WARWICK

58th Meeting of the INTC

Production of phosphorus-vacancy centers in diamond for optical and spin characterization

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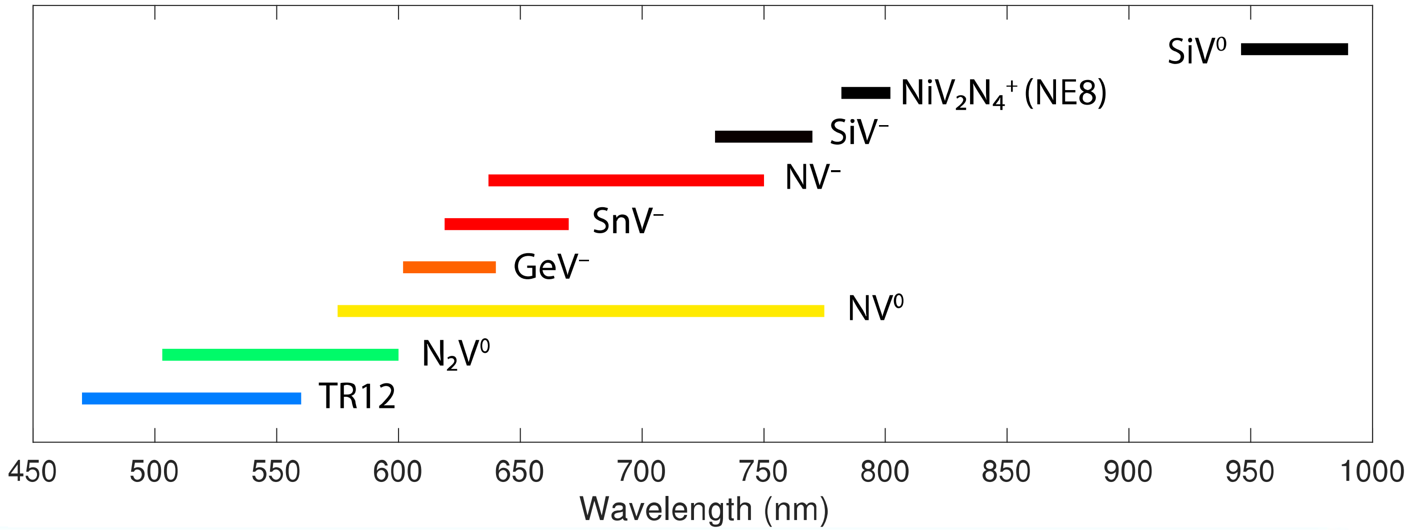
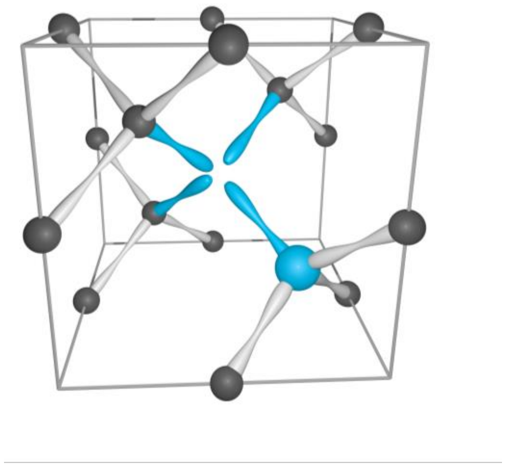
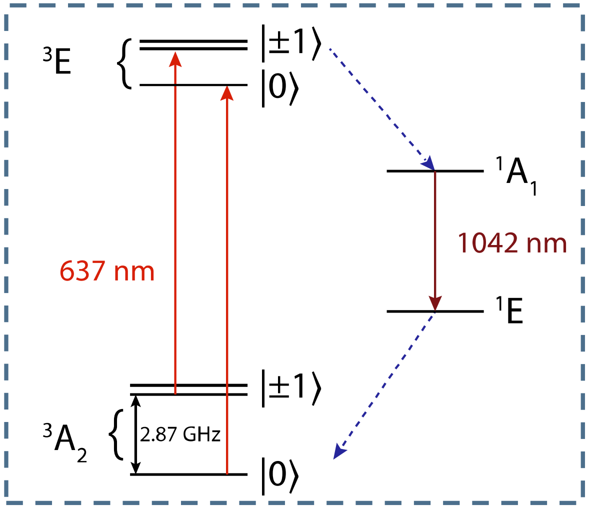
Single emitters in diamond

