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After Dinner Remarks
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"Saper Vedere: 50 Years of Insights through Laser"

Dr. Ikossi, Members of the Washington Academy of Sciences, participants in the Capital Science 2010 Conference, and guests: it is my great pleasure to welcome you to the National Science Foundation.
And it is my distinct honor to be invited to serve as the banquet speaker this evening.

Tonight we celebrate the happy coincidence that this conference falls within 11 days of the 50th anniversary of the first light of a laser.

But the saga of light as science, as art, and as metaphor extends far back into humanity's story.

Literally and figuratively, light is central to how we see our world, and how we make sense of it.

The power of light as metaphor extends to the earliest passages in the books of Moses. The first spoken words recorded in Genesis were "Let there be light" as rendered in the King James Bible. And in the next sentence came the first critical review of a creative work: light "was good."

2010 is also the 500th anniversary of Leonardo Da Vinci's *Anatomy*, a stunning work of science and art based in part on dissections of cadavers. In detailed descriptions and in breathtaking illustrations, Da Vinci probed and drew what few people had ever explored before: the internal architecture and intricate workings of the human body.

One of Da Vinci's mottoes was "saper vedere" and whether we translate the phrase as "to know how to see" or "to see is to know," Da Vinci's eye and hand cast new light into the human condition.

The laser has become one of the great stories of beating swords into plowshares. Invented with an eye towards its potential use as a weapon, lasers have become a tool essential to manufacturing, communications, imaging and health.

The laser is the most famous player in a team of technologies that make up photonics.

Combine photonics with electronics—that other team of technologies, but based on control of electrons rather than photons—and you have two of the greatest franchises of technology in the 20th Century.

In 1954 Charles Townes at MIT and, independently, Nicolay Basov [BAH-zof] and Aleksandr Prokhorov [praw-KHUH-rawf] of the Soviet Union, published the theoretical basis for lasers and described how a laser might be built.
For this work, they shared the Nobel Prize in Physics in 1964.

But it was Theodore Maiman, working at the Hughes Research Labs, who on May 16, 1960, first demonstrated the functional laser. He used a ruby laser energized or "pumped" by shining a high-power flash lamp on the ruby. While he didn't see what is now the iconic red dot of such lasers, his analysis of the spectrum emitted by the pumped ruby proved he had made a laser.

Yet there's a twist in the next step of the story.

As Charles Townes reported in an essay published in 2003, "Maiman promptly submitted a short report of the work to the journal *Physical Review Letters*, but the editors turned it down….
Eager to get his work quickly into publication, Maiman then turned to *Nature*, usually even more selective than *Physical Review Letters*, where the paper was better received and published on 6 August 1960."

And here Townes gives high praise to Maiman's paper:

“Maiman's paper is so short, and has so many powerful ramifications, that I believe it might be considered the most important per word of any of the wonderful papers in *Nature* over the past century.”

For those of you familiar with the famously concise Watson and Crick paper describing the double helix of DNA, published in *Nature* on April 25, 1953, this is saying quite a lot.

The laser, according to Townes, was quickly dubbed by many researchers as “a solution looking for a problem.”

Few other solutions in search of a problem have been so successful in finding so many.

The laser brings music to our ears through compact discs, and movies to our homes through DVDs.

The laser drives the fiber-optic network that is the basis of our computer and internet platforms, and our global internet communications—wireless and landline.

Laser-based bar codes speed us through supermarket check-outs, and laser printers feed us paper print-outs of text, graphics and photos.

In LASIK surgery, lasers reshape our eyes to resharpen our vision.

In photolithography, lasers let us carve intricate designs on delicate materials to fabricate materials ranging from biomembranes to silicon chips.

Most important of all to academic types, laser pointers let us wag a red dot on our PowerPoint slides.

Equally remarkable were the uses researchers found for lasers as tools to probe, analyze, and manipulate the stuff of Nature, from tracking the quantum quirks of subatomic particles to measuring the distance from the Earth to the Moon down to a precision of three centimeters.

For a solution in search of a problem, lasers have been remarkably fruitful in yielding Nobel Prizes.

In 1971 Dennis Gabor [gah-BORE]won the prize for pioneering work in holography—3-D images that depend on laser technology.

In 1981 Nicolaas Bloembergen [BLOOM-burg-in] and Arthur Schawlow [SHA-low] were recognized for their work on laser spectroscopy, which now includes the switches and amplifiers used in broadband communications through optical fibers.

In 1997 Steven Chu, Claude Cohen-Tannoudji [COHEN-tan-NEW-jee] and William Phillips won the prize for inventing ways to use lasers to cool and trap atoms.

And in 2001 Carl Wieman [why-man], Eric Cornell and Wolfgang Ketterle [KET-er-lee] won for producing Bose-Einstein Condensate, a state of matter achieved by using lasers to cool atoms to 20 degrees nanoKelvin – (20 millionths of a degree Kelvin above absolute zero).

Of course, Steven Chu serves today as Secretary of Energy, and just this week, President Obama nominated Carl Wieman to be associate director of the Office of Science and Technology Policy.

As laser technology approached its 40th anniversary, it certainly was no longer a solution in search of a problem.
Yet it seemed to some visionaries that the laser’s promise still far outshone its applications.

In 1998 the National Research Council issued a report entitled “Harnessing Light: Optical Science and Engineering for the 21st Century.”

The report pointed out opportunities to speed discoveries into applications, especially in the non-invasive diagnosis of disease and the monitoring of health.

The NRC recommended programs to assemble cross-disciplinary teams of physical and life scientists, engineers and physicians.

