Exploring Optical Neural Networks for Real-Time Adaptive Optics in Large Telescopes

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What we are doing in Adaptive Optics

- New ways of sensing
- Predicting the future

What we want to do in Adaptive Optics

- Speeding up: Optical neural networks

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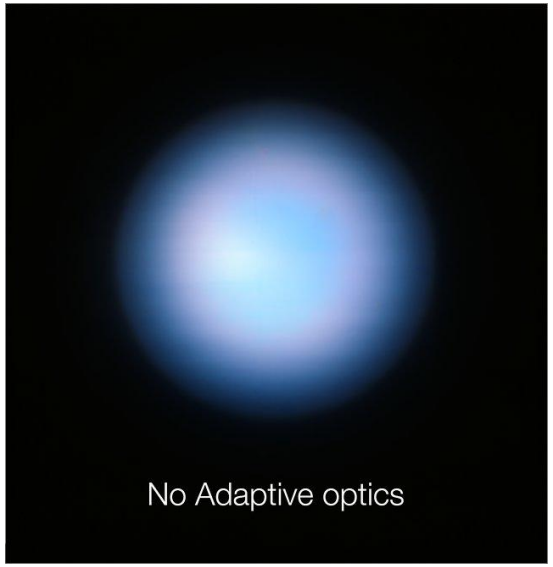
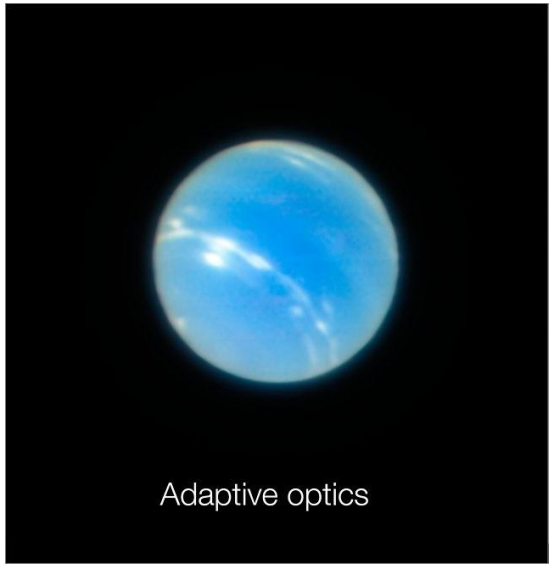
Earth’s atmosphere

- Adaptive Optics helps to remove the effect of the atmosphere in terrestrial telescopes





