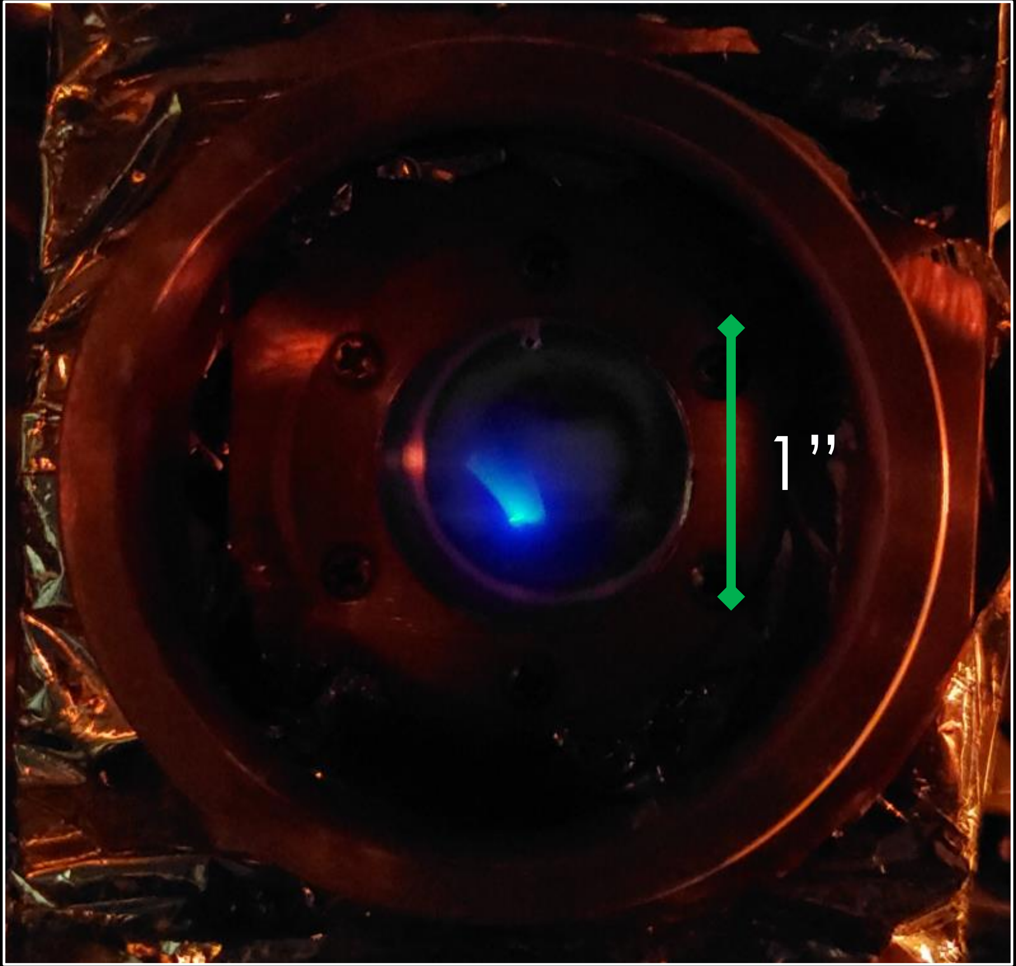
Progress Towards a Single Atom Microscope for Nuclear Astrophysics



Erin White, whiteer@frib.msu.edu

17^{th} Russbach School on Nuclear Astrophysics
9:30a.m. March 17, 2022

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Additionally, my work is supported as a 2020 NSF GRFP recipient via grant DGE-1848739.

JINA-CEE

SAM's Motivation

Novel detector technique for **nuclear astrophysics**

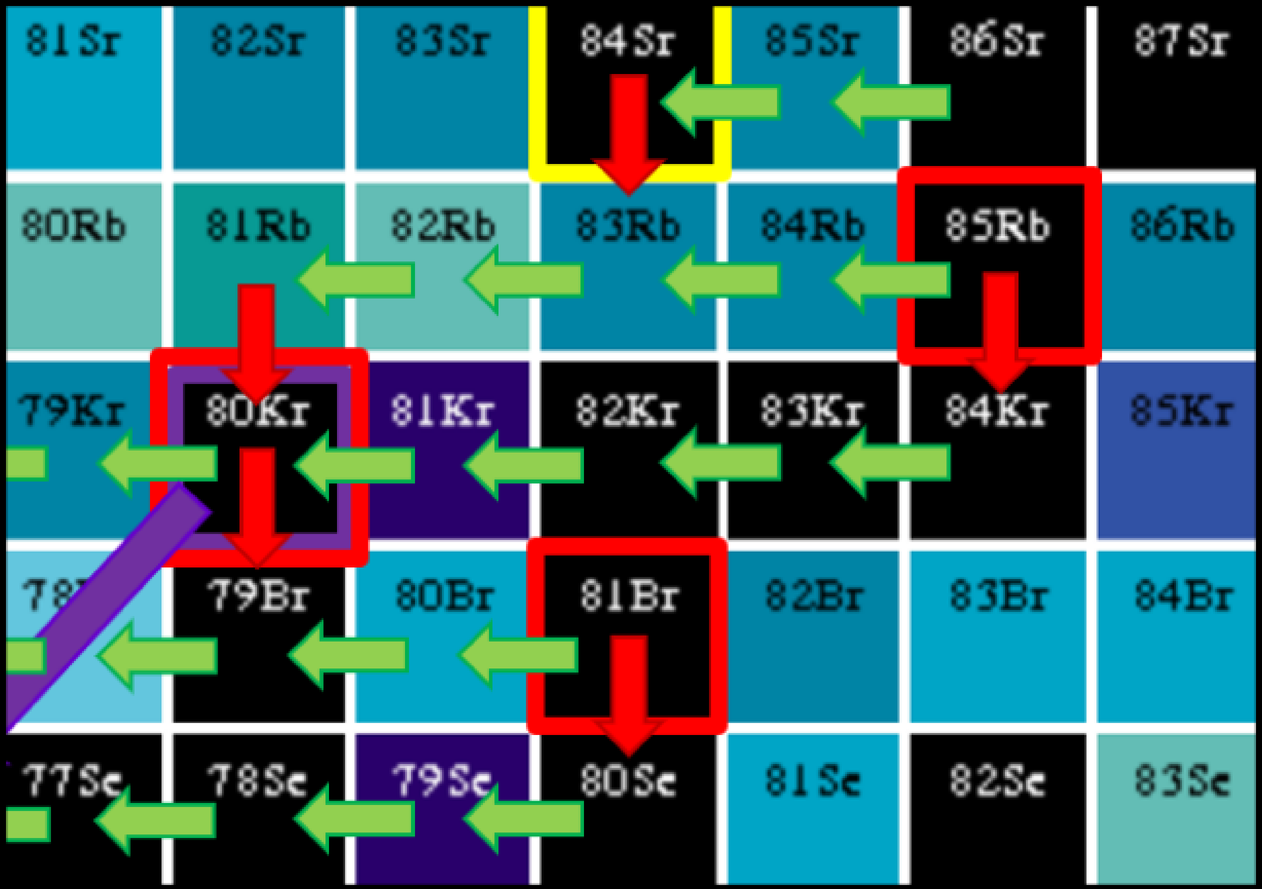
$^{84}Kr(p, \gamma)^{85}Rb$

- Determines reaction flow of p process, A. Palmisano (MSU 2020)
- Proof of principle measurement

$^{22}Ne(\alpha, n)^{25}Mg$

- Key source of neutrons for s-process

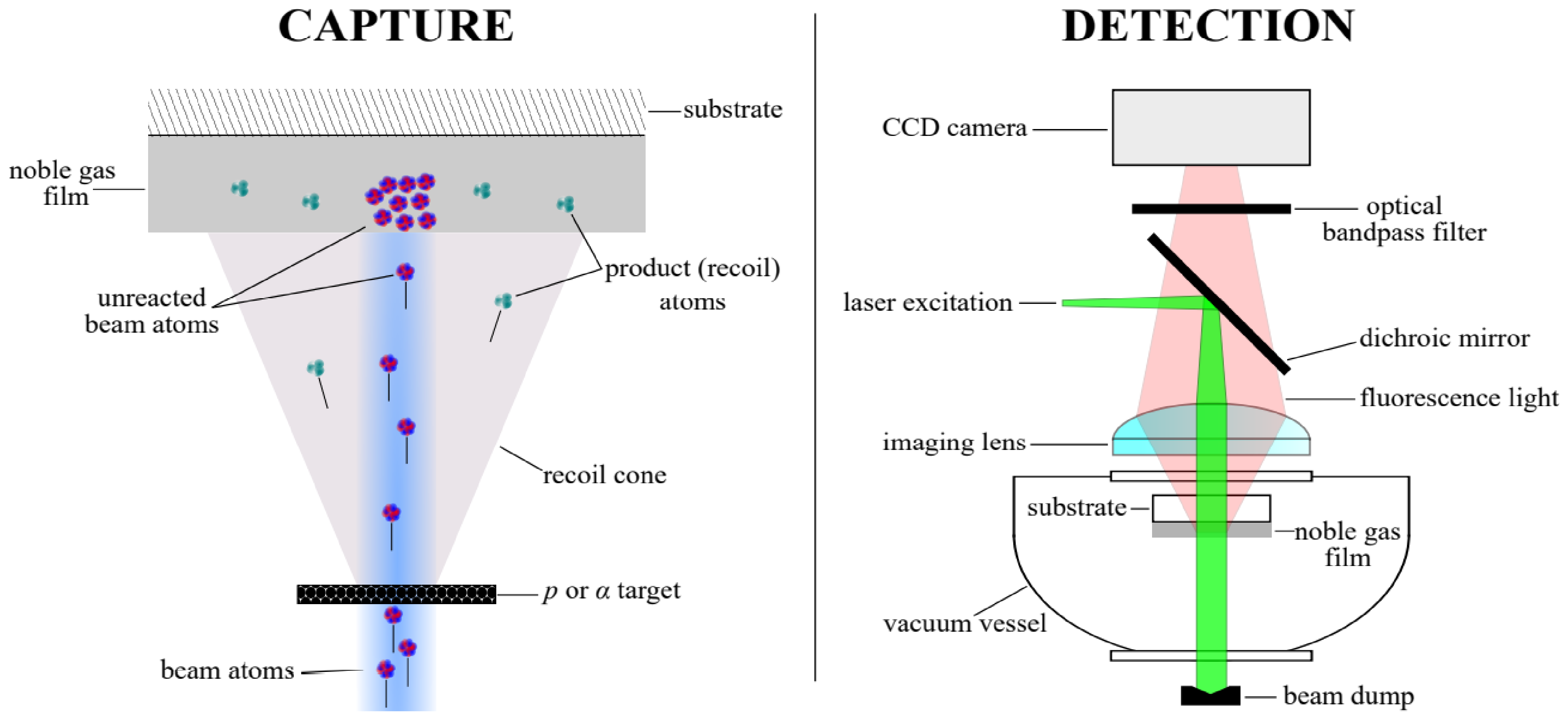
Loseth, et. al. Phys. Rev. C 99:065805 (2019)



