Color Centers as Direct DM Detectors

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מכון ויצמן למדע
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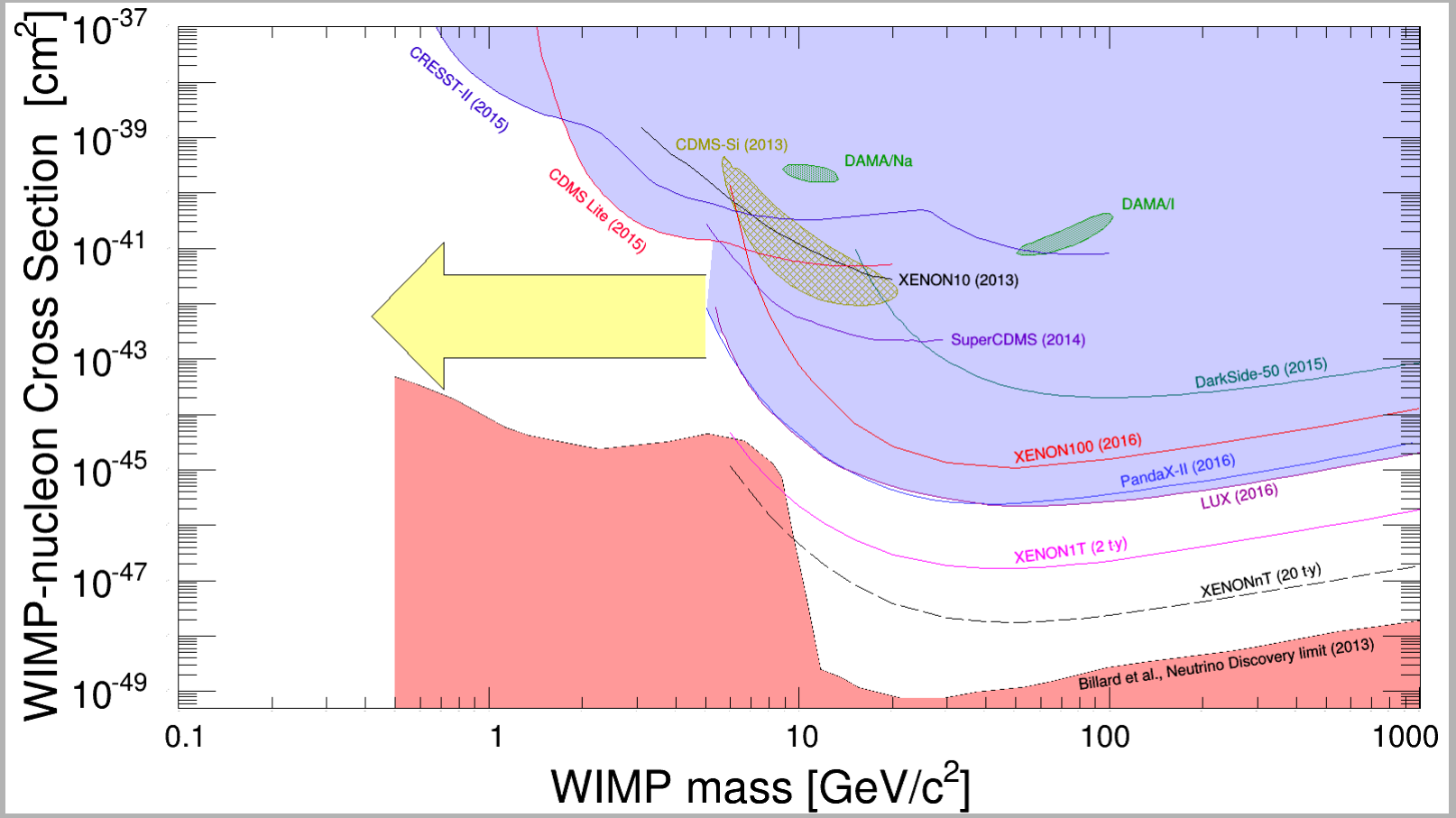
The goal:

Open a new window
for low mass DM

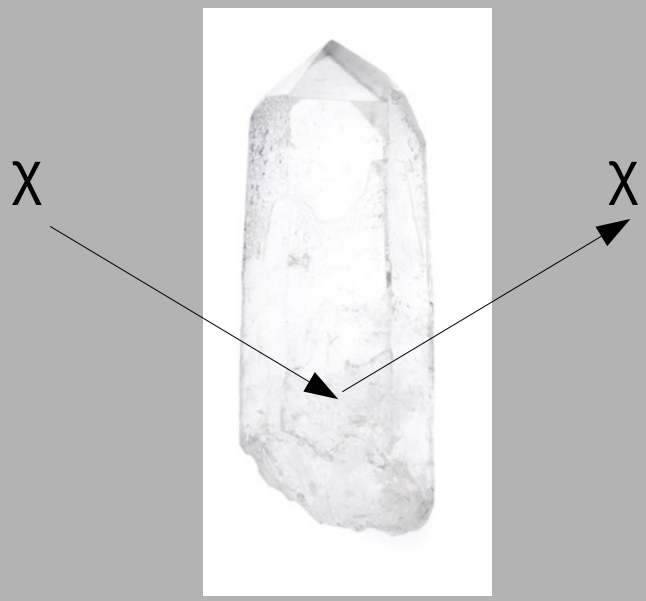


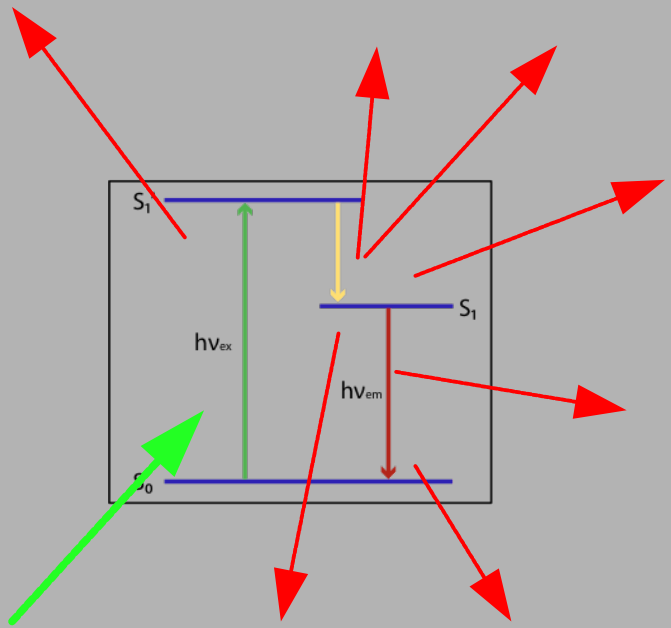
The short version

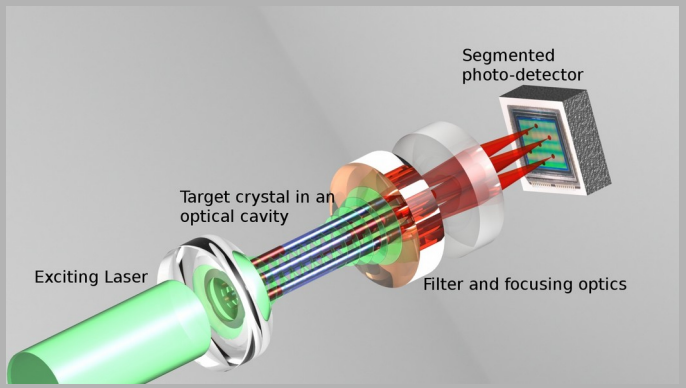
Transparent monocrystal hit by DM, dislocating an ion