- Diamond is an ideal host matrix for functional point defects with optically-accessible quantum properties:
  - high Debye temperature
  - low spin-density
  - large band gap → broadband optical transparency (220 – 2400 nm)



Adapted from I. Aharonovich et al.,
Adv. Opt. Mater. 2, 911 (2014)





NV⁻

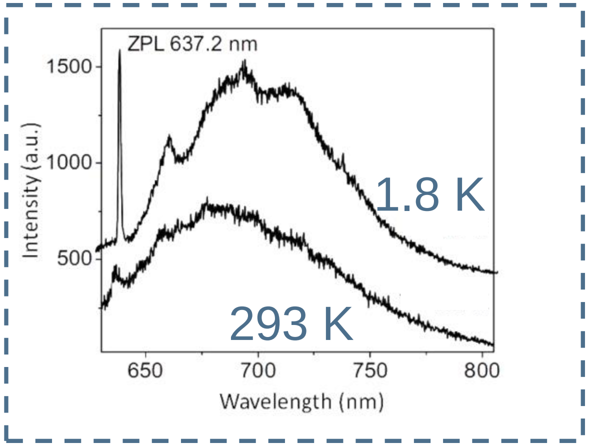
✓ Fast optical spin initialization

✓ High fidelity optical spin readout at room temperature

✓ Long coherence times

χ Broadband emission

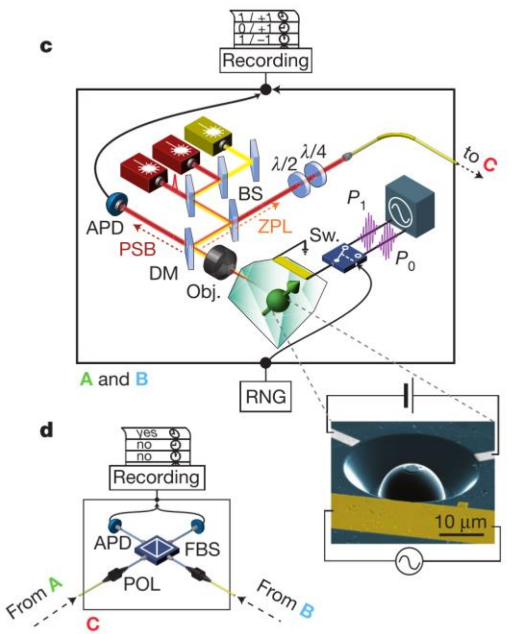
χ Sensitive to strain



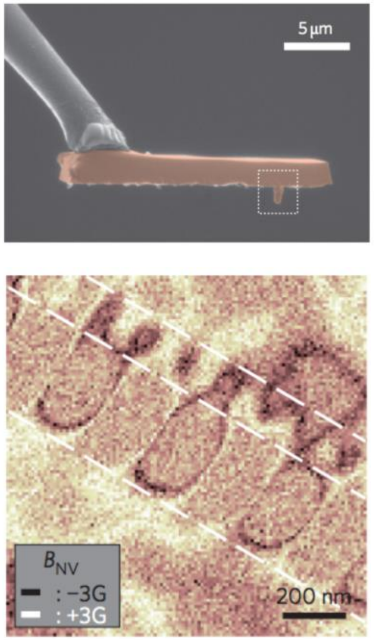
S. Yang et al., Nat. Photonics 10, 507 (2016)
S. Zaiser et al., Nat. Commun. 7, 12279 (2016)
B. Hensen et al., Nature 526, 682 (2015)
W. B. Gao et al., Nat. Photonics 9, 363 (2015)
Y.-C. Chen et al., Nat. Photonics 11, 77 (2017)
W. Pfaff et al., Science 345, (2014)
H. Bernien et al., Nature 497, 86 (2013)
A. Jarmola et al., Phys. Rev. Lett. 108, 197601 (2012)

