Sound bite: 20 cm ranging at 0.2 AU!

1) Introduction:

The MESSENGER spacecraft is seen here as a tiny bright spot during its recent Earth flyby mission phase. Three months earlier, at 200x farther distance, the spacecraft was in view. Nevertheless, MESSENGER was able to image the Earth and Moon with its MDI camera. At the same time, MLA was able to establish a two-way light link with millisecond-level power and set a new distance record for interplanetary laser ranging.

2) The experiment geometry:

In order to transfer pulses, MESSENGER performed an extended fine-born scan of the line-of-sight position of the MLA spacecraft on Earth planet, while the geodesic telescope tracked the position of MLA in the sky, seen here on May 27, 2005, just prior to and just following receipt of laser pulses. Mid-infrared clouds obscured the view much of the time that the HOMER telescope observed above the horizon. A scan of the Earth showed the position of the MLA field of view using its detector as a passive cathode (left). Axes give the angular position of the scan at right relative to the predicted position of the MLA spacecraft and duration of the scan across track. Small dark dots show where honed pointing was obtained at the time pulses were received at Earth, and best tracks were fired. The receiver field of view is considerably wider than the best tracks, which covered a circle about 1900 km across on Earth and was visible for at most 5 seconds per scan line.

4) Detected pulses and timing observables:

The unit of time on the spacecraft is the MET clock, to which all instrument events are calibrated. The laser fires occur irregularly a few hundred microseconds after the 10 Hz trigger pulse that the HOMER telescope received and the 60 µs of the HOMER system. The MET is calibrated to UTC periodically with a stipulated accuracy of 1 ms. In practice this may be much better constrained.

The ground laser pulses were again irregularly fired, but were timed with a stable clock that was calibrated with respect to GPS receivers. Redundant 160 µs event times and a 1.6 GHz waveform digitizer allowed precise recording of received pulses. The irregular pulse time arrivals could be referenced to a common receiver.

5) Asynchronous asymmetric transponder model

Deeg9 described two types of laser transponders for deep space ranging and communication. In the synchronous model, a signal isychronized with a short fixed delay back to the ground station to obtain a two-way range of flight. In the asynchron model, two terminals independently fire pulses at each other. In its original concept, the firing range would match and adjust itself to arrive at a fixed overlap of range closure at a common receiver.

6) Least-squares fit to data

In the present implementation, far more pulses were fired than received, and the firing range was not matched. This was necessary to minimize the performance of the spacecraft in order to correct for range rate. In fact, we can use the 40 downlink pulses and 90 uplink pulses to select for clock offset and drift rate, as well as range, range rate, and acceleration. The basis of operations of the synchrony pose any of the results obtained from a least-squares Deeg model.

7) Comparison with radar tracking ephemeresis+clock sim.

Transit time residuals to and from the apparent position of each terminal are shown below using the best reconstructed spacecraft ephemeris. As the ground laser pulses (black symbols) were received by MLA ~0.15 ms earlier than predicted. Similarly, the ground receive time of MLA pulses was ~0.34 ms earlier on May 27 (red symbols) but ~0.14 ms later on May 31 (blue symbols). Downlink time scales are therefore used to their microsecond limit.

8) General Relativity and light time delay:

Curves of space-time predicted by general relativity affect the path and proper time of light traveling in the vicinity of the Sun's gravitational potential. "Mirror" calculates this effect for the case of a single central body, which accounts for 487 m of the 539 m discrepancy. This effect becomes pronounced for larger bodies, where it may be significant in the mass of a solar system. Laser ranging with 20-nm precision may contribute to new Einstein's theory.