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OPTIMIZE USE OF SPACE RESEARCH AND TECHNOLOGY FOR MEDICAL DEVICES

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ABSTRACT

NASA's Earth and space science programs rely on advanced instruments, telescopes, various complex software systems, and cutting-edge component technologies to conduct a wide range of scientific observations and measurements. These technologies are also considered for practical applications that benefit society in remarkable ways.

At NASA Goddard, the technology transfer initiative promotes matching technologies from Earth and space science needs to targeted industry sectors. This requires clear knowledge of industry needs and priorities and social demands. The process entails matching mature technologies where there are known innovation challenges and good opportunities for matching technology needs. This requires creative thinking and takes commitment of time and resources. Additionally, we also look at applications for known hot industry or societal needs. Doing so has given us occasion to host discussions with representatives from industry, academia, government organizations, and societal special interest groups about the application of NASA Goddard technologies for devices used in medical monitoring and detection tools. As a result, partnerships have been established. Innovation transpired when new products were enabled because of NASA Goddard research and technology programs.

I. TECHNOLOGY TRANSFER AT NASA GODDARD SPACE FLIGHT CENTER

NASA Goddard represents the largest talent pool of Earth and space scientists and engineers in the world. Over the years, these innovators have produced a vast array of inventions and technologies, in fields as diverse as physics, chemistry, optics, robotics, communications, data collection and processing, and many, many others. The primary purpose of this work is to support NASA space and Earth science missions, including the Hubble Space Telescope, the currently active Curiosity Mars rover, and the upcoming James Webb Space Telescope.

Although initially created solely with NASA missions in mind, these technologies offer enormous potential for providing other benefits to society. NASA Goddard inventions have frequently been "spun off," adapted and repurposed to address problems and issues of global concern, often in ways that the inventors themselves may have never imagined. In this way, the Space Program provides an invaluable service to the public, a process that is actively encouraged throughout NASA Goddard and all other NASA Centers.

I.I NASA Goddard Innovative Partnerships Program Office

One of the roles of the NASA Goddard Innovative Partnerships Program (IPP) Office is to facilitate this technology transfer process. The NASA Goddard IPP Office's core responsibilities include actively encouraging and managing technology transfer to extend the application of NASA Goddard technologies to uses that will serve the public good. This often involves intellectual property (IP) management to protect NASA Goddard's inventions.

In performing these responsibilities, the NASA Goddard IPP Office helps NASA Goddard fulfill an important mandate that applies to all public branches of the U.S. Government. The U.S. has long realized the critical importance of ensuring that technologies developed through publicly funded research and development be made available for non-governmental purposes. [*]

I.II Legislation Promoting U.S. Government Technology Transfer

To achieve this goal , the Government has enacted several pieces of legislation, including the following:

- Stevenson-Wydler Technology Innovation Act of 1980 states that "[i]t is the continuing responsibility of the federal government to ensure the full use of the results of the Nation's federal investment in research and development. To this end the federal government shall strive where appropriate to transfer federally owned or

[*] See the author's paper IAC-09.E5.1.3, "Leveraging NASA Technology."

originated [non-classified] technology to state and local governments and to the private sector." The primary goal of the Act is to ensure that technology transfer is an explicit component of each governmental agency's mission.[†]

- Federal Technology Transfer Act of 1986 amended Stevenson-Wydler to ensure that responsibility for technology transfer resides with every federal laboratory scientist and engineer. This Act mandates that technology transfer is part of employee performance evaluations.[‡] In response to this Act, the Federal Laboratory Consortium for Technology Transfer (FLC), a nationwide network of federal laboratories for linking laboratory mission technologies and expertise with the marketplace, was created.[§]

- Bayh-Dole Act of 1980 provides U.S. universities, small businesses, and non-profit organizations intellectual property control of their inventions and other intellectual property that results from government-funded research. This allows these entities to pursue ownership of their invention in preference to the government.[**]

- Technology Transfer Commercialization Act of 2000 Act simplified the process for U.S. federal agencies to license their inventions. The Act decreased the time necessary to obtain an exclusive or partially exclusive license on federally owned patents. The legislation also allows licenses for existing government-owned inventions to be included in Cooperative Research and Development Agreements (CRADAs).[††]

These and similar legislative acts comprise an overarching mandate for NASA to ensure the technologies it develops are made available for public use. The NASA Goddard IPP Office helps NASA Goddard fulfill this mandate by providing a spectrum of services that foster technology transfer, collaboration, and partnership between NASA Goddard and outside entities.