A. Palmisano, MSU 2021 PhD

Capturing and Counting Product Atoms

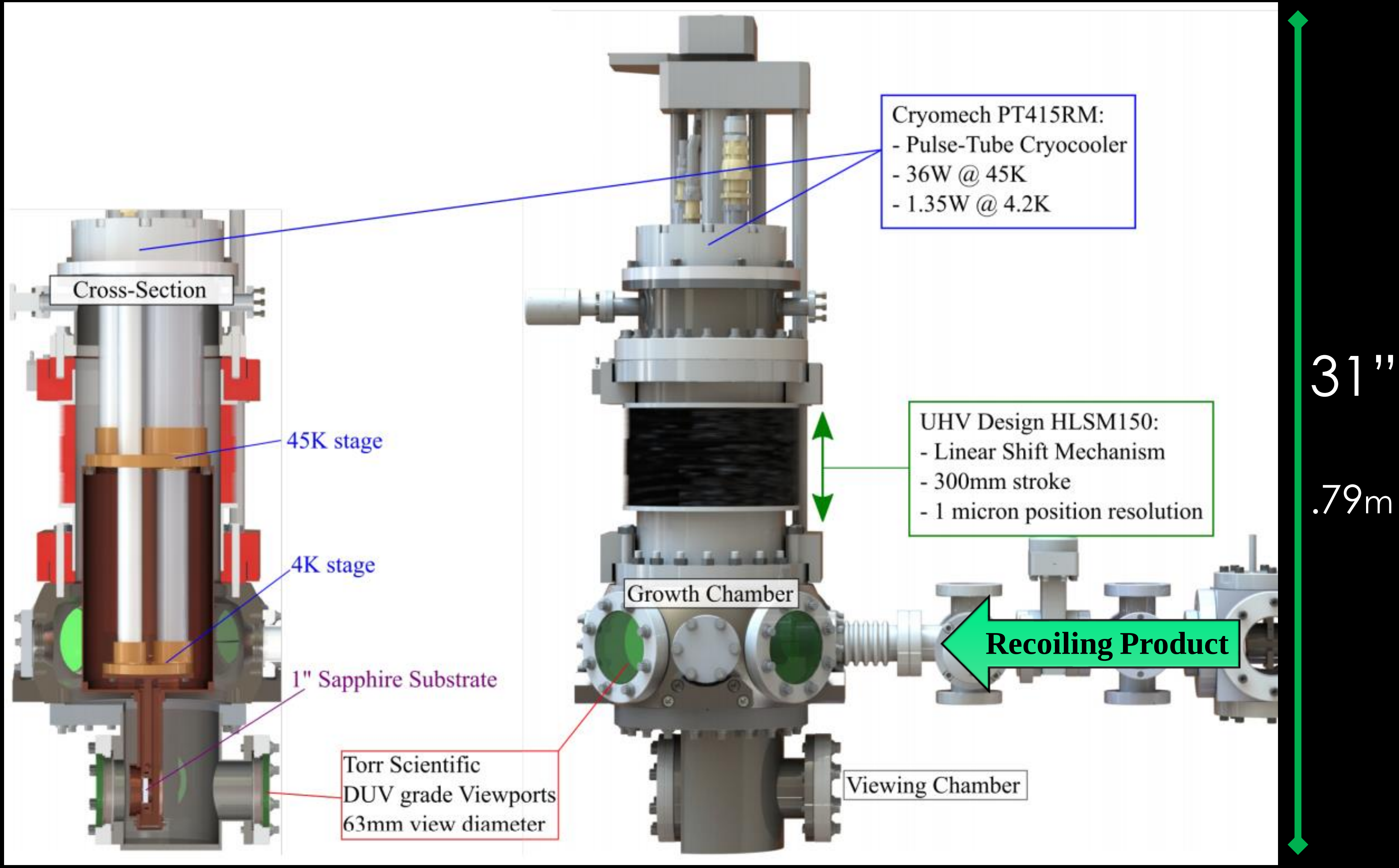
- Reaction products are captured in a solid noble gas film
- Product atoms are detected via fluorescence imaging



B. Loseth *et al.* Physical Review C 99, 065805 (2019). (arXiv:1903.01278)

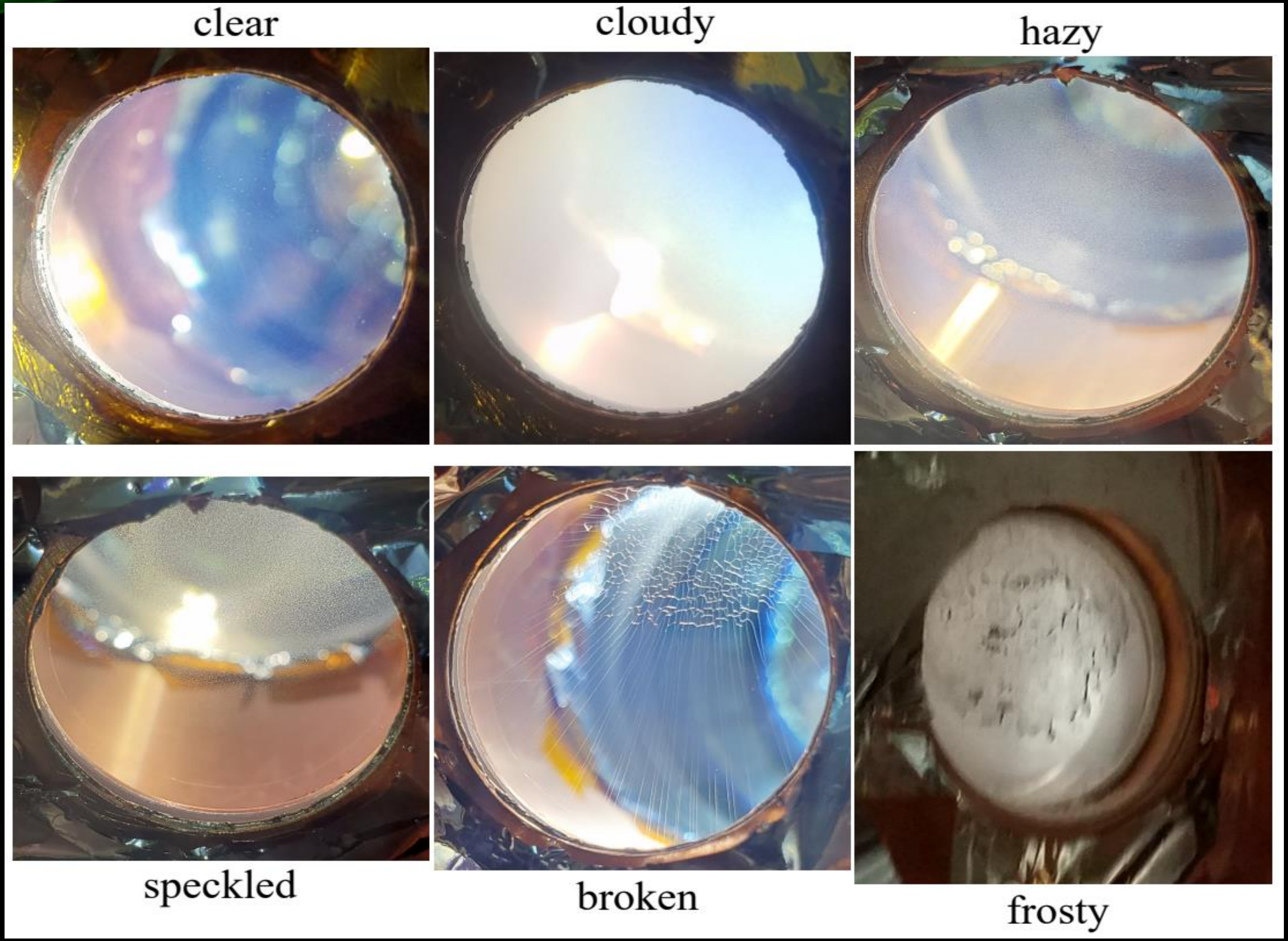
Prototype Single Atom Microscope

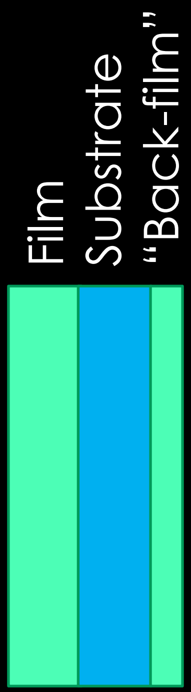
- Cryogenically freeze noble gas onto sapphire substrate
- Embed recoiling product ions into the film
- Use lasers to make the atoms fluoresce



