The New Horizons OpNav Switch

Helen Hart & Karl Whittenburg
APL SES SIO

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New Horizons OpNav Switch - Outline

- Mission Overview
- Optical Navigation
- The OpNav Switch

New Horizons Spacecraft & Instruments

LORRI: high-resolution panchromatic camera

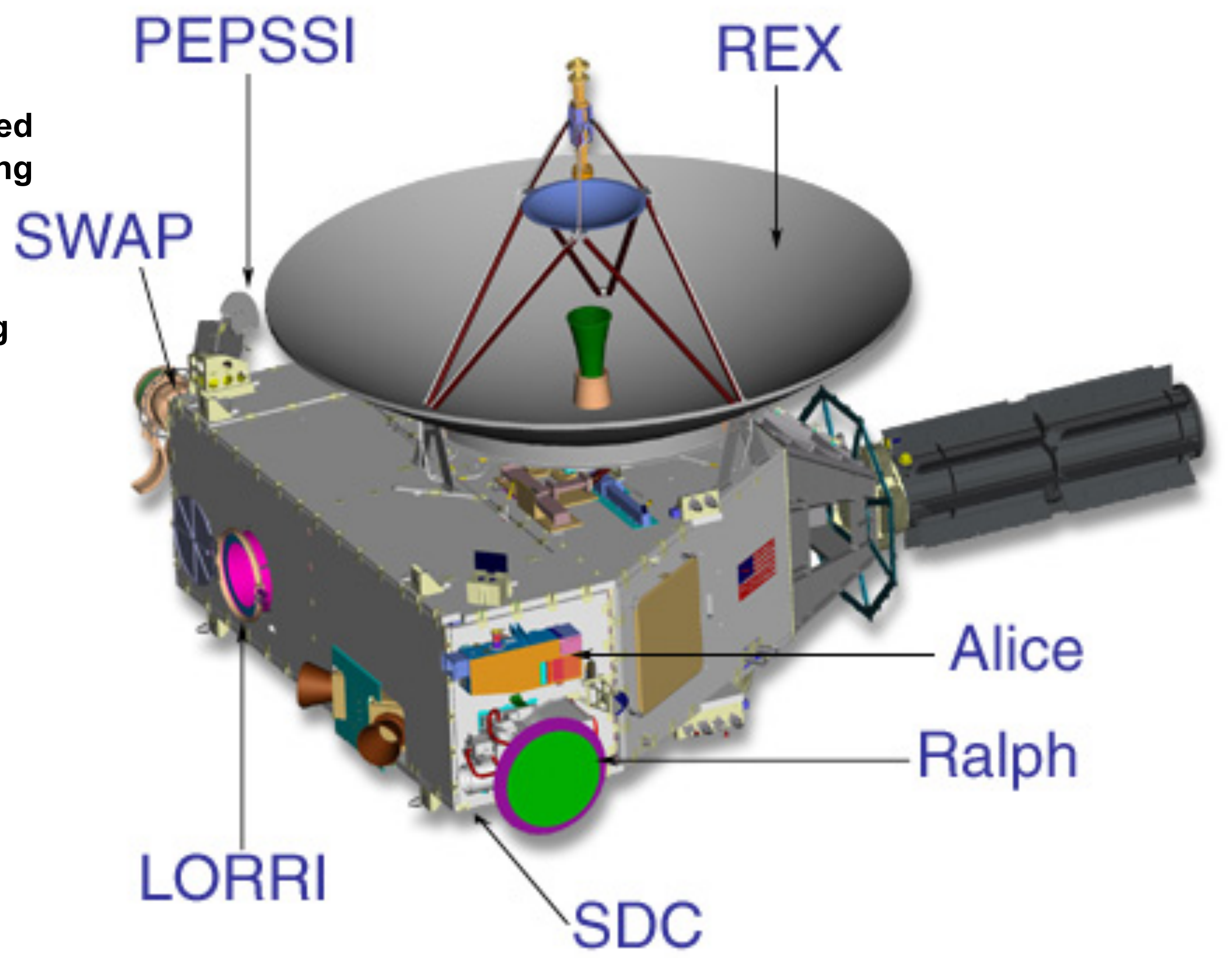
Ralph: visible/near infrared imager (MVIC) and imaging spectrometer (LEISA)

Alice: ultraviolet imaging spectrometer

REX: Radio science experiments

PEPSSI & SWAP: in-situ ionized particle measurement (eg solar wind)

SDC: Venetia Burney Student Dust Counter: counts impacts of in-situ dust on the detector plate

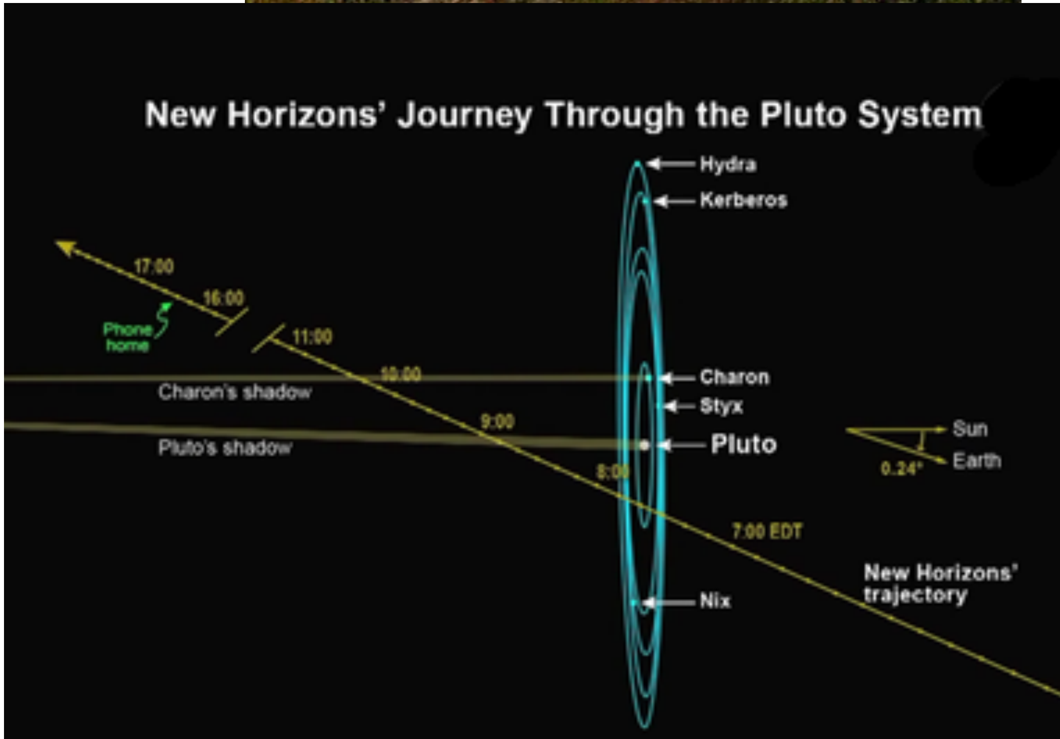


New Horizons Timeline

- Launched: Jan 2006
- Flew past Moon's orbit **in 9 hours**
  - *Previous record holder: Pioneer 10 in 11 hours*

