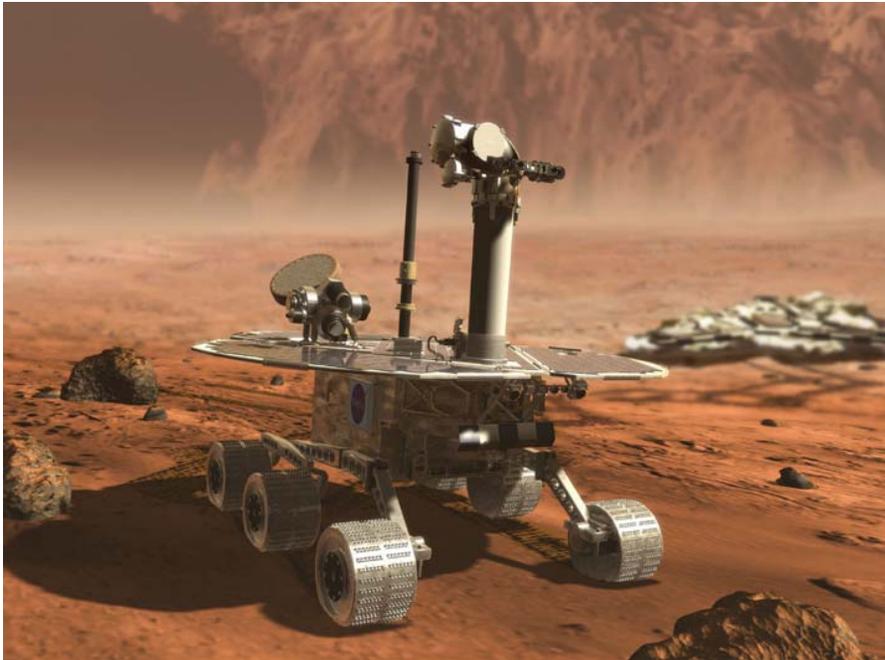




Mars Exploration Rover

VxWorks on the Mars Exploration Rovers





VxWorks on Mars



Mars Exploration Rover

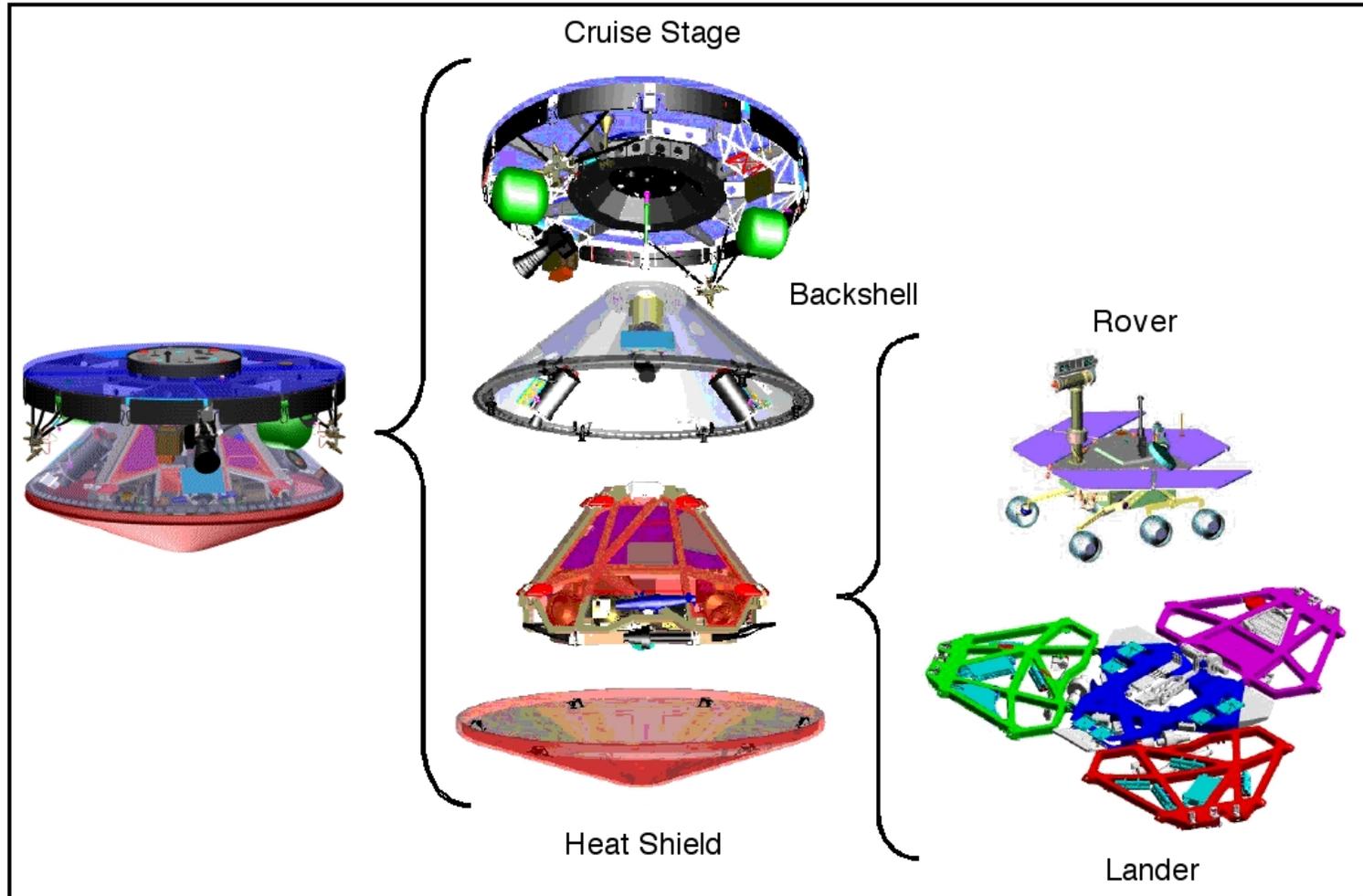
- **What are the Mars Exploration Rovers**
- **VxWorks for the Mars Exploration Rovers**
- **VxWorks Features Used**
- **System Design Constraints**
- **Very Remote Operations**
- **Challenges**
- **Mission Successes**
- **Lessons Learned**
- **A Few Pictures...**



