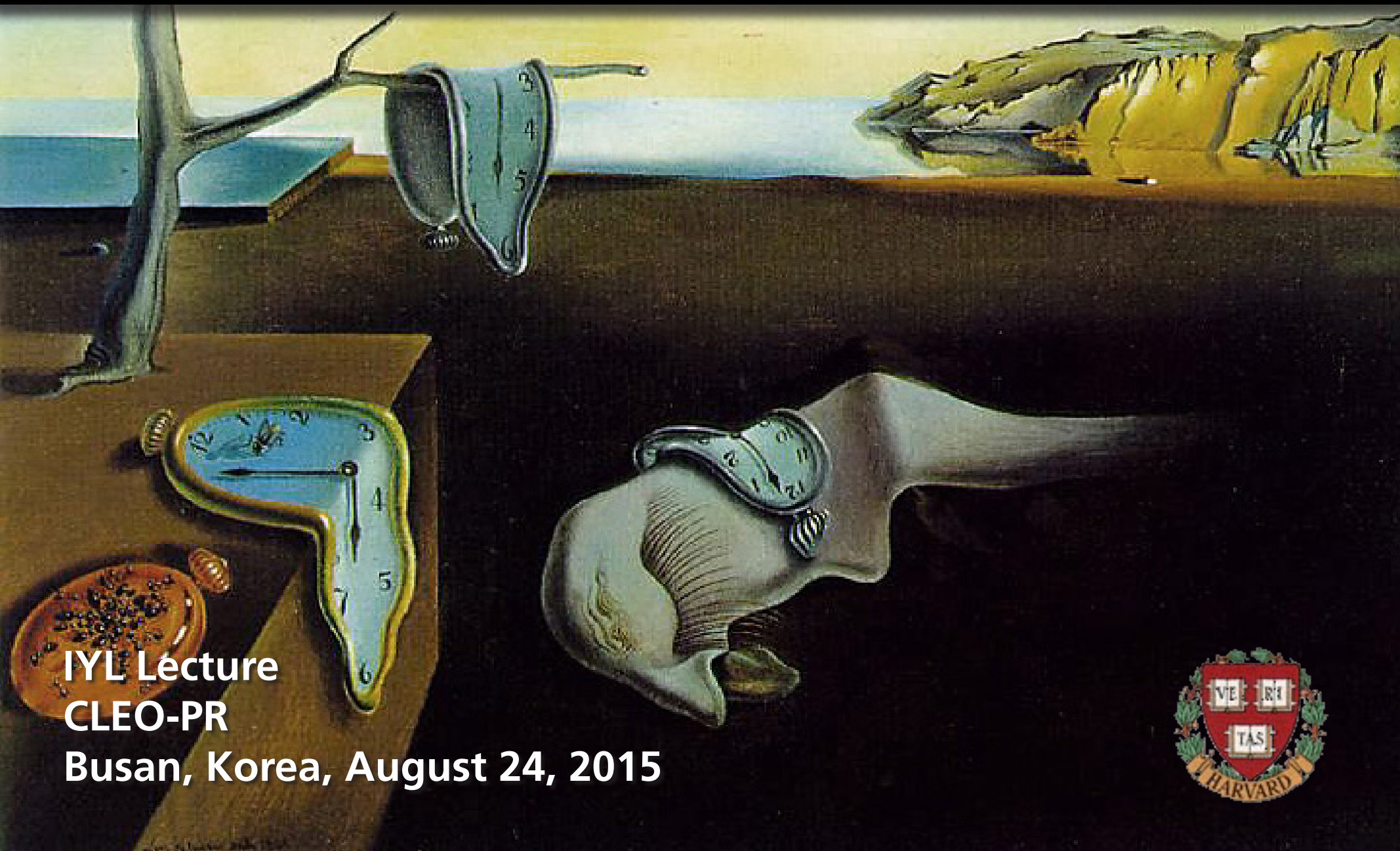


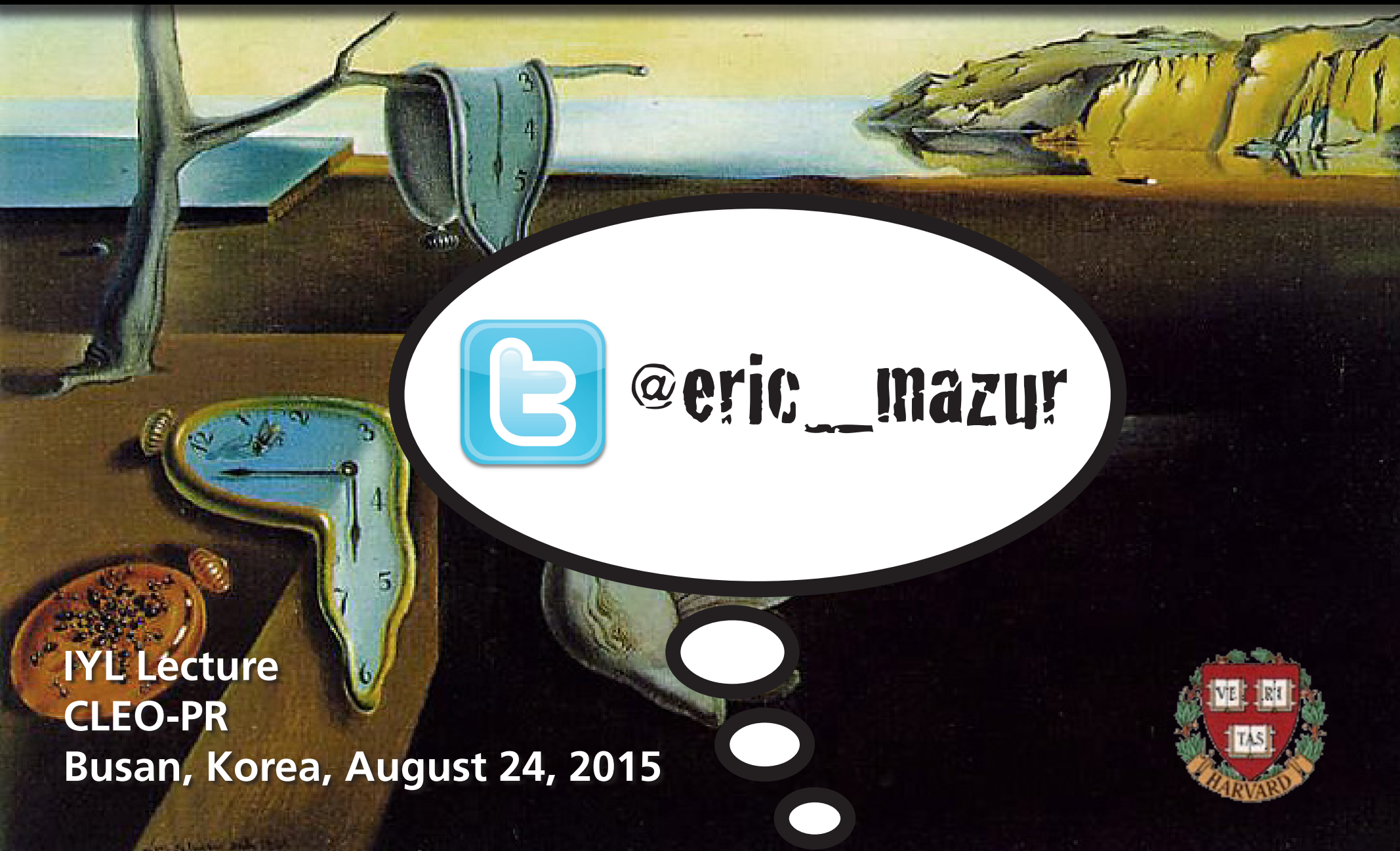
# Stopping time



IYL Lecture  
CLEO-PR  
Busan, Korea, August 24, 2015



# Stopping time

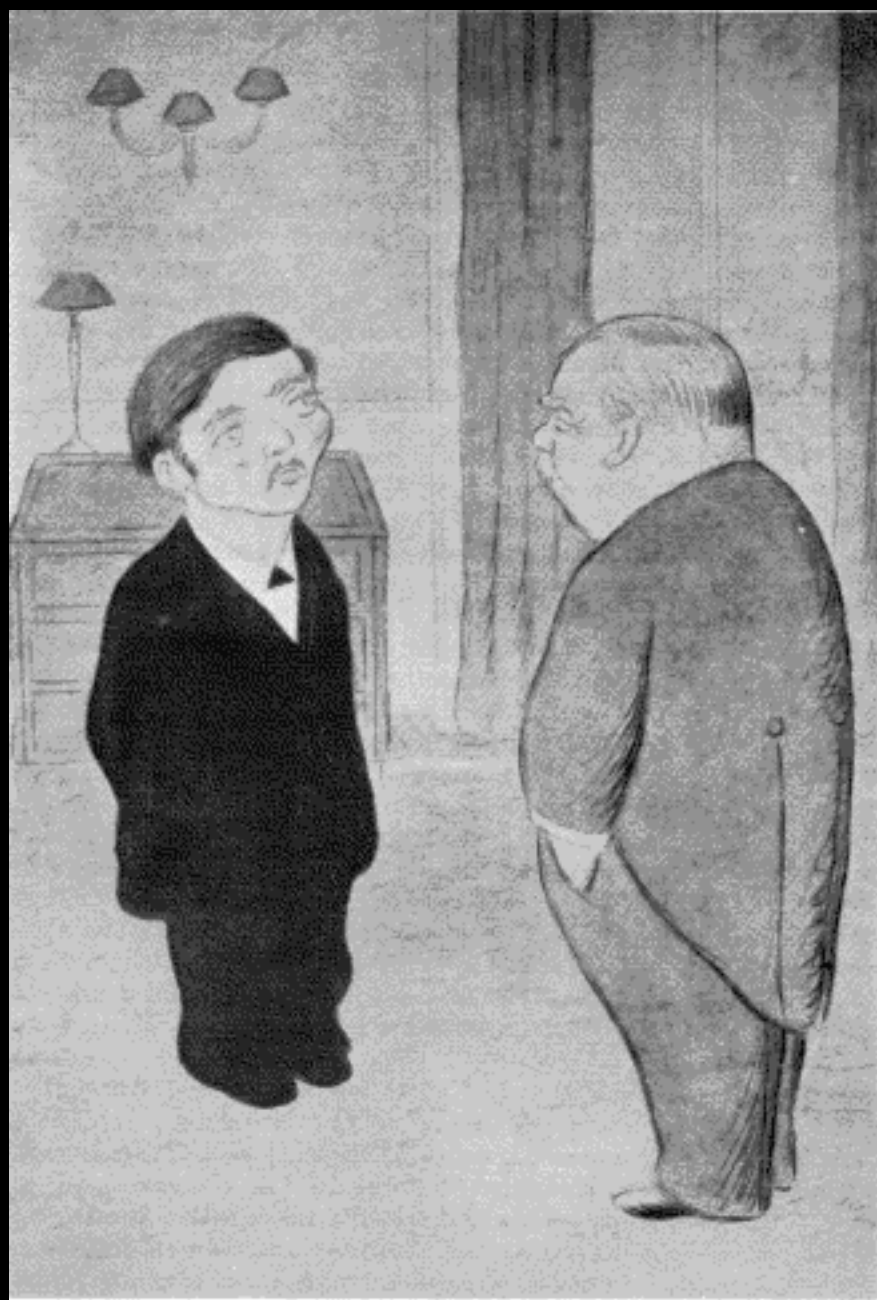


**@eric\_mazur**

IYL Lecture  
CLEO-PR  
Busan, Korea, August 24, 2015







*t*

► **time**

▶ **time**

▶ **time**

A blue sky with white clouds.

▶ **time**

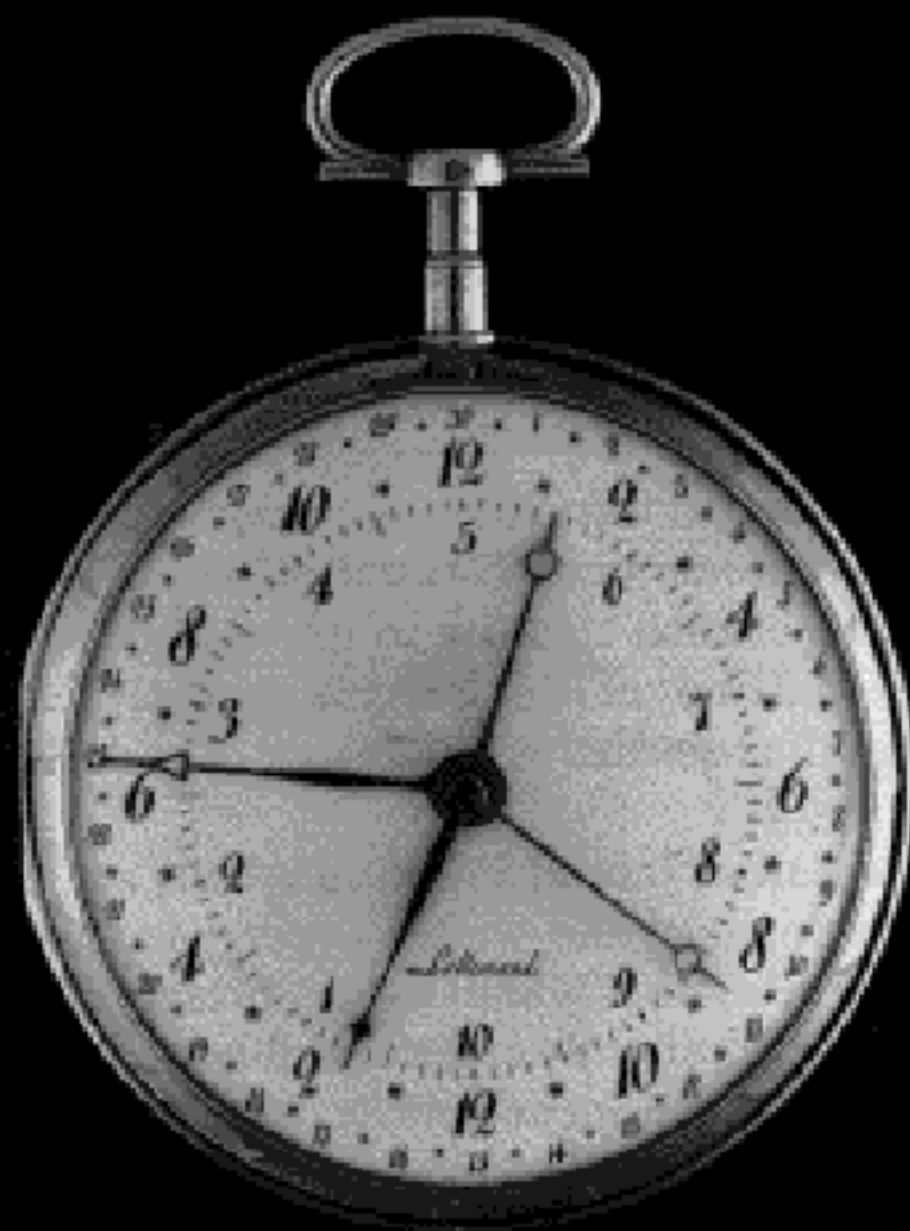
▶ **time**

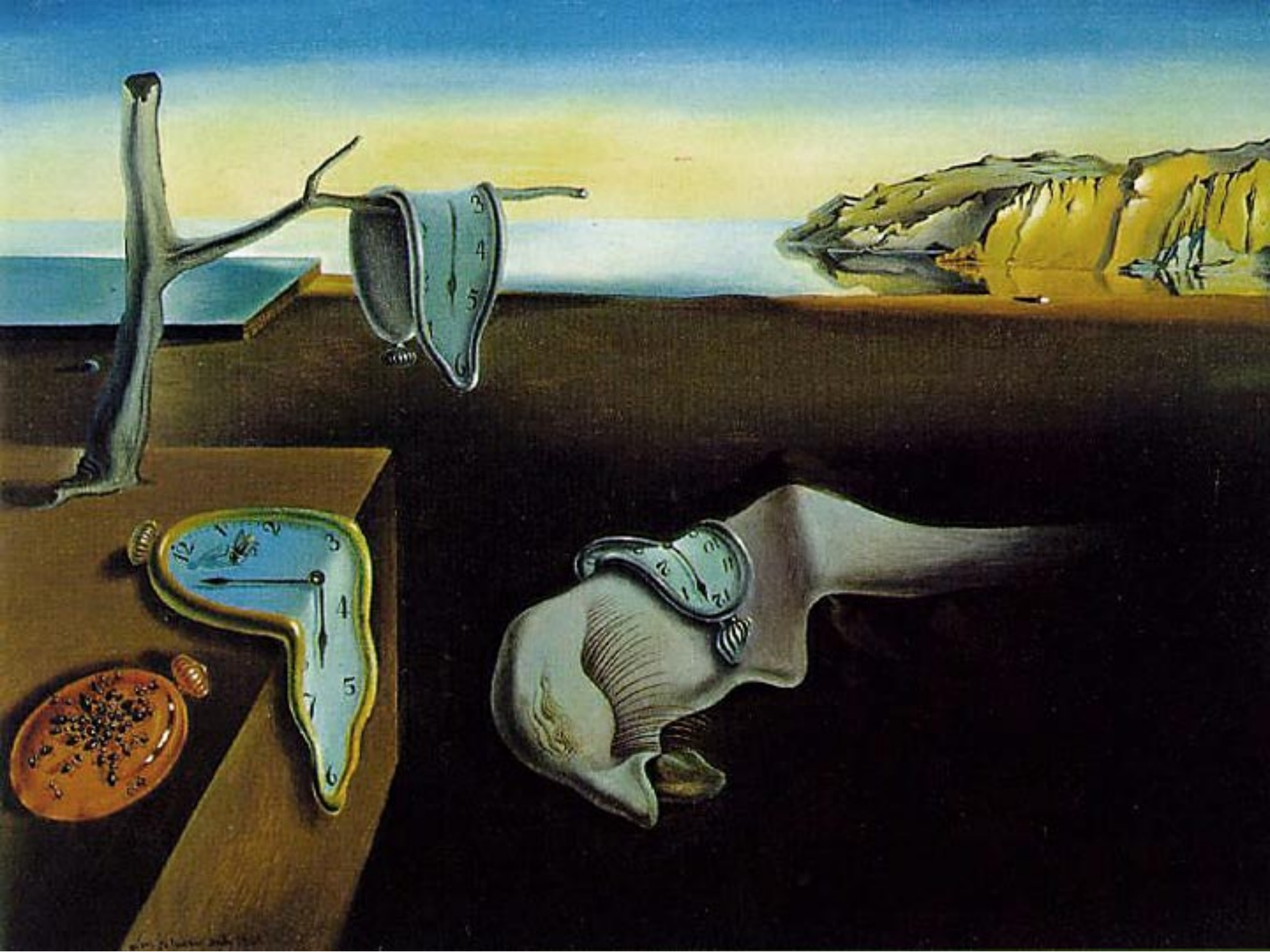
▶ **time**

- ▶ **time: the concept**
- ▶ **time**
- ▶ **time**

- ▶ **time: the concept**
- ▶ **time: stopping it**
- ▶ **time**

- ▶ **time: the concept**
- ▶ **time: stopping it**
- ▶ **time: the new frontier**









vorher angestellten Versuchen die warme Lufthülle, welche die Kerzenflamme umschließt. Und der

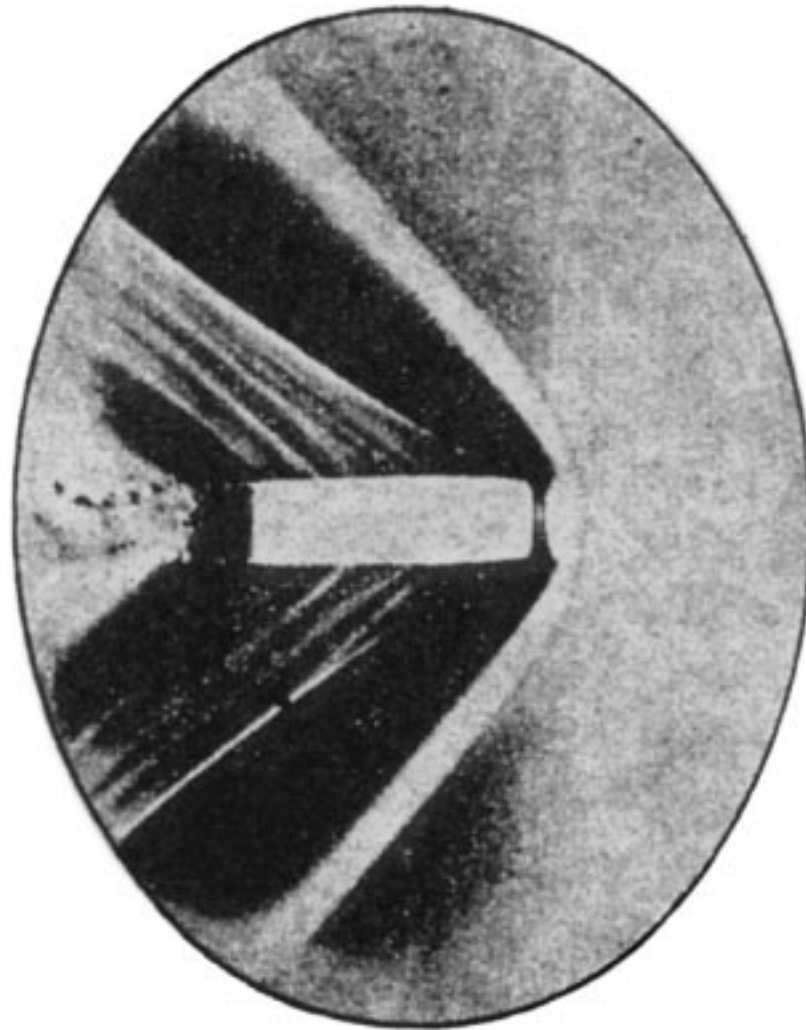
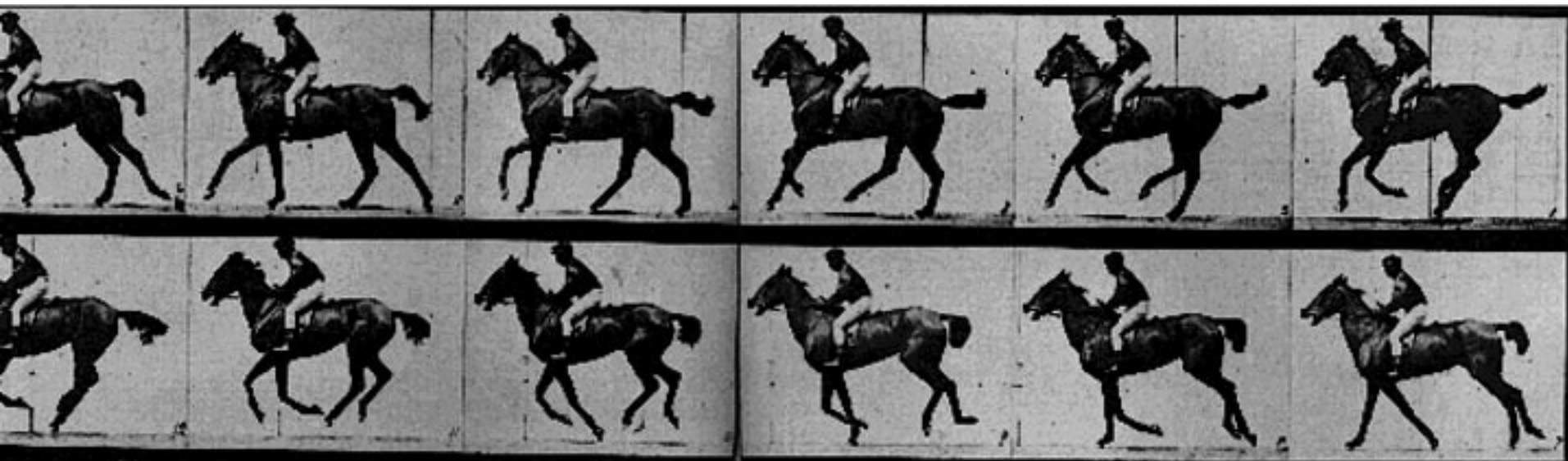
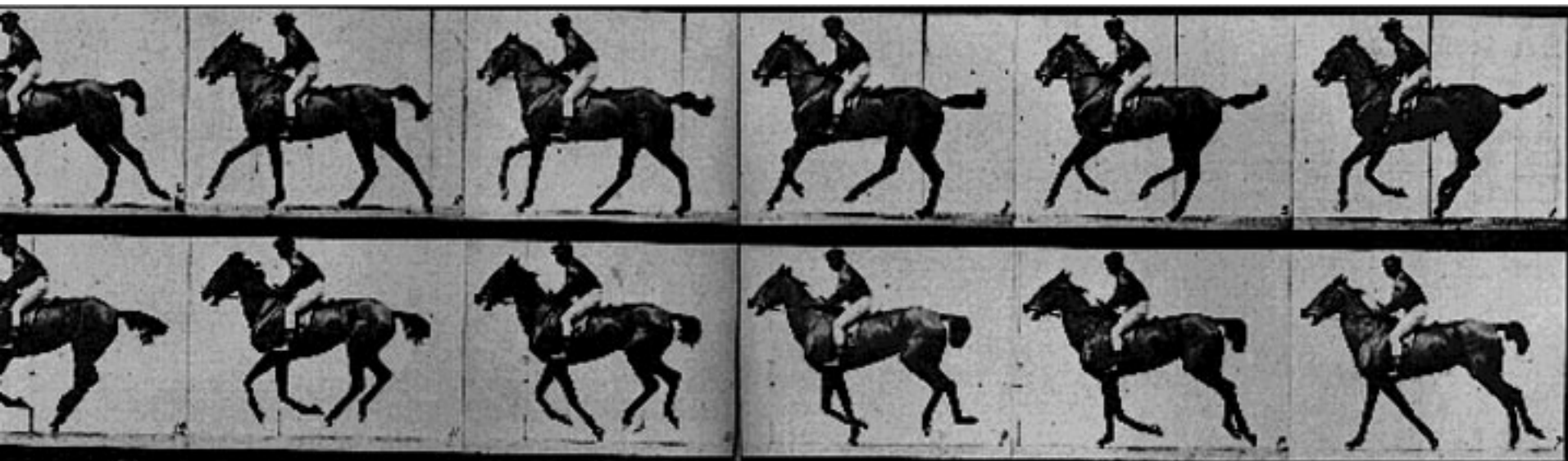


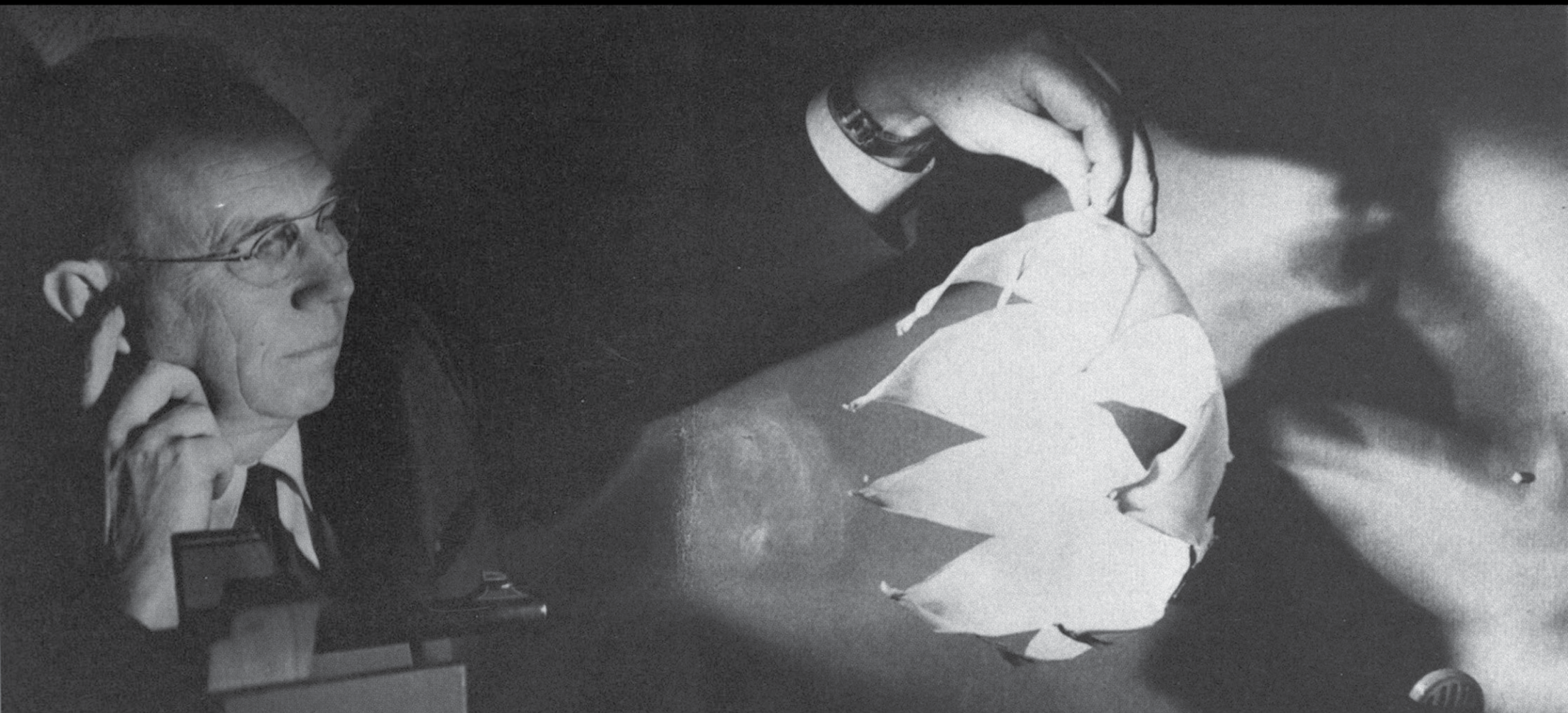
Fig. 52.

