The DM7 and the Future of High Performance Computing in Space

15th Annual CubeSat Developers Workshop
April 30, 2018

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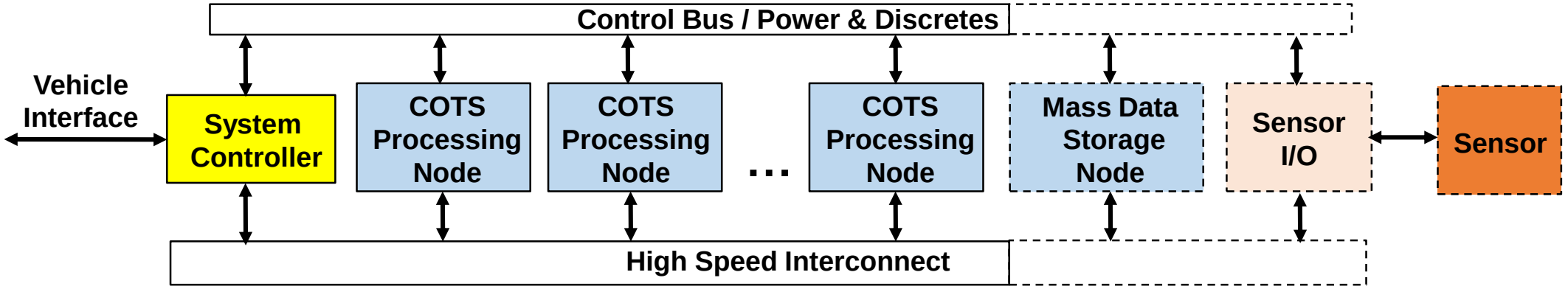
Overview

- DM (Dependable Multiprocessor) technology
- DM Development
- DM7 ISS flight experiment
  - Experiment
  - Lessons learned
- Ongoing & Future Work
- Applications
- Summary and Conclusion

DM Technology

- DM (Dependable Multiprocessor) technology is a cluster of high-performance COTS processors that can fly in space
- Originally developed by Honeywell for NASA
- Hardware architecture and software framework
- DM Middleware (DMM) - Software-enhanced radiation/fault tolerance
  - Self-checking, triple modular redundancy and algorithm-based fault tolerance
- Hardware, platform, & application-independent
  - Supports homogeneous and heterogenous processing operations
  - GPP, DSP, GPU, FPGA, neural processing, and multicore
- User-configurable, environmental and mission adaptive fault tolerance
- Operates under a system controller via high speed interconnect

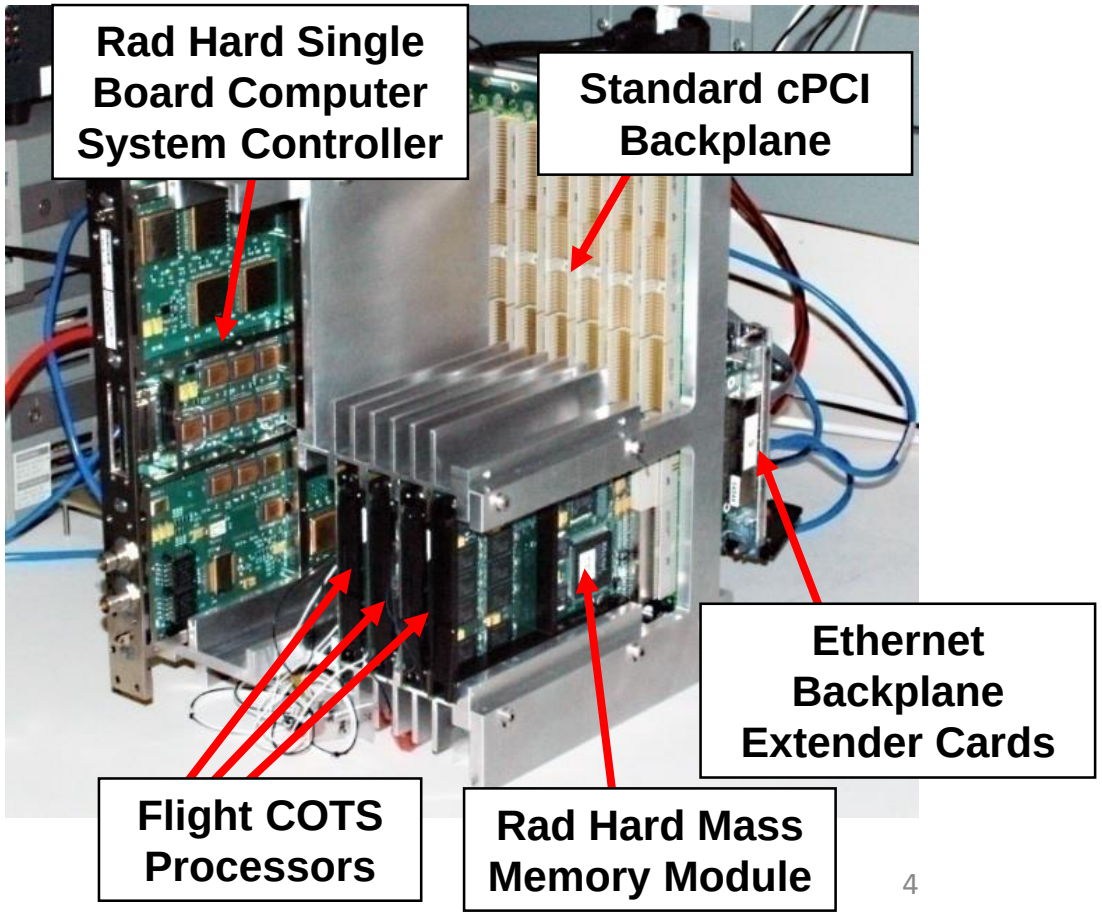
DM Flight System



DM Technology Development

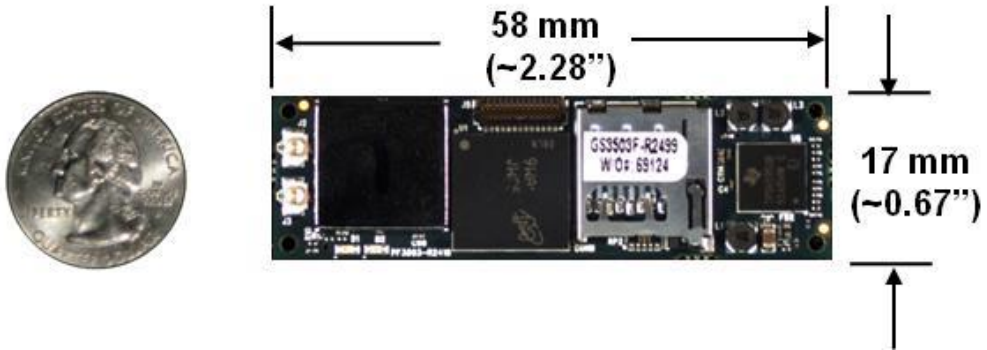
- New Millennium Program ST-8 project
  - TRL6
  - Successful operation in a radiation environment
- Demonstrated:
  - High performance and availability
  - Timely and correct delivery of data
  - Consistency with performance models
- Multiple applications:
  - Hyper-Spectral Imaging
  - Synthetic Aperture Radar
  - Astrophysics applications
    - (CRBLASTER, QLWFPC2)
  - FFTs, matrix operations, etc.
- Easy to Use/Low Overhead:
  - Independent 3rd party ports
  - <10% overhead throughput and memory of application

