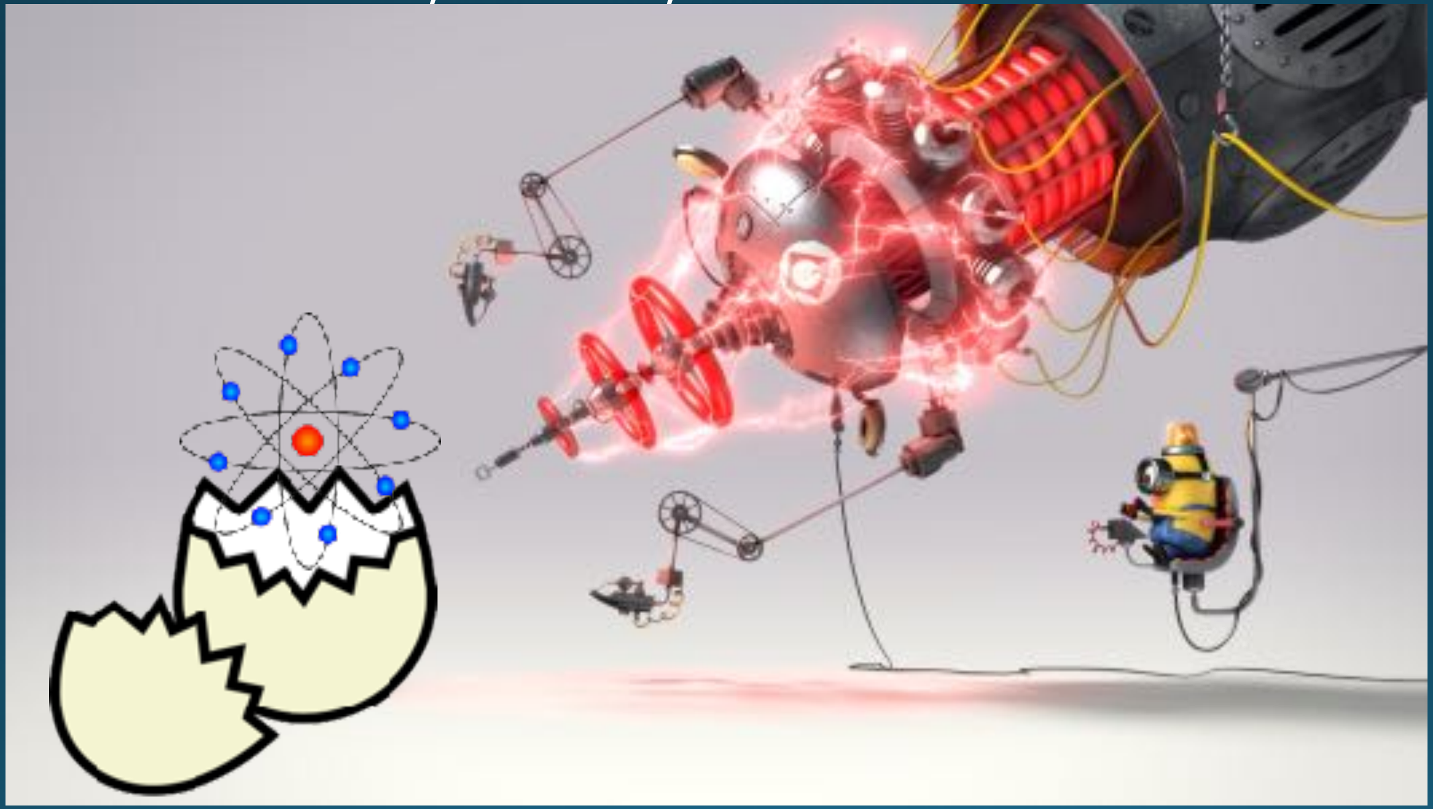
Using Light Hammers to Crack the Nano-Quantum Eggshell:

How Ultra-Intense and X-ray Lasers are Changing the Way We Observe Nature's Smallest, Fastest, and Most Exotic Phenomena



Kevin M. Dorney

Kapteyn-Murnane Group, JILA and University of Colorado Boulder

Allow myself to introduce… Myself

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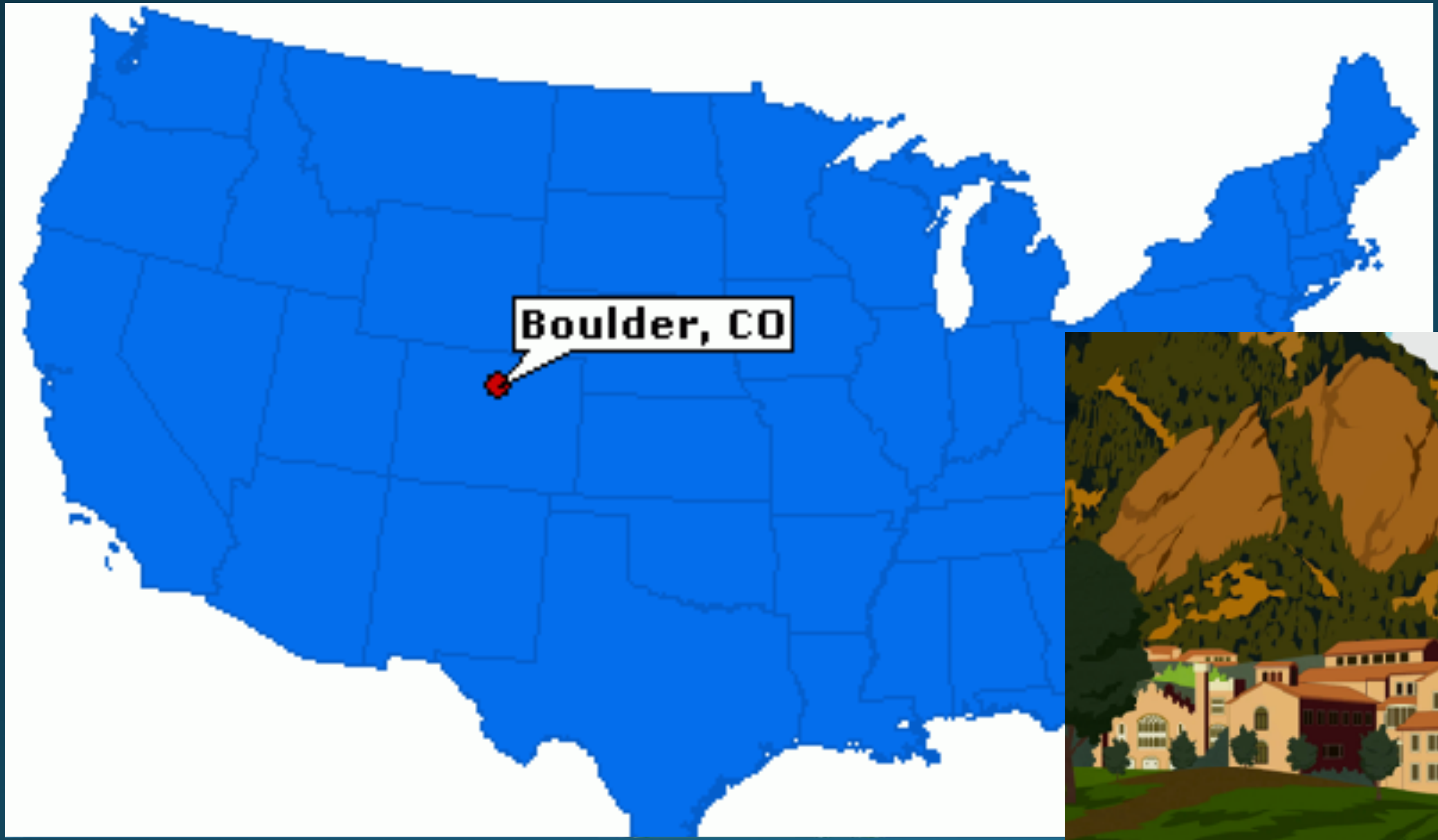

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- The journey to being a college student in your late 20s does not get procrastinated over night…

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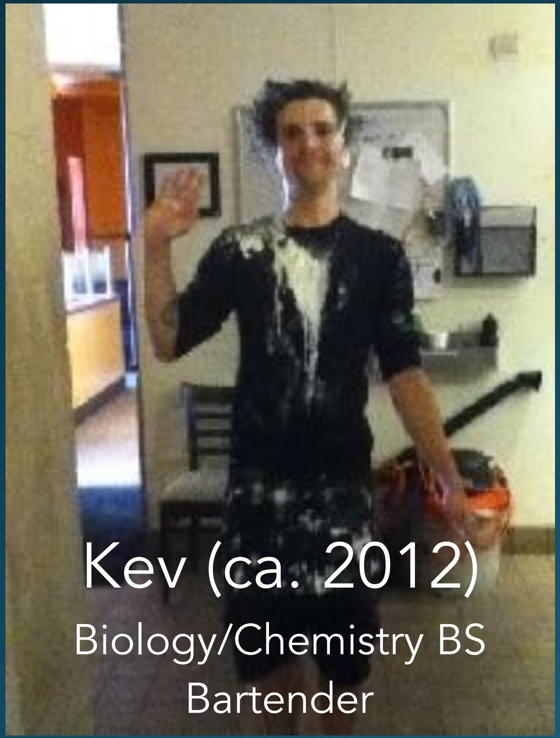

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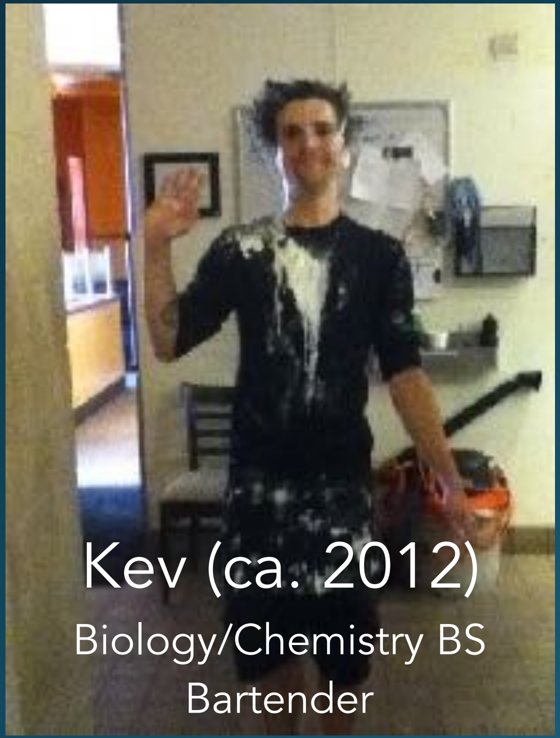

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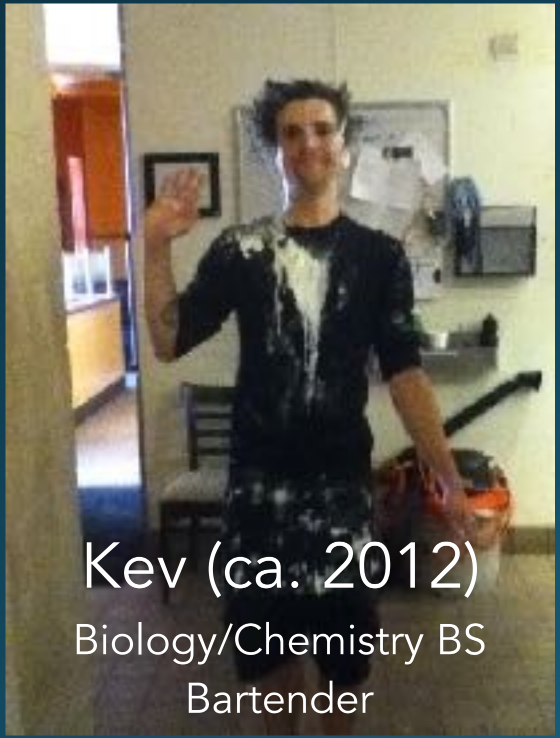

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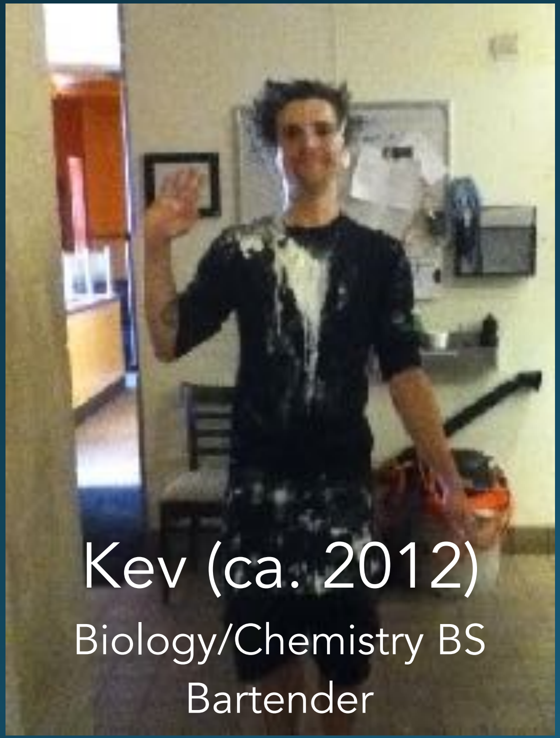

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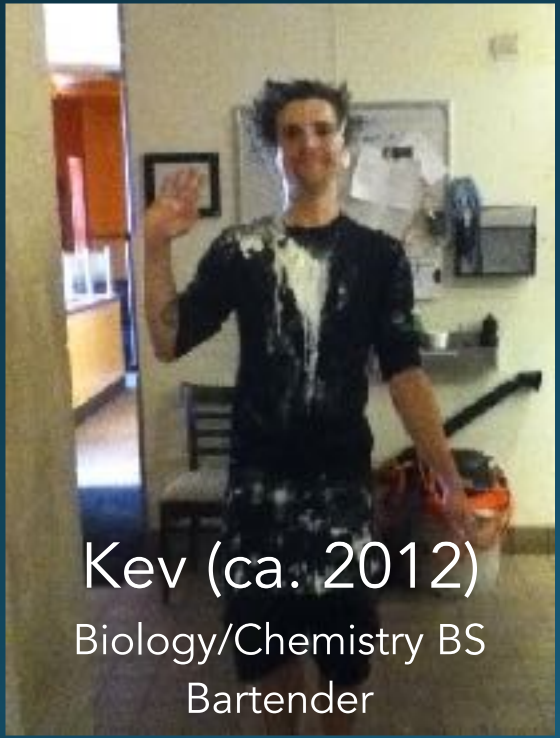

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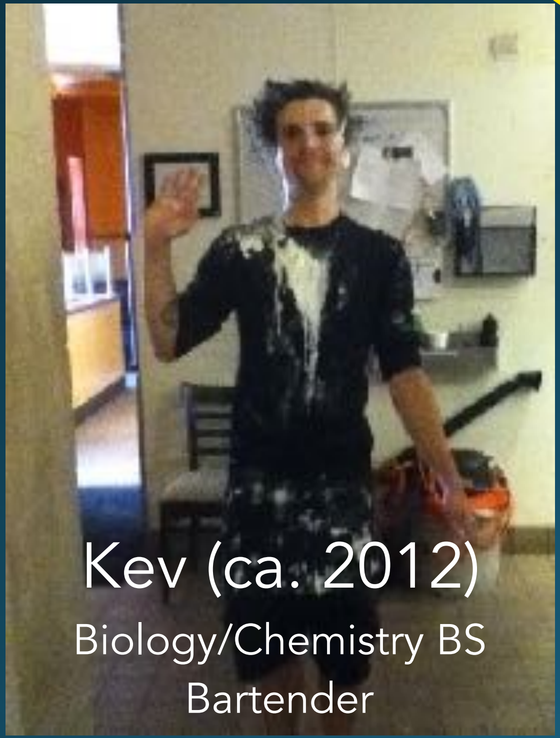

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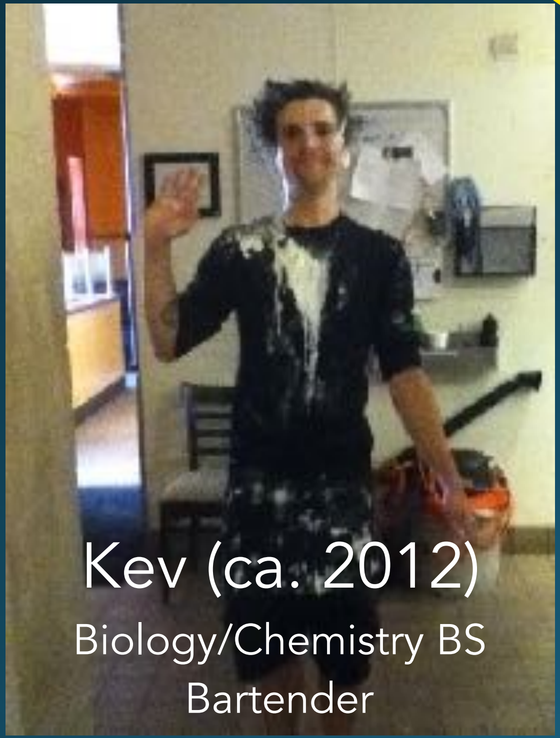

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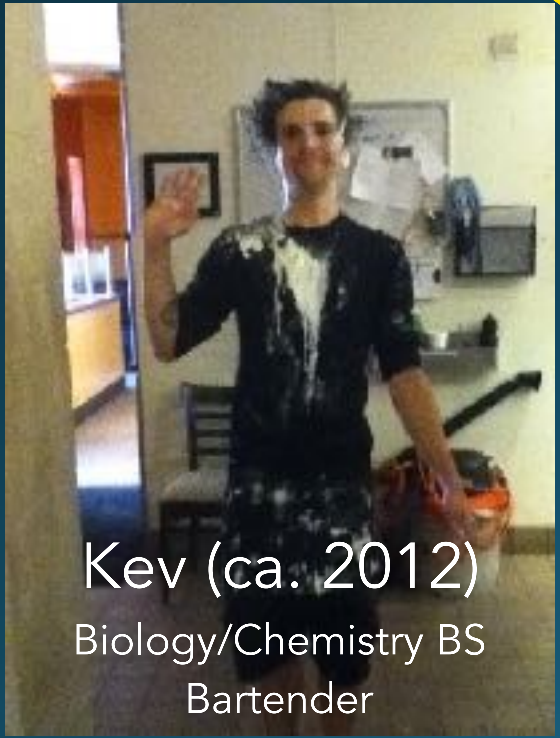

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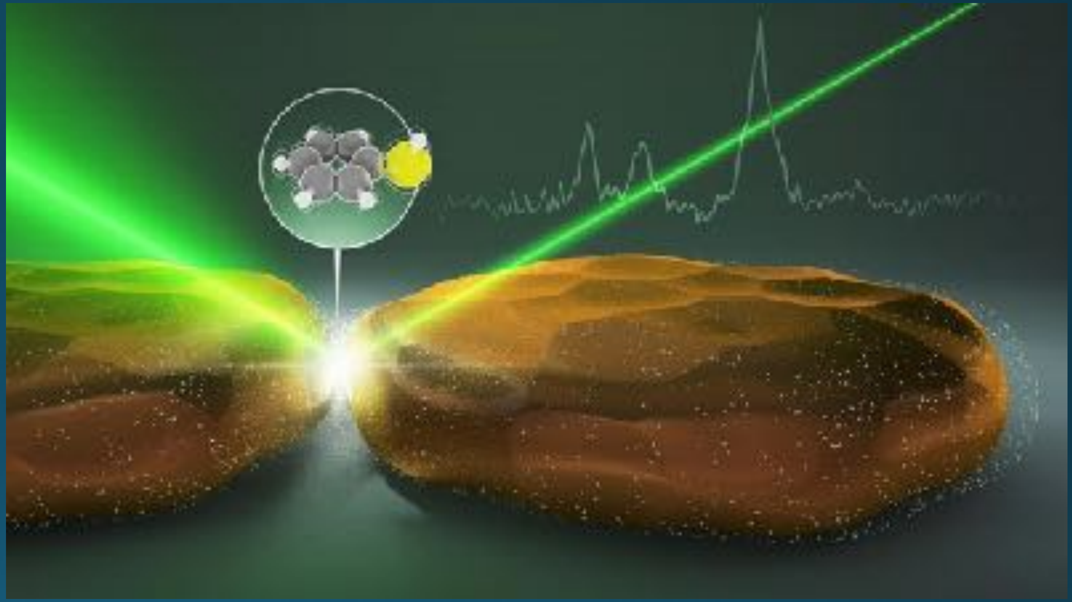

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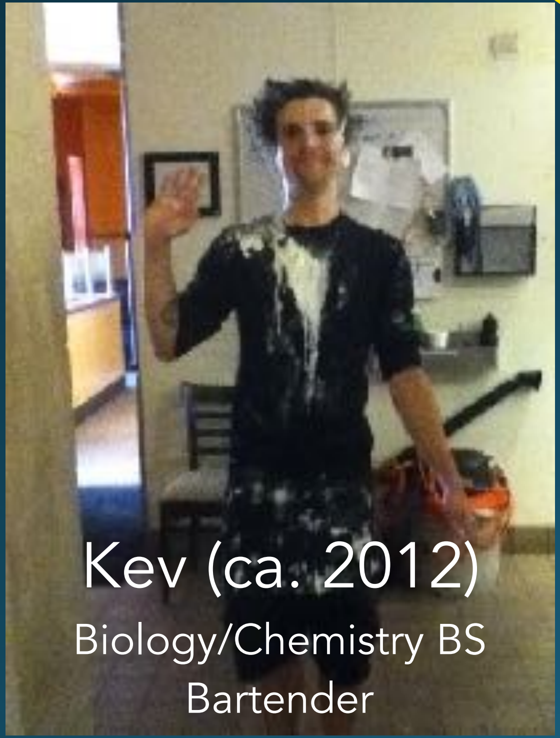

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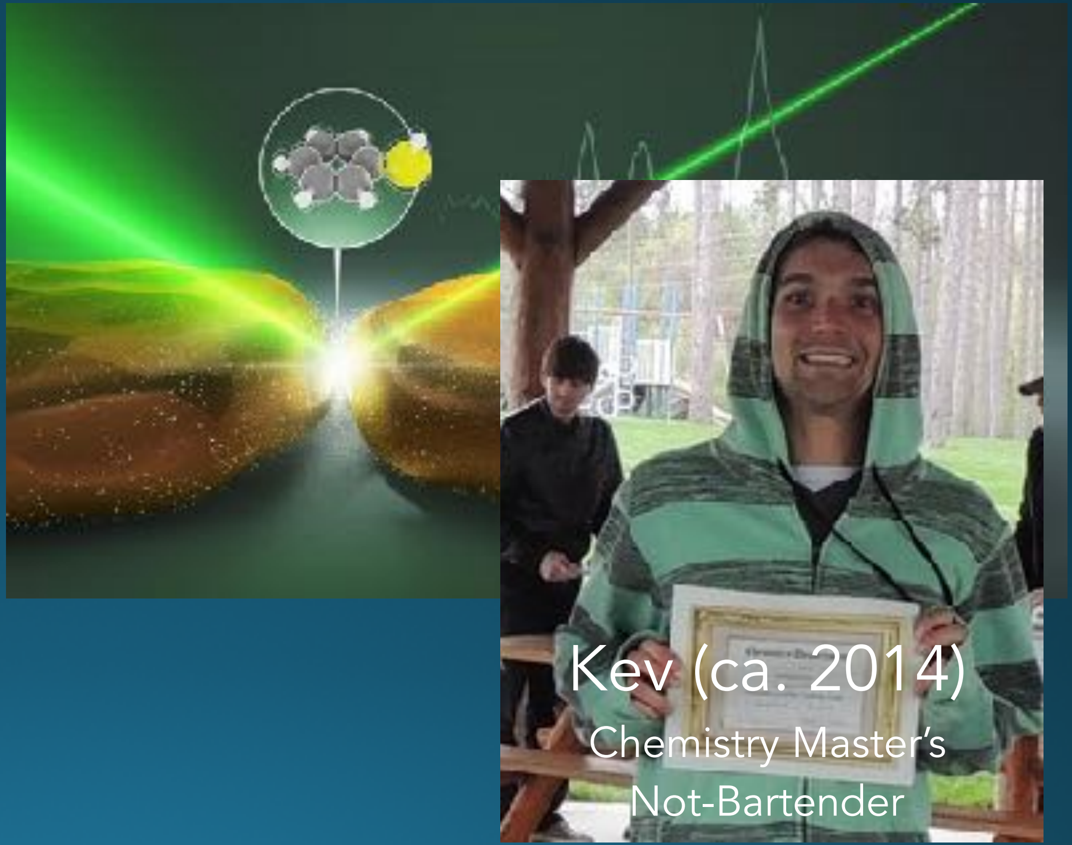

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Not-Bartender

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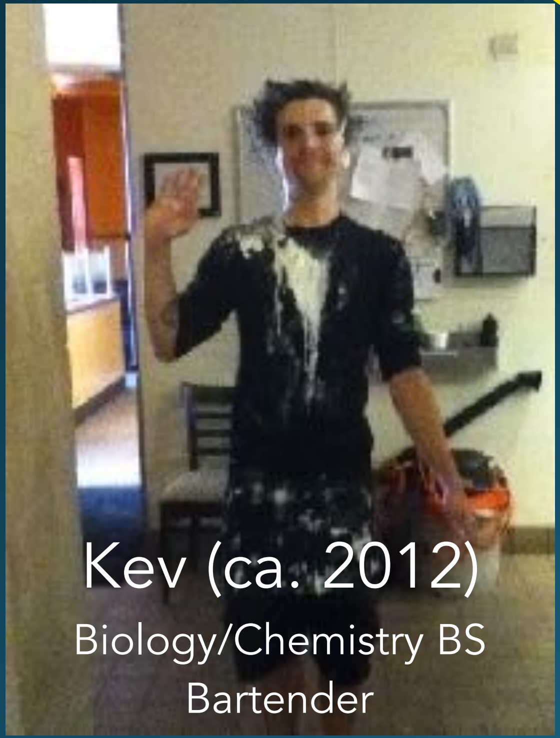

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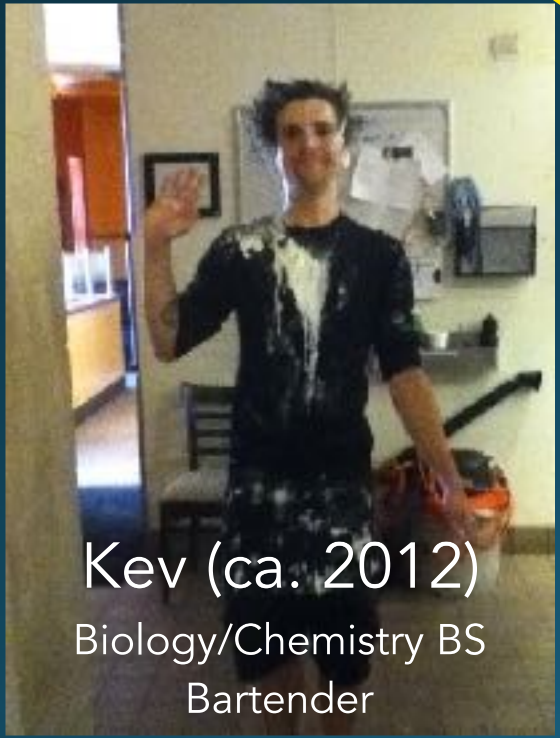

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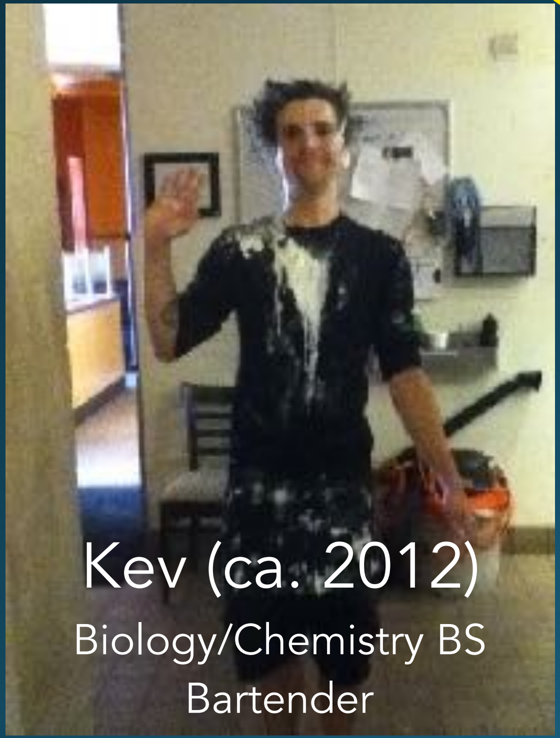

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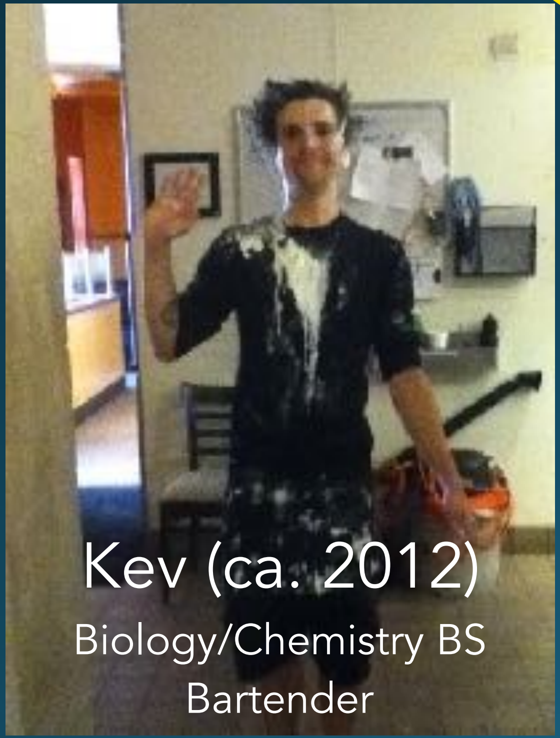

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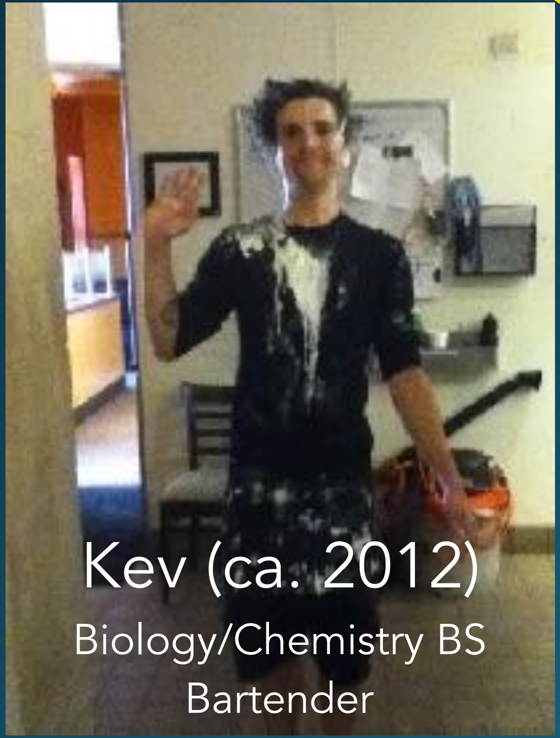

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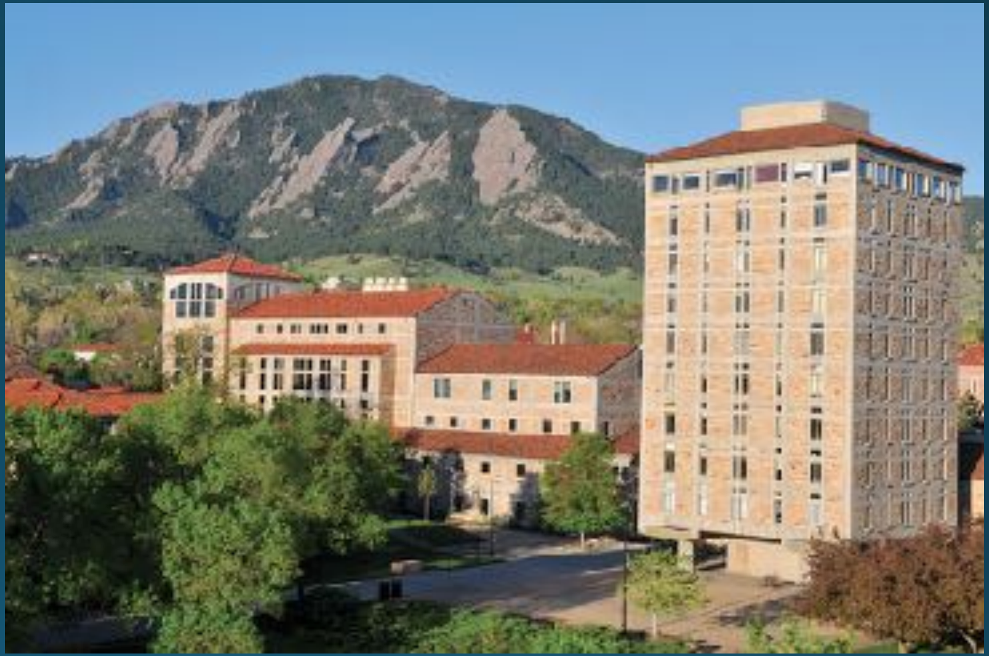

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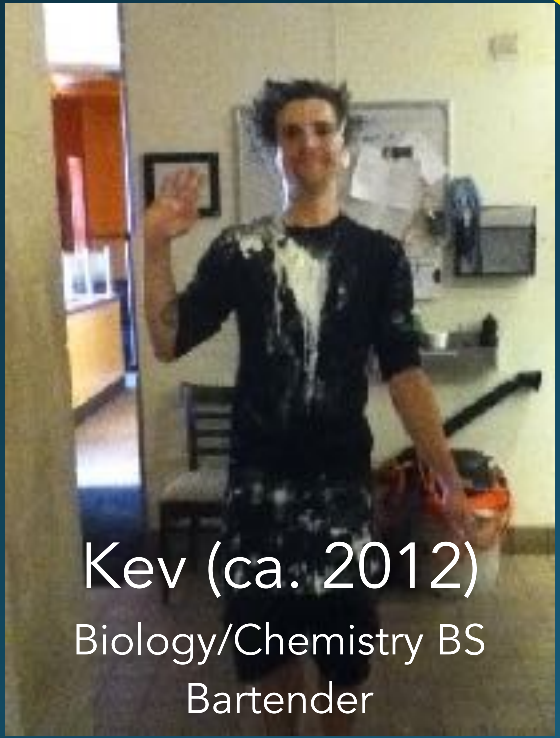

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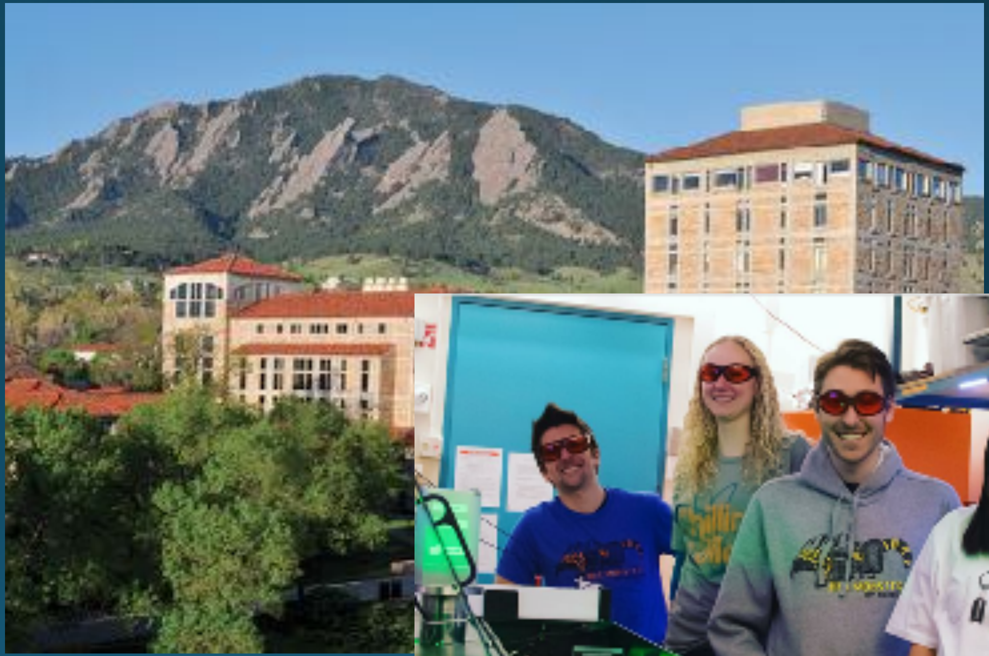

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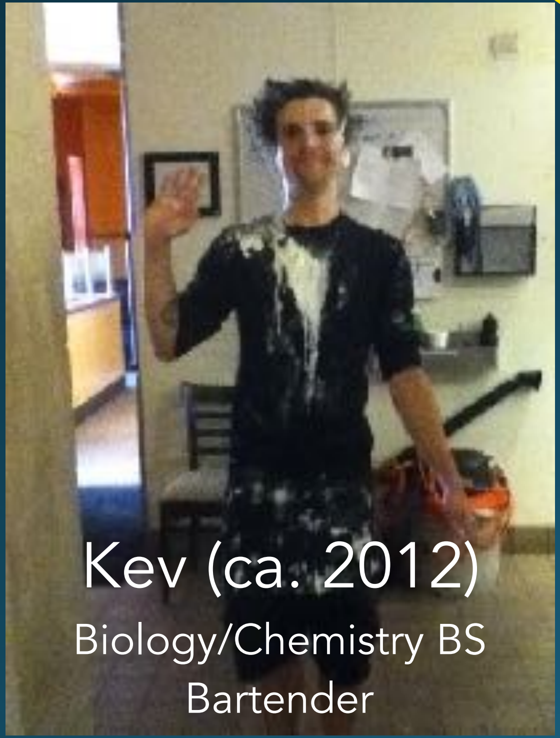

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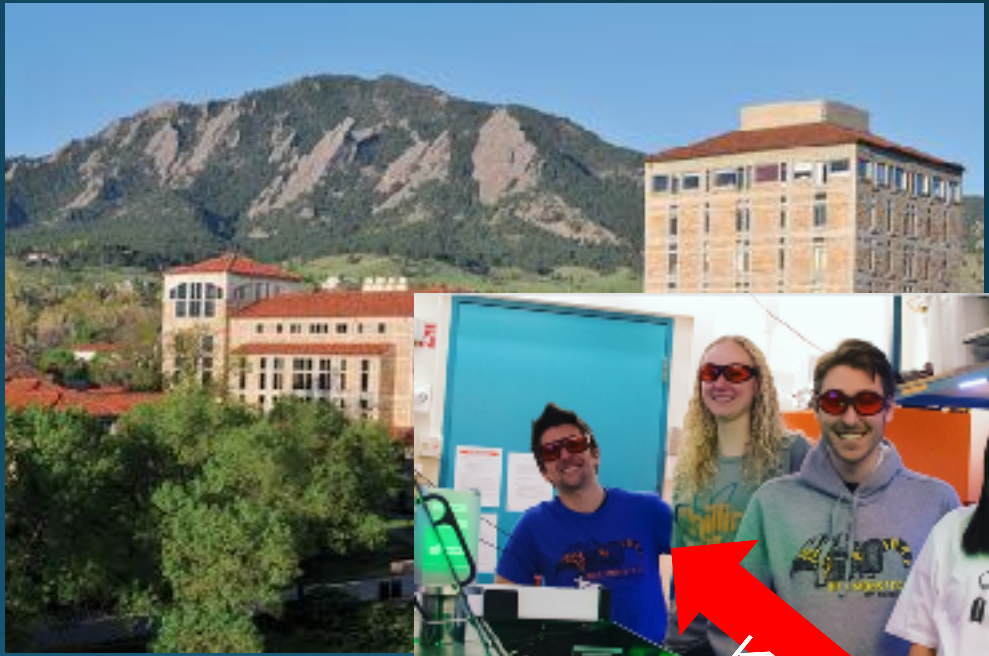

Delayed Adulthood…Dungeons… Lasers… Worth it?

