Ultra-fast science at the CSIR:NLC
XXXI ENFMC

Dr Lourens Botha, Dr Anton du Plessis and Prof C Strydom

May 2008

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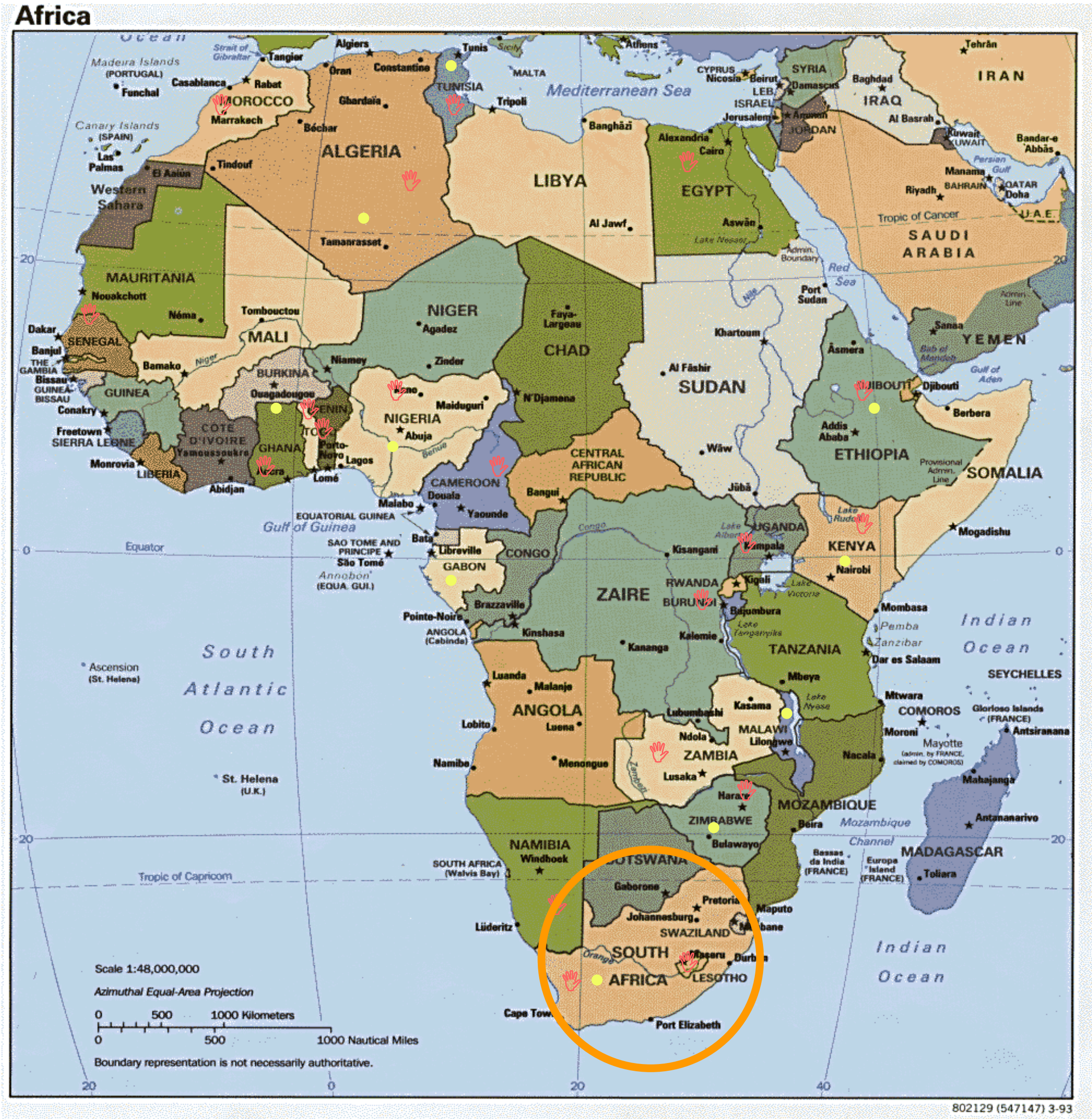

= member = research collaboration

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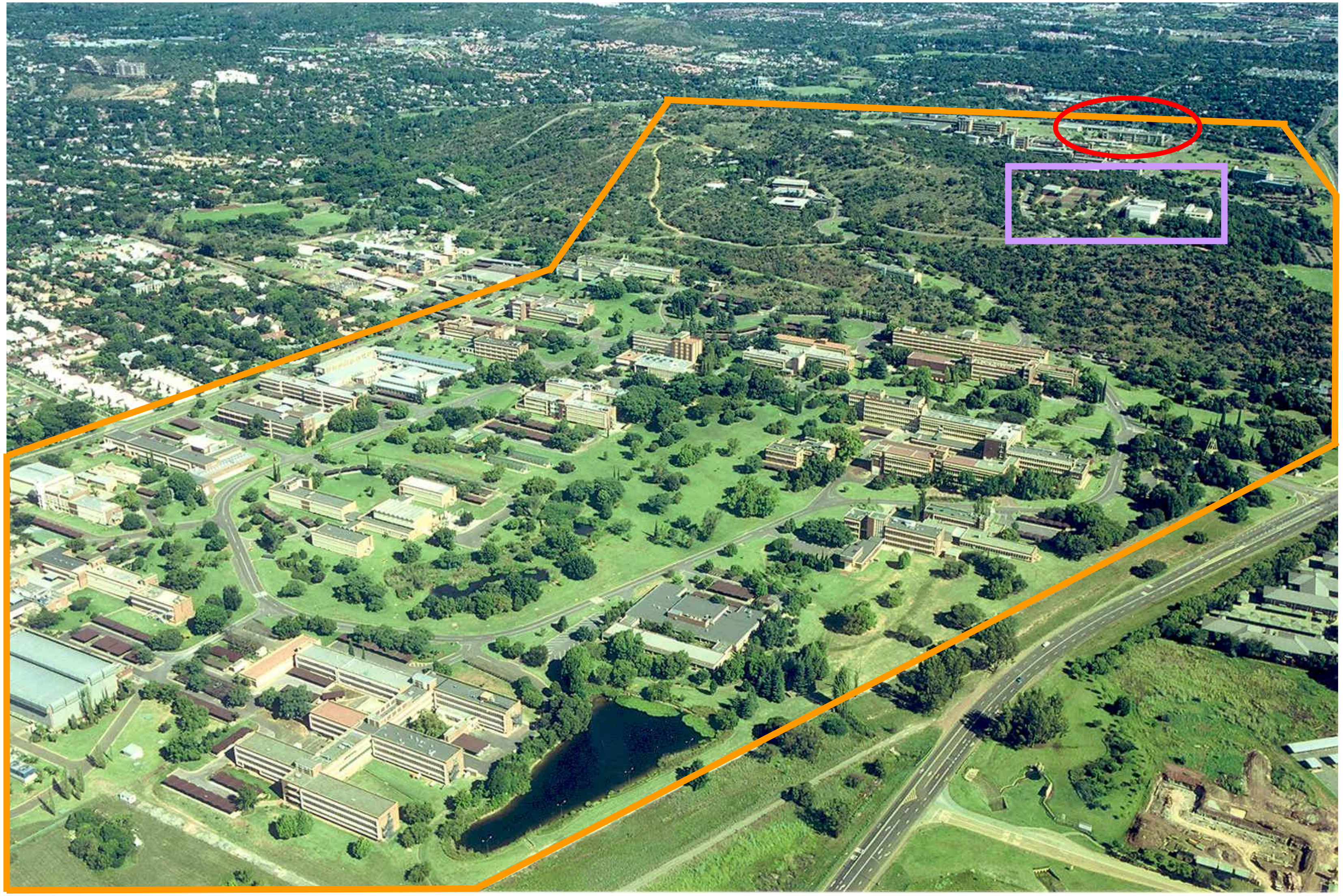

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CSIR – Leading Science Council in South Africa

- Council for Scientific and Industrial Research established in October 1945
- Contributing to national development and fulfilling our mandate by:
  - building and transforming human capital
  - strengthening the S&T base
  - performing relevant knowledge-generating research and transferring it to industry
- Staff – 2250 permanent staff members
  - 845 Research staff (M and PhD)
- SET Output
  - 340 Publication Equivalents
  - International patents and technology demonstrators
- Financial
  - 2006/7 Turnover R 1 120 million (€ 120 million)
  - 42% Base funding

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CSIR Organisational Units

BioSciences
Discovery chemistry
Bio prospecting
Discovery biology
Plant biotechnology
Bioprocess technologies
Product and process development
Analytical chemistry
Aptamer technology

