NMP ST8 Dependable Multiprocessor (DM)

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Outline

- **Introduction**
  - Dependable Multiprocessor * technology
    - overview
    - hardware architecture
    - software architecture
- **Current Status & Future Plans**
- **TRL6 Technology Validation**
- **Summary & Conclusion**

*** formerly known as the Environmentally-Adaptive Fault-Tolerant Computer (EAFTC); The Dependable Multiprocessor effort is funded under NASA NMP ST8 contract NMO-710209.**

DM Technology Advance: Overview

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- A high-performance, COTS-based, fault tolerant cluster onboard processing system that can operate in a natural space radiation environment

NASA Level 1 Requirements (Minimum)

- high throughput, low power, scalable, & fully programmable >300 MOPS/watt (>100)
- high system availability > 0.995 (>0.95)
- high system reliability for timely and correct delivery of data >0.995 (>0.95)
- technology independent system software that manages cluster of high performance COTS processing elements
- technology independent system software that enhances radiation upset tolerance

Benefits to future users if DM experiment is successful:

- 10X – 100X more delivered computational throughput in space than currently available
- enables heretofore unrealizable levels of science data and autonomy processing
- faster, more efficient applications software development
  - -- robust, COTS-derived, fault tolerant cluster processing
  - -- port applications directly from laboratory to space environment
    - --- MPI-based middleware
    - --- compatible with standard cluster processing application software including existing parallel processing libraries
- minimizes non-recurring development time and cost for future missions
- highly efficient, flexible, and portable SW fault tolerant approach applicable to space and other harsh environments
- DM technology directly portable to future advances in hardware and software technology

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Dependable Multiprocessor Technology

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- Desire - -> 'Fly high performance COTS multiprocessors
  - To satisfy the long-held desire to put the power of today's PCs and supercomputers in space, three key issues, SEUs, cooling, & power efficiency, need to be overcome

DM has addressed and solved all three issues

- Single Event Upset (SEU): Radiation induces transient faults in COTS hardware causing erratic performance and confusing COTS software

DM Solution {
- robust control of cluster
- enhanced, SW-based, SEU-tolerance

- Cooling: Air flow is generally used to cool high performance COTS multiprocessors, but there is no air in space

DM Solution { - tapped the airborne-conductively-cooled market

- Power Efficiency: COTS only employs power efficiency for compact mobile computing, not for scalable multiprocessing

DM Solution { - tapped the high performance density mobile market

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DM Hardware Architecture

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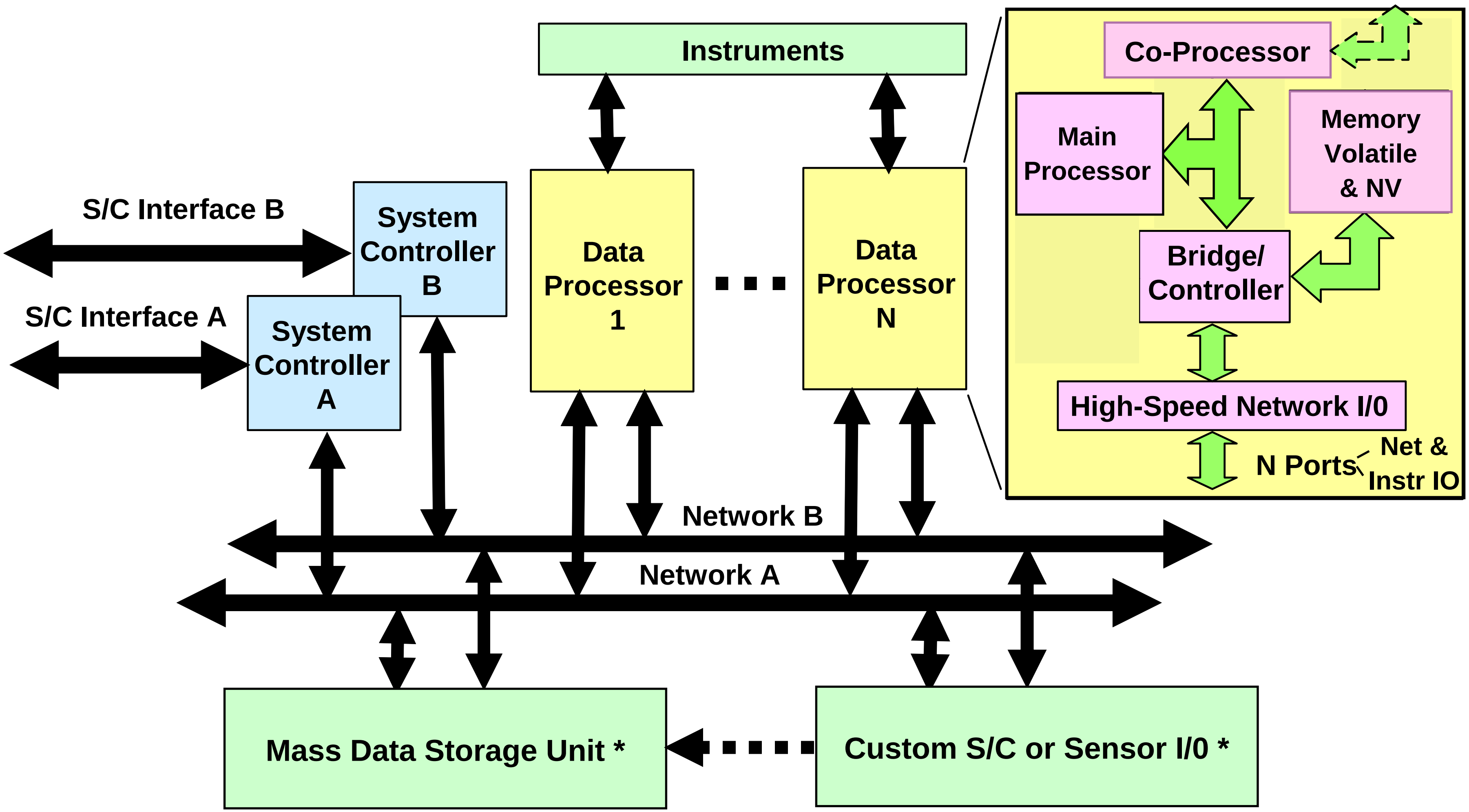

