Towards 20 GHz realtime neural network processors via semiconductor lasers

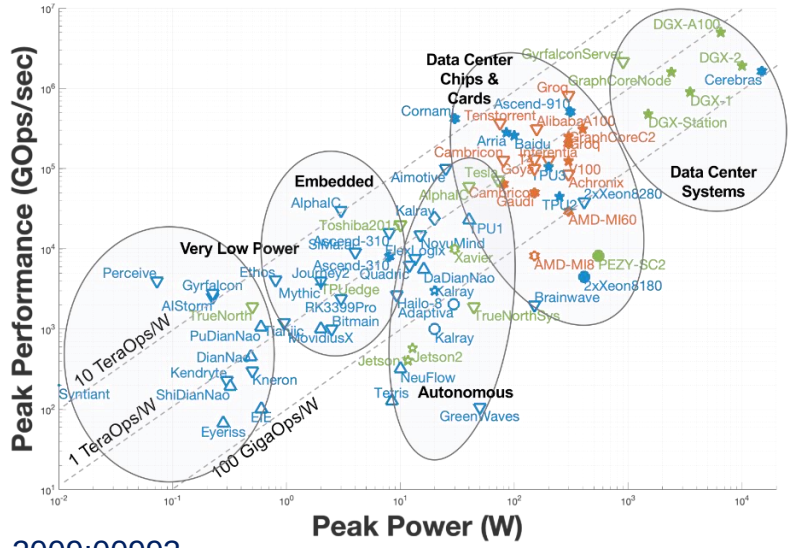
X. Porte[1], A. Skalli[1], N Haghighi[2], S. Reitzenstein[2], J.A. Lott[2], D. Brunner[1]

[1] FEMTO-ST / Optics Dept., CNRS Univ. Bourgogne-Franche-Comté, Besançon, France

[2] Institut fur Festkoerperphysik, Technische Universitaet Berlin, Hardenbergstraße 36,10623 Berlin, Germany

Swiss Photonics Workshop on Optical Computing: current / emerging approaches & applications

NN architecture and energy consumption



Reuther, et al., Arxiv: 2009:00993.

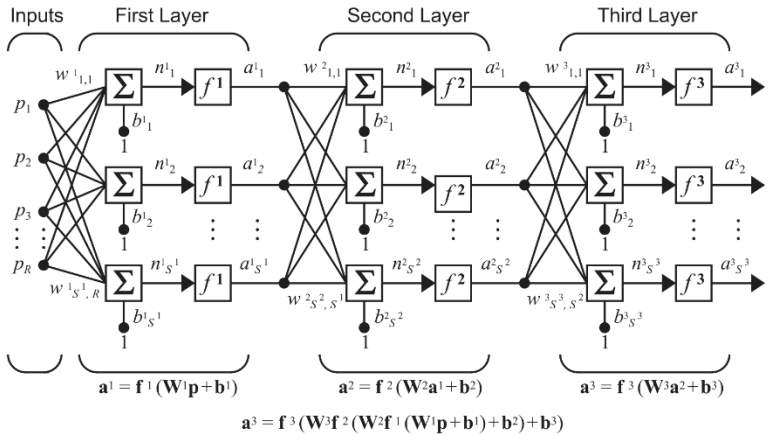
MIT Technology Review

Artificial Intelligence / Machine Learning

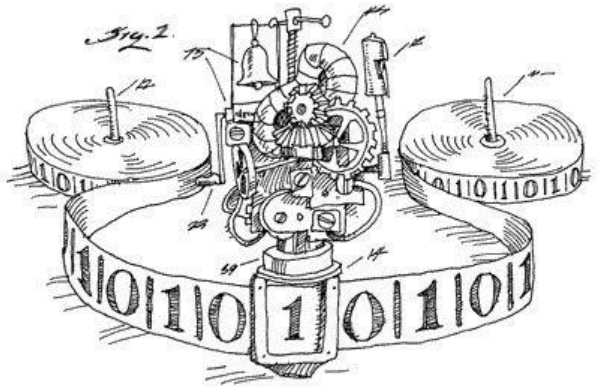
Training a single AI model can emit as much carbon as five cars in their lifetimes

Deep learning has a terrible carbon footprint.

