ISS Inspection Capabilities and Challenges

NASA Johnson Space Center
Astromaterials Research and Exploration Science (ARES)
Image Science and Analysis Group (ISAG)
KX/Randy Moore
http://isag.jsc.nasa.gov/

July 2014

ISAG Background

- **The JSC Image Science and Analysis Group (ISAG) provides NASA with expertise in all areas of imaging science.**
  - **IS&AG homepage http://isag.jsc.nasa.gov/**

- **ISAG emerged and evolved during the Shuttle Program.**
  - **ISAG formed from the Crew Earth Observation image analysis capability to fulfill a STS-51L lesson learned for screening/analyzing launch/landing imagery**
  - **Tasks grew to include support of ISS assembly**
  - **STS-114 brought near-realtime mission support for characterization of ascent debris shedding and on-orbit vehicle inspection.**

- **ISAG expertise built and honed for Shuttle is now applied to ISS, Orion Multi-Purpose Crew Vehicle, Space Launch System, and Commercial Crew & Cargo Programs.**
  - **Imagery acquisition planning**
  - **Requirements development**
  - **Imagery operations and data management**
  - **Imagery based inspection surveys**
  - **2D and 3D photogrammetric measurements**
  - **2D and 3D high-precision motion tracking**

ISAG Support to ISS Program

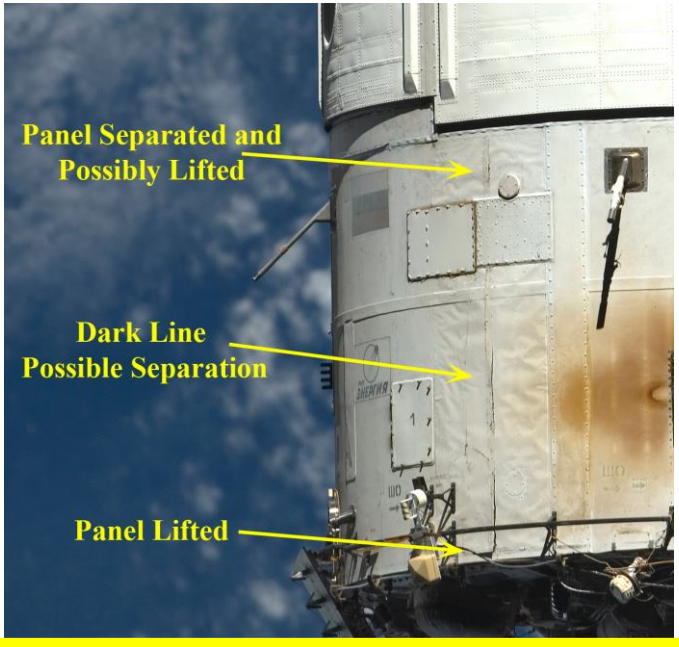
- **Primary focus is on maintaining the safety of the crew and vehicle.**

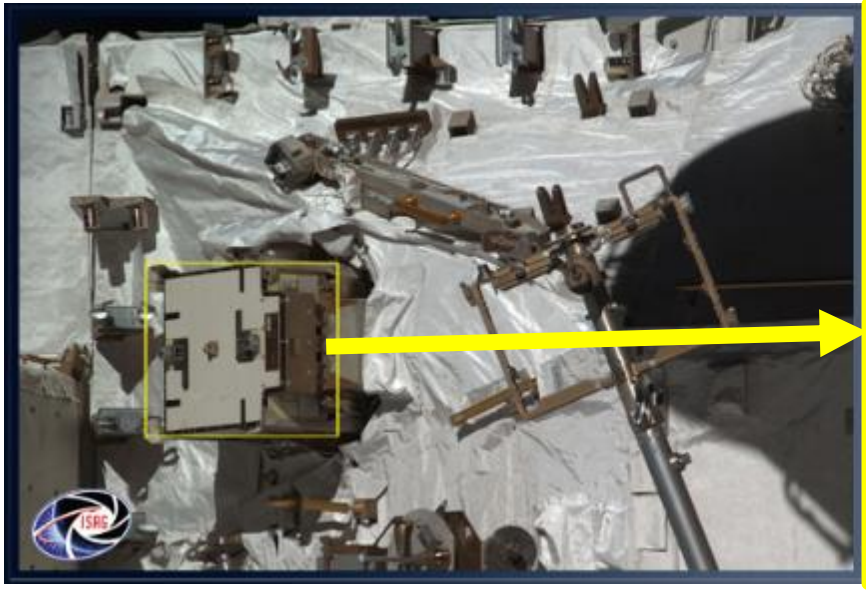
- **ISAG personnel screen downlinked imagery to:**
  - **Monitor for, and report changes in the ISS external condition**
    - **Anomalous indications**
    - **Hardware out of configuration**
  - **Detect Micro-Meteoroid or Orbital Debris (MMOD) impacts leading to:**
    - **Hardware failure**
    - **EVA sharp edges**

- **ISAG personnel assist in planning for acquiring the imagery needed to derive engineering data, supporting:**
  - **Anomaly investigation**
  - **3-D structural dynamics measurements**
  - **Clearance assessments**
  - **Verifying ISS configuration against models and requirements**
  - **Jettison trajectory calculation**

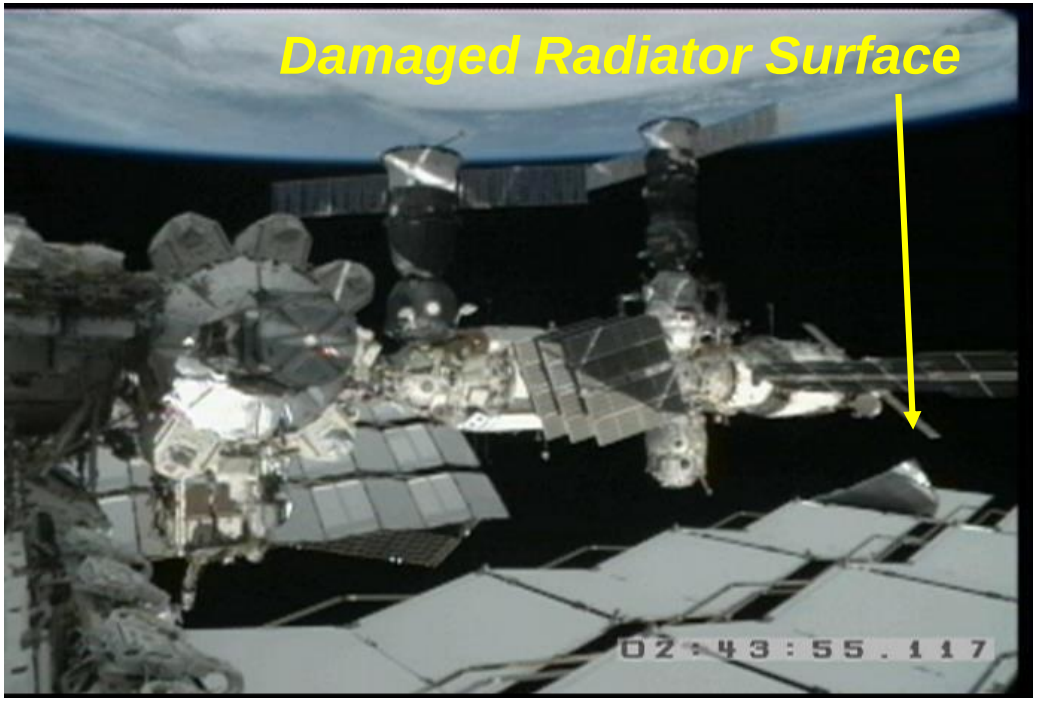
Uses and Examples
ISS Inspection Imagery

Monitoring the ISS External Condition





Monitoring the ISS External Condition



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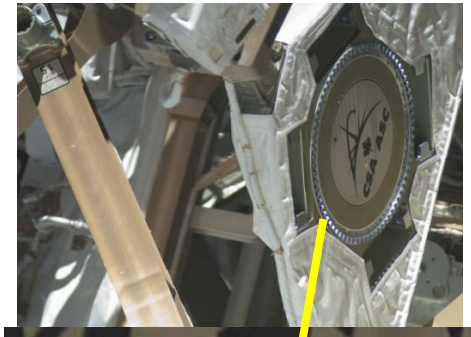

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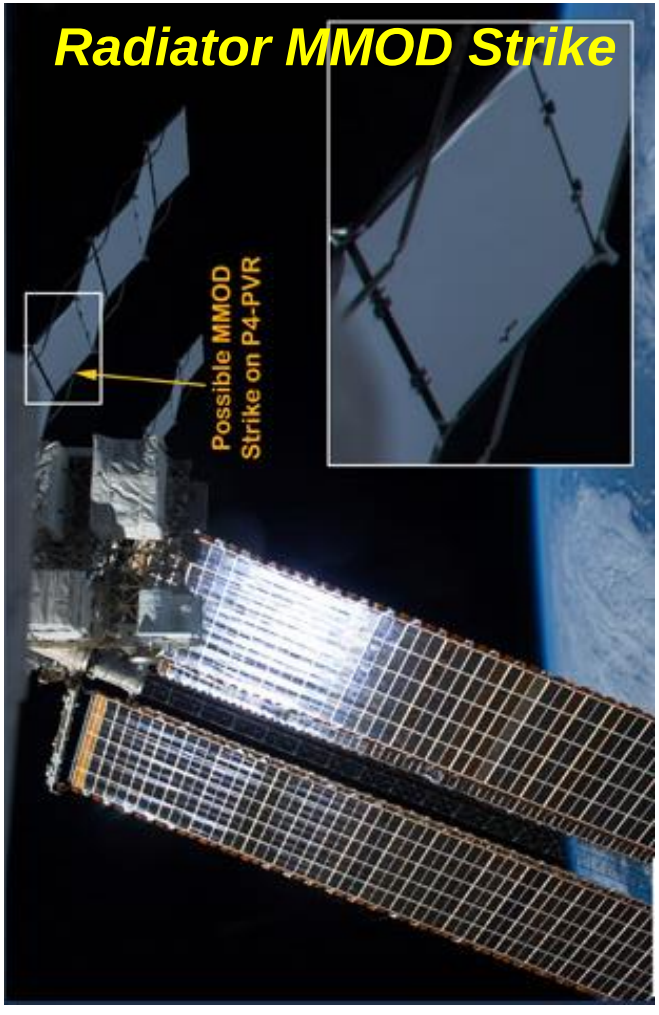

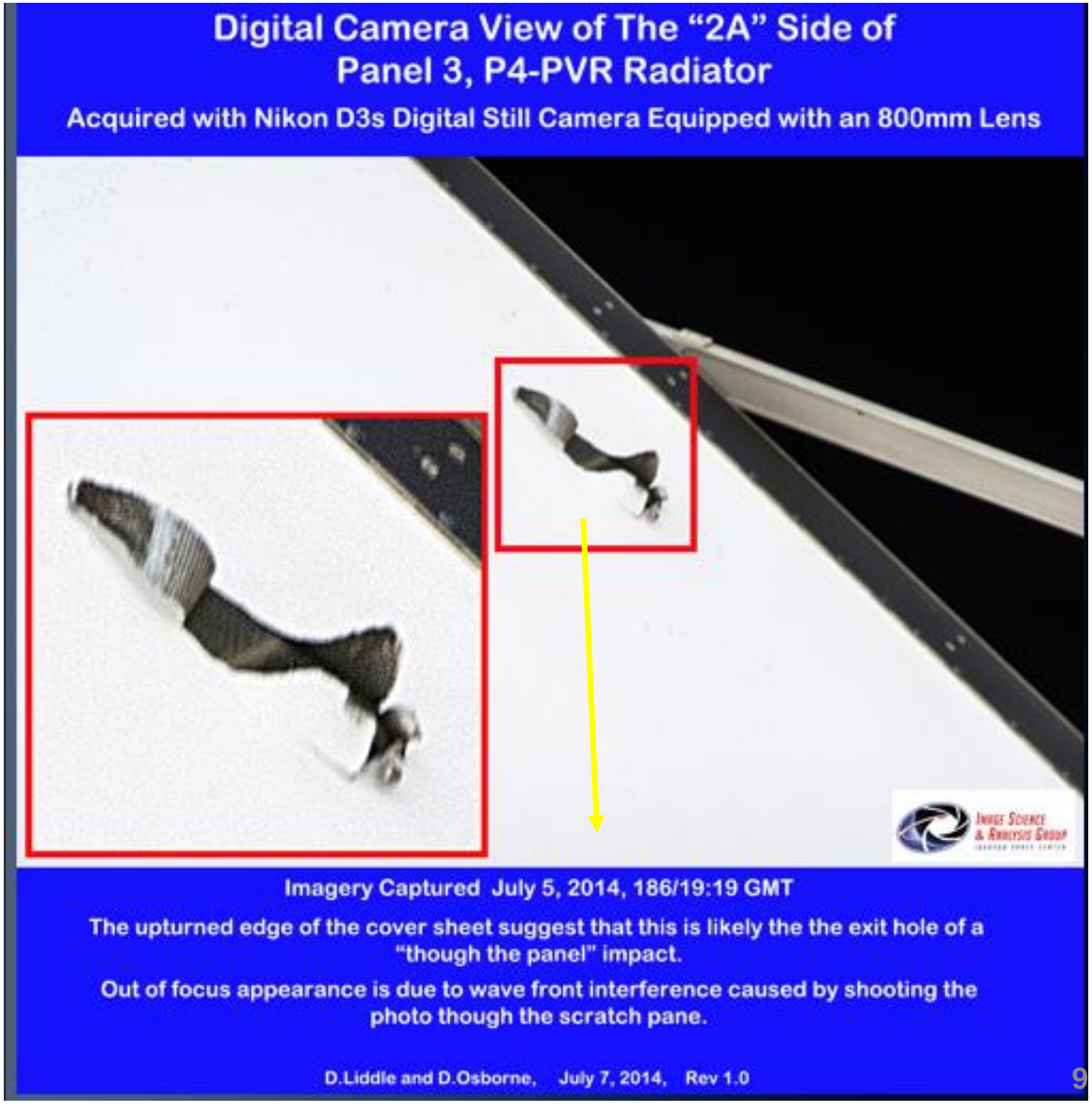

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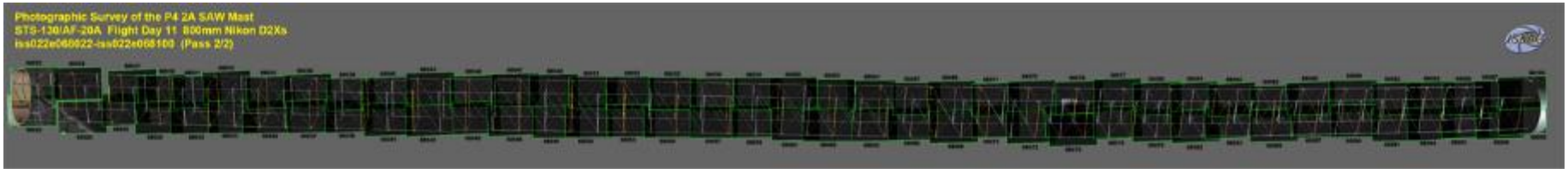

