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Silicon photonics with T centre spin-photon devices

Daniel Higginbottom

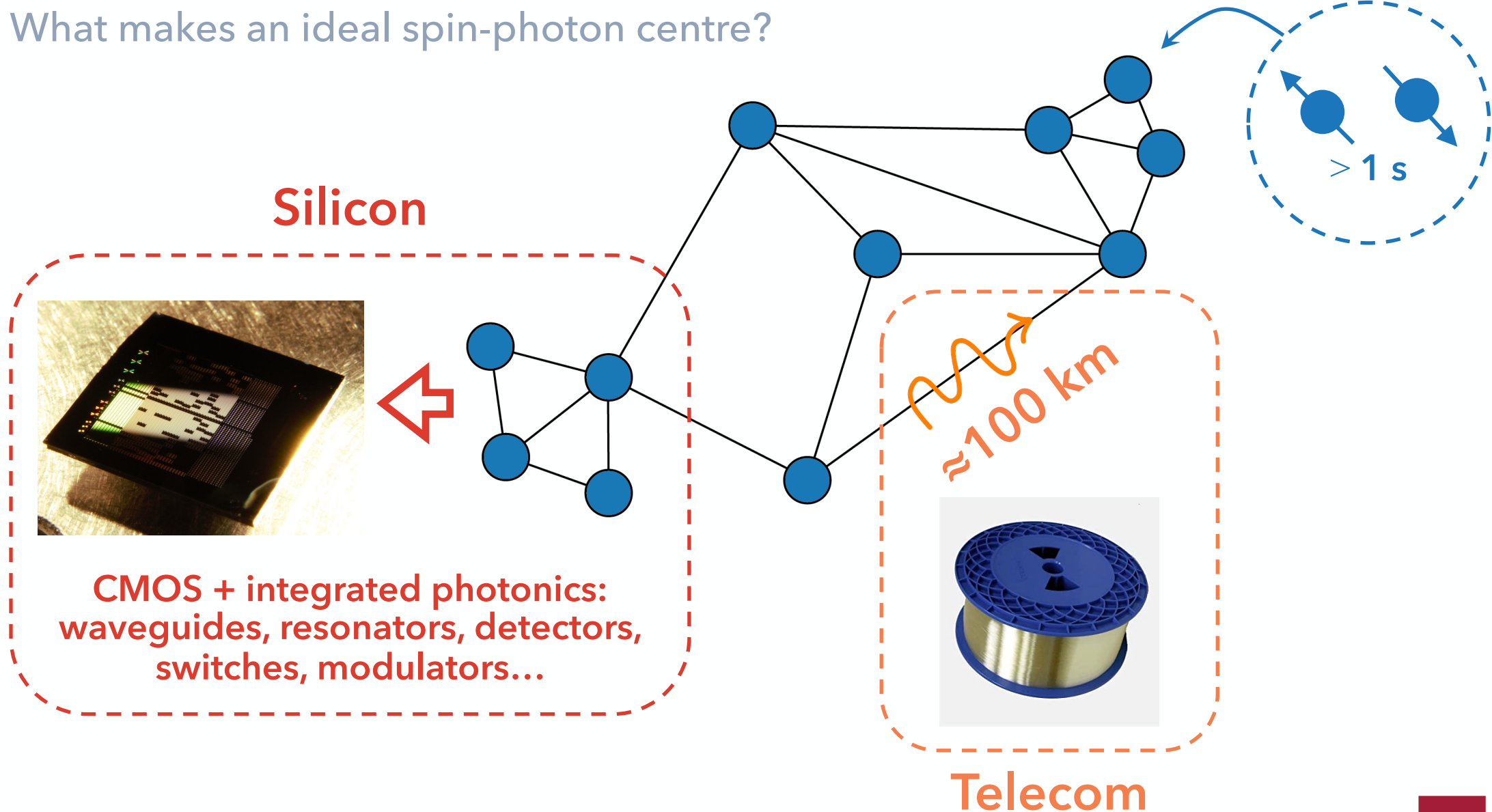
Silicon Quantum Technology, Simon Fraser University

ANZCOP/AIP Congress 2022, Adelaide

13th December 2022

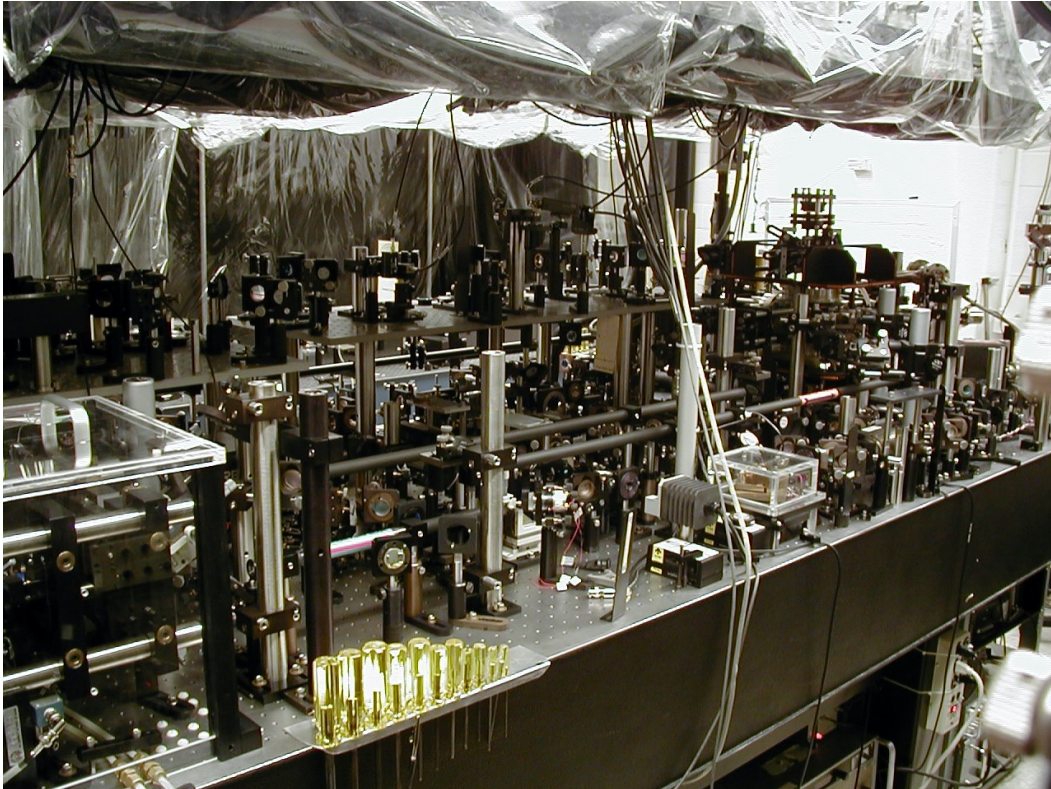
Quantum networks

What makes an ideal spin-photon centre?

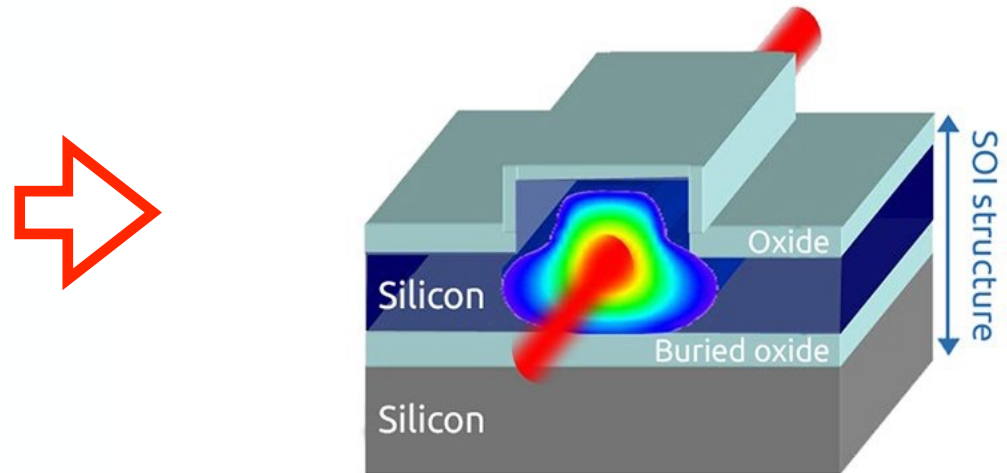


Integrated silicon photonics

An optical table on a chip

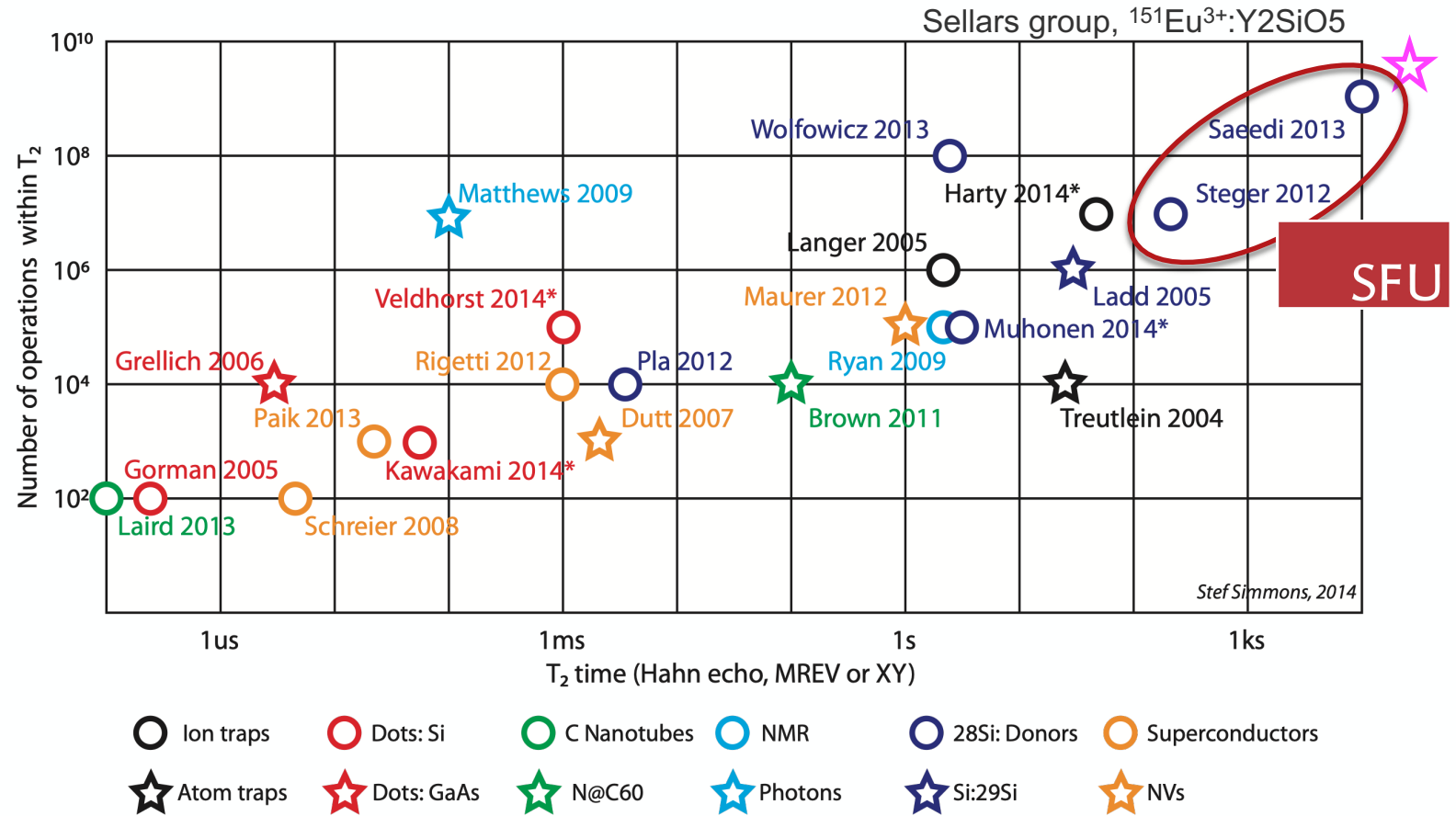
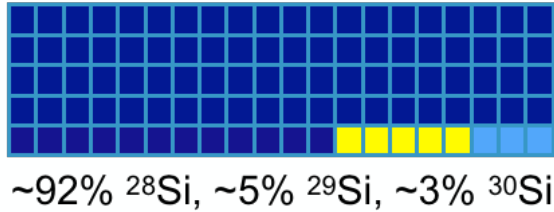


