Observations of the LCROSS Impact with NIFS on the Gemini North Telescope

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Background

The LCROSS (Lunar Crater Observation and Sensing Satellite) Mission intentionally maneuvered the upper stage of the spent Centaur launch vehicle into the Cabeus crater near the southern pole of the Moon at 11:31 UTC October 9, 2009. The instruments on board the shepherding spacecraft (which met its demise four minutes later) successfully imaged the new crater created by the impact, and data from the LCROSS near infrared spectrometer revealed the presence of water in the plume of material from the bottom of the permanently shadowed crater.

In addition to the LCROSS satellite, ground-based telescopes also observed the impact. On the summit of Mauna Kea on the Big Island of Hawaii, several of the largest telescopes in the world coordinated their observing programs to point their sensitive suite of instrumentation toward the southern pole of the Moon in order to catch a glimpse of this ejected material which had not been sunlight in billions of years. Gemini Observatory was part of this observing campaign, using the Near Infrared Integral Field Spectrograph (NIFS) to capture 3D K-band imaging spectroscopy with seeing-limited spatial resolution, searching for water ice in the central 3” x 3” around the impact site.

The Gemini telescope is not normally used for lunar observations! There were several operational details to be addressed before such a campaign could be successful. Engineering data was taken on four separate occasions when the lunation and libration closely matched those occurring on the event date. These data were used to refine the details of tracking, imaging and guiding on our very bright fast-moving nearest neighbor, the Moon. The GMOS and NIRI images obtained were used by the LCROSS ground based team to refine the pointing and acquisition algorithms, and the experience has led to enhanced methods being employed for semester 2010A for conducting more efficient observations of non-sideral science objects in the Gemini queue.

Background Image: short He II GMOS–N exposure obtained while guiding with PWFS2 on a lit mountain top

NIRI f/32

NIFS on the Gemini North Telescope

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Tracking using Ephemerides

The first engineering challenge facing us was to track a specific crater on the Moon with the Gemini telescope. Non-sideral targets are routinely observed in the queue, but none with such high and rapidly changing track rates. Furthermore, the Gemini Observing Tool (OT) does not provide the capability to track a specific crater (tracking the center of the Moon is not sufficient due to lunar librations). We quickly discovered that we could not update the track rates manually and with high enough precision to reliably track a specific location on the Moon for more than a few minutes. This limitation, if not solved, would have seriously compromised Gemini’s ability to contribute to the coordinated ground-based LCROSS campaign. Fortunately a solution presented itself in a little known and minimally documented feature of the Gemini Telescope Control System (TCS) where an ephemeris file can be read directly into the TCS and the telescope will automatically updates its track rates once every minute, interpolating between successive lines in the ephemeris.

This breakthrough understanding of the Gemini TCS has immediate implications for the queue observations of non-sideral targets whose orbital elements cannot be found in the JPL comet or minor planet databases (the only formats automatically supported by the OT currently). This includes objects such as satellites of other planets or newly discovered Kuiper Belt Objects, and comprise a significant fraction of the non-sideral Gemini queue and classical observations. Prior to the LCROSS campaign, the method to observe these targets was to recompute an ephemeris into the OT as a text file, requiring the observer to set coordinate to manually read off and update the coordinates and track rates in the OT corresponding to the expected time when the target was to be observed. If the track rates are changing appreciably, this requires precision timing. This method, while sound, is cumbersome and subject to error particularly at Mauna Kea altitude.

Starting in semester 2010A, Program PIs observing such non-sideral targets will be able to instead upload their ephemerides into the OT and Gemini staff will make them accessible to the TCS. To enable this option the target name is changed to target.ephr in the OT, matching the name of the ephemeris file. We envision this will lead to much smoother observing of non-sideral targets, greater efficiency, and minimization of time lost due to mistakes. There are still some details to be sorted out (eg. the ephemerides can only have a maximum of 1440 lines and the format is rather specific) and objects closer than Saturn likely need to have their coordinates divided into multiple files. More information on how to create and submit ephemerides for observing non-sideral targets can be found on the Gemini public webpages.

http://www.gemini.edu/node?q=node/11203

Guiding on the Moon

The second engineering challenge was to guide while observing the Moon. We could not guide on a background star because the lunar track rates are ~0.5°/sec, corresponding to ~30° over the 1-hour duration of the LCROSS observations, which is much larger than the wavefront sensor patrol field. The Gemini telescopes are too susceptible to wind shake to hold precision pointing without guiding. It was obvious we needed to guide on a bright crater or mountain top on the surface of the Moon. The ephemeris method also applies to the Gemini guide probes, so along as we could identify a proper guide object we could load the coordinates into the guide. The problem is that the guide probes were not designed for such a bright target, and the signal was saturated when guiding on the sunlit side of the Moon with the peripheral wavefront sensor. We were able to guide on a sunlit peak in the shadows on the dark side of the terminator when creating the GMOS-NIR finding chart during the 2009 September engineering period. However, these lit peaks are not long lived as the terminator marches across the face of the Moon, and we had no resources to predict in advance where and when suitable guide peaks would appear. A solution presented itself with the ALTAIR adaptive optics guide probe which has an ND filter attenuating ~8 magnitudes enabling guiding on very bright stars. Unfortunately the bright craters were not round enough for us to close loop with full adaptive optics. The novel approach adopted was to disable the voltages to the deformable mirror and only use the tip-tilt stage of the AO system. This allowed us to guide on the Waypoint 5 crater identified in the GMOS-N image during the LCROSS event.

Results

The Gemini observation campaign of the LCROSS impact event was a success! We overcame several technical challenges in order to execute a difficult observation. Some of the lessons learned will become immediately implemented as improvements in our queue operations. The NIFS instrument obtained K-band 3D imaging spectroscopy pointed at the center of the impact. The telescope tracked the Cabeus crater while ALTAIR tip-tilt guided on the Waypoint 5 crater. The science data is still being analyzed by the LCROSS Gemini science team, looking for signs of water in the plume ejected high enough to clear the Cabeus mountain ridge and be visible to telescopes on the Earth. From the LCROSS shepherding spacecraft we already know there was water in the impact site; the Gemini data will hopefully be able to shed more light on the total ice mass, size and distribution of the ice particles, and the plume evolution with time.

Gemini data was obtained as part of program GN-2009B-Q-35 (PI Wooden) and all GMOS images obtained during engineering are immediately downloadable from the Gemini Science Archive:

http://www4.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/gsa/

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