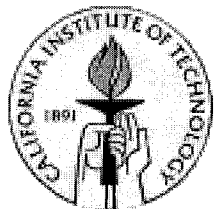# A Fault Tolerant Spacecraft Supercomputer to Enable a New Class of Scientific Discovery

## Part 1: The Core Cluster
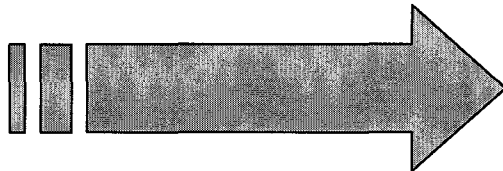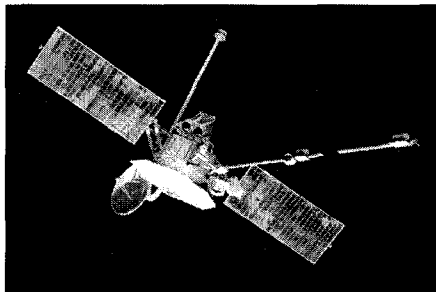
Supercomputing 2000
November, 2000
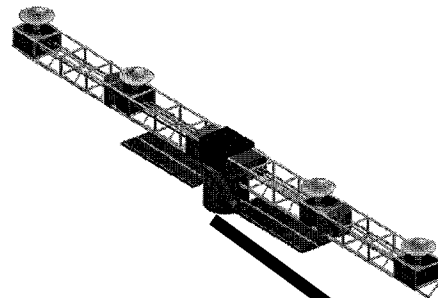R. Ferraro, D. Katz, A. Silliman,
Jet Propulsion Laboratory

# Past

# Future

Moving high performance
computing and applications
to the spacecraft
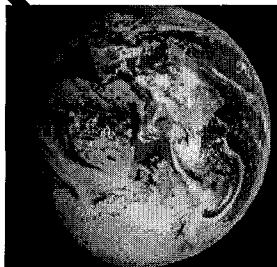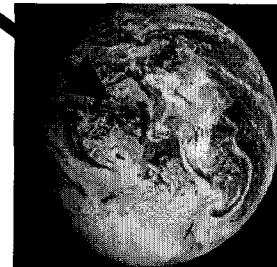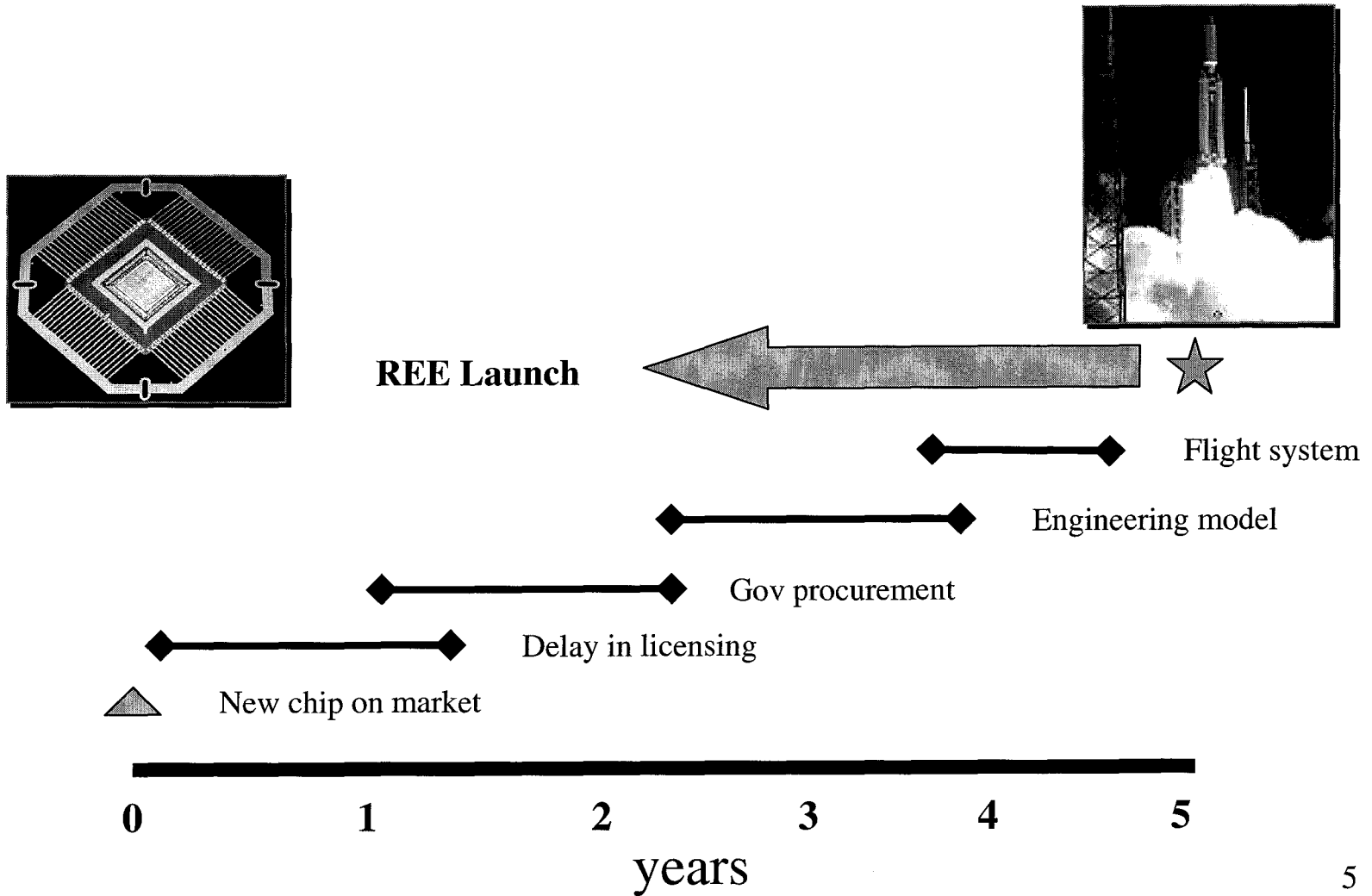
Raw data
sent to Earth
for processing