Credit ESO - P. Weilbacher

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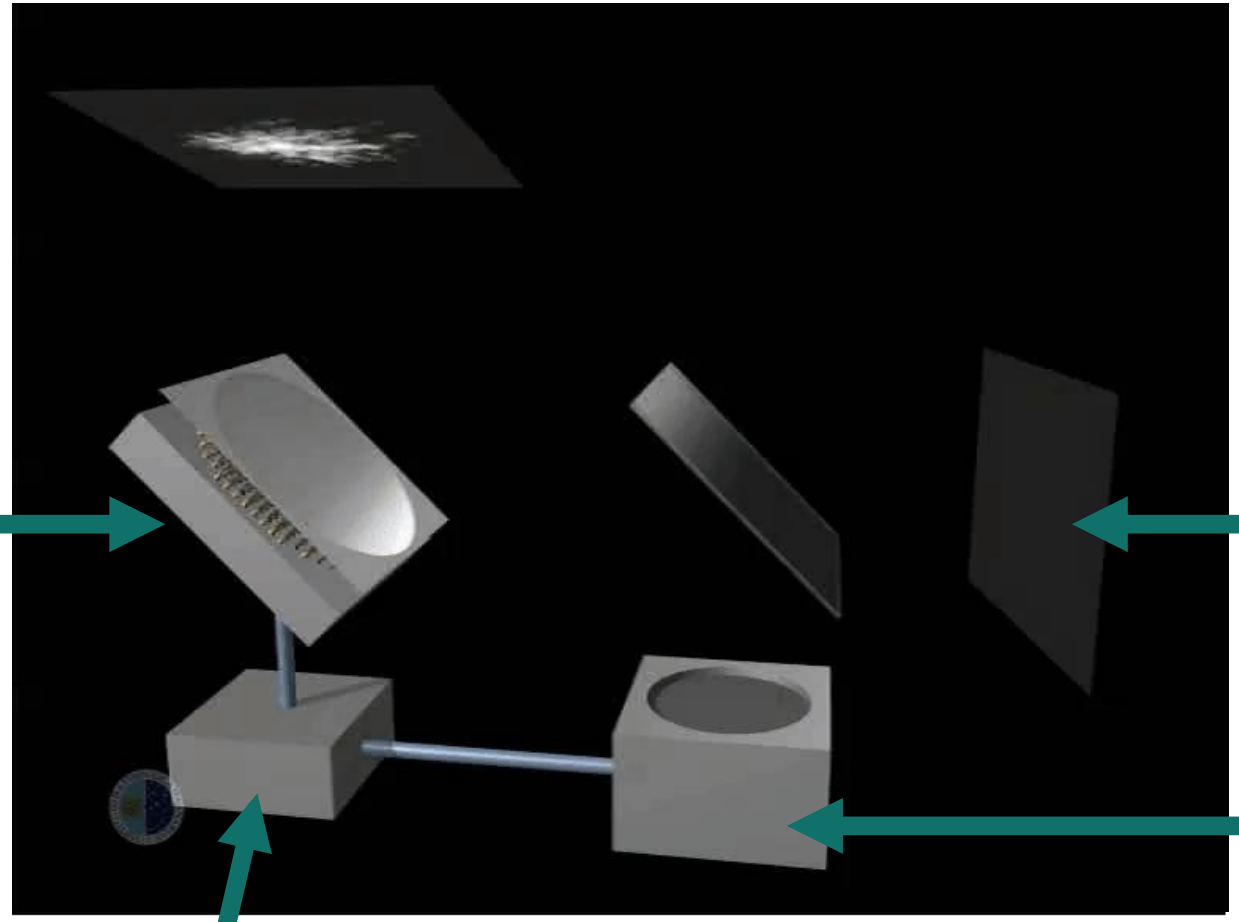
Adaptive Optics



Credit: Instituto de Astrofísica de Canarias

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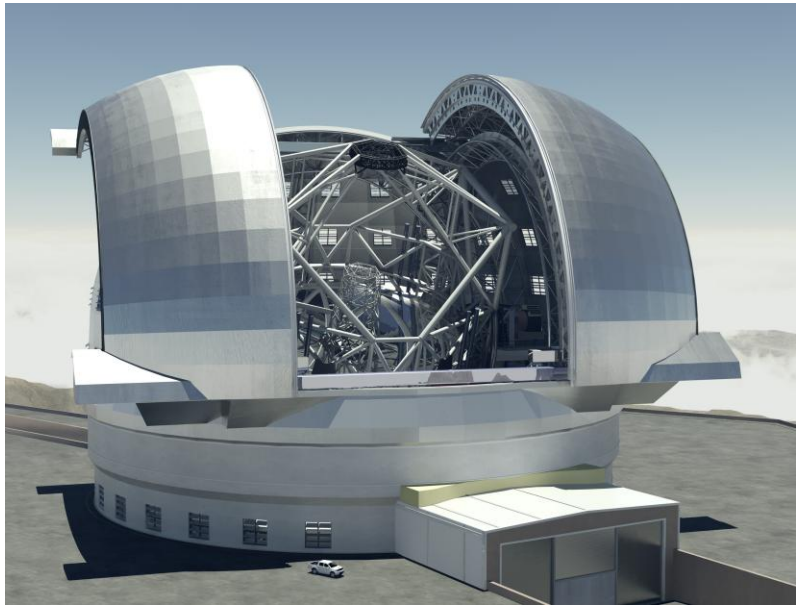
Challenges



