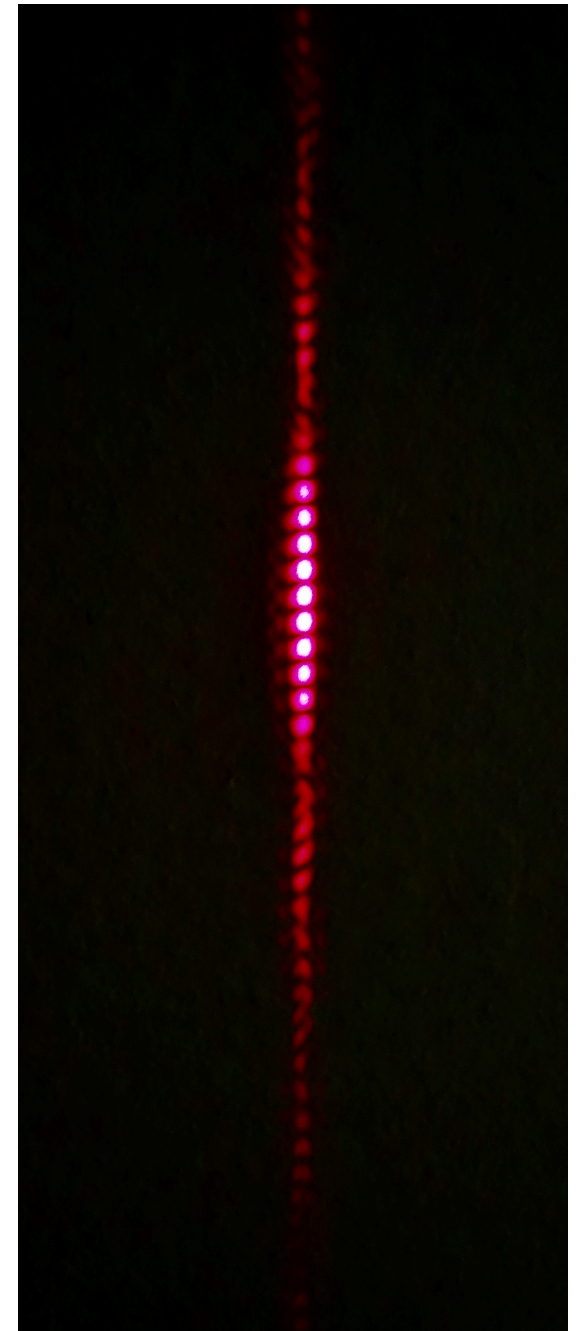
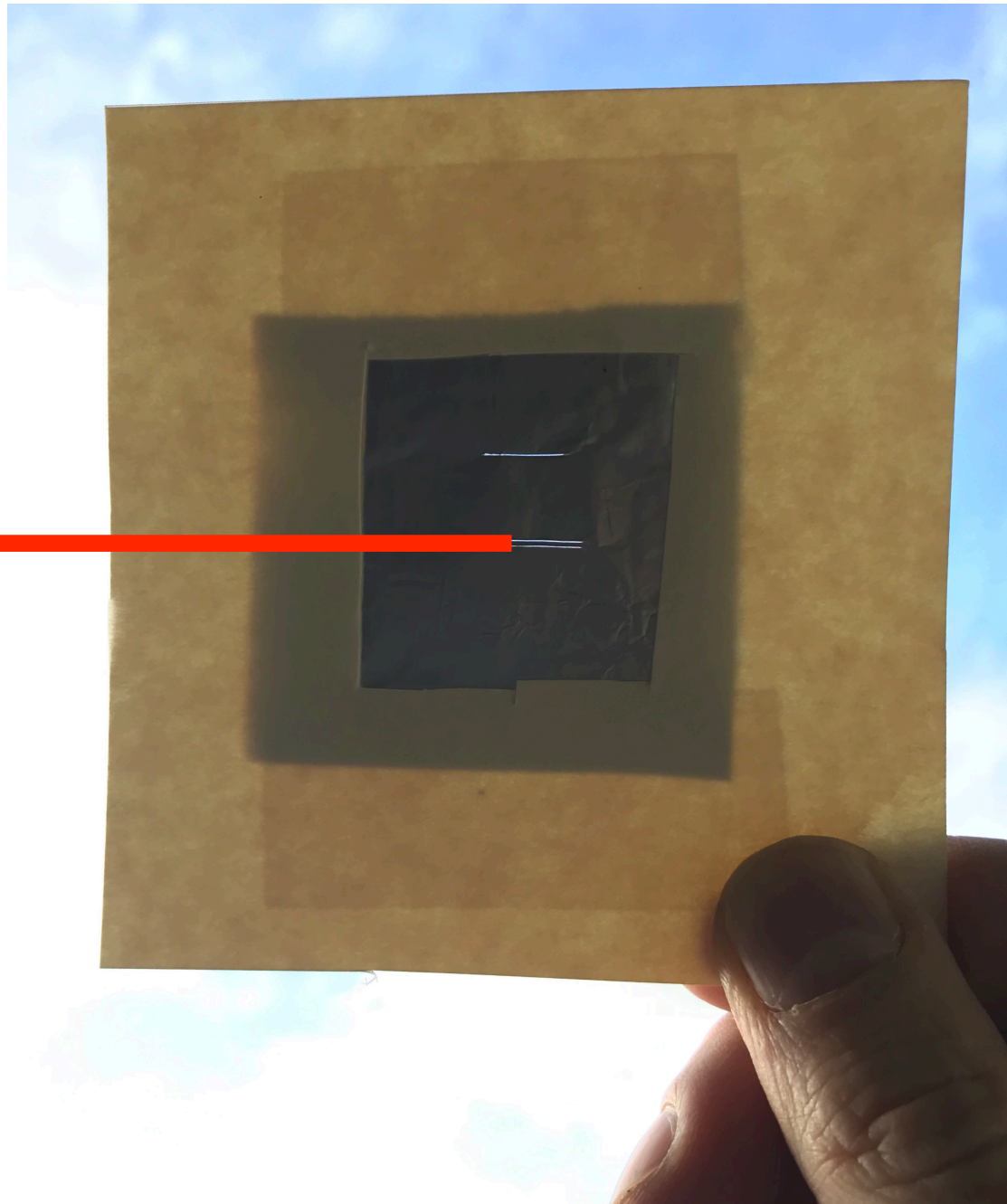


