Machine Learning 4 Quantum Technology, Erlangen, Germany, 07.11.2024

Towards an Artificial Muse for new Ideas in Science

Mario Krenn

Artificial Scientist Lab, Theory Division

@mariokrenn6240

http://mariokrenn.wordpress.com/

MAX PLANCK INSTITUTE FOR THE SCIENCE OF LIGHT

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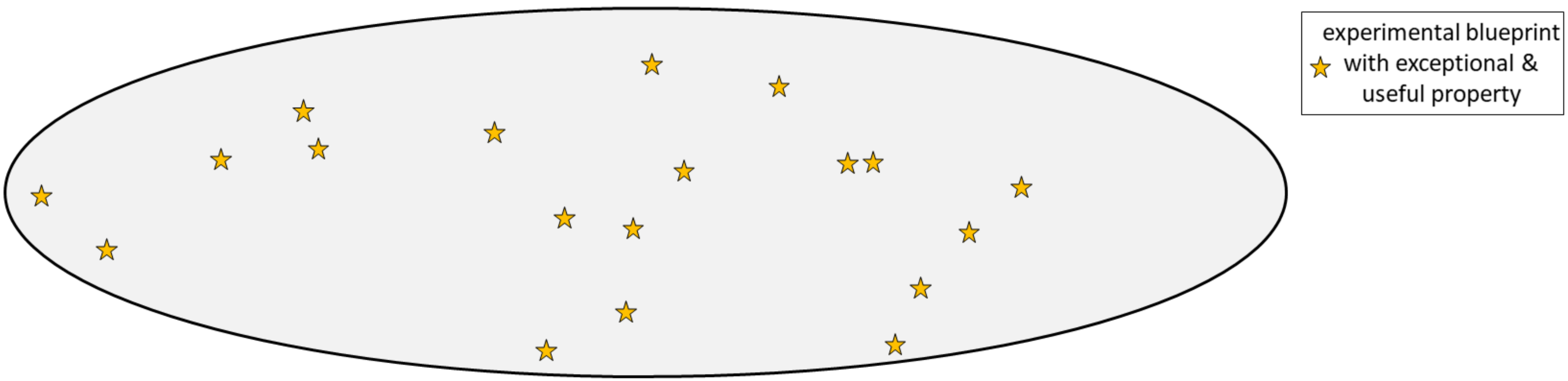
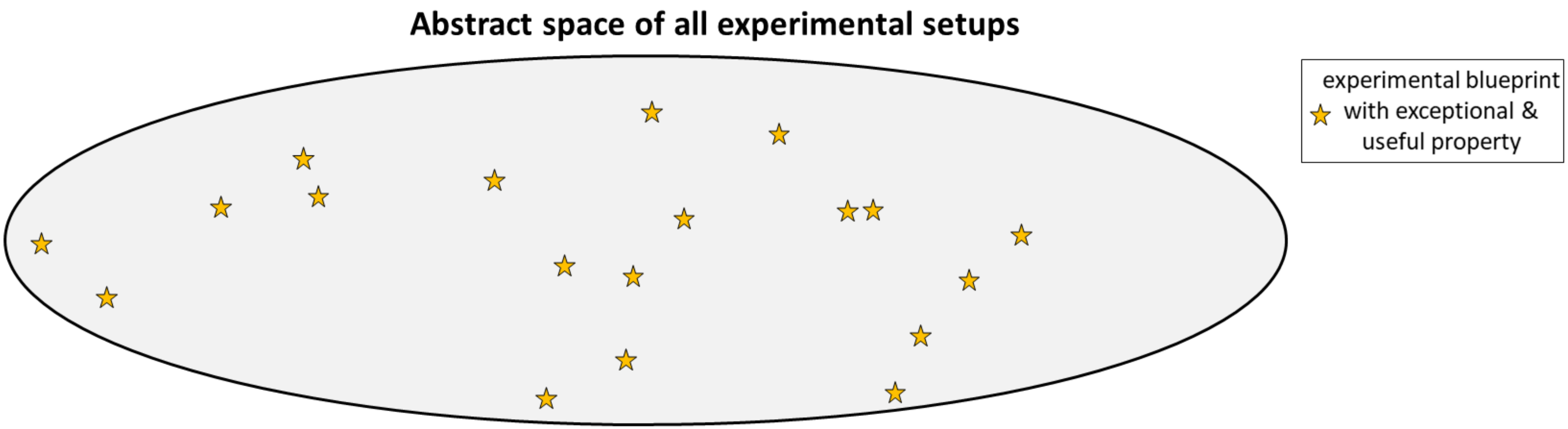
Abstract space of all experimental setups



Some examples:

3 lasers, 3 BS, 3 detectors: 1000 combinations

5 lasers, 5 BS, 5 detectors: 81,000 combinations (!)



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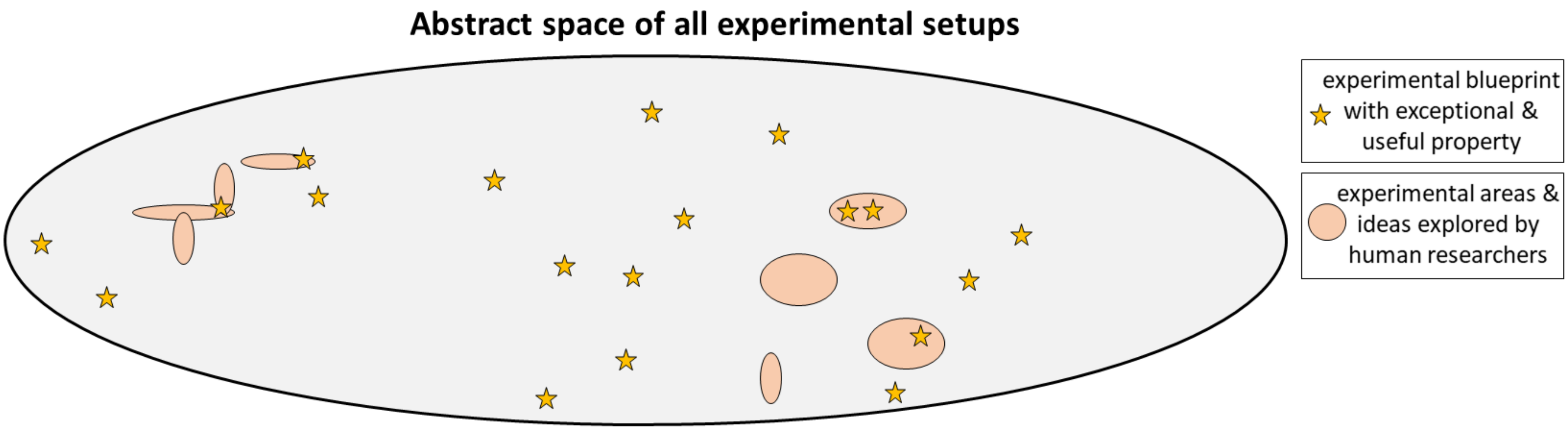

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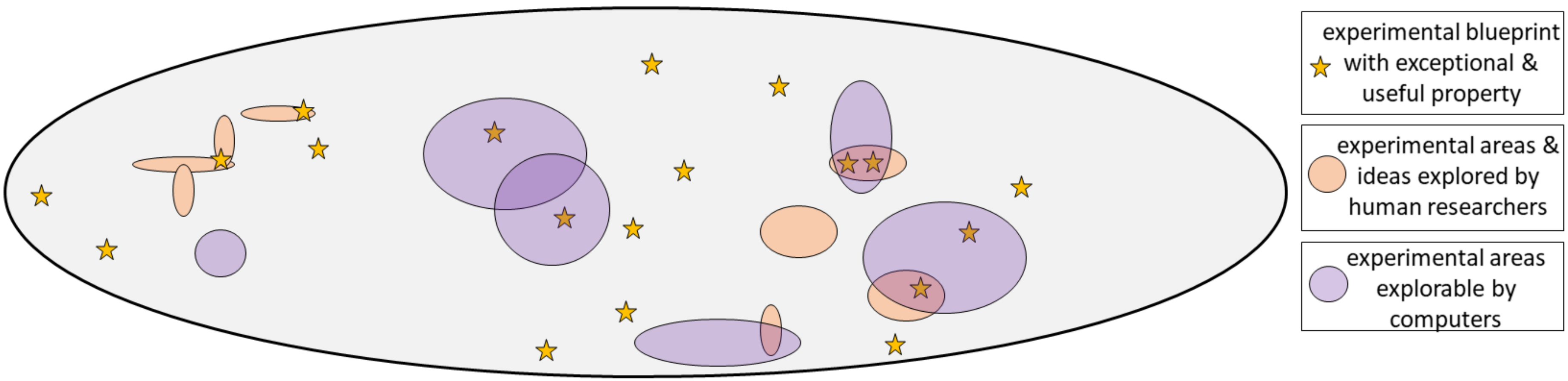

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How to design quantum experimental setups?

High-dimensional multipartite entanglement

$$|\psi\rangle_{GHZ-3D} = \frac{1}{\sqrt{3}}\left(|000\rangle + |111\rangle + |222\rangle\right)$$

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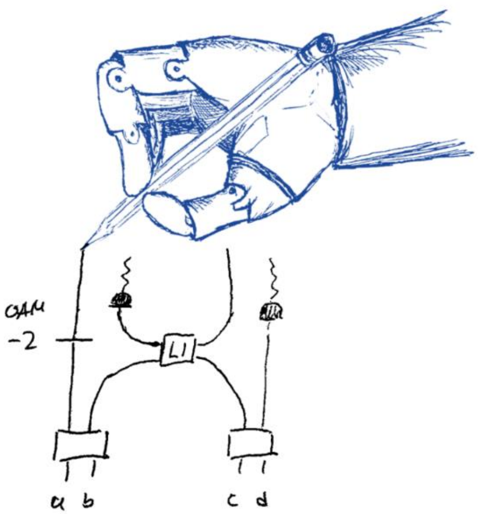

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How to design quantum experimental setups?

