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GSFC NEWS

tech transfer

Wavefront Sensing Issue

Six of the James Webb Space Telescope's primary mirror segments. These mirrors will be aligned and controlled by software developed at GSFC.

Photo by Chris Gunn

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from the chief

Electromagnetic radiation (EMR) is our primary tool for learning about deep space. The universe is awash in EMR, from radio waves, through visible light, and into the upper portions of the spectrum. And historically, one of GSFC's most important accomplishments has been to help capture and analyze various EMR wavelengths and extract all the invaluable information it contains, through high profile missions such as the Hubble Space Telescope (HST) and the upcoming James Web Space Telescope (JWST).

Nona Cheeks

At the forefront of these efforts is GSFC's Wavefront Sensing and Control Group, headed by Dr. Bruce Dean. Bruce's team, along with numerous other Goddard scientists and inventors, has produced a wide variety of wavefront sensing technologies that support our current and future space science missions. These technologies comprise a substantial and versatile intellectual property (IP) portfolio. And the features and advantages that these inventions provide — many of which were designed to maximize optical performance while minimizing size, weight, and energy requirements — make them attractive to many potential terrestrial applications.

In this issue of *Goddard Tech Transfer News*, we focus on our wavefront sensing portfolio and the markets in which these technologies may offer significant commercialization opportunities. We begin with an interview of Bruce and his colleague Rick Lyon, who worked together to develop the Hybrid Diversity Algorithm (HDA) now currently used on JWST and other applications. We then look at four commercial markets for our wavefront sensor portfolio: astronomical research, ISR (intelligence, surveillance, and reconnaissance), metrology, and optometry/ophthalmology. We'll briefly summarize the opportunities provided by each of these markets, and how wavefront sensing technologies such as adaptive optics can provide significant value within each. We'll conclude each article with a quick review of some of the individual GSFC inventions for which the market being discussed could be a good fit.

In addition, in this issue we introduce a new feature – "Patenting Perspectives." This feature will highlight patenting issues from the perspective of GSFC's Chief Patent Counsel, Bryan Geurts and Erika Arner, Partner at the law firm, Finnegan, Henderson, Farabow, Garrett, and Dunner. Our goal in introducing this column is to help educate GSFC inventors (and our partners within the research and business communities) about the nuances and value of IP protection.

As you can see, we have a lot of information to share. So please read on — and as always, please feel free to contact the Innovative Partnerships Program Office if you have any questions about any of the GSFC technologies discussed in this issue.

Nona Cheeks
Chief, Innovative Partnerships Program Office
NASA Goddard Space Flight Center

Can You See It Now?

NASA Goddard Space Flight Center is opening its doors to industry in a whole new way in 2011.

Beginning in May, with the CLEO-2011 conference in Baltimore, continuing through August with SPIE West in San Diego, and leading up to Industry Day at Goddard in Fall 2011, GSFC will be introducing its entire suite of advanced wavefront sensing technologies, procedures, and lab equipment to private industry. This unprecedented campaign has just one focus – enable firms to dig through GSFC's treasure chest of innovative technologies to find ways to create exciting new products for consumers and industry. Many of these technologies are detailed throughout this issue of *Tech Transfer News.*

Numerous technologies are available and span these broad functional categories:

Optical System Design, Simulation & Testing Tools
Lenses, Gratings & Mirrors
Wavefront Detection Algorithms
Wavefront System Operating Software

GSFC's preliminary commercialization reviews suggest these technologies could enable significant advancements in a wide range of applications, including interferometers, biological microscopes, optometry, ophthalmology, iris identification, free space optical communications, advanced cameras and other advanced optical systems

But, there's more than just patents or software code available to private industry. The inventors will be on hand at each of the three major promotional events this year to explain the functional details of specific technologies of interest to any firm and can be tapped to help adapt the technologies to specific product needs. This campaign is the result of many years of hard work, much of which was conducted by two prominent inventors, Rick Lyon and Bruce Dean, PhD., who are featured on page 4.

Enidia Santiago-Arce

Code: **504**

Years with NASA: **10**

Education: **BS Electrical Engineering, University of Puerto Rico-Mayaguez; Pursuing MS Technology Commercialization, Northeastern University**

Heading up the campaign for the Innovative Partnerships Program Office is Technology Transfer Manager Enidia Santiago-Arce. Ms. Santiago-Arce's interest in promoting these technologies stems from the realization that this expansive suite of valuable technologies had not been adequately evangelized outside of Goddard.

"When I first heard about wavefront sensing, I was amazed by its versatility; this suite of technologies can be used in applications from astronomy to medicine, among many other areas," she said. "I was very surprised by the fact that we didn't have any licenses or partnerships in this area so, with the cooperation of my management and the innovators involved in this research, we put together this new campaign to actively promote this wealth of NASA's technologies."

For more information about the Can You See It Now? campaign, please contact
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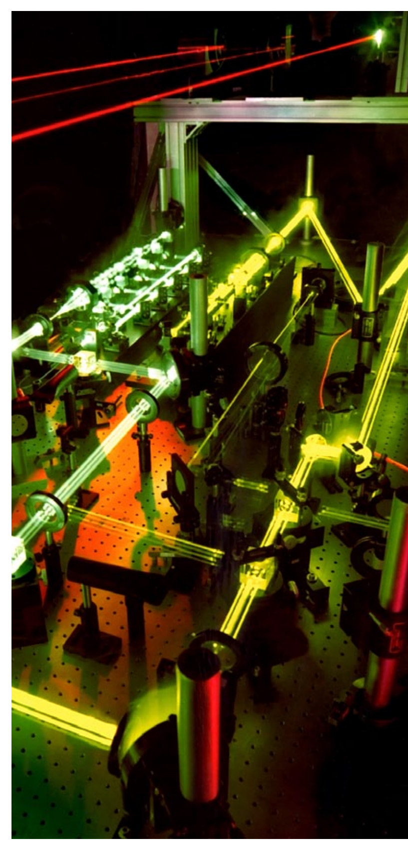
To view listings and descriptions of all the wavefront sensing and control technologies available as part of this campaign, please visit:
http://ipp.gsfc.nasa.gov/wavefront



Featured Interview

In this issue we speak with Optical Physicist Dr. Bruce Dean (Group Leader for the Code 551 Optics Branch Wavefront Sensing and Control Group) and Rick Lyon (Optical Scientist, currently working on exoplanet detection). Bruce and Rick discuss Goddard's Wavefront Sensing Control System Portfolio technologies, how they were developed, and how they can be leveraged to other applications and markets, both within and outside of NASA.

Could you tell us a little about your backgrounds, and how you ended up working together?

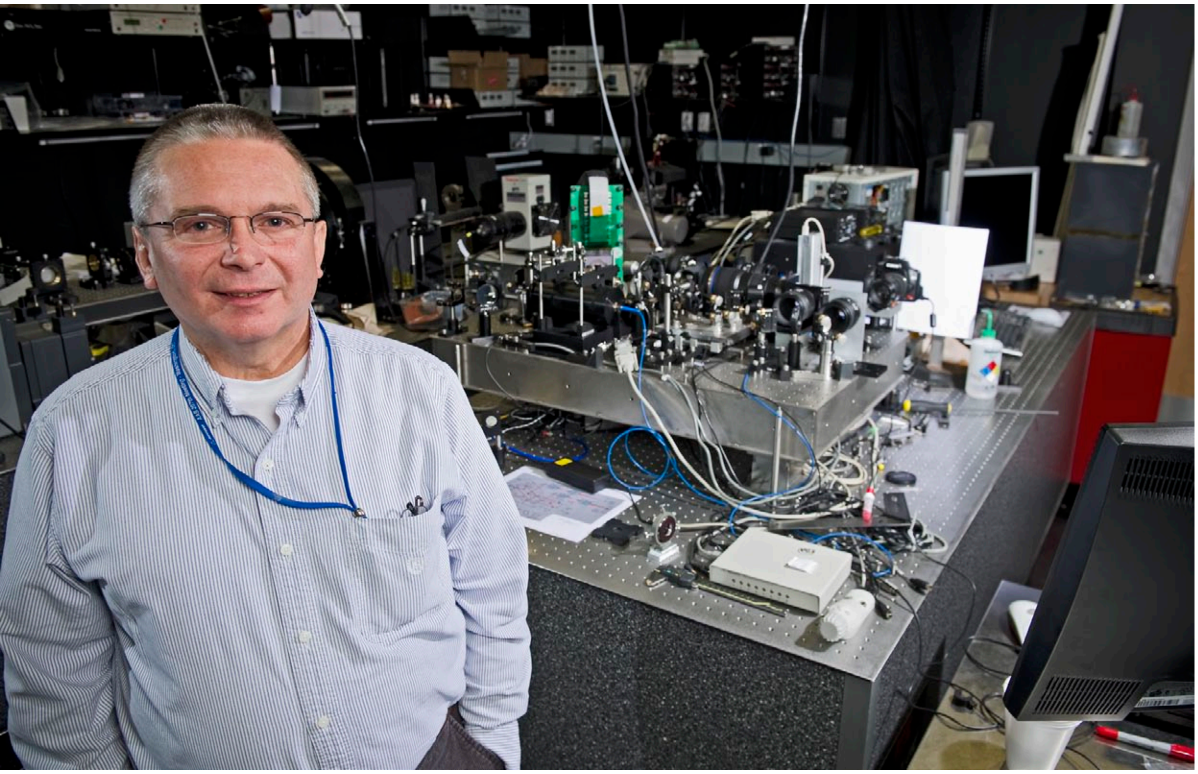
Rick: Back in the late 1980's, while working for Perkin-Elmer. I was given the task of creating a phase-retrieval algorithm for the Hubble Space Telescope (HST). This algorithm was intended as a backup, and was never expected to be used. However, after Hubble was launched, and it was discovered that it had an optical problem, my algorithm was selected as an approach to determining the errors in the telescope using images from the onboard science instruments as part of the fix. And it's still the algorithm of choice for Hubble; it's routinely used to refocus the secondary mirror.

Following the correction of Hubble with the installation of new instruments and the Corrective Optics Space Telescope Axial Replacement (COSTAR), the algorithm was used to validate the correction. Additionally the algorithm was successively refined in the early 1990's and used to precisely estimate Hubble wavefront errors, and it was subsequently used to synthesize high fidelity point spread functions suitable for deconvolution. The details of this approach were openly published in *Applied Optics*. This work also led to a new form of maximum entropy based deconvolution using synthetic point spread functions, published in the *Astrophysical Journal*. This work culminated in a bevy of published scientific results in the *Astrophysical Journal* combining Hubble, Chandra and Green Bank radio telescopes to further scientific understanding of symbiotic jet systems. This approach was also studied for deconvolution of NOAA/GOES imagery via phase retrieval of GOES data, and for a number of ground telescopes. And it's still used, with modifications, on a number of ground testbeds for the James Webb Space Telescope (JWST), stellar interferometry and exoplanet testbeds.

In 1996, John Mather (Senior Project Scientist, James Webb Space Telescope) contacted me and informed me that he was interested in such an approach for the Webb Telescope. Study funding was provided that allowed the development of the algorithm, parallel computing code, and modeling and simulation. These indicated that an image-based wavefront-sensing approach was viable; this was published in *Optics and Photonics News* and in a large NASA report that became the foundation for the current work for JWST. Now variations of this approach are used all over NASA, the European Space Agency (ESA) and in ground based astronomy (and even Earth sciences). Previously, you needed complicated hardware to measure the wavefront (e.g., an interferometer) but now hardware is replaced with software that is easily adaptable. I've been involved in various forms of phase retrieval and phase diversity more or less continually since 1988.

A year or two later I met Bruce. He had just come to Goddard, and was interested in working in this area.

Bruce: At the time I was working on my PhD in General Relativity at West



Optical Scientist Rick Lyon Photo by Chris Gunn

Virginia University. With about a year to go, I joined GSFC as a graduate student CO-OP. Ever since I was a kid, I thought working at NASA would be a great job. I recall seeing the National Radio Astronomy Observatory 300 ft radio telescope (located at Green Bank, WV) from my grandmother's house and really wanted to be involved with exploration work; I knew from when I was about 7 years old that I wanted to work in science. Eventually, I majored in physics.

When I first came to GSFC, I was working in optical design. One of my first projects was on a testbed project in support of JWST. While working on this project I studied the general literature and also Rick's papers on phase retrieval. As a kid I always wrote computer code to solve various problems. So I did the same thing for phase retrieval to help further develop the application.

Around 2001, I formed the GSFC Wavefront Sensing and Control Group and have served as Group Leader ever since. We've grown to about eight members now and we are probably the largest single group working full-time on phase retrieval. This work is important because image based wavefront sensing can help to replace complex and expensive flight hardware with software. This is an amazing technology that can really help to reduce mission costs, because in general, software is cheaper than hardware, and also not as risky for failure because software is not vulnerable to burn-outs or mechanical problems. Phase retrieval is an interesting application where multiple length scales come together, for instance, we start at the quantum scale with semiconductor properties and photon detection. We next "sense" surface positions to the nanometer scale, and then finally control mirror segment positions at the meter scale.

Since 1999 we have developed phase retrieval algorithms, beginning first with the general approach that was used for Hubble. Some of this work evolved into the HDA [Hybrid Diversity Algorithm] with the goal of adapting it to the needs of the James Webb telescope. Our concern was that once the Webb was on-orbit, we'd encounter larger than expected commissioning errors that we might not be able to recover from. The HDA helps to solve this problem. We eventually transferred the technology to Ball Aerospace & Technologies Corporation where Scott Acton took over and developed the Webb flight software. Having folks like Scott Acton on the project has been great. (*Editor's note: The HDA estimates imperfections in an optical system via an adaptive iterative process. This process helped to increase the range of sensing and diagnostic capabilities. Being image-based, the HDA uses very little additional hardware beyond what an observatory already uses for science, while providing an accurate and precise characterization of the optical system alignment.*)

What are you currently working on?

