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ASTROD I: Mission Concept and Venus Flybys

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ASTROD I with one spacecraft ranging optically with ground stations is a first step for a full ASTROD (Astrodynamical Space Test of Relativity using Optical Devices) mission. The goals are testing relativity with the relativistic parameter γ measured to 10^{-7}, measuring solar-system parameters more precisely, and improving the present-day sensitivity for gravitational wave detection using Doppler tracking by radio waves. In this paper, we present the mission concept and the orbit design for ASTROD I with an emphasis on Venus flybys. The spacecraft is to be launched into an inner solar orbit with initial period about 290 days to encounter Venus twice to receive gravity-assistance for achieving shorter period (165 days or less) to reach the other side of the Sun for a sooner measurement of Shapiro time delay. For a launch on June 17, 2010, after two encounters with Venus, the orbital period can be shortened to 165 days and the spacecraft orbit reaches inside Mercury orbit. After about 400 days from launch, the spacecraft will arrive at the other side of the Sun and the relativistic parameter γ can be determined to 0.1 ppm or better. A simulation of the accuracy for determining the relativistic parameters γ and β, and the solar quadrupole parameter J_2 gives 10^{-7}, 10^{-7} and 10^{-8} for their respective uncertainties. In this simulation, we assume a 10 ps timing accuracy and 10^{-13} m/s^2(Hz)$^{1/2}$ at frequency $f \sim 100\mu$Hz inertial sensor/accelerometer noise. Other orbits separated by synodic periods of Venus can readily be found. We discuss the sensitivity and noise reduction requirements, the atmosphere transmission noise, timing noise, spacecraft environmental noise, test-mass sensor back-action, and test mass-spacecraft control-loop noise and stiffness. In the second Venus flyby, the ASTROD I could also be swung into an elliptic 360-day orbit and stay near opposite side of the Sun for many good measurements of the Shapiro time delays — 19 times in 10 years. This is an interesting alternative. In the two Venus flybys, Venus multiple moments can be determined very precisely. In this paper, we also review ASTROD and discuss its gravitational-wave sensitivities.