The defect acquires an electron and probed by fluorescence repeatedly

DM mass sensitivity can go below 100 MeV

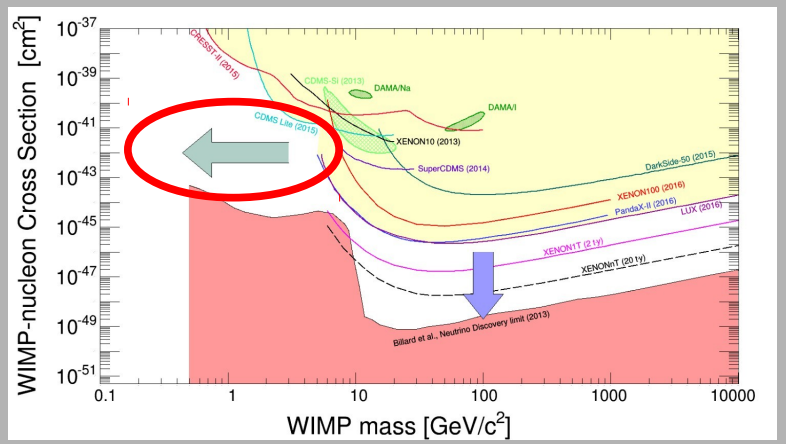






Special issues related to LDM

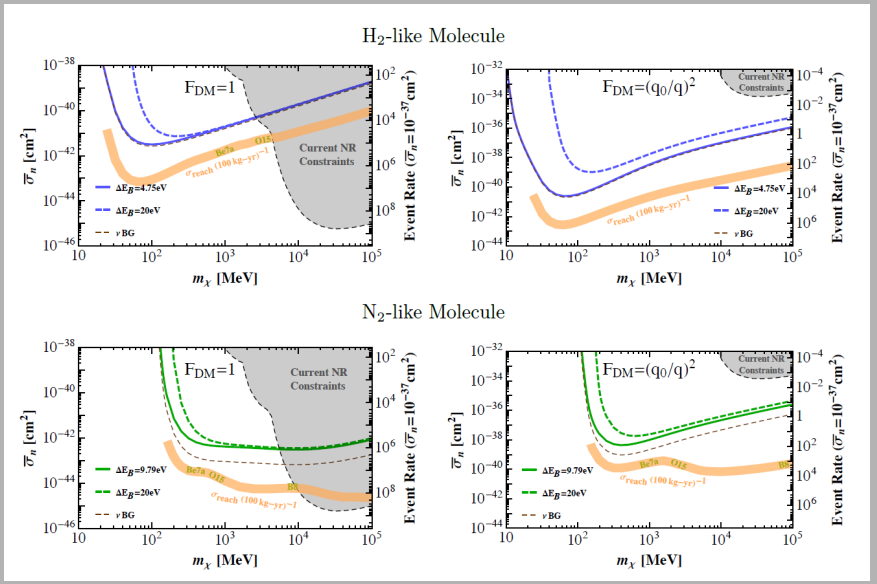
- Very few quantas or very low gap (high “error rates”) - in the eV range
- “Instrumental” backgrounds defeat good old radiogenic backgrounds
- Calibrating signal becomes challenging
- Technologies are generally not mature, need development from scratch



A way to overcome LDM challenges

- searching for inelastic processes may allow to significantly lower the experimental threshold Essig, Mardo, Volansky 2012

- Chemical bond-breaking phenomena has been studied in detail Essig, Mardon, Slone, Volansky 2016



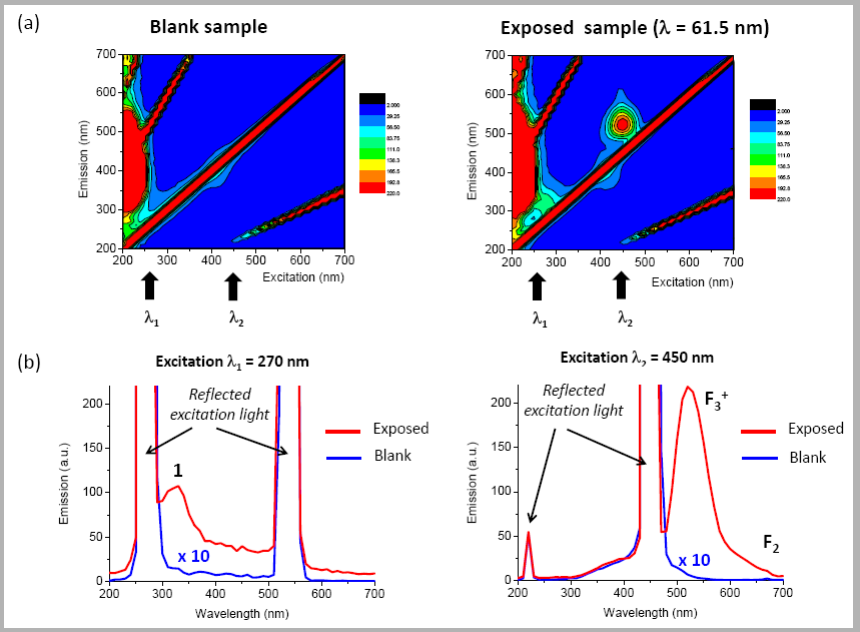
- However, a practical implementation still missing – here our proposal steps in

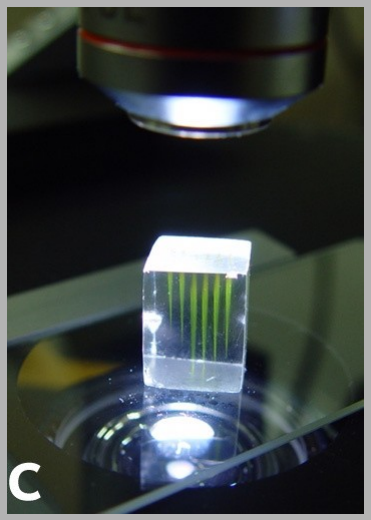
The Color of Fancy Sapphire

All are Al_2O_3 >99.99%

Color Centers

- It is known for many years that radiation damage gives color to transparent windows near e.g. nuclear power plants
- There are various mechanisms causing this effect, and the incident radiation can be gamma, neutron or charged particles





