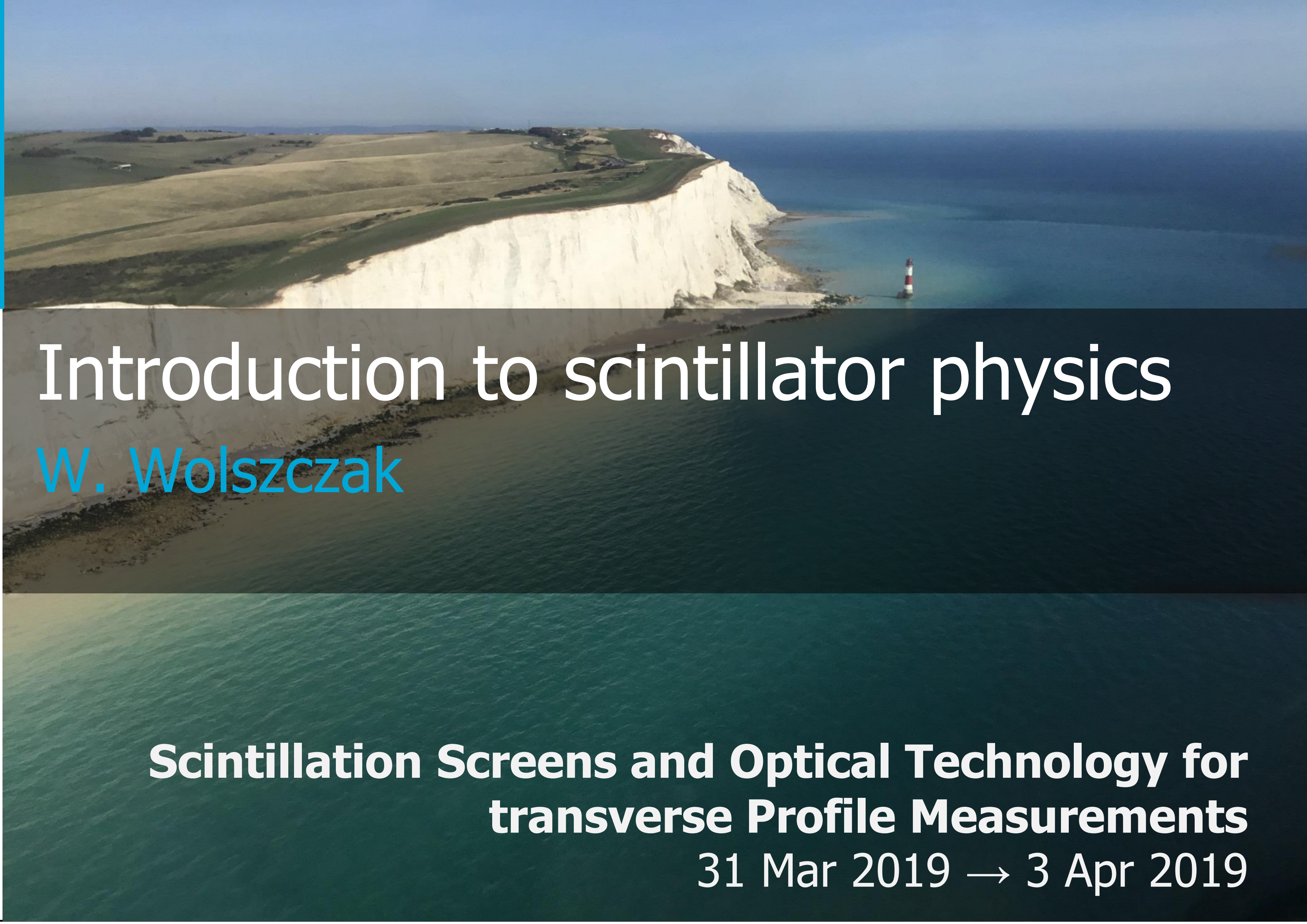


Introduction to scintillator physics

W. Wolszczak

Scintillation Screens and Optical Technology for transverse Profile Measurements

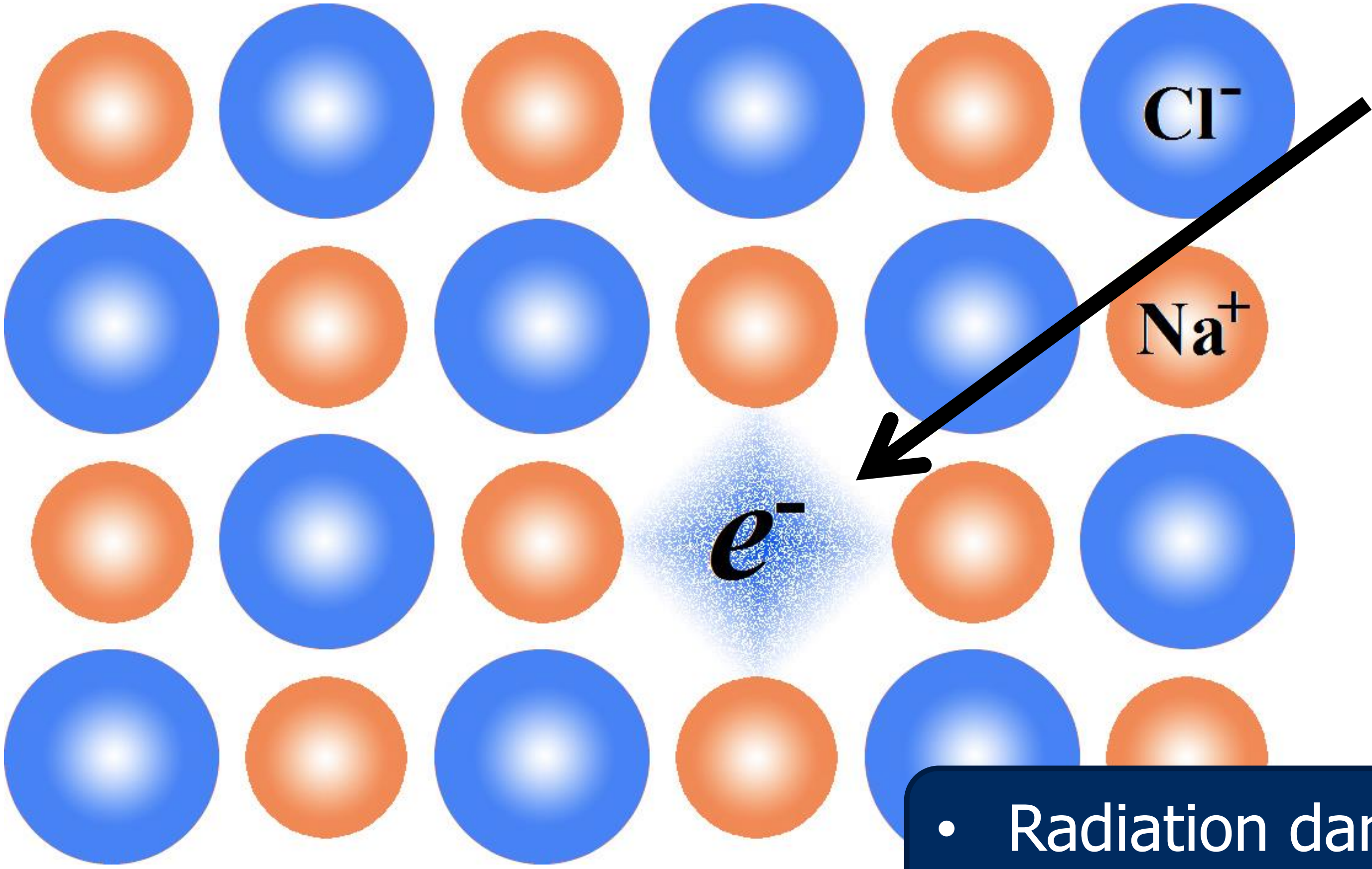
31 Mar 2019 → 3 Apr 2019

The outline

- Short recap on solid state physics
  - Point defects, polarons, self-trapped charges
- Scintillation mechanisms
  - The state of the art CsI:Tl model
- Non-proportionality of response
  - How it is measured?
  - At what conditions is observed?
  - What is the reason?

