NASA Goddard Space Flight Center

2002 Director's Discretionary Fund Annual Report

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GSFC Director's Discretionary Fund 2002 Annual Report

EXECUTIVE SUMMARY

The Director's Discretionary Fund (DDF) supports new, cutting-edge ideas, concepts, and activities. There is no way to guarantee that the funded work will result in useful science or technology. But the funded projects, when successful, have high payoff.

In support of this goal, the GSFC DDF funded 50 projects, for a total of about $2.6 million. The projects included both continuations and new inceptions. A few examples are summarized here.

Measuring atmospheric transport of water, carbon, and other quantities is crucial to understand their balance among sea, land, and air. Currently, such measurements are taken at fixed locations, with the danger that these don't adequately sample variation with location. The work done by Houser to develop a miniaturized eddy covariance instrument to make such measurements from small unmanned aerial vehicles (UAVs) is an example of an instrument with development risks, primarily in achieving affordable miniaturization on the scale needed. This work will enable investigation of the complexities of sea-land-atmosphere interactions on scales not previously possible. New miniaturized electronic sensors were used, along with the Global Positioning System (GPS) to build an integrated sonic anemometer, an IR gas analyzer, and a net radiometer that are small enough to be flown on a small, low-flying UAV. This new concept has great potential to change the way such measurements are made in the future, or to validate current methods.

Benford proposed a new approach to measuring position in the dark and cold. He is building a superconducting "capacitance meter" of unprecedented sensitivity and speed. In a cryogenic environment, linear positions should be measurable to a resolution of ~1 nm at an update rate of 100Hz—calculated for a 1-mm separation capacitor—thereby providing ten-fold higher resolution than a typical optical encoder. It features high resolution and high speed, dissipates essentially zero power, and can be used at extremely low temperatures or across temperature boundaries. It can be used where no light is permitted, and has the added benefit of simultaneous temperature measurement. Since this transducer converts a distance measurement into a time measurement, the readout can have the high resolution and broad dynamic range that such time measurements permit. There is no problem in principle in making such an instrument, but it is an open question as to whether practical problems will preclude attaining the specifications cited. For example, the project is currently addressing the issue of unbudgeted capacitance in the inductor.

Finding novel ways to interest, involve, and engage students is often difficult. The Baltimore student Sun Photometer Network (BSSN), being addressed by Holben, is an education and outreach project designed to enhance the science, math, and technology skills of students in elementary, middle, and high schools in Baltimore and vicinity; to improve their understanding of their local environment; and to involve them as partners in an ongoing scientific investigation. The plan is to improve the data set for the Baltimore Children's Asthma Study by having students provide daily local information across the region to allow comparison between clinical and environmental data. In addition, spatial and temporal trends in aerosol loading

regionally are to be identified with school-based retrievals to allow NASA scientists to make atmospheric corrections on a pixel level, and to provide Earth Observing System Moderate-Resolution Imaging Spectrometer (EOS MODIS) and Multiangle Imaging Spectroradiometer (MISR) science teams with a unique data set to validate their aerosol data products. Because of our seed money, BSSN is likely to get outside funding.

Lightweight mirrors are crucial in improving exploration of our planet and space. Bly is developing a process to fabricate lightweight mirrors from single crystal silicon (SCS). A four-inch-diameter mirror, flat to better than one-tenth wave of visible light peak-to-peak and better than one-eightieth-wave rms, was produced. The mirror weighs 82 grams, or approximately one-fourth the weight of a solid quartz mirror of the same size. This mirror is a single monolithic structure of single crystal silicon, making it one of the most homogenous mirrors ever made. Because it is made of silicon it has much better thermal properties than lightweight mirrors made of other materials. An initial patent application was submitted to the U.S. Patent Office in March 2002. A final patent application is presently being prepared. There is now considerable interest from developers of satellite instruments in using his mirrors.

The material that follows is comprised of short reports, each containing text that places the work in a larger context, a description of the work accomplished during FY 2002, and what remains to be done, either to complete the work, or to move it to a next stage.

It is a pleasure to have been able to provide the means whereby this work was accomplished, and to be able to present these results. This is a program that can make real changes in science and technology.

A.V. Diaz
Director

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EARTH SCIENCE AND TECHNOLOGY

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Title of Investigation:	Analysis of In Situ and Remote Sensing Aerosol Absorption Data
Principal Investigator:	Yoram Kaufman/913
Other Investigators/Collaborators:	J. Vanderlei Martins/University of Maryland Baltimore County (UMBC)/Joint Center for Earth Systems Technology (JCET)
Initiation Year:	FY 2001
Funding Authorized for FY 2002:	$60K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $35K Contracts: JCET, $25K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with additional FY 2003 funding (if available)
Expected Completion Date:	FY 2003

Purpose of Investigation

In recent years, black carbon (BC) has gained new importance in the scientific community due to its role in absorbing solar radiation and its large effects on the radiative balance of the atmosphere. Unlike all other aerosol types, BC may produce a warming effect in the atmosphere and on the Earth's surface, causing significant positive radiative forcing of the climate system. Quantitatively, the effects of BC can be estimated as about one-third of the effect caused by CO_2. As part of this effort, the PI proposed a new remote sensing technique in 2002 for the retrieval of aerosol absorption (mainly caused by BC and dust) over the ocean using the brightness of sun glint. The importance of these measurements and the potentiality of this technique made it suitable for the proposal of future satellite missions specially designed for measuring aerosol absorption from space. Although members of this team successfully simulated this methodology in 2001, experimental verification and validation strategies are still sought. This project is attacking the aerosol absorption issue by combining remote sensing and *in situ* measurement techniques. The experimental demonstration of the sun glint technique for the measurement of aerosol absorption from space is being performed using a combination between the Moderate-Resolution Imaging Spectroradiometer (MODIS) sensor on the Terra Satellite and NASA Aerosol Robotic Network (AERONET) sunphotometers. The main objectives for this work are the experimental demonstration of the measurements from space of aerosol absorption over the ocean sun glint, development of *in situ* validation strategies for aerosol absorption measurements, and improvement of basic knowledge of aerosol absorption properties.

FY 2002 Accomplishments

Several oceanic stations were selected around the globe and are used to provide information of optical depth and size of the aerosols over the selected area. The MODIS aerosol algorithm and its look-up tables were modified to fit the Sun glint data and to provide the aerosol single-scattering albedo. This work is successfully ongoing and should soon produce publishable results.

The *in situ* component was motivated by the lack of reliable spectral measurements. A multiple reflection extinction cell was designed and the first prototype was built under this DDF project. The multiple-reflection cell prototype currently has three wavelengths (532, 632, and 795 nm), and a set of mirrors producing about 140 reflections into the aerosol volume. The optical path is about 100 m, and allows good sensitivity for the retrieval of the aerosol extinction coefficient (B_{ext}). Sideways-mounted scattering detectors provide measurement of the light scattering coefficient (B_{scat}); the ratio B_{scat}/B_{ext} is the single-scattering albedo (w_o), which is considered one of the most-important and least-known relevant parameters useful for determining aerosol radiative forcing of climate.

A spectral reflectance technique, covering the range 350 - 2500 nm was applied to the measurement of spectral absorption efficiencies in size-resolved aerosol particles from several different sites including the Amazon (for biogenic and biomass burning aerosols), urban areas (Saő Paulo, Santiago del Chile, and the U.S. East Coast), and Antarctica. To our knowledge there is no previous measurements of aerosol absorption efficiency in this spectral range. These measurements have proved to be accurate and fairly sensitive, allowing measurement of aerosol absorption even under background conditions (*e.g.*, wet season Amazon Basin, and Antarctica). The Amazon Basin results show very strong absorption efficiency due to biogenic aerosols and evidence of dust absorption during transport episodes from the Sahara Desert. Urban aerosols from Saő Paulo and Chile show significant absorption in the coarse-mode aerosols, and a comparison between the absorption efficiency of U.S. and Saő Paulo aerosols shows a factor of 10 greater absorption in Saő Paulo than over the U.S. East Coast, emphasizing basic differences between aerosols produced in developed countries and countries under development.

Some results of this project will be presented in the European Geophysical Society – American Geophysical Union – European Union of Geosciences (EGS-AGU-EUG) Joint Assembly, in April 2003, in Nice, France.

Planned Future Work

The experimental demonstration over the sun glint is starting to provide good results and will be performed over several worldwide locations and different types of aerosols and conditions. *In situ* measurements will be performed in upcoming field experiments, and will help in characterizing intrinsic properties of aerosols. The extinction cell prototype will be finished in FY 2003, and will serve as a standard instrument for aerosol measurements.

Title of Investigation:	New Lidar Technique to Measure Direct and Indirect Effects of Aerosols
Principal Investigator:	David Whiteman/912
Other Investigators/Collaborators:	Igor Veselovskii/Physics Instrumentation Center, Troistk, Russia; Belay Demoz/912; Oleg Dubovic/University of Maryland, Baltimore County (UMBC)
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$50K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $10K Grants: Igor Veselovskii/UMBC, $40K
Status of Investigation at End of FY 2002:	To be continued in FY 2003, with additional (FY 2003) funding: $50K
Expected Completion Date:	FY 2004

Purpose of Investigation

This proposed work was to develop, to test, and use a new lidar technique remotely and simultaneously to quantify aerosol and cloud droplet properties. The method consists of combining two different remote sensing techniques into the same multi-wavelength lidar instrument: multi-wavelength retrieval of aerosol properties and retrieval of cloud droplet properties. Together, these techniques will permit retrieval of aerosol size distribution, refractive index, volume density, cloud droplet number density, and cloud droplet radius, among other parameters. This combined set of measurements would allow remote studies of the indirect effects of aerosols on clouds in a manner never before possible. Such measurements would also provide insight into fundamental cloud physics involved in cloud droplet nucleation processes.

FY 2002 Accomplishments

A prototype receiver system providing all necessary measurements for simultaneous remote detection of both aerosol and cloud properties was constructed and tested in the Code 912 Raman lidar laboratory at GSFC. This work was published by I. Veselovskii, A. Kolgotin, V. Griaznov, D. Muller, U. Wandinger, D. N. Whiteman, "Inversion with regularization for the retrieval of tropospheric aerosol parameters from multiwavelength lidar sounding" *Applied Optics 18,* 41, 3685-3699 (2002). Dr. Whiteman received the Optical Society of America Allen Prize for 2001.

Planned Future Work

The second-year continuation of this activity will focus on developing algorithms to simultaneously analyze the multi-wavelength aerosol data and the Raman liquid water data. Lidar instrumentation will be operated from GSFC to acquire data simultaneously with Aerosol Robotic Network (AERONET) measurements to validate aerosol-sizing retrievals. Retrievals of liquid cloud properties will also be studied, using results from cloud physics models as validation.

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Title of Investigation:	Development of Prototype Holographic Fabry-Perot Filters for Daytime Lidar Measurements
Principal Investigator:	Matthew McGill/912
Other Investigators/Collaborators:	Redgie Lancaster/Goddard Earth Sciences and Technology Center (GEST)
Initiation Year:	FY 2001
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years:	$50K
Funding Authorized for FY 2002:	$25K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $50K Contracts: Various vendors, $3K; GEST, $17K
Status of Investigation at End of FY 2002:	Completed in FY 2002
Expected Completion Date:	Completed July 2002

Purpose of Investigation

Lidar systems are becoming increasingly important in remote sensing of environmental parameters. While narrow bandwidth filtering in the receiver is needed for most types of lidar systems, very narrow bandwidth filters are essential for daytime measurements. Developing and miniaturizing such lidar systems is hampered by a lack of small, rugged, tunable, and inexpensive filters. Further, developing spaceborne lidar systems is critically dependent upon having a filter mount capable of withstanding launch vibrations without degrading the optical quality of the filter.

Developing high-quality Fabry-Perot etalon filters is critical to advance lidar technology generally, and to the success of future spaceborne atmospheric lidar missions. This is especially true in developing instruments capable of daytime operation. In such cases, it is the Fabry-Perot type etalon that provides the filtering needed to detect the atmospheric return signal against the contamination of strong background emissions. A conventional Fabry-Perot etalon filter consists, basically, of a pair of partially reflecting mirrors. This apparent simplicity is deceptive, as proper performance of this device requires very strict alignment of these mirrors, a quality that is typically defeated by even the most non-intrusive of mount assemblies. Consequently, the cost of developing robust, high-quality etalons quickly reaches several tens to hundreds of thousands of dollars.

Holographic etalons offer an attractive alternative to the difficulties and cost that accompany the use of these conventional etalon devices. The primary advantage offered by a holographic etalon is that the mirrors exist within a holographic emulsion and not on the surface of a substrate. As a result, the holographic etalon is not as sensitive to surface roughness and external strains such as those imposed by the mounting apparatus. However, actual development of high quality holographic etalons has not previously been achieved.

The purpose of this DDF effort is to develop high-quality solid and air-gap holographic etalons; the initial emphasis is on solid etalons.

FY 2002 Accomplishments

During FY 2001, several solid etalons with dichromated gelatin holographic emulsions were designed and evaluated. Prototype holographic solid etalons were demonstrated with efficiency of ~40% over small apertures. The optical performance was lower than anticipated due to irregularities in the holographic emulsion. While at least one of the etalons performed quite well over small (~1 cm) subapertures, reaching peak transmission of >40%, this performance is still not at the desired level. After examining the details of the preparation and exposure processes, it was determined that greater care in preparation and more careful control of the exposure process would likely yield etalons that meet the expected performance of >80% transmission over a two-inch aperture.

During FY 2002, the exposure process was refined, and anticipated performance targets for solid etalons were met. Measured instrument functions over the entire aperture (1.5 inches) were nearly identical to those measured using small apertures. Samples with peak transmission as high as 80% over the full aperture were generated. Procedures and test processes were thoroughly documented. A patent disclosure is being prepared for submission. A journal paper is in preparation for submission to either *Applied Optics* or *Optical Engineering*.

Planned Future Work

The next focus of this work will be to develop a piezoelectrically tuned version that can be used for spectroscopic applications.

Title of Investigation:	Fiber Optic Raman Laser Amplification for Remote Sensing Spectroscopy
Principal Investigator:	Mark Flanegan/554
Other Investigators/Collaborators:	J. Ken Vanhille/Utah State University
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$30K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $30K
Status of Investigation at End of FY 2002:	Completed in FY 2002
Expected Completion Date:	FY 2002

Purpose of Investigation

This work was proposed to model and to develop a fiber Raman amplification system that will amplify light at the water vapor absorption line of 935.68 nm using a low-power semiconductor source as the master oscillator and a Raman fiber amplifier as the power oscillator.

FY 2002 Accomplishments

A mathematical model was developed of the Raman amplification at 935 nm using parameters from available pump lasers, fibers, and sources. The components were purchased and a breadboard power amplifier was constructed. Experiments were conducted to determine the best method of coupling light into the fiber and the efficiency of coupling from the pump laser. Getting a pump laser with sufficient power in the 900 nm region to amplify in the 935 nm region proved more difficult than expected. It proved impossible to raise the efficiency of coupling into the fiber to a level sufficient to overcome the relatively low power output of the pump laser. As a result, other options were investigated which could provide either higher power fiber optic pump lasers at 900 nm or much higher power pumps or sources for signals in the 1300 nm region. Discussions were opened with vendors to discuss these options.

Planned Future Work

Discussions will continue with selected vendors to address the options described above. Should suitable technologies be found, the work will continue.

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Title of Investigation:	Global Carbon Cycle: Development of a Bicarbonate Ion Lidar
Principal Investigator:	Frank E. Hoge/972
Other Investigators/Collaborators:	E.G. & G.
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$76K
Actual or Expected Expenditure of FY 2002 Funding:	In-house: $24K Contracts: E.G. & G., $12K; to-be-selected laser and monochromator manufacturers, $40K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with additional (FY 2003) funding, $52K (estimated)
Expected Completion Date:	FY 2003

Purpose of Investigation:
This work was proposed to develop an airborne lidar system to sense remotely the bicarbonate ion by measuring the intensity of its laser-induced Raman emission relative to the concurrent water Raman signal. Initially, laboratory investigations are required to determine the signal strengths and other concerns associated with remote measurement of the bicarbonate ion Raman signal.

FY 2002 Accomplishments
An existing laser spectrometer was reconfigured to perform measurements of saturated solutions of sodium bicarbonate. The carbonate ion Raman emission was observed in the laboratory down to a 12% solution. The preliminary laboratory configuration very successfully defined new improvements to accomplish the observation of 100 times lower concentrations, commensurate with natural sample concentrations.

Planned Future Work
To reach the goal of 0.1% saturation, new holographic filter configurations are planned to allow better rejection of the on-wavelength laser radiation scattered into the spectral regions occupied by the bicarbonate ion. A more optimum 90^0 laser excitation/Raman-emission configuration will accompany the new filter. A liquid core optical fiber system will be investigated to increase the signal-to-noise ratio. Upon reaching the required signal level, dilute solutions will be replaced with actual seawater samples to determine the impact of chromophoric dissolved organic matter (CDOM) fluorescence emission falling within the bicarbonate ion Raman emission bands. A new double monochromator and new laser(s) will be used to enhance the laboratory detection of the bicarbonate ion Raman emission and thereby assess the feasibility of its measurement from remote platforms.

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Title of Investigation:	Snowfall Inference from Microwave Radiometry
Principal Investigator:	James Weinman/975
Other Investigators/Collaborators:	Gail Skofronick Jackson/UMBC, Robert Houze, University of Washington
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$30K
Actual or Expected Expenditure of FY 2002 Funding:	Contract: University of Washington, $30K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with additional FY 2003 funding (if available)
Expected Completion Date:	To be continued with remaining funding from FY 2001 and funding from other sources

Purpose of Investigation

Snowfall is a significant aspect of weather at mid-latitudes: its presence can impede transportation, and thaws can contribute to flooding. On the other hand, there are benefits to snowfall, as agriculture and hydroelectric power generation depend on it. Its importance is also felt in climate models, as latent heating from snowfall and other frozen particles is a significant geophysical parameter. This study was proposed to use atmospheric microwave brightness temperature observations to retrieve characteristics of snowfall and frozen hydrometeors over landmasses. The relationships between snowfall rates and microwave brightness temperatures are both under-constrained and nonlinear. The retrieval problem is especially challenging over land where surface features—such as antecedent snow accumulated on the ground—can affect ground emission at frequencies less than ~100 GHz. Nonetheless, spaceborne microwave measurements above a blizzard at frequencies greater than 100 GHz suggest that snowfall can be retrieved over land because water vapor in the lowest layers of the atmosphere obscures emission from the snow-covered ground. Water vapor in the upper atmosphere also affects microwave radiation from a snowing atmosphere; it, too, must be part of any retrieval.

