

***International Symposium on Contemporary
Physics***

***National Centre for Physics
Quaid-i-Azam University Campus, Islamabad***

Lasers - Light sources for the 21st Century

Martin Richardson

College of Optics & Photonics

CREOL & FPCE

University of Central Florida

Orlando Florida



College of Optics and Photonics

CREOL & FPCE

College of Optics and Photonics: CREOL & FPCE



Built in 1995
83,000 sq. ft.
85 labs
FULL!!

<http://www.creol.ucf.edu>

The College of Optics & Photonics at the University of Central Florida

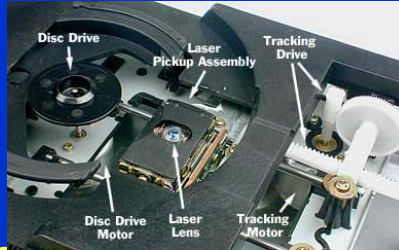


One of the three major optics graduate research schools in the USA

OPTICS IS AN ENABLING, PERVASIVE TECHNOLOGY . . .

In the Home

- TV remote
- CD player
- CD ROM
- Motion sensor
- Smoke detector
- Light bulbs
- Etc.



In Medicine

- Tattoo removal
- Various types of surgery
- Vision correction
- Various diagnostics
- Cosmetic surgery
- Blood monitors
- Etc.



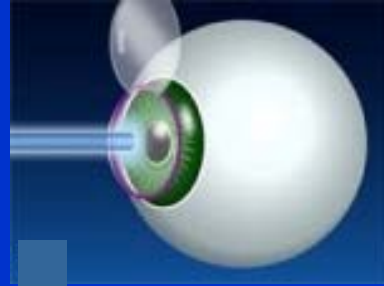
In the Economy

- Telecommunications
- Bar code scanners
- Surveying
- All sorts of manufacturing
- Crop dusting
- Entertainment
- Etc.



In National Defense

- Night vision
- Reconnaissance systems
- Communications
- Range finders
- Designators
- Smart weapons
- Etc.



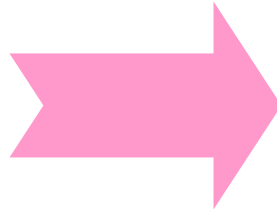
Photonic Engineering with Lasers

Nineteenth Century

The Electron



Excuse me... how can you discover a particle so small that nobody has ever seen one?



J.J. Thomson 1897

Twentieth Century

Electronic Engineering

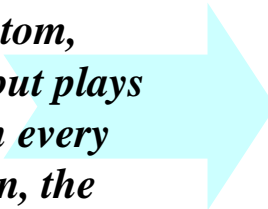


Twentieth Century

The photon

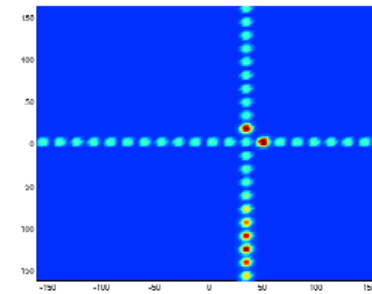


"I therefore take the liberty of proposing for this hypothetical new atom, which is not light but plays an essential part in every process of radiation, the name photon." Gilbert N. Lewis, Nature 1926

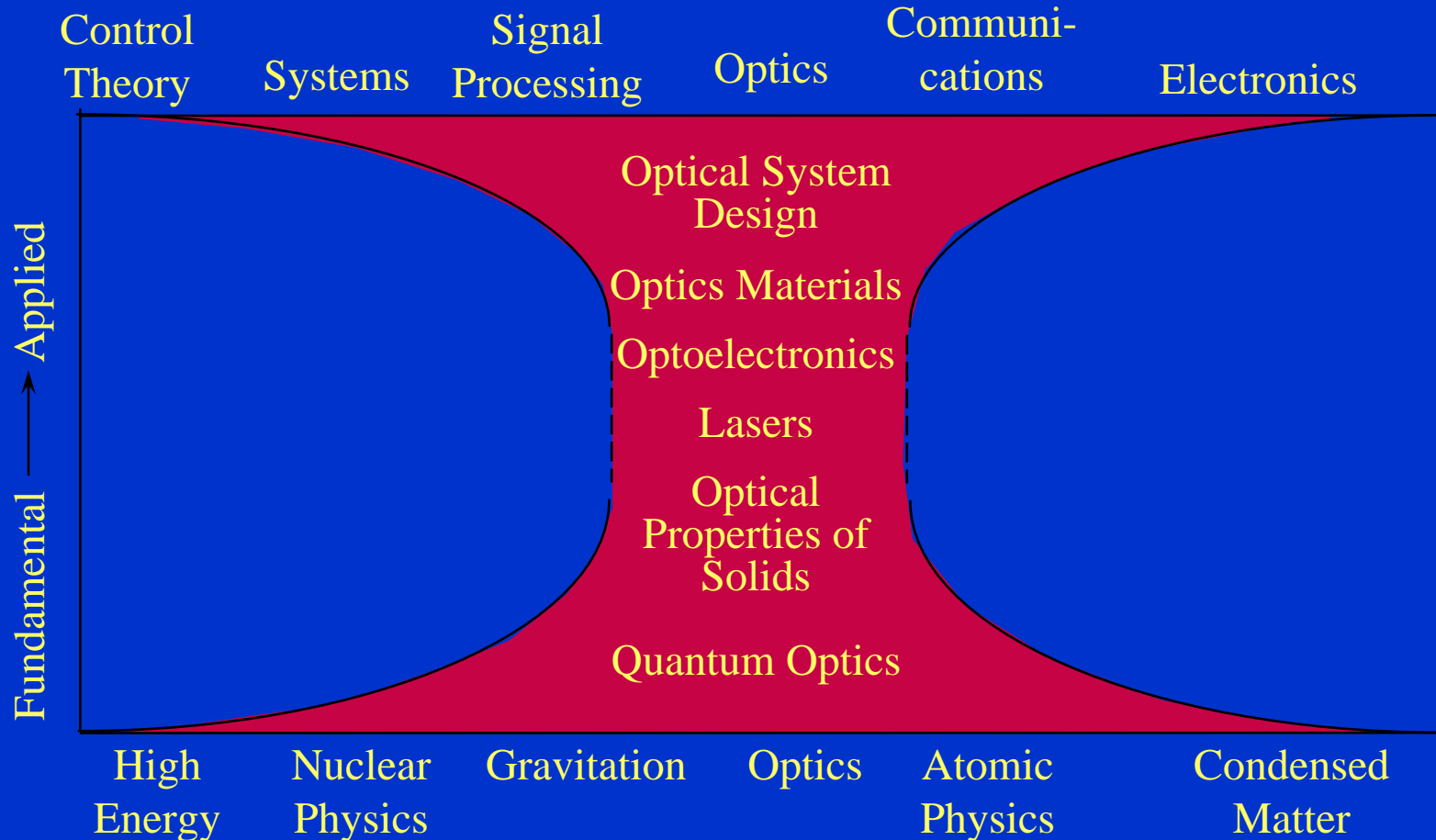


Twenty-first Century

Photonic Engineering



UCF's Academic Program Organized Along the "other" Axis



Personnel



Research Staff
45

Admin Staff
18

Students
150

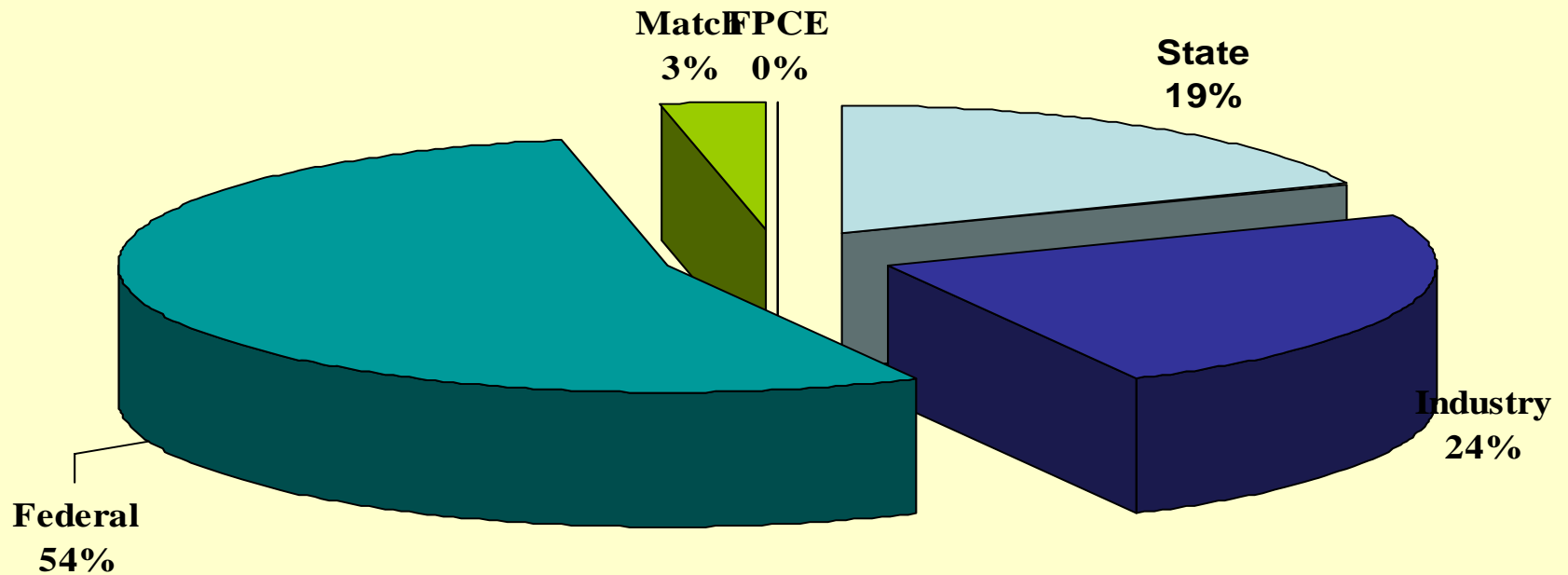
Research and
Associate Faculty
11

Faculty
26

Total Personnel
250

University of Central Florida

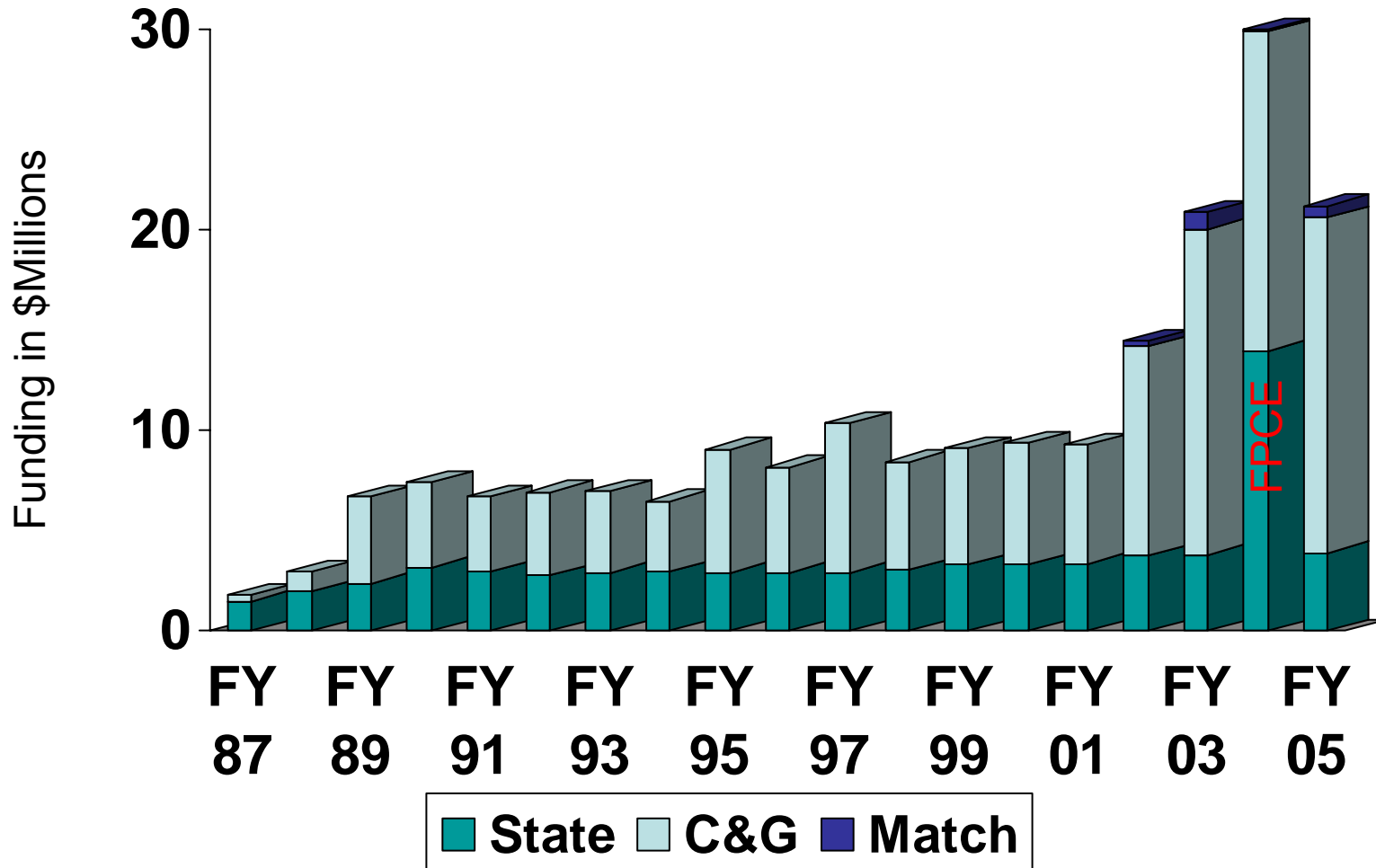
Source of Funding FY 06 (May 1)



Optics Courses

- ◆ OSE-505X Fund. and Appl. of Photonics
- ◆ OSE-5111 Optical Wave Propagation
- ◆ OSE-5115 Interference and Diffraction
- ◆ OSE-5143 Fiber Optics Communication
- ◆ OSE-5203 Geometrical Optics
- ◆ OSE-5234L Applied Optics Laboratory
- ◆ OSE-5312 Optical Properties of Materials
- ◆ OSE-5414 Fundamentals of Optoelectronics
- ◆ OSE-542X Integrated Optics
- ◆ OSE-5511 Laser Principles
- ◆ OSE-5630C Thin Film Optics
- ◆ OSE-6118 Optical Propagation in Inhomogeneous Media
- ◆ OSE-6211 Fourier Optics
- ◆ OSE-6225 Radiation and Detection
- ◆ OSE-6265 Optical Systems Design
- ◆ OSE-6335 Nonlinear Guided Wave Optic
- ◆ OSE-6347 Quantum Optics
- ◆ PHY-5455 Modern X-ray Science
- ◆ OSE-6334 Nonlinear Optics
- ◆ OSE-641XL Optoelectronic Device Fabrication Laboratory
- ◆ OSE-6432 Electro-optics
- ◆ OSE-6445 High Speed Photonics
- ◆ OSE-6455L Photonics Laboratory
- ◆ OSE-6457 Photonics Signal Processing
- ◆ OSE-6526L Laser Engineering Laboratory
- ◆ OSE-6528 Specific Laser Systems
- ◆ OSE-6534 Solid State Laser
- ◆ OSE-6560 Laser Engineering
- ◆ OSE-657X Optical Networks
- ◆ OSE-6644 Advanced Microlithography
- ◆ PHY-5455 Modern X-ray Science
- ◆ PHZ-5505 Plasma Physics
- ◆ MEA-5610 Laser Material Processing

Total Funding Received by Year



Faculty Research Topics

- ◆ IR Systems Technology
 - ◆ Optics Design Scattering
 - ◆ Diffractive Optics
 - ◆ Free-Electron Laser
 - ◆ Solid State Lasers
 - ◆ Optical Information Processing
 - ◆ Semiconductor Lasers
 - ◆ Nonlinear Optics & Limiting
 - ◆ NLO Characterization
 - ◆ High Speed Fiber Communication
 - ◆ Liquid crystals
 - ◆ Nano-photonics-Chem
 - ◆ Nano-photonics-Quantum dots
- G. Boreman
J. Harvey
M.G. Moharam
L. Elias
M. Bass
N. Riza
P. Delfyett
E. Van Stryland
D. Hagan
G. Li
S.T. Wu
S. Kuebler
W. Schoenfeld

- ◆ Nonlinear Guided-wave Optics
 - ◆ Laser Induced Damage
 - ◆ Quantum Well Optoelectronics
 - ◆ X-ray Sources, Lithography
 - ◆ Ultrashort Pulse, X-rays, Plasma Physics
 - ◆ Laser Processing of Materials
 - ◆ Theory of Light/Matter Interactions
 - ◆ Virtual Reality & 3D Imaging Systems
 - ◆ Optical Diagnostics, Scattering
 - ◆ Diffractive optics for Telecom.
 - ◆ Photorefractive glass
 - ◆ Lasers and host crystal growth
 - ◆ OPTICS!
 - ◆ Soliton theory for telecom
 - ◆ Nano-photonics
- G. Stegeman
M.J. Soileau
P. LiKamWa
W. Silfvast
M. Richardson
A. Kar
B. Zel'dovich
J. Rolland
A. Dogariu
E. Johnson
L. Glebov
H. Jensen
E. Wolf
D. Christodoulides
P. Kik

Joint Faculty Research Topics

- Atmospheric propagation
 - Polymeric optical materials
 - Far Infrared semiconductor lasers
 - Propagation through random media
 - Raman Spectroscopy
 - Computer vision
 - “spray cooling” of diode laser bars
 - Nano-particle chemistry
 - Soliton theory
 - X-ray sources for material characterization
 - Glass Sciences
 - Crystal Growth
 - Nanophotonics
 - Nanophotonics
- L. Andrews, Math
 - K. Belfield, Chemistry
 - R. Peale, Physics
 - R. Phillips, ECE
 - A. Schulte, Physics
 - M. Shah, ECE
 - L. Chow, MMAE
 - F. Hernandez, Chemistry
 - D. Kaup, Math
 - C. Siders
 - K. Richardson
 - B. Chai
 - S. Kuebler, Chemistry
 - K. Busch, Physics

Research Experiences for Undergraduates (REU) Program

- Brings students from all over USA to work on research projects in CREOL labs.
- Supplemental programs include optics and laser classes, industrial visits, special seminars, research tutorials, ethics...
- Funded by NSF (cumulative >\$1M since 1991)
- New International REU program - US students travel to labs abroad, Foreign students invited to CREOL - First ever such program



New NanoPhotonics Systems Fabrication Facility

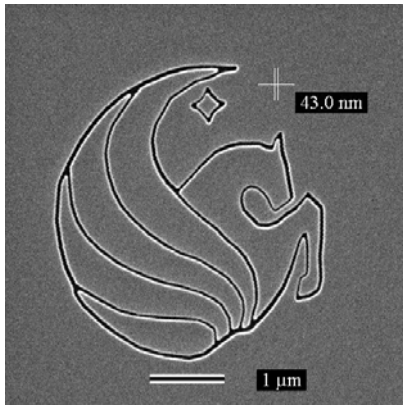
3,000 sq ft clean room
Class 100/1000

resource center for univ &
user facility for industry.

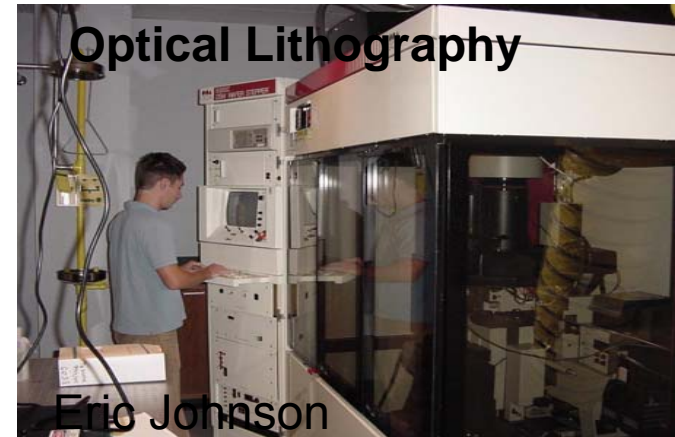


Leica 5000 + e-beam lithography
1 of 3 in the country
10 nm resolution!

Nano-Photonics Systems Fabrication Facility



3,000 sq. ft of class 100-1000
cleanroom space
(\$1.5M + \$5M equipment):
Serves as a resource center
- user facility for industry



Optical Lithography

Eric Johnson

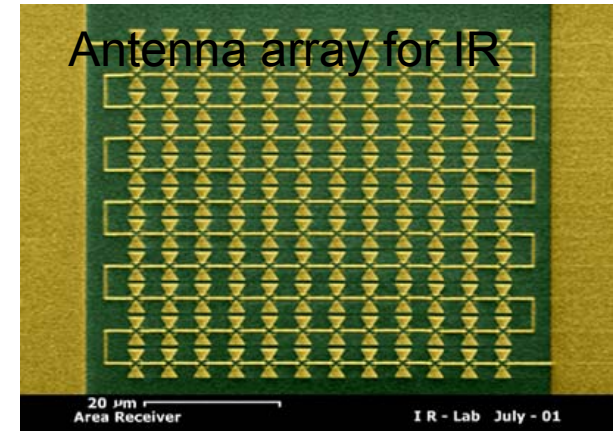
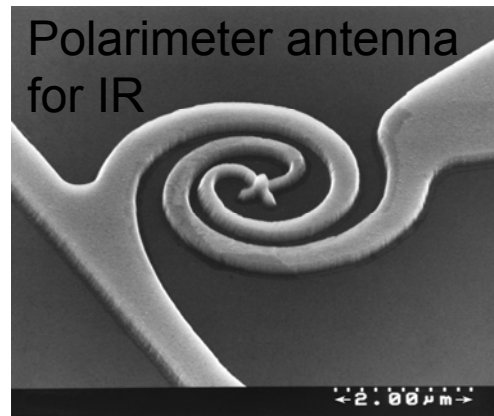
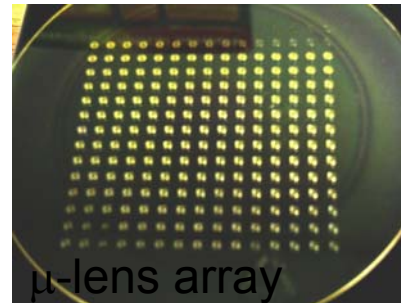
Optical and e-beam lithography to 10 nm



Infrared Systems Lab

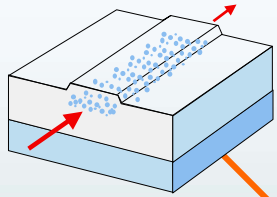
Glenn Boreman

- Antenna-Coupled IR Detectors
- IR Frequency-Selective Surfaces

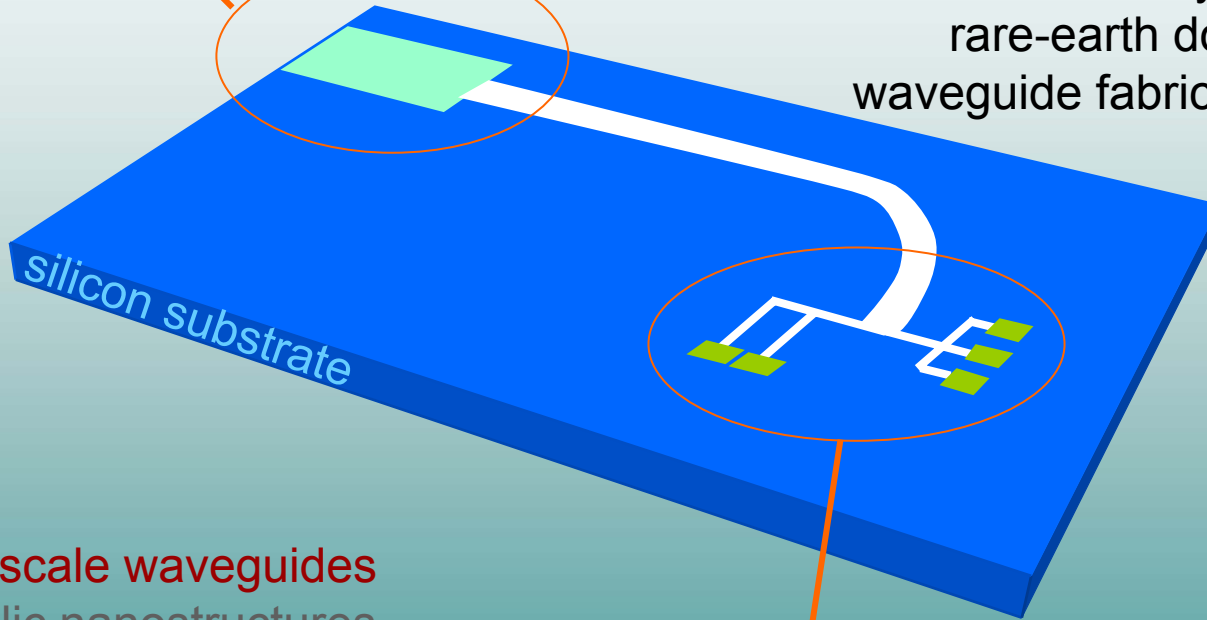


Wavelength-tunable and
polarization-tunable
antennas, leading to, e.g. pixel
integrated spectrometers

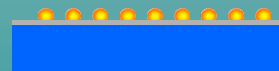
Nanophotonics and Near-field Optics



Nanostructured optical gain media
semiconductor nanocrystals
rare-earth doping
waveguide fabrication



Nanoscale waveguides
metallic nanostructures
e-beam lithography
electromagnetic modeling (FDTD)



**Near-field Scanning
Optical Microscopy**
waveguide mode mapping
local surface plasmon excitation
high-resolution lithography



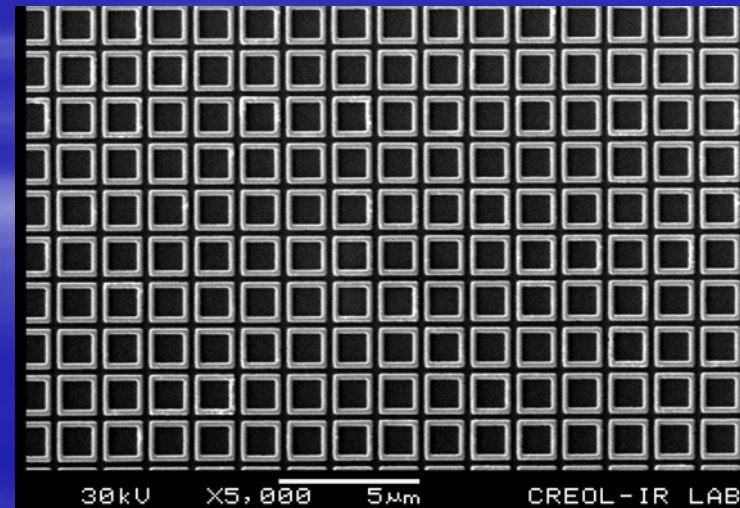
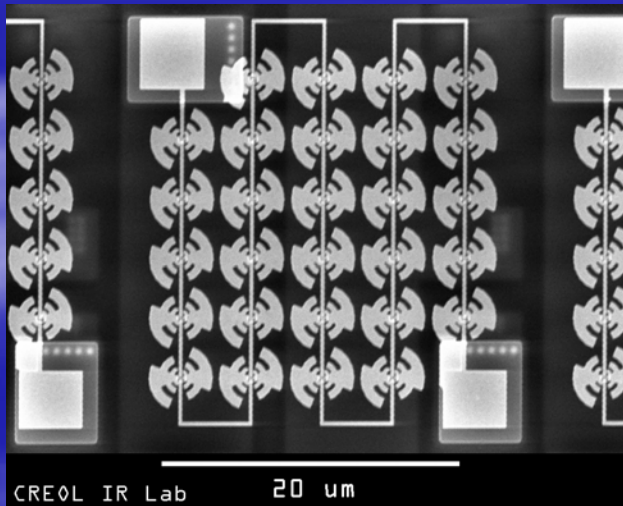
More information: <http://kik.creol.ucf.edu>

New Lithography fabricated IR optics

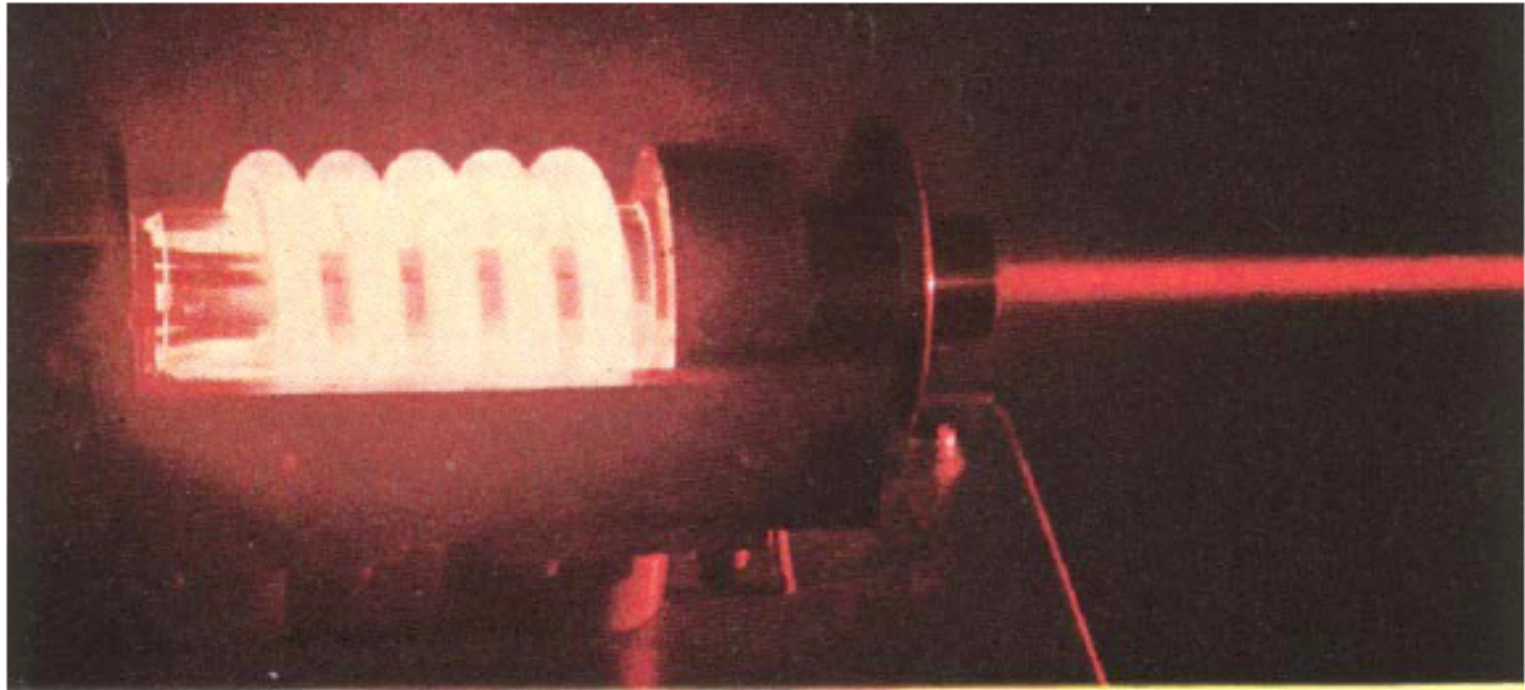
(Glenn Boreman, CREOL)