Health status and
"interesting" result
transmitted to Earth

# Chip flight qualification cycle



REE Launch

Flight system

Engineering model

Gov procurement

Delay in licensing

New chip on market

| 0 | 1 | 2 | 3 | 4 | 5 |

years

# Microcomputer Processor History



Chart showing Computational Rate (MIPS) on the vertical axis (0.01 to 1000, logarithmic) versus Launch Year (86 to 02) on the horizontal axis.

Data points and labels:
- 68020/33
- 68030/50
- 80386/33
- 68040/40
- 80486/25
- 80486/50
- Pentium/60
- PPC601/60
- PPC601/110
- Mars Pathfinder AIM (RAD6000)
- Stardust (RAD6000)
- Deep Space 1 (RAD6000)
- Clementine HKP (1750)
- Cassini (1750A)
- Mars Global Surveyor (1750A)
- Galileo CDS (1802)
- Mars Observer EDF (1750A)
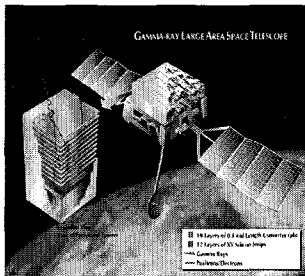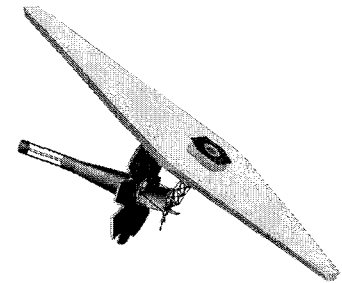- Mars Pathfinder Rover (80C85)

