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Quantitative effects of neutron irradiation on silicon radiation detectors

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on behalf of the

WODEAN collaboration

Can we find the concentrations of the different defects?

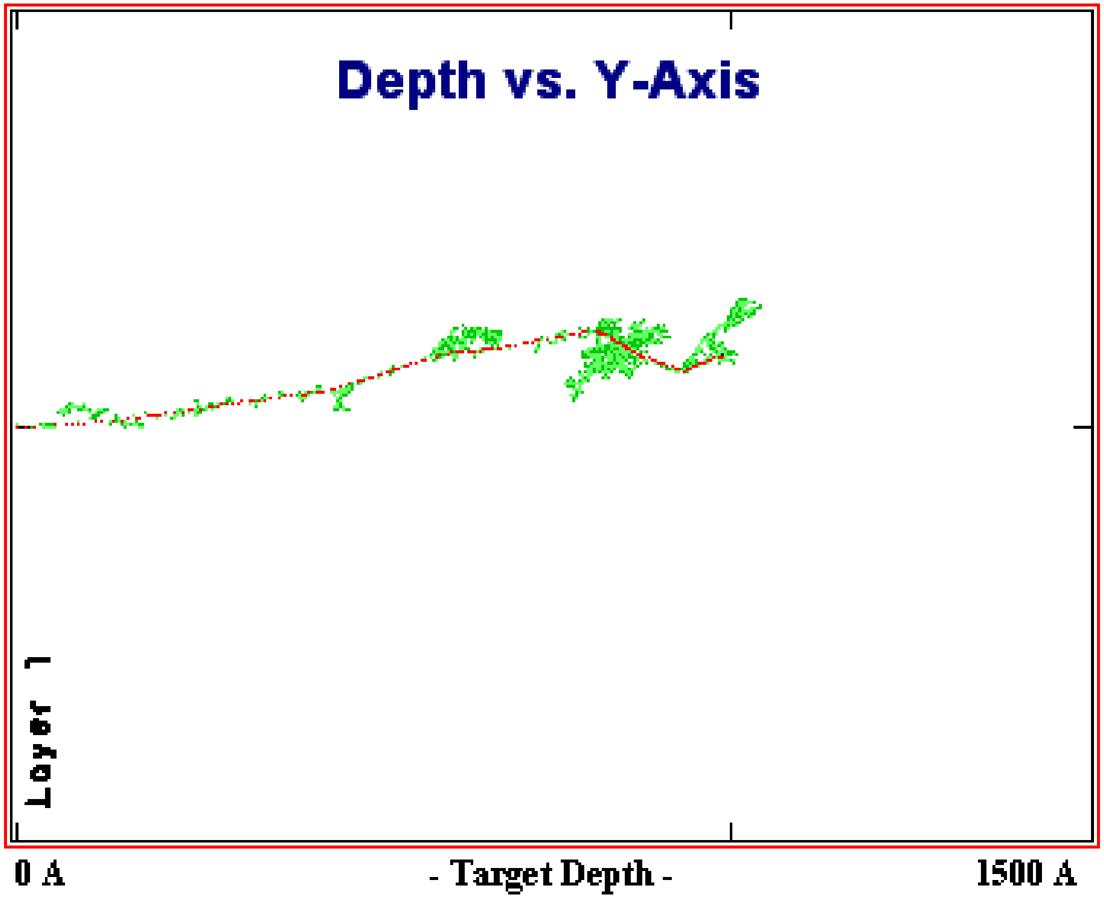
Outline

- Use TRIM as a guide to the amount of damage.
- We can separate the damage into ‘point defects’ and disordered regions.
- One example: I_2O and E4: leakage currents?
- What are the limits of our techniques?