Defence Peace Safety & Security
Systems modelling
Safety and security
Landwards sciences
Technologies for special ops
Aeronautic systems
Radar & elec. warfare systems
Optronic sensor systems

Natural Resource & the Environment
Mining
Forestry
Pollution and waste
Water resources
Resource-based sustainable development
Ecosystems

Built Environment
Planning support systems
Infrastructure engineering
Construction
Architectural sciences
Infrastructure systems & operations
Logistics and quantitative methods
Rural infrastructure and services

Material Science & Manufacturing
Metals and metals processes
Polymers, ceramics & composites
Fibres and textiles
Manufacturing science & technology
Energy and processes
Sensor science and technology

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CSIR National Research Centre & Emerging Research Areas

National Laser Centre

Laser materials processing
Novel laser sources and beam propagation
Laser spectroscopy
Biophotonics
HEI & African Laser Centre support
PULSE

Satellite Application Centre

Satellite tracking and command services
Earth Observation Data services

Nano-technology

Synthetic Biology

Meraka

Human Language Technologies
Digital Doorway
Wireless Africa
Open Source Centre
National Accessibility Portal
ICT in Education
ICT for Earth Observation
Remote Sensing Research Unit
High Performance Computing

Mobile Intelligent Autonomous Systems

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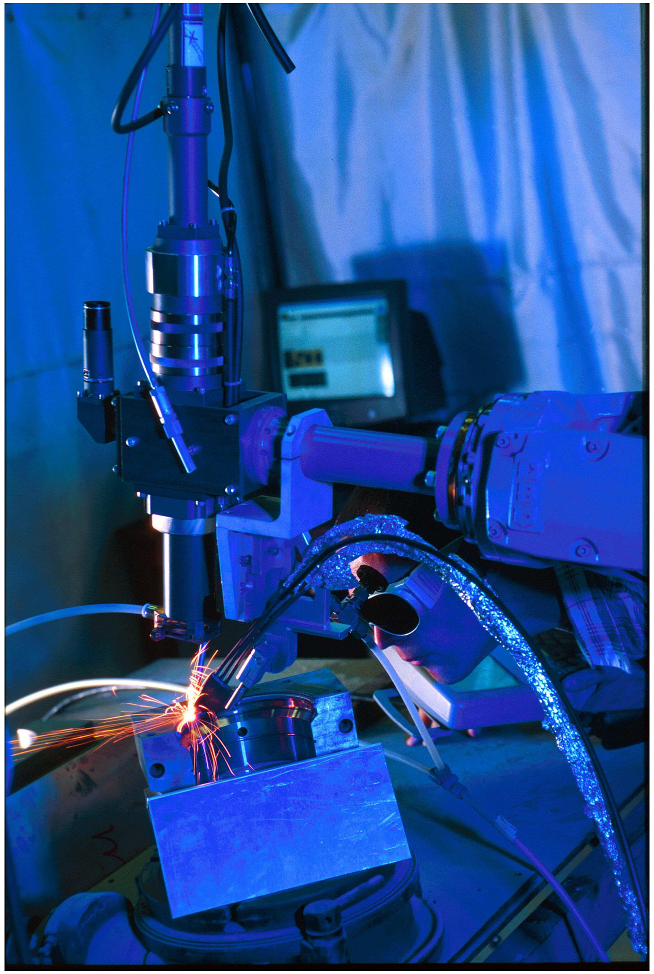
National Laser Centre

- Research and development Centre
  - Focus on Lasers and Laser application development
- Organisation with a Dual Role
  - Act as National Asset
    - Enabling role in Academic Environment
    - Research Partner
    - Promote the use of Lasers in Industry
  - Operate as a business
    - Contractual R&D for industry
    - Development of laser based processes, systems and services
- 65 Staff members
  - 18 Students at M and PhD level
- Budget R 42 million (€ 4 million , $5.55 million)
  - 37% base funding
  - 63% Competitive CSIR, public, private and international funding



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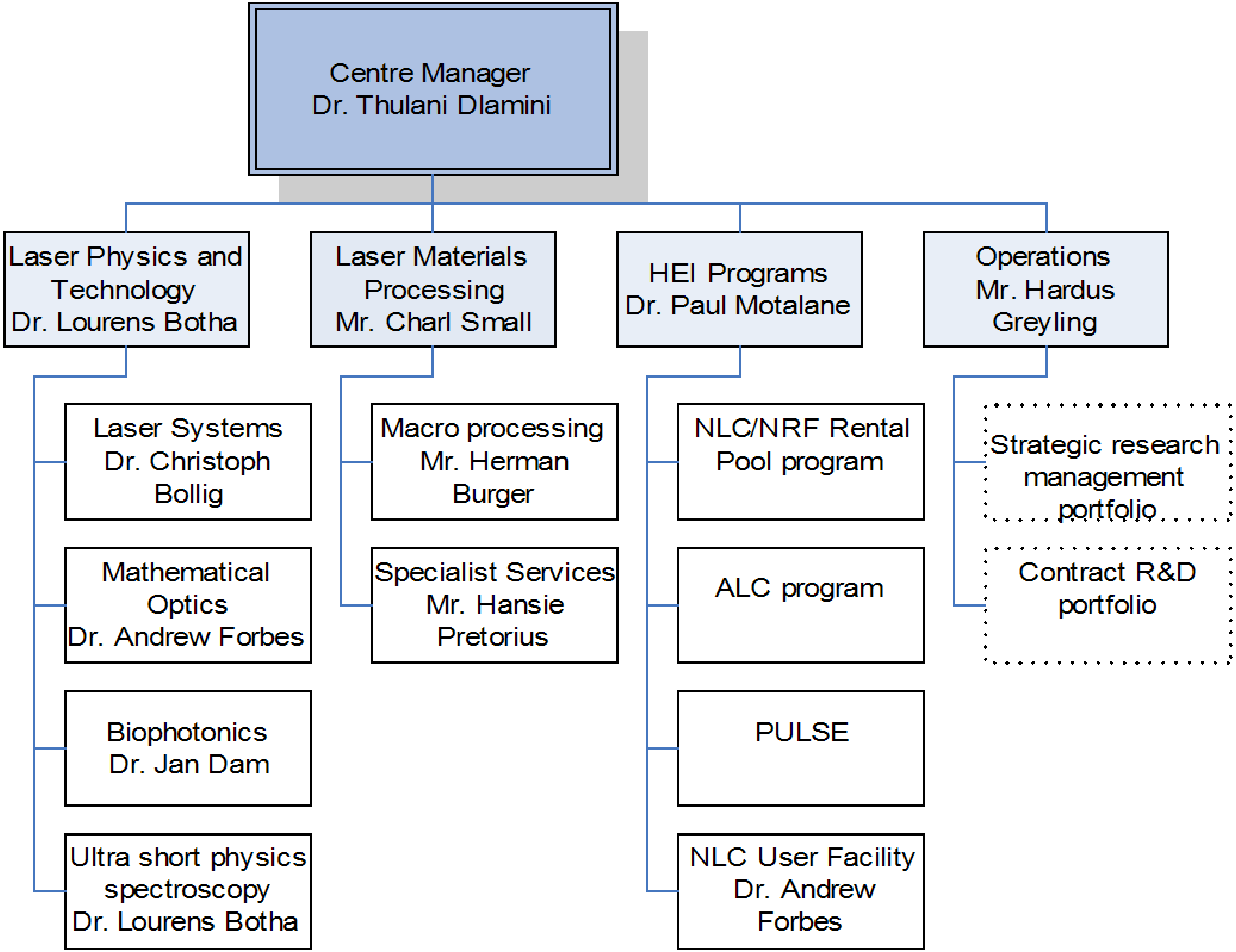
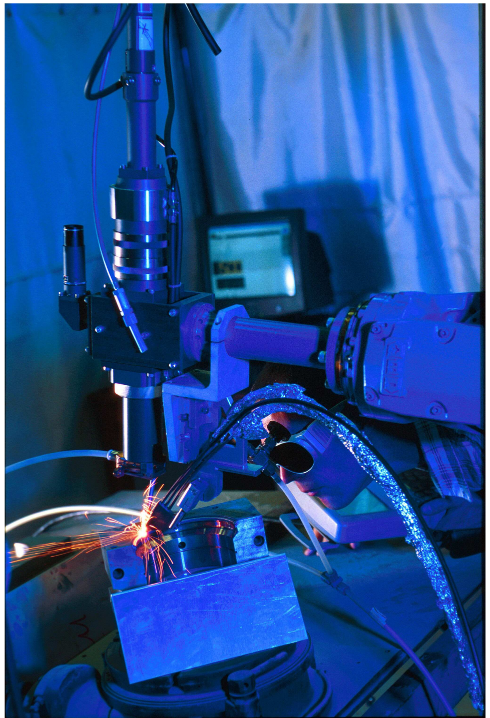
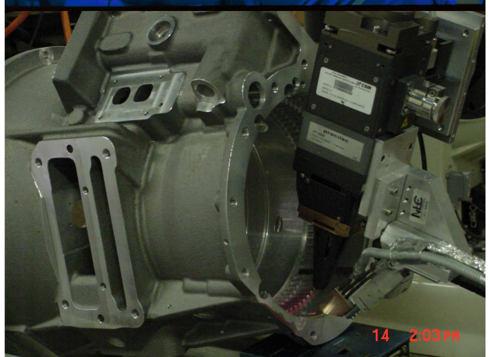
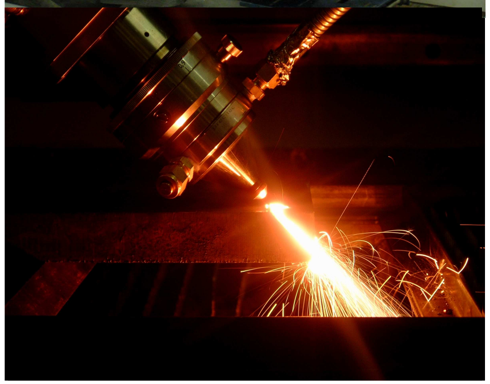

