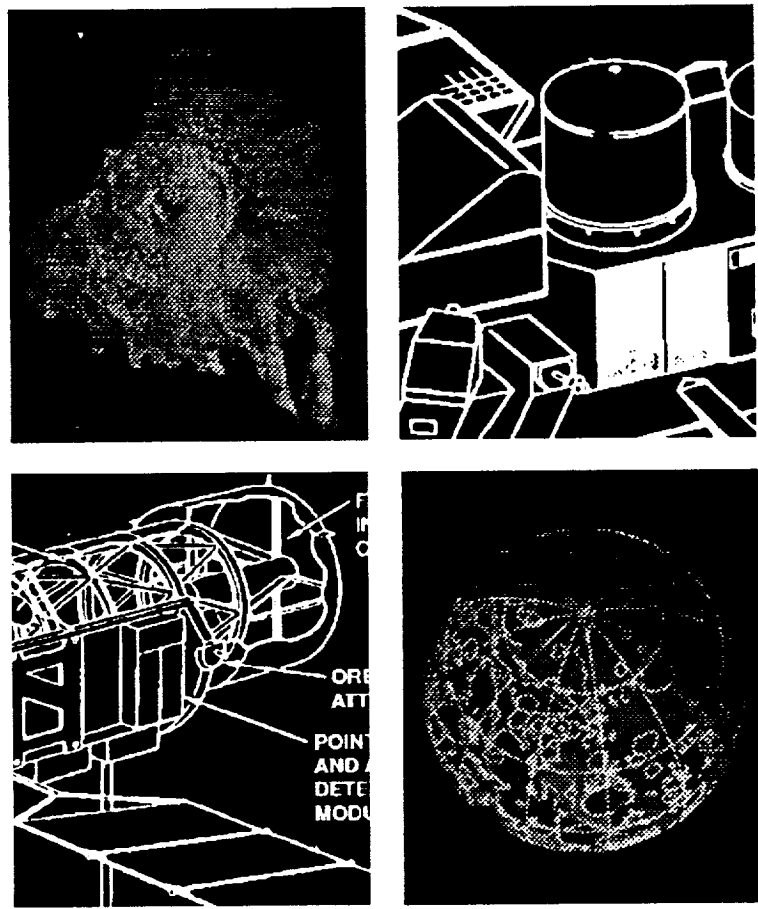


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# WORKSHOP ON ADVANCED TECHNOLOGIES FOR PLANETARY INSTRUMENTS



## LPI Technical Report Number 93-02, Part 2

Lunar and Planetary Institute 3600 Bay Area Boulevard Houston TX 77058-1113  
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ADVANCED TECHNOLOGIES FOR PLANETARY  
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**WORKSHOP ON  
ADVANCED TECHNOLOGIES FOR  
PLANETARY INSTRUMENTS**

Edited by

J. Appleby

Held at  
Hyatt Fair Lakes  
Fairfax, Virginia

April 28-30, 1993

Sponsored by  
NASA's Solar System Exploration Division (Office of Space Science)  
NASA's Office of Advanced Concepts and Technology  
DoD's Strategic Defense Initiative Organization  
Lunar and Planetary Institute

Lunar and Planetary Institute 3600 Bay Area Boulevard Houston TX 77058-1113

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## Preface

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NASA's robotic solar system exploration program requires a new generation of science instruments. Design concepts are now judged against stringent mass, power, and size constraints—yet future instruments must be highly capable, reliable, and, in some applications, they must operate for many years. The most important single constraint, however, is cost: New instruments must be developed in a tightly controlled design-to-cost environment. Technical innovation is the key to success and will enable the sophisticated measurements needed for future scientific exploration. As a fundamental benefit, the incorporation of breakthrough technologies in planetary flight hardware will contribute to U.S. industrial competitiveness and will strengthen the U.S. technology base. The Workshop on Advanced Technologies for Planetary Instruments was conceived to address these challenges, to provide an open forum in which the NASA and DoD space communities could become better acquainted at the working level, and to assess future collaborative efforts.

Over 300 space scientists and engineers participated in the two-and-a-half-day meeting held April 28–30, 1993, in Fairfax, Virginia. It was jointly sponsored by NASA's Solar System Exploration Division (SSED), within the Office of Space Science (OSS); NASA's Office of Advanced Concepts and Technology (OACT); DoD's Strategic Defense Initiative Organization (SDIO), now called the Ballistic Missile Defense Organization (BMDO); and the Lunar and Planetary Institute (LPI). John Appleby (NASA Headquarters) organized the workshop, served as general chair, and headed the program committee. Other program committee members included Henry Brinton (NASA Headquarters), Scott Hubbard (NASA Ames Research Center), Dwight Duston (BMDO), Stuart Nozette (BMDO), and Gregg Vane (Jet Propulsion Laboratory).

The meeting included invited oral and contributed poster presentations, working group sessions in four subdisciplines, and a wrap-up panel discussion. On the first day, the planetary science community described instrumentation needed for missions that may go into development during the next 5 to 10 years. Most of the second day was set aside for the DoD community to inform their counterparts in planetary science about their interests and capabilities, and to describe the BMDO technology base, flight programs, and future directions. The working group sessions and the panel discussion synthesized technical and programmatic issues from all the presentations, with a specific goal of assessing the applicability of BMDO technologies to science instrumentation for planetary exploration.

Invited oral presentations are listed in the agenda with their assigned times. Abstracts for these talks are compiled in this report. Although each of the listed DoD specialists made an oral presentation, several did not submit an abstract; for further information, you may phone the BMDO at 703-693-1671. The agenda also lists contributed posters; abstracts for these investigations were compiled in LPI Technical Report 93-02, Part 1, which was provided to all participants at the workshop (address inquiries to the Order Department at LPI). The executive summary presents the conclusions and recommendations from each of the four working groups, and also incorporates some comments drawn from the panel discussion. The list of workshop participants, including addresses and telecom numbers, is given at the end of this report.

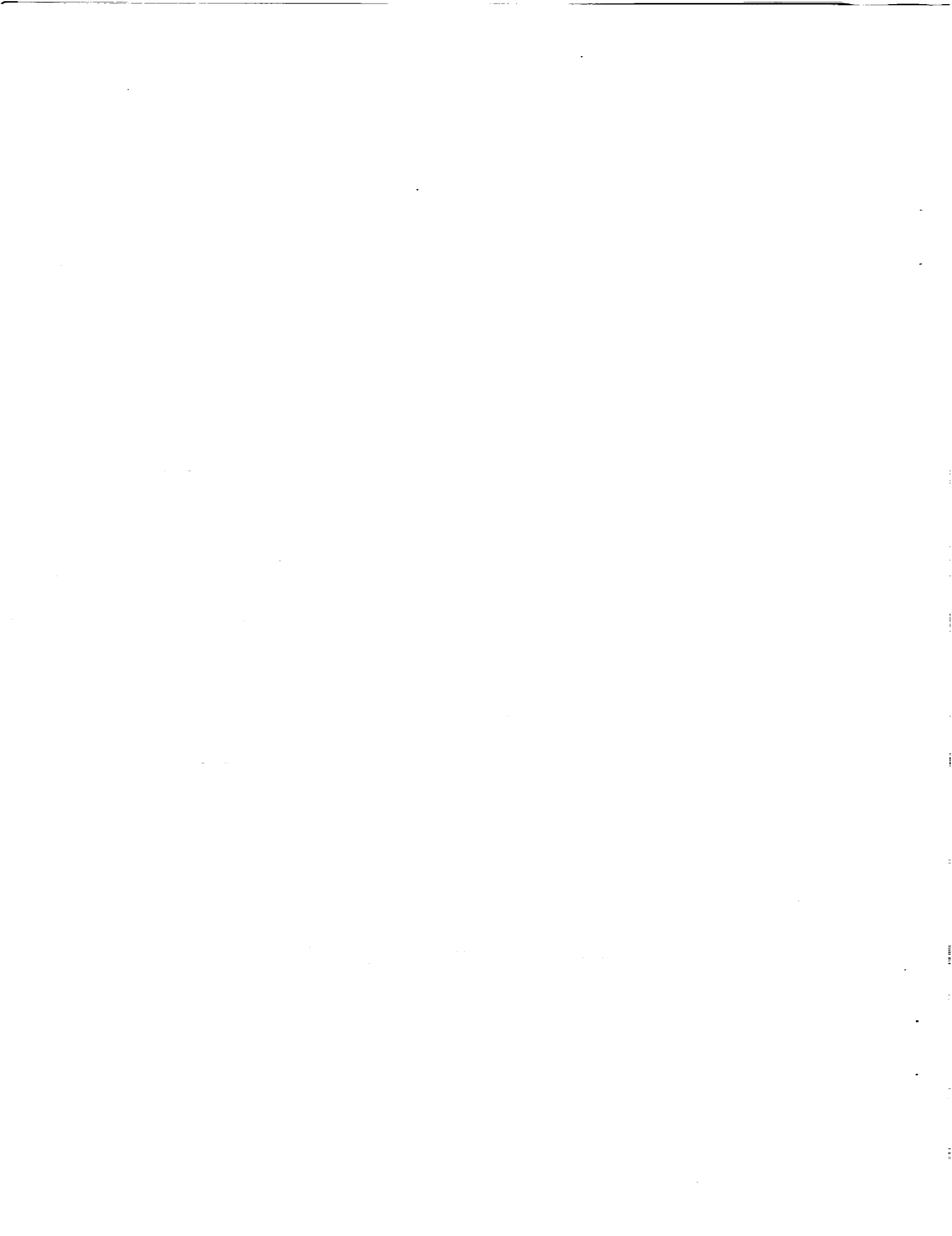
This report also includes a description of an extensive database called the Technology Applications Information System (TAIS), compiled and supported by the BMDO. TAIS promises to be a valuable resource for future collaborative efforts between the NASA and DoD space communities. It is unclassified and available to U.S. citizens. TAIS provides synopses of BMDO-sponsored research and development programs, including instrumentation and sensor technology, and it contains points of contact (principal investigators and program managers), institutional affiliations, and supporting contractors.

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## Agenda

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*Wednesday, April 28*

- 8:30 a.m. *Welcome and Introduction/Objectives of the Workshop*  
 Dr. John F. Appleby, **General Chair**  
 Advanced Studies Branch, Solar System Exploration Division (SSED)  
 Office of Space Science (OSS)
- 9:00 a.m. *Advanced Instrument Concepts*  
 Mr. Samuel L. Venneri  
 Director, Spacecraft and Remote Sensing Division,  
 Office of Advanced Concepts and Technology (OACT)
- 9:30 a.m. *Strategic Defense Initiative Science and Technology Program*  
 Dr. Dwight Duston  
 Director, Innovative Science and Technology  
 Strategic Defense Initiative Organization (SDIO)
- 9:45 a.m. *Solar System Exploration During the Next Five to Ten Years*  
 Dr. Carl B. Pilcher  
 Chief, Advanced Studies Branch, SSED
- 10:05 a.m. *Selection and Development of SSED Science Instruments*  
 Mr. Henry C. Brinton  
 Chief, Planetary Science Branch, SSED
- 10:25 a.m. BREAK
- PLUTO FAST FLYBY MISSION**  
 Moderator: H. Reitsema, Ball Aerospace
- 10:40 a.m. *Current Baseline Mission, Science and Measurement Objectives, and Strawman Instrument Payload*  
 A. Stern, Southwest Research Institute  
 Chair, SSED's Outer Planets Science Working Group
- 11:00 a.m. *Visible Imaging System*  
 M. Malin, Malin Space Systems, Inc.
- 11:20 a.m. *Infrared Mapping Spectrometer*  
 W. H. Smith, Washington University
- 11:40 a.m. *Ultraviolet Spectrometer*  
 W. McClintock, University of Colorado

12:00 noon LUNCH

**MARS ENVIRONMENTAL SURVEY (MESUR) MISSION**

Moderator: J. Appleby, SSED

- 1:00 p.m. *Current Baseline Mission, Science and Measurement Objectives, and Strawman Instrument Payload*  
S. Squyres, Cornell University  
Chair, SSED's MESUR Science Definition Team
- 1:20 p.m. *Visible Imager*  
E. Danielson, California Institute of Technology
- 1:40 p.m. *Micro-Meteorological Package*  
W. Kaiser, Jet Propulsion Laboratory (JPL)
- 2:00 p.m. *Alpha-Proton-X-ray ( $\alpha$ -p-x) Spectrometer*  
T. Economou, University of Chicago
- 2:20 p.m. *Micro-Seismometer*  
B. Banerdt, JPL
- 2:40 p.m. *Thermal Analyzer/Evolved Gas Analyzer (TA/EGA)*  
W. Boynton, University of Arizona
- 3:00 p.m. BREAK