Particles

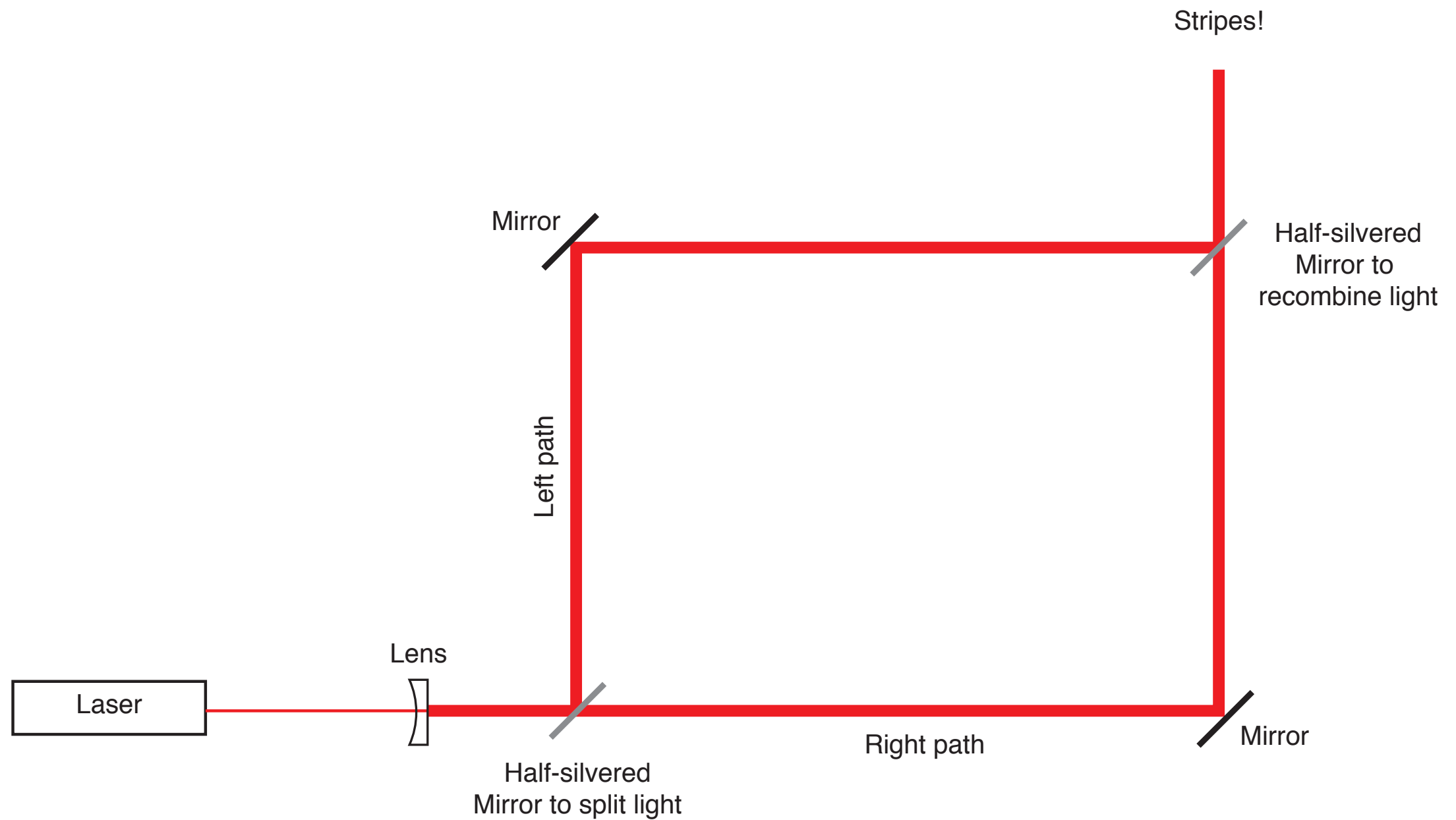
# Double slit

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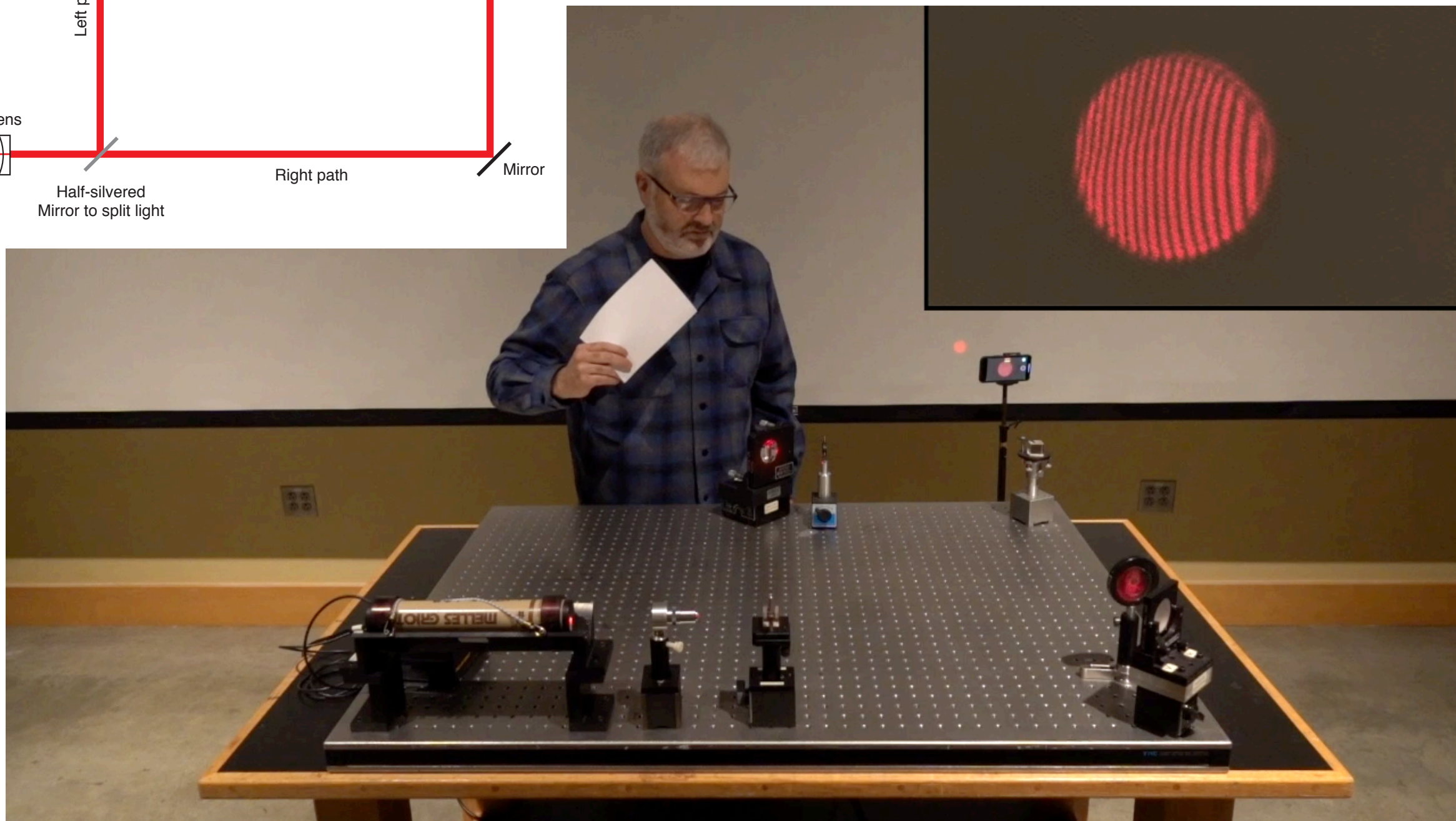
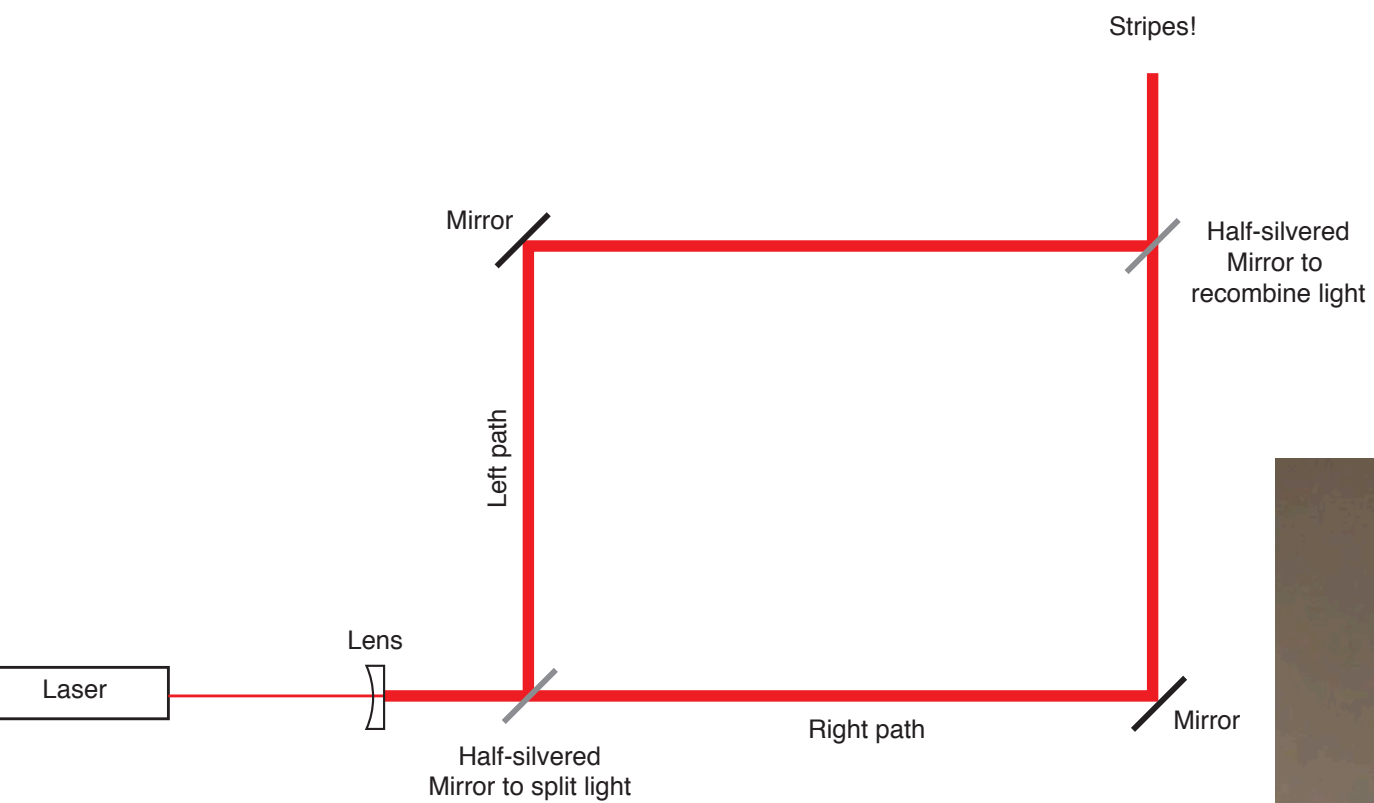


