Renormaliser le spectrogramme : pourquoi ? comment ?

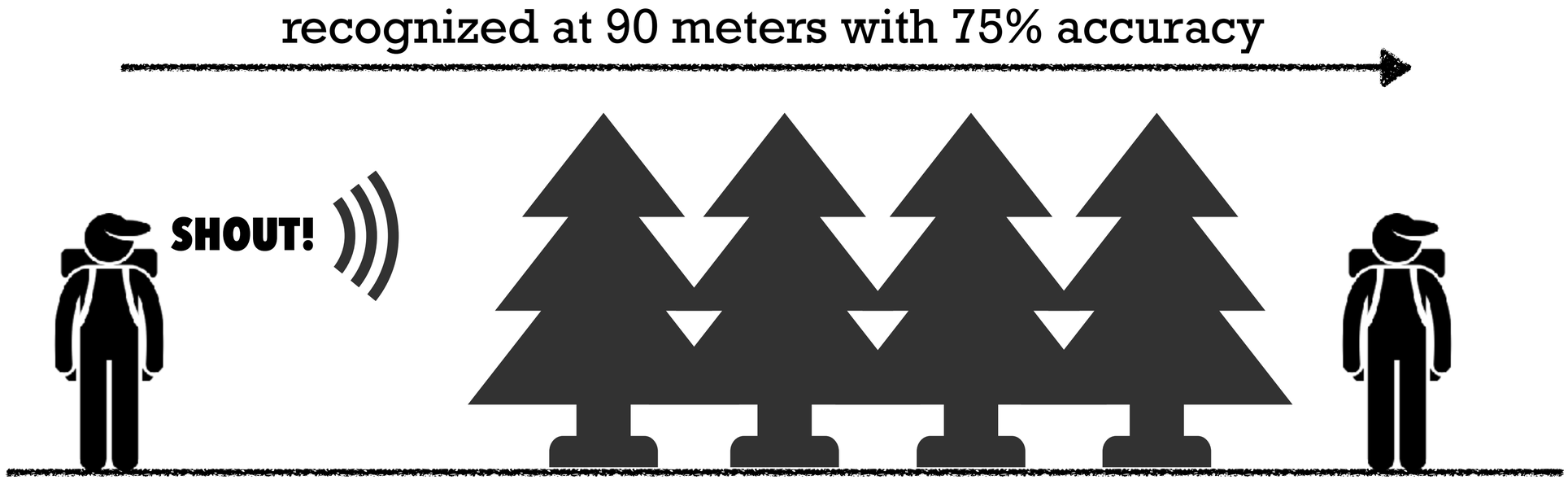
Vincent Lostanlen

LS2N, Centrale Nantes, CNRS

Paris, FR, March 2022. My research is funded by the French government.

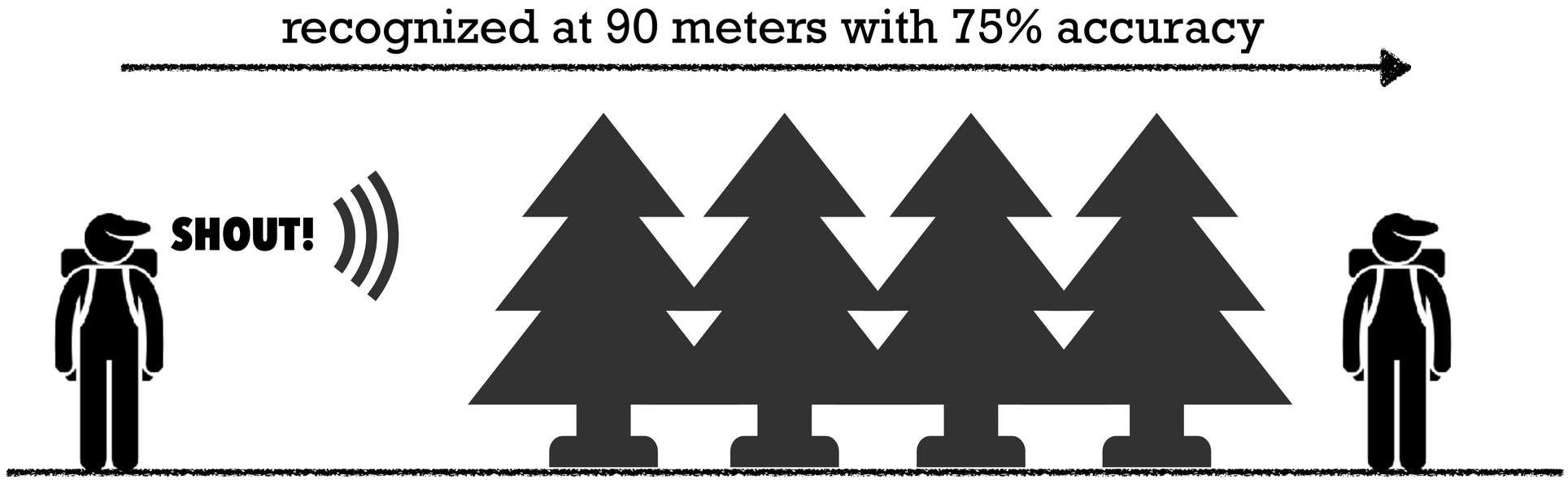
Hearing at a distance

[Meyer et al. 2018]



Hearing at a distance

[Meyer et al. 2018]



