The Care and Feeding of the Mars Exploration Rover (MER) Ground Data System (GDS)

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The Scope of This Presentation

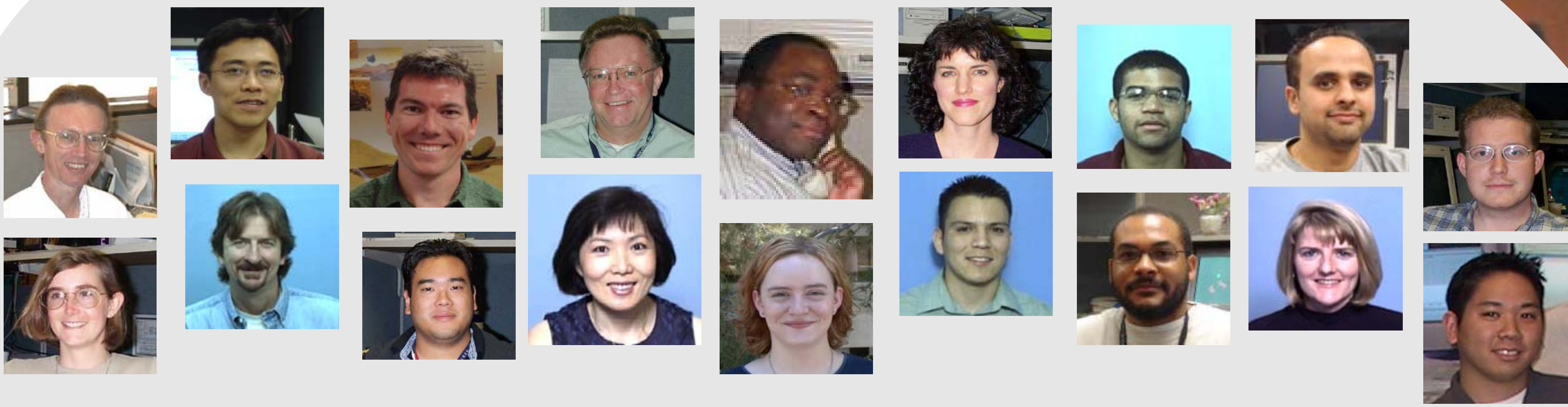
- Will discuss challenges and lessons learned through the design, adaptation, deployment and operations of the MER GDS
- Speaks from the perspective of the Mission GDS Deployment (MGD) team
  - The MER GDS is an extensive system consisting of many components and personnel. This presentation will focus on a small subset of and by no means attempts to be representative of the entire MER GDS effort.

MGD? Who are we?

The Mission GDS Deployment Team:

- Is an 18 member group, focused on customer needs
- Works in cooperation with mission ground data system engineers and JPL institutional software development organizations to provide GDS system solutions
- Designs, develops or adapts, tests, deploys and maintains ground solutions such as processes, software tools and user environments
- Seamlessly integrates into mission GDS engineering and support
- Provides user training, and on-call and on-site customer support
- Provides real-time GDS analysis for spacecraft mission operations

