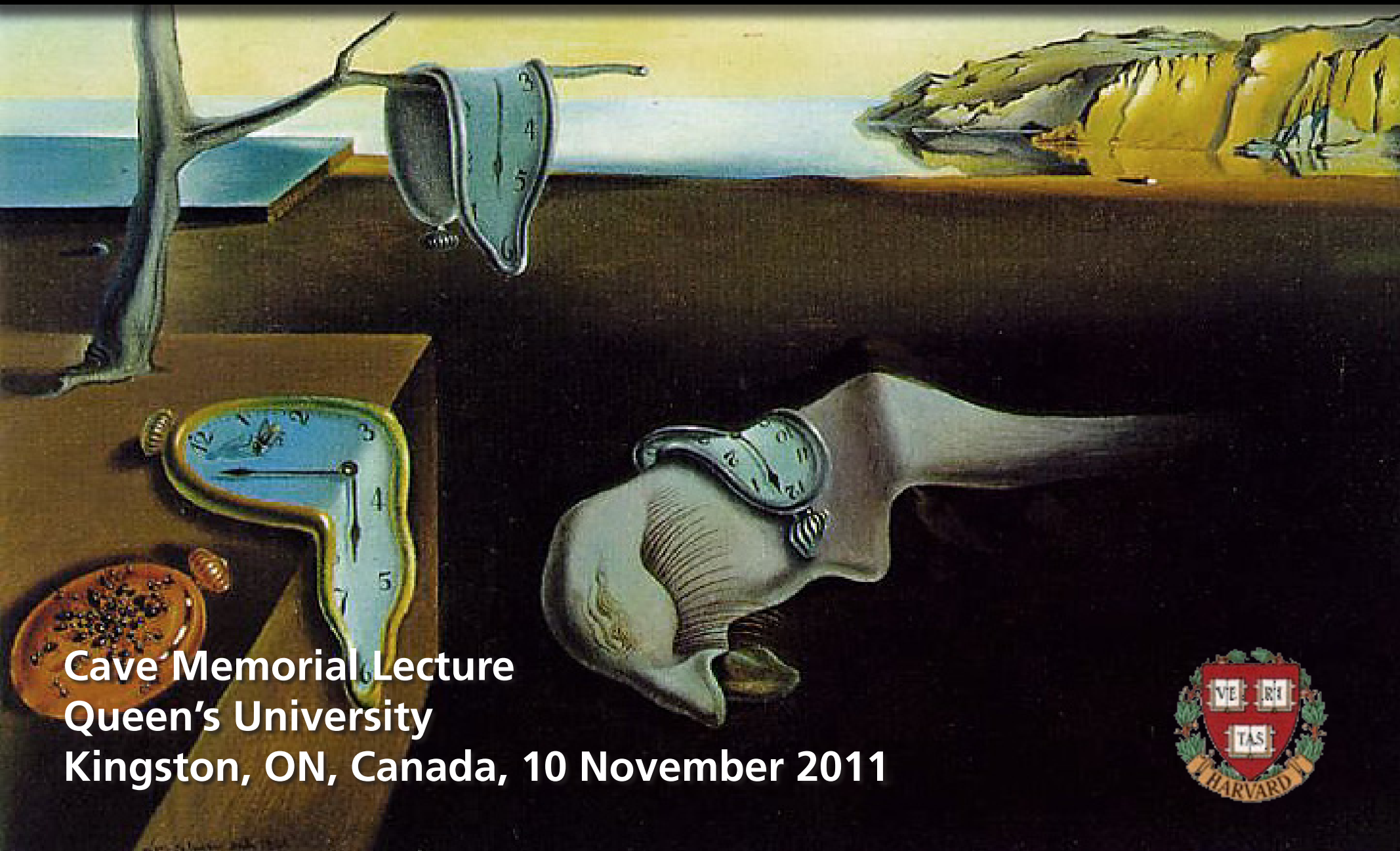


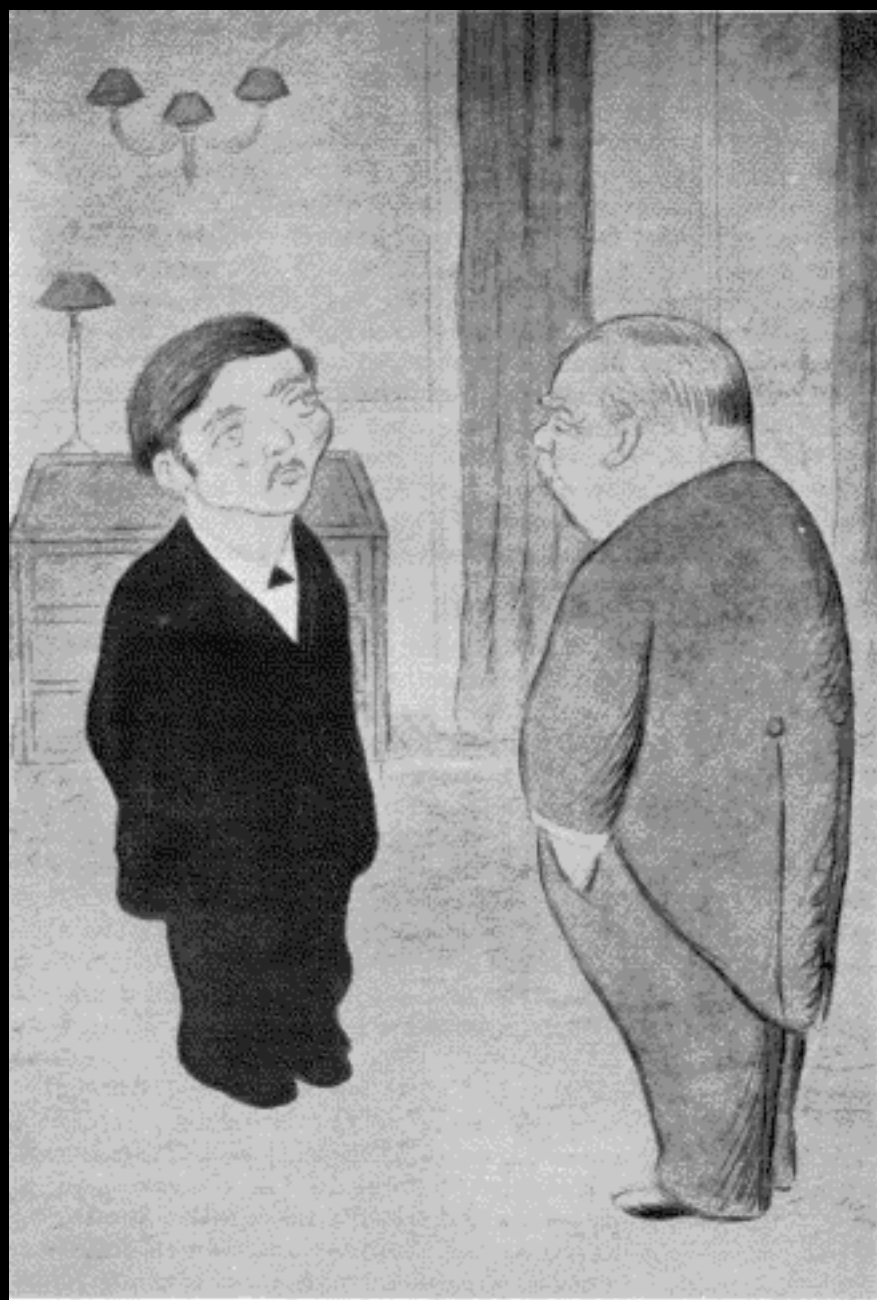
# Stopping time



Cave Memorial Lecture  
Queen's University  
Kingston, ON, Canada, 10 November 2011







*t*

► time





▶ time

▶ time

A blue sky with white clouds.

▶ time

▶ time

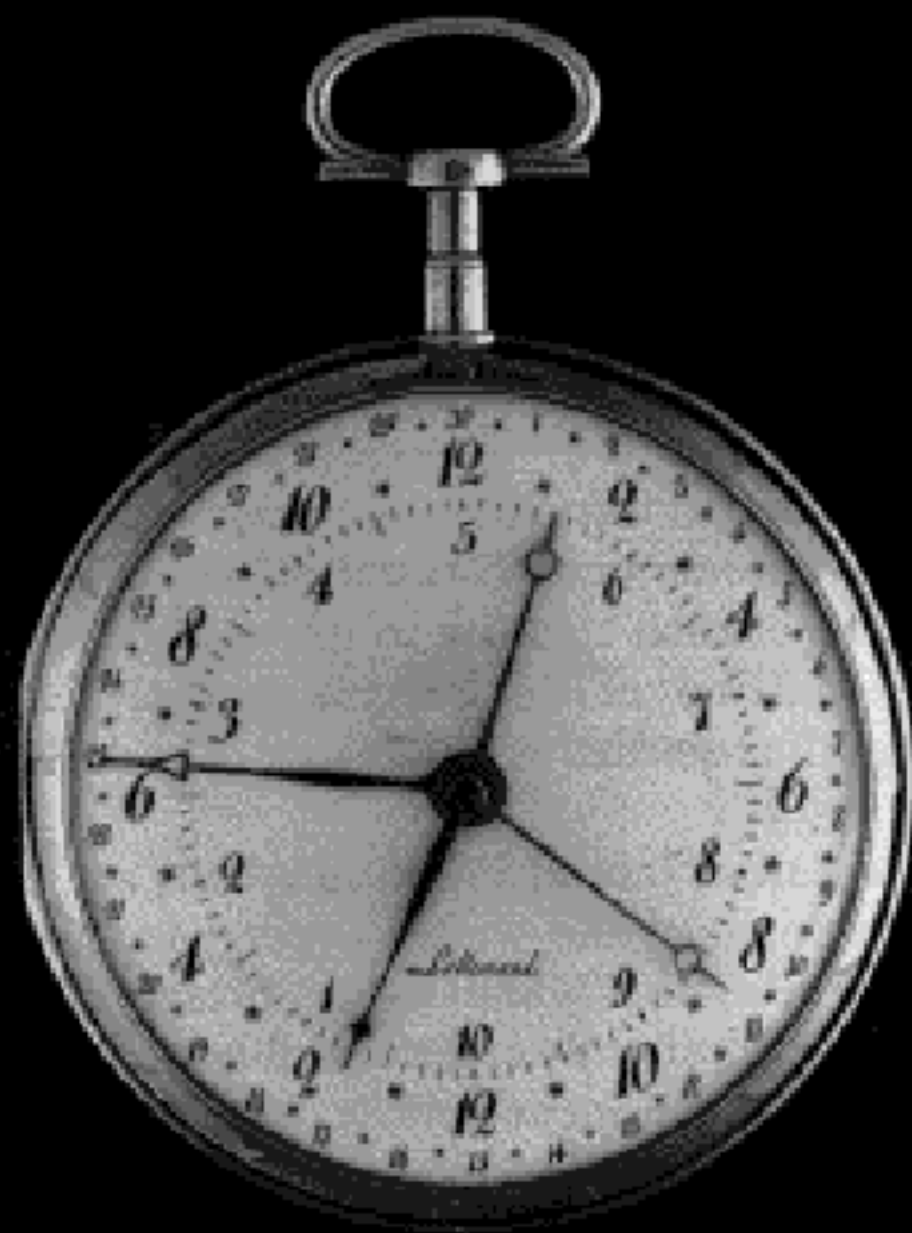
▶ time

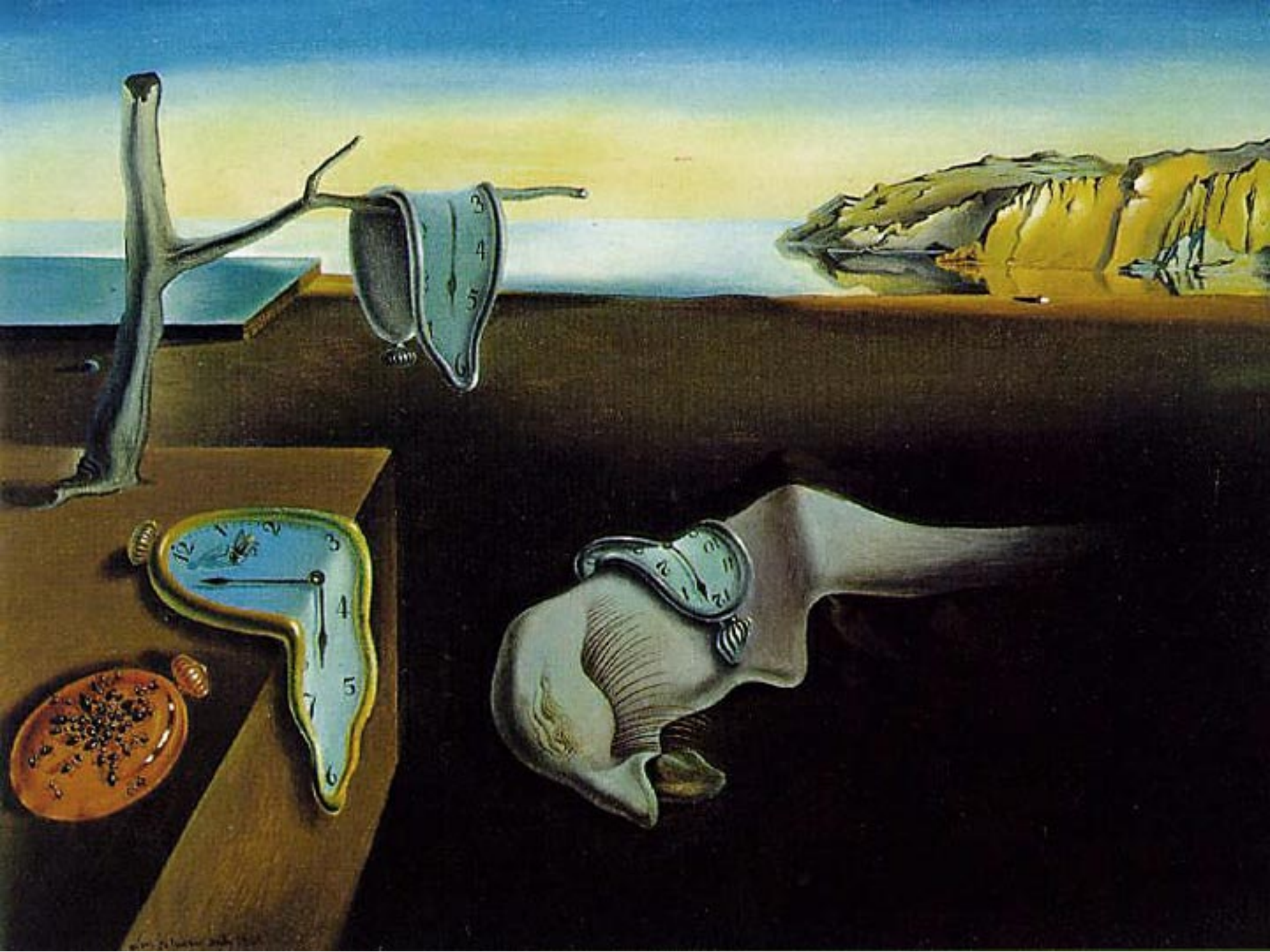
- ▶ **time: the concept**
- ▶ **time**
- ▶ **time**



- ▶ **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

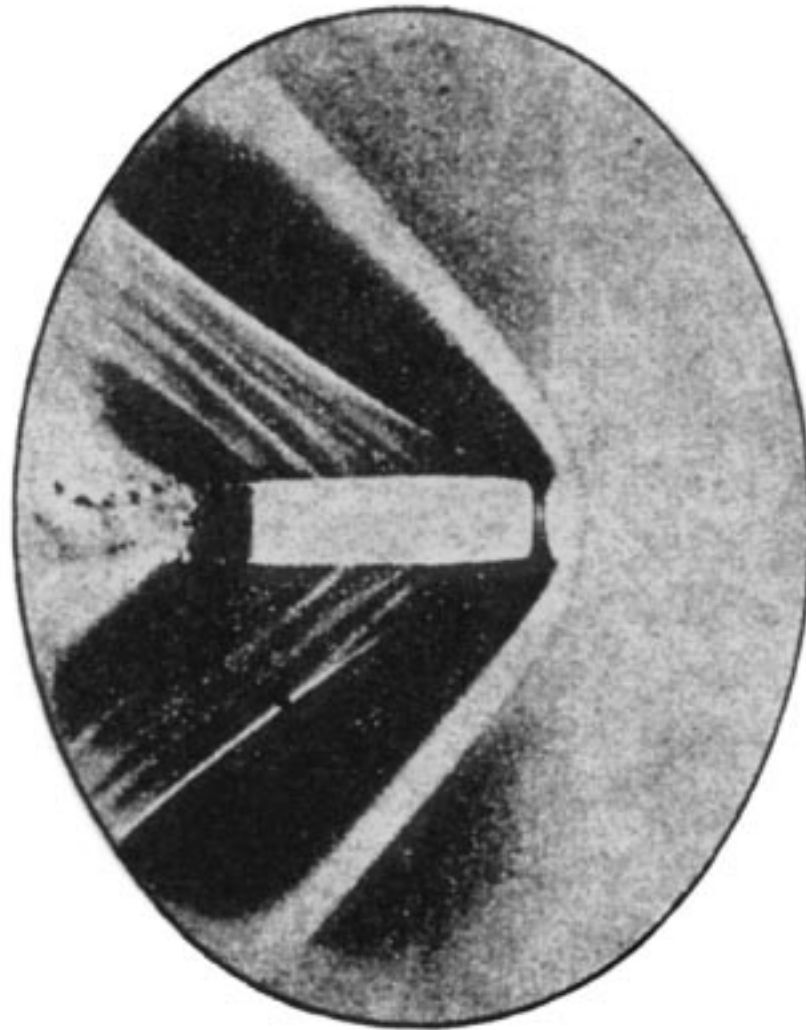
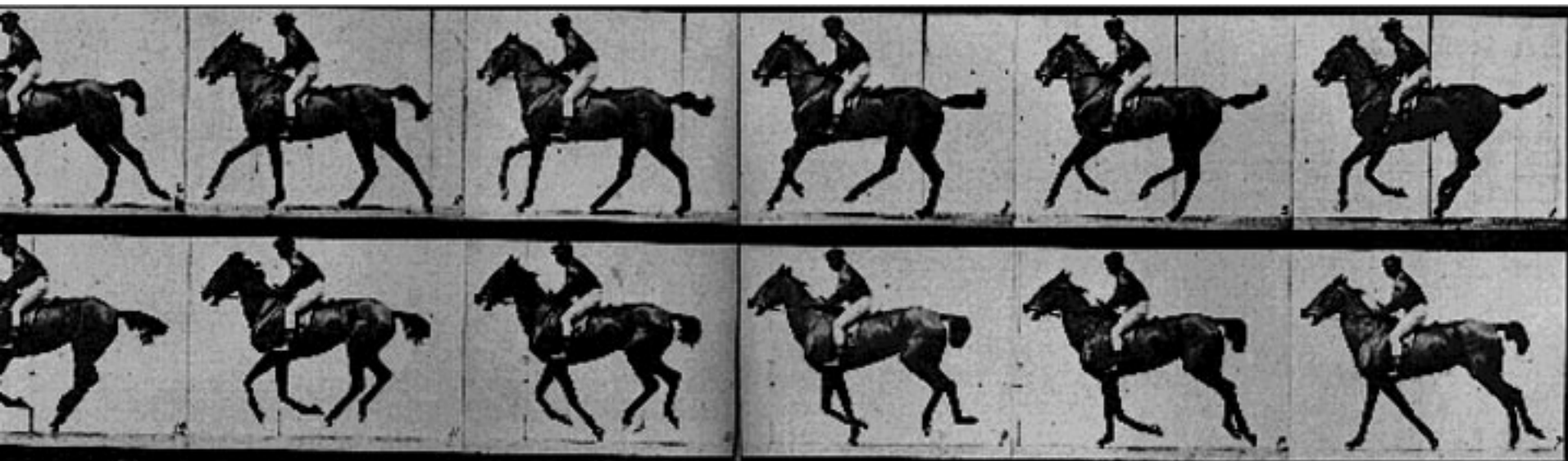
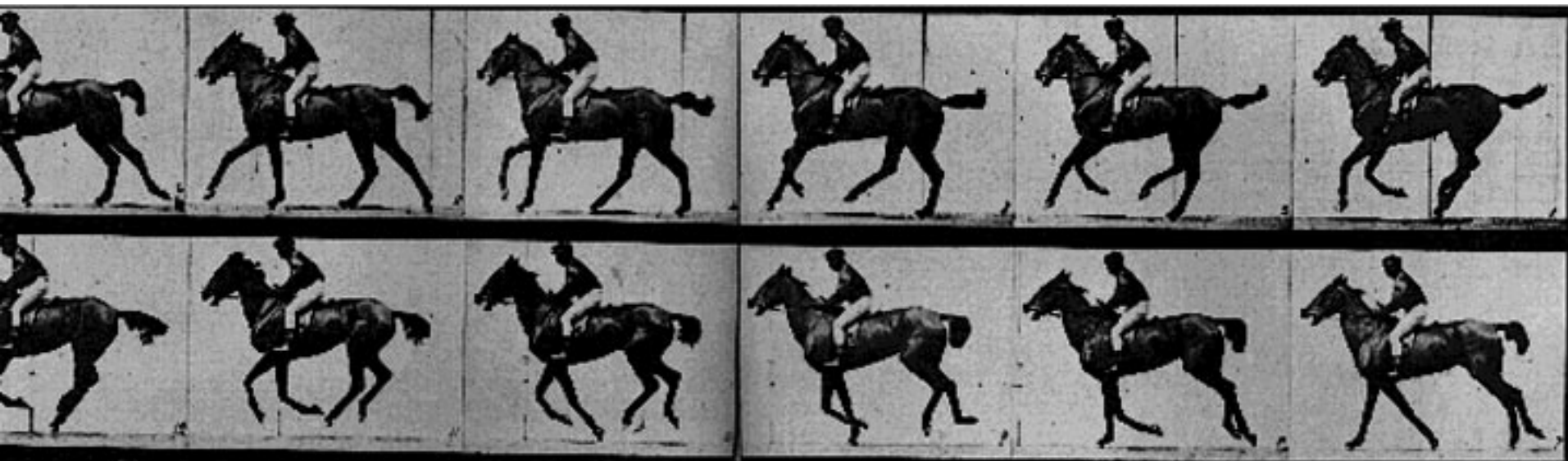


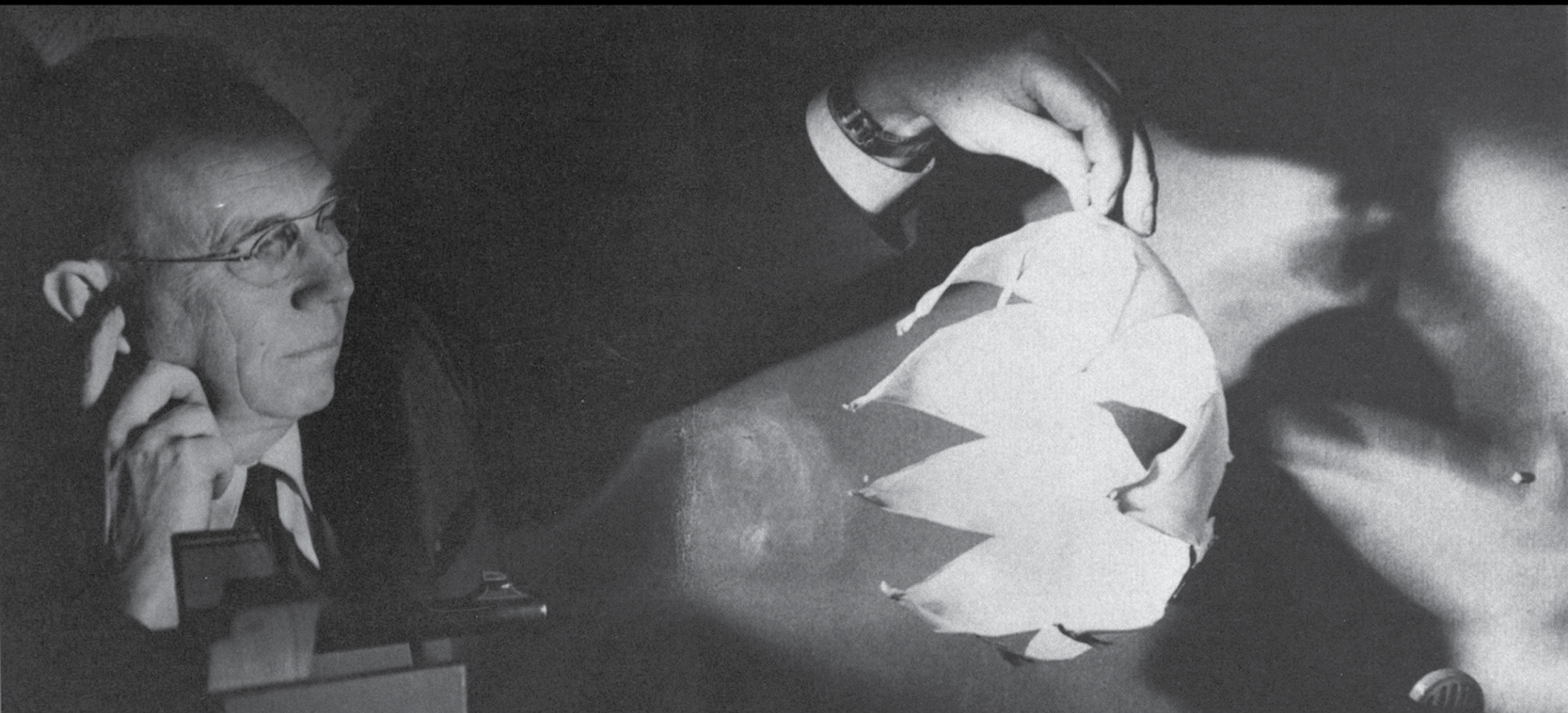
Fig. 52.