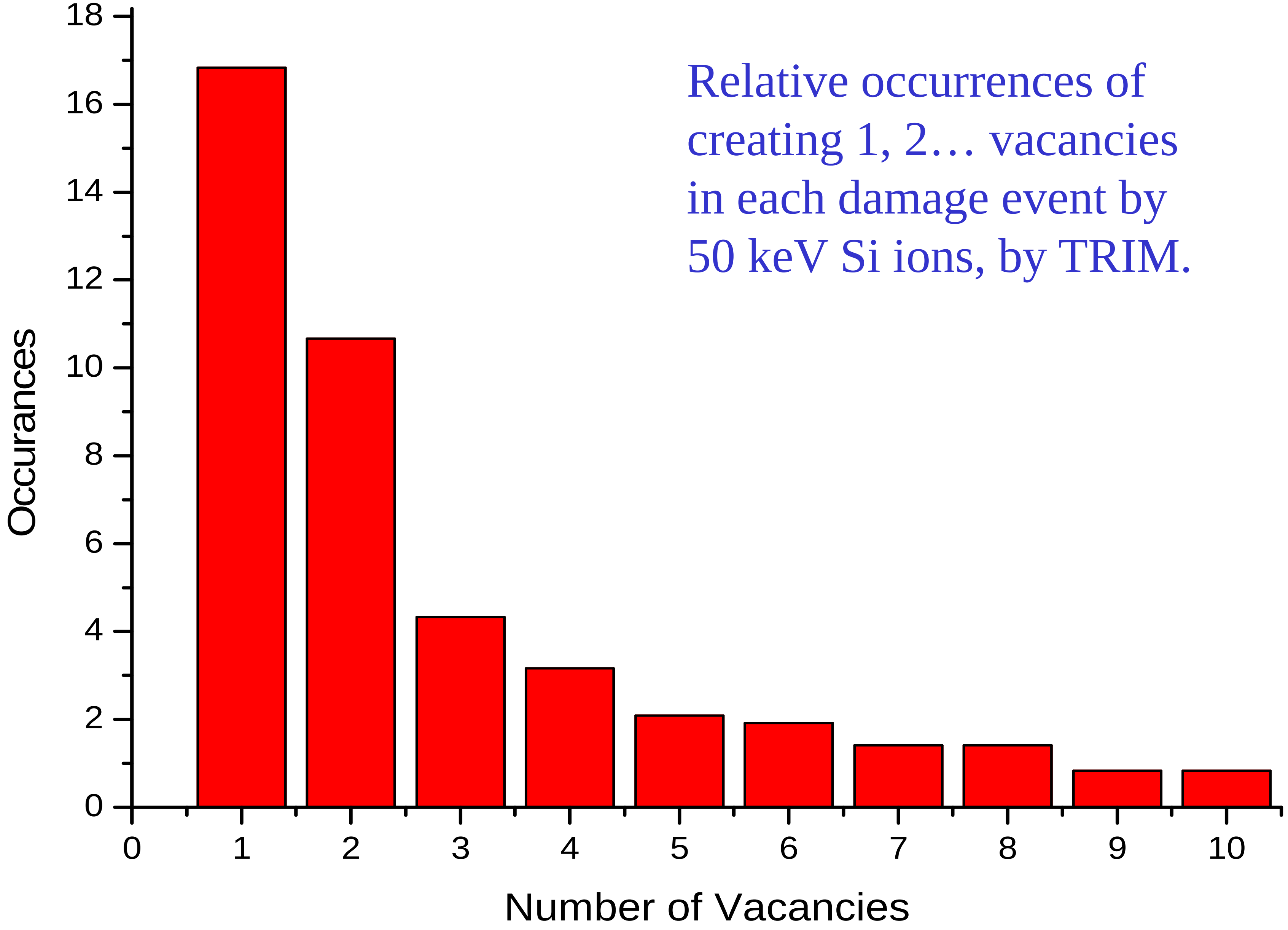
Samples

- n-type, [P] ~ 1e12 cm^{-3},
- oxygen [O] = 5e17 cm $^{-3}$,
- carbon [C] < 5e15 cm $^{-3}$.
- irradiations at the TRIGA reactor, fluence up to 3e16 cm $^{-2}$.
- cooled by water, stored ~ -20 ^{o}C.

Largest fluence, $3x10^{16}$ cm^{-2}, gives $3x10^{15}$ cm^{-3} tracks. Typical knock-out energy of Si atom is 50 keV. TRIM simulation of damage created by a 50 keV Si ion:



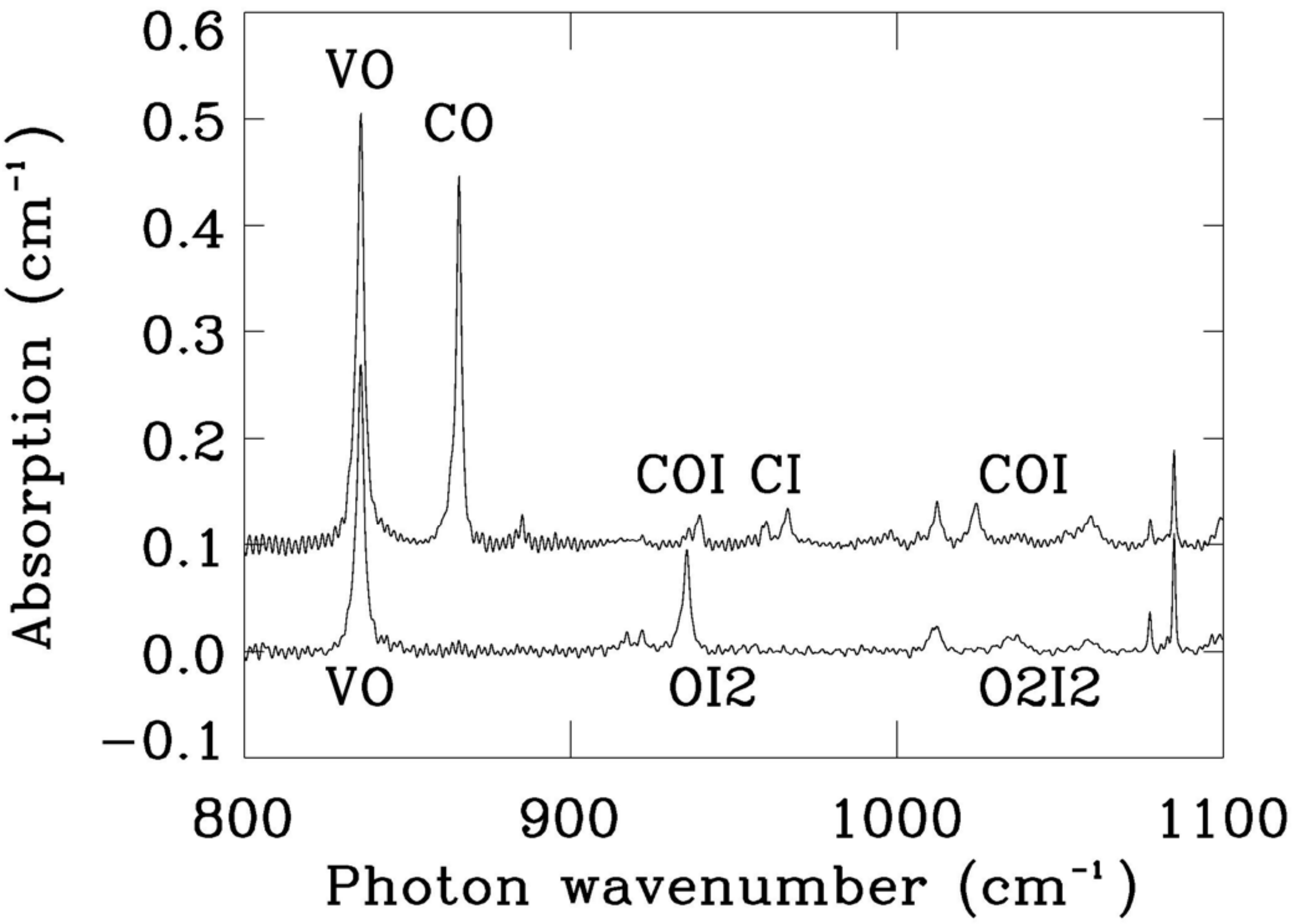
Each track has about 700 vacancies.



Relative occurrences of creating 1, 2… vacancies in each damage event by 50 keV Si ions, by TRIM.