* Examples: Other mission-specific functions

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DMM Top-Level Software Layers

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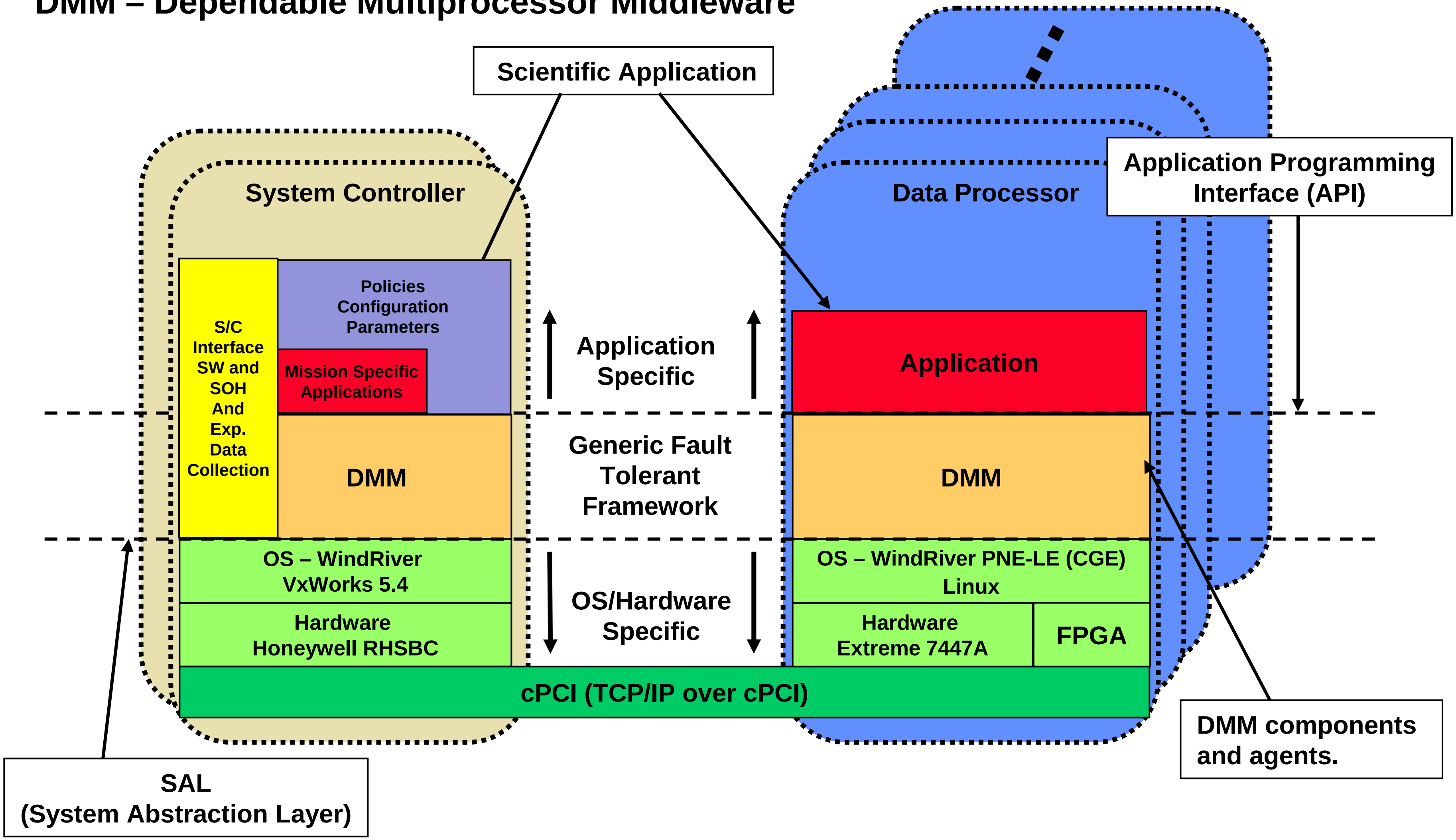
DMM – Dependable Multiprocessor Middleware



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DMM Software Architecture "Stack"

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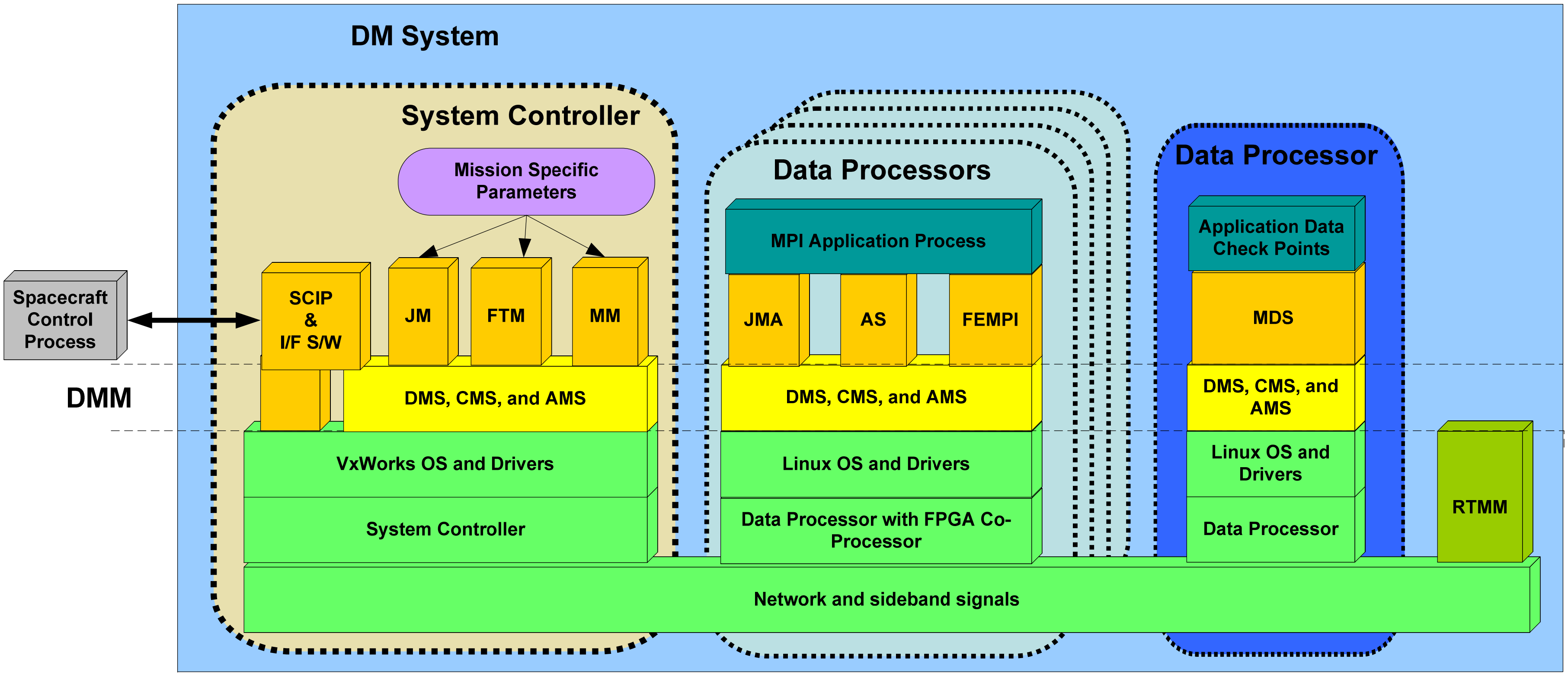

