Changing the Game

SOFT SPACECRAFT

Applying Lessons from High Technology Start-Up Entrepreneurs

READY

Use massive and general purpose on-board *computation, memory, bandwidth, and connectivity* to assemble a maximally flexible spacecraft.

FIRE!

Confirm assembly, connectivity, and sub-system functionality. Basic ACS, command, and telemetry capability.

Then launch!

AIM

After launch, develop integrated and coordinated behaviors. Change behaviors over time as opportunities appear.

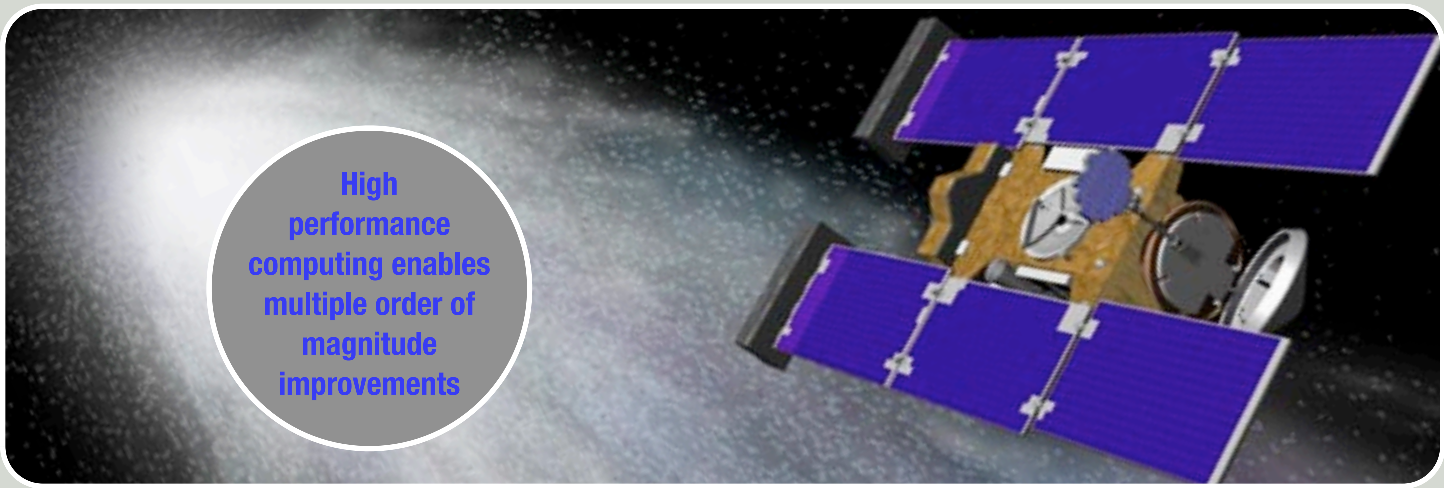
David E. Smyth
Jet Propulsion Laboratory
David.Smyth@jpl.nasa.gov

Changing the Game

SOFT SPACECRAFT

Computing Power Enables:

Dramatically lower risk, greatly improved ability to meet schedules and budget, combined with unbounded capability and mission flexibility.



SPACECRAFT ARE HARD... DO THEY HAVE TO BE?

Limitations in shared resources — computation, memory, connectivity, bandwidth — forces early optimization across the spacecraft, resulting in point solutions, and worse...

We all know that mission schedules and budgets through launch are dependent upon the development, integration, and test of each and every subsystem (instruments, propulsion, power, thermal, and so on).

We also know that coupling between subsystems, where constraints are tight, lead to high impact risks: insufficient margin (e.g., "not quite enough") *tremendously increases complexity* and therefore risks to cost, schedule, and even mission success. Yet early in the project, decisions are made to provide "just enough" capability in a short term game of lowering costs.

Therefore**, providing far-more-than-enough of the resources that are in contention can lead to dramatically simpler spacecraft with far* ***more certain schedules and budgets.

We all know that only the software can be improved after launch. Hardware can only degrade over the life of the vehicle.

