Advanced Sensor Technologies Assessment, Test Techniques, and Predictive / Mitigative Methods :

Midyear Review

Presented by Cheryl Marshall for the

NASA ERC Project

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For further Information:

cmarshall2@aol.com

Outline

- **Goals & Approach**
- **Radiation effects of interest for sensors (IR & Visible)**
- **Subtask Descriptions: Objective, Schedule, Accomplishments, Deliverables, Plans & Issues**
  - **Visible Sensor Efforts: APS, CCDs, HyViSI, CID, SOHO**
  - **IR Sensor Efforts with NGST**

Overview

Task 11 Title:	**Advanced Sensors**
Program Area:	**NEPP/ERC**
Lead Center:	**GSFC**
Participating Center:	**GSFC**
Non-NASA Contributors:	**DTRA, SAIC, AFRL, Photobit, MRC**
NASA Partner:	**AMES (through NGST), JPL**
Task Manager:	**Cheryl Marshall (GSFC)**
GSFC Participants:	**Paul Marshall (Ctr), Robert Reed, Jim Pickel (Ctr), Ray Ladbury (Ctr), George Gee (Ctr), Mike Jones (Ctr), Scott Kniffin (Ctr), Ken LaBel**
FY02 Funding:	**$300K NASA ERC**

Advanced Sensors Task Goals/Objectives

- **Radiation assessment of advanced sensor technologies for visible and infrared (IR) imaging, star-tracking and spectrographic applications.**
- **Identification of new sensor technologies that demonstrate significant improvements in radiation hardness required to insert them reliably into flight programs.**
- **Develop lessons learned document on sensor radiation testing and performance prediction techniques.**
- **Provide technology validation and limitation guidelines on emerging radiation tolerant sensor technologies.**

Task Approach

- **Perform radiation evaluations of advanced visible and infrared sensor technologies.**
  - **Includes sensors such as P-channel Si-based charge coupled detectors (CCD), and Si active pixel sensors (APS), state-of-the-art Si charge injection detector (CID) arrays, HgCdTe and InSb IR arrays with Si readout circuitry.**
  - **Team approach enhances measurement / modeling capabilities.**
- **Evaluate radiation effects modeling approaches as well as the measurement techniques themselves.**

Leveraging Relationships

- **Characterization funding and possible devices of interest from DTRA.**
- **Synergistic funding from NASA flight & research programs:**
  - **Next Generation Space Telescope (NGST), Living With A Star Space Environment Testbed (LWS/SET), Space Environment and Effects Program (Pickel), Wide Field Camera III (WFC III), SOLSTICE.**
- **Collaborators:**
  - **Detector Characterization Lab @ GSFC, Detector Groups @ GSFC & JPL, SAIC, AMES, Mission Research Corporation (MRC), and Johns Hopkins University.**