Extension of RF concepts to IR through advanced lithography

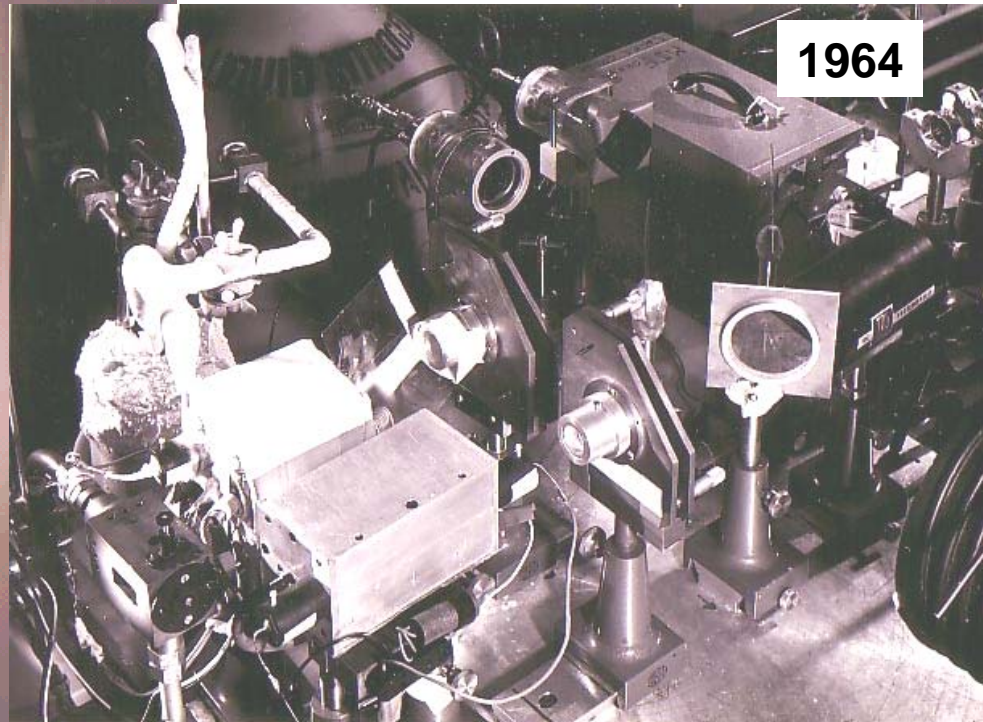
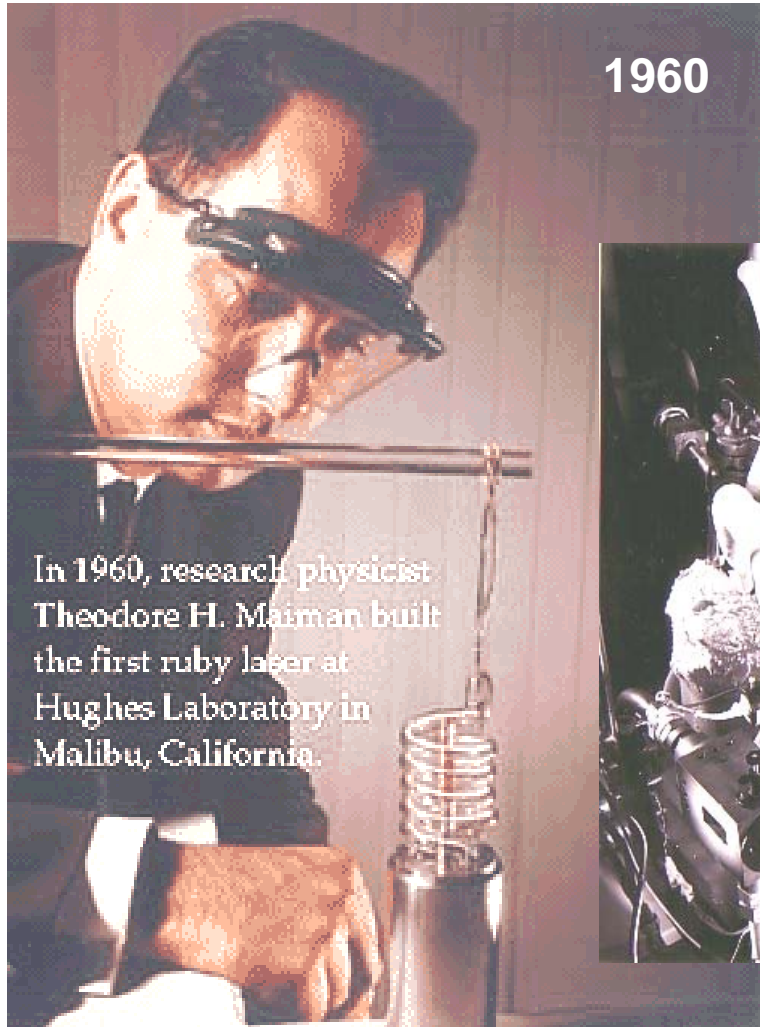
- Antenna-Coupled IR Detectors
- IR Frequency-Selective Surfaces
- THz & mm-Wave Sensors



May 17, 1960: Ted Maiman's ruby laser



The Ruby Laser

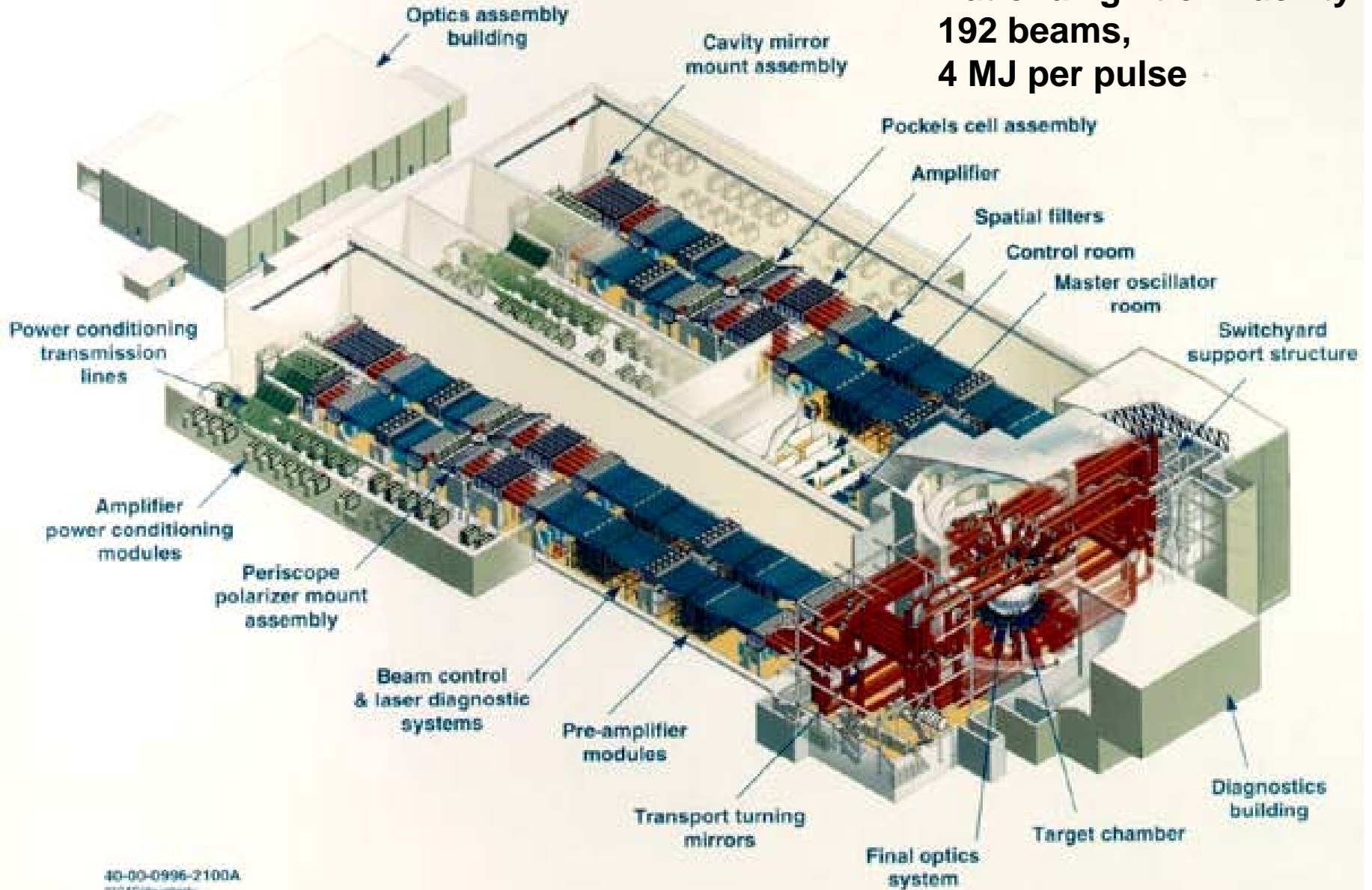


A solution looking for a problem!



THE LARGEST LASER IN THE WORLD

National Ignition Facility
192 beams,
4 MJ per pulse



SINGLE ATOM LASER

"Experimental realization of a one-atom laser in the regime of strong coupling," J. McKeever, A. Boca, A. D. Boozer, J. R. Buck and H. J. Kimble, [Nature 425, 268 \(2003\)](#).

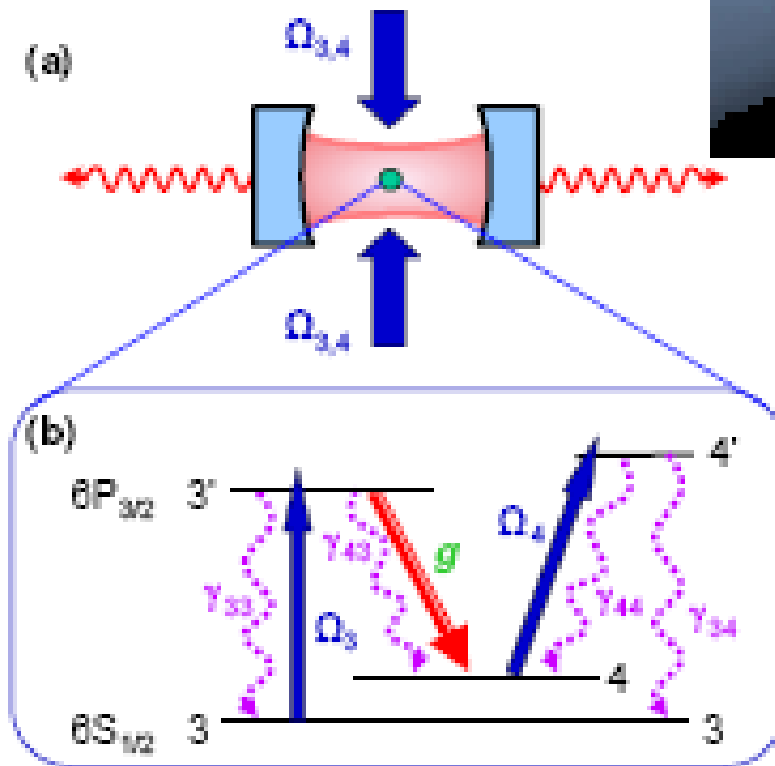
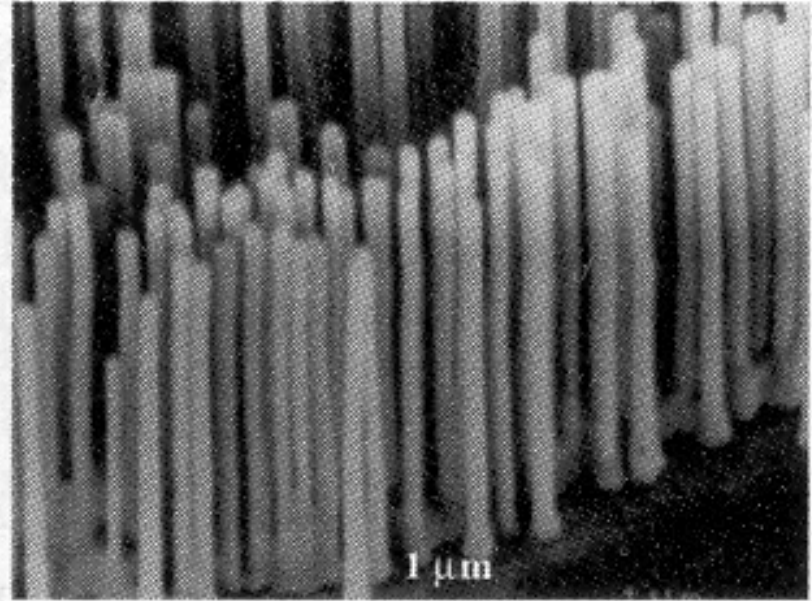
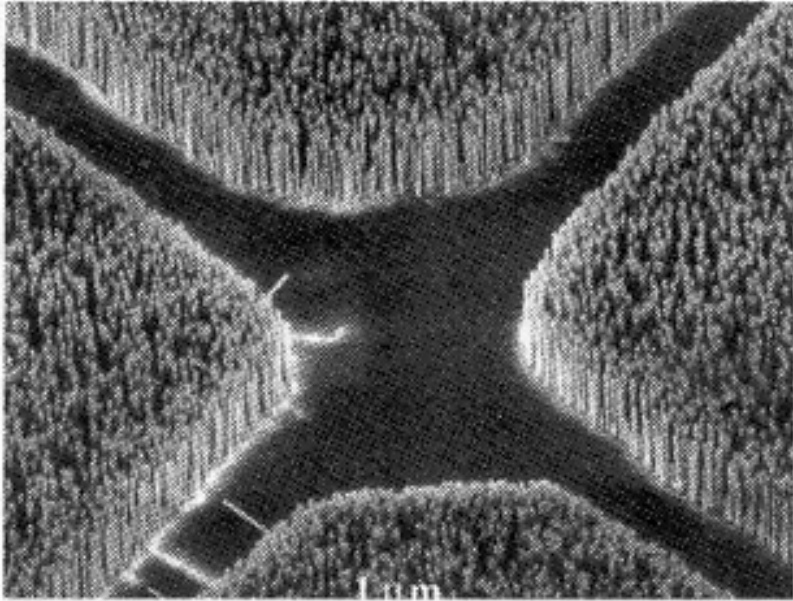


FIG. 1: Illustration of a one-atom laser. (a) The atom is located in a high-Q optical cavity of decay rate κ , and is driven by the fields $\Omega_{3,4}$. (b) Inset of the atomic level scheme relevant to our experiment with the $6S_{1/2} \leftrightarrow 6P_{3/2}$ transition in atomic Cesium. The 'lasing' transition is from the excited level $F = 3'$ to the ground level $F = 4$. Pumping of the excited $3'$ level is by way of coherent excitation from a laser with Rabi frequency Ω_3 . Effective decay from the ground 4 level is provided by the combination of a second field with Rabi frequency Ω_4 and spontaneous decay $4' \rightarrow 3$. Various radiative decay rates γ_{ij} appropriate to the D_2 line in Cs are given in the text.

NANOLASERS *The first room temperature UV nanowire lasers*



A forest of zinc oxide nanowire lasers [in close-up, right] sprang from a sapphire substrate [left]. The lasers average 70-100 nm in diameter, at a density of 11 billion/cm².

*Zinc oxide wires on a sapphire substrate self organized nano-wire forest
Pumped by 266 nm beamed at a slight angle laser wavelength 385 nm*

Absorption and Stimulated Emission

We can write the rate of change of population

$$\left(\frac{dN_2}{dt} \right)_{st} = -W_{21} N_2$$

However, now the *rate of stimulated emission* is dependent on the intensity of the EM wave

$$W_{21} = \sigma_{21} F$$

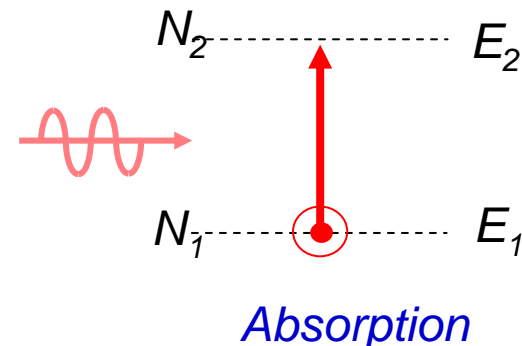
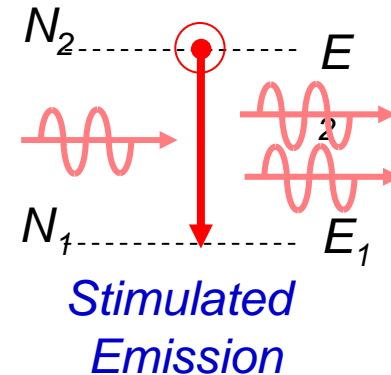
stimulated emission cross-section (units = area) ← *Photon flux (number of photons/ unit area/unit time)*

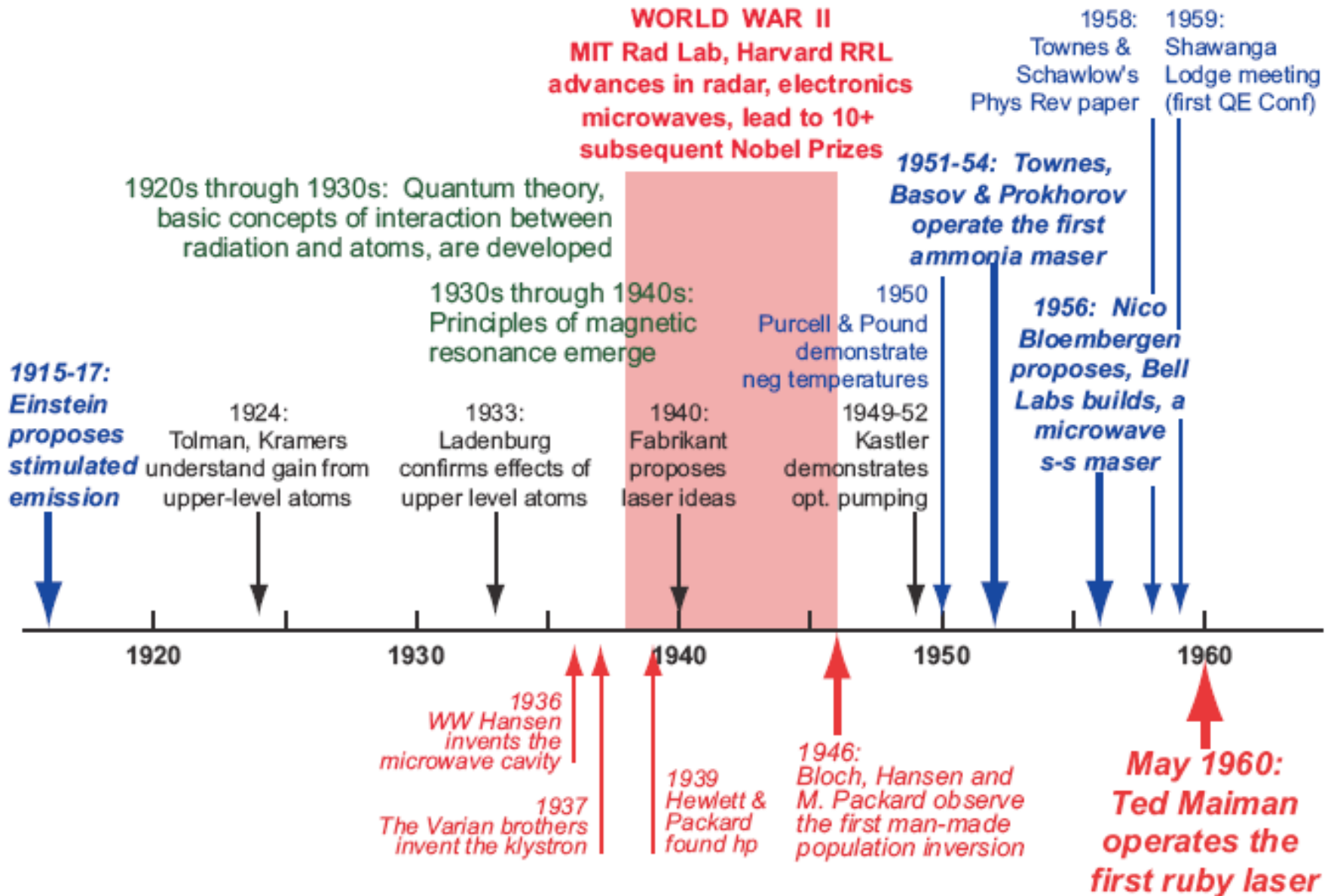
Similarly for Absorption

$$\left(\frac{dN_1}{dt} \right)_{ab} = -W_{12} N_1$$

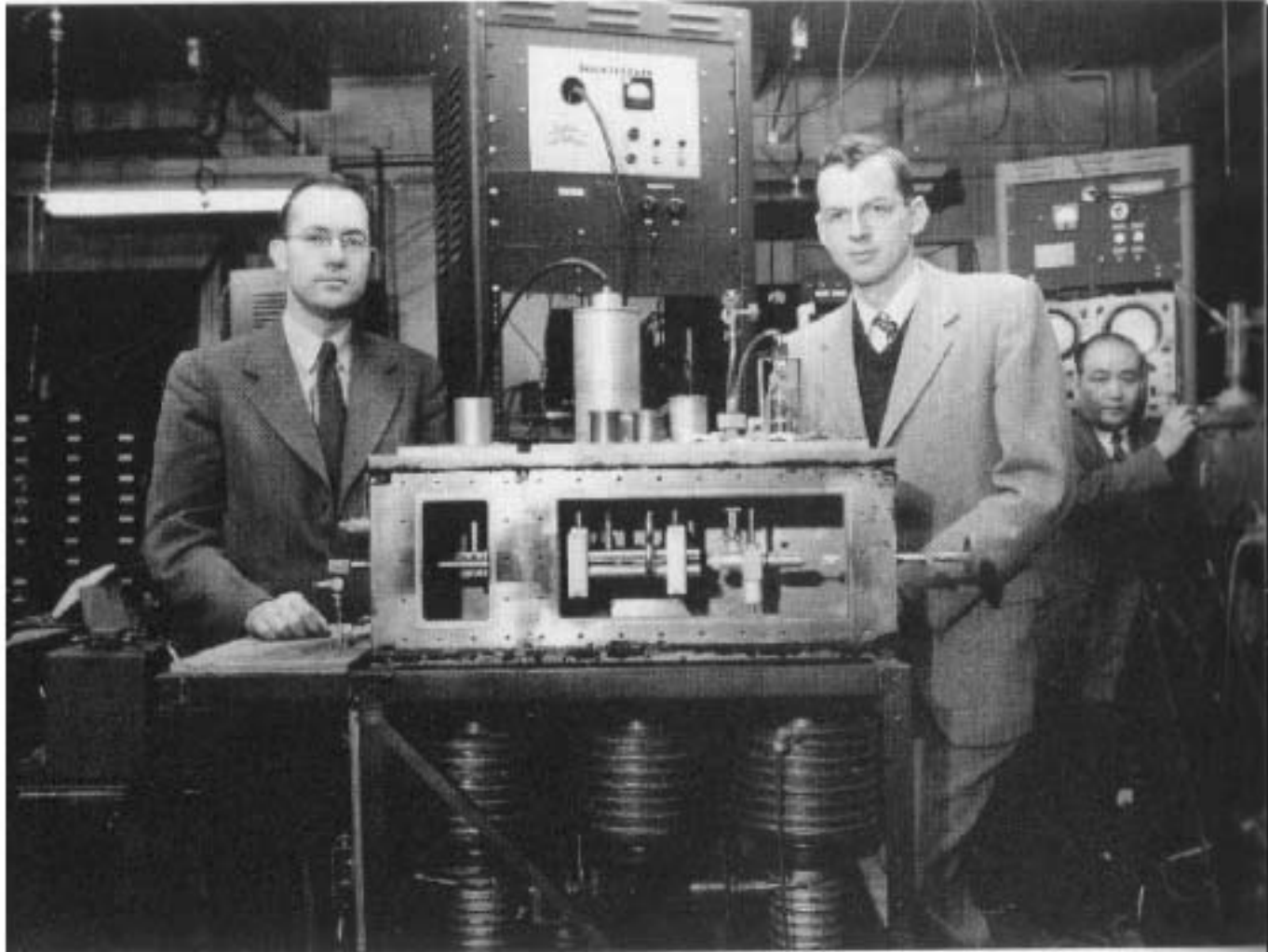
$$W_{12} = \sigma_{12} F$$

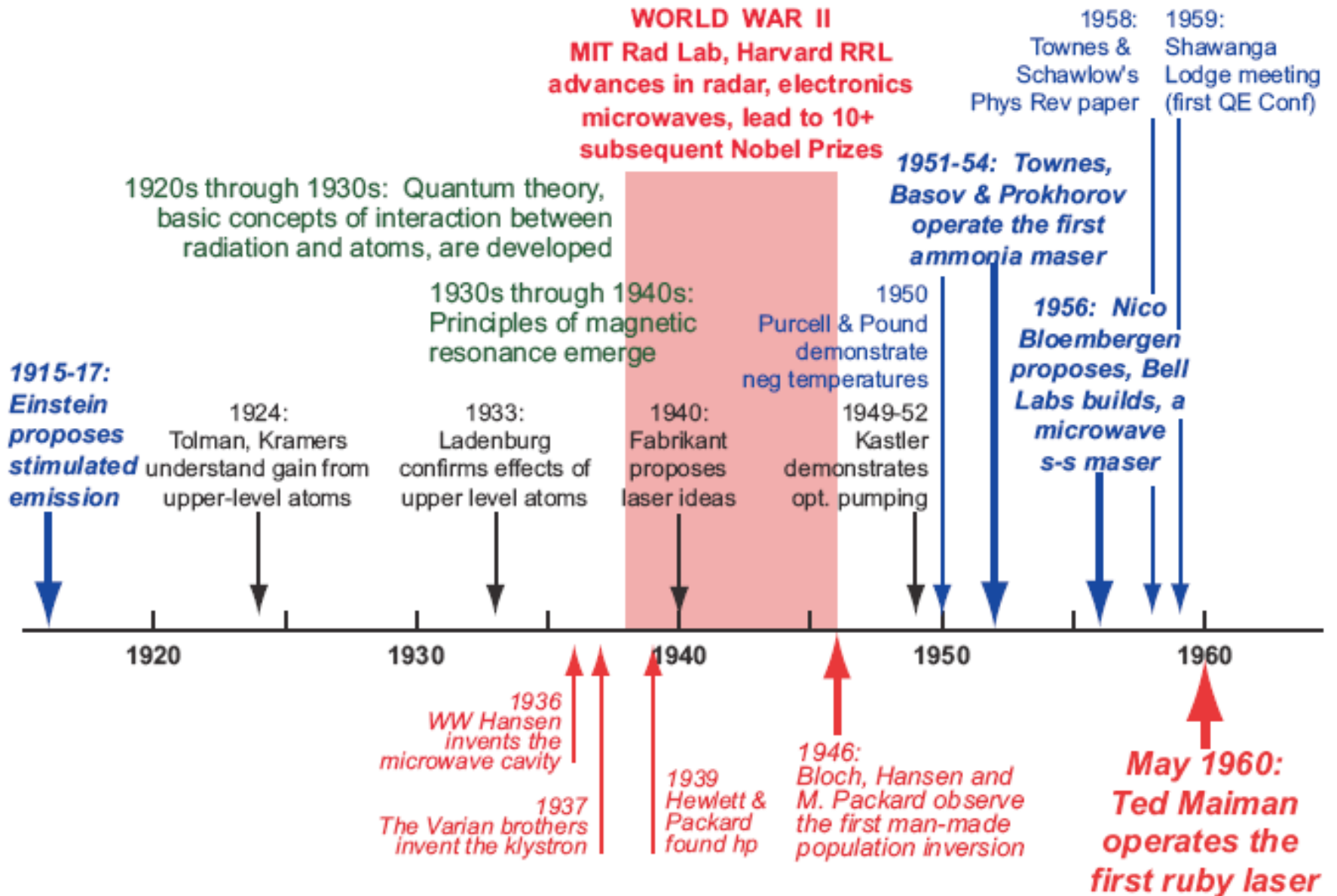
absorption cross-section



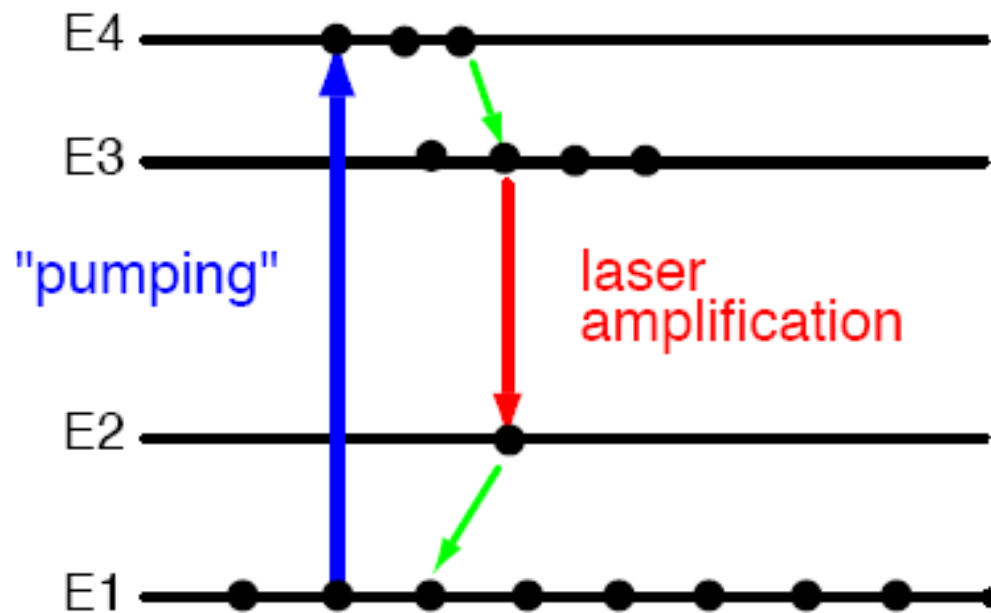
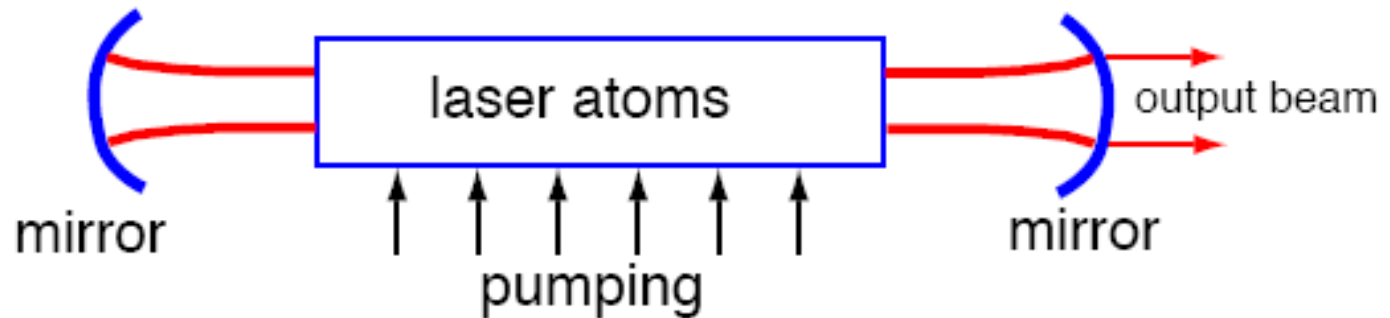


1954: Charles Townes and Jim Gordon: the NH₃ maser





How a laser operates



HIGH IMPACT FACTORS ON NEW LASERS

NEW MATERIALS AND MATERIALS FABRICATION TECHNIQUES

Ceramic crystal laser materials

Photonic crystal laser devices

NEW LASER CONFIGURATIONS

Slab – 67 kW demonstrated in

Fiber - approaching 10 kW

Thin disc - cw power of several kW

NEW PUMP TECHNOLOGIES

High power bars approaching 1 kW

High efficiency diodes (SHEDS program) ~ 75% efficiency

Precision diodes (spectrum, collimation) – ADHELIS program

Quantum Dot devices - very high efficiency

NEW LASER ARCHITECTURES

multiple amplifier chain

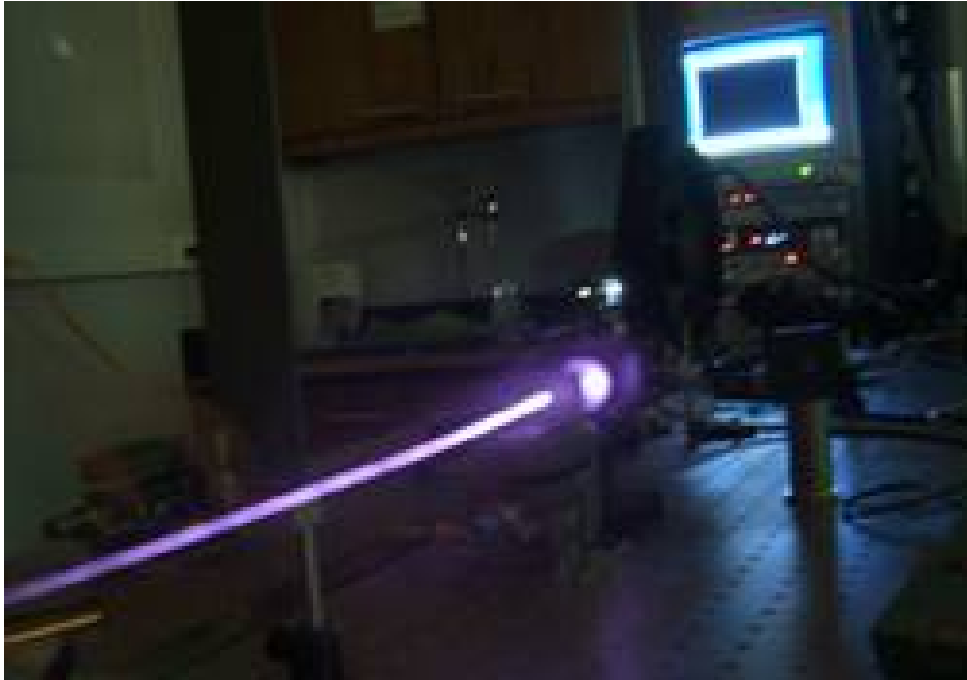
multiple synchronized lasers

spectral combining

phase combining

NEW LASER MATERIALS

Fiber lasers



*Peak powers limited by
fiber core diameter – typically ~ 10's microns
non-linear optical effects in the fiber*



High Power Fiber Lasers - JTO MRI 2005

PI's: John Ballato, *Clemson Univ.*, Martin Richardson, *UCF*

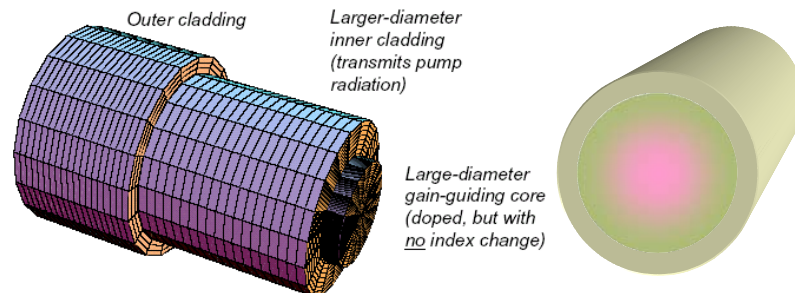
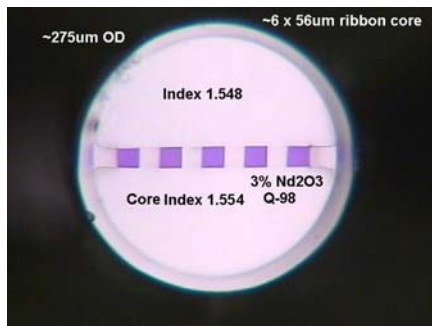


Program Goals

- Develop kW class “eye-safe” fiber lasers.
- Focus on novel materials and designs.
- Guiding Principles: Large mode area, purely single mode, single frequency, and polarization, minimize nonlinear effects, buffer coating greater than 200°C stability.