II. NASA GODDARD INNOVATION

NASA Goddard research is "all about the science." First and foremost, NASA scientists and engineers are dedicated to developing mission-critical solutions. These missions include some of NASA's most noteworthy past and current successes, as well as several high-profile missions of the future.

II.I Science for NASA Goddard Missions

For example, NASA Goddard has developed numerous in-house technologies to support the Hubble Space Telescope and its future successor, the James Webb Space Telescope. Both instruments rely on image processing developed at NASA Goddard to obtain the most information possible from each captured raw image. In addition to its obvious value in space exploration and astronomy, image processing is also critical to Earth science involving the monitoring of our planet's surface features, in fields such as agriculture and energy production. And many of these image processing technologies can be applied to other terrestrial applications.

One mission currently in the headlines is the Curiosity rover on Mars. Curiosity carries an instrument known as the Sample Analysis at Mars (SAM) built by NASA Goddard. SAM allows scientists to check for organic molecules on the Martian surface. SAM can detect a fainter trace of organics and identify a wider variety of them than any instrument yet sent to Mars. It also can provide information about other ingredients of life and clues to past environments. Similarly, NASA Goddard's In Situ Wet Chemistry Laboratory is currently being developed to detect and analyze biological molecules in a sample for missions to Mars and other Solar System bodies.

Fig. I. Curiosity Rover on Mars

[†] "Stevenson-Wydler Technology Innovation Act of 1980," U.S. Department of Agriculture web site, http://www.csrees.usda.gov/about/offices/legis/techtran.html
[‡] "Federal Technology Transfer Act," Cuyamaca College web site, http://www.cuyamaca.net/cuyamaca/academic/dept/envt/tech_transfer/3c-federal.htm
[§] Federal Laboratory Consortium for Technology Transfer web site, http://www.federallabs.org/home/about/
[**] Bayh-Dole Act web page, http://b-d30.org/
[††] "Technology Transfer Commercialization Act," IT Law Wiki web site, http://itlaw.wikia.com/wiki/Technology_Transfer_Commercialization_Act

Another mission, the Solar Dynamics Observatory (SDO), was recently featured in *National Geographic Magazine*.[‡‡] The SDO helps monitor activity on our Sun, allowing Earth-based scientists to detect and predict solar storms. In addition to the scientific aspect of this research, such predictions could have a very important practical application for identifying potential risks to our satellites, terrestrial energy and communication grids, and other delicate electronics systems. Another solar-related mission is the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI). This instrument has significantly advanced understanding of solar flares since its launch in 2002. Data gathered by RHESSI has revealed how magnetic fields in the vast expanse of the solar atmosphere may be the force that drives these immense explosions.

The innovators supporting these missions have taken the necessary action to disclose their innovative technologies to the NASA Goddard IPP Office. This allows assessment of the technologies to ensure (1) the best possible opportunities are considered, and (2) there is follow-through to achieve technology transfer to benefit societal needs.

II.II Keeping Abreast of NASA Goddard Innovations

As NASA Goddard scientists and engineers work to support many other projects that require the development of state-of-the-art technologies; their success in meeting mission engineering and technology designs for scientific research is an ongoing process that yields many new inventions being developed each year. In fact, over the period of NASA's 2007 through 2011 fiscal years, the overall trend of new technology reporting at NASA Goddard has increased significantly.

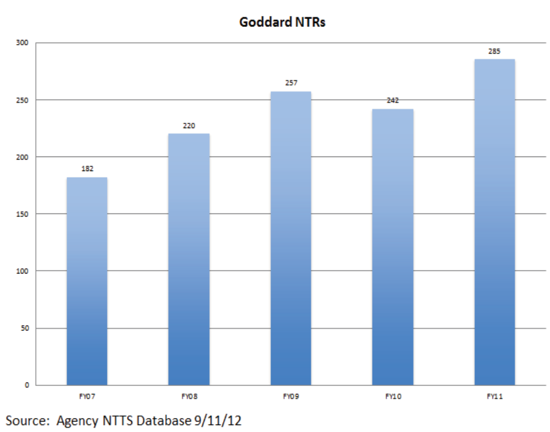

Fig. II. NASA Goddard New Technology Reports, FY 2007 through FY 2011

This is encouraging as it improves the opportunity for many more space based technologies to be transferred.