- HA Middleware
- Platform Components
- Application Components
- Mission Specific Components
- Dependable Multiprocessor MW Specific Components

JM – Job Manager
JMA – Job Manager Agent
MM - Mission Manager
FTM- Fault Tolerance Manager
FEMPI – Fault Tolerant Embedded Message Passing Interface
SCIP - Space Craft Interface Message Processor

AS – Application Services
MDS – Mass Data Storage
CMS – Cluster Management Services
AMS – Availability Management Services
DMS – Distributed Messaging Services
RTMM – Radiation Tolerant Mass Memory

Examples: User-Selectable Fault Tolerance Modes

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Fault Tolerance Option	Comments
NMR Spatial Replication Services	Multi-node HW SCP and Multi-node HW TMR
NMR Temporal Replication Services	Multiple execution SW SCP and Multiple Execution SW TMR in same node with protected voting
ABFT	Existing or user-defined algorithm; can either detector detect or detect and correct data errors with less overhead than NMR solution
ABFT with partial Replication Services	Optimal mix of ABFT to handle data errors and Replication Services for critical control flow functions
Check-pointing Roll Back	User can specify one or more check-points within the application, including the ability to roll all the way back to the original
Roll forward	As defined by user
Soft Node Reset	DM system supports soft node reset
Hard Node Reset	DM system supports hard node reset
Fast kernel OS reload	Future DM system will support faster OS re-load for faster recovery
Partial re-load of System Controller/Bridge Chip configuration and control registers	Faster recovery that complete re-load of all registers in the device
Complete System re-boot	System can be designed with defined interaction with the S/C; TBD missing heartbeats will cause the S/C to cycle power

DM Technology Readiness & Experiment Development Status and Future Plans

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5/30/05 — TRL4 Technology Validation
Technology Concept Demonstration

5/17/06 — TRL5 Technology Validation
Technology in Relevant Environment

10/27/06 — NASA ST8 Project Confirmation Review

9/08 & 1/09 * — TRL6 Technology Validation
Technology Demonstration in a Relevant Environment *

X*

~~Launch 11/09 *~~
~~Mission 1/10 - 6/10 *~~

TRL7 Technology Validation
Flight Experiment

5/31/06 — Preliminary Design Review
Preliminary Experiment HW & SW Design & Analysis

6/27/07 — Critical Design Review
Final Experiment HW & SW Design & Analysis

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5/06, 4/07, & 5/07 — Preliminary Radiation Testing
Critical Component Survivability & Preliminary Rates

5/08, 7/08, 8/08, & 10/08 — Final Radiation Testing
Complete Component & System-Level Beam Tests

Key: [shaded box] - Complete

- Per direction from NASA Headquarters 8/3/07;
  The ST8 project ends with TRL6 Validation;
  Preliminary TRL6 demonstration 9/15/08;
  Final TRL6 demonstration 1/10/09

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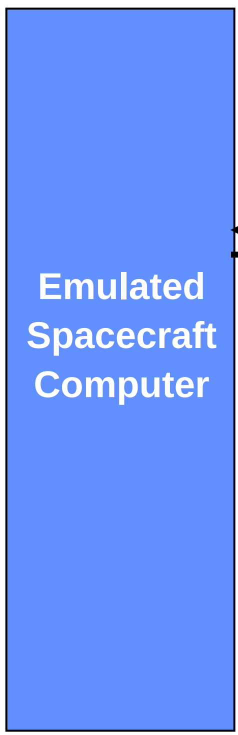
DM TRL6 Testbed System



System Controller:
Wind River OS
- VxWorks 5.4

Honeywell Ganymede SBC (PPC 603e)