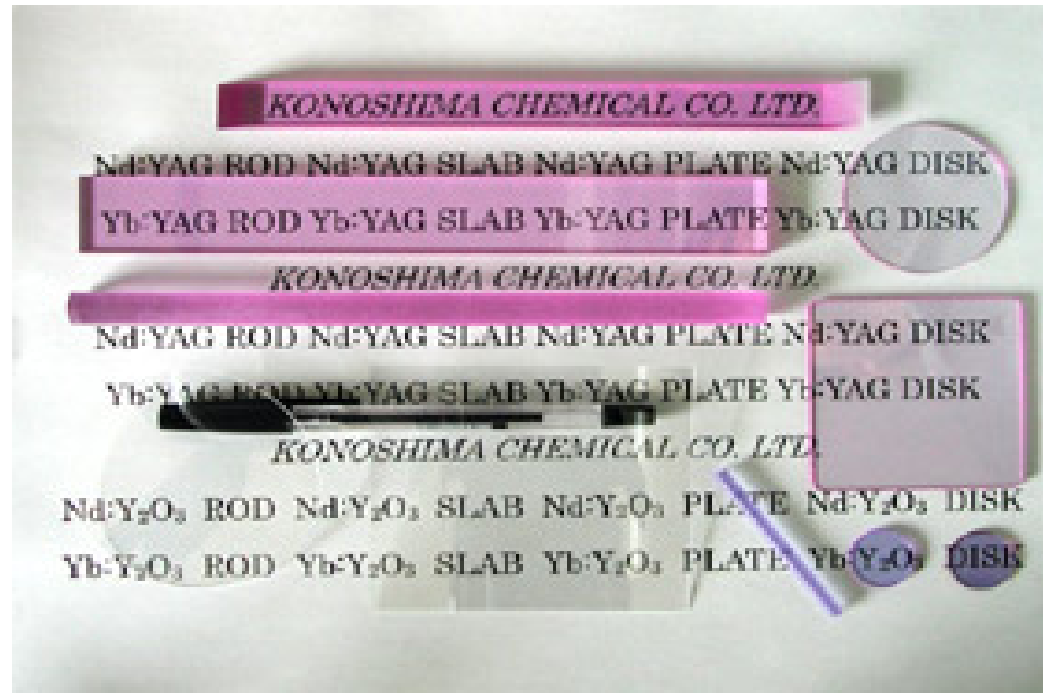
Fundamental Significance

- Focus on erbium 1.55 μm emission and thulium “2-for-1” emission at 2 μm .
- Silica and non-silica materials focusing on (a) *multicores* and (b) *gain-guiding*.



NEW LASER MATERIALS

Ceramic lasers

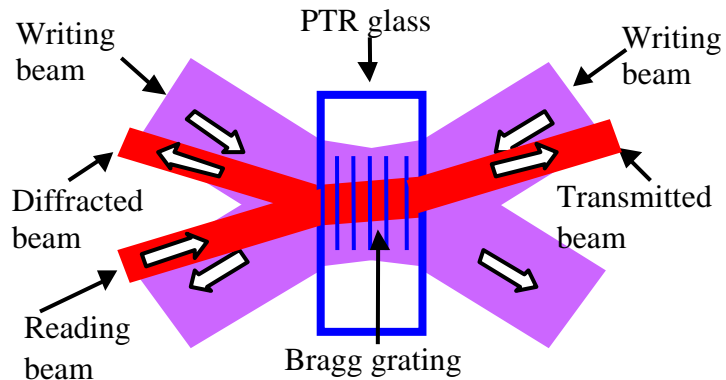


NEW LASER MATERIALS

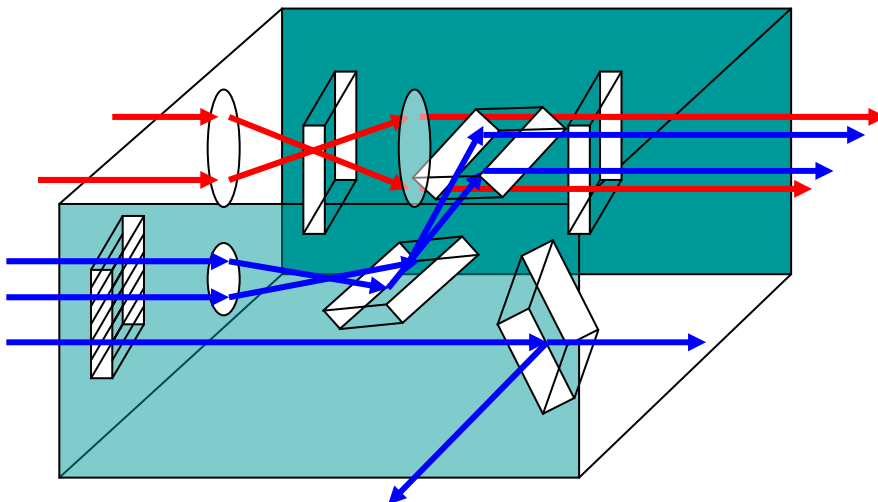
Novel high power optics

Volume Holograms in Glass

Leon Glebov - Photo-Thermal-Refractive (PTR) glass

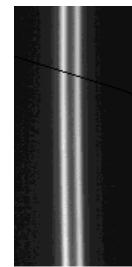


Multiple integrated optics functionality
e.g. lens, pol., grating, mirror, filter, etc.



APPLICATIONS

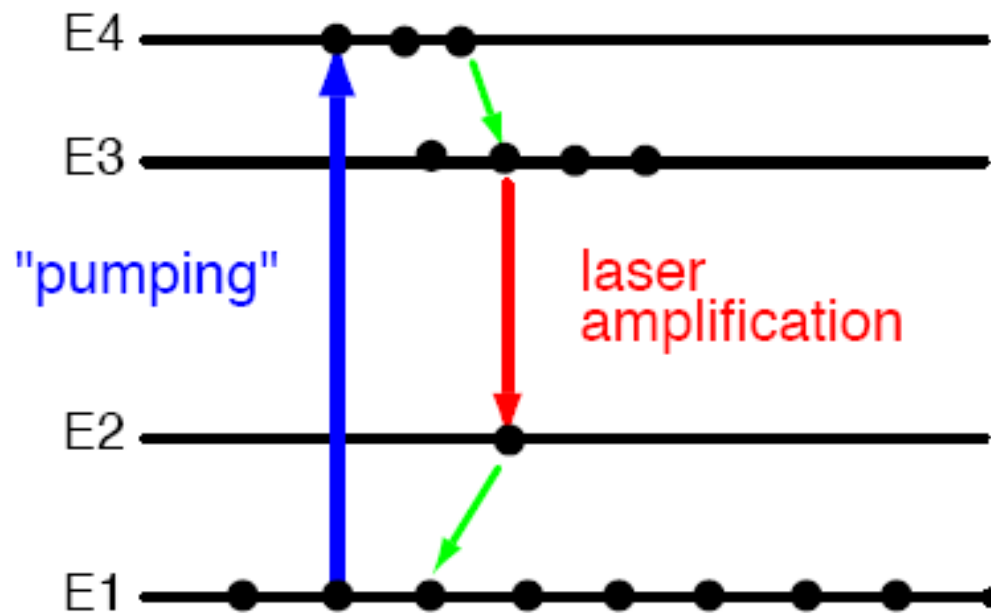
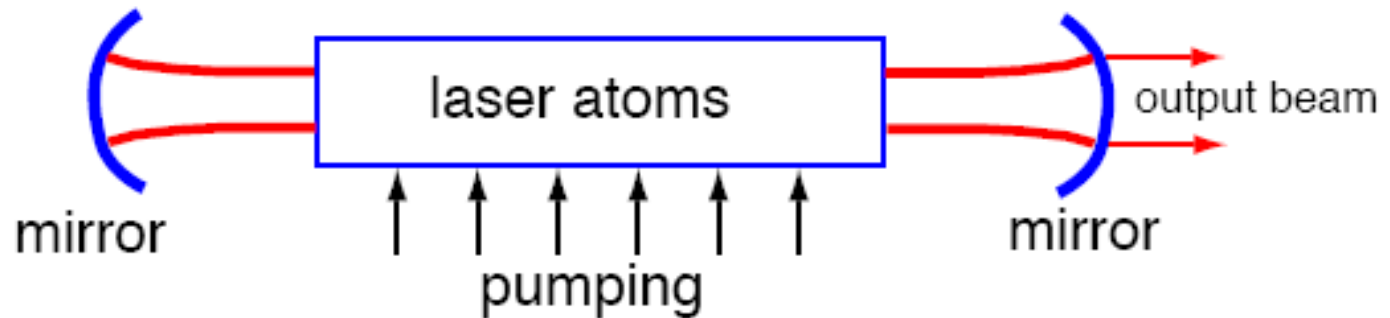
- Conventional optics
beam splitters, polarizers, atten.
- Laser systems
attenuators, mode selectors, ...
- Opt. Com.- WDM filters,
add/drop, equalizers, ...
- Data storage -unlimited reading



e.g. Na doublet (0.6 nm)
resolved without
collimator or slit

Optics in a 3-D chip

How a laser operates



Quantum Dots & Nanophotonics

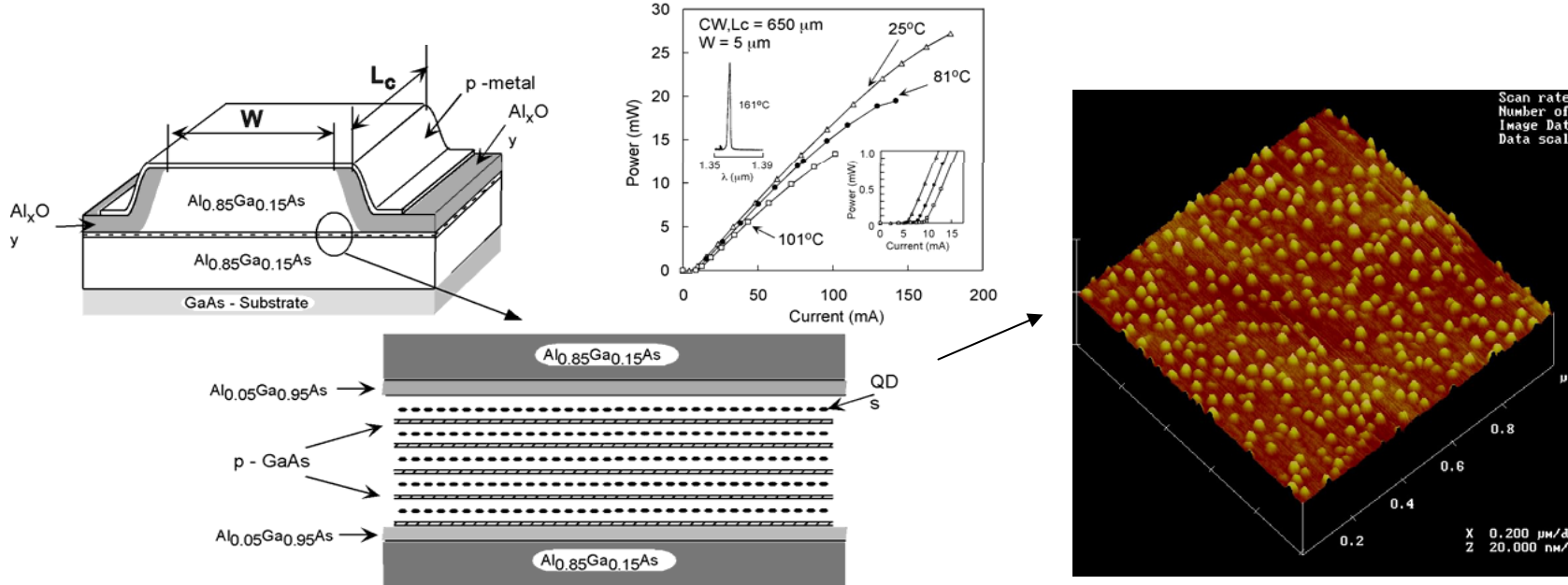
Ultimate Scaling of Semiconductor Light Sources

Dennis Deppe UCF

Quantum dots are an enabling technology for:

- Temperature insensitive, ultrafast lasers and amplifiers
- High beam stability, narrow linewidth high power laser diodes
- Photonic crystal, microcavity VCSEL, and quantum light sources

Record high T_0 1.3 μm laser using p-doped InAs QDs (APL 80, 3277 (2002), EL 38, 712 (2002)).



demonstrated the first 1.3 μm QD lasers in 1998

SOME LASER APPLICATIONS

LASERS IN MICROFABRICATION

3D laser polymerization

lithography

micro-structuring

LASER IN ADVANCED IMAGING

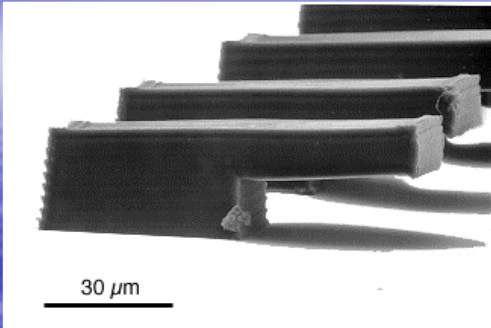
2-photon confocal imaging

X-ray imaging

LASERS IN ENVIRONMENT AND SECURITY SENSING

atmospheric propagation

stand-off detection



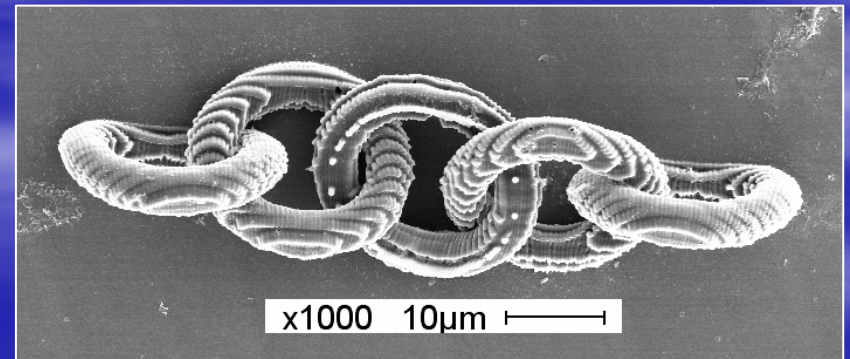
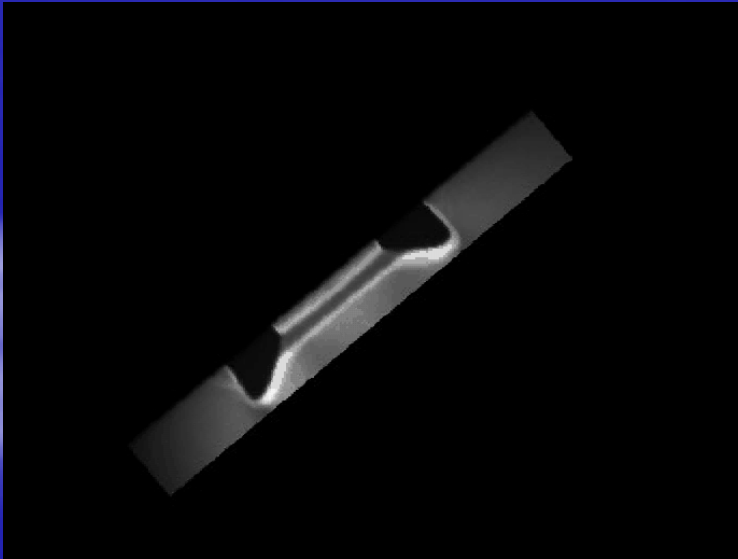
- *Micro-fluidics*
- *Micro-optical devices*
- *Bio-nanophotonic systems*



CAD-defined target structure



*Automated 3D
microfabrication*



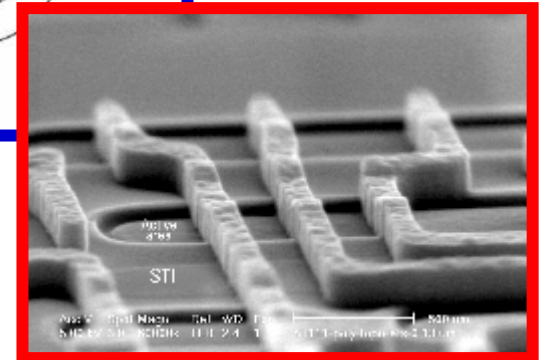
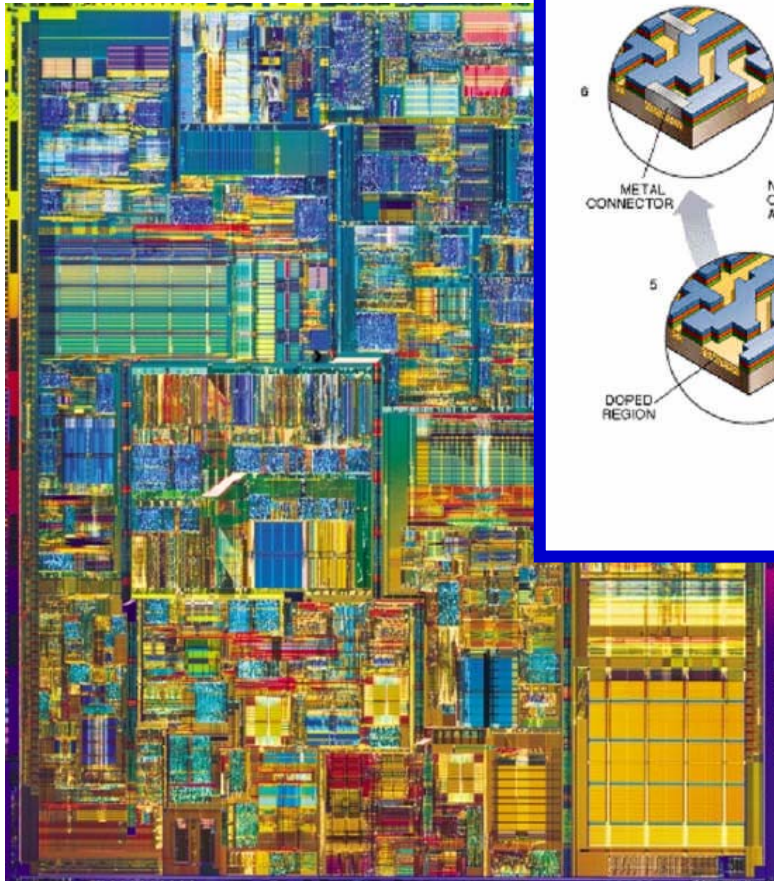
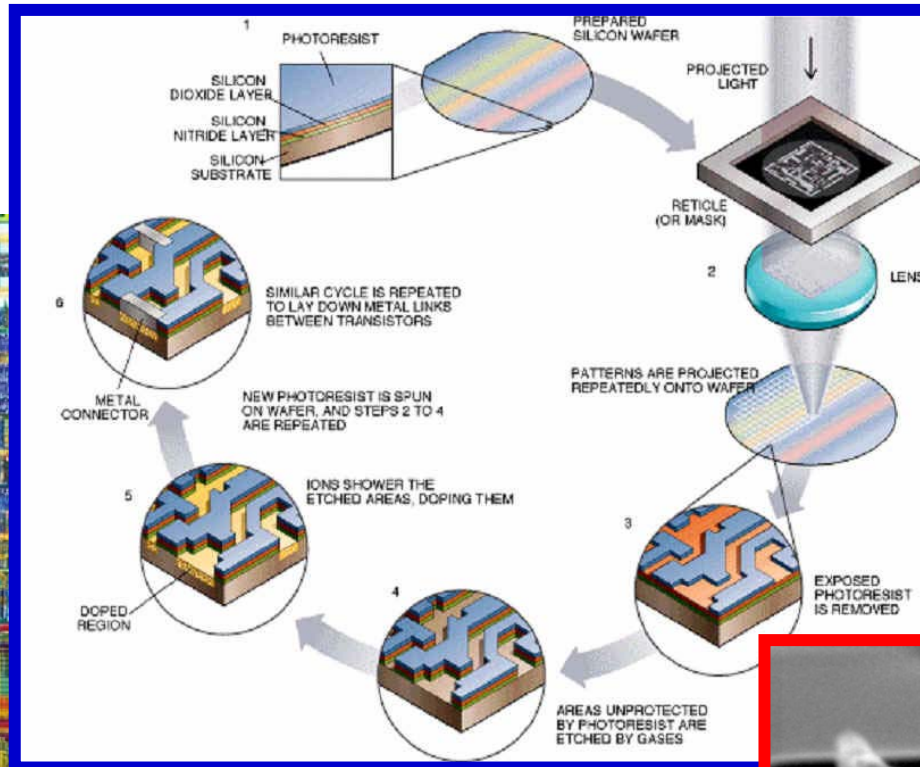
Final structure

Cumpston et al., Nature, 1999

Kuebler et al., J. Photopolym. Sci. Technol., 2001

Zhou et al., Science, 2002

Lithography is the technology that produces today's computers



Process

0.130mm process

Pentium 4™

Trends in Lithography- the minimum feature size

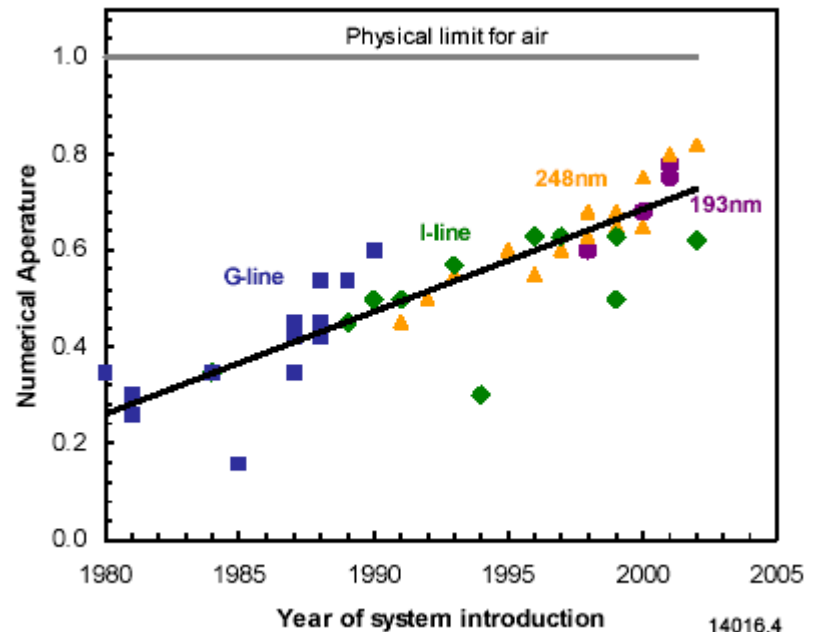
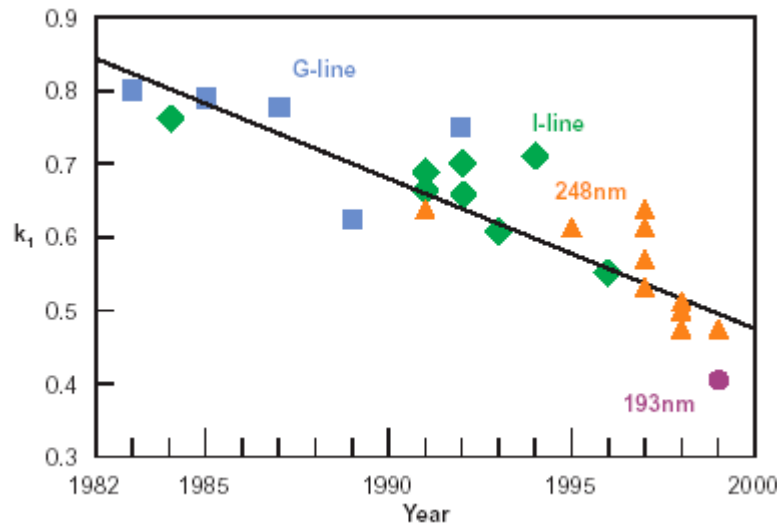


Minimum features size

$$W = \frac{k_1 \lambda}{NA}$$

$$W = \frac{k_1 \lambda}{NA} = \frac{0.25 \times 193}{0.93} = 52 \text{ nm}$$

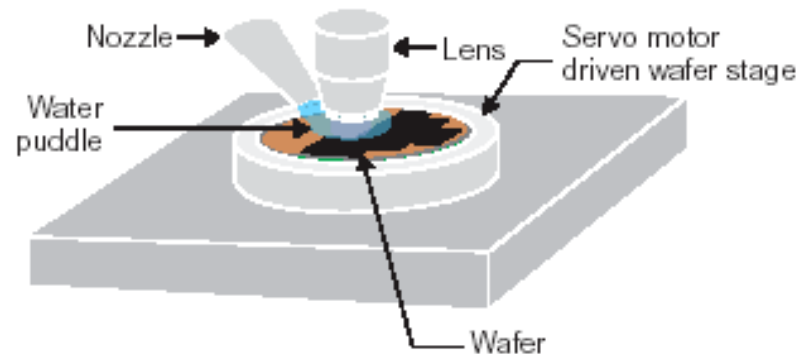
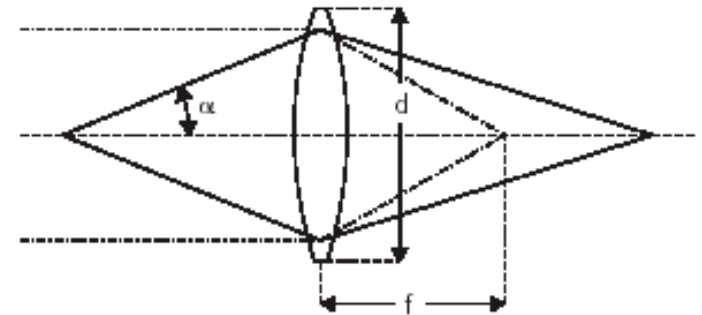
Year	Linewidth (nm)	Wavelength (nm)
1986	1,200	436
1988	800	436/365
1991	500	365
1994	350	365/248
1997	250	248
1999	180	248
2001	130	248
2003	90	248/193
2005 (fcst)	65	193
2007 (fcst)	45	193



The case for Immersion

$$NA = n \sin \alpha = \frac{d}{2f}$$

$$W = \frac{k_1 \lambda}{n \sin \alpha} = \frac{0.25 \times 193}{1.47 \times 0.93} = 35 \text{ nm}$$



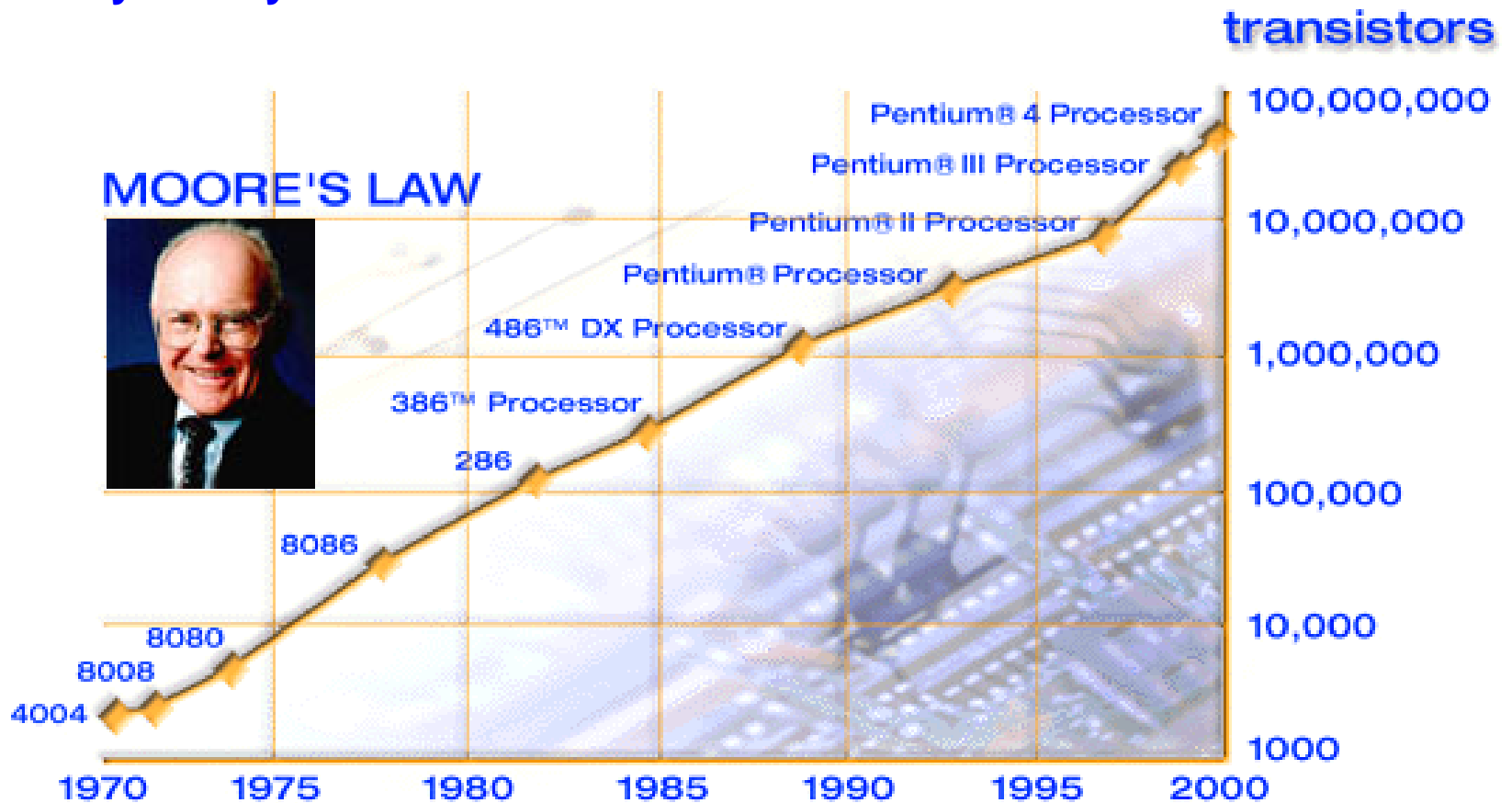
Stability and processing speed issues

Materials lifetime.