Point defects in crystals

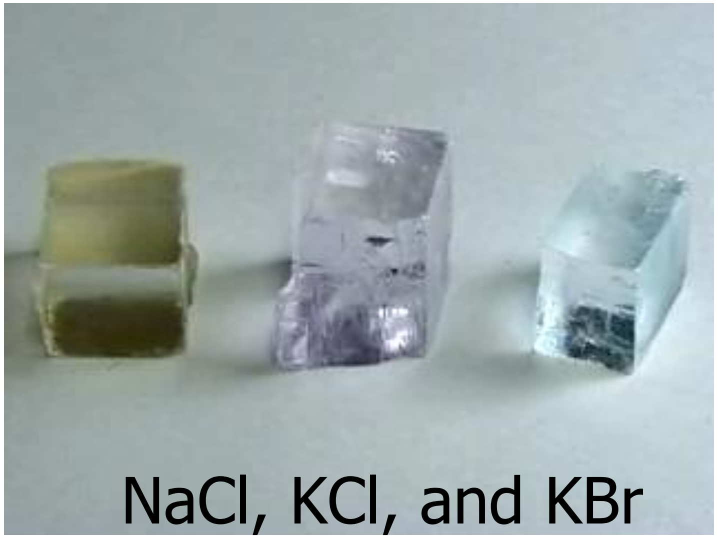
F-centers

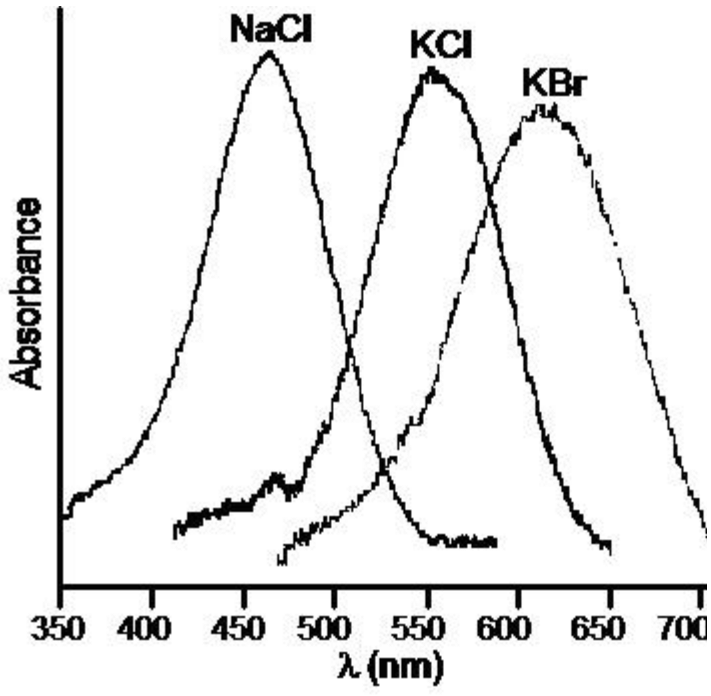


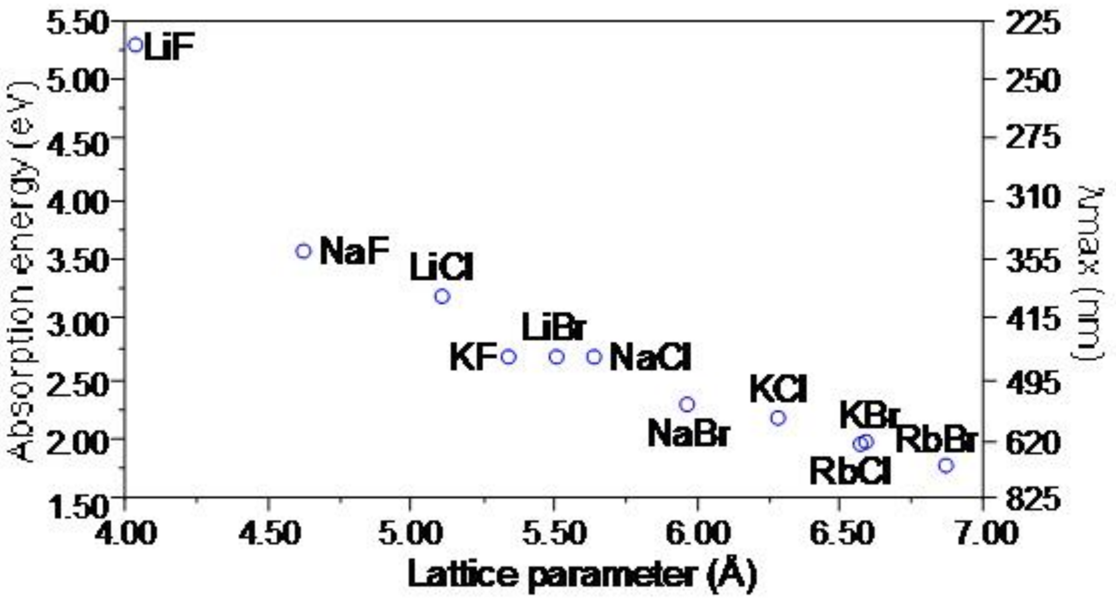
An anion vacancy can trap an electron

- Radiation damage
- Non-stechiometric growth

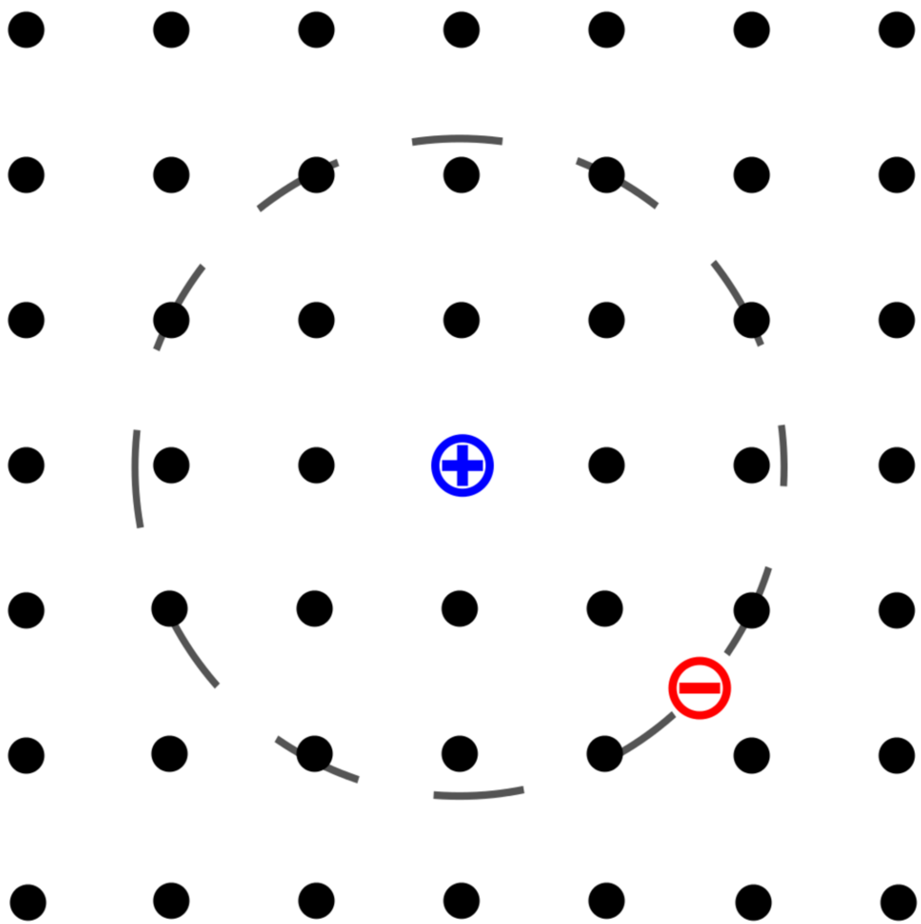
F-center absorbance

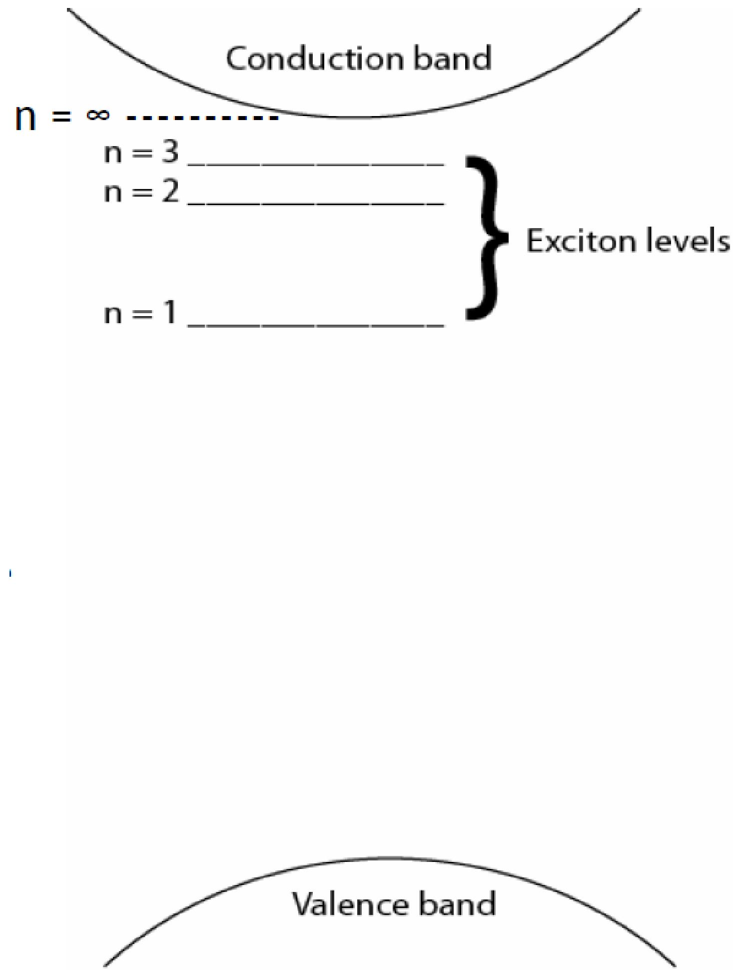




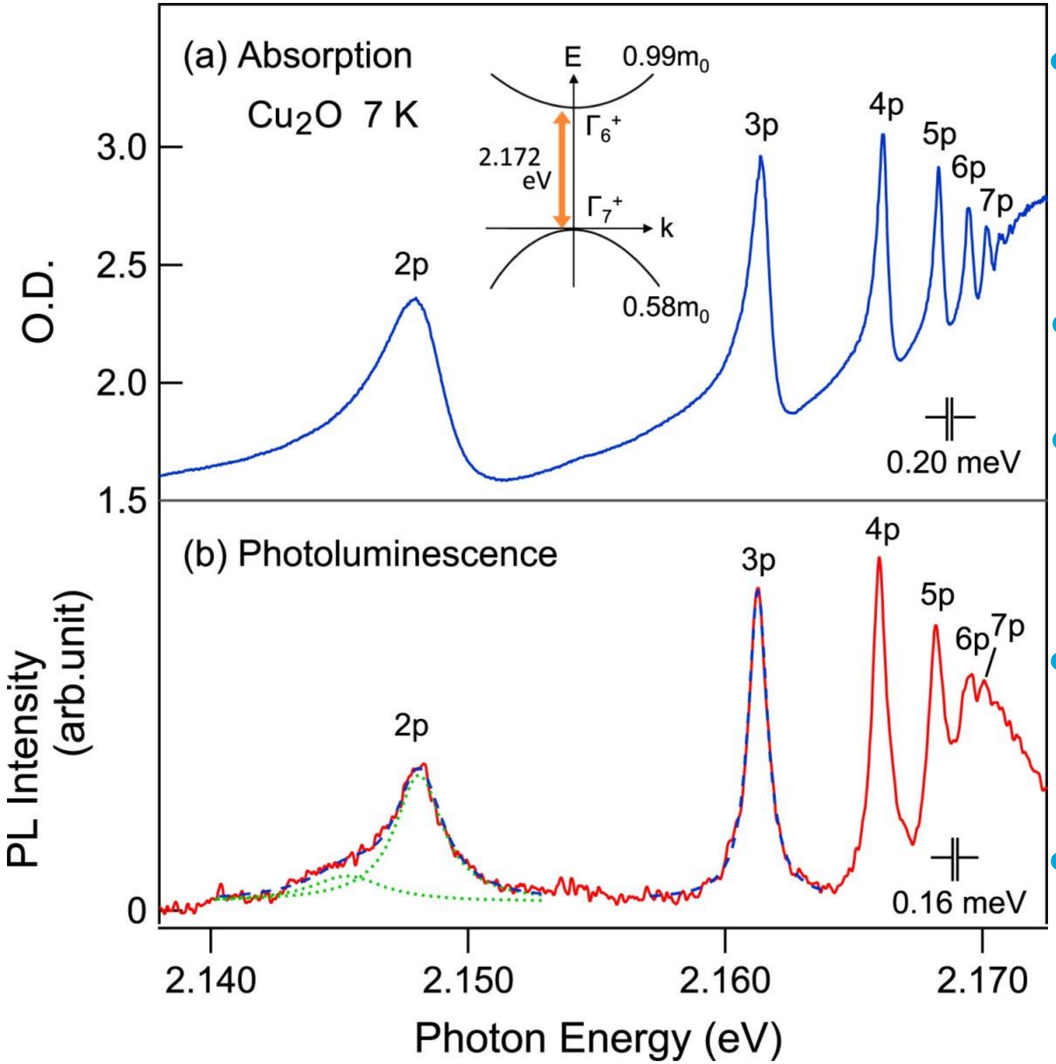


Exciton – a hydrogen-like neutral quasiparticle





Free excitons absorption and emission



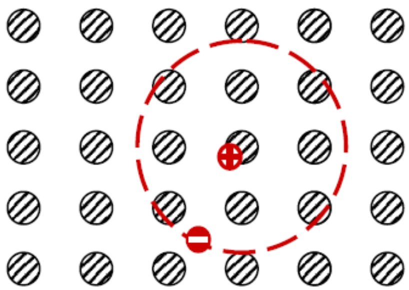
- Excitons in semiconductors behave like a hydrogen atom
- $E_n = E_g - \frac{\mu e^4}{2\hbar^2 \varepsilon^2 n^2}$
- $\frac{1}{\mu} = \frac{1}{m_e{}^*} + \frac{1}{m_h{}^*}$
- The bandgap energy E_g = 2.17 eV
- Exciton binding energy in Cu_2O = 150 meV (n=1)

Kitamura et al., Quantum number dependence of the photoluminescence broadening of excitonic Rydberg states in cuprous oxide, 2017

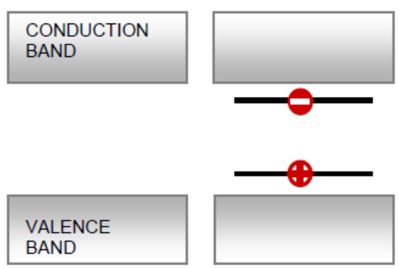
Excitons (bound electron-hole pairs)

Wannier exciton

(typical of inorganic semiconductors)



SEMICONDUCTOR PICTURE



GROUND STATE WANNIER EXCITON

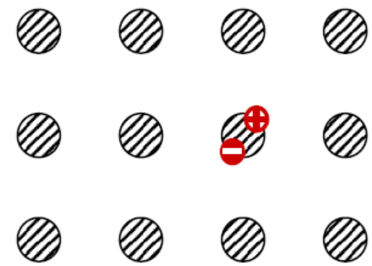
binding energy ~10meV
radius ~100Å

treat excitons as chargeless particles capable of diffusion,

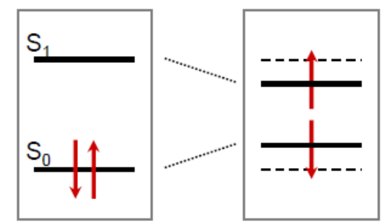
also view them as excited states of the molecule

Frenkel exciton

(typical of organic materials)



MOLECULAR PICTURE



GROUND STATE FRENKEL EXCITON

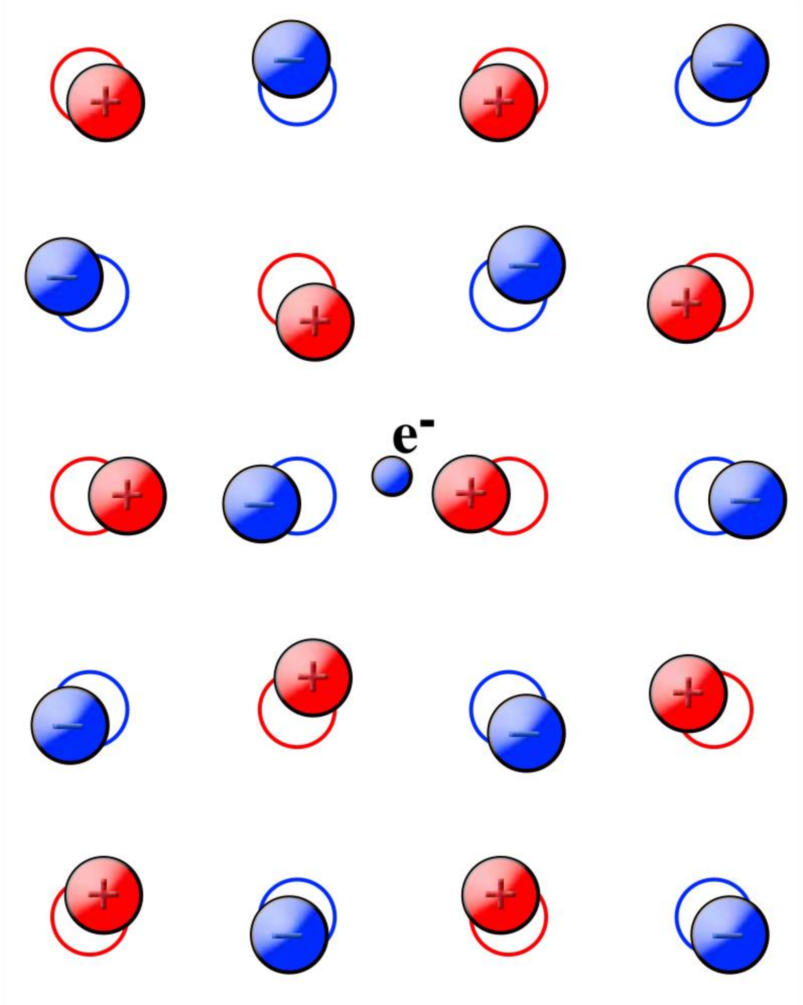
binding energy ~1eV
radius ~10Å

Charge Transfer (CT) Exciton

(typical of organic materials)

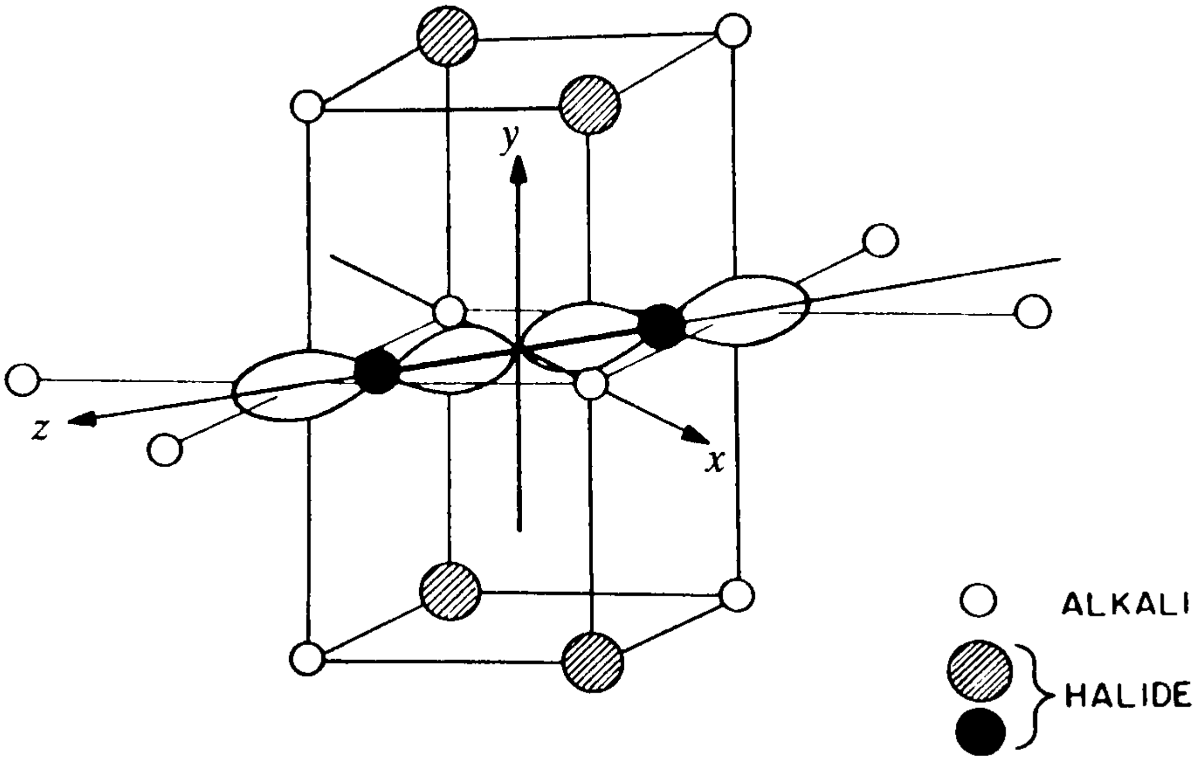
Electronic Processes in Organic Crystals and Polymers by M. Pope and C.E. Swenberg 3