- Jupiter Flyby & Gravity Assist: Feb. 28, 2007

  History of Earth-2-Jupiter transit times:
  - *Pioneer 10: 20 months*
  - *Pioneer 11: 20 months*
  - *Voyager 1: 17 months*
  - *Voyager 2: 23 months*
  - *Galileo: 6 years, 2 months*
  - *Cassini: 3 years, 2 months*
  - *New Horizons: 13 months*



- **Pluto Flyby: July 14, 2015**

- KBO flyby January 2017
  - If extended mission approved

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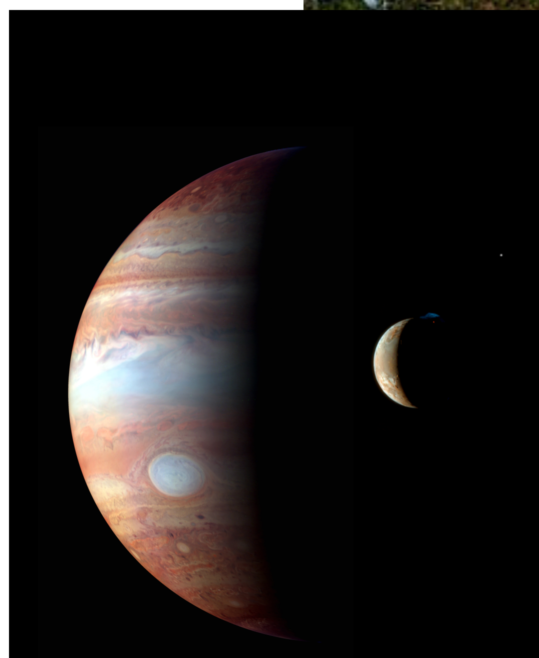

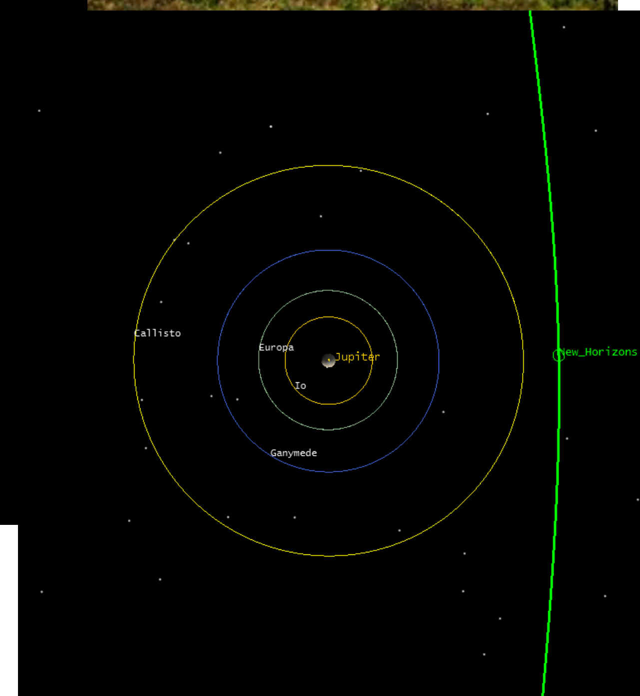

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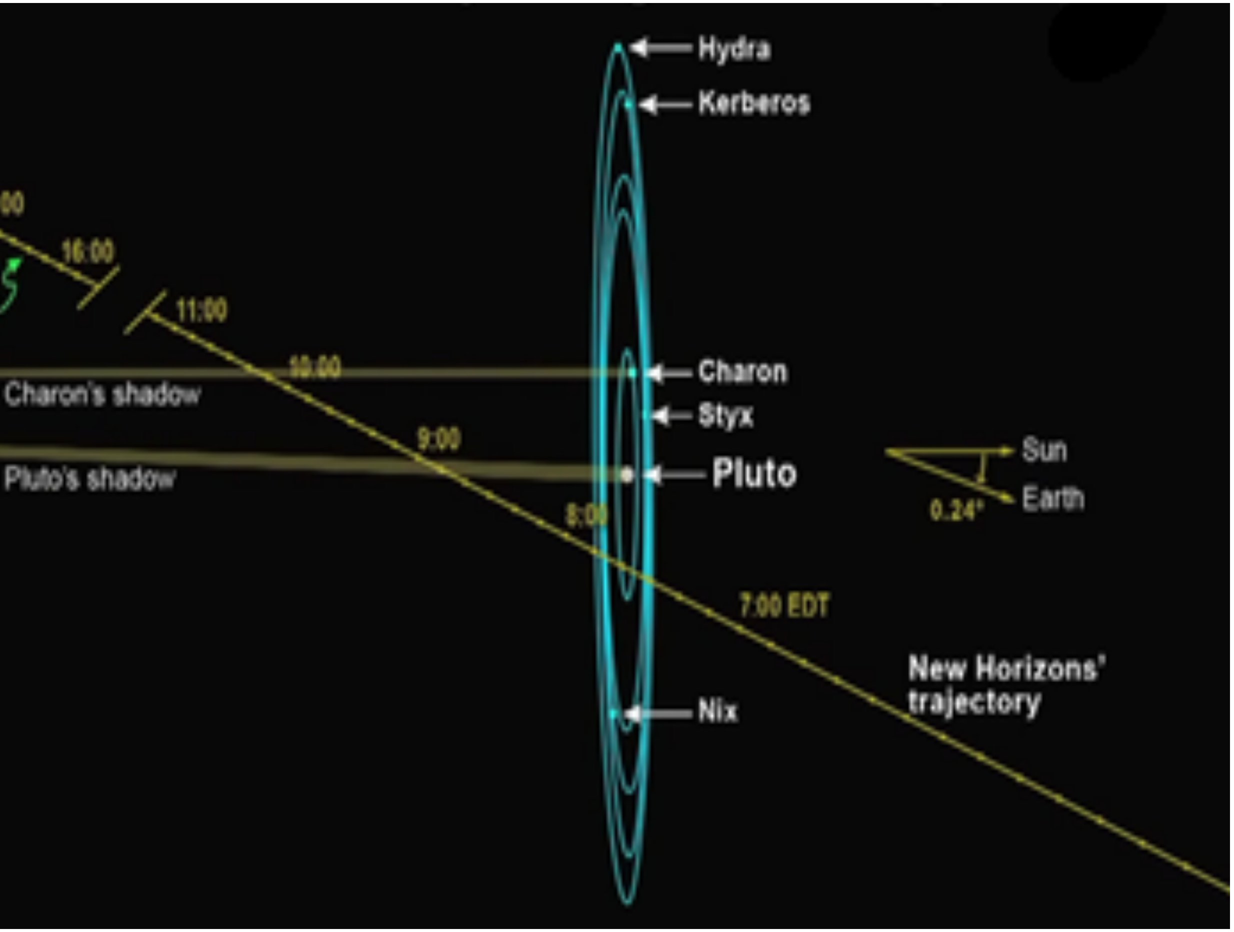
Flyby Trajectory Requirements



Closest Approach:

- **Position**: 12,500 km from Pluto's surface
  - +/-50 km (1-sigma)
- **Time**: 2015 July 14, 11:51:05 UTC
  - +/-100 s (1-sigma)

Sources of uncertainty:

1. Spacecraft position relative to Pluto.
2. Pluto position relative to the system barycenter.
3. Position of Pluto relative to the Sun.