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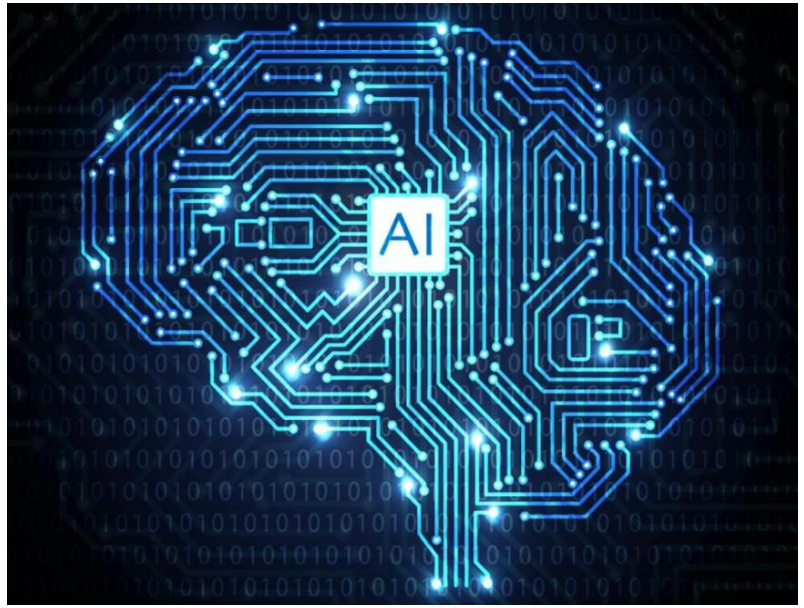

How can we use AI to keep pushing AO to its limits?