SOI enables optical component manufacturing silicon



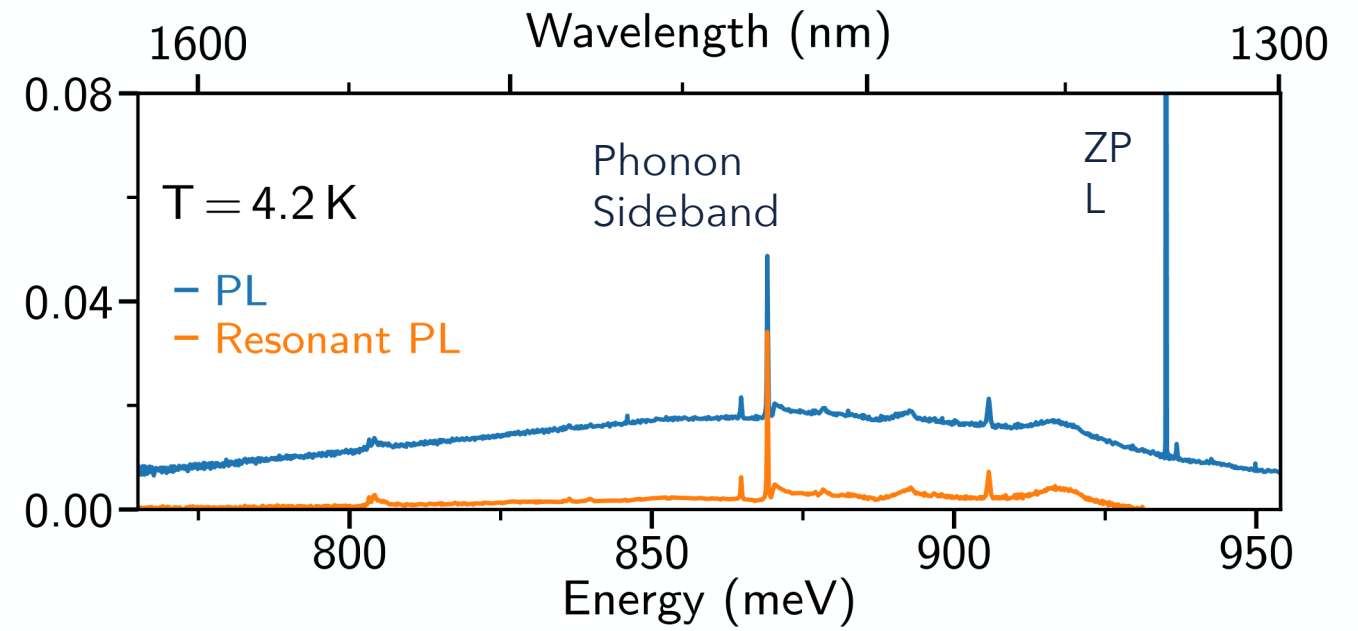
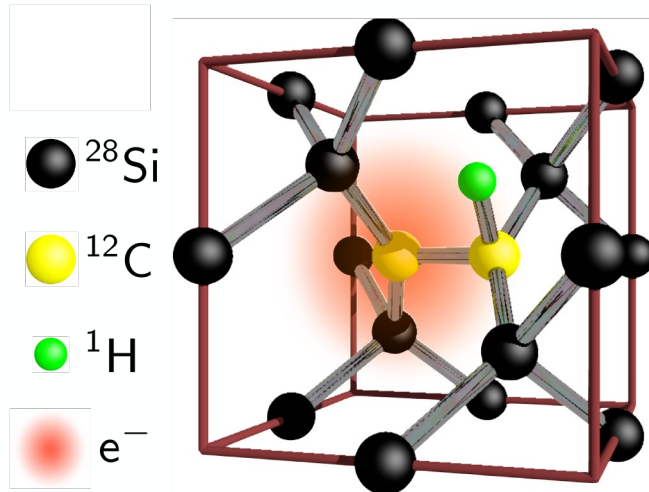
Light is guided through silicon thanks to SOI buried oxide

Silicon as a quantum host



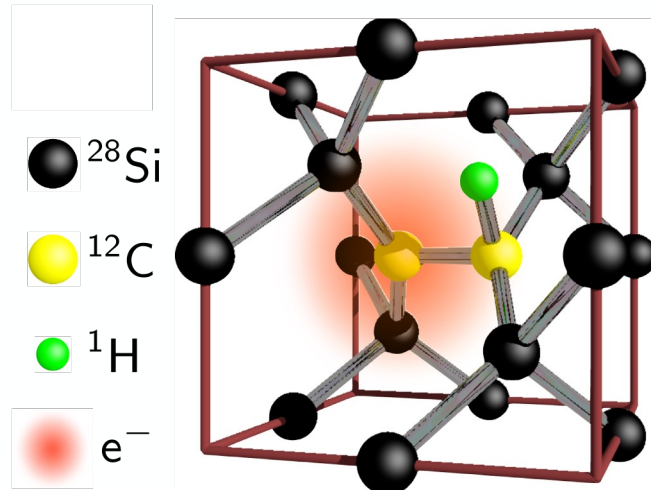
Avogadro Material: 99.996% ^{28}Si (~40ppm ^{29}Si , ~1ppm ^{30}Si)

The T centre



L. Bergeron et al., PRX Quantum 1, 020301 (2020).

T centre properties

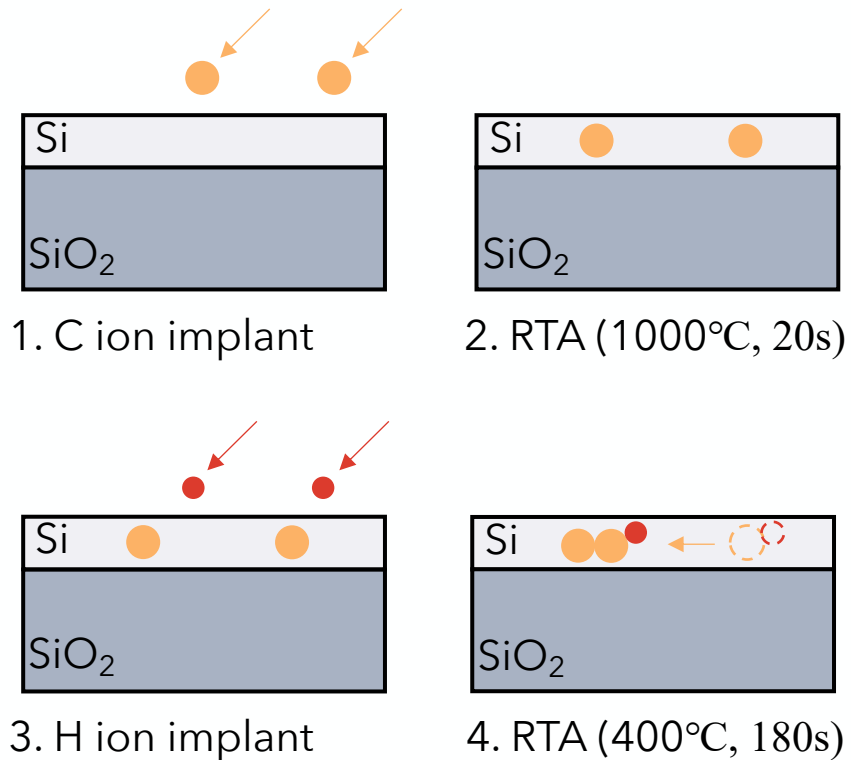


	T centre
Wavelength	1326 nm
Linewidth	< 33 MHz
Optical lifetime	940 ns
Debye-Waller factor	0.23(1)
T_{1E}, T_{1N}	> 30s
T_{2E}	2.1 (1) ms
T_{2N}	> 1.1 (1) s

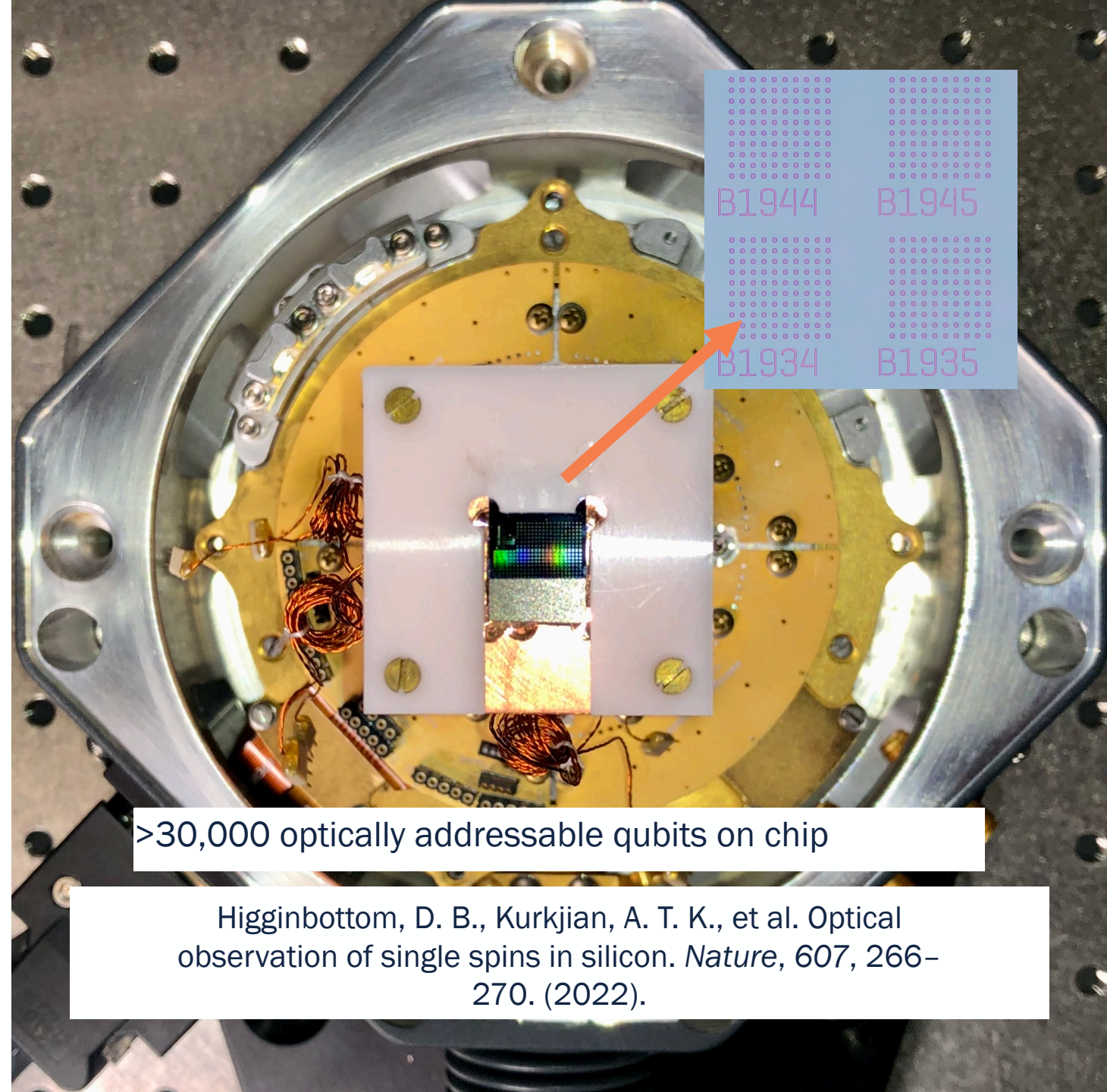
L. Bergeron et al., PRX Quantum 1, 020301 (2020).

Now do it on chip!

Two stage implant and anneal process



MacQuarrie, E. R. et al. Generating T centres in photonic silicon-on-insulator material by ion implantation. *New J. Phys.* 23, 103008 (2021).