Higher refractive index liquids, possible towards 22 nm node

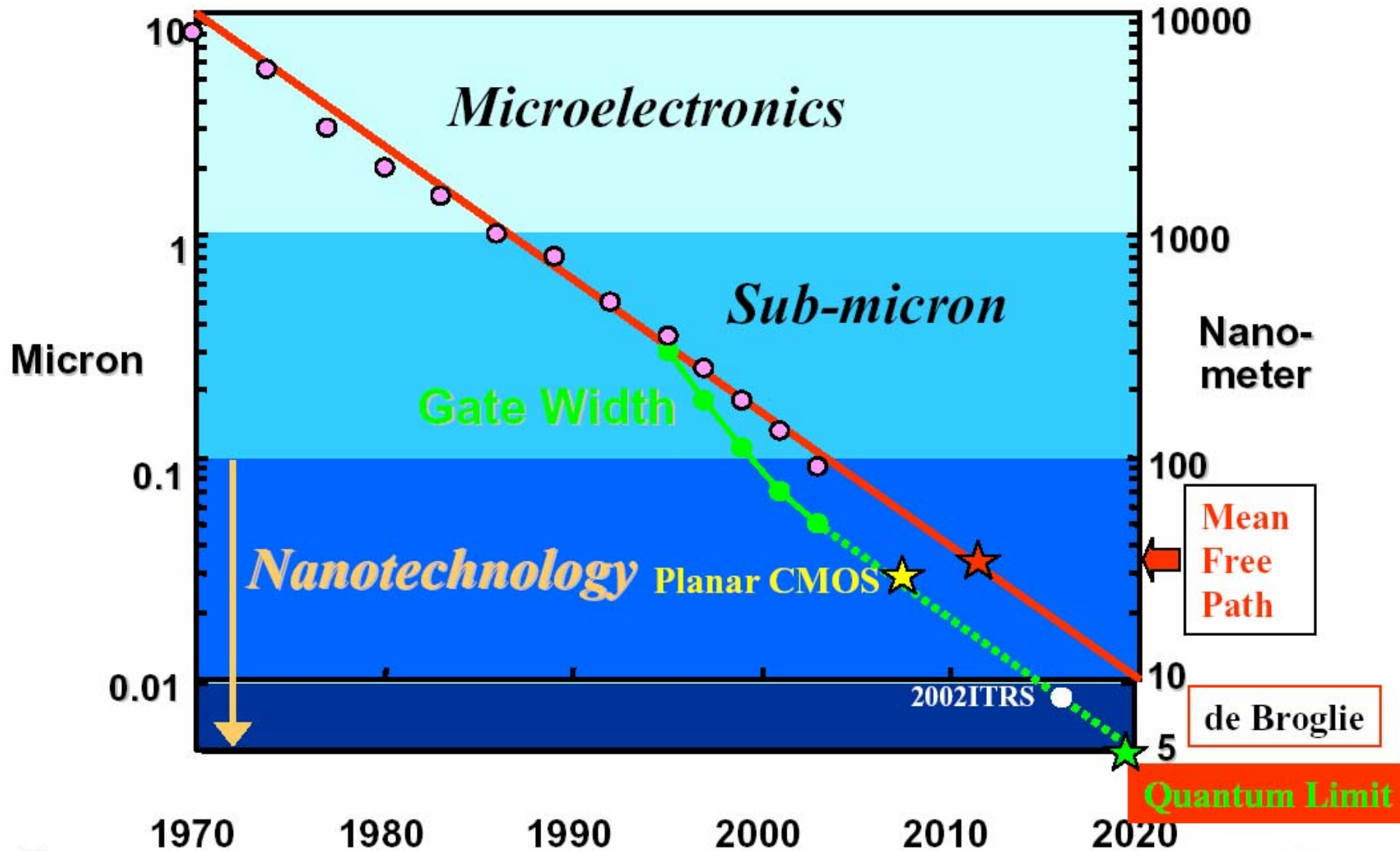
The computer chip industry is driven by Lithography

Computer chip development has been governed for 30 years by Moore's Law



The minimum feature size on a computer chip

From microelectronics into the world of nanotechnology



Today's computer chips are made with **UV** laser light sources



Lithography machine

Minimum feature size

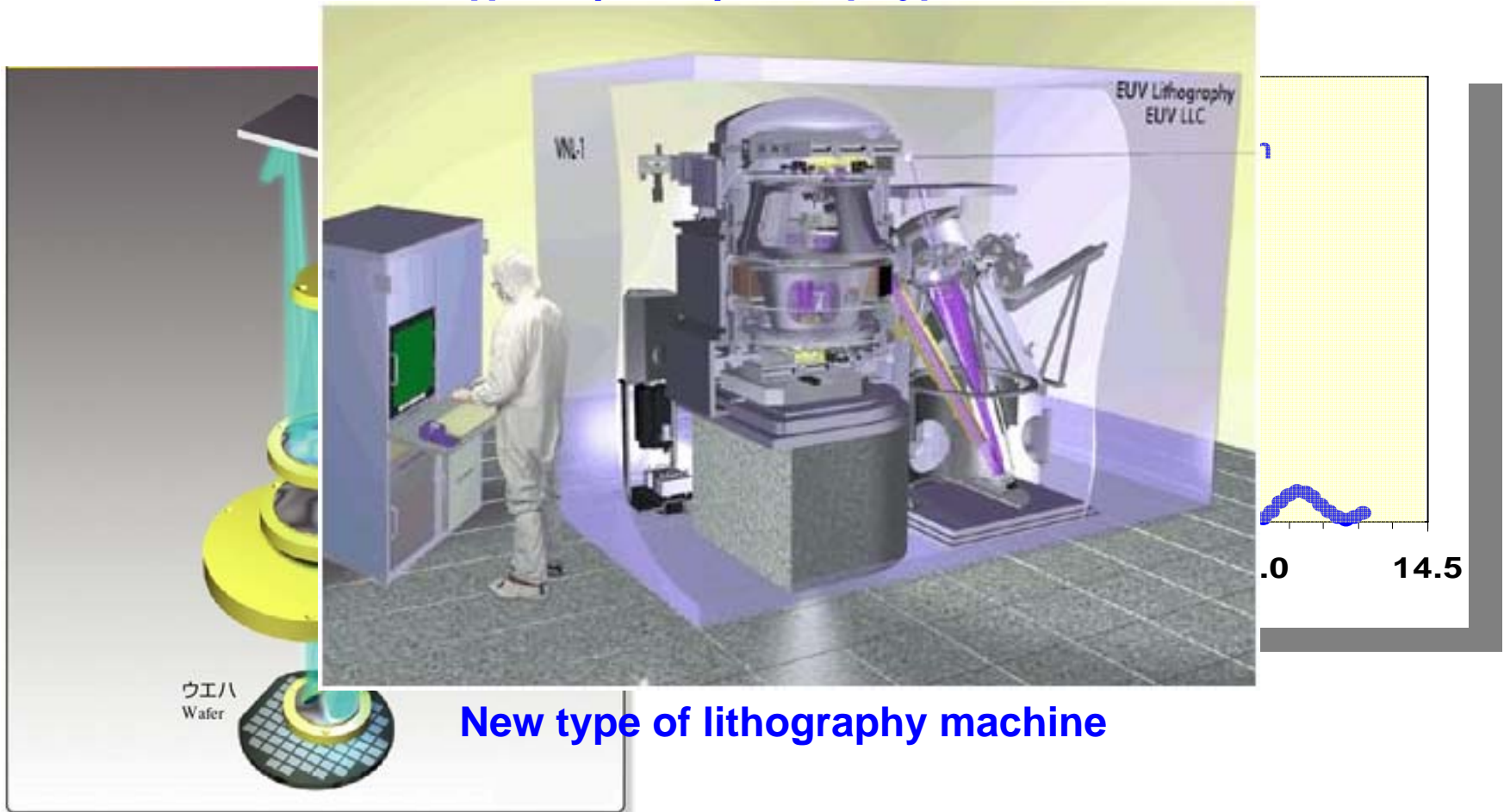
Wavelength

$$W = \frac{k_1}{NA} \lambda$$

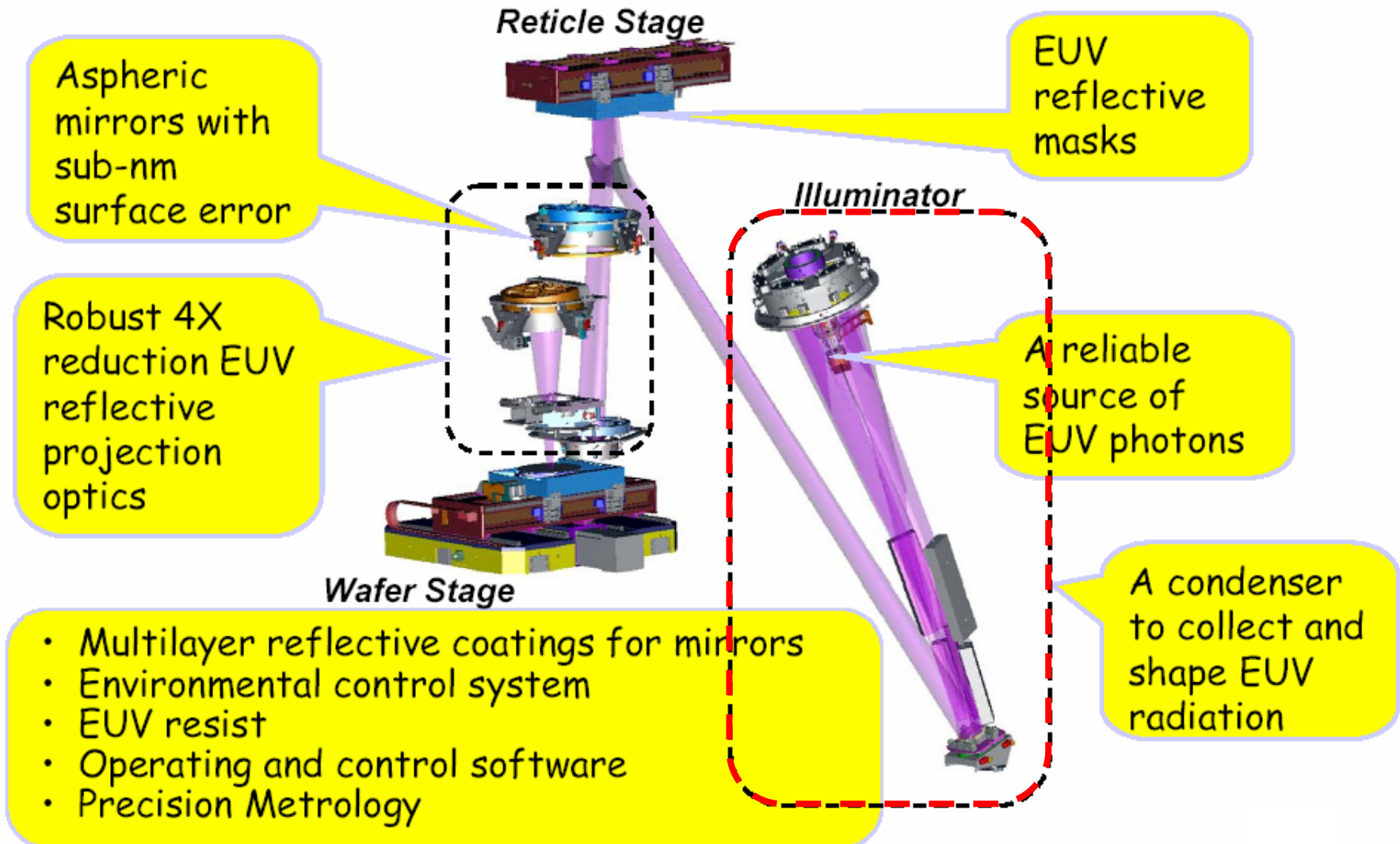
The wavelength of these UV sources is too large for *tomorrow's* lithography...

Tomorrow's lithography will use EUV sources

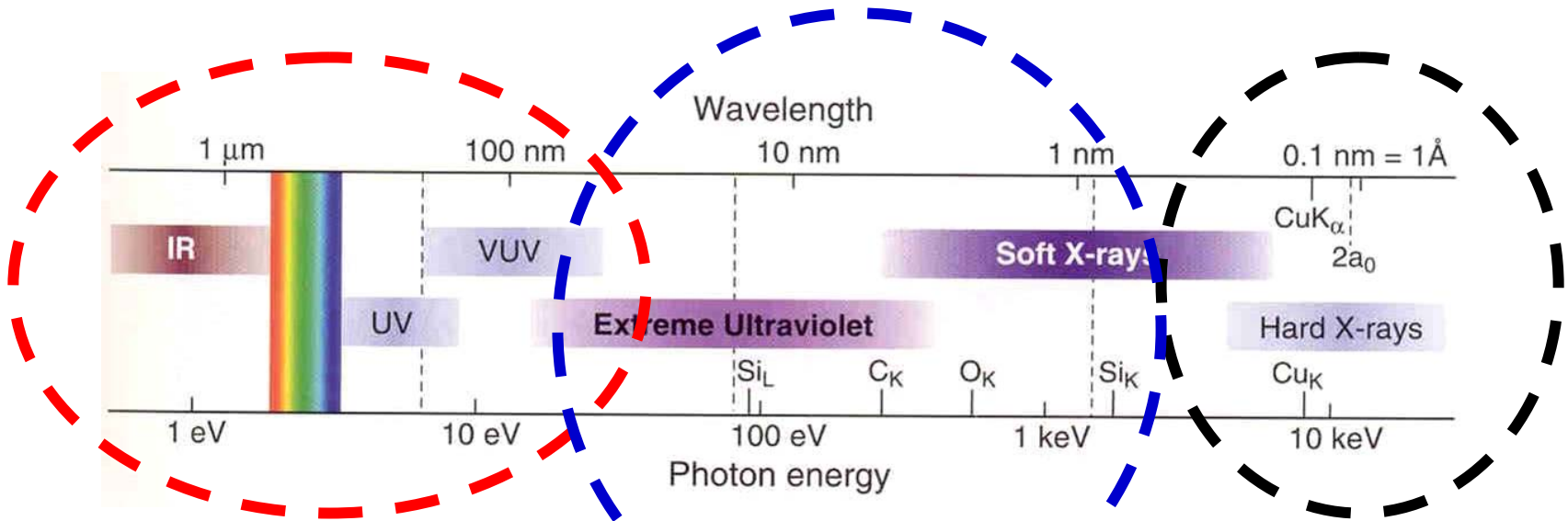
- Year 2010 Wavelength $\lambda = 13$ nm (EUV)
 - Completely new optics for lithography



Many new technologies to be developed for EUV Lithography



The EUV – Soft X-ray region of the electromagnetic spectrum



The IR - visible – UV region

The x-ray region

The EUV – Soft X-ray region

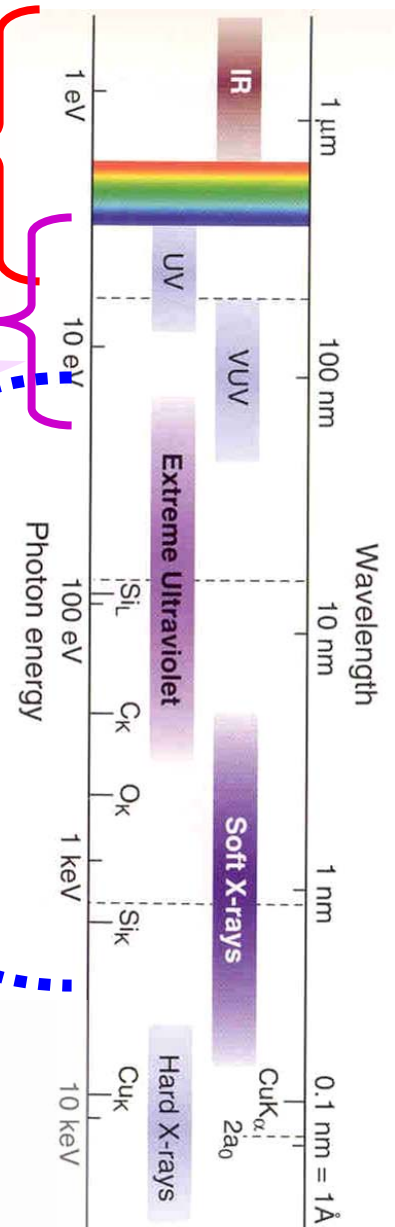
The EUV – Soft X-ray region – a black part of the spectrum

*Many sources, incoherent and coherent,
Single photon sensors
Multiple applications
Sophisticated imaging technologies
Photonics, fabrication, medical..*

*Sources, incoherent and coherent
Conventional detectors
High resolution imaging
Industrial applications (lithography..)
Medical applications (Lasik..)*

*Few sources – all weak..
Few detectors....
Inefficient optics..
No applications ..*

*Industrial incoherent sources
Many sensor systems
Imaging technologies
Materials analysis technologies
Medical technologies*

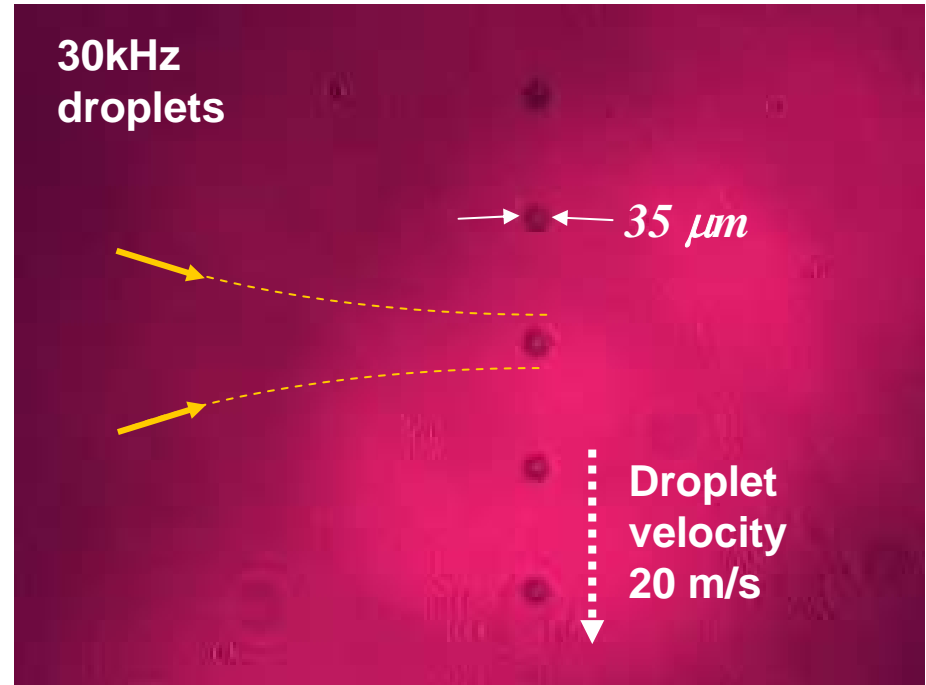


Sn-doped mass limited laser plasma source

- ❑ Small diameter droplet
- ❑ Number of source atoms should be equal to number of radiators
- ❑ Target needs to be fully ionized by the end of laser pulse

Multi-component target

- [1] Chemical tin liquids
- [2] Liquid solutions of tin nanoparticles



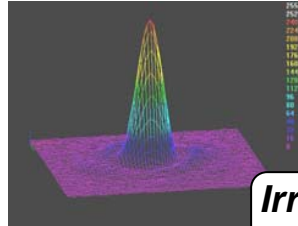
*Stability of droplets in target region ~ 3 μm.
Plasma located far from nozzle. No nozzle erosion.*

High repetition-rate 20-100kHz.

A combined theory – experimental approach

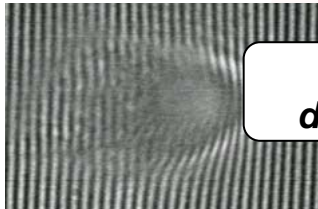
Experimental Studies

Theoretical codes



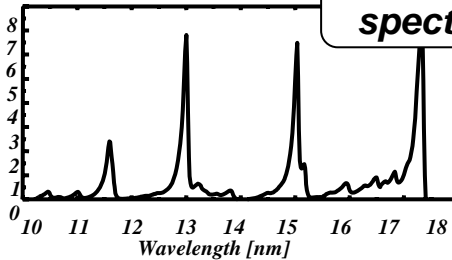
Irradiation conditions

Quantitative energetics

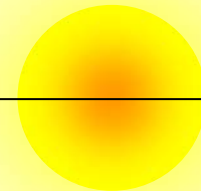


Plasma diagnostics

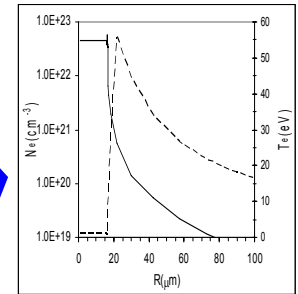
High resolution spectroscopy



In-band radiometry

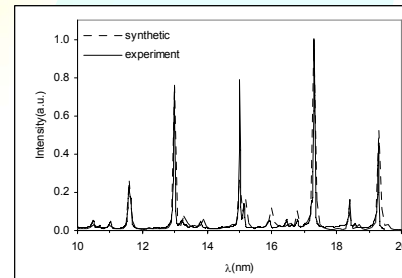


hydro codes
Plasma Expansion & parameters



Radiation code
Ionization & radiation dynamics

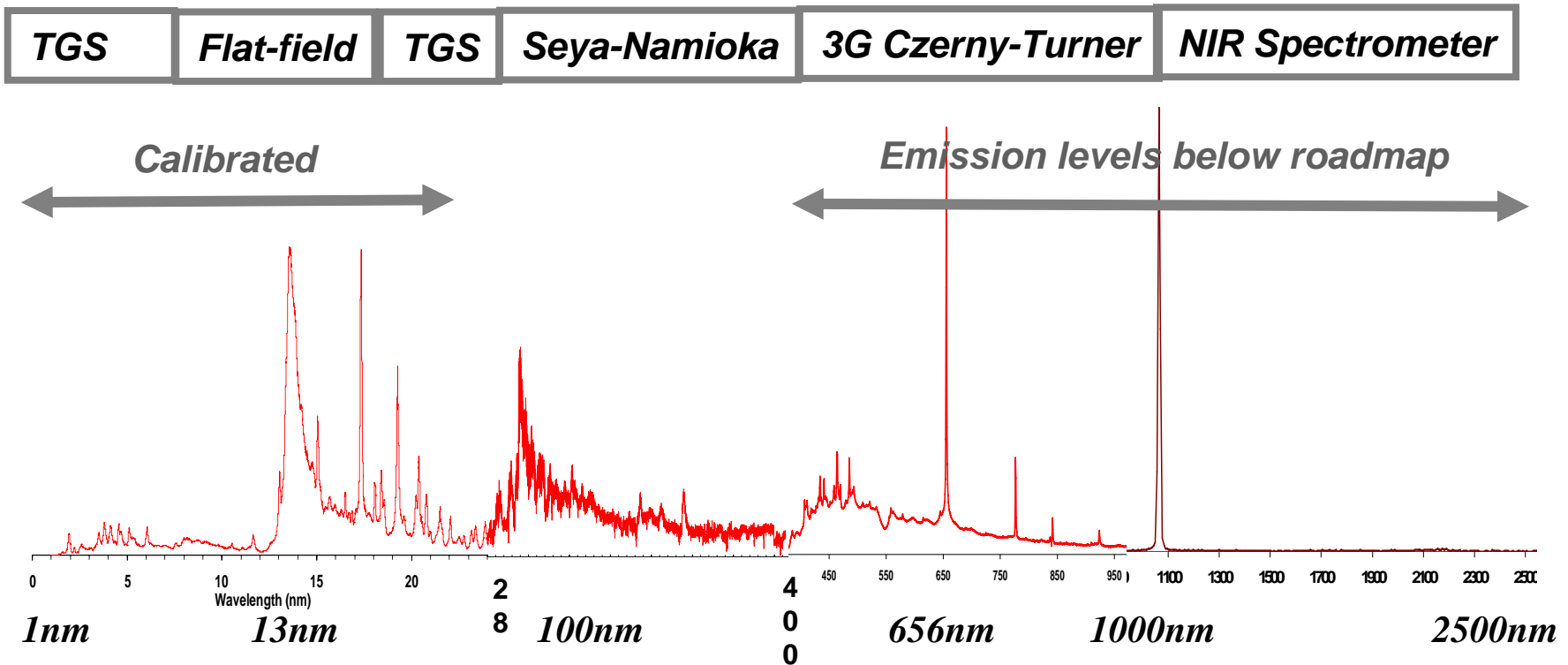
Atomic databases



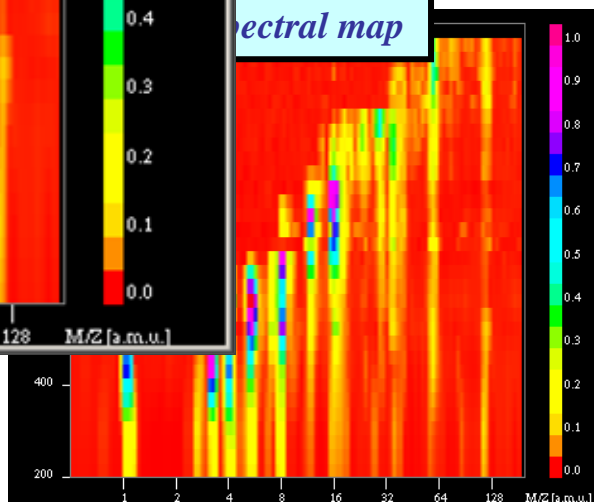
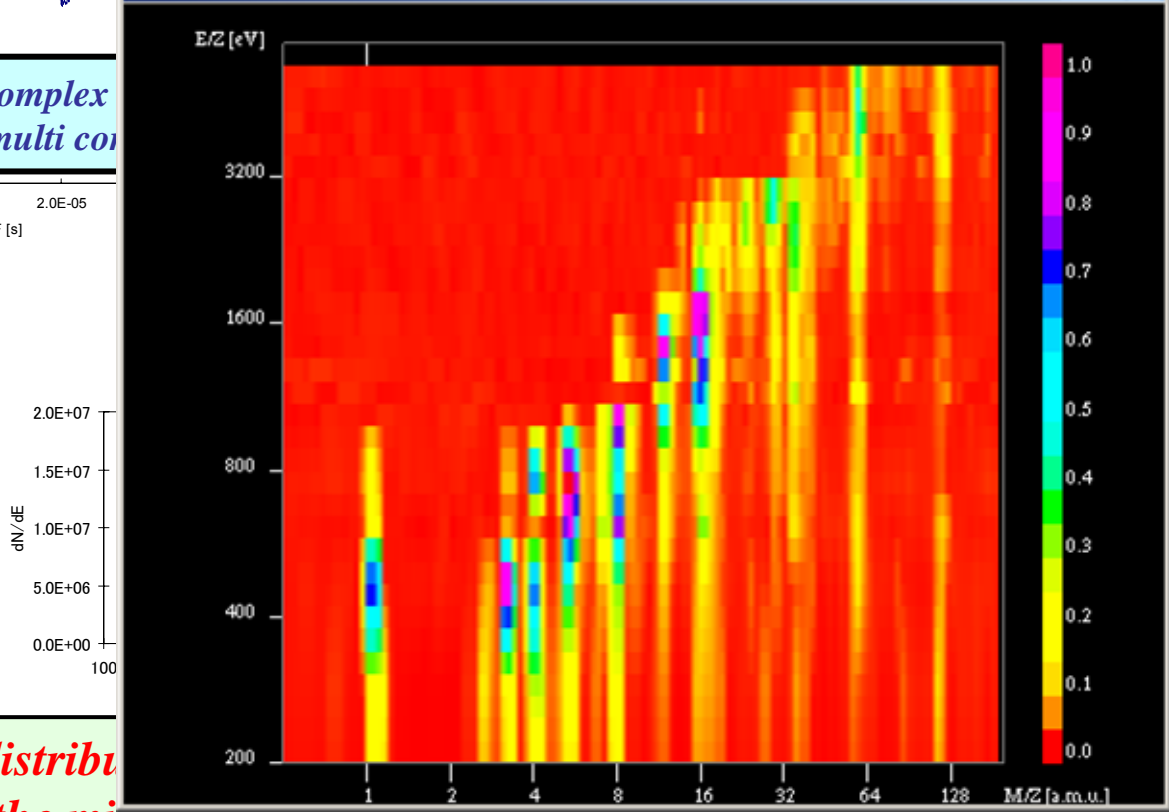
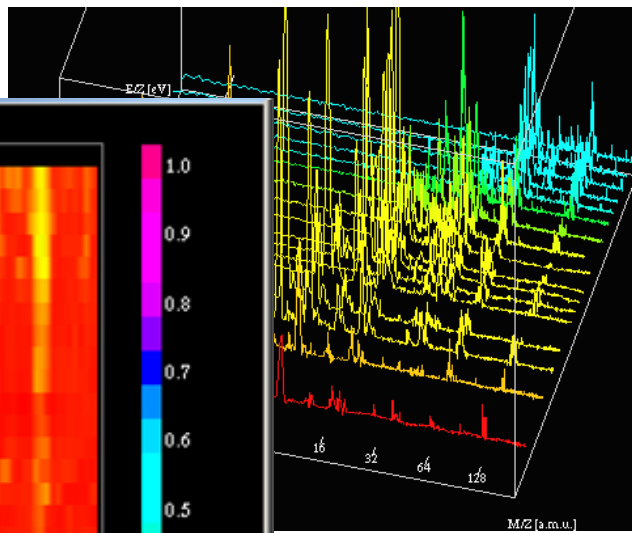
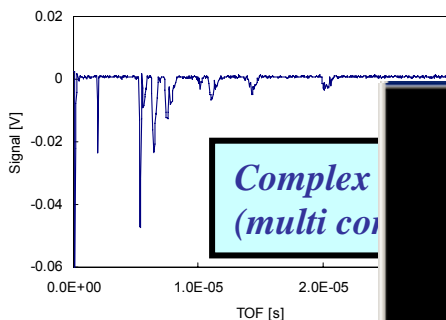
Code predictions of spectra

Quantitative Spectral Emission

Complete out-of-band spectral characterization



Comprehensive absolute ion spectrometry



Ion energy distribution
at the mirror distance (100mm)
for each ion species
Number of ions per solid angle

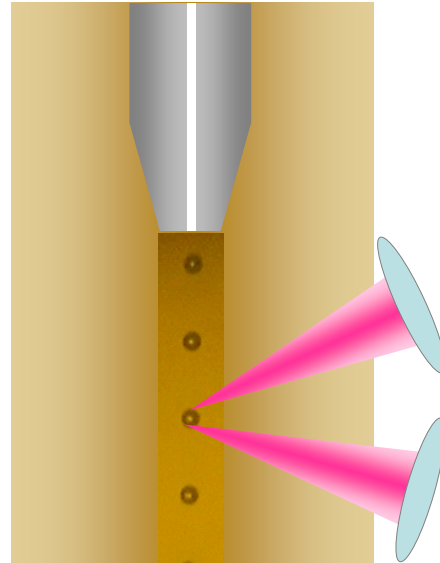
23 W Laser Plasma EUV source

Powerlase – UCF Collaboration

**23 W sustained EUV
power at 6.6 kHz**

CE = 2.4%

**Hours of operation
without debris
mitigation**



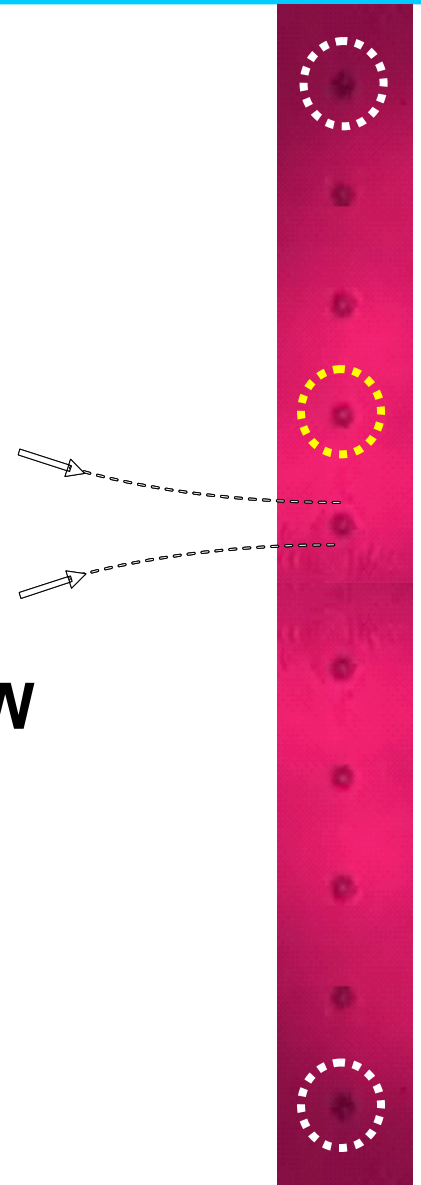
***Two commercial 500W,
3.3 kHz DPSL lasers***