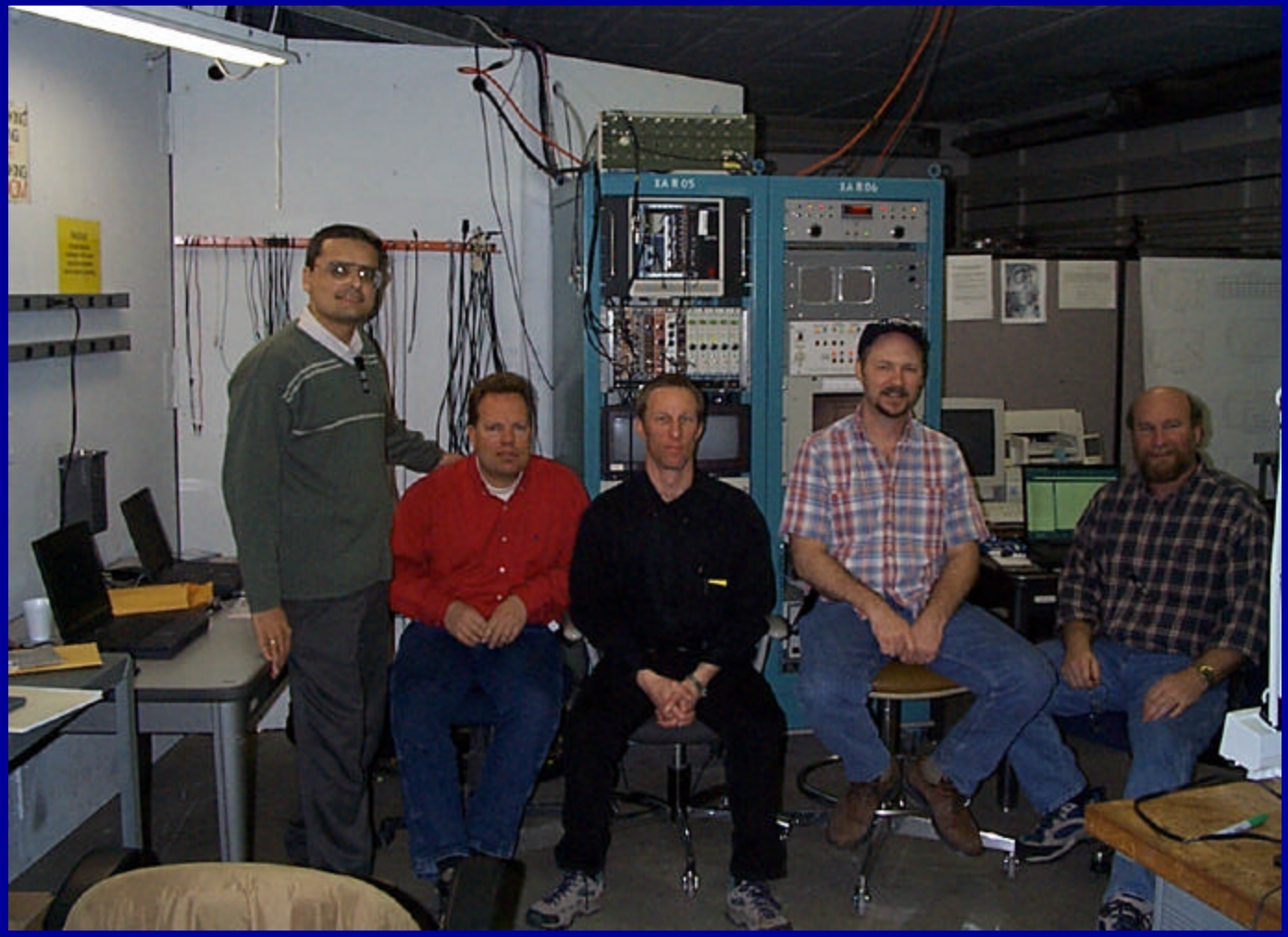
Radiation Effects in Sensors

- **Particle-induced ionization transients**
- **Increase in dark current**
- **Dark current non-uniformity**
- **Temporal fluctuations in pixel dark current**
- **Degradation in Charge Transfer Efficiency (CTE)**
- **Single event effects and total ionizing dose effects in associated circuitry**

Radiation Effects Evaluation of Si Active Pixel Sensor (APS)

- **Motivation**
  - **Camera-on-a-chip with power, mass and cost advantages compared to CCDs for some applications.**
  - **Pixels are directly addressed so displacement damage-induced charge transfer losses not an issue as with CCDs.**
  - **Technology not mature but it has promise and is active.**
- **Participants**
  - **GSFC, DTRA, Micron (formerly Photobit), Gentex Corporation, SAIC, PR&T Inc.**
  - **Leverage with Military and GSFC technology development.**