by **Karen Hao** Jun 6, 2019

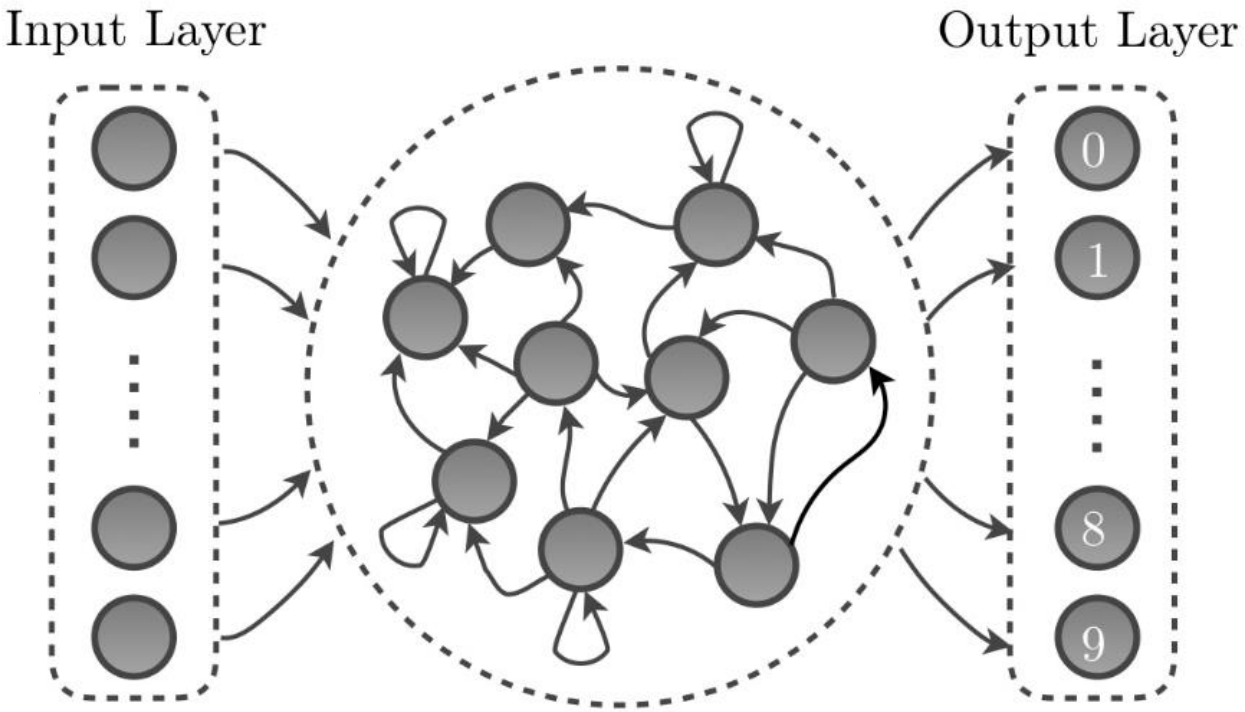


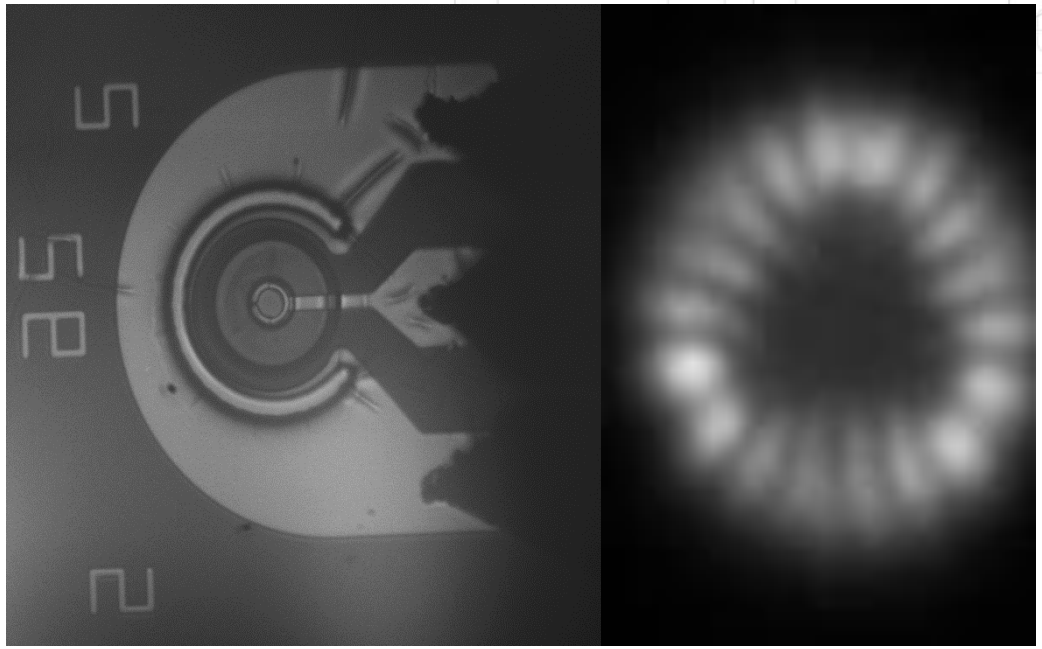
≠



© Hussein Nur

Experimental setup / scheme

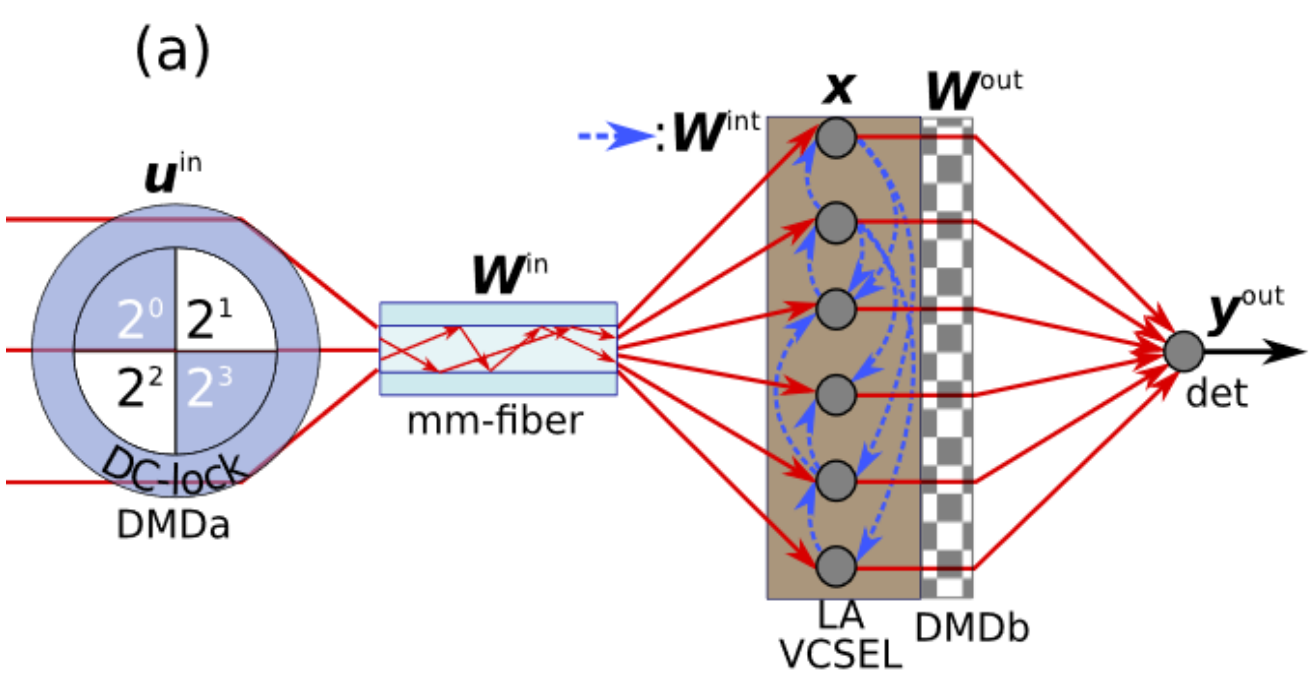


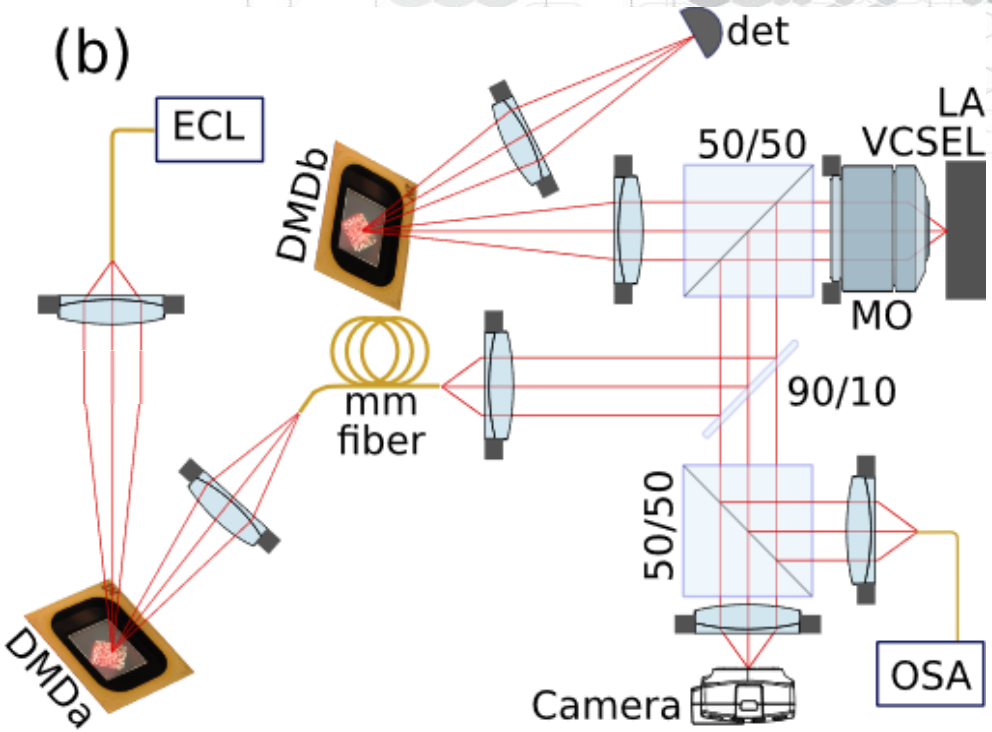


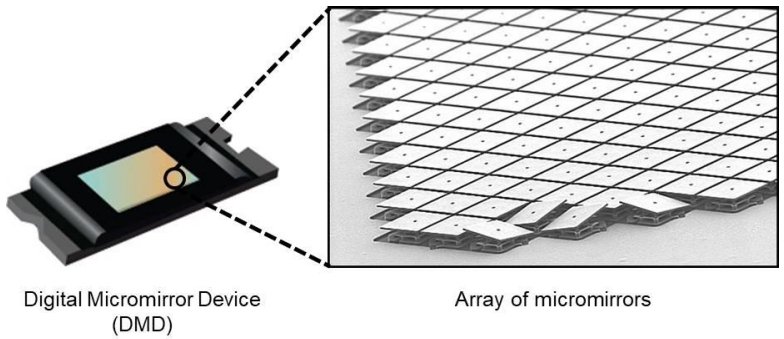
Reservoir	VCSEL Reservoir
Nodes / Neurons	Modes ≈ 30
Connections	Carrier diffusion / Cavity diffraction

Porte, et al., *J. Phys. Photonics* https://doi.org/10.1088/2515-7647/abf6bd.

