THE ASTRONOMICAL ALMANAC

FOR THE YEAR

2004

and its companion

The Astronomical Almanac Online

Data for Astronomy, Space Sciences, Geodesy, Surveying, Navigation and other applications

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Julian date

A tabulation of Julian date (JD) at 0^h UT against calendar date is given with the ephemeris of universal and sidereal times on pages B8–B15. The following relationship holds during 2004:

$$\text{Julian date} = 245\ 3004{\cdot}5 + \text{day of year} + \text{fraction of day from } 0^h \text{ UT}$$

where the day of the year for the current year of the Gregorian calendar is given on pages B2–B3. The following table gives the Julian dates at day 0 of each month of 2004:

0^h UT	JD	0^h UT	JD	0^h UT	JD
Jan. 0	245 3004·5	May 0	245 3125·5	Sept. 0	245 3248·5
Feb. 0	245 3035·5	June 0	245 3156·5	Oct. 0	245 3278·5
Mar. 0	245 3064·5	July 0	245 3186·5	Nov. 0	245 3309·5
Apr. 0	245 3095·5	Aug. 0	245 3217·5	Dec. 0	245 3339·5

Tabulations of Julian date against calendar date for other years are given on pages K2–K4. Other relevant dates are:

400-day date, JD 245 3200·5 = 2004 July 14·0

Standard epoch, 1900 January 0, 12^h UT = JD241 5020·0
Standard epoch, B1950·0 = 1950 Jan. 0·923 = JD243 3282·423
B2004·0 = 2004 Jan. 1·002 = JD245 3005·502
J2004·5 = 2004 July 2·125 = JD245 3188·625
Standard epoch, J2000·0 = 2000 Jan. 1·5 = JD245 1545·0

The "*modified Julian date*" (MJD) is the Julian date minus 240 0000·5 and in 2004 is given by: MJD = 53004·0 + day of year + fraction of day from 0^h UT.

A date may also be expressed in years as a Julian epoch, or for some purposes as a Besselian epoch, using:

$$\text{Julian epoch} = \text{J}[2000{\cdot}0 + (\text{JD} - 245\ 1545{\cdot}0)/365{\cdot}25]$$
$$\text{Besselian epoch} = \text{B}[1900{\cdot}0 + (\text{JD} - 241\ 5020{\cdot}313\ 52)/365{\cdot}242\ 198\ 781]$$

where JD is the Julian date; the prefixes J and B may be omitted only where the context, or precision, make them superfluous.

Notation for time-scales

A summary of the notation for time-scales and related quantities used in this Almanac is given below. Additional information is given in the Glossary, in the Explanation and in the Supplement to the Almanac for 1984.

UT	= UT1; universal time; counted from 0^h at midnight; unit is mean solar day
UT0	local approximation to universal time; not corrected for polar motion
GMST	Greenwich mean sidereal time; GHA of mean equinox of date
GAST	Greenwich apparent sidereal time; GHA of true equinox of date
TAI	international atomic time; unit is the SI second
UTC	coordinated universal time; differs from TAI by an integral number of seconds, and is the basis of most radio time signals and legal time systems
ΔUT	= UT−UTC; increment to be applied to UTC to give UT
DUT	= predicted value of ΔUT, rounded to $0^s{\cdot}1$, given in some radio time signals
ET	ephemeris time; was used in dynamical theories and in the Almanac from 1960–1983. ET was replaced by TDT and TDB

Notation for time-scales (continued)

TDT terrestrial dynamical time; TDT = TAI + $32^{s}184$. It was used in the Almanac from 1984–2000. TDT was replaced by TT.

TDB barycentric dynamical time; used in previous years (1984–2003) as time-scale of ephemerides referred to the barycentre of the solar system

T_{eph} the dynamical time scale for the JPL DE 405 ephemeris

TT terrestrial time; used as time-scale of ephemerides for observations from the Earth's surface. TT = TAI + $32^{s}184$

ΔT = ET − UT (prior to 1984); increment to be applied to UT to give ET

ΔT = TT − UT (2001 onwards); increment to be applied to UT to give TT. For 1984–2000, ΔT = TDT − UT

ΔT = TAI + $32^{s}184$ − UT

ΔAT = TAI − UTC; increment to be applied to UTC to give TAI

ΔET = ET − UTC; increment to be applied to UTC to give ET

ΔTT = TT − UTC; increment to be applied to UTC to give TT. For 1984–2000, ΔTT = TDT − UTC

For most purposes, ET up to 1983 December 31 and TT from 1984 January 1 can be regarded as a continuous time-scale. TDT was renamed TT following an IAU resolution. Values of ΔT for the years 1620 onwards are given on pages K8–K9.