Photobit APS Heavy Ion Transient Test



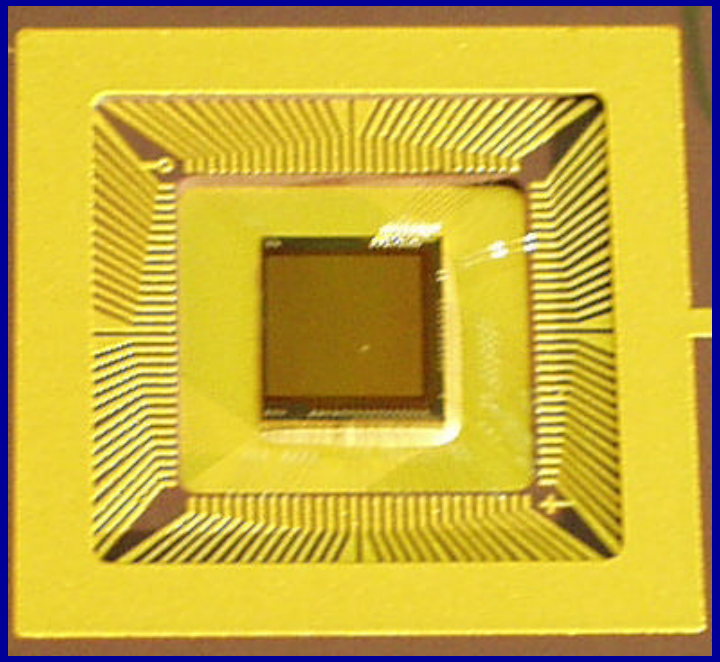
GSFC

Photobit

SAIC

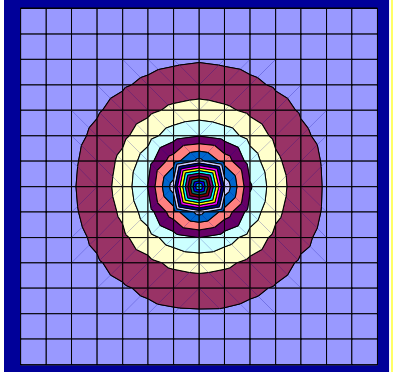
APS Radiation Effects Evaluation

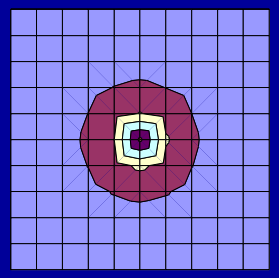
- **Cost effective design hardening via enclosed geometry and p-channel guard rings in 0.5, 0.35 & 0.25 mm standard CMOS.**
- **Robust to Total Ionizing Dose (TID) levels ~30 Mrad(Si).**
- **256 X 256 0.35 mm test chip with 4 different quadrants.**
- **Variations in pixels:**
  - **Photodiode (PD) area**
  - **N-well PD (photosensitivity)**
  - **PD salicide (photosensitivity)**
  - **PD contact salicide**
  - **Recessed n^+ implant**

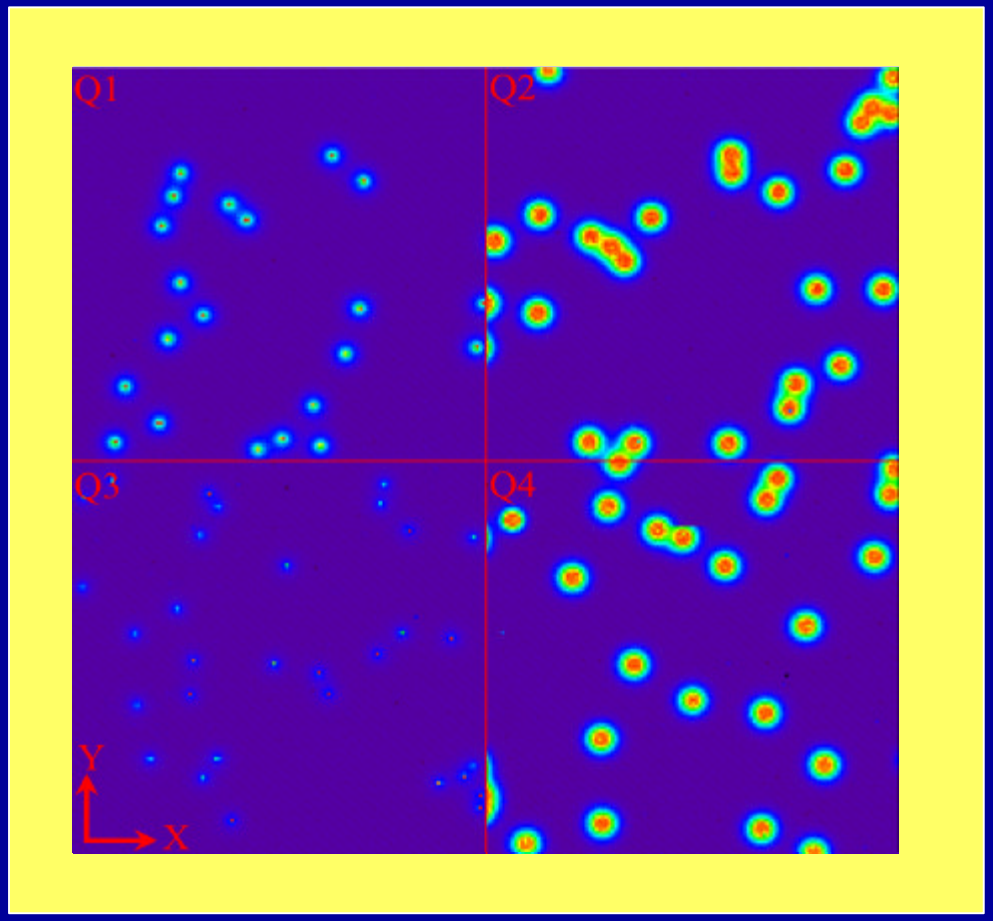


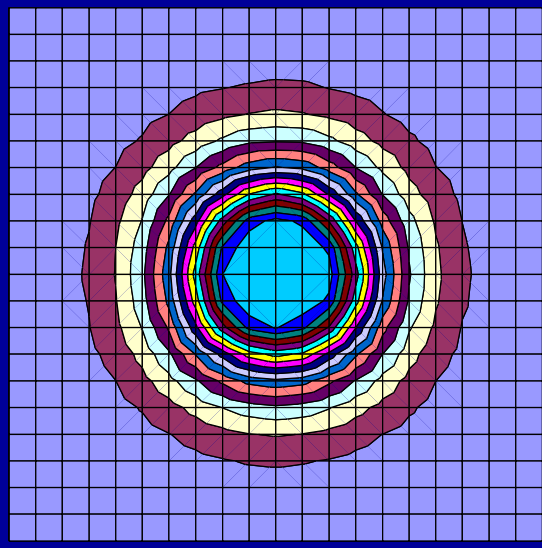
Normal Incidence Ar on Photobit APS

Comparison of transient response of 4 cell designs.

