Two Future Avenues for DM Direct Detection

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מכון ויצמן למדע
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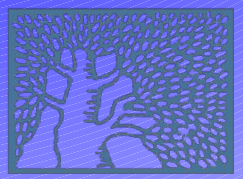
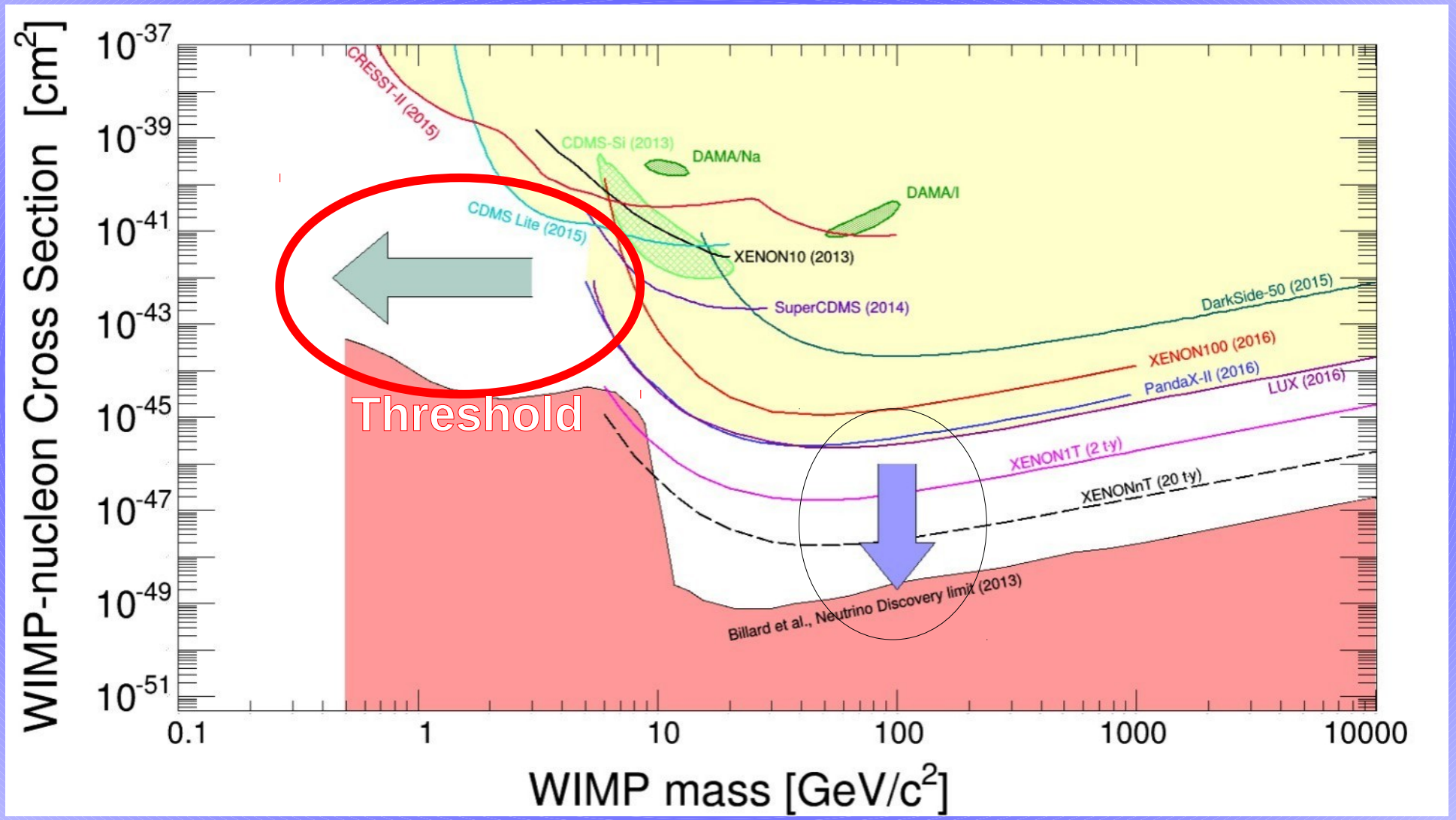


