National Aeronautics and Space Administration

Demonstration of Advanced Ranging Techniques

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Program: Strategic Initiative

Project Objective:.

The objective is to demonstrate an order-of-magnitude improvement and the independence of the Sun-Earth-Probe (SEP) angles of the range measurement accuracy through ARI (Advanced Ranging Instrument). The current average ranging accuracy at X-band is ~1 meter in one-way range, which is substantially dependent on the SEP angles. JPL has developed ARI on DSS-25, and it will improve the precision of ranging measurements by an order of magnitude. At Ka-band, utilizing dual frequency links, the accuracy is expected to drop to ~10 cm unconditionally by calibrating the solar plasma noise completely (Figure 1). With the launch of BepiColombo, the mission to Mercury and the only spacecraft in operation compatible with ARI by regenerating dual frequencies onboard, we are able to perform end-to-end ranging experiments with BepiColombo and assess the range measurement accuracy of ARI.

Benefits to NASA and JPL:

General Relativity (GR) has passed many experimental tests. In order to test violations of GR, a much more accurate determination of the Parameterized Post Newtonian (PPN) parameter gamma (about a level of 10^{-7}) is required, and there is no better solar system body than Mercury on which to carry out such tests. However, the solar plasma noise would be the greatest difficulty in the radiometric measurements near Mercury. We can overcome this obstacle through ARI, and an order-of-magnitude improvement in the precision of the PPN parameter gamma can be achieved. ARI can also enable future planetary missions to conduct precision exploration of their environments and may prove beneficial to future high-precision interplanetary navigation. ARI can expedite more precise global orbit solutions with higher ranging accuracy and promote future missions that will have the capability of coherent communications and ranging modulation at X-band and Ka-band simultaneously. The demonstration of the advanced ranging techniques at DSS-25 could encourage other missions to request advanced ranging and lead to a development effort to add advanced ranging as a future DSN standard service.

FY18/19 Results:

Three end-to-end spacecraft tracking campaigns with BepiColombo were carried out. Through these ranging experiments, we were able to configure DSN setups for new ranging experiments with BepiColombo and test end-to-end configurations including DSS-25, DSN Open Loop Receiver (OLR), and ARP (processor of new range data). Through the 2-way ranging experiments, we have been able to resolve many issues in the ranging operation with BepiColombo. These preliminary range measurements have demonstrated through the 3-way Ka/Ka range measurements that the 10-cm accuracy in range measurement is feasible in this new ranging system.

Preliminary Test on Dec. 9, 2018: Through this initial test of 3-way shadow track (Malargue (MLG) station uplinked Ka-band to BepiColombo, and KaT (the payload Ka-band translator of BepiColombo) regenerated PN ranging and downlinked to DSS-25), we were able to verify PN ranging at Ka-band, proper compatibility, receiver tuning predictions, pointing of DSN antenna, and recording through OLR.

Tracking campaign in May 2019: Four DSS-25 2-way tracks and eight MLG 3-way tracks were carried out.

- For 2-way passes, we were able to track the ranging tone of both spacecraft and Test Translator for the X/X and X/Ka links. Since DST (the payload X-band translator of BepiColombo) was configured to transparent ranging during this period, it retransmitted the PN ranging to DSS-25 without regenerating. Even though KaT was configured to regenerative PN ranging, we were able to track only the carrier, not the ranging tone.

- For 3-way passes, we were not able to track the ranging tone of the spacecraft signal from X-band uplink because DST was configured for ESA standard ranging, rather than PN ranging, during this period. We were able to track the ranging tone of the 3-way Ka/Ka passes and measure the precision of 24 Mcps ranging. Figure 2 shows the comparison of DSN open-loop ranging residuals of the 3-way Ka/Ka pass and ESA closed-loop ranging residuals of the 2-way Ka/Ka pass on DOY (day of year) 137. Figure 3 shows DSN open-loop ranging residuals of the 3-way Ka/Ka pass on DOY 149 with RMS of 7 mm over 2.5 hours. These noises correspond to the10 cm accuracy in one-way range measurements.

- During this campaign, we were able to optimize operational configurations: 1) Uplink frequency should be constant, not ramped. This will greatly simplify the analysis of the ranging observables. For radio metrics, we prefer not to ramp because the timing of the ramps could possibly introduce an error into the Doppler and range data, so we would want to eliminate as many small errors as possible. 2) The turnaround ratio for Test Translator should be the same as that for the spacecraft transponder. The different ratio causes the downlink Test Translator signal to be offset by a large amount in frequency, so it does not calibrate the station delay at the correct frequency.