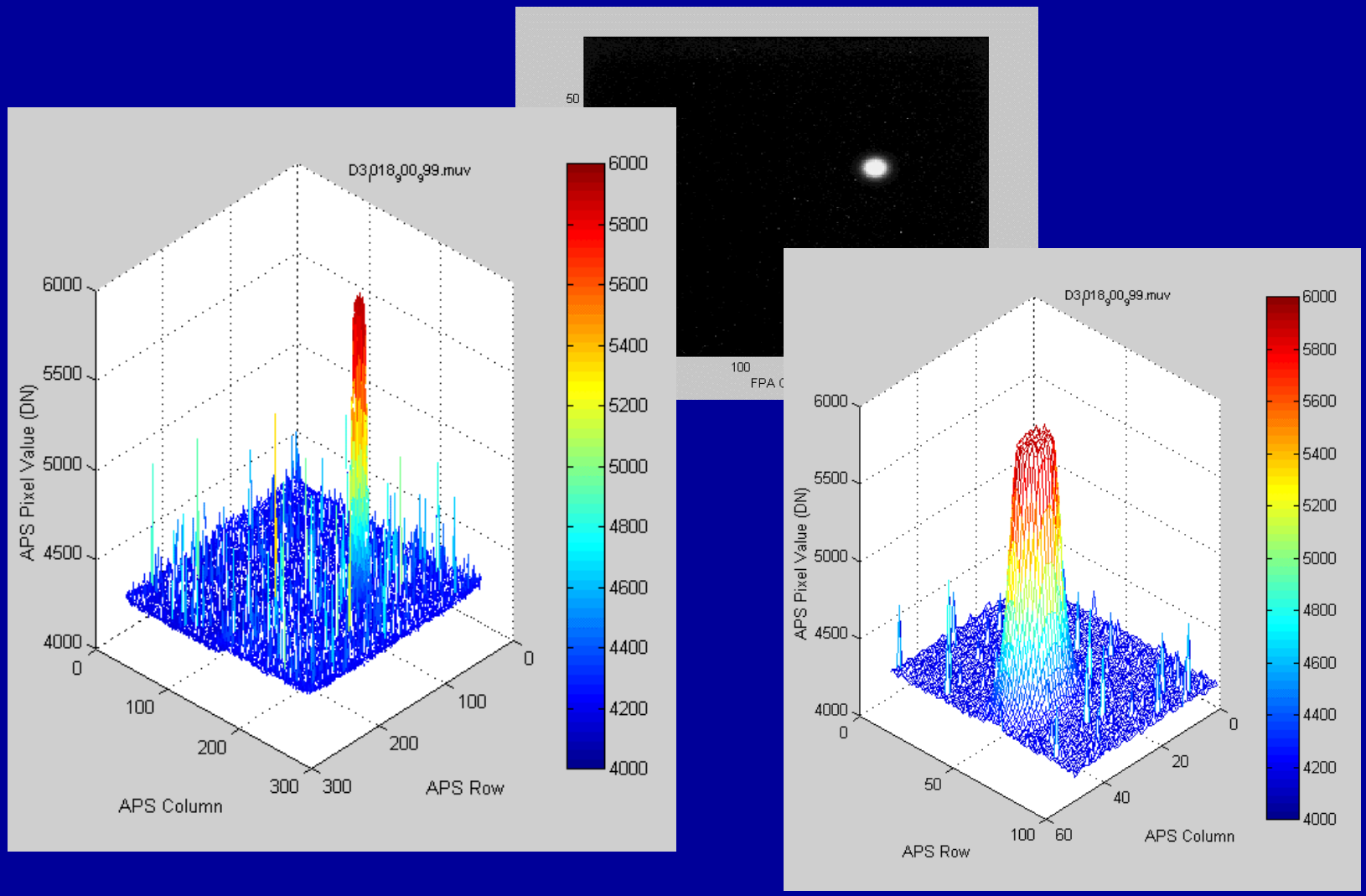








Single Heavy Ion Events



APS Subtask Accomplishments

- **Completed heavy ion data analysis and report for normal incident Ar on Photobit APS sensor.**
  - **No latch-up up to LET = 85 MeV-cm^2/mg.**
  - **Design in Q3 clearly provides superior transient response.**
  - **Angular data suggest active regions in Q2 and Q4 are relatively deep compared to active regions in Q1 and Q3.**
  - **Software developed serves as generic transient analysis tool.**
- **Comparison with simplified charge diffusion model begun.**
  - **First generation charge diffusion model in collaboration with NGST is ready. (Summary submitted to 2002 NSREC.)**
  - **Negotiated release of proprietary vertical processing parameters essential for model / data comparison.**