Landscape of DM direct detection

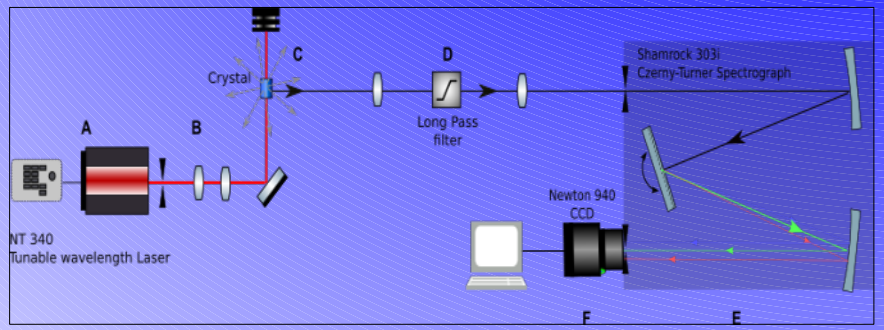


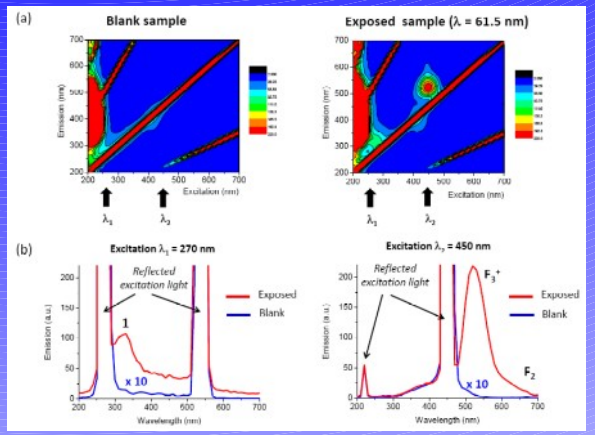
The Color of Fancy Sapphire

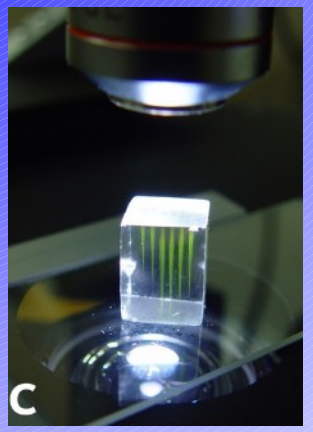
All are Al_2O_3 >99.99%

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**

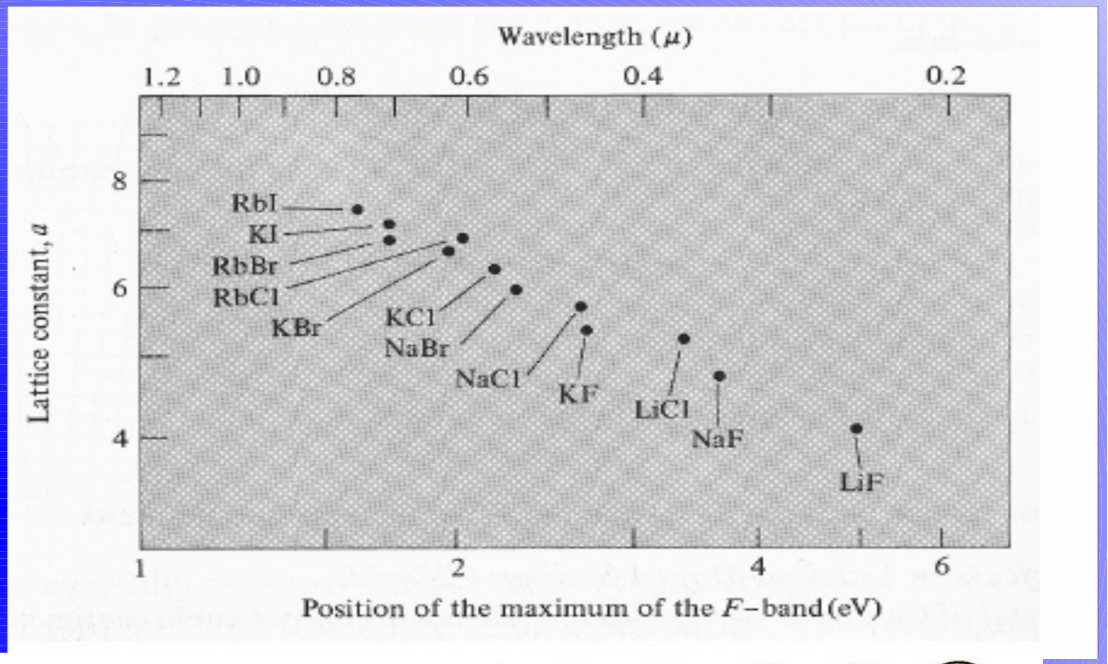


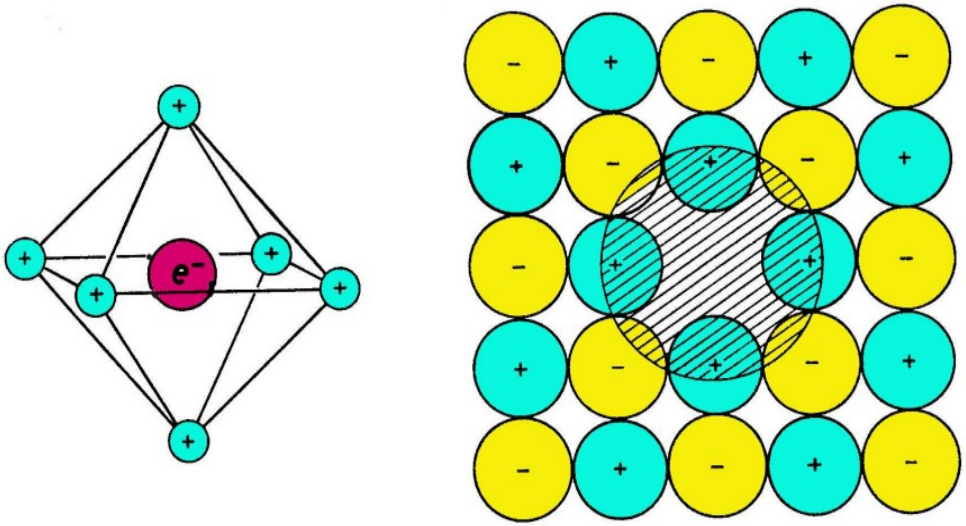




F-center in a nutshell

- 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) – O(10) eV





Atomic structure of the F center

F-center in a nutshell

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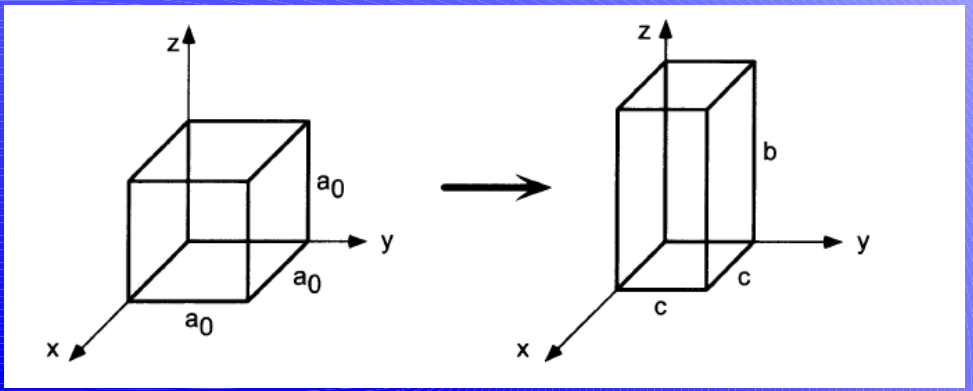
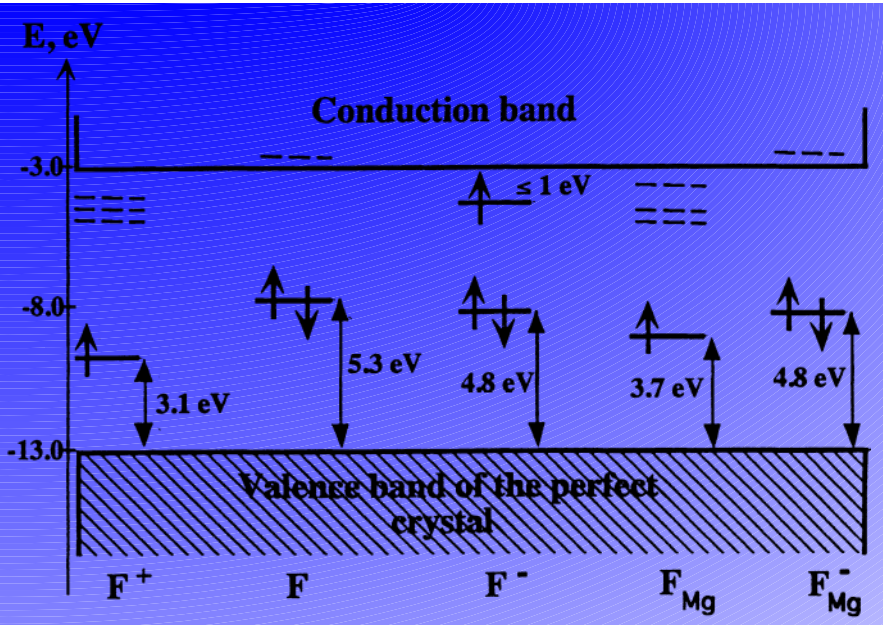




The challenges of CCs

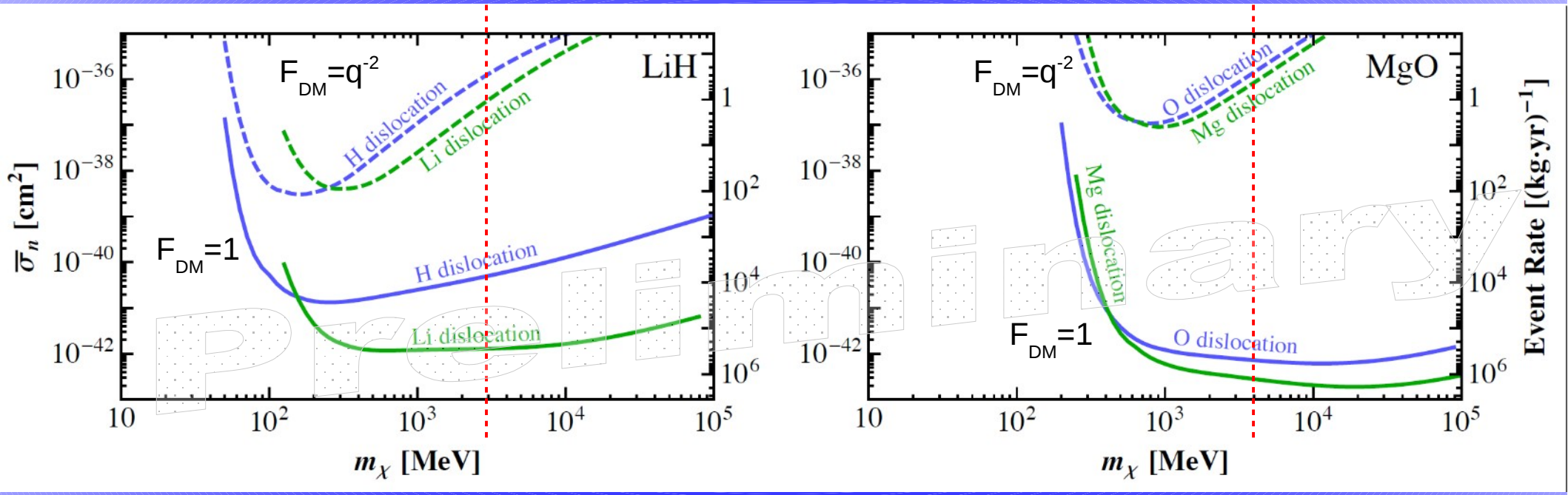
- Missing orders of magnitudes in background
- Direct calculation extremely hard due to phase space (thresholds, types, electronic structures...)
- However, only extremely difficult once established the signal
- Need to understand and achieve:
  - Annealing, bleaching, counting, production, discrimination,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

