DEEP IMPACT COMET ENCOUNTER

Design, Development, and Operations of the Big Event at Tempel 1

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Topics

Deep Impact Mission Overview

Comet Encounter Design

Encounter Test Program

Execution at Tempel 1

Questions

Deep Impact Mission

- Deep Impact: First Look Inside a Comet
  - An artificial meteorite impact
  - 370 kg at 10.2 km/s
  - Are there pristine ices at depth?
  - What are the surface material properties?

- Primary Scientific Themes
  - Understand the differences between interior and surface
  - Determine basic cometary properties
  - Search for pristine material below surface

- Secondary Scientific Theme
  - Distinguish extinction from dormancy

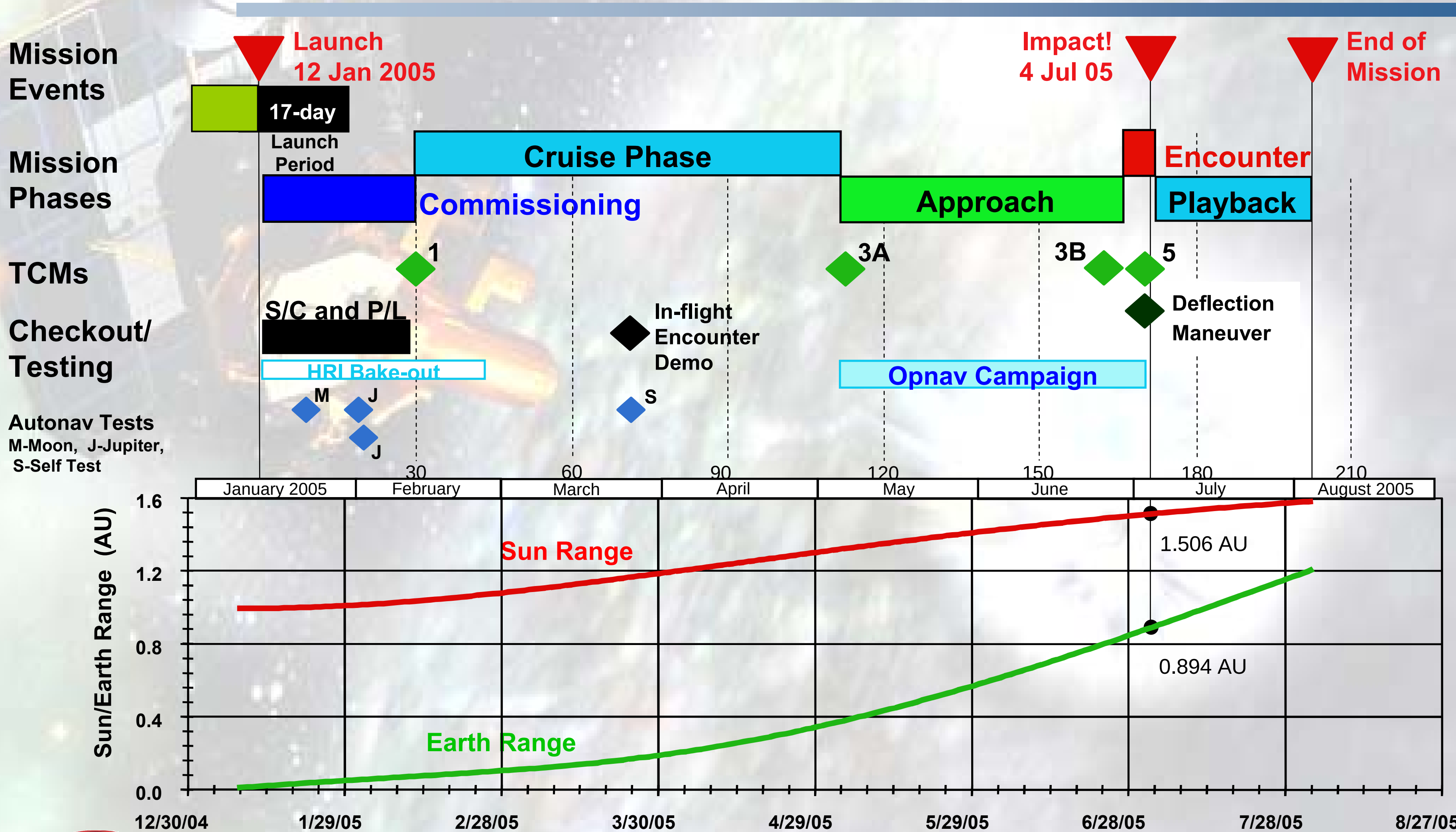
- Additional Science Addressed
  - Address terrestrial hazard from cometary impacts
  - Search for heterogeneity at scale of cometesimals
  - Calibration of cratering record