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



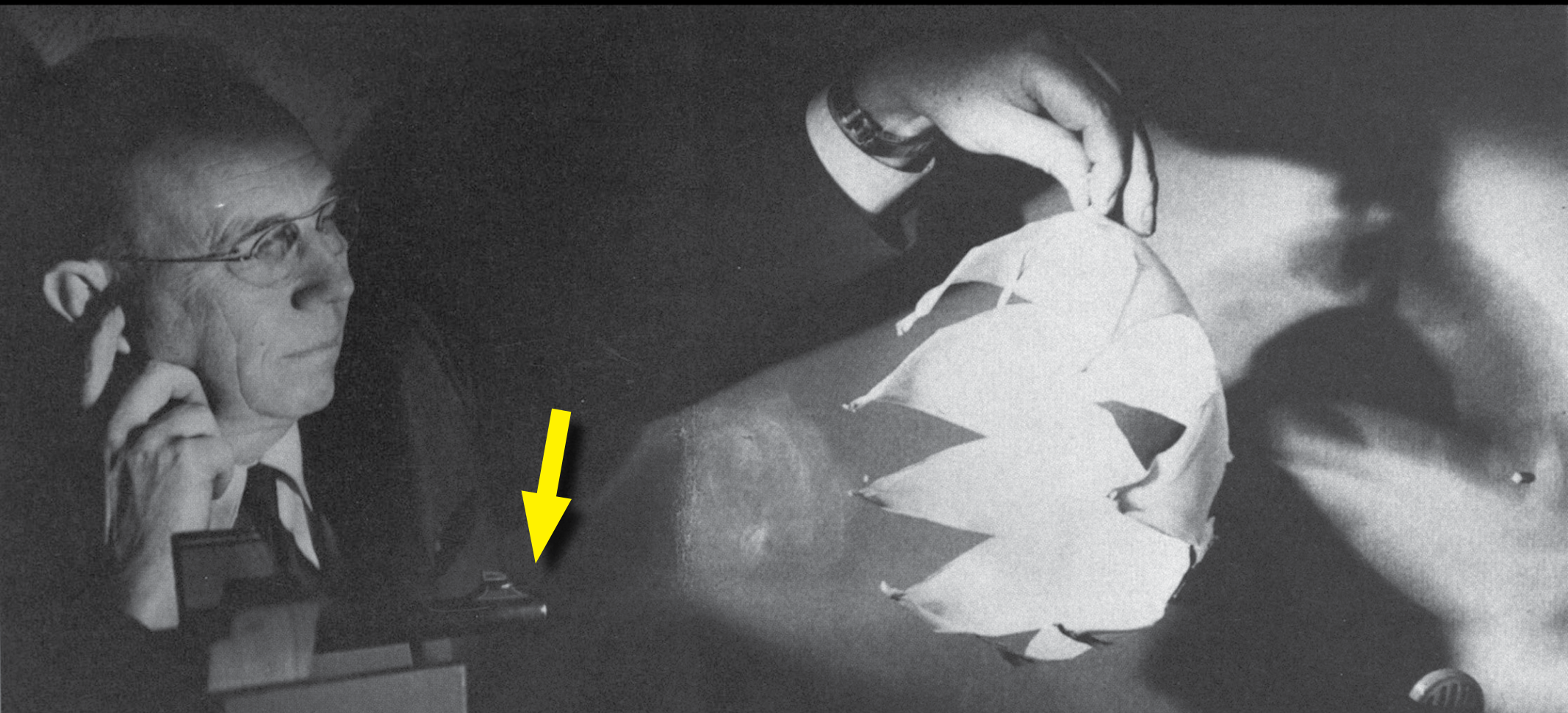






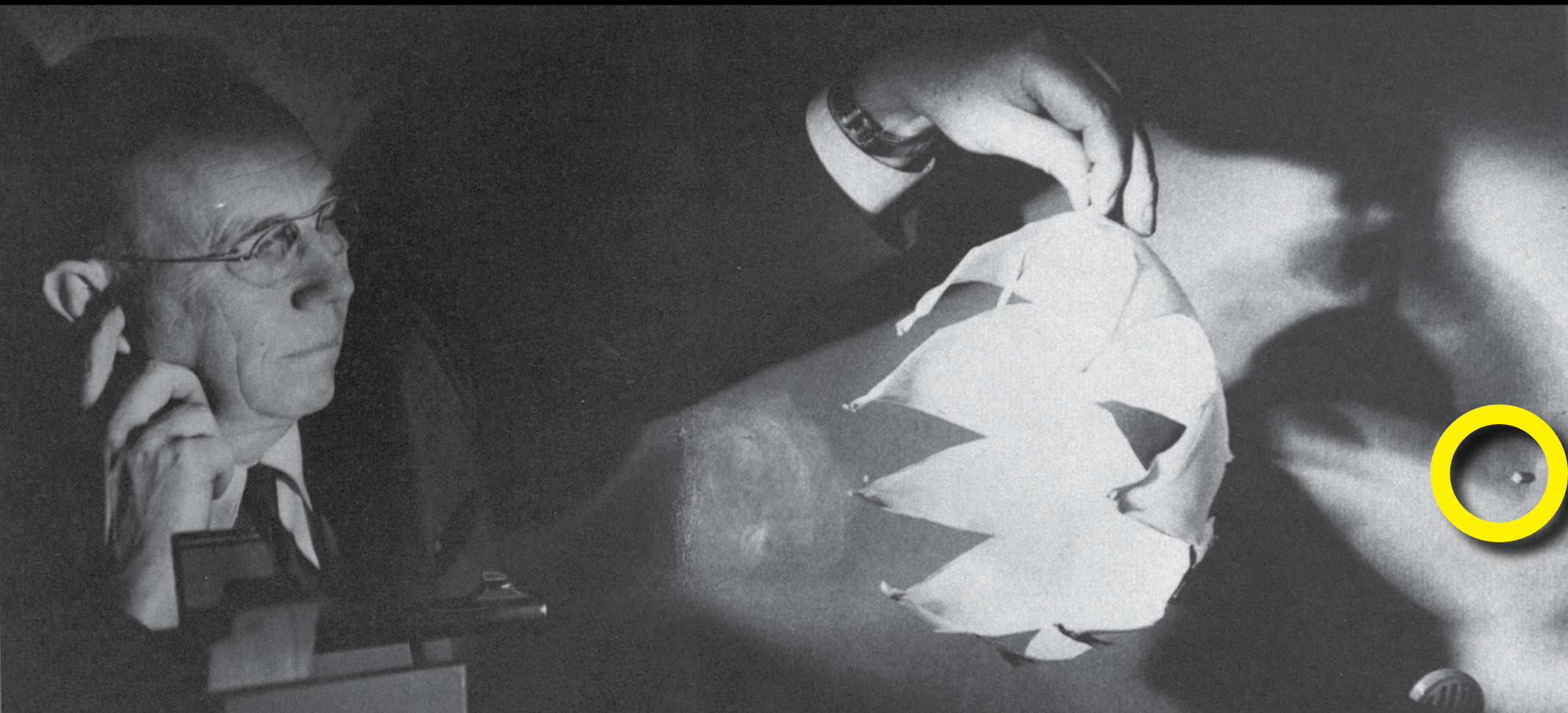
**Harold Edgerton (1903 – 1990)**



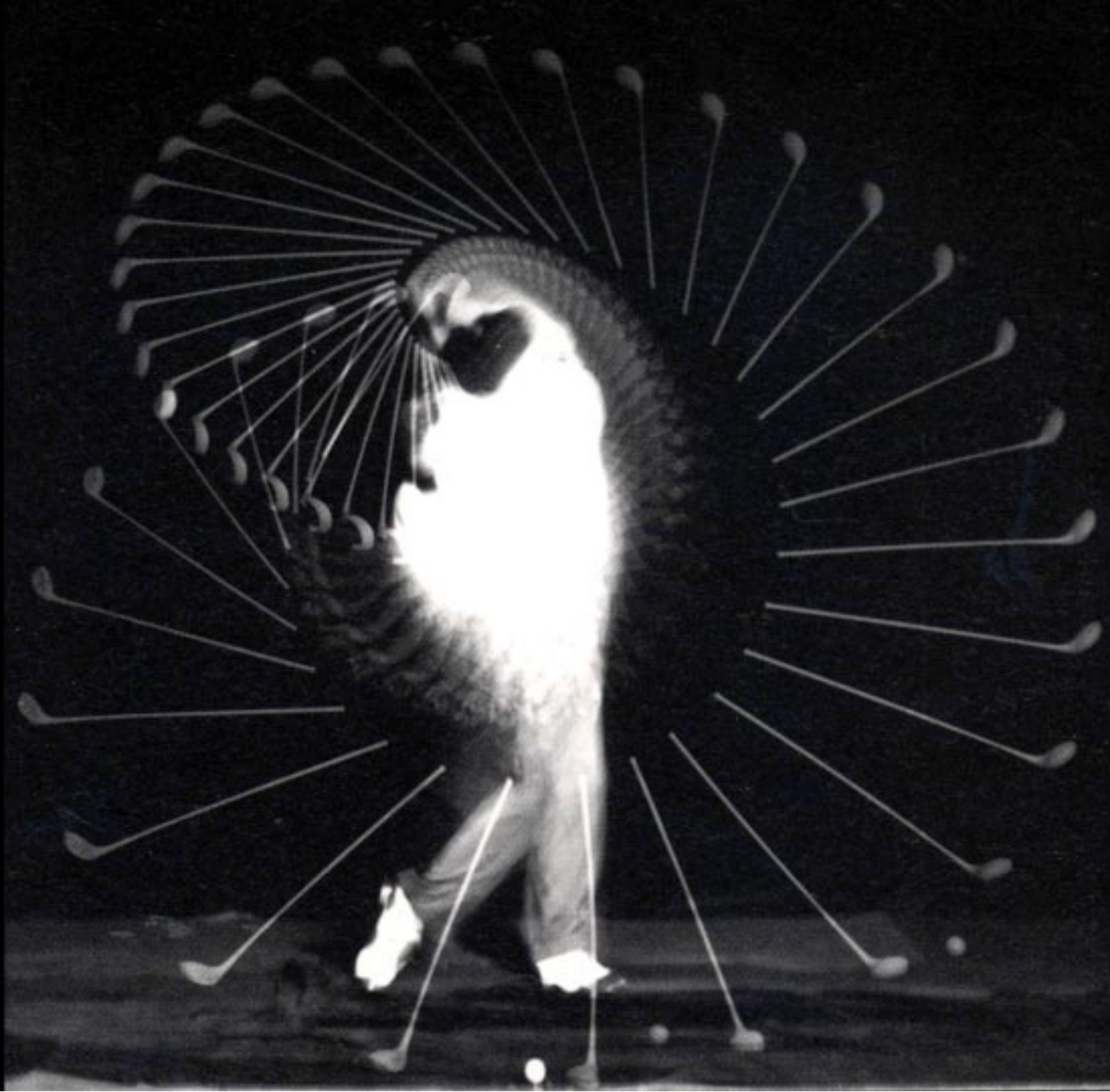


**Harold Edgerton (1903 – 1990)**





**Harold Edgerton (1903 – 1990)**







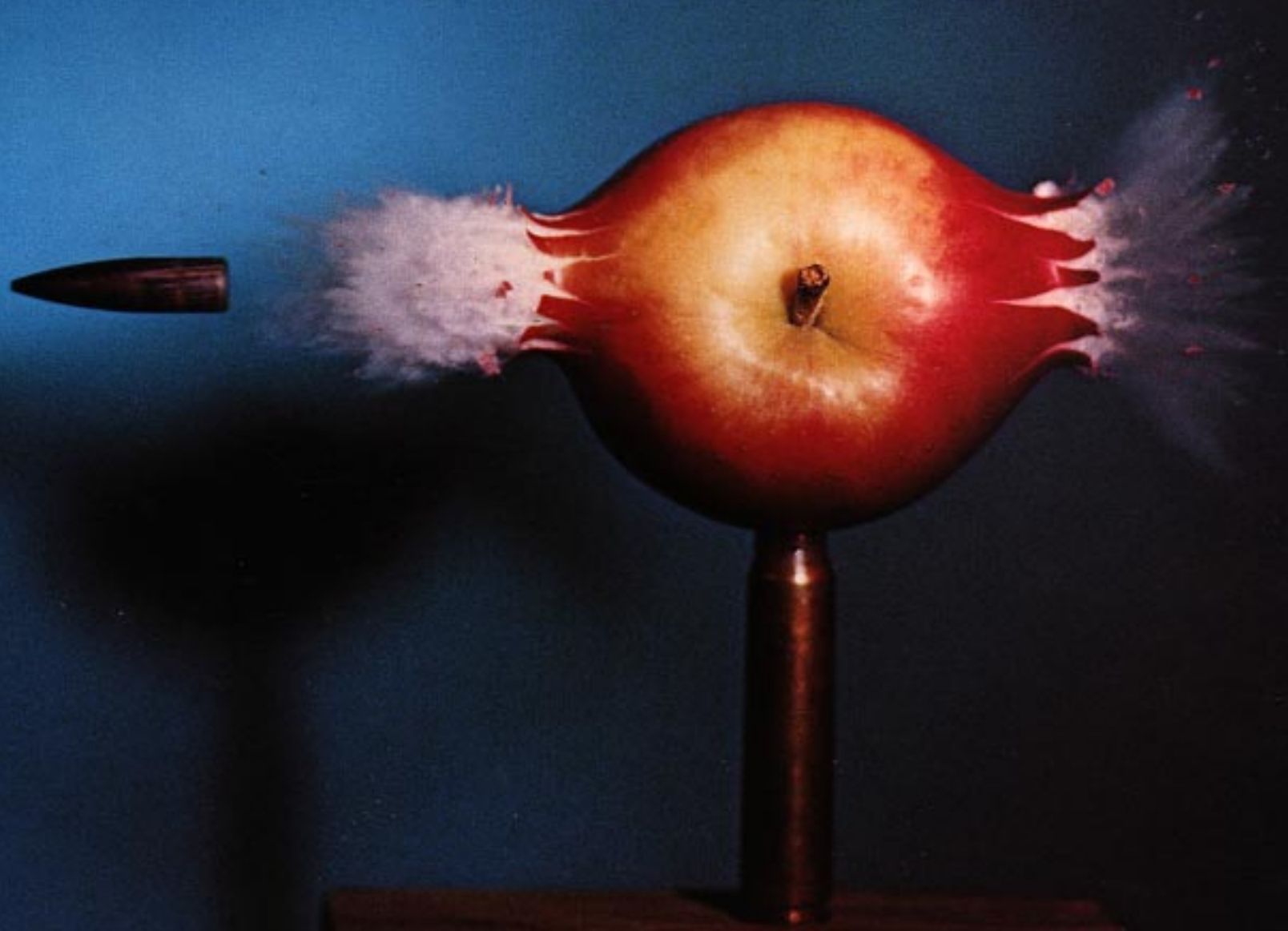




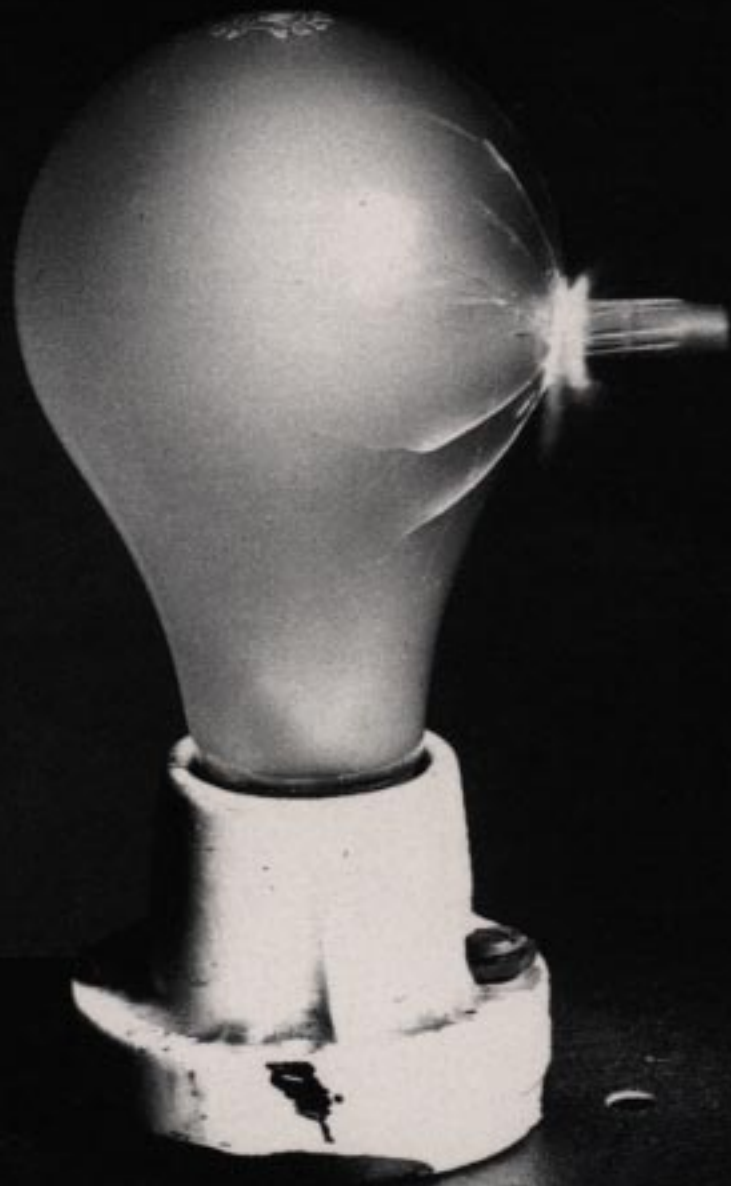






















moon

$10^0$  s



one second

moon

$10^0$  s



one second

moon

$10^0$  s



one second

moon

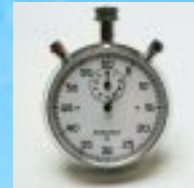
$10^0$  s



one second

moon

$10^0$  s



one second



$10^1$  s



10 seconds

$10^1$  s



10 seconds

$10^1$  s



10 seconds

$10^1$  s



10 seconds



$10^1$  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

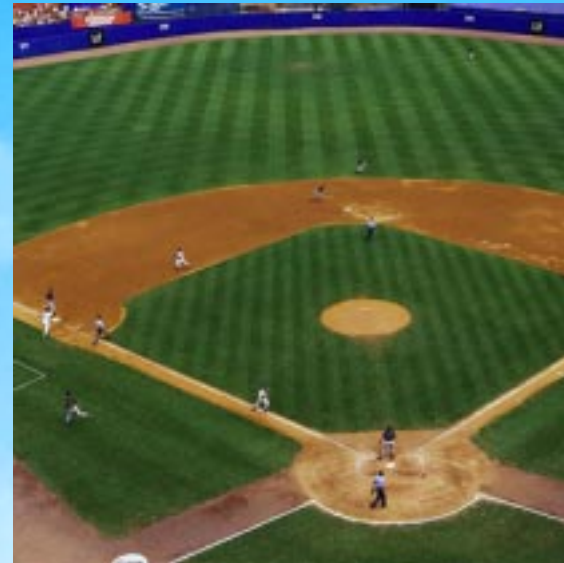
$10^4$  s



average baseball game

# Uranus

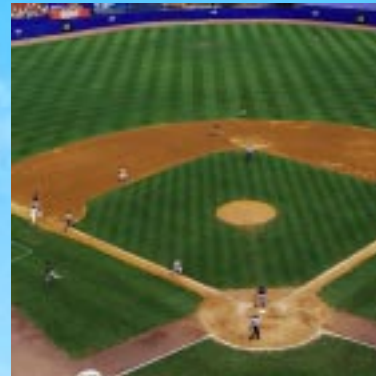
$10^4$  s



average baseball game

# Uranus

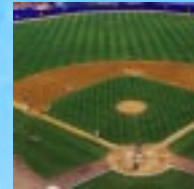
$10^4$  s



average baseball game

# Uranus

$10^4$  s



average baseball game



$10^5$  s



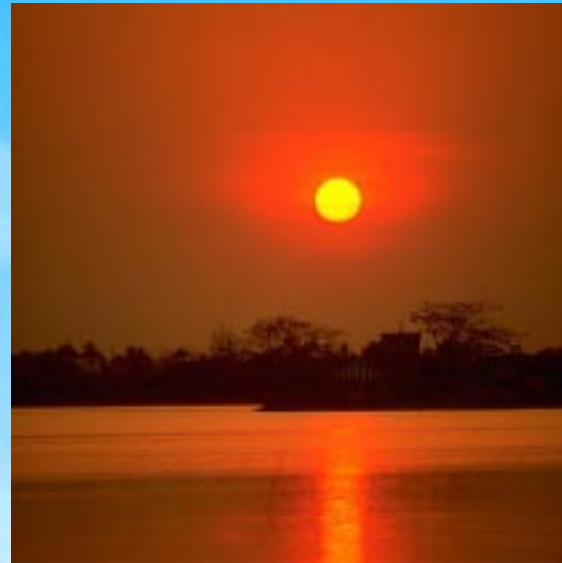
1 day

$10^5$  s



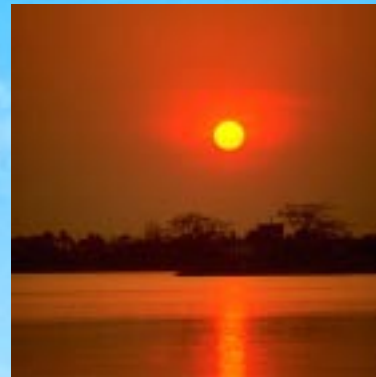
1 day

$10^5$  s



1 day

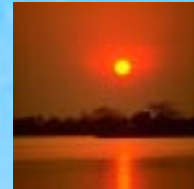
$10^5$  s



1 day



$10^5$  s



1 day

$10^6$  s



2 weeks

$10^6$  s



2 weeks

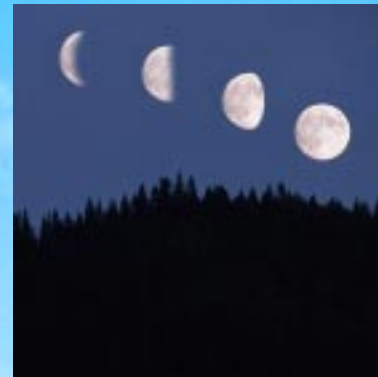
$10^6$  s



2 weeks



$10^6$  s



2 weeks

$10^6$  s



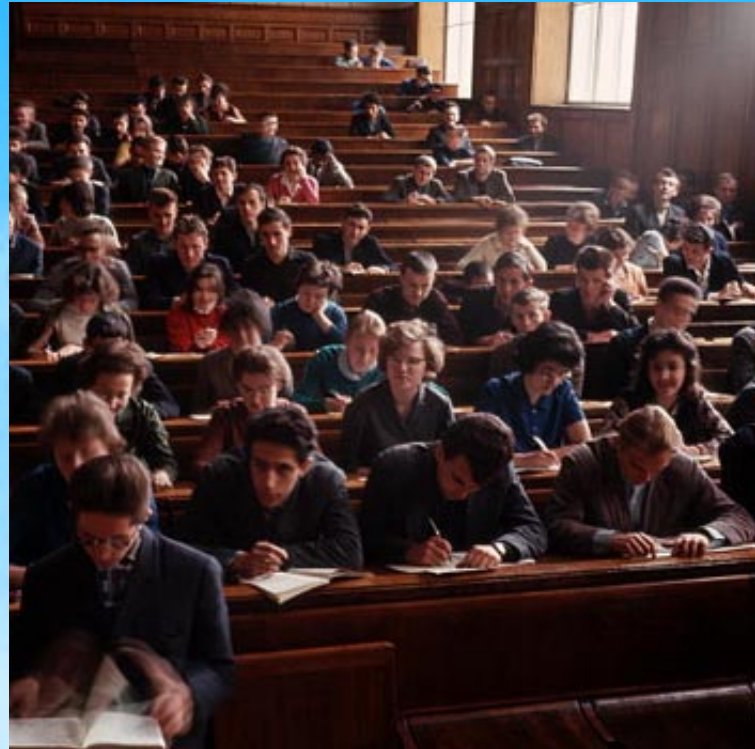
2 weeks

$10^7$  s



one semester

$10^7$  s



one semester

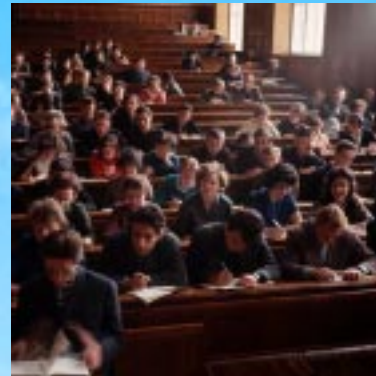


$10^7$  s



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

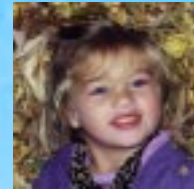
$10^8$  s



3 years

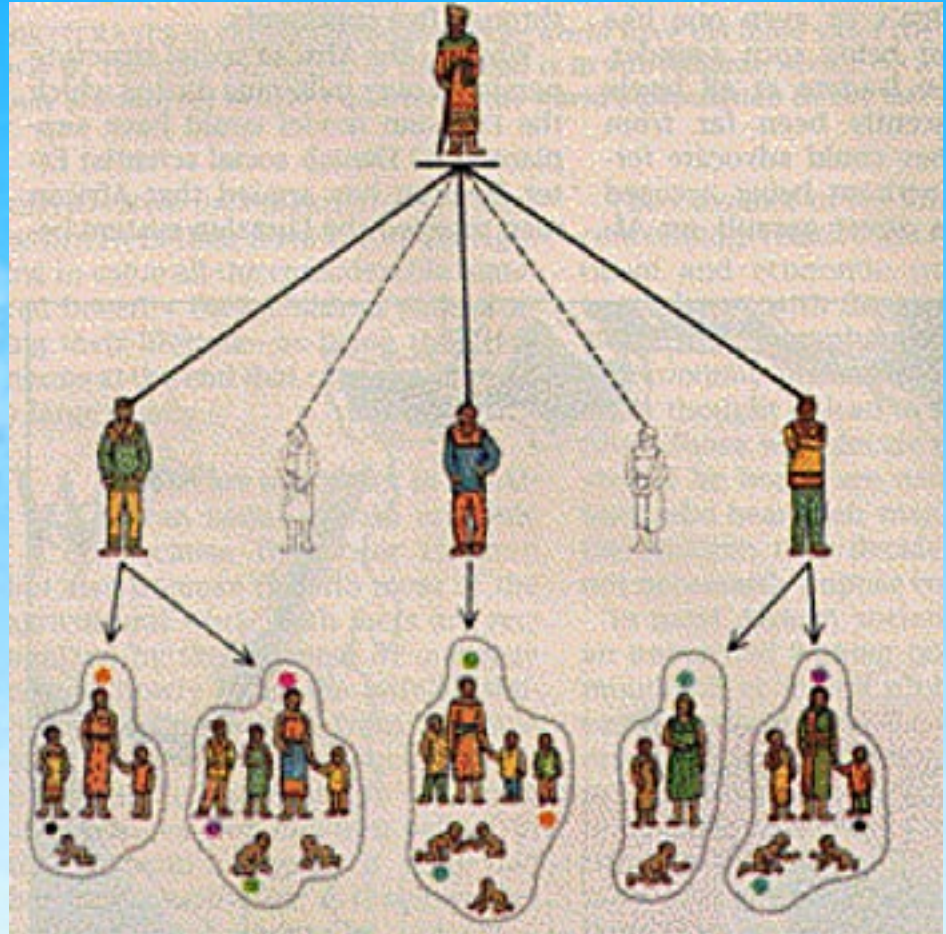
# Proxima Centauri

$10^8$  s



3 years

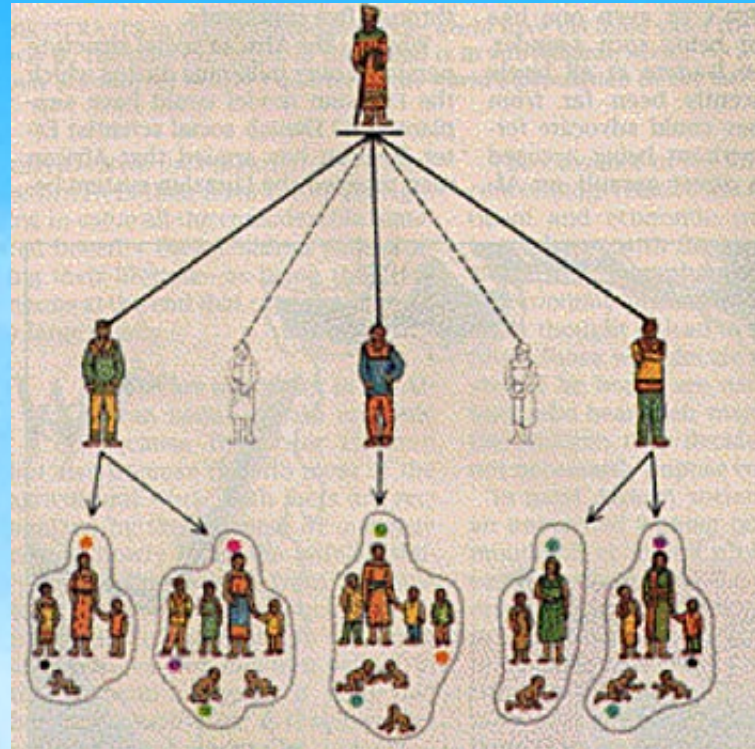
$10^9$  s



human generation



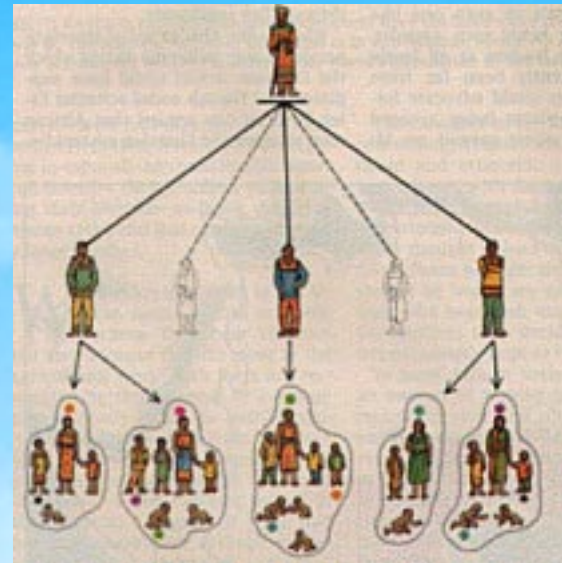