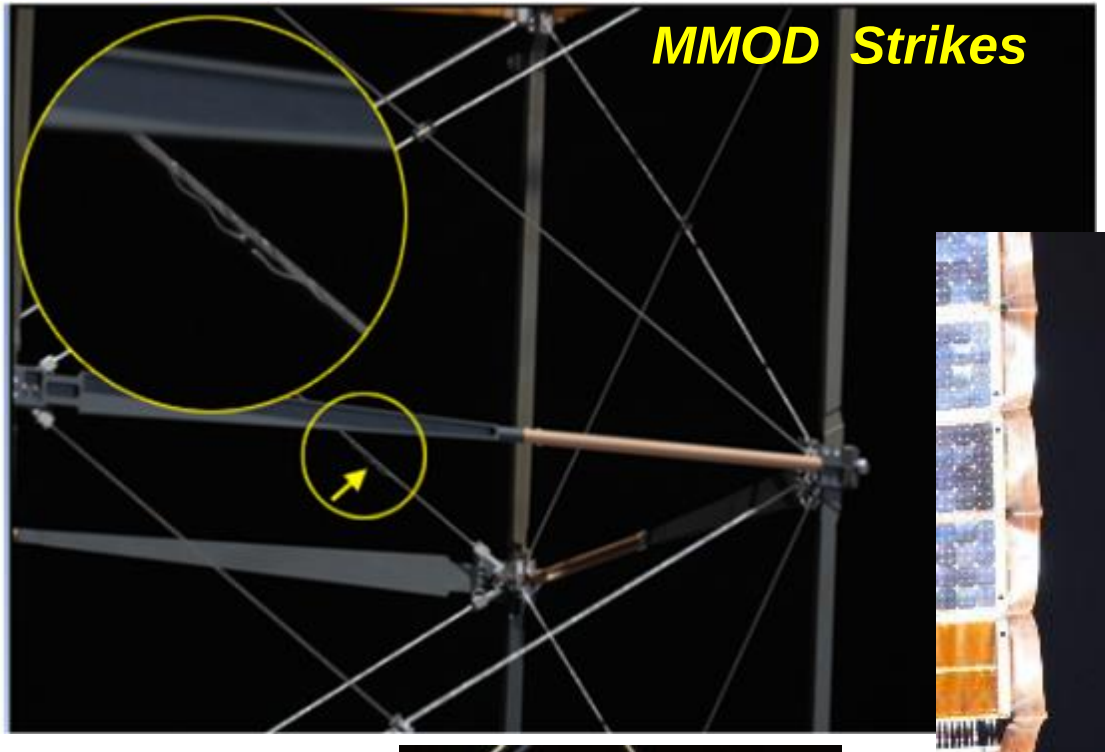

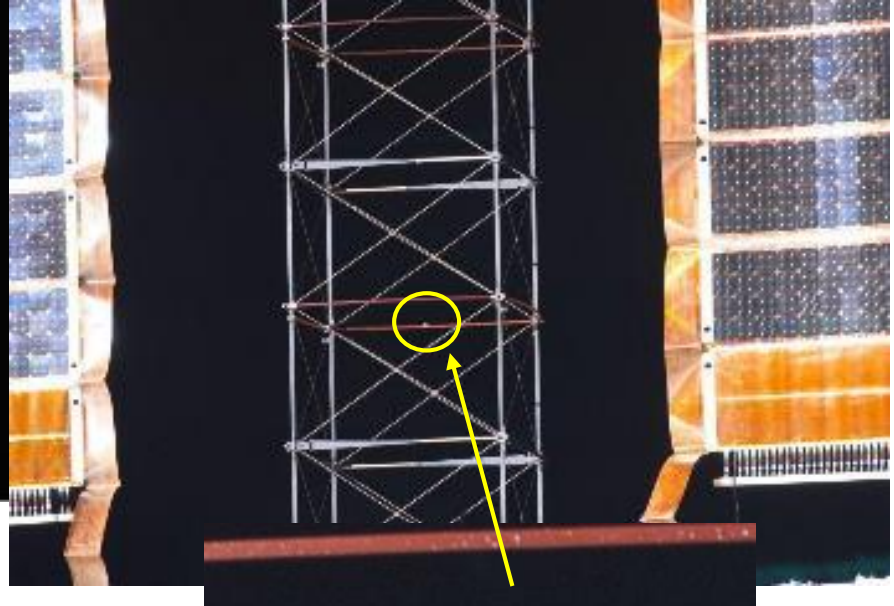

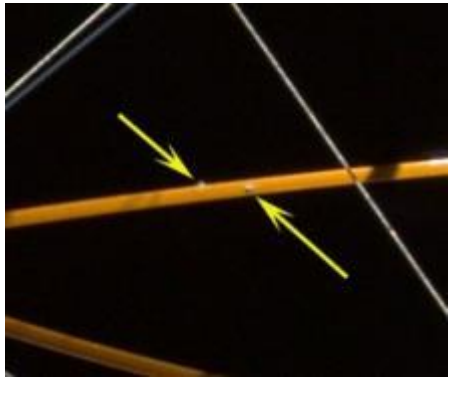

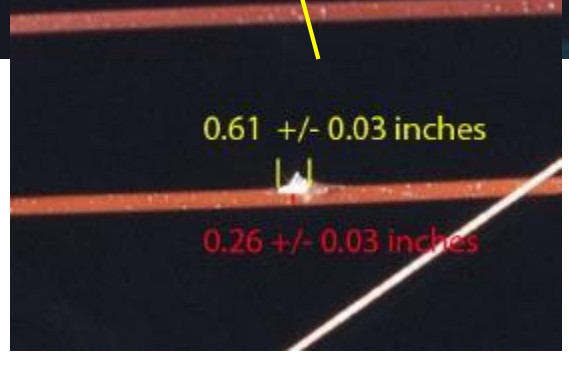

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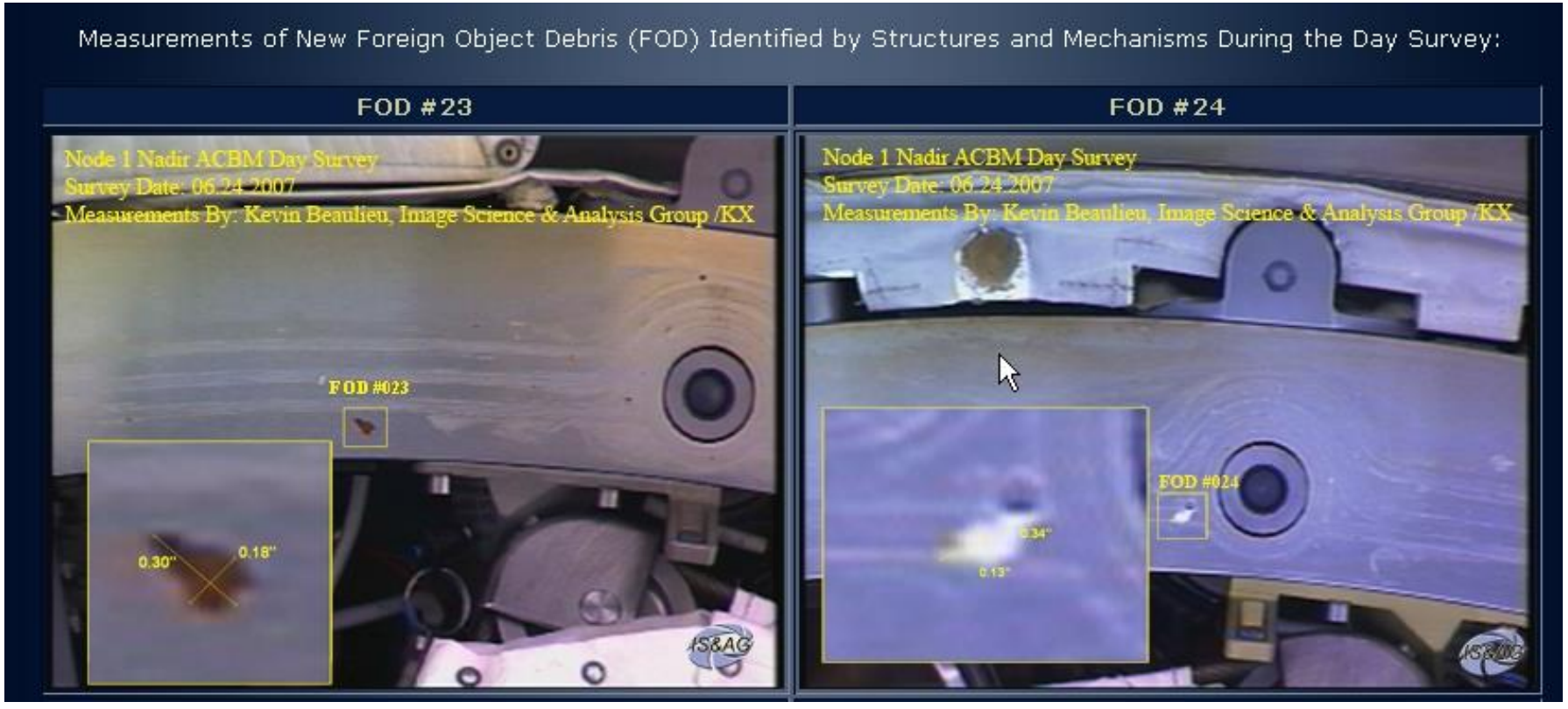
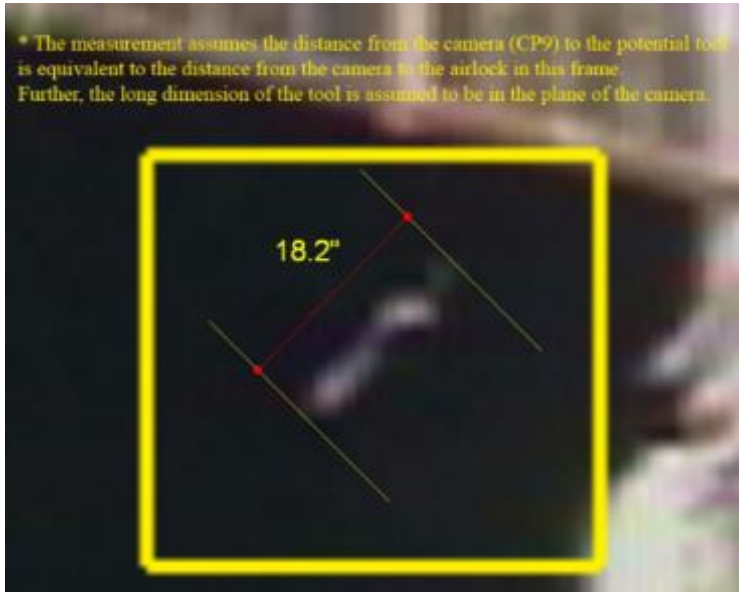


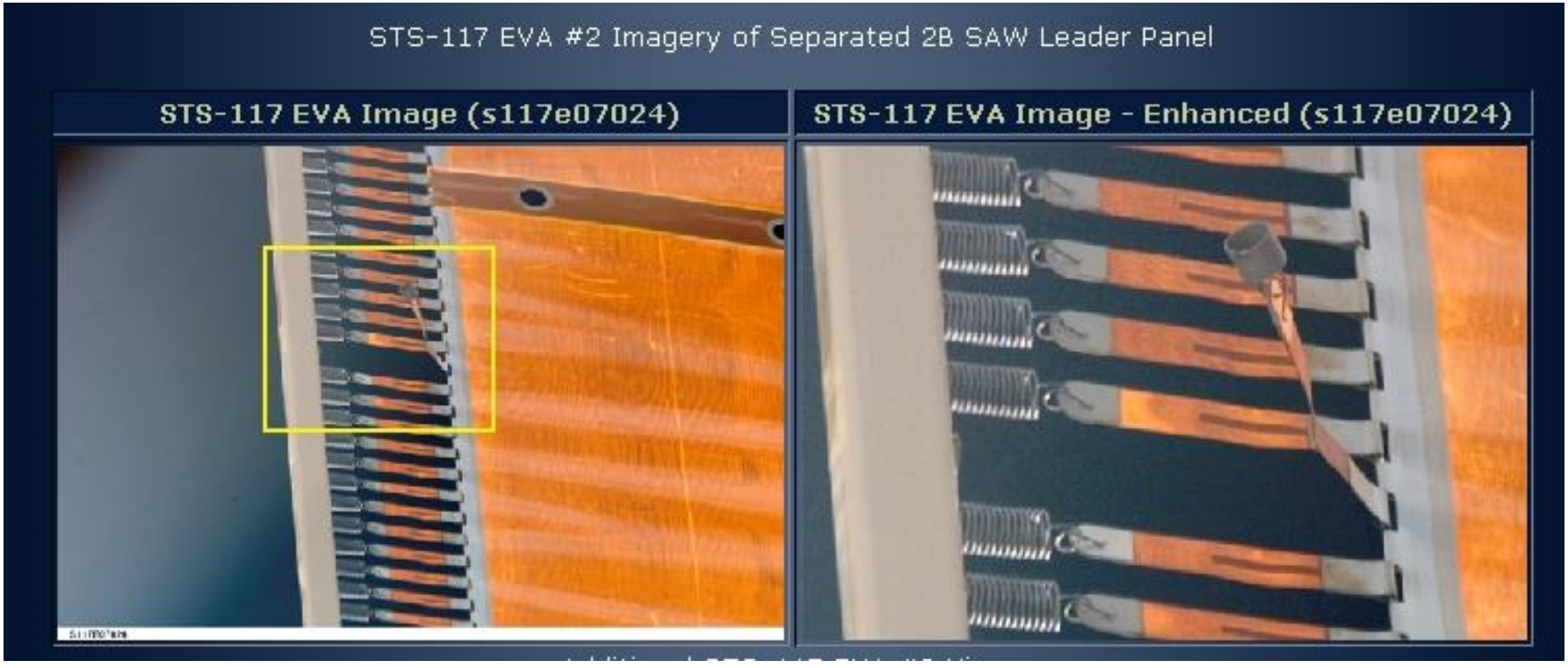
Foreign Object Debris detected in pre-berthing survey

