Determination of the True Exposure Time of New Horizons LORRI Images

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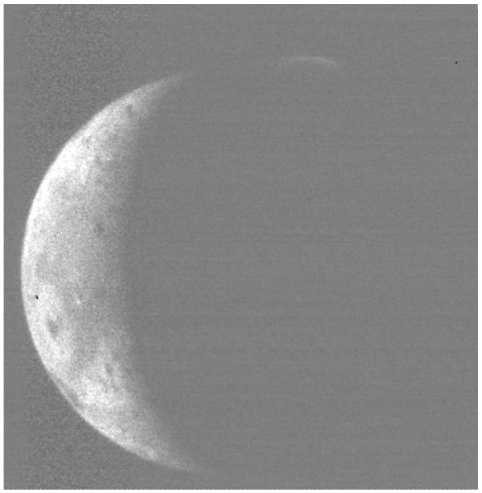
Issue

- In June 2019, Spencer found, by comparison of New Horizons LORRI images of the same scene with different short exposures, that signal was only proportional to exposure time if the true exposure time was assumed to be roughly 0.6 msec longer than commanded or reported at that time in the FITS headers
- These slides provide a more systematic determination of the true value of the exposure increment relative to the commanded time
  - This is done by comparing LORRI images of Io taken 3 seconds apart with different exposure times
- The cause of this offset is now understood and is detailed on the final slide

Method

- For a pair of Level 2 LORRI images of the same scene with different exposure times:
  - Assume
    (true exposure time) = (FITS header exposure time) + δt
    where δt (the "exposure offset") is a constant between images
  - Ratio images to their assumed true exposure times, for a given value of δt, to produce DN/sec images
  - Difference the DN/sec images (after alignment)
    - If the exposure times are correct, the two DN/sec images should be identical, and their difference should be zero
    - The difference is <u>not</u> zero for δt = 0 (example in top image)
  - The bottom image shows a difference image from the same image pair, with δt = 0.74 msec
    - This estimate for δt is too large, leaving a negative residual
  - Determine the optimum value of δt in two ways:
    - Vary δt to minimize the standard deviation of the pixels in the difference image in the yellow box (on Io's disk)
    - Vary δt to minimize the signal from Io in the difference image (defined as the mean DN in the yellow box (on Io's disk), minus the mean DN in the green box (off Io's disk)



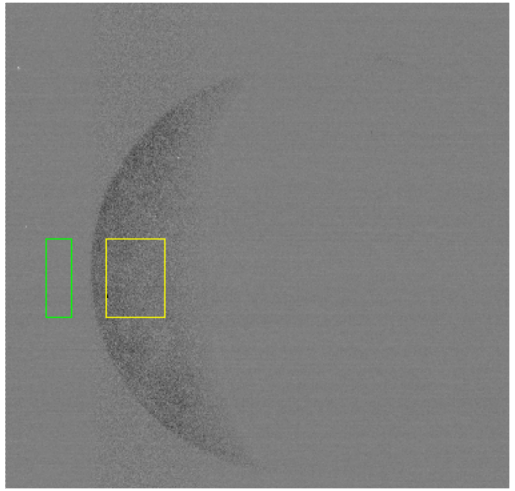
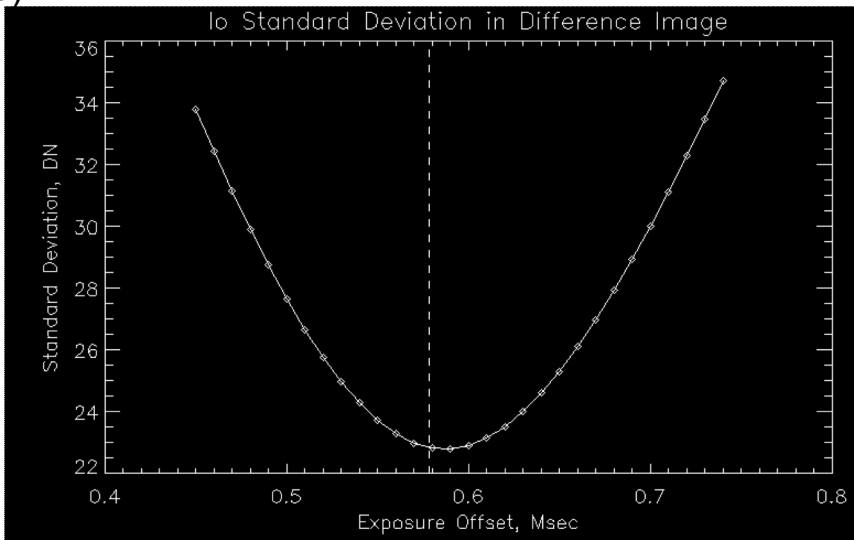