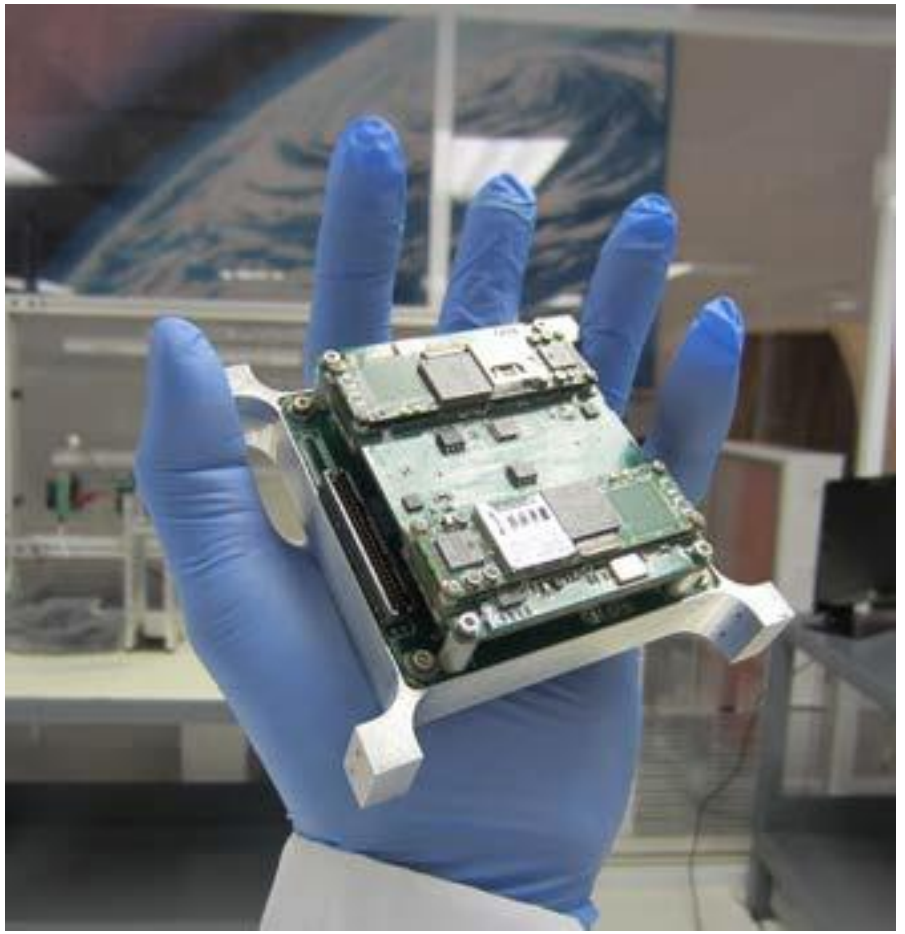
DM TRL6 Flight Experiment Testbed



DM Cube

- Morehead State University (MSU) and Honeywell developed the DM into the CubeSat formfactor
- DM Cube
  - 1/3 U
  - 120 grams
  - 8 Computer-on-Modules (COM)
- Gumstix Overo® WaterSTORM COM
  - 800 MHz each
  - 256 MB RAM, 256 MB Flash each

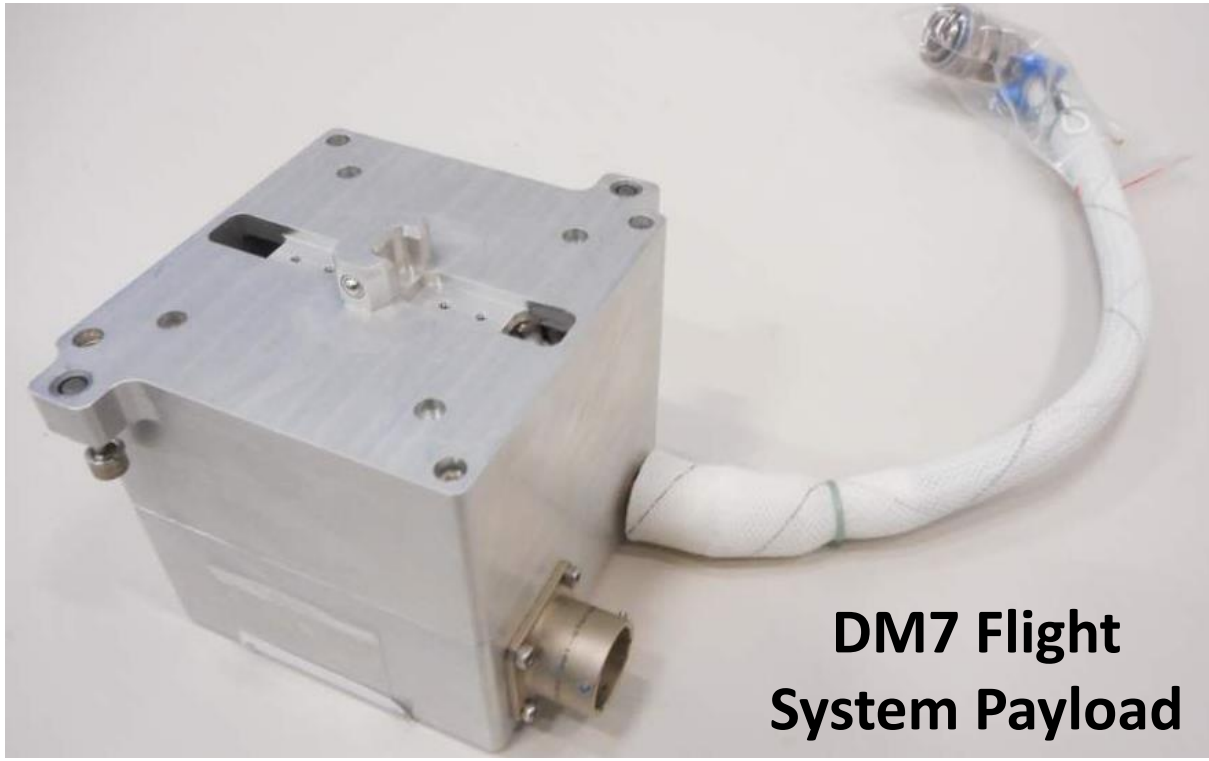




DM CubeSat payload processor flight prototype fabricated by MSU

DM7 ISS Flight Experiment

- **Hosted on the NanoRacks External Platform (NREP)**
- **Sponsored by CASIS**
- **Center for the Advancement of Science in Space**
- **Goals:**
  1. **Demonstrate DM operation in a real space environment**
  2. **Achieve TRL7 for DM technology**
  3. **Validate the predictive DM performance models**