Legend: ● Intel  ● Motorola 680X0  ● PowerPC  ● Missions

# Five Science Application Teams Chosen to Drive Requirements and Demonstrate Benefits of HPC Onboard

**Next Generation Space Telescope - John Mather/GSFC**
- Onboard Cosmic Ray correction of the data
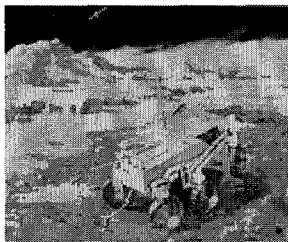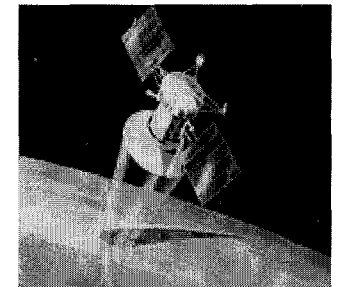- Autonomous control and optimization of the adaptive optics



**Gamma-ray Large Area Space Telescope - Toby Burnett/U Washington**
- Onboard cosmic ray rejection
- Real time gamma ray burst identification

**Orbiting Thermal Imaging Spectrometer - Alan Gillespie/U Washington**
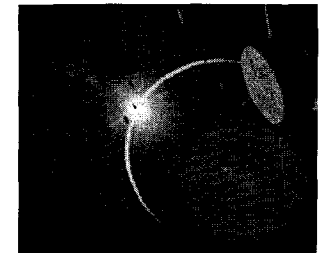- Onboard Atmospheric corrections, Radiance calculations

**Mars Rover Science - R. Steve Saunders/JPL**
- Autonomous optimal terrain navigation
- Autonomous Field Geology

**Solar Terrestrial Probe Program - Steve Curtis/GSFC**
- Constellation/Formation Flying missions to probe the Sun-Earth Connection
- Onboard Plasma moment calculations, multi-instrument cross correlations, autonomous operations