Zylinder aus durch Reibung erwärmter Luft, welche das Projektil in Form von Wirbelringen abgestreift

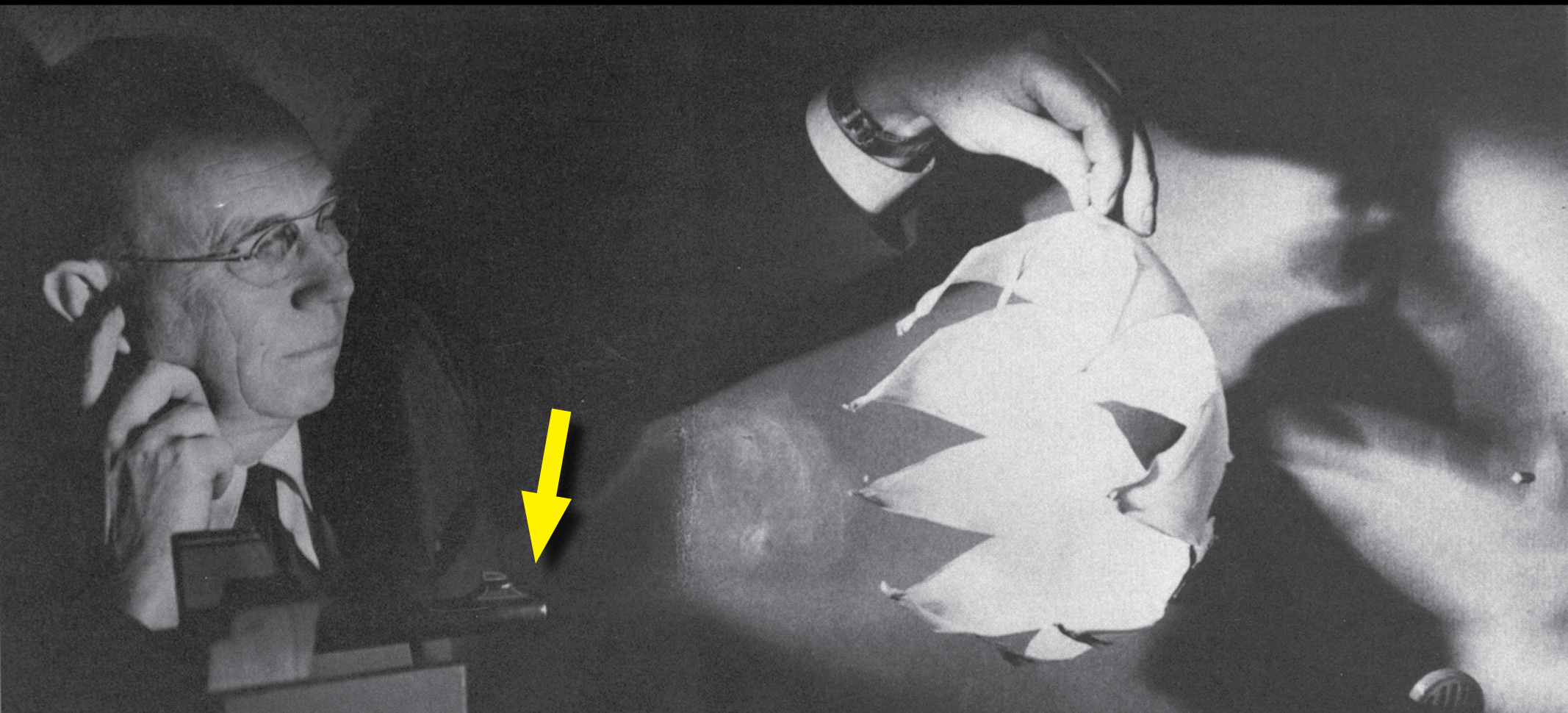




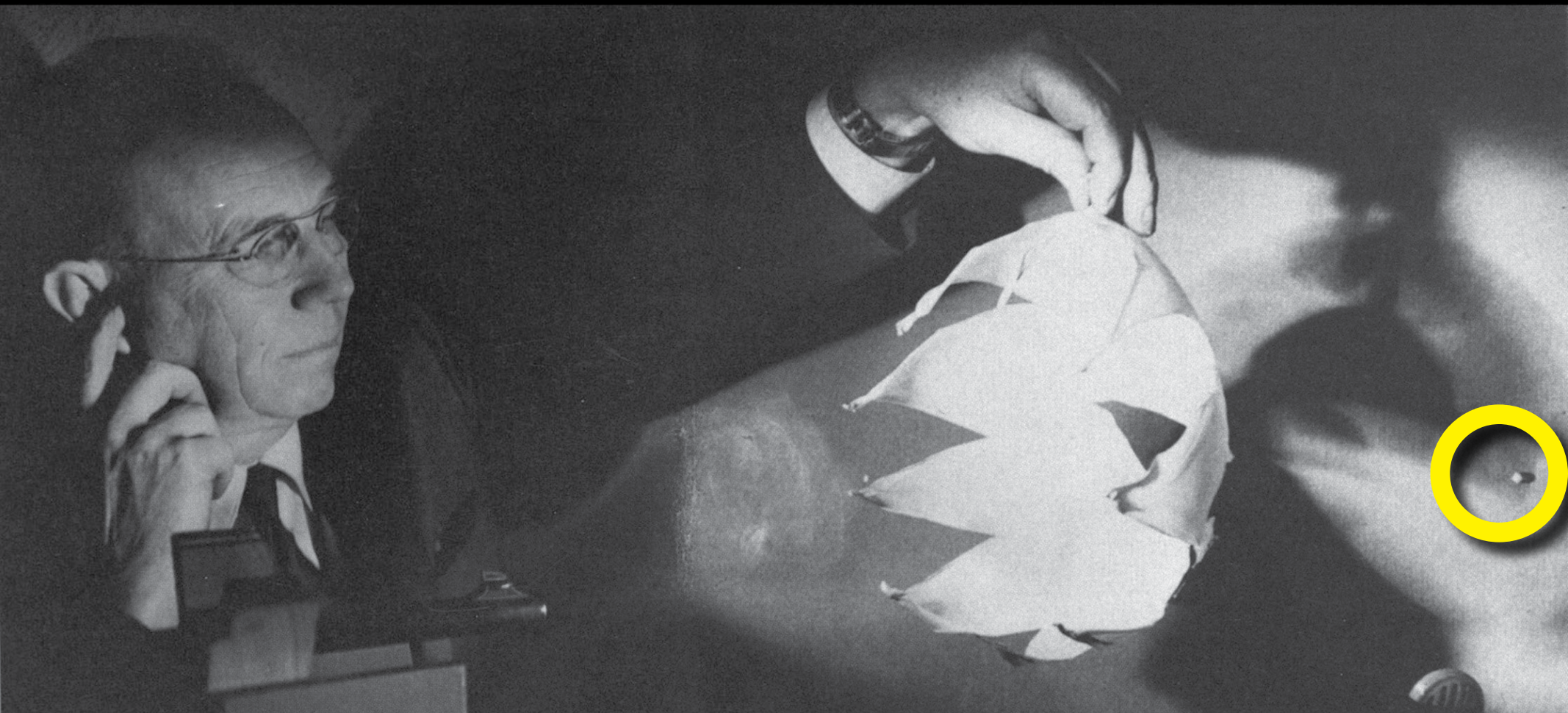




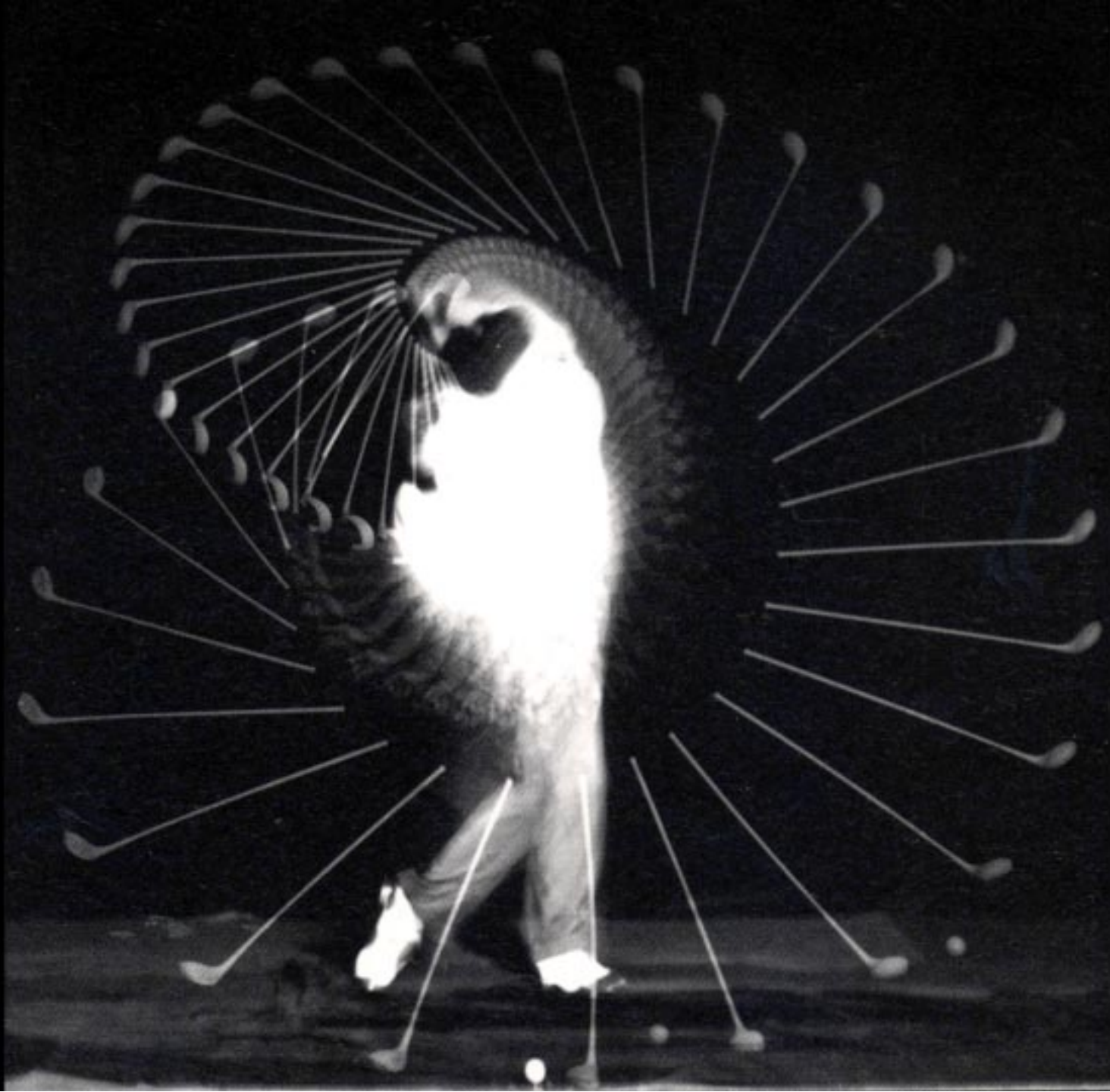
**Harold Edgerton (1903 – 1990)**



**Harold Edgerton (1903 – 1990)**



**Harold Edgerton (1903 – 1990)**



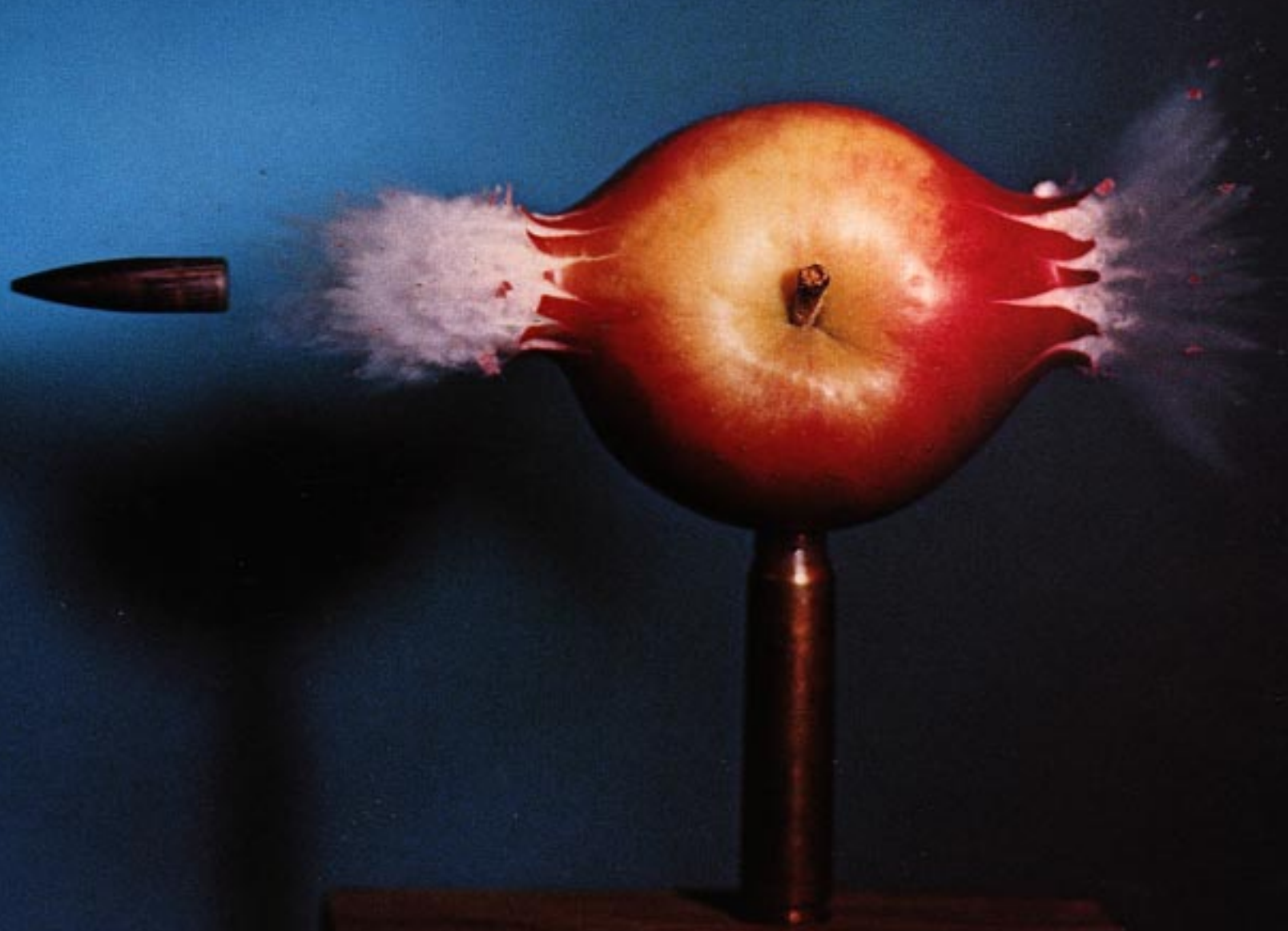




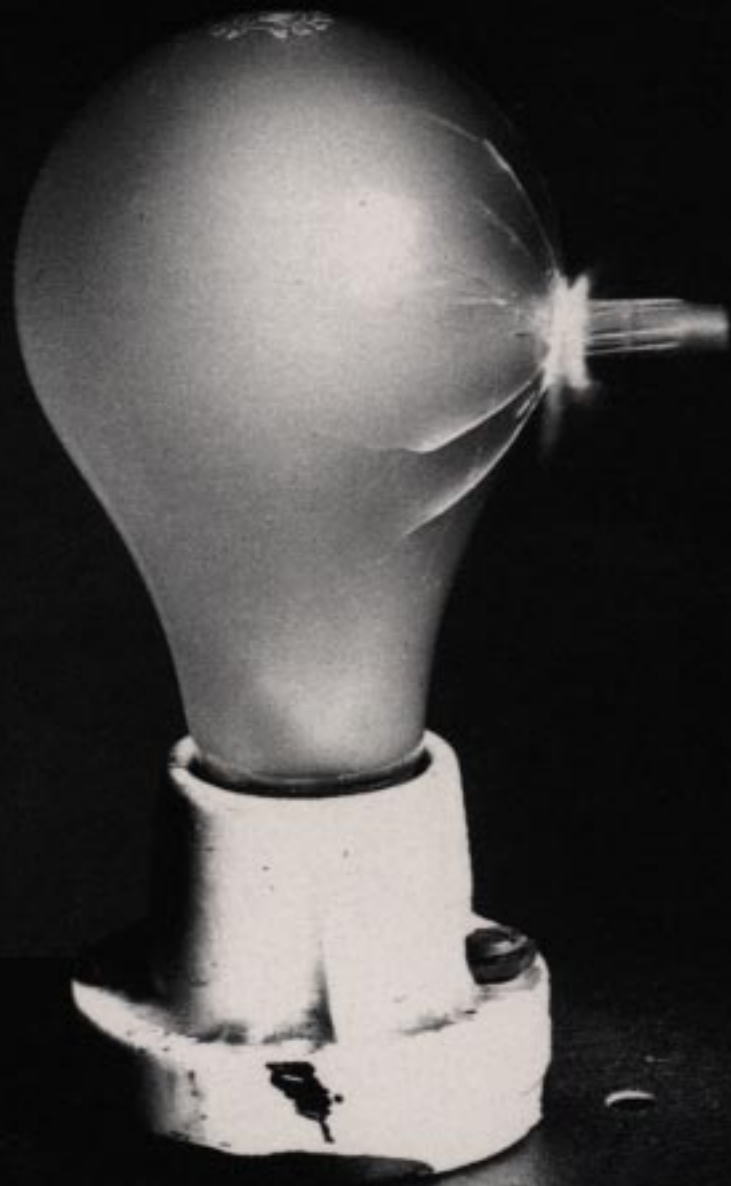


















moon

$10^0$  s



one second

moon

$10^0$  s



one second

moon

$10^0$  s



one second

moon

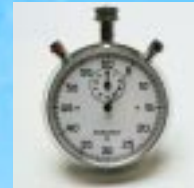
$10^0$  s



one second

# moon

$10^0$  s



one second

$10^1$  s



10 seconds

$10^1$  s



10 seconds

$10^1 \text{ s}$



10 seconds

$10^1 \text{ s}$



10 seconds

$10^1 \text{ s}$



10 seconds

$10^2$  s



one minute

$10^2$  s



one minute

$10^2$  s



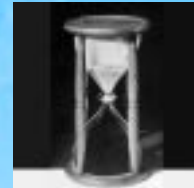
one minute

$10^2$  s



one minute

$10^2$  s



one minute

# RT to sun

$10^3$  s



17 minutes

# RT to sun

$10^3$  s



17 minutes

# RT to sun

$10^3$  s



17 minutes

# RT to sun

$10^3$  s



17 minutes

# RT to sun

$10^3$  s



17 minutes

# Uranus

$10^4$  s



average baseball game

# Uranus

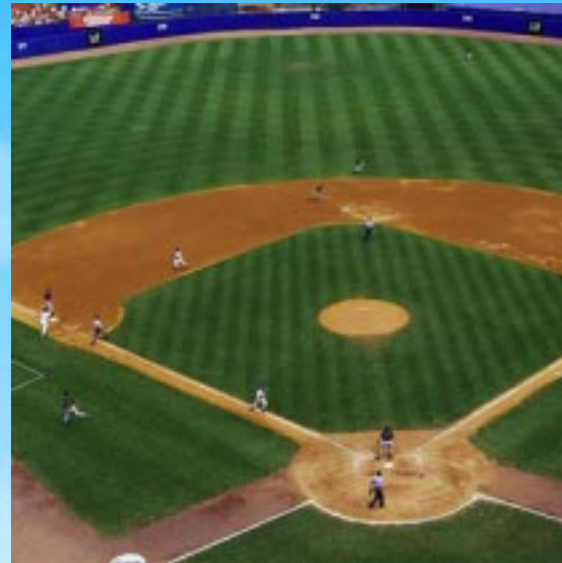
$10^4$  s



average baseball game

# Uranus

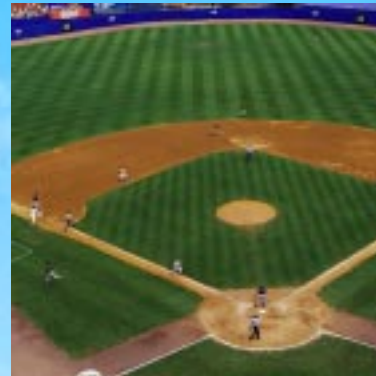
$10^4$  s



average baseball game

# Uranus

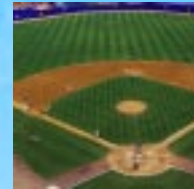
$10^4$  s



average baseball game

# Uranus

$10^4$  s



average baseball game

$10^5$  s



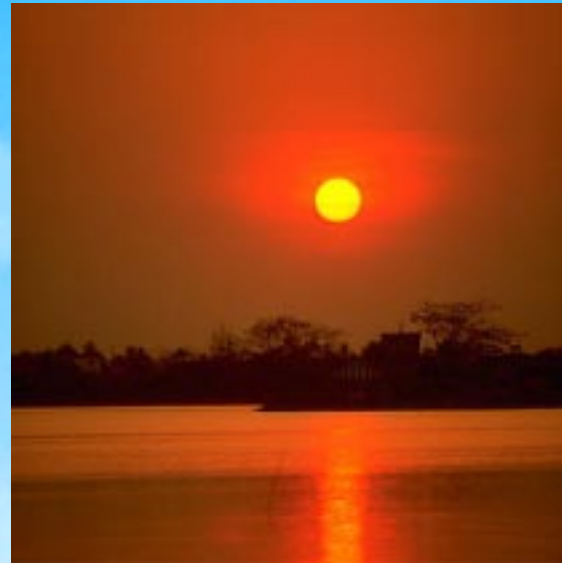
1 day

$10^5$  s



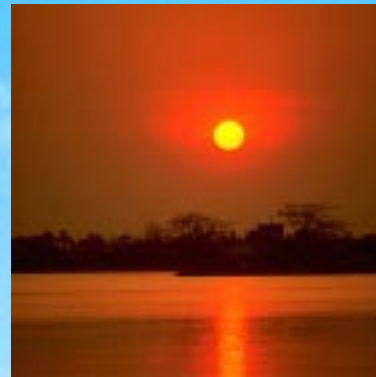
1 day

$10^5$  s



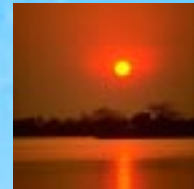
1 day

$10^5$  s



1 day

$10^5$  s



1 day

$10^6$  s



2 weeks

$10^6$  s



2 weeks

$10^6$  s



2 weeks

$10^6$  s



2 weeks

$10^6$  s



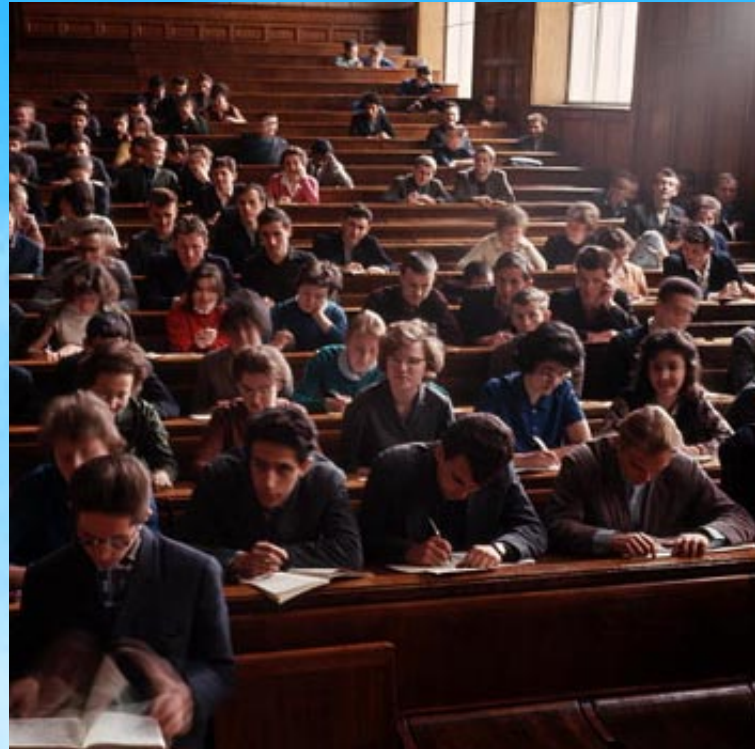
2 weeks

$10^7$  s



one semester

$10^7$  s



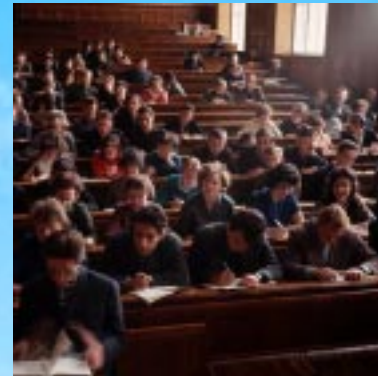
one semester

$10^7$  s



one semester

$10^7$  s



one semester

$10^7$  s



one semester

# Proxima Centauri

$10^8$  s



3 years

# Proxima Centauri

$10^8$  s



3 years

# Proxima Centauri

$10^8$  s



3 years

# Proxima Centauri

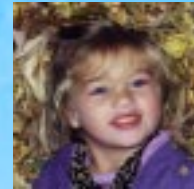
$10^8$  s



3 years

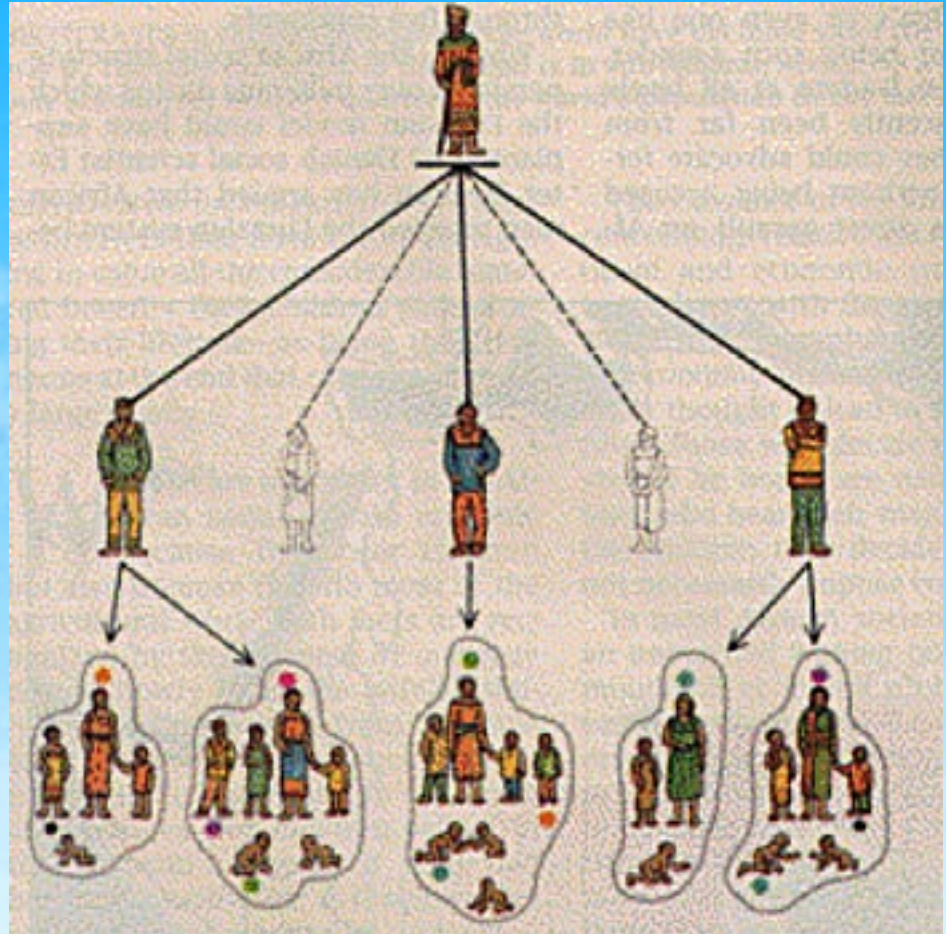
# Proxima Centauri

$10^8$  s



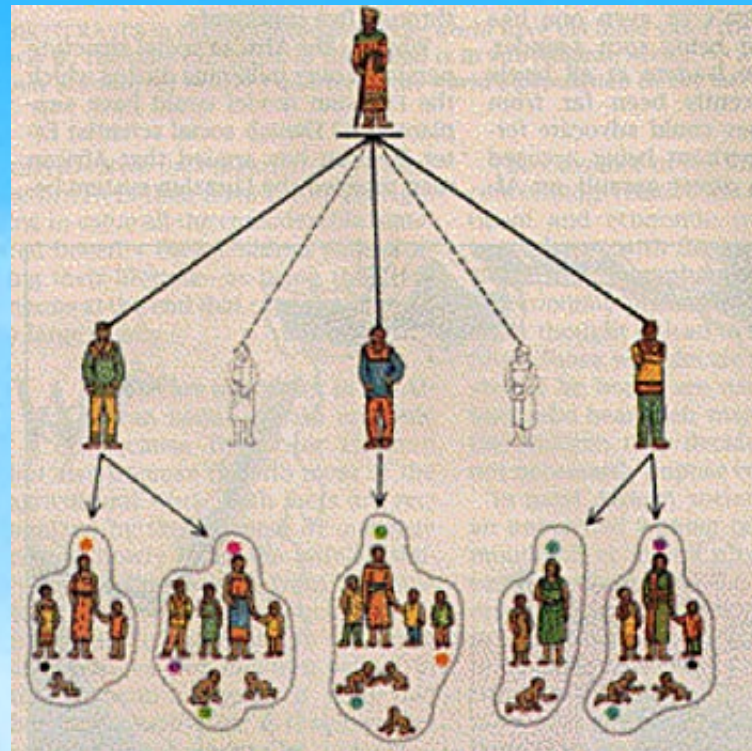
3 years

$10^9$  s



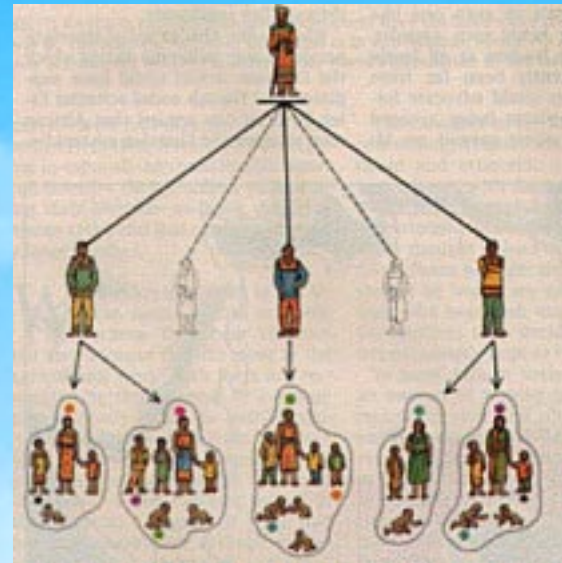