The benefits of CCs

- 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

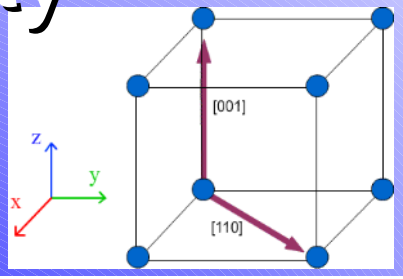


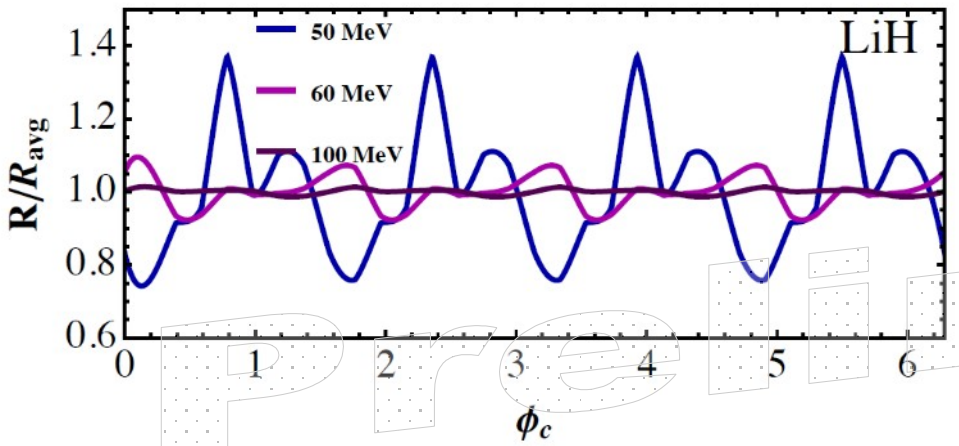
Two candidate crystals with known CCs and thresholds. The vertical red dashed line is where traditional experiments lose sensitivity.

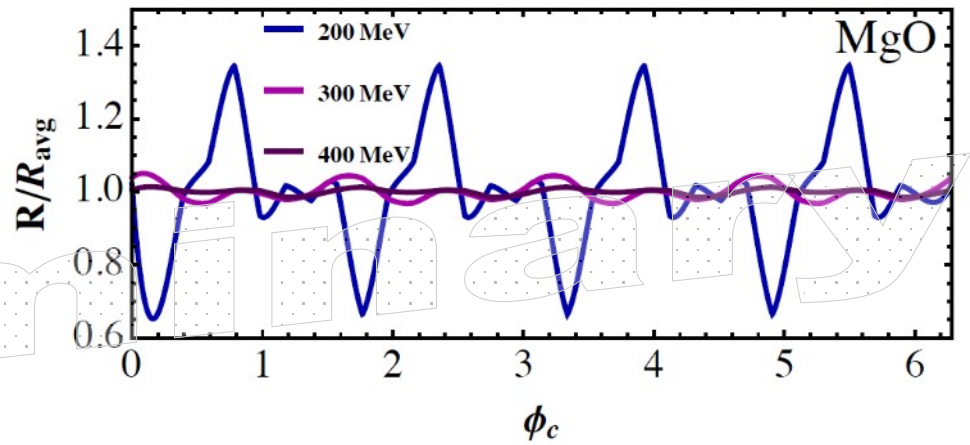
Dashed/solid lines represent different DM form factors.

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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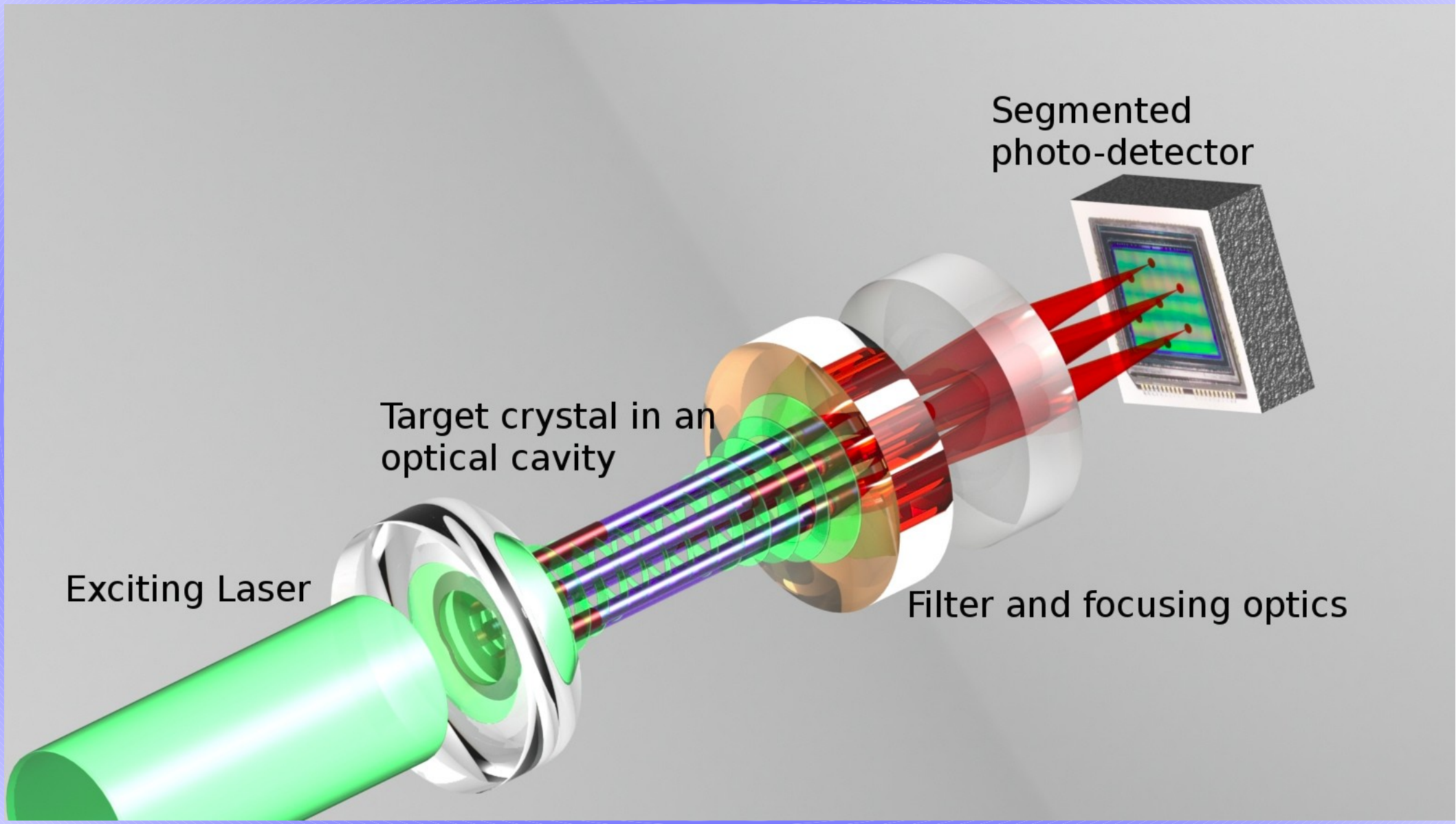
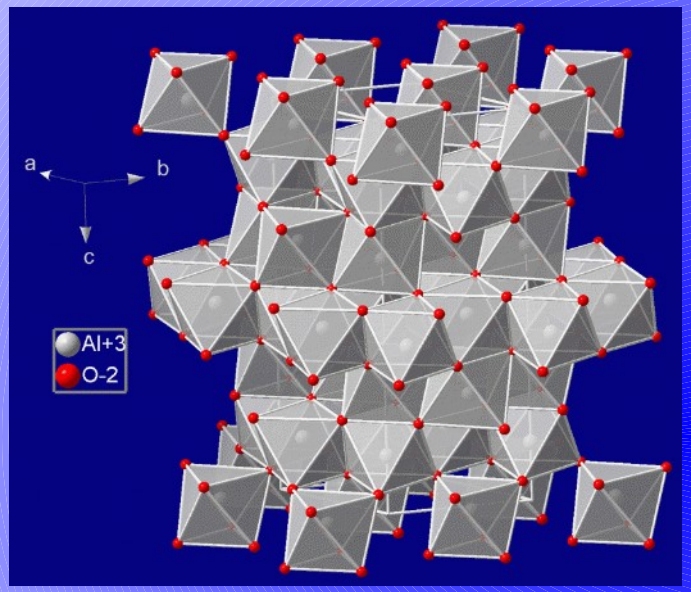
Two parallel ongoing efforts:

