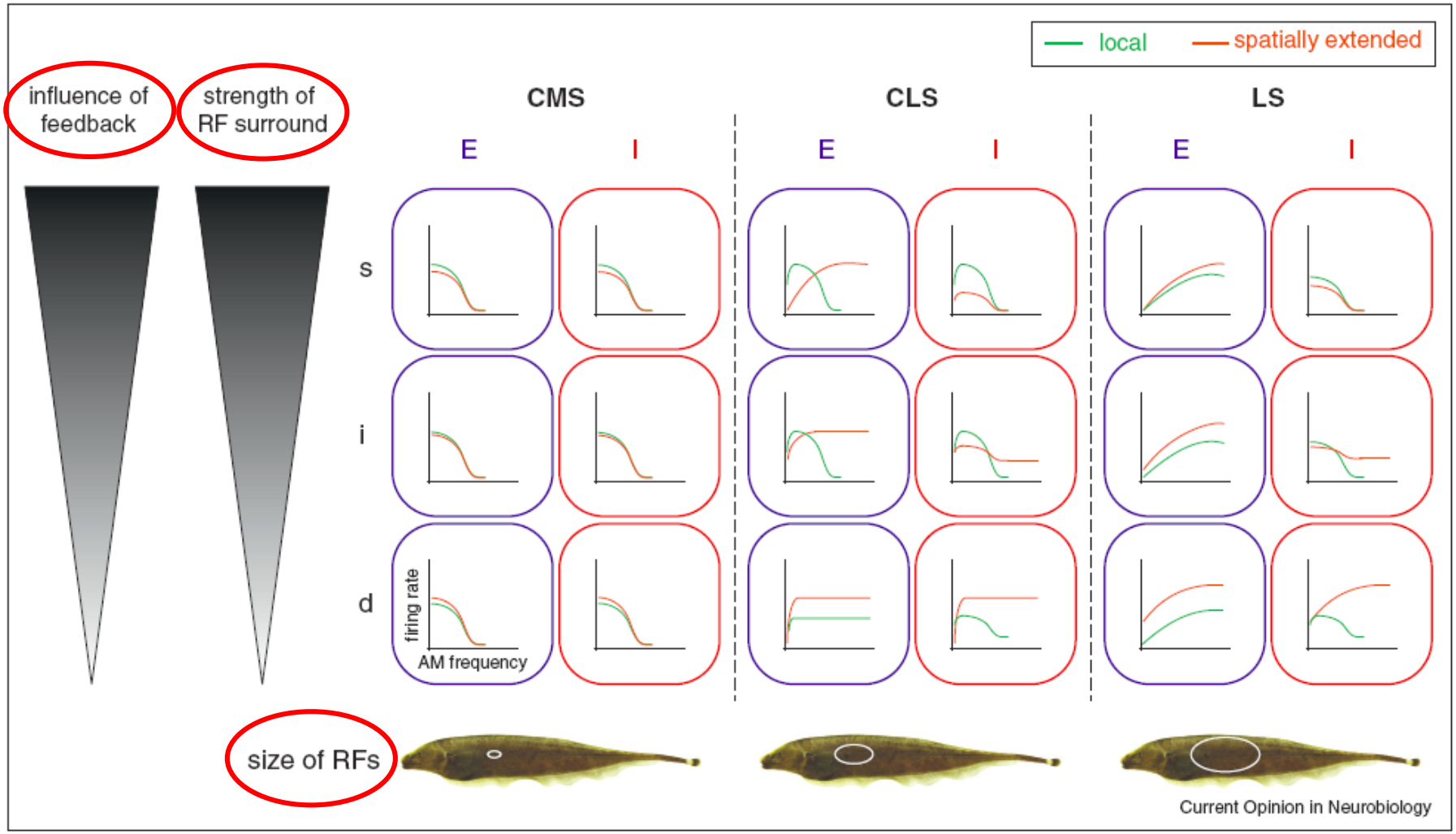
Krahe et al. (2008) J Neurophysiol 100:852-867