Hit the Closest Approach Aimpoint via:

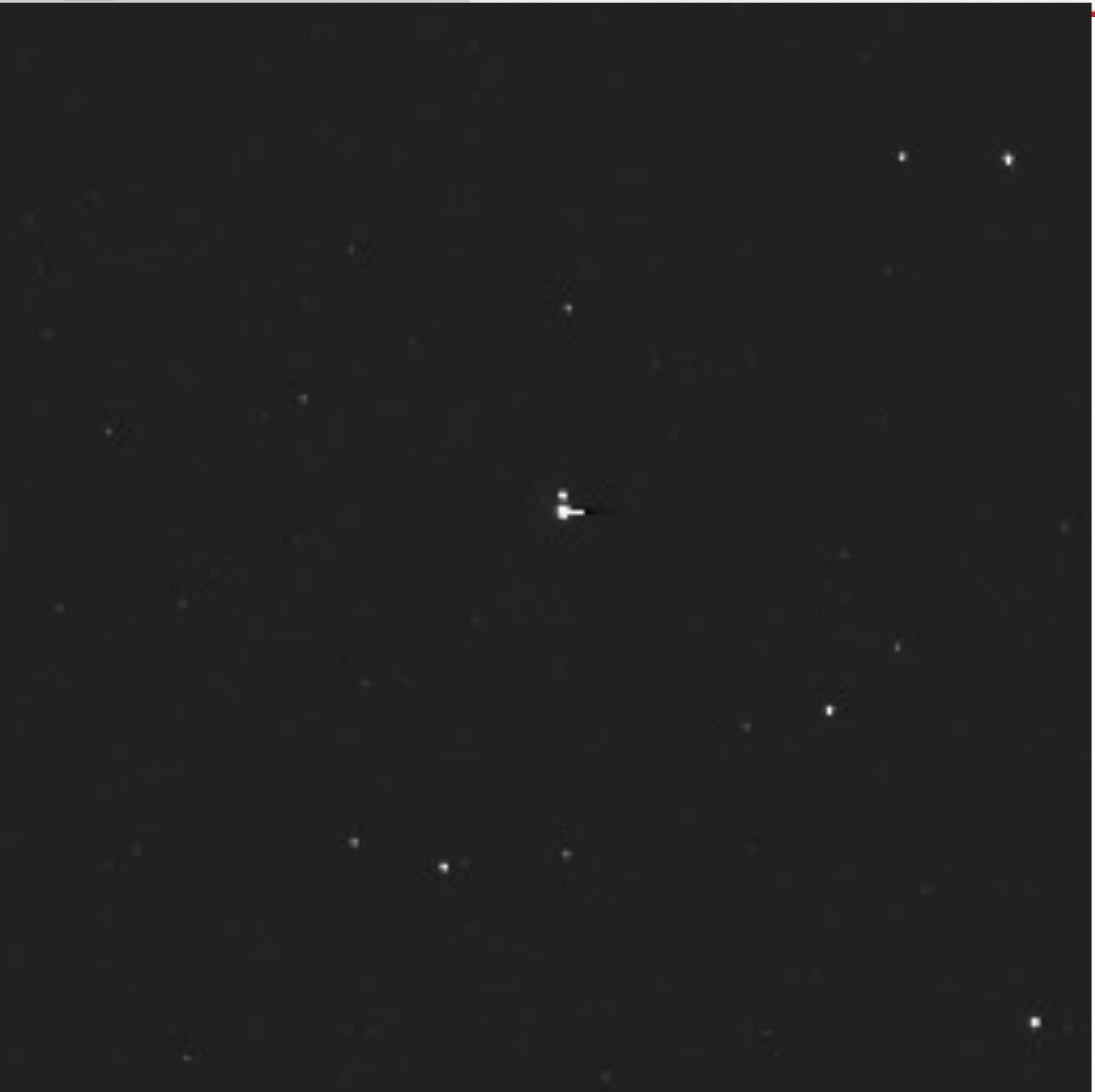
- Frequent radio and optical measurements to improve position knowledge.
- Making small adjustments to the trajectory direction and speed.

What is Optical Navigation

- Deep space navigation accomplished by means of optical imaging.
  - Optical Navigation Objective:
    - To measure the position and velocity of the spacecraft relative to the target.
  - Images must include both the target(s) and several background stars from an astrometric catalogue.
    - The apparent stellar positions must be known to high levels of accuracy.

- Contrast with navigation by means of radiometric measurements.
  - Radiometric Navigation Objective:
    - To measure the position and velocity of the spacecraft relative to the Earth.
  - Radiometric measurements are made using the communication antennas on the spacecraft and on the ground, and sometimes with reference to a very distant natural radio source (usually a quasar).

OpNav Image Example



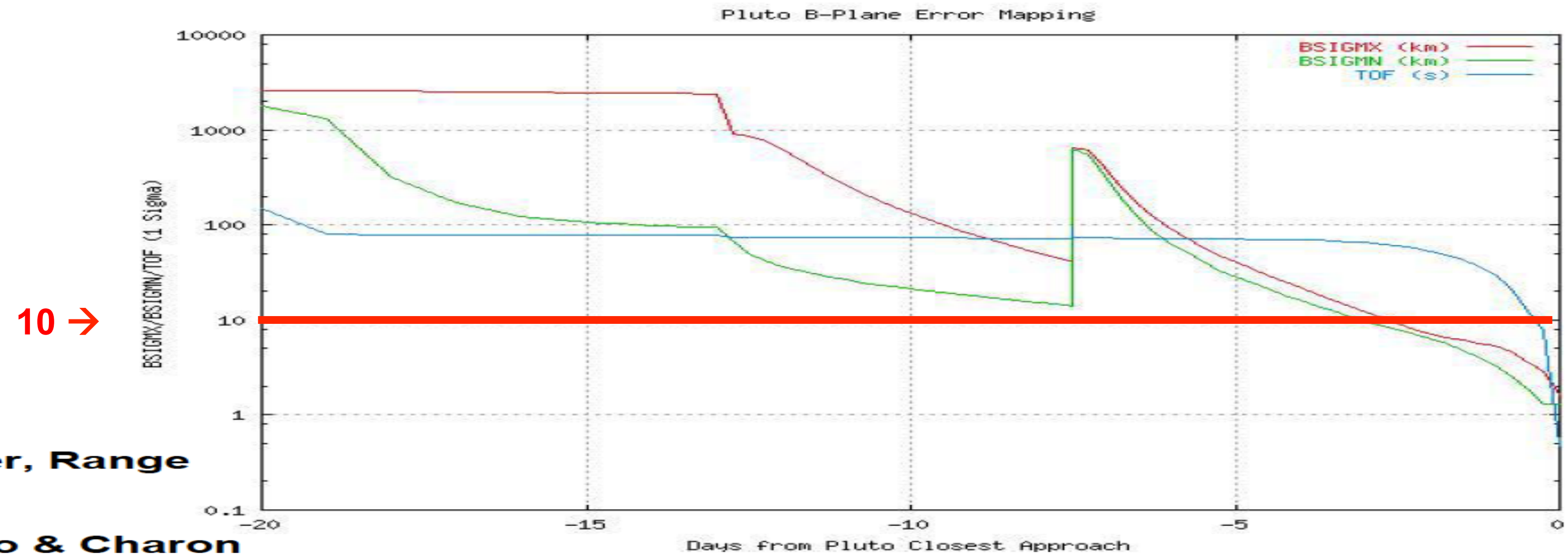
NH LORRI OpNav Campaign 2
Image Pluto, Charon, Nix
2015-01-25 02:06:09 UTC
3967 msec
Range: 203 million km
~6 mo. before closest approach