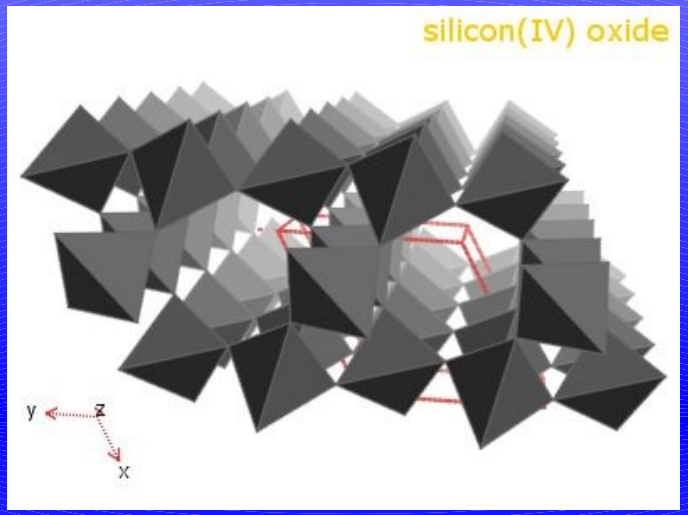
1) Irradiation of as many crystals as possible

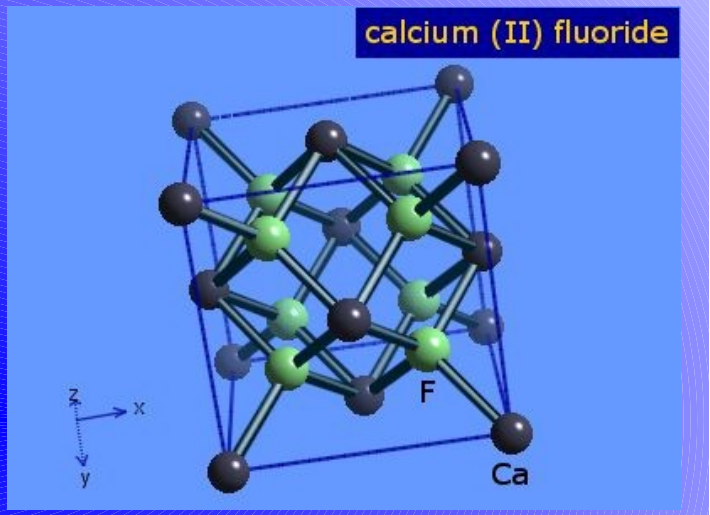
2) Establish an optical setup for F-centers measurement

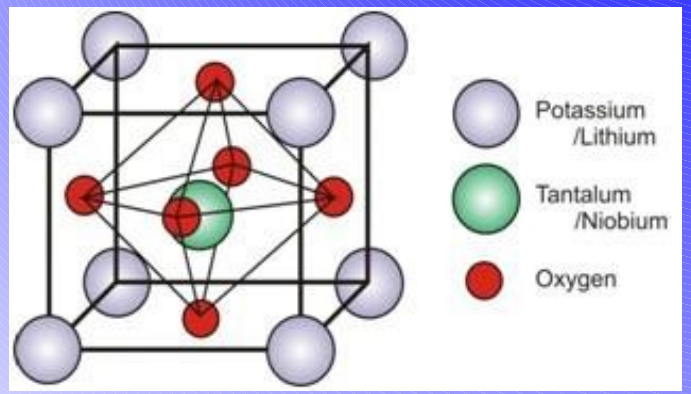

Segmented
photo-detector
Target crystal in an
optical cavity
Exciting Laser
Filter and focusing optics

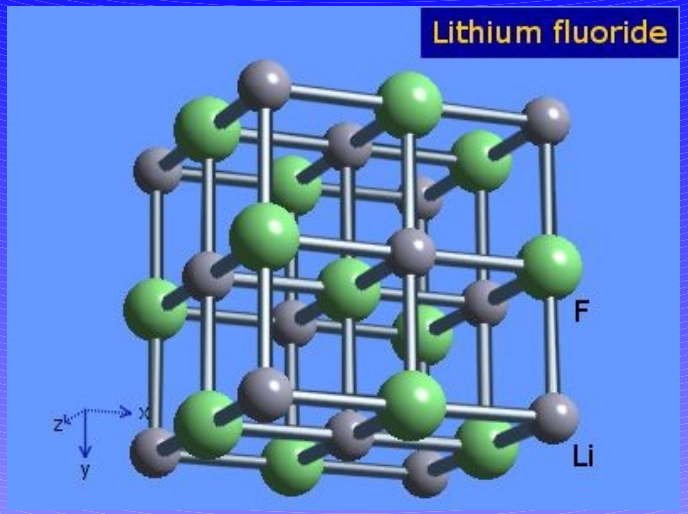
Many optional targets, but little is known