NV^{-}

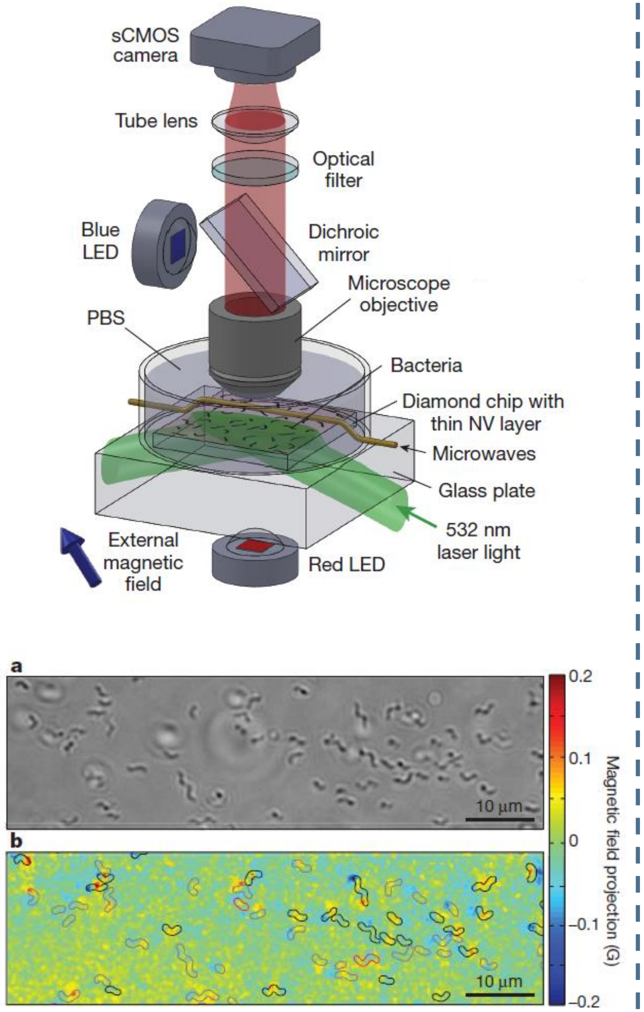
- Now a well-understood system
- Applications include:



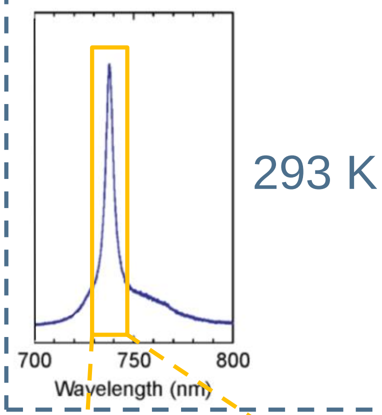
Fundamental quantum mechanics
10.1038/nature15759

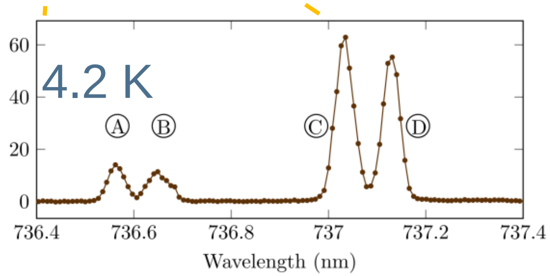


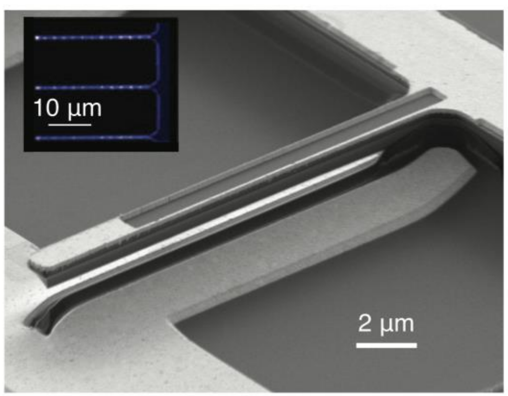
Nanoscale metrology
10.1038/nnano.2012.50