Experimental setup / scheme



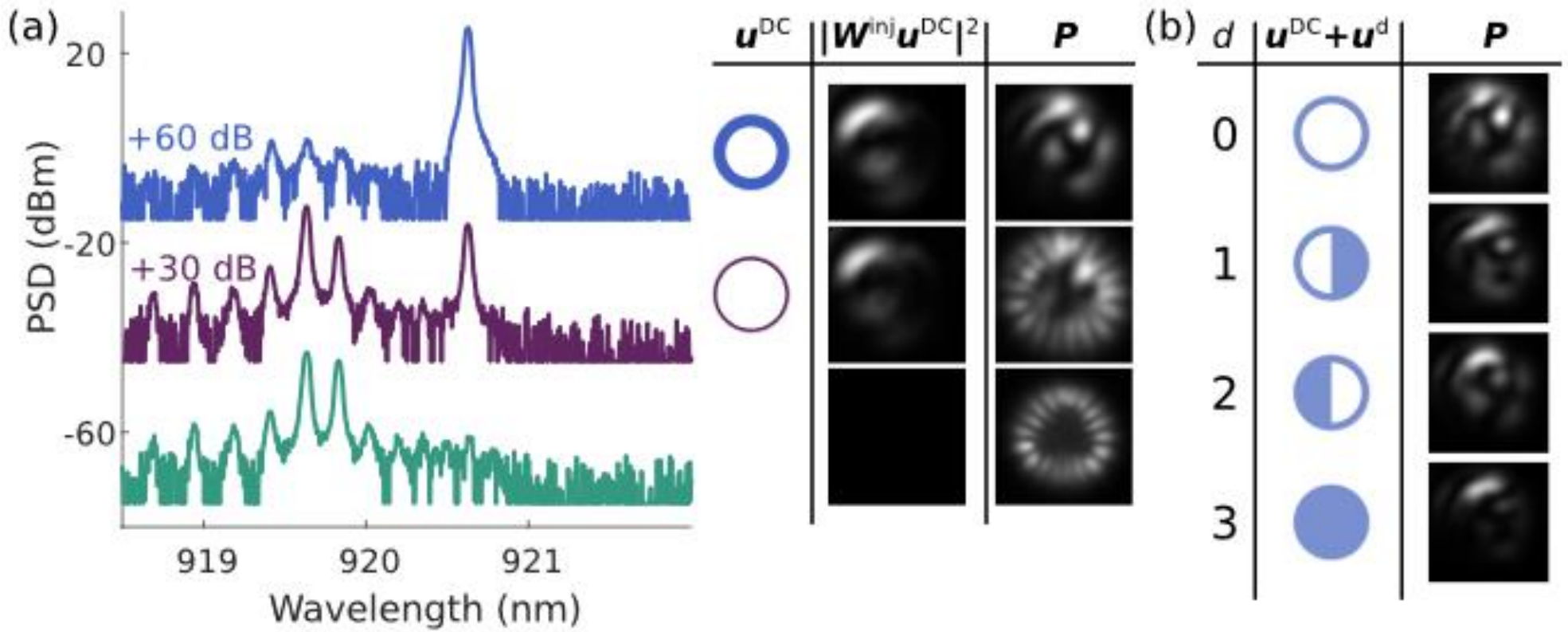




Reservoir	VCSEL Reservoir
Input Information	DMDa
Input weights	Multi Mode Fiber $\approx 20\ modes$
Output weights	DMDb

Porte, et al., *J. Phys. Photonics* https://doi.org/10.1088/2515-7647/abf6bd.