The name Greenwich mean time (GMT) is not used in this Almanac since it is ambiguous and is now used, although not in astronomy, in the sense of UTC in addition to the earlier sense of UT; prior to 1925 it was reckoned for astronomical purposes from Greenwich mean noon (12^{h} UT).

Relationships between time-scales

The relationships between universal and sidereal times are described on page B6 and a daily ephemeris is given on pages B8–B15; examples of the use of the ephemeris are given on page B7.

The scale of coordinated universal time (UTC) contains step adjustments of exactly one second (leap seconds) so that universal time (UT) may be obtained directly from it with an accuracy of 1 second or better and so that international atomic time (TAI) may be obtained by the addition of an integral number of seconds. The step adjustments are usually inserted after the 60th second of the last minute of December 31 or June 30. Values of the differences ΔAT for 1972 onwards are given on page K9. Accurate values of the increment ΔUT to be applied to UTC to give UT are derived from observations, but predicted values are transmitted in code in some time signals.

The difference between the terrestrial time scale (TT) and the dynamical time scale of the DE 405 (or equivalent) ephemeris (T_{eph}) is often ignored, since the two time scales differ by no more than 2 milliseconds of time (Standish, E.M. (1998) Astron. Astrophys. **336**, 381-384). However, including the first term gives:

$$T_{eph} = TT + 0^{s}001\,658 \sin g$$
$$g = 357^{\circ}53 + 0^{\circ}985\,600\,28(JD - 245\,1545{\cdot}0)$$

where higher-order terms are neglected and g is the mean anomaly of the Earth in its orbit around the Sun. For the current year

$$g = 356^{\circ}01 + 0^{\circ}985\,600\,28\,d$$

where d is the day of the year tabulated on pages B2–B3.

Relationships between universal and sidereal time

The ephemeris of universal and sidereal times on pages B8–B15 is primarily intended to facilitate the conversion of universal time to local apparent sidereal time, and vice versa, for use in the computation and reduction of quantities dependent on local hour angle. Numerical examples of such conversions using the ephemeris and other tables are given opposite on page B7. Alternatively, such conversions may be carried out using the basic formulae and numerical coefficients given below.

Universal time is defined in terms of Greenwich mean sidereal time, (i.e. the Greenwich hour angle (GHA) of the mean equinox of date), by:

$$\text{GMST at } 0^{\text{h}} \text{ UT} = 24\,110^{\text{s}}.548\,41 + 8640\,184^{\text{s}}.812\,866\, T_{\text{U}} + 0^{\text{s}}.093\,104\, T_{\text{U}}^2 - 6^{\text{s}}.2 \times 10^{-6}\, T_{\text{U}}^3$$

where

$$T_{\text{U}} = (\text{JD} - 245\,1545.0)/36\,525$$

T_{U} is the interval of time, measured in Julian centuries of 36 525 days of universal time (mean solar days), elapsed since the epoch 2000 January 1^{d} 12^{h} UT.

The following relationship holds during 2004:

on day of year d at t^{h} UT, GMST $= 6^{\text{h}}.600\,8633 + 0^{\text{h}}.065\,709\,8245\, d + 1^{\text{h}}.002\,737\,91\, t$

where the day of year d is tabulated on pages B2–B3. Add or subtract multiples of 24^{h} as necessary.