FY 2002 Accomplishments

Ms. M.J. Kim, the student supported by this grant, finished her M.Sc. degree in the Atmospheric Science Department of the University of Washington. A paper is in preparation for publication. Ms. Kim worked with the radiative transfer model that is part of the GSFC PROFiling (GPROF) algorithm to retrieve precipitation. In the course of that study, she introduced the effect of melting snow in the GPROF (V-5) model. She also improved several other components of the GPROF algorithm, such as adapting the range of cloud models used in the Bayesian retrieval. Her study improved the surface rainfall retrieved over Kwajalein. The results of her work were presented at the Hawaii Tropical Rainfall Measuring Mission International Science Conference.

Ms. Kim has been accepted as a Ph.D. candidate and has begun her doctoral research based on this work. Ms. Kim's study yielded a provisional model—based on the MM5 mesoscale model and an Eddington radiative transfer model—to retrieve the frozen hydrometeor distribution in the atmosphere from microwave radiation measured at several frequencies greater than 100 GHz. Those inferences have been crudely validated with ground-based radar measurements.

Planned Future Work

Appropriate microphysical models of snow are needed. This includes determining realistic size distributions, shapes, and particle density profiles. The plan is to determine what assumptions can be made and what information should not be assumed. For parameters that cannot be measured, statistics from other investigations and literature searches will be used or necessary components of field campaigns will be identified for future experiments.

Electromagnetic (EM) models of snow will also be needed. Although dielectric mixing theories have been used to describe microwave EM properties at low to moderate frequencies, they are not appropriate to describe mm-wave properties of large particles. The equivalent sphere representation of scattering by anisotropic particles that was developed by Grenfell and Warren in 1999 to describe the IR properties of cirrus clouds will be adapted to millimeter-wave frequencies.

Knowledge of the characteristics of frozen hydrometeor profiles is needed to determine latent heating budgets and to improve cloud model simulations. The understanding gained from these studies will be needed to develop extra-tropical frozen precipitation retrievals for the forthcoming Global Precipitation Mission (GPM).

Title of Investigation:	A New Approach for Measuring Ozone from the Ground
Principal Investigator:	Scott Janz/916
Other Investigators/Collaborators:	Gordon Labow/916, Nader Abuhassan/916
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$52K
Actual or Expected Expenditure of FY 2002 Funding:	In-house: $37 K Contracts: Science Systems & Applications Incorporated (SSAI), $15K
Status of Investigation at End of FY 2002:	To be continued in 2003 with remaining funds
Expected Completion Date:	FY 2003

Purpose of Investigation

This work was proposed to develop, build and test a new ground-based instrument that will measure total column ozone, ozone profiles, and aerosol optical depths. The instrument is to be portable, inexpensive, fully automated, easily calibrated, and to require minimal human supervision. Current ozone measurement instruments are large, expensive, and require significant manpower to operate, maintain, and calibrate. Since many government agencies (and private industry) are under pressure to reduce spending, the costs of purchasing and operating such existing instruments are unacceptable, and many atmospheric monitoring programs are, therefore, cutting back on personnel and hardware. Conversely, acquiring and maintaining long-term ozone measurements would be facilitated by development of an instrument such as is described here.

FY 2002 Accomplishments

An initial prototype, called the Goetz Filter Radiometer (GFR) has been built and is fully operational. There have been many iterations of optical design, detector, micro-processor and filter selection, as well as mechanical refinements, and weather-proofing concerns. The preliminary version of the operating software to control the unit has been developed and refined. The instrument's power source has evolved from an A/C cable to a small solar cell and battery, enabling the instrument to be completely standalone and requiring no infrastructure whatsoever. The current unit is approximately 15 cm in diameter, 30 cm in length, and weighs slightly under 3 kilograms. Initial calibration results indicate that the photodiode detectors and ion-assisted deposition (IAD) filters are very stable and the instrument's response is highly linear. The first version of a retrieval algorithm based on radiance lookup tables has been constructed and tests are under-way to determine the accuracy of this method. The retrieved column ozone and aerosol optical depth values appear to be consistent with those measured by the Goddard Brewer spectrophotometer and Cimel sun photometers from the Aerosol Robotic Network (AERONET).

This work resulted in presentation of a paper, "The Goetz Filter Radiometer: A new Instrument to Measure Total Ozone

and Ozone Profiles from the Ground", at the National Detection of Stratospheric Change (NDSC) meeting in Acachon, France 20-25 Sept, 2002.

Planned Future Work

A second (and final) prototype will be completed with a new design, updated software, and new IAD filters. The instrument will be smaller and more portable than the first (8 cm in diameter, 20 cm tall, and weighing 1kg). It will be more easily programmable with a RS-232 computer interface, and will be constructed more ruggedly to survive rough handling and harsh weather conditions. Remaining FY 2002 funds have already been committed to machine the instrument's outer shell and optical housing. Calibration work will be done at no cost in Code 916's state-of-the-art Radiometric Calibration and Development Facility (RDCF). Absolute radiometric calibrations and wavelength and detector linearity calibration will be performed at routine intervals using NIST-traceable standard lamps, integrating spheres, and tunable dye lasers. The majority of the unfinished work deals with the retrieval algorithm(s). Algorithm work will continue and the retrieval methodology will be refined in order to achieve highly accurate total ozone and aerosol optical depth measurements. Ozone profiles (measured by the "umkehr" effect) are much more difficult, and work with standard "maximum likelihood" methods as well as neural network retrievals is just beginning. This second (and hopefully, final) prototype should be completed by mid-year and the retrieval algorithms should be finished by the end of FY 2003.

Title of Investigation:	Retrieval of Harmful Algal Bloom Signatures from Oceanic Radiances
Principal Investigator:	Tiffany A. Moisan/972, Wayne Wright/972
Other Investigators/Collaborators:	Tony Baldwin/584, Robert W. Swift/EG&G Services), Jim Yungel/EG&G Services, Viktor Feygels/EG&G Services
Initiation Year:	FY 2001
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years:	$30K
Funding Authorized for FY 2002:	$44.8K
Actual or Expected Expenditure of FY 2002 Funding:	In-house: $ 35.18K Contracts: EG&G Services, $9.62K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with additional Internal NASA program funding
Expected Completion Date:	FY 2003

Purpose of Investigation

The objectives in this research project were to advance the technological state of aircraft equipment to characterize distinct spectral signatures of harmful algal blooms (HABs) in the ocean using airborne ocean color remote sensing; to identify key spectral band combinations; and to develop algorithms and techniques to identify key taxonomic phytoplankton groups. The purpose was to develop a real-time information platform to remotely sense harmful phytoplankton algal blooms to bridge the operational gap between the needs of coastal research planners and data currently obtained by ocean color remote sensing activities.

FY 2002 Accomplishments

Lightweight aircraft instrumentation was developed, which included an upward- and downward-looking hyperspectral spectroradiometer that will be mounted with an accompanying charge-coupled device (CCD) array and an infrared sensor. Engineering capabilities to develop a lightweight, hyperspectral device to be mounted on a twin- or single-engine plane were implemented. Detailed laboratory measurements have been conducted at new UV wavelengths to enhance the output of chlorophyll *a* algorithms for ocean color remote sensing. Real-time software capabilities for data acquisition of the hyperspectral sensor were conducted, and laboratory tests for integration, time peak wavelength, sensitivity, and signal-to-noise ratios are ongoing.

This work was featured on National Public Radio and Earth and Sky radio, to educate the general population about the importance of harmful algal blooms in the marine ecosystem.

Planned Future Work

Tests will be conducted to examine requirements for integration time and to enhance sensor sensitivity. Development of new techniques and technologies will

continue to allow capture of low-concentration harmful algal blooms in the initial stages of their development. Laboratory tests will continue, and a field test is anticipated for spring 2003.

Title of Investigation:	Quantifying Microwave Transmission through Dynamic Vegetation
Principal Investigator:	Paul R. Houser/974
Other Investigators/Collaborators:	P. O'Neill/974, E. Kim/975
Initiation Year:	FY 2001
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years:	$25K
Funding Authorized for FY 2002:	$30K
Actual or Expected Expenditure of FY 2002 Funding:	Contracts: Goddard Earth & Sciences Technology Center (GEST), $30K
Status of Investigation at End of FY 2002:	Completed in FY 2002
Expected Completion Date:	FY 2002

Purpose of Investigation

This project was proposed to quantify the effects of vegetation changes on land surface microwave emission by developing and validating a coupled dynamic vegetation microwave emission model. The information gathered would be used to develop remotely sensed data products and in other techniques to manage the effects of spatial variability of crops and soils at the site. As part of the project, the impacts of soil moisture and the effects of vegetation on the meteorological and hydrological variables that result from the various crop systems will be analyzed, and their effectiveness in comparison with simulation models will be evaluated.

FY 2002 Accomplishments

The FY 2002 experiment took place at the heavily instrumented USDA-ARS Optimizing Production Inputs for Economic and Environmental Enhancement (OPE^3) site from May to October. Continuous dual-polarized passive microwave data at 1.4 GHz were collected using GSFC's new L-band radiometer (L-rad). Weekly active microwave data were collected at dual frequencies (1.6 and 4.75 GHz), L and C-bands, and quad-polarization (HH, HV, VV, and VH) using the truck-mounted radar system. In addition, extensive ground validation measurements were taken. Initial analysis of the data collected has begun.

In November 2002 a paper, entitled, "Active/passive microwave remote sensing for soil moisture retrieval through a growing season" was submitted for publication to the International Society for Electromagnetic Aquametry (ISEMA) by Peggy O'Neill.

Planned Future Work

To continue this work in the future, a new proposal will be submitted to enhance this investigation. Data analysis will continue for the data collected from L-rad and the truck-mounted radar in conjunction with ground validation data. Further, the project will be enhanced by including microwave observations from the Advanced Microwave Scanning Radiometer (AMSR) sensor in orbit on the Earth Observing System- AQUA (EOS-AQUA) satellite.

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Title of Investigation:	A Land Surface Patch-Based Ensemble Kalman Filter
Principal Investigator:	Paul R. Houser/974
Other Investigators/Collaborators:	Xiwu Zhan/UMBC-GEST
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$55K
Actual or Expected Expenditure of FY 2002 Funding:	Contracts: Goddard Earth Sciences and Technology Center (GEST), $55K
Status of Investigation at End of FY 2002:	Completed in FY 2002
Expected Completion Date:	FY 2002

Purpose of Investigation

Accurate initialization of land surface moisture and energy stores in models is critical for meteorological and hydrological prediction over periods ranging from days to seasons because of their regulation of surface water and energy fluxes between the land surface and the atmosphere over a variety of time scales. Many innovative new land surface observations are becoming available that may provide additional information necessary to constrain the initialization of land surface states critical for long-term prediction. This work was proposed to develop an Ensemble Kalman Filter (EnKF) land surface assimilation scheme to synergistically utilize a unique method for ensemble generation that is based on subgrid-scale vegetation patch and precipitation disaggregation methods pioneered by GSFC scientists over the past 15 years. This innovative combination of GSFC-based tools will enable propagation of subgrid variability in land surface models, while imposing remote sensing constraints at larger scales.

FY 2002 Accomplishments

An Extended Kalman Filter (EKF) was implemented in NASA's Land Data Assimilation System (LDAS) to investigate the efficiency of Kalman Filter data assimilation of surface soil moisture into land surface models. Using field measurements from the Southern Great Plan 1999 (SGP99) experiments and a soil moisture retrieval data set from the Tropical Rainfall Measurement Mission (TRMM) Microwave Imager (TMI), the Kalman filter data assimilation method was found to be superior to the Direct Insertion method, which produced land surface flux and state simulations similar to what was found when no data assimilation was applied.

Planned Future Work

The results from the intercomparison will be used to validate Advanced Microwave Scanning Radiometer for EOS (AMSR-E) land data products, the task of another NASA-funded project.

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Title of Investigation:	Intraplate Crustal Dynamics Study for the Global Earthquake Satellite System
Principal Investigator:	Paul D. Lowman, Jr./921
Other Investigators/Collaborators:	Jacob Yates/SSAI
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$40K
Actual or Expected Expenditure of FY 2002 Funding:	Contract SSAI, $33K Various vendors: $7K
Status of Investigation at End of FY 2002:	Continued into FY 2003 with funds remaining from FY 2002. All funds were spent by January 2003; a proposal for renewal was rejected
Expected Completion Date:	FY 2003 pending additional funding from an as yet to be determined source

Purpose of Investigation

The Global Earthquake Satellite System (GESS) is a $2M study to develop a spaceborne system to monitor earthquakes and crustal ground motion, with JPL as the lead NASA field center. The GESS will likely include interferometric Synthetic Aperture Radar (SAR) and electric/magnetic field sensors. The GESS is currently focused on plate-boundary earthquakes, such as those in California and other Pacific Rim locations. This work was proposed to extend the study area to include intraplate areas, where potentially catastrophic earthquakes—such as the Gujurat, India, earthquake of January 2001, which killed some 30,000 people—can occur. The purpose of our investigation is to study intraplate seismicity, with the broad objective of clarifying the causes and distribution of intraplate earthquakes. Specific objectives are to identify potential problem areas and calibration/validation sites, meriting further study by remote sensing and other techniques, to focus GESS investigations when the program is funded.

FY 2002 Accomplishments

Although funding did not begin until April 2002, considerable progress was made in FY 2002. Two specific calibration/validation sites were selected: the Aegean Sea (Greece), and northern New England and adjacent Canada. Cooperative arrangements were made with the University of the Aegean and the University of Southern Maine. Dr. Nikos Soulakellis and Dr. Irwin Novak spent several weeks at GSFC. Mr. Yates spent two weeks in Greece as a guest of the University of the Aegean, carrying out fieldwork on active faults on the island of Lesvos. Mosaics of MODIS images of Turkey, Greece, and southern Italy were prepared and used as a baseline map to compile seismic and other geophysical data. Shaded relief maps of global seismicity from 1963-1998 were compiled. New maps were prepared, showing global and regional (Aegean) stresses from the digital data, and maps of seismicity of Greece were compiled. Members of the team presented five papers, reporting on the project's accomplishments

in 2002, at the American Geophysical Union annual meeting, the Geological Society of America annual meeting, and the Geological Society of America Northeastern Section meeting.

Planned Future Work

While Dr. Soulakellis will spend three months at GSFC under a Fulbright Grant, unless additional funding for SSAI can be found the project will be terminated within a few months.

Title of Investigation:	From Iturralde Structure to Araona Crater
Principal Investigator:	Peter Wasilewski/691
Other Investigators/Collaborators:	Compton Tucker/923
Initiation Year:	FY 2001
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years:	$35K
Funding Authorized for FY 2002:	$25K
Actual or Expected Expenditure of FY 2002 Funding:	In-house: $ 5K Contracts: Friends of Museo Noel Kempff, Santa Cruz, Bolivia, $20K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with funds remaining from FY 2002 and earlier years. Plans include transition to other funding, as funds for the Website came from Community Action of Southeastern West Virginia and the West Virginia Economic Development program, which is supporting updates to the Website.
Expected Completion Date:	DDF-funded work was completed November 2002

Purpose of Investigation

This work was proposed as a combined Science and Education project, sponsored by the Education side of the DDF program. The program was called "Teacher as Scientist". The program had scientists from Codes 600, 900, Conservation International, and the Denver Museum; high school students from Santa Cruz, Bolivia; and field support from natives of Riberalta and the indigenous Araona tribe. The U.S. Embassy in La Paz was instrumental in providing C-130 and helicopter support. Biological and geophysical research was conducted to verify the likelihood that the Iturralde structure is an impact crater. Webcasts, video clips near-real-time slide shows, and textual information were used to keep the educational audience abreast of activities.

FY 2002 Accomplishments

Listed below are Websites that resulted from the DDF funding. These were accessible during the events of this year's work, and are currently being used in the classrooms and are being upgraded to serve as teacher resources.

http://www.blueiceonline.org/blueweb/ice2002.html

http://www.blueiceonline.org/bolivia/bolflass5.html

http://www.blueiceonline.org/howsite/howindex.html

The Websites listed below were created as a NASA top story and by the U.S. Embassy in Bolivia during the expedition. Consequently we had English/Spanish coverage.

http://bolivia.usembassy.gov/DOCS/091747.html

http://bolivia.usembassy.gov/english/engindex.htm

http://www.space.com/scienceastronomy/planetearth/crater_expedition_020924-2.html

http://www.eldeber.com.bo/20021013/nacional_7.html

http://www.eldeber.com.bo/20021013/nacional.html

http://ea.el-nuevodia.com/2002/09-Septiembre/29Septiembre2002/Tendencias/Septiembre/ten020929a.html

http://www.eldeber.com.bo/20020909/santacruz_11.htmlhttp://epod.usra.edu/archive/epodviewer.php3?oid=85216

http://www.gsfc.nasa.gov/topstory/2002/20020904icecrater.html

http://www.gsfc.nasa.gov/news-release/releases/2002/02-036n.htm

Presentations were made to The Potomac Geophysical Society, and results will be presented at the IUGG meeting in July 2003. Papers are currently being written for submission to *Science* magazine and *Geophysical Research Letters*.

Planned Future Work

The expedition, while successful, did not provide proof that the Iturralde structure is a crater. Returned samples and geophysical data will continue to be evaluated, and data to interpret the region encompassing the area studied in this work will be acquired from oil exploration geophysical surveys. Drilling several hundred meters down to obtain materials that might contain evidence of high-velocity impact is still necessary. Consequently, funding will be solicited from NASA Headquarters and the National Geographic Society (among other potential funding sources) to support a return to the Iturralde structure for continued work.

Title of Investigation:	Remotely Sensed Isotopic Constraints on Hydrologic Processes in the GISS GCM
Principal Investigator:	David Rind/940
Other Investigators/Collaborators:	Gavin Schmidt/Columbia University, Yongyun Hu/Columbia University
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$30K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $15K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 using remaining funds
Expected Completion Date:	To be determined

Purpose of Investigation

This work was proposed to explore whether remotely sensed values of the isotopic composition of water (O^{18}/O^{16} and deuterium-hydrogen ratios) in the stratosphere and tropopause region can be used to constrain estimates of stratosphere-troposphere air mass exchange and mechanisms of water transport into the stratosphere. In stratosphere-resolving models that include water isotope tracer variations in the vertical resolution, parameterizations of the gravity wave drag, and the physics of moist convection will significantly alter the isotopic composition. The desire is to assess accuracy requirements for remotely sensed data (for instance, in the zonal mean) to significantly constrain the model. These remotely sensed data are relatively experimental, and it is important for their future development that a modeling component exist to allow proper data interpretation.