# REE First Generation Testbed

**Standard" VME Chassis**

**20 REE Node Modules**

**Expansion Slots**
(Spare Node Modules or Standard VME Modules)

Spare Module

Spare Module

VME Module

VME Module

**Myrinet Network**

**Standard VME Backplane**

External Myrinet Switch

**4 Sun Workstations with RAID Disks**

**REE Testbed**

**IP Connection**

Mass Storage

Remote User Access

**Remote Users**

8
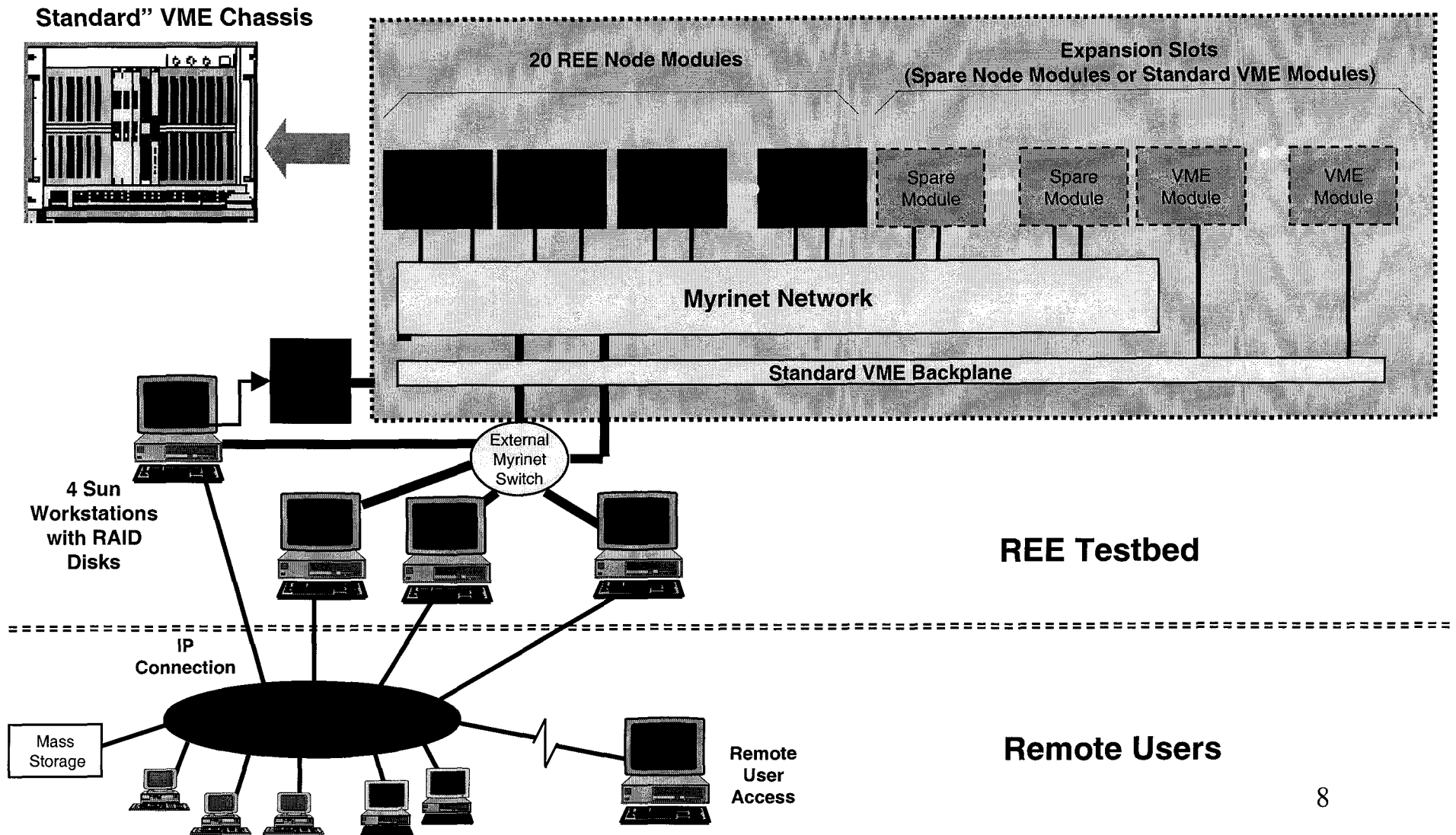
# The SIFT
# Recovery Hierarchy

**The Core Cluster contains the scheduler and resource manager**
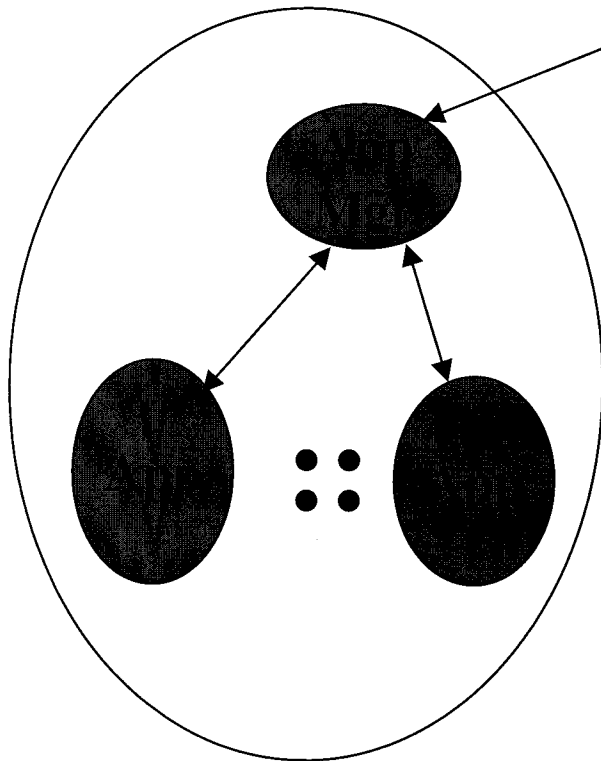
System Exec
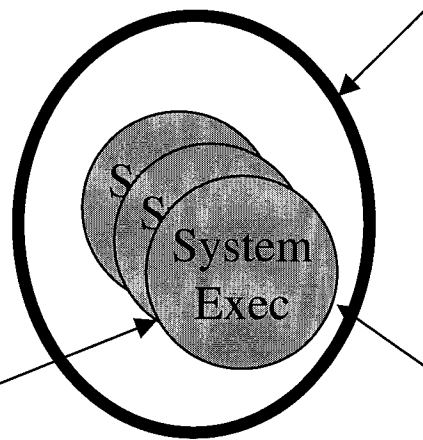
**Application support includes application manager and application services**