Injection locking / Information injection

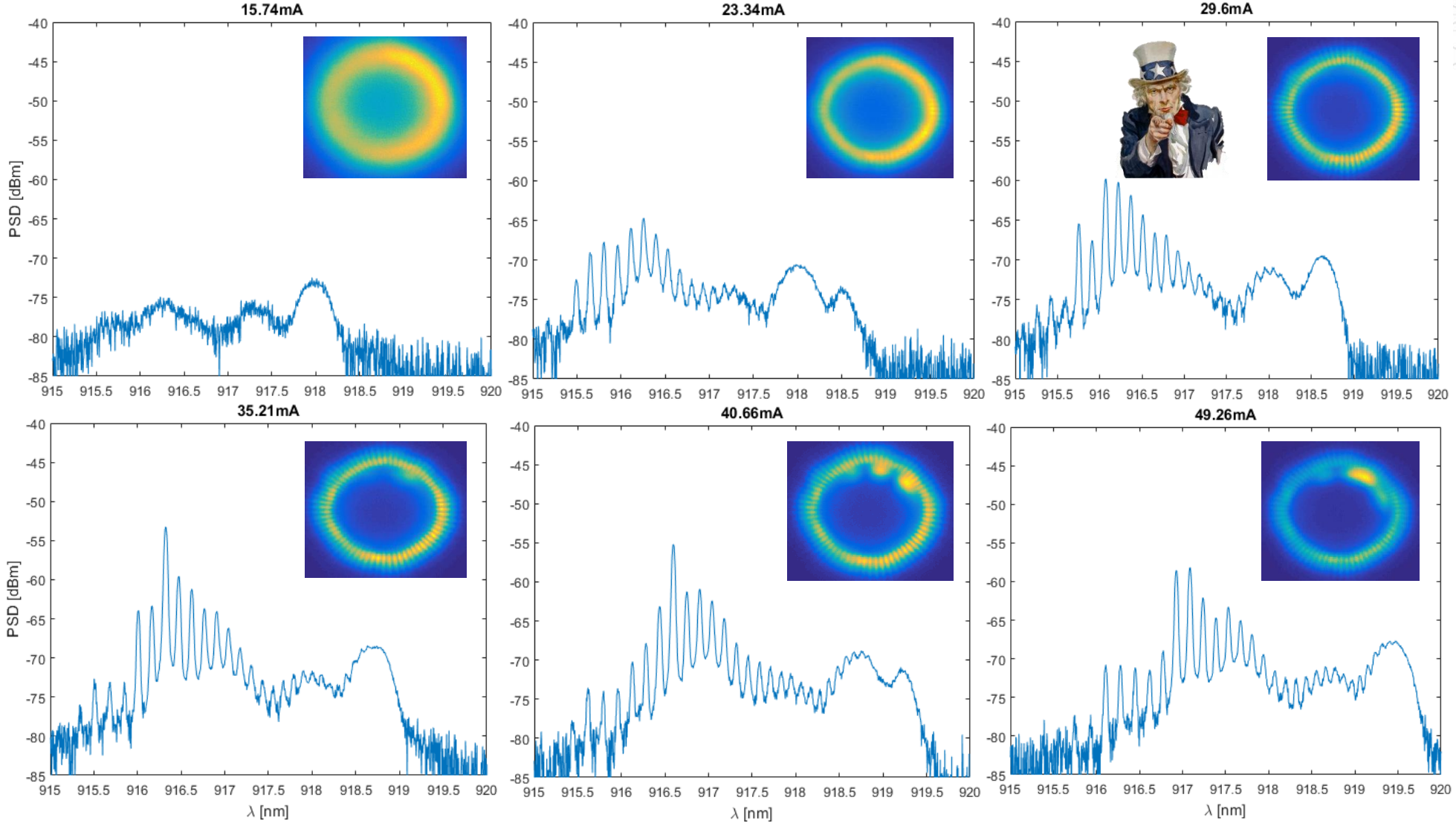


Scan λ :highest susceptibility to optical injection

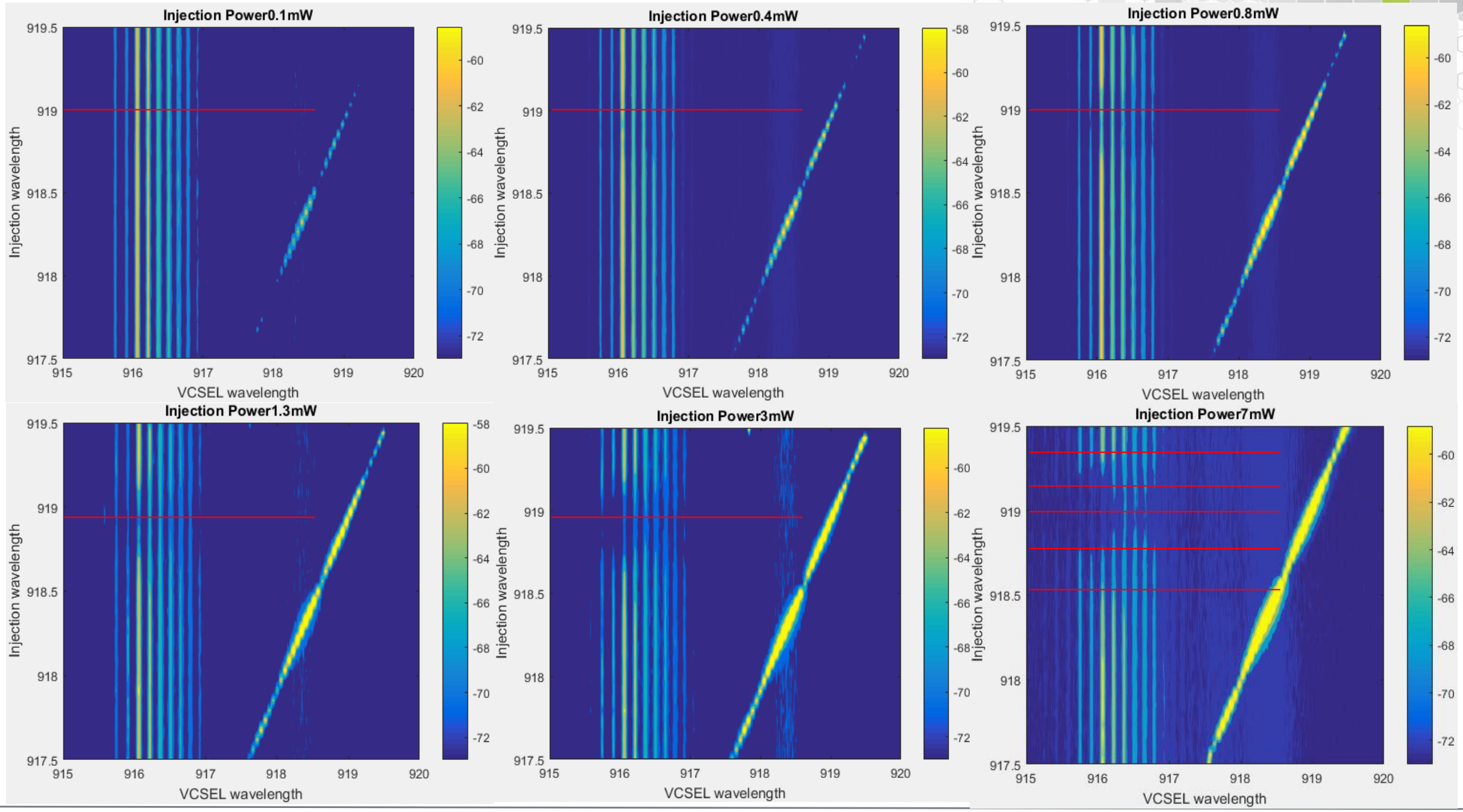
Locking: scan the injection ring width to fully lock the VCSEL.

Porte, et al., *J. Phys. Photonics* https://doi.org/10.1088/2515-7647/abf6bd.

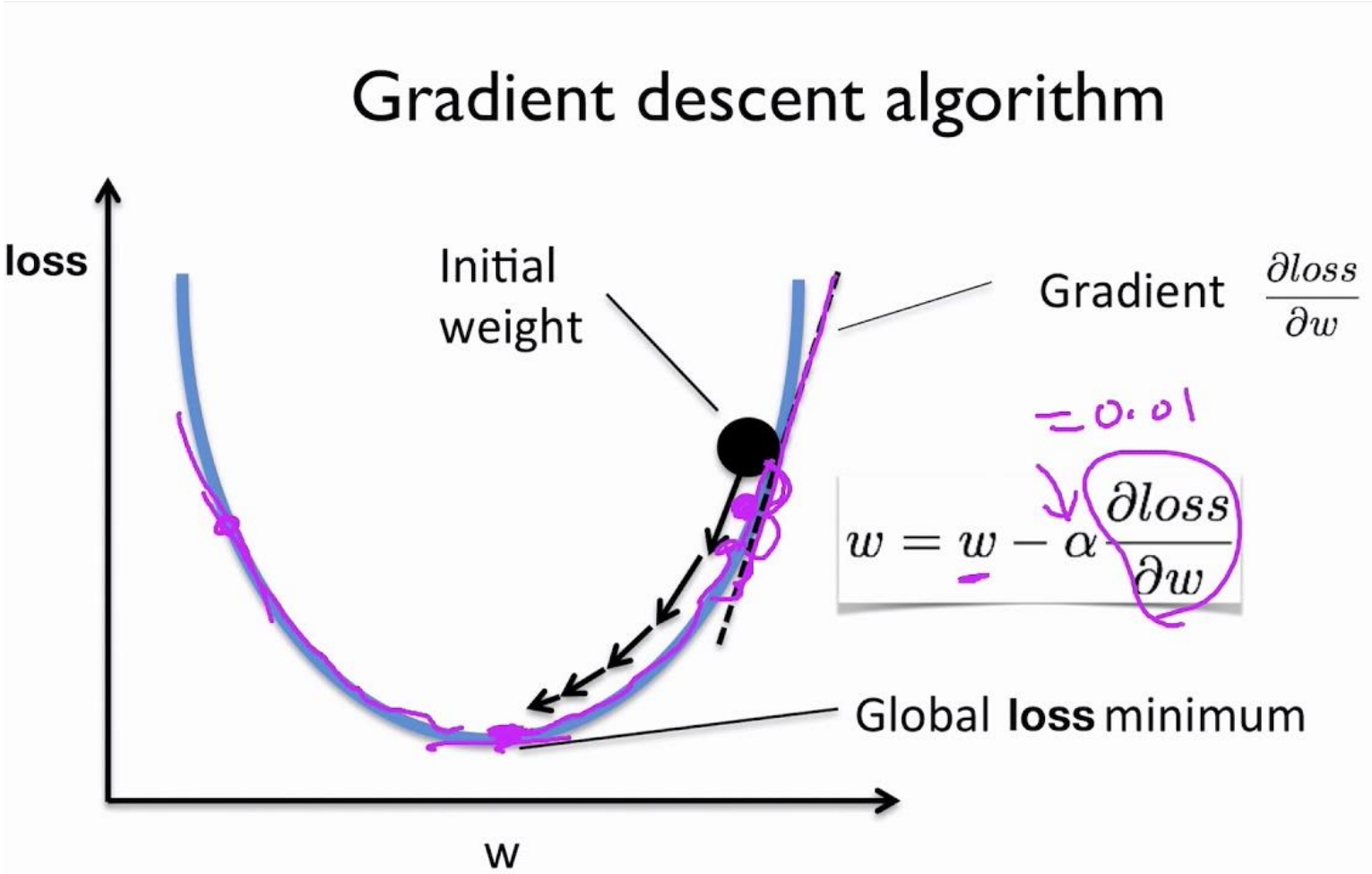
Optical modes: neurons embedding in near field