Centre Manager
Dr. Thulani Dlamini
Laser Physics and Technology
Dr. Lourens Botha
Laser Materials Processing
Mr. Charl Small
HEI Programs
Dr. Paul Motalane
Operations
Mr. Hardus Greyling
Laser Systems
Dr. Christoph Bollig
Mathematical Optics
Dr. Andrew Forbes
Biophotonics
Dr. Jan Dam
Ultra short physics spectroscopy
Dr. Lourens Botha
Macro processing
Mr. Herman Burger
Specialist Services
Mr. Hansie Pretorius
NLC/NRF Rental Pool program
ALC program
PULSE
NLC User Facility
Dr. Andrew Forbes
Strategic research management portfolio
Contract R&D portfolio

Laser Materials Processing

- Development of laser welding procedures
  - Research focused on light metals
- Laser cladding of materials
  - Improve wear and corrosion resistance, repair worn components
- Advanced laser cutting facilities
  - 3D cutting for automotive industry
  - Thick section cutting
- Laser Hardening process development
- Laser assisted corrosion prevention
- Laser milling and ablation
  - Laser texturing
  - Laser polishing

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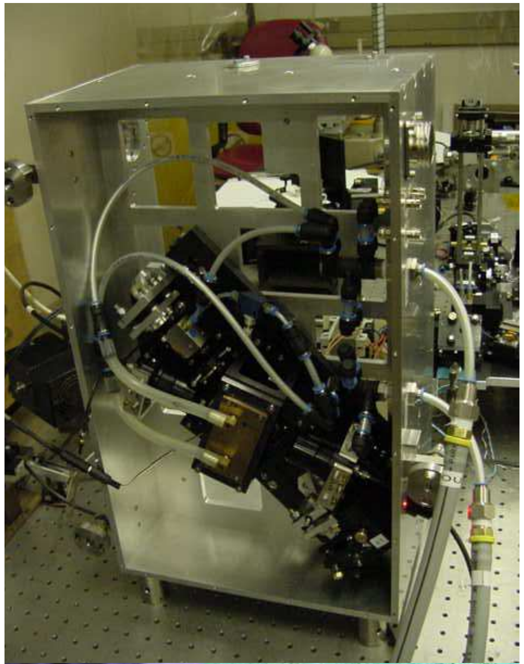

Laser Physics and Technology

- Biophotonics
  - 3D skin models
  - PDT
  - OCT
- Ultra–fast science
  - Setting up of a state-of-the-art fs laser system → Unique in Africa
  - Time domain laser beam shaping and coherent control
  - Femto-chemistry, transient spectroscopy

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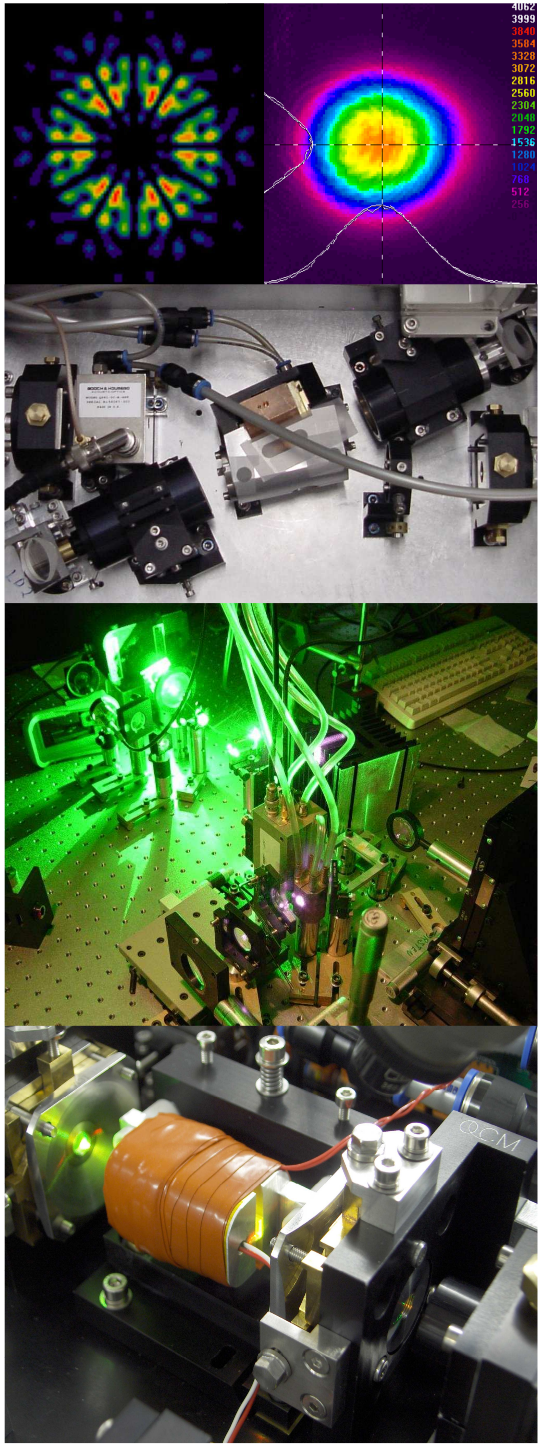
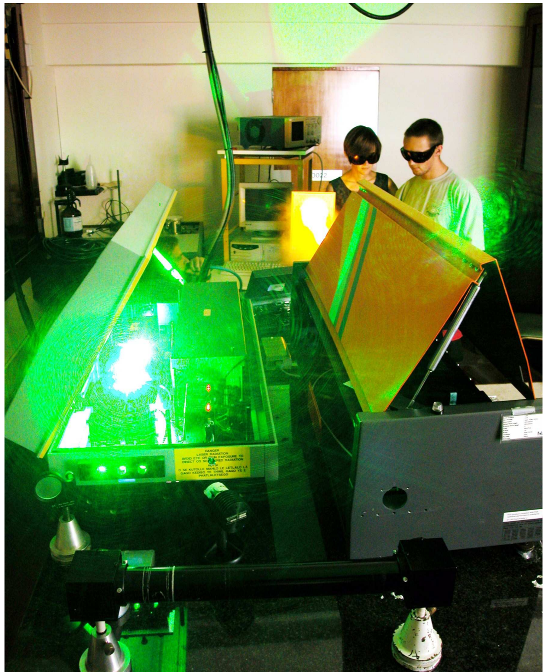
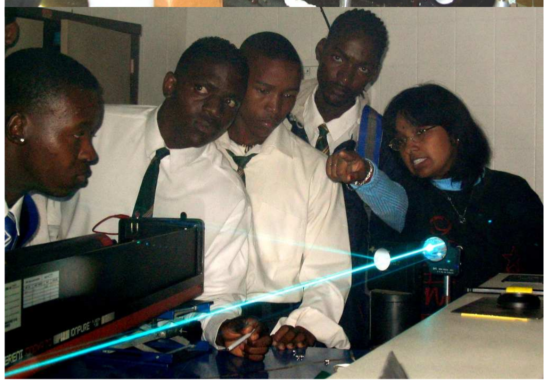