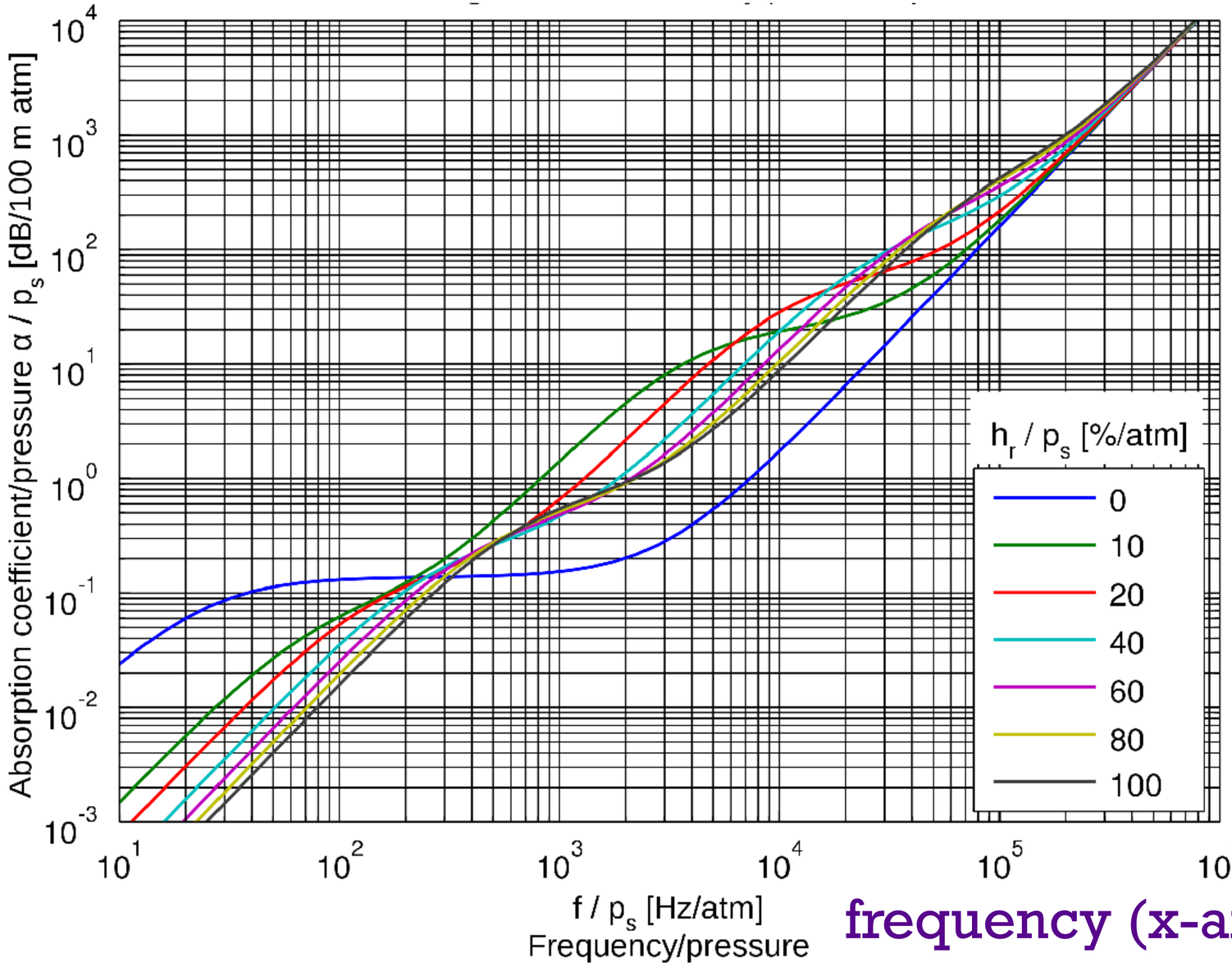
Yet, long-distance recognition is difficult for machines.

Why?

Atmospheric absorption

[Bass et al. 1984]

absorption (y-axis)

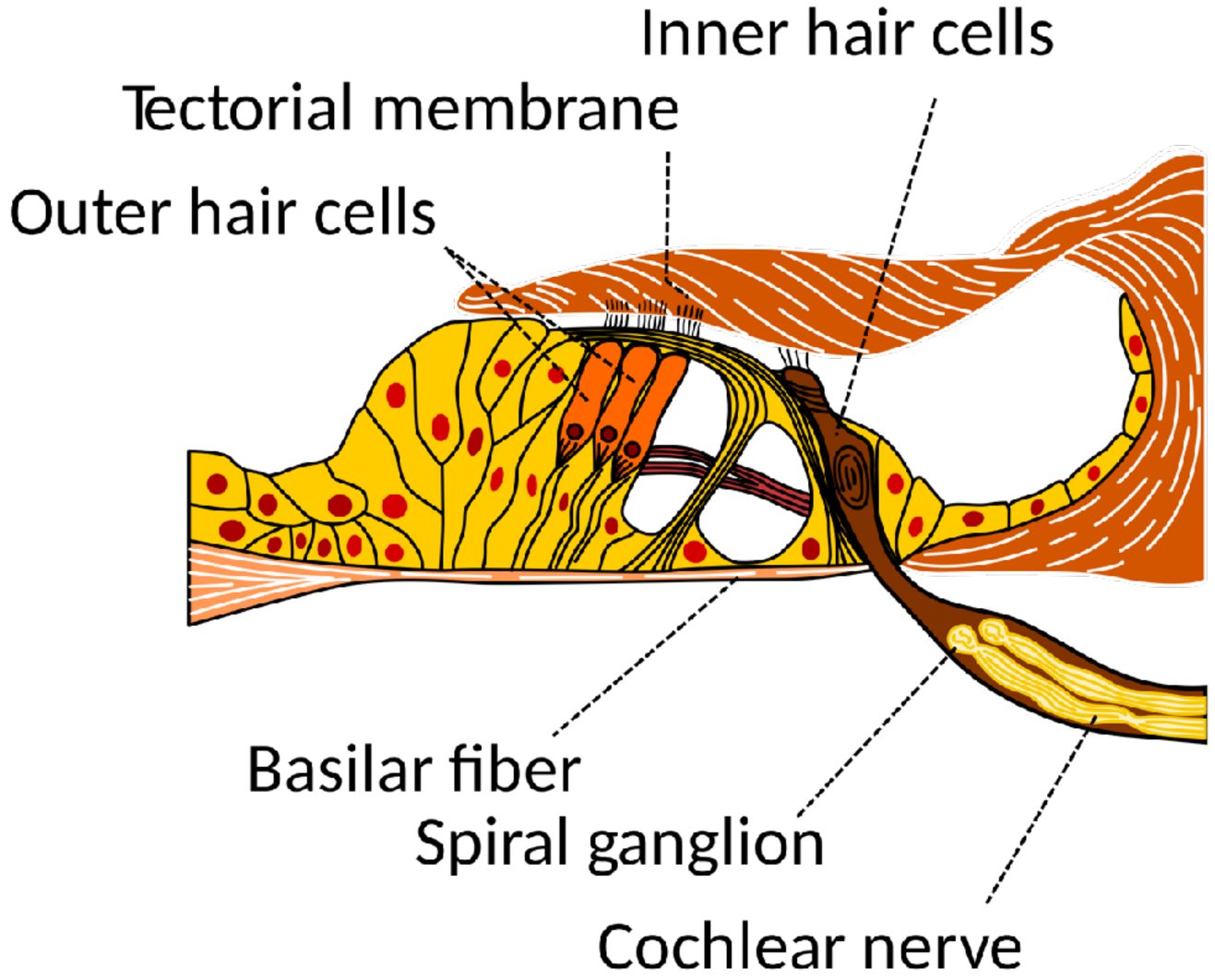


hygrometry (color)

frequency (x-axis)

