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Major Goals: We propose a broadly tunable fiber-distributed light source configured as a user facility, to be used in a multidisciplinary program of DoD-relevant research, education, and training. The heart of this system is is an "optical swiss army knife": a titanium:sapphire laser with second-harmonic and difference-frequency generation modules, capable of producing tunable narrowband spectroscopy-grade light at wavelengths ranging from the visible to the mid-infrared. The light from this source will be delivered by optical fiber to eight user stations, consisting of educational and research labs within the UC Santa Barbara physics building. End users at those locations will reserve instrument time and remotely request desired wavelengths using a web interface. The light will be used to advance a wide variety of DoD educational and research priorities, including new modules for undergraduate laboratory classes, terahertz science, solid-state defect studies, ultracold atomic physics, single-molecule biophysics, molecular spectroscopy, and solid-state cavity quantum electrodynamics. The flexibility and accessibility of the proposed system will greatly broaden the access of UC Santa Barbara students and researchers to tunable spectroscopy-grade light, opening up a variety of new opportunities in training, education, and research. As a top-ten physics department in a minority-serving institution, and one of the five largest physics bachelor's programs in the United States, the UC Santa Barbara physics department is in a unique position to positively impact the training of the next generation of researchers. The proposed system's name, Broadly-tunable Illumination Facility for Research, Outreach, Scholarship, and Training (BIFROST), reflects its multispectral and connective character, alluding to the rainbow bridge Bifrost which links earth and Asgard in Norse mythology.

Accomplishments: We have accomplished all major goals of the proposal. We have acquired, installed, commissioned, and begun using the instrument described in the proposal, and acquired and successfully installed the fiber-optic network which delivers the light to research and teaching labs in Broida Hall. Details of these accomplishments are presented in the attached PDF.

Training Opportunities: This grant did not support personnel. However, significant training opportunities did take place for two Weld group graduate students (Peter Dotti and Quinn Simmons) during the installation and commissioning of the instrument.

Results Dissemination: We presented the unique concept of this instrumentation in various venues including an NSF midscale instrumentation workshop.

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI
Participant: David Minot Weld
Person Months Worked: 1.00 **Funding Support:**
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Final Report: Broadly-tunable Illumination Facility for Research, Outreach, Scholarship, and Training (W911NF1710496)

Prepared for Dr. Paul Baker, ARO

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Summary

We have accomplished all major goals of this proposal, creating an instrument which we believe to be nationally unique: a broadly-tunable spectroscopy-grade light source shared via fiber network among ten research and teaching laboratories. We have acquired, installed, commissioned, and begun using the distributed titanium:sapphire laser described in the proposal, and acquired and successfully installed the broadband single-mode fiber-optic network in Broida Hall. Because the assembly, installation, and operation of this novel instrument was performed largely by undergraduate and graduate students and postdocs, BIFROST also gave rise to unique research-related educational opportunities for scientists in training at UCSB. Details of these accomplishments are presented below.

Final Report

A. Major goals of proposal

We proposed a broadly tunable fiber-distributed light source configured as a user facility, to be used in a multidisciplinary program of DoD-relevant research, education, and training. The heart of this system is is an “optical swiss army knife”: a titanium:sapphire laser with second-harmonic and difference-frequency generation modules, capable of producing tunable narrow-band spectroscopy-grade light at wavelengths ranging from the visible to the mid-infrared. The light from this source was to be delivered by optical fiber to eight user stations (actually ten in the final installation), consisting of educational and research labs within the UC Santa Barbara physics building. End users at those locations can reserve instrument time and remotely request desired wavelengths using a web interface. The light will be used to advance a wide variety of DoD educational and research priorities, including new modules for undergraduate laboratory classes, terahertz science, solid-state defect studies, ultracold atomic physics, single-molecule biophysics, molecular spectroscopy, and solid-state cavity quantum electrodynamics. The flexibility and accessibility of the proposed system greatly broadens the access of UC Santa Barbara students and researchers to tunable spectroscopy-grade light, opening up a variety of new opportunities in training, education, and research. As a top-ten physics department in a minority-serving institution, and one of the three largest physics bachelor’s programs in the United States, the UC Santa Barbara physics department is in a unique position to positively impact the training of the next generation of researchers. The proposed system’s name, Broadly-tunable Illumination Facility for Research, Outreach, Scholarship, and Training (BIFROST), reflects its multispectral and connective character, alluding to the rainbow bridge Bifrost which links earth and Asgard in Norse mythology.

