Impactor Spacecraft Encounter Sequence Design for the Deep Impact Mission

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Presentation Overview

- Mission & Flight System
- Targeting Strategy for Impactor Spacecraft
- Autonomous Navigation (AutoNav)
- Encounter Sequence Design
- Contingency Planning
- Encounter Performance
- Summary

Mission & Flight System Overview

Deep Impact Mission

- NASA Discovery Mission
  - Principal Investigator: Dr. Michael A'Hearn , U of Maryland
  - Project Managed at Jet Propulsion Laboratory
  - Flyby and Impactor spacecraft built at Ball Aerospace Technologies Corporation
- Engineering Objectives
  - Impact comet Tempel 1 in an illuminated area
  - Track the impact site for 800 sec using the Flyby s/c imaging instruments
- Science Objectives
  - Expose the nucleus interior material and study the composition
  - Understand the properties of the comet Tempel 1 nucleus via observation of the ejecta plume expansion dynamics and crater formation characteristics

Mission Requirements

- Baseline Mission Requirements for Impactor Spacecraft
  - Target a short period comet understood to have a nuclear radius > 2 km
  - Deliver an impactor of mass > 350 kg to an impact on the cometary nucleus at a velocity > 10 km/s. The impact event and crater formation shall be visible from the flyby spacecraft and observable from Earth
  - Obtain pre-impact visible-wavelength images of the impact site including one with resolution < 3 m and FOV > 50 pixels

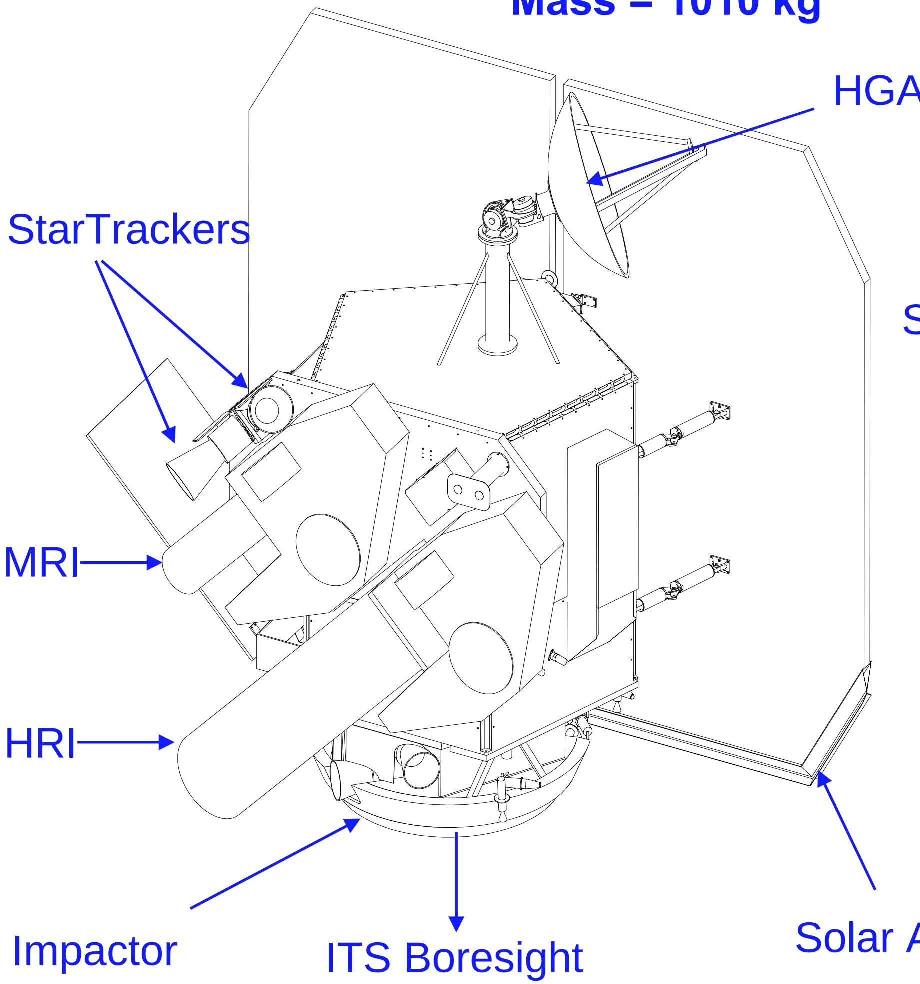
Deep Impact Flight System

- Dual Spacecraft Mission launched on January 12, 2005
  - The two spacecraft separate 24 hrs before impact (E-24 hrs) following a short 6 month cruise to Tempel 1
  - Flyby Spacecraft (640 kg)
    - Delivers the Impactor s/c on an intercept trajectory
    - Tracks the nucleus with the Medium Resolution Imager (MRI)
    - Observes impact event and provides high-resolution images (~3.4 m) of the fully developed crater (~90 m diameter) left by the Impactor with the High Resolution Imager (HRI)
  - Impactor Spacecraft (350 kg)
    - Tracks and Impacts nucleus using the Impactor Targeting Sensor (ITS)
    - Provides pre-impact high-resolution (~ 20 cm) images of nucleus surface

