Dark Current curves:
Numerical Approach

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Introduction

- We studied the dependence of dark current with temperature when turning the LTA on and increasing the temperature.
    - Temperatures:
        - **135K, 150K, 160K** measured during ~**7 days**.
        - **170K** measured during ~**20 days**.
- We tried to **fit** the curves to a **sum of exponential** decays*.
    - Fitted to a maximum of **6 exponentials**. However:
        - All the curves could be fitted to 6 exponentials up to 12 (with good χ^2).
            - Equilibrium constant does not increased with temperature (the curves are not fully decayed).
            - The only curve that agrees with Erase and purge measurements is 170K.
- We tried to **fit** the curves to a **Power Law**. https://royalsocietypublishing.org/doi/pdf/10.1098/rspa.1945.0025
    - Equilibrium constant still does not increase with temperature.
        - The only one fitted to a positive value was the 170K curve.

*See other talks with the exponential results.

Power Law and numerical Model: Theory

- **Direct Power Law** → Continuum of traps energies from [0,∞] eV.
  - *A:* Density per energy level.
  - μ: Effective decay constant.
  - α: Energy shape parameter.
  - DC_{eq}: Equilibrium constant.
- **Numerical model** → We are measuring only the range $[E_{min}, E_{max}]$.
  - We need to compute the numerical solution of the integral in order to fit the curves.
    - We used scipy to do the numerical integral.
    - We used MINUIT to do the fit.
      - *MIGRAD, MINI, IMPROVE, HESSE, MINOS.*

Direct Power Law

$$DC = \int_0^\infty A\mu e^{-\mu t e^{-E/kT}} e^{-E/kT - \alpha E} + DC_{eq}$$

Solution ↓

$$DC = AkT\mu^{-\alpha kT}\Gamma(1+\alpha kT)\cdot t^{-1-\alpha kT} + DC_{eq}$$

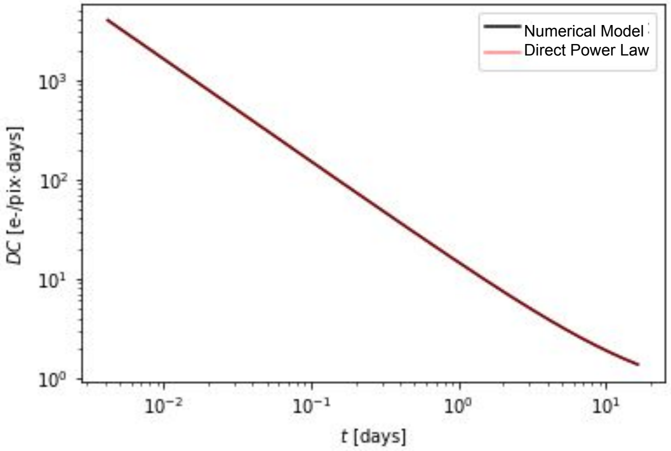
Numerical Model

$$DC = \int_{E_{min}}^{E_{max}} A\mu e^{-\mu t e^{-E/kT}} e^{-E/kT - \alpha E}$$

Assume the Population of traps is distributed as follows: $\frac{dN(E)}{dE} = Ae^{-\alpha E}$

170K curve: Power Law and numerical Model, Cross Checking

- Fitted the 170K curve to the **Numerical Model** with limits $E_{min} = 0$ and $E_{max} = \infty$.
- Using the **fitted parameters from the numerical in the Direct Power Law** → We obtained the **same curve.**



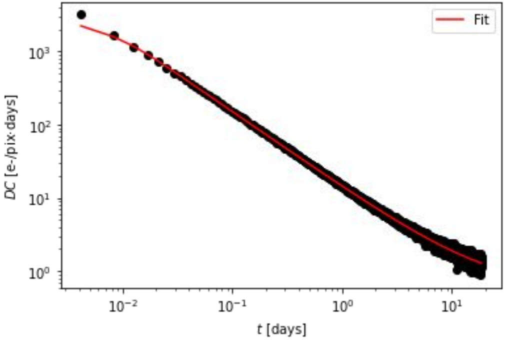
χ^2/ndf	A [e-/pix·eV]	μ [days^{-1}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]
1.43	1183	475	0	∞	2.2	0.6

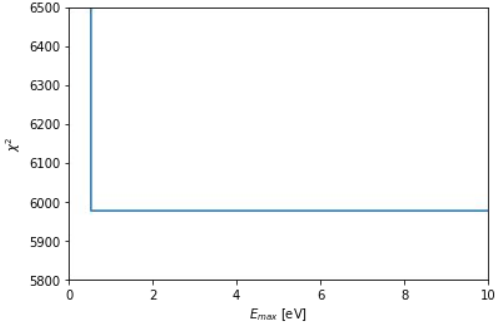
Parameters used to calculate the curve: Obtained from a curve fit with good χ^2.

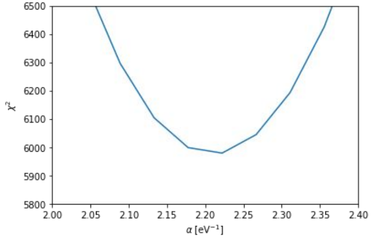
170K Curve:
Numerical model fit

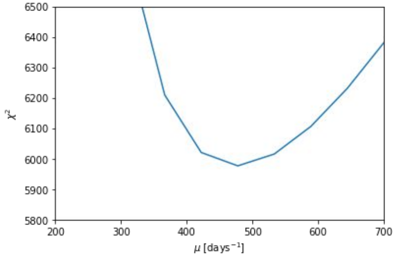
- We obtained a **good** χ^2 from the fitting to the **numerical model**.
  - We were able to fit the curve in the energy range of *[**0.01**, **6.9**]* **eV**.

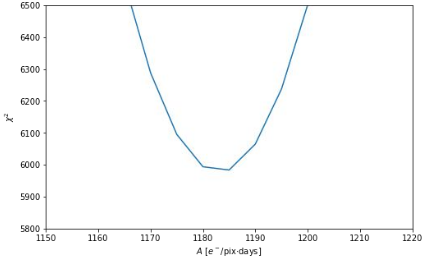
- The **fit converge**.
  - E_{max} doesn't have a minimum.
  - We have a flat χ^2 region in the energy ranges ~[1.9,10] eV.
  - All the other variables are in a χ^2 minimum.







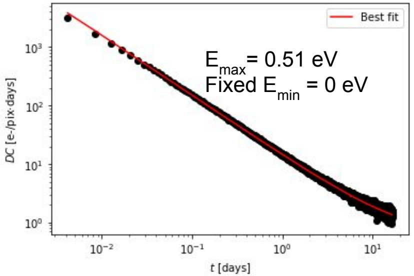


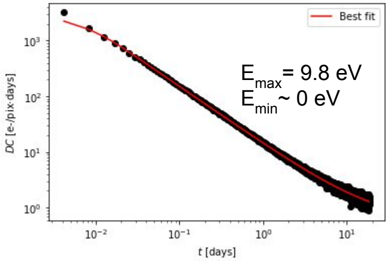


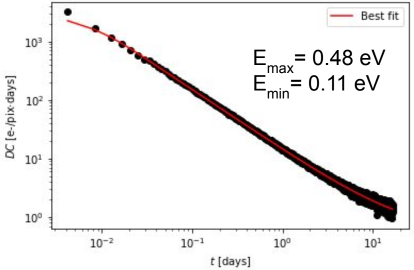
χ^2/ndf	A [e-/pix·eV]	μ [days^{-1}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]
1.35	1183 ± 8	475 ± 105	0.012 ± $3\cdot10^{-3}$	6.9 ± 6.3	2.21 ± 0.04	0.607 ± 0.004

170K Curve: Numerical model fit: other results

- Changing the initial parameters, steps of the fit and number of iterations (up to $5{\cdot}10^5$).
    - None of the fits converged.
    - Fits with good χ^2, but different parameters.
    - Energy ranges changes from [0.18,9] eV.
    - μ value moves from 10^5 to 10^3 days^{-1}.
    - A is not much affected.
    - α can change from [2,5] eV^{-1}.
    - DC_{eq} is not much affected.



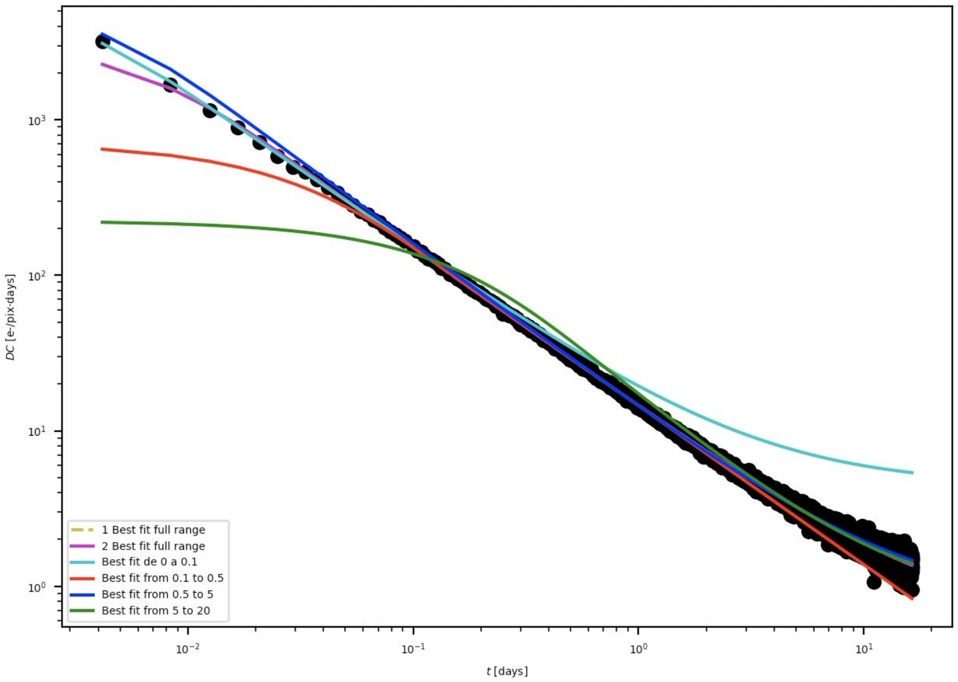




χ^2/ndf	A [e-/pix·eV]	μ [days^{-1}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]
1.43	1172	961	**0**	0.51	1.85	0.57
1.35	1256	3073	0.03	**9.8**	2.21	0.6
1.32	1451	379342	**0.11**	0.48	2.14	0.59

170K Curve: Numerical model fit: fitting by ranges

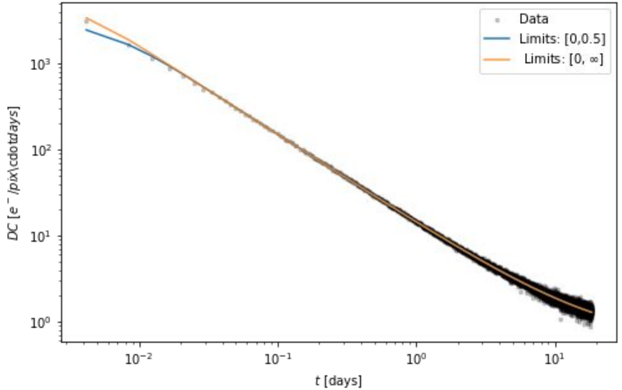
- ***t < 0.1* days**.
  - The χ^2 for the fitted range is good.
  - With the full curve:
    - The first points are better fitted.
    - The last points of the curves are bad fitted.
- **0.5 ≤ t ≤ 20**.
  - The χ^2 for the fitted range is good.
  - With the full curve:
    - The first points are bad fitted.
    - The last points are well fitted.

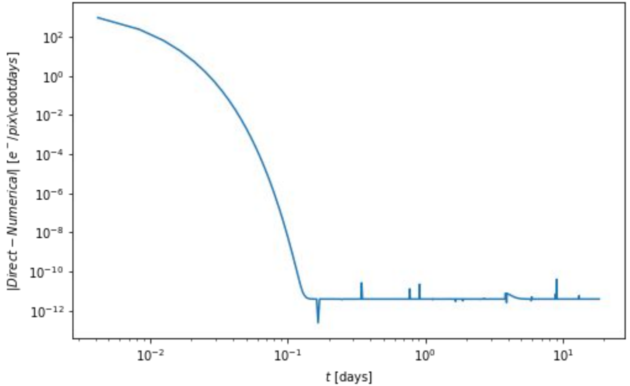


170K Curve: Direct Power Law and Numerical Model fitting by ranges

Compared the numerical model with energy **limits** [**0,∞**] **eV and** *[****0.11,0.48****]* **eV:**

- The **difference** between an infinite and discrete **depends** on the ***t*** < ***0.02*** **days region** of the curve.
  - This region has the less measurements.
  - This makes harder to determine the E_{max} value.





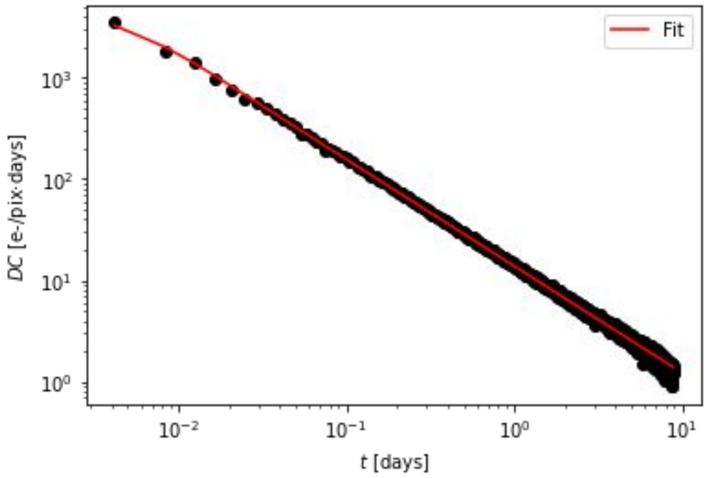
A [e-/pix·eV]	μ [days^{-1}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]
1183	475	0	0.48	2.2	0.6
1183	475	0	∞	2.2	0.6

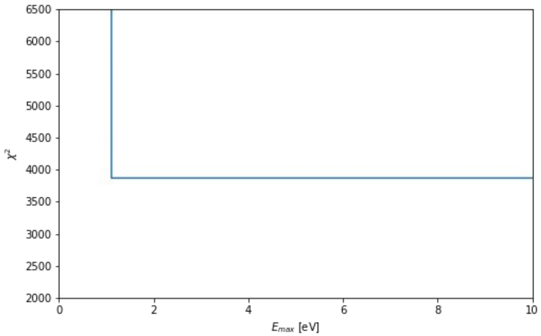
160K curve: Numerical Model Fit

The **fit converge**:

- The χ^2 of the fit is good.
- The range of energies is ***[0,0.36]* eV.**
    - E_{min} very similar to curve 170K,
    - but not E_{max}, which is pretty small
- Equilibrium constant is ~0 e-/pix·days.

- **E_{max} is not at a minimum** (again, like 170K curve)





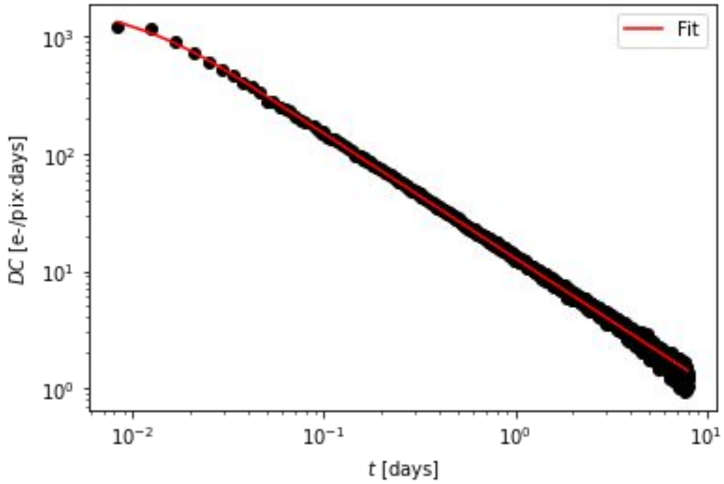
χ^2/ndf	A [e-/pix·eV]	μ [days^{-1}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]
1.84	1447 ± 12	558 ± 86	0.007 ± $2 \cdot 10^{-3}$	0.36 ± 7	3.8 ± 0.03	$7 \cdot 10^{-11}$ ± $1 \cdot 10^{-4}$

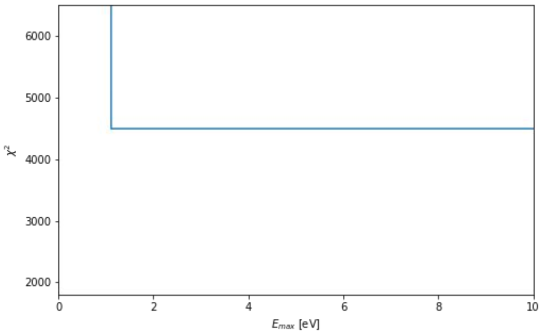
150K curve: Numerical Model Fit

The **fit converge**:

- The χ^2 of the fit is good.
- The range of energies is ***[0.01,6.9]* eV.**
  - consistent with curve 170K
- Equilibrium constant is ~0 e-/pix·days.