Deposition Temperature Controls Film Quality

1”
(2.54cm)
Sapphire
Substrate

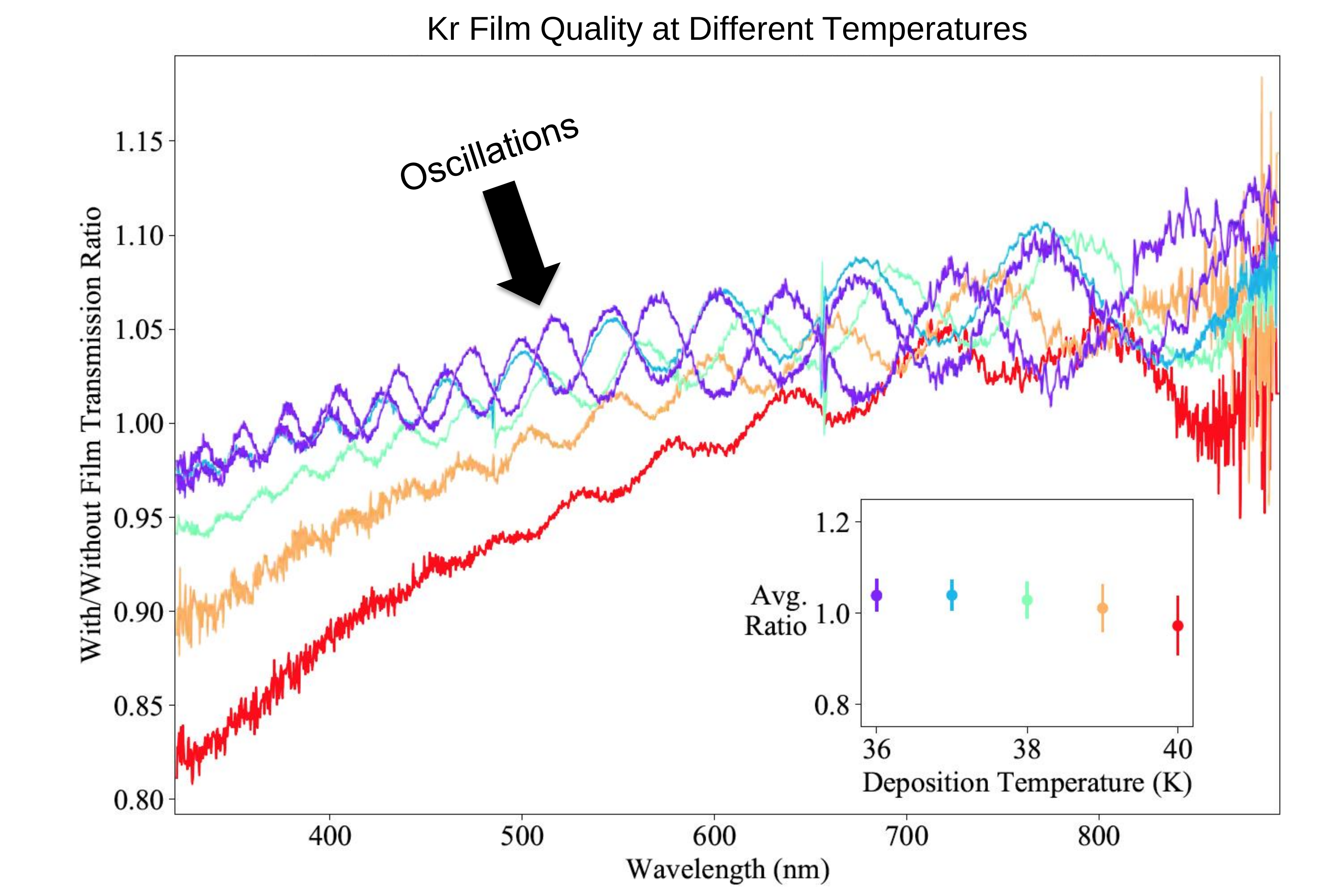




FILM TRANSPARENCY VS WAVELENGTH AT VARIED DEPOSITION TEMPERATURES

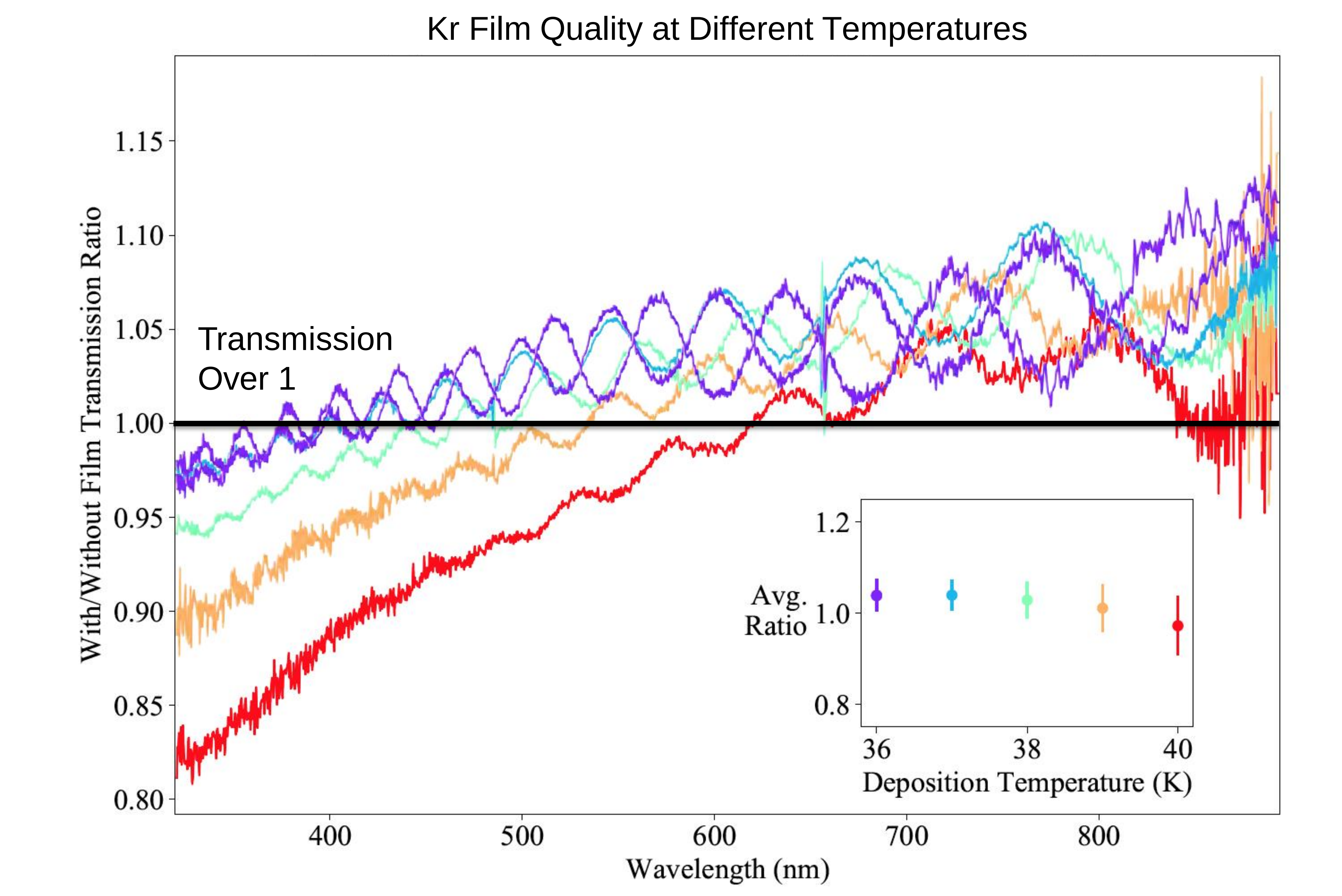
The presence of a "back-film" leads to these interference patterns created by constructive and destructive interference.

BTL PhD Thesis 2019



FILM TRANSPARENCY VS WAVELENGTH AT VARIED DEPOSITION TEMPERATURES

The "back-film" creates an anti-reflective coating effect in which reflections at the surface boundaries can lead to more light transmitting through the film than through the substrate alone before the film's growth.



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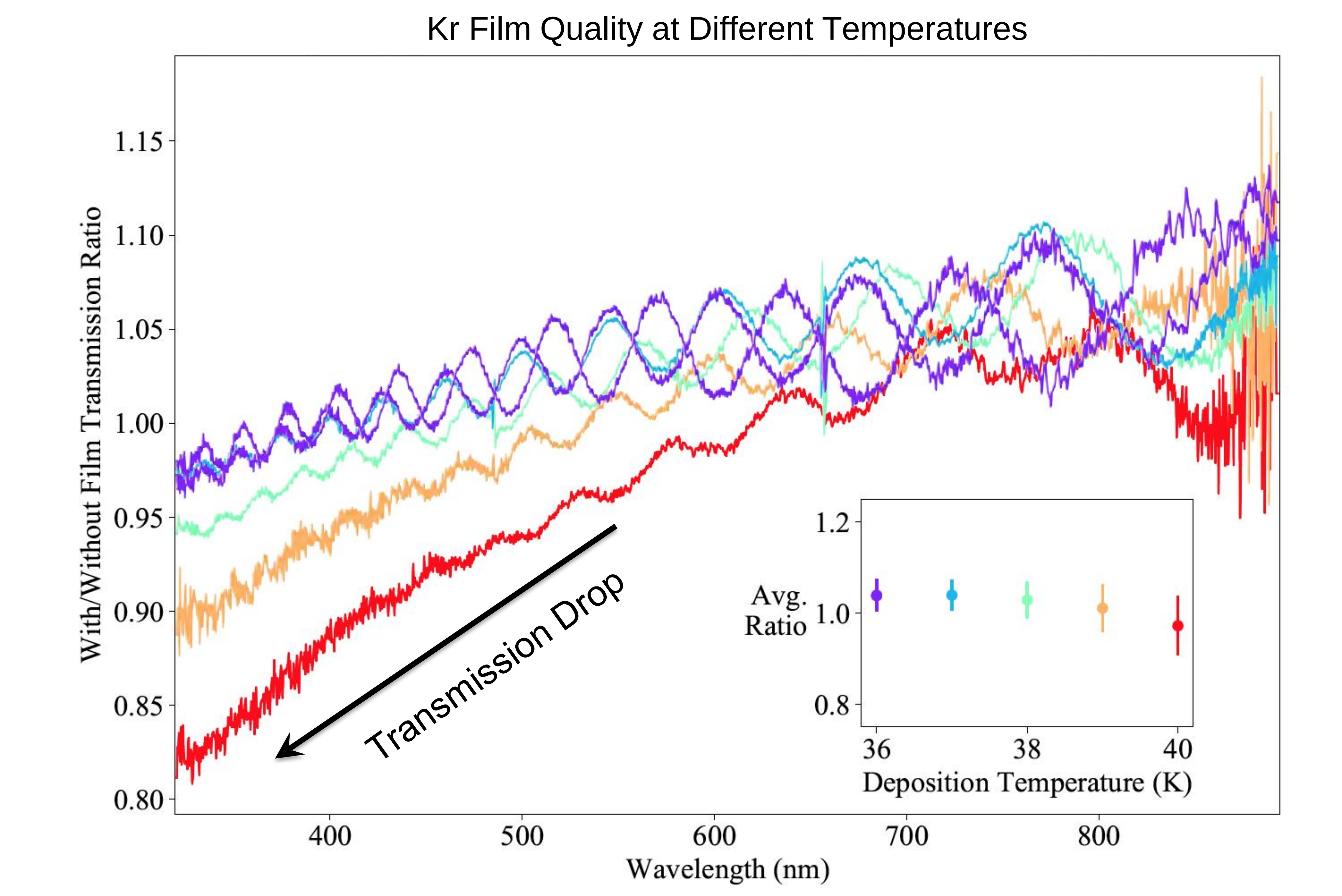
FILM TRANSPARENCY VS WAVELENGTH AT VARIED DEPOSITION TEMPERATURES

The transmission drops off at low wavelengths due to Mie Scattering off of small vacuum pockets contained within the film.