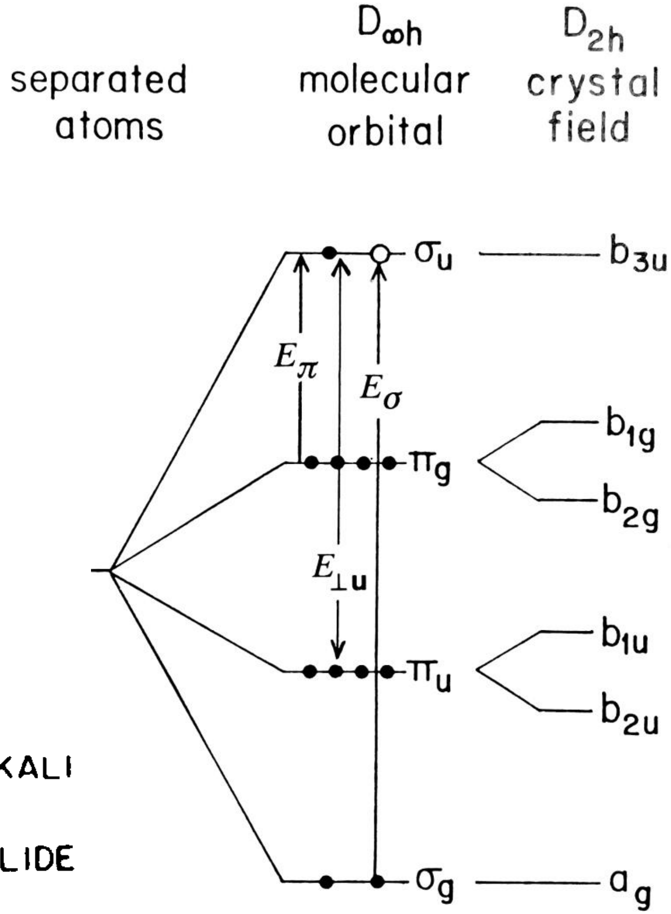
Polaron model



- Electron/hole interacts with phonon modes
- Lattice polarization

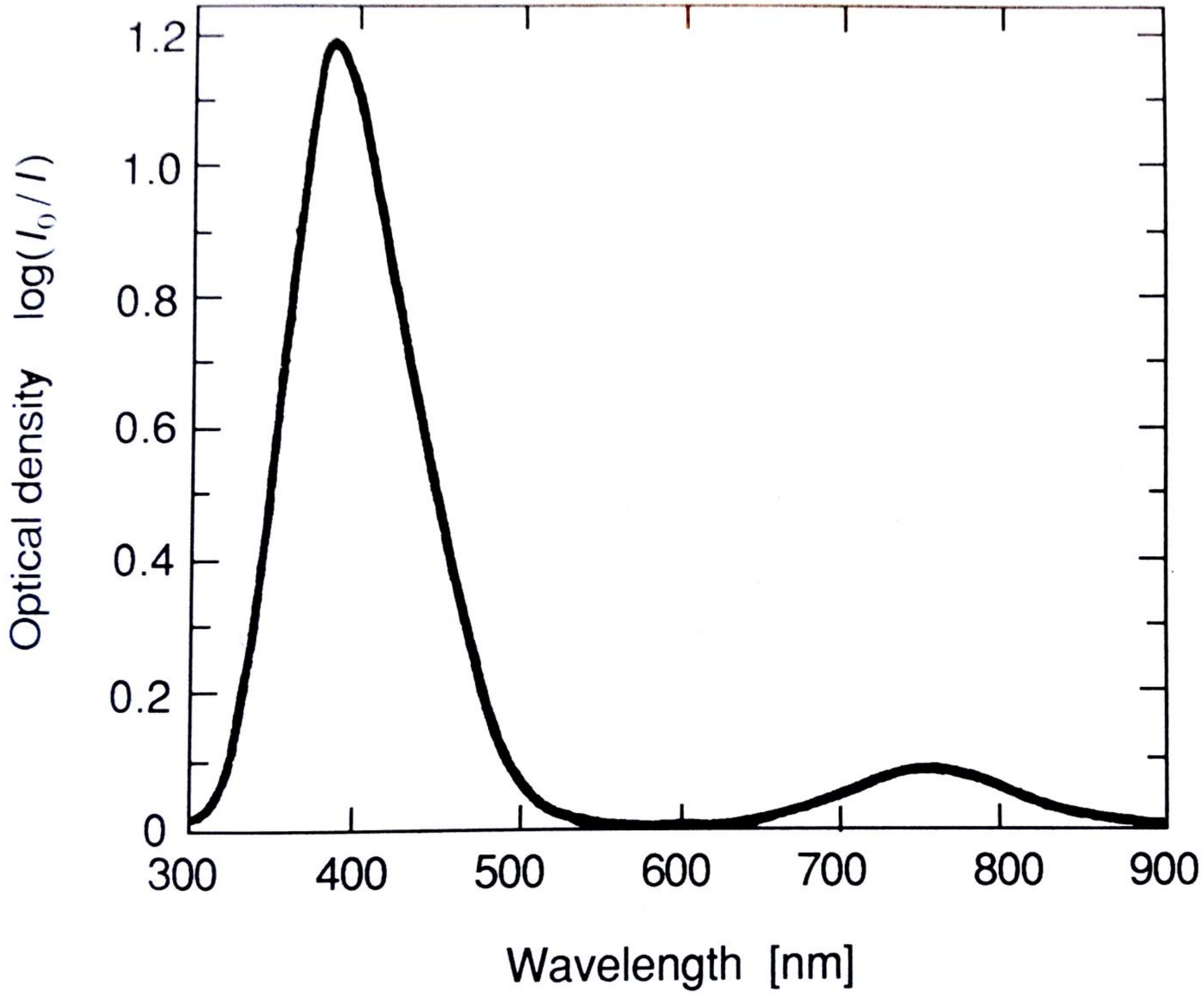
Self-Trapped Hole





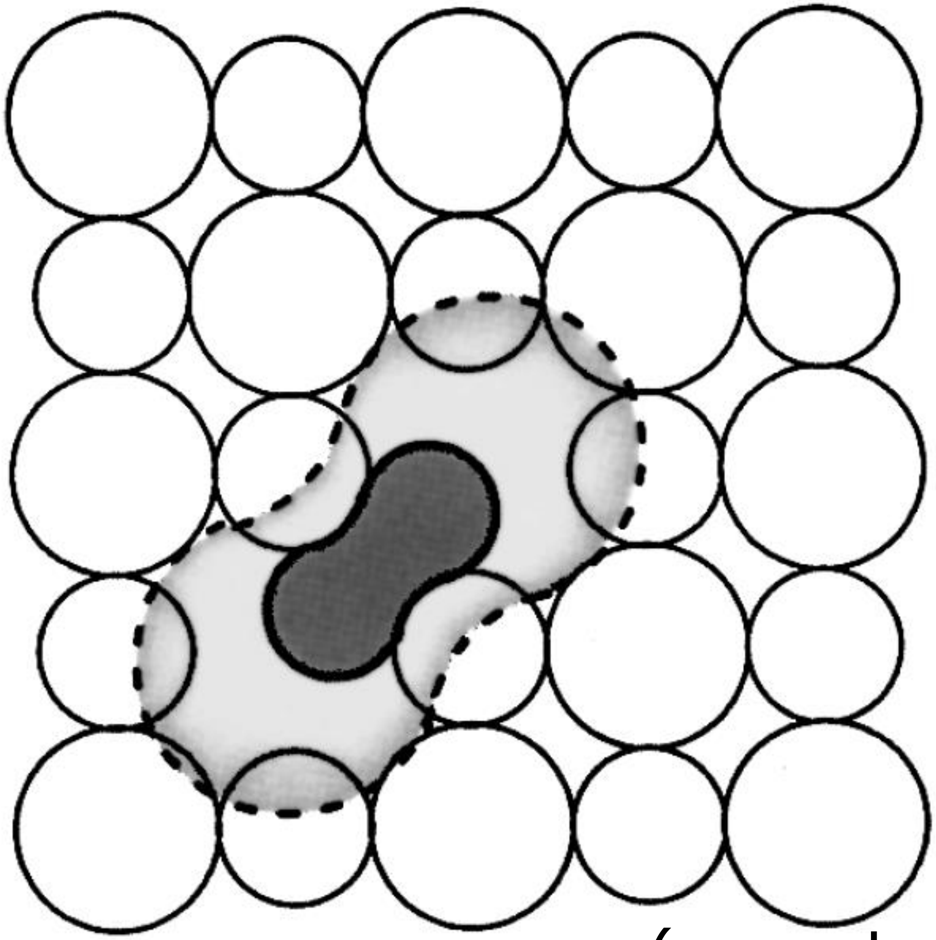
Self-trapped hole (V_k center) in an alkali halide with the NaCl structure

Optical absorption o STH



Optical absorption of STH in KBr

Self-trapped exciton: V_k centre + e^-



(on-centre configuration)

STE luminescence in alkali halides

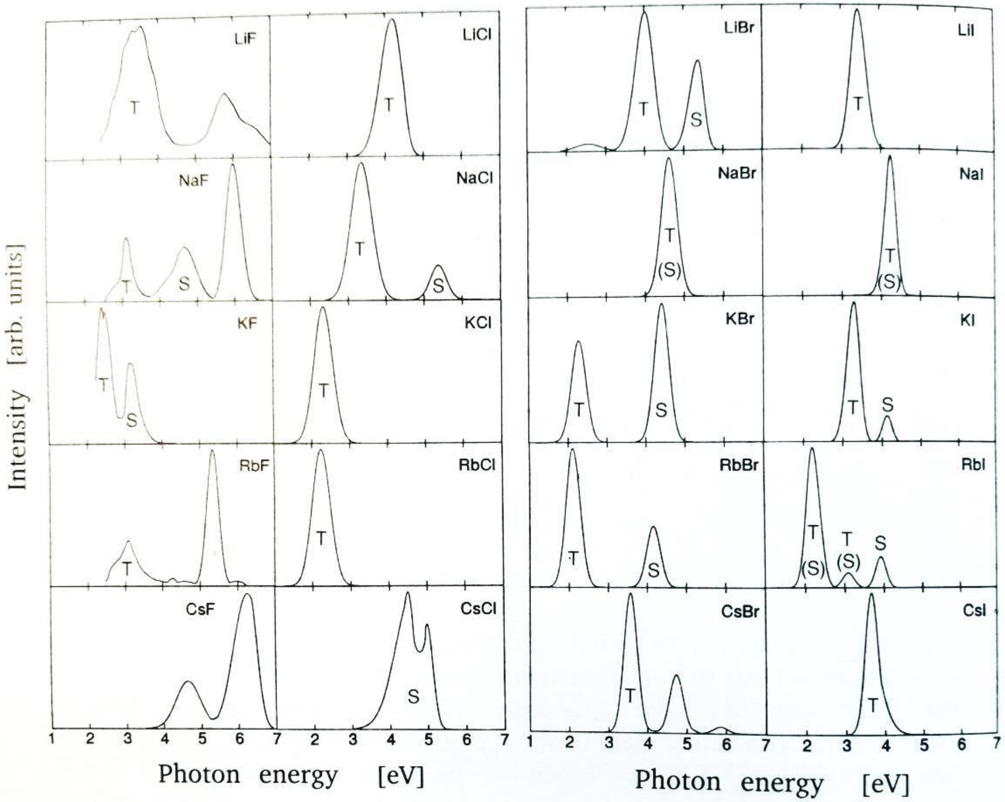
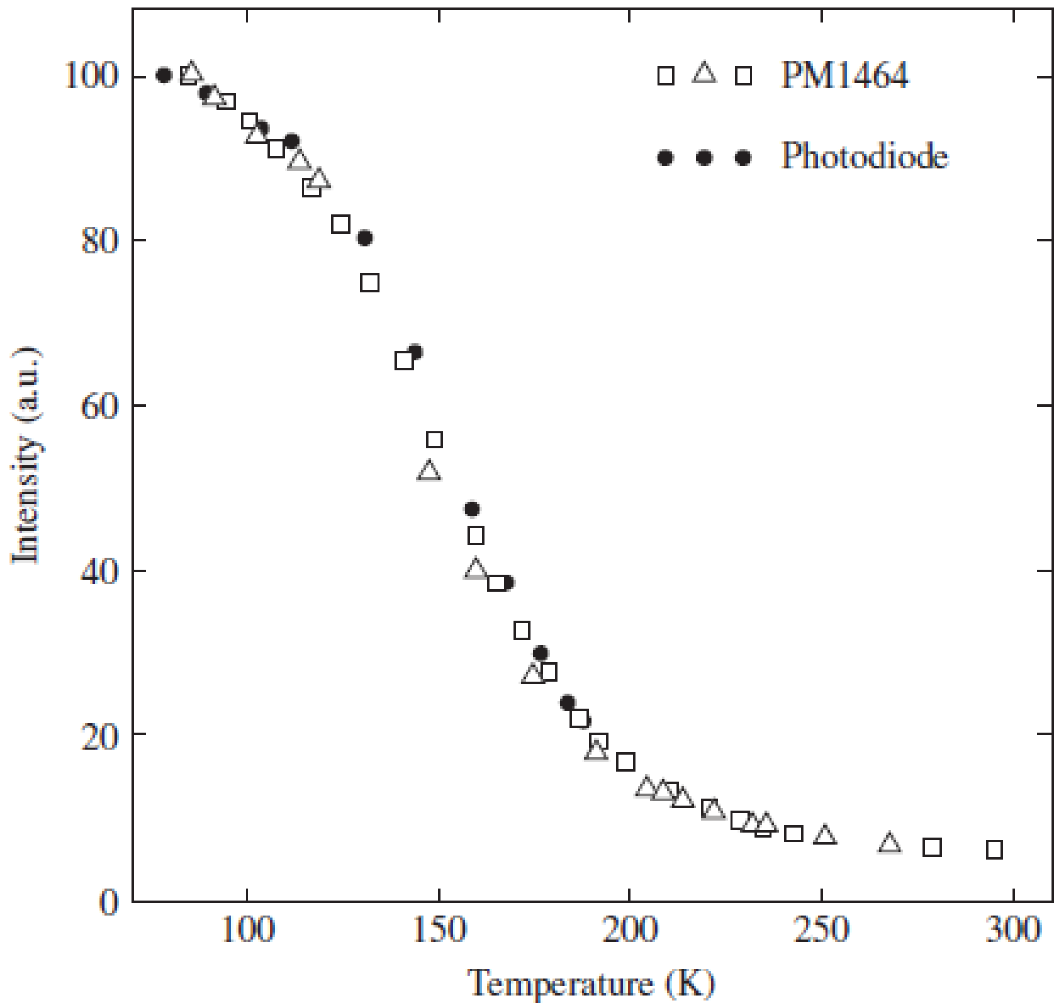


Fig. 5.5. STE luminescence spectra excited by X-ray or electron irradiation in 20 alkali halide crystals at temperatures in the range 4.2–11 K. Known triplet bands are marked T; known singlet bands are marked S; newly discovered singlet components to be discussed are marked (S); and unmarked bands have not been definitely identified by either lifetime or polarization. The spectra have been normalized so that the most intense peak is full scale. These spectra have been digitized and re-plotted from the following original works: NaCl, NaBr, KCl, KBr, RbCl, and RbBr from [5.67]; LiF, LiCl, LiBr, NaF, NaI, RbF, CsCl, CsBr, and CsI from [5.66]; LiI from [5.74]; KF from [5.75]; KI and RbI from [5.73]; CsF from [5.76]