- **E_{max} is not at a minimum** (again as the previous curves)





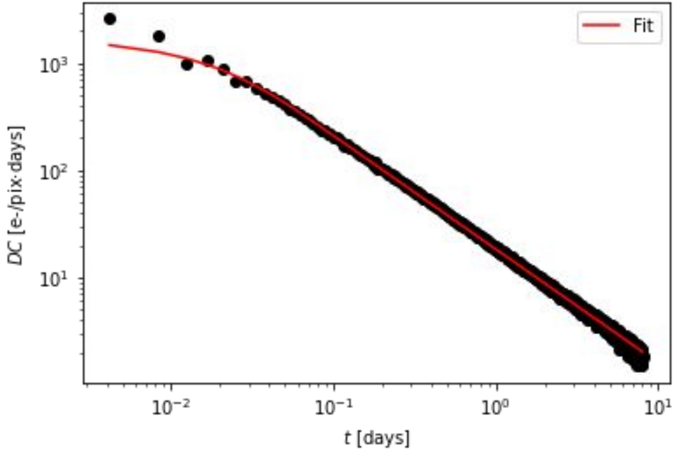
χ^2/ndf	A [e-/pix·eV]	μ [days^{-1}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]
1.43	1517 ± 12	396 ± 47	0.01 ± $2\cdot10^{-3}$	6.9 ± 6.3	4.98 ± 0.04	$1.1\cdot10^{-12}$ ± $1\cdot10^{-4}$

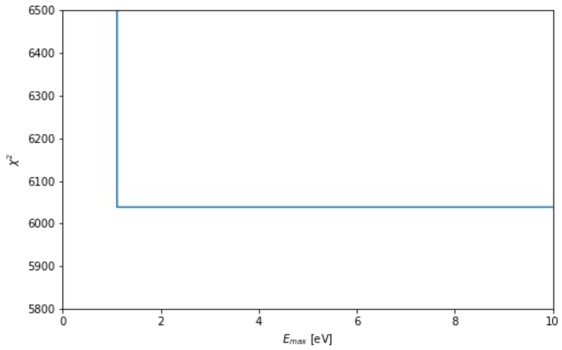
135K curve: Numerical Model Fit

The **fit converge**:

- The χ^2 of the fit is good.
- The range of energies is *[0,2]* **eV.**
    - E_{min} consistent with 150K
    - E_{max} energy is half of the one for 170K
- Equilibrium constant is ~0 e-/pix·days.

- **E_{max} is not at a minimum** (again as the previous curves)



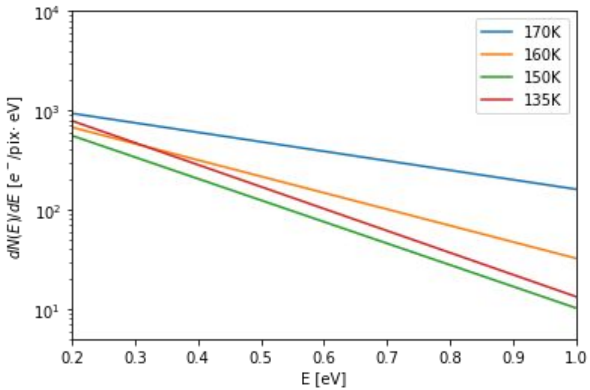


χ^2/ndf	A [e-/pix·eV]	μ [days^{-1}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]
3.20	2182 ± 8	137 ± 12	0.007 ± $9\cdot10^4$	2 ± 8	5.09 ± 0.04	$1\cdot10^{-12}$ ± $1\cdot10^{-4}$

All curves: Energy level population

Population of traps: $\frac{dN(E)}{dE} = Ae^{-\alpha E}$

- The **density of traps** per energy level **depends on temperature**.
  - α decreases with temperature.
  - However, the theoretical expression does not have a dependence with temperature.



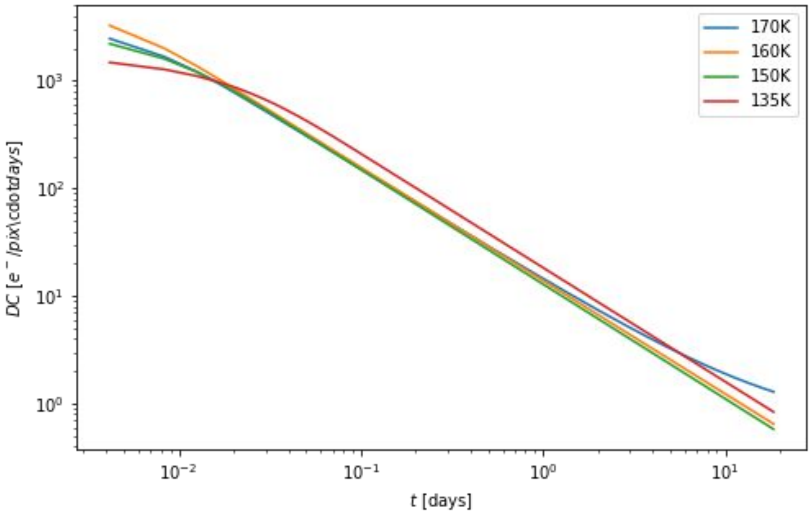
T [K]	χ^2/ndf	A [e^-/pix]	α [eV^{-1}]
170	1.38	1451	2.2
160	1.73	1447	3.8
150	1.43	1517	5.0
135	3.21	2182	5.1

All Curves: Fitted Parameters

T [K]	χ^2/ndf	A [e-/pix·eV]	μ [days^{-1}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]
135	3.20	2182 ± 8	137 ± 12	$0.007 \pm 9\cdot10^{-4}$	2 ± 8	5.09 ± 0.04	$1\cdot10^{-12} \pm 1\cdot10^{-4}$
150	1.43	1517 ± 12	396 ± 47	$0.01 \pm 2\cdot10^{-3}$	6.9 ± 6.28	4.98 ± 0.04	$1.1\cdot10^{-12} \pm 1\cdot10^{-4}$
160	1.84	1447 ± 12	558 ± 86	$0.007 \pm 2\cdot10^{-3}$	0.36 ± 7	3.8 ± 0.03	$7\cdot10^{-11} \pm 1\cdot10^{-4}$
170	1.35	1183 ± 8	475 ± 105	$0.012 \pm 3\cdot10^{-3}$	6.9 ± 6.3	2.21 ± 0.04	0.607 ± 0.004

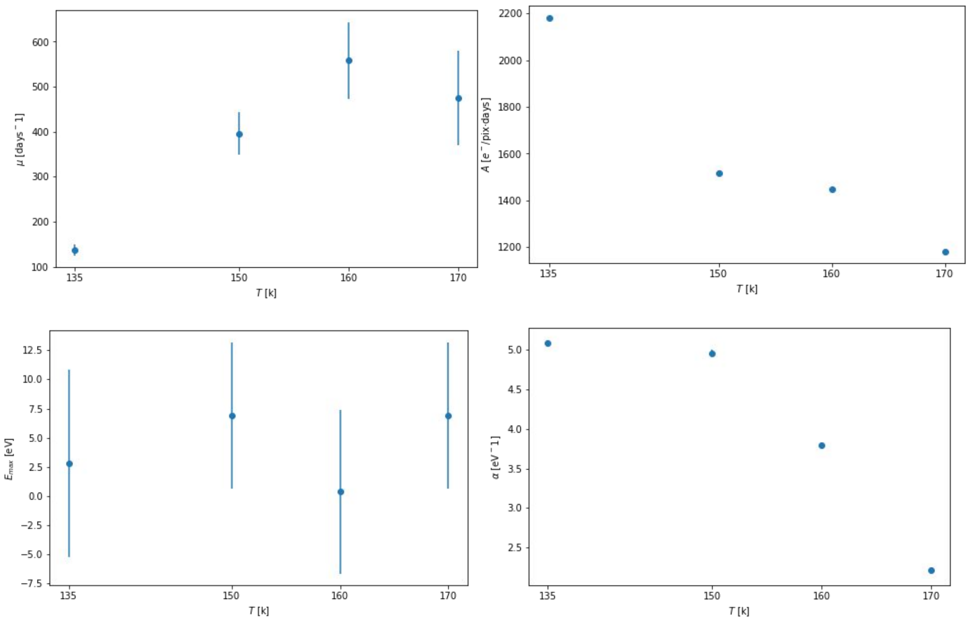
All curves: Numerical Model Fit Comparison

- The 135K is the most different of all the curves. The curves are different in time ranges:
    - At ***t*** < ***0.02*** **days**.
    - At ***t*** > ***10*** **days** (135,150,160 curves are measured until ~8days).
- In the ***0.02*** ≤ ***t*** ≤ ***10*** **days** all the curves are close to each other (except 135K).



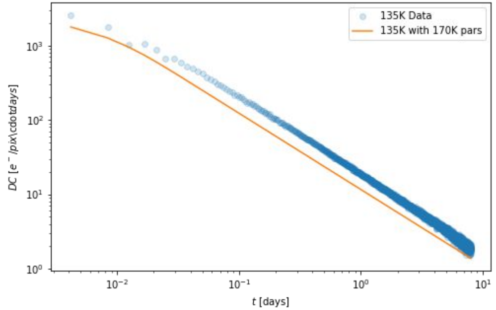
All curves: Parameters Evolution With Temperature

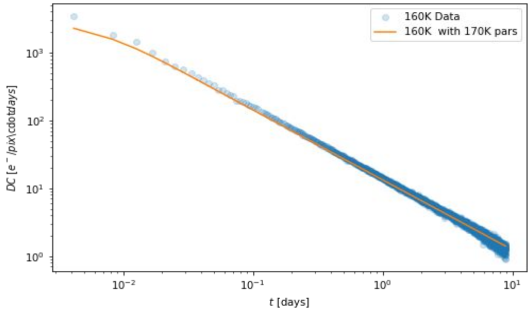
- E_{max} are compatible within the error.
- μ increases with temperature (except 170K).
- A decreases with temperature.
- α decreases with temperature

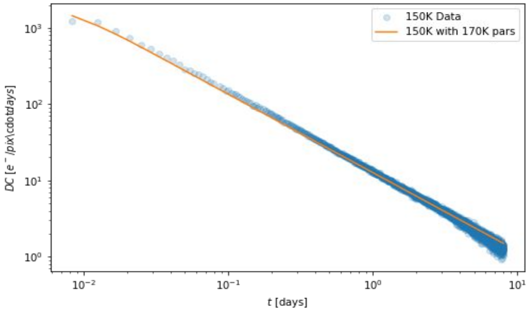


Different temperatures with 170K fitted parameters

- Extrapolated the numerical model with the 170K fitted parameters to other temperatures.
    - The 160K and 150K extrapolated model is not to far away of the data points.
    - The 135K extrapolated model does not match the the data.

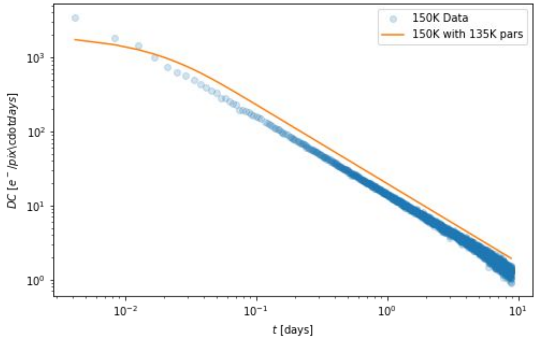


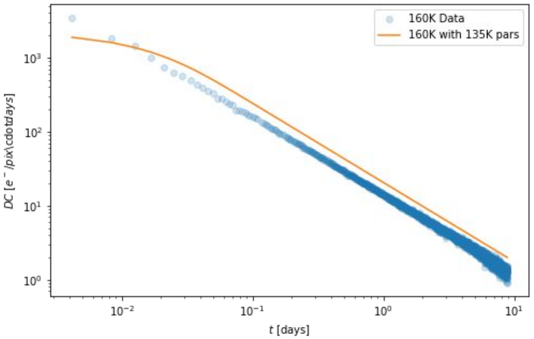


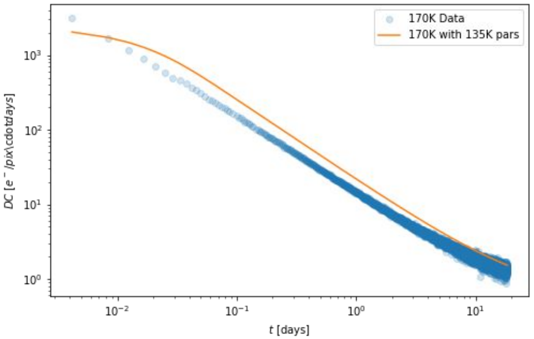


Different temperatures with 135K fitted parameters

- Extrapolated the numerical model with the 135K fitted parameters to other temperatures.
  - The extrapolated model does not match the data points at any temperature.

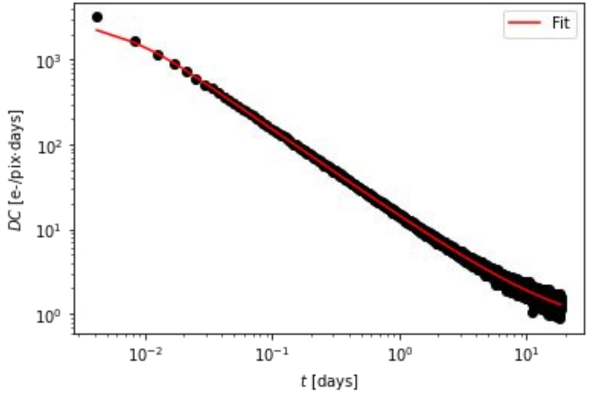




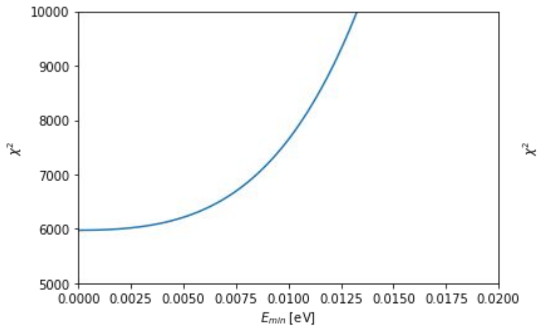


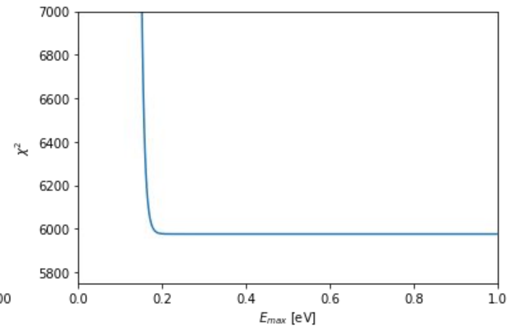
Limiting E_{max} and E_{min}: 170K Curve

- We fix $E_{min} = 0$ and $E_{max} = \infty$ and fit the curve.
- We calculate the χ^2 of E_{max} and E_{min}.
  - E_{max} is flat from in the range ~[0.17,∞] eV.
  - E_{min} is flat from in the range ~[0,0.0025] eV.



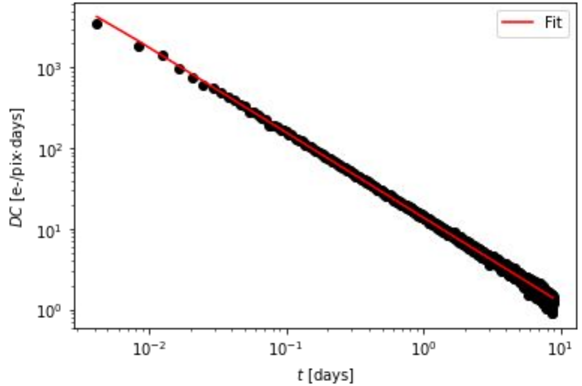
χ^2/ndf	A [e-/pix·eV]	μ [days^{-1}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]
1.35	1151 ± 3	205 ± 8	0	∞	2.21 ± 0.04	0.601 ± 0.004

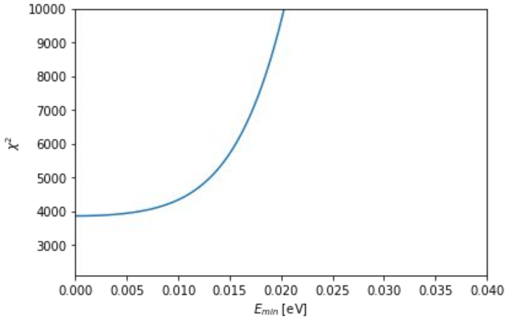


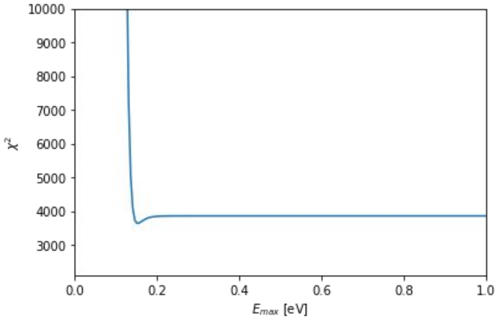


Limiting E_{max} and E_{min}: 160K Curve

- We fix $E_{min} = 0$ and $E_{max} = \infty$ and fit the curve.
- We calculate the χ^2 of E_{max} and E_{min}.
  - E_{min} is flat from in the range ~[0,0.0025] eV.
  - E_{max} is flat from in the range ~[0.19,∞] eV.
    - E_{max} has a mininum in ~0.17 eV.



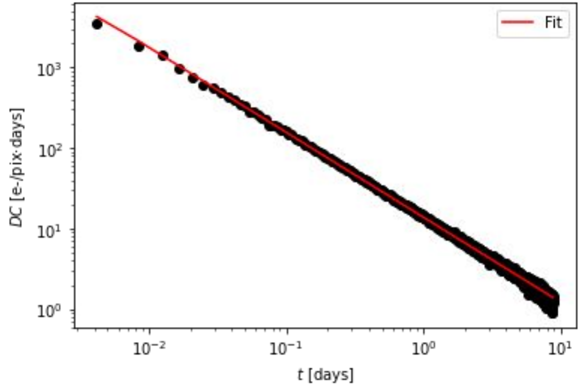


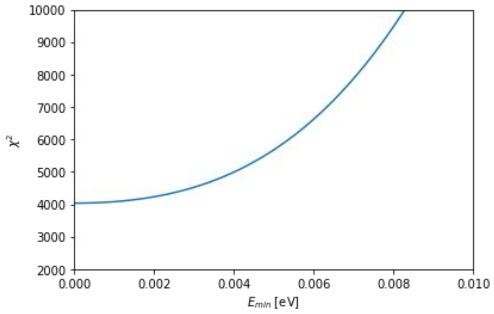


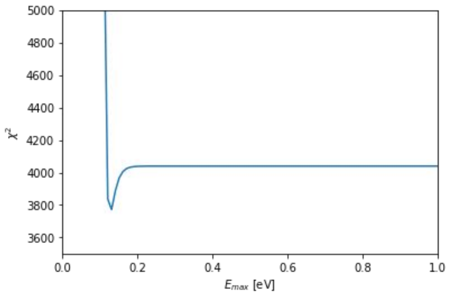
χ^2/ndf	A [e-/pix·eV]	μ [days^{-1}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]
1.92	1408 ± 4	335 ± 2	0	∞	3.82 ± 0.02	$8\cdot10^{-13} \pm 10^{-4}$

Limiting E_{max} and E_{min}: 150K Curve

- We fix $E_{min} = 0$ and $E_{max} = \infty$ and fit the curve.
- We calculate the χ^2 of E_{max} and E_{min}.
    - E_{min} is flat from in the range ~[0,0.0025] eV.
    - E_{max} is flat from in the range ~[0.19,∞] eV.
        - E_{max} has a minimum in ~0.17 eV.