Mission Overview

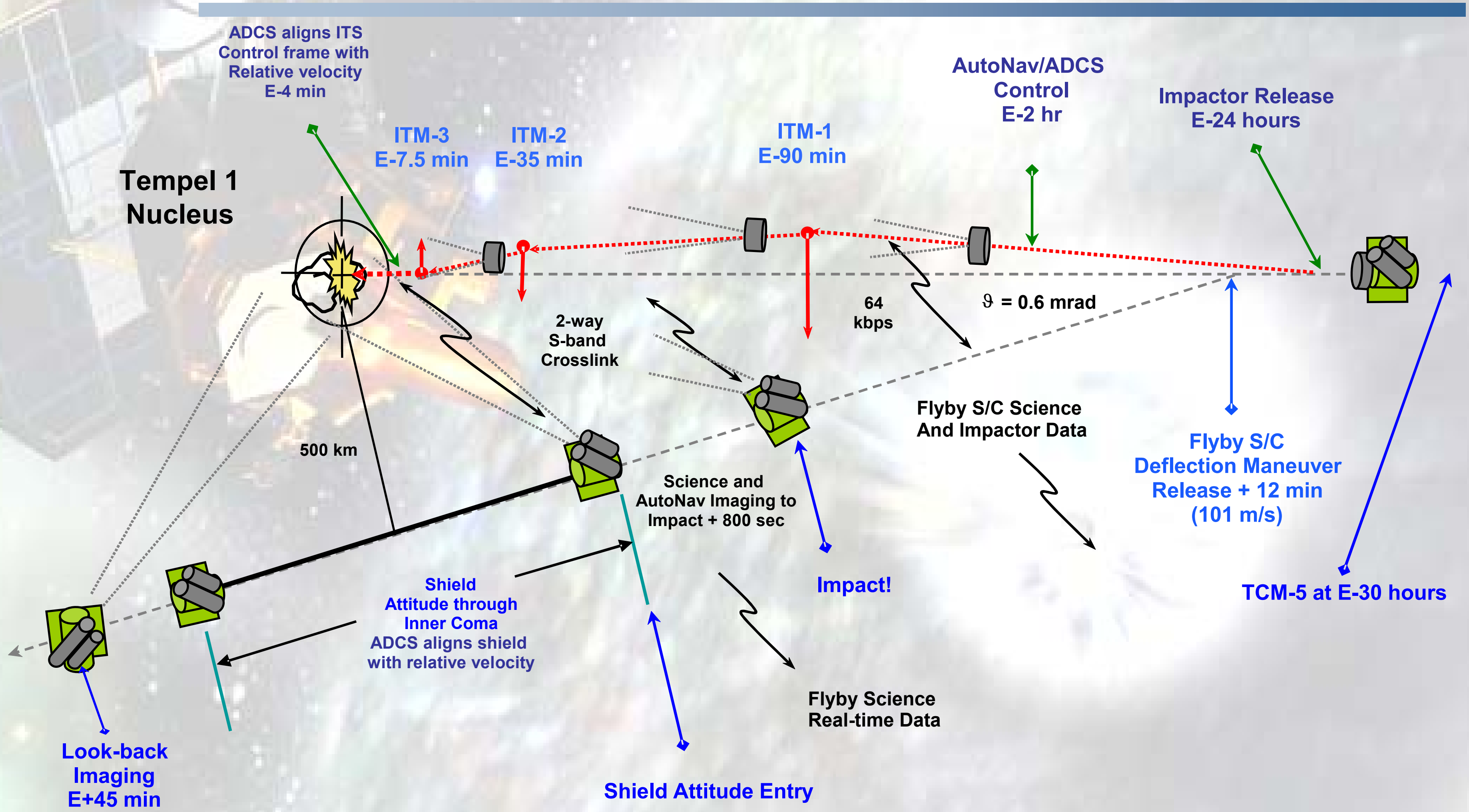
- 2 spacecraft – Smart Impactor + Flyby
  - Fly together until 1 day before impact
  - 6-month Earth-to-comet trajectory
- Smart Impactor
  - Impactor Targeting Sensor (ITS)
    - Scale 10 μ-rad/pixel
    - Used for active navigation to target site
    - Images relayed via flyby to Earth for analysis
  - Cratering mass (~360 kg at 10.2 km/s)
    - Excavates ~100m crater in few*100 sec
    - Baseline prediction - other outcomes are possible
- Flyby Spacecraft
  - Diverts to miss by 500 km
  - Slows down to observe for 800 sec
  - Instruments body-mounted – spacecraft rotates to follow comet during flyby

- Instruments on Flyby Spacecraft
  - High Resolution Imager (HRI)
    - CCD imaging at 2 μ-rad/pixel (0.4 arcsec/pixel)
    - 1-5 micron long-slit spectroscopy (R>200, 10 μ-rad/pix)
  - Medium Resolution Imager (MRI)
    - CCD imaging at 10 μ-rad/pixel
    - Identical to ITS but with filter wheel added
- Major Earth-Based Observing Campaign