Situational Awareness

Foreign Object Debris

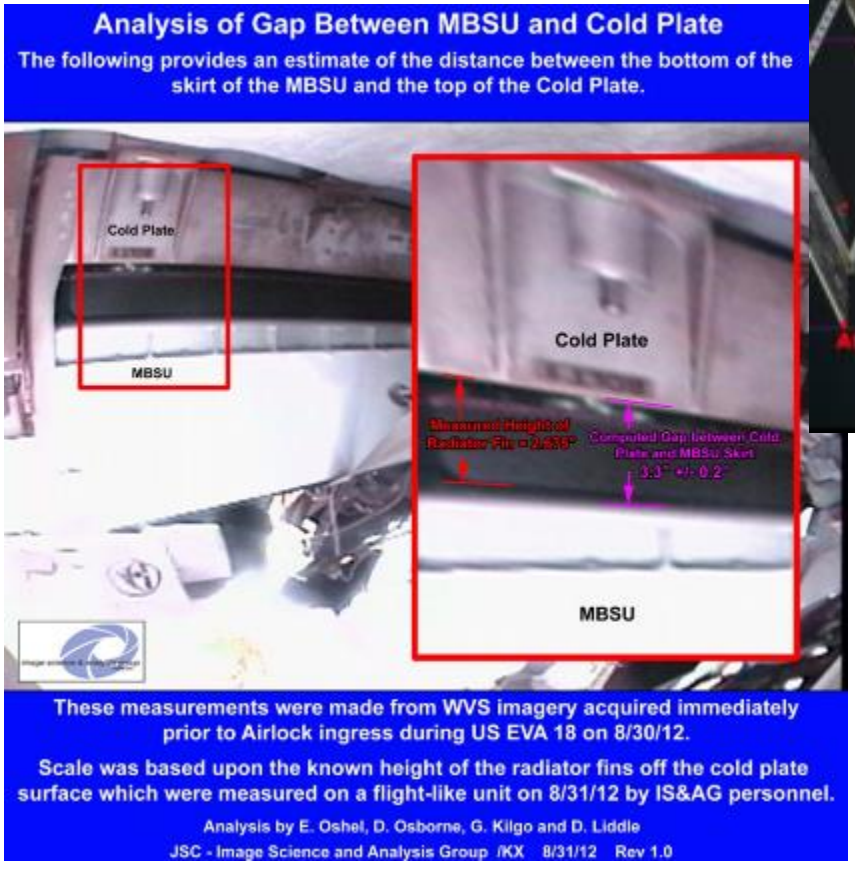


Verifying the ISS Configuration

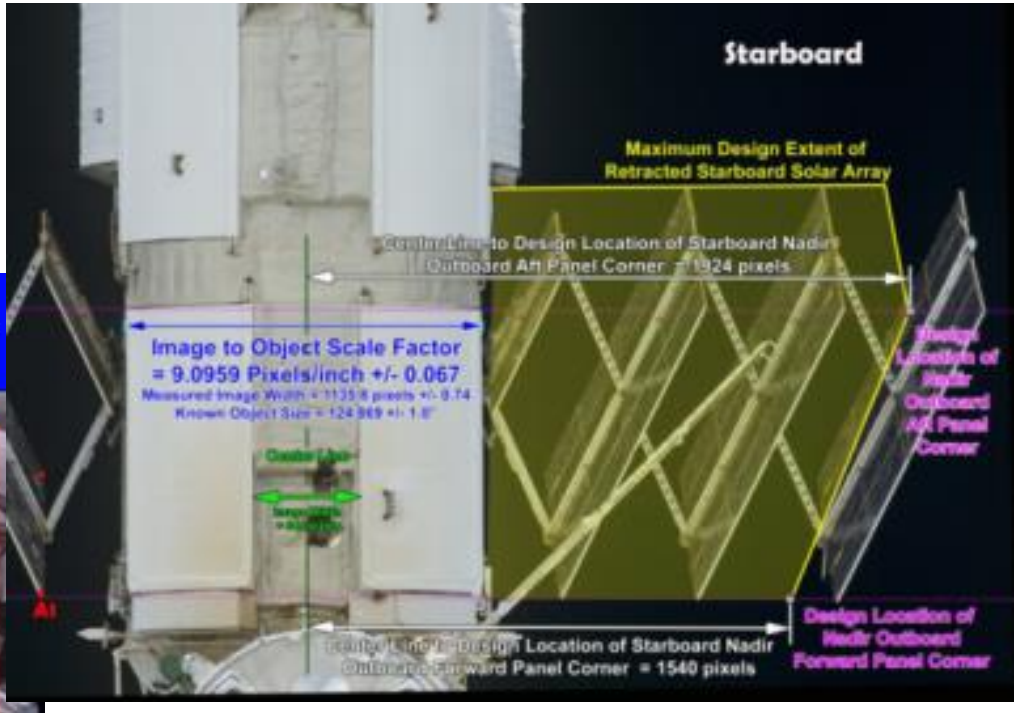


Separated Solar Array Leader Panel

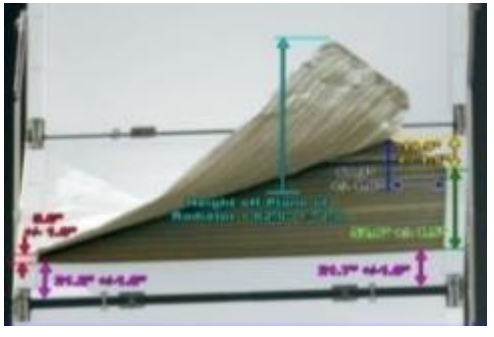
Verifying the ISS Configuration



Installation gap measured from EVA helmet video

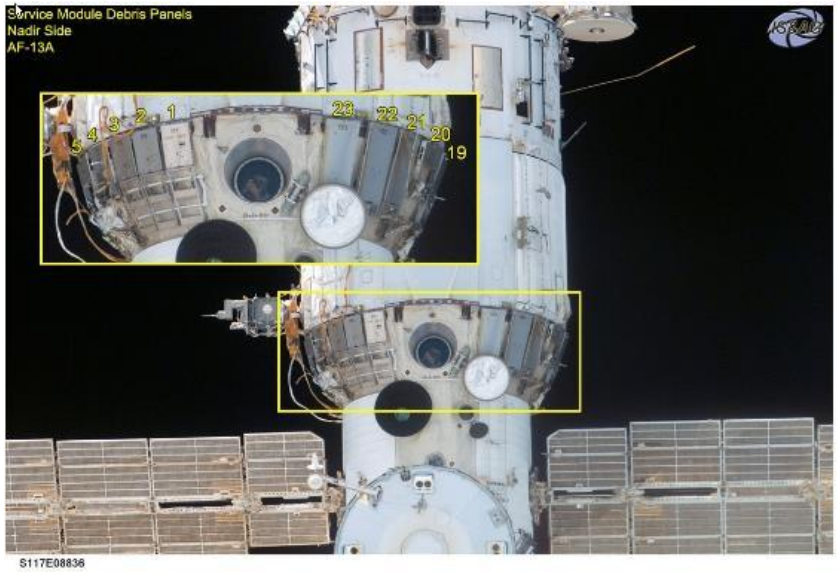


Clearance study found FGB Solar Array was not fully retracted



Periodic Inspection of Damaged Radiator Panel

Visual Documentation



Service Module Debris Panel Installations

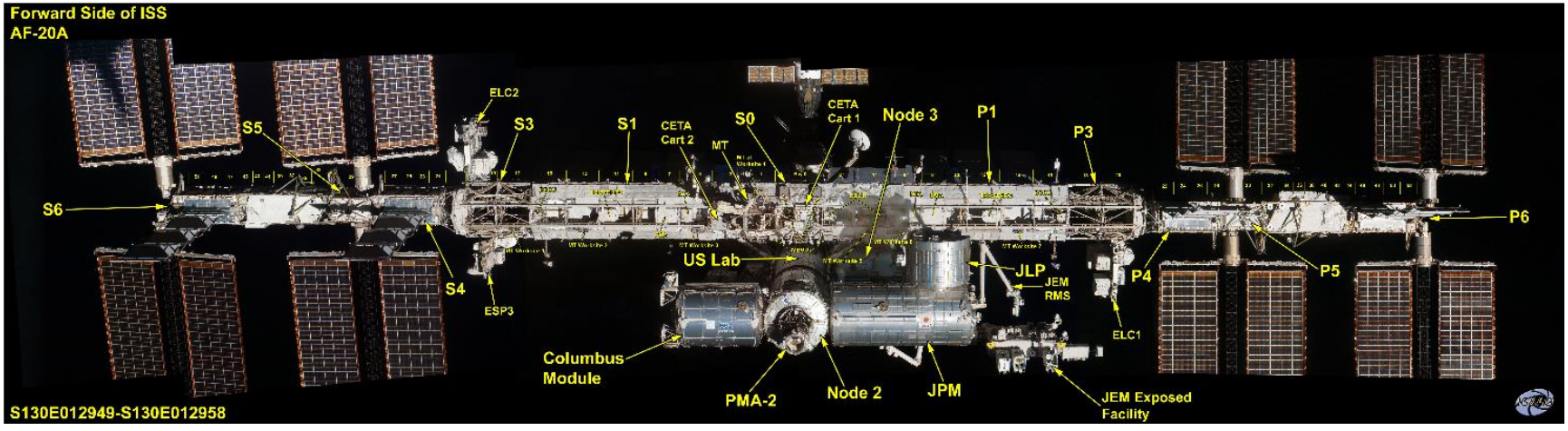
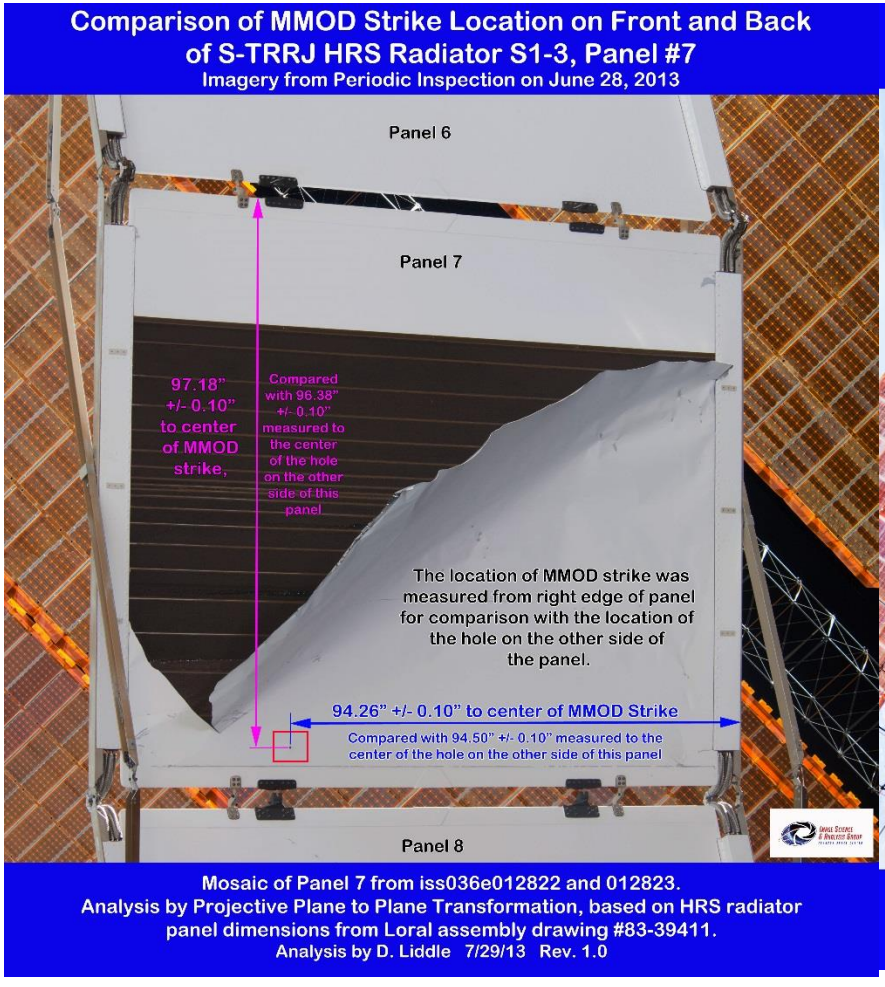
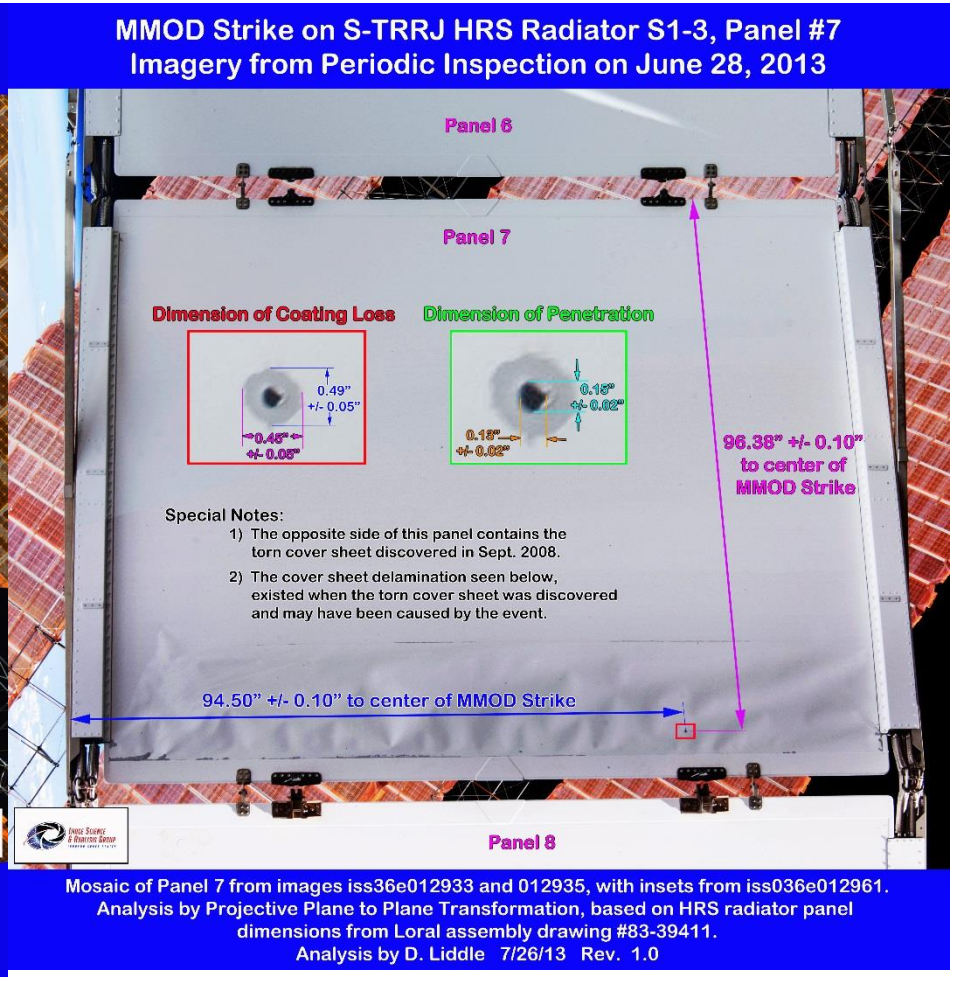


Photo-mosaic constructed from ISS Survey Images

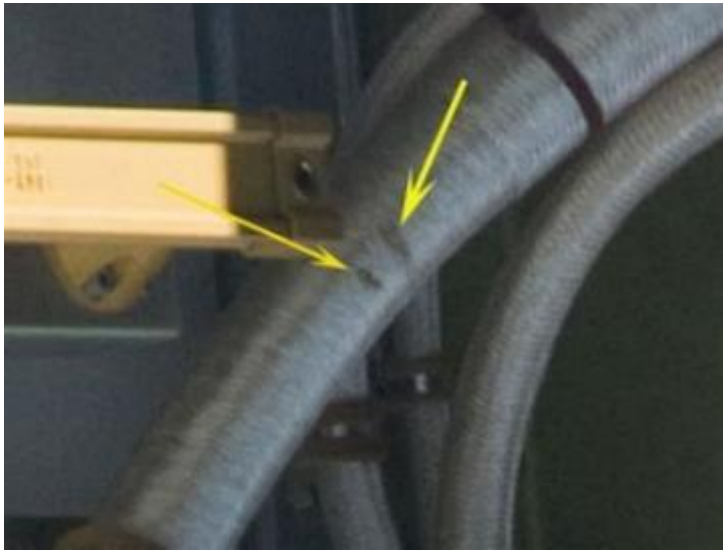
Anomaly Assessment



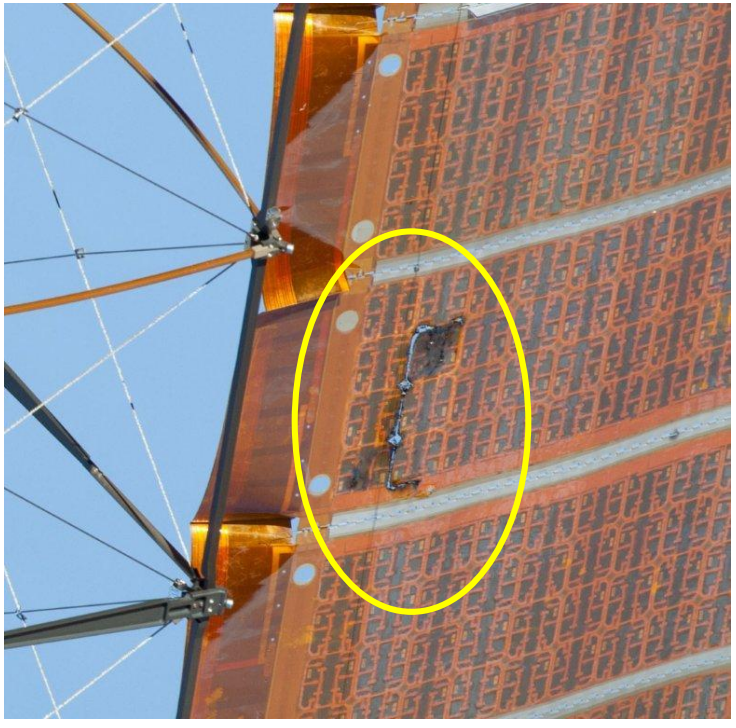


Photogrammetric measurements of thermal radiator panel damage and MMOD strikes

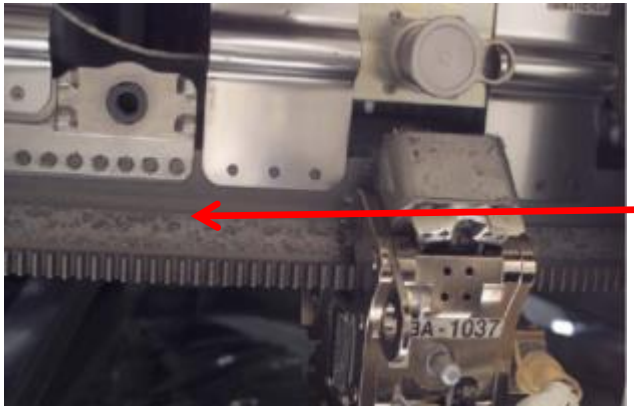
Anomaly Assessment

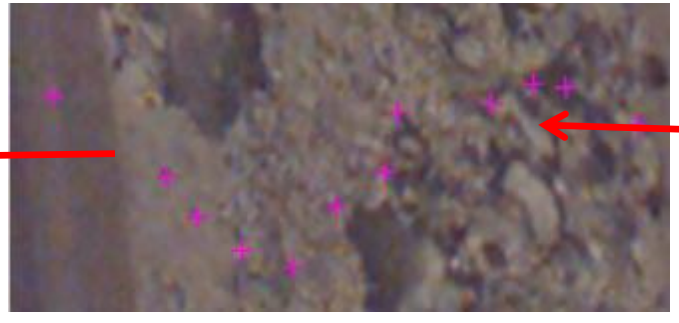


Wire Harness Survey for S4 Electrical Anomaly



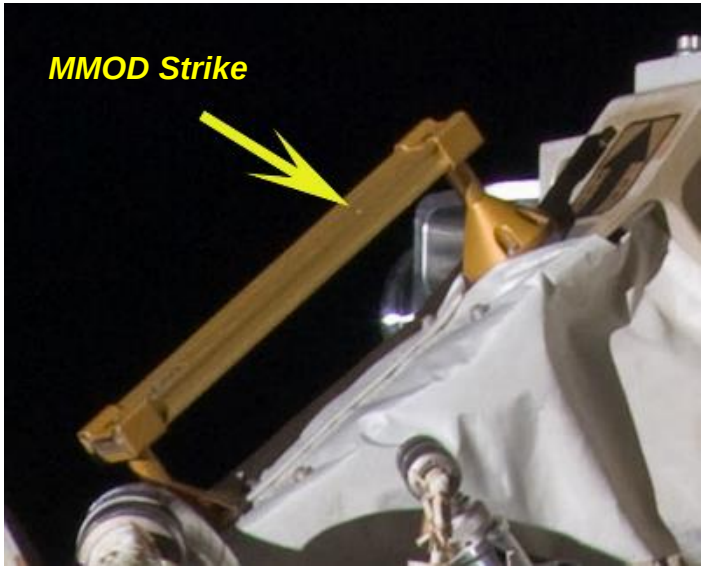
Solar Array Survey for S4 Electrical Anomaly





