National Aeronautics and Space Administration

Micrometeoroid and Orbital Debris Impact Inspection of the HST WFPC2 Radiator

J.-C. Liou and the HST WFPC2 MMOD Inspection Team

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Objectives

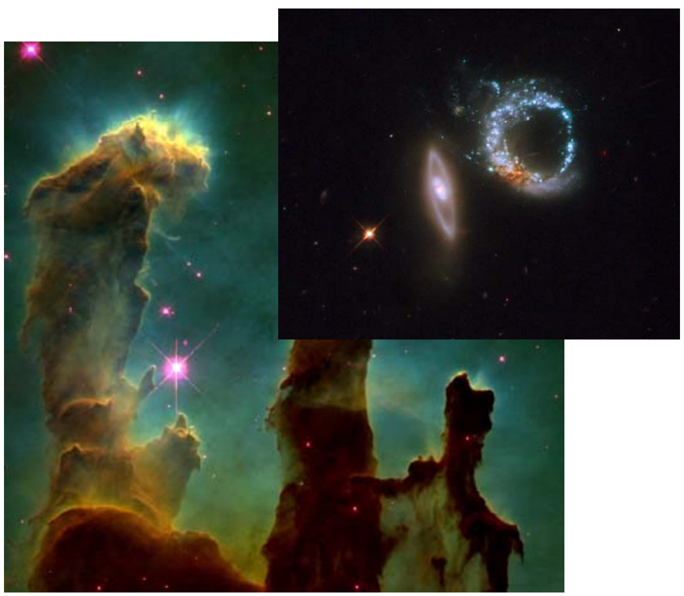
- Conduct micrometeoroid and orbital debris (MMOD) impact inspection of the Hubble Space Telescope (HST) Wide Field Planetary Camera 2 (WFPC2) radiator
  - Document the physical characteristics of large (≥300 μm) impact features
    - Locations and distribution
    - Crater shape, size, depth, volume
  - Extract residues from craters for compositional analysis
  - Perform hypervelocity impact tests for data interpretation
- Use the data to validate or improve the near-Earth MMOD environment definition
  - Flux
  - Orbital debris versus meteoroids
  - Time history (limited)

Team

- **NASA Orbital Debris Program Office (lead)**
  - **J.-C. Liou, P. Anz-Meador, J. Opiela, E. Stansbery, et al.**
- **NASA Curation Office**
  - **K. McNamara**
- **NASA Hypervelocity Impact Technology Facility**
  - **E. Christiansen, T. Hedman, J. Hyde, D. Ross, *et al.***
- **NASA Meteoroid Environment Office**
  - **D. Moser, D. Edwards**
- **NASA HST Program**
  - **B. Reed**

History

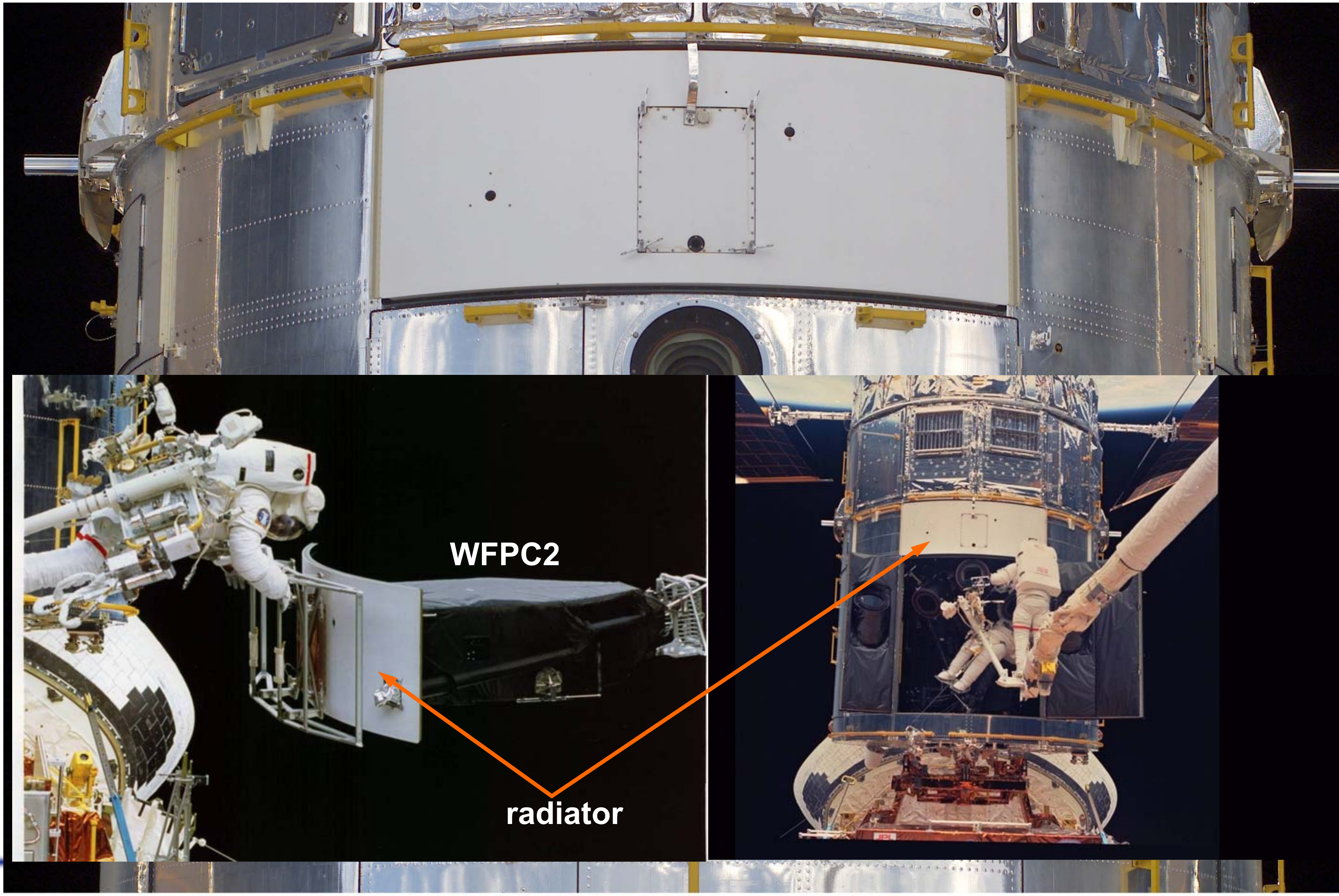
- **HST was launched from Discovery on 24 April 1990**
- **WFPC1 was replaced by WFPC2 during STS-61 HST Servicing Mission 1 (SM1) in December 1993**
  - **WFPC2 is the "workhorse" instrument behind nearly all of the most famous Hubble pictures**
- **WFPC2 was replaced by WFC3 during STS-125 HST SM4 in May 2009**