Mission Timeline



Comet Encounter Overview




DEEP IMPACT
NASA ★ JPL ★ U of MARYLAND ★ BALL AEROSPACE
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DESIGN
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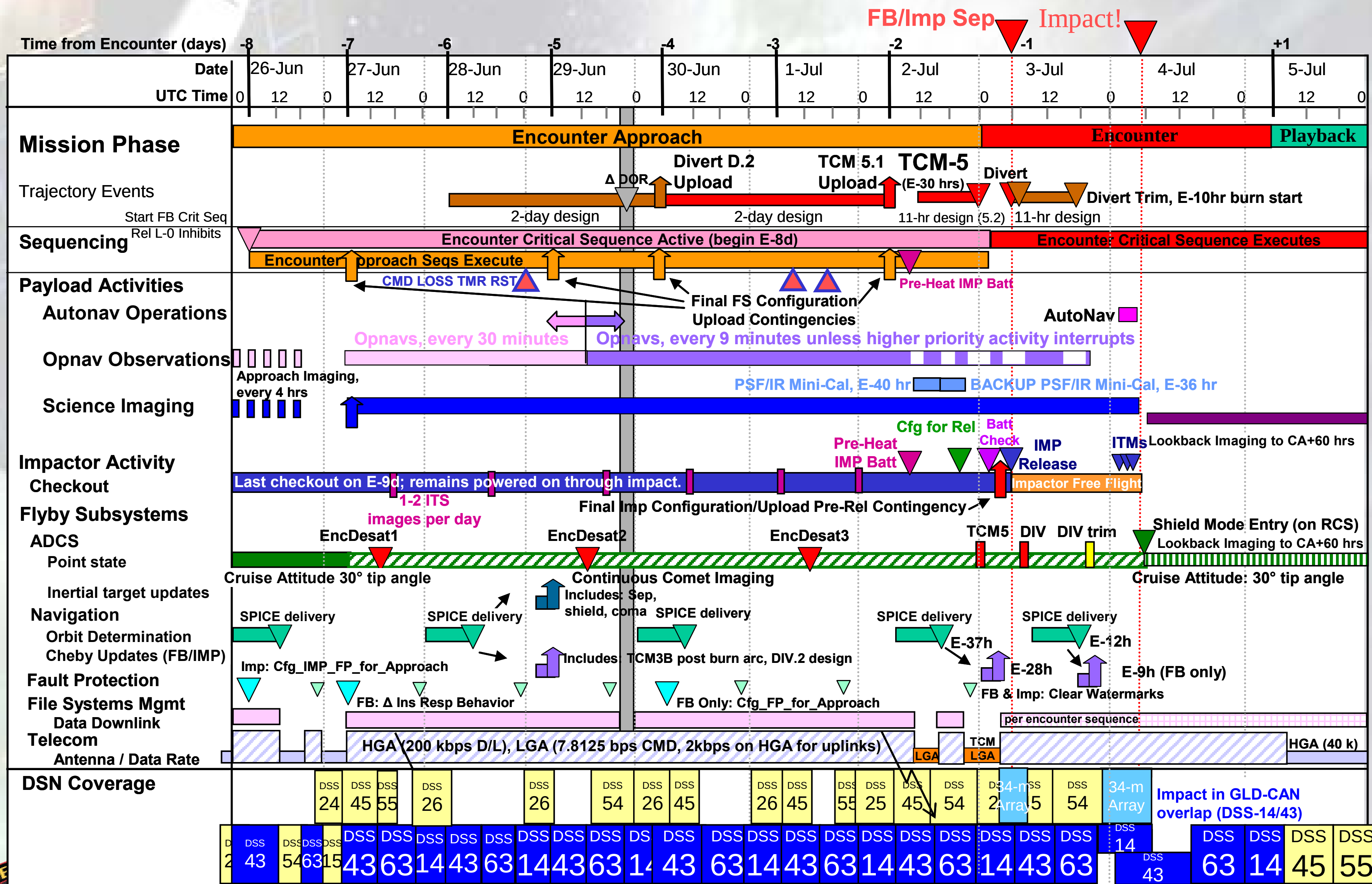
Design Envelope

- Live for the moment science return
- High resolution crater imaging
- 30km Impactor release accuracy
- On-board autonomous fault protection and critical sequence resumption
- De-scope Accommodation:
  - NVM Storage Reduction
  - Flight Computer-to-Flight Computer Communication Link Elimination
  - Downlink Data Rate Reduction

Encounter Timeline



Flyby Encounter

- Impactor Release
  - Release Impactor within 30 Km (B-Plane) and 180 Seconds Time of Flight
  - Alter Flyby trajectory to allow for ~800 second imaging of impact and crater formation and a closest approach of 500 Km
- Comet Encounter
  - Periodic Science and OP-Nav imaging of the comet
  - High rate imaging of impact event
  - High resolution imaging of impact crater
  - Return prime science images and engineering telemetry in real-time
  - Protect Flyby spacecraft during closest approach
- Post-Encounter
  - Return all stored images and near-encounter engineering telemetry
  - Periodic images looking back at the comet

Autonomous Navigation

- Closed-loop AutoNav/ADCS control used to point MRI & HRI instruments starting 2 hrs before nominal time-of-impact (TOI)
- AutoNav consists of image processing to form the observations & trajectory determination to estimate comet-relative position & velocity
- Attitude Determination & Control System (ADCS) uses AutoNav relative position information and pointing offsets to compute desired attitude
  - Pointing offset allows ADCS to point instruments at predicted impact site and is computed using parallel Scene Analysis
  - Pointing offset requested & applied 4 min before nominal TOI and maintained through remainder of encounter
- AutoNav responsible for computing updated TOI and updated time-of-final-imaging (TOFI)
  - Time-shifts requested via sequence command and applied to optimize the start time of the appropriate science imaging sequences

Robustness

- Sequence Design
  - Mark/Rollback: Fault Tolerant Sequencing Capability
  - Critical Sequencing: Autonomous Re-Start of Encounter Activity
  - Mark Point Selection: Ensures Critical Activity Completion Prior to Roll Forward
- Fault Protection Enabling Strategy
  - Encounter Approach: Cruise FP plus Instrument FP
  - Critical Sequence Start: Cruise FP plus Instrument FP, Point State FP, HGA FP
  - E-2 Hours: Only System Responses, System Safing Disabled
  - E-7.5 Minutes: All System Responses Disabled, Only Basic Hardware Protection
- Contingency Plans
  - Unexpected Comet Albedo: Alternate Imaging Sequences
  - Late Release: Release at E-10hr instead of E-24hr
  - Flight System Impact: Entire Flight System on Impact Trajectory