Bruce: The Wavefront Sensing and Control Group continues to support the James Webb project, and Rick has continued to work with us on this from time to time. We are developing parallel processing to support the numerically intensive

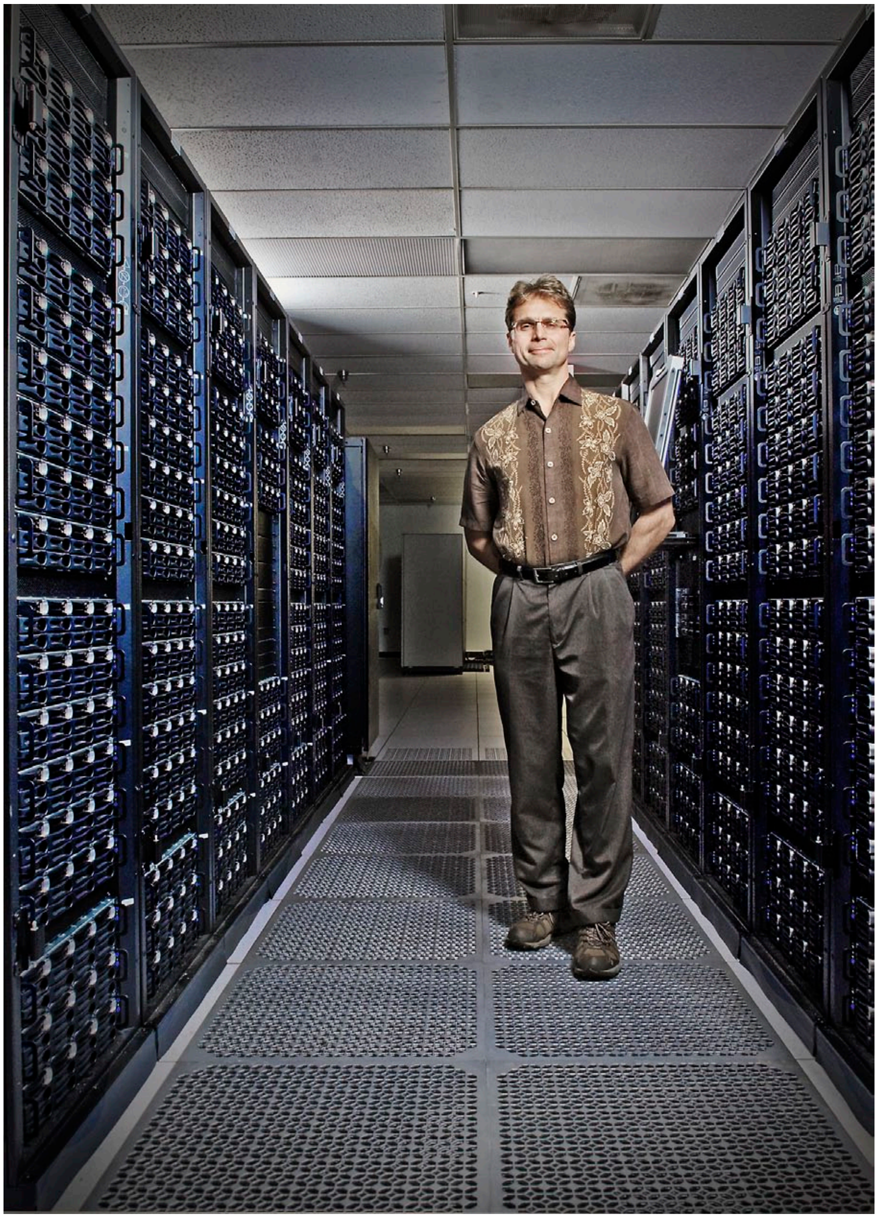


Photo by Chris Gunn

Dr. Bruce Dean, Group Leader, Wavefront Sensing and Control Group computations required by the software, such as the Fourier transform.

Rick: It's important to bear in mind that Hubble has a single monolithic mirror. The JWST, on the other hand, has a special segmented primary with a 6.5 meter diameter. This requires modifications to my original algorithm.

As an aside, it's interesting to hear Bruce speak of parallel processing. The first phase retrieval work we did years ago also used parallel processing, running on Cray computers.

So basically, you're working to replace expensive and cumbersome hardware, such as interferometers, with software?

Bruce: Correct. That's the beauty of phase retrieval; for the most part you can use existing hardware that is already in place, such as the science camera, with few additional components. In summary, when a software-based approach is adopted, there's less hardware to launch into orbit, which also means there's more mass available to other systems. Less hardware also means reduced power requirements, and more importantly, fewer moving parts (we don't like things to get stuck or break on-orbit).

Rick: The operative word here is risk. Software is considered low risk compared to hardware. It has lower probability of failure, and costs less. It's always cheaper to deliver software into an orbiting platform, making updates easier.

Bear in mind that laboratory interferometers are notoriously prone to failures. Perhaps once a year they break down. In addition, they require extensive training to use.

Bruce: And they're expensive, some models can cost many thousands of dollars.

Are there speed advantages to using software?

Bruce: No, using software can introduce latency. This is why our work on parallel-processing is so important because it helps to make the results as real-time as possible. The whole process works something like this: the telescope collects the light from a star and then transmits the image back to Earth for processing. Using software, we then estimate the misalignments that could exist in the telescope. Although the Webb telescope is not designed to perform optical correction in real-time (it is a quasi-static design), with software and parallel processing, we can come close, especially with some of the newer computing hardware on the market such as the Graphical Processing Units (GPUs), whose development has been driven largely by the video gaming market. Goddard has also developed super-computing resources such as the NASA Center for Climate Simulation (NCCS).

Rick: For fast systems the hard part is actually getting the data in and out of the system due to camera and computer bus limitations, but we're getting better at this too.

Bruce: For smaller images we can get close to real-time performance, but we are now able to get closer to real-time when using larger images too.

What commercial applications come to mind for these algorithms?

Bruce: Wavefront sensing techniques could be adapted to any application that requires fast image correction. This could also be incorporated into a handheld device.

Rick: Turbulence correction, LASIK surgery, confocal microscopy, and medical imaging come to mind. For instance, MRI already implicitly uses a form of active phase retrieval.

Bruce: LASIK is an interesting application. Several commercial devices are based on a Shack-Hartmann type sensor, which requires direct access to the aperture stop, but phase retrieval does not.

Rick: Our approach could better identify which surface in your eye is causing the problem — the retina, one of the corneal surfaces, and so on. This would provide a better way to guide the shaping of the cornea.

Bruce: We've also been involved in forensic imaging. I've worked with several law enforcement agencies to reconstruct surveillance imagery. The work has helped solve some real cases. The technique could also be used with altitude-mounted surveillance cameras.

What are some of the potential challenges facing commercialization of phase retrieval technology?

Bruce: One of the biggest challenges in any new field is communicating the progress to potential users of the technology. Industry can sometimes be slow to pickup on new technologies, so marketing is definitely important. As mentioned earlier, interferometers can be expensive. In certain applications this type of hardware can be replaced with software that runs on a PC, and with a webcam. This is game-changing technology. Applying simpler and cheaper solutions, which can be just as accurate, is what we are striving for -- in other words, the principle of Occam's razor.

Astronomy

It probably goes without saying that over the years, one of Goddard's primary purposes has been to develop technologies that support NASA's astronomy research missions, such as the Hubble Space Telescope (HST) and its next-generation successor, the James Webb Space Telescope (JWST). Perhaps a lesser-known fact is that the astronomical instruments, both research grade and hobbyist, comprise a substantial market outside of NASA — a market in which several GSFC developed technologies could offer significant value.

JWST – Technologies Beyond NASA Use

The JWST (named after the late James E. Webb, former NASA administrator) is one of the most ambitious science projects ever undertaken. As with its predecessor, the HST, the JWST represents a major leap forward in our ability to peer deeper into space. Designed to observe primarily in the infrared (with some capability in the visible spectrum), the JWST is scheduled for launch in 2014, and views an observing window in time that is unreachable from Hubble nor any existing ground telescope.

At the heart of the JWST observatory is its massive 6.5 meter primary mirror. Unlike HST's smaller (2.4 meter) primary, the JWST mirror will consist of 18 individual hexagonal segments. A large primary mirror will offer unprecedented observing opportunities, such as galaxy formation and exoplanet science. However, the segmented primary presents a number of technical challenges, particularly with operating as a single monolithic unit, i.e. phasing of the segments. Such performance requires precise alignment of all 18 segments and the ability to stably hold these segments to a fraction of the wavelength of light throughout science observations.

Six of JWST's eighteen mirror segments, which will rely on the Hybrid Diversity Algorithm to ensure the telescope is properly focused.

To achieve this alignment, GSFC's Wavefront Sensing and Control (WFSC) Group (Code 551) has developed the Hybrid Diversity Algorithm (HDA) to sense the relative location of the segments and secondary mirror enabling feedback to "phase up" the segments. The HDA, based on technology originally developed and used for the HST, will be part of an eight-step commissioning process that will be implemented periodically to ensure that the JWST produces the sharpest images possible.

Wavefront Control and Adaptive Optics

In addition to the HDA, GSFC has developed a suite of other wavefront control technologies. The portfolio includes wavefront algorithms (such as the HDA), calibration tools, and adaptive optics. The last category, which includes deformable mirrors, is interesting in that these technologies can be used to improve the performance of ground based telescopes, medical imaging, satellite tracking, laser communications and a host of other applications.

Basically, adaptive optical systems are designed to correct optical wavefront errors introduced by Earth's turbulent atmosphere, vibration, thermal drift, amplitude errors (scintillation) and other deleterious effect, which blur astronomical images for ground-based observers. (These phenomena, in fact, served as primary motivations for constructing space-borne instruments such as HST and JWST.) Adaptive optics can help compensate and reduce this blurring effect, producing high-resolution, diffraction-limited images that approach the theoretical performance limit of the telescope.

For example, GSFC has developed a microelectromechanical system (MEMS) deformable mirror and spatial filter array (GSC-16143-1) designed to provide simultaneous amplitude and wavefront control. This technology was originally created for exoplanet coronagraphy, a task that requires extremely high optical resolution. This capability can be leveraged to a variety of possible applications, including consumer cameras/photography, military imaging (for instance, tracking satellites and viewing through a thermally-disturbed environment), and research telescopes/astronomy. In this approach, a single MEMS deformable mirror is coupled to a passive device known as a spatial filter array. The mirror is of a special type called a "hexagonal packed MEMS segmented deformable mirror." This consists of segments which are separately controlled; each segment is optically mapped to a single fiber of the spatial filter array. This effectively decimates the optical beam into an array of so-called "beamlets." The fiber passively spatially filters the higher spatially frequency errors in both amplitude and wavefront, and the lower spatial frequencies of wavefront are controlled via pistoning of the deformable mirror segments. Amplitude is controlled via tip/tilting the segments to slightly steer the focused beam on the end of the fiber to balance the brightness of the individual beamlets.

Another GSFC wavefront control technology developed for astronomy is the visible nulling coronagraph (GSC-16163-1). As with the deformable mirror technology, the coronagraph is designed for direct imaging of exoplanets. The instrument is based on a nulling interferometer with modifications for high-bandwidth extremely accurate wavefront control. This allows the stability tolerances on the collection telescope system to be relaxed compared to other known methods of high contrast imaging. The purpose of this instrument is to provide the precise sensing, control, and stability required for imaging a very dim target near a very bright one. This technology can be theoretically miniaturized to allow for "on the chip" type devices, for potential use in mobile/hand held applications, such as medical imaging.

These are just two examples of GSFC's IP portfolio of wavefront control and adaptive optics technologies, offering numerous licensing opportunities within a wide variety of markets and applications.

The Astronomy Market

We may not often think of it as such, but research-grade astronomy is actually a reasonably substantial global market, estimated at $100 million or more worldwide (excluding potential large-scale projects)[1]. Currently there are approximately 15 telescopes in the 8+ meter aperture range, with plans for future instruments with primaries of 30 meters in diameter and even up to 100 meters. Adaptive optics will be increasingly needed to ensure that these giant instruments perform up to expectations, by compensating for atmospheric effects that would otherwise compromise their optical performance.

It's easy to see how GSFC's wavefront and adaptive optics technologies could play an important role with these large research telescopes. Although in many cases these technologies have been developed for space instruments — and thus not subject to the vagaries of Earth's atmosphere — their ability to derive the highest theoretical performance from optical systems could be of high value to ground-based observatories, especially in applications where fine resolution and contrast are critical.

Perhaps a less obvious market is that of consumer telescopes, purchased by amateur enthusiasts. Amateur telescopes also represent a substantial market, similar to and perhaps larger than the market for advanced telescopes. This market encompasses a range of instruments, from small, entry level telescopes sold through retail outlets up to larger instruments up to 20 inches or more in aperture (although only rarely approaching the one-meter level that is typical in research-grade instruments). Increasingly, characteristics such as size and weight are important in this market, as users seek portable equipment. In recent years, light pollution (sky glow produced by stray outdoor lighting) has become a growing problem for amateur astronomers. This has increased interest in portable telescopes that can be easily transported to remote dark-sky sites. And many amateurs are delving into astrophotography, producing images of high quality far beyond those that can be directly viewed by the human eye.

GSFC wavefront technologies may offer commercialization possibilities within this market as well. Bear in mind, technologies developed with an eye towards minimal size and weight (a crucial requirement for launching instruments into orbit) can fit well with the consumer's increasing need for portability. And GSFC's creative use of technologies such as software may be able to bring relatively sophisticated capabilities within the reach of the serious hobbyist. For example, Bruce Dean, Group Leader of the Wavefront Control and Adaptive Optics team, notes that the HDA and a webcam could conceivably be used in place of an interferometer costing many thousands of dollars. Other GSFC adaptive optics technologies, such as the aforementioned deformable mirror, could possibly be leveraged as the foundation for other economical products that allow astronomy mavens to get the most from their telescopes.

Summary

Although astronomy may appear as a somewhat niche market, it does offer some potentially attractive commercialization possibilities, especially since GSFC technologies, originally developed to support astronomy applications, might be adapted to this market relatively quickly and easily. In addition to supporting current ground-based astronomical research, GSFC technologies could enhance the capabilities of the amateur market — where they could serve to help educate and inspire the next generation of future space scientists.