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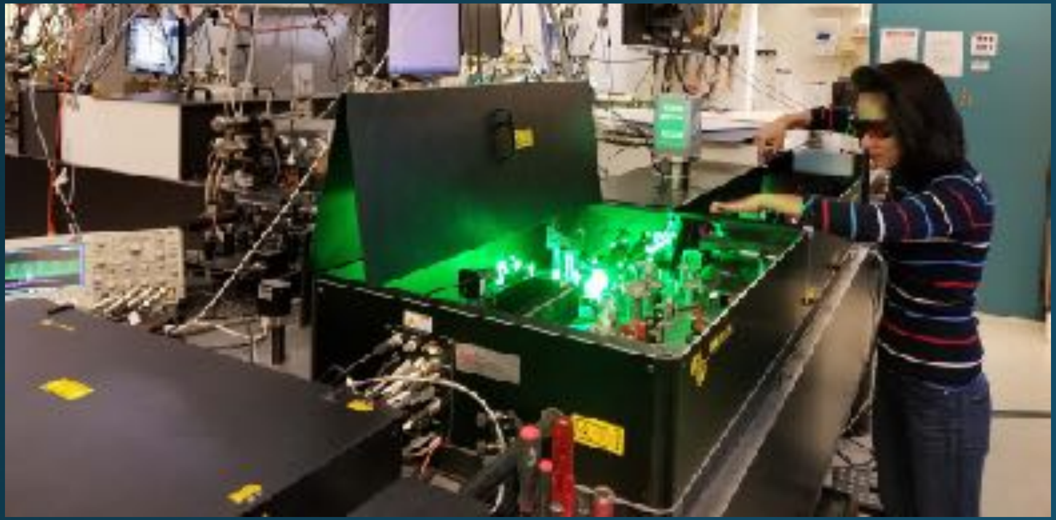

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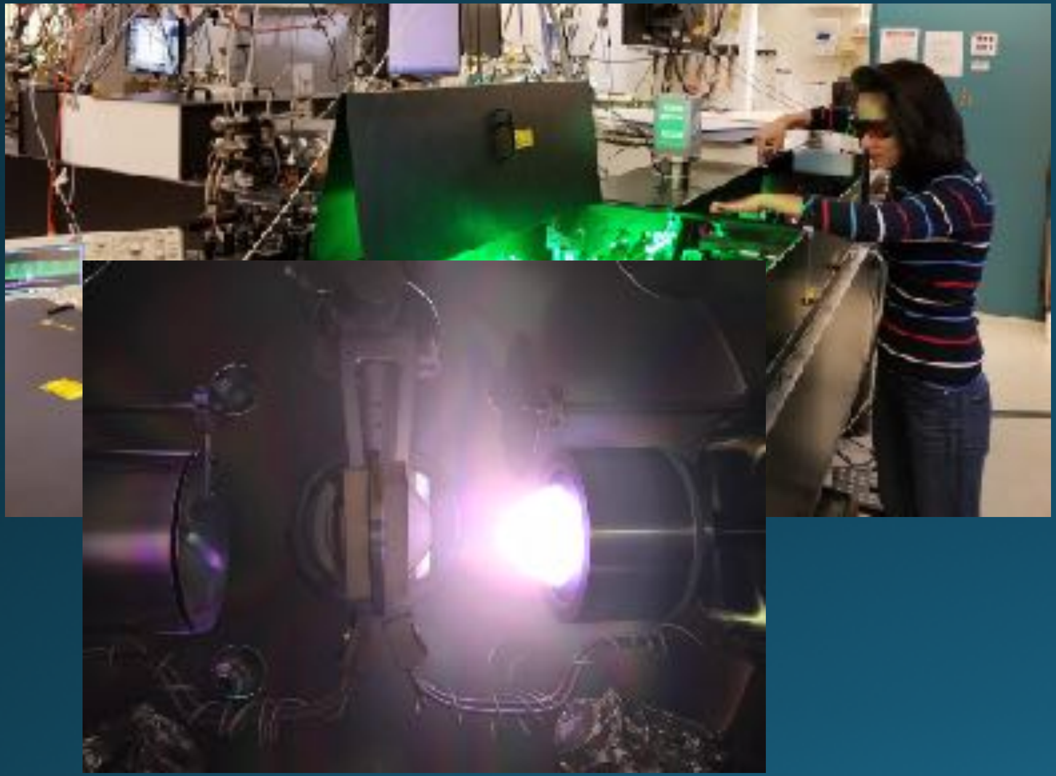

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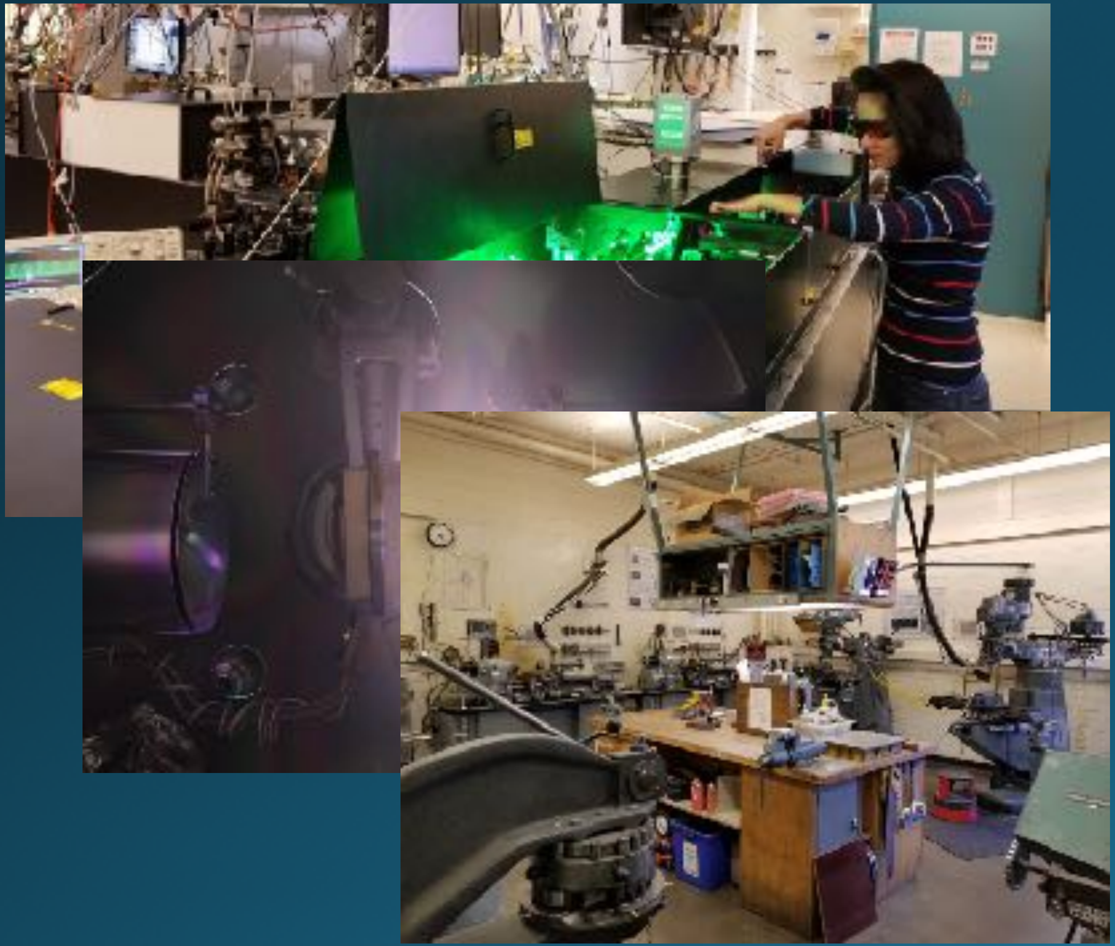

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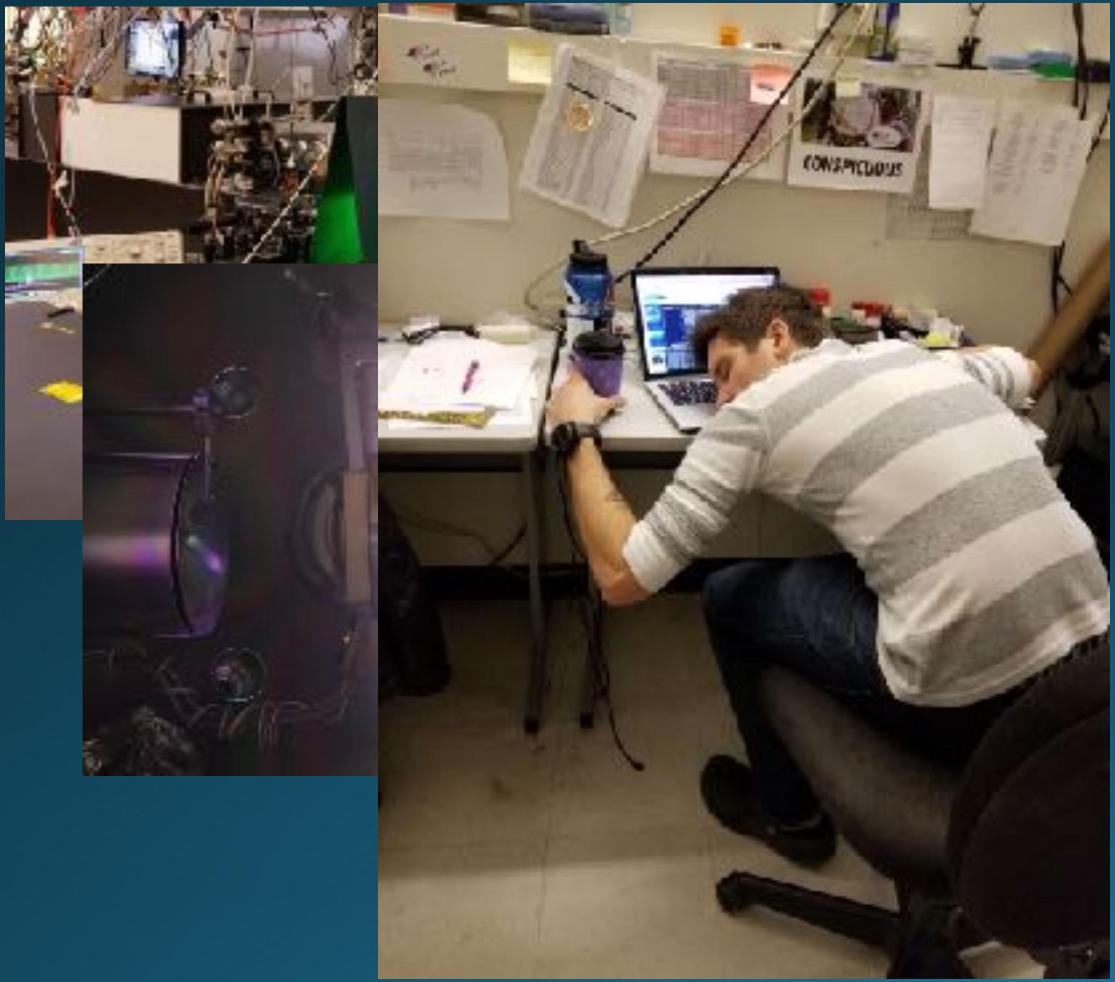

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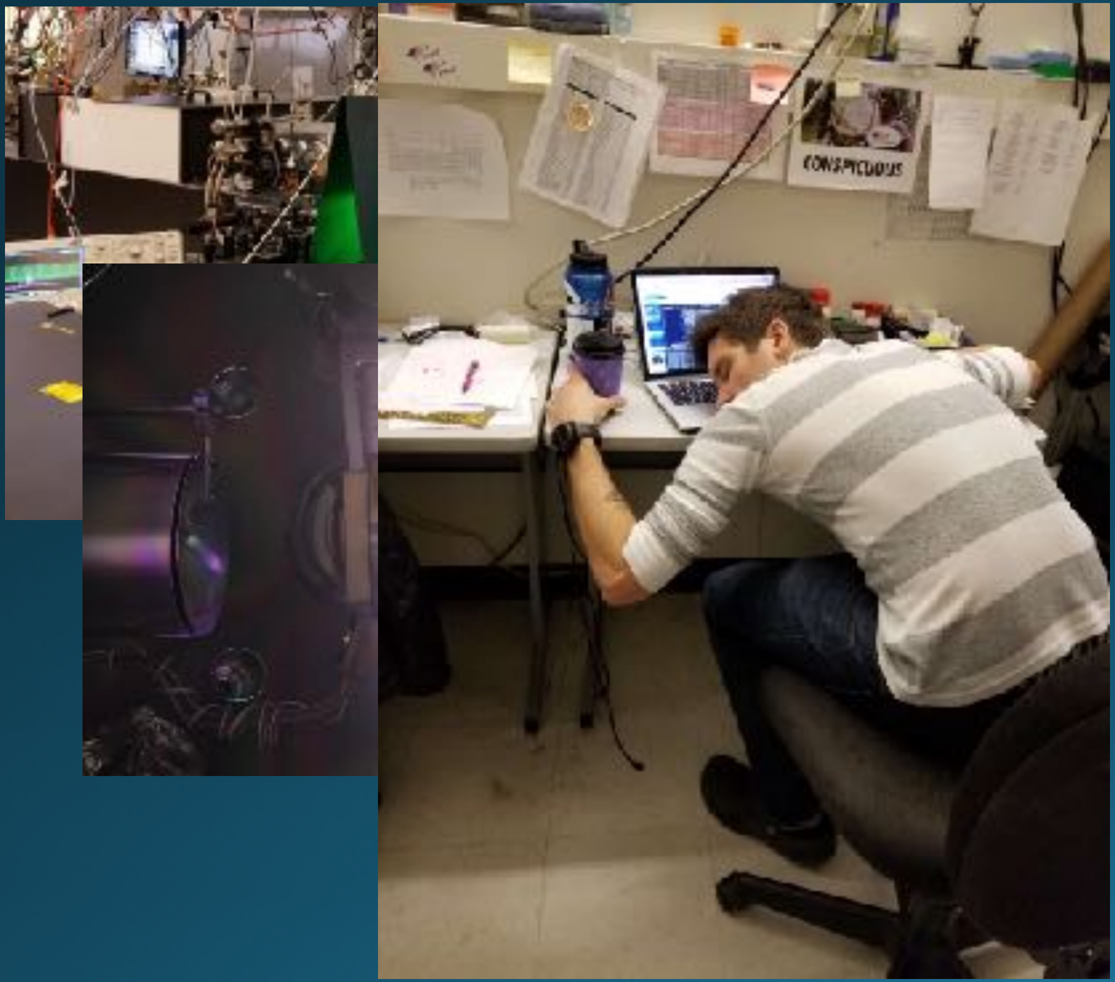

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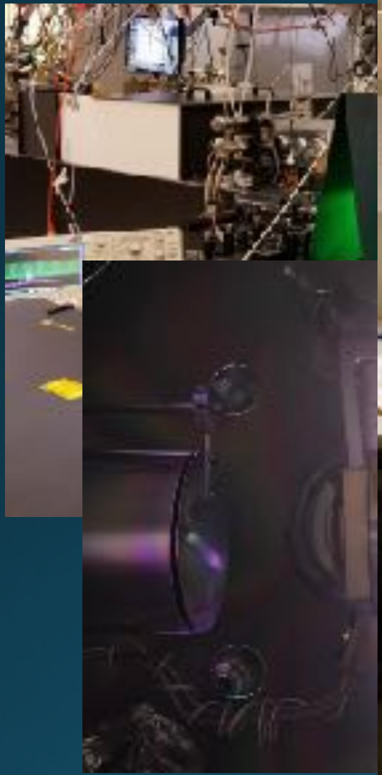

Just a regular ol' day in the KM Group…
Blowing up air and making little Suns

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KM Group and JILA:
Excellent students, collaborators, and **advisors**

KM Group Spring 2017

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Collaborators

VNIVERSiDAD D SALAMANCA

Berkeley
UNIVERSITY OF CALIFORNIA

TU WIEN
TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

COLORADO SCHOOL OF MINES

MAX BORN INSTITUTE

MAX-PLANCK-GESELLSCHAFT

TAIWAN TECH

Colorado State University

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University of Tsukuba

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KMLABS
LEADING IN ULTRAFAST

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KMLABS LEADING IN ULTRAFAST

$$$$

intel

DARPA

NSF

Fundamental Science Research… Who Cares?

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"Oh, you do scientific research? Neat! What exactly are you working on???"

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Mastering Fundamentals

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<u>Mastering Fundamentals</u>

"If ya want to dunk,
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- Basic research
- Small-scale systems
- Idealized environments
- Little (initial) real world impact

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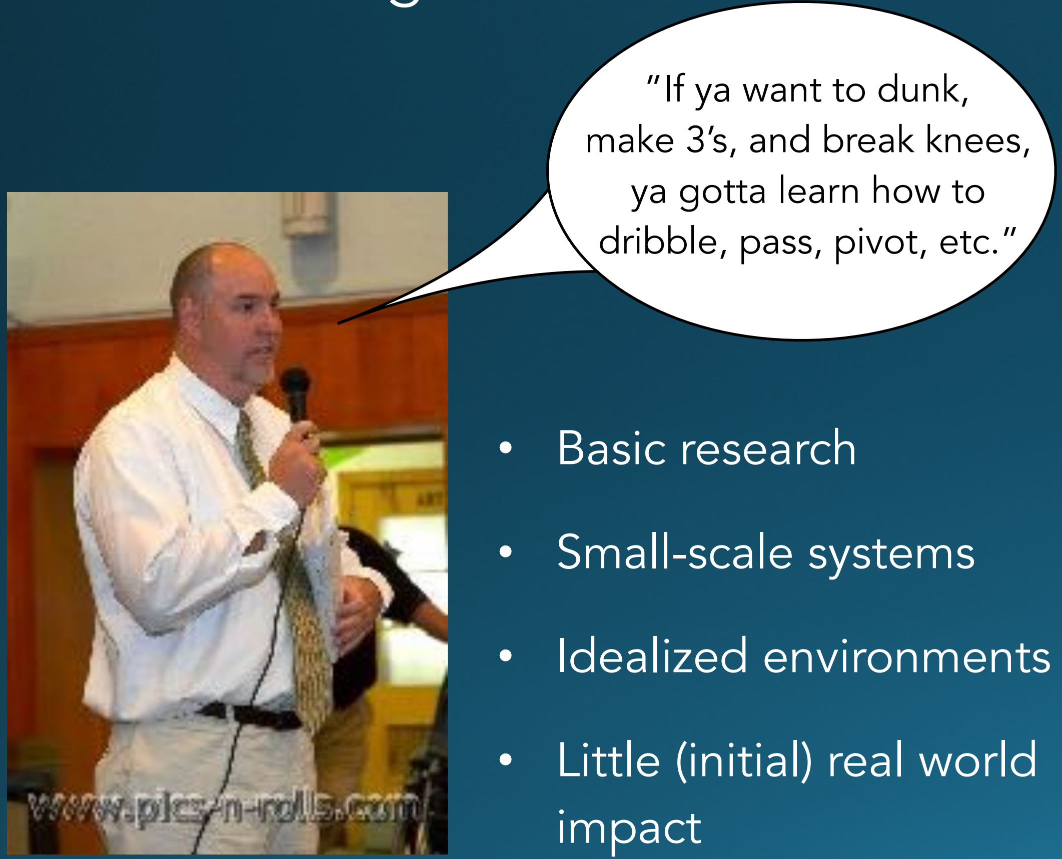

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Mastering Fundamentals → Understanding and Manipulating Nature!

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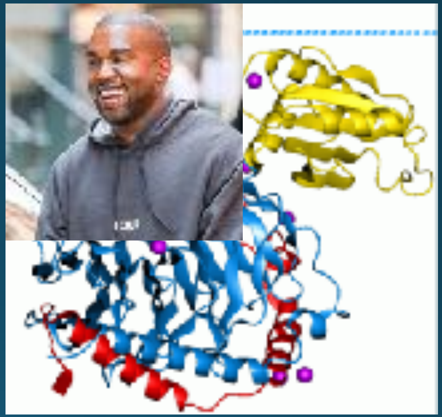
Blue LEDs (2014)

G Proteins (2012)



CCDs Detectors (2009)

Laser (1964)

Green Fluorescent Protein (2008)

Fundamental Light Science in the KM Group: Where Lasers Meet X-Rays!

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Visible/Invisible Laser Benefits Society

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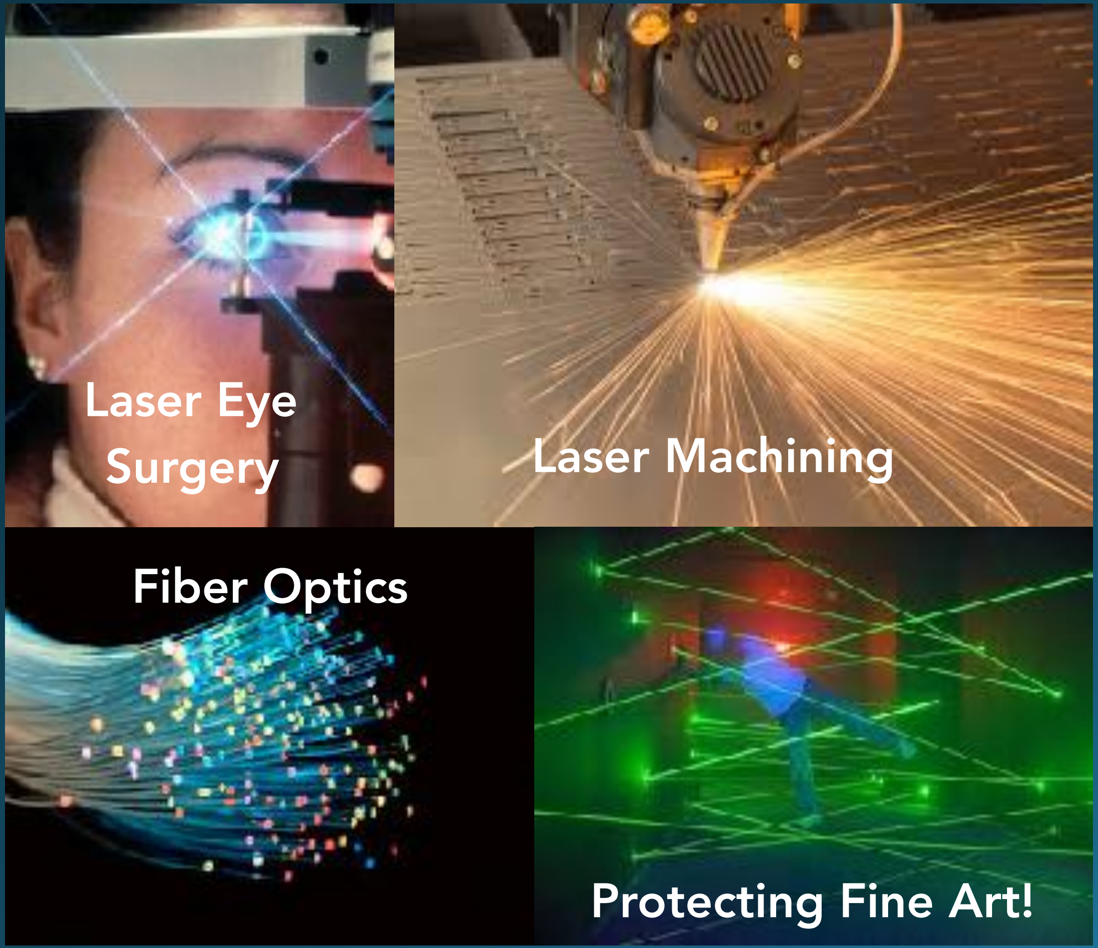

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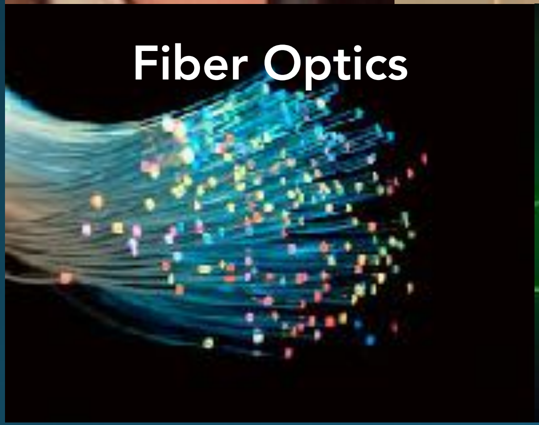

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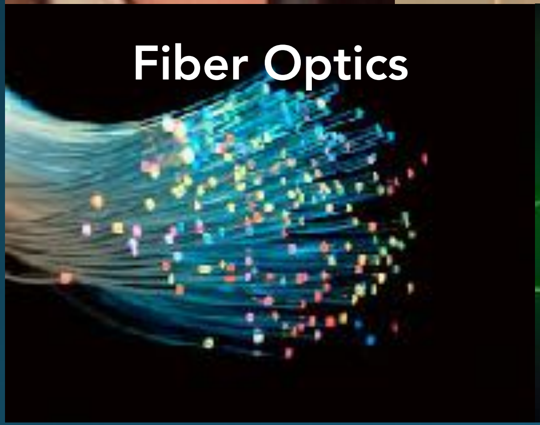

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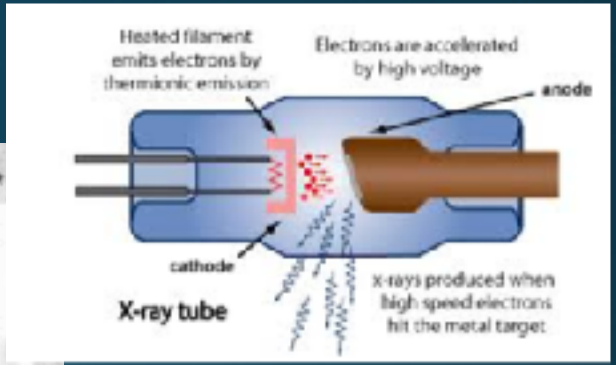

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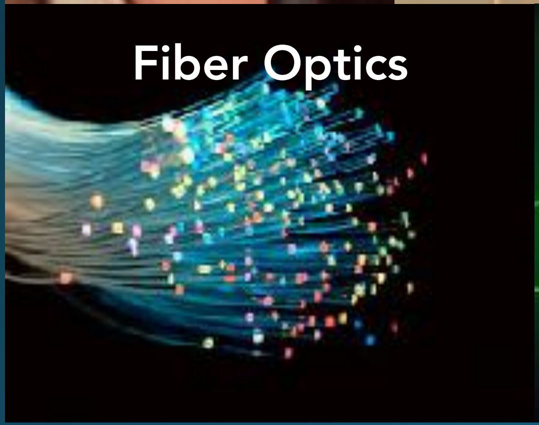

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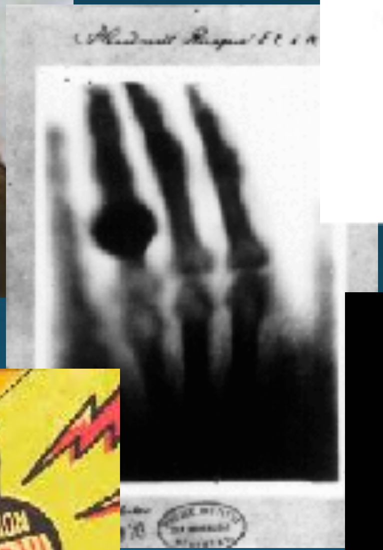

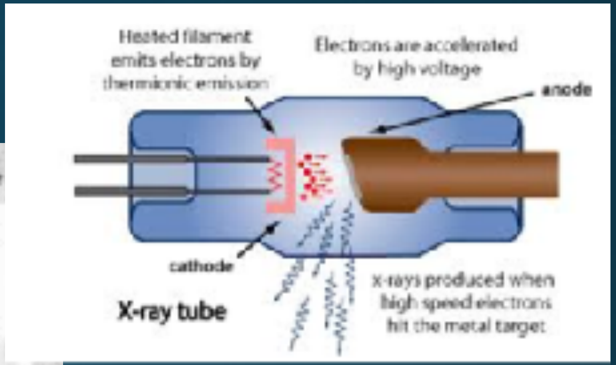

OK… Lasers Seem Good… X-rays Seem Neat… Why do We Need to Combine Them?

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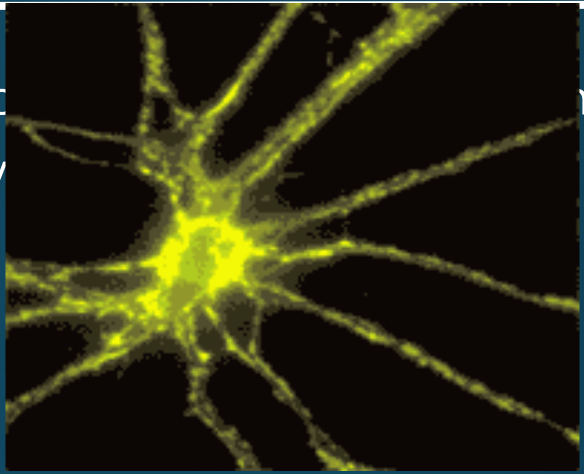

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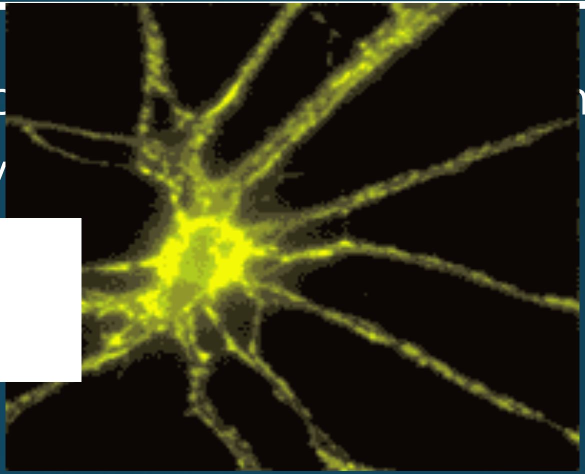
- In order to observe anything, you always need so  n smaller bits!) and faster (or works faster!) than the thing y

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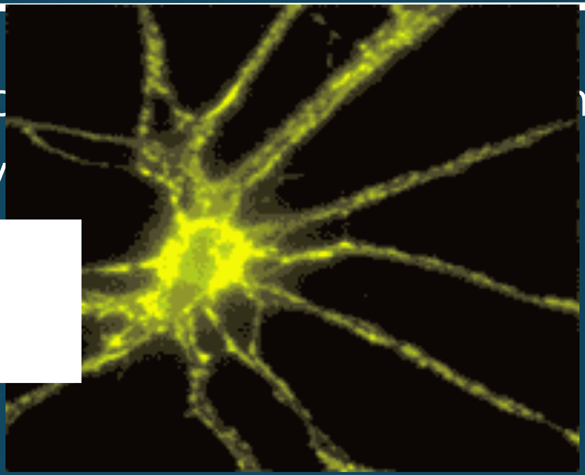

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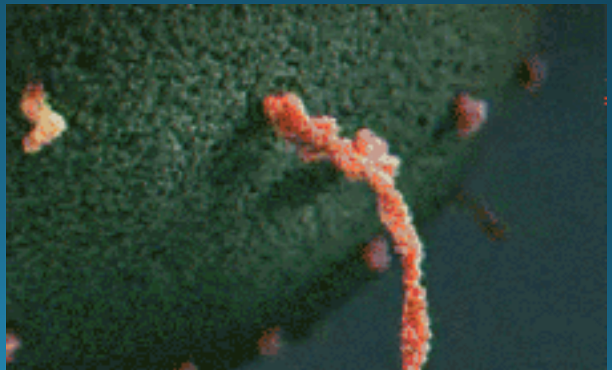

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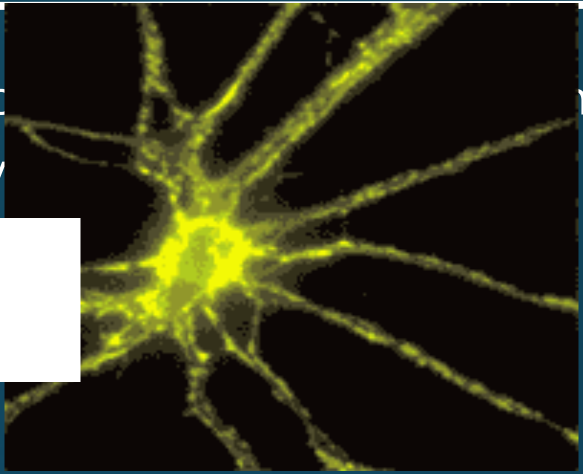

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10^{-6} to 10^{-9} s
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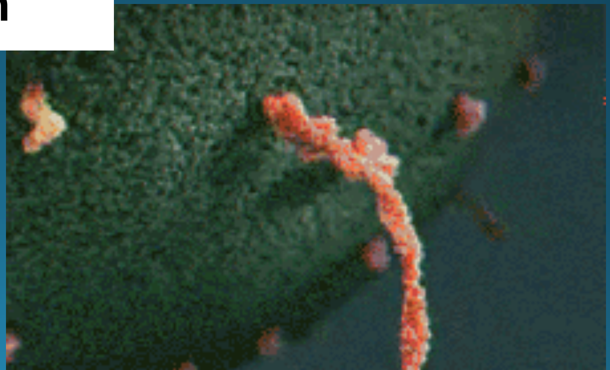

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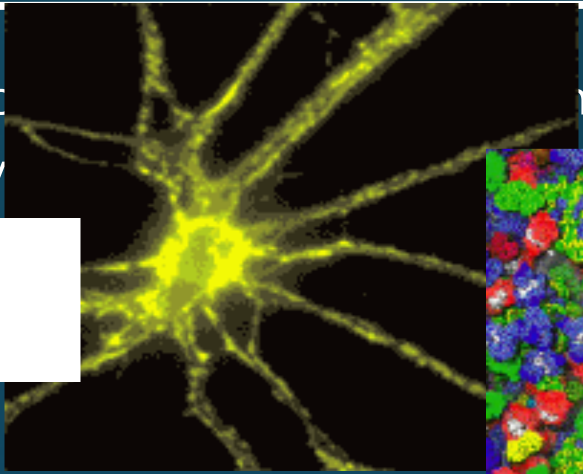
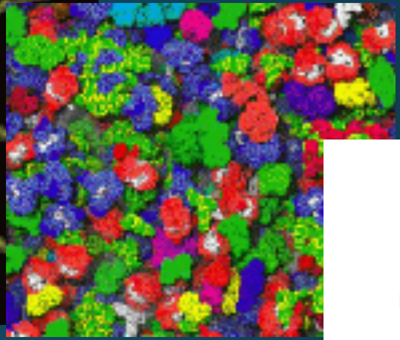
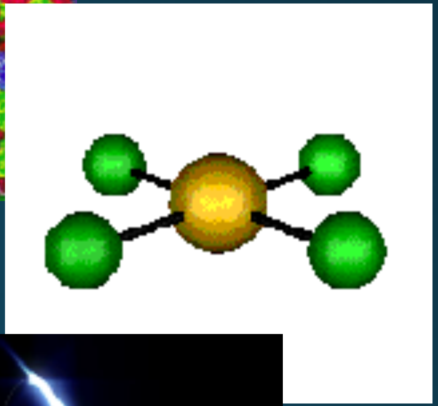
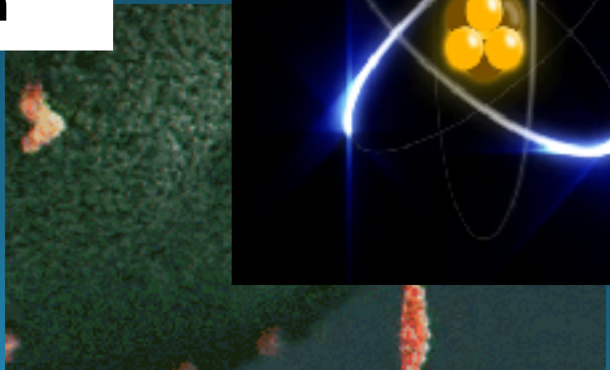
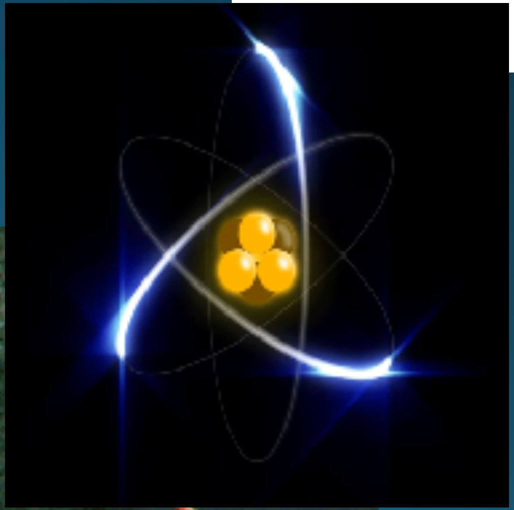




Time: hours, minutes, seconds
Size: meters, millimeters

10^{-6} to 10^{-9} s
10^{-6} to 10^{-9} m

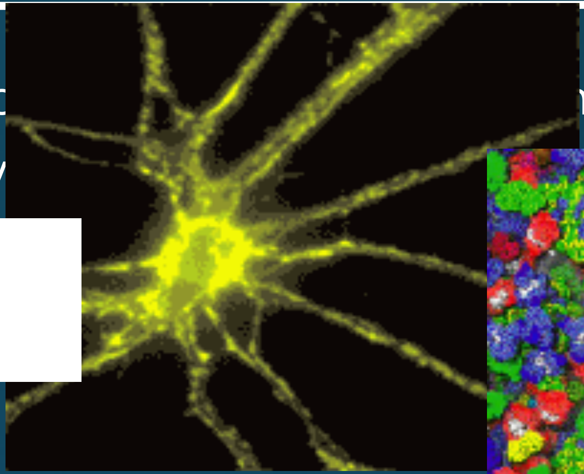



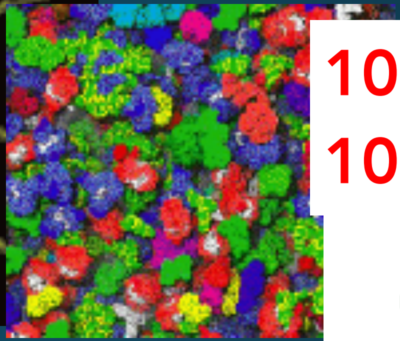
OK… Lasers Seem Good… X-rays Seem Neat… Why do We Need to Combine Them?

- In order to observe anything, you always need so[…] smaller bits!) and faster (or works faster!) than the thing y[…]

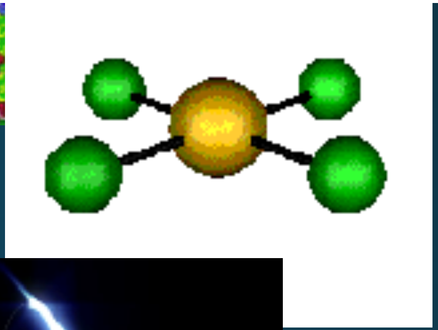
Time: hours, minutes, seconds
Size: meters, millimeters

10^{-3} to 10^{-8} s
10^{-4} to 10^{-6} m

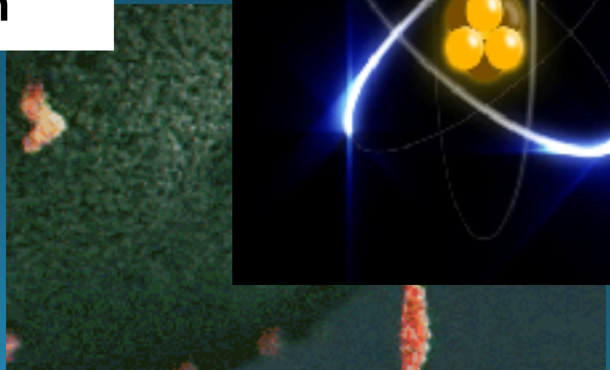


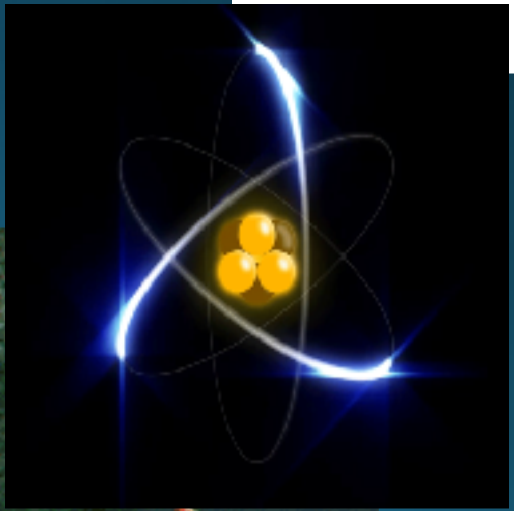


10^{-10} to 10^{-18} s
10^{-8} to 10^{-12} m



10^{-6} to 10^{-9} s
10^{-6} to 10^{-9} m





But First… Why are X-ray and Ultra-Intense Lasers Good for Observing the Fast and Small?