Remarks:

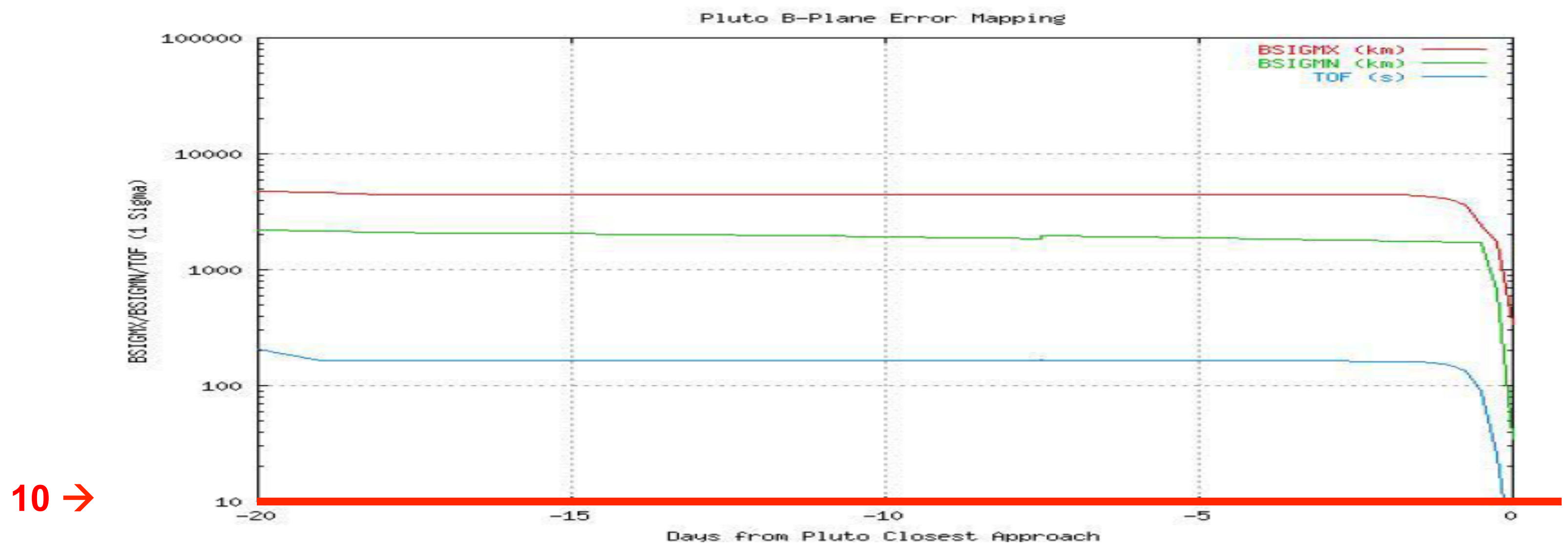
- Saturation tail to the right of Pluto
- A few cosmic ray streaks.

Source http://pluto.jhuapl.edu/

Efficacy of Optical Navigation



Doppler, Range and Opnav of Pluto & Charon

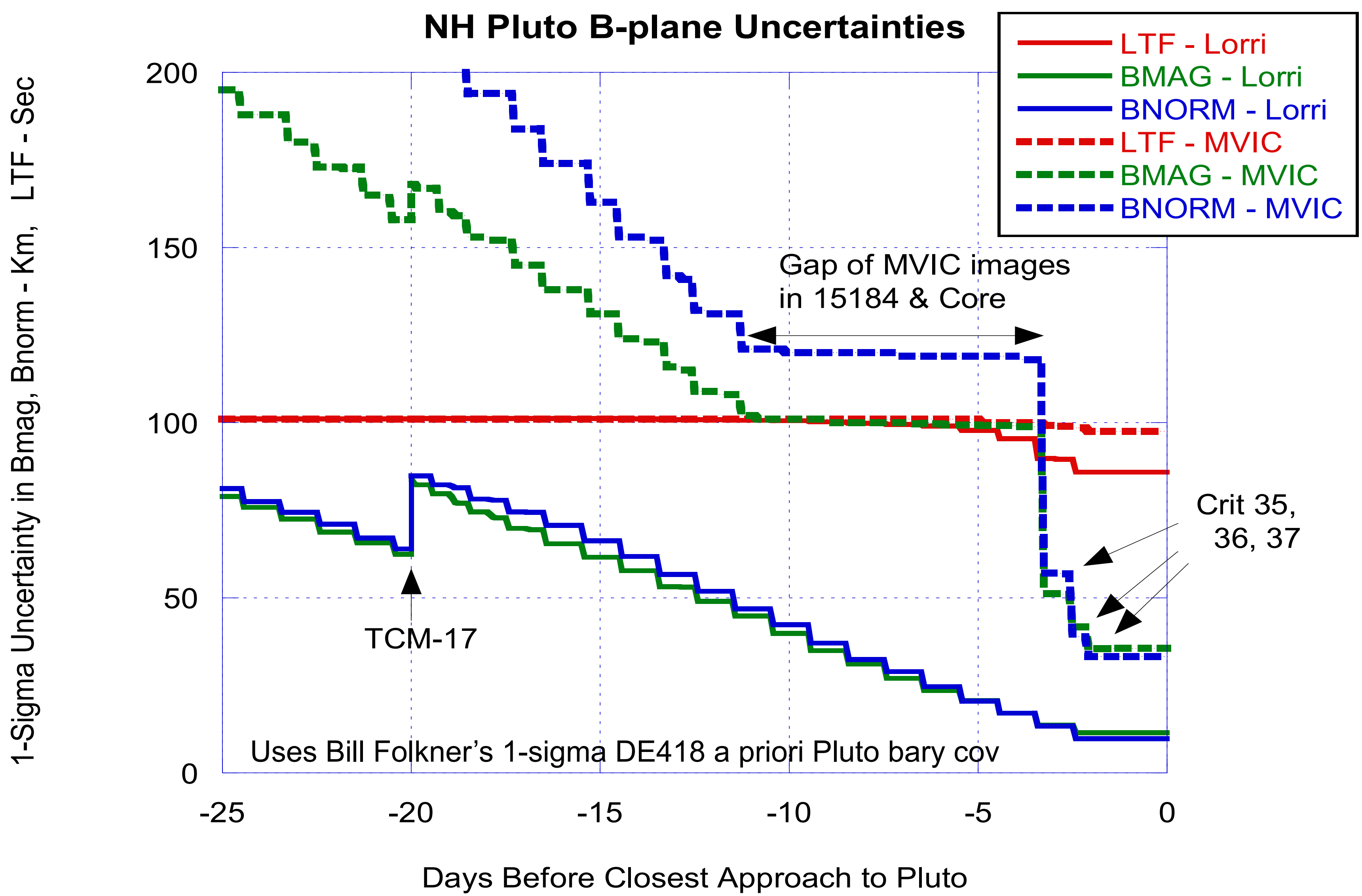


Doppler and Range only

Motivation for the OpNav Switch

- Failure of the LORRI instrument was identified as a single-point failure for New Horizons Optical Navigation.
  - Low probability event, but large consequence for the science objectives.
    - Positional and time of flight uncertainties would be out of spec by factors of 10 (see previous slide).
    - Large uncertainties could cause loss of the occultations and much of the high-spatial resolution science in the few hours around closest approach.
  - The only mitigation available was to co-opt the Ralph MVIC imager for Optical Navigation.
    - MVIC spatial resolution is ¼ that of LORRI, and its sensitivity for faint objects is much lower.
    - The relative capabilities are shown on the next slide.
  - Multiple studies were done in various parts of the project to determine how and when to employ MVIC OpNavs. The final recommendation was to use both imagers where practical, and to develop a means to choose between them.
- Thus, Mission Operations was directed to develop the OpNav Switch.