Laser Physics and Technology

- Mathematical Optics
  - Novel resonator designs and modelling
  - Propagation of beams through diffractive optical systems
  - Intra-cavity beam forming
  - Atmospheric beam propagation studies

- Solid-State lasers
  - Mid-infrared lasers and non-linear materials for 2-8 µm generation
  - Ultra-Short-Pulse solid state Laser systems
    - High-energy short-pulse generation for Lunar Laser Ranging
    - Ultra-short-pulse lasers for science and micro-machining
  - High Energy Laser sources

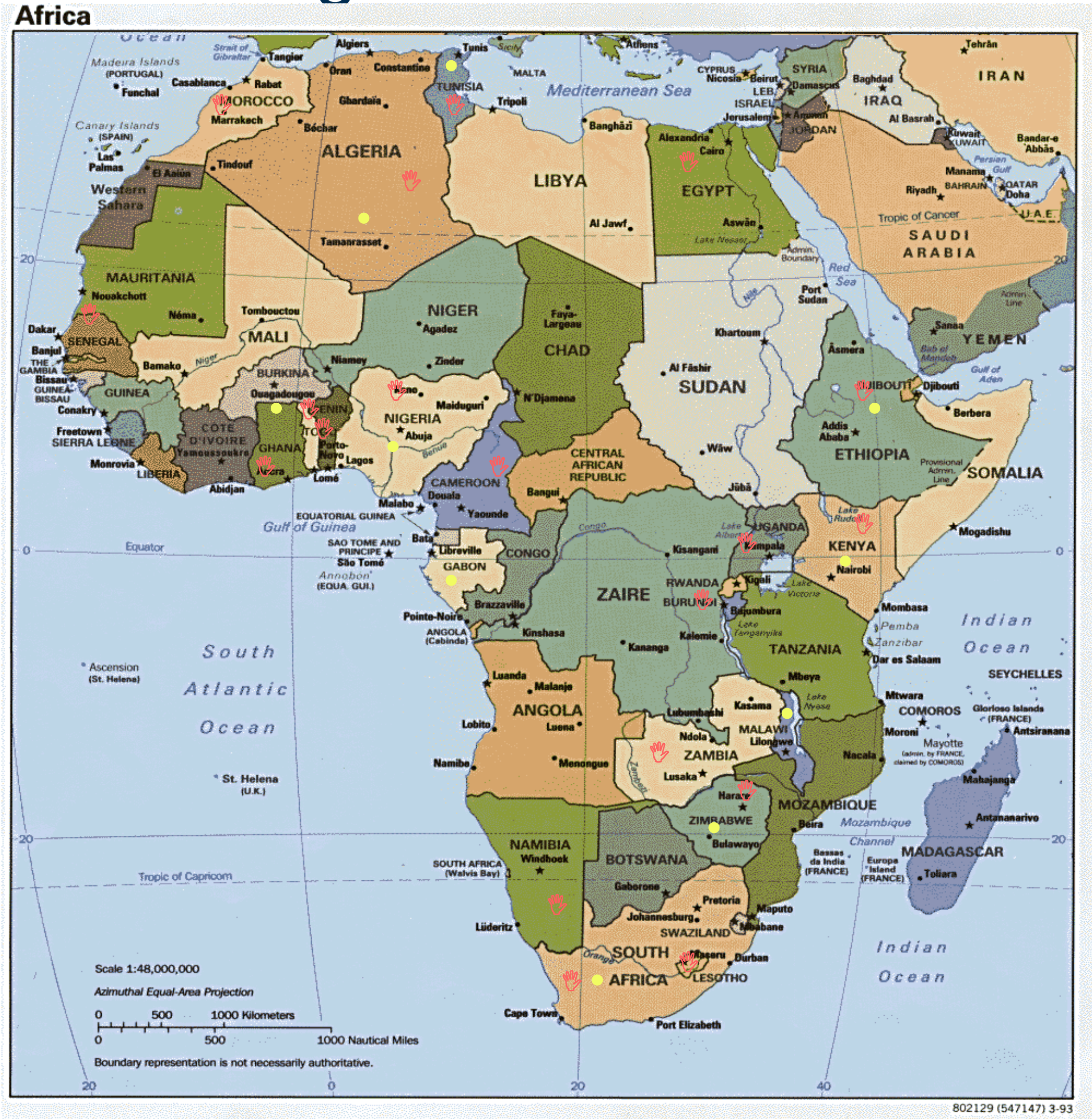




HEI

- Objectives
  - Stimulate & grow laser research programs
    - Access to equipment
    - Access to NLC laboratories
  - Accelerate the development of students
  - Develop new competencies in the South African environment
  - Establishment of focused laser research programs & facilities
  - Networking
  - Stimulate and develop understanding of laser, science and engineering

ALC covering Africa



= member = research collaboration

Ultra-fast science at the South African National Laser Center

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Why ultra-fast science and why the NLC ?

- Ultra-fast science is a rapidly expanding field with a huge application potential
- Most US and European Physics and Chemistry departments at Universities have at least one ultra-fast laboratory
- However, Africa and particularly South Africa is lacking in this field
- One of the roles of the NLC is to promote laser based technology in South Africa
- A strategic decision was made to launch a ultra-fast science program in South Africa based at the NLC

Focus area

- Ultra-fast science is a very broad field, what do we intend to concentrate on ?
- We want to do relevant work for our local industry and we want to train students with skills that are relevant
- Therefore we do not want a too narrow focus
- In consultation with international experts we decided to start a program focusing on coherent control of complex systems starting with molecules
- Covers a very wide range of ultra-fast science and technology
- Has a potential for industrial spplications

Control of chemical reaction paths using light

- Since the development of the laser the quest to use light to control the future of matter has been one of the holy grails of chemistry
- Can we develop general ways to use lasers to specifically to control the quantum behaviour of molecules ?
- Can we control the nature and products of chemical reactions by, for example, breaking a selected bond in a polyatomic molecule ?
- Originally it was thought that mode selective chemistry was possible using narrow band lasers, however IVR relaxation proved to be a insurmountable problem
- However, the development and progress in femtosecond lasers promised an alternative method, i.e. coherent control

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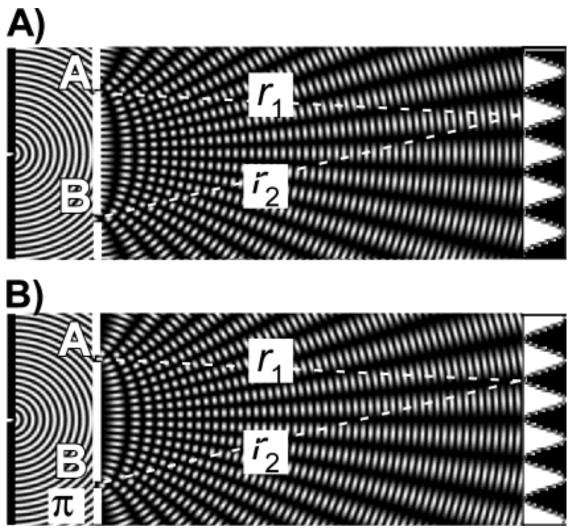
Basics



$$\left|\Psi_i\right\rangle \xrightarrow[\text{+ System evolution}]{\text{Optimal field } \varepsilon(t)} \left|\Psi_f\right\rangle$$

- Using interference of quantum wave functions
- Similar to double slit interference experiment of classical optics
- Transfer phase from optical field to wave function and use interference to optimize a specific state
- However, for molecules and other complex systems the calculation becomes extremely complicated
- Hence the idea of coherent control was developed

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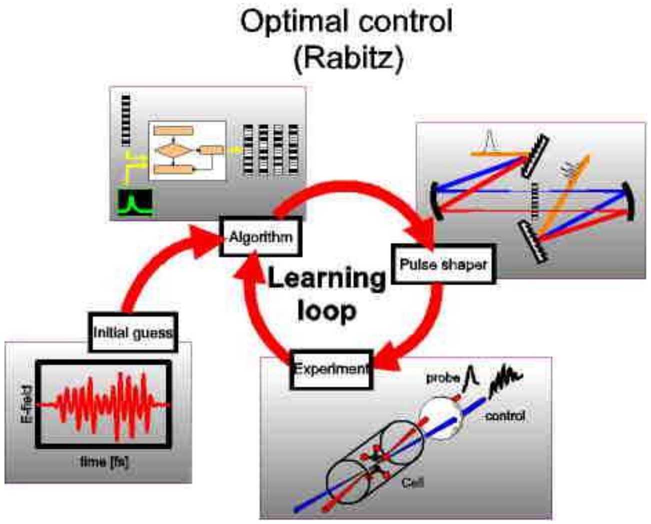
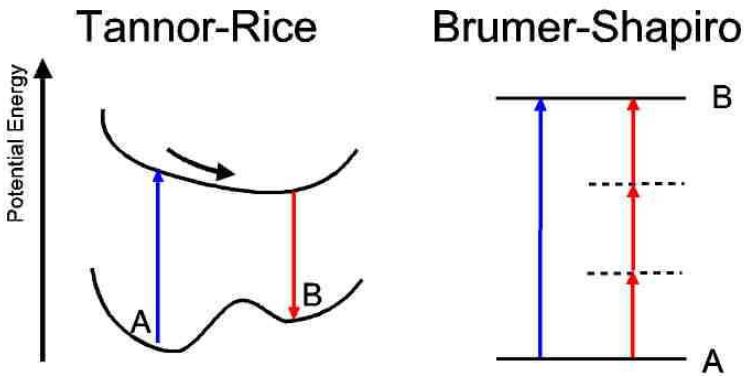
Coherent control