Image Ratio 1

- Compare:
  - Image1: MET 34966574 (4 msec reported exposure)
  - Image2: MET 34966577 (20 msec reported exposure)

- In the difference image (below), δt = 0.59 msec minimizes the standard deviation on Io (top plot, right), while δt = 0.58 msec minimizes the signal from Io (bottom plot, right)
- The discrepancy may be due to very small imperfections in frame transfer smear removal



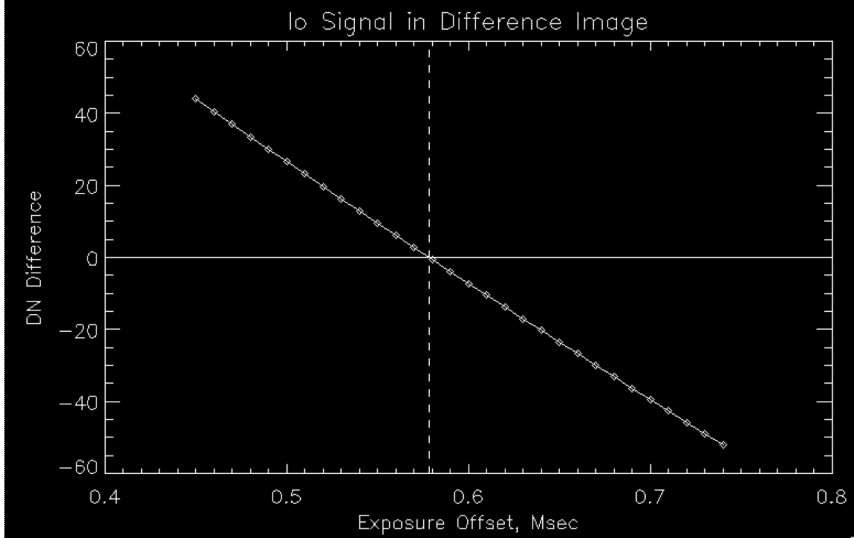


Image1

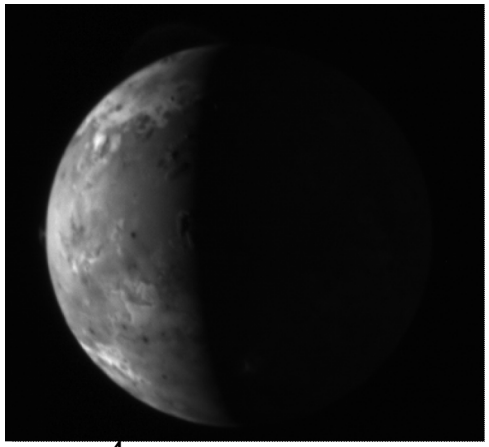


Image1/(4.58 msec) – Image2/(20.58 msec)