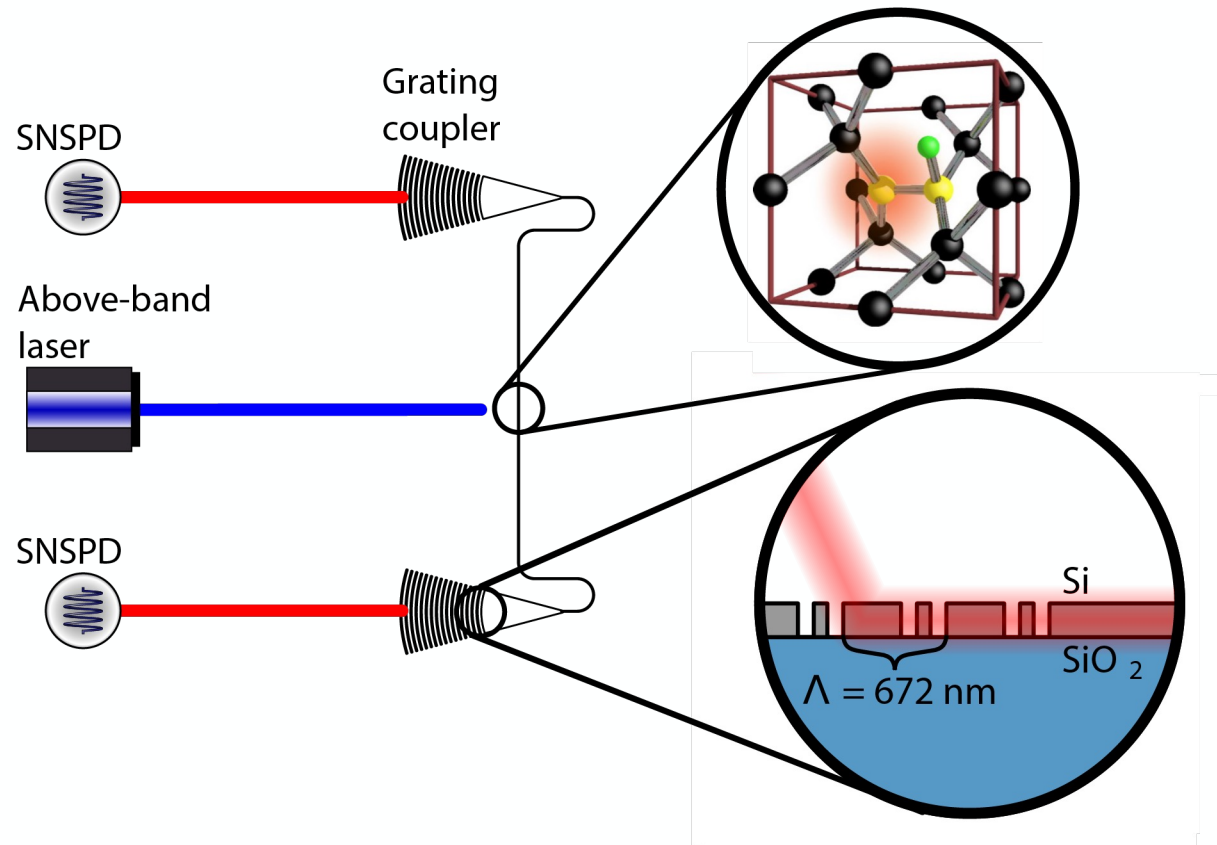


>30,000 optically addressable qubits on chip

Higginbottom, D. B., Kurkjian, A. T. K., et al. Optical observation of single spins in silicon. *Nature*, 607, 266–270. (2022).

Waveguide integrated devices on chip

Single-mode waveguide devices



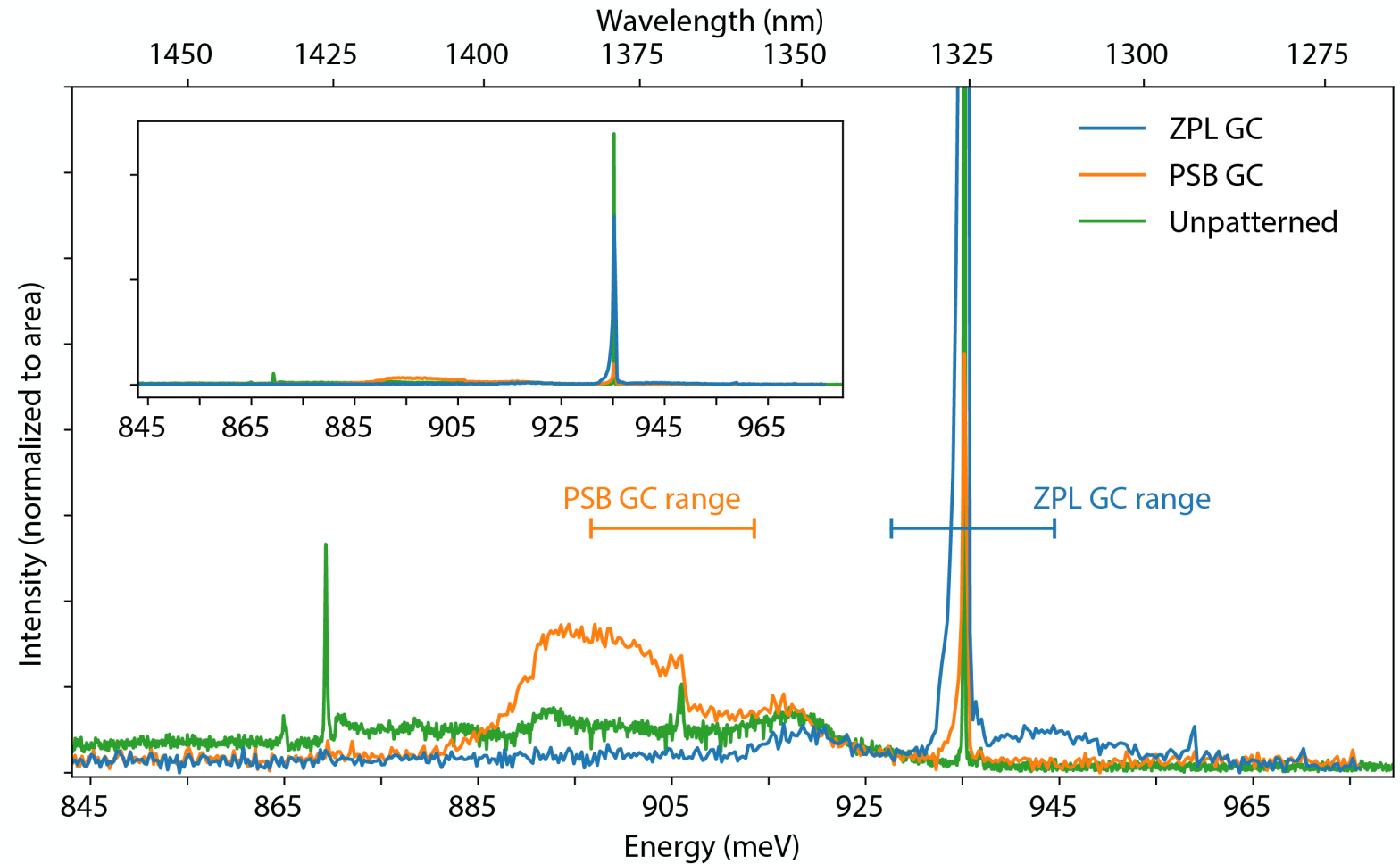
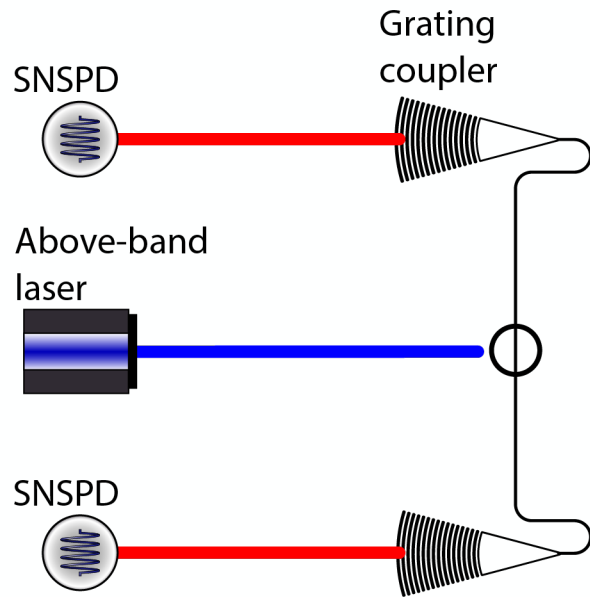
Adam DeAbreu



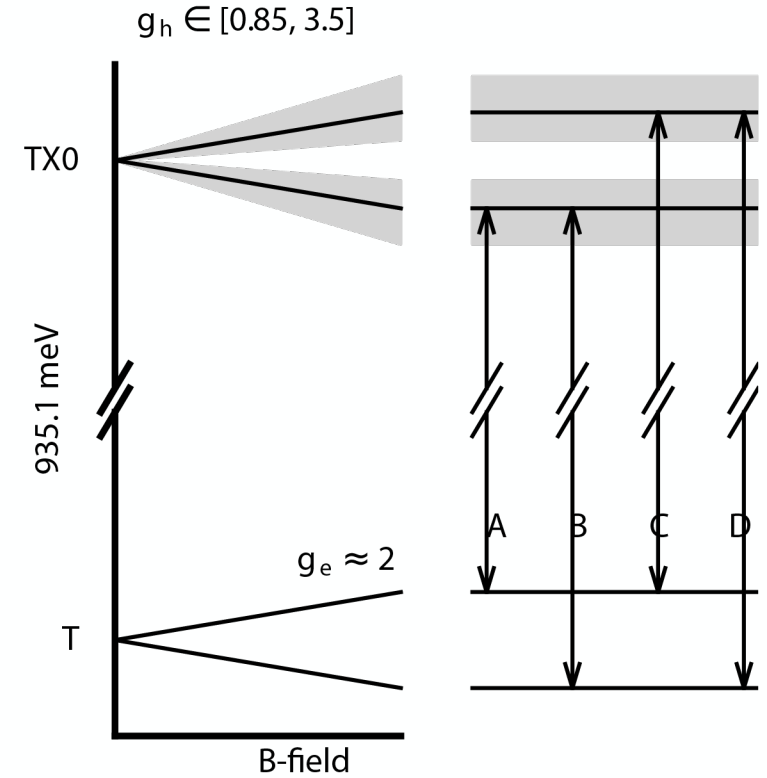
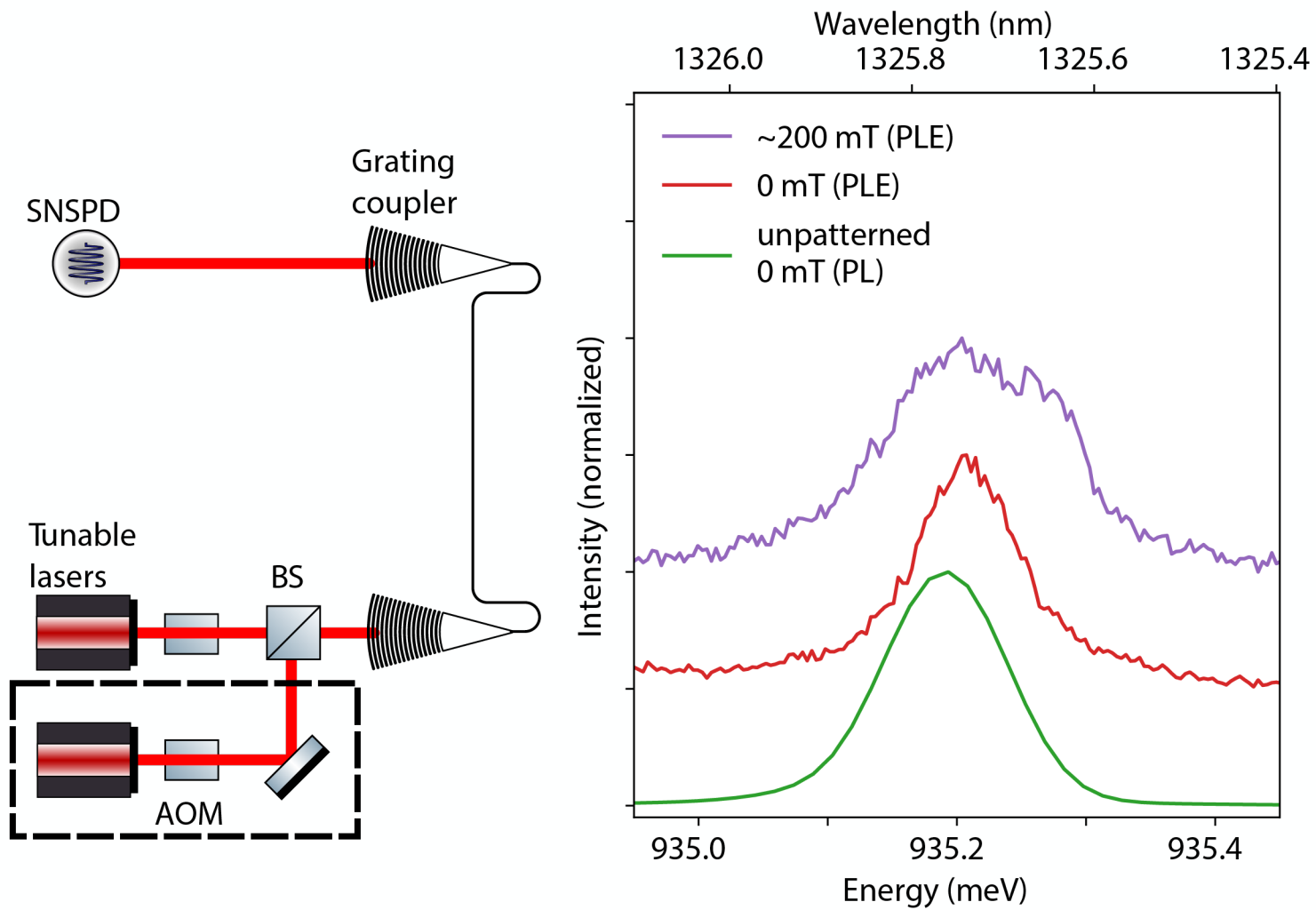
Camille Bowness

Deabreu, A. et al. Waveguide-integrated silicon T centres. *ArXiv Preprint*. 2209.14260v1 (2022).