human generation

$10^9$  s



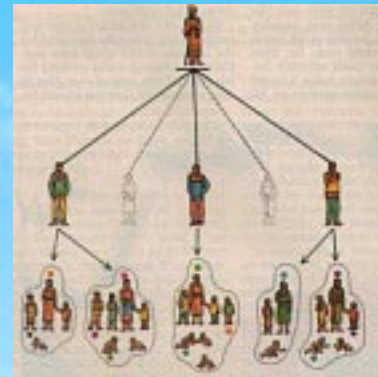
human generation

$10^9$  s



human generation

$10^9$  s



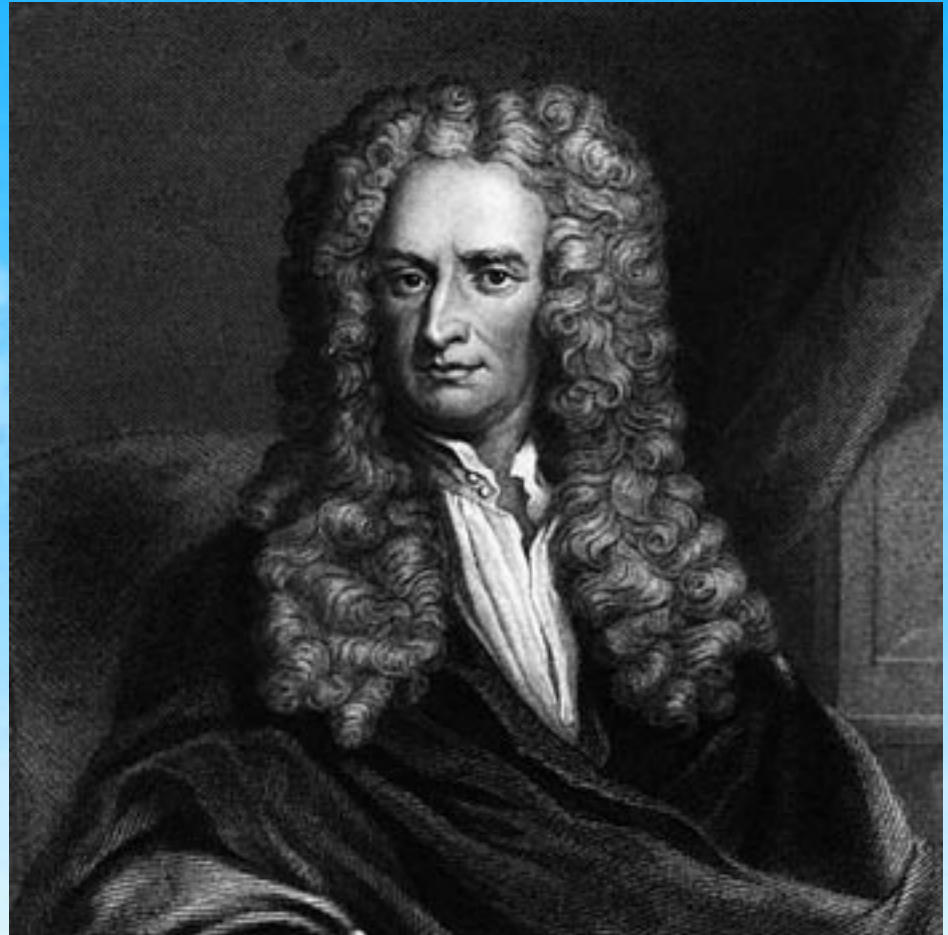
human generation

$10^9$  s



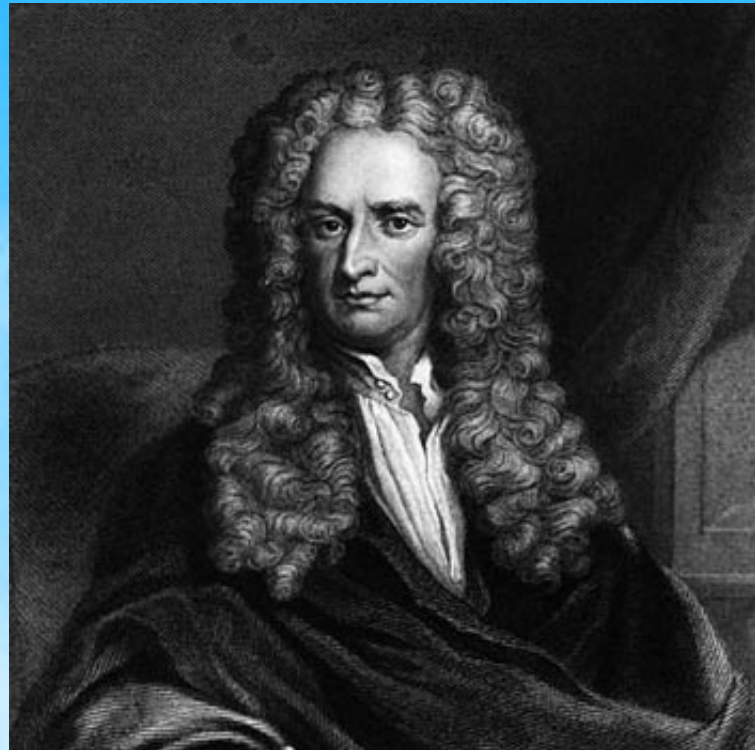
human generation

$10^{10}$  s



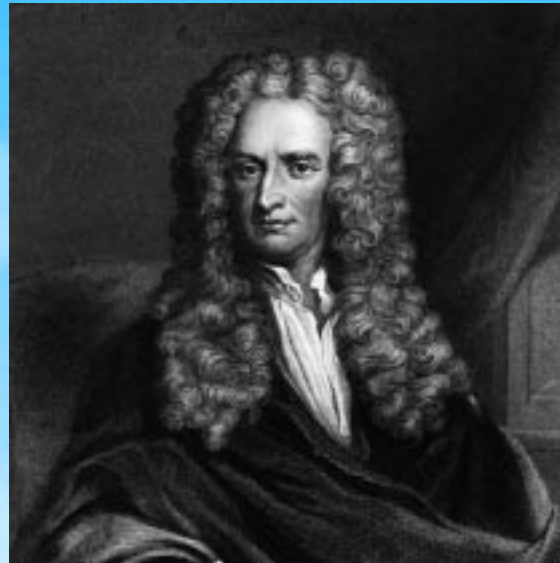
time since Newton

$10^{10}$  s



time since Newton

$10^{10}$  s



time since Newton

$10^{10}$  s



time since Newton

$10^{10}$  s



time since Newton

$10^{11}$  s



ancient civilizations

$10^{11}$  s



ancient civilizations

$10^{11}$  s



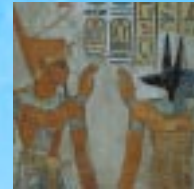
ancient civilizations

$10^{11}$  s



ancient civilizations

$10^{11}$  s



ancient civilizations

center of galaxy

$10^{12}$  s



most recent ice age

center of galaxy

$10^{12}$  s



most recent ice age

center of galaxy

$10^{12}$  s



most recent ice age

center of galaxy

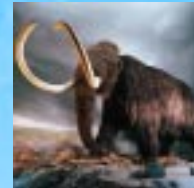
$10^{12}$  s



most recent ice age

center of galaxy

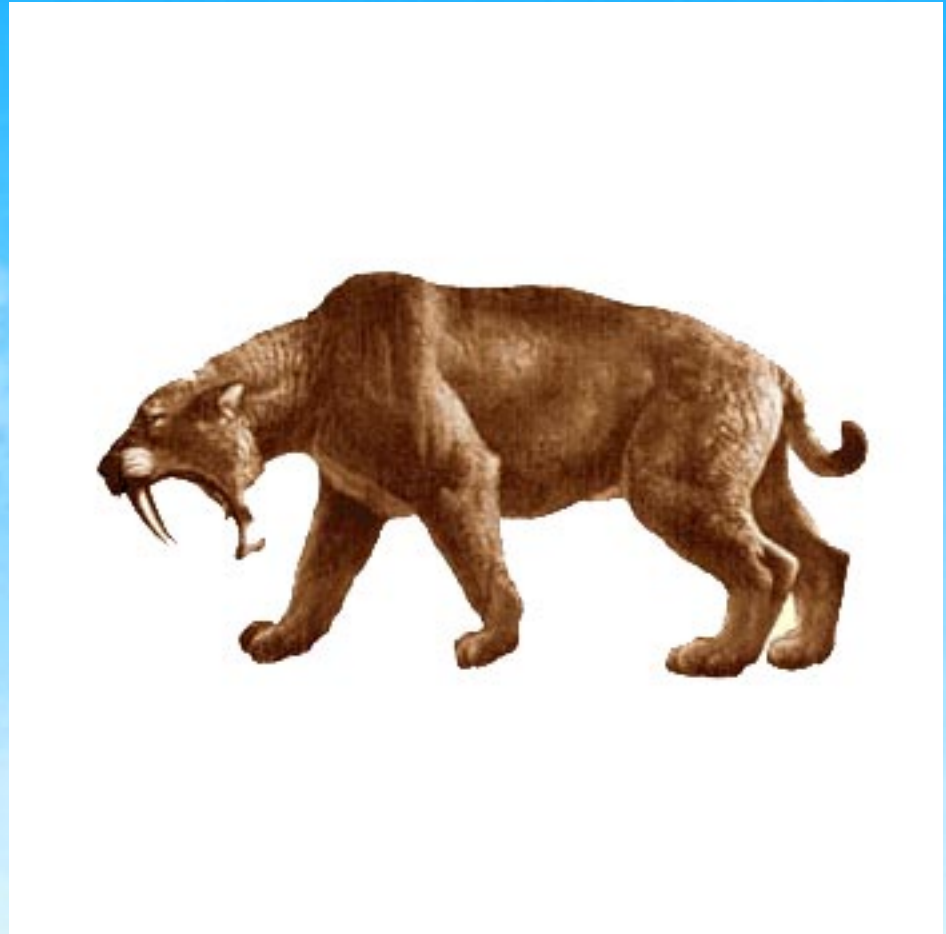
$10^{12}$  s



most recent ice age

# Andromeda galaxy

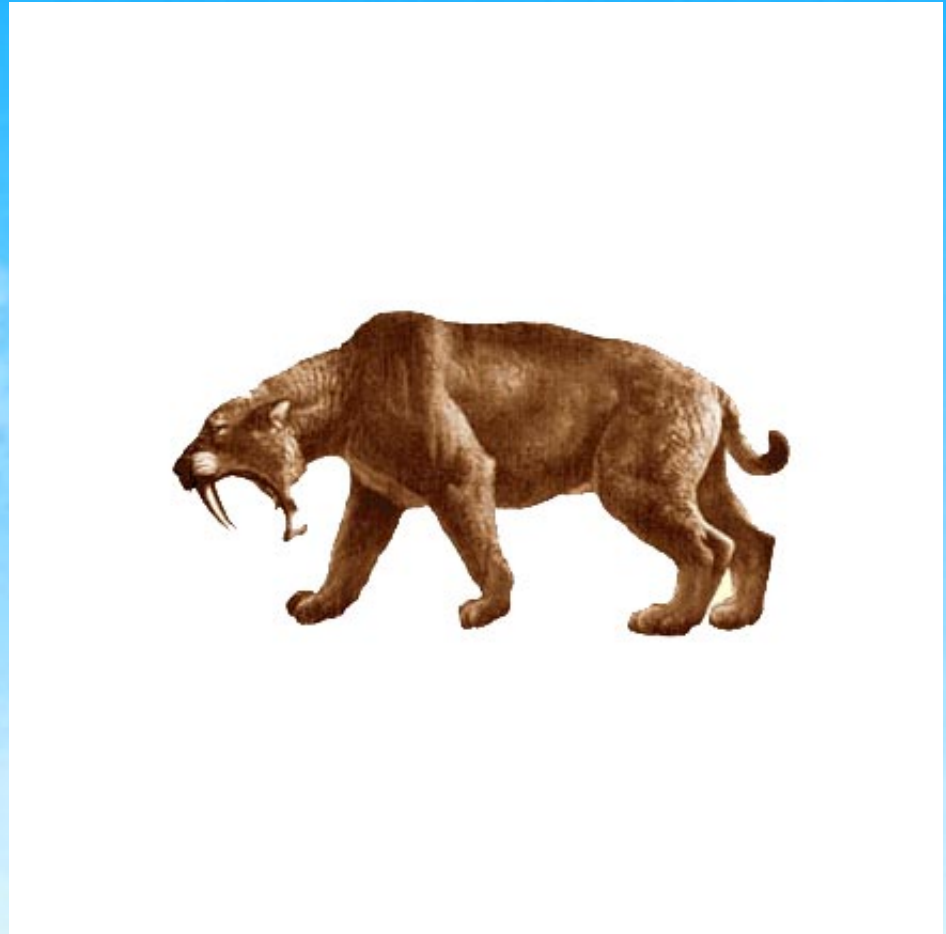
$10^{13}$  s



300,000 years

# Andromeda galaxy

$10^{13}$  s



300,000 years

# Andromeda galaxy

$10^{13}$  s



300,000 years

# Andromeda galaxy

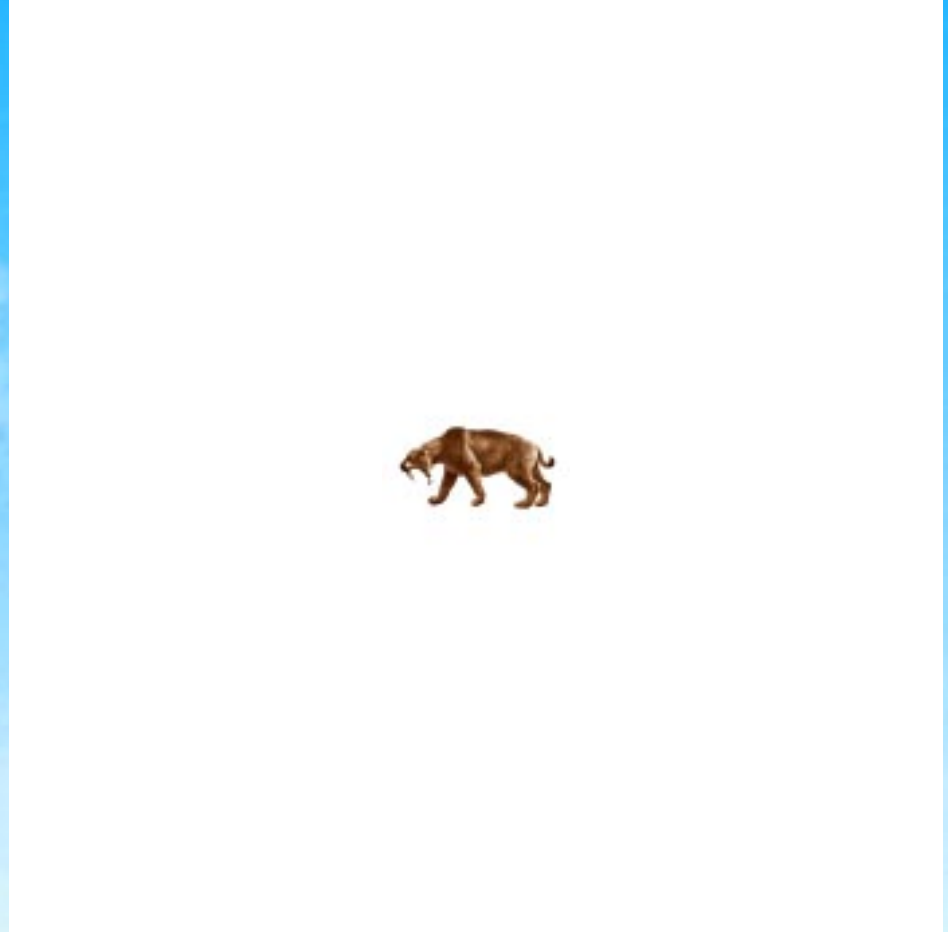
$10^{13}$  s



300,000 years

# Andromeda galaxy

$10^{13}$  s



300,000 years

$10^{14}$  s



earliest human

$10^{14}$  s



earliest human

$10^{14}$  s



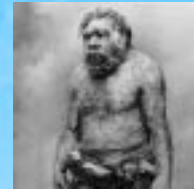
earliest human

$10^{14}$  s



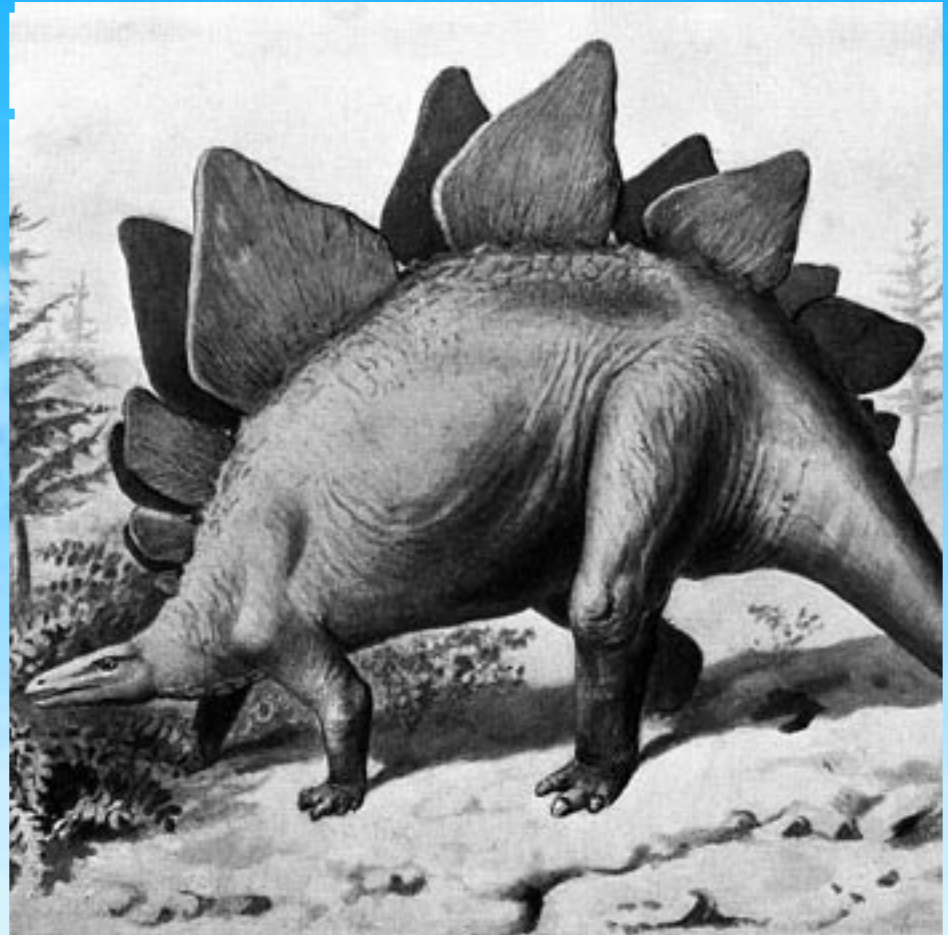
earliest human

$10^{14}$  s



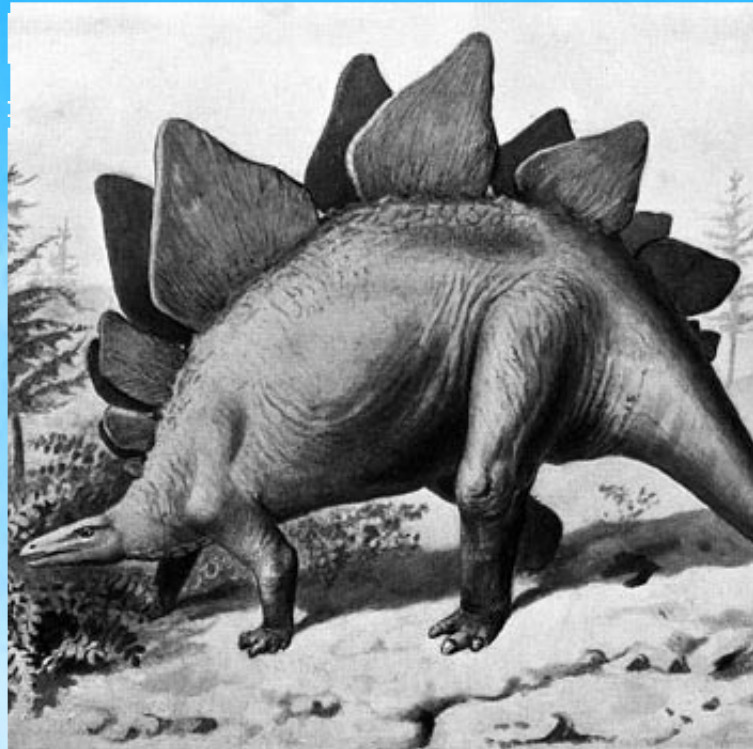
earliest human

$10^{15}$  s



dinosaurs

$10^{15}$  s



dinosaurs

$10^{15}$  s



dinosaurs

$10^{15}$  s



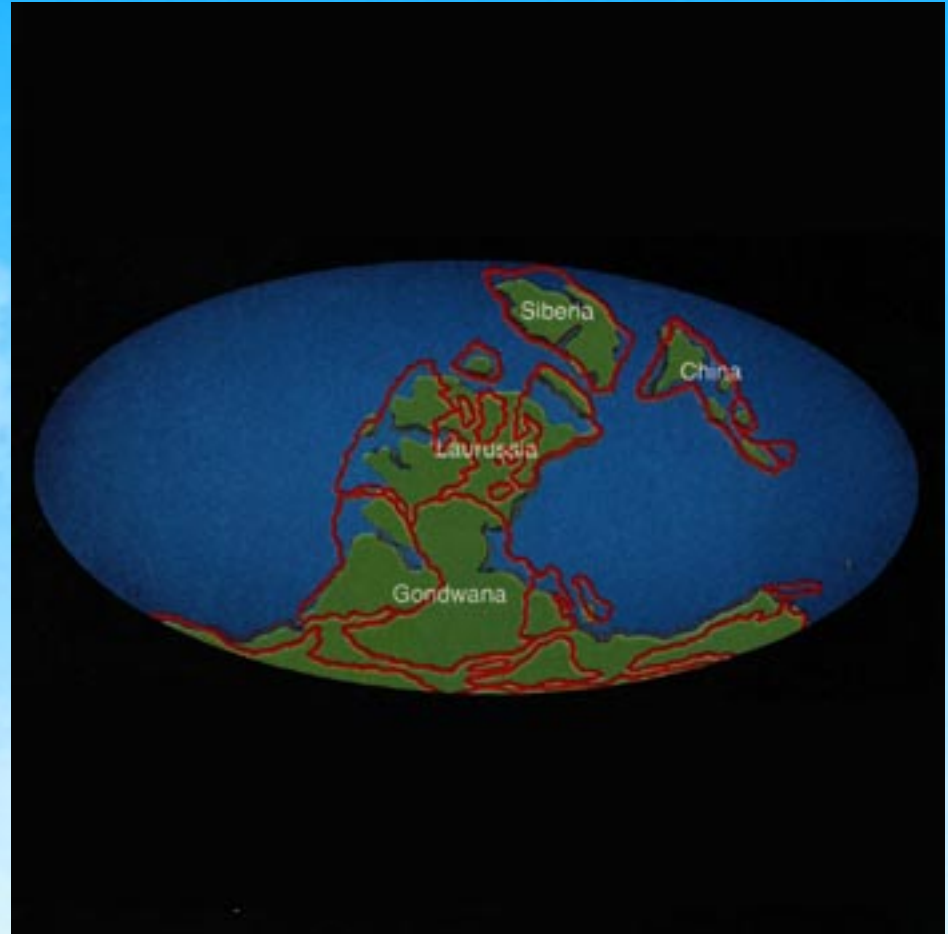
dinosaurs

$10^{15}$  s



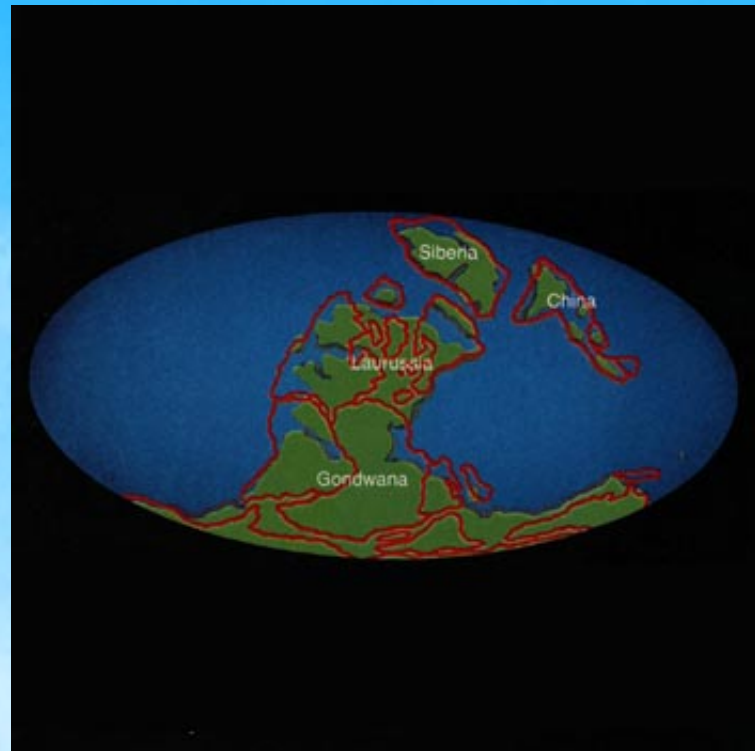
dinosaurs

$10^{16}$  s



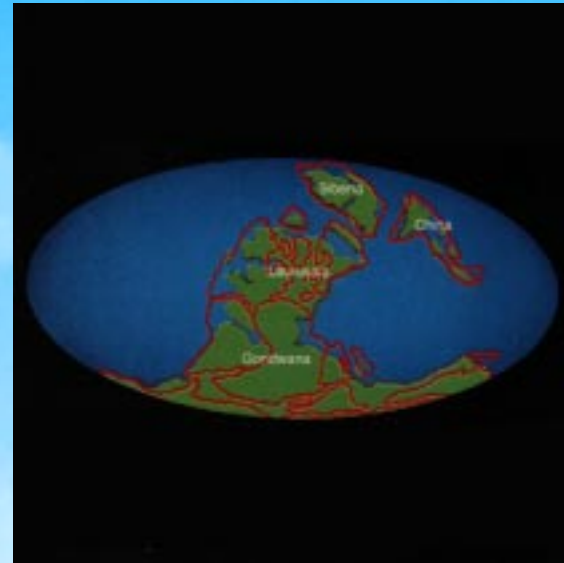
continental drift

$10^{16}$  s



continental drift

$10^{16}$  s



continental drift

$10^{16}$  s



continental drift

$10^{16}$  s



continental drift

$10^{17}$  s



age of the solar system

$10^{17}$  s



age of the solar system

$10^{17}$  s



age of the solar system

$10^{17}$  s



age of the solar system

$10^{17}$  s



age of the solar system

# edge of the universe

$10^{18}$  s



# age of known universe

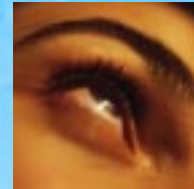