APS Plans for Remainder of FY02

Task 11 Effort	Begin	Completion
Radiation assessment of APS sensor technology		**4QFY03**
• Completion of data analysis & report for heavy ion transients in APS	1QFY02	2QFY02
• Validation of charge collection model using FY01 heavy ion APS data	1QFY02	3QFY02
• Report on possible hardening techniques & particle rejection models	3QFY02	3QFY03
• Assessment of emerging sensors in the APS technology family	1QFY02	4QFY03

Other Visible and IR Sensor Tasks

- **p-channel CCD (DTRA / SAIC / LWS/SET)**
- **Critical review of CCD displacement damage testing techniques. (GSFC Detector Characterization Lab and Wide Field Camera III)**
- **Planned proton evaluations**
  - **Hybrid CMOS Visible Sensor (Rockwell HYViSI with AFRL)**
  - **Europa Charge Injection Device (CIDTECH CID with MRC)**
  - **BAE CCD (with Ball Aerosapce & JHU). Possibly a JPL APS.**
  - **HgCdTe 14.5 micron cut-off focal plane array (with AFRL)**
- **Space Environment Effects Working Group *(*SEEWG)**

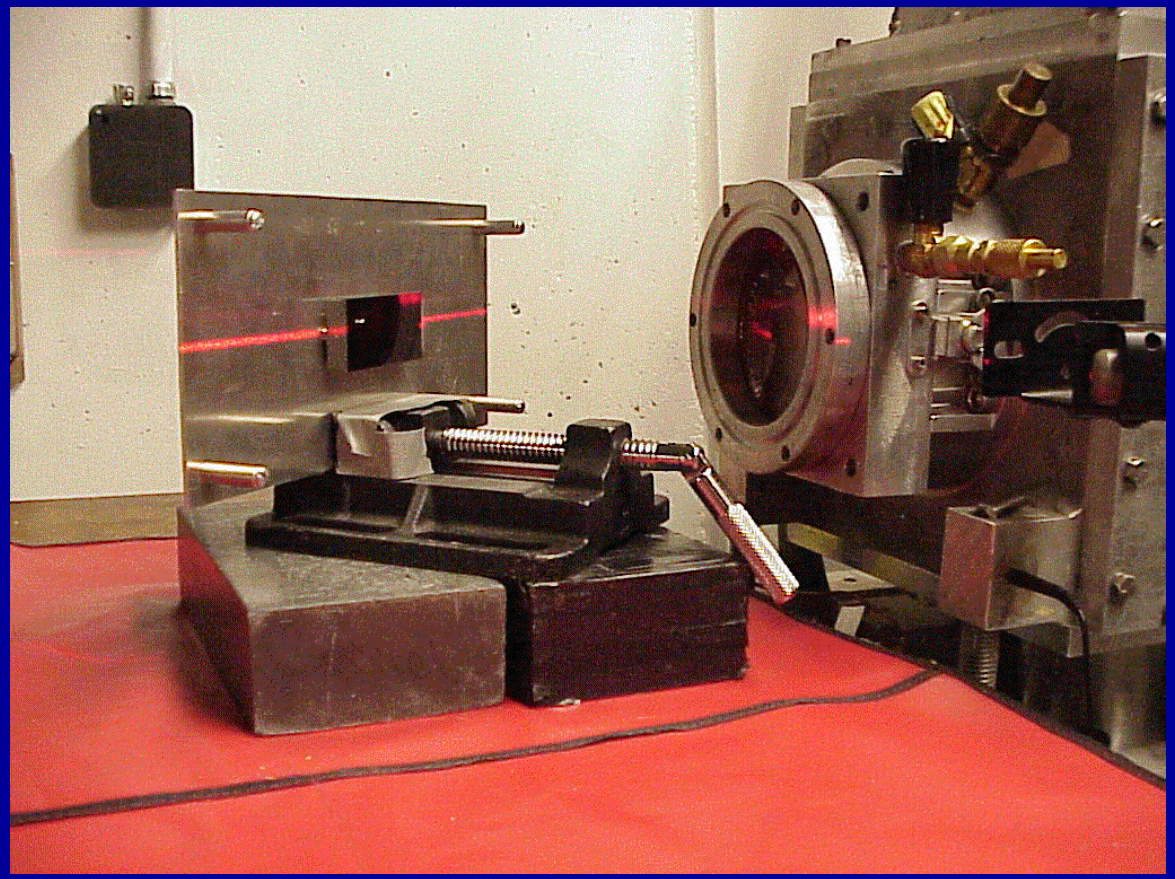
Visible p-channel CCD Arrays

- **Motivation: P-channel CCDs show promise for increased radiation hardness to displacement damage.**
- **Status (via bi-weekly technical interchange meetings (TIMs)) :**
  - **Second sub-lot of generation II devices fabricated at Mitel (now Dalsa) are in test at SAIC. Processing changes resulted in improved device performance. Cautiously optimistic.**
- **Plans for Remainder of FY02:**
  - **SAIC will complete packaged die evaluation and TID test 5/02.**
  - **Depending on results, proton testing as soon as 6/02.**
    - **Potential sensor for Living With a Star / Space Environment Testbed**
  - **Data analysis and final report by 9/02.**