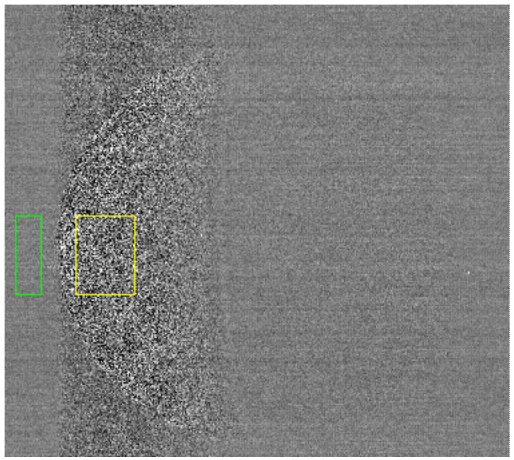
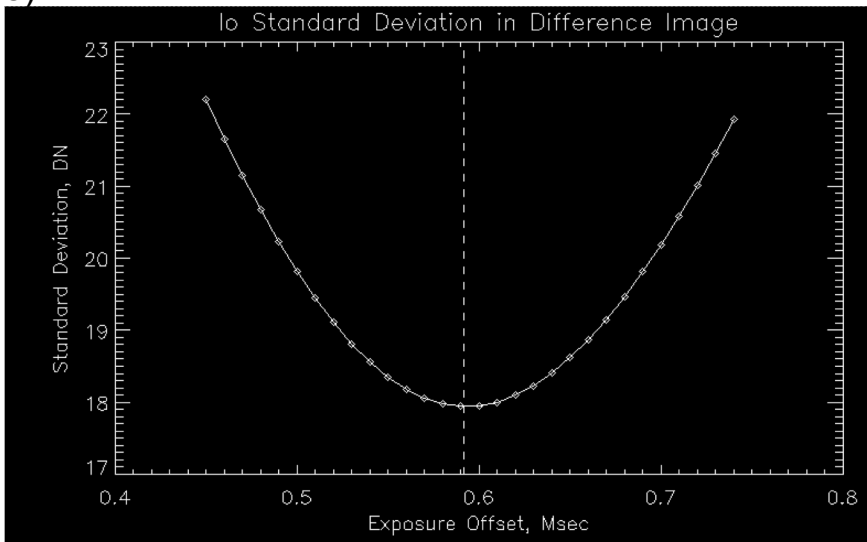


Image Ratio 2

- Compare:
  - Image1: MET 35029094 (4 msec reported exposure)
  - Image2: MET 35029097 (20 msec reported exposure)

- In the difference image (below), δt = 0.59 msec minimizes both the standard deviation on Io (top plot, right) and the signal from Io (bottom plot, right)