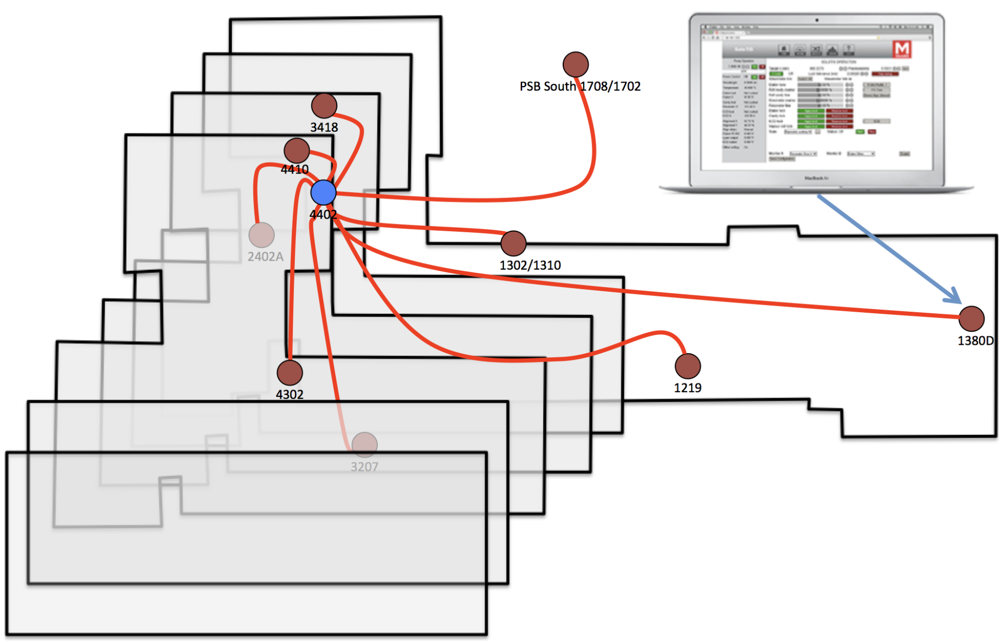

FIG. 1: Layout of BIFROST optical fibers in the UCSB physics building. Each pathway has three installed fibers so as to distribute light across the entire wavelength range that the instrument can produce. Inset shows web interface for remote operation.

B. Results

1. Description of Installed Instrument

The instrument consists of three major components: a master Ti:Sapph oscillator (an M Squared SolsTi:S), sum-frequency and harmonic modules to extend the operating range across the visible regime (also purchased from M Squared), and a fiber-optic network to distribute the light throughout the physics building at UC Santa Barbara (fibers purchased from OZ Optics and installed by Smith Electric and UCSB facilities personnel).

The laser as installed can produce light at wavelengths from 350-500 nm, 515-660 nm, and 700-1000 nm, covering nearly the entire visible range as well as a fraction of the near-infrared. All wavelength ranges have been demonstrated and coupled to remote labs via the fiber network. The agility of the system is demonstrated by the fact that researchers have used it to produce 468 nm light one morning (for radium laser cooling) and their colleagues have used it to produce 820 nm light the same afternoon (for spectroscopy of semiconductor micropillar cavities). The unique web interface of the SolsTiS titanium:sapphire master laser and its “dial-a-wavelength” feature allows researchers in any of the laboratories to log on to the instrument, select a desired wavelength or tuning range, and simply begin their work. Laser operations can also be easily integrated with individual lab tools and experiments via TCP/IP command sets.

The successful installation of the fiber network was a significant challenge. Kilometers of fibers at several different wavelength ranges needed to be installed along existing cable runs in a relatively old physics building. Since no standard single-mode fiber can carry all the wavelengths available from BIFROST, the wavelength ranges have been broken down into subcategories, each of which have a dedicated fiber. Strong support from the UCSB administration and facilities was critical for the successful installation of this complex network, which now connects ten separate research and teaching laboratories (two more than originally proposed). The UCSB Physics department provided lab space to house the laser elements of the BIFROST facility and significant administrative support for the fiber installation. As a side note, the fiber infrastructure installed as part of this proposal now constitutes a sort of “optical circulatory system” for Broida Hall. In the context of research collaboration within the department, it is often desirable to share light sources between groups. Previously this was done on an ad-hoc basis with hand-strung fiber, and was only practical for adjoining labs. By plugging the BIFROST fibers into each other, it is now possible to connect any two of the fiber-equipped rooms to each other with a continuous armored single-mode fiber link. This enhances collaborative opportunities in both research and training, as laser resources of one participating group can now be shared easily with another group or teaching lab.