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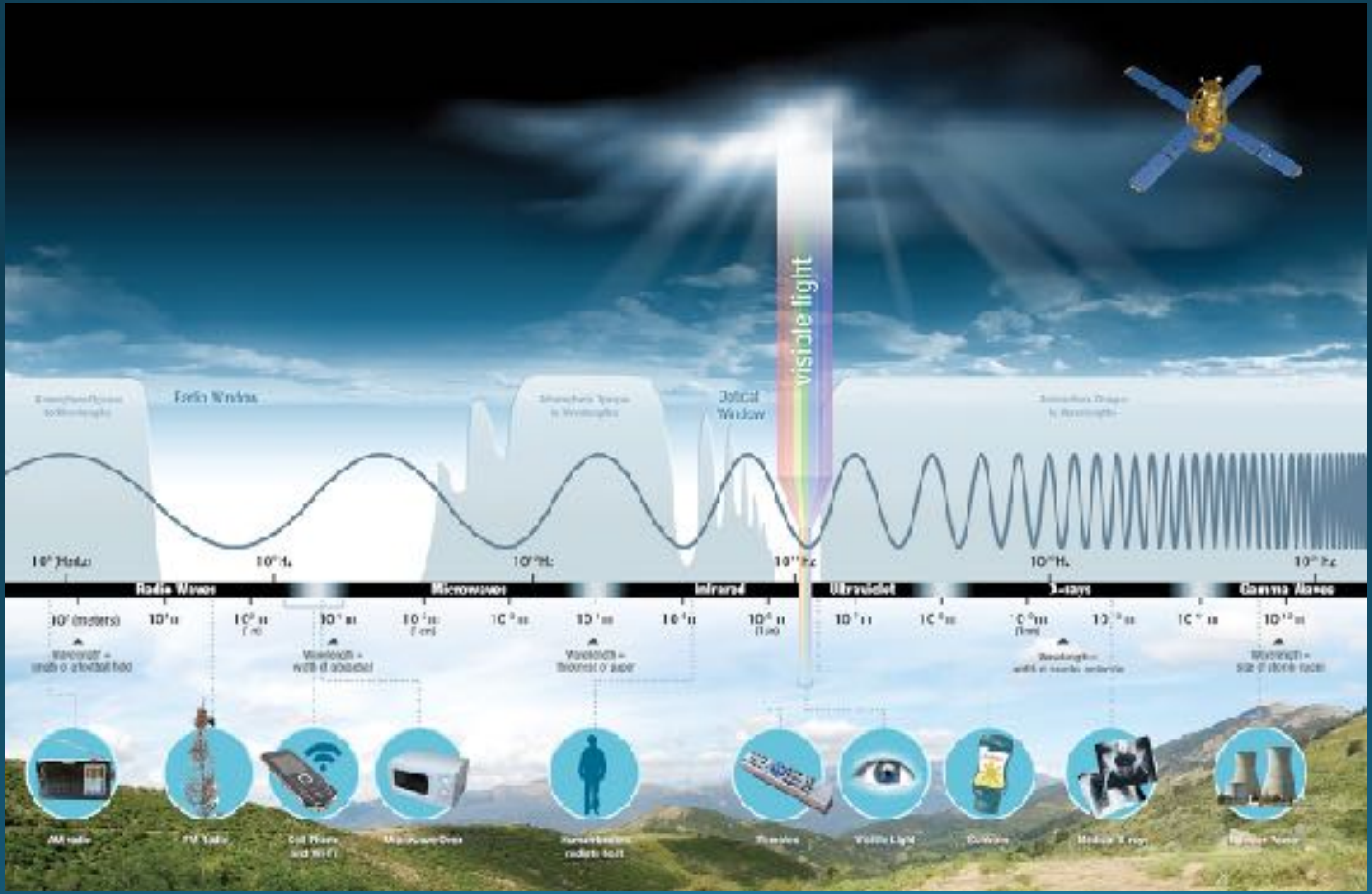

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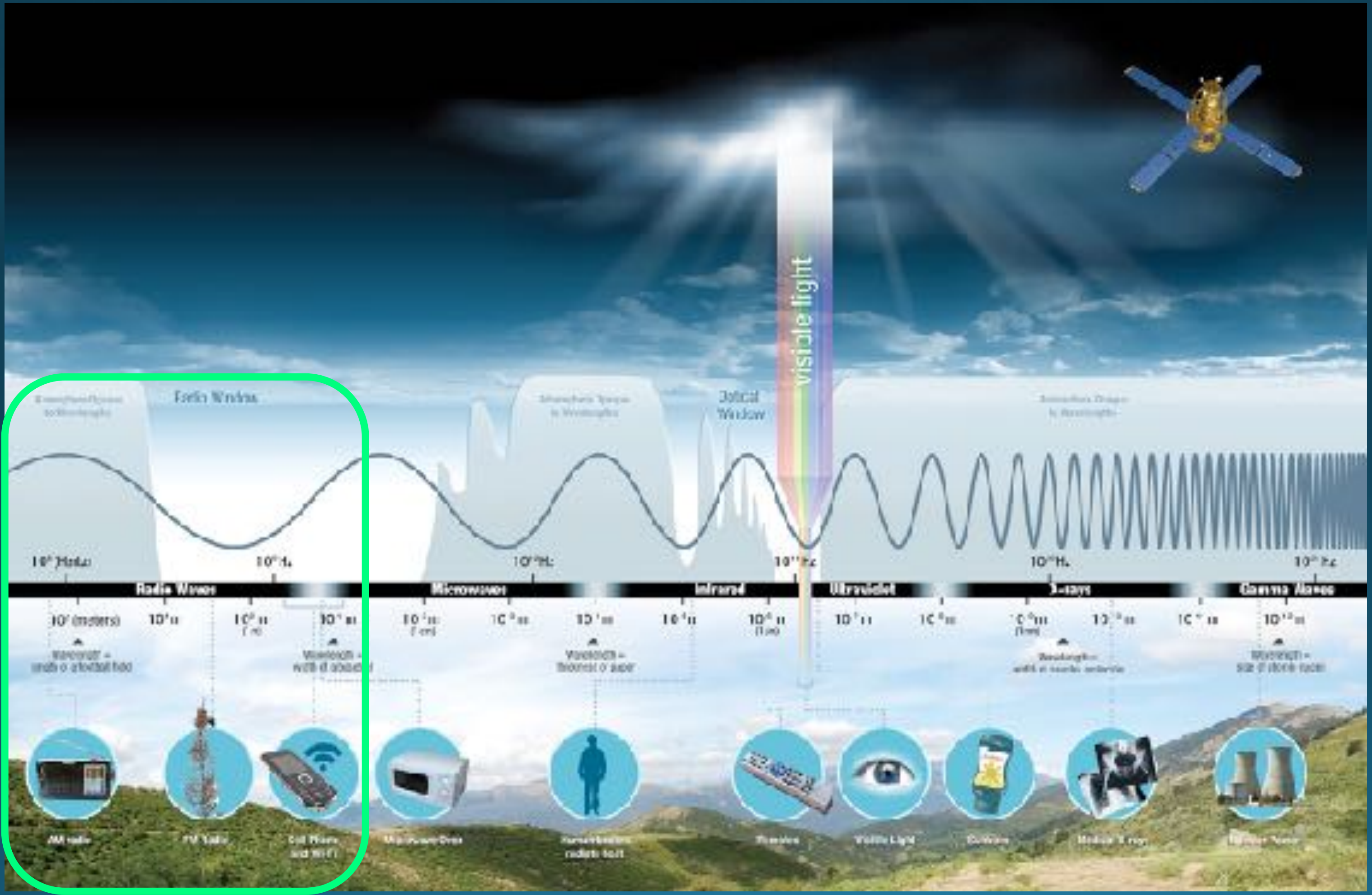

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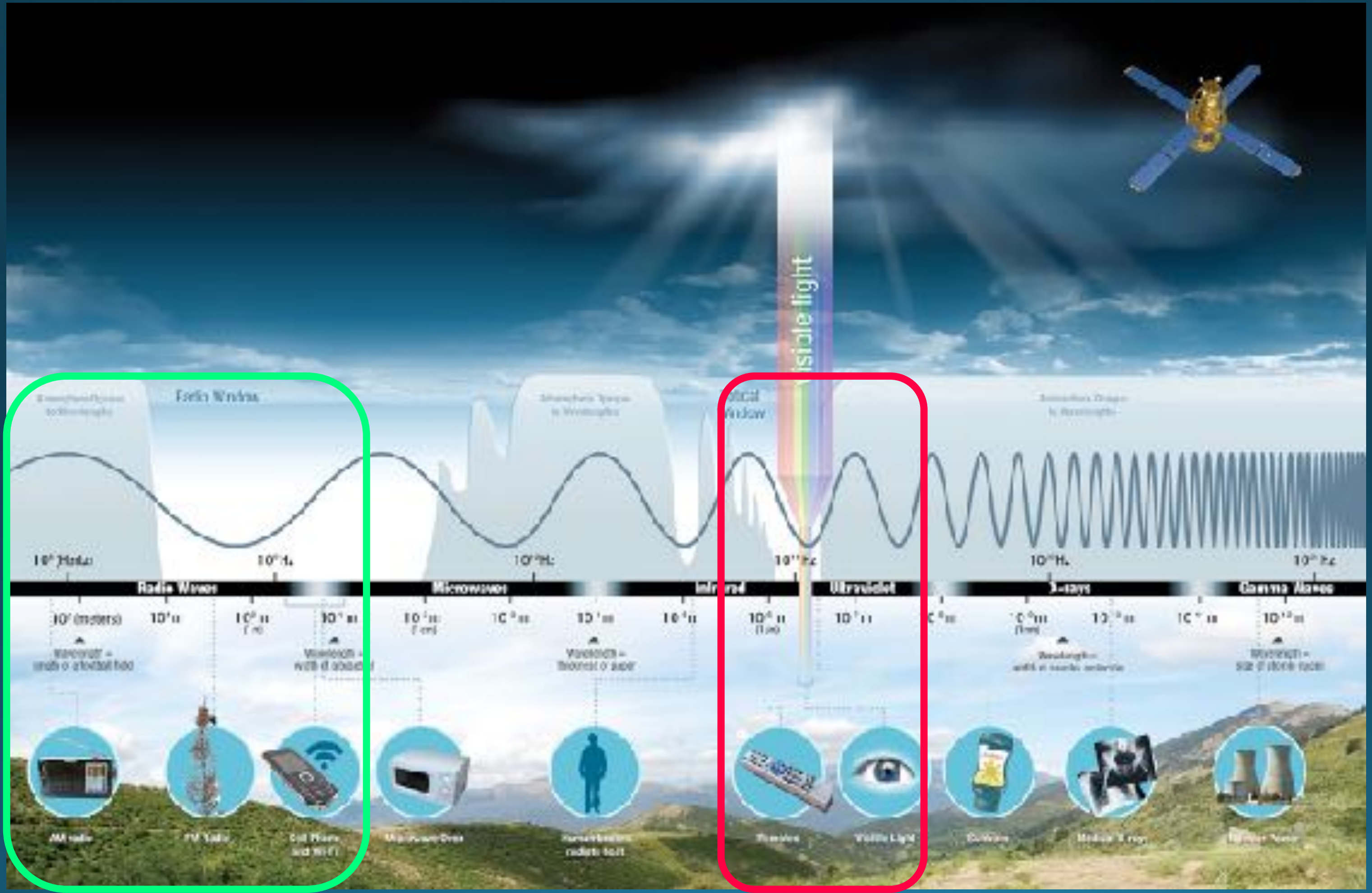

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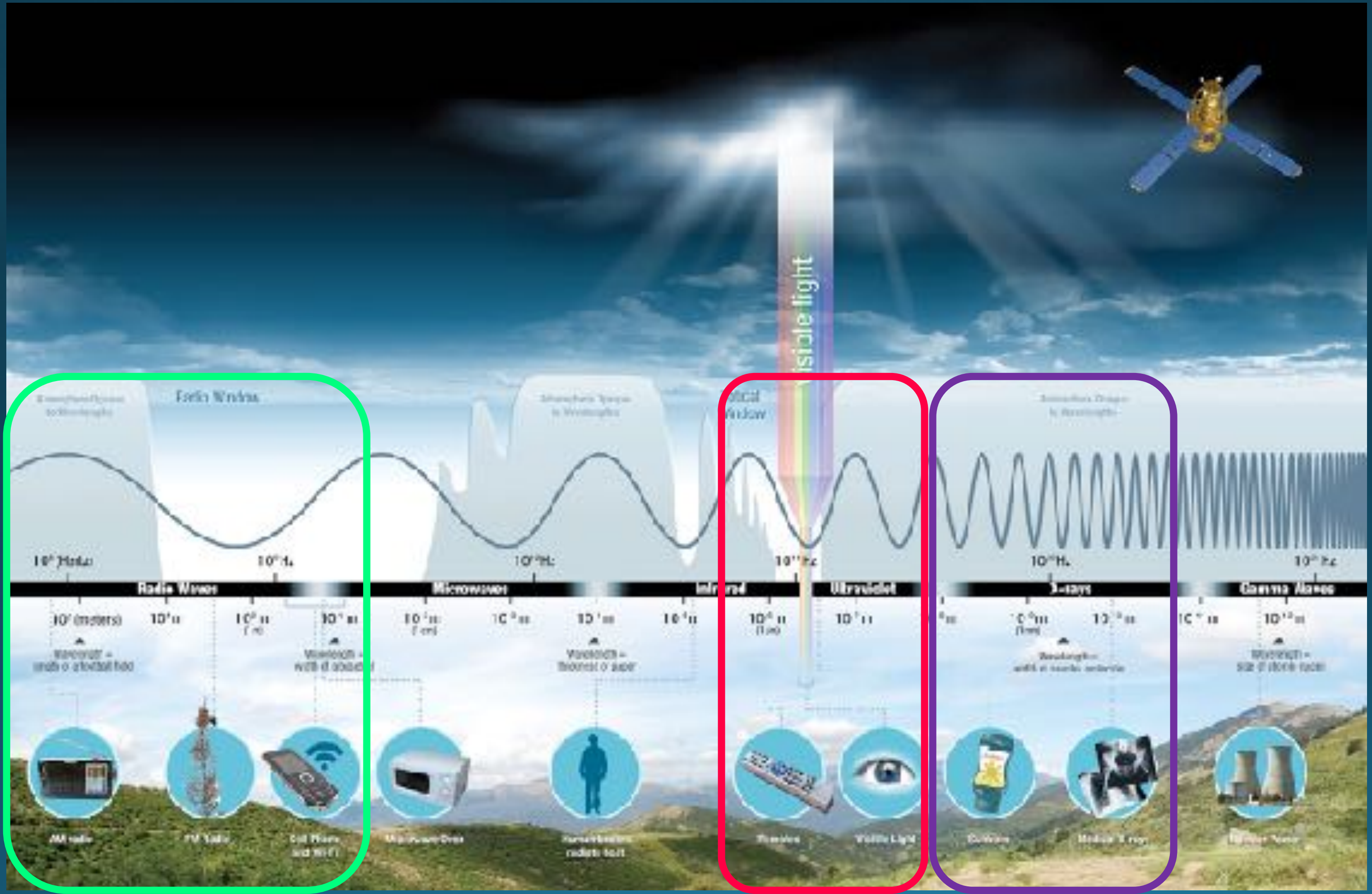

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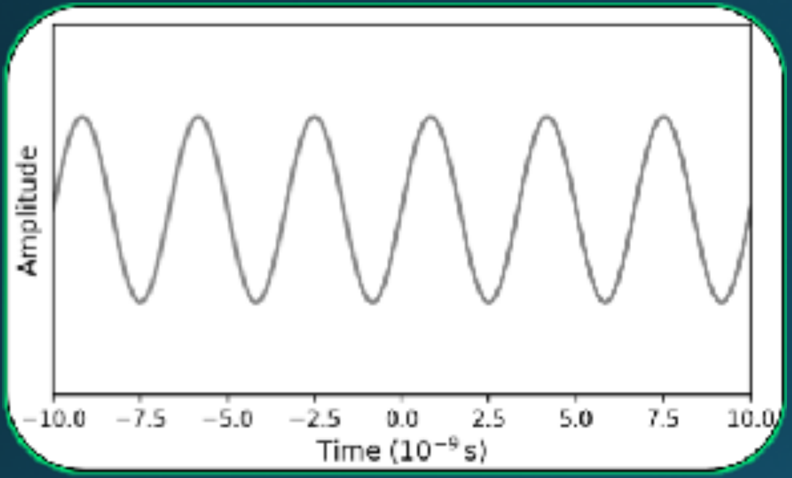
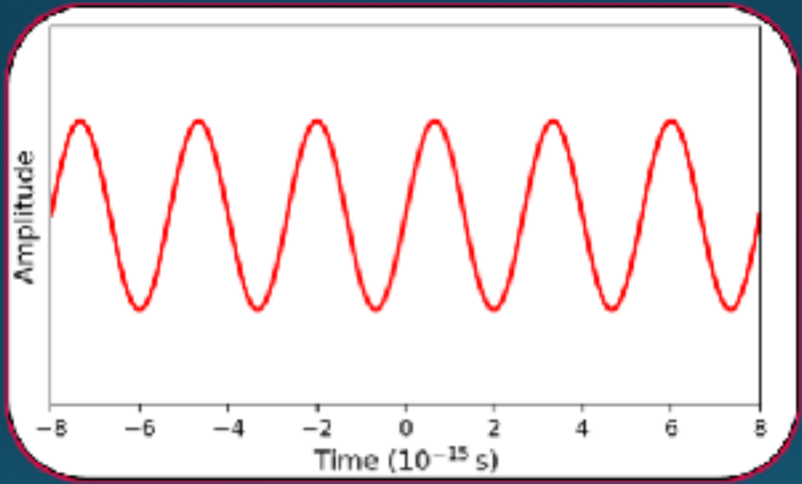
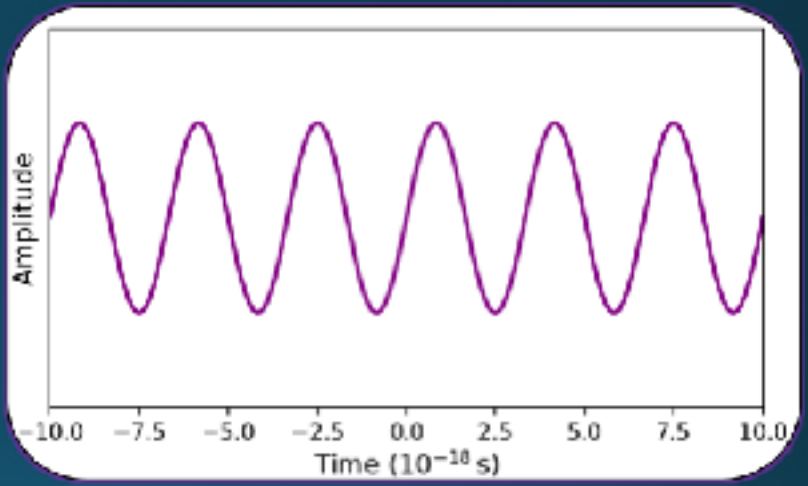


Visible Waves



X-ray Waves



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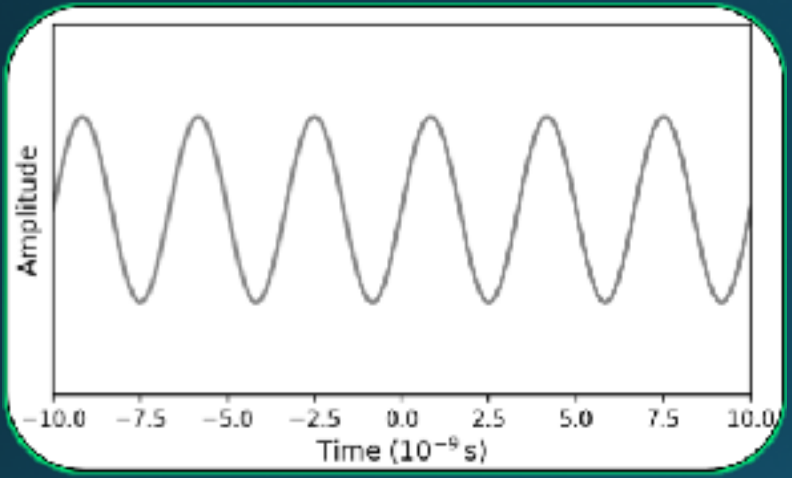

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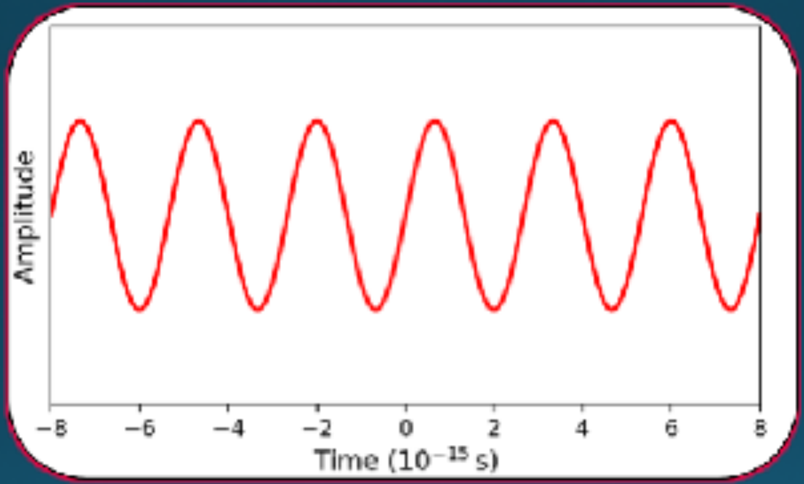

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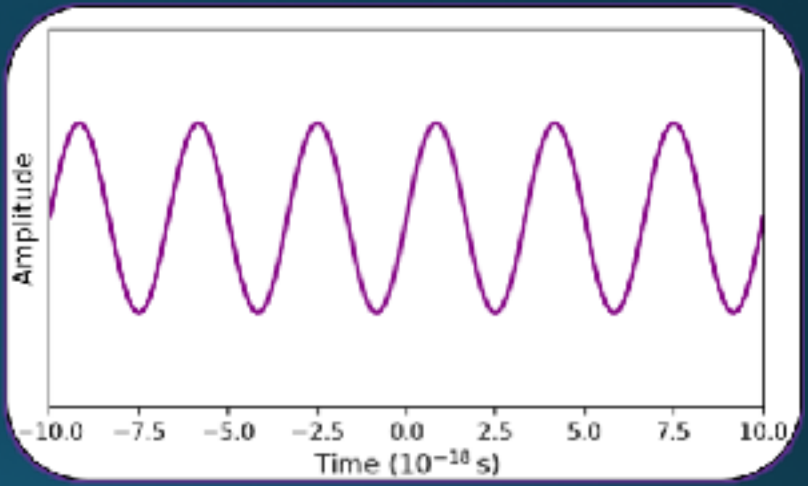

Long wavelengths (> m)
"Slow" oscillations

Can "see" big and slow things

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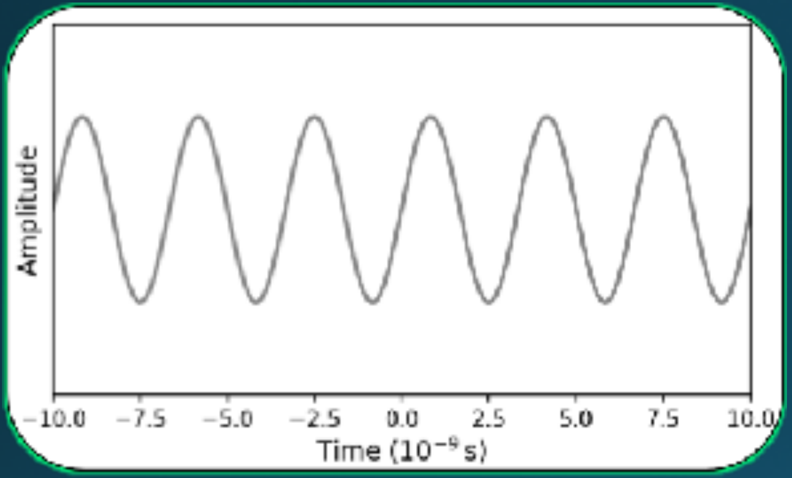

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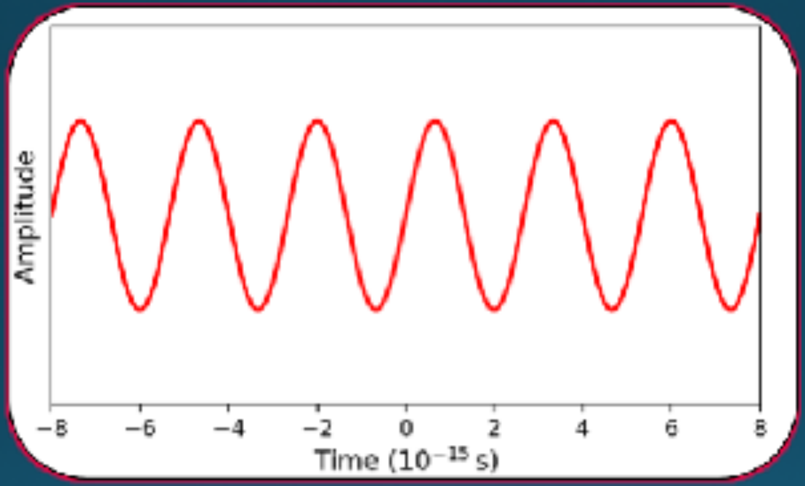

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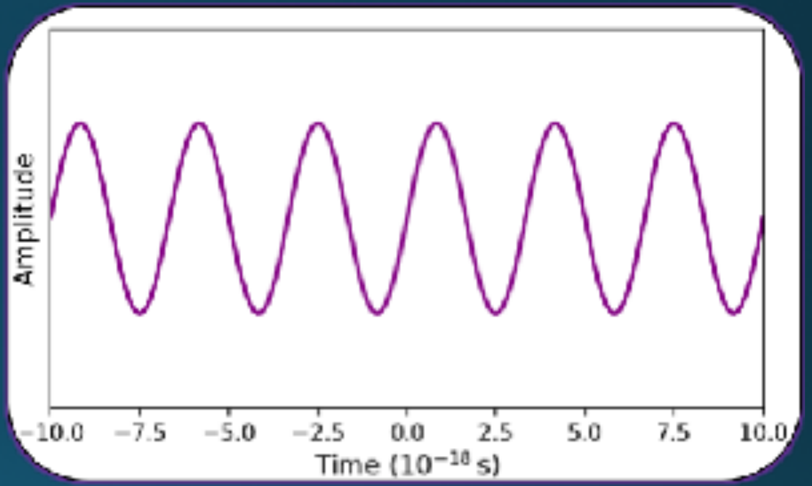

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Short wavelengths (~um)
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Can "see" moderately fast and small things

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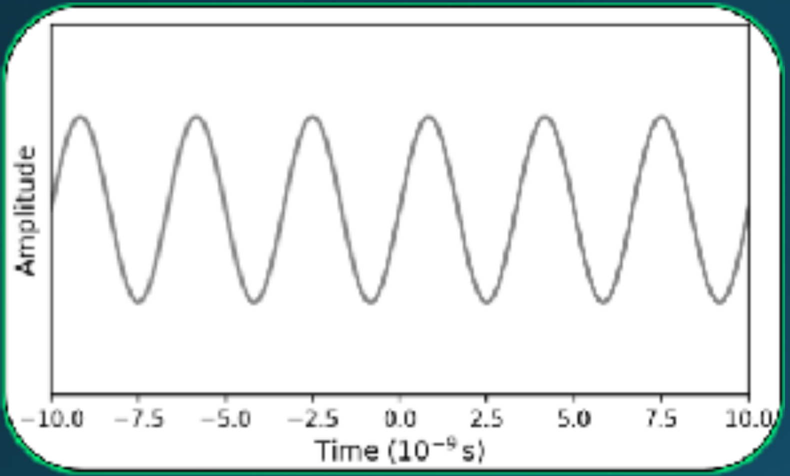

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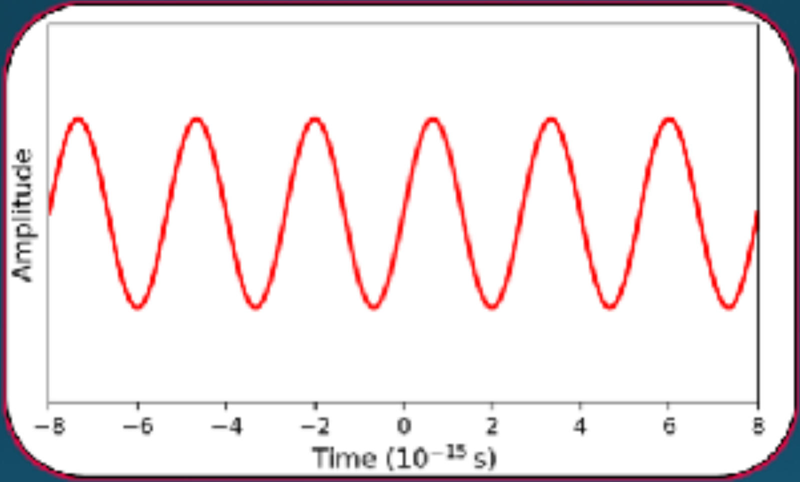

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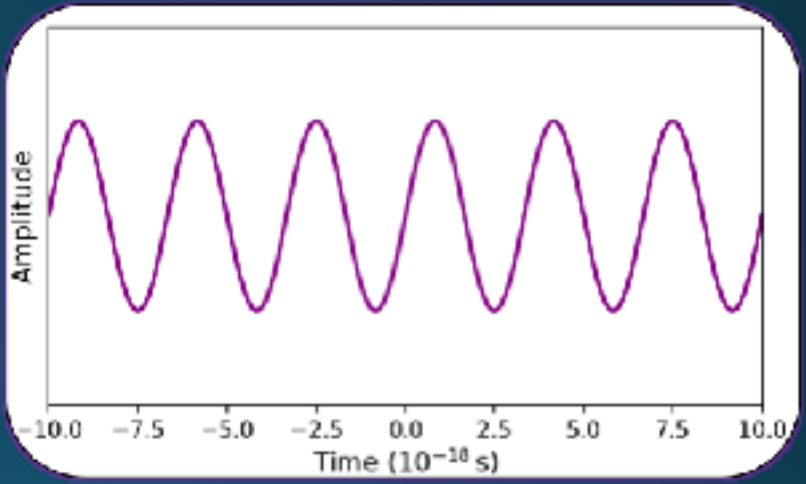

Long wavelengths (> m)
"Slow" oscillations

Can "see" big and slow things

Short wavelengths (~um)
"Fast" oscillations

Can "see" moderately fast and small things

Very Short wavelengths (nm)
Very "Fast" oscillations

Can "see" very small and very fast things

Wait, Wait, Wait… You Promised X-ray AND Ultra-Strong Lasers! What about Those?

- Aside from frequency and wavelength, the amplitude of a light wave can be used to tell us even more about nature!

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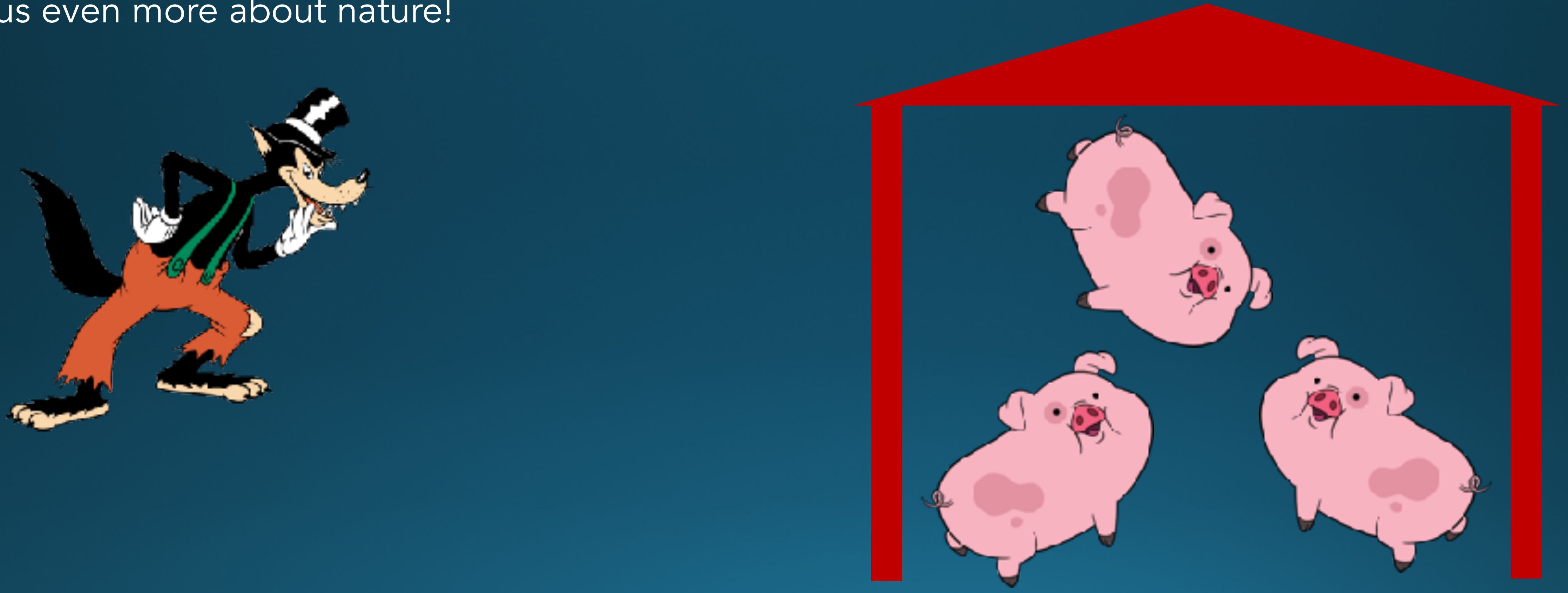

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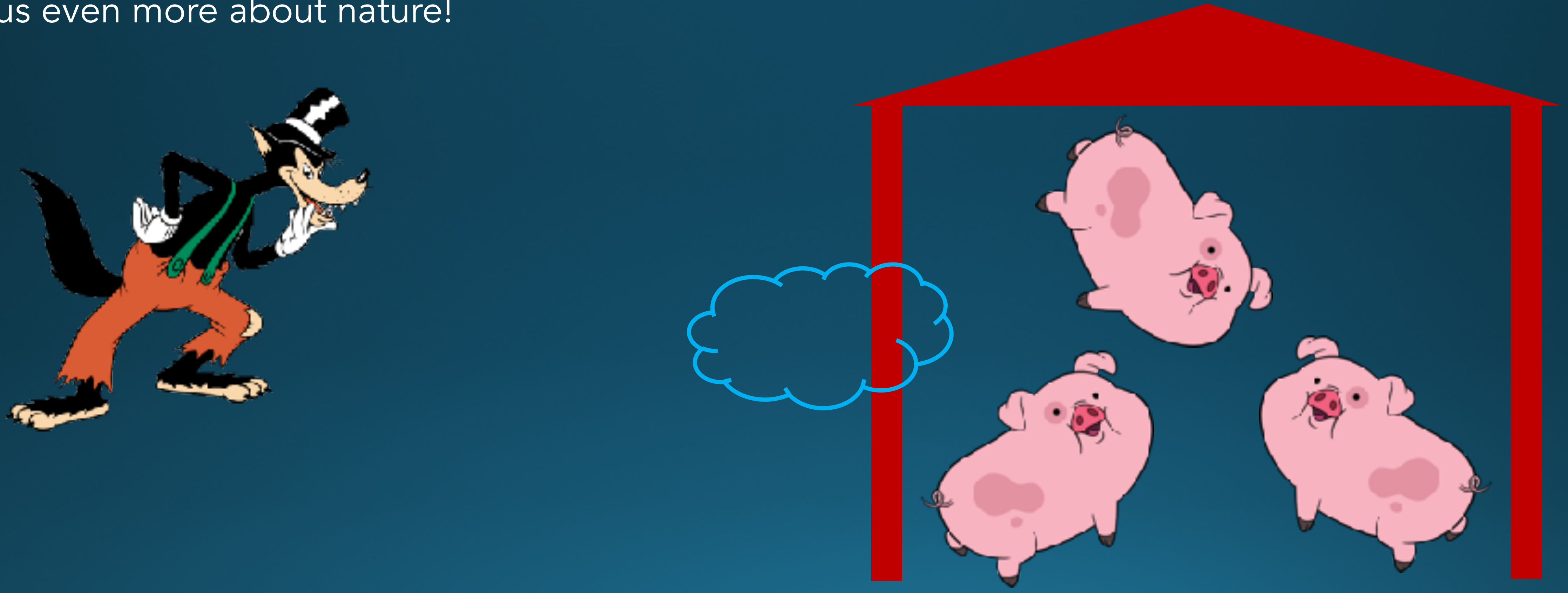

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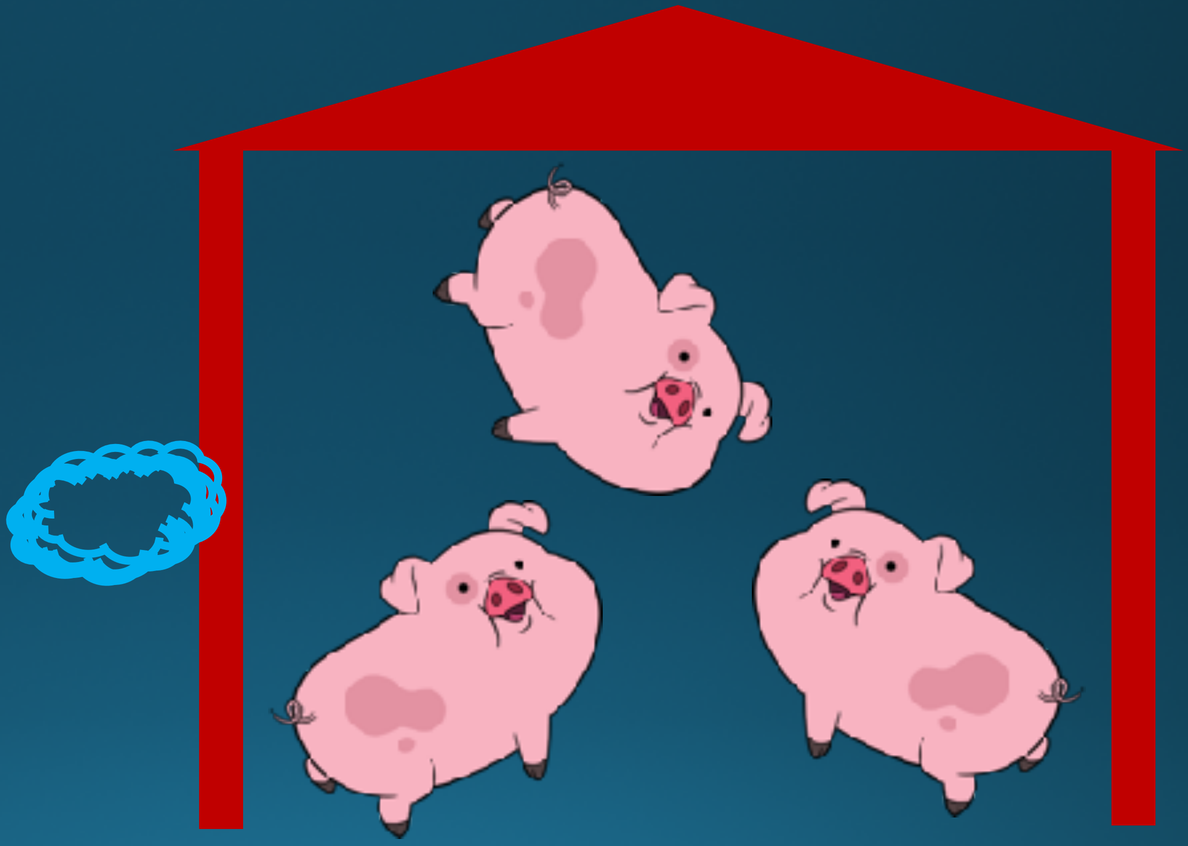

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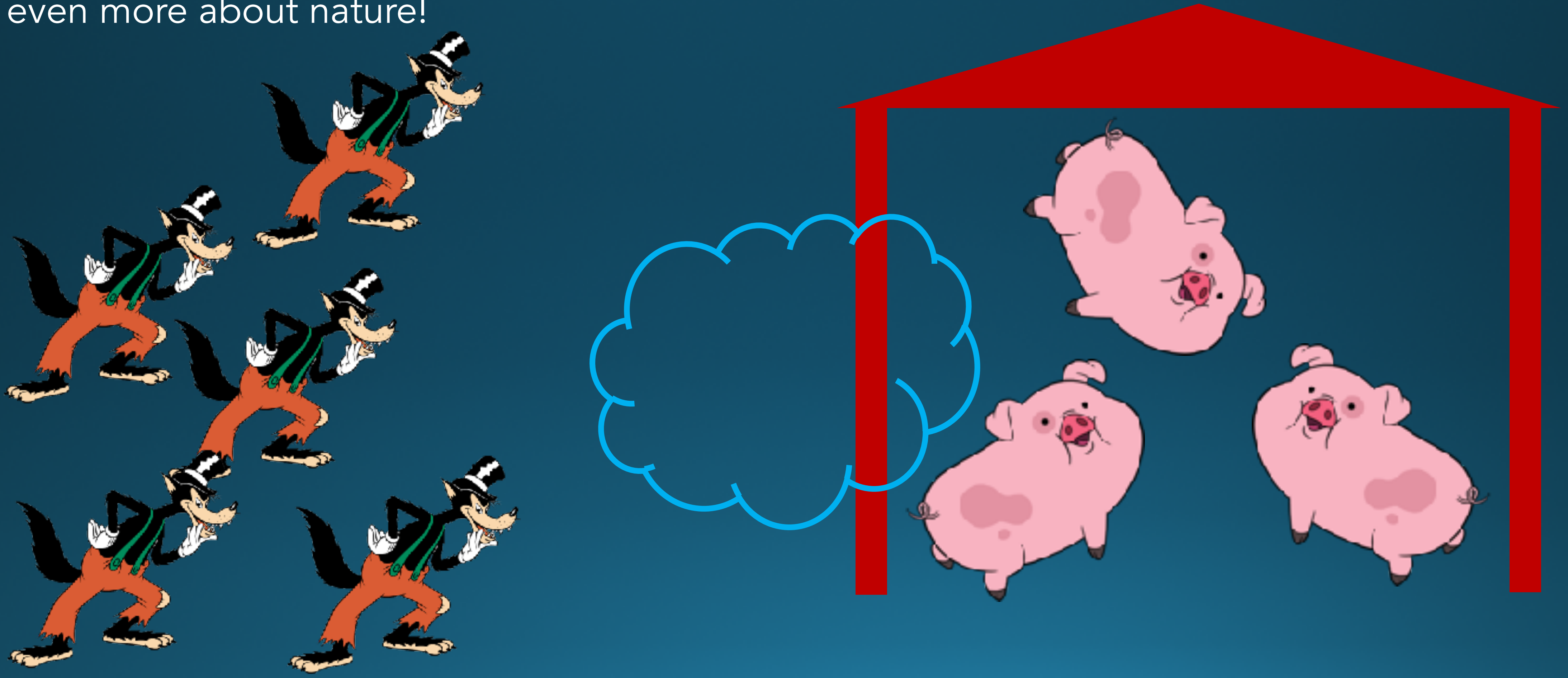

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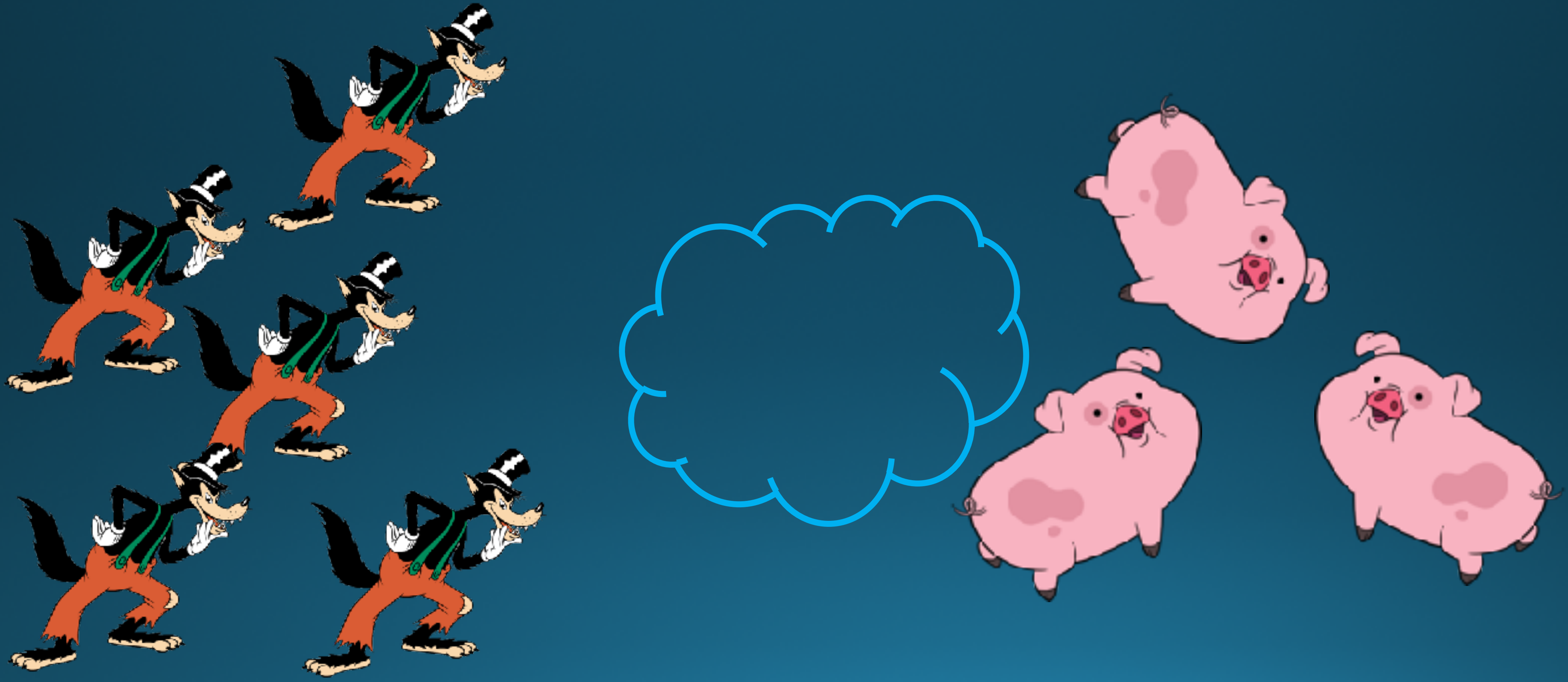