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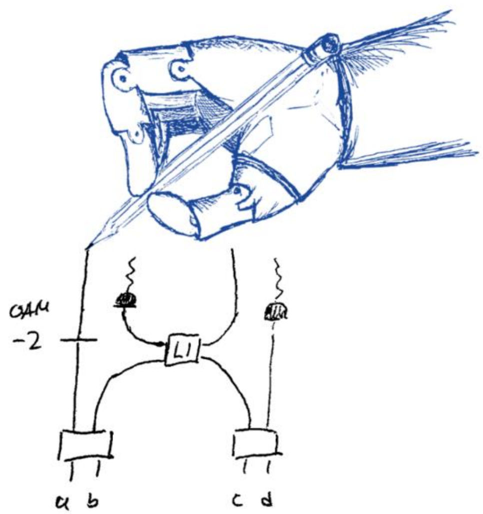
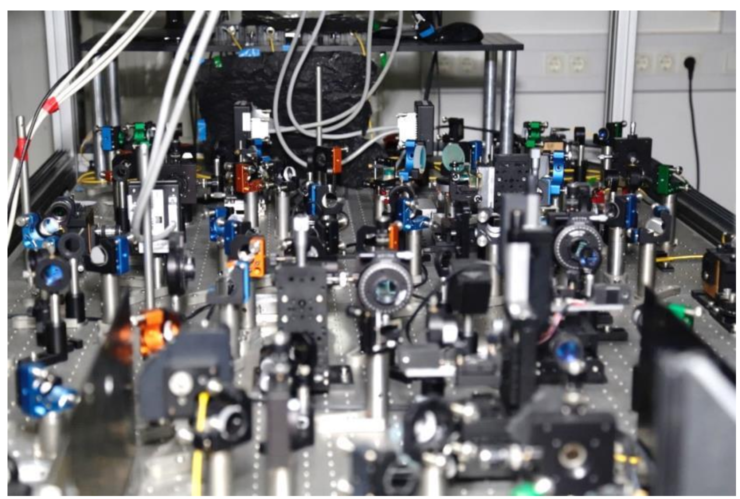


Erhard et al., *Nature Photonics* **12**, 759 (2018)



Krenn, Malik, Fickler, Lapkiewicz, Zeilinger, Automated Search for new Quantum Experiments*, Phys. Rev. Lett.* **116**, 090405 (2016)
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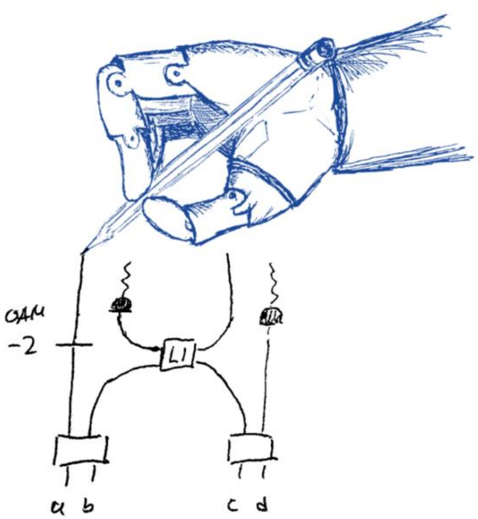

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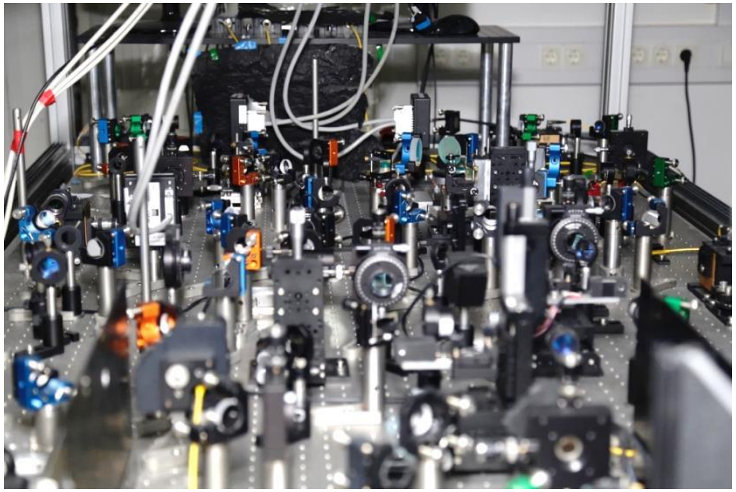

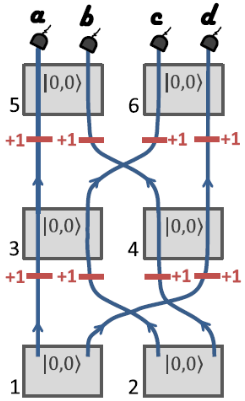

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Computer-inspired ideas and concepts

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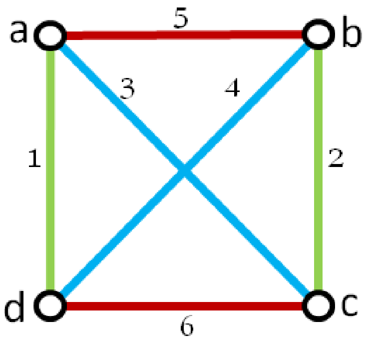
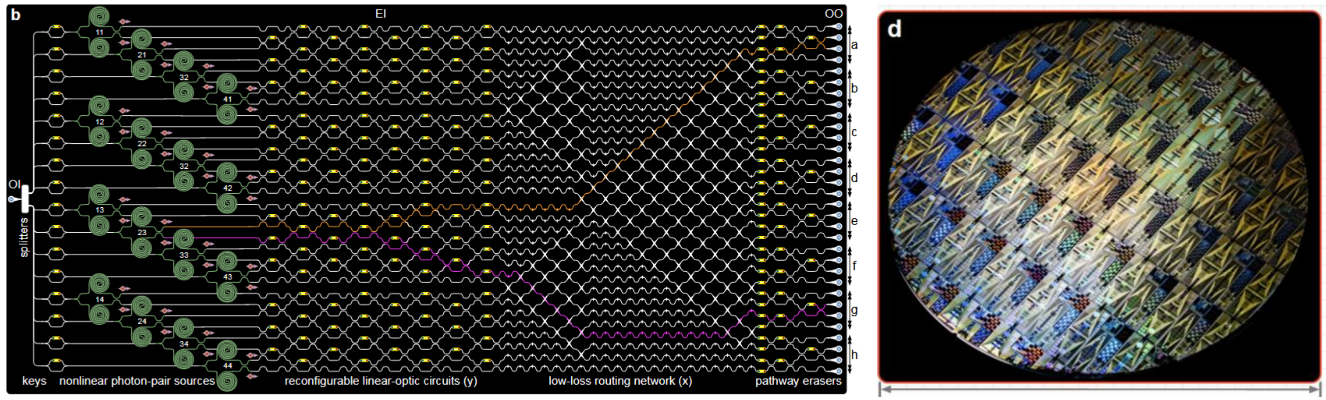
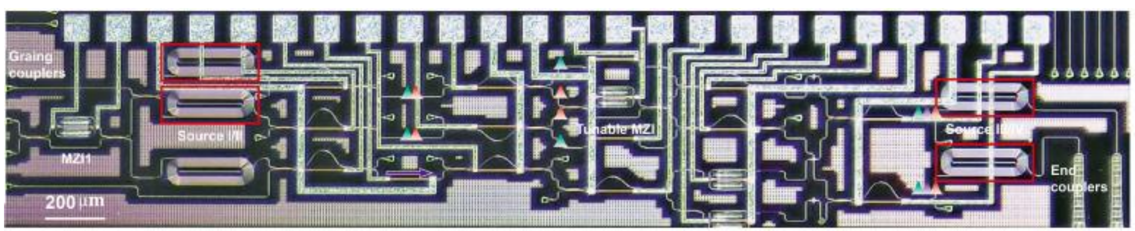


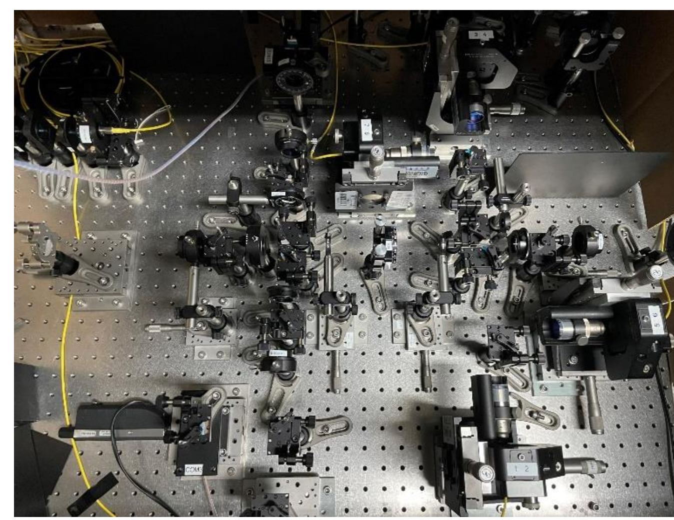
Gu, Erhard, Zeilinger, MK, *PNAS* **116** (2019).

Bao et al., Very-large-scale integrated quantum graph photonics, *Nature Photonics*, **17**, 573 (2023) .





Feng, et al., *On-Chip nonlocal quantum interference between the origins of a four-photon state, Optica* (2023).



Qian et al., *Multiphoton non-local quantum interference controlled by an undetected photon, Nature Communications* **14** (1), 1480 (2023)

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Highly efficient computer-designed quantum experiments

MK, Kottmann, Tischler, Aspuru-Guzik, Conceptual understanding through efficient inverse-design of quantum experiments, *Phys. Rev. X* **11**, 031044 (2021).