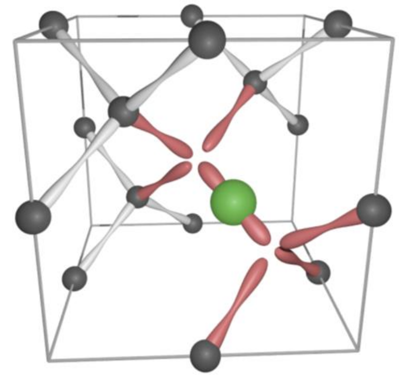


Widefield biological magnetometry
10.1038/nature12072









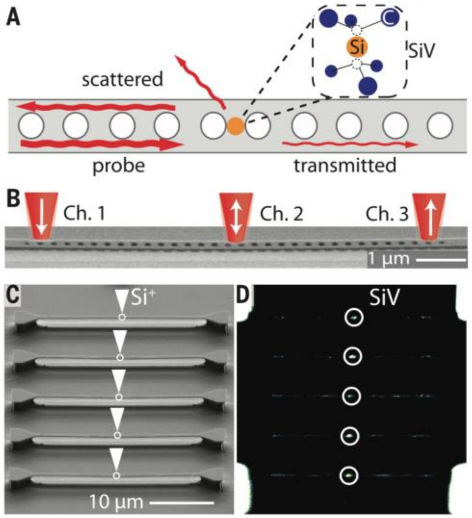
SiV$^-$

- x Slow spin initialization
- x Slow spin readout (and only at 4 K or lower)
- x Short coherence at >100 mK

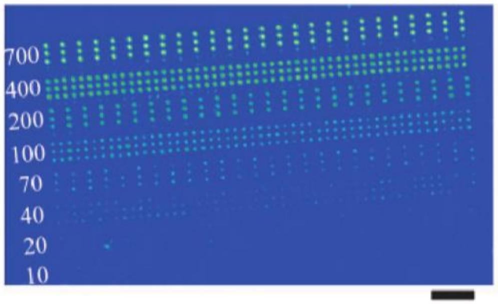
- ✓ Narrowband emission
- ✓ Tuneable ZPL

B. Pingault et al., Nat. Commun. 8, 15579 (2017)
D. D. Sukachev et al., Phys. Rev. Lett. 119, 223602 (2017)
A. Sipahigil et al., Phys. Rev. Lett. 113, 113602 (2014)
A. Sipahigil et al., Science 354, 847 (2016)
Y.-I. Sohn et al., arXiv:1706.03881 (2017)

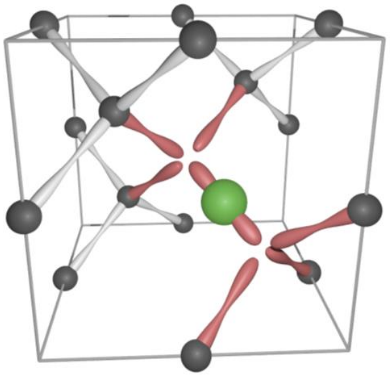
▶ Applications primarily photonic



Integrated photonic networks
10.1126/science.aah6875



Arrays of SiV⁻ for QKD
10.7567/APEX.7.115201



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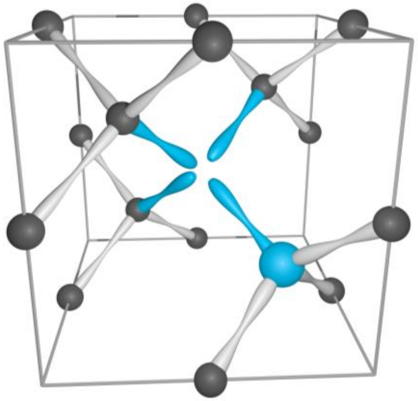