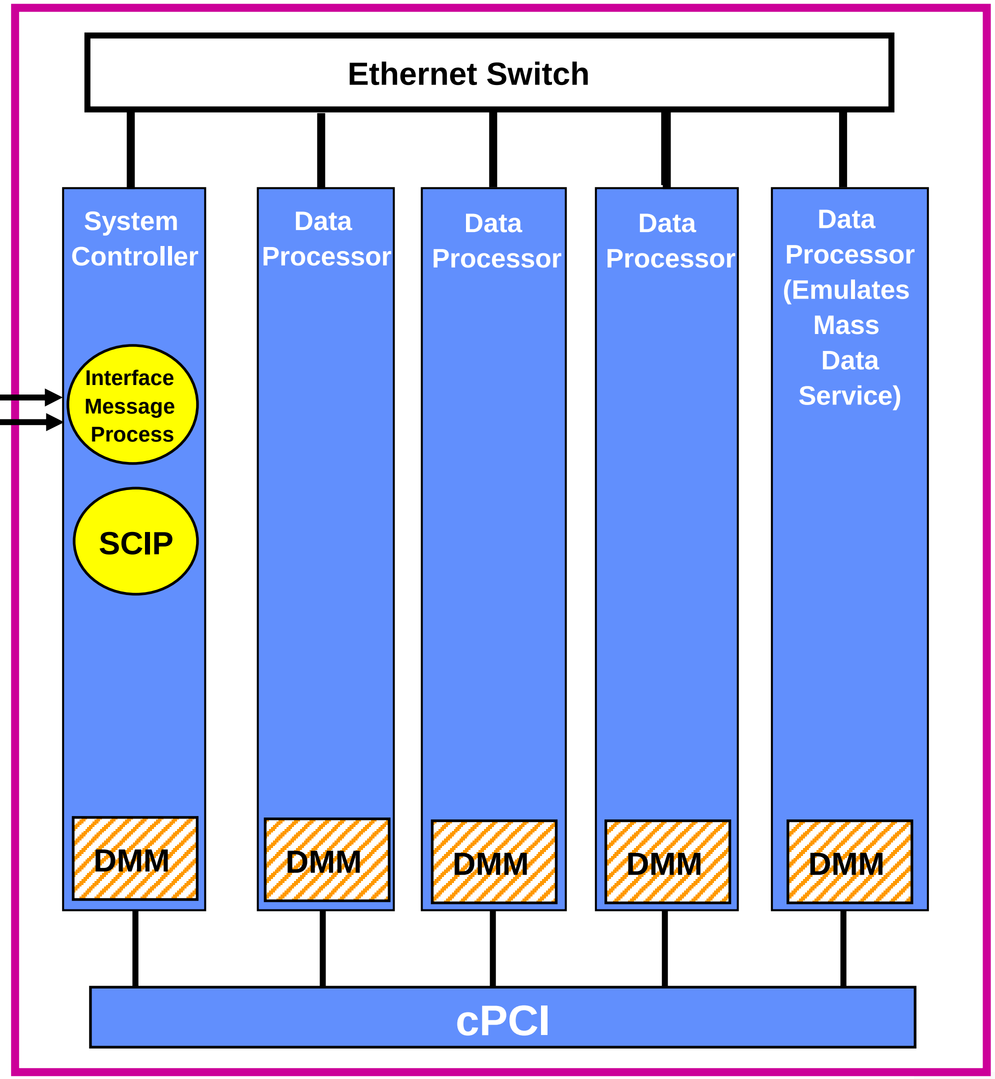
RS422

Data Processor:
Wind River OS
- PNE-LE 4.0 (CGE) Linux

Extreme 6031
PPC 7447a with AltiVec co-processor

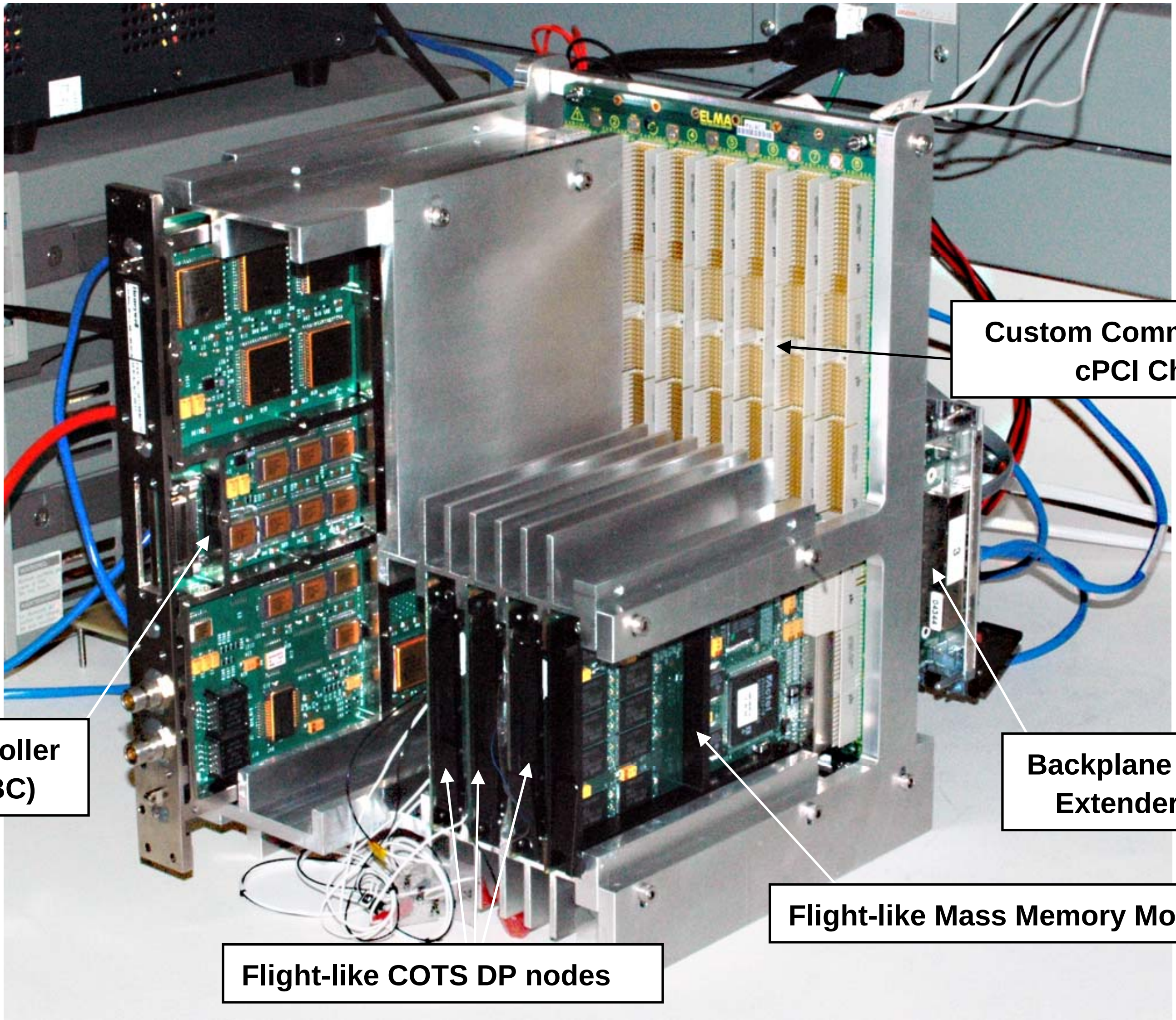
Memory Card:
Aitech S990

Networks:
cPCI
Ethernet: 100Mb/s



SCIP – S/C Interface Process

DM TRL6 (Phase C/D) Flight Testbed