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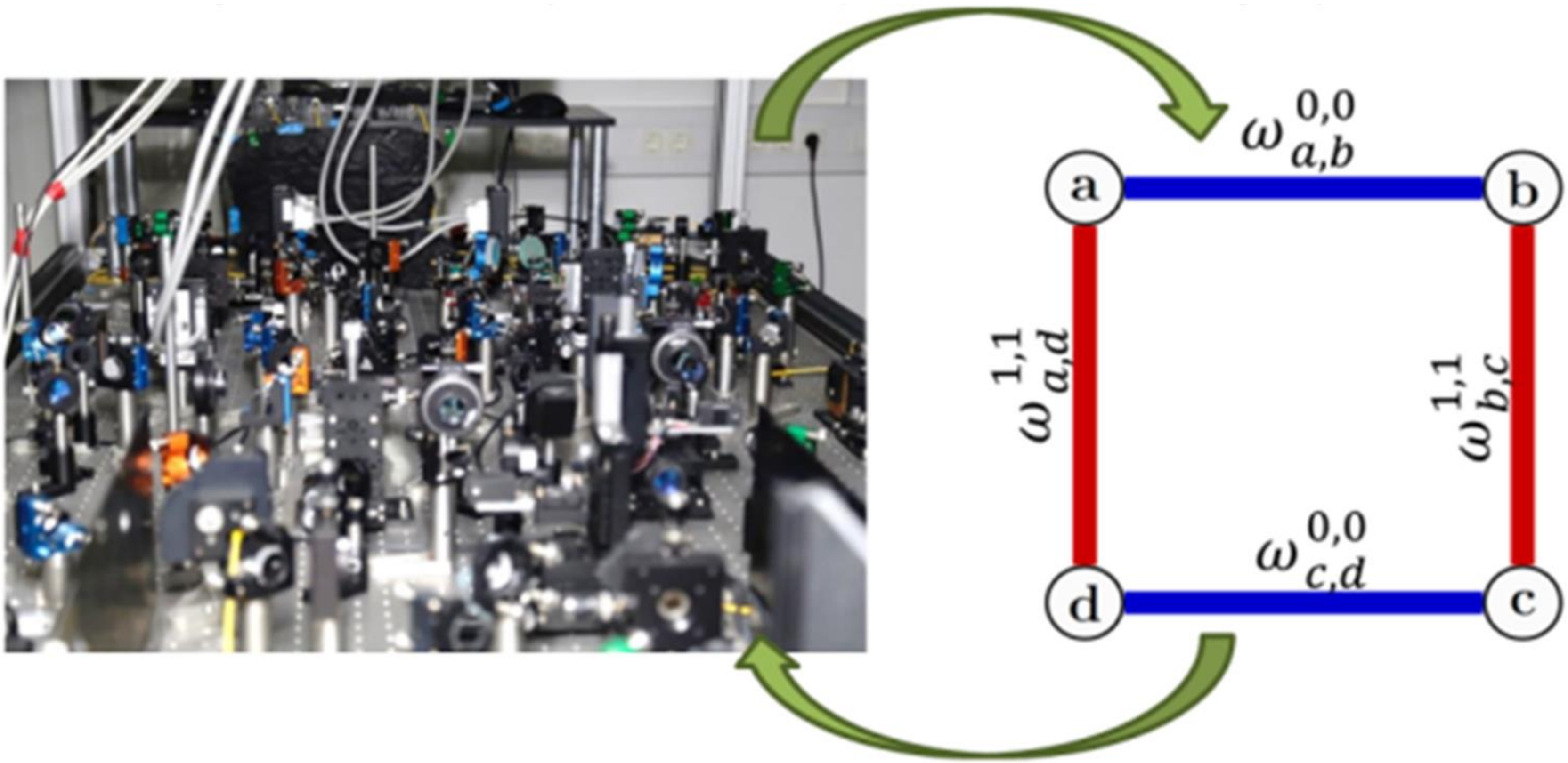
Change Perspective:

New representation -> orders of magnitude speed-up.



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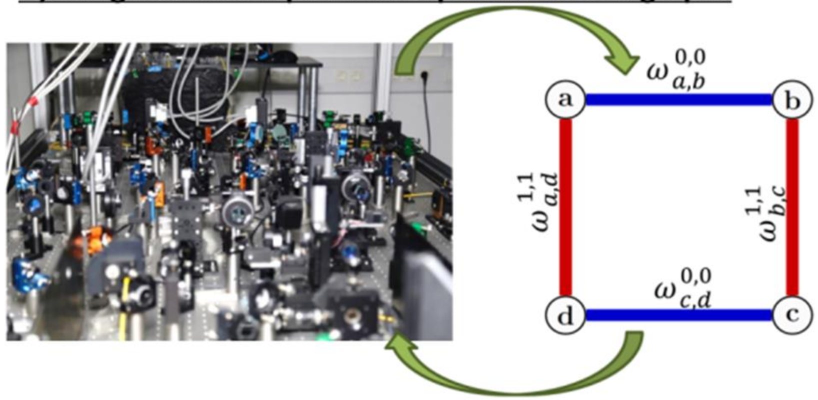
Change Perspective:

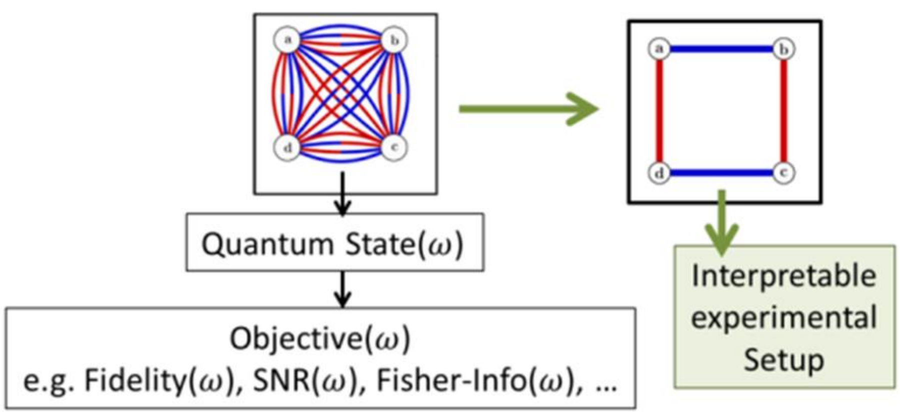
New representation -> orders of magnitude speed-up.

Vertex: Photonic path
Edge: Photon pair
Edge weight: amplitude
Color: Photonic Mode

A) Bridge between quantum experiments and graphs



B) Gradient-based optimization + discrete topological optimization



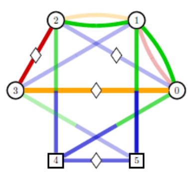
Highly efficient computer-designed quantum experiments

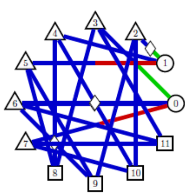
Quantum
the open journal for quantum science

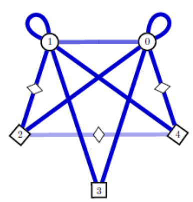
Digital Discovery of 100 diverse Quantum Experiments with PyTheus

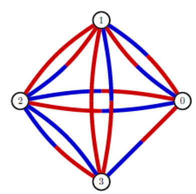
Carlos Ruiz-Gonzalez[§1], Sören Arlt[§1], Jan Petermann[1], Sharareh Sayyad[1], Tareq Jaouni[2], Ebrahim Karimi[1,2], Nora Tischler[3], Xuemei Gu[1], and Mario Krenn[1]

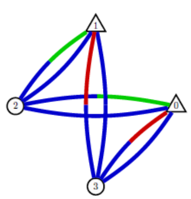
Quantum 7, 1204 (2023).

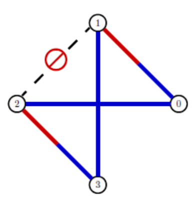

(a) Four-dimensional four-photon GHZ state (overcoming the 3-dimensional barrier for multiphoton entanglement)

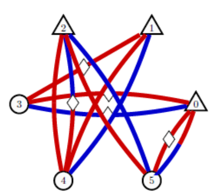

(b) Heralded 3D Bell state with single photons (improves state-of-the-art design by requiring less ancilla photons)

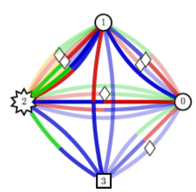

(c) Two-mode five-photon N00N state $|50\rangle + |05\rangle$ (very symmetric shape with an inscribed pentagram)


(d) A 4-qubit entangled states with unit coefficients, which requires complex-valued weights for generation


(e) Quantum measurement for a quantum communication task with quantum advantage (Mean King's Problem)


(f) Entanglement swapping without using two Bell states


(g) Toffoli quantum gate without ancilla photons


(h) Mixed state with bound entanglement that can violate a Bell inequality (counterexample to the Peres conjecture from 1999, solved 2014)

github.com/artificial-scientist-lab/PyTheus

`pip install pytheusQ`

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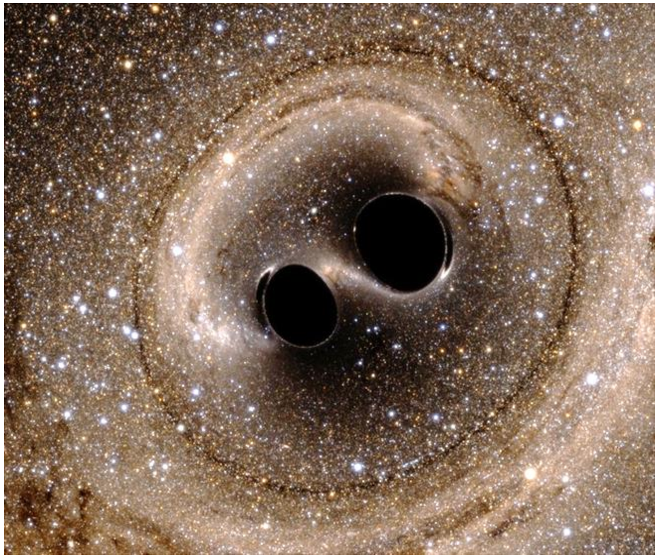
AI-driven design of new Gravitational Wave Detectors

with Yehonathan Drori, Rana X. Adhikari (Caltech, LIGO): arXiv:2312.04258



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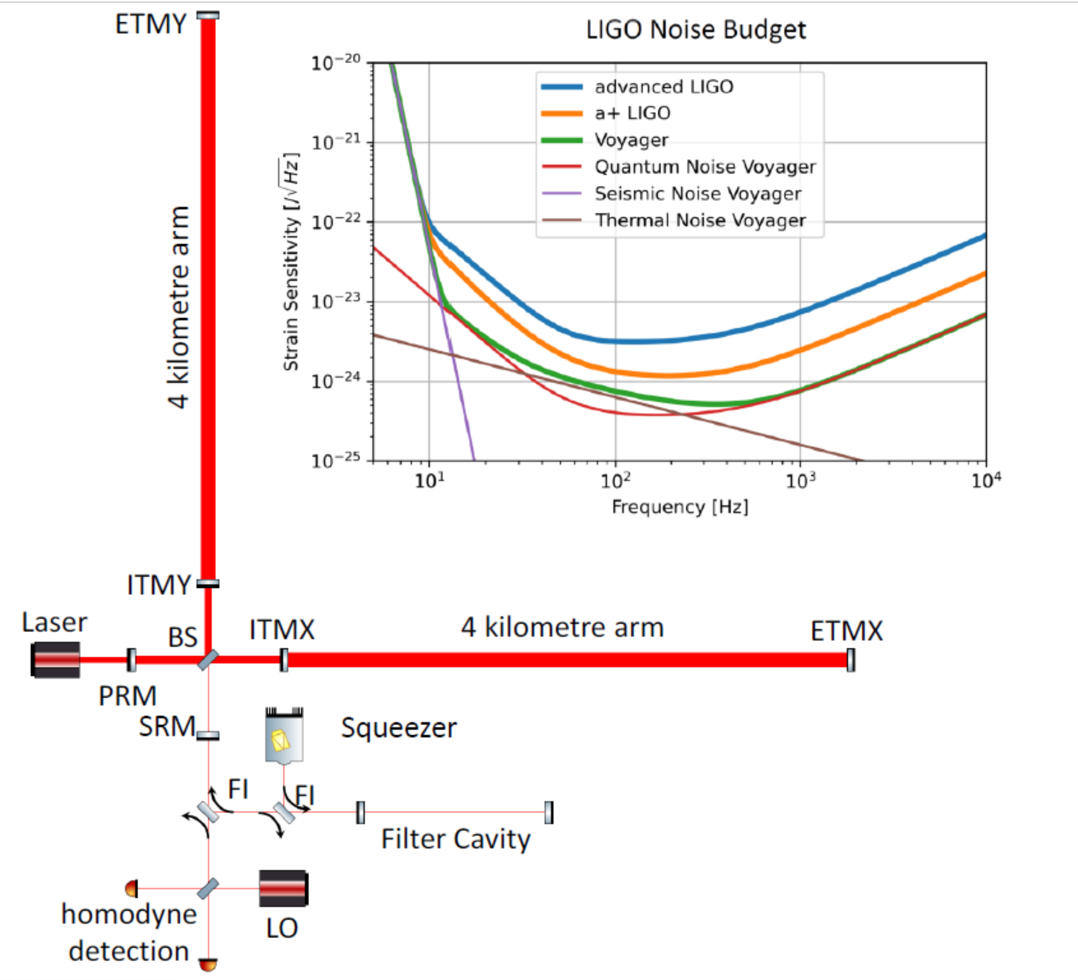
LIGO's next Generation Detector Update: Voyager



