Radar Observations of Spacecraft in Lunar Orbit

Marina Brozović,[1*] Ryan Park,[1] Joseph McMichel,[1] Jon Giorgini,[1] Martin Slade[1], David Berry,[1] Joseph Jao,[1] Frank Ghigo[2], Patrick Taylor[3], Edgard Rivera-Valentín[3] et al.
[1]*Jet Propulsion Laboratory/California Institute of Technology, USA;* [2]*Green Bank Observatory, USA;* [3]*Arecibo Observatory/Universities Space Research Association, USA*
marina.brozovic@jpl.nasa.gov

Keyword: radar astrometry, lunar spacecraft, orbit determination

We report the first use of ground-based radar to detect and determine the trajectories of spacecraft in lunar orbit, using techniques developed for radar observations of near-Earth asteroids (NEAs) (http://echo.jpl.nasa.gov/). The spacecraft orbiting the Moon are equivalent to meter-sized metallic NEAs at one lunar distance. Our objective was to recover two inactive lunar polar orbiters that had their last known locations estimated in 2009 and 2010: Chandrayaan-1, a spacecraft designed by the Indian Space Research Organization, and Ouna, a small relay satellite that was originally carried by the Japan Aerospace Exploration Agency's lunar orbiter SELENE.

Radar measurements of relative position and velocity (via round-trip time-delay and the Doppler frequency-shift of the return echo) provide powerful constraints for orbit determination. Maintaining the orbital knowledge of old spacecraft that are still orbiting the Moon is important because these spacecraft pose a potential impact hazard for future human missions. In particular, the Orion spacecraft will be using the Moon for gravity assist, and although the chances of a collision with Chandrayaan-1 or Ouna are very small, we need to be able to predict their orbital positions in order to eliminate hazard concerns.

We used Goldstone's 70 m DSS-14 antenna (X-band, 8560-MHz) and the Arecibo observatory (S-band, 2380-MHz) to transmit and the Green Bank Observatory (GBO), Goldstone's 34 m DSS-13 antenna, and Arecibo to receive in various configurations during five days from July 2 to September 23, 2016. We targeted the high-power, narrow beamwidth planetary radars at points in space generally offset from the lunar poles, corresponding to locations most likely to intersect the trajectory evolution since last contact 6–7 years ago. The transmitting and receiving antenna have their 3 dB beamwidths between 30″–312″, which translates into several tens to several hundred of km at one lunar distance. We transmitted a circularly polarized continuous wave (CW) at a carrier frequency plus a nominal transmit offset. The received reflection echo from the spacecraft has its frequency shifted with respect to the reference frequency due to its motion relative to the transmitter and receiver. These Doppler measurements are used for orbit determination.

For the first radar observations on July 2, we transmitted CW for several hours while waiting for Chandrayaan-1 to cross the radar beam. The spacecraft was detected twice and the beam-crossing times implied a shift of ~160° in mean anomaly with respect to the orbit that was estimated from the last known position in 2009. We were able to predict and confirm Chandrayaan-1's position for the later tracks. Overall, we collected Doppler data for seven polar passes and we also used a binary phase coded waveform (BPC) on July 3 to obtain both round-trip time-delay and Doppler frequency-shift for one north and one south lunar pole pass.

The Lunar Reconnaissance Orbiter (LRO) also crossed the radar beam on July 2, 3, and 31 while we were waiting to detect Chadrayaan-1. LRO is an active mission with precise orbital determination that allowed timing predictions of the beam crossings. We successfully detected LRO as predicted, which confirmed that we could detect a spacecraft in a lunar orbit, and this also provided useful pointing and system checks.

Our second objective was to search for Ouna, but this is a small spacecraft, <1 m in diameter, with large orbital uncertainties. The radar line-of-sight at the time of our observations covered a small portion of Ouna's uncertainty space. Using Arecibo to transmit and Green Bank to receiver, we obtained candidate detection on August 26 when we were pointed 715 km from the north lunar pole, but further evidence is needed to confirm the spacecraft recovery.