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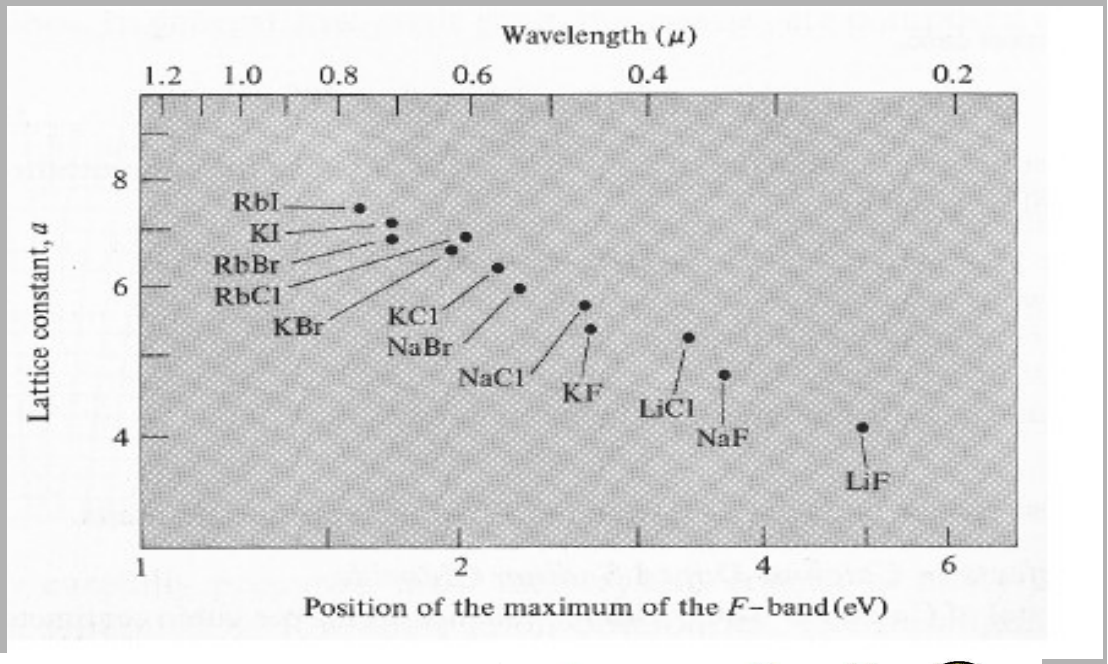
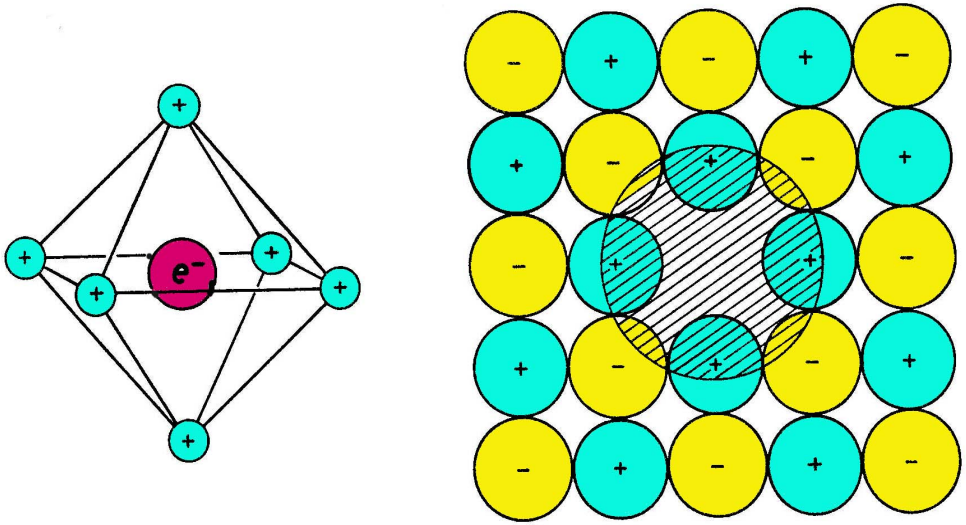
F-center in a nutshell

- The absorption dependency on the lattice constant is a power law (particle in a box)
- By this mechanism a transparent medium becomes colored
- Elastic collision may produce displacement (gamma, electron, neutron and ions)





Atomic structure of the F center

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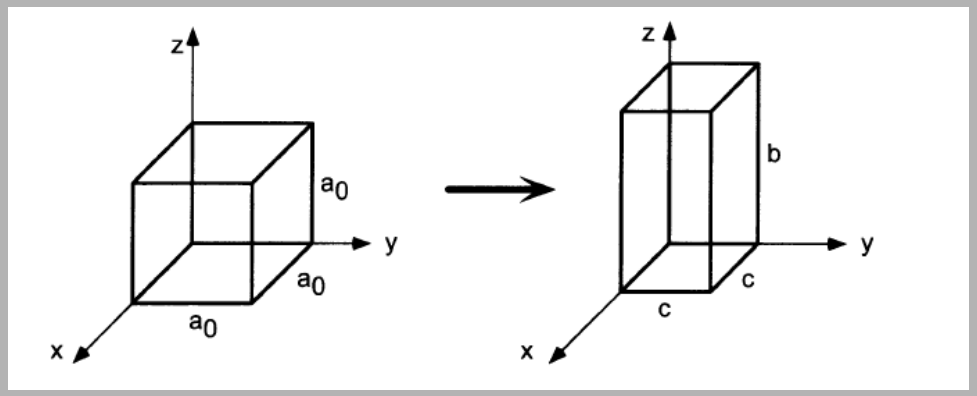
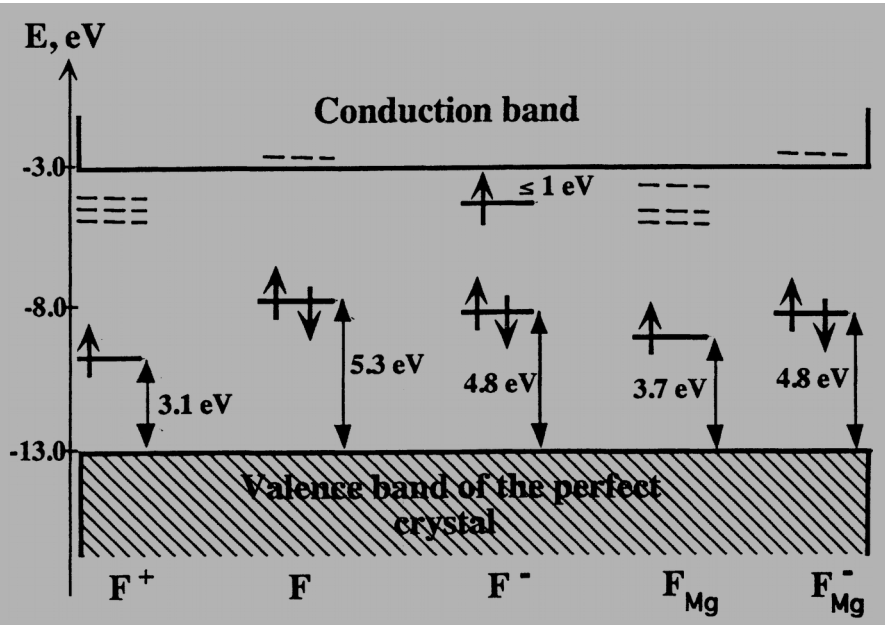
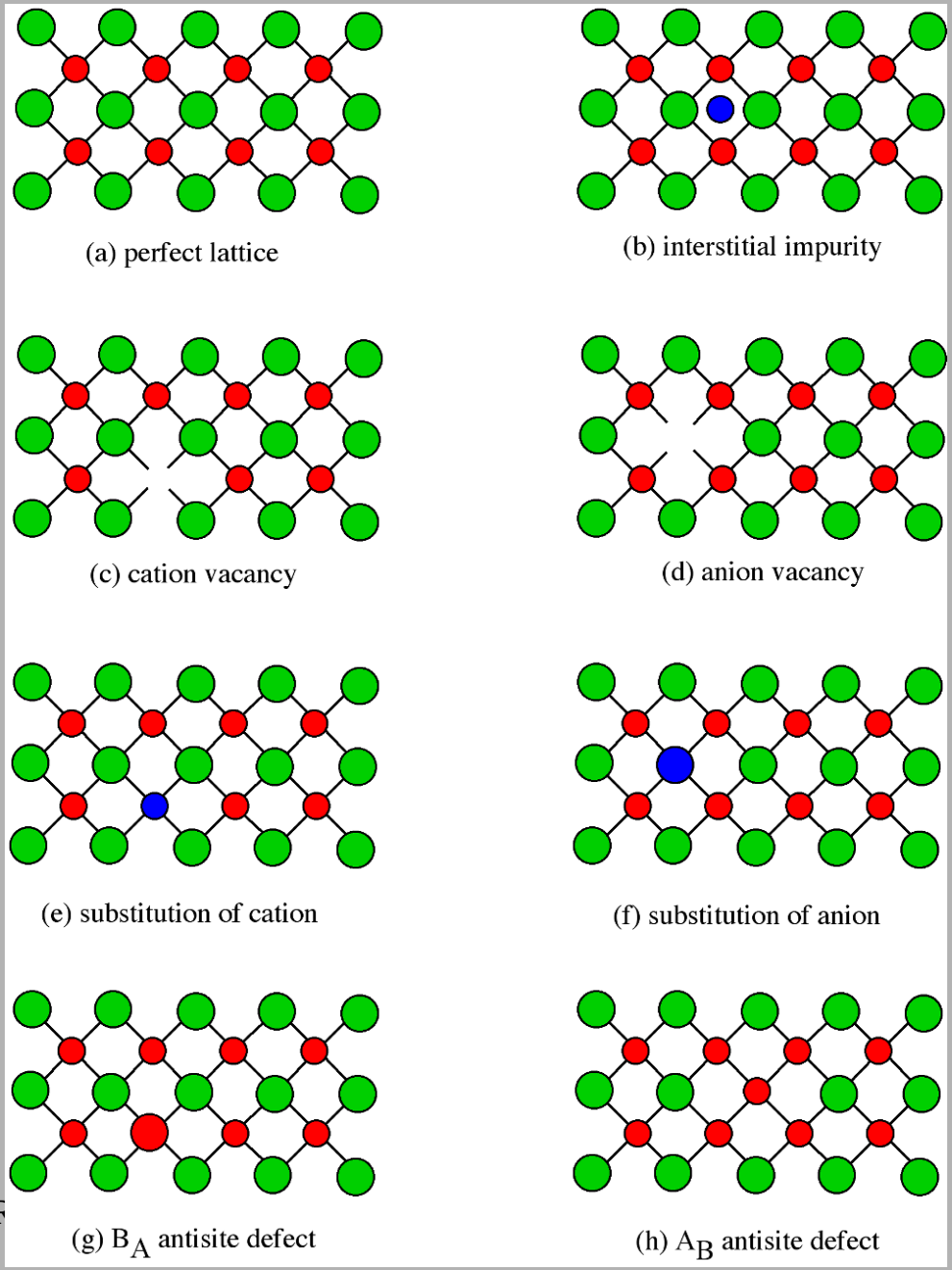