At the same time, the U.S. legislation cited earlier in this paper requires NASA Goddard to be ever-mindful of the need to ensure that all these technologies are eventually made available for use within the public sector. Ensuring that both these objectives are met – the timely development of new mission-critical technology, and the eventual transfer of this technology – is a key goal of the NASA Goddard IPP Office.

To meet this goal, the NASA Goddard IPP Office proactively works with NASA Goddard innovators to ensure that each invention is properly acknowledged and recorded. This is an essential first step towards making sure that every new technology is given the opportunity to be made available for use outside NASA Goddard. The NASA Goddard IPP Office meets regularly with scientists and engineers, to stay current with their research areas and all ongoing developments within those areas. This involves a formal systematic procedure used at NASA Goddard known as the New Technology Assessment (NTA) process. Through regular meetings and other communications, the NTA process allows the IPP Office to maintain an up-to-date understanding of the technologies NASA Goddard innovators (both civil servants and contractors) are developing.

II.III Partnering with Intermediaries to Evaluate a Technology's Potential

Evaluating the potential for a new NASA Goddard technology can be challenging. In many cases an innovation may be suitable for applications that have little to do with space science. Giving due consideration to all possible uses of an invention often requires a great deal of imagination and a wide variety of perspectives. It also requires a thorough and up-to-date understanding of societal demands and industry trends. This allows the NASA Goddard IPP Office to match the most appropriate available technologies to the most pressing areas in which they may be of use.

The NASA Goddard IPP Office often collaborates with intermediary partners when evaluating the potential utility of NASA Goddard technologies. These intermediaries, who frequently represent a specific region, market segment, or portion of the community, can be essential for helping to identify how and by whom a new NASA Goddard could be leveraged.

For example, there are numerous NASA Goddard technologies (such as control software and sensors) that offer significant potential to manufacturers. To help ensure that potential partners in the manufacturing sector are matched to the appropriate technologies, the NASA Goddard IPP Office collaborates with institutions and organizations whose mission is to help support and

[‡‡] Timothy Ferris, "Sun Struck," *National Geographic*, September 2012.

develop manufacturing and technology on a national or regional level.

The NASA Goddard IPP Office also makes special effort to hear from all possible perspectives. NASA Goddard routinely collaborates with organizations and agencies dedicated to supporting business development and opportunities within traditionally under-represented segments of the population that have not always received the prominence and stature within industry that might otherwise be merited.

Small businesses often make excellent commercialization targets for NASA Goddard technologies, particularly those ideally suited for specialized niche markets and applications. To reach small companies, the NASA Goddard IPP Office works with organizations dedicated to the promotion and development of small technology businesses in a particular state or region.

The NASA Goddard IPP Office also partners with other entities. For example, NASA Goddard is collaborating with the University of Baltimore's Merrick School of Business to analyze and consider the commercial potential for a variety of NASA Goddard technologies. The goal is to equip the students with sufficient technical background about the invention and its capabilities to define potential new uses for it. In return, NASA Goddard will receive formal reports, assessments, and commercialization recommendations from the University.

II.IV Protecting Intellectual Property

Protecting NASA Goddard intellectual property (IP) is another important consideration for the technology transfer process. IP protection improves the potential value of a technology to prospective commercialization partners. It is also useful for technologies which NASA Goddard plans to freely distribute, since it can prevent any other entity from filing a patent on the same invention and claiming it at their own.

The NASA Goddard IPP Office works with NASA Goddard's Office of Patent Counsel to help define which technologies are good candidates for IP protection. In many cases, a technology is determined to be appropriate for patenting and eventually becomes part of NASA Goddard's overall IP portfolio. The NASA Goddard IPP Office also helps to answer any questions innovators may have about the patenting process and how it applies to their inventions. This is an especially timely topic in the U.S., which is currently in the process of implementing many sweeping changes to its patenting processes to make them more aligned with international patenting law.