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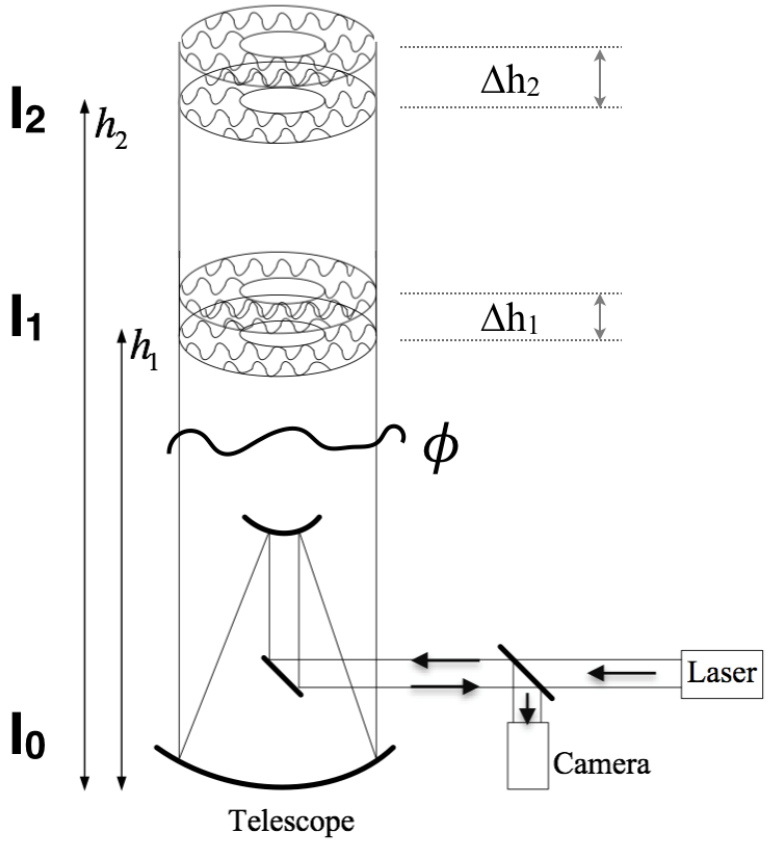
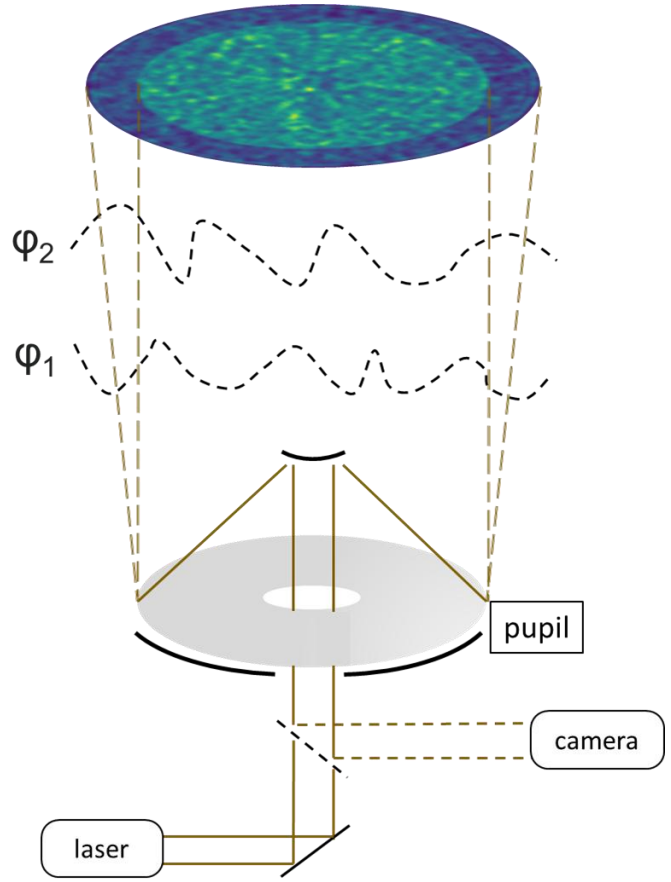
Projected Pupil Plane Pattern (P4)