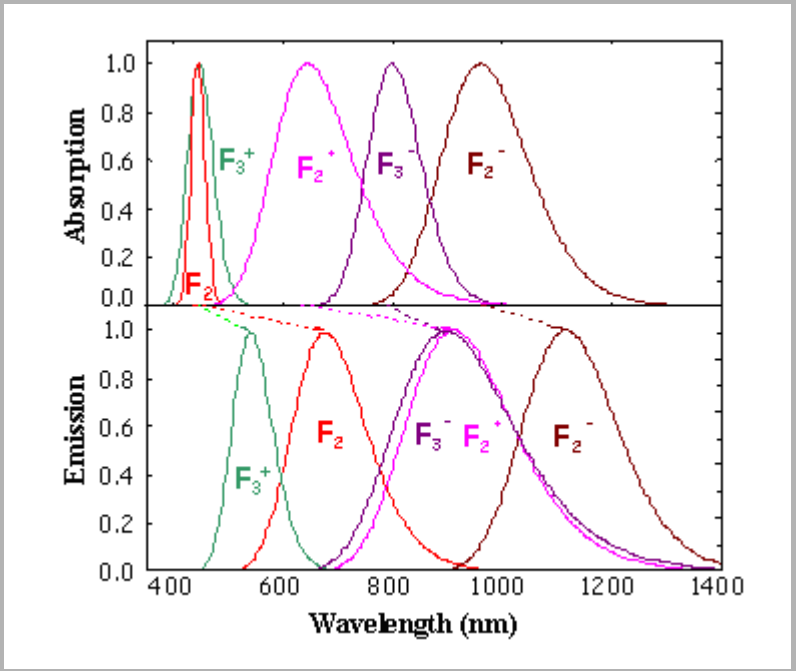


Known states of Ionic crystals

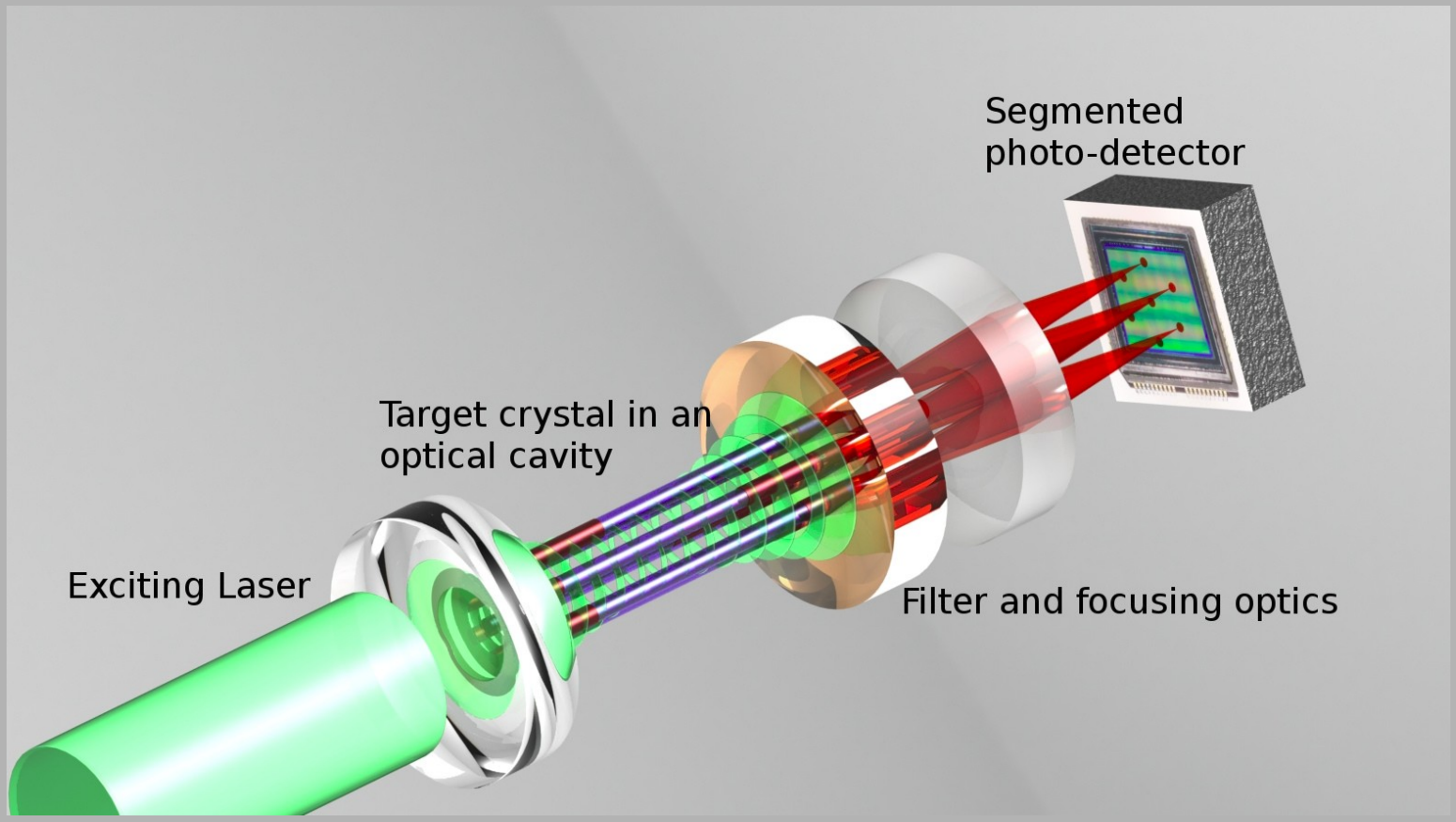


F-center

A vacancy filled by an electron can exhibit fluorescence.