CCD Radiation Evaluation Techniques

- **Motivation: Critical assessment of charge transfer efficiency (CTE) measurement techniques which are highly application dependent. Results will be used to validate proposed operational mode for improved radiation hardness.**
- **Status:**
  - **In Dec. 2001 paper, comparison of CTE measurement techniques was reported. Found that post-processing assumption of uniform distribution of traps not sufficient for on-orbit predictions.**
  - **Two devices in hand for new proton tests and demonstration of proposed hardening technique.**
- **Plans for Remainder of FY02:**
  - **Pre-rad characterization of devices.**
  - **Development of test plan followed by proton tests.**
  - **Preliminary data analysis and report by 9/02.**

Recent Proton Irradiation of WFC III Si CCD



- **WFC III visible CCD**
- **Large array with excellent CTE:**
  - **2k x 4K (three side abuttable)**
  - **CTE ~6 9's with very low dark currents**

Infrared (IR) Focal Plane Array Task

- **Motivation: Low noise assessment of proton transient response of IR sensor and readout technology which are increasingly important to NASA missions (e.g. NGST).**
  - **A cosmic ray impact on a pixel injects charge into the detector, causing total loss of information if it occurs during an observation.**
- **Accomplishments and Status:**
  - **Completed proton transient tests on 14.5 mm cut-off HgCdTe focal plane array (FPA) with AFRL.**
  - **Data analysis of proton transients is underway.**
- **Plans for Remainder of FY02:**
  - **Complete proton transient analysis and submit final reports by 9/02.**

Radiation Issues with IR Sensor Arrays

- **Sensitivity to displacement damage is less as a result of less pristine materials used in fabrication.**
- **IR detectors are typically bonded to Si CMOS readout circuits operated and cold temperatures, and both the detector and readout circuit can be subject to degradation from exposure to ionizing radiation.**
- **Transient events produced by proton strikes may also be an issue, particularly for low background applications, or those requiring precise radiometric calibration.**

Effort	Begin	Completion
Radiation assessment of p-channel sensor technology		4QFY05
• Measurement & analysis report for DTRA sensor	2QFY02	1QFY03
• Follow-on assessments of future devices	1QFY03	4QFY05
Radiation assessment of emerging promising Si & HgCdTe technologies		4QFY05
• HYViSI Si Hybrid	1QFY02	1QFY03
• Europa-developed Si charge injection device (CID)	3QFY02	3QFY03
• HgCdTe 14.5 micron cut-off focal plane array (FPA)	1QFY02	4QFY02
• Wide Field Camera III Si CCD	1QFY01	4QFY02