SARJ Roller Bearing Surface Damage

EVA Sharp Edge Inspection

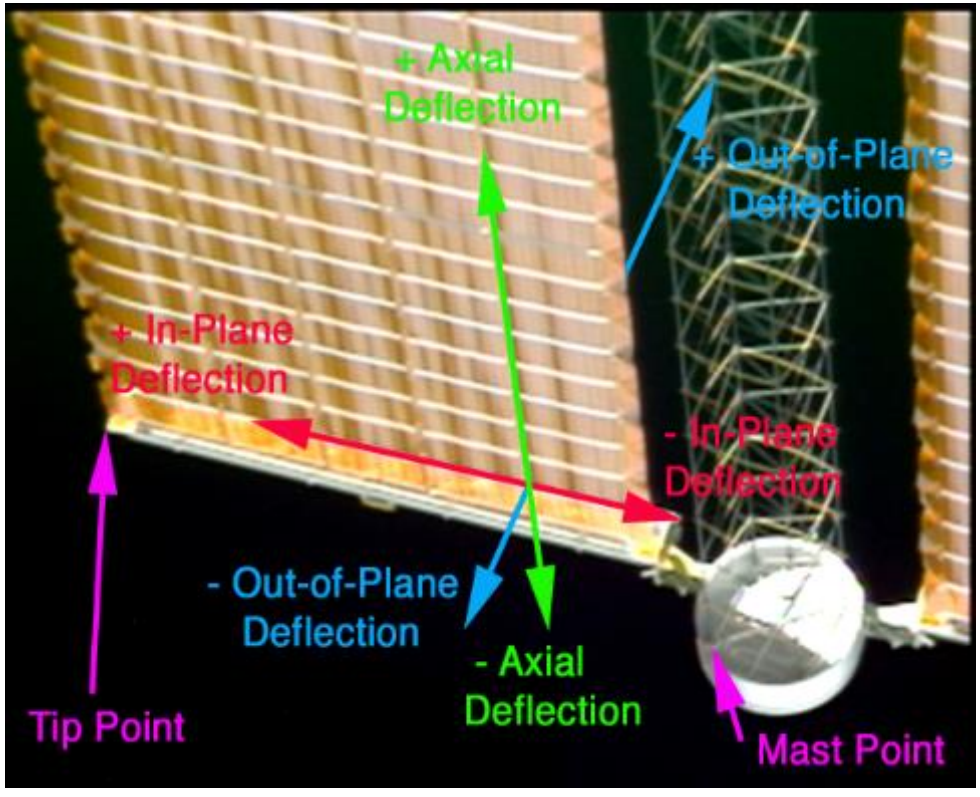


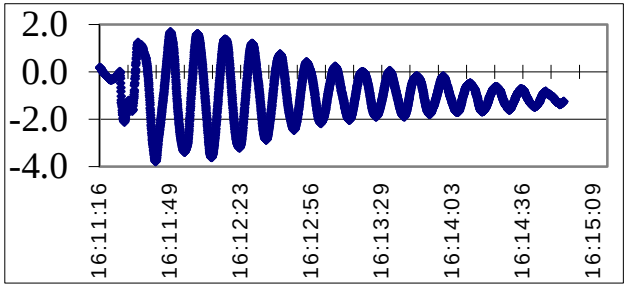
EVA Sharp Edge Tracking

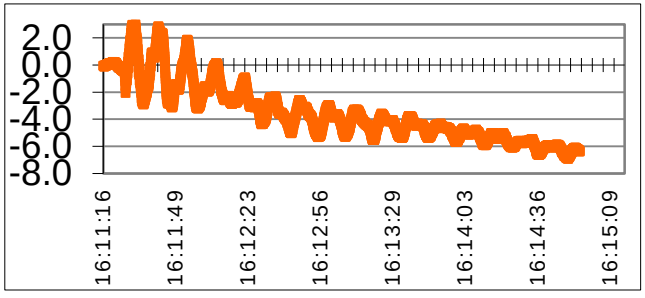
Element	View	Detection Type	SubSystem Owner		
US_Airlock	nadir	Any	Any	Go Filter!	Count: 2

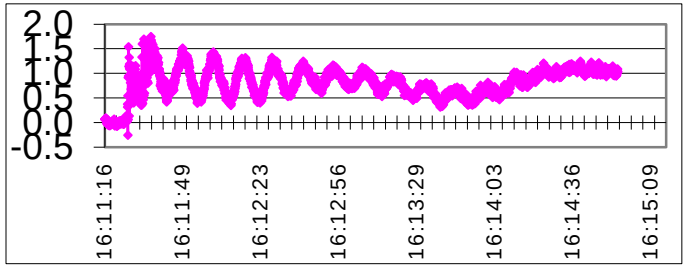
Issue ID, Owner	Mission, Element, View	Title, ISAG Docs	Type, SharpEdge, XPath	IFI #, PRACA #, Docs	Comments	User, Modified Time
79 ATCS	AF-20A/STS-130 US_Airlock Nadir	Possible MMOD Strike on Center Airlock O2 Tank next to Handrail. doc	MMOD Strike No Yes	TBD TBD	sharp edge should be no because of soft goods	rscharf 5/15/2011 12:00:00 PM
88 TBD	AF-1E/STS-122 US_Airlock Nadir	MMOD strike on US Airlock handrail adjacent to hatch doc	Sharp Edge Confirmed Yes	TBD TBD	sharp edge is marked with a wrete, but not repaired or covered.	rscharf 5/15/2011 12:00:00 PM

Verification of Structural Dynamics



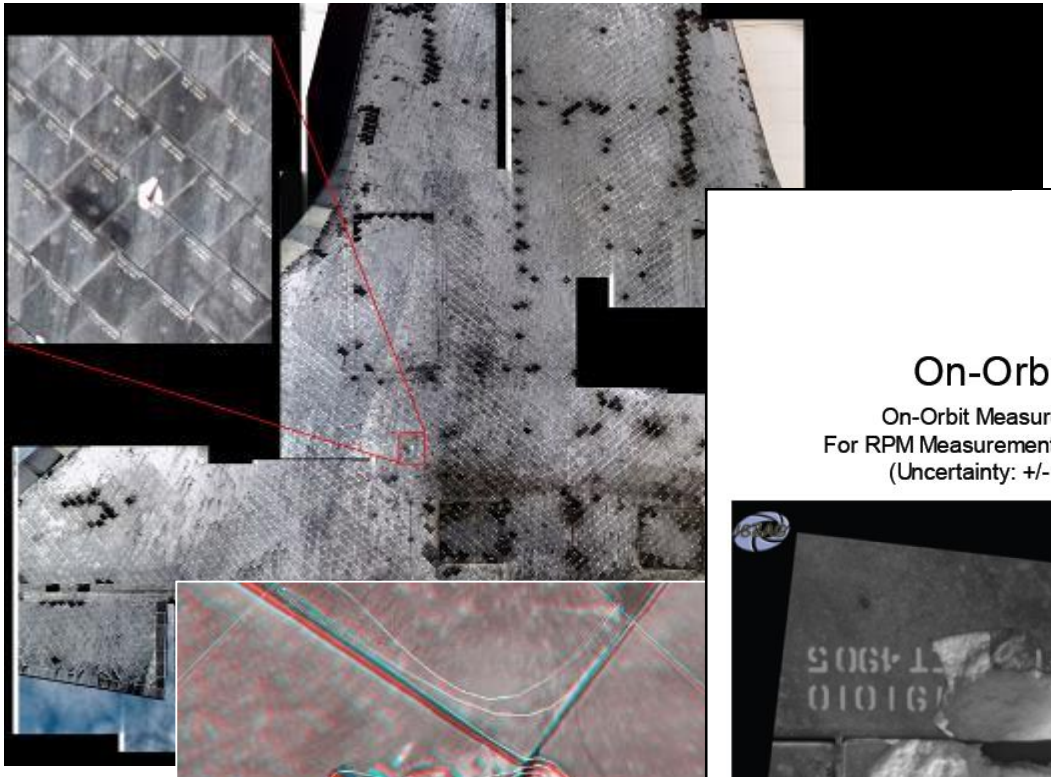


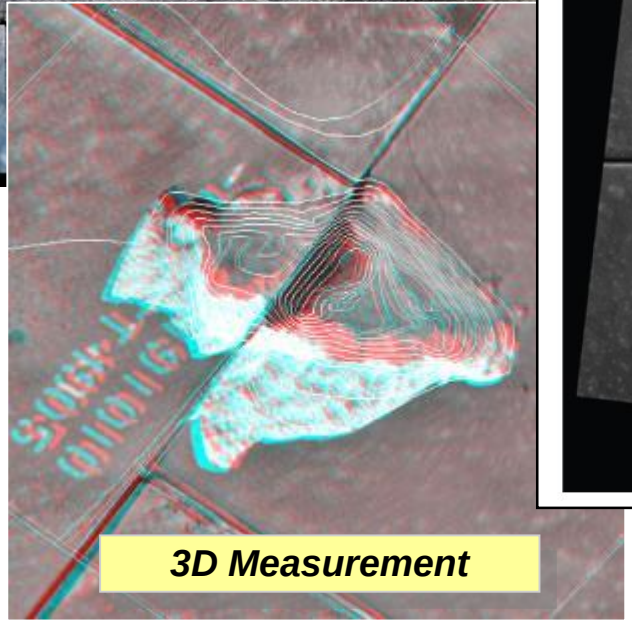




Tracking motion of solar array response to thruster firings

Visiting Vehicle Inspection and Assessment





STS-118 Shuttle TPS Damage

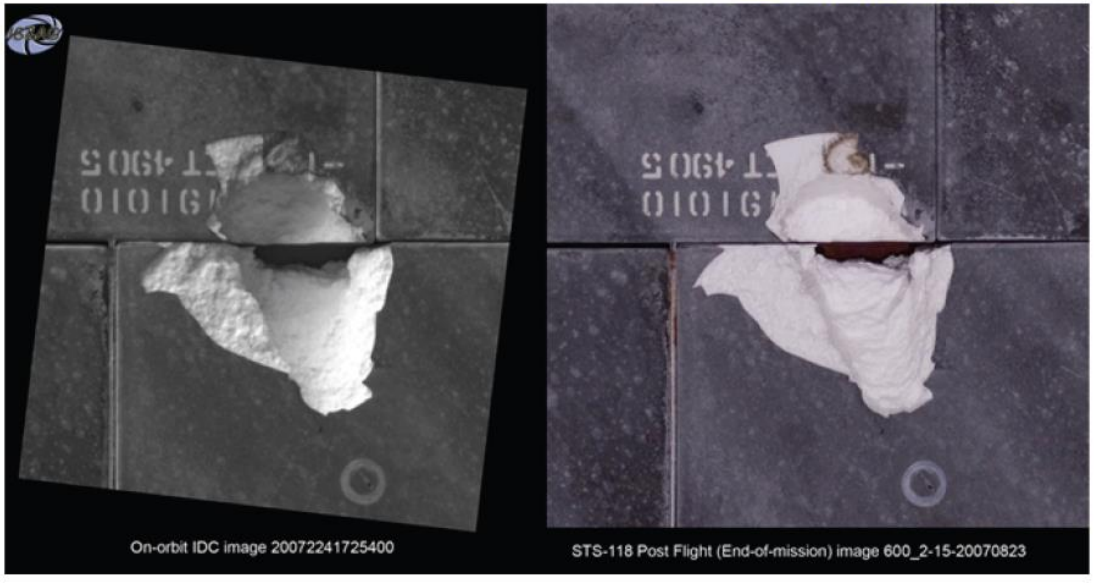
On-Orbit

On-Orbit Measurements:
For RPM Measurements, click here.
(Uncertainty: +/- 0.15")

Post-Flight

Post-Flight Measurement: 3.45" x 2.66" (ISAG)
(Measuring in the same direction as on-orbit,
Length - 3.35", Width - 2.44")

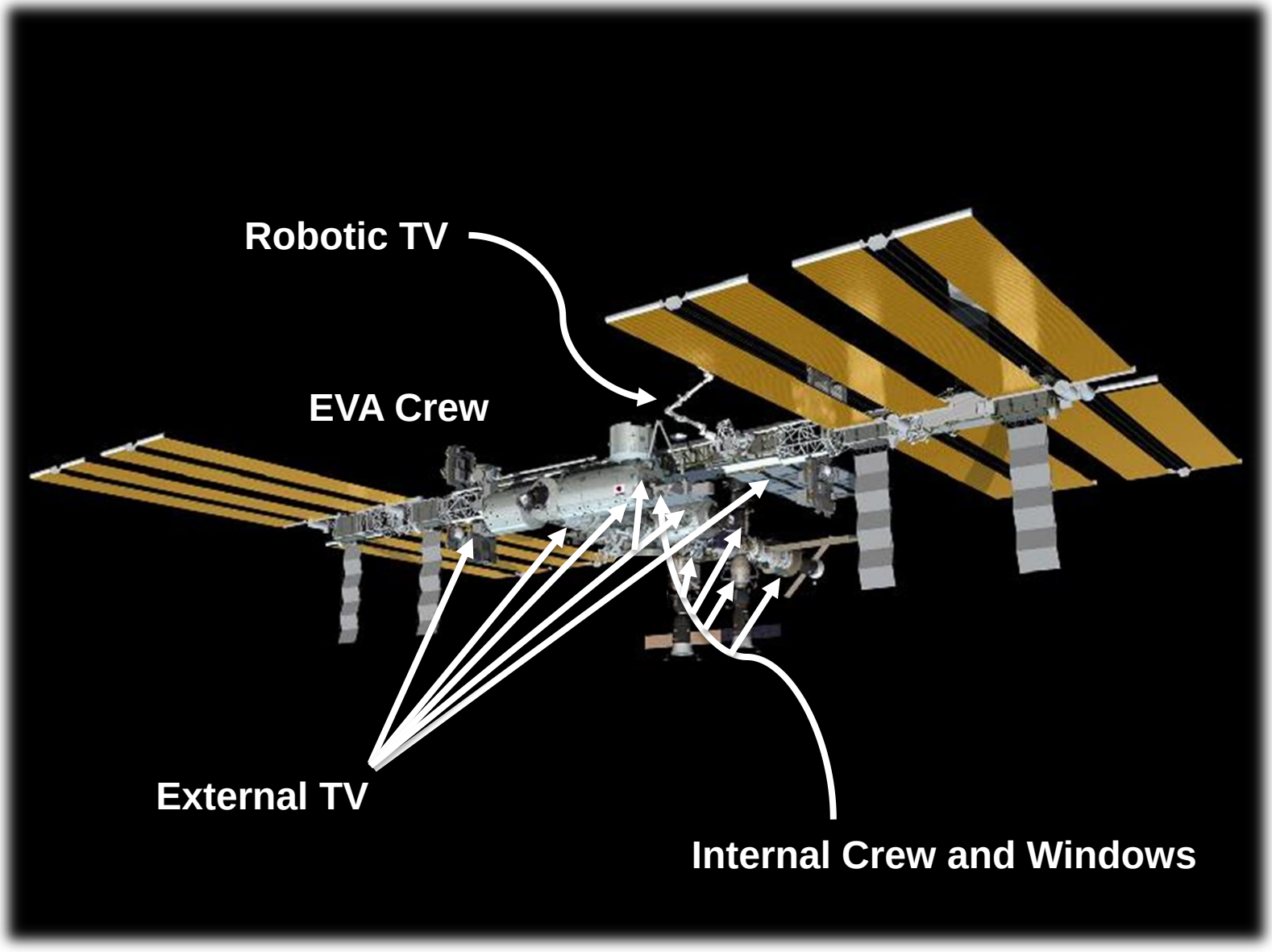
CLICK HERE FOR ORIGINAL IMAGE



Visiting Vehicle Inspection and Assessment

ISS Inspection Assets

ISS Visual Inspection Assets



ISS Camera Assets

- **EXTERNAL**
  - **Mounted to structure**
    - 4 standard definition TV cameras with lights on pan/tilt units
    - 4 standard definition TV cameras on the JEM bulkhead and JEM Exposed Facility
    - *4 high definition video/still cameras in production*
  - **Mounted to robotics**
    - 4 standard definition TV cameras (2 with lights and pan/tilt) on SSRMS
    - 4 standard definition TV cameras (2 with lights and pan/tilt) on SPDM
    - 1 standard definition TV cameras with light and pan/tilt on MBS
    - 3 standard definition TV cameras (2 with pan/tilt) on JAXA JEM EF arm
  - **Crew equipment**
    - 3 standard definition TV cameras with lights (wireless) on helmet
    - Nikon digital SLR with selection of lenses and a flash unit
    - Infrared Camera
- **INTERNAL**
  - **Mounted to structure**
    - Wall mounted video camcorders for MCC situational awareness & public affairs
    - Centerline Berthing camera system
  - **Crew handheld**
    - Selection of Nikon D2XS, D3S and D4 digital SLRs, lenses, and flashes
    - 1 Nikon D3S modified for near-IR
    - Selection of 2D and one 3D Video Camcorders
    - Minicam with fiberscope