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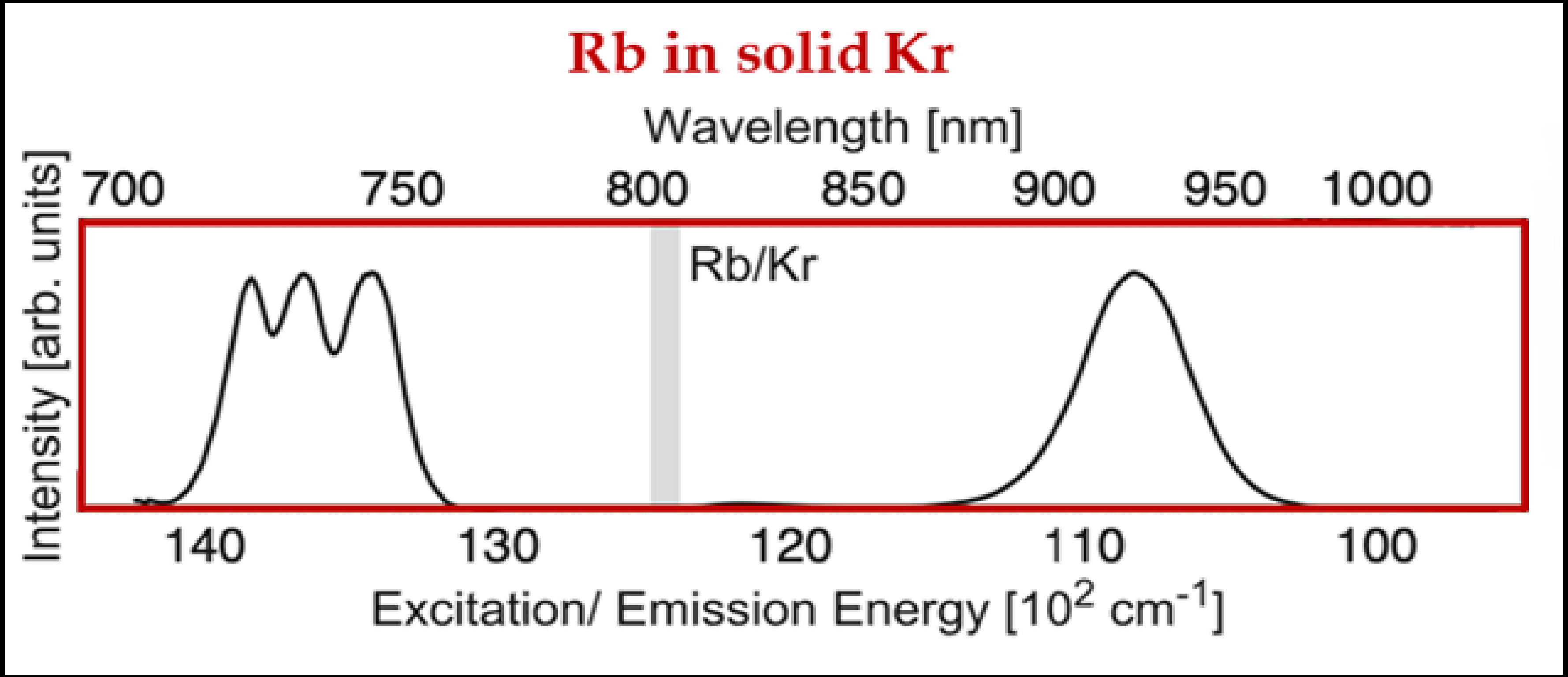
Limits & Requirements

- Limits:
  - No isotope selectivity—no clean way to determine which isotope we have w/o recoil separator
  - Need laser-friendly atoms—quick, efficient excitation-emission cycle
  - Stable or longish (τ > 1 day) lifetime
  - Product species should be uncommon and different from the beam

Limits & Requirements

- Requirements:
  - Efficient—capture all products
  - Selective—distinguish between products and unreacted beam
  - Sensitive—count individual atoms



J. Chem. Phys. 137, 014507 (2012)

Limits & Requirements

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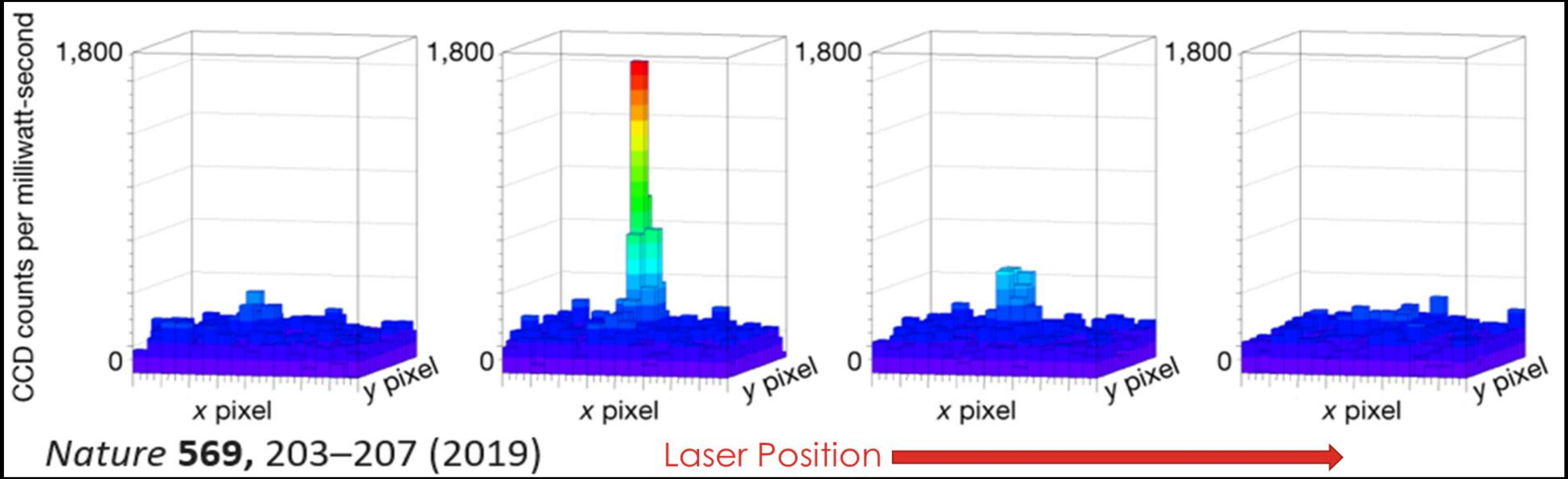
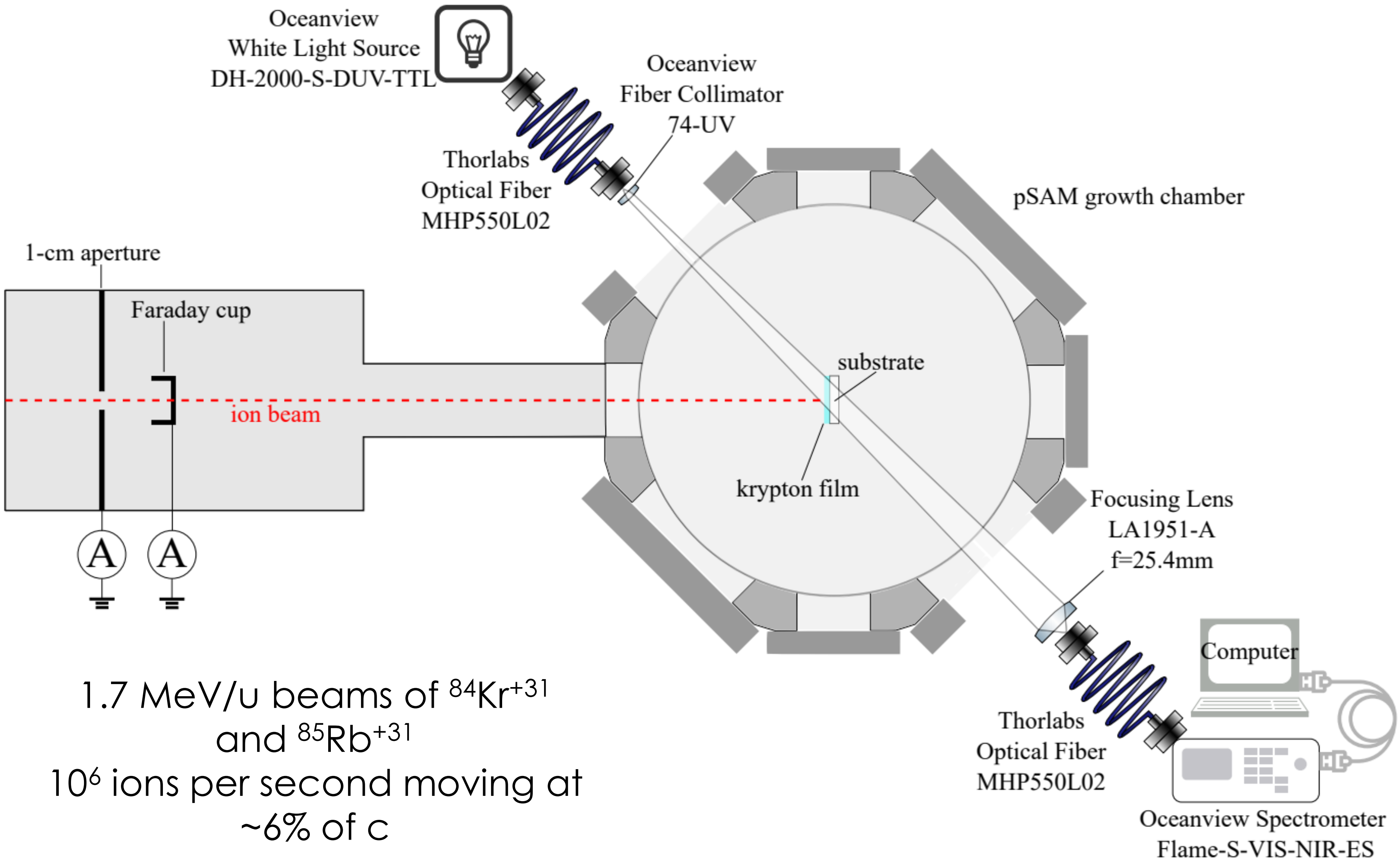


E19501 COMMISSIONING OF SAM

- Goals:
  1. Determine if charged particle beam affects clarity
  2. Determine if implanted ions neutralize in film