These teams would focus on three themes: (1) to figure out the mechanisms of transport and interaction of photons in living cells, tissues and organs;
(2) to identify critical priorities where photonics could advance biomedical research and clinical medicine; and

(3) to put these advanced biophotonics to work in monitoring health and in detecting and defeating disease.

In response to the “Harnessing Light” report, the following year NSF established a new biophotonics program. Leon Esterowitz came from the Naval Research Lab to the Foundation to lead the program.

One of the outcomes of this initiative was NSF’s funding in 2002 of the Center for Biophotonics at the University of California, Davis.

Like many centers that NSF funds, the Biophotonics center is a consortium of many universities (8, in this case) and a national laboratory (Lawrence Livermore, in this case).

Centers such as the one at UC Davis and others like it around the world have catapulted laser technology to the forefront of the life sciences.

Lasers now come in a seemingly endless variety of frequencies and powers—as little as 1 milliWatt for a laser pointer, as high as a million billion Watts (10 to the 15th power) for a laser at Lawrence Livermore Lab.

Better yet, lasers are astonishingly adaptable in size and in use.

As Andrew Lague [lag]of UC Davis points out, life scientists can use photonics, including lasers, for three critical functions: to image, to analyze, and to manipulate. And most remarkably, lasers can do all three with minimal invasiveness.

I want to share some specific examples of lasers and biophotonics from the Davis center.

Using Raman Spectroscopy fitted with a laser trap, researchers can identify, isolate, sort, and purify human stem cells from a mixture. This means researchers can select and collect stem cells for both research and clinical applications.

Lasers not only round up and cull cells, they can also build new components into cell membranes.

Using a femtosecond laser—one that shoots a pulse of light as brief as 1 x 10 to the minus 15th of second—researchers have built into cell membranes new components as small as 100 nanometers wide.

And one last example from biophotonics: Using lasers along with other modes of imaging, researchers have observed and recorded on real-time video the cell-to-cell transmission of HIV.

This is remarkable because prior to this work, scientists thought that free virus particles were the sole route in spreading the virus.

This type of imaging, called CARS, for Coherent anti-Stokes Raman Spectroscopy, uses three separate laser beams to generate an image. When these are near-infrared lasers, the lasers do little damage to cells. CARS allows for deep tissue penetration and may provide a way to watch how live cells work at the molecular level.

Thus we come full circle to Leonardo. Five hundred years ago, DaVinci looked into the human body and saw things in a way nobody had before, and produced images that still inspire awe for their detail, beauty and insight.

Biophotonics continues that tradition of seeing life in a new light, and extending the insights to the cellular and molecular level.

And, remarkably, this time these are *living* cells the researchers are exploring.

This work in biophotonics represents the kind of audacious innovation NSF pursues to advance all fields of discovery.

NSF's motto is to be "where discoveries begin." We do this across all fields of science and engineering.

We fund transformative work that can make and break paradigms—work that can open up new ways of thinking and probing and creating.

Scientific discoveries and technological innovations can create whole new fields of endeavor, as well as the jobs of the future.

Such explorations enoble humanity, feed the spirit of adventure, and fuel global prosperity.

The laser, in all its amazing variety, is a vital tool for researchers probing intriguing questions about the fundamental workings of Nature.

So with high aspirations for the future, we take inspiration from the past and recognize the innovations wrought by lasered light.

The book of Genesis got it right: Light is good. And lasered light is *really* good.

In DaVinci's words, the laser helps us in our quest to know how to see—to see in bold new ways, and with ever-finer clarity.

Thank you for this opportunity to talk with you tonight, and once again, I am delighted to welcome you to the National Science Foundation.

Now, with your indulgence, I'd like to share four more examples from the past year of how NSF-funded researchers are harnessing light even as they are helping invent the future.

In May 2009 researchers figured out how to shine a tunable red laser on strontium atoms that were cooled and held in place by another set of infrared lasers. One result: a more precise atomic clock—precise to within one second in 650 million years. This new clock is significantly more precise than the cesium clock that is the basis of the current international standard definition of the second. Thus, ingenious use of lasers is redefining time, and timekeeping.

Last year, scientists from the University of Iowa published results of research on the disastrous floods that hit Iowa, including the University campus, in summer 2008. The investigators called on the National Center for Airborne Laser Mapping. The Center operates a single engine airplane outfitted with ground-scanning radar coupled with a high-precision GPS. Overflights by the laser-mapping airplane during the flood provided key data on the workings of the watershed. That data now undergirds a model that gives more reliable projections of future floods.

Now, from mapping flood waves to looking for ways to detect gravity waves: The Laser Interferometer Gravity Observatory consists of three interferometers, two at Hanford, Washington and one in Louisiana. These devices are analogous to the ones used by Michelson and Morley in their famous experiments in 1887 in search of the light-bearing ether. There's a beam of light—in LIGO's case, it's laser light—that is arranged so as to detect a gravity wave—for example, one triggered by the collapse of a binary star system.

Finally, lasers are key to the possibility of quantum computing—computers based on quantum mechanics rather than digital electronics. Last year researchers in Wisconsin funded by NSF developed a quantum CNOT logic gate, using lasers as an optical tweezers to control single atoms of rubidium. A workable quantum CNOT logic gate is a big step towards achieving the vision Richard Feynman proposed in 1982 of a quantum computer that could solve problems that are impossibly difficult for current digital computers.

Finally, according to Charles Townes, the timing of the invention of lasers raises the question: why weren't lasers invented long ago, perhaps by 1930 when all the necessary physics was already understood, at least by some people? What other important phenomena are we blindly missing today?