TRL6 Technology Validation Demonstration (1)

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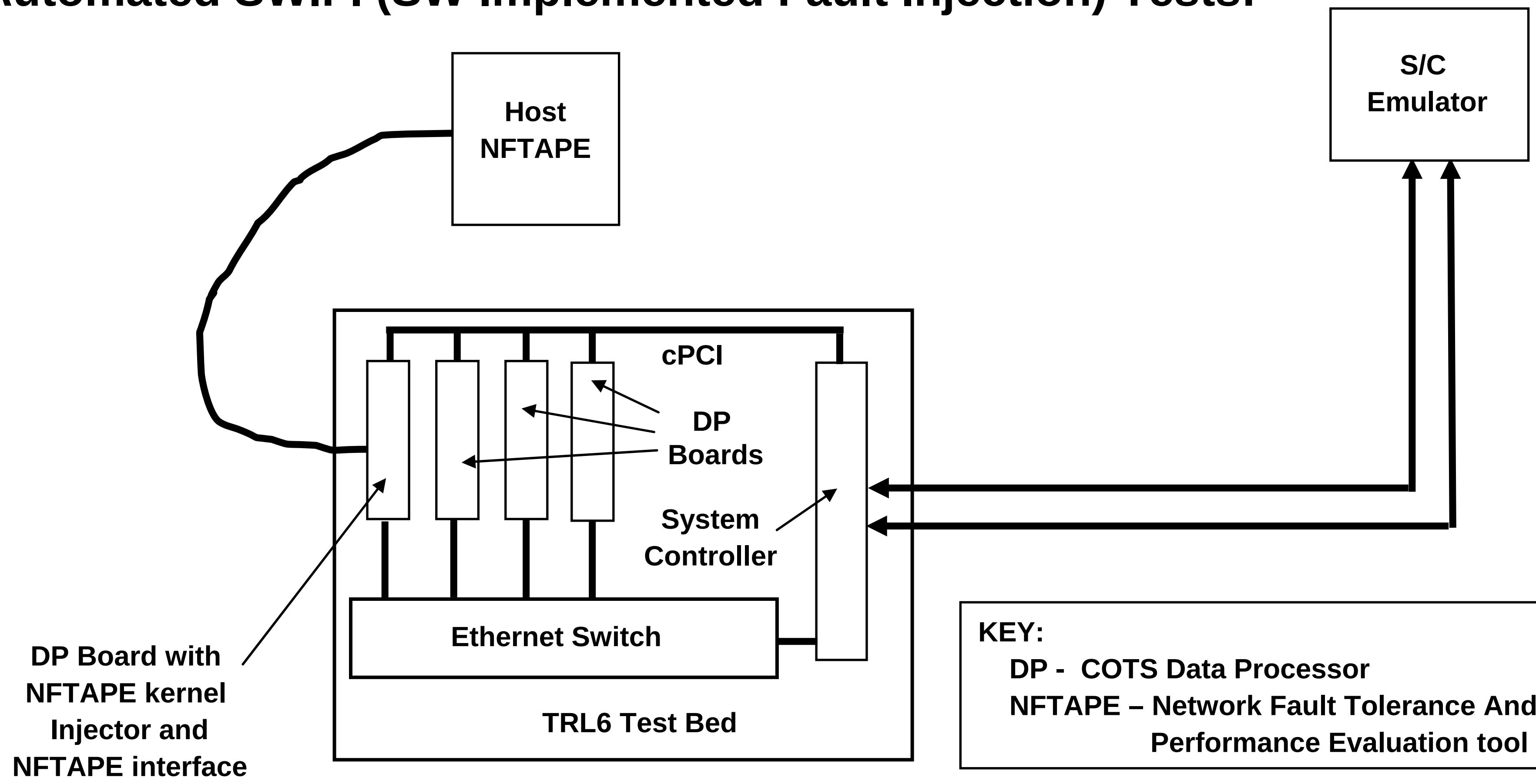
Automated SWIFI (SW Implemented Fault Injection) Tests:



KEY:
- DP - COTS Data Processor
- NFTAPE – Network Fault Tolerance And Performance Evaluation tool