B. Loseth PhD Thesis 2019



1.7 MeV/u beams of $^{84}Kr^{+31}$ and $^{85}Rb^{+31}$
10^6 ions per second moving at ~6% of c

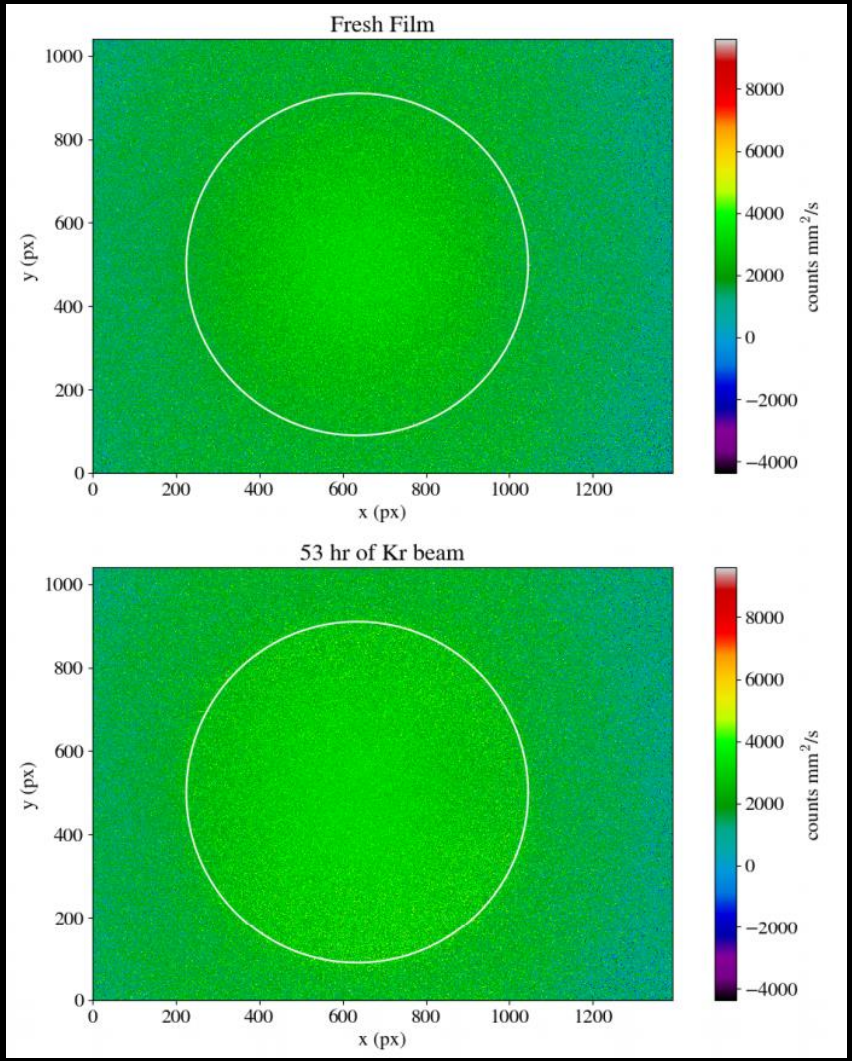
Laser Induced Fluorescence Images of Films

White circle indicates area of the substrate and film.

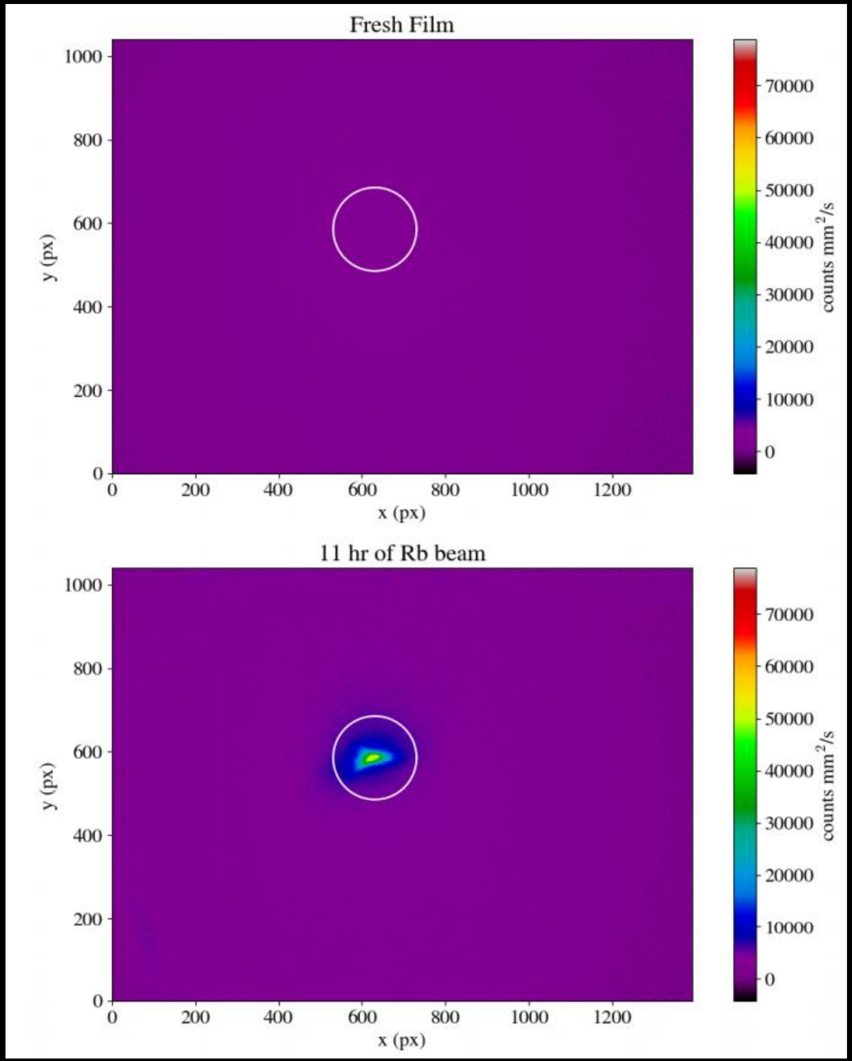
Fresh Film

After Beam

Kr^{+31} Beam on Kr Film



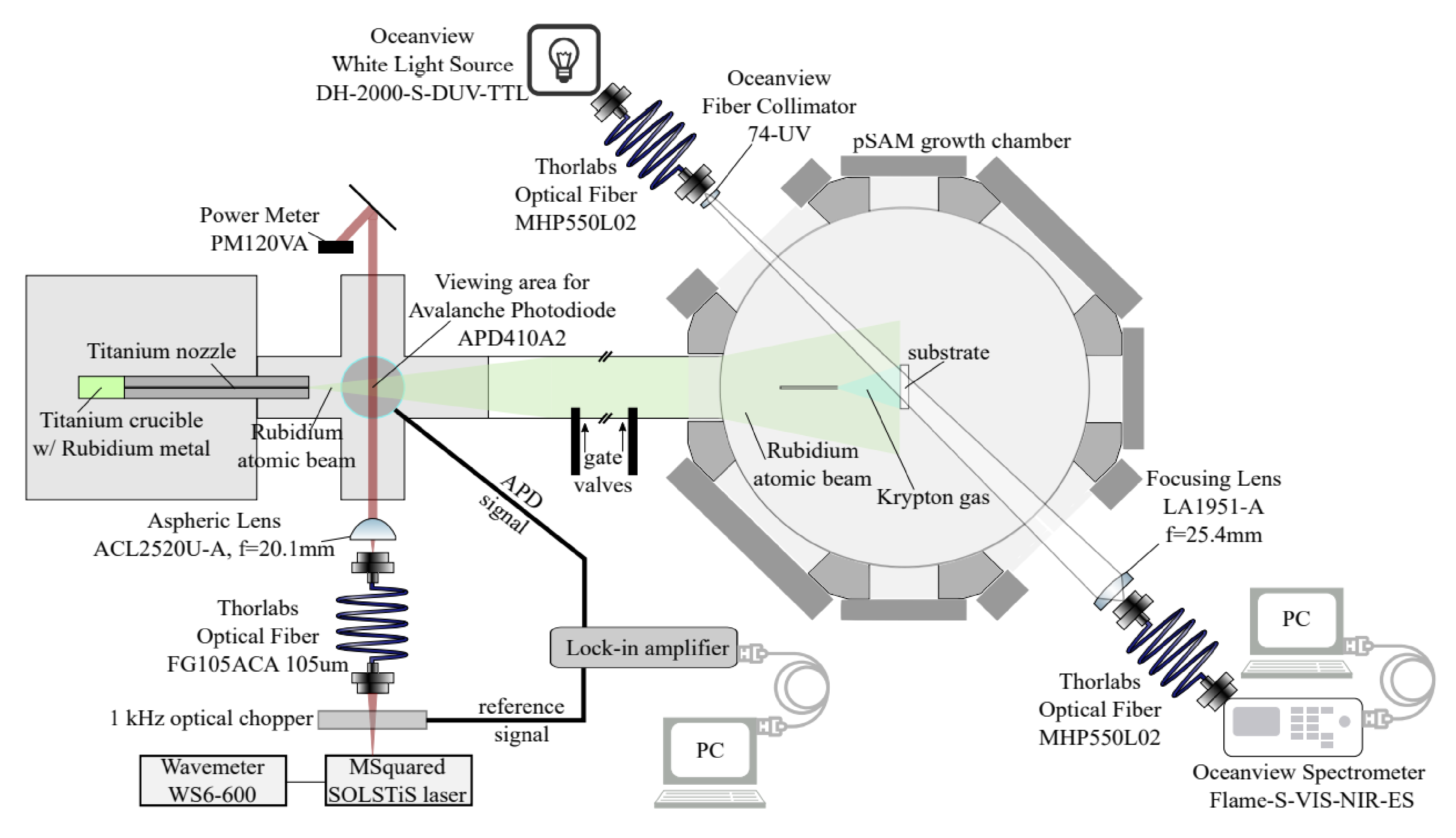
Rb^{+31} Beam on Kr Film



White circle indicates area of interest that shows fluorescence from neutralized Rubidium.