# Bigger

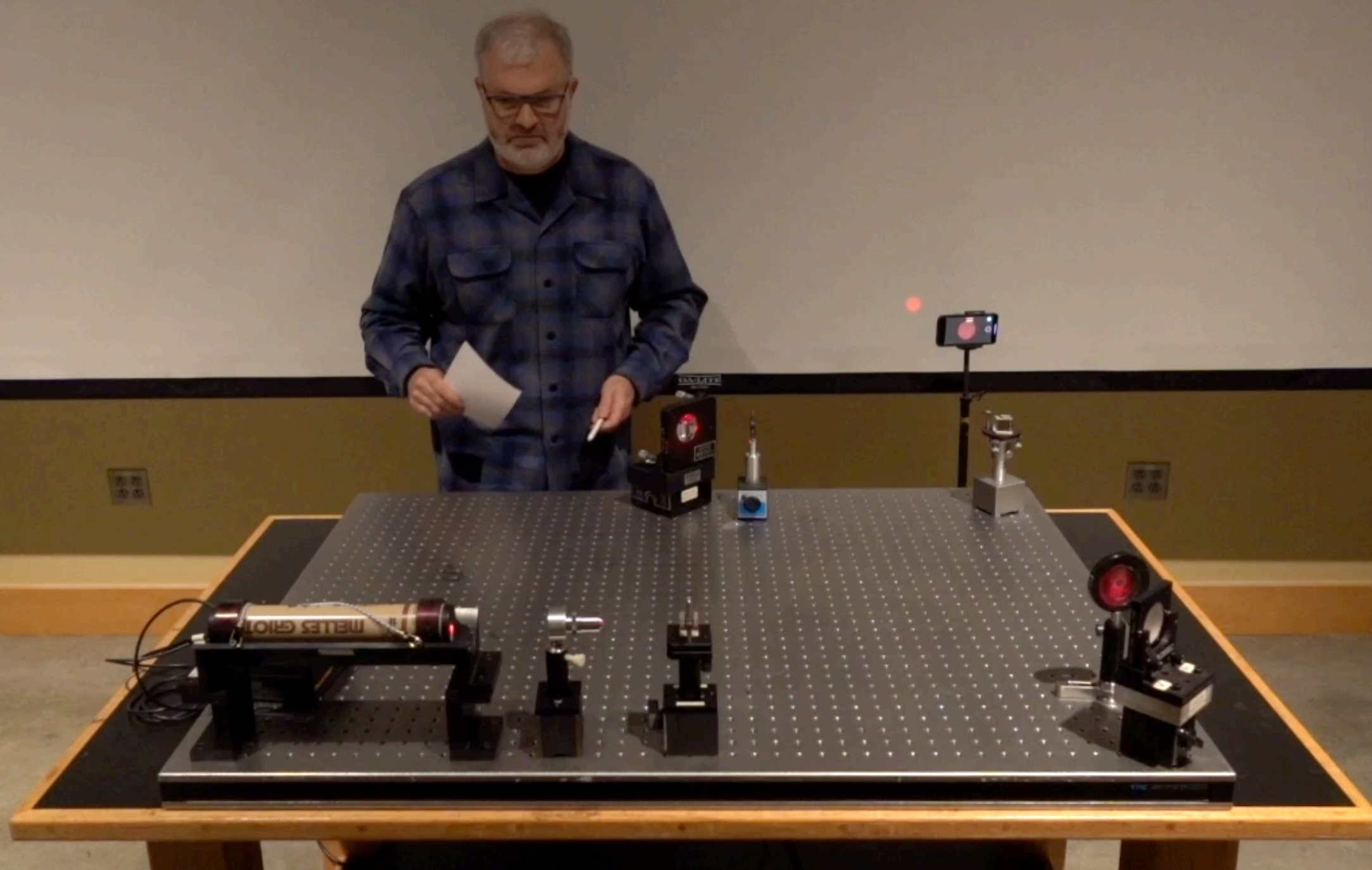
---



# Bigger

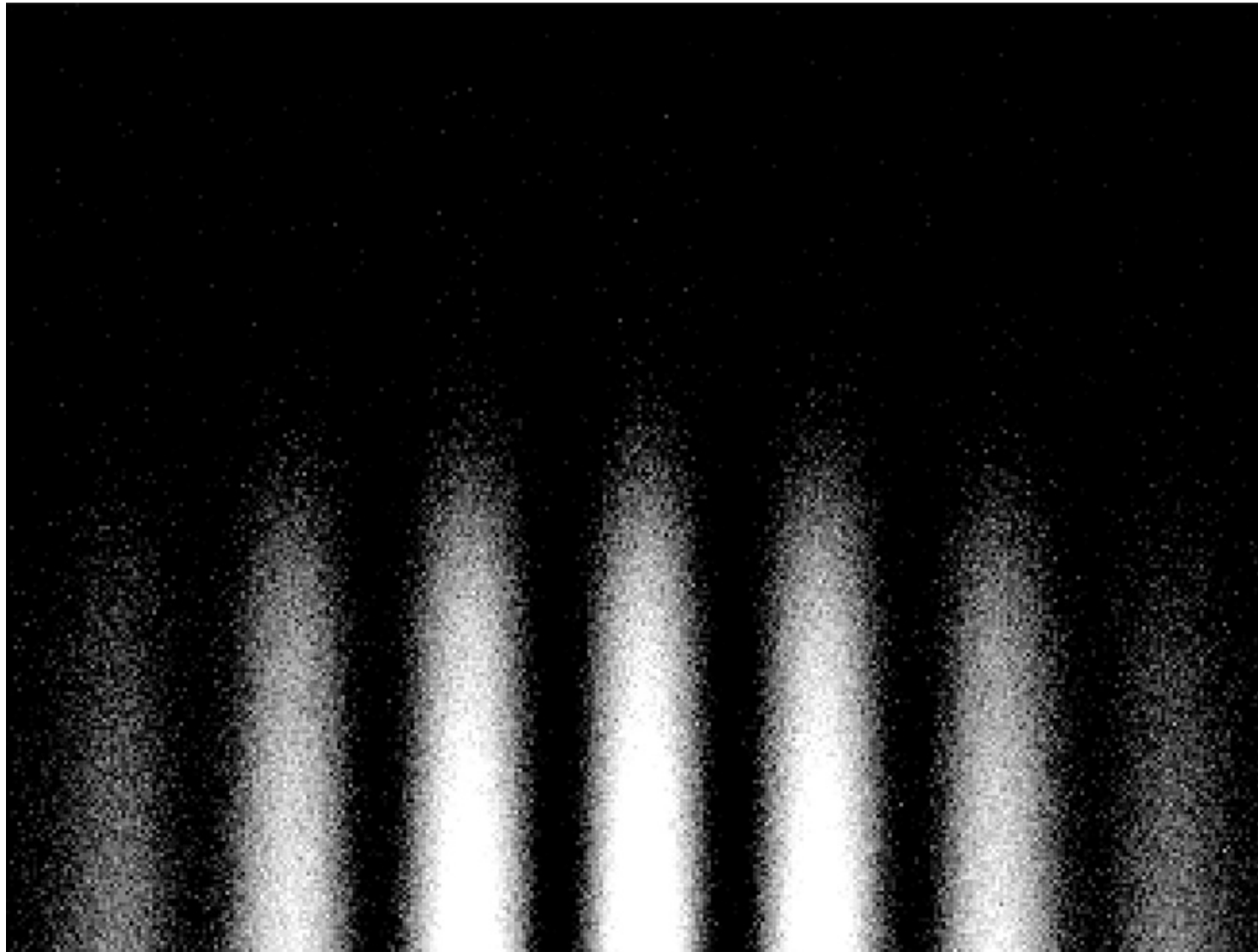






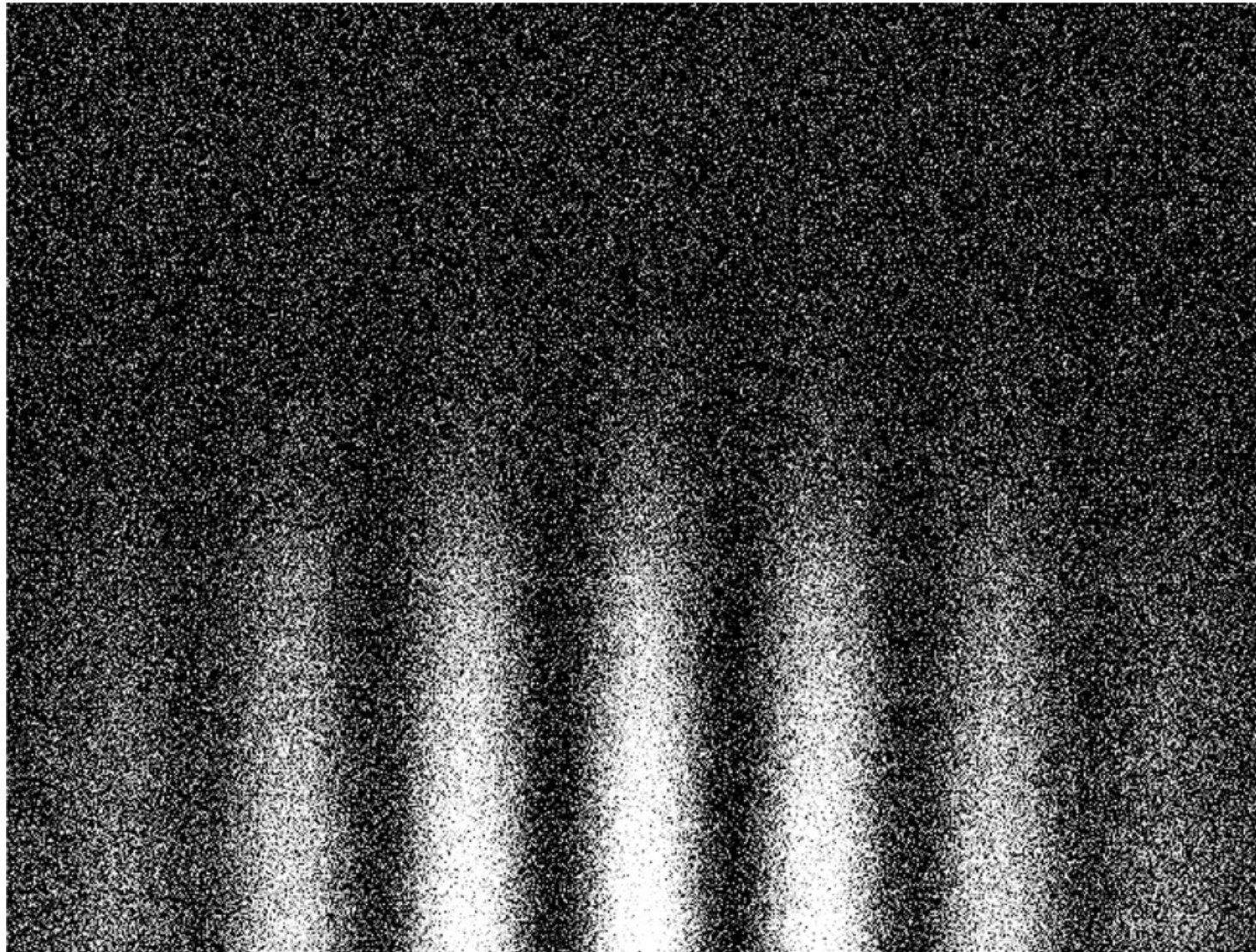
# Bright laser

---



# Dimmer

---



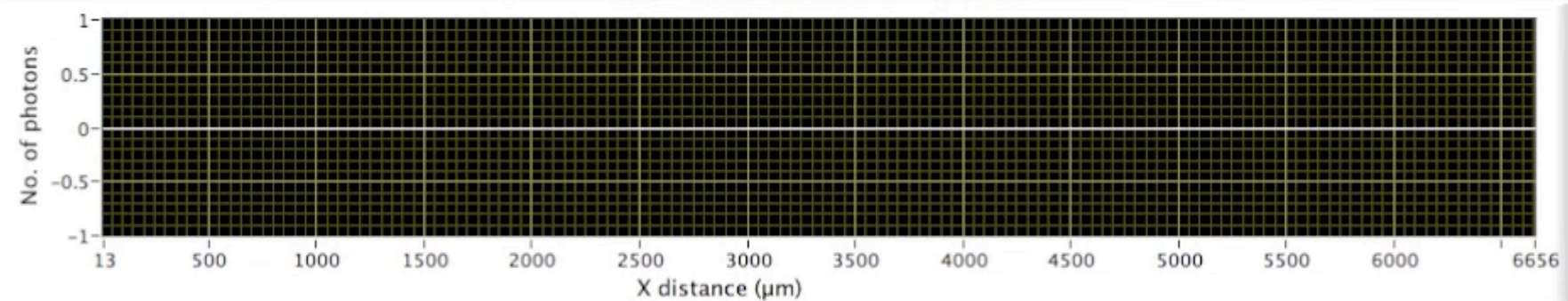


# Young's double slit with a coherent source photon by photon

Vertical  
Cross  
Section

No. of photons= 0

Vertical cross section





# Photons

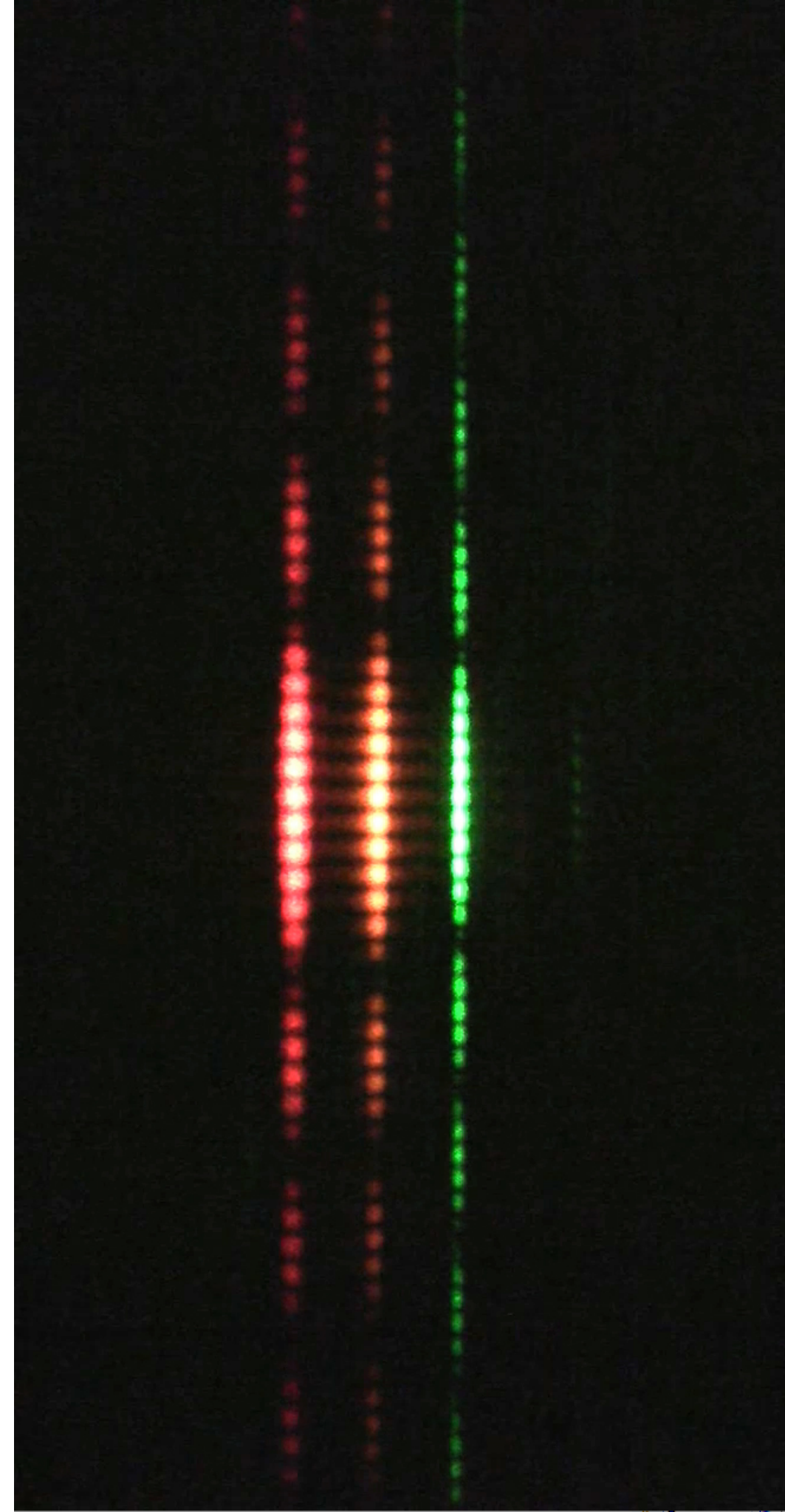
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- Hit the screen like little paintballs