$10^9$  s



human generation

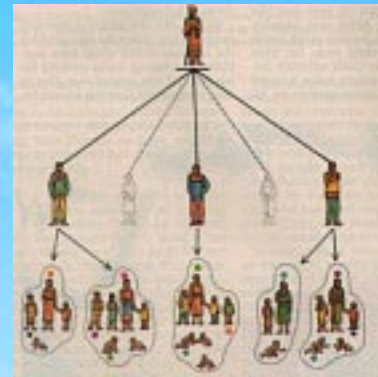


$10^9$  s



human generation

$10^9$  s



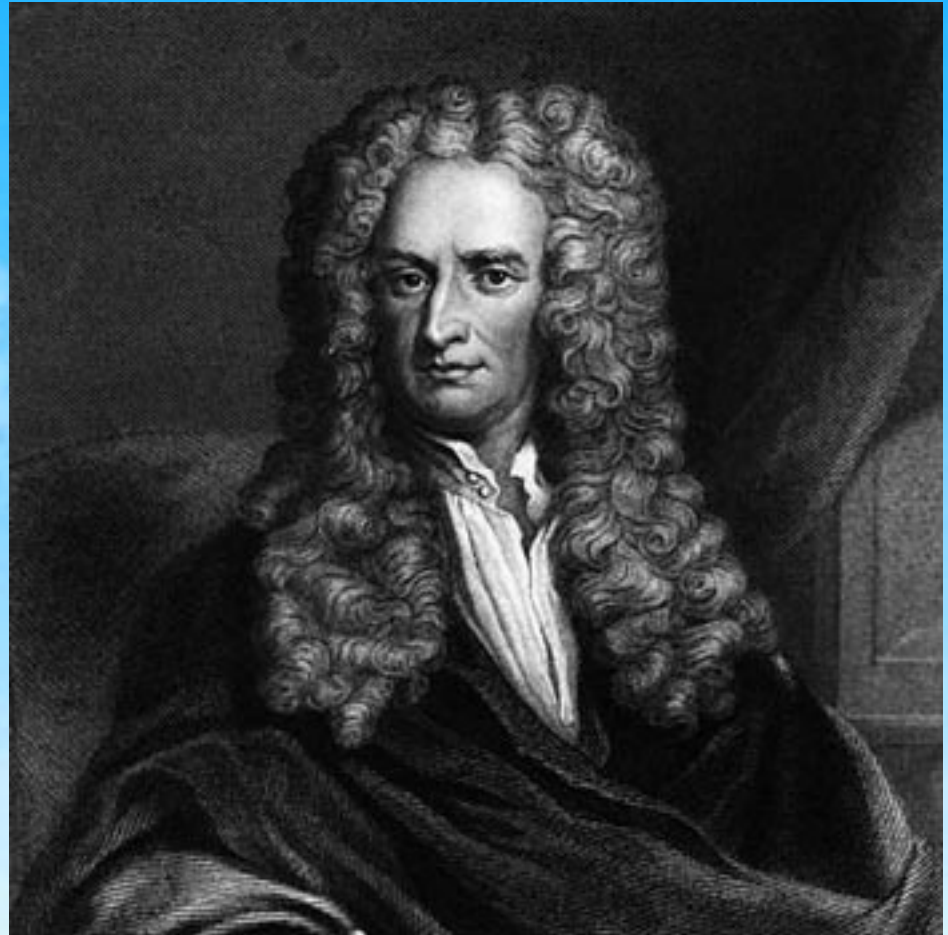
human generation

$10^9$  s



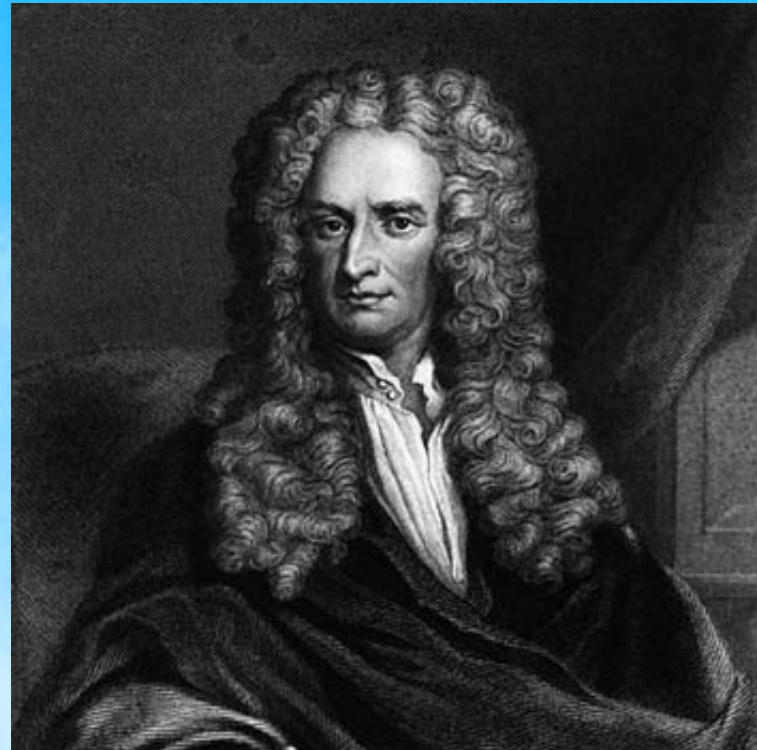
human generation

$10^{10}$  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



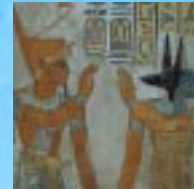
ancient civilizations

$10^{11}$  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

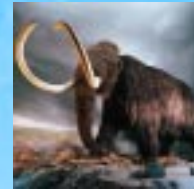
$10^{12}$  s



most recent ice age

center of galaxy

$10^{12}$  s

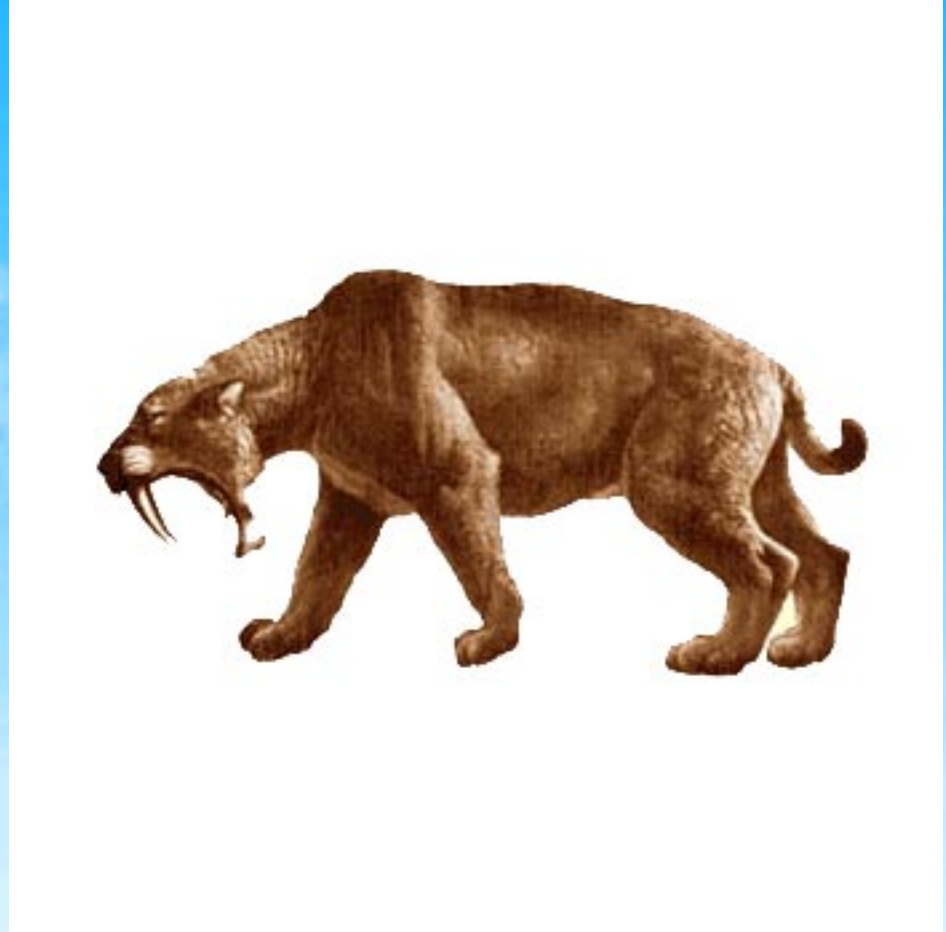


most recent ice age



# 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

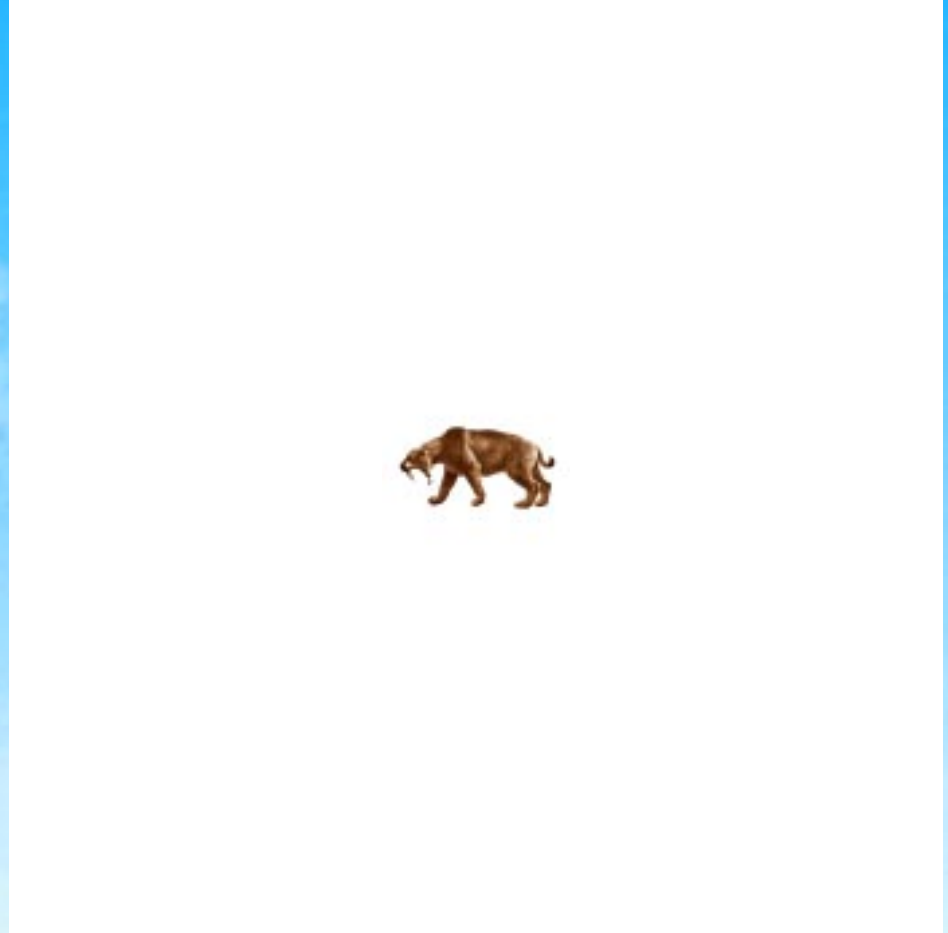


300,000 years



# Andromeda galaxy

$10^{13}$  s



300,000 years

$10^{14}$  s



earliest human

$10^{14}$  s



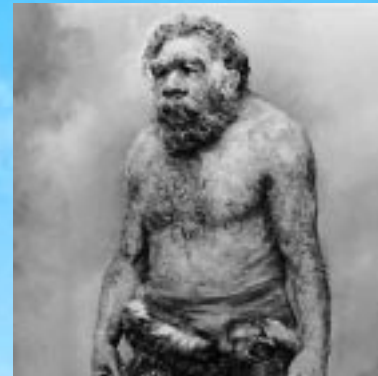
earliest human

$10^{14}$  s



earliest human

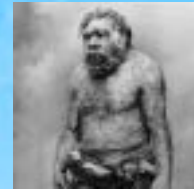
$10^{14}$  s



earliest human

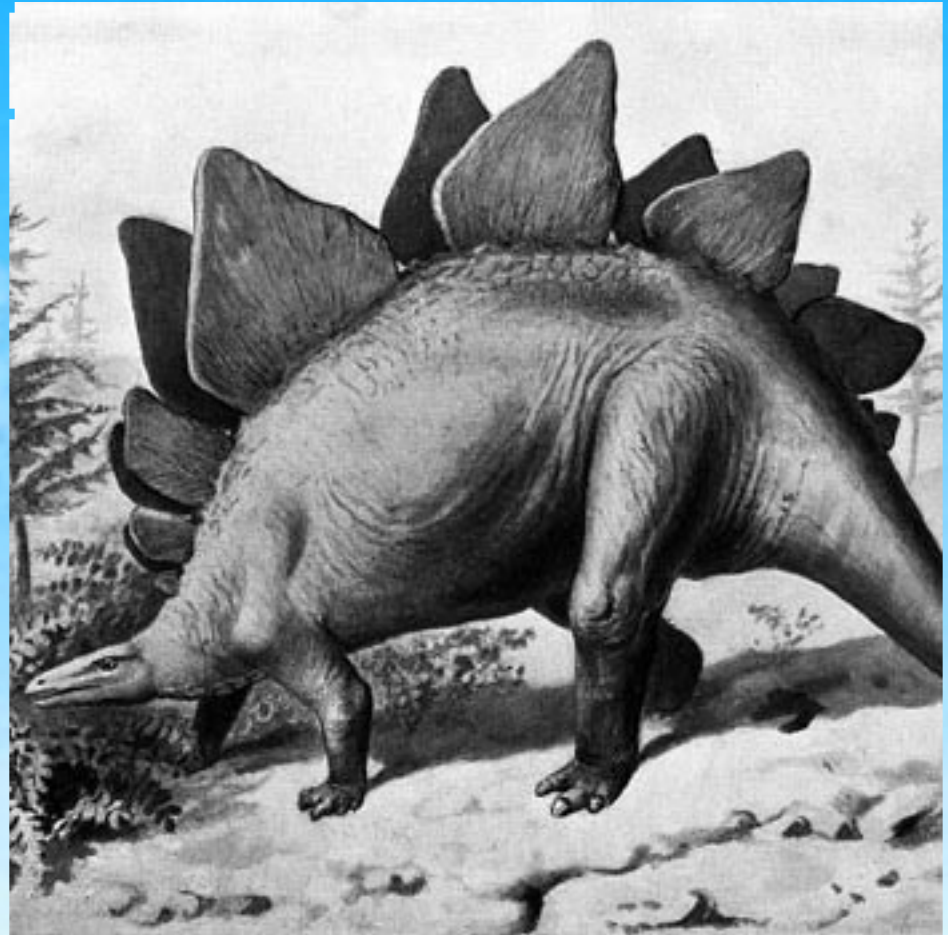


$10^{14}$  s



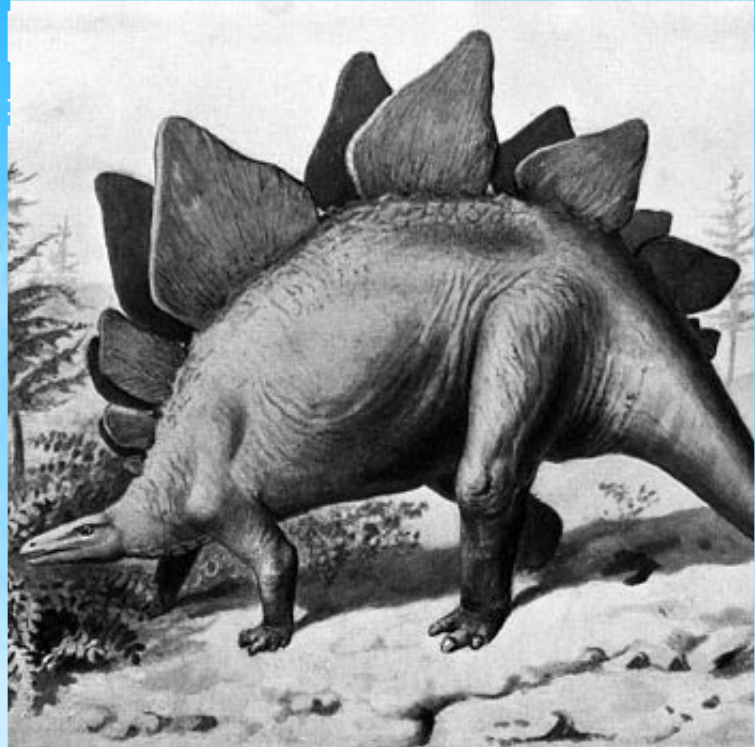
earliest human

$10^{15}$  s



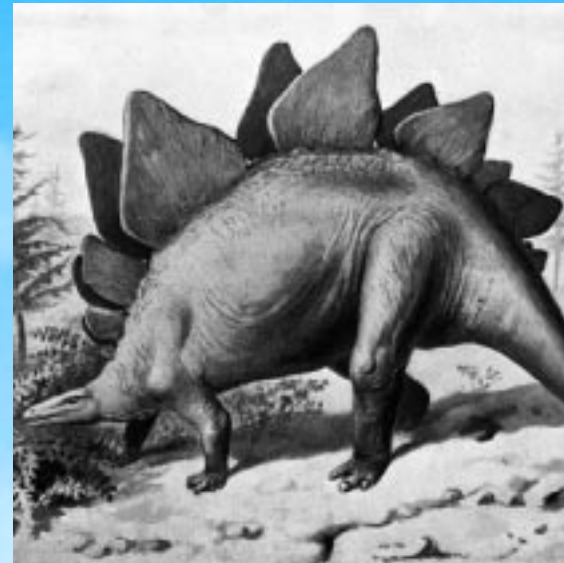
dinosaurs

$10^{15}$  s



dinosaurs

$10^{15}$  s



dinosaurs

$10^{15}$  s



dinosaurs

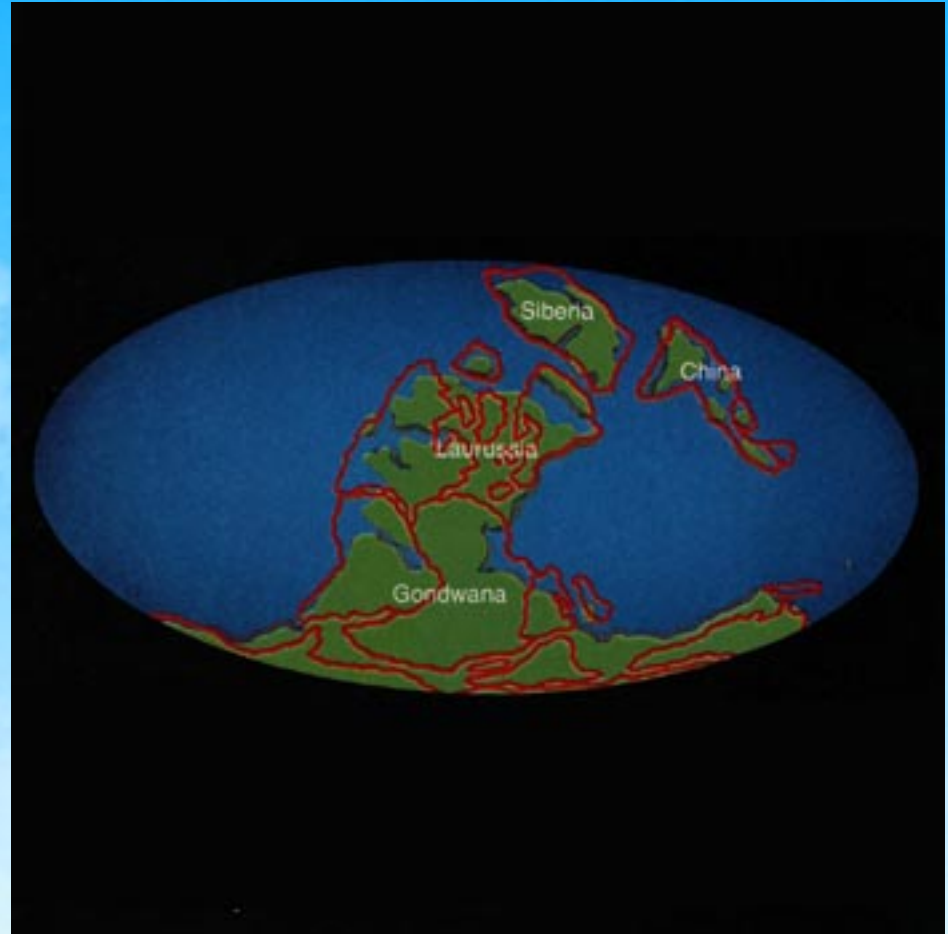


$10^{15}$  s



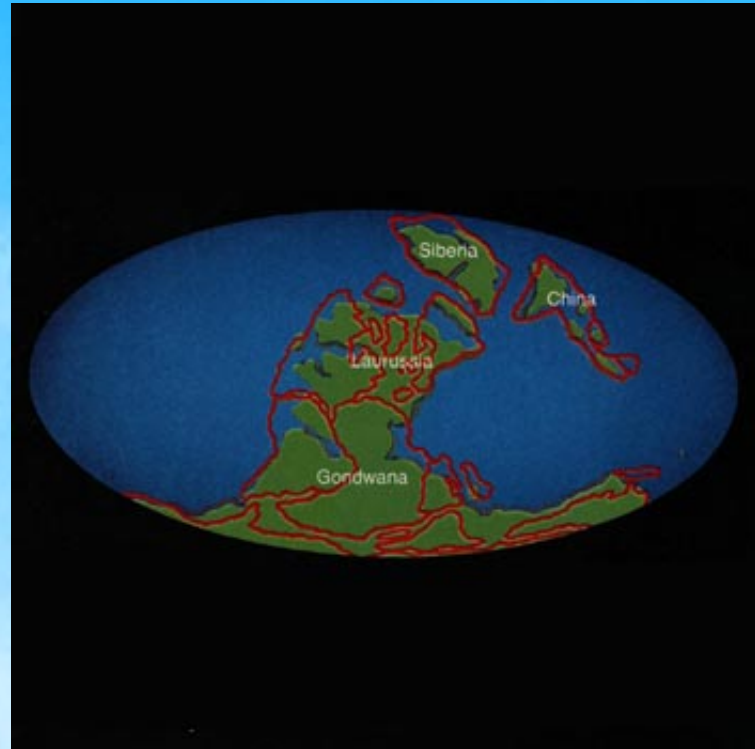
dinosaurs

$10^{16}$  s



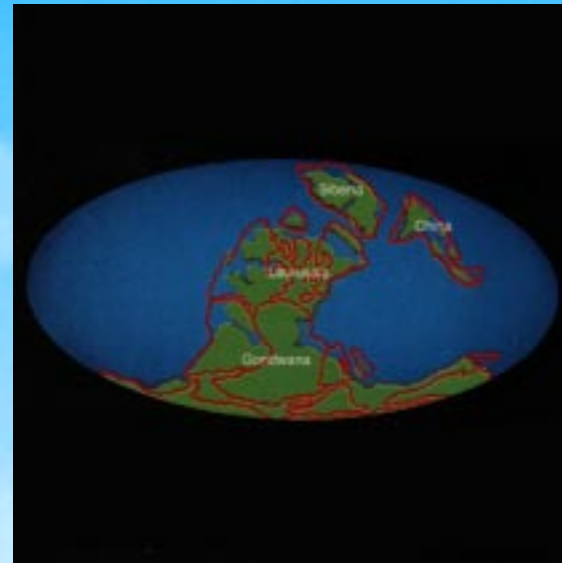
continental drift

$10^{16}$  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

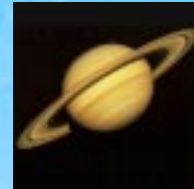
$10^{17}$  s



age of the solar system



$10^{17}$  s



age of the solar system

# edge of the universe

$10^{18}$  s



# age of known universe

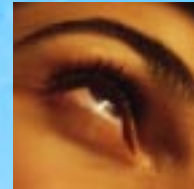
moon

$10^0$  s



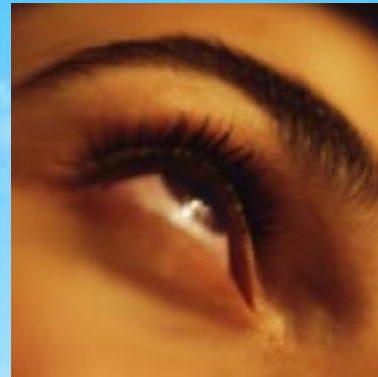
one second

$10^{-1}$  s



blink of an eye

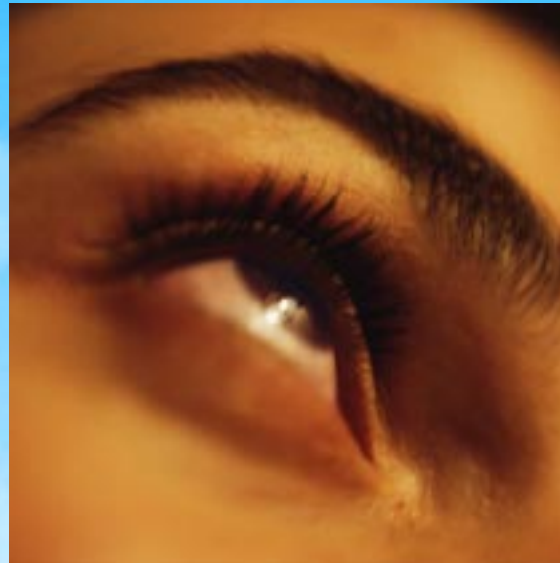
$10^{-1}$  s



blink of an eye