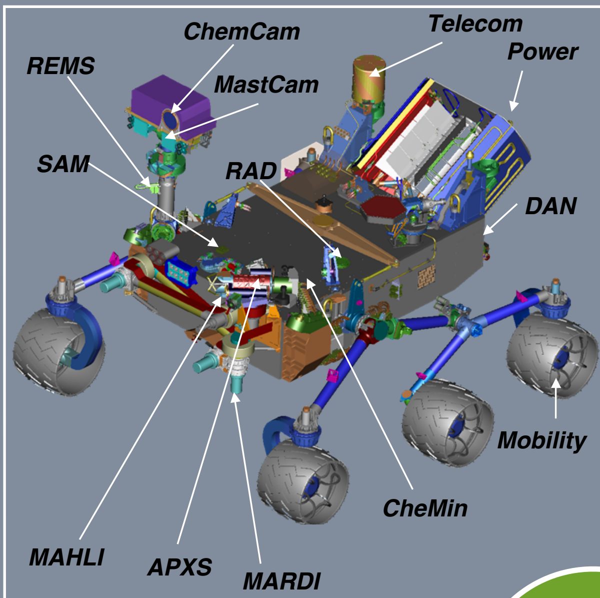
We also know that deep understanding of the operability and capabilities of a spacecraft is only obtained long after the spacecraft is launched. Yet conventional spacecraft missions try to specify these concepts early, for the most part prior to PDR.

We also know that the ability to clearly assign responsibility for managed resources to each deliverable subsystem is fundamental to project management.

Therefore**, implementing behaviors in software in a general purpose very high performance platform with modern security and resource management* ***enables complex and flexible missions.

Deep Impact becomes EPOXI
After the seemingly one-shot mission of ***Deep Impact***, the vehicle was first successfully re-purposed as an interplanetary communication research asset, and now is on its way to another comet encounter.

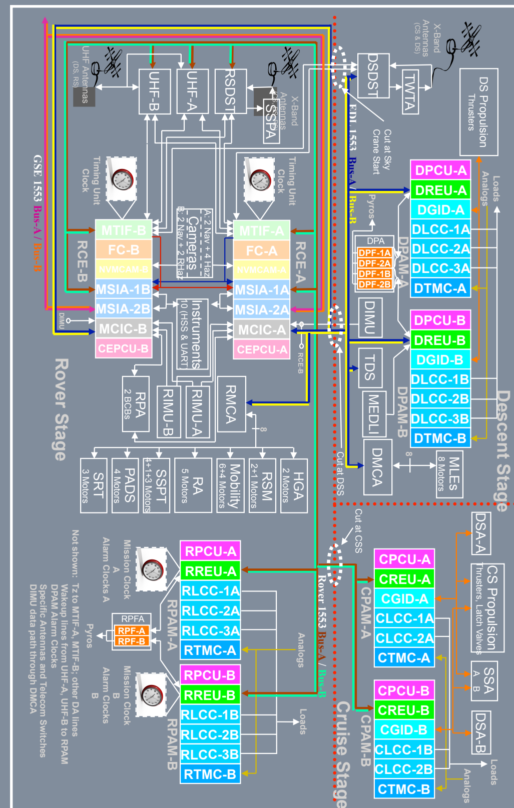
INCIDENTAL COMPLEXITY



Inherent Complexity

The basic component diagram of the MSL spacecraft is shown above.

Complexity due to Inadequate Margins



Incidental Complexity due to Constraints

The actual block diagram of the MSL spacecraft is shown above. The shocking increase in complexity is due to inadequate margins for computation, memory, internal connectivity and bandwidth.

Mass and Power are Limited

Mass and electrical power are very constrained shared resources on deep space missions. Usually, the mass and energy limits are firmly capped very early in the mission by the budget, launch vehicle, and trajectory. Hence there usually is no ability to provide far-more-than-enough of these resources, so the mass and energy coupling between subsystems, and therefore incidental but mission threatening complexity, is unavoidable in the near term.

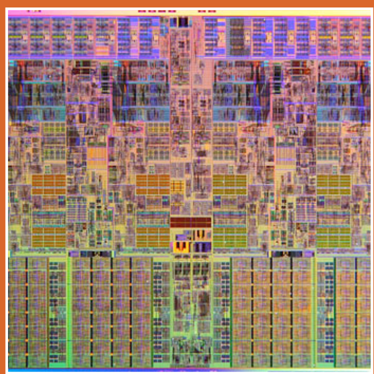
30% of the flight software on Mars Surface Laboratory exists simply to deal with bandwidth and connectivity limitations of the 1553 bus

Computation, Memory, Connectivity, and Internal Bandwidth Don't Need To Be Limited

Recent space missions struggle mightily due to the incidental complexity due to inadequate margins of computation, memory, connectivity, and internal bandwidth. For example, over 30% of MSL Flight Software is due to the connectivity and bandwidth limitations of the internal 1553 bus.

With multicore computers, substantial memories, and high speed non-scheduled networks the far-more-than-enough levels of computation, memory, connectivity, and internal bandwidth can be provided at current levels of mass and power.