WFPC2 Radiator Background

- **The WFPC2 radiator was in space for 15.5 years (3.6 years for WFPC1 radiator)**
- **Dimensions of the radiator: 0.8 m × 2.2 m**
- **Outer layer: an aluminum plate (4.06 mm thick) coated with 4~8 mils Zinc Orthotitanate (ZOT, a ceramic thermal control paint)**

HST SM1 (STS-61, 1993)



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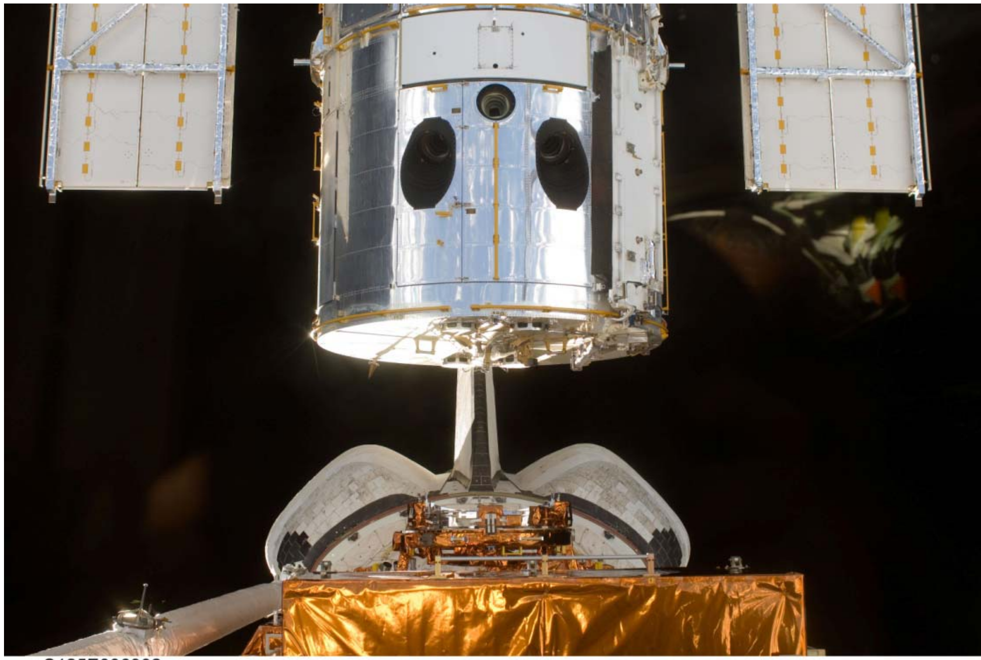
HST SM4 (STS-125, May 2009)



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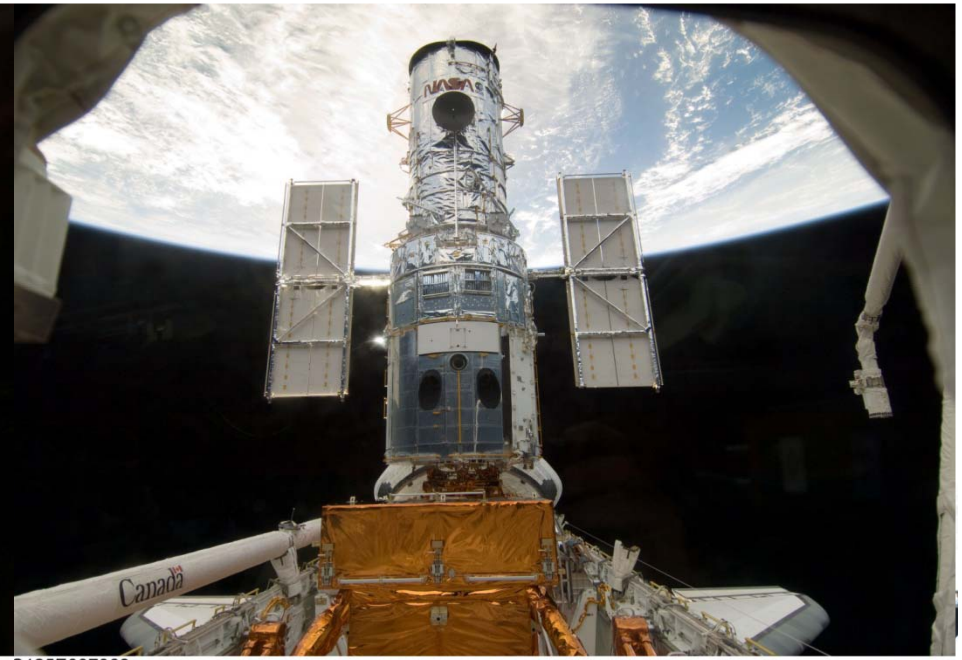