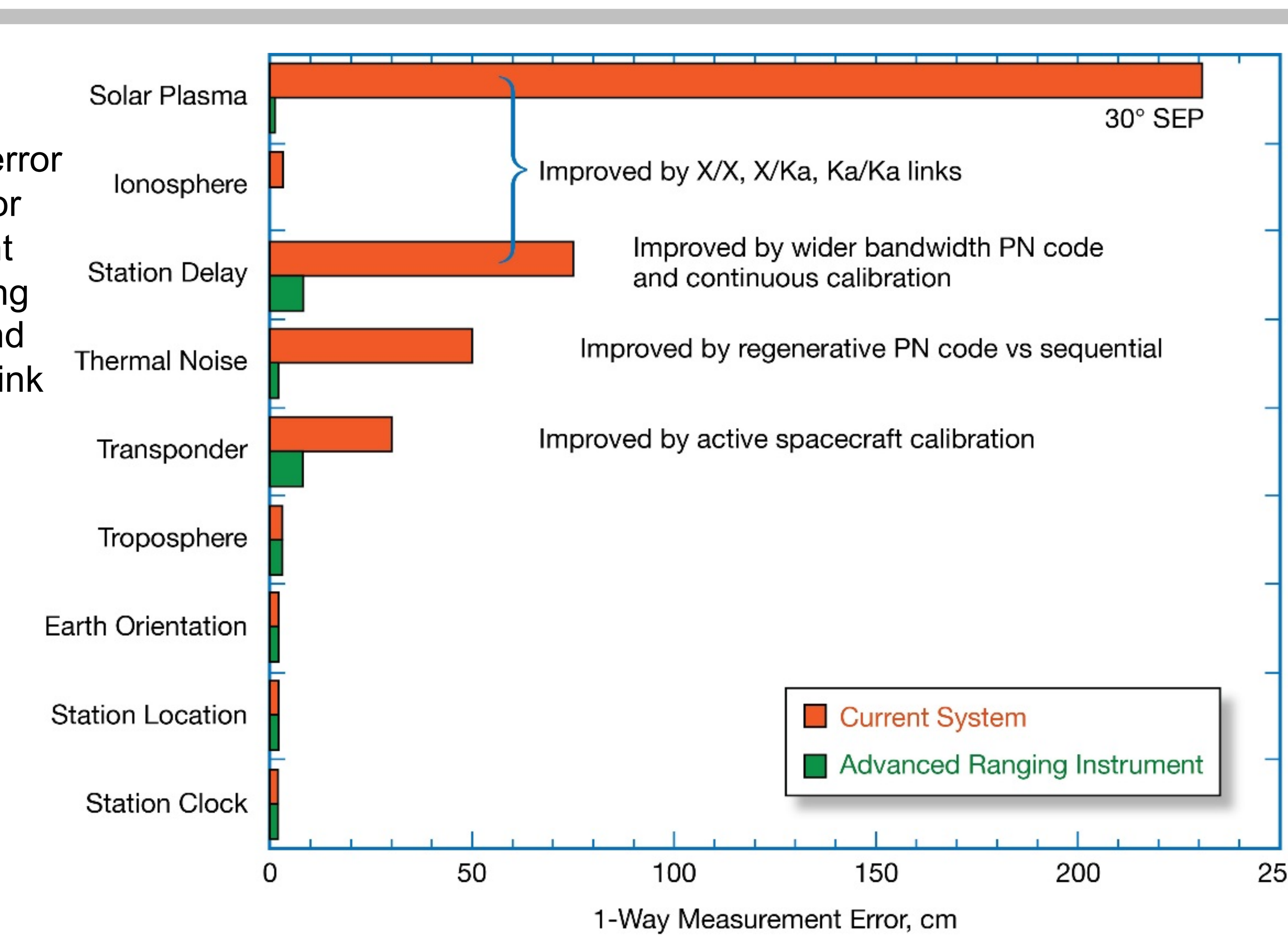
- Ka-band uplink polarization issue: It was discovered that DSS-25 Ka-band uplink is LCP (left-hand circular polarization) only, as implemented on JUNO, while BepiColombo is RCP (right-hand) only.

Tracking campaign in August 2019: Six DSS-25 2-way tracks were carried out. During this campaign, DST Ka downlink was turned off, i.e. only the X/X link on DST and the Ka/Ka link on KaT were available, and the X/Ka link was not available.