Auditory neurophysiology 101

[Mann and Kelley 2011, Robles et al. 2001]



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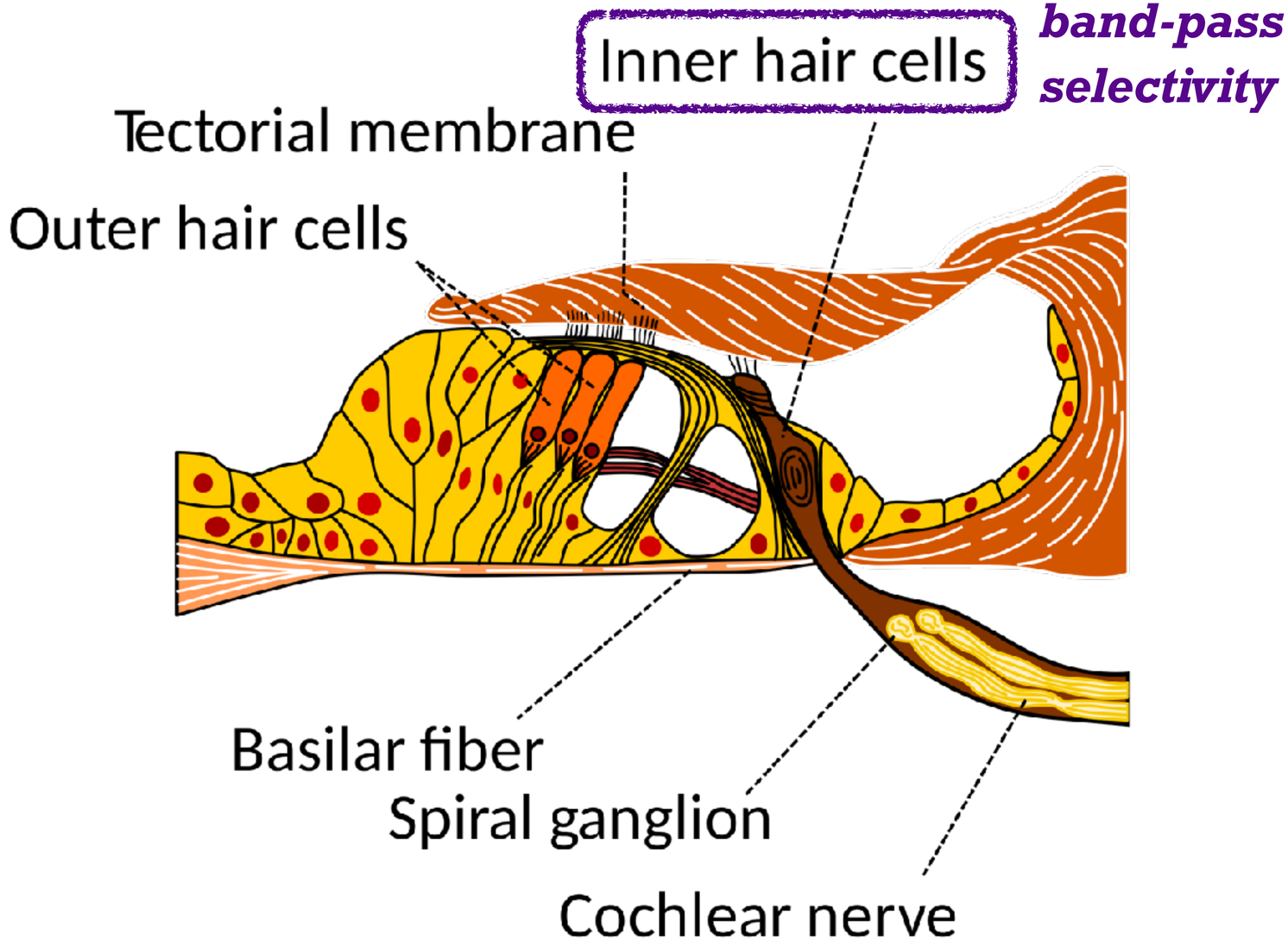

