INTRODUCTION

As in the last years, the Ephemerides of Minor Planets for 2017 are prepared by the IAA RAS only in the electronic form. Distribution of the EMP-2017 is accomplished via Internet or through sending compact disks (CD) by mail.

As compared with period before 2012, the substantial changes are introduced in the process of preparing of the EMP. Orbital elements of all numbered planets have been determined in IAA all over again on the ground of available observations in the catalog of the Minor Planet Center. Some changes have been introduced in the procedure of taking into account for perturbations. More detailed information on orbital elements used in the present volume of EMP and their accuracy is given in section "Information on new orbital elements".

The data on CD for 2017 embrace information on elements and ephemerides for 464622 numbered objects as of March 23, 2016. The form of representation of these data is traditional. Orbital data and ephemerides for several dwarf planets defined by the resolution of 26th General Assembly of the IAU are also included in the volume. Besides, the volume contains special Table of elements of all numbered near-Earth asteroids (NEAs). Two more additional Tables contain orbital elements of Centaurs and transneptunian objects and those of some unusual asteroids. Ephemerides of NEAs and unusual asteroids covering near-opposition intervals and intervals of close approaches to the Earth are also given.

The data are presented as PDF files. They can be displayed/ printed by a variety of applications, in particular by Acrobat Reader. Apart from full set of Tables of EMP for 2017 the CD contains also the integrated software package AMPLE (Adaptable Minor Planet Ephemerides) which is intended for computation various ephemeris data for 2017 and solving a number of problems associated with their use (see information on AMPLE at the end of Introduction).

The volume of the EMP for 2017 (the seventy first year of publication) contains:

information on new orbital elements;

orbital elements of 464622 minor planets numbered as of March 23, 2016 and dates of their oppositions in 2017;

special Table of orbital elements of all near-Earth asteroids (NEAs) numbered as of March 23, 2016 and dates of their oppositions in 2017;

special Table of orbital elements of Centaurs and transneptunian objects and dates of their oppositions in 2017;

special Table of orbital elements of some unusual minor planets (Jupiter-crossers, Jupiter-approachers and some Mars-crossers) and dates of their oppositions in 2017;

osculating elements of perturbing planets;

minor planet lightcurve parameters;

ambiguos periods of lightcurves;

binary asteroid lightcurves;

binary asteroid parameters;

non-principal axis rotation (tumbling) asteroids;

asteroid spin axes;

list of all minor planets in order of opposition dates in 2017;

opposition ephemerides for 2017;

ephemerides of NEAs and some unusual minor planets;

status of minor planet observations as of March 23, 2016;

positions of the antisun and the Moon;
information on the "Updated Ephemerides of Minor Planets" service;
information on the AMPLE package.

In conformity with the resolution of IAU Commission 20 (New Delhi, November 1985, the Minor Planet Circulars 10193–10194), the so-called H, G magnitude system for minor planets is used in the EMP. A formula for the prediction of the apparent magnitude is

$$V = 5\log(r\Delta) + H - 2.5\log[(1-G)\Phi_1 + G\Phi_2], \tag{1}$$

where r and Δ are the heliocentric and geocentric distances, respectively, H is the absolute magnitude (in the V band unless otherwise specified) at solar phase angle $\beta = 0°$, G is termed the slope parameter, and Φ_1 and Φ_2 are two phase functions given by the expressions:

$$\Phi_i = \exp\left\{-A_i\left[\tan\left(\beta/2\right)\right]^{B_i}\right\}, \quad i = 1, 2,$$
$$A_1 = 3.33,\ A_2 = 1.87,\ B_1 = 0.63,\ B_2 = 1.22.$$

The formula (1) predicts the observed opposition surge and the non-linear drop off in brightness at large phase angles, and is valid for $0° < \beta < 120°$. H and G are fundamental photometric parameters for each minor planet. They are related to the previously used absolute magnitude $B(1,0)$ and the phase coefficient. In particular, conversion from the B band of the old system to the V band of the new system is conveniently carried out using the approximate relationship $H = B(1,0) - 1$ mag. Further details have been given by E. Bowell, B. Hapke, D. Domingue, K. Lumme, J. Peltoniemi, and A. W. Harris in "Asteroids II" (eds. R. P. Binzel, T. Gehrels and M. S. Matthews), p. 524–556, Univ. of Arizona Press, Tucson, 1989).

The magnitudes in the present volume of EMP are based on those values of H and G which were published in MPC 28103–28116 and in subsequent issues. The parameters for the first 3200 minor planets were determined mainly by E. F. Tedesco (Jet Propulsion Laboratory, U.S.A.). For almost all remaining minor planets the H value were determined by G. V. Williams (Harvard-Smithsonian Center for Astrophysics, U.S.A.).