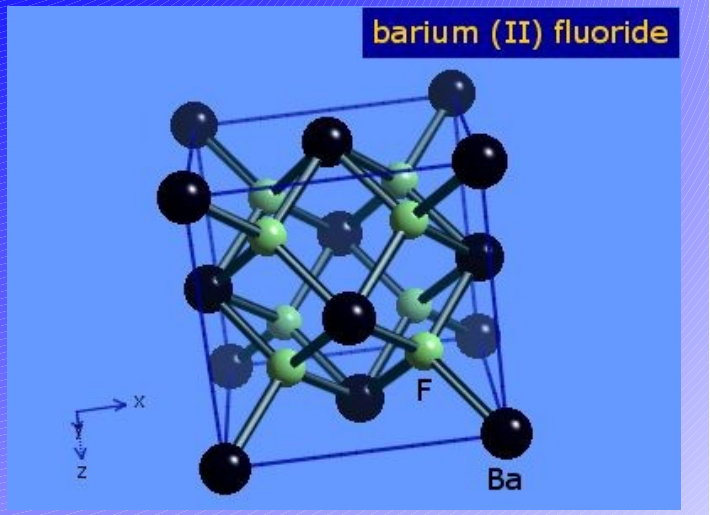




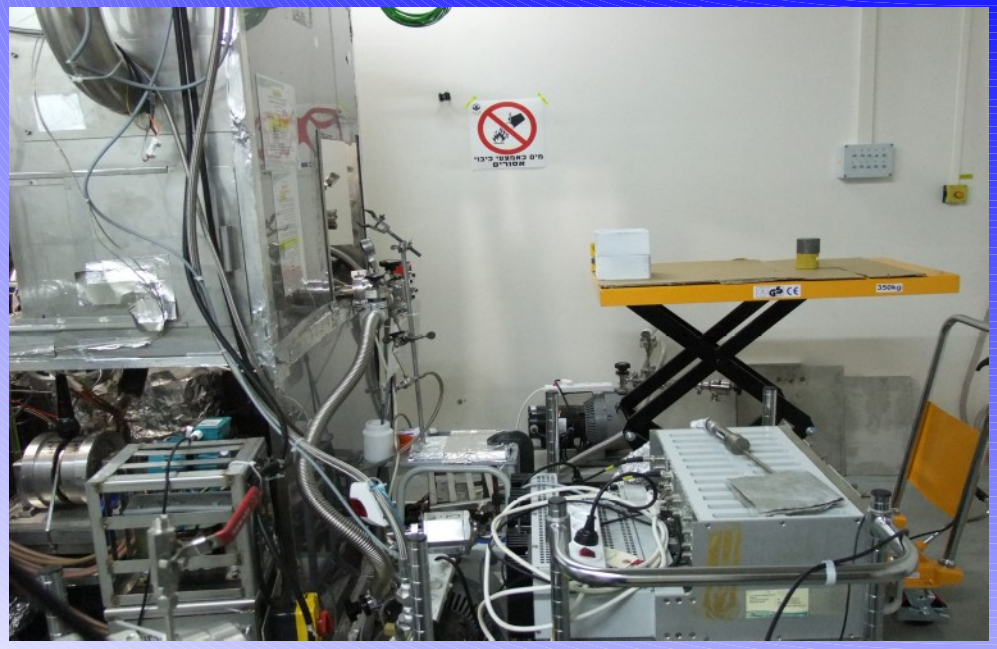


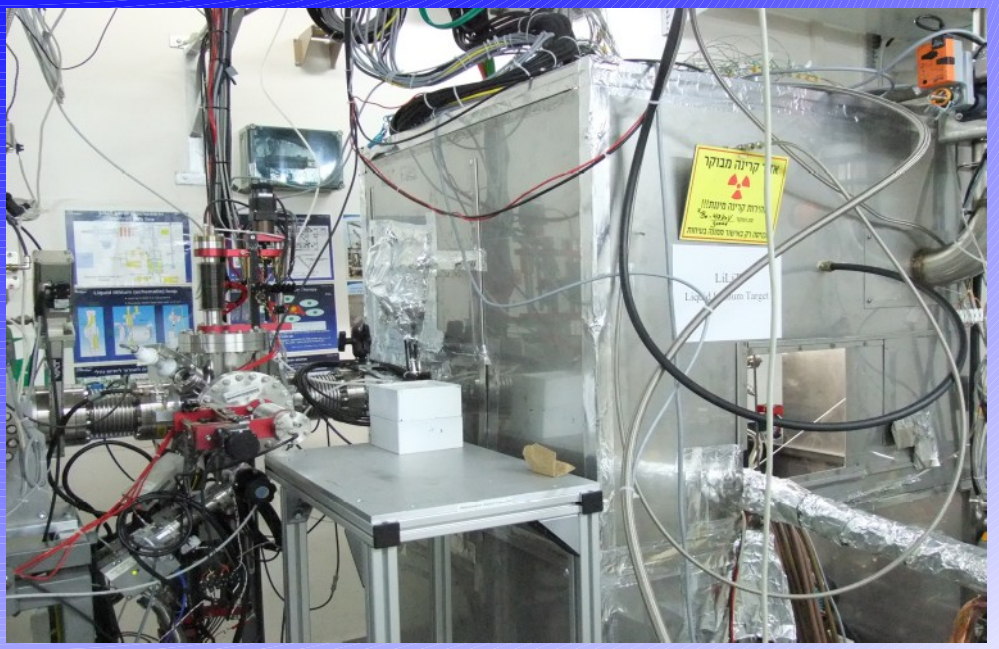






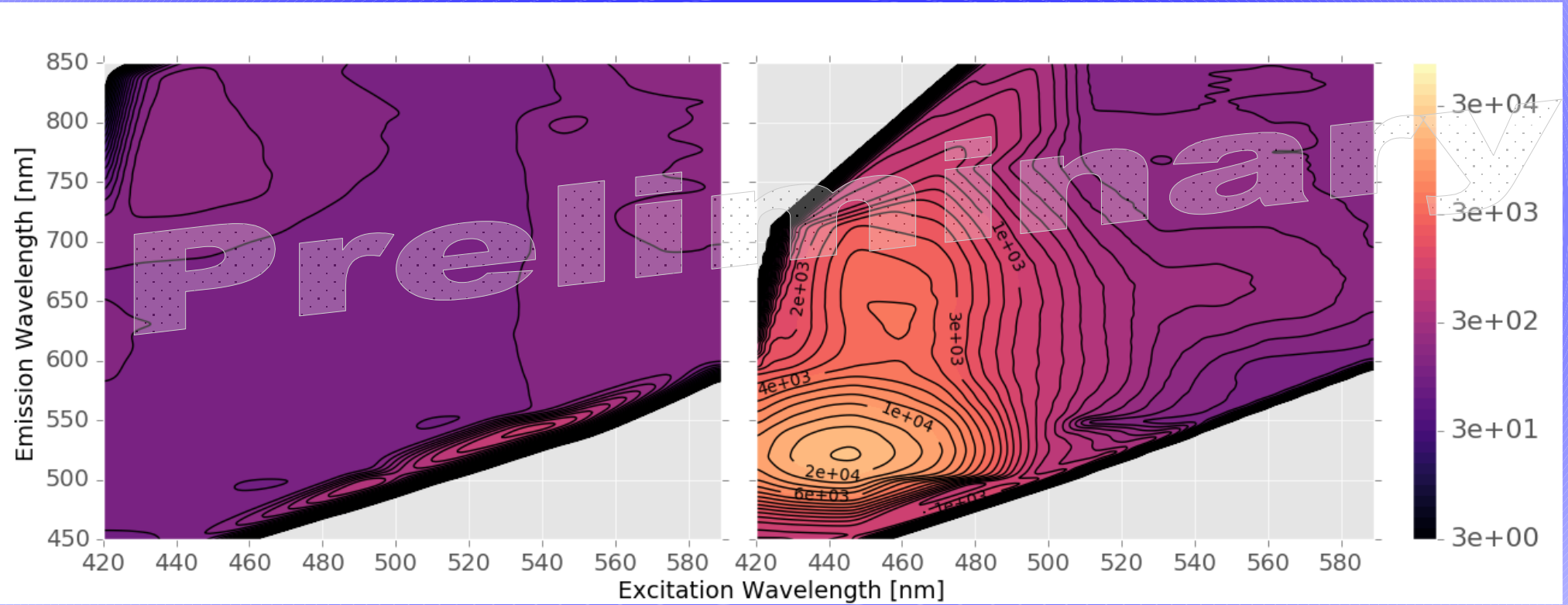
Crystal Irradiation in SARAF – 30 keV neutrons