TESTING

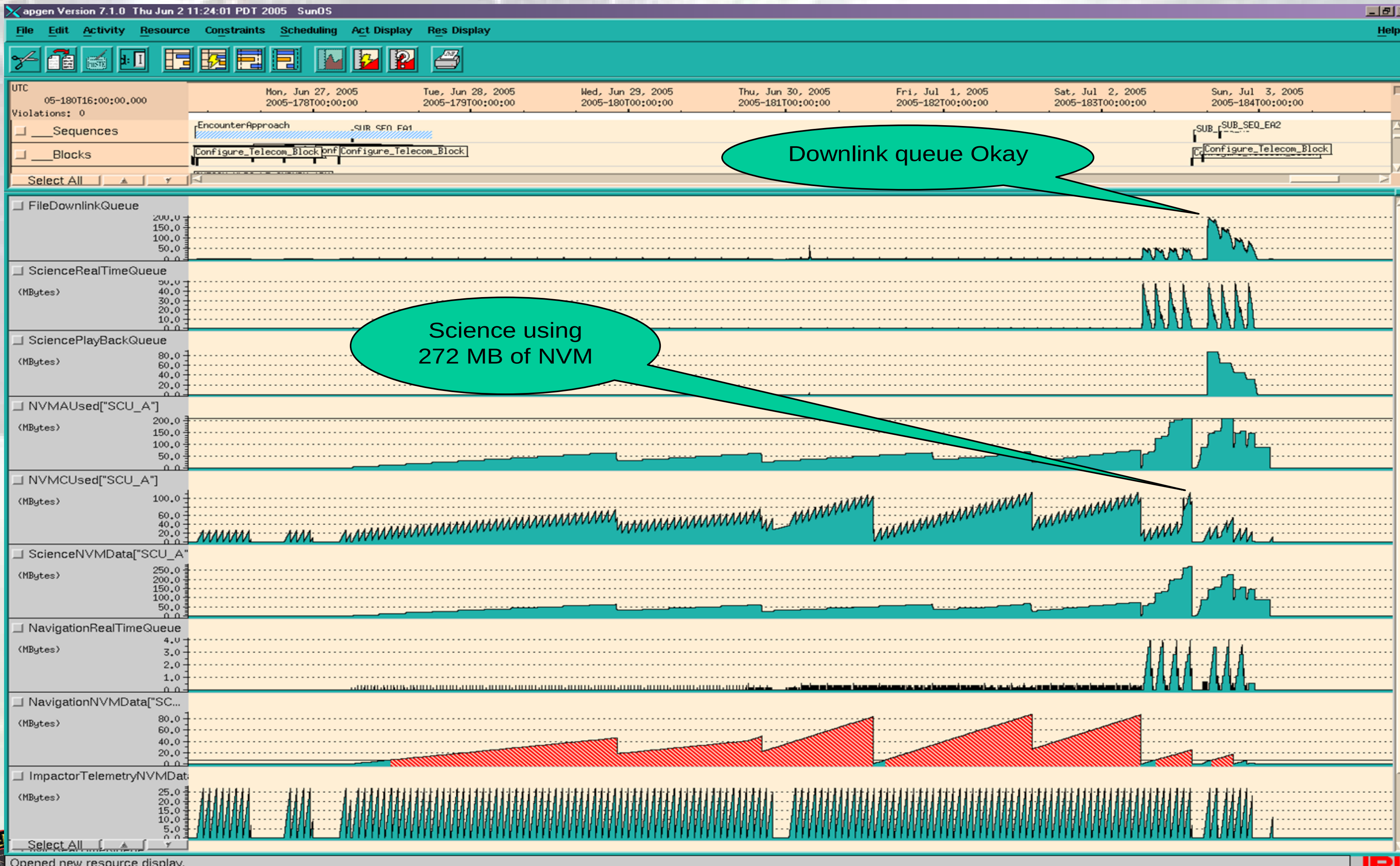
Test Program

- Objectives
  - Ensure normal encounter operation does not trigger Fault Protection
  - Ensure system is robust under all expected encounter conditions
  - Ensure system responses are predictable, and the results are acceptable
  - Ensure system operates in off-nominal (within-specification) conditions
  - Push boundary conditions of the system to investigate the ability to operate outside of specification, and understand when overstress occurs and how it is handled