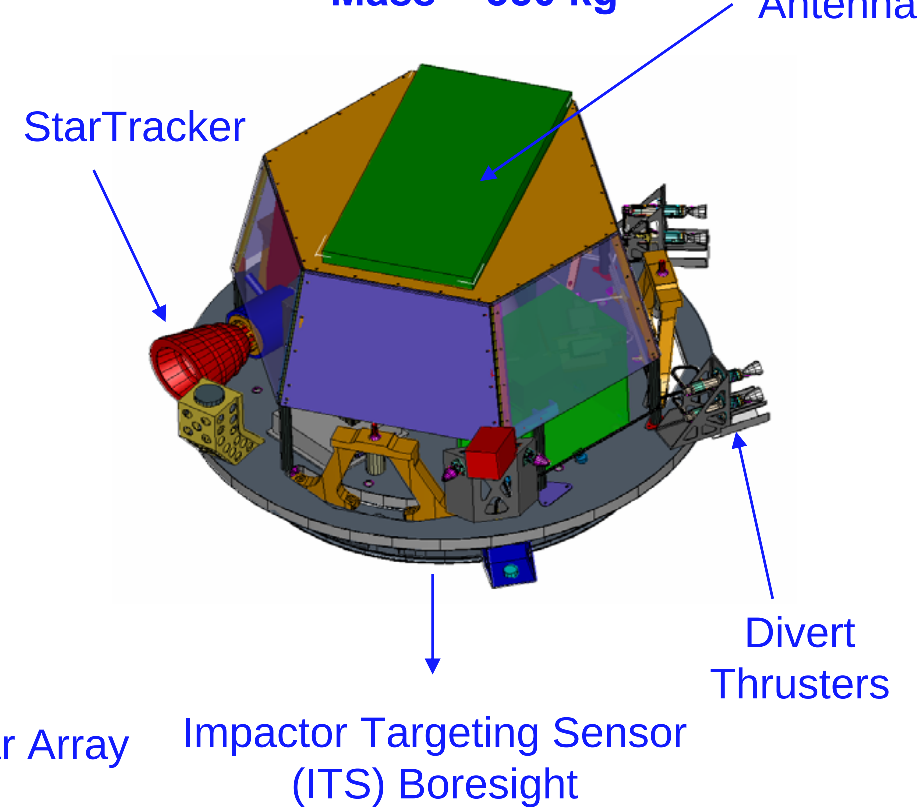
Description of Flight System

Combined Flyby/Impactor Flight System

Mass = 1010 kg



Impactor Flight System
Mass = 350 kg



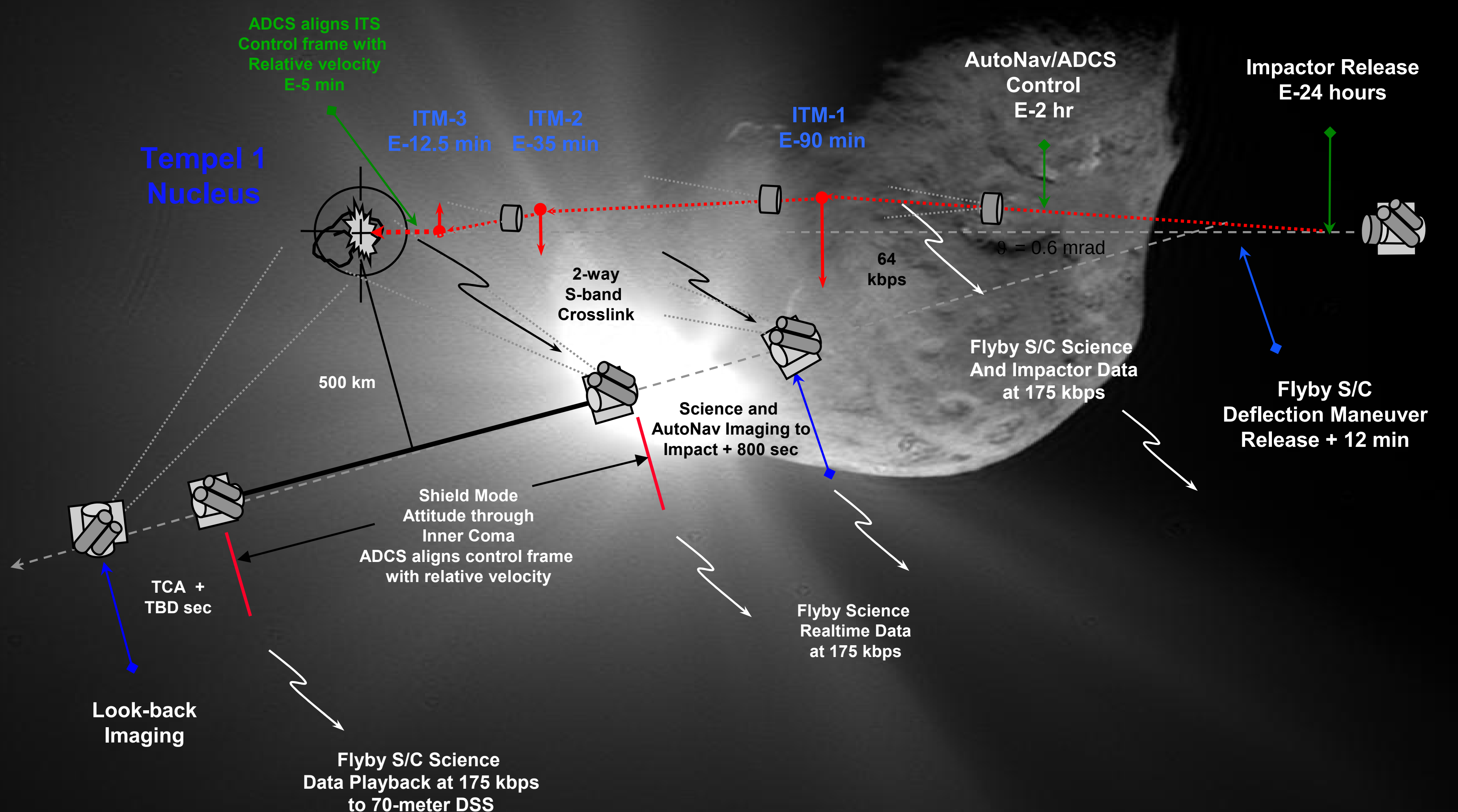
Deep Impact Imaging Instruments

- Imaging instruments (ITS, MRI, HRI) have common camera electronics
  - 1008 x 1008 CCD array
  - Full well = 450,000 e - with 14 bit digitization
  - System noise = 27 e -