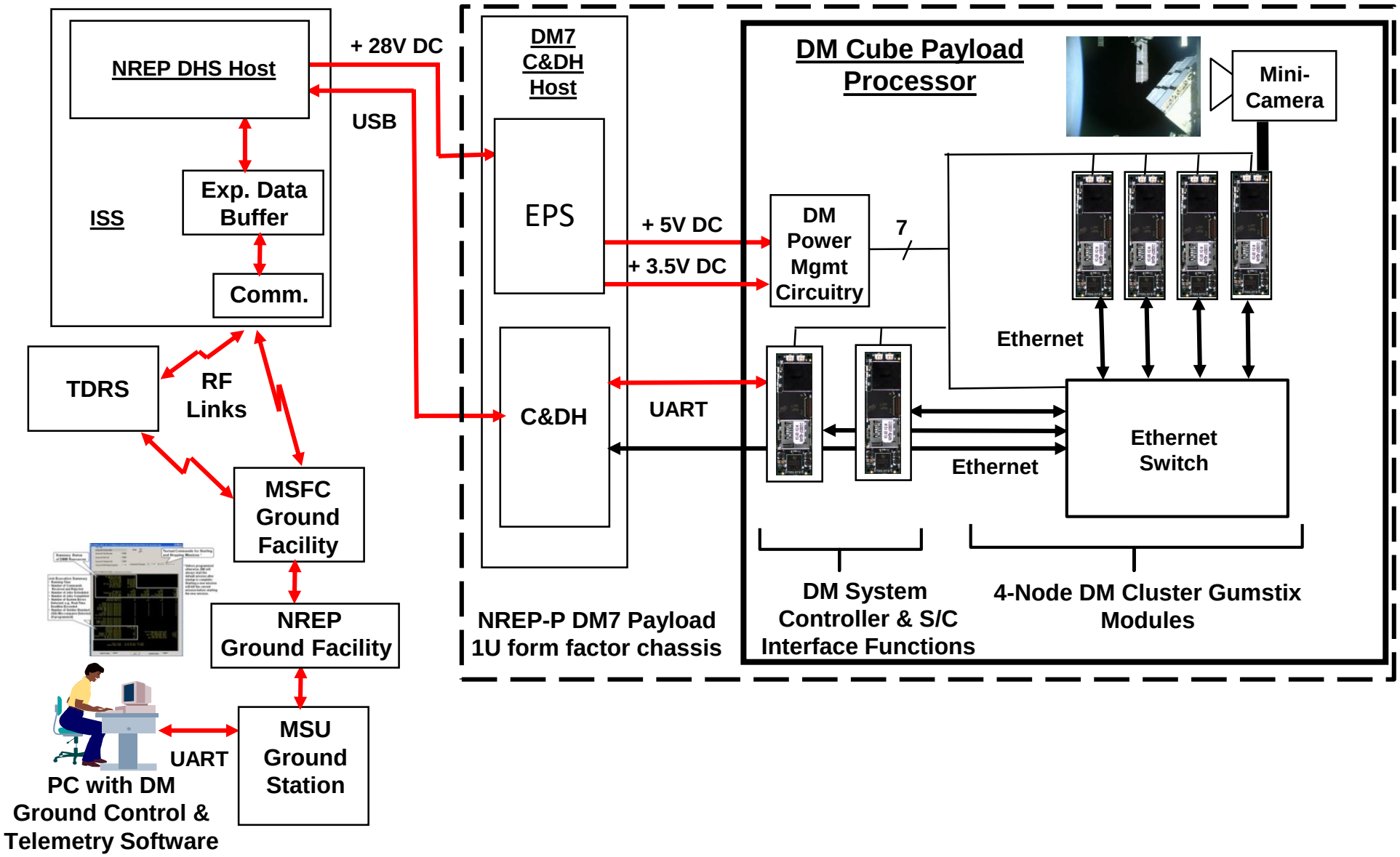
DM7 Flight System Payload

DM7 Experiment Operation

1. **System-level Radiation Performance Mission Experiment**
   - Logic Test, LUD, Golden Standard (GS) LUD compare
2. **System Capabilities Mission Experiment**
   - MM, FFT, SAR, HSI, LUD, Logic Test, CRBLASTER with a full range of DM fault tolerance modes
3. **Camera Mission Experiment**
   - 100x and 1000x compressed images captured

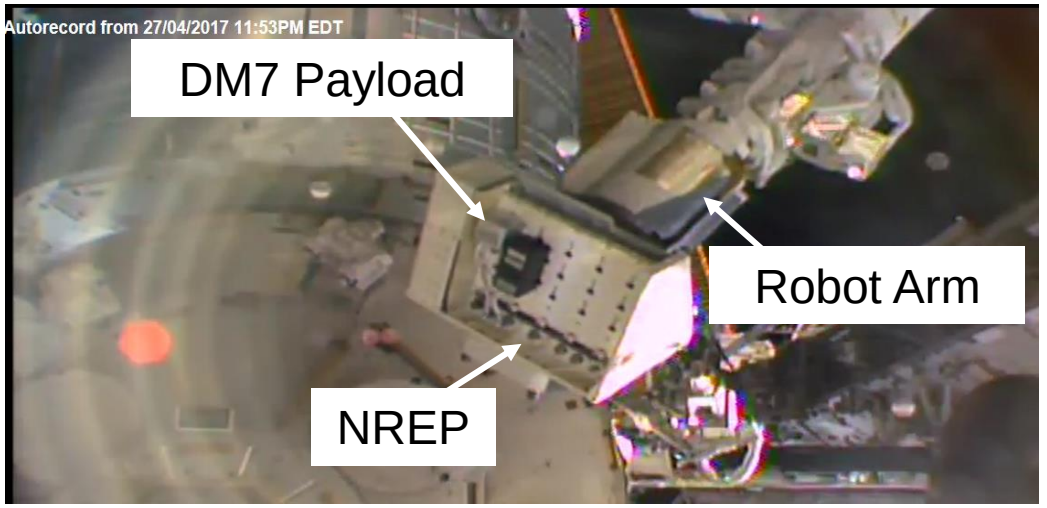
All data was continuously downlinked to the ground