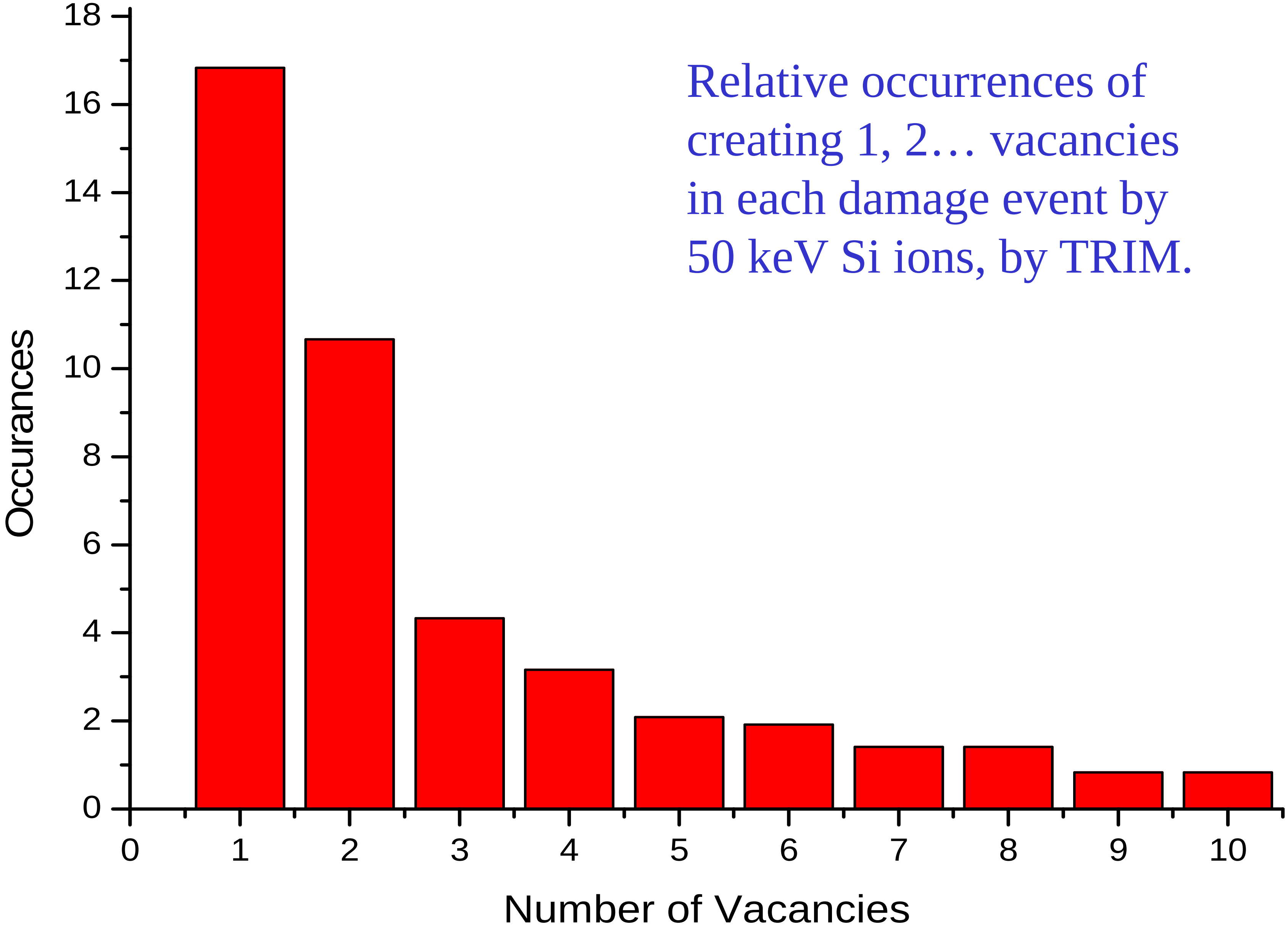
- Most of the damage (95%) is in the large disordered regions.
- But 5 % is in small damage events (V, V_2, V_3…)
- The small damage will have well-defined energy levels and so *can be measured accurately*.

Infrared absorption spectrum. (Murin)



Summary so far...

- TRIM suggests that we can separate the damage into ‘point defects’ and disordered regions.
- **One example of point defects: I_2O and E4: leakage currents?**

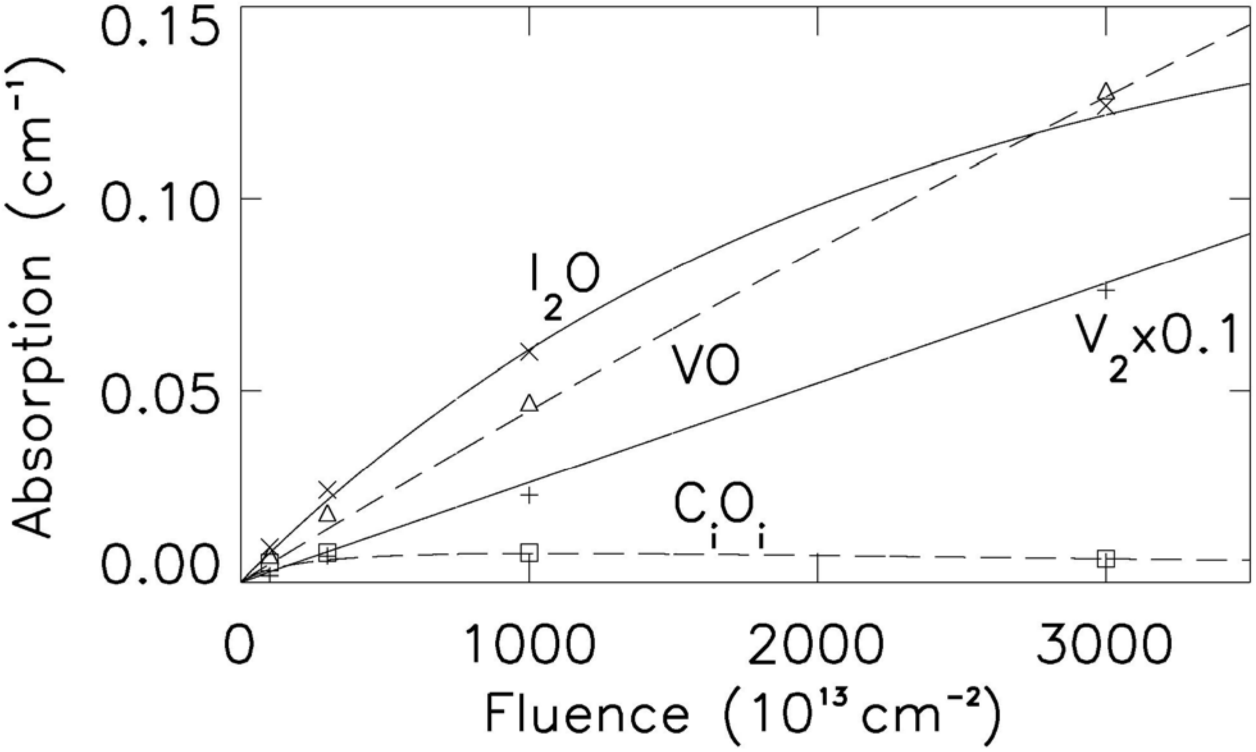


Relative occurrences of creating 1, 2… vacancies in each damage event by 50 keV Si ions, by TRIM.

Di-interstitials I_2

- Each 50 keV PKA produces about 11 double vacancies by direct displacement, according to TRIM.
- From proton irradiations, it appears that each V_2 also results in one I_2 , which is mobile and combines with O.
- [I_2O] should be *produced* in proportion to the fluence ...

