Introduction to the NLS Project:

A proposal for a New Light Source Facility in the UK

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NLS (New Light Source) is a working title for the first phase

Contents of this Presentation

Executive Summary

- STFC seeks to examine the case for a New Light Source Facility in the UK with unique and world leading capabilities
- The proposal is jointly supported by STFC and Diamond Light Source Ltd, coupled to strong HEI involvement
- The first phase is broad-based science consultation
  - Workshops and Working Groups coordinated by the leaders of the "Photon Science Research Institute" and the 4GLS project
  - Direct input from anyone in the community

Science Consultation

- The first phase of the NLS project will determine, through wide consultation, the key long term scientific objectives for the UK light source strategy and establish the light source capability we need
  - *"What is the compelling science?"*
- NLS will examine the balance between objectives which can be achieved by exploiting the existing array of international next generation light sources and those which will require a new UK capability
  - *"Do we need a new UK source?"*

What is NLS?

- A science driven project
  - *First*: define the key science drivers
  - *Next*: assess the technical solution
  - *Then*: assess funding and location
- Must take the long view of high level objectives that are likely to be relevant for decades
- The NLS facility, if built, will probably adopt an integrated approach;
  - e.g. incorporating advanced conventional lasers alongside FEL(s) to achieve the science objectives

2. Example Scientific Frontiers

- *How do we control material processes at the level of electrons?*
- *How do the properties of matter emerge from complex correlations of atoms and electrons?*
- *How can we engineer matter on the nanoscale?*

These are some of the basic questions that directly feed into new technology for information, energy and healthcare.

The NLS Science Challenges Include

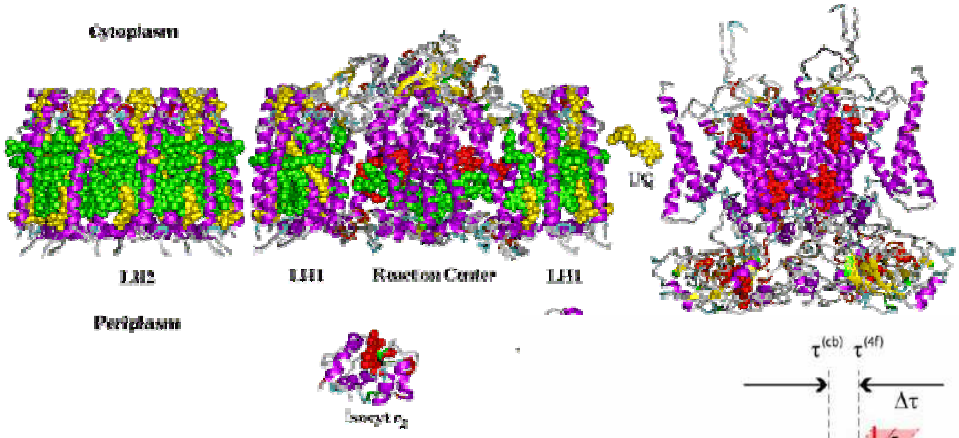
- Measuring structural dynamics in matter of all kinds
- Structural and spectral imaging of bio-molecules not accessible to conventional methods
- Understanding high energy density matter
- Using light to control, rather than simply observe, complex matter
- Studying matter far from equilibrium and tracking phase changes in real time
- Measuring electron dynamics in real time: attosecond science

To meet these challenges we need to measure **structure and dynamics** to understand, control and fabricate at the sub-nm scale where dynamics are typically ultra-fast

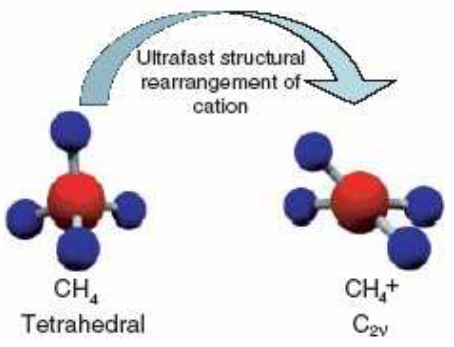
Additional Challenges will be Identified Through the Consultation