Parallel processing of electrosensory stimuli



Krahe and Maler (2014) Curr Opin Neurobiol 24:13-21

Receptive field properties, feedback circuitry, ion channels, and neuromodulators



Plus cell-intrinsic properties (ion channels) and neuromodulation

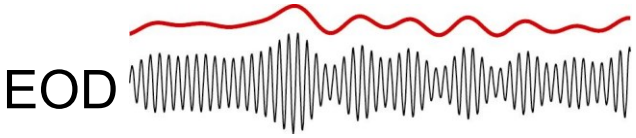
Krahe and Maler (2014) Curr Opin Neurobiol 24:13-21

Trying to understand sensory processing?
➔ Natural sensory scenes

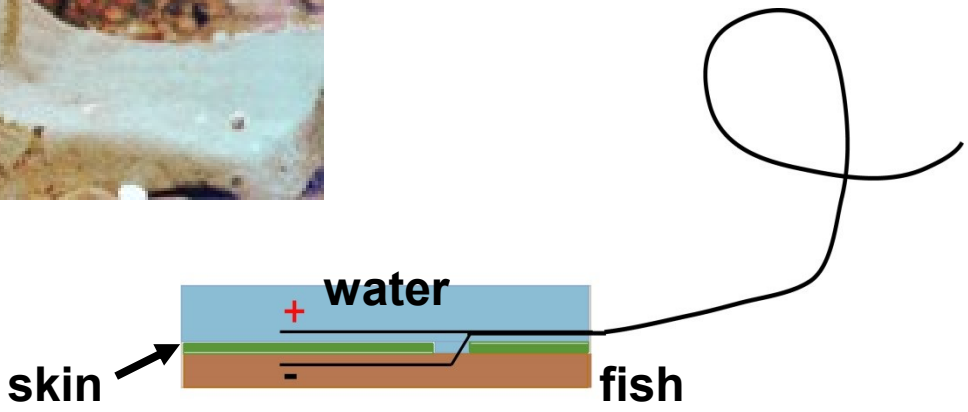
http://www.gigantofraktulus.de/newyork/sonstiges.html

Measurement of natural electrosensory scenes

Amplitude Modulations

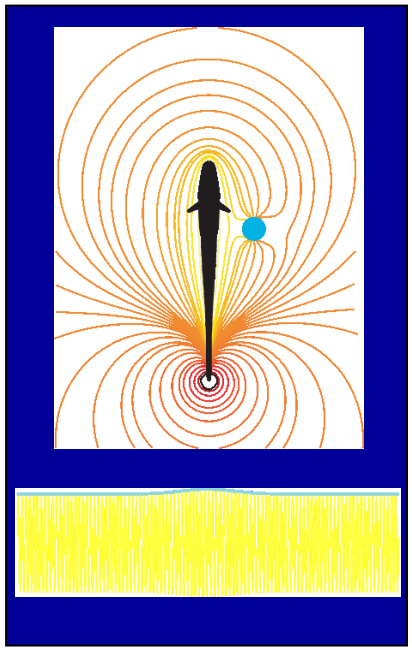


Start with recordings of the transdermal potential from an immobilized fish



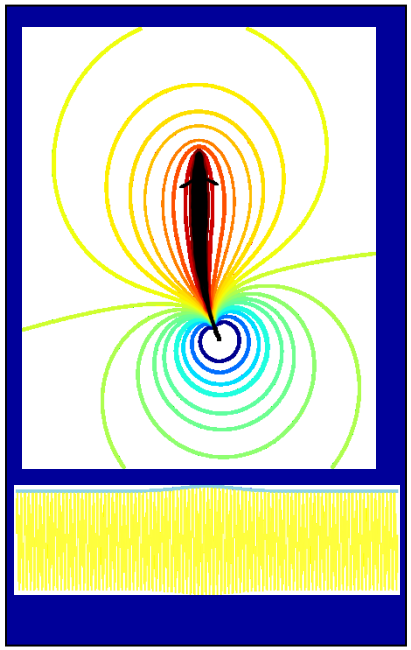
Estimating the amplitude of electrosensory stimuli in immobilized fish