**Local Fault Detection uses Algorithm-Based Fault Tolerance**
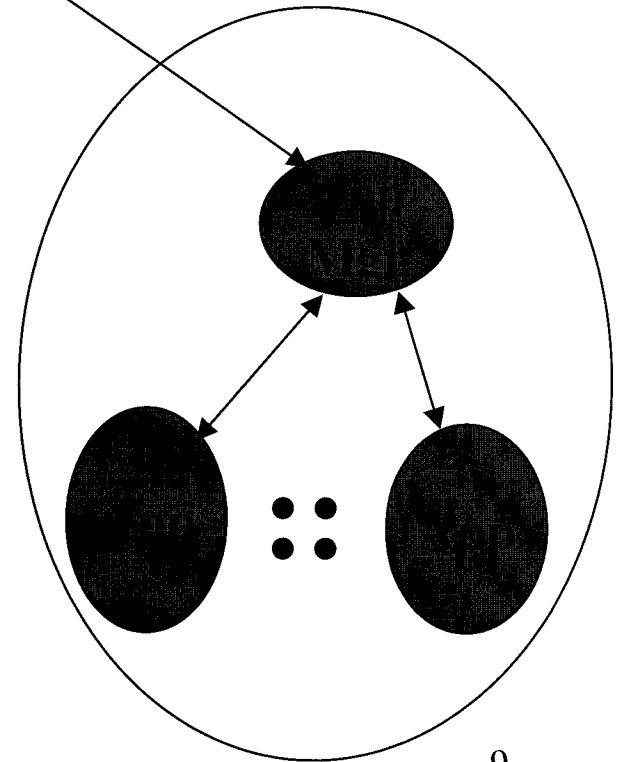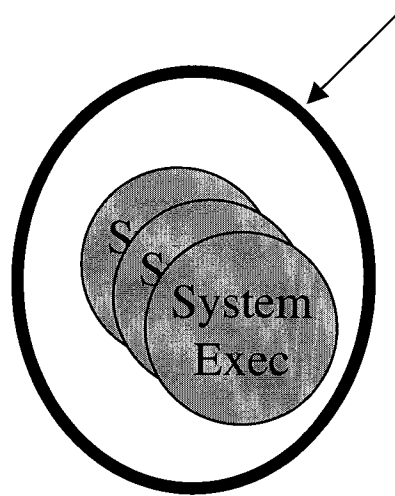
9

# Demonstration
# of core cluster
# fault tolerance

The Core Cluster
contains the scheduler
and resource manager

**This is an example of the functionality
required for REE using:**

**N-Modular Redundancy (NMR)**

**Four nodes (currently)**

First demonstration will be to
corrupt a message in node 1

# System Status: Full Up

## FTP 1

Application
Maintain Group

Clock Sync
Maintain Group

## FTP 2

Application
Maintain Group

Clock Sync
Maintain Group

## FTP 3

Application
Maintain Group

Clock Sync
Maintain Group

## FTP 4

Application
Maintain Group

Clock Sync
Maintain Group

## Network

## Fault Data

| FTP 1: | No faults detected |
|--------|--------------------|
| FTP 2: | No faults detected |
| FTP 3: | No faults detected |
| FTP 4: | No faults detected |