Laser injection locking: linking neurons to input information



Learning strategy

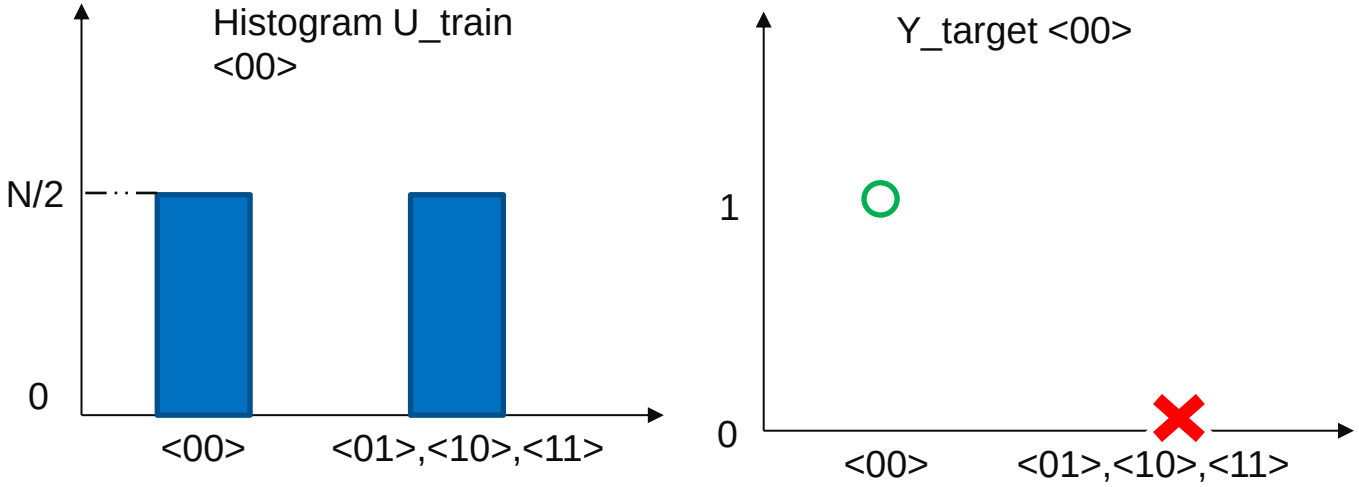


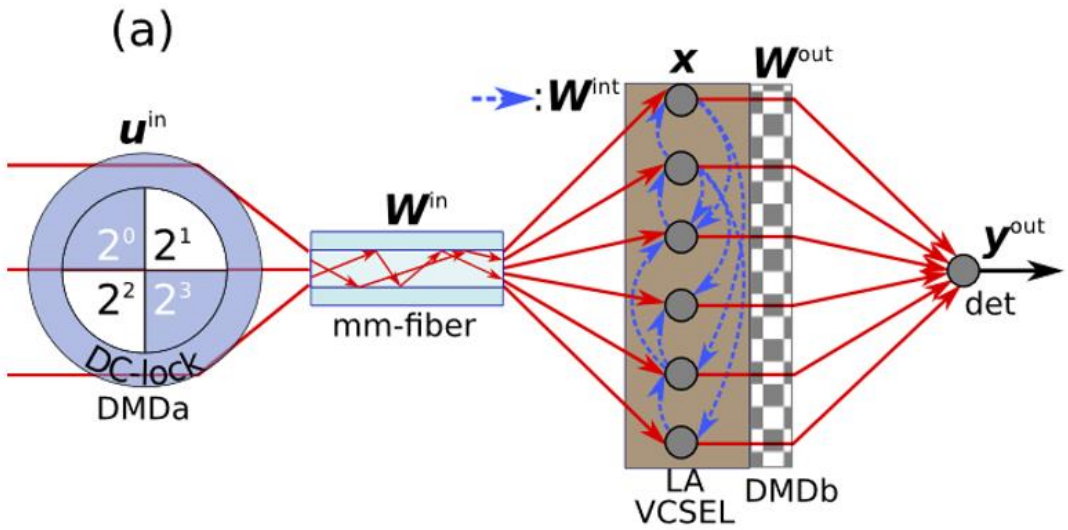
$$n_{\text{mirrors}} = \text{ceil}(\alpha * \text{MSE})$$

Porte, et al., *J. Phys. Photonics* https://doi.org/10.1088/2515-7647/abf6bd.

Header recognition task

- Training sequence of size N (batch size): 50% of the classification target, 50% of the other digits:





- After each epoch flip mirrors on DMDb:
  - If the MSE decreases keep the change
  - If it increases: revert the change then flip other mirrors
- Keep going until the error is bellow a threshold.

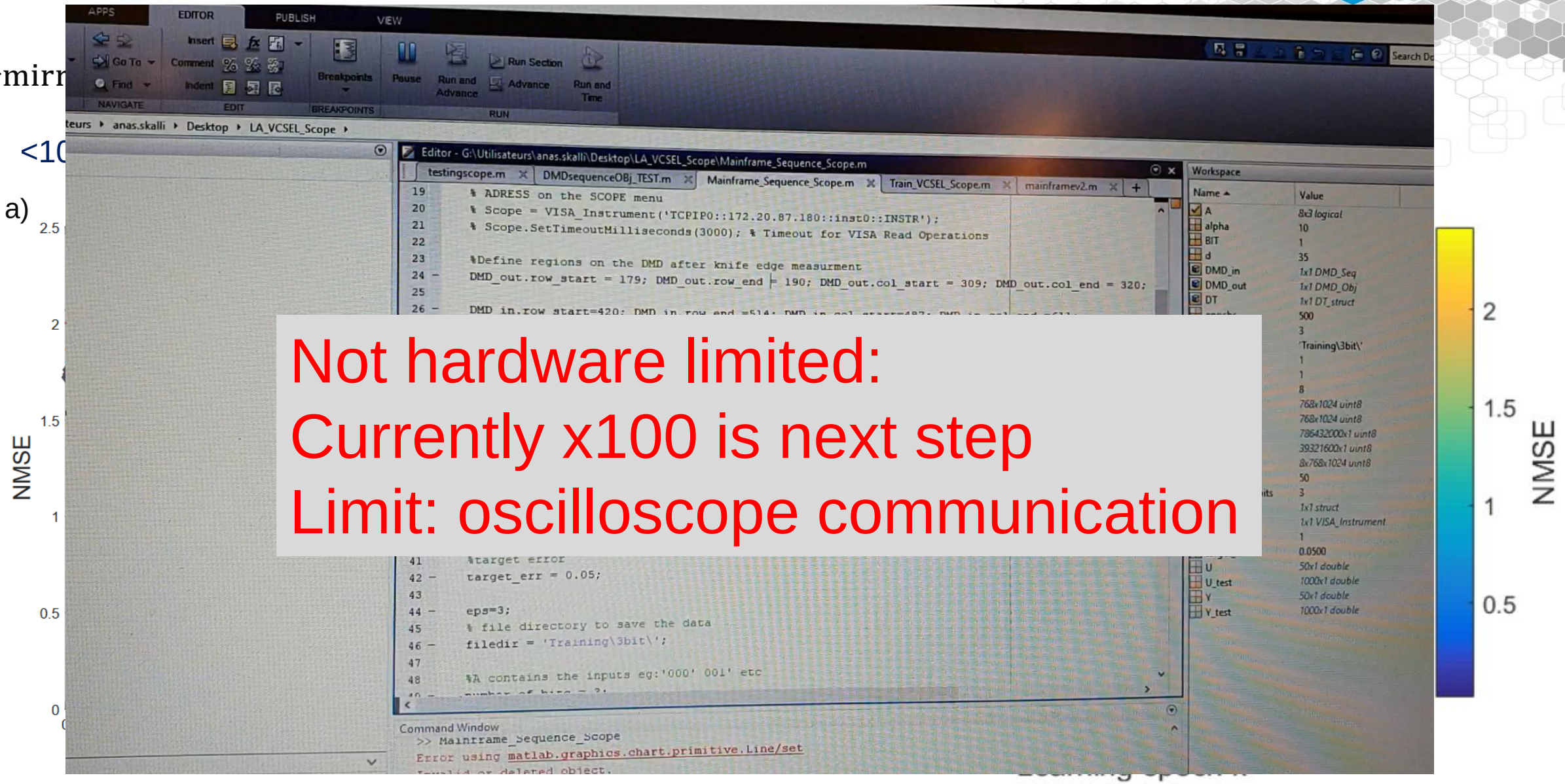
Porte, et al., *J. Phys. Photonics* https://doi.org/10.1088/2515-7647/abf6bd.