local



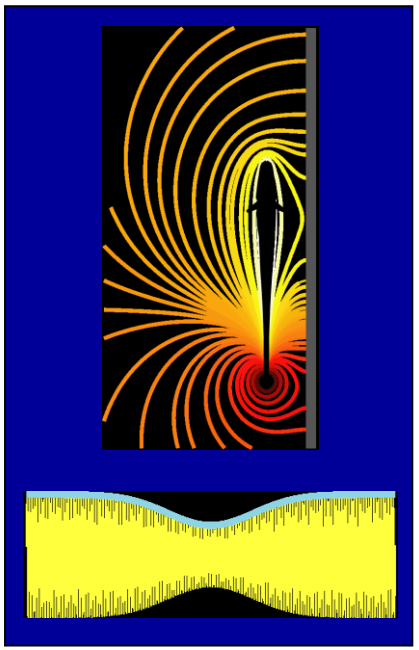
prey stimulus:
up to **~3%**

global



tail bending:
up to **~5%**

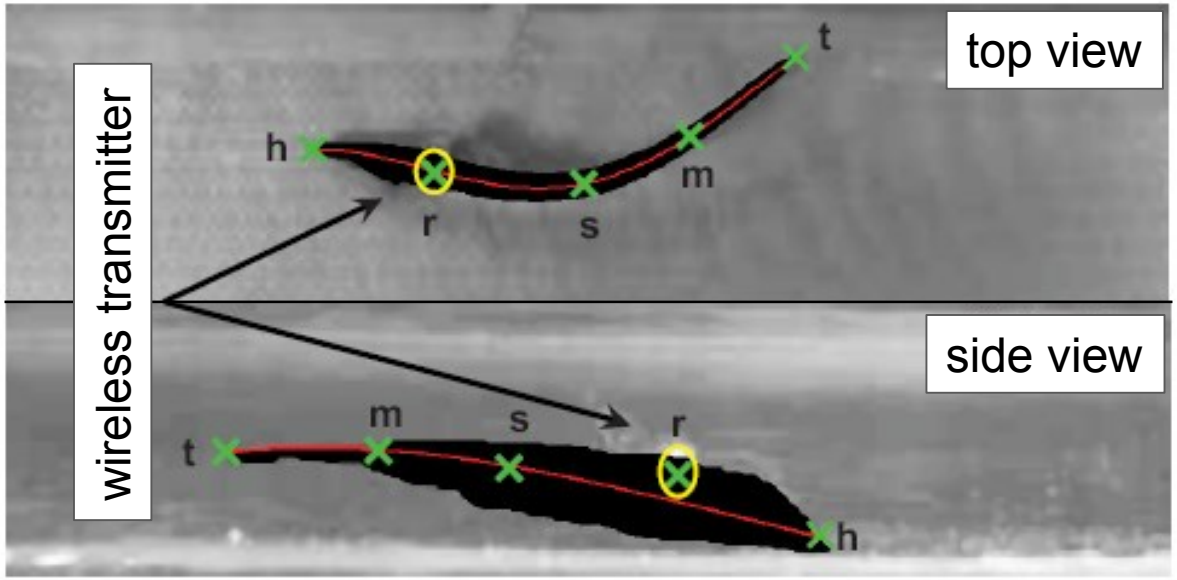
global



non-conducting boundary:
up to **~40%**

Chen et al. (2005) J Comp Physiol A 191:331–345

The dynamics of natural stimuli is determined by environmental movement AND self-movement