INFORMATION ON NEW ORBITAL ELEMENTS

Since the last year's EMP, the number of newly numbered minor planets has increased by 34217. Elements of all numbered minor planets have been determined by IAA. The sets of elements are given for the standard epoch September 4.0, 2017. They were determined as a result of orbit improving on the base of all kinds of optical observations available in the catalog of observations of the Minor Planet Center on March 23, 2016 (radar observations have not been used at this stage). The brief information on the accuracy of each set of elements is given in the Table on p. 10–977. It contains the following data.

1) Number of planet.

2) The number of oppositions with observations used for determination of the orbit.

3) The time interval covered by the observations used for determination of the orbit.

4) The mean-root-square error of observations, expressed in arcsec, with respect to orbits fitted by the least squares.

When estimating these data it is necessary to take into consideration the following.

1) Corrections to the initial sets of elements were determined by the least square fit of weighted conditional equations. In so doing, the observations made before 1901 were assigned weight equal to 1/16, the observations made during the time interval from 1901 to 1950 were assigned weight equal to 1/9, the observations made during the time interval from 1951 to 1995 were assigned weight equal to 1/4, and at last the observations starting from 1996 were considered as having unit weight.

2) Observations of only standard accuracy were used for orbit improvement.

3) Observations in right ascension and in declination were considered as independent, so that conditional equation, e.g. in right ascension, could be excluded by "the three sigma criterion" from solution whereas equation in declination could be used or vice versa.

4) Observation is considered as used, if both conditional equations in right ascension and in declination or at least one of them are used for finding solution.

5) The mean-root-square error of observations, given in column 4 of the Table was computed by the formula

$$\sigma = \sqrt{\frac{\sum_{i=1}^{l}[(\alpha_O - \alpha_C)\cos\delta]_i^2 + \sum_{j=1}^{m}[\delta_O - \delta_C]_j^2}{l + m - 6}},$$

where l is the number of equations in right ascension and m is that of in declination.

Note that weights appearing in the conditional equations are not used in the above formula.

In the Table below the brief information on the accuracy of orbital elements which are publishing in EMP 2017 is correlated with corresponding information on the accuracy of orbital elements included in minor planet orbit file maintained by Minor Planet Center. For different intervals of σ value the Table gives number of sets of elements, determined with mean errors that fall in the indicated limits.

Interval of σ	Number of sets within interval	Percent of the total	Number of sets within interval	Percent of the total
	EMP orbits		MPC orbits	
$\sigma \geq 1.0''$	6	0.001	18	0.004
$0.9'' \leq \sigma < 1.0''$	8	0.002	5	0.001
$0.8'' \leq \sigma < 0.9''$	38	0.01	9	0.002
$0.7'' \leq \sigma < 0.8''$	215	0.05	52	0.01
$0.6'' \leq \sigma < 0.7''$	3369	0.72	644	0.14
$0.5'' \leq \sigma < 0.6''$	60803	13.09	77721	16.73
$0.4'' \leq \sigma < 0.5''$	157880	33.98	225547	48.54
$0.3'' \leq \sigma < 0.4''$	139180	29.96	125115	26.93
$0.2'' \leq \sigma < 0.3''$	95617	20.58	34692	7.47
$0.1'' \leq \sigma < 0.2''$	7483	1.61	819	0.18
$\sigma < 0.1''$	23	0.005	0	0.00

These data show that quality of improvement of new sets is in general good. At least, 86.1 % the EMP orbits have $\sigma < 0.5''$, as compared with 83.1 % of MPC orbits. True, in the more wide interval $\sigma < 0.8''$ the MPC orbits and EMP orbits are presented approximately in equal amounts for the expense of more dense concentration of MPC orbits within interval $0.4'' \leq \sigma < 0.6''$.

The estimation of precision of new systems would not be complete without comparing the number of observations actually used for determining orbits. As the MPC orbits do not all were improved simultaneously with EMP orbits, only 340063 sets of elements were used for data comparison (for selected sets of elements process of improvement had started with the use of the same observations). From this number of orbits in 51322 cases the number of actually used observations was equal both for EMP and MPC orbits. In 269076 cases the number of observations used for determination of EMP orbits proves to be greater than that of used for MPC orbits and only in 19665 cases MPC orbits have been found from greater number of observations. It can be added that 5662 EMP orbits were determined on longer time interval at the expense of usage of more earlier observations.