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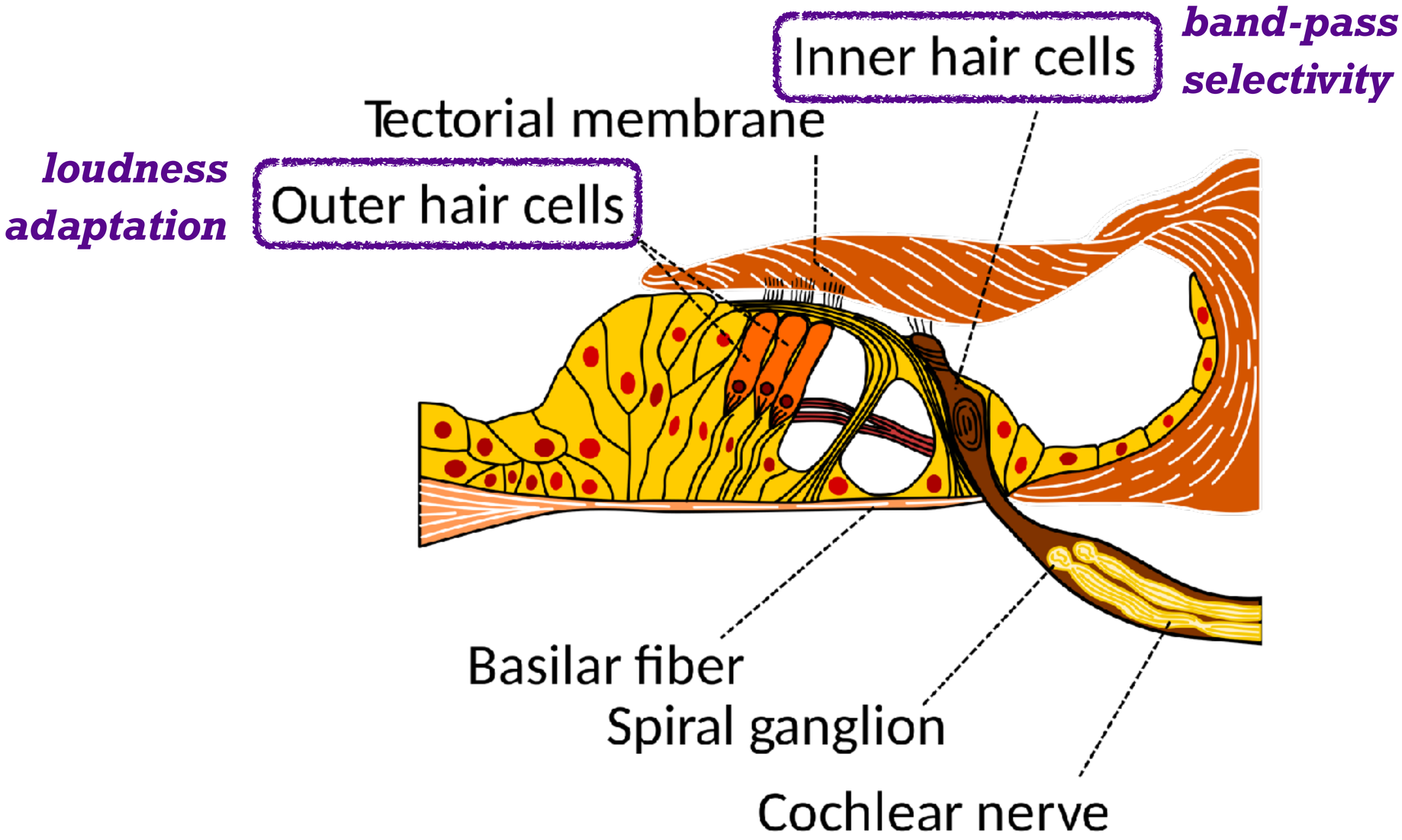
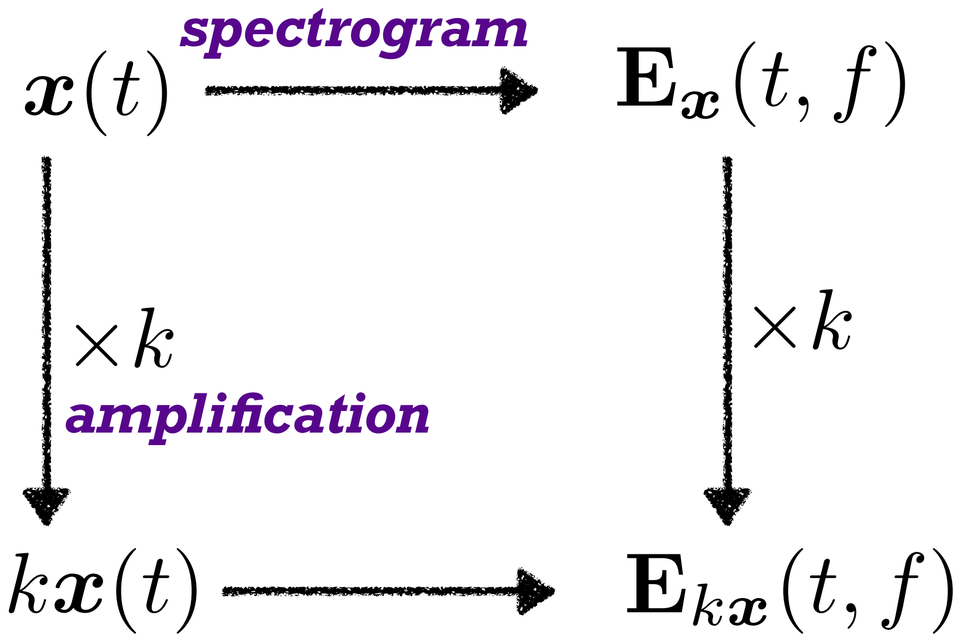
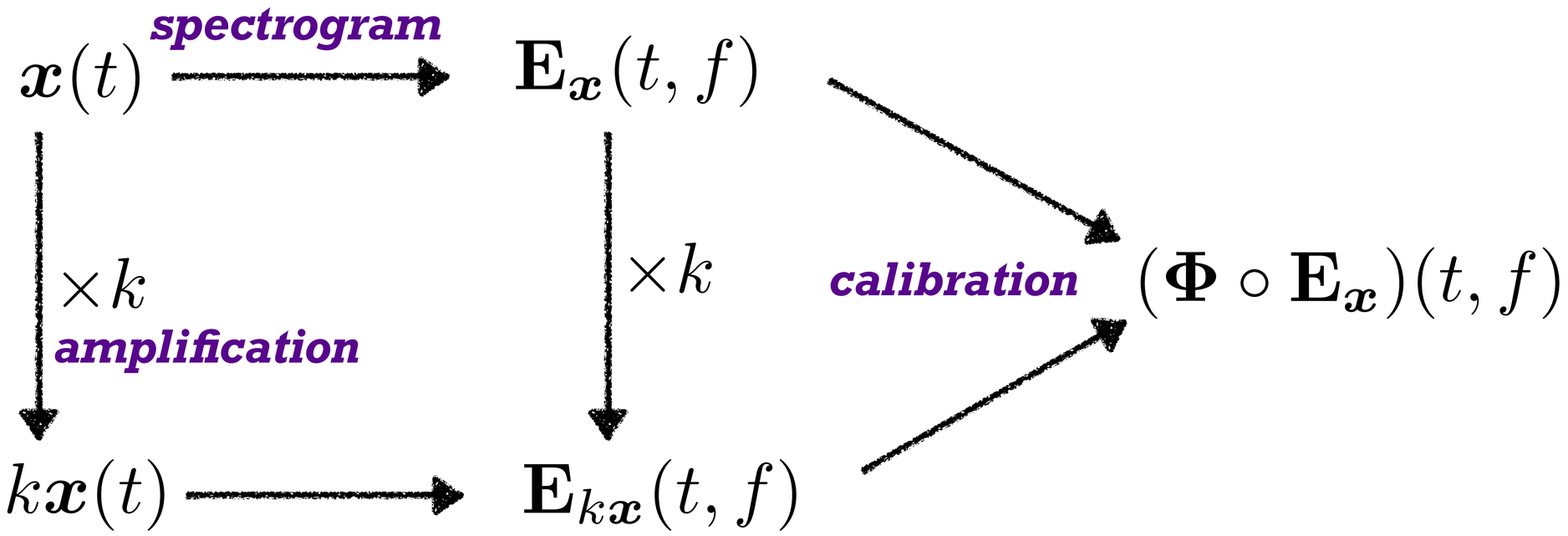