Responsible for the host luminescence in alkali halides

K. Song, R.T. Williams, Self-Trapped Excitons, 1993

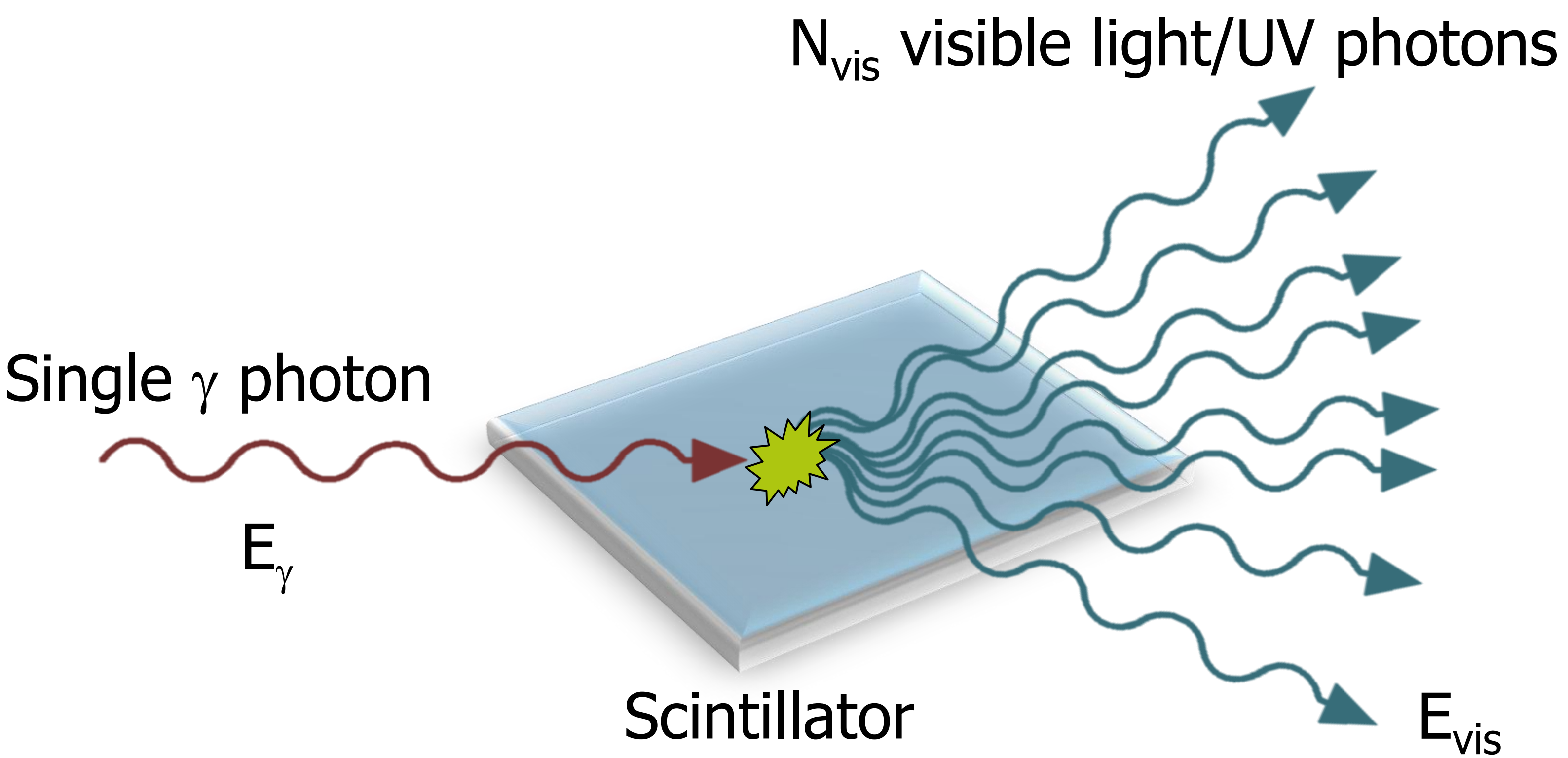
CsI light yield vs temperature



STE emission is strongly quenched at room temperature

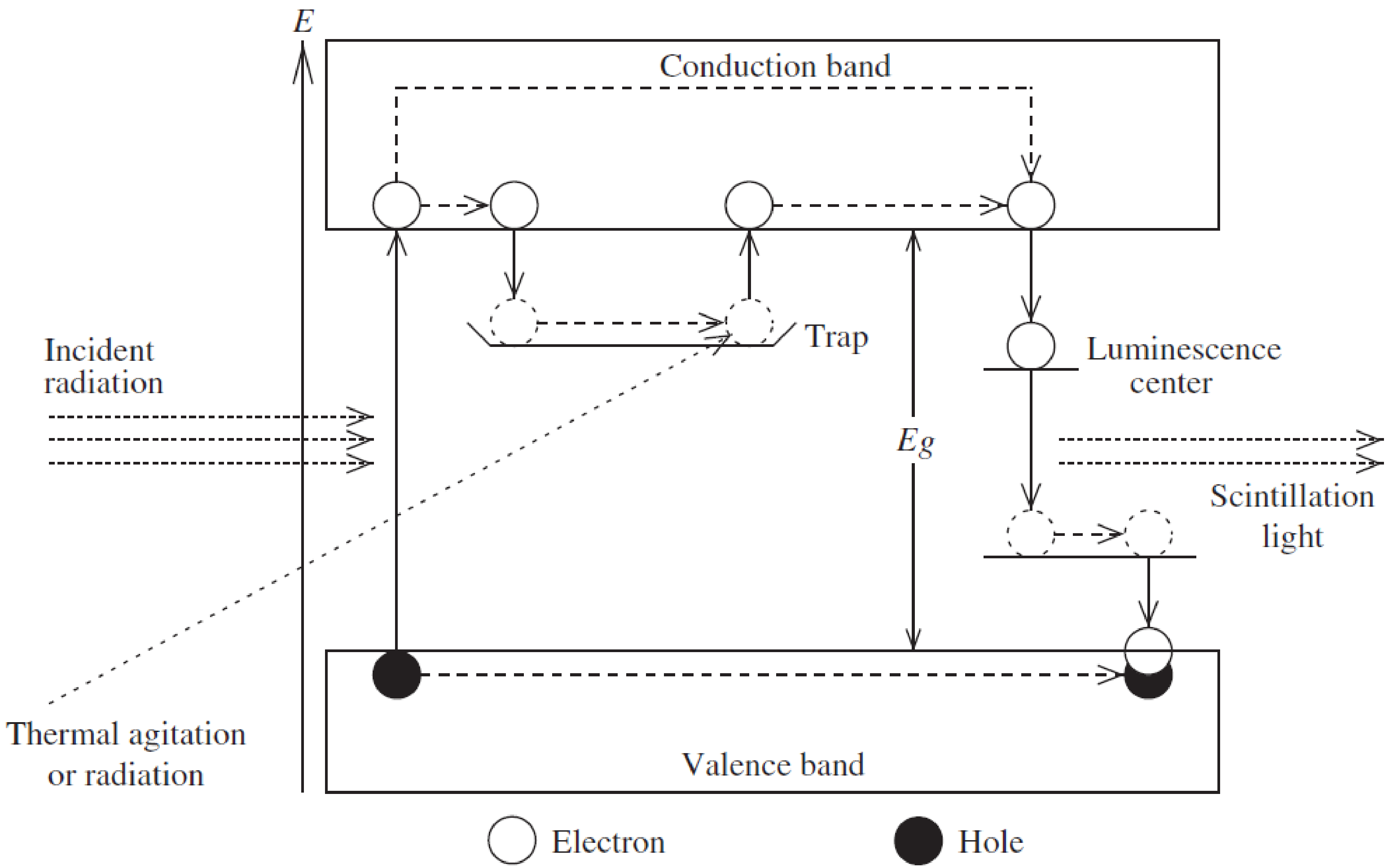
Scintillation mechanism

Scintillator

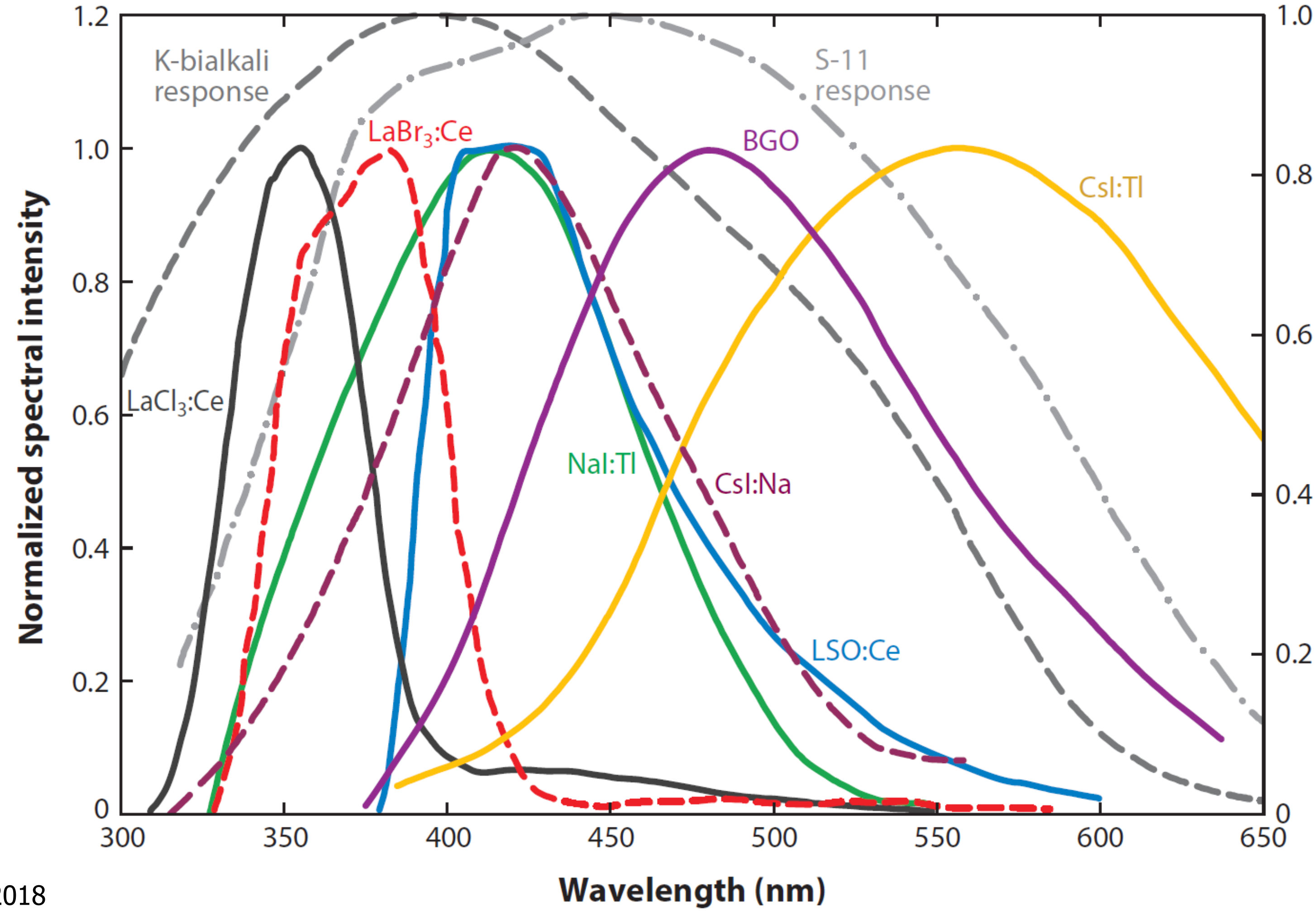


- $N_{vis} \sim E_\gamma$
- $\sigma_{Nvis} \rightarrow \sqrt{N_{vis}}$

Basic scintillation mechanism

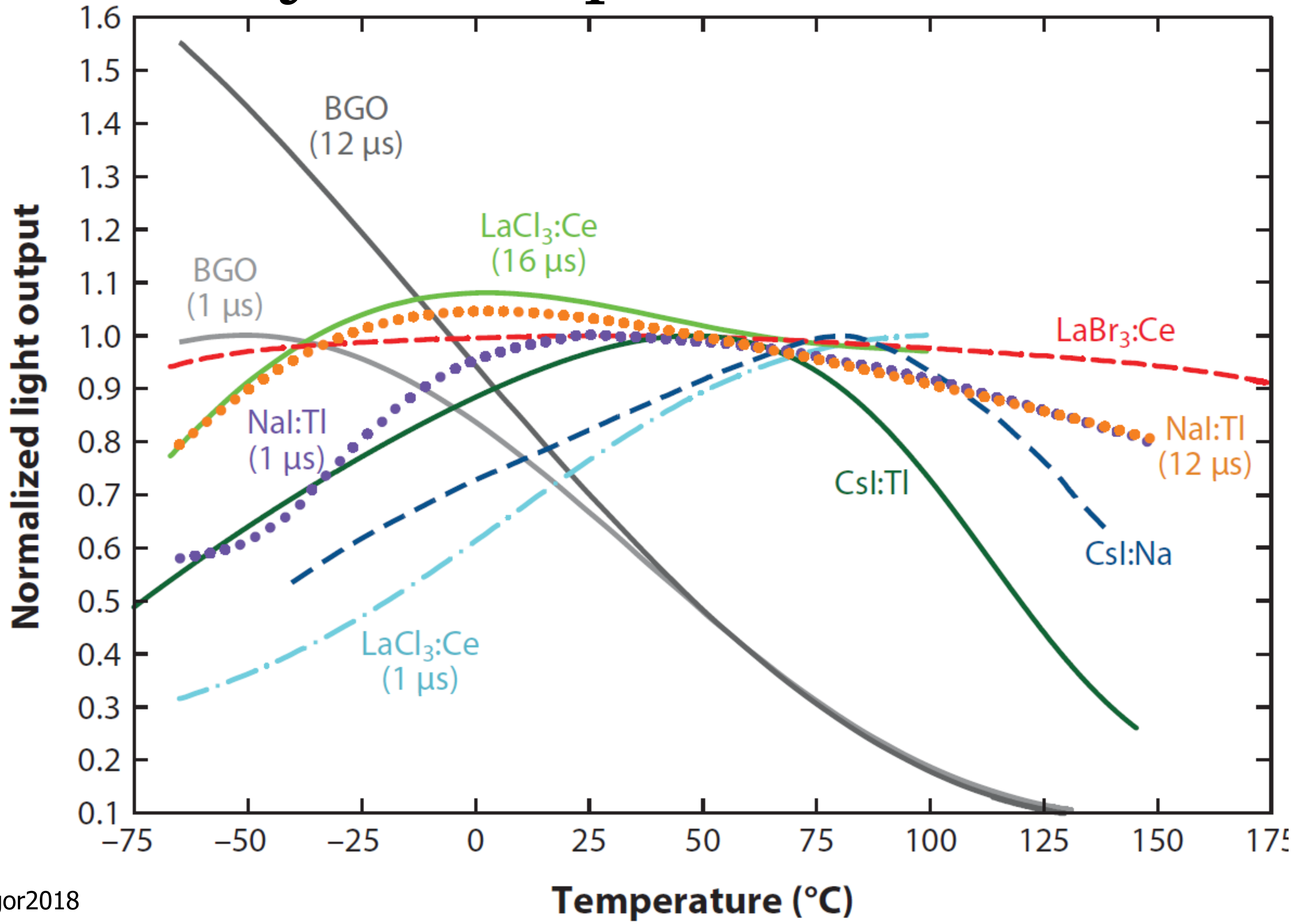


Emission wavelength



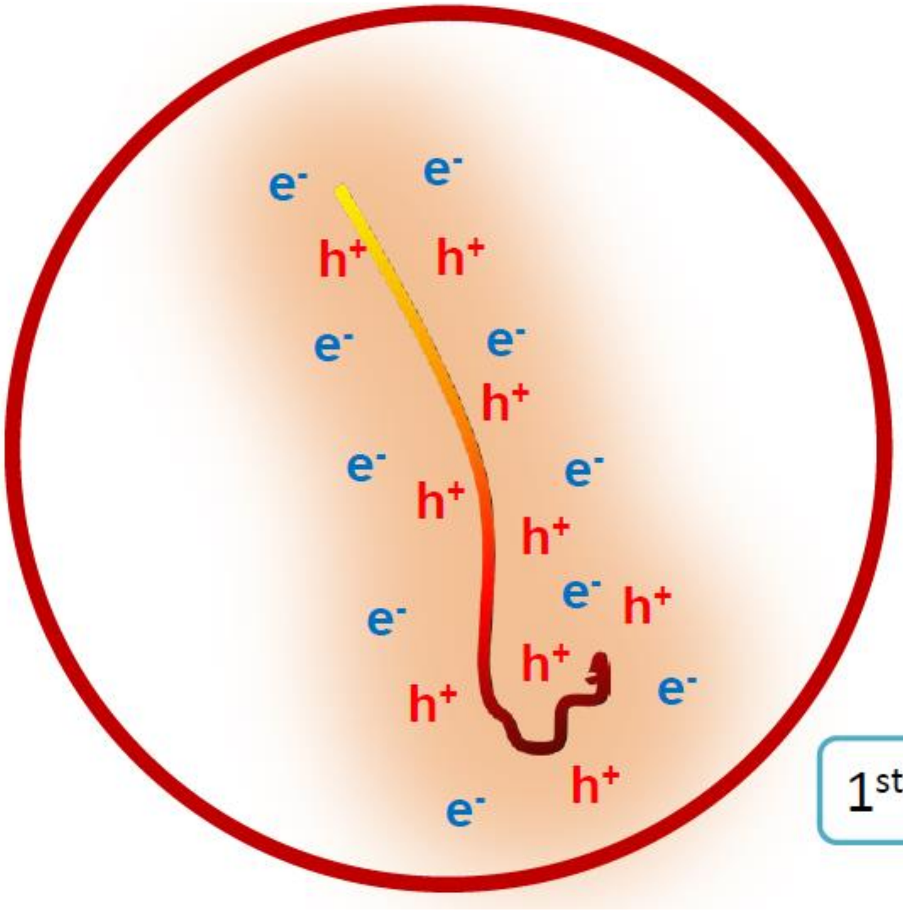
From McGregor2018

Intensity vs temperature



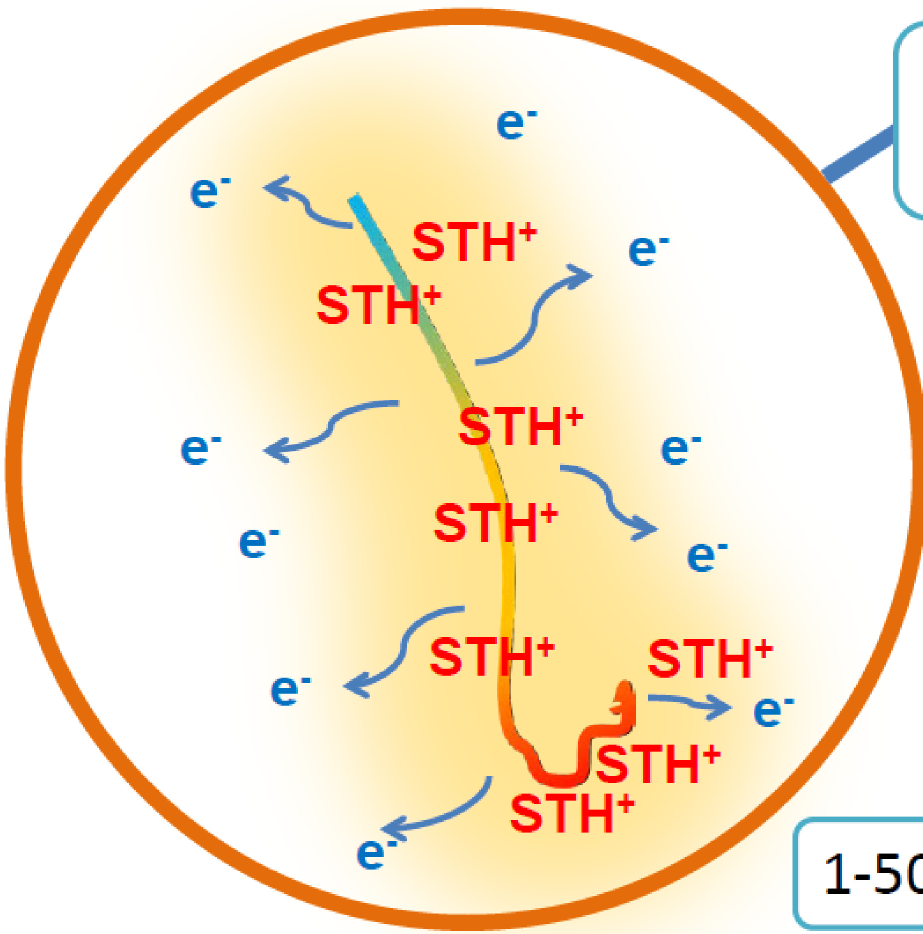
