Scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics of the Academy of Sciences of the USSR (21–22 November 1979)

Usp. Fiz. Nauk 131, 511–513 (July 1980)
PACS numbers: 01.10.Fv

A joint scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics of the Academy of Sciences of the USSR was held on November 21 and 22, 1979 at the P. N. Lebedev Physics Institute of the Academy of Sciences of the USSR. The following papers were delivered at the sessions:

November 21

1. *S. I. Nikol'skiĭ*, Investigation of hadron interactions in cosmic rays.

2. *E. L. Feĭnberg*, Cosmic rays and particle physics at superaccelerator energies.

3. *É. M. Mamidzhanyan and S. G. Matinyan*, A proposed complex experiment in cosmic rays at $10^{15}-10^{18}$ eV.

November 22

4. *M. D. Kislik, Yu. F. Kolyuka, V. A. Kotel'nikov, G. M. Petrov, and V. F. Tikhonov*, Determination of the orbits of Venus, the Earth, and Mars from 1962–1978 radar observations of Venus and Mars.

5. *Ya. B. Zel'dovich and R. A. Syunyaev*, Intergalactic gas in clusters of galaxies. Relic radiation as the "new ether."

We publish below the condensed content of one of the papers.

M. D. Kislik, Yu. F. Kolyuka, V. A. Kotel'nikov, G. M. Petrov, and V. F. Tikhonov. *Determination of the orbits of Venus, the Earth, and Mars from* 1962–1978 *radar observations of Venus and Mars.* Radar observations of the planets and measurements of the trajectory parameters of unmanned interplanetary spaceprobes have detected noticeable errors in the classical theories of the motion of Venus, the Earth, and Mars. These theories were created in the works of Newcomb, Duncombe, Morgan, and Clemence at the end of the Nineteenth and during the first half of the Twentieth Century on the basis of optical observations of the planets. The errors of the theories range up to several hundred kilometers, and this makes it difficult to solve navigational problems in flights to the planets.

After accumulation of radar observations over several synodic periods of Venus and Mars, the Institute of Radioengineering and Electronics of the Academy of Sciences of the USSR has collaborated with several other organizations in work toward construction of new theories of the motion of these planets and the Earth.[1] For this purpose, they wrote and computer-programmed algorithms for the determination of the orbits that provide for simultaneous reduction of radar and optical observations of the planets, optical observations of the sun, and measurements of the trajectory parameters of artificial planetary satellites and unmanned interplanetary probes. The motions of the celestial bodies are described in these algorithms by numerical integration of the equations of motion by a recurrent power series expansion method that was developed in detail for this particular problem. The method has practically no computational error. The sun, all the major planets (except Neptune and Pluto), and the moon are treated as attracting bodies. The parameters to be determined are the orbital elements of Venus, Mars, the barycenter of the Earth-moon system, and of artificial space objects, as well as the astronomical unit and the mean radii of the planets for the regions responsible for reflection of the radar signal in the series of experiments under consideration. The measurements are reduced by least squares, using an iterative technique. The accuracy criteria for the solution are the difference ΔD between the actual and computed radar ranges to the planet's surface and the difference ΔR between the actual and computed distances to the artificial space object, as the most accurate experimentally determined characteristics of the motion under investigation.

The orbital elements of Venus and the Earth-moon barycenter, the astronomical unit, and the mean radius of Venus were determined in the first stage. The initial measurement information included results of Soviet and American radar observations of Venus (1962–1975) and optical observations of Venus and the sun (1960–1975). The error of the resulting solution was estimated on the basis of 1977–1978 radar observations of Venus and measurements of the distances to the artificial Venusian satellites Venera-9 and Venera-10 in 1976 and to the Venera-11 and Venera-12 unmanned interplanetary spaceprobes in 1978. The dif-

[1] The Institute of Applied Mathematics of the Academy of Sciences of the USSR has also carried out similar work for Venus and Earth.