ELEMENTS AND OPPOSITION DATES IN 2017

The elements of the numbered minor planets are given with respect to the ecliptic and equinox J2000.0. The computation of osculating elements for the new standard epoch JDT 2458000.5 = 2017 September 4.0 TT was carried out by numerical integration of relativistic equations of motion in rectangular coordinates taking into account the perturbations from Mercury to Neptune and from Pluto, Ceres, Pallas, and Vesta. Coordinates and masses of perturbing planets were taken from *DE* 405. The perturbations from the Earth and the Moon were considered separately.

Osculating elements of minor planets are given on p. 978–6785. The first column of the Table gives the number and name or principal provisional designation of each minor planet. The second gives the absolute magnitude, H, that is, the brightness averaged over rotation for minor planets having known lightcurves and reduced to unit heliocentric and geocentric distances and to zero phase angle. The third column gives the slope parameter, G.

As noted above, the values of H and G are given in this year in accordance with the listing published in MPC 28103–28116 and in subsequent issues. In general the parameters given for the first 3200 minor planets are

precisely those of the previous listing, prepared mainly by E. F. Tedesco. When H and G values were determined sufficiently precisely from photoelectric observations, frequently by least-square fitting, although in some instances G was selected, H values are given to 0.01 mag. Actual solutions for G (ranging from -0.12 to $+0.60$) have been made in only 110 cases. In the Table these values are given to 0.01. For by far the majority of minor planets the default value of G equal to 0.15 is used and it is denoted in the Table by X. Magnitudes based solely on photographic or CCD observations or for photoelectrically observed asteroids with large lightcurve and/or aspect variations (cf. lightcurve parameter Table, p. 6822–6922) are given to 0.1 mag. For almost all minor planets with numbers greater than 3200 the values of H were found by G. V. Williams (also to 0.1 mag and using $G = 0.15$) from magnitudes given on the astrometric records collected by the Minor Planet Center. For photoelectrically observed NEAs (3361), (3551), (3554), (3757) and (4015) the more precise H values from previous listing are preserved. For (4179) the H and G values suggested by D. J. Tholen (Institute for Astronomy, University of Hawaii, U.S.A.) are adopted. The new values of H determined by G. V. Williams are also adopted for 98 minor planets with numbers less than 3200. In three other discordant cases the improved H values were suggested by A. W. Harris (Jet Propulsion Laboratory, U.S.A.).

The orbital elements (mean anomaly, M, argument of perihelion, ω, longitude of ascending node, Ω, inclination, i, eccentricity, e, mean motion, μ, and semi-major axis, a) are given in the columns from 4 to 10.

Eleventh column of the Table headed TE contains last two digits of the title year of the EMP in which the orbit was first introduced and where the information on its precision can be found.

12 and 13 columns of the Table contain opposition date of minor planet in 2017 and its apparent magnitude for the fourth ephemeris date. A dash indicates that there is no opposition in 2017.

ELEMENTS AND OPPOSITION DATES OF NEAS

The Table of elements and opposition dates of the near-Earth asteroids (NEAs) (see p. 6786–6812) contains osculating elements of the numbered minor planets with perihelion distances q less or equal to 1.3 a.u., and dates of their oppositions in 2017. It is patterned after corresponding Table of elements of minor planets. The minute differences are as follows: the semi-major axis is given with less number of decimals and instead column headed TE the columns with approximate values of perihelion distance q and aphelion distance Q are given. The column headed T (Type) contains indication of minor planet type where Am stands for Amor type ($a > 1$ a.u., 1.017 a.u. $< q \leq 1.3$ a.u.), Ap stands for Apollo type ($a > 1$ a.u., $q \leq 1.017$ a.u.), At stands for Aten type ($a < 1$ a.u., $Q \geq 0.983$ a.u.), and Ar stands for Atira type ($Q < 0.983$ a.u.). (163693) Atira is the first numbered asteroid of new type ($Q < 0.983$ a.u.) for which in literature one can find also other names (Apohele type, Arjuna type and so on).

ELEMENTS AND OPPOSITION DATES OF CENTAURS AND TRANSNEPTUNIAN OBJECTS

The Table of elements and opposition dates of Centaurs and transneptunian objects (see p. 6813–6817) is constructed like that of NEAs. Column headed T (Type) contains indication of object's type where Ct stands for Centaurs ($a < 30$ a.u., $q > 5.45$ a.u.), Tn stands for transneptunian objects ("kjubiwanos" (like classical (15760) 1992 QB_1) or Plutinos (in commensurabilities with Neptune or Uranus)), Sd stands for scattered disk objects.

