Report on GMOS timestamp accuracy

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Summary:
The observation start timestamp accuracy of GMOS-S and GMOS-N was measured using observations of GPS satellites. The average difference at GMOS-S from the predicted satellite trajectory compared to the UTSTART header keyword was 0.164±0.03s, and for GMOS-N was 0.207±0.02s. This information has been added to the Gemini webpages[1].

Motivation:
The motivation of this experiment is to provide an estimate of the start timestamp (the fits header keyword UTSTART) error for Gemini Observations. This is to help users with precise timing requirements to estimate the error associated with the UTSTART keyword. This is a recommended action of the UCG 2019[2].

Method:
Observations of GPS satellites, with known high-precision orbits are used as time clocks, enabling a measurement of the timestamp precision down to the 10ms level. The basic principle is to track a GPS satellite with a high-precision orbit using GMOS imaging. The difference between the predicted satellite position, and the observed position corresponding to the start of the observation[3], can be used to work out the UTSTART timestamp error.

Current status:
In 2019 and 2020, observations of around 10 satellites with high-precision orbits following the method outlined were conducted using GMOS-S and GMOS-N at both Cerro Pachón and Mauna Kea. Similar experiments were also performed using the visiting instrument Alopeke at Mauna Kea[4]. Analysing the observations, it was found that the GMOS-S and GMOS-N UTSTART header keywords when used as the start timestamp were ahead of the predicted time using the satellites orbit. For GMOS-S, and GMOS-N, the UTSTART header keyword was ahead by 0.164±0.03s and 0.207±0.02s respectively. The observations were also analysed to search for any trends with the observation time and telescope pointing. No clear trends were identified.

A similar study on the timing precision of Alopeke at Gemini North was conducted by the instrument team[4]. The authors of the study concluded that their observations were 0.163±0.07s deviant from the timestamp.

Future plans:
Further plans are being explored to conduct similar observations using the optical Zorro imager, and examining the timing accuracy of the near-infrared Flamingos-2, both at Pachón, as well as follow-up observations using GMOS-S and GMOS-N. Incremental improvements in the measurement precision can be made by improving the mirror coordinates of both telescopes[5]. Available coordinates of both telescopes are currently slightly offset towards the telescope foundations.
Currently, there are multiple variables that can alter the precision of the timestamp. But, the maximum achievable precision is limited by the telescope's GPS clock (1 ms level). For this methodology, the limit is set by the known precision of the satellite orbit (around 10ms). Future extreme time precision observations may require GPS time receivers to automatically trigger the camera to achieve precision beyond the 1ms level.

References:
[1] Gemini Observatory, 2021, Timing information in Gemini Instruments, Rantakyro, F. viewed Oct. 11, 2021 https://www.gemini.edu/observing/phase-iii/understanding-and-processing-data/timing-information#
[2] Gemini User's Committee, 2019, *Gemini User's Committee 2019 Report,* Gemini Observatory http://www.gemini.edu/science/UCG/public/reports/ucg201907_report.pdf
[3] Gray, B., 2017, gps_ephem, GitHub repository https://github.com/Bill-Gray/gps_ephem
[4] Scott N.J. et al., 2021, FrASS, 8, 138.
[5] http://www.gemini.edu/observing/telescopes-and-sites/sites Coordinates are from the original construction site surveys and represent the point on the telescope foundation directly under the center of azimuth rotation of the telescope. These positions have been verified by GPS (see Mamajek,E., 2012,arXiv:1210.1616) and also by virtue of the fact that positional errors would cause errors in the telescope pointing on sky. The elevation axis of the telescopes will be few meters above the nominal altitudes presented (prv. communication. A. Shugart, V. Garrel).