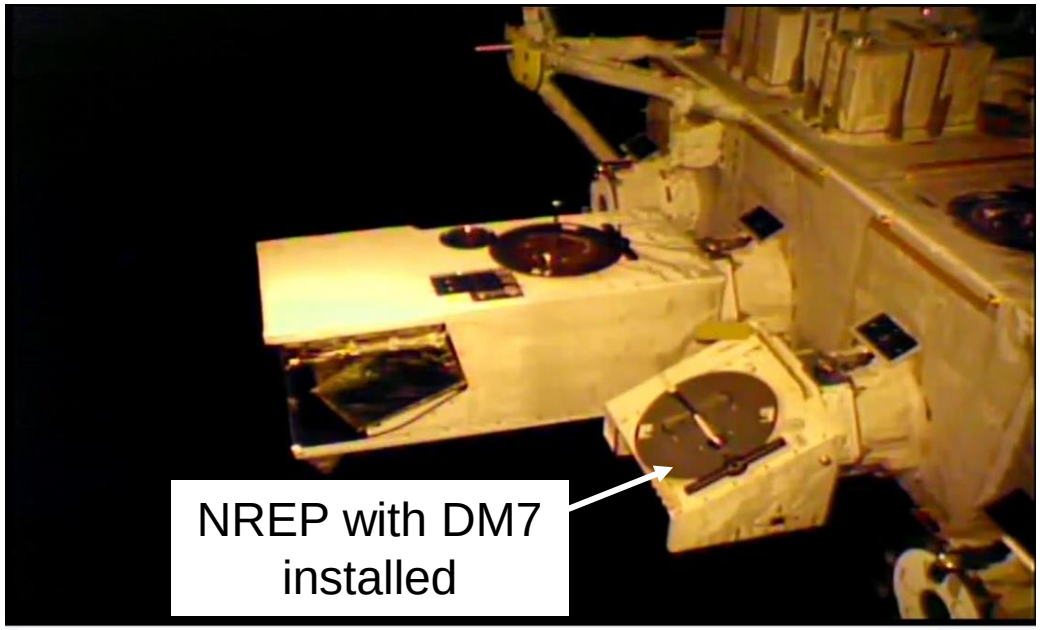
DM7 Flight Experiment Configuration



DM7 Mission Timeline

- Launched to the ISS on HTV6 on Dec 9, 2016
- NREP Mission 1 / Mission 2 switch-over took place on Apr 27, 2017
- Activated on Apr 28, 2017 and started streaming downlink telemetry
- Minor downlink issues were quickly remedied
- Initial on-orbit testing demonstrating all 3 DM7 experiment missions
- Some anomalies were experienced
- 6-month experiment ended on Nov 2017
- Continued to down-link health status until powered down on Dec 20, 2017
- NREP Mission 2 / Mission 3 switch-over on Jan 4, 2018
- Placed in ISS storage
- DM7 to be returned to MSU by end of 2018





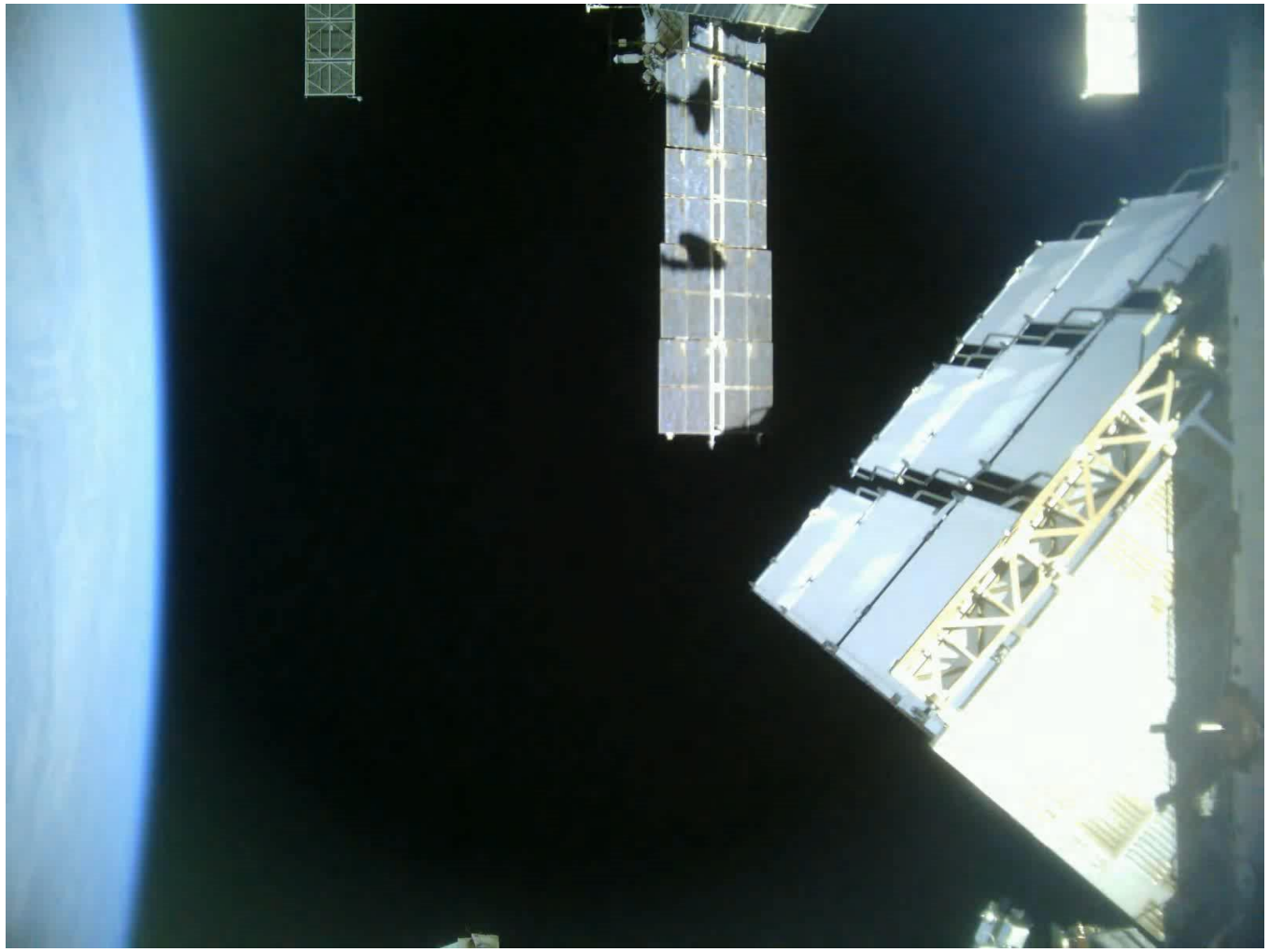
Images courtesy of NASA

DM7 Experiment Results

Three Successful on-orbit experiments

- DM system measured for availability and computational correctness
- No SEU-induced errors detected
  - Performance consistent with Gumstix ground-based radiation tests
  - No radiation-induced latch-up
  - Low SEE rates

DM7 Montage



- Montage of 29 consecutive 100x compression snapshots created by Dr. Conner (MSU)
- https://www.moreheadstate.edu/College-of-Science/Earth-and-Space-Sciences/Space-Science-Center