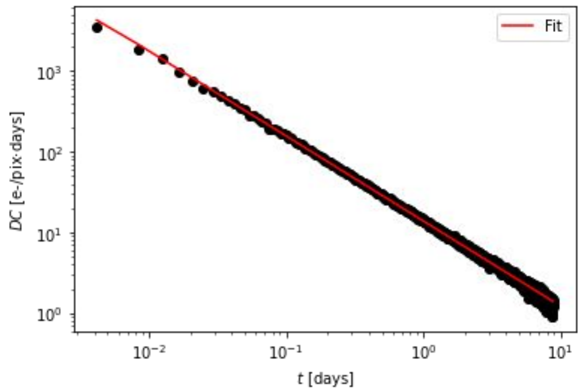


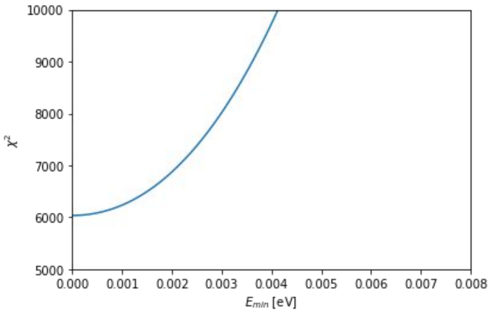


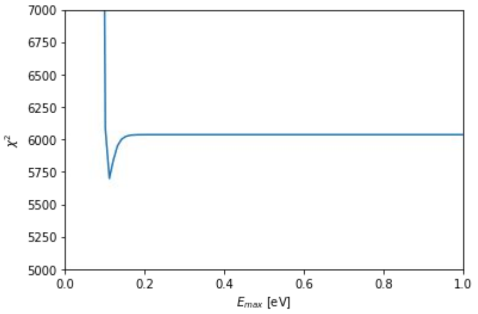
χ^2/ndf	A [e-/pix·eV]	μ [days^{-1}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]
2.13	1412 ± 3	131 ± 2	0	∞	4.98 ± 0.04	0 ± 10^{-4}

Limiting E_{max} and E_{min}: 135K Curve

- We fix $E_{min} = 0$ and $E_{max} = \infty$ and fit the curve.
- We calculate the χ^2 of E_{max} and E_{min}.
    - E_{min} is flat from in the range ~[0,0.0005] eV.
    - E_{max} is flat from in the range ~[0.19,∞] eV.
        - E_{max} has a minimum in ~0.17 eV.





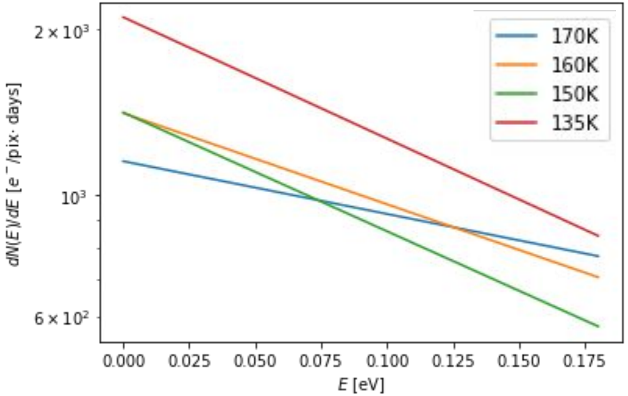


χ^2/ndf	A [e-/pix·eV]	μ [days^{-1}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]
3.2	2105 ± 4	745 ± 0.6	0	∞	5.09 ± 0.04	0 ± 10^{-4}

Limiting E_{max} and E_{min}: Density of traps per energy level

- From the previous results we observed that the minimum limits for the integral are ~[0,0.17] for all the temperatures.
  - This range of energies is quite small.
  - All the energies above 0.17 give the same χ^2.
- The **density of traps** per energy level **depends on temperature**.
  - α decreases with temperature.
  - However, the theoretical expression does not have a dependence with temperature.

Population of traps: $\frac{dN(E)}{dE} = Ae^{-\alpha E}$



T [K]	A [e^-/pix]	α [eV^{-1}]
170	1151	2.2
160	1408	3.8
150	1512	4.9
135	2105	5.1

Finding the correct parameters

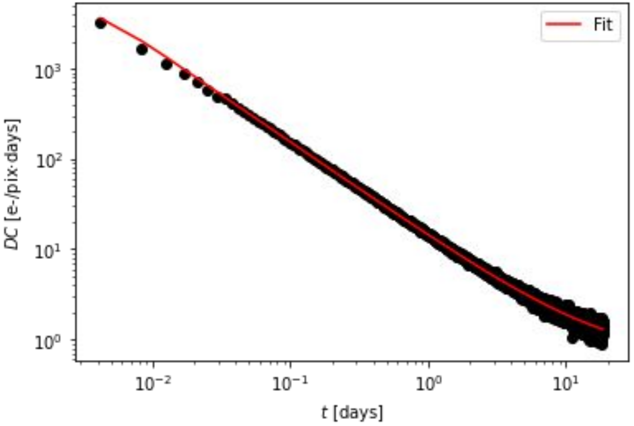
- We added a new term to the power law accounting the error on the readout time (δt).

$$DC = \int_{E_{min}}^{E_{max}} A\mu e^{-\mu t e^{-E/kT}} e^{-E/kT - \alpha E} \longrightarrow DC = \int_{E_{min}}^{E_{max}} A\mu e^{-\mu (t+\delta t) e^{-E/kT}} e^{-E/kT - \alpha E}$$

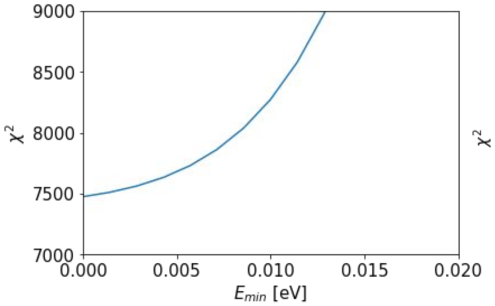
- The difference between finite and infinite range of values is given by times *t<0.02* days.
  - We should fit in a range where the difference is not so important.
    - We choose the region $t > 0.1$ days.
    - We fix $E_{max} = \infty$ and $E_{min} = 0$.
    - We allow DC_{eq} to be fitted to a negative value.
    - We should be able to obtain the correct A, μ, α, δt parameters of the curve.

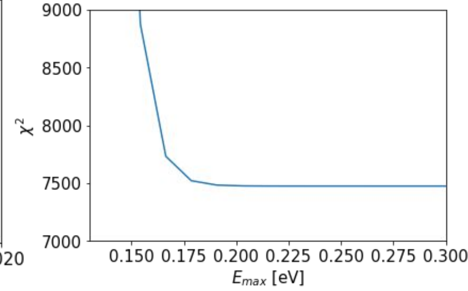
Finding the correct parameters: 170K Curve

- We fix $E_{min} = 0$ and $E_{max} = \infty$ and fit the curve in the range $t>0.1$ days.
- We calculate the χ^2 of E_{max} and E_{min}.
  - E_{min} is flat from in the range ~[0,0.0005] eV.
  - E_{max} is flat from in the range ~[0.18,∞] eV.
- The parameters are about the same as before.



χ^2/ndf	A [e-/pix·eV]	μ [days^{-1}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]	δt [days]
1.65	1381 ± 19	324 ± 50	0	∞	4.01 ± 0.07	0.677 ± 0.004	$6\cdot10^{-3}\pm 5\cdot10^{-4}$





Outlook

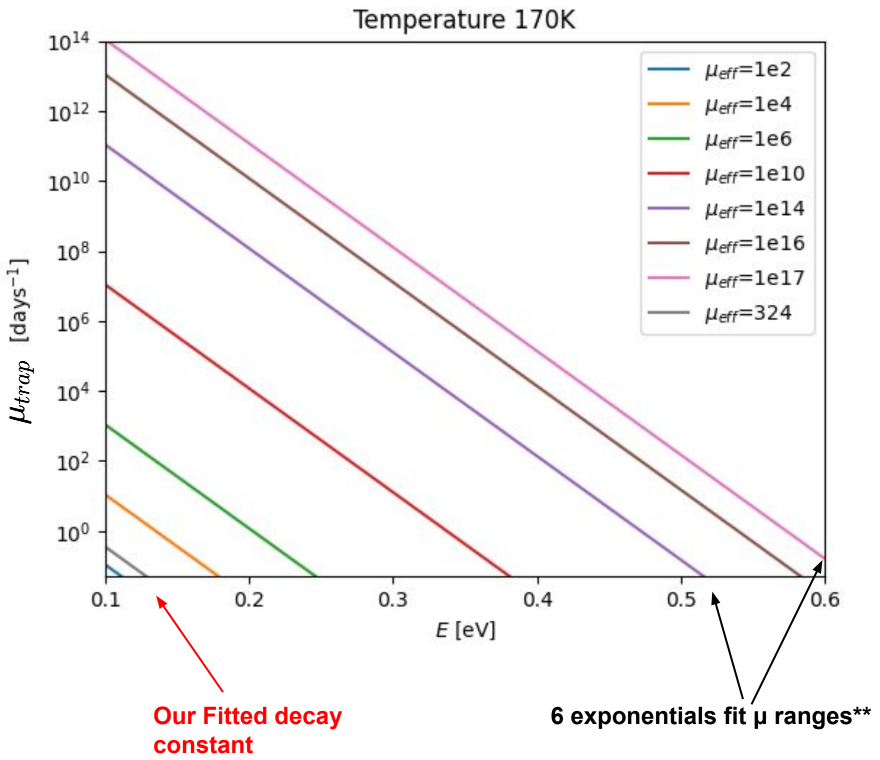
- We fitted the curves to a numerical model based on a continuum of traps.
  - Fitted the curves in a finite energy rate.
  - **There are more than one solution for the fitted parameters.**
    - However, the χ^2 of the curves are good.
    - E_{max} can give good χ^2 in a range of [0.18,9] eV.
    - μ can vary from 10^2 to 10^5 days.
    - α is found in the range [1,7] eV^{-1}.
    - DC_{eq} is ~0 for all temperatures except 170K.
    - A is consistent for all the fits in the range ~$[1,3]\cdot 10^3$ e-/pix.
  - The $\boldsymbol{t < 0.02}$ **days** part of the curve will **determine if the energy ranges are finite or not.**
  - We tried to find the correct parameters of the curve on t > 0.1 days part of the curve.
    - We added a **new variable $\boldsymbol{\delta t}$** to account the readout time error.
    - Allowed $\boldsymbol{DC_{eq}}$ to be fitted to a **negative value**.
      - The parameters and energy ranges where the same.

Why Energies are so low? Decay constant

- The dependence between decay constant and energy is

$$\mu_{trap}(E) = \mu e^{-E/kT}$$

- We are obtaining μ~300 $days^{-1}$.
  - 170 K curve lasts ~20 days.
    - The minimum μ we can measure is ~ 1/20 = 0.05 $days^{-1}$ (minimum of the x axis).
    - The highest energy we will reach with this fitted μ is E_{max} ~ 0.1 eV.
- From the paper* the expected value is μ~10^9 sec^{-1} (10^{13} $days^{-1}$).
- For 6 exponential fits**:
  - **μ~[10^{14} ,10^{16}] $days^{-1}$, E~[0.3,0.5] eV.**



*https://royalsocietypublishing.org/doi/pdf/10.1098/rspa.1945.0025

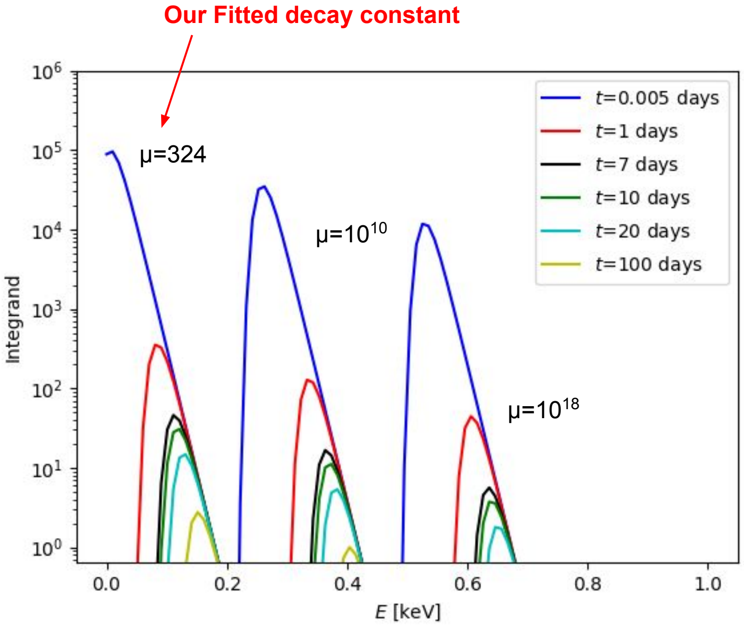
** See back up: *Study of the 170K curve by ranges*

Why Energies are so low? Decay constant Integrand

- We will observe the integrand dependence with energy of the numerical model.
  - The integrand can be interpreted as the contribution of energy level to DC.
    - The area under each t_i curve should be ~ data point at t_i.

$$A\mu e^{-\mu(t+\delta t)e^{-E/kT}}e^{-E/kT-\alpha E}$$

- Looking at the dependence with energy of the integrand for different times, we see:
  - For μ~ 324 days^{-1}.
    - The energy range ~[0.1, 0.2] eV.
      - This is why we obtain the flat region of χ^2 for E_{max} > 0.2 eV.
  - For μ~10^{10} and 10^{18} days^{-1}.
    - We have a higher range of energies from ~[0.2,0.4] eV and ~[0.5,0.7] eV.
  - For the 6 exponential fit we obtained*:
    - E_T~0.4-0.5 eV → μ~10^{10} days^{-1}.



A [e-/pix·eV]	α [eV^{-1}]
1381 ± 19	4.01 ± 0.07

*See other talks with the exponential results.

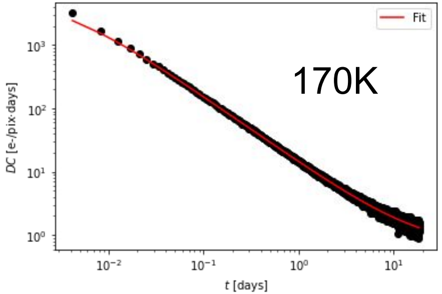
Why Energies are so low? Fixing Cross section

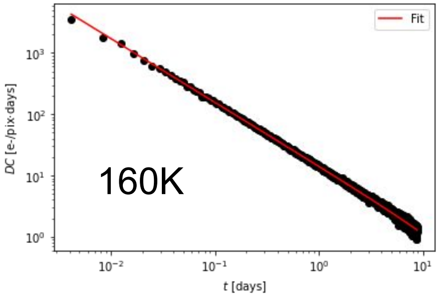
- The relation between μ and the cross section is given by

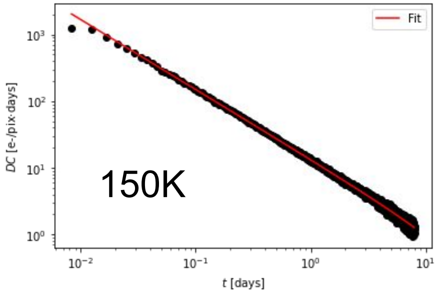
$$\mu = CT^2 g\sigma_\infty$$

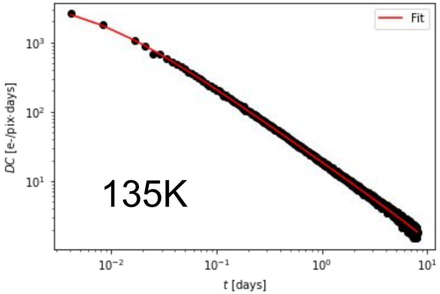
  - Where $C = 1.6\cdot10^{21}$ [$cm^2/K^2\cdot sec$] (Janesick).
  - g is the degeneration factor of the energy level.
  - σ_∞ is the cross section of the traps when $T \rightarrow \infty$.

- We can fix the cross section to a value that match the curve.
  - The maximum cross section to be able to fit the curve was $\sigma_\infty < 10^{-19}$ cm^2.
  - We used:
    - $\sigma_\infty = 10^{-19}$ cm^2.
    - $E_{max} = \infty$ and $E_{min} = 0$ fixed.
    - Curve fitted for *t>0.1* days.