III. TECHNOLOGY TRANSFER EXAMPLES: MEDICAL APPLICATIONS

The multiple areas in which NASA Goddard technologies have been adapted to non-space applications are almost too numerous to list. This section will present examples from one of these areas, medical technologies. It probably goes without saying that advancements in medical devices are of overriding public interest, especially in these days of aging global populations.

NASA has a long history of developing technologies of potential use to the medical profession. Some of these were initially designed with health and safety in mind, such as systems for monitoring an astronaut's vital signs while in orbit. Other technologies have been created for different purposes – often very far removed from terrestrial considerations – and subsequently adapted for medical use.

The following are a few examples of NASA Goddard technologies that have either found their way into the medical field, or offer significant promise to do so in the near future.

III.I From Space Telescopes to Eye Care

The James Webb Space Telescope (JWST) represents one of the most ambitious science missions ever undertaken. JWST presents some unprecedented and unique challenges. For example, the telescope requires a 6.5 meter primary mirror, far too large and cumbersome to easily launch into orbit. So the primary has been designed as a set of 18 hexagonal mirrors with a common center of focus which collectively work like a single, extremely high-precision mirror.

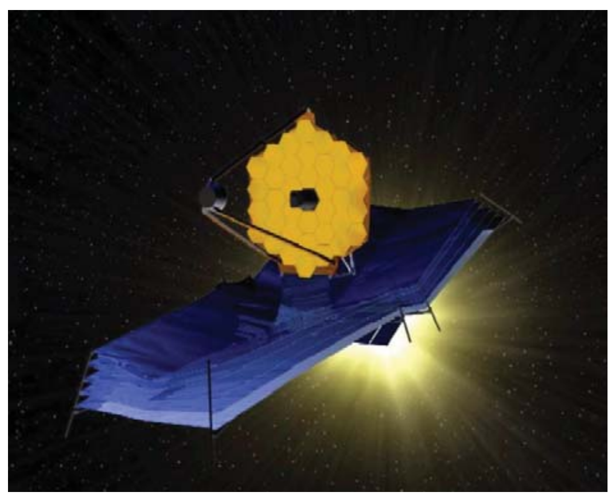

Fig. III. James Webb Space Telescope

To address this challenge, NASA Goddard employs adaptive optics and wavefront sensing. Basically, this involves continuously monitoring the system's optical performance, and making real-time corrections as necessary.

These techniques can be adapted to any application that requires fast image correction, including lasik surgery, confocal microscopy, and medical imaging (MRI already uses active phase retrieval). According to Dr. Dan Neal of Abbott Medical Optics, technology developed for JWST has enabled a number of improvements in measurement technology for measurement of human eyes, diagnosis of ocular diseases, and potentially improved surgery. Eye doctors can use these technologies to get far more detailed information about the shape of the patient's eye, in seconds rather than hours.

NASA Goddard technologies originally developed for the Hubble Space Telescope (HST) have also been adapted to health care. One example is technology designed to enhance HST's images, which has now evolved into a "micro-endoscope" that helps physicians perform micro-invasive arthroscopic surgery with more accurate diagnoses. This enables surgeons to view what is happening inside the body on a screen, eliminating the need for a more invasive diagnostic procedure that could add time, money, and discomfort to a patient's treatment.

The eye care community has begun to recognize other potential benefits of wavefront sensing, including personalized corrective lens which correct for higher order aberrations than can be currently detected. Another potential application is ophthalmology, the second science (after astronomy) to adopt adaptive optics techniques. There are a wide variety of NASA Goddard inventions which could be adapted to the requirements and challenges of optometry and ophthalmology. For instance, the iterative Transform Phase-Retrieval Utilizing Adaptive Diversity is suitable for multiple applications, including as an alternative to interferometers in applications that require wavefront sensing and control. Wavefront calculations occur in the software, making the expensive hardware used in interferometry unnecessary.

III.II Earth Science Technology Adapted to Space Shuttle Damage and Brain Injury Detection

Another very versatile technology developed at NASA Goddard is the Hilbert-Huang Transform (HHT). This is highly efficient, adaptive, and user-friendly set of algorithms used to analyze, encode, or modulate signals or data sets for a multitude of applications. HHT was originally developed as part of NASA's ongoing research into ocean waves. Since its introduction, it has also been used for testing and damage detection for the Space Shuttle orbiters and other structures and vehicles.

