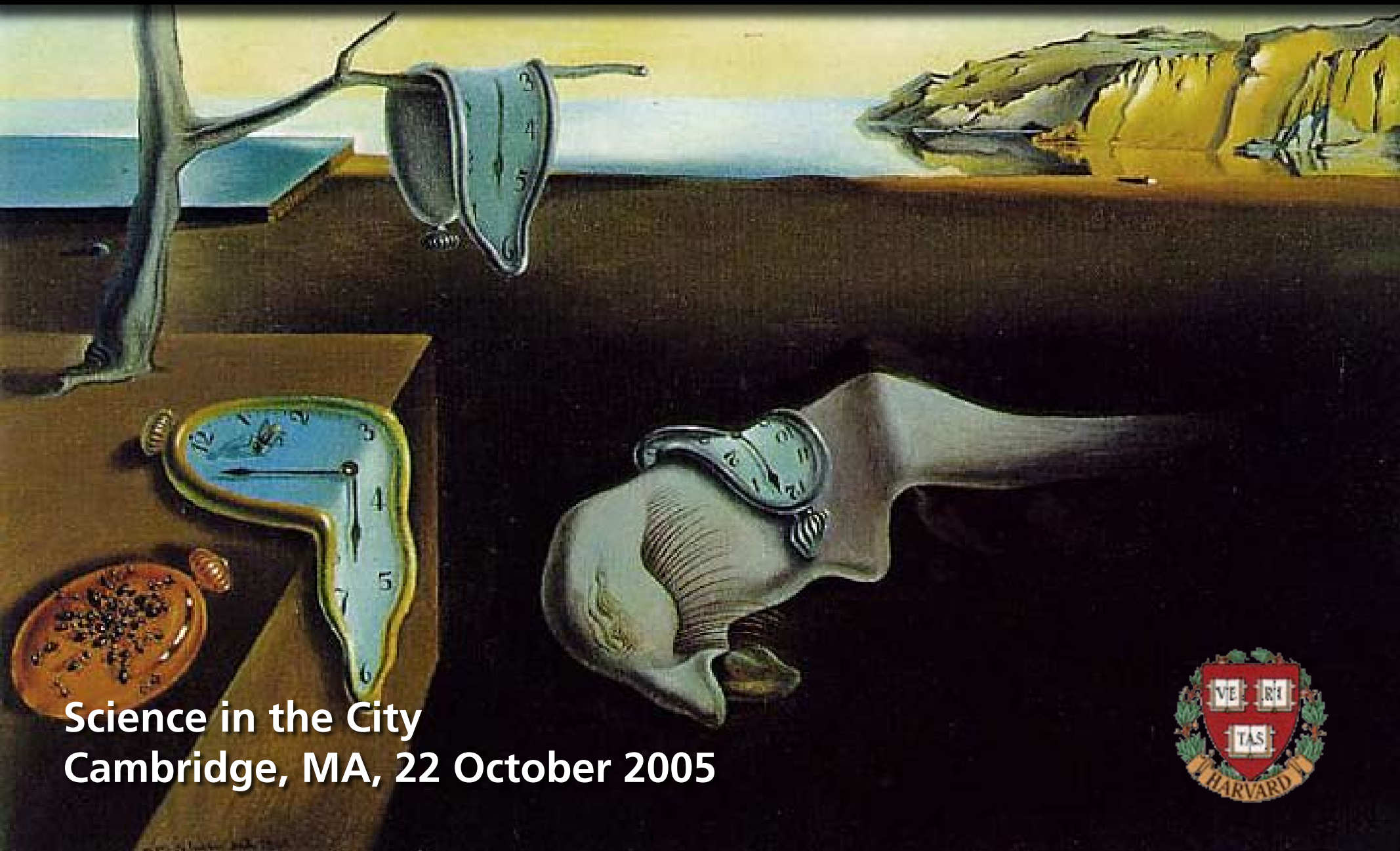


Stopping Time



Science in the City
Cambridge, MA, 22 October 2005



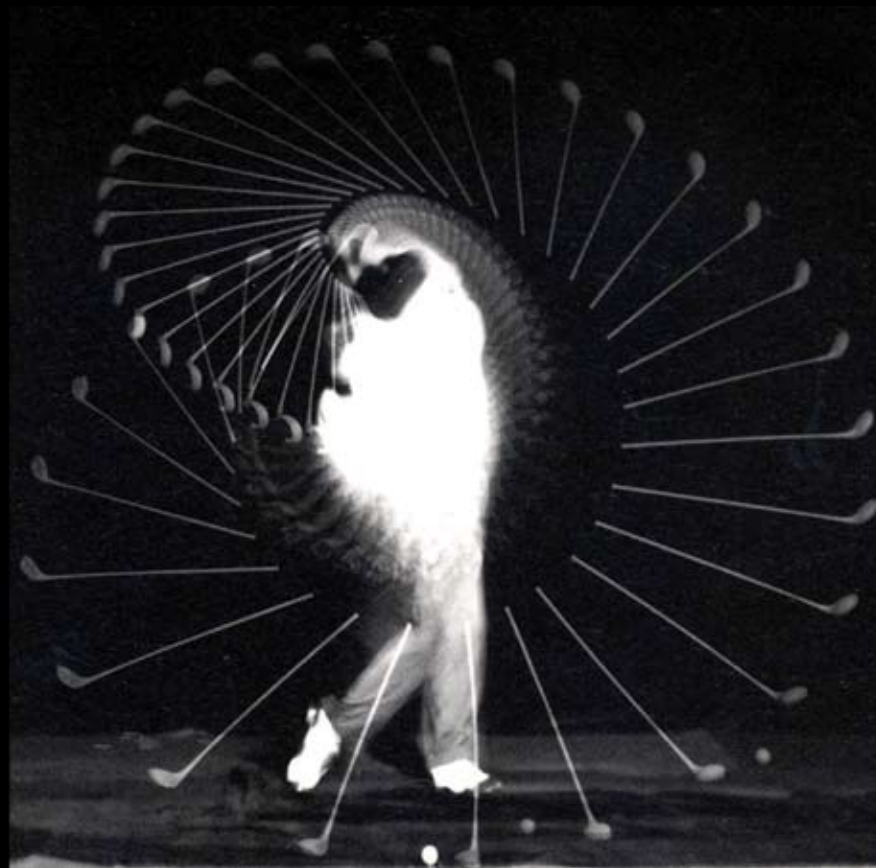




Speed up clock: see things that go slowly

Slow down clock: see things that go fast

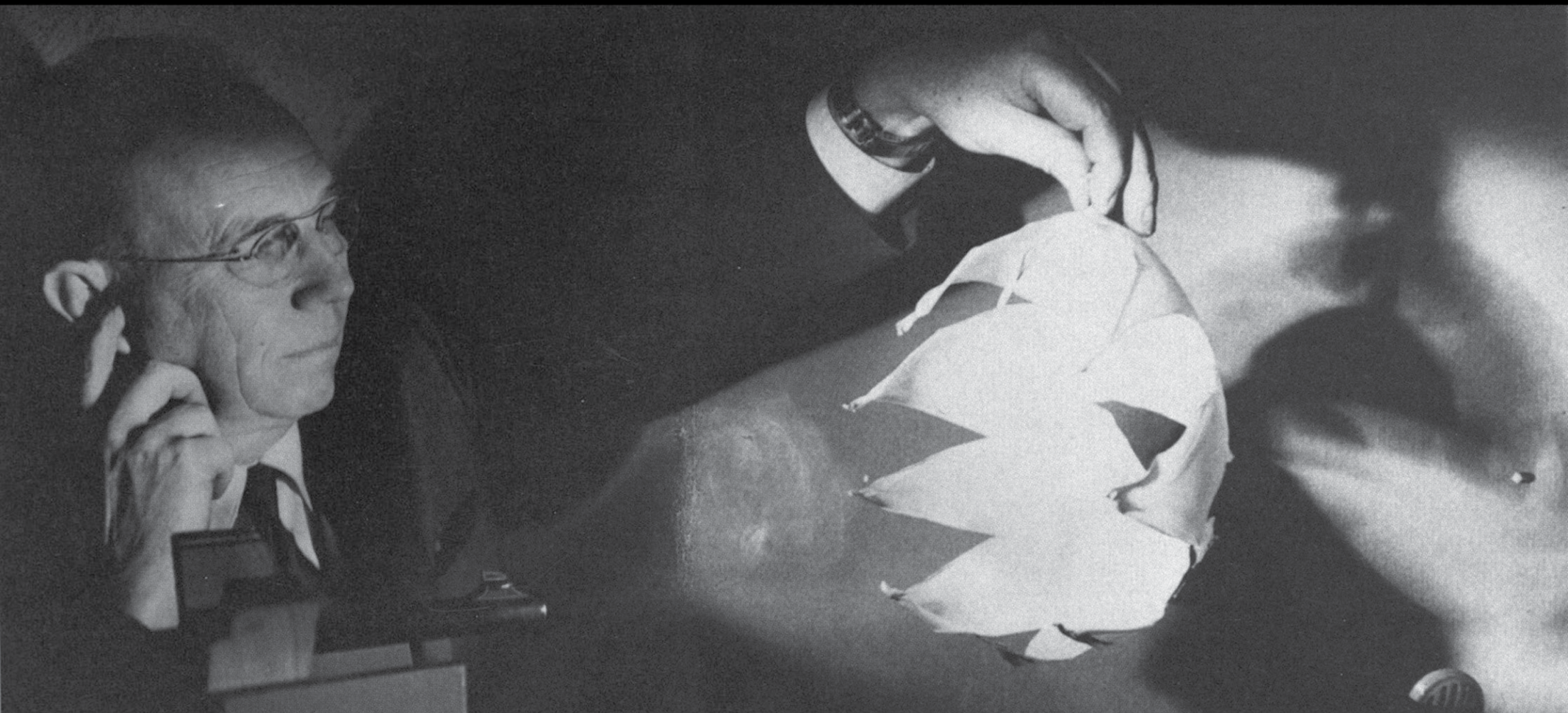
How can we slow down clock?



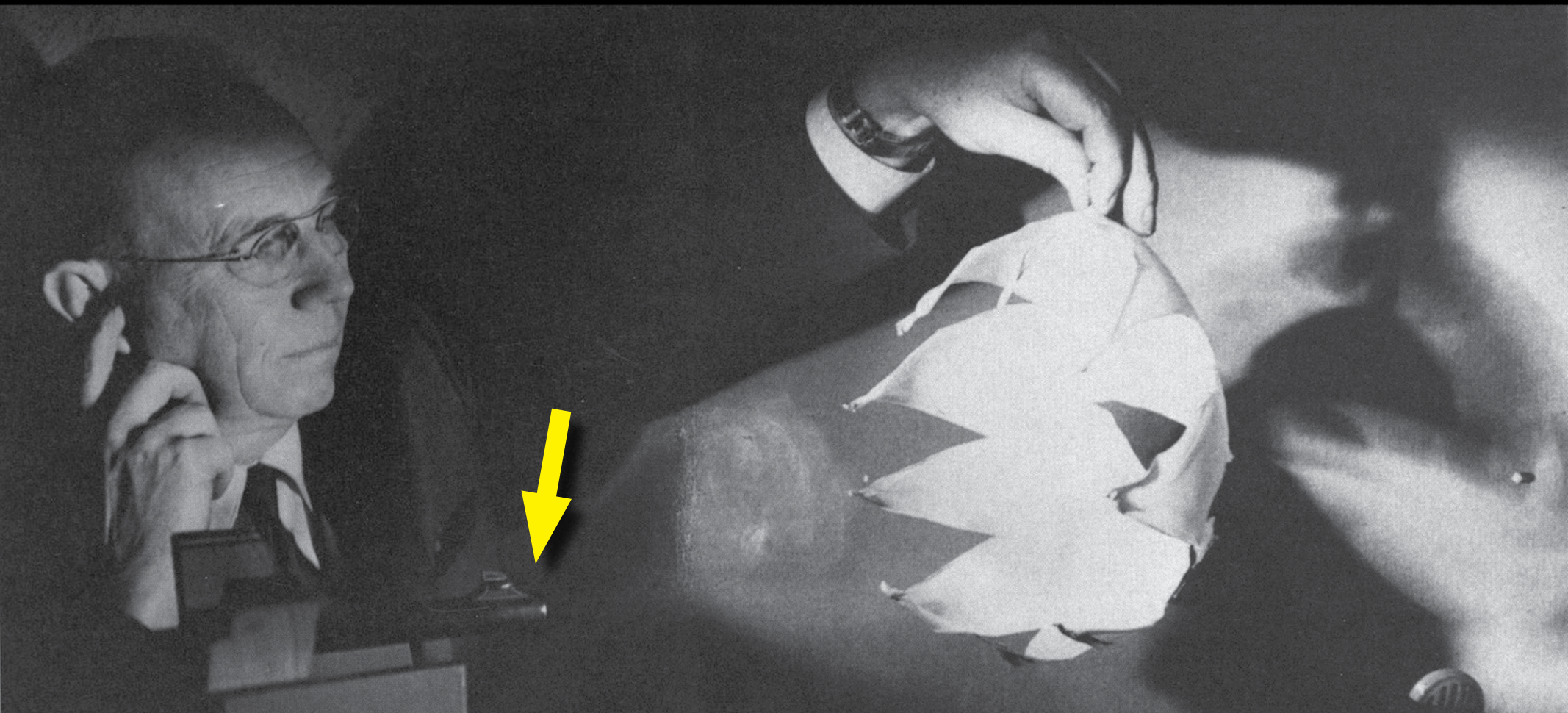
Harold Edgerton (1903 – 1990)