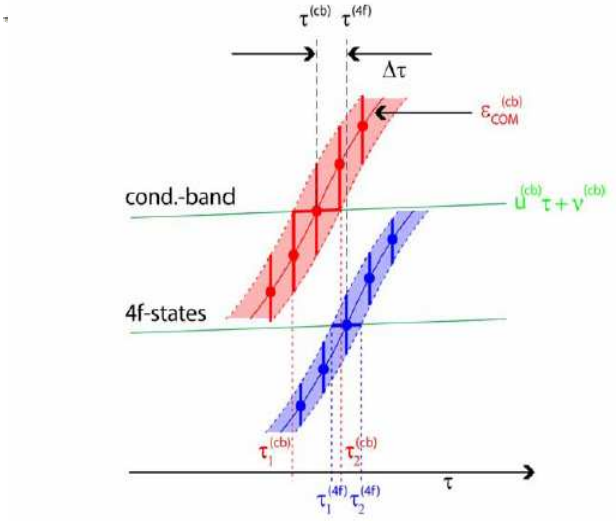
Structure and Dynamics are universally important to our understanding of structure and function

From Large Biomolecules



Through fundamental events in molecules





To electron dynamics

Measuring structural dynamics:
A challenge across the sciences

- Protein folding
  - (~10^{-6} – 10^{-8} s / 100 – 10nm)
- Conformational changes in large molecules
  - (~10^{-8} – 10^{-12} s / 10 – 1nm)
- Phase changes in solid state
  - (10^{-9} – 10^{-14} s / 10 – 0.1nm)
- Chemical changes (bond making and breaking)
  - (10^{-12} – 10^{-15} s / 1 – 0.1nm)
- Electron motion in matter
  - (10^{-15} – 10^{-18} s / 1 – <0.1nm)

Many key processes in matter
take place on a small spatial scale in an ultra-fast timescale

Conventional techniques for measuring structural dynamics

- X-ray diffraction with storage ring sources:
  - Sub-0.1nm spatial resolution / 10ps temporal resolution
- Electron diffraction:
  - Sub-0.1nm resolution / 1ps temporal resolution
- Time-resolved laser spectroscopy:
  - indirect spatial information / 10fs temporal resolution

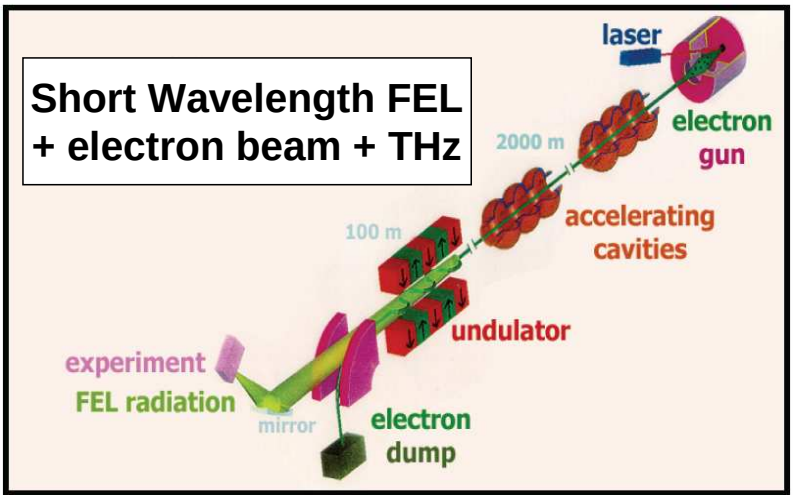
We are presently blind to structural changes occurring
on the critically important sub-picosecond timescale