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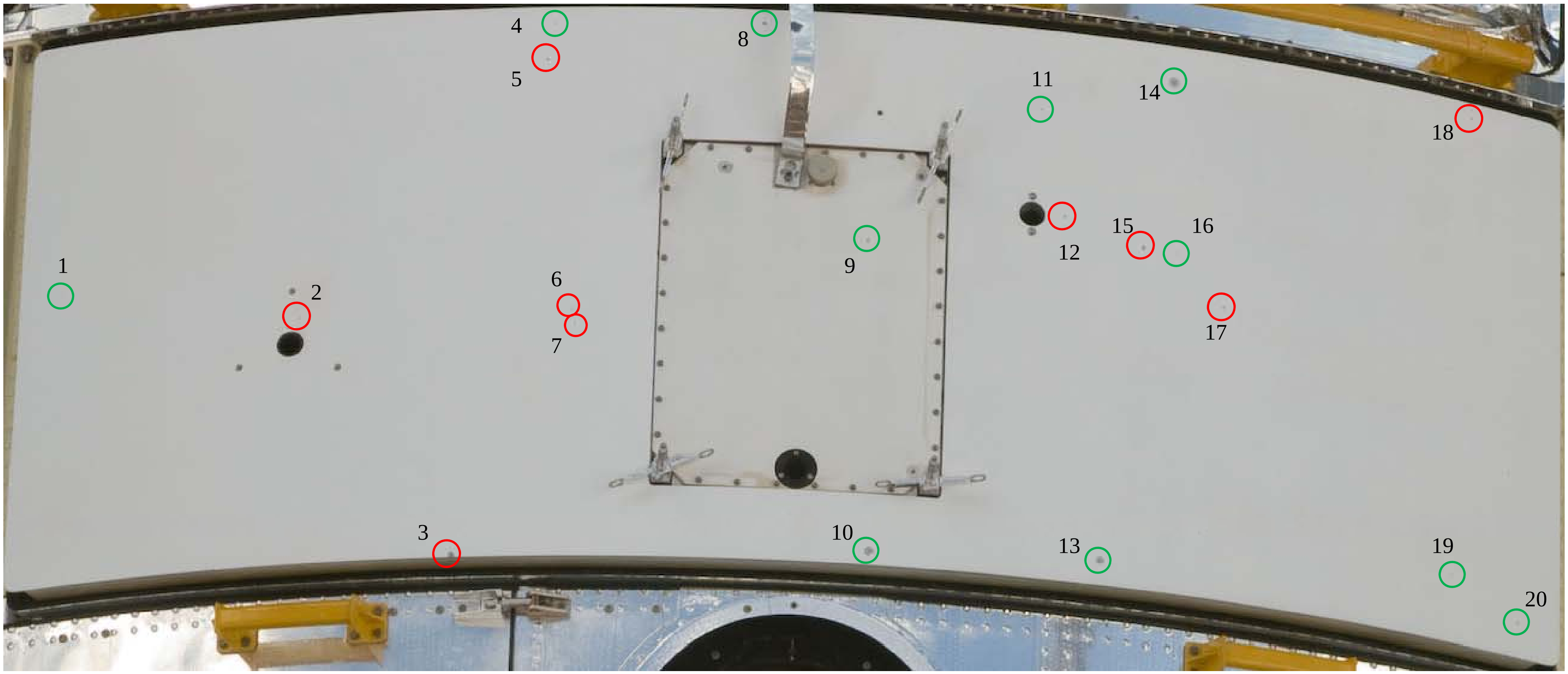
Visible MMOD Impacts from the On-orbit Imagery Survey



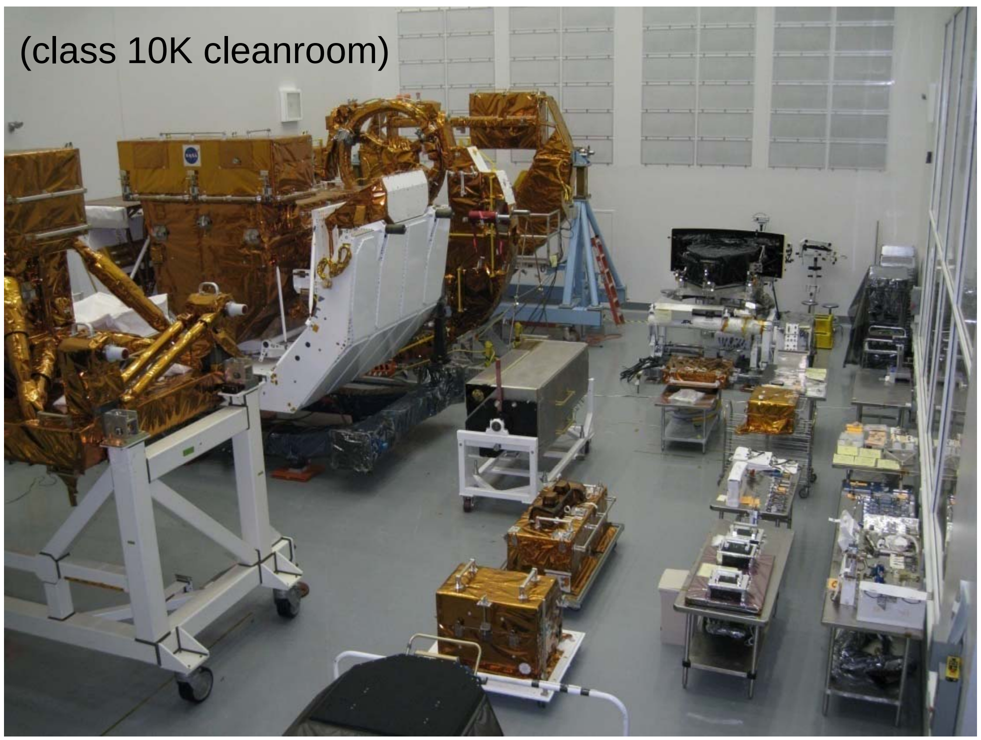
S125e006995.jpg (edited)

- Red circles: Impacts identified from SM3B images (2002)
- Green circles: Impacts identified from SM4 images (2009)