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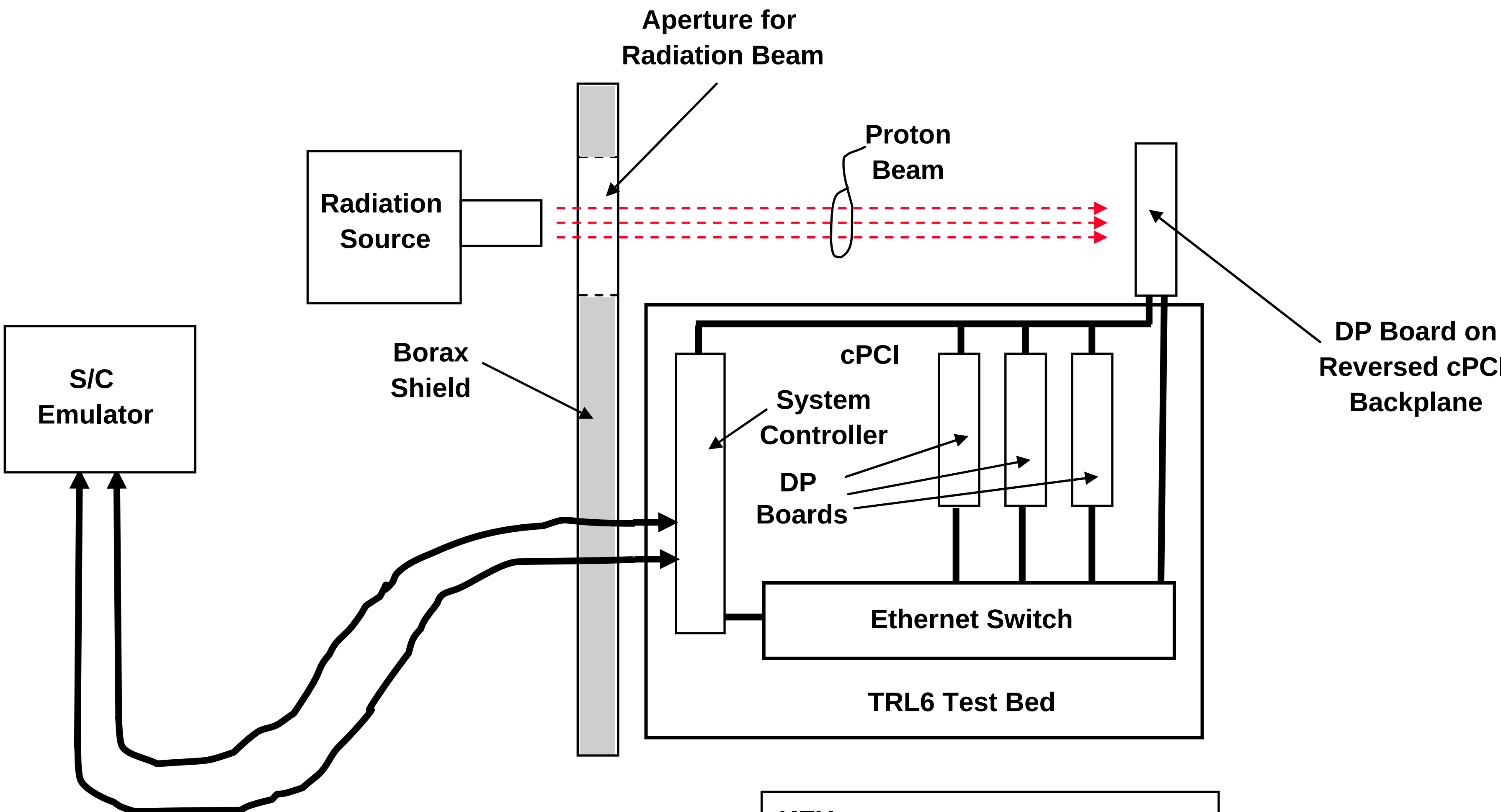
TRL6 Technology Validation Demonstration (2)

System-Level Proton Beam Tests:



KEY:
DP - COTS Data Processor

Dependable Multiprocessor Experiment Payload on the ST8 "NMP Carrier" Spacecraft

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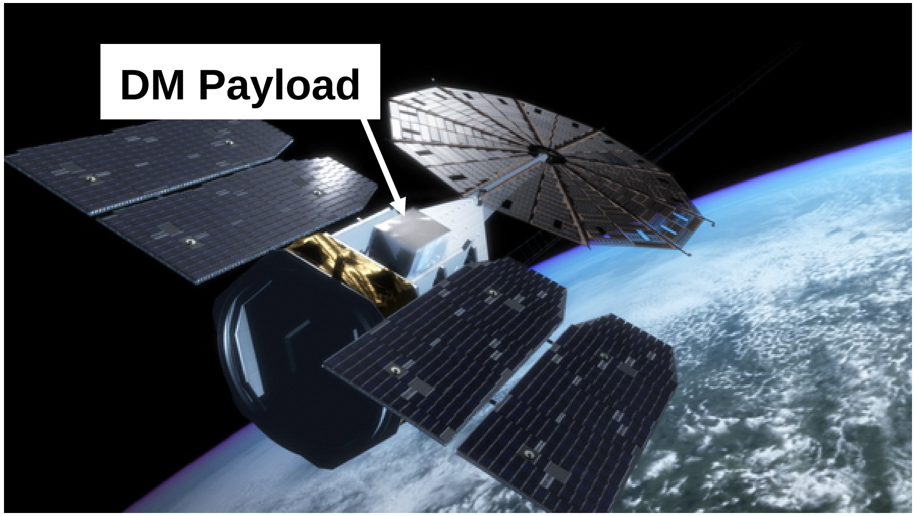
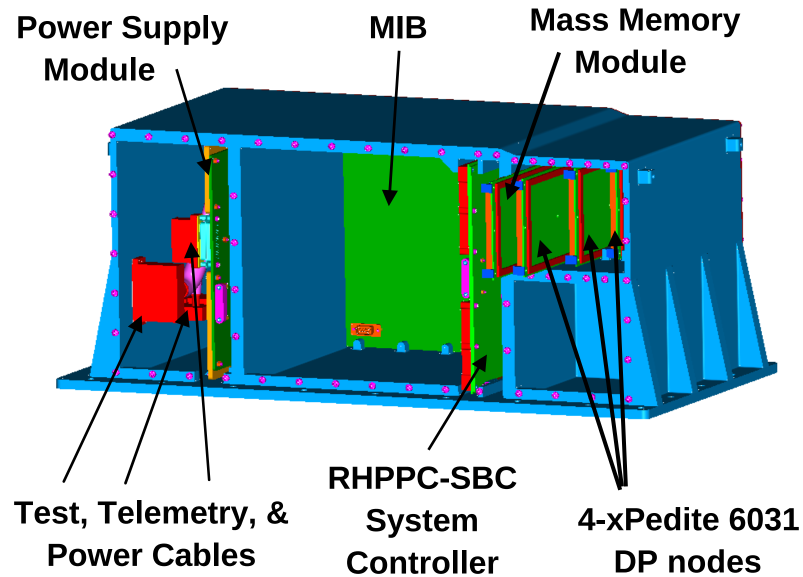
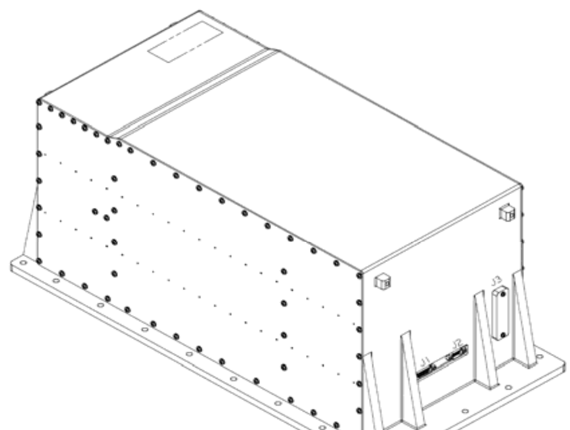