- Impactor Targeting Sensor (ITS) and Flyby Medium Resolution Instrument (MRI) are identical:
  - Aperture diameter = 12 cm, FOV = 10 milliradians
  - FOV = 7 km @ r = 700 km

- Flyby High Resolution Instrument (HRI):
  - Aperture diameter = 30 cm, FOV = 2 milliradians
  - FOV = 1.4 km @ r = 700 km

Deep Impact Encounter Schematic



Impactor Targeting Strategy

Impactor Targeting Strategy

- Impactor targeting strategy depends on observing system and guidance control system
  - Optical observations (ITS) are best during non-thrust periods ⇒ a pulsed guidance system is most suitable
  - Target body (Tempel 1) and interceptor (Impactor) dynamics are well-known ⇒ a predictive guidance approach

- Impactor uses predictive guidance strategy and pulsed guidance system
  - 3 primary lateral, discrete magnitude burns (Impactor Targeting Maneuvers or ITMs)
  - ITMs based on estimated initial conditions and integrated equations of motion of the Impactor s/c and the evaluated position of comet Tempel 1 at the time of intercept to compute the "zero effort" miss distance
  - "Zero effort" miss vecotor is used to compute the magnitude and direction of each ITM to achieve the desired impact

Autonomous Navigation (AutoNav)

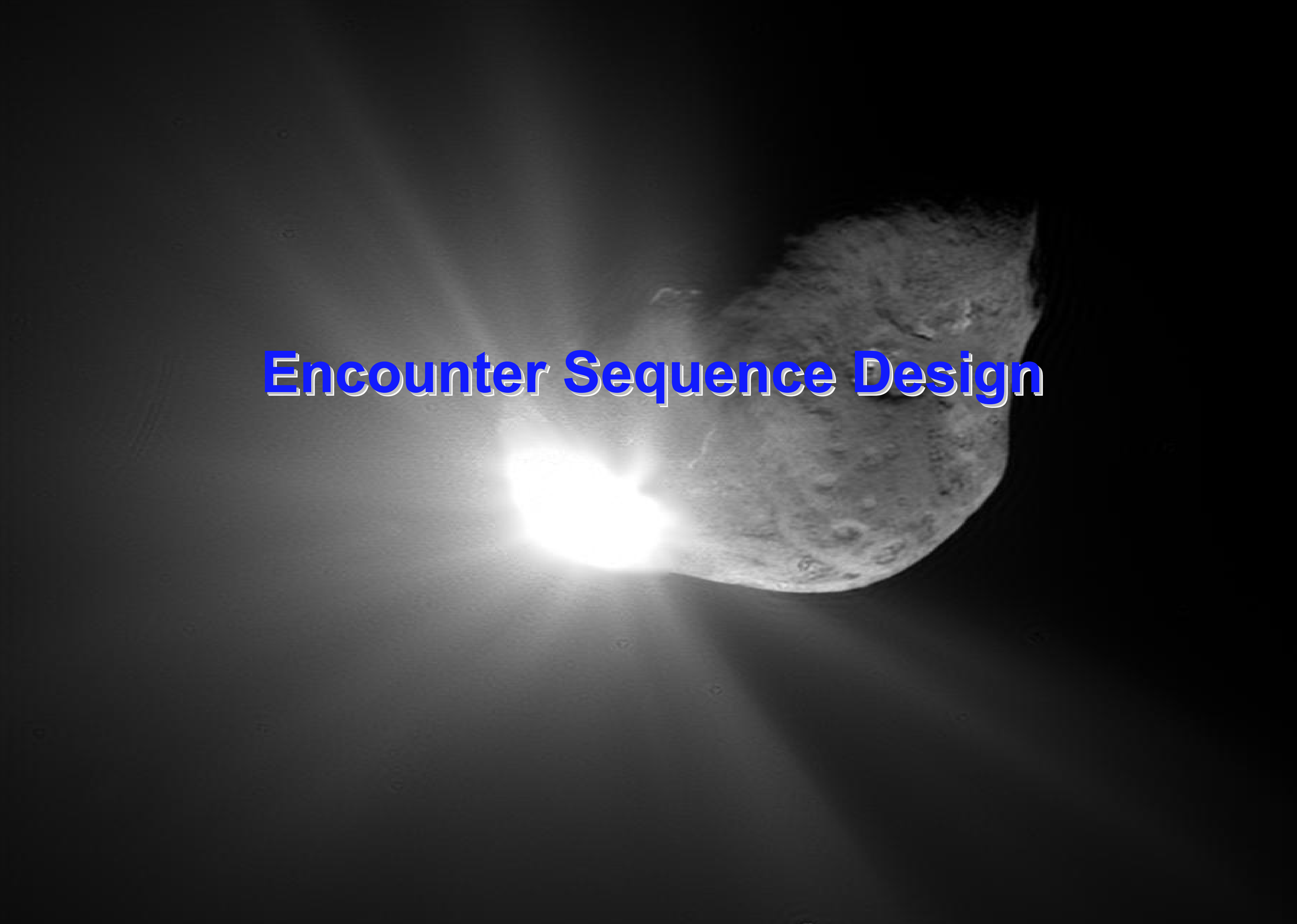
Impactor Terminal Guidance Depends on AutoNav/ADCS Interaction

- AutoNav software
  - Originally developed for the DS1 mission
  - Consists of 3 modules: Image Processing, Orbit Determination, trajectory correction maneuver Computation
  - AutoNav has two modes: Star-relative and Starless
  - AutoNav Starless mode selected for Deep Impact encounter operations
    - Attitude Determination and Control System (ADCS) performance will provide camera attitude estimates sufficient to support Starless AutoNav

- Impactor ADCS Subsystem
  - 1 Ball CT-633 StarTracker
  - 1 Northrup-Grumman Space Inertial Reference Unit (SSIRU)
    - 4 gyros and 3 accelerometers
  - Accuracy of attitude estimates < 150 μrad (3σ)
  - Noise associated with attitude estimates < 60 μrad (3σ)
  - Stability of attitude estimates < 50 μrad/hr (3σ)