Post-Flight Deintegration at KSC

MMOD Inspection at NASA Goddard

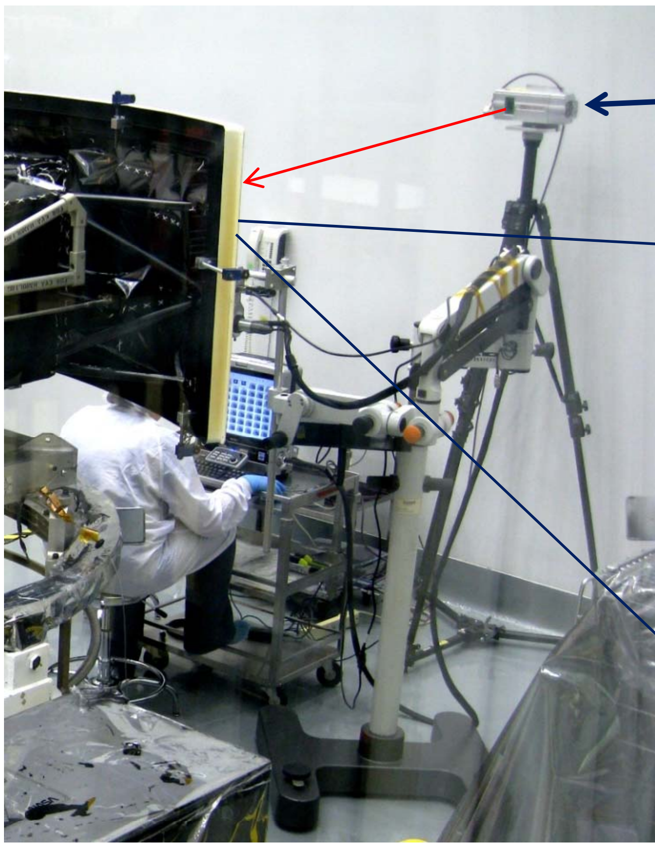
- **WFPC2 was shipped to Goddard in late June 2009**
- **MMOD inspection: 6-17 July, 24 August – 4 September, and 14-25 September 2009**
  - **Major inspection instruments: LAP CAD-Pro laser template projector and VHX-600 digital microscope**



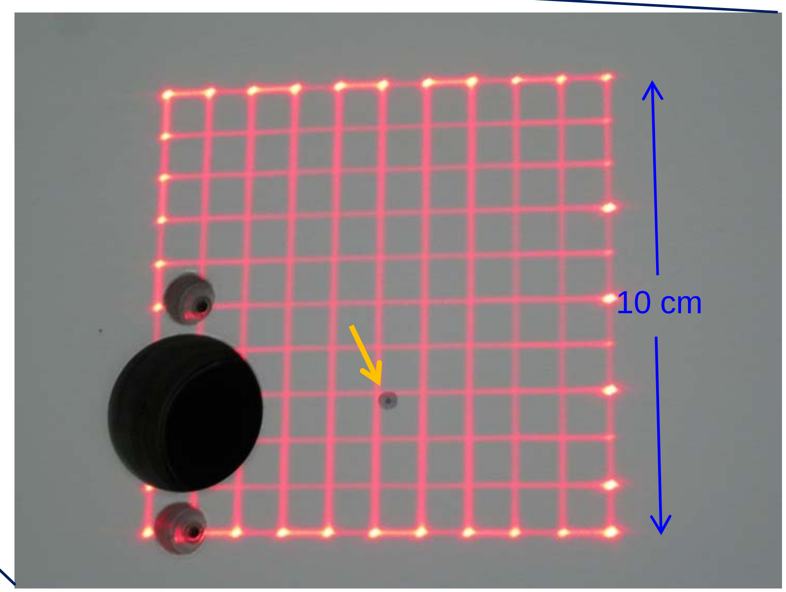
Inspection Instruments (2/3)

- **LAP CAD-Pro laser template projector**
  - **Provide crater coordinates for VHX-600 operator**