Clear technology path for LPP source for the β -tool

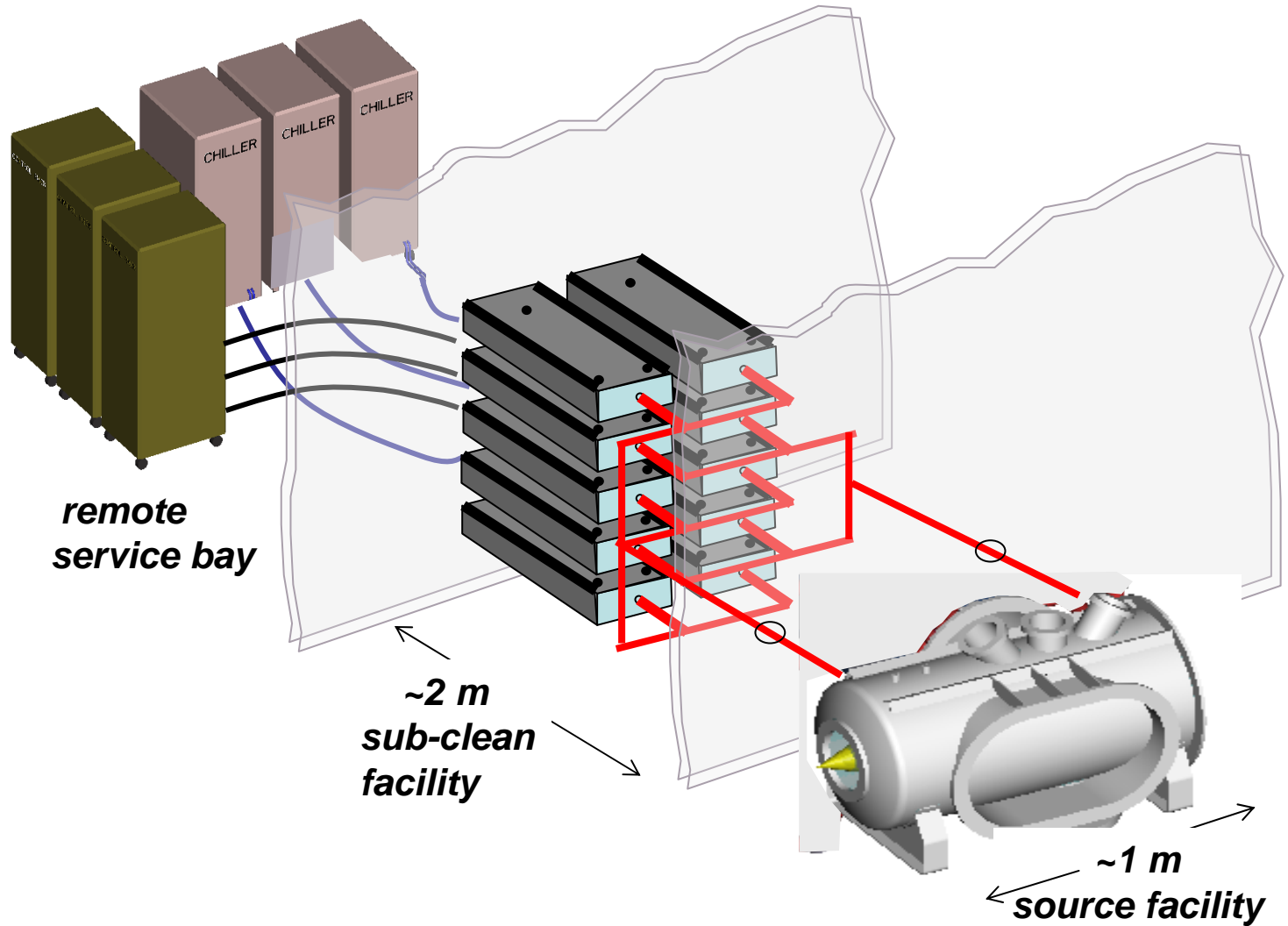
Extension to HVM requirements

Current Power at Source 24 W
Two 500 W lasers
Shooting 2 targets out of 10
Current laser shot rate 6.6 kHz
Target rate 33 kHz

With 10 lasers Source Power = 120 W
Source repetition rate
... equals target rate = 33 kHz
At least 30 W at IF



Footprint of a DPSL LPP HVM Source



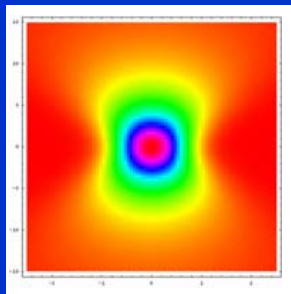
Femtosecond direct laser writing

- *Focusing a femtosecond near-IR beam in a transparent material produces a local change of the refractive index*
- *Femtosecond regime allows volumetric processing and minimizes thermally induced defects*
- *Sub-micron precision 0.5 mm demonstrated*

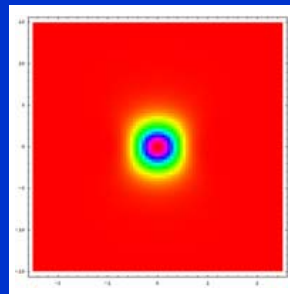
Single set fabrication method not amenable to bulk processing.

Real time serial fabrication.

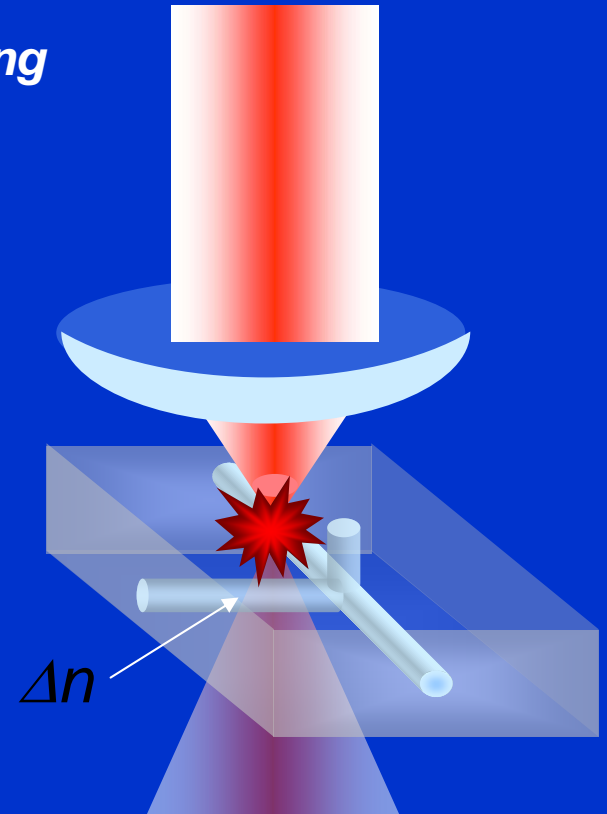
3 – dimensional structuring



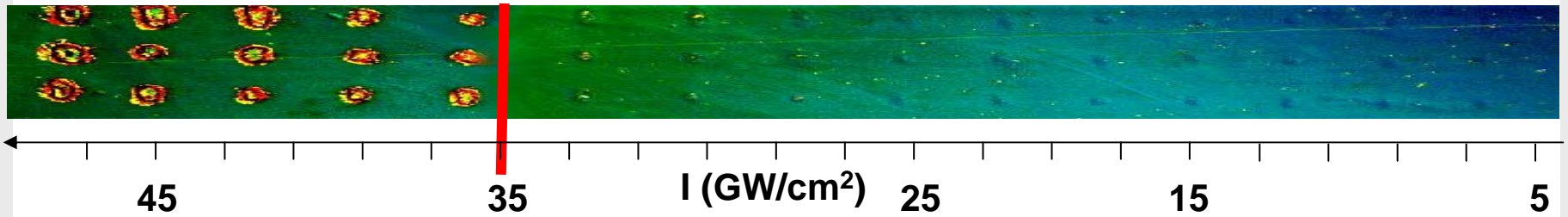
1-photon



3-photon

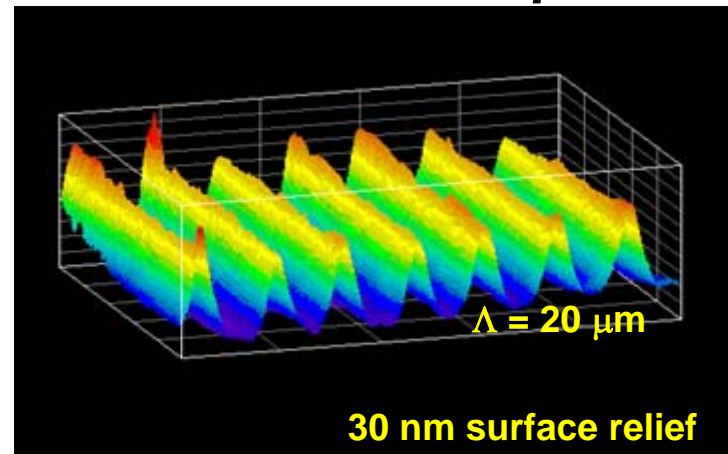
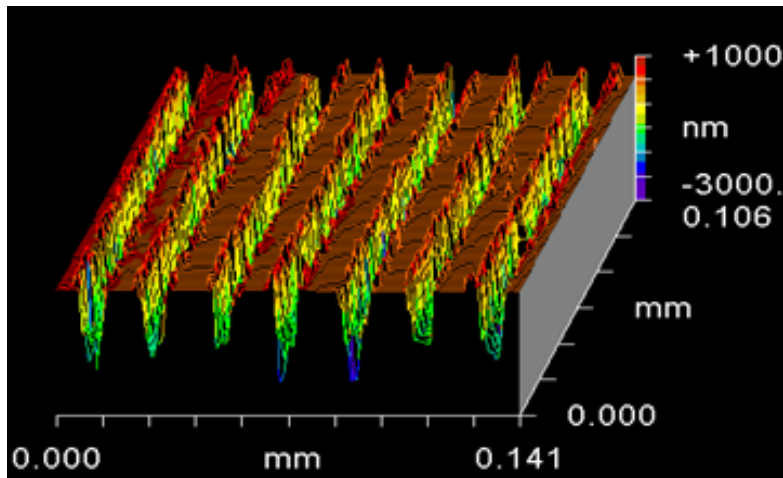


Just below plasma production.....



*Micro-ablation
relief features*

*Micro-restructuring of material
Photo-induced expansion*



Surface profile
(interferometer microscope)
Typical width $\sim 10 \mu\text{m}$ (FWHM)

Free electron excitation leads to structural change

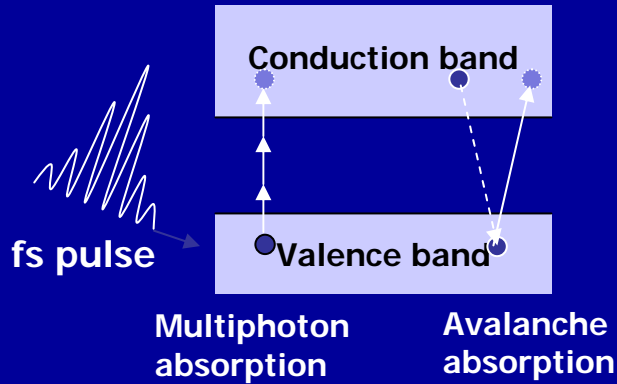


Photo-chemical: bond changes

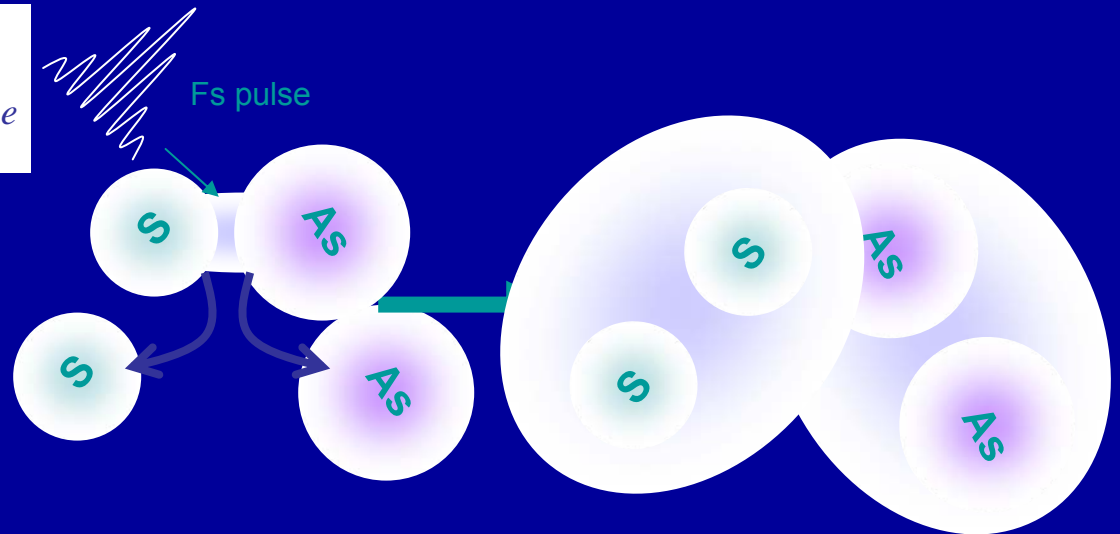
Photo-expansion: ΔV

Photo-refraction: Δn

Photo-darkening: $\Delta\alpha$

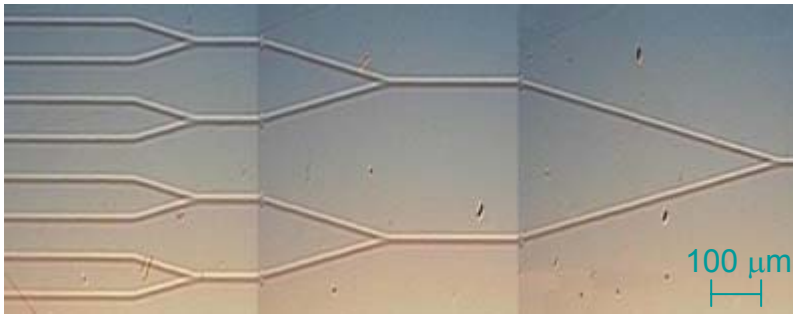
Increase in thermal conductivity: $\Delta\kappa$

$$\frac{\partial n_e}{\partial t} = \sigma_k I(t)^k + \alpha I(t) n_e$$

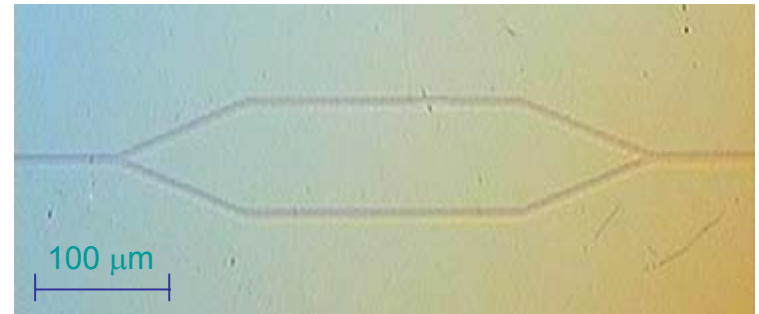


Device fabrication

Direct laser writing is a rapid and versatile technique to fabricate more complex waveguide structures



Optical microscope image of a 1 x 8 coupler



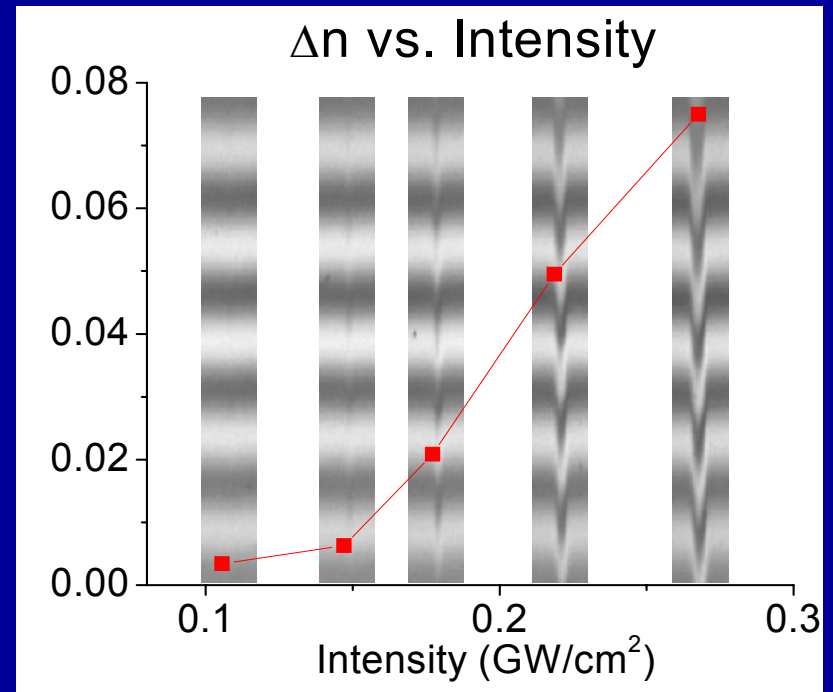
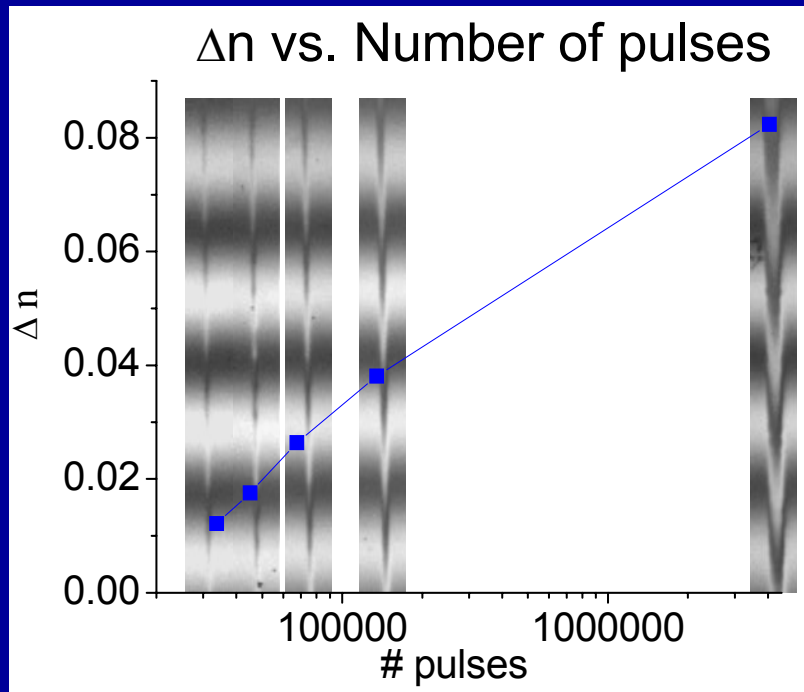
Optical microscope image of Mach-Zehnder interferometer

Typical width $\sim 10 \mu\text{m}$ (FWHM)

Translation speed = 0.5 mm/s

Typical fabrication time $\sim 10\text{min}$

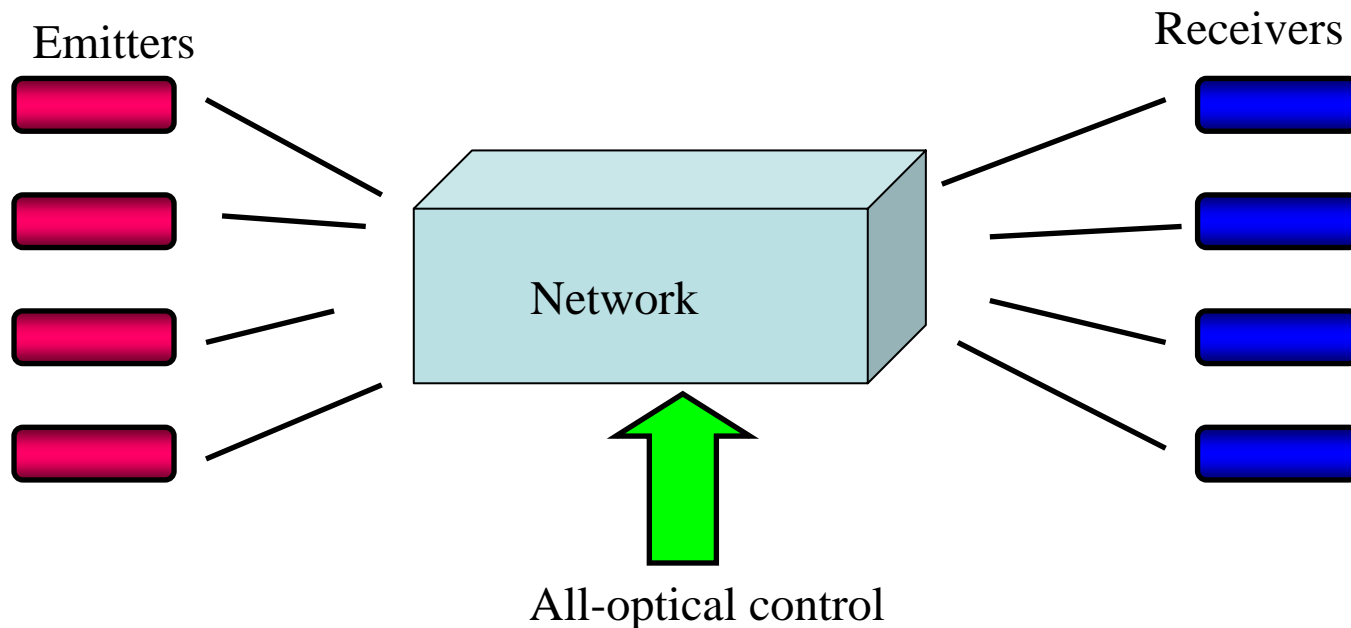
Δn measurement in As_2S_3



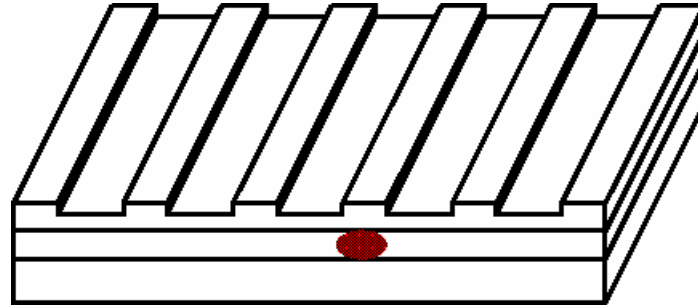
The Δn values measured for As_2S_3 (> 0.08) are much larger than for oxides glasses

3D-optical circuits

- ***Femtosecond direct-writing allows fabrication of basic elements (channel, Y-coupler, grating, directional coupler, FBG...)***
- ***High potential for 3D fabrication in bulk material: Photonic networks using discrete solitons-all-optical routers***



Discrete solitons in nonlinear waveguide arrays



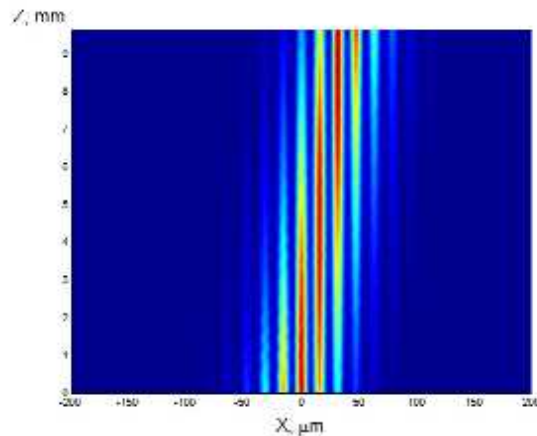
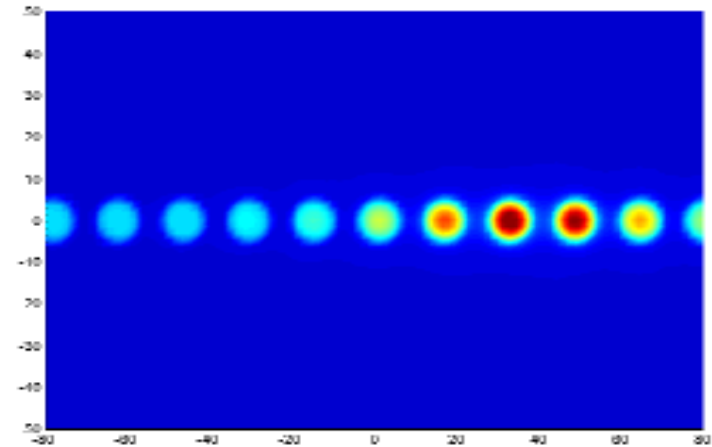
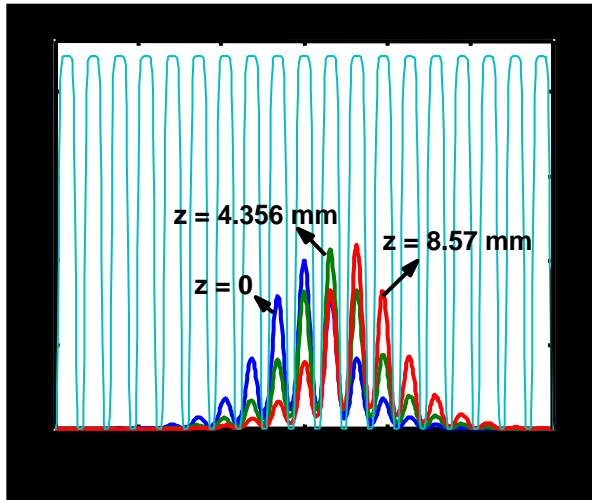
- *From coupled-mode theory, the modal fields in a nonlinear waveguide array are governed by a discrete nonlinear Schroedinger equation*

$$i \frac{dE_n}{dz} + c(E_{n+1} + E_{n-1}) + \gamma |E_n|^2 E_n = 0$$

*linear coupling effects
between nearest neighbors*

*Nonlinear self-phase
modulation effects
in each waveguide*

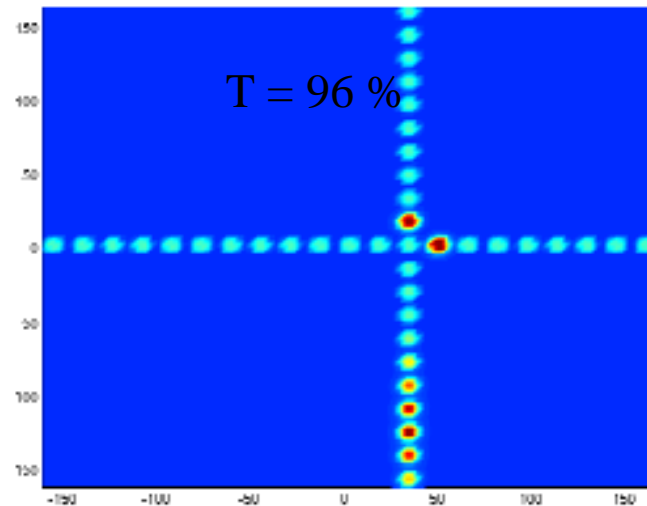
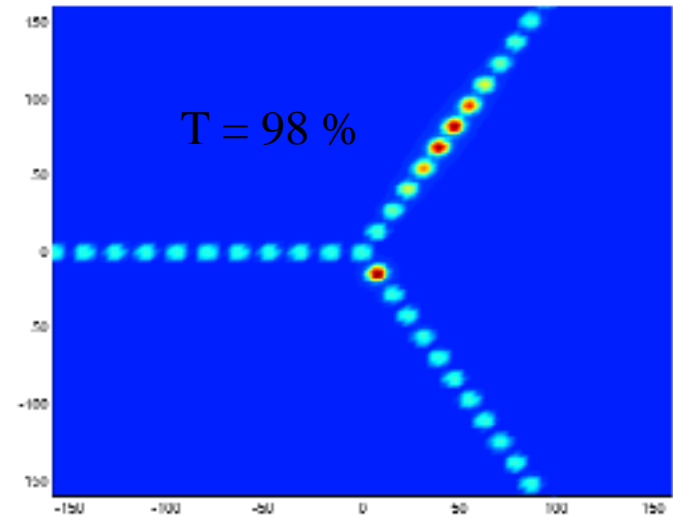
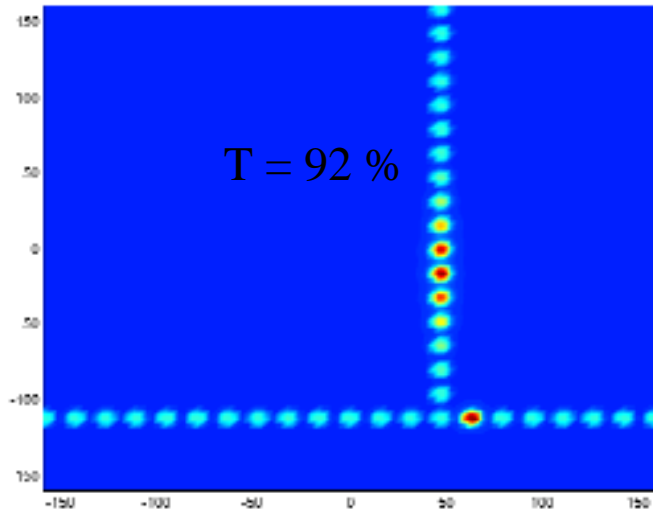
Moving discrete solitons



Discrete solitons move on predefined tracks and thus can be “navigated” in an optical network

Demitrios Christodoulides, George Stegeman

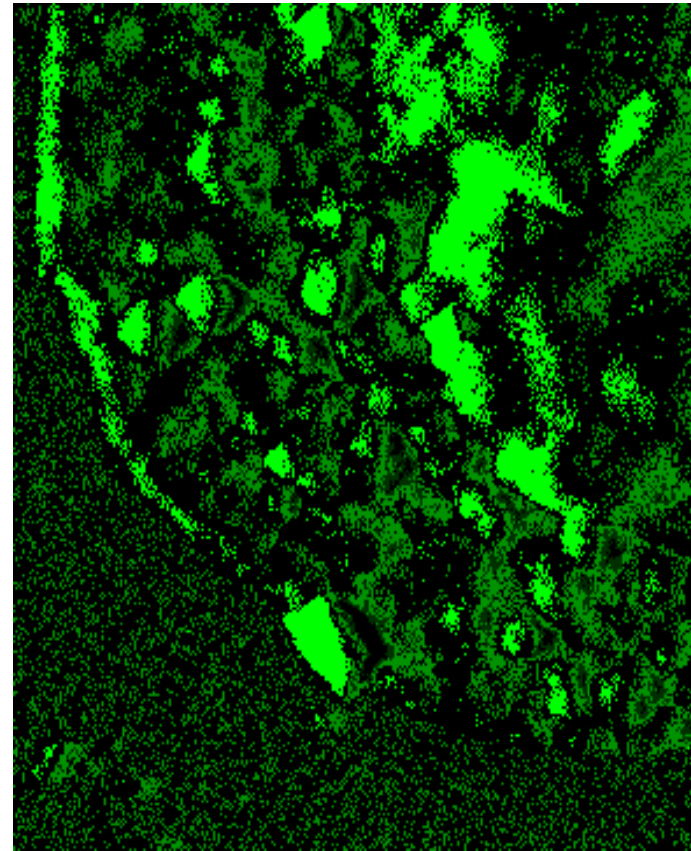
Blocking discrete solitons at network junctions



Blockers (strongly confined discrete solitons) can be used as control solitons for all-optical switching applications

E. D. Eugenieva, N. K. Efremidis and D. N. Christodoulides, Opt. Lett. 26, 1978 (2001)

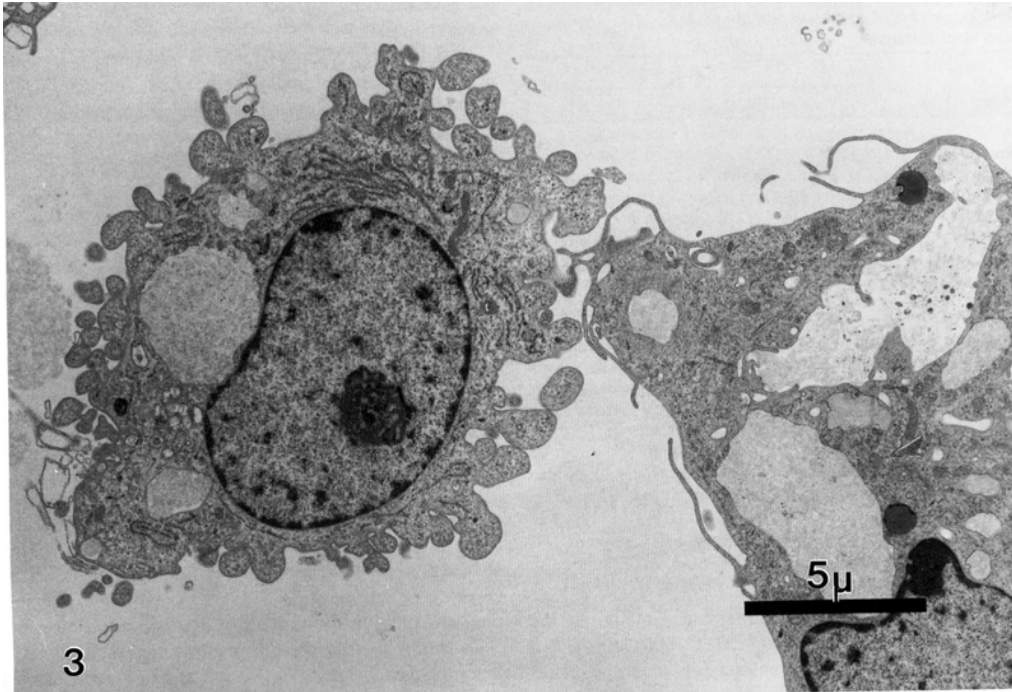
X-ray microscopy of labeled live biological organisms with a nanosecond laser-plasma source



Scanning Electron Beam Microscopy

Accepted imaging technique for small biological organisms

Resolution ~ 1 nm , Depth of field < 1nm



Macrophage from mouse

Elaborate preparation of specimen .