From McGregor2018

High density track



1st fs

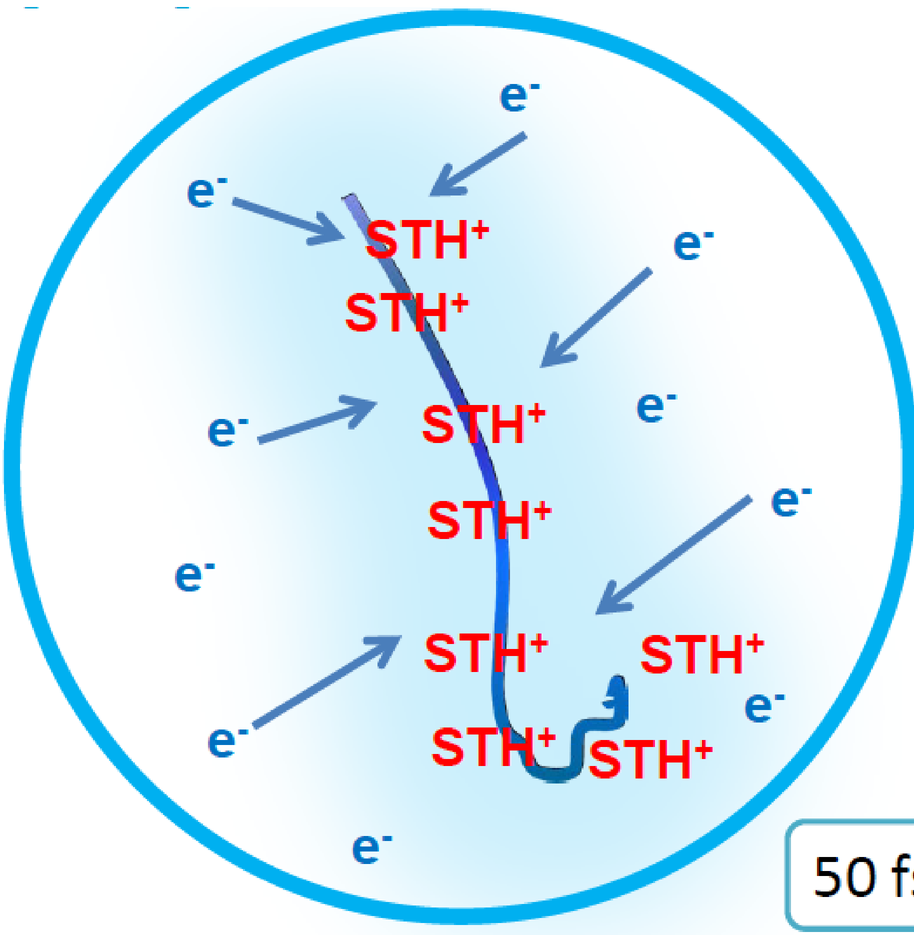
STH formation



Holes become self-trapped within 50 fs

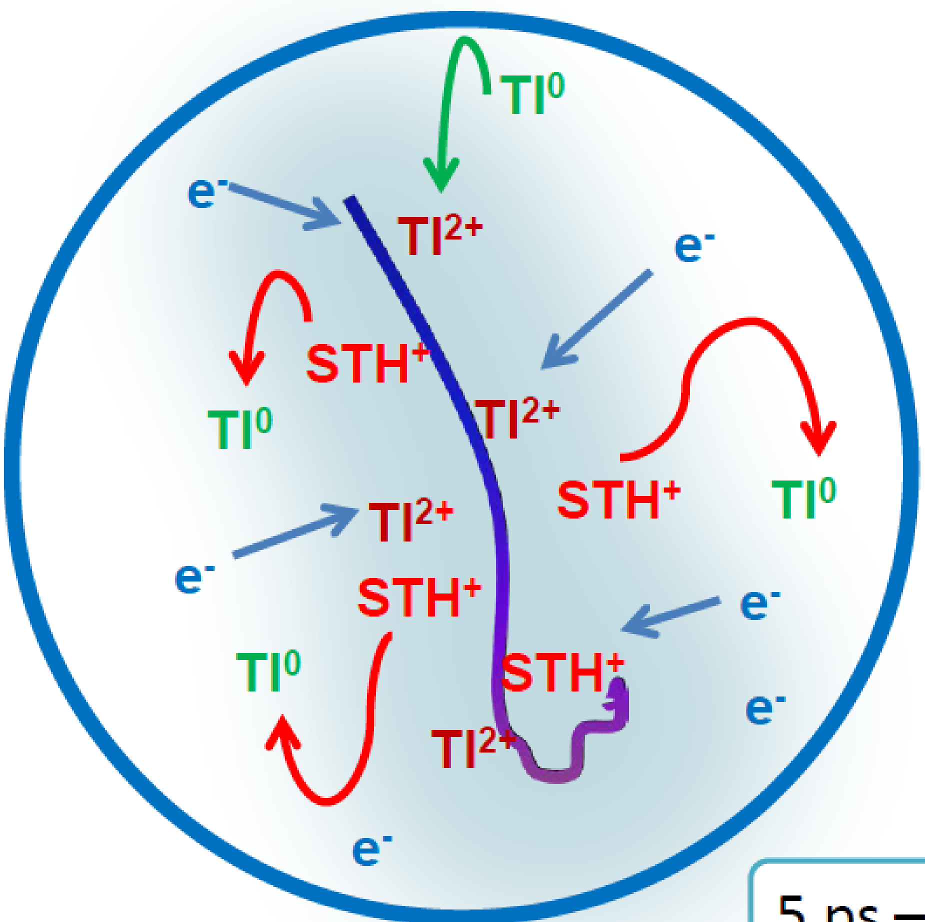
1-50 fs

Electrons at thermal equlibrium



50 fs -5 ps

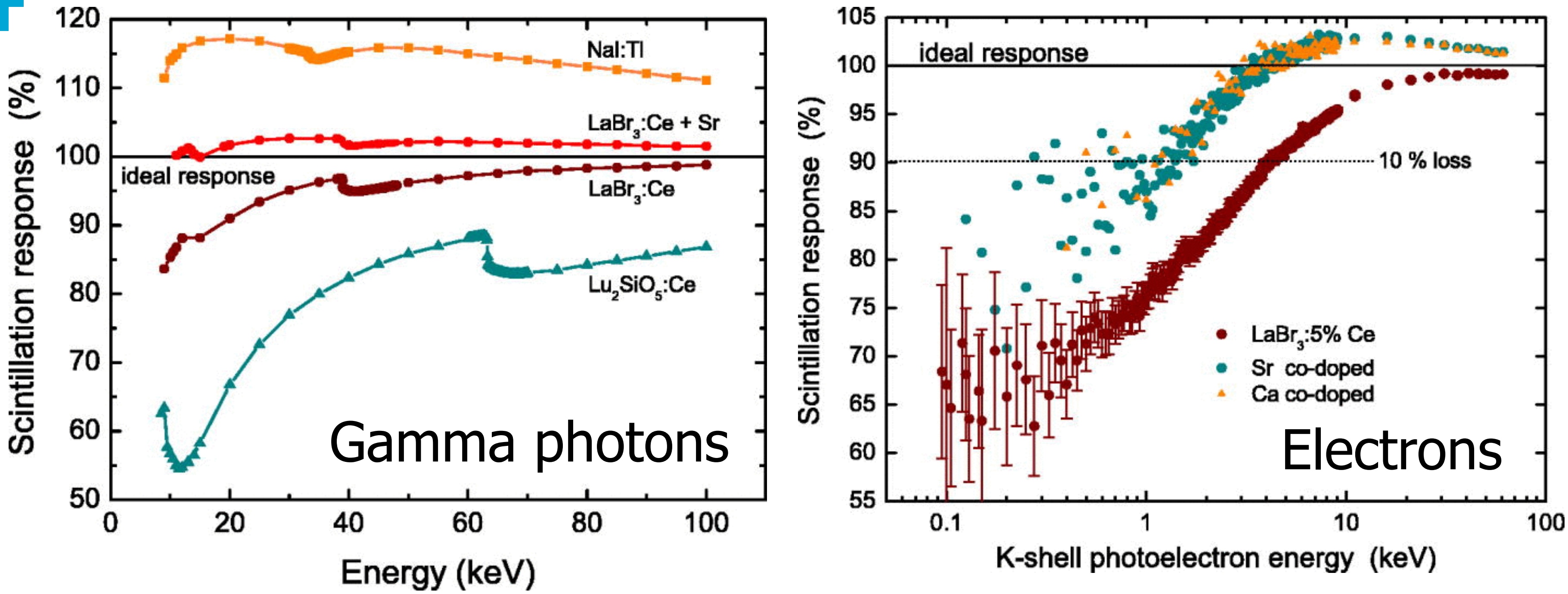
Trapping and recombination



5 ps – 100 μs

Non-proportionality of response

Non-proportional response



Alekhin2013

Surface effects

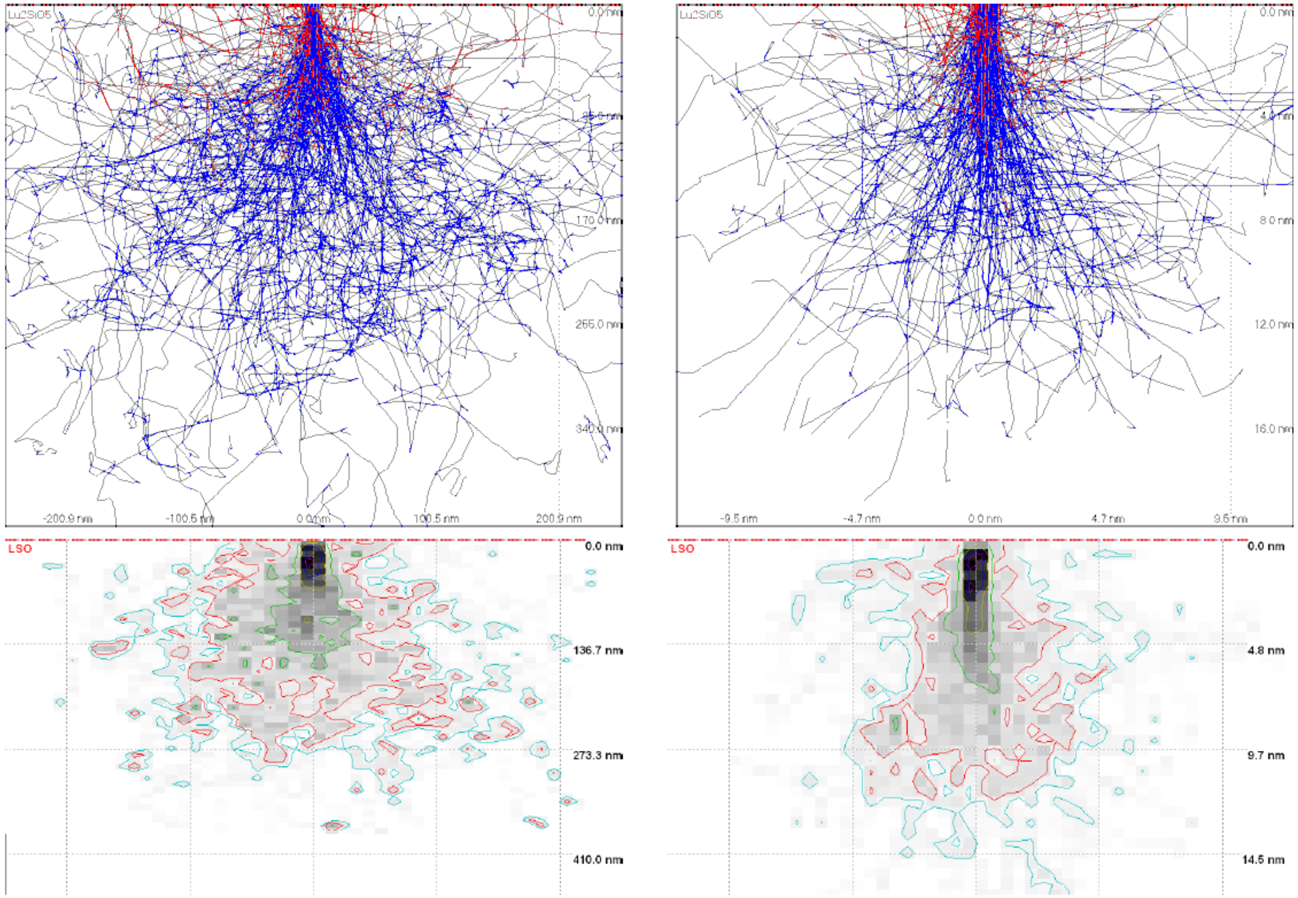


Fig. 1.5 Monte-Carlo simulations of energetic electron trajectories (top) and energy dissipation (bottom) in Lu_2SiO_5 crystal using Casino v2.42 software. Left – 10 keV electrons; right – 1 keV electrons.