Pluto/Spacecraft Location Uncertainties LORRI vs MVIC

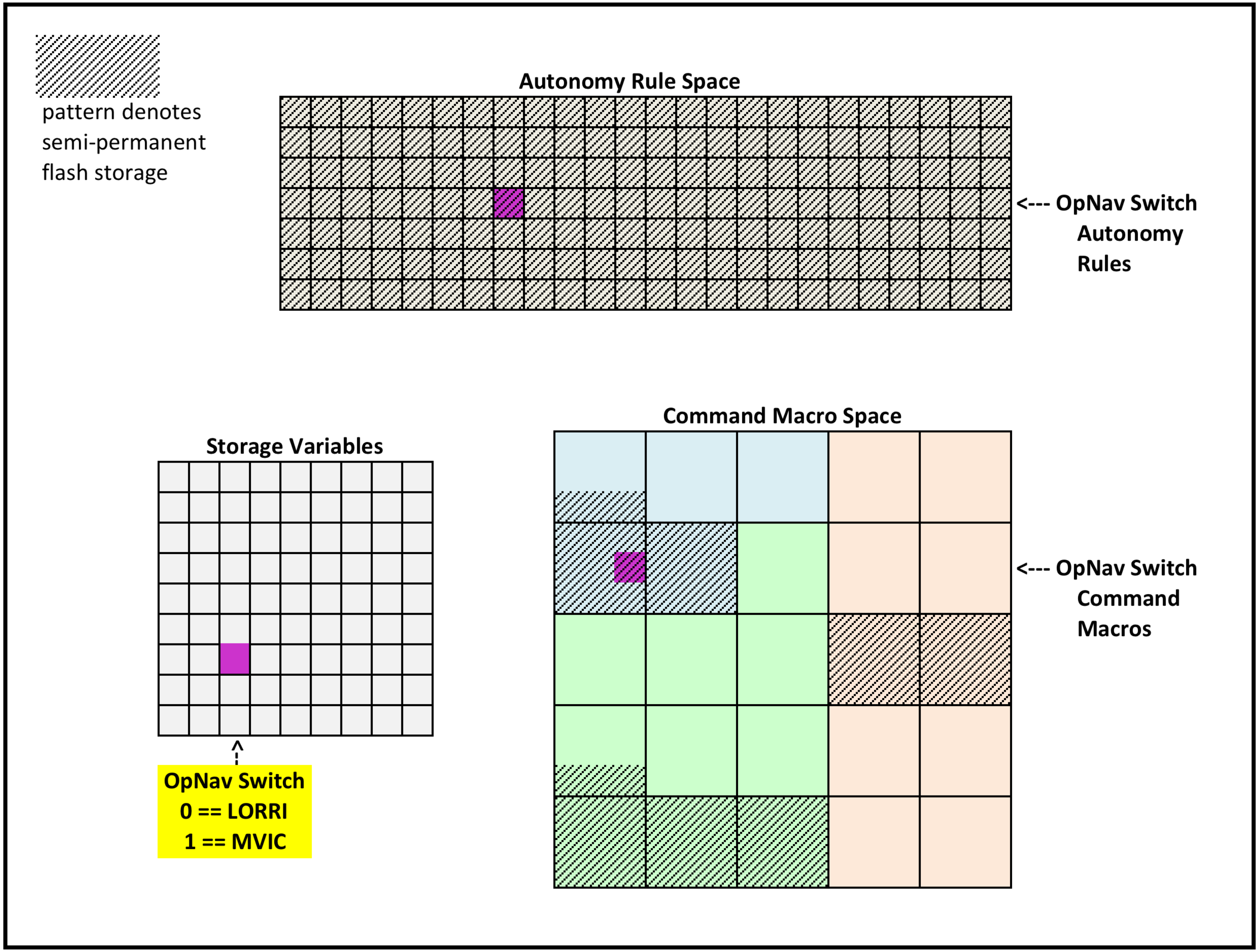


Critical and Regular OpNav Image schedule v14

OpNav Switch: Goals, Strategy, Challenges

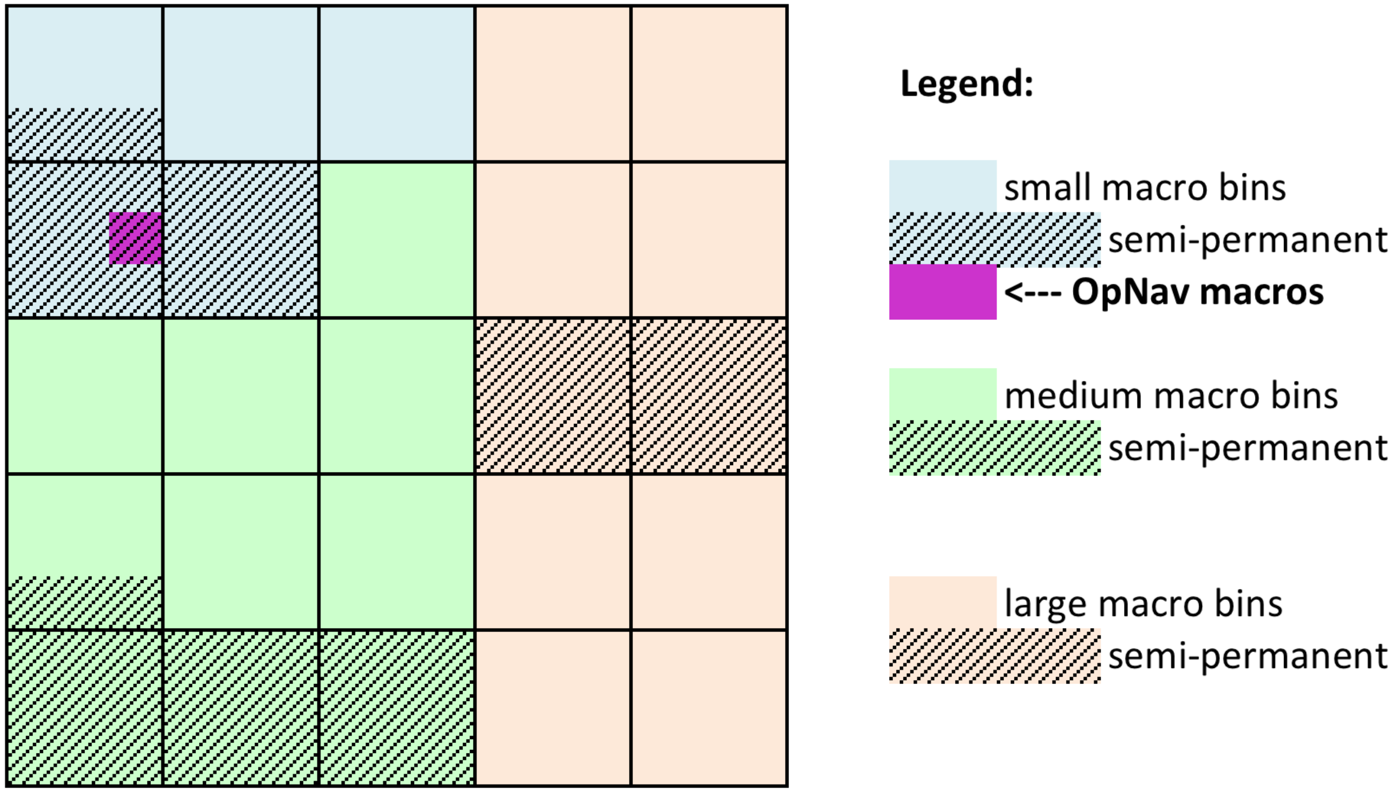
- Goals
  - Protect Navigation Mission Requirements against problems with or failure of the primary OpNav imager.
  - Do not fill the available downlink with un-needed images.
    - OpNav images are big – downlinking unnecessary images would seriously reduce the available downlink for Science.
    - Even so, other extraordinary efforts were required to bring down the Approach Phase Science.
- Strategy
  - Acquire each scheduled OpNav with both the primary and the backup imagers.
    - Primary imager: LORRI
    - Backup imager: MVIC (part of the Ralph instrument)
  - Default state: Compress and downlink the primary OpNavs.
  - Create a mechanism to switch compression and downlink to the backup OpNavs via real-time command.
- Challenges
  - Work with available C&DH software structures.
  - Work within the Operations sequenced command load paradigm.
  - Work within the Operations real-time commanding paradigm.