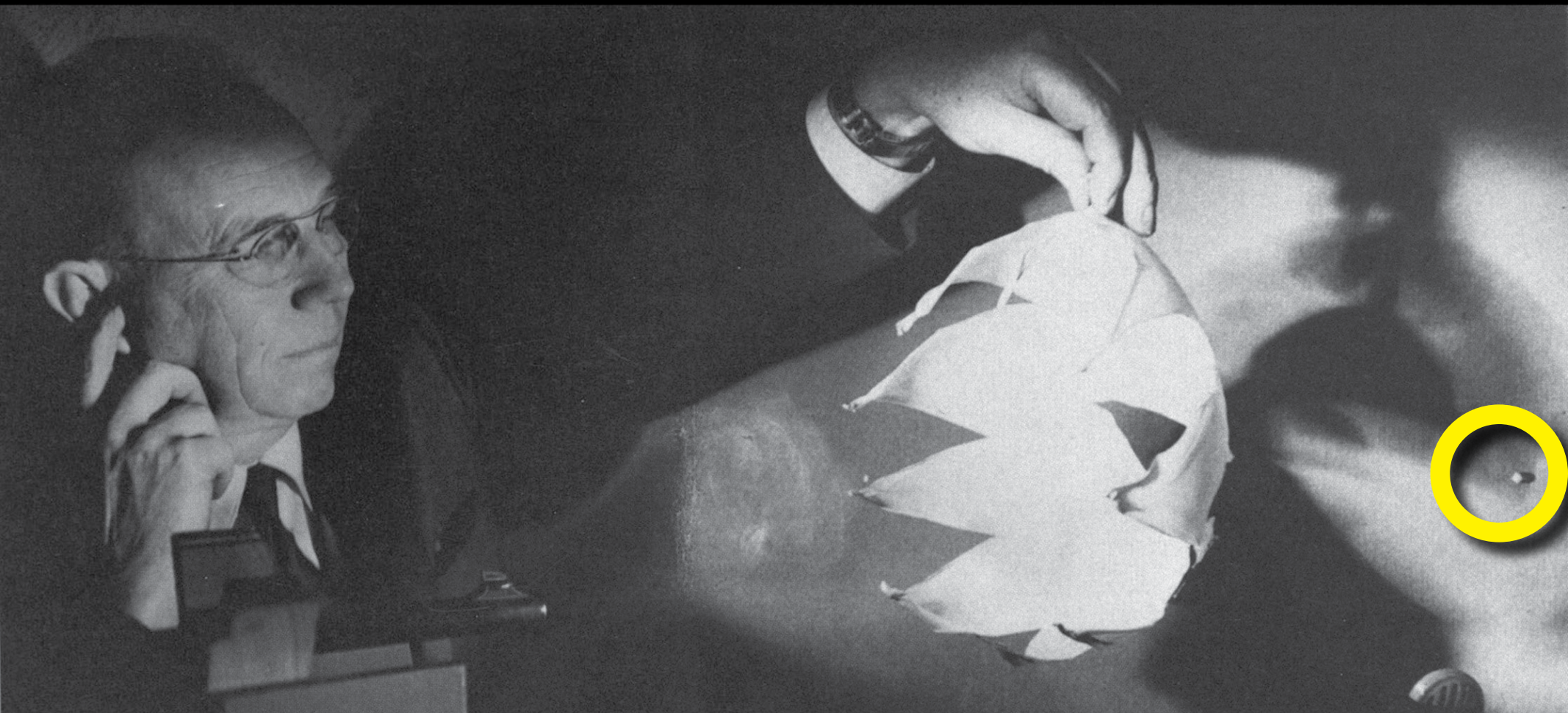
Harold Edgerton (1903 – 1990)



Harold Edgerton (1903 – 1990)

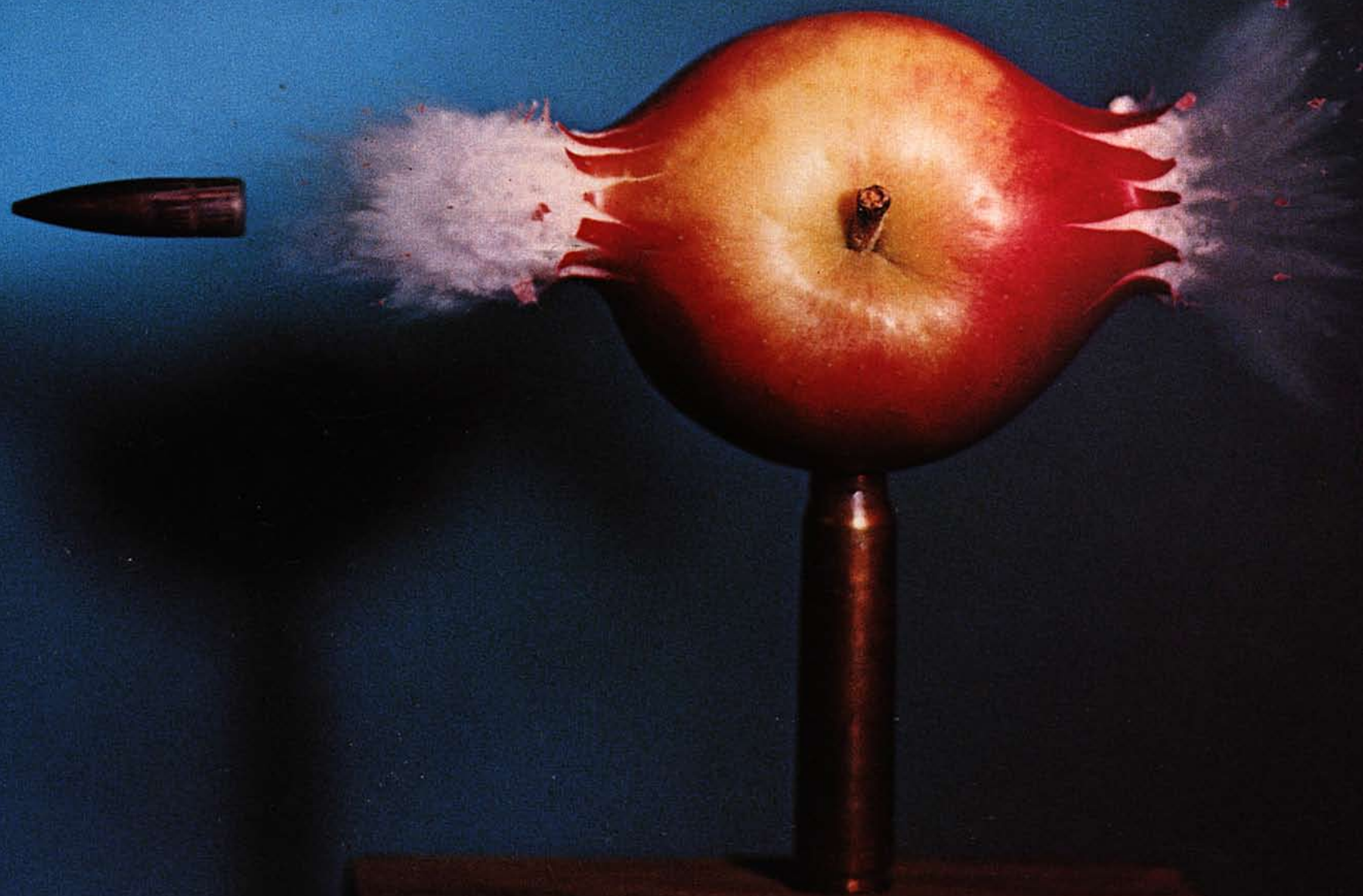


Harold Edgerton (1903 – 1990)

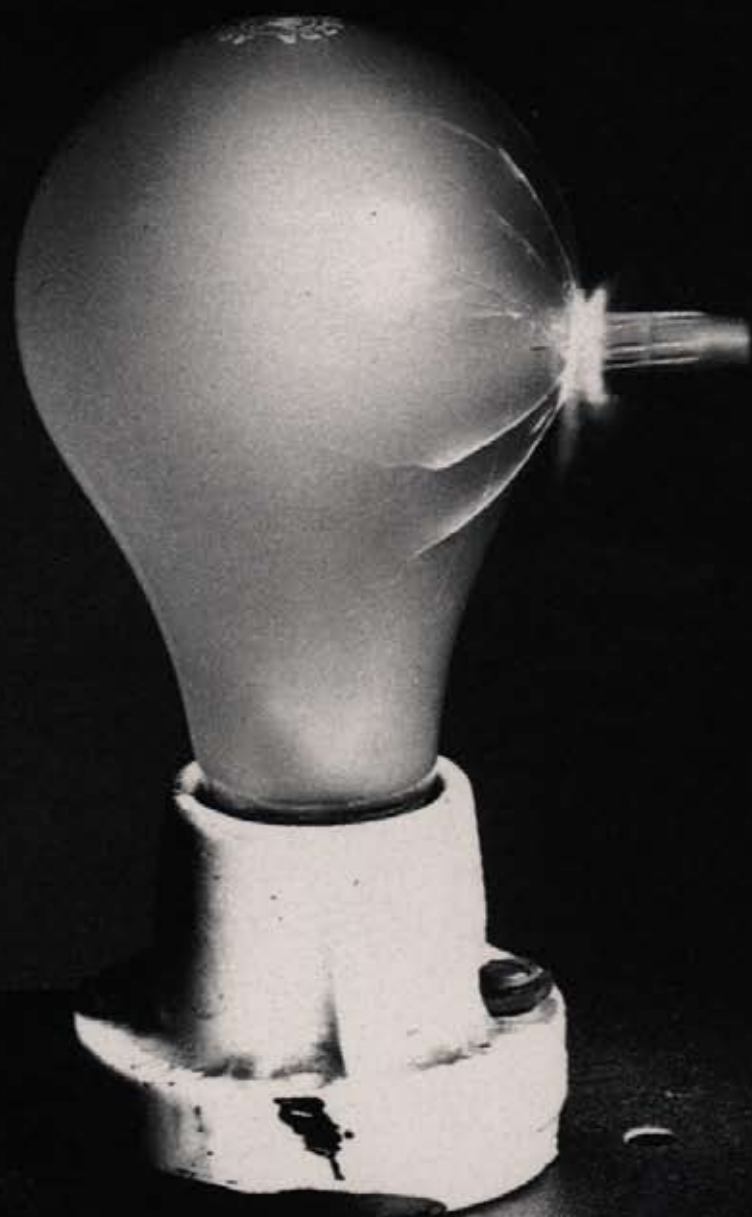


Harold Edgerton (1903 – 1990)

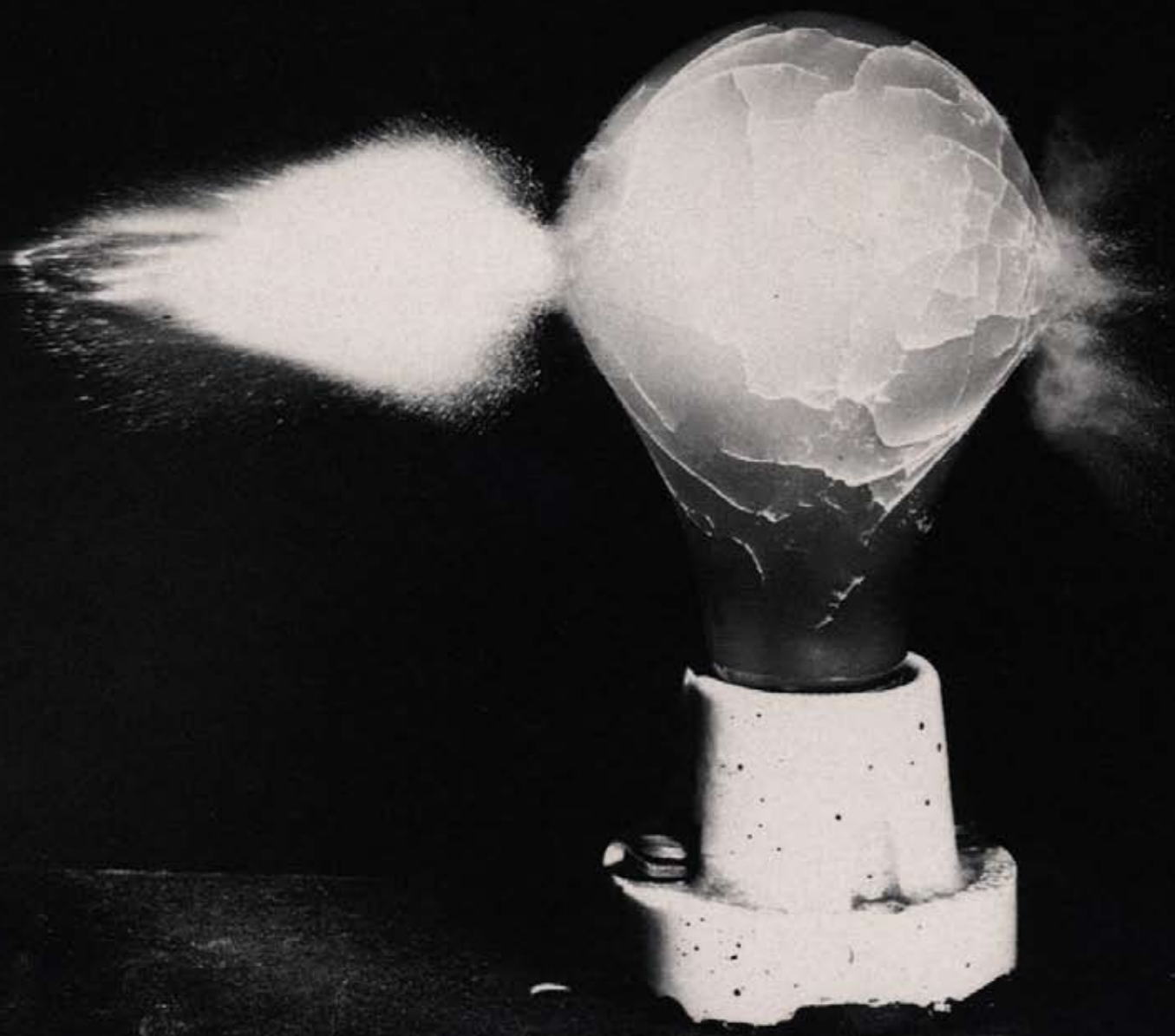












How do you capture a bullet in a light bulb?

flash exposure: about one microsecond

flash exposure: about one microsecond

that's one millionth of a second!

a microsecond is to a second...

a microsecond is to a second...

what a second is to two weeks!



in 1 s light travels 300,000,000 m



in 1 s light travels 300,000,000 m



that's from here to the moon!