moon

$10^0$  s



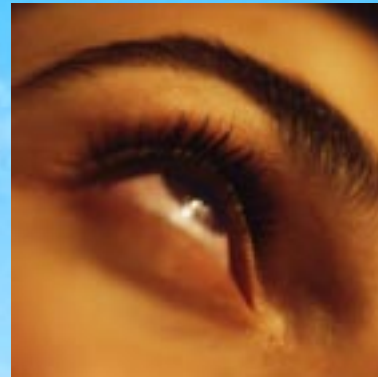
one second

$10^{-1}$  s



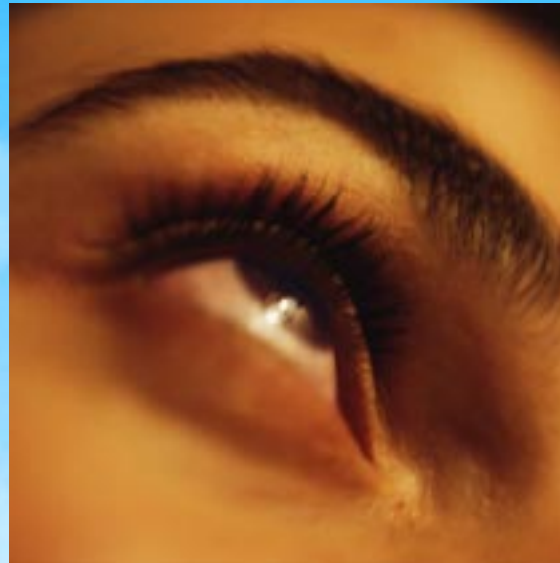
blink of an eye

$10^{-1}$  s



blink of an eye

$10^{-1}$  s



blink of an eye

$10^{-1}$  s



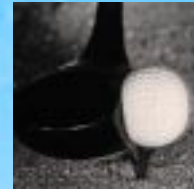
blink of an eye

$10^{-1}$  s



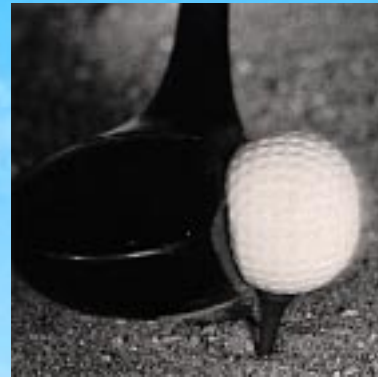
blink of an eye

$10^{-2}$  s



golf swing

$10^{-2}$  s



golf swing

$10^{-2}$  s



golf swing

$10^{-2}$  s



golf swing

$10^{-2}$  s



golf swing

# San Francisco

$10^{-3}$  s



wingbeat of fly

# San Francisco

$10^{-3}$  s



wingbeat of fly

# San Francisco

$10^{-3}$  s



wingbeat of fly

# San Francisco

$10^{-3}$  s



wingbeat of fly

# San Francisco

$10^{-3}$  s



wingbeat of fly

$10^{-4}$  s



lightning

$10^{-4}$  s



lightning

$10^{-4}$  s



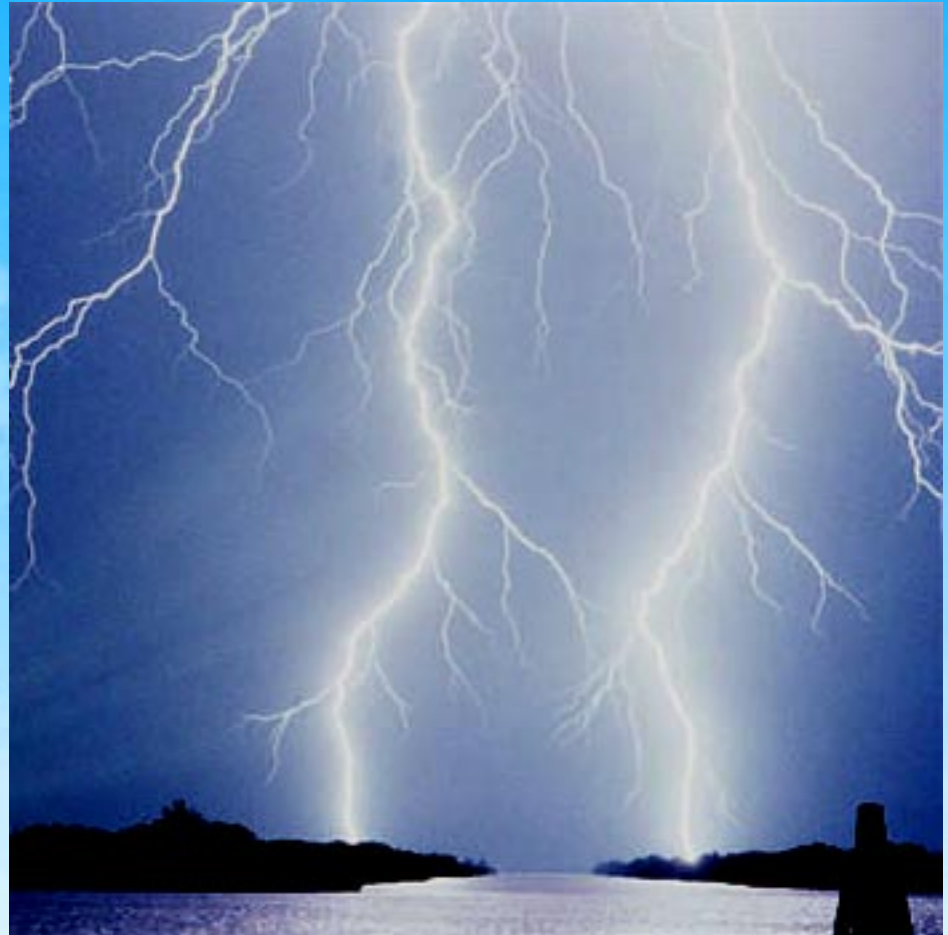
lightning

$10^{-4}$  s



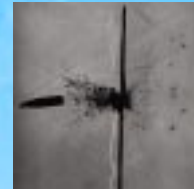
lightning

$10^{-4}$  s



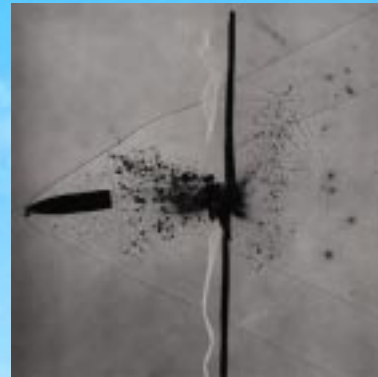
lightning

$10^{-5}$  s



bullet through glass

$10^{-5}$  s



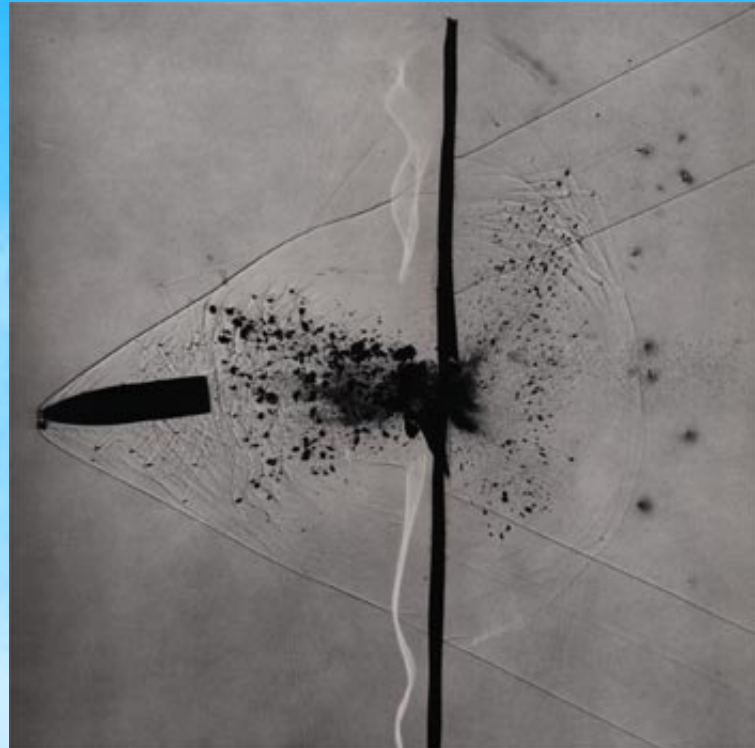
bullet through glass

$10^{-5}$  s



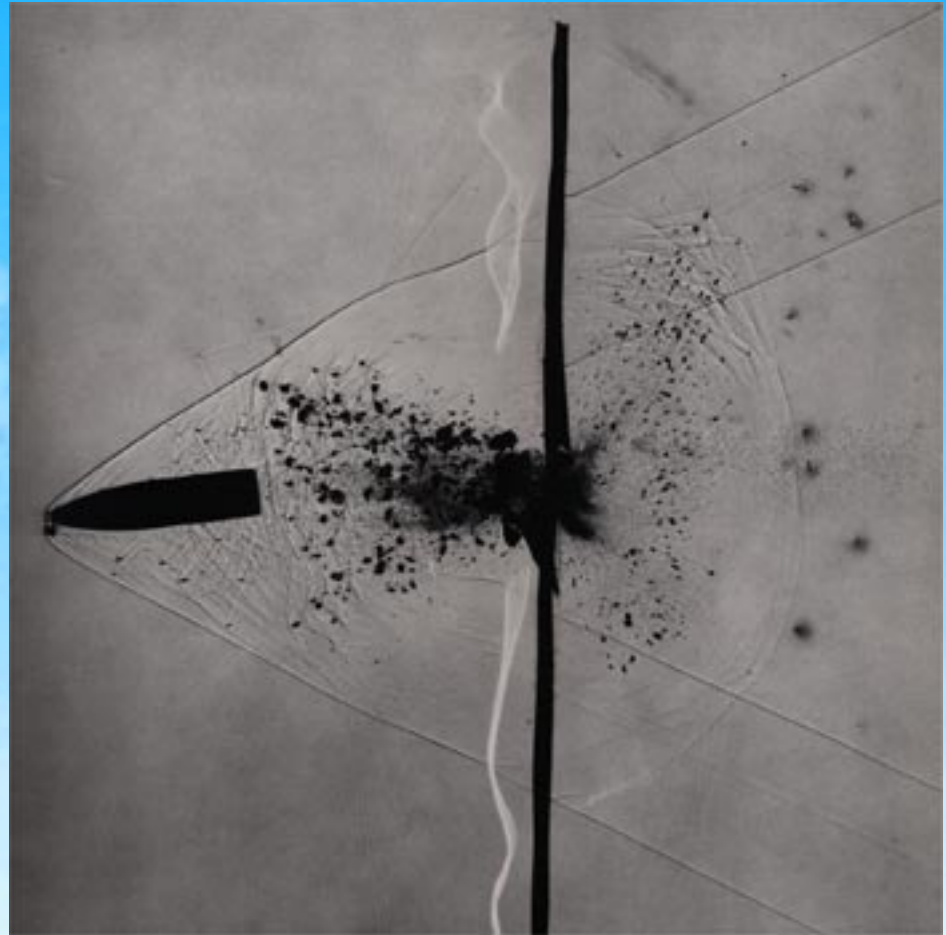
bullet through glass

$10^{-5}$  s



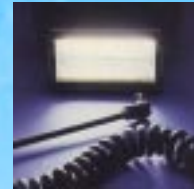
bullet through glass

$10^{-5}$  s



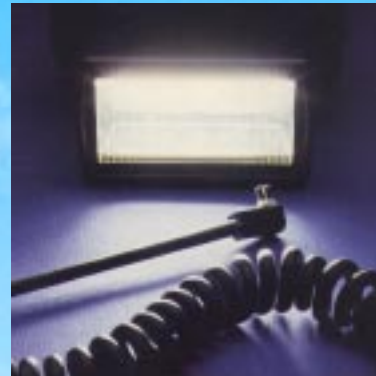
bullet through glass

$10^{-6}$  s



strobe flash

$10^{-6}$  s



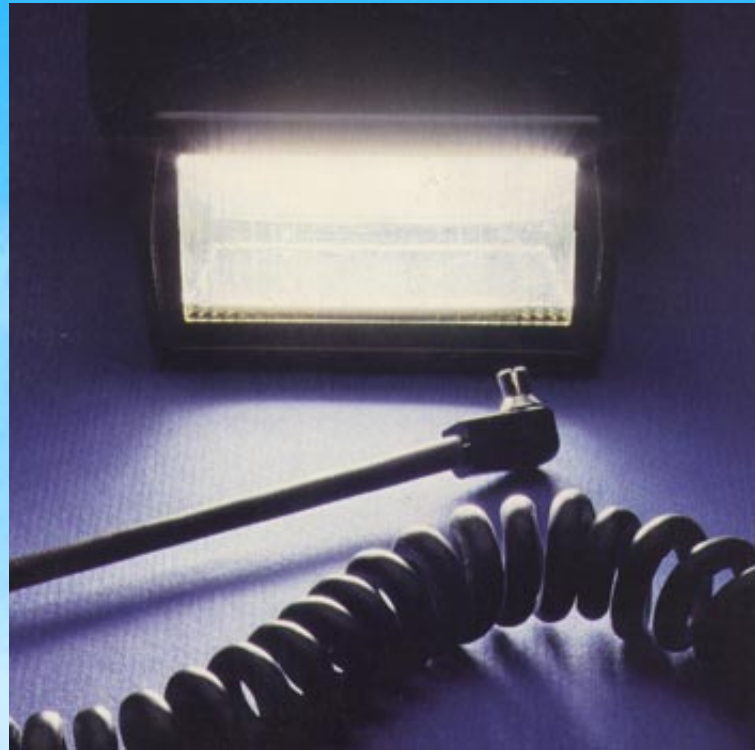
strobe flash

$10^{-6}$  s



strobe flash

$10^{-6}$  s



strobe flash

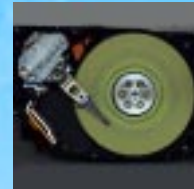
$10^{-6}$  s



strobe flash

# lecture hall

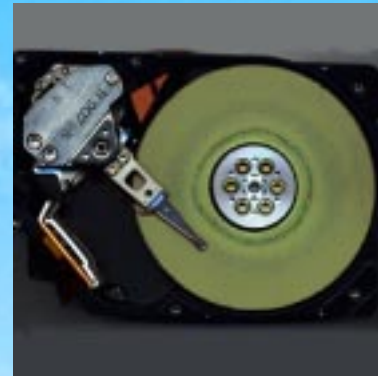
$10^{-7}$  s



hard disk write time

# lecture hall

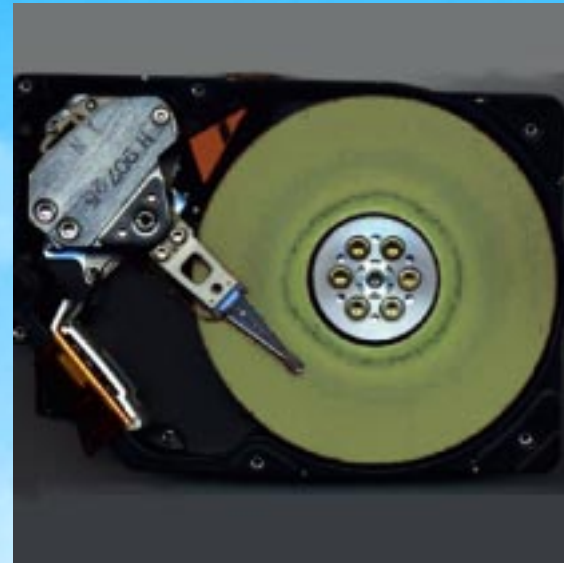
$10^{-7}$  s



hard disk write time

# lecture hall

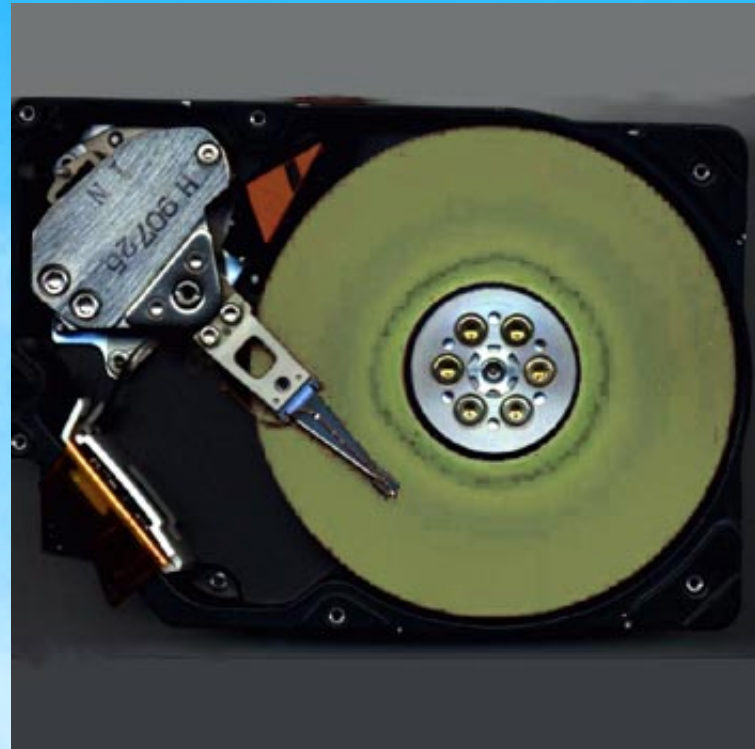
$10^{-7}$  s



hard disk write time

# lecture hall

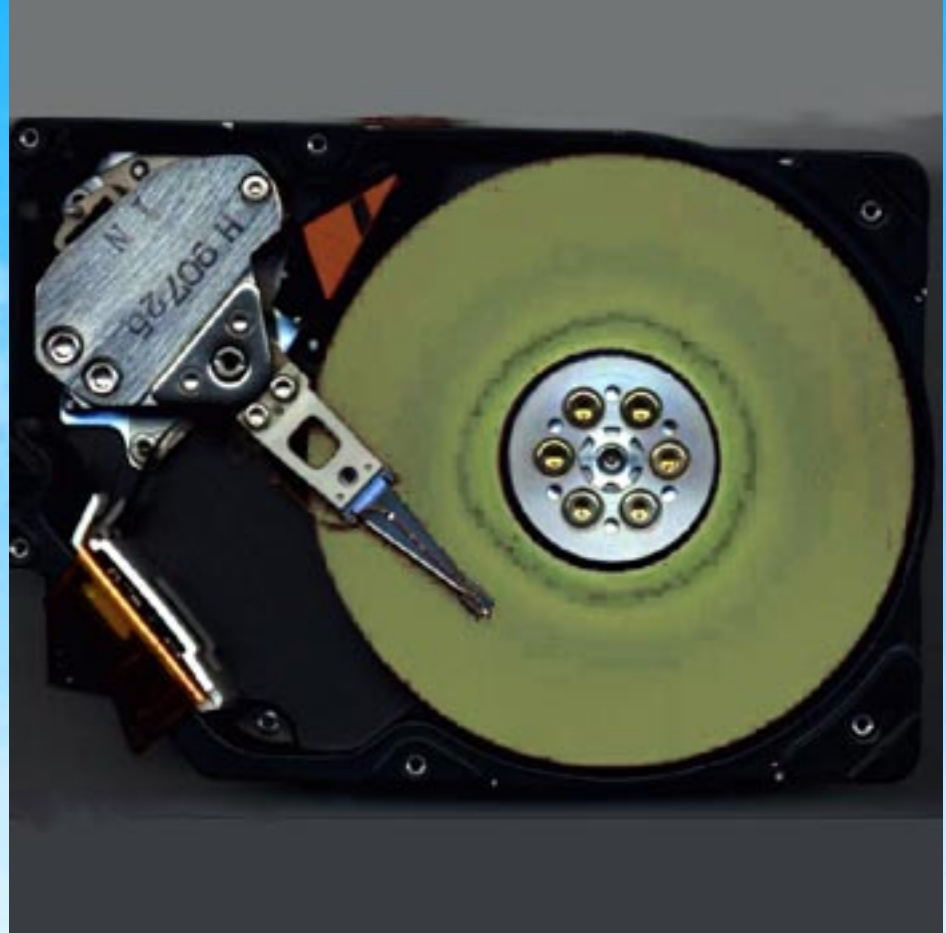
$10^{-7}$  s



hard disk write time

# lecture hall

$10^{-7}$  s



hard disk write time

$10^{-8}$  s



Deep Blue calculation

$10^{-8}$  s



Deep Blue calculation

$10^{-8}$  s



Deep Blue calculation

$10^{-8}$  s



Deep Blue calculation

$10^{-8}$  s



Deep Blue calculation

one foot

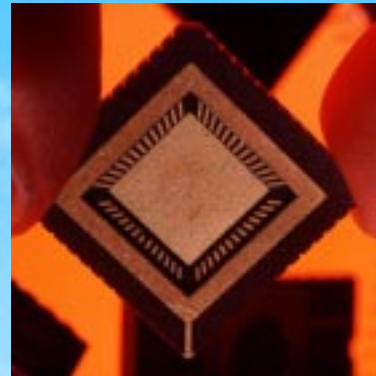
$10^{-9}$  s



clock speed of chip

one foot

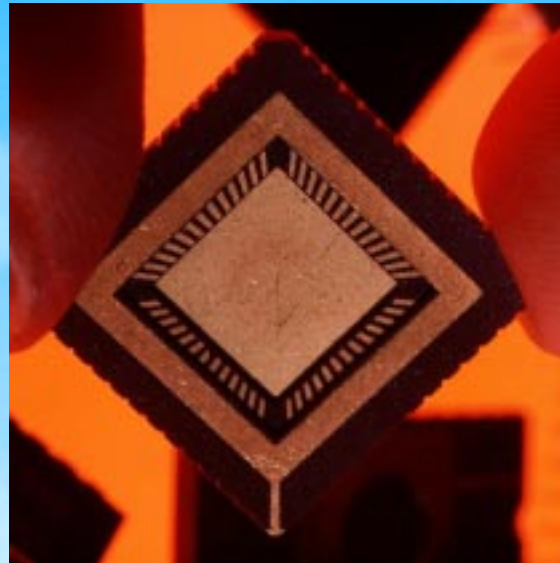
$10^{-9}$  s



clock speed of chip

one foot