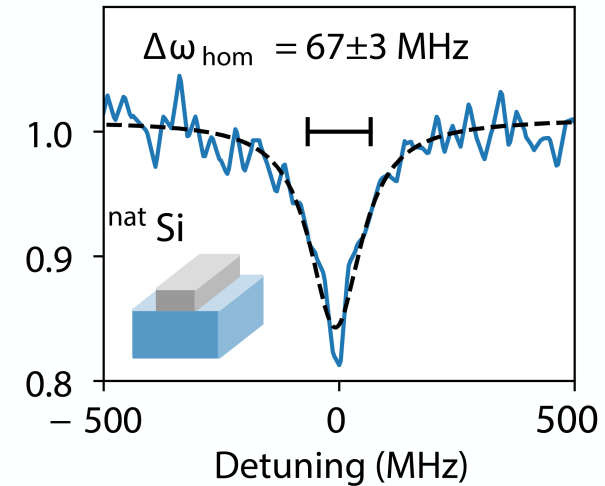
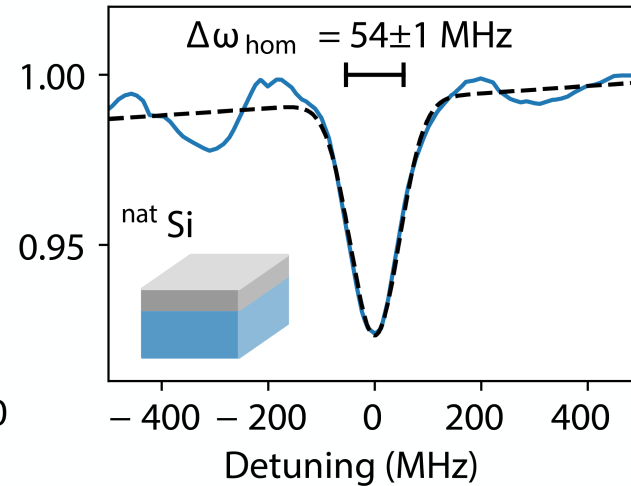
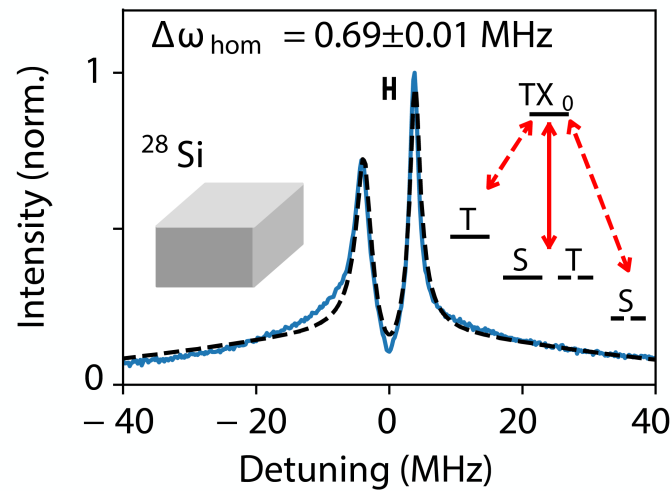
Photolumuminescence spectra



Photoluminescence excitation spectra



Instantaneous linewidths



Adam DeAbreu



Amir Alizadeh

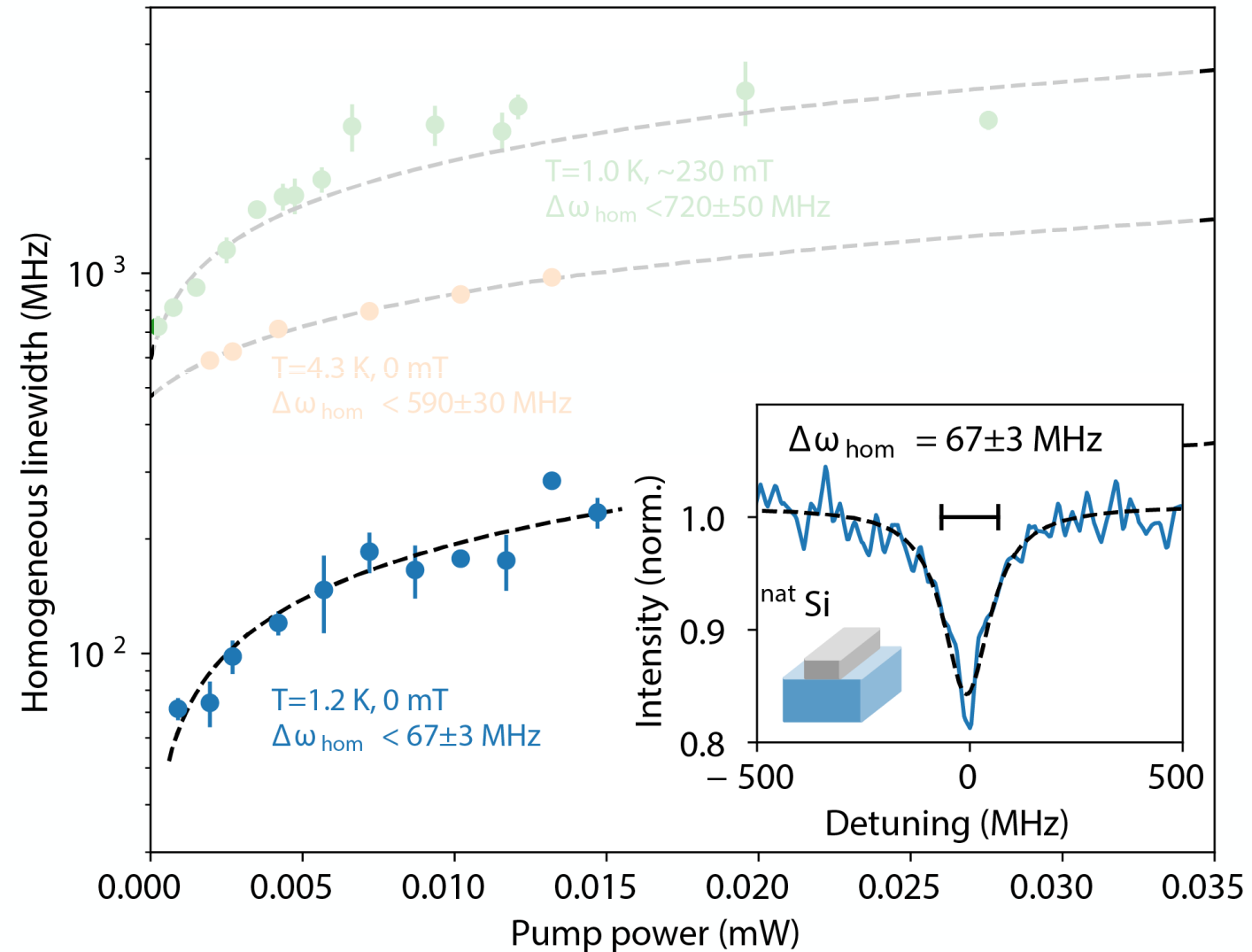
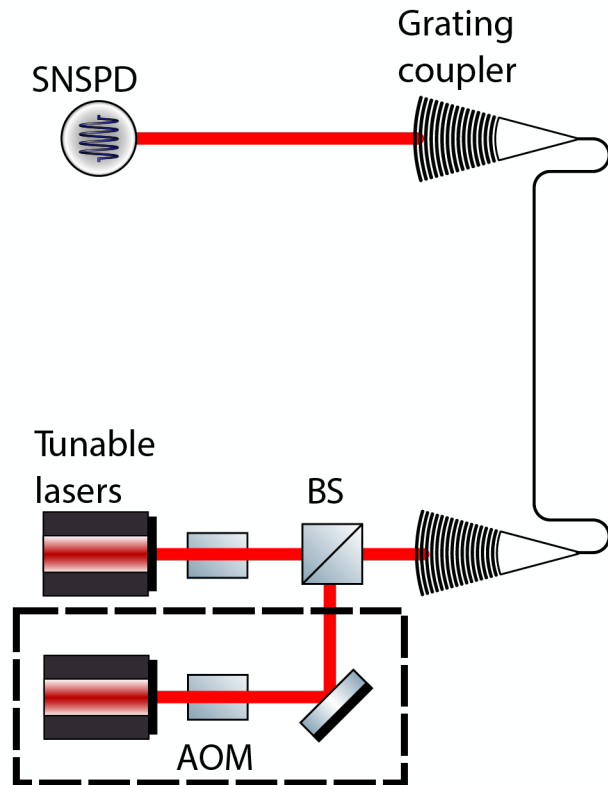


Nicholas Brunelle

Deabreu, A. et al. Waveguide-integrated silicon T centres. *ArXiv Preprint*. 2209.14260v1 (2022).