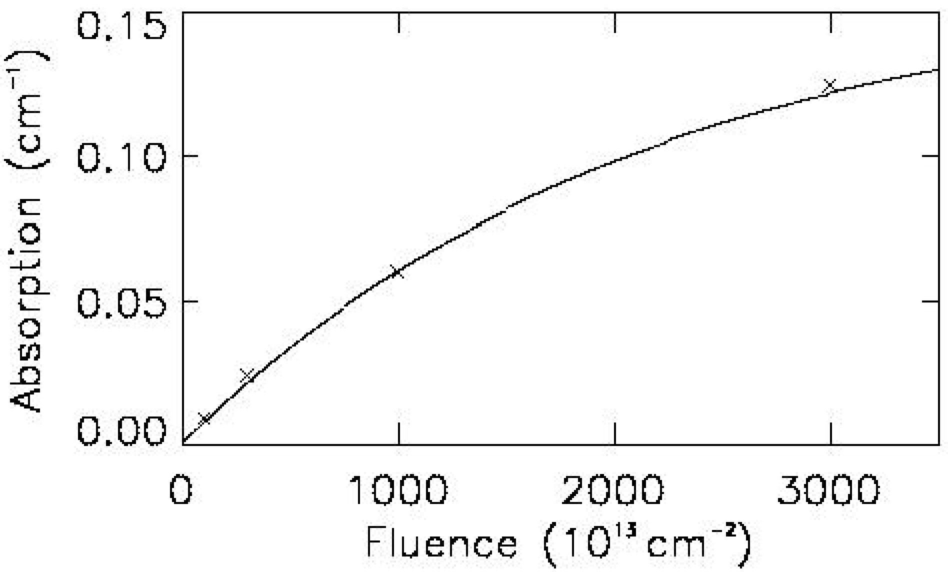
Apply the radiation damage model (as for electron irradiations):



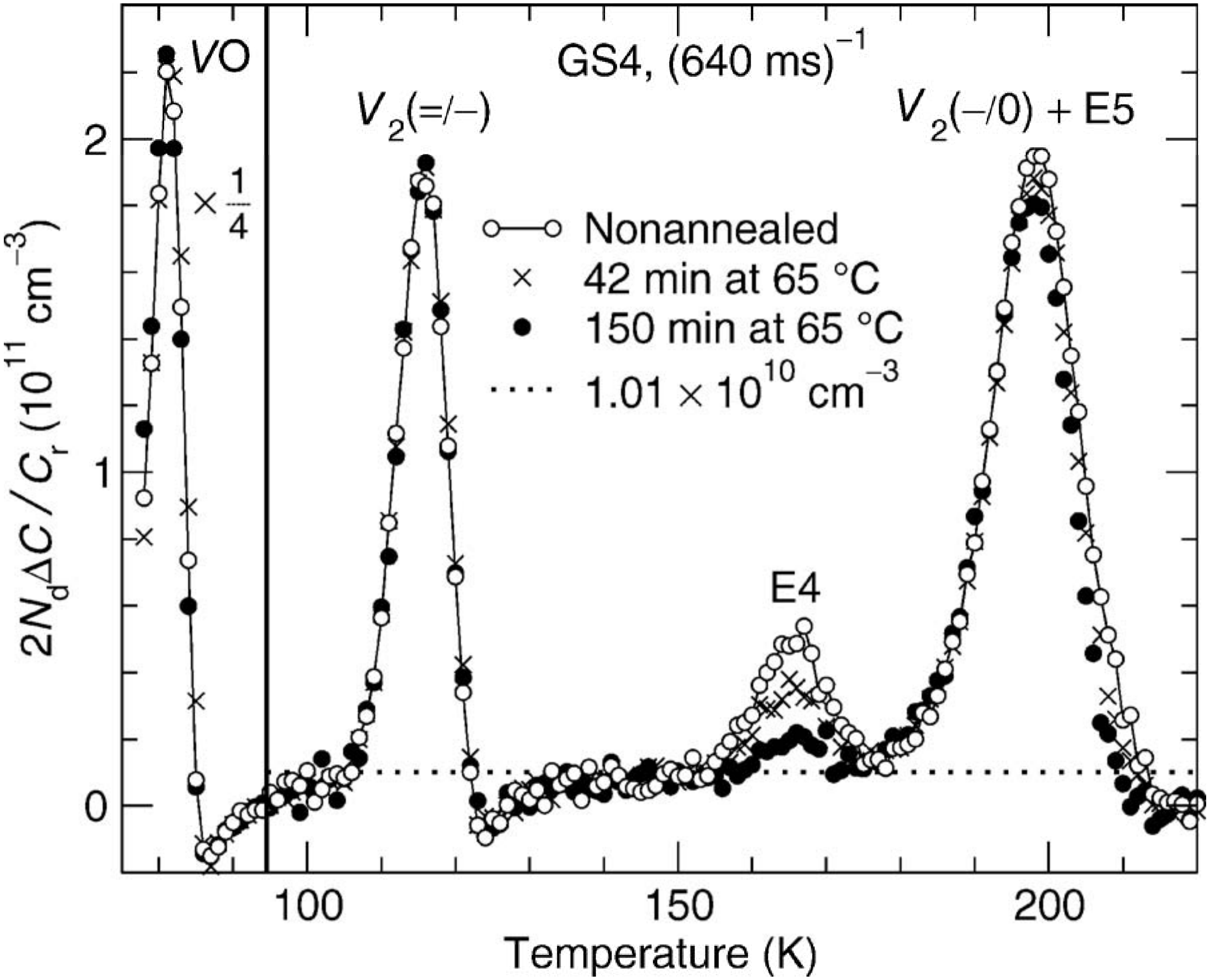
I_2O

- I_2O is not proportional to the fluence.
- It is not very stable:
- $\tau = \tau_o \exp (E / kT)$,
- $\tau_o = 4 \times 10^{-14}$ s, $E = 1.16 \pm 0.1$ eV (Murin).
- In an irradiation lasting time t, with I_2 produced at a rate r per second,
- $[I_2O] = r\tau [1 - \exp(-t/ \tau)]$.
- Hence, τ, and hence the irradiation temperature can be found:

I_2O measured and fitted.