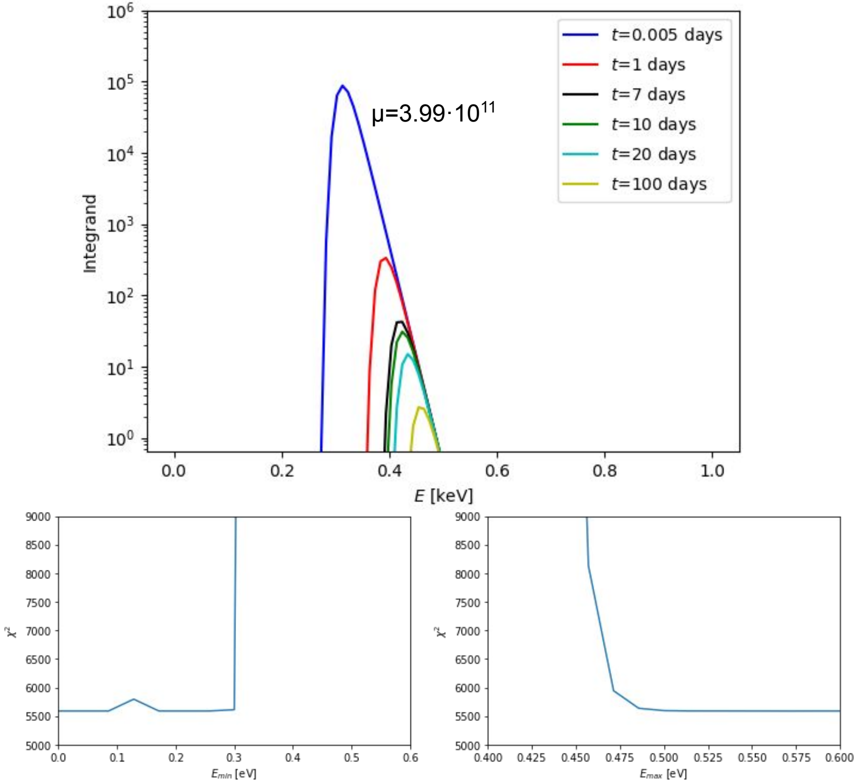


Why Energies are so low? Fixing Cross section

T [K]	χ^2/ndf	A [e-/pix·eV]	σ_∞ [cm^2] Fixed	μ_{Traps} [days^{-1}] Fixed	E_{min} [eV] Fixed	E_{max} [eV] Fixed	α [eV^{-1}]	DC_{eq} [e-/pix·days]	δt [days]
135	1.50	9597 ± 673	10^{-19}	$2.51 \cdot 10^{11}$	0	∞	5.66 ± 0.04	-2.13 ± 0.02	0.0067± 0.0008
150	1.51	3684 ± 110	$4.57 \cdot 10^{-20}$	$1.42 \cdot 10^{11}$	0	∞	3.74 ± 0.09	-0.192 ± 0.009	$3 \cdot 10^{-10} \pm 1 \cdot 10^{-4}$
160	1.51	3040 ± 85	$4.57 \cdot 10^{-20}$	$1.62 \cdot 10^{11}$	0	∞	2.96 ± 0.08	-0.192 ± 0.009	$2 \cdot 10^{-15} \pm 7 \cdot 10^{-5}$
170	1.27	3166 ± 32	10^{-19}	$3.99 \cdot 10^{11}$	0	∞	3.02 ± 0.02	0.6436 ± 0.0004	0.0006 ± 0.001

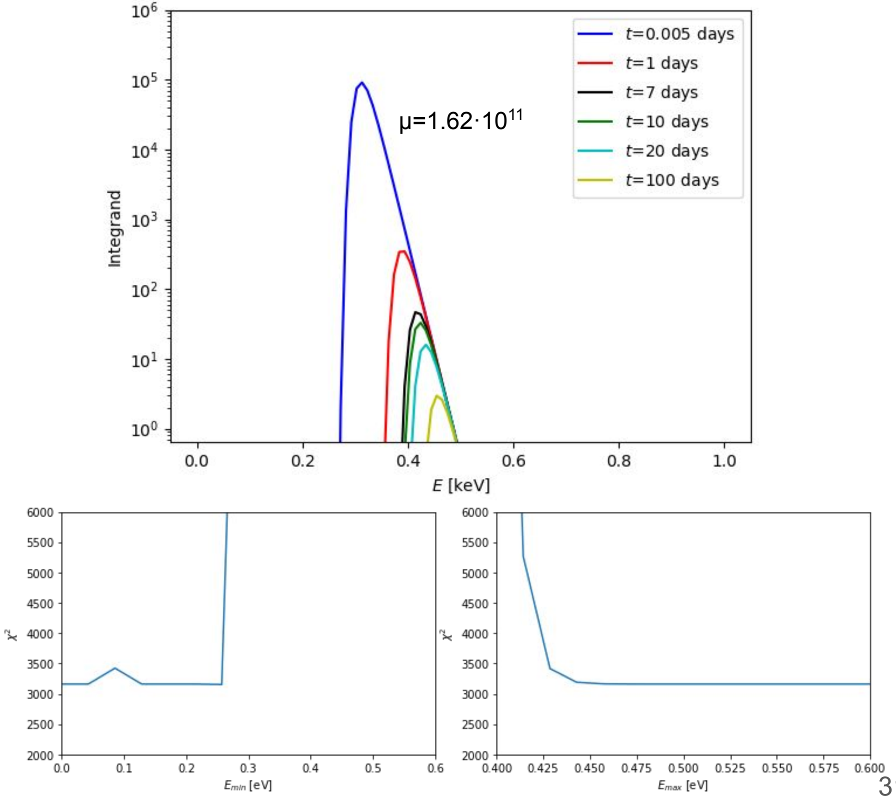
Why Energies are so low? Fixing Cross section 170K

- If we take the fixed cross section as valid we obtain a range of energies in which the integrad is not negligible.
    - For 170K and $\sigma_\infty = 10^{-19}$ cm^2 → $\mu = 3.99 \cdot 10^{11}$ days^{-1}.
        - We obtain a range of energies ~[0.28,0.48] eV.
        - The integrand at the first point of our dark current curve (t=0.005 days) will give us an estimation of the energy ranges we are able to measure.



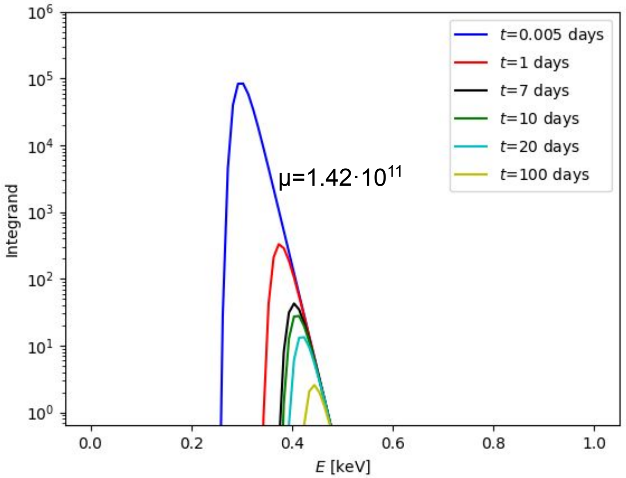
Why Energies are so low? Fixing Cross section 160K

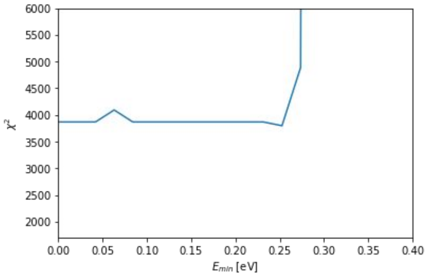
- If we take the fixed cross section as valid we obtain a range of energies in which the integrad is not negligible.
  - For 160K and σ_∞=4.57·10^{-19} cm^2 → μ = 1.62 ·10^{11} days^{-1}.
    - We obtain a range of energies ~[0.28,0.45] eV.
    - The integrand at the first point of our dark current curve (t=0.005 days) will give us an estimation of the energy ranges we are able to measure.

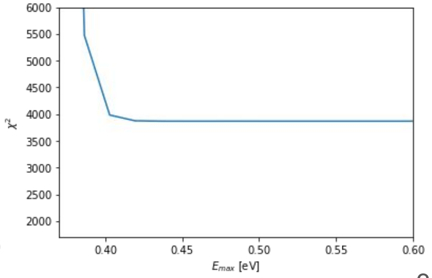


Why Energies are so low? Fixing Cross section 150K

- If we take the fixed cross section as valid we obtain a range of energies in which the integrad is not negligible.
  - For 150K and σ_∞=4.57·10^{-19} cm^2 → μ = 1.42 ·10^{11} days^{-1}.
    - We obtain a range of energies ~[0.22,0.41] eV.
    - The integrand at the first point of our dark current curve (t=0.005 days) will give us an estimation of the energy ranges we are able to measure.

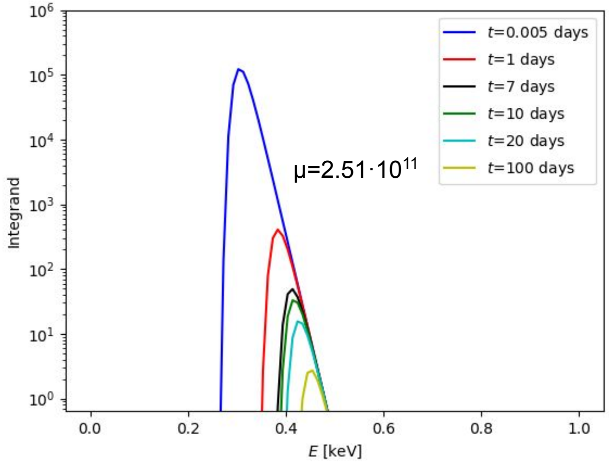


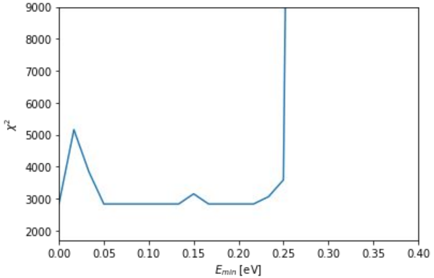


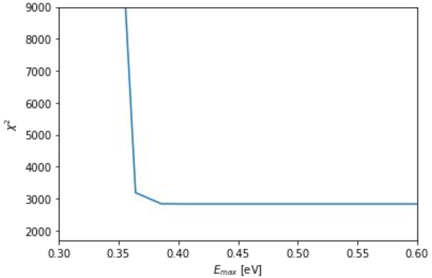


Why Energies are so low? Fixing Cross section 135K

- If we take the fixed cross section as valid we obtain a range of energies in which the integrad is not negligible.
  - For 135K and σ_∞=10^{-19} cm^2 → μ = 2.51·10^{11} days^{-1}.
    - We obtain a range of energies ~[0.22,0.37] eV.
    - The integrand at the first point of our dark current curve (t=0.005 days) will give us an estimation of the energy ranges we are able to measure.





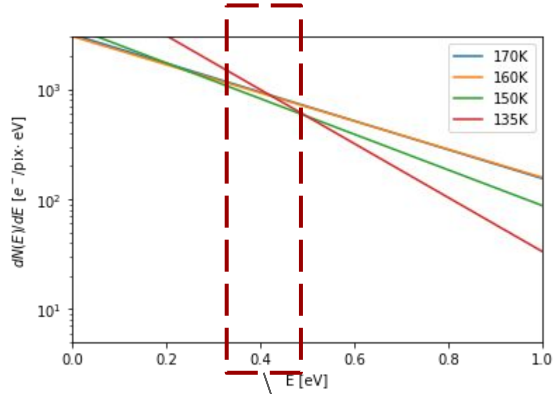


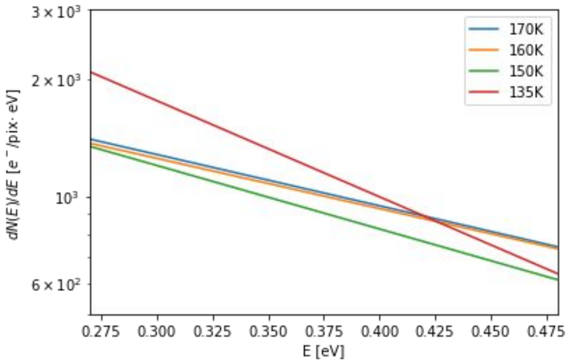
Why Energies are so low? Fixing Cross section Energy Ranges

T [K]	E_{min} [eV]	E_{max} [eV]
135	0.22	0.37
150	0.22	0.41
160	0.28	0.45
170	0.28	0.48

Why Energies are so low? Density of traps per energy level

- Density of traps per energy of level in the range [0.27,0.48] eV.
    - 170K and 160K are quite similar.
    - 135K is the most different curve.





T [K]	A [e-/pix·eV]	α [eV^{-1}]
135	9597 ± 673	5.66 ± 0.04
150	3684 ± 110	3.74 ± 0.09
160	3040 ± 85	2.96 ± 0.08
170	3166 ± 32	3.02 ± 0.02

Fixed σ to a value from literature: Fit values

- We fixed $\sigma=10^{-15}$ cm^2, E_{min}=0 and E_{max}=∞ and fitted the full curves*.
  - Cross section values:
    - https://indico.cern.ch/event/1019603/contributions/4279286/attachments/2212446/3744669/06045257.pdf
      - For Si/SiO2 interface we may expect σ~10^{-15} cm^2.
- We expect to obtain the same value of *A* and *α* for all the curves.
  - 170K and 160K → **A and α** are compatibles within the error.
  - **135K and 150K** → **A and α** are not compatible within the error.
    - A and α have lower errors than 160K and 170K.

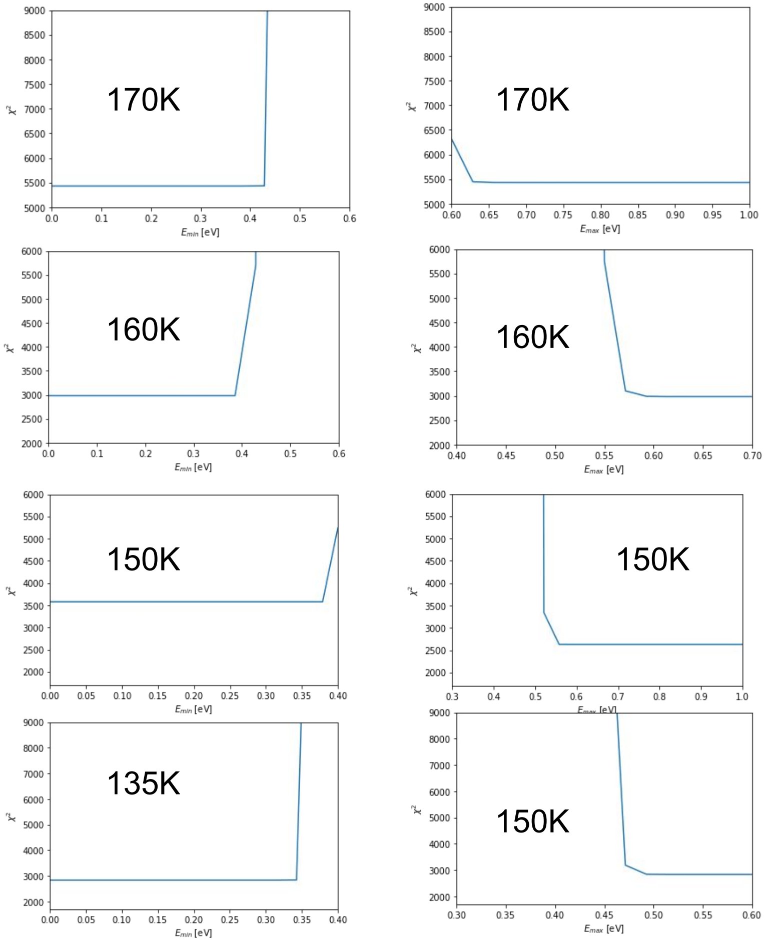
T [K]	χ^2/ndf	A [e-/pix·eV]	σ_∞ [cm^2] Fixed	E_{min} [eV] Fixed	E_{max} [eV] Fixed	α [eV^{-1}]	DC_{eq} [e-/pix·days]	δt [days]
135	1.50	**(18 ± 1)·10^3**	10^{-15}	0	∞	**5.7 ± 0.2**	-0.21 ± 0.01	0.00067±0.00007
150	1.39	**(6.6 ± 0.4)·10^3**	10^{-15}	0	∞	**3.96 ± 0.02**	-0.243 ± 0.007	(1.46± 0.08)·10^{-5}
160	1.42	**(5.1± 0.2)·10^3**	10^{-15}	0	∞	**3.17 ± 0.07**	-0.178 ± 0.008	(7.1±0.7)·10^{-7}
170	1.23	**(5.3 ± 0.2)·10^3**	10^{-15}	0	∞	**3.32 ± 0.06**	0.648 ± 0.008	(2.19±0.09)·10^{-3}

*We don't use the first point of the 150K curve and the third point of 135K.

Fixed σ to a value from literature: Energy ranges

- The energy ranges decrease with temperature.
- From the exponential fit the range of energies were [0.42,0.55] eV.

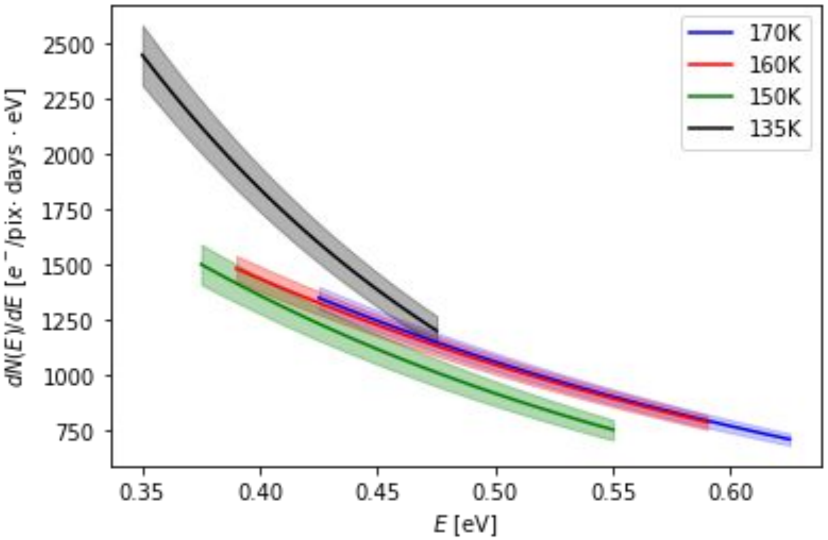
T [K]	E_{min} [eV]	E_{max} [eV]
135	0.35	0.475
150	0.375	0.55
160	0.39	0.59
170	0.425	0.625



Fixed σ to a value from literature: Density of states

- 170K and 160K are compatible within the error in the overlapping energy intervals.
- 150K curve is not compatible within the errors.
  - Parameter *A* is compatible but not *α*.
    - A error is to small.
- Total densities* for each temperature are about the same order of magnitude <ρ> = (9.5±0.7)·10^7 e-/cm^2.
  - From exponential fits we had ρ~6.8·10^6 e-/cm^2.