**MISSIONS TO SMALL BODIES (ASTERIODS AND COMETS)**

Moderator: P. Feldman, Johns Hopkins University

- 3:20 p.m. *Current Mission Concepts, Scientific and Measurement Objectives*  
M. Neugebauer, JPL
- 3:40 p.m. *Remote Sensing Science*  
J. Veverka, Cornell University  
Chair, SSED's Small Bodies Science Working Group
- 4:00 p.m. *In Situ Measurements*  
W. Boynton, University of Arizona
- 4:20 p.m. *Lunar Science: Using the Moon as a Testbed*  
G. J. Taylor, University of Hawaii  
Chair, SSED's Lunar Exploration Science Working Group
- 4:40 p.m. *Mars '94 Oxidant Experiment*  
F. Grunthaner, JPL

- 4:50 p.m. *Planetary Instrumentation: Closing Comments*  
S. Hubbard, NASA Ames Research Center (ARC)
- 5:00 p.m. POSTER SESSION with Wine and Cheese Social (contributed posters are listed at the end of the agenda)
- 6:30 p.m. ADJOURN FOR THE DAY

*Thursday, April 29*

**SDIO-DEVELOPED INSTRUMENT TECHNOLOGY FOR  
PLANETARY EXPLORATION**

- 8:30 a.m. *Overview*  
D. Duston, SDIO

**TECHNOLOGY SCHEDULED TO BE FLIGHT TESTED**

- 8:45 a.m. *Small Satellite Sensors and Image Processing*  
P. Rustan, SDIO  
A. Ledebuhr, LLNL  
L. Pleasance, LLNL
- 10:15 a.m. BREAK
- 10:30 a.m. *Phenomenology Sensors and Processors*  
J. Mill, PRA
- 11:30 a.m. *Lightweight LIDAR*  
D. Holtkamp, SDIO
- 12:00 noon LUNCH

**TECHNOLOGY STILL IN THE LABORATORY**

- 1:00 p.m. *Interceptor Seeker Technology*  
W. Dyer, SDIO
- 1:30 p.m. *Advanced Processor Technology*  
C. Lau, ONR
- 2:00 p.m. *Advanced Sensors*  
W. Frederick, SDIO  
C. Kukkonen, JPL  
D. Duston, SDIO

- 3:15 p.m. BREAK
- 3:30 p.m. *Superconducting Sensors/Processors*  
M. Nisenoff, NRL
- 3:45 p.m. *Neutral Particle Beam Sensing: Proposed Experiment*  
E. Heighway, LANL
- 4:00 p.m. BREAK
- 4:20 p.m. **INFORMAL WORKING GROUP MEETINGS, POSTER SESSION CONTINUES**  
W/G 1: UV-Visible Remote Sensing    Chair: G. Lawrence, University of Colorado  
W/G 2: IR Remote Sensing            Chair: S. Chase, Electro-Optical Consultant  
W/G 3: Data Processing                Chair: L. Pleasance, LLNL  
W/G 4: *In Situ* Measurements        Chair: W. Boynton, University of Arizona
- 5:30 p.m. ADJOURN FOR THE DAY

*Friday, April 30*

**WORKING GROUP REPORTS AND PANEL DISCUSSION**

Moderator: G. Vane, JPL

- 8:30 a.m. Working Group 1: UV-Visible Remote Sensing  
Chair: G. Lawrence, University of Colorado
- 9:00 a.m. Working Group 2: IR Remote Sensing  
Chair: S. Chase, Electro-Optical Consultant
- 9:30 a.m. Working Group 3: Data Processing  
Chair: L. Pleasance, LLNL
- 10:00 a.m. Working Group 4: *In Situ* Measurements  
Chair: W. Boynton, University of Arizona
- 10:30 a.m. BREAK
- 10:45 a.m. *Panel Discussion: Conclusions and Recommendations*  
H. Brinton, NASA, SSED  
W. Hudson, NASA, OACT  
L. Pleasance, LLNL  
G. Vane, JPL  
B. Wilson, JPL  
A. Delamere, Ball Aerospace Corp.  
J. Martin, Martin Marietta Corp.  
H. Plotkin, NASA Goddard Space Flight Center  
T. Krimigis, Applied Physics Laboratory, Johns Hopkins University (APL)

11:45 a.m. **Workshop Summary Documentation**  
T. Krimigis, APL

12:00 p.m. **WORKSHOP ADJOURNS**

### CONTRIBUTED POSTERS

*The HYDICE Instrument Design and Its Application to Planetary Instruments*

R. Basedow, P. Silverglate, W. Rappoport, R. Rockwell, D. Rosenberg, K. Shu, R. Whittlesey,  
and E. Zalewski

*Design of a Particle Beam Satellite System for Lunar Prospecting*

D. H. Berwald and P. Nordin

*Laser-induced Breakdown Spectroscopy Instrument for Elemental Analysis of Planetary Surfaces*

J. Blacic, D. Pettit, D. Cremers, and N. Roessler

*Clementine II: A Double Asteroid Flyby and Impactor Mission*

R. J. Boain

*High-Performance Visible/UV CCD Focal Plane Technology for Spacebased Applications*

B. E. Burke, R. W. Mountain, J. A. Gregory, J. C. M. Huang, M. J. Cooper, E. D. Savoye,  
and B. B. Kosicki

*Every Good Virtue You Ever Wanted in a Q-switched Solid-State Laser and More—Monolithic,  
Diode-pumped, Self-Q-switched, Highly Reproducible, Diffraction-limited Nd:YAG Laser*

Y. C. Chen and K. K. Lee

*Planetary and Satellite X-Ray Spectroscopy: A New Window on Solid-Body Composition by  
Remote Sensing*

D. L. Chenette, R. W. Wolcott, and R. S. Selesnick

*Polarimetric Multispectral Imaging Technology*

L.-J. Cheng, T.-H. Chao, M. Dowdy, C. Mahoney, and G. Reyes

*A Remote Laser-Mass Spectrometer for Determination of Elemental Composition*

R. J. De Young and W. Situ

*Investigation of Mars Rotational Dynamics Using Earth-based Radio Tracking of Mars Landers*

C. D. Edwards Jr., W. M. Folkner, R. D. Kahn, and R. A. Preston

*Design Concept for an IR Mapping Spectrometer for the Pluto Fast Flyby Mission*

U. Fink, F. Low, B. Hubbard, M. Rieke, G. Rieke, M. Mumma, S. Nozette, G. Neukum, H. Hamel,  
M. DiSanti, M. Buie, and A. Hoffman

*Multibeam Laser Altimeter for Planetary Topographic Mapping*

J. B. Garvin, J. L. Bufton, and D. J. Harding

*Acousto-Optic Infrared Spectral Imager for Pluto Fast Flyby*

D. A. Glenar and J. J. Hillman

*Thermal Analyzer for Planetary Soils (TAPS): An In Situ Instrument for Mineral and Volatile-Element Measurements*

J. L. Gooding, D. W. Ming, J. E. Gruener, F. L. Gibbons, and J. H. Allton

*Microtextured Metals for Stray-Light Suppression in the Clementine Startracker*

E. A. Johnson

*Lightweight Modular Instrumentation for Planetary Applications*

P. B. Joshi

*Optical Technologies for UV Remote Sensing Instruments*

R. A. M. Keski-Kuha, J. F. Osantowski, D. B. Leviton, T. T. Saha, D. A. Content, R. A. Boucarut, J. S. Gum, G. A. Wright, C. M. Fleetwood, and T. J. Madison

*Multiscale Morphological Filtering for Analysis of Noisy and Complex Images*

A. Kher and S. Mitra

*A Unique Photon Bombardment System for Space Applications*

E. J. Klein

*Detection of Other Planetary Systems Using Photometry*

D. Koch, W. Borucki, and H. Reitsema

*An Integrated XRF/XRD Instrument for Mars Exobiology and Geology Experiments*

L. N. Koppel, E. D. Franco, J. A. Kerner, M. L. Fonda, D. E. Schwartz, and J. R. Marshall

*Remote Measurement of Planetary Magnetic Fields by the Hanle Effect*

C. K. Kumar, L. Klein, and M. Giraud

*Resolution-enhanced Mapping Spectrometer*

J. B. Kumer, J. N. Aubrun, W. J. Rosenberg, and A. E. Roche

*Proposal for a Universal Particle Detector Experiment*

J. C. Lesho, R. P. Cain, and O. M. Uy

*OPTIMISM Experiment and Development of Space-qualified Seismometers in France*

P. Lognonné, J. F. Karczewski, and the DT/INSU-CRG Garchy Team

*Filtering Interpolators for Image Comparison Algorithms*

R. L. Lucke and A. D. Stocker

*Mass Spectrometric Measurement of Martian Krypton and Xenon Isotopic Abundance*

P. Mahaffy and K. Mauersberger

*A DTA/GC for the In Situ Identification of the Martian Surface Material*

R. L. Mancinelli, M. R. White, and J. B. Orenberg

*Onboard Signal Processing: Wave of the Future for Planetary Radio Science?*

E. A. Marouf

*Spaceborne Passive Radiative Cooler*

S. Mathias

*Systematic Processing of Clementine Data for Scientific Analyses*

A. S. McEwen

*Sources Sought for Innovative Scientific Instrumentation for Scientific Lunar Rovers*

C. Meyer

*Honeywell's Compact, Wide-Angle UV-Visible Imaging Sensor*

D. Pledger and J. Billing-Ross

*Gamma Ray/Neutron Spectrometers for Planetary Elemental Mapping*

R. C. Reedy, G. F. Auchampaugh, B. L. Barraclough, W. W. Burt, R. C. Byrd, D. M. Drake, B. C. Edwards, W. C. Feldman, R. A. Martin, C. E. Moss, and G. H. Nakano

*Infrared Rugates by Molecular Beam Epitaxy*

M. Rona

*Plasma, Magnetic, and Electromagnetic Measurements at Nonmagnetic Bodies*

C. T. Russell and J. G. Luhmann

*A Compact Imaging Detector of Polarization and Spectral Content*

D. M. Rust, A. Kumar, and K. E. Thompson

*Prototype Backscatter Mössbauer Spectrometer for MESURment of Martian Surface Mineralogy*

T. D. Shelfer, R. V. Morris, D. G. Agresti, T. Nguyen, E. L. Wills, and M. H. Shen

*Spacecraft Computer Technology at Southwest Research Institute*

D. J. Shirley

*The Backgrounds Data Center*

W. A. Snyder, H. Gursky, H. M. Heckathorn, R. L. Lucke, S. L. Berg, E. G. Dombrowski, and R. A. Kessel

*The Enhanced-Mode Ladar Wind Sensor and Its Application in Planetary Wind Velocity Measurements*

D. C. Soreide, R. L. McGann, L. L. Erwin, and D. J. Morris

*Venus Interior Structure Mission (VISM): Establishing a Seismic Network on Venus*

E. R. Stofan, R. S. Saunders, D. Senske, K. Nock, D. Tralli, P. Lundgren, S. Smrekar, B. Banerdt, W. Kaiser, J. Dudenhofer, B. Goldwater, A. Schock, and J. Neuman

*Plasma Diagnostics by Antenna Impedance Measurements*

C. M. Swenson, K. D. Baker, E. Pound, and M. D. Jensen

*Use of Particle Beams for Lunar Prospecting*

A. J. Toepfer, D. Eppler, A. Friedlander, and R. Weitz

*Subnanoradian, Groundbased Tracking of Spaceborne Lasers*

R. N. Treuhaft

*A Team Approach to the Development of Gamma Ray and X-Ray Remote Sensing and In Situ Spectroscopy for Planetary Exploration Missions*

J. I. Trombka, S. Floyd, A. Ruitberg, L. Evans, R. Starr, A. Metzger, R. Reedy, D. Drake, C. Moss, B. Edwards, L. Franks, T. Devore, W. Quam, P. Clark, W. Boynton, A. Rester, P. Albats, J. Groves, J. Schweitzer, and M. Mahdavi

*Miniature Long-Life Space Cryocoolers*

E. Tward

*Environmental Monitors in the Midcourse Space Experiments (MSX)*

O. M. Uy

*Development of Miniaturized Optimized Smart Sensors (MOSS) for Space Plasmas*

D. T. Young

*X-Ray, Far, and Extreme Ultraviolet Coatings for Space Applications*

M. Zukic and D. G. Torr



# Executive Summary

*T. Krimigis, editor*

## INTRODUCTION

The overall objectives of this meeting (to bring together spacecraft designers, instrument builders, scientists, and engineers from NASA, DoD, DOE laboratories, universities, and industry) were by-and-large achieved, with the participation of over 300 attendees and 83 oral and poster presentations. Exchange of technical information took place not only in the formal sessions, but also in informal discussions and during the poster session. With so many presentations, it is extremely difficult to summarize the salient points of each, so a collective approach was clearly called for and arranged by the organizers in the form of four working groups covering UV-visible remote sensing, IR remote sensing, data processing, and *in situ* measurements.