- ***drying, staining,***
- ***sectioning, coating..***

No capability to observe whole cell phenomena.

Impossible to observe in natural state.

No potential for dynamic studies

X-ray micro-radiography with pulsed x-ray source overcomes many of these limitations

Single – shot, nanosecond x-ray micro-radiography

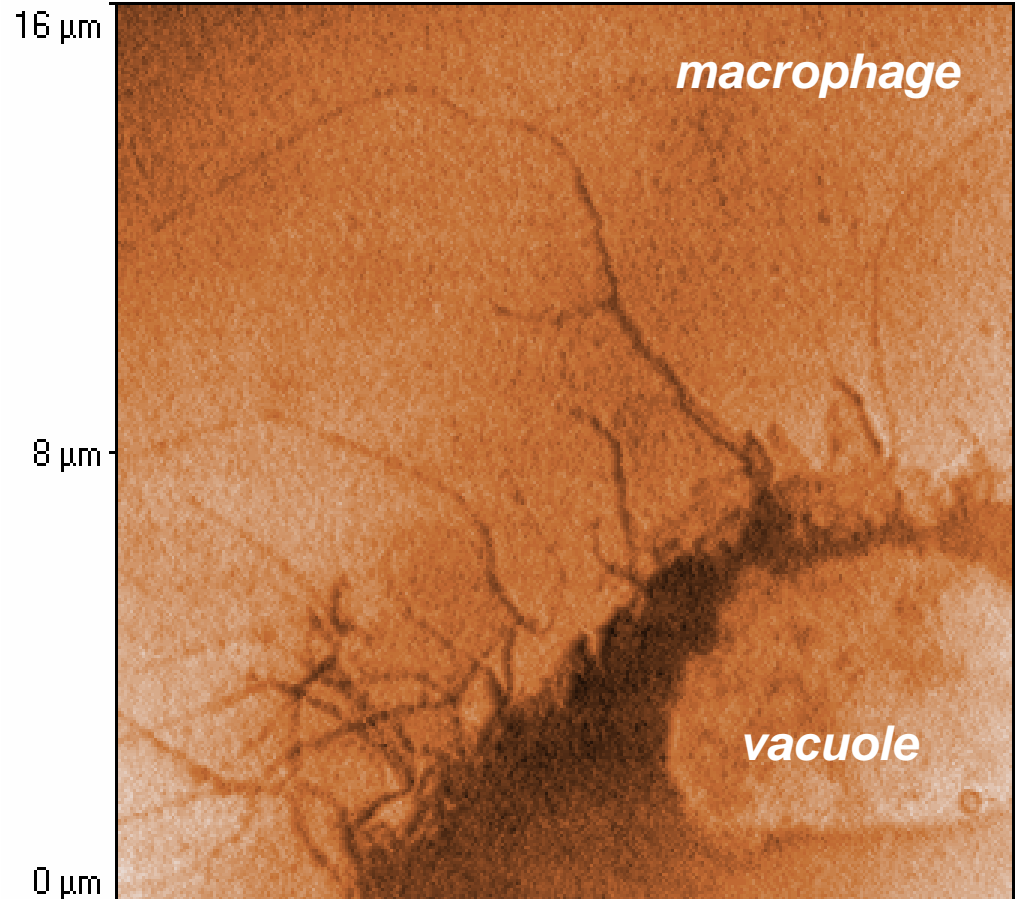
Spatial resolution ~ 10 times better than optical microscopy

In-vitro imaging – specimens in their natural state

30 nm-scale tendrils attached to surface of macrophage .

Tendrils seek contact with latex in close proximity to macrophage.

Tendrils not easily observed with electron microscopy.

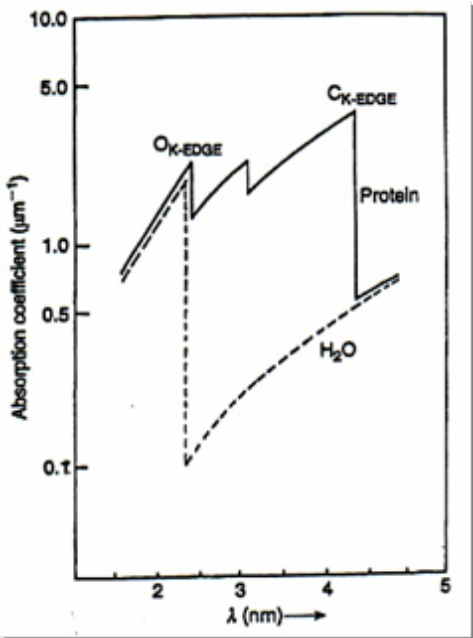
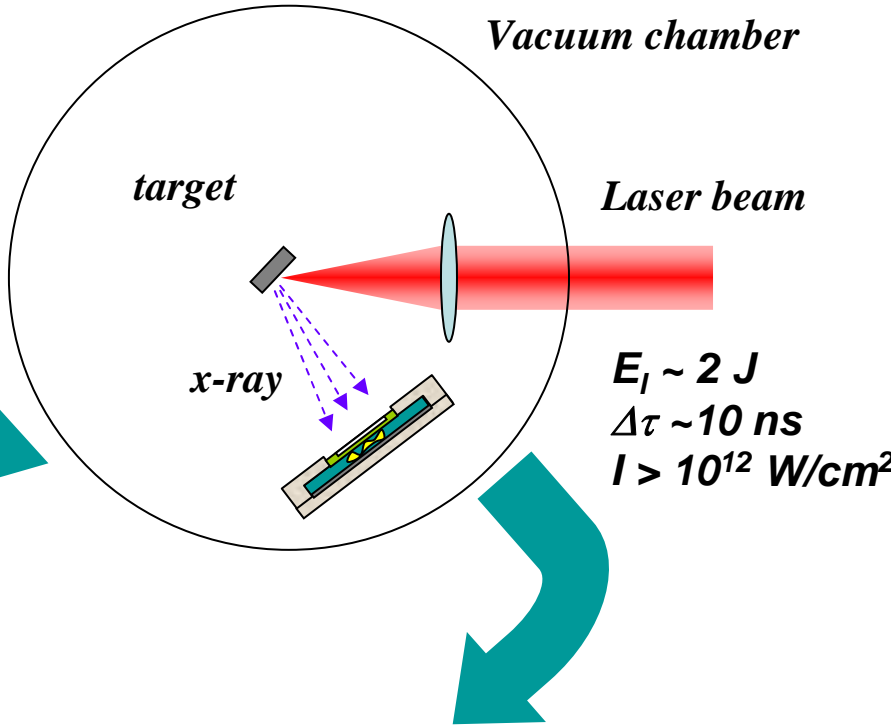
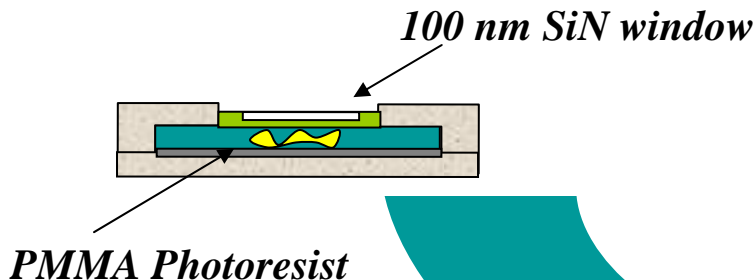


Nanosecond laser-plasma x-ray microradiograph of Macrophage from mouse

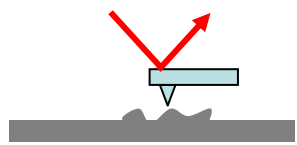
Laser-plasma Microscopy Photo-radiographic process

Specimen is encapsulated in thin liquid cell

Single shot x-ray exposure



AFM readout of processed photoresist

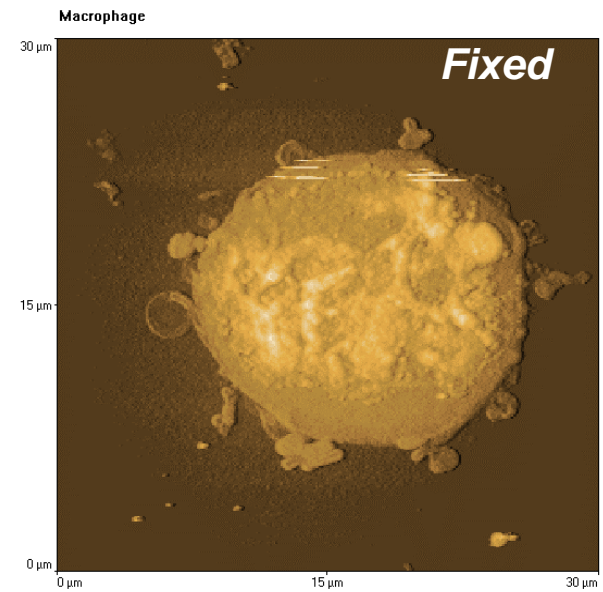
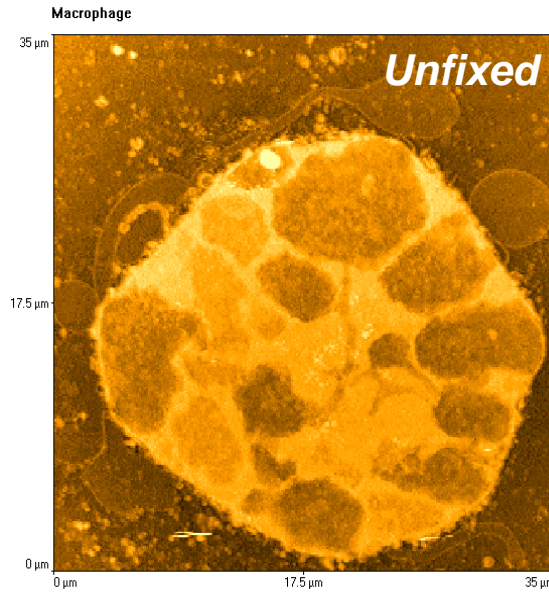


Laser – plasma X-ray microscopy

.....permits observation of structural changes

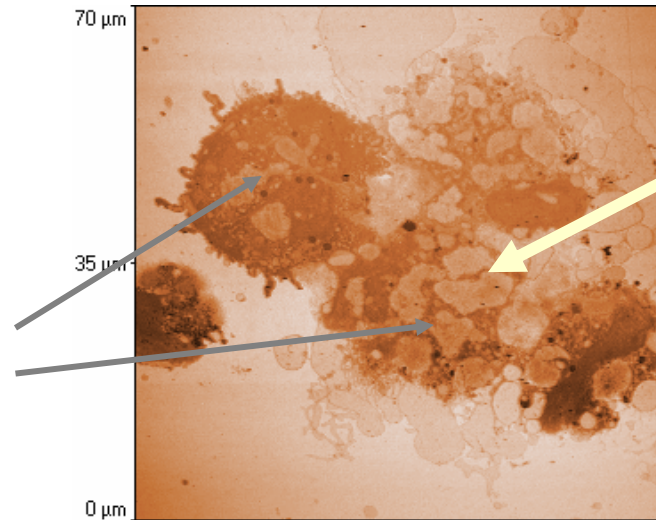
Macrophage from mouse
Single-shot laser-plasma micro-radiograph

X-ray microscopy shows effects of specimen preparation for electron beam microscopy



Single nanosecond x-ray exposure of macrophage interacting with Candida albicans (yeast)

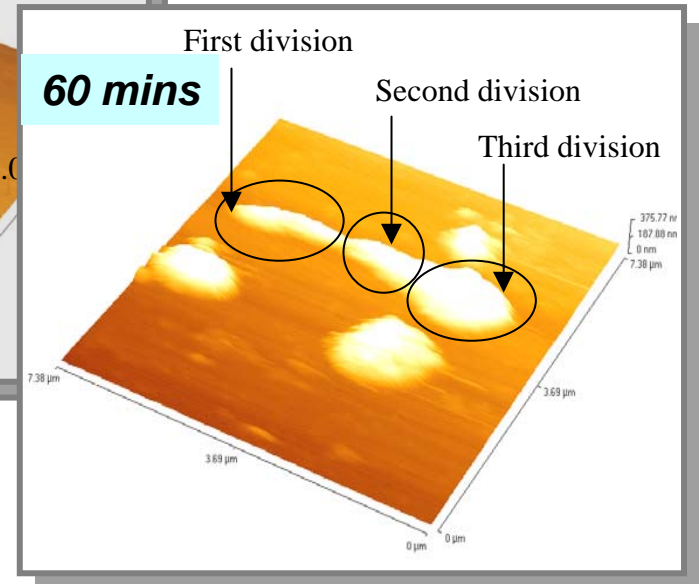
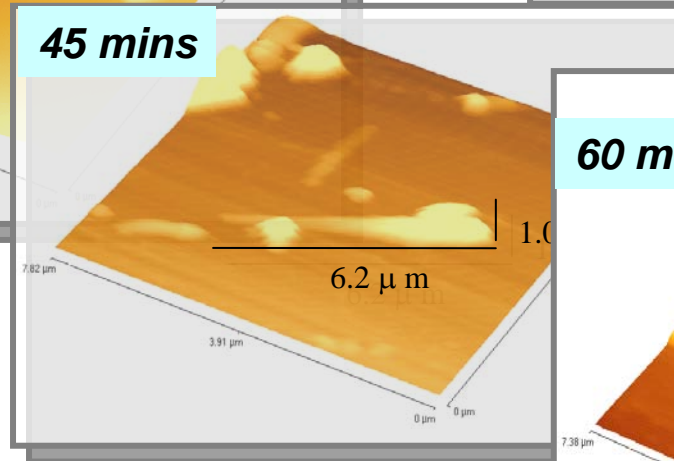
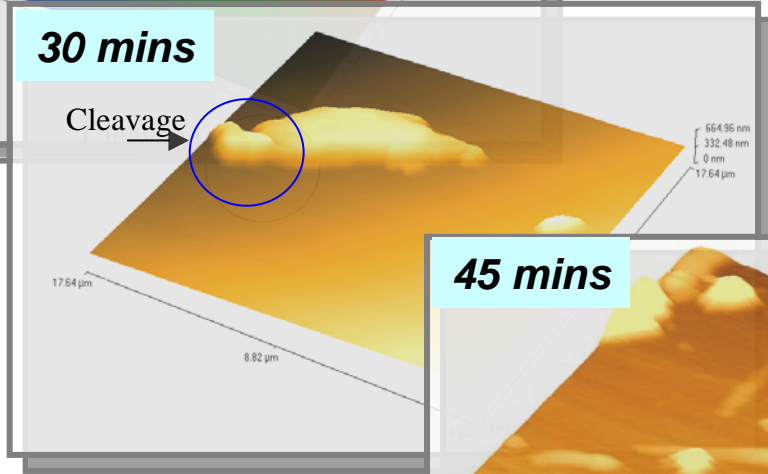
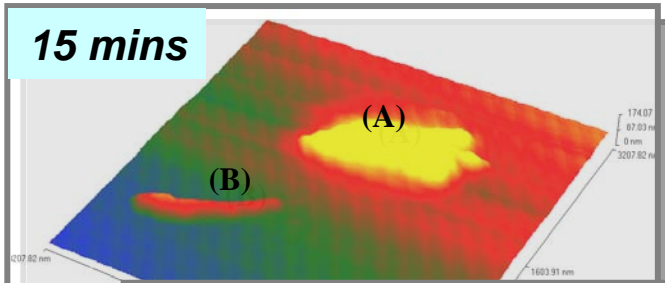
macrophage



Macrophage consuming *Candida albicans*

Time-resolved studies of the effects of drugs on bacteria

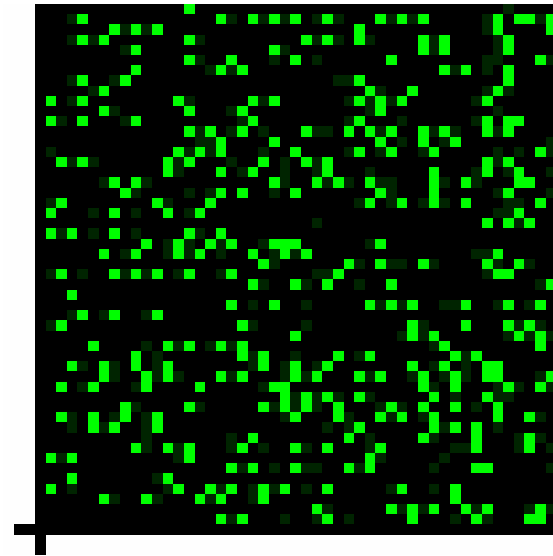
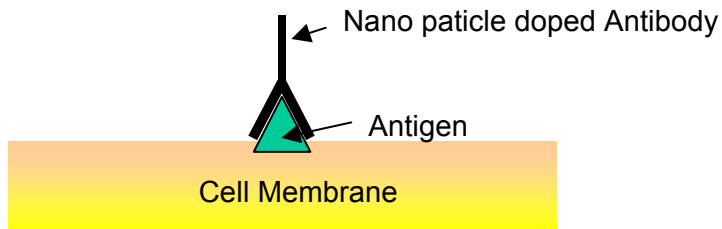
Burkholderia Cepacia



***X-ray micrographs
taken after
Burkholderia Cepacia
was exposed to
Gentamicin***

X-ray imaging of single cells – protein labeling

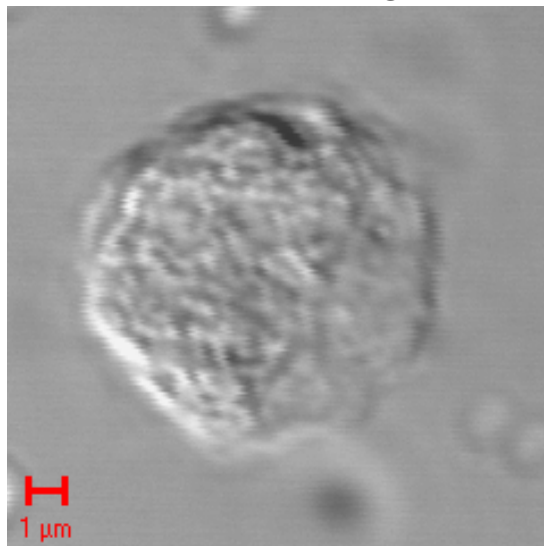
Dr Ma'an Al- Ani
PhD -2001



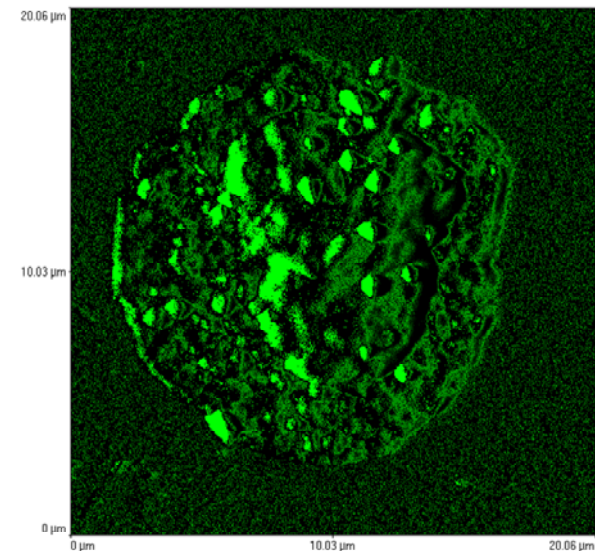
Individual 18
nm gold
nanoparticles

X- ray image

Optical image



*human
lymphocytes*

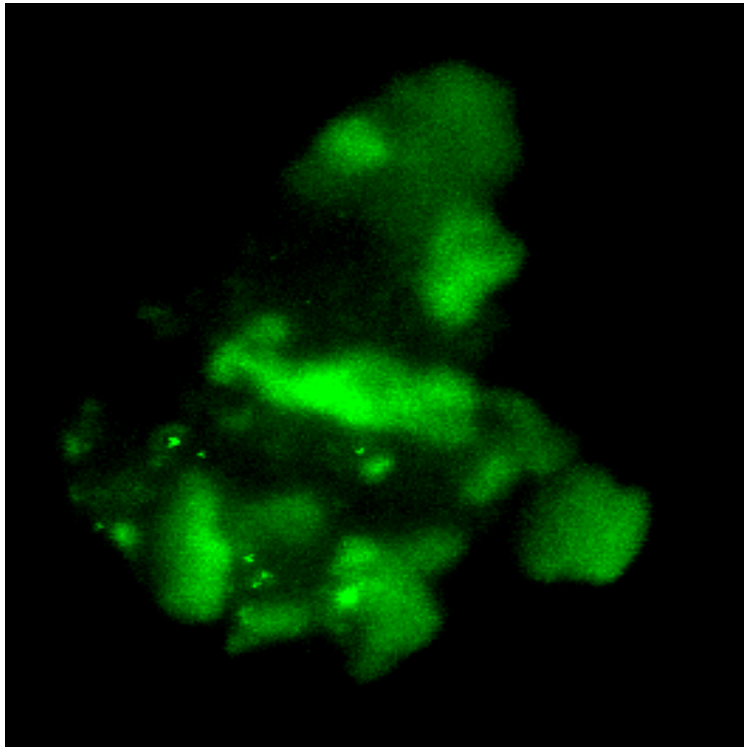


Comparison of confocal and X-ray images

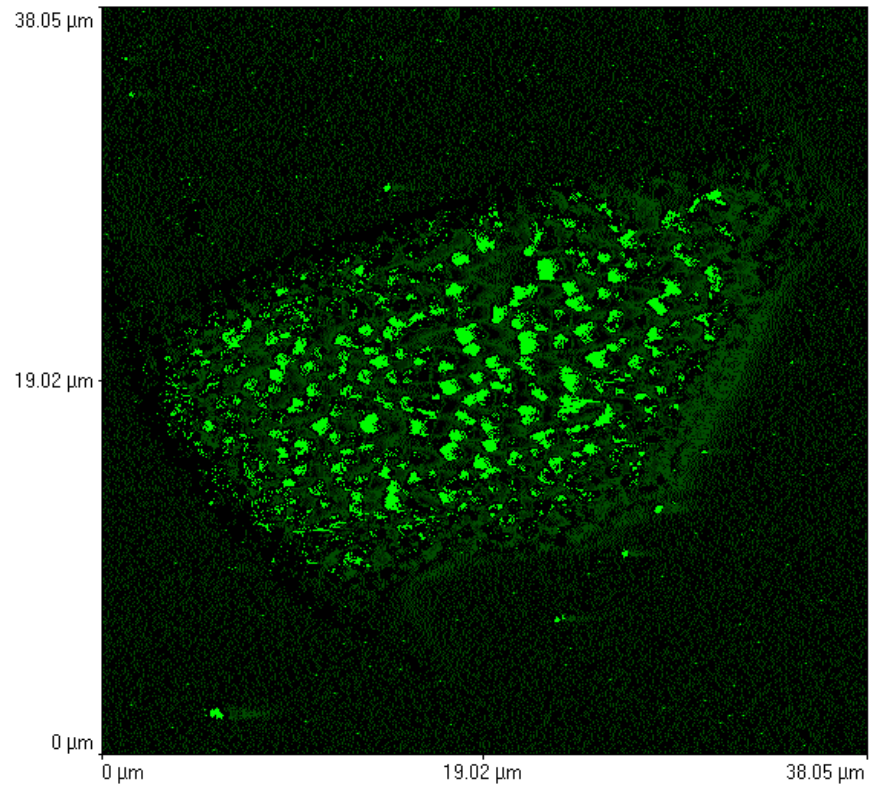
A375 amelanotic melanoma cells

Monoclonal mouse anti-human CD54

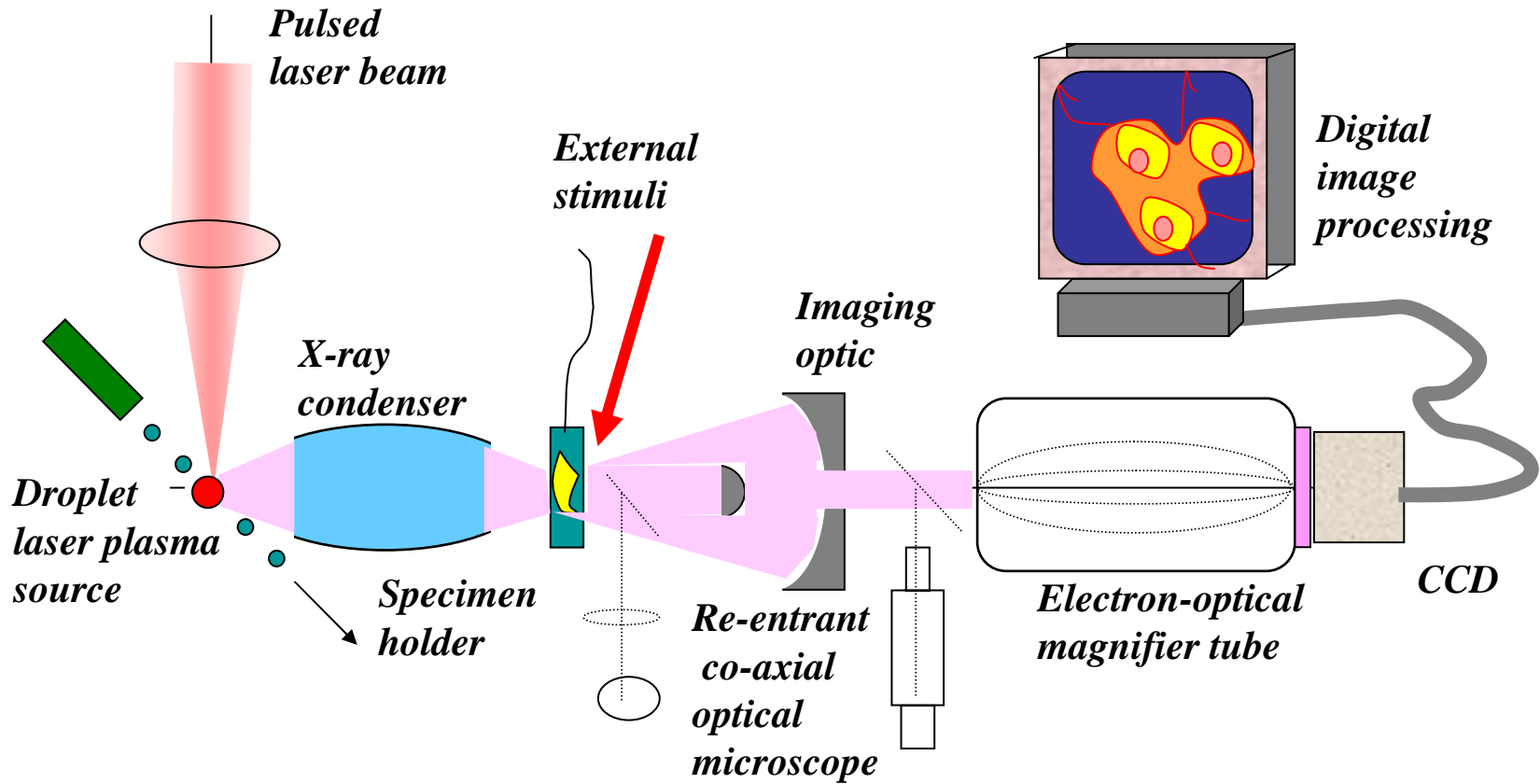
Confocal Image



X-ray image with Au labels



Design of a real-time imaging x-ray microscope

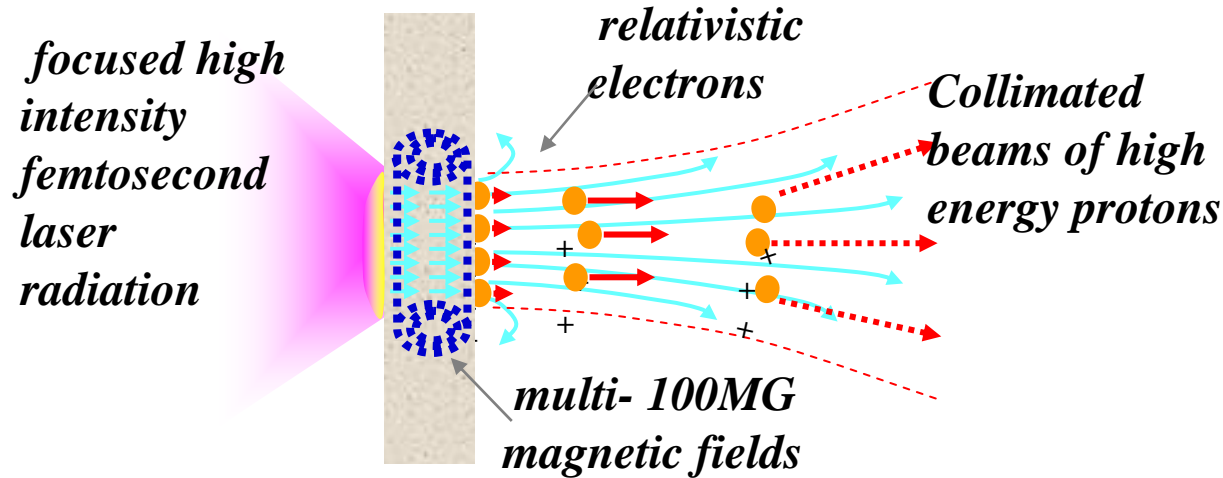
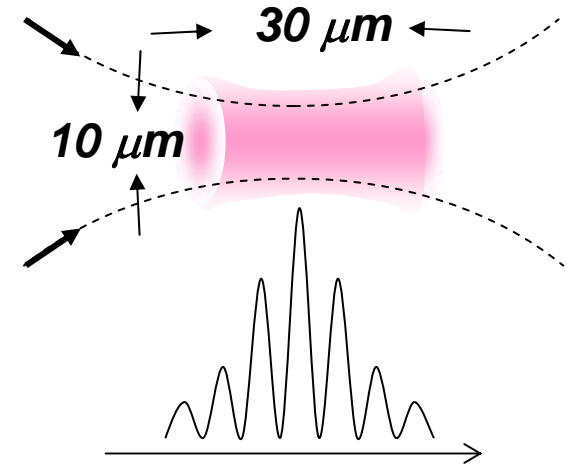