T [K]	A [e-/pix·eV]	E_{min} [eV] Fixed	E_{max} [eV] Fixed	α [eV^{-1}]	ρ* [e-/cm^2]
135	(18± 1)·10^3	0.35	0.475	5.7±0.2	9.72·10^7
150	(6.6± 0.4) ·10^3	0.375	0.55	3.96 ± 0.02	1.03·10^8
160	(5.1± 0.2) ·10^3	0.39	0.59	3.17 ± 0.07	9.75·10^7
170	(5.3 ± 0.2) ·10^3	0.425	0.625	3.32 ± 0.06	8.39·10^7

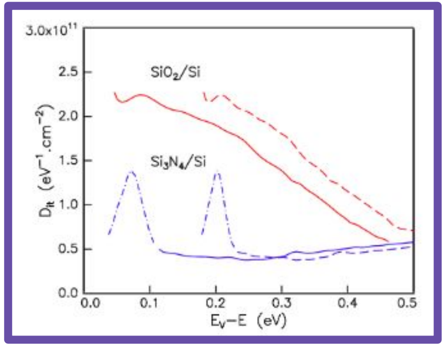


Shaded regions from: [Model(A-δA,α), Model(A+δA,α)]

*Total Densities obtained from: $\rho = \int_{E_{min}}^{E_{max}} Ae^{-\alpha E} dE$

Fixed σ and linear Density of states Model: Fit values

- We **fixed σ=5·10^{-15} cm^2, E_{min}=0 and E_{max}**=∞ and fitted the full curves*.
  - Cross section values:
    - https://indico.cern.ch/event/1019603/contributions/4279286/attachments/2212446/3744669/06045257.pdf
      - For **Si/SiO2 interface** we may expect **σ~10^{-15} cm^2**.
      - Densities of states in the order of **10^{11} eV^{-1}·cm^{-2}**.
- We changed **density of states** to a **linear model** → **dN(E)/dE = A·(1-αE).**
  - From the paper it seems that the density of states of **Si/SiO2 may follow a linear distribution.**
- We expect to obtain the same value of *A* and *α* for all the curves.
  - **170K and 160K** → **α** is compatibles within the error. **A** parameters are close to each other.
  - **150K and 135K A and α are not compatible with the other curves.**
- **Fitted densities of states** are in the order of **10^9 e-/cm^2·eV.**
  - Lower than the **paper densities of states** ~**10^{11} e-/cm^2·eV**.



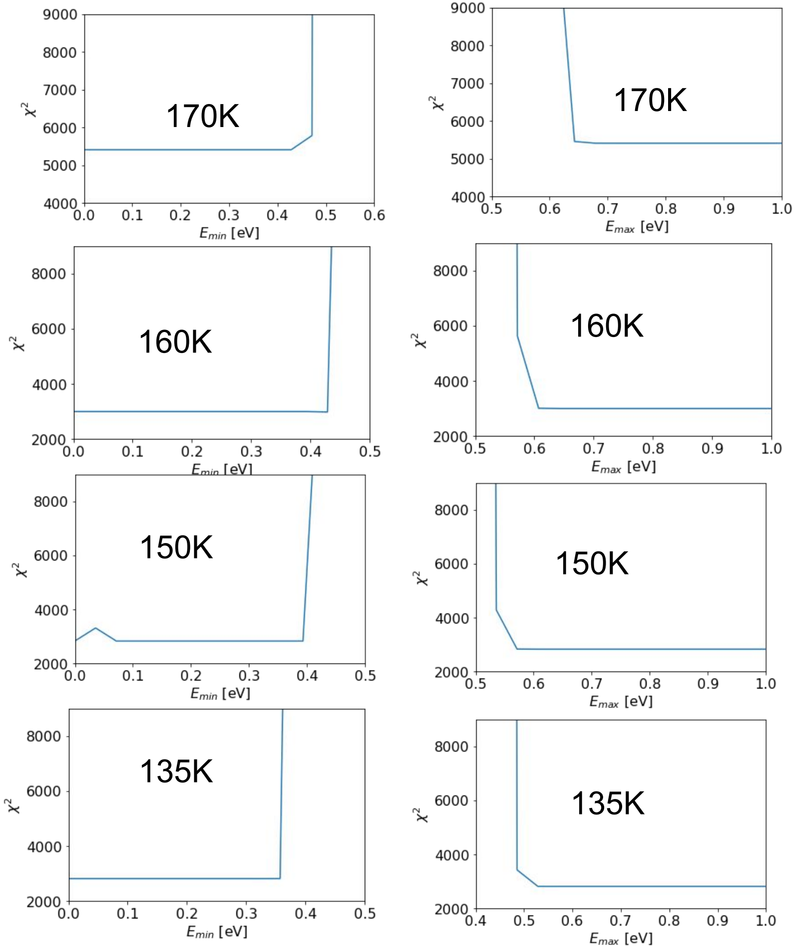
T [K]	χ^2/ndf	A [e-/pix·eV]	A [e-/cm^2·eV]	σ_∞ [cm^2] Fixed	E_{min} [eV] Fixed	E_{max} [eV] Fixed	α [eV^{-1}]	DC_{eq} [e-/pix·days]	δt [days]
135	1.50	**(5.75 ± 0.01)·10^3**	**2.56·10^9**	5·10^{-15}	0	∞	**1.631 ± 0.009**	-0.19 ± 0.01	0.006±0.00001
150	1.39	**(3.14 ± 0.05)·10^3**	**1.40·10^9**	5·10^{-15}	0	∞	**1.36 ± 0.01**	-0.22 ± 0.01	(1.22± 0.09)·10^{-5}
160	1.42	**(2.84± 0.04)·10^3**	**1.26·10^9**	5·10^{-15}	0	∞	**1.21 ± 0.01**	-0.160 ± 0.009	(5.8±0.6)·10^{-4}
170	1.23	**(2.72 ± 0.03)·10^3**	**1.21·10^9**	5·10^{-15}	0	∞	**1.16 ± 0.08**	0.663 ± 0.005	(2.01±0.08)·10^{-3}

*We don't use the first point of the 150K curve and the third point of 135K.

Fixed σ and linear Density of states Model: Energy ranges

- The energy limits do not change with the linear model.
  - This is expected as they depends on the cross section.
- The energy ranges decrease with temperature.
- From the exponential fit the range of energies were [0.42,0.55] eV.

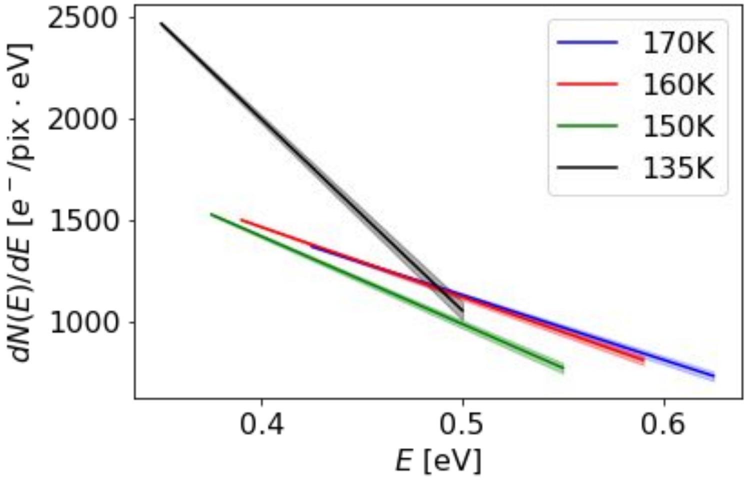
T [K]	E_{min} [eV]	E_{max} [eV]
135	0.35	0.51
150	0.375	0.55
160	0.39	0.6
170	0.425	0.625



Fixed σ and linear Density of states Model: Density of states

- 170K and 160K are compatible within the error in the overlapping energy intervals.
- 150K and 135K curve is not compatible within the errors.
- Total densities* for each temperature are about the same order of magnitude <ρ> = $(1.0 \pm 0.1) \cdot 10^8$ e-/cm^2.
  - With the exponential density of states <ρ> = $(9.5 \pm 0.7) \cdot 10^7$ e-/cm^2.
  - From exponential fits we had ρ~$6.8 \cdot 10^6$ e-/cm^2.
  - From the paper we expect a total density of ~10^{10}.

T [K]	A [e-/pix·eV]	E_{min} [eV] Fixed	E_{max} [eV] Fixed	α [eV^{-1}]	ρ[e-/cm^2]
135	$(5.75 \pm 0.01) \cdot 10^3$	0.35	0.51	1.631 ± 0.009	$1.22 \cdot 10^8$
150	$(3.14 \pm 0.05) \cdot 10^3$	0.375	0.55	1.36 ± 0.01	$9.06 \cdot 10^7$
160	$(2.84 \pm 0.04) \cdot 10^3$	0.39	0.6	1.21 ± 0.01	$1.06 \cdot 10^8$
170	$(2.72 \pm 0.03) \cdot 10^3$	0.425	0.625	1.16 ± 0.08	$9.45 \cdot 10^7$



Shaded regions from: [Model(A-δA,α), Model(A+δA,α)]

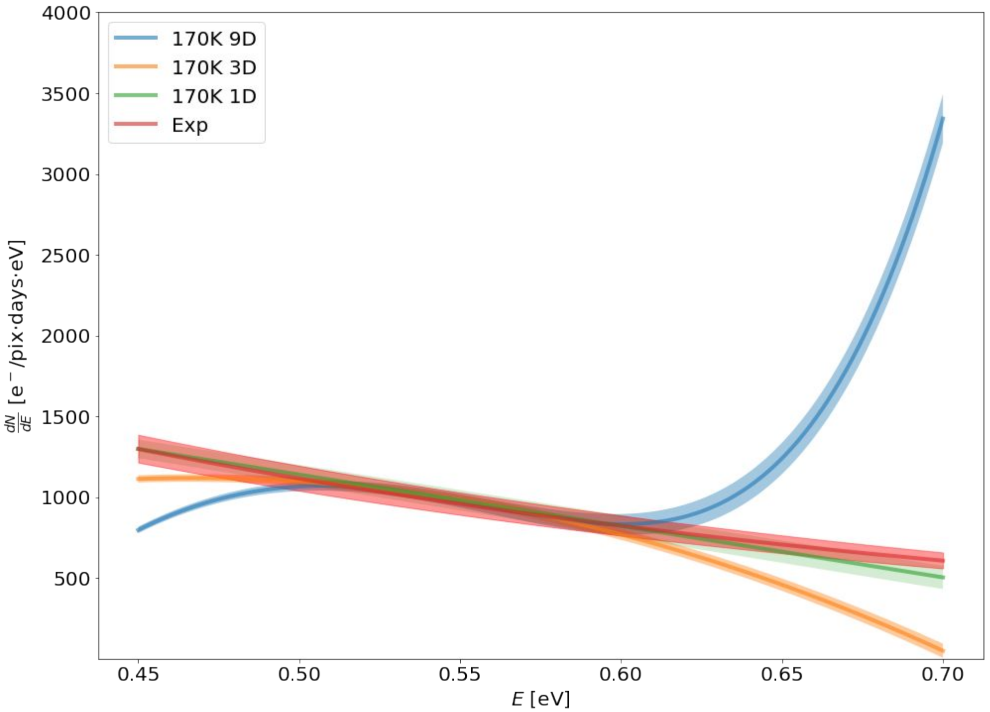
*Total Densities obtained from: $\rho = \int_{E_{min}}^{E_{max}} A(1-\alpha E)dE$

Outlook

- We **fixed the cross section** to $\sigma_\infty = 10^{-19}$ cm^2 (μ~10^6 days^{-1}).
    - The range of energies ~[0.22, 0.48] eV.
    - The ranges slightly increases with temperature.
        - The first measured point of the curve will give as an estimation of the range of energies we are able to measure.
- We **fixed the cross section** to a **literature value** $\sigma_\infty = 10^{-15}$ cm^2 (μ~10^{10} days^{-1}).
    - **$\sigma_\infty = 10^{-15}$ cm^2 → May be related with Si/SiO2 interface.**
    - We were able to find the same *A* and α for 160K and 170K curves.
        - 150K and 135K A and α are not compatible with the other curves .
        - The total densities are about the same order of magnitude ~$9 \cdot 10^7$ cm^{-2}.
            - Lower than the expected from the paper ~10^{10} cm^{-2}.
    - We used a **linear model of density of states**.
        - 160K and 170K parameters *A* and α are compatible within the error.
        - 150K and 135K A and α are not compatible with the other curves .
        - The total densities are about the same order of magnitude ~10^8 cm^{-2}.
            - Lower than the expected from the paper ~10^{10} cm^{-2}.

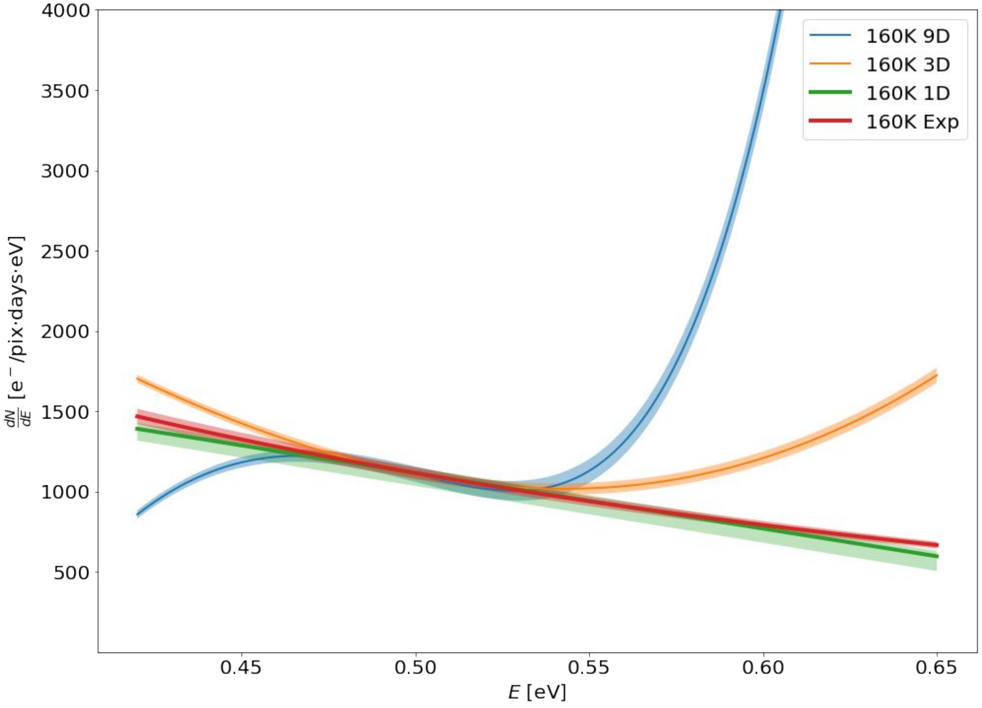
Fixed σ to a value from literature: 170K Polynomial fit

- We **fixed σ=5·10^{-15} cm^2, E$_{min}$=0 and E$_{max}$**=∞ and fitted the full curves*.
    - Cross section values:
        - https://indico.cern.ch/event/1019603/contributions/4279286/attachments/2212446/3744669/06045257.pdf
- We changed **density of states** to a **polynomial model → dN(E)/dE** = **Σa$_i$x^i.**
    - **Compared degree 3 up to degree 9 with the linear and exponential model.**



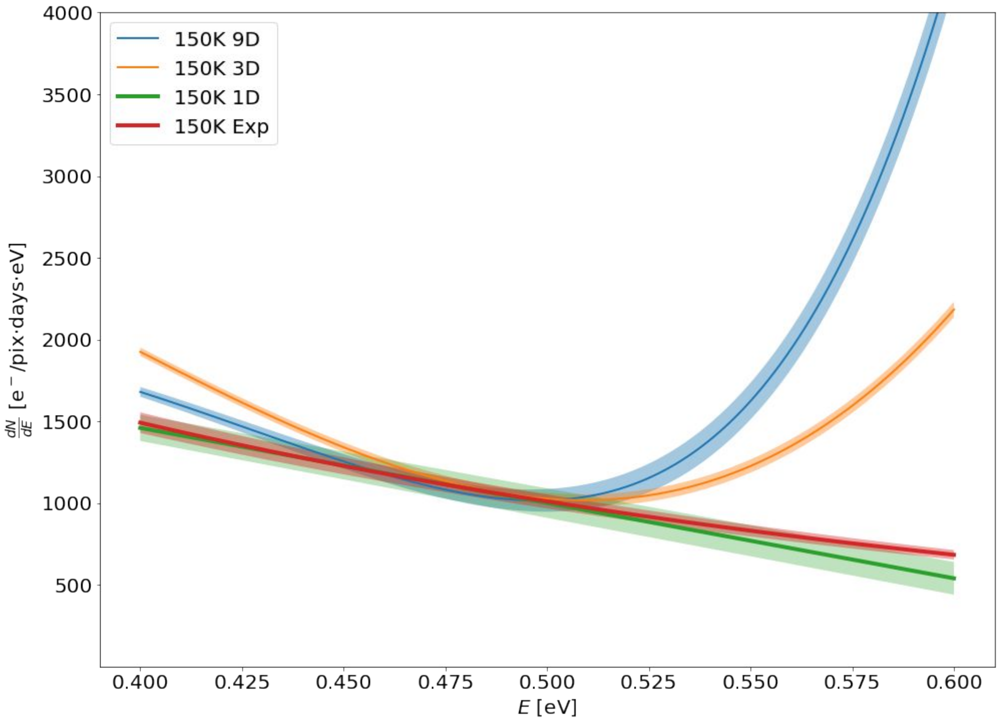
Fixed σ to a value from literature: 160K Polynomial fit

- We **fixed σ=5·10^{-15} cm^2, E_{min}=0 and E_{max}**=∞ and fitted the full curves*.
  - Cross section values:
    - https://indico.cern.ch/event/1019603/contributions/4279286/attachments/2212446/3744669/06045257.pdf
- We changed **density of states** to a **polynomial model → dN(E)/dE** = **$\Sigma a_i x^i$.**
  - **Compared degree 3 up to degree 9 with the linear and exponential model.**