The Cast of Characters…



…And the Missions We Support

Mars Reconnaissance Orbiter

Spitzer Space Telescope

2001 Mars Odyssey

Genesis

Stardust

Mars Global Surveyor

Mars Exploration Rover

Galileo

Deep Space 1

JPL NASA Voyager I & II — Jupiter Saturn Uranus Neptune and Beyond…

Dawn

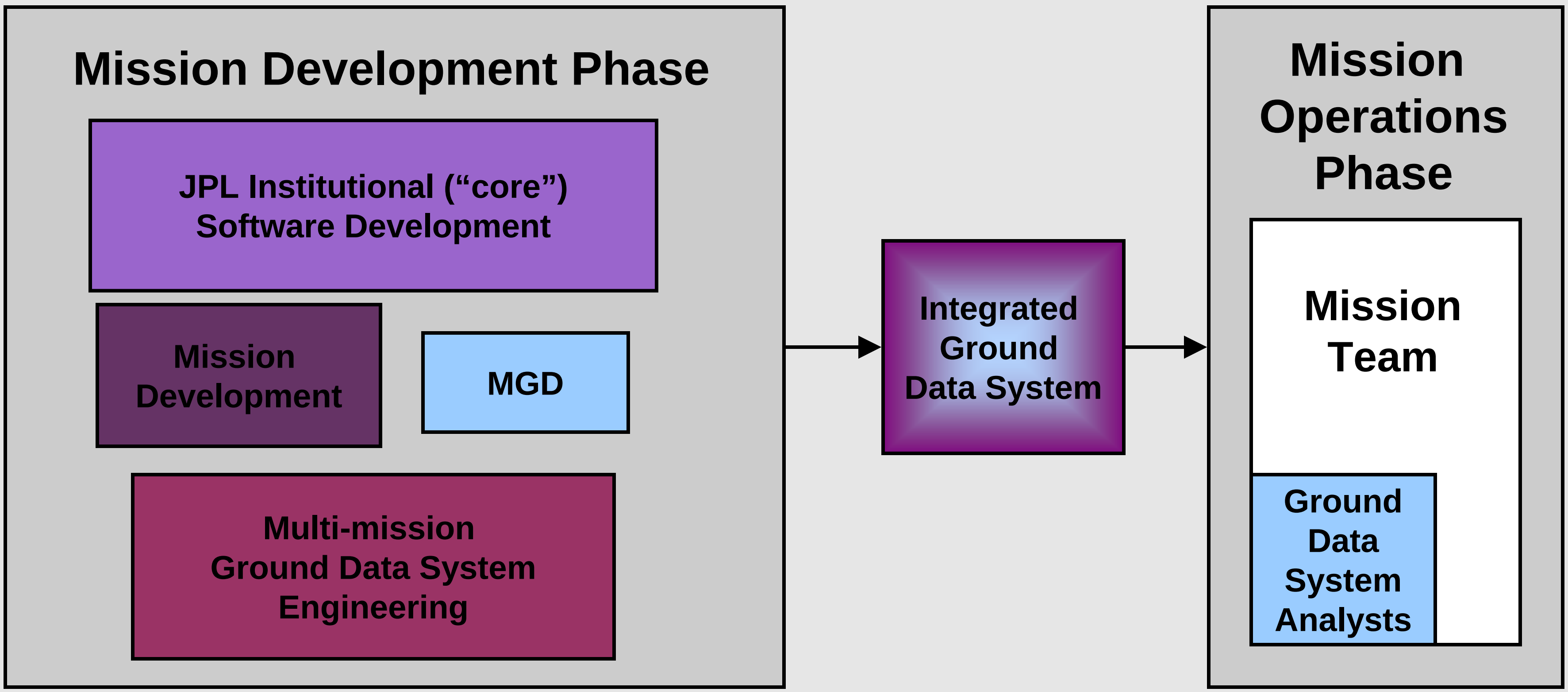
Ulysses

Phoenix Mars Lander 2007

Cassini-Huygens — Mission to Saturn & Titan

Deep Impact

MER MGD - Where we fit in



A very simplified diagram

MER MGD Products & Services

- MGD provides the mission with many products and services

MER Areas receiving some or all of these MGD Services

FSW Development Testbed
In-Situ Instrument Lab ISIL
Assembly, Test and Launch Operations (ATLO) at JPL and KSC
GDS Testbed
Cruise Mission Support Area
Surface Mission Support Areas

- Development of customized, project specific tools
- GDS design support and testing
- GDS Deployment
- Distribution and management of detailed project controlled files
- Adapted end-user workstations
- Project-specific GDS training
- Operational Readiness Test (ORT) support
- Launch Support
- Realtime GDS analysis and troubleshooting

An MGD Perspective on Challenges & Resolutions

Baseline Changes

- MER was a very dynamic mission with compressed development time
- Due to time constraints, the project constantly had to look for ways to increase productivity in order to meet deadlines
- The operational baseline changed to optimize science data return
- Changes to the mission baseline presented our team with its biggest challenge