$1/1000 \text{ s}$

1 ms



(one millisecond)

in 1 ms light travels 300,000 m

1/1000 s

1 ms



(one millisecond)

in 1 ms light travels 300,000 m

1/1000 s



1 ms

(one millisecond)

that's from here to New York

$1/1,000,000$ s

1 μ s

(one microsecond)

in 1 μ s light travels 300 m

1/1,000,000 s

1 μ s

(one microsecond)

in 1 μ s light travels 300 m

1/1,000,000 s

1 μ s

(one microsecond)

that's the length of an aircraft carrier



$1/1,000,000,000$ s

1 ns

(one nanosecond)

in 1 ns light travels 0.3 m

$1/1,000,000,000$ s

1 ns

(one nanosecond)



in 1 ns light travels 0.3 m

1/1,000,000,000 s

1 ns

(one nanosecond)

that's one foot

$1/1,000,000,000,000 \text{ s}$

1 ps



(one picosecond)

in 1 ps light travels 0.3 mm

1/1,000,000,000,000 s



1 ps

(one picosecond)

in 1 ps light travels 0.3 mm

1/1,000,000,000,000 s



(one picosecond)

that's a few times the width of a hair

$1/1,000,000,000,000,000$ s

1 fs

(one femtosecond)

in 1 fs light travels 0.3 μm

1/1,000,000,000,000,000 s

1 fs

(one femtosecond)

in 1 fs light travels $0.3\text{ }\mu\text{m}$

$1/1,000,000,000,000,000\text{ s}$

1 fs

(one femtosecond)

that's a few thousandths the width of a hair

note that the smaller the time interval...

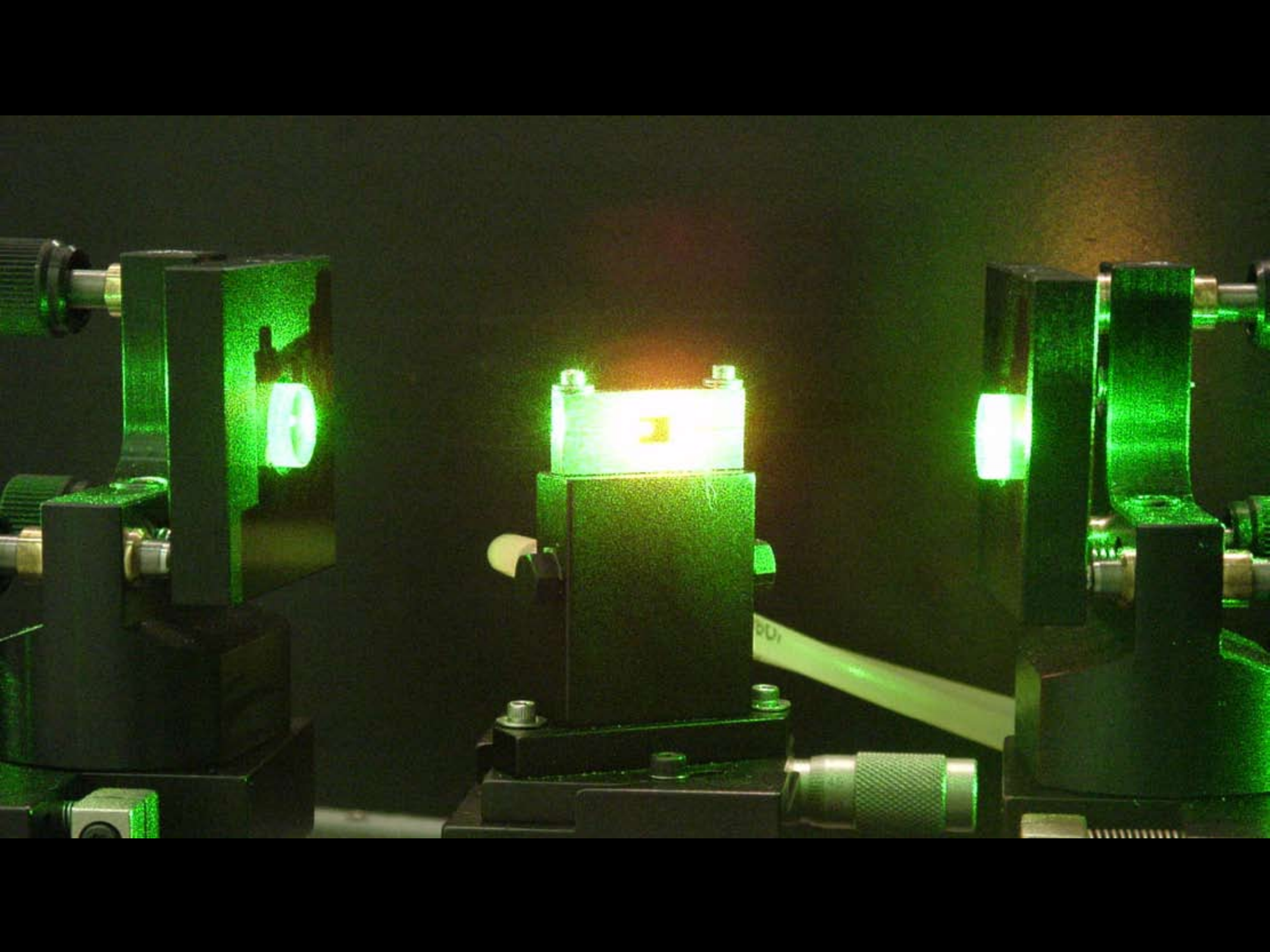
note that the smaller the time interval...

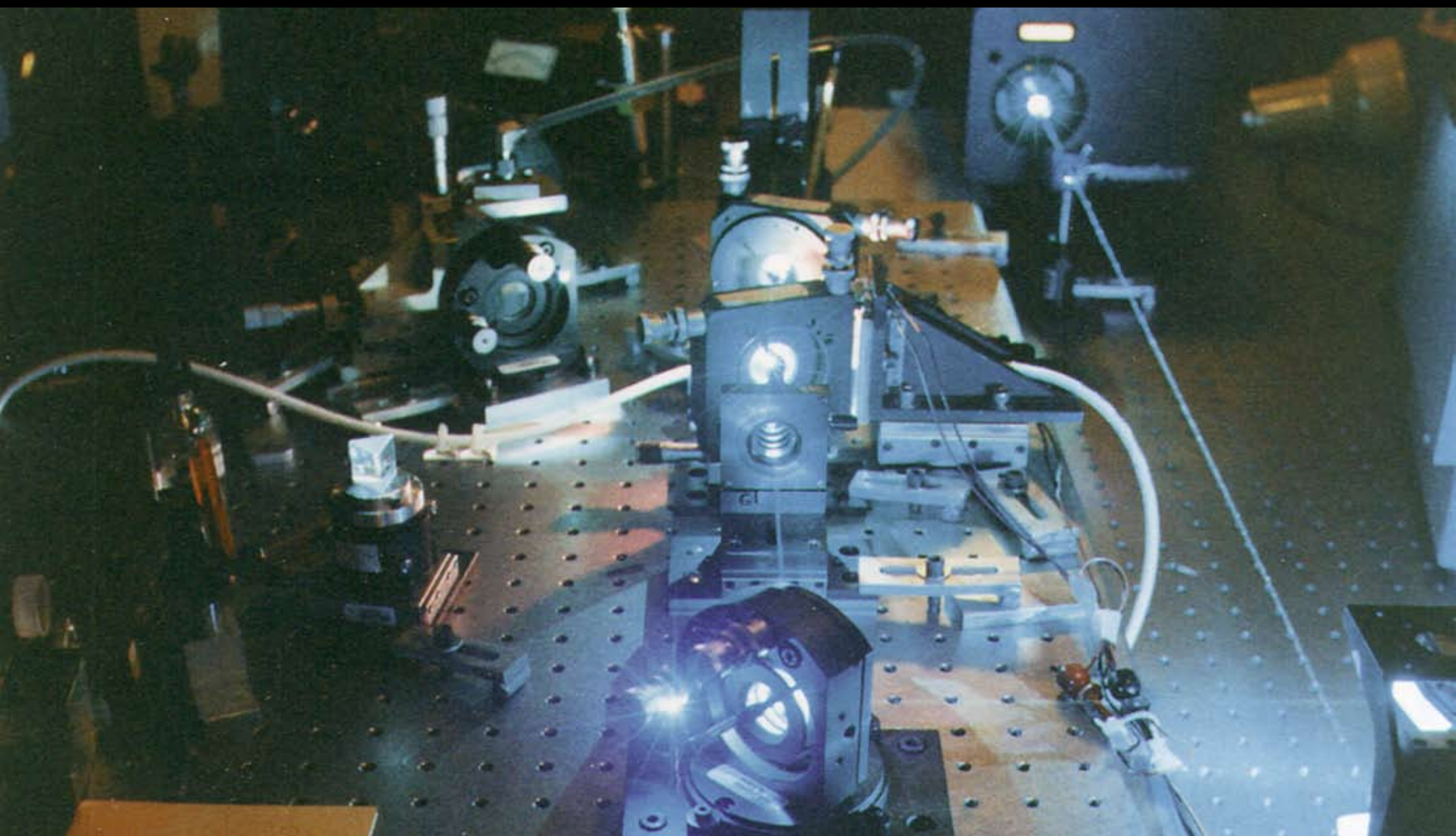
...the smaller the scale things happen on

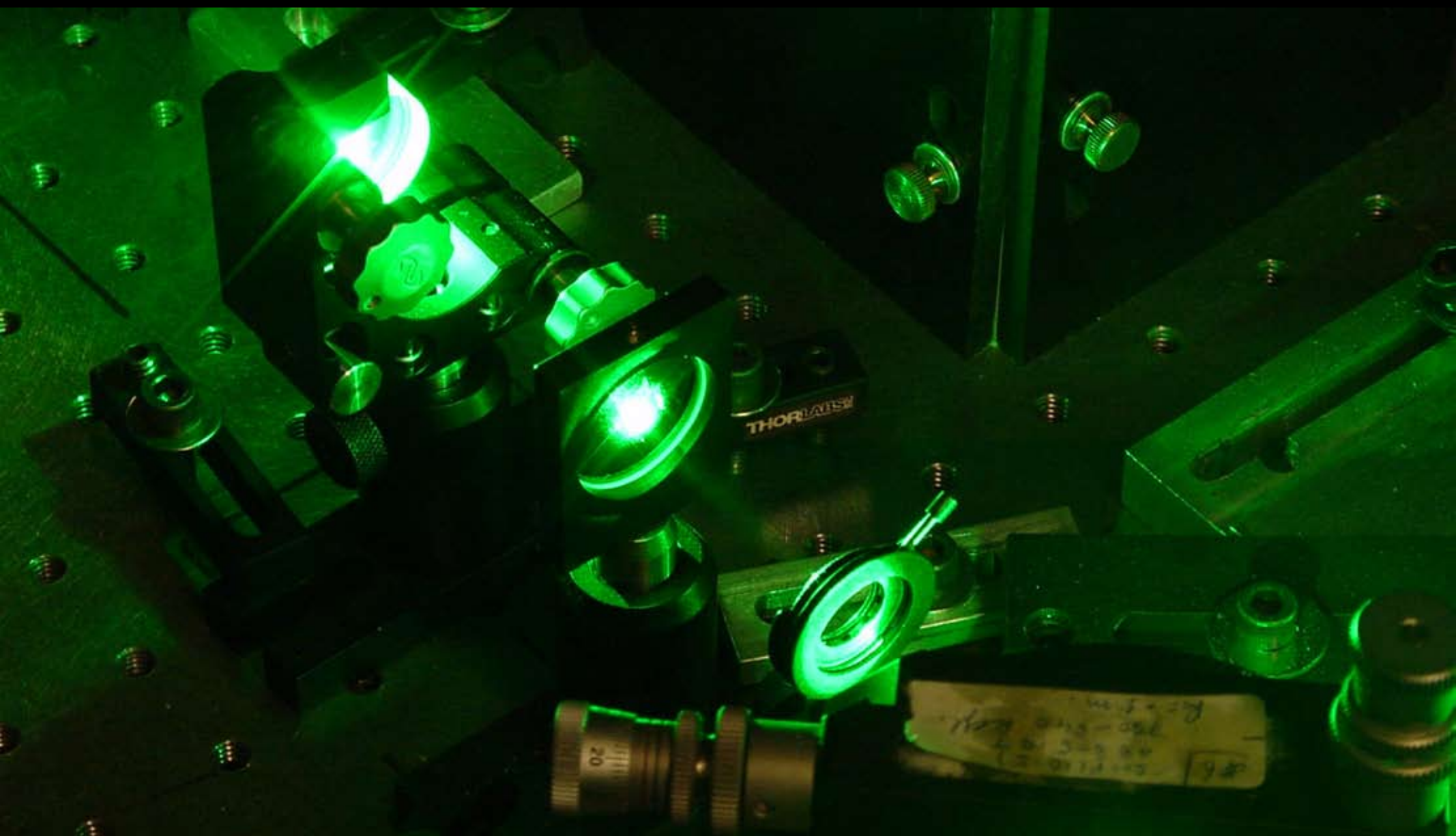
a flash of just a few femtoseconds...