- What is coherent control ?
  - Ultimate goal is to rearrange a molecule into new compound by using only light
  - Controlled transition between states
  - Complicated calculations required for molecules
  - Breakthrough: Leave the designing of the pulse to a learning algorithm



- Principle
  - Tannor-Rice: Proper timing of several pulses that would enhance transition from molecular configuration A to B
  - Brumer-Shapiro: Interference between different pathways to the same state

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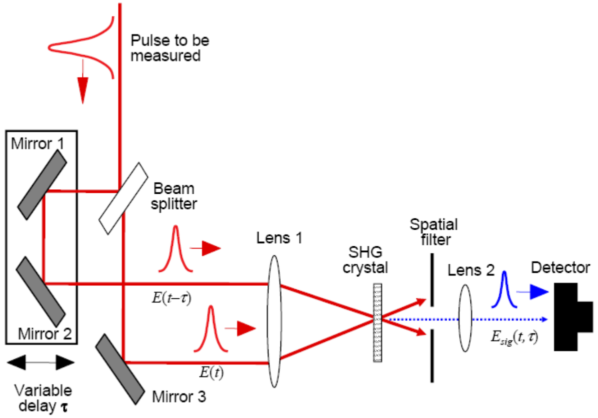
What is required for a coherent control experiment

- Short pulse => broad bandwidth
- Pulse shaping mechanism
- Diagnostics to measure the pulses
- Feedback mechanism
- Optimization algorithm

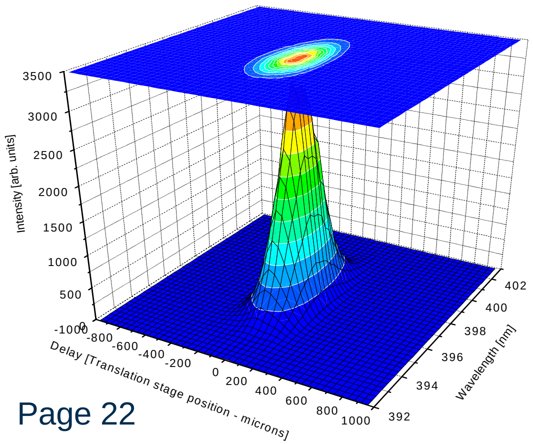
NLC femtosecond laboratory



- Laser systems
  - Coherent Mira Oscillator
  - Coherent Legend Amplifier
  - Output energy 1 mJ/pulse @ 800nm and @ 1000Hz
  - Pulse width 110 fs and $M^2 < 1.2$
  - Topas OPA and DFG
  - Tunable from 500nm to 20 micron

Pulse shape measurements

- Background free autocorrelator
- FROG system allows measuremnt of amplitude and phase thus complete information of pulse



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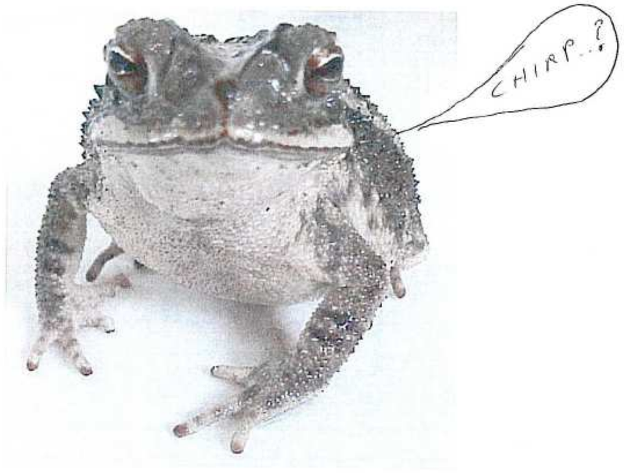
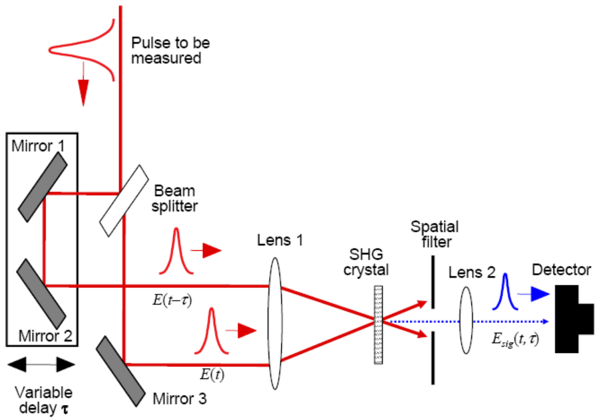
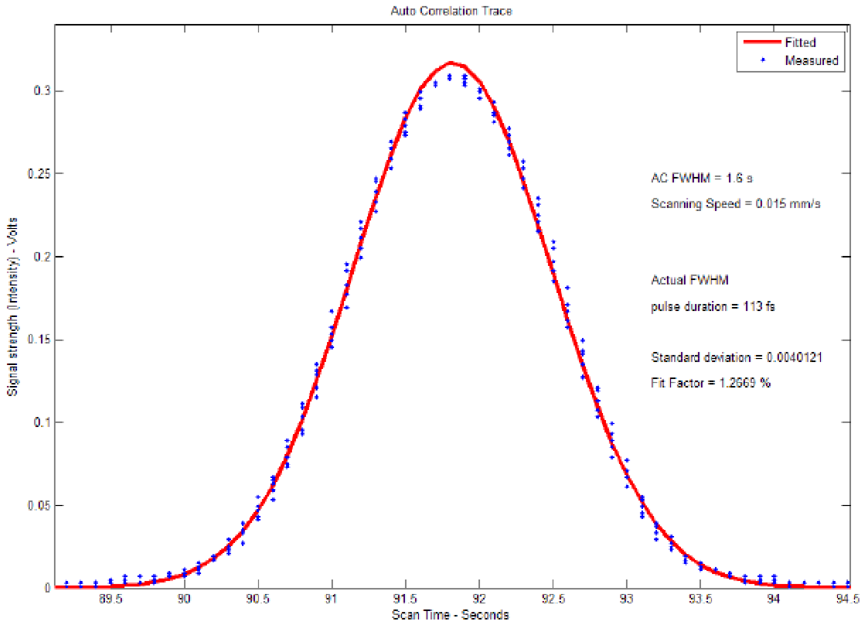
Pulse shape measurements: pulse duration



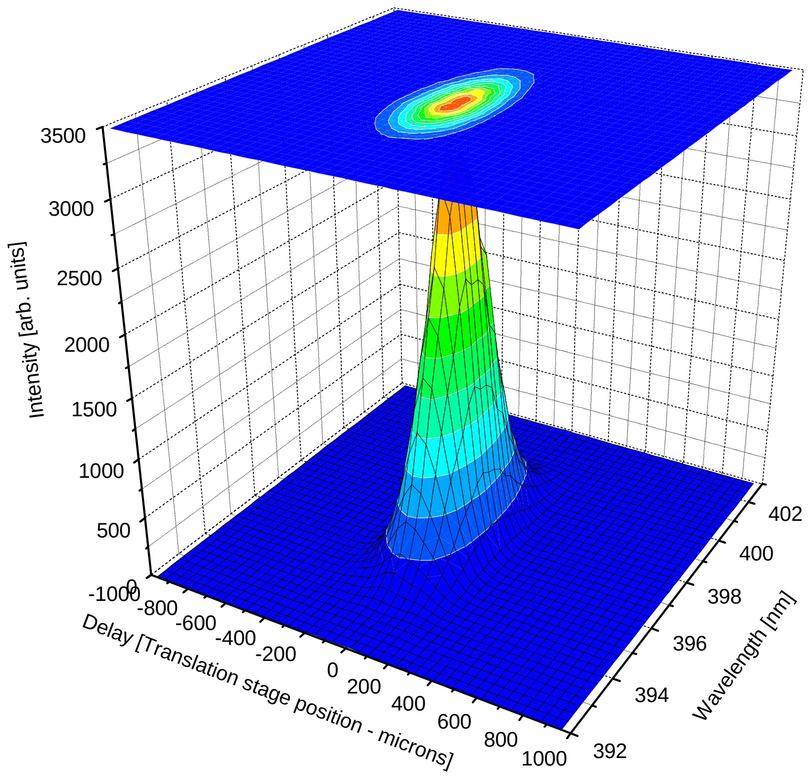
Terribly Ordinary Autocorrelation Device