Takeaways

Wavefront control and adaptive optics technologies, originally developed for JWST, can be adapted to the commercial market for research-grade and amateur astronomical telescopes. GSFC technologies in this niche could include the MEMS deformable mirror and spatial filter array, and the visible nulling coronagraph. These and other technologies could help enhance the performance of these terrestrial based instruments.

For more information on these and other Goddard wavefront sensing technologies, please contact Enidia Santiago-Arce, enidia.santiago-arce-1@nasa.gov, (301)-286-8497, or visit:

http://ipp.gsfc.nasa.gov/wavefront

1"SWT Perspective Program: Smart Optics Systems." *STW.* Technology Foundation STW. March 2008. Web. 10 September 2010.

Application Insight

We spoke recently with Dr. Scott Acton, Physicist at Ball Aerospace, subcontractor for the James Webb Space Telescope (JWST). Ball Aerospace is responsible for designing JWST's advanced optical technology and lightweight 6.5 meter mirror system. Dr. Acton works with GSFC's Wavefront Sensing and Control Group to develop wavefront sensing and control algorithms. He has received Goddard's "Webbie" award for his work on JWST. Dr. Acton provided us with the following report on some of the challenges presented by the JWST, and how the Hybrid Diversity Algorithm (HDA), originally developed at GSFC, helps address these challenges.

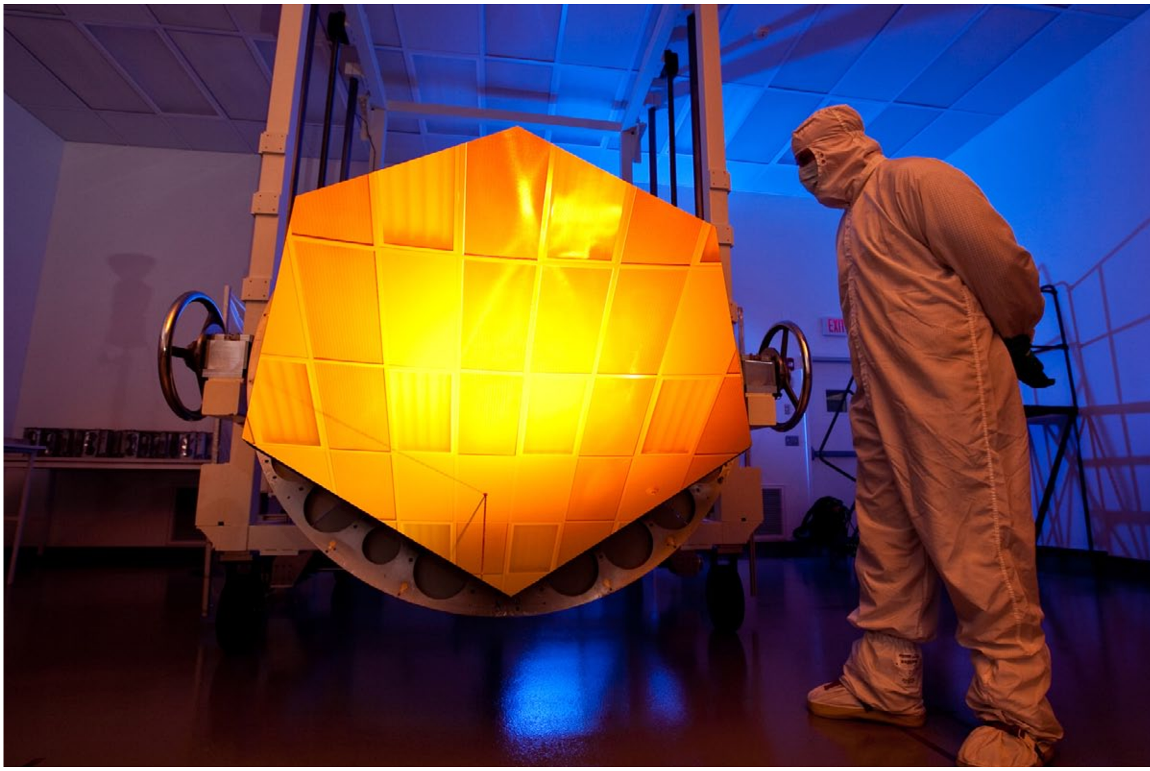
When discussing the JWST, it's important to understand the totally unprecedented and unique problems it presents. For example, even if you could fabricate an optically perfect 6.5 meter primary mirror, there's really no way to launch something that big into orbit (never mind its shield, which is about the size of a tennis court). So the primary has been designed as set of 18 hexagonal mirrors with a common center of focus, which collectively work like a single mirror. This immediately creates all sorts of alignment issues, such as how do you keep all these segments working together in a way that delivers diffraction-limited resolution, to take full advantage of the space-based platform? On the ground, where the atmosphere is going to introduce some blurring effects anyway, you might be able to accept a certain amount of imprecision. However, in space the tolerances are literally orders of magnitude tighter.

To address these issues, we looked at an approach, which at the time was called "active optics," although currently it's often referred to as "adaptive optics" (which is a bit of a misnomer, since adaptive optics are usually associated with correcting for atmospheric effects, which of course is one thing the JWST doesn't have to deal with). We adapted a technique known as phase retrieval, in which we acquire a number of defocused images from the optical system, and then analyze them to determine the wavefront. To do this requires a great deal of computing power, which is why we need an algorithm for this.

Unfortunately, these algorithms are subject to something called phase wrapping errors, which can be a major pain. Basically, phase wrapping errors can result in two different wavefront measurements for the same system. Getting rid of them has been a huge challenge. Think of it this way: up to now, methods for correcting phase wrapping errors tend to fall into two categories: simple techniques that don't work very well, and very complex techniques… which also don't work very well!

This is where the HDA came in — it provides phase retrieval without phase wrapping. This is a huge innovation, because we can now capture multiple images, and then analyze the images to determine the wavefront — without being bothered by phase wrapping errors. And the HDA is far simpler than previous algorithms. As a graphical example of how much simpler, a previous algorithm we used required something like 20 pages of code; a printout completely covered the door of my office. The HDA printout, on the other hand, is only a single page. And the "diversity" part of the HDA is critical for us, because it lets us do things like introduce a known optical error, and then capture images to see how much they deviate from what we'd expect. Perhaps equally important, this doesn't require any special instruments to be launched into orbit — this can all be done simply by capturing defocused images, using the JWST's onboard science package.

We now use the HDA for many different applications. And in all the time I've used it, I have never seen it suffer from phase wrapping errors. And it's easy to imagine other uses for the HDA beyond the JWST, since it requires very little hardware. This is very, very robust code.


A NASA engineer inspects a mirror segment for the James Webb Space Telescope

Metrology

Metrology — the scientific discipline of surface measurement — requires tools that provide extreme precision over a wide dynamic range. This is especially true nowadays, as science and industry often find themselves requiring accuracy to the nanometer (nm) level (a human hair is about 40,000 nm). Thus there is increasing need for users to get the highest possible levels of performance out of their instruments, which include optical devices such as microscopes and interferometers. Optical metrology offers a spectrum (no pun intended) of applications in precision manufacturing, semiconductors, data storage, medical applications, and optical manufacturing, and even remote sensing surface flatness and/or roughness of distant objects.

The metrology community has adopted a number of techniques designed to coax optimum precision from their optical tools. One area of recent interest is adaptive optics, which is now being explored for its metrology potential. Although originally designed for space and astronomy applications (as described elsewhere in this magazine), GSFC adaptive optics technologies already offer significant promise in advancing the science of metrology.

The Metrology Market

The field of metrology represents a fairly substantial market opportunity. For example, sales of so-called “inline” metrology tools (white light scanners, laser gauges, and other systems) totaled over $217 million in 2008, with annual growth projected to be around 5%.[1] Within this market, interferometry is considered a complimentary technology, providing fast, specific analysis capabilities to a metrology toolkit. Optical interferometers, such as white light laser systems, play an important role in 3D surface metrology. These devices are used in a variety of industries and applications.

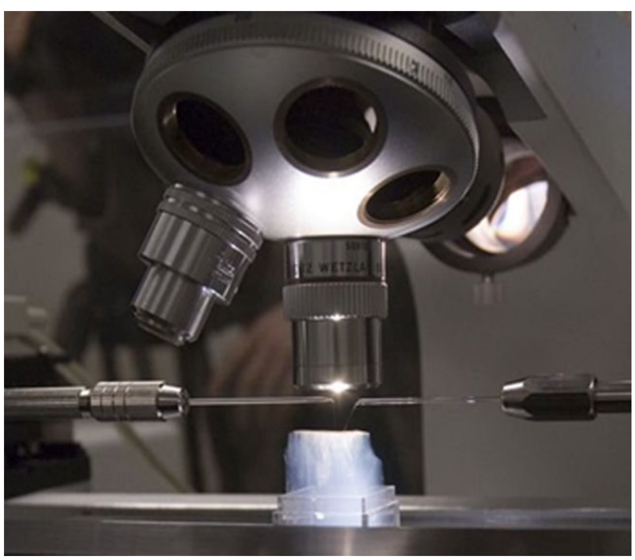
Interferometers were originally designed for surface analysis of smaller parts, but are now also being used in the metrology of much larger components. This trend has resulted in significant research into how best to apply optical interferometry within a machining environment. Currently, one of the bigger challenges facing optical metrology systems such as interferometers is the measurement of surfaces on aspheres (surfaces based on a conic section, for instance a parabola). Some consider this problem the “holy grail” of optical metrology capabilities because of the uncertainties involved in testing of steep slopes. Additionally there is need for active metrology of structures to determine vibrational modes of running motors and devices and/fluids that are always in active motion.

Another field associated with metrology (and in particular, the expanding field of nanotechnology) is microscopy. The sales of microscopes and accessories comprise a billion-dollar global market, expected to top $3 billion by 2014, with a healthy growth rate exceeding 12%.[2]

Microscopy is also a rapidly evolving field, in which the development of new techniques has become an area of intense research focus, in particular due to its beneficial effect on biomedical applications, including pathology detection, pharmacology, and treatment evaluation. For instance, biological specimens (such as deep tissue samples) possess optical properties that can distort wavefronts. This can result in a significant degradation of resolution and image quality. Cells tend to be transparent objects that modify only the phase of incoming light and thus microscopes which convert phase to intensity (phase contrast microscopes) are in high demand.

Adaptive Optics and Microscopy

Among the novel techniques being considered for advancing microscopy is adaptive optics. Numerous research studies have demonstrated that adaptive optics can improve image quality in high-end microscopy applications. For example, adaptive optical elements in a wide-field microscope solve a number of problems, including correcting aberrations due to the refractive index mismatches, focusing through thick samples without moving the sample or the objective, and correcting for aberrations caused by three-dimensional index variations within the sample, and also identifying phase and intensity objects over many orders of



Adaptive optics can allow microscopes to overcome aberrations caused by imaging through thick tissue in biological samples.

1 “World Inline Metrology Markets.” Frost & Sullivan. June 2009. Web. 24 September 2010.

2 “Microscopy: The Global Market.” BCC Research. July 2009. Web. 16 September 2010.

magnitude (high dynamic range imaging).

Adaptive optics have been incorporated into numerous imaging processes, ranging from simple widefield fluorescence to nonlinear approaches (such as two-photon excitation fluorescence, second- and/or third-harmonic generation, and coherent anti-stokes Raman spectroscopy), and confocal microscopy and optical coherence tomography (OCT).

Software for controlling adaptive optical microscopes tends to be custom designed by the vendors. Instead of directly measuring the wavefront, most adaptive-optics microscopes have historically used a “hill-climbing” algorithm to optimize a signal received at a photodetector. This approach has been popular because the alternative of adding a wavefront sensor complicates an optical system; and in biology there is no natural point-source reference such as the “guide star” used in astronomy. Although fast, the “hill-climbing” approach does not always reach the global maximum. Direct image reconstruction has also been used extensively in this application area, in particular, blind deconvolution; however, this has typically been used as a post-processing technique and has seen limited use in commercial systems to date.

As with any novel technology being applied to a new application, there are a number of technical challenges to overcome. For example, there are a wide variety of microscopy techniques available today; an ideal adaptive optics tool should work with as many of them as possible. In addition, each microscope manufacturer has its own requirements (configurations, focal distances, and individual element sizes), and if possible an adaptive optics tool should be compatible with them all.

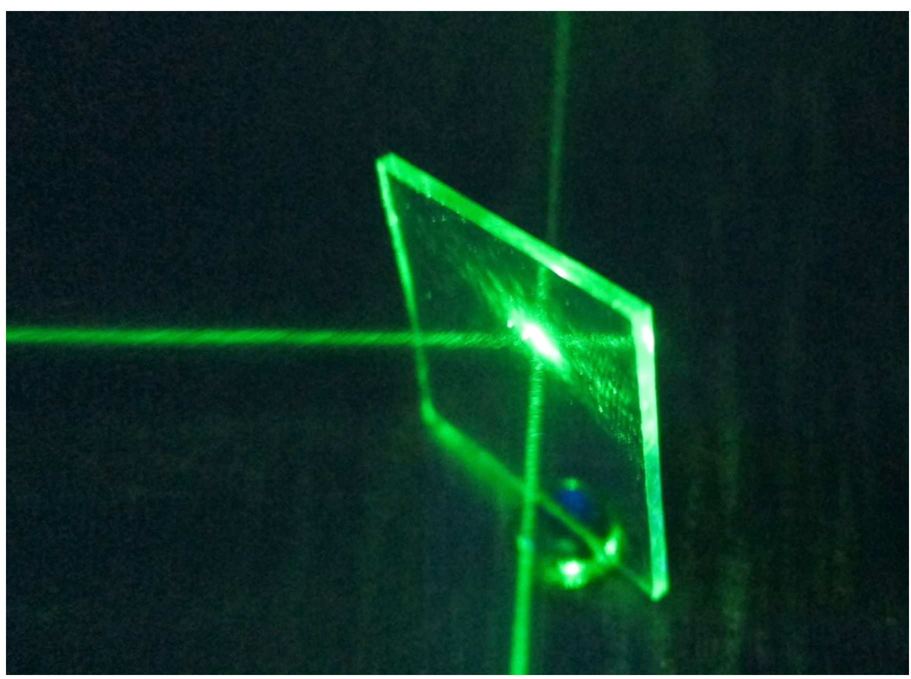
Goddard Technologies

As we’ve noted in the other articles in this issue of *Tech Transfer News*, GSFC is very active in developing advanced optical capabilities such as phase retrieval. Wavefront analysis via phase retrieval estimates the wavefront from one or more images via incorporation of a model of the system; yet can measure the surface with comparable accuracy, spatial resolution, and dynamic range as conventional interferometry but with less physical hardware – in effect trading easily changed and reconfigurable software for fixed hardware; and is capable of testing a much more general class of surfaces, lenses and other phase objects. Phase retrieval is a promising tool for optical metrology, one that could prove to be very useful due to the simplicity of the approach, and by the variety of surfaces and systems that it could be used to measure.