Zero-power linewidth projection

Ensemble hole burning, zero-power linewidth (projected) = 11 MHz



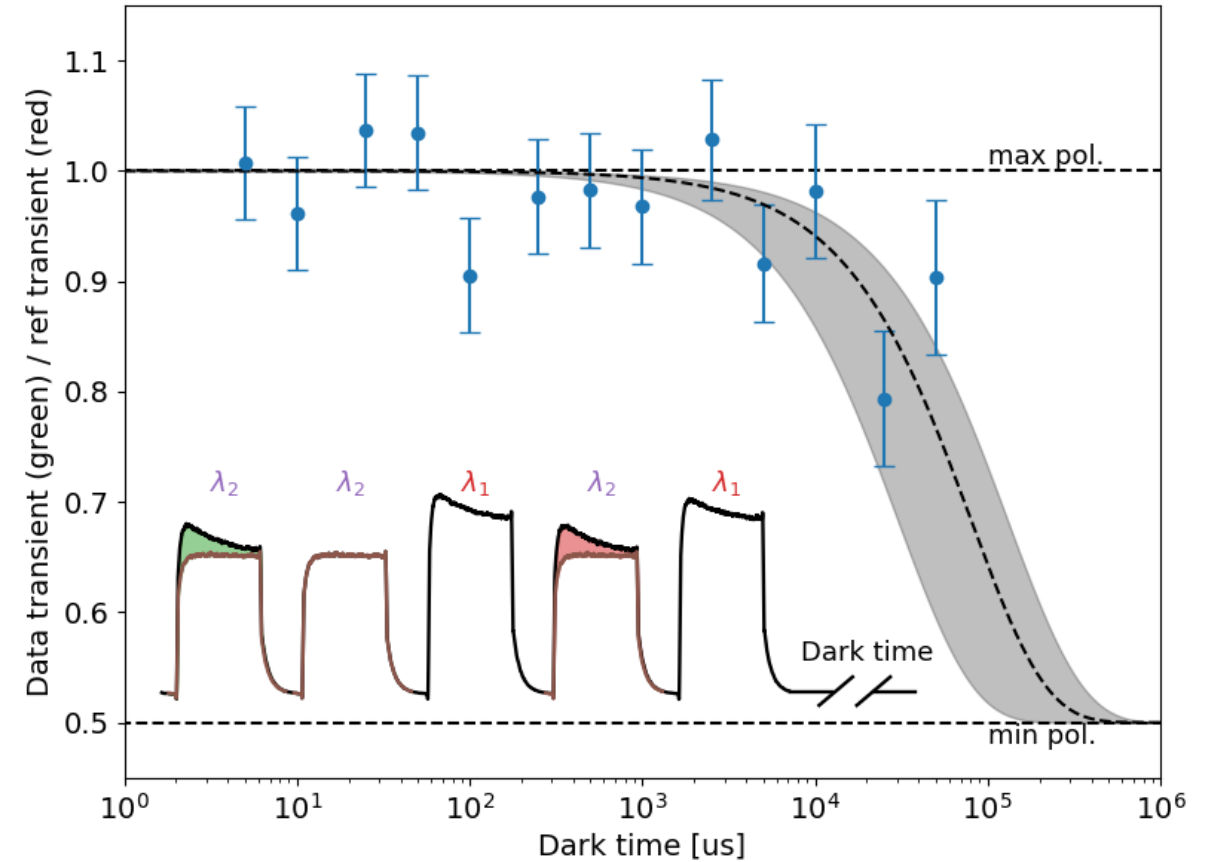
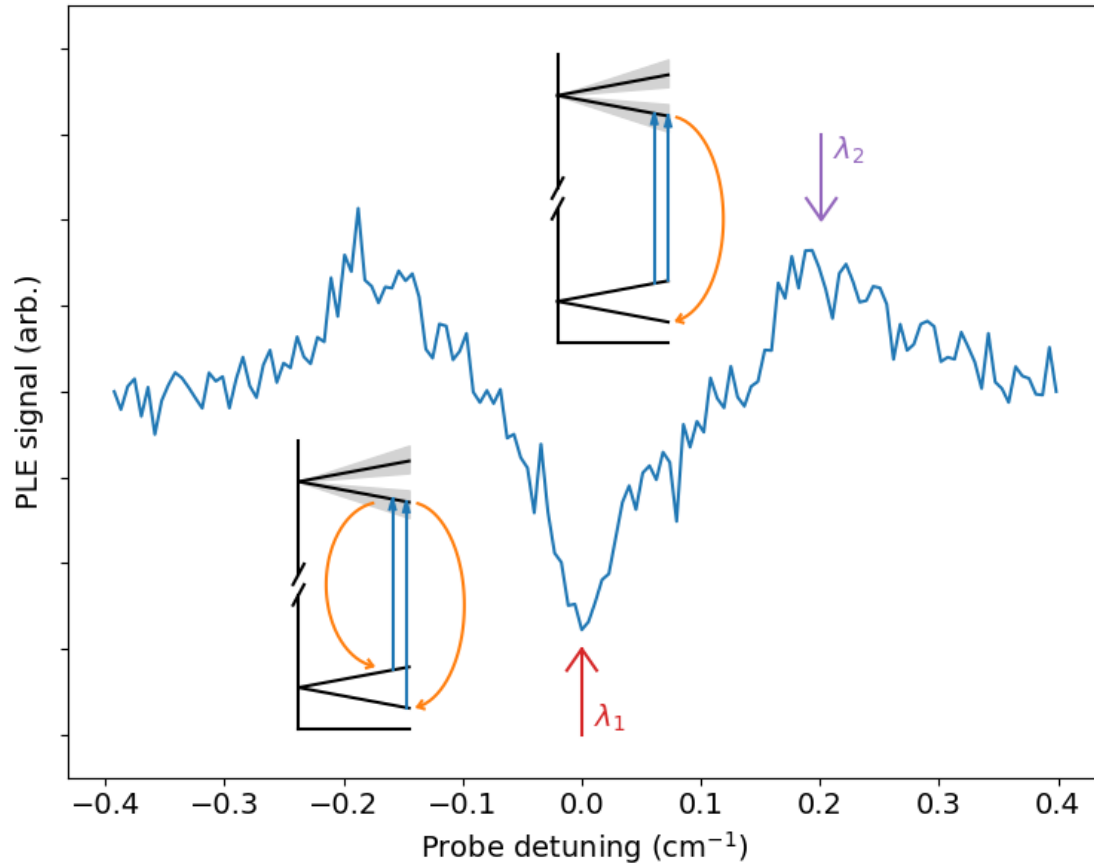
Adam DeAbreu



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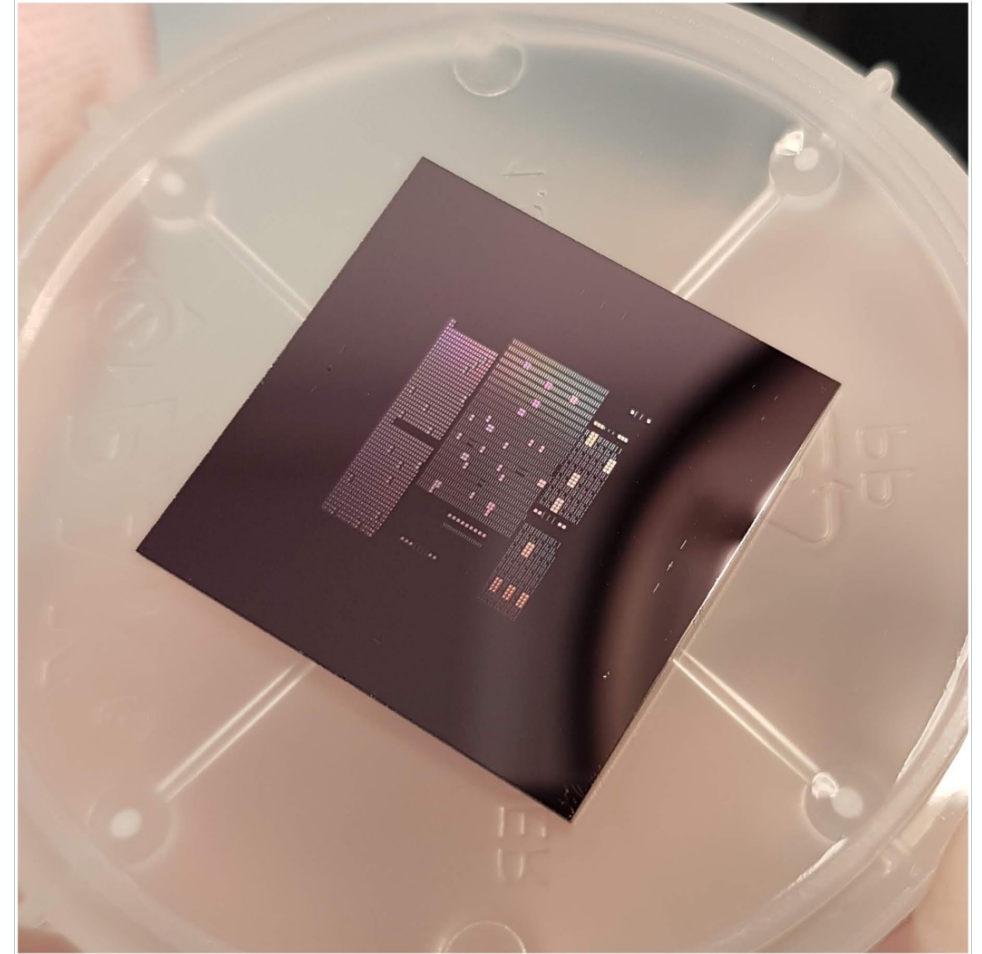
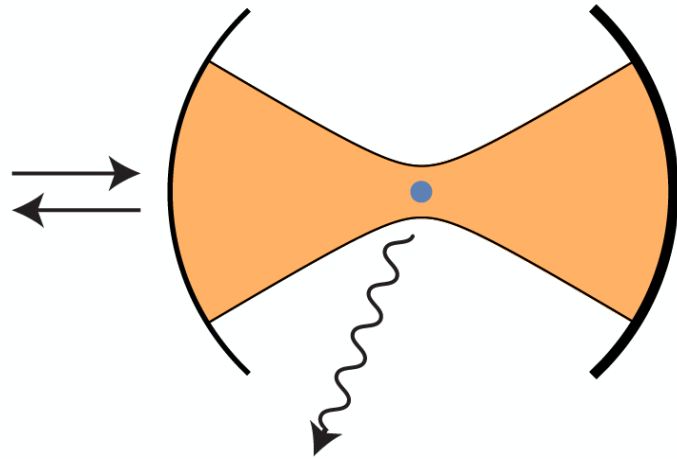
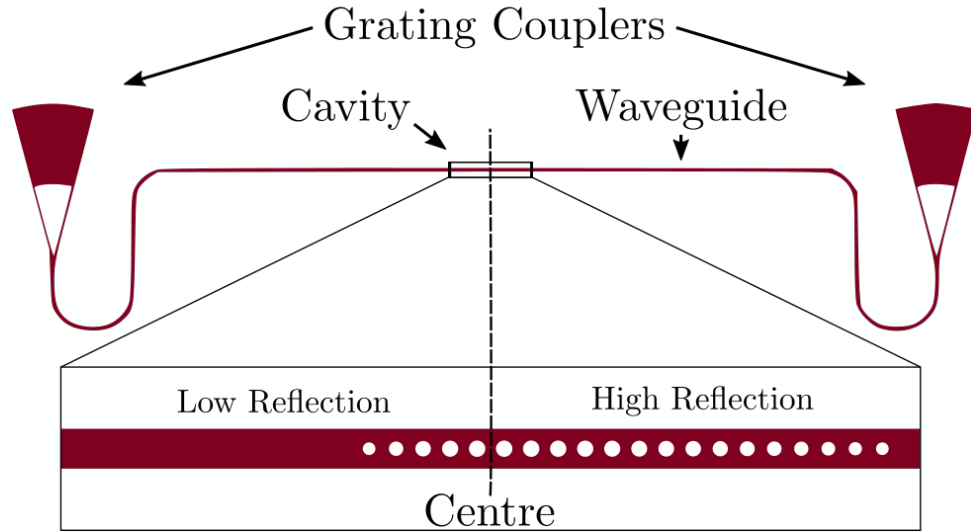
Electron spin lifetime measurement (optical)

$T_1 > 80$ ms (optically limited)

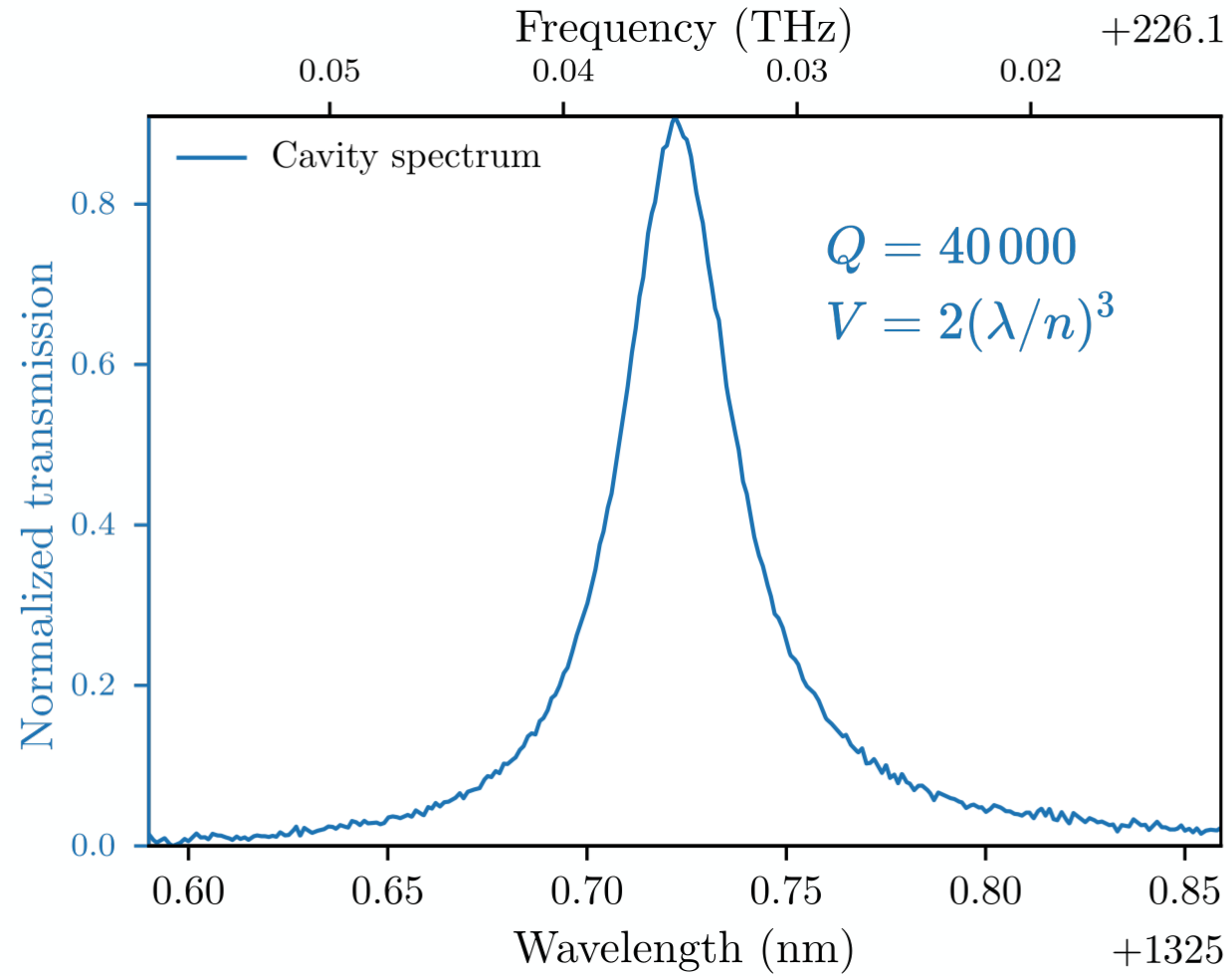
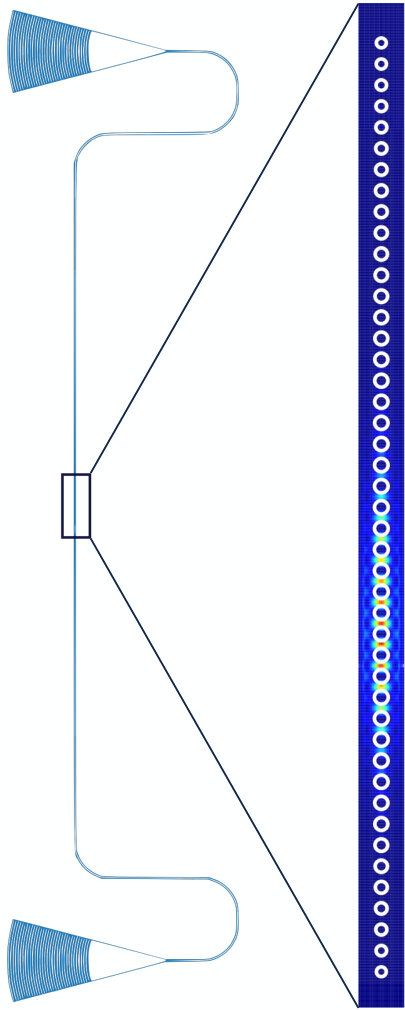


Deabreu, A. et al. Waveguide-integrated silicon T centres. *ArXiv Preprint*. 2209.14260v1 (2022).