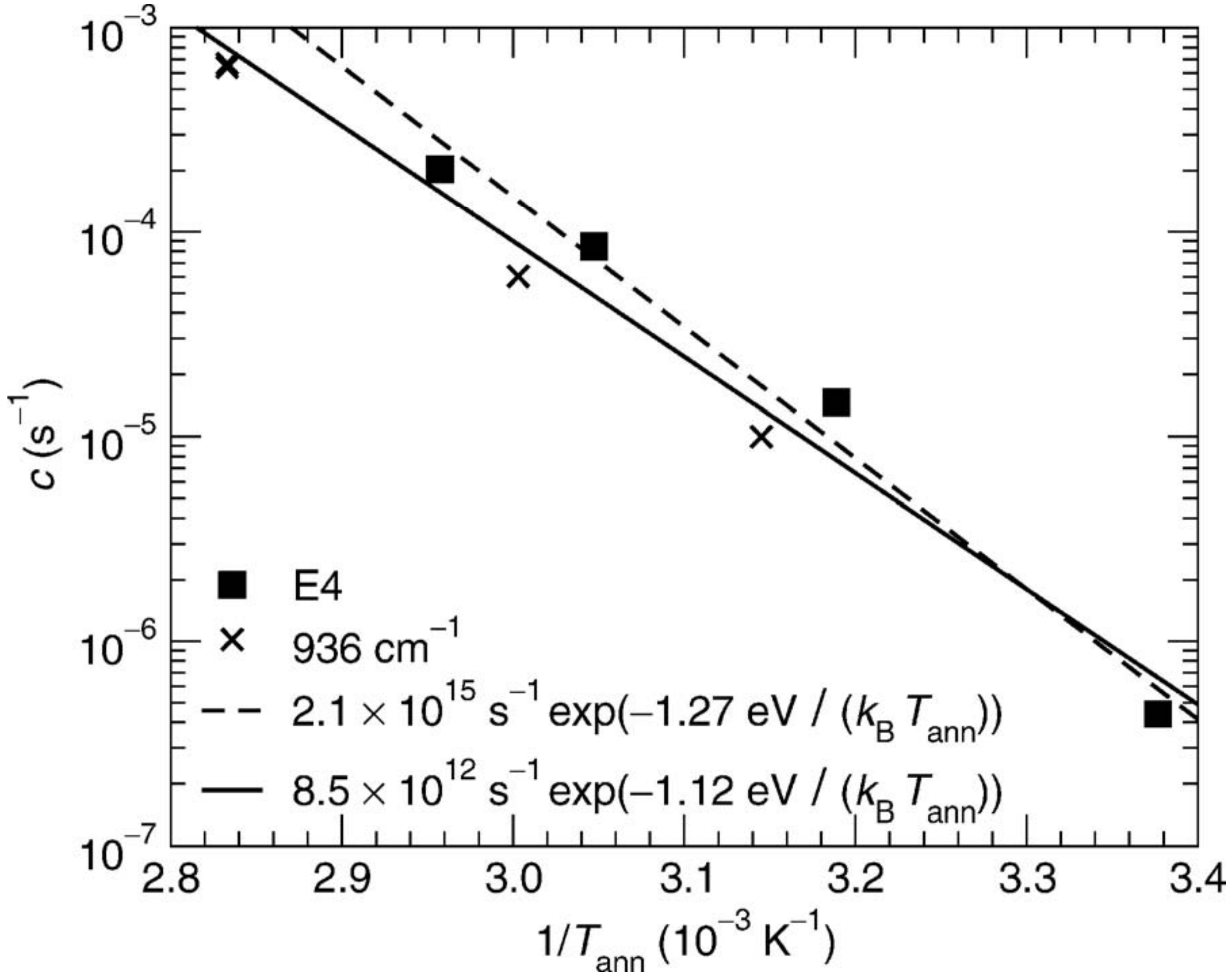


The time constant for the annealing gives an irradiation temperature of 62 °C.



E4 and E5

Bleka et al APL **92**, 132102 (2008)



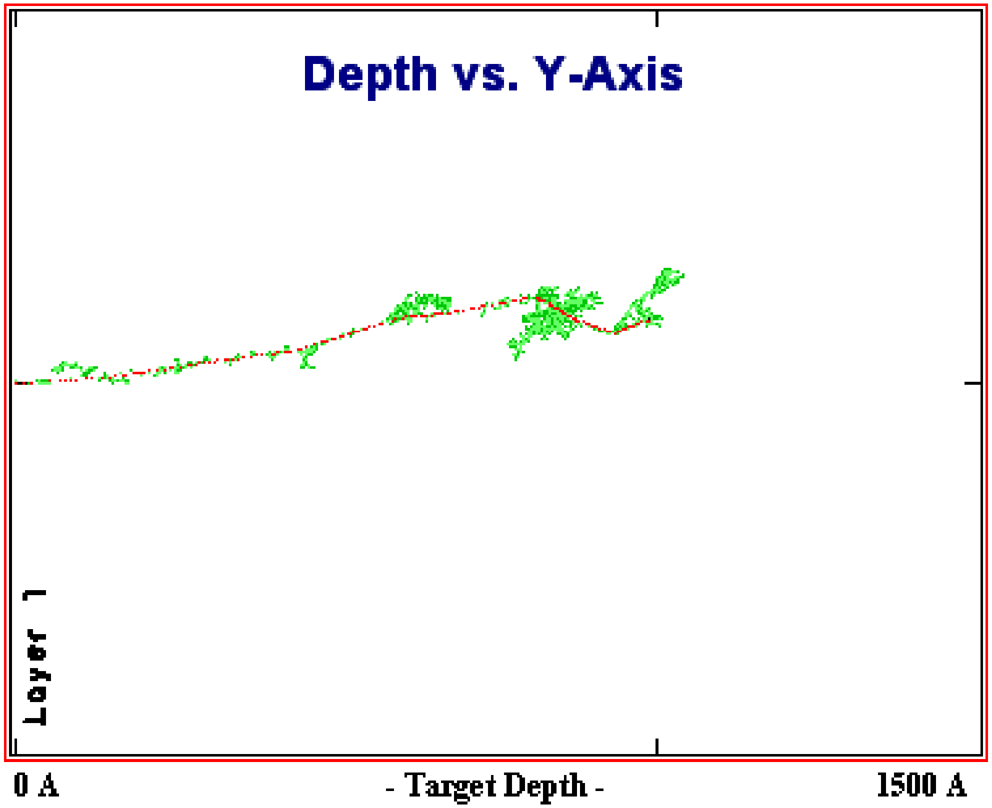
Annealing of E4 and I_2O.

Bleka et al APL **92**, 132102 (2008)

Summary so far...