CHEAP EXCESS



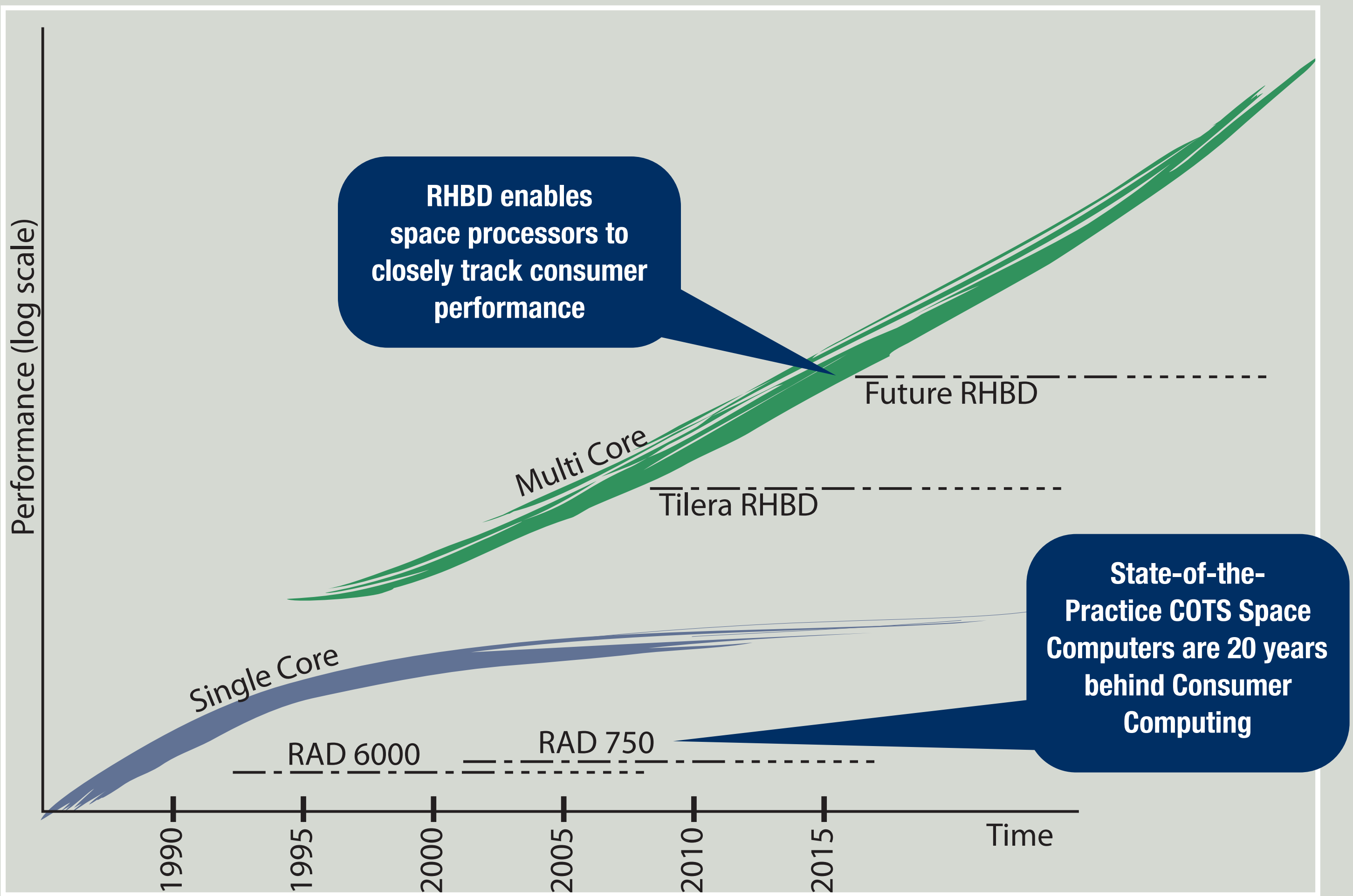
Transform consumer component design to rad hard using DARPA and DTRA developed RHBD libraries and DoD Trusted Foundry program

RHBD: Rad Hard by Design Enables High Capability Space Computing

Consumer electronics has led the way to low cost, low power, high performance computing. Due to unavoidable radiation hardness requirements, space electronics are expensive, low performance, and power inefficient. Current state of the art general purpose space computers are 20 years behind consumer computing. How do we get space computing on the consumer electronics performance growth curve?

The simple fact is that consumer computing is leaving the single core behind for multi core processors. Such processors demonstrate performance previously obtained by super computing clusters, and power-performance previously obtained only by special purpose array processors.

The DARPA rad-hard by design (RHBD) program is developing and proving libraries to alter existing IC designs to become radiation hardened. This enables new processors to become rad hard for one time engineering costs in the $10M range, as currently being demonstrated by the Maestro processor that is based on a Tilera 64 processor multi-core chip design.



HOW DO WE GET THERE

Small studies and experiments to trail blaze the path to Soft Spacecraft