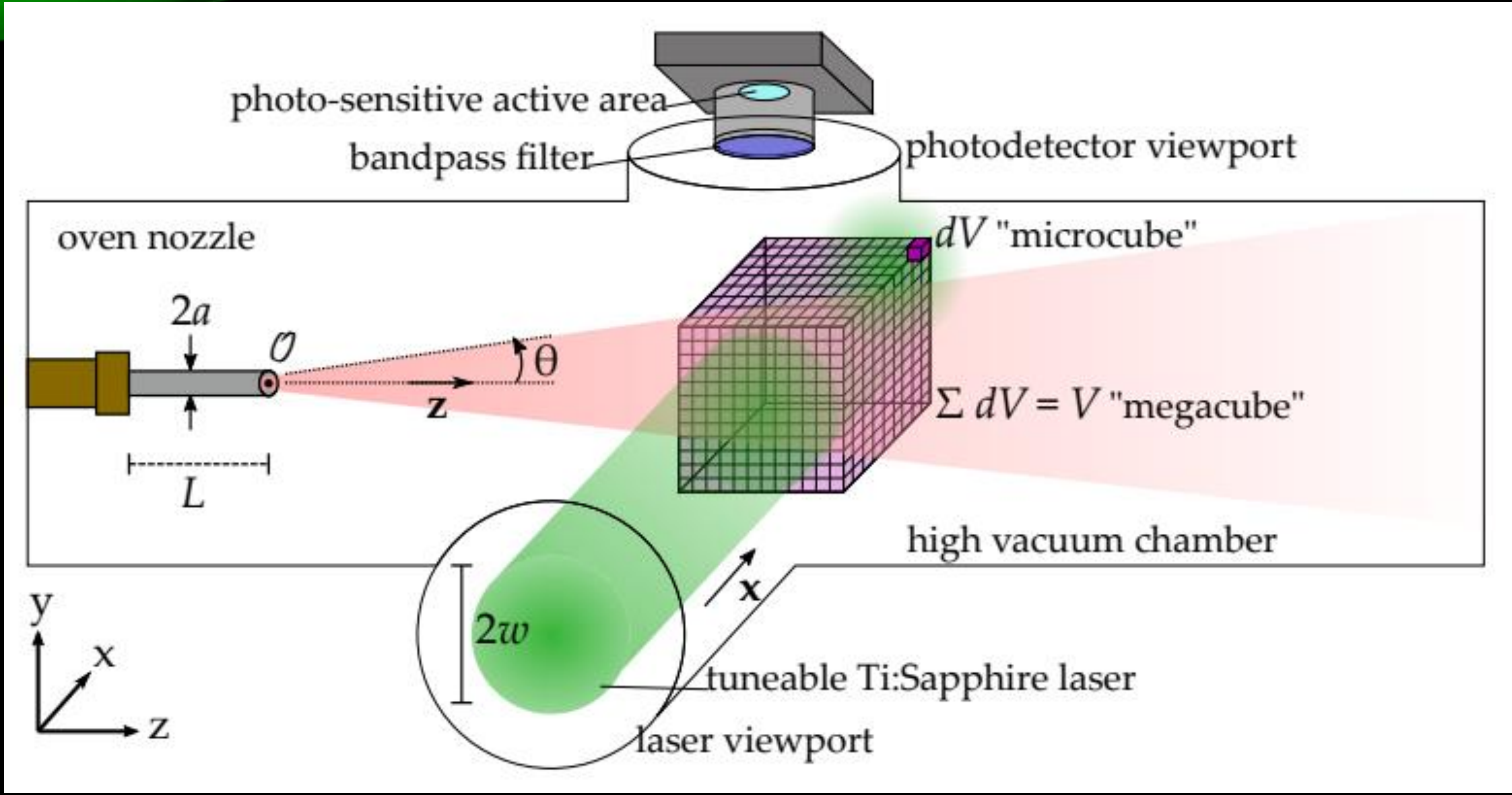
BTL PhD Thesis 2019

Calibrating Brightness of Rubidium in Krypton



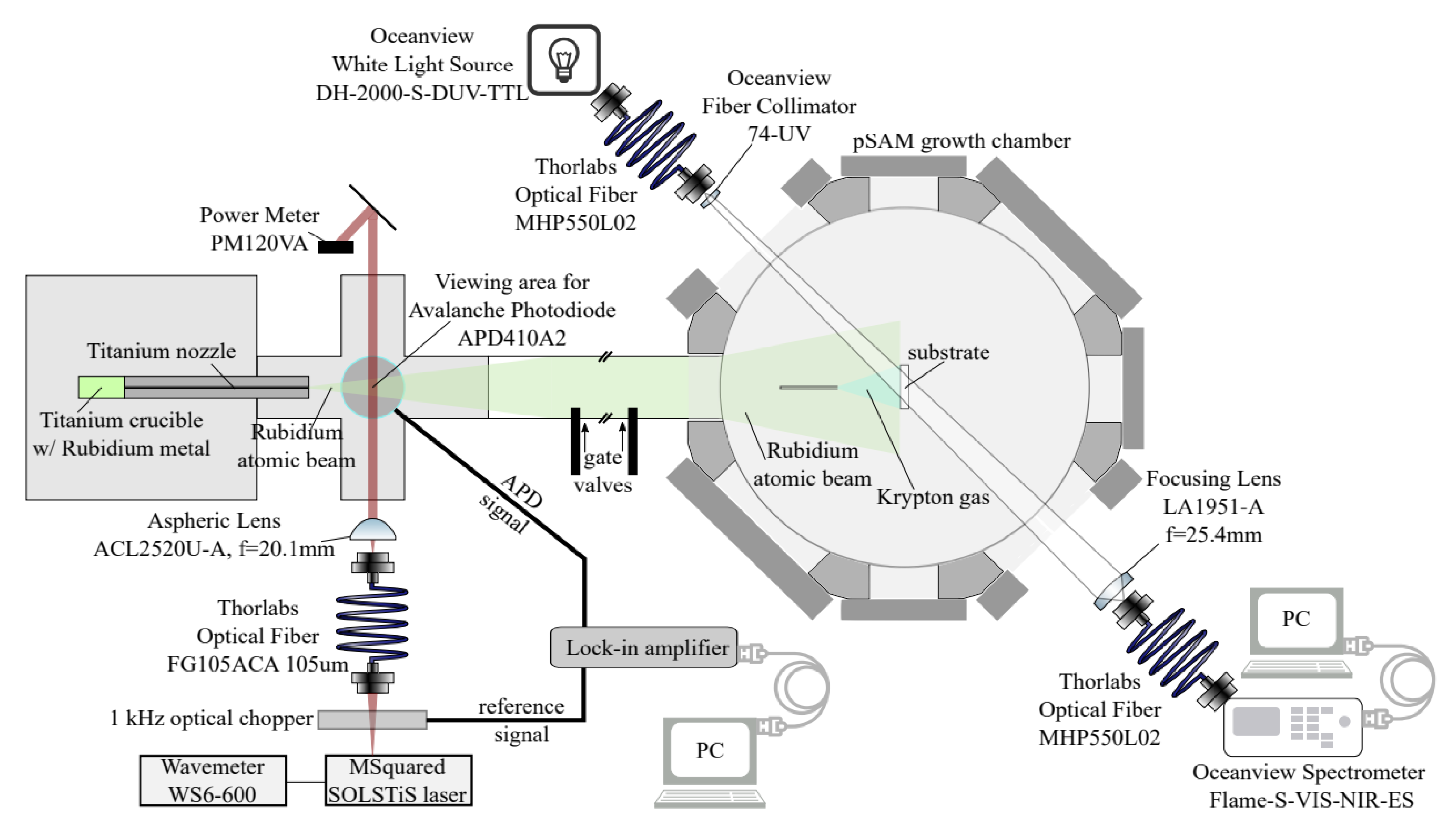
B. Loseth (MSU 2019)

Simulating the Brightness of Rubidium in Krypton



R. Ready, MSU 2021 PhD

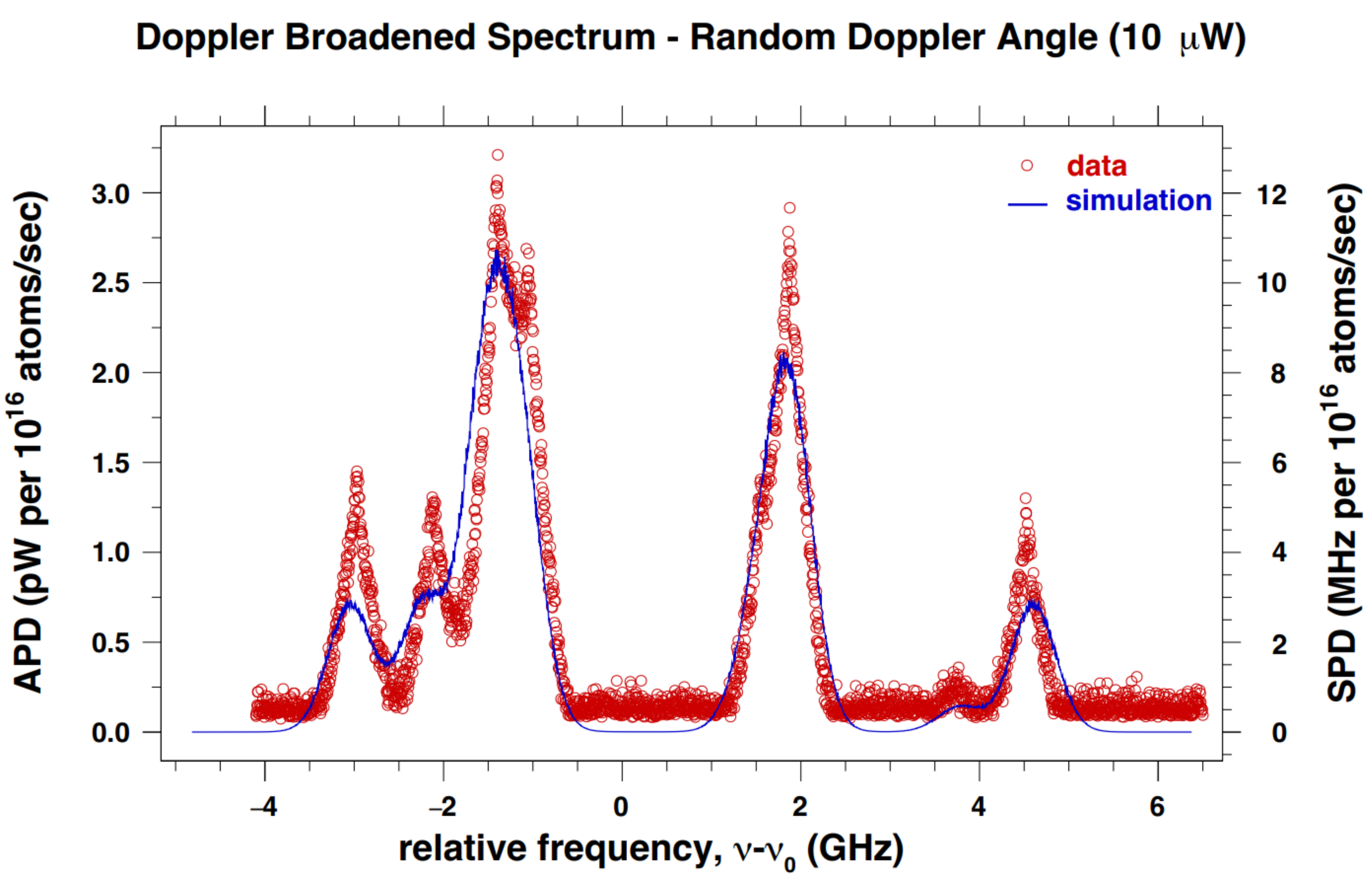
Calibrating Brightness of Rubidium in Krypton