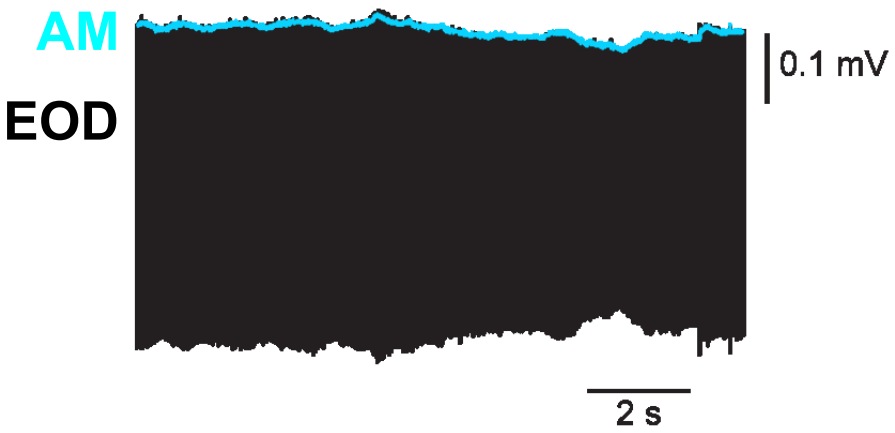


Telemetric recording of the transdermal potential from freely swimming fish

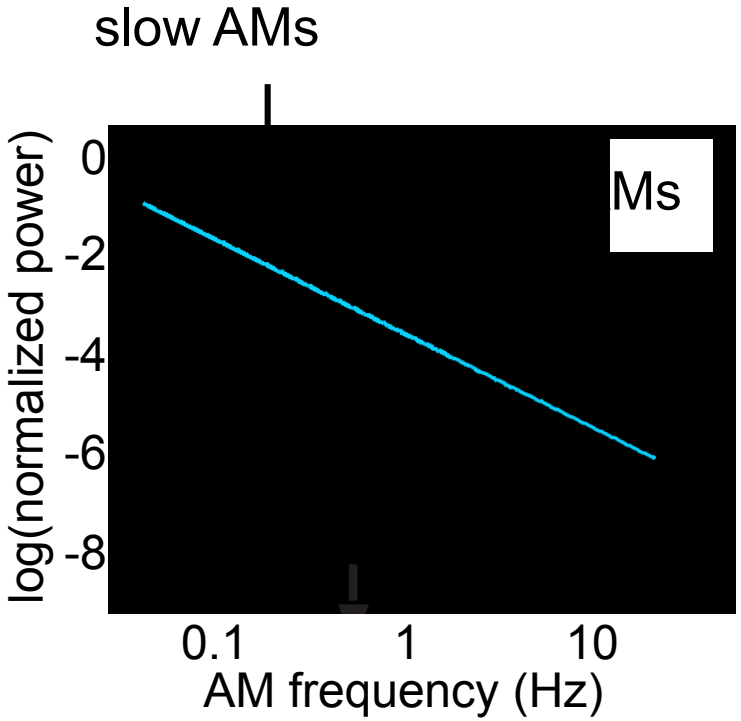
Haleh Fotowat

Fotowat et al. (2013) J Neurosci 33:13758-13772