- Wide laser beam reflected off primary mirror
- Remove cone-effect and anisoplanatism
- Can work with only one image



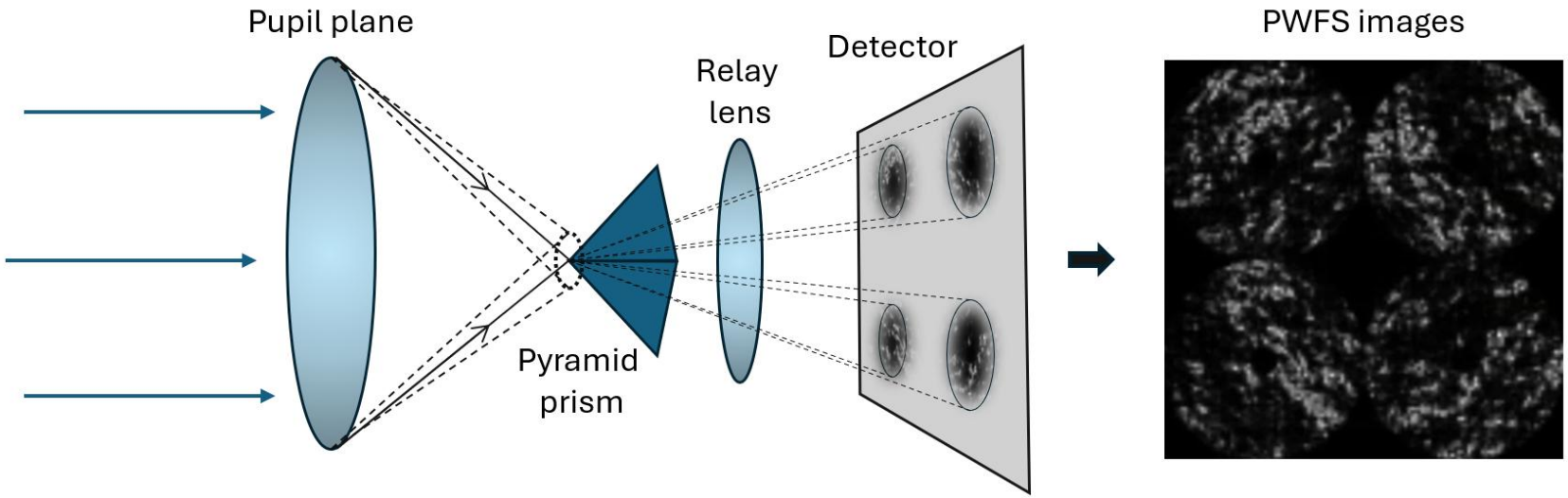
WOMBAT

- P4 evolution: Single image but focus/defocus
- Off-axis stars
- Wider field of view



Pyramidal sensor

- New type of sensor
- Huge bust in performance by using CNNs



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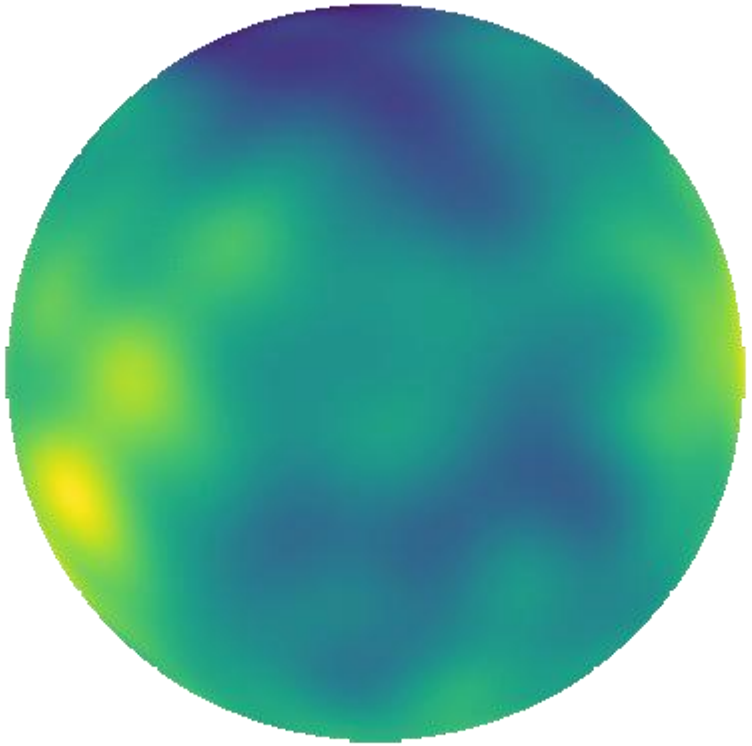
Atmospheric prediction

- Wavefront aberration -> Milliseconds
- Is it purely random? Can we predict it?



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Atmospheric prediction

- **Recurrent neural networks**
  - Robust prediction under varying observation conditions
  - Strong performance when predicting several time-steps ahead