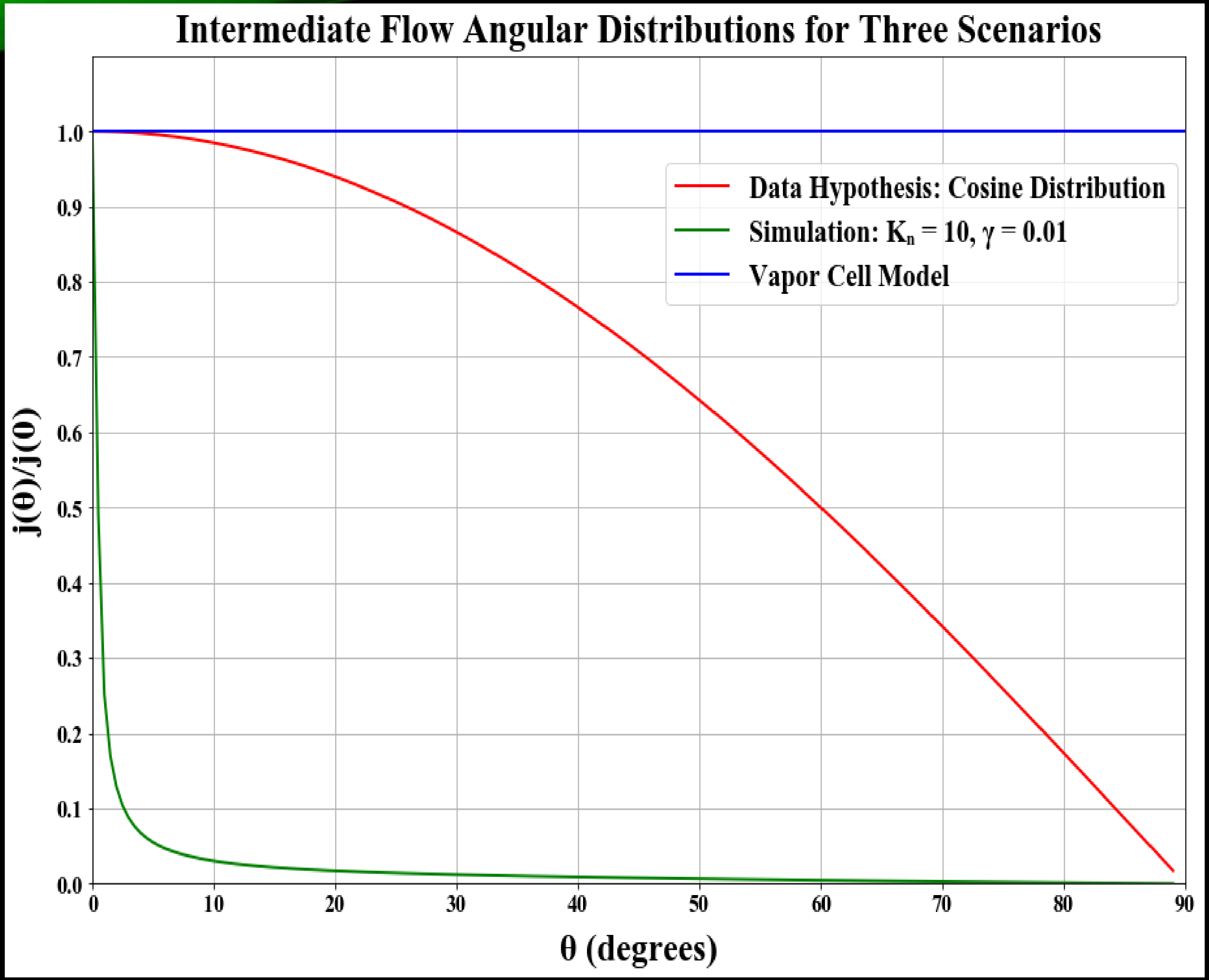
B. Loseth (MSU 2019)

Status of ABF Measurement

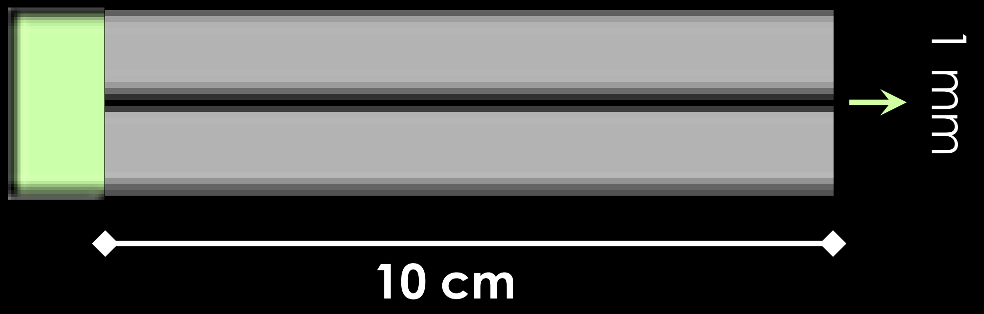
- Iterative process of improving experimental set-up and simulation
- Accounting for atom-nozzle collisions
- Doppler Broadening related to angular distribution



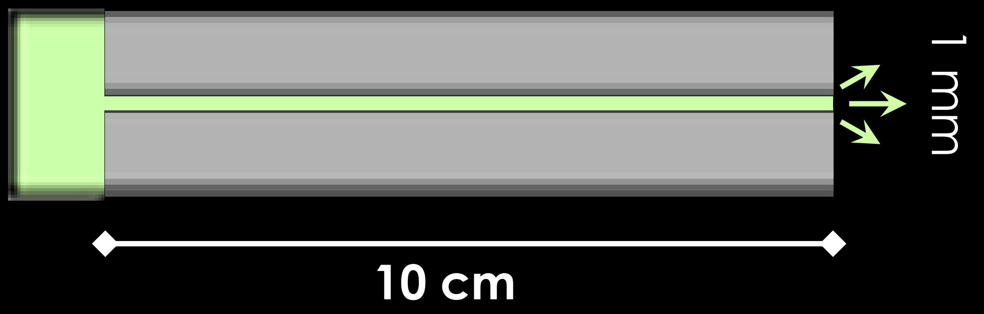
Status of Simulating the Atomic Beam



Simulated, Rb flows as vapor down nozzle out in one direction:



Working Hypothesis: during measurement Rb leaked and liquid filled up nozzle, vapor emitted in various directions:



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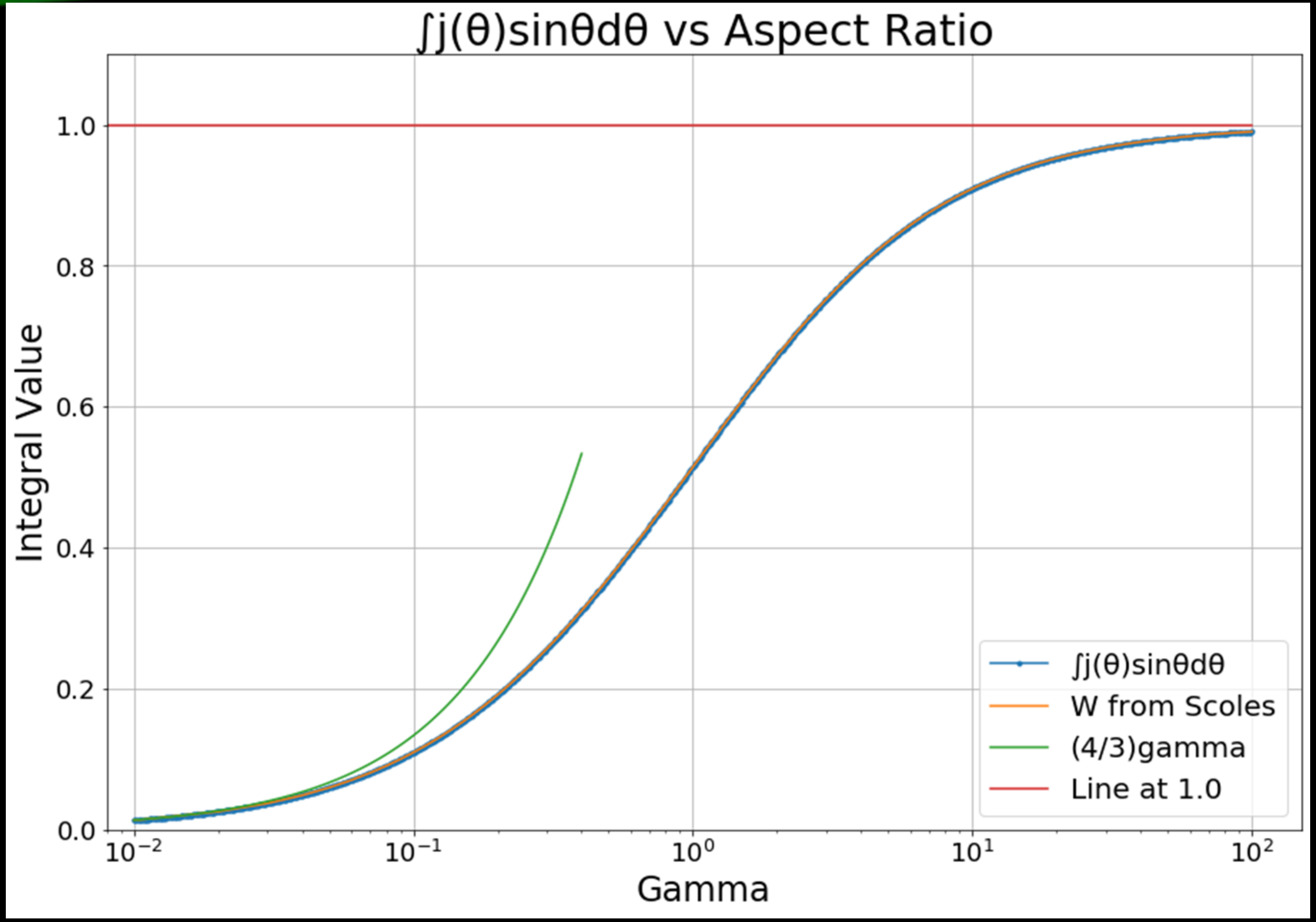