New Horizons C&DH in a Nutshell



New Horizons C&DH OBBs

C&DH S/C Command Macro Space



semi-permanent:

These macros are stored in FLASH memory to preserve the command definitions across C&DH resets.
Also known as **OBB**s (On Board Blocks).

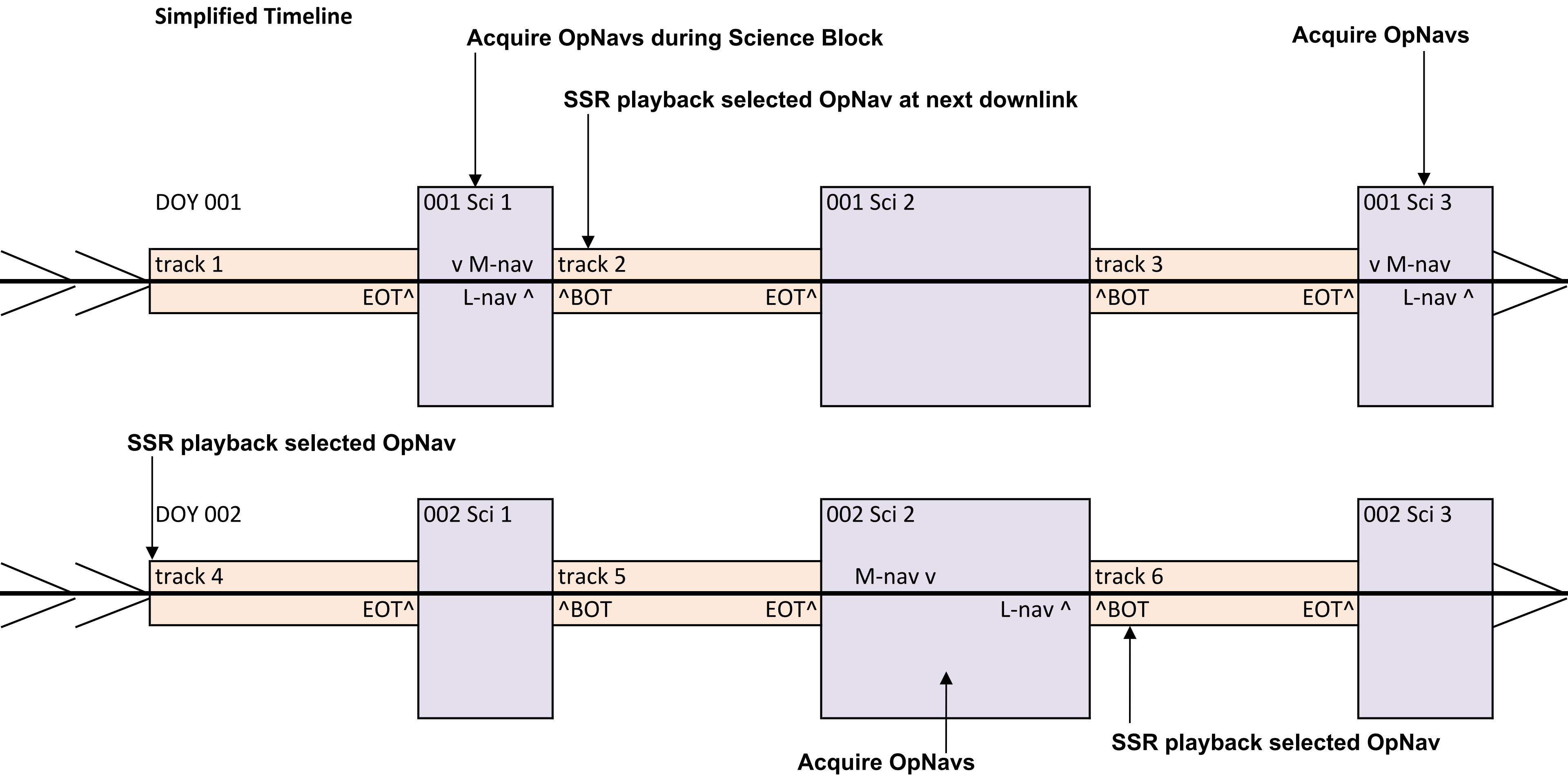
New Horizons Solid State Recorder

- Raw science data is streamed from the high-speed science instruments to the recorder at high rates rates.
  - The LORRI and Ralph/MVIC imagers are high-speed instruments.
- Raw science data must be compressed before it can be played back.
  - Compression reads the raw data from the SSR, passes it through the specified compression algorithm, and writes the compressed data packets back to the SSR.
- Raw science data, compressed science data, and Spacecraft data are written to the SSR as individual data types.
  - All data is tagged with the MET time of acquisition.
- Accessing data on the SSR may be accomplished by MET time range or by bookmark.
  - **Bookmarks** allow access of data associated with a specific activity.
    - The bookmark is opened at the start of the activity and closed at the end of the activity.
    - The **data types** collected into a bookmark are specified when it is opened.
    - Bookmark-able activities can include **data acquisition and compression**.
    - Data can be played back by bookmark.