Impactor Autonomous Guidance Process

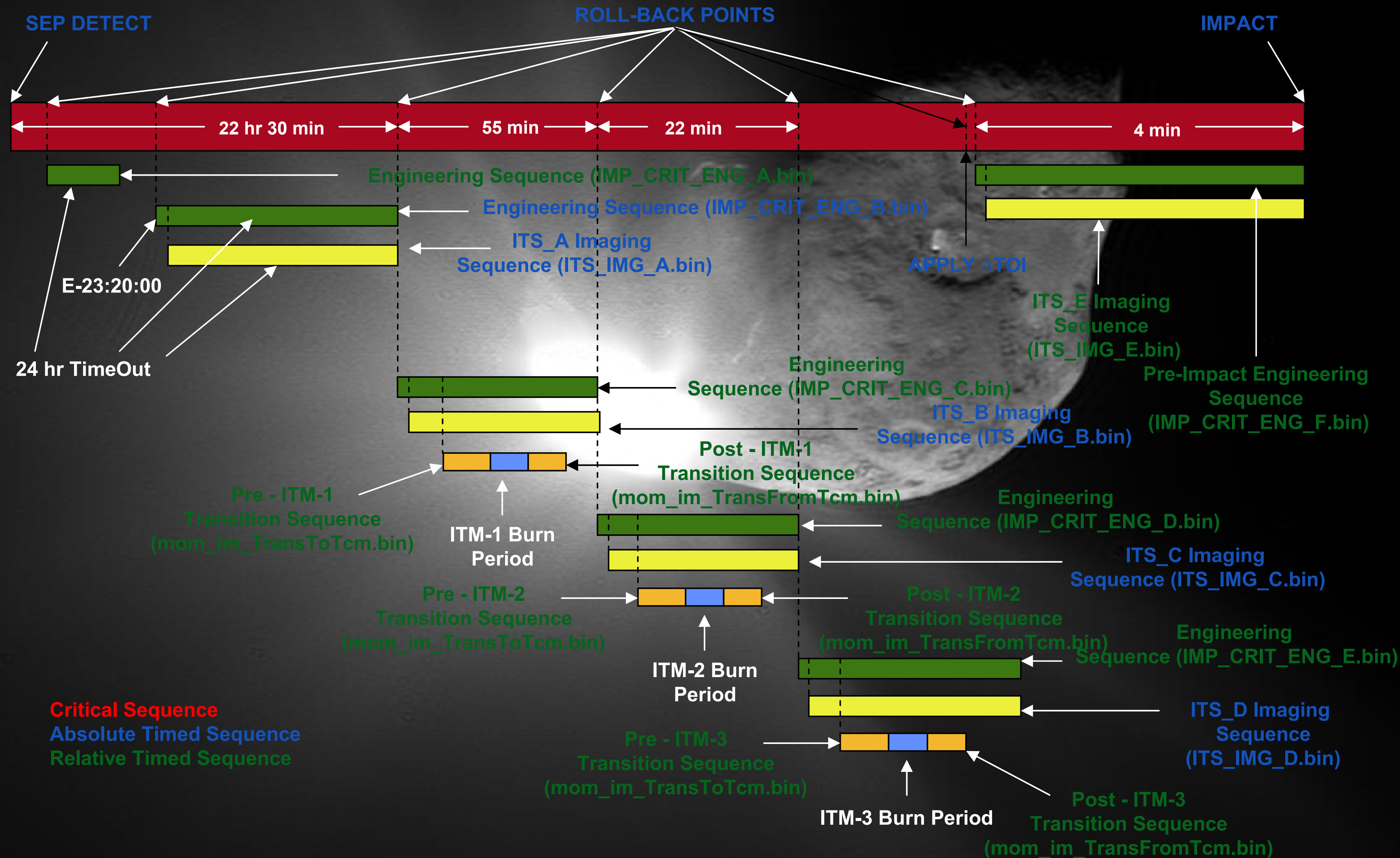
- Acquire ITS images of the comet nucleus
  - every 15 sec starting 2 hrs before the expected time of impact
- Process ITS images to compute pixel/line location of the nucleus center of brightness (CB)
- Use observed CB pixel/line locations to compute measurement residuals for comet-relative trajectory estimation
- Perform trajectory determination updates (OD)
  - Every minute starting 110 minutes before the expected time of impact
- Perform three (3) primary Impactor targeting maneuvers
  - ITM-1 @ E-90 min, ITM-2 @ E-35 min, and ITM-3 @ E-12.5 min
- Acquire ITS images for Scene Analysis (SA) based offset @ E-16 min
- Use SA offset for computation of final targeting maneuver (ITM-3)
- Align the ITS boresight with the AutoNav estimated comet-relative velocity vector starting @ E-5 min
  - Capture and transmit high-res images (3 m resolution) of the nucleus surface