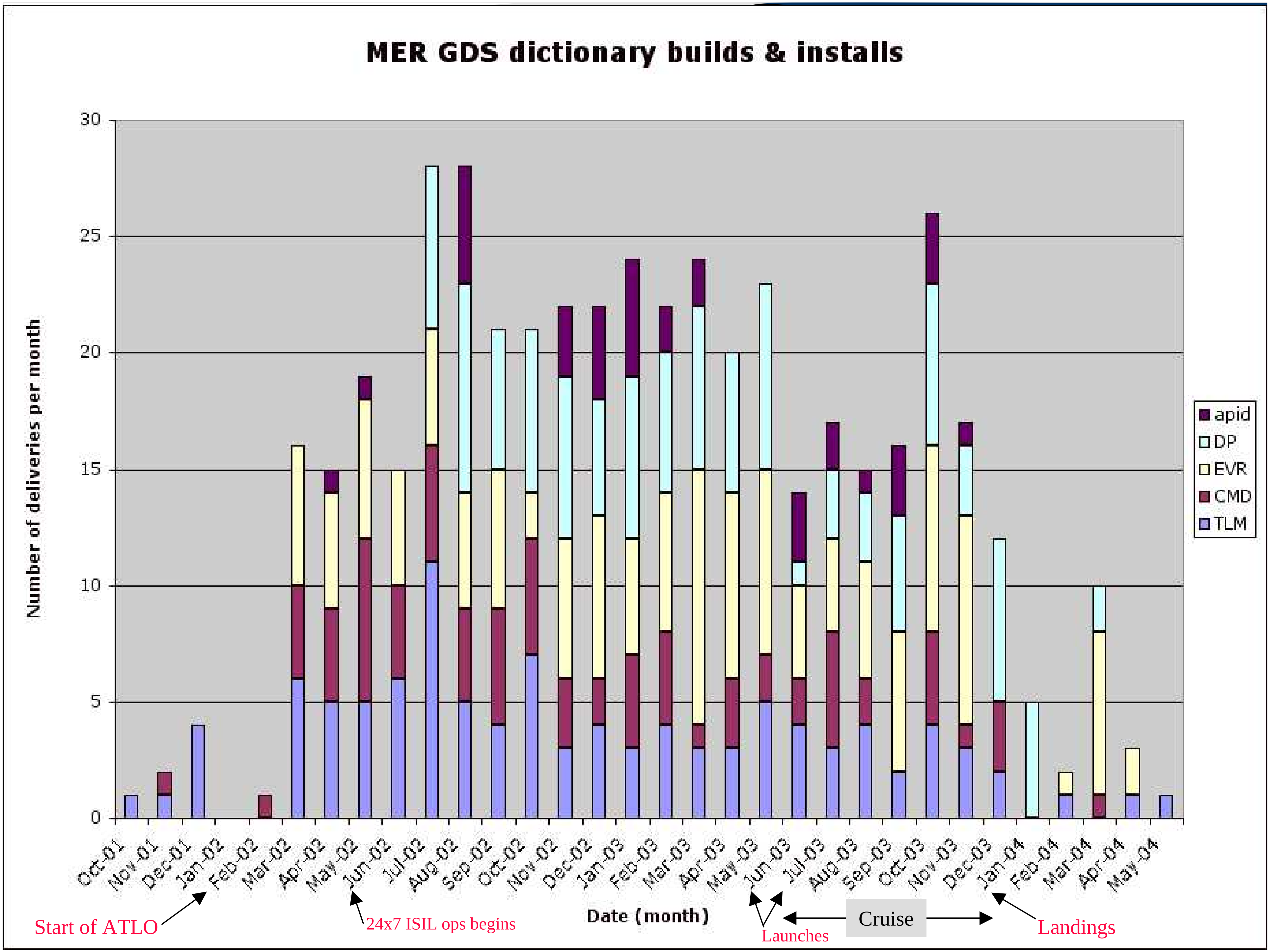
Development Challenges

"…Oh, just one more thing…"