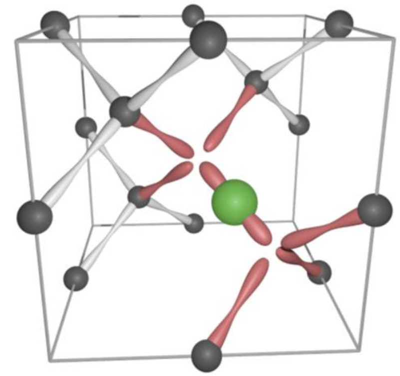

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SiV^-

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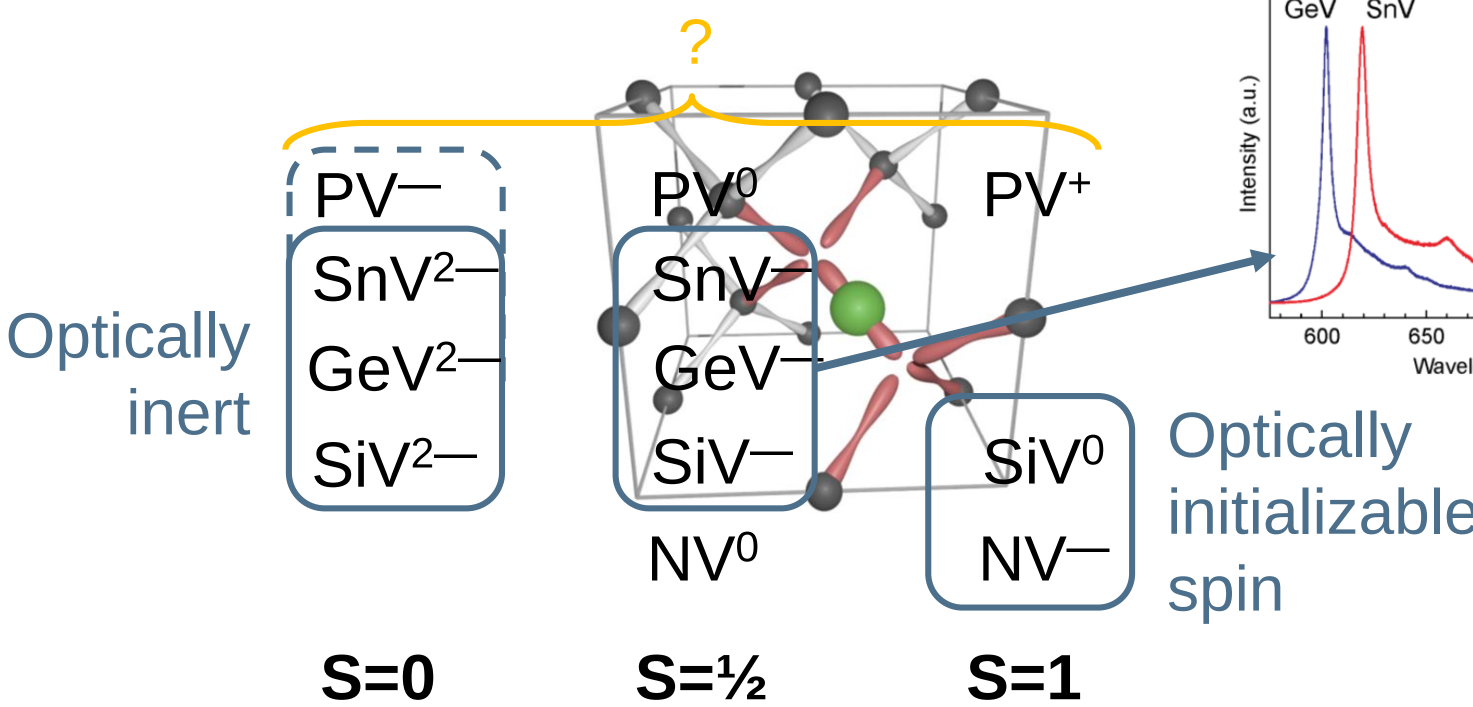
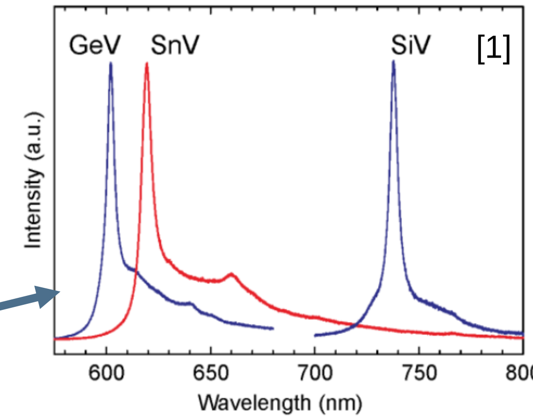
Single emitters in diamond

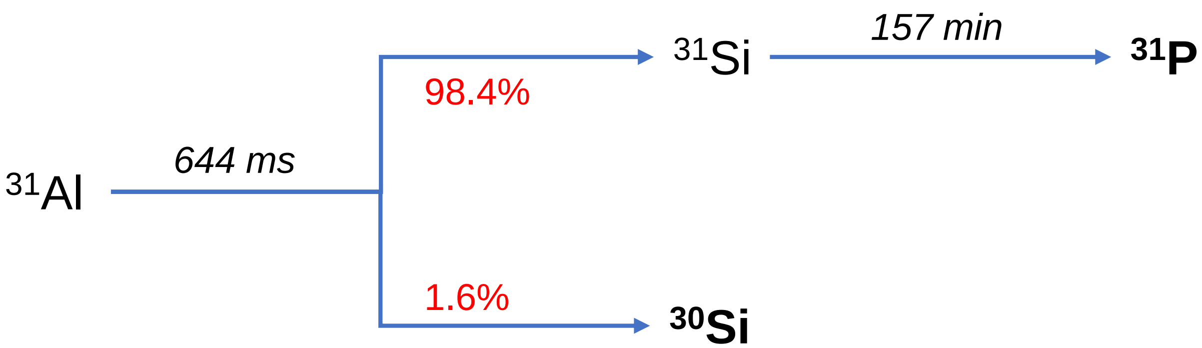
- Significant similarities between different "vacancy-cage" optical emitters