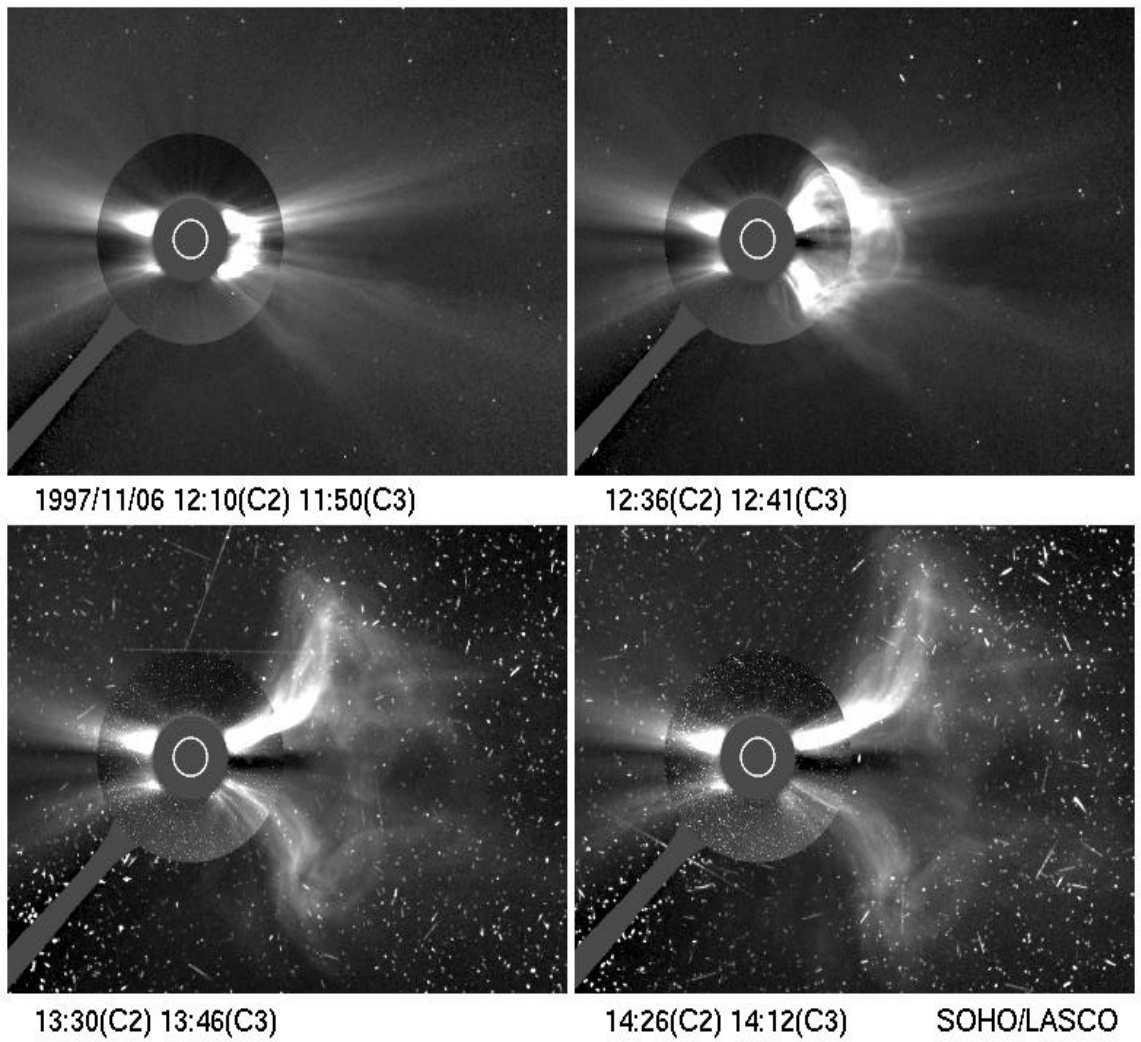
Joint NGST / ERC Tasks

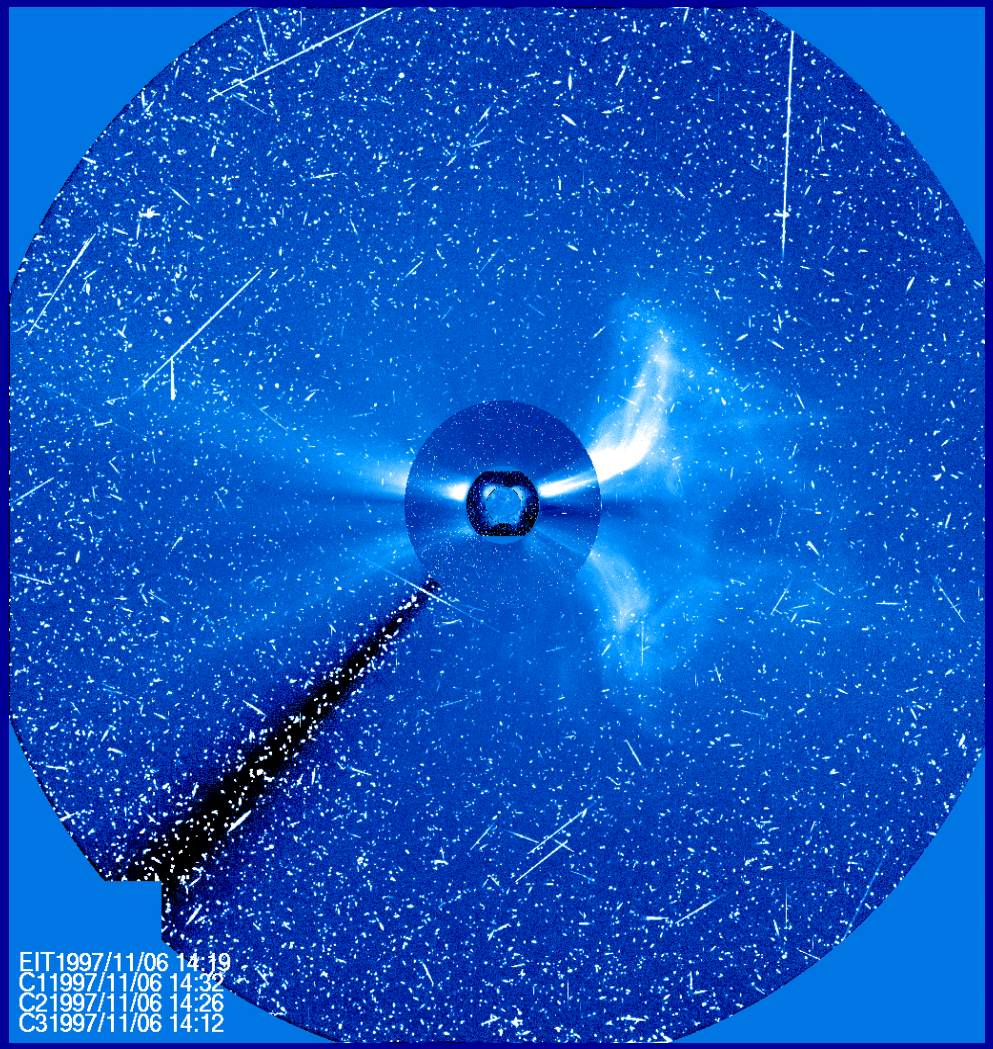
- **Status of flight data mining:**
  - **Analysis of Near IR Camera and Multi-Object Spectrometer (NICMOS) flight data to assess performance predictions and secondary particle issues is underway.**
    - **Effects of prompt and delayed components by examining dark frames as function of time after South Atlantic Anomaly passage.**
    - **The charge collection model currently being validated using APS data will be used to analyze results.**
    - **Results to date submitted to NSREC 2002.**
  - **Analysis of SOHO flight data to assess visible CCD performance predictions to begin in FY02.**