Conceptual setup



- High intensity **laser exciting beam** in a cavity
- Constantly monitoring outgoing relevant **fluorescence photons**
- Resolution of **single CC in ~10^5** with reasonable parameters

The challenges of CCs

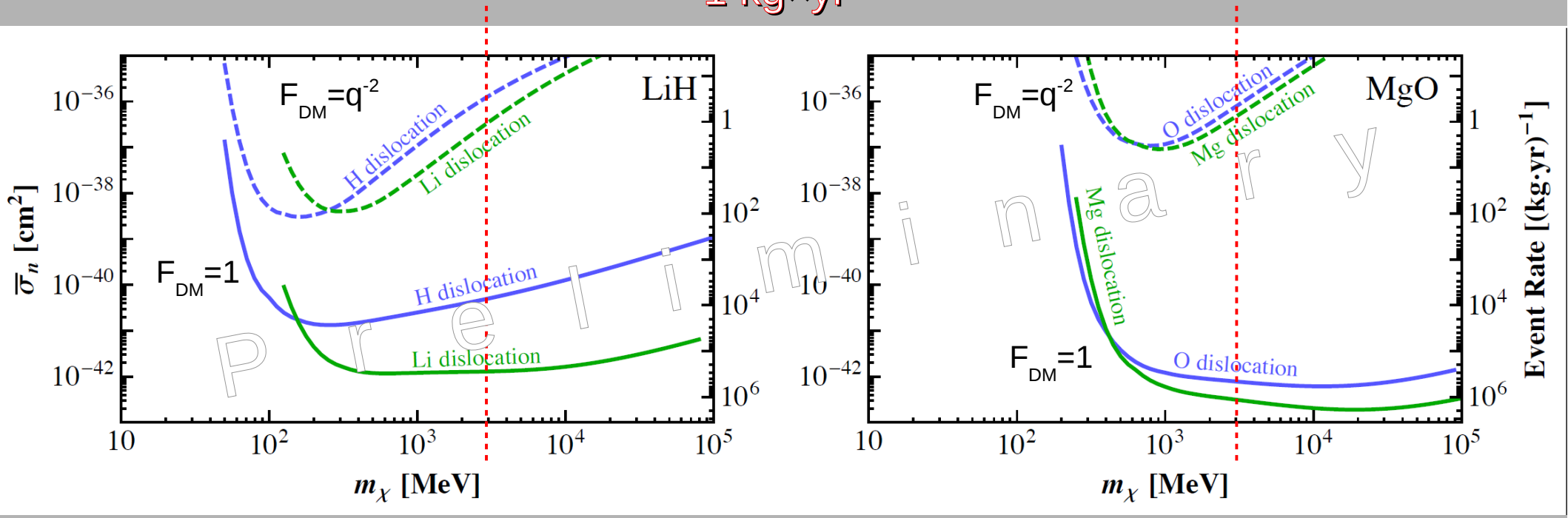
- Missing orders of magnitudes in background
- Direct calculation extremely hard due to phase space (thresholds, types, electronic structures...)
- However, only very difficult once established the signal
- Need to understand and achieve:
  - Annealing, bleaching, counting, production, discrimination, accurate calibration sources, low price, high purity….

The benefits of CCs

- Identified several ways to battle backgrounds
  - Annealing, spatial resolution, spectral separation...
- Natural discrimination
- Likely directional
- Multiple targets, each with different signal
- Calibration is possible
- Many optional handles: B field, RF, polarization...
- And of course, almost the only one on that side of town (10 eV town)!

Physics reach

Humble exposure of
1 kg×yr

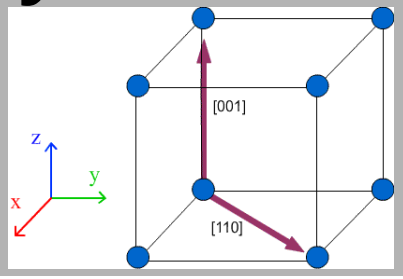


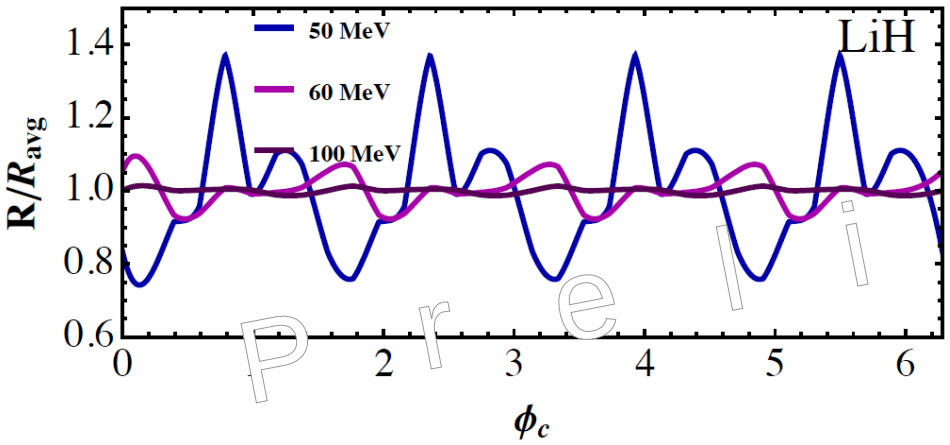
Two candidate crystals with known CCs and thresholds. The vertical red dashed line is where traditional experiments lose sensitivity.

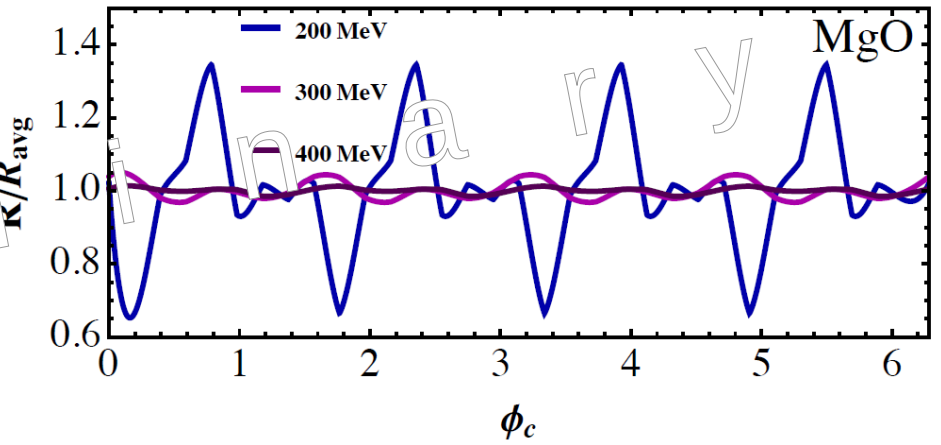
Dashed/solid lines represent different DM form factors.

With Cheshnovsky, Volansky and Slone (in preparation)

Modulation and directionality







- Sub-daily modulation due to different thresholds wrt the lattice axes
- Strongest for near-threshold masses
- A unique signature that differs from all types of background
- On top of that, annual modulation is still expected

With Cheshnovsky, Volansky and Slone (in preparation)

The goal:

Identifying a crystal which is sensitive to low-energy-neutrons (and LDM...)

(and check the discrimination between Nuclear Recoils coming from neutrons, and Electronic Recoils originating from gammas)

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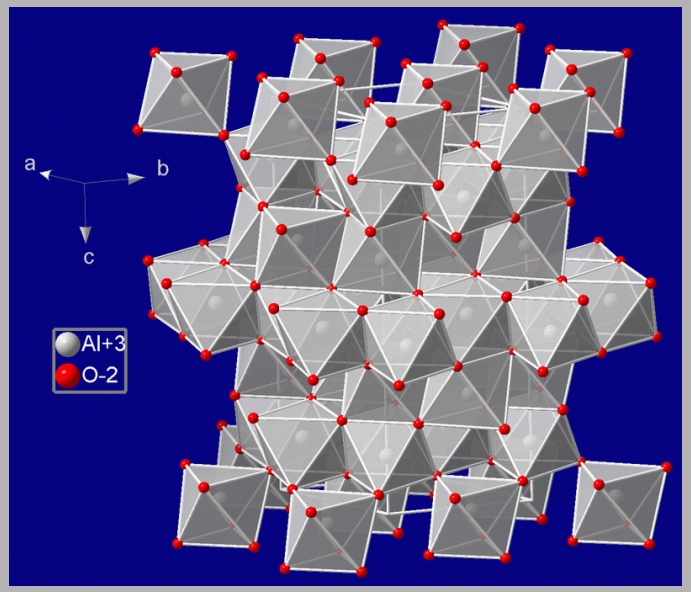
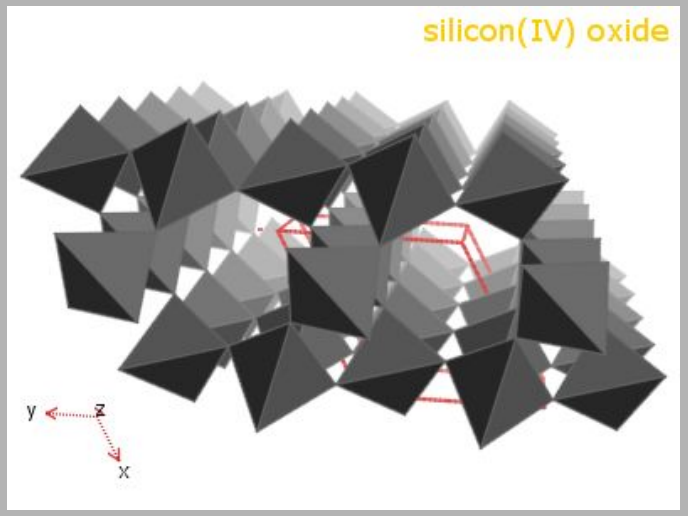
Two parallel ongoing efforts:

