National Science Foundation

Light Source Panel
Report

September 15, 2008

NSF Advisory Panel on Light Source Facilities

Contents

BACKGROUND
(Supplied by NSF)

There are currently six federally-supported light source facilities in the US, as follows (dates show year of commissioning)[1]:

- Stanford Synchrotron Radiation Laboratory (SSRL) at the Stanford Linear Accelerator Center (1974)
- Cornell High Energy Synchrotron Source (CHESS) at Cornell University (1980)
- National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory (1982)
- Synchrotron Radiation Center (SRC) at the University of Wisconsin (1985)
- Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory (1993)
- Advanced Photon Source (APS) at Argonne National Laboratory (1996)

The Department of Energy (DOE) Office of Basic Energy Sciences supports the four facilities located at national laboratories; NSF (through the Division of Materials Research) is the steward for the two facilities located at universities. These six facilities support an extremely broad range of 'small science' experiments involving users from a wide variety of disciplines, including physics, chemistry, materials science, biological sciences, many branches of engineering, earth sciences, and even art conservation.

In addition to major investments in construction, operation, and instrument development made by the steward agencies, several partner agencies - including NIH, DARPA, and NSF – have made significant contributions to instrumentation and beamline development at various light sources. For example, in 2004 NSF's Division of Materials Research (DMR) initiated support of Mid-Scale Instrumentation Projects as part of the Instrumentation for Materials Research Program. The IMR-MIP Program supports both conceptual engineering design and construction projects for instruments located at US user facilities and costing between \$2M and \$20M. The steward agency takes responsibility for the operation of the instrument after construction.

In 1999 the National Research Council published a report on "Cooperative Stewardship: Managing the Nation's Multidisciplinary User Facilities for Research with Synchrotron Radiation, Neutrons, and High Magnetic Fields". The report strongly endorses a cooperative stewardship model for managing such facilities, stating that:

> There are two components to multidisciplinary user facilities: the core of the facility and the individual experimental units, and this division leads to a natural division of management responsibilities. Responsibility for the core components should reside with the steward. Responsibility for the experimental units, including the training and support of new users, could also reside with the steward; alternatively, it could reside with the sponsors of the experimental units, the partners, which could be either other government agencies or organizations in the private sector.

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[1] A complete list of current light source facilities worldwide is available at http://www.lightsources.org/cms/?pid=1000098

The Department of Energy is likely to remain the principal source of support for major light sources in the U.S. for the foreseeable future. Recent workshops, however, have also examined the scientific case for major new light source facilities that might in some circumstances be university-based.[2,3,4] NSF's Directorate for Mathematical and Physical Sciences (MPS) currently supports a 4-year award to Cornell University for conceptual and engineering design of an Energy Recovery Linac, which represents one possible approach to state-of-the-art light sources.

Construction costs for such facilities are estimated to be several hundred million dollars, bringing them under the aegis of NSF's Major Research Equipment and Facility Construction account. The MREFC account was established to support large construction and/or acquisition projects with costs comparable to annual NSF Division budgets; interim and final approval of each project is the responsibility of the National Science Board (NSB)[5].

While construction funding for major facilities is now provided from the MREFC account, initial planning costs and subsequent operational costs are assumed by the appropriate Research and Related Activities Directorate(s). Existing MPS user facilities and their operating costs are listed in the *MPS Facilities Funding Table* in the NSF Budget Request for FY 2008.[6] The list includes smaller facilities constructed using Directorate or Division funds.

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[2] ERL X-ray Science Workshops, Cornell University, May 2006. http://erl.chess.cornell.edu/gatherings/erl%20workshop/index.htm.

[3] "New Scientific Opportunities with VUV and Soft X-ray Free Electron Lasers", workshop report, Synchrotron Radiation Center, University of Wisconsin, Madison, October 2006. http://www.src.wisc.edu/

[4] CMMP-2010 Facilities Workshop, National Research Council, Irvine, CA, January 28-29, 2007. http://www7.nationalacademies.org/bpa/CMMP2010_Facilities_Workshop.html

[5] The process and criteria for establishing priorities for MREFC projects are described in detail in *A Joint National Science Board – National Science Foundation Management Report: Setting Priorities for Large Research and Facilities Projects Supported by the National Science Foundation* (NSB-05-77, September 2005) http://www.nsf.gov/pubs/2005/nsb0577/index.jsp.
MREFC projects under consideration must undergo a multi-phase internal and external review and approval process. This includes a review by the internal NSF MREFC Panel, which makes recommendations to the NSF Director with attention to criteria such as scientific merit, importance, readiness, and cost-benefit. An overarching cross-disciplinary context for assessing the value of a proposed facility in comparison to other investments is presented annually by NSF to the NSB. The *Facility Plan* combines in one document a report on major facilities under construction and in various stages of development, together with a discussion of the science objectives and opportunities that provide the context and compelling need for each facility. The *Facility Plan*, updated regularly and made public, provides a comprehensive exposition of the needs and plans to inform decisions, and serves as an important vehicle for communicating with the research communities. See NSF-07-22 at http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf0722&org=NSF.
NSF MREFC projects currently approved or under construction are listed in the *MREFC Funding Table* (page 8 below). Detailed descriptions of each project are given in the budget request and the *Facility Plan.*

[6] NSF budget request for FY 2008. http://www.nsf.gov/about/budget/fy2008/toc.jsp.

The operational costs for a future major light source facility will be substantially higher than current operating costs for the NSF synchrotron facilities; these future costs are likely to be $30 - $50 million per year or more. The NSF organization with lead responsibility for management and oversight of such a facility is likely to be the Division of Materials Research within MPS. However, broad, cross-disciplinary partnership and support representative of the diverse user communities involved will be essential to ensure responsible long-term stewardship for NSF facilities of this scope and magnitude.

MPS Committee of Visitors reports and the NSB have stated the importance of maintaining an appropriate balance among funding modes. DMR Committees of Visitors in particular have emphasized the need for balanced support for individual investigators and small groups, centers, and user facilities.[7] In view of the constraints of cost, program balance, broad cross-disciplinarity, and the national needs for future research and education related to high-intensity light sources, a careful assessment of NSF's potential role in support of such facilities is essential. Expert guidance from the relevant science and engineering communities represented by this Panel will be a critical aspect of the assessment.

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[7] Committee of Visitors Report, 2005, NSF Division of Materials Research. http://www.nsf.gov/od/oia/activities/cov/mps/2005/DMRcov.pdf

CHARGE TO THE PANEL

The Panel is charged to provide guidance to the Directorate for Mathematical and Physical Sciences regarding future NSF stewardship and/or partnership in support of coherent light source facilities and instrumentation. Specifically:

- What is the current view of opportunities for future research using major advanced light source facilities, and what facilities are envisioned to carry out such research in the U.S.?
- What does the Panel see as the most effective role for the NSF in helping to develop, construct, instrument and operate such facilities?
- Do university-based light sources now under discussion in the community (for example, a soft X-Ray Free Electron Laser and/or an Energy Recovery Linac) have a critical role to play in realizing the opportunities?

The Panel's guidance is requested in the context of:

1. Science drivers in research fields and subfields likely to make use of major light source facilities
2. The potential for interagency, private sector, and international partnerships
3. Department of Energy and other federal agency plans for advanced light sources in the US, and new facilities planned or under construction worldwide
4. Education and future workforce needs
5. The multidisciplinary nature of the anticipated user communities
6. Budget outlook and balance for NSF, MPS, and DMR
7. NSF's responsibility to maintain appropriate balance at all levels among funding modes, including resources for individual investigators, groups, centers, and instrumentation, as well as major user facilities.

Subject to subsequent proposal review and approval, possible outcomes may include future NSF support for construction and stewardship of one or more major new light source facilities; NSF support for conceptual development and engineering design projects related to future light sources; NSF partnership through support of instrument development projects at national laboratories stewarded by the Department of Energy; or some combination of these approaches.

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REPORTING MECHANISM

The Advisory Panel on Light Source Facilities will report to the MPS Advisory Committee through the MPSAC Chair. A member of the Advisory Committee will serve *ex officio* as MPSAC Liaison on the Panel.

RESOURCE MATERIALS

- *Cooperative Stewardship*; Commission on Physical Sciences, Mathematics and Applications; Committee on Developing a Federal Materials Strategy, NRC 1999.
  http://www.nap.edu/catalog.php?record_id=9705
- *Advanced Research Instrumentation and Facilities*; Committee on Science, Engineering and Public Policy; Committee on Advanced Research Instrumentation, NAS 2005.
  http://books.nap.edu/catalog.php?record_id=11520
- *Setting Priorities for Large Research Facilities Projects Supported by the National Science Foundation*, NAS 2004.
  http://books.nap.edu/catalog.php?record_id=10895
- *Setting Priorities for Large Research and Facilities Projects Supported by the National Science Foundation* (NSB-05-77, September 2005; response to the NAS Report).
  http://www.nsf.gov/pubs/2005/nsb0577/index.jsp.
- *Science and Engineering Infrastructure for the 21st Century: The Role of the National Science Foundation*, NSB 02-190, National Science Board 2003.
  http://www.nsf.gov/nsb/documents/2002/nsb02190/nsb02190.pdf
- *Facility Plan* (NSF-07-22)
  http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf0722&org=NSF.
- *Midsize Facilities: The Infrastructure for Materials Research*; NRC 2006.
  http://www.nap.edu/books/0309097029/html
- Facilities Workshop Presentations, CMMP-2010 Committee, NAS Board on Physics and Astronomy, January 28-29 2007.
  http://www7.nationalacademies.org/bpa/
- *European Roadmap for Research Infrastructures*; European Strategy Forum on Research Infrastructures, European Commission 2006.
  http://cordis.europa.eu/esfri/
- NSF, MPS and DMR budget request data for FY 2008.
  http://www.nsf.gov/about/budget/fy2008/toc.jsp).

MEMBERS OF THE MPS PANEL ON LIGHT SOURCE FACILITIES

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LIGHT SOURCE PANEL REPORT

EXECUTIVE SUMMARY

Coherent, ultra-short pulse, exceptionally high brightness X-ray sources (so called 4th generation sources) have properties that far surpass those of current X-ray sources. The laser-like properties of these new sources promise to open up new scientific frontiers such as lens-less imaging and ultrafast dynamics and spectroscopy. Applications span an exceptionally broad array of scientific and engineering disciplines. There is strong, world-wide interest in the development of these sources especially in Europe and Japan, and the United States needs to move more aggressively in this new era. NSF-supported, university-based light source facilities have historically played, and are now playing, a vital role in advancing the state of the art and in education and training of the next generation of scientists and engineers.

University-based light source developments currently under discussion such as the Energy Recovery Linac (ERL) and the soft X-ray Free Electron Laser (XFEL) have a critical role to play in realizing the opportunities afforded by 4th generation sources. The Panel recommends that NSF play a stewardship role in the design, construction and operation of university-based 4th generation light sources. In fact, pursuing the science that requires either VUV/soft X-ray photons (e.g. photoemission and nanotechnology) or hard X-ray photons (e.g. magnetic scattering and crystallography) may require two separately optimized 4th generation sources. The NSF stewardship must reflect the breadth of the science and engineering and must therefore involve multiple Directorates and Divisions. NSF should simultaneously explore the considerable opportunities for partnerships with other federal agencies such as DOE and NIH, universities, state governments and other nations.

The operation of the two main NSF-supported university light source facilities, CHESS and SRC, as presently constituted will ultimately cease to be funded. The Panel emphasizes that sustaining the critical expertise at these two facilities through the transition to a new NSF-sponsored facility is the key to success for NSF. If a critical mass of excellent people is lost, NSF will have neither the visionaries and advocates for the 4th generation facility nor the brain trust to make it happen.

Since the ultimate goal of the next-generation light sources is to address transformational science, the user research communities must be involved from the beginning in developing the facility specifications and design. To help communication, it is advantageous to continue active user research programs where next-generation light source R&D work is being pursued.

In addition, the NSF should concurrently support university-based research on advanced concepts (for example, so-called "table top" sources) for light sources that go beyond the 4th generation, and on those concepts, more modest in cost, that could be supplemental to 4th generation sources.

The rationale for these statements and a more detailed set of findings and recommendations are given in the main body of the report.

PROCESS

The Panel commenced its work with a plenary meeting in Washington, DC on August 23, 2007 which included initial presentations by appropriate experts. A more detailed workshop with key stakeholders from universities, national labs, federal agencies and industry was held at Livermore, CA on January 9-10, 2008. The agendas for these meetings/workshops are attached in Appendices 5 and 6 and detailed presentations were made available at a NSF website for future use. Sub-groups from the Panel also made site visits to CHESS at Cornell, SRC at Wisconsin, ALS at LBNL and SSRL and LCLS at SLAC (Appendices 7 – 10) These site visits gave the Panel an opportunity to visit both NSF-funded and DOE-funded facilities at or close to university sites. The Panel held a working meeting on June 7-9 2008 at NSF to draft its findings and recommendations.