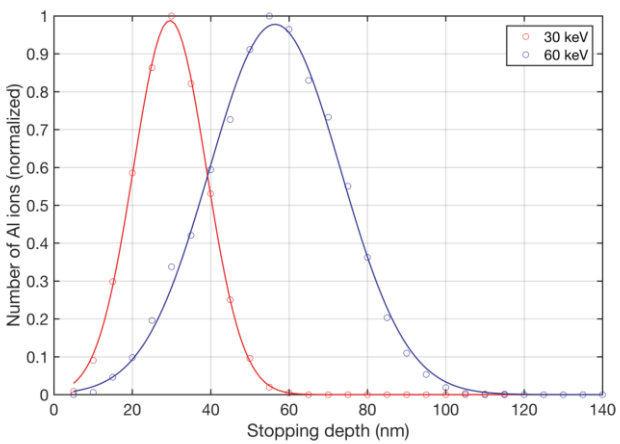
[1] T. Iwasaki et al., arXiv:1708.03576 (2017)

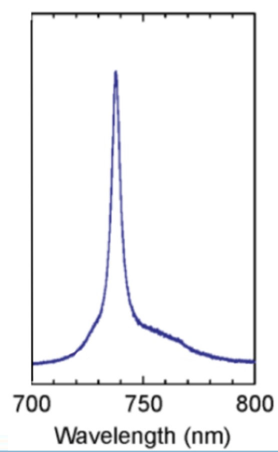
Production at ISOLDE

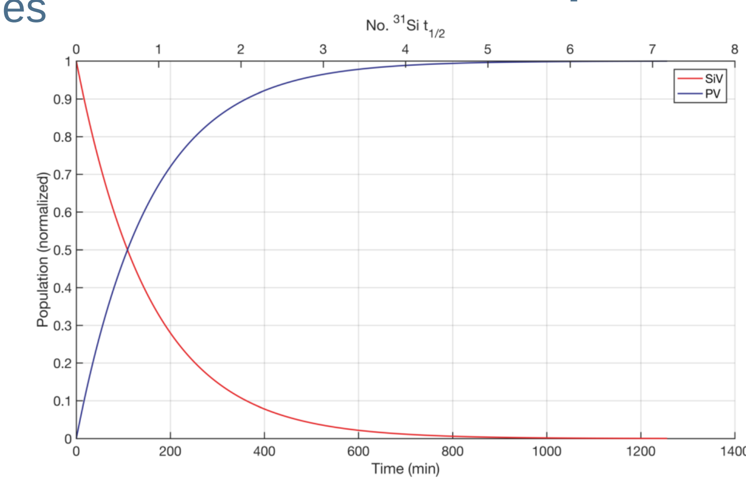


Implant at ~50 keV → **Anneal to form ^{31}SiV** → **Monitor decay of SiV**
Look for PV spectrum