FY 2002 Accomplishments

Initial work was done to ensure that the stratosphere-resolving Goddard Institute for Space Studies (GISS) General Circulation Model (GCM) to be used for these experiments was giving reasonable estimates for stratospheric climate. A standard panoply of tracers was employed, each of which is independently useful as a measure of, for example, stratosphere-troposphere air mass exchange (*via* bomb radiocarbon and CFC-11) and stratospheric residence time (*via* SF_6). Control simulations have been run, including water isotopes. Two simulations have been completed: with and without a methane-derived source of stratospheric water vapor. The isotopic composition of the water derived from the oxidation of methane (CH_4) is a function of a large number of reaction pathways between CH_4 and various oxygen reservoirs (O_3, O_2, and O(1D)) in the stratosphere. As a first estimate, no fractionation from the CH_4 and O_2 reservoirs was assumed. The difference between the two cases is large, indicating that the correct prescription of the methane component is likely to be crucial in these experiments.

Additional experiments were performed where the model's upper boundary is significantly lower than for the full stratospheric model (0.1 mb; 60 km compared to 0.001 mb; 85 km). This config-

uration does not provide a good measure of stratosphere-troposphere exchange, and stratospheric residence times are too short. By comparing the two configurations the sensitivity of the isotope fields to those factors is being assessed. Significant differences in composition have been found in both cases (with and without methane derived sources), but they are smaller than the differences between including, or not including, the methane source.

An abstract and presentation is being prepared for the EGS-AGU meeting in Nice, 2003, to be presented by G. A. Schmidt, Columbia University, entitled, "Impacts of stratosphere-troposphere exchange and methane oxidation on the water isotope distribution in the stratosphere".

Planned Future Work

Assessment of the sensitivity of the isotopic composition to a better prescription of the methane-derived source (based on 2-D chemistry/isotope modeling), changes to the model parameterization of gravity wave drag, and changes to the physics of moist convection will be done. The gravity wave drag is an important component of stratospheric circulation, but it requires parameterizing in the model because it mainly occurs at unresolved scales. However, the correct prescription of gravity waves is highly uncertain. Similarly, some aspects of the moist convection in the model are not well constrained by current observations. By adjusting these parameterizations within reasonable bounds, the stratospheric circulation and penetrating convection will be modified and, hence, the isotopic composition in the stratosphere. The full set of experiments will give the sensitivity of the isotopes to important physical uncertainties in parameterizations, and thus assessment of the required accuracy for the remotely sensed isotope fields to be a constraint on those processes in the real world.

Title of Investigation:	Development of a "Modeling Workbench" Facility to Parameterize Global Biogeochemical Models
Principal Investigator:	John R. Moisan/972
Other Investigators/Collaborators:	Tiffany Moisan/972, Pam Pittman/588, Tony Baldwin/589, John Elliott/589
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$59K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $59K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with funding from an as yet unidentified source
Expected Completion Date:	FY 2003

Purpose of Investigation

This proposal seeks to develop a laboratory-based "modeling workbench" to obtain continuous data on phytoplankton physiology under controlled environmental conditions. The "modeling workbench" (laboratory/modeling system) can be used to investigate poorly resolved biogeochemical processes, and to develop a sophisticated biogeochemical model of phytoplankton growth. The combined forcing and response data sets will be used in a data assimilative model to develop the appropriate phytoplankton growth parameterizations. The data assimilative model already exists and has been tested in a twin experiment. The knowledge gained from this research is needed in order to better understand how microalgae are able to live under continuously varying light, nutrient, and temperature fields. Our initial experiments will focus on validating a set of theoretical results on the response of phytoplankton growth to variations in temperature.

FY 2002 Accomplishments

The research is continuing in its developmental stage. All required instruments have been purchased. The majority of the instruments have been interfaced with the computer control system. At this time, interfacing of two final instruments is being completed, and the calibration methodology is being developed. Initial experiments will be conducted this spring. Calibration standards and software to correctly measure gas fluxes are being developed. Laboratory experiments will be fully underway in FY 2003. The Workbench is in the final stages of development.

See http://oosa.wff.nasa.gov/archives/modelingworkbench.html for additional details.

Planned Future Work

Initial experiments will be conducted during the summer of 2003. A proposal will be submitted in response to a NASA NRA for support of several science efforts. A science research proposal requesting financial support for a technician to maintain the facility and carry out experiments will be resubmitted to NASA HQ.

Title of Investigation:	Programmable Gate Array (PGA) to allow Global Positioning System (GPS) Navigation to be used in High Earth Orbits
Principal Investigator:	Luke Winternitz/573
Other Investigators/Collaborators:	Greg Boegner/573, Miriam Wennersten/573
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$50K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $29K Contracts**:** QSS, $21K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 and later with funding from other sources
Expected Completion Date:	FY 2003

Purpose of Investigation

Current technology Global Positioning System (GPS) receivers are not capable of operating effectively at high Earth orbits (HEO). This is primarily because the GPS signals available there are 10-100 times weaker and much more sparsely present than on the Earth's surface or at low Earth orbit (LEO). However, GPS provides a very accurate and economical means of navigation and has become very popular for LEO missions and would be popular for HEO missions as well if the technology were available. Code 573, the Guidance Navigation and Control Hardware Components Division, is in the process of developing this technology, in the PiVoT 2.0 GPS receiver. To make this task feasible, new signal processing algorithms must be developed, and dedicated hardware (*e.g.*, programmable gate arrays; PGAs) must be designed to implement these algorithms.

FY 2002 Accomplishments

Signal processing algorithms for the PiVoT 2.0 GPS receiver have been developed that effectively acquire and track weak GPS signals. They provide sensitivity improvements over the current state-of-the-art GPS technologies by one to two orders of magnitude. PiVoT 2.0 will also provide full GPS data message demodulation during signal tracking and does not rely on *a priori* knowledge of the data message for its weak acquisition. However, it may be able to use data message uploads to achieve large sensitivity improvements. Dr. Mark Psiaki of Cornell University carried much of the algorithm development out through a grant partially funded by this DDF. Code 573 is developing the hardware implementation of these algorithms.

Planned Future Work

Hardware development and algorithmic refinements will be carried through and the PiVoT 2.0 GPS receiver will be completed. PiVoT 2.0 is tentatively scheduled to fly on the Global Precipitation Measuring Mission, as a primary navigation system component; and the Solar Dynamics Observatory Mission, as an experiment.

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Title of Investigation:	Neutral Winds and Temperatures in the Low-altitude Thermosphere with a MEMS Sensor
Principal Investigator:	F. A. Herrero/553
Other Investigators/Collaborators:	Joe Grebowsky/695, Sachi Babu/553
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$55K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $34.9K Contracts**:** Raytheon, $8.6K; EduTech, $11.5K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with funds remaining from FY 2002
Expected Completion Date:	October 2003

Purpose of Investigation

Wind and temperature measurements in the lower region of the Earth's thermosphere (altitudes from 120 to about 200 km) are required to understand the dynamics and energetics of the upper atmosphere and ionosphere. This region is coupled to the regions above and below it by many processes, including atmospheric wave propagation, believed to be the source of many dynamical features (*e.g.,* the midnight temperature maximum; several aspects of the atmospheric dynamo). Additional measurements in the lower thermosphere are required to assess such hypotheses. Existing numerical models can only feebly reproduce the observed features, and then only with the arbitrary addition of waves propagating through this region from below. Microelectromechanical system (MEMS) techniques provide attractive alternatives for trouble-free operation of satellite-based wind and temperature measurements in the low thermosphere. In contrast with current techniques that require high voltage devices, the MEMS approach offers very-low-voltage operation with a measurement approach that takes advantage of the high density of the air in the yet-unexplored low thermosphere.

FY 2002 Accomplishments

Realistic simulations of the signal were performed and reported by our student assistant in her Senior Physics thesis at St. Mary's College of MD/June 2002. A neutral beam MEMS sensor design consisting of a 1 μm-thick titanium (Ti) foil electrode, spring mounted on a silicon (Si) substrate, was adopted. At rest, the Ti foil is suspended 5 μm above a fixed titanium electrode deposited on the substrate. Under bombardment by the air stream, the foil is pushed toward the fixed electrode inducing an electric charge detected by a charge-sensitive amplifier. The charge-sensitive amplifier has already been tested. The laboratory test of the prototype will use an ion beam in place of the neutral air stream that the sensor would experience in actual flight. The ion beam system is already assembled and under test.

In preparation for these tests, the test methodology for the MEMS sensor was first developed using a chopped ion beam with

intensity and energy that will provide controllable fluxes to achieve forces in the 1 micro Newton range, as expected in the upper atmosphere application. This makes it possible to test the MEMS sensor without the MEMS chopper while the chopper is being designed and fabricated. The work done to date will allow us to begin assembly and tests of the Ti-Si MEMS sensor in March 2003.

In close collaboration with the U.S. Air Force Academy (USAFA; Prof. L. Krause), a USAFA cadet configured the prototype during the summer of 2002 to test it in the re-entry phase of the Falcon-Sat 3 satellite to be launched late 2005. The USAFA and the Air Force Research Laboratory (AFRL) are interested in this technology; AFRL is a likely customer. Based only on the DDF funds and some leveraging with other projects, GSFC Code 553 will be able to supply the laboratory prototype sensor to flight-test it in the USAFA FalconSat-3, a significant step to push this technology to flight readiness.

Planned Future Work

Work in the coming year will include testing the chopped ion beam system concurrently with fabrication of the Ti-Si MEMS sensor. The neutral beam MEMS chopper will be fabricated, while the Ti-Si sensor is tested with the ion beam. The Ti-Si sensor response function will be generated, including performance tests and data at pressures in the millitorr range, corresponding to altitudes just below 120 km. The neutral beam MEMS chopper will be integrated with the Ti-Si sensor in a laboratory prototype of the instrument. Laboratory tests of the prototype will be performed with a continuous ion beam (DC mode) to gauge performance of the MEMS neutral beam chopper. The prototype will be turned over to USAFA for integration to FalconSat-3. A report on final design approach will be generated, and focus will turn to a NASA NRA proposal, the Small Explorer (SMEX) process, or AFRL/ Communication and Navigation Outage Forecast System (CNOFS) opportunities to develop an integrated wind and temperature sensor using the chopper and a full array of MEMS detectors with supporting electronics. Presentations to GSFC Codes 690 and 910 will begin in January 2003. Coordination of the work with the Goddard Chief Technologist began January 9, 2002 to support Goddard's Instrument Miniaturization Initiative.

Title of Investigation:	Tethered Balloon Activities with Science and Technology
Principal Investigator:	Antoinette C. Wells/130.3
Other Investigators/Collaborators:	Geoffrey Bland/972, Lou Mayo/Raytheon
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$20K
Actual or Expected Expenditure of FY 2002 Funding:	$0
Status of Investigation at End of FY 2002:	Terminated FY 2002. Partner relocated and administrative/legal matters prevented project from being initiated
Expected Completion Date:	Not Applicable

Purpose of Investigation

This work was proposed to provide science/technology activities related to Earth science research using tethered balloons, including data manipulation and potential application of those data.

FY 2002 Accomplishments

Not Applicable

Planned Future Work

Undetermined

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SPACE SCIENCE AND TECHNOLOGY

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Title of Investigation:	A Holographically Speckle Corrected Telescope
Principal Investigator:	Richard G. Lyon/935
Other Investigators/Collaborators:	Michael Hayden/UMBC
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$60K
Actual or Expected Expenditure of FY 2002 Funding:	Contracts: UBMC, $60K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with additional funds ($20K of Code-R FY 2003 funds)
Expected Completion Date:	December 2003

Purpose of Investigation

A prime limitation in coronagraphic imaging for exoplanet imaging is coherent speckle due to interference of the residual structure on the optics. Reduction of speckle to acceptable levels requires the wavefront error to be less than $\lambda/15000$ rms in the spatial frequency band of 3 – 30 cycles per aperture; in principle this could be accomplished by a combination of superpolishing, static correction and active correction. The limits of static correction have yet to be determined. This DDF-funded project is an attempt to determine the limits for one type of static correction. Figure 1 shows a layout of the benchtop system. A reference and signal beam are mixed in a photorefractive polymer resulting in a stored hologram of the signal beam. Blocking of the reference beam results in an image of the signal beam on the detector. A reticle focal plane mask is inserted in the focal plane to bandlimit the spatial frequency content and to reduce the dynamic range required of the hologram. Figure 2 shows part of the benchtop layout, the apodizing mask, and reticle, respectively. Figure 3 shows an object, object imaged through a phase aberrator, an interferogram of the object and hologram, and a holographic image of the object respectively.

The overall goal of this work is proof-of-principle holographic speckle correction with a benchtop laboratory demonstration by storing a volume phase hologram of a benchtop optical system telescope and correcting the mid-spatial frequency speckle.

FY 2002 Accomplishments

The benchtop system was set up, and the laser source, optics, mounts and reticles successfully stored and retrieved multiple holograms. Sources of diffraction and scatter were debugged. The system layout and holographic materials are being optimized. A patent disclosure will be submitted. This work is being written up for submission to the *Journal of Applied Optics.*

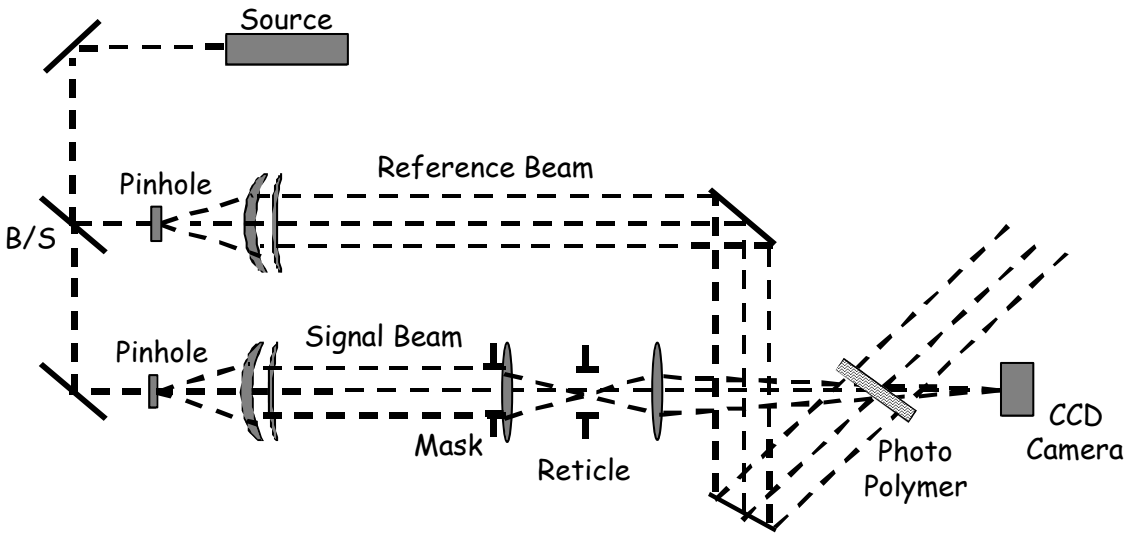
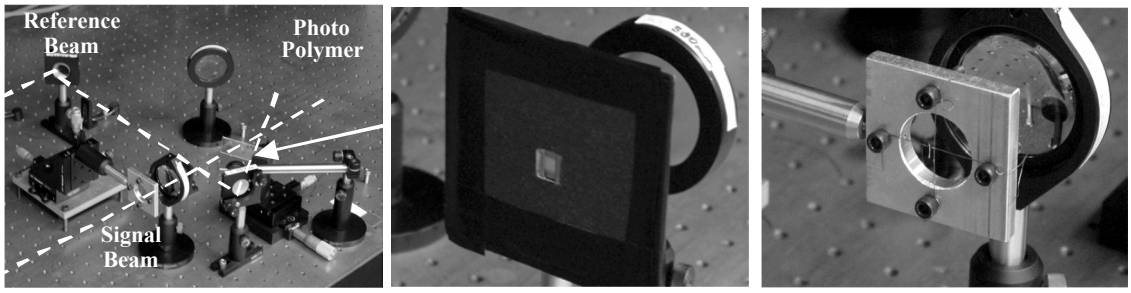


Figure 1–*Optical Layout*



Beam Mixing Layout **Square Mask (Apodizer)** **Spatial Filter (Reticle)**

Figure 2–*Optical Bench Components*

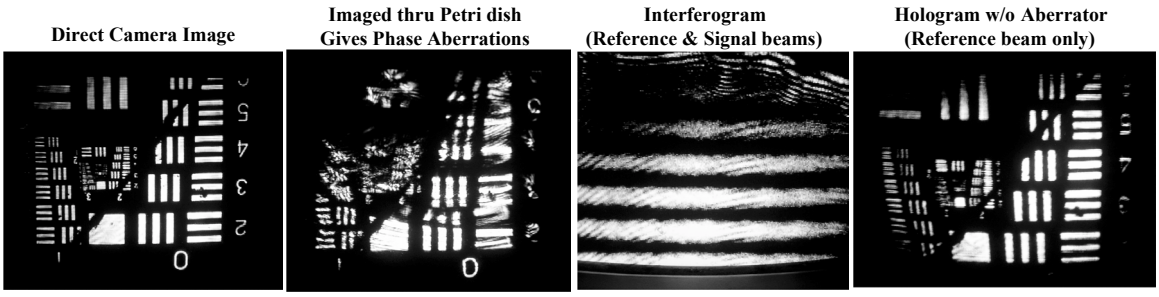


Figure 3–*Stored and Retrieved Images*

Planned Future Work

Images (with aberration) of an object will be stored and corrected as a precursor to correcting the speckle. The technique will be tested on a proposed testbed for potential implementation on the Terrestrial Planet Finder mission.

Title of Investigation:	High Temperature Superconducting (HTS) Far-IR Bolometer Array on Sapphire Membranes with Integrated Readout SQUIDs
Principal Investigator:	Brook Lakew/693
Other Investigators/Collaborators:	John Brasunas/693, Shahid Aslam/ Raytheon ITSS, Rainer Fettig/Raytheon ITSS
Initiation Year:	FY 2001
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years:	$50K
Funding Authorized for FY 2002:	DDF: $40K; Space-based Initiative (Code R): $100K
Actual or Expected Expenditure of FY 2002 Funding:	Contractors: Raytheon ITSS, $10K; Neocera, Inc., $24K; Miscellaneous Vendors, $6K
Status of Investigation at End of FY 2002:	Transitioned to Other Funding: Code R
Expected Completion Date:	FY 2004

Purpose of Investigation

The purpose of this investigation is to develop far-infrared bolometers using thin, high-T_c superconducting (HTS) films on monolithic, ultrathin, sapphire membranes.

FY 2002 Accomplishments

The originally funded work in FY 2001 developed the etch mask necessary to micromachine sapphire wafers. The FY 2002 DDF extension funding was used to create monolithic sapphire membranes and to do preliminary design work for HTS-readout superconducting quantum interference devices (SQUID). HTS thin films have been deposited on monolithic membranes, and bolometer fabrication is under way.

Planned Future Work

The newly fabricated HTS bolometers will be characterized, and a study of the effects of ionizing radiation on the bolometers' noise performance is planned. Recently observed etch pits on the monolithic membranes' surfaces will be studied to minimize their numbers.