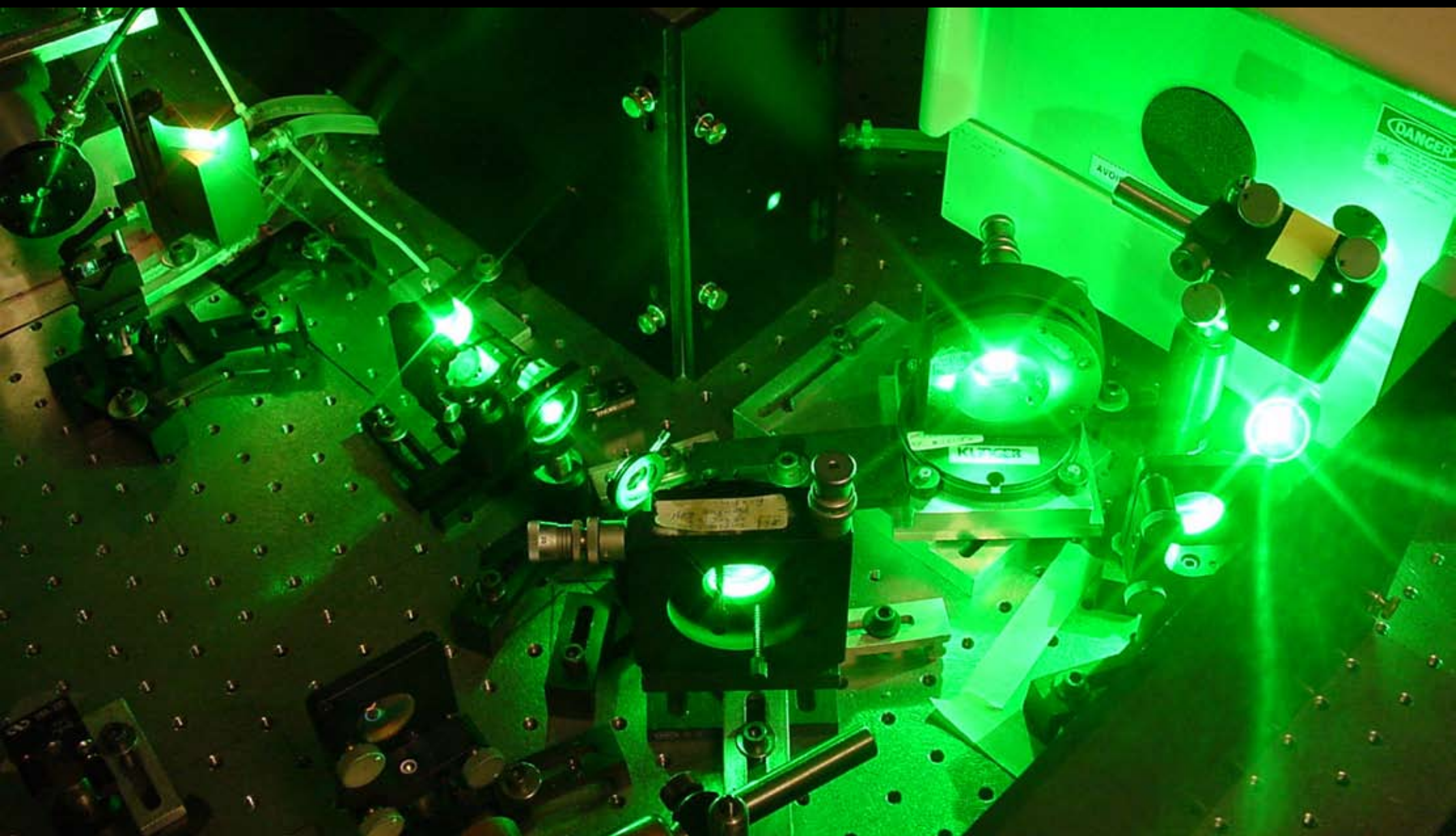
a flash of just a few femtoseconds...

...is a lot of light in very little time









a flash of just a few femtoseconds...

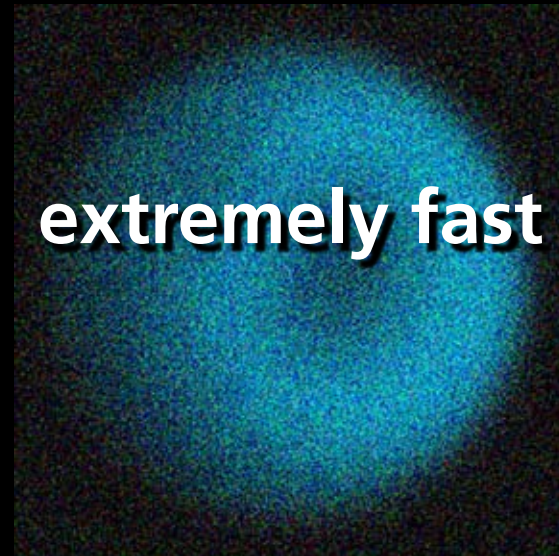
...is a lot of light in very little time



femtosecond pulses

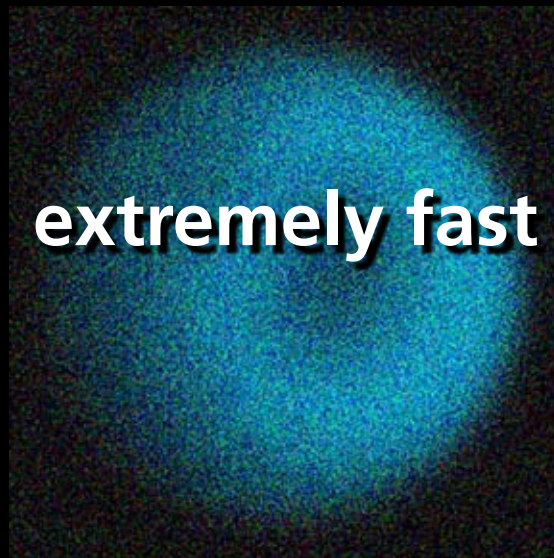
open the door to...

**femtosecond pulses
open the door to...**

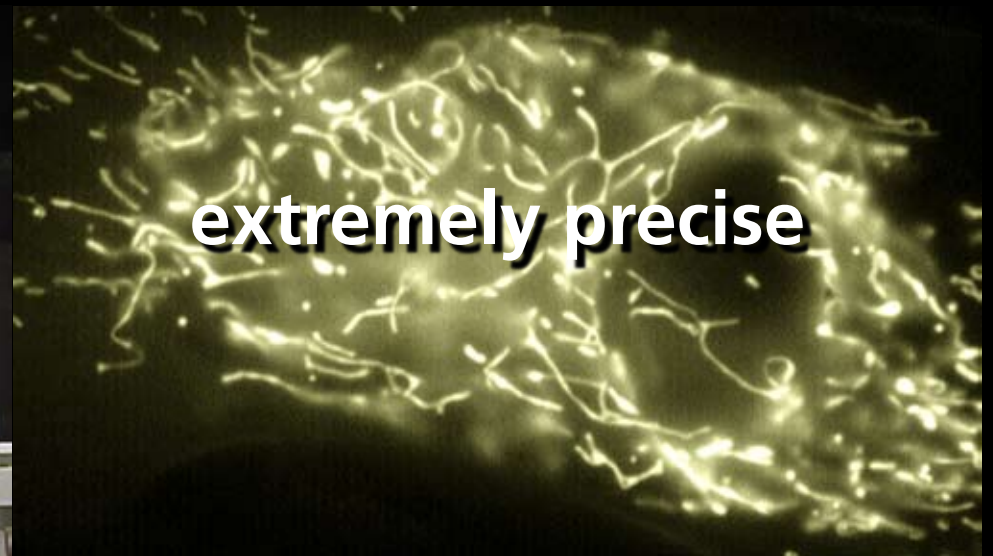
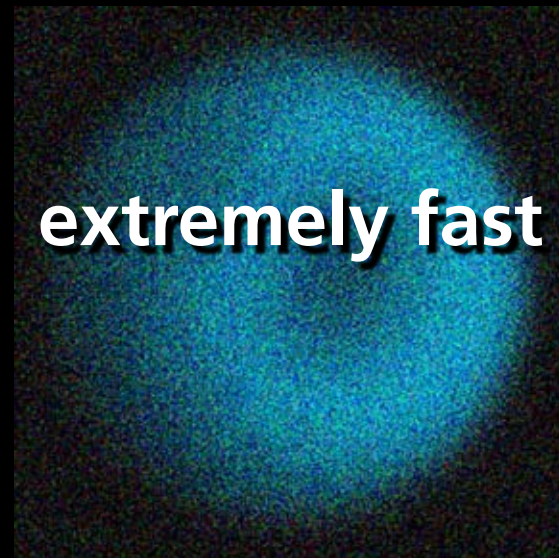


extremely fast

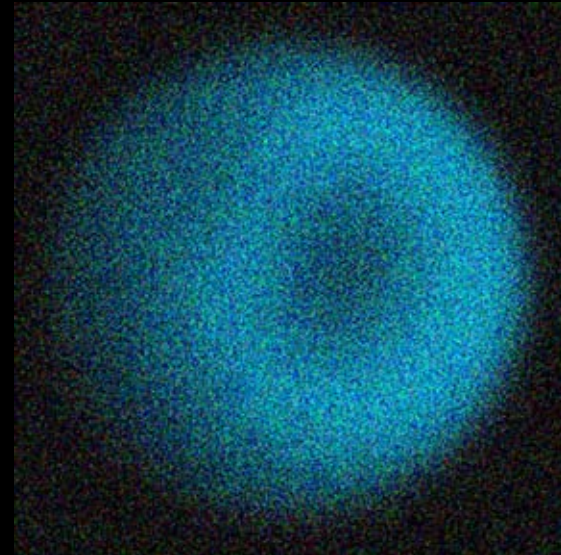
**femtosecond pulses
open the door to...**



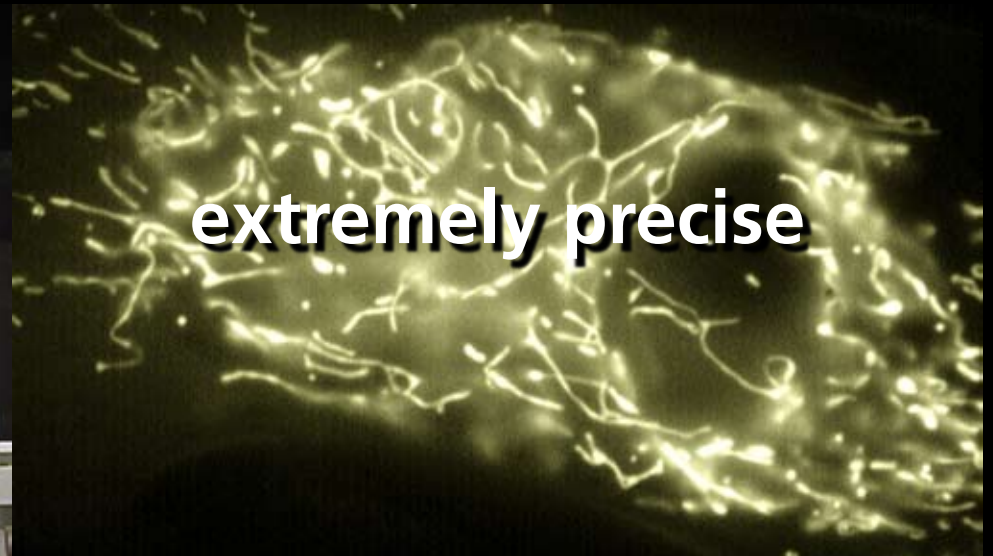
**femtosecond pulses
open the door to...**



femtosecond pulses
open the door to...