On-Orbit Anomalies

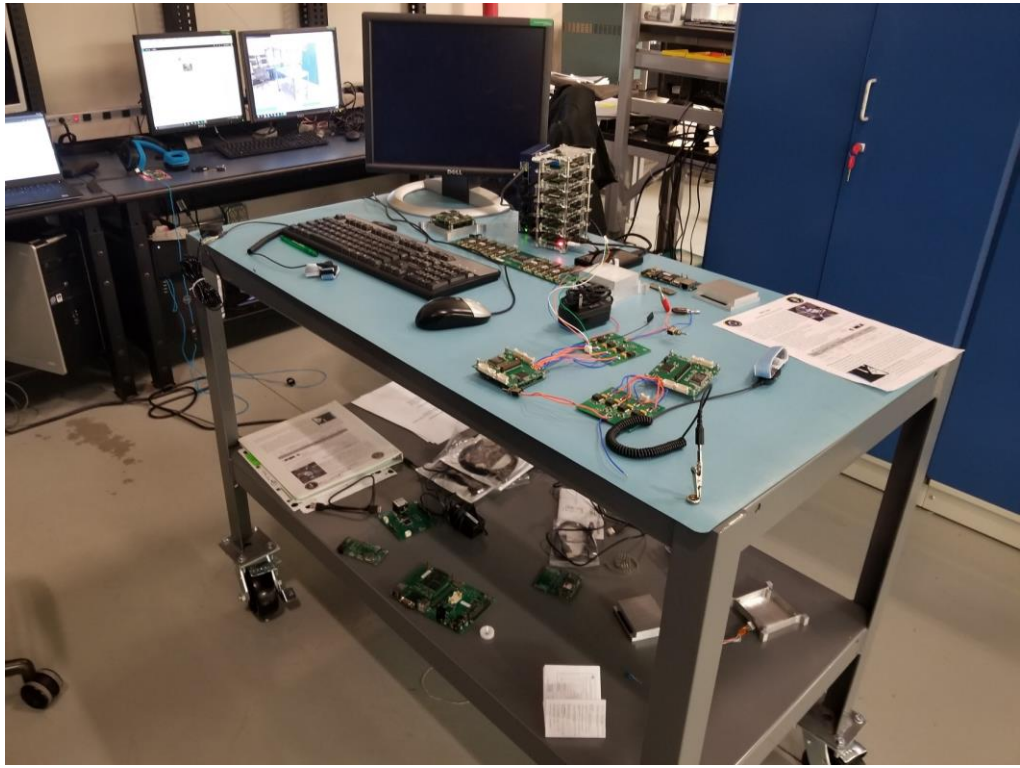
- 1st Anomaly: Unexplained cessation of telemetry
  - Power cycling would restore operation
- 2nd Anomaly: Inability to consistently boot-up all four DP nodes
  - Operating with only three processing nodes was not catastrophic
  - System easily capable of handling node failure
  - Loss of one node only reduced the effective system SEU rate by <17%
- After two months of operation:
  - All commands, including the contingency commands had been implemented
  - Good understanding how the DM7 payload was performing on-orbit
- 3rd Anomaly: Loss of Ethernet connectivity after a power cycle
  - Interface could no longer “find” the Ethernet_0 device

Lesson's Learned

1. **Ensure adequate on-orbit thermal sensing**
   - No way to determine thermal conditions on-orbit
2. **Check and check again**
   - Software debug collection still enabled on one DP node
3. **Remote on-orbit debugging is limited**
   - Limited by ISS and NanoRacks schedules
4. **Retain as much ground testing capability as possible**
   - COM's console ports were used during ground testing to analyze processor issues but were capped off for flight.
   - Would have been useful for on-orbit anomaly resolution
5. **Keep the payload team together**

Ongoing and Future Work

- Analysis of the anomalies using experiment data
- Testing DM7 when it is returned to MSU
  - Power and thermal testing
  - Attempt to re-establish Ethernet_0 device connection
- Upgrade DM Cube
  - Redundancy, e.g. ethernet, control, power, etc.
  - Additional on-orbit debugging features
  - Thermal sensing and control
- Improvements to DMM
- Demonstrate application code on new platforms
  - DM-Pi using Raspberry Pi's
  - Rad-hardened Hardware
- DM Cube on several MSU supported CubeSat proposals and studies



DM development workstation at MSU Space Science Center. DM-Pi and other hardware shown

Applications (1 of 2)

- DM allows CubeSat missions to fly COTS processing technology
- No longer need to fly technologies that are 2 – 3 generations behind the state of the art terrestrial processing technology
- DM can be used for any mission or application that needs programmable high performance computing

Applications (2 of 2)

- Reducing downlink bandwidth requirements/usage
  - Real time data, image and video compression
  - On-orbit data mining
- "Smart" Mission operations
  - Multi mission and autonomous control
- Hazardous terrestrial environments
  - e.g. nuclear decommissioning robotics
- Looking for partners who have applications for DM technology
  - If interested please contact: azucherman@moreheadstate.edu
  - Come visit the Morehead State University Booth

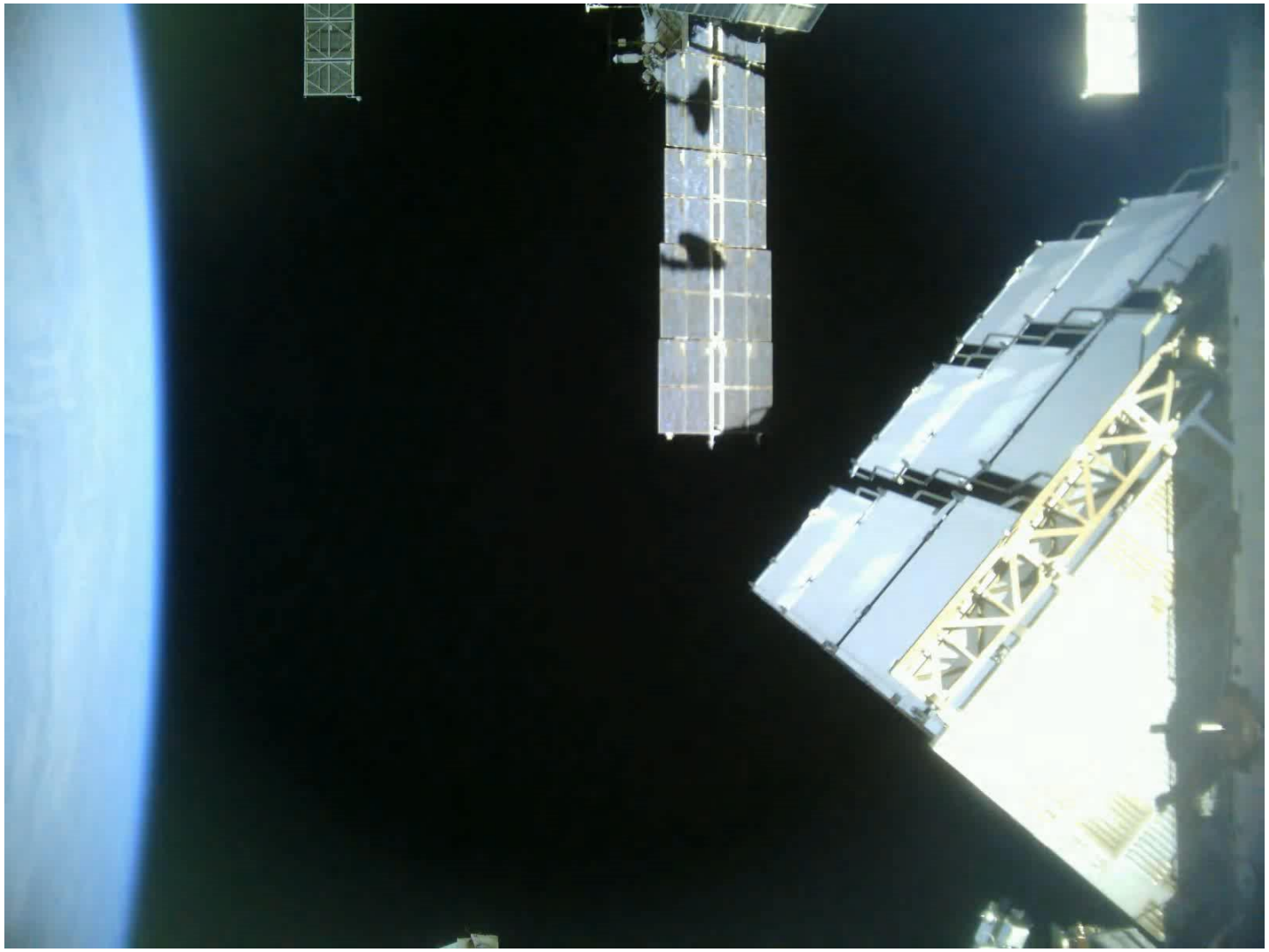
Summary and Conclusion

- DM is a way to fly a cluster of high-performance COTS Processors for Space
- DM is TRL-7
- Ongoing work to improve DMM middleware and DM cube
- The DM is a low-cost, scalable and high performance processing solution