• Background free autocorrelator “TOAD”

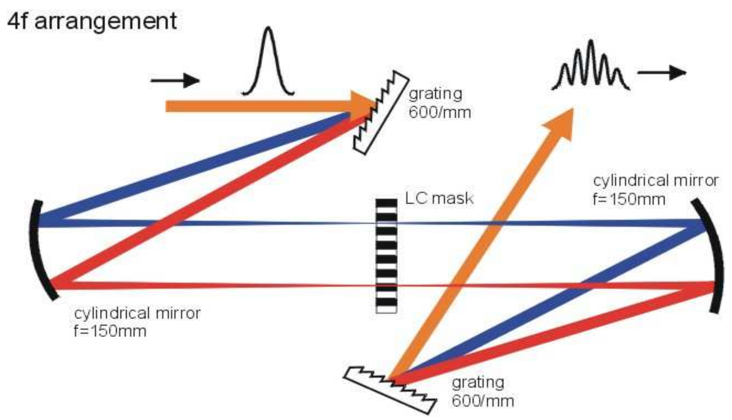


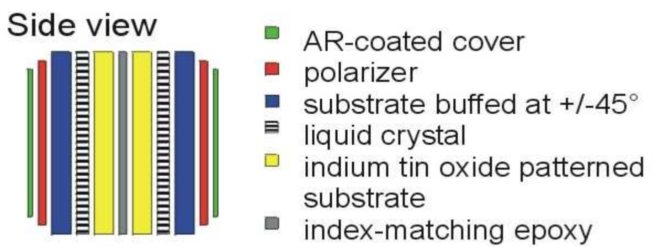
Pulse duration mesurements: amplitude and phase

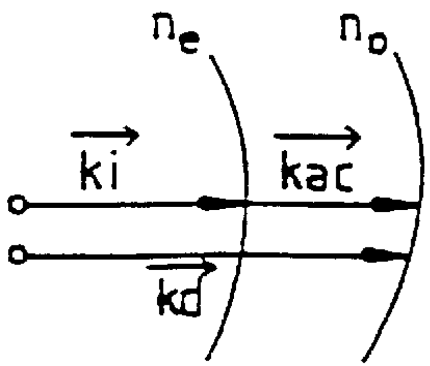


- FROG (Frequency Resolved Optical Gating)
- As previous but detector replaced by spectrometer
- Gives amplitude and phase information

Beam shaping







- 4-f shaper
  - Shaping done in frequency domain
  - 2xLCD's required for amplitude and phase modulation

- Acousto-optic modulator
  - Commercial product using an acousto-optic signal generated in a crystal
  - Phase matching of acoustic and optical signals inside the crystal

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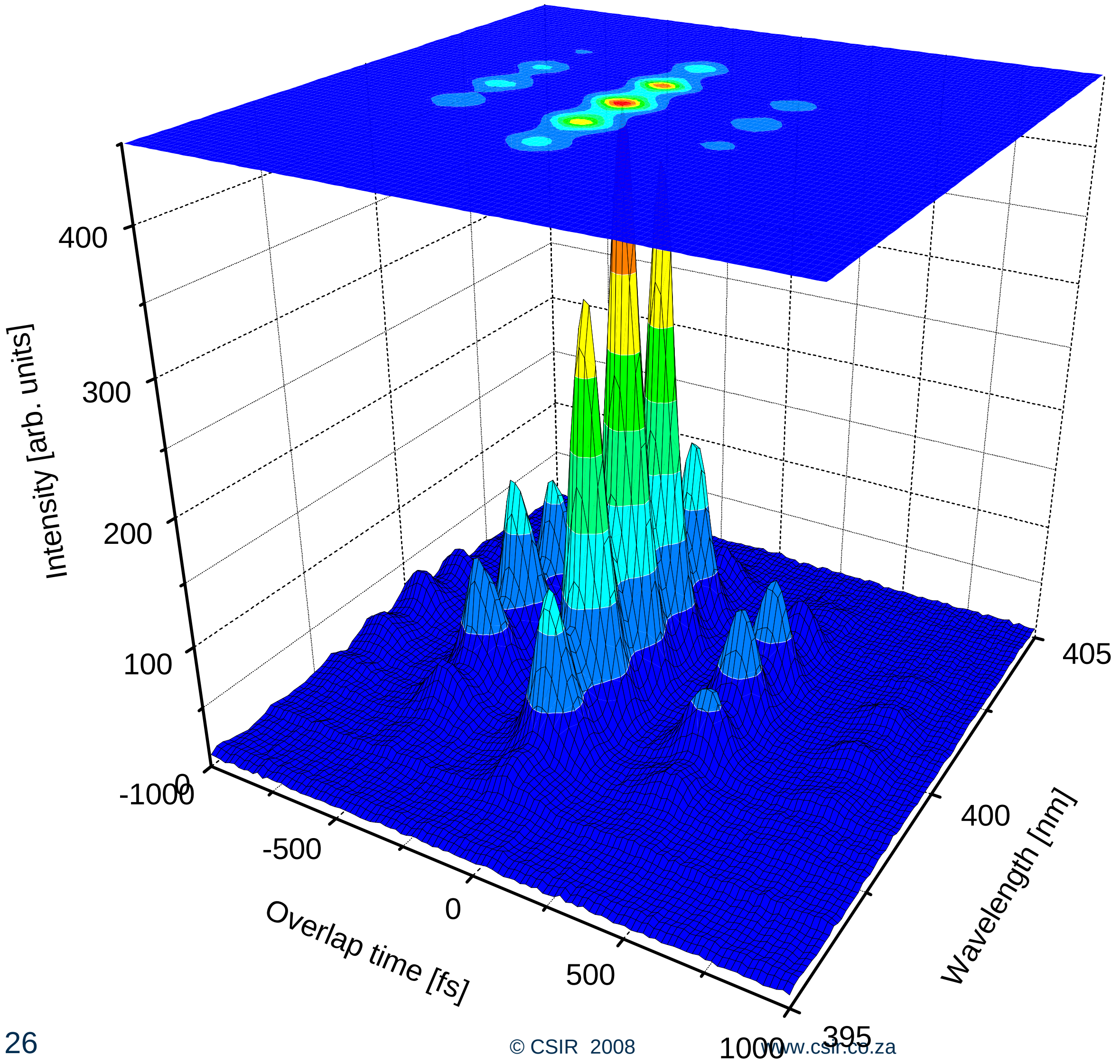
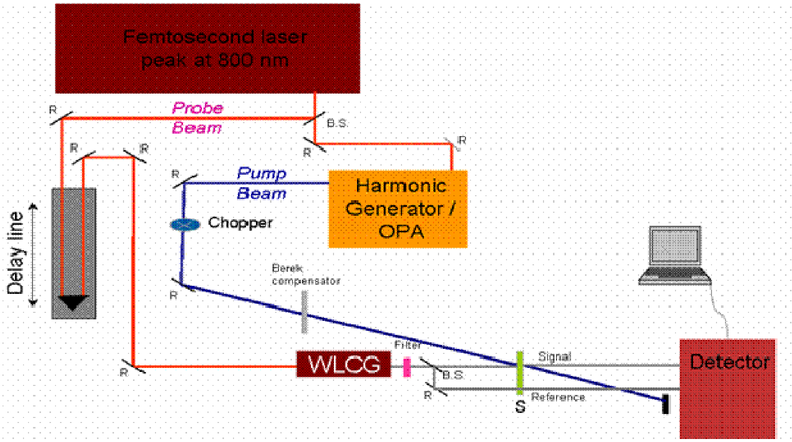
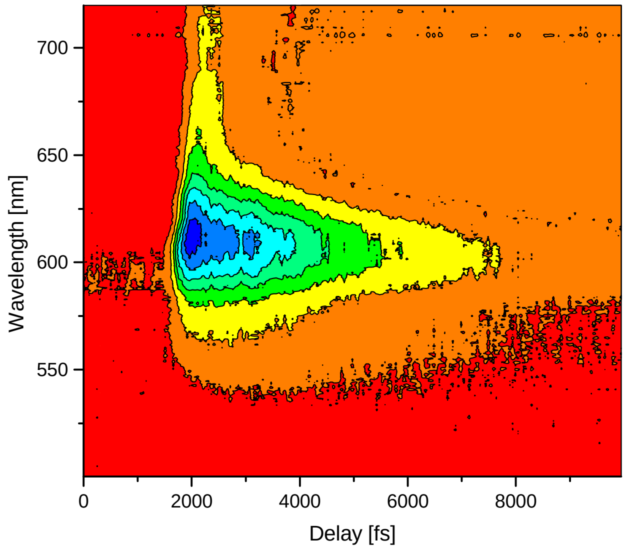
FROG trace of complex pulse