In 2004:	1 mean solar day	=	1.002 737 909 35	mean sidereal days
		=	$24^{\text{h}}\ 03^{\text{m}}\ 56^{\text{s}}.555\ 37$	of mean sidereal time
	1 mean sidereal day	=	0.997 269 566 33	mean solar days
		=	$23^{\text{h}}\ 56^{\text{m}}\ 04^{\text{s}}.090\ 53$	of mean solar time

Greenwich apparent sidereal time (i.e. the Greenwich hour angle of the true equinox of date) is given by:

$$\text{GAST} = \text{GMST} + \text{equation of equinoxes}$$

where equation of equinoxes $= \frac{1}{15}(\Delta\psi \cos\epsilon + 0''.002\,64 \sin\Omega + 0''.000\,063 \sin 2\Omega)$

and $\Delta\psi$ is the total nutation in longitude, ϵ is the mean obliquity of the ecliptic and Ω is the mean longitude of the ascending node of the Moon. The equation of the equinoxes is tabulated on pages B8–B15 at 0^{h} UT for each day and should be interpolated to the required time if full precision is required.

Relationships with local time and hour angle

The following general relationships are used:

local mean solar time = universal time + east longitude
local mean sidereal time = Greenwich mean sidereal time + east longitude
local apparent sidereal time = local mean sidereal time + equation of equinoxes
= Greenwich apparent sidereal time + east longitude
local hour angle = local apparent sidereal time − apparent right ascension
= local mean sidereal time
− (apparent right ascension − equation of equinoxes)

A further small correction for the effect of polar motion is required in the reduction of very precise observations; for details see page B50.

Examples of the use of the ephemeris of universal and sidereal times

1. *Conversion of universal time to local sidereal time*

To find the local apparent sidereal time at $09^h\ 44^m\ 30^s$ UT on 2004 July 8 in longitude 80° 22′ 55″.79 west.

	h m s
Greenwich mean sidereal time on July 8 at 0^h UT is (page B12)	19 05 08·6280
Add the equivalent mean sidereal time interval from 0^h to $09^h\ 44^m\ 30^s$ UT (multiply UT interval by 1·002 737 9094)	9 46 06·0185
Greenwich mean sidereal time at required UT:	4 51 14·6465
Add equation of equinoxes, interpolated using second-order differences to approximate UT = $0^d.41$	−0·5829
Greenwich apparent sidereal time:	4 51 14·0636
Subtract west longitude (add east longitude)	5 21 31·7193
Local apparent sidereal time:	23 29 42·3443

The calculation for local mean sidereal time is similar, but omit the step which allows for the equation of the equinoxes.

2. *Conversion of local sidereal time to universal time*

To find the universal time at $23^h\ 29^m\ 42^s.3443$ local apparent sidereal time on 2004 July 8 in longitude 80° 22′ 55″.79 west.

	h m s
Local apparent sidereal time:	23 29 42·3443
Add west longitude (subtract east longitude)	5 21 31·7193
Greenwich apparent sidereal time:	4 51 14·0636
Subtract equation of equinoxes, interpolated using second-order differences to approximate UT = $0^d.41$	−0·5829
Greenwich mean sidereal time:	4 51 14·6465
Subtract Greenwich mean sidereal time at 0^h UT	19 05 08·6280
Mean sidereal time interval from 0^h UT:	9 46 06·0185
Equivalent UT interval (multiply mean sidereal time interval by 0·997 269 5663)	9 44 30·0000

The conversion of mean sidereal time to universal time is carried out by a similar procedure; omit the step which allows for the equation of the equinoxes.