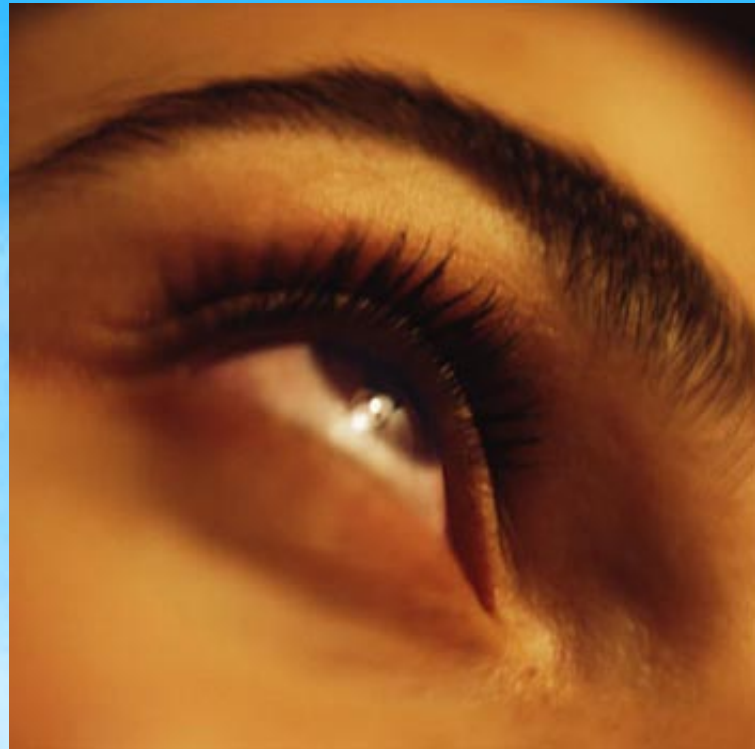


$10^{-1}$  s



blink of an eye

$10^{-1}$  s



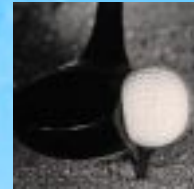
blink of an eye

$10^{-1}$  s



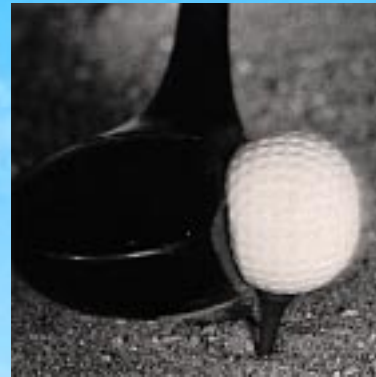
blink of an eye

$10^{-2}$  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



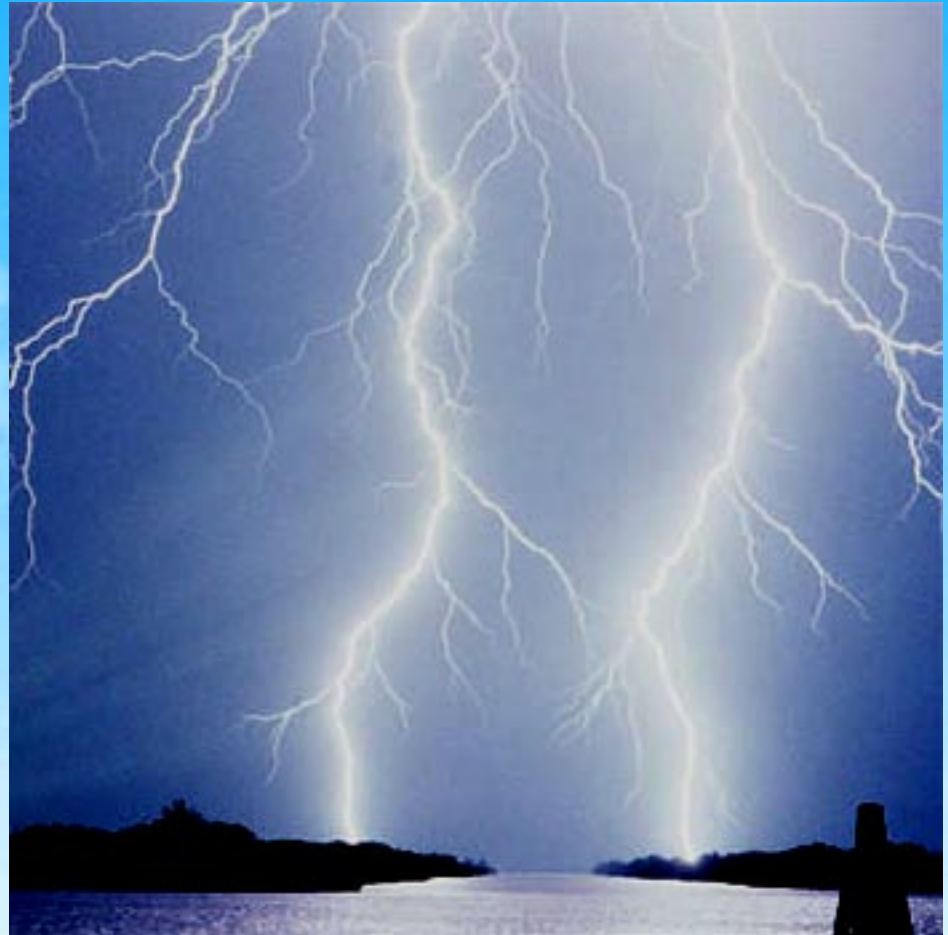
lightning

$10^{-4}$  s



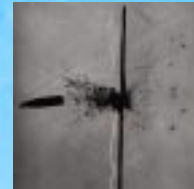
lightning

$10^{-4}$  s



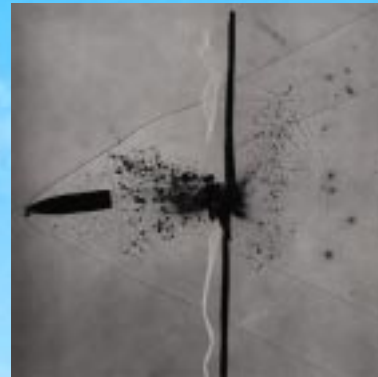
lightning

$10^{-5}$  s



bullet through glass

$10^{-5}$  s



bullet through glass

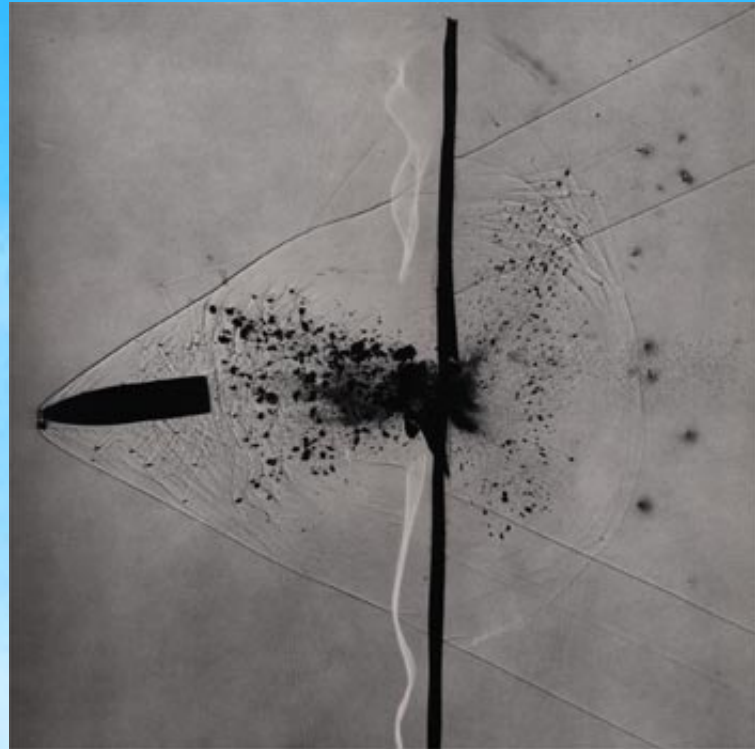


$10^{-5}$  s



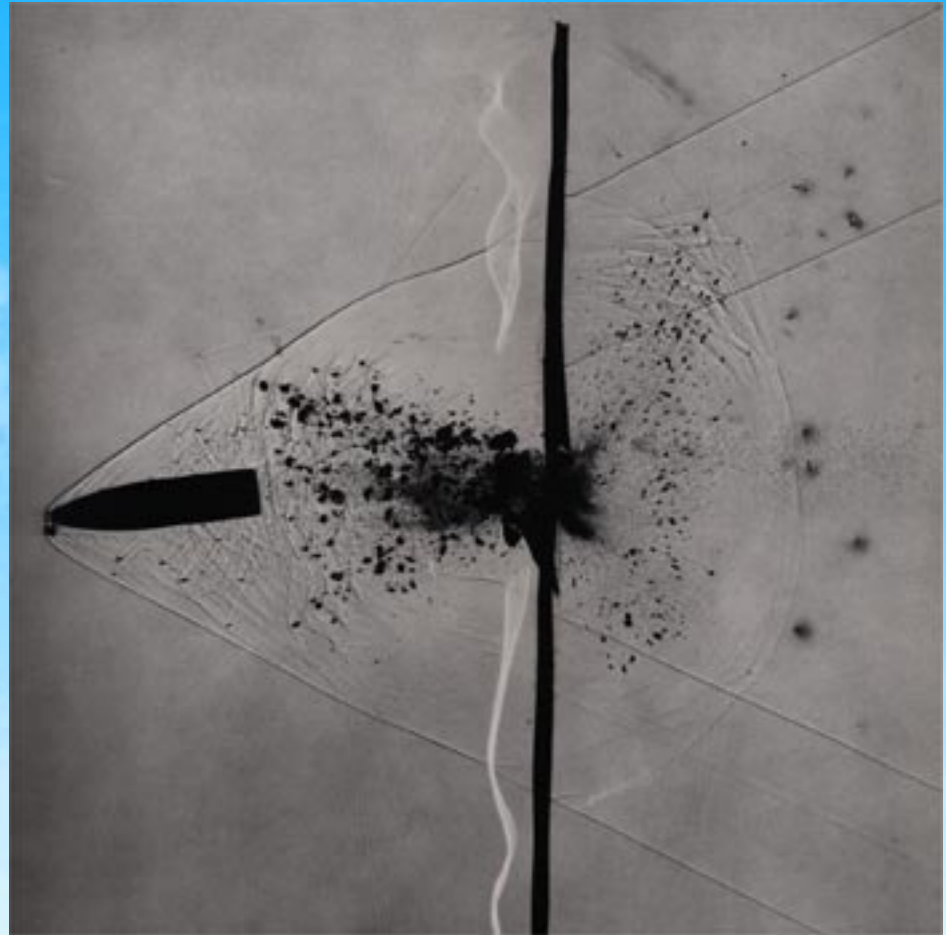
bullet through glass

$10^{-5}$  s



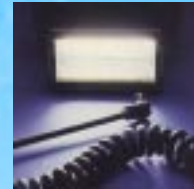
bullet through glass

$10^{-5}$  s



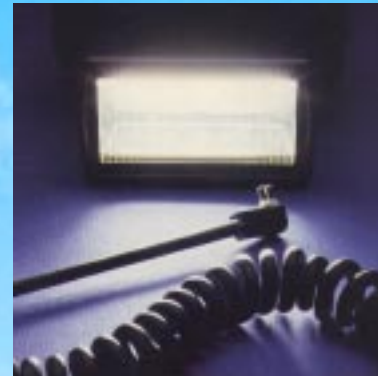
bullet through glass

$10^{-6}$  s



strobe flash

$10^{-6}$  s



strobe flash

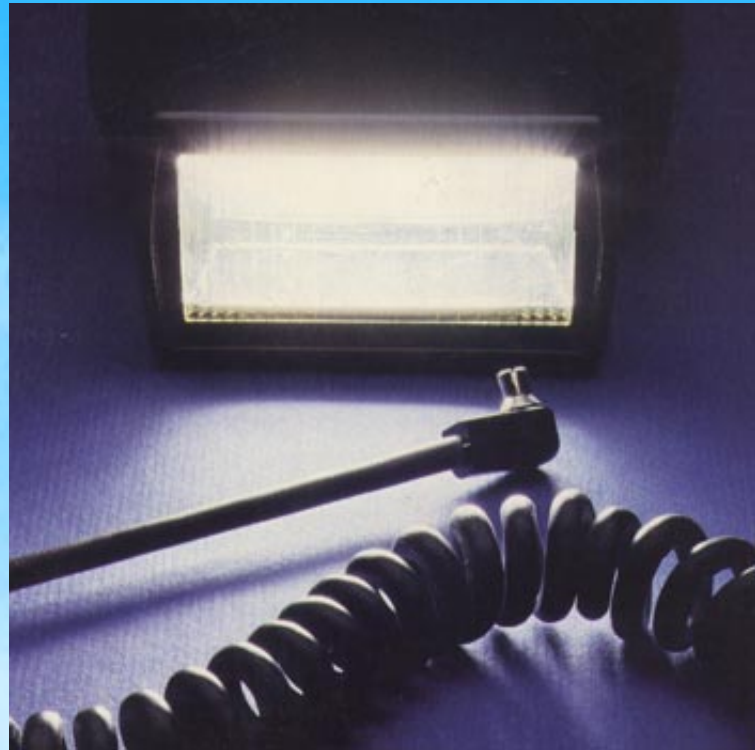


$10^{-6}$  s



strobe flash

$10^{-6}$  s



strobe flash

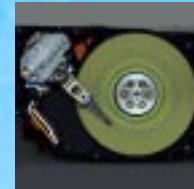
$10^{-6}$  s



strobe flash

# lecture hall

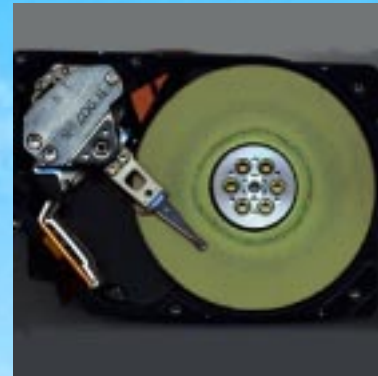
$10^{-7}$  s



hard disk write time

# lecture hall

$10^{-7}$  s

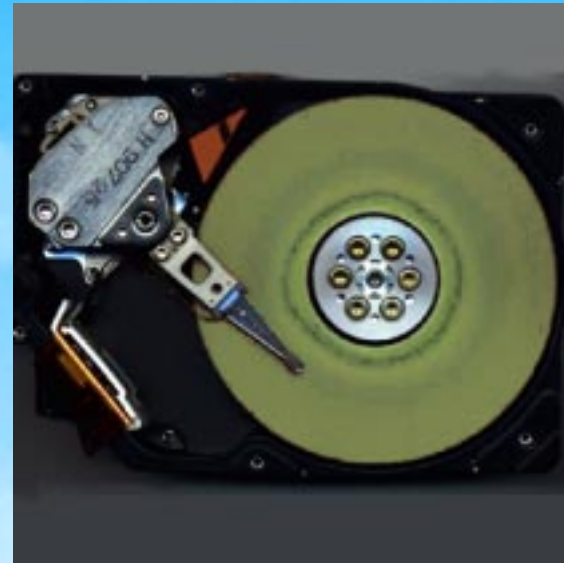


hard disk write time



# lecture hall

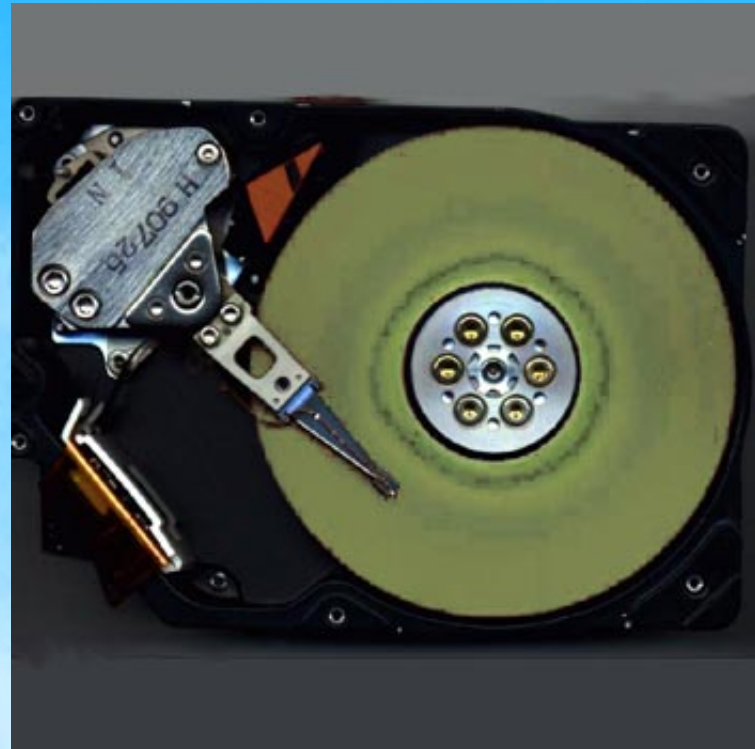
$10^{-7}$  s



hard disk write time

# lecture hall

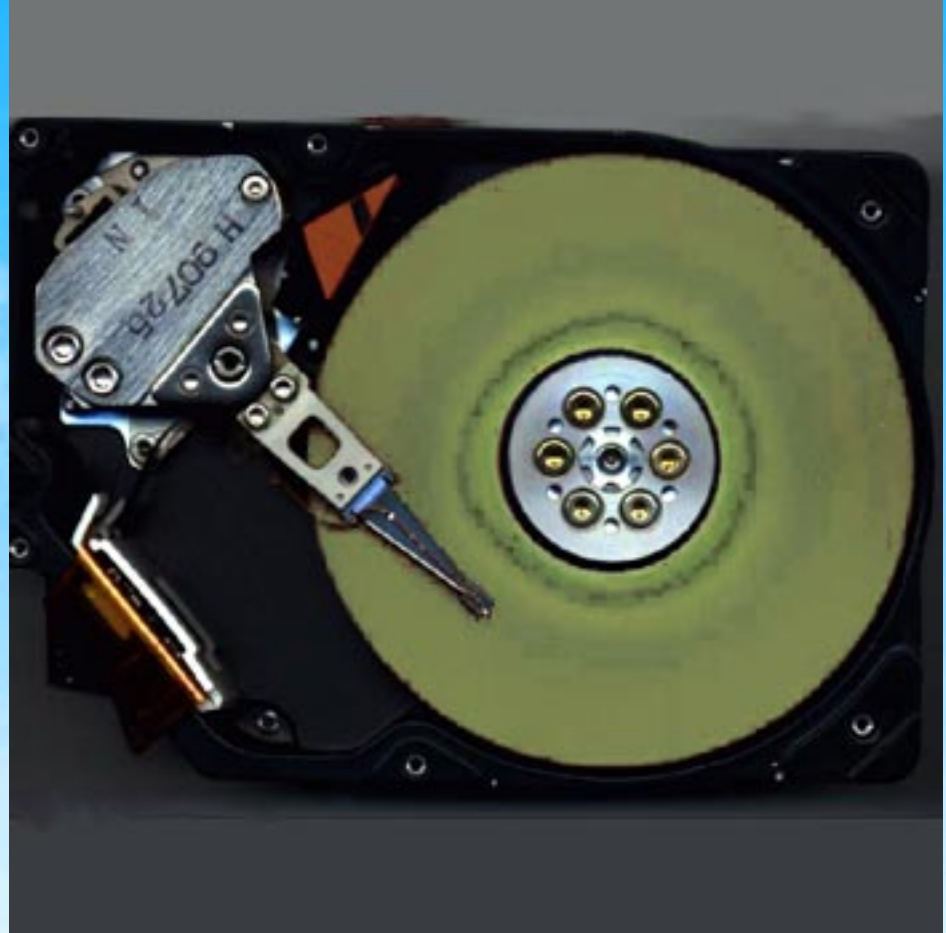
$10^{-7}$  s



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

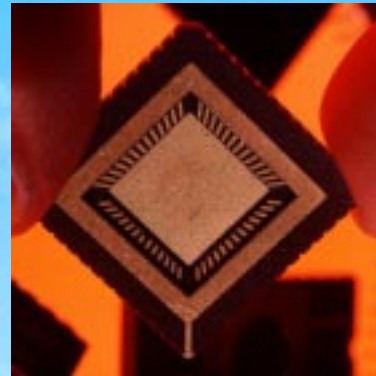
$10^{-9}$  s



clock speed of chip

one foot

$10^{-9}$  s

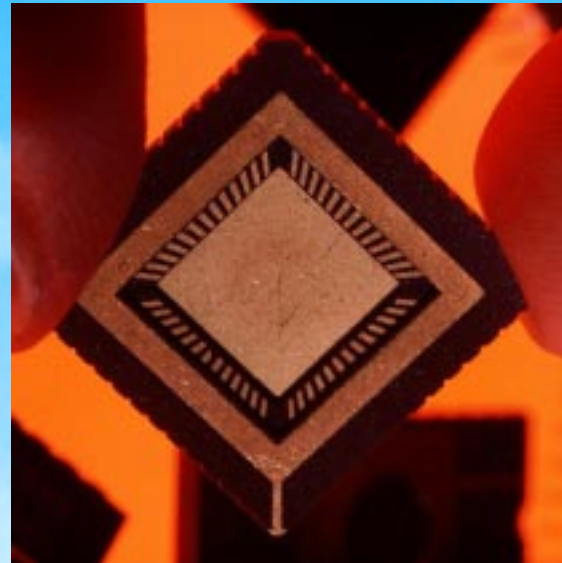


clock speed of chip



one foot

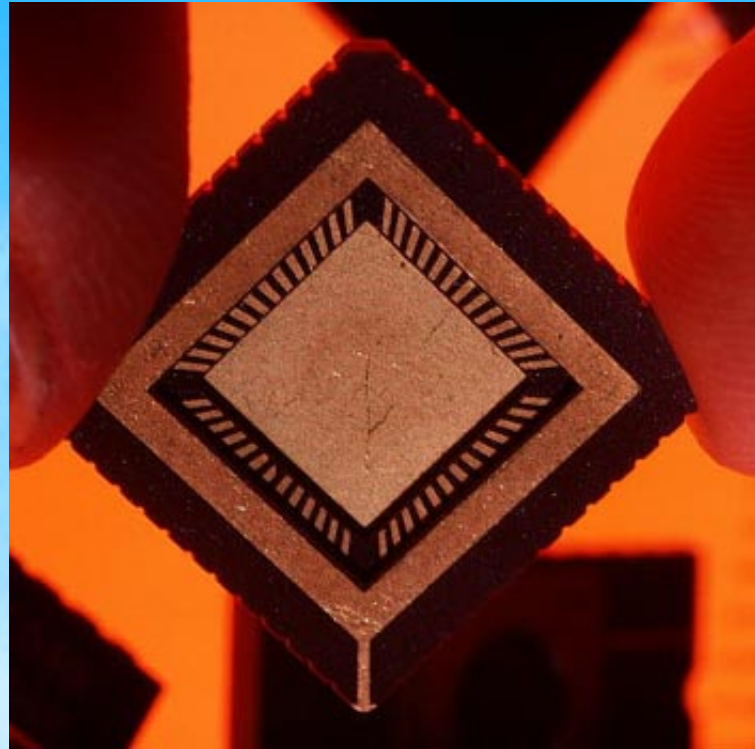
$10^{-9}$  s



clock speed of chip

one foot

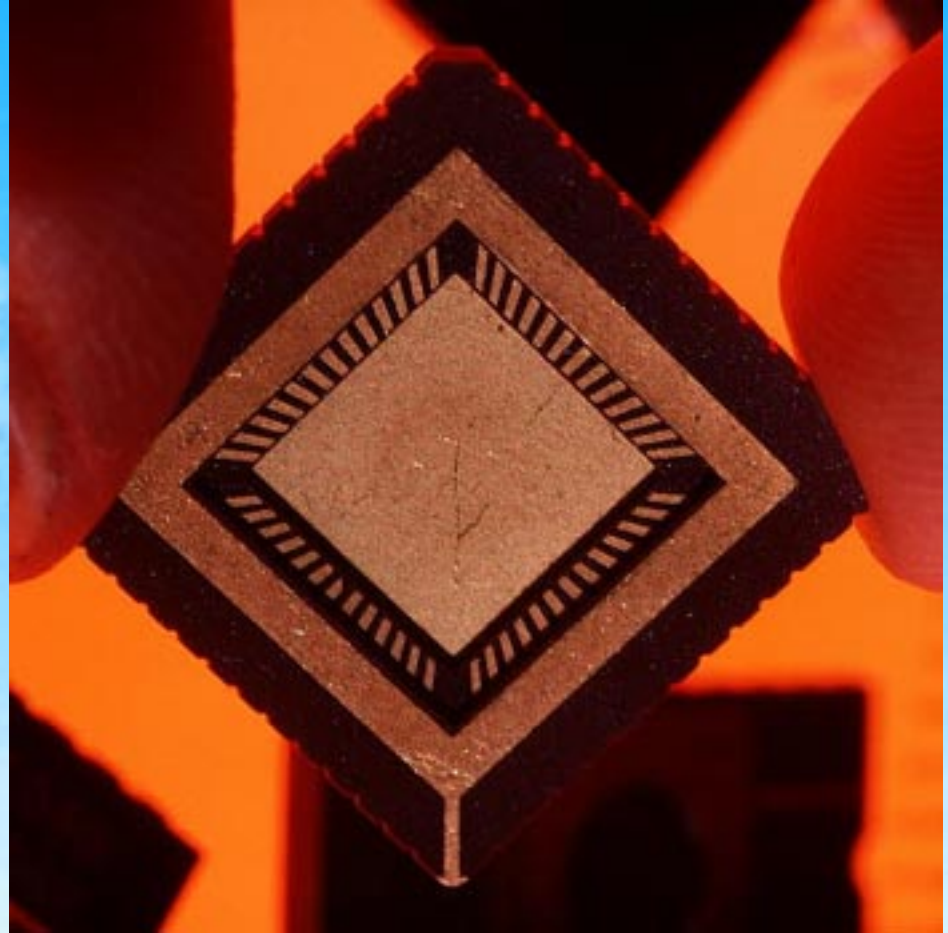
$10^{-9}$  s



clock speed of chip

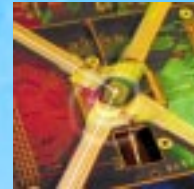
one foot

$10^{-9}$  s



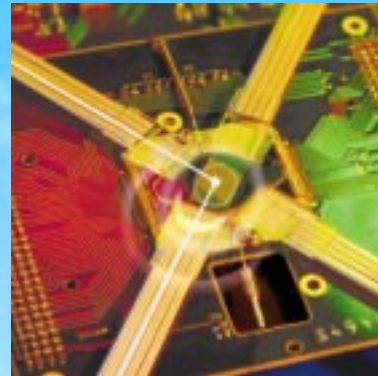