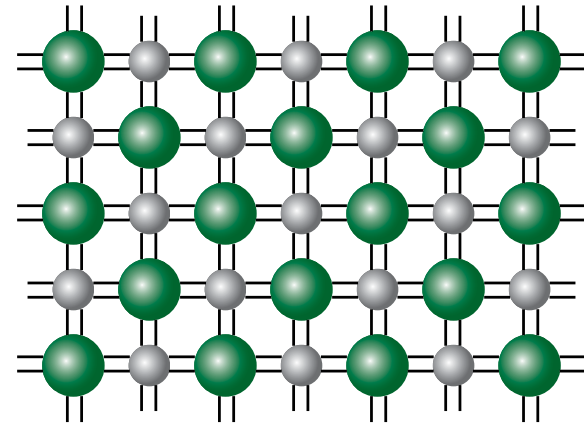


extremely hot



extremely precise

**femtosecond pulses
open the door to...**

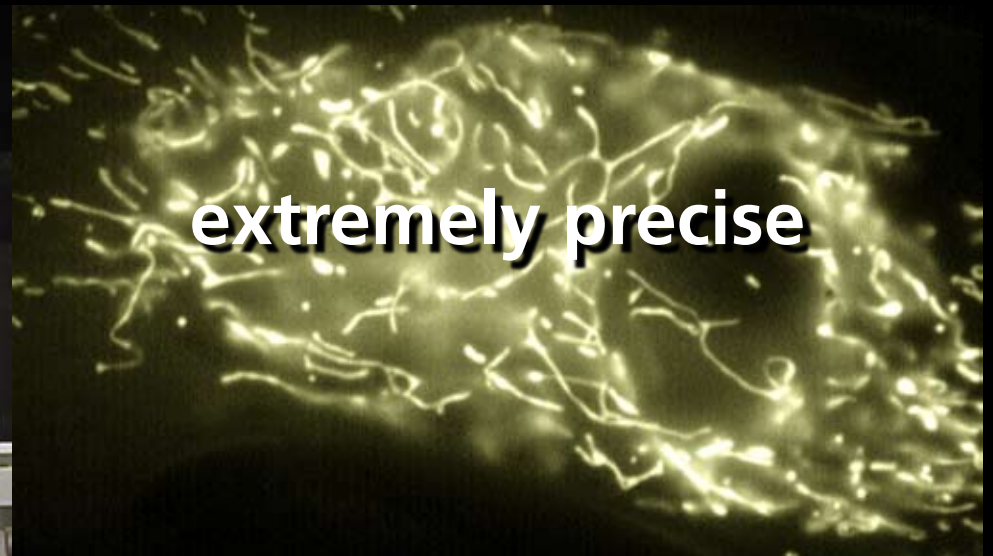
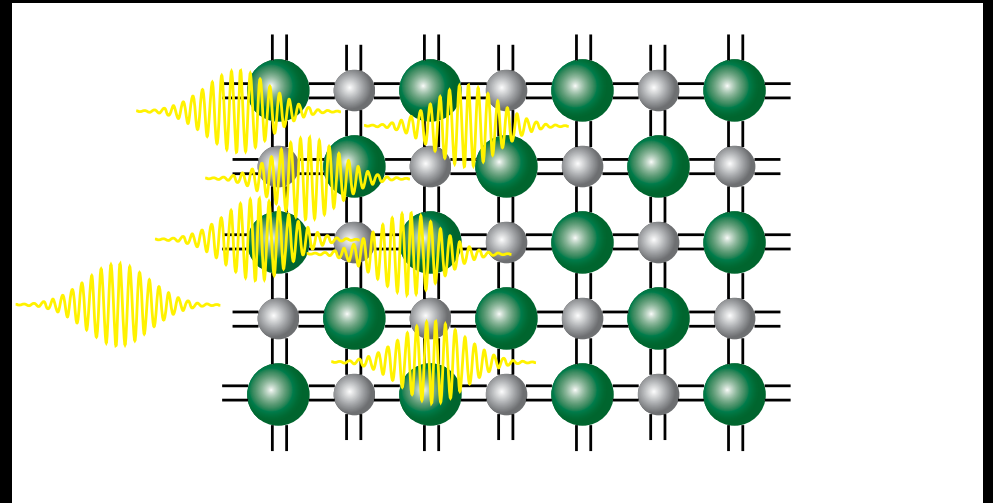
A photograph of a laser cutting head in operation. The head is a cylindrical metal component with a bright red laser beam focused on a metal workpiece. The text "extremely hot" is overlaid on the image. The background is dark and out of focus.

extremely hot

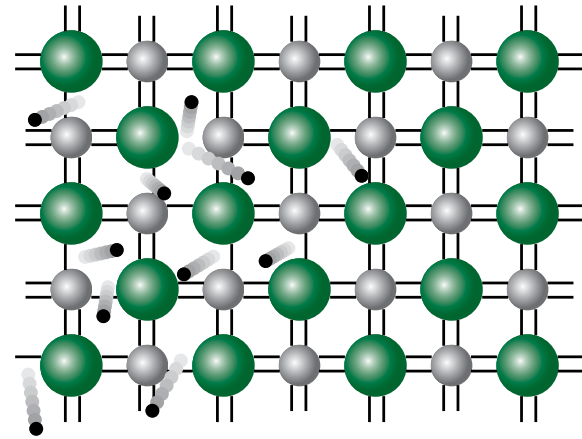
A photograph showing a complex, branching, yellowish-green structure, possibly a biological or chemical network. The structure is composed of many thin, interconnected filaments. The text "extremely precise" is overlaid on the image.

extremely precise

**femtosecond pulses
open the door to...**



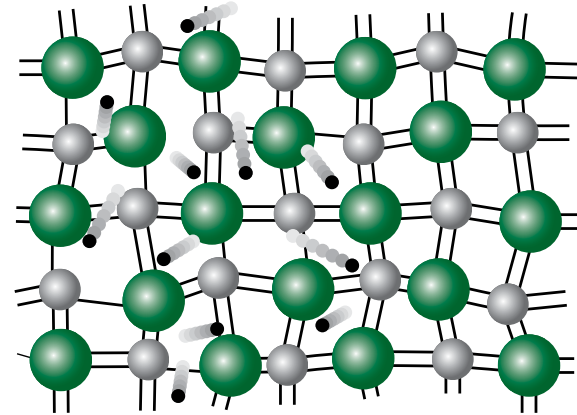
**femtosecond pulses
open the door to...**



extremely hot

extremely precise

**femtosecond pulses
open the door to...**

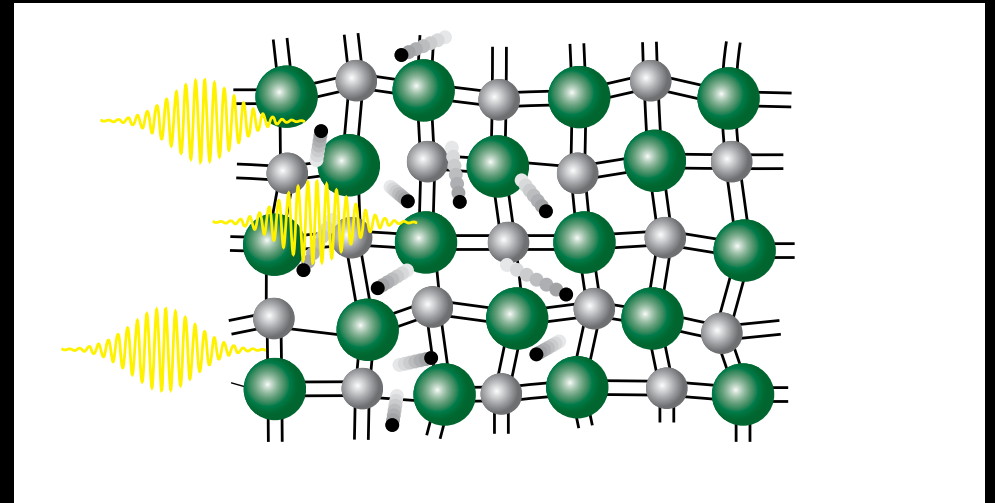


extremely hot

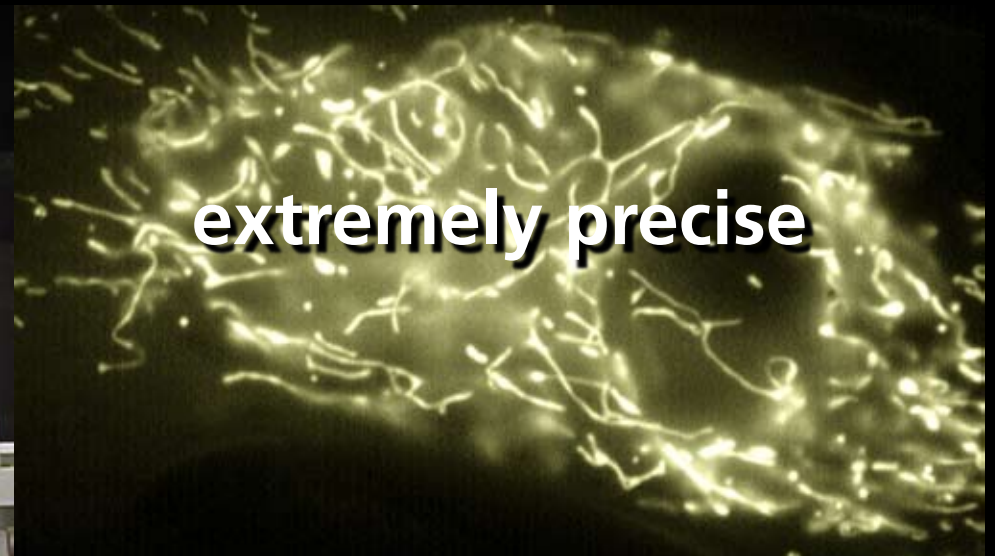


extremely precise

**femtosecond pulses
open the door to...**



extremely hot



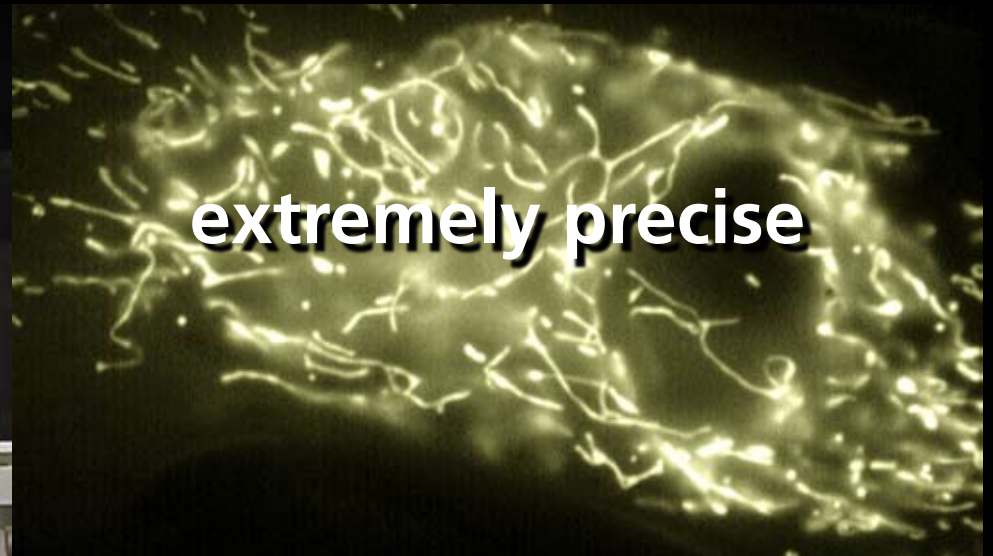
extremely precise

femtosecond pulses

open the door to...