Describing all the individual GSFC technologies that offer significant potential for metrology applications would require far more space than could be easily accommodated by a single article. Instead, we’ll look at a representative sampling to provide a glimpse into some of the many commercialization and licensing possibilities these technologies offer:

Direct Solve Image Based Wavefront Sensing (GSC-15208-1) calculates the wavefront from a single in-focus image. The algorithm can use an image from a simple charge-coupled device (CCD) or other camera sensor, and then directly solves for the wavefront in a fraction of a second on a single processor computer. It accomplishes this without the use of iterative algorithms or extra hardware, such as lab interferometers. This algorithm is useful in adaptive optics systems where complex, closed loop performance techniques may be too costly and can be implemented on nearly any existing system with little to no modification, however complex the system is. The Direct Solve method does not require complicated phase retrieval algorithms — in fact, no human interpretation of the results is required.

PseudoDiversity (Direct Wavefront Control and Image Restoration at High Bandwidth) (GSC-15464-1) is a simplified, high speed adaptive optical system based on wavefront sensing. It simultaneously recovers the wavefront



Imaged-based software approaches to wavefront sensing can be used to replace complex and costly optical interferometry hardware.

and the object or scene being studied. This approach allows for accurate and precise alignment of segmented and sparse/interferometric optical systems. Images are corrected first by the actuators in the deformable mirrors, and then any remaining errors are corrected using an algorithmic approach. This can be useful for microscopy applications for imaging through viscous media (such as cells) and through water. It is useful for rapid sensing and correction of a temporal sequence of images. PseudoDiversity does not require defocusing of the system or the addition of other lenses or mirrors. It also sees the same optical path through to the detector of the science instrument, avoiding any non-common path errors.

Computer Generated Hologram System for Wavefront Measurement System Calibration (GSC-15676-1) creates a hologram that is an image conjugate to a wavefront measurement system image of an optical system or surface under test. This hologram is used to calibrate the wavefront measurement system. It is capable of calibrating middle and high spatial frequency errors. This system is especially well suited to calibrate wavefront measurement systems that include a reflective null lens.

Variable Sampling Mapping (GSC-15693-1) is an alternative method for performing phase estimation for under-sampled optical systems that also incorporates additional detector blurring functions in the estimation process. When combined with any iterative transform algorithm, this data-to-model mapping method calculates the wavefront utilizing undersampled images (just a few pixels across) when the optical system is illuminated with a point source or with a source of known shape and characteristics. In combination with the Hybrid Diversity Algorithm (GSC-14879-1), this technology can be used in place of interferometers to test optical surfaces and to align optical elements in a system. It can also be useful in microscopy, where multiple broadband images are collected in 3D via defocusing, such that a given plane is in focus. Unlike conventional interferometric methods, this technique requires very little additional hardware.

Summary

The metrology community endorses the use of adaptive optics technology. As Dr. Bruce Dean, Group Leader for the GSFC Optics Branch Wavefront Sensing and Control Group, notes, the interferometry market is “ripe” for adoption of wavefront sensing techniques. Adaptive optics have been successfully implemented in a number of microscope architectures, and clear improvements in imaging quality have been demonstrated. This is still a relatively new arena for adaptive optics, and the opportunities for pioneers and early adopters in this niche may be varied and numerous.

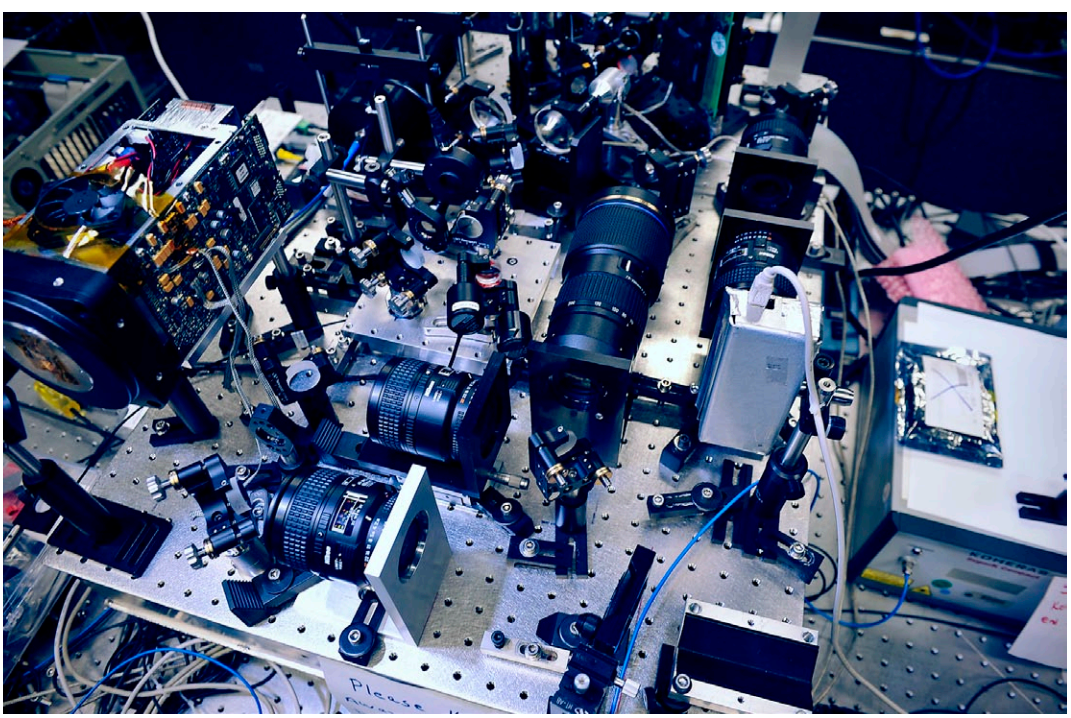
Takeaways

The metrology market, which includes fields such as interferometry and microscopy, is actively looking at new and novel technologies that can improve the performance of its tools. One area of potential interest to this market is adaptive optics. There are a wide variety of adaptive optics technologies within the GSFC portfolio which could be of potential value in this application. These include Direct Solve Image Based Wavefront Sensing, PseudoDiversity, Computer Generated Hologram System for Wavefront Measurement System Calibration, Hybrid Diversity Algorithm, and Variable Sampling Mapping, to name a few.

For more information on these and other Goddard wavefront sensing technologies, please contact Enidia Santiago-Arce, enidia.santiago-arce-1@nasa.gov, (301)-286-8497, or visit:

http://ipp.gsfc.nasa.gov/wavefront

Photo by Chris Gunn



Wavefront sensing techniques used by GSFC to simulate relationships between exoplanets and their host stars can be readily adapted for applications in microscopy and interferometry.

Intelligence, Surveillance, and Reconnaissance

The term "Intelligence, Surveillance, and Reconnaissance" (ISR) is one of those catchall phrases that is so broad it isn't always easy to define with precision. In general, ISR involves the collection of data to support the coordination of intelligence and operations. As such, it is heavily reliant on technology to help provide the "eyes and ears" of data collection. And since this issue of *Tech Transfer News* is devoted to Goddard's wavefront capabilities, you can probably anticipate where this discussion is headed: GSFC has developed a wide variety of technologies, originally intended for space and Earth science missions, that can potentially be adapted to provide novel and enhanced features and functionality to the ISR market.

In this article, we look at three segments of ISR: advanced surveillance, imaging and optical systems; free space optical communications; and iris recognition. We also briefly review several examples of GSFC inventions that could offer commercialization possibilities within these ISR market segments.

Advanced Surveillance, Imaging and Optical Systems

Video surveillance is currently a high-growth market, driven by heightened public concerns over security issues — concerns that extend into private industry as well. As a result, this market niche continues to seek technological advances for applications such as homeland security and defense. In 2010, global spending on military video surveillance systems was an estimated $7.7 billion[1]; spending for airborne ISR programs alone for the years 2006 to 2013 is projected to be $4.9 billion[2]. So clearly, this is a large and expanding commercial opportunity for new technologies in this sector.

Adaptive optics can greatly increase the functional range and resolution of mounted surveillance cameras.

For instance, consider the problem of atmospheric turbulence, which can strongly affect the performance of long-distance imaging systems (especially during daylight hours, where heat from the sun can introduce thermal effects). To help address this issue, DARPA is funding advanced efforts to develop optical systems to correct for atmospheric turbulence. Although various methods to compensate for atmospheric turbulence in long range imaging systems exist, there is still a need to operationally extend the ranges and conditions under which a device can provide clear, high resolution imagery. Thus there are significant needs to develop improved hardware and software solutions to compensate for severe imaging conditions caused by factors such as high humidity, large concentrations of particulate matter, strong and variable wind conditions, and large temperature fluctuations.

Among the technological areas being studied to address the problem of turbulence is adaptive optics. One of the primary motivations for initially developing this science was to minimize atmospheric turbulence from ground-based astronomical observations. These concepts can be adapted and applied to long range imaging applications, particularly for ground and maritime ISR applications. For example, to address target tracking needs, adaptive optics research is underway to develop long-range infrared cameras operating in the 1 to 2-micron light wavelength. For this application, performance is important, requiring low noise (no greater than 10 electronics of read noise per pixel, and greater than 80% quantum efficiency) and a high frame rate in the thousands of frames per second range. Another example involves sea-based applications, which are affected by particularly turbulent imaging environments; the atmosphere around the boundary layer above oceans or other bodies of water is highly problematic, thus this application could well benefit from advanced adaptive optics systems.

Free Space Optical Communications

Another application where atmospheric turbulence is a significant problem is free space optical communications (FSOC). As the name implies, this involves transmitting communication signals via the visible portion of the electromagnetic spectrum (typically using laser), without using an interconnecting medium such as cable. FSOC technologies are highly attractive to a host of military applications, as in theory they can greatly improve both air-to-air and ground-to-air links, while providing smaller

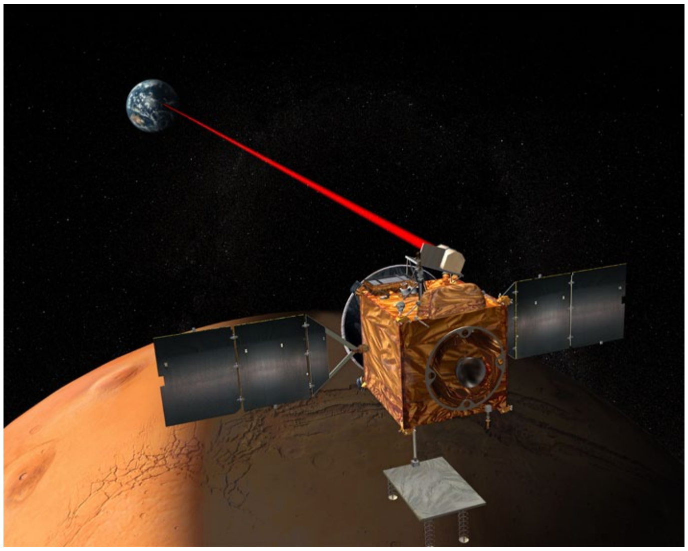
intel, surveillance, recon

1 "Military Video Surveillance Systems Market 2010-2020." ASD Reports. June 2010. Web. 20 September 2010

2 "U.S. Airborne ISR Platforms Markets." Frost & Sullivan. 9 January 2008. Web. 22 September 2010.

size, weight, and power requirements (as well as cost savings) compared to equivalent RF systems. In addition, FSOC systems can benefit large commercial, academic or governmental research campuses or complexes. Further, FSOC may also allow for the extension of fiber optic systems to rural areas without laying additional cable, and may even expand internet access into the third dimension by allowing airplane passengers a clear, continuous signal. The market for laser telecommunications and data communications in 2009 was estimated to be $1.8 billion.[3]

FSOC devices are dependent on adaptive optics to function properly. Laser based transmissions through air turbulence experience essentially the same issues as astronomical imaging. Due to atmospheric turbulence, the optical beam can wander, resulting in significant signal fading and degradation, severely impacting performance and reliability. Therefore adaptive optics are required to rectify the distortion and improve signal quality over meaningful distances. This is critical, since (for example) long distance battlefield optical communications capability may save lives by enabling the military to access ultra-high bandwidth ISR information in real-time from various manned and unmanned airborne platforms. There are currently several technical challenges facing adaptive optics in the FSOC arena. For example, sampling and compensating for atmospheric distortion is a very processor-intensive application. And currently available actuator driven deformable mirrors are expensive, can be difficult to maintain, and consume a lot of space. Technologies such as microelectromechanical systems (MEMS) and transmissive liquid-crystal devices could be critical developments to help bring down costs and shrink the size of adaptive optics systems.


Artist's rendering of a satellite communicating with Earth via a free space optical connection.

Iris Recognition

This is an application that, just a few years ago, might have seemed like science fiction — rapid identification through analysis of the subject's iris. However, in recent years there's been strong focus on upgrading security systems, which has helped drive interest in novel techniques such as iris screening and other biometric security technologies. And this presents another opportunity for adaptive optics.

For instance, biometric iris screening can be improved through the use of curvature adaptive optics, which corrects for subject motion, thereby minimizing motion blur and providing in-focus images with a capture distance of 2 meters. In addition, efforts such as the planned NIST Multi-Biometric Grand Challenge (funded in part by the FBI) are continually promoting better recognition accuracy. And as detection distances become greater, problems of thermal interference arise; and there will definitely be need to compensate for such disturbances. (Within the DoD, there are standoff iris and facial detection requirements, with goals of successful identification out to 20 meters and beyond.)