clock speed of chip

$10^{-10}$  s



fastest electronic switch

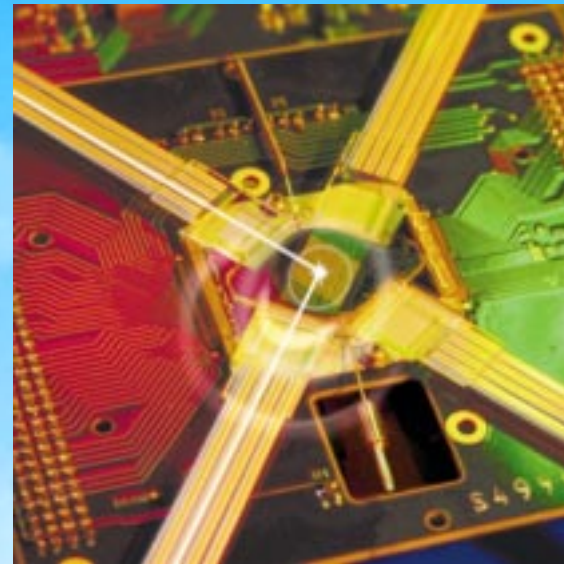
$10^{-10}$  s



fastest electronic switch

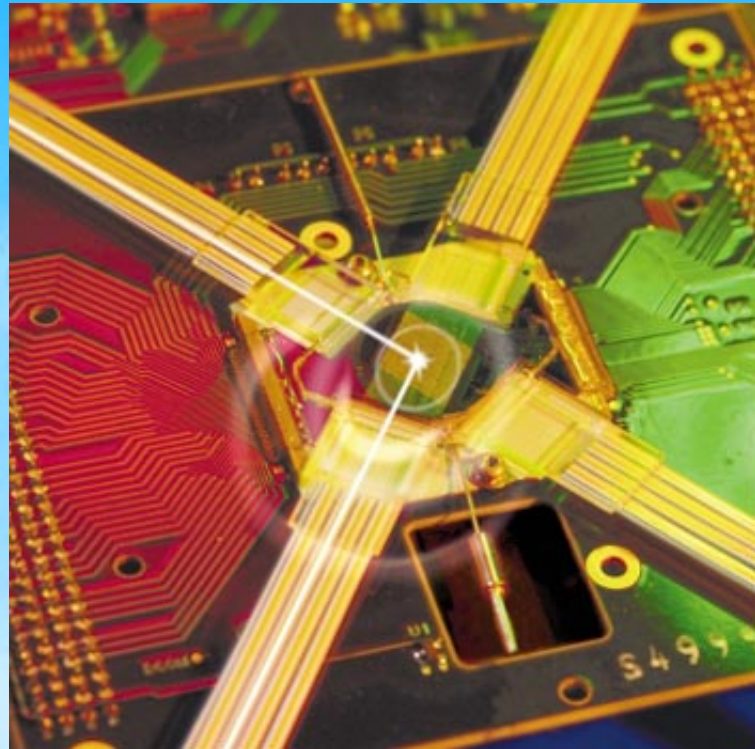


$10^{-10}$  s



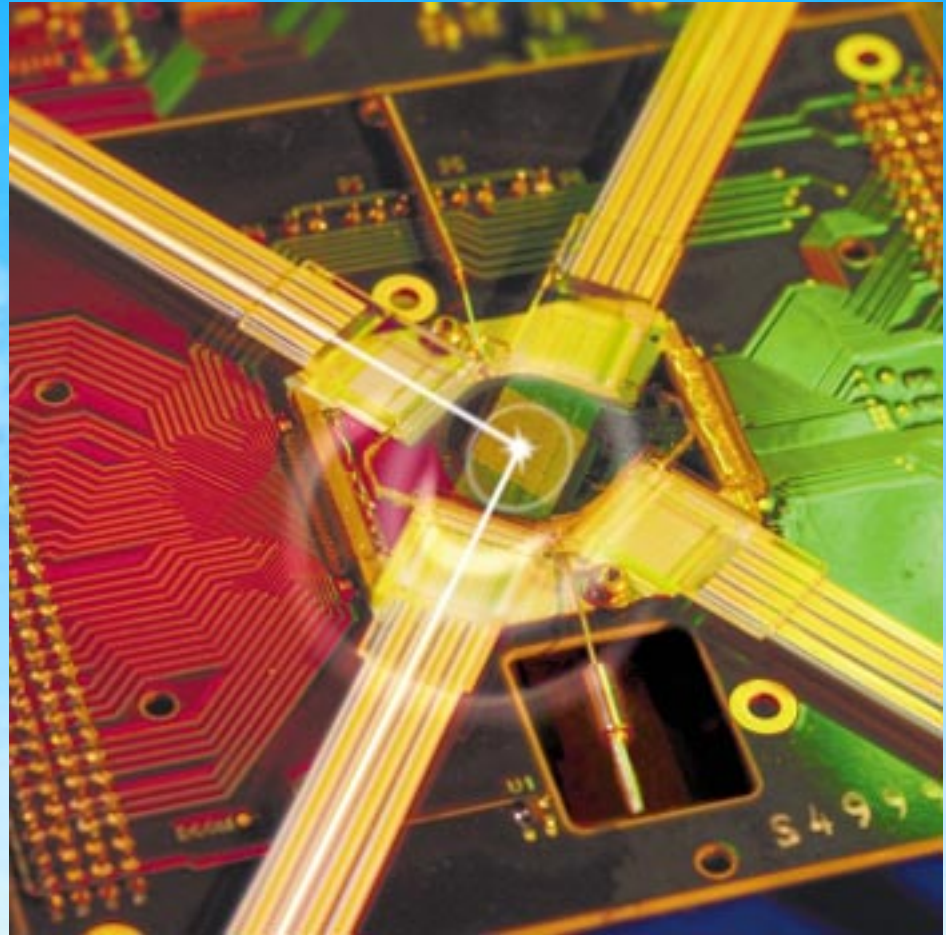
fastest electronic switch

$10^{-10}$  s



fastest electronic switch

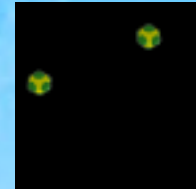
$10^{-10}$  s



fastest electronic switch

window pane

$10^{-11}$  s

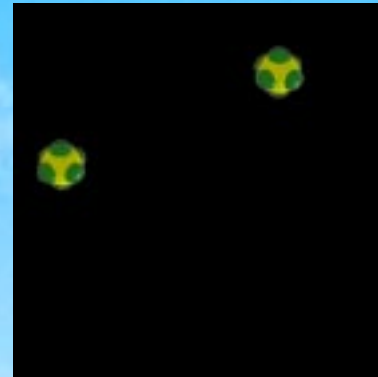


molecular collision



window pane

$10^{-11}$  s

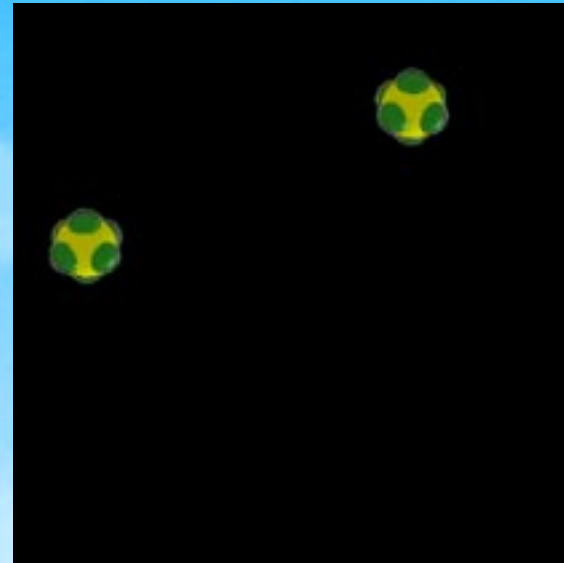


molecular collision



window pane

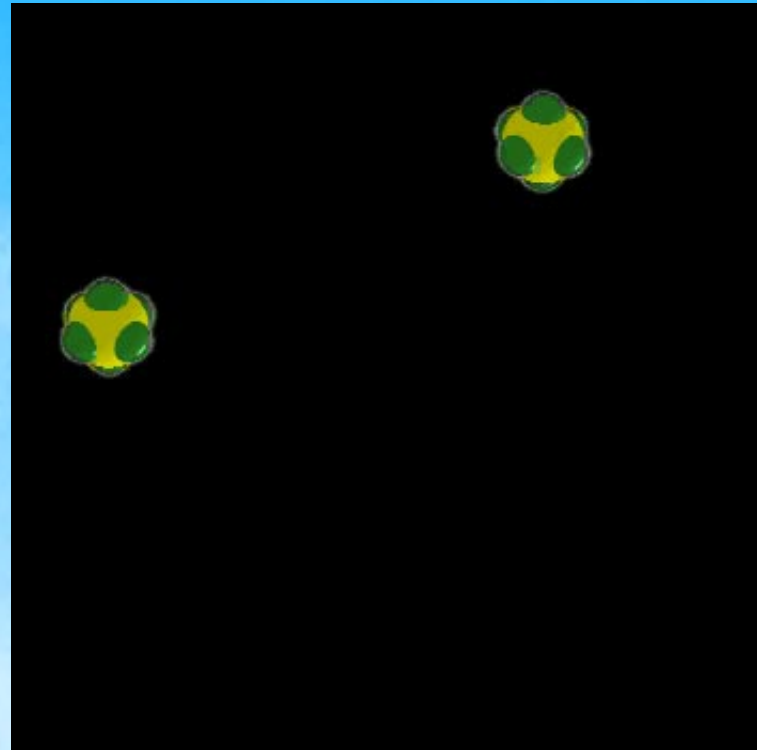
$10^{-11}$  s



molecular collision

window pane

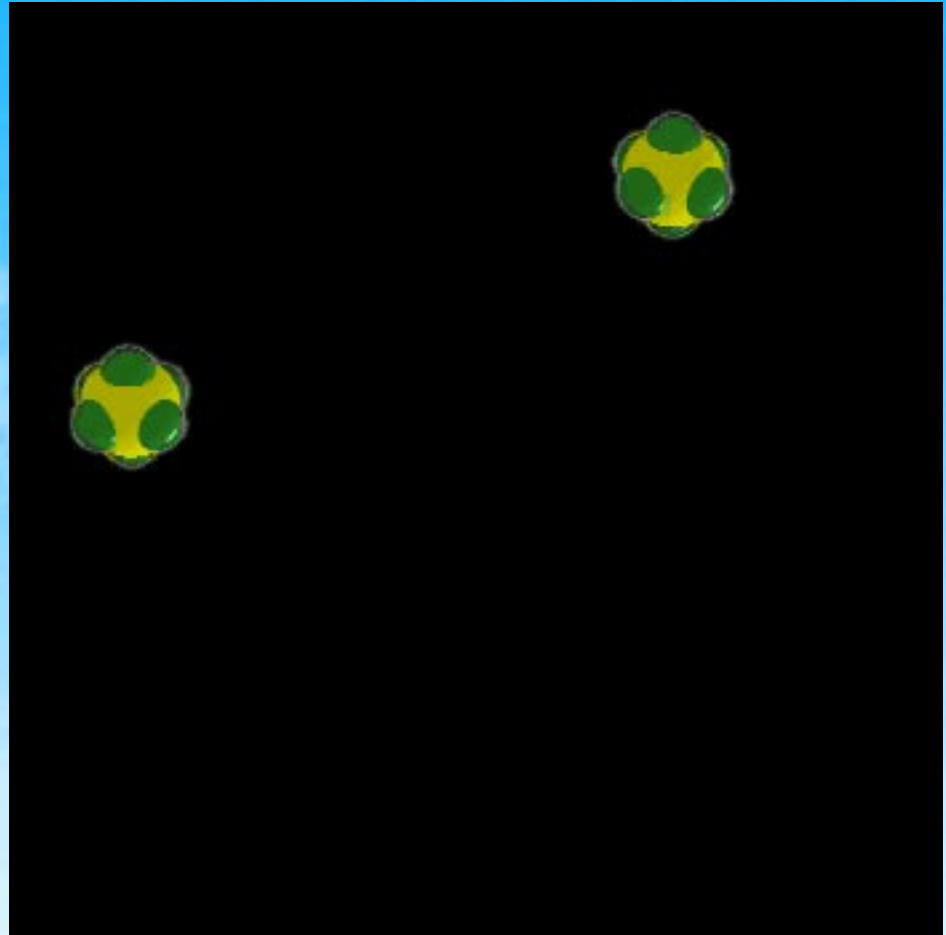
$10^{-11}$  s



molecular collision

window pane

$10^{-11}$  s



molecular collision

$10^{-12}$  s



molecular rotation

$10^{-12}$  s



molecular rotation

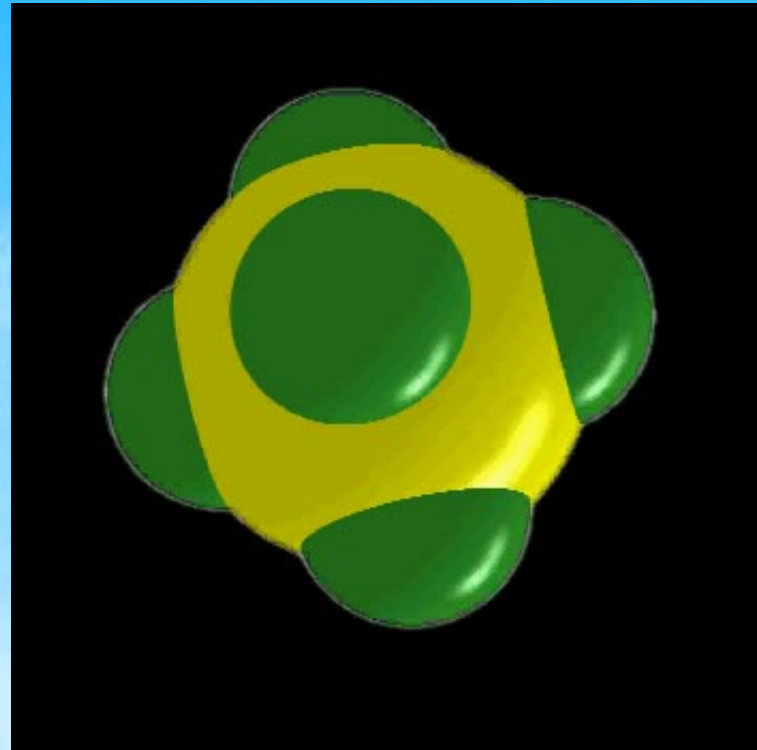


$10^{-12}$  s



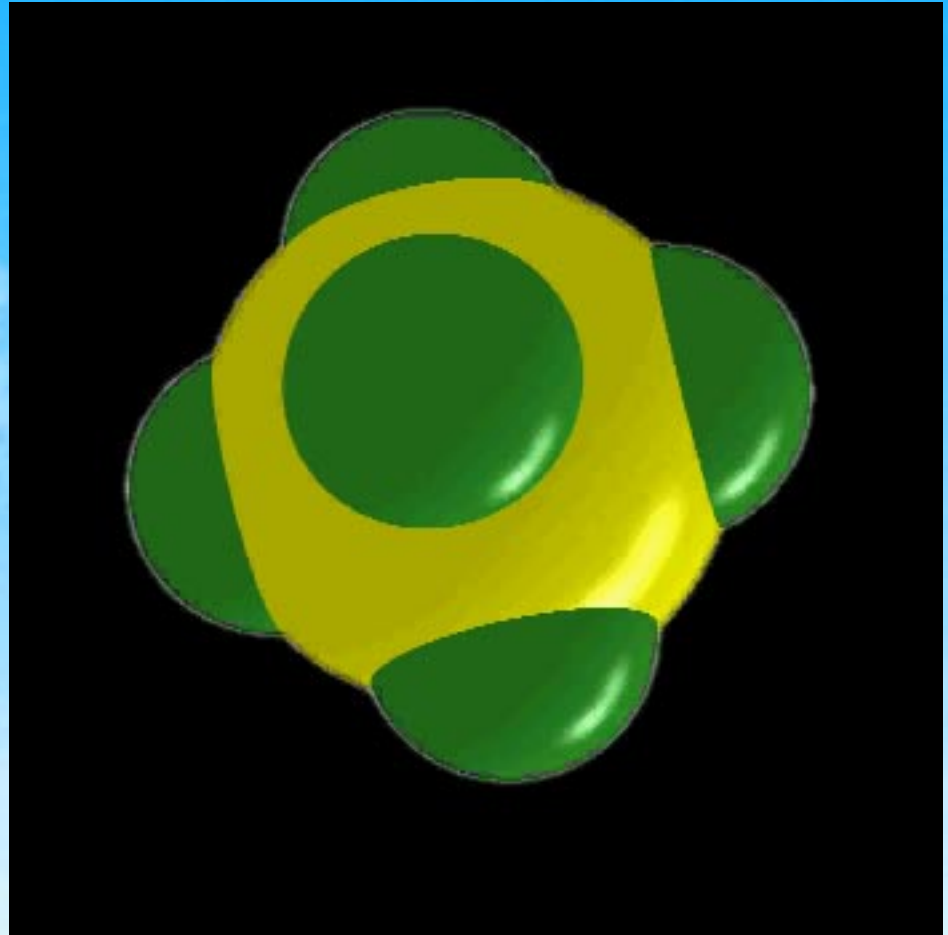
molecular rotation

$10^{-12}$  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

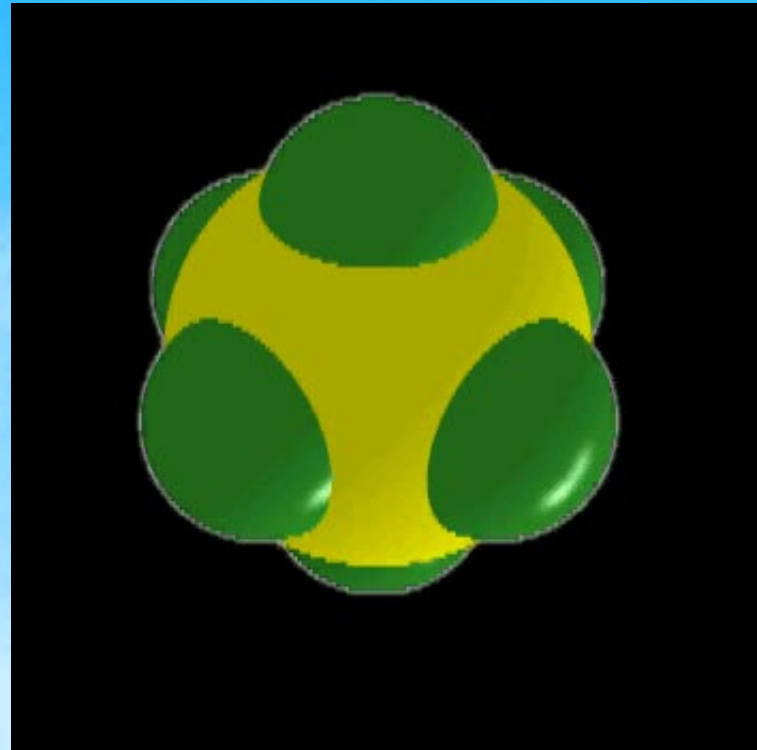
$10^{-13}$  s



# molecular vibration

# width of human hair

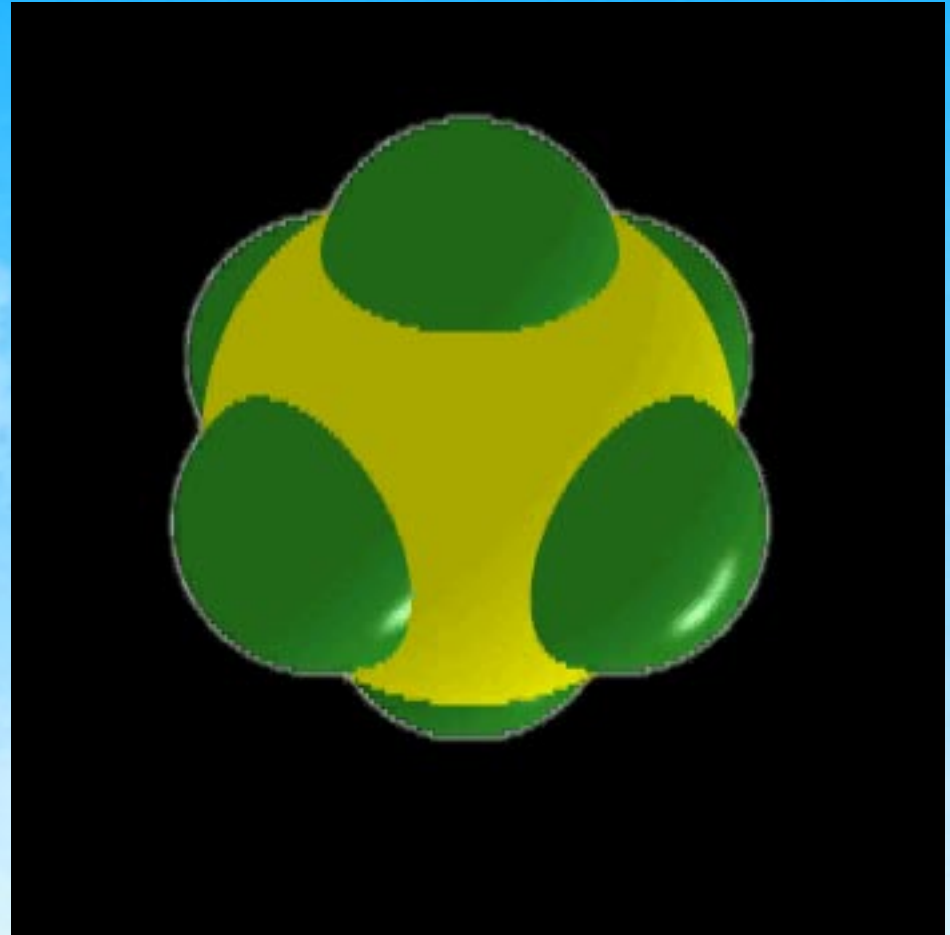
$10^{-13}$  s



# molecular vibration

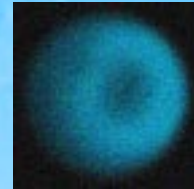
width of human hair

$10^{-13}$  s



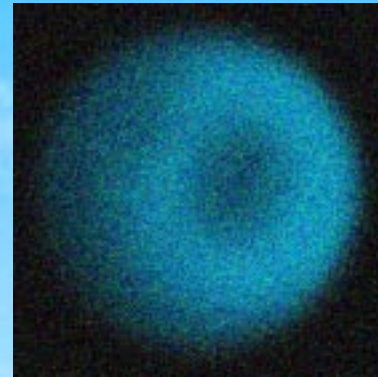
molecular vibration

$10^{-14}$  s



electronic collision

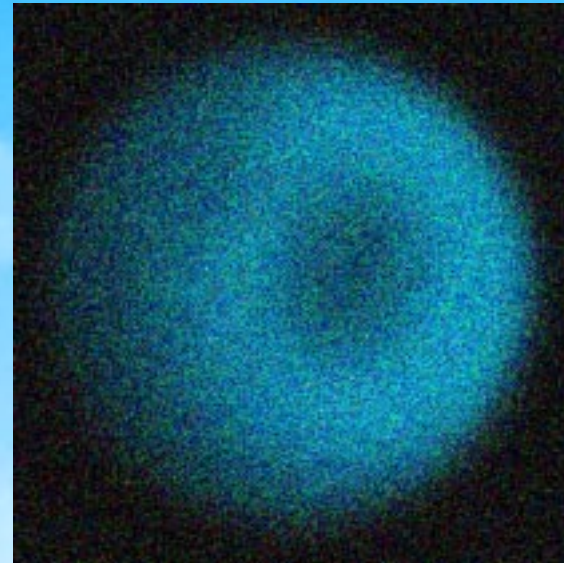
$10^{-14}$  s



electronic collision

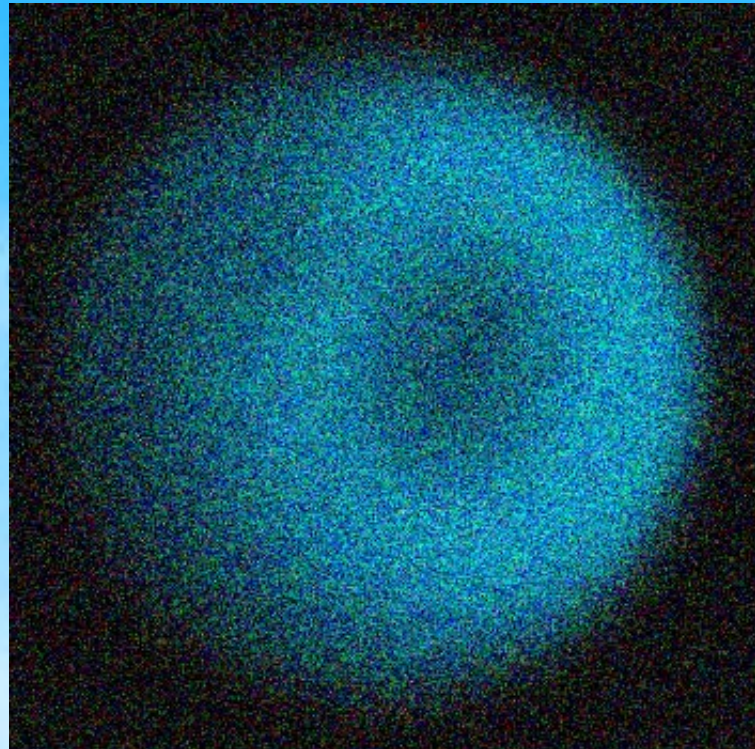


$10^{-14}$  s



electronic collision

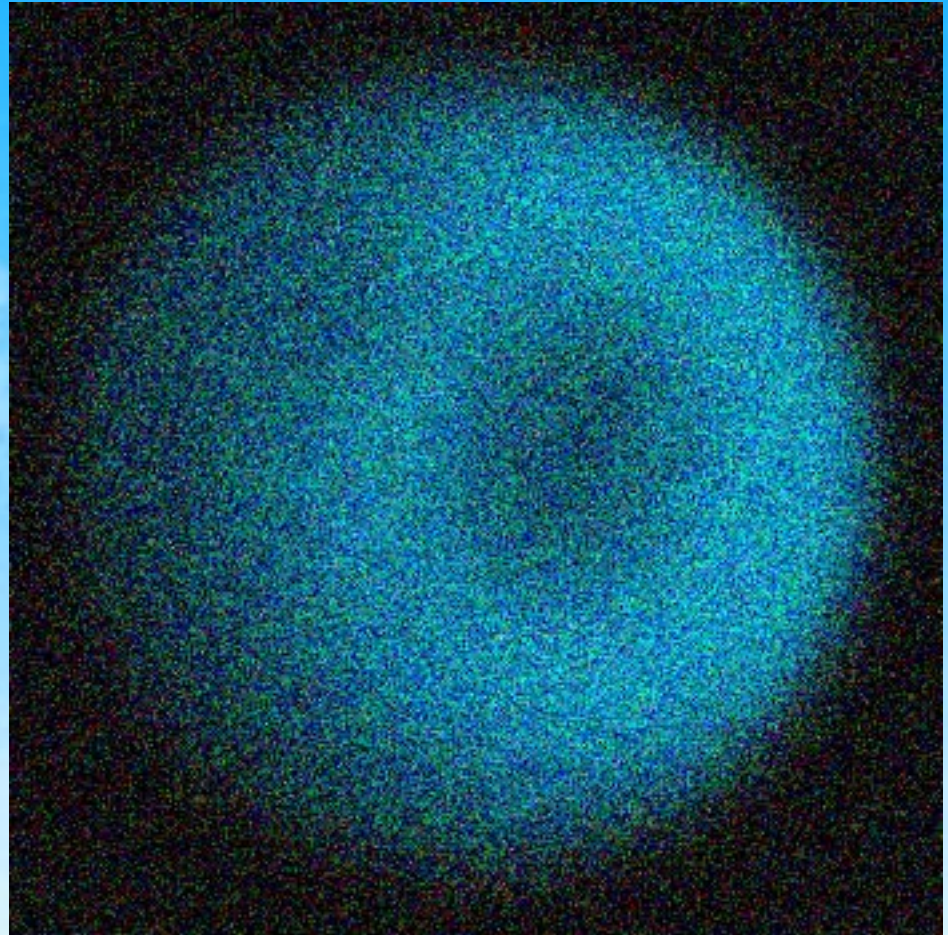
$10^{-14}$  s



electronic collision



$10^{-14}$  s



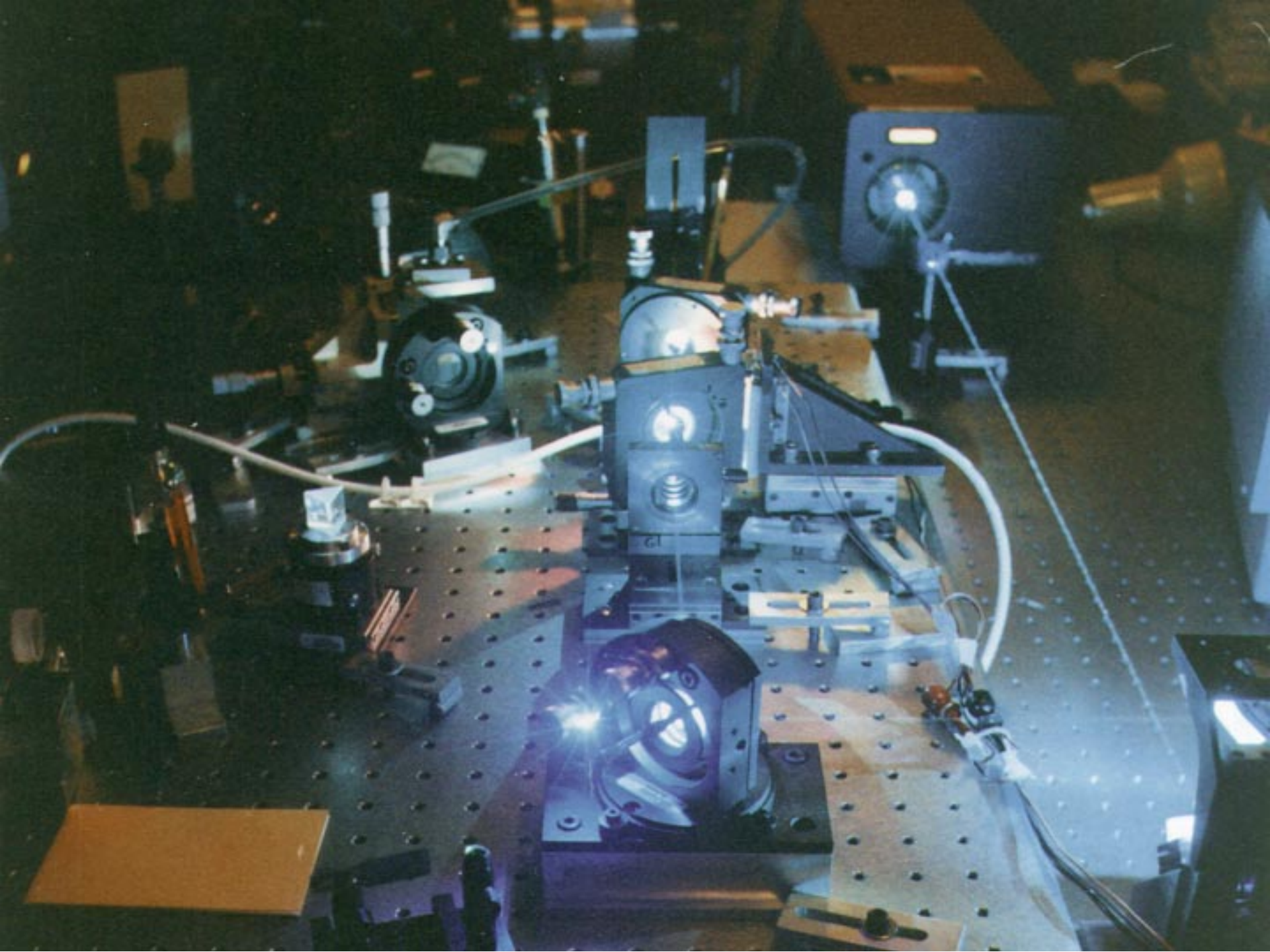
electronic collision

100 atomic layers

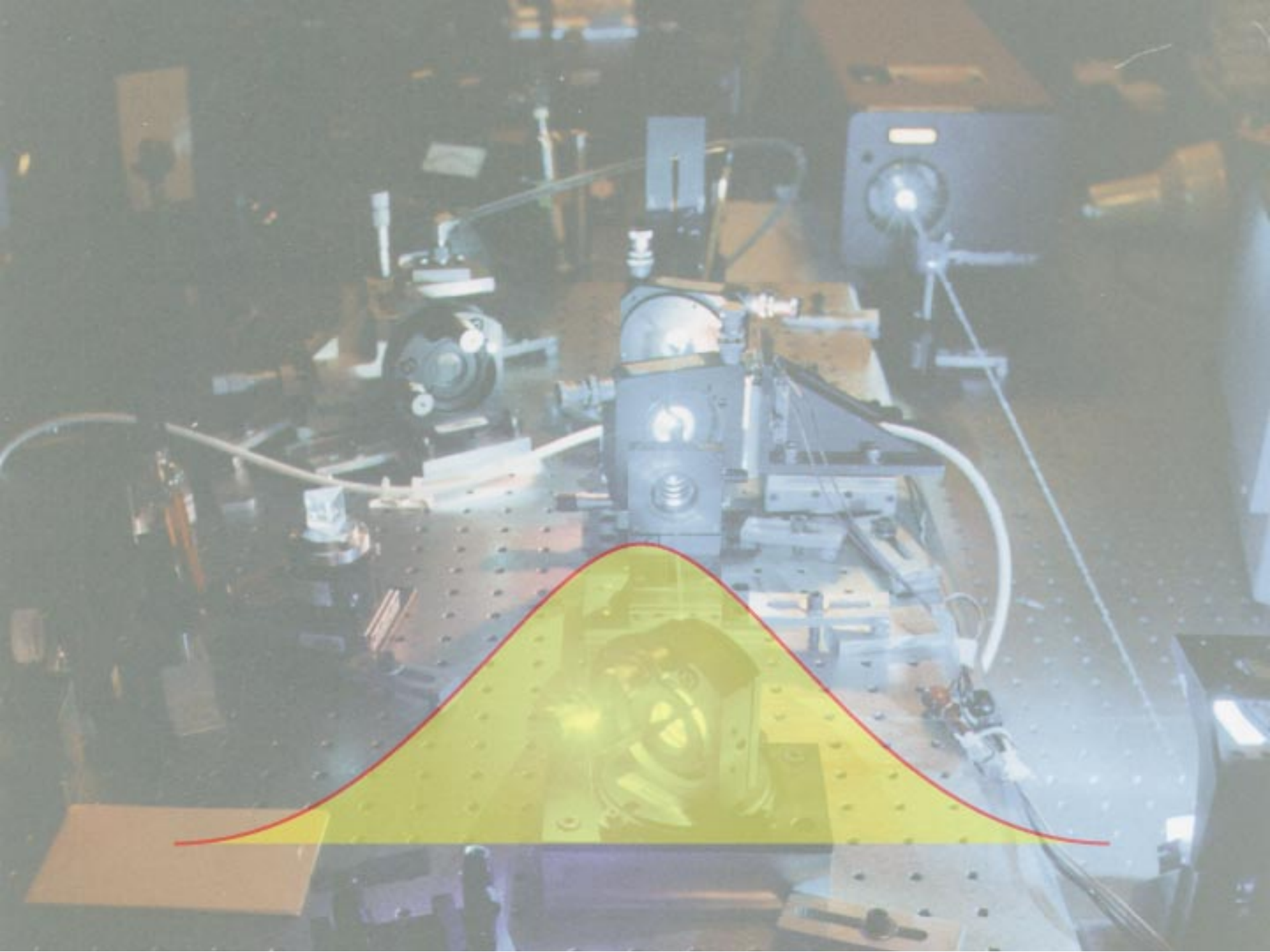
$10^{-15}$  s

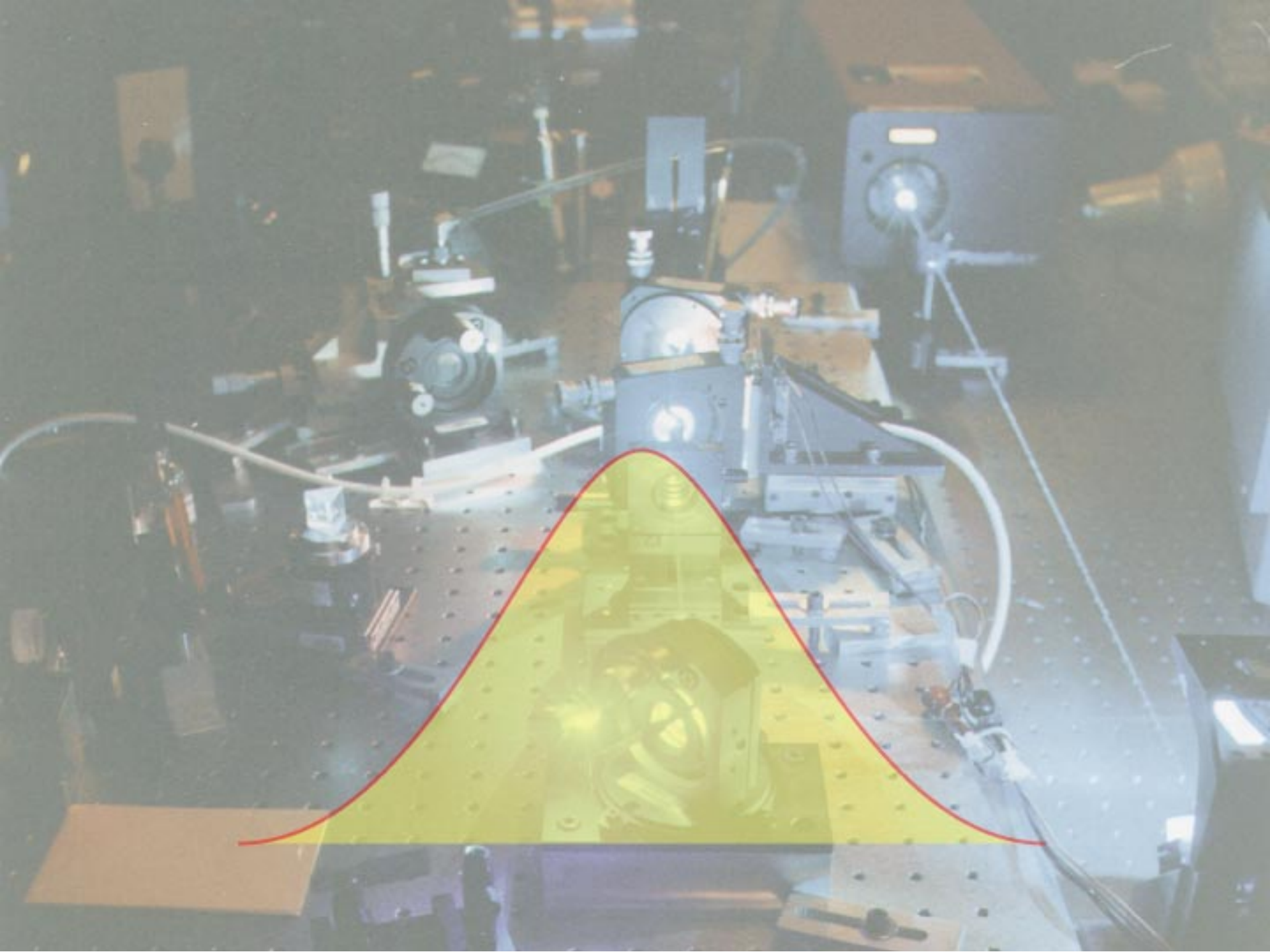
one "femtosecond"