Joint NGST / ERC Tasks, cont.

- **Plans for Remainder of FY02:**
  - **Proton testing of H1RG IR ReadOut IC (ROIC) at 30K in 5/02.**
  - **Complete NICMOS and ROIC data analysis and submit final reports by 9/02.**
  - **Rockwell HgCdTe and Raytheon InSb sensor at 30K, and ROIC tests at 30K and 6K still possible by 9/02.**

SOHO/LASCO During Solar Particle Event





Particle Tracks in SOHO /L ASCO CCD

Joint Task with LWS / SET for Sensors

- **ERC will provide ground-based radiation testing required to assess suitability of potential sensors in order to design the flight demonstrations, and to interpret the flight data.**
- **Some potential sensors identified: DTRA/SAIC p-channel, CIDTECH CID, Berkeley p-channel, JPL APS.**
- **In process of placing Aerospace Corporation under contract to develop sensor test bed concept (engineering trade and feasibility studies for various flight experiment approaches.)**
  - **Effort will be underway by 5/02.**

Space Environment Effects Working Group (SEEWG)

- **Purpose: To develop technology roadmaps to facilitate insertion into U.S. space systems**
- **Sponsors: NASA, Navy, Army, Air Force, DARPA, NOAA, NRO, and DoE**
- **Focal Plane Sensor Elements Session**
  - **Chairs: Tom Grycewicz, Terry Lomheim & Paul Marshall**
- **Meeting in November, 2002**
  - **ERC/LWS is collaborating to provide needs assessment.**

Effort	Begin	Completion
Lessons learned document on sensor test & on-orbit performance predictions	1QFY01	4QFY05
• Lessons learned for visible sensor testing	1QFY01	4QFY02
• Lessons learned for visible sensor performance predictions	3QFY02	3QFY03
• Lessons learned for IR sensors & updates for visible sensors	1QFY03	4QFY05
Completion of joint NGST projects		4QFY05
• Analysis of NICMOS flight data to assess performance predictions & secondary particle issues	1QFY02	2QFY02
• Analysis of SOHO flight data to assess performance predictions	1QFY02	4QFY02
• Second generation charge collection model	4QFY02	1QFY04
• Radiation evaluation of NGST candidate IR readout ICs & detectors	3QFY02	4QFY05
Develop insertion guidelines for emerging sensor technologies into NASA programs	1QFY02	4QFY05
• Draft prepared at end of each FY		

Effort	Begin	Completion
Technology validation and limitation guidelines	2QFY02	4QFY05
Lessons learned document on sensor test & on-orbit performance predictions	1QFY01	4QFY05
• Lessons learned for visible sensor testing	1QFY01	4QFY02
• Lessons learned for visible sensor performance predictions	3QFY02	3QFY03
• Lessons learned for IR sensors & updates for visible sensors	1QFY03	4QFY05
Radiation assessment of APS sensor technology		4QFY03
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• Wide Field III Si CCD	1QFY01	4QFY02
Completion of joint NGST projects		4QFY05
• Analysis of NICMOS flight data to assess performance predictions & secondary particle issues	1QFY02	2QFY02
• Analysis of SOHO flight data to assess performance predictions	1QFY02	4QFY02
• Second generation charge collection model	4QFY02	1QFY04
• Radiation evaluation of NGST candidate IR readout ICs & detectors	3QFY02	4QFY05
Develop insertion guidelines for emerging sensor technologies into NASA programs	1QFY02	4QFY05
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