External ISS Television Cameras

CP3

Robotics

CP13

CP7
(moving to CP8, latter 2014)

JEM Camera

JEM Camera

CP8

CP9

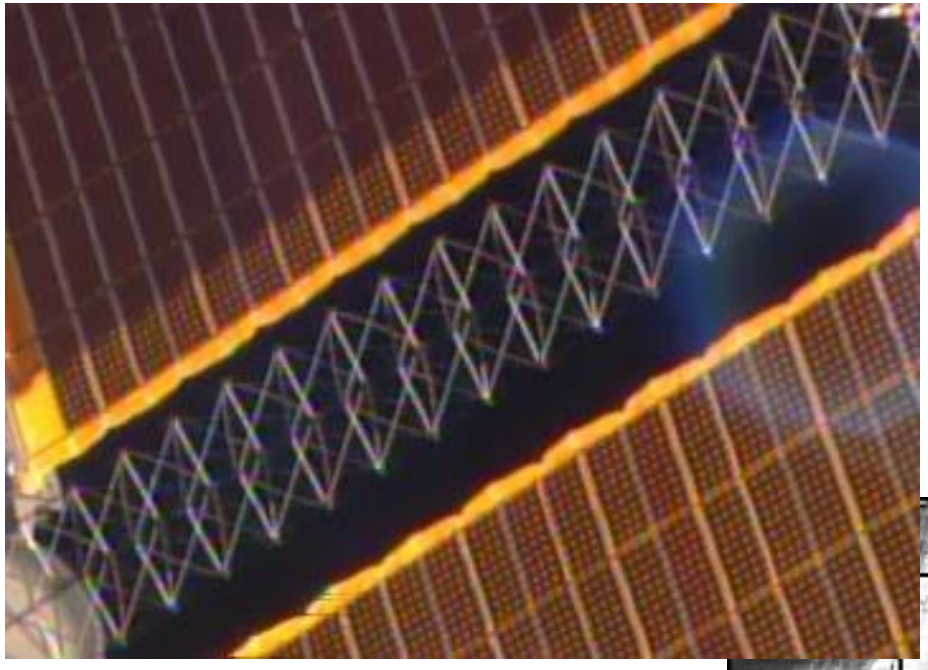
JEF Cameras

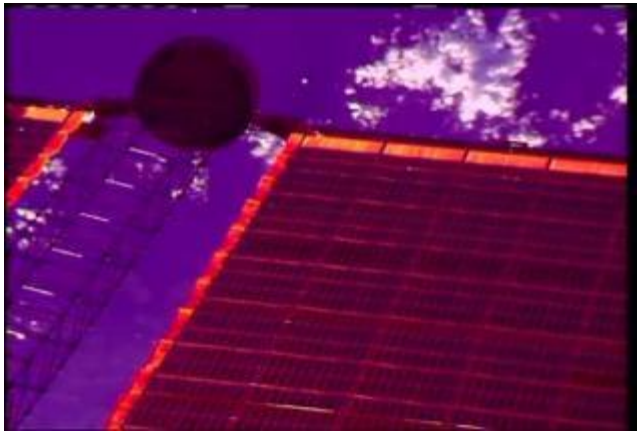
ETVCG – External TV Camera Group (4)
NTSC, 525 horizontal lines (USOS Standard)
CCD sensor
FOV: Max: 77x61 Min: 10x8º
Zoom ratio ~8:1

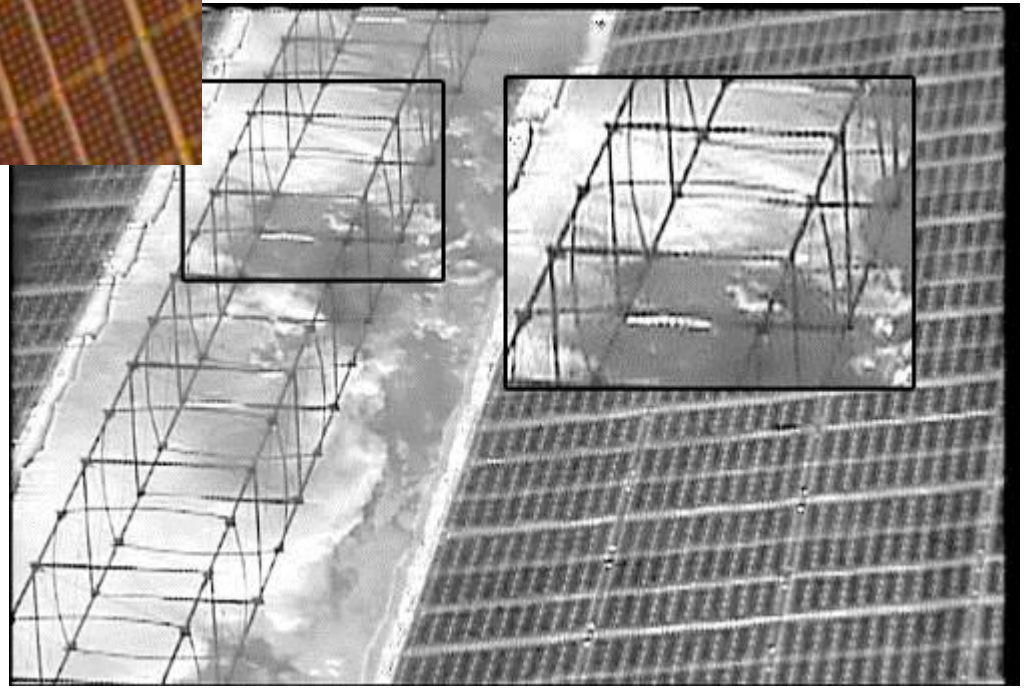
JEM EF – JAXA Experiment Module Exposed Facility
NTSC, CCD

Note: High Definition Video/Still DSLR/zoom lens to be attached to each ETVCG beginning 2015

External ISS Television Cameras
(Structurally Mounted)







ETVCG Inspection Challenges

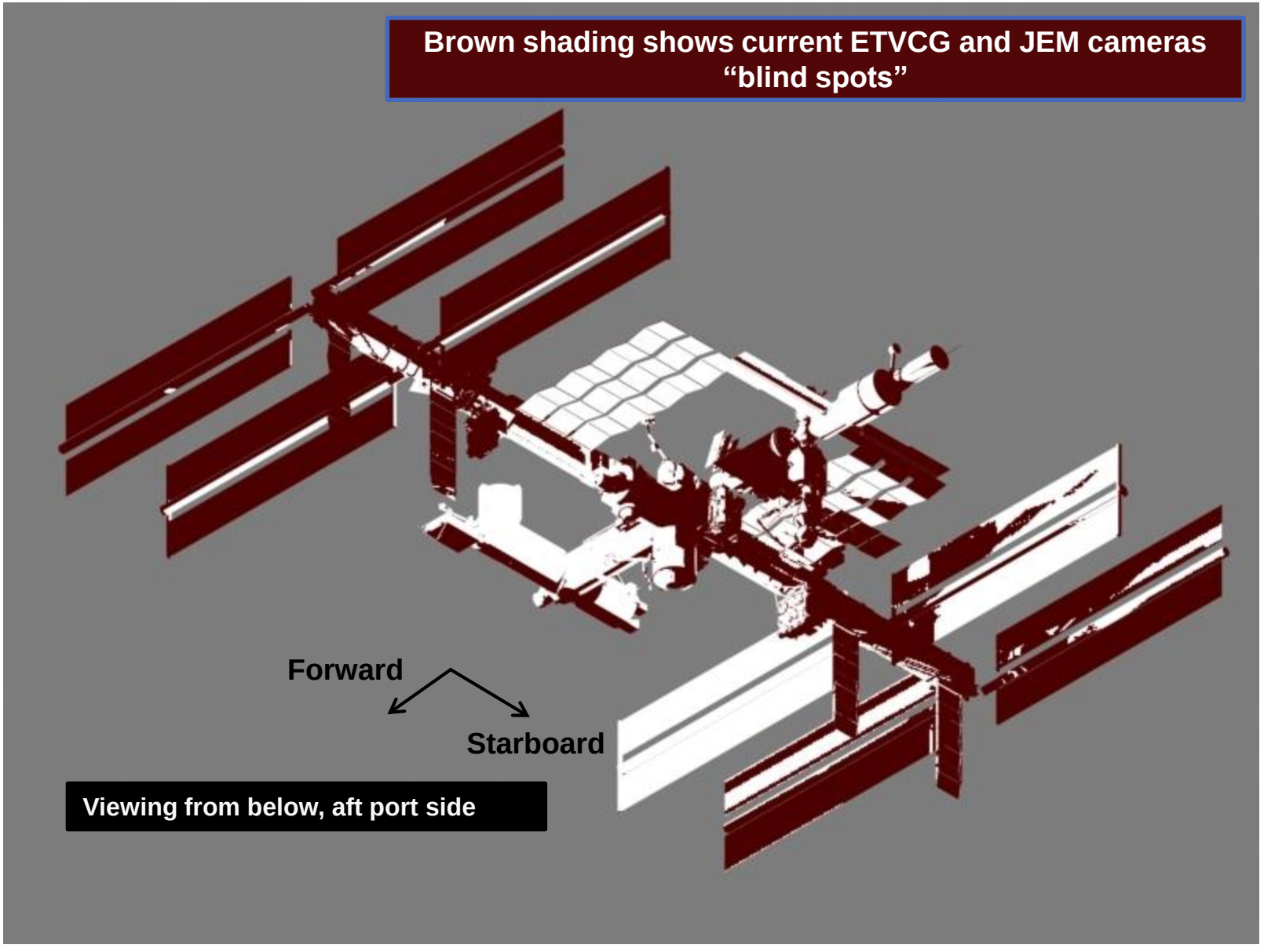
- **Limited camera installation locations, numerous blindspots**

- Resolution limitations – generally not adequate for detailed inspections
  - Standard definition TV
  - Compression of the video for downlink
  - Distance and high incidence viewing
  - *External high definition cameras planned for 2015 should dramatically improve capability*

- Hardware failure and degradation reduces capability
  - Three of four ETVCG cameras currently have issues (pink tint, intermittent stuck zoom and intermittent stuck iris)
  - Limited spares and opportunities to replace

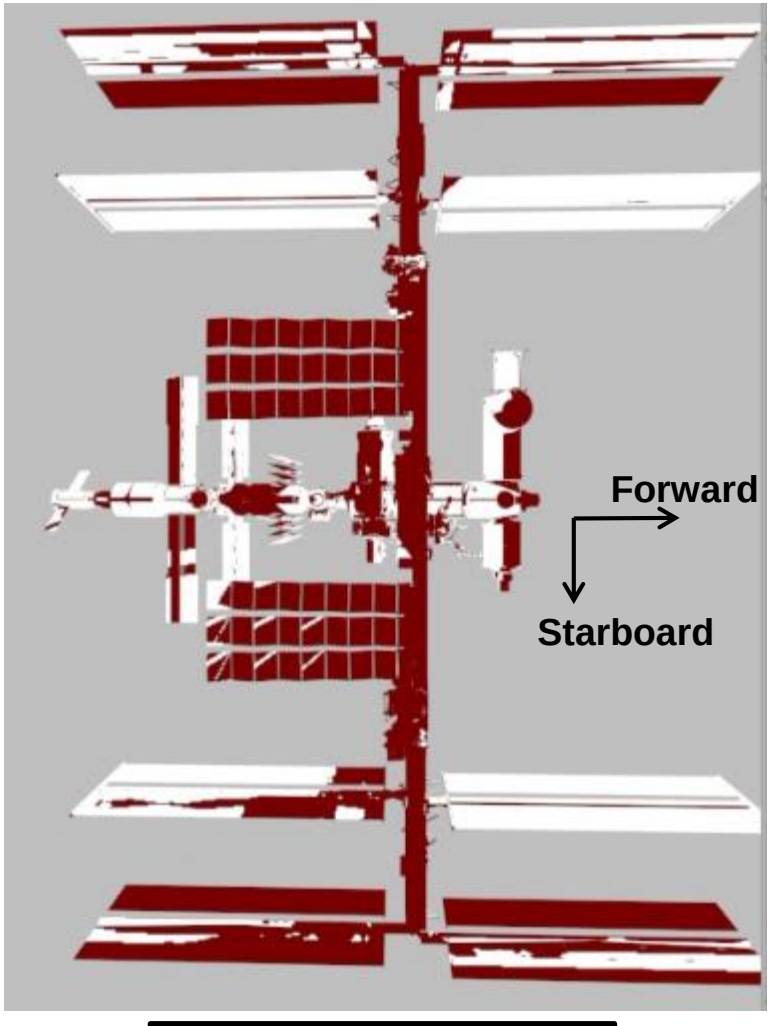
- JEM cameras are not readily available
  - Camera operational time is minimized to conserve life
  - Pan and tilt via uplinked command script

External TV Camera Coverage (ETVCGs (4) + JEM (4))

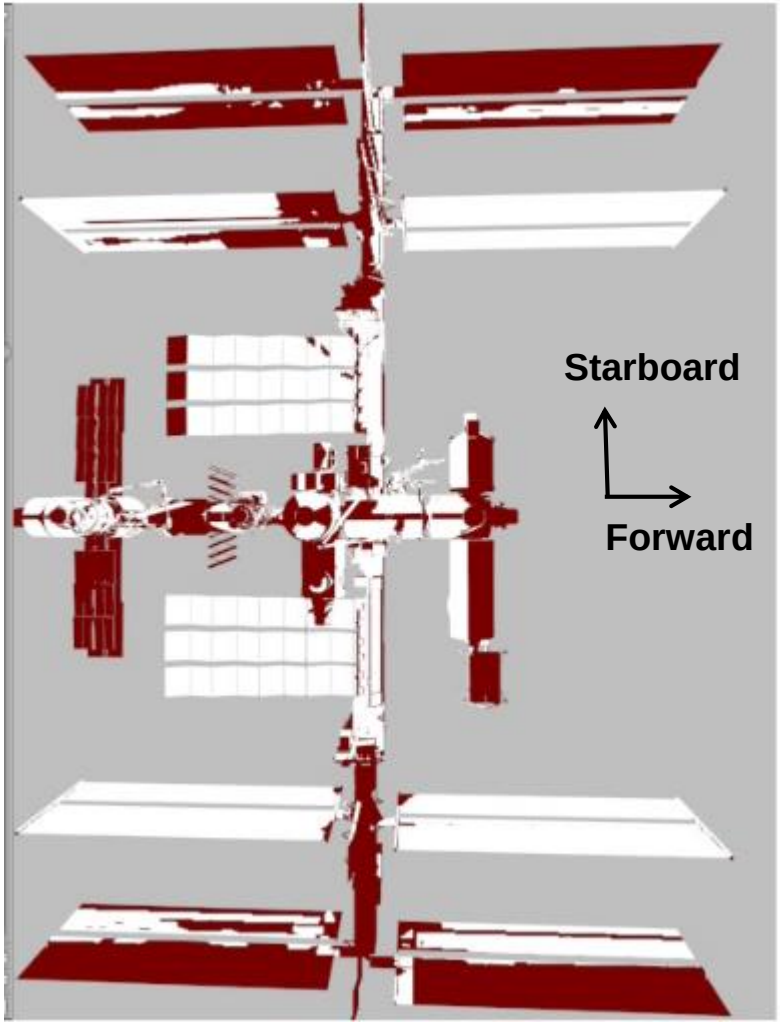


External TV Camera Coverage (ETVCGs (4) + JEM (4))