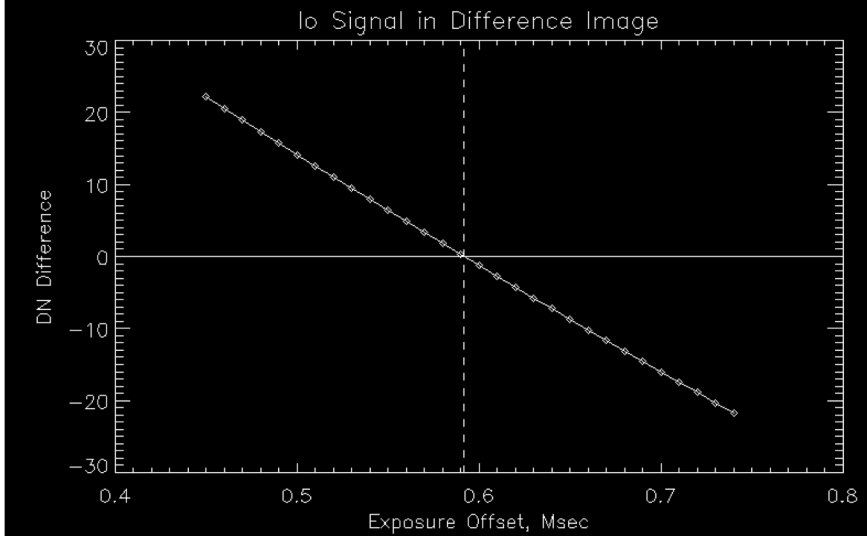


Image1

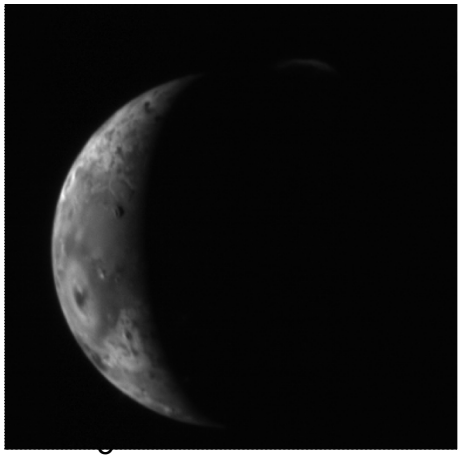
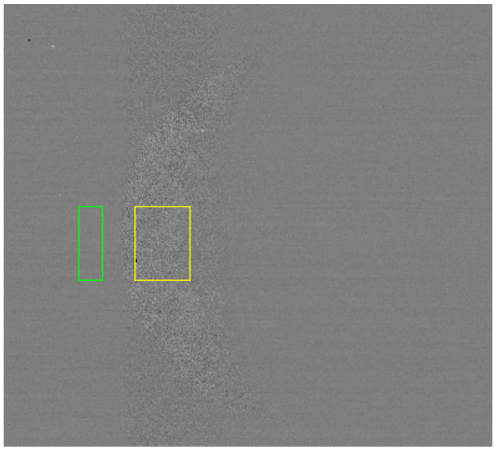


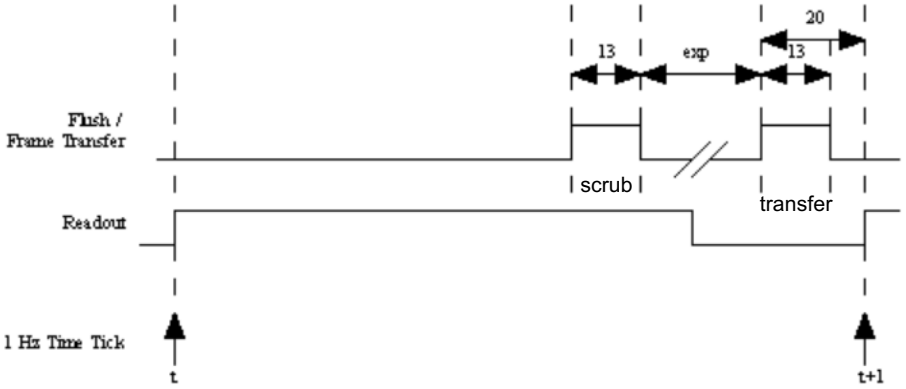
Image1/(4.59 msec) – Image2/(20.59 msec)



Conclusions

- For these two image pairs, the exposure offset needed to correct reported (and commanded) exposure times to true exposure times is close to +0.6 msec
  - 0.59 msec may be a better value, but it's not clear that including the extra digit of precision would have any practical benefit
- This number is consistent with the +0.6 msec number that Spencer found in June 2019, using different Io and Jupiter images
- This technique can't be used to determine reliably the exposure offset for images with much longer exposure times, but the same offset should apply to *all* LORRI images, as explained on the next slide
  - In any case, note that the small offset isn't significant for typical exposure times used during the Pluto and Arrokoth flybys (i.e., exp times >30 ms)
- Thus, the LORRI Team has adopted +0.6 msec as the difference between the true LORRI exposure times and the commanded exposure times
  - The LORRI pipeline has been updated to add 0.6 msec to the exp times reported in the relevant FITS header keywords (e.g., EXPTIME)

Root Cause of Exposure Time Discrepancy



- Figure above shows a simplified LORRI CCD timing diagram
  - All events are driven by a 1 Hz clock
  - All images are comprised of a frame “scrub”, followed by an expose (“exp”) step for the commanded exposure time, followed by a frame “transfer”
  - All images end exactly 20 ms before the next 1 Hz clock signal
    - Within a single clock cycle, the longest commanded exposure time is 1000-20-13 = 967 ms
- The flight s/w assumes that the scrub and transfer times are exactly 13 ms (as shown in the diagram), but the actual scrub time is 12.384 ms and the actual transfer time is 11.546 ms, which are set by a Field Programmable Gate Assembly (FPGA)
  - The flight s/w employs integer arithmetic, which means the actual exp time is 13-12.384 ms = 0.616 ms *longer* than the commanded exposure time because the scrub ends 0.616 ms sooner than expected by the flight s/w
- The figure and descriptions above refer to *all* images, independent of their exposure times