- Original GDS support plan for In-Situ Instrument Lab (ISIL): Support three testbeds, requiring one shift Monday-Friday
- An early provisional update to the support plan showed the possibility of as much as six months of 24x7 testbed usage
- Final reality
  - 24x7 ISIL operations started in June 2002 and continued past Jan. '04 landings
  - Two-shift operations (7:30 AM to 11:30 PM) began well before June 2002
  - There were *four* testbeds in ISIL (one mobile)
  - 12 FSW development single-board computers
  - In addition, support was provided for
    - 2 ATLO testbeds
    - GDS Testbed
    - Cruise MSA
    - Surface MSA

"…Oh, just one more thing…" (Cont…)

- All of this meant many more users of the GDS, so more training, more questions, and many more calls at 3 AM from sleepy test engineers…
- These increases were all mirrored with a greater number of GDS dictionary deliveries. The expectation was for about 8-10 per month - but here's what really happened:


MER GDS dictionary builds & installs
Number of deliveries per month
30
25
20
15
10
5
0
apid
DP
EVR
CMD
TLM
Oct-01
Nov-01
Dec-01
Jan-02
Feb-02
Mar-02
Apr-02
May-02
Jun-02
Jul-02
Aug-02
Sep-02
Oct-02
Nov-02
Dec-02
Jan-03
Feb-03
Mar-03
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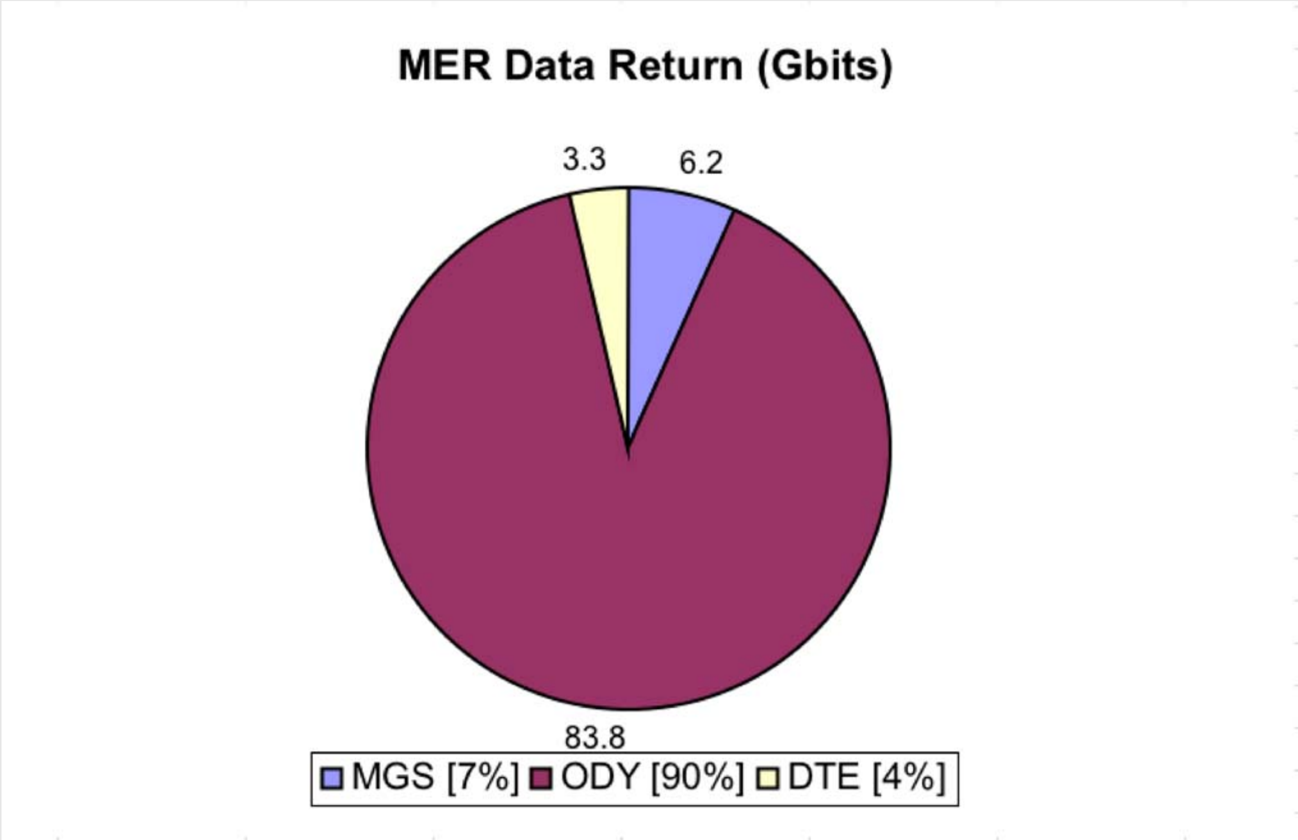
May-03
Jun-03
Jul-03
Aug-03
Sep-03
Oct-03
Nov-03
Dec-03
Jan-04
Feb-04
Mar-04
Apr-04
May-04
Date (month)
Start of ATLO
24x7 ISIL ops begins
Launches
Cruise
Landings