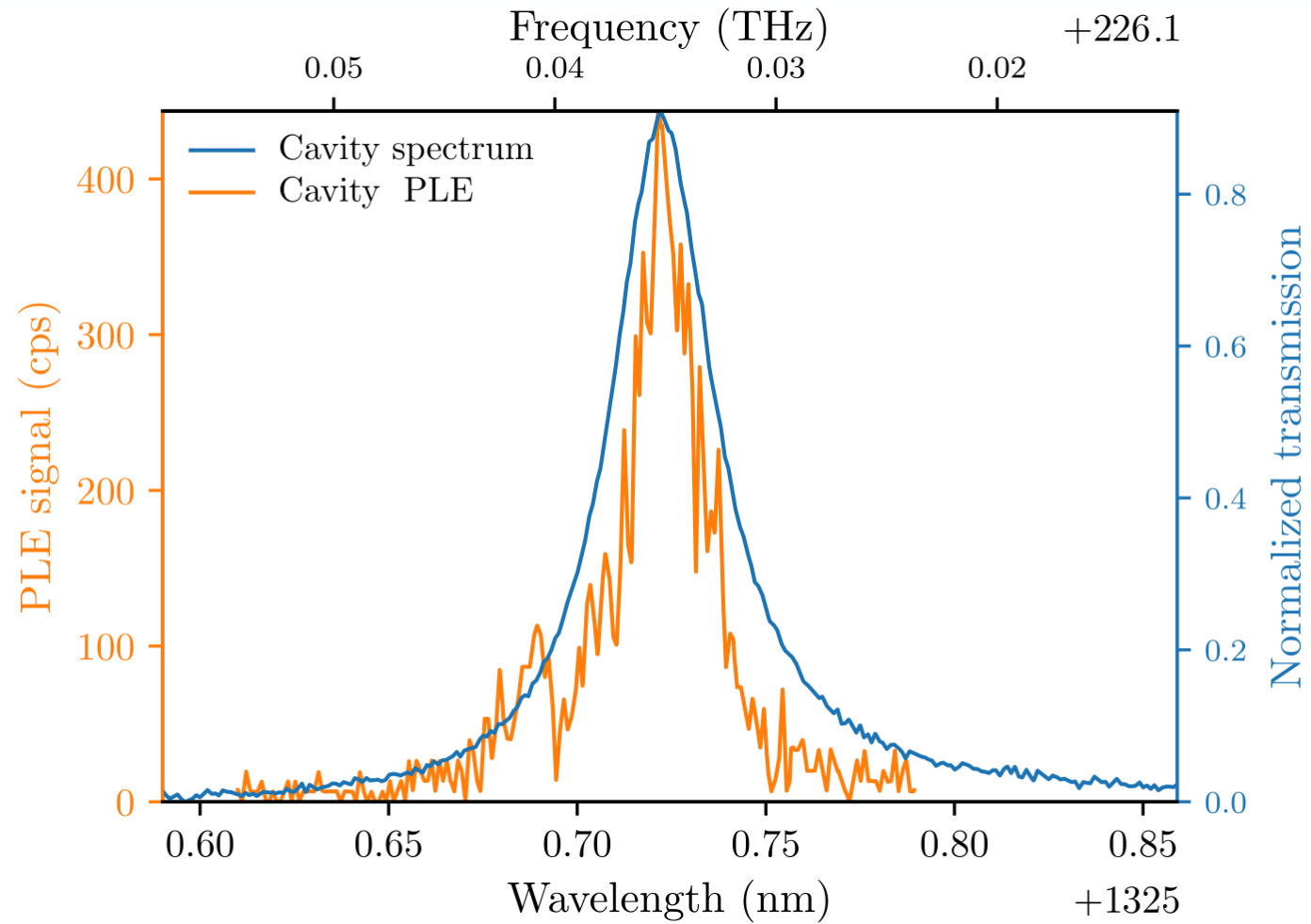
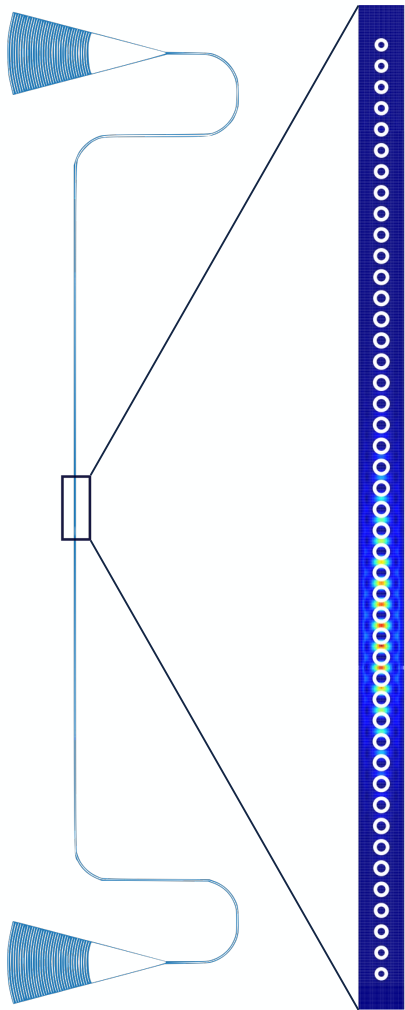
Photonic crystal nanobeam cavities



Photonic crystal nanobeam cavity spectrum



Resonant excitation of cavity-coupled T centres

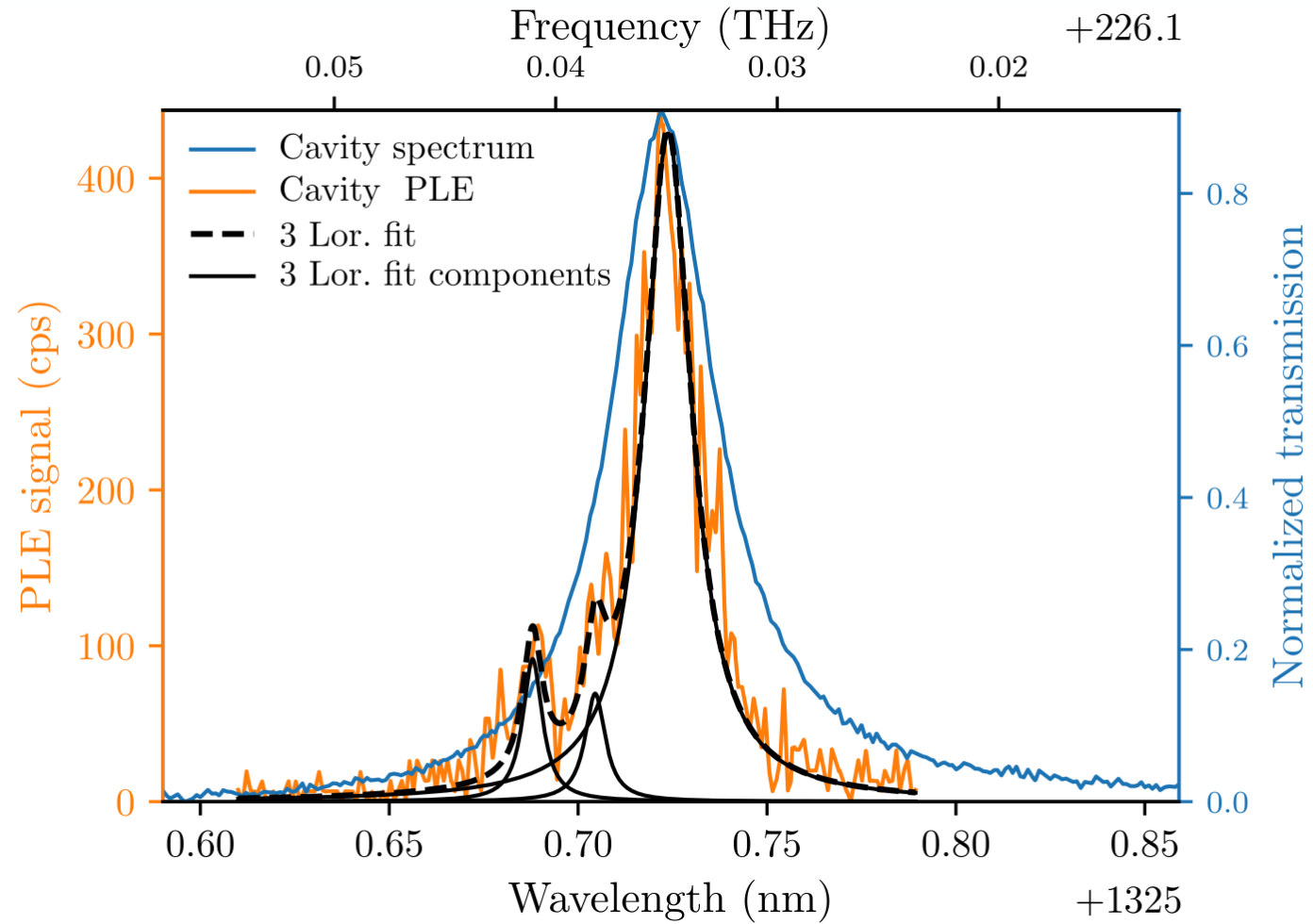
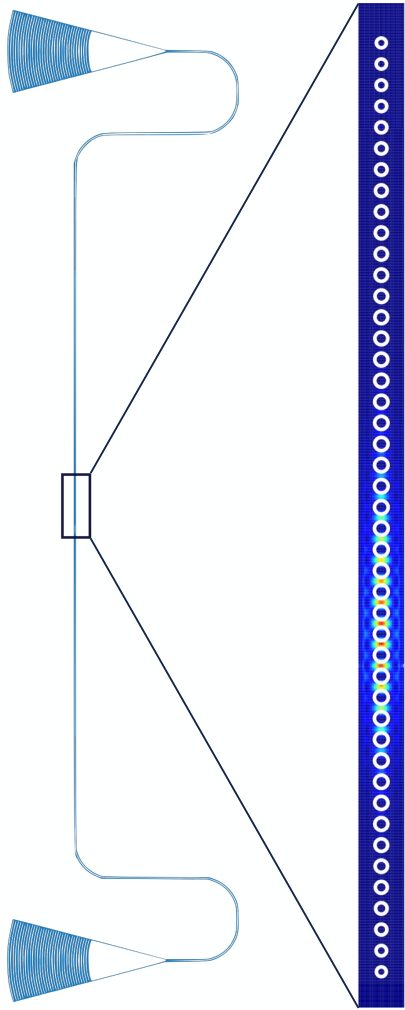


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Resonant excitation of cavity-coupled T centres