THE SCIENCE CASE

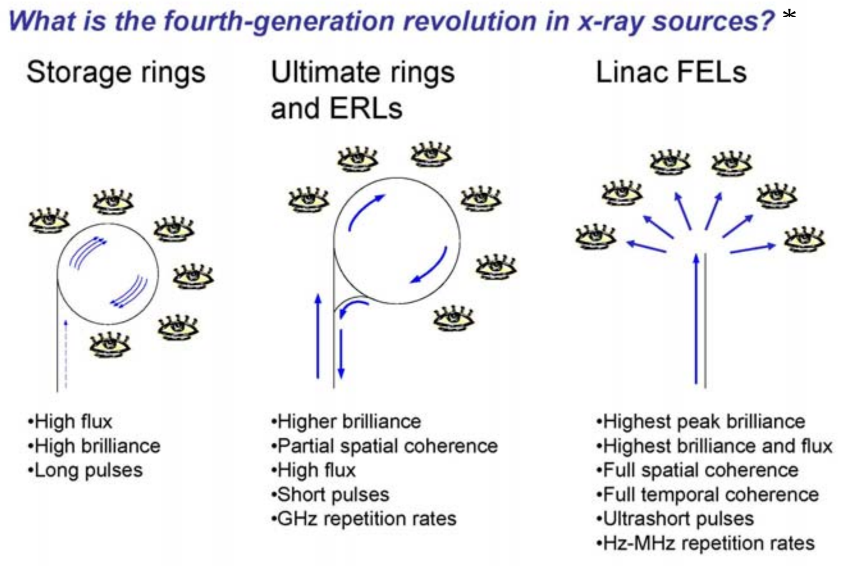
Introduction

A new era of light source development is underway that will lead to significant improvements in the coherence properties of photons on a sample. These improvements will make practical novel methods for imaging and for probing of sample dynamics. This era has been brought about by two advances: the energy recovery linac (ERL) provides efficient operation at high brightness; the free electron laser (FEL) provides very high peak brightness and coherence. For both, superconducting rf (SRF) acceleration cavity development is an enabling technology. Both use a low emittance electron beam in a single pass through the photon generator, a distinct advantage over present day storage ring light sources where the beam circulates for many turns resulting in much larger emittance and longer pulses. This leads to photon beams with short time structure (ps, fs), high transverse coherence, and the possibility of longitudinal coherence. **Coherent, ultra-short pulse, exceptionally high brightness X-ray sources have properties that far surpass those of the current generation of X-ray sources.** This leads to high peak and average brightness orders of magnitude beyond 3rd generation sources and the possibility of a very narrow frequency spectrum, giving rise to the possibility of single shot measurements and pump-probe experiments with very high time resolution. The thinking on ways to do experiments to make use of the new properties of 4th generation sources is only beginning to develop. For example, one-shot measurements on living samples may be possible rather than gathering data over many pulses on painstakingly prepared frozen samples. Short time dynamics measurements are possible, for example probing picosecond properties of magnetic materials. **Exciting new scientific frontiers in areas such as lensless imaging, and ultrafast dynamics and spectroscopy are enabled by these properties. Exploiting this scientific frontier in the US is essential for our competitiveness in strategic areas of science, engineering, workforce development and could have significant commercial impact.**

Below we outline the historical development of light sources, list the capabilities of 4th generation sources, and discuss the status of construction plans for such facilities around the world. In the next section, examples of potential scientific impact will be addressed. In a later section Accelerator R&D and the ideas associated with “table top sources” are discussed.

History of Light Sources and Their Evolution

The first synchrotron light beamline was built on the Cornell 300 MeV Synchrotron and the radiation characterized in the early 1950s. Like that synchrotron, "1st generation" light sources were built primarily for nuclear and high energy physics and were used parasitically as sources for photon science. "2nd generation" synchrotrons were then designed, optimized and built exclusively for light source applications. These were followed by "3rd generation" synchrotron sources optimized for reduced beam emittance that made extensive use of "insertion devices", primarily undulators, which increased the brilliance of the photon beams by orders of magnitude. **While the concept of a generation is not uniquely or unambiguously defined, next generation sources have typically exceeded current generation sources by at least one order of magnitude in some important parameter, such as the brilliance.** The properties of synchrotron-based light sources are characterized by the electron beam that circulates in the ring for an extended time and relaxes to an equilibrium state determined by the photon radiation process and the optical properties of the synchrotron beam lattice.



*This figure is a modified version of a figure from Murray Gibson of Argonne.

This leads to electrons bunched with larger transverse emittance (especially in the horizontal plane) and longer bunch length than can be produced by a modern electron injector. The ring arrangement with the continuously revolving beam can support many user beam lines with high flux, but with relatively low brilliance and long (many tens of ps) pulse length. Examples of the interdisciplinary science that has been done with 3rd generation sources is highlighted in Appendix 1.

The Key Characteristics of 4th Generation Sources

Each preceding generational change in light sources has resulted in a broadening of the scientific impact and the user base. The capabilities and potential of 4th generation linac-based light sources go far beyond those of 3rd generation synchrotron based sources, and are expected to have a correspondingly large scientific impact.

Capabilities include:

- Increase in peak and average brightness by orders of magnitude
- Short X-ray pulses, 10-100 fs as compared with 10s -100s ps
- Transform-limited photon beams
- High percentage spatial coherence, as compared with minimal low percentage and low intensity coherence of 3rd generation
- High energy resolution and related long temporal coherence is possible in some configurations
- Small size beams, suitable for nano-sized targets
- Pump probe capabilities (X-ray – laser, X-ray – X-ray) offering as low as 10 fs temporal resolution
- Harmonic X-ray generation, enabling shorter X-ray wavelengths to be obtained from low energy electron beams

These result in the ability to provide: high brightness, small, intense beams of short duration, well-defined beam energy and narrow bandwidth, spatial and in some cases temporal coherence. They enable time-resolved experiments, and pump probe experiments for observing the effects of various intensity and wavelength pump excitations with time delays as short as tens of fs.

4th generation light sources will allow experiments not feasible at present because of intensity limitations. They should simplify sample preparation of proteins (e.g. crystals may not be required) and allow investigation of initially living cells. They should make possible the investigation of very small structures – nanostructures and crystals, clusters, magnetic materials, macromolecules and proteins.

The coherence properties of 4th generation light sources should allow for lens-less imaging, and holographic techniques. The new frontiers opened up by exploiting X-ray coherence are discussed in Appendix 2.

The pump probe and time-resolved capabilities down to times of a few fs should allow measurement of the time evolution of energy states, chemical interactions, measurements of time scales of magnetic properties, spin dynamics and magneto-optical coupling. Exploration of the interaction of light with biological systems on the fs time scale relevant to photochemistry should be possible.

The capabilities of ERLs and FELs will enable the study, evaluation and refinement of small amounts of materials at the nanoscale, materials under very high pressure in diamond anvil cells, and the time evolution of biological materials.

However, ERLs and FELs have rather different source characteristics and as presently conceived, offer somewhat different X-ray properties in such areas as overall pulse structure and generation of VUV/soft or hard X-rays. For example, pursuing science that requires either VUV/soft X-ray photons (e.g. photoemission and nanotechnology) or hard X-ray photons (e.g. magnetic scattering and crystallography), or that depends critically on a particular pulse structure, may require two separately optimized 4th generation sources.

Status of 4th Generation Light Source Plans and Construction around the World

State of the art synchrotron-based light sources (generation 3½) are under construction at BNL (NSLS II) and DESY (Petra III).

FLASH at DESY is a VUV (vacuum ultra violet) SASE (self amplified spontaneous emission) FEL operating at up to 1 GeV electron energy and down to 7 nm wavelength. Typically it delivers 20-30 mJ photon pulse energy. This R&D facility has been operating for user experiments and accelerator development for a few years, and is rapidly developing the techniques of using and improving FELs.

The JLab FEL-ERL is a 150MeV energy recovery linac with IR (Infrared) and THz (Tera –Hertz) light capability. It is the proof of principle accelerator for the ERL concept.

The XFEL (European X-Ray Free Electron Laser) is about to start construction and will come into operation in 2014-15. There is planning underway for a number of other European facilities including BESSY, Fermi@Elettra. In Japan at Spring-8, SCSS is under development and should start operation in 2011. Numerous activities are underway internationally as exemplified by worldwide participation in the FEL Conference 2007 held in Novosibirsk. Europe has a significantly higher number of light sources (see http://www.als.lbl.gov/als/synchrotron_sources.html) than the U.S. . Japan, with a smaller number of scientists than the U.S., has a comparable number of light sources to the U.S. .

At present, LCLS (built by DOE at SLAC) is the only new linac-based facility in the U.S. For electron acceleration it uses part of the SLAC linac. It is being commissioned and will come into operation for user experiments in the summer of 2009, initially operating in the soft X-ray range of from 0.8 to 2 keV photon energy.

DOE-BES will be evaluating its needs for future facilities, and both ANL and LBNL are developing designs. ANL is working on an ERL that could use much of the present APS facility. LBNL's present design is for a cascaded harmonic FEL, with possible pulse lengths in the as (attosec) range.

The NSF has two university proposals under general consideration, as mentioned in the Background section and in the charge to this panel.

Although the LCLS is almost ready to come into operation, the U.S. appears to be behind the rest of the world in this new era of light sources, even though the research opportunities seem extraordinarily compelling. There is no current, coordinated, interagency plan involving DOE, NSF, NIH, … for next generation light source facilities, that could set U.S. national and international science policy.

Accelerator R&D in Support of 4th Generation Light Source Development

Development and utilization of these sources requires advances in many areas such as accelerator physics, detectors and X-ray optics, instrumentation, data management, and cyberinfrastructure.

The accelerator research and development for these new light source applications has undergone a revolution. Technology development in the area of superconducting cavities (SRF) over past decades has led to the feasibility of generating electron beams suitable for single pass linacs, and to demonstrations of the proof of principle of the ERL, the SASE FEL and the seeded FEL. The key to these accelerators is low emittance electron beams suitable for intense photon generation yet requiring reasonable power usage. The SRF capability to provide beam acceleration in CW or quasi CW (long pulse) operation with minimal power loss is an essential ingredient.

There remain challenges to be worked on and improvements to be made in the development of these sources and their further generations. These challenges are part of the intellectual, scientific, and technological driving force.

For the accelerator and photon lines these challenges include:

- small beam emittance generation, injector
- beam emittance control, linac
- beam current control, beam instabilities, higher order mode damping (HOM)
- SRF technology, CW operation, cavity Q & efficiency
- RF control, phase and amplitude very tight requirements
- timing distribution and control, relative control of lasers and accelerator to within 10fs or less
- laser development, HHG seed lasers, laser timing distribution
- cascaded seeded HGHG FELs (frequency multipliers)
- X-Ray beam line optics, detectors

The NSF has a culture that particularly values high risk, innovative, leading edge research. Historically, university research has been a major source of new designs for light sources and associated experimental techniques. Accordingly, the panel suggests the challenges listed above are well suited to the NSF university facility environment, which offers students and post-graduate researchers significant opportunities in advancing accelerator physics and photon science.

Table Top Light Sources

Light sources as we know them today, and those being proposed for 4th generation facilities of the future, are large scale, major projects. Construction investments are at the few 100M$ to 1B$ level. They are “big science” facilities to serve “small science” users. **New concepts for light sources beyond the 4th generation (e.g. table top, laser wakefield .…) are exciting and may create revolutionary or “disruptive” technologies.** There is quite naturally a wish to look toward sources that could be provided on a much smaller scale and at less cost (~$10M), with the idea that these might be suitable for typical university and industrial installations.

The overall design issue is to provide from a small or low energy electron source, photons of a wavelength and at sufficient intensity to be interesting to some sectors of the photon science community. The present thinking on these sources follows lines similar to that on 3rd to 4th generation sources: to generate electron beams of even lower emittance and shorter bunch length that can provide both high brightness and short duration photon pulses.

Three such activities will be mentioned here.

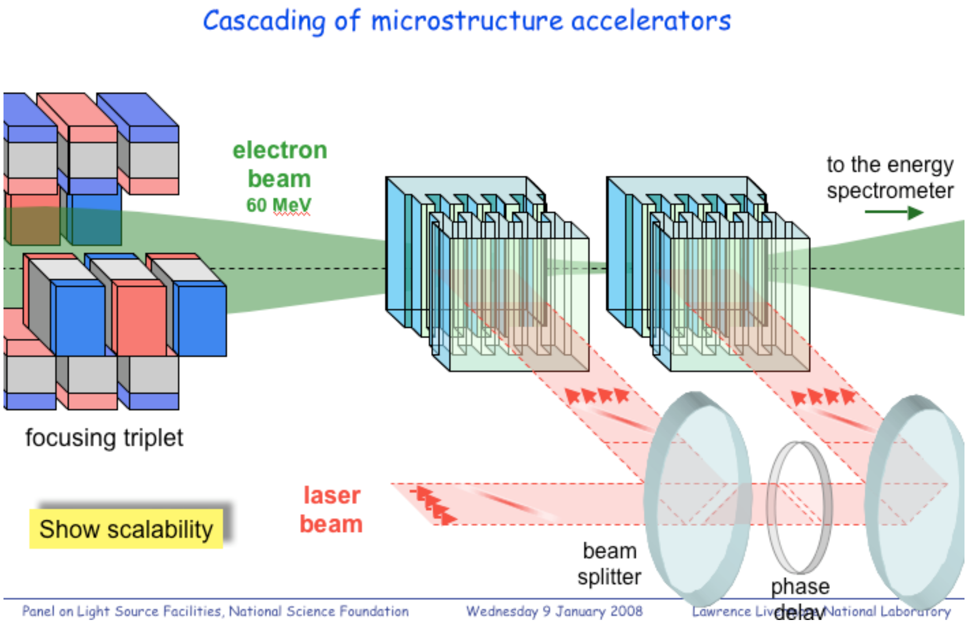
1) Compact Light Source (CLS) - LYNCEAN Technologies, Inc.
This source has been developed with the support of NIH. It consists of a small electron injector and storage ring coupled with a 1 μm wavelength laser resonator to provide soft X-rays in the 1 nm wavelength region. The basic process is inverse Compton scattering or Thompson scattering, where a standard magnetic undulator has been replaced by the laser beam with its effective undulator wavelength at the μm scale instead of the mm scale.