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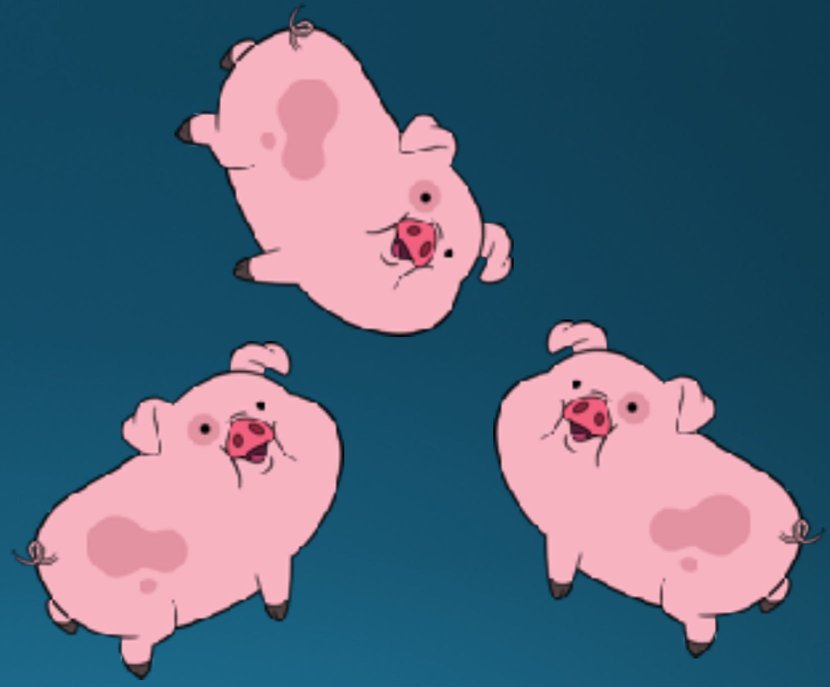

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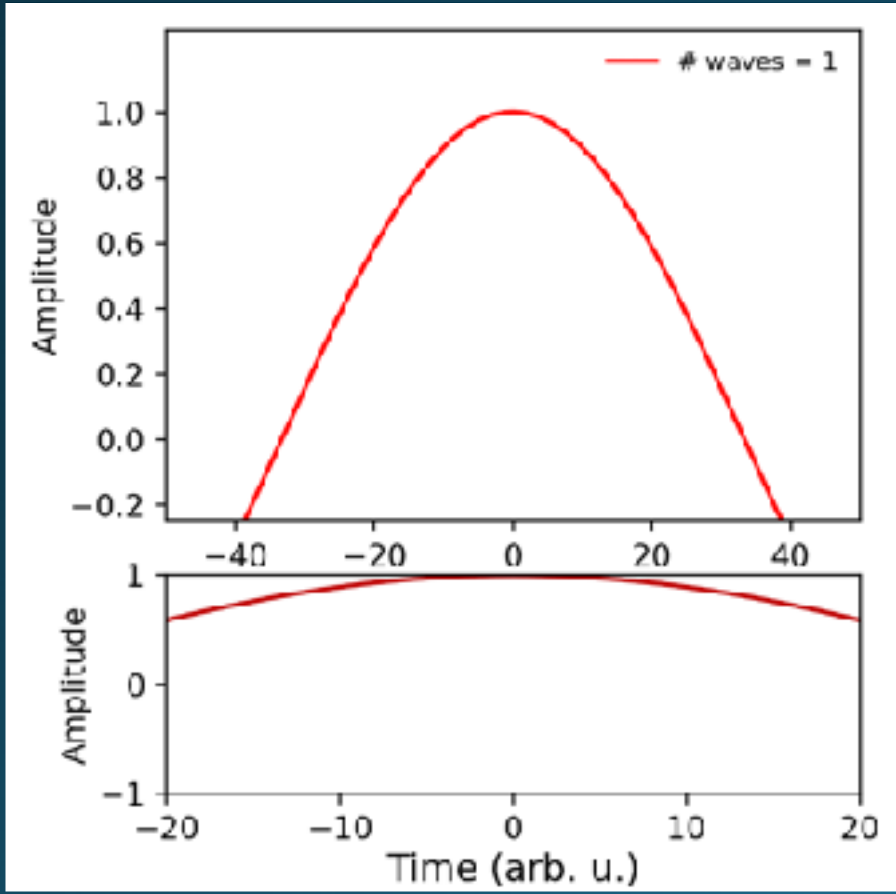

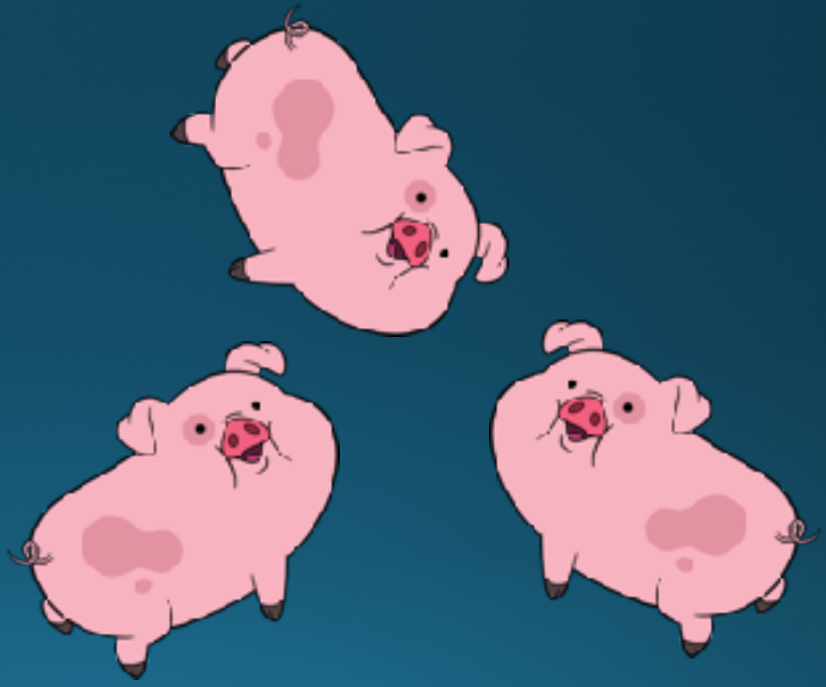

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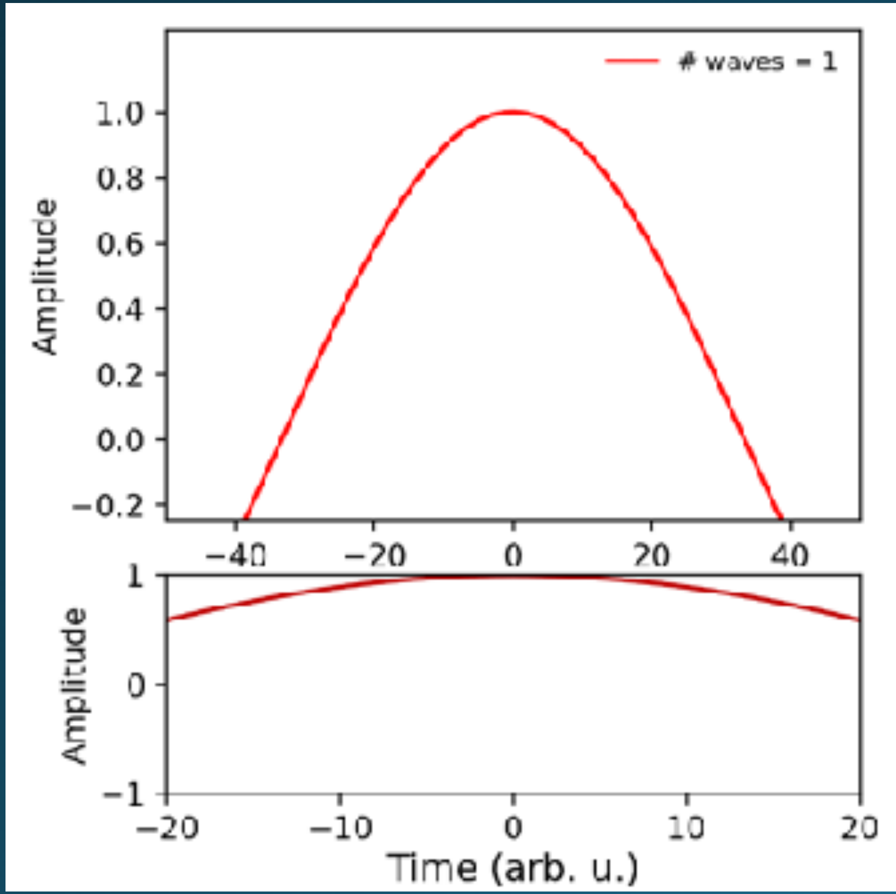

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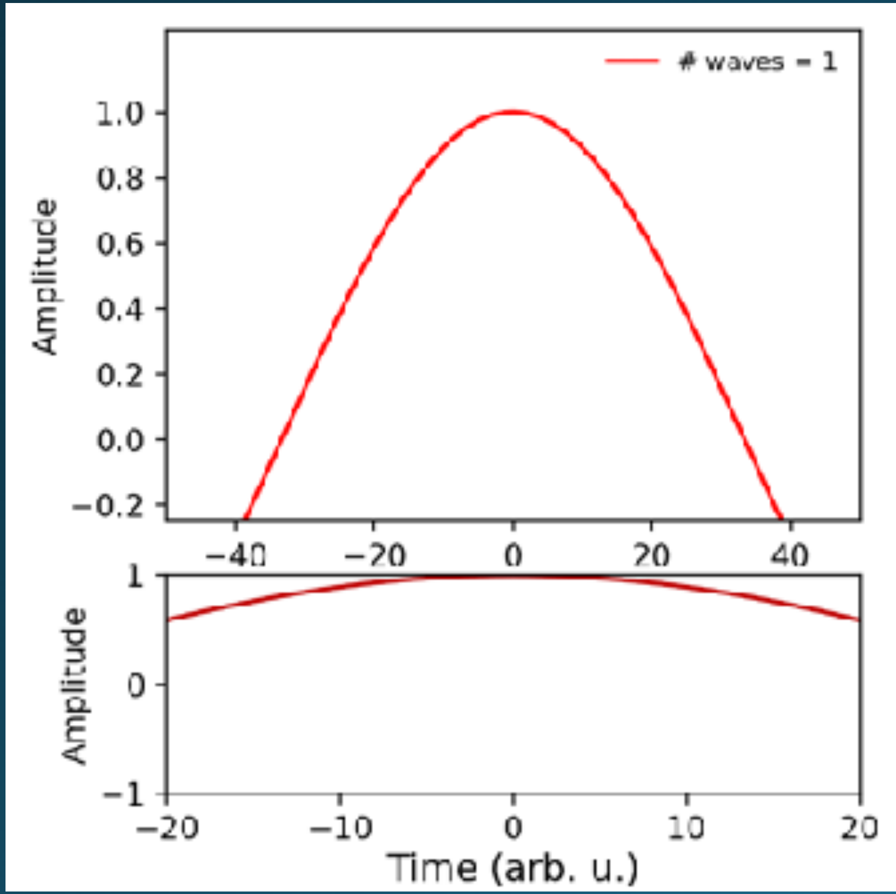

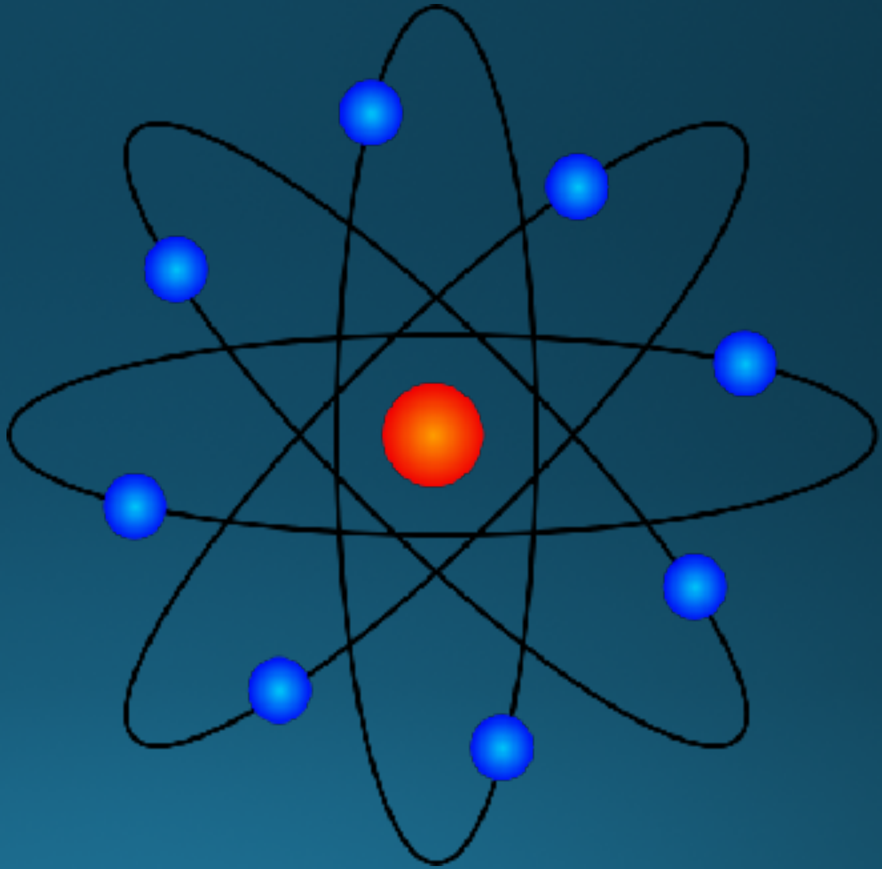

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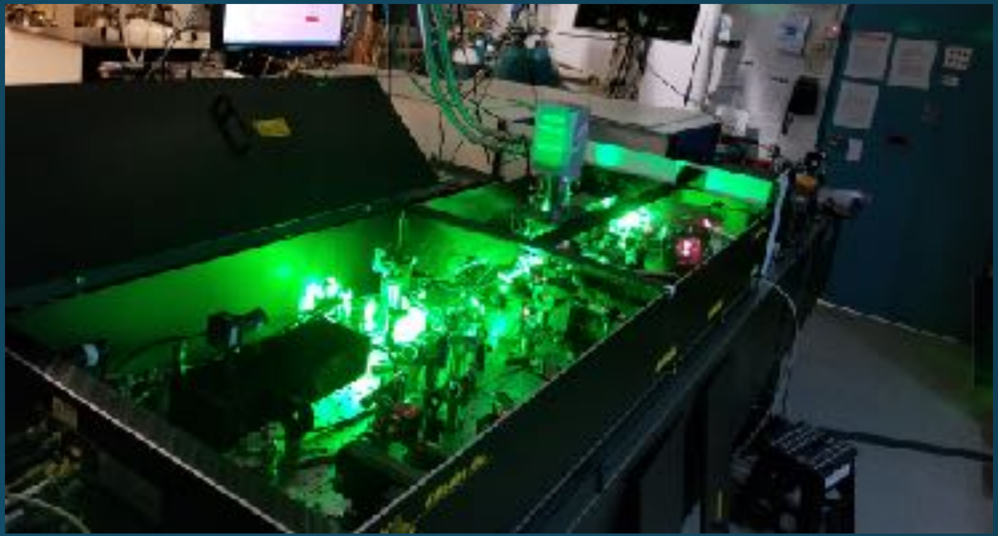

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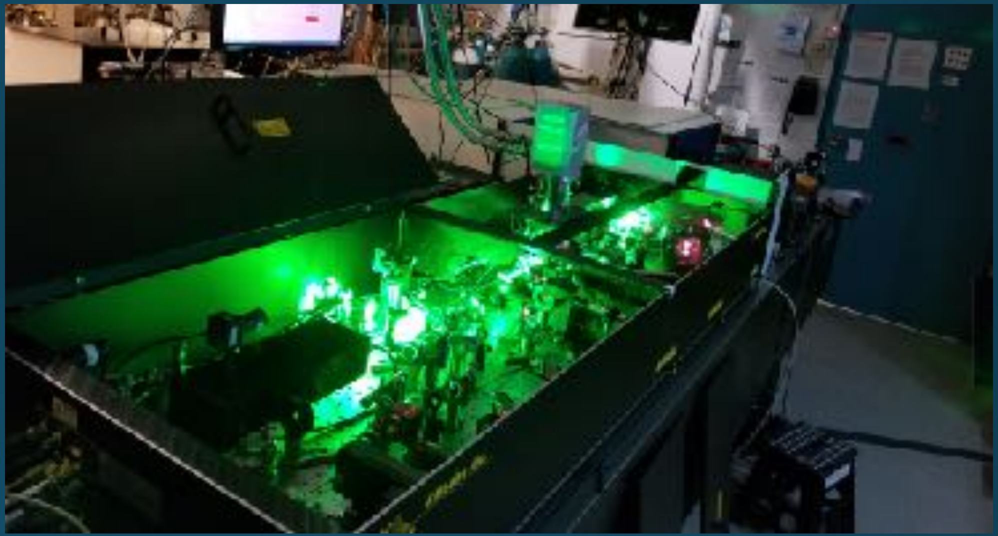

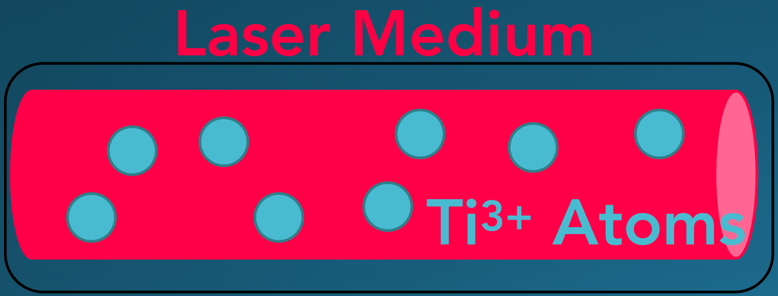

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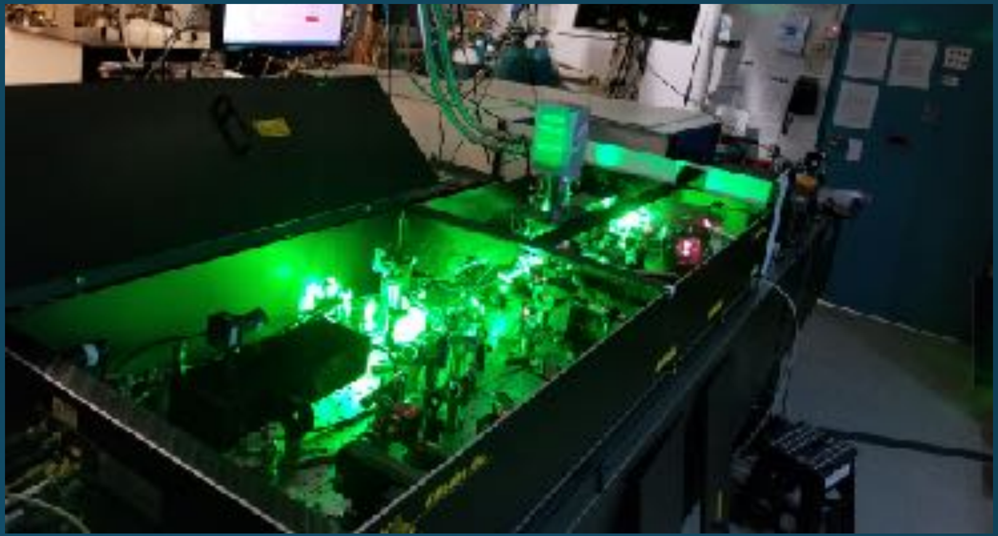

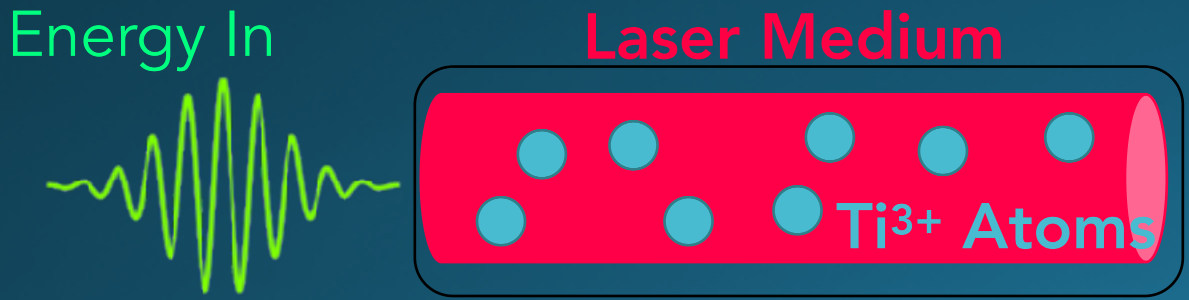

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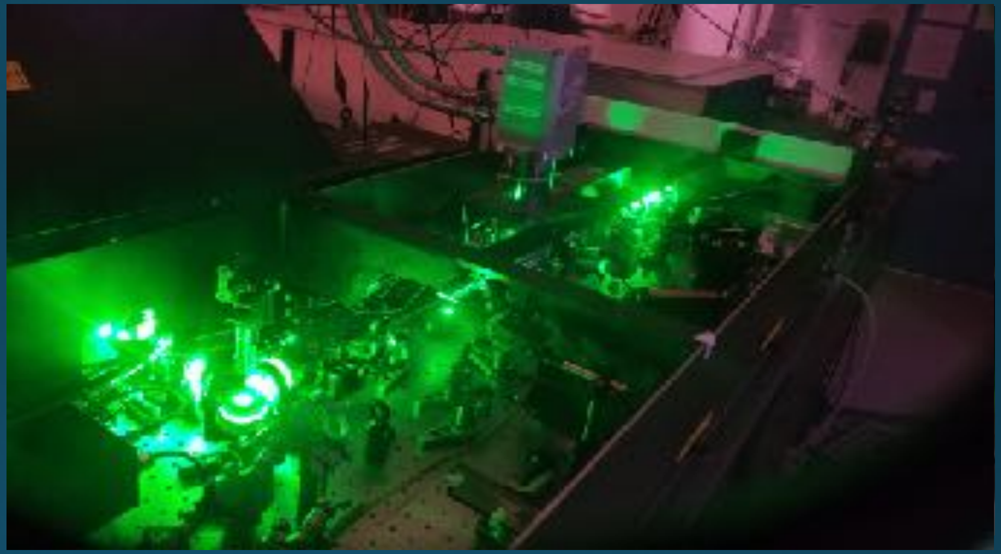

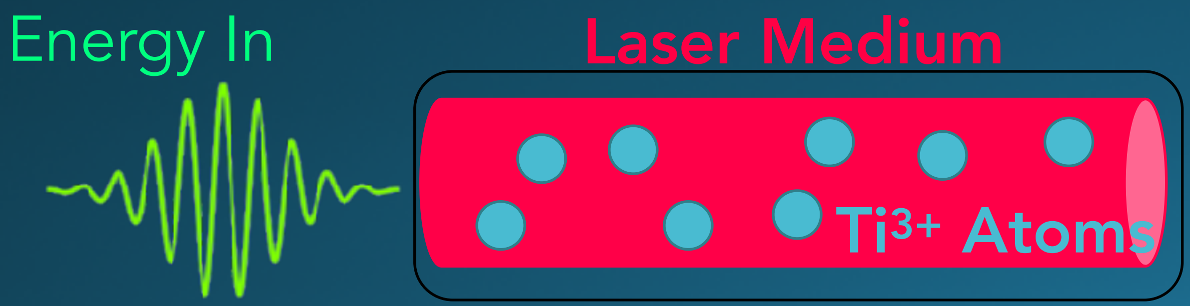

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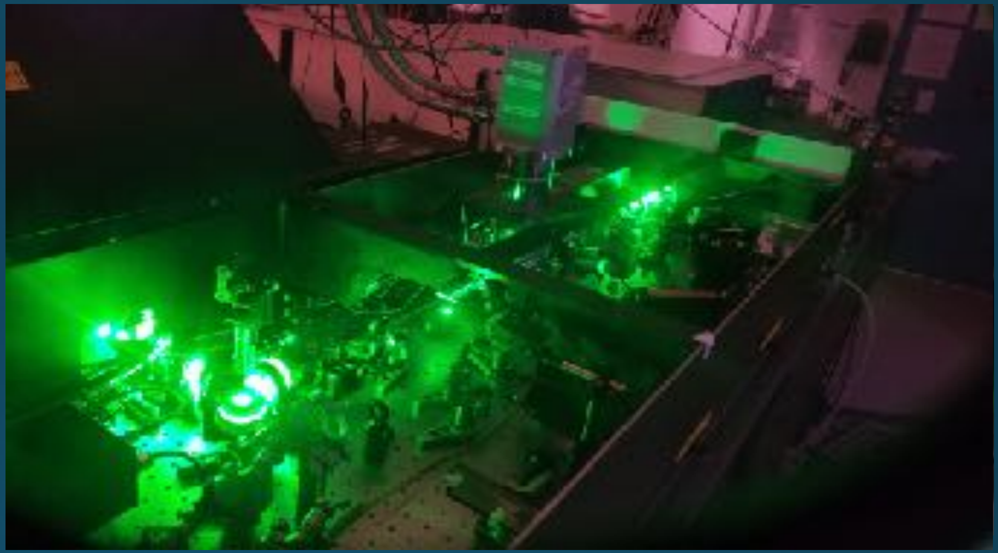

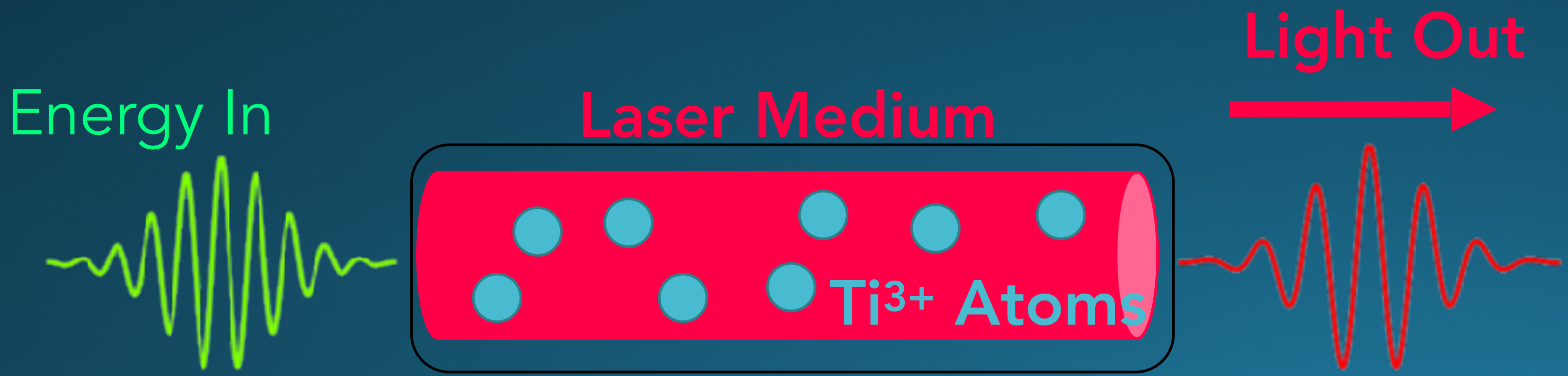

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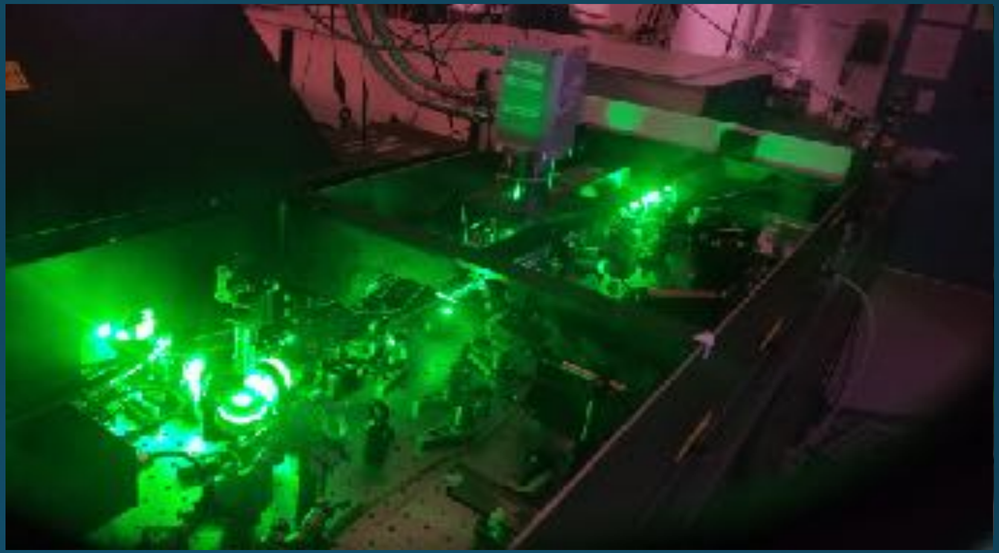

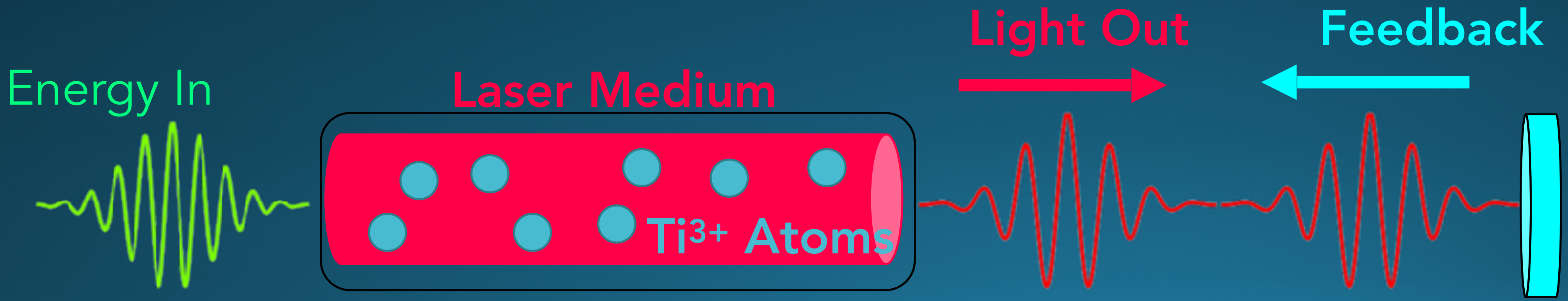

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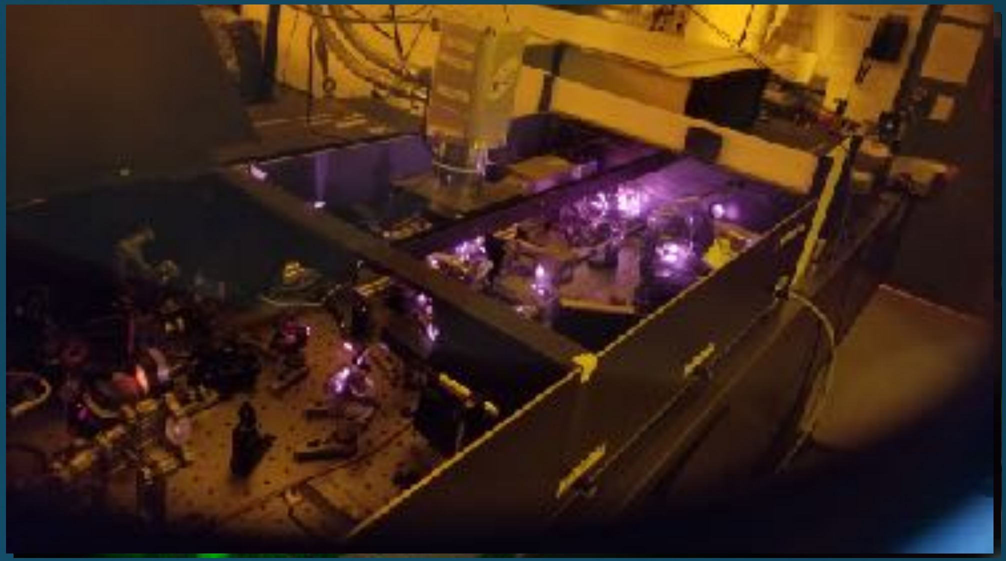

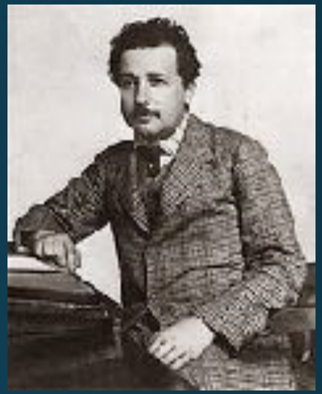

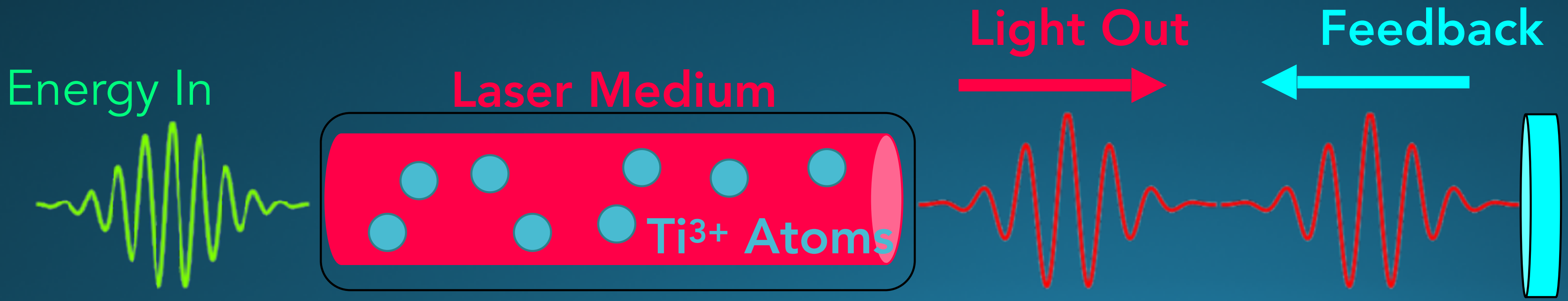

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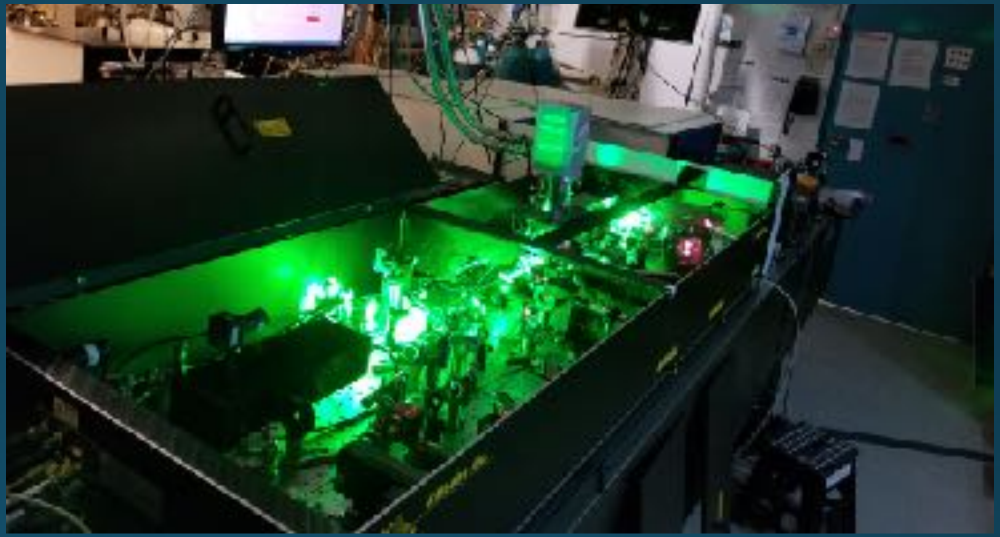

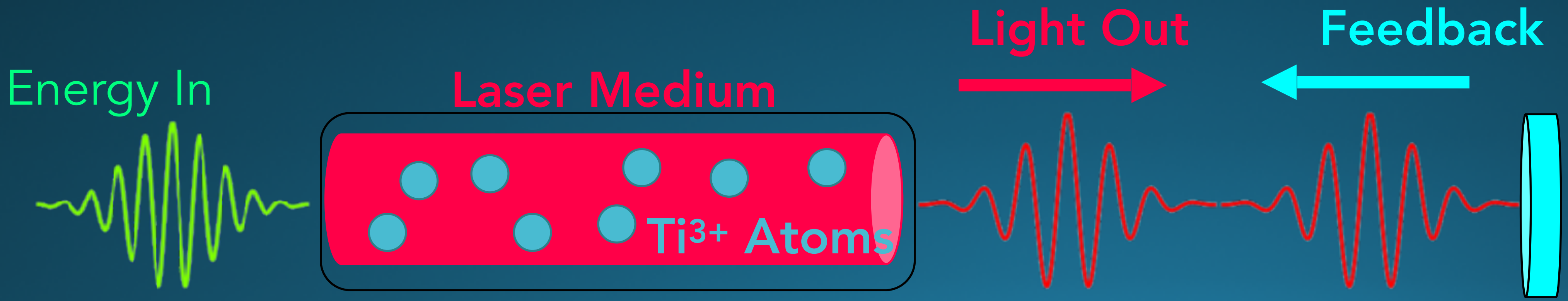

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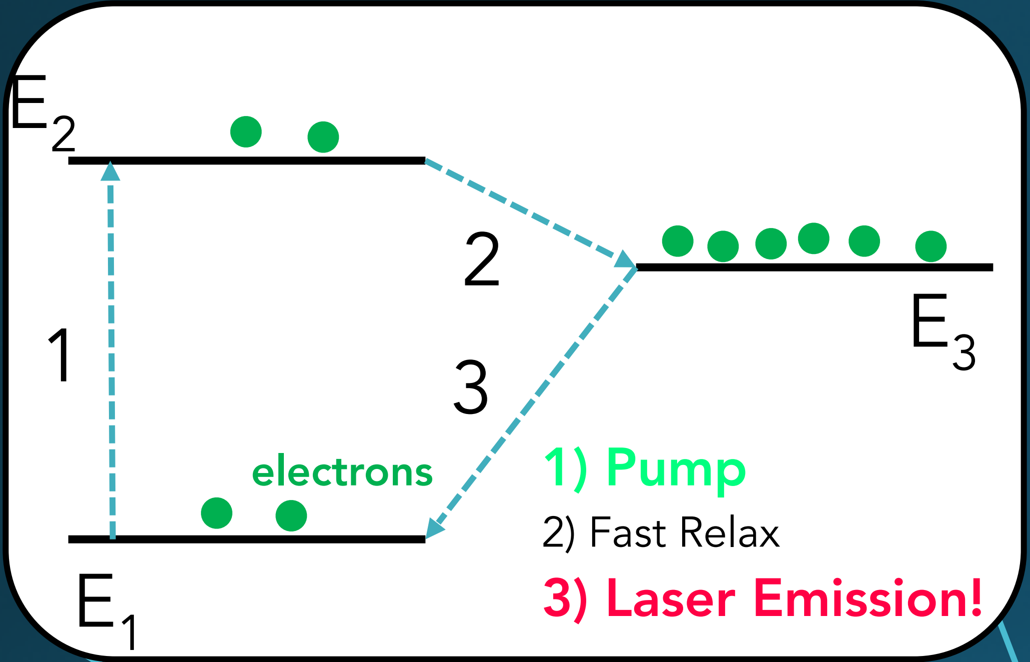