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Title of Investigation:	Investigation of MgB_2 for Use in Far-IR Bolometers Operating at 30 Kelvin
Principal Investigator:	Brook Lakew/693
Other Investigators/Collaborators:	John Brasunas/693, Sahid Aslam/Raytheon ITSS, Rainer Fettig/Raytheon ITSS
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$65K
Actual or Expected Expenditure of FY 2002 Funding:	Contractors: Raytheon/ITSS, $35K; Various vendors: $2K Grants: Center for Superconductivity Research/UMCP, $28K
Status of Investigation at End of FY 2002:	Transitioned to other funding: Code R/Space-based Initiative, $10K
Expected Completion Date:	FY 2004

Purpose of Investigation

This work was proposed to perform a preliminary study of the noise performance of MgB_2 thin films to determine the feasibility of their use in mid-temperature, superconducting, far-IR bolometers.

FY 2002 Accomplishments

Several MgB_2 thin films, pulse laser deposited (PLD) on sapphire substrates at the University of Maryland, College Park (UMCP), have been tested at GSFC, and noise level measurements were made. The results suggest that noise levels are higher than traditional high-temperature superconductors. PLD deposition will need to be optimized to avoid O_2 contamination. Other films deposited via the high-pressure chemical vapor deposition (HPCVD) technique have also been obtained from Pennsylvania State University, and are awaiting characterization. A poster on MgB_2 thin film characterization was presented in April at the *Far IR/sub-mm Detector Technology Workshop*, in Monterey, CA.

Planned Future Work

Already-characterized MgB2 thin films will be exposed to ionizing radiation, with subsequent measurements of noise signatures to see if there are any changes in the noise level after such treatment. The collaboration with the Physics Departments at UMCP and Pennsylvania State University will continue on a no-exchange-of-funds basis. MgB_2 thin films of optimal quality will be obtained, and their noise performance will be measured. The possibility of building far-IR bolometers with MgB_2 temperature sensors will be explored.

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Title of Investigation:	Finger Detectors: Simple Far Infrared/Submillimeter Bolometric Arrays
Principal Investigator:	Robert Silverberg/685
Other Investigators/Collaborators:	Tina Chen/Global Science and Technology, Alex Bier/Global Science and Technology
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$70K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $18K Contracts: Global Science and Technology, $40K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with funds remaining from FY 2002
Expected Completion Date:	Unknown

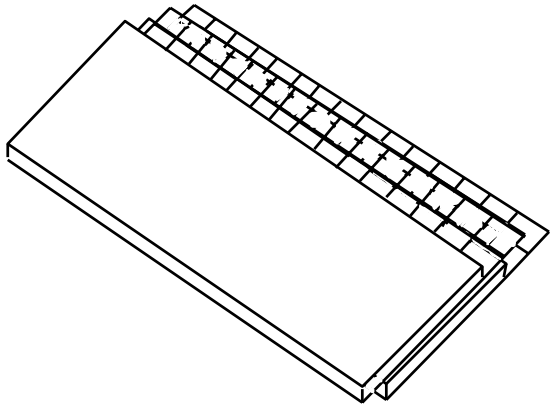
Purpose of Investigation

Many instruments are currently under development that require the use of close-packed arrays of far infrared/submillimeter detectors to provide imaging and high efficiency. While some monolithic arrays are currently under development, practical large monolithic devices appear to be many years away.

GSFC has taken an early lead in developing close-packed bolometric arrays with the High-resolution Airborne Wide Bandwidth Camera (HAWC). While this promises to be a very impressive and capable instrument, its cost will likely make observing time a precious commodity; duplicate instruments are not likely for similar reasons. A lower-cost array would provide opportunities for more researchers to take advantage of expertise available at GSFC, and to produce more efficient instruments.

Inresponse, concept of finger detectors has been introduced. These devices offer many of the same advantages of other assembled array detectors, but without such complexities as folding and difficult individual alignment problems. The devices are initially produced as linear rows of detectors supported from one side by small legs that serve as both thermal isolators and electrical conductors. These rows are then assembled into a two-dimensional array (see Figure 1). Because of the great strength and stiffness of crystalline silicon, high resonant frequencies (~1 kHz) and minimal droop (~5 micron) can be achieved in a small (~1mm^2 active area) cantilevered structure.

Figure 1–*A partially assembled finger detector. Three layers are offset and overlayed to produce an active area of the array that nearly fills the focal plane.*



FY 2002 Accomplishments

The design and fabrication of the mechanical test device was completed and a mechanical test was done showing that the finger detector had the expected mechanical properties. A holder for the array of the linear devices and electrical contacts to them was also designed (see Figure 2).

Figure 2–*Schematic diagram of finger detector mount. The mounting provides the aligment of the finger detector elements and their read-out electrical contacts. This mount is placed in the focal plane of the instrument.*

Planned Future Work

With remaining FY 2002 funds, attempts will be made to build a mount for the already-built mechanical models to demonstrate the ability to make effective electrical contact with the devices.

Title of Investigation:	Making High Angular Resolution X-Ray Optics by Combining Diamond Turning Technology and Thin Glass Sheets
Principal Investigator:	William Zhang/662.0
Other Investigators/Collaborators:	Robert Petre/662.0, Peter Serlemitsos/662.0
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$46.5K
Actual or Expected Expenditure of FY 2002 Funding:	Contracts: Swales, $30K Various vendors: $16K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with other sources of funds, to be determined
Expected Completion Date:	FY 2003

Purpose of Investigation

High-angular-resolution X-ray optics have been difficult to fabricate for a number of reasons, the most prominent of which is the difficulty in achieving highly accurate figures and extremely smooth micro-roughness. The requirements of nesting shells and light weight further compound the difficulty. This work was proposed to combine the figure accuracy of diamond-turning technology with the highly smooth surface of very thin float glass sheets to make moderately high-angular-resolution (a few arc-seconds) and lightweight X-ray optics.

FY 2002 Accomplishments

The design and analysis of the structure onto which we will attach the thin glass sheets has been completed. Assembly work is underway.

Planned Future Work

The thin glass sheets (Schott D263 100-micron thickness) will be attached to the structure and then coated with gold for metrology with visible light and X-ray testing.

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Title of Investigation:	Optically Thin Pixel Detectors for a Broadband X-ray Polarimeter
Principal Investigator:	Keith Gendreau/662
Other Investigators/Collaborators:	Kevin Black/Forbin, Phil Deines-Jones/Universities Space Research Association (USRA), Keith Jahoda/662, Tom Jackson/ Pennsylvania State University (PSU)
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$75K
Actual or Expected Expenditure of FY 2002 Funding:	Grants: Pennsylvania State University, $30K Contracts: USRA, $45K
Status of Investigation at End of FY 2002:	The DDF-funded part of this project is complete at the end of FY 2002. The PSU effort is partially supported in FY 2002 and completely supported in FY 2003 by NASA High Energy Astrophysics (HEA) Supporting Research and Technology (SR&T) funding (PI: Stanley Hunter). The GSFC effort is supported in FY 2002 through HEA SR&T funding (PI: William Zhang). Related work on advanced micro-pattern polarimeters is supported by a new DDF (PI: Robert Petre) in FY 2003.
Expected Completion Date:	FY 2003

Purpose of Investigation

X-ray polarization studies have long been recognized to be of great astrophysical relevance to separate competing models of, for instance, the accretion disks around massive black holes and to provide insight into the geometry of X-ray emitting regions. Recent advances in micropattern proportional counters have allowed an Italian group to demonstrate a breakthrough technology that would allow use of sensitive polarimeters in the context of a Small Explorer mission. Even so, much room for improvement remains, as the detectors are efficient only to a few percent. The purpose of this investigation is to extend the earlier results by developing detectors with optically thin gas multiplication and readout components so that detectors may be stacked, thus increasing sensitivity.

FY 2002 Accomplishments

The manufacture of gas electron multipliers (GEM) in the GSFC Laboratory for High Energy Astrophysics (LHEA) was substantially improved. Using a UV ablation laser, GEMs have been fabricated on substrates of 50-micron acrylic or polyimide with pitch as small as 100 microns. These devices have been tested and have useful gain of several thousand. At PSU, process development has prepared that research group to fabricate (in FY 2003) a thin film transistor (TFT) array suitable to read out the charge signal produced by the GEM.

The development of GEMs at GSFC positioned us to initiate collaboration with the Palo Alto Research Center (PARC), where TFT arrays on glass substrates (which are optically thick to X-rays) are used in medical imaging research. The collaboration allows this group to gain experience with micropattern polarimeters prior to the completion of the PSU readout devices on thin substrates.

Planned Future Work

The development of optically thin readout structures for micropattern polarimeters remains promising, and will be pursued through our collaboration with PSU, and possibly through the collaboration with PARC established during the period of DDF support. The performance properties of various proportional counter gases will be studied for their ability to work with micropattern polarimeters and detector geometries suitable for use in sounding rockets or small missions. Improving processes for GEM production remains a priority at GSFC. Expanded funding from the SR&T program will be sought. While much development remains, Small Explorer mission concepts, based on the work to date, appear feasible. Publications and professional presentations related to this work are expected in FY 2003.

Title of Investigation:	X-ray Interferometer Fringe Magnifier
Principal Investigator:	Keith Gendreau/662
Other Investigators/Collaborators:	Scott Owens/551, Richard Lyons/550
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$25K
Actual or Expected Expenditure of FY 2002 Funding:	Contracts: BRO Research $17K; Dell Computers $2K; Newport, Inc. $2K; K.J. Lesker $4K
Status of Investigation at End of FY 2002:	To be continued in FY 2002
Expected Completion Date:	September 2003

Purpose of Investigation

This work was proposed to support the design of a magnifier to enlarge fringes from an X-ray interferometer, based on the purchase of a ray-tracing software package that would have sufficient numerical accuracy to keep track of the phase of light with wavelengths measured in Ångstroms over distances measured in kilometers. The Microarcsecond X-ray Imaging Mission (MAXIM) X-ray interferometer would then be modeled, and then a similar approach taken to analysis of a simple magnifier. Once the model is validated, tolerances for components of the magnifier within the interferometer would be tested. In parallel, concepts would be tested with red laser light, and then components would be purchased to test the concept within the X-ray interferometry testbed.

FY 2002 Accomplishments

Using 633 nm light, the fringe magnification effect was verified qualitatively, using spherical mirrors. The ray tracing code was used to model the X-ray interferometry testbed. Detection of the first X-ray fringes with the testbed at 23.6 and 8.35 Å was done in parallel with the other work. This work resulted in measurement at 8.35 Å, the shortest wavelength ever measured in a broad bandpass interferometer. Even without the magnifier in place, the ray tracing code has been very useful in evaluating the laboratory results.

Planned Future Work

Refining the testbed optical model will continue, using the ray tracing code as we get additional fringe results, and the coding will be optimized. Once the ray tracing and the experimental data better agree, the spherical mirror fringe magnifier model in the code will be implemented. The magnifier will also be implemented mechanically, in parallel with this other work.

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Title of Investigation:	Kirkpatrick-Baez X-ray Mirrors in Astronomy: Historical Interest or a Future Application?
Principal Investigator:	Peter J. Serlemitsos/662
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$57K
Actual or Expected Expenditure of FY 2002 Funding:	In-house: $3K Contracts: RJH Scientific, $12K; Various machine shops, $13K; USRA, $29K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with funds obligated in FY 2002
Expected Completion Date:	FY 2003

Purpose of Investigation

It is generally accepted that the only way to assemble the required number of mirrors for the Constellation X-ray Mission (Con-X) and yet still maintain acceptable instrument weight is to use a segmented mirror approach, similar to what has been done with foil mirrors for the Japanese ASCA (formerly Astro-D) and Astro-E missions. The baseline Con-X mirror research is based on thin glass substrates, formed off flat ~300-400-micron-thick glass sheets by slumping at over quartz mandrels at high temperature. The process requires subsequent surface smoothing *via* epoxy replication. Key steps in this complex procedure and the intricate assembly of the many reflectors into a workable mirror remain to be established. Because it is important to have an alternative approach for Con-X should present efforts encounter insurmountable difficulties, revisiting another segmented mirror approach, known as the Kirkpatrick-Baez (K-B) geometry, was proposed. K-B mirrors for space astronomy have been deemed of secondary importance over the years because of well-known disadvantages when compared to highly accepted Wolter type II-geometry mirrors. The primary impetus for this proposal emerged from the recent availability of adequately smooth, inexpensive, thin glass sheets, developed primarily for flat panel displays. The approach outlined was to use small flat segments of this glass as an approximation to the precise K-B geometry, much the way conical reflectors have been used in other applications to approximate a cylindrical geometry.

FY 2002 Accomplishments

As envisioned, a prototype K-B mirror segment would consist of a large number of ~10x10-cm, thin glass sheets, held together in a housing appropriately grooved by wire electrical discharge machining. Consequently, a contract was awarded to RJH Scientific, Inc. of El Cajon, CA to design this housing. Schott display glass (~200 microns thick) was purchased. Segments were cut from the large sheets, and then measured with a laser scanner for flatness. As expected, residual stresses in the glass caused curvature in orthogonal directions, providing a "potato chip" shape, usually with curvature in one direction dominant. Since this application calls for flat surfaces, attempts were made to flatten these pieces by heat treatment, but with no success. Possible solutions to this problem include a

painstaking selection process involving a large number of measurements, and a degree of correction is expected from the constraining grooves if the residual curvature is appropriately chosen.

Planned Future Work

The project suffered from the late availability of funding, so considerable work remains to be done in 2003, although all funds have already been obligated. A workable design is available, based on which a prototype housing will be fabricated. An appropriate vendor for the required precision glass cutting remains to be found; all cutting so far has been done by hand. If the project progresses to a stage that appears promising, an effort will be made to secure additional funding from other sources.

Title of Investigation:	Next-Generation 2-D Planar Bolometer Arrays for Far-IR and Sub-mm Astrophysics
Principal Investigator:	Minoru M. Freund/685
Other Investigators/Collaborators:	Brent Mott/553, Jim Loughlin/542, Harvey Moseley/685
Purpose of Investigation:	Not submitted
Initiation Year:	FY 2001
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years	$60K
Funding Authorized for FY 2002:	$25K
Status of Investigation at End of FY 2002:	No further information was submitted for this project, as Dr. Freund has left GSFC

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INSTRUMENT DEVELOPMENT AND TECHNOLOGY

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Title of Investigation:	Broadband Single-mode Millimeter/Submillimeter-Wave Polarization Diplexers
Principal Investigator:	E. Wollack/685
Other Investigators/Collaborators:	M. Limon (GSFC/National Research Council); W. Grammer (National Radio Astronomy Observatory (NRAO)/Tucson)
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$30K
Actual or Expected Expenditure of FY 2002 Funding:	Contracts: Various vendors, $28.8K
Status of Investigation at End of FY 2002:	Completed DDF in FY 2002; will expand research with funds from an as yet unidentified source
Expected Completion Date:	January 2003

Purpose of Investigation

This investigation's goal is to realize full-band high performance of polarization diplexers at millimeter wavebands. In particular, high-performance orthomode transducer (OMT) design prototypes at 7 mm and 1 mm were fabricated and tested. This instrument configuration is preferred to reduce mass, volume, and improve performance for low-noise receivers in these wavebands. The structures investigated in this collaboration are of general interest for precision radio astronomy instrumentation at millimeter and submillimeter wavelengths.

FY 2002 Accomplishments

The elements of proposed investigation were successfully completed in FY 2002. The performance of the OMT at room temperature was consistent with modeled response. Structures were fabricated for 7 mm and 1 mm, the wavebands that achieved a return loss of ~20 dB (side/main-arm) and isolation > 45 dB. Room temperature transmission was ob- served to be consistent with the theoretical ohmic loss.

To carry out this measurement effort, a 1 mm test set (HP8510C Network Analyzer with WR03.7 heads) was configured from GSFC/NRAO hardware and interface components provided by Olsen Microwave. The possibility of better limits on the performance of the 1 mm devices was anticipated with the microwave metrology available on site. This is the first demonstration of a full waveguide band orthomode transducer at 1 mm wavelength. The test set up was also used to verify the beam pattern, cross-polarization, and loss of a novel 0.9 mm platelet feed array fabricated with 2001 DDF funds awarded for a different proposal, which addressed high-efficiency feed structures for millimeter/submillimeter-wave focal plane arrays.

Efforts on the 7 mm device concentrated on verification and improvement of the device's model fidelity. The electrical performance of electroformed, milled, and

precision chemical etched septa was tested in the 7 mm OMT split block. This effort demonstrated that chemically etched septa more closely realize the desired geometry to reliably achieve high isolation and yield.

This work has resulted in three publications:

Wollack, E.J., W. Grammer and J. Kingsley, "*The Boifot Orthomode Junction*," May 2002, NRAO, ALMA memo series #425, (released).

Wollack, E.J. and W. Grammer, "*A High Performance Orthomode Junction at 1 mm Wavelength*," THz 2003 Symposia, (in preparation).

Keating, B.R. and E.J. Wollack, "*Cutoff Wavelengths for Micro-Machined Waveguide*," (in preparation).

Planned Future Work

The prototype devices will be used in the field to make astronomical measurements and to verify the suitability of the design for wide use. Verification of the electromagnetic performance at cryogenic temperatures will be carried out in test radiometers at various sites. The 1 mm device will be tested in an antenna bed designed for the Millimeter Array at NRAO. The 7 mm devices will be used in a polarization-sensitive receiver test bed at GSFC. Efforts will continue to reduce the production and fabrication costs of these devices by minimizing the number of precision components in the finished assembly. The feasibility of an optimized split-block hybrid septum polarizer (constructed using a similar approach) that potentially can be extended to allow micromachining is currently under consideration. Production of a high-isolation device appropriate to study the cosmic microwave background radiation is to be transitioned to ground- and balloon-based experimental efforts. Modification of the 1 mm OMT device for production will be carried out by the NRAO as an element of the Millimeter Array development effort.

Title of Investigation:	Dual Slot Antenna Development for Millimeter/ Submillimeter-Wave Focal Plane Arrays
Principal Investigator:	E. Wollack/685
Other Investigators/Collaborators:	G. Hinshaw/685, H. Moseley/685, R. Henry/551
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$33K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $14.7K Contracts: Various vendors, $18.3K
Status of Investigation at End of FY 2002:	To transition to funding from Space Astrophysics Research and Analysis (SARA) for a proposal entitled, *Silicon Hot Electron Bolometers*
Expected Completion Date:	January 2004

Purpose of Investigation

Arrays of dual-slot antennas provide a clear path toward greatly enhancing antenna focal plane sampling and sensitivity at millimeter and submillimeter wavelengths. The angular response, cross-polarization, and bandwidth of a dual-slot antenna compare favorably to that of an ideal feed. However, this fully planar approach has the additional practical benefit of being amenable to production in large numbers by photolithographic techniques, and it is compatible with readout and multiplexing schemes presently under development. This device is, therefore, a strong candidate for future missions requiring large-format plane array technologies that function at long wavelengths.