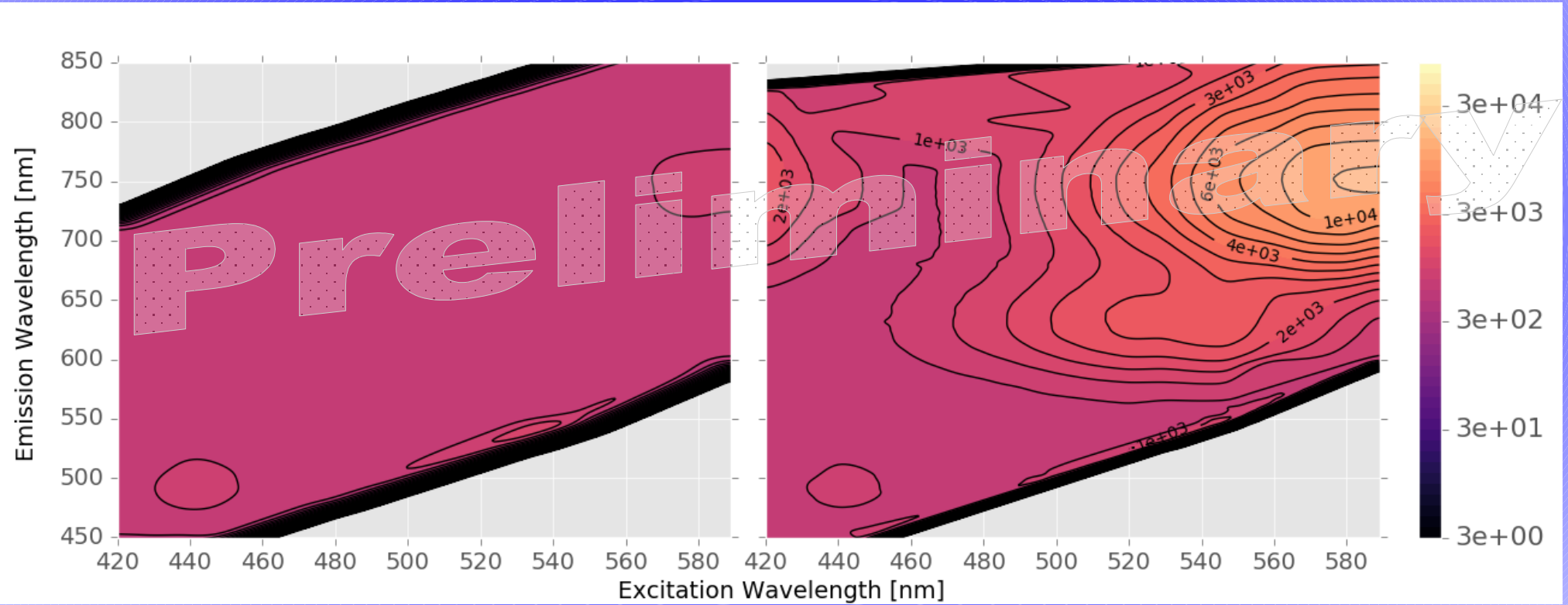
Preliminary results

LiF, before and after n irradiation

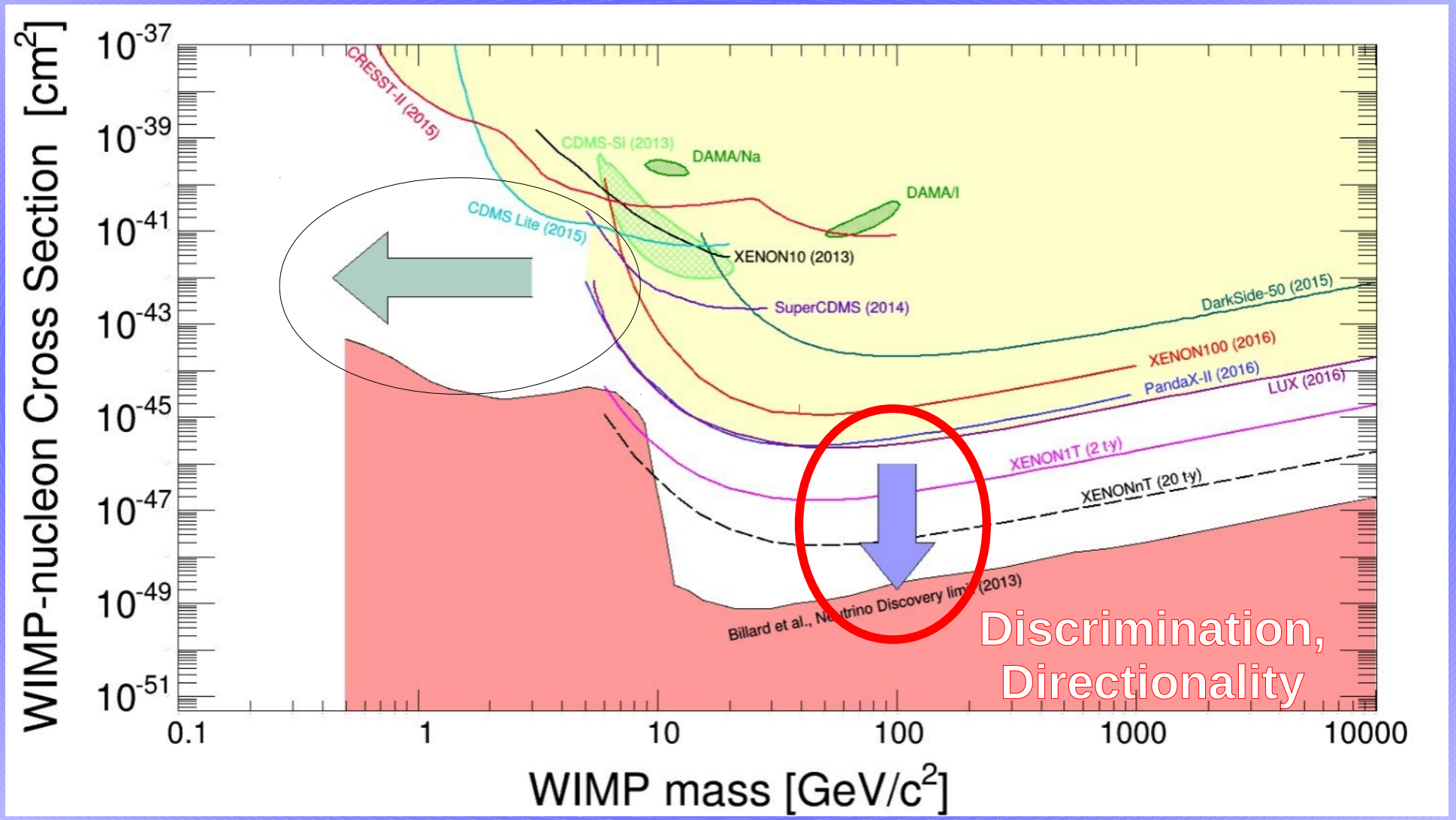


Preliminary results

CaF, before and after n irradiation

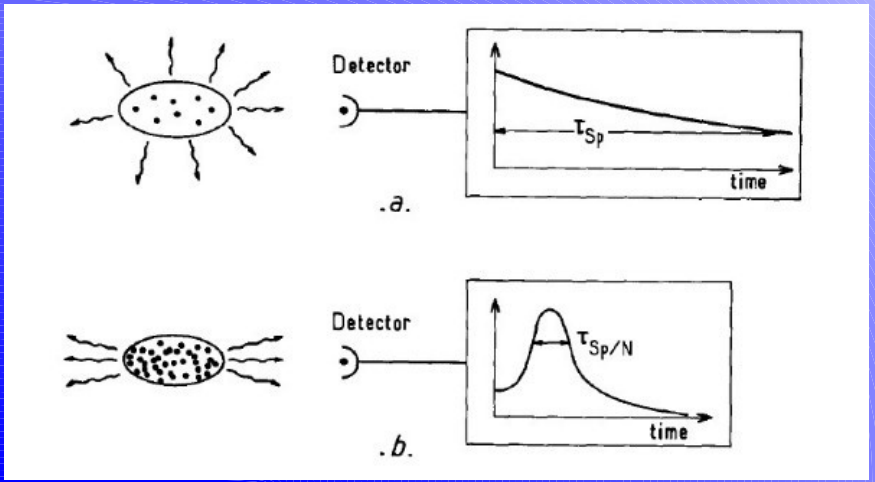


Landscape of DM direct detection



Superradiance

- A quantum-correlation phenomena knows since Dicke 1954
- Demonstrated in many systems
- Basic properties:
  - Correlated timing of EM decay of similar states
  - Correlation in photon directions



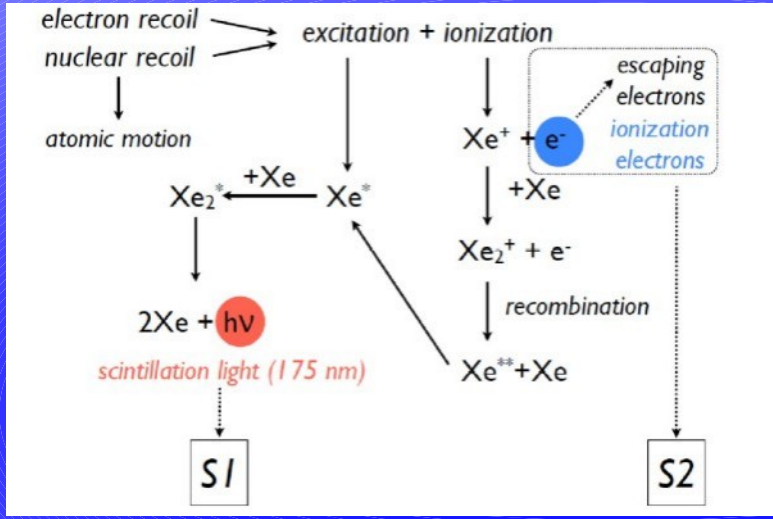
- Requirements:
  - Density >> λ^{-3}
  - Lifetime >> formation time, light crossing
  - "Population inversion"
  - "no disturbances"

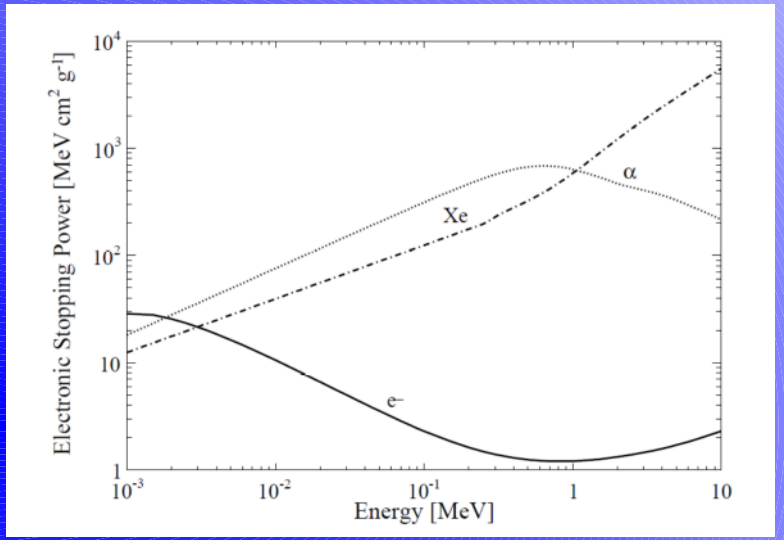
Superradiance possible in xenon?