Fs high energy electron, x-ray, particle source

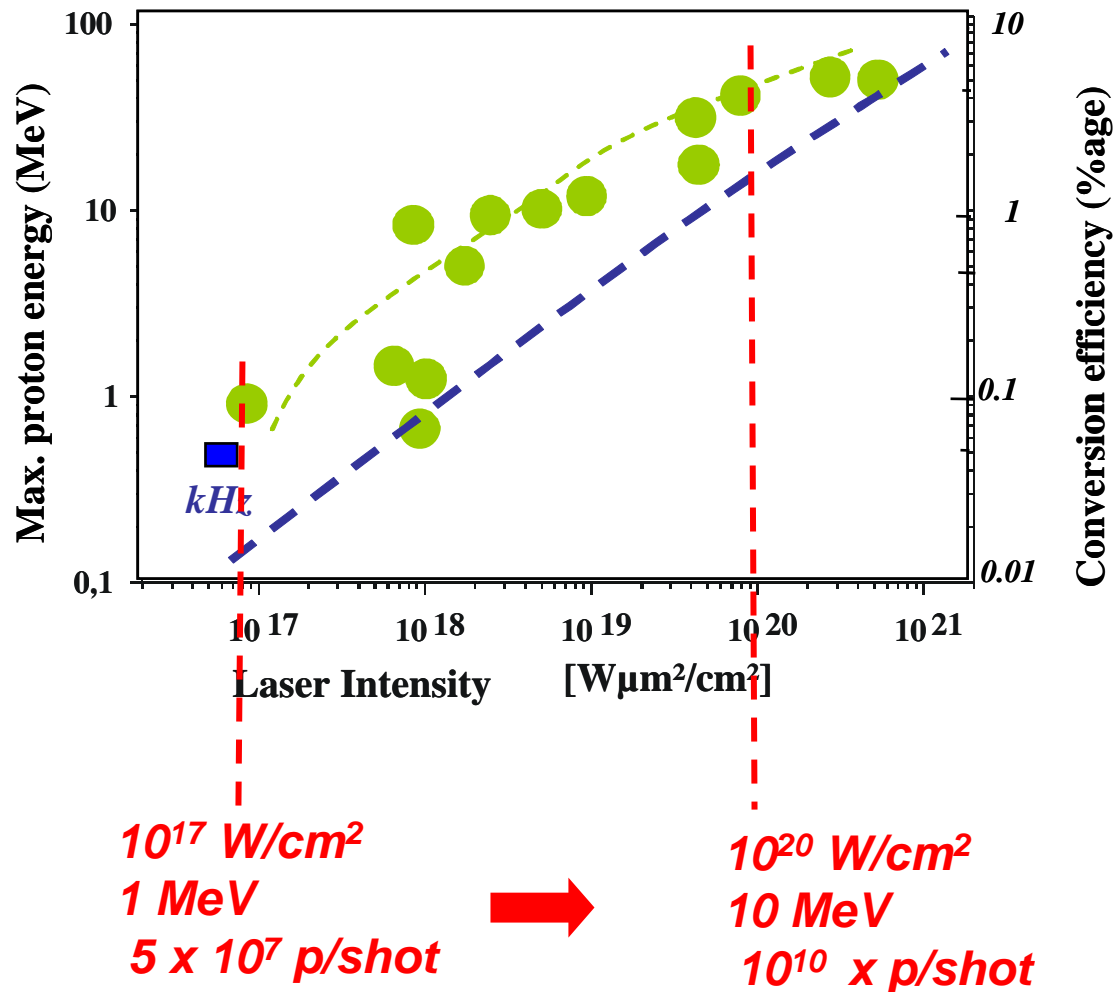
$$U = 100 \text{ mJ}, \quad \Delta t = 100 \text{ fs}, \quad w_0 = 10 \mu\text{m}$$

$$I = \frac{E^2 (V \cdot m^{-1})^2}{377} = 10^{20} \text{ W} \cdot m^{-2}$$

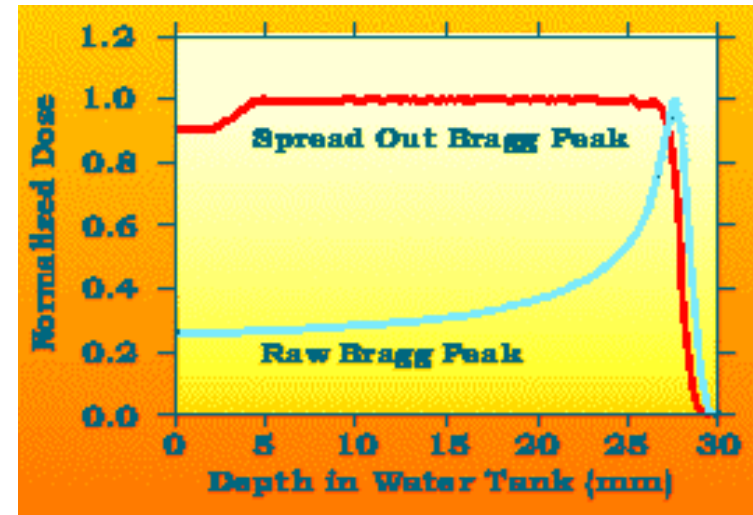
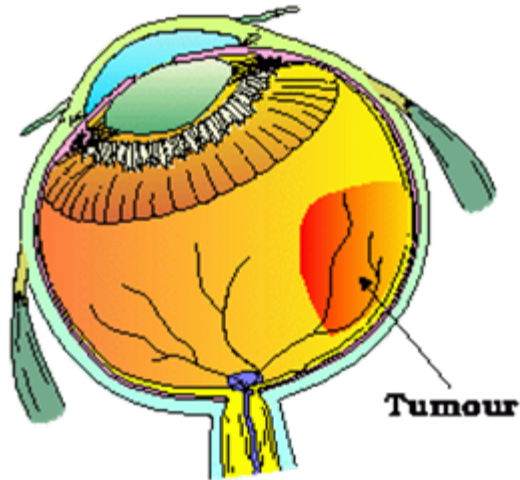
$$\therefore E = 2 \times 10^{11} \text{ V} / m$$



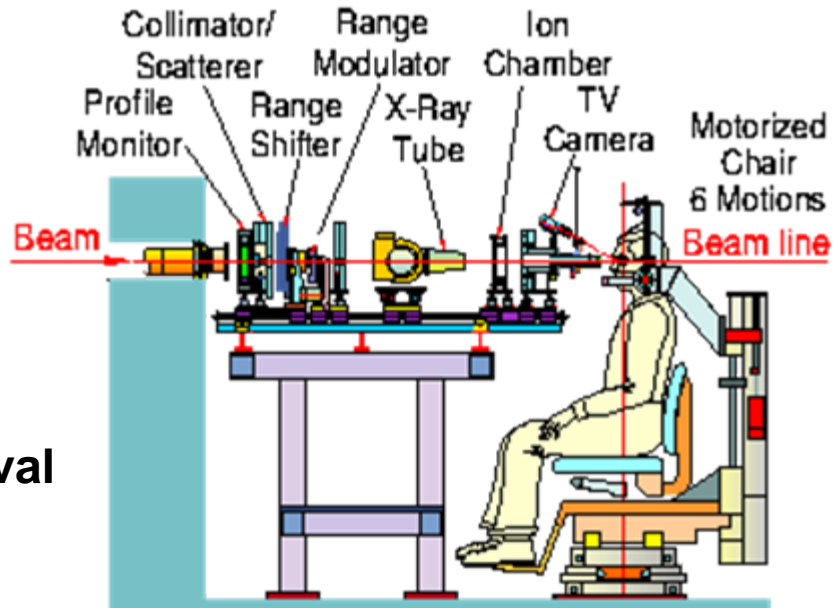
High proton fluxes at viable laser intensities



Proton Therapy of Choroid Melanoma of the eye



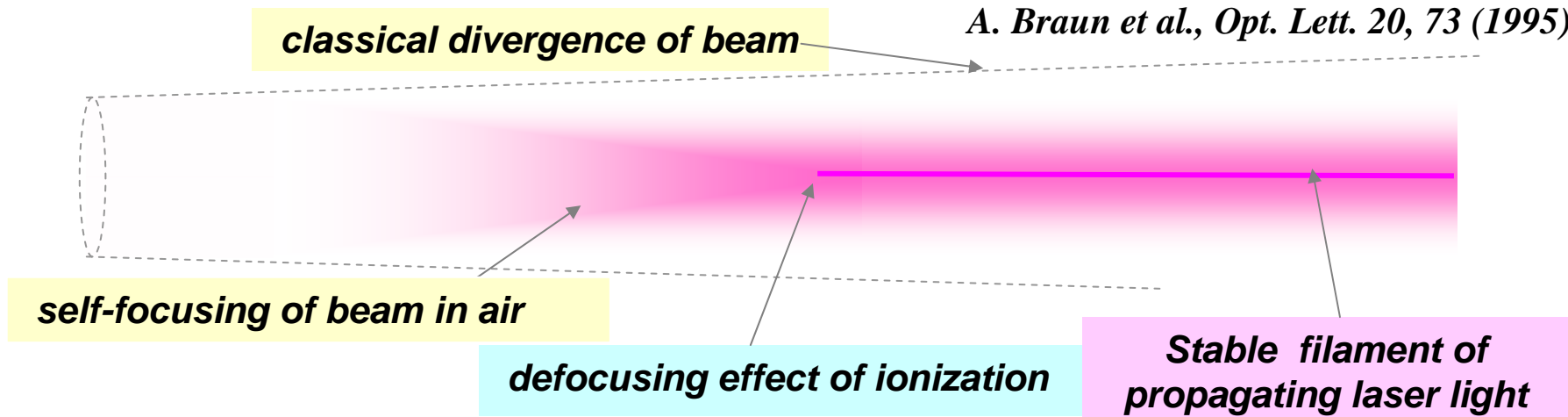
- 50% of all proton cancer therapy
- 70 MeV - modulated
- 5 – 6 facilities worldwide
- Only alternatives –isotopes or removal



<http://www.triumf.ca/welcome/proton>

Atmospheric propagation of fs laser pulses

A. Braun et al., *Opt. Lett.* 20, 73 (1995).



At sufficiently high intensities (10^{12} W), the second-order, intensity-dependent refractive index n_2 of the air comes into play, increasing the overall refractive index of the air through which the beam propagates, according to the relation,

$$n = n_0 + n_2 I$$

$$n_2 = 5 \times 10^{-19} \text{ cm}^2 / \text{W}$$

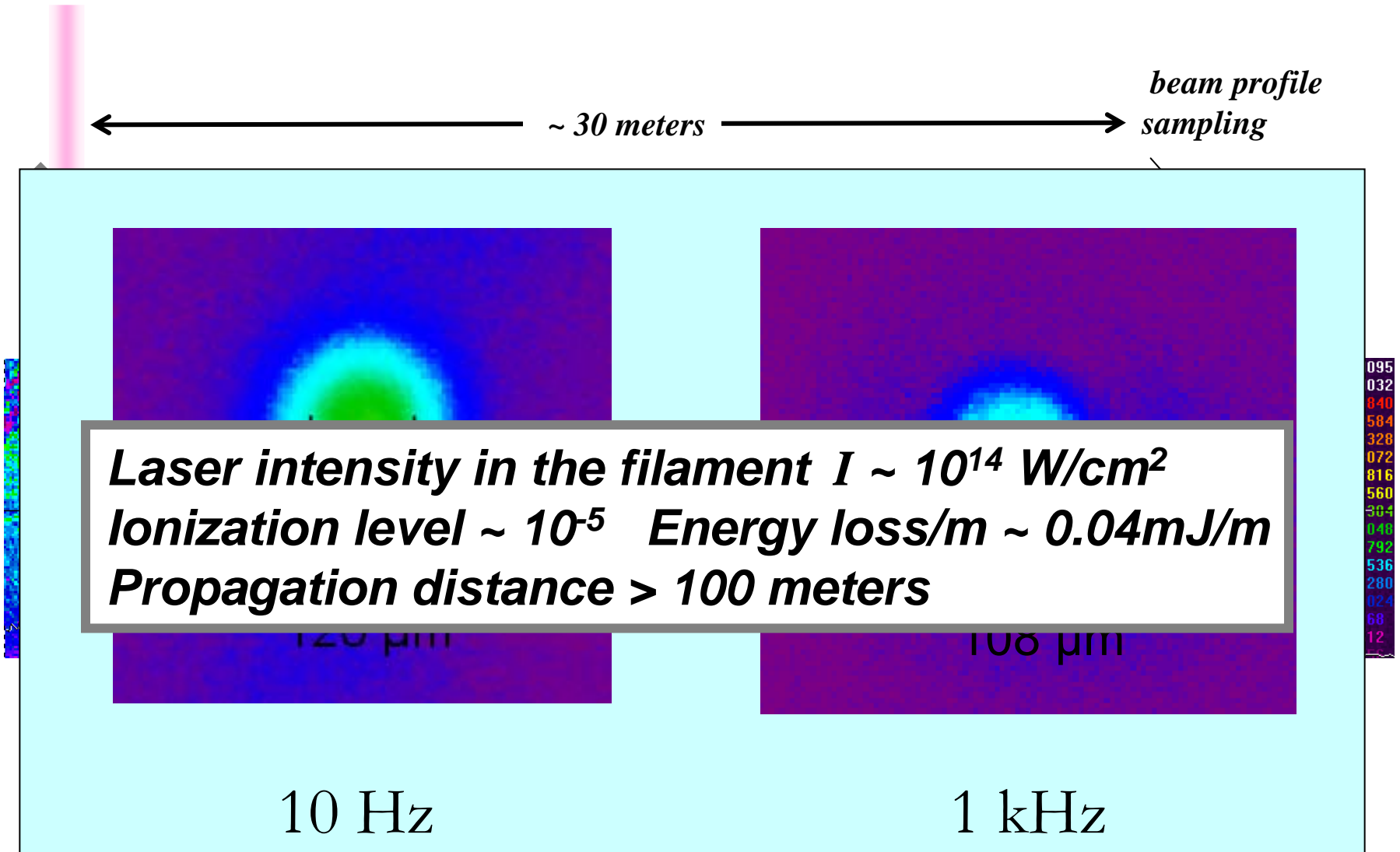
When the intensity of the light within the focusing beam reaches a threshold (about 10^{14} W/cm² at atmospheric pressure), weak ionization of the air begins to occur by multi-photon ionization. Free electrons are created from the molecules of the air by the intense oscillating electric fields within the laser pulse. Since free electrons provide a negative contribution to the total refractive index, they produce a counteracting weakly defocusing effect.

$$n_e \sim 1 \times 10^{17} \text{ cm}^{-3} \quad I \sim 200 \text{ mA}$$

$$\eta < 1.2 \Omega$$

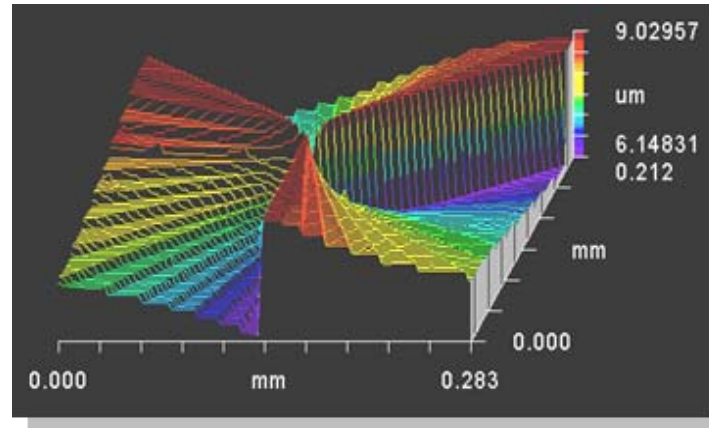
(S. Tzortzakis, *Opt. Comm.* 181, 123 (2000))

Beam collapse with increasing energy

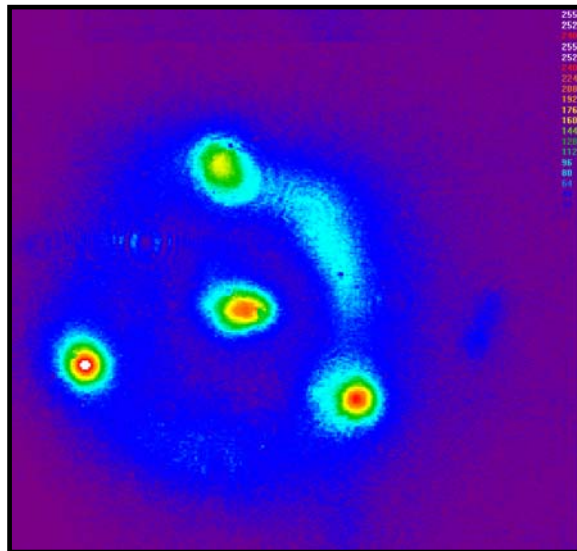


Novel optics for new fs laser channel structures

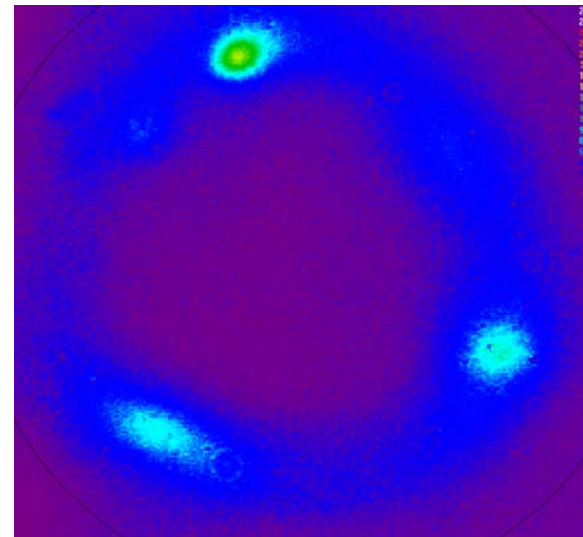
***Vortex lens
(C. Siders,
E. Johnson
M. Fisher,
CREOL, UCF)***



Beam Profile without Vortex

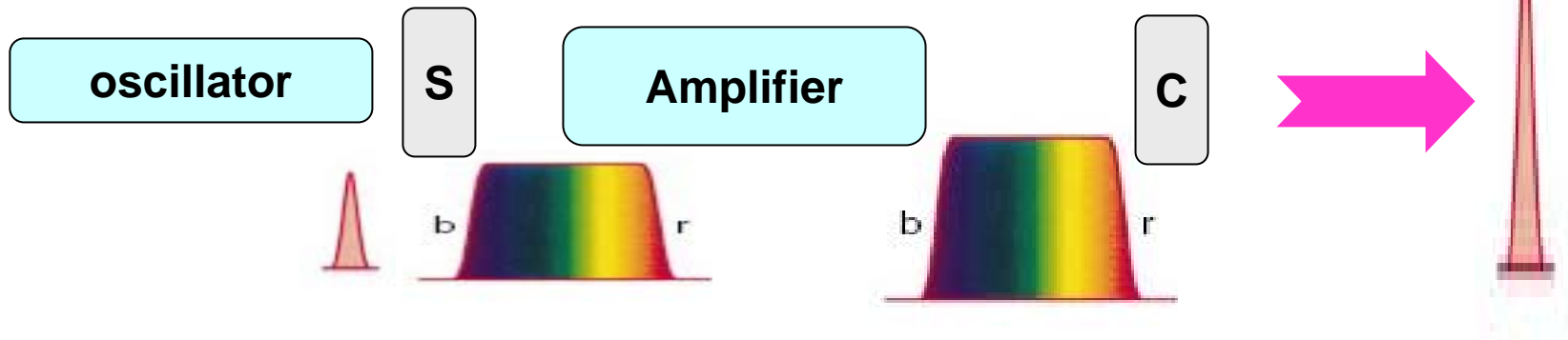


Beam Profile with Vortex plate

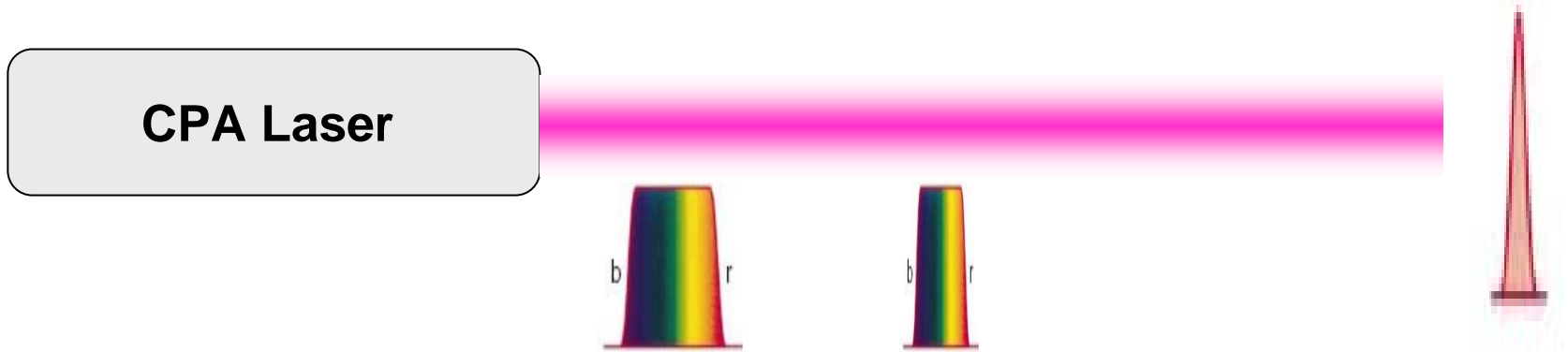


Creating the filament at any desired range

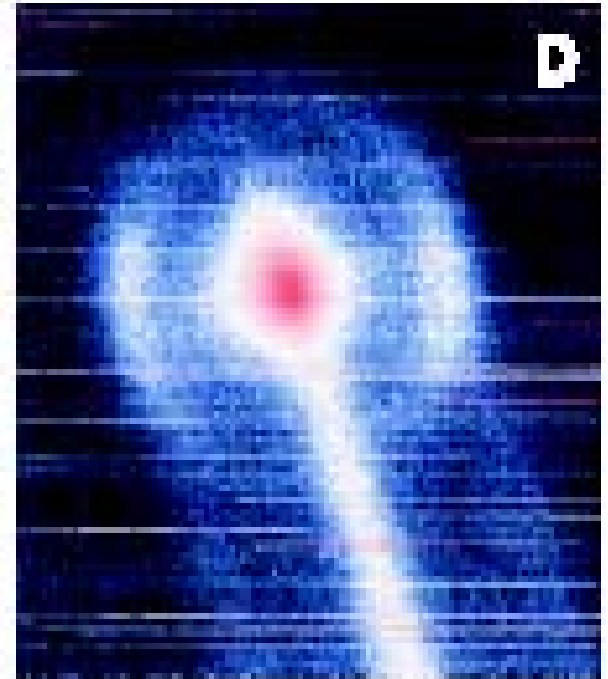
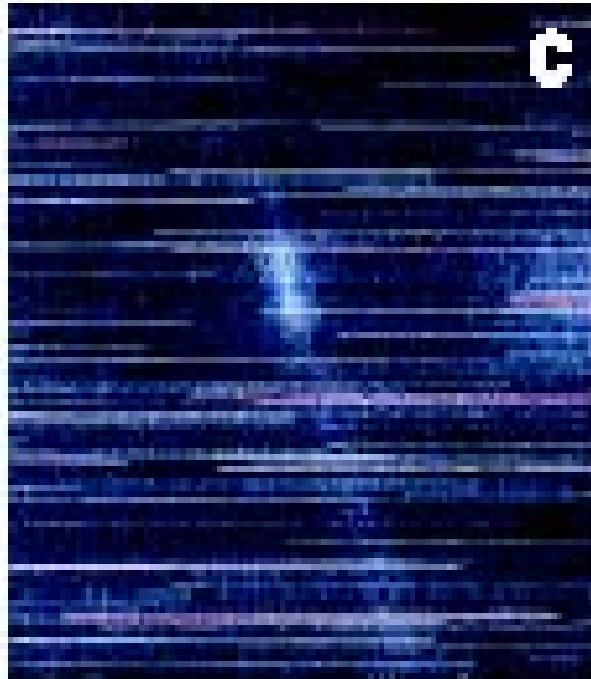
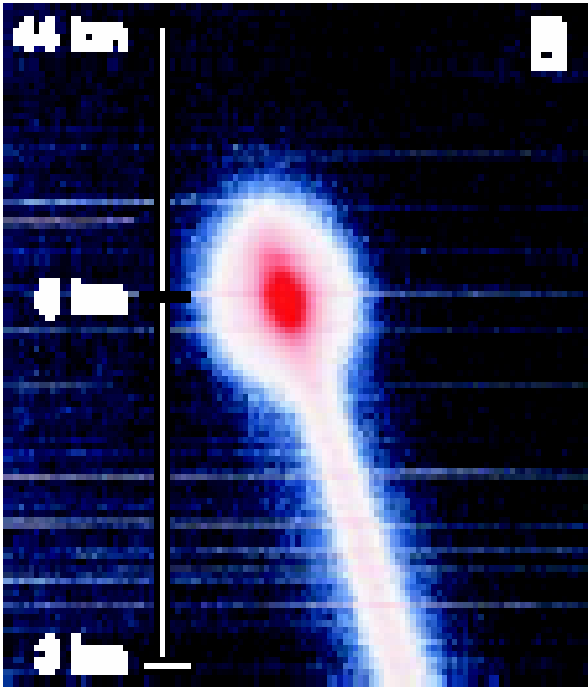
CPA Laser Architecture



Pulse compression in the Atmosphere



Creating the filament at any desired range

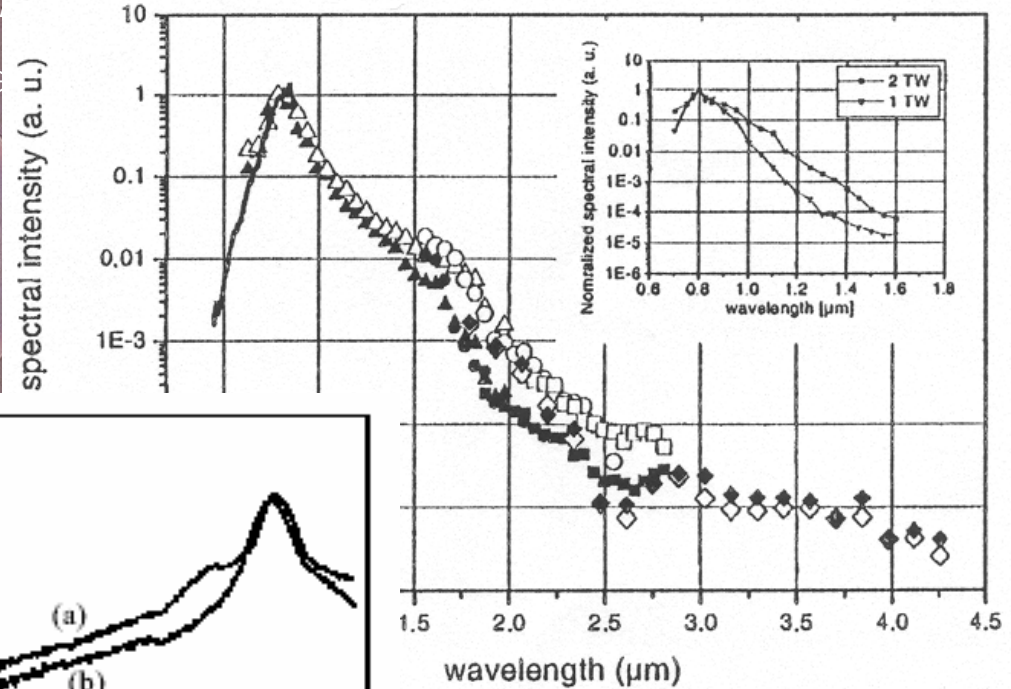
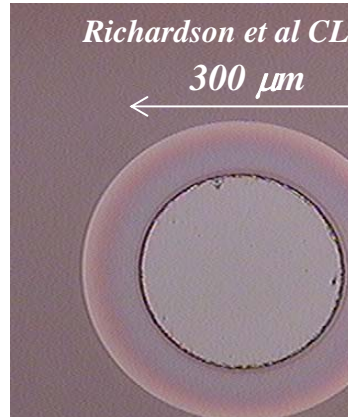


Compensating for self-phase modulation and GVD, with negative pre-chirp creates white light at different altitudes

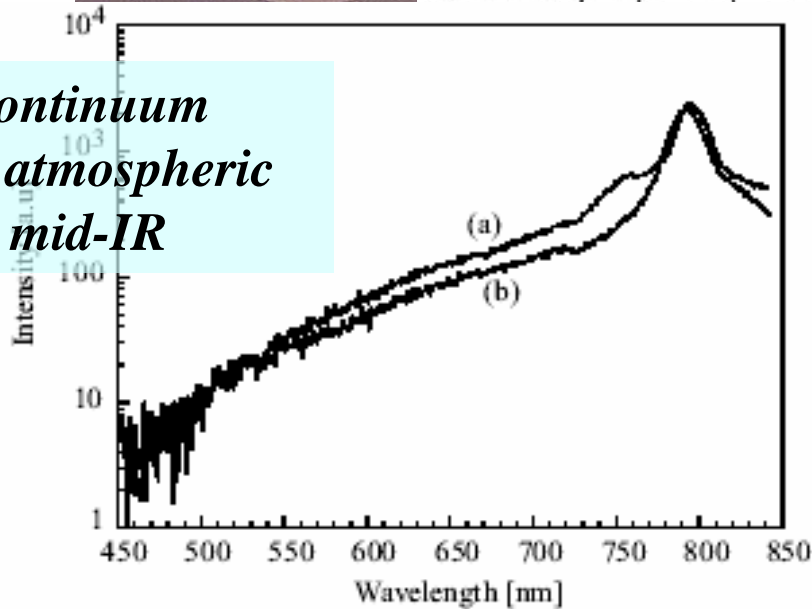
Kasparian Science 301, 61-64 (2003).

Unique propagation characteristics.....