The working groups met after the formal presentations and formulated their summaries on the basis of both the prepared abstracts and the oral presentation by each author. The membership of the working groups was open and many of the attendees participated in the discussions and formulation of the summary and recommendations. The result of their deliberations was presented to the participants on the last day of the meeting. These presentations were followed by questions and discussion, some of which resulted in revisions of the final text given in the next several pages. The content of the summaries was accepted by the organizers without change.

### WORKING GROUP ON UV-VISIBLE REMOTE SENSING

*G. Lawrence, Chair*

#### UV-Visible Technology

The working group generally admired the cameras and spectrographs summarized by the SDIO. The structures and optics were well engineered and highly weight-relieved. The structures use weight-saving but expensive materials such as composites, beryllium, and silicon carbide. SDIO funding has supported and created companies and trained people that can deliver these structures.

The SDI programs made miniature camera electronics using custom silicon gate arrays (ASICs) and the latest in miniature packaging. The current commercial or aerospace path of development for complicated electronics involves (1) circuit design using individual logic functions ("jelly bean design"), (2) breadboards using Field Programmable Gate Arrays (FPGA), and (3) fabrication of ASICs (~\$20K).

The working group noted that SDI development and funding has concentrated on IR rather than visible technologies because of SDIO's need to observe objects both day and night.

Visible sensors are incidental to most SDI applications and have received minimal funding. Therefore, the SDI instruments use commercial-grade, imported CCDs. U.S.-made, scientific-quality CCDs are far superior for the science of NASA planetary observations.

We applauded the SDI effort to make a U.S. aerospace product of the Oxford Stirling cycle cryogenic cooler. This development shows promise as a silicon CCD cooler as well as an infrared cooler.

The SDI UV instruments used fairly conventional detectors and optics. Most of them were for the near UV.

A new technology was the High Band Gap Semiconductors. These are essentially insulators with conduction stimulated by heat or by UV light. As an eventual substitute for silicon, these materials show promise for high-temperature electronics and solar-blind UV photodetectors. In principle, a CCD-type array detector could be built for the near or far UV that did not suffer from the red leak problem of silicon CCDs.

### WORKING GROUP ON IR REMOTE SENSING

*S. Chase, Chair*

In the IR Remote Sensing Working Group we used the themes presented by S. Hubbard, namely (1) identify instrument technologies that are new to the planetary community, but are still proven; (2) aggressively fund "up front" technical development; (3) take more risk; and (4) require missions to accept more new technology.

#### Clementine Mission

There was considerable discussion of the Clementine mission, much of it critical. However, the strengths and weaknesses of the program as viewed by our group can be summarized as follows:

**Strengths.** The program has the flexibility to accept risk, instruments are small and light, and the integrated data bus and processor approach saves weight.

**Weaknesses.** The integrated data architecture lacks redundancy, complicates software, and may be prone to single-string failures; the small size and weight of sensors is due, in part, to lack of redundancy and calibration features normally found on NASA experiments; and a cooler lifetime was marginal for mission goals.

#### Instrument Technologies

Generally, we agree that the NASA community was well aware of technologies being applied by SDIO. The differences lie mainly in when and how they are applied. SDIO appears

able to apply new technologies sooner than NASA, without extensive test verification and heritage (more on this aspect later). In addition, SDIO can apply them without the extensive risk assessment required by NASA.

The following technologies, gleaned from the abstracts, poster sessions, oral presentations, and even hallway conversations, should be pursued for future NASA missions.

**Spectral separation.** There is interest in multispectral (hyperspectral) imaging, but mainly below 2.5  $\mu\text{m}$ . Hyperspectral means contiguous spectral coverage at high resolution, whereas multispectral implies a number of discrete spectral bands. The following technologies may be applied to NASA experiments:

1. Acousto-optical tunable filters (AOTF) offer the possibility of a hyperspectral imager with no mechanical scan. Liquid crystal tunable filters are another possibility. The only other technique offering this capability is the imaging interferometer (like SPIRIT). All others, as described below, require pushbroom scan.

2. The Sagnac (no moving parts) interferometer, as described by W. H. Smith, is functionally similar to a dispersive spectrometer.

3. A linear variable filter with wedged etalon, as described by J. Kumer of Lockheed, improves the spectral resolution and overcomes several shortcomings of LVFs.

4. Holographic grating spectrometers may offer more compact packaging options than conventional designs.

**Focal planes.** Primary scientific interest appears to be below 2.5  $\mu\text{m}$ , partly because solar reflectance spectroscopy is well understood, and partly due to the availability of high-performance focal planes that require minimal cooling. Longer-wavelength devices (photovoltaic HgCdTe operating out to 12  $\mu\text{m}$ , for example) are also becoming more readily available, and these are being applied to atmospheric sounding and composition experiments.

Focal-plane enhancements such as the microlens (binary) technology are well known and will be readily accepted by NASA experimenters when development is further along. Focal-plane suppliers are focused on better process control, better yield, and better uniformity of focal-plane arrays. Some are addressing producing low-volume, but low-cost, IPAs for strategic programs. This same capability could apply as well to NASA programs.

Thermal detectors are still viable for NASA missions. JPL MicroDevices Laboratory is developing a tunnel-diode "Golay" detector that has performance comparable to the best current thermal detector, but has a frequency response orders of magnitude higher (10 kHz).

Near-ambient detectors such as the InGaAs should be explored for planetary science applications.

**Detector cooling.** The development of miniature Stirling and pulse-tube coolers should be pushed so that longer lifetimes can be validated. These devices hold the key to many

experiments that would benefit from detector temperatures in the 65 K range. In fact, a number of EOS experiments currently depend on the successful life test of these coolers.

Passive radiative cooling is still practical for experiments requiring temperatures in the 80–200 K range. In this temperature range the choice of mechanical or passive cooling would depend on system trades.

**Calibration.** Calibration has been an essential part of all NASA planetary experiments. The apparent lack of calibration on Clementine was cause for concern. The use of ground-truth and the Moon as a calibration source were mentioned. In fact, H. Kieffer at the U.S. Geological Survey, Flagstaff, has been developing a lunar calibration system, and P. Slater at the University of Arizona has a well-developed ground-truth calibration program using White Sands facility.

As the sophistication of science experiments grows, so does the requirement for improved calibration (better radiometric and spectral accuracy and better stability).

## WORKING GROUP ON DATA PROCESSING

*L. Pleasance, Chair*

The handling of large amounts of data generated by modern sensors was an underlying concern at the workshop. Approximately 20 conference attendees participated in the data handling working group session. The topics for discussion were selected by a poll of workshop participants. The group was primarily interested in the software and hardware aspects of spacecraft data handling and in-ground data handling. The equally important issues associated with onboard data generation and utilization, data storage, and transmission links were considered only in passing by the workshop attendees.

The four principal areas of discussion and review were: (1) advanced processors and processor system architecture for onboard data handling, (2) software development requirements for high-speed processors, (3) data compression approaches and issues, and (4) ground-data processing and archiving.

The use of advanced, high-resolution, optical sensor arrays on spacecraft for mission-oriented and scientific data collection has raised a significant problem in the handling of the large amounts of data that can be generated by these devices. A single silicon-based CCD camera with 1,000,000 pixel array can operate at readout rates of the order of 10 Mpixel per second. With 10-bit quantization, such a sensor can generate 100 Mbps. Even larger arrays are under testing and development and the technology is being extended into the IR. Advances in electronic packaging have reduced the weight and size of these sensors. Most spacecraft do and will carry multiple sensors.

Unfortunately, the technology and efficiency of data transmission have not improved commensurably. Effective use of advanced sensor technology will require commensurate tech-

nology development in the areas of lightweight digital storage technology, onboard processing, data compression techniques, and bandwidth-efficient modulation techniques.

### Advanced Processors

One of the major areas of improvement in technology over the past few years has been the rapid increase in the performance of advanced RISC architecture processors and their associated electronic components, spurred by the growth of consumer electronics. Many of the DoD applications require onboard processing of sensor images for immediate spacecraft or system control. There has recently been a growing interest within the NASA spacecraft developers and the science community for the possibility of applying this advanced processing technology to establish some degree of onboard autonomy in control and data processing.

The need for and use of advanced processors were discussed extensively by the workshop participants. The current lack of a well-characterized RISC processor for space applications was noted. The long duration of the development cycle (eight years or more in the conventional space development cycle against three years in the commercial community) was discussed. Approaches to improve radiation tolerance, both total dose and SEU sensitivity, was discussed. Approaches under investigation with several DoD programs for the use of commercial advanced processors in a radiation-upset-tolerant architecture such as dual-lockstep processing with software error correction were discussed. The consensus of the workshop participants was that there was a need for the development of a "workhorse" radiation-hard, RISC processor for spacecraft control and data handling applications. There was less consensus on the detailed architecture for this processor, although it was generally agreed that none of the available systems were optimum for all applications.

### Software Development

Several of the participants in the workshop proposed the use of a custom processing architecture with neural-net-type configurations for spacecraft control and data-handling applications. After discussion, the consensus was that the techniques warranted further investigation, but that the application of these techniques would require faster turnaround in the design and cycle for custom processors.

It was the consensus of the group that a technology development program for testing advanced systems in space in a timely fashion was needed. It was noted that the DoD seemed significantly more aggressive than NASA on this area.

### Data Compression

A significant amount of discussion was directed at the issues of data compression. The need for some form of data

compression was universally acknowledged. However, the loss or degradation of critical data through the compression process continues to be of primary concern to the scientific community. There was consensus that for maximum data return there was a need for more intimate coupling between the experimenter and the design of the experiment and the capabilities and constraints of the datacompression algorithms. One size does not fit all in data compression.

The increase in the power of modern processors, coupled with the availability of larger onboard memory, has allowed the use of more complex onboard processing and control algorithms. As the software becomes more complex, the issues of error and error correction become of more concern. This has focused attention on the processes of development, testing, and reliability of the software needed for extensive onboard processing. The potential for adaptive techniques such as neural nets was discussed but was considered as a development for the future. The consensus was that the use of advanced processors will require far more testing prior to launch and the development of simulation and fault testing techniques to improve reliability.

### Ground Processing

One consequence concerning the trend of current spacecraft system development is the large amount of data, generally in the form of images, that must be processed and archived on the ground if it is to be available to and used by the community at large. Concern was expressed that the technology and facilities for handling such data were not currently available. CD-ROM technology was discussed as a potential low-cost distribution technique, although concern was expressed that the cost of producing a small number of disks may be higher than expected. There was a discussion on the need for improved coordination among the archiving centers of the DoD and NASA.

### Summary and Recommendations

There was general consensus that much more effort and attention must be applied to the problems of data handling if the potential of advanced processing technology is to be effectively utilized for space applications.

NASA and the DoD should encourage the development and testing of advanced processors for spacecraft applications. Effort should be applied to shorten the qualification process. Increased cooperation should be encouraged between NASA and DoD communities for data archiving policies and methods.

Research and development of advanced processing techniques, such as neural nets and adaptive AI algorithms, should be nurtured while their potential is being evaluated.

While the needs and approaches of the DoD and NASA spacecraft communities are not totally the same, there is a

great deal of commonality that can be exploited to benefit both communities. Increased interaction between the two communities should continue to be encouraged. More attention should be applied to the issues of data handling in modern spacecraft. A workshop devoted to the subject or explicit sessions on the subject should be considered for future workshops and conferences.

## WORKING GROUP ON *IN SITU* MEASUREMENTS

*W. Boynton, Chair*

### Introduction

*In situ* studies, as the term is used for this workshop, includes those studies made in direct contact with solid surfaces, atmospheres, and cometary comae. It also includes measurements of particles and fields in space and any remote sensing not included in the two remote sensing groups, which include IR, visible, and UV spectroscopy. These studies clearly include a broad group of instrument types, and not all the relevant technology could be represented at the meeting.