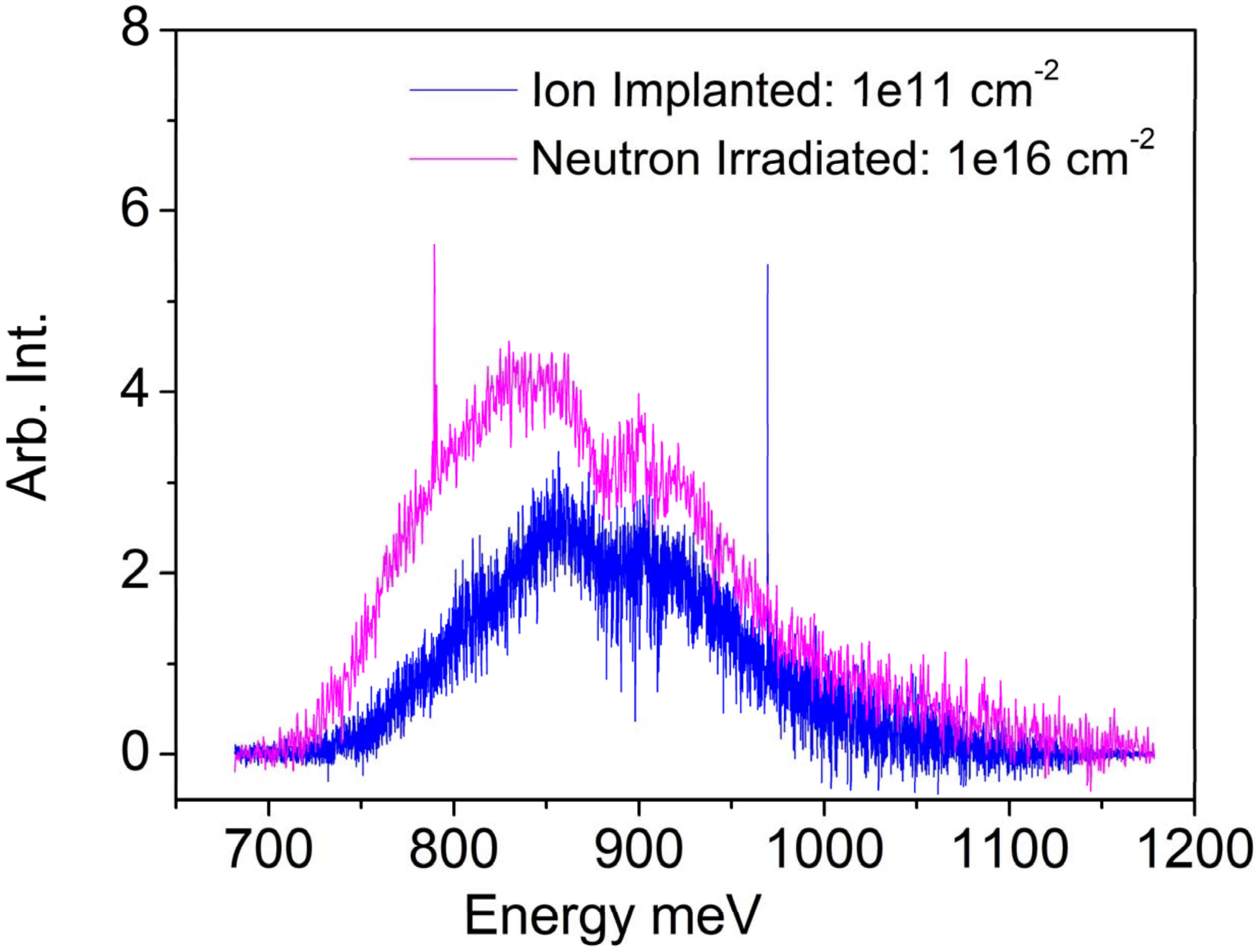
- TRIM says that we can separate the damage into ‘point defects’ and disordered regions.
- We can understand point defect production.
- **What are the limits of our techniques?**
- **Photoluminescence.**

Damage by neutrons is similar to implantation damage by Si ions. Use information from Si-ion implants.

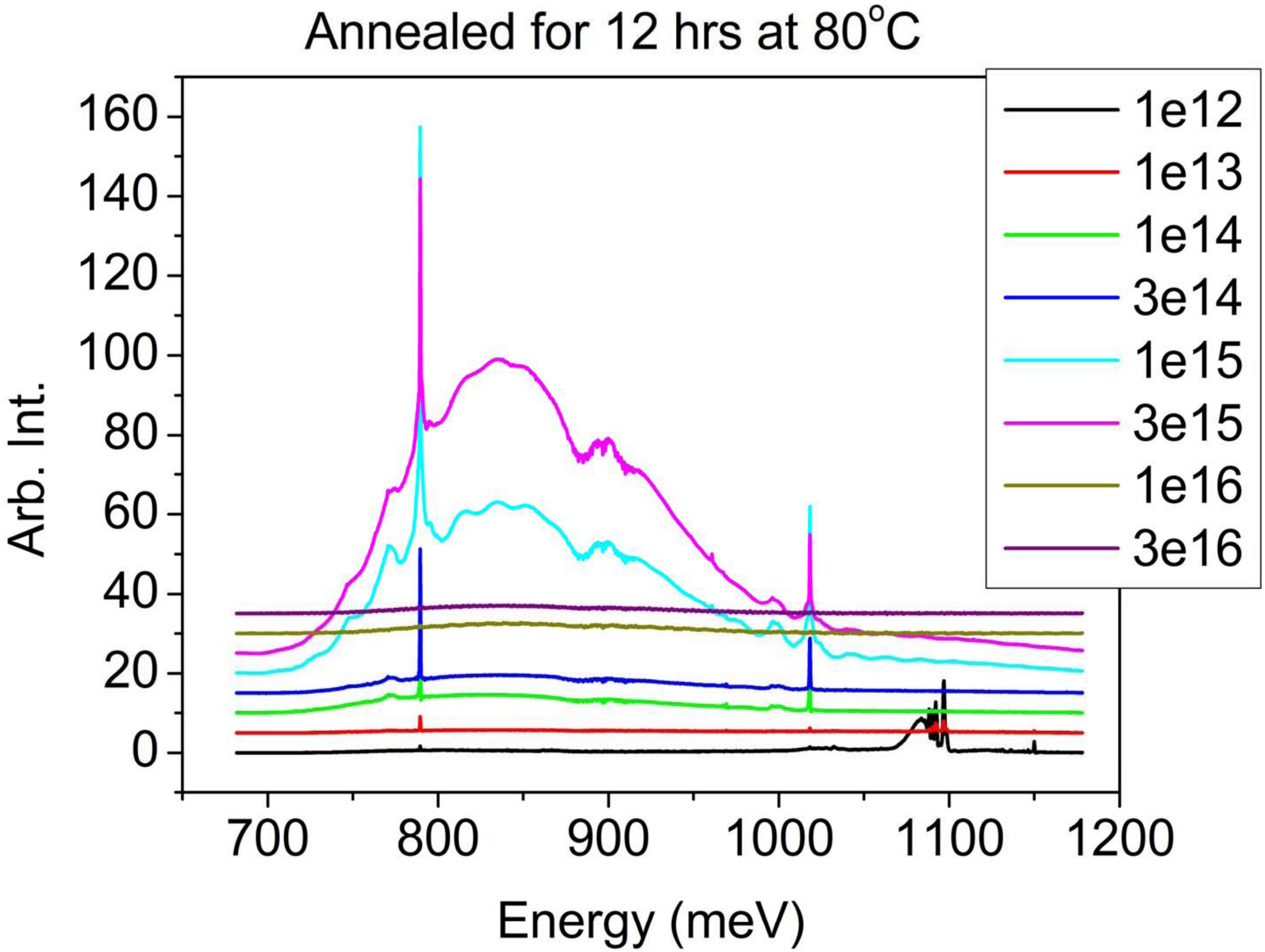


1e16 cm^{-2} neutrons create 7e17 cm^{-3} vacancies.