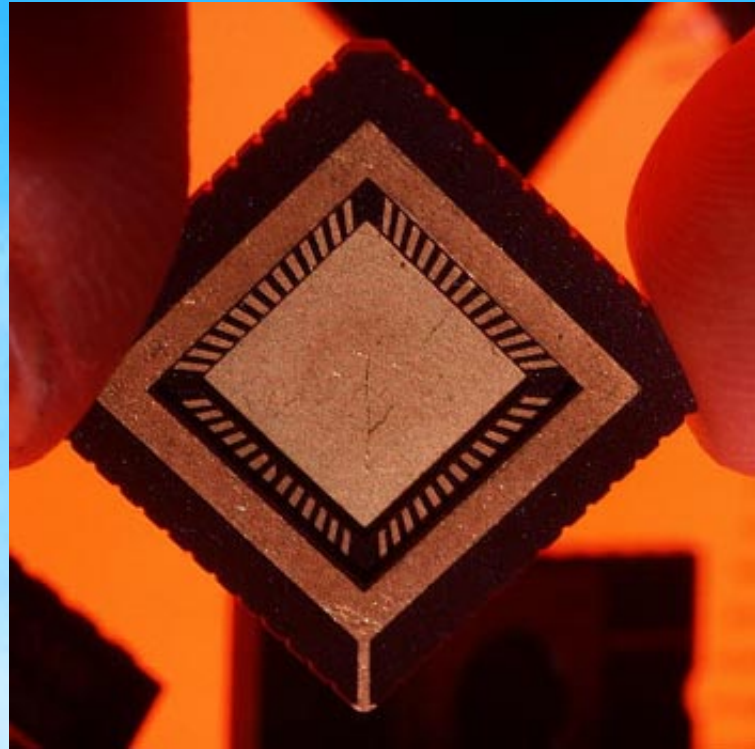
$10^{-9}$  s



clock speed of chip

one foot

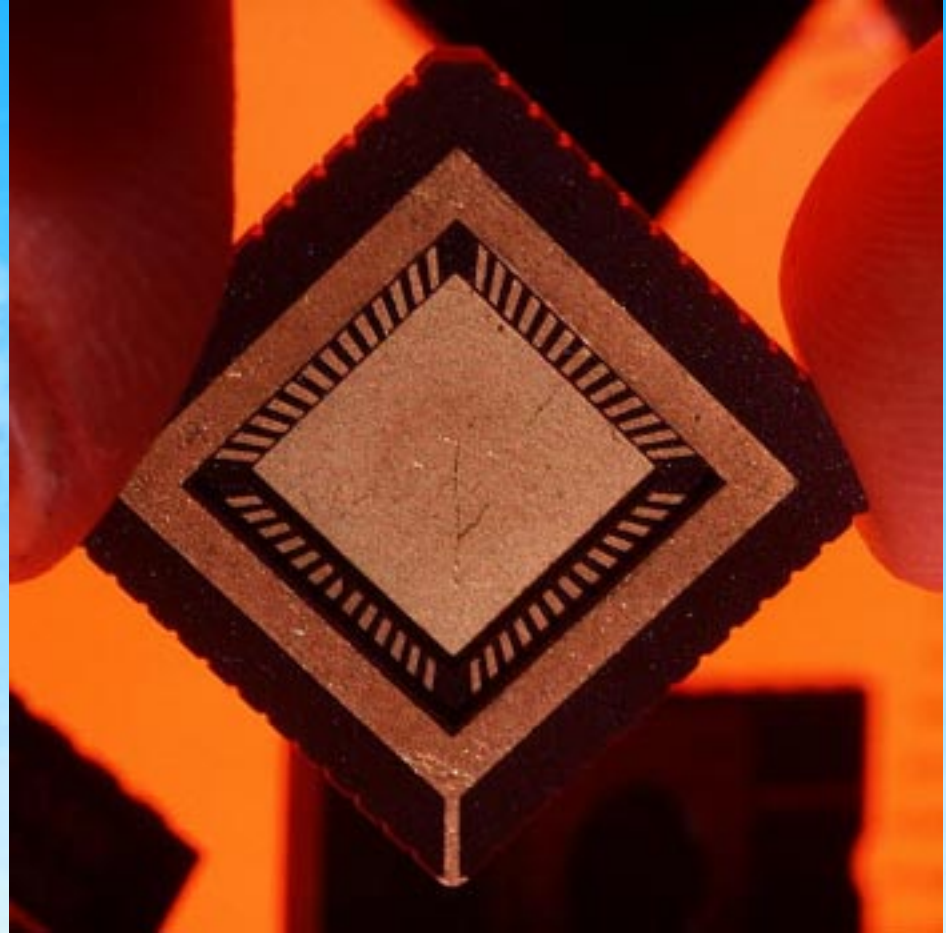
$10^{-9}$  s



clock speed of chip

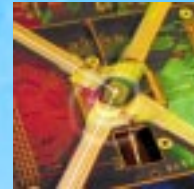
one foot

$10^{-9}$  s



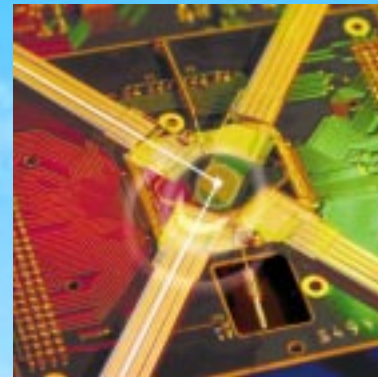
clock speed of chip

$10^{-10}$  s



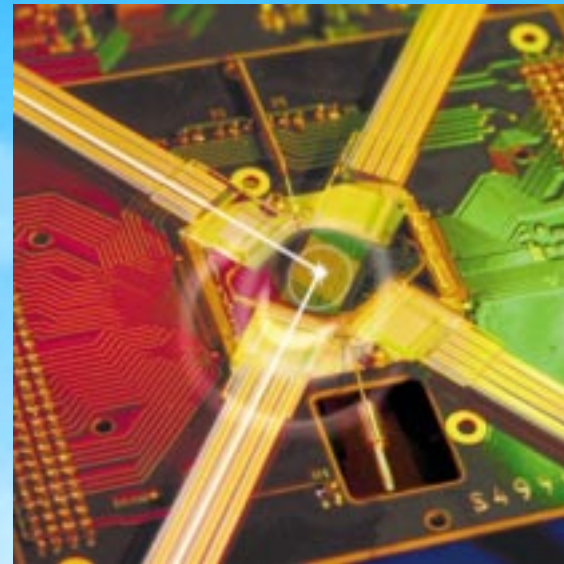
fastest electronic switch

$10^{-10}$  s



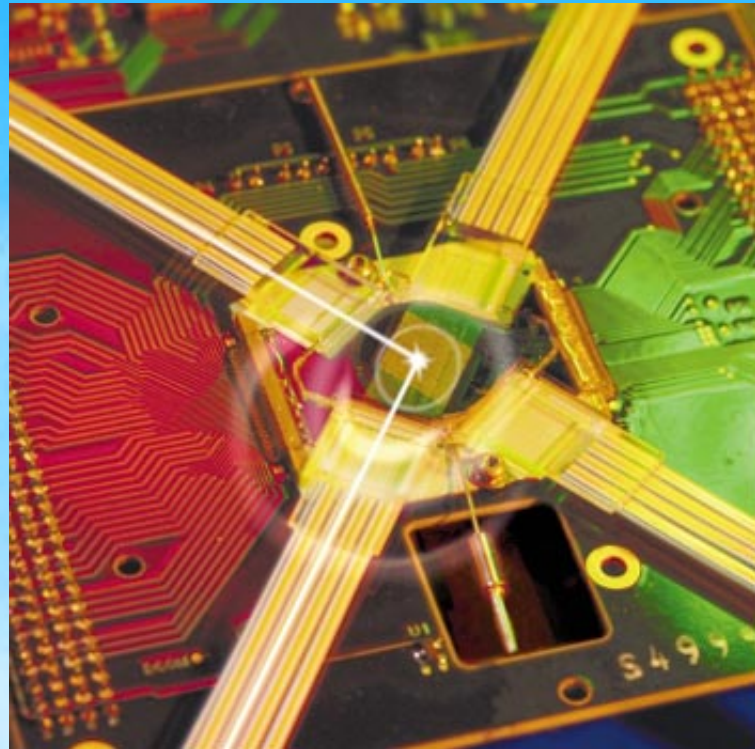
**fastest electronic switch**

$10^{-10}$  s



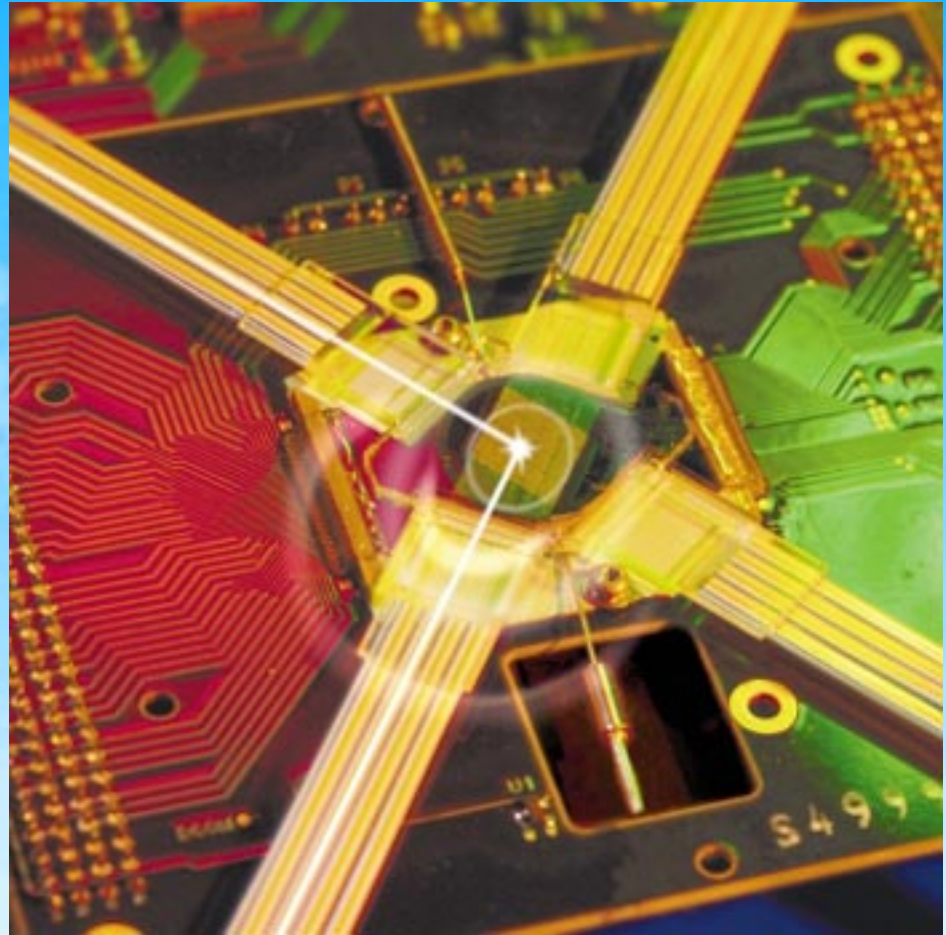
**fastest electronic switch**

$10^{-10}$  s



fastest electronic switch

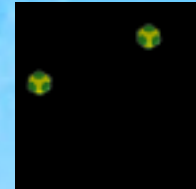
$10^{-10}$  s



fastest electronic switch

window pane

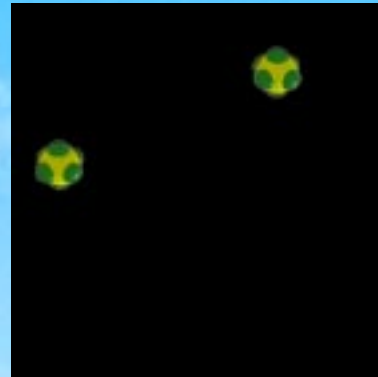
$10^{-11}$  s



molecular collision

# window pane

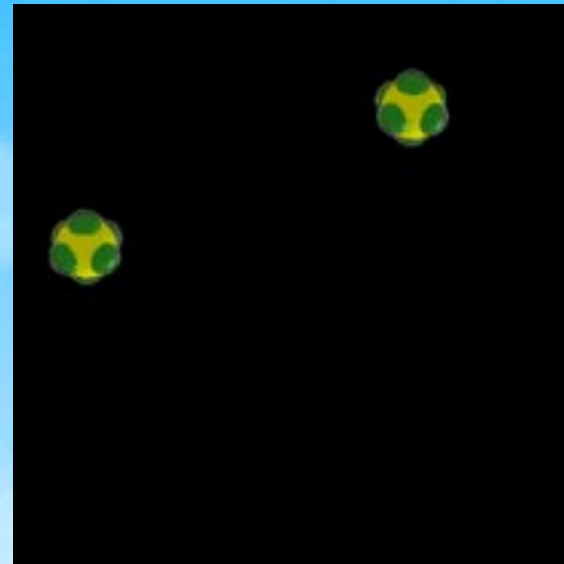
$10^{-11}$  s



# molecular collision

window pane

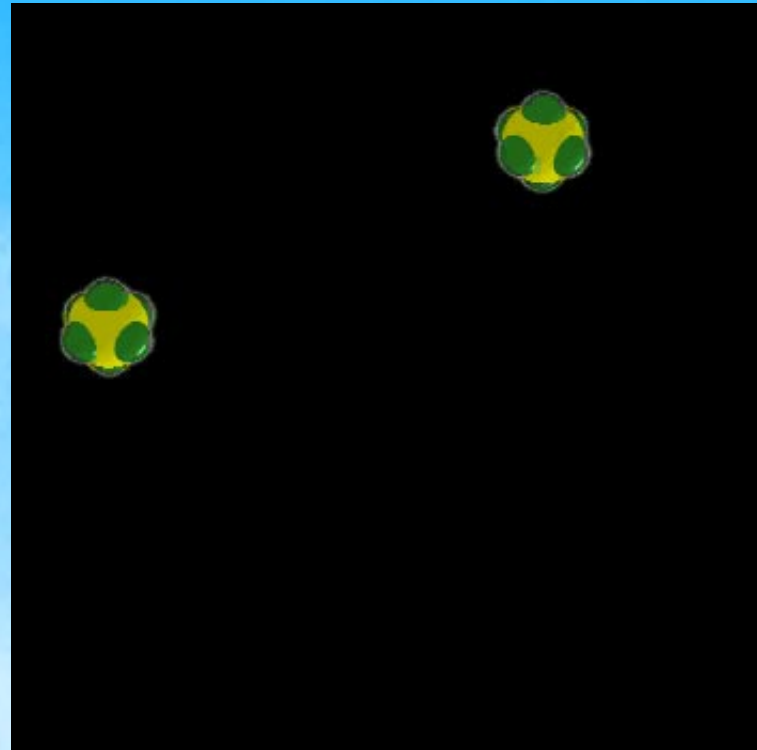
$10^{-11}$  s



molecular collision

# window pane

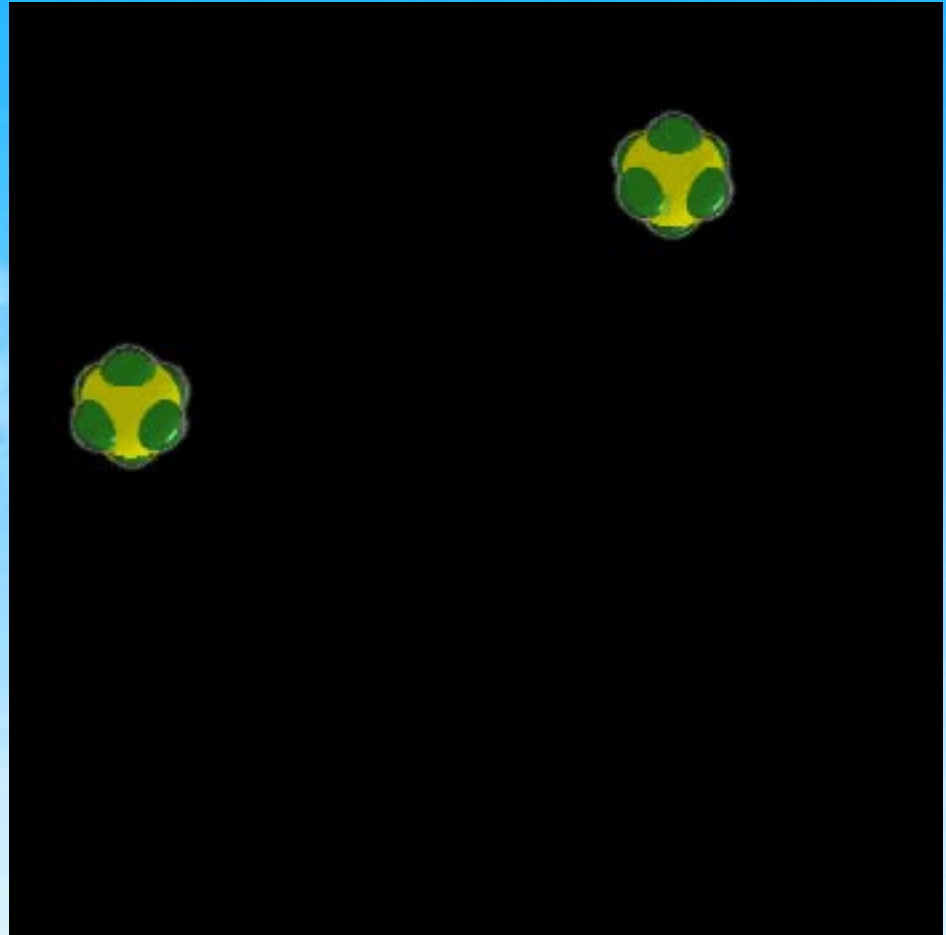
$10^{-11}$  s



# molecular collision

# window pane

$10^{-11}$  s



# molecular collision

$10^{-12}$  s



molecular rotation

$10^{-12}$  s



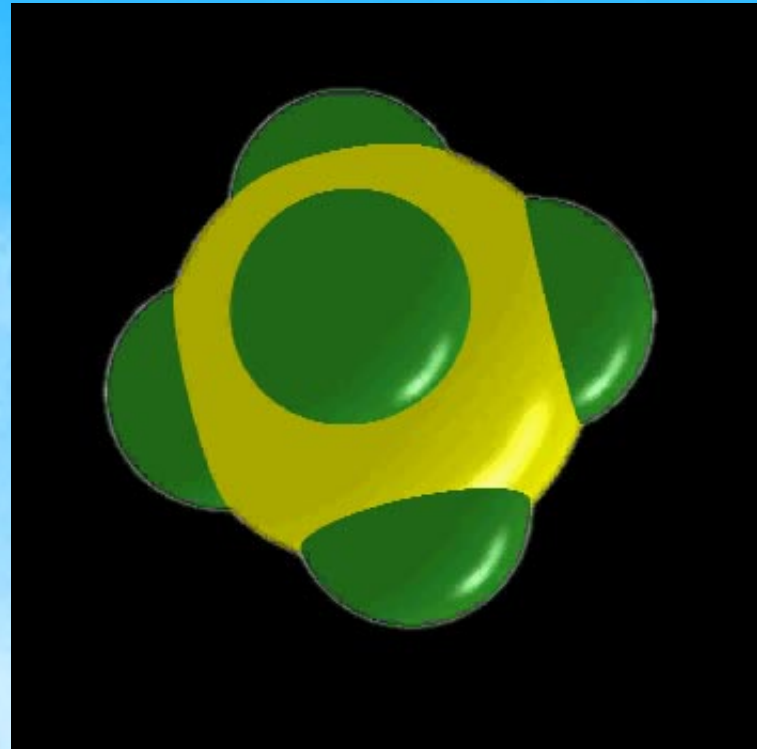
molecular rotation

$10^{-12}$  s



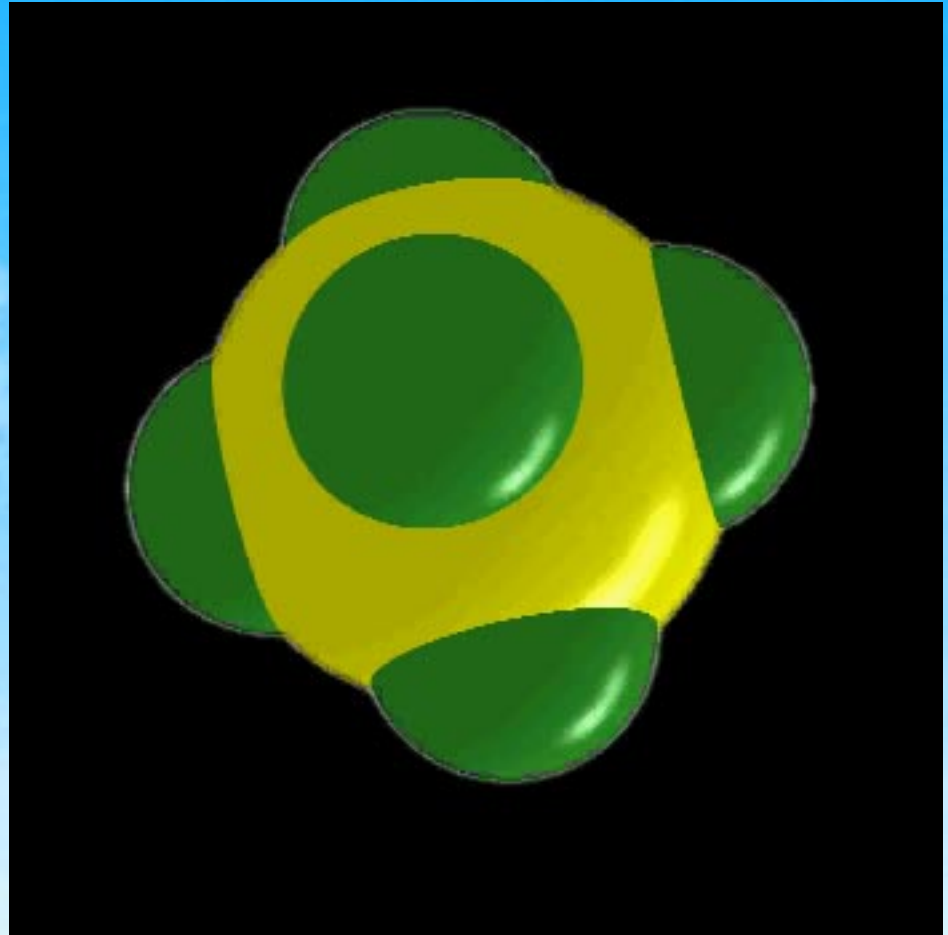
molecular rotation

$10^{-12}$  s



molecular rotation

$10^{-12}$  s



molecular rotation

# width of human hair

$10^{-13}$  s



# molecular vibration

# width of human hair

$10^{-13}$  s



# molecular vibration

# width of human hair

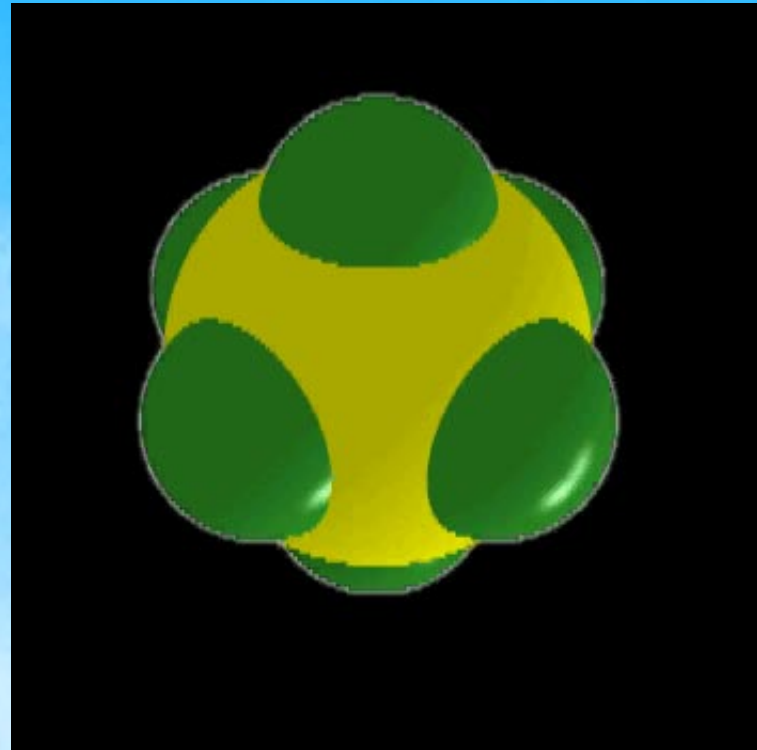
$10^{-13}$  s



# molecular vibration

# width of human hair

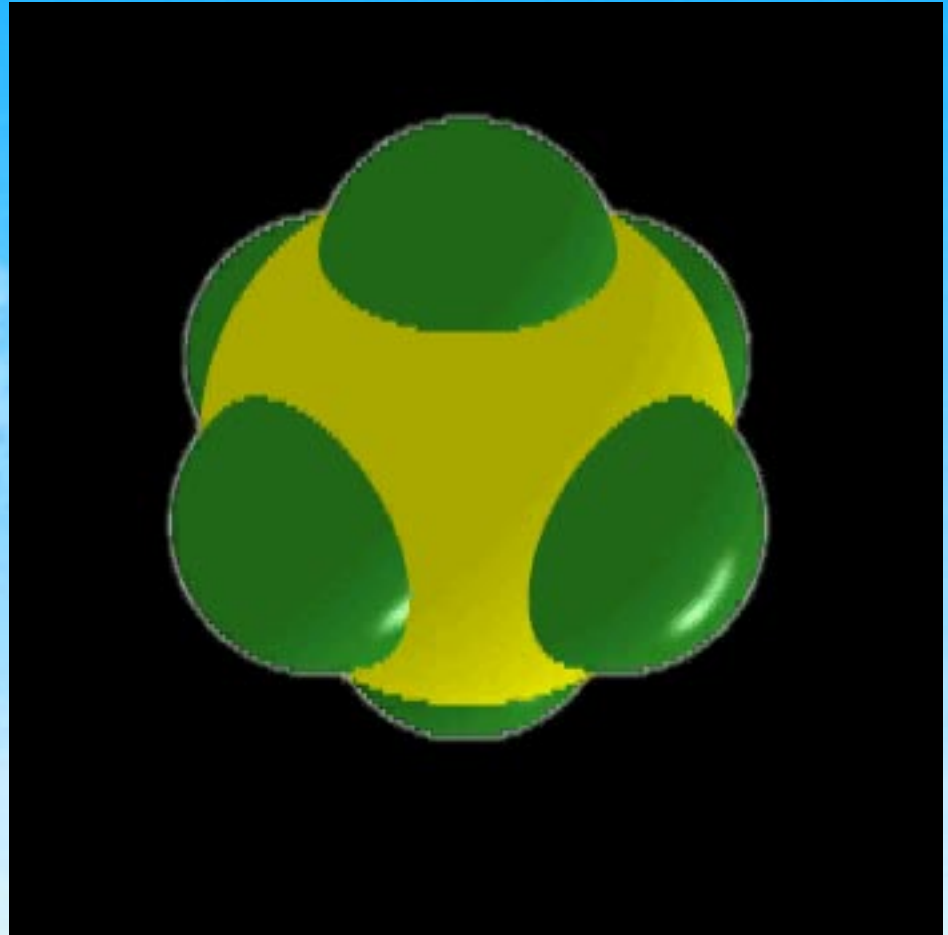
$10^{-13}$  s



# molecular vibration

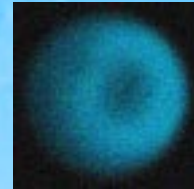
# width of human hair

$10^{-13}$  s



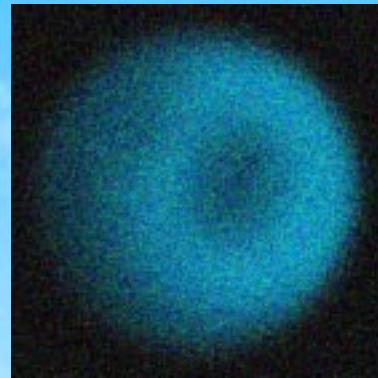
# molecular vibration

$10^{-14}$  s



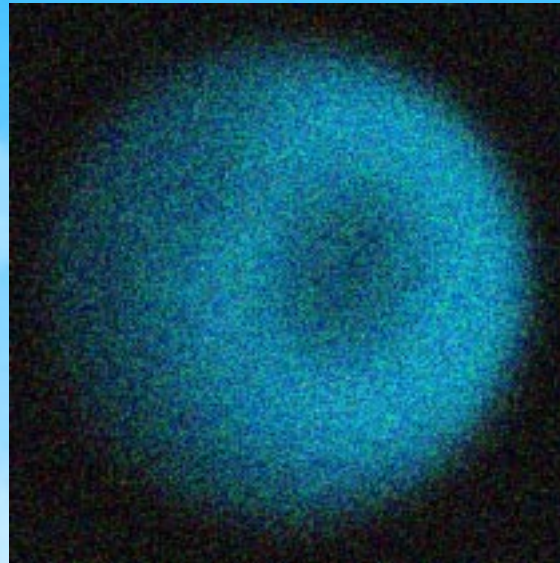
electronic collision

$10^{-14}$  s



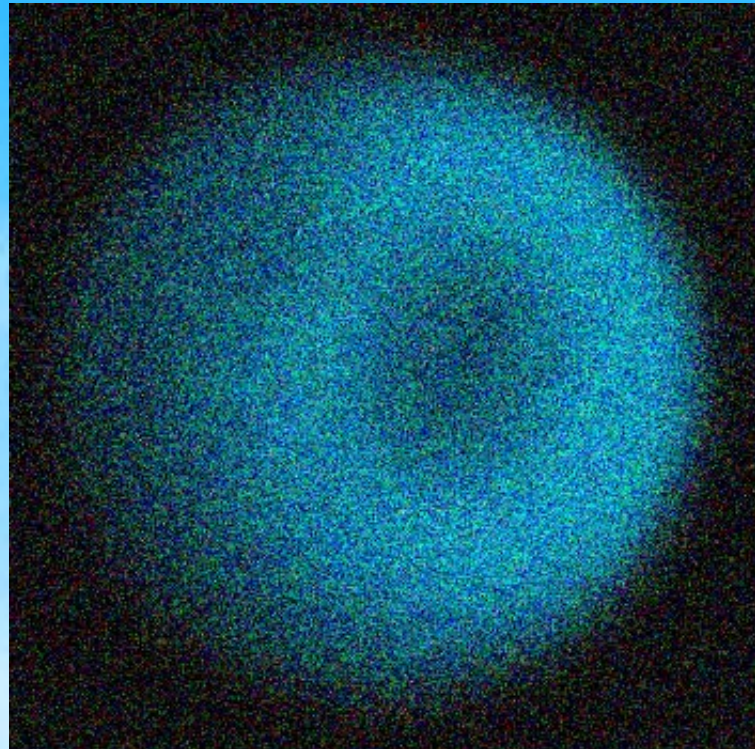
electronic collision

$10^{-14}$  s



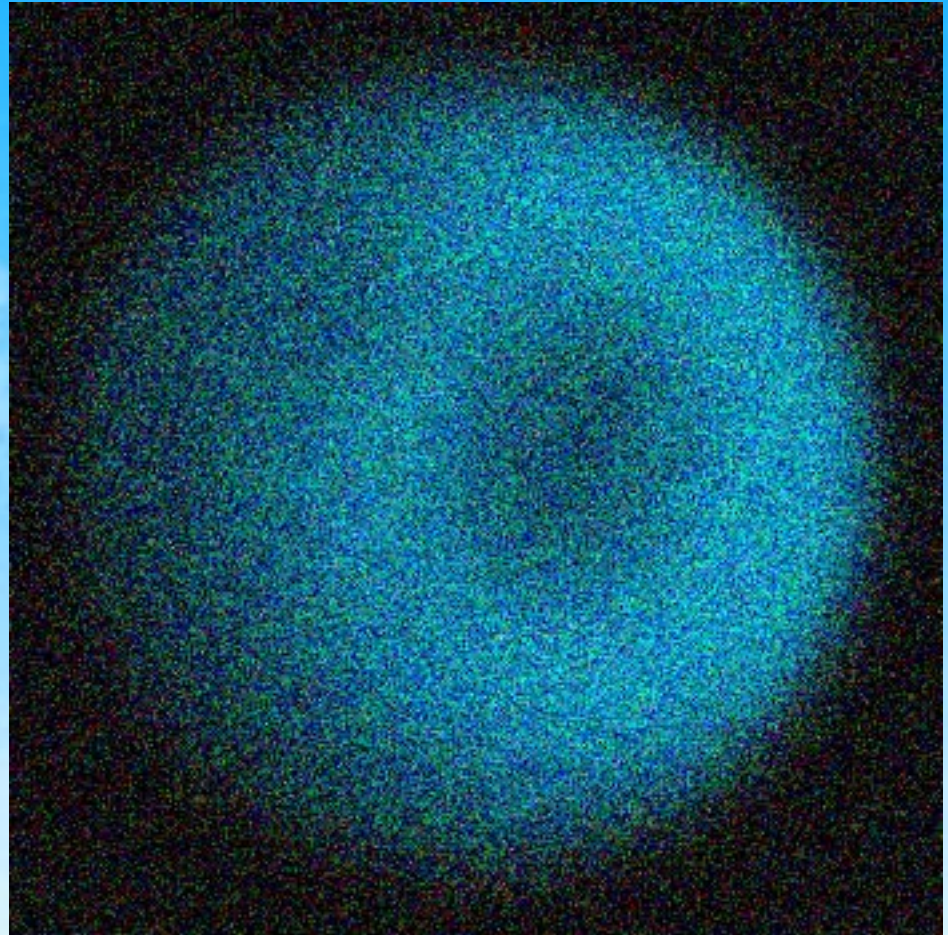
electronic collision

$10^{-14}$  s



electronic collision

$10^{-14}$  s

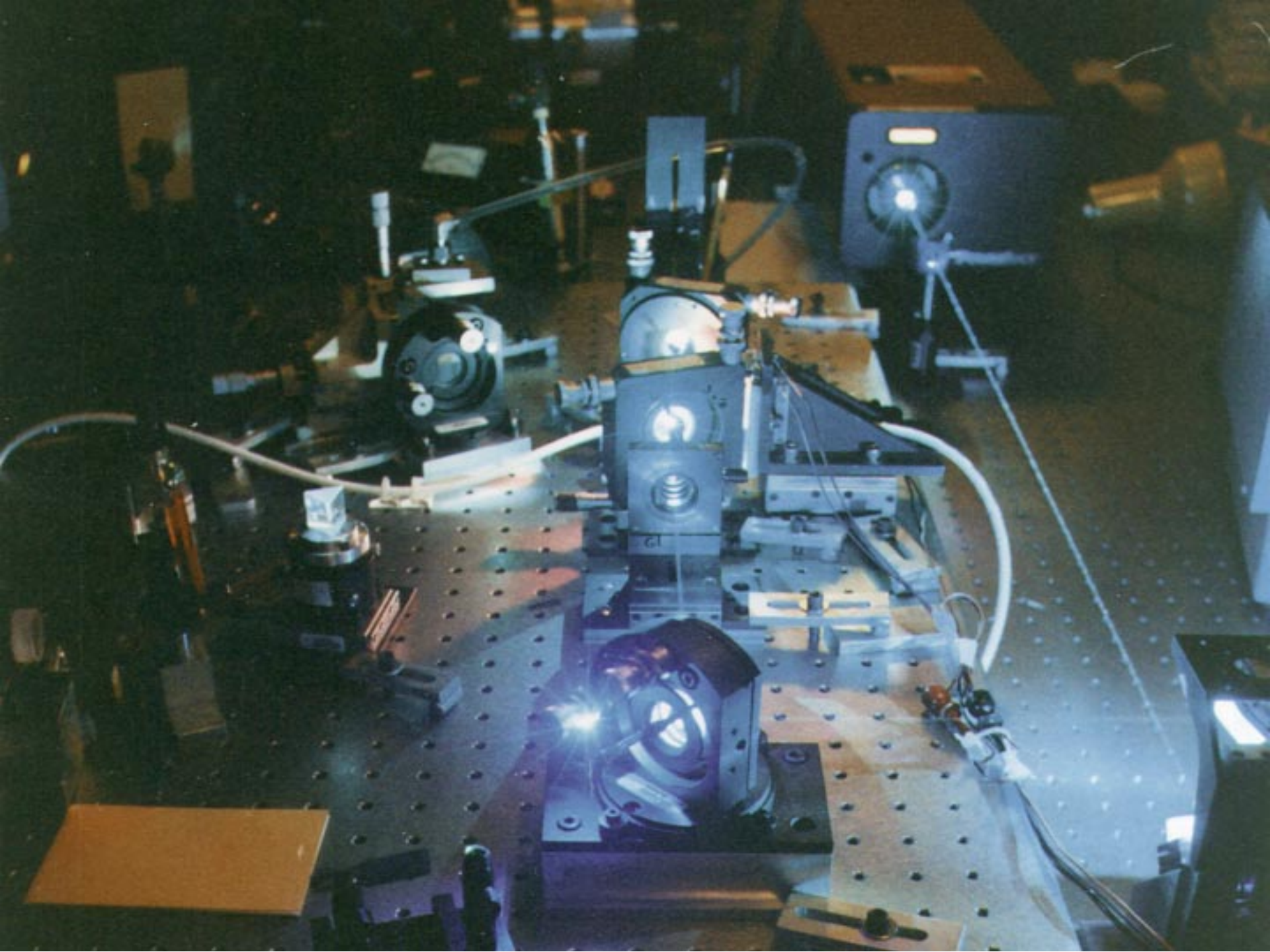


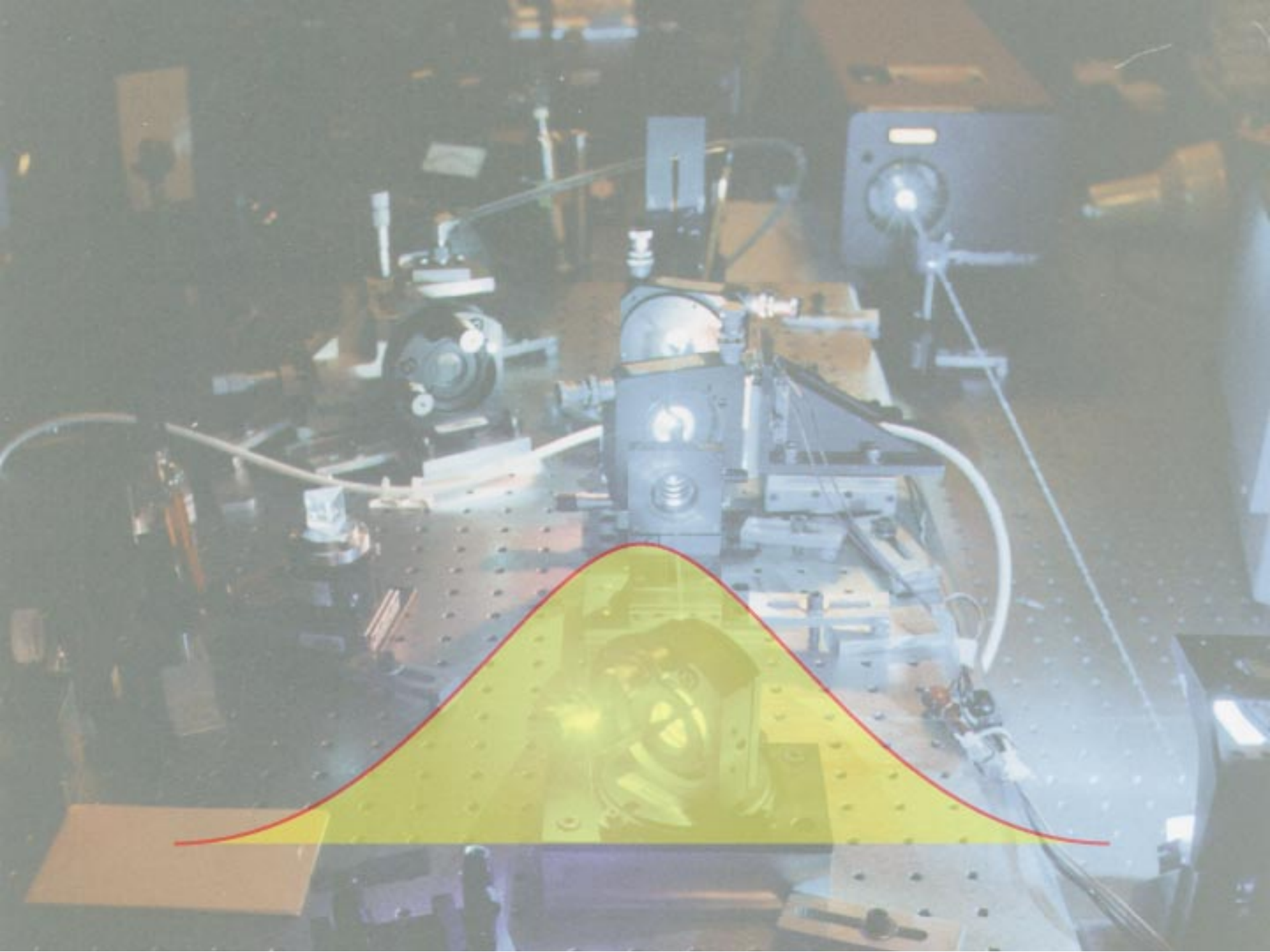
electronic collision

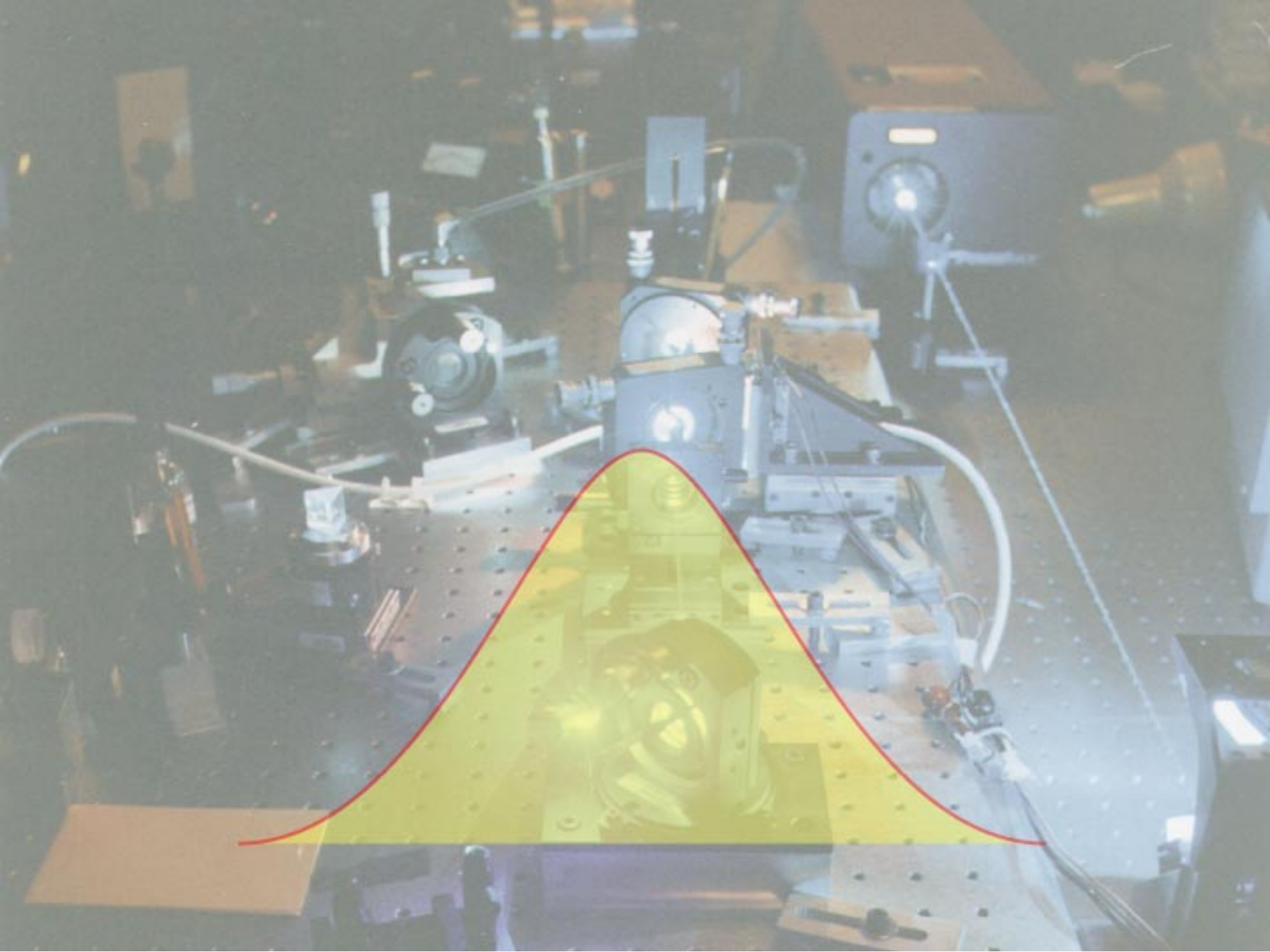
# 100 atomic layers

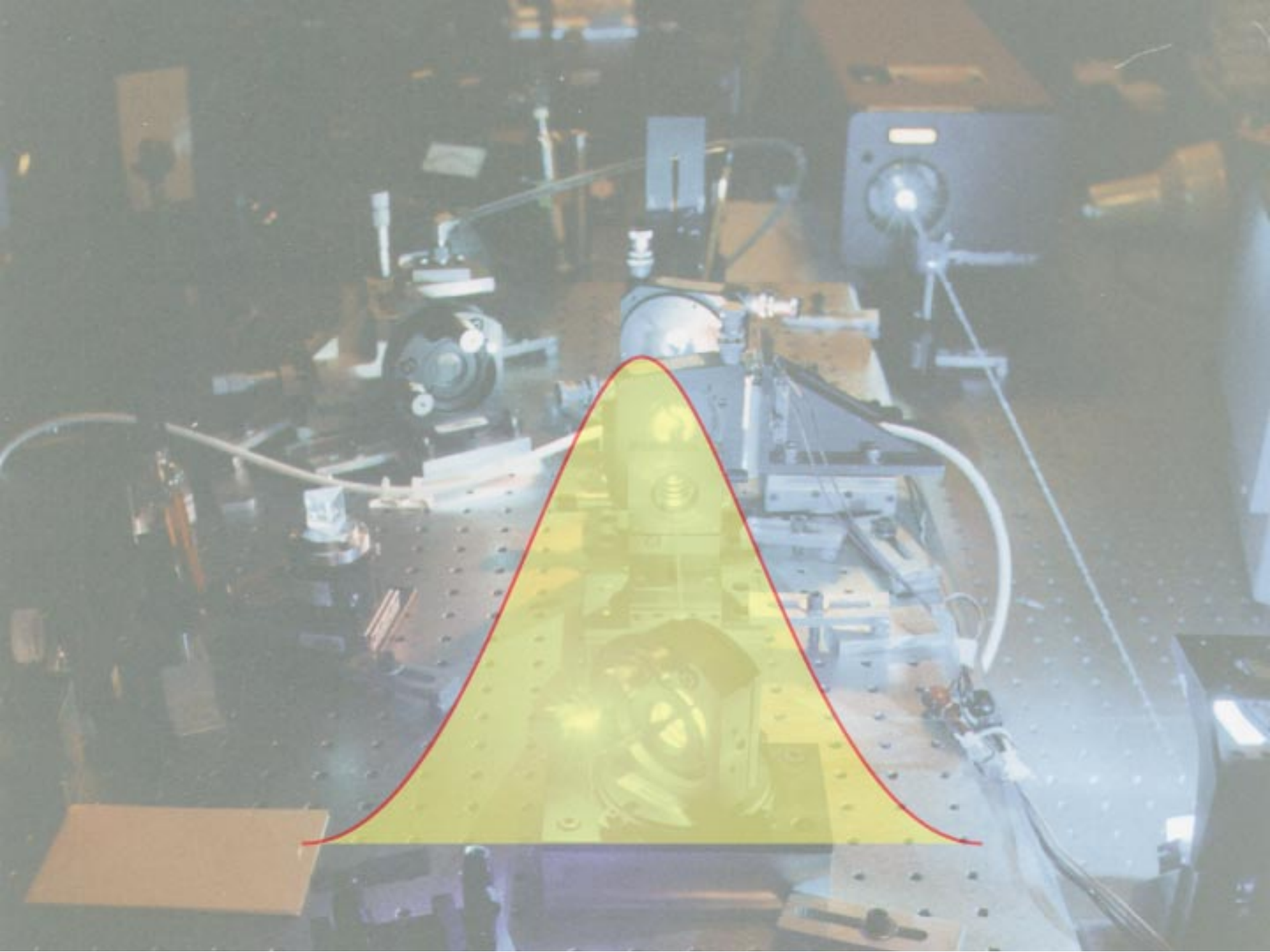
$10^{-15}$  s

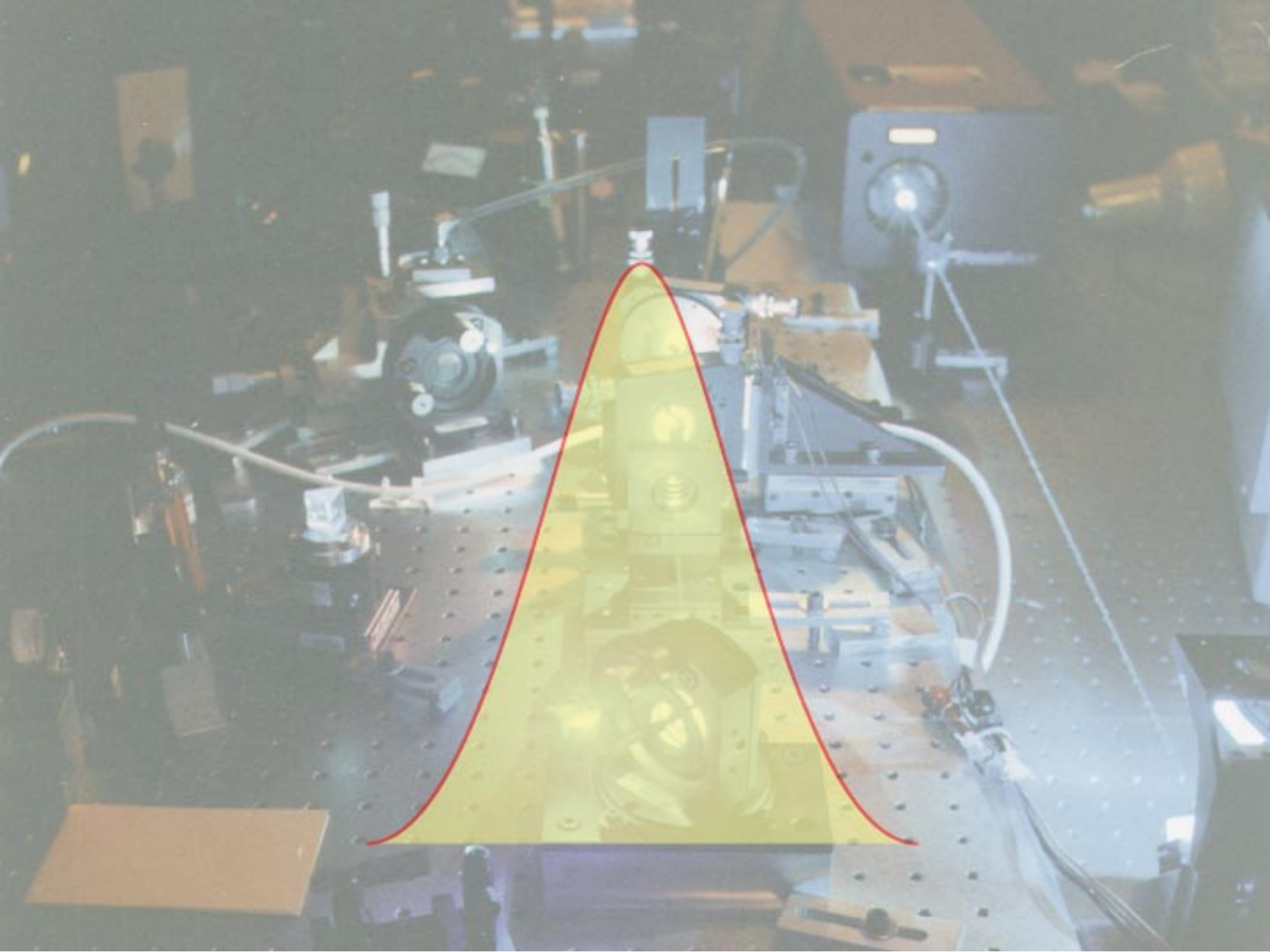
one "femtosecond"