Notes Regarding Previous Chart

- Showing deliveries per month has the effect of smoothing things out
- All of these deliveries were propagated to between five and ten *different* environments (different servers, separate logins.) The Telemetry (TLM) deliveries were customized for *each* location
- Planning assumed four TLM deliveries per month; several months exceeded that rate. TLM deliveries took the most processing (typically two person-days for a complete build, checkout, and install)
- Deliveries did not cease before launch! Development rate during cruise was practically at same rate as before launch, yet GDS engineers were responsible then for additional tasks (flight support, readiness tests, operations development.) Note there were still deliveries after landing!
- Yes, indeed, there were some months when there were more deliveries per month than there were workdays. “Weekends” & “Holidays” grew quote marks. But we had the easy job - the test engineers seemingly never slept. Their fatigue increased our support calls
- EVR deliveries were relatively easy, but often time-critical (two-hour turnaround, no matter the day or hour.) Due to the FSW development cycle, oftentimes EVR installs had to be done after business hours or on weekends, driven by a phone call or page from the FSW engineer

Operational Challenges

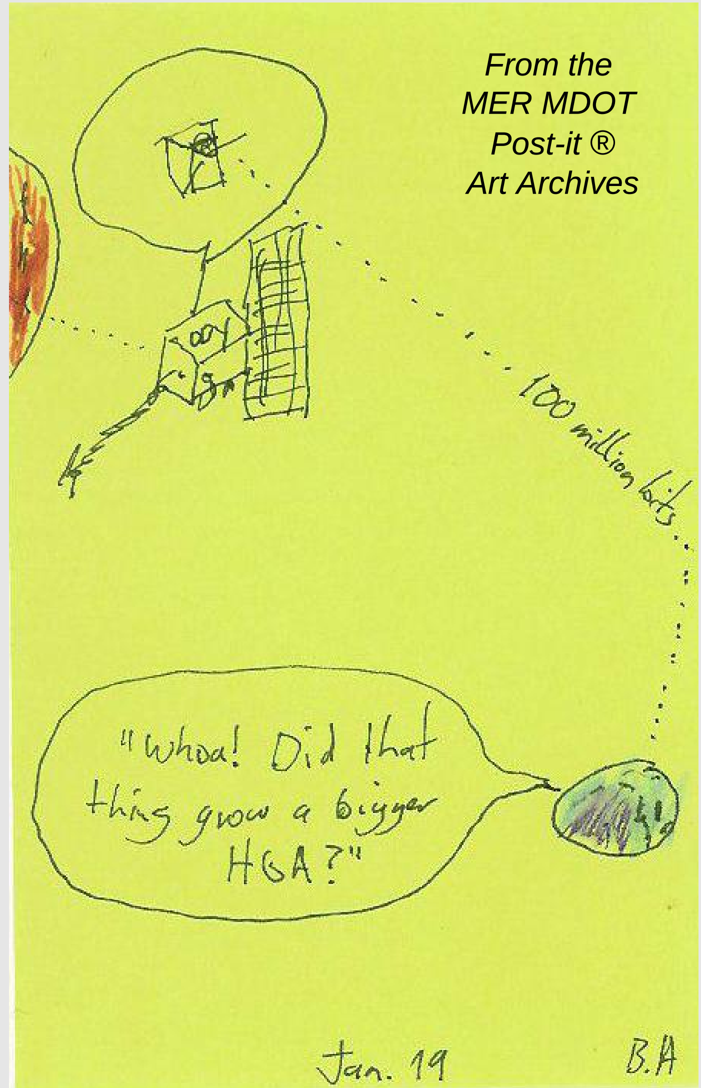
Changing from DTE to UHF Relay



Data Volumes as of Jan. 19, 2005

Maximizing Data Volume

- The original plan was to rely on Direct To Earth (DTE) as prime downlink method
  - 12.1 Mbits avg
  - Two or three passes per Sol
- Early in operations discovered the benefits of UHF relay
  - Data volume at 128k - 56.9 Mbits avg
  - Data Volume!
- UHF radio had 256k rate
- Tested MER requirement was 128k
- Project decided to use 256k - why not - more data - 96.1 Mbits avg
- Use the UHF relay and use it to the max
- Problems were discovered with 256k
  - MER had no requirement to operate at this rate
  - Little testing was done…



From the MER MDOT Post-it ® Art Archives

256k Extra Byte Problem

- At the 256k rate it was suspected that the UHF radio inserted an extra byte in the transfer frame