Results

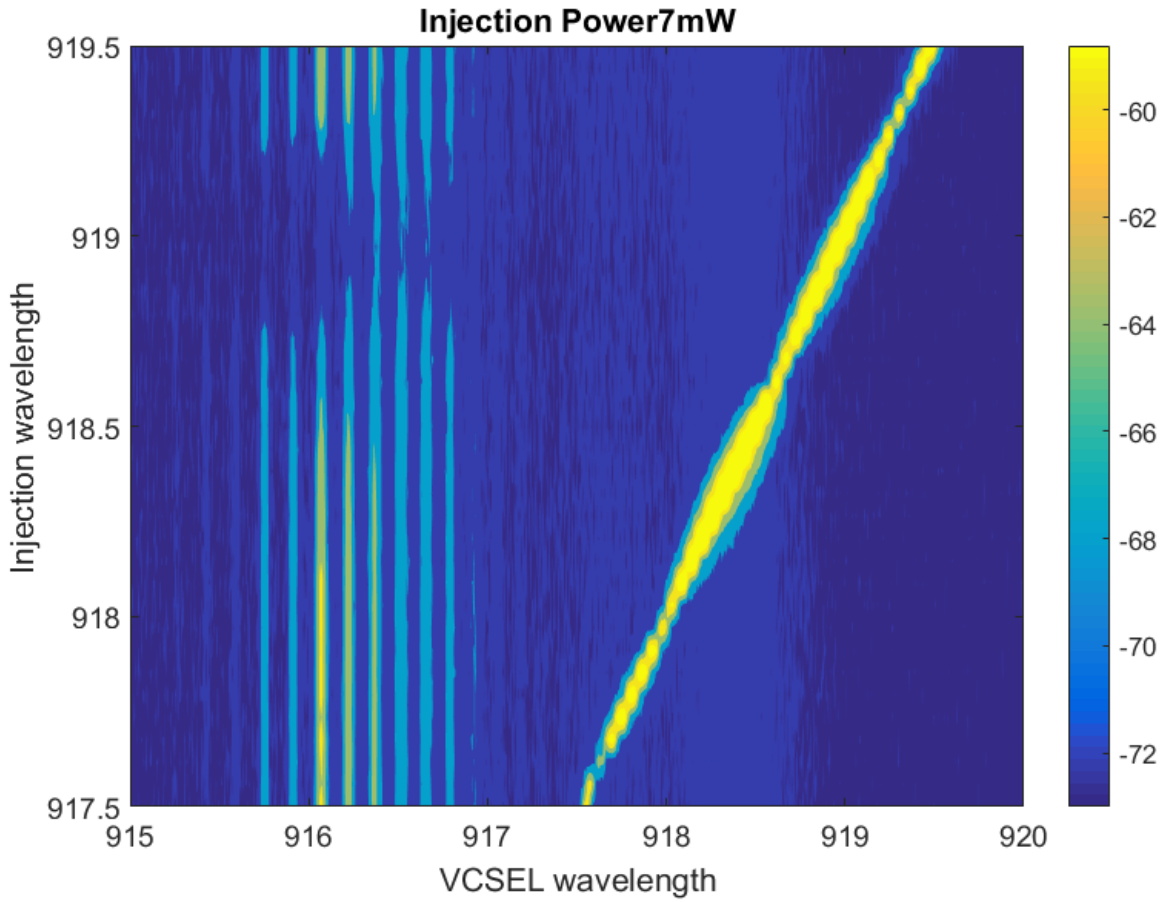
n_{mirr}

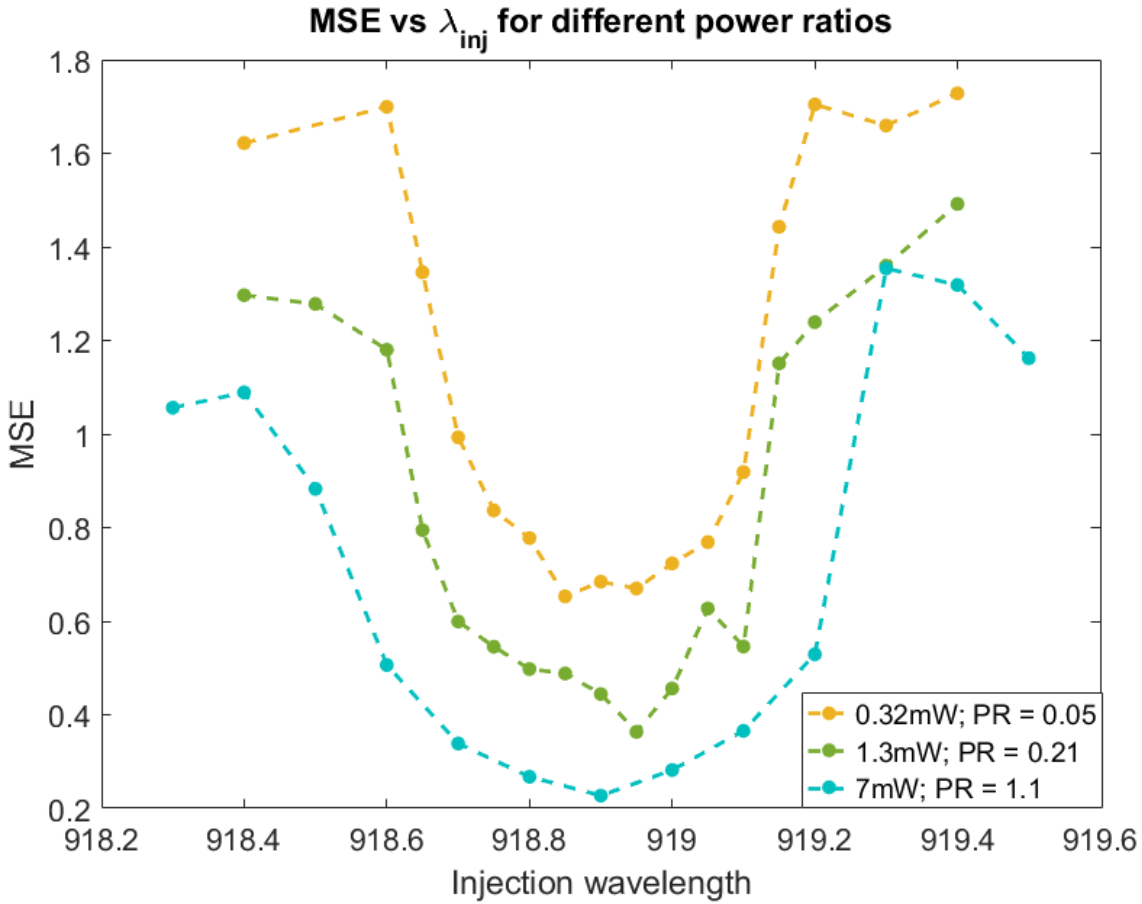
<10

a)