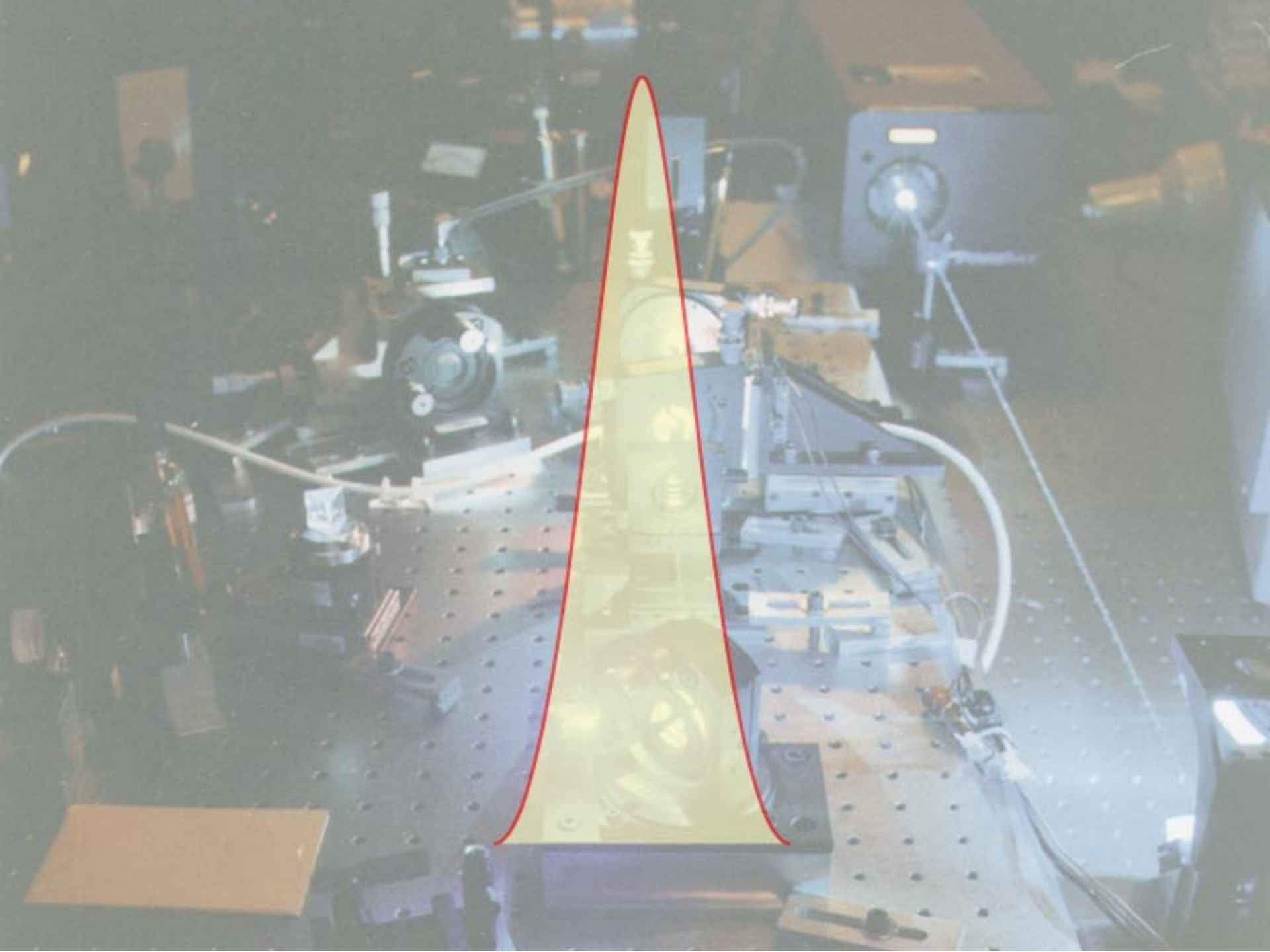


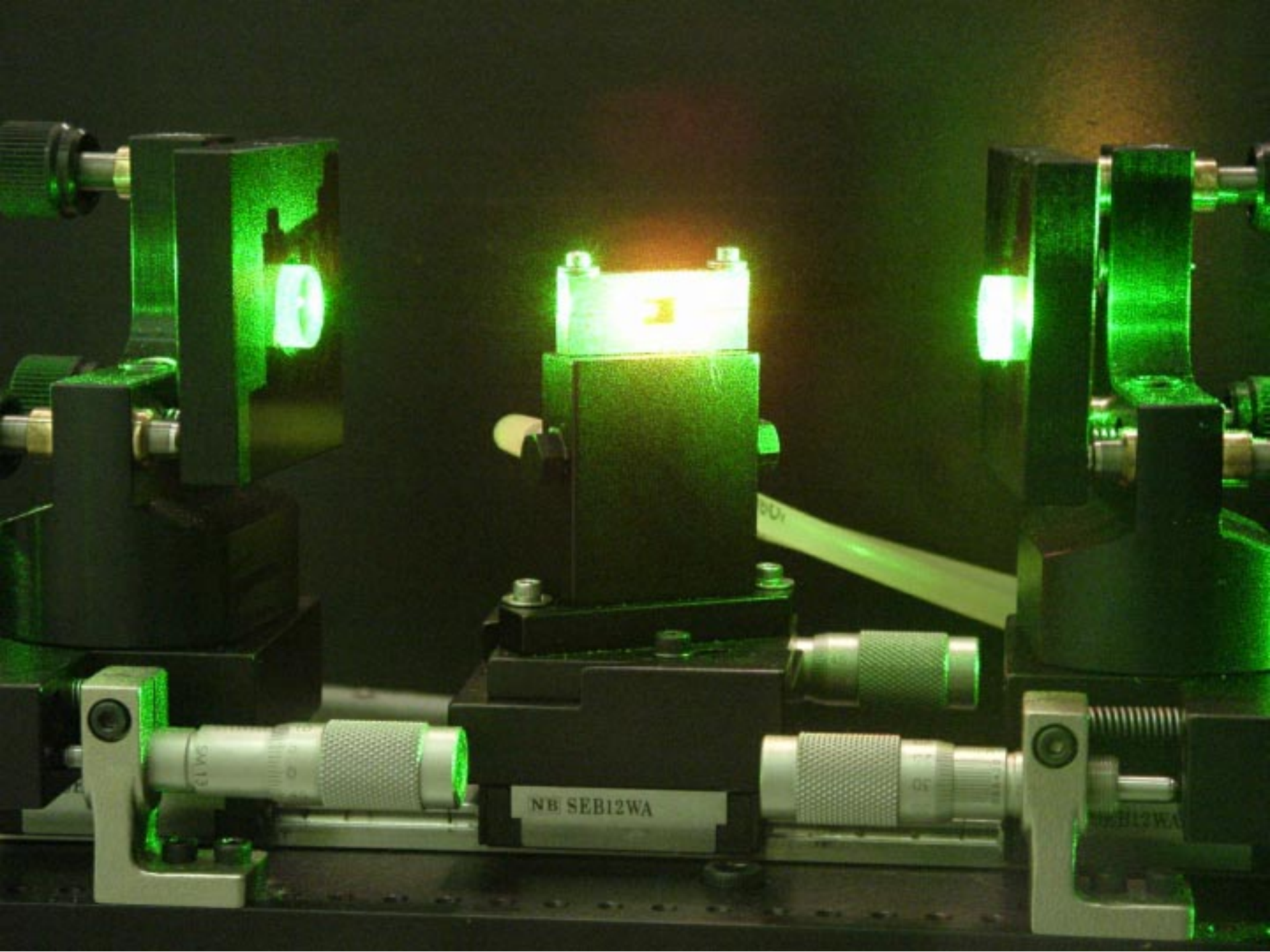


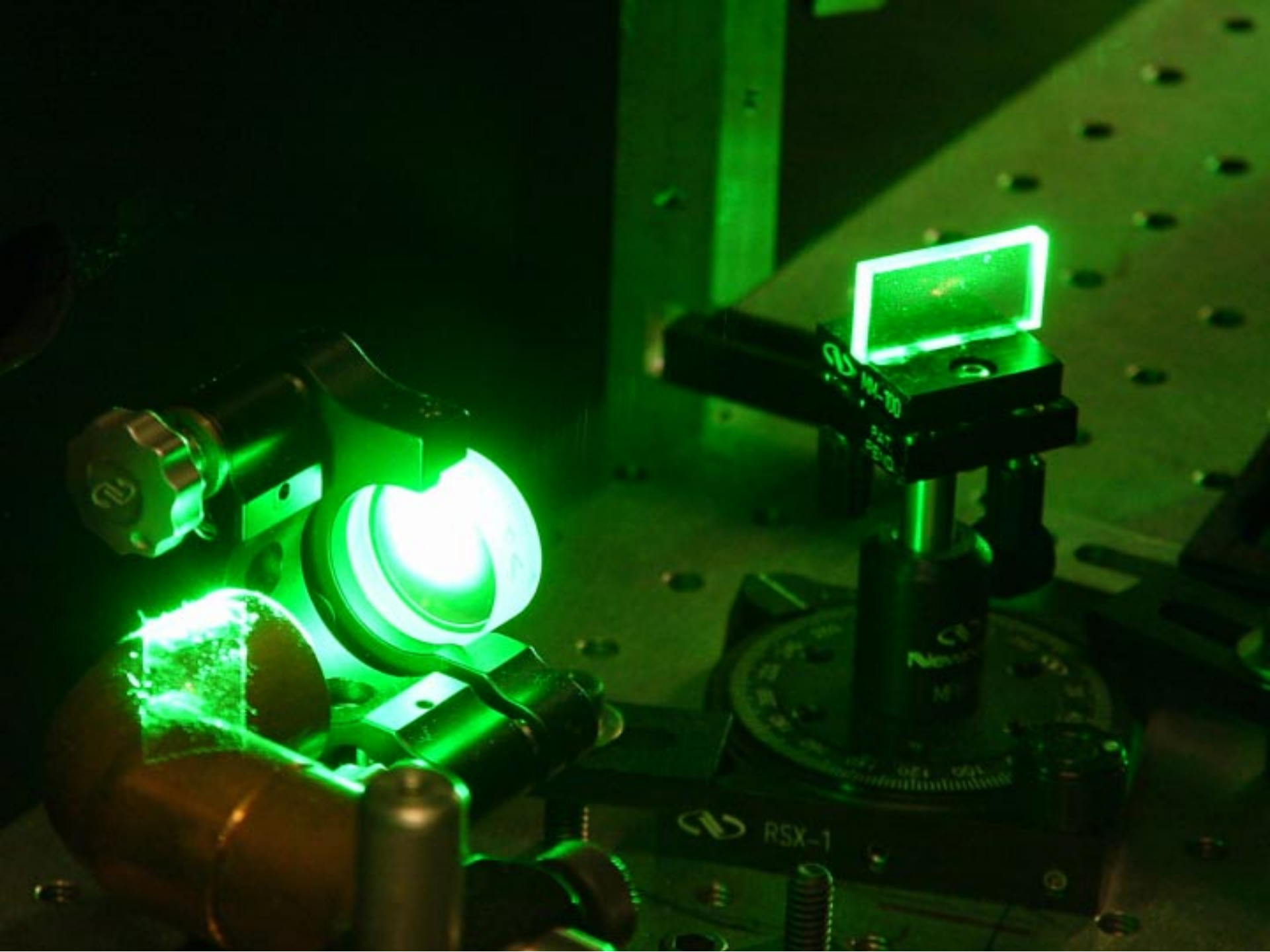


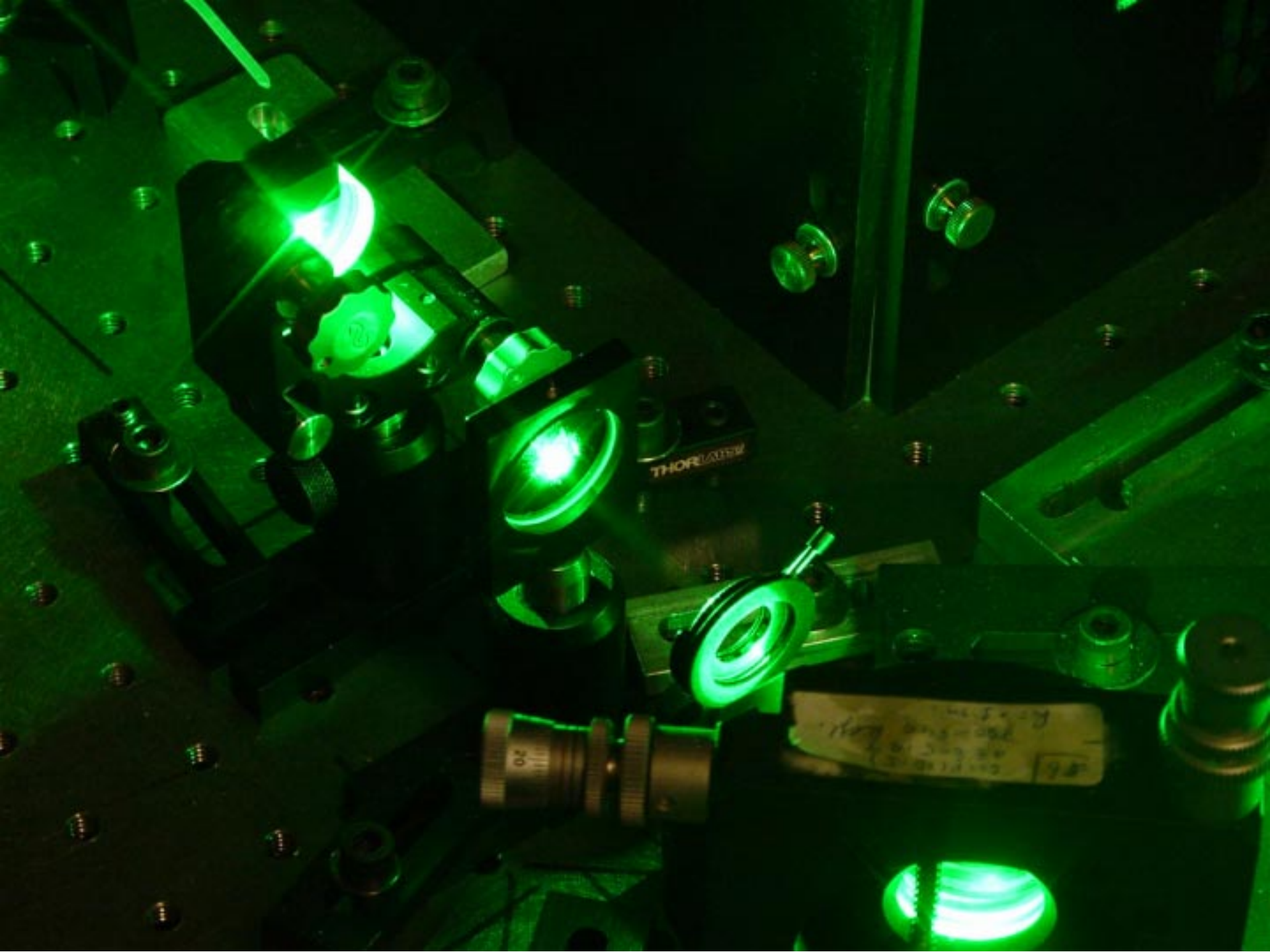


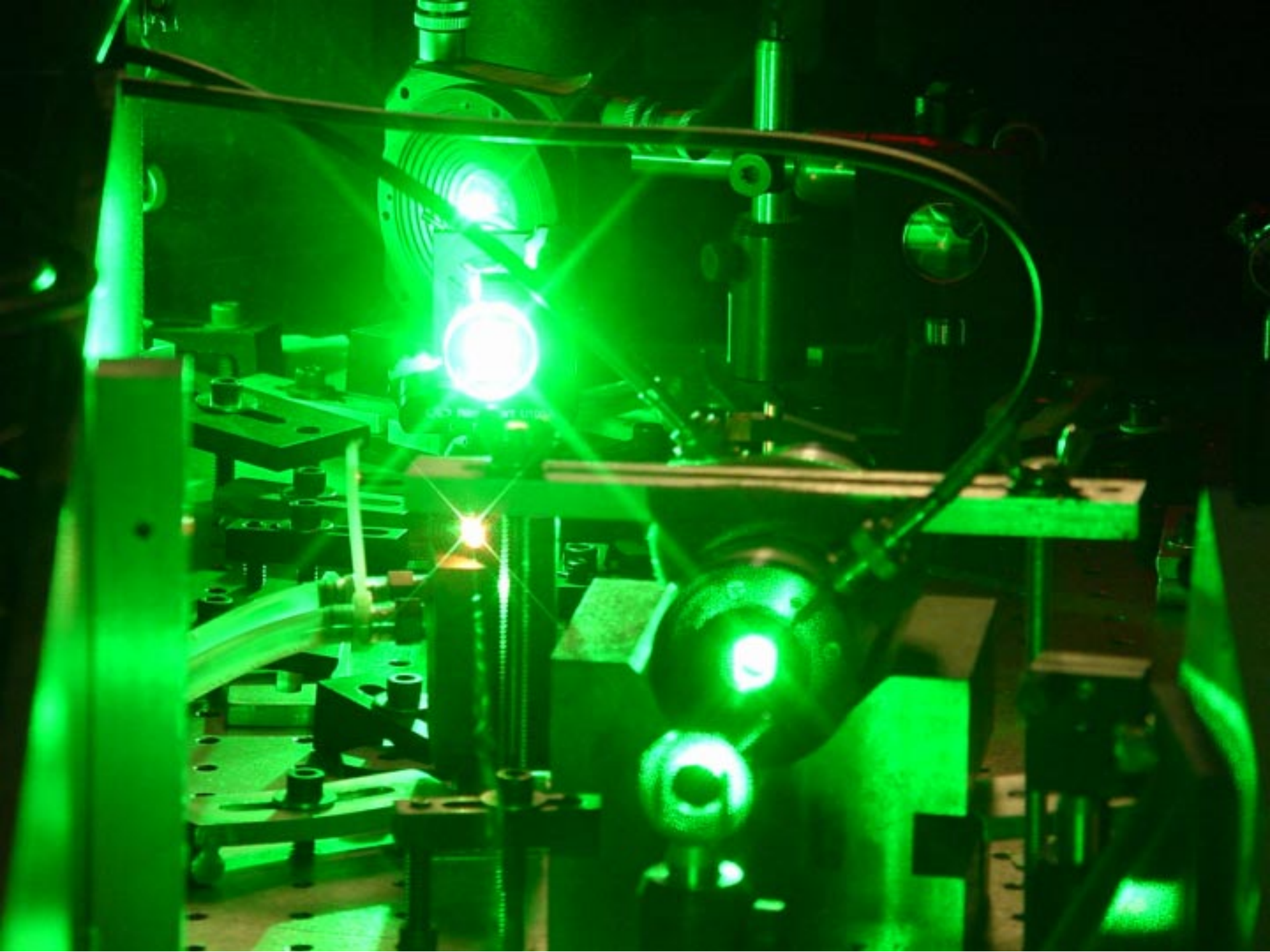


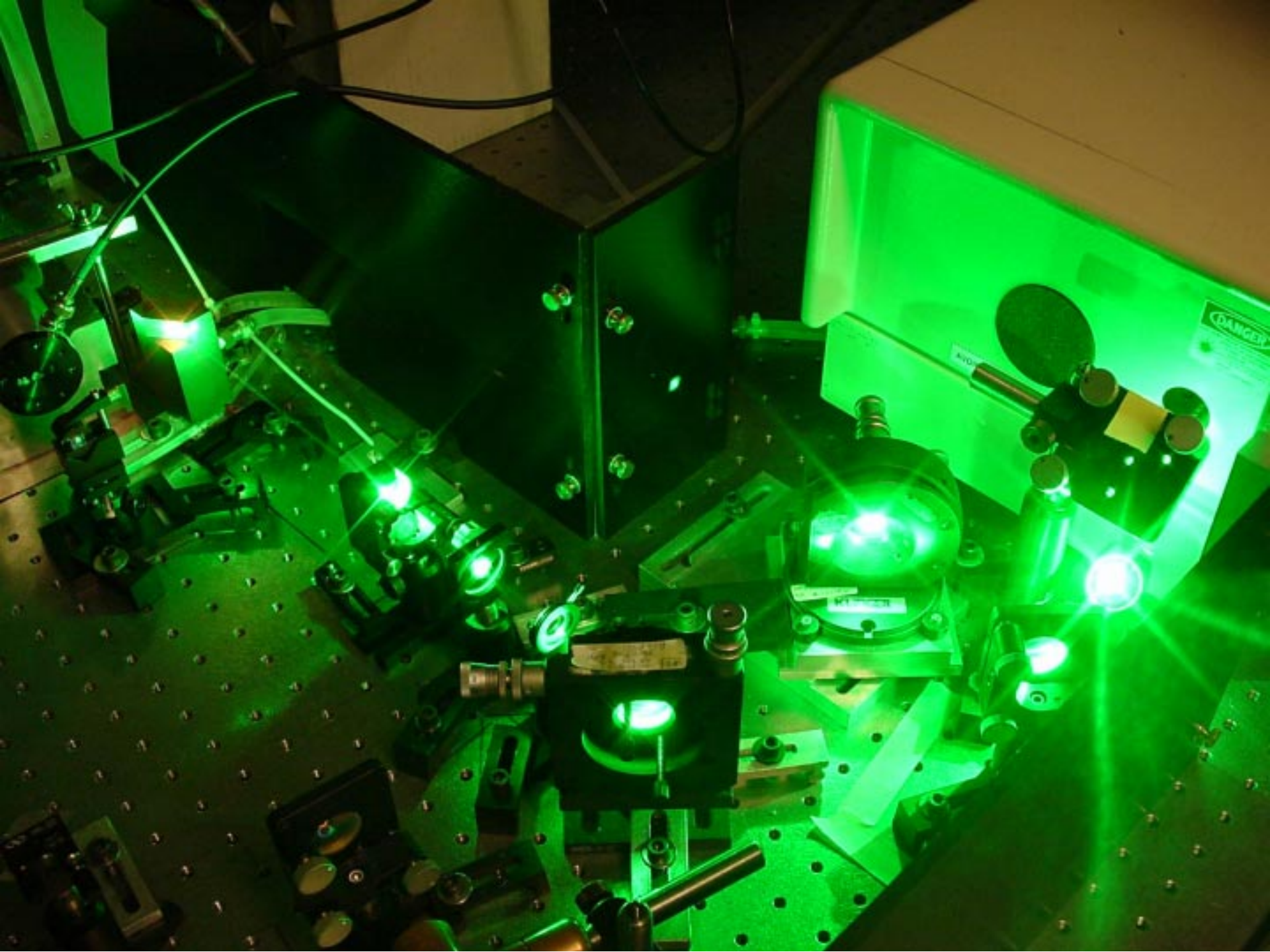




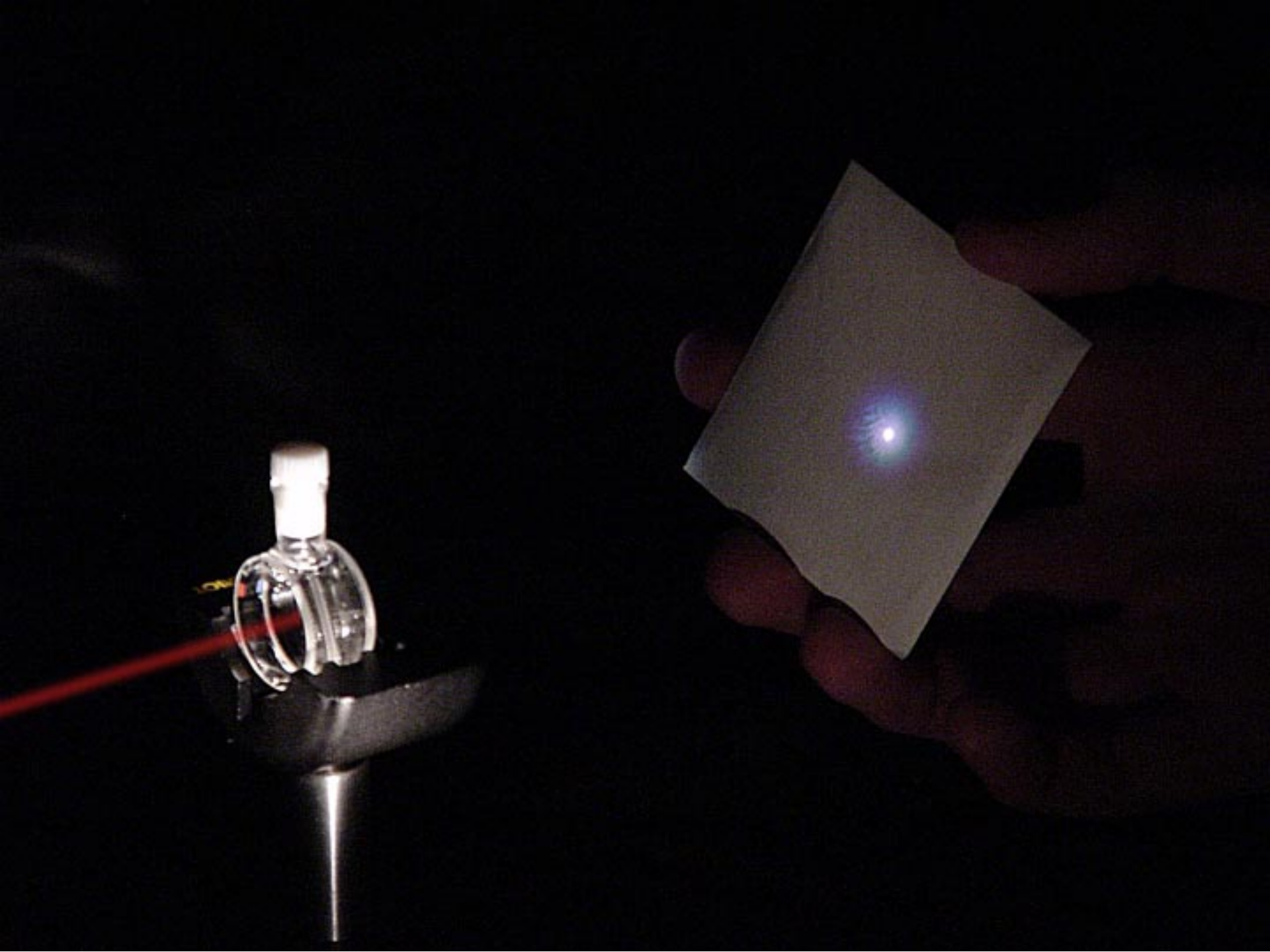


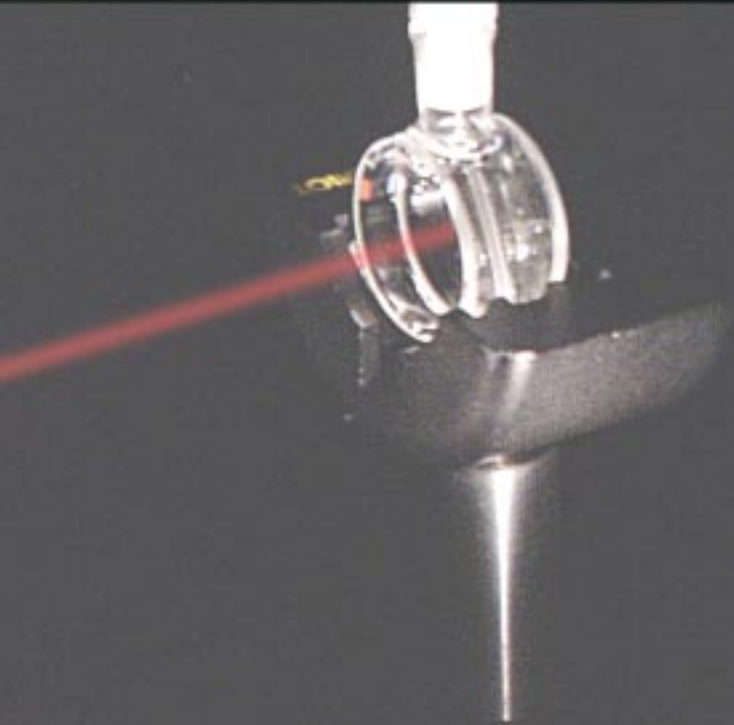


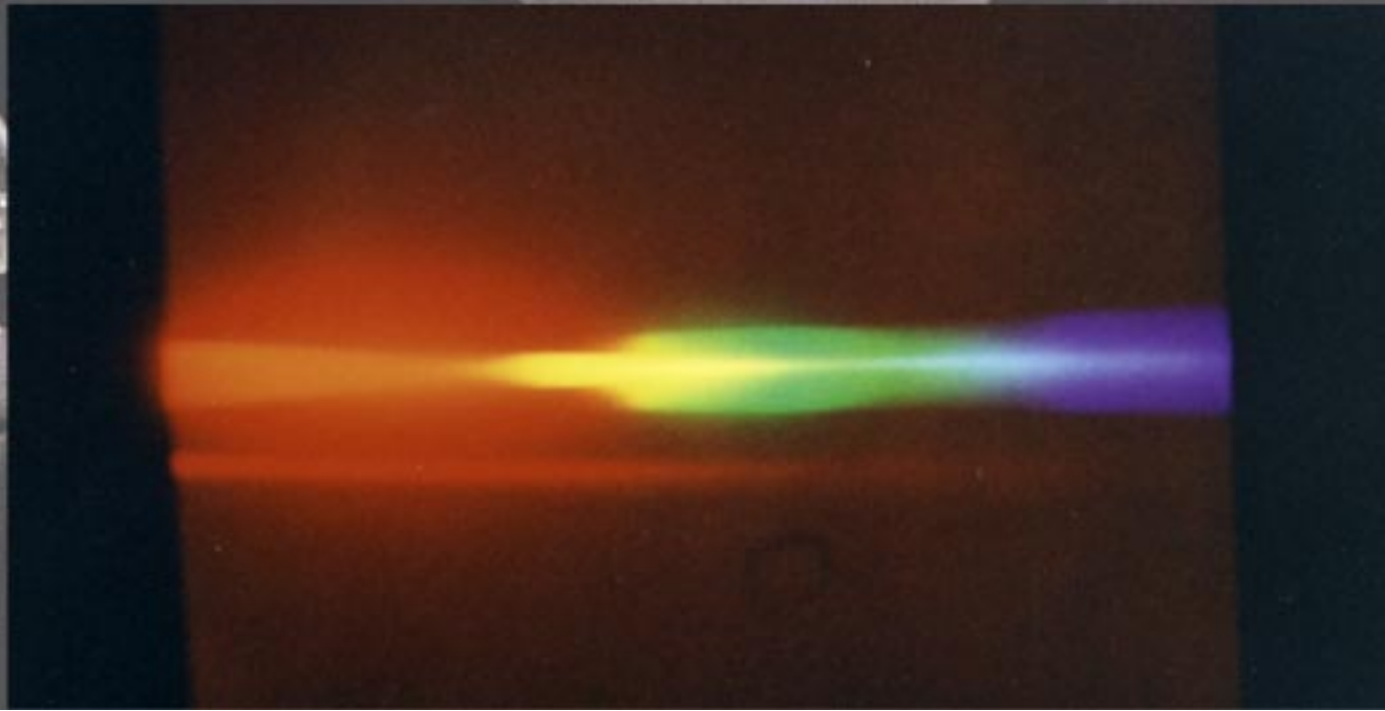






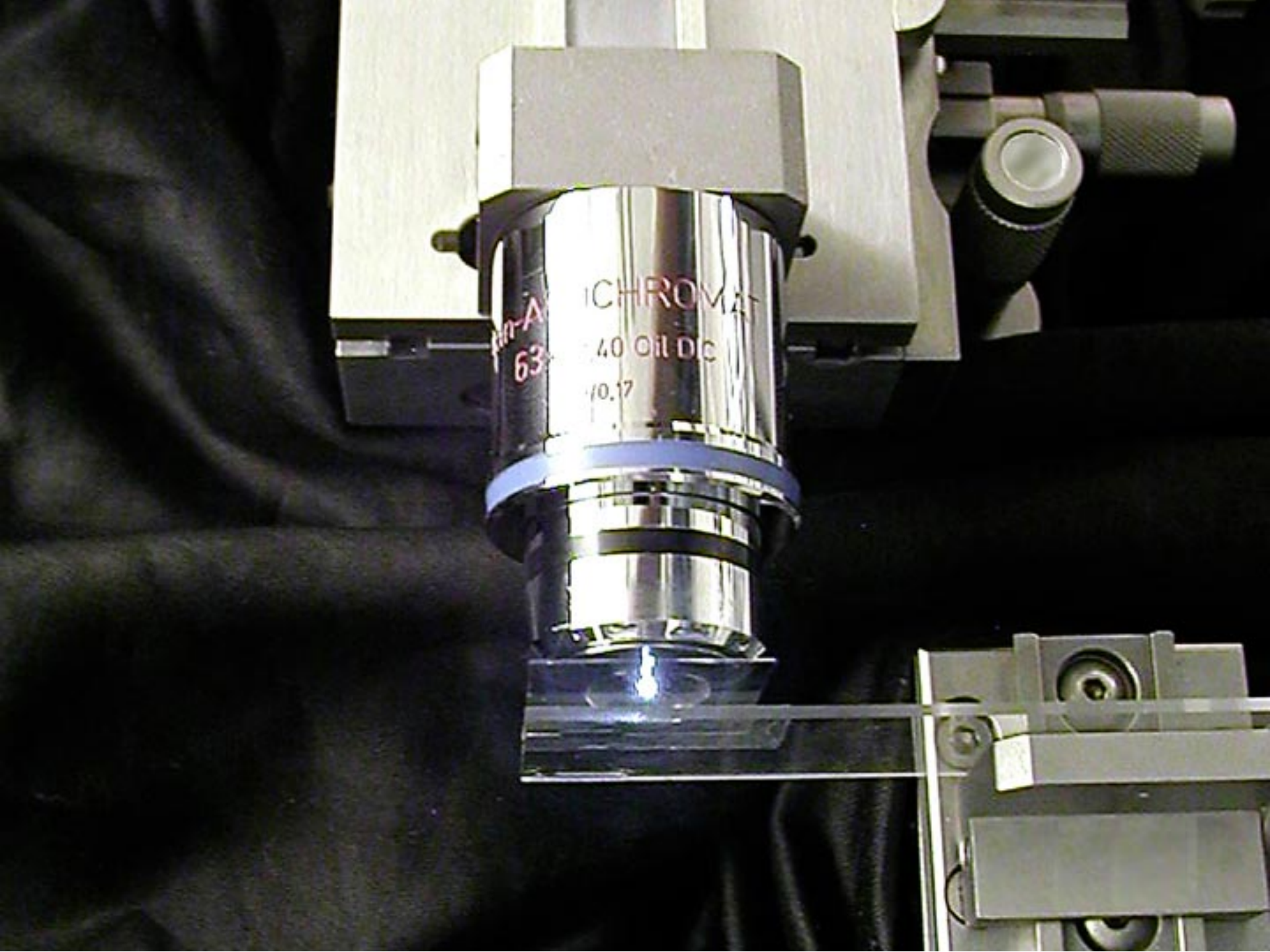




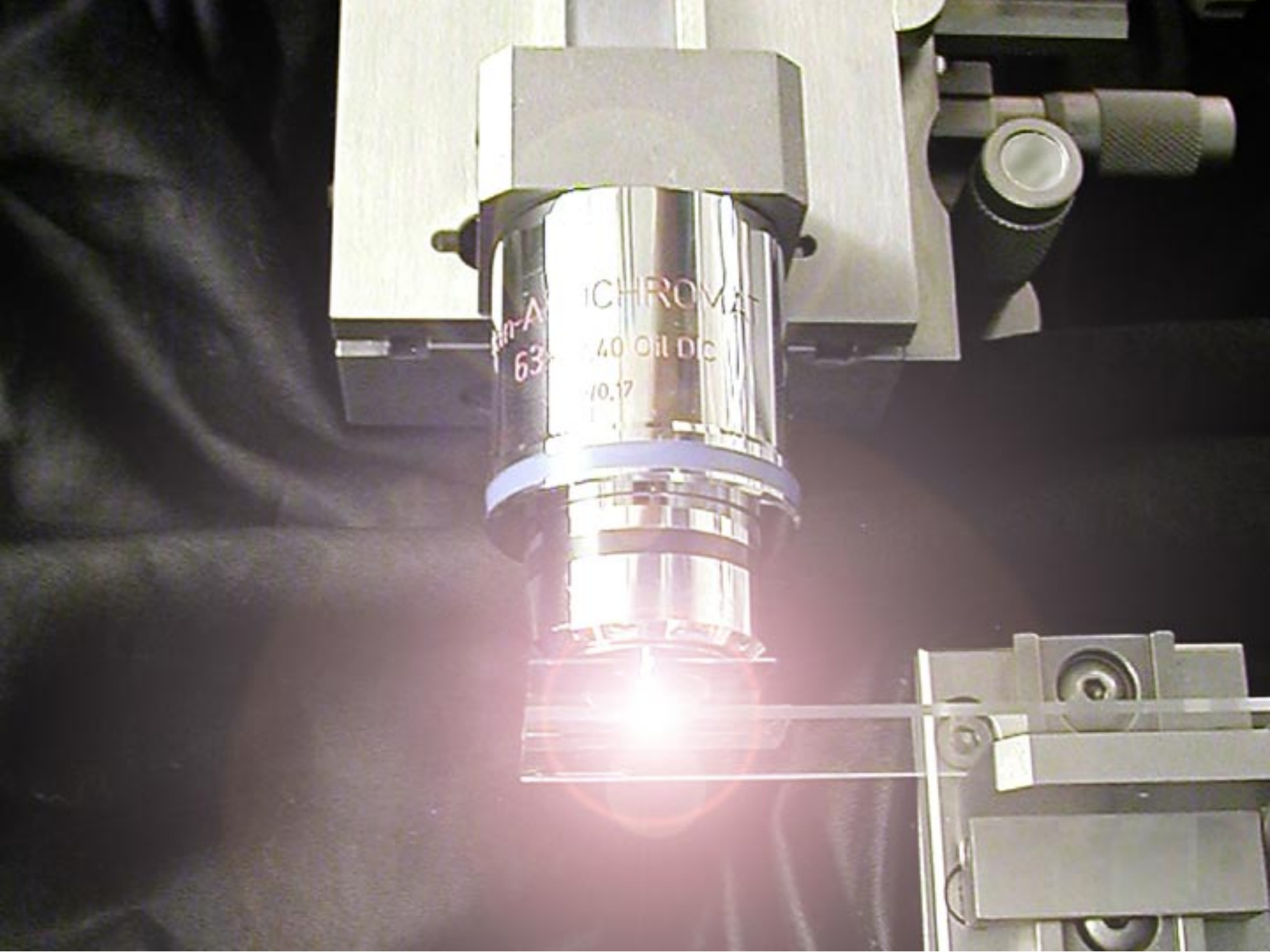


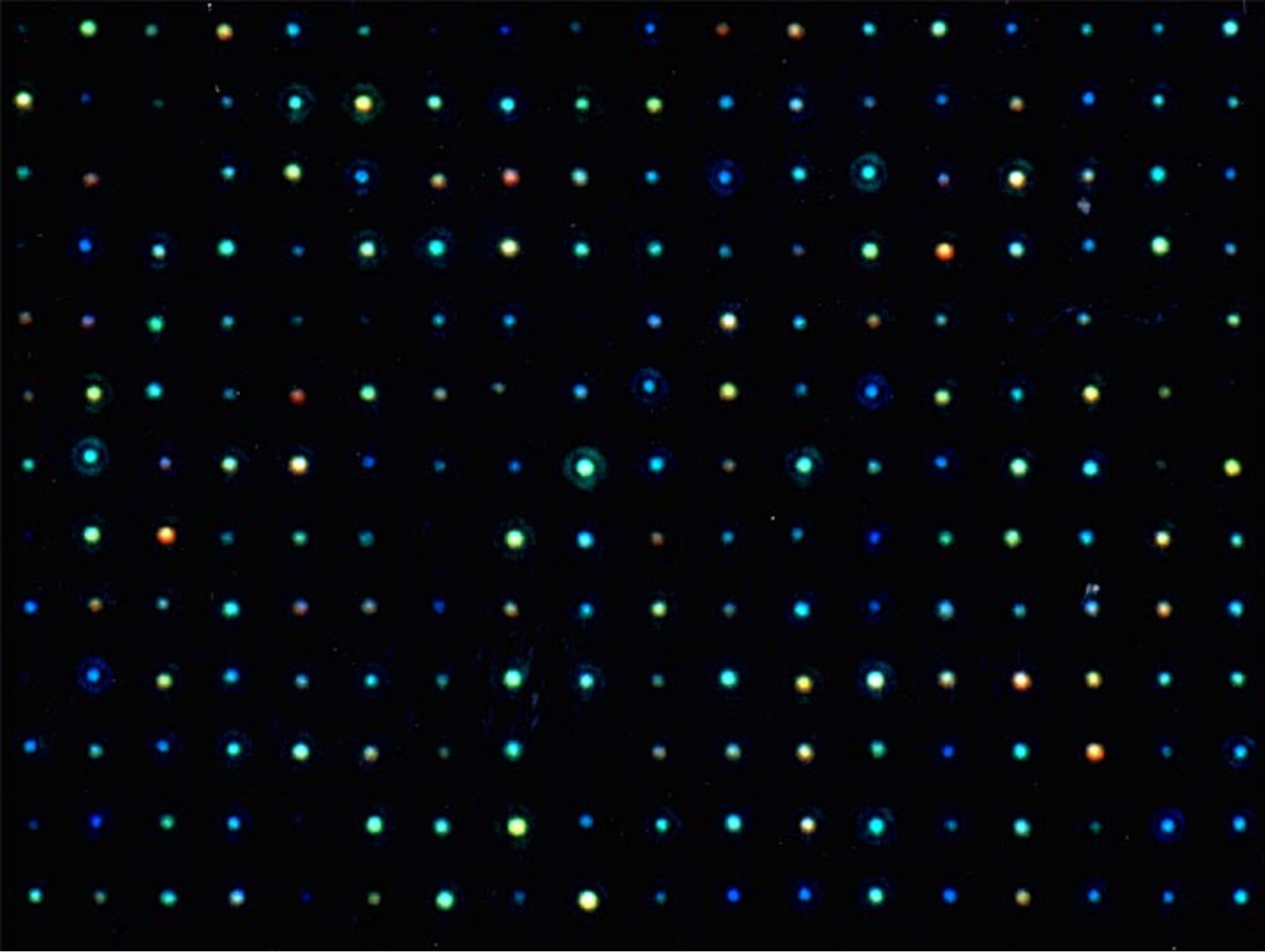


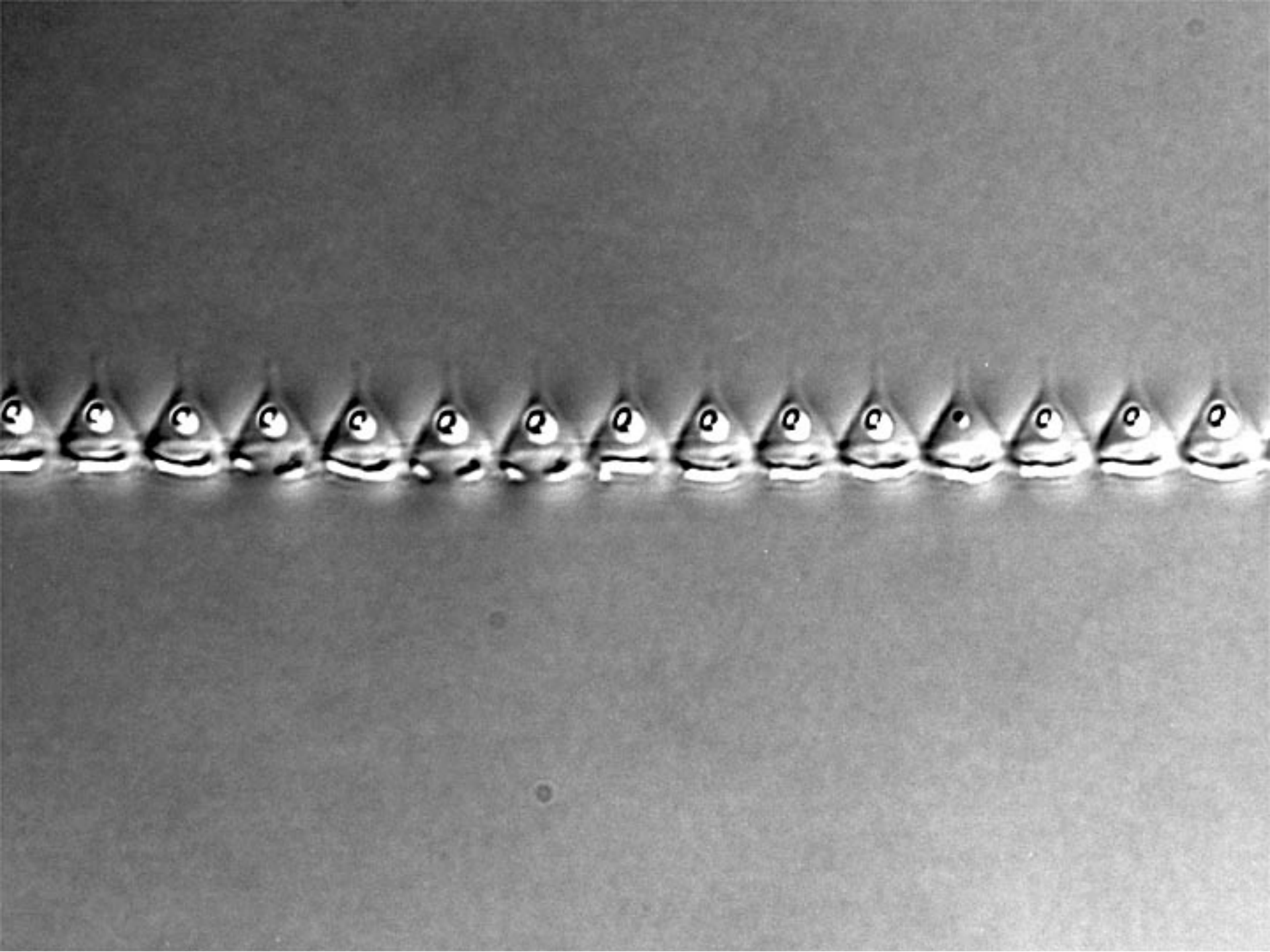


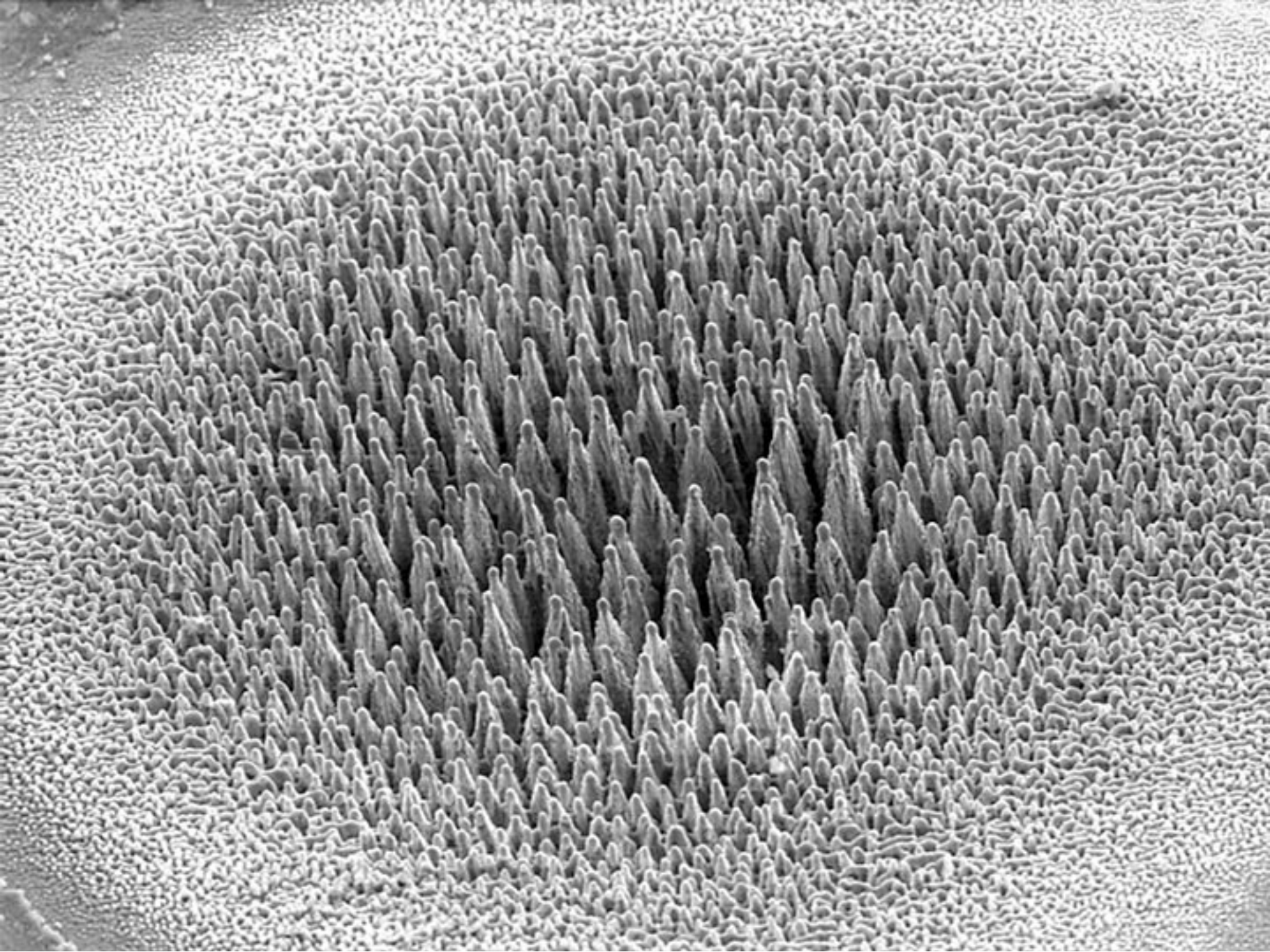


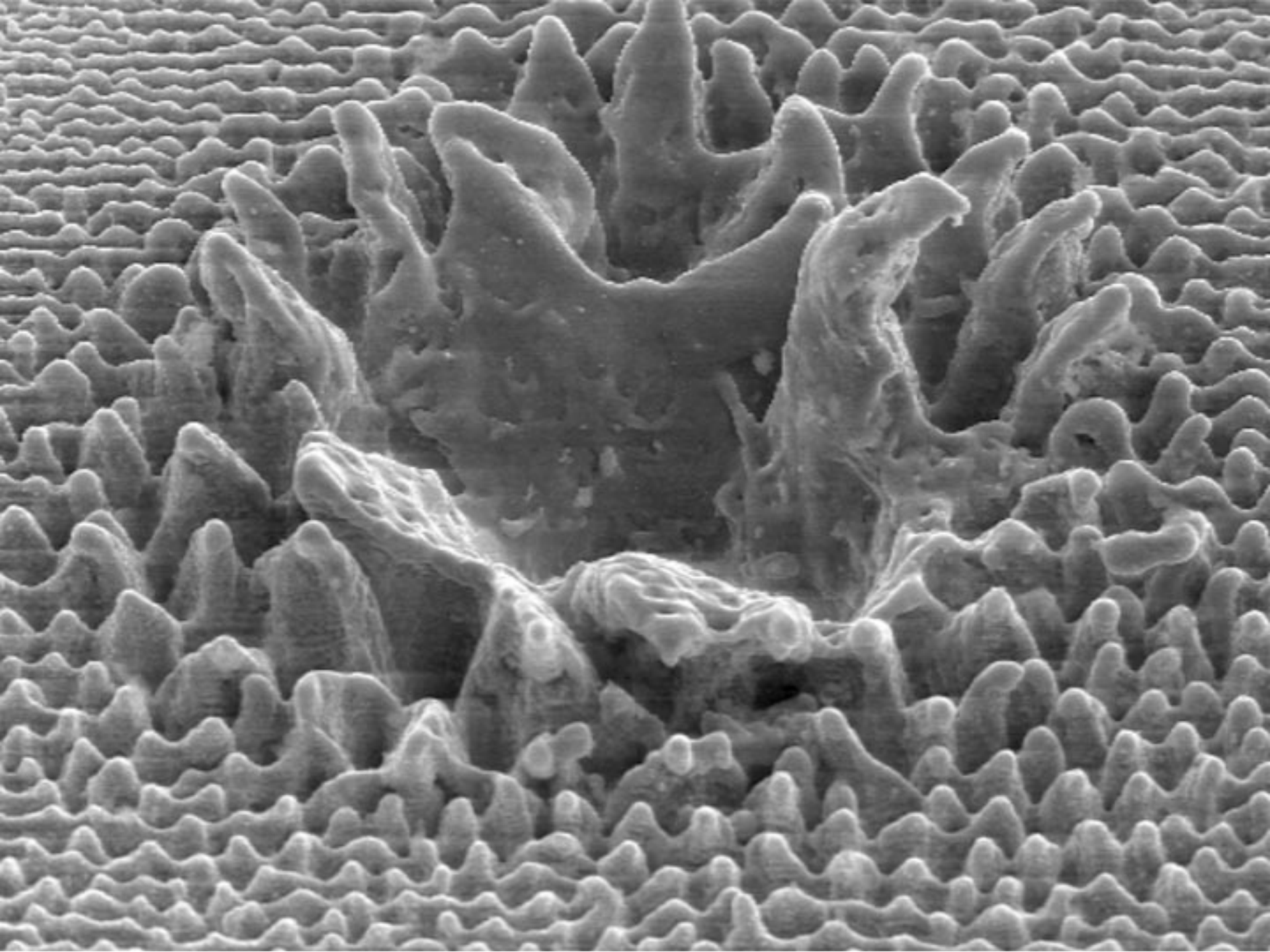
CHROMAT  
40 Oil DC  
0.17



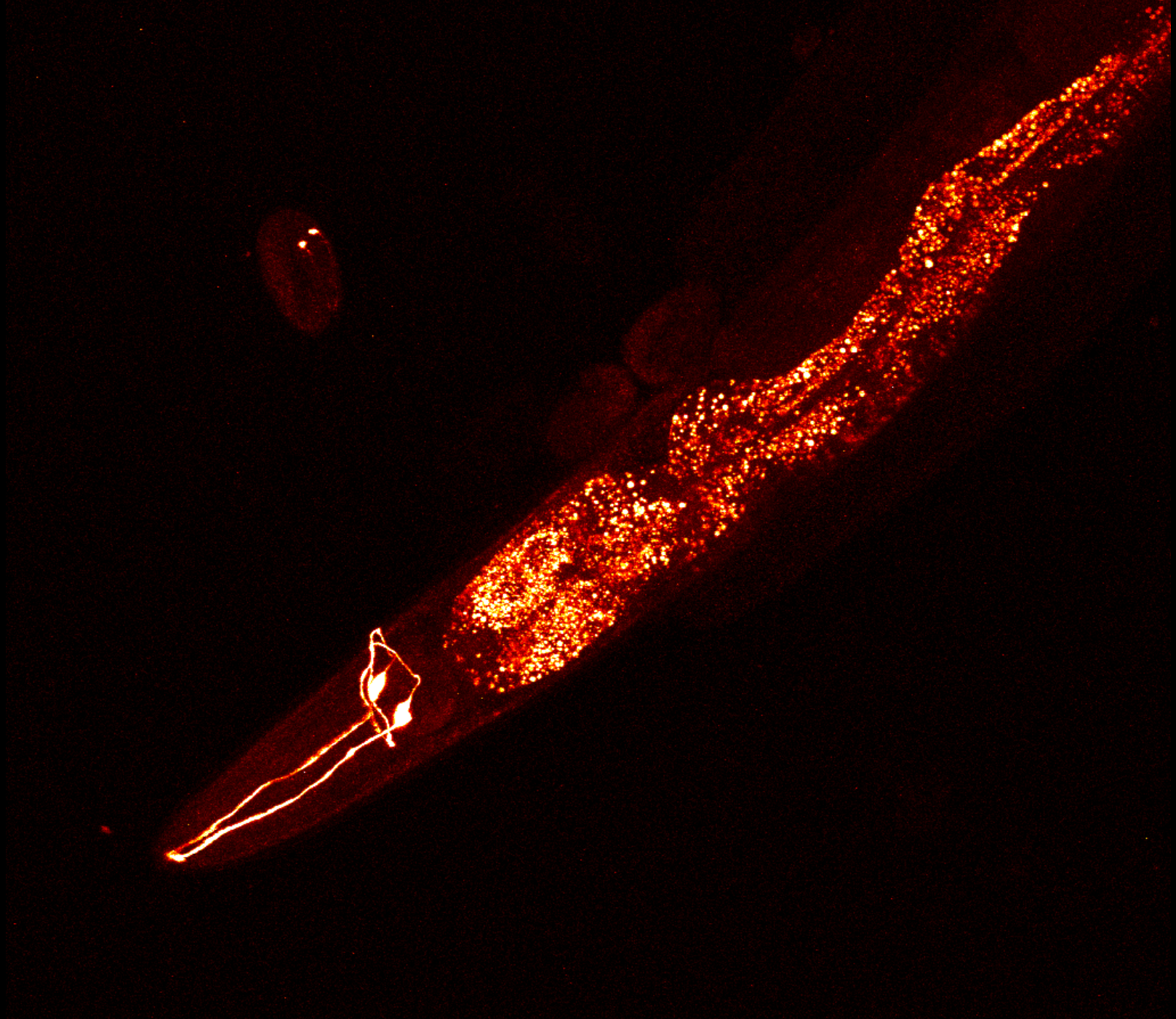




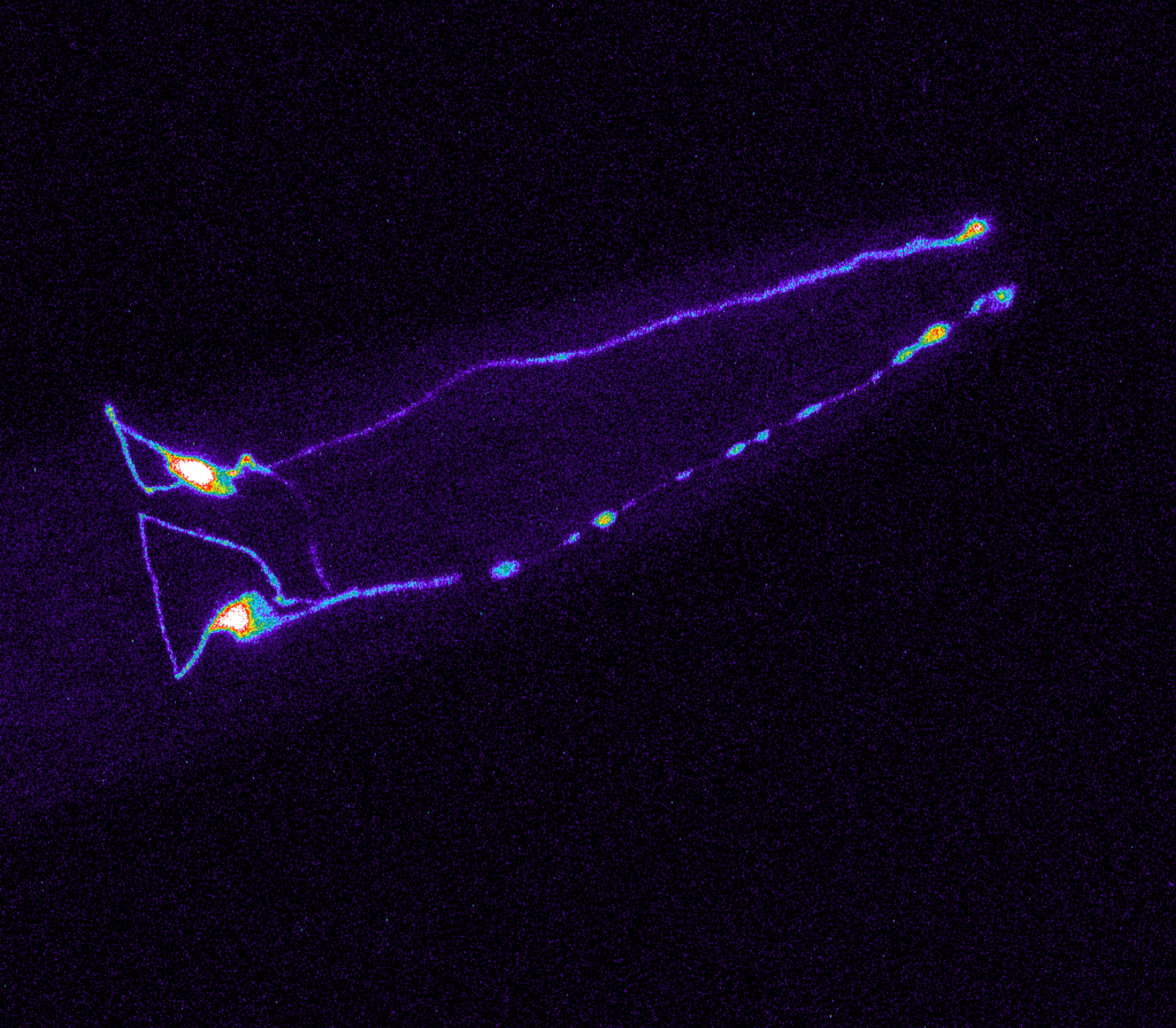


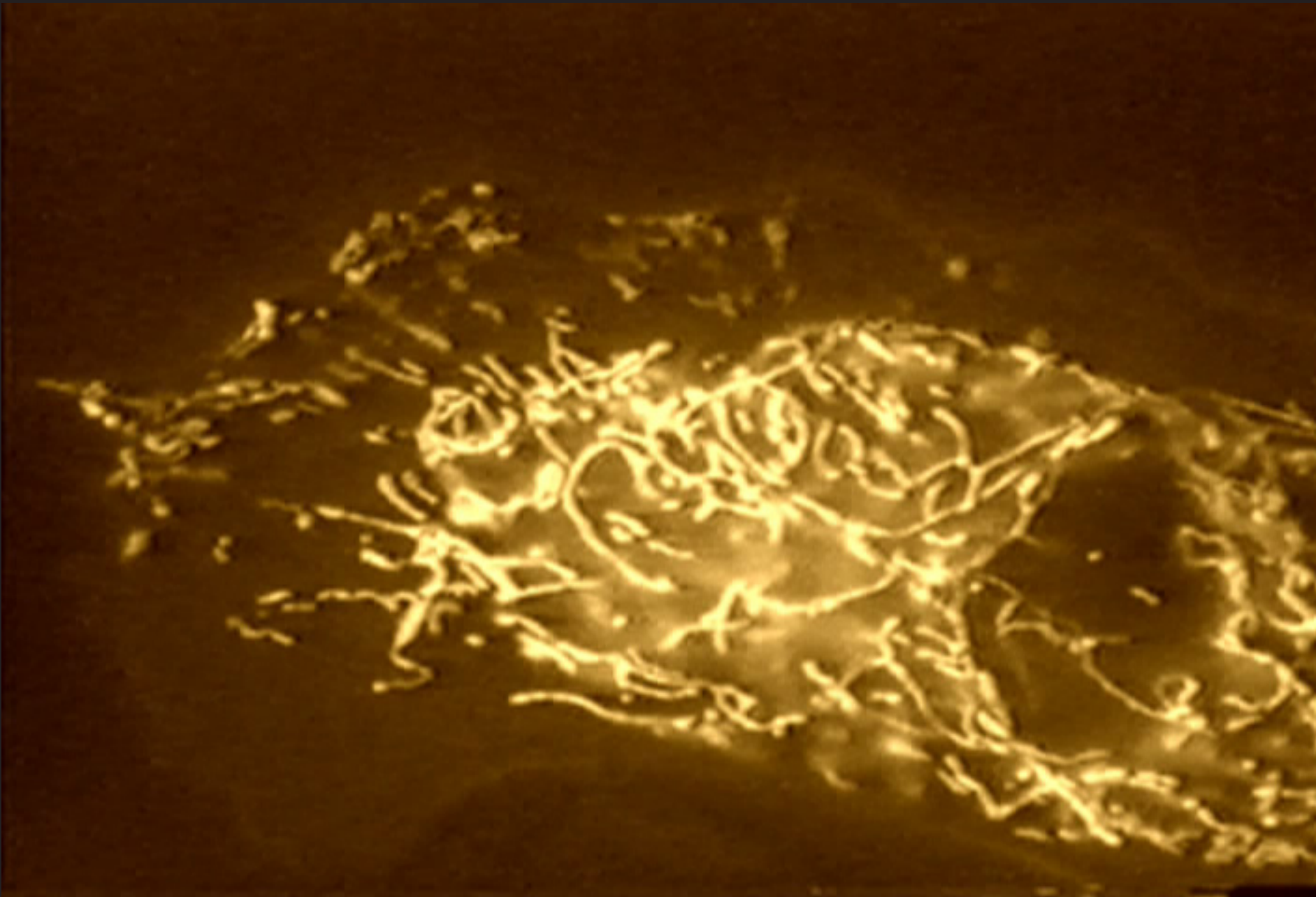


# Nanoneurosurgery



# Nanoneurosurgery





**Oh, Time, suspend your flight!  
and you, auspicious hours,  
suspend your course!  
Let us savor the fleeting joy  
of our most beautiful days!**

***Alphonse de Lamartine (1817)***

**Plenty of unhappy ones down here**

**beg you; fly by for them!**

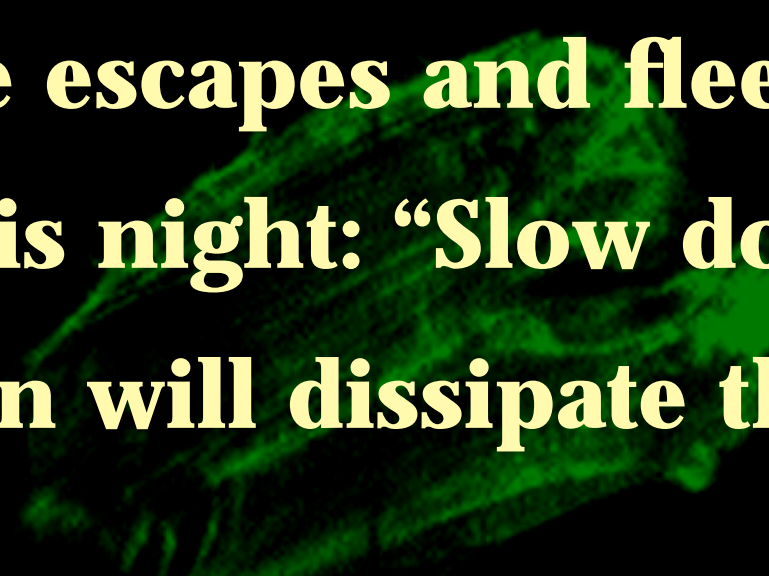
**Along with their days**

**take the worries that consume them;**

**Forget the happy ones!**

***Alphonse de Lamartine (1817)***

**In vain I ask for a few more moments,  
But time escapes and flees;  
I say to this night: “Slow down,”  
but dawn will dissipate the night.**



***Alphonse de Lamartine (1817)***

# Special Thanks to:

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Yakir Siegal

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Eli Glezer

Walter Mieher

Juen Kai Wang



**For additional information  
and a copy of this talk:**

**<http://ericmazur.com>**

# Celebrating the International Year of Light



INTERNATIONAL  
YEAR OF LIGHT  
2015

# Outreach Activities

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## Global Celebration

### 2015 Education Poster Series

# Global Celebration

# celebration



## THE POWER OF LIGHT

### A Bright Future

Light. It is all around us. It is a natural and powerful resource. Light is the brightness of the sun and the heat that comes from it. Imagine, just for a second, a universe without light. The world would certainly be a cold, dark and lifeless place. But