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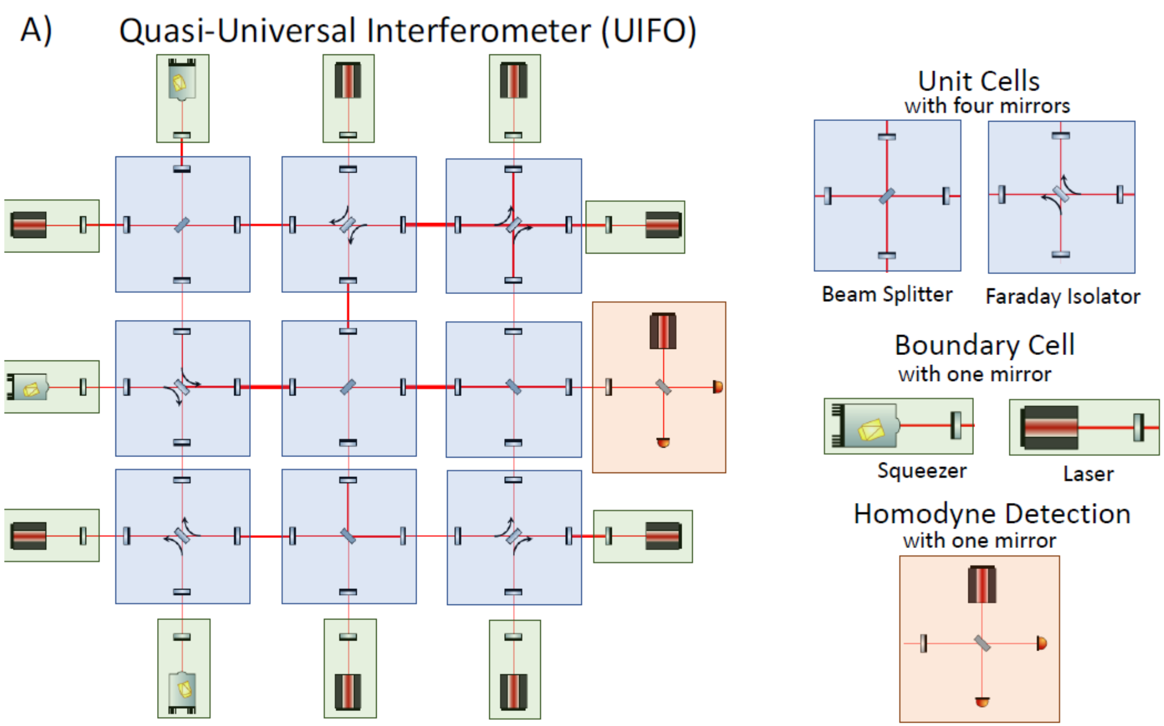

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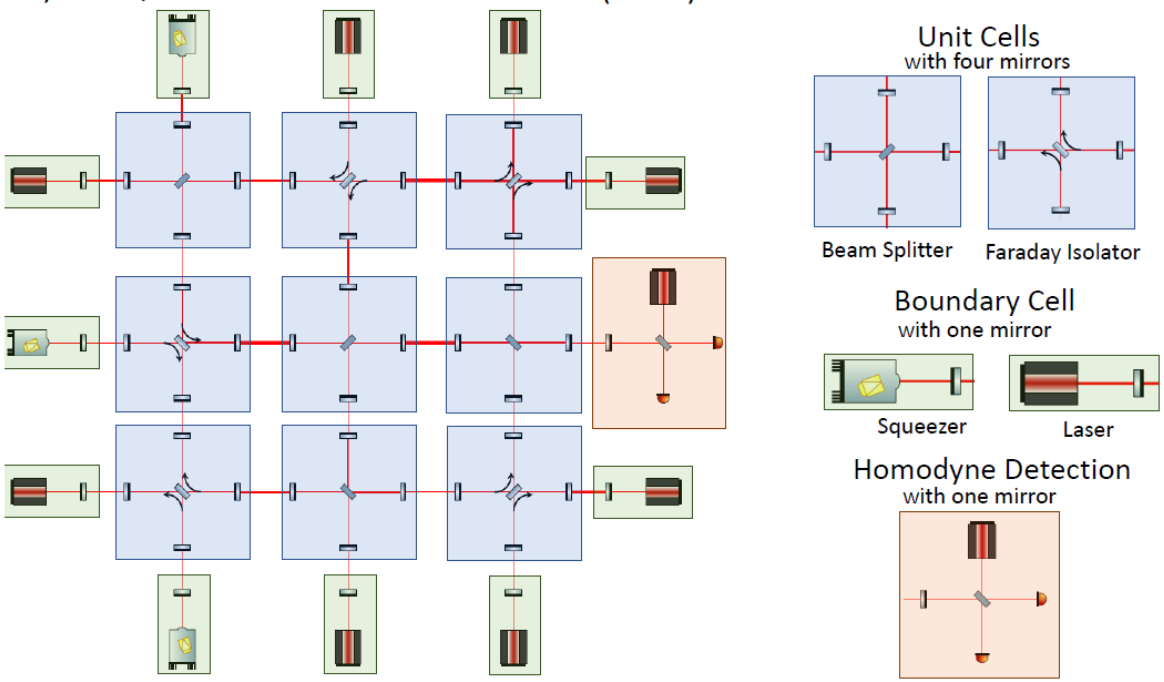
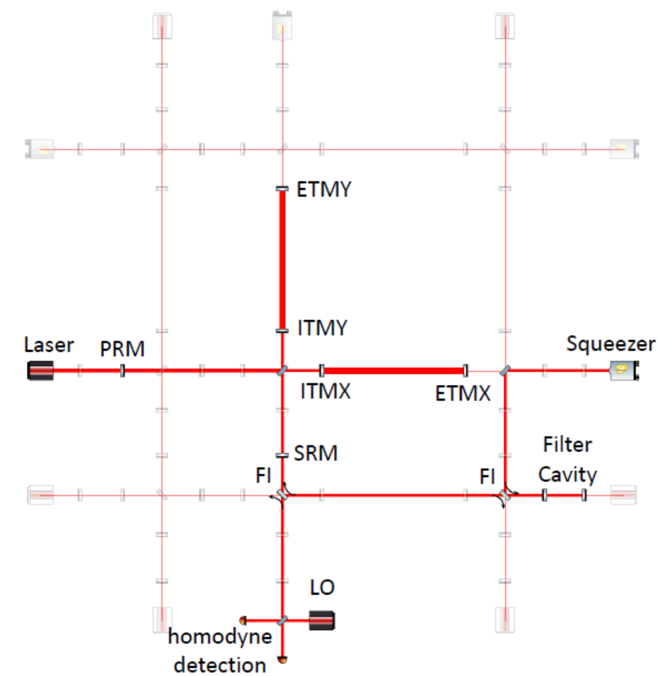
A) Quasi-Universal Interferometer (UIFO)



B) LIGO Voyager in UIFO



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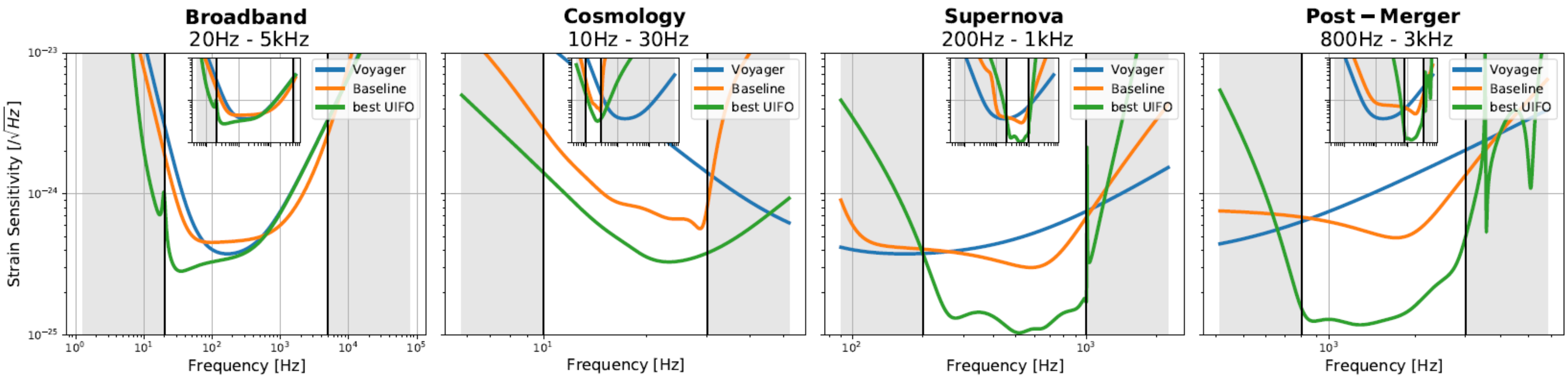