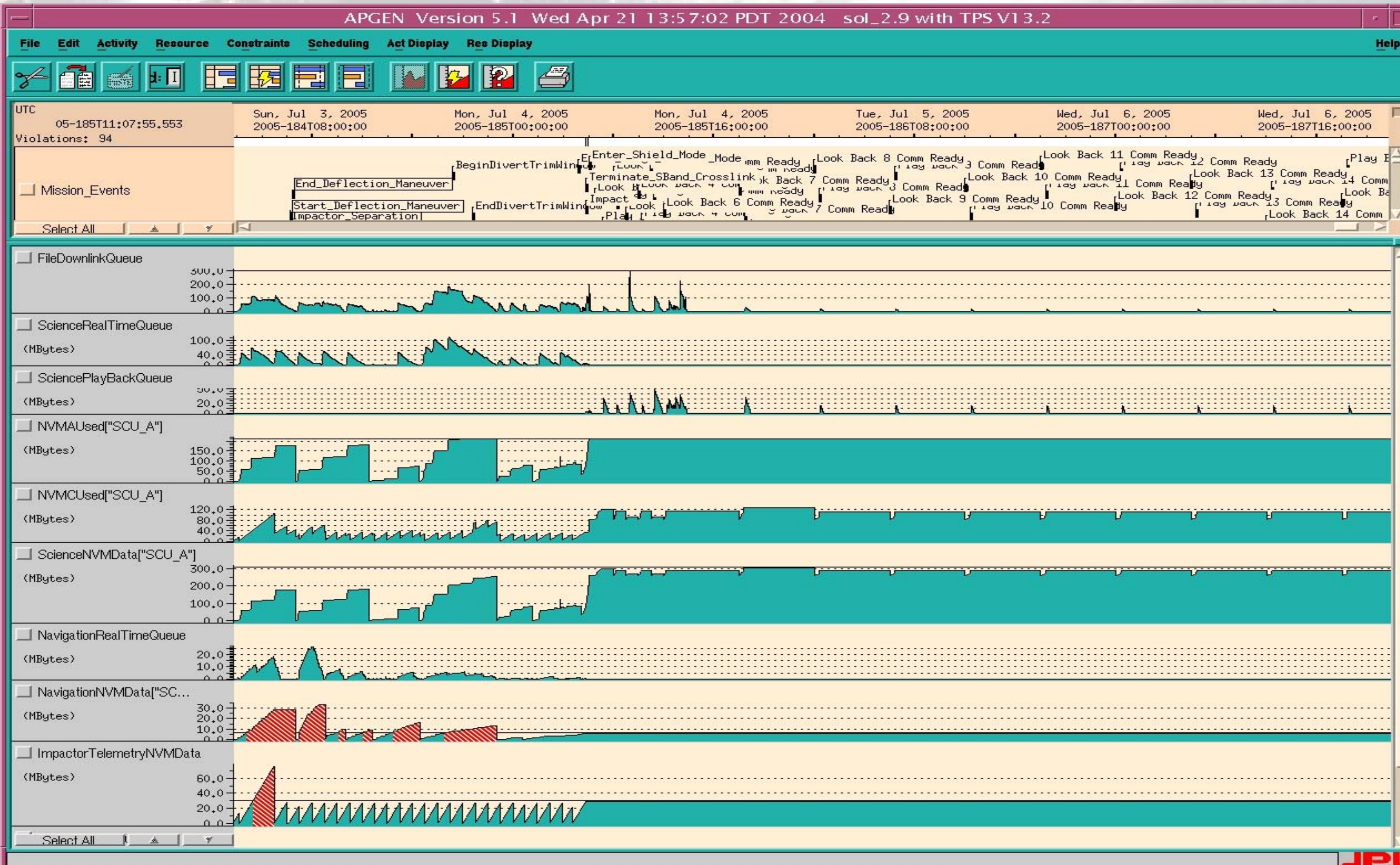
- Architecture

TEST TYPE	NUMBER OF CASES	TOTAL # EXECUTED	# ON ITL	TOTAL HOURS
MSTs	3	279	3	5160
Faulted MSTs	16	25	8	300
Robustness Tests	11	35	11	288
ORTs	7	7	5	400
Totals	**37**	**346**	**27**	**6148**

