Remembering the Past from the Depths of Space

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Acknowledgment

Much of this information was derived from the draft version of the

New Frontiers in the Solar System

An Integrated Exploration Strategy

by the Space Studies Board of the National Research Council and supporting mission studies
Chartered to survey the subject of what is already known and to create an integrated strategy for future solar system exploration.

Key themes identified:
- The First Billion Years of Solar System History
- Volatiles and Organics: The Stuff of Life
- The Origin and Evolution of Habitable Worlds
- Processes: How Planets Work
Context

• Example missions were identified to address these themes
  – Some are doable with today’s technology
  – Some require near term technology
  – Some require significant advances in technology

• The exploration of the solar system is a technically challenging and expensive endeavor.
Deep Impact
Deep Impact Mission

- Catch up with Comet Tempel 1 on July 4, 2005
- Send 370 kg probe to impact surface
- Observes and records data from material dissipated into space and fresh material exposed on surface
- Mission duration 19 months
  - Science portion 1-2 days
  - Data return 30 days
Dawn spacecraft - courtesy Orbital Sciences Corp.
Dawn Mission

- Visiting 2 protoplanets in search of the role of size and water in determining the evolution of the planets
- 11 month orbital period around each of Vesta and Ceres
Landers/Probes

- Landers and Probes are used for extreme environments
  - Temperature – Venus
  - Radiation - IO/Europa
  - Pressure – Jupiter
  - Shock – Deep Space 2 (Mars)

Outer Planets Multiprobes
• Dumb landing/
decending systems –
Air Bags: Mars
Pathfinder, Parachute:
Huygens, Galileo Probe

• Smart landing/
descending systems –
Rocket Descent: Mars
98, Viking, Mars
Science Laboratory
Landers and Probes are extremely volume, power and mass constrained. Usually have to relay data to mothership such as an orbiter. Small buffers for science data storage and computer processing. Must survive environmental requirements.
Flyby Missions

- Large flyby velocities
  - data acquired very rapidly
  - Little time for data compression during acquisition
  - Attitude control for maneuvering during science acquisition is computer intensive
- On-board data storage required to hold data until it can be returned after flyby
Orbiters

- Long one way light time
- Data return limited by telecommunications state-of-the-art
  - State of the art gets about 1 Mb/s from 6 AU
- Deep Space Network a shared resource
- Further distances severely limit rate requiring more data stored on board until it can be returned

Neptune Orbiter
On-Board Autonomy

- Entry-Descent-Landing requires intense computer resources
  - Extensive data taking and reconciliation by computer algorithms require fast memory access times
- Rendezvous and docking requires tight control loops for attitude control with stored
- Interferometry requires precise tracking and position determination
Environmental Factors

- Solar Flares and Galactic Cosmic Ray environments create havoc for memory data retention and data integrity
  - SEE and SEU drive computer system reset rates and mass memory system EDAC requirements

- Missions to the Jovian systems require radiation tolerance or hardness
  - 100 Krad tolerable
  - 1 Mrad much better
  - Example – FLASH for mass memory on Europa Orbiter required approximately 4 kg Tungsten/Copper shielding per 2 Gbit
Jupiter Orbiters

- Jovian system of high import to planetary science community
- Environment harsh for memory systems
- Large operations teams required to effectively compensate for on-board anomaly
The Europa Orbiter total dose environment is harsh compared to current experience.

- At Europa an astronaut inside an EVA suit receives a lethal dose every 12 minutes.

The Europa Orbiter must operate with high reliability during the 30 day mission.

- Science objectives
- Achieve quarantine orbit

Impact

- High technology, high risk, high cost electronics development to reduce risk
Environmental Factors

- Many mass memory chips only available from commercial manufacturing lines
  - Lose insight into manufacturing processes
  - Not consistent from lot to lot
  - No traceability to investigate failures
  - Less stringent screening and life testing requirements
## Data Storage Technologies

### A Small Historical Perspective

<table>
<thead>
<tr>
<th>Item</th>
<th>MGN</th>
<th>CAS</th>
<th>MPF</th>
<th>X2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cap.</td>
<td>1.8Gb</td>
<td>2.5Gb</td>
<td>2Mb</td>
<td>2Gb</td>
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<tr>
<td>Media</td>
<td>Tape</td>
<td>DRAM</td>
<td>EPROM</td>
<td>Flash</td>
</tr>
<tr>
<td>Qty</td>
<td>1/3 Mile</td>
<td>640</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>Pwr</td>
<td>35W, 28V</td>
<td>12W, 28V</td>
<td>7W, 5.12V</td>
<td>3W, 3.3V</td>
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<tr>
<td>Mass</td>
<td>22kg</td>
<td>17kg</td>
<td>4kg</td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td>16x12x8 (inches)</td>
<td>16x8x7 (inches)</td>
<td>6U VME (2 cards)</td>
<td>3U PCI</td>
</tr>
<tr>
<td>VOLATILE</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>
Data Storage Technologies

CAS

- 2.5 Gb, incl. Spare
- 12 W, 17-kg
- 20 kRads
- 18 ASICs
- 1 Mbps full-custom serial
- 35ms hold-up by capacitor bank

X2000 NVM

- 1.7 kg shielded
- 100 kRads
- 1 ASIC
- 33 MHz PCI interface
- True Non-Volatility
A Comparison of Generations

< Cassini SSR
17 kg, 12W, Volatile

< X2000 NVMS
220g (unshielded), 3W, NONVOLATILE
Prior Art: GLL & MGN Recorder
Major Drivers

- **Mass/Density**
  - Space missions are constrained by current launch capabilities – what can be launched
  - Defined by orbital mechanics
  - Can directly effect flight time to target
  - Always severely mass constrained
  - The less engineering systems weigh, the more science for the dollars
  - Orbiting bodies or landing masses require significant amounts of infrastructure mass
Major Drivers

- Power
  - Solar power drops off as square of distance from sun
  - Nuclear power required for some missions
  - Therefore, deep space missions require low power electronics

- Volume
  - Constrained by launch vehicle shroud
  - Ultimately translates to mass or performance
Major Drivers

• Speed
  – Access time extremely important to get best performance from processors

• Radiation/SEE performance
  – Jupiter deemed important target, need radiation tolerant/hard electronics
  – Deep space missions need to endure GCR and solar flares
Future Needs

- Consistent Space Product
  - High quality
  - Proven life
  - Predictable behavior

- Low Cost
  - Mass production
  - Pin-for-pin replacements for current product
Future Needs

- Super Dense Volatile Memories
  - Fast access time
  - Radiation hardened
  - Keep pace with computer processor improvements

- Dense Non-Volatile Memories
  - Prime science data storage
  - Low power
  - Large read/write cycles for long mission engineering data storage
  - Radiation hardened
MER Rover