It is estimated that iris recognition will rapidly evolve in capabilities and ease of use over the next 10 to 15 years. In 2007, iris recognition systems generated $102 million; the market is expected to grow to $1.4 billion by 2015 (a very robust compound annual growth rate of 38.7%).[4]

American soldiers in Iraq use retina scans to verify the identities of members of the new Iraqi police force.

3 “LASER MARKETPLACE 2009: Photonics enters a period of high anxiety.” *OptoIQ*. January 2009. Web. 17 September 2010.

4 “The Transformation of the Iris Recognition Market 2007 – 2020.” Acuity Market Intelligence. September 2007. Web. 17 September 2010).

Goddard Technologies

As we noted earlier, the GSFC wavefront technologies that could potentially be utilized to solve some of the ISR challenges noted above are many and varied. This section briefly highlights a few of these:

Fixed Lens Wavefront Sensing (GSC-14901-1) introduces diversity defocus into the optical beam path by using a fixed-lens WFS technique. It incorporates a fixed or stationary lens into a converging beam ahead of the imaging focal plane, and enables the creation of diversity defocus data without translating the imaging camera along the optical axis. No motion is required from the imaging camera to generate a known diversity defocus. The optical design is cost-effective and easily constructed using readily available catalog components and mounting hardware. This technology could be useful in iris detection and retinal imaging applications.

Wavefront Sensing and Optical Control Software (GSC-14725-1) is a comprehensive suite of wavefront sensing and optical control tools designed to measure the wavefront and control the optical systems in order to correct for distortion. It combines phase retrieval and phase diversity algorithms with a variety of control strategies. This software tool can be used for applications such as remote sensing. It can also perform large scale modeling due to its inherently parallel nature.

Filter Function for Wavefront Sensing & Control over an Extended Field of View (GSC-14900-1) analyzes and optimizes multiple wavefront estimates from multiple field points. This allows for more balanced optical system performance over the entire field of view. Instead of adapting the control scheme for the entire field of view to a wavefront reading from a single point, this algorithm takes multiple wavefront measurements from across the field of view and synthesizes them to achieve better overall optical system performance.

Phase Controlled Magnetic Mirror for Wavefront Correction (GSC-16008-1) allows electrical modification of the reflected wavefront, resulting in a deformable mirror that can be used for wavefront control. More specifically, it allows the modification of the incident wavefront to correct wavefront errors introduced by fabrication and alignment. In a magnetic mirror, a patterned nanowire is fabricated over a metallic layer with a dielectric layer in between. Oscillation of the electrons in the nanowires in response to the magnetic field of incident photons causes a re-emission of photons, and thus operates as a "magnetic mirror." By controlling the index of refraction in the dielectric layer using a local applied voltage, the phase of the emitted radiation can be controlled, resulting in the deformable mirror. The device operates with no moving parts and can modify the phase of incident light over many spatial scales. Potential advantages of the device include a higher degree of wavefront correction accuracy at increased spatial resolution. This is particularly useful for applications requiring extreme wavefront correction (nanometer or below).

Imaging System Aperture Masks for Image Plane (GSC-16162-1) is a low cost and simple aperture mask architecture that characterizes an imaging system's exit pupil using image intensity variations at the system's image plane. As exit pupil characteristics are typically difficult and expensive to directly measure due to the use of powered optical elements (such as lenses and curved mirrors), the masks eliminate the need for such components and enable exit analysis of pupil distortion and illumination characteristics. The masks generate far-field diffraction patterns that can be analyzed to determine both exit pupil distortion and illumination characteristics. A new exit pupil characteristic can be measured with the mask, allowing for characterization of the absolute distance between an imaging system's detector plane and its exit pupil.

Summary

ISR has gained prominence in our increasingly security-conscious world, providing an arena in which the needs of information gathering, communication, and operations intersect. This places enormous challenges on technology, as ISR demands tools that offer the highest possible level of performance, reliability, speed, and precision — demands that can translate into commercialization opportunities for the innovative. And GSFC's adaptive optics portfolio may offer some attractive ways for taking advantage of these opportunities.

Takeaways

Intelligence, Surveillance, and Reconnaissance (ISR) involves the collection of data to support the coordination of intelligence and operations. ISR is heavily reliant on optical technologies for data gathering. These technologies are subject to effects, such as atmospheric turbulence, that can significantly impact the efficacy of devices designed for applications such as advanced surveillance, imaging and optical systems; free space optical communications; iris detection. GSFC adaptive optics technologies, developed for space missions, may offer significant potential in addressing the issues associated with these and other ISR systems.

For more information on these and other Goddard wavefront sensing technologies, please contact Enidia Santiago-Arce, enidia.santiago-arce-1@nasa.gov, (301)-286-8497, or visit:

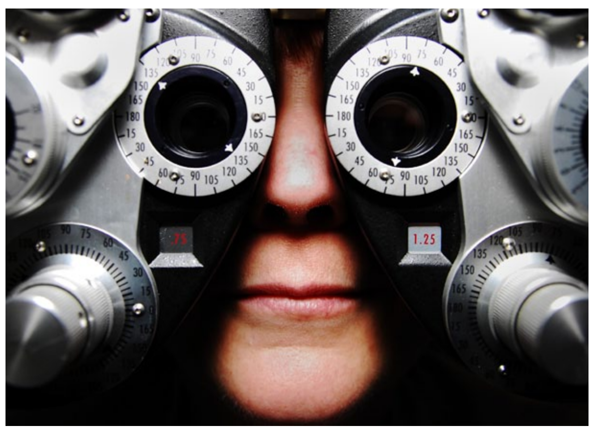
http://ipp.gsfc.nasa.gov/wavefront

Optometry and Ophthalmology

Compared to some of the other markets examined in this issue of *Tech Transfer News*, optometry and ophthalmology may seem relatively mundane — they don't offer the cutting edge science of astronomy, or the "gee-whiz" factor of ISR. Nevertheless, optometry and ophthalmology are major markets; ones in which Goddard's wavefront sensing portfolio may offer some very interesting commercialization opportunities, particularly within retinal imaging applications.

Optometry

Although a relatively simple medical science, optometry may be one of the more intriguing and robust markets for wavefront sensing. Only recently has the optometry community begun to recognize the potential benefits of wavefront sensing, including earlier and better detection of the onset of eye disease, and personalized corrective lenses (which correct for higher order aberrations than can be currently detected). These issues will become increasingly acute as the population ages. Another advantage of this market is that optometric devices do not need clinical trials and FDA review to enter. Thus, the path to market is relatively straightforward.



Adaptive optics may one day take the guesswork out of diagnosing eyesight.

It is anticipated that wavefront-related innovations in spectacles and contact lenses will continue as long as they provide superior vision outcomes for patients. They can also be used for the diagnosis of conditions other than refractive error. For instance, clinicians can use wavefront techniques to objectively detect the visual effects of early cataracts, and to determine whether or not surgery is needed. Retinal scans can also be used as early indicators of diabetes.

Consider this example: a standard perimetry test administered by an optometrist cannot detect a disease until it affects the patient's vision. However, an examination with an adaptive optics imaging system could reveal such a disease. If adaptive optics is integrated into clinical instruments, the systems could enable earlier diagnosis of the eye's receptors, improve monitoring of therapy, and provide a better understanding of pathogenesis. Devices currently used for optometric diagnostics have changed little in over 100 years; while new developments in adaptive optics can turn an ophthalmoscope into a microscope, and effectively count cells in the back of an eye. Because of this, a new set of applications may arise from adaptive optics to simulate vision, and to create devices that are possibly cheaper than phoropters for multifocal corrections.

Ophthalmology

After astronomy, it has been said that ophthalmology was the second science to adopt adaptive optics techniques. There are a number of potentially significant uses for adaptive optics in ophthalmology. This is particularly true for eye imaging. Adaptive optics technologies could be used in a range of applications, offering the potential to diagnose a variety of specific diseases, and could be highly useful for clinical studies of rare diseases.

There is a strong interest, and even strong commercial efforts, to integrate adaptive optics into retinal imagers, most notably optical coherence tomography (OCT) devices. The aging population is creating a growth market for high resolution retinal imaging to detect the onset of disease or to guide corrective surgery. OCT devices can cost up to $100,000, and often include closed loop systems with deformable mirrors.

One area where relatively small and inexpensive adaptive optics systems could be most useful is laser eye surgery. With adaptive optics, doctors can now measure the higher-order distortions in the eye lens compared to the simpler systems now in use.

Standard vision tools do not mitigate the imperfections in the cornea and lens in living subjects, so adaptive optics is the primary option for studying living retinal tissue. Furthermore, a full adaptive optics system can compensate for micro-fluctuations in eye muscles, thus the patient's eye does not have to be temporarily paralyzed while under examination.

Future imaging platforms will combine multiple modalities in a single instrument, for instance OCT and adaptive optics, OCT and multiphoton microscopy, or adaptive optics and fluorescence. For example, OCT can now provide high axial resolution of a few microns, while adaptive optics can provide comparable transverse resolution. The two technologies together can provide resolution smaller than most retinal cells in all three spatial dimensions.

The global ophthalmology device and drug market is witnessing significant growth due to the increasing incidence and prevalence of eye related disorders such as presbyopia, macular degeneration, and diabetic retinopathy. Additionally, individuals are increasingly choosing ophthalmic surgeries to correct their eye related disorders. In 2008, the global refractive vision correction treatment market totaled nearly $6 billion;[1] the overall market for retinal exams was estimated to be $2 billion to $3 billion in 2009.[2]

Goddard Technologies

There are a wide variety of GSFC inventions which in theory could be adapted to the requirements and challenges of optometry and ophthalmology. The following briefly highlights a few of these technologies:

Iterative-Transform Phase-Retrieval Utilizing Adaptive Diversity (GSC-14879-1) is suitable for multiple applications, including as an alternative to interferometers in applications that require wavefront sensing and control. This is a phase-diverse-phase-retrieval iterative-transform algorithm for image-based wavefront sensing. It recovers high-spatial frequency, high-dynamic range wavefront data using only video or still camera inputs. This algorithm combines iterative-transform and parametric phase recovery techniques to allow for both high-spatial frequency and high dynamic range wavefront sensing. Wavefront calculations occur in the software, making the expensive hardware used in interferometry unnecessary.

Null Control Breadboard (GSC-16164-1) is a white light Michelson interferometer with a reference flat in one arm of the interferometer and a deformable mirror in the other arm. It was built to test and evaluate new deformable mirror technologies, and to develop and assess wavefront sensing and control algorithms. The mounting and placement of the beam splitter, deformable mirror, source and reference flat allow certain degrees of freedom that greatly facilitate optical alignment. The deformable mirror can be changed to test differently sized and formatted deformable mirrors from different vendors. This technology has potential application in retinal imaging systems such as in LASIK eye surgery.

Variable Sampling Mapping (GSC-15693-1) is an alternative method for performing phase estimation for under-sampled optical systems that also incorporates additional detector blurring functions in the estimation process. When combined with any iterative transform algorithm (ITA), this data-to-model method calculates the wavefront in high fidelity by using images obtained when the optical system is illuminated with a point source or other light source of known shape and characteristics. This data-to-model mapping technique facilitates a more robust and accurate way of incorporating the pupil and image-plane constraints. Unlike conventional interferometric methods, this technique does not require additional complex and expensive hardware. LASIK for the human eye, whereby higher resolution and broadband wavefronts are required for more accurate correction of the human cornea, is a potential application for this technology.

PseudoDiversity – Direct Wavefront Control at High Bandwidth (GSC-15464-1) is an approach that simultaneously recovers the wavefront, needed for active and adaptive optical control, that is then fed back to actuators in an optical system. It simultaneously recovers the object or extended scene under study. It is useful for both astronomical and Earth sensing imaging and spectroscopic systems, and removes the need for complex metrology and nonlinear phase retrieval and phase diversity approaches. It is computationally fast and lends itself well to accurate and high bandwidth control of an optical system. It is primarily a software-based approach that uses a temporal sequence of images from a focal plane camera and would likely have applications in optometry and ophthalmology, as well as military applications for imaging through lateral turbulence.

Direct-Solve Image-Based Wavefront Sensing (GSC-15208-1) is an approach that directly solves for wavefront errors using only a single broadband in-focus image as input. No nonlinear, iterative algorithms (e.g., phase retrieval) are required. The single image is fed to a software algorithm, which directly solves for the wavefront in a fraction of a second on a single-processor computer. This technique is designed for speed and can be used in any open- or closed-loop control system.

Summary

However routine optometry and ophthalmology may be at first glance, there's more to them than meets the eye — in fact, they comprise an important area of medical science, one that affects literally billions of people. New technologies in this space therefore can offer significant benefits to public health, as well as significant revenue opportunities to developers of vision correction products and services. With the aging population driving demand and innovation in these markets, GSFC's wavefront portfolio may represent a very important IP pool upon which to base the next generation of innovative tools.

Takeaways

Optometry and ophthalmology form a billion-dollar global market. This market is expanding significantly as the population ages and incidence of eye disease and other vision issues rises. This market is actively seeking new and better technologies, and has been quick to investigate adaptive optics techniques. GSFC's wavefront technologies may offer some attractive commercialization opportunities in this space.

For more information on these and other Goddard wavefront sensing technologies, please contact Enidia Santiago-Arce, enidia.santiago-arce-1@nasa.gov, (301)-286-8497, or visit:

http://ipp.gsfc.nasa.gov/wavefront

1Ledue, Chelsey. "LASIK will propel ophthalmology market to greater heights." *Healthcare Finance News*. July 2009. Web. 21 September 2010.
2"Optos to cement leadership in '$2-3bn' retinal imaging market." *Optos.* 2009. Web. 21 September 2010.

Attention NASA scientists, engineers, and technologists:

Enter your best ideas (unrelated to your work at NASA and not developed with NASA resources) for new products and compete with engineers worldwide for the $20,000 grand prize. You could also win an HP computer and other great prizes.

The Create the Future Design Contest was launched in 2002 by the publishers of *NASA Tech Briefs* magazine to help stimulate and reward engineering innovation. The annual event has attracted more than 7,000 product design ideas from engineers, entrepreneurs, and students worldwide. The contest's principal sponsors are COMSOL, PTC, and Tech Briefs Media Group.