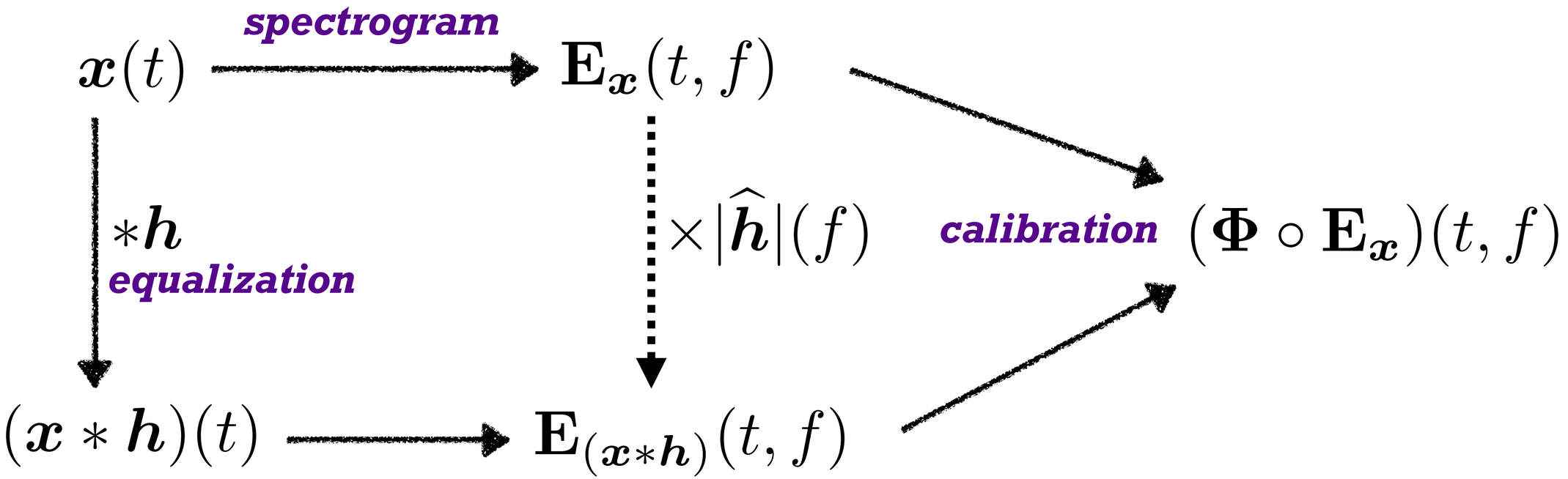
Invariance to amplitude



Invariance to amplitude



Invariance to equalization



Per-Channel Energy Normalization

[Wang et al. 2017, Lostanlen et al. 2019]

$$(\Phi \circ \mathbf{E}_{\boldsymbol{x}})(t, f) = \left(\delta + \frac{\mathbf{E}_{\boldsymbol{x}}(t, f)}{\left(\varepsilon + (\mathbf{E}_{\boldsymbol{x}} \overset{t}{*} \boldsymbol{\phi}_T)(t, f)\right)^{\alpha}} \right)^{r} - \delta^{r}$$

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hyperparameters
(predefined or learned)

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adaptive gain control

dynamic range compression

Per-Channel Energy Normalization

[Wang et al. 2017, Lostanlen et al. 2019]

$$\phi_T(t) = \exp(-t/T)\mathbf{1}(t > 0)$$

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low-pass filter

adaptive gain control

dynamic range compression

Typically:

- **r ~ 0.33**
- **delta ~ 0.5**
- **epsilon ~ 0**
- **alpha ~ 1**
- **T ~ 400 ms**

Simplified PCEN

Under the simplest parametrization, PCEN boils down to

$$(\mathbf{\Phi} \circ \mathbf{E}_{\boldsymbol{x}})(t, f) = \frac{\mathbf{E}_{\boldsymbol{x}}(t, f)}{\mathbf{M}_{\boldsymbol{x}}(t, f)}$$

where $\mathbf{M}_{\boldsymbol{x}}(t, f)$ is a moving average of $\mathbf{E}_{\boldsymbol{x}}(t, f)$.

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- If $\mathbf{E}_{\boldsymbol{x}}(t, f)$ is a **"noise"** region: $\mathbf{E}_{\boldsymbol{x}}(t, f) \approx \mathbf{M}_{\boldsymbol{x}}(t, f)$

  and thus $(\mathbf{\Phi} \circ \mathbf{E}_{\boldsymbol{x}})(t, f) \approx 1$ on average

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- If $\mathbf{E}_{\boldsymbol{x}}(t, f)$ is a **"transient"** region: $\mathbf{E}_{\boldsymbol{x}}(t, f) \gg \mathbf{M}_{\boldsymbol{x}}(t, f)$

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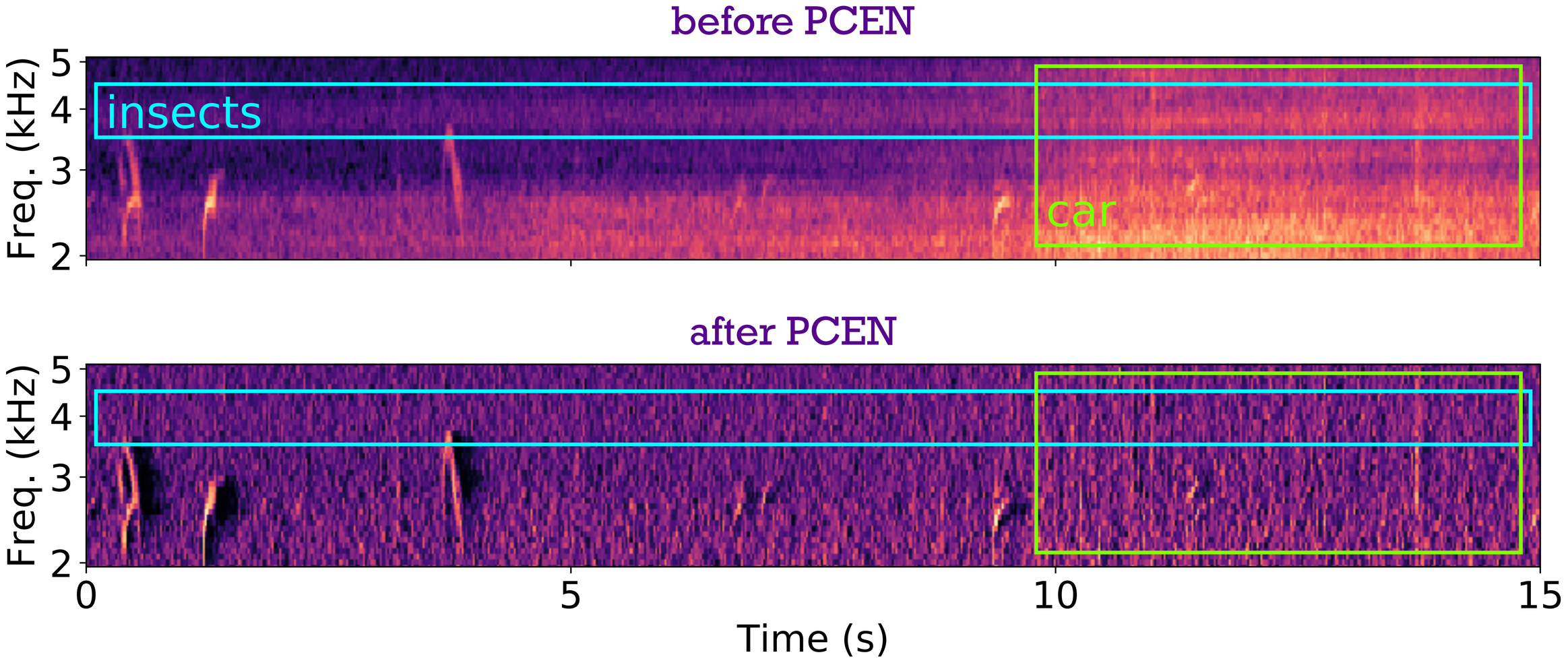
PCEN in practice