Encounter Approach Predictions

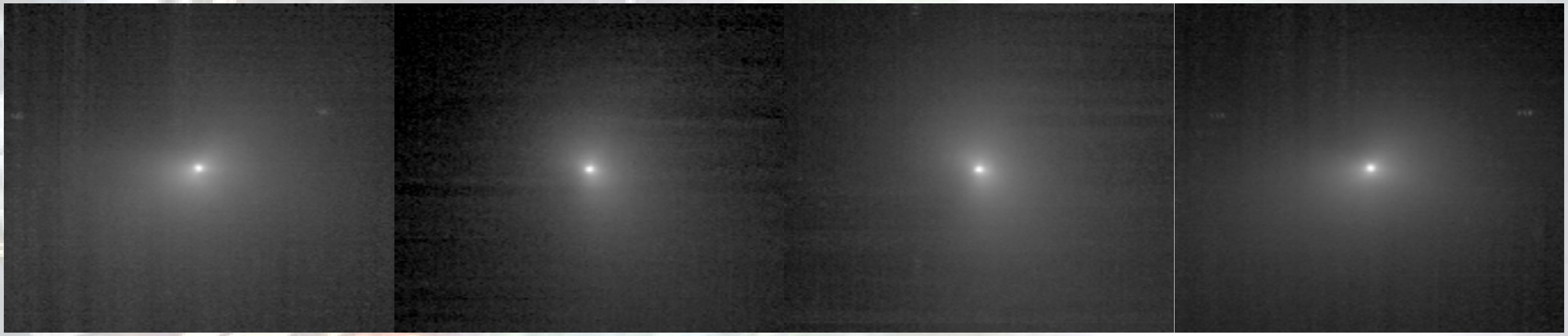


Encounter Predictions



EXECUTION

Encounter Approach Performance

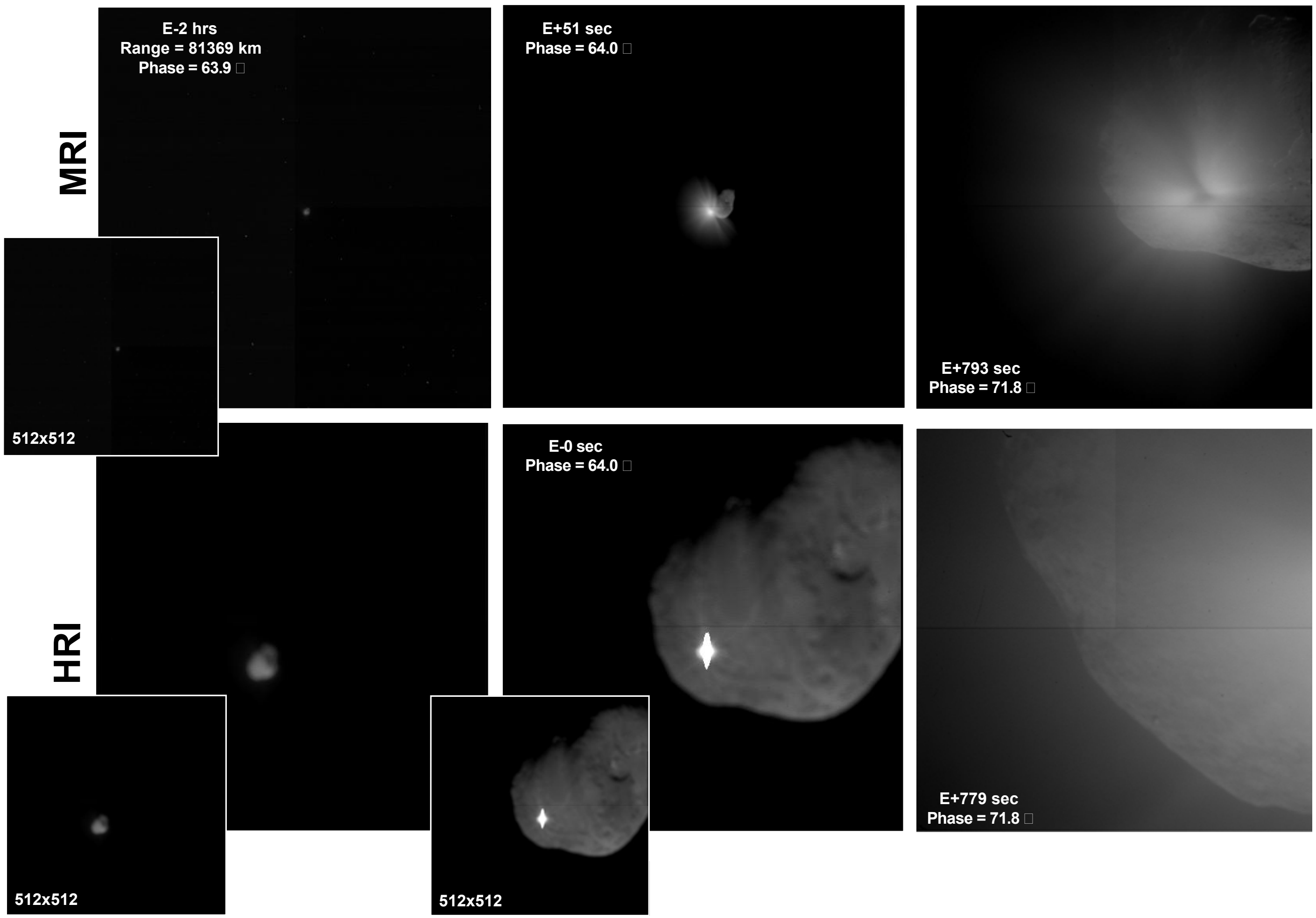


- MRI Images from the last week – on right, flight system was 2,446,529 km, > 3 days out
- Imaging Campaign
  - Total Images Taken: 4839, Total Impactor Files Downlinked: 31,903
  - Images Lost Prior to Downlink: 127, deleted prior to downlink due to single telemetry over-subscription
- Mini Calibrations
  - Point Spread Function 100% Successful, all images captured, targets acquired
  - Infrared 100% Successful, all images captured, targets acquired
  - Rapid turn-around allowed high resolution images using de-convolution soon after impact
- TCM 5 within 2% of desired, Flight System within 2 km of impact trajectory at end of phase
- NVM Clean-Up successful, all drives contain only critical encounter products at end of phase
- All performance metrics for each subsystem, flight team, and science team were met/exceeded

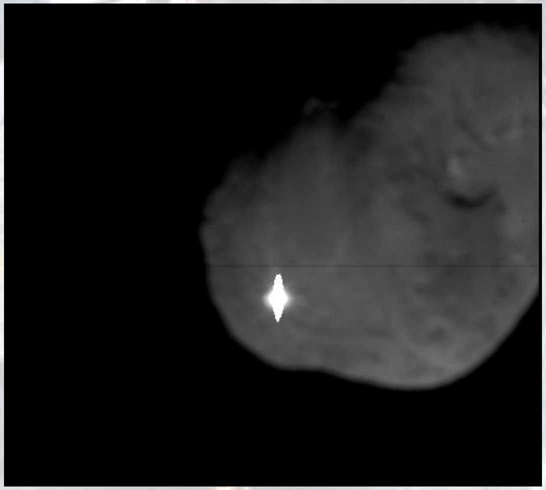
Encounter

- Impactor Release
  - Impactor released within 2 Km (B-Plane) and 2 Seconds Time of Flight
  - Divert maneuver placed Flyby within 2 seconds time of flight and within 2 Km of the targeted 500 Km miss distance
- Comet Encounter
  - All of the highest priority science and navigation images were collected and returned, minor loss of early encounter imaging due to Deep Space Network transmitter problem.
  - Flyby Spacecraft survived closest approach without any detectable damage