Entry Requirements:

Contest ends June 30, 2011. Your entry must be received by 11:59 pm ET on June 30, 2011. For your entry to qualify for consideration, you must meet the following requirements:

- Complete the official Entry Form and upload image(s) with your entry.

- Choose one of seven categories for your entry:

  Consumer Products: Products that increase quality of life in the workplace, at home, during leisure time, or while traveling.

  Electronics: Products that improve computing, communications, and other fields that rely on advances in electronic components and systems.

  Machinery and Equipment: Products that speed and improve work, manufacturing, or scientific research processes.

  Medical Products: Products that improve the efficiency and quality of healthcare.

  Safety and Security: Products that enhance the security or safety of individuals, businesses, communities, or nations.

  Sustainable Technologies: Products that help reduce dependence on non-renewable energy resources, as well as products designed for other purposes using environmentally friendly materials or manufacturing processes.

  Transportation: Products that enable movement of people and goods from one place to another.

- Provide a complete description of your entry (up to 500 words), in the form of a technical abstract. You will be judged on these criteria:

  Innovation

  Manufacturability

  Marketability

  Cost-effectiveness

- Upload at least one (but no more than three) visual illustrations. You may submit:

  Scanned sketches, charts, and 2D CAD drawing images

  3D CAD images

  Simulation or CAE images

  eDrawings files

Complete details can be found at: http://contest.techbriefs.com

Patenting Perspectives

In this issue we introduce "Patenting Perspectives," a new regular feature in Goddard Tech Transfer News. As the name implies, the purpose of this column is to highlight the latest developments within the world of intellectual property (IP), and how they might affect GSFC, our inventors, and our partners within the business community. The perspectives will be provided by attorneys Bryan Geurts (Chief Patent Counsel for GSFC's Office of Patent Counsel) and Erika Arner (Partner for the law firm Finnegan, Henderson, Farabow, Garrett & Dunner).

patenting perspectives


Bryan Geurts


Erika Arner

Could you tell us a bit about your respective backgrounds as patent attorneys?

Bryan: I actually stumbled into patent law during my time in law school at Brigham Young University. Back then, patent law wasn't as well-defined as a career track as it is today. Entering law school, I really had little clue what patent law is about. However, my technical background in civil engineering made me a good fit for this area of the law, so I was advised to check it out.

Erika: I joined my current firm, Finnegan, Henderson, Farabow, Garrett & Dunner, about 12 years ago. My technical background is in Computer Science, so I primarily have focused on electronic technology, computer software, and the Internet as a patent attorney. Most notably during my time here at Finnegan, I have had the opportunity to argue before the U.S. Supreme Court for the petitioners in *Bilski v. Kappos*. The case involved the most basic part of patent law: what kinds of inventions can be patented. The Court reaffirmed that the Patent Act is quite broad, and does extend to business processes.

Bryan, what did you do before coming to Goddard and how does your work at NASA compare?

Bryan: I began my career in the private sector, working both for non-profit organizations as well as large companies such as Disney, 20th Century-Fox, and Warner Brothers. In fact, I probably still have some of the private sector in me which taints my perspective a bit. I joined NASA nine years ago, and I really enjoy working with intellectual property in the government. In the private sector, we generally have to wait until someone approaches us for legal help patenting an invention, so we see only a small part of the process. At Goddard, there are dozens of labs working on many interesting inventions and ideas at any given time. This affords me the opportunity to witness many of the amazing technologies being created throughout all stages of development. Day in and day out, we're on the cutting edge.

Erika, as someone currently in the private sector, what do you see as some of the main differences between your work and Bryan's?

Erika: In my work, I deal with a much broader spectrum of clients. Basically, Bryan has one client: NASA. At Finnegan, we have dozens of different clients — universities, government agencies, and private companies. I've worked with clients as diverse as casinos, the postal service, and software developers. This offers a very broad range of technologies to cover, although computer software is generally my focus area.

How long does it generally take to get a patent?

Erika: The Patent Office strives to grant patents within 3 years from filing, although in some technology areas, the examination process can take longer. The Patent Office makes quite a bit of data available on its website, including application pendency information using a Patents Dashboard, available at http://www.uspto.gov/dashboards.

What is the significance of having a patent for government technology?

Bryan: The benefits for the government from patents include the ability to establish new markets and industries through licensing of government technology, recognition of government inventors for their hard work, and the ability to prevent others from charging the government for using government sponsored technology and inventions.

What are the benefits for inventors in terms of reward when applying for and receiving government patents?

Bryan: Besides the cachet that comes from having your name listed as an inventor on a patent, NASA monetarily rewards inventors who have their technology submitted to the US Patent Office as a patent application. Additionally, inventors whose patents and patent applications are successfully licensed to industry receive a generous portion of the royalties earned.

What topics do you plan on covering in the future with this column?

Erika: This is currently a very exciting time in the patenting world. The current session of the Supreme Court has three separate patent cases scheduled, which is very unusual and may indicate a trend to emphasize patenting as a critical component of the economy. In fact, the recent State of the Union address specifically mentioned the patent system as a key driver to encourage innovation and economic growth. But more broadly, our goal in writing this column is to help educate readers about the value of intellectual property, as well as patenting and the application process. We want to make sure no one loses the right to protect their critical IP simply because they didn't properly understand the basic legal issues involved.

Bryan: Sometimes the public and private perspectives largely coincide, while in other cases they may diverge significantly. Either way, we hope to offer valuable insight in this area of the law.

Readers, what patent issues would you like to have Bryan and Erika discuss in future issues? Please send suggestions to lucy.a.stefanelli@nasa.gov.

Business Networking and Outreach

18th Annual New Technology Reporting Program
(October 20, 2010, Newton White Mansion in Mitchellville, MD)

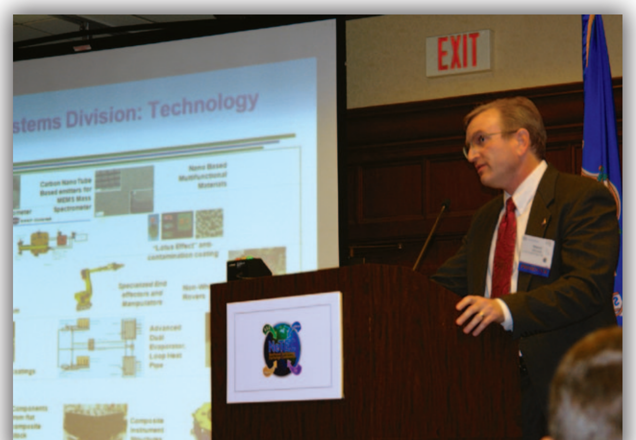
Goddard Space Flight Center's IPPO hosted the 18th Annual New Technology Reporting Program to recognize innovators who actively support GSFC technology commercialization efforts. Goddard Center and Technical management, scientists and engineers applauded patent achievements and honored the 2010 James Kerley Award Winner. The annual event recognizes leadership in technology development and the support of outreaching to industry for commercial applications of Goddard technology. Refreshments were served as Jeff Smith, President of Flight Landata, delivered a keynote on successfully partnering with GSFC IPPO to license and commercialize the Spacecube technology.

AETD Director Dennis Andrucyk presents the 2010 James Kerley Award to Tom Flatley, Code 581, in recognition for his outstanding contributions and support of NASA's IPPO program.

Keynote speaker, Jeff Smith, Chief Executive Officer and Director of Flight Landata, discusses his company's successful partnership with NASA.

Northeast Technology Exchange Conference
(November 1, 2010, Windsor, CT)

The Connecticut Center for Advanced Technology, Inc. presented the Northeast Technology Exchange Conference (NeTEC) 2010. NeTEC is the Northeast's primary conference focused on aerospace and defense technology transfer where emerging technologies with great commercial potential are showcased to entrepreneurs and investors interested in partnership opportunities. NASA Goddard Space Flight Center (GSFC) was among nearly 60 NeTEC 2010 exhibitors. The conference integrated presentations from University Technology Transfer Offices, OEM's and Federal Labs, which included a presentation by GSFC IPPO's Sr. Technology Manager, Darryl Mitchell, who discussed GSFC technologies available for licensing as well as thrust areas of deep research and expertise.



IPPO Senior Technology Manager Darryl Mitchell discusses the many Goddard technologies available for licensing at the 2010 Northeast Technology Exchange Conference.

Next Steps in Managing Innovation Workshop
(November 3, 2010, Uniondale, NY)

NASA Goddard Space Flight Center's IPPO held its semiannual Next Steps in Managing Innovation Workshop on November 3, 2010 at the Long Island Marriott Hotel and Conference Center in Uniondale, NY. The workshop focus is for NASA GSFC Small Business Innovation Research (SBIR) Program and the Small Business Technology Transfer (STTR) Program contractors along with other prime contractors to have the opportunity to learn about new technology access channels and how to leverage mutual opportunities of interest. 29 individuals from 23 SBIR companies, along with several prime contractors and three GSFC Associate Chiefs for Technology (ACTs) discussed the advancement and use of the SBIR technologies.

Workshop attendees enjoy a midday networking lunch before returning to panel topic discussions at the Next Steps in Managing Innovation Workshop.

National Middle School Association's 37th Annual Conference and Exhibit
(November 4-6, 2010, Baltimore, MD)

IPPO staff members attended the National Middle School Association's 37th Annual Conference and Exhibit to help promote the NASA OPTIMUS PRIME video contest, and to demonstrate NASA's Massively Multiplayer Online (MMO) educational game "Astronaut: Moon, Mars and Beyond." Both projects received strong interest from conference attendees as well as the many teachers who attended the booth.

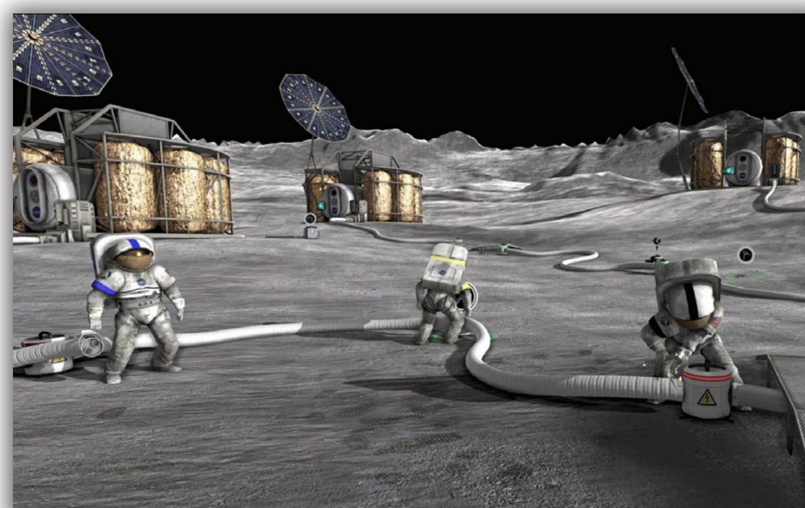
IPPO staff members Brent Newhall and Dennis Small speak with a participant visiting the Goddard booth at the National Middle School Association's 37th Annual Conference and Exhibit.

ICAP Ocean Tomo Live Auction
(November 9 – 11, 2010, Napa, CA)

Since April 2006, ICAP Ocean Tomo, and its predecessor organization, Ocean Tomo Transactions, has held ten live intellectual property (IP) auctions across the United States and Europe resulting in the successful transaction of over $135 million in IP. On November 11, 2010, Goddard Space Flight Center's IPPO entered a lot of 5 NASA patents into a live auction held in Napa Valley, CA. This was GSFC's second time participating in a live IP auction. The GSFC lot contained patents related to automated software development. The final bid of $225K offered for the GSFC Lot did not meet the pre-established reserve price of $250K, and as a result ICAP Ocean Tomo is following up with the interested bidders to close a deal post-auction. The event also included keynote presentations and panel discussions from best-selling author Steven Johnson and pioneering technologist Kevin Ashton.

5th Annual I/ITSEC Serious Games Showcase and Challenge (SGSC)
(November 28 – December 2, 2010, Orlando, FL)

IPPO staff members attended the 5th Annual I/ITSEC Serious Games Showcase and Challenge (SGSC). Finalists were chosen by a panel of leaders in the gaming, industry and academic fields and were invited to showcase their serious games at the Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), where over 17,000 attendees viewed and voted on each of the finalists' games. NASA's Massively Multiplayer Online (MMO) game, Moonbase Alpha, was presented with the award for Best Government Game.



Moonbase Alpha won the award for Best Government Game at the Serious Games Showcase and Challenge.

Business Networking and Outreach

Annual IRAD Poster Session

(December 2, 2010, GSFC Building 8 Auditorium in Greenbelt, MD)

The Goddard Space Flight Center's IPPO exhibited at the Annual IRAD Poster Session to participate in inreach activities involving technologies and concept studies that the Center's IRAD program funded this past fiscal year. At this event showcasing R&D achievements, the IPPO participated in opportunities to connect, share ideas and forge new partnerships that could lead to new technologies. The IPPO aimed to reach out to attendees regarding how IPPO manages partnerships that begin with NTRs. IPPO staff met with scientists and engineers exhibiting at the poster session to learn of new technologies developed and ensure the submission of new technology reports and identify areas where IPPO can potentially help facilitate new partnerships. The IPPO distributed *Tech Transfer* and *Tech Briefs* magazines, brochures on spinoff technologies and partnership opportunities, and demonstrated the MMO game "Moonbase Alpha" to attendees as they enjoyed refreshments.

IPPO staff members Ted Mecum, Enidia Santiago-Arce and Dr. Bedford Boylston demonstrate the MMO game "Moon Base Alpha" to Annual IRAD Poster Session attendees.

The Juxtopia® Urban Learning Technology (JULT) 2010 3rd Annual Conference

(December 8, 2010, Baltimore, MD)

The Juxtopia® Urban Learning Technology (JULT) 2010 3rd Annual Conference was held on the campus of Morgan State University on December 8, 2010. The conference showcases urban learning technology that has the potential to improve the academic proficiency of underserved and disadvantaged youth. At JULT 2010, speakers, exhibitors, and vendors presented innovative learning technologies and underlying instructional methods designed to increase test scores in K-college STEM disciplines, and enhance workforce and entrepreneurial skills. The luncheon Keynote Speaker was Nona Cheeks, Chief of NASA Goddard's Innovative Partnerships Programs Office.