Brown shading shows current ETVCG and JEM cameras "blind spots"



Viewing from above



Viewing from below

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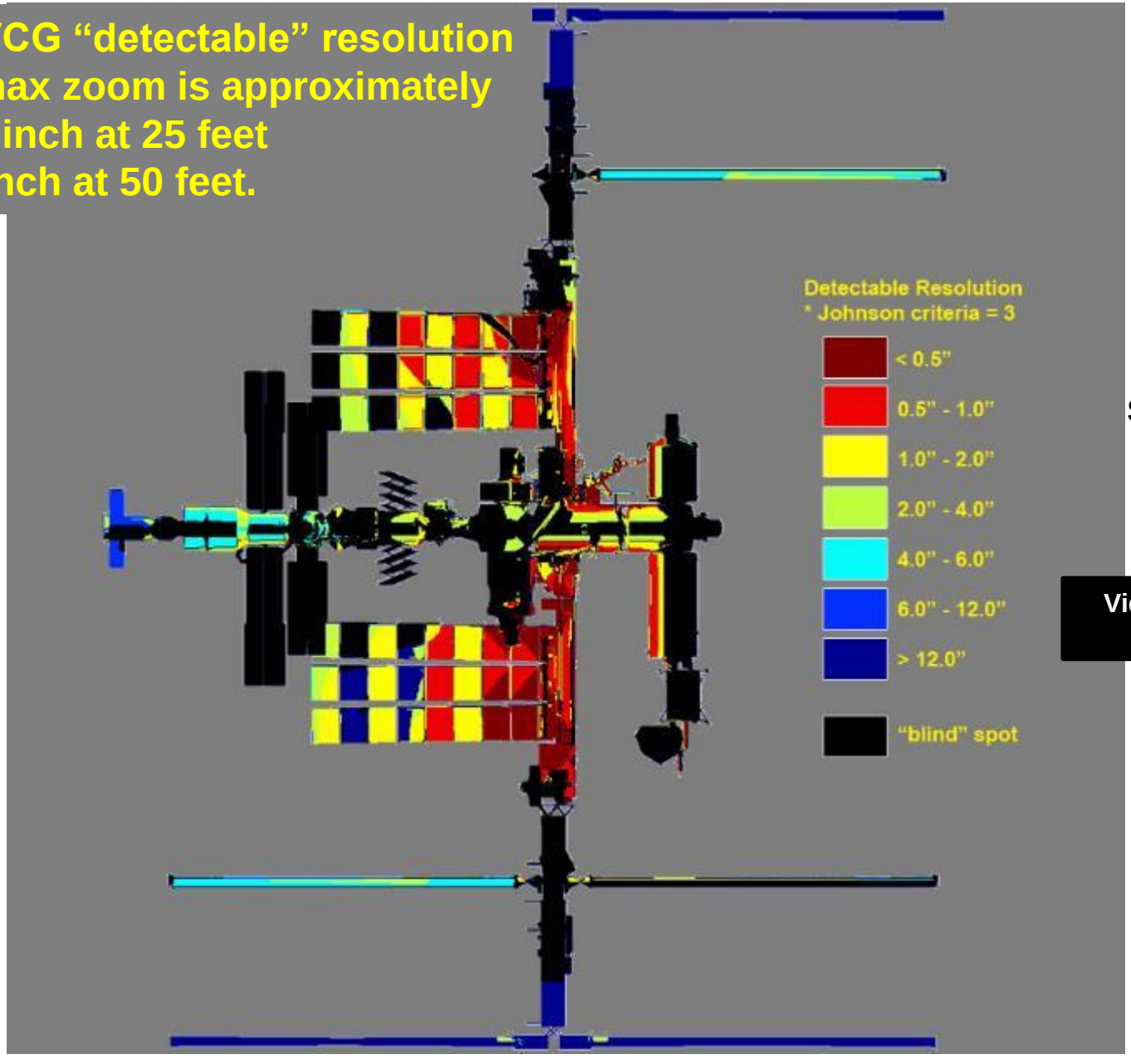
External TV Cameras Resolution Analysis
All ETVCGs Combined (4)

ETVCG "detectable" resolution at max zoom is approximately
.25 inch at 25 feet
.5 inch at 50 feet.



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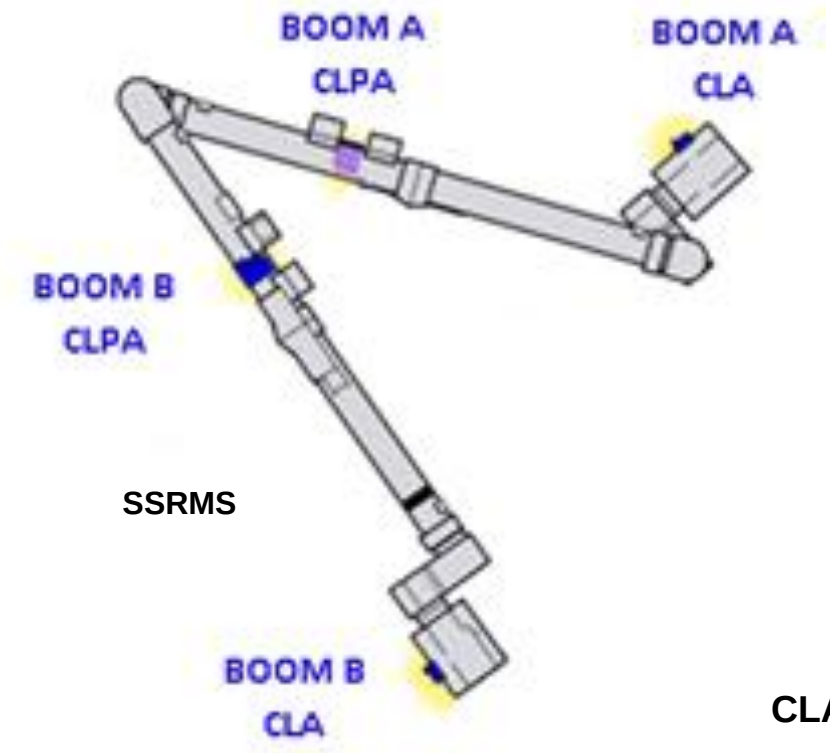
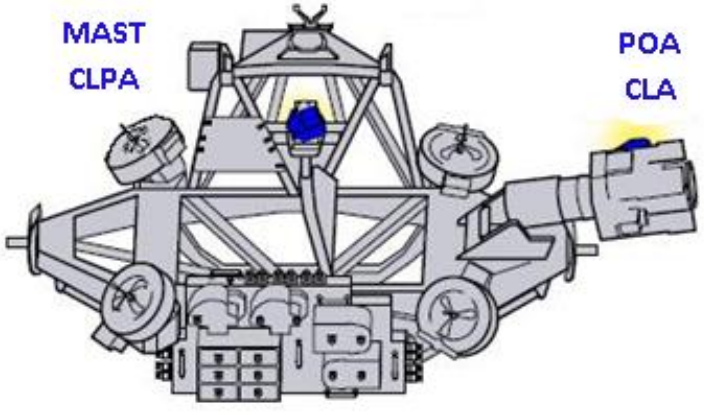
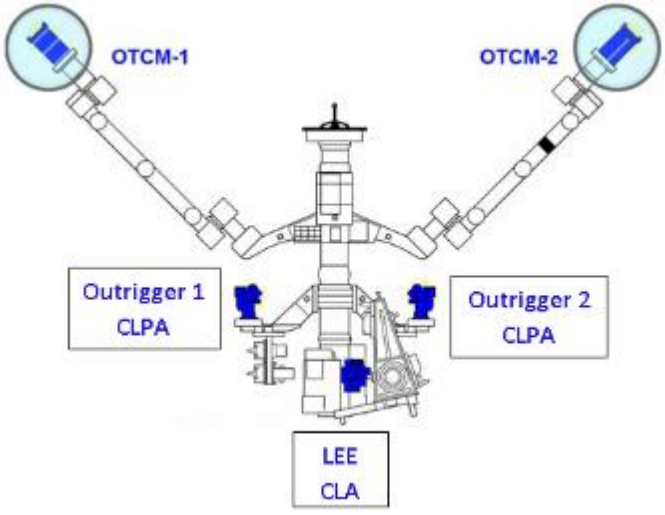
External Television Cameras
(Mobile Servicing System)



SSRMS



Mobile Base System



Special Purpose Dexterous Manipulator (SPDM)/DEXTRE

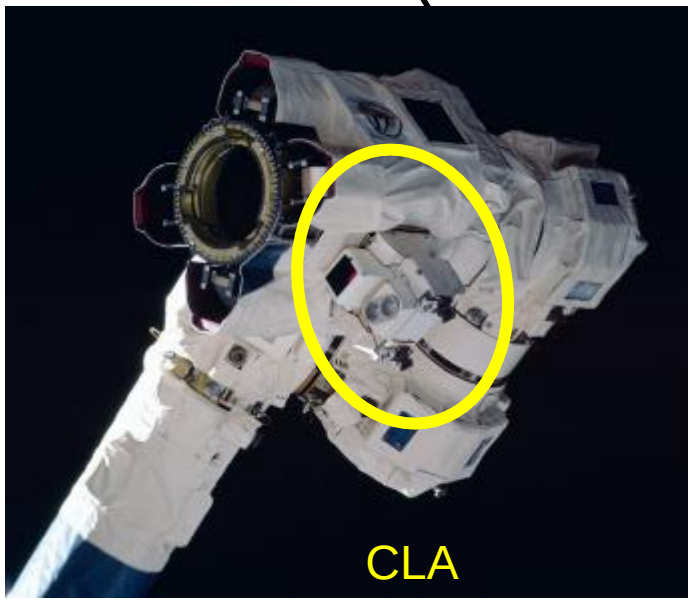
CLA - Camera and Light Assembly (CLA)

CLPA - Camera / Light / Pan-Tilt Unit Assembly

SSRMS moves along truss when attached to Mobile Transport/Mobile Base System (MT/MBS).

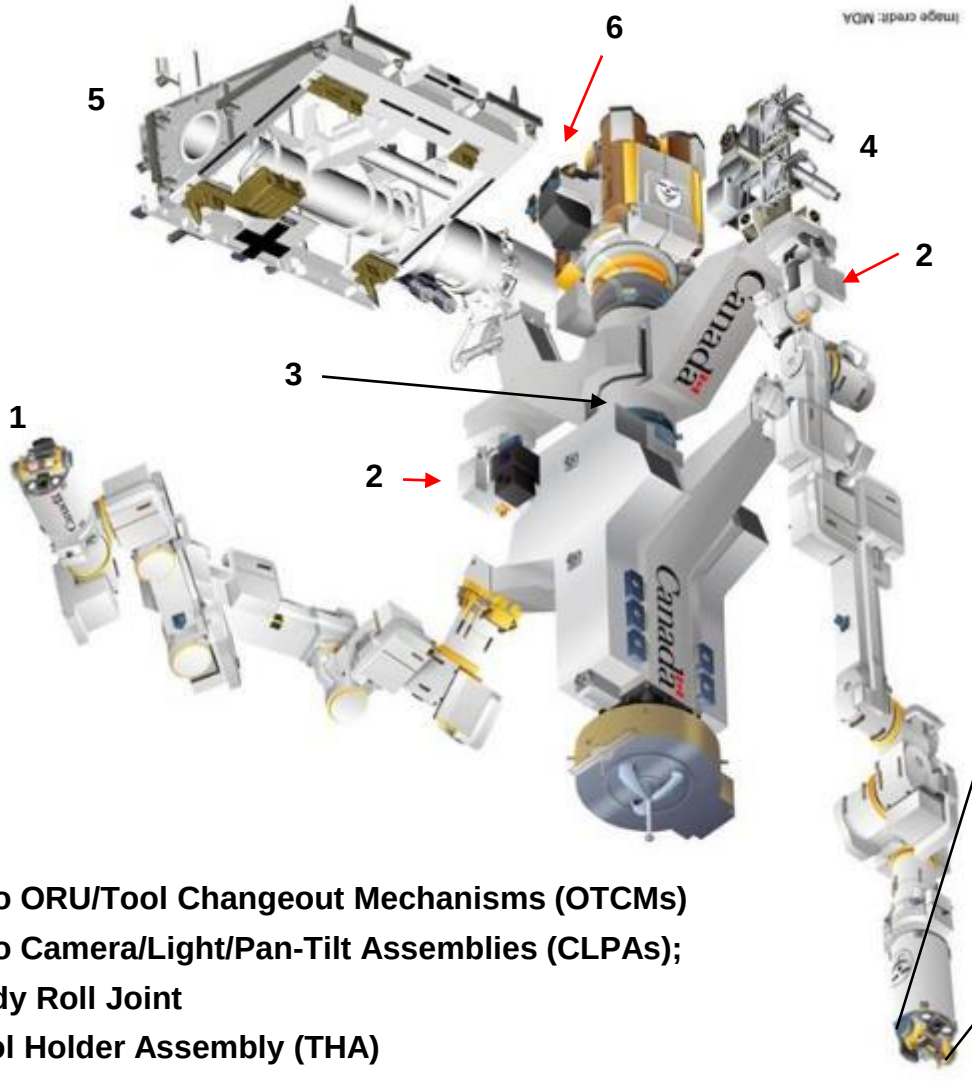
SSRMS is operational along truss at MT Worksites and Power and Data Grapple Fixtures (PDGF) located on USOS modules and Russian FGB.