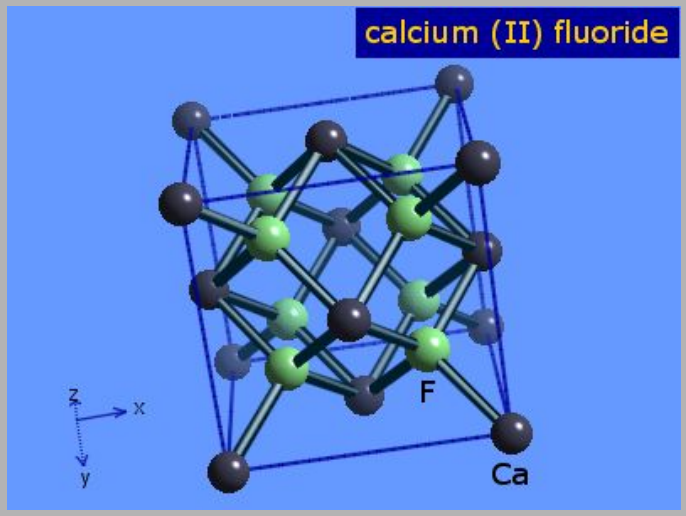
1) Irradiation of as many crystals as possible

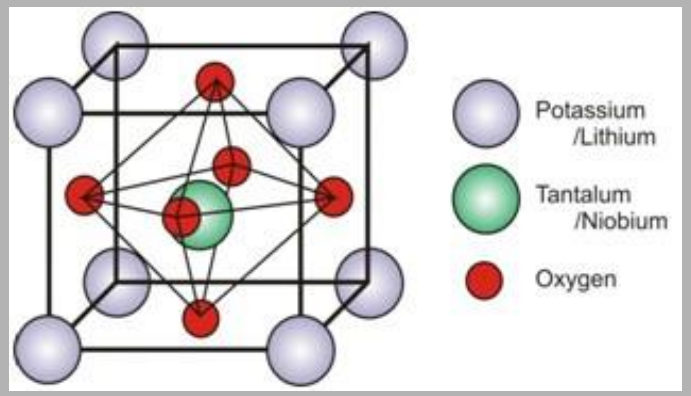
2) Establish an optical setup for F-centers measurement

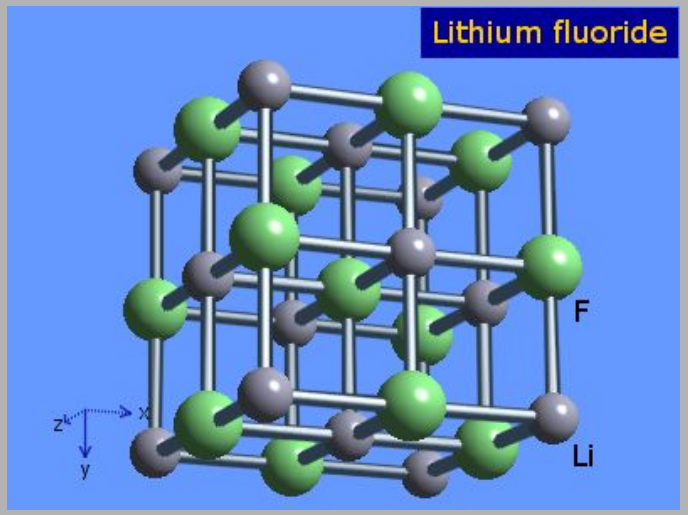
Many optional targets, but little is known