JULT
JUXTOPIA URBAN LEARNING TECHNOLOGY CONFERENCE

Fourth Annual Sciences & Exploration Directorate (SED) Poster Session

(January 31, 2011, Greenbelt, MD)

Members of Goddard's IPPO staffed a table at the 4th Annual Sciences & Exploration Directorate (SED) New Year's Poster Session on January 31st, 2011. This event brought together scientists from across the Directorate, along with invited presenters from the Applied Engineering and Technology Directorate (AETD), to display their posters from 2010 meetings. IPPO staff members distributed information on the IPPO's role in managing new technology reporting as well as efforts in partnership development, success stories and outreach events.

IPPO staff member, Jassonn Garcia, assists an attendee visiting the IPPO's display at the Fourth Annual Sciences and Exploration Directorate Poster Session.

University of Baltimore
(February 2, 2011, Baltimore, MD)

IPPO staff members Darryl Mitchell and Enidia Santiago-Arce gave a presentation on NASA'S Technology Transfer Process to an MBA class at the University of Baltimore's Merrick School of Business. The IPPO executed a Space Act Agreement with the university in 2010 to collaborate in the University's Lab to Market Program. Under the program, students will choose a candidate from a list of Goddard technologies which they will analyze for its commercial viability. IPPO will receive copies of the students' analysis for its own utilization, and in some instances students may choose to form a start-up company around their chosen technology and license the intellectual property.

Association of University Technology Managers® (AUTM®) Annual Meeting
(February 27 – March 2, 2011, Las Vegas, NV)

IPPO staff attended the annual meeting of the Association of University Technology Managers® (AUTM®) organization, with 1,600 in attendance. AUTM's members represent intellectual property managers from more than 300 universities, research institutions, teaching hospitals, businesses, and government agencies.

The 49th Robert H. Goddard Memorial Symposium
(March 30-31, 2011, Greenbelt, MD)

IPPO staff members Tom Bagg and Dennis Small attended the 49th Robert H. Goddard Memorial Symposium where top level managers from NASA, Industry and other government agencies held discussions that explored ideas relating to this year's theme "NASA: More Than You Imagine." Sponsored by the American Astronautical Society (AAS) with support from NASA Goddard Space Flight Center, the symposium provided a historical context, science priorities, discussions on moving to commercial for routine access to low earth orbit (LEO), NASA developments for beyond LEO, including the Multi-Purpose Crew Vehicle (MPCV) for human presence throughout the solar system, and the Space Launch System (SLS) for heavy lift.

Project Management (PM) Challenge
(February 9-10, 2011, Long Beach, CA)

Project Management Challenge is an annual NASA training event. The theme for this year's PM Challenge was "Explore and Inspire" to acknowledge not only the central role of space exploration to the Agency's mission, but also how the exploration of new ideas and lessons learned in project management increase the chances of mission success. The GSFC IPPO team coordinated exhibit efforts to outreach to program and project management staff and attendees to identify opportunities to work with various elements of the OCT.

IPPO's Software Release Assistant, Brent Newhall, speaks with a PM Challenge attendee at NASA Goddard Space Flight Center's Applied Engineering and Technology Directorate booth.

ICAP Ocean Tomo Live Auction
(March 31, 2011, New York, NY)

Representatives from the Goddard Space Flight Center's IPPO attended a live intellectual property auction hosted by ICAP Ocean Tomo in New York City on March 31, 2011. The Goddard IPPO did not enter any lots in the Spring 2011 Auction but utilized the opportunity to meet with representatives from the Lawrence Livermore National Laboratory and the National Cancer Institute technology transfer offices, as well as licensing representatives from various companies and universities. In addition, the event also included a special keynote address from internationally best-selling author Malcolm Gladwell.

Tech Transfer Metrics October 2010- March 2011

New Technology Reports: 47

Space Weather iPhone App; A Standalone iPhone/ iPod Touch Application Which Displays Space Weather Information to Users by Michael Hesse (Code 674), Marlo Maddox, David Berrios, Richard Mullinix (Code 587)

Climate@Home App for Mobile Devices by Ryan Boller (Code 587), Robert Cahalan (Code 613.2), and Michale Seablom (Code 610.3)

General Mission Analysis Tool (GMAT) by Steven Hughes, Edwin Dove, John Downing, James Carpenter, Joel Parker (Code 595), Linda Jun, Wendy Shoan (Code 583), Tuan Nguyen (Code 582), Thomas Grubb (Code 588), Darrel Conway (Code 595), Moriba Jah (Air Force Research Lab), Gene Stillman, Matthew Wilkins, Dunning Idle, and Phillip Silvia (Schafer Corporation)

MUTATEES (Multiple Utilization of Total Autonomy Technologies for Evolving Environment Scenarios) by Steven Curtis (Code 690)

Method for Determining Temperature Differential to Prevent Hardware Cross Contamination in a Vacuum Chamber by David Hughes (Code 546)

Wicket CDAWeb by Reine Chimiak (Code 583)

Data Quality Screening Service by Christopher Lynnes, Richard Strub, Thomas Hearty (Code 610.2), Young-In Won (Code 690.1), Peter Fox and Stephan Zednik (Rensselaer Polytechnic Institute)

Weekly Status Reporting & Approval Application Revision 2 by Chris Durachka and Jorge Lugo (Code 585)

Surface Temperature Data Analysis by James Hansen and Reto Ruedy (Code 611)

High-speed, High-resolution Time-to-Digital Conversion by Richard Katz, Igor Kleyner, and Rafael Garcia (Code 564)

Marker-based Hierarchical Segmentation and Classification Method by Yuliya Tarabalka and James Tilton (Code 606.3)

Back Boost Inverter by John Lagadinos and Ethel Poulos (Code 555)

GMSEC C2:Space Missile Command Security Module by Robert Wiegand, Vuong Ly, Matt Handy (Code 583), Tom Sullivan, James Gilbertson, Heather Jakub, Alex Martinello, Eric Nelson, and Wai Troyer (Aerospace Corporation)

Fortran Testing and Refactoring Infrastructure by Stefan Muszala and David Alexander (Code 610.3)

An Effective Implementation of an approach for Identifying Potential Archaeological Sites Using Student's T-Test by Douglas Comer and James Tilton (Code 606.3)

Mission Operations Center - Precipitation Processing System (MOC-PPS) Interface Software System (MPISS) by William Calk, William Atwell (Code 441), and Jeffrey Ferrara (Code 583)

Further Refinement of the Computationally Efficient HSEG Algorithm by James Tilton (Code 606.3)

Synthetic Imaging Maneuver Optimization (SIMO) SBIR Phase 2 by John Merk (Code 667)

The Core Flight Executive (cFE) is Software that Provides a Core Set of Services. The Services Include Software Bus, Time Services, Event Services, Executive Services, Table Services, and File Services by Robert McGraw, Maureen Bartholomew, Jane Marquart, Michael Blau, Susanne Strege, David McComas, Barbara Medina, Alan Cudmore, Jonathan Wilmot, Lonnie Walling (Code 582), and David Kobe (The Hammers Company)

NASA Unified WRF by Christa Peters-Lidard, Jospeph Santanello, Sujay Kumar (Code 614.3), Jainn Shi, Wei-kuo Tao, Scott Braun, Toshihisa Matsui (Code 613.1), Qian Tan, Mian Chin (Code 613.3) Shujia Zhou (Code 610.3), WIlliam Lau (Code 613), Benjamin Zaitchik (Johns Hopkins University), and Jonathan Case (ENSCO, Inc.)

The NASA Viz Application Aims to Develop an Intuitive and Highly Interactive Application for the iPad to Showcase the Best Multimedia Content Produced by the NASA GSFC Storytelling Team by Wade Sisler, (Code 130), Joycelyn Jones (Code 551), Carl Hostetter, Richard Mullinix (Code 587), Horace Mitchell, Helen Kostis (Code 610.3), Chris Smith, Michael Starobin (Code 444), and Neema Mostafavi (Code 610.6)

Conductive Structural Adhesive for Spaceflight Applications by David Robinson (Code 543)

Modular Flooring System by Robert Thate (Code 547)

High Interactivity Visualization Software for Large Computational Data Sets by Homa Karimabadi (Code 610.3)

Remote Data Access with IDL by Michael Galloy (Code 407)

ISTP CDF Skeleton Editor by Phillip Williams (Code 670), Reine Chimiak, and Bernard Harris (Code 587)

Laser Radar Through the Window (LRTW) Coordinate Correction Software by David Kubulak, Theodore Hadjimichael, Raymond Ohl, Randal Telfer, Joseph Hayden, and Bente Eegholm (Code 551)

SMAP Radiometer L1B Algorithm Processing for RFI Detection, Using Algorithms Previously Developed in Matlab by Others, Is Converted to ANSI C Code by Elisabeth Brinker (Code 587)

LVGEMS (Low-voltage GEMS): Time-Of-Flight Mass Spectrometry on Satellites by Federico Herrero (Code 553)

Self Spinning Airplane Tire by Armando Morell (Code 544)

Cryogenic Rotary Piezoelectric Motor and Electronics Drivers by Jeffrey Paine (Code 544), Matthew Paine, Patrick McGirt (Dynamic Structures & Materials)

Composite Laminate with Coefficient of Thermal Expansion Matching D263 Glass by David Robinson and Benjamin Rodini (Code 543)

Enhanced Adhesion Multiwalled Carbon Nanotubes on Titanium Substrates for Stray Light Control by John Hagopian, Manuel Quijada (Code 551), and Stephanie Getty (Code 541)

Global Precipitation Measurement (GPM) Operational Simulator (GO-SIM) Core by Justin Morris (Code 180), Charles Rogers (Code 582), Arturo Ferrer (Code 581), Steven Seeger (MPL), Brandon Bailey, Jeffrey Joltes (IRC Federal), and Dan Nawrocki (Athena Sciences)

New Sounding Rocket Flight Performance Analysis Structure for Designing a Vehicle to Meet Desired Flight Performance Objectives by Margaret Fernandez (Code 548)

Weka to Web Coverage Processing Service Translator by Justin Rice and Dan Mandl (Code 581)

Global Precipitation Measurement (GPM) Operational Simulator (GO-SIM) Instrument Simulations by Justin Morris (Code 180), Steven Seeger (MPL), Jeffrey Joltes (IRC Federal), and Dan Nawrocki (Athena Sciences)

ITC Synchronous Communications Bus - 1553 (ITCSB_1553) / GPM Operational Simulator (GO-SIM) 1553 API by Justin Morris, Justin McCarty (Code 180), Steven Seeger (MPL), and Jeffrey Joltes (IRC Federal)

Fabrication of Metallic Mesh Bandpass Filters for IR Astronomy by Ari Brown (Code 553)

Identity Management Service for SensorWebs by Pat Cappelaere and Dan Mandl (Code 581)

Open Geospatial Consortium (OGC Compatible Publish/ Subscribe Service - Basic (OPSB) by Pat Cappelaere and Dan Mandl (Code 581)

Campaign Manager (Alternate Name GeoBPMS) by Pat Cappelaere and Dan Mandl (Code 581)

EO-1 Sensor Planning Service (EO-1 SPS) by Pat Cappelaere and Dan Mandl (Code 581)

EO-1 Sensor Observation Service (EO-1 SPS) by Pat Cappelaere and Dan Mandl (Code 581)

Web Coverage Processing Service (WCPS) by Pat Cappelaere and Dan Mandl (Code 581)

Flood Dashboard by Pat Cappelaere, Matt Handy, and Dan Mandl (Code 581)

Spaceflight Refuelling Tools by Jill McGuire (Code 442)

Patent Applications Filed: 2

Electrospray Ionization for Chemical Analysis of Organic Molecules for Mass Spectrometry by David Franz, Yun Zheng (Code 553), and Stephanie Getty (Code 541)

Discrete Fourier Transform in a Complex Vector Space by Bruce Dean (Code 551)

Provisional Patents Filed: 8

Programmable High-Rate Multi-Mission Receiver for Space Communication by Thomas Drago (Summation Research Inc.)