2) MIT Compact X-Ray Source
This proposal also uses inverse Compton scattering. A high quality electron beam with state of the art emittance and bunch length would be required. Here the electron beam is provided by a linac configuration or an ERL. The 5 KW drive laser would pump a high Q laser cavity to 5 MW of stored power. Tunable short pulse photons (~1 ps) of about 10 keV energy would be produced with a ~25 MeV electron beam. The brilliance should be much greater than for the CLS because of the higher quality single pass electron beam (as it is for 4th compared with 3rd generation sources). Time resolved experiments in the ps time scale would be possible. This source needs development of the laser system in particular and the CW cavities.

3) Advanced Accelerator Concepts
Within the framework of advanced accelerator R&D, many ideas directed toward very high gradient acceleration of electron beams are being worked on. There has been dramatic success in the areas of plasma wakefield acceleration, and laser and laser-plasma acceleration. In the long run such activities may see application in the areas of high energy physics accelerators and in light source photon production.

One such proposal was outlined for the Panel by Robert Byer (Stanford). The basic idea hinges on the use of planar grating dielectric micro structures (silica) as the accelerating (or deflecting) cavities. Energy would be fed to the structure by a laser beam from the side. The grating periodicity would be that of the incident laser wavelength and the laser wave front as a function of z would be phased with the electron bunch propagation. Deflecting mode structures could be configured as well, into undulator arrays with a typical period of 1mm. The motivation or long term goal would be to work toward a GeV electron beam in 1 to 2 m of space, with pulse structure of a few attosec preserved on the photons.

Research activities and small scale facilities such as those noted briefly above have a place in the development of new paradigms and experimental techniques and in workforce development. They will not replace the large scale facilities, certainly not in the near term, but they point a path for developments toward the longer term future. Even today they show promise to fill a niche at universities as accelerator technology development and photon research tools. Their educational potential is very large. Certainly NSF should be in the position to evaluate and support such activities.


Cascading of microstructure accelerators

Show scalability

Panel on Light Source Facilities, National Science Foundation   Wednesday 9 January 2008   Lawrence Livermore National Laboratory

EDUCATION AND TRAINING

The initial presentations to the Panel, the Panel's familiarity with DOE national lab facilities not located at universities and the ensuing site visits to DOE/university- and NSF/university–operated light sources provided a valuable opportunity to compare the modes of operation and the educational opportunities afforded at the different types of facilities. The Panel saw it as an educational strength to have a variety of operational models for light sources within the U.S. . . Models range from a high throughput/high user impact style facility that dependably serves a large population of researchers to facilities that encourage major student access inside the shielding walls. The latter results in both a deeper understanding of light source design and operation and in additional machine time available for individual research projects. It thus provides the opportunity to develop higher risk/higher payoff paradigms. In the remainder of this section, we briefly summarize our findings and present recommendations in the form of various options.

All types of facilities provide very strong support for users, and afford ample opportunities for users to become intimately familiar with the design and operation of end stations (experimental areas). Of course, the end stations were frequently designed and constructed by users. Some types of end stations are operated in a fashion that enables relatively unsophisticated users to obtain valuable research data (e.g. some end stations directed at structure determination enable experiments in which the user needs to do little more than load the sample). Overall, both DOE- and NSF-funded facilities provide education and training needed to create the next generation of users, especially those at university-operated sites.

It is in the development and implementation of higher-risk approaches that the committee sees a significant difference between the types of facilities. The pressures at the leading edge DOE light source facilities are to maximize available beam time and throughput, with the result that users are significantly isolated from the actual beam operations.

In contrast, at the NSF/university facilities, light source operation is much more a partnership between users and staff “accelerator scientists.” Users are able to prescribe beam functions and to operate “inside the shielding walls” at a level that is hard to achieve when the defining parameter is beam “up time.” As a consequence of this difference the users at university light source facilities have the opportunity to become deeply involved in machine operation, design and development. This leads to well-trained, next generation scientists and to new research programs and paradigms.

Powerful evidence of this difference is apparent from the degree to which accelerator scientists originally trained at the NSF/university light sources have become the leading machine developers at the next generation DOE light sources! A substantial benefit of NSF as steward or major partner in light source facilities has thus been the opportunity to train young scientists and engineers by engaging them directly in planning, construction, and operation of the facility, and in research and development of beamline and optical instrumentation.

It was also clear to this Panel that the perceived pressures on DOE preclude a significant commitment of their state-of-the-art facilities to the development of the next generation of accelerator scientists. **Until recently the materials science community has relied on the high energy physics community for the development of accelerator scientists and engineers. However, responsibility for the development of the next generation of accelerator scientists and engineers is presently undefined.** Such development of the next generation of accelerator scientists is critical to the continued preeminence of U.S. facilities, and it appears that this role must (and appropriately, in our view) fall mainly to NSF.

This Panel sees several possibilities for NSF that could enable it to sustain this crucial education/training role. Any of these might provide the needed education of next-generation accelerator scientists but the various models have different cost/benefit aspects, and their detailed analysis is clearly beyond the purview of this Panel. Cost/benefit must also include the national competitiveness of the U.S. in this research area.

We begin with our primary conclusion in this area:

- **NSF has a crucial and unique role to play in the education and training of the next generation of accelerator and light source scientists and engineers, who will provide the platform and opportunity to take our discoveries to the next level of excellence.**

This role can be fulfilled in a variety of ways, each with different costs and benefits. All involve providing "hands-on" operation of light sources, and the options involving partnership with DOE involve collaborations that, at present, are best described as "unprecedented."

- NSF could construct, operate and be the steward of a 4th generation light source (with or without partners), with the stated intention that appropriate beam time will be allocated to education and training of accelerator scientists and engineers. Since NSF has a diverse portfolio of research areas and researchers under its aegis, it can continue its mission of funding multidisciplinary scientific investigation and education while serving as the primary steward of a light source.
- With an appropriately constructed partnership with DOE, NSF could use designated time from a 4th generation light source stewarded by DOE to provide training for the next generation of acceleration/light source scientists and engineers. A university site for the partnership would help to facilitate the culture (and access) to students, post docs and young researchers.
- NSF could support existing light sources (stewarded by either DOE or NSF) in a way that provides the necessary training for the next generation of innovators in new light sources. This has been typical of past partnerships between the agencies and universities. Conceptual development of new light sources is ongoing now and should continue even if a major construction project is funded.
- NSF could partner with light sources based abroad to provide the education and training required for the continued development of light source leadership. This might be less expensive as an initial infrastructure cost, but could have a high cost in national competitiveness, economic impact and educational access for the U.S.
- DOE could assume fuller responsibility to create the next generation of light source scientists and engineers, and restructure its light source usage

appropriately to maintain U.S. competitiveness and educational opportunities.

The issue of education and training must be addressed promptly. The potential shutdown of currently operating NSF/university light source facilities could produce a significant gap in the pipeline for education and training of the next generations of accelerator researchers and scientists.

Operation of the two main NSF-supported university light source facilities, CHESS and SRC, as presently constituted will ultimately cease to be funded. The Panel emphasizes that sustaining the critical expertise at these two facilities through the transition to a new NSF-sponsored facility is the key to success for NSF. If a critical mass of excellent people is lost, NSF will have neither the visionaries and advocates for the next generation facility, nor the brain trust to make it happen and to train the next generation of accelerator and light source scientists and engineers.

The Panel notes a highly relevant assertion contained in the 2003 NSF report, Science and Engineering Infrastructure for the 21st Century: The Role of the National Science Foundation. "*The opportunity is to build a new infrastructure that will create future research frontiers and enable a broader segment of the S&E community. The challenge and opportunity must be addressed by an integrated strategy. As current infrastructure is replaced and upgraded, the next-generation infrastructure must be created. The young people who are trained using state-of-the-art instruments and facilities are the ones who will demand and create the new tools and make the breakthroughs that will extend the science and technology envelope. Training these young people will ensure that the U.S. maintains international leadership in the key scientific and engineering fields that are vital for a strong economy, social order, and national security*."

In any event, it is essential that some actions be taken to assure continued US preeminence in this important, multidisciplinary area. The NSF/university culture and environment has supported innovative/cutting edge/high risk projects of graduate students and young scientists and it is of paramount importance that this be maintained.

PARTNERING AND NSF STEWARDSHIP

MPS should partner with other directorates to develop an NSF-wide science case and the requirements for the US 4th generation facilities. NSF should partner with other agencies to further develop the specific science case and the requirements for such facilities. Partnerships must be formed or strengthened between NSF and the scientific user community via, for example, workshops to develop the full scientific case for a particular facility. See, for example: http://erl.chess.cornell.edu/gatherings/erl%20workshop/index.htm and http://www.wifel.wisc.edu/workshops.htm.

However, in this section we focus on partnerships within NSF and between NSF and other organizations, to design, construct and operate light source facilities once the specific science case is produced. **There are examples of both effective and ineffective partnerships within NSF and between NSF and others that can inform future partnerships.**

Introduction

NSF has played a long-running, active, and successful role as a steward of university-based X-ray facilities, most notably through CHESS at Cornell University and SRC at the University of Wisconsin. These X-ray facilities, along with those supported by DOE, are notable for the wide breadth of disciplines (e.g. materials science, chemistry, condensed matter physics, structural biology, earth and environmental sciences, medicine, agriculture, and even art history and archaeology) and range of experimental approaches (e.g. elastic and inelastic scattering, single crystal crystallography, spectroscopy, microscopy and other forms of imaging) represented there. That is, the facilities are highly multi-disciplinary. They also enhance inter-disciplinary activities, often through experimental approaches that extend between disciplines. For example, a time-resolved experimental capability may be originally developed to address problems in structural biology, but be equally applicable to addressing scientific problems in chemical crystallography, materials science or geophysics. Or, an imaging capability developed for a medical application may be directly applicable to problems in soil and environmental science. The panel is convinced that this diversity will be maintained in the 4th generation sources and beyond.

In considering various levels of partnership, it is useful to consider the three elements that go into an X-ray facility. 1) The core accelerator facility and an initial, small suite of beamlines covering a subset of experimental types must be designed, constructed and operated; 2) a larger suite of beamlines covering a broader set of experimental types and scientific disciplines must be designed, constructed and operated; and 3) R&D must be pursued to further develop next-generation X-ray facilities (e.g. new accelerator concepts), beamlines (e.g. new X-ray optical elements or detectors) and the experiments themselves. Effective partnerships can be established to address all three elements, and need not be identical at all three. For example, a single agency may act as the steward of the core facility at the first, but multiple agencies, foundations, industry and international partners may contribute to the second and third. The partnership for facility support must cover the entire lifetime and all life stages of a light source facility.

Design, construction, operations and use by researchers of major light sources need to be projected in cost plans for > 10-20 years. Budgets need to be balanced between the seven life stages of light source facilities, several of which overlap in time: 1) conceptual design and supporting technologies, 2) design and construction of core facility, 3) operation of core, 4) design and construction of beamlines, 5) operation of beamlines, 6) PI research, and 7) decommissioning.

User funding

While 4th generation light sources will be large-scale facilities, the science carried out there will be small scale and driven by individual investigators. It is important that the users not be charged for utilization of the X-ray facilities. The light sources, as multi-user facilities, will only be scientifically effective and cost-effective if the users – scientists from universities, national labs and industry – are able to obtain individual research support for their own laboratories, support that is essential to develop the scientific techniques and samples to be brought to the facility. The experience from existing light sources is that the composition of the user base varies over the lifetime of the facility. For example, while one user group e.g. materials scientists may reduce their participation in a light source, another user group e.g. structural biologists increases its participation. Thus a broad diversity of funding sources is needed for user research support.

A successful facility will attract a large number of excellent users. Thus, success depends on the overall funding balance between support of the core facility and its beamlines, and support of the individual users, during the seven life stages of light source facilities noted above.

Scale Of Cost

The construction and operation costs of the new accelerator-based facilities being considered by, for example, the University of Wisconsin and Cornell University groups are fully comparable to extant or planned NSF expenditures in other areas. Our estimated construction cost of the core facility of a new 4th generation light source is ~$500M. This cost is comparable with those of other current, university-operated NSF construction projects such as Ice Cube (~$250M; University of Wisconsin), ALMA (~$500M;) LIGO (~$360M; CalTech/MIT), Adv-LIGO (~$200M; CalTech/MIT) and DUSEL (~$500M;). The operations cost for the core 4th generation light source facility is estimated to be 10 - 20% of the construction cost, or $50 – 100M per year. This operating cost is comparable with those of other NSF facilities such as CESR (~$30M; Cornell University), National High Magnetic Field Lab (~$30M; Florida State University), ALMA (~$40M), LIGO (~$50M), and DUSEL (~$50M). Additional beamlines must also be constructed and operated beyond the initial complement associated with the core facility. Each beamline is anticipated to cost ~$20M and will require ~$2M/ year to operate.

The Panel emphasizes that, in accord with the model for light sources (and also for nuclear and high energy facilities) in place both nationally and internationally, access to the facility must be free (for all non-proprietary users); there must be no charge for photons.

Facility Funding

The structure for partnering between different agencies or entities for the seven life stages of the light source facility is critical to the long- term success of any future light source to which NSF contributes significant funding. We consider four main types: 1) an intra-NSF partnership, 2) inter-agency governmental partnerships, 3) international partnerships, and 4) partnerships with other entities such as a state, industry, foundation or university.