As NASA moves from the eras of reconnaissance through exploration to intensive study, the details of the questions asked become greater, and the need for higher technology generally increases to permit more detailed investigations to be conducted. Even though we have launched few missions that had *in situ* objectives of solid surfaces as a primary goal, our ability to formulate detailed questions in this area is also high due to detailed studies of extraterrestrial materials: meteorites, interplanetary dust, and lunar samples. Unfortunately, even though NASA is moving toward the era of detailed study, which usually implies *in situ* measurements, not much of the technology being developed by SDIO appears relevant to this area of inquiry.

### Specific Areas of Technology Development

These areas will be discussed below, but the discussion will focus as much on technology needs as on new technology identified at the meeting that may be relevant to *in situ* studies.

**Mineralogy.** Measurements in this area involve using thermal analysis, which looks for phase transitions; Mössbauer spectroscopy, which determines the minerals in which iron is located; X-ray diffraction (XRD), which measures the lattice spacings of the minerals; and scanning electron microscopy (SEM), which determines the elemental composition of the individual mineral grains. None of the presentations of SDIO were relevant, but some technology needs were discussed in the group. One useful development is the use of a photon conversion coating on CCDs to make them sensitive in the X-ray region of the spectrum. This technology will be useful for XRD and will also be useful for X-ray fluorescence, which is discussed below. At one time a SEM was under development

for the CRAF comet mission, but we understand that development stopped with the cancellation of the mission. A less-quantitative, but still useful, means of studying mineralogy is with imaging. A geologist's hand lens can tell an experienced eye much about a rock. The development of a small low-magnification microscope with a large depth of field could make a significant contribution to *in situ* studies of rocks.

**Elemental composition.** These measurements are usually made with energetic photons or charged particles. The common techniques are X-ray fluorescence (XRF) and gamma ray spectrometry, either *in situ* or from orbit, and alpha and proton spectroscopy. Relevant technology outside SDIO includes the development of photon conversion coatings discussed above, and the adaptation of neutron sources developed for well logging. It was reported that nuclear-weapons-developed neutron sources may have substantial advantages for planetary applications, but the technology is still classified.

**Molecular and atmospheric composition.** The composition of gases is generally determined by gas chromatography or mass spectrometry, but occasionally compound-specific detectors can be useful. One of the presentations of technologies developed within the life sciences division at NASA can be very useful for the detection of water. This technique actually measured the dew point of the gas, from which water vapor pressure is readily determined. Another technology discussed in the group that will be useful was the conversion of nonvolatile, high-molecular-weight organic compounds to simpler, more volatile forms to permit gaseous analysis. This technology could be very useful for the analysis of cometary organics.

**Isotopic composition.** Most scientific problems in this area require accuracies that may be far too demanding to be made outside the laboratory. An exception is the analysis of noble gases. It may be possible to perform K/Ar dating.

**Geophysics.** Many new technology sensors are being developed that promise to drastically reduce requirements for mass, volume, and power on future space missions. However, in many cases these developments are being made by technology groups with weak linkages to the potential user community. We recommend that these development groups establish stronger linkages, determine the measurement needs of the planetary science community, and compare the sensitivity, linearity, and measurement ranges of these new instruments with the traditional instruments. Examples include the tunneling magnetometer and broadband microseismometer.

Advances in geophysical remote sensing of planetary subsurfaces would probably come from some SDIO and DOE programs that were not discussed during the workshop. Examples include very-high-pulsed power radar that could be used to image the lunar, martian, and small body subsurfaces to great depths. This new EM source could be combined with advanced data handling and computer-based analysis tech-

niques for both EM and seismic data that are under development with DOE sponsorship.

*Particles and fields.* There appears to be little technology development in sensors used directly for measurements, with the possible exception of the tunneling magnetometer. There is, however, considerable progress in miniaturization of electronics and in powerful processors that could perform considerable in-flight processing and analysis, thereby reducing the need for high-rate storage and telemetry in spacecraft.

### Programmatic Issues

This workshop was seen as a beginning of communication among diverse groups working on space instrumentation and spacecraft/instrument components. Several participants noted that there are many more organizations involved in technology development than those represented at the meeting: SDIO, OACT, and the NASA Solar System Exploration Division. Others include most other divisions in NASA (e.g., life sciences, astrophysics), the DOE national laboratories, industry (including some not traditionally in the aerospace business), and other federal agencies. For example, national laboratories have developed capabilities in areas related to *in situ* analysis such as materials science, analytical techniques, drilling technologies, and explosives and detonators that are useful for exposing unweathered rock. The participants in the *in situ* working group were pleased with the results of the meeting, even as limited as they were in this area, but would like to see a formal effort made to explore some of these other areas for relevant technology.

More communication is needed, and it needs to be two-way. This includes close collaboration between instrument developers and technology developers. This collaboration needs to take place during the early stages of technology development; the instrument developer cannot wait for the technologist to develop a prototype instrument.

Although not strictly technology related, the topic of spare components and instruments was also discussed. These items could be extremely valuable to both spacecraft and instrument builders, but it is not clear how an individual program or instrument team will find out about the availability, or at least potential availability, of the spares. Some suggested an on-line clearinghouse of available equipment. Others suggested that program managers from different organizations meet with managers from other organizations to exchange information. However it is done, individual PIs building instruments need to know what is available.

With all this new technology being introduced, we should not lose sight of the importance of rigorous testing on the ground. We need to quantitatively compare new techniques to the traditional tried-and-true methods. This requires controlled, rigorous tests.

### Technology with General Applicability to *In Situ* Instrumentation

Although there were generally not many developments in SDIO presented that were directly applicable to *in situ* instrumentation, workshop participants identified a few areas where SDIO technical advances could be used in planetary missions.

*Delivery systems.* In order to make *in situ* measurements of solid surfaces, the instruments need to be delivered to the surface. A key area where SDIO could make a substantial contribution is in penetrator technology, with emphasis on guidance systems and penetration capabilities. It was noted that many of the technologies used in interceptors are directly applicable to penetrators. Specific technologies include the nature of thrusters for attitude control and guidance and the shapes of penetrators. *In situ* studies of atmospheres would be aided by more aggressive development of airplanes, lifting bodies, and balloons. These were not discussed at the meeting, but could provide exceptional platforms for use on Mars and Venus. Power is also a key issue. Conventional wisdom says that missions to the outer solar system require RTGs, but there may be alternatives such as components that require little or no power during cruise, or primary batteries that are not activated until the destination is reached. New technologies must be identified in this vital area.

*Thermal control and mitigation.* The development of high-temperature, silicon-carbide-based electronics could enable substantial science to be returned from Venus. Currently, the only alternative is massive cooling systems, which may not yet be practical. There is, however, the need to continue development of high-capacity, low-vibration mechanical cooling systems. Cooling requirements range from small focal-plane detectors, to large-volume detectors such as X-ray and gamma ray detectors, to entire instrument packages landed on Venus.

### Other Technology Not Presented

There is apparently considerable new technology that was not formally presented at the meeting but was discussed in the *in situ* subgroup. Useful technologies for drilling and mining are being developed in the DOE national labs and the U.S. Bureau of Mines. Examples include explosive systems and laser and electron beam drilling approaches: The 20-year-old DOE rock-melt drilling technology is ideally suited to the lunar environment and could easily be developed for use there and on asteroid/comet nuclei. In addition, very small, high-flux neutron generators have been developed for the nuclear weapons program. These devices are the basis for the commercially available well-bore logging devices, but more advanced versions may be available if their classified status can be accommodated.

## WORKSHOP CONCLUSIONS AND RECOMMENDATIONS

Even though the principal objective of the meeting was discussion of advanced technology for planetary instruments, there were several more global issues that came to the forefront during the discussion, both in the plenary session and within the working groups. One of the observations made repeatedly by several participants was that the principal difference between SDIO and NASA programs is that SDIO is driven by technology, while NASA programs are driven by science. This distinction is key, in that it presumably frees SDIO to perform technology experiments in space, with that as the end result, whereas NASA must consider the scientific return to be obtained by a particular technology. This particular rationale has been used to explain the very long duration of NASA programs, and consequent use of relatively old technology when the spacecraft is finally launched. Several participants, however, pointed out that the reason goes beyond that, for in order to have a proposed instrument accepted for a NASA mission, a major criterion is the heritage of the particular technology, especially its flight heritage. This, by definition, discourages use of more current technologies and makes the attempt to introduce new technology in NASA programs very risky on the part of the investigators.

These considerations, in turn, brought up the issues of technical and programmatic risk. The SDIO programs are generally nonredundant, but provide quick access to space for testing and evaluation of new technologies. The NASA programs, on the other hand, are generally redundant, avoid risk, and consequently increase cost and duration of the program, resulting in infrequent access to space. Several participants thought that early flights of new technology on sounding rockets, SDIO Techsats, or possible future NASA Techsats

would be very useful in proving technology and mitigating risk. The suggestion was made that NASA can learn from the successes and failure of the SDIO program in that the NASA programs could take prudent risk, do more experimenting, and do less planning, without spending an excessive amount of time on considering expensive, unrealized options.

Coming back to the general theme of "faster, better, cheaper," the following points became clear during the discussion. (1) Technologies and sensors were presented that could clearly benefit planetary exploration. The SDIO instruments on Clementine, for example, are light, small, and relatively low power, and hence present reduced requirements for the spacecraft. This, in turn, implies that the spacecraft's subsystems are smaller, and therefore reduces the energy requirements for launch. (2) Sensor heads, themselves, are somewhat smaller, but not a lot. One still needs to collect a certain number of photons to get adequate signal to noise. The greatest gain appears to be in the electronics, but to take advantage of this fact one needs substantial funding. Therefore, what is smaller is by no means always cheaper.

It is debatable that a number of planetary missions have not happened because the sensor technology was not there. These missions did not happen, by and large, because they cost too much. The discussions during the meeting would not tend to change that reality, unless NASA management practices change. Some of these changes include changing the philosophy of the agency to allow more risk, to strive for faster execution times for programs, and to eliminate unnecessary R&QA and accompanying paperwork requirements. The agency should consider some of the management practices of SDIO to see to what extent these can be adopted in a way that meets the principal NASA science requirements, but enables the program to proceed in a cost-constrained, higher-risk, faster-access-to-space mode in the future.

## Oral Presentations

OMIT

**A MICROSEISMOMETER FOR TERRESTRIAL AND EXTRATERRESTRIAL APPLICATIONS.** W. Banerdt, W. Kaiser, and T. Van Zandt, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA.

The scientific and technical requirements of extraterrestrial seismology place severe demands on instrumentation. Performance in terms of sensitivity, stability, and frequency band must match that of the best terrestrial instruments, at a fraction of the size, mass, and power. In addition, this performance must be realized without operator intervention in harsh temperature, shock, and radiation environments. These constraints have forced us to examine some fundamental limits of accelerometer design in order to produce a small, rugged, sensitive seismometer.

Silicon micromachined sensor technology offers techniques for the fabrication of monolithic, robust, compact, low-power and -mass accelerometers [1]. However, currently available sensors offer inadequate sensitivity and bandwidth. Our implementation of an advanced silicon micromachined seismometer is based on principles developed at JPL for high-sensitivity position sensor technology. The use of silicon micromachining technology with these new principles should enable the fabrication of a  $10^{-11}$  g sensitivity seismometer with a bandwidth of at least 0.01 to 20 Hz. The low Q properties of pure single-crystal silicon are essential in order to minimize the Brownian thermal noise limitations generally characteristic of seismometers with small proof masses [2].

A seismometer consists of a spring-supported proof mass (with damping) and a transducer for measuring its motion. For long-period motion a position sensor is generally used, for which the displacement is proportional to the ground acceleration. The mechanical sensitivity can be increased either by increasing the proof mass or decreasing the spring stiffness, neither of which is desirable for planetary applications. Our approach has been to use an ultra-sensitive capacitive position sensor with a sensitivity of better than  $10^{-13}$  m/Hz<sup>1/2</sup>. This allows the use of a stiffer suspension (leading to a wider operating bandwidth and insensitivity to physical shock) and a smaller proof mass (allowing lower instrument mass).

We have built several prototypes using these principles, and tests show that these devices can exhibit performance comparable to state-of-the-art instruments. The total volume of the final seismometer sensor is expected to be a few tens of cubic centimeters, with a total mass and power consumption of approximately 100 g and 100 mW.

**References:** [1] Petersen K. E. (1982) *Proc. IEEE*, 70, 420.  
[2] Melton B. S. (1976) *Rev. Geophys. Space Phys.*, 14, 93.

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**INSITU STUDIES OF PRIMITIVE BODIES.** W. V. Boynton, Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721, USA.

We are now completing the reconnaissance phase of planetary exploration and are entering the detailed discovery phase, which generally calls for *in situ* measurements to address the next level of scientific questions. We have flown by all the planets except Pluto,

for which a flyby is now being planned, and we have flown by asteroids and comets. We have made *in situ* measurements of some planetary atmospheres and on the surface of Mars. NASA has yet to launch a mission with a small body as a primary objective, but such missions may soon take place.