ST8 Orbit: - sun-synchronous
- 955 km x 460km @ 98.2^{o} inclination

Software

- Multi-layered System SW
  - OS, DMM, APIs, FT algorithms
- SEU-Tolerance
  - detection
  - autonomous, transparent recovery
- Applications
  - 2DFFT, LUD, Matrix Multiply, FFTW SAR, HSI
- Multi-processing
  - parallelism, redundancy
  - combinable FT modes



Flight Hardware

- Dimensions
  10.6 x 12.2 x 24.0 in.
  (26.9 x 30.9 x 45.7 cm)
- Weight (Mass)
  ~ 61.05 lbs
  (27.8 kg)
- Power
  ~ 121 W (max)

The ST8 DM Experiment Payload is a stand-alone, self-contained, bolt-on system.

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DM Markov Models

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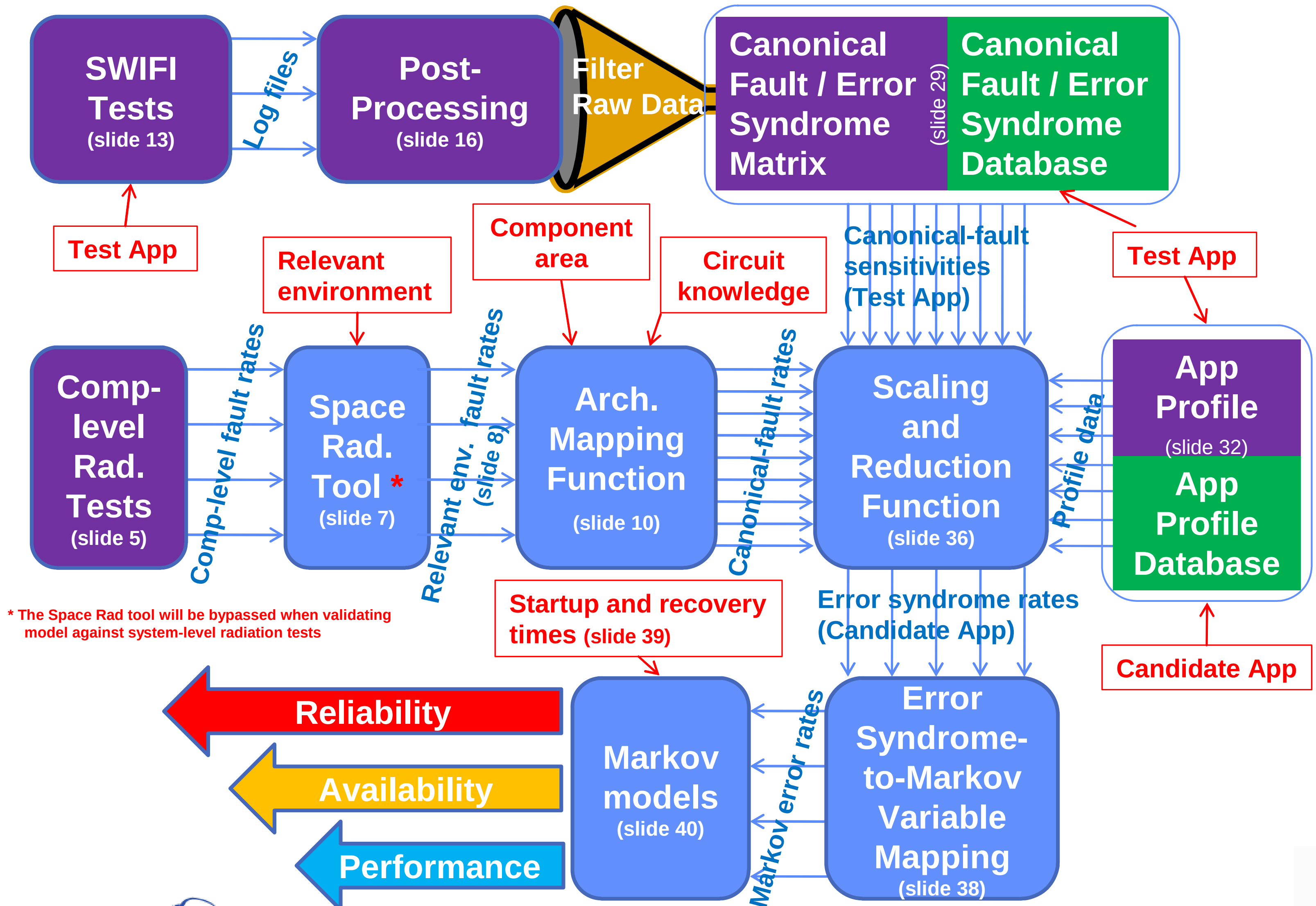
Data Flow Diagram for DM Markov Models