PCEN enhances the visual contrast between events and background.

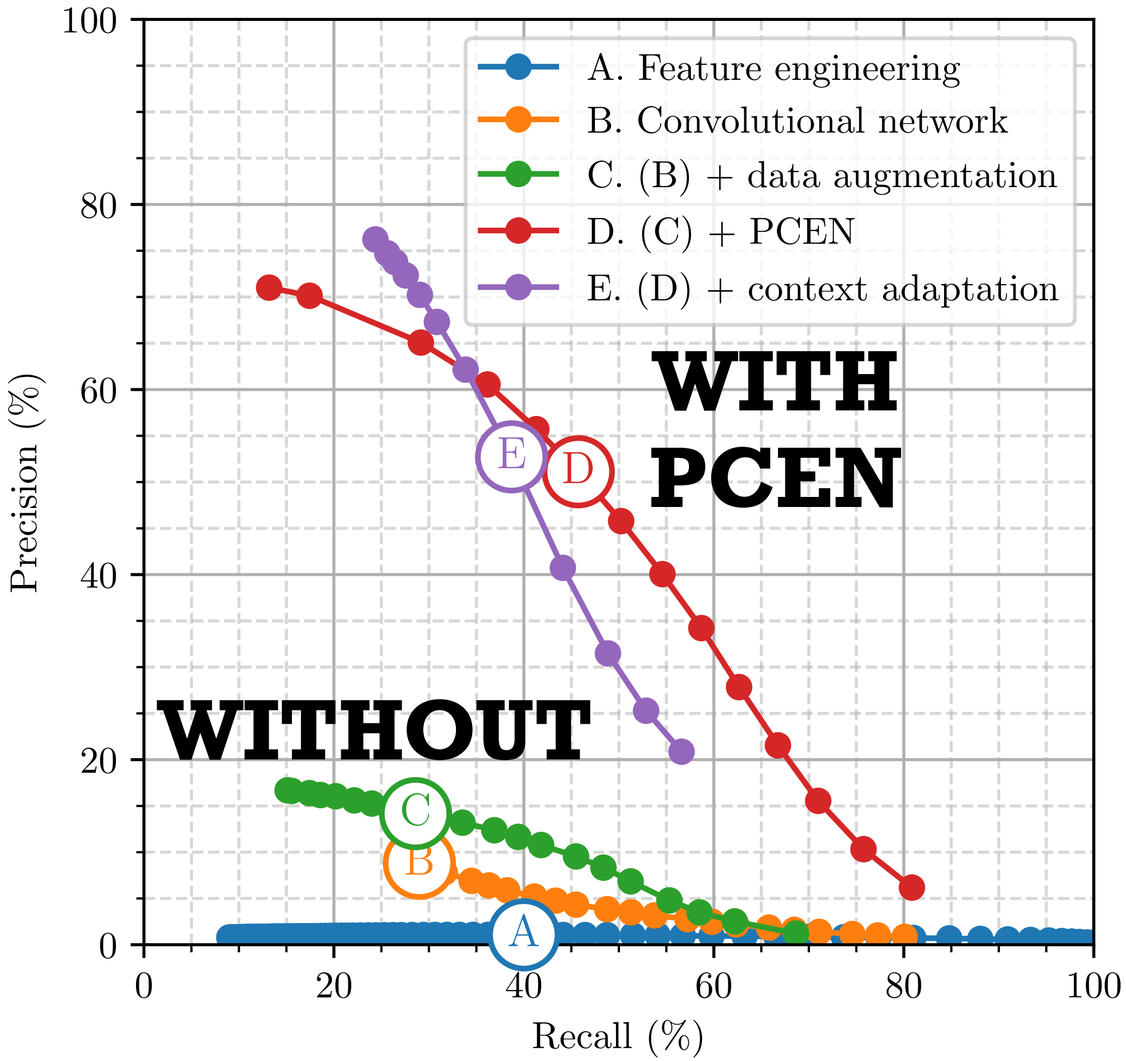


Data: BirdVox project

PCEN + deep learning

[Lostanlen et al. 2022]

Evaluated on 300h hours of annotated audio from a sensor network.



PCEN plays a crucial role in statistical generalization.