The scientific questions that can be formulated for the small bodies of the solar system are far more detailed than might be expected based on our limited astronomical data. This is because NASA has been funding the study of meteorites and cosmic dust in the laboratory for many years. These studies have brought the full complement of laboratory instrumentation to bear on understanding the information these objects contain on how they formed and evolved. Because meteorites come from the asteroid belt and possibly from comets, we know to a large extent what types of measurements provide the most insight in understanding different aspects of these bodies.

Generally, the types of measurements encompass elemental abundances, mineralogy and texture, and isotopic studies, including age dating. The state of the art is such that not all these measurements can be made *in situ*, but many can. Elemental abundances can be determined with a variety of instruments. Gamma ray spectroscopy can determine all major elements, some minor elements, and a few trace elements based on the emission of gamma rays from nuclei that either have interacted with cosmic-ray-produced neutrons or are radioactive. A combined alpha, proton, and X-ray spectrometer can determine most major and some minor elements, but is not sensitive to trace elements (limit about 100 ppm). It has the advantage over gamma ray spectrometry of being smaller and needing less calibration, but it requires a sample to be brought to it, whereas the gamma ray spectrometer analyzes a large volume near the instrument. Mineralogy can be determined via X-ray diffraction, Mössbauer spectroscopy, or combined thermal and evolved gas analysis. Each technique has its merits for specialized applications; they are listed in decreasing order of specificity. Isotopic studies are not so easy to carry out on a planetary body. Analysis of noble gases and light elements are probably the only isotopic measurements that have the precision necessary to address science issues. Age determinations by K/Ar dating may be possible in some situations.

The Comet Penetrator/Lander of the CRAF mission will be discussed as an example of a combined approach for *in situ* studies.

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**THERMAL AND EVOLVED GAS ANALYSIS FOR THE MESUR MISSION.** W. V. Boynton, Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721, USA.

The MESUR mission will place several landers (currently 16) on the surface of Mars in a variety of locations selected to sample the diversity of martian environments. The landers will be small and will have limited resources of mass, power, volume, and data rate. Among the instruments in the strawman payload, the thermal and evolved gas analyzer is probably the least mature.

This instrument is actually a combination of two instruments: a calorimeter that heats a sample and carefully determines the heat required and a gas analyzer that determines the molecular compo-

sition of gases evolved from the sample during the heating process. The calorimeter is sensitive to phase changes, e.g., the melting of ice, and can thus be used to characterize at least some of the phases present. By correlating the evolution of gases with a phase change, one can better determine the nature of the phase change. For example, a high-temperature endothermic phase change occurring with evolution of  $\text{CO}_2$  suggests decomposition of carbonate. More subtle information can be determined by looking at details of the phase change. For example, ice will "pre-melt" at temperatures below  $0^\circ\text{C}$  in a fashion that depends on the nature of the silicate surface with which it is in contact.

Several concepts exist for the calorimeter. The two most common are the differential scanning calorimeter (DSC) or the differential thermal analyzer (DTA). The former generally denotes a device where sample and reference cells are actively controlled to heat at the same rate and the difference in power is recorded. The latter generally refers to a device in which sample and reference cells are heated with the same power input and the temperature difference is monitored. The DSC is more accurate but the DTA is simpler.

The evolved gas analyzer can be either a collection of a few specific sensors, e.g., one for water and one for  $\text{CO}_2$ , or it can be a general nonspecific analyzer such as a gas chromatograph. Normally a general-purpose instrument is preferred since it can detect surprises, but with the limited resources of MESUR and our knowledge of the two Viking lander sites, it may make sense in this case to use the simpler approach. Such an approach may preclude an exciting discovery in the polar regions where our knowledge of the martian volatiles is limited.

This talk describes a candidate DSC and EGA as a basis for discussion of issues associated with using a combined thermal and evolved gas analyzer on MESUR.

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**INTERCEPTOR TECHNOLOGY.** W. R. Dyer, Ballistic Missile Defense Organization, The Pentagon, Washington DC 20301, USA.

BMDO interceptor sensor technologies that can support NASA planetary missions include lightweight, nuclear-hard LWIR seekers; nuclear-hard LWIR HgCdTe FPA producibility, multiple quantum array detectors; multianode microchannel array UV seekers; high-speed, lightweight, nuclear-hard signal processors; and miniature solid-state and  $\text{CO}_2$  ladar.

The nuclear-hard LWIR (8–14  $\mu\text{m}$ ) Advanced Technology Seeker (LATS) has cooled optics, microscan mirrors, and microlenses for long acquisition range and nuclear hardness. Its mass is 4.5 kg and its volume is 14,000 cc. The LATS consumes 2 W of power and uses a  $128 \times 128$  HgCdTe FPA 25- $\mu\text{m}$  pitch. Readout noise is 190 electrons, and  $D^*$  at the 40K FPA operating temperature is  $10^{13}$   $\text{cm}^2\text{-Hz}^{0.5}/\text{W}$ .

The BMDO Pilotline Experiment Technology (PET) program is developing producible nuclear-hard HgCdTe FPAs for both low-background ( $10^9$ – $10^{13}$  photons/ $\text{cm}^2/\text{s}$ ) and high-background ( $10^{13}$ – $10^{15}$  photons/ $\text{cm}^2/\text{s}$ ) applications. Both  $128 \times 128$  and  $256 \times 256$  FPAs will be addressed. A total of 80–100 FPAs will be constructed to demonstrate producibility. The detectors have 30- $\mu\text{m}$  pitch, 14- $\mu\text{m}$  cutoff, 70% quantum efficiency,  $10^{14}$   $\text{W}/\text{cm}^2$  NEFD, and a dynamic range of 94 db.

GaAs and AlGaAs LWIR multiple quantum well arrays ( $128 \times 128$ ) are under development. These arrays have 8.5–10.5 spectral bands, 60- $\mu\text{m}$  pitch, and  $D^* = 10^{10}$   $\text{cm}^2\text{-Hz}^{0.5}/\text{W}$ . The program goal is 2–4% conversion efficiency with a responsivity of 0.1–0.2 amps/W.

A  $224 \times 224$  multianode microchannel array solar blind (0.25–0.238  $\mu\text{m}$ ) UV seeker was under development in the BMDO Ultraseek program. A brassboard weighing 7.7 kg was built. The seeker had 10–20% quantum efficiency, 10–100-Hz variable frame rate,  $10^\circ$  FOV, and 100- $\mu\text{rad}$  IFOV with an off-axis telescope and 10-cm aperture. A six-position filter wheel with 0.5-s response time was used.

The signal processor used in the Ultraseek brassboard was from the Signal Processor Packaging Design (SPPD) program. It has a throughput of 396 MOPS. The SPPD uses hybrid wafer-scale integration, weighs 75 g, and consumes 10 W of power. A hardened signal processor called the Advanced Hardened Avionics Technology (AHAT) processor is also under development. AHAT was to have a 3-GOP throughput and weighed 1 kg.

Miniature solid-state and  $\text{CO}_2$  laser radars are under development. They will have 200–400-km acquisition range against –23 db targets, with 20-cm range and cross-range resolution. Mass of the laser radars will be 3–5 kg. Optical phased array beam steering is also under development for use with both BMDO laser radars.

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**THE APX SPECTROMETER FOR MARTIAN MISSIONS.**

T. Economou, Laboratory for Astrophysics and Space Research, University of Chicago, Chicago IL 60637, USA.

Obtaining the chemical composition of any planetary body should be a prime science objective of each planetary mission. The APX spectrometer has been designed to provide a detailed and complete chemical composition of all major (except H) and minor elements with high accuracy, *in situ* and remotely. From such complete analyses a first-order mineralogy of analyzed samples can be deduced. Laboratory studies in the past have shown that rock types (e.g., dunites, basalts, Philippinite 300 sample) were identified uniquely in blind test analyses. Such identification is more accurate than can be obtained from any other remote spectroscopic technique.

The APX technique is based on three modes of nuclear and atomic interactions of alpha particles with matter resulting in three different energy spectra containing the compositional information. The instrument uses 50 to 100 mCi of  $^{242}\text{Cm}$  or  $^{244}\text{Cm}$  transuranium radioisotopes to provide a monoenergetic beam of alpha particles (6.01 MeV and 5.80 MeV respectively) and solid-state detectors for acquiring the energy spectra.

The technique has been used for the first time on the Surveyor missions in 1967–1968 to obtain the first chemical composition of the Moon. Since then the instrument has been miniaturized and refined to improve its performance. The alpha and proton detectors were combined into a single telescope with a very thin Si front detector that acts like an alpha detector and at the same time as an absorber of alpha particles for the proton detector in the back. An X-ray mode was incorporated into the instrument that is by itself equivalent to an X-ray fluorescence instrument. A rather complicated logic determines if the particle is an alpha, proton, or an unwanted background event. This arrangement has improved the



energy resolution of proton lines, eliminated the need for an additional guard detector system, and substantially reduced the size of the sensor head.

However, the big saving in size and power in the APX instrument comes from replacing the cryogenically cooled Si or HP Ge X-ray detectors in the X-ray mode with HgI<sub>2</sub> ambient-temperature X-ray detectors that do not require cryogenic cooling to operate and still achieve high-energy resolution. These detectors are being provided by Xsirius, Inc. in Marina del Rey.

The spectrometer as it is implemented for Mars '94 and Mars '96 Russian missions (the Mars '94 and Mars '96 APX experiment are a collaboration of IKI of Moscow, The University of Chicago, and Max Planck Institut für Chemie in Mainz) and for NASA's Pathfinder mission (the APX experiment for Pathfinder will be a collaboration of MPI Mainz and The University of Chicago) to Mars in 1996 has a combined weight of about 600 g and operates on 250 mW of power. It still can benefit from higher-quality alpha sources available from the Russians and more hybridized electronics.

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**CLEMENTINE SENSOR PROCESSING SYSTEM.** A. A. Feldstein, Innovative Concepts, Inc., 8200 Greensboro Drive, Suite 801, McLean VA 22102, USA.

The design of the DSPSE Satellite Controller (DSC) is baselined as a single-string satellite controller (no redundancy). The DSC performs two main functions: health and maintenance of the spacecraft, and image capture, storage, and playback. The DSC contains two processors, a radiation-hardened Mil-Std-1750, and a commercial R3000. The Mil-Std-1750 processor performs all housekeeping operations, while the R3000 is mainly used to perform the image processing functions associated with the navigation functions, as well as performing various experiments. The DSC also contains a data handling unit (DHU) used to interface to various spacecraft imaging sensors and to capture, compress, and store selected images onto the solid-state data recorder.

The development of the DSC evolved from several key requirements: The DSPSE satellite was to (1) have a radiation-hardened spacecraft control and be immune to single-event upsets (SEUs); (2) use an R3000-based processor to run the star tracker software that was developed by SDIO (due to schedule and cost constraints, there was no time to port the software to a radiation-hardened processor); and (3) fly a commercial processor to verify its suitability for use in a space environment.

In order to enhance the DSC reliability, the system was designed with multiple processing paths. These multiple processing paths provide for greater tolerance to various component failures. The DSC was designed so that all housekeeping processing functions are performed by either the Mil-Std-1750 processor or the R3000 processor. The image capture and storage is performed either by the DHU or the R3000 processor.

The DSC interfaces to six sensors using two data and control buses. The image data are compressed using a JPEG compression device. The DHU is configured on a frame-by-frame basis to either store data in an uncompressed form or store data in a compressed form using one of the four compression tables stored in the JPEG device. The captured images are stored in a 1.6-Gbit solid-state

recorder that is part of the DSC for playback to the ground. Images can be captured by the DSC either on demand, one frame at a time, or by preloading a sequence of images to be captured by the DHU without processor or ground intervention.

As for the future, the Naval Research Laboratory is currently developing a fault-tolerant spacecraft controller using the RH3000 processor chip set. The processor includes shadow checker, real time hardware rollback, fault-tolerant memory, hardware cache coherence, and more.

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**ADVANCED SURVEILLANCE SENSORS.** W. G. D. Frederick, Ballistic Missile Defense Organization, The Pentagon, Washington DC 20301, USA.