Acknowledgements

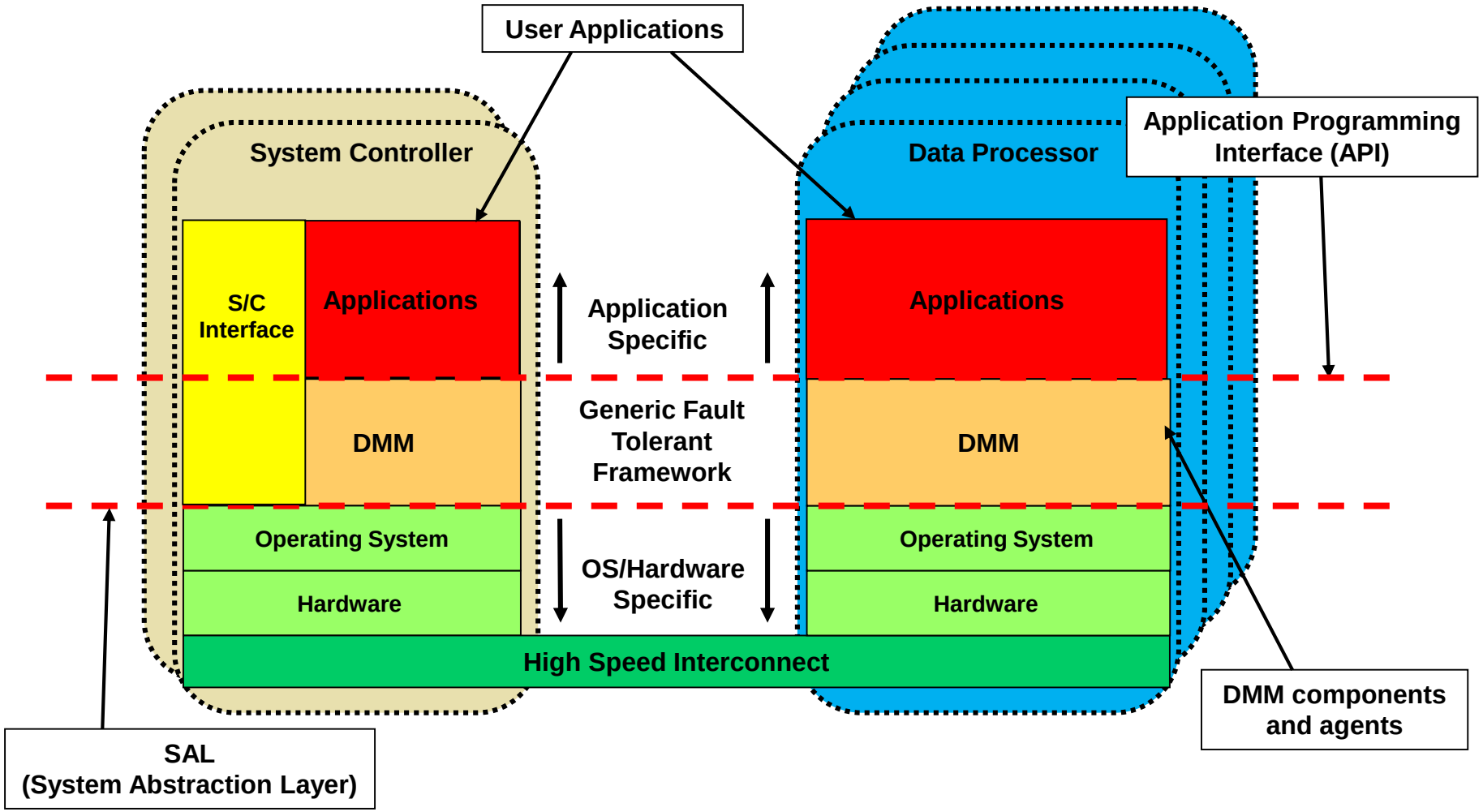
- The Dependable Multiprocessor effort was funded under NASA NMP ST8 contract NMO-710209
- The DM CubeSat development was funded by Honeywell
- The SMDC TechSat Phase 2 effort was funded under SMDC contract W9113M-08-D-0001/0023
- The DM7 ISS flight experiment effort was performed under CASIS grant GA-2014-149
- The DM7 CASIS project was flown as an ISS National Laboratory flight experiment
- Thanks to NanoRacks personnel for their support during development, pre-flight testing, and on-orbit testing and operation of the DM7 payload
- Thanks to Dataseam for ongoing support

Questions?



Back-up slides

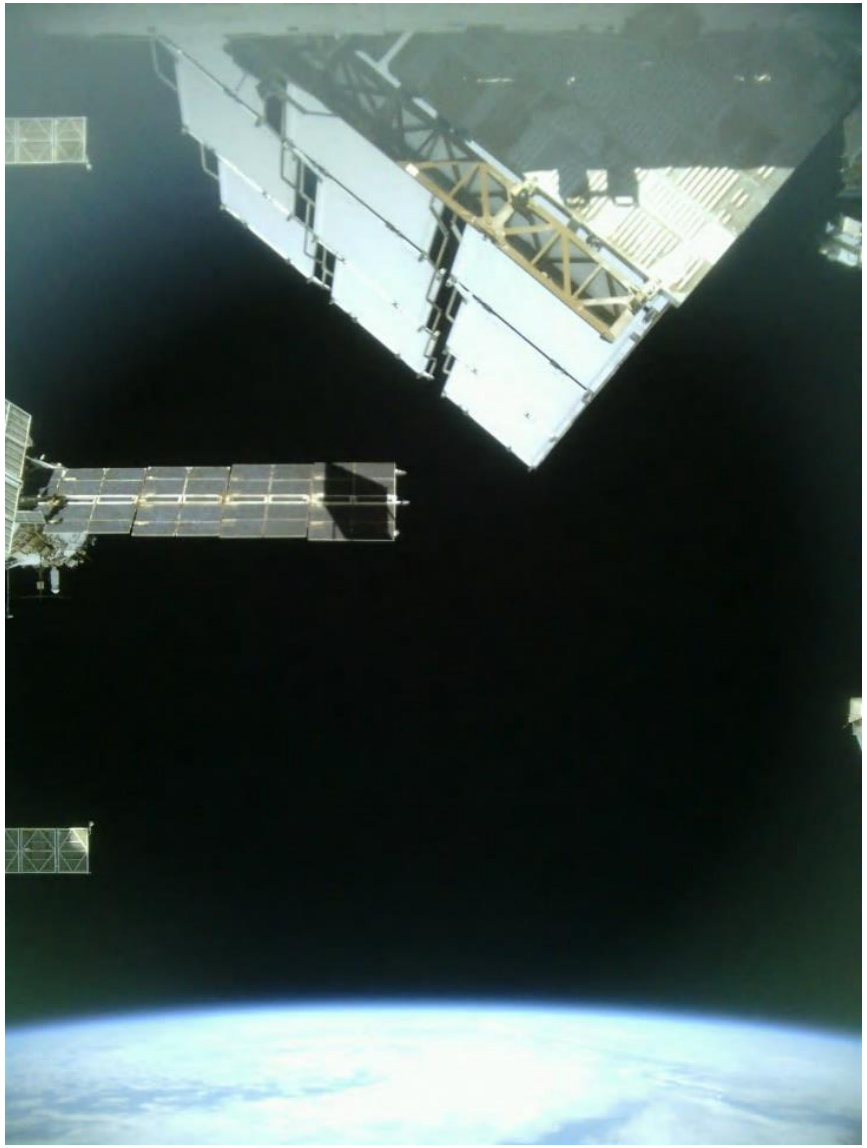
DMM - Dependable Multiprocessor Middleware