Self-movement produces relatively small and slow amplitude modulations



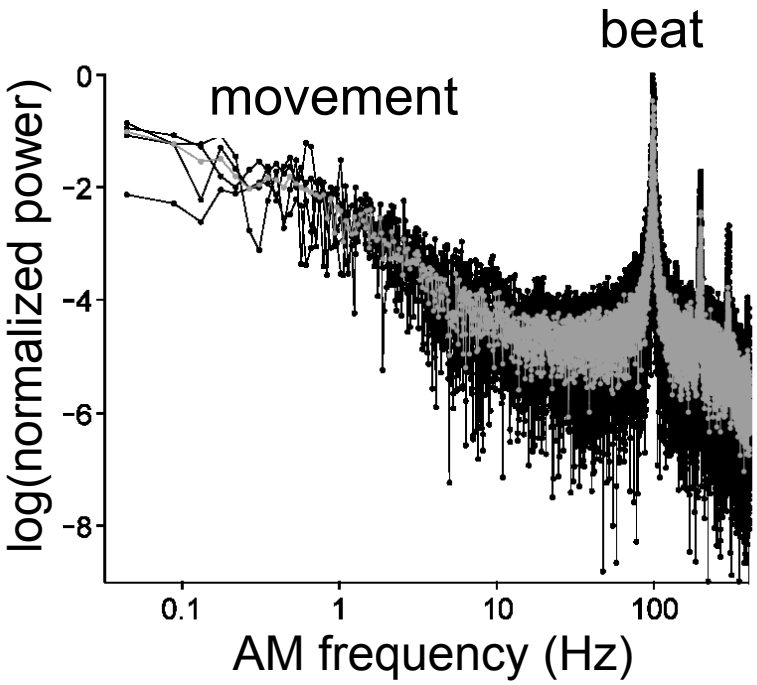
modulation depth < 20%

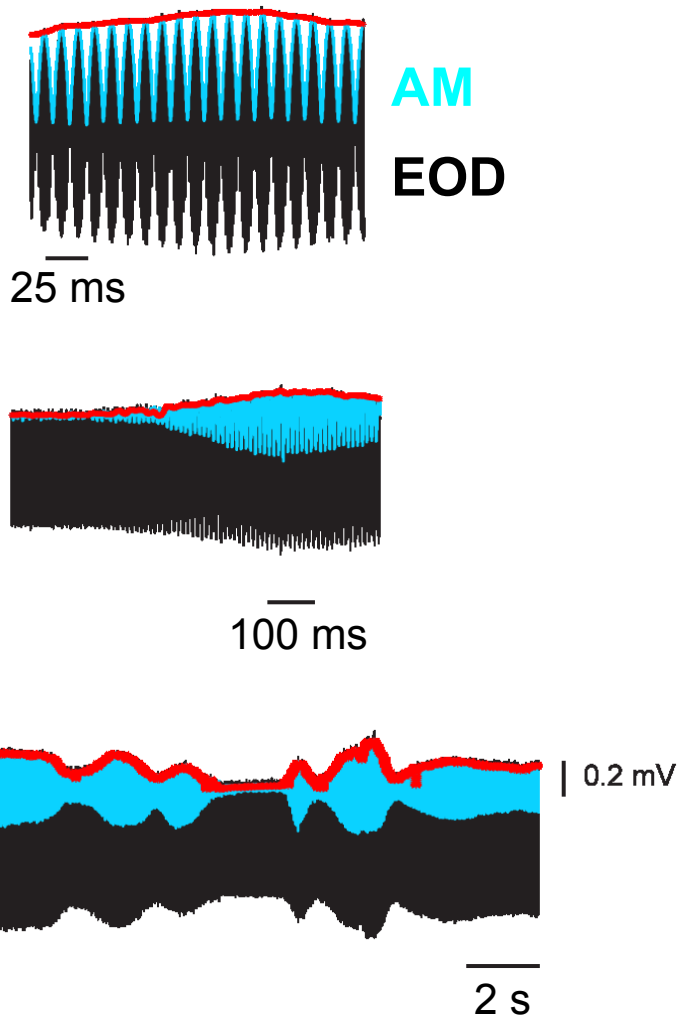


➔ body bending, boundaries