## Interface Node

Node Status
Maintain Group

Network Status

## Parallel Processing Cluster

# System Status: Full Up

## FTP 1

Application

Maintain Group

Clock Sync

Maintain Group

## FTP 2

Application

Maintain Group

Clock Sync

Maintain Group

## FTP 3

Application

Maintain Group

Clock Sync

Maintain Group

## FTP 4

Application

Maintain Group

Clock Sync

Maintain Group

## Network

## Fault Data

| FTP 1: | Asymmetric fault detected |
| FTP 2: | No faults detected |
| FTP 3: | No faults detected |
| FTP 4: | No faults detected |

## Interface Node

Node Status

Maintain Group

Network Status

## Parallel Processing Cluster

# System Status: Triplex Mode

## FTP 1



Application

Maintain Group

Clock Sync

Maintain Group

## FTP 2



Application

Maintain Group

Clock Sync

Maintain Group

## FTP 3



Application

Maintain Group

Clock Sync

Maintain Group

## FTP 4



Application

Maintain Group

Clock Sync

Maintain Group

## Network

## Fault Data

| FTP 1: | No faults detected |
|--------|--------------------|
| FTP 2: | No faults detected |
| FTP 3: | No faults detected |
| FTP 4: | No faults detected |

## Interface Node



Node Status

Maintain Group

Network Status

## Parallel Processing Cluster

# System Status: Full Up

## FTP 1

Application

Maintain Group

Clock Sync

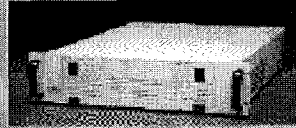Maintain Group

## FTP 2

Application

Maintain Group

Clock Sync

Maintain Group

## FTP 3

Application

Maintain Group

Clock Sync

Maintain Group

## FTP 4

Application

Maintain Group

Clock Sync

Maintain Group

## Network

## Fault Data

| FTP 1: | No faults detected |
|--------|--------------------|
| FTP 2: | No faults detected |
| FTP 3: | No faults detected |
| FTP 4: | No faults detected |

## Interface Node

Node Status

Maintain Group

Network Status

## Parallel Processing Cluster

# System Status: Full Up

## FTP 1

Application

Maintain Group

Clock Sync

Maintain Group

## FTP 2

Application

Maintain Group

Clock Sync

Maintain Group

## FTP 3

Application

Maintain Group

Clock Sync

Maintain Group

## FTP 4

Application

Maintain Group

Clock Sync

Maintain Group

## Network

## Fault Data

| FTP 1: | Asymmetric fault detected |
|--------|---------------------------|
| FTP 2: | No faults detected |
| FTP 3: | No faults detected |
| FTP 4: | No faults detected |

## Interface Node

Node Status

Maintain Group

Network Status

## Parallel Processing Cluster

# System Status: [ Triplex Mode ]

## FTP 1

Application

[ Not Connected ]

Clock Sync

[ Not Connected ]

## FTP 2

Application

[ Maintain Group ]

Clock Sync

[ Maintain Group ]

## FTP 3

Application

[ Maintain Group ]

Clock Sync

[ Maintain Group ]

## FTP 4

Application

[ Maintain Group ]

Clock Sync

[ Maintain Group ]

## Network

## Fault Data

| FTP 1: | No faults detected |
|--------|-------------------|
| FTP 2: | No faults detected |
| FTP 3: | No faults detected |
| FTP 4: | No faults detected |

## Interface Node

Node Status

[ Maintain Group ]

Network Status

## Parallel Processing Cluster

# Demonstration of core cluster fault tolerance

**The Core Cluster contains the scheduler and resource manager**

**This is an example of the functionality required for REE using:**

**N-Modular Redundancy (NMR)**

**Four nodes (currently)**

Second demonstration will be to Inject a fault into node 3

# System Status: [Triplex Mode]
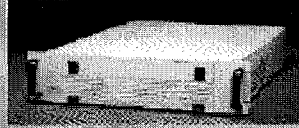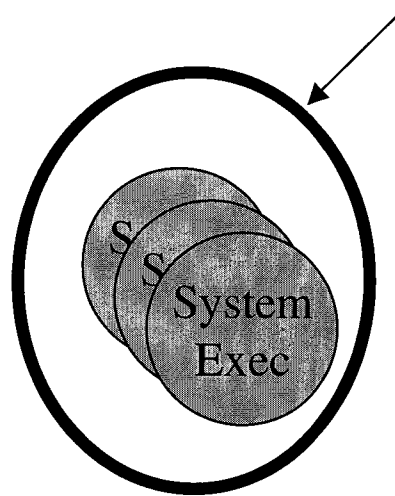
## FTP 1