Processing Multiple Image Feeds from a Rotating System by Tristam Hyde and James Hyde (Code 500)

Prototype Genomics Based Keyed-Hash Message Authentication Code Protocol by Harry Shaw (Code 567) and Sayed Husseing (George Washington University)

Modular Flooring System by Robert Thate (Code 547)

Enhanced Adhesion Multiwalled Carbon Nanotubes on Titanium Substrates for Stray Light Control by John Hagopian, Stephanie Getty, and Manuel Quijada (Code 551)

Apparatuses and Methods to Enable Sub-MHz Precision in Fast Laser Frequency Tuning by Jeffrey Chen, Kenji Numata, Stewart Wu, and Guangning Yang (Code 554)

A High Event Rate, Zero Dead Time, Multi-Stop Time-to-digital Converter Application Specific Integrated Circuit by George Suarez and Jeffrey DuMonthier (Code 564)

Double Pass Laser Ring Amplifier by Steven Li (Code 554)

Patents Issued: 8

Multiple Frequency Optical Mixer and Demultiplexer and Apparatus for Remote Sensing by Jeffrey Chen (Code 540)

Advanced Adhesive Bond Shape Tailoring for Large Composite Primary Structures Subjected to Cryogenic and Ambient Loading Environments by James Pontius (Code 542)

A Compact Magic-T Using Microstrip-Slotline Transitions by Edward Wollack, Terence Doiron (Code 555), Kongpop U-Yen (Code 665), and Samuel Moseley (Code 685)

A Method and Apparatus for Relative Navigation Using Reflected GPS Signals by Ian Cohen and Gregory Boegner (Code 596)

Systems, Methods And Apparatus For Autonomic Safety Devices by Michael Hinchey (Code 585) and Roy Sterritt (University of Ulster Northern Ireland)

Systems, Methods and Apparatus for Generation and Verification of Policies in Autonomic Computing Systems by Michael Hinchey (Code 585), Christopher Rouff (Code 500), Walter Truszkowski (Code 587), James Rash (Code 588), Roy Sterritt (University of Ulster Northern Ireland) and Denis Gracanin (Virginia Polytechnic University)

Optical Source And Apparatus For Remote Sensing by Donald Coyle (Code 601)

Systems, Methods and Apparatus for Quiesence of Autonomic Systems by Michael Hinchey (Code 585) and Roy Sterritt (University of Ulster Northern Ireland)

ICB Awards October 2010- March 2011

Patent Application Awards: 2

Spring Joint with Overstrain Sensor by Peter Phelps and Bryan Gaither (Code 602)

SpaceCube 2.0/Advanced On-Board Data Processor by Thomas Flatley, Allessandro Geist, Daniel Espinosa, David Petrick (Code 587), John Godfrey, and Michael Lin (Code 561)

Board Action Awards: 1

International Polar Orbiter Processing Package (IPOPP) by Patrick Coronado (Code 606.3)

Tech Brief Awards: 47

Global Precipitation Mission (GPM) Visualization Tool for Validation Network Geometrically-Matched Ground- and Space-based Radar Data by Matthew Schwaller (Code 587) and Liang Liao (Code 613.1)

Target Assembly to Check the Boresight Alignment of LIDARS Laser Altimeters, or Any Other Active Sensor by Michael Rodriguez, Vibart Scott, Peter Liiva, Harris Riris (Code 694), John Cavanaugh (Code 554) and Luis Ramos-Izquierdo (Code 551)

Spectroelectrochemical Total Organic Carbon (TOC) Sensor by Samuel Kounaves (Code 600)

JDataDownloader, a Java-based Tool for Downloading Online Data by Mahabaleshwara Hegde (Code 310.2)

Variable Sampling Mapping: A Novel Supplement to Iterative-transform Phase Retrieval Algorithms for Undersampled Images, Broadband Illumination, and Noisy Detection Environments by David Aronstein (Code 551) and Richard Lyon (Code 667)

A Quantum Well Infrared Photodetector (QWIP) Focal Plane Assembly for the Thermal Infrared Sensor (TIRS) instrument on Landsat Data Continuity Mission (LDCM) by Murzy Jhabvala (Code 550), Christine Jhabvala, Audrey Ewin, Ahn La, Larry Hess, and Thomas Hartmann (Code 553)

Mode Selection for Single Frequency Fiber Laser by Jian Liu (Code 663)

Development of a Silicon Wafer Scale Substrate for Microshutters and Detector Arrays by Babu Sachidananda, David Franz, Stephen Snodgrass, Nicholas Costen, and Christian Zincke (Code 553)

Cryogenic Compatible Winchester Connector Mount and Retaining System for Composite Tubes - Adhesive Free by James Pontius (Code 542) and Douglas McGuffey (Code 544)

Mercury Software Toolset for Spatiotemporal Metadata by Bruce Wilson, Giri Palanisamy, Ranjett Devarakonda, Timothy Rhyne, James Green, Chris Lindsley (Code 600)

IMAGESEER (IMAGEs for Science, Education, Experimentation and Research), a NASA Image Database by Thomas Grubb (Code 588), Barbara Milner, and Jacqueline LeMoigne (Code 583)

Low-Noise Large-Area Quad Photoreceivers Based on Low-Capacitance Quad Photodiodes by Abhay Joshi (Code 600)

An Approach to Positively Verify Mating of All Flight Connectors which were Considered or Thought to be Not Verifiable by Radha Pandipati and Marion Enciso (Code 565)

A Low-Cost, Helium-Cooled, Black Shroud for Subscale Cryogenic Testing by James Tuttle, John Francis, Michael Jackson, and Michael DiPirro (Code 552)

ICB Awards October 2010- March 2011

The Invasive Species Forecasting System - Applications/QuickMap by John Schnase (Code 606)

Monitoring of a Digital Closed Loop Feedback Circuit by Richard Katz and Igor Kleyner (Code 564)

Innovative Thermal Control Method for High Current Wire Bundles by Injecting Thermally Conductive Filler Inside Bundle by Juan Rodriguez-Ruiz (Code 545) and Russell Rowles (Code 547)

Spaceflight Ka-Band High Rate Rad Hard Modulator by Jeffrey Jaso (Code 567)

FUSE Mission Planning Tools Using The Sustainable Objective Valuation and Attainability Algorithm by Raymond Lanzi and Scott Heatwole (Code 598)

Iterative Transform Phase Diversity: An Image-based Object and Wavefront Recovery Algorithm by Jeffrey Smith (Code 551)

Optical Fiber Array Assemblies for Space Flight by Adam Matuszeski (Code 544) and Melanie Ott (Code 562)

Two-Stage Winch for Kites and Tethered Balloons/ Blimps by Geoffrey Bland (Code 614.6) and Ted Miles (Code 569)

Strength Enhancement of Composite Bonded Joints using Tape Setback Method by Daniel Polis (Code 541)

Mission Operations Planning and Scheduling System (MOPSS) by Terri Wood (Code 586) and David Hempel (Code 583)

Aperture Mask for Unambiguous Parity Determination in Long Wavelength Imagers by Brent Bos (Code 551)

An Architecture for a 1GHz Digital RADAR by Udayan Malik (Code 564)

Radius of Curvature Measurement of Large Optics Using Interferometry and Laser Tracker by John Hagopian (Code 551) and Joseph Connelly (Code 581)

Low Outgassing Photogrammetry Targets by Benjamin Reed (Code 442) Jason Gross, and Henry Sampler (Code 551)

Dust Mitigation Vehicle by Eric Cardiff (Code 597)

Goddard Mission Services Evolution Center (GMSEC) VCR by Thomas Grubb (Code 583)

Test Port for Fiber-Optic Coupled Laser Altimeter by Luis Ramos-Izquierdo (Code 551), Vibart Scott (Code 694), Harris Riris, and John Cavanaugh (Code 554)

Data Distribution System (DDS) and Solar Dynamic Observatory Ground Station (SDOGS) Integration Manager by Kim Pham (Code 587) and Thomas Bialas (Code 564)

SpaceCube 2.0/Advanced On-Board Data Processor by Thomas Flatley, Allessandro Geist, Daniel Espinosa, David Petrick (Code 587), John Godfrey, and Michael Lin (Code 561)

Monolithic Large Format Infrared Bolometer Arrays With Integrated Optically Reflective Backshorts by Christine Jhabvala (Code 553)

Broadband Achromatic Phase Shifter for Nulling Interferometer by Richard Lyon (Code 667) and Matthew Bolcar (Code 551)

Link Analysis in the Mission Planning Lab (MPL) by Jessica McCarthy (Code 598), Benjamin Cervantes, and Sarah Daugherty (Code 589)

Use of CCSDS Packets Over SpaceWire to Control Hardware using Hardware Compatible with the Software Bus Utilized within the Core Flight Executive (CFE) by Dennis Albaijes, Noosha Haghani (Code 561), Omar Haddad (Code 560), and Michael Blau (Code 582)

Enabling Access to Digital Media for the Profoundly Disabled by Glenn Beach and Ryan O'Grady (Code 600)

Lightweight Magnetic Cooler With a Reversible Circulator by John McCormick and Weibo Chen (Code 500)

10-100 Gbps Offload NIC for WAN, NLR, Grid Computing by Arthur McCabe and Patricia Crowley (Code 500)

A Small, High Reliability Microprocessor for ASIC and FPGA Implementation by Hugh Blair-Smith (Code 564)

Miniaturized Airborne Imaging Central Server System by Xiuhong Sun (Code 583)

Radiation-Tolerant, Space Wire-Compatible Switching Fabric by Vladimir Katzman (Code 561)

Titanium alloy Strong Back for IXO Mirror Segments by Byron Glenn (Code 543) and Chan Kai-Wing (Code 662)

Sci-Share: Social Networking Adapted for Distributed Scientific Collaboration by Homa Karimabadi (Code 586)

Novel Ultralow-Weight Metal Rubber; Sensor System for Ultra Long-Duration Scientific Balloons by Andrea Hill (Code 500)

NBL Pistol Grip Tool (NPGT) - A Lightweight Version of the PGT used in Underwater Training of NASA Astronauts by Michael Liszka (Code 442), Mark Behnke, Matthew Ashmore (Code 540), Tod Waterman (Cdoe 443), and Walter Smith (Code 544)

Software Release Awards: 10

Distributed System Integration Lab Communication Adapter (DSILCA) by Eric Lidwa, Edgar Jackson, (Code 582) and Larry Alexander (Code 584)

Distributed System Integration Lab Interface Unit (DSILIU) by Thomas Jackson, (Code 581), Sara Haugh, Carlos Ugarte, Eric Lidwa, James Dailey, Gregory Menke, Christine Kelly, Edgar Jackson (Code 582), Larry Alexander (Code 584), and Jacob Hageman (Code 596)

Gold Standard Test Set (GTST) by Edgar Jackson, Sara Haugh, Carlos Ugarte, Christine Kelly, Gregory Menke (Code 582), and Larry Alexander (Code 584)

Scenario Scheduler Timeline Execution Application Suite by James Busch (Code 444)

Advanced Spacecraft Integration & System Test Software (ASIST), Front End Data Systems/ Digital History Data Store Software (FEDS/DHDS) by Daniel Grogan, Timothy Ray, Larry Alexander, Edwin Fung (Code 583), Richard Hollenhorst (Code 565), Jeffrey Condron (Code 560), and Thomas Bialis (Code 564)

Core Flight Software (CFS) Memory Dwell Application v.1 by Nancy Schweiss and Maureen Bartholomew (Code 582)

The Invasive Species Forecasting System - Framework by John Schnase (Code 606) and Neil Most (Code 614.5)

The Invasive Species Forecasting System - Architecture and Operation by Peter Ma And Roger Gill (Code 614.5)

The Invasive Species Forecasting System - Applications/QuickMap by Peter Ma, and Roger Gill (Code 614.5)

Generic Reusable Aerospace Software Platform (GRASP) by Susannah Warner (Code 589)

Partnership Agreements October 2010- March 2011

The IPPO is pleased to announce the recent signing of these partnership agreements.

Partner	Technology/ Focus	Type	NASA Goals/Benefits
Lockheed Martin, Orlando, FL	CHARMS testing, demo	Reimbursable Space Act Agreement	The purpose of this Agreement is for Goddard Space Flight Center (GSFC) to provide LMCO the services necessary to conduct refractive index measurements of two LMCO-supplied sample prisms as technically specified by GSFC. The measurements will be performed using GSFC's Cryogenic, High Accuracy, Refraction Measuring System (CHARMS) facility located in the Optics Branch Infrared Laboratory at NASA's Goddard Space Flight Center. The current capabilities of the CHARMS facility include: absolute (i.e. in vacuum) refractive index measurements at wavelengths from 0.4 μm to 5.6 μm and at temperatures ranging from as low as 20K (depending on thermal properties of the sample) to 320K. Typical absolute measurement accuracies are in the range 0.0001-0.00001 (10^-4 – 10^-5) depending on measurement conditions and optical material characteristics of the sample. The two sample prisms are: Prism 1: fused silica, prism apex angle: 59.0 degrees; and Prism 2: zinc selenide, prism apex angle: 29.0 degrees.
Johns Hopkins University, Baltimore, MD	cFE/CFS	Non-Reimbursable Space Act Agreement	The purpose of the NASA GSFC and Johns Hopkins University Applied Physics Laboratory (JHU-APL) collaboration is to enhance NASA GSFC's Flight Executive (cFE) component architecture to support memory protection. This effort will minimize cost and risk for upcoming missions by leveraging respective experiences for developing spacecraft software architecture systems. The outcome of the work will produce a pre-release version of the cFE that supports memory protection. This pre-release version of cFE will be compatible with existing cFE target platforms and be ready for inclusion in a future official cFE release with minimal modifications for use on future missions.
Juxtopia, Baltimore, MD	STEM and technology marketing partnerships	Non-Reimbursable Space Act Agreement	The purpose of this Agreement is to establish a partnership between NASA GSFC and Juxtopia to collaborate on an Urban Space Entrepreneurship (USE) initiative. The objective of the USE initiative is to facilitate collaborations between industry and academic entities interested in utilizing NASA technologies for commercial applications that have potential to motivate science, technology, engineering and math (STEM) interest in space-based research and development (R&D). The partnership will also help to educate industry and academic entities on how to pursue entrepreneurial activities using NASA GSFC technologies. Additionally, NASA and Juxtopia will collaborate to target industry and academic entities that are unfamiliar with and interested in learning more about NASA GSFC's Technology Transfer Program. Specifically, The Juxtopia Group's USE initiative will collaborate with Historically Black Colleges and Universities (HBCUs), Minority Serving Institutions (MSIs), and small businesses about the benefits and processes of technology transfer and technology commercialization with NASA GSFC.
Flight Landata, North Andover, MA	DDL (Interested in developing the TIRS LWIR QWIP Sensor technology)	Reimbursable Space Act Agreement	The purpose of this agreement is for NASA and Flight Landata to work together on the development of a sensor utilizing two GSFC's technologies. By engaging into this activity GSFC will be enabling technology development to benefit the science community by demonstrating the uses of this advance new technology. This collaboration has also opened up the potential commercialization of this technology/ component which will amortize costs and yield a capability that can be utilized in other activities and missions at NASA.
Mindrum Precision, Rancho Cucomonga, CA	Miniaturized Double Latching Solenoid Valve (GSC 15039-1)	Non-Reimbursable Space Act Agreement	NASA GSFC and Mindrum Precision Incorporated collaborated to fabricate NASA's patented Miniaturized Double-Latching Solenoid Valve technology for use on NASA's Sample Analysis at Mars (SAM) instrument suite testbed. Mindrum and NASA GSFC have also executed an exclusive patent license to the Miniaturized Double-Latching Solenoid Valve technology and the collaboration assisted in the transfer of "know-how" from NASA GSFC to Mindrum, while at the same time providing Mindrum personnel for hardware fabrication support to the SAM project

Members of GSFC's Wavefront Sensing and Control Group, clockwise from bottom left: Dr. Matt Bolcar, Dr. Ron Shiri, J. Scott Smith, Dr. Timo Saha, Dr. Bruce Dean, and Dr. David Aronstein.

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