  - Caused the ground system to label the frame as corrupted
  - Created gaps in essential data
- MGD participated in diagnosing the problem
  - Verified that the ground system was not a part of the problem
    - it was correctly identifying corrupted data
  - Problem coming from the spacecraft
  - Solution was to correct the problem on the ground
- How did MGD help with the solution?
  - Collected data sets for test cases
  - Set up test cases
  - Collaborated with the development team to validate the ground software fix

Data Corruption Problem

- Due to an issue in the flight software, corrupted data products were occasionally transmitted
- The flight and ground teams work in partnership to determine whether the problem should be solved on-board or on the ground
- In this case, it was determined that a ground solution could be implemented
- Our members worked with the MER data management team to develop an automated replacement mechanism to work around the problem
  - Corrupted data in our ground storage system is automatically replaced once the non-corrupted version is available

Changes to Scenarios

- Our MER GDS Analysts are responsible for maintaining and initiating an automated end-of-pass report generation tool
- Two major operational scenario changes impacted the process
  – Using the UHF Relay passes rather than DTE Direct to Earth
  – Reduced staffing during extended mission
- Needed to address processing speed issues due to increased data volume
- The questions we asked in order to develop an automated process
  – How much automation will be needed
  – How will the compression of the tactical timeline impact the need to speed up end of pass reporting
  – How much time do we have until something must be in place
  – What procedural changes are necessary
  – What code changes are necessary
  – How can the software automatically recognize the “end-of-pass”
    - This was complicated because our relay data does not always arrive in “one chunk”
    - Ultimately, we developed an automated ground process, that correlates our predicted pass information with our actual pass information to resolve which pass the data belongs to