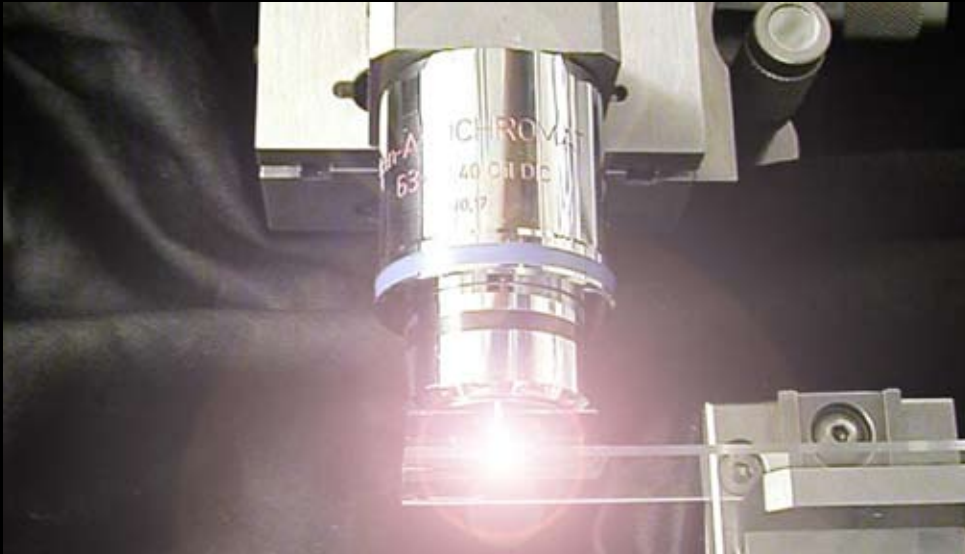
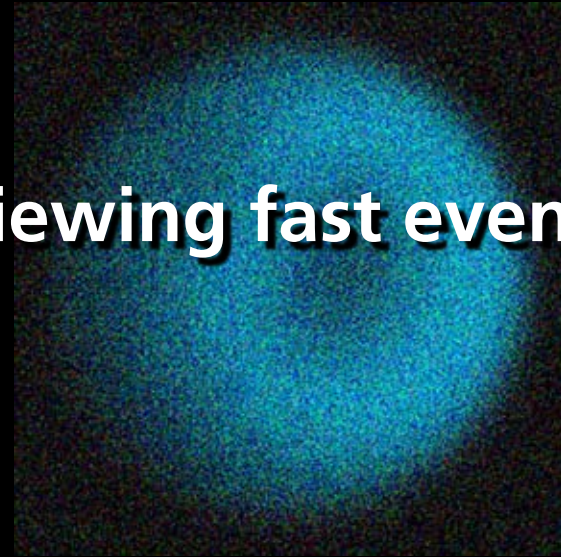
extremely hot



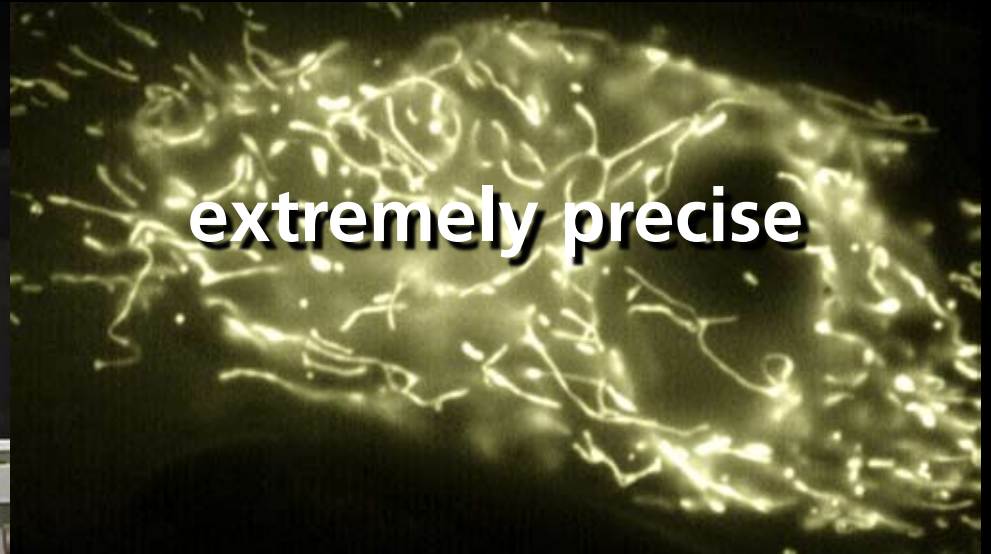
extremely precise

**femtosecond pulses
open the door to...**

viewing fast events

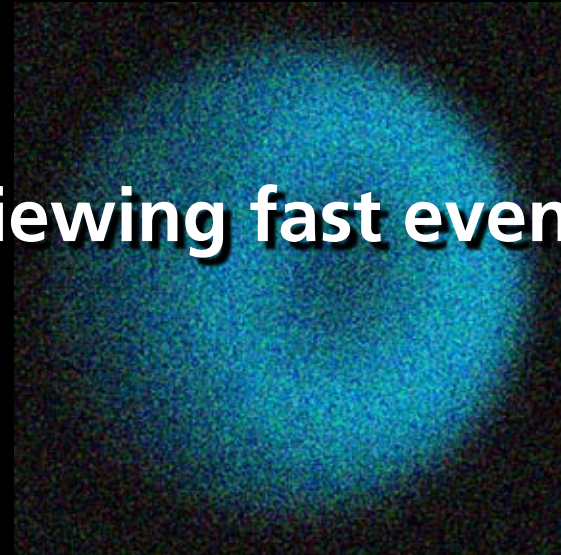


extremely precise



**femtosecond pulses
open the door to...**

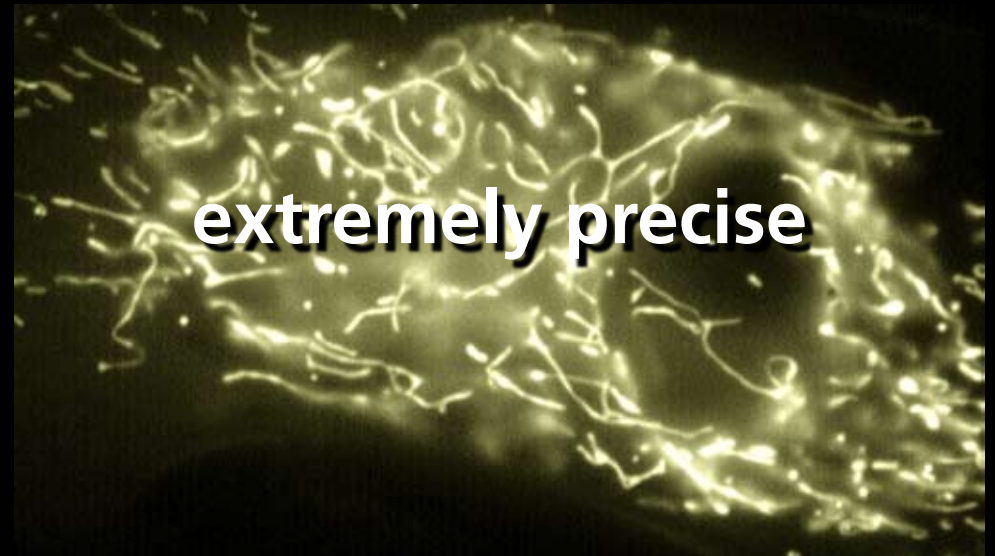
viewing fast events



**usually matter
controls light**

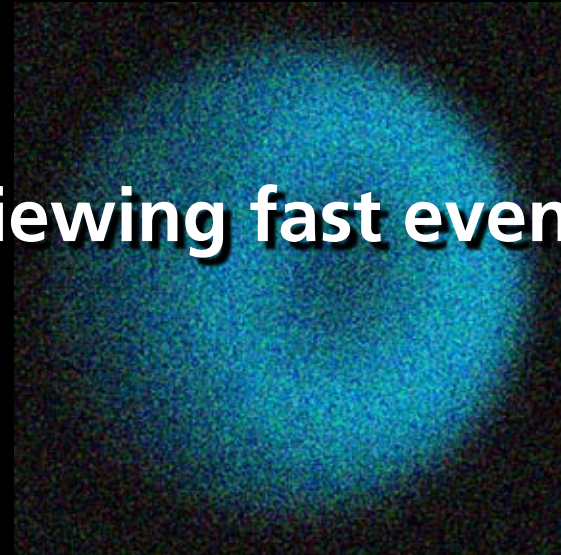


extremely precise

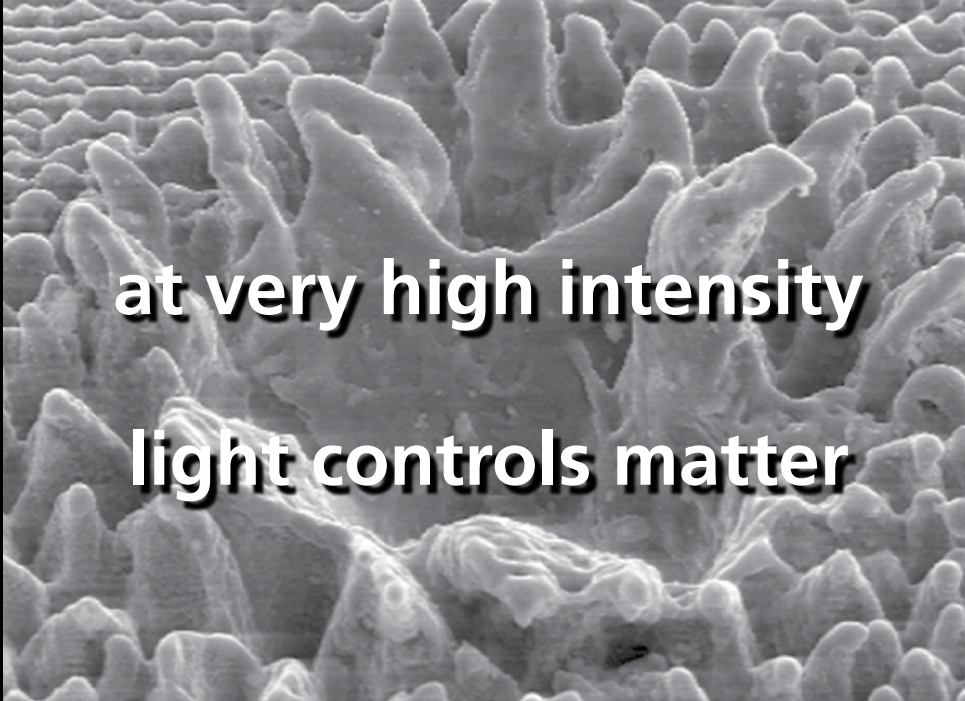


**femtosecond pulses
open the door to...**

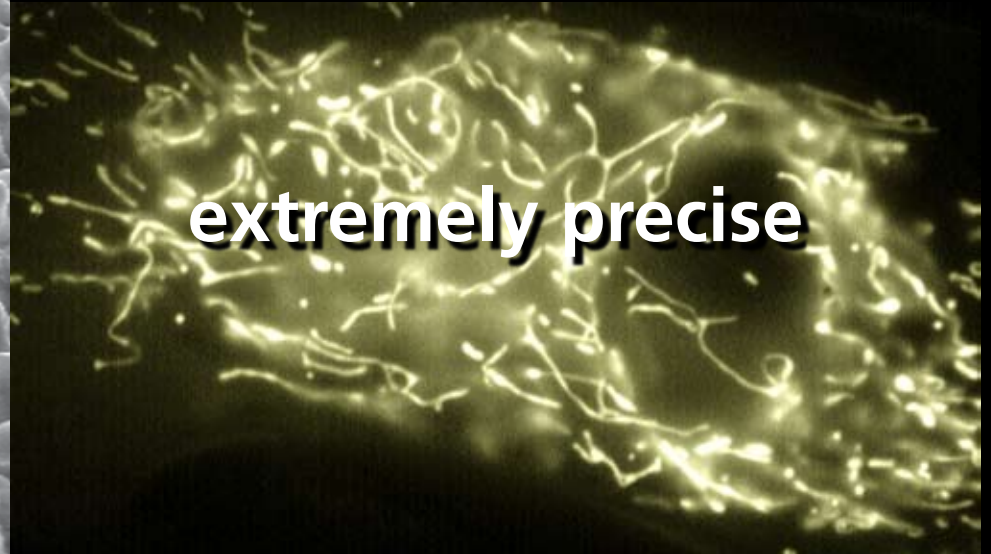
viewing fast events



**at very high intensity
light controls matter**

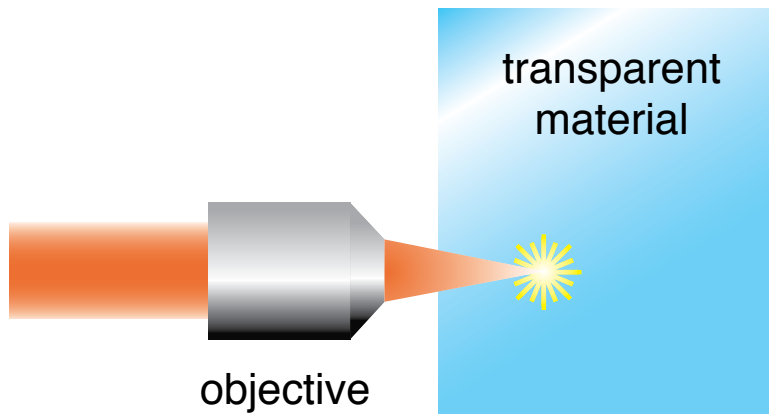
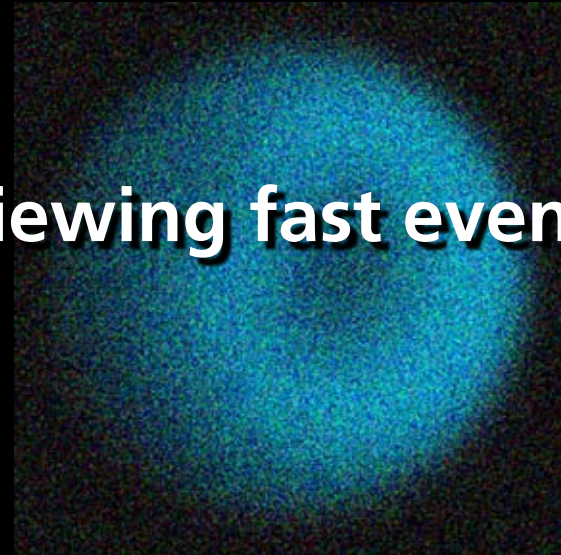


