Deep Space Navigation: Present and Future

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On 19 October 2018 a dedicated launch of Ariane 5 injected the ESA-JAXA mission BepiColombo into a complex interplanetary orbit toward Mercury, its final destination. The Mercury Planetary Orbiter (MPO), one of the two craft to be inserted in orbit around the planet, is endowed with the most advanced tracking system ever flown on a deep space probe. In addition to the standard TT&C radio system, the spacecraft is equipped with a novel science and navigation Ka-band transponder, an element of the Mercury Orbiter Radioscience Experiment (MORE). The radio system will enable radio links to ground in X and Ka band, providing range rate measurements accurate to 1 micron/s (at 1000 s integration time) at nearly all solar elongation angles. Range observables accurate to 20 cm (two-way, 10 s integration time) will be attained using a novel, wideband (24 Mcps) ranging system, based upon a pseudo-noise modulation scheme. Precise orbit reconstruction is eased by an onboard, high accuracy accelerometer (Italian Spring Accelerometer, ISA).

The BepiColombo tracking system attains radio-metric accuracies close to the ultimate performances of microwave technologies, enabling unprecedented precisions in the orbital reconstruction. While these developments have been driven by the demanding science goals of the mission (geodesy and topography of Mercury, tests of relativistic theories of gravity, and improvements in solar system ephemerides), they are equally beneficial to spacecraft navigation. The operational system (based on X band radio links and no accelerometer) will be compared with the augmented science system (Ka band, accelerometer, and a more refined dynamical model) to assess the improvements in the navigation accuracy.

Is there any prospect to improve deep space microwave tracking systems? And, equally important, what motivates further improvements? While the infrastructure developed for BepiColombo seems adequate for most planetary exploration missions, crucial science questions will hugely benefit from novel and more accurate navigation systems. The investigation of planetary subsurfaces and interiors through gravity, rotation and altimetry requires better Doppler measurements and new configurations. Improvements in solar system dynamics and, more generally, the search for new laws of gravity rely on improved range and angular observables. We review the new tools currently being considered, such as the time-delay noise cancellation system, same beam interferometry, multi-node, planetary wide, tracking networks such as the TRILOGY concept, and two-way asynchronous links enabled by accurate clocks.