Intra-NSF Partnership In the historically-successful model in place at CESR/CHESS and the SRC, NSF constructed and operates the facility as a whole. That is, NSF/DMR serves as the steward, establishes the style of operations for the whole facility, and collaborates with junior partners such as other NSF directorates, NIH, New York State and Cornell University. With NSF/DMR as the steward, the opportunity is present to take risks that can realize new, high-risk / high-benefit research programs and provide comprehensive education of next generation accelerator and beamline scientists, engineers and technologists.

If (as noted below) NSF is to act as the steward of a light source facility, the Panel recommends that stewardship be established in a single organizational entity within NSF. If this entity is to be an existing directorate, then MPS is the most appropriate. However, since the range of disciplines pursued at any new facility embraces those supported by other NSF directorates, other directorates and divisions/units must from the outset become active partners with MPS. This intra-NSF partnership has both scientific and budgetary aspects. The latter are if anything more important, both for the construction phase and for operations of the core facility and the individual beam lines. Without NSF-wide support, efforts by MPS alone to argue for stewardship and to construct and operate a highly multi-disciplinary facility and its beamlines are not likely to be successful. More organizations within NSF are likely to benefit from the enhanced capabilities of a 4th generation facility than those three that are currently benefiting from current NSF 2nd generation sources: Math and Physical Sciences, Biological Sciences, and Geosciences..

Inter-agency governmental partnerships and NSF stewardship There are two ways in which NSF could partner with another federal agency (or agencies) to construct and operate the core facility: NSF is the steward and the other agency plays a secondary role; or vice versa, the other agency is the steward and NSF secondary. Inevitably, the style is fully set by the steward. Unless NSF is the steward, it will not capture the unique scientific, educational and administrative advantages offered by its major participation. Unlike mission-oriented agencies, NSF is a unique agency in the breadth of scientific disciplines under its masthead. The NSF–funded, university-based light sources have a history of transformative, cutting-edge research and development of novel techniques and are an essential source of well-trained scientists. The modes of operation at NSF-funded university facilities encourage the experimentation and risk-taking so necessary for advancing the state of the art and for education and training. Even though the DOE may remain the principal steward for major light sources in the U.S., the Panel believes that there is a compelling need for NSF/ university-based facilities to handle/enable low-volume, non-traditional users and emerging applications. **The benefits of multiple funding sources, healthy scientific competition, and not concentrating all light source stewardship in a single agency cannot be minimized.** Thus, the Panel recommends that if NSF partners with another federal agency in the design, construction and operation of a 4th generation light source, it only do so with agreement that NSF will act as the steward.

DOE as partner At the facility level, DOE has only a limited history of playing a junior role (e.g. in management of the National High Magnetic Field laboratory). DOE has a clear responsibility to act as the steward of large-scale research facilities, a responsibility that it discharges with vigor. Since a new NSF-funded light source will have unique characteristics, it is anticipated that NSF and DOE could collaborate effectively on accelerator-related, specialized projects. Novel insertion devices offer one example; these could be developed and tested at the NSF facility, and then replicated or further developed at the facilities for which DOE is the steward, to further improve their performance.

NIH as partner In a new departure for that agency, NIH provided substantial funds for the construction of the SPEAR II storage ring at SSRL. The possibility that NIH might provide significant funding for the design and construction of a new facility should be vigorously explored by NSF. We are confident that NIH will continue to play the role it has established at existing light sources, namely to fund the construction and operation of specialized beam lines in imaging and crystallography, and to provide extensive support to individual users. For example, NIH supports individual synchrotron beam lines in partnership with NSF (e.g. MacCHESS at CHESS) and DOE (e.g. NCRR/NIH-supported beam lines at SSRL, NSLS, APS and ALS, and a GM-CA/NIH-supported beamline at APS).

International partnerships As we note above, at the international level, scientific colleagues in Europe and Japan are actively pursuing their own advanced X-ray sources, which though expensive are still on a scale where a national approach is seen as both desirable and financially feasible. A new U.S. X-ray facility will offer scientific capabilities significantly beyond those of relatively new, domestic sources in countries such as Canada and Australia. These countries have actively and successfully partnered with existing U.S. light sources recently, and are therefore candidates to partner with NSF in the construction and operation of the new core facility. Though it is less likely that international collaborators would play a significant role as major partners in the core facility, they could play a minor - but nonetheless very valuable - role. Such countries have played and are likely to continue to play an essential role in the construction and operation of beam lines. These possibilities should be explored by NSF with these goals in mind. International collaboration on R&D for accelerator and photon sciences has played and should continue to play a vital role in the generation and implementation of new ideas.

Other partnerships Other entities that have not traditionally had a major role at light sources could become partners, such as NASA, USDA, individual states, major foundations such as the Howard Hughes Medical Institute and host universities. These partnerships are more likely to be of a scale suitable for the construction and operation of beamlines and for user support, rather than of the core facility.

The Panel notes that industry involvement as users at existing X-ray sources waxes and wanes. At present it is at a relatively low level both nationally and internationally. Industrial presence is concentrated in structural biology through the Industrial Macromolecular Crystallography Association beamlines at the APS and efforts by individual biotechnology and pharmaceutical companies at e.g. ALS and SSRL, and in materials science, broadly defined.

The extent of industrial involvement balances the knowledge gained by their basic and applied, product-oriented research against budgetary pressures and recognition that there is a long path between the marketplace and basic science of the type largely conducted at X-ray facilities. Nevertheless here too, industry may become engaged in the construction and operation of beamlines, and has an opportunity to partner on R&D and construction of the accelerator, detectors, optics, diagnostics, control systems and data management at these facilities.

FINDINGS AND CONCLUSIONS

Findings

- **Coherent, ultra-short pulse, exceptionally high brightness X-ray sources have properties that far surpass those of the current generation of X-ray sources.**

- **Exciting new scientific frontiers in areas such as lensless imaging, and ultrafast dynamics and spectroscopy are enabled by these properties.**

- **The scientific areas impacted are increasingly multidisciplinary and include biology, chemistry, physics, medicine, earth and environmental sciences, archeology, materials, physics and engineering. Interdisciplinary interactions will be greatly enhanced.**

- **Development and utilization of these sources requires advances in many areas such as accelerator physics, detectors and X-ray optics, instrumentation, data management, and cyberinfrastructure.**

- **Exploiting this scientific frontier in the US is essential for our competitiveness in strategic areas of science, engineering, workforce development and could have significant commercial impact.**

- **NSF has a culture that particularly values high risk, innovative, leading edge research.**

- **NSF emphasizes the education and training of the next generation of scientists and engineers.**

- **Historically, support by the high energy physics community for the development of accelerator scientists and engineers has benefited the light source community. However, responsibility for the development of the next generation of light source accelerator scientists and engineers is presently uncertain.**

- **NSF and universities together have demonstrated competence to design, construct and operate major instrumentation and large-scale facilities.**

- **Historically, university research has been a major source of new designs for light sources, and experimental techniques that utilize such sources.**

- **While 4th generation light sources will be large-scale facilities, almost all of the science done there will be small scale and driven by individual investigators.**

- **There are examples of both effective and ineffective partnerships within NSF and between NSF and others that can inform future partnerships.**

- **New concepts for light sources beyond or supplemental to 4th generation (e.g. table top, laser wakefield, …) are exciting and may create revolutionary or "disruptive" technology.**

- **Industrial support for beamline use/research has waned, but the potential is there for resurgence.**

- **There is no current coordinated - interagency plan (DOE, NSF, NIH, …) for next generation light source facilities that can set US national and international science policy.**

Conclusions & Recommendations

- **There is a strong science case for 4th generation light sources to be built in US in next 10 years.**

- **NSF has the capability to design, construct and operate a 4th generation light source as its steward and it is appropriate for NSF to do so.**

- **NSF's stewardship must reflect the breadth of the science and engineering and therefore involve multiple Directorates and Divisions. Nevertheless, management should be under the leadership of one NSF entity.**

- **As the steward, NSF should retain clear leadership even though there are opportunities for joint stewardship with other agencies (e.g. DOE, NIH), universities, state governments, and other nations.**

- **NSF should continue to partner in beamline construction, mid-scale instrumentation R&D, and operation of research facilities stewarded by others.**

- **Design, construction, operations and use by researchers of major light sources need to be projected in cost plans for > 10-20 years.**

- **Budgets need to be supported that are balanced over the 7 life stages of light source facilities: 1) conceptual design and supporting technologies, 2) design and construction of core facility, 3) operation of core, 4) design and construction of beamlines, 5) operation of beamlines, 6) PI research, 7) decommissioning.**

- **NSF should concurrently support university-based research on concepts for light sources beyond or supplemental to the 4th generation.**

- **NSF must support training of a new generation of accelerator scientists and engineers for the US to remain world class.**

- **The issue of education and training must be addressed promptly, as the potential shutdown of currently operating NSF/university light source facilities could produce a significant gap in the pipeline for education and training of the next generation of accelerator researchers and scientists.**

- **MPS should work with other directorates to explore possibilities for an NSF-wide science case and the requirements for the US 4th generation facilities.**

- **NSF should partner with other agencies to produce a specific science case and the requirements for proposed US 4th generation facilities.**

APPENDICES

APPENDIX 1

THE SCIENCE CASE

History and context: The inter-disciplinary nature of science at existing synchrotrons

While there are many places to obtain a clear picture of the scientific output and full impact of the traditional users of the existing light sources, here we choose to highlight some of examples that reflect the interdisciplinary nature of the NSF. Most of the material has been taken from the annual highlights of the synchrotron facilities. The key features of X-ray photons that have enabled this impact are a) the wavelengths can be comparable to inter-atomic spacing, b) photon energies can be comparable to binding energies of the elements, and c) the weak interaction with matter allows photons to penetrate deep into matter, and often makes the data directly interpretable.

History and context: Biology

While the early synchrotron efforts were primarily motivated by the needs of materials scientists and other physical scientists, the largest group of users at many synchrotrons today are the macromolecular crystallographers. Through its large-scale Structural Genomics Project, NIH is planning to solve 10,000 structures in 10 years based on access to existing light source facilities, and has invested in facilities across the country. Two recent Nobel Prizes (see Fig. A1.1a, b) have been awarded in which highly accurate

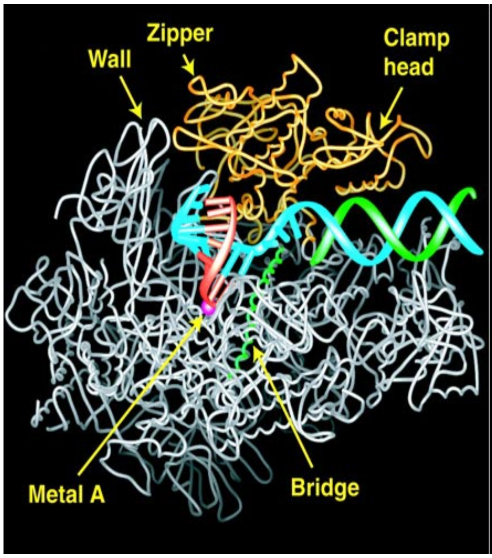


Figure A1.1a
2006 Nobel Prize: The transcription process visualized by Roger Kornberg and his colleagues in his X-ray crystallography studies were published online April 19, 2001, in *Science*. The protein chain shown in grey is RNA polymerase, with the portion that clamps on the DNA shaded in yellow. The DNA helix being unwound and transcribed by RNA polymerase is shown in green and blue, and the growing RNA stand is shown in red.

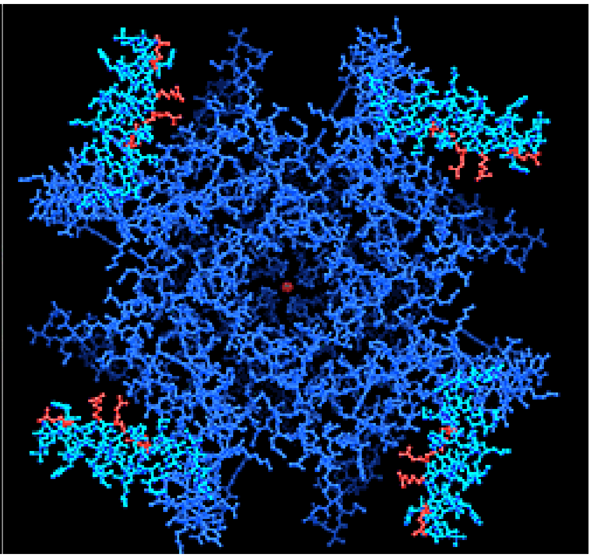


Figure A1.1b
2003 Nobel Prize: An overhead view of potassium ion channel structure solved by Rod Mackinnon and group. This structure shows for the first time the molecular mechanism by which potassium ions are allowed in and out of cells during a nerve or muscle impulse.

synchrotron scattering data were essential to the success of the projects.

X-ray crystallography is currently the technique most widely used by biologists but there is a growing field of fluorescent microprobe study of metal ions (Zn,Cu..) in tissue, with a possible impact on Alzheimer's disease. A beamline has been proposed at the APS to be dedicated to this class of problems.

History and context: Geosciences

The pressures in the earth's core are as high as 360 GPa, and temperatures are as high as 5500-6000 K , conditions that are quite extreme. Nevertheless, scientists are able to create such conditions in the laboratory, albeit in very small volumes. Using a diamond anvil cell (Fig. A1.2), one can create and exceed these pressures, and using lasers one can heat to temperatures that exceed these core temperatures, in a volume of order 20 μm^3. At these temperatures and pressures, many new familiar materials take on unfamiliar crystal structures with bulk elasticity, bonding and other properties that differ substantially from the atmospheric results. In order to model seismic data for example, one needs to be able to properly characterize the temperature/pressure dependence of the bulk properties, but most existing sources of limited coherence and brilliance limit the experiments. The proposed 4th generation sources, especially for high photon energies of 20keV and above, could make a big impact in the understanding of the interiors of the earth and other planets.