ELEMENTS AND OPPOSITION DATES OF SOME UNUSUAL MINOR PLANETS

The Table (p. 6818–6820) contains data for Jupiter-crossers, Jupiter-approachers as well as for some Mars-crossers, mainly with unusual orbits. Minor planets whose stability is protected by special mechanisms (like Trojans, Hildas and so on) are not included in the Table except in a few special cases.

The Table is constructed like two preceding ones. The header T (Type) indicates type of minor planet where Jc stands for Jupiter-crosser, Ja stands for Jupiter-approacher, Mc stands for Mars-crosser, MT stands for Mars Trojan, and NT stands for Neptune Trojan.

It should be noted that all objects included into the Tables of NEAs, Centaurs and transneptunian objects, and some unusual planets can be also found in the Table of elements and opposition dates of all minor planets.

OSCULATING ELEMENTS AND INVERSE MASSES OF PERTURBING PLANETS

The osculating elements of all perturbing planets and their inverse masses used in *DE* 405 are given in the Table on p. 6821. They can be applied in continued numerical integration. For Ceres, Pallas, and Vesta the osculating elements correspond to those in the Table on p. 978.

On the same page values of some constants used when preparing ephemeris volume are given. Also Julian Day Number for some dates in 2016 – 2018 are given there.

MINOR PLANET LIGHTCURVE PARAMETERS

The lightcurve parameters for some minor planets are given on p. 6822–6922. The data of the Table are based on the data published by C.-I. Lagerkvist, A. W. Harris and V. Zappalá (see: "Asteroids II machine-readable data base: March 1988 floppy disk version", National Space Science Data Center, Greenbelt MD). The Table was updated for publication in the volume for 2017 by B. Warner (Palmer Divide Observatory, Colorado Springs, U.S.A.), A. W. Harris (Space Science Institute, U.S.A.), and P. Pravec (Astronomical Institute, Academy of Sciences of Czech Republic).

The Table contains the number and name or principal provisional designation of minor planet, the period of rotational lightcurve expressed in hours, the amplitude of variation or range of amplitude observed, and a reliability code. More detailed explanations are given in the notes on p. 6921–6922.

AMBIGUOUS PERIODS OF LIGHTCURVES

The Table on p. 6923–6932 includes alternative values of period and amplitude for minor planets marked in the Table "Minor planet lightcurve parameters" as having ambiguous value of period. The data for publication in the Table were supplied by B. Warner (Palmer Divide Observatory, Colorado Springs, U.S.A.), A. W. Harris (Space Science Institute, U.S.A.) and P. Pravec (Astronomical Institute, Academy of Sciences of Czech Republic).

BINARY ASTEROID LIGHTCURVES

The Table on p. 6933–6943 contains additional data for the lightcurves of the objects marked in the Table "Minor planet lightcurve parameters" as known or suspected binaries. The data are meant to provide a quick overview of a primary period and amplitude of the lightcurves as well as a secondary period and, if available, amplitude. The data for publication in the Table were supplied by B. Warner (Palmer Divide Observatory, Colorado Springs, U.S.A.), A. W. Harris (Space Science Institute, U.S.A.) and P. Pravec (Astronomical Institute, Academy of Sciences of Czech Republic).

BINARY ASTEROID PARAMETERS

The data in the Table on p. 6944–6946 embrace estimated parameters for 155 binary systems in near Earth, Mars crossing, main belt and Trojan orbits (more than 90 % of corresponding objects are marked in the Table "Minor planet lightcurve parameters" as undoubtedly binary and in other cases as suspected binary). The Table contains such data as estimated diameters of primary and secondary components, their rotation periods, semi-major axis of orbit of the secondary component, etc (see more detailed explanation in the Table footnote). The data were presented by P. Pravec (Astronomical Institute, Academy of Sciences of Czech Republic) (see Pravec, P., Harris, A. W., 2007. Binary Asteroid Population. 1. Angular Momentum Content, Icarus, 190 (2007) 250–259. The July 2011 update of the data was made by P. Pravec and 41 colleagues for paper "Binary Asteroid Population. 2. Anisotropic distribution of orbit poles of small, inner main-belt binaries", Icarus, 218 (2012) 125–143. The September 2015 update of the data was made by P. Pravec et al. for paper "Binary asteroid population. 3. Secondary rotations and elongations", Icarus 267 (2016) 267–295).

NON-PRINCIPAL AXIS ROTATION (TUMBLING) ASTEROIDS

The Table on p. 6947–6958 includes additional data for the asteroids for which non-principal axis rotational motion (tumbling) has been reported. The data for publication in the Table were prepared by B. Warner (Palmer Divide Observatory, Colorado Springs, U.S.A.), A. W. Harris (Space Science Institute, U.S.A.) and P. Pravec (Astronomical Institute, Academy of Sciences of Czech Republic).