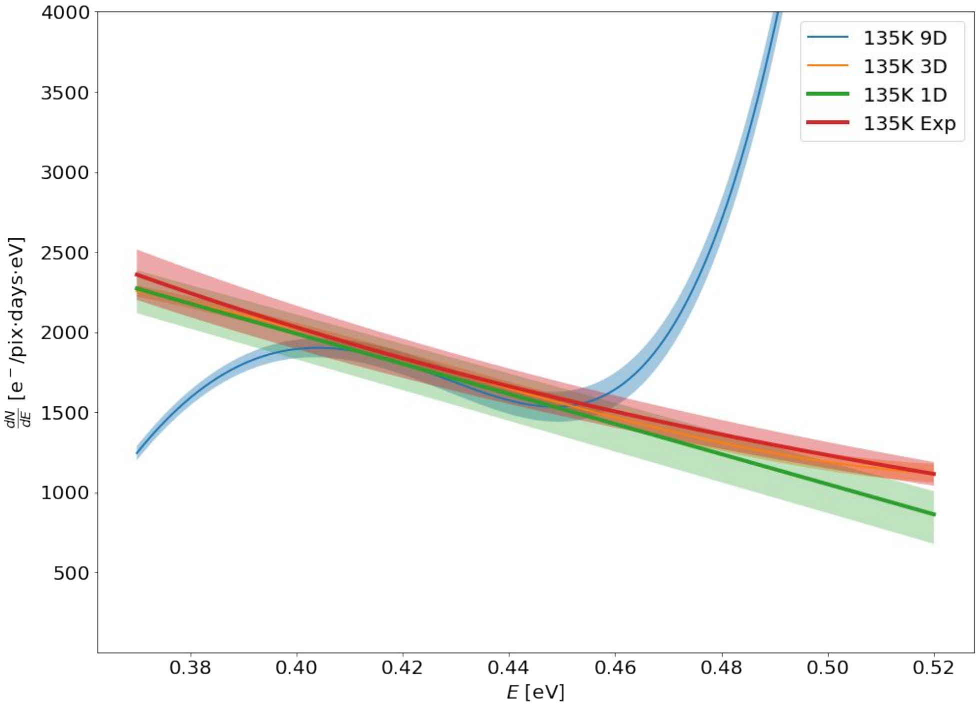
Fixed σ to a value from literature: 150K Polynomial fit

- We **fixed σ=5·10^{-15} cm^2, E$_{min}$=0 and E$_{max}$**=∞ and fitted the full curves*.
    - Cross section values:
        - https://indico.cern.ch/event/1019603/contributions/4279286/attachments/2212446/3744669/06045257.pdf
- We changed **density of states** to a **polynomial model → dN(E)/dE = $\Sigma a_i x^i$.**
    - **Compared degree 3 up to degree 9 with the linear and exponential model.**

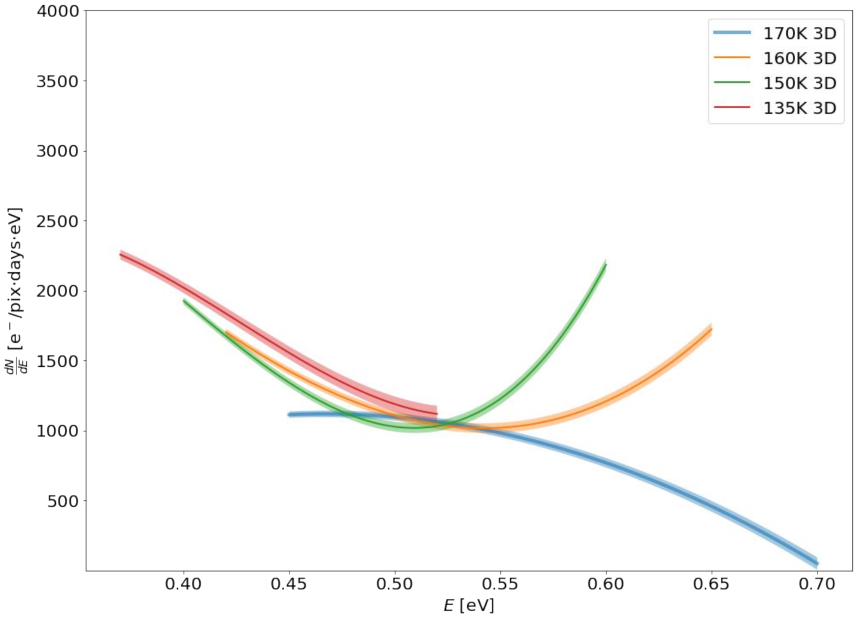


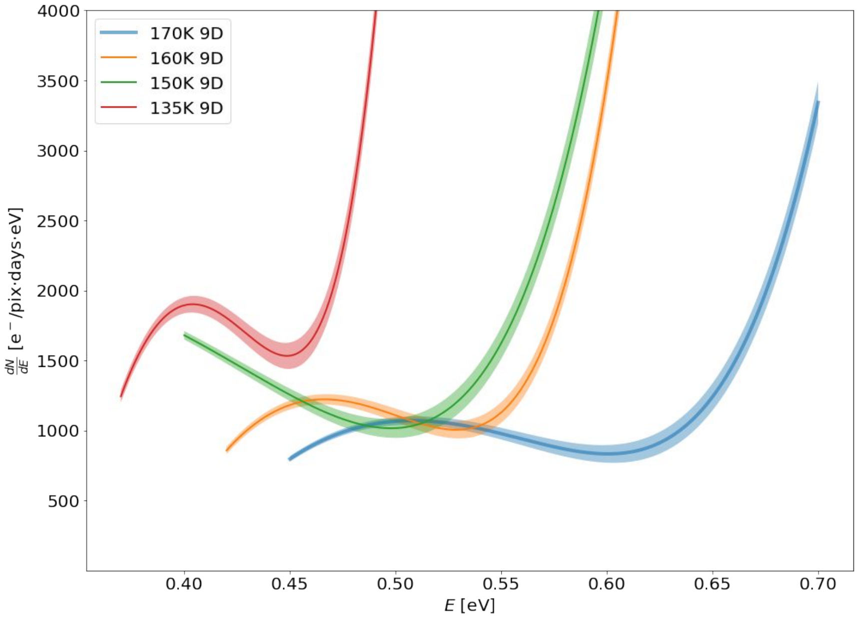
Fixed σ to a value from literature: 135K Polynomial fit

- We **fixed σ=5·10^{-15} cm^2, E_{min}=0 and E_{max}=∞** and fitted the full curves*.
    - Cross section values:
        - https://indico.cern.ch/event/1019603/contributions/4279286/attachments/2212446/3744669/06045257.pdf
- We changed **density of states** to a **polynomial model → dN(E)/dE = $\Sigma a_i x^i$.**
    - **Compared degree 3 up to degree 9 with the linear and exponential model.**



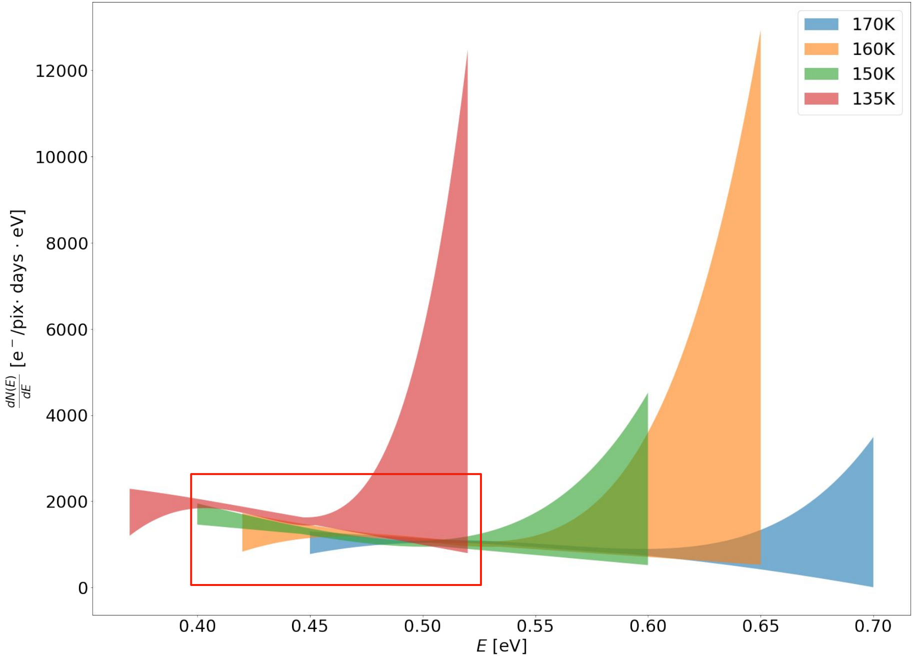
Fixed σ to a value from literature: Polynomial fit Comparison





Fixed σ to a value from literature: Polynomial CI

- The confidence level is obtained by taking the minimum and maximum value of all the polynomials at each energy.
- In the energy region where all the curves coincide, the density of states is compatible (135K is only partially compatible in all the interval).
  - Can we confirm that we have the same continuum of traps at all temperatures?



Outlook

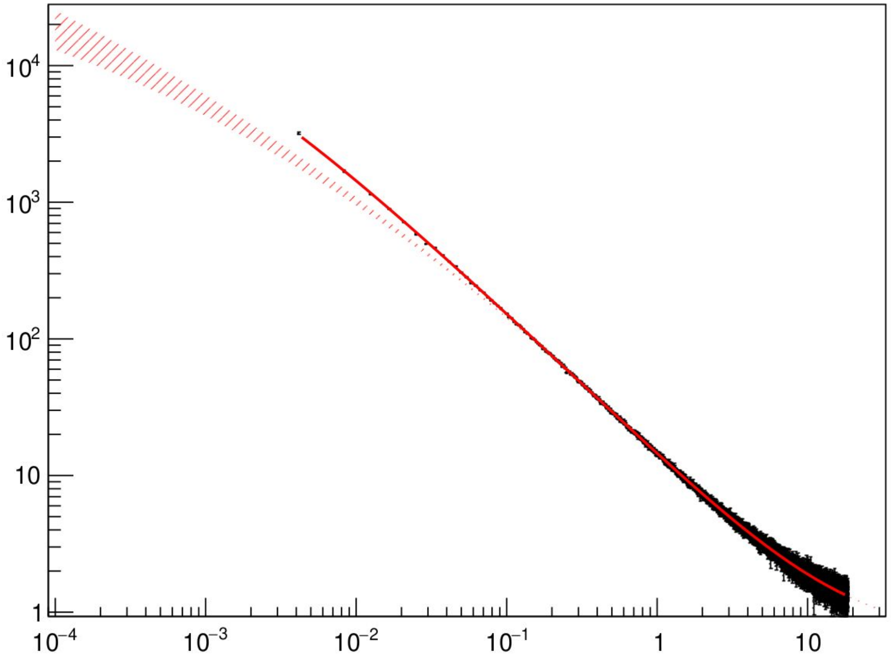
- We **fixed the cross section** to a **literature value** $\sigma_\infty = 5{\cdot}10^{-15}$ cm^2 (μ~10^{10} days^{-1}).
    - **$\sigma_\infty = 5{\cdot}10^{-15}$ cm^2 → May be related with Si/SiO2 interface.**
    - We fitted the curves with a polynomial distribution of states from degree 3 to 9.
        - The different polynomials and the exponential are compatible in a certain region of energies.
            - Exponential and flat distributions are a first approach of a more general function.
        - For the different temperatures there is an energy range ~[0.5,0.55] eV where all the curves are compatible for degree 3, expect 135 for degree 9 (TiH3 or H-related defects?)
        - Density of states compatible within the confidence interval between polynomials.

Table 6.6 Activation energies, apparent capture cross sections, and assignment for all defects observed in n- and p-type silicon. After Scheffler et al. [195]

Label	E_a (eV)	σ_n or σ_p (cm^2)	Assignment
E40	$E_C - 0.08$	6×10^{-15}	Ti
E40′	$E_C - 0.07$	8×10^{-16}	TiH
E150	$E_C - 0.27$	5×10^{-16}	Ti
E170	$E_C - 0.34$	4×10^{-14}	TiH
E170′	$E_C - 0.37$	4×10^{-14}	TiH_2
E260	$E_C - 0.55$	4×10^{-15}	TiH_3
E260′	$E_C - 0.50$	3×10^{-15}	H-related
H180	$E_V + 0.29$	9×10^{-17}	Ti

Polynomials Confidence intervals

- Confidence level out the fit.
  - Using TVirtualFitter the fits do not converge. The confidence intervals are not well calculated.



Fixed σ to a value from literature: Fit values

- We fixed **σ=10^{-16}** cm^2, E_{min}=0 and E_{max}=∞ and fitted the full curves*.
  - Cross section values:
    - https://hal.archives-ouvertes.fr/jpa-00244672/document
- We expect to obtain the same value of *A* and *α* for all the curves.
  - 170K and 160K → **A and α** are compatibles within the error.
  - **135K and 150K** → **A and α** are not compatible within the error.
    - A and α have lower errors than 160K and 170K.

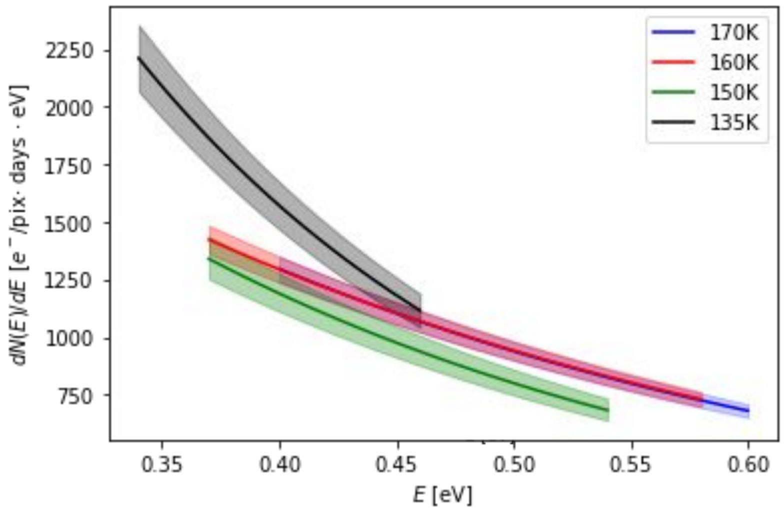
T [K]	χ^2/ndf	A [e-/pix·eV]	σ_∞ [cm^2] Fixed	E_{min} [eV] Fixed	E_{max} [eV] Fixed	α [eV^{-1}]	DC_{eq} [e-/pix·days]	δt [days]
135	1.50	**(15.3 ± 0.4) ·10^3**	10^{-16}	0	∞	**5.69 ± 0.07**	-0.212 ± 0.008	0.0069±0.0001
150	1.39	**(5.8 ± 0.2)·10^3**	10^{-16}	0	∞	**3.96 ± 0.09**	-0.243 ± 0.009	(1.5± 0.2)·10^{-3}
160	1.42	**(4.6± 0.2)·10^3**	10^{-16}	0	∞	**3.17 ± 0.07**	-0.178 ± 0.008	(7.1±0.7)·10^{-4}
170	1.23	**(4.7 ± 0.1)·10^3**	10^{-16}	0	∞	**3.22 ± 0.06**	0.648 ± 0.005	(2.19±0.09)·10^{-3}

*We don't use the first point of the 150K curve and the third point of 135K.

Fixed σ to a value from literature: Density of states

- 170K and 160K are compatible within the error in the overlapping energy intervals.
- 150K curve is not compatible within the errors.
  - Parameter A is compatible but not α.
    - A error is to small.
- Total densities* for each temperature are about the same order of magnitude $\langle\rho\rangle = (9.0 \pm 0.5)\cdot 10^7$ e-/cm^2.
  - From exponential fits we had $\rho \sim 6.8\cdot 10^6$ e-/cm^2.

T [K]	A [e-/pix·eV]	E_{min} [eV] Fixed	E_{max} [eV] Fixed	α [eV^{-1}]	ρ* [e-/cm^2]
135	$(15.3 \pm 0.4)\cdot 10^3$	0.34	0.47	5.69 ± 0.07	$9.02\cdot 10^7$
150	$(5.8 \pm 0.2)\cdot 10^3$	0.36	0.56	3.96 ± 0.09	$8.6\cdot 10^8$
160	$(4.6 \pm 0.2)\cdot 10^3$	0.37	0.58	3.17 ± 0.07	$9.7\cdot 10^7$
170	$(4.7 \pm 0.1)\cdot 10^3$	0.4	0.6	3.22 ± 0.06	$8.49\cdot 10^7$



Shaded regions from: [Model(A-δA,α), Model(A+δA,α)]

*Total Densities obtained from: $\rho = \int_{E_{min}}^{E_{max}} Ae^{-\alpha E} dE$

Fixed σ to a value from literature: Fit values

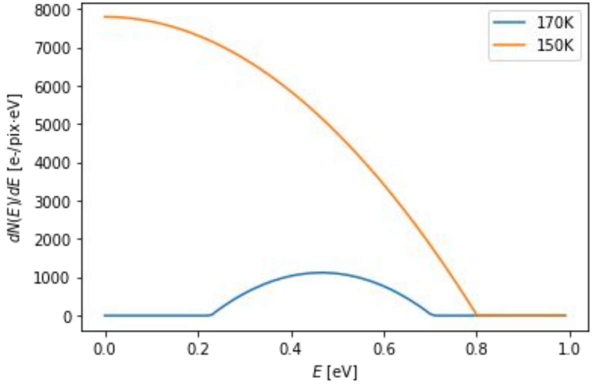
- We fixed **$\sigma=10^{-14}$** cm^2, $E_{min}=0$ and $E_{max}=\infty$ and fitted the full curves*.
  - Cross section values:
    - https://indico.cern.ch/event/1019603/contributions/4279286/attachments/2212446/3744669/06045257.pdf
      - For **Si3N4/Si** we may expect **$\sigma\sim10^{-14}$ cm^2**.
- We expect to obtain the same value of A and α for all the curves.
  - 170K and 160K → **A and α** are compatibles within the error.
  - **135K and 150K** → **A and α** are not compatible within the error.
    - A and α have lower errors than 160K and 170K.