>800°C to mobilize vacancies







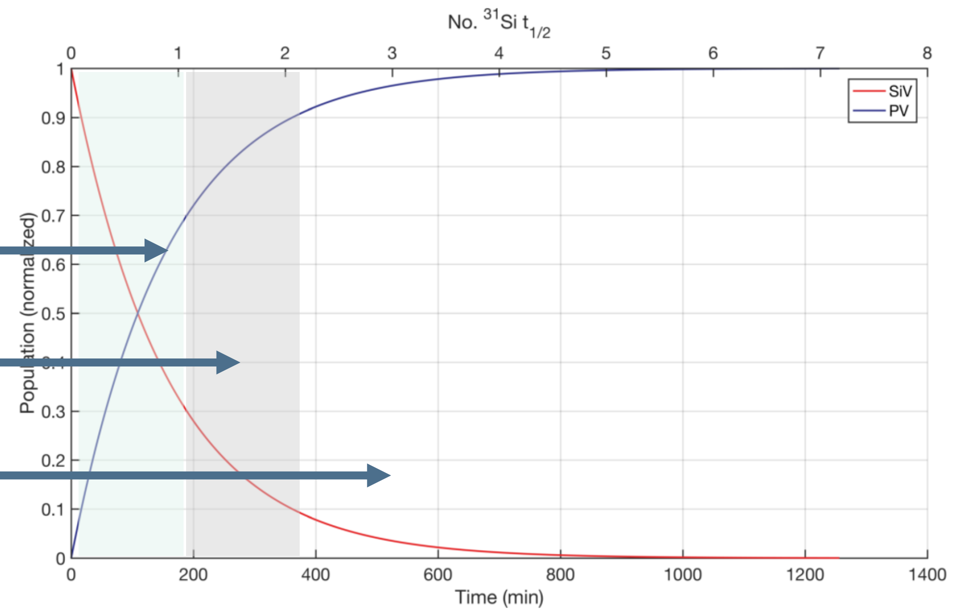
Production at ISOLDE

$^{31}Si \xrightarrow{157\ min} {}^{31}P$

Implant

Anneal

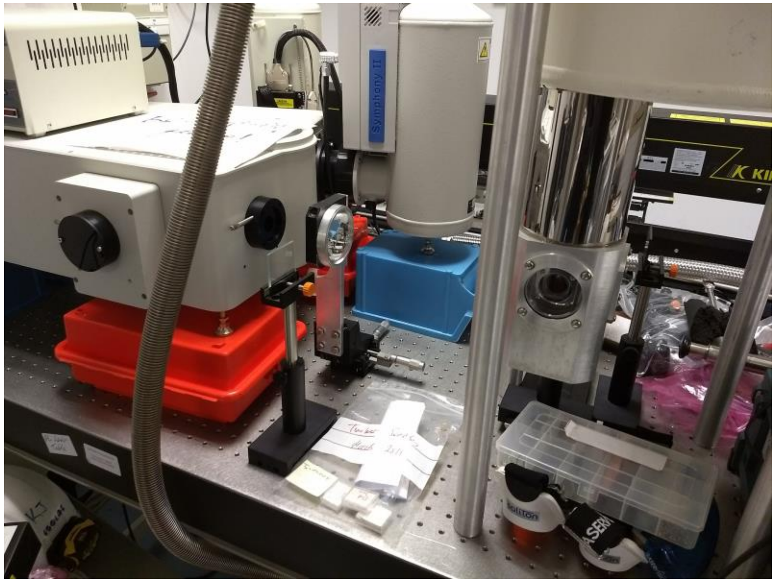
Measure



Time	No. ^{31}Si $t_{1/2}$	Stage	Notes
00:00	0	Implantation of ^{31}Al	Decays to Si with $t_{1/2}$<1 s
02:30	1.0	Insertion into furnace	Furnace at 850°C
04:30	1.7	Removal from furnace	
05:00	1.9	Insertion into cryostat	Cryostat pre-cooled to 100 K
05:30	2.1	PL measurements begin	

Measurement at ISOLDE

- Close proximity of implantation beam and measurement enables rapid turnaround
  - Measurements start at ~2 $t_{1/2}$
  - Matrix of doses (single to ensemble)
- Modular PL system
  - Simple to add additional excitation
- Wide detection window
  - High efficiency detection 350-1700 nm



➢ Conditions at ISOLDE are unique for maximising the probability of detecting PV^x

Charge state control

- Problem:
  - substitutional phosphorus in diamond is a donor (~0.6 eV)
  - PV is predicted to be a deep acceptor [1]

  ➔ Hard to stabilize neutral and positive charge states of PV:

  $$P^0 + PV^0 \rightarrow P^+ + PV^-$$

- Solution:
  - charge state control through doping and surface termination

  ➔ Light (~10^{17} cm^{-3}) B-doping → p-type

  ➔ Ultrapure (<10^{13} cm^{-3} impurities) material → intrinsic

  ➔ Samples to be supplied at zero cost by the Quantum Technologies group at Element Six Ltd.

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Conclusion

Primary goal:

- Identification and optical / spin characterization of PV^x in diamond

Approach:

- Use rapid turnaround, high-efficiency measurements at ISOLDE to maximise the chance of detecting transient decay of

$$^{31}SiV \rightarrow {}^{31}PV$$

- Use offline time between first and second requested runs to:
  - feedback from original measurements and optimize second run
  - perform additional experiments at Warwick e.g. confocal microscopy, optically detected magnetic resonance