Fotowat et al. (2013) J Neurosci 33:13758-13772

Movement and communication

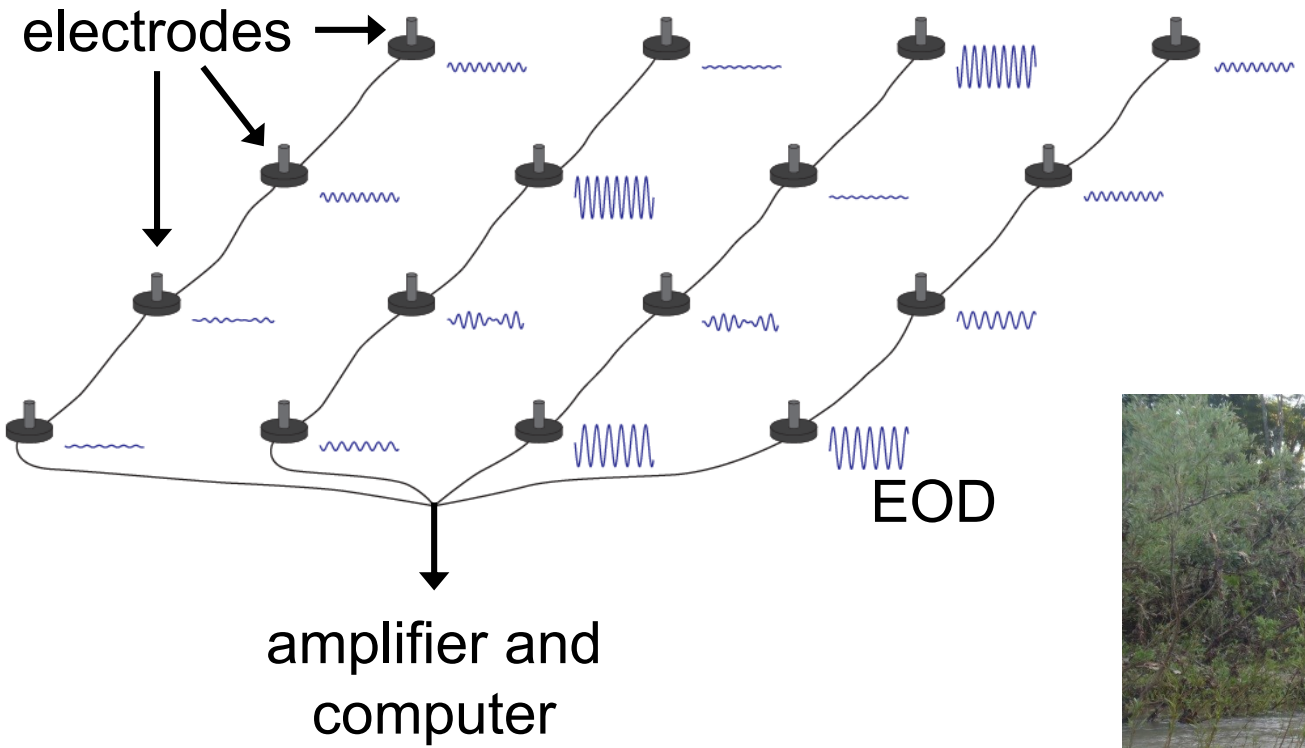




Fotowat et al. (2013) J Neurosci 33:13758-13772

The natural electrosensory world?