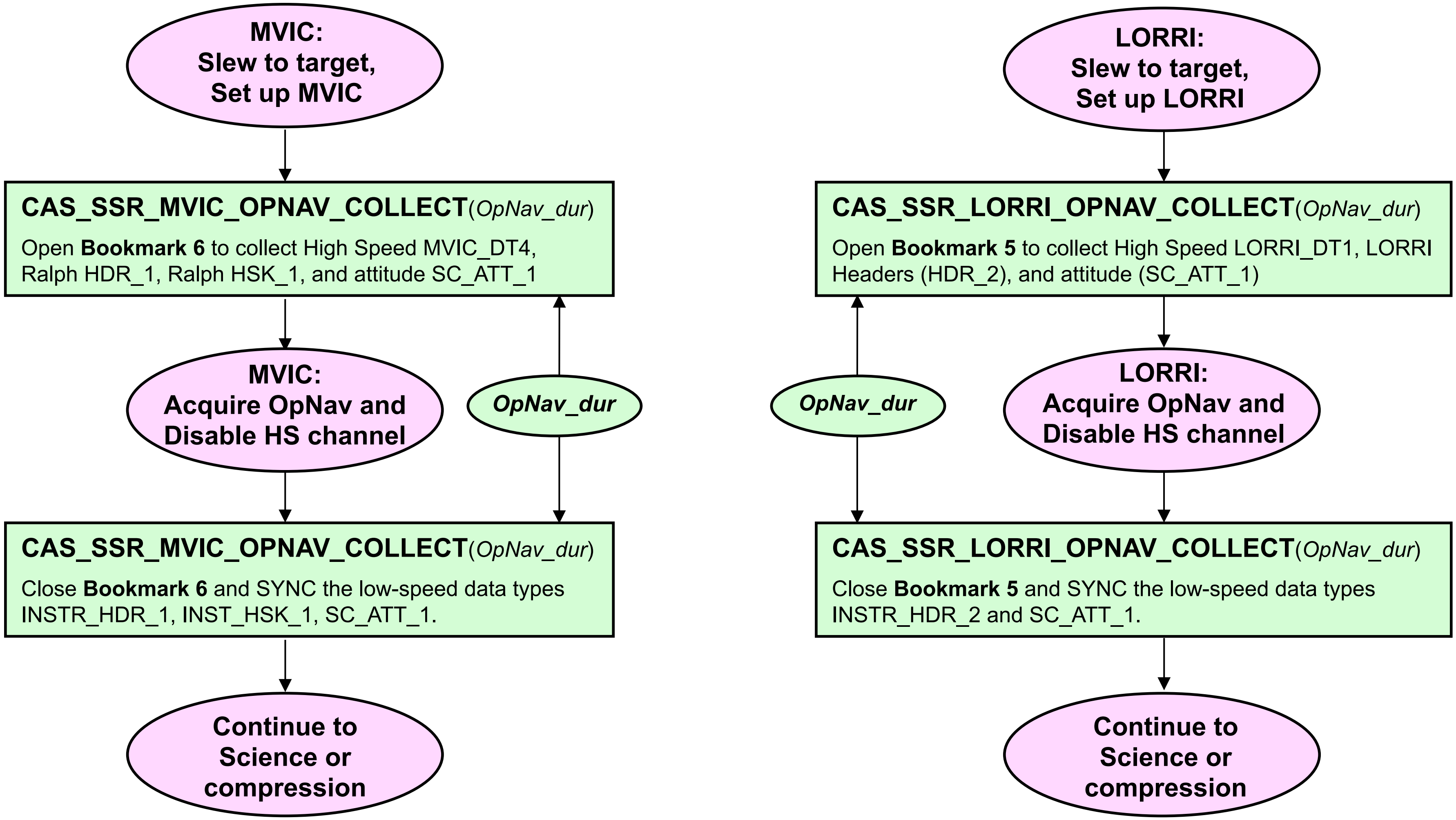
OpNav Switch: Tactics

- Data capture, compression and downlink
  - Use **<u>bookmarks</u>** to capture the OpNav data for both primary and backup imagers.
  - Create **<u>Autonomy rules</u>** to select the primary or backup images based on **<u>storage variable</u>** that can be set from the ground.
- Infrastructure (ground system development)
  - Create **<u>Onboard Block macros (OBBs)</u>** to handle compression and playback by bookmark, one for each of the primary and backup OpNavs data types.
  - Create MOps Autonomy Rules that will fire in response to the setting of C&DH Storage Variable 50, and call the appropriate compression/playback OBB.
  - Create **<u>CASs</u>** to sequence data capture and initiate compression.
    - CAS == Canned Activity Sequence.
      - A user-friendly "subroutine" that takes input parameters and creates a sequence of commands with correct parameters and relative timing.
      - CAS library and all command sequencing done with SEQ_GEN/SST.
  - Create **<u>STOL</u>** scripts to set Storage Variable 50.
    - STOL = Satellite Test and Operations Language
  - Test all of the above via the software and hardware simulators.
- Infrastructure (spacecraft)
  - Load the new OBBs and MOps Autonomy Rules to the spacecraft.