- PN polarity issue of Ka-band uplink: The first pass on DOY 223 was committed to the testing of Ka-band uplink ranging. While uplinked at Ka-band only, we switched the PN polarity from plus (not inverted) to minus (inverted) in the middle of the pass to verify the polarity of range modulation in Ka-band uplink on the spacecraft. The ranging tone of Ka/Ka was detected for the first half of the pass. This test proved that the PN polarity on BepiColombo is not inverted (by the DSN convention) for Ka-band uplink. In spite of the opposite polarization Ka-band uplink of DSS-25 and BepiColombo, the ranging tone of Ka/Ka was detected when the PN polarity was matched.

- PN polarity issue of X-band uplink: Because PN ranging was selected on DST from July 29, 2019, the DOY 231 pass was the first test of regenerative PN ranging for X-band uplink. Since the ranging tone was not detected on this pass, we needed to check the polarity of range modulation in X-band uplink in the same way as for Ka-band uplink. This proved that the PN polarity on BepiColombo is opposite in X- and Ka-band uplinks.

Figure 1. Ranging error budgets for the current X/X ranging system and the multi-link ARI



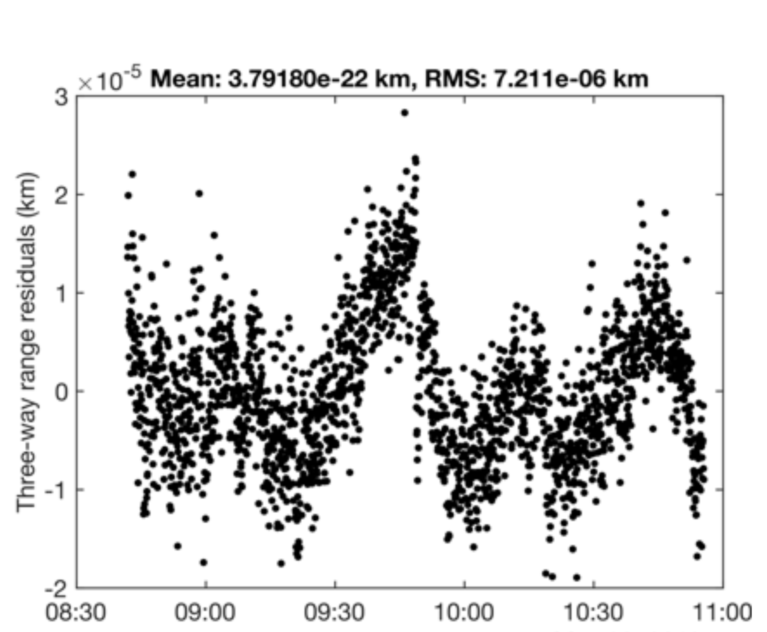


Figure 3. DSN open-loop ranging residuals of 3-way Ka/Ka pass with RMS of 7 mm over 2.5 hours on DOY 149

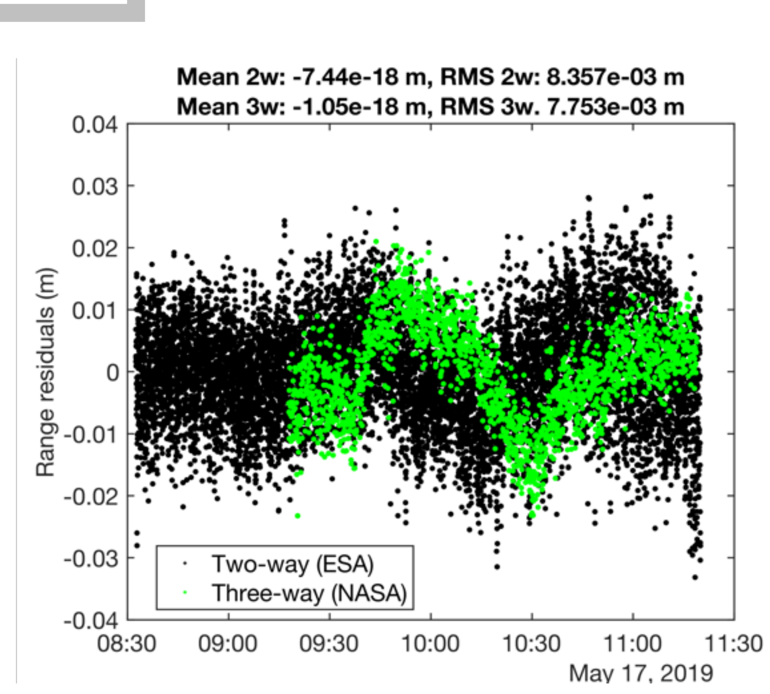


Figure 2. Comparison of DSN open-loop ranging residuals of 3-way Ka/Ka pass with ESA closed-loop ranging residuals of 2-way Ka/Ka pass on DOY 137

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