Laser projector head



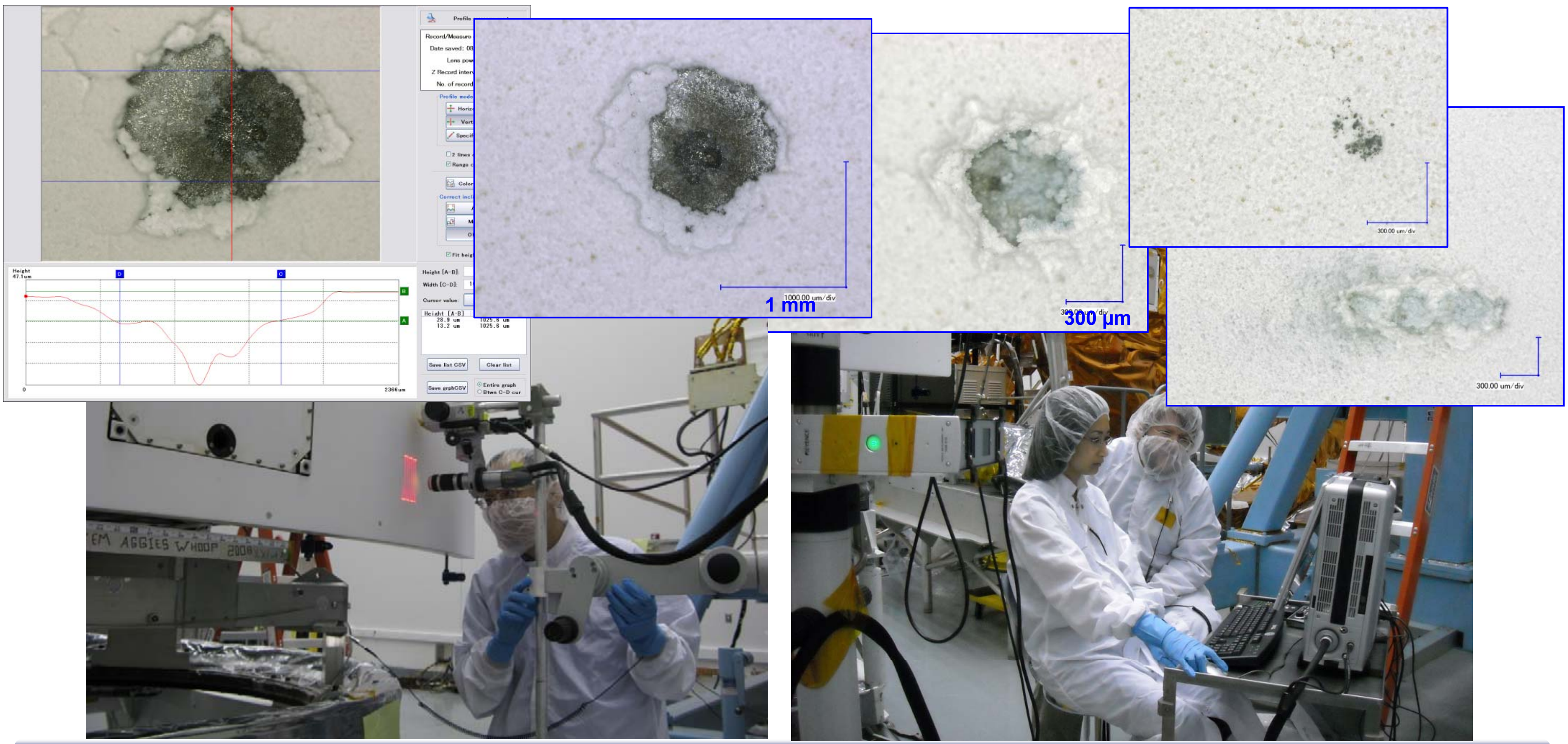
Cleanroom setup



Square grid projected on a curved surface

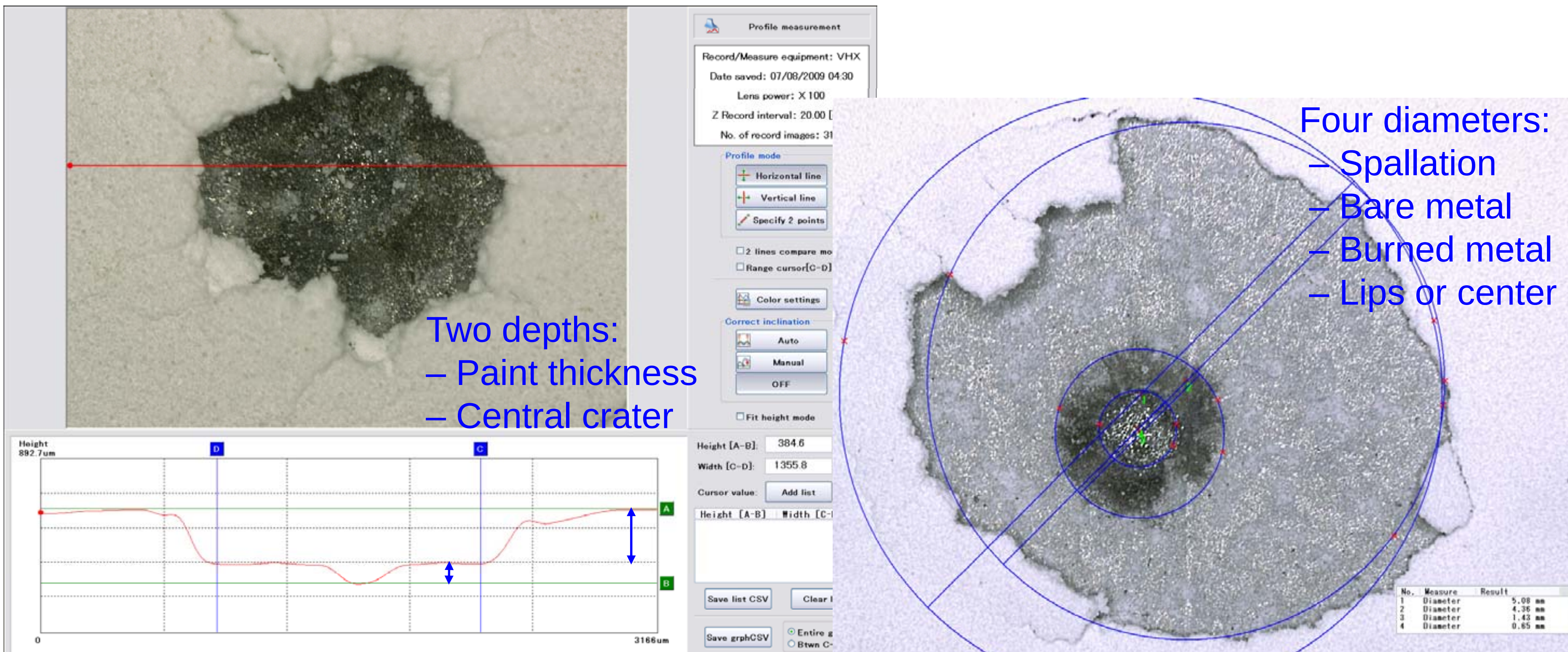
Inspection Instruments (3/3)

- **Keyence VHX-600 digital microscope (up to 5000x optical magnification, 2-D and 3-D imagery)**
  - **Record each impact feature's shape, size, depth, and volume**