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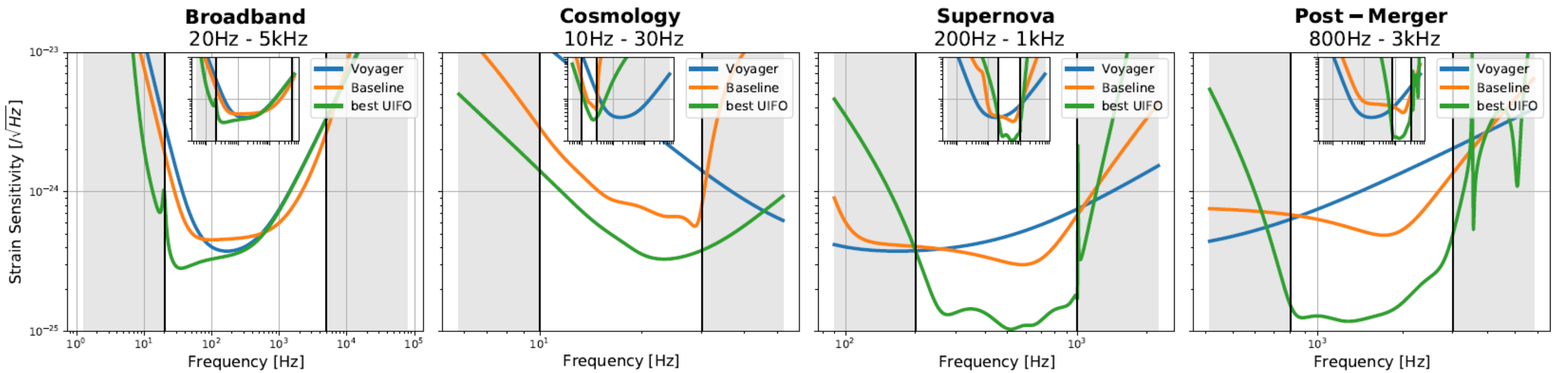
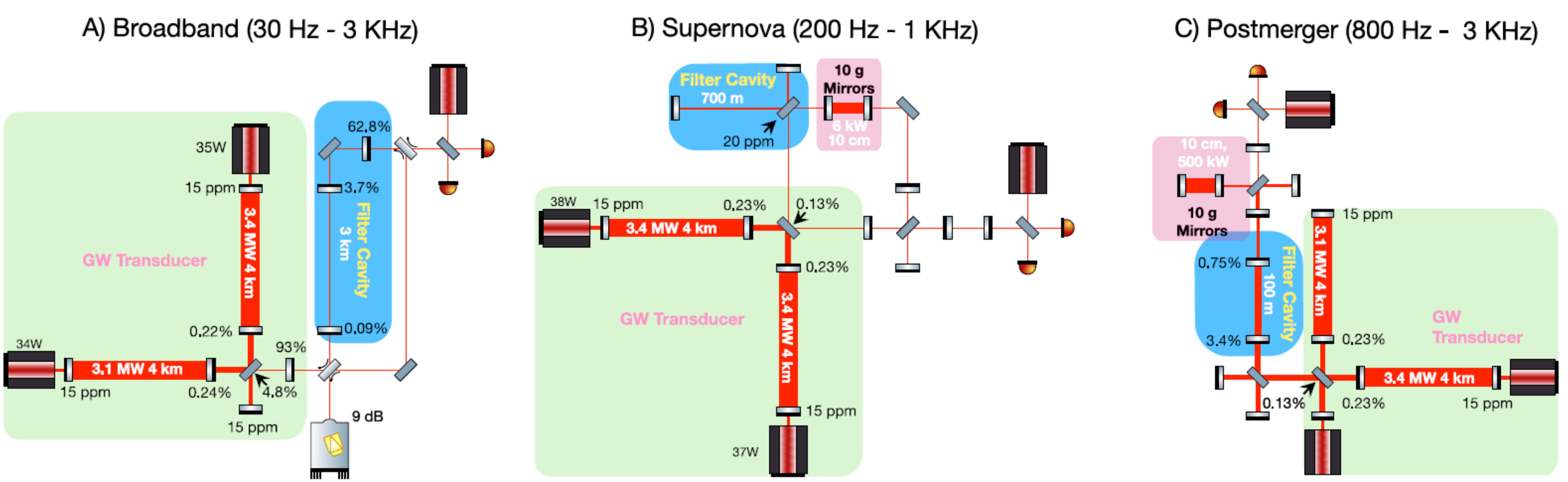
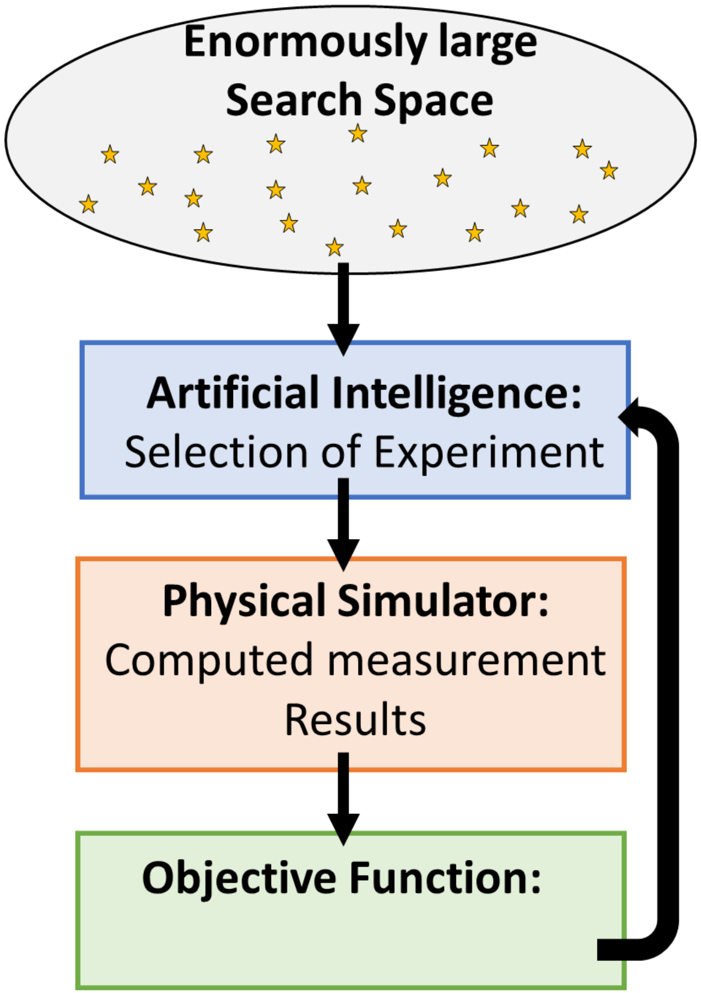




XLuminA: An Auto-differentiating Discovery Framework for Super-Resolution Microscopy

Carla Rodríguez, Sören Arlt, Leonhard Möckl, Mario Krenn - **arXiv:2310.08408 (in press: Nature Comm.)**

github.com/artificial-scientist-lab/XLuminA/



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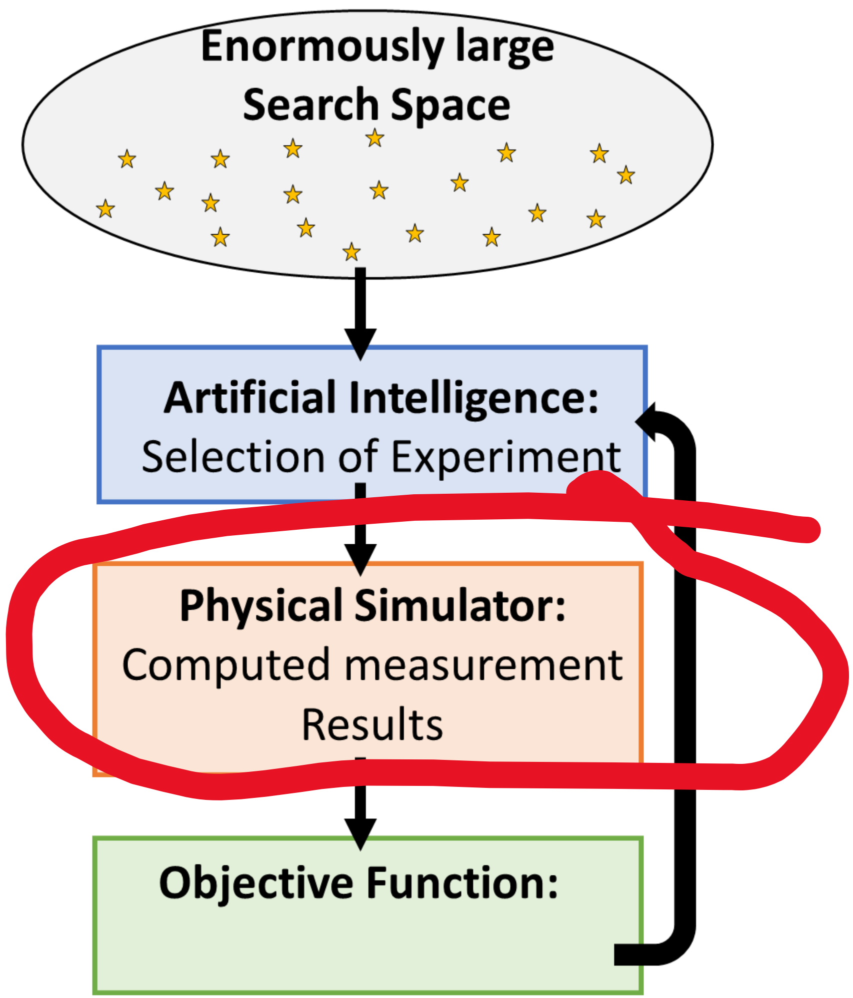

Simulator:
- Reliable
- Fast
- General

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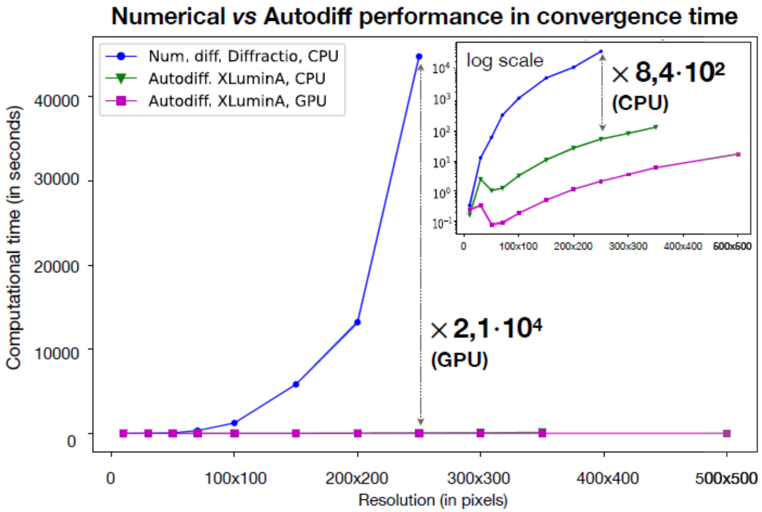
	CPU			
	RS	CZT	VRS	VCZT
Diffractio	4.14	1.91	12.33	6.17
Our approach	**2.39**	**1.39**	**5.22**	**4.04**
	GPU			
	RS	CZT	VRS	VCZT
Diffractio	/	/	/	/
Our approach	**0.006**	**0.027**	**0.151**	**0.075**