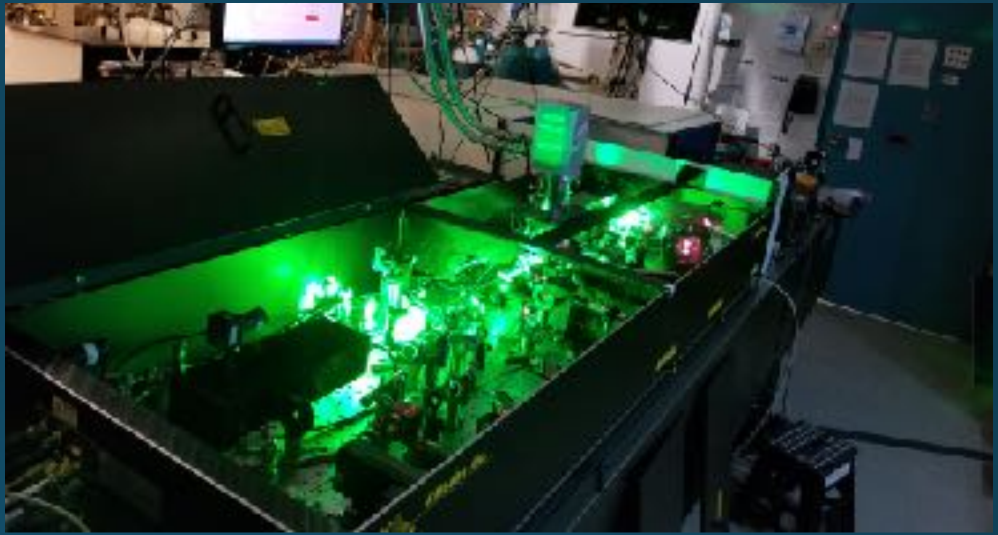

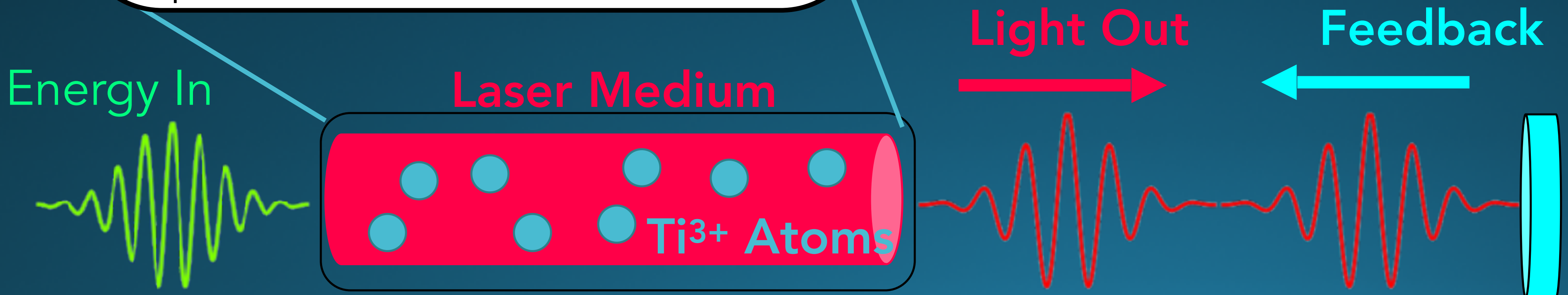

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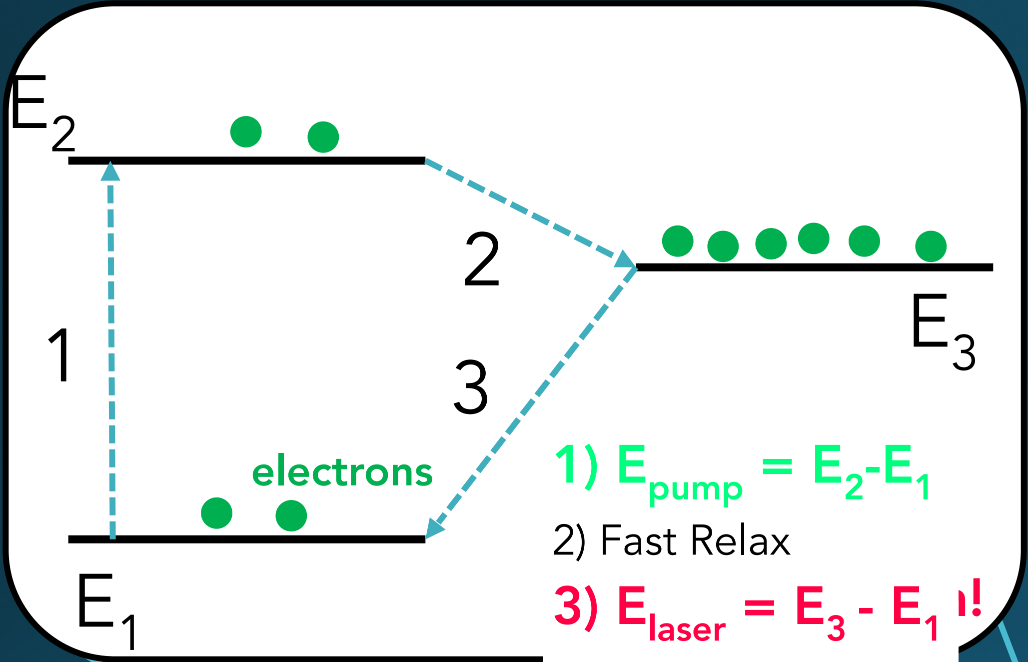

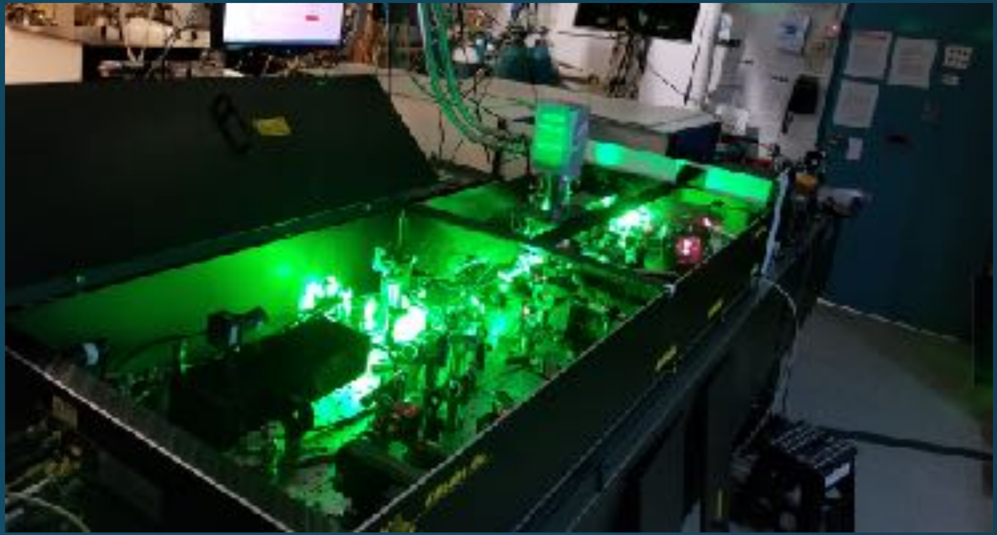

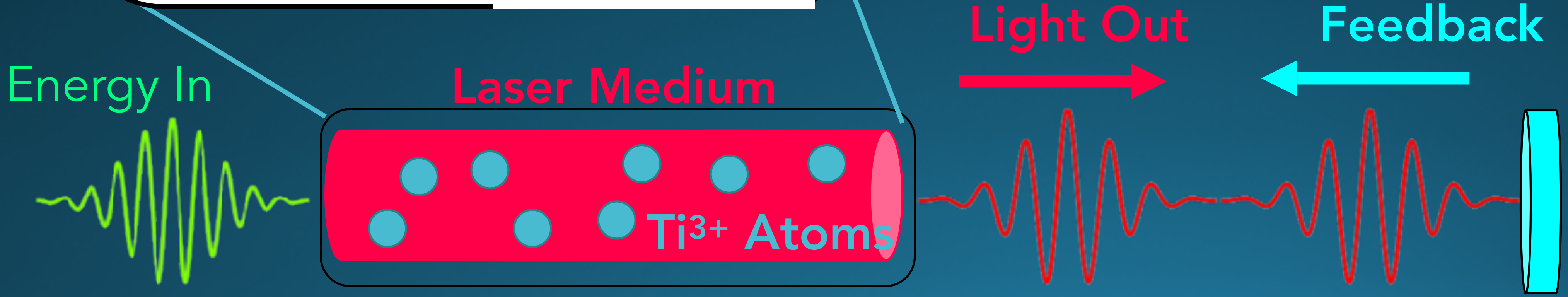

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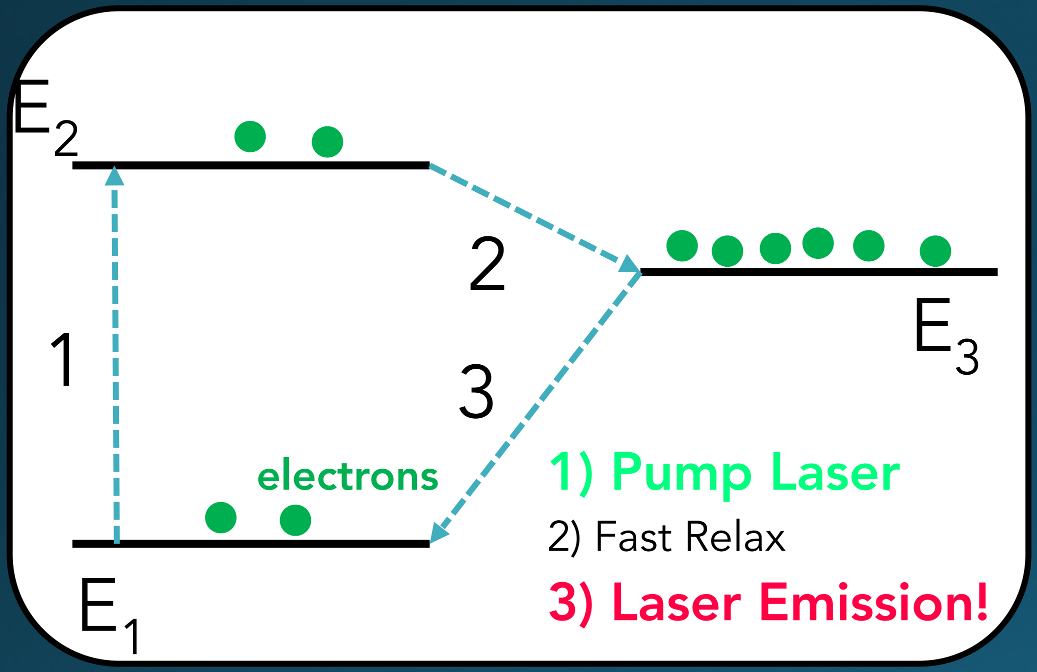

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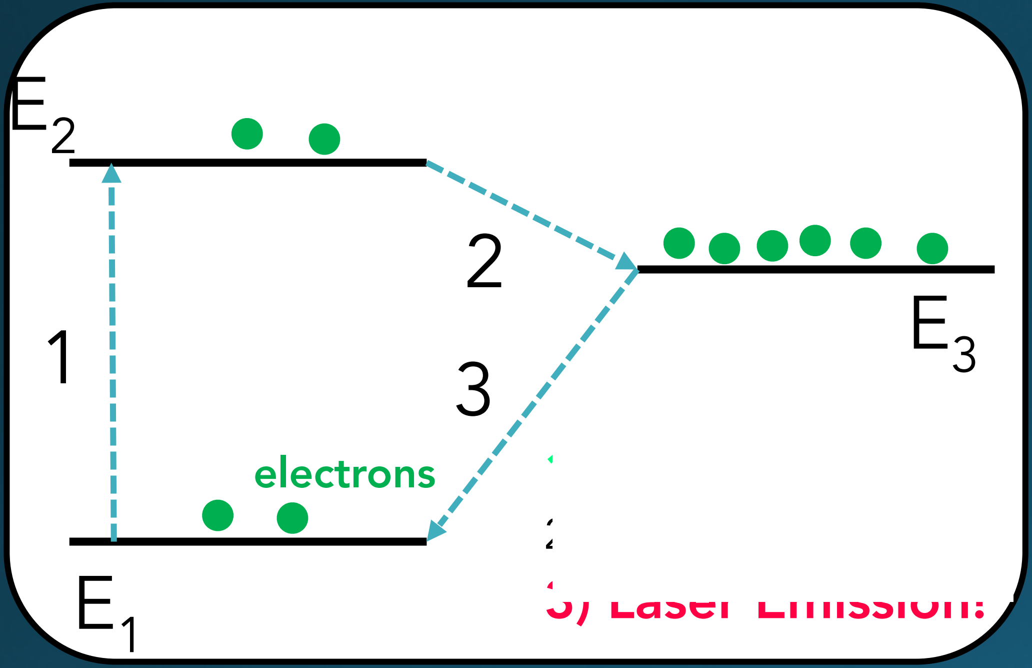

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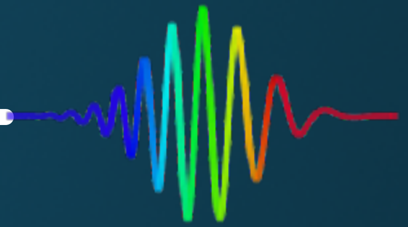

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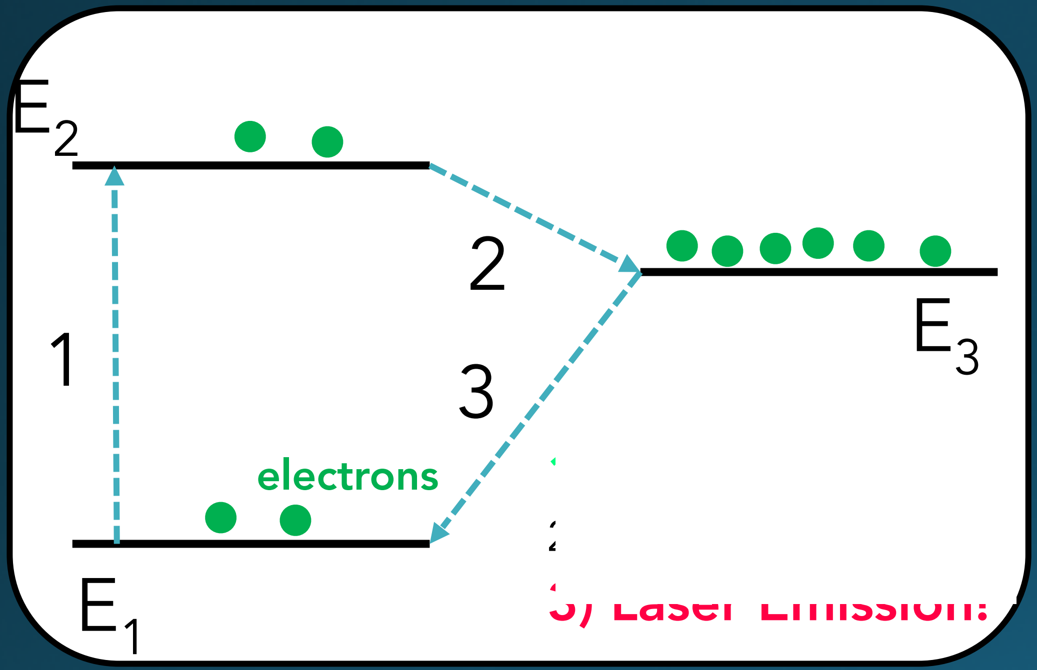

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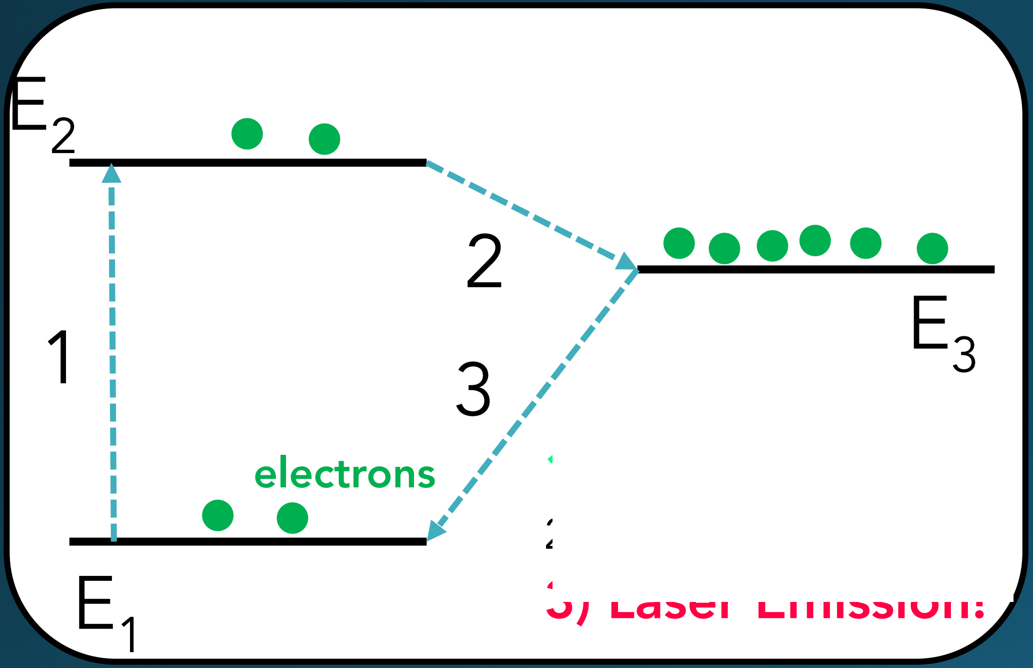

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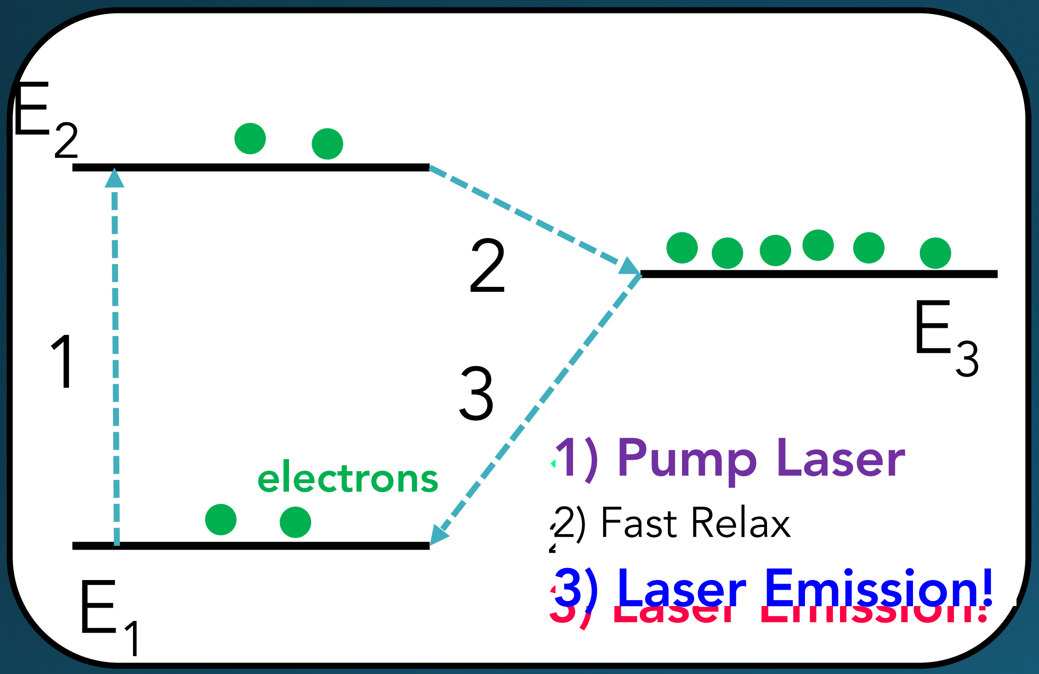

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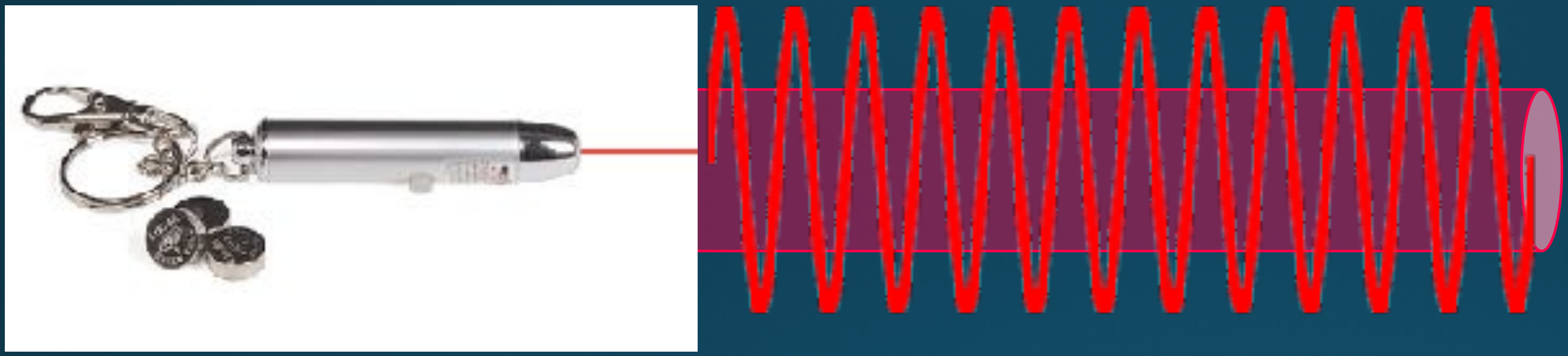

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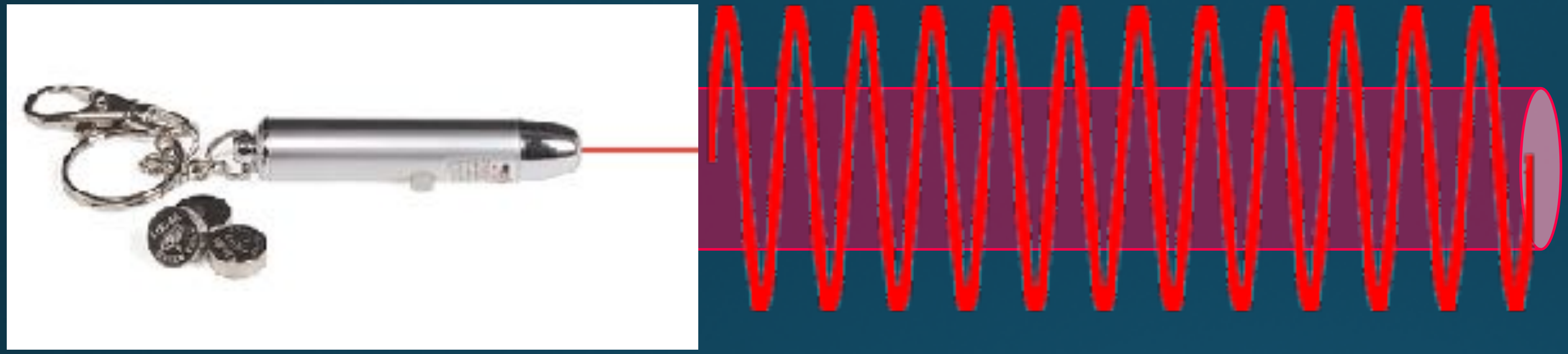

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Precise frequency/wavelength
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Long-Term Stability
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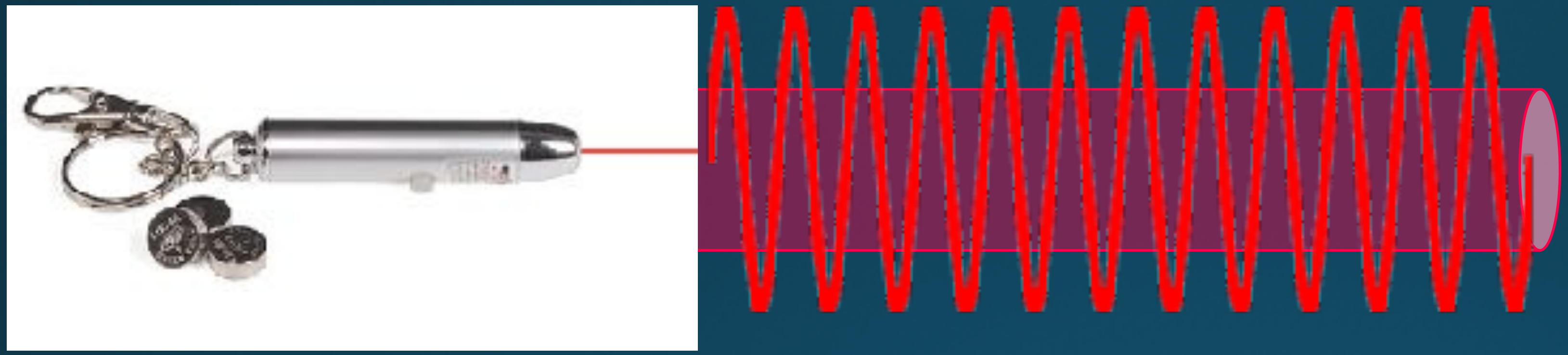

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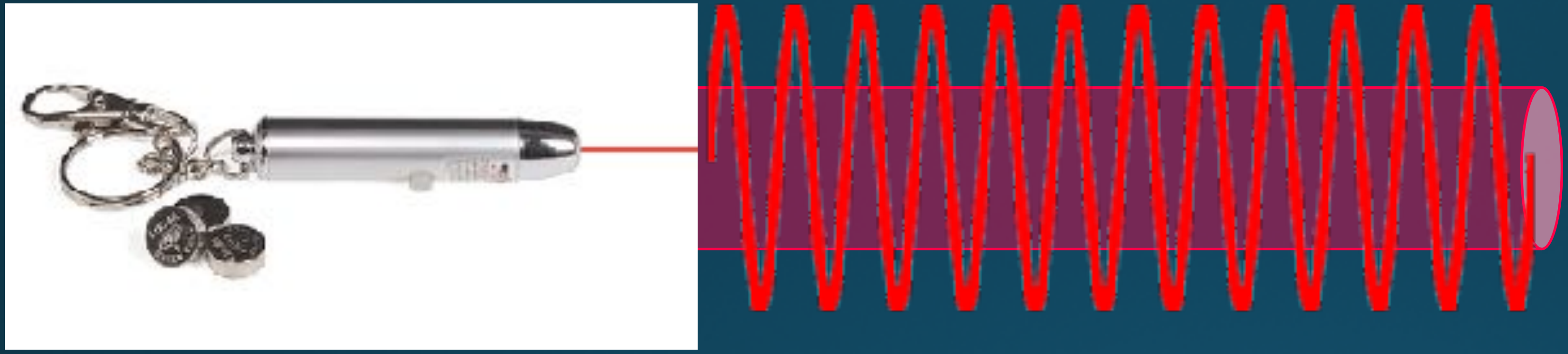

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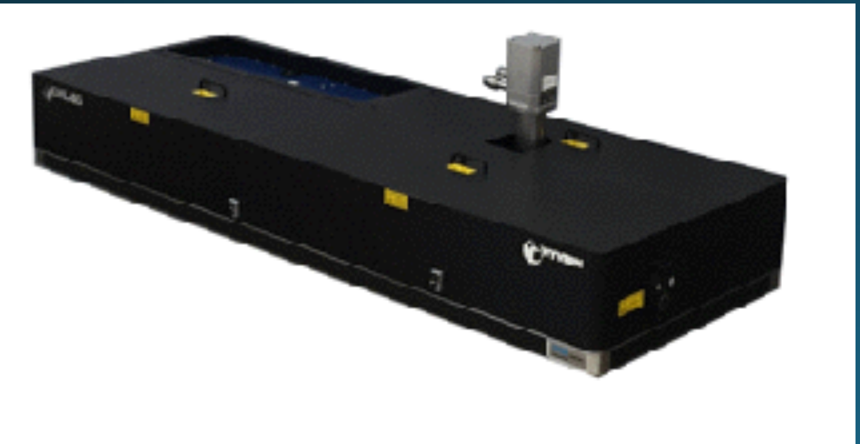

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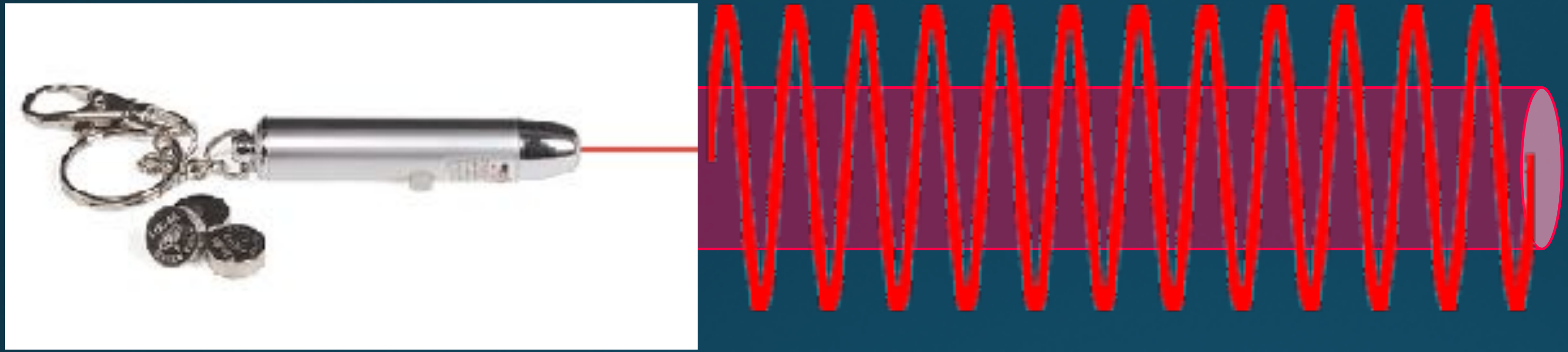

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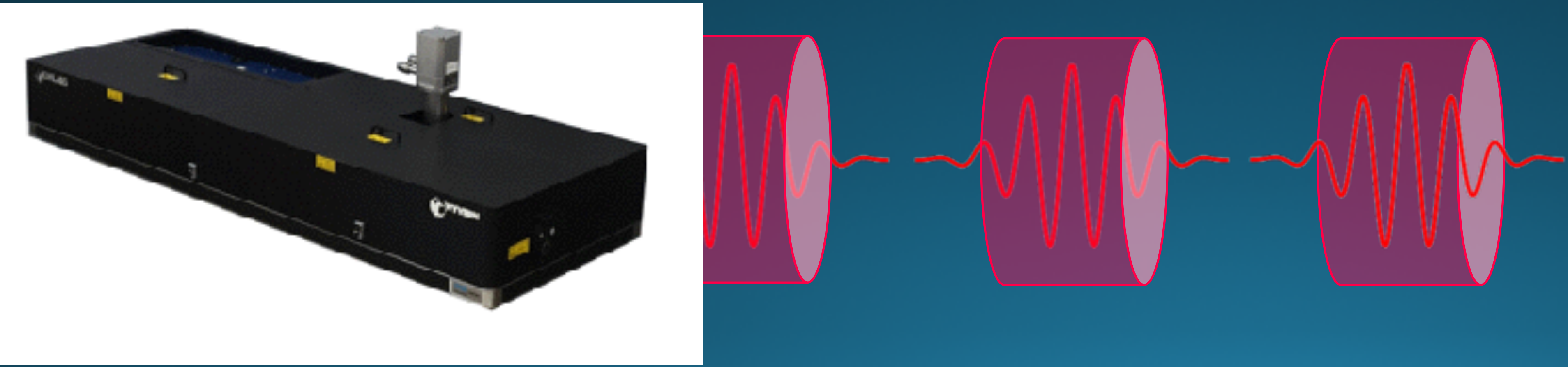

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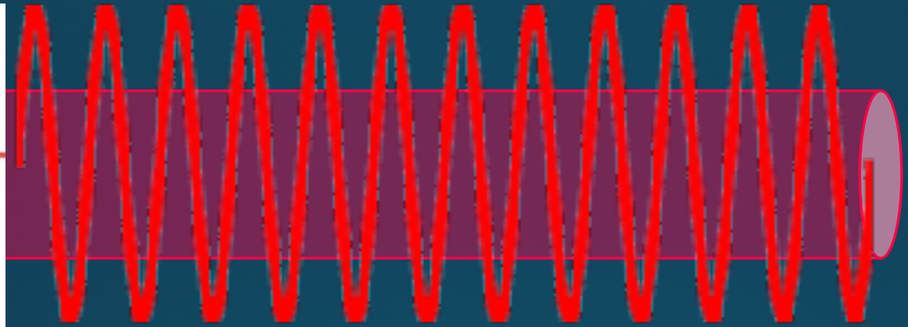

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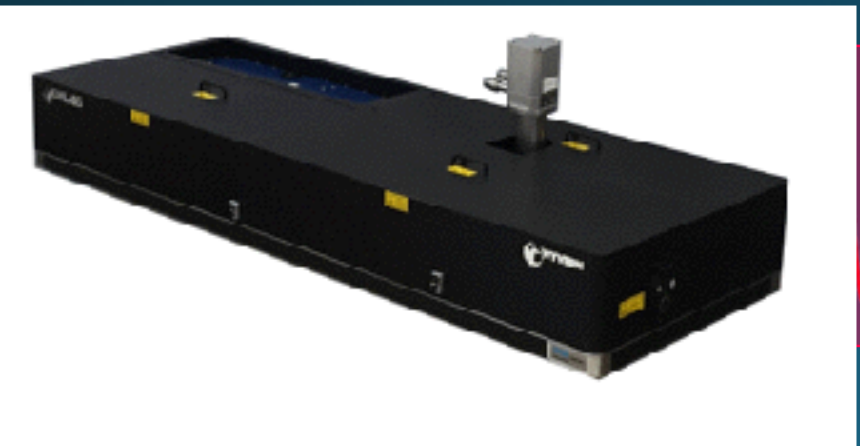

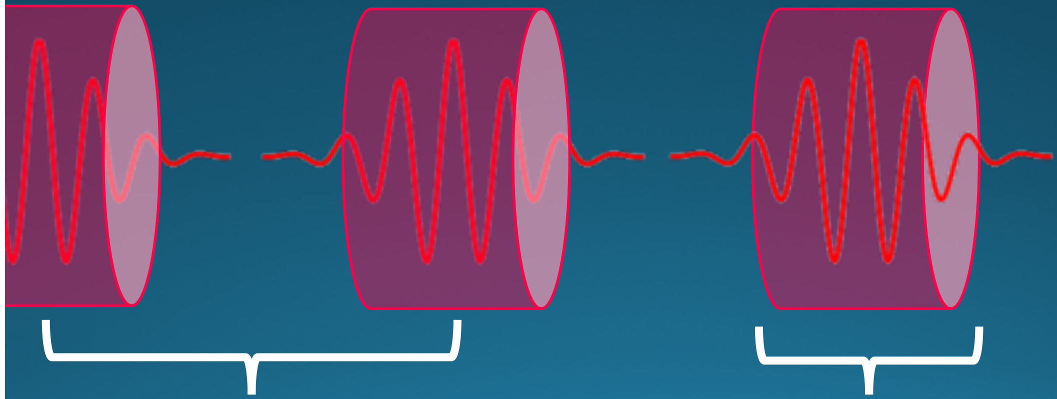

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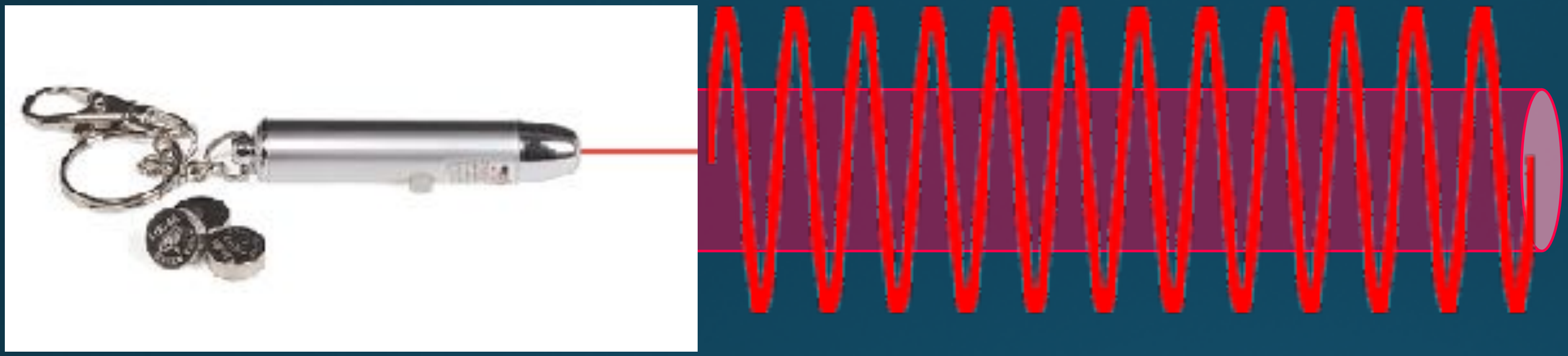

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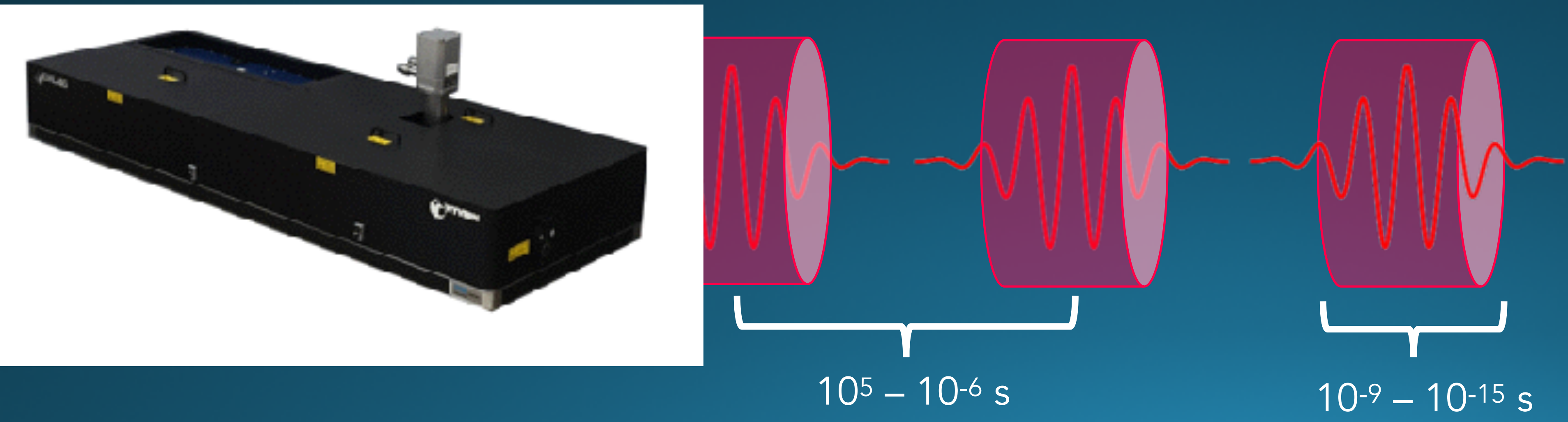

UF Laser Light

Many Frequencies/Wavelengths
Very High Intensity
Flashes "on" for 10^{-9} – 10^{-15} s
More Complicated to Design

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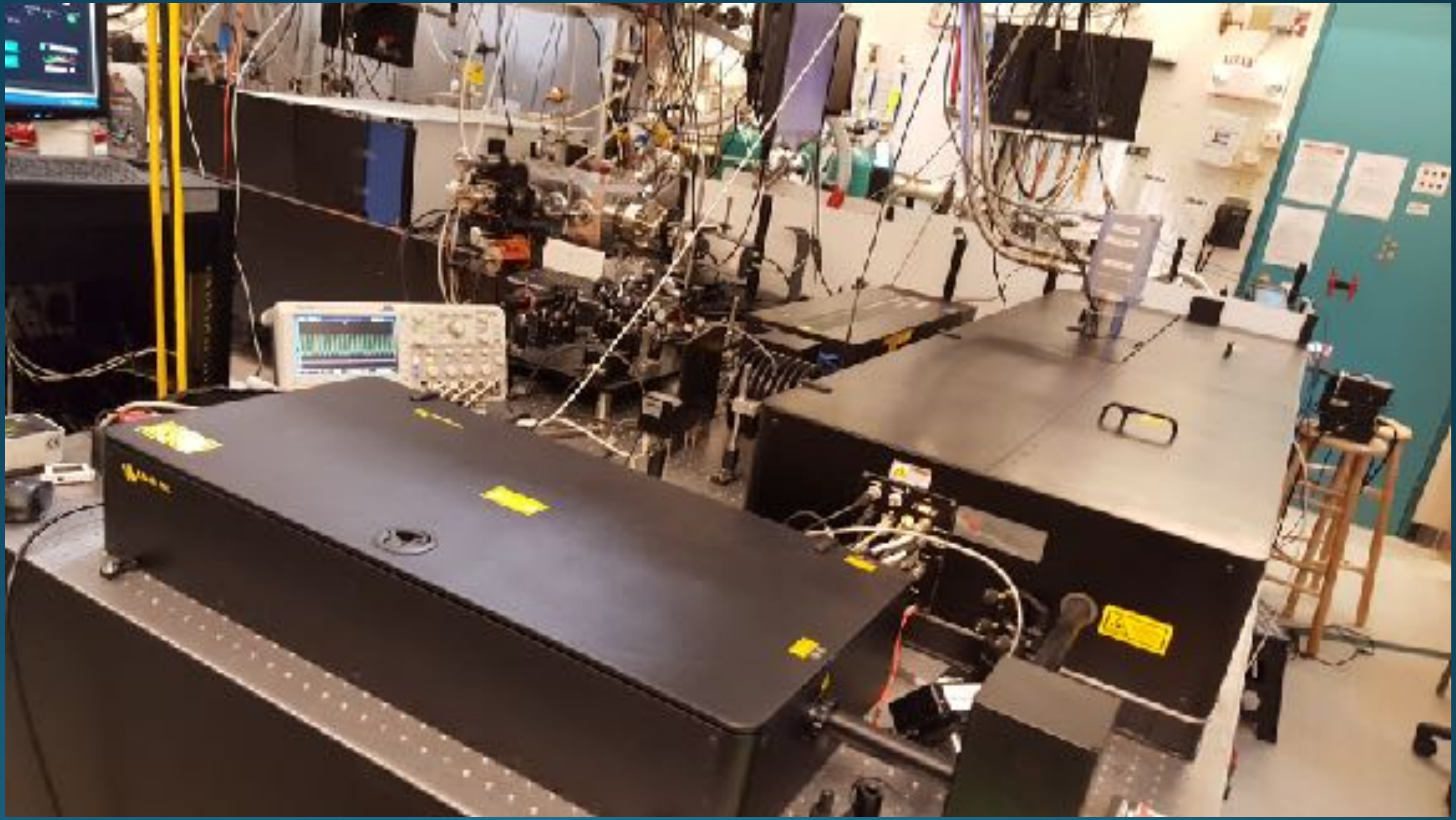