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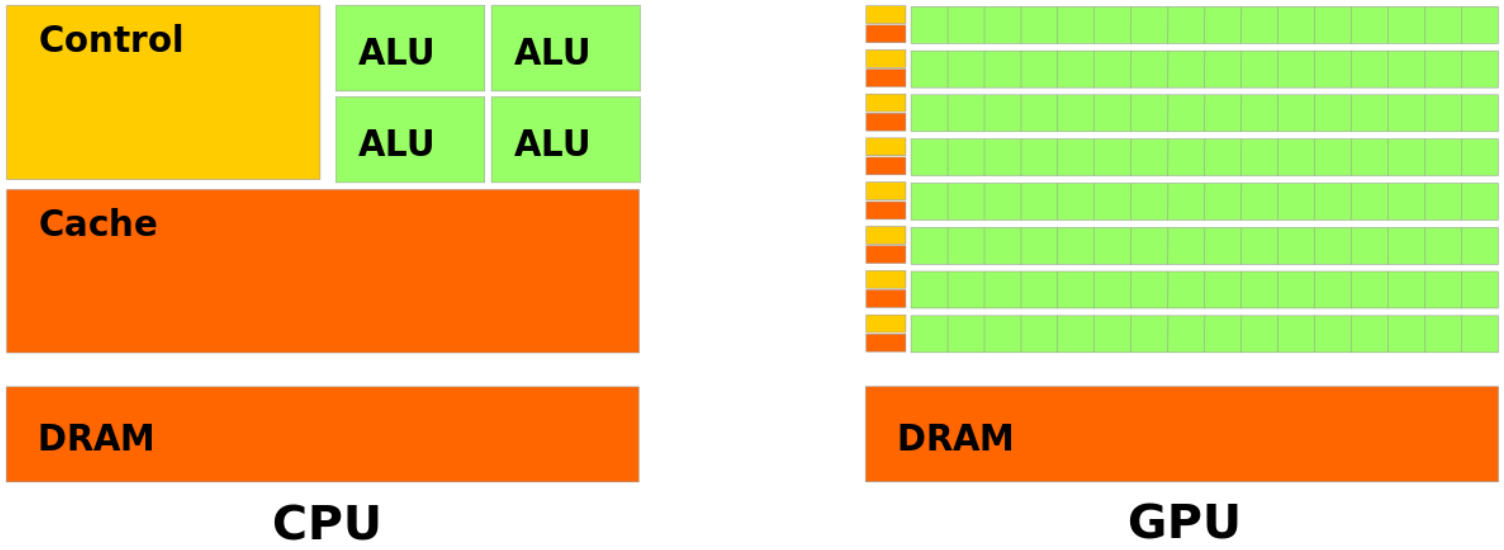
Graphics Processing Units

- Widely used in neural networks
- Faster than CPUs, but not always enough



Credit Nvidia

Optical Neural Networks (ONN)

- Fast computation -> Speed of light!
- Classifier -> MNIST or ImageNet

Science

HOME > SCIENCE > VOL. 361, NO. 6406 > ALL-OPTICAL MACHINE LEARNING USING DIFFRACTIVE DEEP NEURAL NETWORKS

REPORT

All-optical machine learning using diffractive deep neural networks

XING LIN, YAIR RIVENSON, NEZIH T. YARDIMCI, MUHAMMED VELI, YI LUO, MONA JARRAHI, AND AYDOGAN OZCAN Authors Info & Affiliations