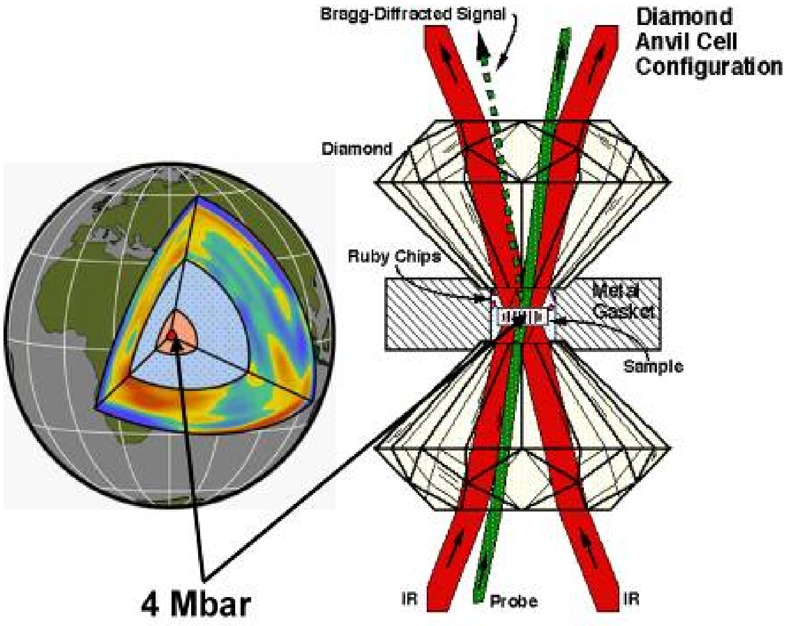


Figure A1.2
The diamond anvil cell allows one to simulate the pressures and temperatures at the center of the earth. However, it does this for small samples, typically of order 20 microns in size. To probe the crystal structures and other novel phases present in-situ, one can benefit from a photon source that is transversely coherent and hence can be focused efficiently to such small spots.

History and context: Paleontology

Transparent pieces of amber have long been known as a source of fossils. However, opaque amber accounts for up to 80% of the amber found in Cretaceous sites like those in Charentes (France). From the outside, it is impossible to tell whether something may be contained inside. Malvina Lak and her colleagues from the University of Rennes and Paul Tafforeau of the ESRF, together with the National Museum of Natural History of Paris, have applied a synchrotron X-ray imaging technique known as propagation phase contrast microradiography to the investigation of opaque amber. (See Fig. A1.3) This technique permits X-rays to reach the interior of this dark amber, which resembles a stone to the human eye. Researchers have tried to study this kind of amber for many years with little or no success. For the first time they can actually discover and study the

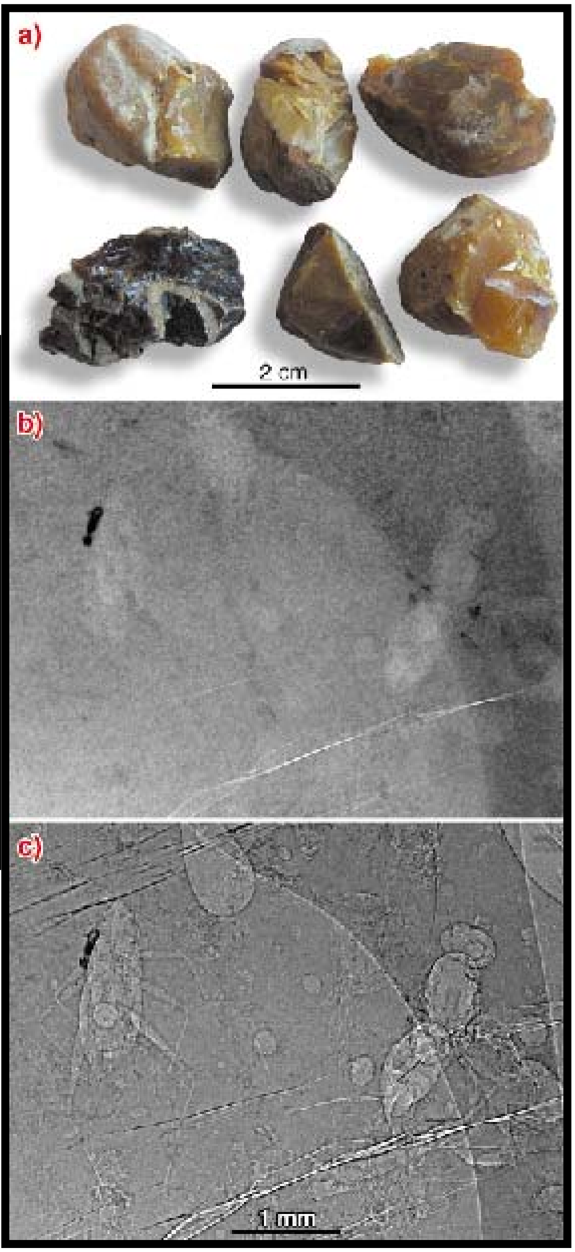


Figure A1.3

Coherent sources will lead to improved methods of x-ray imaging. The development of these methods is already underway at existing facilities. a)A visible light picture of typical amber blocks to be studied. b) Radiography of an amber block with inclusions viewed in absorption mode. There fossils can be barely detected. c) The same radiograph in propagation phase contrast mode with 990 mm of propagation distance (pixel size: 5 μm). Credits: M. Lak, P. Tafforeau, D. Néraudeau (ESRF Grenoble and UMR CNRS 6118 Rennes).

fossils contained within the amber.

History and context: Art Preservation

Synchrotron radiation has been used in some art history preservation, where it is used to study the composition of coatings and paints on artwork. In one related application of these techniques to a document of historical significance, is the Archimedes Palimpsest. Scientists at SSRL used X-ray micro-fluorescence to detect the iron based ink that was covered up by "palimpsesting" which is Greek for "scraped over". (See Fig. A1.4) In the upper panel is a visible light picture of a page from the manuscript, and the bottom panel is an x-ray image of the bottom left corner of the upper panel. One can see Archimedes' writing come through in the x-ray imaging in the lower panel.

Figure A1.4
In the top panel is shown a visual light image of a page from the manuscript.
In the lower panel is a expanded view of a portion of the same page but taken with x-ray fluorescence from the ink. This shows Archimedes' writing that was covered up by the re-use of the manuscript for a painting centuries later.

History and context: Fuel injection Sprays

The fuel injection process is critical to attaining high fuel efficiency and low emissions in modern engines. Accurate control of fuel injection parameters (timing, delivery, flow rate, pressure, spray geometry, etc.) is the most effective means to influence fuel and air mixing and to achieve both clean burning and high efficiency. Unfortunately, the physics of spray atomization and its influence on combustion, pollutant formation, and fuel efficiency are not well understood, and final tuning of the engine is a trial-and-error procedure. A deeper understanding of the injection process and spray atomization is needed to enable new strategies for clean and efficient combustion.

Argonne scientists have developed several novel diagnostic techniques that use x-rays to study the detailed structure of fuel sprays. X-rays are not hindered by multiple scattering processes that are highly penetrative in materials with low atomic numbers; therefore, they do not encounter the multiple scattering problems typical of diagnostic methods that use visible light. **By using highly time-resolved monochromatic X-rays (See Fig. A1.5) generated at the Cornell High Energy Synchrotron Source (CHESS), researchers from Cornell and Argonne have developed a non-intrusive absorption technique that yields a highly quantitative characterization of the dynamic mass distribution in the spray from both diesel and gasoline engine injectors.**

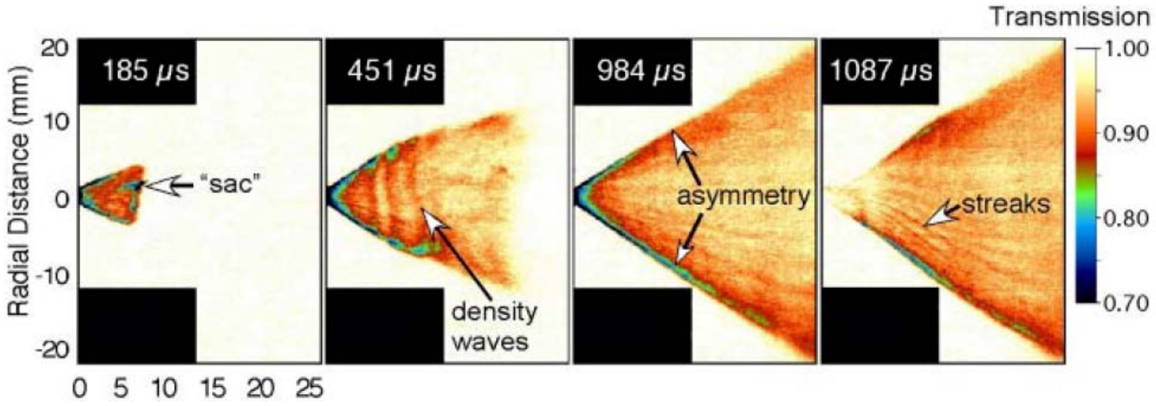


Figure A1.5 A series of x-ray images showing the time evolution of the fuel flow in a automobile fuel injector. Due to the penetrating nature of x-ray imaging it is possible to quantify the fuel density profile, and this could lead to improved fuel economy.

The new frontiers

The existing x-ray light sources will continue to have an impact into the foreseeable future, even if the sources were to freeze their experimental capabilities/techniques to the current palette of tools. However experiments at existing sources point the way to the new frontiers in the production and use of X-ray photon beams. These new frontiers are more completely documented in the existing science cases LCLS, XFEL, NSLS2, ESRF, however we give a few highlights below. Figure A2.1 shows the evolution of the average brilliance of accelerator based X-ray sources. The key source properties that are at issue are transverse and longitudinal coherence, shorter X-ray pulses, high peak brilliance, and high average brilliance, and polarization.

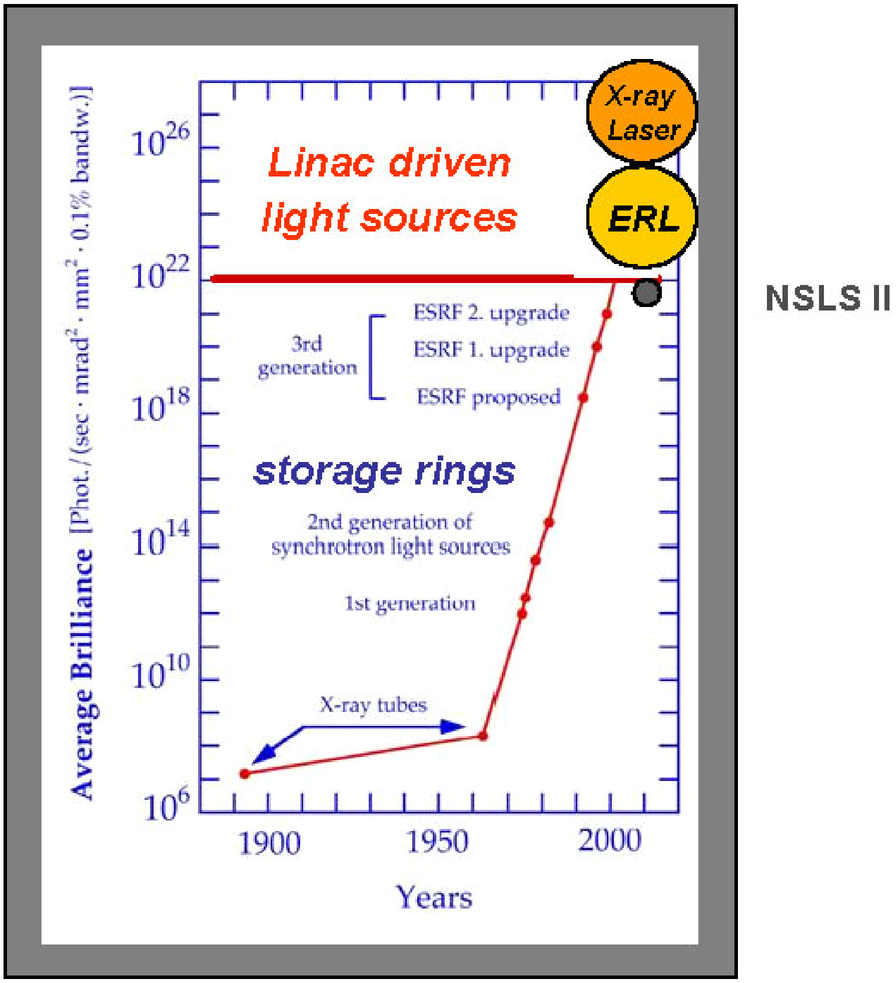
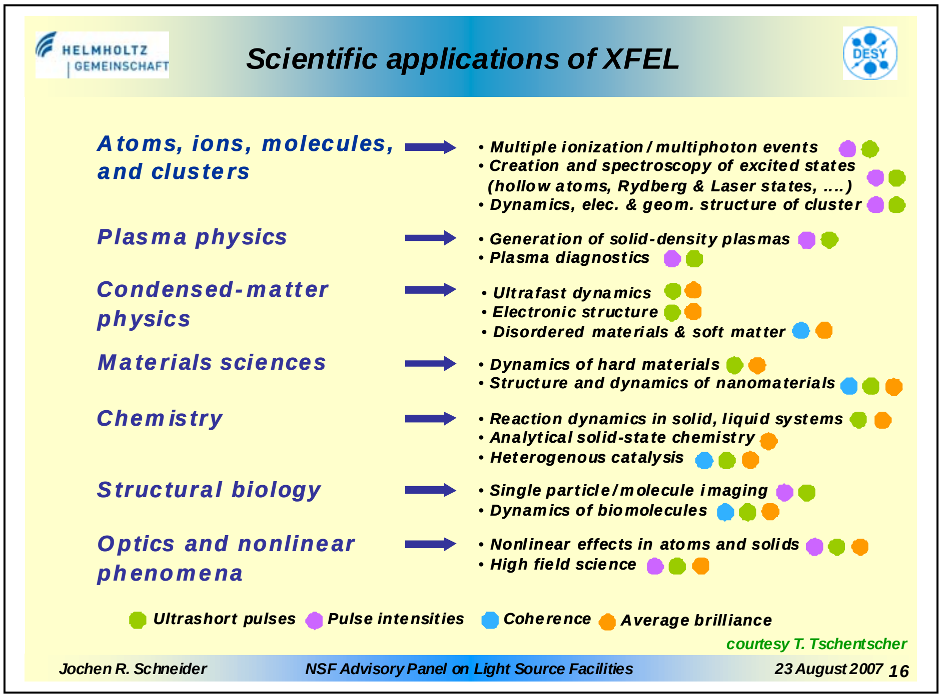


Fig.A2.1 Modern Accelerator-based X-ray sources

In the figure below, (Fig. A2.2) extracted from the scientific case for the XFEL in Europe, some general scientific fields are listed, and the properties of the new sources that would be of impact in those specific fields.