FY 2002 Accomplishments

Over the course of the last year, work has concentrated on evaluating analysis tools for the proposed class of dual slot antennas structures. The double-slot coplanar waveguide (CPW) and the double-slot antenna, which have been extensively studied, have served as a starting point to evaluate the model's fidelity in reproducing the radiation pattern, polarization response, and coupling. In addition, benchmark tests for representative microstrip, CPW, and slotline geometries have been simulated and compared for relative accuracy, convergence, and simulation speed. Where appropriate, limiting cases have been chosen which allow comparison with analytical analysis. Off-the-shelf electromagnetic simulation packages and custom evaluation tools have been utilized in this effort. At this time, custom implementation remains preferable to synthesize the desired structures.

This work generated one paper:

Moseley, Jr., S.H., E. Wollack, G. Hinshaw, "*Limits to the Efficiency of Imaging Systems*," 2002, Proceedings of the Far-infrared, Submm, and mm Detector Technology Workshop, J. Wolf, J. Farhoomand and C. R. McCreight (eds.), NASA/CP-211408, (in press).

Planned Future Work

The simulations and measurements to date have provided an understanding of surface wave excitation for this class of single-mode planar coupling structures, preliminary estimates and mitigation concepts for cosmic rays in dielectric half space, and fundamental limits for array coupling structures. Further effort in understanding modeling the overall optical efficiency of the sensor in the presence of the dielectric lens is required at this time, and will be pursued.

Over the course of the past year we have concentrated on the survey and evaluation of modeling capability for this family of electromagnetic structures as well as addressing basic metrology issues. Significant strides have been made in understanding how to control surface wave excitation in the structure within the realm of realizable sensor geometries which can be readily fabricated. Over the course of the next six months efforts will be directed at finalizing the optimization of the device geometry. This will enable validation of the model over the course of the summer. A continuation of this effort into 2003 has been requested to allow prototyping and evaluation of test antenna structures.

Title of Investigation:	Silicon "Grass" as Infrared Material
Principal Investigator:	Mary J. Li/553
Other Investigators/Collaborators:	Ross Henry/541, Rainer Fettig/553/Raytheon
Initiation Year:	FY 2000
Aggregate Amount of Funding Authorized in FY 2001 And Earlier Years:	$18K
Funding Authorized for FY 2002:	$26K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $10K Fabrication, Detector Development Lab $8K Computer modeling $8K Optical testing and analysis, Optics Branch
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with funds remaining from FY 2002 and earlier years
Expected Completion Date:	March 30, 2003

Purpose of Investigation

The research was proposed to apply antireflection surface structuring in the visible-to-microwave spectral range, a faint-signal region of historical and ongoing interest to GSFC researchers.

FY 2002 Accomplishments

Silicon "grass" structures were fabricated in GSFC's Detector Development Lab (Code 553) using deep reactive ion etch (DRIE) technology, based on various recipes. Varying etching parameters enabled control of width, length, and density of the silicon grass. Simulation work was initiated, and transmission and reflection measurements were performed at the Optics Branch to determine the optical performance at the corresponding equipment. A mask was made to "plant seeds" for grass growth. This work was presented in a Student Internship Report at GSFC.

Planned Future Work

New grass wafers will be made using the "seeds" mask and DRIE. Transmission and reflection measurements will follow.

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Title of Investigation:	Development of Cooled Schottky CdTe Detector Systems
Principal Investigator:	Jacob Trombka/691
Other Investigators/Collaborators:	Samuel Floyd/691, Yossi Eisen/SOREQ Israel, Richard Starr/CUA
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$65K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $14K Contracts: AmpTek, $10.5K; OSC, $10K Grants: Catholic University of America, $30.5
Status of Investigation at End of FY 2002:	Completed in FY 2002
Expected Completion Date:	Completed in FY 2002

Purpose of Investigation

X-ray remote sensing and *in situ* analysis are important techniques for determining elemental composition of Solar System bodies. Such remote sensing systems were flown during the Apollo, the Near-Earth Asteroid Rendezvous (NEAR) mission, and the Mars Pathfinder mission. They will be included on the upcoming Mercury Surface, Space Environment, Geochemistry and Ranging (MESSENGER) mission and on other future Discovery and Mars missions. Evaluation of instrument performance on earlier missions showed that solid-state detectors are a better choice than proportional counters to facilitate science on future missions. For example, the NEAR X-Ray Spectrometer (XRS) has successfully completed a year of orbital operations. To infer elemental abundances from a measurement of the surface emission spectrum, a detailed knowledge of the incident solar differential energy flux is required. The NEAR XRS had two X-ray detectors monitoring the incident solar flux: A low-resolution gas proportional counter, and a Si positive-intrinsic-negative (PIN) detector. During the early part of the NEAR mission, the Si-PIN detector operated and yielded the best solar X-ray spectrum information, but long-term radiation effects prevented the use of this detector during orbital operations. The proportional counter suffered from cosmic ray background noise. A significant limitation of the Si-PIN detector was the loss of sensitivity to X-rays above 10 keV. A significant lesson learned from the NEAR mission was that an understanding of the solar incident flux to energies above 10 keV would have greatly improved our ability to infer elemental composition from the measurement of the surface emission spectrum. The NEAR XRS experience also indicated that a major background reduction in the energy domain of interest could be achieved with wide-bandgap semiconductor detectors as compared with gas proportional counters that were flown on the NEAR mission. If large-area, low-noise Schottky cadmium-telluride (CdTe) systems can be developed, a major improvement over the proportional counters used for measuring the surface emission can be achieved. This improvement yields better energy resolution, elimination of K-edge filters, and reduction of noise due to cosmic-ray energetic particles. Therefore, this work was pro-

posed to advance the development of Schottky CdTe(Cl) detectors for both orbital and *in situ* X-ray spectrometers to investigate the elemental composition of planetary bodies.

FY 2002 Accomplishments

Work done under this task has demonstrated that Schottky CdTe detectors would be a good detector choice for determining planetary chemistries from the analysis of the X-ray emission spectra on future science missions. The energy domain that can be covered extends from ~0.7 keV to ~30 keV, with unity efficiency over the domain. The energy resolution for a 2 mm x 2 mm x 1 mm detector is 230 eV at the Fe^{55} line, and for a 3mm x 3 mm x 1 mm detector the resolution should be approximately 350 eV. These detectors are very important for use as solar monitors on planetary orbital missions and as the detector of choice for lander X-ray fluorescence (XRF) systems. Elements with atomic weights from Na and heavier can be measured, including important high-Z components.

A major problem with use of these detectors during planetary exploration missions can be attributed to radiation damage in the space environment. A study of this effect was carried out. This study investigated the damage of a 2 mm x 2 mm x 1 mm Schottky CdTe detector after being irradiated by 200 MeV protons to a total fluence in the range 10^{10}-10^{11} p/cm^2; such exposures may be typical for a MESSENGER mission. The results showed that Schottky CdTe detectors are severely damaged by 200 MeV proton fluence of 10^{11}/cm^2 and cannot be completely recovered by annealing at 65^0 C for 40 hours. After annealing, the detector does partially recover, and shows good spectroscopic characteristics when operated at -30^0 C. Thermal annealing was previously carried out in planetary missions for high-purity germanium (HPGe) and silicon detectors. The high density of created traps increased the polarization rate, even at -30^0 C. An increase of the applied bias above 300 V causes an increase in peak position and improves the charge collection effi-ciency and the peak-to-valley ratio. These are indications that the proton irradiation created a partially depleted detector. Calculations based on an assumption of the deep ionized traps show that the Schottky detector irradiated by a fluence of 10^{10} p/cm^2 and then followed by a thermal annealing process, can still function as a good X-ray spectrometer at -30^0 C. These are rather extreme conditions, but at lower fluence this type of detector operates very well. The results of this study have been accepted for publication in *Nuclear Instruments and Methods.*

Planned Future Work

Schottky CdTe detectors will be used in the portable XRF system being developed under a dual technology program sponsored by NASA and the Department of Justice's National Institute of Justice. The XRF system will be used for the non-destructive analysis of physical evidence at crime scenes and for home security programs. A proposal that would incorporate the Schottky CdTe detector in an XRF system is being prepared for the Mars Smart Rover 2009 mission.

Title of Investigation:	A Deposited Palladium-Iron Thermometer for Very Low Temperatures
Principal Investigator:	Jim Tuttle/552
Other Investigators/Collaborators:	Mike DiPirro/552, Ed Canavan/552, Thomas Stevenson/553, Dave Franz/553
Initiation Year:	FY 2001
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years:	$40.3K
Funding Authorized for FY 2002:	$20K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $20K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with no additional funding
Expected Completion Date:	Summer 2003

Purpose of Investigation

To develop a deposited magnetic thermometer using iron-doped palladium. The device is designed to control temperatures in detector stages below 1 K — specifically, from 30 mK to 0.1 K.

FY 2002 Accomplishments

Tests were run on thermometers with 2 mm and 4 mm coils on two different chips. The tests were conducted in an adiabatic demagnetization refrigerator down to T = 0.03 K. The output signal's temperature dependence did not follow the expected Curie-Weiss law below 100 mK. It should be possible to improve this temperature dependence (at the cost of temperature resolution) by decreasing the palladium coating's iron content. A maximum temperature resolution of 12 μK/√Hz in the 4 mm coil design at T = 75 mK was demonstrated; however, the excitation current was limited to about 5 mA by the chip crossovers. Also, the circuit noise was about a factor of 4 higher than the expected superconducting quantum interference device (SQUID) noise. Both of these problems should be solvable on future runs.

Planned Future Work

Another set of chips will be fabricated, with the following design changes: larger crossovers, to increase the excitation current by a factor of approximately eight; redesigned coils, to improve the field/current ratio; and a thicker palladium layer. With these changes and an anticipated reduction in the SQUID noise, resolution should improve to well below 1 μK/√Hz.

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Title of Investigation:	Continuous ADR Cooling from the Passive Cooling Limit to Sub-Kelvin Temperatures
Principal Investigator:	Todd King/541
Other Investigators/Collaborators:	Peter Shirron/552, Ed Canavan/552, Mike DiPirro/552, James Tuttle/552, John Panek/552
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$40K
Actual or Expected Expenditure of FY 2002 Funding:	Contracts: Omega, Coorstek, $5K CM Furnace, $10K Swales Aerospace, $20K Science Systems Applications, $5K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with additional DDF and CETDP funding
Expected Completion Date:	August 2003

Purpose of Investigation

The goal of this investigation was to develop an All-adiabatic Demagnetization Refrigeration (ADR) system that can efficiently cool high-resolution, large-format detector arrays from the passive radiative cooling limit of approximately 30K down to sub-Kelvin temperatures, thereby eliminating the need for costly mechanical cryocoolers in future spacecraft. The primary limitation impeding the design of a complete ADR system is the lack of core ADR coolant materials that possess sufficient entropic cooling capacity at high temperatures ($T > 5$ K) under low magnetic fields ($H < 3$ Tesla). This DDF effort focused on the discovery, synthesis, and characterization of new ADR materials.

FY 2002 Accomplishments

Based upon the magnetic entropy change (ΔS_{mag}) results obtained during the first year of this DDF effort, the 2002 research focused on completing the characterization of the most promising ADR candidate material identified, gadolinium fluoride (GdF_3). The heat capacity (C) of commercially obtained GdF_3 powder was measured as a function of cryogenic temperature ($0.5 \text{ K} < T < 15 \text{ K}$) and applied magnetic field ($0 \text{ T} < H < 5 \text{ T}$). By integrating the magnetic entropy change and heat capacity data with respect to the applied magnetic field, the cooling potential of GdF_3 was fully determined. Figure 1 illustrates the temperature dependence of the overall entropy (S) of gadolinium gallium garnet (GGG) and GdF_3 subjected to applied magnetic fields of 0 T and 3 T. Comparison of the cooling power (P) associated with a proposed ADR operation cycle ranging from 10 K to 4 K and utilizing only a 3 T applied magnetic field shows that GdF_3 ($P = 0.3603$ J/cc) exhibits 38% greater cooling power than GGG ($P = 0.4971$ J/cc) representing a significant increase in performance.

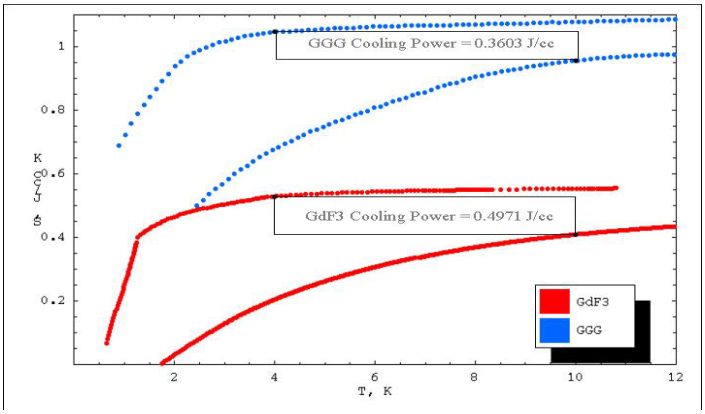

Figure 1–*Overall entropy change of GGG and GdF3 as a function temperature and applied magnetic field. The area enclosed by the two rectangles represents the cooling power associated with a proposed ADR operational cycle.*

Having demonstrated the exceptional magnetocaloric properties of GdF_3, the feasibility of its incorporation into an ADR system was interrogated from an engineering perspective by measuring its cryogenic thermal conductivity (k). Figure 2 illustrates the thermal conductivity results obtained on several ADR materials including polycrystalline melt-grown GdF_3 and $GdLiF_4$ (magnetically similar to GdF_3) as well as single crystal samples of $GdLiF_4$, chromium potassium alum (CPA) and Gd-Elpasolite as a function of cryogenic temperature. Comparison with the $GdLiF_4$ thermal conductivity results indicate that single-crystal performance is one to two orders of magnitude greater than that of a polycrystalline solid, due to the elimination of phonon scattering defects such as grain boundaries.

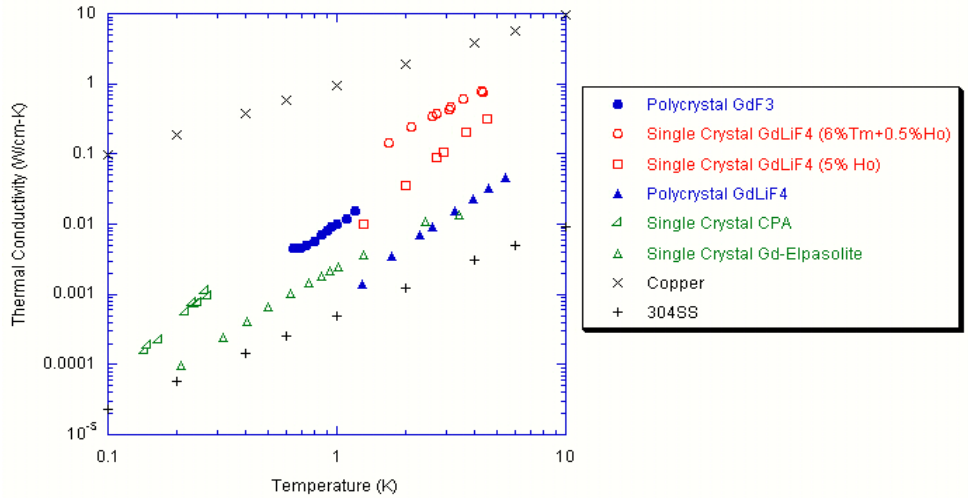

Figure 2–*Thermal conductivity of several ADR materials as a function of cryogenic temperature.*

Planned Future Work

Based upon these exciting 2002 DDF results, the next phase of the research will focus on growing high quality, engineering-scale (~3 cm diameter), single crystals of both GdF_3 and $GdLiF_4$. The proven magneto-caloric and thermal conductivity properties of these exceptional materials will then be utilized in a multistage ADR cooling system capable of efficient cooling down from 30 K.

Title of Investigation:	A Passive, Solid-State Heat Switch for the Continuous ADR
Principal Investigator:	Edgar Canavan/552
Other Investigators/Collaborators:	Michael DiPirro/552, Peter Shirron/552, James Tuttle/552, Yury Flom/541
Initiation Year:	FY 2001
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years:	$35.5K
Funding Authorized for FY 2002:	$25K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $25K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 - transitioned to other funding: Cross-enterprise Technology Development Program (CETDP)
Expected Completion Date:	August 2003

Purpose of Investigation

Heat switches are critical components in adiabatic demagnetization refrigerators (ADRs), magnetic refrigerators that can provide cooling to very low temperatures—typically tens of milliKelvin (mK). These temperatures are approximately two orders of magnitude lower than can be provided by stored cryogens or mechanical coolers. Such extremely low temperatures are required by ultrasensitive superconducting photon detector arrays to be used on future missions. A breakthrough in the development of ADRs came recently with GSFC's invention of the Continuous ADR (CADR). In existing flight ADRs, a large single stage absorbs heat from the detector for up to a day; operations then must cease temporarily to allow the ADR to warm up and discharge its heat. In the CADR a small stage remains continuously at the operating temperature while periodically passing heat to a series of small stages, each of which lifts the heat to the next, higher-temperature stage. Because science operations are completely decoupled from ADR operations, the ADR stages can be cycled rapidly, allowing at least 30 times higher cooling power per unit mass and allowing heat to be raised to temperatures of 10 K or higher, where closed-cycle mechanical coolers are reasonably efficient.

Because the CADR comprises several small stages—each with a heat switch—there is a strong need for small, lightweight, highly reliable heat switches. A magnetoresistive heat switch was developed under a previous DDF award. This small, simple, solid-state device exploits the fact that—in certain pure metals—a moderately strong magnetic field "turns off" thermal conductance. Unfortunately, such a switch requires its own large magnet if it is to be operated independently. However, it was realized that a magnetoresistive switch, operating between any two stages in a CADR, could be placed in the bore of one of the magnets that generates the cooling. That magnet's field then turns the switch on

and off in the proper sequence. As a result, the switch adds negligible mass to the system. In this work, this "passive" switching concept was to be further developed and demonstrated in a simple, two-stage ADR.

FY 2002 Accomplishments

The main goals for this year's work were to test a new heat switch and to test a system with a paramagnetic material with a more suitable ordering temperature. Several attempts were made to fabricate a new heat switch using existing material. These attempts were greatly delayed because a critical instrument was often either busy or not functioning. The Branch recently acquired one of these instruments and has developed proficiency in its use, so future fabrication can be done under direct supervision. This acquisition will greatly enhance the ability to manufacture a functioning unit. Two new crystals, with higher purity than the previous one, were purchased. Unfortunately, crystals with the diameter of the previous one were no longer available, so a new design had to be developed. Extensive structural modeling was performed to eliminate stress concentrations and to develop a thermal link to the active element that was thermally conductive but structurally soft. The new design has constructed to fit into existing, advanced ADR hardware.