What are the Mars Exploration Rovers (1)



Mars Exploration Rover





What are the Mars Exploration Rovers (2)



Mars Exploration Rover

- **Mission inception July 2000**
- **Launched June and July 2003**
- **Landed January 2004**
- **Nominal mission 90 martian days (sols) on the surface of Mars**
- **Primary intent to discover geologic evidence of past water on Mars**



- **MER used VxWorks 5.3.1 for the R6000, with TFFS**
- **Compiled with Green Hills 3.5**
- **Special version of both, so that VxWorks was compiled from source code. We wanted a validated toolchain for the R6000**
- **Tight schedule left no room for upgrades**
- **Heritage from Mars Pathfinder**



VxWorks Features Used



Mars Exploration Rover

- **Scheduler (94 user tasks)**
- **Pipes (used for inter-process communication)**
- **Filesystem (allowed storage of data files in RAM and Flash memory)**
- **Shell (used to adjust configuration on the fly)**
- **Watchdog services (64 Hz hardware timer drove VxWorks time source)**



System Design Constraints



Mars Exploration Rover

- **R6000 processor at 20 MHz**
- **Limited power led to multiple shutdown/wakeup cycles per sol**
- **Excessive communications delays (round trip light time between 20 and 45 minutes) led to sequenced execution and autonomous communication**



Very Remote Operations



Mars Exploration Rover

- **One way light time from Earth to Mars was 11 minutes at landing, 22 minutes at conjunction --> between 20 and 45 minutes to hear back from rovers!**
- **Best direct to earth data rate ~16 kbps (*very slow modem!*)**
- **Best relay data rate ~60 kbps (still not terribly fast)**
- **Best uplink rate ~2000 bps**
- **Communications with rovers usually one direct from earth uplink session and one relay downlink session (through Mars Odyssey spacecraft) per sol**
- **Emergency service hooks**



Challenges



Mars Exploration Rover

- **Sol 18 anomaly (interplanetary roadside assistance)**
 - **Flash filesystem takes RAM space**
 - **VxWorks configuration set to suspend on malloc failure**
 - **Delayed reset and crippled boot allowed recovery of system**
 - **Excellent support from VxWorks dedicated support engineer essential to understanding and fixing system**
 - **File system memory recovery instituted, resulted in flight software update**
- **Still discovering features of the system more than one year after landing**
 - **Data product autodeletion**
 - **Race conditions**



Missions Wildly Successful



Mars Exploration Rover

- **Still going well beyond 400 martian days (sols)!**
- **Still investigating 2 different sites on the surface of Mars**
- **Discovered evidence of past liquid water (at both sites)**
- **As of [tbd date], Opportunity has traversed over [4] kilometers, Spirit has traversed over [2] kilometers**
- **Updated flight software three times since launch**
- **Two rovers have taken over 50,000 pictures**
- **How many billion web hits?**



Lessons Learned



Mars Exploration Rover

- **Keep it simple**
- **Test what you fly, fly what you test**
- **Build in self-preservation behavior – system takes care of itself**
- **Build in emergency service hooks to handle unanticipated problems**



Pictures (1 of several)



Mars Exploration Rover