Autonomous Navigation

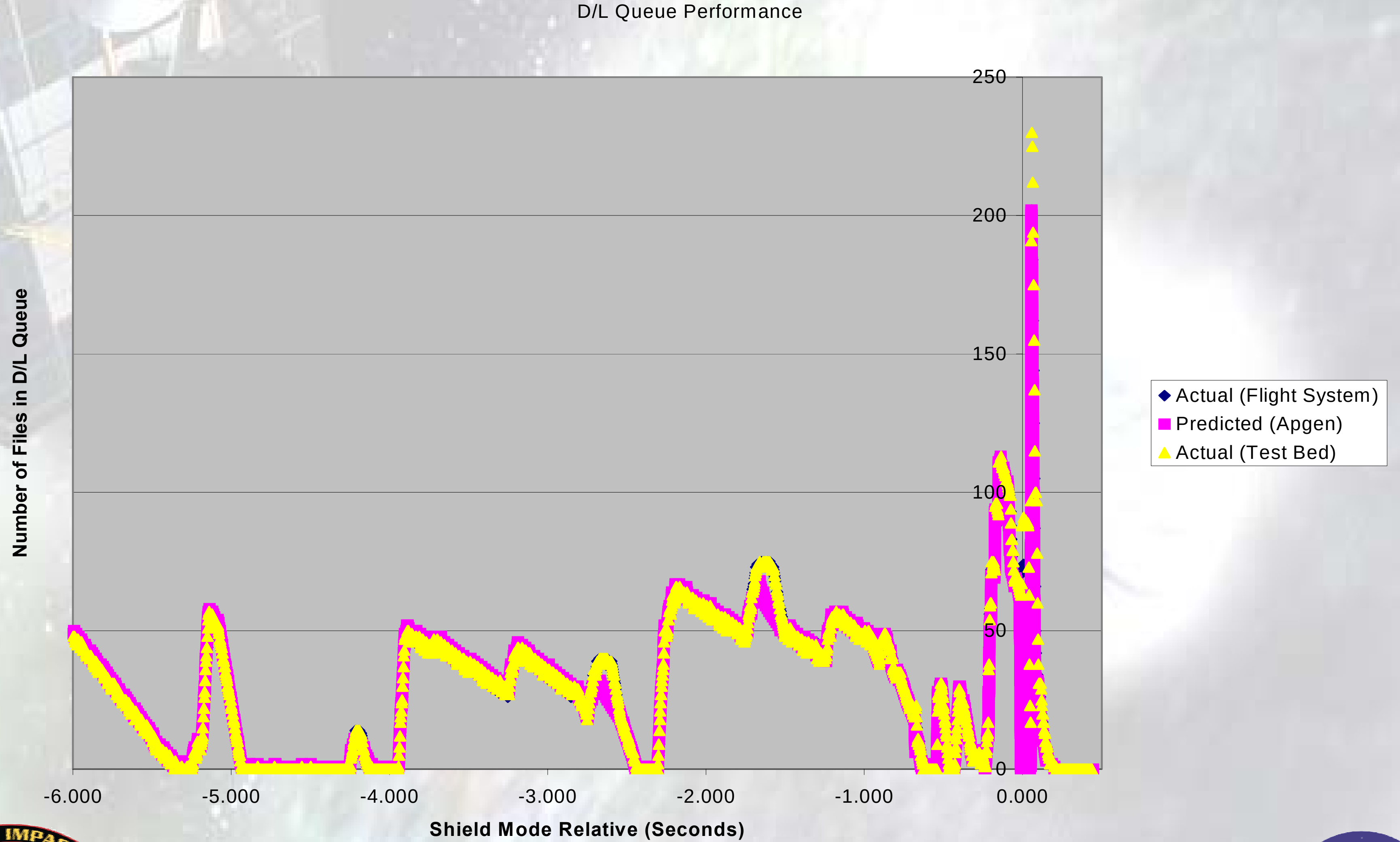


Autonomous Navigation



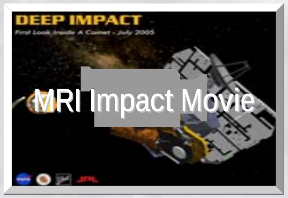
- HRI image capture at the moment of impact
- Saturated pixels are located within 31 pixels of the center of the HRI FOV
- Each HRI pixel is 2 microradians and therefore indicates that the total of all error sources was less than 62 microradians at TOI
- This includes the following error sources:
  - AutoNav estimation
  - ADCS attitude estimation
  - HRI camera alignment errors
  - Independent Scene Analysis induced errors
  - Errors associated with updated estimates of TOI
- Full-frame MRI image of the impact site just 7 sec before shield attitude entry
- 3 Picture mosaic (scan), added to improve probability of capturing crater, gave Science Team opportunity to quantify crater size

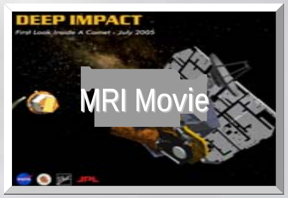
Encounter Data Return



Impact Imaging

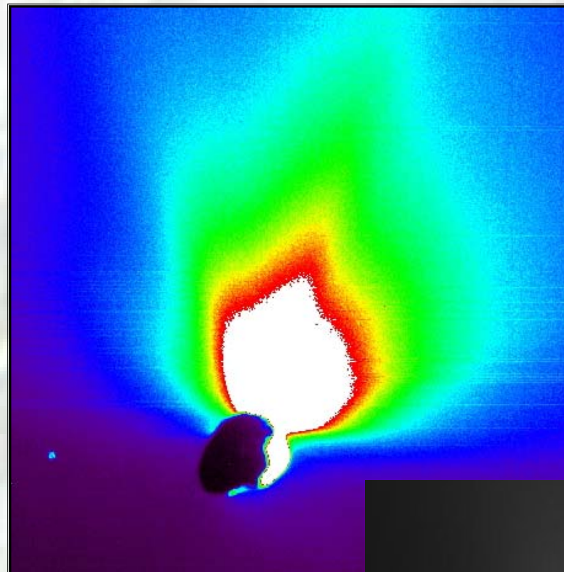
- HRI Image Taken 67 seconds Post Impact
- Scattered light from the collision saturated the camera's detector, creating the bright splash
- Linear spokes of light radiate away from the impact site, while reflected sunlight illuminates most of the comet surface
- Images revealed topographic features, including ridges, scalloped edges and possibly impact craters formed long ago