HELMHOLTZ | GEMEINSCHAFT

Scientific applications of XFEL

DESY

Atoms, ions, molecules, and clusters →
- Multiple ionization / multiphoton events 🟣🟢
- Creation and spectroscopy of excited states (hollow atoms, Rydberg & Laser states, ...) 🟣🟢
- Dynamics, elec. & geom. structure of cluster 🟣🟢

Plasma physics →
- Generation of solid-density plasmas 🟣🟢
- Plasma diagnostics 🟣🟢

Condensed-matter physics →
- Ultrafast dynamics 🟢🟠
- Electronic structure 🟢🟠
- Disordered materials & soft matter 🔵🟠

Materials sciences →
- Dynamics of hard materials 🟢🟠
- Structure and dynamics of nanomaterials 🔵🟢🟠

Chemistry →
- Reaction dynamics in solid, liquid systems 🟢🟠
- Analytical solid-state chemistry 🟠
- Heterogenous catalysis 🔵🟢🟠

Structural biology →
- Single particle/molecule imaging 🟣🟢
- Dynamics of biomolecules 🔵🟢🟠

Optics and nonlinear phenomena →
- Nonlinear effects in atoms and solids 🟣🟢🟠
- High field science 🟣🟢🟠

🟢 Ultrashort pulses 🟣 Pulse intensities 🔵 Coherence 🟠 Average brilliance

courtesy T. Tschentscher

Jochen R. Schneider NSF Advisory Panel on Light Source Facilities 23 August 2007 16

Figure A2.2 An example from the science case of the XFEL, showing how various properties of the photon beam can have impact in different scientific areas.

New Frontier: Transverse Coherence

One new frontier is the reduction of the electron beam emittance at existing and planned sources, which results in a photon source that is more transversely coherent, and in the best case diffraction limited with a coherent fraction approaching unity. The source coherence decreases with photon energy, so one can have sources that are diffraction limited in the soft X-ray region, but be far from diffraction limited at higher photon energies in the hard X-ray region. A transversely coherent beam impacts at least three key areas a) focused spots for scanned probe methods b) phase contrast methods, and c) phase retrieval methods.

The combination of high resolution X-ray optics with transversely coherent beams enables the production and use of small X-ray beams, a rapidly evolving area. At this point the quality of the optics is being improved dramatically, and one can now obtain 30nm resolution optics at 10keV commercially, and better resolution in R&D labs around the world. One driving force for the development of nanometer-sized beams allows one to interrogate individual nanoparticles; one expects this to have an impact in nano-science and catalysis. The larger the coherent fraction, the larger the fraction of photons that can be put into the focused spot. This is desirable to improve detectability. The limiting case for detectability is the current experimental challenge for existing and planned sources to be able to detect the fluorescence signal from a single atom.

A transversely coherent beam also has large impact in imaging. One key advantage of imaging with X-rays is the penetrating nature of radiation, particularly with higher energy photons. The improved transverse coherence at 3rd generation sources as compared with 2nd generation sources has hinted at the potential of this method. The images of insect buried in amber shown above were due to this improved 3rd generation coherent flux. However even at 3rd generation sources the coherent fraction is of order 1% and below, but the new 4th generation sources will have coherent fractions of 20% and higher. Improved coherence will allow one to obtain better images, but with lower dose and better resolution. The lower dose might allow more applications to biological systems, for example phase contrast images of thick tissue without the need of a microtome.
Finally there is the phase retrieval method also known as "lensless" method of imaging that requires illumination of the sample with a coherent beam. Instead of using a lens to obtain an image, the diffraction pattern of the sample is reconstructed by iterative methods. Unfortunately, as one decreases coherence of the illumination, the algorithms eventually cannot reconstruct an image. This method is active area of research, both on the experimental and theoretical front, but again the coherent fraction limits the photon flux on the sample. The potential payoff here is that this may be a practical way to get images with highest spatial resolutions, limited only the wavelength of the radiation and not by the quality of an objective lens.

New Frontier: Short pulses/Longitudinal Coherence

Another frontier is offered by the time resolution. While existing synchrotron rings are intrinsically pulsed sources, the majority of experiments do not exploit this pulsed nature, and instead use the time averaged properties of the source. The small set of users who take advantage of the pulsed nature have clarified the need and the scientific potential that exists for improved sources with shorter pulses.

An example (see Fig. A2.3) is the study of intermediate states of chemical and biochemical reactions on the ultrashort time scale. Chemical reactions and physical transformations involve the breaking and rearranging of intra- or intermolecular bonds for which the time scale of fundamental steps is on the order of femtoseconds or picoseconds and distance is measured in angstroms. Ultra-short pulsed lasers, with pulse widths on the order of a few femtoseconds, have been the tool of choice to study a wide array of atomic, molecular and macroscopic transformations. However one major drawback for this probe is that the typical laser wavelengths of these laser sources are three orders of magnitude too large to resolve the evolution of the inter-atomic spacing during the chemical reaction. A brilliant short pulse X-ray source has wavelengths more closely matched to the inter-atomic spacing, and could provide this important structural information.

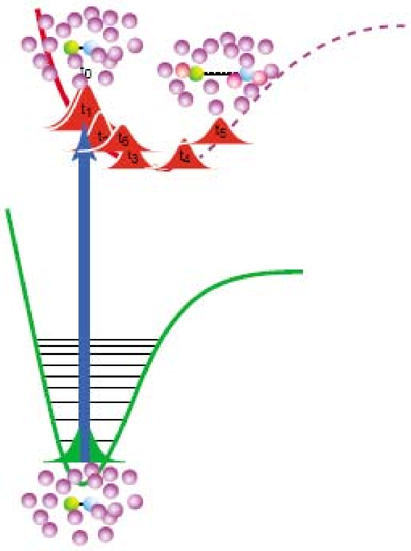


Figure A2.3: A schematic showing a representative chemical reaction and its intermediate states that can be mapped in time with a short pulses of high brightness x-ray photons. Shown is a representation of a photo-dissociation experiment in the condensed phase. The solvent molecules are represented by purple balls and the diatomic are blue and yellow. The dashed purple line represents the molecule solvent interaction. After excitation (blue arrow) with a pump laser into the excited state, the excited state evolves in time (t_1 - t_5). The wavelength of x-ray photons will allow the direct measurement of the spacing of the molecule through the entire reaction. (Source: LCLS science case)

In addition to the ultra-fast femtosecond chemical reaction regime, all slower process such as phonons, other cooperative phenomena such as magnetic domain motion, and tertiary structural transitions in biological macromolecules can be studied with the combination of small spots and short pulses.A further area of impact occurs in the warm dense plasma regime. Warm dense matter is the part of density-temperature phase space between cold condensed matter (T < Fermi temperature) and standard plasma physics. This regime is present in planetary interiors, cool dense stars, and in every plasma device where one starts from the solid phase. While one can create the plasmas with visible light lasers, visible light will not propagate when the density is ~ 10^{22}cm^{-1}, and so cannot provide diagnostics of the internal properties of the plasma. However X-rays do not suffer from a similar limitation and will allow one to extract S(Q,ω) for the plasma and with suitable modeling, will allow these previously inaccessible plasma regimes to be more extensively studied.

For biological molecules that crystallize, the determination of their crystal structure is now a routine if exacting process, that represents a major, ongoing enterprise at most existing light sources. However, there many molecules that will not crystallize, or will crystallize only to sizes of order 1 μm^3. Improved transverse coherence will allow the determination of molecular structure using such small crystals, but an alternative scheme has been suggested that is based on the ultra-fast pulses possible at 4th generation sources. (See Fig. A2.4) In this method one arranges for a stream of nominally identical copies of the molecule to pass through a pulsed, brilliant X-ray beam. For each pulse one collects the diffraction pattern from a fresh molecule. The fluences expected at 4th generation sources are sufficiently high that the molecules will disintegrate; however, it may be possible to collect a diffraction pattern before this occurs. The analysis consists of sorting the diffraction patterns to account for the random orientations of the molecule and obtain the complete, three-dimensional, continuous transform before solving the structure. These general types of analysis methods have been demonstrated successfully with electron diffraction.

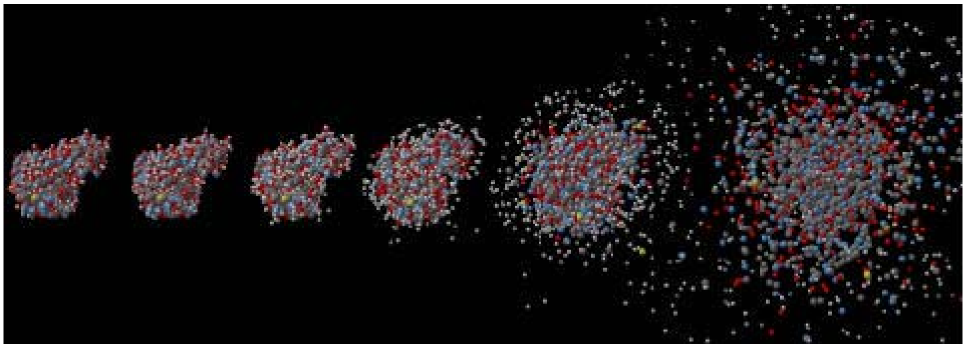


Figure A2.4: A simulation of a radiation-damage-induced explosion of T4 lysozyme (white: H, gray: C, blue: N, red: O, yellow:S). Integrated x-ray intensity was 3x1012 (12 keV) photons/100 nm diameter spot (3.8x106 photons/Å2) . (a) Protein exposed to a 2 fs FWHM x-ray pulse, and disintegration followed in time. The atomic positions in the first two structures (before and after the pulse) are practically identical at this pulse length due to an inertial delay in the explosion. (Source: LCLS science case)

NSF Advisory Panel on Light Source Facilities
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Meetings, Fact-finding Workshops and Site Visits

- August 23, 2007 Kickoff Meeting at NSF
- Jan 9-10, 2008 Fact Finding Workshop, Lawrence Livermore National Laboratory (LLNL)
- Site Visits March – April, 2008
  - March 20 Advanced Photon Source, Argonne National Laboratory
  - March 21 The Stanford Synchrotron Research Laboratory and the Stanford Linear Accelerator Center
  - March 27 Cornell High Energy Synchrotron Source
  - March 28 The Synchrotron Radiation Center, Wisconsin
  - April 3 Interim Observations Venkatesh Narayanamurti (Panel Chair)
- April 21, 11 a.m., 2008, Teleconference
- June 8-9 2008 Panel Meet at NSF
- Talks and pertinent info available at: http://www.nsf.gov/events/index.jsp?org=DMR

NSF Advisory Panel on Light Source Facilities

AGENDA
Thursday, 23 August 2007
National Science Foundation, Arlington, VA
Room 1060

7:30	Convene	
8:00	Welcome and Introductions Charge to Panel Timetable and reporting mechanism	T.F. Chan / AD-MPS / NSF
8:30	OSTP Perspective	K. Beers / OSTP J.M. Gibson / APS-Argonne
8:45	Science Opportunities I	Gibson / APS-Argonne J.R. Schneider / DESY
9:30	Science Opportunities II	J.R. Schneider / DESY K. Beer OSTP
10:15	Break	
10:30	Perspectives on the development and use of US synchrotron light sources	P. Gallagher / NIST
11:10	International context	G.X. Tessema / DMR / NSF
11:30	NSF context	W.L. Haworth / DMR / NSF
12:00	Working Lunch Informal Q&A with speakers Panel discussion and planning ▪ Introduction / identify further information needed & sources	V. Narayanamurti
1:30	Panel discussion and planning ▪ Map out future meetings – in person and/or teleconference as needed ▪ May include DOE/BES staff, NIH staff; DOE labs; Cornell group, Wisconsin/MIT group; other? ▪ Set panel assignments ▪ Set timetable & calendar	V. Narayanamurti
3:00	Adjourn	

APPENDIX 6

AGENDA Panel on Light Source Facilities

NATIONAL SCIENCE FOUNDATION (NSF)