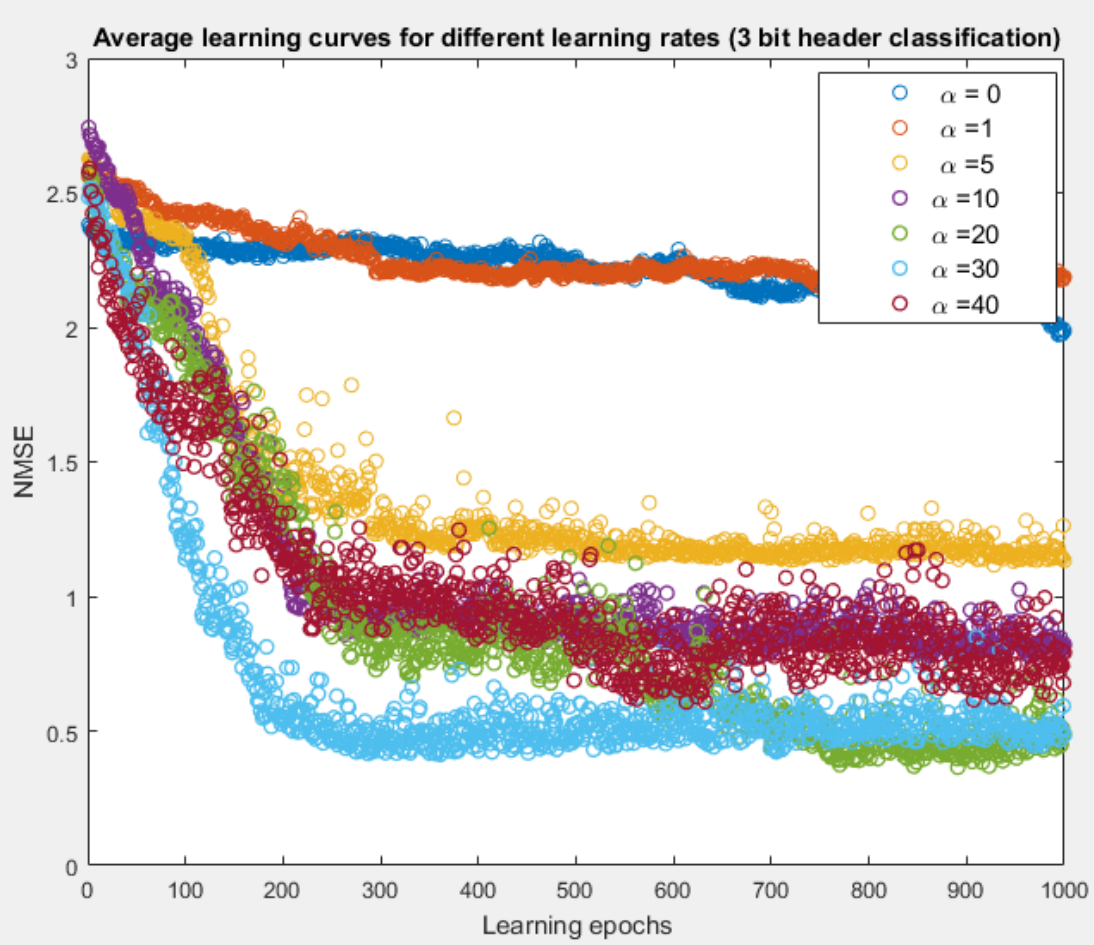


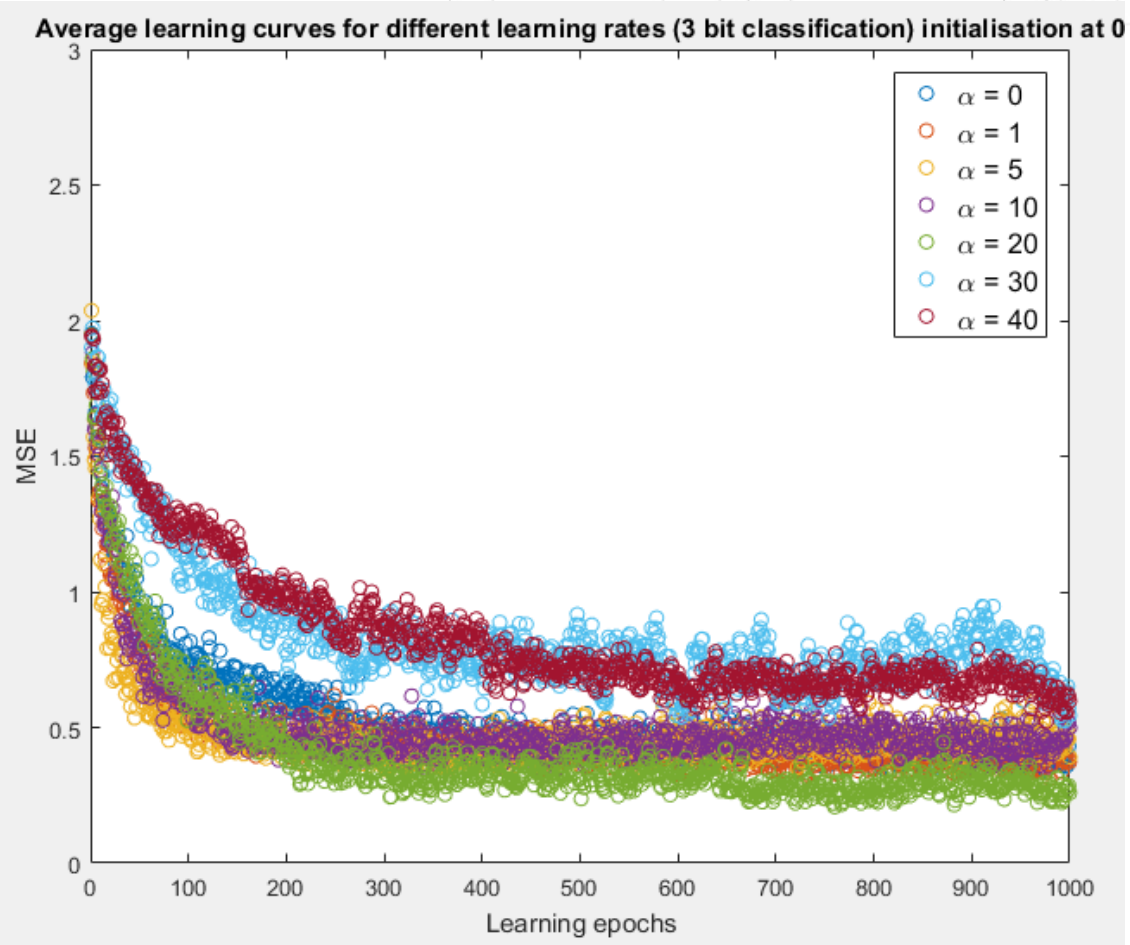
Error and injection locking parameters





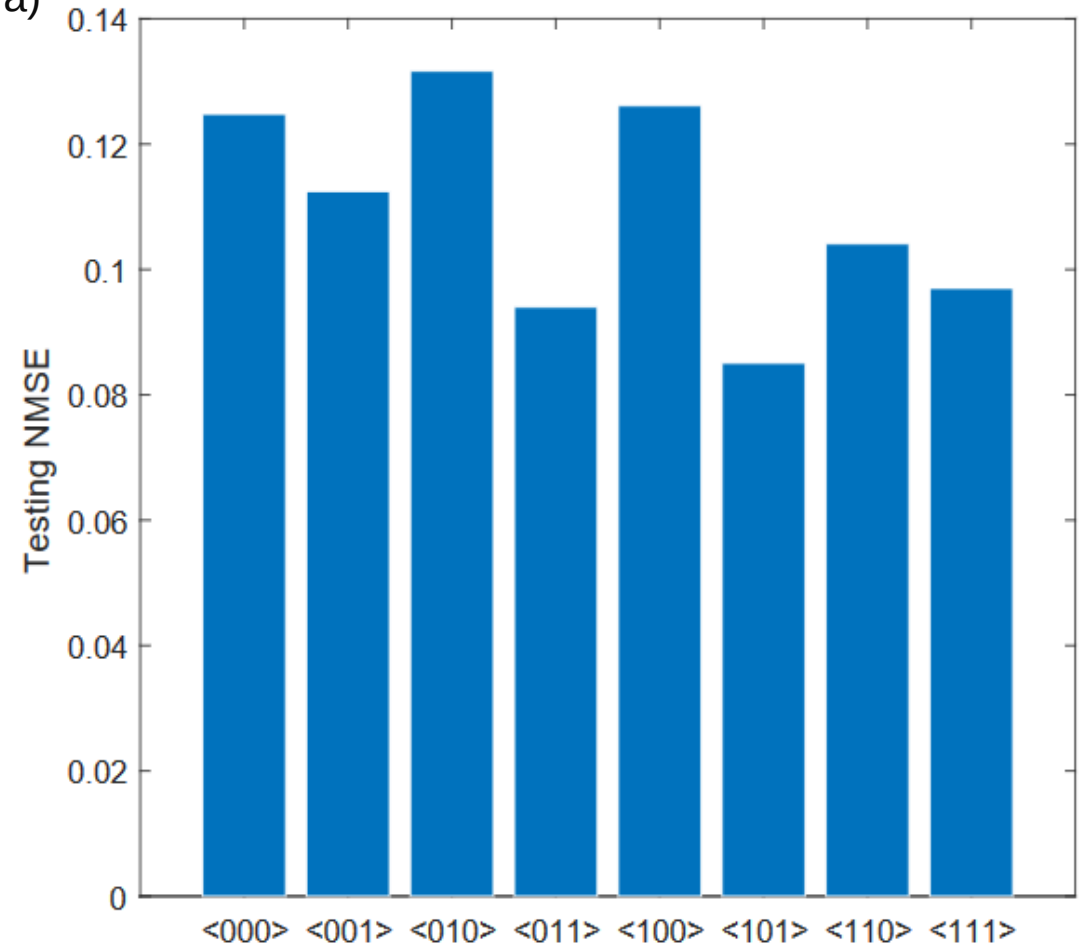
Weight initialization matters (for classification)