3. The NLS capability?

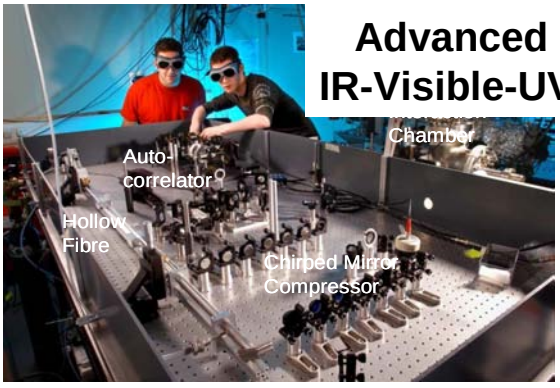
- Based on analyses performed to date, NLS is likely to be a coupled set of facilities including, e.g.
  - state of the art conventional lasers (high field/ultra-short pulse)
  - long wavelength sources
  - electron beam sources
  - at its core a short wavelength (<100nm) free electron laser

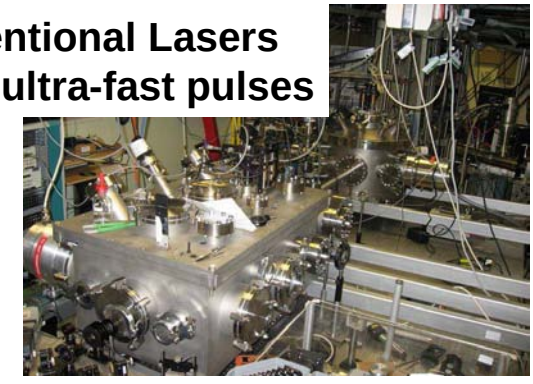
- The facility should have unique capabilities compared to other projects under construction around the world

To Address the Challenges
All Relevant Advanced Technology Should be Exploited in an Integrated Facility

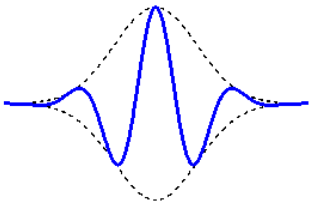


Advanced Conventional Lasers
IR-Visible-UV-VUV ultra-fast pulses

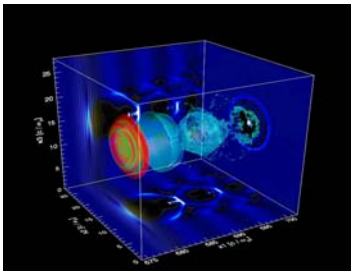




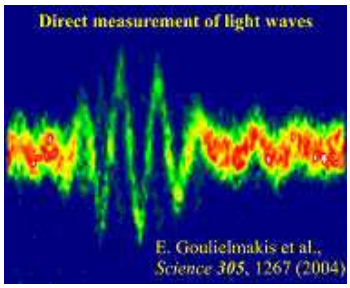
Key Capabilities of
Conventional Advanced Lasers



- High field / ultra-fast lasers are now available in the visible and IR with pulse durations of only a few optical cycles
- These can drive electrons in new ways:
  - plasma wakefield accelerators,
  - surface harmonics,
  - gas phase harmonics



- **Attosecond duration events** are now accessible to measurement because of these developments
- Multi-colour **fully synchronised** ultra-short pulses in range from 0.3-100eV



Projected key capabilities of
Next generation free electron lasers

- X-ray wavelength (down to 0.1 nm):
  - enabling atom scale structure determination
- Tuneability (THz- soft X-ray – 0.1 nm)
- Ultra-short pulses (< 10 fs to ~100 as):
  - enabling measurement of structural dynamics at extreme timescales
- Highly Intense (up to 10^{12} photons/pulse):
  - enabling single molecule structure determination and multi-photon X-ray science
- Polarization control
- Flexible/high repetition frequency (Hz to MHz)
- Access to synchronised THz radiation and relativistic electron beam

Science Drivers will Determine the Facility Specification

- **Ability to upgrade** will be a key objective
  - Budget likely to prohibit us from having all of the above specifications (at least not straightaway)
  - Also need to be open to emerging new technologies and science priorities
- **Staged project** delivering some capabilities sooner and others later is a viable approach
- We need to identify the most exciting and far reaching science to set the target specification