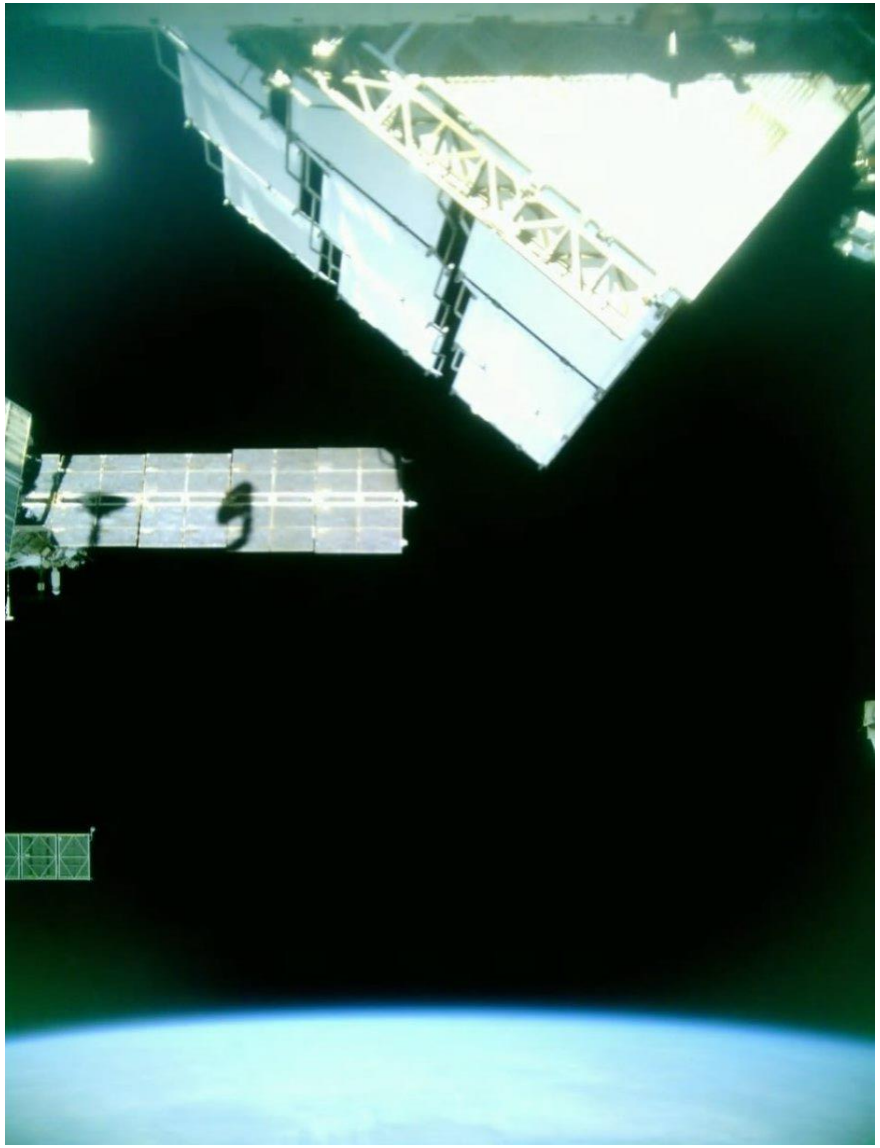
The DM Middleware (DMM) is DM technology; DM technology is not the underlying hardware