The HHT has been licensed by DynaDx Corporation and added to DataDemon, their graphical signal analysis tool. HHT is part of DataDemon's Multimodal Pressure-Flow (MMPF) application module. MMPF is a computational method for analyzing and evaluating autoregulatory dynamics, based on instantaneous phase analysis of non-linear and non-stationary signals from blood pressure and cerebral blood flow velocity oscillations. Medical professionals can use the data from MMPF to create a reliable index of cerebral autoregulation. It can also help identify impairment of cerebral vasoreactivity, caused by medical conditions such as traumatic brain injury or stroke (and associated with other conditions such as hypertension and diabetes).

The MMPF module has potential use for medical diagnosis and prediction in a wide range of clinical settings. One of the many possible applications is a portable device for use by medical personnel at sporting events to identify the extent of head trauma in athletes.

III.III Improving Diagnoses from Medical Images

NASA Goddard scientists have developed a technology called hierarchical image segmentation (HSEG). HSEG was originally developed to enhance and analyze images such as those taken of Earth from space by NASA's Landsat and Terra missions.

Fig. IV. Landsat

HSEG has been adapted to medical imaging. Bartron Medical Imaging has licensed HSEG to enhance its medical imagery products, allowing for quicker and more accurate identification of problematic tissues such as cancer. The technology has now been developed as MED-SEG, a tool to help specialists interpret medical images. MED-SEG has received clearance from the U.S. Food and Drug Administration (FDA) as a Class II Medical Device.

III.IV Mapping Earth – and the Human Body – One Photon at a Time

An advanced micro-pulse, multi-beam, multi-channel instrument that times the flight of single photons has been developed as a pathfinder for next-generation laser altimetry. The upcoming ICESat-2 mission will be the first use of this measurement approach in space.

While NASA will use this technology to map the Earth and planets, someday doctors may use it to map the intricacies of the human body. This technology could probe tissue within the human body, potentially discerning, for example, the difference between non-cancerous and malignant tumors based on the way they scatter and depolarize multi-wavelength laser pulses.

III.V Portable Space Lab May Help Identify Health Risks on Earth

The In Situ Wet Chemistry Laboratory is a lab-on-a-chip device designed for detecting and analyzing biological molecules in a sample. This combines multiple NASA Goddard technologies into a compact, lightweight unit designed for exobiology analysis on Mars, Titan, Europa, or any New Frontiers or Discovery Program missions that focus on the search for biologically relevant organic materials. And by offering the promise of portable, quick identification of DNA, this technology may also be useful in important health applications, such as testing drinking water in the field.

The lab not only offers the potential of detecting whether or not a sample is biological; it could also be eventually developed to the point where it may actually be able to identify whether or not certain DNA is present. This immediately raises a broad spectrum of possible health and medical related applications. For example, this capability could theoretically be used to analyze a sample of drinking water, to detect a variety of dangerous microbes or pathogens. And the fact that this unit is potentially portable means it could be used in the field, for example in remote locations where consuming contaminated drinking water is often the most common means for contracting disease.

III.VI Venusian Camera Technology for Non-Invasion Internal Human Body Examination

Due to the thick Venusian atmosphere, a probe landing on Venus does not use a parachute to control its decent to the surface. Instead, it falls slowly through the dense atmosphere. This creates a challenge to any onboard camera that attempts to stay focused on the probe's landing spot -- it would be very difficult (if not impossible) for a single camera to stay steadily aimed on a single spot or object while the lander is rotating or otherwise moving in unpredictable ways.

To address this challenge, NASA Goddard has preliminarily designed a multi-camera system for the probe. The cameras would have wide fields of view that overlap, thereby ensuring that the desired spot would be within the view of at least one camera at all times. Thus the spot would remain focused and in view at all times, irrespective of how violently or unpredictably the probe rotated. In addition, the system can make use of many small, readily available image chips (such as those used in cell phones) rather than a single expensive unit equipped with heavy, large field-of-view "fisheye" optics. Thus it could be fairly easy and inexpensive to build.