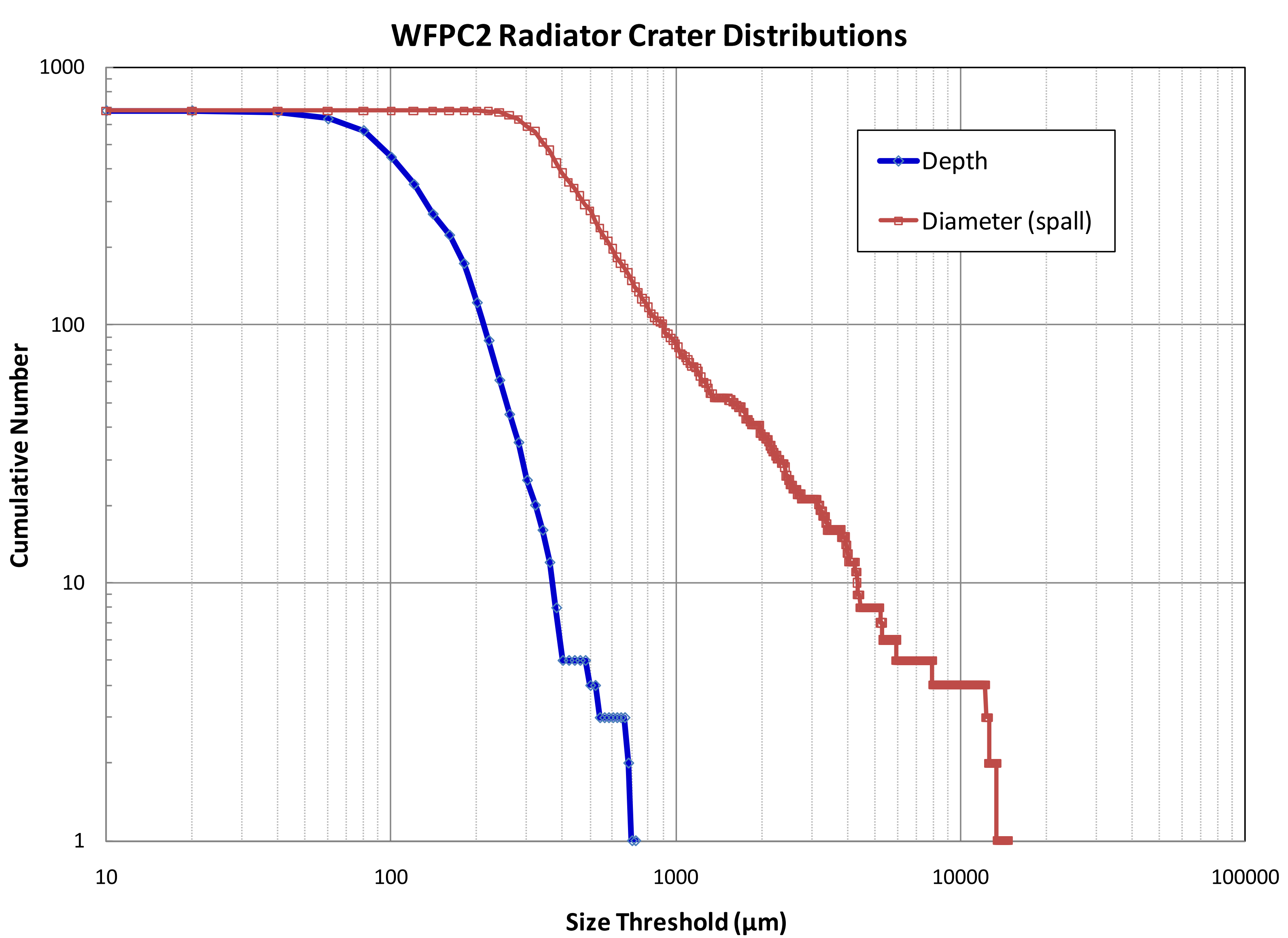
Inspection Results and Data Processing

- **Documented 685 impact craters (≥300 μm) and numerous non-impact features**
- **No through-hole**
- **The largest one: 1.6 mm crater plus 1.4 cm spall zone**