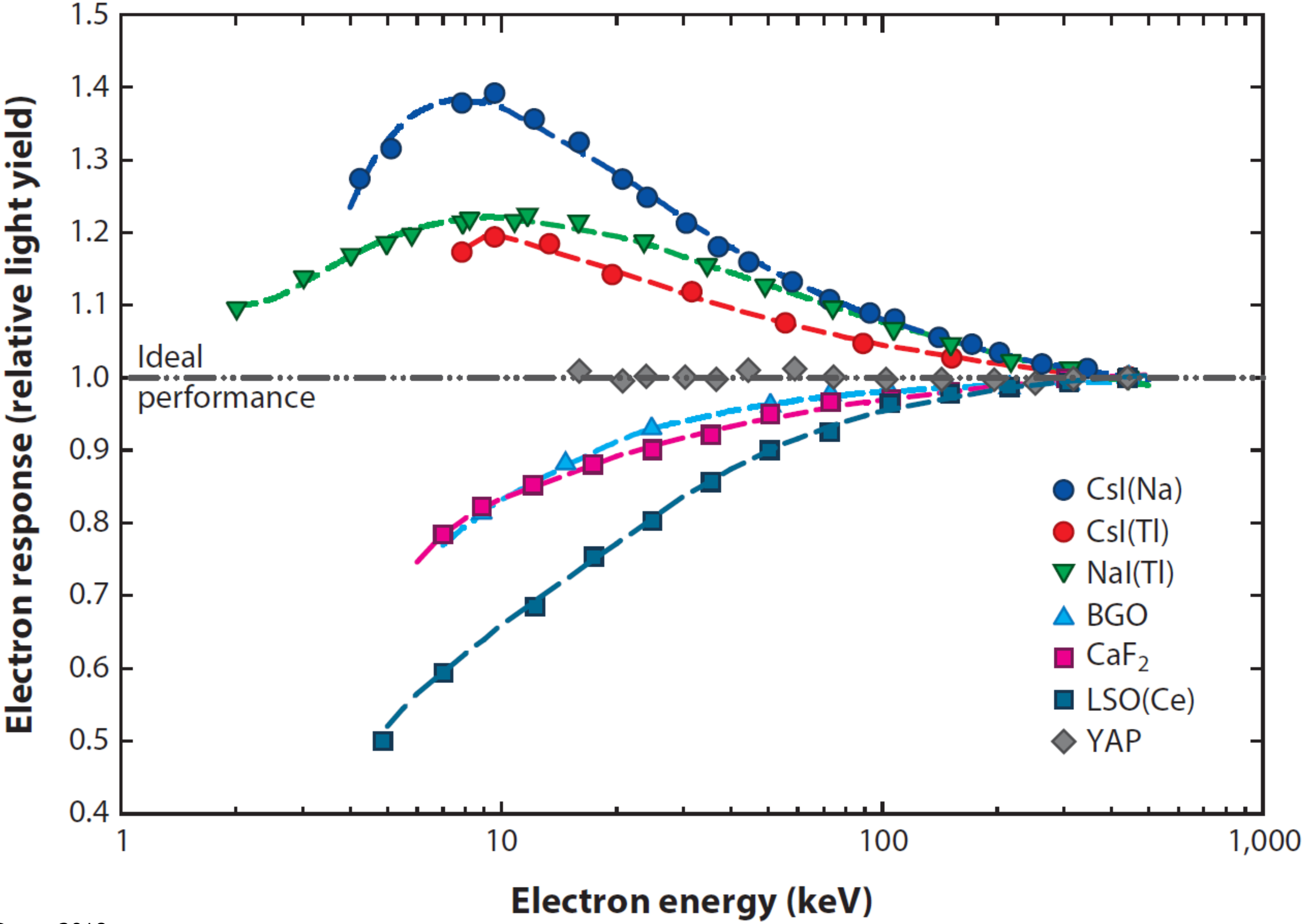
Khodyuk2013

Characterization of non-proportionality

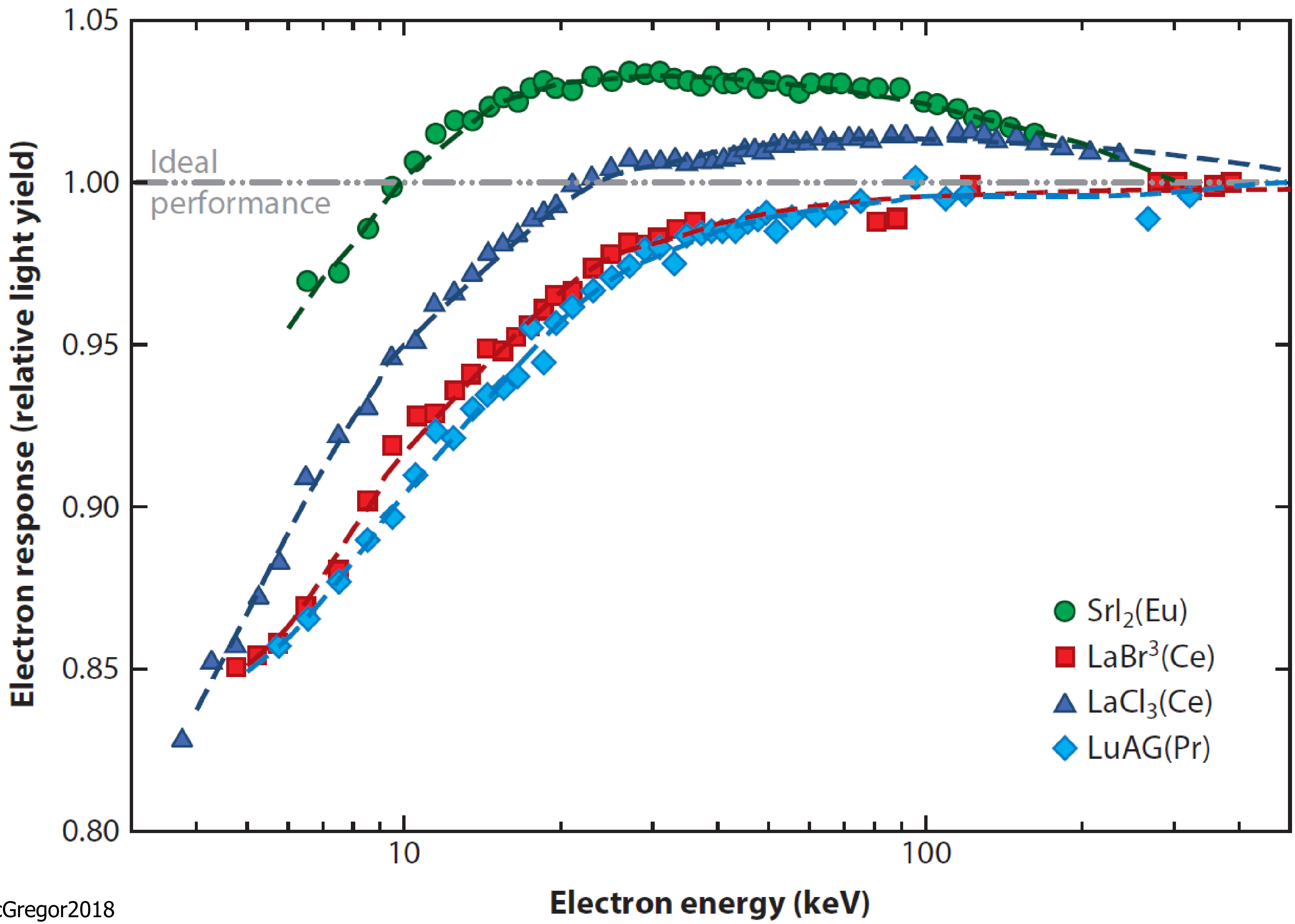
- With radioactive sources
- Compton Scattering Coincidence Technique
- K-dip spectroscopy
- Alpha/beta ratio
- Z-scan ← optical

} Nuclear techniques

K-dip spectroscopy



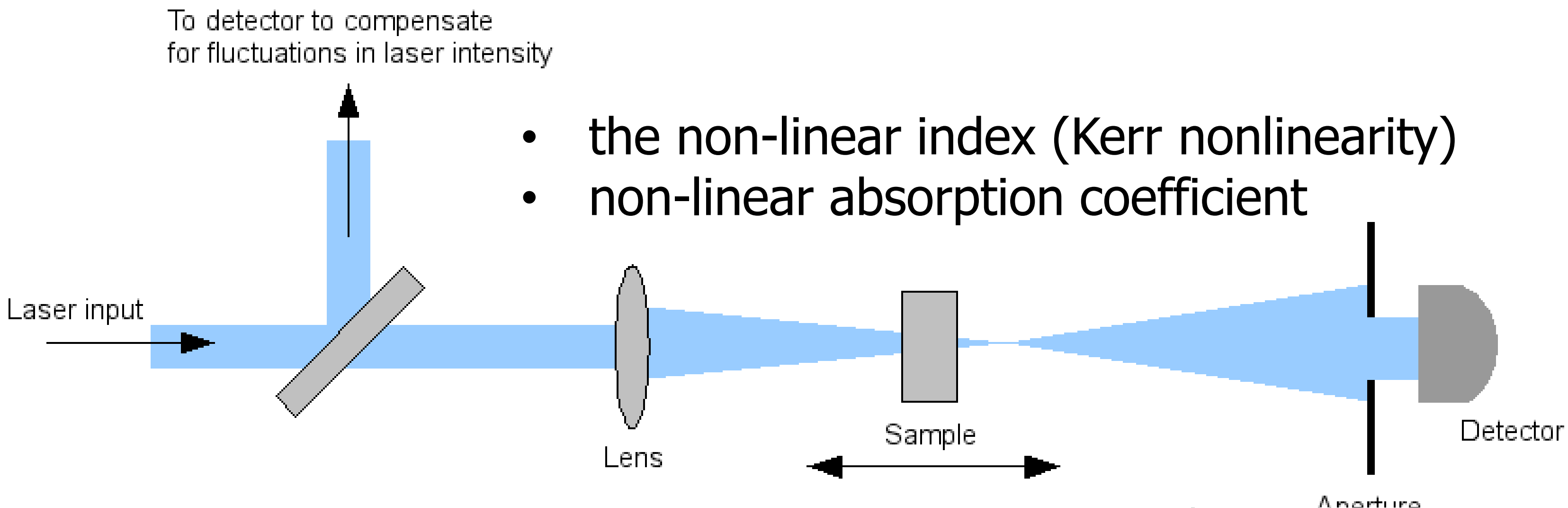
From McGregor2018



From McGregor2018

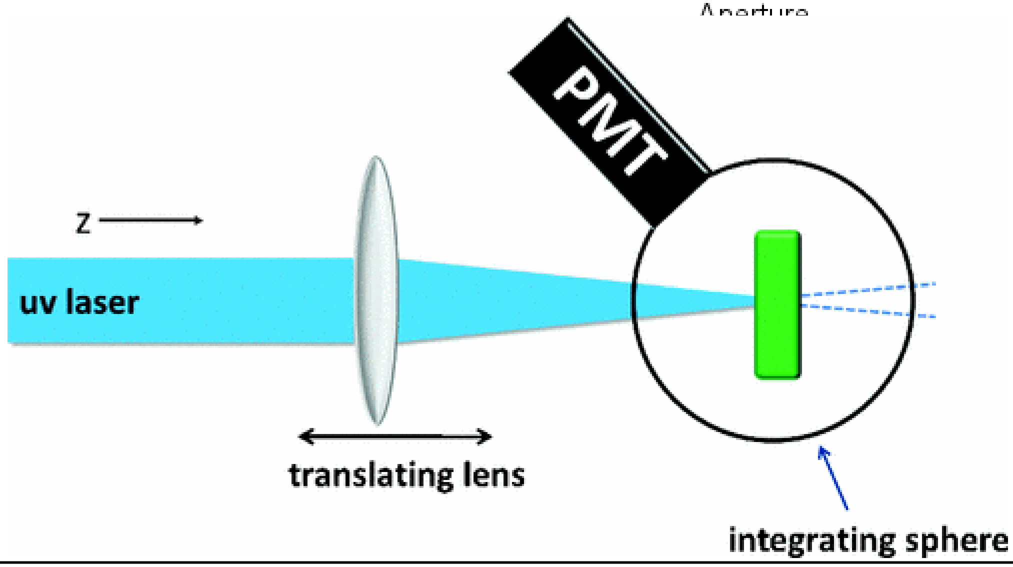
Z-scan

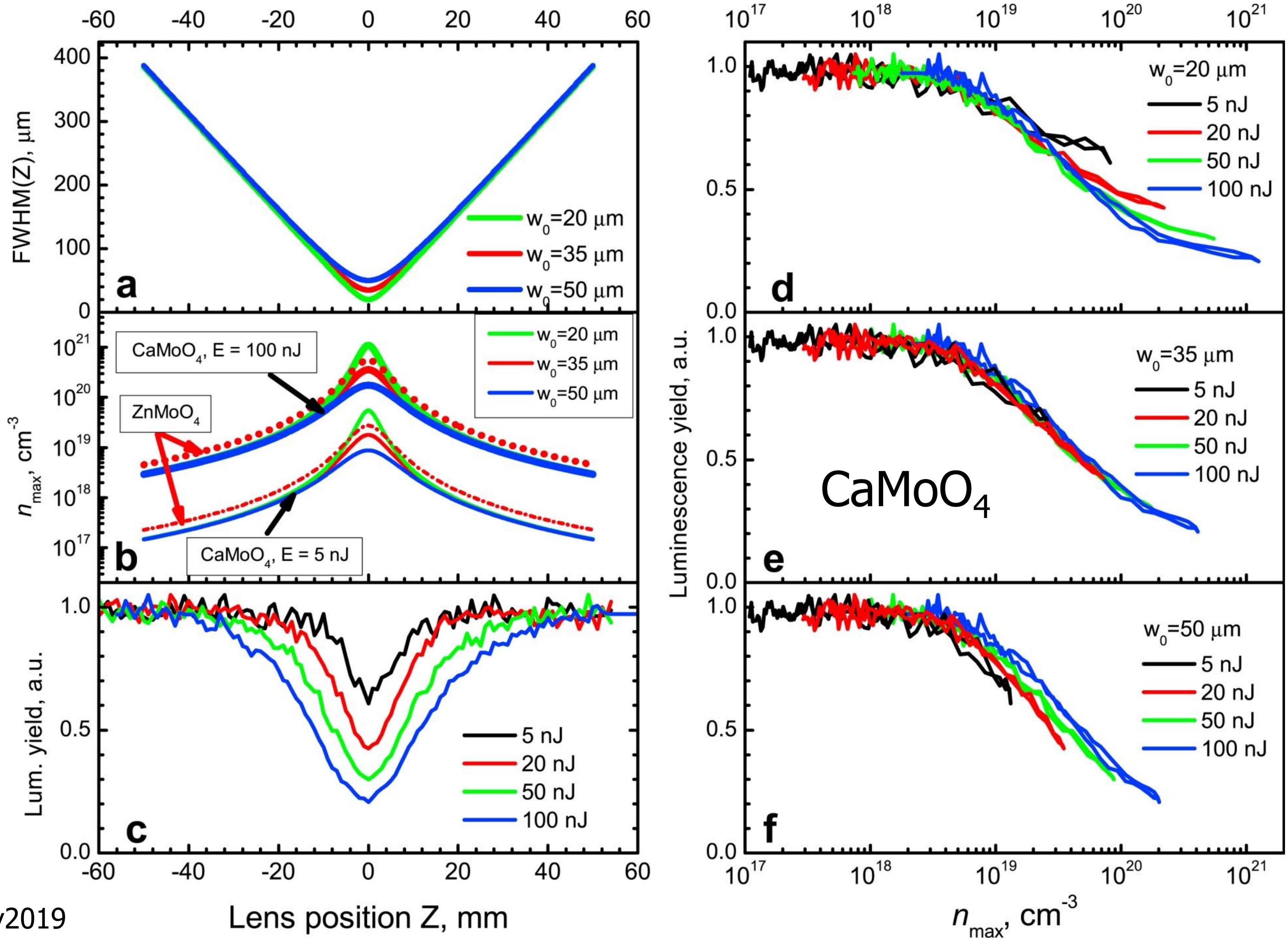
Schematic of a z-scan setup



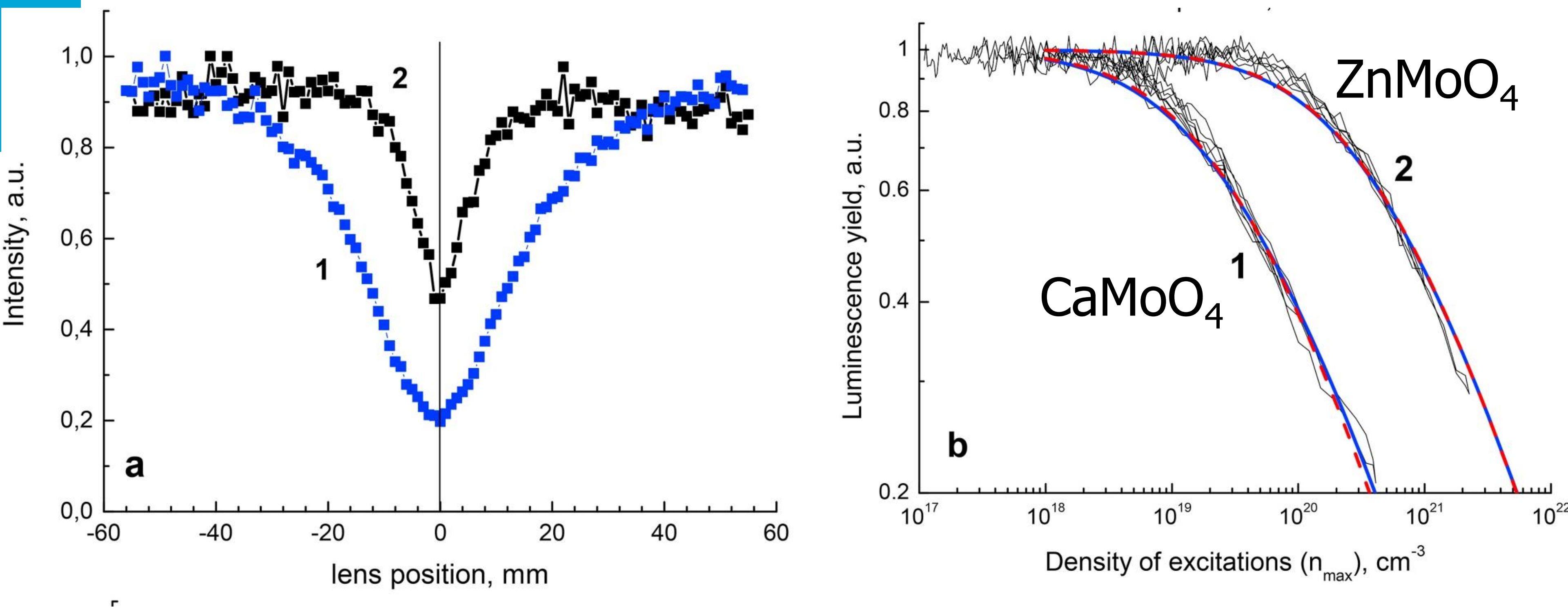
- the non-linear index (Kerr nonlinearity)
- non-linear absorption coefficient