One application of potential interest to the medical community could be internal imaging of the digestive tract. For example, micro-scale imaging chips could be attached to the surface of a pill-sized probe. When the patient swallows the pill, its on-board cameras would provide raw imaging data that could be synthesized into images useful for later analysis by medical specialists. The pill could record and/or transmit the data for later (or even real-time) viewing. In this way, a single pill could image the entire digestive tract; the specialist could then select specific areas to inspect, effectively replaying the journey down the intestines while "joy-sticking" the view to examine areas of interest. This could provide a relatively inexpensive and non-invasive method for internal examination.

III.VII Neutron Imaging

NASA Goddard's Neutron Imaging Camera (NIC) leverages technology developed for the Three-Dimensional Track Imager (3-DTI) device created for gamma-ray imaging. NASA Goddard has had discussions with a medical school concerning NIC and its potential for neutron imaging applications. In recent years, there has been considerable attention devoted to using neutrons for medical imaging, an application in which neutrons possess some significant advantages. For example, they are highly penetrating, offering the potential to image structures deep within the body. They can also be used to identify virtually any chemical element that naturally appears in the human body. Another significant advantage is that neutrons interact very weakly with matter, and thus can be relatively non-destructive to complex or delicate biological tissues. This allows internal organs and other body structures to be examined more safely than with other forms of radiation, such as x-rays. In this way, neutron imaging may eventually be developed as a complementary option among other medical imaging techniques.

III.VIII Solar Observation Technology Improves CT Imagery

As noted previously, NASA efforts to monitor and understand our Sun's activity include the Solar Dynamics Observatory (SDO) and the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI). This latter instrument's spectrometer is outfitted with metal grids incorporated in devices called rotation modulation collimators (RMCs).

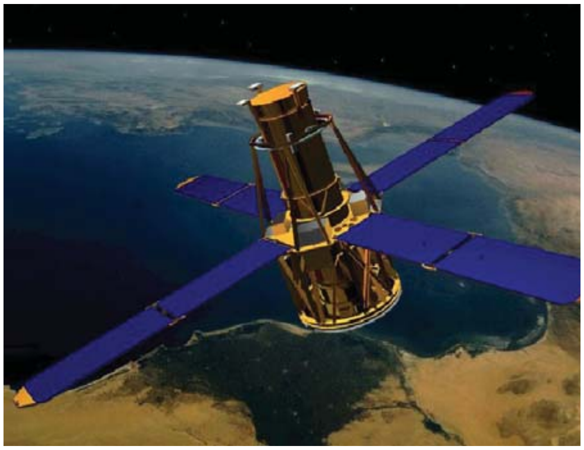

Fig. V. Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI)

This setup requires finely crafted grids. NASA Goddard collaborated with Thermo Electron Tecomet to produce these grids using photoetched tungsten foils built up into precise stack laminations, a process that is now patented.

The company is now applying this technology for computed tomography (CT) machines used to image injuries and other conditions in regions such as the brain, heart, and lungs. These features can lead to newer CT machines that move the detector-carrying gantry around patients at higher speeds and produce more comprehensive imagery.

IV. CONCLUSION

These are only a few examples that demonstrate how NASA Goddard seeks to "optimize use of space research and technology for medical devices." Beyond medical devices, NASA Goddard technologies can be applied to other industry and interests such as:

- Environmental monitoring
- Agriculture
- Food
- Weather and climate
- Transportation
- Energy
- Communications
- Computer science and software
- Manufacturing
- Sports and entertainment
- Health and safety

…and many others. A complete accounting of all the ways NASA Goddard technologies can benefit the public is well beyond the scope of this paper; the goal has been to offer a small representational sampling in one arena of specific (and growing) importance to society.[§§]

A critical point to bear in mind is that in the majority of cases, not a single one of these applications was foremost on the innovators' minds when they developed their NASA Goddard technology. Instead, their primary focus is always on the NASA missions they are tasked to support, and the experiments these missions conduct.

This is why the role of the NASA Goddard Innovative Partnerships Program Office is so critical in fulfilling the U.S. Government's mandate for technology transfer. The NASA Goddard IPP Office continues to ensure that these cutting-edge technologies are provided the widest opportunity possible to address problems and issues here on Earth, even as they serve their original purpose to advance our understanding of the Earth, Solar System, and Universe.

[§§] See also the NASA Spinoff web site, http://spinoff.nasa.gov/.