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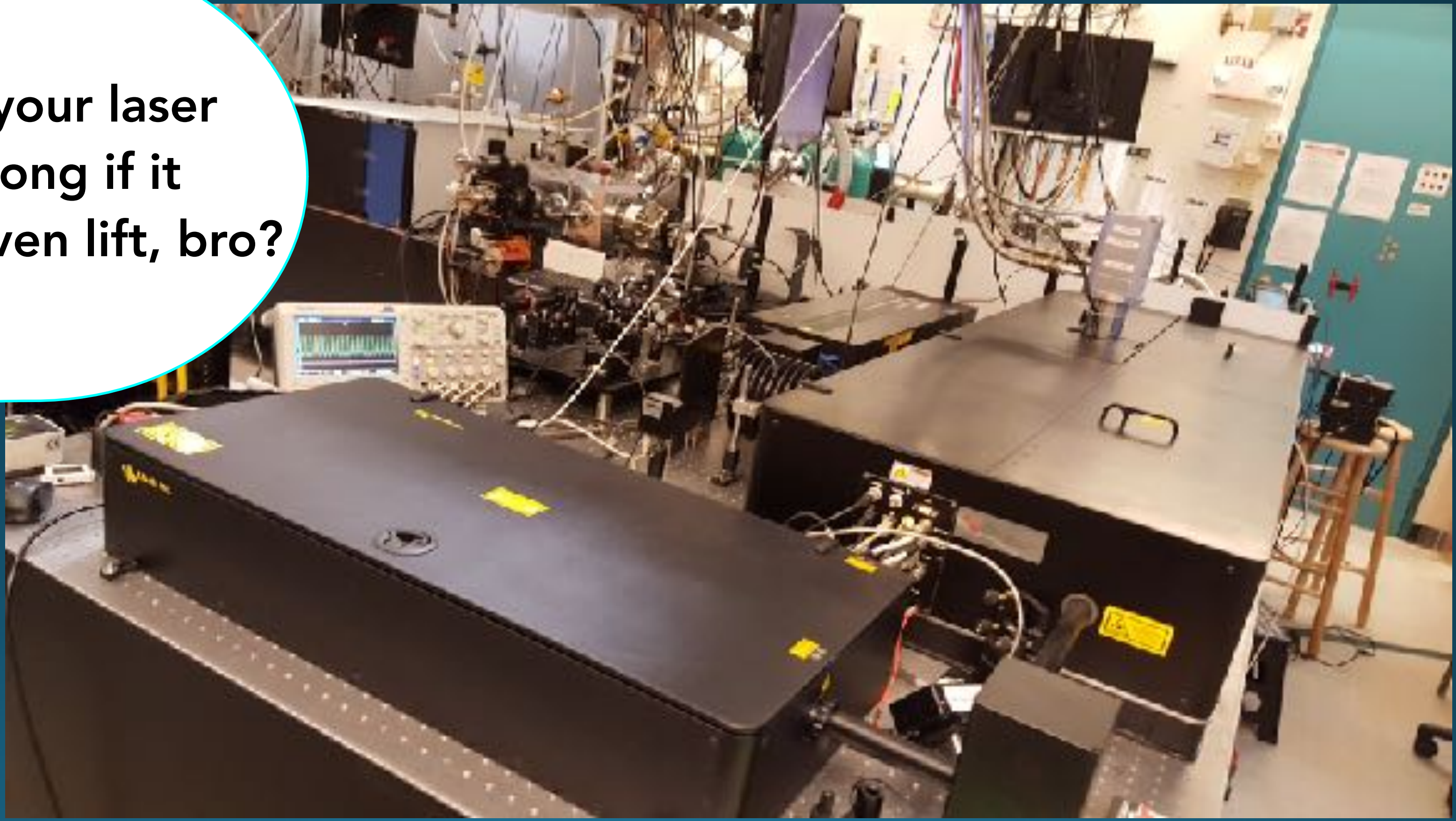

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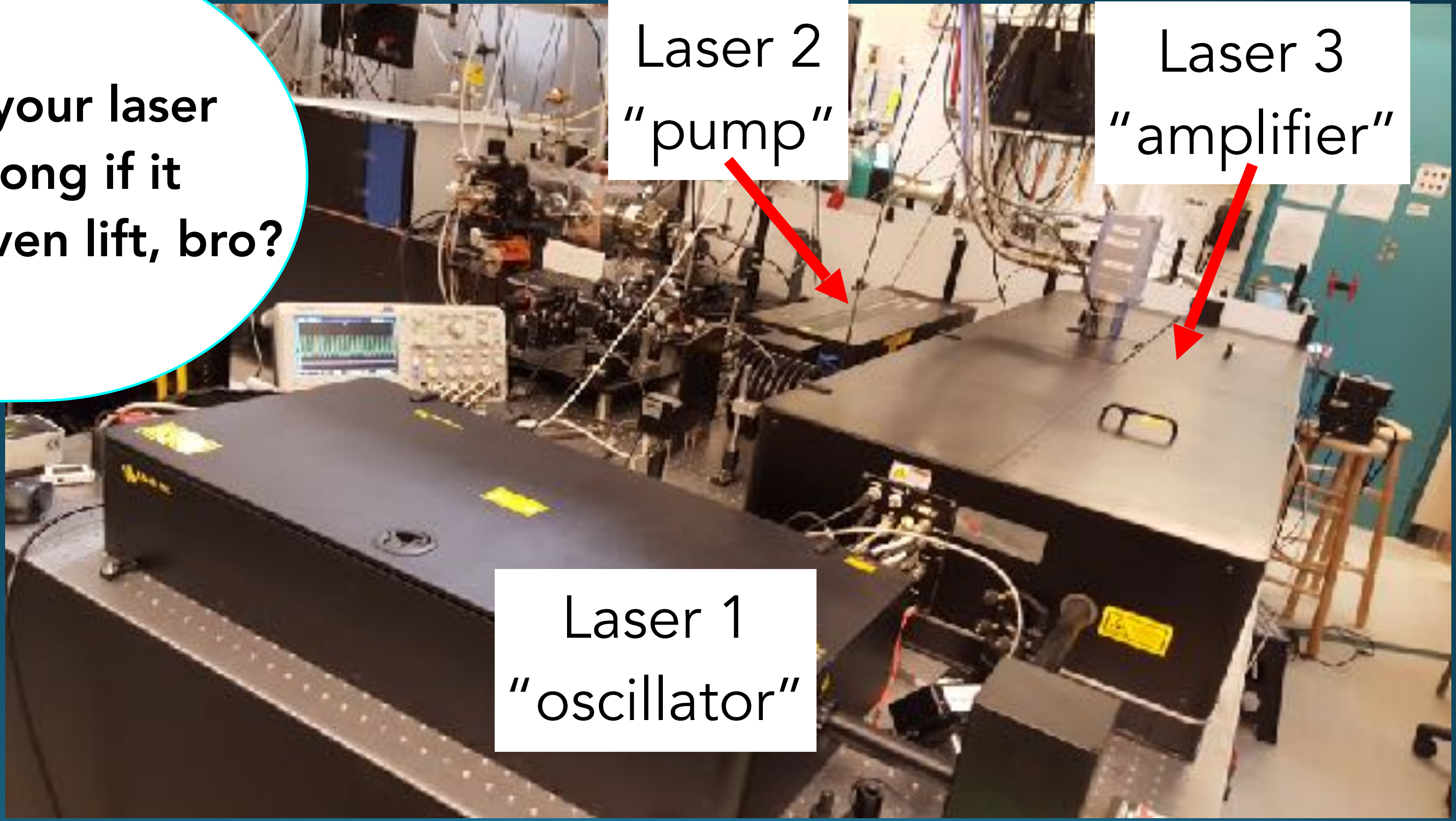

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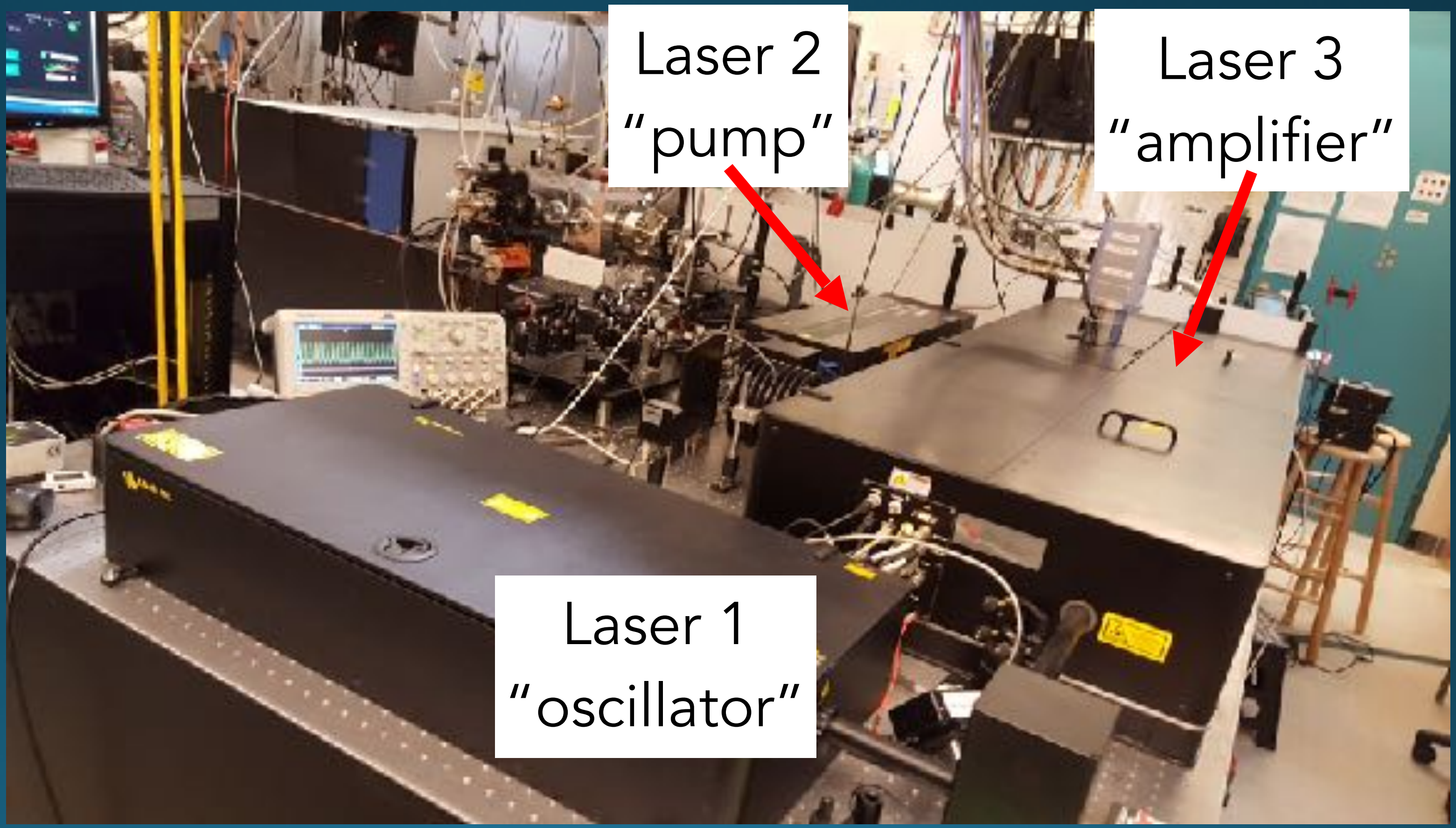

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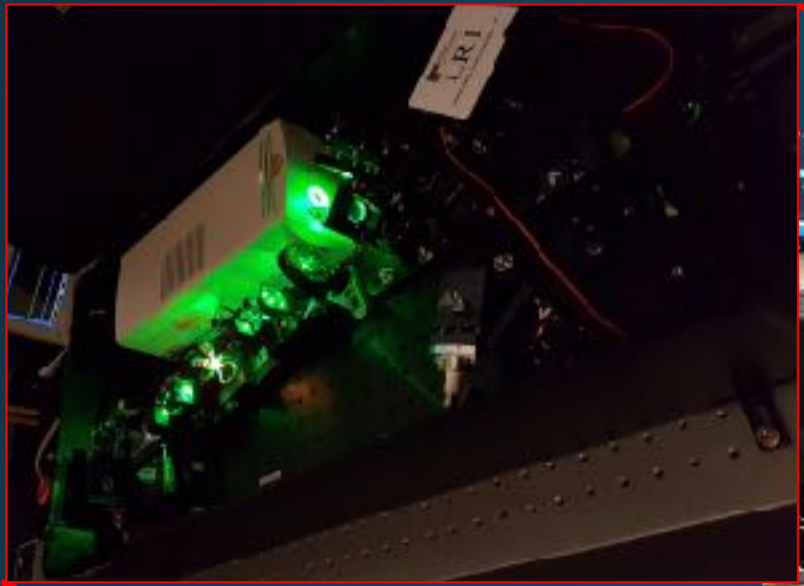

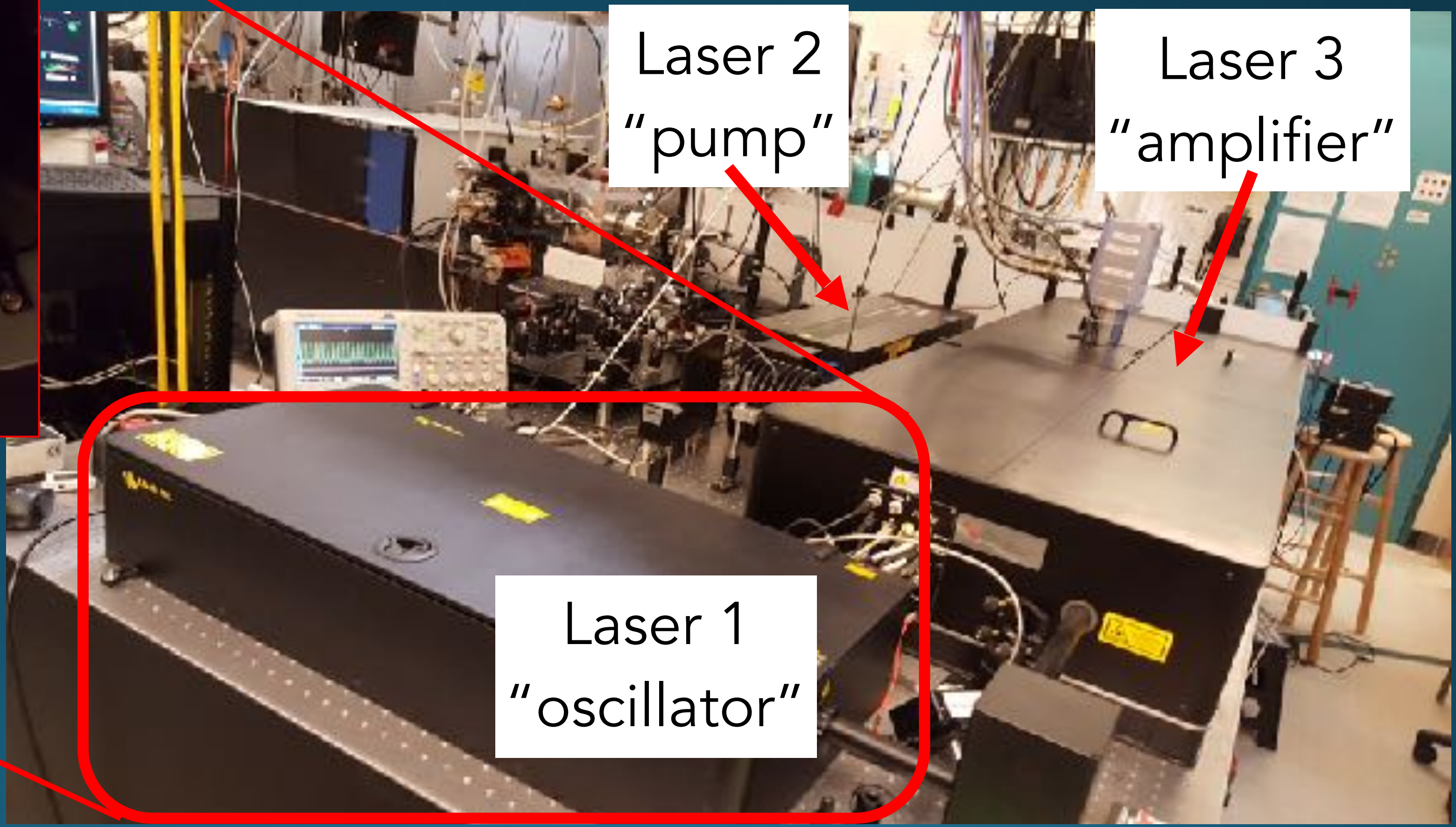

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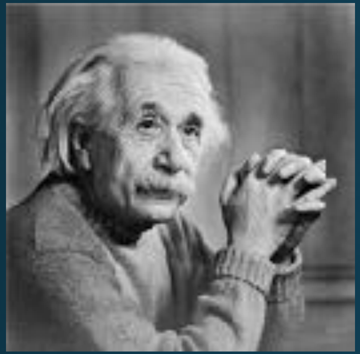

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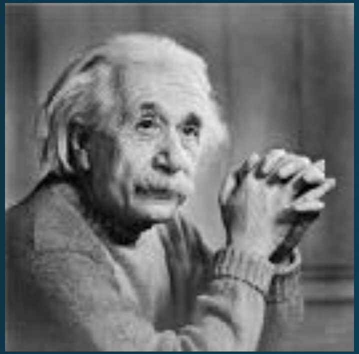

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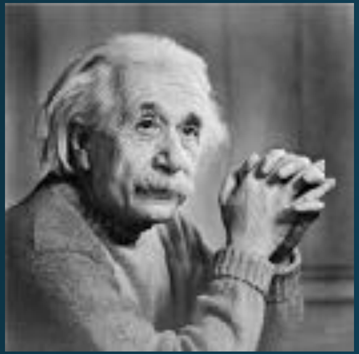

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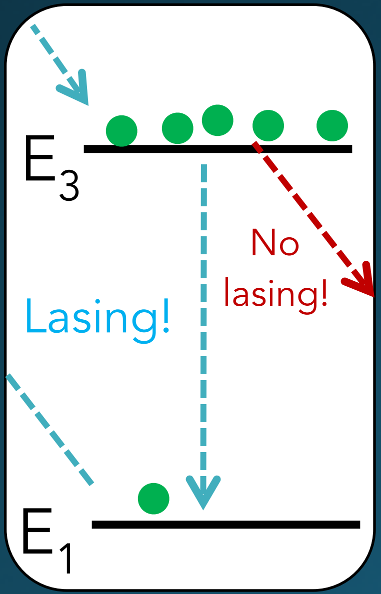

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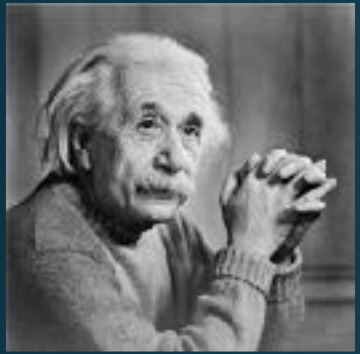

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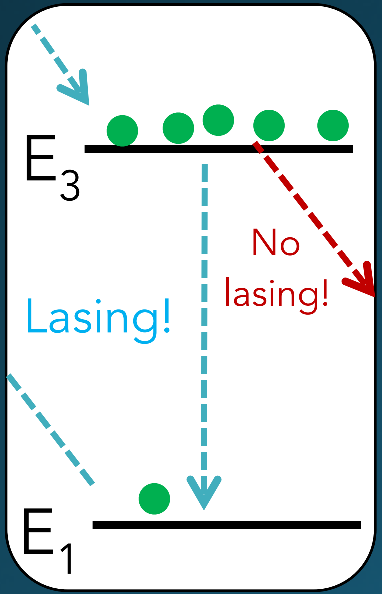

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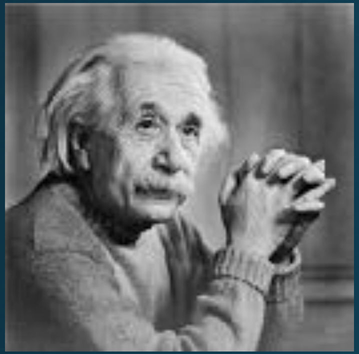

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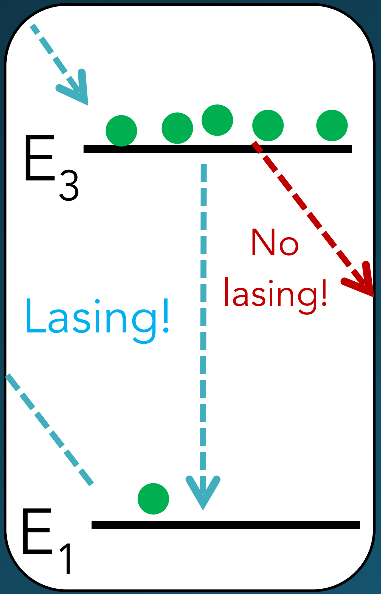

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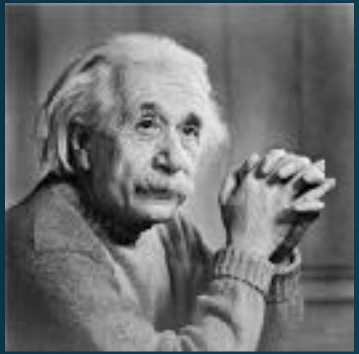

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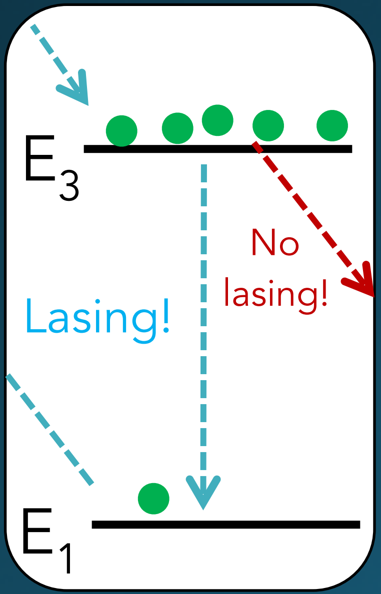

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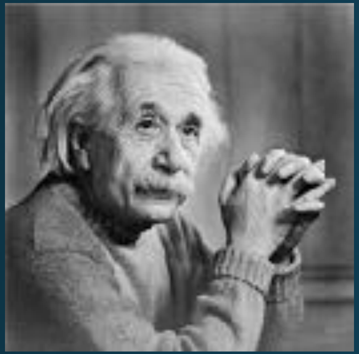

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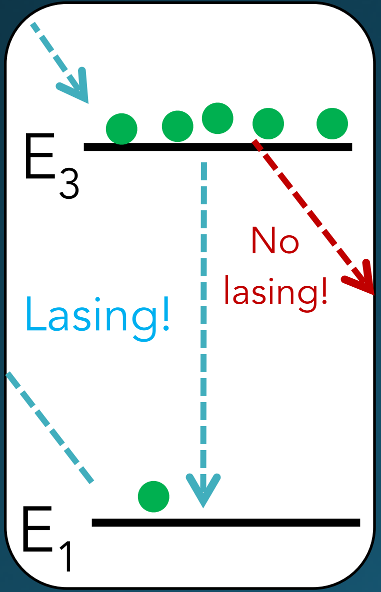

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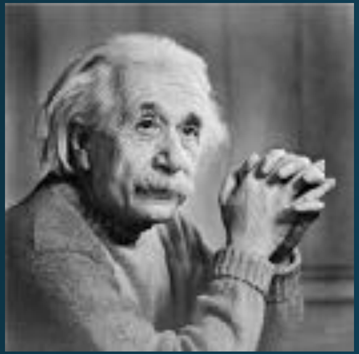

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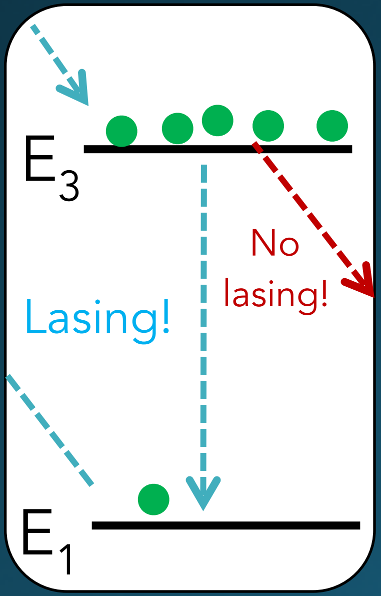

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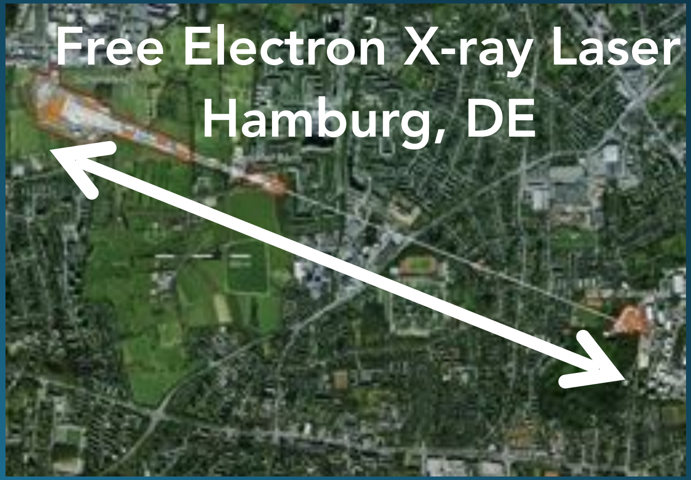

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   - **Average power produced by human body ~ 100 W**
   - **Power of mid-class 2017 sedan (250 horsepower) = 186,500 W**

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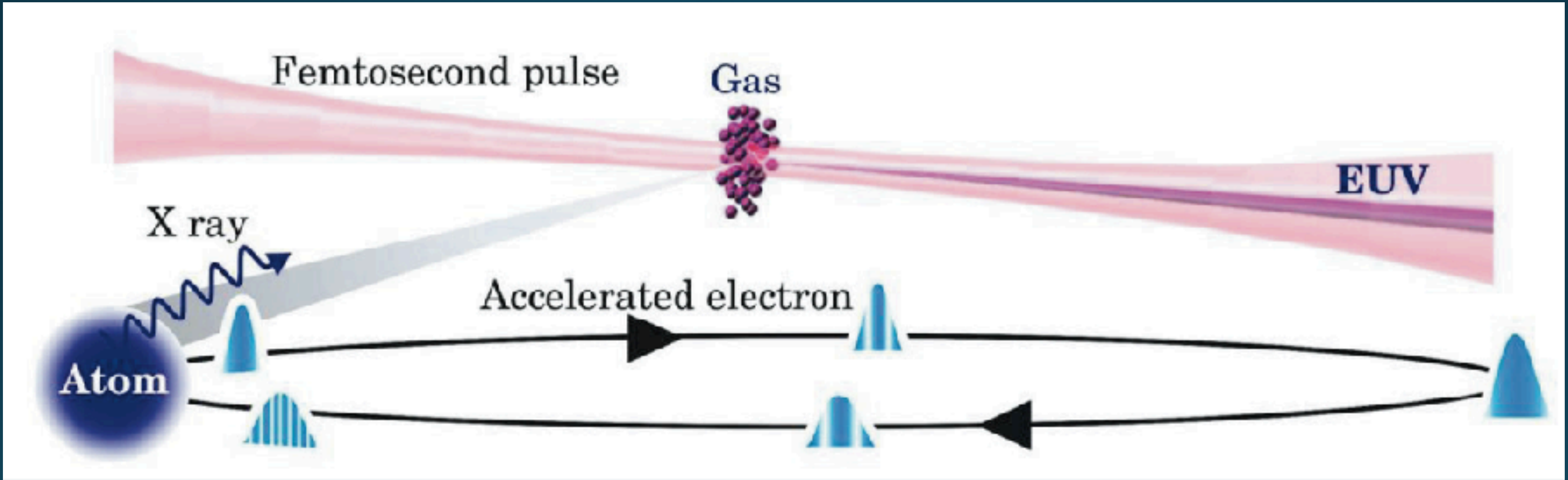

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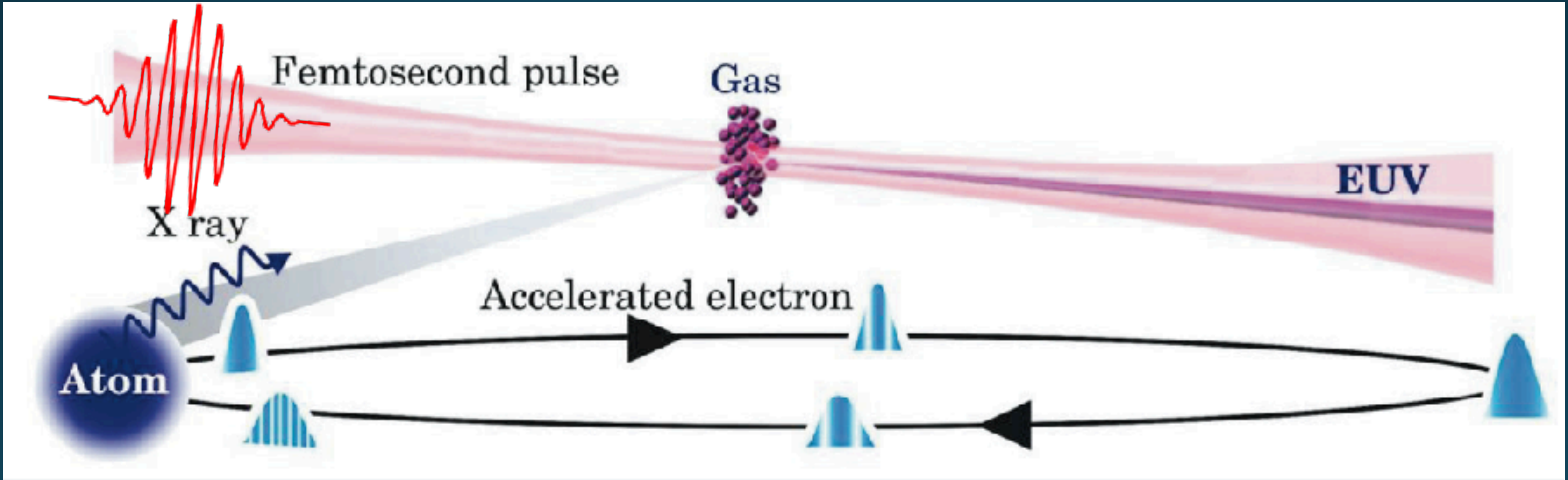
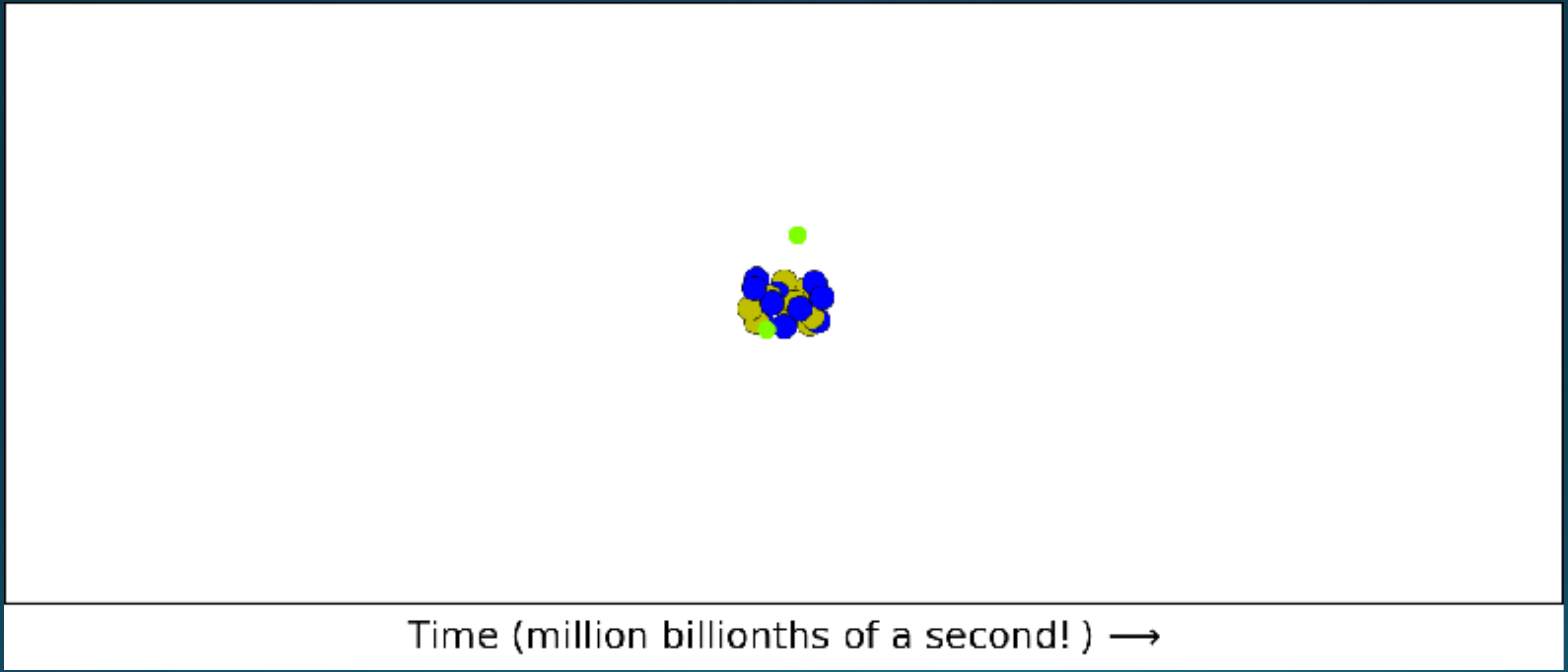


The X-ray Atomic Antenna: Little Electron, High Energy Laser Pulses!



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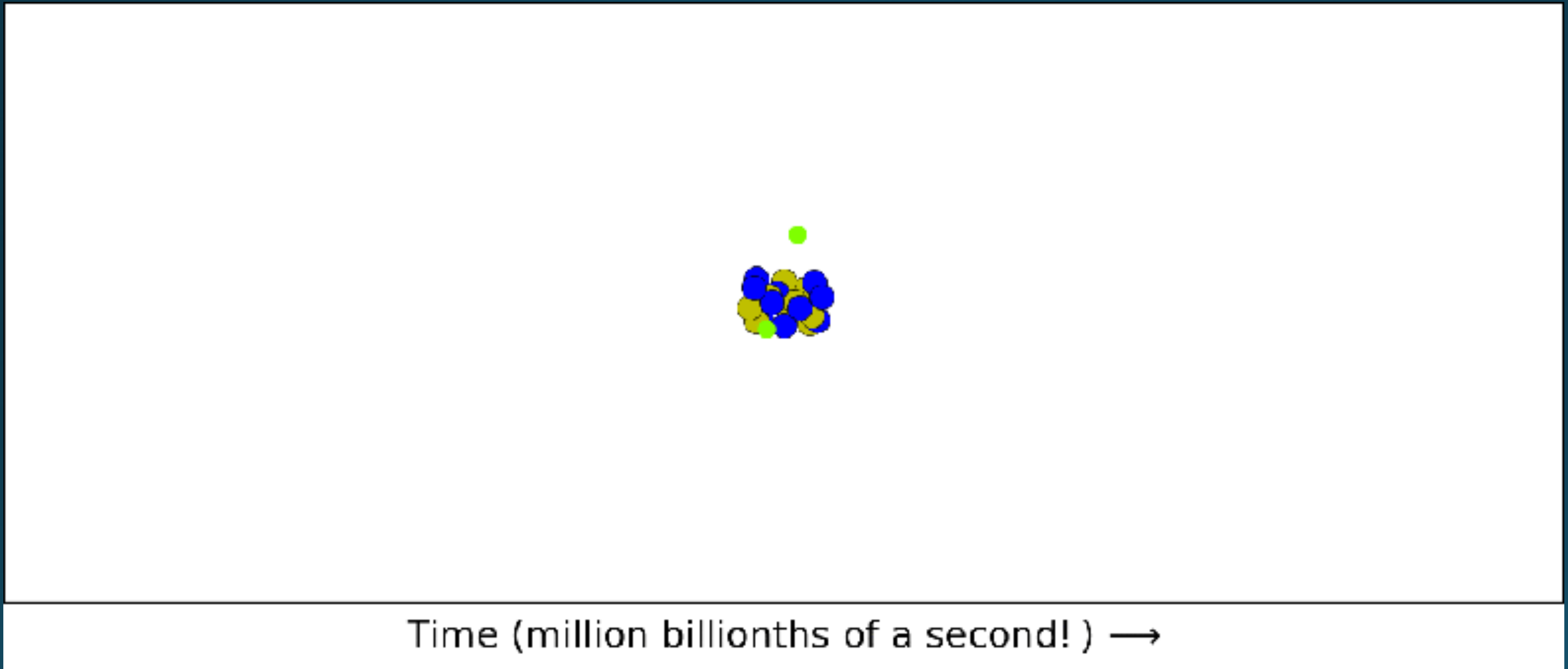
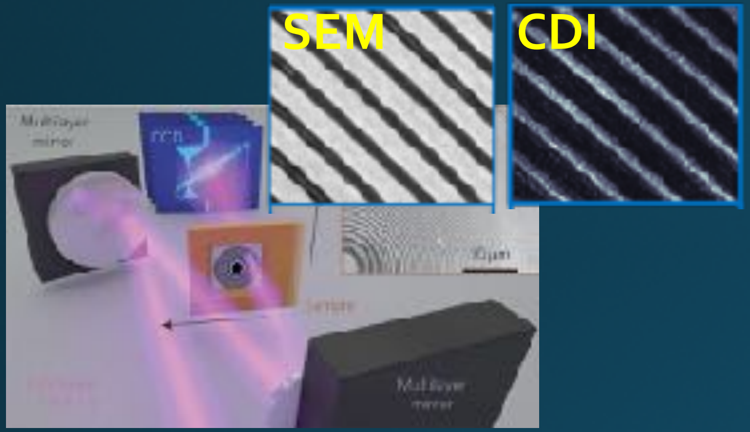
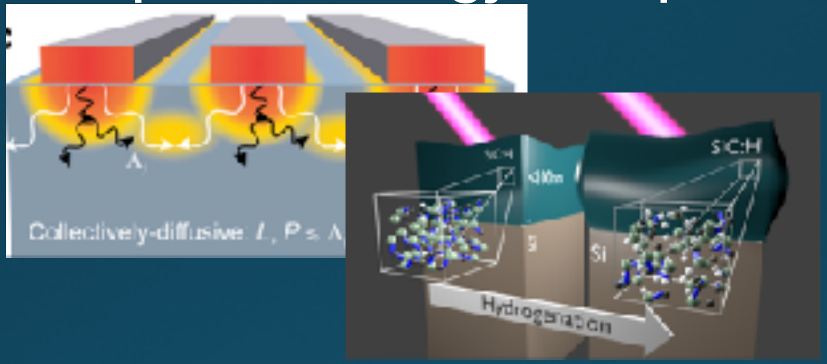


Tailored HHG Waveforms: Ideal Probes for the Nano and Atto Worlds

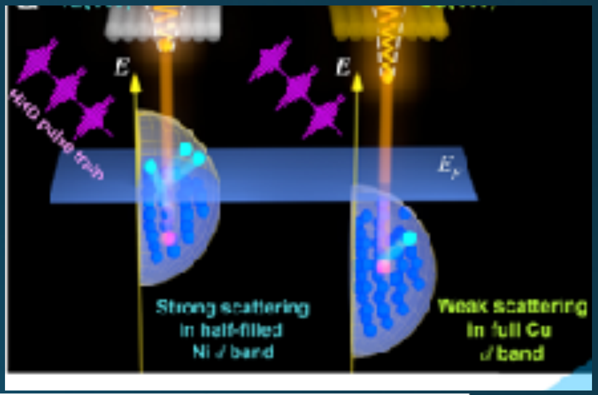
Nanoscale Imaging/Dynamics

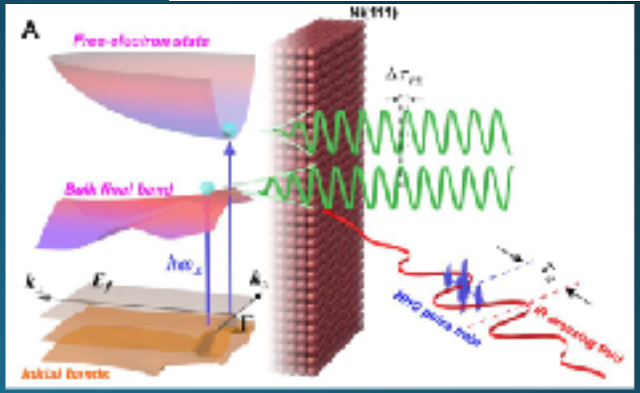


Nanoscale Mechanical Properties, Energy Transport



Unraveling Coupled Dynamics in Condensed Materials





Charge/Energy Flow in Molecular/Nano Systems

Spin Transport in Magnetic
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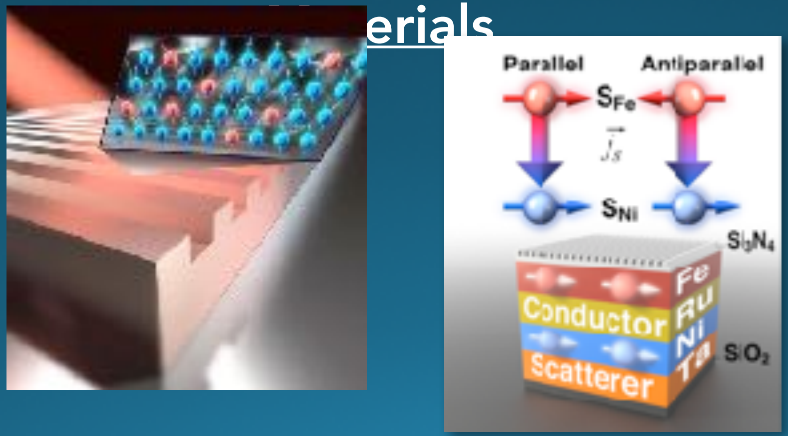