**Celebrating light**  
For thousands of years humans have tried to understand light and harness its amazing power. From the first use of fire a million years ago to the development of light-based technology today, humans have come a long way in our quest...don't you think?

Light touches our lives more now than at any other time in history. And do you know what? We celebrate light every day without even knowing it when we interact with nature and technology!

**Science and Light**  
Consider science, smart phones, high-power research lasers and optical fibers are just a few examples of the lasers and optical fibers are just a few examples of the many technologies powered by light. What makes many technologies powered by light. What makes light so special? Well, light is really good at carrying information and energy so it can be used as a communication wire.

Scientists use light to gather information about the universe with telescopes. Modern telescopes not only allow us to see distant stars and galaxies, but also can detect visible light from planets and stars, but also can detect light that is invisible to the human eye. This research is helping to unlock the mysteries of the universe.

Light helps scientists study how atoms are put together. Atoms are the smallest pieces of matter that make up everything in the universe. Even humans! The light an

atom emits is as small as a fingerprint. Measuring on earth and in space can be analyzed based on how they interact with light. Awesome!

Because light is so good at delivering energy humans can use the sun to make electricity. This is called solar energy. Sunlight is absorbed on special materials which causes electrons to move around and create an electrical current that can be used to heat or cool buildings. Oh, and solar power can operate things like cell phones, calculators, smart lights and just about anything imaginable!