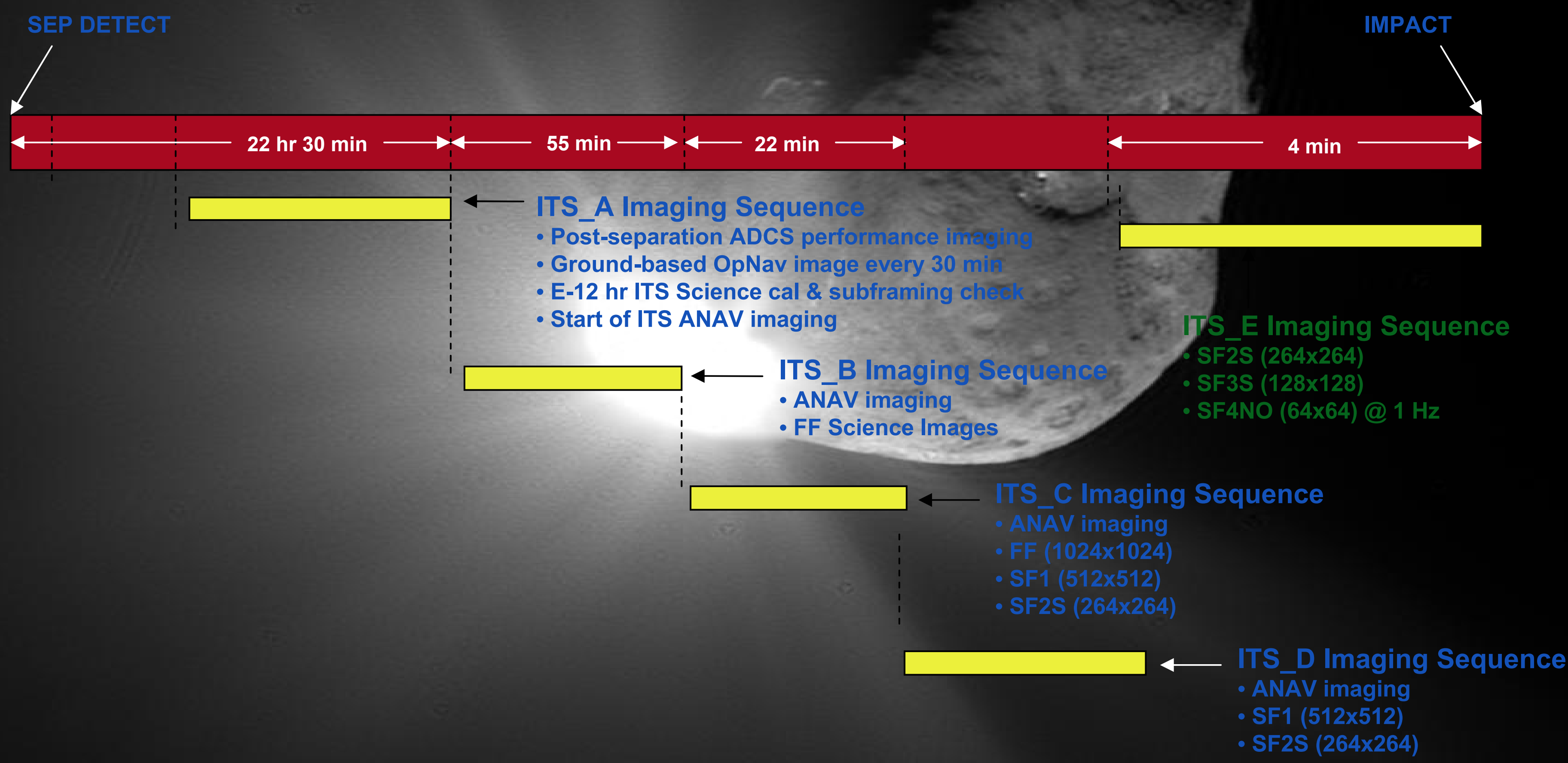
Encounter Sequence Design

Impactor Encounter Critical Sequence

(SAM_IM_SEPARATION_SEQ.bin)



Impactor Encounter Imaging Sequences

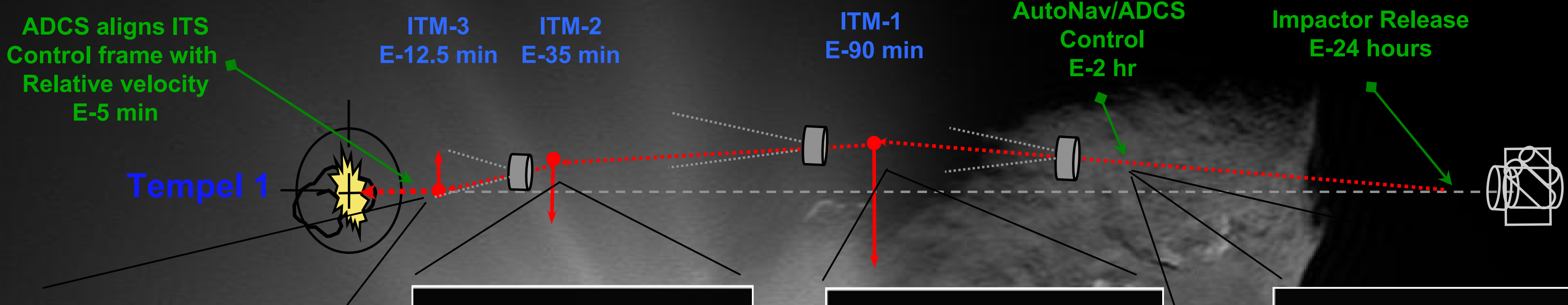


Contingency Planning

- Impactor encounter sequence was designed to handle late release contingency
  - Relative time-nature of rate-capture sequence tied to separation detection
  - Absolute-time nature of IMP_CRIT_ENG & ITS_IMG_A sequences allowed for expiration and “catch-up”
  - Post-separation events could be activated at any time up to E-3 hrs
- Uncertain nucleus albedo led to a multiple sequence sets with various exposure settings
  - ITS_IMG_*_Bright: Exposure settings a factor of 2 shorter than nominal
  - ITS_IMG_*_Dim: Exposure settings a factor of 2 longer than nominal
  - Commands built and tested to switch sequence sets anytime before E-3 hrs
- Summit Meeting held at E-30 hrs to select sequence set
  - Based on Science and Navigation observations over the preceding weeks
  - Science and Nav recommendation to stay with nominal set of sequences
  - Unanimous decision to fly with nominal set of sequences