- interband Z-scan luminescence yield measurements of nonlinear quenching rates and kinetic order





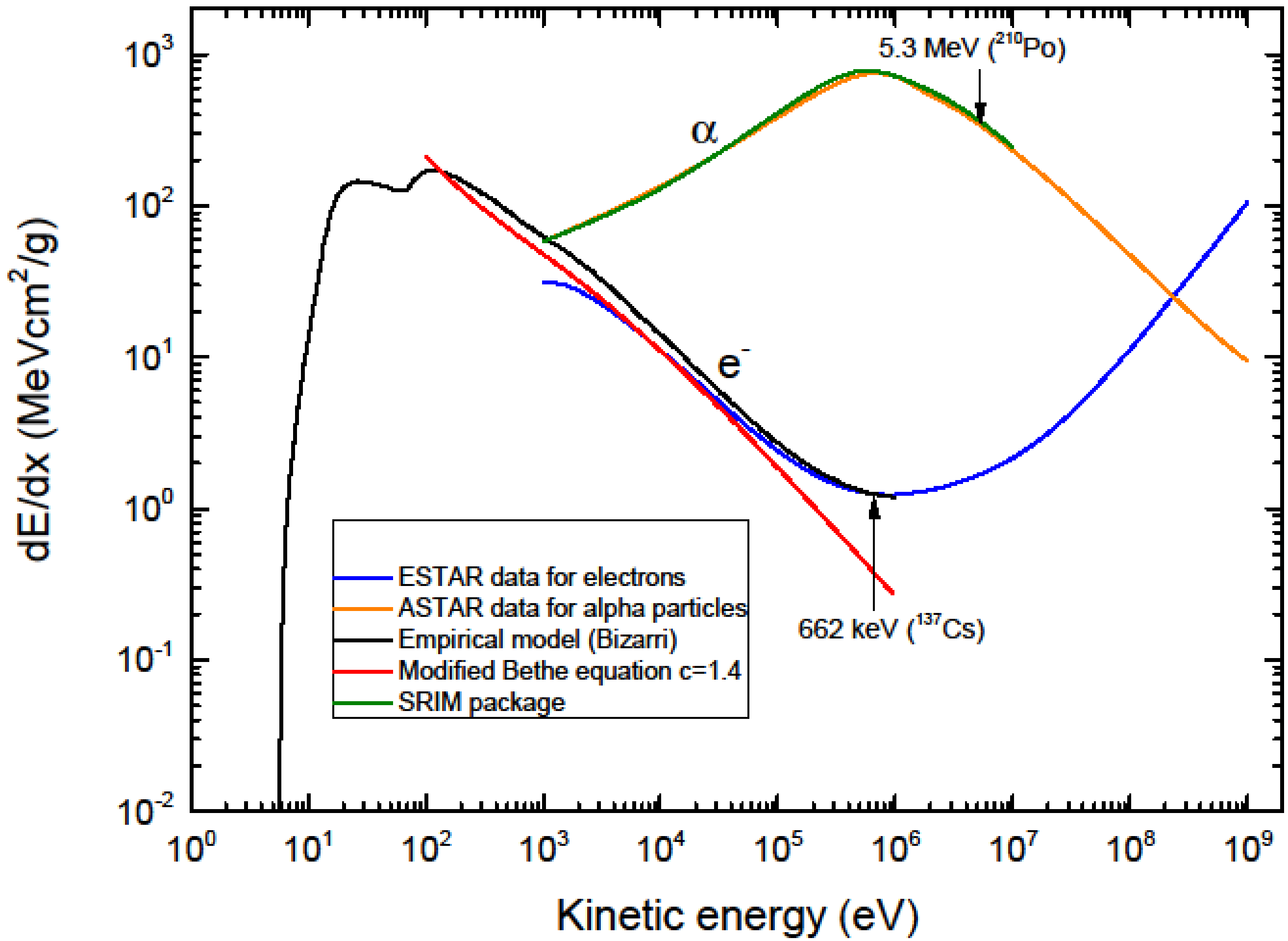
Spassky2019

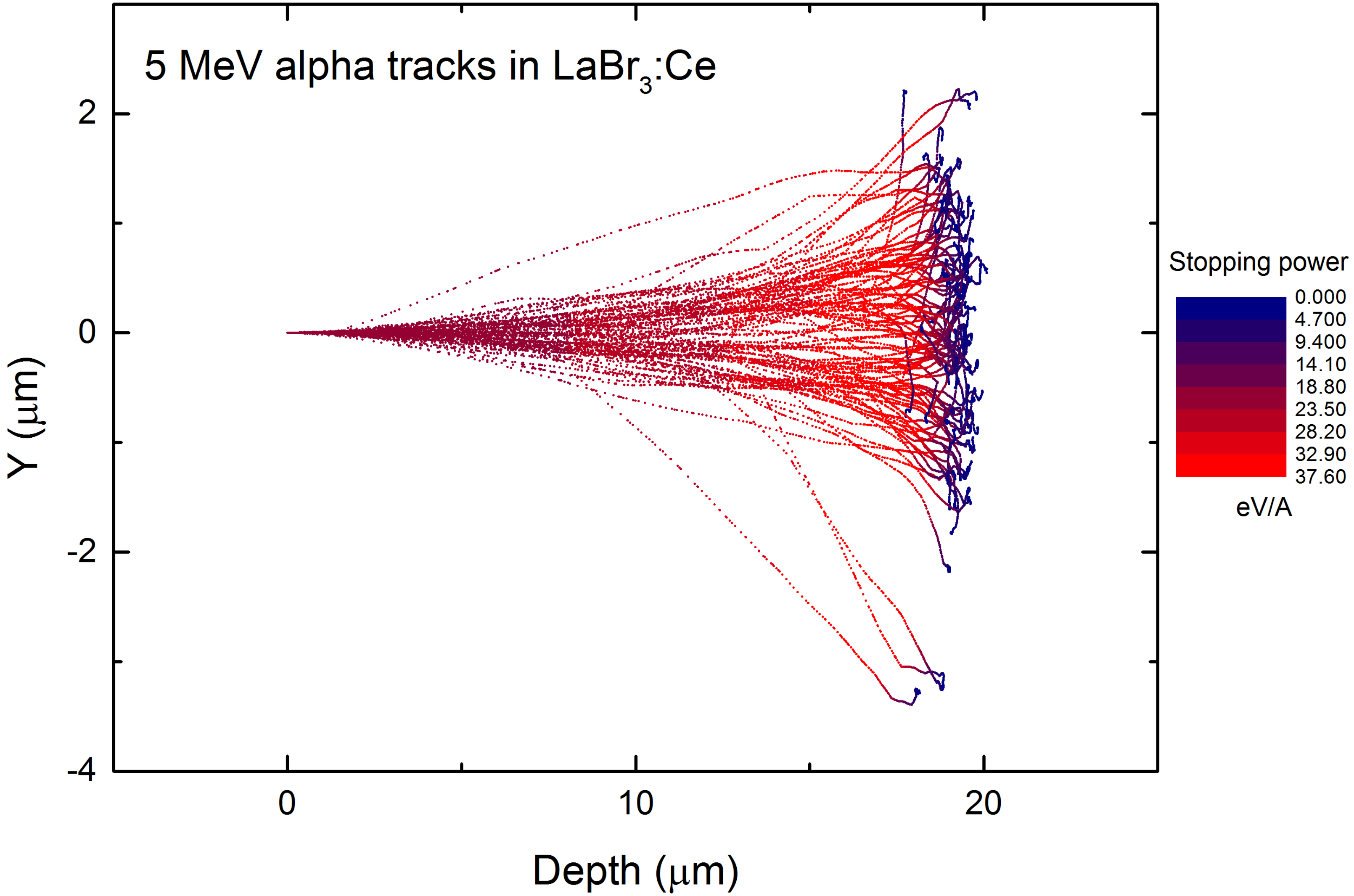


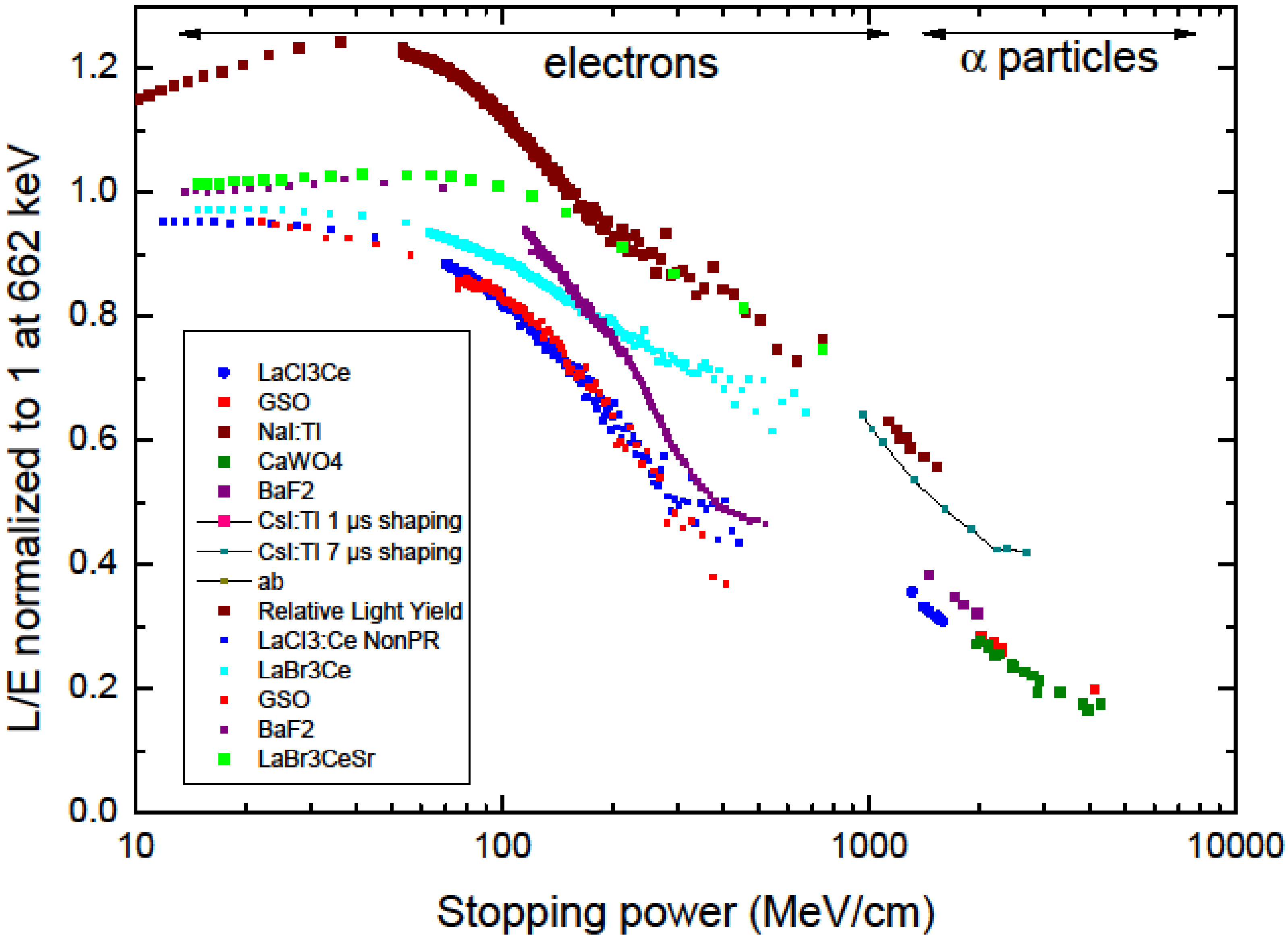
Spassky2019

The alpha/beta ratio

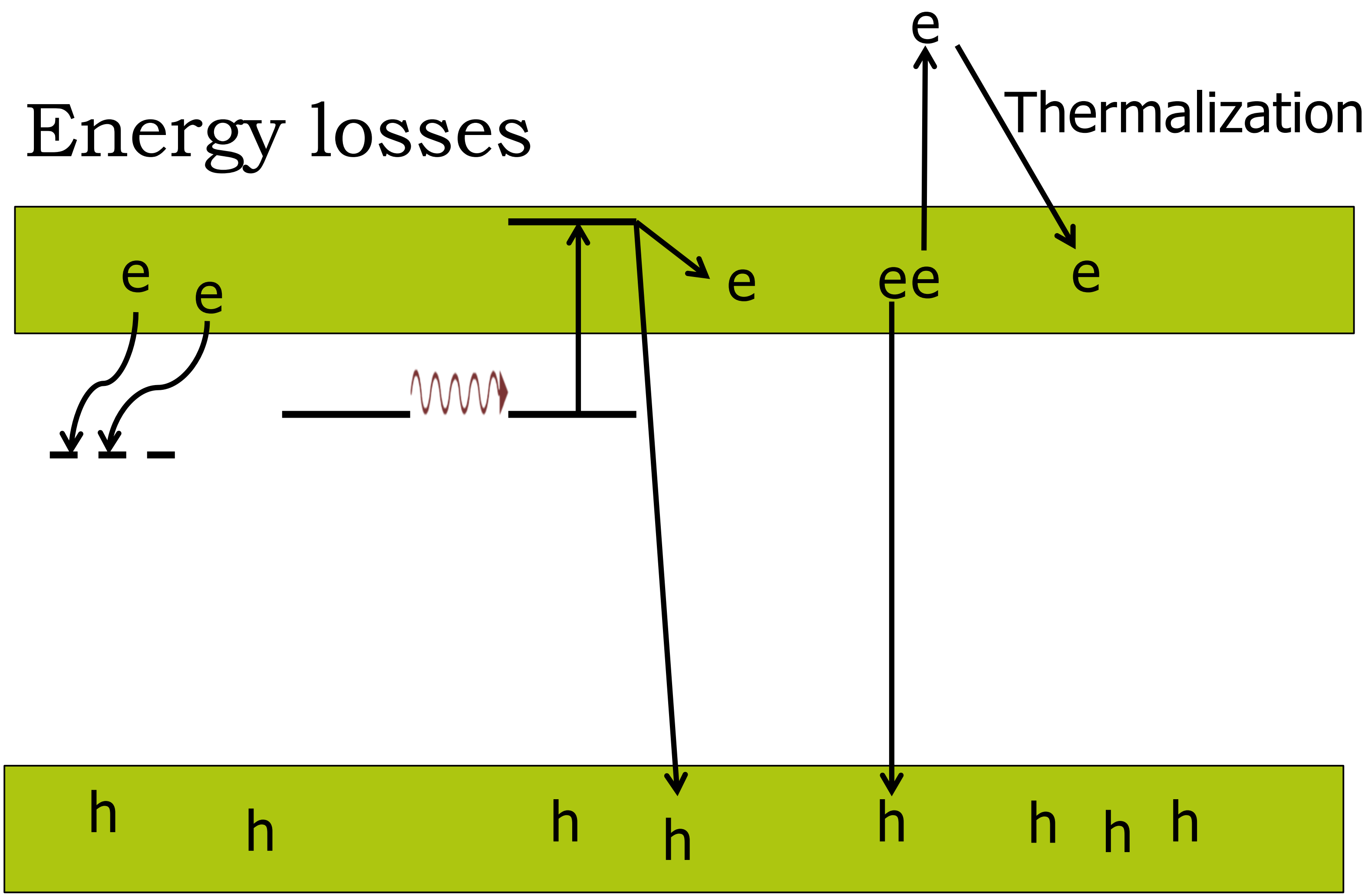
Stopping power




5 MeV alpha tracks in $LaBr_3$:Ce
2
0
-2
-4
Y (μm)
0
10
20
Depth (μm)
Stopping power
0.000
4.700
9.400
14.10
18.80
23.50
28.20
32.90
37.60
eV/A