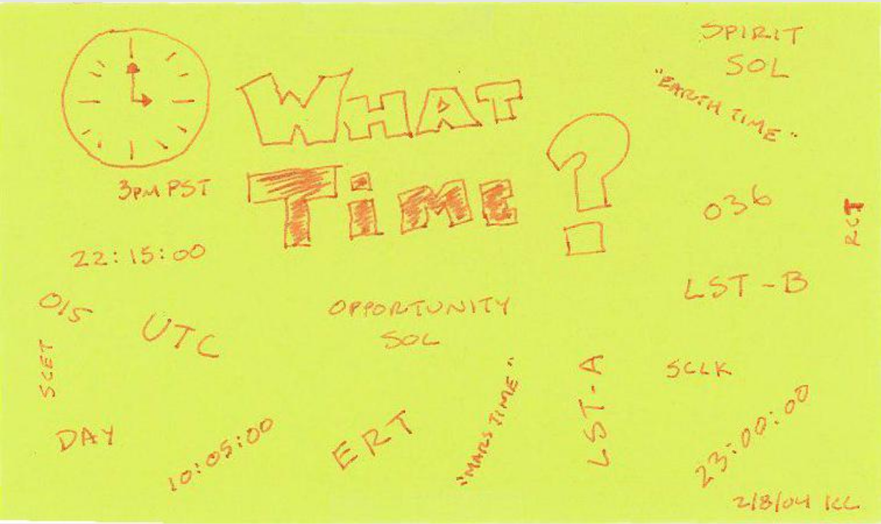
Other Challenges

Am I looking at data from Spirit or Opportunity?

- Needed to ensure that users could easily distinguish which spacecraft was being displayed
  - GDS binaries and GDS nomenclature were unique to each spacecraft
    - Transitioned from dedicated spacecraft workstations to workstations that displayed data simultaneously for both rovers
    - MER 1 = MERB = Opportunity
    - MER 2 = MERA = Spirit
- Methods for usability
  - Each tool adapted with color-coding and spacecraft labels
  - Implemented a process where the user is immune to version changes
    - Pulldown menus allowed users to run updated deliveries without changing their process

Telling Time

- Often heard statements like: “the data is coming down at 3”
- But what does “3” mean?
  - It’s currently 5pm Pacific Standard Time (PST)
  - Data could be arriving at …
    - 3am PST
    - 03 UTC (8pm PST)
    - MER-A (Spirit) data 3 LMST (Local Mean Solar Time) ~6:40pm PST
    - MER-B (Opportunity) data, LMST ~6:58am PST the next morning



From the MER MDOT Post-it ® Art Archives

Telling Time (Cont.)

- MGD deployed mission clock
  - Displayed PST, UTC, LMST (MER-A) and LMST (MER-B) together for quick correlation of the current time
  - Identified spacecraft with their spacecraft IDs as well as by color convention
- MGD internally deployed a time-conversion tool
  - The tool converted between UTC LMST (MER-A) and LMST (MER-B) for quick correlation of user-specified times
- Just one of many cases where we had to pay careful attention to usability of the tool and needs of the operations team
  - This is an example of a tool that must be adapted for a specific mission
    - Unique because it must identify two spacecraft
    - Local rover time depends on the physical location of the rover

Lessons Learned

- Learn to anticipate creeping requirements
  - Consult those with lots of mission experience
  - Attend mission design meetings and pay attention to changes; think about what impact those changes have on your system
- Frequently interact with the flight system engineers working in the areas upstream to characterize impact on operational GDS
  - Strive for tool consistency between the test environment and the flight environment
- Suggestions for overcoming challenges
  - Attitude/Philosophy
  - Remain Flexible
  - Modular development
  - Develop processes and automation for deployment
  - Talk to the users, find out how they intend to use the GDS, what are their expectations and assumptions
  - Cross-train your team so they can easily backfill one another

Acknowledgements

We would like to recognize the organizations that provided our team with leadership and those with whom we collaborated to perform our work in support of the MER mission

- The entire MER Development and Operations Team
- The MER Telemetry and Command Support Element (TCSE)
- The MER Common Services Element (CSE)
- The MER Mission Data Operations Team (MDOT)
- The Mission Information System Testbed (MIST) Team
- JPL Mission Management Office (MMO)
- JPL Deep Space Mission Systems (DSMS)
- JPL Telemetry, Tracking, Command and Data Management Element (TTC&DM)
- JPL Data Systems Operations Team (DSOT)
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