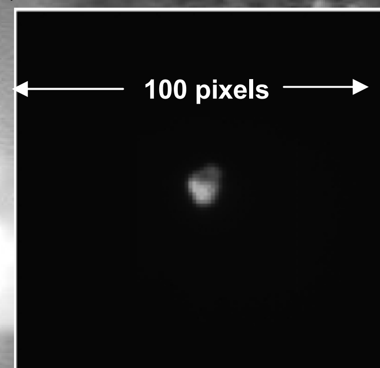
Encounter Performance

Impactor Encounter

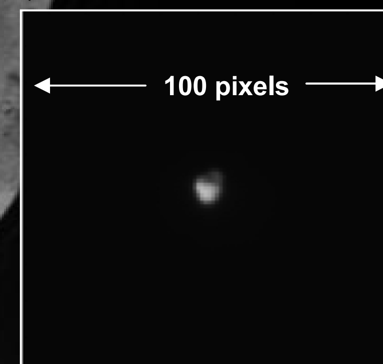


- Final fine targeting maneuver
- Complete before E-6 min to avoid dust upsets
- Range to nucleus is ~7,700 km at time of ITM-3
- Range to nucleus is ~9,600 km at time of SA
- Targeting for SA offset biased toward Flyby CA
- SA based ITM-3 was **2.29 m/s lateral ΔVç**

- Used for redundancy; improved targeting over ITM-1
- Range to nucleus is ~21,000 km
- Nucleus spans ~35 ITS pixels
- Targeting for CB
- ITM-2 maneuver magnitude was **2.26 m/s lateral ΔV**

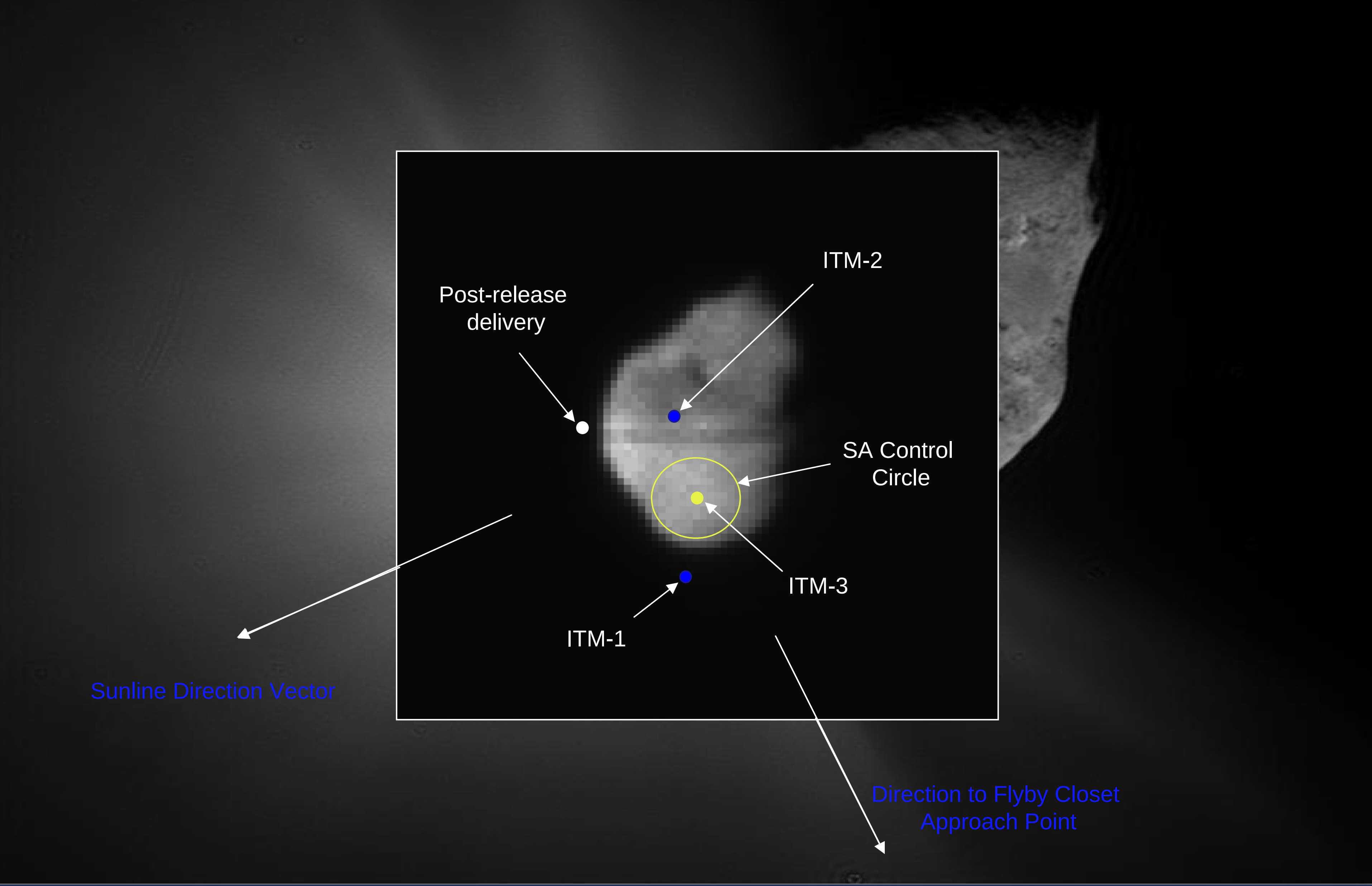


- Range to nucleus is ~60,000 km
- Nucleus spans ~12 ITS pixels
- Targeting for CB
- Pre-release delivery error was ~2.2 km
- ITM-1 manevuer magnitude was **1.27 m/s lateral ΔV**