extremely precise

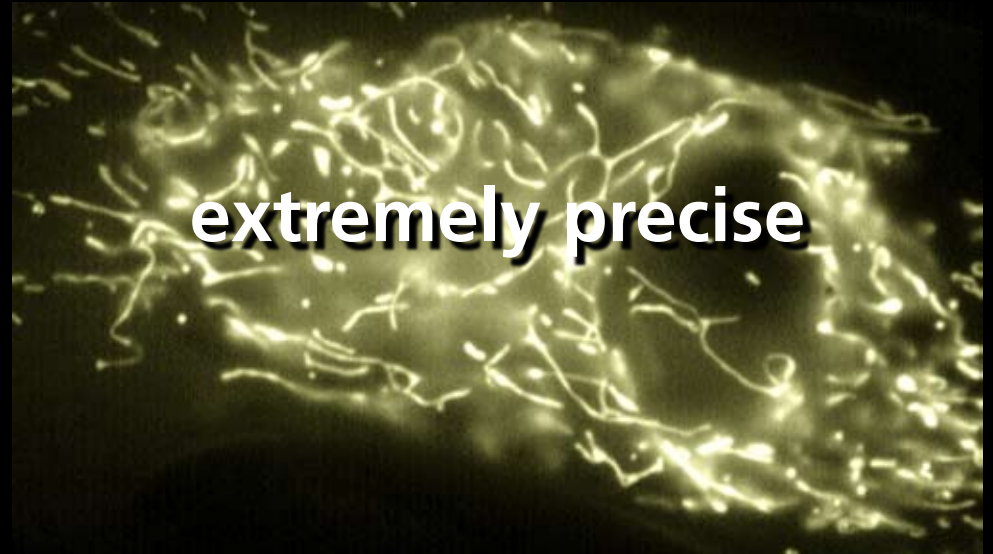


**femtosecond pulses
open the door to...**

viewing fast events

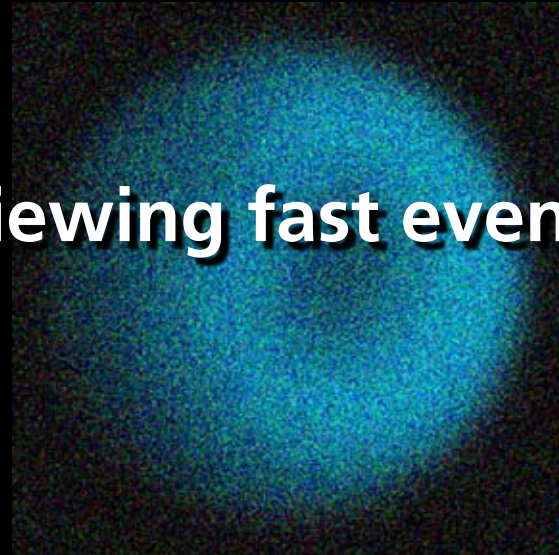


extremely precise

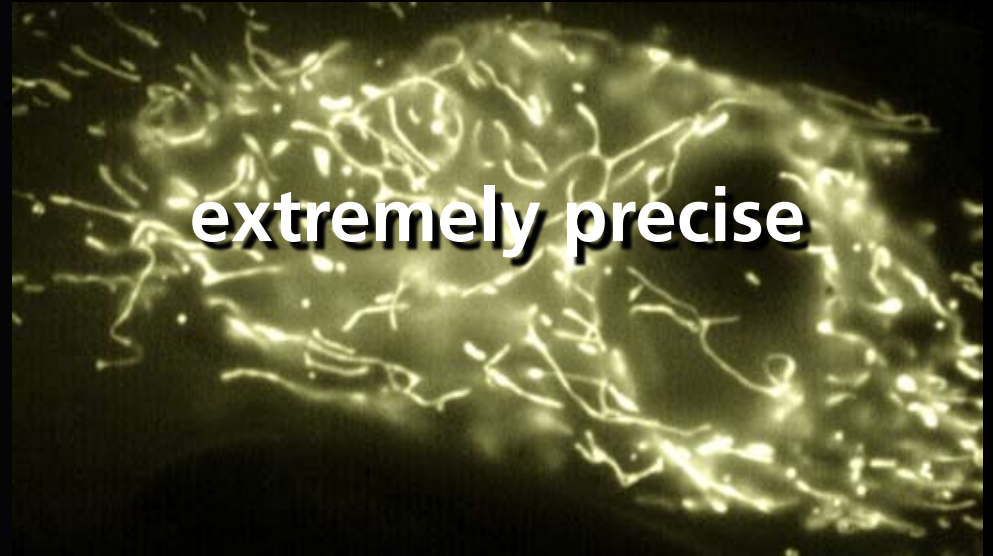


**femtosecond pulses
open the door to...**

viewing fast events

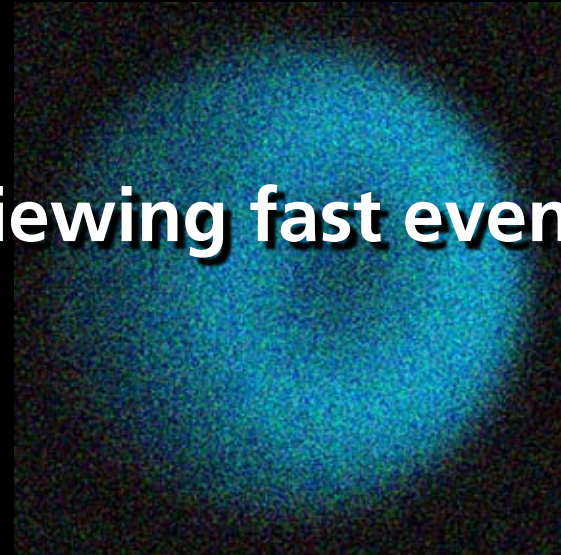


extremely precise



**femtosecond pulses
open the door to...**

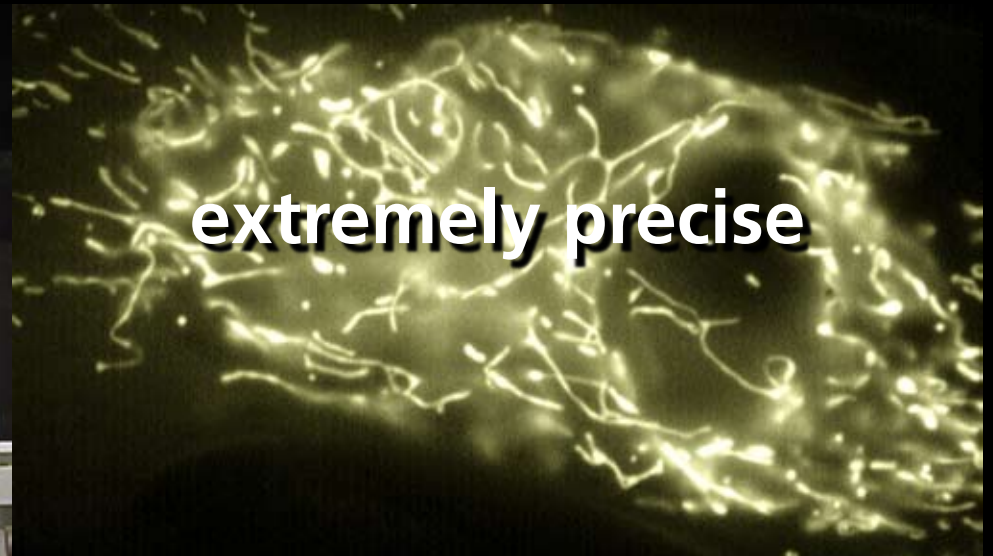
viewing fast events



shaping matter with light

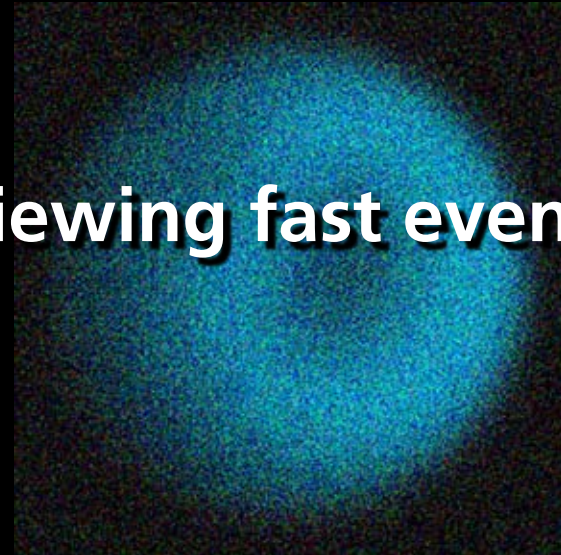


extremely precise



**femtosecond pulses
open the door to...**

viewing fast events



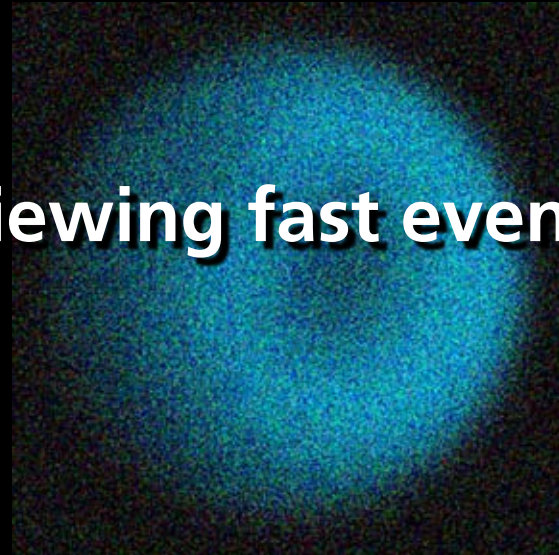
shaping matter with light



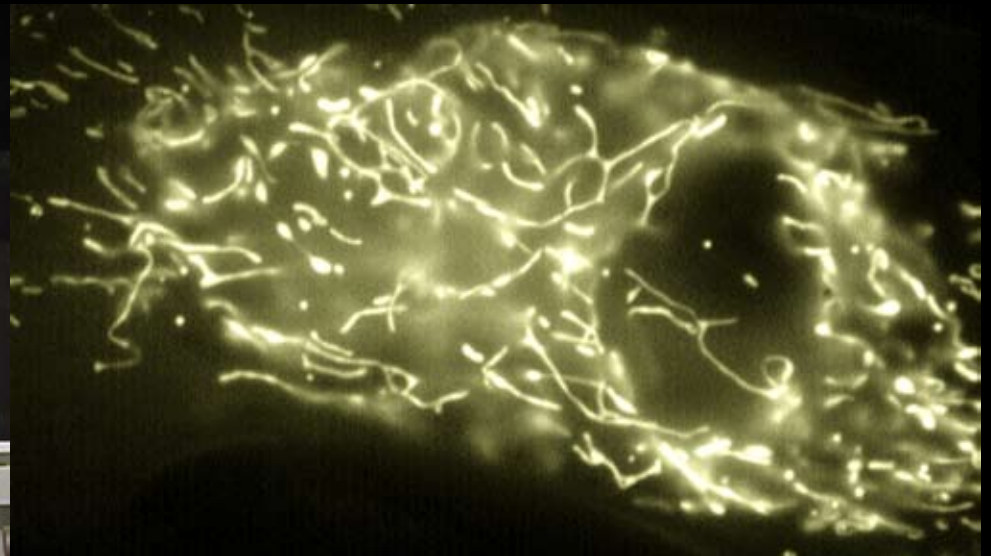
**even at low energy
high intensity!**

**femtosecond pulses
open the door to...**

viewing fast events

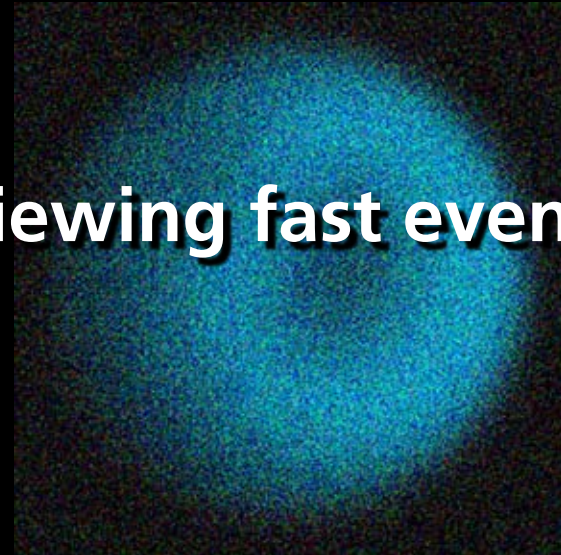


shaping matter with light

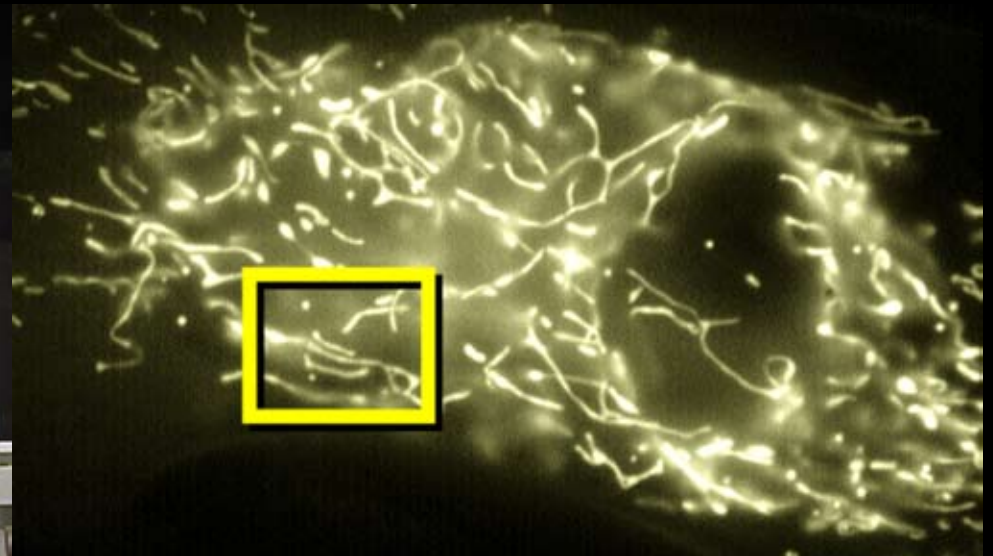


**femtosecond pulses
open the door to...**

viewing fast events

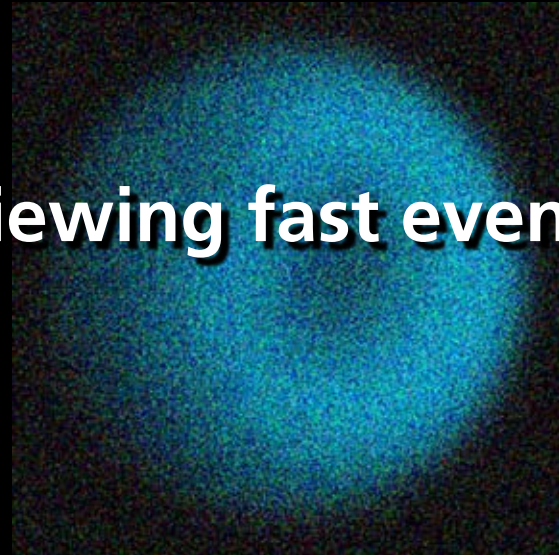