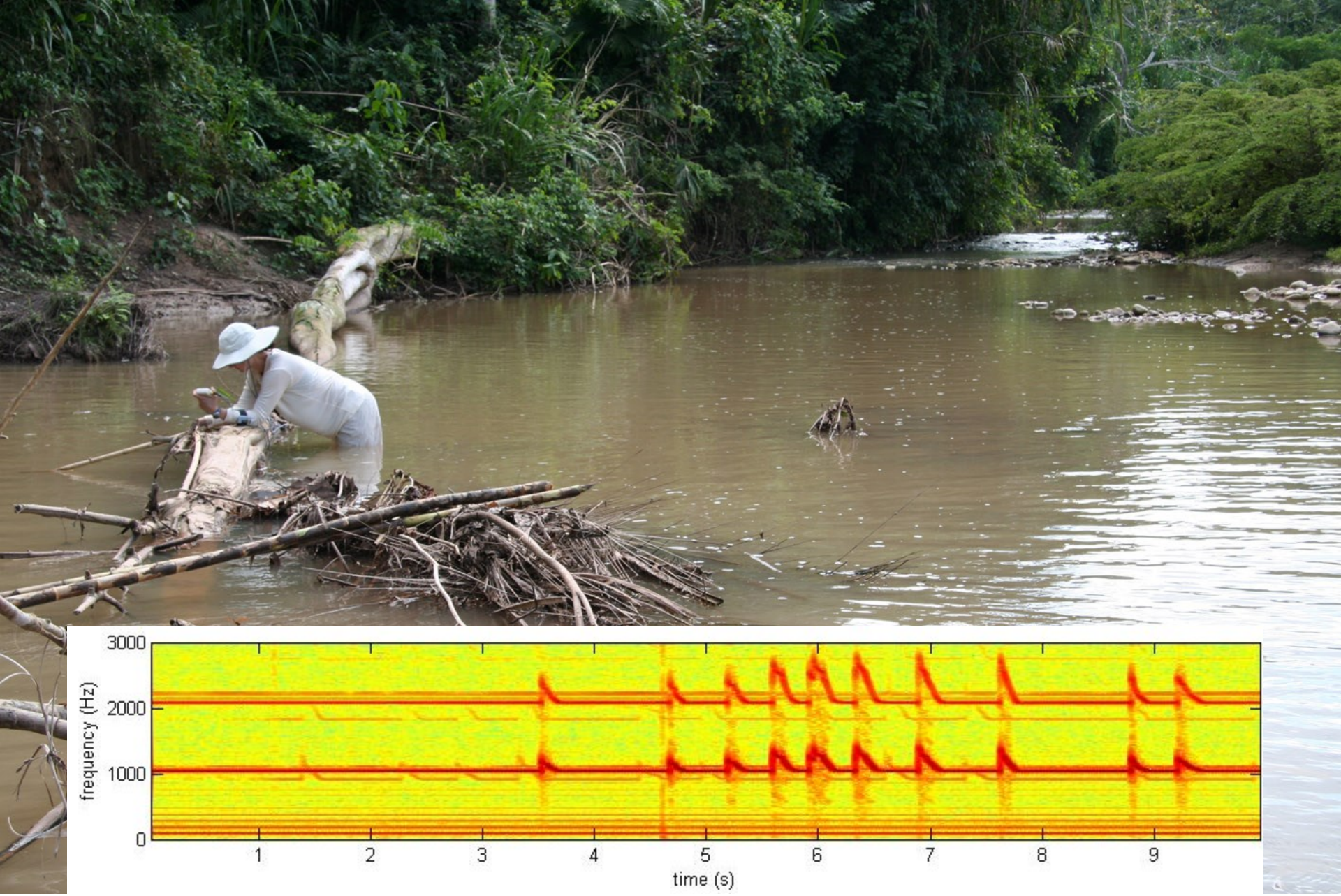
"The Grid": Long-term "electric observation" in the natural habitat



Jan Benda

Jörg Henninger

Peña Vijagual, Darien, Panama



Chirps are brief modulations of EOD frequency

Summary

- Weakly electric fish actively generate electric fields and sense their perturbations (caused by self-movement, objects in the environment, communication).
- Electroreceptor organs are distributed over the skin.
- The electrosensory body surface is mapped multiple times in parallel in the hindbrain (and multiple times at higher levels).
- Parallel processing streams filter sensory input in different ways depending on receptive field structure, feedback circuitry, cell-intrinsic properties, and the activation of neuromodulators.
- (Higher levels of processing become increasingly selective for specific stimulus patterns).
- Weakly electric fish are an excellent system in which to quantify the properties of natural sensory stimuli (i.e., constraints on sensory processing) and to use that knowledge for probing mechanisms of sensory processing.

Thanks!

Postdoc:

- **Haleh Fotowat**

Grad students:

- **Jörg Henninger** (Universität Tübingen)
- Brenda Toscano Márquez (McGill)
- Sophie Picq (McGill)
- Alex Tran (McGill)
- Vincent Fugère (McGill)

Collaborators:

- Jan Benda (U. Tübingen)
- Maurice Chacron (McGill)
- Len Maler (U. Ottawa)
- Mark Nelson (U. Illinois)

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NSERC
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Fonds de recherche
sur la nature
et les technologies
Québec

Bernstein Award
to Jan Benda

Literature

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