Date 0h UT	Julian Date	G. SIDEREAL TIME (GHA of the Equinox) Apparent	Mean	Equation of Equinoxes at 0^h UT	GSD at 0^h GMST	UT at 0^h GMST (Greenwich Transit of the Mean Equinox)	
	245	h m s	s	s	245		h m s
Apr. 1	3096·5	12 38 45·4871	46·2019	−0·7148	9814·0	Apr. 1	11 19 22·1949
2	3097·5	12 42 42·0394	42·7573	−0·7179	9815·0	2	11 15 26·2854
3	3098·5	12 46 38·5889	39·3126	−0·7237	9816·0	3	11 11 30·3760
4	3099·5	12 50 35·1362	35·8680	−0·7318	9817·0	4	11 07 34·4665
5	3100·5	12 54 31·6826	32·4234	−0·7408	9818·0	5	11 03 38·5570
6	3101·5	12 58 28·2299	28·9787	−0·7488	9819·0	6	10 59 42·6476
7	3102·5	13 02 24·7801	25·5341	−0·7540	9820·0	7	10 55 46·7381
8	3103·5	13 06 21·3345	22·0895	−0·7550	9821·0	8	10 51 50·8286
9	3104·5	13 10 17·8932	18·6448	−0·7517	9822·0	9	10 47 54·9192
10	3105·5	13 14 14·4551	15·2002	−0·7451	9823·0	10	10 43 59·0097
11	3106·5	13 18 11·0183	11·7556	−0·7373	9824·0	11	10 40 03·1002
12	3107·5	13 22 07·5807	08·3109	−0·7302	9825·0	12	10 36 07·1908
13	3108·5	13 26 04·1405	04·8663	−0·7258	9826·0	13	10 32 11·2813
14	3109·5	13 30 00·6968	01·4217	−0·7248	9827·0	14	10 28 15·3718
15	3110·5	13 33 57·2495	57·9770	−0·7276	9828·0	15	10 24 19·4623
16	3111·5	13 37 53·7991	54·5324	−0·7334	9829·0	16	10 20 23·5529
17	3112·5	13 41 50·3468	51·0878	−0·7410	9830·0	17	10 16 27·6434
18	3113·5	13 45 46·8941	47·6431	−0·7491	9831·0	18	10 12 31·7339
19	3114·5	13 49 43·4422	44·1985	−0·7563	9832·0	19	10 08 35·8245
20	3115·5	13 53 39·9923	40·7539	−0·7616	9833·0	20	10 04 39·9150
21	3116·5	13 57 36·5449	37·3093	−0·7644	9834·0	21	10 00 44·0055
22	3117·5	14 01 33·1001	33·8646	−0·7645	9835·0	22	9 56 48·0961
23	3118·5	14 05 29·6577	30·4200	−0·7623	9836·0	23	9 52 52·1866
24	3119·5	14 09 26·2170	26·9754	−0·7584	9837·0	24	9 48 56·2771
25	3120·5	14 13 22·7772	23·5307	−0·7536	9838·0	25	9 45 00·3677
26	3121·5	14 17 19·3373	20·0861	−0·7488	9839·0	26	9 41 04·4582
27	3122·5	14 21 15·8965	16·6415	−0·7450	9840·0	27	9 37 08·5487
28	3123·5	14 25 12·4539	13·1968	−0·7429	9841·0	28	9 33 12·6392
29	3124·5	14 29 09·0089	09·7522	−0·7433	9842·0	29	9 29 16·7298
30	3125·5	14 33 05·5613	06·3076	−0·7463	9843·0	30	9 25 20·8203
May 1	3126·5	14 37 02·1114	02·8629	−0·7516	9844·0	May 1	9 21 24·9108
2	3127·5	14 40 58·6599	59·4183	−0·7584	9845·0	2	9 17 29·0014
3	3128·5	14 44 55·2087	55·9737	−0·7650	9846·0	3	9 13 33·0919
4	3129·5	14 48 51·7595	52·5290	−0·7695	9847·0	4	9 09 37·1824
5	3130·5	14 52 48·3143	49·0844	−0·7701	9848·0	5	9 05 41·2730
6	3131·5	14 56 44·8739	45·6398	−0·7659	9849·0	6	9 01 45·3635
7	3132·5	15 00 41·4376	42·1951	−0·7575	9850·0	7	8 57 49·4540
8	3133·5	15 04 38·0037	38·7505	−0·7469	9851·0	8	8 53 53·5445
9	3134·5	15 08 34·5695	35·3059	−0·7364	9852·0	9	8 49 57·6351
10	3135·5	15 12 31·1330	31·8612	−0·7283	9853·0	10	8 46 01·7256
11	3136·5	15 16 27·6928	28·4166	−0·7238	9854·0	11	8 42 05·8161
12	3137·5	15 20 24·2486	24·9720	−0·7233	9855·0	12	8 38 09·9067
13	3138·5	15 24 20·8012	21·5273	−0·7262	9856·0	13	8 34 13·9972
14	3139·5	15 28 17·3515	18·0827	−0·7312	9857·0	14	8 30 18·0877
15	3140·5	15 32 13·9011	14·6381	−0·7370	9858·0	15	8 26 22·1783
16	3141·5	15 36 10·4513	11·1935	−0·7421	9859·0	16	8 22 26·2688
17	3142·5	15 40 07·0031	07·7488	−0·7457	9860·0	17	8 18 30·3593