2. Enhancement of DoD-relevant Research

The BIFROST light is being used to advance a wide variety of DoD research priorities, including terahertz science (currently supported at UCSB by a subcontract from ONR), solid-state defect studies (currently supported at UCSB by AFOSR), ultracold atomic physics (currently supported at UCSB by ARO), single-molecule biophysics, molecular spectroscopy, ion trapping, and cavity quantum electrodynamics. The flexibility and accessibility of the proposed user facility greatly broadens the access of UCSB students and researchers to tunable spectroscopy-grade light, opening up a variety of new opportunities in training, education, and research. In this section we give just two illustrative examples of uses to which the BIFROST facility has already been put. Additional ongoing uses not discussed here include defect spectroscopy in diamond and variable-period optical lattices for trapping ultracold atoms.

Ion Trapping: The BIFROST laser system's ability to produce spectroscopy-grade light at 468 nm was used to realize the first laser cooling of trapped radium ions at UCSB (Fig. 2). Radium is a species that is exciting for quantum information due to its compatibility with photonic technology and its large nucleus. In addition applications in fundamental physics are particularly promising for this unstable heavy element. In a separate effort also in the Jayich lab, the BIFROST laser will serve as a cornerstone to make the first measurements of molecular ions that hold promise for direct laser cooling and optical control.

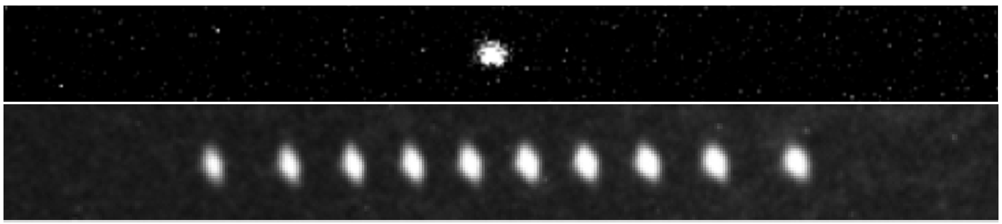

FIG. 2: Top: the first radium ion cooled and trapped in the Jayich lab at UCSB. Cooling and imaging was performed using light from BIFROST. Bottom: a Coulomb crystal of radium ions in the same apparatus.

Cavity QED: The TeraScan capability of the BIFROST instrument is being used for resonant spectroscopy of semiconductor micropillar cavities, generally in the near-IR. The automation and ease of use of TeraScan allows for fast characterization of cavities over a wide range of wavelengths. The system can also be used to resonantly excite embedded quantum dots. In addition to the extremely powerful wavelength flexibility, Titanium:sapphire lasers have an advantage over tunable lasers with semiconductor gain mediums, in which the spontaneous emission background is greatly suppressed. For quantum optics experiments, the low background makes it easier to filter unwanted light from the detection system.