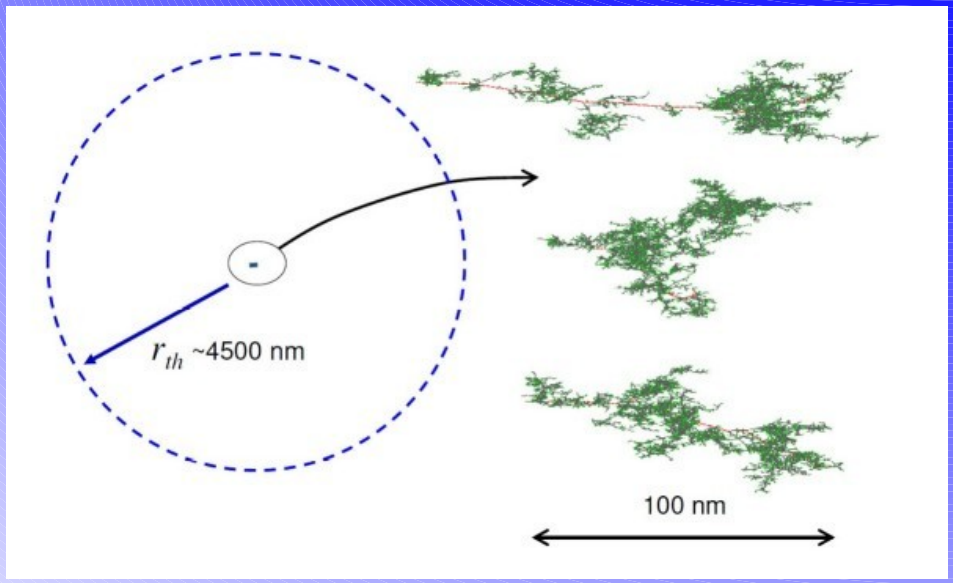
- Seems that the basic requirements are there...

<ns formation

>ns decay time







Why is it interesting?

1. Discrimination
2. Directionality!

Chepel 2013, Aprile 2010 and more

Extra motivation

- Lasing has been demonstrated with bulk ionization (1971, Basov)
- Some features of measurements might be a hint (time structure, XMASS)

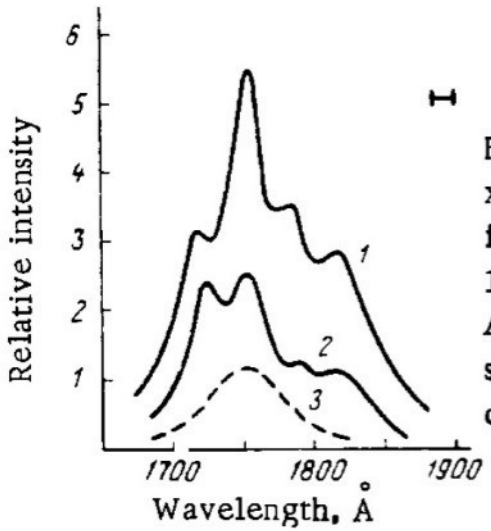
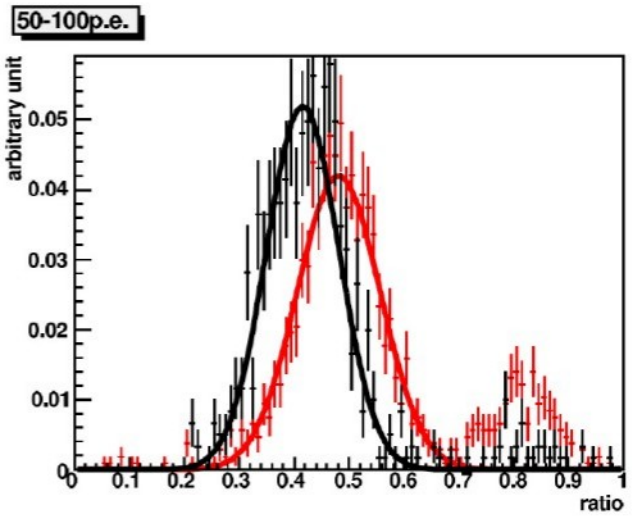


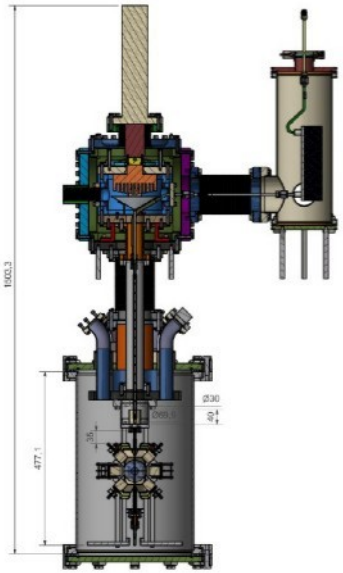
Fig. 3. Emission spectra of liquid xenon (the spectrometer resolution is shown in the right-hand corner): 1) pumping current density 150 A/cm^2; 2) pumping current density 70 A/cm^2; 3) low excitation density.

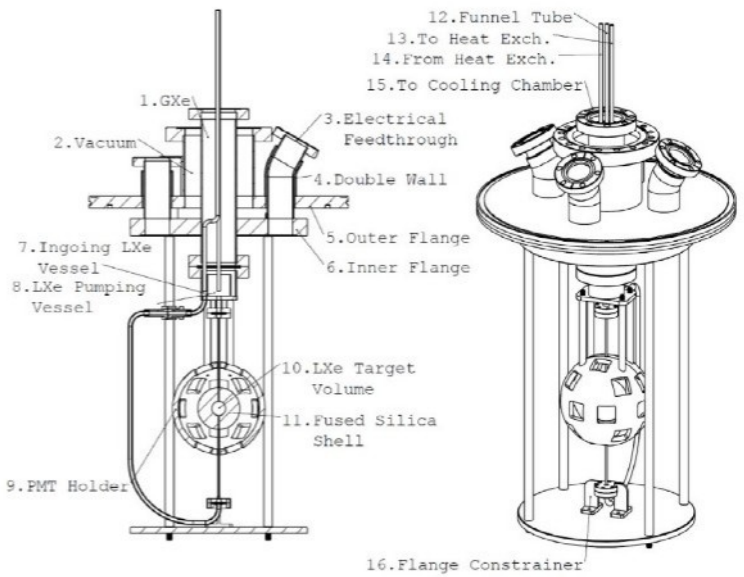


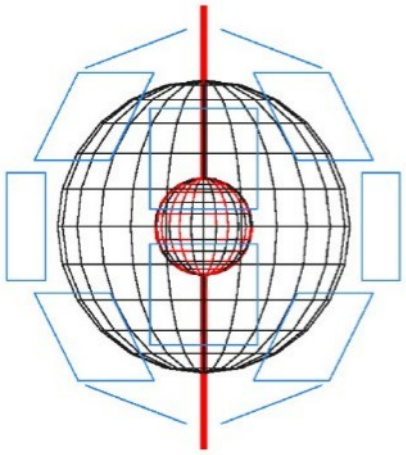
Why haven't we seen anything?