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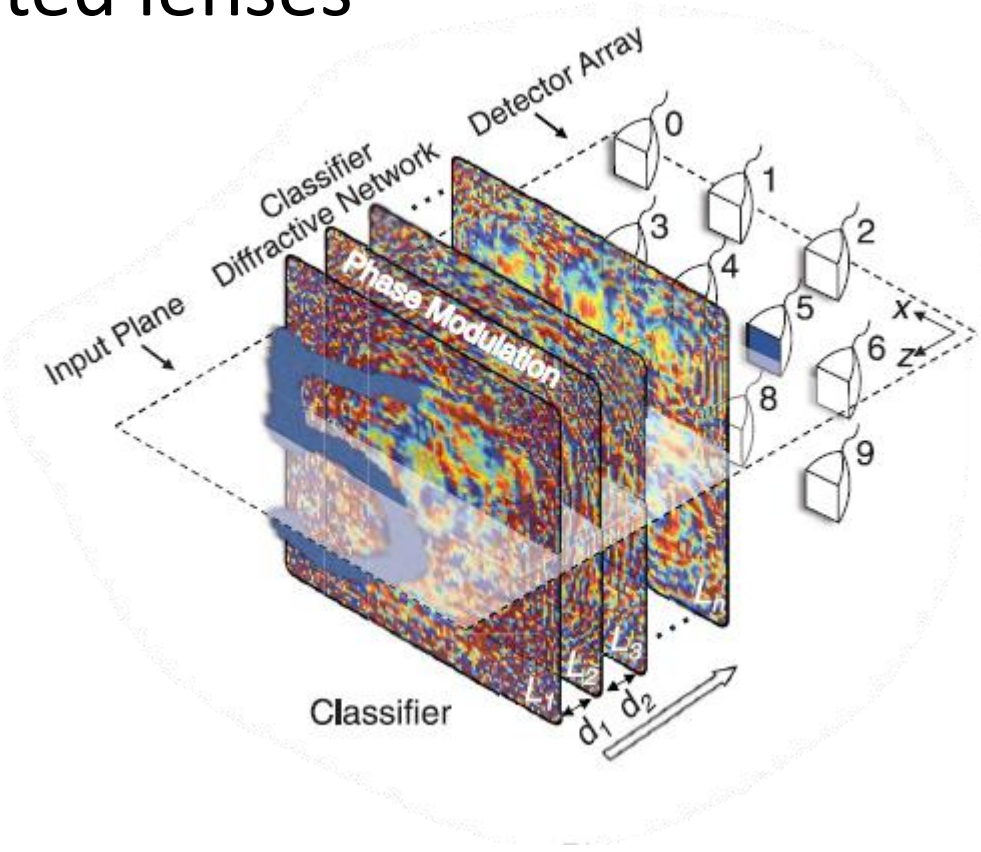
Optical Neural Networks

- Change phase and amplitude
- Printed lenses



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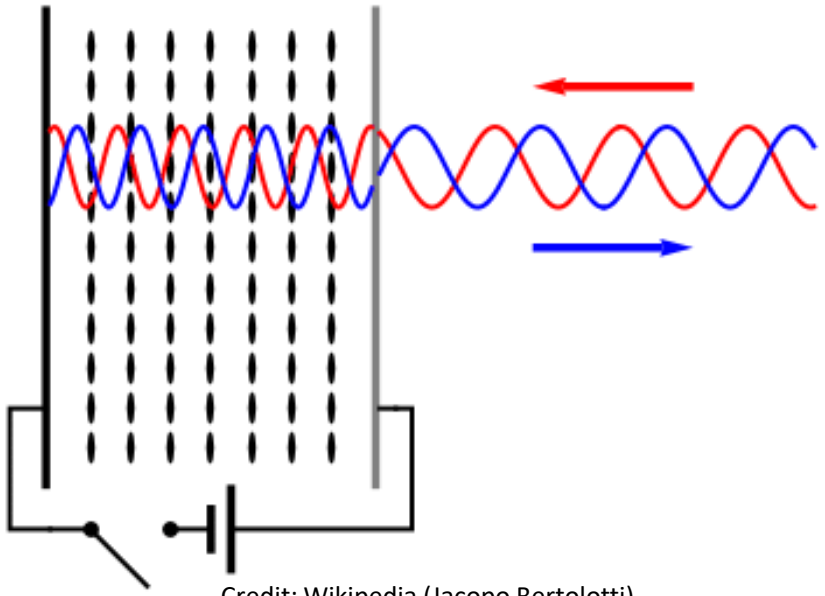
Spatial Light Modulator (SLM)

- More flexible, not statically printed
- Easy to adapt to different conditions



Credit: Wikipedia (Jacopo Bertolotti)

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Project

- Optical Neural Networks + SLM + AO
- Speed up our reconstructors:
  - CARMEN
  - ConvCARMEN
  - P4 / WOMBAT

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Optical vs Traditional

- Pros:
  - Powerful option for large neural networks
  - Really fast
- Cons:
  - Harder to test
  - Big networks require complex system

Summary

- Neural networks + Adaptive optics
- Optical Neural Networks + SLM + AO
- New networks ⇔ New challenges

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Thank you

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