Towards an artificial Muse:
An artificial Source of Inspiration for Science

nature reviews physics

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On scientific understanding with artificial intelligence

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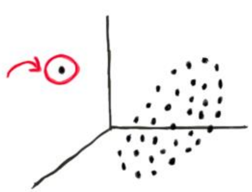
Anomaly Detection



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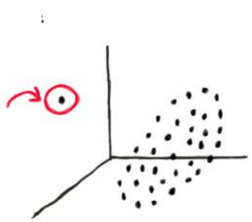
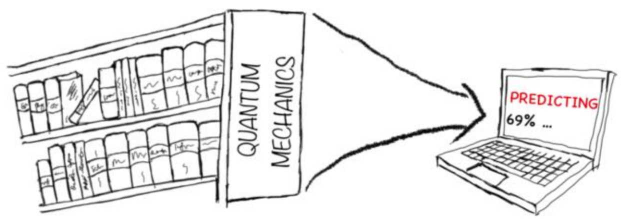
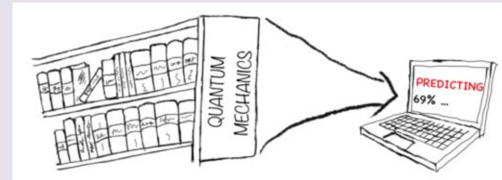


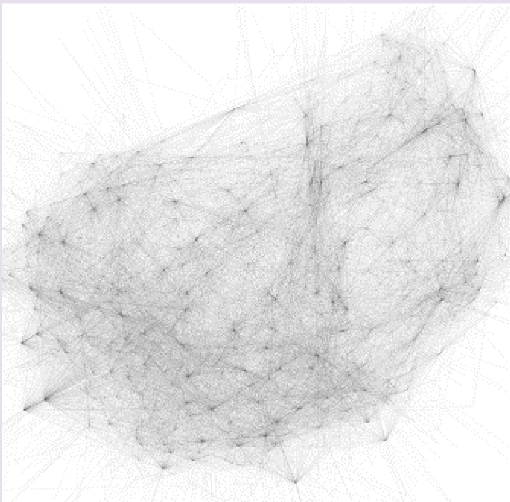
From Large Collection Of Literature



Class II: Re-Source of Inspiration

From Large Collection Of Literature





Semantic Network of QM from 750k papers

Vertices: Concepts
Edges: Co-Occurance

Krenn, Zeilinger, *PNAS* **117**, 1910 (2020)
Krenn et al., *Nat. Mach. Intell.* (2023)

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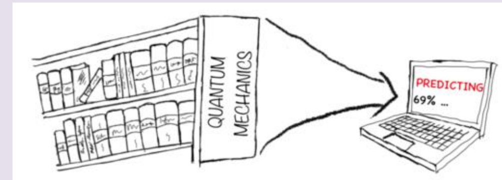

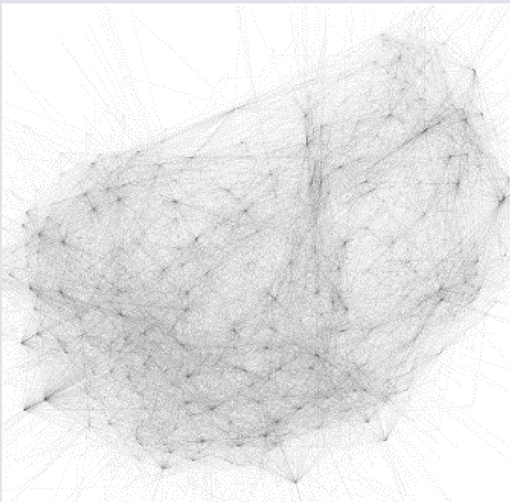

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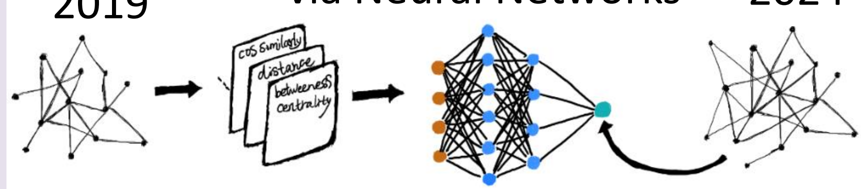
Link Prediction via Neural Networks



Then: From 2024 to 2029!

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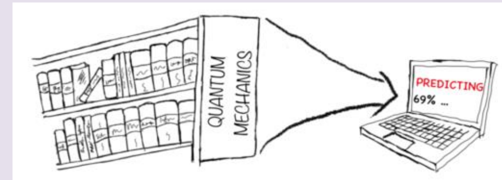

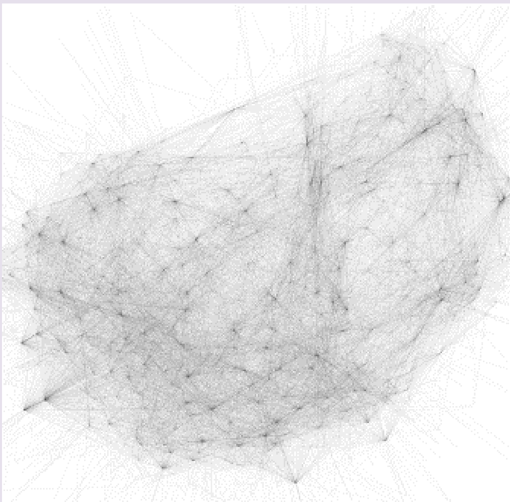

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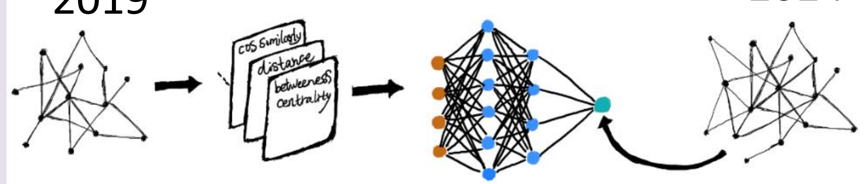
Edges: Co-Occurance

Link Prediction



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Gu, Krenn, arXiv:2402.08640: **Impact4Cast**

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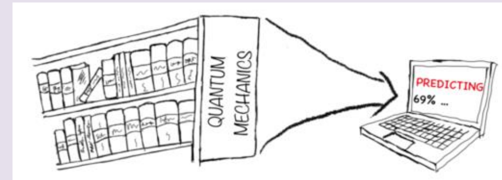

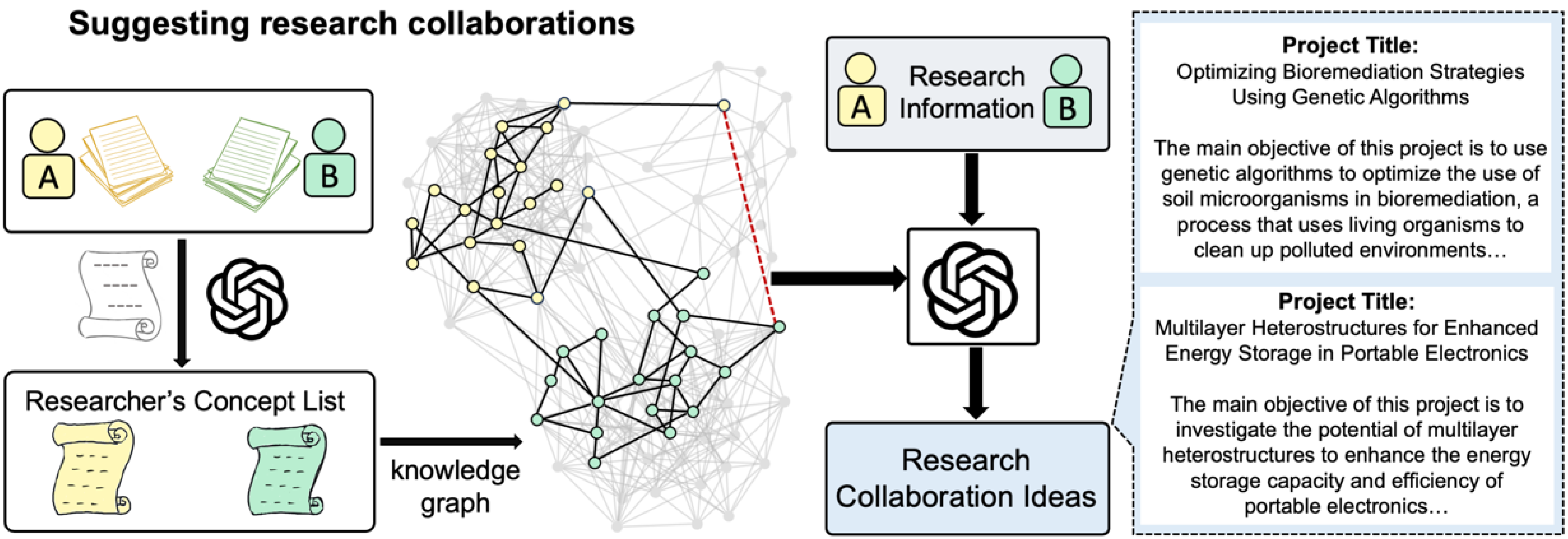

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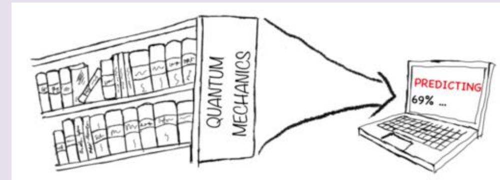