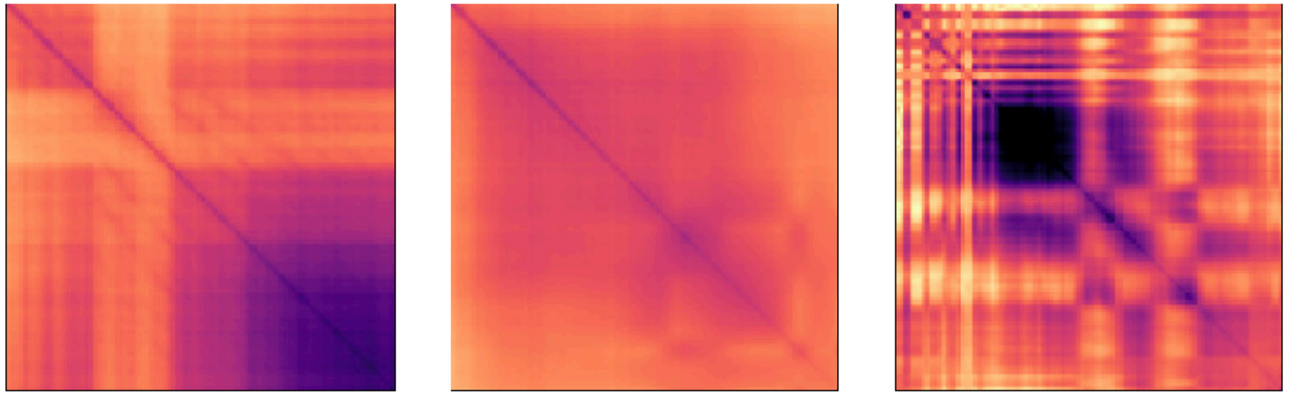
Models A, B, C: without PCEN
Models D, E: with PCEN

how to justify this?

PCEN decorrelates subbands

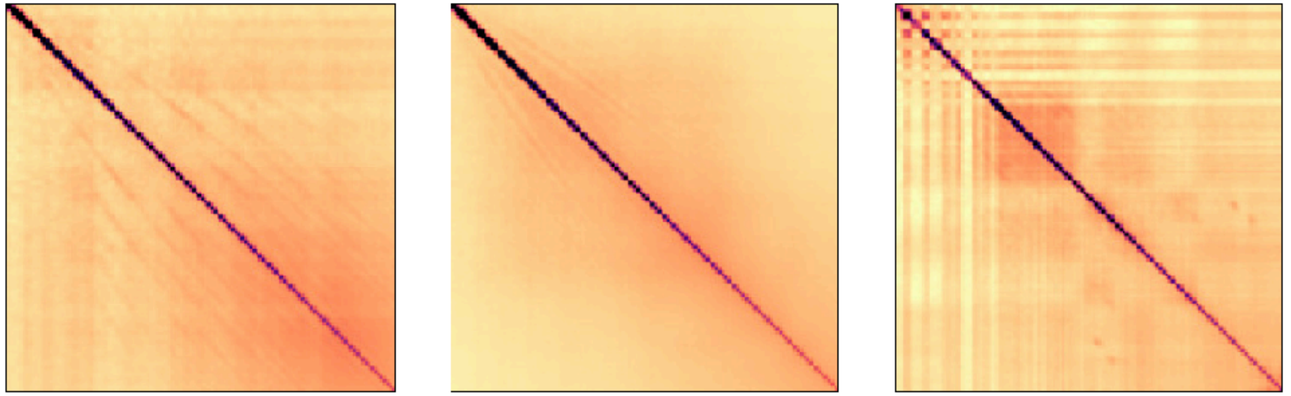
[Lostanlen et al. 2019a]

SONYC | DCASE 2013 SC | BirdVox



(a) Logarithmic transformation.

(urban noise) | *(indoor noise)* | *(rural noise)*

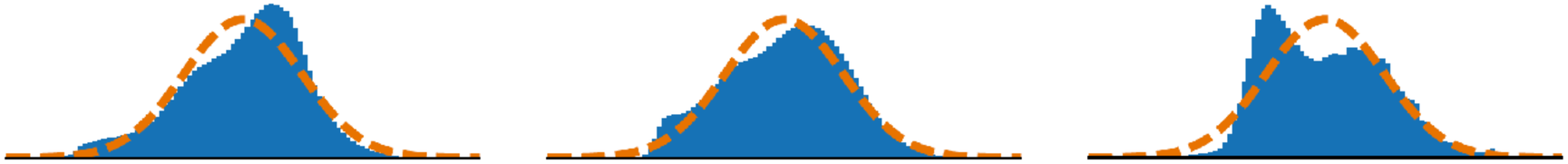


(b) Per-channel energy normalization (PCEN).

PCEN Gaussianizes magnitudes

[Lostanlen et al. 2019a]