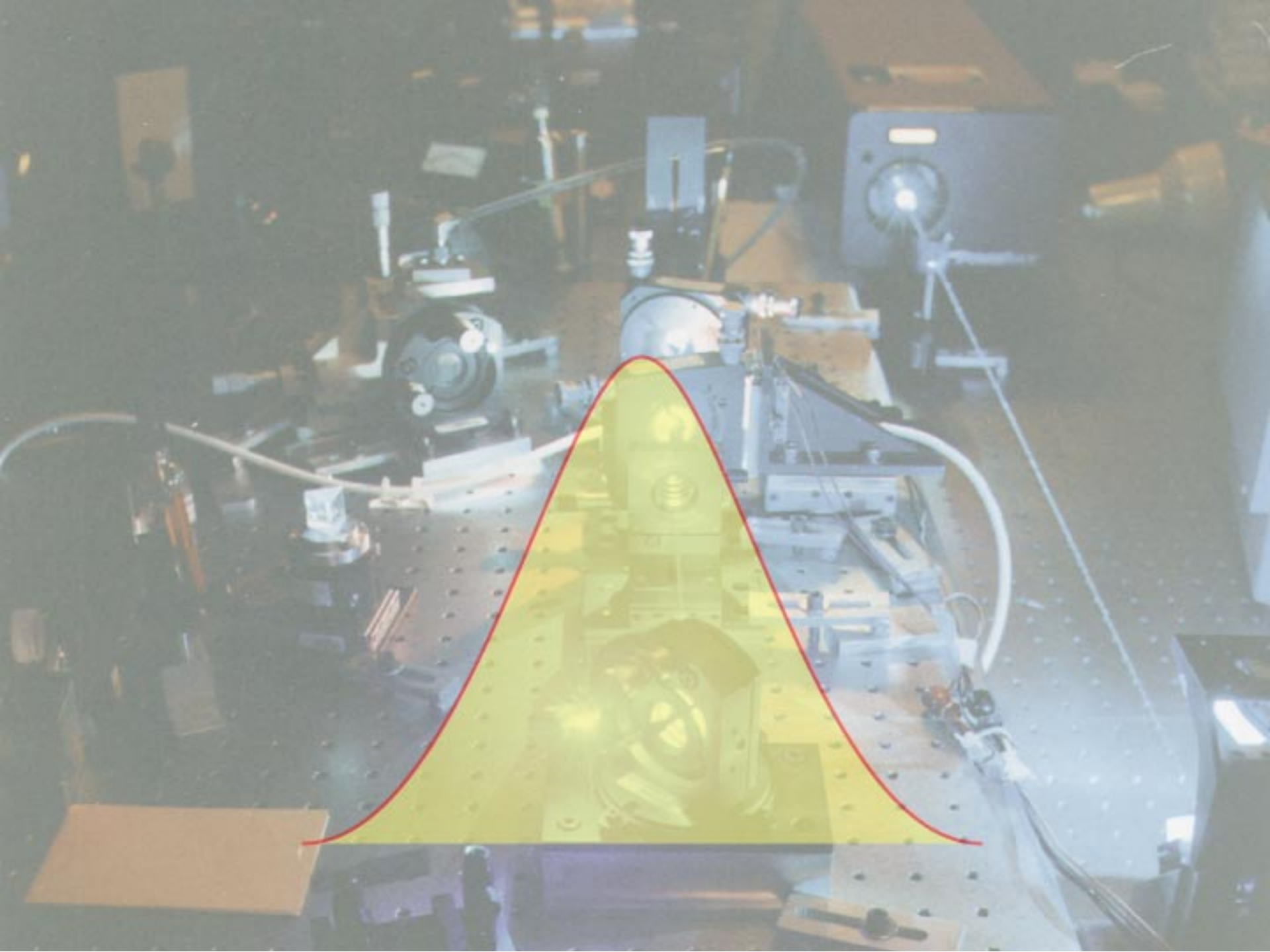




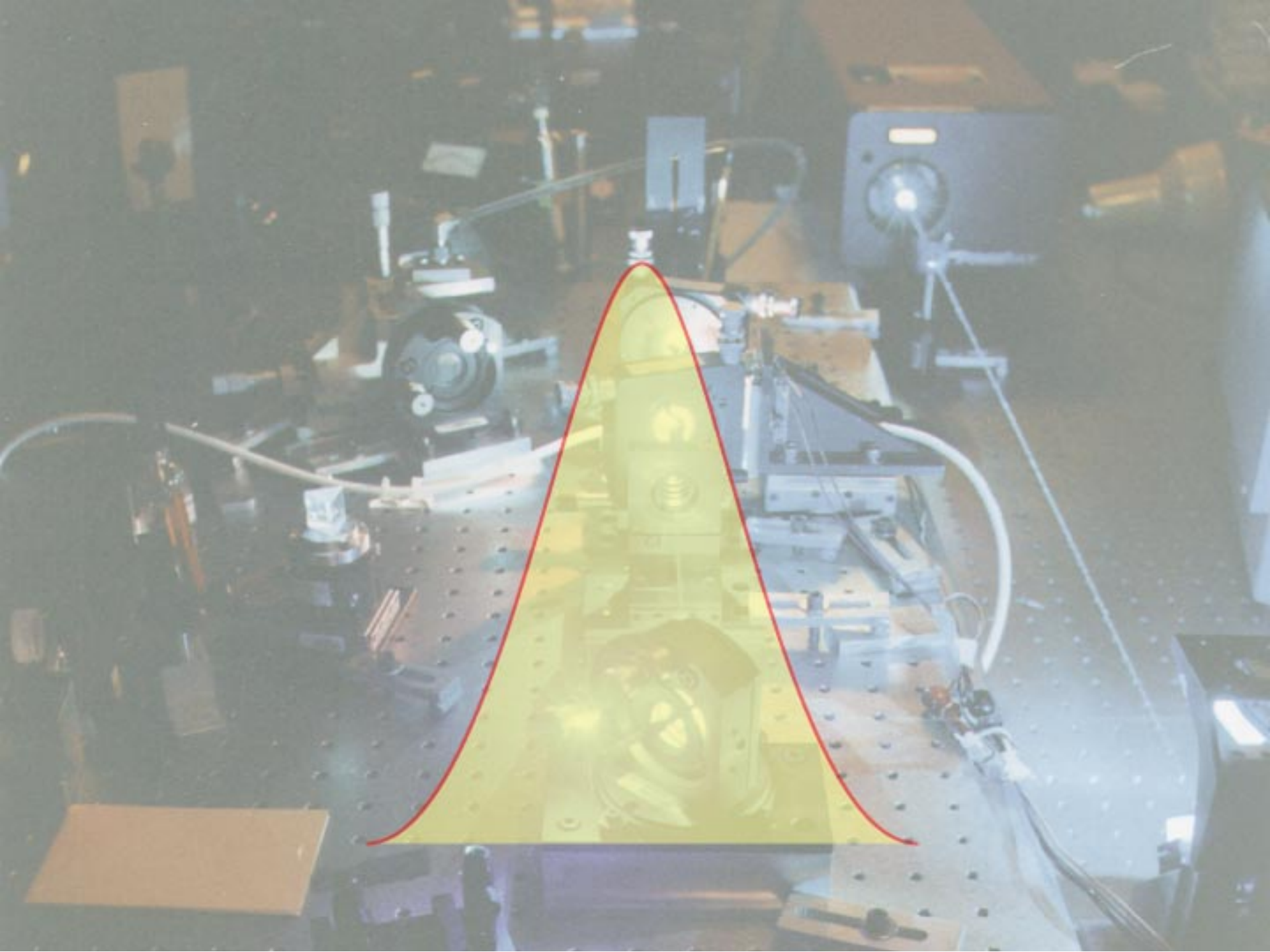


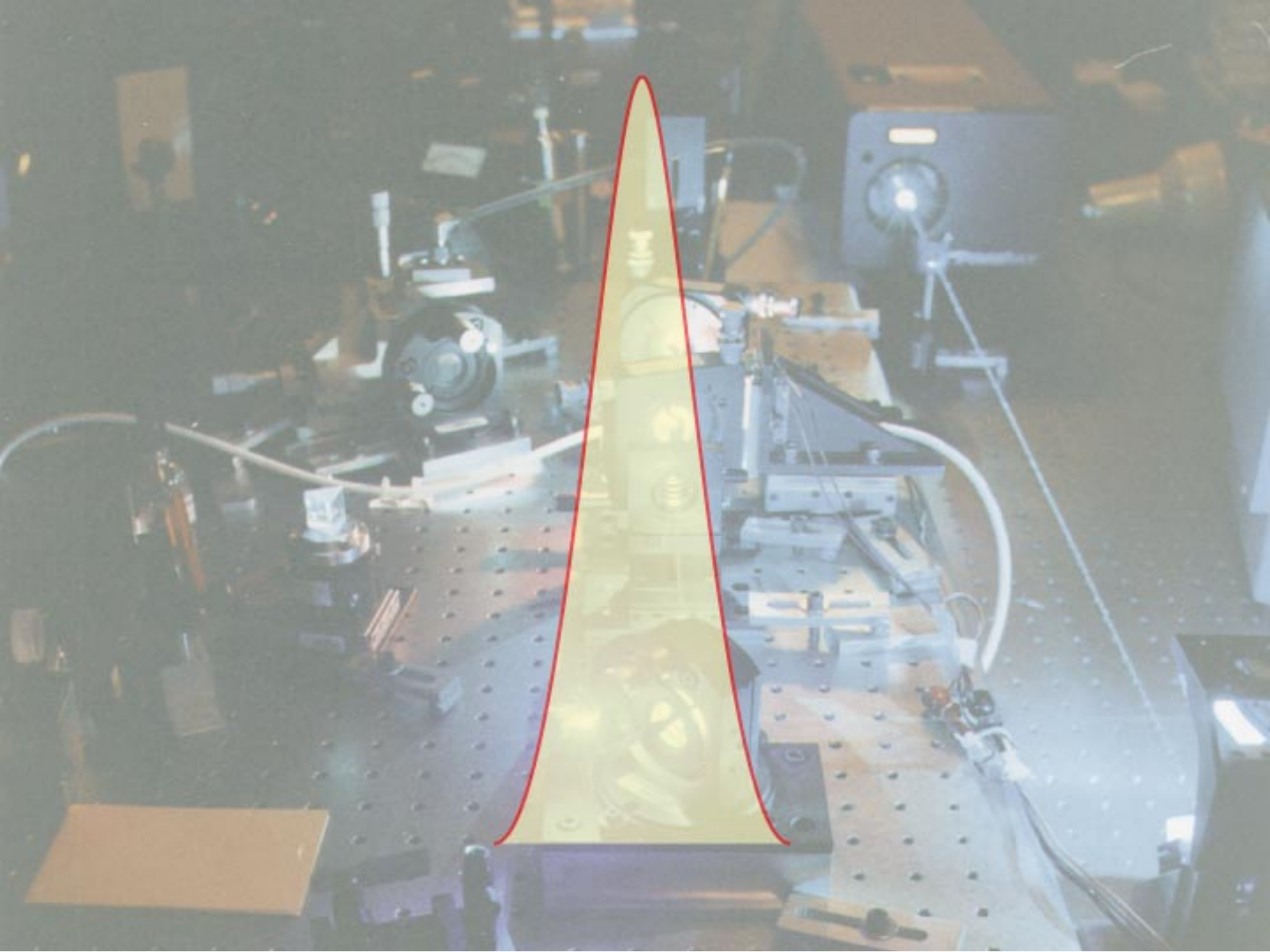




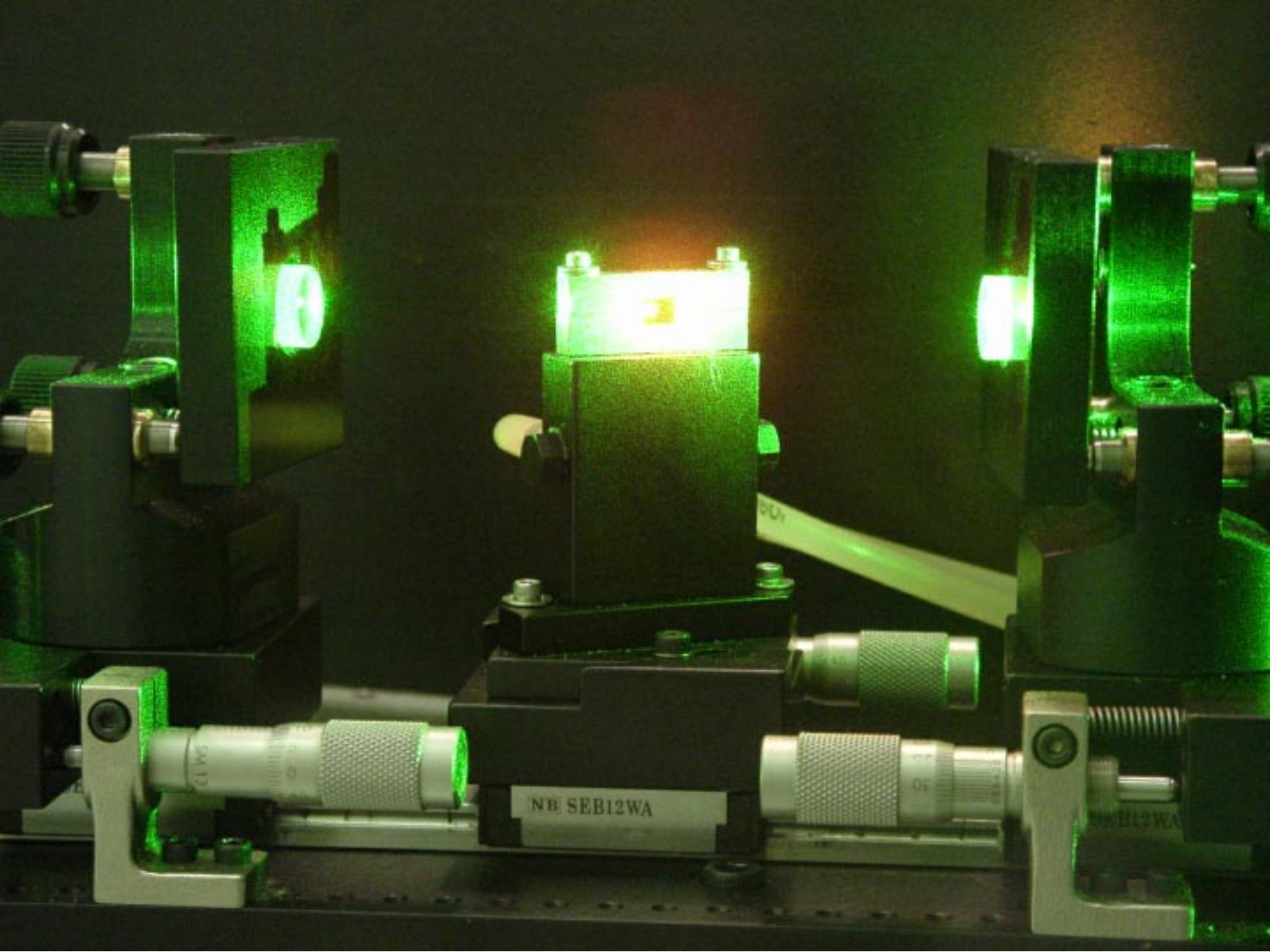


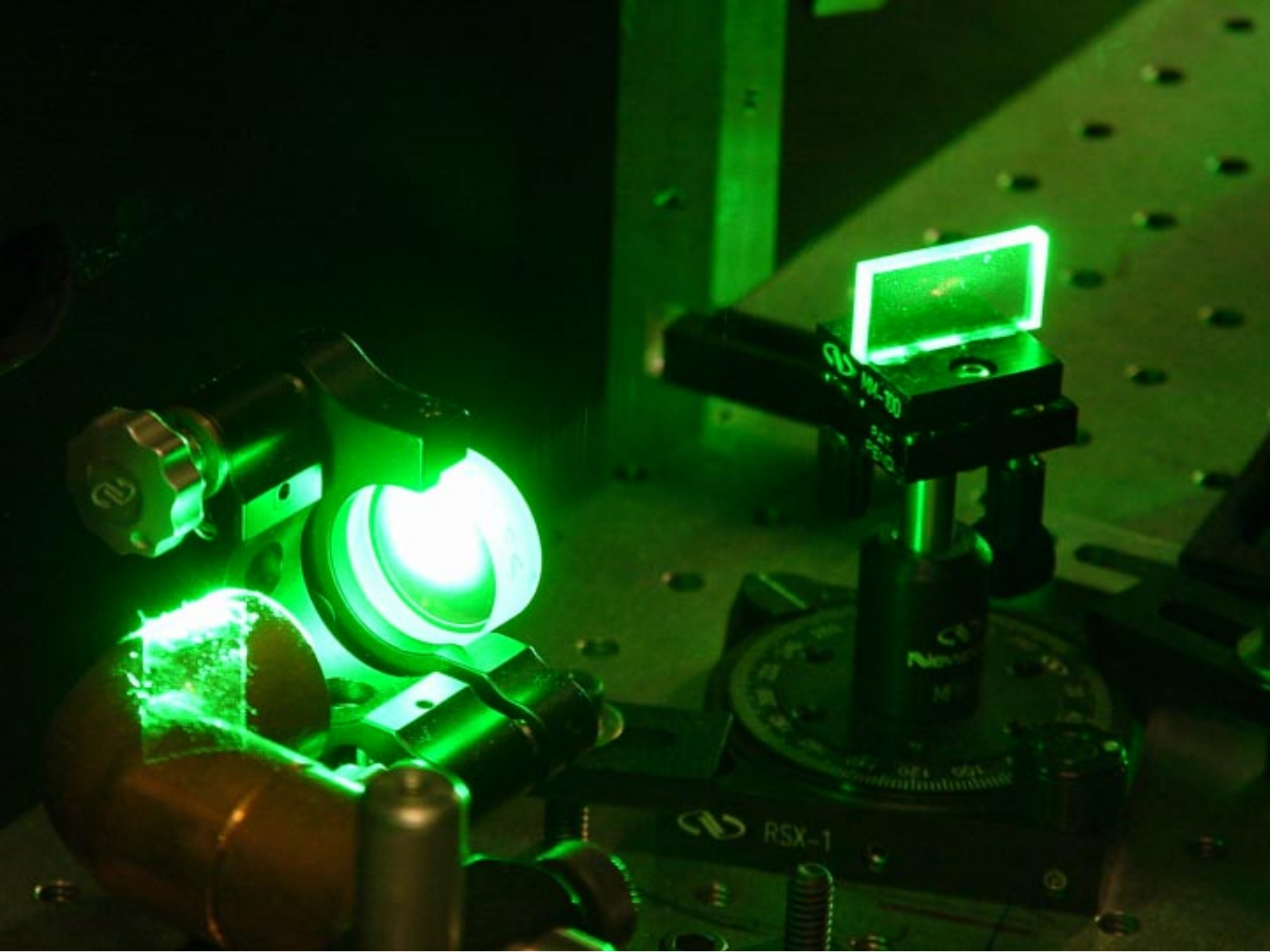




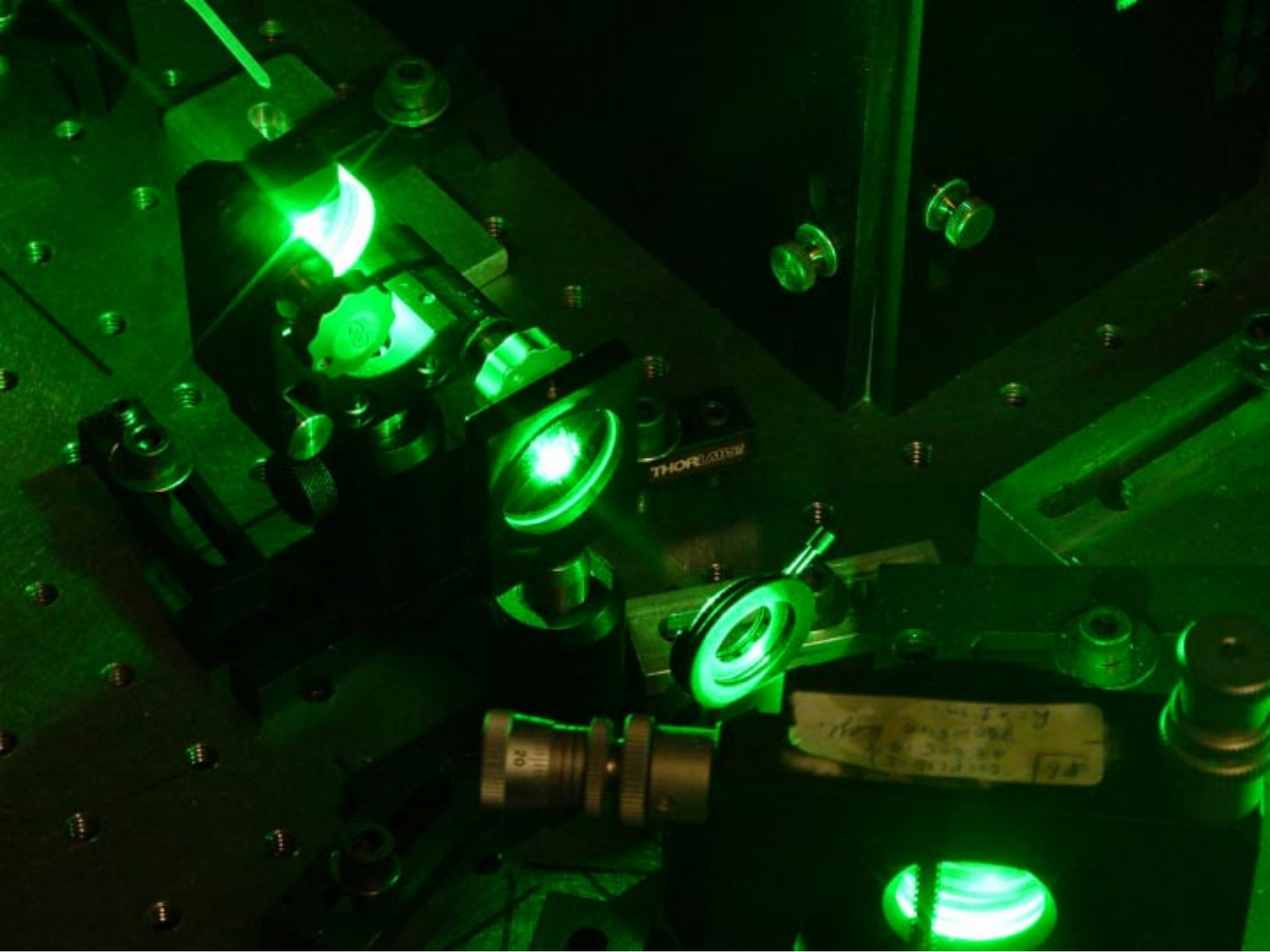


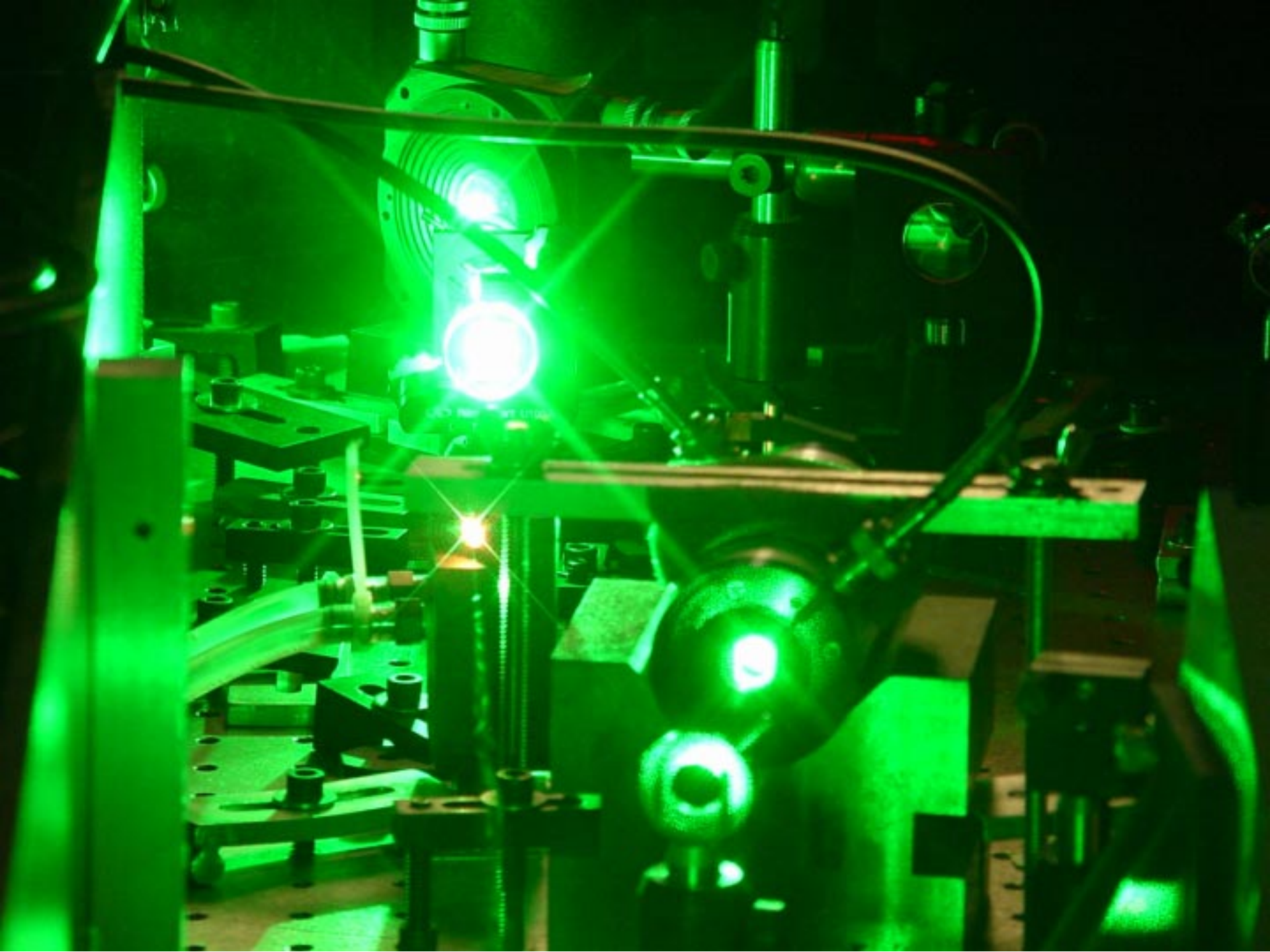




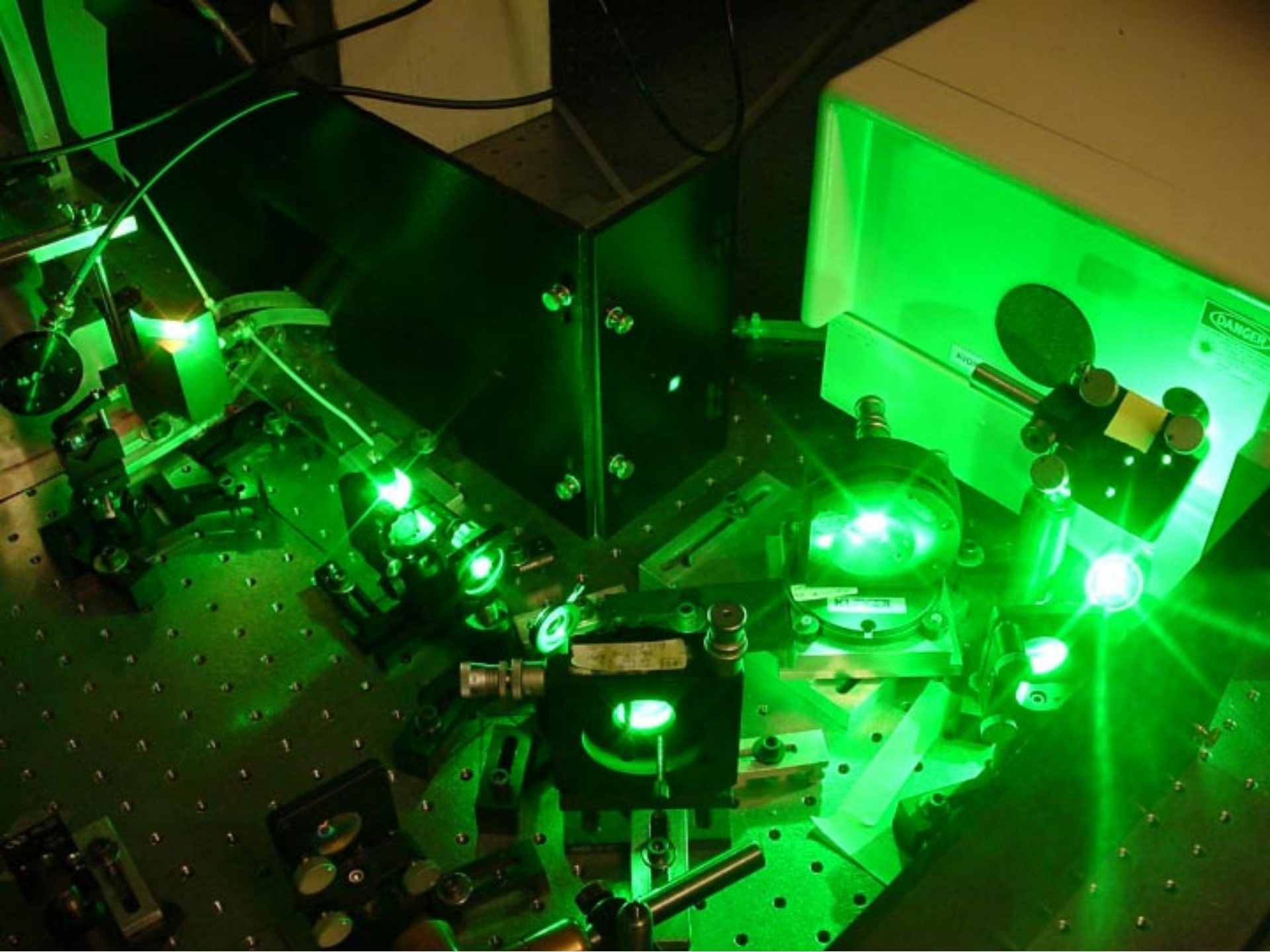




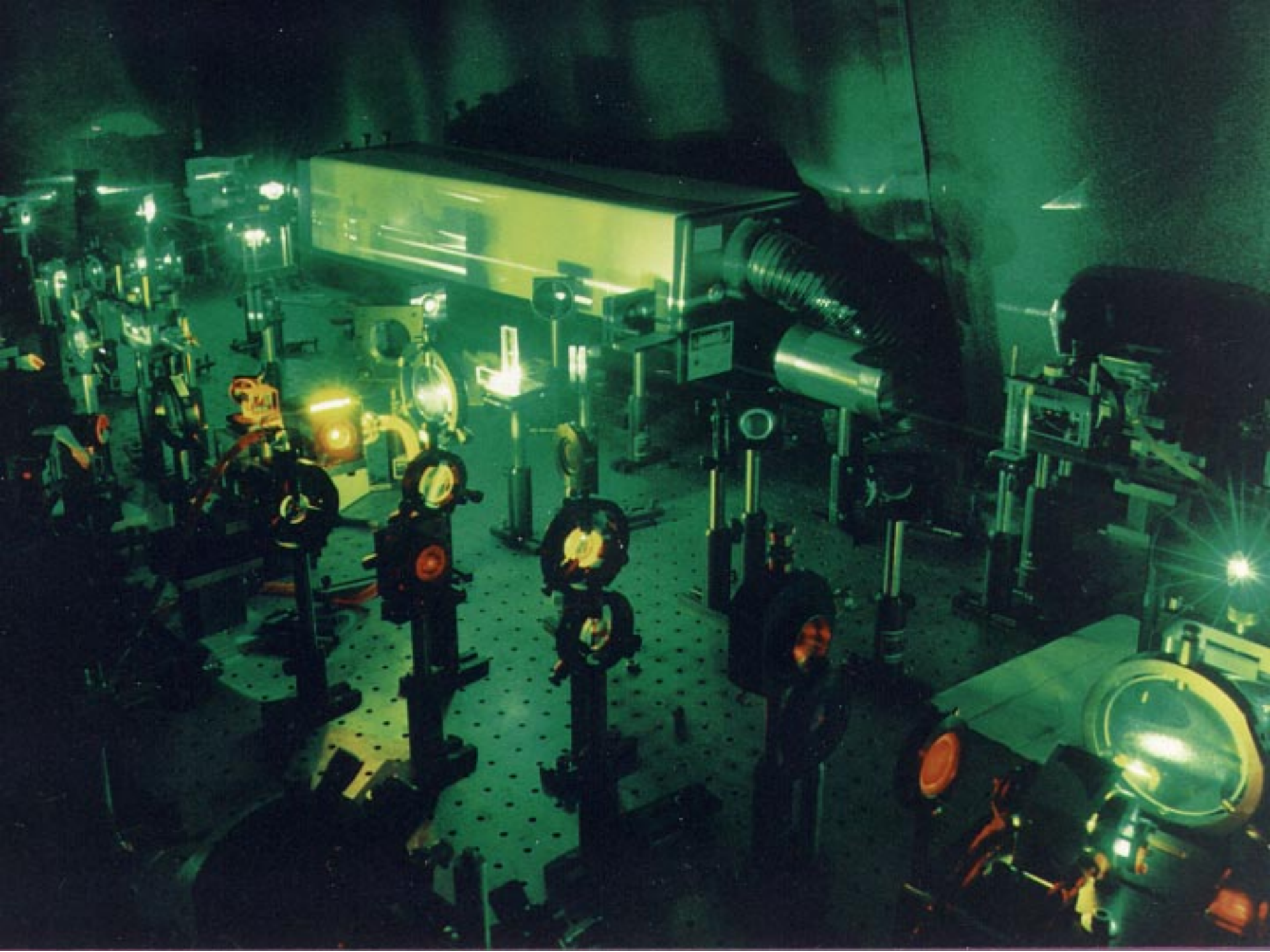