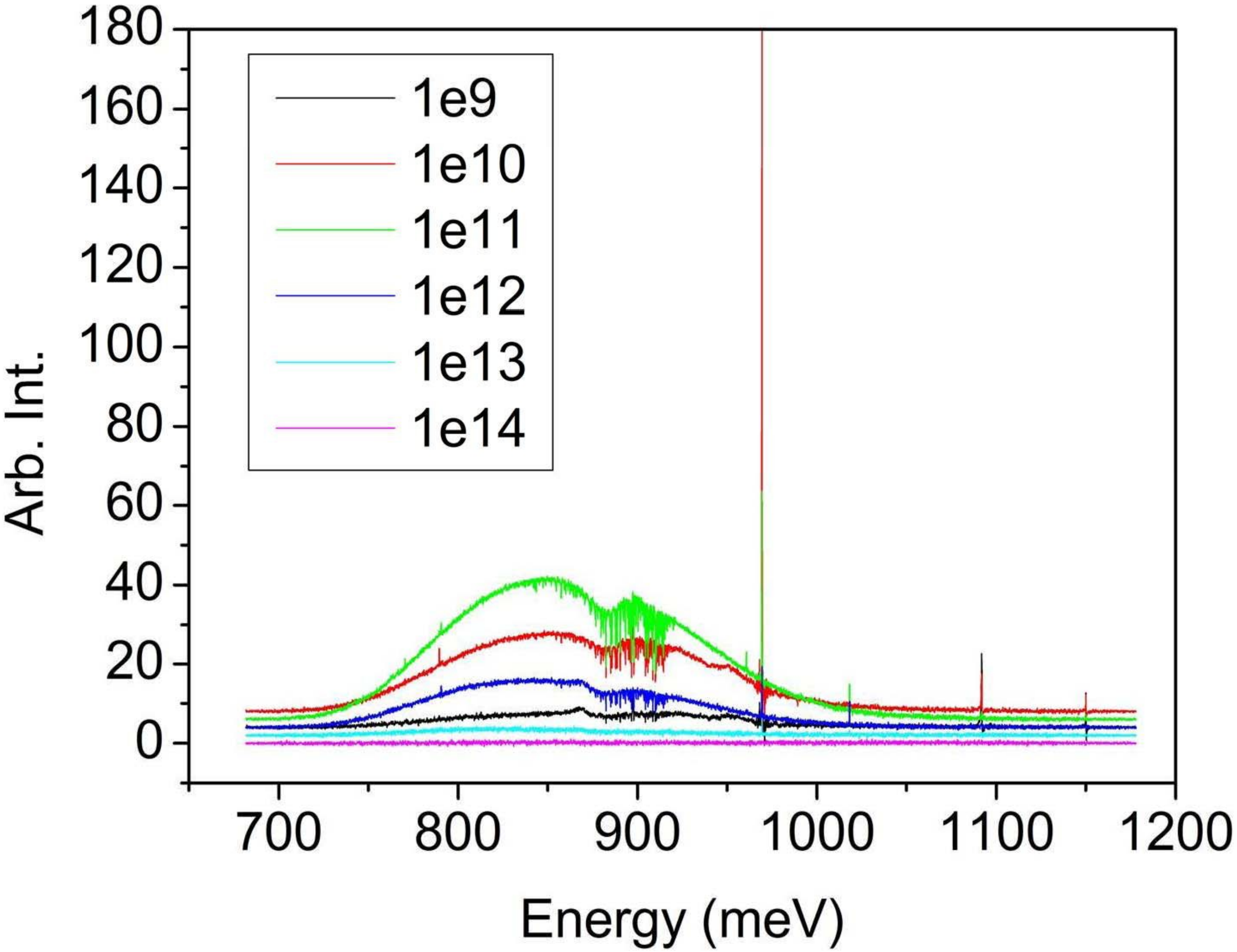
1e11 cm^{-2} 3-MeV Si ions create 1e18 cm^{-3} vacancies.