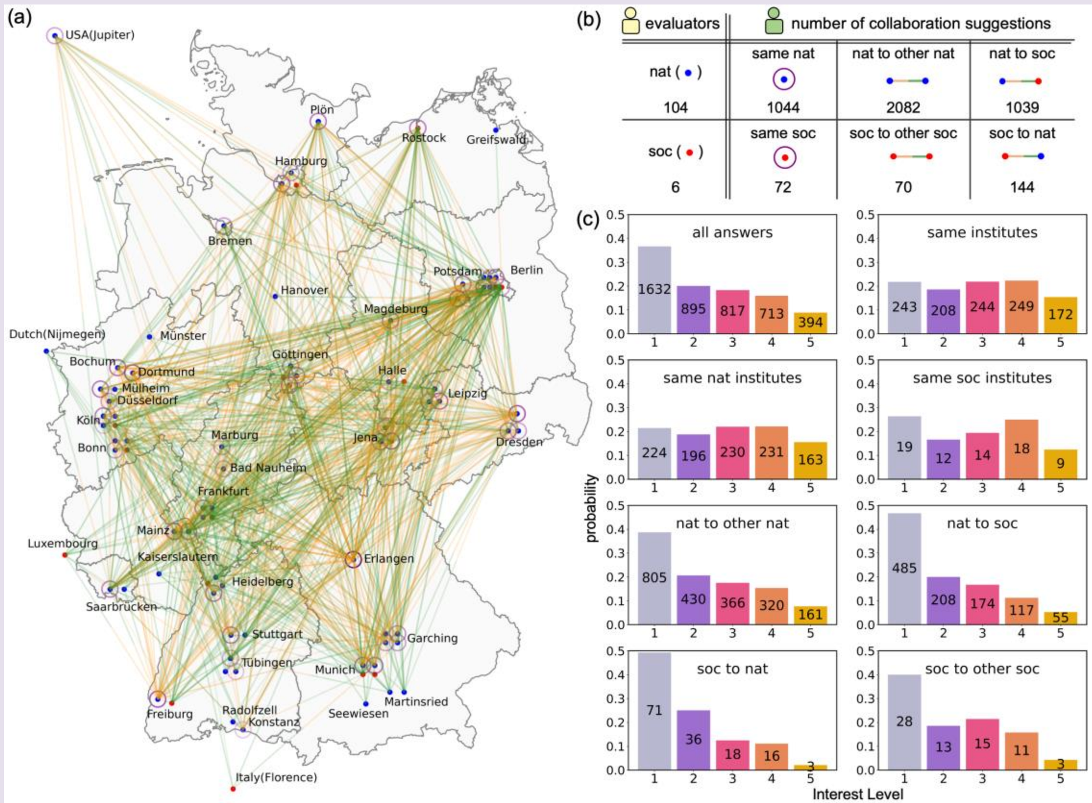

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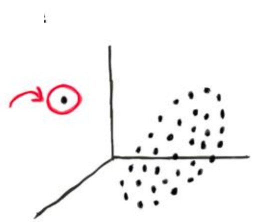

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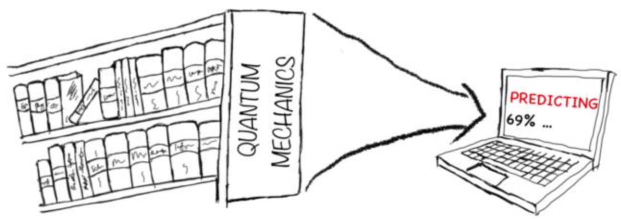

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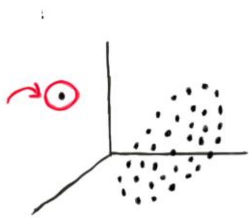

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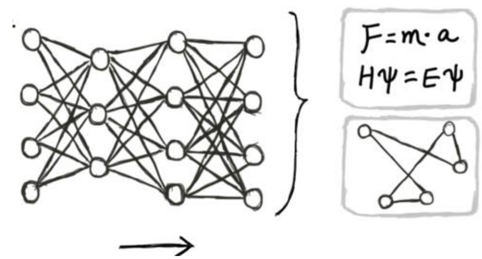
Interpretable Results



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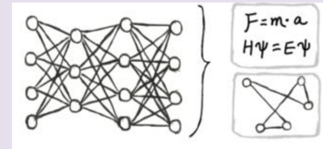

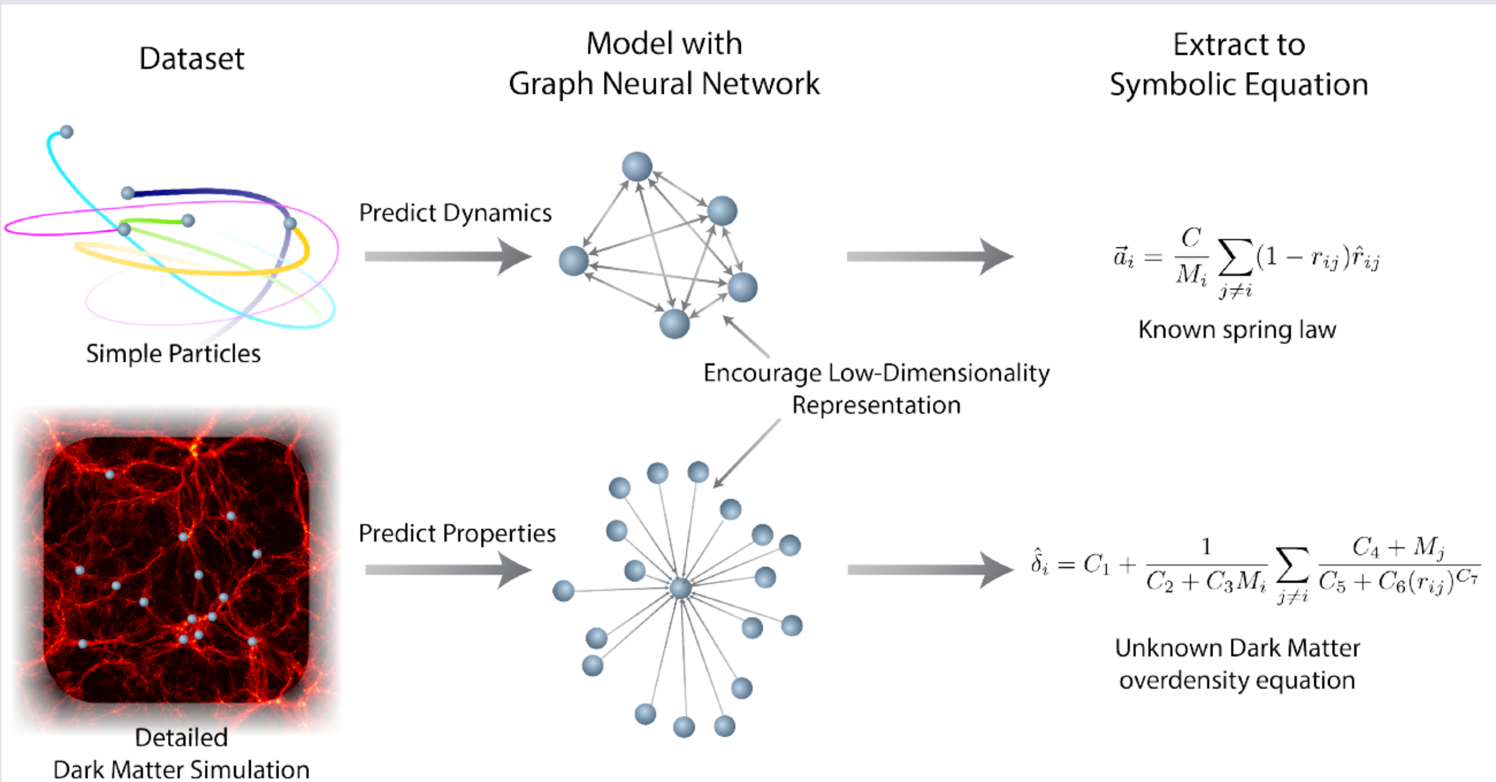

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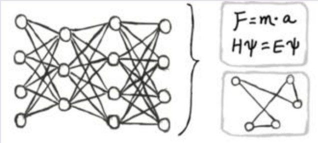

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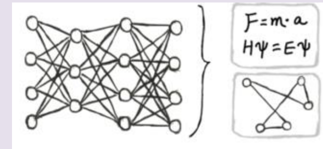

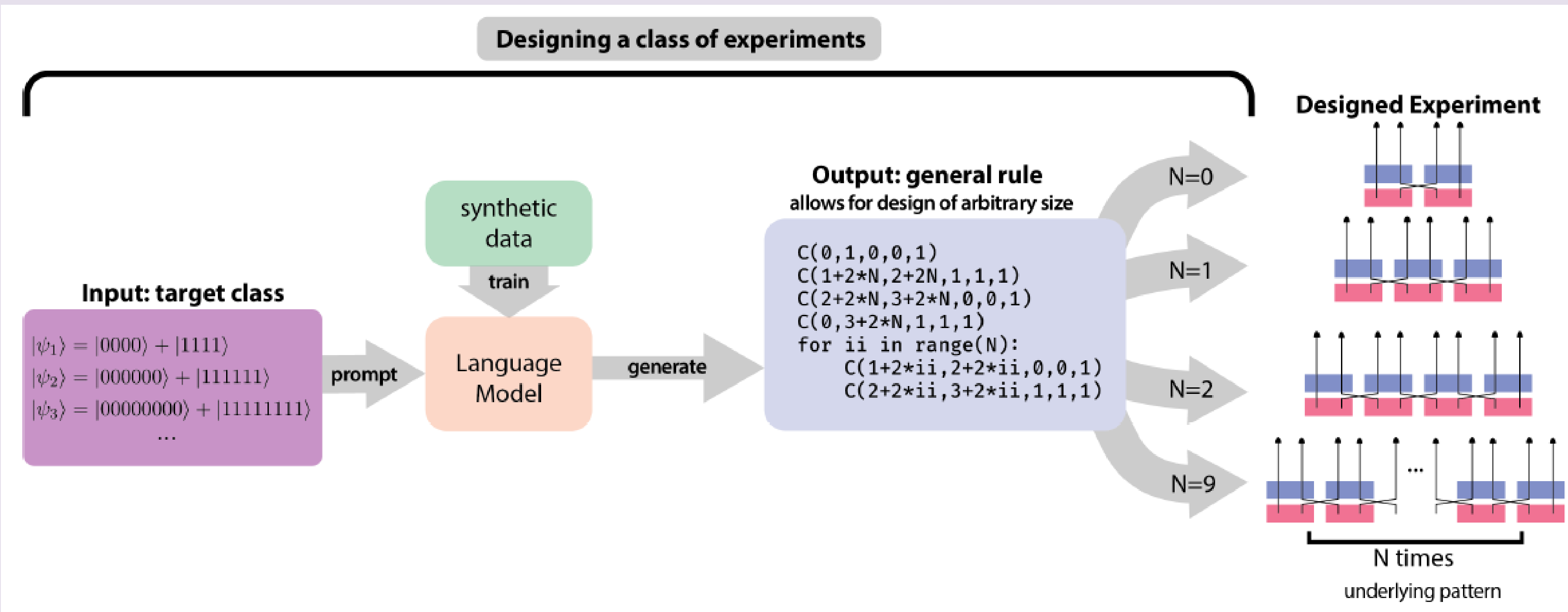

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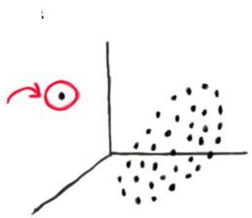