Wednesday-Thursday, January 9-10, 2008

Wednesday, January 9, 2008

7:15 a.m. *Pickup at the Hilton Garden Inn and transport to LLNL* LLNL Driver
Met by Protocol

7:30 a.m. *Arrival and Badging*
Transport to Bldg. 170 Westgate Badge Office
LLNL Driver

8:00 a.m. Opening Remarks Venky Narayanamurti
Bldg. 170, Rm. 1091

8:15 a.m. Federal Agency Perspectives Tony F. Chan – NSF
(PDF)

Pedro A. Montano -

DOE (PDF)

Jeremy M. Berg –NIH

(PDF)

10:00 a.m. *Break*

10:15 a.m. New Light Source Facilities
Upgrades to 3rd Generation Synchrotrons
- NSLS II Steven Dierker -BNL
(PDF)
- APS J. Murray Gibson -
APS (PDF)

11:15 a.m. Beyond 3rd Generation
- Overview Samuel Krinsky -BNL
(PDF)
- Laser-based accelerator R&D Roger W. Falcone -UC
Berkeley (PDF)
needs

12:15 p.m.	*Working Lunch*	Kathryn L. Beers - OSTP
1:30 p.m.	Beyond 3rd Generation (continued)	
	- LCLS	Jerome B. Hastings - SLAC (PPT)
	- ERL Concept	Sol M. Gruner -Cornell (PDF)
	- XFEL Concept	Joseph J. Bisognano – Wisconsin (PDF)
		David E. Moncton – MIT (PDF
3:45 p.m.	*Break*	
4:00 p.m.	Supporting Technologies	
	— Optics, Detectors and Data Challenges	Gopal Shenoy -APS (PDF)
4:30 p.m.	Alternative Technologies	
	— Table top Synchrotrons	Robert L. Byer - Stanford (PDF)
5:00 p.m.	Partnerships	
	— Chem-Mat-CARS	P. James Viccaro -U Chicago (PDF)
	— Magnets & Light Sources	Gregory S. Boebinger –NHMFL (PDF)
	— J-Lab Activities	George R. Neil -J-Lab (PDF)
	Transport non-committee members to the Central Cafeteria (Bldg. 471)	*LLNL Driver*
6:15 p.m.	Closed session	NSF committee members only
	Transport non-committee members to the Central Cafeteria (Bldg. 471)	*LLNL Driver*
6:45 p.m.	Working dinner	Central Cafeteria – Bldg. 471
	— Perspective from Europe	Yves Petroff -ESRF (PPT)
8:00 p.m.	*Transport to the Hilton Garden Inn*	LLNL Driver

Thursday, January 10, 2008

7:30 a.m. *Pickup at the Hilton Garden Inn and transport to LLNL* LLNL Driver
Met by protocol

8:00 a.m. Opening Remarks Venky Narayanamurti
Bldg. 170, Room 1091

8:10 a.m. Potential Users
— Condensed Matter Science Simon Mochrie -Yale
P. (PPT)
— Chemistry and Materials James Viccaro -U
Chicago (PDF)
— Biological & Health Sciences Dagmar Ringe-
Brandeis (PDF)

— AMO Physics Phillip H. Bucksbaum
-Stanford (PDF)

10:30 a.m. *Break*

10:45 a.m. Panel Discussion – Focus on Key Issues Narayanamurti,
Murray;
Agency
Representatives;
Science Community
Representatives

12:00 p.m. Working Lunch: NIF as a User Facility Edward I. Moses

1:30 p.m. *Transport to Bldg. 581* LLNL Driver

1:45 p.m. National Ignition Facility (NIF) Tour* Edward I. Moses

2:45 p.m. *Transport non-committee members to the Hilton Garden Inn* LLNL Driver
Non-committee
members

3:00 p.m. Next Steps NSF committee
members only
— What do we need to do now Bldg. 581, Rm. 100
— Identify Site Venues, Dates and Subgroups
— Plans For Next Meeting and Report Writing

4:00 p.m. Wrap-up By Invitation

4:30 p.m. Adjourn

Panel for Light Source Facilities (NSF)

Committee Members

Venkatesh Narayanamurti (Chair)
Harvard University

Helen Edwards Fermi National
Accelerator Laboratory

Kenneth Evans-Lutterodt
Brookhaven National Laboratory

Michael L. Klein University
of Pennsylvania

Michael L. Knotek
Consultant

W. Carl Lineberger University of
Colorado at Boulder

Keith Moffat
University of Chicago

Cherry A. Murray (Co-Chair) Lawrence
Livermore National Laboratory

Monica Olvera de la Cruz (liaison to MPSAC)
Northwestern University

Elsa Reichmanis Bell Laboratories –
Lucent Technologies

Mary Jane Saunders
Cleveland State University

Charles V. Shank University of
California, Berkeley

Richard York Michigan
State University

NSF Staff

W. Lance Haworth, Director of the Office of Integrative Activities
G.X. Tessema, Division of Materials Research

Draft Agenda
Visit of National Science Foundation Panel on Light Source Facilities

Thursday, March 20, 2008

8:00 a.m. Transportation from Hotel to LBNL

8:30 a.m. Welcome Director Chu; Deputy Director Alivisatos

8:45 a.m. Overview and Scientific Vision of Advanced Light Source, Present and Future Roger Falcone, ALS Director

9:45 a.m. Discussion

10:00 a.m. Working Discussions and Refreshments

10:15 a.m. Picture of a DOE Light Source Budget
Ben Feinberg, ALS Division Deputy

10:45 a.m. Science Programs at ALS Beamlines: Prelude to Beamline Visits
Zahid Hussain, Deputy, Scientific Support Group

11:45 a.m. Discussion

12:00 – 12:45 p.m. Working Discussions and Lunch

12:45 p.m. – 2:45 Beamline Visits with Faculty, Staff, and Students
[Note: tentative; not yet confirmed]

- Alessandra Lanzara, UC-Berkeley, Physics
- Charles Fadley, UC-Davis, Chemistry
- Robert Birgeneau, UC-Berkeley, Physics
- Ramamoorthy Ramesh, UC-Berkeley, Materials Science
- Yuri Suzuki, UC-Berkeley, Materials Science

2:45 – 3:00 p.m. Concluding Discussions; Departure

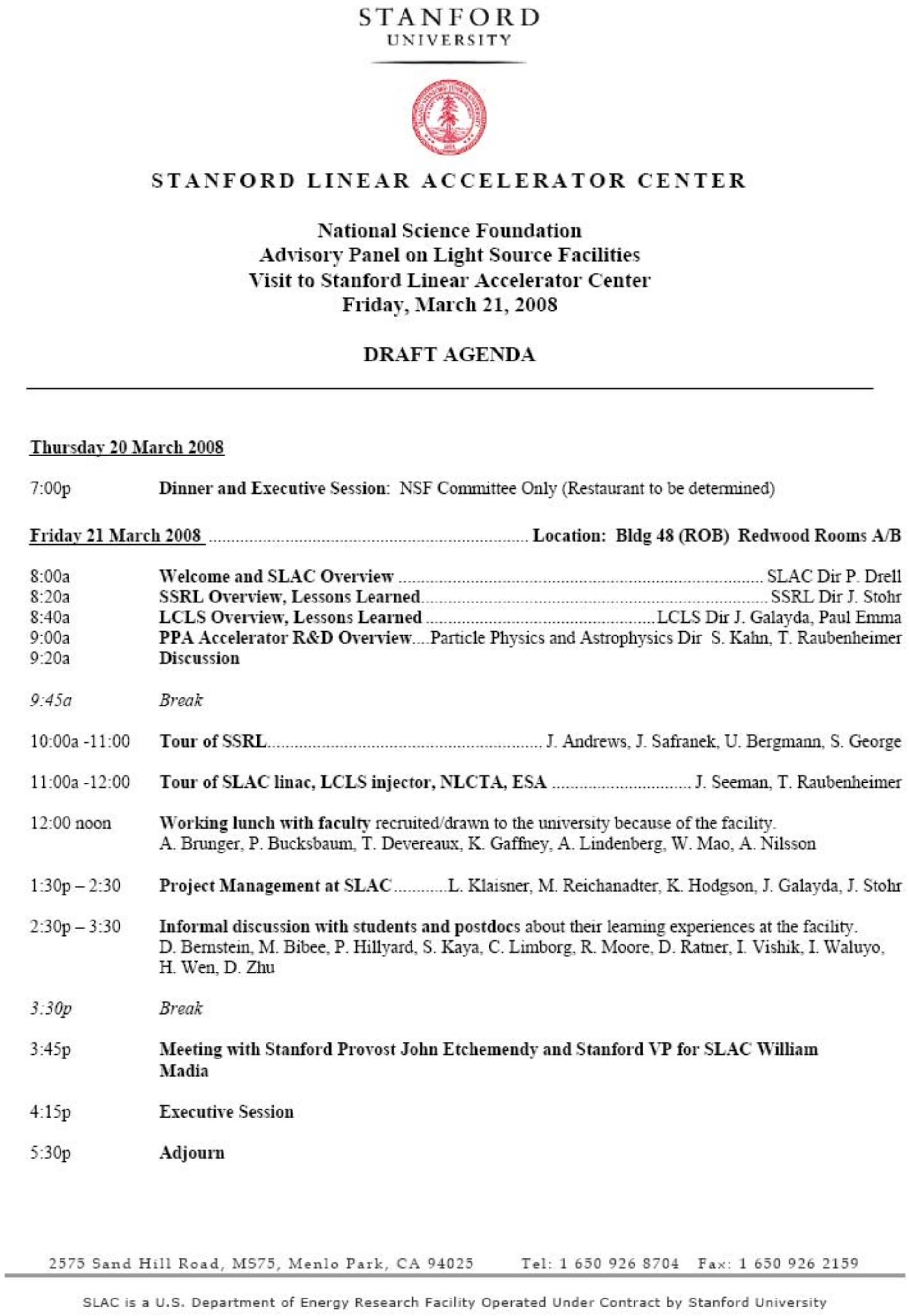
Panel Members

Venkatesh Narayanamurti, (Chair) Harvard University
Cherry Murray, (Co-chair) Lawrence Livermore National Laboratory
Kenneth Evans-Lutterodt, Brookhaven National Laboratory
Michael Knotek, Consultant
Monica Olvera de la Cruz, liason to MPSAC, Northwestern University

NSF Staff

G. X. Tessema, Division of Materials Research

APPENDIX 8



STANFORD
UNIVERSITY

STANFORD LINEAR ACCELERATOR CENTER

National Science Foundation
Advisory Panel on Light Source Facilities
Visit to Stanford Linear Accelerator Center
Friday, March 21, 2008

DRAFT AGENDA

Thursday 20 March 2008

7:00p	**Dinner and Executive Session**: NSF Committee Only (Restaurant to be determined)

Friday 21 March 2008 .... **Location: Bldg 48 (ROB) Redwood Rooms A/B**

8:00a	**Welcome and SLAC Overview** .... SLAC Dir P. Drell
8:20a	**SSRL Overview, Lessons Learned** .... SSRL Dir J. Stohr
8:40a	**LCLS Overview, Lessons Learned** .... LCLS Dir J. Galayda, Paul Emma
9:00a	**PPA Accelerator R&D Overview**....Particle Physics and Astrophysics Dir S. Kahn, T. Raubenheimer
9:20a	**Discussion**
9:45a	*Break*
10:00a -11:00	**Tour of SSRL**........................ J. Andrews, J. Safranek, U. Bergmann, S. George
11:00a -12:00	**Tour of SLAC linac, LCLS injector, NLCTA, ESA** .... J. Seeman, T. Raubenheimer
12:00 noon	**Working lunch with faculty** recruited/drawn to the university because of the facility. A. Brunger, P. Bucksbaum, T. Devereaux, K. Gaffney, A. Lindenberg, W. Mao, A. Nilsson
1:30p – 2:30	**Project Management at SLAC**............L. Klaisner, M. Reichanadter, K. Hodgson, J. Galayda, J. Stohr
2:30p – 3:30	**Informal discussion with students and postdocs** about their learning experiences at the facility. D. Bernstein, M. Bibee, P. Hillyard, S. Kaya, C. Limborg, R. Moore, D. Ratner, I. Vishik, I. Waluyo, H. Wen, D. Zhu
3:30p	*Break*
3:45p	**Meeting with Stanford Provost John Etchemendy and Stanford VP for SLAC William Madia**
4:15p	**Executive Session**
5:30p	**Adjourn**

2575 Sand Hill Road, MS75, Menlo Park, CA 94025 Tel: 1 650 926 8704 Fax: 1 650 926 2159

SLAC is a U.S. Department of Energy Research Facility Operated Under Contract by Stanford University

Background Information on Participants

Welcome and SLAC Overview

Persis Drell (persis@slac.stanford.edu)
Director, SLAC. In 2001, Drell was named deputy director of Cornell's Laboratory of Nuclear Studies. In 2002, Dr. Drell accepted a position as Professor and Director of Research at SLAC. Her current research activities are in particle astrophysics. She has recently been working with the GLAST project as Deputy Project Manager.

SSRL Overview, Lessons Learned

Joachim (Jo) Stohr (stohr@slac.stanford.edu)
Director, SSRL. PS Faculty. Recent work emphasizes the study of magnetic materials and phenomena, especially the use of polarization dependent spectroscopy and the development of x-ray magnetic imaging techniques for the study of the ultrafast magnetic nanoworld. Development of novel experimental soft x-ray synchrotron radiation techniques.