In order to meet the surveillance, acquisition, tracking, and kill assessment requirements for SDIO sensor and interceptor platforms, research and development has been underway for the last 10 years on focal plane arrays, cryocoolers, optics and coatings, digital and memory circuit components, and spacebased signal and data processors. Focal plane array efforts have concentrated on radiation-hardened SWIR, MWIR, and LWIR Hg Cd telluride; MWIR In antimonide; visible silicon CCDs; and VLWIR As-doped silicon. Cryocooler research and development included the development of long-life (>7 years) coolers operating at 10, 40, and 65K to provide cooling of focal plane arrays and optics. The radiation-hardened optics work comprised the preparation and figuring of Be in sizes up to 1 m in diameter, as well as research and development on the preparation and characterization of Si carbide. In addition, techniques were developed to deposit antireflection coatings on Be and Si carbide optics. Radiation-hardened digital and memory components (such as A/D converters, SRAMs, ferroelectric memories, etc.) were developed through extension and hardening of DARPA VHSIC technology. Finally, radiation-hardened, time-dependent, and object-dependent signal processors and data processors have been developed for spacebased applications, including Brilliant Pebbles and Brilliant Eyes satellites.

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**THE ULTRAVIOLET PLUME INSTRUMENT (UVPI).** D. M. Horan, Naval Center for Space Technology, Naval Research Laboratory, Washington DC 20375-5354, USA.

The Ultraviolet Plume Instrument (UVPI) was launched aboard the Low-power Atmospheric Compensation Experiment (LACE) satellite on February 14, 1990. Both the spacecraft and the UVPI were sponsored by the Directed Energy Office of the Strategic Defense Initiative Organization. The mission of the UVPI was to obtain radiometrically calibrated images of rocket plumes at high altitude and background image data of the Earth, Earth's limb, and celestial objects in the near- and middle-UV wavebands. The UVPI was designed for nighttime observations, i.e., to acquire and track relatively bright objects against a dark background.

Two coaligned, intensified charge-coupled device cameras were used to locate the object of interest, control UVPI, and obtain images and radiometric data. The tracker camera and the plume camera shared a fixed 10-cm-diameter Cassegrain telescope that used a

gimbaled plane steering mirror to view a field of regard that was a 50° half-angle cone about the spacecraft's nadir. Additionally, a plane mirror on the instrument's door could be used with the steering mirror to extend the field of regard to view the Earth's limb and stars near the limb in a southerly direction.

The tracker camera had a relatively wide field of view, 2.0° by 2.6°, and a single bandpass of 255–450 nm. The tracker camera had three functions. First, its wide field of view and bright image were used to find the object of interest. Second, images from the tracker camera could be processed within UVPI and the results used to control the gimbaled mirror for autonomous tracking of the target. Third, the tracker camera was calibrated and could obtain radiometric data within its bandpass.

The plume camera had a much narrower field of view, 0.18° by 0.14°, and had a correspondingly higher resolution than the tracker camera. The plume camera had a four-position filter wheel to provide four bandpasses: 195–295 nm, 220–320 nm, 235–350 nm, and 300–320 nm. Only one bandpass could be selected at a time. The purpose of the plume camera was to obtain high-resolution images and radiometric data within its bandpasses.

The UVPI collected high-quality, calibrated UV emission images from four rocket launches in four attempts. These successful observations have provided more than 150 s of calibrated plume images from space. The plume camera data obtained for these high-altitude plumes in the 195–295 nm and 220–320 nm bandpasses is not obtainable from the ground because it is blocked by the Earth's ozone layer. All UVPI plume observation data have been processed by the NRL LACE Program and archived in the SDIO Plumes Data Center at Arnold AFB, Tennessee, and the SDIO Backgrounds Data Center at NRL.

Background observations include southern auroral events, measurements of the Earth's limb under different lighting conditions, nadir scans, measurements near an erupting volcano, and measurements of emission from city and highway lighting. Data from all UVPI observations has been processed and deposited in the SDIO Backgrounds Data Center at NRL.

Radiometric calibration of the UVPI was done before launch and confirmed after launch by star observations. Stars of known emission spectrum based on measurements by other spaceborne sensors were used. The calibration values obtained using the stars are close to the calibration values obtained before launch.

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**MICRO WEATHER STATION FOR EARTH AND MARS.**  
W. J. Kaiser, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena CA 91109, USA.

Recent trends in planetary and Earth science include the development of compact spacecraft and planetary landers. This leads to opportunities for advanced science return by the use of multiple vehicles and lander networks. The wide deployment of instruments is an important part of new programs for understanding planetary atmospheres, for monitoring seismicity and probing planetary structure, and for space science. An important part of this initiative is the development of compact, low-mass, low-power sensors and instruments that enable science return by small spacecraft.

Challenges arise for sensor and instrument development because user requirements call for advances in performance with

simultaneous large reduction in device mass, volume, and cost. Many important, conventional instruments operate at or near theoretical limits. Furthermore, for fundamental reasons, reducing the scale (volume and mass) of typical conventional instruments leads to a sharp reduction in performance. Clearly, new methods are required for sensor and instrument technology. The JPL microsensor and microinstrument program is directed toward developing a class of devices based on new measurement principles for emerging science applications.

Recent developments at JPL include accurate, miniaturized instruments for measuring pressure, temperature, and humidity in the martian planetary boundary layer and in Earth's upper troposphere and lower stratosphere. These instruments incorporate state-of-the-art electronics and silicon micromachined structures along with more conventional measurement technologies to reduce their size, cost, and power consumption. Our sensors are based on measurement technologies that are inherently accurate, durable, and offer simple calibration. In addition, these devices take advantage of silicon micromachining batch fabrication and calibration to enable low-cost production. Their small size, mass, and inherent ruggedness make them ideal for deployment on a variety of measurement platforms, including the Mars MESUR landers, radiosondes, and dropsondes.

Requirements for meteorological measurements on Mars and Earth will be reviewed first, and the Micro Weather Station instrument concept for Mars and Earth will be described. Components of the Micro Weather Station have been demonstrated. Highlighted in this presentation will be a new microhygrometer operating on accurate dewpoint principles. This device combines a millimeter-scale surface acoustic wave oscillator element with a compact temperature control element. This compact structure, packaged on a conventional power transistor header, has a volume of approximately 1 cm<sup>3</sup>. Precision testing of this instrument demonstrates 0.1K dewpoint accuracy. In addition, new pressure-sensor devices have been developed for the Micro Weather Station. These devices employ silicon micromachined structures, including thin, free-standing membrane elements. The pressure sensors measure absolute pressure using thermal conductance techniques. Their sensitivity exceeds the requirements for Mars and upper atmosphere applications. The development of temperature, wind, and atmospheric aerosol sensors will also be described.

The program described here provides new instrument capabilities for a wide range of applications and many new opportunities for Earth and planetary science. The Team Leader for this investigation is Dr. David Crisp; team members include Drs. W. Kaiser, M. Hoenk, and T. VanZandt, all at JPL.

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**VISIBLE IMAGING ON THE PLUTO FAST FLYBY MISSION.** M. C. Malin, Malin Space Science Systems, 3535 General Atomics Court, Suite 250, San Diego CA 92121, USA.

Objectives for visible imaging of the Pluto-Charon system, as prescribed by the Outer Planets Science Working Group, are to acquire (1) global observations (FOV of ~5000 IFOVs) at 1 km/line-pair for the purpose of characterizing surface morphology and geology, (2) global observations in 3–5 broadband colors at 5–10 km/line-pair for studies of surface properties and composition as

it relates to morphology, and (3) selected observations at higher spatial resolution for study of surface processes.

Several factors of the Pluto Fast Flyby mission make these difficult objectives to achieve: At Pluto's distance from the Sun, there is nearly 1/1000 the amount of light as at the Earth, the flyby velocity is high (~15 km/s), and the science requirements dictate a large data volume (1 km/line-pair implies between 20 and 50 MBytes for the panchromatic global image, and a comparable amount for the multispectral dataset).

The low light levels can be addressed through a large aperture, image intensification, long exposures with precision pointing and image motion compensation (scan mirror or spacecraft movement), or time-delay integration. The high flyby velocities require short exposures, image motion compensation, or observations from considerable distance (e.g., longer focal lengths and larger apertures). Large data volume requires a large spacecraft data buffer, an internal instrument data buffer, or real-time data compression. The difficulty facing the successful Pluto Fast Flyby imaging investigation will be overcoming these technical challenges within the extremely limited mass (~2 kg) and power (~2 W) available.

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**REQUIREMENTS FOR AN ULTRAVIOLET SPECTROMETER FOR THE PLUTO FAST FLYBY MISSION.** W. E. McClintock and G. M. Lawrence, Laboratory for Atmospheric and Space Physics, University of Colorado, 1234 Innovation Drive, Boulder CO 80303-7814, USA.

Ultraviolet spectroscopy can answer fundamental questions about Pluto's atmosphere, including its composition, pressure and temperature profile, and aerosol characteristics. Ultraviolet results will contribute to comparative studies of Triton and Pluto, two distant bodies known to have CH<sub>4</sub> and N<sub>2</sub> in their atmospheres.

Potential atmospheric constituents have strong emission and absorption signatures in the wavelength range 55–200 nm. These species are best observed using a variety of techniques, including disk maps, limb scans, and solar and stellar occultations. The Voyager UVS observations of Triton provide a template to which Pluto observations should be designed.

The mission design dictates that the UVS have a mass and power approaching 1 kg and 1 W respectively. The science objectives dictate the following functional requirements for a UVS: (1) an airglow mode with imaging spectroscopy; (2) a well-baffled telescope for limb scans; (3) a solar/stellar occultation mode; (4) wavelength coverage of 55–200 nm with a spectral resolution of 0.5 nm; and (5) sensitivity comparable to or better than the Voyager UVS.

One instrument that meets the mission and science requirements is a dual-channel airglow/solar occultation design. The airglow channel is based on a single channel of the Cassini UltraViolet Imaging Spectrometer (UVIS), which is modified to cover the range 55–200 nm. The solar occultation channel, which consists of a concave grating in a Wadsworth mount feeding a vacuum photodiode array, looks transverse to the airglow channel through the spacecraft antenna. We estimate that such an instrument can be constructed using current technology that will weigh less than 1.3 kg and consume less than 1 W of power.

The concept of combining the UVS with a visible imager and an infrared mapper in a single remote sensing instrument package is

attractive from a programmatic standpoint. It should be recognized that planetary observations at extreme ultraviolet (EUV) wavelengths require special technologies and may be compromised by this approach.

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**SCIENTIFIC AND MEASUREMENT OBJECTIVES AND CURRENT CONCEPTS FOR COMET AND ASTEROID MISSIONS.** M. Neugebauer, Mail Stop 169-506, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA.

Studies of comets and asteroids address most of the major goals of solar system exploration because (1) they are the best-preserved samples of the material from which the solar system formed, (2) they record the radial properties of and the degree of mixing in the protoplanetary nebula, (3) they contain complex organic material that may have been responsible for the origin of life on Earth, and (4) the coma of an active comet displays a wealth of astrophysical processes involving interactions between gas, dust, plasma, and sunlight. The scientific and measurement objectives of space missions to comets and asteroids developed in detail in the early 1980s by groups such as the Space Science Board and NASA's Comet Rendezvous Science Working Group remain relevant despite the intervening observations by the flybys of three comets and one asteroid. The sophistication of the measurements that can be made increases as one scales up from flybys to flythroughs to rendezvous missions, which may carry either penetrators or soft landers, to sample-return missions of various types, such as fast collection of gas and dust from the coma of a comet or surface or subsurface samples of an asteroid or the nucleus of a comet.

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**SUPERCONDUCTING SENSORS/PROCESSORS.** M. Nisenoff<sup>1</sup> and C. Byvik<sup>2</sup>, <sup>1</sup>Naval Research Laboratory, Washington DC 20375, USA, <sup>2</sup>W. J. Schafer Associates, Inc., 1901 North Fort Myer Drive, Arlington VA 22209, USA.

One requirement of an SDIO surveillance mission is the capability of acquiring and tracking cold bodies against the cold background of space, a requirement paralleling the NASA mission to planets such as Pluto. A technology that enables very high speed at very-low-power, on-focal-plane array signal processing for large (10,000–1,000,000 pixels) VLWIR sensors required to operate at 10 K is low-temperature superconductivity (LTS). Significant progress has recently been made in LTS digital signal processing. Superconducting transimpedance amplifiers (TIA), 12-bit analog-to-digital converters (ADC), high-speed shift registers (SR), digital multiplexers (MUX), and wide-band superconducting detectors have been demonstrated and operated at 10 K in Nb nitride technology. A proof of concept for the conversion of photons to bits for detection by a LTS single pixel through the ADC was demonstrated in 1992. An operational focal plane with interface electronics and an LTS analog signal processor all operating at 10 K will be demonstrated using a scene generator in the 4QFY94. A LTS foundry exists that is capable of providing custom circuits with appropriate interface electronics. Today's superconductor technology will enable the achievement of

low-power, low-weight, high-fidelity goals for future NASA planetary missions.