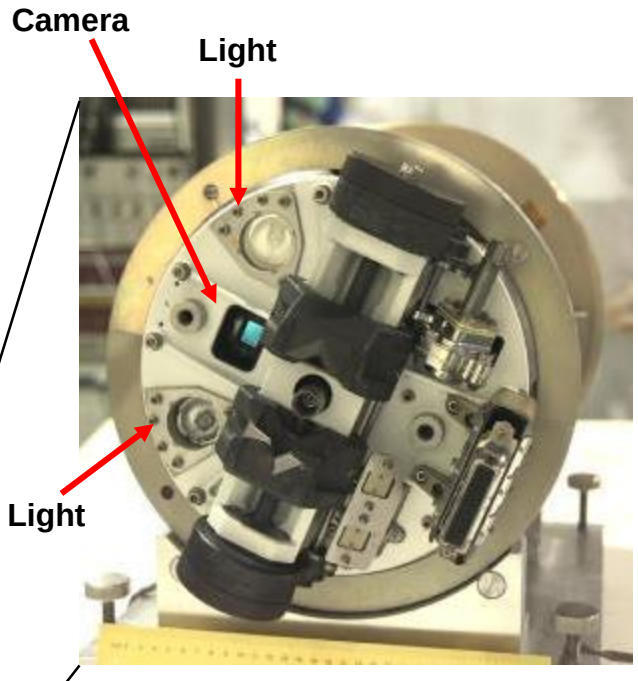
External Television Cameras
(Mobile Servicing System)



- **Both CLA and CLPA utilize the same CCD camera and lights**
- **FOV Max ~ 52° x 40°, ~9mm focal length,**
  Min ~ 6°x4° , ~84mm focal length
- **Zoom ratio ~9:1**
- **The minimum viewing distance is 14 in.**
- **MSS camera "detectable" resolution at max zoom is approximately**
  - **~.2 inch at 25 feet**
  - **~.4 inch at 50 feet.**
- **Standard ETVCG and MSS frame rate: 30 fps**

SPDM (DEXTRE) Overview



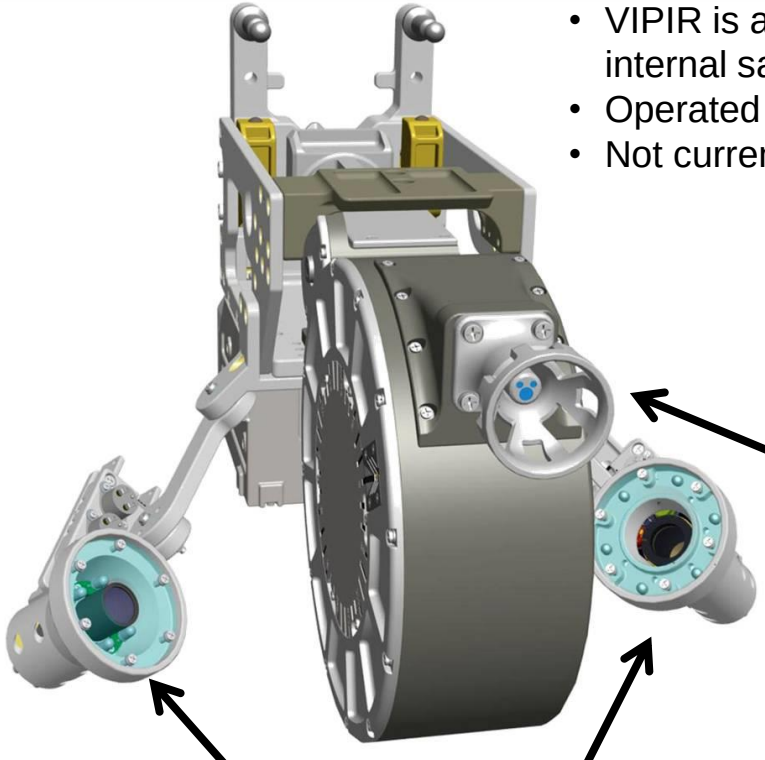


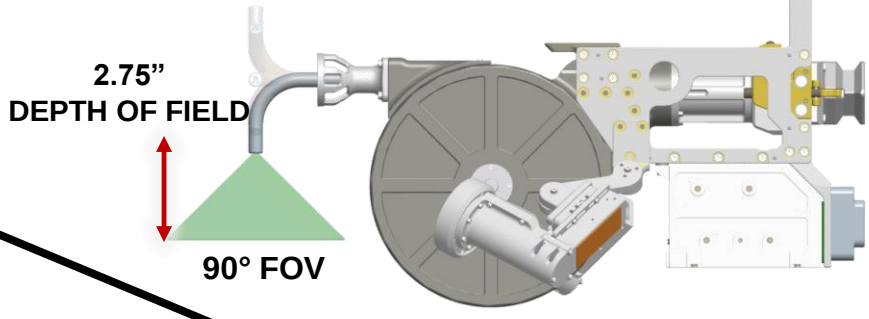
OTCM

1. Two ORU/Tool Changeout Mechanisms (OTCMs)
2. Two Camera/Light/Pan-Tilt Assemblies (CLPAs);
3. Body Roll Joint
4. Tool Holder Assembly (THA)
    a) 2 Robot Micro Conical Tools (RMCTs)
    b) Socket Extension Tool (SET)
    c) Robotic Offset Tool (ROST)
5. Enhanced ORU Temporary Platform (EOTP)
6. SPDM Latching End Effector (LEE) with Camera/Light Assembly (CLA)

Visual Inspection Poseable Invertebrate Robot (VIPIR)

- Manifested on ATV-5 for the Robotic Refueling Mission demonstration.
- VIPIR is a "boroscope" inspection tool that provides a set of eyes for internal satellite repair jobs.
- Operated through SPDM (DEXTRE)
- Not currently planned for permanent stowage on ISS.





Video Borescope Assembly (VBA)

- **Miniaturized Close-range Inspection Camera and light**
- **NTSC Color Video (224 x224 pixels)**
- **0.93” diameter tube**
- **36” maximum deployment - straight line**
- **Tip manipulation only**
- **Tip Control, limited monitoring from ground**
- **Limited to one camera view at a time through SPDM**

Primary and Secondary Tool Vision Cameras

- **NTSC, Color, VGA (640 x 480)**
- **Fixed 6mm and 8-24mm zoom focal lengths**
- **Full view of Reel Position visual indicators**

Robotics Inspection Challenges

- **Robotic Operations are generally complex and require extensive planning.**

- **After planning joint angles/operations and then moving the manipulator to the inspection location, the viewing and resolution still might not be sufficient.**

- **Future inspection systems could plan to launch internally, but then go external, however the only robotic option is to go through the JEM Airlock**
  - **JEM Airlock usage is limited to a certain number of cycles per year**
  - **JEM Airlock usage requires use of limited IVA crew time**

EVA Crew Cameras

Wireless Video System

- Three SONY XC-999 cameras
- HFOV = 85°, 56° and 30°
- Fixed depth of focus 12 inches to 25 feet.
- Detectable resolution .25-.5 inch at 10 feet.

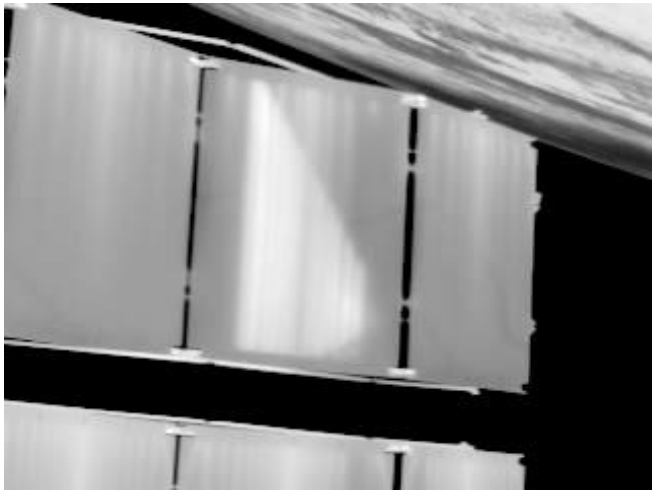
Digital SLR

- Nikon D2XS and soon, D4
- Lens focal lengths 10.5-180mm

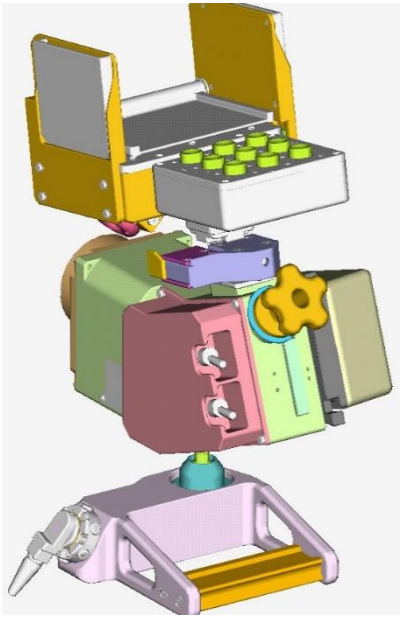
External/Internal IR Camera

Repackaged FLIR Systems ThermaCAM S60 Infrared Camera

Used for inspections of:
- **Electrical components**
- **Radiators**
- **Solar Arrays**
- **Heaters**



Infrared View of Damaged Thermal Radiator (back-side surface)



Internal Crew Cameras

- **Handheld still cameras provide the highest imaging resolution of any of the existing ISS imaging assets.**

- **Nikon D2XS, D3S and D4 Digital Still Cameras**
- **Lenses ranging from 8mm to 1200mm**
- **One Nikon D3s modified for near IR photography/video**

High Definition Video

Canon XF305 – mounted and handheld.

Panasonic 3DA1 – 3D video capability

Internal Crew Cameras

Drift Ghost S Action Camera used for:

- **Obtaining HD video in tight spaces**
- **Over the shoulder views for ground situational awareness.**

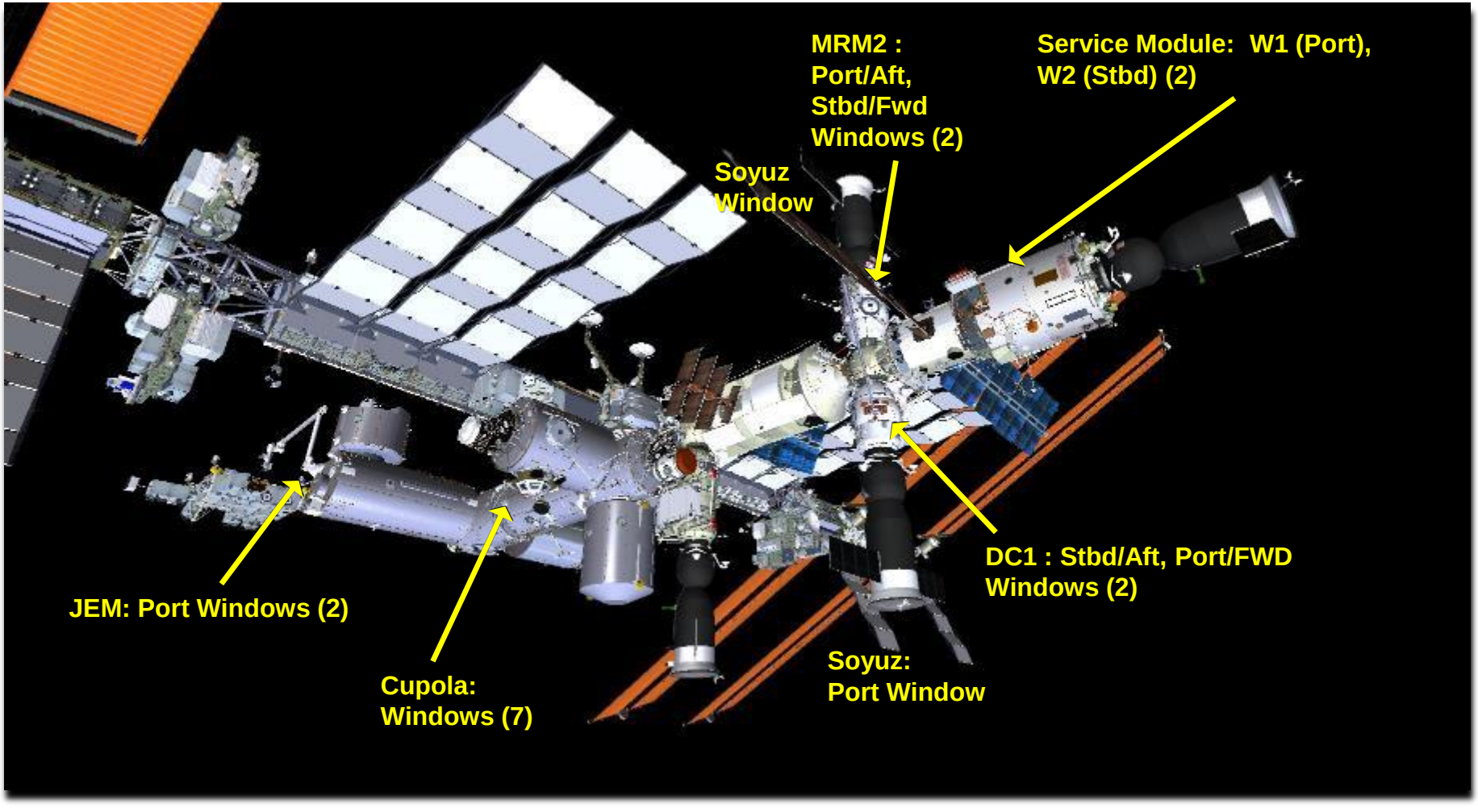
Sony XC-999 Mini-cam

Video camera with fiberscope

Binoculars

- **8x32**
- **20x60**

Windows for External Surface Inspection

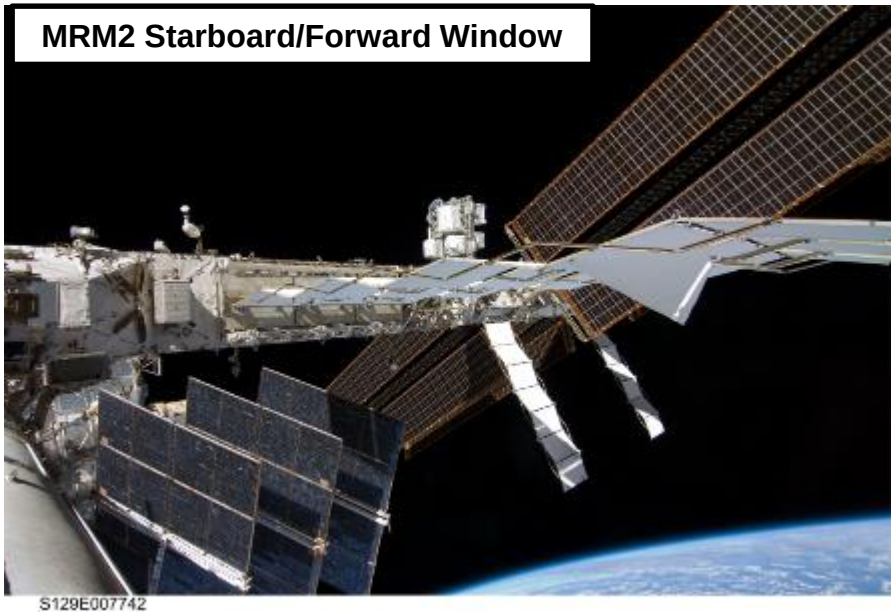


Russian segment and Cupola windows provide coverage of truss aft surfaces and JEM windows provide coverage of port, forward truss surfaces not visible in ETVCG blind spots.

Not all windows are referenced

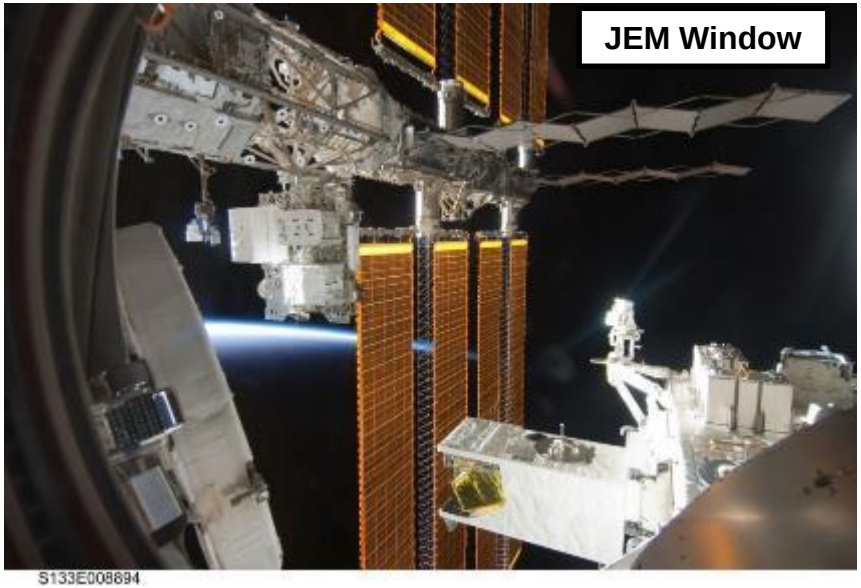
Example Views from ISS Windows

MRM2 Starboard/Forward Window



S129E007742

JEM Window



S133E008894

MRM2 Port/Aft Window

Cupola Windows

Crew External Inspection Challenges

- **Limited windows, numerous blindspots**
  - **Distance and high incidence viewing**