E-100 sec

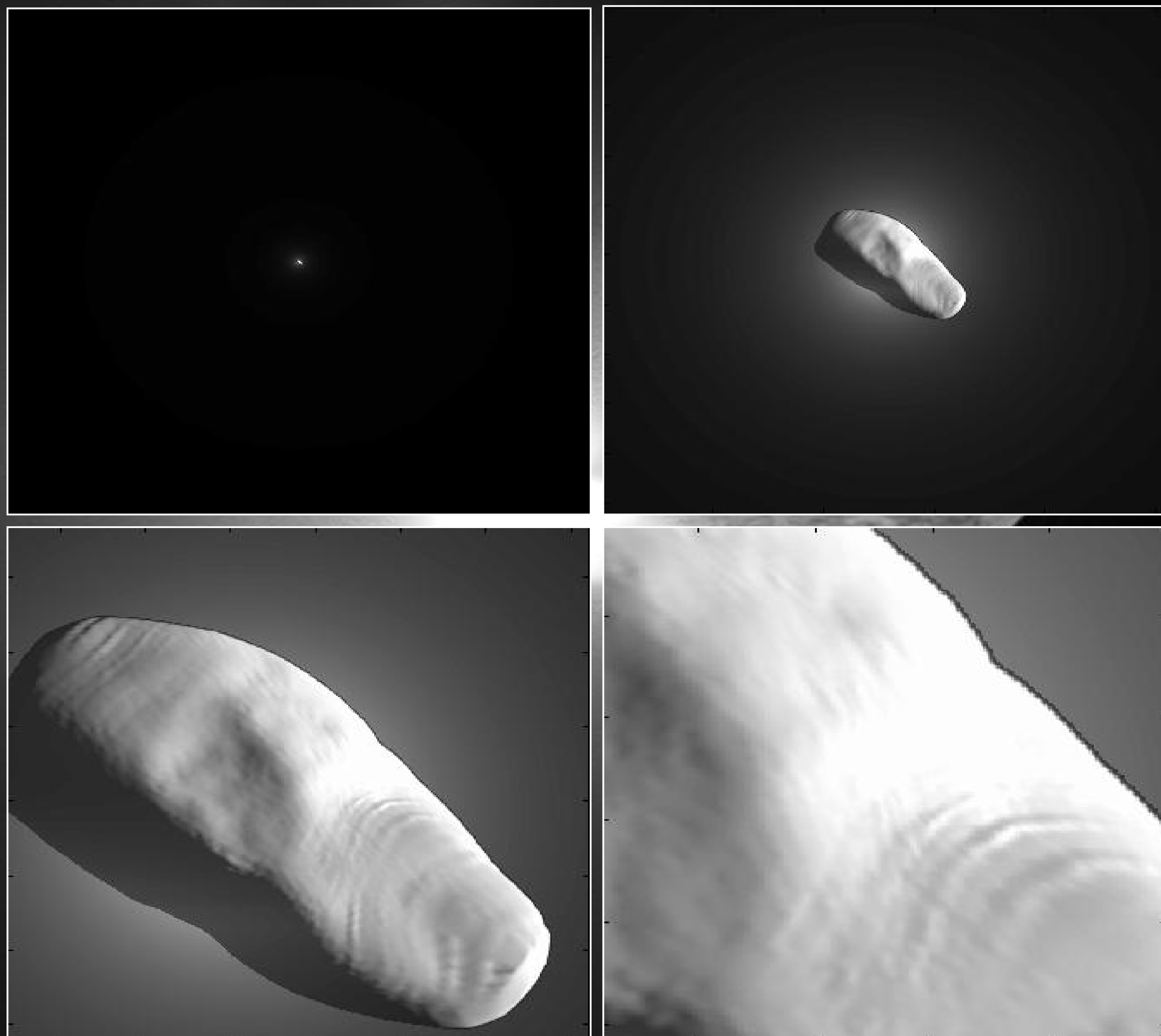
Impactor Encounter



Expected - Simulated Halley Model

E-2 hrs

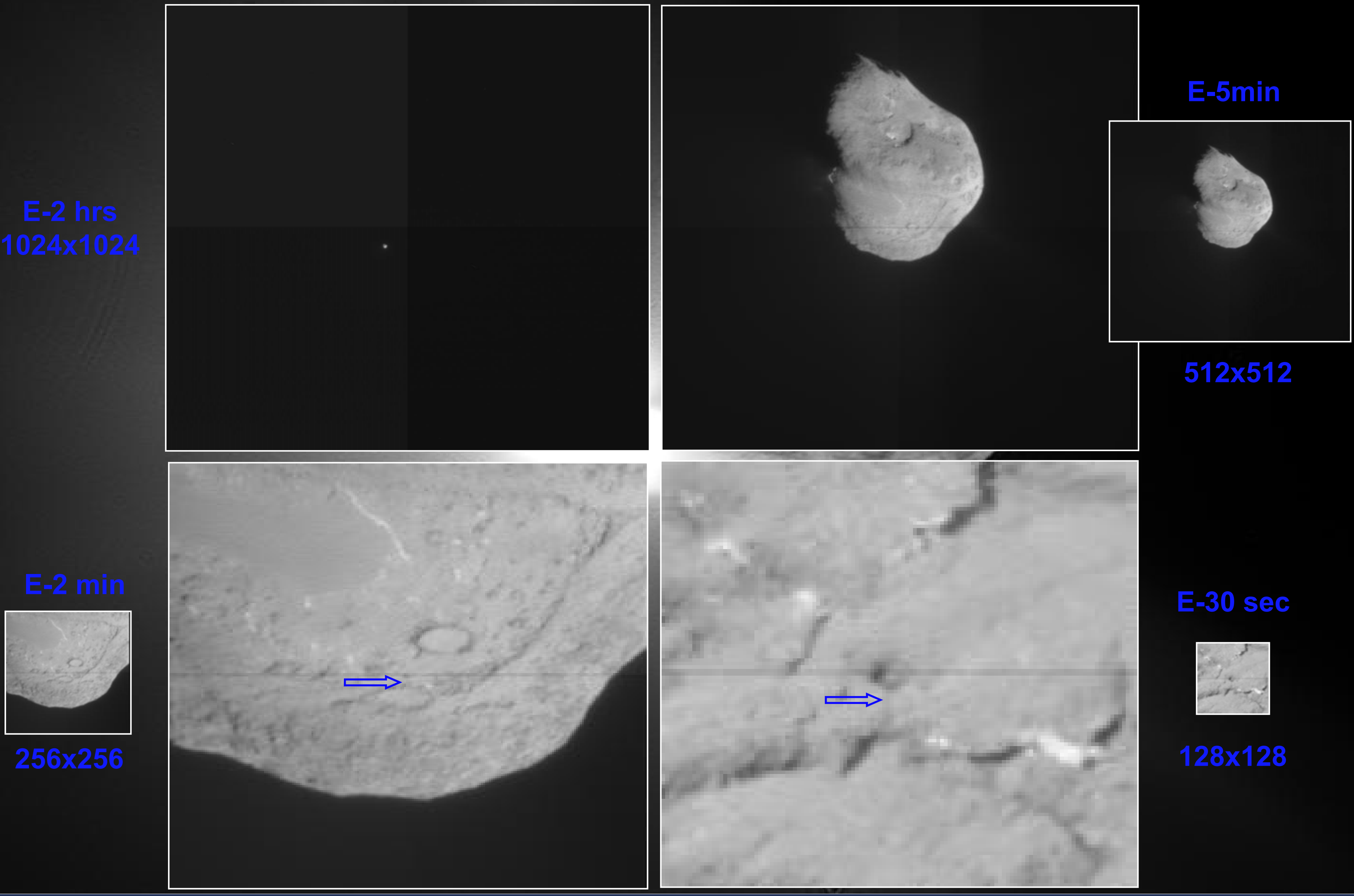
E-5min



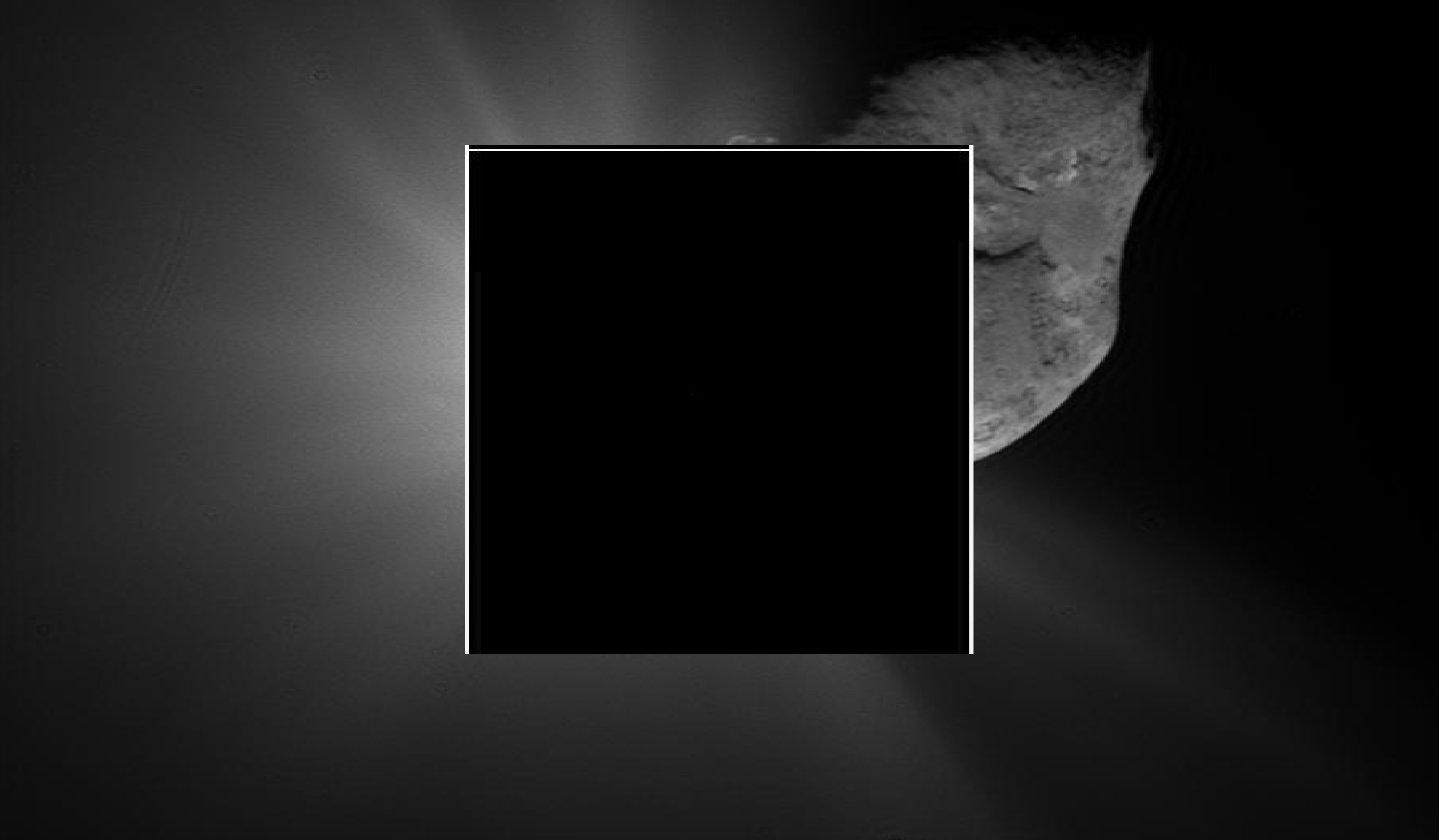
E-1 min

E-30 sec

Actually Observed - Tempel 1



Impactor Encounter Imaging Movie



Summary

- Impactor targeting led to an illuminated impact that was viewable from the Flyby s/c
- Science imaging sequences captured images of the nucleus surface with the desired temporal and spatial resolution
- The Impactor s/c captured several high-resolution context images of the actual impact site, with the last being captured only 3.7 sec before impact providing the highest resolution (40 cm) images ever taken of the surface of a cometary nucleus
- The Impactor s/c transmitted all Science and Engineering telemetry needed for post-encounter reconstruction and Scientific interpretation