# How hard do they hit?

---

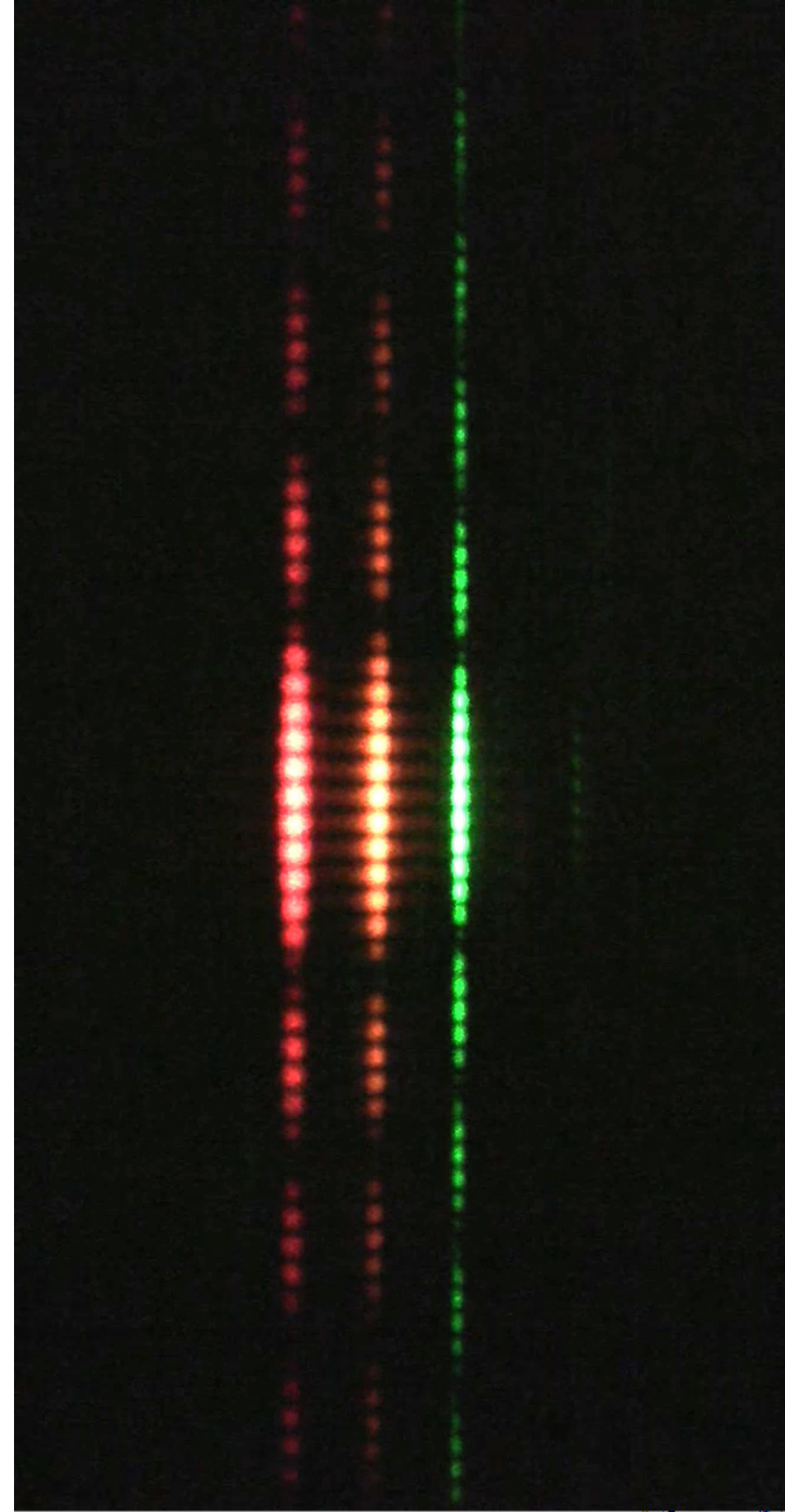
- With fancy detectors, can measure how much each pixel heats up when hit—how hard it was hit.



# How hard do they hit?

---

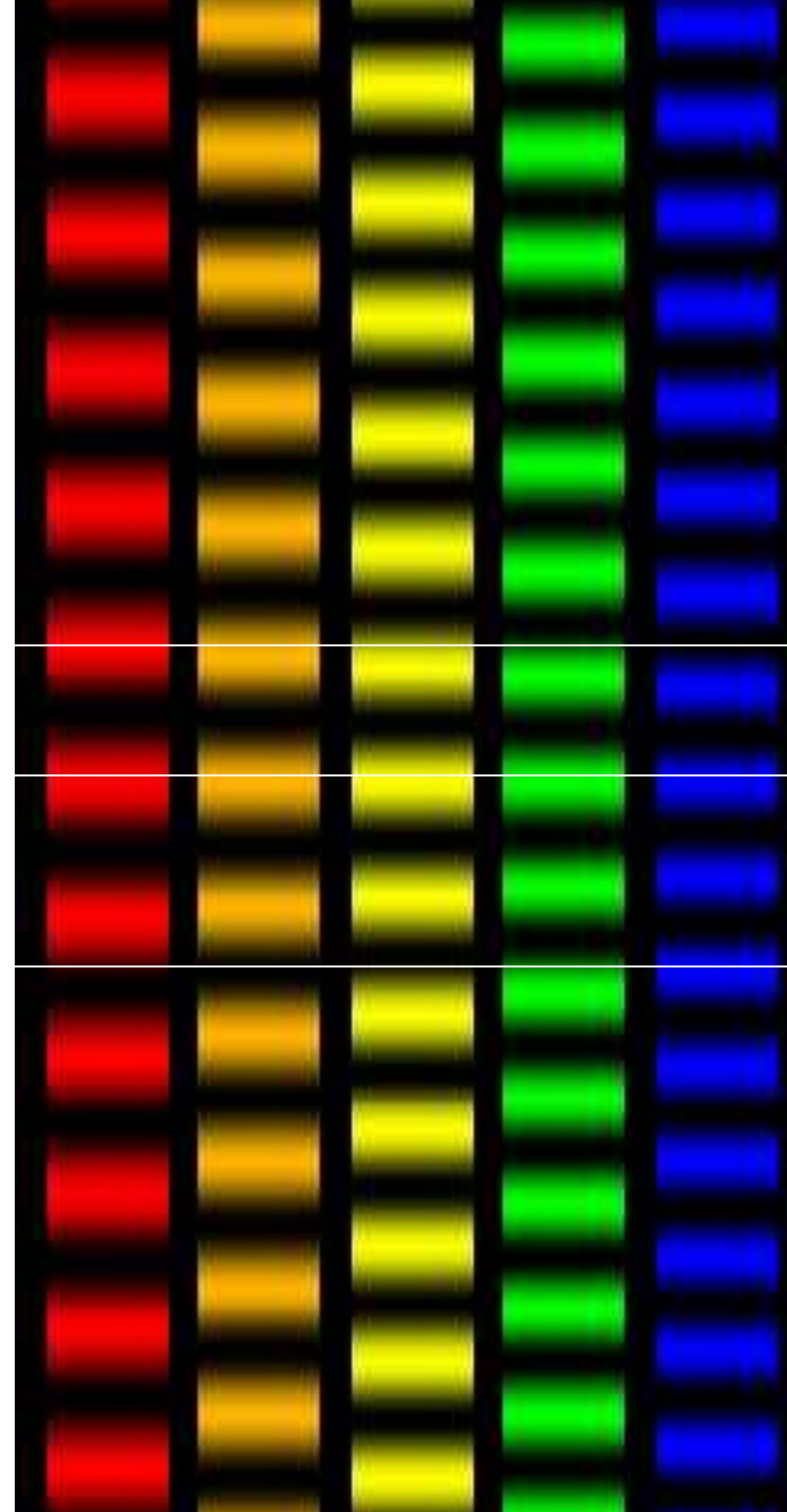
- Every red photon hits with the same strength (energy)
- Every green photon hits with the same strength as other green photons; and harder than red photons



# Color

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- Color is related to the length of the wave (blue short, red long), *and*
- Color is related to how hard each photon hits (blue hard, red soft)