T [K]	χ^2/ndf	A [e-/pix·eV]	σ_∞ [cm^2] Fixed	E_{min} [eV] Fixed	E_{max} [eV] Fixed	α [eV^{-1}]	DC_{eq} [e-/pix·days]	δt [days]
135	1.50	**$(20.7 \pm 0.8)\cdot10^3$**	10^{-14}	0	∞	**5.69 ± 0.09**	-0.212 ± 0.001	0.0069 ± 0.0001
150	1.39	**$(7.5 \pm 0.3)\cdot10^3$**	10^{-14}	0	∞	**3.96 ± 0.09**	-0.243 ± 0.009	$(1.5\pm 0.1)\cdot10^{-3}$
160	1.42	**$(5.6\pm 0.2)\cdot10^3$**	10^{-14}	0	∞	**3.18 ± 0.07**	-0.178 ± 0.008	$(7.1\pm0.7)\cdot10^{-4}$
170	1.23	**$(5.9 \pm 0.2)\cdot10^3$**	10^{-14}	0	∞	**3.22 ± 0.06**	0.648 ± 0.005	$(2.19\pm0.09)\cdot10^{-3}$

*We don't use the first point of the 150K curve and the third point of 135K.

Fixed σ and polynomial density of states: Fit values

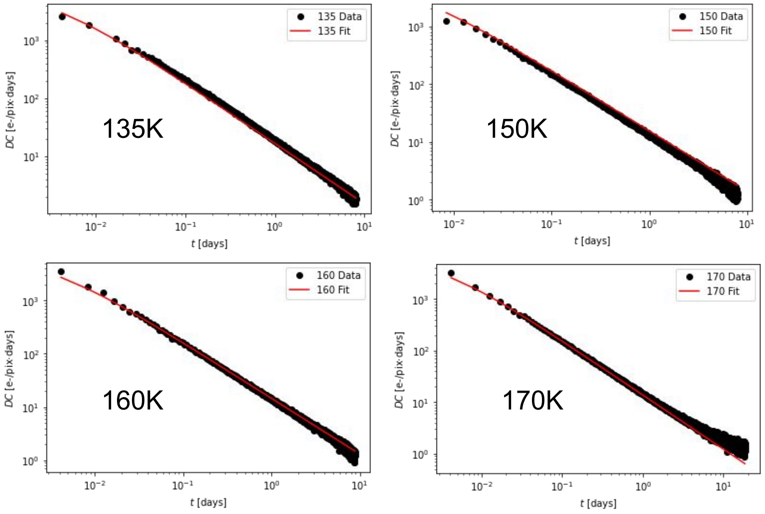
- We fixed $\sigma=10^{-15}$ cm^2, $E_{min}=0$ and $E_{max}=\infty$ and fitted the full curves at the same time*.
  - Cross section values:
    - https://indico.cern.ch/event/1019603/contributions/4279286/attachments/2212446/3744669/06045257.pdf
      - For Si/SiO2 interface we may expect $\sigma\sim10^{-15}$ cm^2.
- We expect to obtain the same polynomial for all the curves.
  - **170K and 150K → Do not have the same polynomial.**



T [K]	a_0 [e-/pix·eV]	a_1 [e-/pix·eV^2]	a_2 [e-/pix·eV^3]	σ_∞ [cm^2] Fixed	E_{min} [eV] Fixed	E_{max} [eV] Fixed	DC_{eq} [e-/pix·days]	δt [days]
150	257.79	7538	-12155.19	10^{-15}	0	∞	-0.2	$2\cdot10^{-7}$
170	-3160	18367	19698	10^{-15}	0	∞	0.718	0.00125

Fixed σ and multiple fit: Fit values

- We fixed $\sigma=10^{-15}$ cm^2, $E_{min}=0$ and $E_{max}=\infty$ and fitted the full curves at the same time.
  - Cross section values:
    - https://indico.cern.ch/event/1019603/contributions/4279286/attachments/2212446/3744669/06045257.pdf
      - For Si/SiO2 interface we may expect $\sigma \sim 10^{-15}$ cm^2.
- We expect to obtain the same value of A and α for all the curves.
  - A and α are about the average value of the individual fits.



χ^2/ndf	A [e-/pix·eV]	σ_∞ [cm^2] Fixed	E_{min} [eV] Fixed	E_{max} [eV] Fixed	α [eV^{-1}]	DC_{eq} [e-/pix·days]	δt [days]
18.82	$(7.1 \pm 0.3)\cdot 10^3$	10^{-15}	0	∞	3.872 ± 0.008	0.312 ± 0.002	$(1.71 \pm 0.02)\cdot 10^{-5}$

Reminder of the exponential

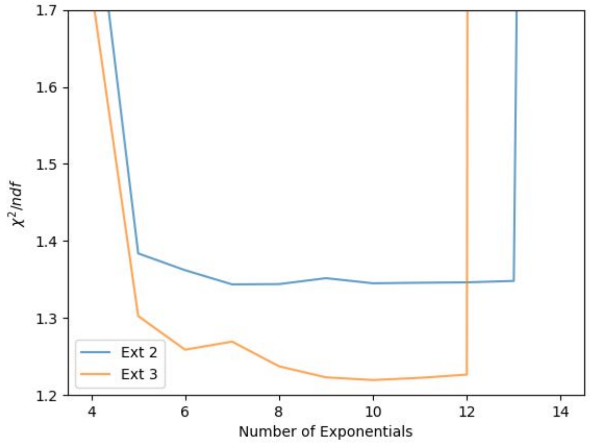
- The observed **number of exponentials with a good chi2 can be up to 12**.
    - However, they start to give amplitudes lower than the equilibrium constant at 7 expos.
- Study the parameters of the fit: **Cutting the curve by the tail and the beginning to see how affect the fits**.
    - The decay constants seem to stabilized when using more point of the DC curve.
    - Removing the first point of the curve (reducing the fully decay components) -> the fitted parameters starts to degenerate.
    - The fitted values of the amplitudes and decay constants seems to compensate each other
    - The total density of the fit seems to stabilized with larger decay tail.
- Studied how the **individual decaying components** of the exponential model affects the 170K curve.
    - Most of the decaying components are found before 2.5 days.
    - The equilibrium value can be fixed to the one expected from erase and purge measurements.
- Studied the curve by **ranges**.
    - Tried to obtain the **energies and cross sections**.
        - For the **same temperature** we obtain the **same energies**.
    - It seems that there are **more ranges than 6**.

How many exponentials do we have?

- At least 5 exponentials are required to have a good fit in terms of χ^2 being reasonable up to 12 exponentials

    - For more than 6 exponentials there is not real improvements in χ^2 -> Results with 6 exponential (5 expos in backup)

    - We do not have power with our test to discriminate new contributions (traps). -> more details later on in slide 31.



Theoretical Model:

$$DC_{Total}(T,t) = \sum_i DC_i(T) \cdot e^{-\mu_i(T)t} + DC_{eq}(T)$$

Traps Amplitudes

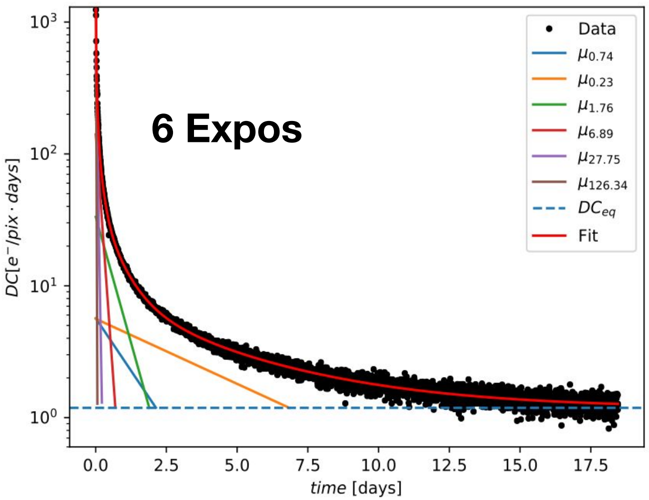
Decay Constants

Equilibrium Constant

How many exponentials do we have?

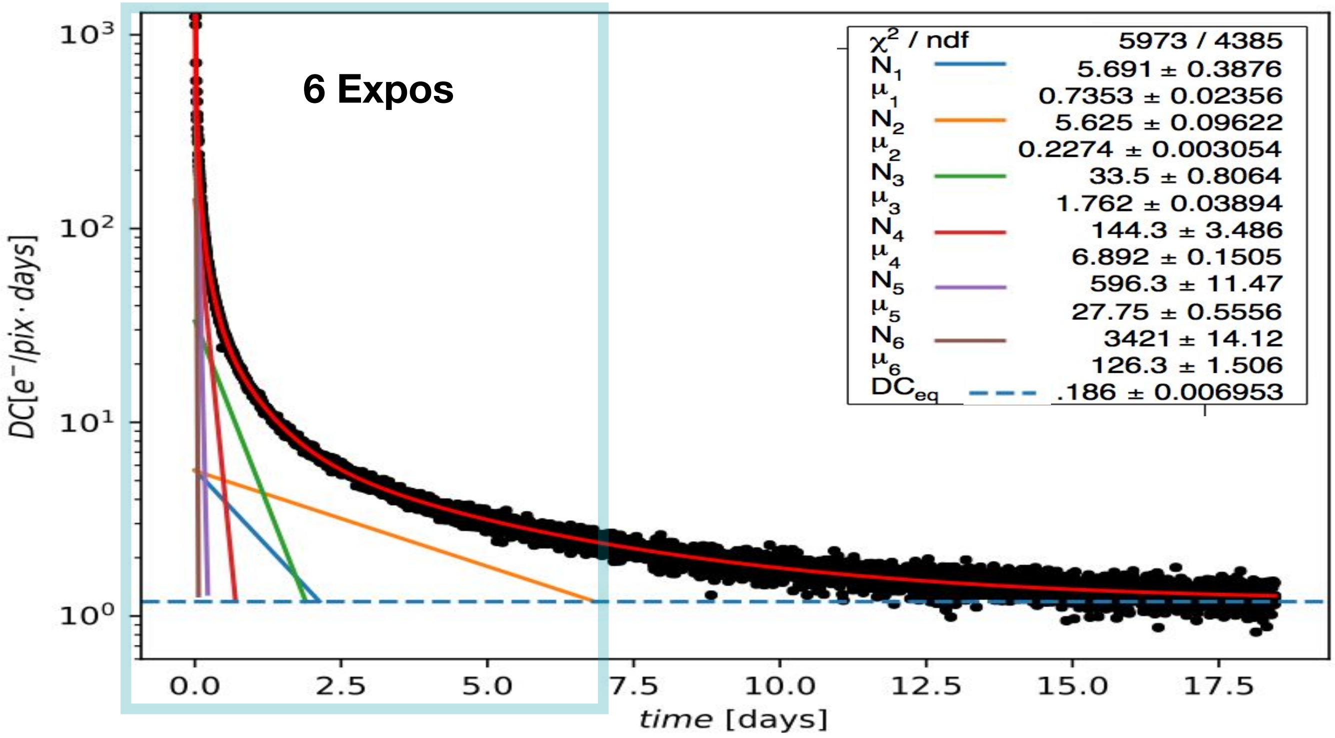
- **At least 5 exponentials** are required to have a good fit **in terms of χ^2** being **reasonable up to 12** exponentials
    - For more than 6 exponentials there is not real improvements in χ^2
    - We do not have power with our test to discriminate new contributions (traps). -> more details later on in slide 31.

Why 6 instead of 3?
previously 3 exponential gave best results because the fast decay of the curve was less populated (see next slide)



- The new component 0.74 days^{-1} has low amplitude and decays at ~2.5 days.

Fitting the full 170K curve: 6 exponentials results



Fitting the full curves: Densities and energies fixing σ

- We fixed $\sigma=10^{-15}$ cm^2 expected for Si/SiO2 interface .
  - https://indico.cern.ch/event/1019603/contributions/4279286/attachments/2212446/3744669/06045257.pdf
- Densities in the range of [10^3,10^7] cm^{-2}.
- Energies in the range [0.35,0.55] eV.

T K	ρ_1 cm^{-2}	ρ_2 cm^{-2}	ρ_3 cm^{-2}	ρ_4 cm^{-2}	ρ_5 cm^{-2}	ρ_6 cm^{-2}	E_1 eV	E_2 eV	E_3 eV	E_4 eV	E_5 eV	E_6 eV	σ cm^2
135	$5{\cdot}10^7$	$3.5{\cdot}10^6$	$1.1{\cdot}10^7$	$1.1{\cdot}10^7$	$9.5{\cdot}10^6$	$3{\cdot}10^3$	0.42	0.41	0.39	0.37	0.36	0.35	$1{\cdot}10^{-15}$
150	$1{\cdot}10^7$	$9{\cdot}10^5$	$8{\cdot}10^6$	24.12	$7{\cdot}10^6$	$8.6{\cdot}10^6$	$4{\cdot}10^5$	0.47	0.46	0.45	0.42	0.41	$1{\cdot}10^{-15}$
160	$1.1{\cdot}10^7$	$7{\cdot}10^5$	$9{\cdot}10^6$	$1{\cdot}10^7$	$1{\cdot}10^7$	$1{\cdot}10^7$	0.51	0.5	0.48	0.46	0.44	0.42	$1{\cdot}10^{-15}$
170	$1.1{\cdot}10^7$	$3.7{\cdot}10^5$	$9{\cdot}10^6$	$9{\cdot}10^6$	$1{\cdot}10^7$	$9{\cdot}10^6$	0.55	0.53	0.51	0.49	0.47	0.45	$1{\cdot}10^{-15}$

Study of the 170K curve by ranges

Supposing a component it's dominating the decay in some region of the curve, we can approximate the exponential model to:

$$ln|DC_{range}| \simeq ln|DC_i| - \mu_i \cdot t$$

The relation of the decay constant, the cross section and the energy is given by:

$$\mu(T)\ [\mathrm{sec}^{-1}] = X_n \sigma_n v_{th} N_C \cdot e^{-E_T/KT}$$

So the model in that range can be fitted to:

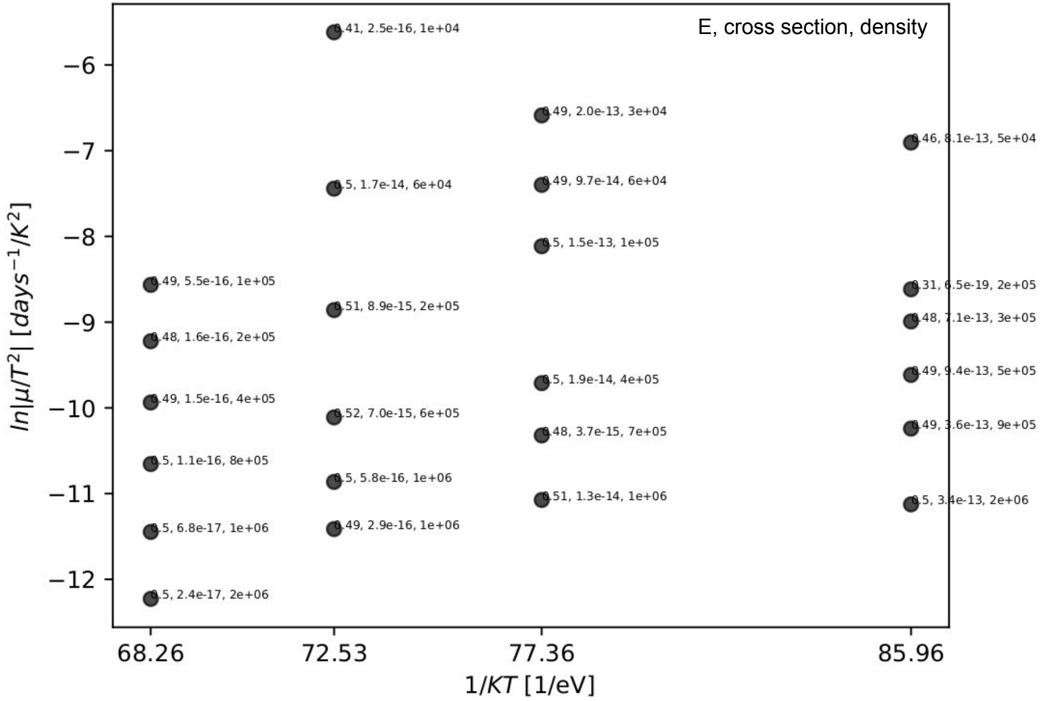
$$ln|DC_{range}| \simeq ln|DC_i| - X_n \underbrace{\sigma_n}_{\text{Cross section}} v_{th} N_C \cdot e^{-\overbrace{E_T}^{\text{Energy of the trap}}/KT} \cdot t$$

Study of the 170K curve by ranges: Arrhenius plot

- Calculated the decay constant based on:

$$\mu(T)\ [\mathrm{sec}^{-1}] = X_n \sigma_n v_{th} N_C \cdot e^{-E_T/KT}$$

- There are **repeated energies** at the **same temperature**.
  - There are **no match between energy and cross sections** at different temperatures.
  - Is this related with having **more ranges?**
- μ ranges:
  - 135K: [1.04, 2.54] days^{-1}.
  - 150K: [0.78, 20] days^{-1}.
  - 160K: [0.34, 9.9] days^{-1}.
  - 170K: [0.13, 6.1] days^{-1}.
- ρ ranges:
  - 10^4-10^6 cm^{-2}.