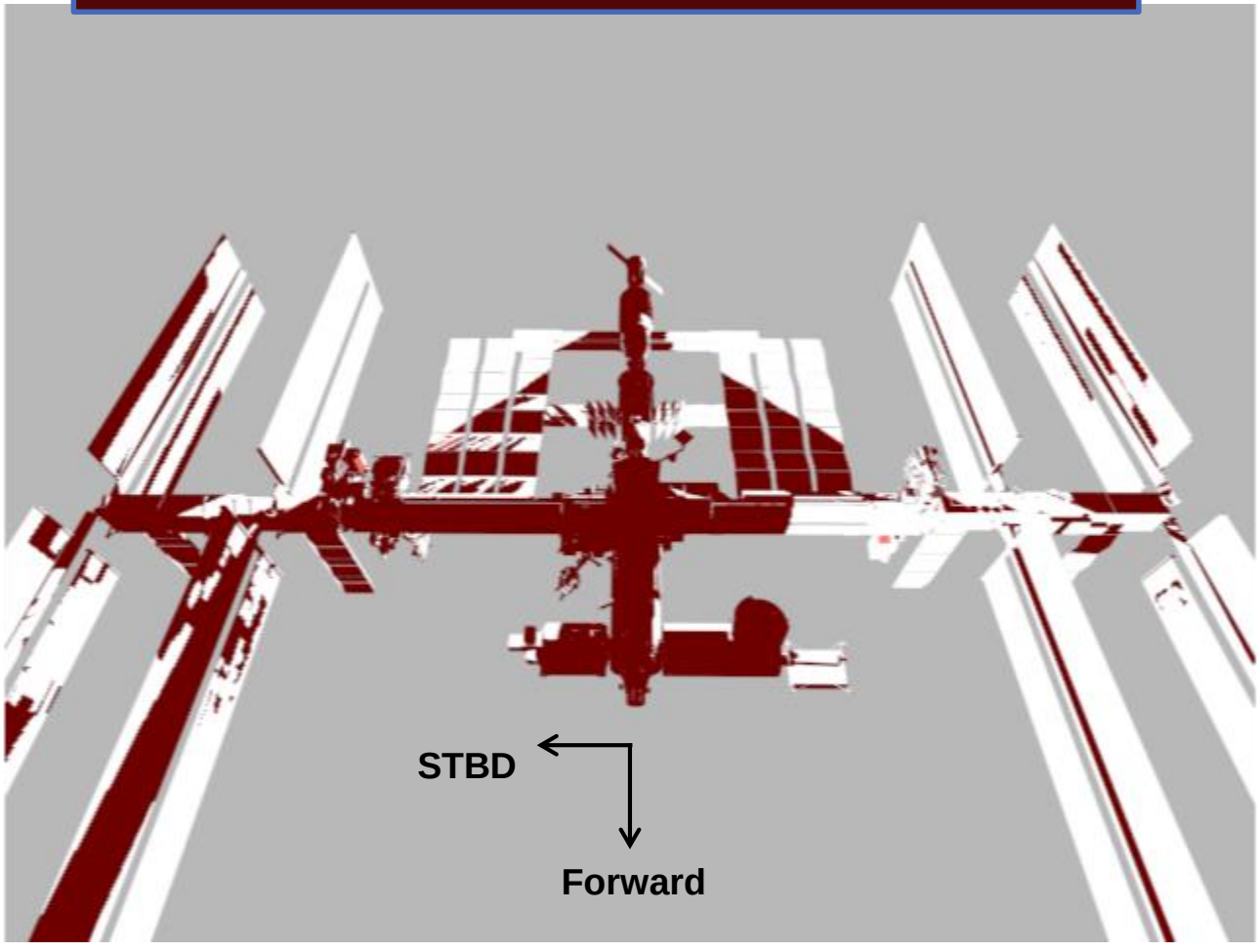
- **Protective plastic scratch panes installed over Cupola and JEM windows reduce image resolution but need justification for removal and the removal and reinstallation process is time consuming (Cupola ~4 hours).**

- **Limited crew time for imagery acquisition support (IVA and EVA)**

- **EVA – no time for dedicated surveys**
  - **Lens usually selected for large field of view**

ISS Window View Coverage

Brown shading shows window "blind spots"



Viewing from above

ISS Window View Coverage

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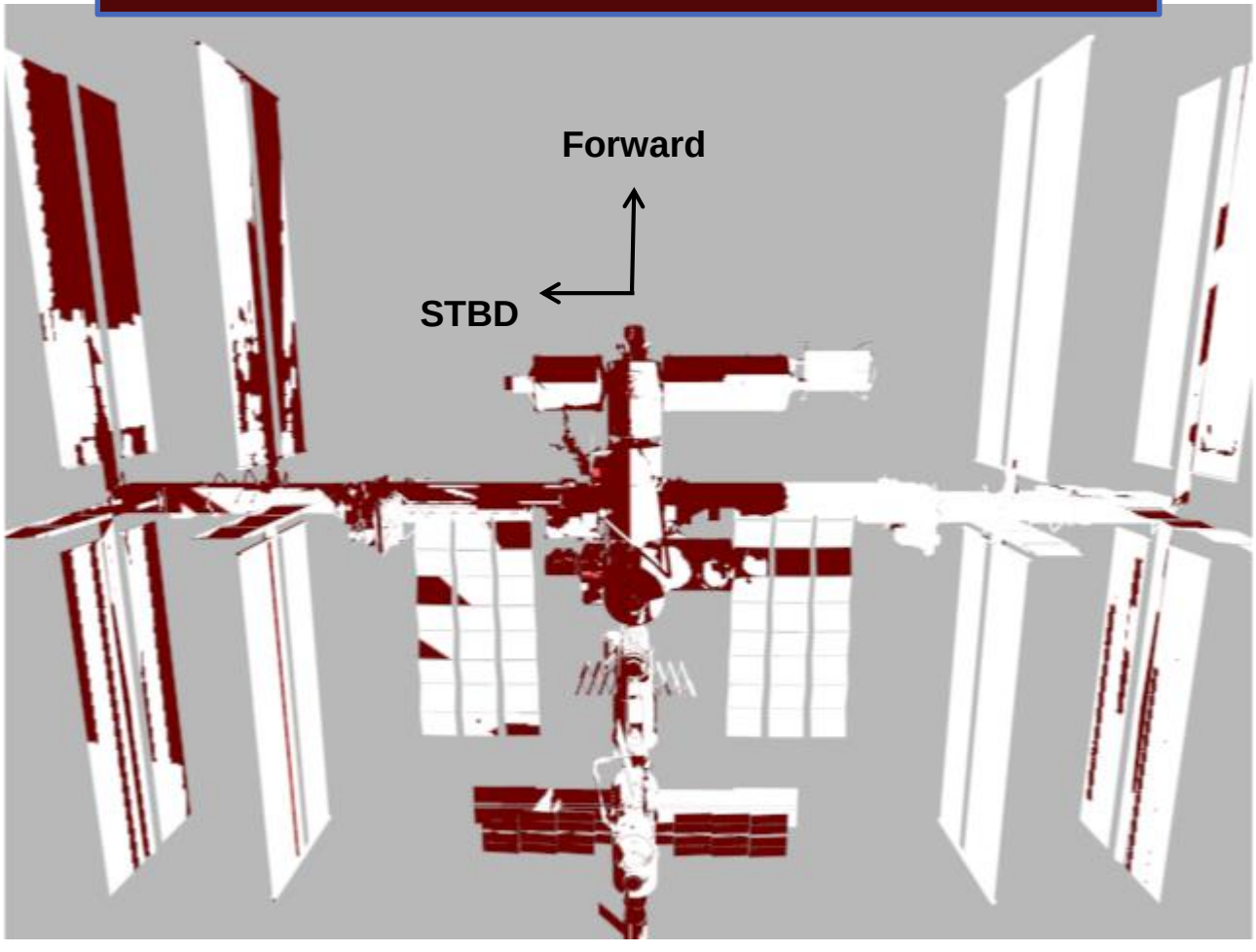
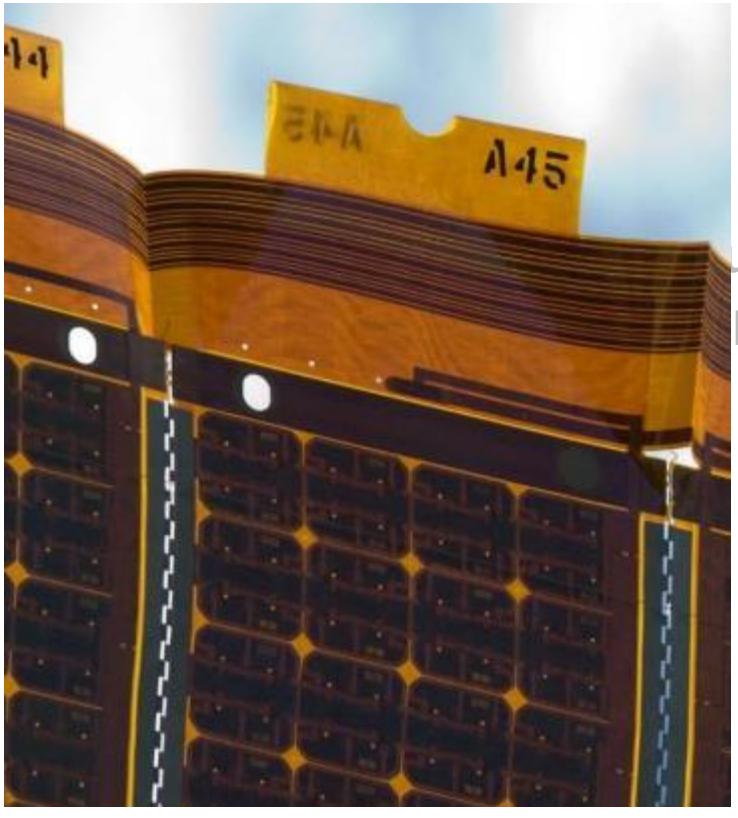
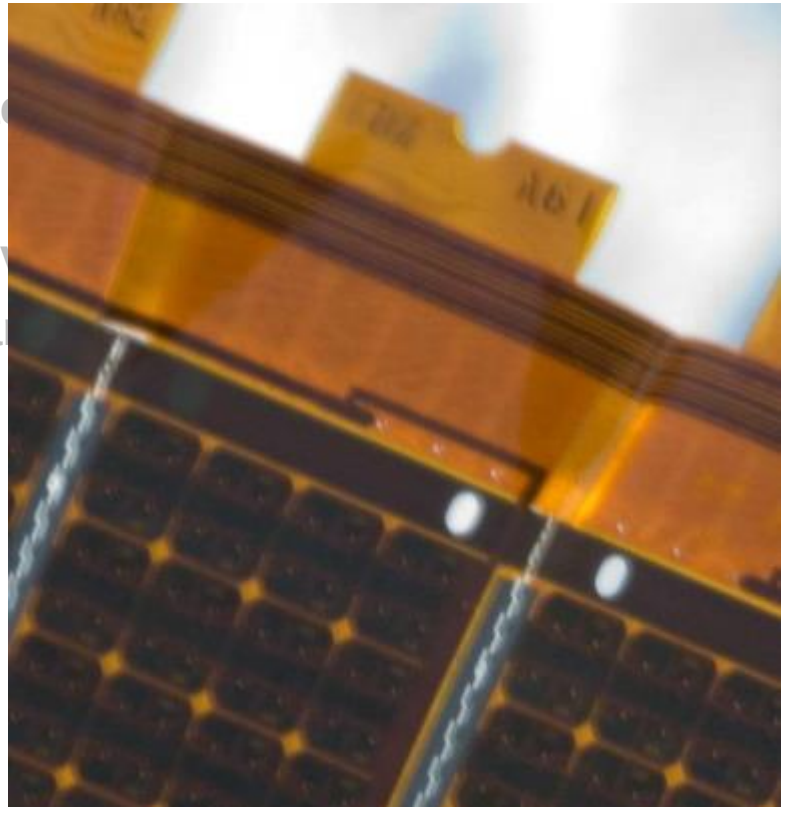


Viewing from below

Crew External Inspection Challenges

- Limited windows, numerous blindspots
  - Distance and high incidence viewing
- **Protective plastic scratch panes installed over Cupola and JEM windows reduce image resolution but need justification for removal and the removal and reinstallation process is time consuming (Cupola 1-4 hours).**





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Other ISS Inspection Technologies

- Handheld Ultrasonic leak detector
- Ammonia Mass spectrometer

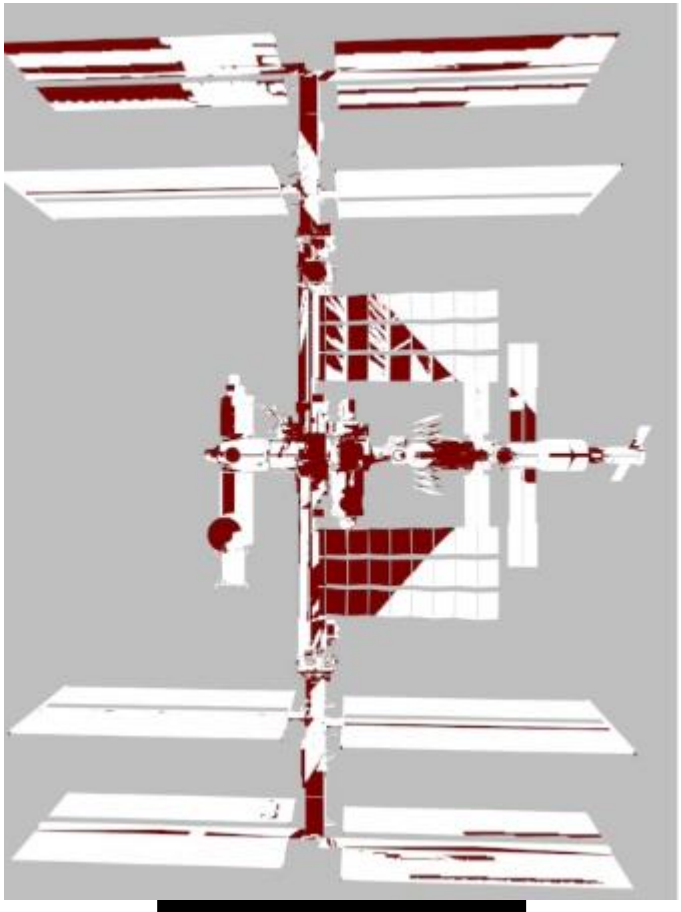
- <u>Challenges for Internal Inspection</u>:
  - Stowage can be in the way
  - Crew time to rotate racks can be hours
  - Some issues (e.g. module leak) could reduce risk(time) with better IVA tools:
    - Improve Ultrasonic Leak Detector adapters
      - Full-length Controllable Stereo View Endoscopes
      - Access NDE inspection after leak plug has been installed

Inspection Challenges Summary

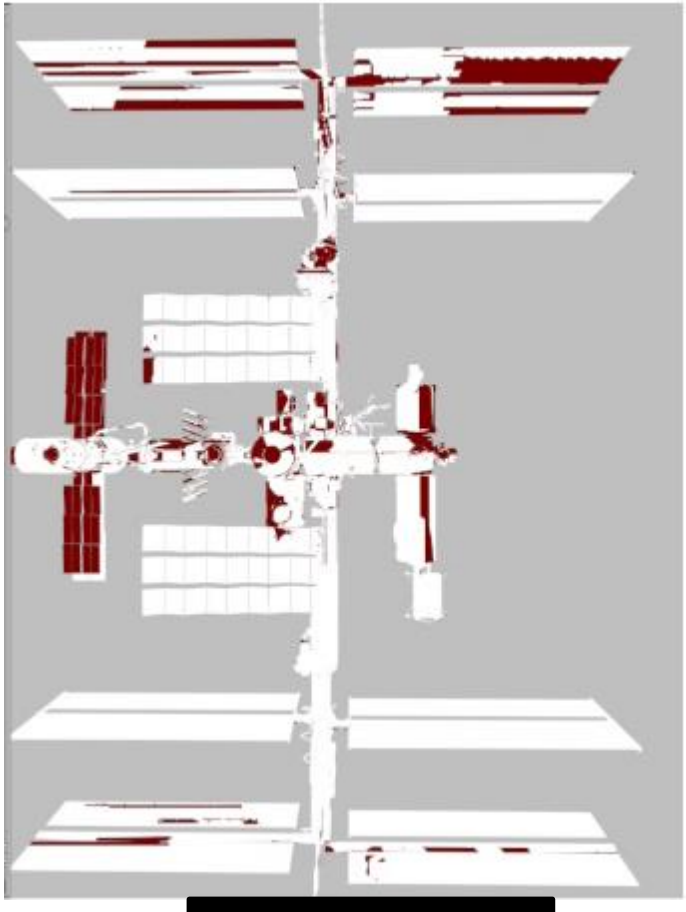
- Regular, periodic inspection is limited to line-of-sight views
- Limited available IVA crew time
  - General ISS periodic inspection is lower priority to science and maintenance
- Scheduling ground controlled imagery surveys with ETVCGs is not an issue, but it is low resolution and there are significant blind spots.
- Complex robotics and EVA planning
- Limited and lack of suitable technology on-orbit (resolution, penetration)
  - Few inspection requirements agreed to – we only buy/fly what we can prove we need ahead of time.
  - Limited Access – internally and externally
  - Observable MMOD surface damage is not indicative of damage underneath.

ETVCG & JEM cameras and Windows Viewing Coverage

Brown shading shows window "blind spots"



Viewing from above



Viewing from below

ISS Visual Inspection Technology Needs

- **Fill in Blind-Spots and areas of low resolution resulting from fixed camera locations and windows**

- **Replace Shuttle fly-around imagery set which provided general ISS periodic inspection and views of overall ISS configuration**

- **Upgraded camera capabilities**
  - Better resolution – lack a good close-up, inspection capability
  - Color, Stereo, 3D vision for better depth determination
  - Penetrating sensor technology (e.g. backscatter x-ray)