(urban noise) SONYC | *(indoor noise)* DCASE 2013 SC | *(rural noise)* BirdVox

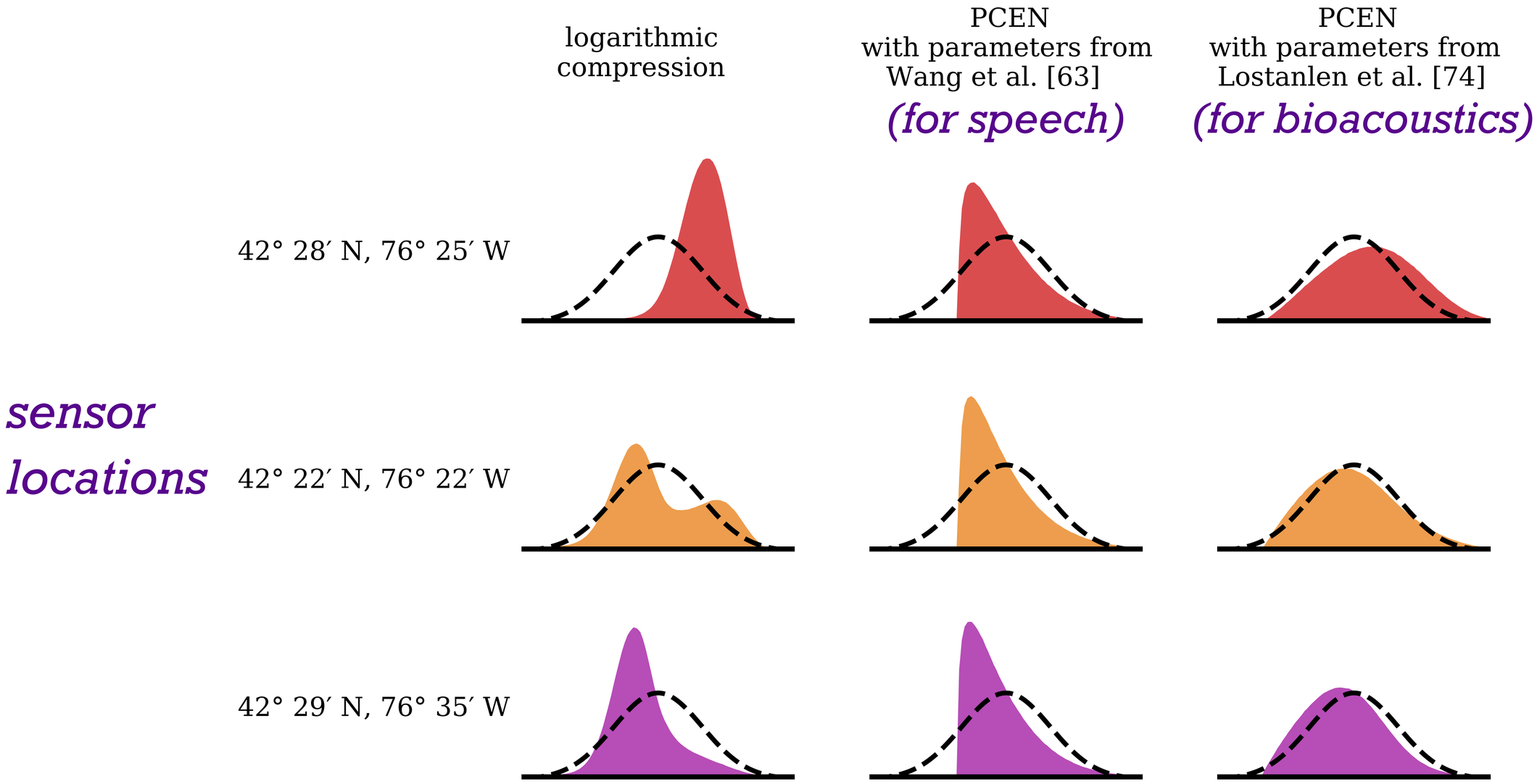


(a) Logarithmic transformation.

(b) Per-channel energy normalization (PCEN).

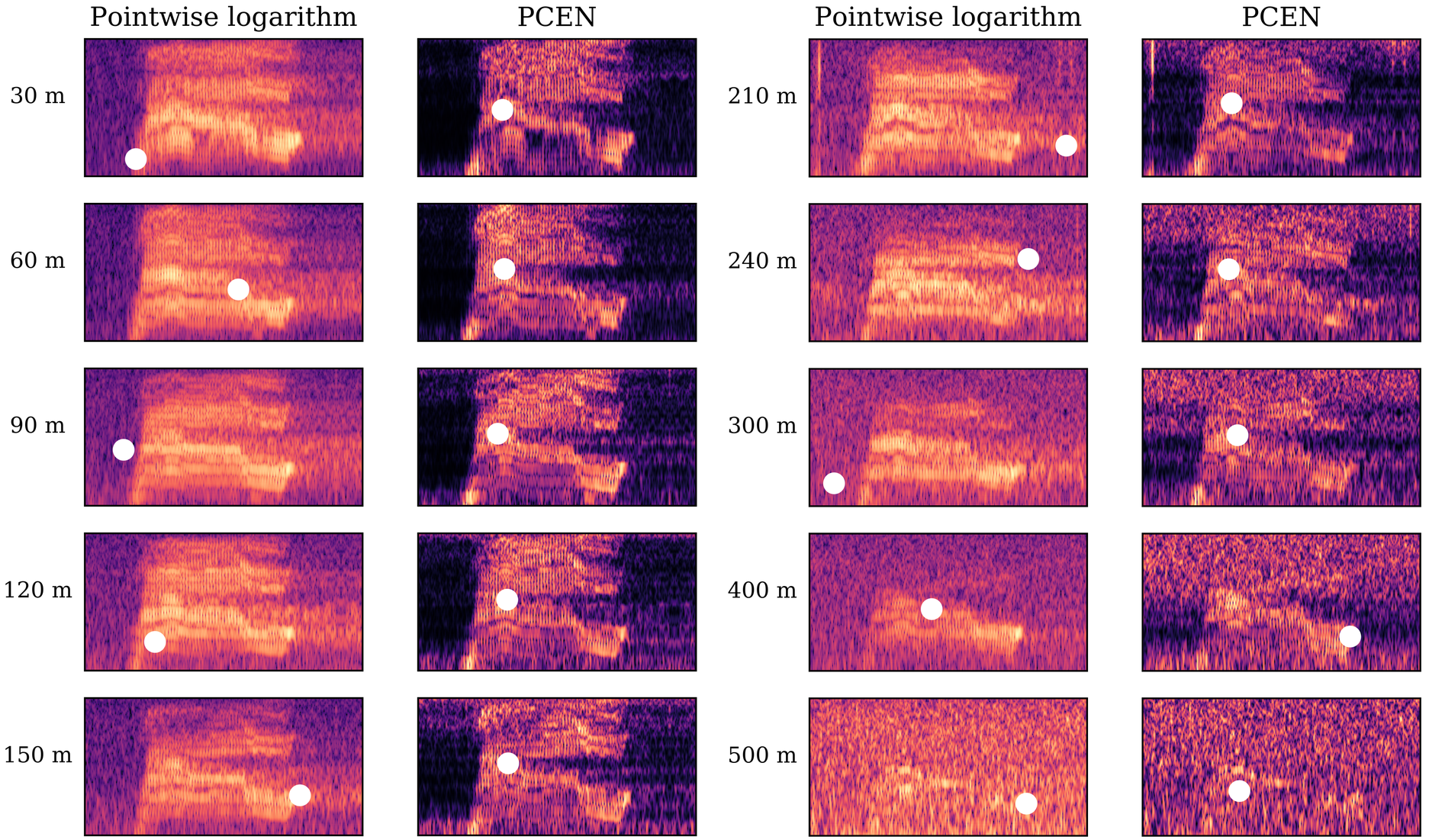
PCEN generalizes (if well-tuned)

[Lostanlen et al. 2019b]



PCEN improves detection range

[Lostanlen et al. 2019c. Audio data from Elly Knight]



End-to-end PCEN learning

[Wang et al. 2017, Zinemanas et al. 2018, Zeghidour et al. 2021, many others]

LEAF (Learnable Audio Frontend) from Google Research.

State-of-the-art performance on many tasks:
speech commands, **birdsong** detection, **musical** instruments …

Table 2: Impact of the compression layer on the performance (single task, average accuracy in %).

	mel-filterbank			LEAF- filterbank		
	log	PCEN	sPCEN	log	PCEN	sPCEN
Average	73.9 ± 0.8	76.4 ± 0.8	76.0 ± 0.7	74.6 ± 0.7	76.4 ± 0.8	$\mathbf{76.9} \pm 0.8$

Table from Zeghidour et al. 2021

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