The Eternal Quest to Make Cell Phones and Computers Smaller than Ever…

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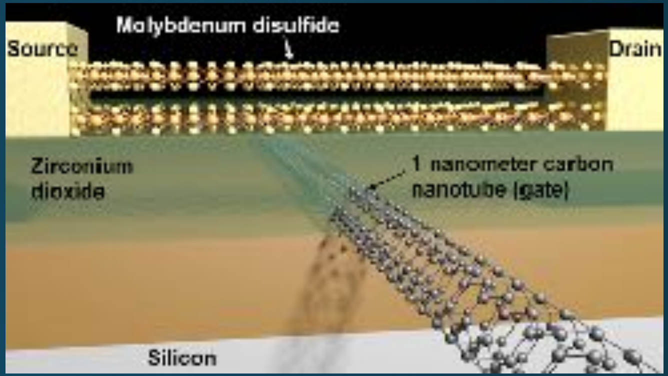

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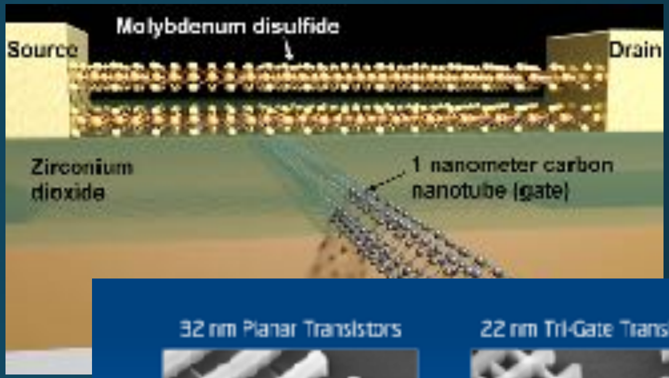

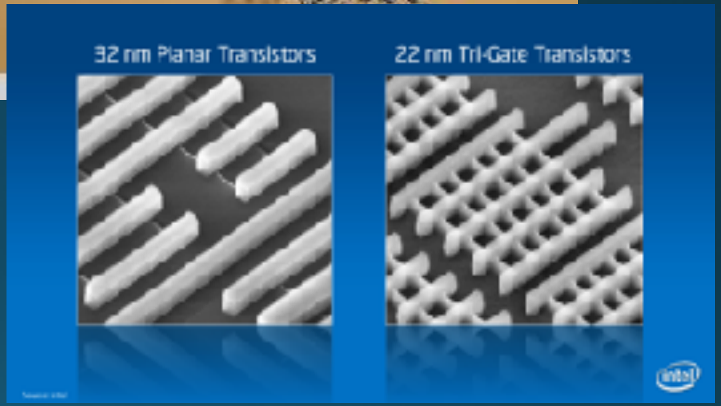

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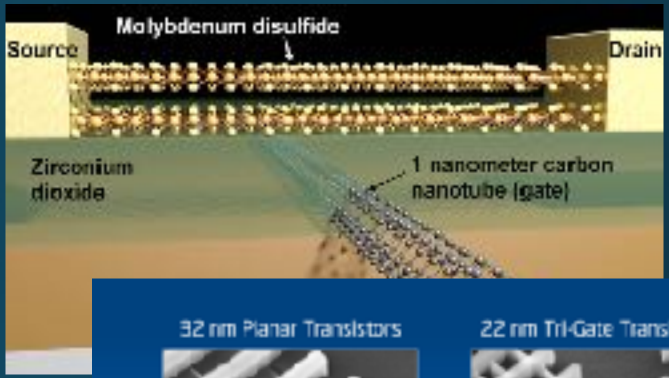

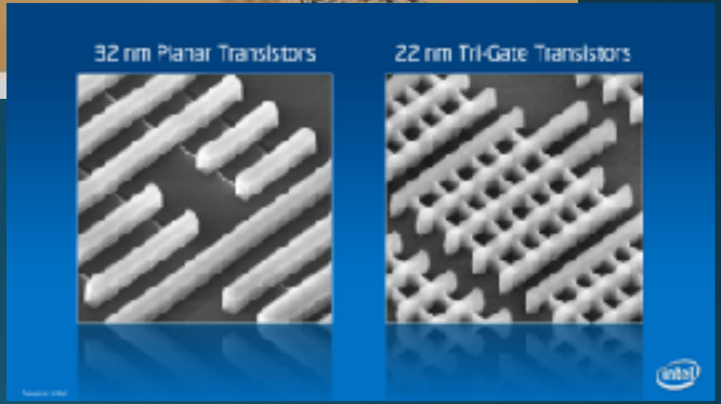

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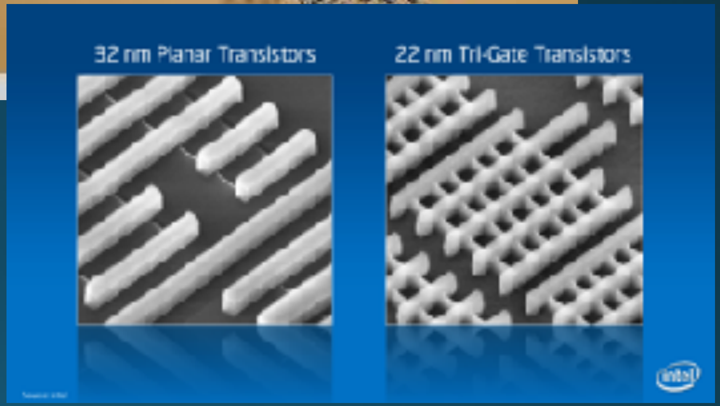

Samsung Note 7 Battery Testing Facility

Nano X-Ray Vision: Directly Visualizing the Nano Landscape

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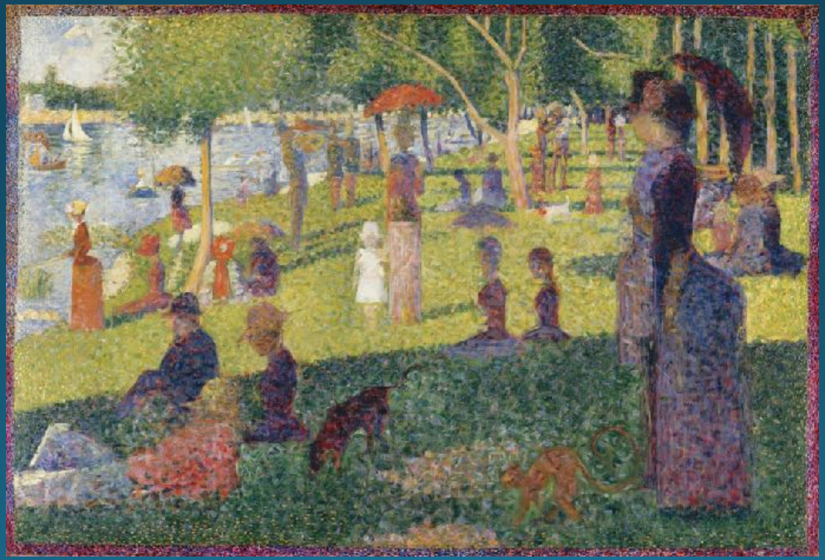

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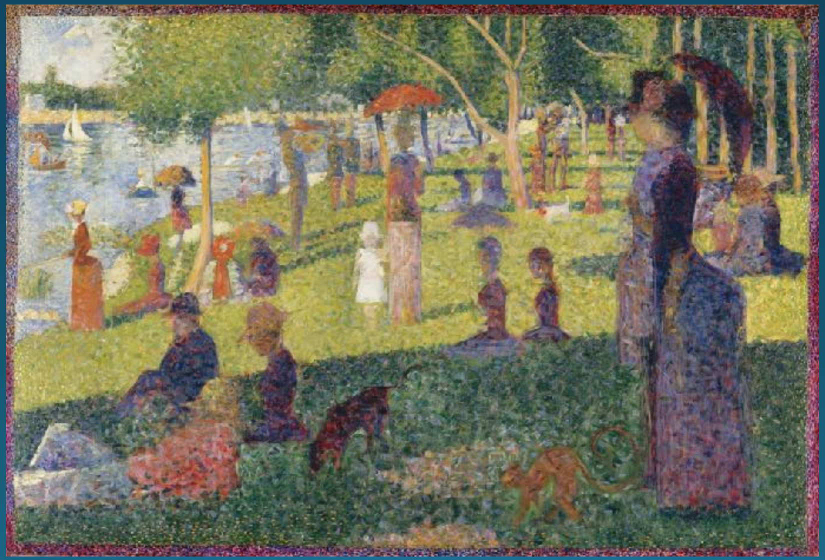

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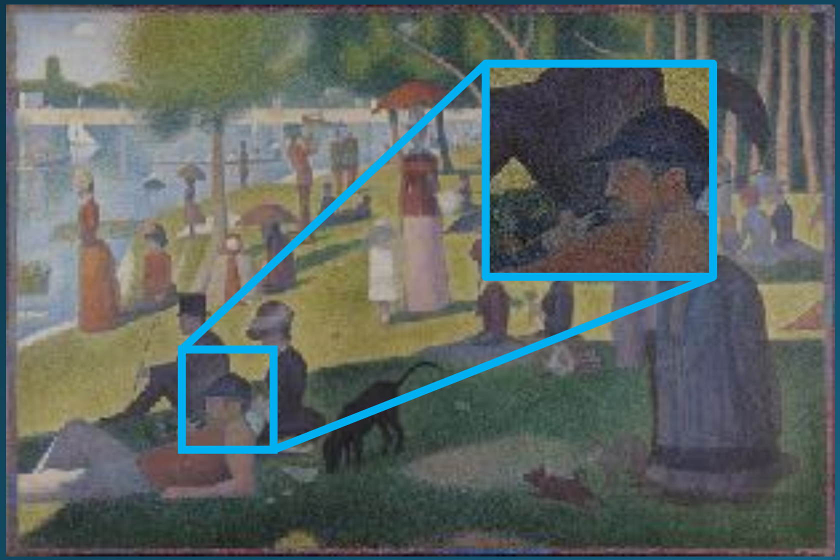

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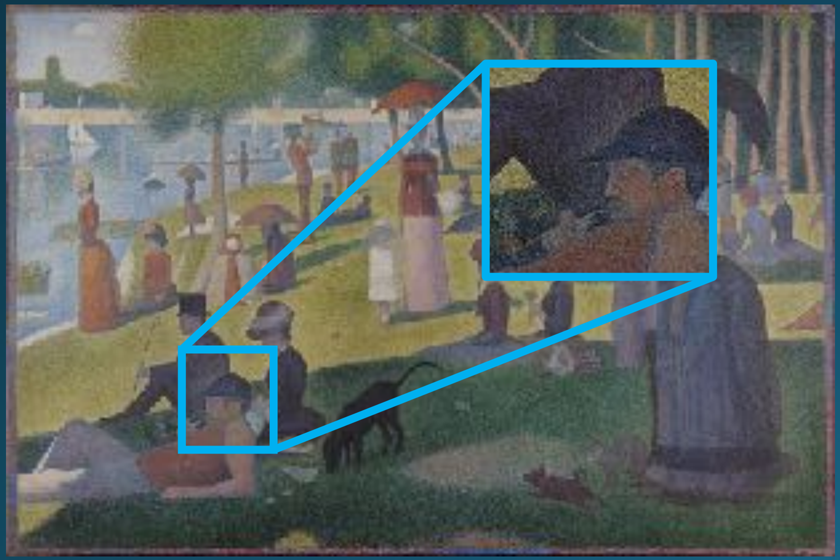

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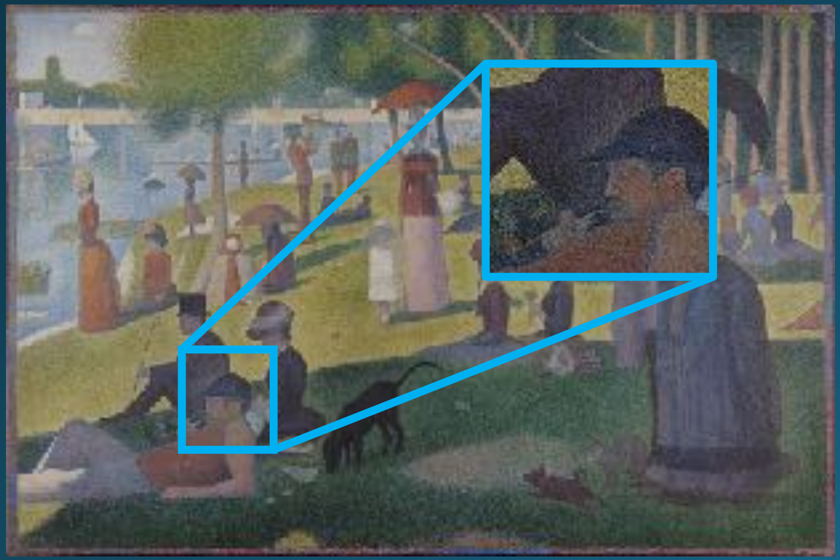

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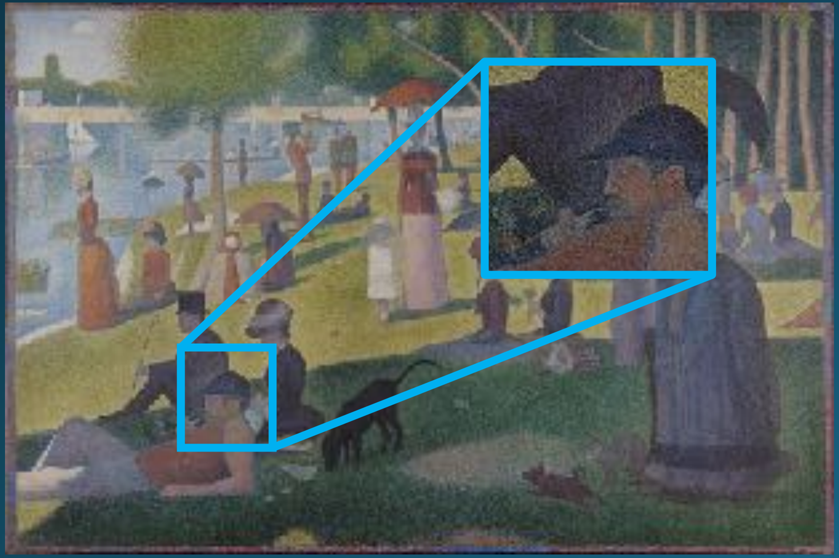
Credit for analogy



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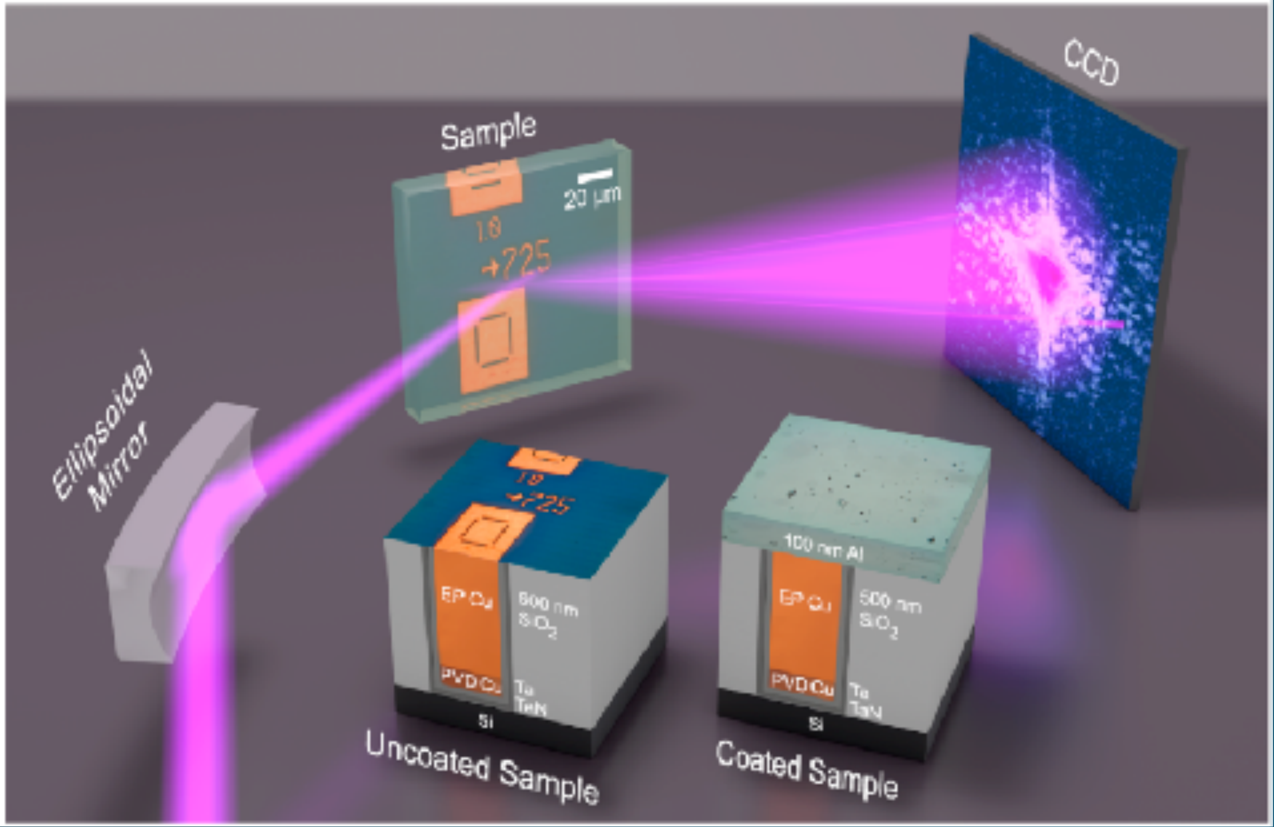
Real (No Really) X-Ray Vision: Peering Through Diffusion Layers in Materials



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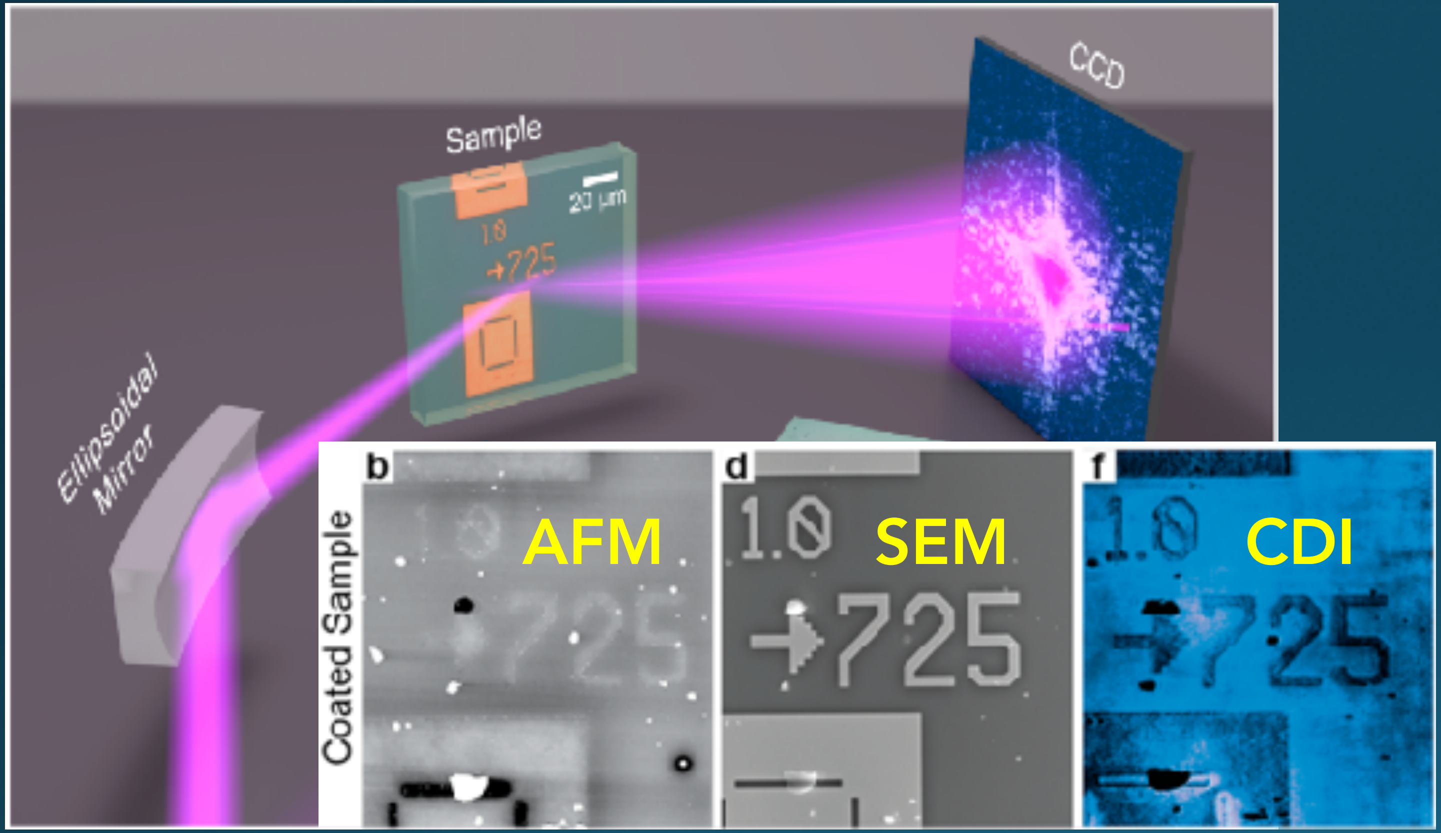

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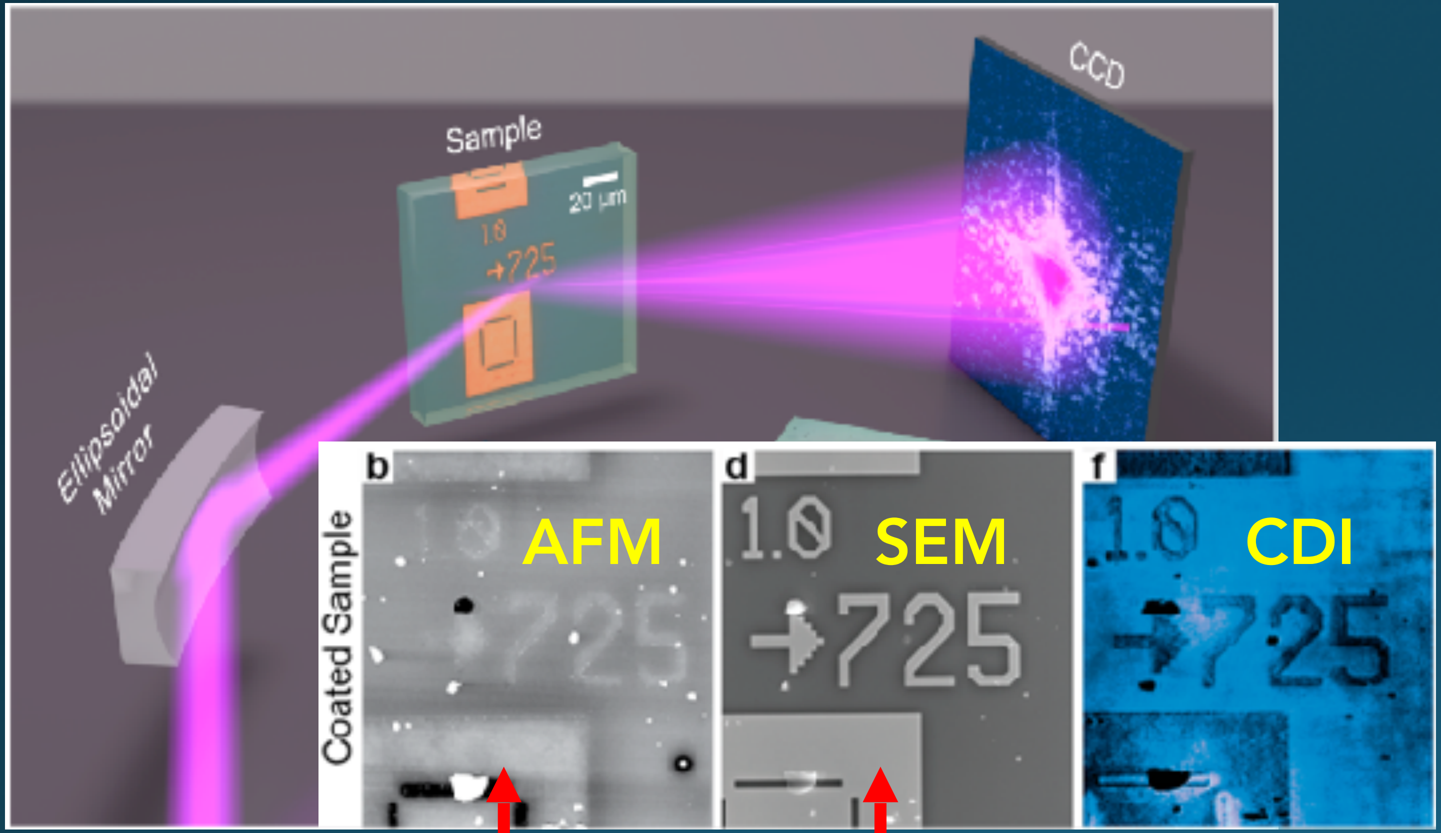

Destructive

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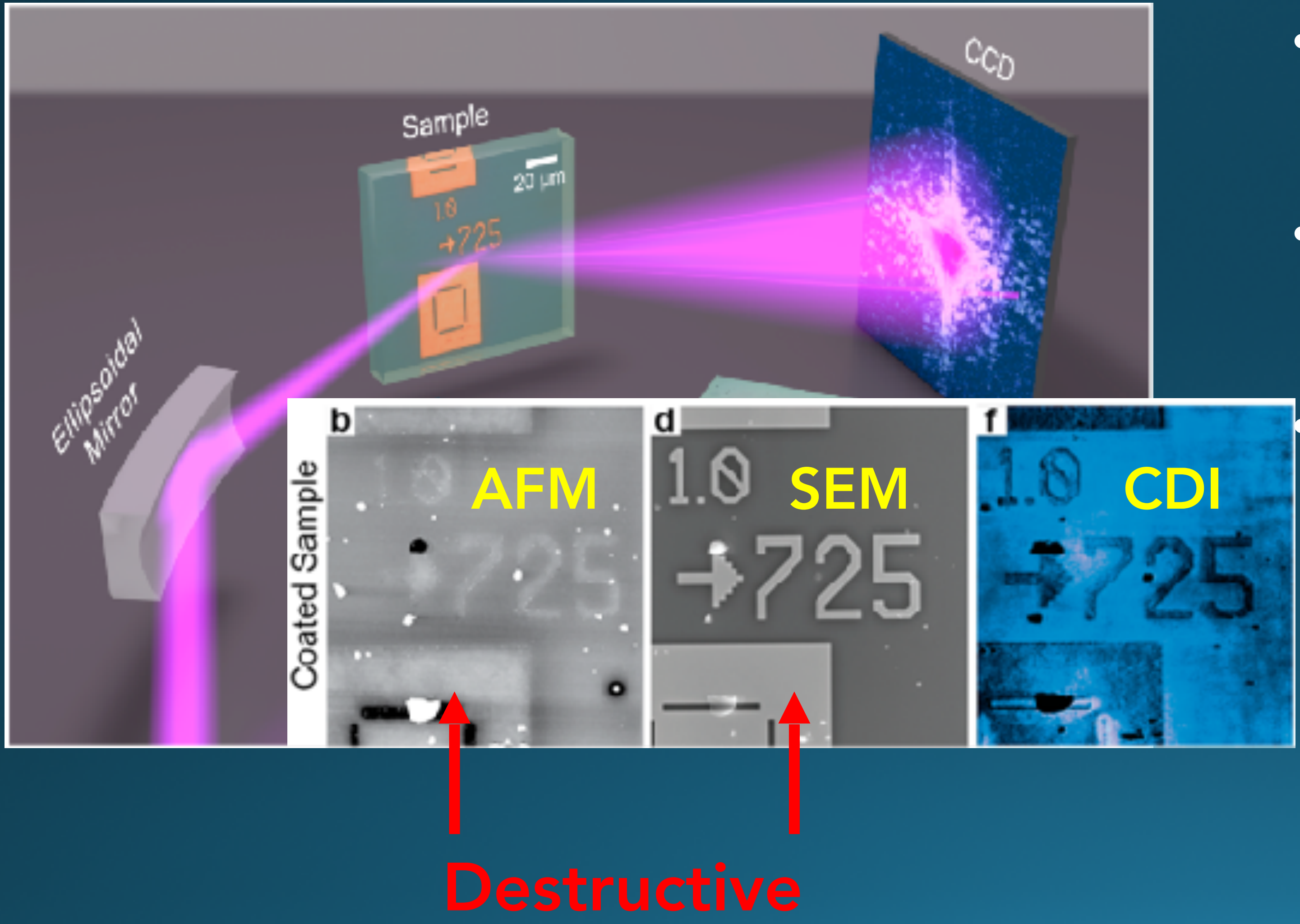

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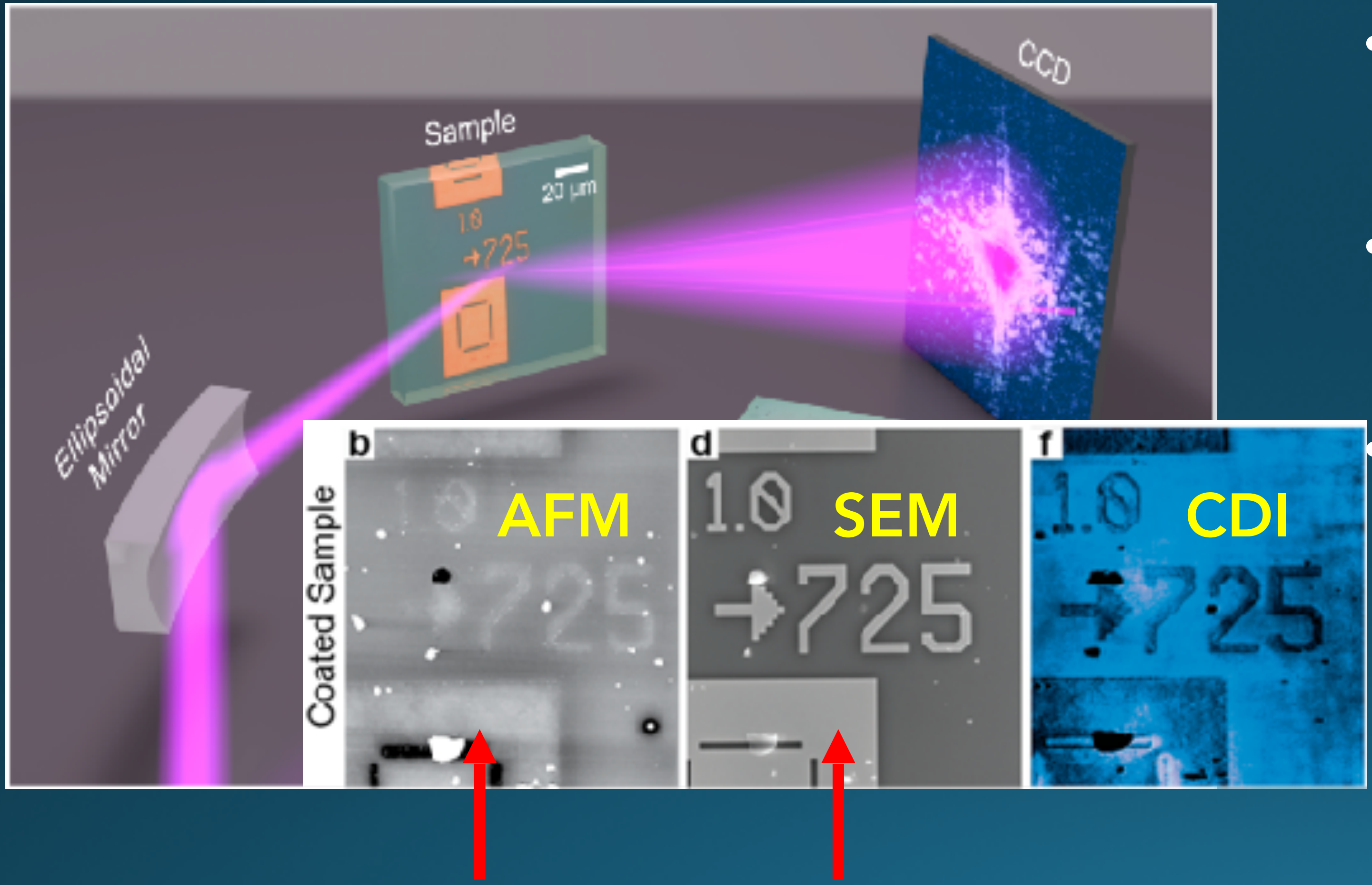

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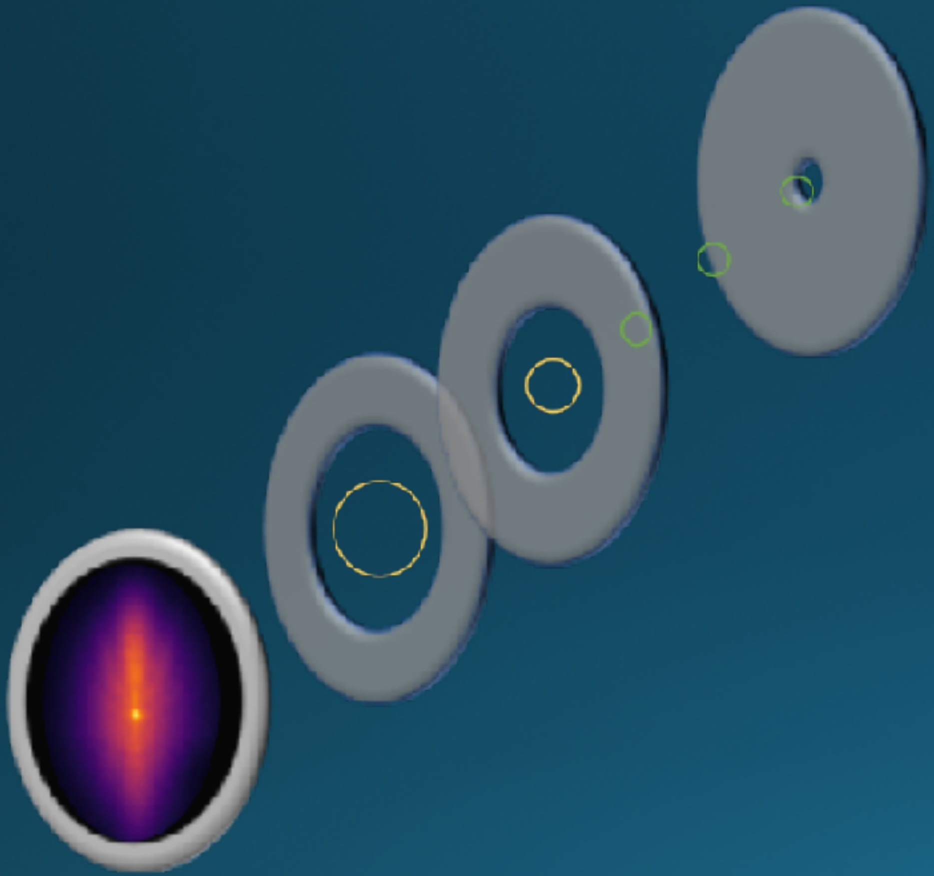

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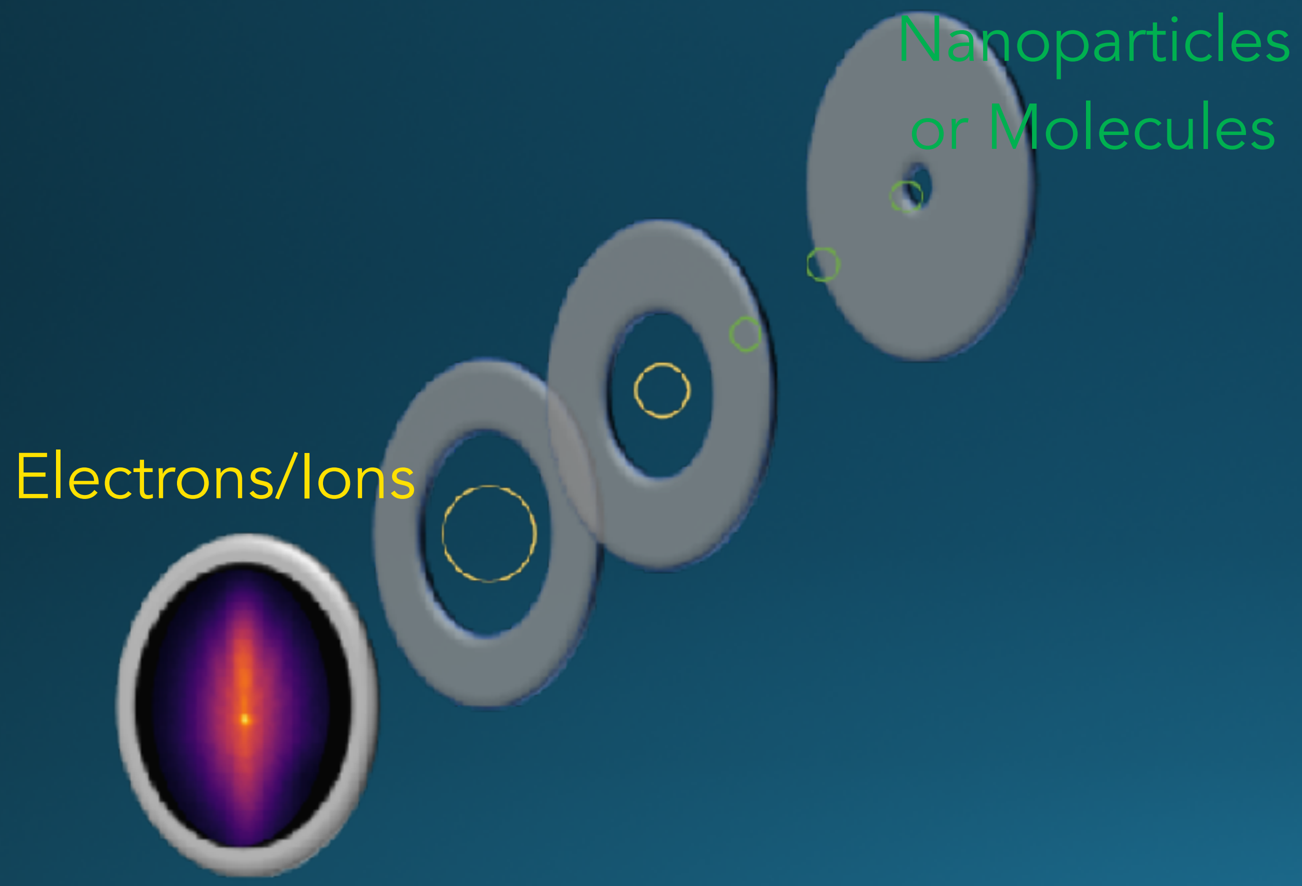

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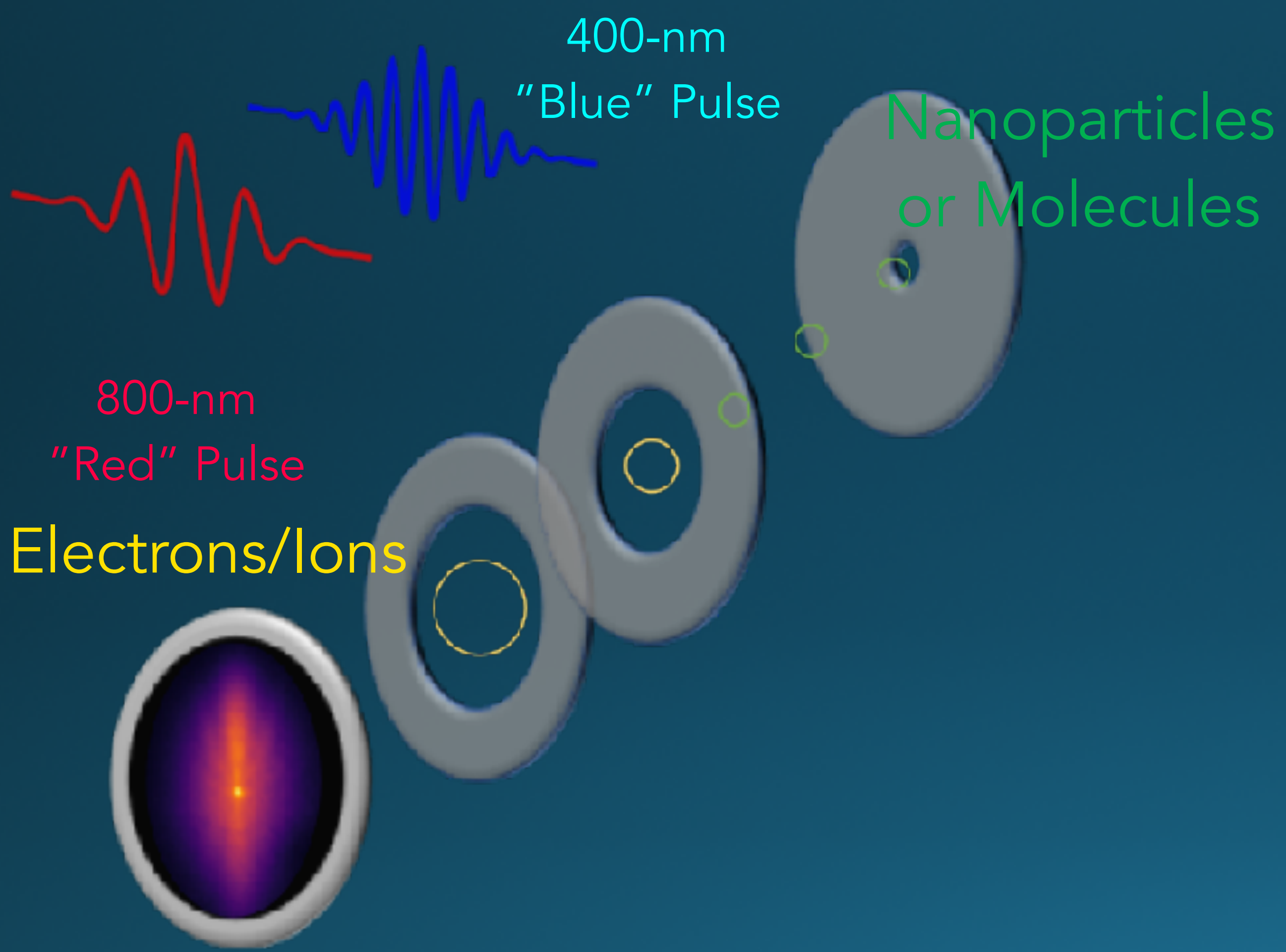