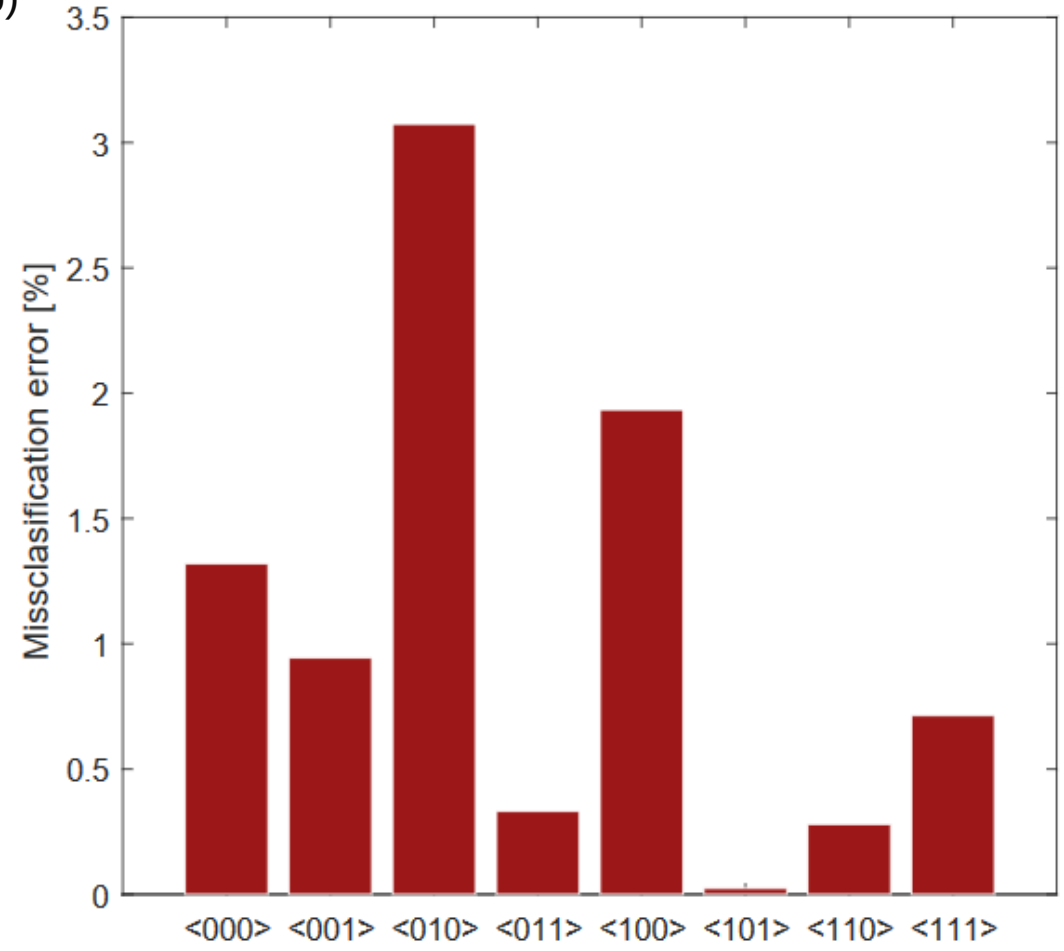


Finally: classification error rates

a)

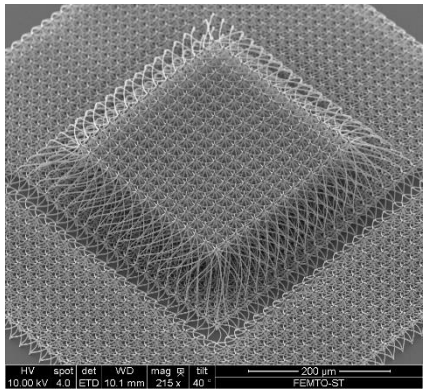


b)



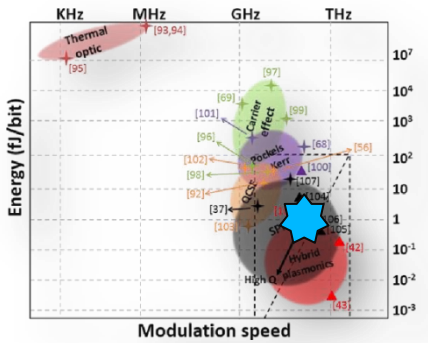
NN breakthrough: long term effort

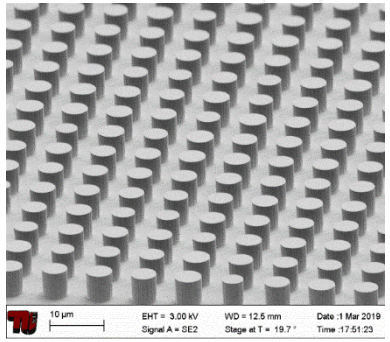
Parallel networks



Moughames, et al., Optica 7, 640 (2020).

Photonic neurons



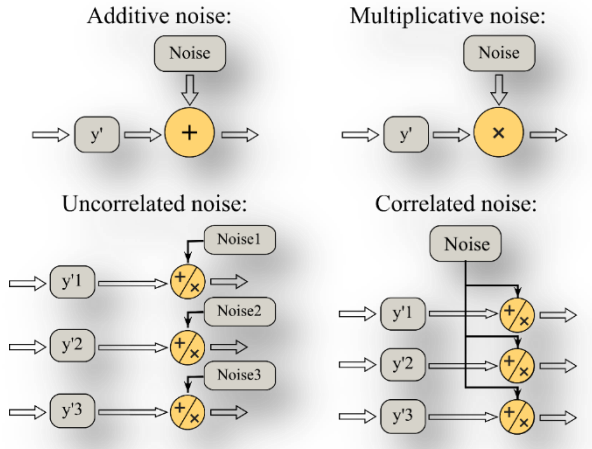


Liu et al., Laser and Photonics Reviews 9, 172 (2015).
Heuser, et al., J. Appl. Phys 3, 116103 (2018).

Hardware-motivated learning

Bueno, et al., Optica 5, 756 (2015).

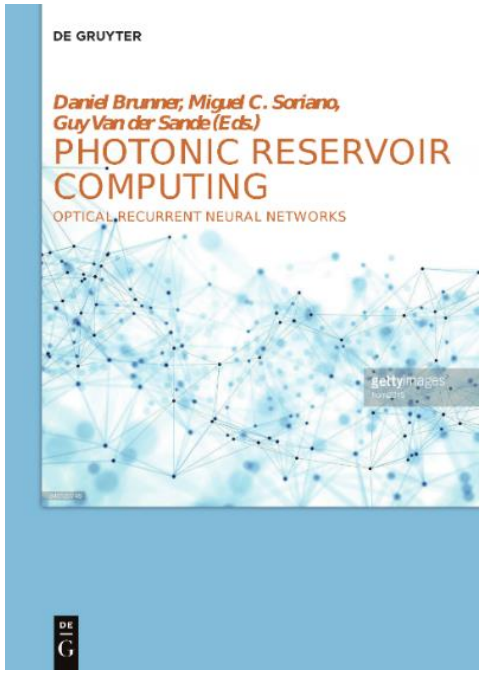
Noise



Semenova , et al., Chaos 29, 103128 (2015).

Summary

- Full implementation of all network connections: truly realtime
- Learning realized on physical substrate
- Very efficient learning and system: 1W power consumption
- Next: push the bandwidth



Emerging Topics in Artificial Intelligence (ETAI) 2021 (OP110)

Conference Chairs: **Giovanni Volpe,** Göteborgs Univ. (Sweden); **Joana B. Pereira,** Karolinska Institute (Sweden); **Daniel Brunner,** Institut Franche-Comte Electronique Mecanique Thermique et Optique (France); **Aydogan Ozcan,** Univ. of California, Los Angeles (USA)