DM Technology - Platform Independence

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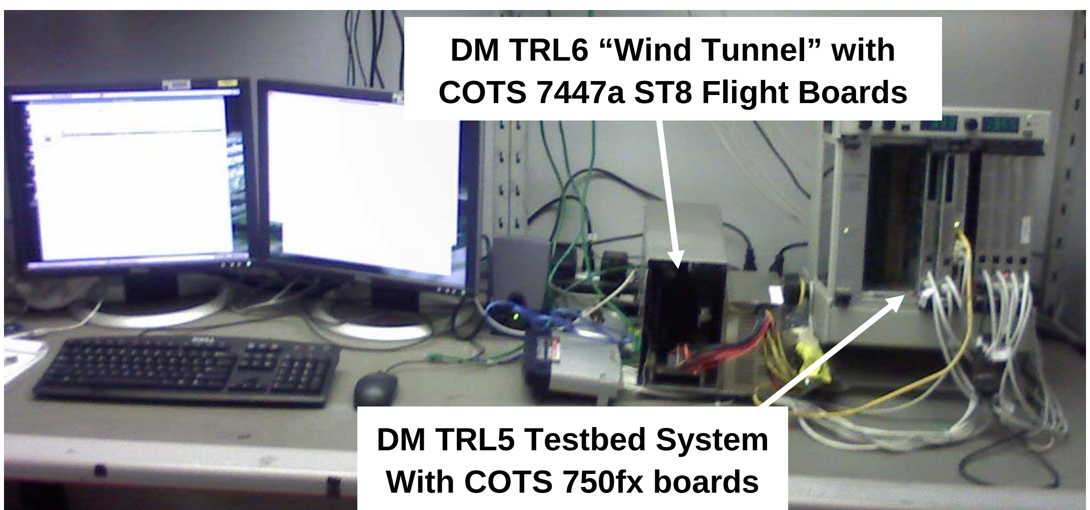
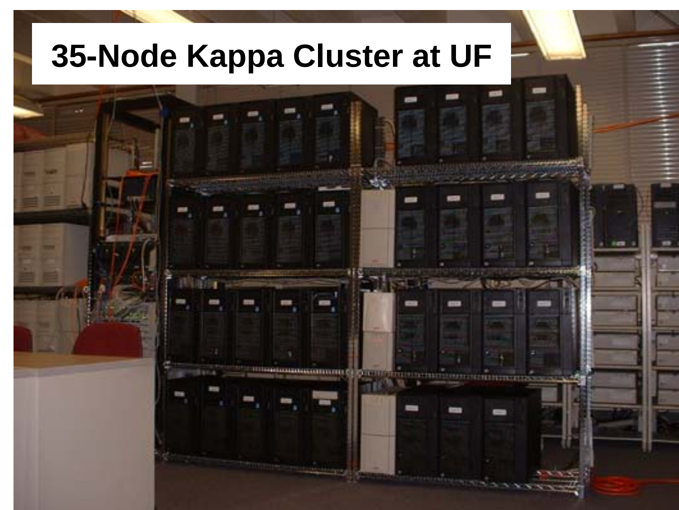
- **DM technology has already been ported successfully to a number of platforms with heterogeneous HW and SW elements**
  - Pegasus II with Freescale 7447a 1.0GHz processor with AltiVec vector processor with existing DM TRL5 Testbed
  - 35-Node Dual 2.4GHz Intel Xeon processors with 533MHz front-side bus and hyper-threading (Kappa Cluster)
  - 10-Node Dual Motorola G4 7455 @ 1.42 GHz, with AltiVec vector processor (Sigma Cluster) with FPGA acceleration
  - DM flight experiment 7447a COTS processing boards with DM TRL5 Testbed
  - DM TRL6 flight system testbed with 7447a COTS processing boards, with AliVec
    - -- > 300 MOPS/watt for HSI application (> 287 MOPS/watt including System Controller power)
  - State-of-the-art PA Semiconductor dual core processor
    - -- demonstrated high performance working under DM DMM umbrella
    - -- > 1077 MOPS/watt for HSI application





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NMP Breakthrough Technologies

DM Technology - Ease of Use

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- Successfully ported four (4) real applications to DM testbeds
  - HSI *
    - eminently scalable MPI application
    - ~ 14 hours to port application to DM system with DMM, hybrid ABFT, and in-line replication
    - ~ 4 hours to implement auto-correlation function in FPGA
  - SAR *
    - eminently scalable MPI application
    - ~ 15 hours to port application to DM system with DMM, hybrid ABFT, in-line replication, check-pointing
  - CRBLASTER (cosmic ray elimination application) **
    - eminently scalable MPI application
    - ~ 11 hours to port application to DM system with DMM, hybrid ABFT, and in-line replication
    - scalability demonstrated ~ 1 minute per configuration
  - QLWFP2C (cosmic ray elimination application) **
    - fully-distributed MPI application
    - ~ 4 hours port application to DM system with DMM
    - scalability demonstrated ~ 1 minute per configuration
  - NASA GSFC Synthetic Neural System (SNS) application for autonomous docking *
    - ~ 51 hours to port application to DM system with DMM (includes time required to find a FORTRAN compiler to work with DM)

* Port performed by Adam Jacobs, doctoral student at the University of Florida and member of ST8 DM team

** Port performed by Dr. Ken Mighell, NOAO, Kitt Peak Observatory, independent 3rd party user/application developer with minimal knowledge of fault tolerance techniques, per TRL6 requirement

Summary & Conclusion

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- **Flying high performance COTS in space is a long-held desire/goal**
  - Space Touchstone - (DARPA/NRL)
  - Remote Exploration and Experimentation (REE) - (NASA/JPL)
  - Improved Space Architecture Concept (ISAC) - (USAF)
- **NMP ST8 DM project is bringing this desire/goal closer to reality**
- **DM TRL6 Technology Validation Demonstration 9/15 & 9/16/08**
  - system-level radiation tests validated DM operation in a radiation environment
  - demonstrated high performance, high Reliability, high Availability and ease of use
- **DM technology is applicable to wide range of missions**
  - science and autonomy missions
  - landers/rovers
  - CEV docking computer
  - MKV
  - UAVs (Unattended Airborne Vehicles)
  - UUVs (Unattended or Un-tethered Undersea Vehicles)
  - ORS (Operationally Responsive Space)
  - Stratolites
  - ground-based systems & rad hard space applications

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NMP Breakthrough Technologies