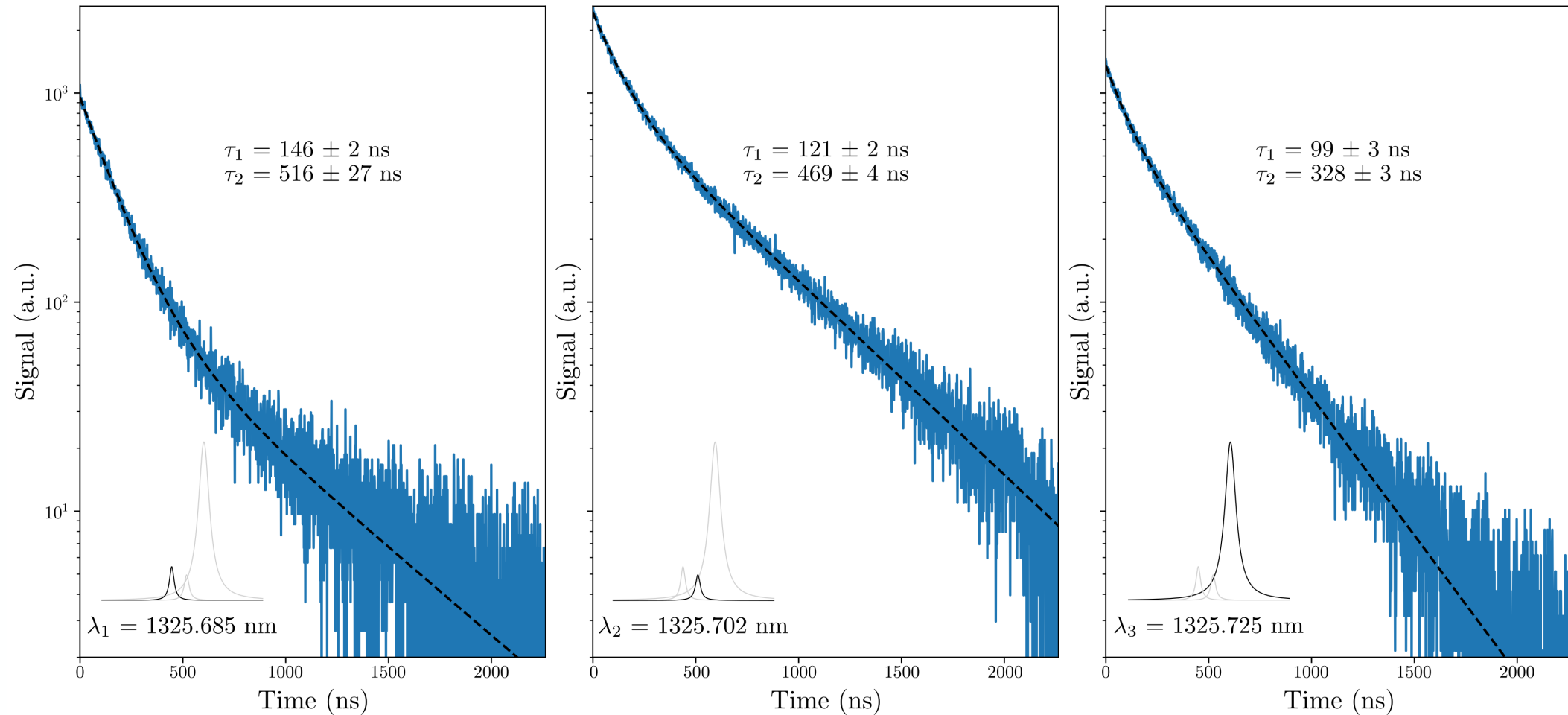


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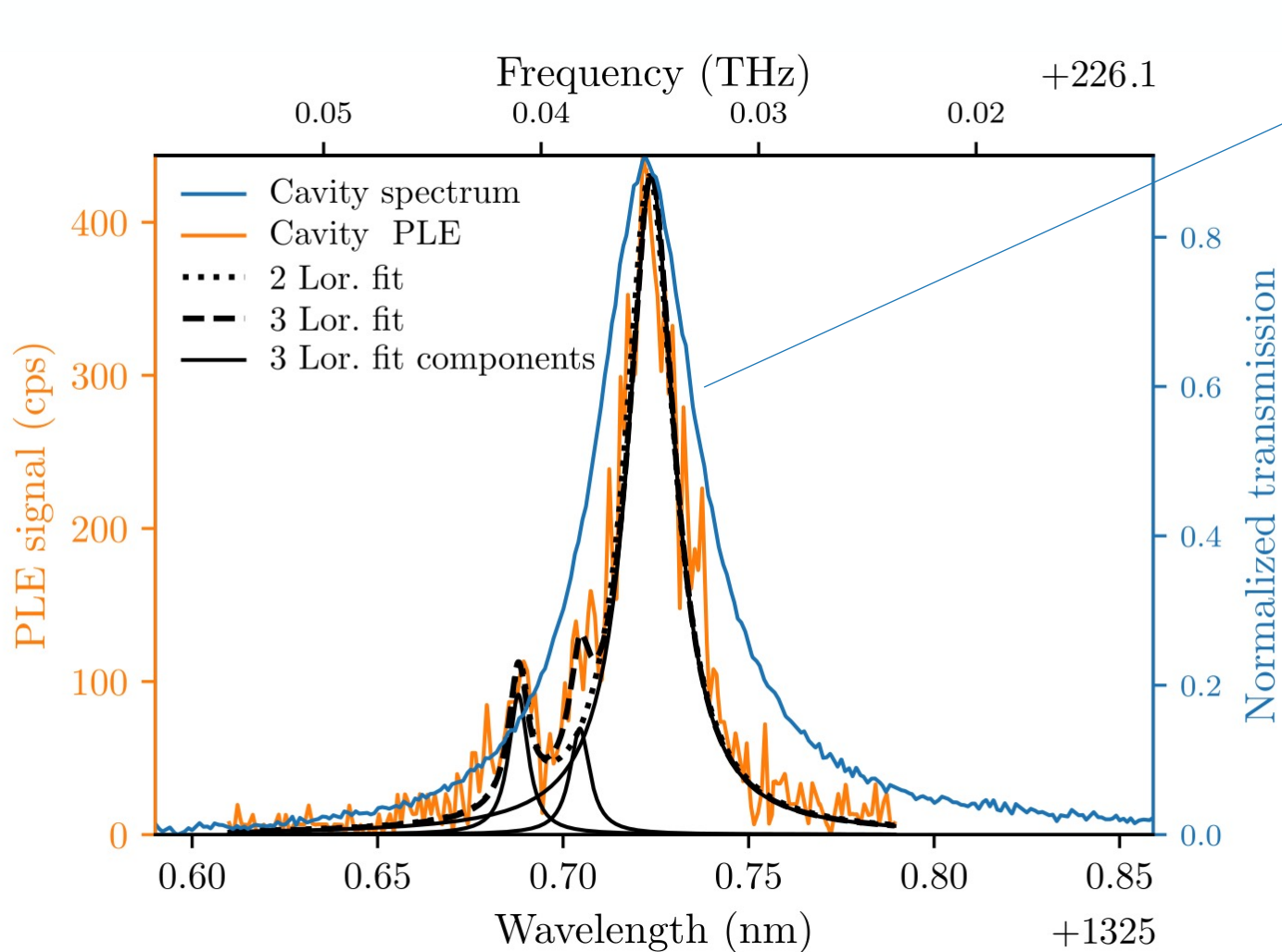
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Lifetime reductions



Detuning dependent lifetime reduction factors of 2-9

Purcell factor estimate



$$Q = 40000$$

$$V = 2(\lambda/n)^3$$

$$P_{\text{ideal}} = 1500$$

$$P_{\text{detuned}} = 300$$

$$P_{\text{estimated}} = 136$$

Summary

The T centre:

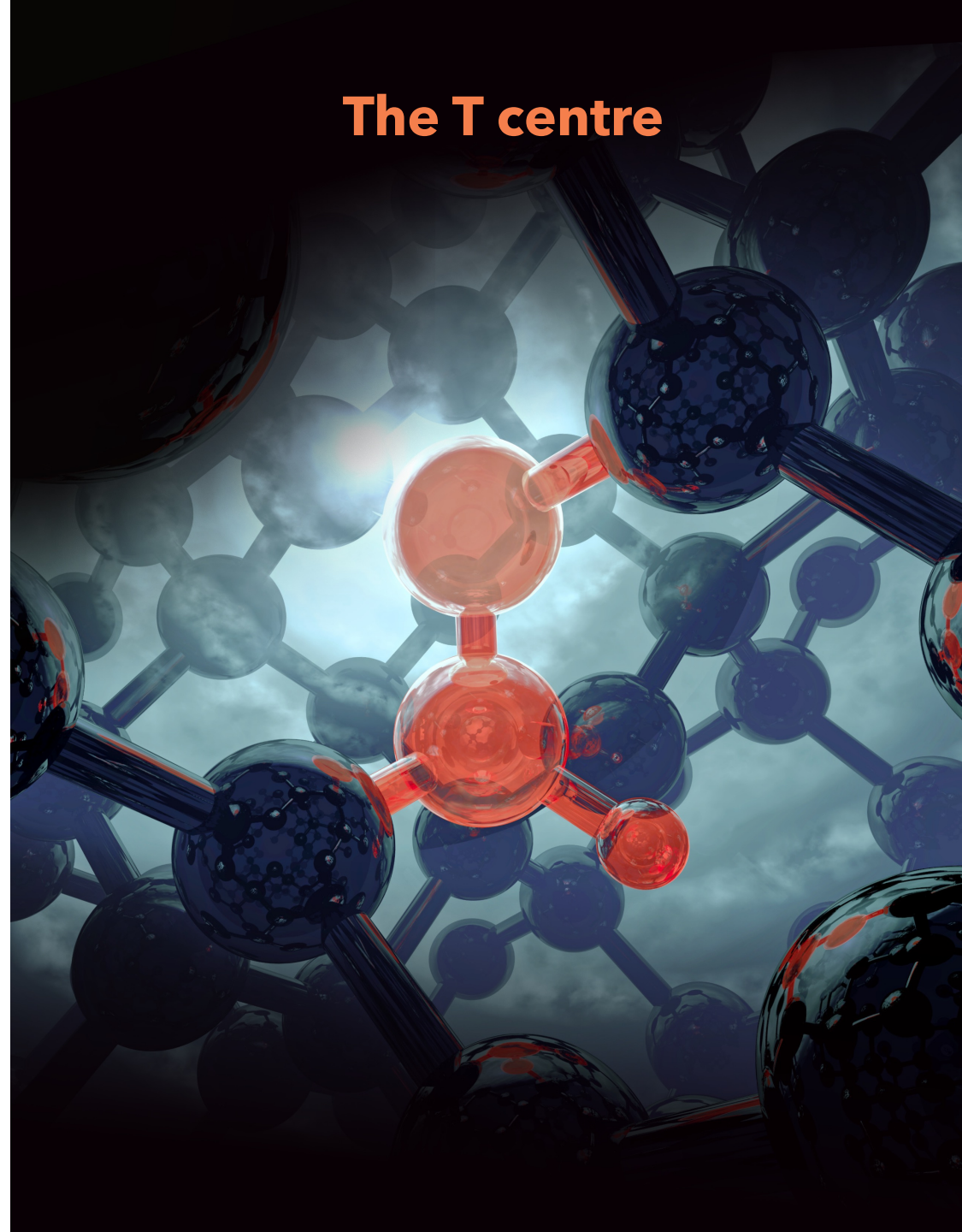
- Telecom O-band emission
- Long spin coherence
- **Integrates with silicon photonics**

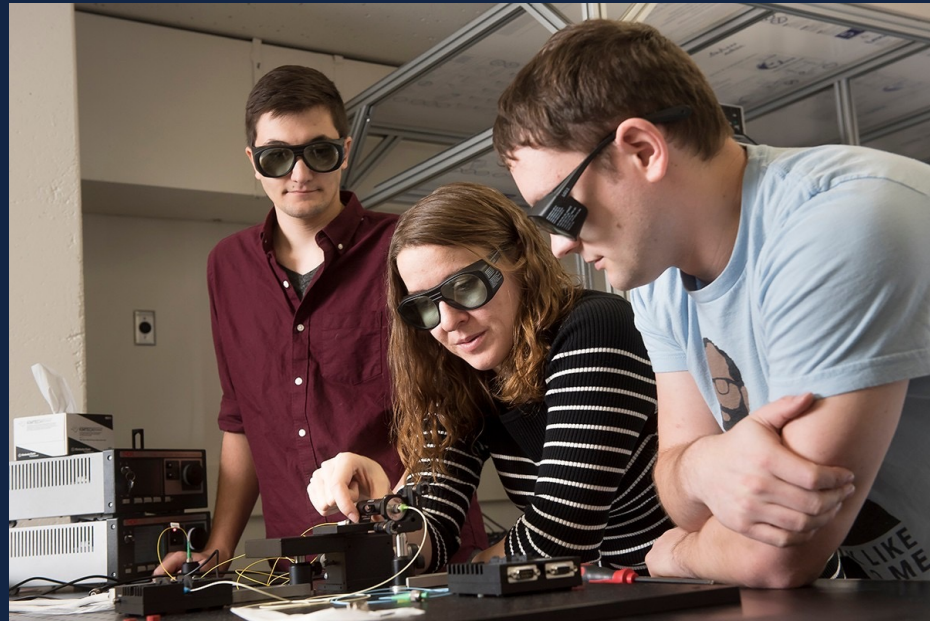
Silicon T centre instantaneous linewidth almost lifetime-limited in ^{28}Si

Instantaneous linewidth of 11 MHz in single mode waveguides.