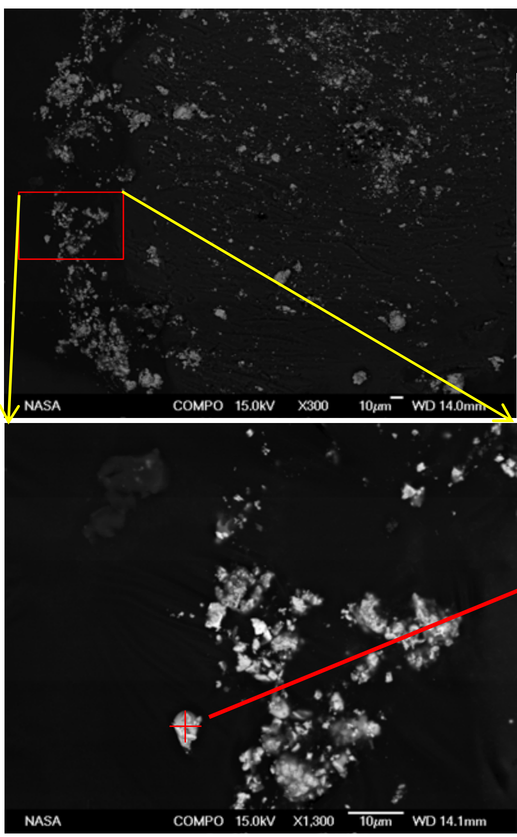
JCL

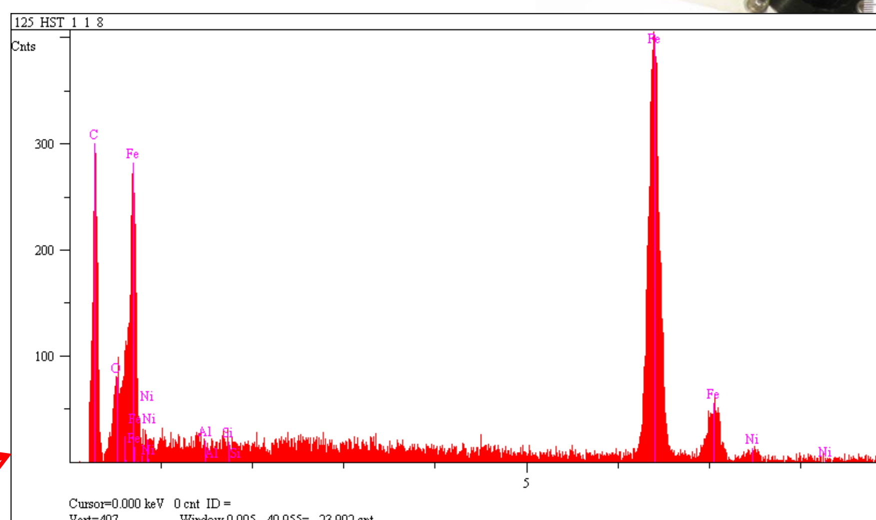
Radiator Crater Data

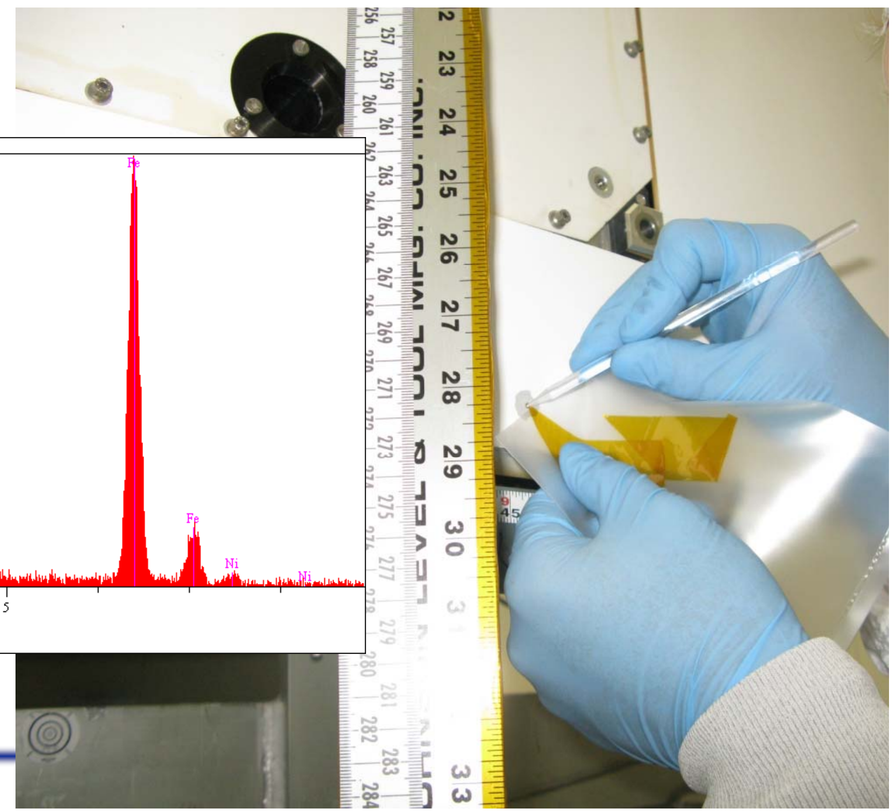


Sample Collection

- **Collected tape pull samples from 50 features in July**
- **Conducted preliminary scanning electron microscope (SEM) analysis on 36 samples**
  - **Identified non-radiator materials (Fe-Ni, Mg-silicate, steel, *etc.*) from 8 of them**