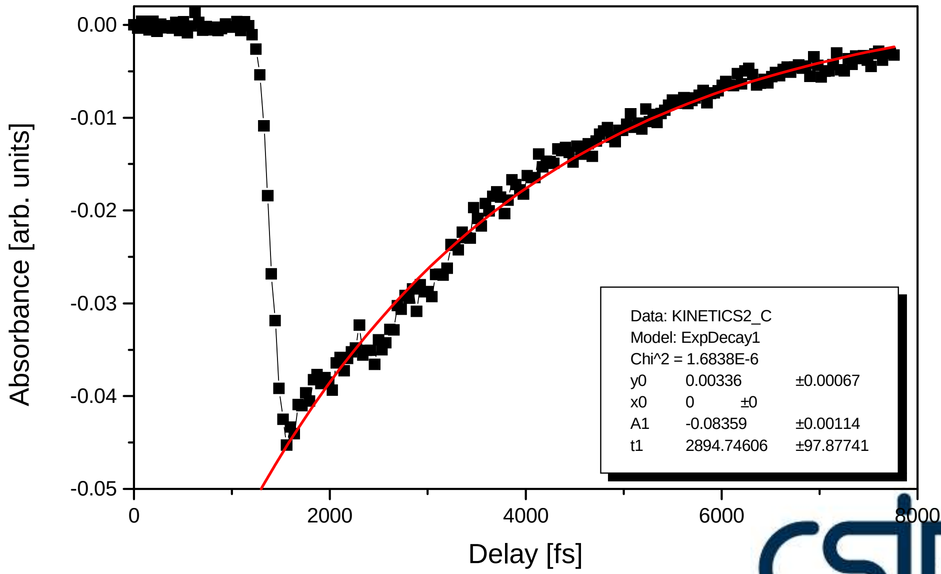


Feedback mechanism: Pump-probe



- Pump-pulse from OPA excited the system
- White light generated by focussing femtosecond pulse onto sapphire plate acts as a probe
- Measured on spectrometer
- Example: Malachite green





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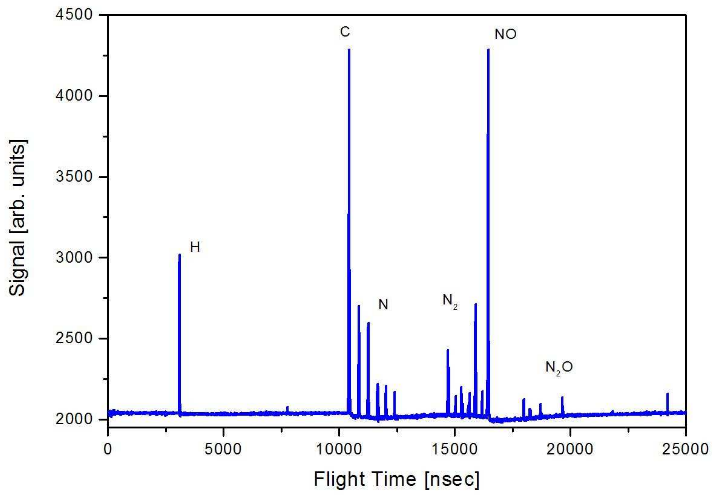
Feedback mechanism: Time of Flight mas spectrometer



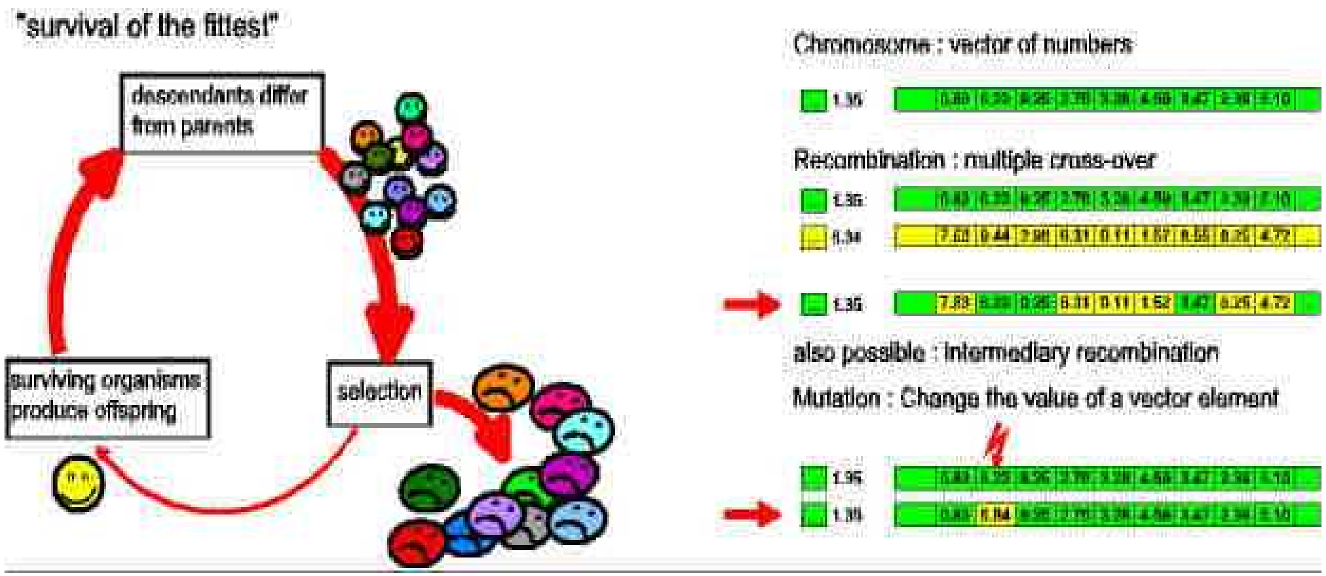
Home built reflectron TOF

Excite molecule with probe pulse

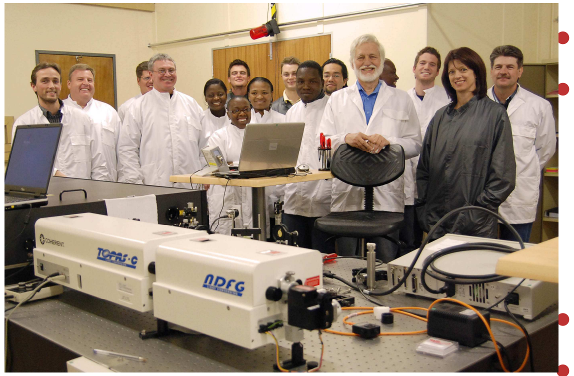
Dissociate with UV laser

Optimization algorithm

- Genetic algorithm
  - We have a complex system that we want to drive to a specific state
  - Computation of these ultra-fast processes is very hard since it requires a full quantum mechanical treatment
  - Trial and error quasi-evolutionary manner => survival of the fittest.
  - Test: SHG first chirp the pulse end then compress using genetic algorithm