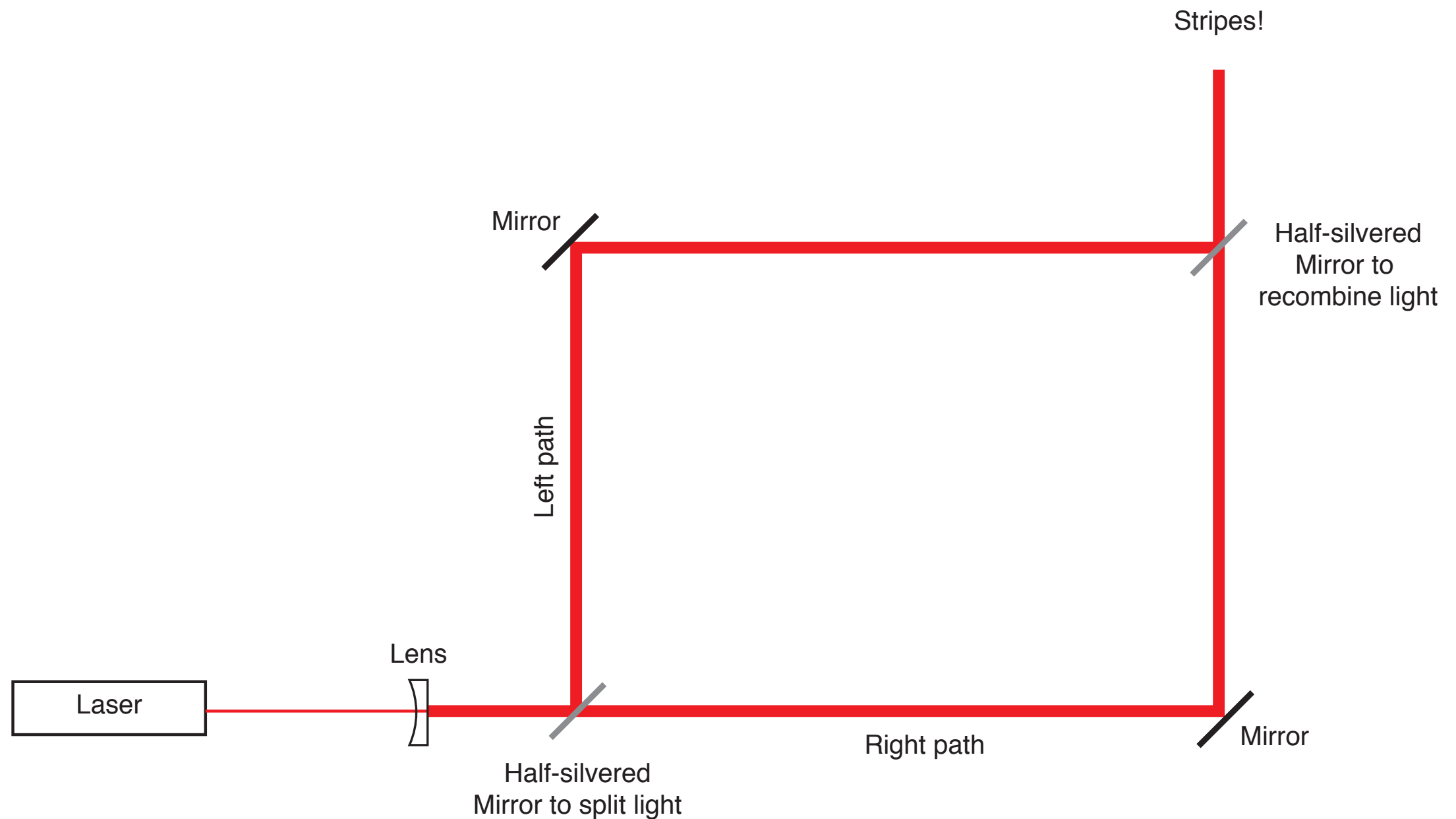




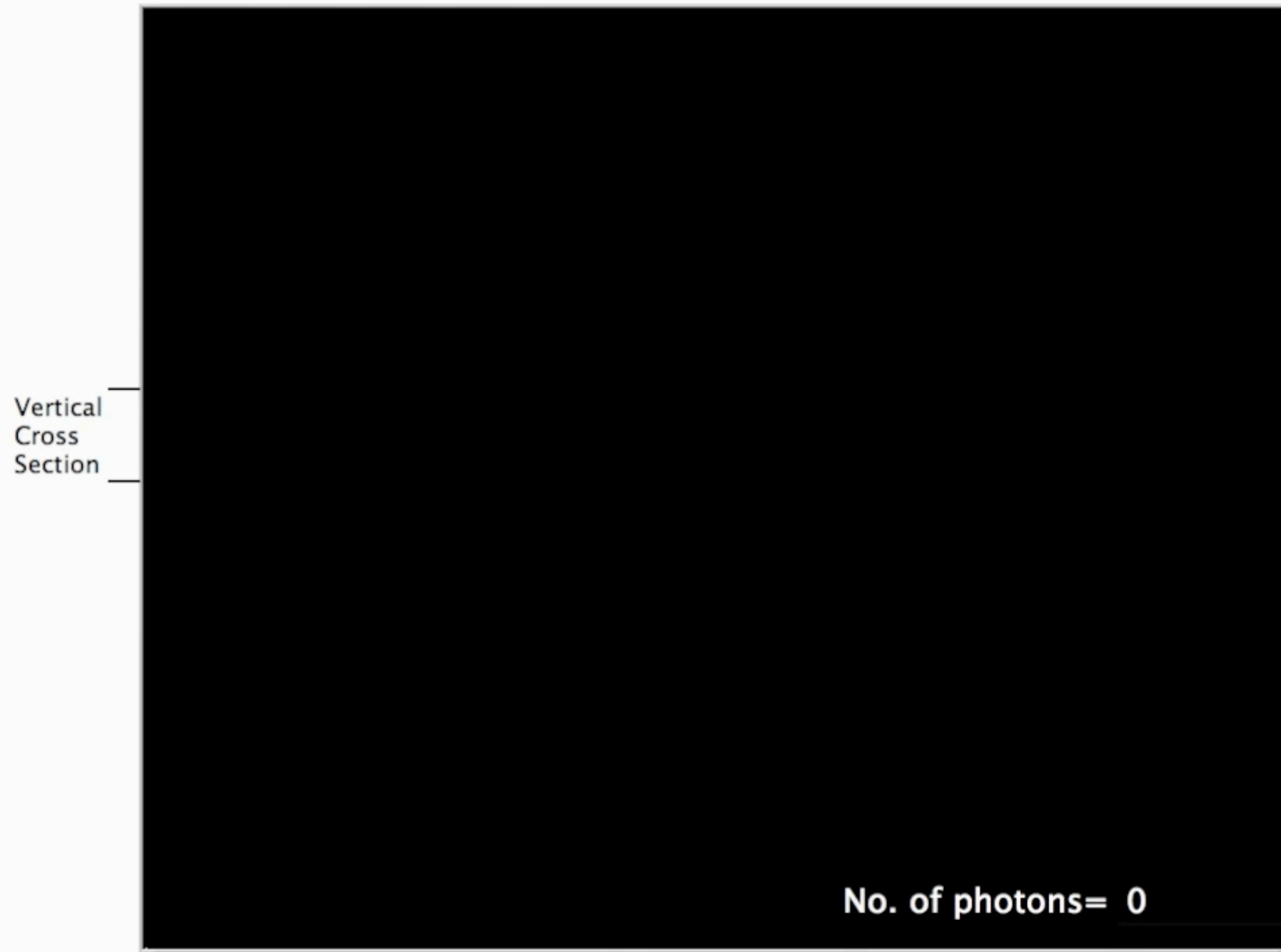
One photon at a time

# Which path did the photon take?

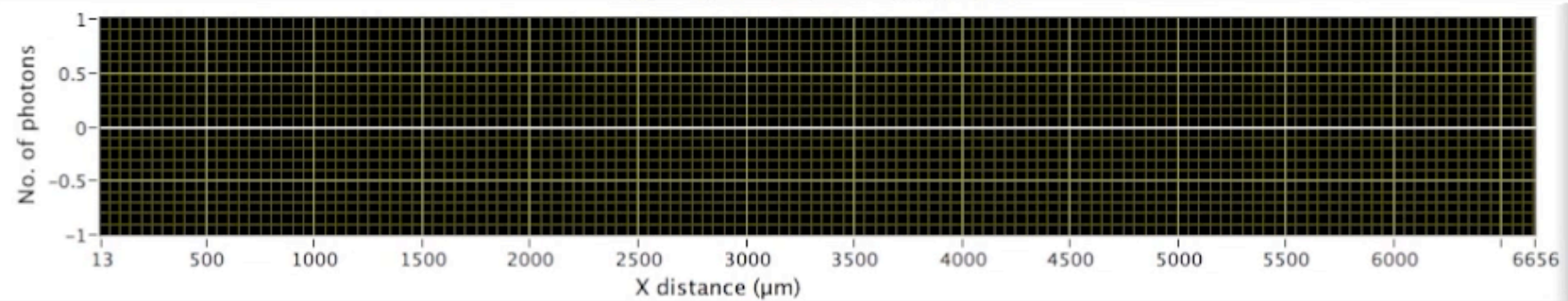
---



# Young's double slit with a coherent source photon by photon

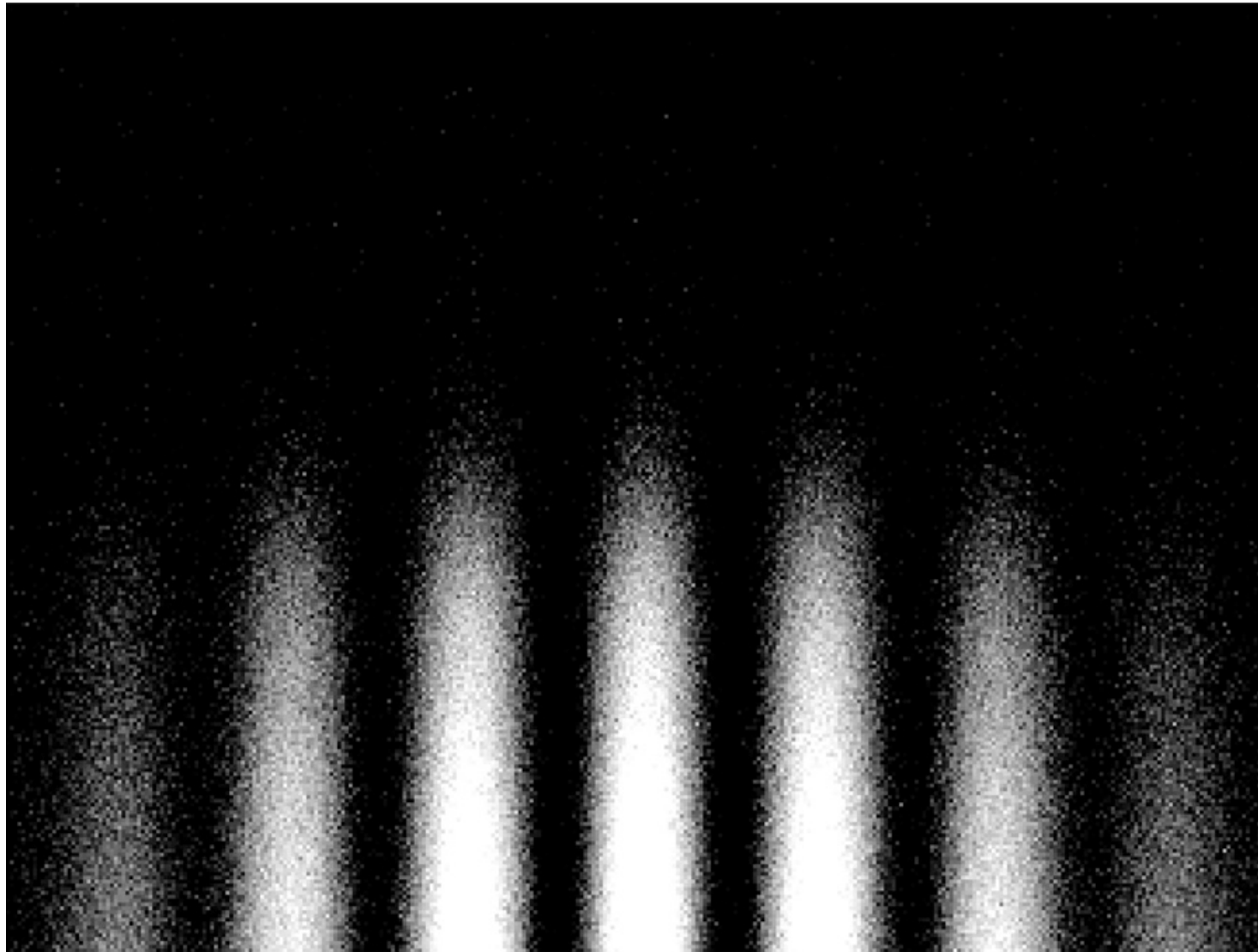