Possible defects

Label	E_a (eV)	σ_{na} (cm^2)	Assignment
E270	$E_C - 0.60$	$2.7 \pm 0.3 \times 10^{-14}$	$NiH_2(0/-)$
E230	$E_C - 0.45$	$1.4 \pm 0.1 \times 10^{-15}$	$Ni_s(0/-)$
E90	$E_C - 0.16$	$3 \pm 2 \times 10^{-15}$	CH
E90'	$E_C - 0.17$	$2.2 \pm 0.8 \times 10^{-15}$	NiH(0/−)
E45	$E_C - 0.07$	$1.2 \pm 0.7 \times 10^{-15}$	$Ni_s(-/2-)$
H280	$E_V + 0.58$	$2 \pm 1 \times 10^{-14}$	$NiH_2(0/-)$
H240	$E_V + 0.49$	$1.5 \pm 1 \times 10^{-14}$	NiH(+/0)
H190	$E_V + 0.46$	$2 \pm 2 \times 10^{-11}$	$NiH_3(0/-)$
H150	$E_V + 0.29$	$4 \pm 1 \times 10^{-15}$	Ni–H-related
H80	$E_V + 0.16$	$1.1 \pm 0.3 \times 10^{-14}$	$Ni_s(+/0)$

Table 6.6 Activation energies, apparent capture cross sections, and assignment for all defects observed in n- and p-type silicon. After Scheffler et al. [195]

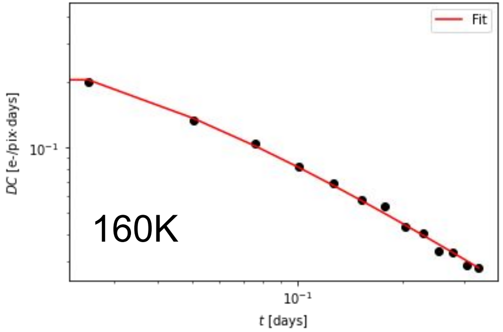
Label	E_a (eV)	σ_n or σ_p (cm^2)	Assignment
E40	$E_C - 0.08$	6×10^{-15}	Ti
E40′	$E_C - 0.07$	8×10^{-16}	TiH
E150	$E_C - 0.27$	5×10^{-16}	Ti
E170	$E_C - 0.34$	4×10^{-14}	TiH
E170′	$E_C - 0.37$	4×10^{-14}	TiH_2
E260	$E_C - 0.55$	4×10^{-15}	TiH_3
E260′	$E_C - 0.50$	3×10^{-15}	H-related
H180	$E_V + 0.29$	9×10^{-17}	Ti

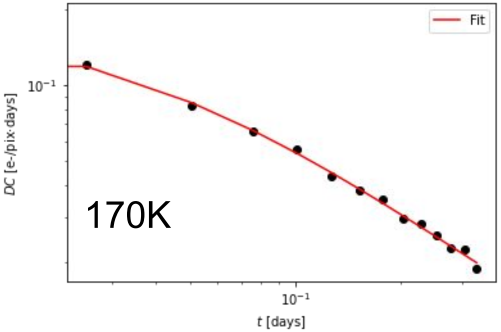
Table 6.13 Energy levels and capture cross sections assigned to the Zn complexes Si. After Lemke [277]

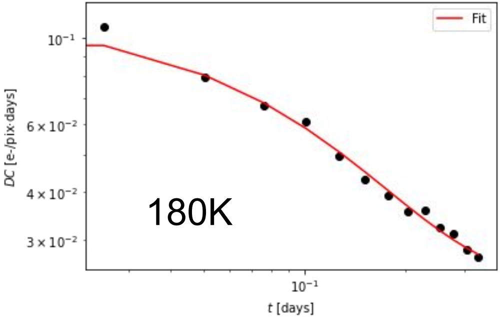
Defect	Defect level (eV)	Capture cross section (cm^2)
ZnCr	$E_C - 0.10$	$\sigma_n = 3 \times 10^{-15}$
ZnFe	E_C-0.47	$\sigma_n = 1 \times 10^{-16}$
ZnV	$E_V + 0.29$	$\sigma_h = 1 \times 10^{-16}$
ZnMn	$E_V + 0.18$	$\sigma_n = 2.4 \times 10^{-15}$

- http://www.ime.cas.cn/icac/learning/learning_4/202005/P020200511520663239854.pdf
- https://iopscience.iop.org/article/10.1088/1748-0221/9/12/C12028/pdf
- https://discovery.ucl.ac.uk/id/eprint/1545182/1/Gow_DonorLevelOfDivacancy.pdf
- https://www.researchgate.net/publication/228375184_Charge_trap_identification_for_proton-irradiated_p_channel_CCDs

Erase and purge: Fermi Fits

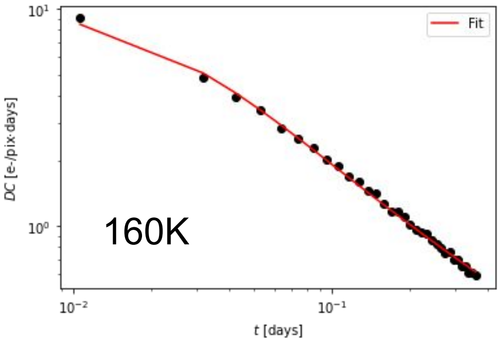


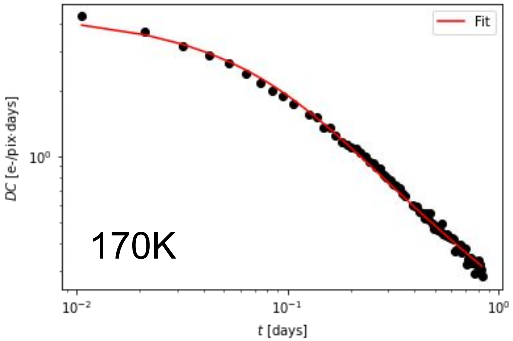


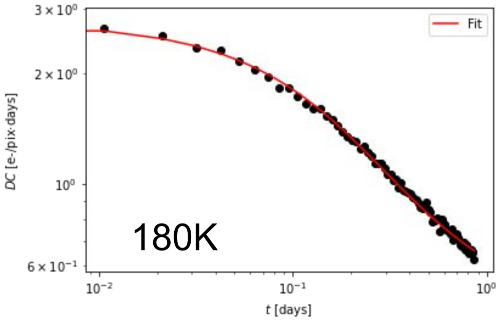


T [K]	χ^2/ndf	A [e-/pix·eV]	σ [cm^{-2}]	E_{min} [eV]	E_{max} [eV]	α [eV^{-1}]	DC_{eq} [e-/pix·days]
160	4.7	1.06 ± 0.072	10^{-27}	0	∞	2.7 ± 0.4	$10^{-10} \pm 4\cdot10^{-4}$
170	3.6	1.5 ± 0.1	10^{-27}	0	∞	14.3 ± 0.9	0.00029±0.0006
180	22.9	26 ±2	10^{-29}	0	∞	2625 ± 200	0.0237± 0.0005

Erase and purge: Snolab Fits

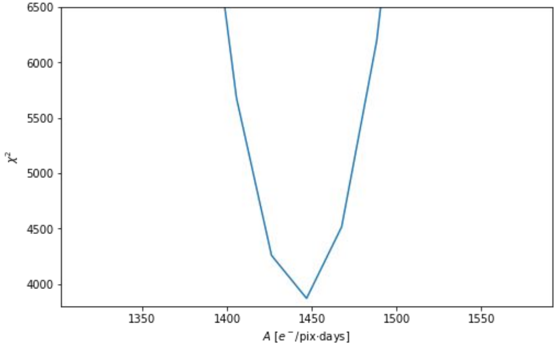


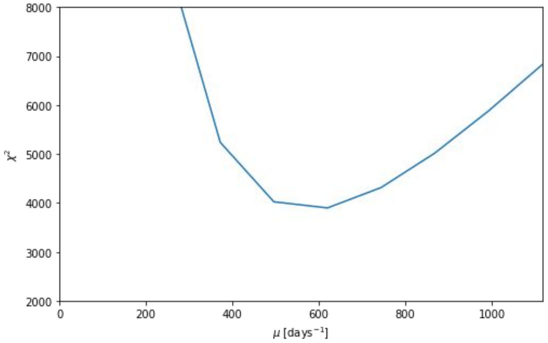


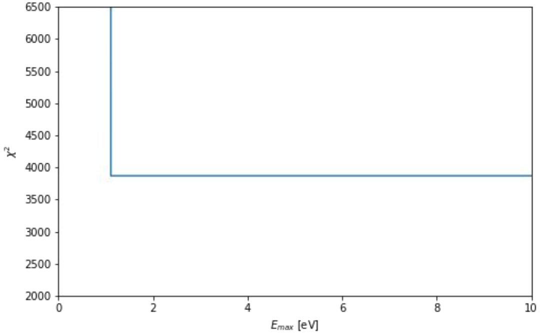


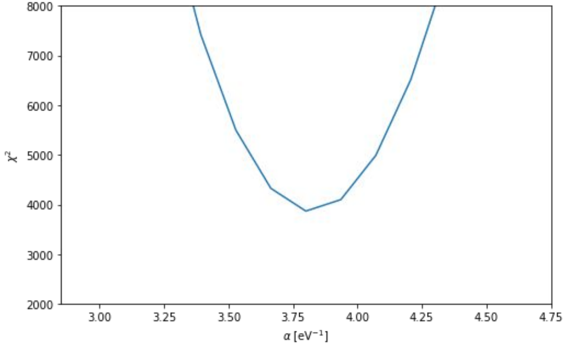
T [K]	**χ^2/ndf**	**A [e-/pix·eV]**	**σ [cm^{-2}]**	**E_{min} [eV]**	**E_{max} [eV]**	**α [eV^{-1}]**	**DC_{eq} [e-/pix·days]**
160	5.4	15.2 ± 0.3	10^{-28}	0	∞	$8\cdot10^{-5}$± 60	0.02 ± 0.01
170	5.5	24 ± 10	10^{-27}	0	∞	3.2± 0.6	$2\cdot10^{-11} \pm 10^{-3}$
180	1.67	48 ± 1	10^{-29}	0	∞	13.9± 0.1	0.9 ± 0.001

Fitted Parameters Minimum (No erase): 160K

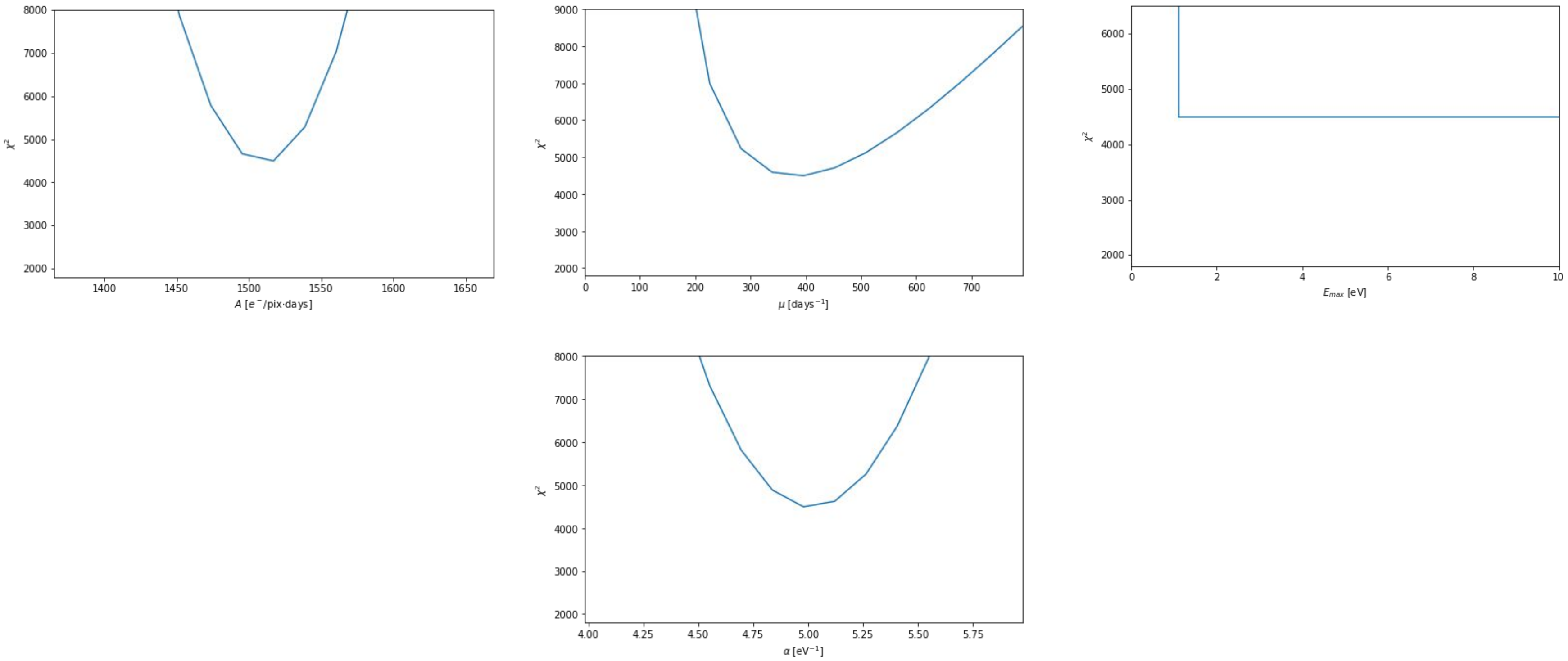




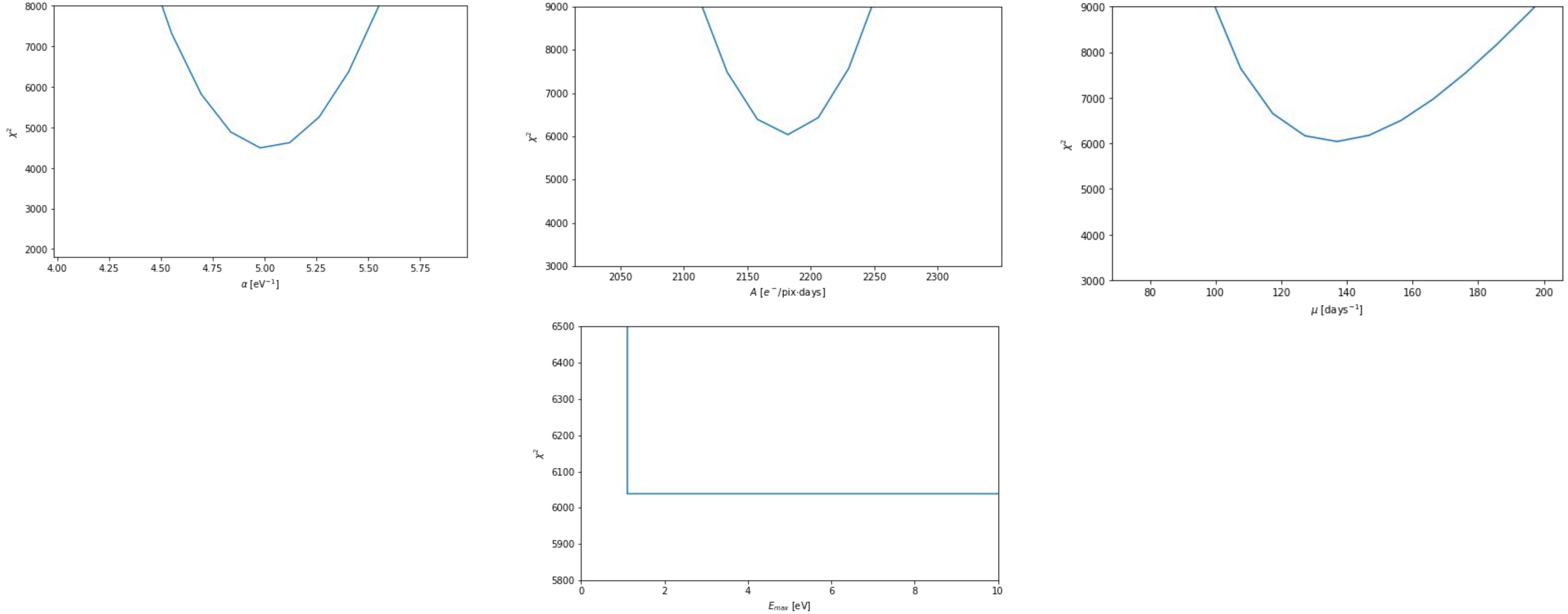




Fitted Parameters Minimum(No erase): 150K

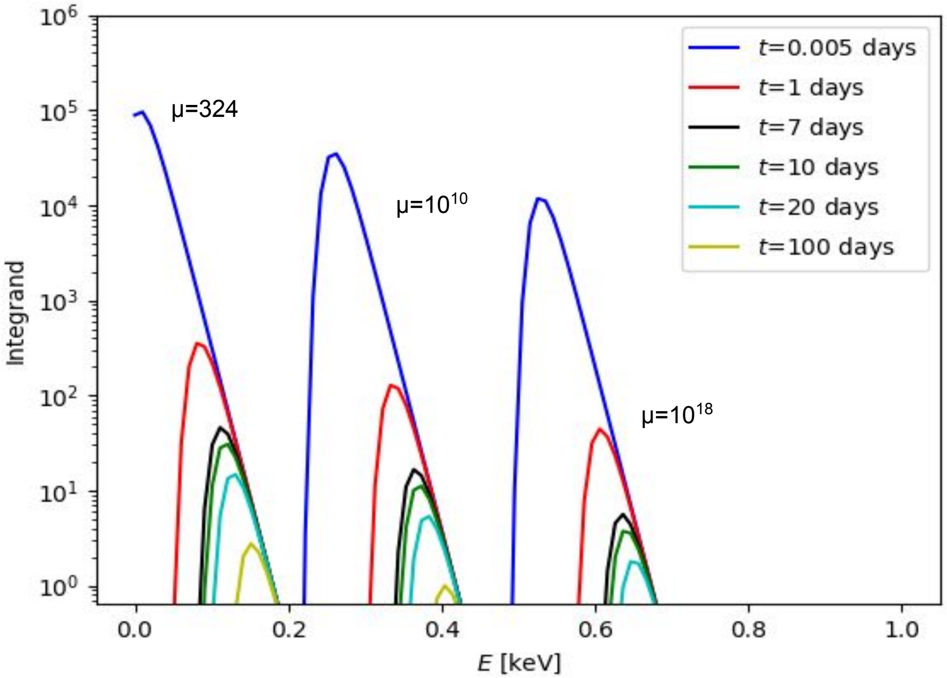


Fitted Parameters Minimum(No erase): 135K



Reminder of the exponential

te pongo slides de las exponenciales que te ayudaran a poner esta informacion de las exponenciales bien que veo que todavia no lo habias hecho, solo mencionado de pasada.
Los plots no se si son los ultimos que tenias, y de hehco los de las densidades no estan muy bien.
en este articulo dan información de tiempos y densidades
https://iopscience.iop.org/article/10.1088/1748-0221/9/12/C12028/pdf
https://discovery.ucl.ac.uk/id/eprint/1545182/1/Gow_DonorLevelOfDivacancy.pdf
y en este densidades y xs
https://www.researchgate.net/publication/228375184_Charge_trap_identification_for_proton-irradiated_p_channel_CCDs



μ=324
μ=10^10
μ=10^18
t=0.005 days
t=1 days
t=7 days
t=10 days
t=20 days
t=100 days
Integrand
E [keV]