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**CLEMENTINE: A DEEP SPACE MISSION TO FLIGHT QUALIFY LIGHTWEIGHT SPACECRAFT COMPONENTS.**

P. Rustan, Ballistic Missile Defense Organization/DTI, The Pentagon, Washington DC 20301, USA.

The Clementine mission will demonstrate and flight qualify several lightweight spacecraft components developed by the Ballistic Missile Defense Organization. The sensors and processors to be tested in the spacecraft were developed to detect ballistic missiles. In the Clementine mission, these technologies will be tested in a dual-use role for a civil scientific sector application, such as looking at cold objects, the Moon, and a near-Earth asteroid against a space background.

Specifically, the mission will test two lightweight star tracker cameras, a UV/VIS camera, a near-infrared camera, a long-wave infrared camera, a lidar, and a 32-bit computer. The star tracker cameras, 370 g each, will provide three-axis attitude determination using only a single starfield image, with a field of view of  $20^\circ \times 43^\circ$ . Each camera consumes 7 W and is accurate to 150 prad. The UV/VIS imaging system is a CCD camera with a bandpass from 250 nm to 1000 nm; it will carry a filter wheel with six positions at 415 nm, 750 nm, 900 nm, 950 nm, 1000 nm, and broadband from 400 to 950 nm. The UV/VIS camera weighs 500 g, uses 6 W of power, and has a field of view of  $4.2^\circ \times 5.6^\circ$ . The near-infrared camera will have a mechanically cooled  $256 \times 256$ -pixel Indium Antimonide Focal Plane Array (InSb FPA) with a bandpass from below 1100 nm up to 2800 nm and a filter wheel with positions at 1100 nm, 1250 nm, 1500 nm, 2000 nm, 2600 nm, and 2780 nm. The camera weighs about 1600 g, uses 30 W of power including the cryocooler, and has a field of view of  $5.6^\circ \times 5.6^\circ$ . The long-wave infrared camera will have a mechanically cooled  $128 \times 128$  HgCd telluride FPA. The array will be mechanically cooled and will have a broadband response from 8000 to 9500 nm. The camera weighs about 1550 g, uses 30 W of power, and has a field of view of  $1^\circ \times 1^\circ$ . The lidar consists of a laser transmitter and a high-resolution camera. The laser transmitter is a diode-pumped Nd-YAG laser with a mass of 1 kg, a pulse energy of 180 mJ at a pulse length of 10 ns, and a repetition rate of 8 Hz. The high-resolution camera is a Si CCD, weighs 1250 g, uses 12 W of power, and has a field of view of  $0.3^\circ \times 0.4^\circ$ . Finally, the 32-bit processor is a reduced instruction set computing (RISC) processor that operates at about 20 Mips and 3.5 MFlops. It has a mass of ~500 g and is expected to be radiation immune to about 15 krad (Si).

Additionally, the mission uses advanced lightweight technologies in the electrical, mechanical, structure and materials, and attitude control systems. The mission is expected to be launched in January 1994 in a Titan IIG launch vehicle, spend two months mapping the lunar orbit from a 400-km orbit, and fly by the near-Earth asteroid Geographos in August 1994.

**PRIMIS: PLUTO REFLECTANCE IMAGING-MAPPING INTERFEROMETRIC SENSOR.**

W. H. Smith<sup>1</sup>, P. Hammer<sup>2</sup>, H. Reitsma<sup>3</sup>, H. Albert<sup>3</sup>, R. Nelson<sup>4</sup>, W. McKinnon<sup>1</sup>, and K. Baines<sup>4</sup>,  
<sup>1</sup>Washington University, St. Louis MO 63130, USA, <sup>2</sup>NASA Ames Research Center, Moffett Field CA 94035, USA, <sup>3</sup>Ball Aerospace, Boulder CO 80306, USA, <sup>4</sup>Jet Propulsion Laboratory, Pasadena CA 91109, USA.

The Pluto Fast Flyby Mission is among the most challenging missions NASA has yet conceived. The challenge lies in achieving the high level of science return sought within the extremely limited resources available. The motivation is the distillation of the resources into instruments that attain the Pluto Fast Flyby science measurement goals. Success in this effort implies a utilization of novel methods and instruments, but to reduce cost must use components and mechanisms that are readily available. Novel implementations must extend the capabilities of the optical instruments beyond those of historically utilized designs in order to achieve the science measurements within mass and power limitations. The concepts, designs, and breadboard fabrication of fully integrated sensors must therefore achieve the ground rule: PFF sensors shall meet or exceed PFF stated science measurement requirements within the mass and power limitations.

PRIMIS, the Pluto Reflectance Imaging-Mapping Interferometric Sensor, centers around an unobscured telescope integrated with a four-color simultaneous imager constructed with polarization beam splitters and digital array scanned interferometers (DASIs) for the infrared and the vacuum ultraviolet. This configuration reduces the instrument's mass but increases the throughput to achieve very high S/N observations. Very careful attention is given to the integration and sharing of electronics, optics, and support structures for mass reduction while constraining power requirements; e.g., PRIMIS uses no moving parts to increase reliability while reducing mass, power usage, and complexity, eliminating many potential failure modes. The telescope is both the light collector and the passive radiator for cooling the focal plane and instruments, eliminating the need for a separate passive cooler.

The appropriate data acquisition timeline and subsequent onboard data analysis that is consistent with anticipated computational and memory resources is outlined. Suggested data acquisition modes (along with examples) that can save substantial data space with acceptable compromises on information content are shown from our measurements with DASIs.

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**THE MESUR MISSION.** S. W. Squyres, Center for Radio-physics and Space Research, Cornell University, Ithaca NY 14853, USA.

The MESUR mission is the most ambitious mission to Mars planned by NASA for the coming decade. It will place a network of small, robust landers on the martian surface, making a coordinated set of observations for at least one full martian year. The mission addresses two main classes of scientific objectives. The first requires a large number of simultaneous observations from widely distributed sites. These include establishing networks of seismic and

meteorological stations that will yield information on the internal structure of the planet and the global circulation of the atmosphere respectively. The second class of objectives requires sampling as much as possible the full diversity of the planet. These include a variety of geochemical measurements, imaging of surface morphology, and measurement of upper atmospheric properties at a range of latitudes, seasons, and times of day.

MESUR presents some major challenges for development of instruments, instrument deployment systems, and onboard data processing techniques. The instrument payload has not yet been selected, but the strawman payload is (1) a three-axis seismometer; (2) a meteorology package that senses pressure, temperature, wind speed and direction, humidity, and sky brightness; (3) an alpha-proton-X-ray spectrometer (APXS); (4) a thermal analysis/evolved gas analysis (TA/EGA) instrument; (5) a descent imager; (6) a panoramic surface imager; (7) an atmospheric structure instrument (ASI) that senses pressure, temperature, and acceleration during descent to the surface; and (8) radio science. Because of the large number of landers to be sent (about 16), all these instruments must be very lightweight. All but the descent imager and the ASI must survive landing loads that may approach 100 g. The meteorology package, seismometer, and surface imager must be able to survive on the surface for at least one martian year. The seismometer requires deployment off the lander body. The panoramic imager and some components of the meteorology package require deployment above the lander body. The APXS must be placed directly against one or more rocks near the lander, prompting consideration of a microrover for deployment of this instrument. The TA/EGA requires a system to acquire, contain, and heat a soil sample. Both the imagers and, especially, the seismometer will be capable of producing large volumes of data, and will require use of sophisticated data compression techniques.

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**PLUTO FAST FLYBY MISSION AND SCIENCE OVERVIEW.** A. Stern, Space Science Department, Southwest Research Institute, 6220 Culebra Road, San Antonio TX 78238, USA.

Planning for the Pluto Fast Flyby (PFF) mission centers on the launch of two small (110–160 kg) spacecraft late in the 1990s on fast, 6–8-year trajectories that do not require Jupiter flybys. The cost target of the two-spacecraft PFF mission is \$400 million. Scientific payload definition by NASA's Outer Planets Science Working Group (OPSWG) and JPL design studies for the Pluto flyby spacecraft are now being completed, and the program is in Phase A development. Selection of a set of lightweight, low-power instrument demonstrations is planned for May 1993. According to plan, the completion of Phase A and then detailed Phase B spacecraft and payload design work will occur in FY94. The release of an instrument payload AO, followed by the selection of the flight payload, is also scheduled for FY94. I will describe the scientific rationale for this mission, its scientific objectives, and give an overview of the spacecraft and strawman payload.

**LUNAR SCIENCE: USING THE MOON AS A TESTBED.** G. J. Taylor, Planetary Geosciences, Department of Geology and Geophysics, SOEST, University of Hawaii, 2525 Correa Road, Honolulu HI 96822, USA.

The Moon is an excellent testbed for innovative instruments and spacecraft. Excellent science can be done, the Moon has a convenient location, and previous measurements have calibrated many parts of it. I summarize these attributes and give some suggestions for the types of future measurements.

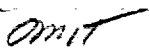
**Lunar Science:** The Lunar Scout missions planned by NASA's Office of Exploration will not make all the measurements needed. Thus, test missions to the Moon can also return significant scientific results, making them more than technology demonstrations.

**Location:** The Moon is close to Earth, so cruise time is insignificant, tracking is precise, and some operations can be controlled from Earth, but it is in the deep space environment, allowing full tests of instruments and spacecraft components.

**Calibrations:** The existing database on the Moon allows tests of new instruments against known information. The most precise data come from lunar samples, where detailed analyses of samples from a few places on the Moon provide data on chemical and mineralogical composition and physical properties. Apollo field excursions provided *in situ* measurement of surface geotechnical properties and local magnetic field strength. Orbital data obtained by Apollo missions also supply a useful set of standards, although not global in extent; data include chemical composition by gamma and X-ray spectrometry, imaging, and magnetic field strength. Observations at high spectral resolution have been obtained from terrestrial telescopes, providing spectral calibration points for numerous 1–5-km spots on the lunar surface. Finally, additional multispectral imaging has been obtained by the Galileo spacecraft and a global multispectral dataset will be acquired by the Clementine mission. Thus, the Moon is a large, Earth-orbiting standard on which to test new instruments.

**Potential Instruments:** The following list shows examples of the types of instruments that could take advantage of the Moon's virtues as a testbed. Lunar Scout I and II do not include items 1–4. Items 5–7 are thus essential if Scout does not fly, but even if Scout is successful, new generations of these instruments (smaller, better resolution, etc.) can still use the global database obtained by Scout as calibrations. (1) Atmospheric sensors, such as UV spectrometers and mass spectrometers. (2) Magnetic field detectors, such as magnetometers and electron reflectometers. (3) Altimeters for topography measurements. (4) Microwave radiometers, especially for heat flow determination. (5) Imaging spectrometers to obtain mineralogical information about the Moon. (6) Imaging systems for geologic mapping. (7) Devices to make chemical analyses from orbit-present instruments, such as gamma ray spectrometers (these are currently large and heavy, so new, smaller devices are essential for future planetary missions).

**In Situ Analyses:** Excellent lunar science could be done using rovers carrying experimental payloads. Possible instruments include devices to do chemical and mineralogical analyses, high-resolution stereo imaging systems, gas analyzers, seismometers, heat flow probes, and atmospheric sensors.



### SMALL-BODY OBSERVATIONS: REMOTE SENSING.

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There are a large number of widely diverse small bodies in the solar system grouped as asteroids, comets, and small satellites. The members of each of these groups are also very diverse, and studies have begun to reveal interrelationships among the groups, e.g., 2060 Chiron, an "asteroid" that became a comet, and 4015 (1979 VA), a comet that became an "asteroid." Improving our understanding of the links between these groups will involve two major types of remote sensing scenarios: flyby missions and rendezvous or orbit missions. Some missions may involve both types, e.g., a flyby of one body on the way to a rendezvous with another. A vigorous program to study small bodies should include both flybys and rendezvous missions to provide complementary information. Multiple flybys will allow us to explore the diversity of small bodies, while rendezvous missions will allow us to gather detailed measurements of a specific type of body. Galileo's encounter with the asteroid Gaspra in October 1991, at a flyby speed of 8 km/s and a miss distance of 1600 km, highlighted some of the challenges of this type of mission. They include the extremely short (~30 min) time interval for acquiring the best data and difficulties in keeping instruments pointed accurately at closest approach. Dust surrounding comets poses an additional hazard for comet close encounters.