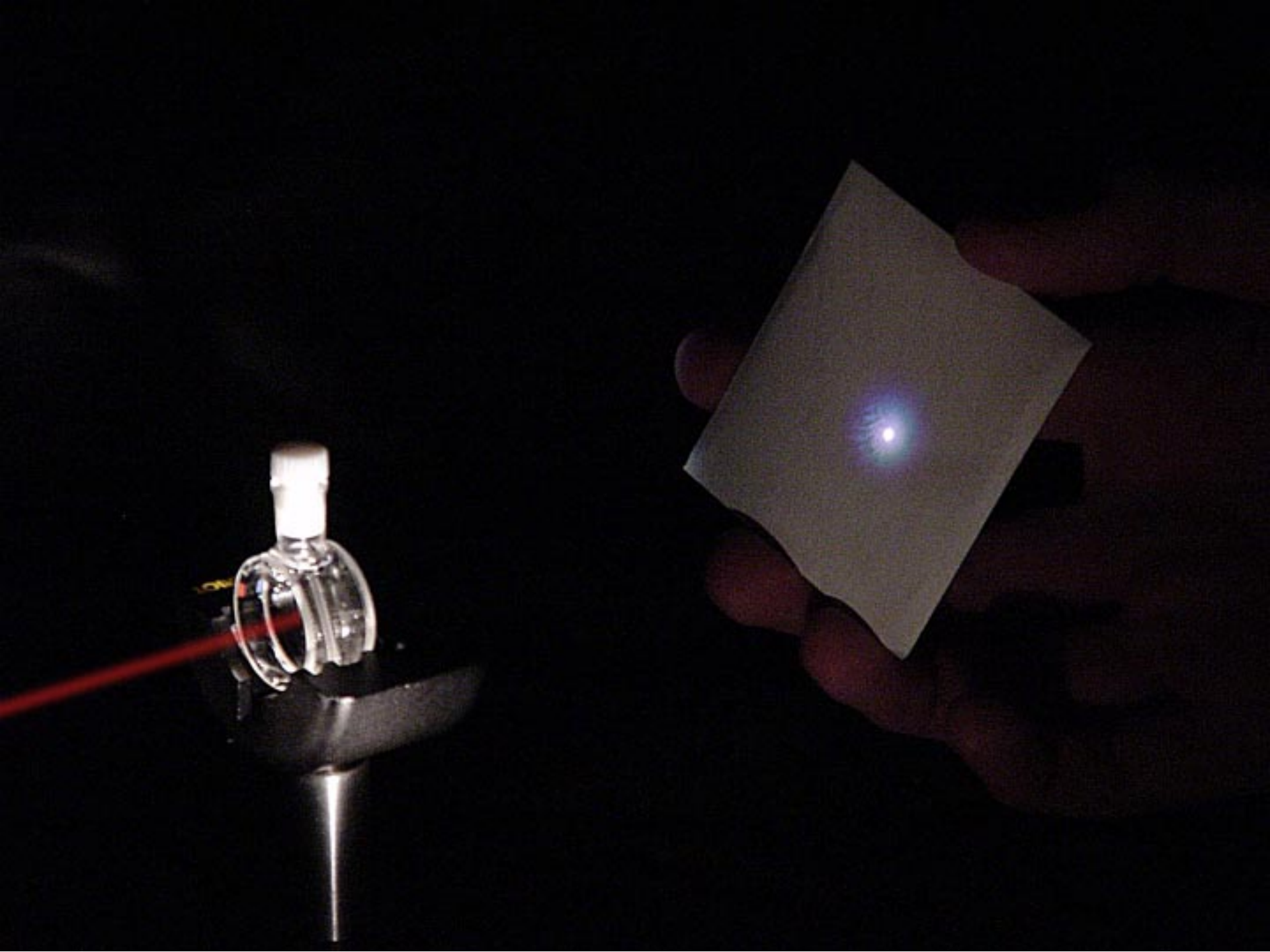




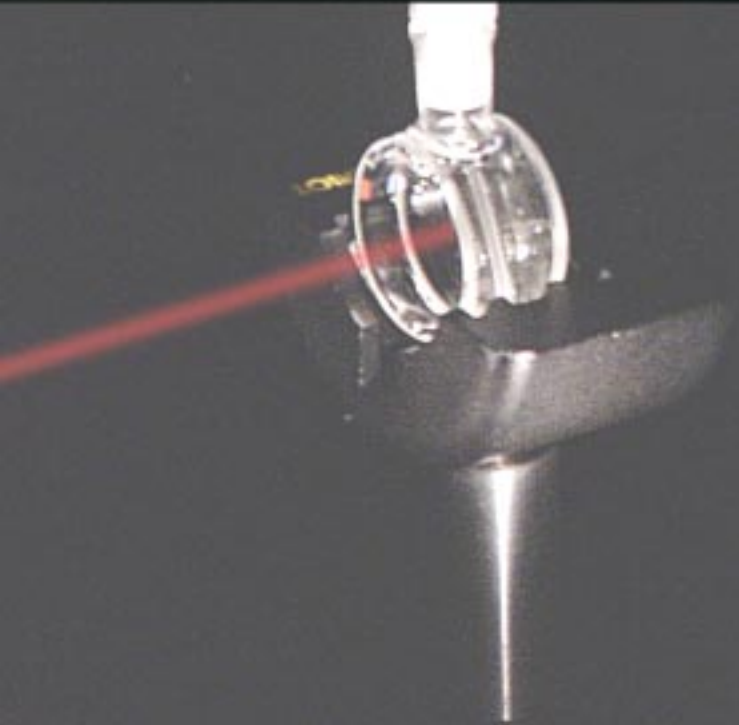


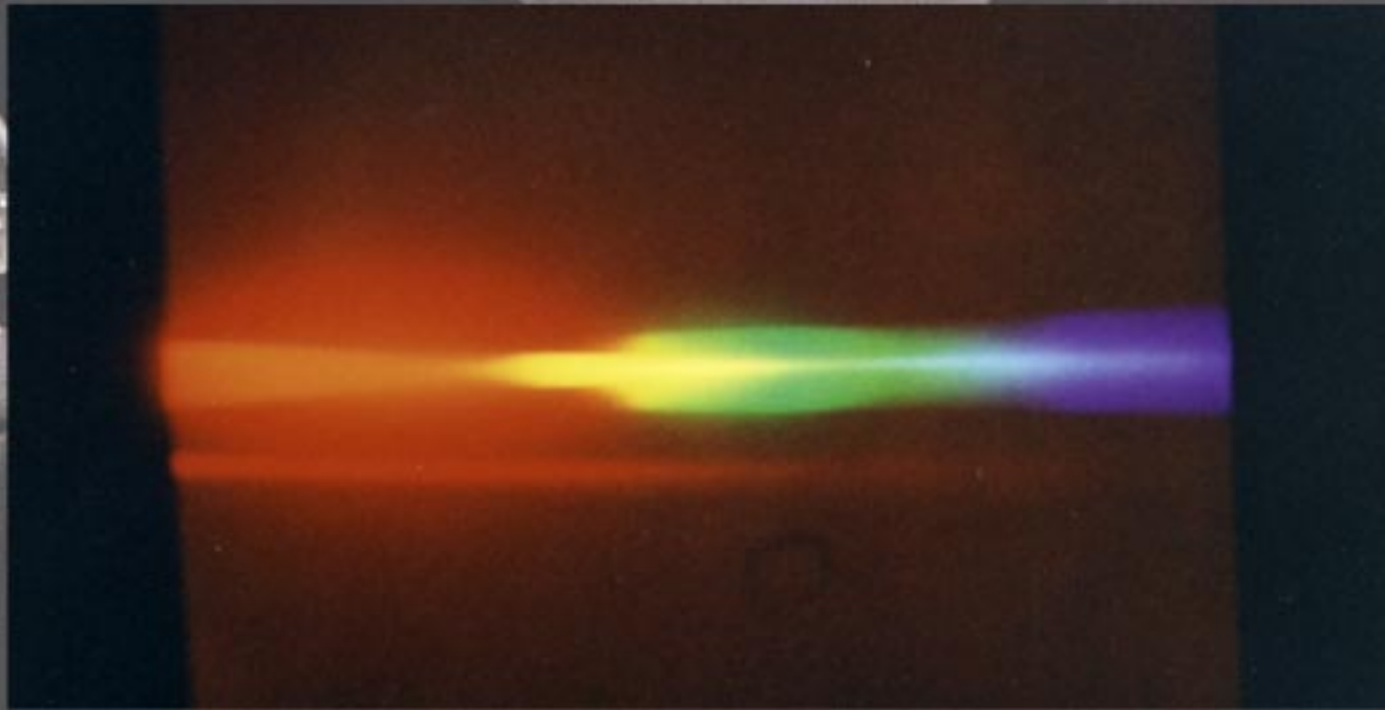








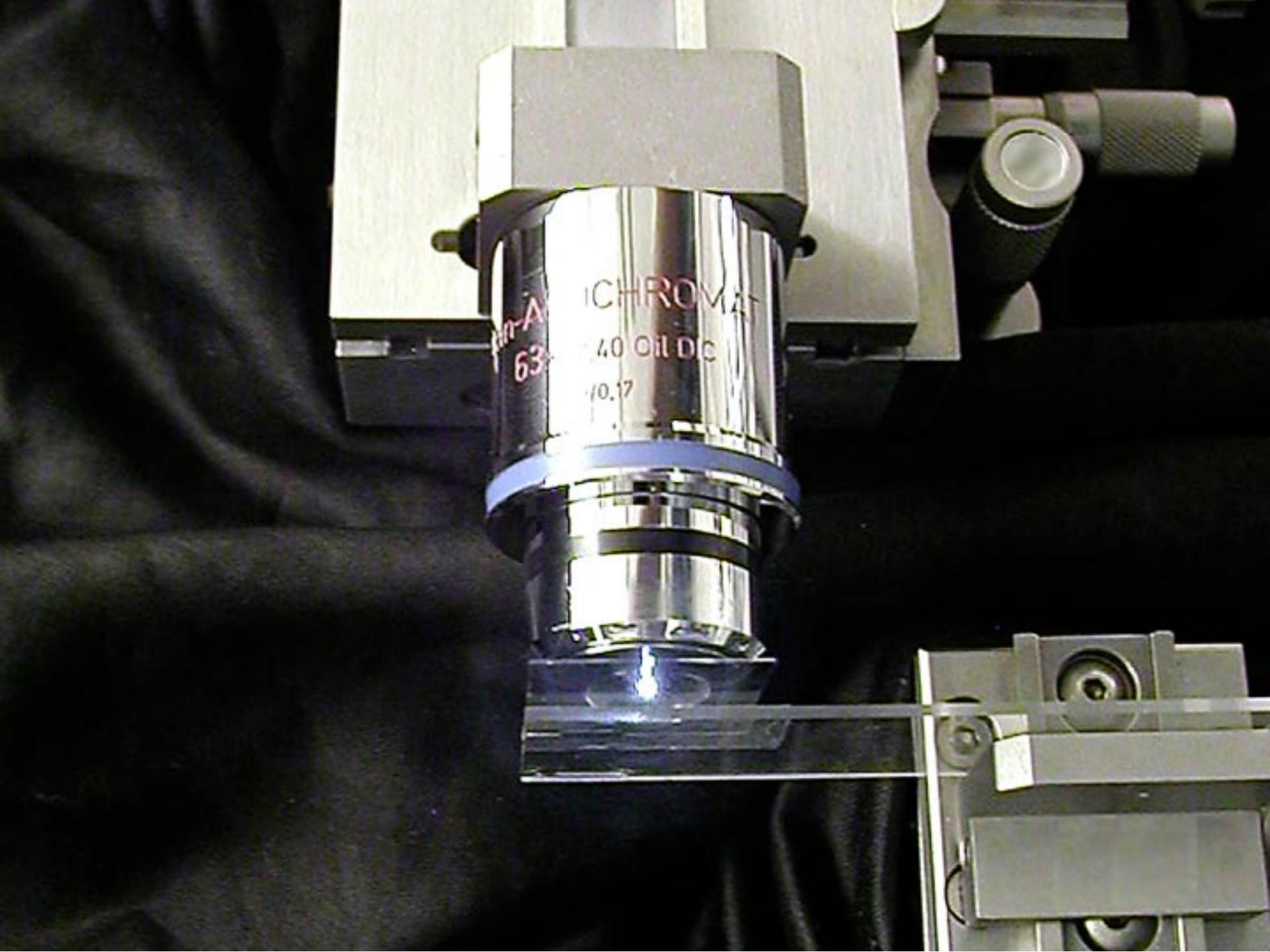




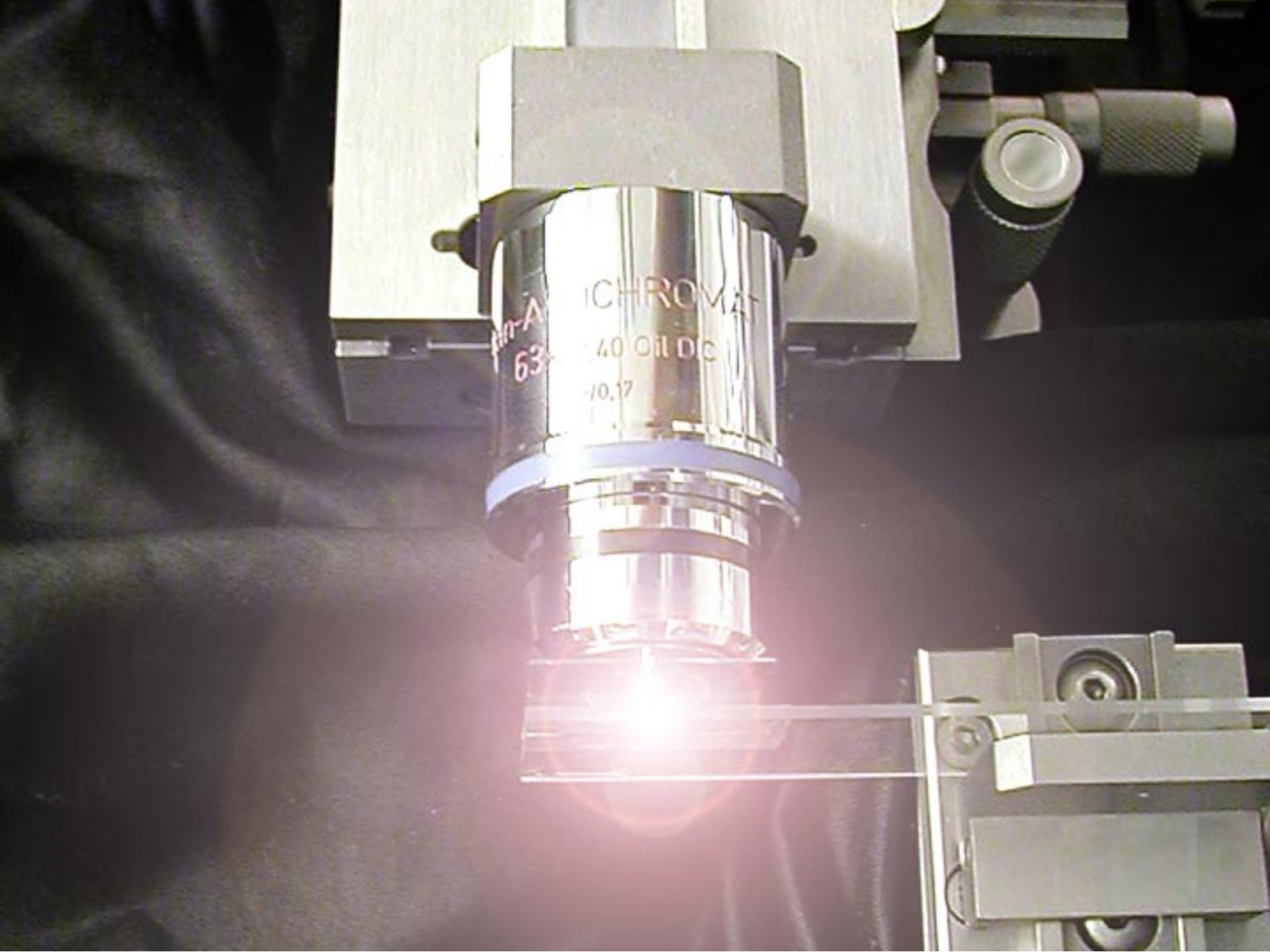


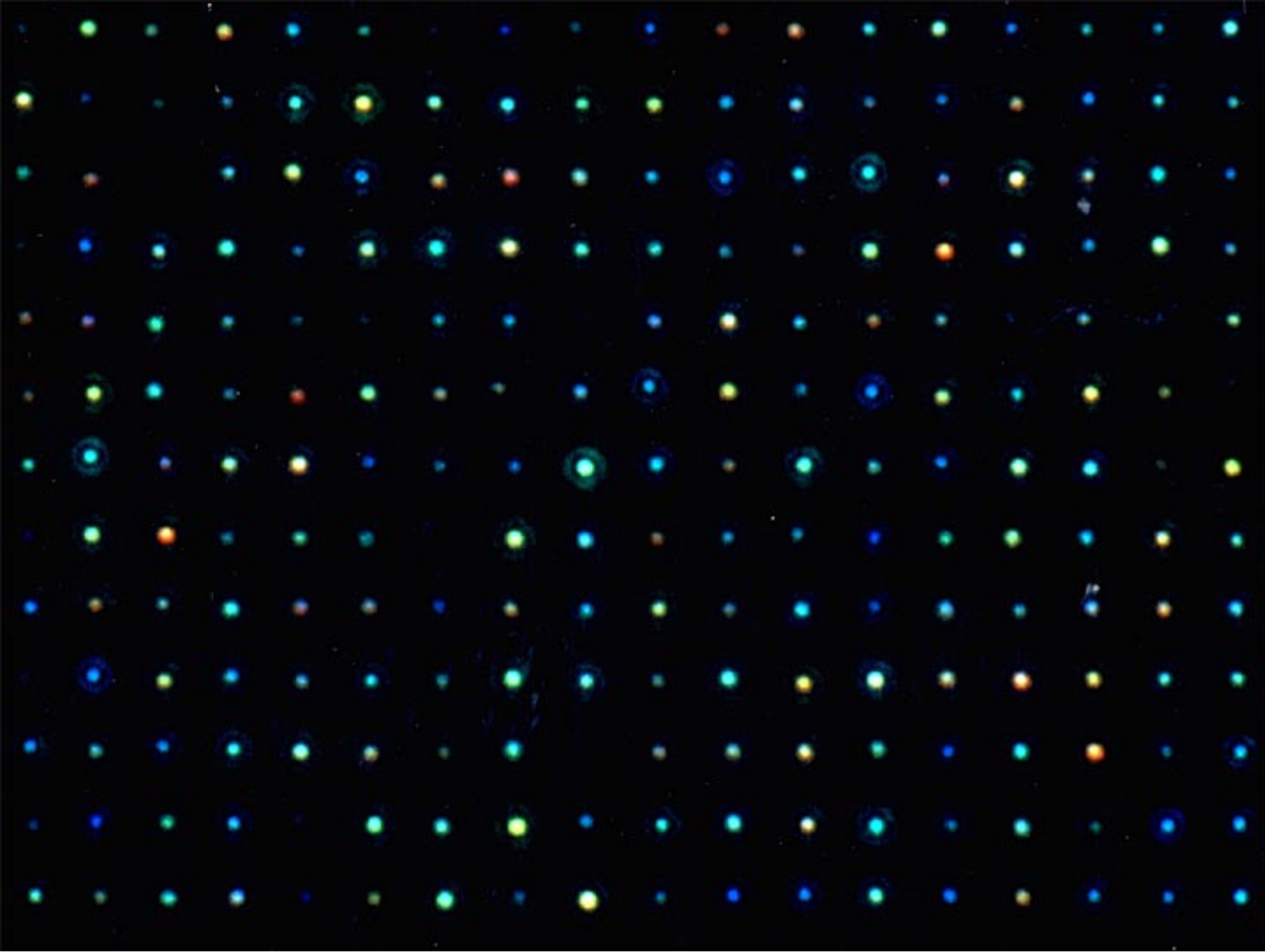


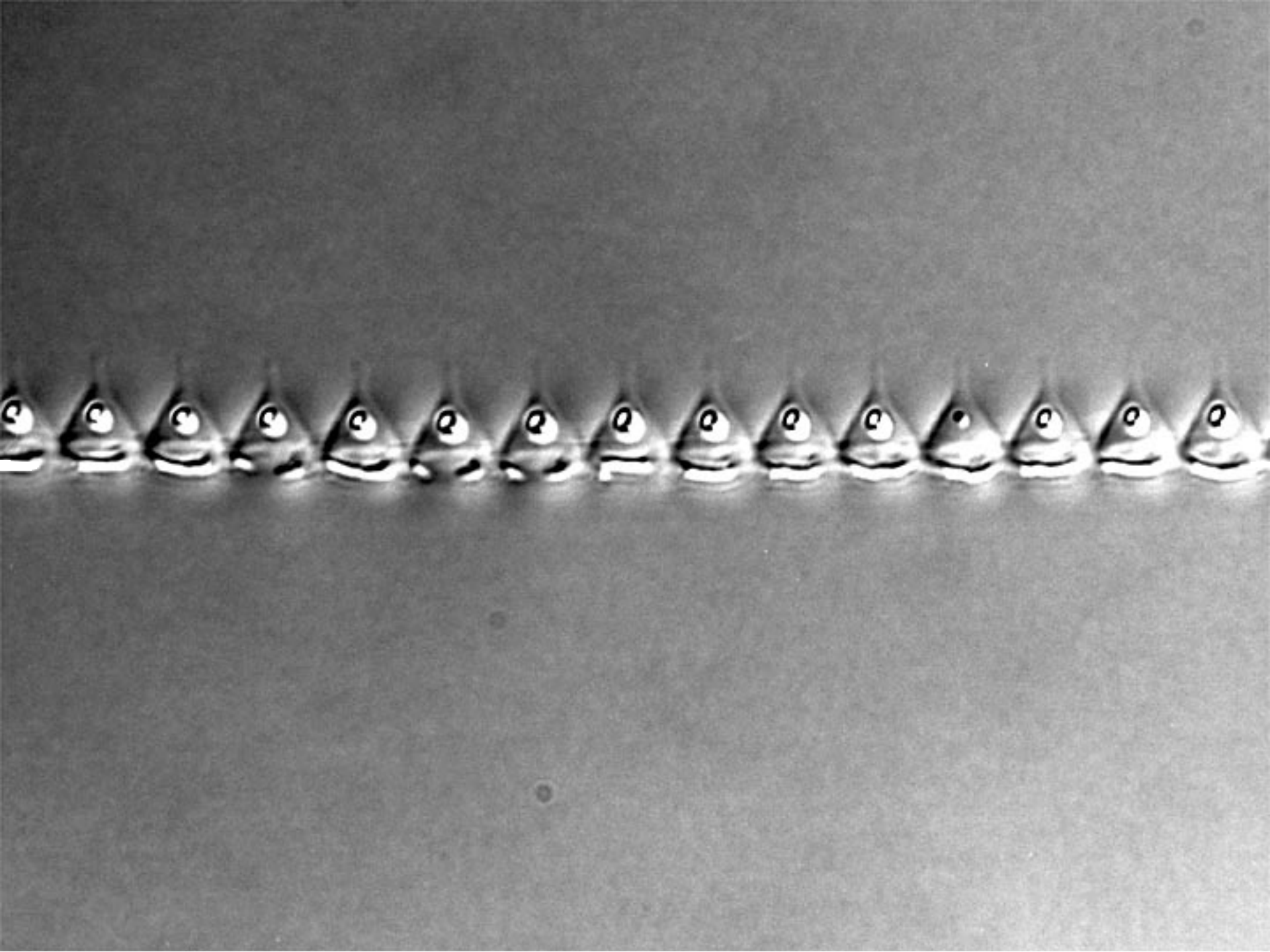




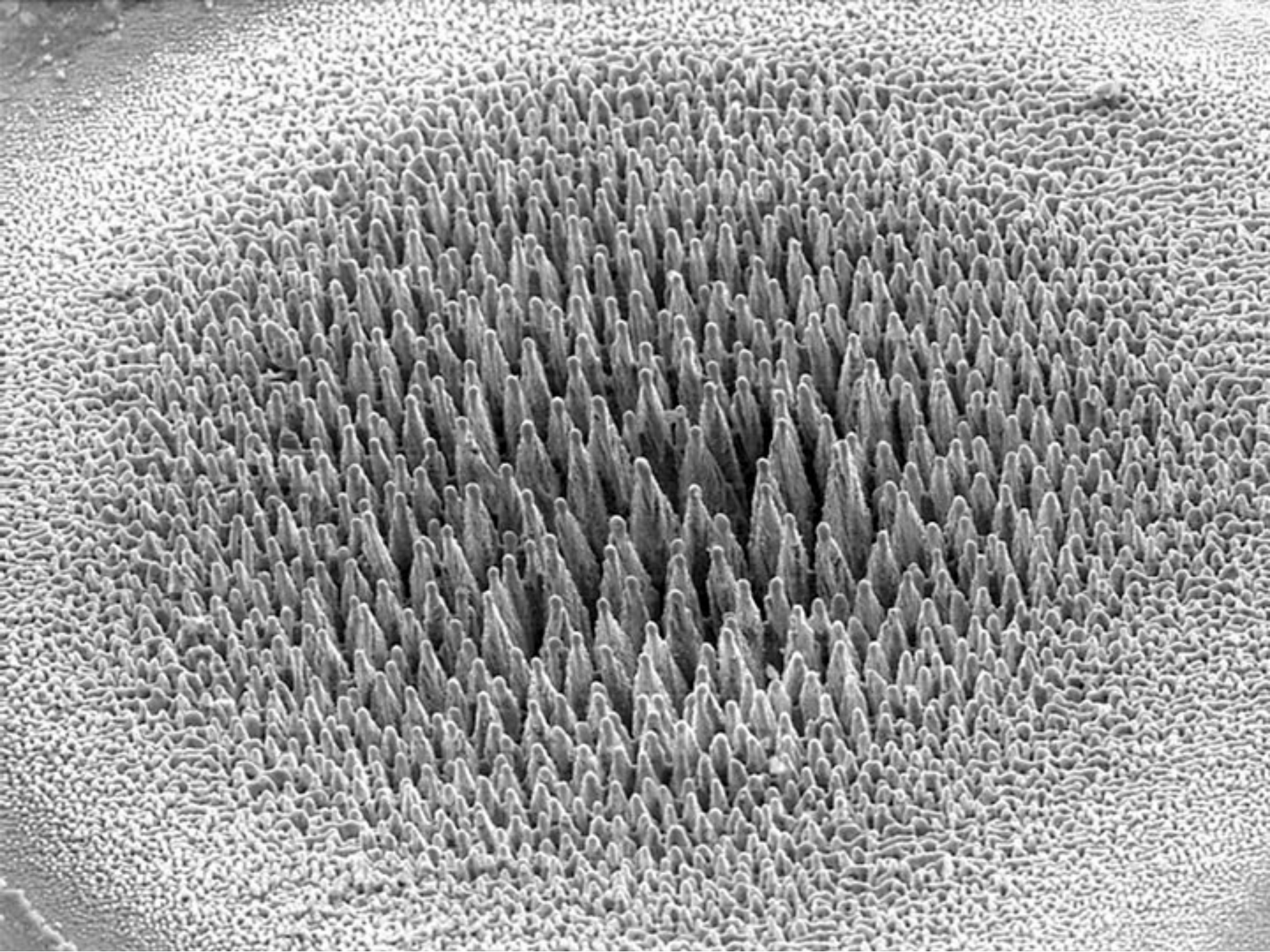


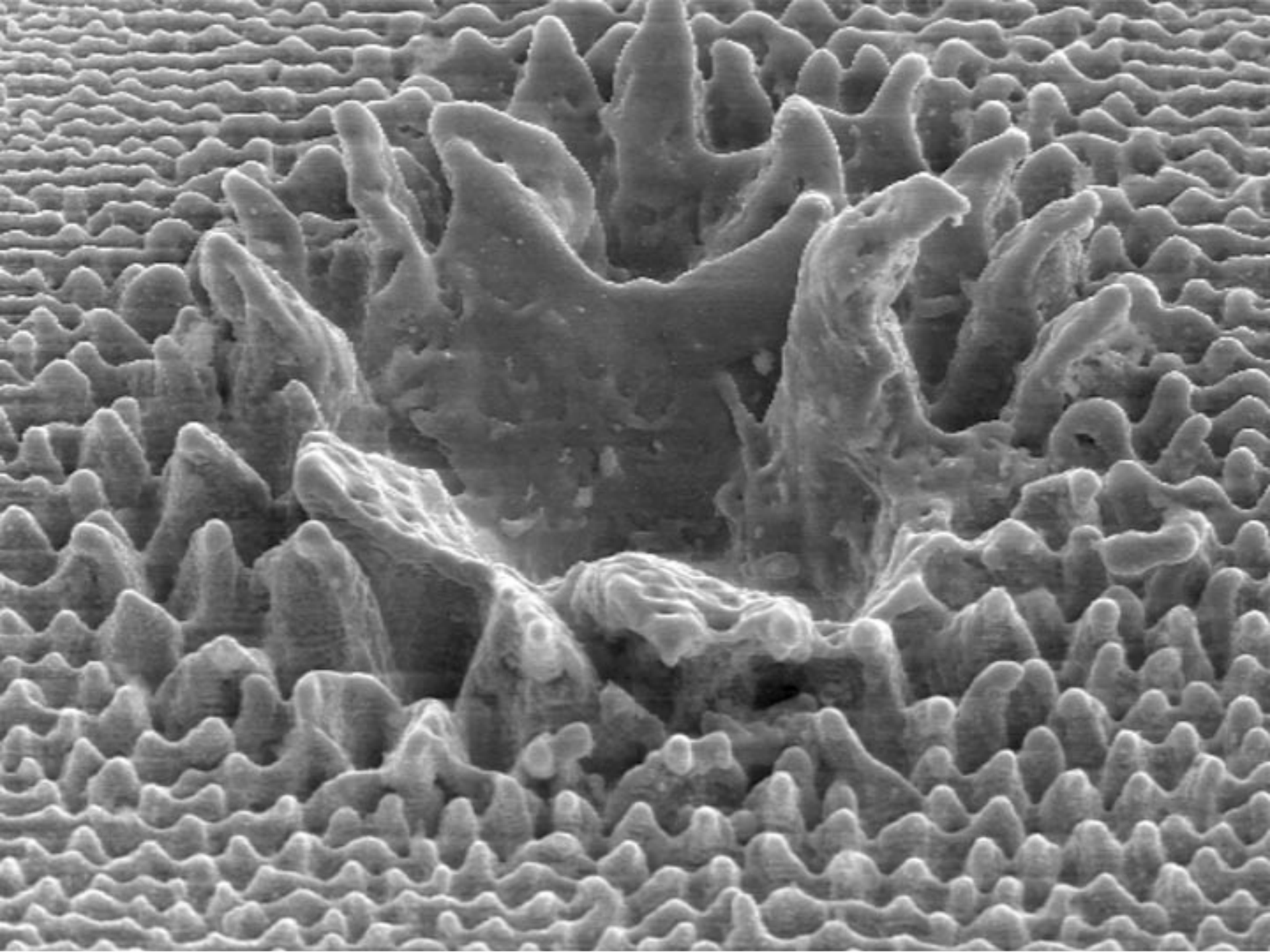