Lifetime reduction factor of nine achieved in photonic crystal nanobeam cavities.

The T centre

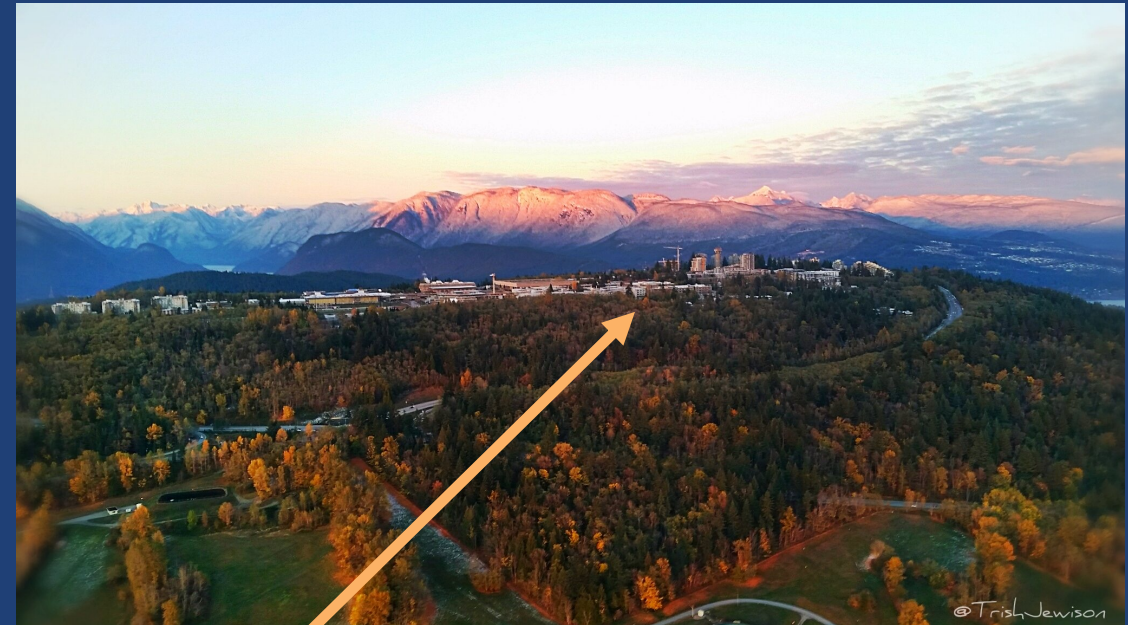




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- Software
- Hardware
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+ many, many more...



Thank you!



Stef Simmons
Mike Thewalt

Daniel Higginbottom
Moein Kazemi
Camille Chartrand

Adam DeAbreu
Mehdi Keshavarz
Nicholas Brunelle
Joshua Kanaganayagam
Myles Ruether
Leea Stott

Amir Alizadeh
Melanie Gascoine

Yehudah Ackermann
Chloe Clear
Michael Dobinson
Austin Woolverton
Camille Bowness

Jean-François Caron
Laurent Bergeron
Sara Hosseini
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Thank you!



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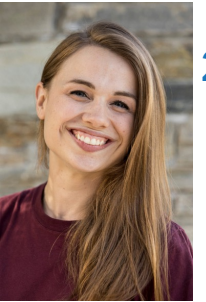
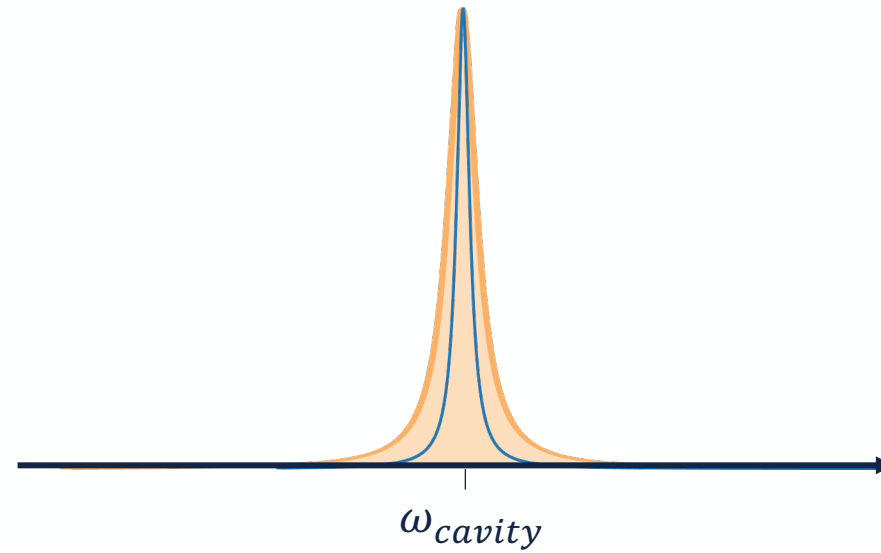
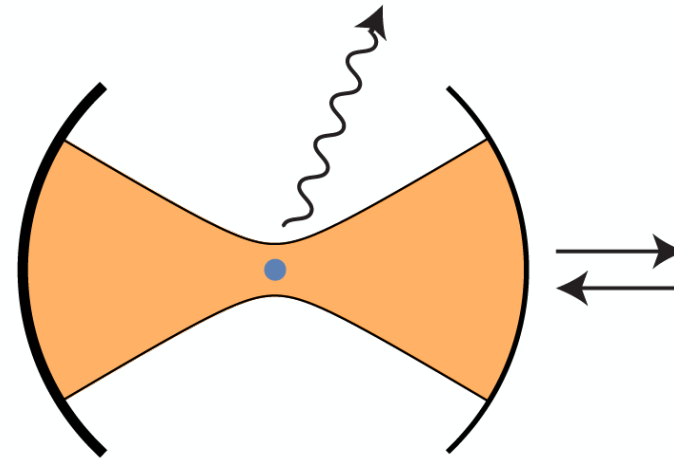
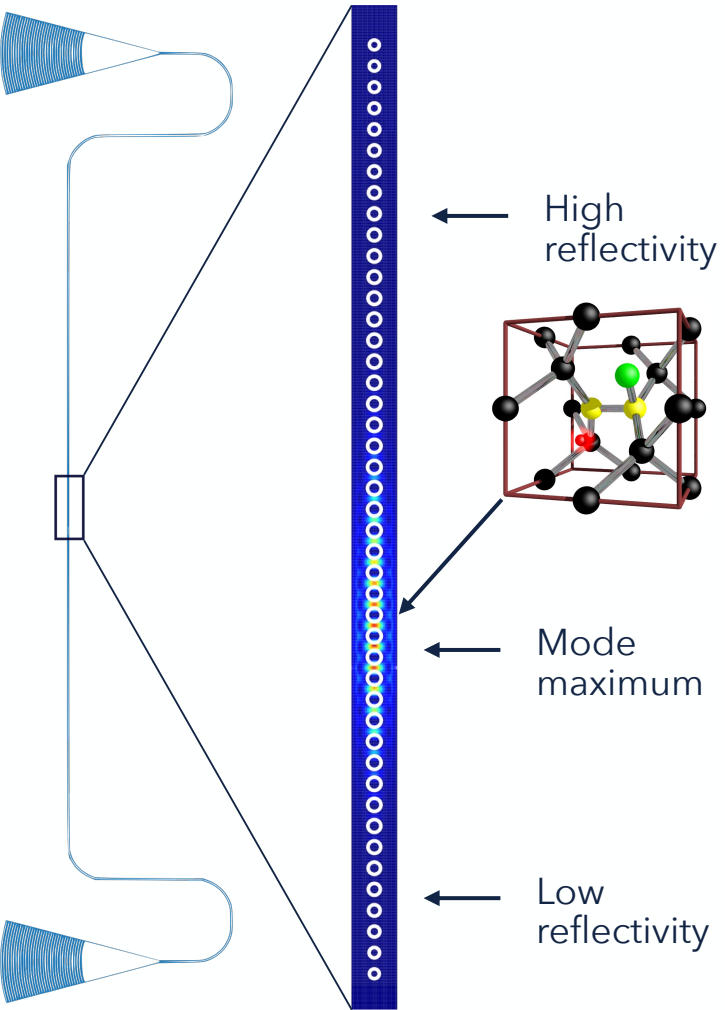
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Integrated optical resonators



Lea Stott



Camille Bowness

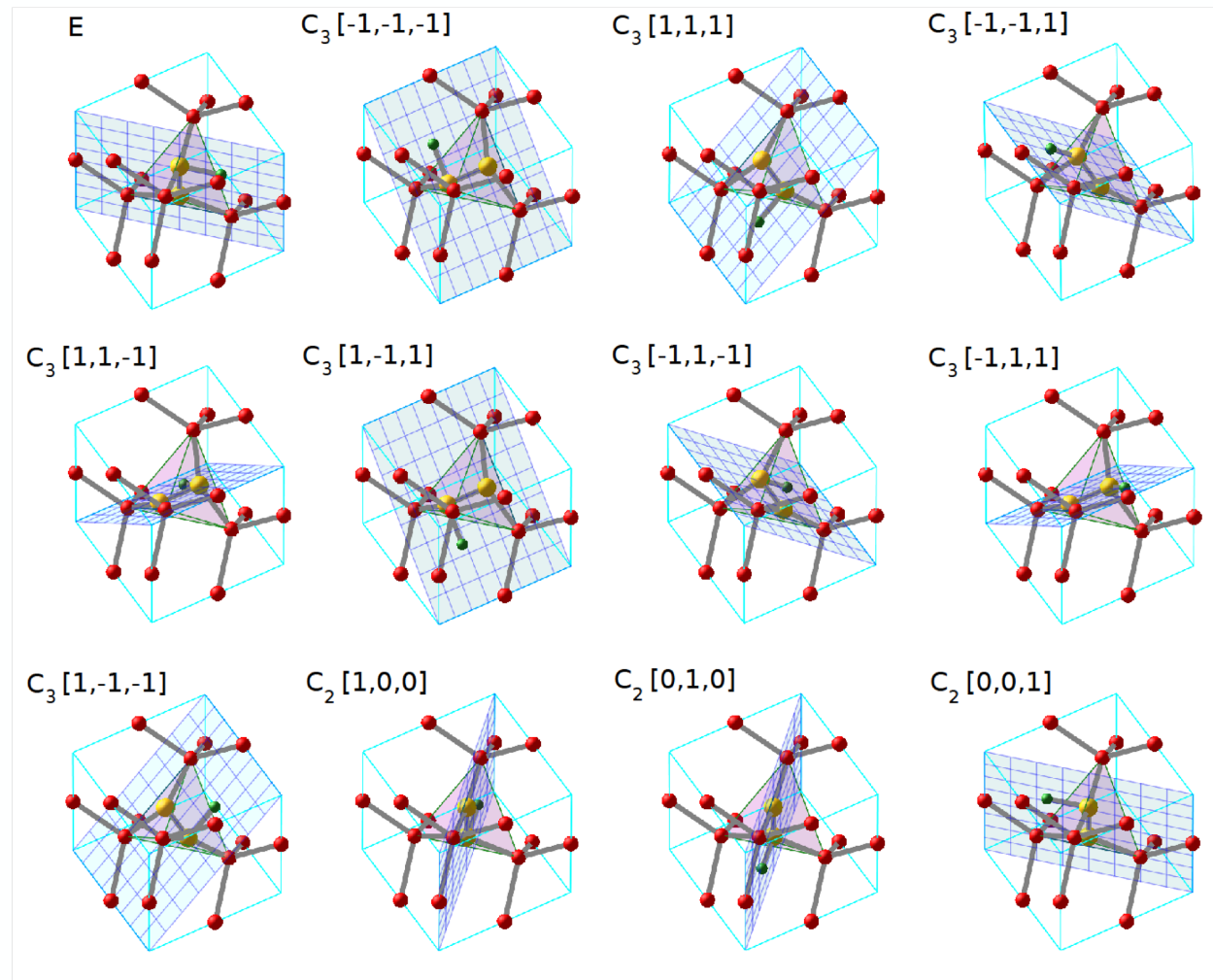


Camille Chartrand



Moein Kazemi

24 orientations



Josh
Kanaganayagam

12 orientational subsets