Comparison of neutron & ion damage; no anneal



Neutron damage

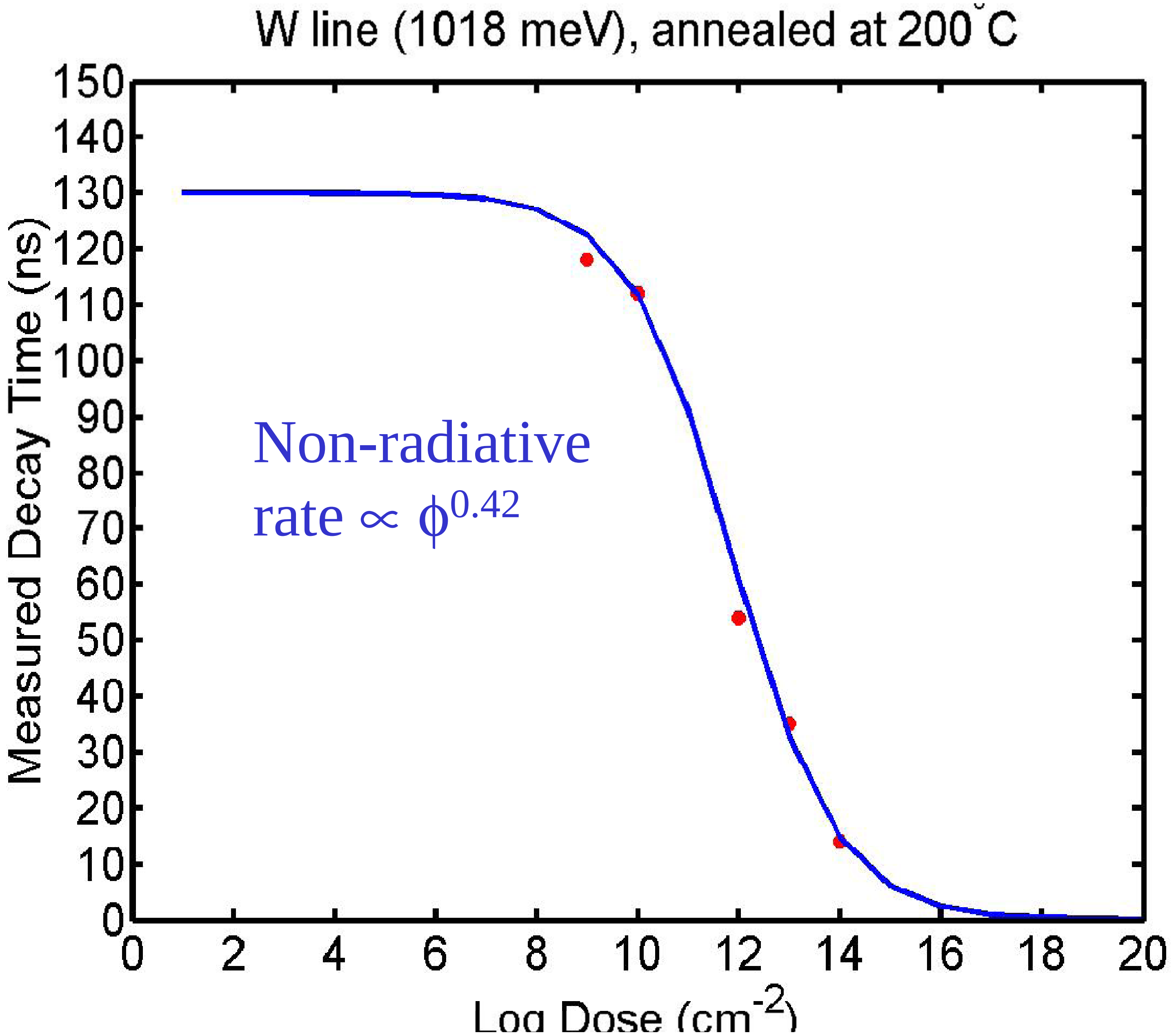


0

3 MeV Si ions; 100 C anneal, 1 hour

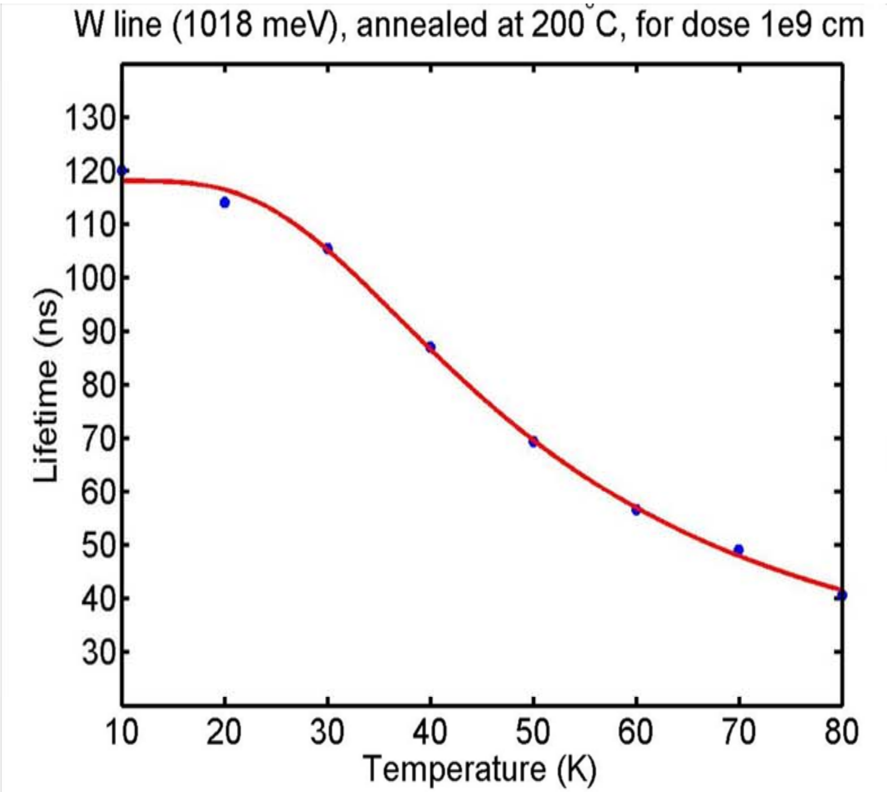
Comparison of neutron and ion damage

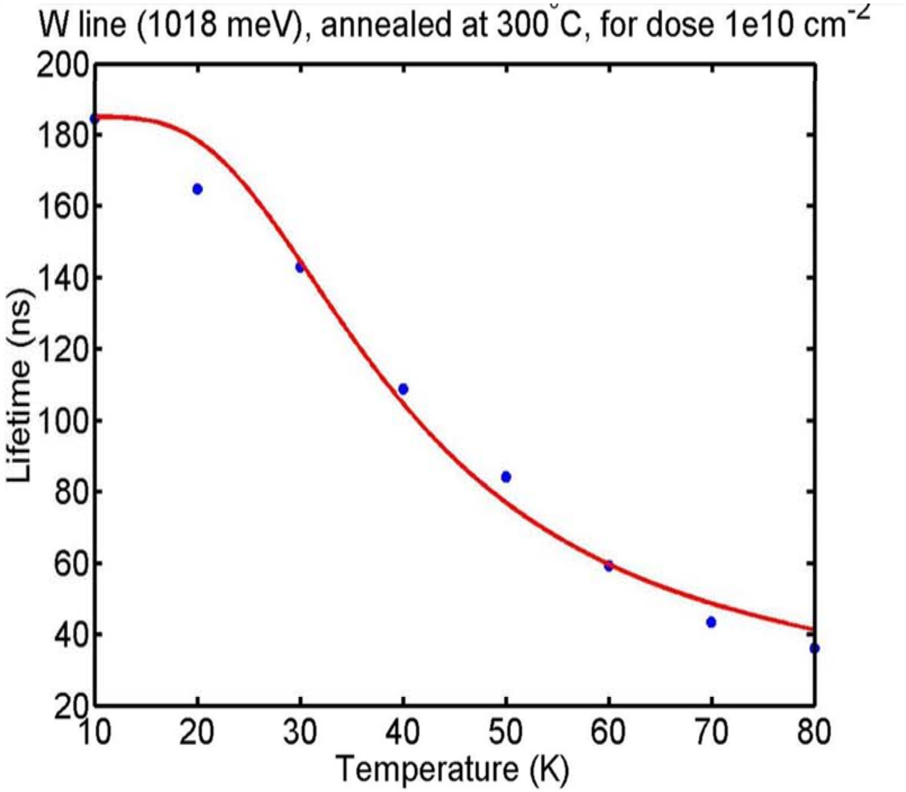
- To get similar levels of damage requires 1e5 times more neutrons than 3 MeV Si ions.



Non-radiative rate $\propto \phi^{0.42}$

3 MeV Si ion implants





Lifetime of PL from W centre; Si ion implanted.

Non-radiative decay activated with 11.2, 11.6 meV.

Energy can be transferred *to* and *from* the W centres.

Final summary

- Using TRIM as a guide to the amount of damage,
- We can separate the damage into ‘point defects’ and disordered regions.
- Point defects can be understood with our conventional modelling.
- Example: I_2O and E4.
- Our techniques are all limited - example of lifetime quenching for photoluminescence.