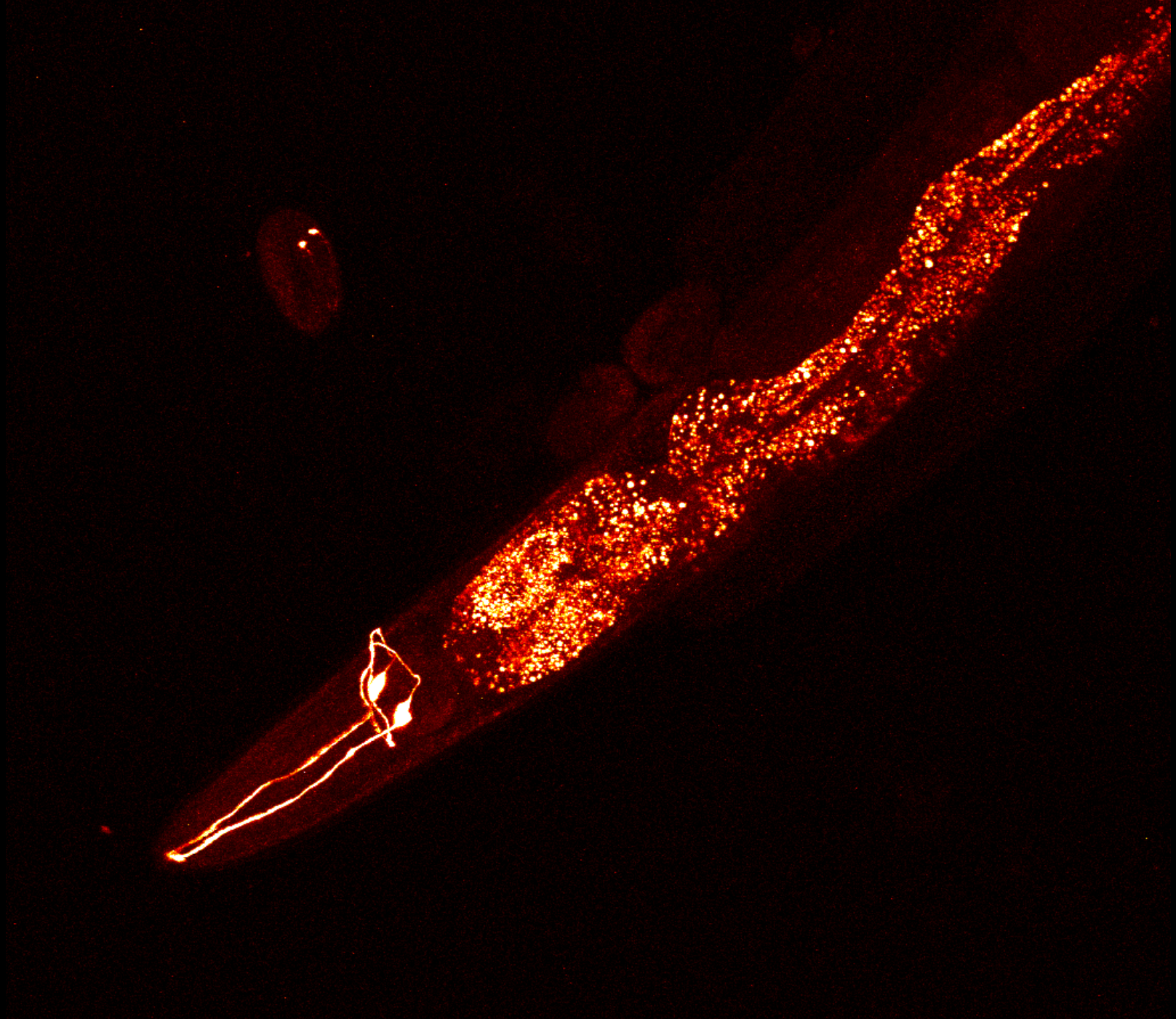






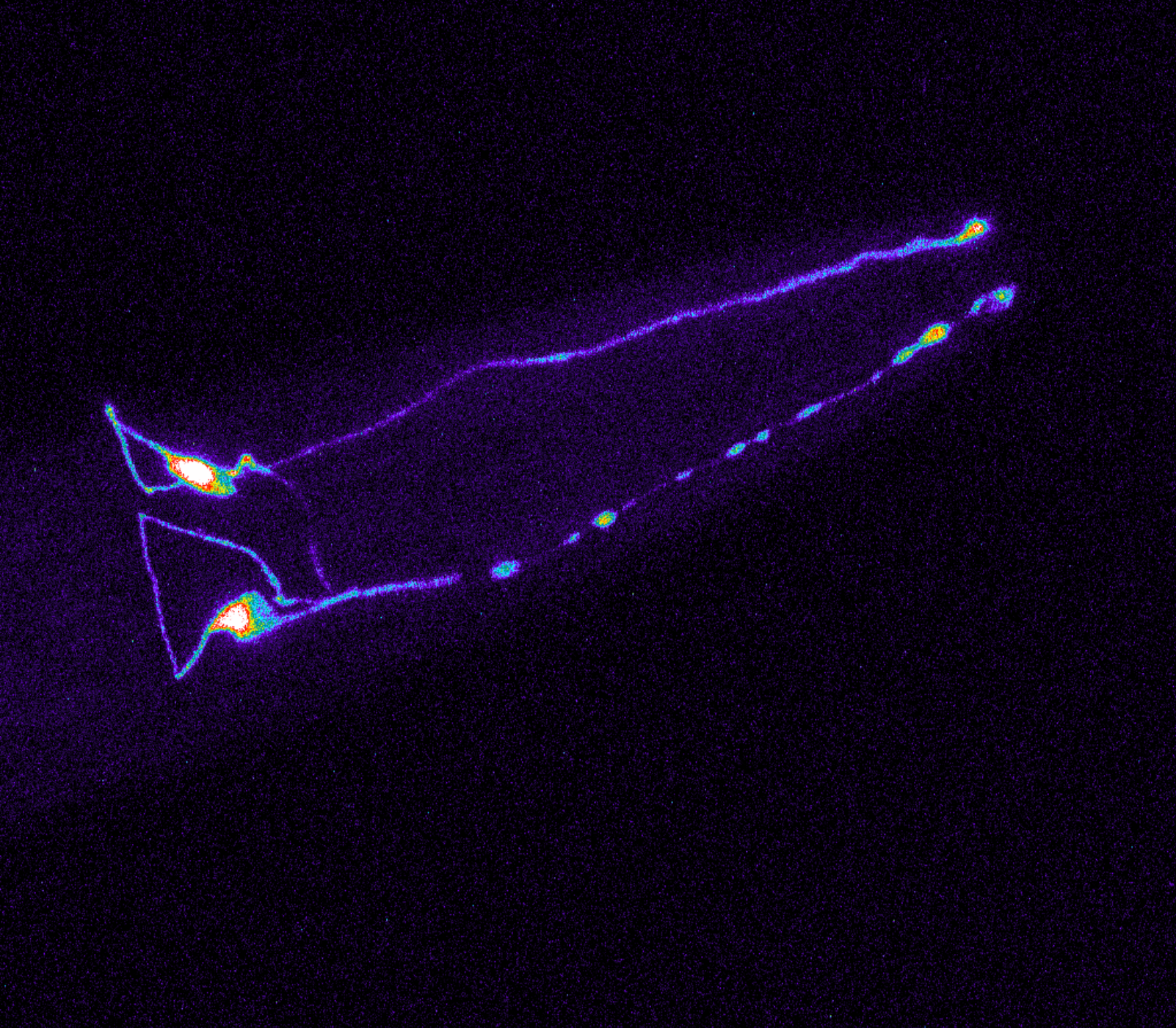


# Nanoneurosurgery

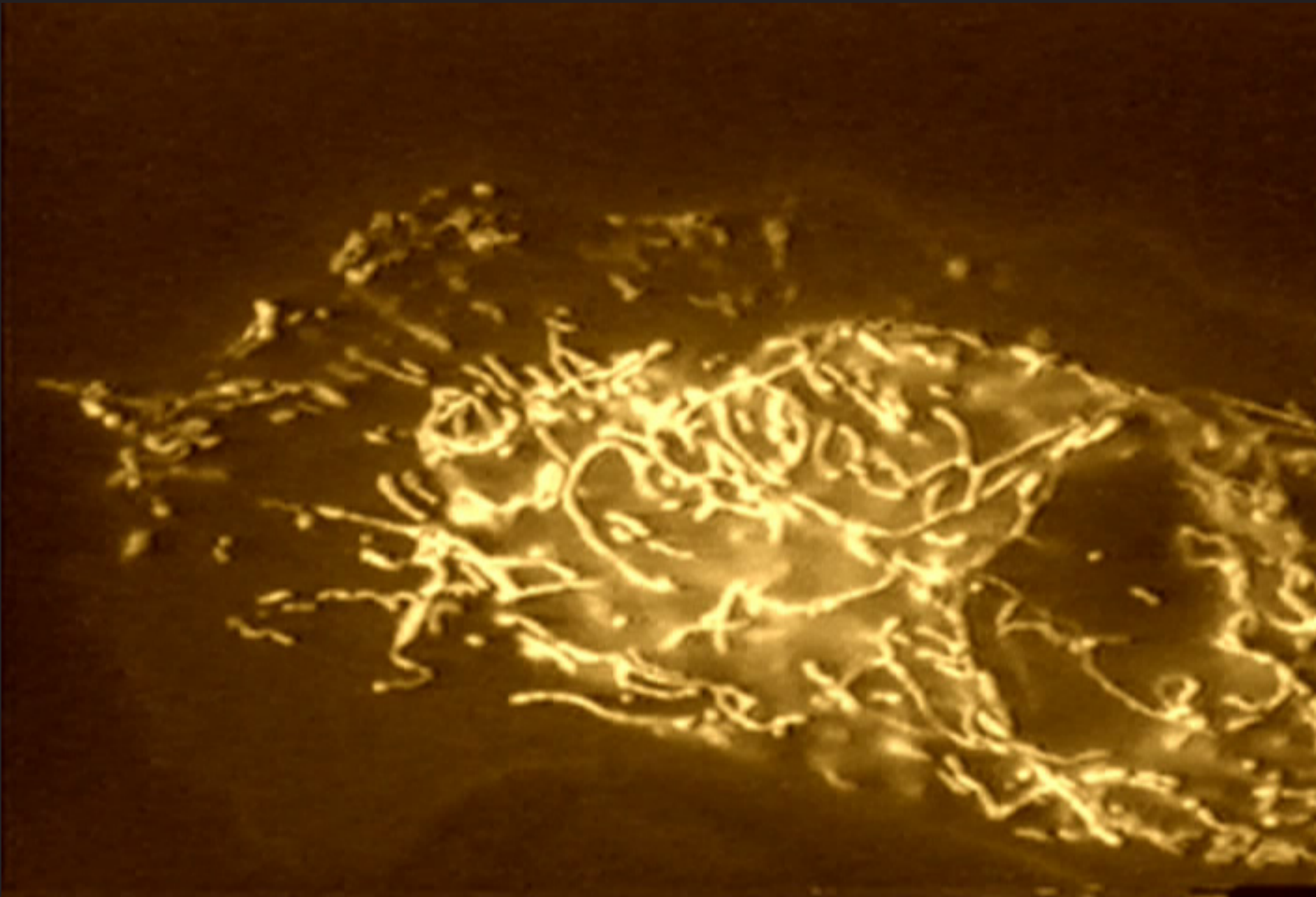




# Nanoneurosurgery









**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!**

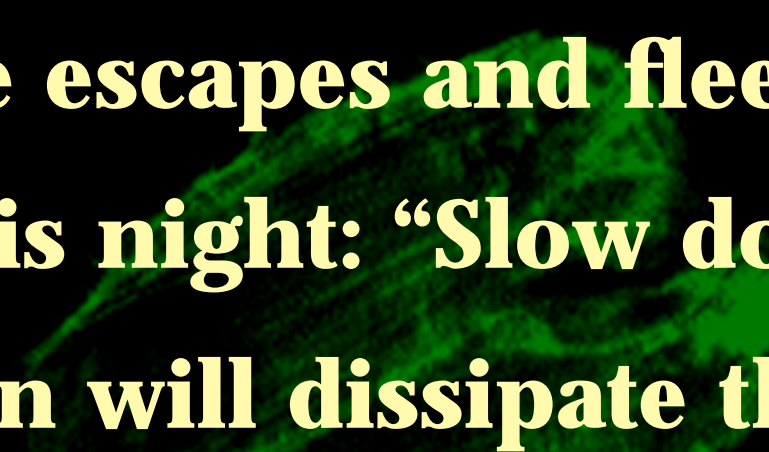
**Along with their days**

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

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