Application

[Not Connected]

Clock Sync

[Not Connected]

## FTP 2

Application

[Maintain Group]

Clock Sync

[Maintain Group]

## FTP 3

Application

[Maintain Group]

Clock Sync

[Maintain Group]

## FTP 4

Application

[Maintain Group]

Clock Sync

[Maintain Group]

## Network

## Fault Data

| FTP 1: | No faults detected |
|--------|--------------------|
| FTP 2: | No faults detected |
| FTP 3: | Symmetric fault detected |
| FTP 4: | No faults detected |

## Interface Node

Node Status

[Maintain Group]

Network Status

## Parallel Processing Cluster

# System Status: `Duplex Mode`

## FTP 1


Application

`Not Connected`

Clock Sync

`Not Connected`

## FTP 2


Application

`Maintain Group`

Clock Sync

`Maintain Group`

## FTP 3


Application

Clock Sync

## FTP 4


Application

`Maintain Group`

Clock Sync

`Maintain Group`

## Network

## Fault Data

| | |
|---|---|
| FTP 1: | No faults detected |
| FTP 2: | No faults detected |
| FTP 3: | No faults detected |
| FTP 4: | No faults detected |

## Interface Node


Node Status

`Maintain Group`

Network Status

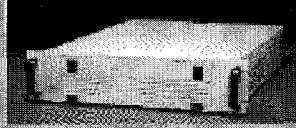## Parallel Processing Cluster
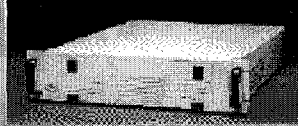
# System Status: Duplex Mode

## FTP 1

Application
Not Connected

Clock Sync
Not Connected

## FTP 2

Application
Maintain Group

Clock Sync
Maintain Group

## FTP 3

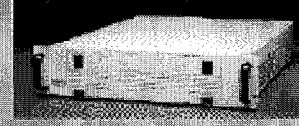Application
Not Connected

Clock Sync
Not Connected

## FTP 4

Application
Maintain Group

Clock Sync
Maintain Group

## Network

## Fault Data

| FTP 1: | No faults detected |
| FTP 2: | No faults detected |
| FTP 3: | No faults detected |
| FTP 4: | No faults detected |