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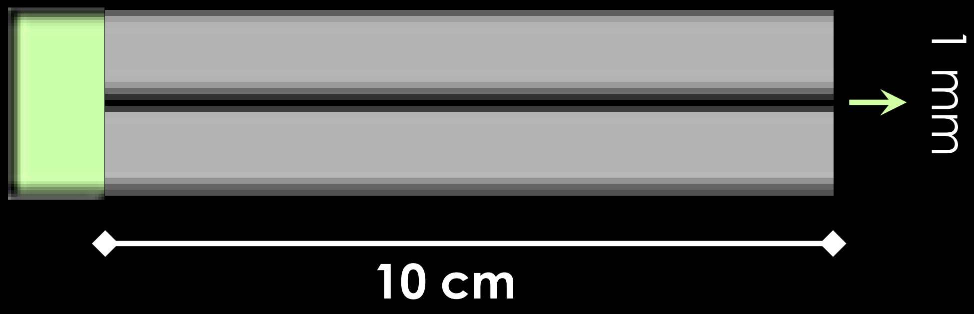

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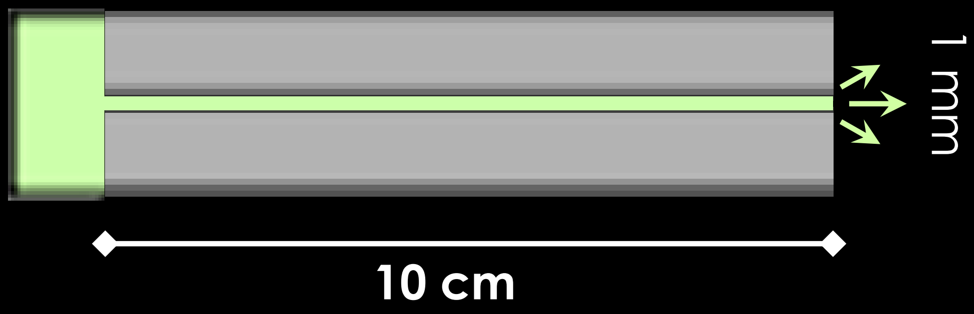
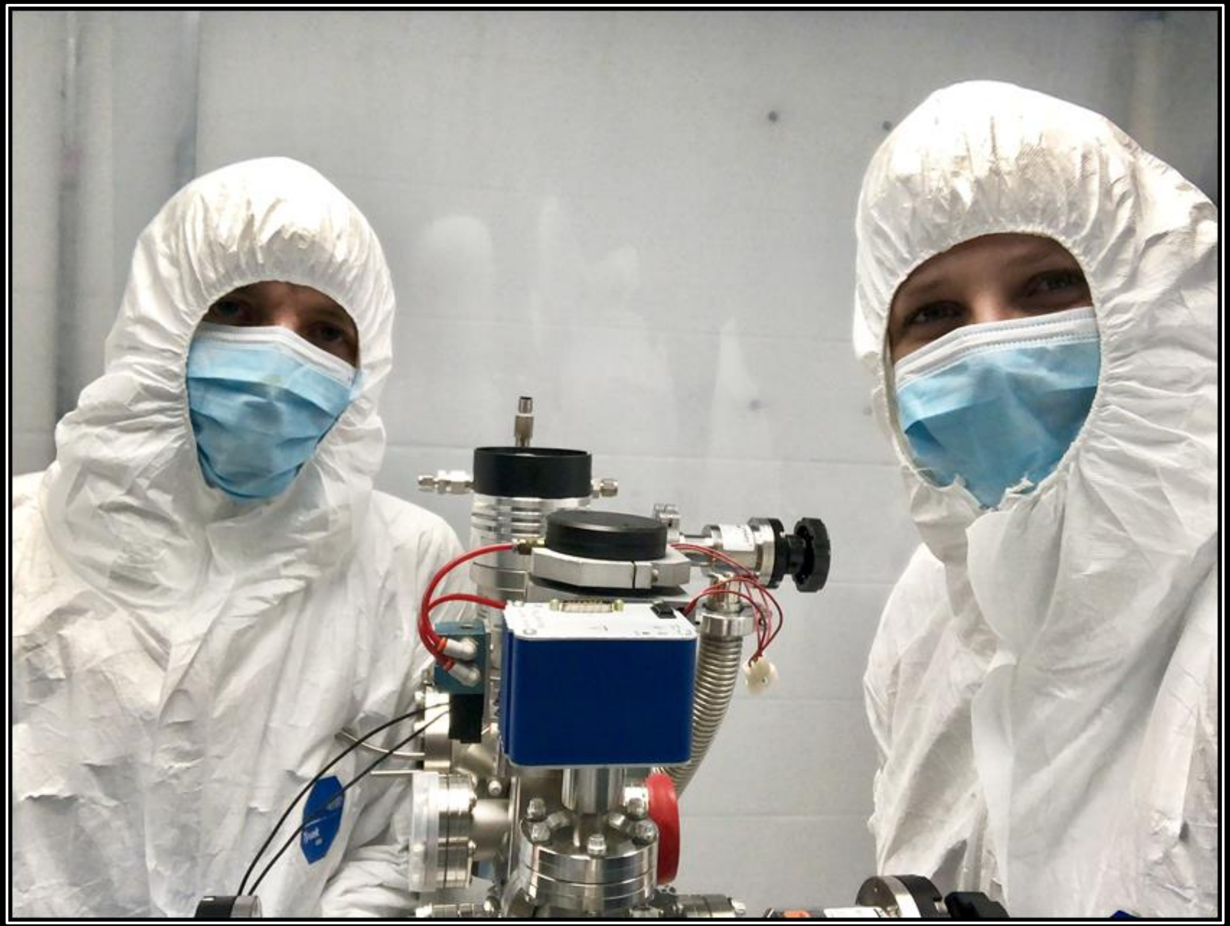


Conclusion & Outlook

- Accomplishments:
  - Assembled and Tested pSAM
    - Manuscript in preparation for RSI
  - Observed Rb ion neutralization
    - Manuscript in preparation for NIMB
- Short Term:
  - Calibration of Implanted Atom Number
  - Demonstrate Single Atom Sensitivity
- Mid-Term:
  - Proof of principle ^{84}Kr(p, γ)^{85}Rb measurement
- Ultimate Goal:
  - ^{22}Ne(α, n)^{25}Mg measurement



Thank you for your time!

Spinlab Team

- Jaideep Singh
- Ben Loseth
- Fry Fang
- Joseph Noonan
- Roy Ready
- Payton Walton
- Gordon Arrowsmith-Kron
- Eric Delgado
- Abby Baratta
- Thu Gibson
- Keara Hayes
- Julia Egbert
- Ben Mellon
- Nick Koester

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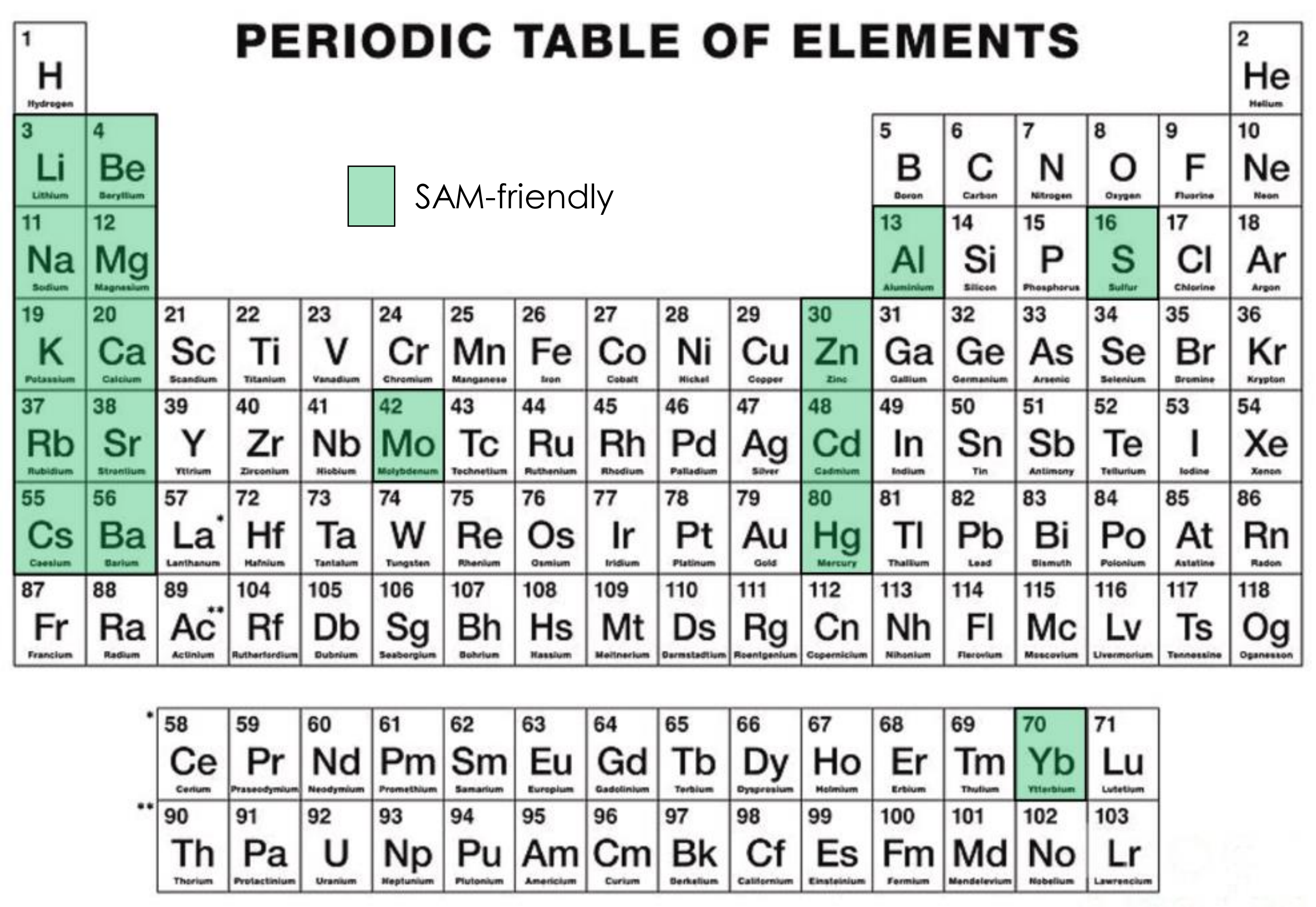
  - Additionally, my work is supported as a 2020 NSF GRFP recipient via grant DGE-1848739.
- Joint-Institute for Nuclear Astrophysics (JINA-CEE)

SCAN ME

QR Code to the SAM Project page on Spinlab's website



Original periodic table image by Peter Hermes Furian, modified by E. White