Vertical cross section



# Bright laser

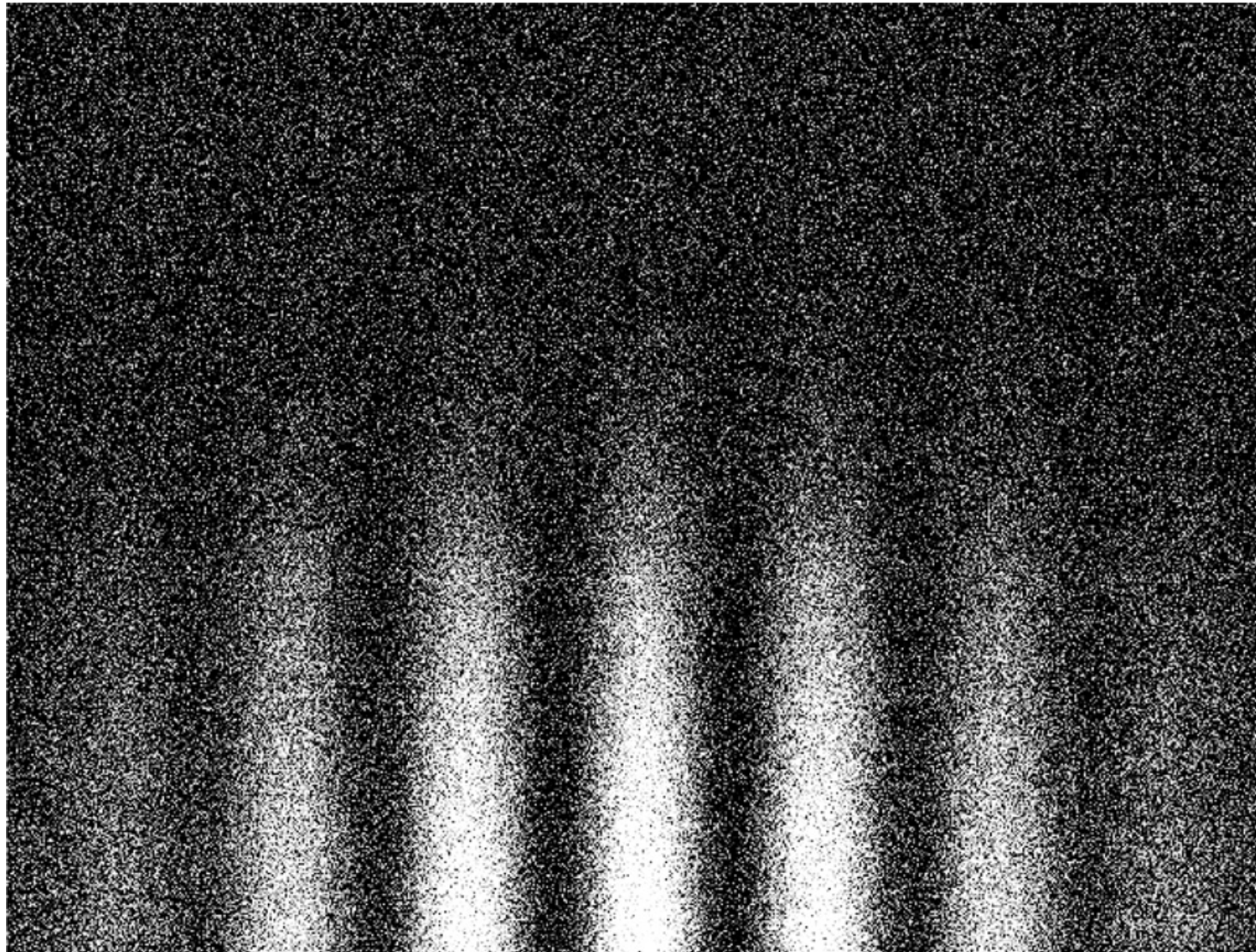
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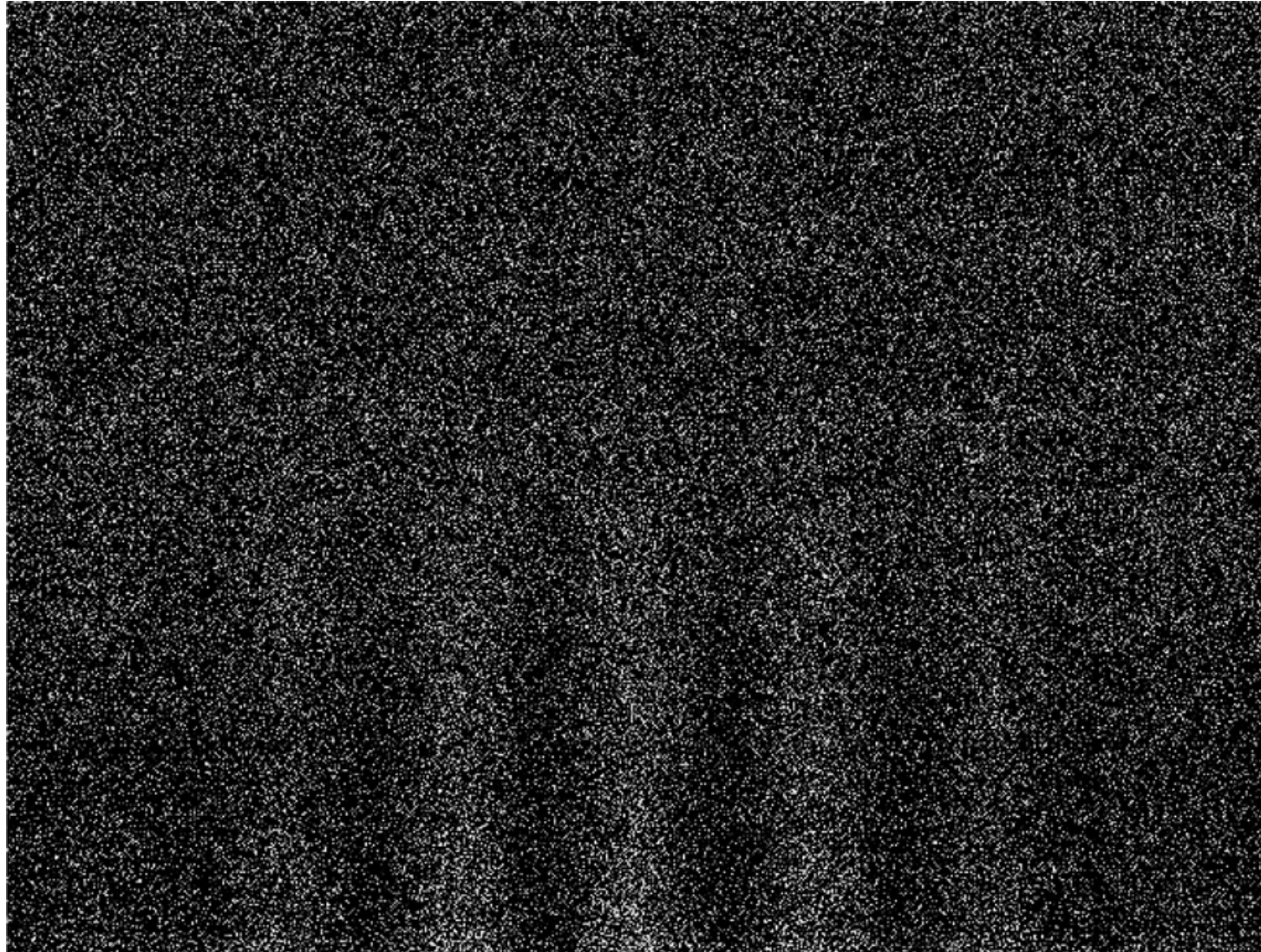
# Dimmer

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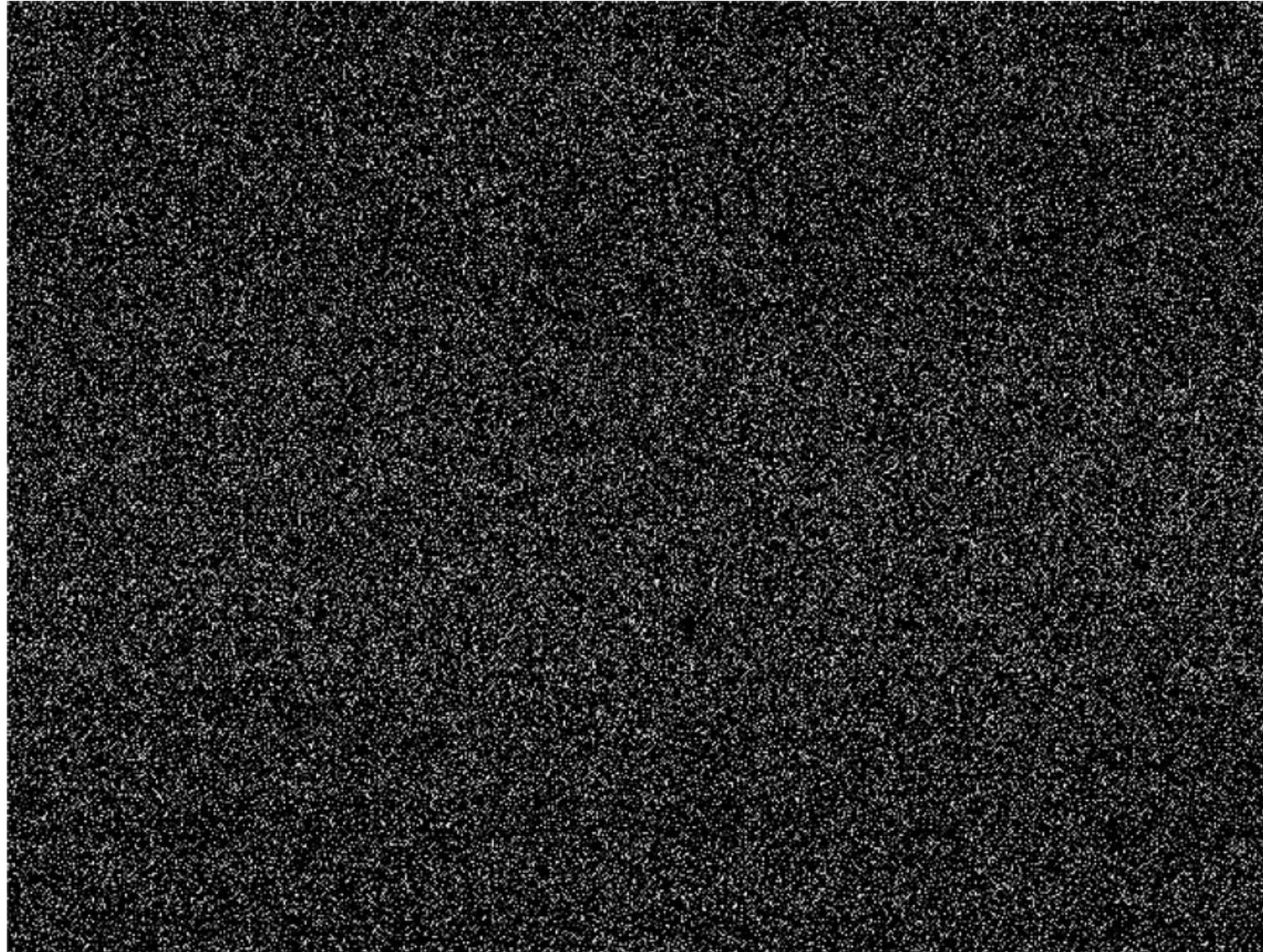
# Even dimmer