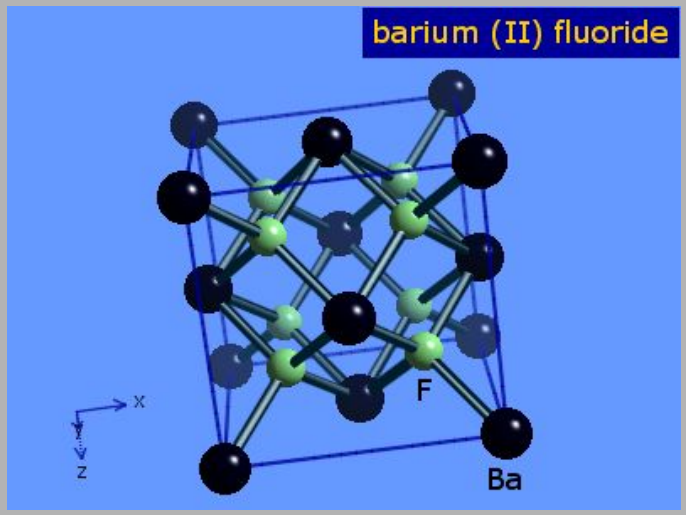












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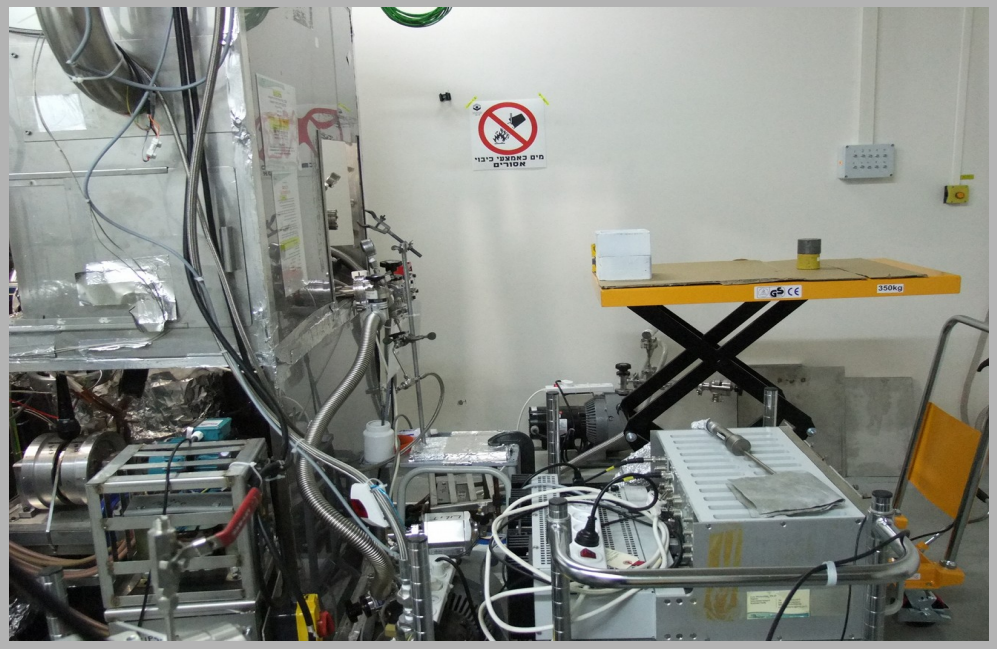
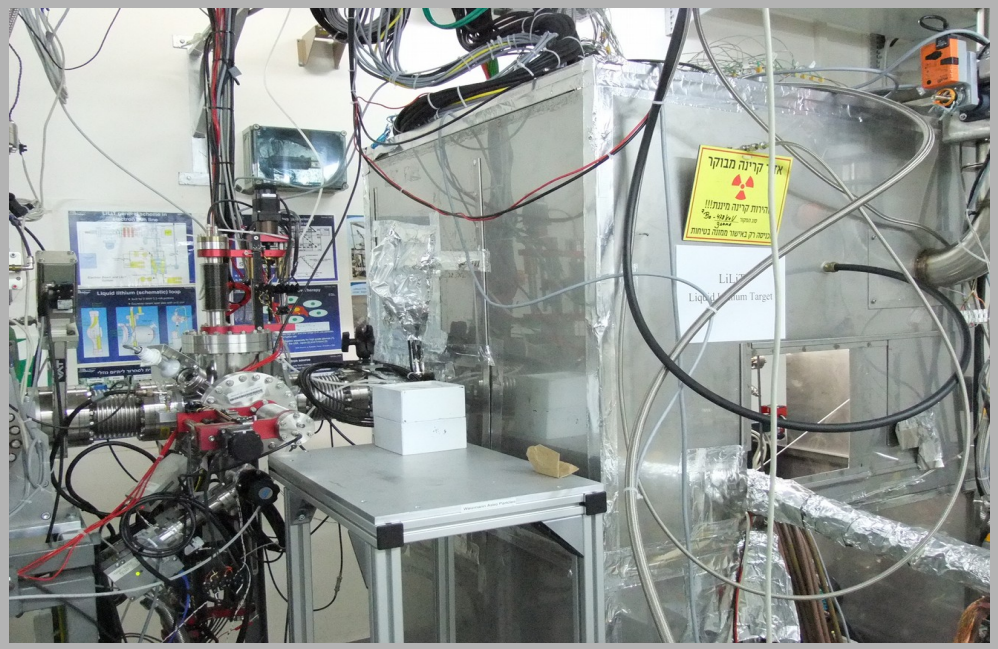
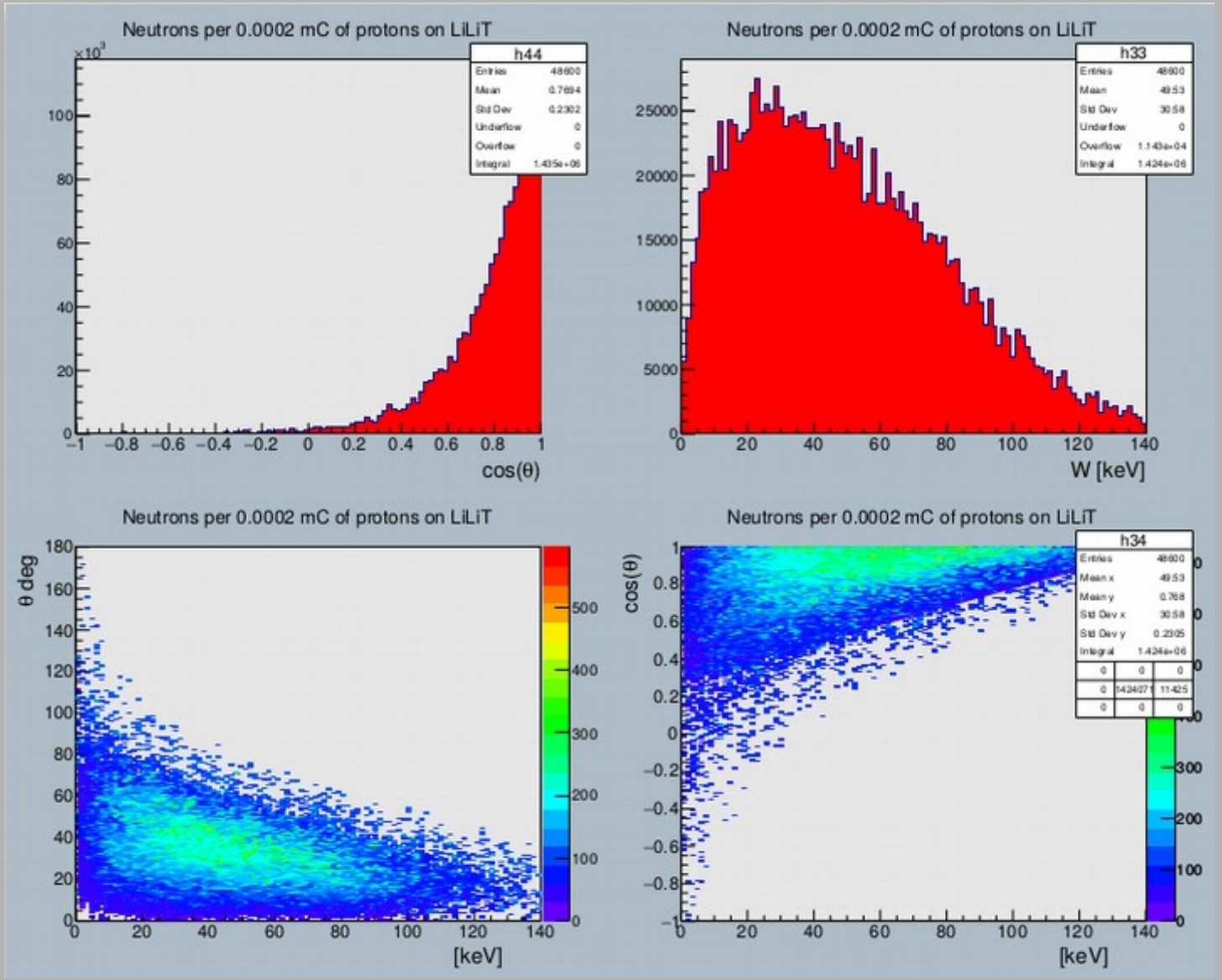
Crystal Irradiation in SARAF – 30 keV neutrons





Crystal Irradiation
Neutron spectrum



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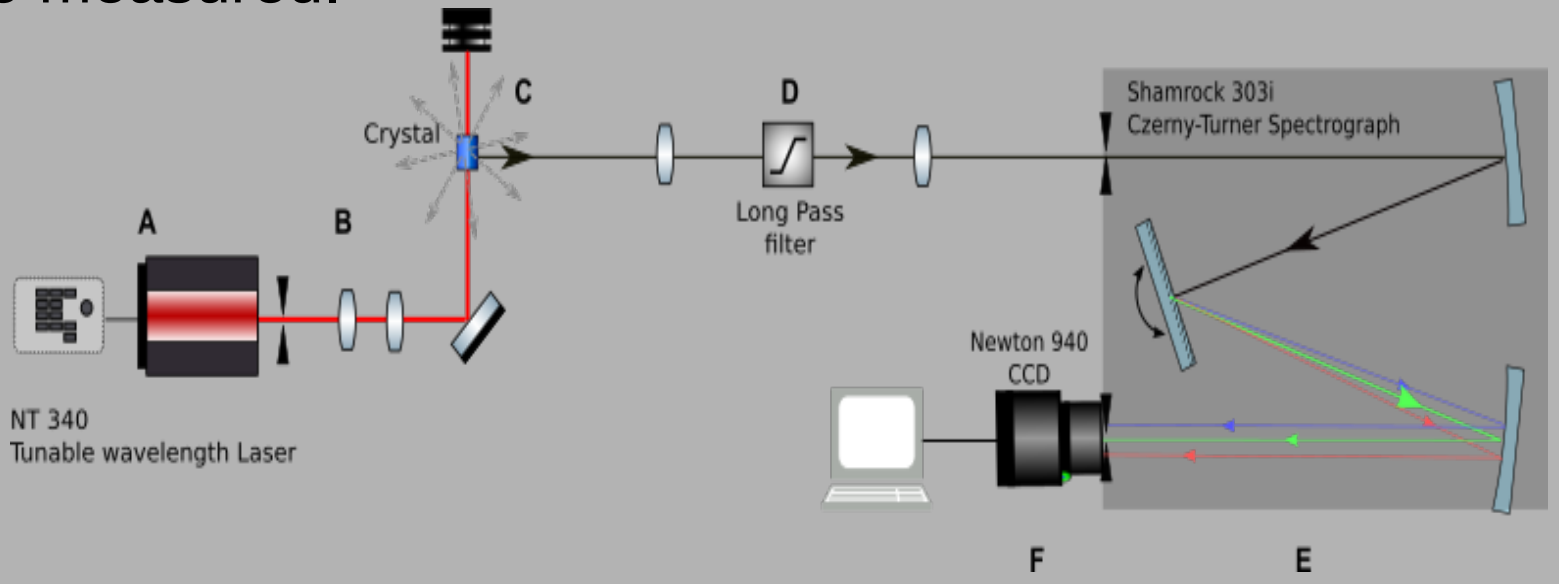
Fluorescence Measurement