The passive magnetoresistive heat switch concept offers great reductions in mass and complexity, but the salt pill to which it is attached must be carefully chosen. In FY 2001, several candidate materials were identified and preliminary tests on powdered samples were performed. This past year, melt-grown samples of the material were acquired and measurements made on the most directly relevant properties: magnetic entropy, which indicates the material's cooling power, and thermal conductivity. The magnetic entropy measurements indicate that the material can be an excellent magnetic refrigerant. Unfortunately, the thermal conductivity of these samples, which were polycrystalline rather than single crystal, is not sufficient. Acquisition of single crystal samples is underway.

Planned Future Work

Completion of the magnetoresistive switch test will be carried out under FY 2003 CETDP funding for the advanced ADR. The switch components will soon go into fabrication. Because the switch has been designed to fit into an existing advanced ADR setup, a system-level test will require very little additional hardware. Work continues with crystal growers to obtain single-crystal samples of candidate magnetic refrigerant materials.

Title of Investigation:	The Turbotrap - A New Technology for Neutral Atom Imaging
Principal Investigator:	John W. Keller/691
Other Investigators/Collaborators:	Jamie Britt/544, Jack Lorenz/Litton Advanced Systems
Initiation Year:	FY 2001
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years:	$50K
Funding Authorized for FY 2002:	$15K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $3K Contracts: Toper Manufacturing, $7K Revolve Magnetic Bearing, $5K
Status of Investigation at End of FY 2002:	Completed in FY 2002
Expected Completion Date:	FY 2002

Purpose of Investigation

This work was proposed to the DDF to build a prototype of the turbotrap, a gaseous-charge exchange cell, to demonstrate its potential use as part of an energetic neutral atom-imaging detector.

FY 2002 Accomplishments

The turbotrap uses rapidly rotating blades that prevent atoms from leaving the unit by sweeping them back into the cell. Energetic neutral atoms move much faster than the blades or the thermal atoms contained inside the cell. These atoms are able to pass through openings between the blades, undergo charge exchange collisions with the gaseous atoms and emerge from the cell as ions, which can be detected and analyzed using conventional charged-particle optics. The turbotrap is effectively transparent to energetic neutral atoms but opaque to the thermal charge-exchange gas inside. A magnetic bearing motor was procured that is capable of rotating at 40,000 rpm. Extensive effort was expended on designing a turbotrap rotor that could withstand the stresses associated with these rotational speeds. The turbotrap was assembled and tested. These tests validated the principles on which the turbotrap is based. Rotation velocities up to 30,000 rpm were obtained with an increase in pressure of a factor of two over the ambient environment (20 mtorr). Further improvements in compression ratio will require reduction of tip losses through the use of sets of rotor and stator blades.

Reports, Journal Articles, Other Publications

Keller, J.W., M. A. Coplan, J. E. Lorenz, and K. W. Ogilvie, "*New Concept for the Measurement of Energetic Neutral Atom Composition and the Imaging of Their Sources*", in Solar and Galactic Composition, R. R. Wimmer-Schweingruber, Ed., AIP Conference Proceedings 2001.

Papers For Presentation At Professional Society Meetings, Seminars, Symposia

Keller, J.W., M.A. Coplan, K.W. Ogilvie, J.E. Lorenz, P. Rozmarynowski, "*New Concept for Energetic Neutral Atom Imaging Using a Gaseous Charge Exchange Cell*", AGU 2002 Spring meeting.

Planned Future Work

Further development of the turbotrap is being transitioned to industry through GSFC's technology transfer program.

Title of Investigation:	Optical Pulse Compression for Lidar Applications
Principal Investigator:	John Cavanaugh/554
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$25K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $15K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with funds remaining from FY 2002 ($10K)
Expected Completion Date:	September 2003

Purpose of Investigation

This work was proposed to the DDF to increase lidar transmitter efficiency.

FY 2002 Accomplishments

In the past year, task work including characterizing a lithium niobate electro-optic modulator, which was found unacceptable for this application. Other proposed fiber topologies were reviewed; one was selected for a testbed demonstration.

Planned Future Work

During the remainder of FY 2003 an alternate electro-optic modulator technology will be selected and characterized. This modulator will be either crystal-based or polymer waveguide-based, implanting the modulator in the fiber with the ultimate goal of reducing the voltage required to modulate the pulse polarization. Further analysis of the selected single modulator fiber topology is also required prior to implementation. Finally, a demonstration testbed will be assembled using commercially available components; its performance will be assessed.

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Title of Investigation:	Single-Crystal Silicon Lightweight Mirrors
Principal Investigator:	Vincent T. Bly/553
Other Investigators/Collaborators:	David A. Content/551, Armando Morell/544
Initiation Year:	FY 2001
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years:	$50K
Funding Authorized for FY 2002:	$40K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $1K Contracts: Bullen Ultrasonics, $31K; Swales, $8K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with funds remaining from FY 2002 and earlier years. Due to the positive results described below, funding from additional sources is becoming available. Some funding from the Cross Enterprise Technology Program is available now. Tentative agreement has been made to provide light weight mirrors for the GeoSpec Instrument Incubator Program. Complete transition from remaining DDF funds is expected during FY 2003.
Expected Completion Date:	FY 2004

Purpose of Investigation

This work was proposed to develop a process to fabricate lightweight mirrors from single crystal silicon (SCS).

FY 2002 Accomplishments

The first major milestone of this project was met during FY 2002. A four-inch-diameter mirror, flat to better than one-tenth wave of visible light peak-to-peak and better than one-eightieth wave rms, was produced. The mirror weighs 82 grams, or approximately one-fourth the weight of a solid quartz mirror of the same size. This mirror is a single monolithic structure of single crystal silicon, making it one of the most homogenous mirrors ever made.

An initial patent application was submitted to the U.S. Patent Office in March 2002. A final patent application is presently being prepared, and will be submitted by March 2003.

An abstract has been accepted for the Optifab 2003 Conference in May 2003, sponsored by SPIE (the International Society for Optical Engineering) and APOMA (the American Precision Optics Manufacturers Association). An abstract has also been accepted for the SPIE International Symposium on Optical Science and Technology.

Planned Future Work

Work has begun on a set of five SCS mirrors with an aspheric curved surface and a central perforation. They are designed to be the primary mirror of a Cassegrain system. The first three mirrors are four inches in diameter; the remaining two are 10 inches in diameter. Optimization of the fabrication process will be made using the four-inch mirrors. The goal for the two 10-inch mirrors, which will be scaled-up versions of the best of the four-inch mirrors, is a surface figure of at least one-eighth wave, peak-to-peak and one-fortieth wave RMS. If this goal is attained, fabrication of a secondary mirror will commence, and the 10-inch aperture Cassegrain system will be completed. Attempts will then be made to merge this optic with an instrument that can be flown on a technology demonstration mission to begin building spaceflight heritage for this new technology.

Title of Investigation:	In-House Development of an Orthogonal Transfer Charge-Coupled Device (OTCCD) Camera
Principal Investigator:	Ronald J. Oliversen/681
Other Investigators/Collaborators:	Keith Gendreau /662, Shahid Aslam/Raytheon ITSS/553, Steve Howell/Planetary Science Institute
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$50K
Actual or Expected Expenditure of FY 2002 Funding:	In house: Raytheon ITSS $2K Contracts: Astronomical Research Cameras (ARC), Inc. $33K; RS Information Systems $2K Grants: Planetary Science Institute $7K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with funds remaining from FY 2002
Expected Completion Date:	FY 2003

Purpose of Investigation

This program will assess the flight potential of OTCCDs and their potential for high-precision photometry. The OTCCD is capable of on-chip charge shifting in both the x-and y-directions while taking an exposure. The OTCCD has the potential for image motion compensation, *i.e.*, an improved point spread function (PSF), to correct for spacecraft motion or atmospheric turbulence. The OTCCD can also be used to create a tailored PSF to improve photo-metric accuracy.

FY 2002 Accomplishments

A model CCID 29 CCD chip was acquired from Dr. John Tonry (University of Hawaii) for evaluation and incorporation into a camera. Work with Bob Leach (ARC, Inc.) has been performed to manufacture a fully customized electronic readout system that will be capable of simultaneously reading from two readout channels of the CCID 29 CCD detector array. This system is near completion, with delivery expected in March 2003. The system is comprised of the following components: (1) A ND-5 liquid nitrogen Dewar (manufactured by Infrared Labs of Tucson, AZ) with a suitably sized window and a three liter nitrogen capacity for extended hold times; (2) A mechanical mount for the CCD inside the Dewar, wiring from the CCD to a connector, and wiring from the Dewar connector to the controller boards. A heater and temperature sensor near the CCD is also provided; (3) Digital signal processing (DSP) readout and control software, customized to operate the CCD in normal whole-frame readout, partial-frame readout, and binning modes, with software selectable by the user over the fiber optic link running between the timing board and the peripheral computer interface (PCI) board; (4) The installation of the GSFC-supplied CCID 29 chip and documentation of chip's readout noise, image quality, full-well capacity, and system gain; (5) Image acquisition software to communicate with the controller through the PCI interface and to interface with the user to allow acquisition commands and writing images in Flexible Image Transport

System (FITS) format to disk. The image acquisition program is written in Java and provided with full source code. The image acquisition program and associated device drivers for the ARC-63 PCI interface board will operate under control of a personal computer (PC) with a Linux operating system. The PC, a version of the Linux operating sytem, other software, and miscellaneous components for lab testing have been purchased.

Planned Future Work

Delivery of the OTCCD electronics and Dewar in the spring of 2003 will enable commencement of complete testing of the OTCCD camera's performance. These tests will characterize the performance of the OTCCD chip, including charge transfer efficiency, quantum efficiency between 360 to 900 nm, dark current, read noise, and photometric precision with and without orthogonal charge transfers. The effects of the frequency and pattern of charge transfers particularly will be investigated to quantify the effects of cosmetic defects and traps within the chip, and to determine its photometric precision limitation. Furthermore, the OTCCD will be evaluated for its X-ray detector capability (*e.g.,* energy resolution, gain stability).

Title of Investigation:	RF MEMS for Microwave Instruments
Principal Investigator:	Eric Simon/555
Other Investigators/Collaborators:	Mary Li/553, Fernando Pellerano/555
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$60K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $60K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with funds from FY 2002 and with additional FY 2003 funding of $40K (estimated)
Expected Completion Date:	FY 2003

Purpose of Investigation

Remote sensing microwave radiometers and radars use many forms of radio frequency (RF) switches. Requirements for loss and stability are beginning to surpass what can be achieved with conventional switch technology. In particular, the need for low-mass, low-power switches is absolutely necessary in synthetically thinned aperture radiometer (STAR) antennas that use many identical radiometers. A technology that will likely meet or surpass such requirements in future microwave instrumentation is provided by RF micro-electromechanical systems (MEMS). The effort funded in FY 2002 focused on bringing RF MEMS expertise to GSFC, and explored the fabrication and characterization of an RF MEMS switch.

FY 2002 Accomplishments

Requirements for the RF MEMS switch were drawn up using a comprehensive literature study, a survey of scientists at GSFC, and discussions with experts from industry and academia. A test station was developed that enables on-wafer probing and RF characterization of switches up to 110 GHz. A set of masks containing several prototypes of a shunt capacitive RF MEMS switch was designed. Fabrication of these prototypes began in August 2002 in the Detector Design Lab (DDL) at GSFC, and is still underway.

Planned Future Work

Upon completing the fabrication of the prototypes, RF performance, reliability, and life cycle of the RF MEMS switches will be characterized. Depending on the assessed performance of the prototype switches, the design and fabrication of a second batch of RF MEMS switch prototypes with improved performance may proceed. Using the experience gained from the FY 2002 development effort, packaging RF MEMS components into a radiometric system and their impact on system performance will be explored.

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Title of Investigation:	Applicability of Dielectric Mixing Theories for Use at Microwave Frequencies
Principal Investigator:	Robert Meneghini/975
Other Investigators/Collaborators:	Gail Jackson/975, Liang Liao/Caelum Corp.
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$40K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $20K Contracts: Caelum Co., $20K
Status of Investigation at End of FY 2002:	To be transitioned to RTOP funding under NRA-02-OES-05, Precipitation Measurements Missions
Expected Completion Date:	April 2003

Purpose of Investigation

Finding the electromagnetic scattering properties of composite materials, such as melting ice particles, requires a great deal of computation. When particles of different sizes and liquid water contents are present in the atmosphere, the computational time becomes impractically large. The standard procedure is to replace the composite with a uniform material whose dielectric constant gives the same scattering properties as the composite. A method, based on Maxwell's Equations, has been developed to compute this effective dielectric constant over a range of microwave frequencies and a range of fractional water contents. The objective of this investigation is to provide the needed experimental tests to determine the accuracy and applicability of the theory.

FY 2002 Accomplishments

An X-band calibration kit and a surface probe have been purchased to carry out reflection and transmission measurements on the HP 8510 Network Analyzer. Blocks of plastic and water, with water contents of 10%, 20% and 30%, have been fabricated for use as inserts in an X-band waveguide. At microwave frequencies plastic is electrically similar to ice; plastic-water composites can therefore be used to model melting ice particles. Surface probe and waveguide reflection and transmission measurements have been performed for the solid plastic (Delrin) material. Agreement between experiment and theory for this case is excellent. Reflection and transmission measurements in waveguides have been made for the 12 water-plastic composite inserts that have been fabricated. Initial comparisons of experimental and theoretical results have begun. For the cases examined to date, the agreement is good between the measured and predicted reflection coefficients. Initially, discrepancies between experiment and the theory for the transmission coefficients were significant. However, when the theoretical model for the scattering was made more exact by accounting for the fact that the water cylinders in the experimental samples were not drilled entirely through the plastic, the agreement between theory and experiment improved substantially.

Planned Future Work

There are several tasks planned for completion of this research. The first is to fabricate samples that more accurately model melting snow particles. This can be done by drilling holes in the Delrin (plastic) sample along two or three orthogonal planes, a task that should be possible with a numerically-controlled milling machine. A second task is to extend the measurements to higher frequencies. This will require the purchase of additional calibration kits for the network analyzer and fabrication of water-plastic samples for insertion into the appropriate waveguide. The final task is to upgrade the computer code that computes the effective dielectric constant for a specified water-plastic geometry. Evaluation of alternative electromagnetic codes that may be more efficient and accurate than the present code will be explored. The ultimate goal is to determine how well theory and experiment agree as regards the scattering properties of mixed-phase dielectrics for various frequencies and fractional water contents.

Title of Investigation:	Miniaturized Eddy Covariance Instrument for small Unmanned Aerial Vehicles
Principal Investigator:	Paul R. Houser/974
Other Investigators/Collaborators:	Michael Bosilovich/910
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$40K
Actual or Expected Expenditure of FY 2002 Funding:	Contracts: Goddard Earth Sciences & Technology Center (GEST), $40K
Status of Investigation at End of FY 2002:	Project completed in FY 2002, but second phase extension has been requested and approved for FY 2003
Expected Completion Date:	September 2003

Purpose of Investigation

The purpose of this project was to develop a miniaturized eddy covariance instrument for small unmanned aerial vehicles (UAVs) that will enable investigation of the complexities of land-atmosphere interaction on scales not previously possible. New miniaturized electronic sensors were used, along with the Global Positioning System (GPS), and assemblies to build a integrated sonic anemometer, an IR gas analyzer, and a net radiometer that are small enough to be flown on a small, low-flying UAV. This instrument has some fundamental development risks that traditional funding sources will not accept. However, this innovative combination of new technology, innovative science, and integrated concepts has great potential to position GSFC to become the leader in this developing field, and will provide feedback to improve Earth system concepts and predictive capabilities. By working with Geoff Bland at Wallops and other NASA scientists, a small UAV of no more then fifty pounds could deployed at a fraction of the cost of deploying the same system on a manned light aircraft. In addition a small UAV operating at altitudes as low as six feet above the ground can collect spatially distributed data similar to that of fixed tower system. Current mobile eddy correlation systems must operate at much higher altitudes and speeds. By using the most modern technology a system is being tested that, when deployed, will gather data of quality and resolution similar to other moving eddy covariance systems deployed on light aircraft. This system would be simpler to operate, with less overhead and initial startup costs than other systems.

FY 2002 Accomplishments

An eddy covariance system light enough to be deployed on a small UAV was procured and assembled.

Planned Future Work

Work will take place in conjunction with the NASA Wallops Flight Facility (WFF) to develop a small unmanned aerial vehicle that will enable us to investigate the complexities of land-atmosphere interaction on scales not previously possible. By working with Wallops Flight Facility we can build a prototype small UAV capable of

carrying our miniaturized eddy correlation system consisting of the latest in ultra light data loggers, IR Gas Analyzers, 3D sonic anemometers and net radiometers. This instrument has some fundamental development risks that traditional funding sources will not accept, but this innovative combination of new technology, innovative science, and integrated concepts has a great potential to position GSFC and WFF to become the leader in this developing field, and will feed back to improve earth system concepts and prediction.

Title of Investigation:	Printable Wireless Strain Sensors for Membranes
Principal Investigator:	John Blackwood/541
Other Investigators/Collaborators:	Jason Soloff/567, Bob Kiwak/541/SAI
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$50K
Actual or Expected Expenditure of FY 2002 Funding:	Contracts: Nanosonic, $25K; Swales, $8K Various vendors, $17K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with no additional funding
Expected Completion Date:	FY 2003

Purpose of Investigation

Acquiring engineering data on the performance of a film is often quite difficult, as typical measurement devices are intrusive, labor intensive, and expensive. In particular, the challenges of instrumenting an in-flight monitoring system usually require distinctly different ground and in-flight methods. Enabling embedded, nonintrusive, wireless sensors that could be remotely interrogated would provide vital engineering data and a health monitoring capability for film-based structures in space.

The thrust of this investigation concerns the development of remote sensing of film monitoring equipment (*e.g.*, strain gauges, antennas, etc.). A wireless approach will be applied to significantly decrease the associated weight of the monitoring system. Several approaches to remote wireless interrogation of strain sensors are being investigated.

A parallel effort will be undertaken to develop a technique for sensor application onto a thin-film substrate. One promising approach, electrostatic self-assembly (ESA), is under development by Nanosonic Inc., Blacksburg VA. An ESA process allows for engineering a diverse set of coatings on flexible substrates by using charged nanoparticles and individual molecules suspended in aqueous solutions. ESA allows the uniform formation of multiple, nanometer-thick layers of material into functional thin films, thick films, and bulk materials. This research effort will explore the extension of the ESA technique to use an inkjet printer head to precisely deliver extremely small amounts of the aqueous solution, thus building up fine line conductive structures.