ASTEROID SPIN AXES

The Table on p. 6959–7007 includes information about spin axis properties (ecliptic coordinates of spin vector pole and sidereal period) for any numbered minor planet for which corresponding data have been reported. The data for publication in the Table were prepared by B. Warner (Palmer Divide Observatory, Colorado Springs, U.S.A.), A. W. Harris (Space Science Institute, U.S.A.) and P. Pravec (Astronomical Institute, Academy of Sciences of Czech Republic).

LIST OF ALL MINOR PLANETS IN ORDER OF OPPOSITION DATES IN 2017

The list of the numbered minor planets as of March 23, 2016 arranged according to their opposition dates in 2017 is given in the Table on p. 7008–7760. To save space the data are given in six columns on a page. For each minor planet the following data are given: number, date of opposition in 2017, and apparent V magnitude for the fourth ephemeris date (as a rule, this date coincides with the nearest standard Julian day number preceding the opposition). As for most planets on a page the month when the oppositions take place is the same, it enters in header, so that only day of opposition is indicated in the line with number and magnitude.

EPHEMERIDES

Ephemerides of minor planets, arranged in order of opposition date, are given on p. 7761–27643. The first and the last opposition dates occurring on each page are indicated on the left and right sides of the page header, respectively. The ephemerides are computed from numerical integration taking into account perturbations from those planets which were considered in determining the elements. The following data are tabulated for each planet.

1) The number and name or principal provisional designation of the minor planet, the opposition date, the mean anomaly on the fourth ephemeris date, the minimum value of the phase angle and the date of its occurrence, the last two figures of the year of the most recent astrometric observation. In case the planet is on critical list (not observed since 2011 or observed in fewer than four oppositions), the year of the last astrometric observations is followed by symbol C. When it is known that rotational lightcurve variations exceed 0.4 mag, at least on occasion, the ephemeris heading is ended in flag R. Where it is known or suspected that aspect variations cause large excursion (> 0.4 mag) in the observed magnitude from opposition to opposition the flag A is used rather than R.

2) For each of eight ephemeris dates, at 10-day interval: astrometric position (right ascension and declination) for 0^h TT, referred to the equator and equinox of J2000.0, geocentric and heliocentric distances Δ and r, respectively, the phase angle, β, and the apparent V magnitude.

For all minor planets not included in the critical list the ephemeris uncertainty is expected to be less than 5 arcsec. For minor planets being on critical list there is insufficient information to assess the ephemeris accuracy.

EPHEMERIDES OF NEAS AND SOME UNUSUAL MINOR PLANETS

Extended ephemerides of NEAs and some unusual minor planets listed in the Table on p. 6818–6820 (Jupiter-crossers, Jupiter-approachers, some unusual Mars-crossers) are presented on p. 27644–28111. At the end of the Table special index is placed which indicates page numbers where the ephemerides of different planets are given.

Each ephemeris contains astrometric positions for 0^h TT referred to the equator and equinox J2000.0, the geocentric and heliocentric distances Δ and r, respectively, the phase angle, β, the apparent V magnitude, the solar elongation, ψ, and the maximum altitude during darkness at latitudes $+45^\circ$ and -26°. In cases where there is no upper culmination during nighttime, the maximum altitude above the horizon during civil twilight is given; such altitudes are denoted by an asterisk.

STATUS OF MINOR PLANET OBSERVATIONS

The so-called critical list, containing minor planets not observed since 2011 or observed at fewer than four oppositions, is given on p. 28112–28114.

ANTISUN AND MOON

Positions of the antisun and the Moon are given on p. 28115–28116. For 0^h TT of each day of 2017 the Table contains geocentric equatorial coordinates of the antisun (the point diametrically opposite the Sun) and those of the Moon. The solar elongation of the Moon is also given.

INFORMATION ON UPDATED EPHEMERIDES OF MINOR PLANETS SERVICE

Information on the "Updated Ephemerides of Minor Planets" service is given on p. 28117(see also http://www.ipa.nw.ru/PAGE/FUNDAMENTAL/LSBSS/enguemp.htm).

INFORMATION ON AMPLE PACKAGE

Information on the AMPLE integrated software package is given on p. 28117–28118.

Data for the present volume of the EMP have been prepared by Yu. A. .Chernetenko, G. R. Kastel', O. M. Kochetova, V. B. Kuznetsov, V. A. Shor, T. A. Vinogradova, and N. B. Zheleznov. Typesetting and page makeup have been done by D. A. Ryzhkova using system SVITA and TEX.

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