Instrumentation for asteroid studies encompasses a wide range of imaging devices, medium- and high-resolution spectrometers, radiometers, and LIDAR. For example, general considerations for IR reflectance spectroscopy include a signal to noise ratio of 100:1 or better for integration of times of 1 s or less, spatial resolution of the surface of 10–100 m, and pixel size of 50–500  $\mu\text{m}$ . An array

detector is preferred for accurate registration with imaging. Surface mineralogy reflectance spectroscopy should include three important spectral windows: 0.3–1.1  $\mu\text{m}$  for spectral imaging, 0.7–2.8  $\mu\text{m}$  for the primary IR range, and 2.8–4.0  $\mu\text{m}$  for the secondary IR range. The relative importance of each window depends on the type of asteroid to be studied. Thermal emission spectroscopy provides direct information on composition and crystal structure. Instrument requirements include a wavelength range of 6–25  $\mu\text{m}$  at a minimum, 6–50 desirable; spectral resolution of 10  $\text{cm}^{-1}$ ; signal-to-noise ratio of 500:1; and spatial resolution ~5–10 mrad minimum, <1 mrad desirable. An IR radiometer, the best instrument to determine the thermal inertia of the surface, should have a wavelength range of at least 10–30  $\mu\text{m}$ , with 5–100  $\mu\text{m}$  desirable, and should include a VIS channel for albedo measurements. Low spatial resolution, ~1 mrad, is adequate, and sensitivity should be  $\Delta T \sim \pm 1 \text{ K}$  over temperatures of 90–300 K.

Instrumentation for comet studies is equally challenging. For example, coma spectroscopy should include measurements at UV-VIS and mid-IR wavelengths. In the UV-VIS, a wavelength range of 1100–9000  $\text{\AA}$  is desirable; within this range it is essential to measure Lyman- $\alpha$  (1216  $\text{\AA}$ ) and OH (3085  $\text{\AA}$ ). The spectrograph should have an array detector and spectral resolution of ~1  $\text{\AA}$ , and ideally should have no moving parts that could be fouled with dust. Several detectors are needed to cover a broad spectral range. In the mid-IR (5–10  $\mu\text{m}$ ) the spectral region beyond about 5  $\mu\text{m}$  is useful for measurement of polar molecules such as  $\text{H}_2\text{O}$ ,  $\text{CH}_4$ , CO, and  $\text{NH}_3$ , as well as minor organic species that may include prebiotic molecules. A very-high-spectral resolution ( $>10^5$ ) is required. Innovative designs will be needed to meet these requirements while also achieving minimum mass and size.

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## Database on BMDO (SDIO) Technology

The following pages describe an extensive resource called the Technology Applications Information System (TAIS), which is available to U.S. citizens. Created and supported by the SDIO, now called the Ballistic Missile Defense Organization (BMDO), this database is organized in a hierarchical or nested fashion. After entering the system, you may begin your search in an outer shell that allows you to access synopses of basic research programs currently supported by the BMDO; these descriptions help an individual user survey the many programs in BMDO that may be relevant to his/her particular needs and interests. This level, called "R," does not describe hardware. The next shell, called "D," augments information found in the first shell with descriptions of BMDO technologies under study but not ready for production.

The third shell, "M," provides descriptions of mature technologies in which at least some hardware has been built. The "D" and "M" levels include principal investigators, institutional and contractor affiliations, points of contact, etc. The first three levels are now available in the database. A fourth level is planned for addition to this existing resource; in this innermost "P" shell, users will be able to call up synopses of fully integrated instruments, sensors, and other subsystems that have been produced. Inclusion of this fourth level could begin in the next few months, depending on resources available within BMDO. You will notice the identifiers "R," "D," and "M" on the following sample sheets, which indicate that the database contains 26 entries of relevance for the term "infrared sensor."

### QUESTIONS AND ANSWERS ABOUT THE TECHNOLOGY APPLICATIONS INFORMATION SYSTEM (TAIS)

#### What is the TAIS?

- A free online database that contains over 2000 abstracts of technology supported by the Ballistic Missile Defense Organization (BMDO, formerly the Strategic Defense Initiative Organization); it is accessed by computer modem.
- A national referral system that contains unclassified research available for technology transfer to the U.S. commercial marketplace.
- A database containing abstracts of technology from the National Aero-Space Plane (NASP).
- An information system that is available 24 hours a day, 7 days a week.

#### Why Should I Use the TAIS?

- It's free.
- It's easy to use, complete with menus and keyword searches.
- It has over 2000 emerging technologies (and their points of contact) that may solve your engineering, manufacturing, or product problems and lead to collaborations, licensing agreements, or investment opportunities.
- It gives sources of free business assistance from over 800 state and federal organizations.
- It lists other major technology transfer databases.
- It lists ongoing research programs that may provide funding for your organization's technology products or services.

#### What Types of Technologies are in the TAIS?

Technologies in the TAIS are the result of research and development undertaken to help build a future space defense system. New understandings of scientific phenomena and advances in state of the art achieved through this research provide faster, lighter, stronger, more reliable, and more efficient technologies in areas such as lasers, energy, electronics, optics, materials, communications, superconductors, supercomputers, and many more.

#### What's the Catch?

Although the technology abstracts found in the TAIS are unclassified, the technology programs themselves may contain information that is export restricted. Since most are export controlled, they require your completion of a "Military Critical Technical Data Agreement" in which you certify that you are a U.S. citizen and you are aware of export control laws and penalties.

#### How Do I Become Certified to Use the TAIS?

1. Call the Defense Logistics Services Center (DLSC) at 800-352-3572 and request DD Form 2345.
2. Complete the form and mail it back to DLSC (the address is on the back of the form). DLSC will process the request within five days.
3. Allow 4-8 weeks for TAIS access processing. If you require faster processing, call 703-693-1563 to ensure immediate processing of your access codes.
4. You are ready to log on.

Federal agency representatives may obtain access certification by addressing a request on official letterhead to the Office of Technology Applications (see BMDO address on this page). Please identify your office's point of contact for the TAIS.

### **How Do I Log On?**

Set your modem parameters to emulation: VT100; baud rate: 2400 or 1200; parity: even; data bits: 7; start/stop bits: 1; duplex: full.

On your data phone/modem, dial 703-693-3007. (If, after you connect, you get random characters, please enter the break sequence specified in your communications package.)

The first prompt will ask you to type remote. Type the word "remote" in lower-case letters.

The next screen will prompt you for your access codes located on DD Form 2345; note that the TAIS requires two access codes. Type in your access codes, which are as follows:

Qualified Contractor's Name: the first nine characters in block 2a (note: spaces count as characters; periods and commas do not).

Certification Number: seven-digit number in block 7a assigned to your organization by the DLS (note: user does not need to type in the leading zeros).

### **What are the Addresses and Phone Numbers for DLSC and BMDO?**

United States/Canada Joint Certification Office  
Defense Logistics Services Center (DLSC)  
Federal Center  
74 N. Washington  
Battle Creek MI 49017-3084  
Phone: 800-352-3572

Deputy Director, Office of Technology Applications  
Ballistic Missile Defense Organization  
(BMDO/TNI)

ATTN: TAIS Database (Kathy Price)

Washington DC 20301-7100

Phone: 703-693-1563

TAIS Line: 703-693-3007

### **Can I Get Other BMDO Technology Transfer Assistance Besides the TAIS?**

Yes. Call the TAIS systems administrator at 703-693-1563 with your request. Someone on our technology transfer staff will return your call to see if we can provide any additional support. However, remember that BMDO must conform to federal and BMDO policy and guidelines in the information and assistance it can provide. Our goal is to do everything possible to facilitate the transfer of BMDO-funded technology to applications that will benefit the U.S. economy.





Printscreen Window  
 Mon May 3 16:27:55 EST 1993



Shelltool - SDIO/INI Technology Applications System (TAIS) Window

SDIO Technology Applications Information System  
 Keyword/Application Function

Current Keyword/Application

INFRARED SENSOR

26 Innovations Matched

At this point, you may Cancel the current keyword(s), combine the current keyword with another by selecting to Perform another keyword search, or view the matched innovations. Select R to view by technology or S for entire listing.

Note: The same matching innovation may appear under more than one technology.

Until a Cancel is done, only matching innovations can be accessed.

P-Perform Keyword Search  
 R-Return to Innovation Data  
 C-Cancel Current Keyword

H-Help  
 M-Return to Main Menu  
 S-Show Matching Innovations

Enter Selection



Printscreen Window  
Tue May 4 09:18:57 EST 1993



Shelltool - SDIO/INI Technology Applications System (TAIS) Window

SDIO Technology Applications Information System  
Innovations Found in Keyword Search

Current Keyword/Application: INFRARED SENSOR

- 1. (R) Acquisition Range Enhancement for Infrared Sensors
- 2. (D) Adaptive Electro-Optical Signal Processor
- 3. (D) Advanced IR-Focal Plane Array Concept
- 4. (D) Cryocooler Thermal Switch Analysis
- 5. (D) Cryocooler for High Acceleration Systems
- 6. (D) Cryocooler for Space-Based Infrared Sensors
- 7. (R) Hardened Electronics for Cryogenic Temperatures
- 8. (R) HgCdTe for Long Wavelength Infrared Sensor Applications

The above designations preceding the innovation titles represent the status for the corresponding innovation. Specifically, (R) Research In-Progress, (D) Developing Technology, (M) Maturing Technology.

##-Review Innovation Abstract	R-Return to Previous Screen	H-Help
K-Search Keyword/Application	M-Return to Main Menu	N-Next Page
	I-Change Industrial Classification	

Enter Selection



Printscreen Window  
Tue May 4 09:19:21 EST 1993



Shelltool - SDIO/INI Technology Applications System (TAIS) Window

SDIO Technology Applications Information System  
Innovations Found in Keyword Search

Current Keyword/Application: INFRARED SENSOR

- 
- 
- 9. (D) High Speed Infrared Sensor
  - 10. (M) Infrared Detector Characterization Tool
  - 11. (R) Infrared Sensor Calibration Techniques and Standards
  - 12. (R) Infrared Sensor and Imaging System
  - 13. (D) Infrared Sensors
  - 14. (R) Infrared Sensors Using High-Temperature Superconductors
  - 15. (M) MicroMiniature Refrigerator (MMR)
  - 16. (R) Nuclear Environment Simulation Requirements
- 
- 

The above designations preceding the innovation titles represent the status for the corresponding innovation. Specifically, (R) Research In-Progress, (D) Developing Technology, (M) Maturing Technology.

##-Review Innovation Abstract	R-Return to Previous Screen	H-Help
K-Search Keyword/Application	M-Return to Main Menu	N-Next Page
	I-Change Industrial Classification	P-Prev Page

Enter Selection



Printscreen Window  
Tue May 4 09:19:48 EST 1993



Shelltool - SDIO/INI Technology Applications System (TAIS) Window

SDIO Technology Applications Information System  
Innovations Found in Keyword Search

Current Keyword/Application: INFRARED SENSOR

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- 17. (R) Passively-Cooled, Indium-Antimonide Detector Arrays
- 18. (R) Protection of Optical Components by Diamond Coatings
- 19. (R) Rugate Laser Filters
- 20. (R) Schottky Barrier Array Infrared Sensor
- 21. (D) Sorption Compressor Refrigeration System
- 22. (R) Structures and Materials for Infrared Nonlinear Optics
- 23. (R) Target Discrimination Using Polarized Signatures
- 24. (D) Two-Stage Rotary Reciprocating Refrigerator

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The above designations preceding the innovation titles represent the status for the corresponding innovation. Specifically, (R) Research In-Progress, (D) Developing Technology, (M) Maturing Technology.

#-Review Innovation Abstract	R-Return to Previous Screen	H-Help
K-Search Keyword/Application	M-Return to Main Menu	N-Next Page
	I-Change Industrial Classification	P-Prev Page

Enter Selection



Printscreen Window

Tue May 4 09:20:22 EST 1993



Shelltool - SDIO/INI Technology Applications System (TAIS) Window

SDIO Technology Applications Information System  
Innovations Found in Keyword Search

Current Keyword/Application: INFRARED SENSOR

- 
- 25. (M) Visible Image-Emulation of Infrared Sensors
  - 26. (D) Wet Turboexpander for Cryocoolers
- 

The above designations preceding the innovation titles represent the status for the corresponding innovation. Specifically, (R) Research In-Progress, (D) Developing Technology, (M) Maturing Technology.

##-Review Innovation Abstract    R-Return to Previous Screen    H-Help  
K-Search Keyword/Application    M-Return to Main Menu  
I-Change Industrial Classification    P-Prev Page

Enter Selection



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