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# Block one path

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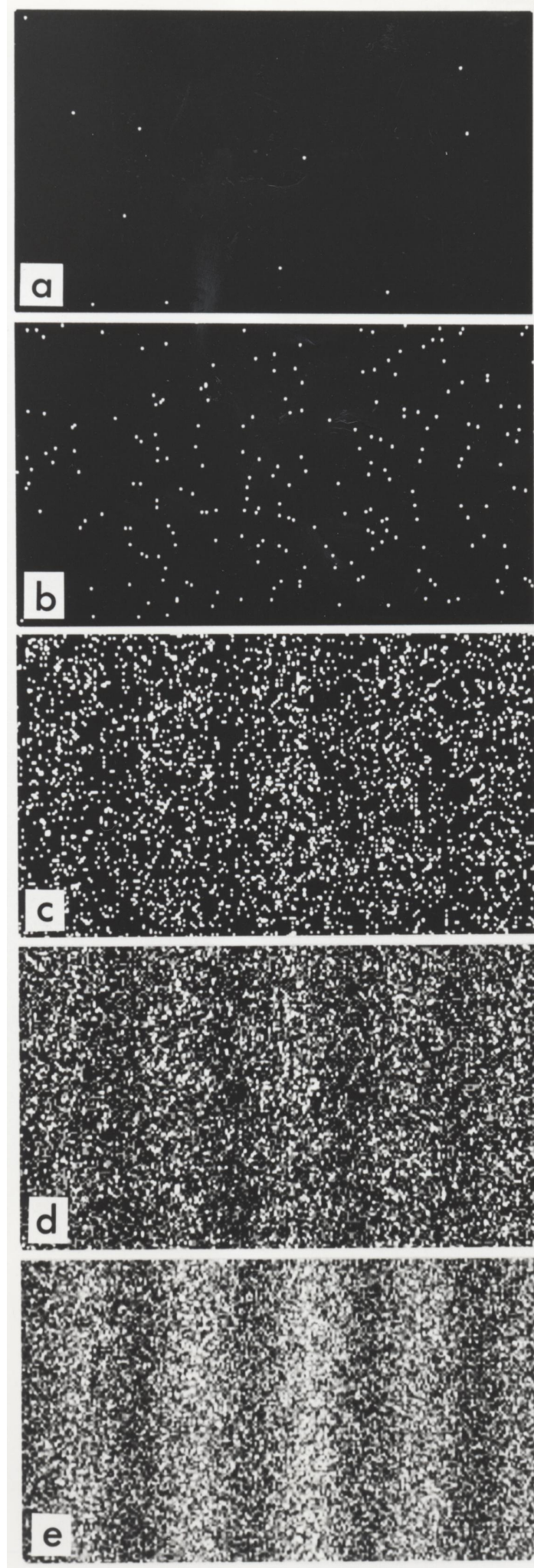
Particles **move** like waves and **hit** like particles

---

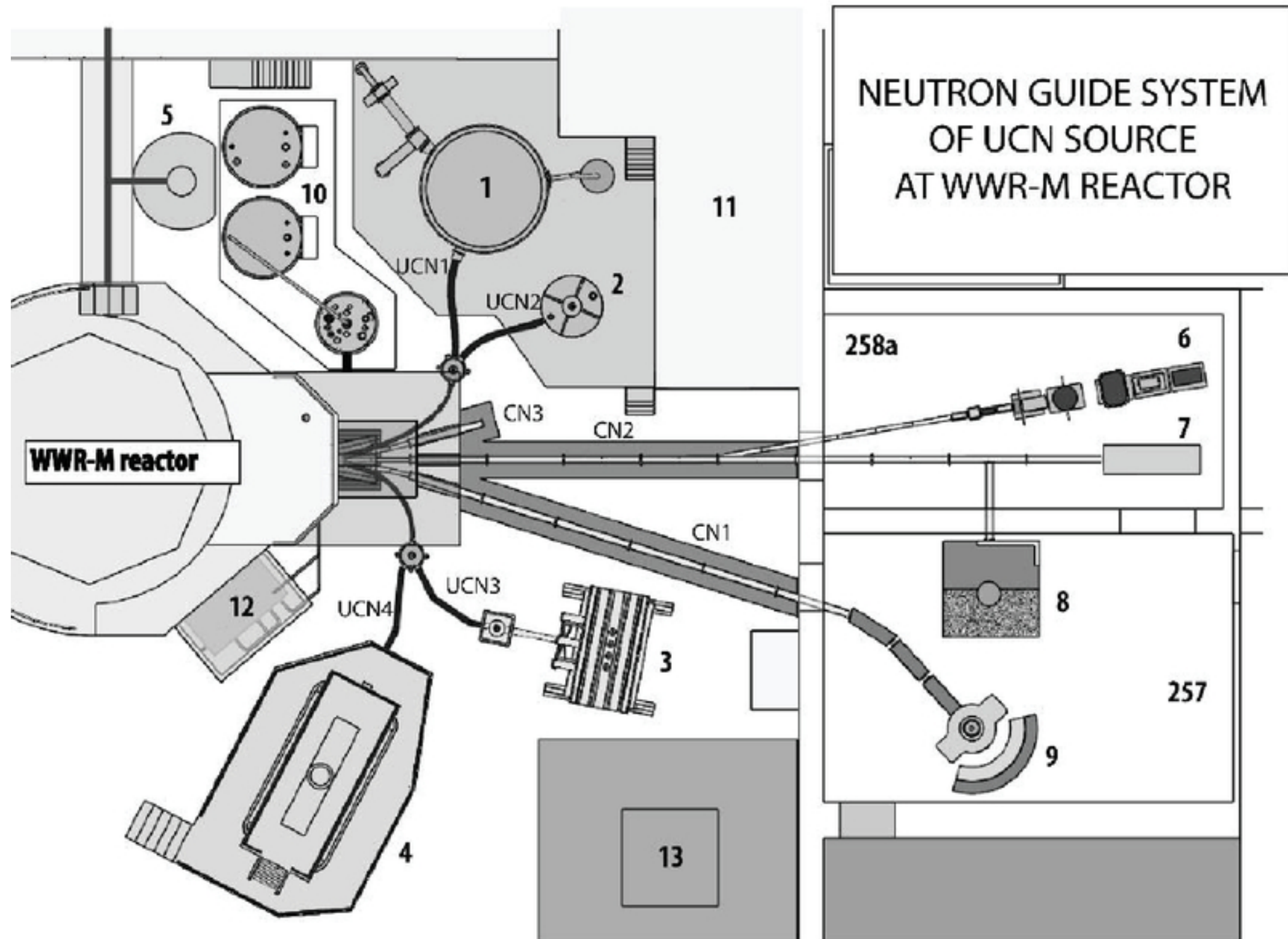


# Electrons

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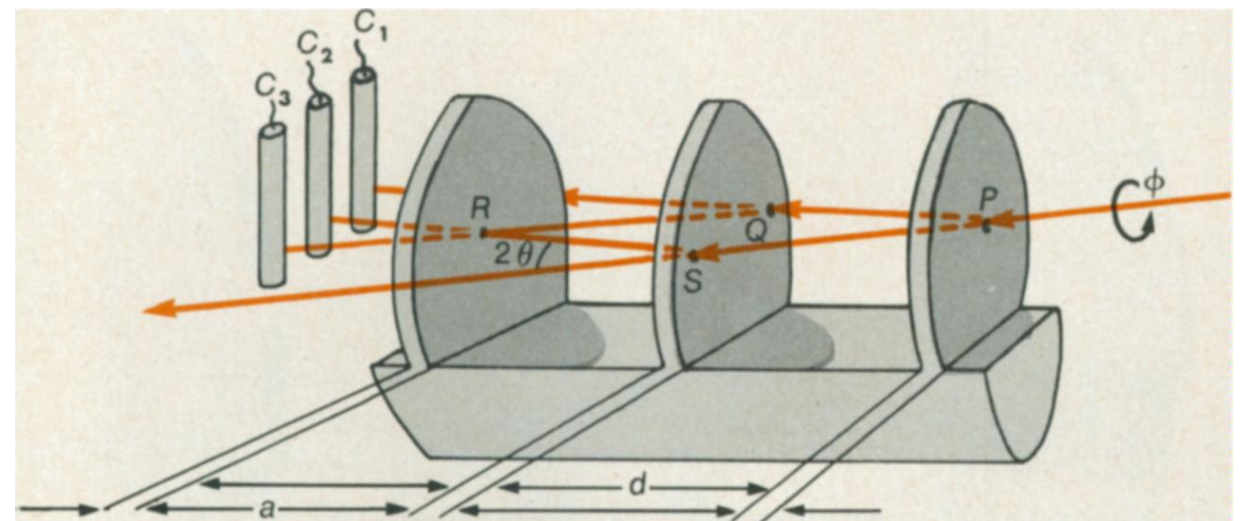
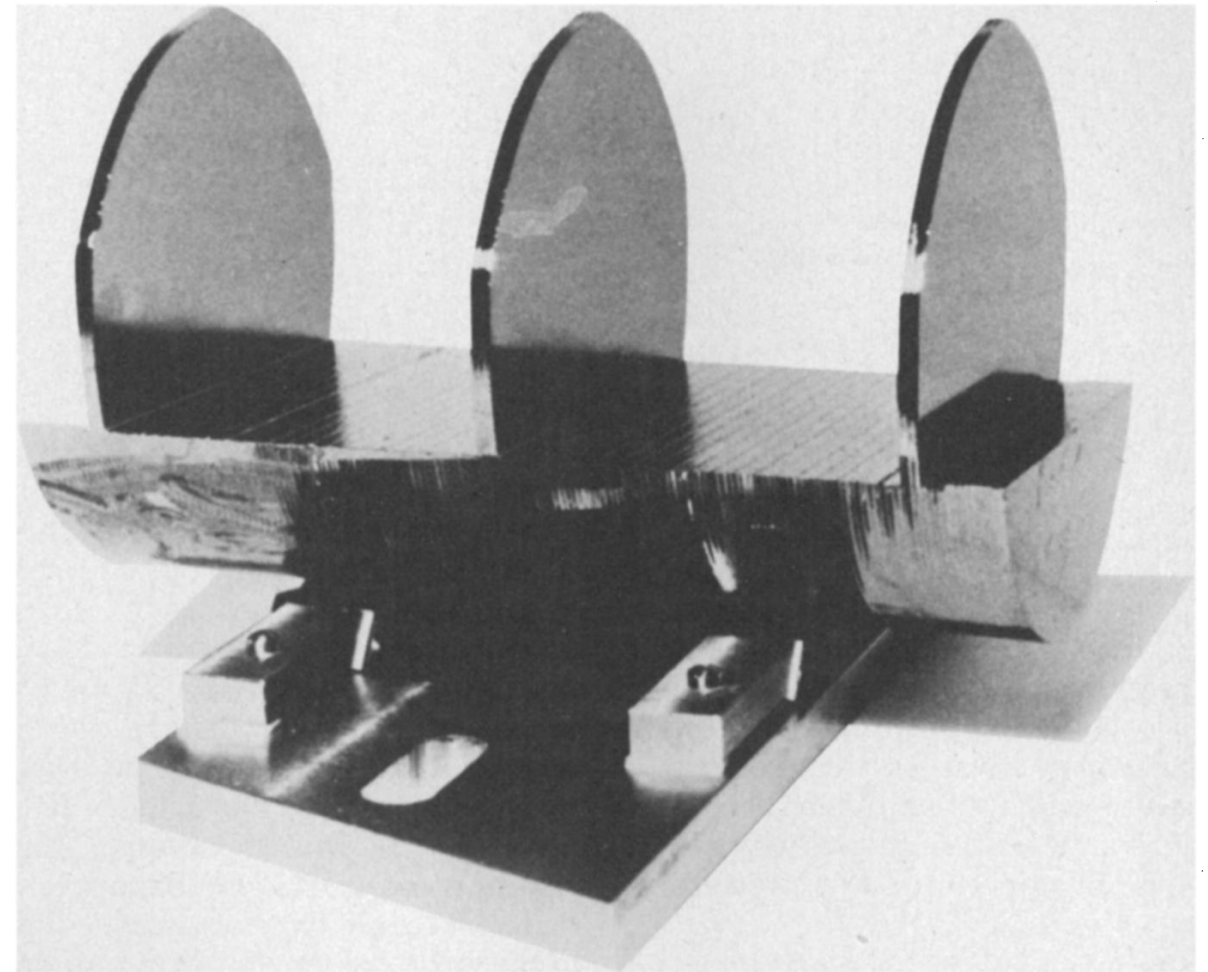