We also needed relevant problem to solve

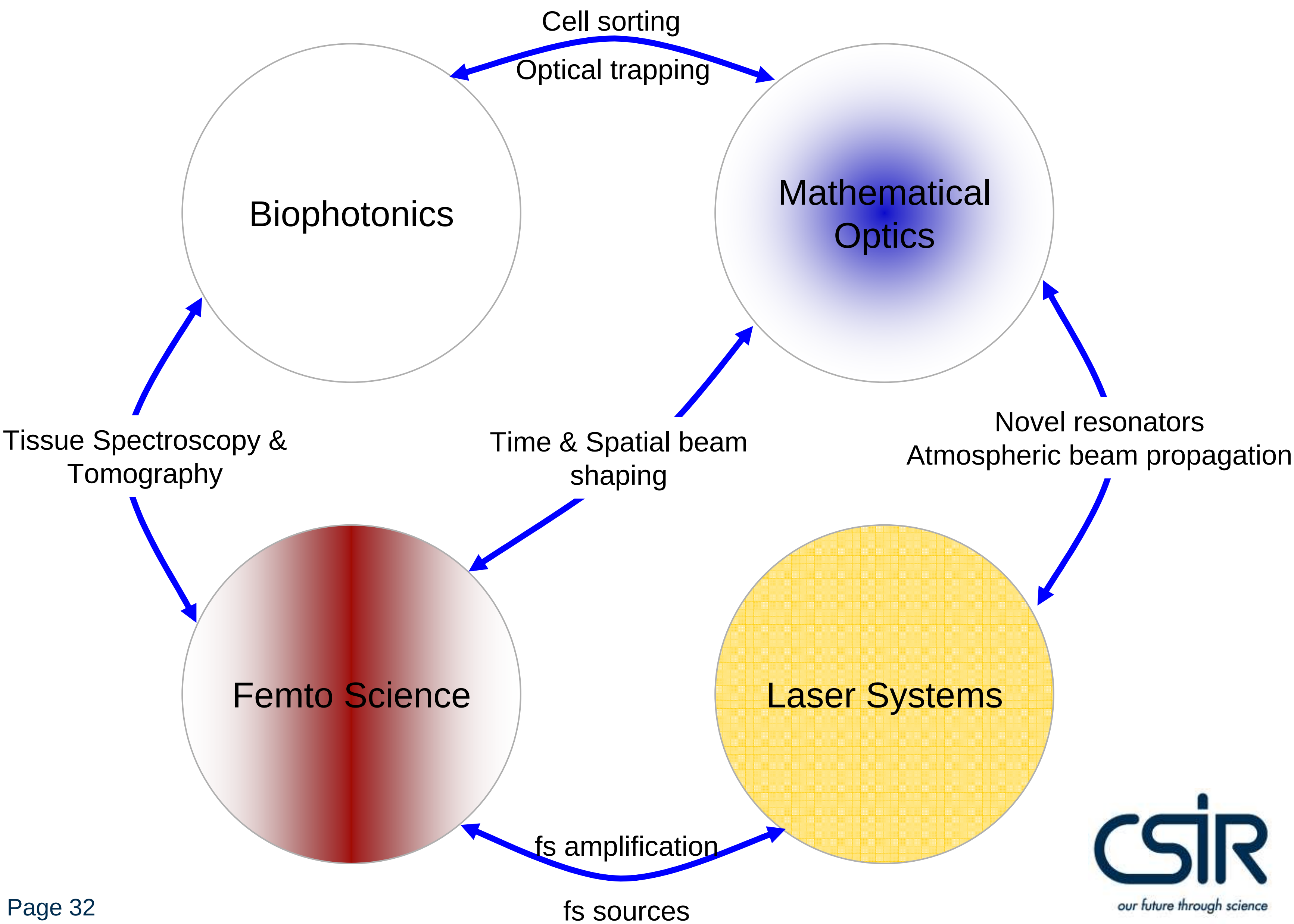


- Pebble Bed Modular Reactor (PBMR) project is one of the largest engineering/scientific projects in South Africa
- Similarly to the CSIR they are interested in human capital development
- SiC is used as a containment layer in the pebbles
- They are interested in improving the coating process
- Coherent control femto-chemistry project would have the following benefits
  - Establish ultra-fast science in South Africa
  - Train students
  - Possibly improve one of their industrial processes
- A joint project was defined between the PBMR/NLC/UNW
- Currently 5 fulltime staff members, 5 MSc students and 3 PhD students on the project

Other projects in group

- Femtosecond LIPS
- Micromachining
- Investigation of light harvesting and transfer in photosynthetic systems
- Spatial beam shaping e.g Bessel beams

LPT Integration and Synergy



South African High Intensity Laser Project

- Kicks off with a workshop in February next yeart
- Currently driven by the NLC/Univ of Stellenbosch/South African Accelerator facility
- Aims to build a very high intensity short pulse facility in South Africa (ultimate aim is a peta-Watt system)
- Miainly for fundamental physics research and nuclear applications e.g. nuclear laser acceleration of particles
- Our Department of Science and Technology is providing some seed funding for the project
- If anybody is interested in attending the workshop I will provide the details

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Photonics in South Africa

CHRISTOPH BOLLIG[1]*, ANDREW FORBES[1,2] AND THULANI DLAMINI[1]

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A growing research and development sector is a sign of a healthy economy. South Africa hop
that a focus on photonics technologies will help drive the country's socio-economic developn

The development of science, engineering and technology (SET) has been identified as one of the key elements for the long-term sustainability and competitiveness of the South African economy. As such, the South African government has set a target to increase expenditure on R&D by both the private and public sectors to 1% of the country's gross domestic product by 2008 and to 2% by 2018. The country's commitment to SET is evident from the various initiatives that have been implemented by the South African Government, such as the International Centre for Genetic Engineering and Biotechnology, the bid to host the Square Kilometer Array, construction of the Karoo Array Telescope and investment in infrastructure for high-performance computing, nanotechnology, astronomy and space science[1].

Figure 1 Philemon Mjwara (left), the Director General of the DST, during a visit to the research labs of th
Thulani Dlamini (right), the director of the NLC, is showing him a high-power Nd:YLF laser developed at t
centre. The DST strongly supports photonics research in South Africa.

South Africa was an early adopter of laser technology, introducing the first laser to the National Physical Laboratory at the Council for Scientific and Industrial Research in the early 1970s, quickly followed by a laser programme at the University of Natal (now University of KwaZulu-Natal) that led to important developments in optical systems[2]. However, lasers in South Africa only gained significance in the 1980s, with the start of a large laser programme in molecular laser isotope separation (MLIS) — an alternative to the ubiquitous centrifuge technology for uranium enrichment. This required a substantial investment in laser and photonics technology in terms of infrastructure and equipment, as well as in competency; it is estimated that several hundred million Rands (tens of millions of US dollars) were spent on the programme. Although South Africa is often lauded for voluntarily halting all of its nuclear-enrichment programmes, the termination in 1997 of the MLIS programme, with over 300 trained scientists and technicians and an estimated $3 million worth of laser and photonics equipment, placed the photonics community in South Africa in a quandary. Clearly an impasse had been reached and a policy to establish better relations with the then Department of Arts, Culture, Science and Technology was required. The outcome was the National Laser Centre (NLC), with an envisaged focus on partnerships with industry and academic institutions for the advancement of laser research and technology adoption in South Africa. In 2000, the NLC (Fig. 1) was formally launched under a trust supported by the Department of Scie
and Technology (DST). In 2003, the
changed status from an independent
funded trust to a research centre wit
the CSIR. With 67 members of staff a
an annual budget of $6 million, the N
is the largest photonics centre in Afri
It performs research and developmer
in a wide range of areas, such as laser
materials processing, solid-state laser
development, atmospheric remote se
mathematical optics, femtosecond-la
applications and biophotonics. Many
these research activities are performe
close collaboration with South Afric
international university research gro

Optics in South Africa

Jean-Noel Maran, Erich G. Rohwer, Johan P. Burger and Lourens R. Botha

The rainbow nation is betting on the optical sciences to support its economic growth and skills development.

When people think about South Africa, they may call to mind its scenic landmarks such as Kruger National Park or the beaches of Durban, or perhaps the country's charismatic leader, Nelson Mandela. But most do not associate South Africa with high-tech photonics. In fact, South Africa has a dynamic optical community that is involved in state-of-the-art research. Despite relatively low funding levels, photonics research in the country compares well with many international benchmarks and has had a significant impact on the whole African continent.

History of optics in South Africa

South African optics and laser research began in the early 1970s at the Council for Scientific and Industrial Research (CSIR) at the National Physical Research Laboratory, where the first solid-state laser in Africa, a ruby laser, was designed and constructed. During the late 1970s and 1980s, laser research focused on military applications, mainly range finding.

By the mid-1980s, a large laser research group devoted to laser-based isotope separation had formed at the Atomic Energy Corporation (AEC, now called the Nuclear Energy Corporation of South Africa). It provided a major injection of resources for developing scientists in the fields of lasers and optics. Although the group disbanded in the late 1990s, another group—the Lasers, Optics and Spectroscopy subgroup of the South African Institute of Physics (SAIP)—helped convince the Department of Science and Technology (DST; then called Arts, Science and Technology) to continue to support laser science in South Africa.

Left: Tebogo Mathope, a Master's student at the University of Johannesburg, conducts laser irradiation of cells in culture. Center and right: laser development at the National Laser Center.

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Thank you

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