The self-channeled beams can be extremely circular



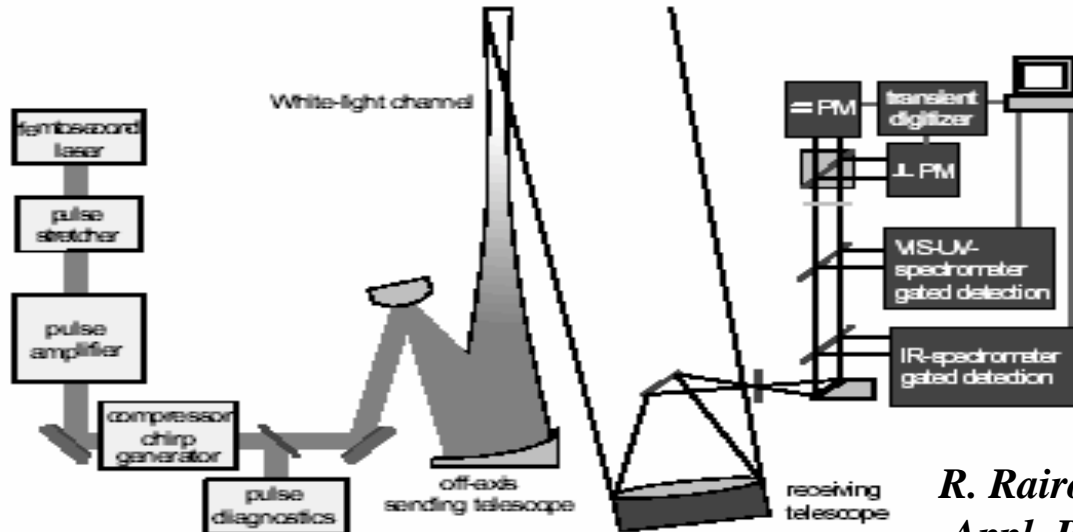
The white light continuum extends from the atmospheric UV cut-off to the mid-IR



Kasparian et al., Opt. Lett. 25, 1397 (2000)

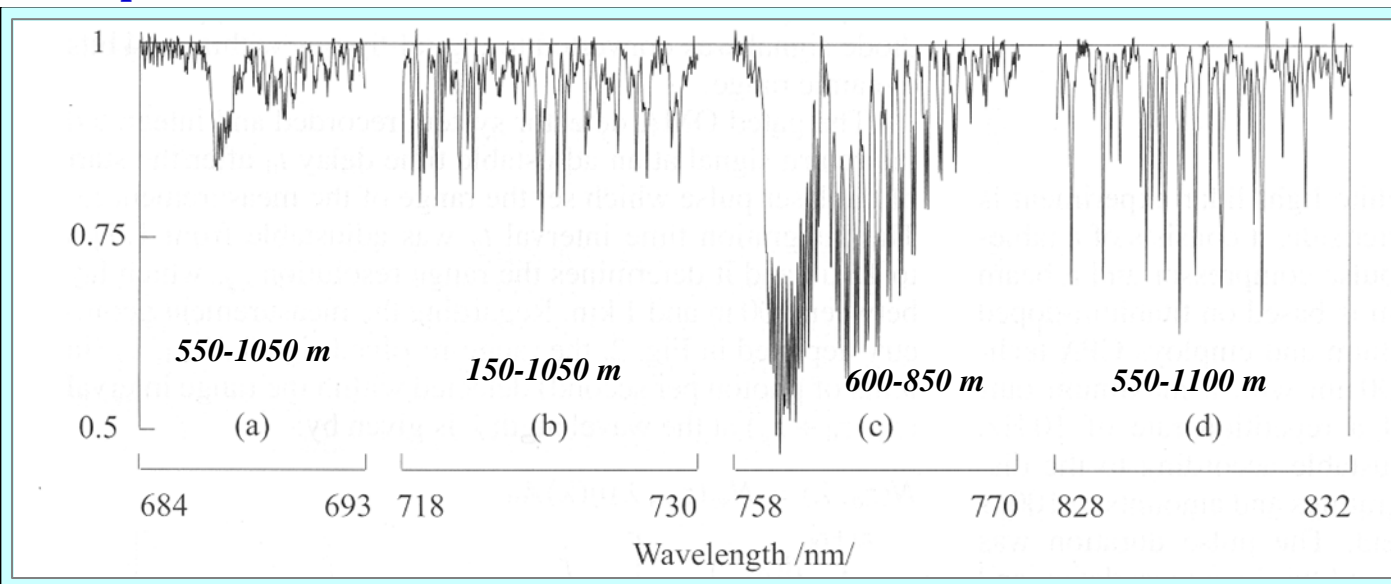
R Rairoux et al., Appl. Phys B 71,573 (2000)

White light absorption spectroscopy LIDAR



*R. Rairoux et al
Appl. Phys. B 71, 573 (2000)*

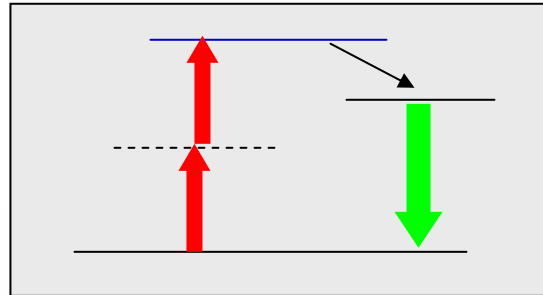
Atmospheric transmission in the vis – IR



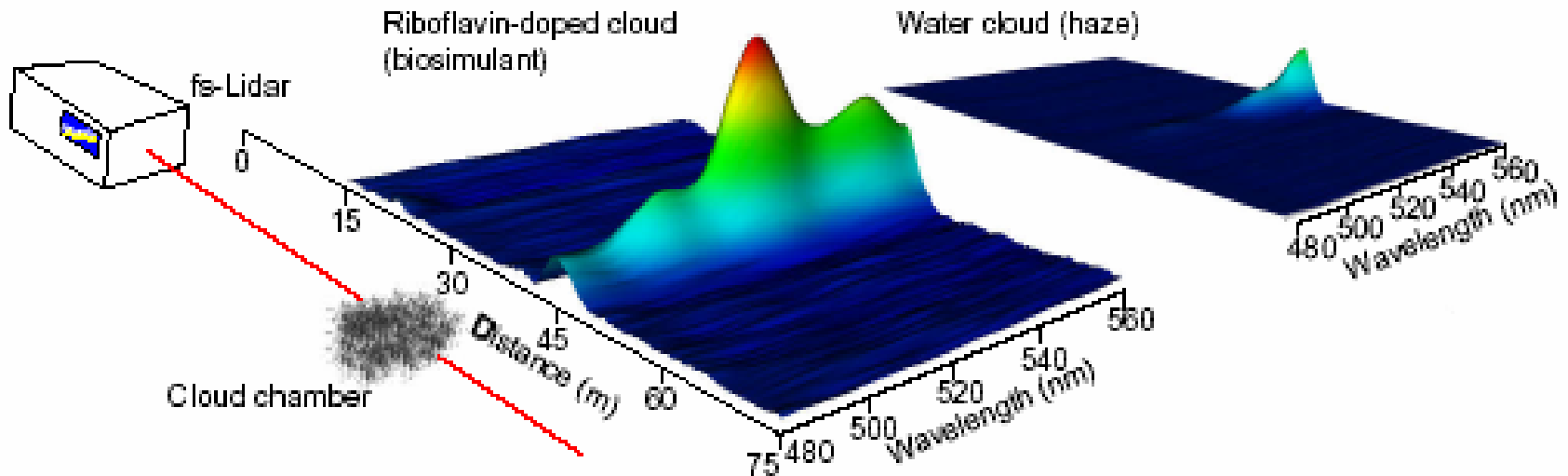
Multiphoton –induced Fluorescence detection

..first detection of and identification of biological aerosols in air by non-linear lidar

Two photon
excited
fluorescence



*Discrimination against
backgrounds
High sensitivity*

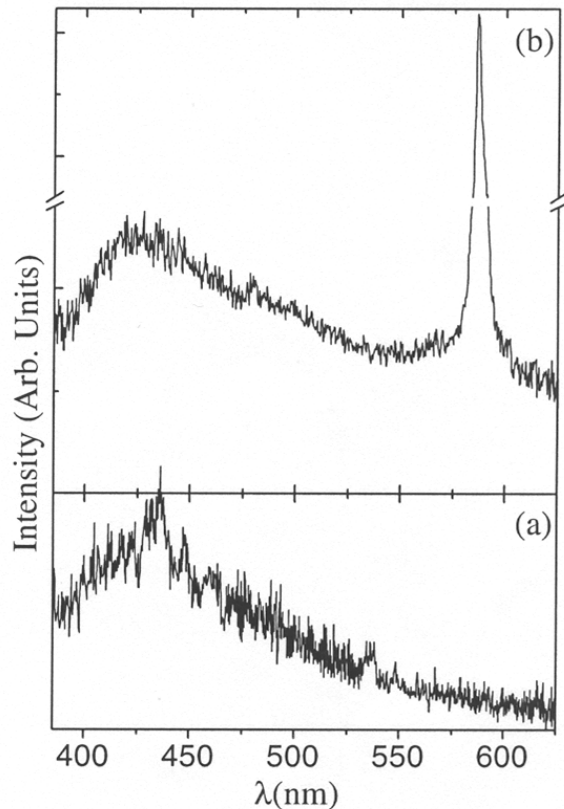


G. Mejean, et al, Appl. Phys. B 78, 535, (2004)

**NON-LINEAR SPECTROSCOPIC DETECTION OF CONTAMINATED AEROSOLS BY
SELF-CHANNELED LASER BEAMS M. Richardson, & A. Gaeta**

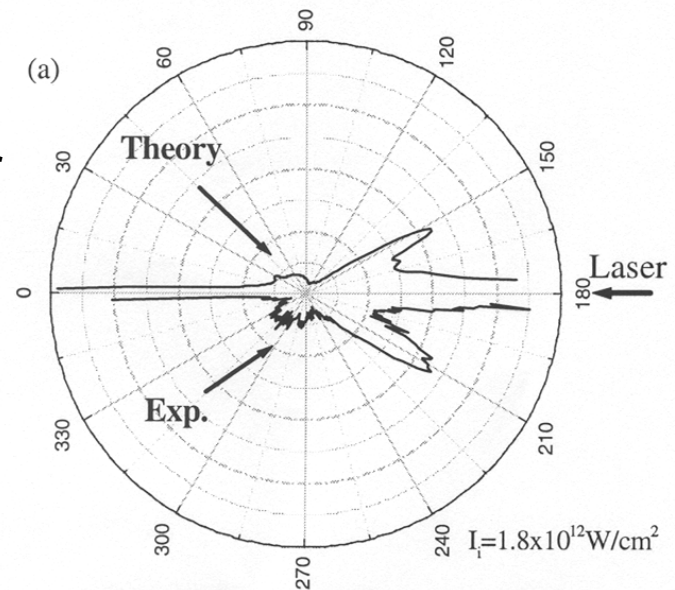
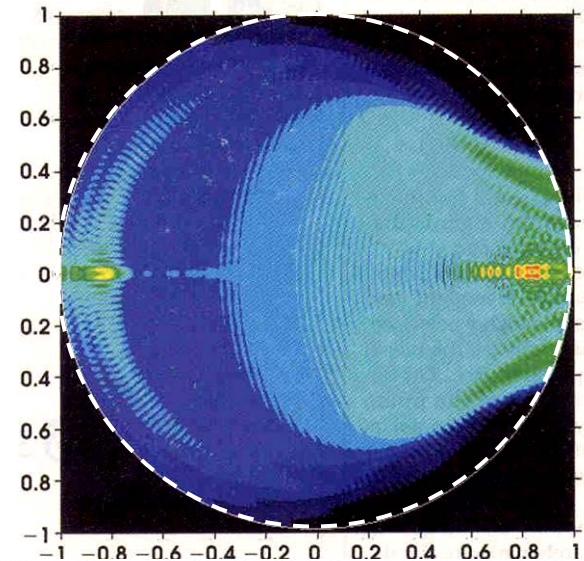
Interaction with Aerosols

**Self-focusing of laser beam inside droplet.
Microscopic plasma formation. Temperatures
in excess of 7000 deg predicted
White light emission dominated by LIB
emission**

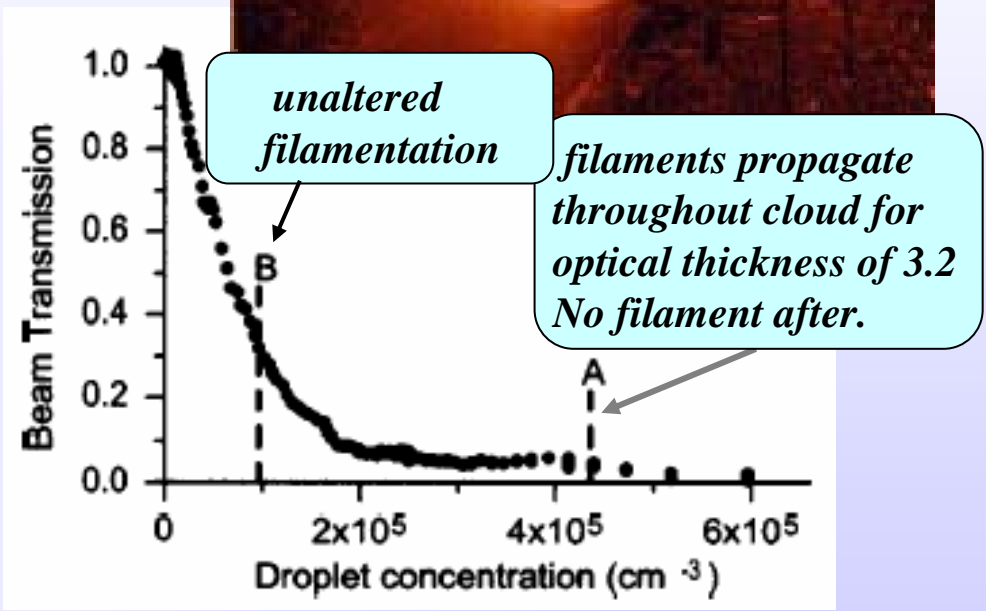
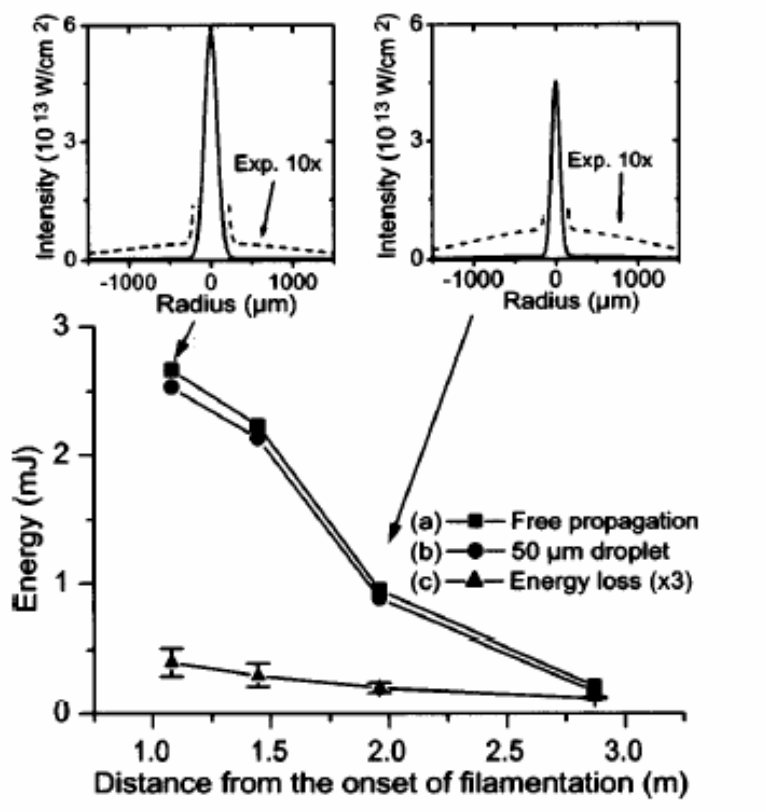
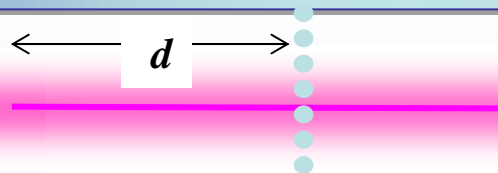


**Na D lines
from saline
solution
droplet**

**Strong angle
dependence of
white light
backscattered
emission**



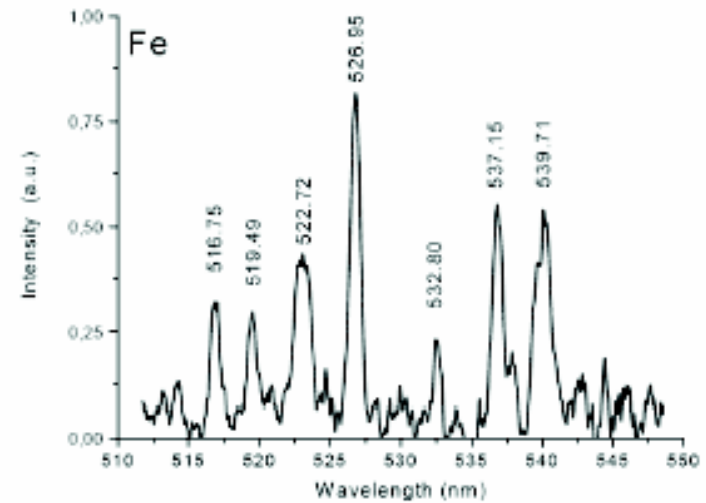
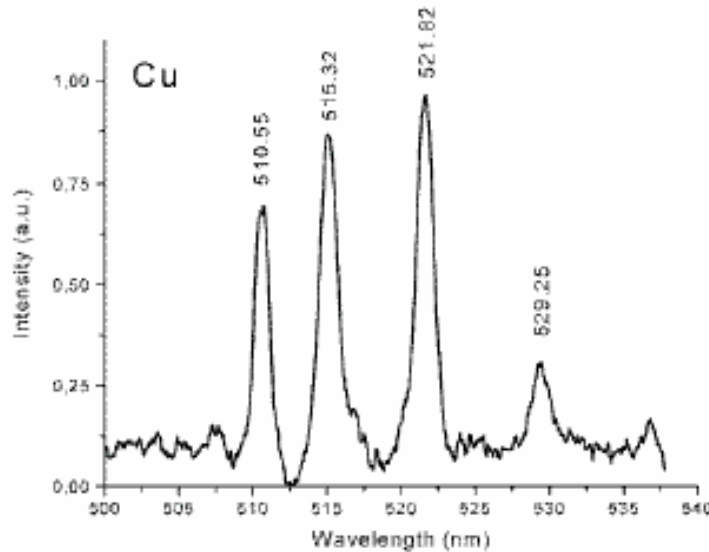
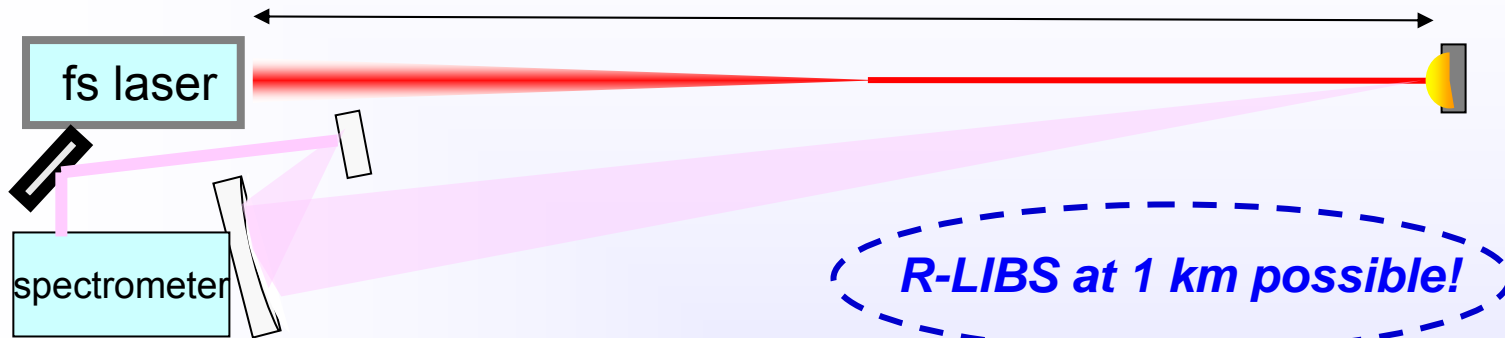
Self-channeled laser beams propagate through clouds



The energy loss in the photon bath by Mie scattering dominates....constitutes the main limitation for filament transmission through clouds

F. Courvoisier et al Appl. Phys. Lett. 83,213, (2003)

Remote LIBs with fs channeling

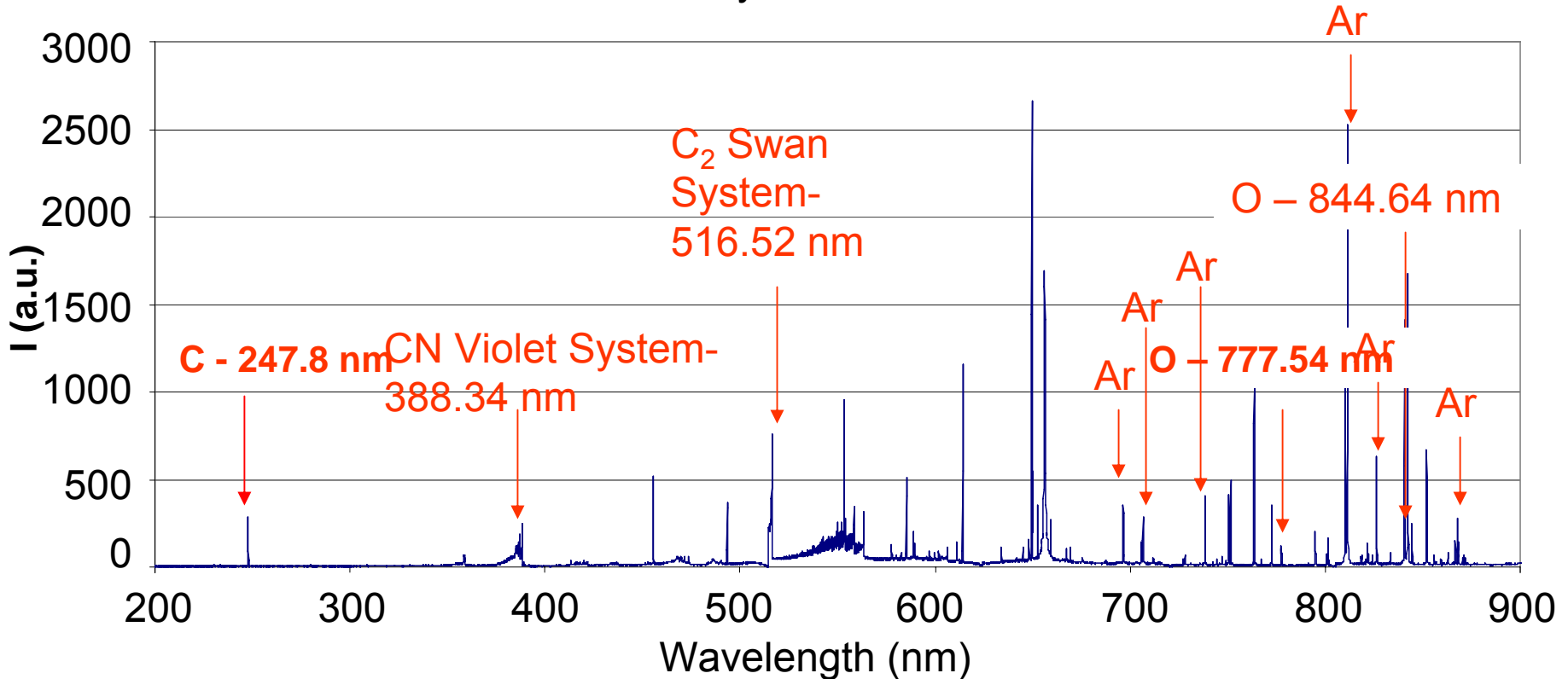


Kamil Stelmaszczyk, et al
Appl. Phys Lett. (to be published)

"Propagation & interaction studies of high intensity fs laser beams in the atmosphere" M. Richardson et al., NTAR VI - Nov.15-17, 2004

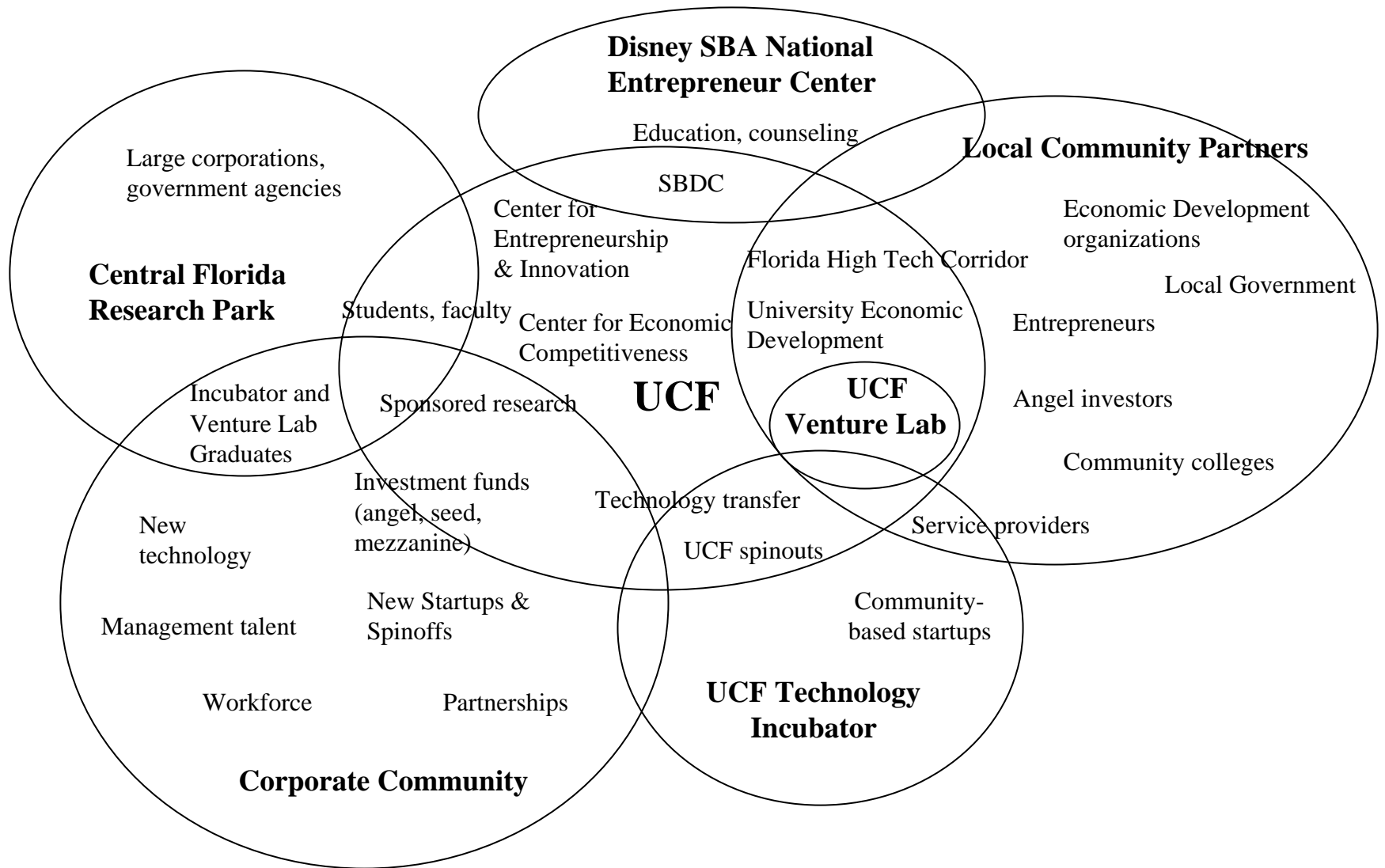
New LIBS data for TNT

Military Grade TNT



Single Pulse Nanosecond LIBS, 1064 nm, 100 mJ/pulse
Argon atmosphere

Entrepreneurial Ecosystem



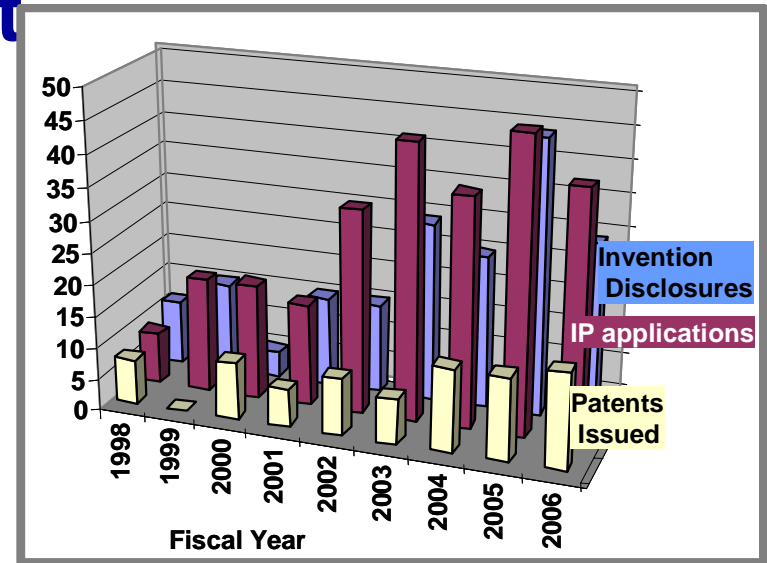
CREOL Economic Impact

Partnerships with industry
Leveraged Federal R&D funding
Enrich high-tech investment environment

METRICS

Technology Transfer,
New industrial facilities
Workforce development
New technologies generated
Patents & IP, Licenses
Spin-off companies
Economic infrastructure

Different Economic Impact
in each sector



CREOL START-UP COMPANIES

CRYSTAL PHOTONICS INC.

BEAM, INC.

LASER CLASSICS

OPTICAL DIAGNOSTICS

LASER ENERGETICS

POLARA

APPLIED PHOTONICS

NUONICS

OPTIUM

RAYDIANCE

FEMTOPTICS

OPTIGRATE

**Florida Photonics Center
of Excellence
FPCE**

A New Center

PHOTONICS
Nanophotonics
Biophotonics
Imaging and Displays

Laser Technology
High power Lasers
New laser materials
***Laser-based
technologies***

FPCE Investment is paying off!

(yellow – FPCE; white – match & contracts)

- **Infrastructure** **\$6.0 M**
 - Endowed chair professorships (3) - \$3.0M
 - 5 new faculty hired so far
 - New equipment and facilities - \$3.0M
- **Commercialization and outreach** **\$0.9M**
 - 4 start-up companies
 - 31 new jobs
- **Partnership projects- R&D; new products** **\$3.1M**
 - Industry Match: **20 companies at 5 universities** **\$5.3M**
- **Infrastructure match** **\$6.6M**
- **Sponsored Research (Federal-\$16.0M; Private-\$3.6M)** **\$19.6M**
 - 40 patent applications & 14 issued; \$181K in license royalties

Total = \$41.5M: \$10M + \$31.5 M = 315% ROI

The FPCE has been very successful

ACCOMPLISHMENTS

- Hired 5 faculty members.
- \$19.6M in outside research funding.
- 3 new startup companies.
- 40 patent applications, 14 issued.
- 24 Partnership Projects with 5 universities and 20 companies that brought \$5.3M of matching funds.
- \$25M in venture capital raised
- leveraged building addition with US Dept. of Commerce, EDA.

Total = \$41.5M: \$10M + \$31.5 M = 315% ROI

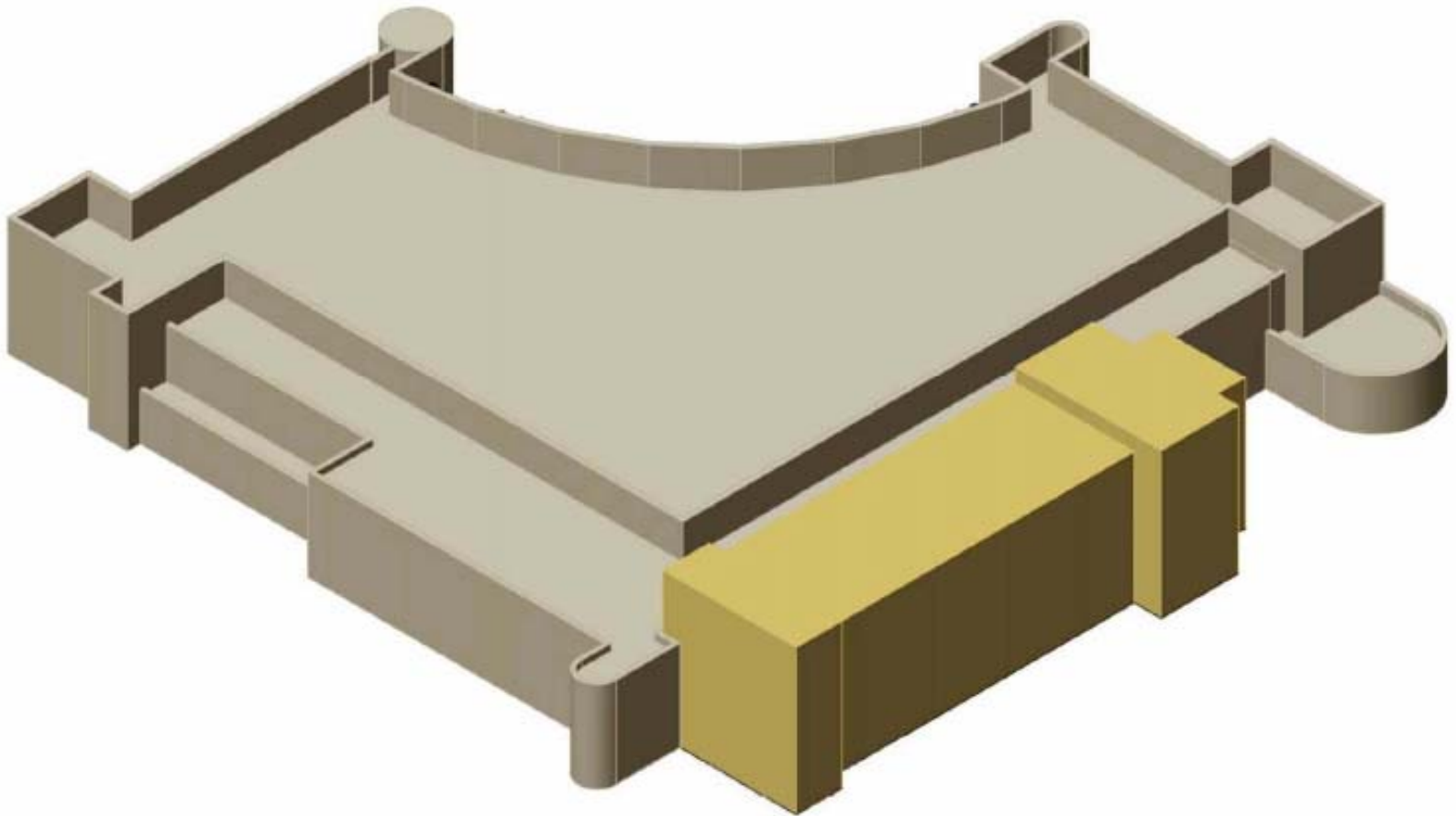
**Florida Photonics Center
of Excellence
FPCE**

A New Center

PHOTONICS
Nanophotonics
Biophotonics
Imaging and Displays

Laser Technology
High power Lasers
New laser materials
***Laser-based
technologies***

CREOL Building Addition Phase 1 block view (draft)



CREOL Building Addition Phase 1 elevation view (draft)



A laser center named after Charles Townes – the inventor of the Laser



Nobel Prize 1964



Templeton Prize 2005

Townes Laser Institute

Establish Florida as the national leader in laser- based technologies and industries enabled by lasers

LASERS in MEDICINE

LASERS in ADVANCED MANUFACTURING

LASERS for DEFENSE TECHNOLOGIES

6 new faculty positions

Charles Townes (and Mrs Townes) - 2006