FY 2002 Accomplishments

An inductively coupled strain gauge has been developed that uses the properties of inductive/capacitive (LC) resonant circuits to indirectly measure the linear strain on a substrate. The device consists of a spiral planar microstrip inductor and an interdigital planar microstrip capacitor. The inductor and capacitor are connected to form a resonant LC tank circuit. A linear strain in the sense axis of the interdigital capacitor will produce a change in capacitance in proportion to the strain; both increases and decreases in strain can be determined. The strain is measured by interrogating the structure with RF energy,

using a frequency-swept continuous wave (CW) signal of constant amplitude or by a broadband, short-duration pulse. In either case, the return signal is measured and is treated as a radar cross section (RCS) problem. This development emphasizes both the innovative use of current technology in an unconventional application and advancing remote wireless interrogation of sensors.

The frequency ranges and physically realizable LC circuit structures have been investigated. Computer-based finite-element and method-of-moments analyses of the electromagnetic properties of the structure have been performed. Work on the technology disclosure and patent process has begun for the new sensor concept.

The ESA technology has not yet matured to a useful point. Due to the additional requirement that the ESA sensor be conductive (using gold particles), the necessary viscosity for application onto a film substrate is still under development.

Planned Future Work

Work on the inductive/capacitive resonant circuit will continue by constructing several sensor devices for operation over various frequency bands. Measurement of actual performance in the anechoic chamber in GSFC Code 567 will be performed. As the technology/idea progresses, signal algorithms must be developed and integrated with the hardware. Development will also include effective sensor structures using low-cost, commercially available thin-film printing processes (*e.g.,* Nanosonic ESA, screen printing, photolithography, etc.). Assuming the development proceeds as expected, patent processes and technology transfer procedures for use in industry will be pursued. Work on the viscosity problem will continue, to provide suitable resolution that will allow application of the ESA process in virtually any desired size or shape.

Title of Investigation:	Improved Position Encoders with Superconducting Resonant Noise Capacitimetry
Principal Investigator:	Dominic Benford/685
Other Investigators/Collaborators:	Harvey Moseley/685
Initiation Year:	FY 2002
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years:	None
Funding Authorized for FY 2002:	$50K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $10K Contracts: SSAI, $25K Purchases: $15K
Status of Investigation at End of FY 2002:	Transitioned or to Transition to Other Funding: *RTOP*: FIBRE (Fabry-Perot Bolometer Research Experiment); *Project*: SAFIRE/SOFIA (Submillimeter and Far-Infrared Experiment aboard the Stratospheric Observatory for Infrared Astronomy)
Expected Completion Date:	FY 2003

Purpose of Investigation

A novel absolute position encoder was proposed, using a superconducting capacitance meter of unprecedented sensitivity and speed. In a cryogenic environment, linear positions should be measurable to a resolution of ~1 nm at an update rate of 100Hz—calculated for a 1-mm separation capacitor—thereby providing ten-fold higher resolution than a typical optical encoder. Superconducting resonant noise capacitimetry presents a reasonable solution, as it features high resolution and high speed, dissipates essentially zero power, can be used if requirements dictate operation at extremely low temperatures or across temperature boundaries, can be used where no light is permitted, and has the added benefit of simultaneous temperature measurement. Finally, since this transducer converts a distance measurement into a time measurement, the readout can have the high resolution and broad dynamic range that time measurement permits.

FY 2002 Accomplishments

The critical electronic components for the measurement were procured, and the cryostat for conducting the tests was acquired. With the help of a summer intern, the capacitor was designed, built, and operated under direct-drive motor power. The circuit for making the electrical measurement was designed and built, but did not operate properly due to excess capacitance in the superconducting inductor coil. A precision coil winder has been purchased, which is expected to produce lower capacitance inductor coils. With this element in place, project completion is expected.

Planned Future Work

The summer student, who graduated in December 2002, has been hired and is now winding a new inductor coil, to be followed by testing the noise capacitimetry. Data needed to demonstrate the successful operation of this technique will be acquired. This encoder can find application in position-sensitive cryogenic instruments such as FIBRE and SAFIRE/SOFIA.

Title of Investigation:	Tilt- and Shear-canceling Interferometer with a Single-substrate Beamsplitter/Compensator
Principal Investigator:	Donald E. Jennings/693
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$48K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $23K Contracts: Catholic University of America, $25K
Status of Investigation at End of FY 2002:	To be continued in FY 2003, with funds remaining from FY 2002
Expected Completion Date:	FY 2003

Purpose of Investigation

This work was proposed to demonstrate an interferometer that uses a beamsplitter and compensator combined on a single substrate. Tilt and shear are cancelled by double passing all optical elements and reflecting the two interferometer beams from a common mirror. By combining the beamsplitter and compensator on a common substrate, the number of passes through the substrate is minimized.

FY 2002 Accomplishments

A tilt- and shear-canceling beamsplitter/ compensator was fabricated. The demonstration unit was made of CaF_2, because it is an easy material to work with and because it allows operation in the visible and infrared regions of the electromagnetic spectrum, as remote sensing applications are conducted primarily in the infrared; an interferometer usually uses a visible laser for metrology. Preliminary characterization indicated that the beam-splitter/compensator meets specifications for the tilt and shear application. Detailed testing of the beamsplitter/compensator will be completed using interferometer optics during winter and spring 2003. No additional funds will be requested from the Director's Discretionary fund beyond those received in 2002. If successful, the tilt- and shear-canceling interferometer will be proposed for spaceflight remote sensing applications in both planetary and Earth science missions.

Planned Future Work

Work in the coming year will include development of a breadboard demonstration model of the tilt- and shear-canceling interferometer to support a transition to instrument incubator and planetary instrument development programs.

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Title of Investigation:	Formation Control Experiments Inside The Space Station
Principal Investigator:	J. Russell Carpenter/572
Other Investigators/Collaborators:	David T. Leisawitz/685, David Miller/MIT
Initiation Year:	FY 2002
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years:	No Director's Discretionary Funds (DDF) were used prior to FY 2002, however GSFC funds paid for two reduced-gravity aircraft tests of SPHERES prototypes in FY 2000 and FY 2001, which cost about $20K each
Funding Authorized for FY 2002:	$35K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $3.5K Grants: MIT $31.5K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with funds remaining from FY 2002 ($3.5k), and with additional FY 2003 funding: $50K to be requested from DDF; $100K from Code M and Code R technology programs
Expected Completion Date:	FY 2003

Purpose of Investigation

The investigation makes use of Synchronized Position Hold Engage Re-orient Experimental Satellites (SPHERES), which is a spacecraft formation flight testbed breadboard developed by Payload Systems Inc. and the Space Systems Laboratory in the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology (MIT). SPHERES provides a shirtsleeve environment testbed to validate metrology, formation flying, and autonomy algorithms to coordinate the motion of multiple satellites in micro-gravity (reduced-gravity aircraft flights, Shuttle middeck, or the International Space Station (ISS). In this investigation, candidate distributed space-craft control technologies developed at GSFC are being adapted for validation via the SPHERES, and defining requirements, interface specifications, and preliminary designs for external payload interfaces, with an end goal of performing formation control experiments onboard the ISS. For our contributions, GSFC will receive approximately one eighth of the on-orbit resources of SPHERES during its time aboard the ISS, which is planned to start in the summer of 2003.

FY 2002 Accomplishments

Two fully functional flight units have been integrated. At least 70 carbon dioxide fuel tank flight units have been painted and coated. A pendulum test is currently being setup to independently determine and verify the inertia properties of the flight units. A science Critical Design Review (CDR) was held at MIT on November 18, 2002 to explain the operations plan. The core elements of the flight software have been completed, including basic state estimation and propulsion functions.

This work resulted in the following list of publications and awards:

Chen, A., *Propulsion System Characterization for the SPHERES Formation Flight and Docking Testbed*, SM. Thesis, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, June 2002.

Hilstad, M., *A Multi-Vehicle Testbed and Interface Framework for the Development and Verification of Separated Spacecraft Control Algorithms*, SM. Thesis, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, June 2002.

Alvar Saenz Otero, David W. Miller, and Mark Hilstad, *SPHERES: a Laboratory for Formation Flight and Docking Research*, 5th Cranfield Space Dynamics Conference, Cambridge, England, July 2002.

Alvar Saenz Otero, David W. Miller, and Mark Hilstad, *SPHERES: Development of an ISS Laboratory for Formation Flight and Docking Research*, IEEEAC paper #081, Big Sky, MT, March 2002.

Alvar Saenz-Otero, and David Miller, *The Spheres ISS Laboratory For Rendezvous And Formation Flight*, ESA GNC paper #29, Frascati, Italy, October 2002.

2002 AIAA College Student Achievement Award for MIT SPHERES ISS Project, December 11, 2002.

Planned Future Work

Full scale electromagnetic interference testing will take place at Johnson Space Center (JSC). SPHERES system identification will take place on reduced-gravity aircraft. Crew training and bench review will take place at JSC, with subsequent hardware delivery to Kennedy Space Center for launch on STS-116.

INFORMATION ACCESS AND TRANSFER

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Title of Investigation:	An Educator Interface for Hera
Principal Investigator:	William D. Pence/662
Other Investigators/Collaborators:	James Lochner/662, Universities Space Research Association (USRA)
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$27K
Actual or Expected Expenditure of FY 2002 Funding:	Contracts: USRA, $2K; Science Systems and Applications, Inc. (SSAI), $10K; SP Systems, $15K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with funds remaining from FY 2002
Expected Completion Date:	FY 2003

Purpose of Investigation

An educational interface to the new Hera data analysis system has been developed. Hera enables professional researchers to analyze archived astronomical data sets over the Internet, without having to download large data files or install complicated data analysis software on their local computers. All necessary data analysis facilities are provided for the users on the Hera server computers at GSFC. The educational interface to Hera that is being implemented using this GSFC Director's Discretionary Fund award puts a simplified shell on top of the Hera graphical user interface that is more suited to student use. It allows the student to choose from only a small set of data files to analyze (as compared with the millions of data sets that are available to professional researchers) and only a dozen different analysis programs are available (compared to the 350+ specialized tools in the full Hera interface). When using the educational interface to Hera, students will be able to extend these explorations using real astronomical data files obtained with NASA satellites. The particular lesson plan being implemented deals with periodic behavior seen in the light curves of astronomical binary X-ray stars as observed with the Rossi X-ray Timing Explorer (RXTE) satellite. As part of this project, new Web pages are being created that provide additional background information about periodic X-ray sources and step-by-step instructions for using the educational Hera interface to analyze the data files. The Hera software system itself was previously developed under a $345K NASA Applied Information Systems Research Program (AISRP) grant.

FY 2002 Accomplishments

All technical programming issues needed to implement a simplified educator interface to Hera have been resolved. A prototype graphical interface that allows users to select a data file and then process it with one of several data analysis programs has been implemented. An outline of the supporting Web pages that will provide background educational lesson plan material and specific instructions for using Hera has been developed. A paper describing the Hera system was presented at the August 2002 SPIE (the International Society for Optical Engineering) meeting.

Planned Future Work

The binary X-ray star lesson plan will be implemented in the educational Hera interface by mid-2003. Based on this working demonstration, an application for funding will be made to expand the education uses of Hera *via* AISRP and the Initiative to Develop Education through Astronomy and Space Science (IDEAS), and other funding opportunities.

Title of Investigation:	HAndheld Mars Exploration (HAMEX)
Principal Investigator:	David Matusow/588
Other Investigators/Collaborators:	Joe Sparmo/585
Initiation Year:	FY 2001
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years:	$5K
Funding Authorized for FY 2002:	$4.5K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $4.5K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with additional funding ($4.5K estimated)
Expected Completion Date:	The HAMEX team has divided the work so that progress can be shown each year. The goal of the entire project is to have a usable environment for the two rovers to be launched to Mars in 2004

Purpose of Investigation

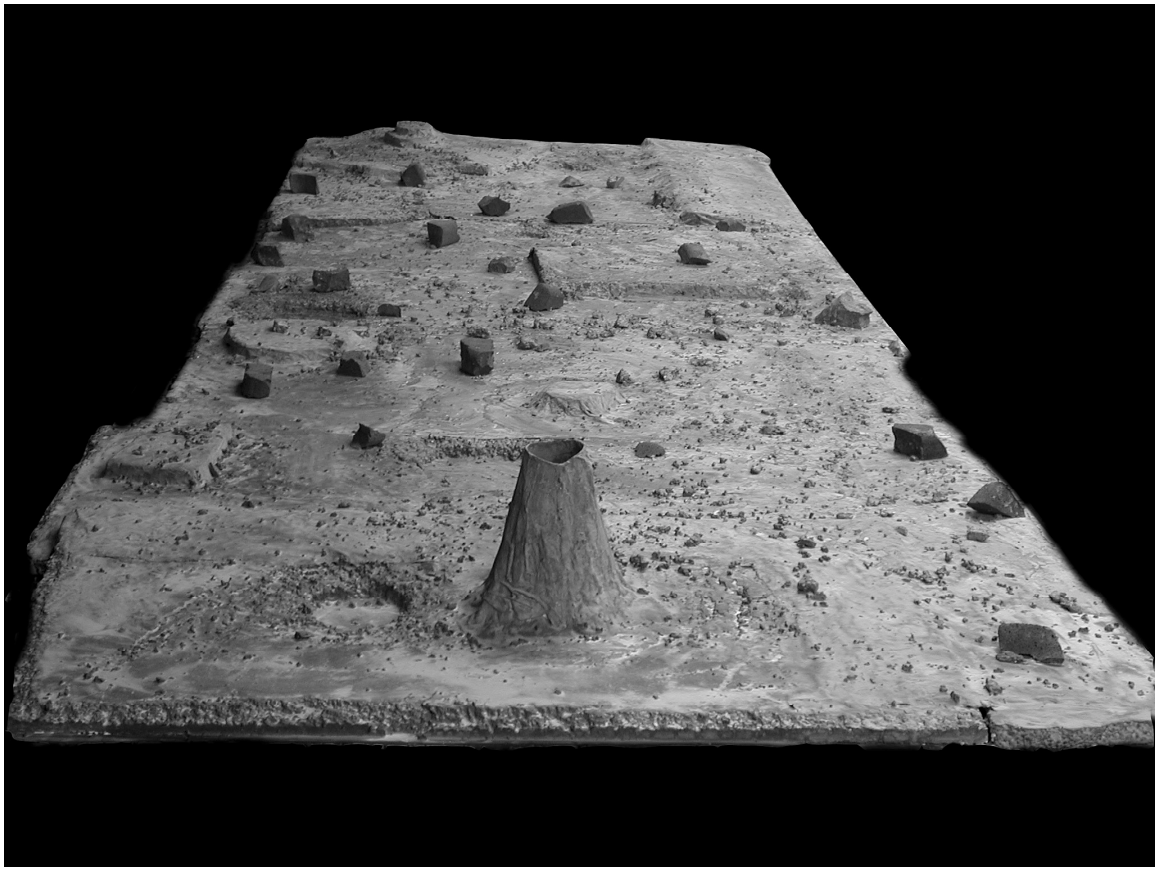
This work was proposed to investigate the use of handheld devices for use in the real-time scientific exploration of Mars, with significant emphasis on educational outreach.

FY 2002 Accomplishments

A white paper on our initial research and experiment with the Odyssey School in Baltimore was completed, with a presentation at the Maryland Instructional Computers Coordinators Association (MICCA) conference in Baltimore. The partnership with Odyssey continued, defining and initiating a Mars simulation experiment, to be conducted in winter, 2003. A simulation facility was created in the GSFC Visitor Center, and a set of applications has been developed that will help Odyssey students conduct a simulated Mars exploration mission, using robots they built.

Planned Future Work

The HAMEX team will conduct the simulated mission with Odyssey students in early 2003, and then write a white paper on the experiment's results. This work should lead to an improved HAMEX for the real Mars rovers, to be launched late in 2003.



A view of the Mars simulation environment constructed last summer for use in this winter's simulated Mars rover landing experiment.

EDUCATION AND OUTREACH

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Title of Investigation:	The Baltimore Student Sun Photometer Network
Principal Investigator:	Brent Holben/923
Other Investigators/Collaborators:	Elissa Levine/923
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$25K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $10K Contracts: SSAI, $15K
Status of Investigation at End of FY 2002:	To be continued in FY 2002 with additional FY 2003 funding ($35K, estimated)
Expected Completion Date:	December 2003

Purpose of Investigation

The Baltimore Student Sun Photometer Network (BSSN) is an education and outreach project designed to enhance the science, math, and technology skills of students in elementary, middle, and high schools in Baltimore and vicinity; to improve their understanding of their local environment; and to involve them as partners in an ongoing scientific investigation. From the science and technology perspective, the goal is to improve the data set for the Baltimore Children's Asthma Study by providing daily local information across the region for comparison with clinical and other environmental data. In addition, spatial and temporal trends in aerosol loading regionally are to be identified through comparison of school-based retrievals to allow NASA scientists to make atmospheric corrections on a pixel level, and to provide EOS MODIS and MISR science teams with a unique data set to validate their aerosol data products.

FY 2002 Accomplishments

In terms of education and outreach, through contacts with the Supervisor of the Office of Science and Health in the Baltimore City Public Schools and schools involved in the GLOBE and University of Maryland Medical System (UMMS) Breathmobile programs, 20 schools across the city were identified with interest in participating in the project. Because DDF funding did not arrive until late spring, coordination with only a few of the schools took place, allowing them to begin making measurements before the end of the '01-'02 school year. However, this provided some "practice" time to prepare for a full measurement campaign for the fall of 2002. Part of this included developing a Web site (http://aeronet.gsfc.nasa.gov:8080/Operational/BSSN/bssn.html) to process all student sun photometer data in real time, and to display it for student scientists and the scientific community in general. Both hard copy and Web-based learning materials were developed to complement the measurements, and to help teachers incorporate the BSSN project into their curriculum. The BSSN appeared as the "Top Story" on the NASA/GSFC News Web page (http://www.gsfc.nasa.gov/topstory/20020614baltasthma.html) on June 26, 2002, and featured a video created by NASA Public Affairs Office.

In August, a training workshop at the Maryland Science Center was conducted for participating BSSN teachers in preparation for the '02-'03 school year. Teachers learned more about the BSSN project and its relationship to NASA's Baltimore Children's Asthma Project and the Aerosol Robotic Network (AERONET) program. They practiced using the handheld sun photometer instruments and discussed techniques to implement taking measurements in the classroom. A support network was established to allow participating teachers to contact and assist each other. In addition, nurses from the UMMS Breathmobile program gave a lecture on asthma and demonstrated a simple measurement for lung function as an option for classroom use to complement the sun photometer measurements.