**Lasers** are another cool tool that harness the power of light. Lasers can deliver incredible amounts of energy to a very precise location. Small lasers solder electronic components together. Lasers are also used to perform surgery, read bar codes, play DVDs, and to carry telephone and television signals over thousands of miles.

**We are living in the century of light**  
Many scientists consider the 21st century to be the century of light. People working with light energy in the 21st century will have discovered many things about light that we haven't even discovered yet. Light can carry information so fast that it can travel faster than the speed of light. If you like traveling, you can travel faster than the speed of light. Light can carry information so fast that it can travel faster than the speed of light. If you like traveling, you can travel faster than the speed of light.

Explore the science of optics. Ask your teacher about light or visit [www.optics4kids.org](http://www.optics4kids.org) today!

make waves • discover science  
explore the science of light and open your eyes to a whole new world

OSA  
The Optical Society

Optical Society of America  
Optics for Kids

# Global Celebration

celebration

THE POWER OF LIGHT

## A Bright Future

everything in the universe. (Even humans!) This is

light at

or visit [www.elsevier.com](http://www.elsevier.com)

OSA  
The Optical Society



OSA  
The Optical Society



## A New Look

cause food poisoning, actually swim around with rotating tails. Whoa!

Explore your unseen world.  
Ask your teacher about microscopes  
or visit [www.optics4kids.org](http://www.optics4kids.org) today.

# Outreach Activities

## Global Celebration

### 2015 Education Poster Series

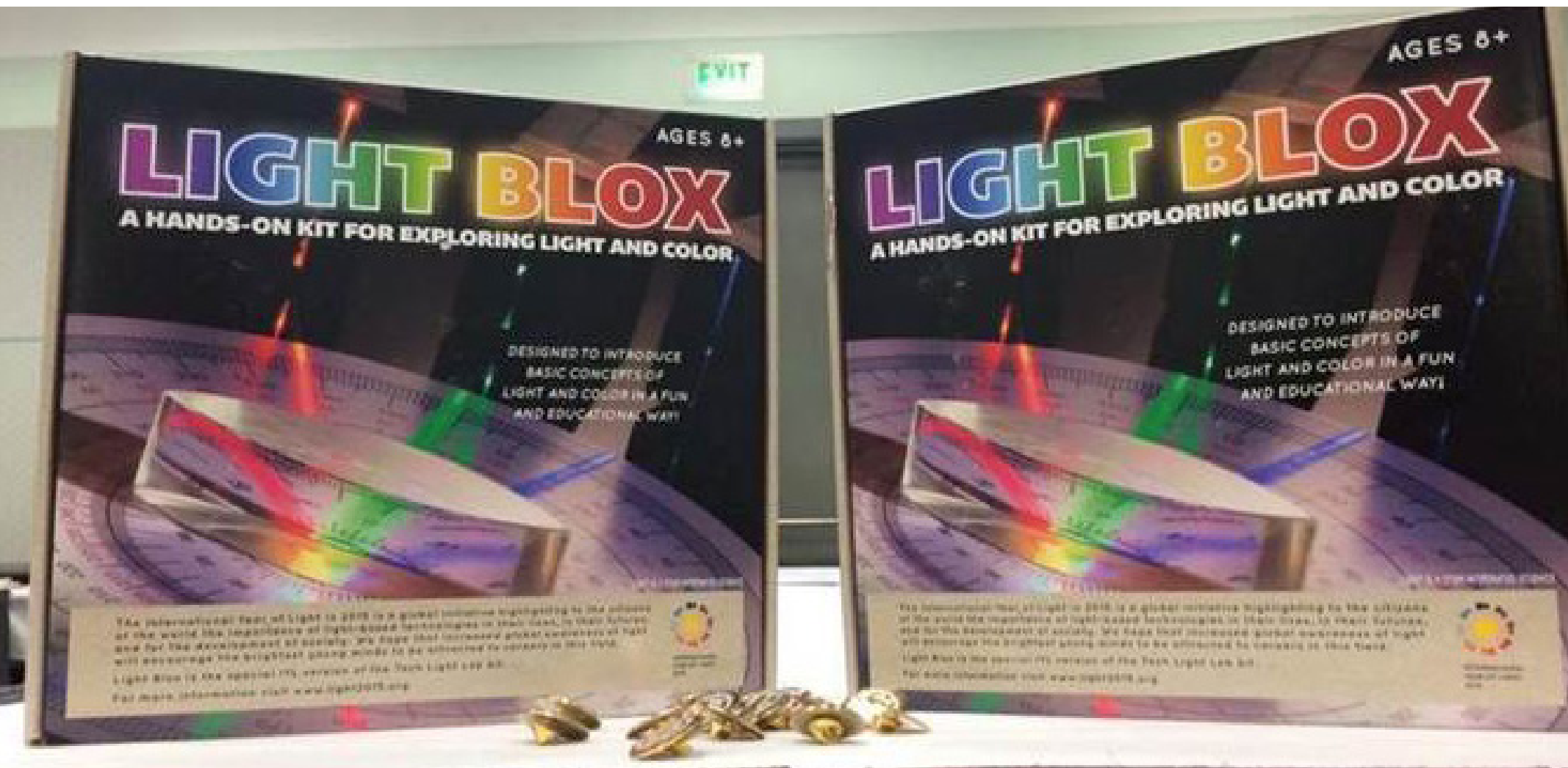
### IYL Education Outreach Grants

- \$20k in grants
- 44 OSA chapters



# Outreach Activities

## Youth Science Educator's Outreach



# Outreach Activities

## Youth Science Educator's Outreach

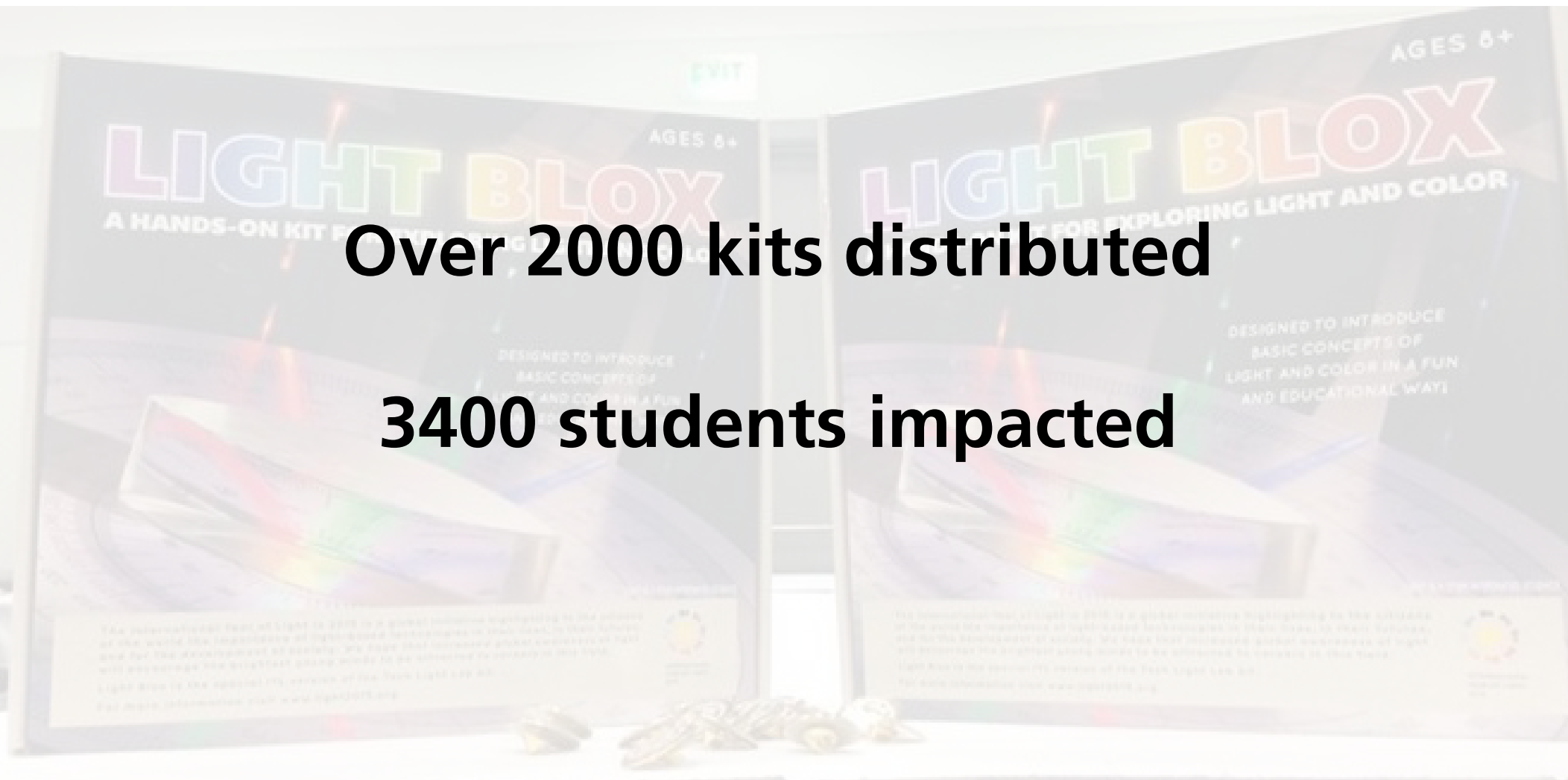


# Outreach Activities

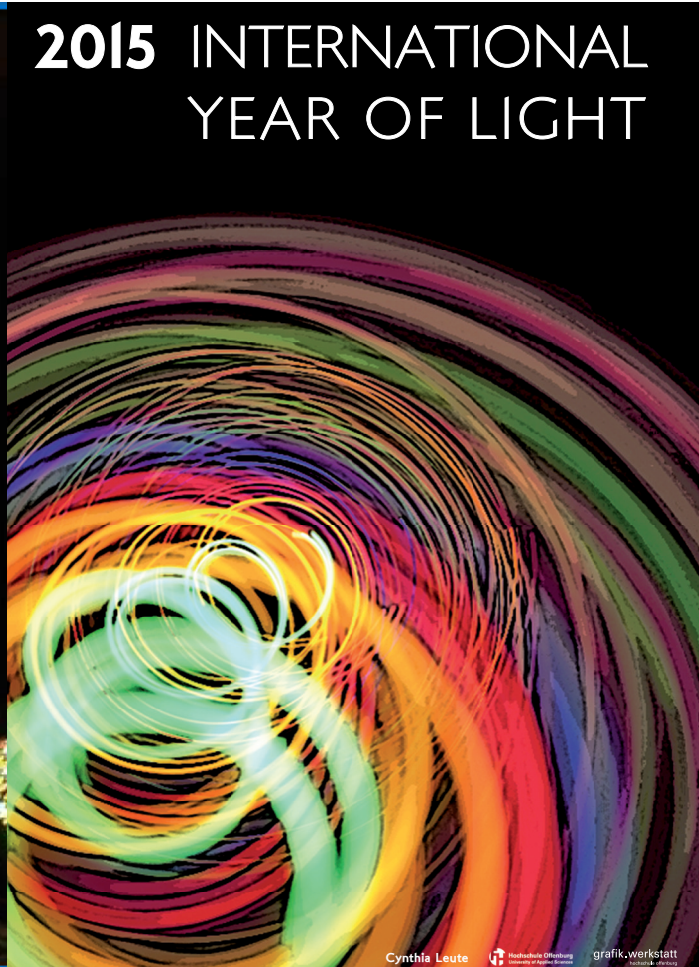
## Youth Science Educator's Outreach

**Over 2000 kits distributed**

**3400 students impacted**



# Global Celebration of Light



# Global Celebration of Light



Join the global movement  
to celebrate light

[www.osa.org/iyl](http://www.osa.org/iyl)



INTERNATIONAL  
YEAR OF LIGHT 2015