# Neutron 'laser pointer'



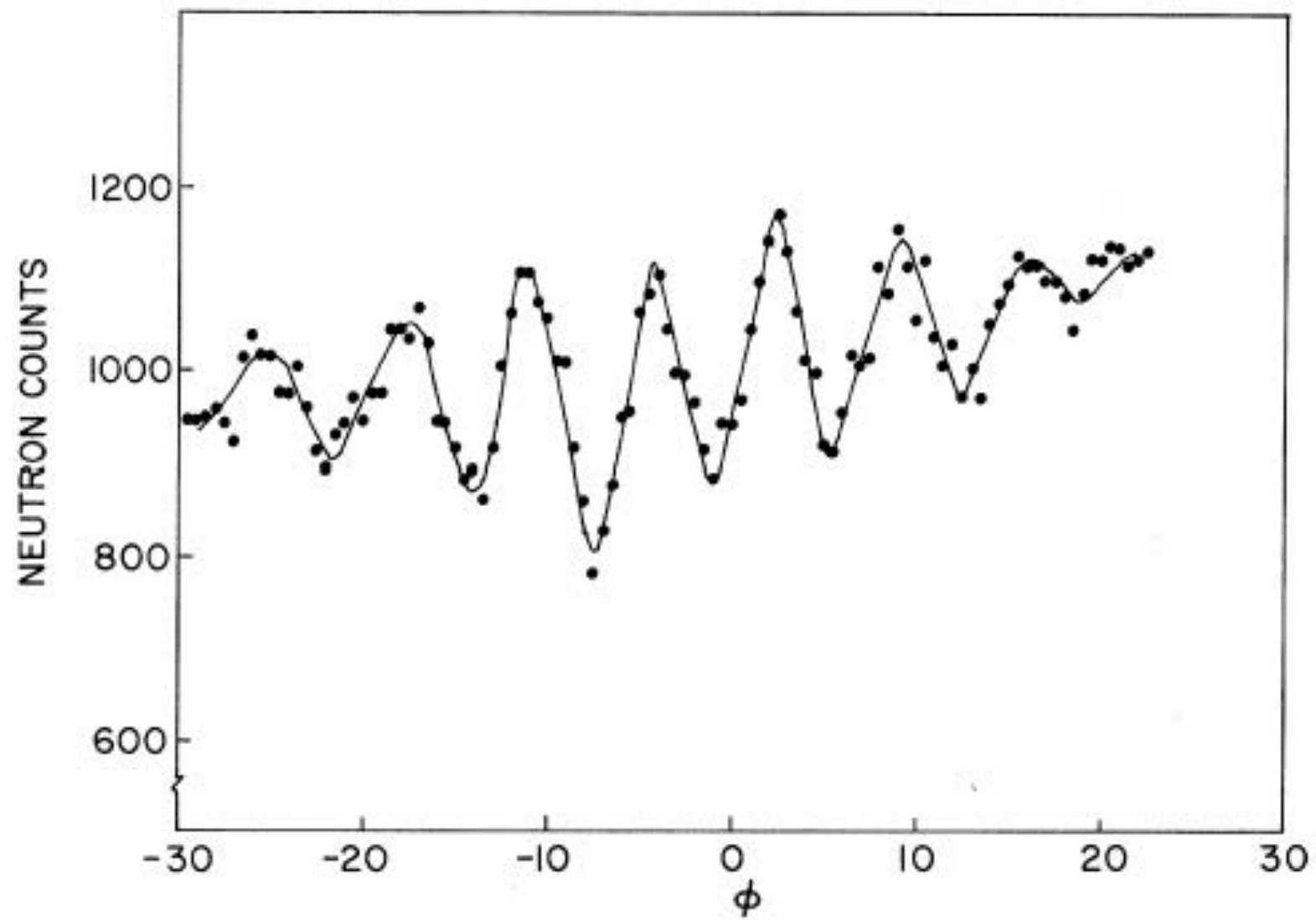


# Neutrons



# Neutrons

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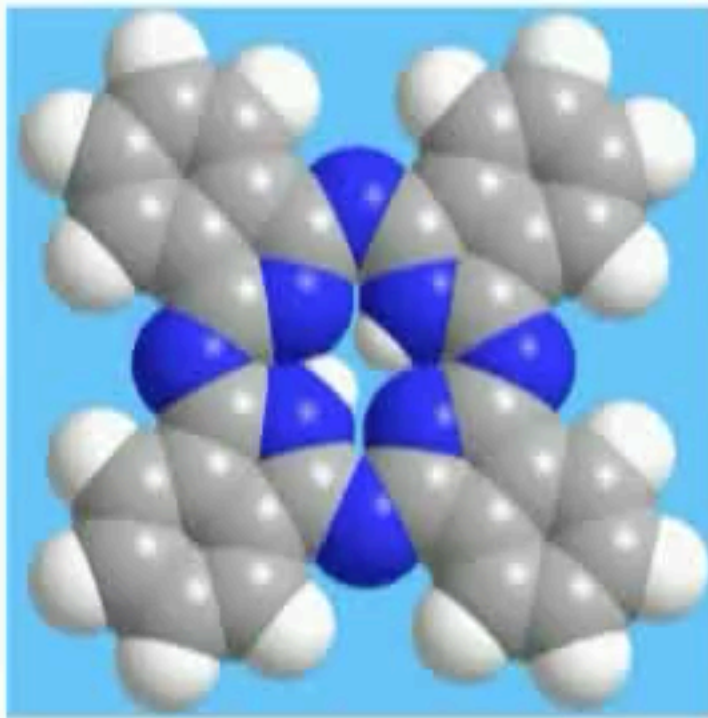




$C_{32}H_{18}N_8$  (~3000 particles)

# The quantum molecular movie

## The wave-particle duality of phthalocyanine



Thomas Juffmann  
Adriana Milic  
Michael Müllneritsch  
Peter Asenbaum  
Alexander Tsukernik  
Jens Tüxen  
Marcel Mayor  
Ori Cheshnovsky and  
Markus Arndt



# **All** particles **move** like waves and **hit** like particles

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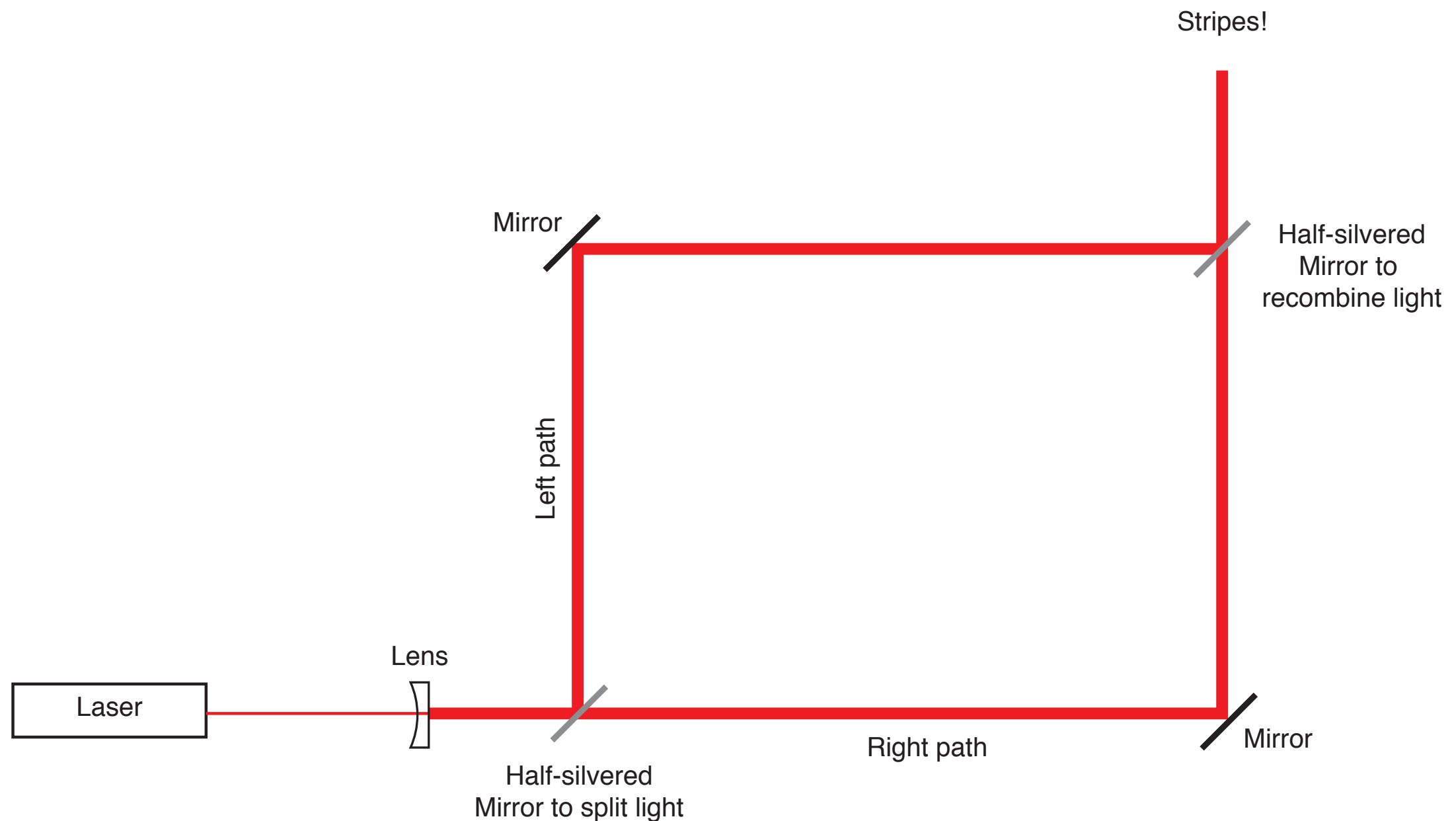
- From photons, to electrons, to neutrons, to molecules, they **all** move like waves and hit like particles
- Color is related to both wavelength and energy

Fundamental feature of how our universe works

# But which path did the particle really take?

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- Problem with the mental model



Particles **move** like waves and **hit** like particles

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