## Interface Node

Node Status
Maintain Group

Network Status

## Parallel Processing Cluster
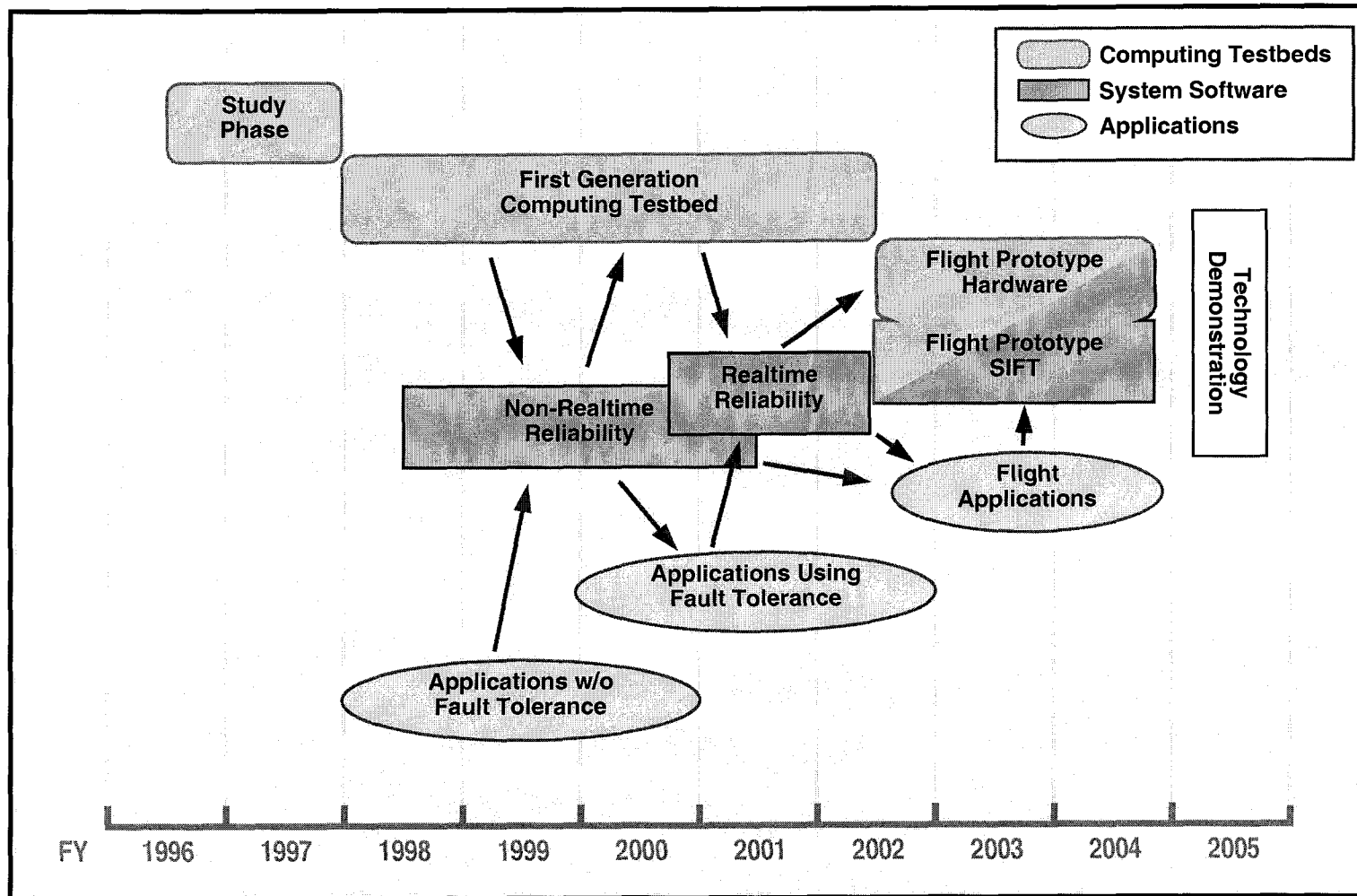
# Where are we ?

- We have demonstrated that the Core Cluster works in the presence of faults
- Current Core Cluster is a prototype ported from a military application
- Over the next 18 months an REE-specific Core Cluster will be developed with:
    - Dynamic node configuration
    - Ability to manage simultaneous applications
    - Ability to configure to required reliability level

# Where do we go from here?



Legend:
- Computing Testbeds
- System Software
- Applications

Study Phase

First Generation Computing Testbed

Flight Prototype Hardware

Flight Prototype SIFT

Technology Demonstration

Non-Realtime Reliability

Realtime Reliability

Flight Applications

Applications Using Fault Tolerance

Applications w/o Fault Tolerance

FY   1996   1997   1998   1999   2000   2001   2002   2003   2004   2005

# Credits

- General Dynamics - Chris Wink and John Pawasuskas
- W. W. Technology Group - Chris Walter and Brian LaValley
- Chalmers University - Neeraj Suri
- University of California Los Angeles – Dave Rennols
- JPL - Fannie Chen, Loring Craymer, Jeff Deifik, Al Fogel, Dan Katz, Al Silliman, Rafi Some, Sean Upchurch, Mike Turmon, Robert Granat, John Davidson, Robert Ferraro, John Beahan, John Thomas, Scott Packard, Yee Lee, Paul Springer, Roger Lee