shaping matter with light



**femtosecond pulses
open the door to...**

viewing fast events

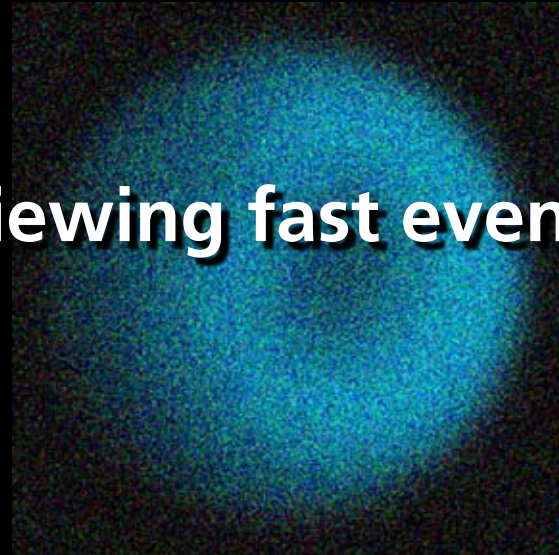


shaping matter with light

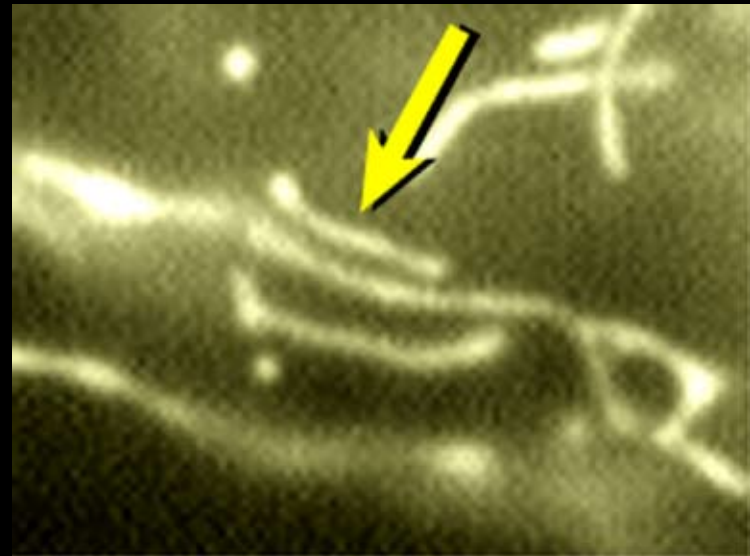


**femtosecond pulses
open the door to...**

viewing fast events

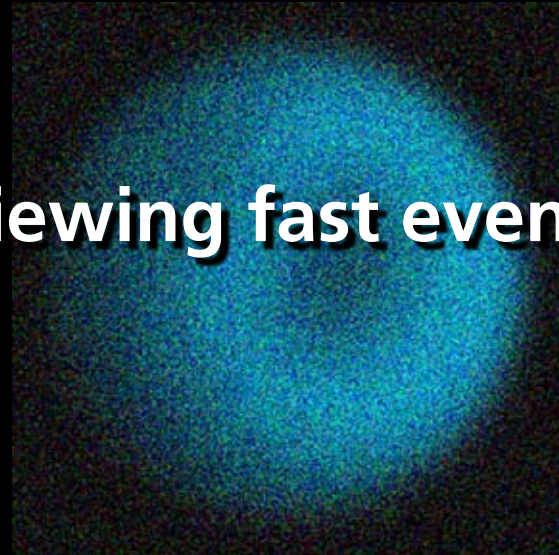


shaping matter with light

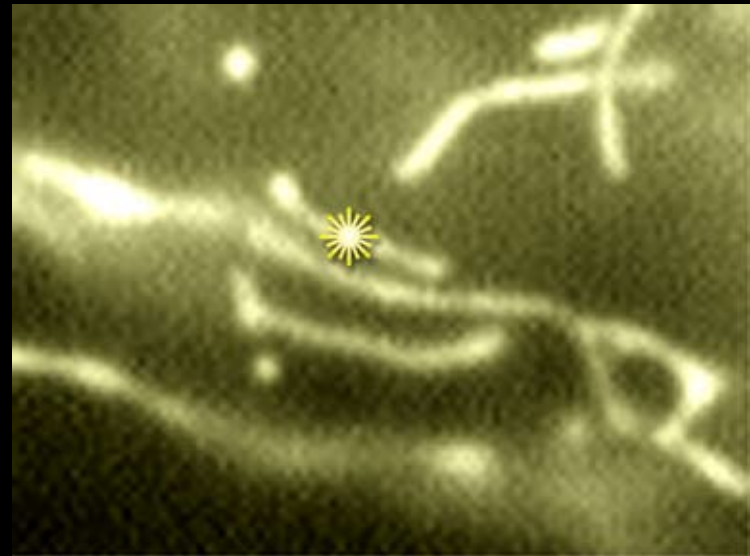


**femtosecond pulses
open the door to...**

viewing fast events

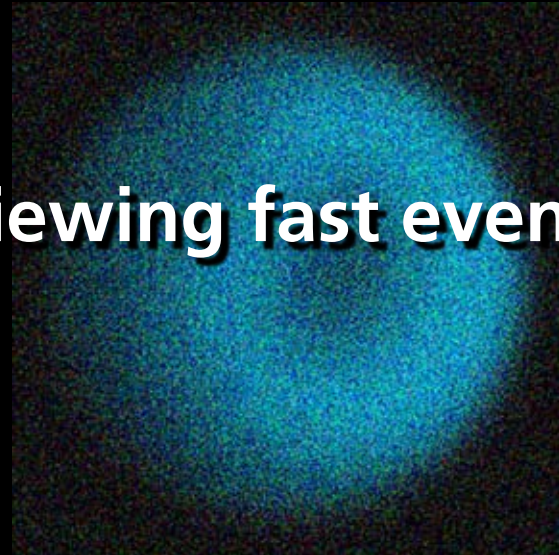


shaping matter with light

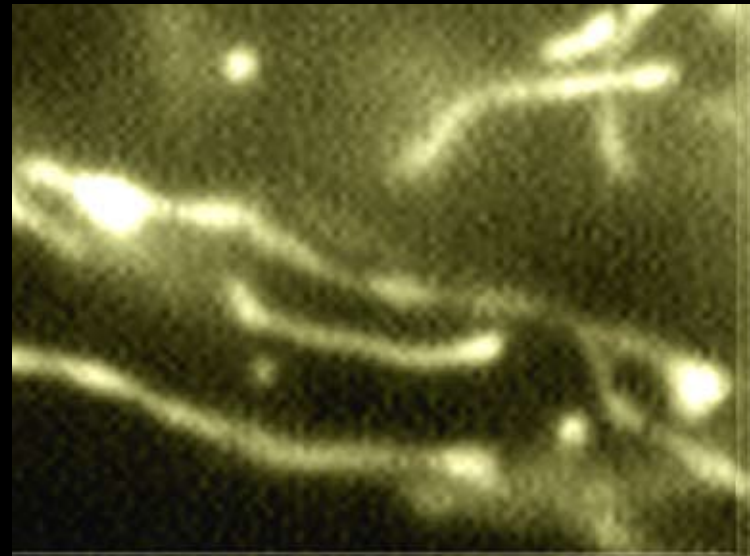


**femtosecond pulses
open the door to...**

viewing fast events

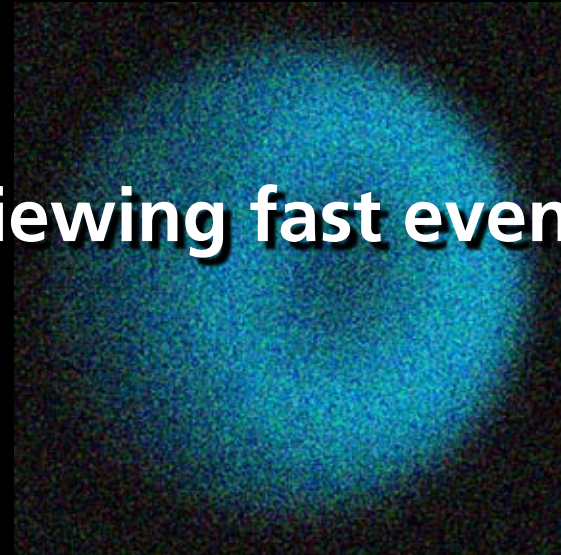


shaping matter with light



**femtosecond pulses
open the door to...**

viewing fast events

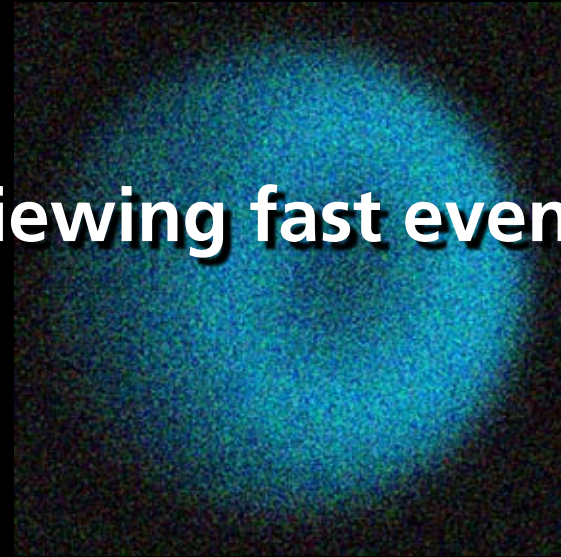


shaping matter with light



**femtosecond pulses
open the door to...**

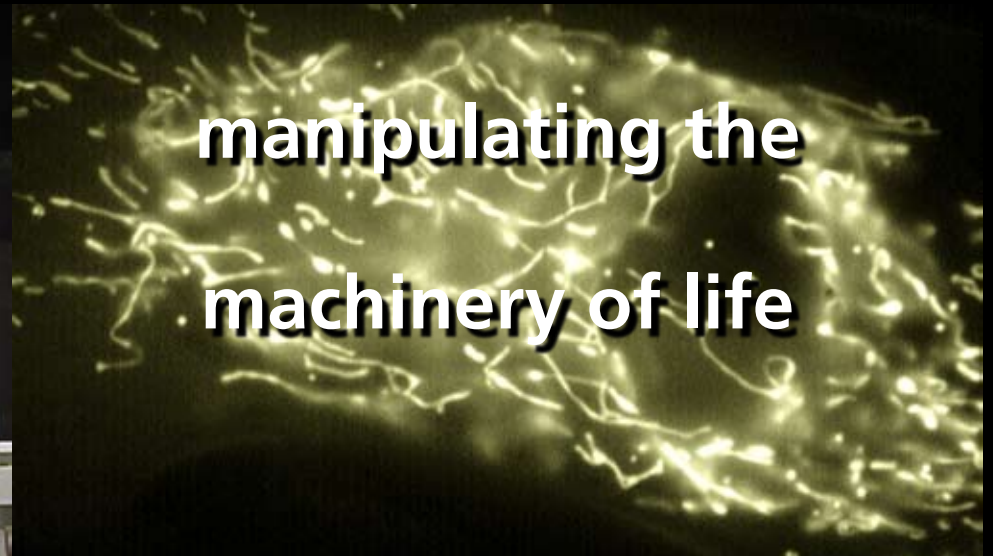
viewing fast events



shaping matter with light



**manipulating the
machinery of life**



On the Web:

<http://mazur-www.harvard.edu>