LCLS Overview, Lessons Learned

John Galayda (galayda@slac.stanford.edu)
Director and Manager, LCLS. PS, PPA Faculty. Manipulation and control of electron beams using laser light, the characteristics of synchrotron radiation from an FEL and beam-based feedback stabilization systems. The last topic is relevant to light sources based on storage rings and energy recover linacs as well as to FELs.

Paul Emma (emma@slac.stanford.edu)
Engineering Physicist. LCLS. Responsible for the LCLS accelerator commissioning.

PPA Accelerator R&D Overview

Steve Kahn (skahn@slac.stanford.edu)
Director, Particle Physics and Astrophysics. PPA Faculty. Engaged in a diverse program of research in high energy astrophysics, including experimental, observational, and theoretical components. Research interests include work in high resolution X-ray spectroscopy, and experimental cosmology.

Tor Raubenheimer (tor@slac.stanford.edu)
Accelerator Research. PPA Faculty. Accelerator physics; design issues in next generation linear colliders; participation in SLC operation; ion/beam-plasma instabilities in rings and linacs; effects during bunch length compression.

Tour of SSRL

Joy Andrews (jandrews@slac.stanford.edu)
Staff Scientist, Chem and Mat Sci, SSRL. Studies heavy metals in the environment using a variety of x-ray methods. Her particular interests are in the speciation of mercury as it transforms through the food web, and in phytoremediation (uptake by plants) to remediate metal contamination.

Uwe Bergmann (bergmann@slac.stanford.edu)
Team Leader, Hard X-ray Group, Chem and Mat Sci, SSRL. Development and application of novel synchrotron based hard x-ray spectroscopic techniques, applications of x-ray spectroscopy, applications for x-ray fluorescence imaging.

Serena George (serena@slac.stanford.edu)
Staff Scientist, Structural Molecular Biology, SSRL. Research focuses on the development and application of synchrotron-based spectroscopies (including XAS, XES and NRVS) as probes of the electronic structure of bioinorganic and organometallic systems.

James Safranek (safranek@slac.stanford.edu)
Accelerator Physicist, Accelerator and FEL Physics, SSRL.

Tour of SLAC Linac

John Seeman (seeman@slac.stanford.edu)
Assistant Director of the PPA/LCLS directorates and Head of the Accelerator Systems Division, leads a group that operates and upgrades the SLAC "two-mile" linac, the PEP-II collider, and recently the LCLS injector.

Tor Raubenheimer (tor@slac.stanford.edu)
Accelerator Research. PPA Faculty. Accelerator physics; design issues in next generation linear colliders; participation in SLC operation; ion/beam-plasma instabilities in rings and linacs; effects during bunch length compression.

Project Management at SLAC

John Galayda (galayda@slac.stanford.edu)
Director and Manager, LCLS. Joint Faculty: PS and PPA. Manipulation and control of electron beams using laser light, the characteristics of synchrotron radiation from an FEL and beam-based feedback stabilization systems. The last topic is relevant to light sources based on storage rings and energy recover linacs as well as to FELs.

Keith Hodgson (hodgson@ssrl.slac.stanford.edu)
Director, Photon Science. Faculty: PS. Inorganic, Biophysical and Structural Chemistry: The use of x-ray absorption spectroscopy (XAS) to investigate the electronic and structural environment of specific metal constituents in non-crystalline macromolecular systems. The use of high-intensity synchrotron radiation for diffraction studies of proteins and phasing by anomalous scattering methods.

Lowell Klaisner (klaisner@slac.stanford.edu)
Director, Engineering and Technical Support. Has managed a number of scientific instrument projects including; Project Manager for the Polarized Electron Gun, Chief Engineer for the B Factory, and Project Manager for the Gamma Ray Large Area Telescope. Currently, he is the Associate Laboratory Director for Engineering and Technical Support.

Mark Reichanadter (reich@slac.stanford.edu)
Deputy Director, LCLS. Accelerator engineering and project management. Accelerator engineering: design and construction of accelerator-based facilities, FELs, synchrotrons, FELs and related detectors. Project Management: management and organization of project teams to design, procure, construct and commission science/research facilities.

Joachim (Jo) Stohr (stohr@slac.stanford.edu)
Director, SSRL. Faculty, PS. Recent work emphasizes the study of magnetic materials and phenomena, especially the use of polarization dependent spectroscopy and the development of x-ray magnetic imaging techniques for the study of the ultrafast magnetic nanoworld. Development of novel experimental soft x-ray synchrotron radiation techniques.

Faculty Working lunch

Axel Brunger (Brunger@stanford.edu)
Mol and Cell Phys., Neurology and Neurological Sciences, PS Faculty. Structural neurobiology, vesicle trafficking and membrane fusion. Structure determination by X-ray crystallography and NMR spectroscopy. Computer simulation of macromolecules

Phil Bucksbaum (phb@slac.stanford.edu)
Director, PULSE (Photon Science/SLAC). Chair, PS Faculty. Non-linear optics, precision measurements, high-intensity physics, ultrafast laser physics.

Tom Devereaux (tpd@slac.stanford.edu)
XLAM (Photon Science/SLAC). PS Faculty. Development of numerical methods and theories of photon-based spectroscopies of strongly correlated materials.

Kelly Gaffney (kgaffney@slac.stanford.edu)
PULSE (Photon Science/SLAC). PS Faculty. Using femtosecond x-ray pulses to study structural dynamics in condensed matter, with emphasis on chemical dynamics in biology and chemistry. This will involve the merger of linear accelerator generated x-rays with ultrafast optical lasers and the development of time resolved x-ray diffraction, scattering, and spectroscopy.

Aaron Lindenberg (aaronl@slac.stanford.edu)
Dep. Dir. PULSE (Photon Science/SLAC). PS, Mat Sci&Engr Faculty. Atomic-scale ultrafast dynamics, phase transitions, liquid-state dynamics, materials under extreme conditions, THz spectroscopy, time-resolved x-ray techniques.

Wendy Mao (wmao@stanford.edu)
Earth Sciences, PS Faculty. High-Pressure Geophysics, Geochemistry, and Petrology; Volatiles in Planetary Systems and Hydrogen Storage Applications; Experimental Mineral Physics.

Anders Nilsson (nilsson@slac.stanford.edu)
Dep. Dir. XLAM (Photon Science/SLAC). PS Faculty. X-ray and electron spectroscopies applied to surfaces and interfaces, chemical bonding and reactions on surfaces, hydrogen bonding in water and organic systems, Aqueous solutions and interfaces, Heterogenous- and biomimetic enzyme catalysis.

Students/Postdocs Meeting

David Bernstein (dpb@slac.stanford.edu)

Matt Bibee (mbibee@SLAC.Stanford.EDU)
Graduate student in Applied Physics. Research consists of using synchrotron x-ray diffraction and related techniques to study strain in multi-layered silicon materials.

Pat Hillyard (phillyar@stanford.edu)
Graduate Student. Department of Chemistry. Research interests lie in observing structural dynamics and electronic changes in chemical systems with time-resolved XAS techniques.

Sarp Kaya (sarpkaya@stanford.edu)
Postdoc. Interaction of water with solid surfaces.

Cecile Limborg (Limborg@slac.stanford.edu)
LCLS Injector Liaison Manager. Design and characterization of RF photo-injectors used as high brightness sources for single-pass Free Electron Lasers.

Rob Moore (rgmoore@slac.stanford.edu)
Postdoc research associate at SSRL. Research focus is angle resolved photoemission studies on correlated electron systems. Currently studying charge density wave systems and organic superconductors.

Daniel Ratner (dratner@slac.stanford.edu)
Graduate student. Worked on several different X-ray FEL topics, including space charge effects, micro-bunching instabilities and eSASE, and I am assisting with the LCLS commissioning.

Inna Vishik (ivishik@slac.stanford.edu)
Graduate student. Using angle resolved photoemission spectroscopy to study the mysterious pseudogap state of the high-temperature superconducting cuprates, which exists at temperatures above the superconducting transition temperature over a wide doping range.

Ira Waluyo (iwaluyo@slac.stanford.edu)
Graduate student.

Haiden Wen (hwen@slac.stanford.edu)
Research Associate, PULSE/SLAC.

Diling Zhu (dlzhu@slac.stanford.edu)
Graduate student. Research focuses on microscopy and the study of fast dynamics of materials using coherent x-ray sources.

Stanford University Administrators

John Etchemendy (etch@stanford.edu) (http://www.stanford.edu/dept/provost/biography/)
Provost, Stanford University. Provost since 2000, Etchemendy has been a faculty member in the Department of Philosophy since 1983 after receiving his doctorate at Stanford in 1982. He is also a faculty member of the Symbolic Systems Program and a senior researcher at the Center for the Study of Language and Information.

Bill Madia (madia@slac.stanford.edu) (http://home.slac.stanford.edu/pressreleases/2008/20080122.htm)
Stanford Vice-President for SLAC, Stanford University. Provides direct linkage between the university and the laboratory, enhance collaboration and ensure coordination between the laboratory, Stanford and the Department of Energy (DOE).

Panel Members

Venkatesh Narayanamurti, (Chair), Harvard University
Cherry Murray (Co-chair), Lawrence Livermore National Laboratory
Kenneth Evans-Lutterodt, Brookhaven National Laboratory
Michael Knotek, Consultant
Monica Olvera de la Cruz, Northwestern University
Mary Jane Saunders, Cleveland State University

NSF Staff

Guebre, X. Tessema

APPENDIX 9

NSF Light Source Panel Visit
CHESS

Tuesday Evening, March 25, 2008.

6:30 pm	Executive session, Rowe Room, Statler Hotel, Cornell Campus
7:30 pm	Dinner, Rowe Room, Statler Hotel, with Directors/University Officials.

Wednesday, March 26, 2008. 380 Wilson Synchrotron Lab

7:30 am	Continental breakfast
8:00 am	Overview of Cornell synchrotron light source activities
9:00 am	Tour of superconducting RF facility, meeting staff, students, etc.
9: 50 am	Coffee Break
10:05 am	Tour of Wilson synchrotron facility, meeting students, staff, etc. Includes synchrotron, CHESS, ERL injector
11:45 am	Large facility management at Cornell.
12:15 pm	Lunch with young faculty, 380 Wilson
1:30 pm	Discussion with students & post-docs
2:30 pm	Discussion with Cornell Administration.
3:00 pm	Coffee
3:15 pm	Executive session
4:00 pm	Adjourn

Venkatesh Narayanamurti (Panel Chair)
Harvard University

Helen Thom Edwards
Fermi National Accelerator Laboratory

Michael L. Klein
University of Pennsylvania

W. Carl Lineberger
University of Colorado at Boulder

Richard C. York
Michigan State University

NSF Staff Liaison:

Charles E. Bouldin
IMR/DMR

Guebre X. Tessema
NAF/DMR

APPENDIX 10

Synchrotron Radiation Center

NSF Light Source Panel Visit
March 28, 2008

March 28, 2008

7:30 a.m.	Transport from Sheraton Madison Hotel to SRC
8:00 a.m.	Continental breakfast
8:15 a.m.	Introduction to facility
9:45 a.m.	Break
10:00 a.m.	Walking tour of facility
12:00 noon	Working lunch with faculty
1:00 p.m.	UW-Madison's management of large projects
1:45 p.m.	Informal discussion with students and postdocs
2:30 p.m.	Closed meeting of Panel
3:00 p.m.	Meeting with UW-Madison administration
3:30 p.m.	Closed meeting of Panel
4:00	Adjournment

Panel Members

Cherry Murray, Co-Chair, Lawrence Livermore National Laboratory
Helen Thom Edwards, Fermi National Accelerator Laboratory
Richard C. York, Michigan State University
Keith Moffat, University of Chicago (APS BioCARS)
W. Carl Lineberger, University of Colorado at Boulder
W. Lance Haworth, National Science Foundation
Guebre S. Tessema, National Science Foundation

APPENDIX 11

List of Acronyms

ALMA	Atacama Large Millimeter/Submillimeter Array
ALS	Advanced Light Source
ANL	Argonne National Laboratory
APS	Advanced Photon Source
BES	Basic Energy Sciences
BNL	Brookhaven National Laboratory
CHESS	Cornell High Energy Synchrotron Source
DESY	Deutsches Elektronen-Synchrotron
DOE	Department of Energy
DUSEL	Deep Underground Science and Engineering Laboratory
ENG	Engineering Directorate (NSF)
ESRF	European Synchrotron Radiation Facility
FLASH	Freie-Elektronen-LASer in Hamburg
GM-CA	General Medicine and Cancer Institutes Collaborative Access Team at APS
IceCube	http://icecube.wisc.edu/science/
JLab	Thomas Jefferson Lab.
LBNL	Lawrence Berkeley National Laboratory
LCLS	Linac Coherent Light Source
LIGO	Laser Interferometer Gravitational-Wave Observatory
MacCHESS	Macromolecular Diffraction Facility at CHESS
MPS	Mathematical and Physical Sciences
NASA	National Aeronautics and Space Administration
NCRR	National Center For Research Resources
NIH	National Institute of Health
NSF	National Science Foundation
NSLS	National Synchrotron Light source
PetraII	**P**ositron-**E**lektron-**T**andem-**R**ing-**A**nlage
SBE	Social, Behavioral & Economic Sciences
SLAC	Stanford Linear Accelerator Center
SPEAR II	Stanford Positron-Electron Asymmetric Ring
SRC	Synchrotron Radiation Center
SSRL	Stanford Synchrotron Radiation Laboratory
USDA	United States Department of Agriculture

FEL	Free Electron Laser
ERL	Energy Recovery Linac
X-FEL	X-ray Free Electron Laser
CT	Computed Tomography
VUV	vacuum ultra violet
SASE	Stimulation of Spontaneous Emission
HHG	High Harmonic Generation