OpNav Switch: Nominal Timeline

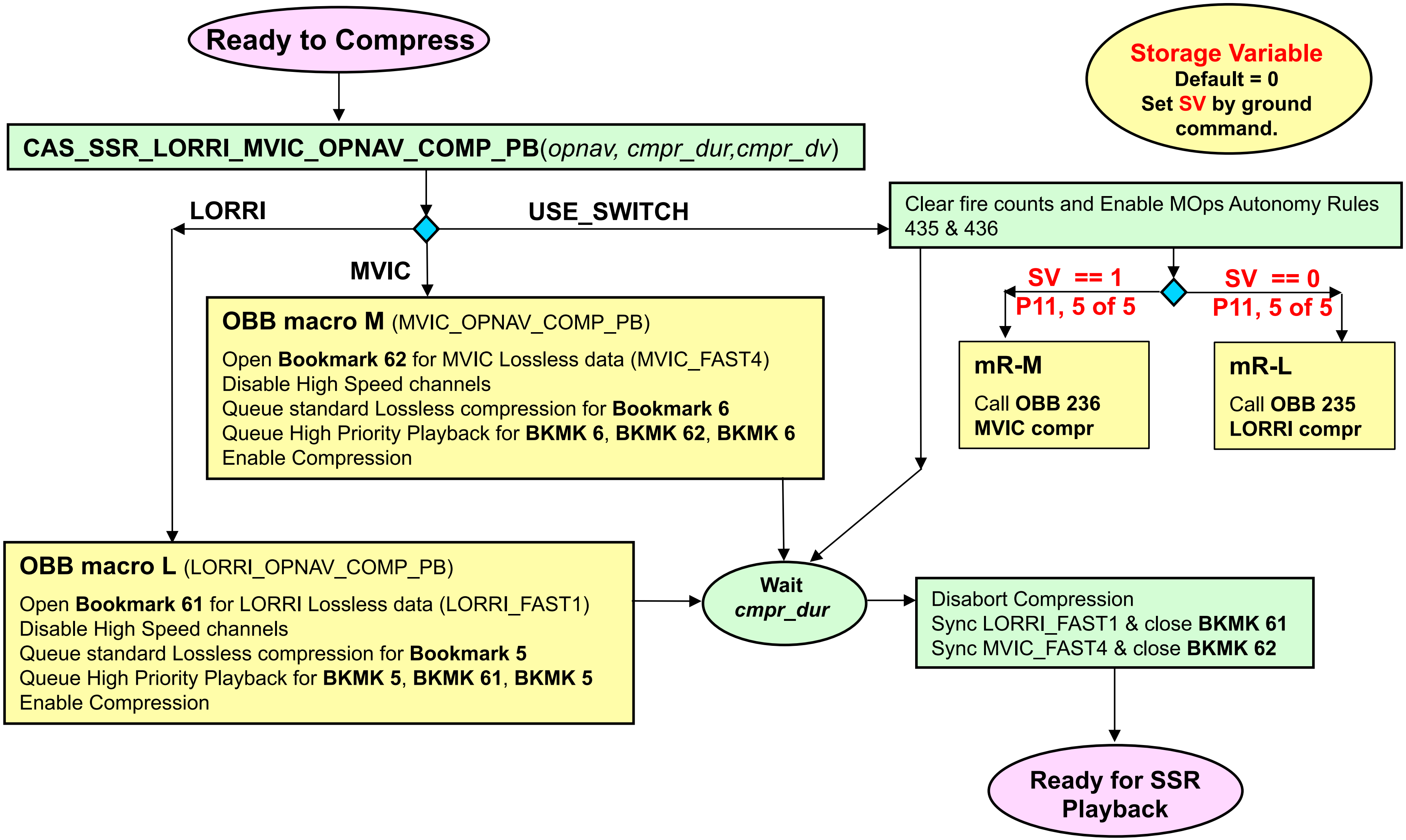


OpNav Switch: Collecting OpNav Data



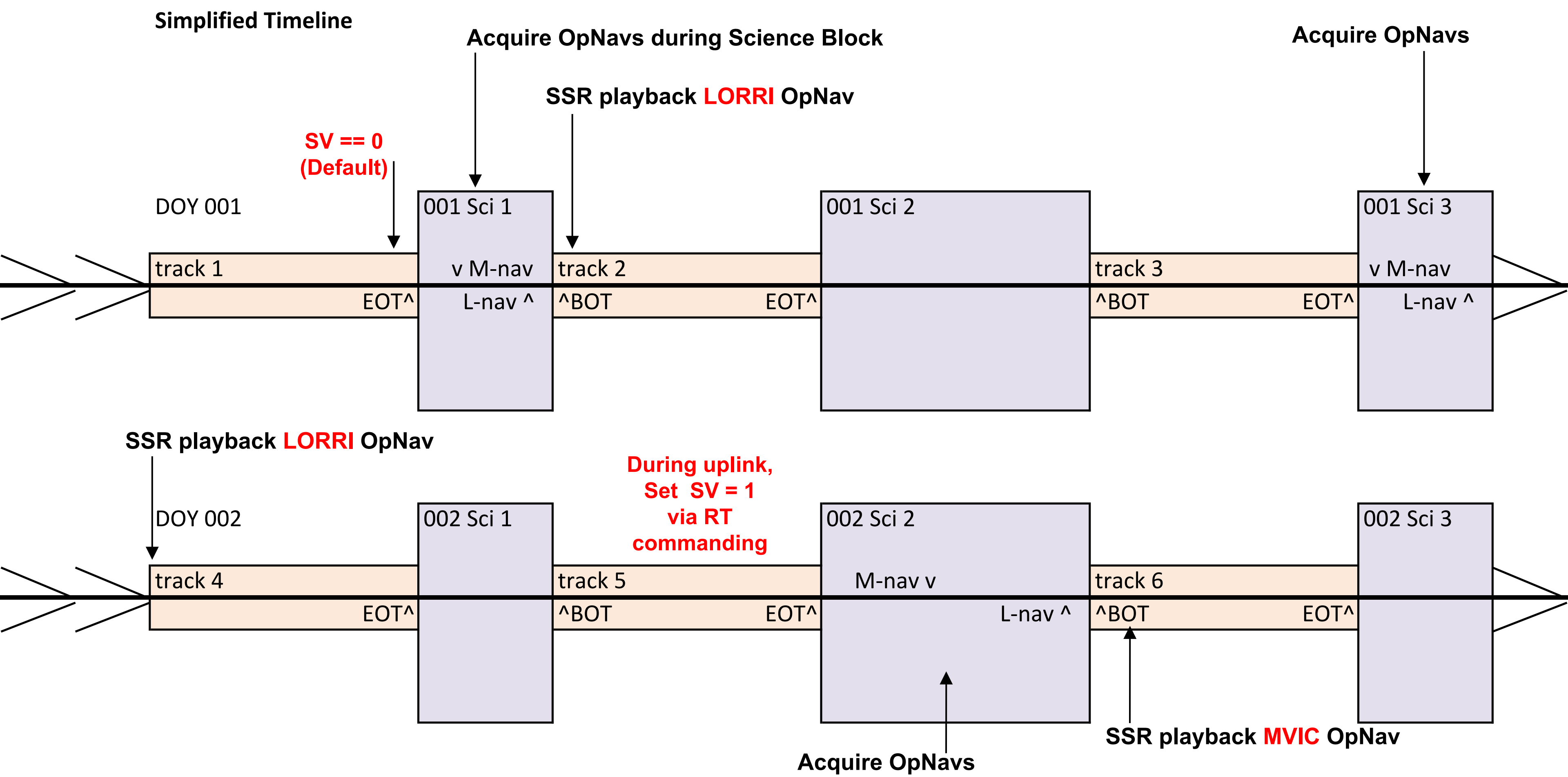
Legend:	Events in the timeline.	CAS commanding	Resides in the C&DH on the S/C

OpNav Switch: Compression & Playback



Legend:	Events in the timeline.	CAS commanding	Resides in the C&DH on the S/C

OpNav Switch: Controlling the Switch



OpNav Switch: Requirements

There are several requirements placed on Switched OpNav data sets beyond the normal requirements for data acquisition.

- Switched OpNav data sets must not exceed specified thresholds for compressed data volume and compression duration:
  - Thresholds were based on the nominal LORRI OpNav designs.
  - This limits the number of images acquired.
- Switched OpNav data types are restricted:
  - One raw data type and one compressed data type for each instrument.
  - Data types are hard-coded in the OpNav CASs and OBBs, and may not be changed on the fly.
- Careful coordination is required between the data acquisition request and the interleaved data capture request.
  - The science instrument sequencer produces the command sequence to acquire the data.
  - The MOps sequencer places the OpNav collection sequence around the acquisition.
  - Must get the timing correct, down to 1-second tolerances.

OpNav Switch: Usage Summary

- For each science block with OpNavs, sequence these activities:
  - Acquisition and capture of one (1) MVIC OpNav set
  - Acquisition and capture of one (1) LORRI OpNav set
  - OpNav compression and playback for the next downlink track
    - USE_SWITCH:
      - The value of Storage Variable 50 at execution time determines which data will be compressed and queued for playback.
        - » SV50 = 0 → LORRI OpNav data set (default value in the C&DH)
        - » SV50 = 1 → MVIC OpNav data set
- Load the sequence to the spacecraft.
- If desired, during an uplink prior to OpNav acquisition send a real time command to change the value of SV50 (default = 0)
- On each downlink track following OpNav collection
  - Receive the OpNav data set specified by the value of Storage Variable 50 at the time the compression occurred.

OpNav Switch: Conclusion

- The switch concept was applied to designated Critical OpNavs during final approach:
  - 2015, May 28 to July 4 (P-47 to P-11).
  - Approximately 30 LORRI/MVIC OpNav pairs in all.
- LORRI did not die or show signs of degradation.
  - The OpNav Switch was never set to use the backup imager.
- Although we didn't use the switch, the capability was there if it had been needed.

References

- "The New Horizons Spacecraft", G.H. Fountain et al., Space Science Reviews, Vol. 140, 2008
- New Horizons Command and Data Handling Users' Guide, A.J. Harris, APL internal document 7399-9175
- New Horizons Navigation Training for Mission Operations, September 2005, Williams & Caranza, Kinetx (Mission Ops internal training document)

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