The science and technology aspects of the project resulted in successfully upgrading the handheld LED sun photometers to photodiodes, increasing their sensitivity by a factor of 100. Eleven high school and college students, recruited to make measurements at various sites within the city of Baltimore, tested this new instrument this summer. Through collaboration with the UMMS Breathmobile program, the students also measured lung function of volunteers within the city and aerosol optical thickness. Data from this exercise have been processed and are being analyzed.

Planned Future Work

Collaboration will continue with the UMMS Breathmobile program to encourage teachers to make simultaneous measurements of lung function and aerosol optical depth for research purposes. A system to provide communication with and encouragement for these teachers is planned, to provide educational tools and to ensure continuous and high-quality student-made measurements. To help ensure continued support, letters and certificates will be issued to teachers and the principals at their respective schools, certifying participation in the project. A research assistant will visit schools to instruct participants in measurement techniques, to assist them with downloading data, and to provide additional information about the project. The research assistant will keep in close contact with the schools, observe the data flow coming in to the Web site, and make repeat visits to further assist and encourage measurement activity. The BSSN Web site will be maintained and expanded to include measurement protocols, URLs for access to related topics and additional learning activities, and to provide an "e-newsletter", providing teachers and students with updates about BSSN activities and opportunities. This newsletter will also highlight and encourage student research through science fairs and other projects. Results from data collection will continue to be posted on the BSSN Web site. Analysis of the data will continue, and will be made available to the Baltimore Asthma project database and to researchers interested in calibrating atmospheric corrections and validating aerosol data products obtained by remote sensing. Relationships between lung function and aerosol levels will be developed in collaboration with the UMMS.

Title of Investigation:	Practical Application of Ocean Color Methodology to an Undergraduate Curriculum
Principal Investigator:	Tiffany A. Moisan/972
Other Investigators/Collaborators:	Andrew Mueller and Julie Ambler/Millersville University, Eric Sherry/VA Marine Science Consortium (VMSC), Brian Cambell/970, Ed Parrot/200
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$13K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $13K
Status of Investigation at End of FY 2002:	To be continued in FY 2002 with additional DDF program funding
Expected Completion Date:	FY 2003

Purpose of Investigation

This investigation seeks to educate undergraduates about remote sensing tools NASA has available to observe phytoplankton. Students at the junior and senior level are shown how to interpret and understand satellite imagery. Specifically, students would be able to observe phytoplankton in the field through several oceanographic cruises to give them a perspective on phytoplankton distribution in the Mid-Atlantic Bight. Students are also supplied with ocean color imagery from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) Web site to allow them to observe their "backyard" via satellite-based imagery. Collaboration with the VA Marine Science Consortium (VMSC), a collective of 14 participating universities, aids this work. The VMSC is conveniently located outside of the NASA Wallops Flight Facility (WFF), easing logistics in coordinating the hands-on cruises, field experiences, and lectures provided throughout the spring and fall by university faculty members from participating institutions.

FY 2002 Accomplishments

In the first year of funding, significant strides were made toward developing a low-cost radiometer, which can be broadly distributed to undergraduate classrooms. In addition to integrating this instrumentation into the VMSC curriculum, classroom material has been developed to address the role of phytoplankton in the carbon cycle. The "hands-on" approach facilitated an in-depth understanding of the principles of spectral absorption and scattering that form the basis for satellite retrieval of phytoplankton abundances from ocean color radiance imagery. The use of the spectroradiometer from dockside and aboard ship was augmented by concurrent investigations with SeaWiFS ocean color satellite imagery. With this observing system, students sampled a subset of the satellite's areal coverage and "calibrated" the satellite with the low-cost device.

The students took part in an oceanographic cruise and used the instrument in the field. The data that were collected on the cruise were reduced and analyzed in the classroom, using an Excel spreadsheet as the analytical tool. The students were able to look at distributions of fluorescence (a proxy for phytoplankton concentration), temperature, salinity, and density in conjunction with the data collected with the newly developed instrument.

An aesthetically and scientifically accurate *Foundations of Phytoplankton* Web site was also developed for a general audience, focusing on understanding ocean color remote sensing and its application to ocean carbon cycle dynamics. The instrument design was shared with high school teachers at the In-service Teacher Training (NIST) for National Teaching Standards.

Planned Future Work

In the second year, project expansion is sought, using the resources at the VMSC developed in Year 1 of funding and resources at University of Maryland, Eastern Shore (UMES). Additional content-comprehensive classroom materials that target the role of phytoplankton in the carbon cycle will be developed by focusing on the East Coast of the United States. In addition, a low-cost radiometer will be provided for use in the classroom and in the field for permanent placement into the curriculum. Several learning objectives will be specifically targeted, using scientific inquiry that will enhance student skills in math, engineering, biology, cellular optics, and remote sensing technologies. Integration of these skills in the classroom is paramount to allow students to develop the ability to synthesize interdisciplinary knowledge and to acquire a comprehensive understanding of remote sensing of ocean color.

Title of Investigation:	Expanding the Spectrum of Student Astronomy Experience Through an Interactive Multi-Frequency Radio Telescope
Principal Investigator:	James Thieman/633
Other Investigators/Collaborators:	Richard Flagg/RF Associates, James Sky/Radio-Sky Publishing, Charles Higgins/Middle Tennessee State University, Joseph Ciotti/Windward Community College, Lou Mayo/Raytheon ITSS
Initiation Year:	FY 2002
Funding Authorized for FY 2002:	$33.2K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $7K Contracts: RF Associates, $10.2K; Radio-Sky Publishing, $ 7.5K Grants: Windward Community College (U. of HI) , $2.8K; Middle Tennessee State University, $5.7K
Status of Investigation at End of FY 2002:	To be continued in FY 2003 with funds remaining from FY 2002
Expected Completion Date:	May 2003

Purpose of Investigation

This work was proposed to modify the Hawaii Windward Community College (WCC) radio telescope to add the capability of transmitting radio spectra to classrooms and Radio JOVE (http://radiojove.gsfc.nasa.gov/) teams through the Internet; to test the viability of, and interest in, various methods of remote student control of a decameter-wavelength radio telescope; and to make students aware, through hands-on experience, that they can learn much more about an object by observing it in different frequencies of radiation.

FY 2002 Accomplishments

The spectroscope was constructed and connected to the 18-28 MHz log periodic antenna operated at WCC in Hawaii. A beta test version of the spectrograph software has been developed and made available for test personnel through the web. Successful tests of the software were made by a number of remote observers allowing them to view the spectrogram simultaneously through the Internet and to choose single frequency higher resolution data from the WCC telescope to be viewed. One remote observer can be granted permission to remotely "tune" or choose which spectrogram channel will be shown as the single frequency high-resolution data histogram. Software and hardware have also been developed and installed to allow a single remote observer to control the pointing of the radio telescope and to start a calibration sequence on command. This is being tested at the present time.

This work has resulted in the following publications and/or presentations:

Mayo, L. and J. R. Thieman, "*The Use of Remote Telescopes in Education and Outreach*",

Division of Planetary Sciences Meeting, Birmingham, AL, October, 2002.

Thieman, J. R. Flagg, J. Sky, B. Pine, A. Davison, J. White, and L. Bueno, "*Radio JOVE, What's New?*", Society of Amateur Radio Astronomers Meeting, Green Bank, WV, July, 2002.

Thieman, J. R., "*The Radio JOVE Project: An Interactive, Hands-on, Radio Astronomy Experience for Students or the General Public*", American Astronomical Society Meeting, Albuquerque, NM, June, 2002.

Thieman, J.R. "*Radio JOVE, An Education and Outreach Project*", National Council of Teachers of Mathematics (NCTM) Meeting, Las Vegas, NV, April, 2002.

Planned Future Work

As soon as the spectrograph software and remote control capability of the WCC radio telescope have been thoroughly tested and the operational limits determined, then education modules and appropriate operational instructions will be finished and advertised to Radio JOVE participants to allow them to have hands-on control of the Hawaii radio telescope. This will be advertised to the school groups associated with the Telescopes in Education (TIE) project as well. Assessment will be performed to see if these activities will inspire additional interest among students to do the full Radio JOVE project and to build their own radio telescopes from the Radio JOVE kit.

In the future we hope to put other spectroscopes at other professional radio observatories such as the University of Florida. The spectroscopic software developed as a result of this DDF would actually be very useful in the research domain as well. Future development and distribution of this capability, however, will be done through new funding sources.

Title of Investigation:	The Mathematics, Engineering, and Science Enrichment Pre-College Program (MESEP)
Principal Investigator:	Lisa Johnson/120
Other Investigators/Collaborators:	Janie Nall/EduTech Ltd., Brenda Holden/Virginia Cooperative Extension Office
Initiation Year:	FY 2002
Aggregate Amount of Funding Authorized in FY 2001 and Earlier Years:	$70K ($20K from DDF in FY2002; $50K from Code 120 in FY 2001)
Funding Authorized for FY 2002:	$20K
Actual or Expected Expenditure of FY 2002 Funding:	In house: $20K
Status of Investigation at End of FY 2002:	To be continued in 2003 with funds remaining from FY 2002 and with additional FY 2004 DDF Funding, estimated $39.4K
Expected Completion Date:	FY 2003

Purpose of Investigation

The MESEP is designed to ignite high school students' interest in science, technology, engineering, and mathematics (STEM) and to stimulate the students' STEM skills and their application. The underlying goal of the project is to increase the number of minorities and female students who are prepared for the rigor of university study in STEM. The program consists of hands-on learning activities, guest lecturers, and field trips at both the University of Maryland College Park (UMCP) and the University of Maryland Eastern Shore (UMES). The UMCP program focuses on exploring the math, physics, engineering, and design behind roller coasters. Saturday Academies convene during the school year. The UMES program includes an eighteen-day Summer Academy and Saturday Academies. In both instances, the students receive instruction in physics, engineering, mathematics, English and analytical skills along with parallel activities.

FY 2002 Accomplishments

The UMES program averaged twelve students for the Summer Academy. The Closing Program included presentations on the projects, trips and other activities that had been experienced. Projects included building and utilizing an angle-o-meter and gravity measurement. The students gained proficiency in use of graphing calculators and Excel spreadsheet generation. Two Saturday Academies have been held to date, with as many as twelve students. One of these featured a guest lecturer from the Virginia Cooperative Extension partnership who addressed watershed and other environmental considerations such as those relative to the Chesapeake Bay.

The UMCP program began in January 2003 and will continue through April 2003. Up to twenty students are being introduced to materials science. The seven-week program includes hands-on activities and interactions with professionals from Goddard Greenbelt as well as other employers. The

students will gain an understanding of how physics and materials affect the development and construction of roller coasters.

Planned Future Work

At both the UMES and UMCP campuses, the program will be repeated for new students during 2003. The goal is to reach as many students as possible within the financial constraints. Program improvements are made continually in order to maximum the programs' effectiveness. Consideration is being given to expanding the role of the partnership with the Virginia Cooperative Extension, to adding the Maryland Cooperative Extension as a partner, and to explore further partnerships.

NASA GSFC Center Director's Discretionary Fund: Distribution of Resources for FY 2002

Project Title and Investigator	Initiation Year	Partnership with Academia	Total Funding Authorized ($)	Project Status	Expected Completion Date (Year)
EARTH SCIENCE AND TECHNOLOGY					
Analysis of In Situ and Remote Sensing Aerosol Absorption Data *Yoram Kaufman*	2001	✓	60K	Open	2003
New Lidar Technique to Measure Direct and Indirect Effects of Aerosols *David Whiteman*	2002	✓	50K	Open	2004
Development of Prototype Holographic Fabry-Perot Filters for Daytime Lidar Measurements *Matthew McGill*	2001	✓	75K	Closed	July 2002
Fiber Optic Raman Laser Amplification for Remote Sensing Spectroscopy *Mark Flanegan*	2002	✓	30K	Closed	2002
Global Carbon Cycle: Development of a Bicarbonate Ion Lidar *Frank E. Hoge*	2002	--	76K	Open	2003
Snowfall Inference from Microwave Radiometry *James Weinman*	2002	✓	30K	Open	2003
A New Approach for Measuring Ozone from the Ground *Scott Janz*	2002	--	52K	Open	2003
Retrieval of Harmful Algal Bloom Signatures from Oceanic Radiances *Tiffany A. Moisan, Wayne Wright*	2001	--	74.8K	Open	2003
Quantifying Microwave Transmission through Dynamic Vegetation *Paul R. Houser*	2001	✓	55K	Closed	2002
A Land Surface Patch-Based Ensemble Kalman Filter *Paul R. Houser*	2002	✓	55K	Closed	2002
Intraplate Crustal Dynamics Study for the Global Earthquake Satellite System *Paul D. Lowman, Jr.*	2002	--	40K	Closed	2003

Project Title and Investigator	Initiation Year	Partnership with Academia	Total Funding Authorized ($)	Project Status	Expected Completion Date (Year)
From Iturralde Structure to Araona Crater *Peter Wasilewski*	2001	--	60K	Closed	2002
Remotely Sensed Isotopic Constraints on Hydrologic Processes in the GISS GCM *David Rind*	2002	✓	30K	Open	TBD
Development of a "Modeling Workbench" Facility to Parameterize Global Biogeochemical Models *John R. Moisan*	2002	--	59K	Open	2003
Programmable Gate Array (PGA) to allow Global Positioning System (GPS) Navigation to be used in High Earth Orbits *Luke Winternitz*	2002	--	50K	Open	2003
Neutral Winds and Temperatures in the Low-altitude Thermosphere with a MEMS Sensor *F. A. Herrero*	2002	--	55K	Open	Oct. 2003
Tethered Balloon Activities with Science and Technology *Antoinette C. Wells*	2002	--	20K	Term.	NA
SPACE SCIENCE AND TECHNOLOGY					
A Holographically Speckle Corrected Telescope *Richard G. Lyon*	2002	✓	60K	Open	Dec. 2003
High Temperature Superconducting (HTS) Far-IR Bolometer Array on Sapphire Membranes with Integrated Readout SQUIDs *Brook Lakew*	2001	--	90K	Open	2004
Investigation of MgB_2 for Use in Far-IR Bolometers Operating at 30 Kelvin *Brook Lakew*	2002	--	65K	Open	2004
Finger Detectors: Simple Far Infrared/Submillimeter Bolometric Arrays *Robert Silverberg*	2002	--	70K	Open	Unknown
Making High Angular Resolution X-Ray Optics by Combining Diamond Turning Technology and Thin Glass Sheets *William Zhang*	2002	--	46.5K	Open	2003

Project Title and Investigator	Initiation Year	Partnership with Academia	Total Funding Authorized ($)	Project Status	Expected Completion Date (Year)
Optically Thin Pixel Detectors for a Broadband X-ray Polarimeter *Keith Gendreau*	2002	✓	75K	Open	2003
X-ray Interferometer Fringe Magnifier *Keith Gendreau*	2002	--	25K	Open	Sep. 2003
Kirkpatrick-Baez X-ray Mirrors in Astronomy: Historical Interest or a Future Application? *Peter J. Serlemitsos*	2002	✓	57K	Open	2003
Next-Generation 2-D Planar Bolometer Arrays for Far-IR and Sub-mm Astrophysics *Minoru M. Freund*	2001	--	85K	Unknown	NA
INSTRUMENT DEVELOPMENT AND TECHNOLOGY					
Broadband Single-mode Millimeter/ Submillimeter-Wave Polarization Diplexers *E. Wollack*	2002	--	30K	Closed	2003
Dual Slot Antenna Development for Millimeter /Submillimeter-Wave Focal Plane Arrays *E. Wollack*	2002	--	33K	Open	Jan. 2004
Silicon "Grass" as Infrared Material *Mary J. Li*	2000	--	44K	Open	Mar. 2003
Development of Cooled Schottky CdTe Detector Systems *Jacob Trombka*	2002	✓	65K	Closed	2002
A Deposited Palladium-Iron Thermometer for Very Low Temperatures *Jim Tuttle*	2001	--	60.3K	Open	2003
Continuous ADR Cooling from the Passive Cooling Limit to Sub-Kelvin Temperatures *Todd King*	2002	--	40K	Open	2003
A Passive, Solid-State Heat Switch for the Continuous ADR *Edgar Canavan*	2001	--	60.5K	Open	2003
The Turbotrap - A New Technology for Neutral Atom Imaging *John W. Keller*	2001	--	65K	Closed	2002

Project Title and Investigator	Initiation Year	Partnership with Academia	Total Funding Authorized ($)	Project Status	Expected Completion Date (Year)
Optical Pulse Compression for Lidar Applications *John Cavanaugh*	2002	--	25K	Open	Sep. 2003
Single-Crystal Silicon Lightweight Mirrors *Vincent T. Bly*	2001	--	50K	Open	2004
In-House Development of an Orthogonal Transfer Charge-Coupled Device (OTCCD) Camera *Ronald J. Oliversen*	2002	--	50K	Open	2003
RF MEMS for Microwave Instruments *Eric Simon*	2002	--	60K	Open	2003
Applicability of Dielectric Mixing Theories for Use at Microwave Frequencies *Robert Meneghini*	2002	--	40K	Open	Apr. 2003
Miniaturized Eddy Covariance Instrument for small Unmanned Aerial Vehicles *Paul R. Houser*	2002	✓	40K	Open	Sep. 2003
Printable Wireless Strain Sensors for Membranes *John Blackwood*	2002	--	50K	Open	2003
Improved Position Encoders with Superconducting Resonant Noise Capacitimetry *Dominic Benford*	2002	--	50K	Open	2003
Tilt- and Shear-canceling Interferometer with a Single-substrate Beamsplitter/Compensator *Donald E. Jennings*	2002	✓	48K	Open	2003
Formation Control Experiments Inside The Space Station *J. Russell Carpenter*	2002	✓	35K	Open	2003
INFORMATION ACCESS AND TRANSFER					
An Educator Interface for Hera *William D. Pence*	2002	✓	27K	Open	2003
HAndheld Mars Exploration (HAMEX) *David Matusow*	2001	--	9.5K	Open	2004

Project Title and Investigator	Initiation Year	Partnership with Academia	Total Funding Authorized ($)	Project Status	Expected Completion Date (Year)
EDUCATION AND OUTREACH					
The Baltimore Student Sun Photometer Network *Brent Holben*	2002	✓	25K	Open	Dec. 2003
Practical Application of Ocean Color Methodology to an Undergraduate Curriculum *Tiffany A. Moisan*	2002	✓	13K	Open	2003
Expanding the Spectrum of Student Astronomy Experience Through an Interactive Multi-Frequency Radio Telescope *James Thieman*	2002	✓	33.2K	Open	May 2003
The Mathematics, Engineering, and Science Enrichment Pre-College Program (MESEP) *Lisa Johnson*	2002	✓	40K	Open	2003
PROGRAMMATIC AND STUDENT INTERNSHIP SUPPORT			258.2K		
TOTAL ALLOCATION OF FY 2002 GSFC DDF SUPPORT			2697K		