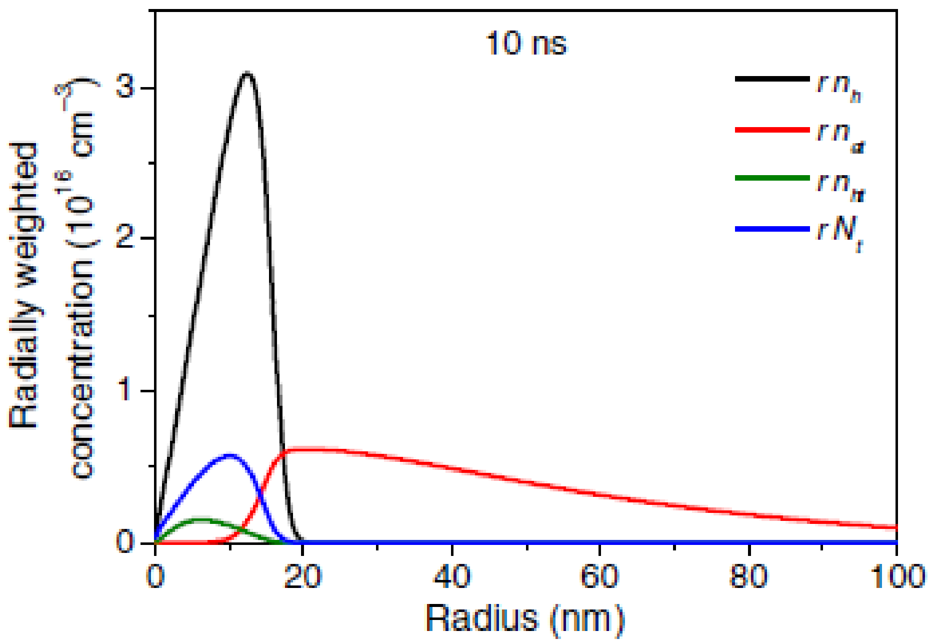

electrons
α particles
L/E normalized to 1 at 662 keV
Stopping power (MeV/cm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
10
100
1000
10000
LaCl3Ce
GSO
NaI:Tl
CaWO4
BaF2
CsI:Tl 1 μs shaping
CsI:Tl 7 μs shaping
ab
Relative Light Yield
LaCl3:Ce NonPR
LaBr3Ce
GSO
BaF2
LaBr3CeSr

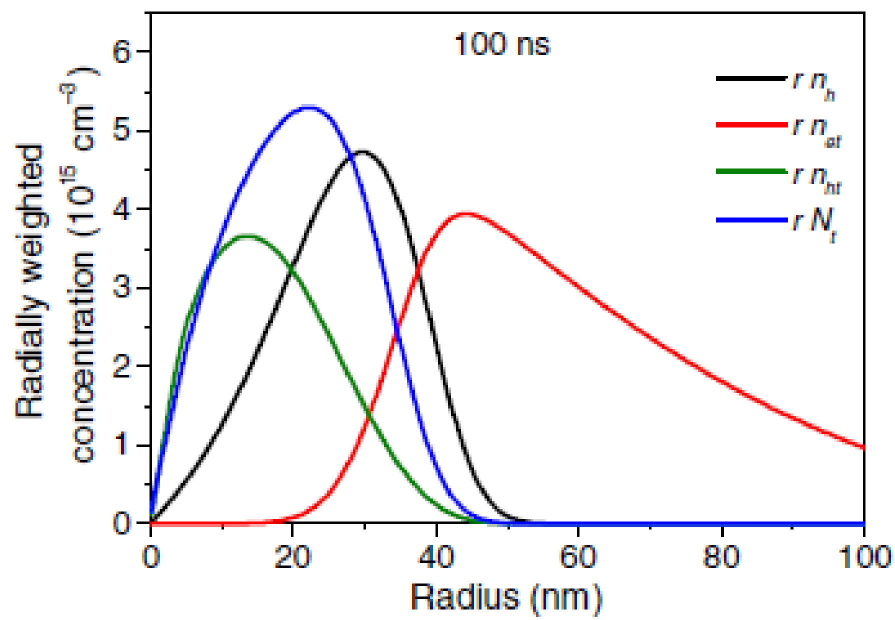
Energy losses



Deep traps 1th order	Exciton-exciton Anihilation 2nd order	Auger quenching 3rd order

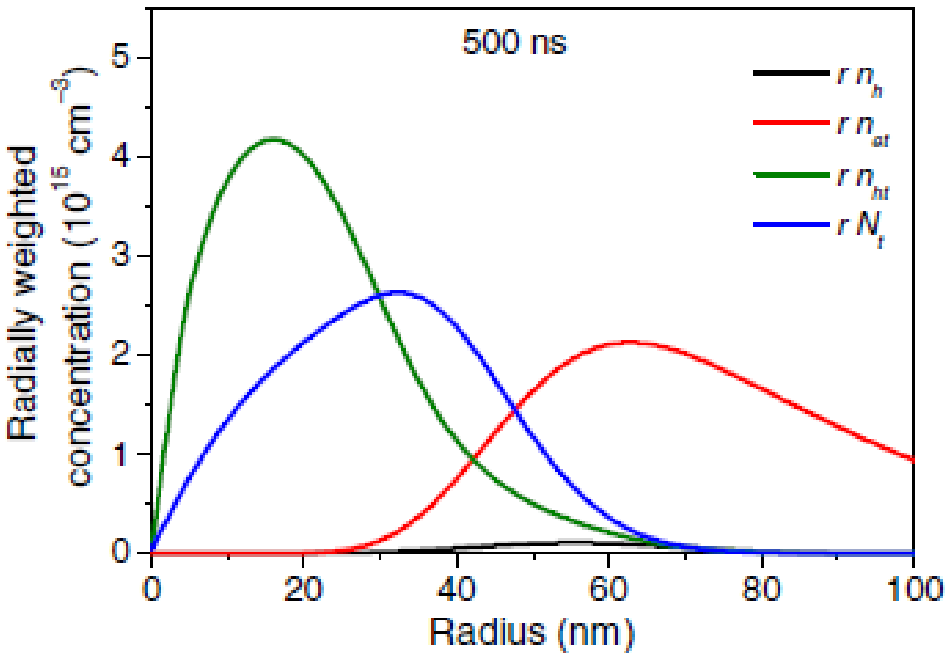
Local densities across ionization track



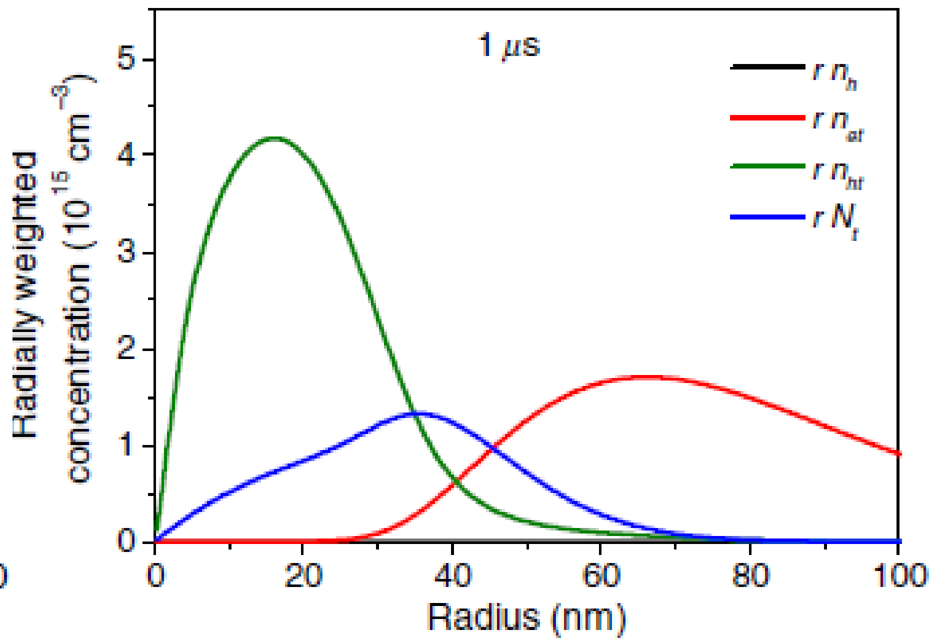


(b)

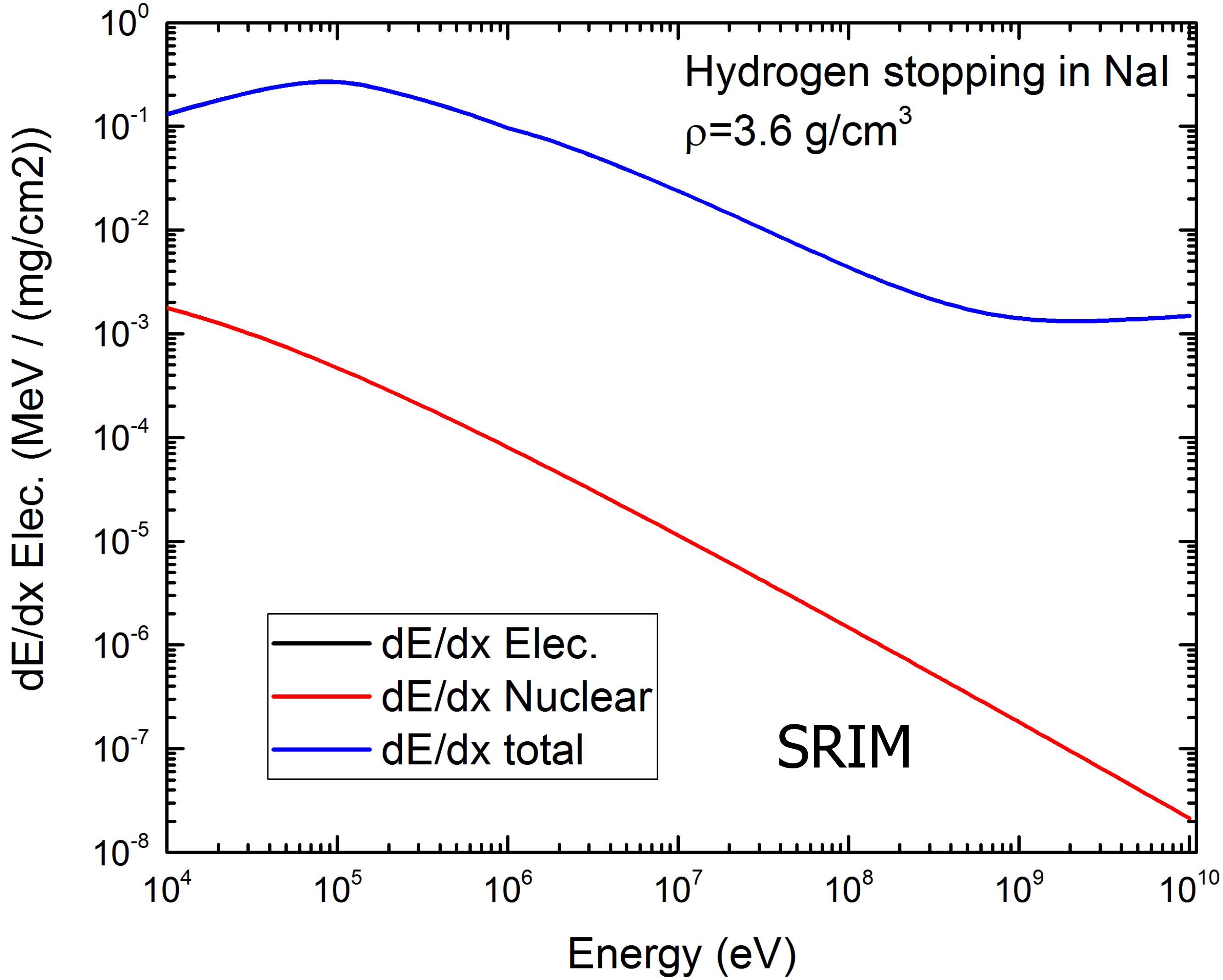
Local densities across ionization track 2

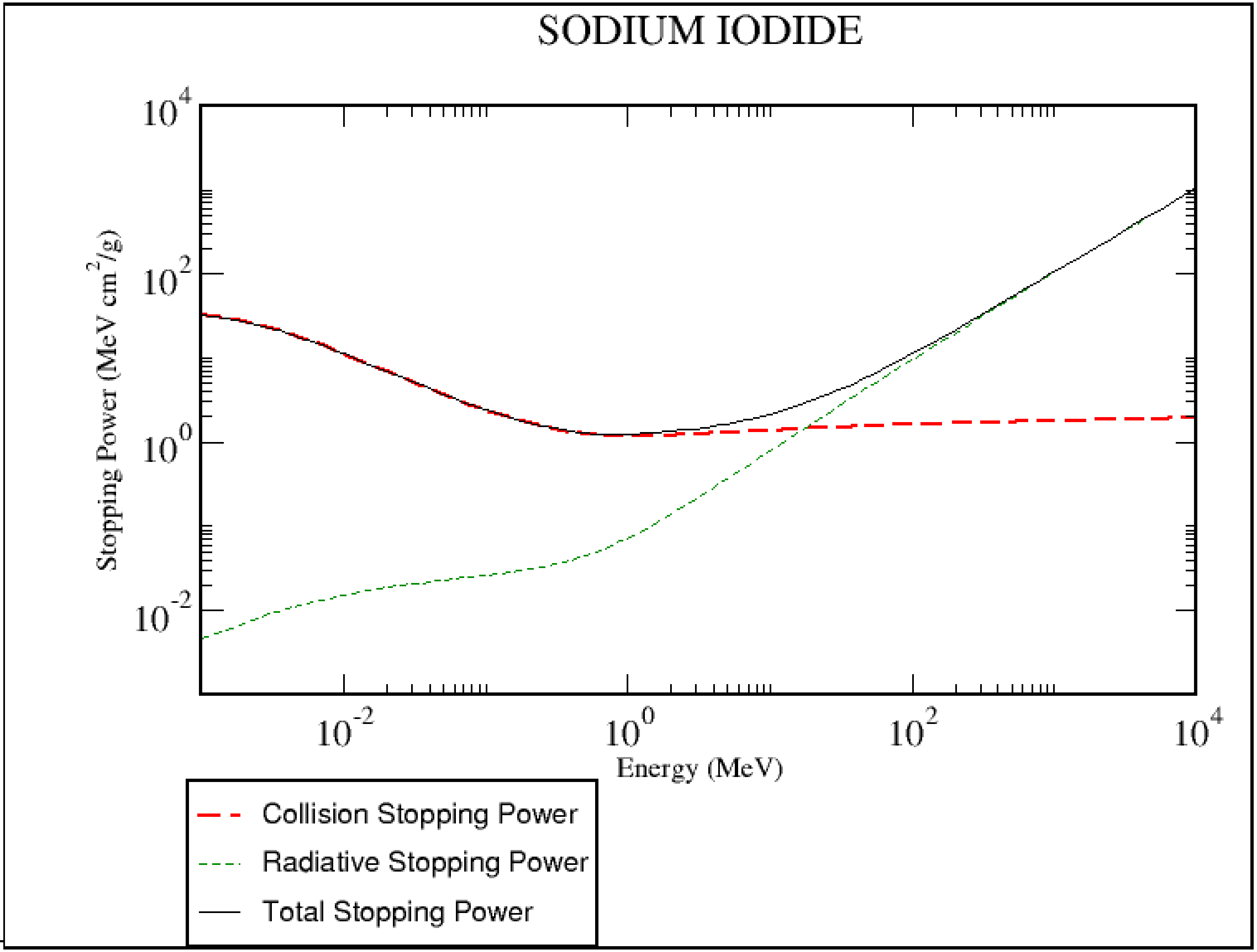


(c)



Stopping power: H^+ in NaI




SODIUM IODIDE
Stopping Power (MeV cm^2/g)
10^4
10^2
10^0
10^{-2}
10^{-2}
10^0
10^2
10^4
Energy (MeV)
Collision Stopping Power
Radiative Stopping Power
Total Stopping Power


Thank you!