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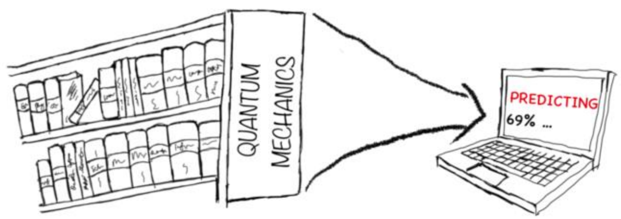

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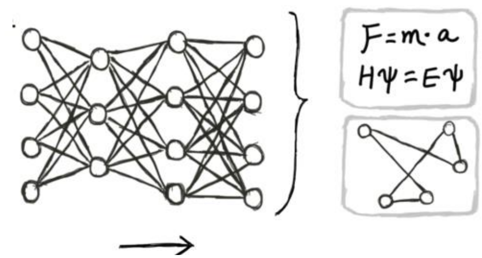
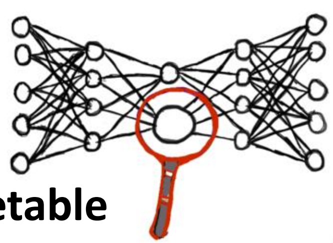
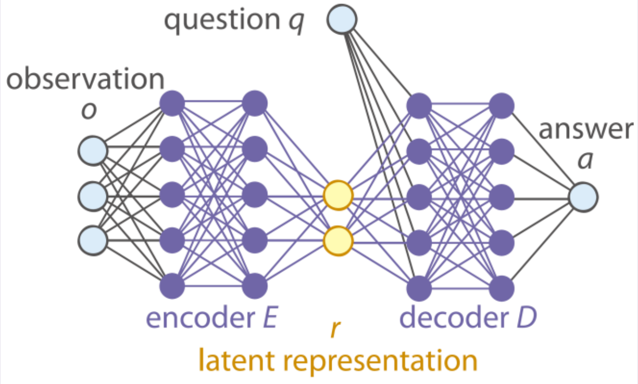


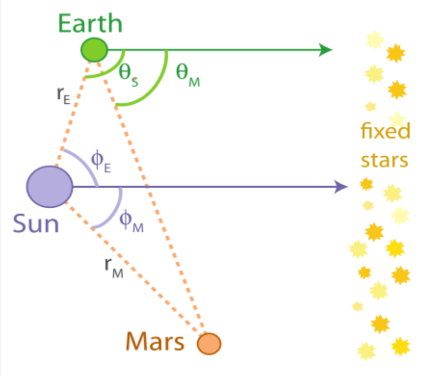


Interpretable internal states

Interpretable internal states

Interpreting Latent Space





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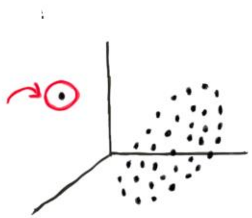

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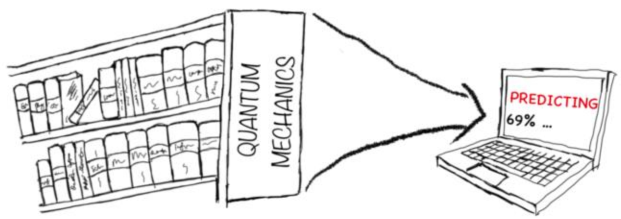

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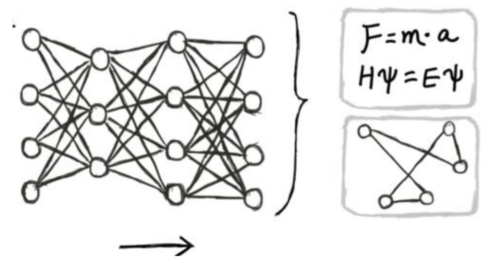

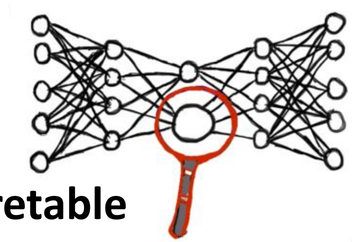

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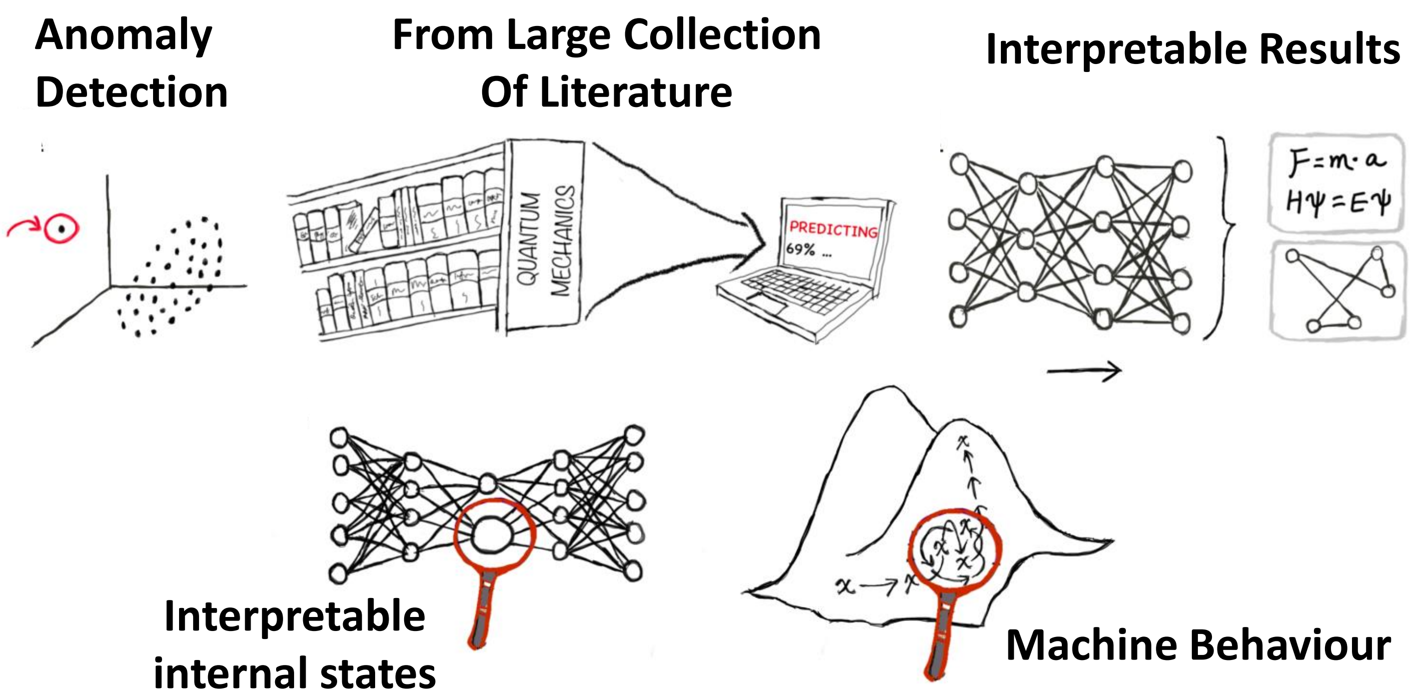

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Conclusion

AI-based Quantum Hardware & Experiment Design:

In many domains in physics (*quantum optics, gravitational wave physics, microscopes/telescopes soon*), we have now algorithms for

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The solutions are presented such that

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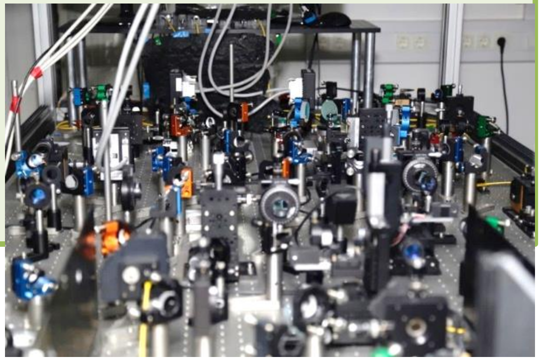

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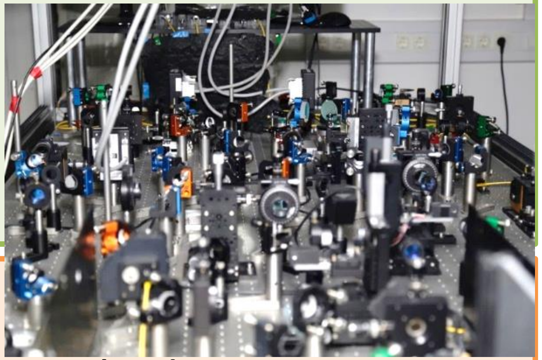

Automated Idea Generation:

Towards personalized, new, high-impact, interesting research idea generation

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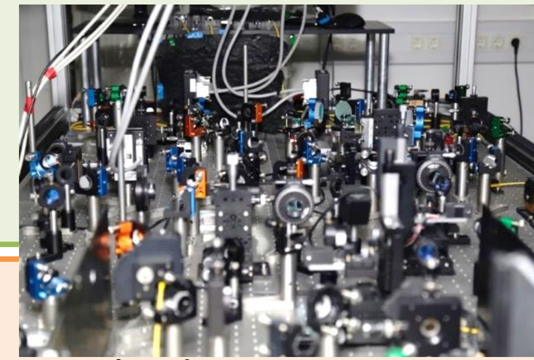

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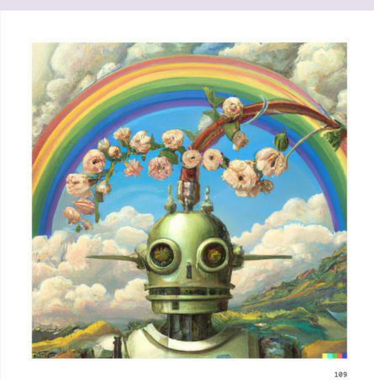
Artificial Scientists

Creativity?



Curiosity?

(a) learn to explore on Level-1 (b) explore faster on Level-2

Understanding?

MK et al., On scientific understanding with artificial intelligence, Nat.Rev.Phys (2022)

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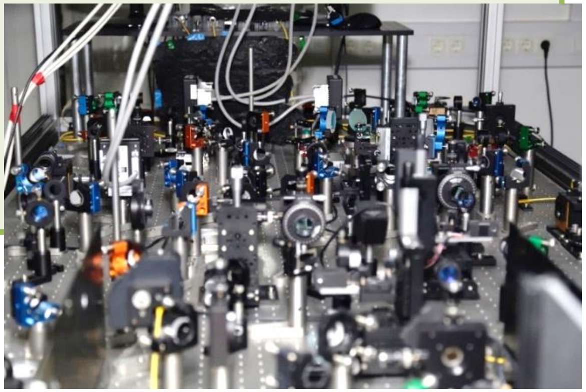

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