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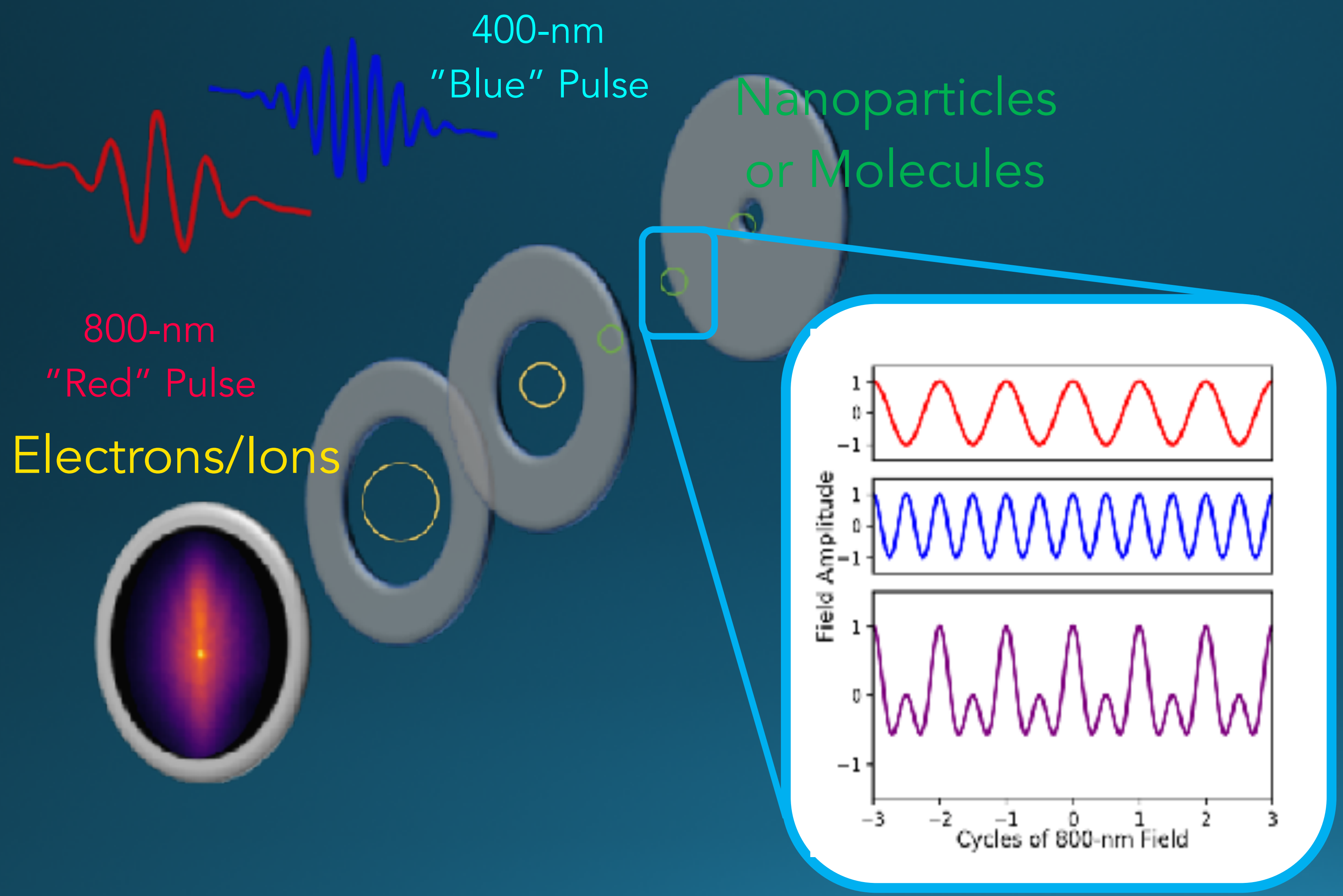

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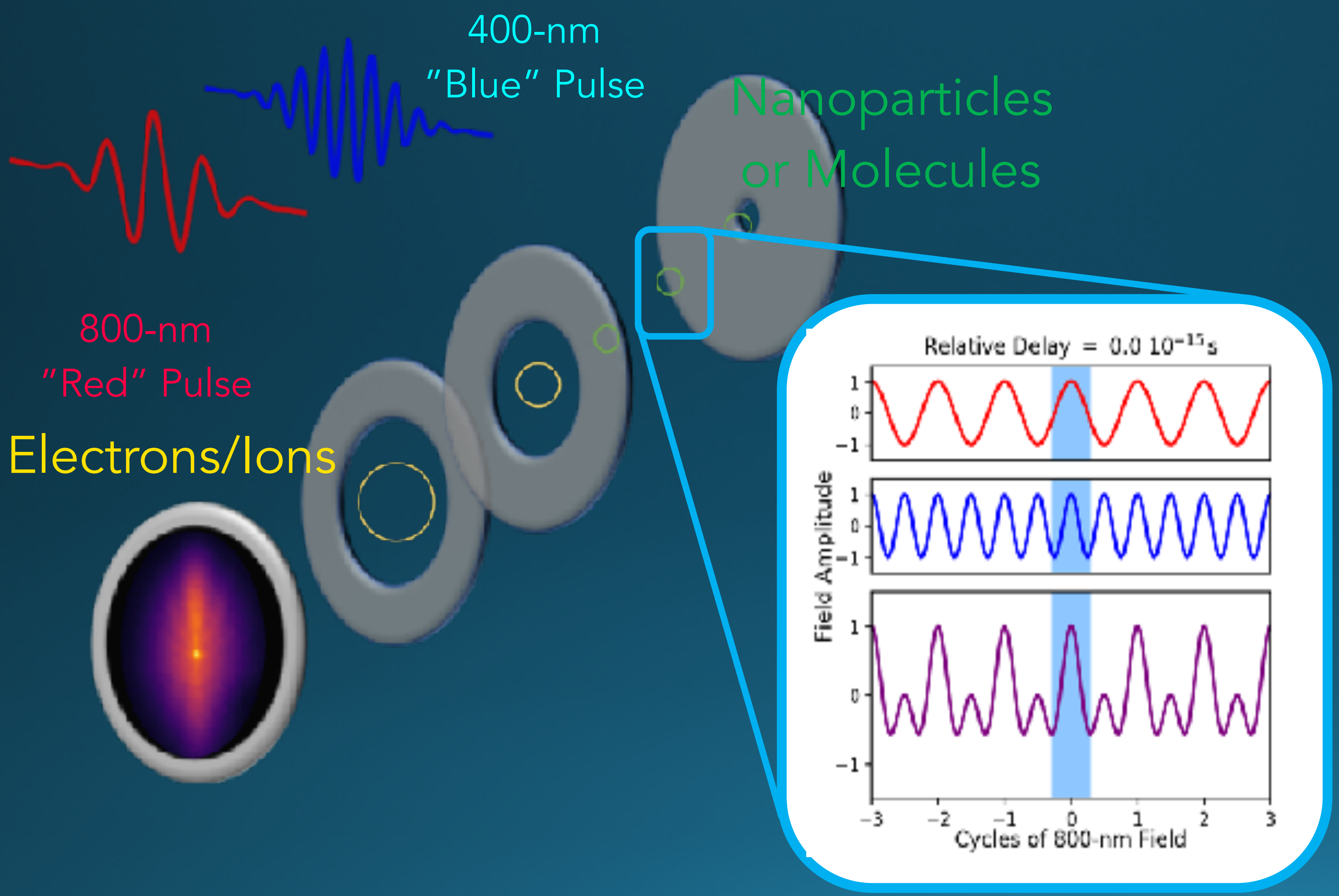

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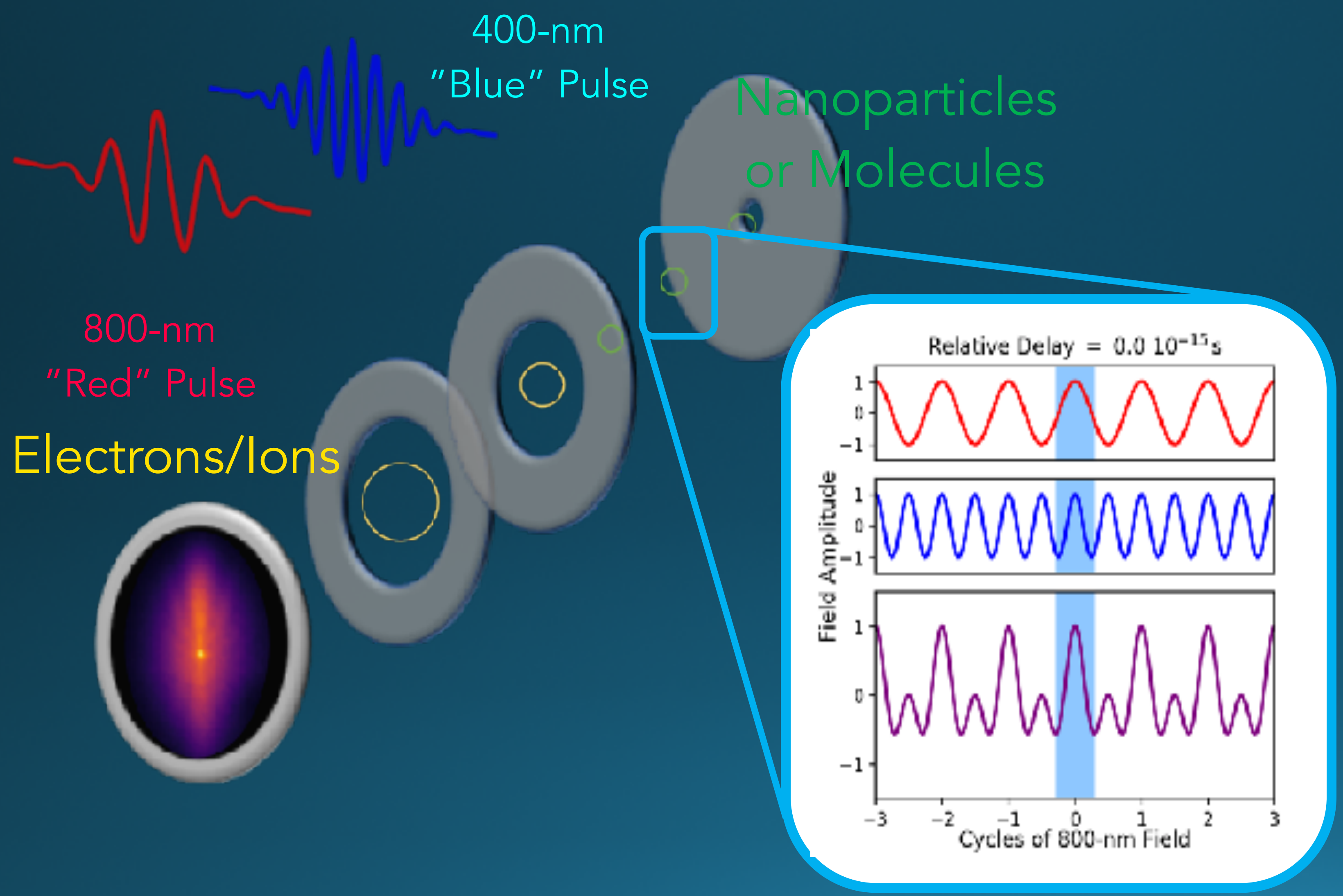

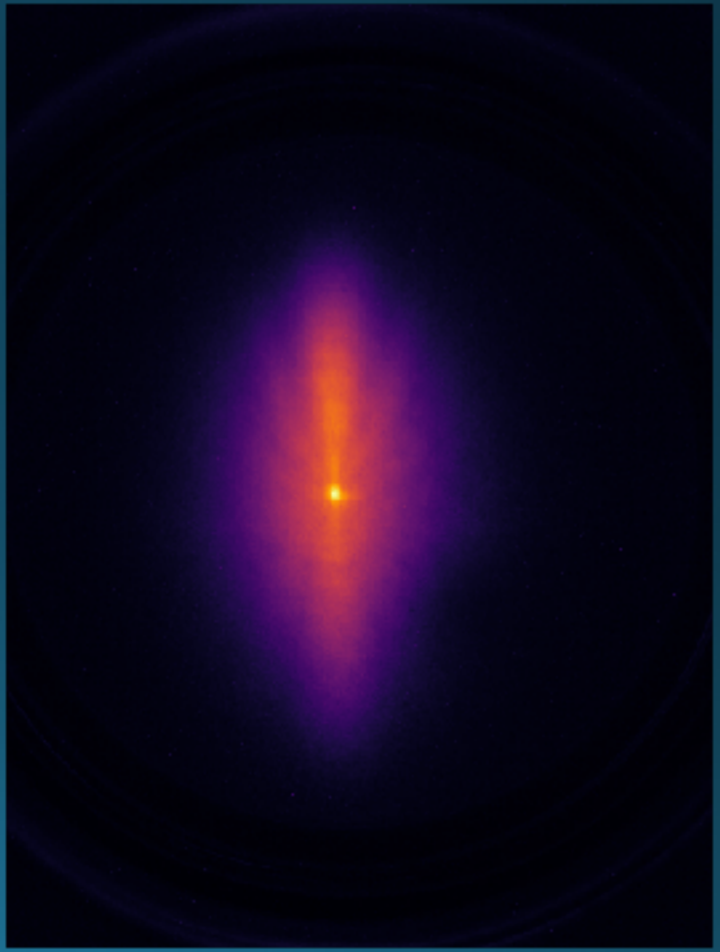

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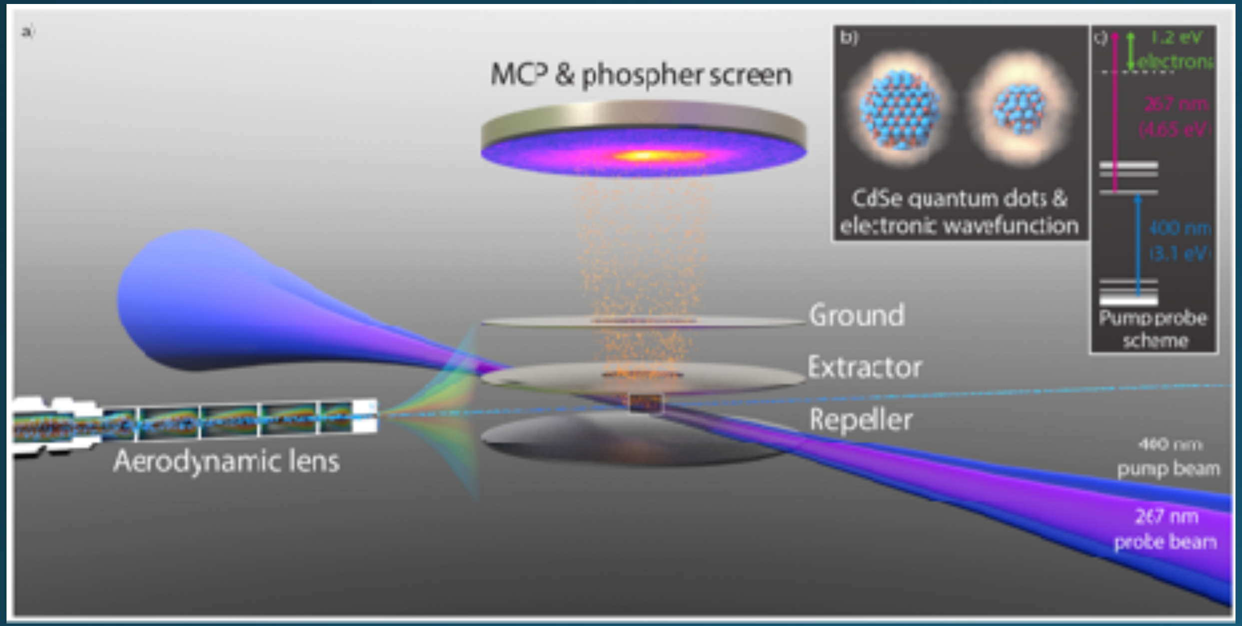

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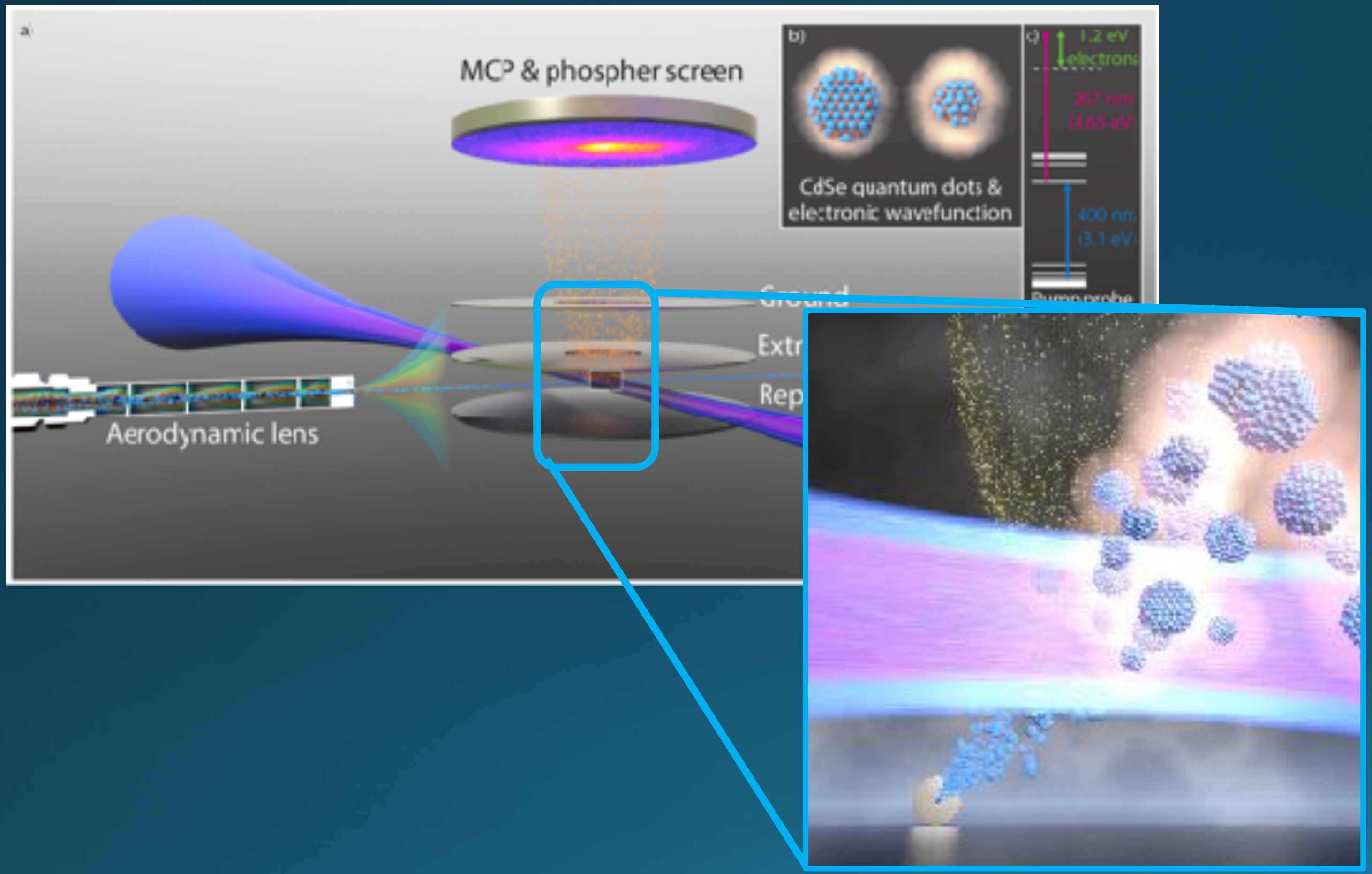

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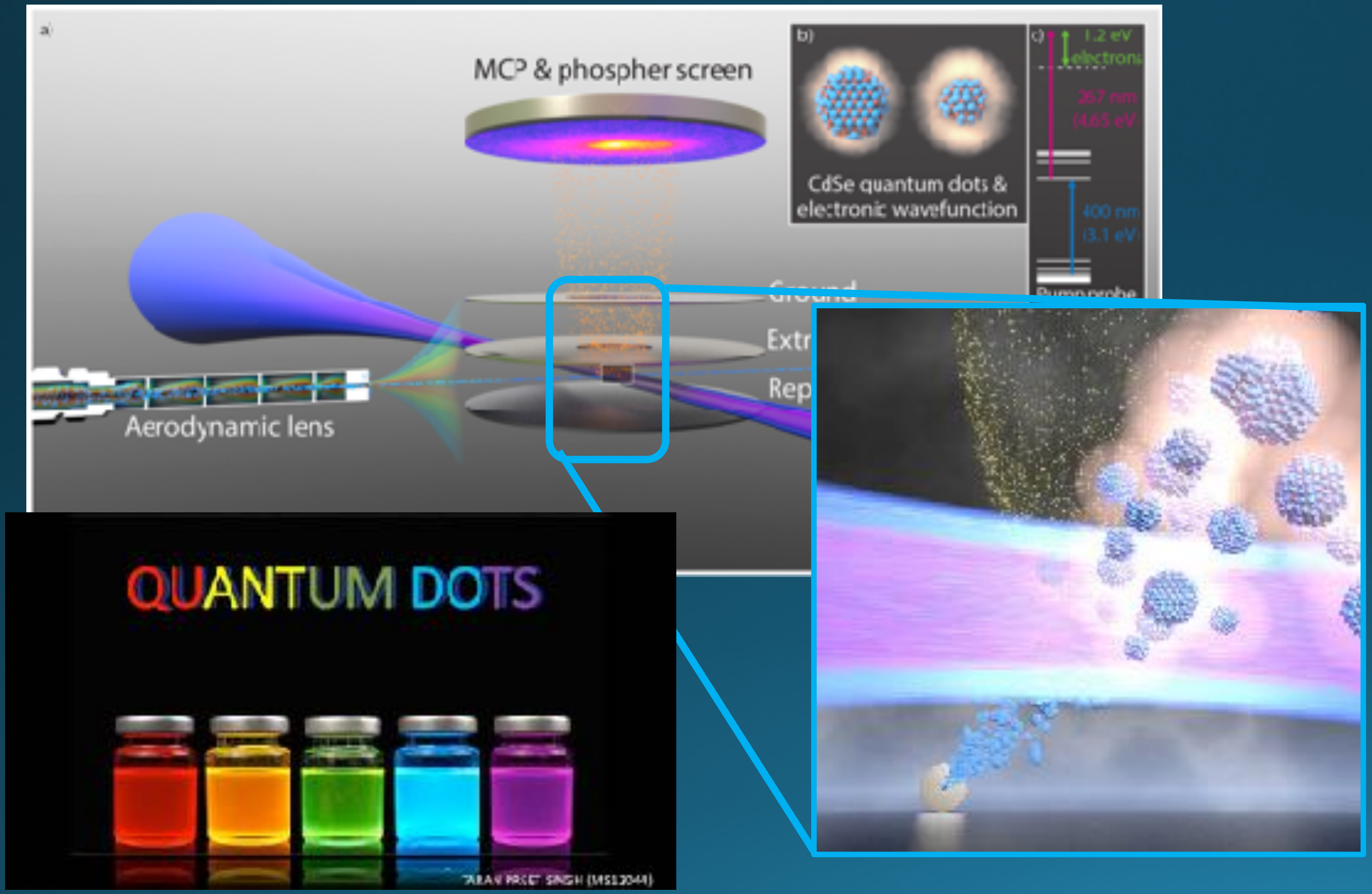

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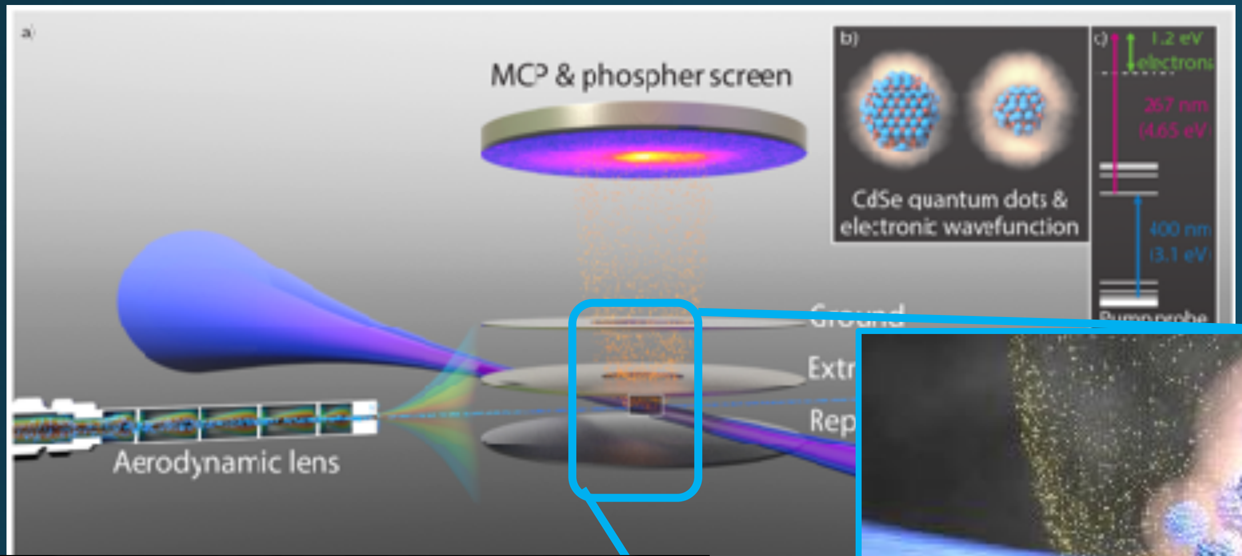

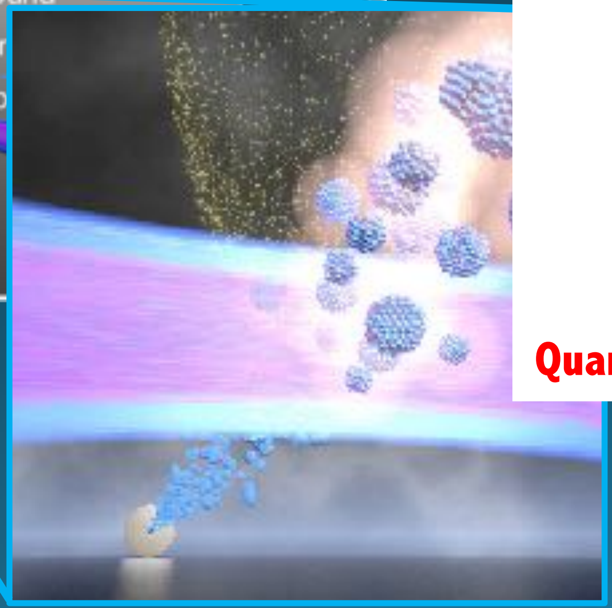

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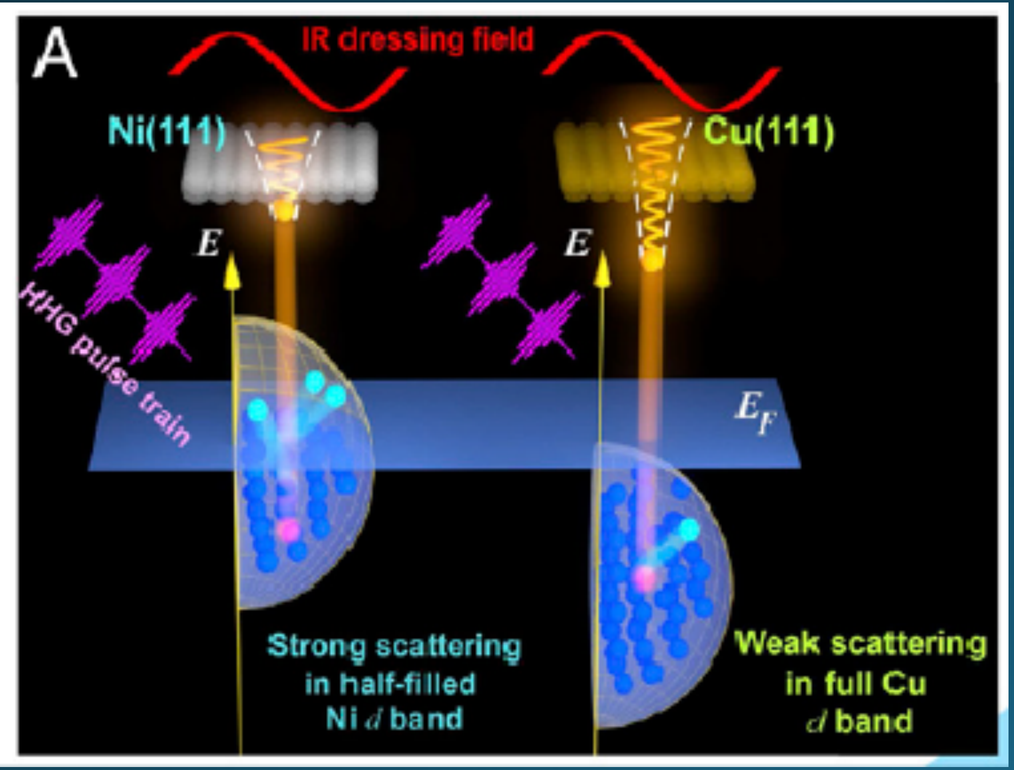

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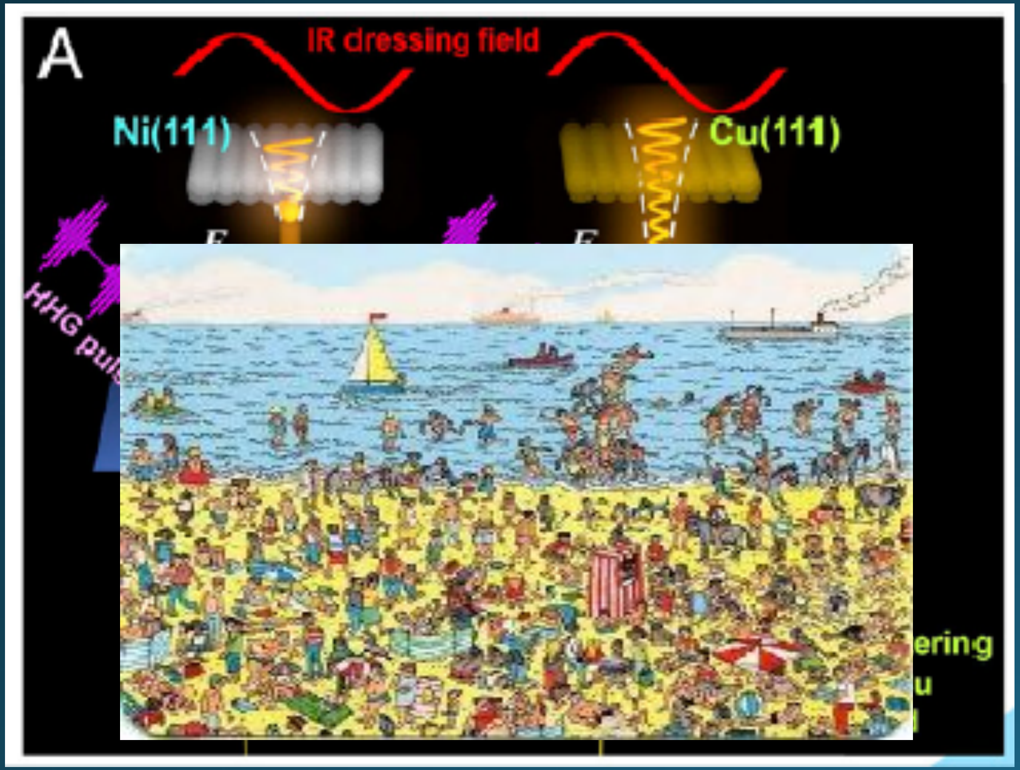

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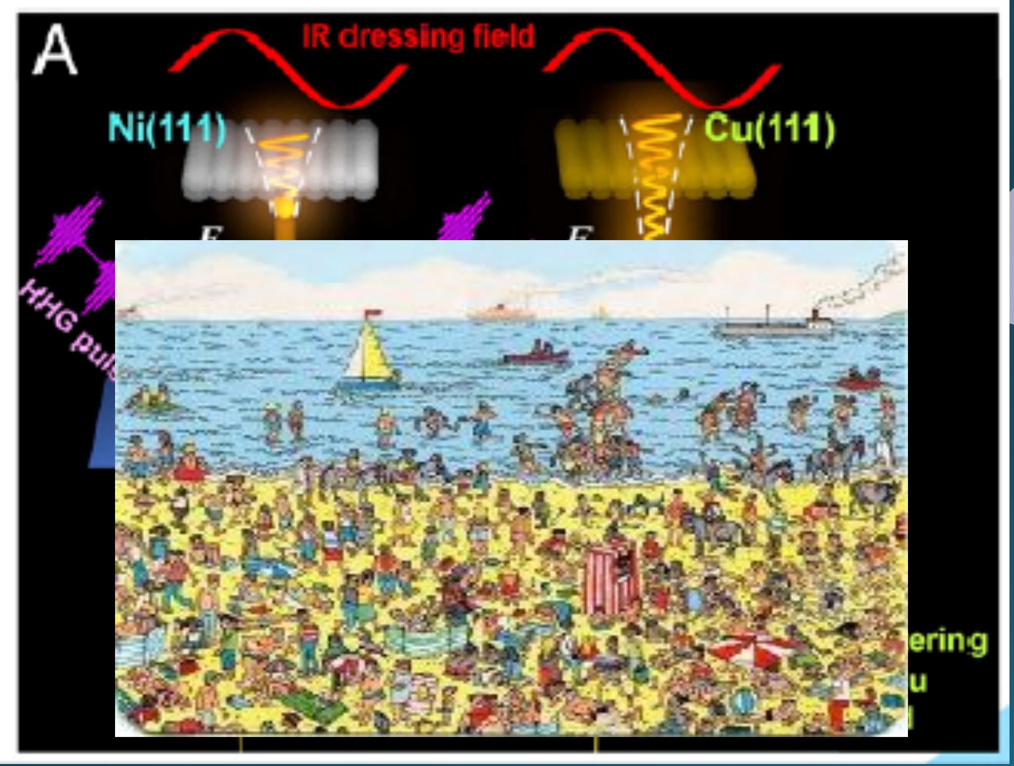

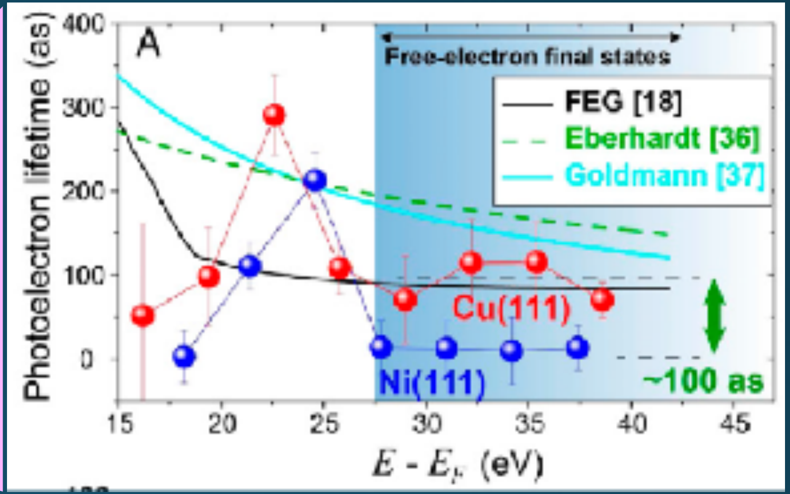

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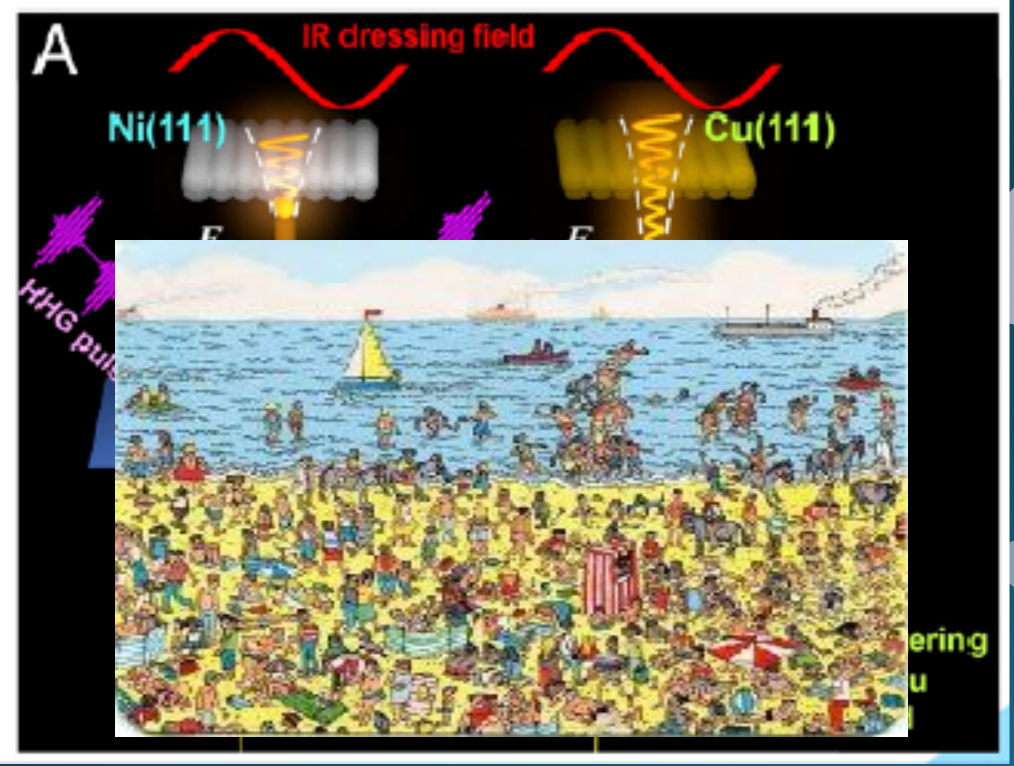

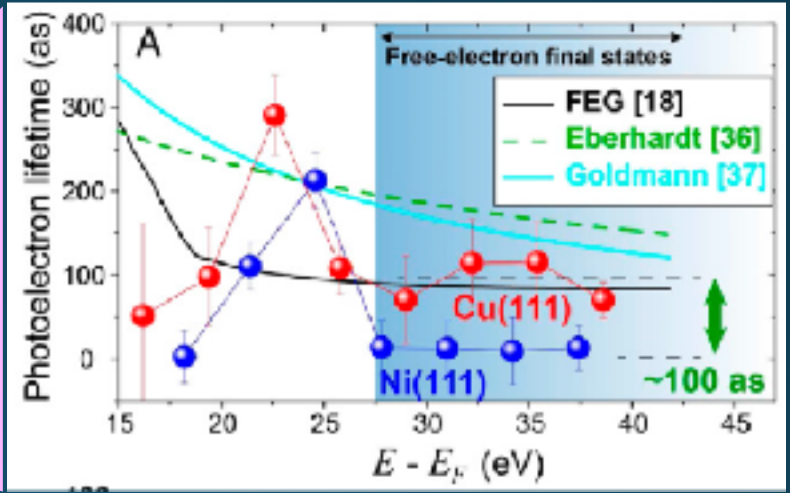

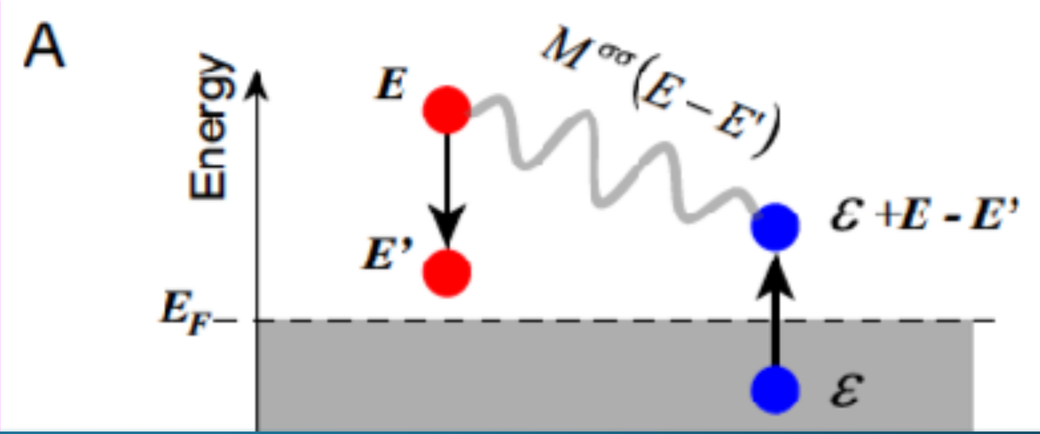

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- **Lasers faster than an electron can snap its fingers**
  - The fastest light pulse on record is ~ 4.3 x 10^{-17} s (about 3 times faster than it takes an electron to orbit hydrogen)
  - But electrons aren't the fastest... The Higgs Boson is produced and destroyed in about 10^{-22} s!
  - How to catch up to the Higgs Boson? A gamma ray laser?

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