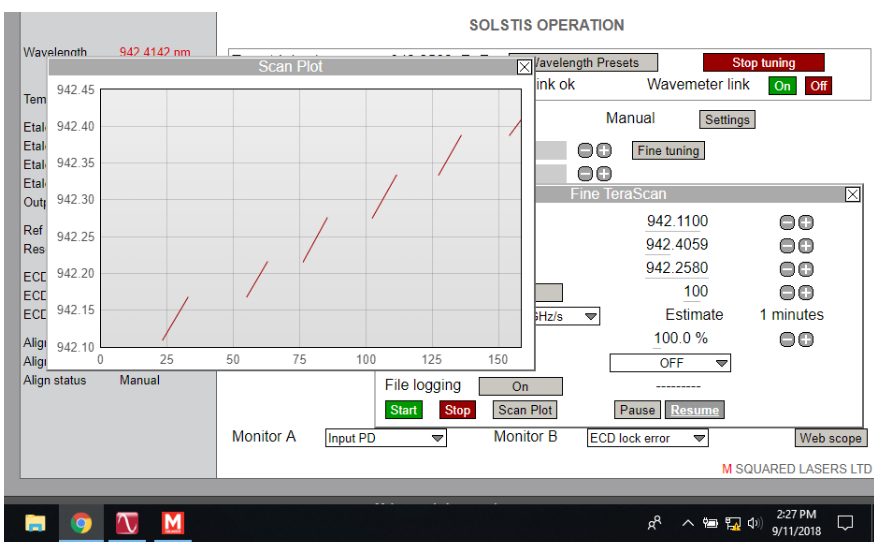

FIG. 3: Screenshot of the web-accessible user interface of the BIOFROST instrument, showing a medium-resolution scan being taken through the resonance of a semiconductor micropillar cavity.

3. Enhancement of Current Research-Related Education

The flexibility and accessibility of the BIFROST user facility greatly broadens the access of UCSB students and researchers to tunable spectroscopy-grade light, opening up a variety of new opportunities in training, education, and research. As a top-ten physics department in a minority-serving institution, the UCSB physics department is in a unique position to positively impact the training of the next generation of researchers. Additional leverage arises from the department's recent growth in undergraduate enrollments, which has made UCSB physics one of the largest physics bachelor's programs in the United States. The BIFROST light is being used to advance a wide variety of DoD educational priorities, including new modules for undergraduate laboratory classes and training opportunities for graduate students and postdocs. Students in the advanced undergraduate laboratory class at UCSB have used the wide tunability of the narrow CW BIFROST laser to carefully measure Planck's constant with the photoelectric effect (Fig. 4). The entire instrument was assembled, tested, and operated by graduate students, postdocs, and undergraduates at UCSB (led by graduate students Peter Dotti and Quinn Simmons). The unique research capabilities of this instrument are thus directly and significantly enhancing research-related education of scientists in training at the University of California by providing young scientists the opportunity to work with the cutting-edge technology of broadly-tunable lasers. The greatly enhanced scientific range of experiments enabled by BIFROST will open opportunities for further undergraduate projects and training of the next generation of researchers.

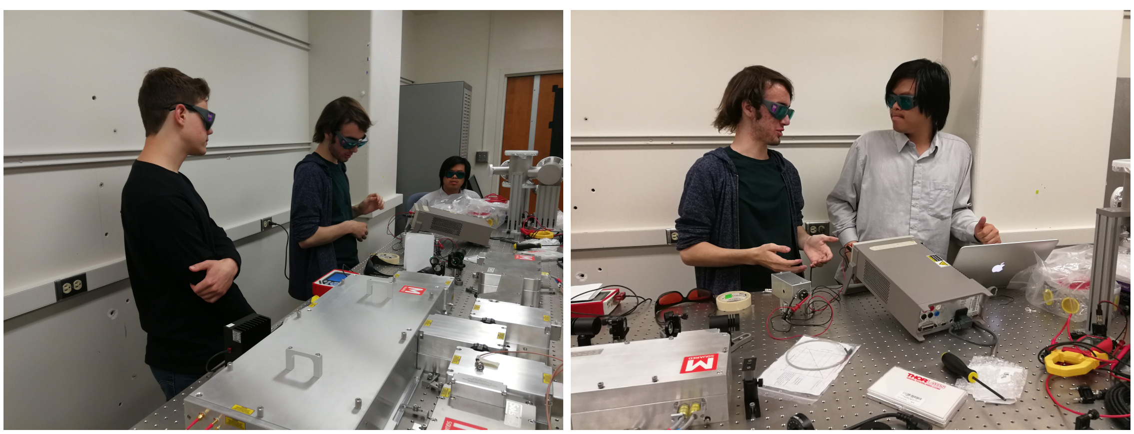

FIG. 4: Students in an undergraduate laboratory class using BIFROST to measure Planck's constant via the photoelectric effect.

C. Summary

This award has supported the purchase of an instrument which as far as we know is unique in the United States: a tunable titanium-sapphire laser with harmonic and sum-frequency generation modules, distributed by fiber to ten research and teaching labs in the physics department at UC Santa Barbara. This instrument substantially extends the scientific range of existing DoD-funded work in multiple research groups at UCSB. Additionally, the instrument gives rise to a broad array of entirely new experimental possibilities in research areas of interest to DoD. Finally, the instrument enhances and multiplies opportunities for research-related education of undergraduates, graduate students, and postdocs in physics at a large minority-serving institution.