The Helios Celestial Mechanics Experiment (E11)

For the 40th anniversary of the Helios-1 launch (10th December 1974) and as the former Helios mission operations manager, I want to salute the – in my opinion – most underestimated experiment of Helios: The celestial mechanics experiment (NSSDC ID Helio-B-14, PI: W. Kundt, University Hamburg, OI: W.G. Melbourne, NASA-JPL, Ref. 1). The experiment was meant "to use the tracking data to obtain a detailed spacecraft orbit and improved knowledge of the orbital elements of the Earth-Moon system and general relativity parameters" (NSSDC description).

According to the experimenter (Ref. 2), the experiment was sacrificed for the success of the other Helios experiments because the distance measurements between Earth and spacecraft ("coherent ranging") had to be discontinued after eight months (on both spacecraft) since the (coherent) ranging transponder failed and the transponder's prime travelling wave tube (TWT) amplifier failed at the same time the backup TWT had to be used in reduced power mode. The expectations of the E-11 experimenter group for precision orbit measurements over a period of longer than 24 months therefore could not be fulfilled and the goal to test Einstein's theory at the approx. 1% level could not be achieved. As a preparatory effect however, a complete and sensitive orbit evaluation code for a heavy n-body-system which is acted upon, at the same time by several parameterized non-gravitational perturbing forces and which is monitored with range and Doppler measurements was generated, the "Conversational Spacecraft and Missile Observation System" (COSMOS, developed by E. Krotscheck, for details see Ref. 1) . According to the experimenter's claim no other such code was known in 1978.

In order to test Einstein's theory at $\geq$1% limit conditions by using the precision orbit of Helios, the orbit should have been measured up to an accuracy of $\geq$100m within the somewhat "bent" orbital plane. This seemed to be possible because the signal travelling times could be measured with an accuracy of < 10ns, corresponding to 15 m (10 ns*c/2). As a precondition it was assumed that travelling time delays due to solar wind plasma effects could be eliminated due to their frequency dependence and their characteristic dependence of the appropriate constellation. At the same time, all non-gravitational forces acting on the spacecraft must be known to an accuracy allowing the modelling of their influences on the orbit up to an accuracy of $\geq$100 m. Non-gravitational accelerations are (in the order of their magnitude): solar radiation pressure (approx. 10^{-8} g), solar wind thrust ($2*10^{-11}$ g), the asymmetrical spacecraft antenna radiation (10^{-11} g) as well as orbit correction maneuvers. Hereby the spacecraft acceleration depends on solar radiation pressure, the weight of the spacecraft, the thermal properties of all materials used at the surface of the spacecraft – some of them movable during the mission. Further disturbances were introduced by the spinning spacecraft causing most of the heat dissipation away from the sun (Yarkowki-thrust, 10^{-13} g), however partly also towards the sun (Poynting-Robertson-braking, $2*10^{-12}$ g).

This shows that the goal was rather ambitious and the expected evaluation effort huge.

The Einstein parameters to be tested:

One must discuss the post-Newtonian single body problem for the spacecraft and the radio signals. The gravitational field of a rotating mass point (sun) is modelled in 2nd order in isotropic coordinates by the

Robertson line element L:

$$L: = \left(\frac{dt}{d\tau}\right)^2 \left\{1 - \boldsymbol{\alpha} \cdot \frac{2m}{r} + \boldsymbol{\beta} \cdot \frac{2m^2}{r^2} - \left(\frac{v}{c}\right)^2 \left[1 + \boldsymbol{\gamma} \cdot \frac{2m}{r} + \boldsymbol{\delta} \cdot \frac{3}{2} \cdot \left(\frac{m}{r}\right)^2\right] + 2 \cdot \vec{v}/c \cdot \vec{A}\right\} = 1$$

The parameter α can be assumed to be 1 (by re-definition of m). In addition, the parameters β, γ and δ assume the value of 1 according to Einstein's theory (the parameters β and γ determine the metric deviations of Einstein's corrections from the Newtonian values in percent).

The goal of the Helios E-11 measurements was to check any deviations from these values up to the accuracy of 10^{-3}.

Despite extensive evaluations and modelling of the obtained data no firm conclusion could be found, however the proper functioning of the COSMOS modelling program could be confirmed, a published COSMOS co-variant analysis using obtained Helios-1 data shows an accuracy between 10^{-2} and 10^{-3} for β and γ (see Ref 1 and Fig. 1).

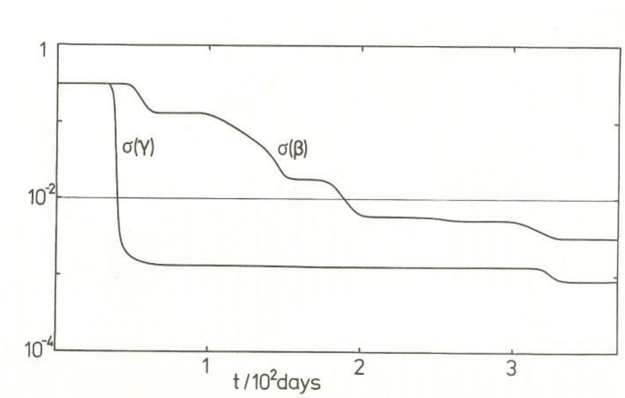

Figure 1:
Result of a co-variance analysis performed with COSMOS for Helios-1. The starting local accuracy was 150 m (at a random time), range accuracy 3 m, and non-modelled disturbing accelerations of $3*10^{-9}$ cm s^{-2}

In order to evaluate the idea and significance of the E-11 experiment, an e-mail interview could be conducted with Messrs W. Kundt and J. Peyn, former E-11 experimenters.

Q: Why have the "Einstein" parameters α, β, γ and δ originally been set to assume the value of 1?

Answer: Only for a-priori estimates, but also, because we had confidence in Einstein's unmodified field equations.

Q: The E-11 experimenters claimed that an accuracy of 6% for γ achieved by previous measurements using the Mariner 6/7 spacecraft (Anderson et al., 1975) could be significantly improved by the Helios measurements. How accurate are the above "Einstein"-parameters known today, and would Helios – would the experiment have worked – have been pioneering to solve a problem which still might require some effort?

Answer: Present best estimates of beta and gamma are equal to unity within less than 10^{-4}, thanks to close flyby missions to Mercury and Saturn (Cassini). On the other hand, there have been years of doubt about "anomalous gravity beyond Saturn", raised by the two Mariner spacecraft, but eventually dismissed as poorly modeled IR radiation recoil.

Q: The Helios orbit was determined accurately enough to fulfill all the other experimenters' requirements. What order of magnitude could be achieved by more accurate "Einstein"-parameters (according to R.M. Georgevic and R.C. Anderson et al., 1972 the modeled parameters could be experimentally confirmed to three valid digits)?

Answer: In front areas of astronomical research, independent determinations of fundamental parameters are always welcome. They should not be considered unimportant.

Q: Was the mentioned COSMOS model been used for other projects (European or international)?

Answer: No: so far, all the subsequent solar-system missions contented themselves with less accurate orbital data than were planned for the Helios mission.

Q: What is the state-of-the art with respect to considering the discussed "Einstein"-parameters for interplanetary navigation?

Answer: During the Helios mission, both spacecraft turned increasingly dark, and thereby heated up monotonous. This increase in absorptivity would have considerably distorted their orbits, had not their spindle shape caused almost the same angular distribution as for a sphere, for which absorptivity does not affect the integrated solar radiation force.

References:

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July 2014, Joachim J. Kehr, Editor SpaceOps News