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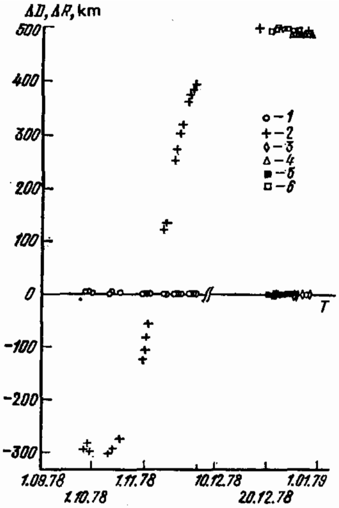

FIG. 1. 1978 measurements: deviations ΔD of the distances to Venus (1, 2) and ΔR of the distances to the unmanned interplanetary spaceprobes Venera-11 (3, 4) and Venera-12 (5, 6) for two variants of determination of the orbits of Venus and the Earth. 1, 3, 5—from planetary orbits as improved in this study; 2, 4, 6) from planetary orbits computed from the classical theories.

ference ΔD did not exceed 2 km over the entire measurement range in 1977, or 6 km in 1978. The corresponding differences for the classical theories of the motion of Venus and the Earth were many times larger, reaching ~500 km in 1978. Similar relationships were obtained for the differences ΔR in the course of determining the orbits of the artificial space objects from radial-velocity measurements and of describing the motion of Venus and the Earth with the solution obtained on the one hand and on the basis of the classical theories on the other. These data are presented in Fig. 1 for 1978 (in predicting over two synodic periods of Venus).

In the second stage, the value obtained for the astronomical unit was used to determine the orbital elements of Mars and of the Earth-moon barycenter from the results of Soviet and American radar observations of Mars (1964–1971) and optical observations of Mars and the Sun (1960–1975). Only for 1964–1965, when the radar measurements were less accurate than they were in subsequent years, did the differences ΔD reach 25–30 km for the obtained solution; they did not exceed 10 km anywhere else in the radar-measurement range. Bearing in mind the features of Martian relief, which has elevation differences of up to 15 km, the agreement obtained between the measured and computed distances

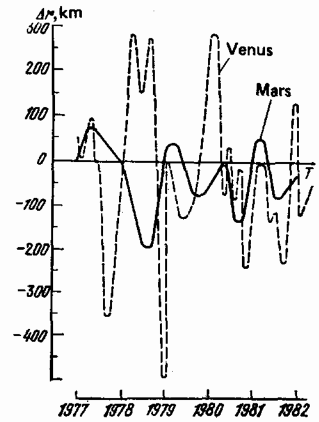

FIG. 2. Deviations Δr of the geocentric distances of Venus and Mars calculated from the classical theories using the values obtained from the improved planetary orbits obtained in this study.

may be regarded as fully satisfactory. The classical-theory differences ΔD range up to 80 km on the measuring interval. The orbital elements obtained for the Earth-moon barycenter in the first and second stages of processing agree closely with one another; the differences are within the limits admitted by formal estimates of the errors of their determination. The only exception is the semimajor axis of the orbit, for which this difference is $6\cdot 10^{-8}$ a.u. Preliminary analysis showed that the latter can be explained to some extent by relativistic effects.

Figure 2 shows the deviations of the predicted geocentric distances of Venus and Mars calculated from the classical theories for 1977–1982 from the values obtained from the planetary orbits determined in the present study. These deviations range up to 500 km for Venus and up to 200 km for Mars. In problems relating to support of flights to Venus and Mars, it will obviously be helpful to use, instead of the classical theories, the new theories of motion of these planets and the Earth that have been derived on the basis of radar observations.

[1]M. D. Kislik, Yu. F. Kolyuka, V. A. Kotel'nikov, G. M. Petrov, and V. F. Tikhonov, Dokl. Akad, Nauk SSSR **241**, 1046 (1978) [Sov. Phys. Dokl. **23**, 526 (1978)].
[2]M. D. Kislik, Yu. F. Kolyuka, V. A. Kotel'nikov, G. M. Petrov, and V. F. Tikhonov, *ibid*. **249**, 78 (1979) [**24**, 870 (1979)].
[3]V. A. Kotel'nikov, *et al*., Astron, Zh. **57**, 3 (1980) [Sov. Astron. **24**, 1 (1980)].

Translated by R. W. Bowers