4. NLS in Context

- There are some powerful and expensive light sources being developed around the world
  - Significant UK access to these is anticipated to be part of our strategy
- NLS must be a powerful facility with unique capabilities
  - It must complement these international light sources (not be a duplicate of what we can use elsewhere)
  - It should provide the UK and partners with sufficient capacity and advanced capability to yield a significant volume of world leading science and technology in key fields not possible otherwise



Unique Capabilities

This uniqueness might be achieved through the provision of, for example, a combination of:

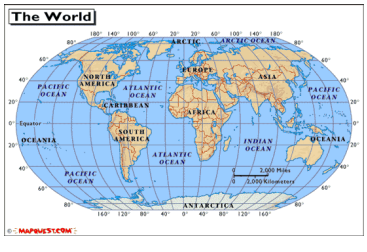
(a) New ranges of photon energy and combinations of photon energy

(b) A superior short pulse capability and better temporal synchronisation than any machine yet available

(c) An infrastructure that provides **simultaneous access to a wider range of laser sources** and other facilities

Relationship to other projects

- NLS will build on the science case developed for the 4GLS project
  - But NLS will not be limited to the science objectives or technical solutions defined for 4GLS
- Other UK activities and proposals will also contribute significantly to shaping the NLS case
  - e.g. Artemis, LSF, Astra-Gemini, ERLP/ALICE, Sapphire, Diamond
- NLS will seek to be International from day-1
  - Scientific and facility consultation with relevant European and International studies



5. The Consultation Process

- Project Launch April 2008
- Phase 1 April – October 2008 (Consultation)
- *Science Review*

- Phase 2 October 2008 – October 2009
- *Full review*
  - Large Facility Capital Fund
  - Proposal to be considered for funding 2010-

Subsequent phases are subject to the outcome of each review

Phase 1: Establishing Key Science Drivers and Outline Specifications

- Workshops held and Working Groups formed
  - May / June 2008
- Working Groups report to Project Leader
  - Mid July 2008
- Science drivers case presented to Science Community for comment
  - September 2008
- Revised case submitted to STFC for consideration
  - October 2008

NLS Science Coordinators

The science case is the responsibility of you – "the Community"

These coordinators are tasked with organising the community's input

- Members of 4GLS Leadership:
  - Prof Wendy Flavell (Manchester)
  - Prof Peter Weightman (Liverpool)
- Photon Science Research Institute Champions:
  - Prof Louise Johnson (Diamond/Oxford)
  - Prof Justin Wark (Oxford)
  - Prof Andrea Cavalleri (Hamburg/Oxford)
  - Dr Jonathan Underwood (UCL)
  - Prof Jon Marangos (Imperial)

Phase 1: Establishing Key Science Drivers and Outline Specifications - the Workshops

- Life Sciences
  - Workshop date mid-June
  - Meeting convenors– Professor Dame Louise Johnson and Professor Peter Weightman
- Condensed Matter
  - 21st May 2008, Rutherford Appleton Laboratory
  - Meeting convenor – Professor Andrea Cavalleri
- Chemical Science
  - 22-23rd May 2008, Daresbury Laboratory
  - Meeting convenors – Dr. Jonathan Underwood and Professor Wendy Flavell
- High Energy Density Science
  - 20th May 2008, Rutherford Appleton Laboratory
  - Meeting convenor – Professor Justin Wark
- Electron Dynamics / Attosecond Science
  - 13th May 2008, Imperial College London
  - Meeting convenor – Professor Jon Marangos
- Advanced Photon Sources
  - 3rd June 2008, Daresbury Laboratory
  - Meeting convenor – Professor Richard Walker

6. Why do it?

- Scientists and technologists in the UK will need access to the capabilities of the new generation of light sources to remain at the forefront of their fields in the coming decades

- NLS will be needed for the scientific demands that cannot be met by using the existing/planned array of international facilities

We need to be thinking in the long term.

The science and technology objectives we identify must be those that will remain important for several decades to come.

The NLS vision is to ensure a strong and versatile capability that enables these objectives, and new ones as yet not imagined, that will maintain UK science at the forefront into the middle of the century.