Each crystals Fluorescence is measured before and after Irradiation. Reference crystals irradiated with Gammas only are also measured.

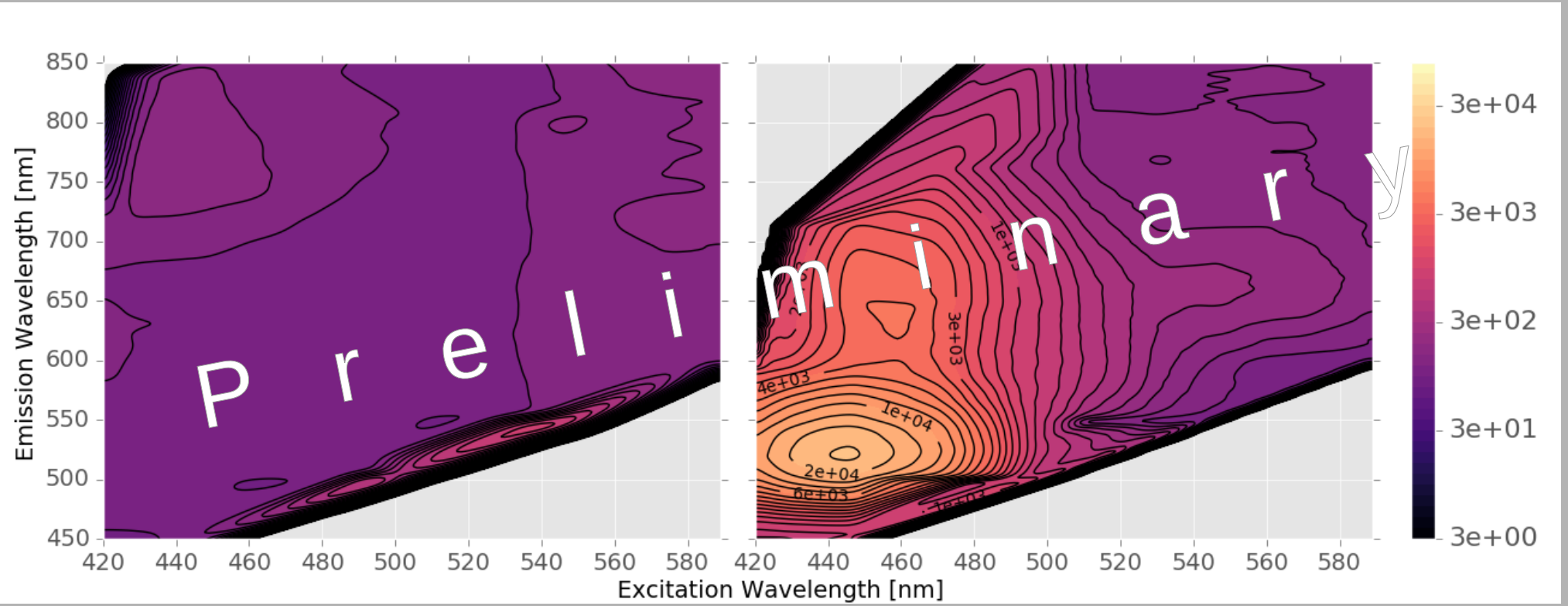


Required sensitivity of **10^{-10}** for initial calibrations, compared to **10^{-6}** of standard wide-band fluorometers

Sensitivity requirements rise as we progress, to reach **10^{-14}** with wide band!

Preliminary results

LiF, before and after n irradiation



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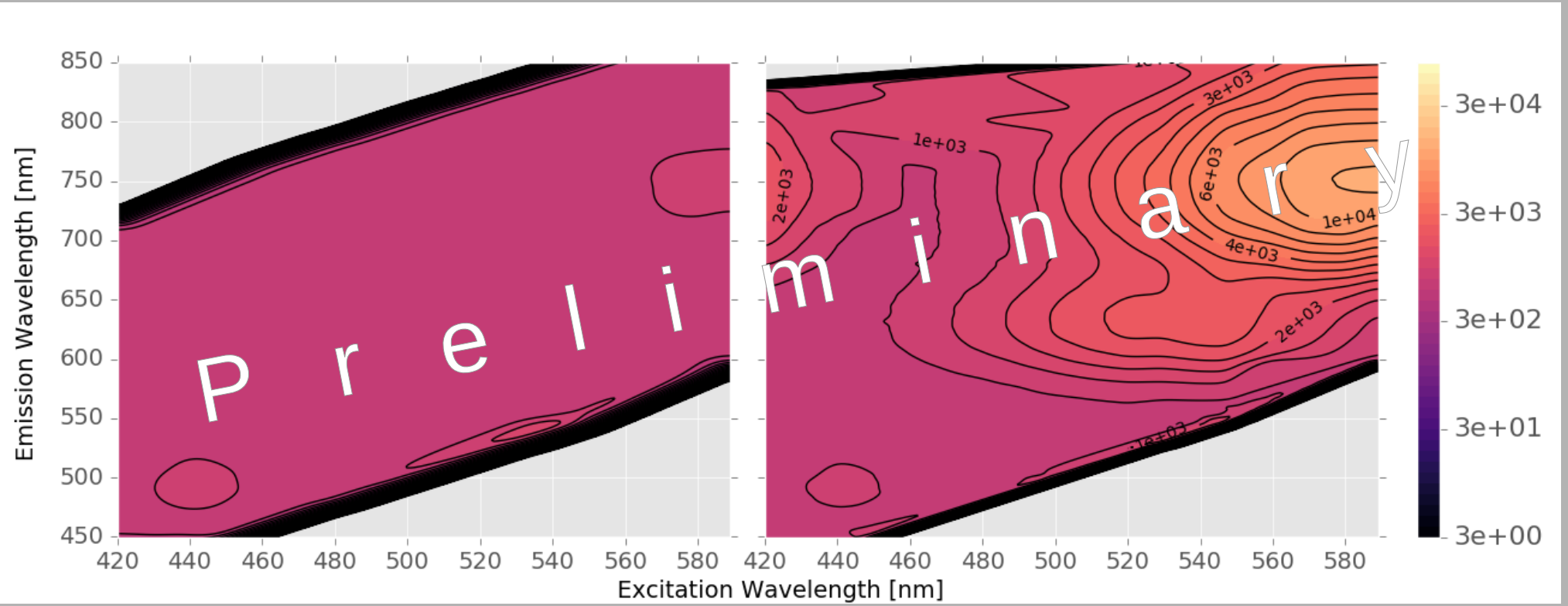
Preliminary results

CaF, before and after n irradiation



Summary

- Color Centers are a promising avenue for low energy NR detection
- The current experimental and theoretical knowledge is insufficient, much work is needed on both
- Irradiation of multiple samples done, and will continue
- Optical system with increased sensitivity is being developed, expected to give results this year
- After identifying the “promising avenues”, the real work begins!