ADVANCED RADIO SCIENCE INSTRUMENTATION FOR THE JUNO, BEPICOLOMBO, AND JUICE MISSIONS

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Introduction: Planetary interior structures can be constrained from knowledge of the gravitational field of the planets or their natural satellites. Techniques of Gravity Science, a branch of Radio Science, have been successfully applied to numerous solar system missions via coherent Doppler tracking of the spacecraft by a station on Earth. Another technique using two spacecraft in formation tracking each other has been applied with tremendous success at the Earth with the GRACE mission, and the Moon with the GRAIL mission. Moving beyond the utilization of the existing telecommunications links between spacecraft and the Deep Space Network (DSN), typically at X-band (~8.4 GHz downlink), Radio Science teams have introduced radio systems at Ka-band (~34 GHz downlink) in order to improve the data quality by one order of magnitude.

Largest Instrument in the Solar System: When carrying out measurements of a planetary gravity field, the spacecraft receives a radio signal from a DSN station and mirrors it back (transponds it) to the station. Thus, the instrument is distributed with elements on the spacecraft and elements on Earth, the quality of each affects the quality of the data. Furthermore, the intervening media, interplanetary plasma and Earth's ionosphere and troposphere also affect the quality of the data, as shown in Figure 1.

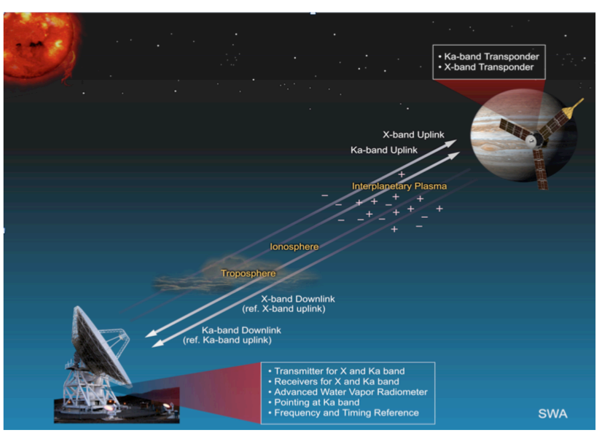

Figure 1: Illustration of Juno Gravity Science Radio Links and Intervening Media

Medial Calibration: As part of the advancement in Radio Science instrumentation, the Ka-band link is less susceptible to the charged particles of the interplanetary plasma and the ionosphere by about one order of magnitude (theoretically by a factor of 16, or the square of the ratio of the Ka to X-band frequencies). Furthermore, in the presence of the X- and Ka-band links simultaneously, the differential Doppler, under proper configurations, leads to complete calibration and removal of the charged media. The Earth's troposphere is calibrated via custom-made advanced water vapor radiometers adjacent to the ground station that co-point to the spacecraft to calibrate to tropospheric delay in the same air column.

Range and Range-Rate Observables: Radio Science-quality Ka-band transponders/translators (KaT) developed at TAS-I in Rome with a model currently flying on the Juno mission [1] can achieve range-rate (Doppler observable) with the quality of a few parts in 10^{-15} at an integration time of 1000 seconds after all calibrations have been applied. An older analog model achieved similar quality during the cruise phase of the Cassini mission [2]. Models of the KaT delivered to the BepiColombo mission [3] and planned for the JUICE mission can also achieve ranging measurements at about 20 cm. In order to take advantage of the superior Ka/X-band radio system on the spacecraft, an Advanced Ranging Instrument has been prototyped for the DSN to make the ranging measurements to the new accuracy.

Science objevtives:

Juno: Coherent X- and Ka-band links will enable precise measurement of spacecraft motion during close polar orbits to determine the gravity field, distribution of mass, core characteristics, and convective motion in the deep atmosphere.

BepiColombo: Order-of-magnitude improved Ka-Band Doppler and ranging will enable: (1) investigating the interior structure of Mercury, (2) testing relativistic gravity and significantly improved General Relativity post-Newtonian parameters, (3) testing any time variation of the gravitation constant to high accuracy, (4) determining the solar oblateness to high accuracy (5) characterizing the structure of the solar wind in and out of the solar ecliptic.

JUICE: Simultaneous coherent X- and Ka-Band tracking data (two orders of magnitude more accurate relative to Galileo) would yield detailed information about satellite interiors from gravity measurements.

Science Simulations: Radio Science teams on the future missions: Juno orbital phase, BepiColombo at Mercury, and JUICE at the Jovian satellites, have shown size of the expected gravitational fields at their planetary targets with this Ka-band-based advanced instrumentation at the spacecraft and especially instrumented ground stations. This paper will describe the scientific objectives of the Radio Science investigations as well as the expected data quality and instrument configuration that are making breakthroughs in the field.

BepiColombo Tests of Fundamental Physics: In addition to planetary objectives at Mercury, the BepiColombo Mercury Orbiter Radio-science Experiment (MORE) team will carry out high precision tests of relativistic gravity in the most desirable laboratory in the solar system, the gravitational field of the Sun. Being the innermost planet, Mercury is an ideal test mass for probing general relativity. Range and range-rate measurements from radio tracking a spacecraft in orbit around Mercury, with frequent superior solar conjunctions, provides abundant occasions to explore relativistic gravitational effects of the sun in addition to the structure of the solar corona. Figure 2 illustrates an example of the Radio Science investigations with BepiColombo. The conventional framework for discussing solar system tests is the post-Newtonian parameterization. General relativity predicts definite values of the parameters but alternate theories of gravity predict deviations from these values. Nearly every metric theory of gravity can fit into the generalized 10-parameter PPN framework except for possible cosmological effects on the gravitational constant. Of the 10 parameters, 4 are considered for improvement by Radio Science techniques: the PPN parameters γ, β, η, and $\alpha 1$. In addition, the solar oblateness will be determined with much improved accuracy, useful information will be obtained on the possible rate of change of the gravitational constant, and properties of the solar corona will be monitored accurately.

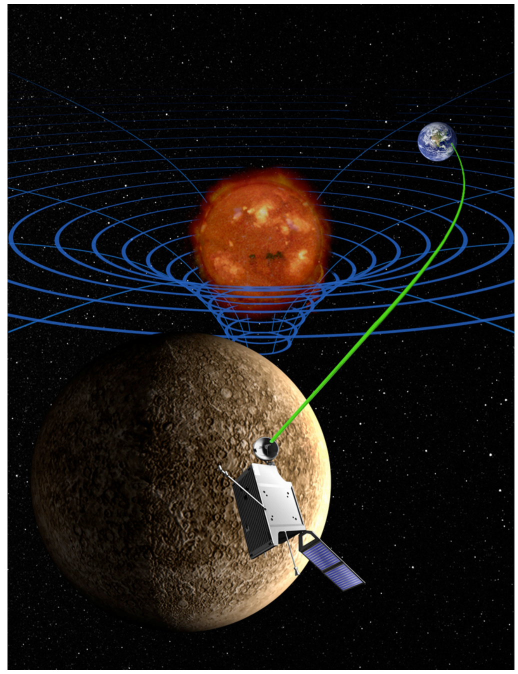

Figure 2:

References: [1] Bolton, S. J. (2010) Proceedings of the International Astronomical Union doi:10.1017/ S1743921310007313. [2] Asmar, S. W., J. W. Armstrong, L. Iess, and P. Tortora (2005), *Radio Science* 40, doi:10.1029/ 2004RS003101. [3] Iess, L, S. W. Asmar, P. Tortora (2009) *Acta Astronautica*, doi: 10.1016/ j.actaastro.2009.01.049.