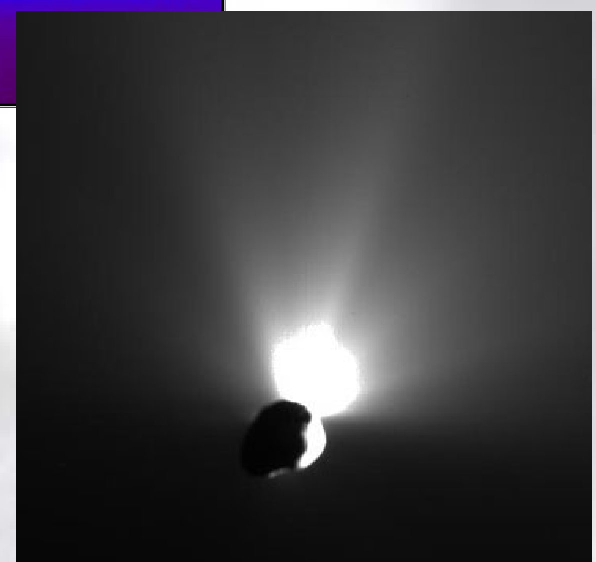




Look Back Imaging

- HRI Images Taken 50 minutes Post Impact
- Impact Site on Far Side of Comet
- False colors represent brightness, with white indicating the brightest materials and black showing the faintest materials
- Comet nucleus is silhouetted against the light reflected from surrounding dust
- Large plume of dust kicked up upon impact can be seen as the colorful, drop-shaped object
- This plume was very bright, indicating that the comet's surface material must be very fine, like talcum powder





Tempel 1 Environment

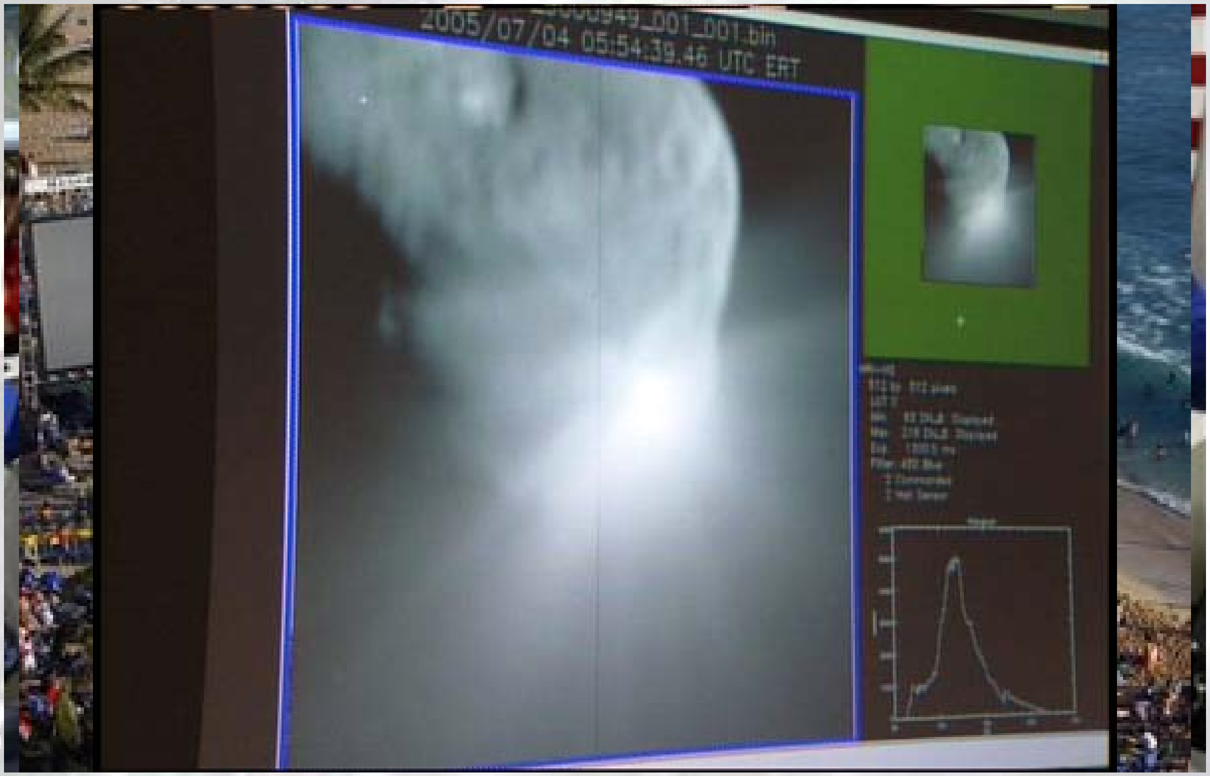
- Tempel 1 Outbursts
  - Several Outbursts Seen During Approach
  - None During Critical Encounter Period

- Comet Albedo
  - Within Nominal Brightness Range for Science and Navigation

- Dust Environment
  - Flyby Spacecraft Shielding Adequate for Environment
  - No Damage to Spacecraft During Closest Approach & Flyby
  - Spacecraft Attitude Impacts Due to Dust were Negligible

Summary

The Pictures Worth One Thousand Words



We Did It!

QUESTIONS ?