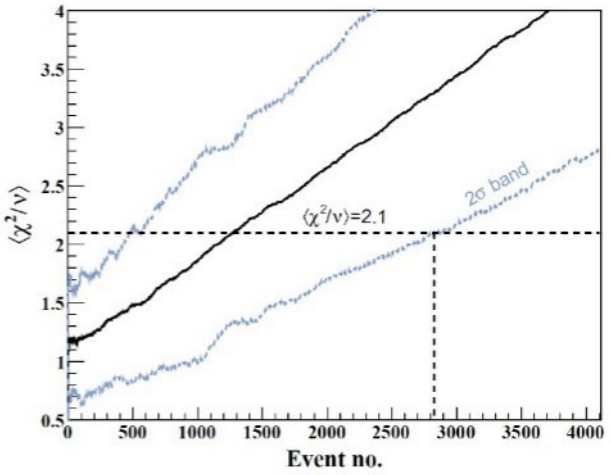
- Temporal:
  - Requires ~ns resolution (not usually employed)
  - Averaging over all parts of a cloud → smooth decay
  - Some hints might exist
- Directional:
  - Averaging over events washes out directionality
  - Reflections, partial collection – usually not considered a "problem"

The Direxeno experiment



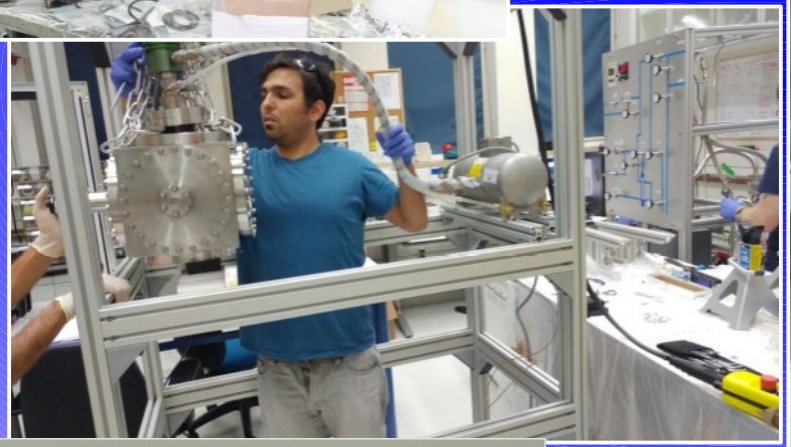


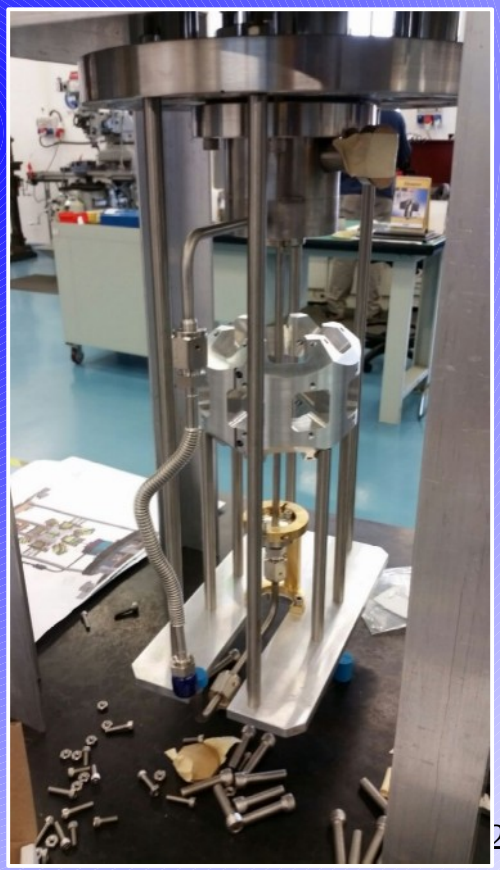




- We will have the ability to **distinguish non-isotropic from isotropic emission**
- Also look at time-direction correlation
- Setup fully designed and under construction

Direxeno



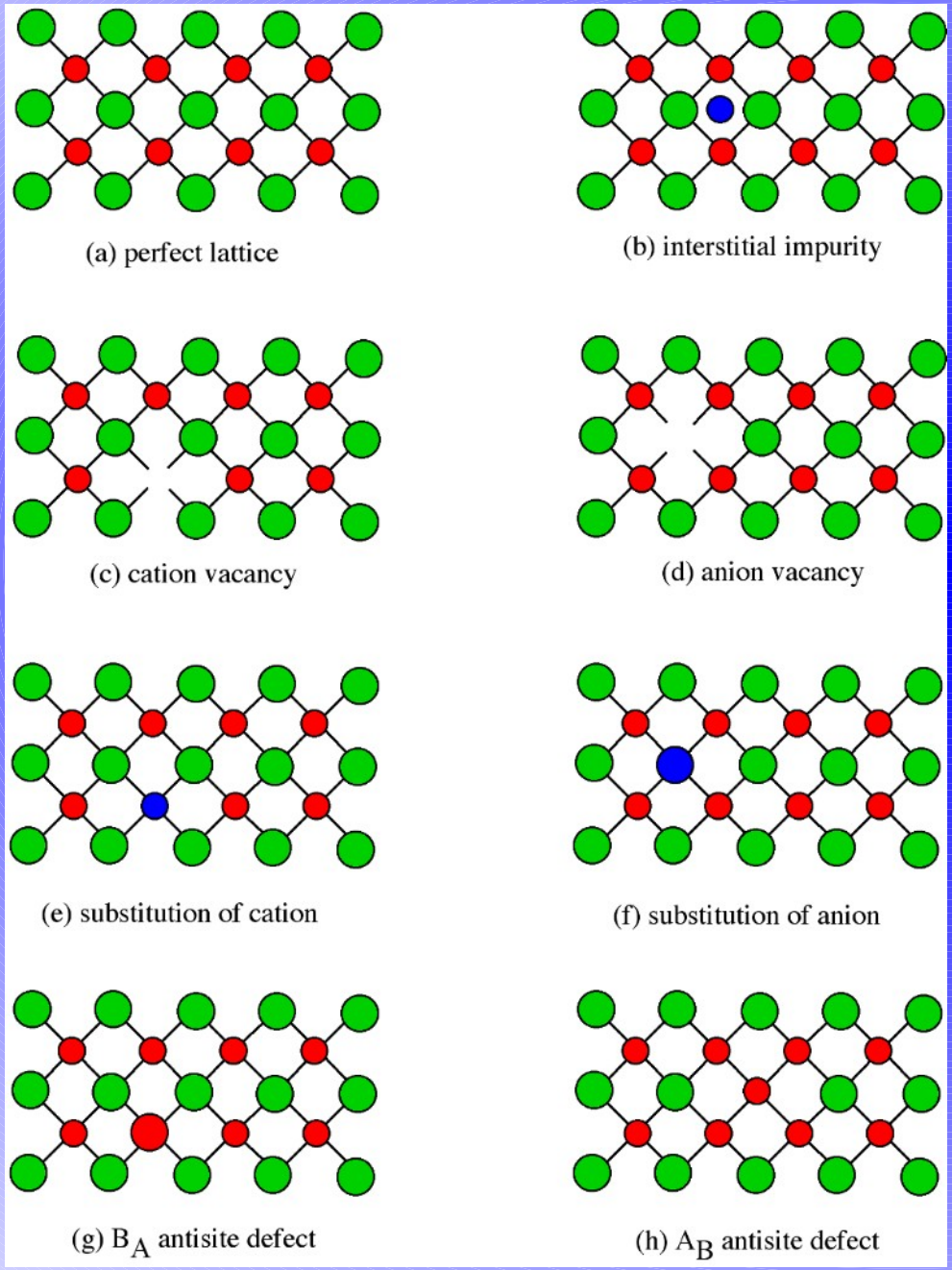


Expected to start operating in a few months

Summary

- Two avenues with possible impact on the future of DD:
  - Color Centers as low threshold NR detectors:
    - Promising prospects
    - Many unknowns on technology, backgrounds, theory
    - Experimental work in progress
  - Xenon Superradiance:
    - Theoretical and experimental motivations for the existence
    - Possibilities in discrimination and directionality
    - Dedicated DIREXENO setup designed and being built
- Stay tuned…

Known states of Ionic crystals



F-center

A vacancy filled by an electron can exhibit fluorescence.