DM7 Compressed Images

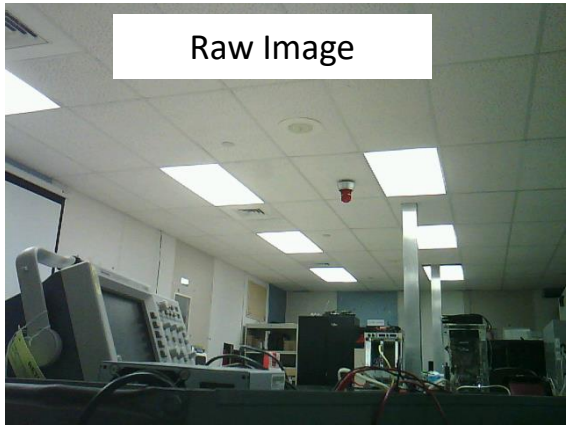
100x compressed image



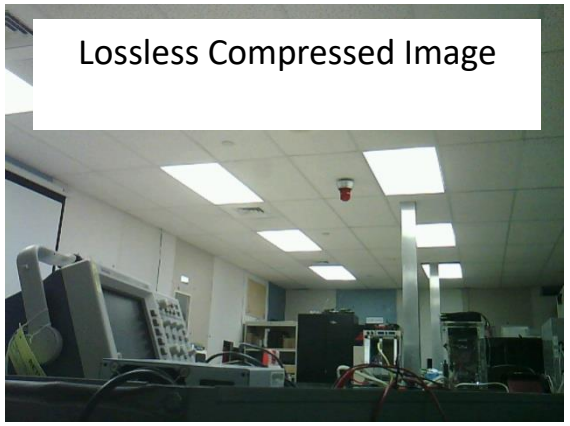
1000x compressed image



DM7 Camera Image Compression Experiment

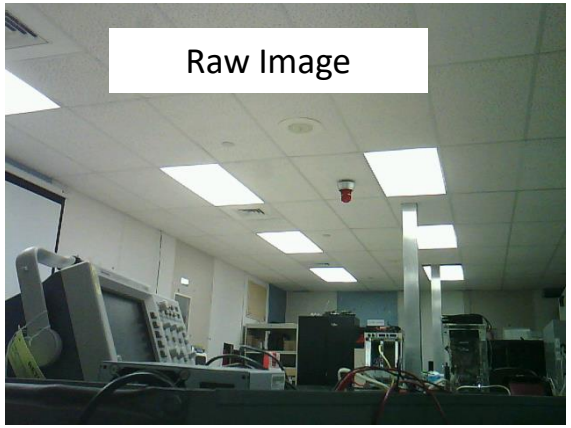


Raw Image Size: 921654 Bytes
Frame Time: 15 seconds

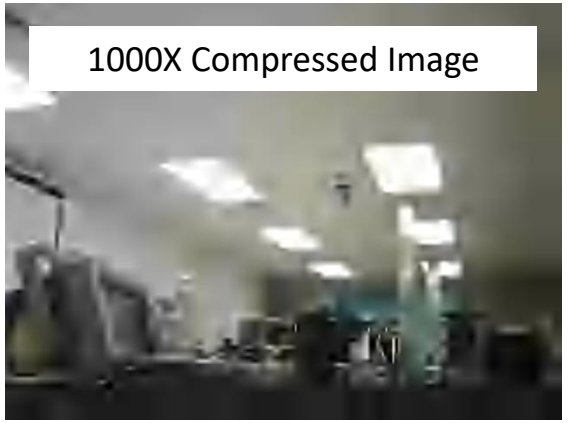


Compressed Image Size: 435734 Bytes
Execution Time: 2.449 seconds

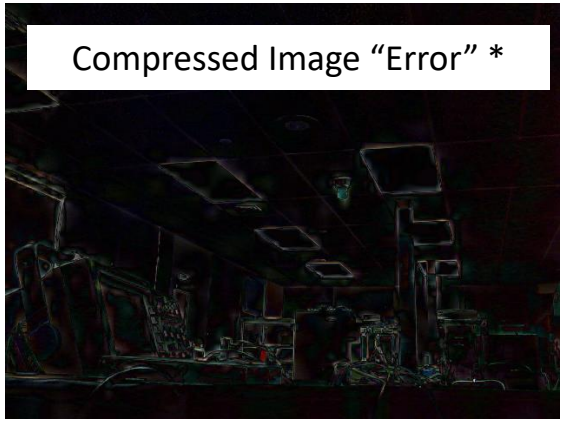
Average R error = 0.0 ^
Average G error = 0.0 ^
Average B error = 0.0 ^



Raw Image Size: 921654 Bytes
Frame Time: 15 seconds



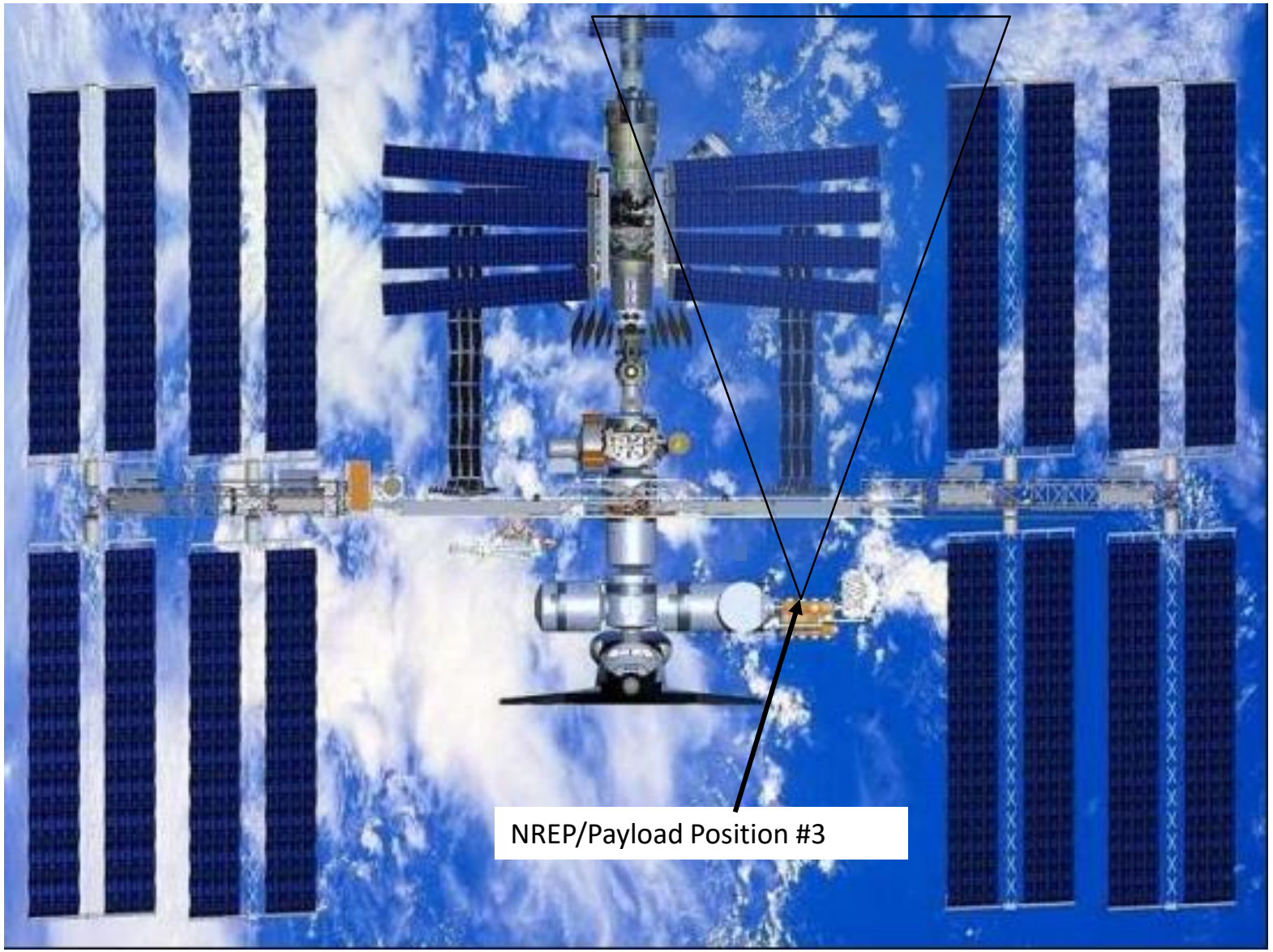
Compressed Image Size: 922 Bytes
Execution Time: 3.041 seconds



Average R error = 11.183 ^
Average G error = 8.626 ^
Average B error = 9.947 ^

*** ABS [Raw Image Pixel (x,y) – Compressed Image Pixel (x,y)]**
^ Average difference in pixel value over the entire image (8-bit pixel data; range 0 - 255)

ISS Top View – Aft-Facing Camera View



From NASA ISS Web Site

Anomalies Other Considerations

- **Possible MSP430 anomaly**
  - **During early on-orbit check-out, it appeared that the MSP430 micro-controller failed to issue an initial heartbeat required to start the DM cluster**
  - **Surprising because of MSP430 space pedigree and the simplicity of the timing circuit which generates the heartbeats**
  - **Cycling power rectified this apparent anomaly which never happened again**
- **Possible unknown/unexpected radiation effects**
  - **Due to limited funding, not all of the components in the DM7 flight system were subjected to pre-flight ground-based radiation testing**
  - **Only the COM's were radiation tested by Honeywell and Yosemite Space as suitable for flying in space**
  - **DM7 payload not radiation tested on a systems level**
  - **Impact of not radiation testing all of the components in the DM7 flight system is uncertain**