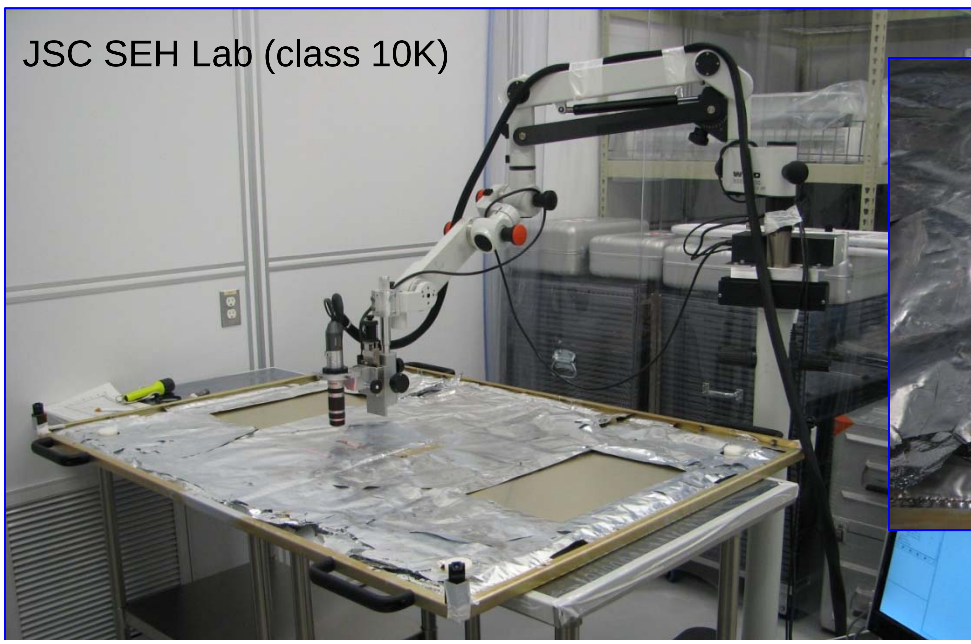


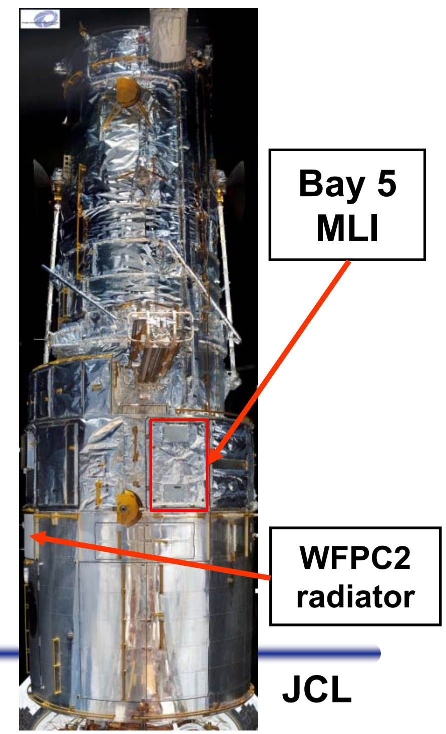




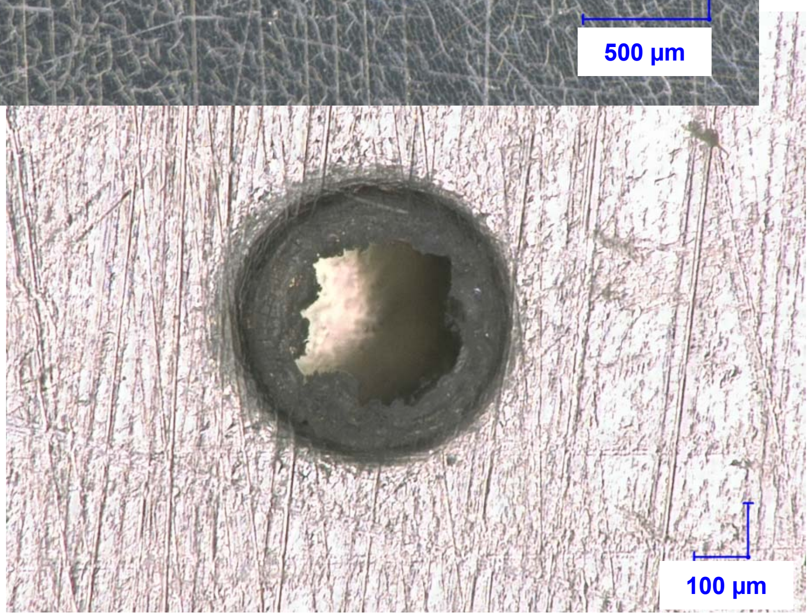
Bay 5 Multi-Layer Insulation (MLI) Inspection

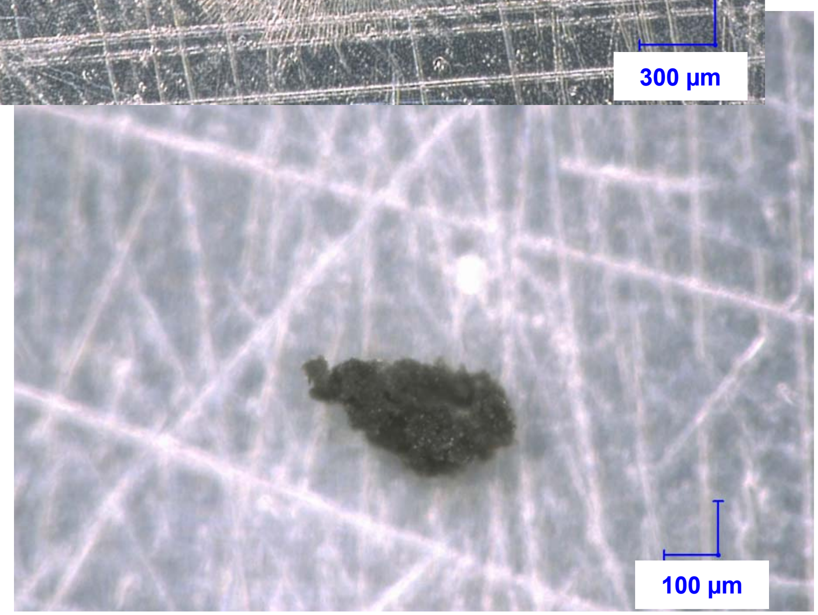
- **The HST Bay 5 MLI was shipped to JSC for 5-week MMOD inspection on 2 Feb 2010**
  - **Bay 5 MLI was in space between 1990 and 2009**
  - **Dimensions of MLI: 1.1 m × 1.5 m (with several cut-out areas)**
  - **Consists of 17 layers**
    - **The outermost layer: 127 μm thick FEP (fluorinated ethylene-propylene) Teflon with vapor deposited Al (VDA) coated on the backside**
  - **Document impact features as small as ~100 μm**





Sample MLI Inspection Data

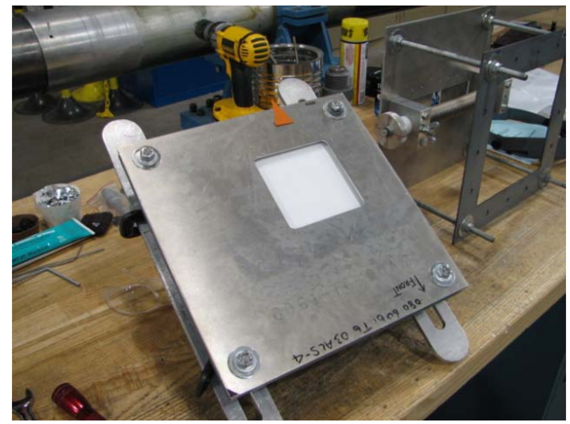




Hypervelocity Impact Tests

- **60 shots scheduled for projectiles of different sizes, materials, impact speed, and impact angle**
  - **Started on 17 Feb 2010**

.17 caliber 2-stage light gas gun at JSC White SandsTest Facility



Forward Plan

- **Proceed with core sample proposal/plan**
- **Complete hypervelocity impact tests**
  - **Process and analyze crater data, as with WFPC2**
  - **Establish feature-to-projectile conversion**
- **Conduct hydrocode simulations**
  - **Supplement hypervelocity impact data**
  - **Extrapolate to impact speed above 8 km/sec**
- **Process and analyze MLI data**
- **Model the orbital debris and micrometeoroid environment**
  - **Separate orbital debris from micrometeoroids**
  - **Compare with previous solar array data**
- **Document and publish the results**

Value of the Radiator Impact Data

- The NASA Orbital Debris Engineering Model (ORDEM)
  - Describes the near-Earth OD environment
  - Is used by NASA (STS, ISS, *etc*.), DoD, and other national and international groups for satellite impact risk assessments and shielding designs
- The database for the 100-μm-to-1-mm particles in the new ORDEM to be released in 2010
  - 211 impacts from 35 STS missions (1995-2002) at 350 to 400 km altitude
  - 17 impacts from 3 STS missions at 560 to 620 km altitude
- Number of impact craters corresponding to particles in the same size regime from the WFPC2 radiator: 685
  - Triple the total database
  - A 40x increase for data at high altitude