Time

Astronomers have always been concerned with time and its measurements. If you read any astronomical text on the subject you are sure to be bewildered by the seemingly endless range of times and their definitions. There's universal time and Greenwich mean time, apparent sidereal time and mean sidereal time, ephemeris time, local time and mean solar time, to name but a few. Then there's the sidereal year, the tropical year, the Besselian year and the anomalistic year. And be quite clear about the distinction between the Julian and Gregorian calendars! (See the Glossary for the definitions of these terms.)

All these terms are necessary and have precise definitions. Happily, however, we need concern ourselves with but a few of them as the distinctions between them become apparent only when very high precision is required.

1 Calendars

A calendar helps us to keep track of time by dividing the year into months, weeks and days. Very roughly speaking, one month is the time taken by the Moon to complete one circuit of its orbit around the Earth, during which time it displays four phases, or quarters, of one week each, and a year is the time taken for the Earth to complete one circuit of its orbit around the Sun. By common consent we adopt the convention that there are seven days in each week, between 28 and 31 days in each month (see Table 1) and 12 months in each year. By knowing the day number and name of the month we are able to refer precisely to any day of the year.

Table 1

January	31	July	31
February	28 (or 29 in a leap year)	August	31
March	31	September	30
April	30	October	31
May	31	November	30
June	30	December	31

The problem with this method of accounting the days in the year lies in the fact that, whereas there is always a whole number of days in the civil year, the Earth takes 365.2422 days to complete one circuit of its orbit around the Sun. (This is the *tropical year*; see the Glossary for its definition.) If we were to take no notice of this fact and adopt 365 days for every year, then the Earth would get progressively more out of step with our system at a rate of 0.2422 days per year. After 100 years the discrepancy would be 24 days; after 1500 years the seasons would have been reversed so that summer in the northern hemisphere would be in December. Clearly, this system would have great disadvantages.

Julius Caesar made an attempt to put matters right by adopting the convention that three consecutive years have 365 days followed by a *leap year* of 366 days, the extra day being added to February whenever the year number is divisible by 4. On average, his civil year has 365.25 days in it, a fair approximation to the tropical year of 365.2422 days. Indeed, after 100 years the error is less than one day. This is the *Julian calendar* and it worked very well for many centuries until, by 1582, there was again an appreciable discrepancy between the seasons and the date. Pope Gregory then improved on the system by abolishing the days October 5th to October 14th 1582 inclusive so as to bring the civil and tropical years back into line, and by missing out three days every four centuries. In his reformed calendar the years ending in two noughts (e.g. 1700, 1800, etc.) are only leap years if they are divisible by 400.

This system, called the *Gregorian calendar*, is the one in general use today. According to it 400 civil years contain $(400 \times 365) + 100 - 3 = 146\,097$ days, so that the average length of the civil year is $146\,097/400 = 365.2425$ days, a very good approximation indeed to the length of the tropical year.

2 The date of Easter

Easter day, the date to which such moveable feasts as Whitsun and Trinity Sunday are fixed, is usually the first Sunday after the fourteenth day after the first new Moon after March 21st. (For a more precise definition see *The Explanatory Supplement to the Astronomical Ephemeris and American Ephemeris and Nautical Almanac*.) You can find the date of Easter Sunday by the method and tables given, for example, in the *Book of Common Prayer*, 1662, or by one of several methods devised by various mathematicians over the centuries. Here I shall describe a method devised in 1876 which first appeared in *Butcher's Ecclesiastical*

Calendar, and which is valid for all years in the Gregorian calendar, that is from 1583 and onwards. It makes repeated use of the result of dividing one number by another number, the integer part being treated separately from the remainder. A calculator displays the result of such a division as a string of numbers before and after a decimal point. The numbers appearing before the decimal point constitute the integer part; the numbers after the decimal point constitute the fractional part. The remainder may be found from the latter by multiplying it by the divisor (i.e. the number you have just divided by) and rounding the result to the nearest integer value. For example, 2000/19 = 105.263 157 9. The integer part is 105 and the fractional part is 0.263 157 9. Multiplying this by 19 gives 5.000 000 100 so that the remainder is 5.

I shall illustrate the method by calculating the date of Easter Sunday in the year 2000.

Method			*Example*
	Integer part	*Remainder*	
1. Divide the year by 19.	—	a	$\frac{2000}{19} = 105.263\,157\,9$ $a = 5$
2. Divide the year by 100.	b	c	$\frac{2000}{100} = 20.000\,000$ $b = 20$ $c = 0$
3. Divide b by 4.	d	e	$d = 5$ $e = 0$
4. Divide $(b+8)$ by 25.	f	—	$f = 1$
5. Divide $(b-f+1)$ by 3.	g	—	$g = 6$
6. Divide* $(19a+b-d-g+15)$ by 30.	—	h	$(19a+b-d-g+15) = 119$ $h = 29$
7. Divide c by 4.	i	k	$i = 0$ $k = 0$
8. Divide $(32+2e+2i-h-k)$ by 7.	—	l	$(32+2e+2i-h-k) = 3$ $l = 3$
9. Divide $(a+11h+22l)$ by 451.	m	—	$(a+11h+22l) = 390$ $m = 0$
10. Divide $(h+l-7m+114)$ by 31.	n	p	$(h+l-7m+114) = 146$ $n = 4$ $p = 22$
11. Day of the month on which Easter Sunday falls is $p+1$. Month number is n (= 3 for March and = 4 for April).			$p+1 = 23$
∴ Easter Sunday 2000 is			**23rd April**

* $19a$ means 19 multiplied by a ($19 \times 5 = 95$ in this example).

3 Converting the date to the day number

In many astronomical calculations, we need to know the number of days in the year up to a particular date. We shall choose our starting point as 0 hours on January 0th, equivalent to the midnight between December 30th and 31st of the previous year; this may seem rather peculiar at first but as it simplifies the calculations we shall adopt it for our purposes. Midday on January 3rd is expressed as January 3.5 because three and a half days have elapsed since January 0.0. This is illustrated in Figure 1.

Finding the day number from the date is then a simple matter. Proceed as follows:

1. For every month up to, but not including, the month in question add the appropriate number of days according to Table 1. These totals are listed in Table 2*b*.
2. Add the day of the month.

For example, calculate the day number of February 17th.

Day number $= 31 + 17 = 48$.

If you own a programmable calculator, you may be able to use the routine R1 to write a program enabling you to carry out the calculation automatically.

Later on in this book we adopt the date 1990 January 0.0 as the starting point, or epoch, from which to calculate orbital positions. Days elapsed since this epoch at the beginning of each year up to 1999 are tabulated in Table 2*a*. To find the total number of days elapsed since the epoch simply add the appropriate number to the day number calculated in the previous paragraph.

Table 2a. Days to the beginning of the year since epoch 1990 January 0.0

*1980:	−3653	1990:	0
1981:	−3287	1991:	365
1982:	−2922	*1992:	730
1983:	−2557	1993:	1096
*1984:	−2192	1994:	1461
1985:	−1826	1995:	1826
1986:	−1461	*1996:	2191
1987:	−1096	1997:	2557
*1988:	−731	1998:	2922
1989:	−365	1999:	3287

* Denotes a leap year.

Table 2b. Days to the beginning of the month

	Ordinary year	Leap year
January:	0	0
February:	31	31
March:	59	60
April:	90	91
May:	120	121
June:	151	152
July:	181	182
August:	212	213
September:	243	244
October:	273	274
November:	304	305
December:	334	335

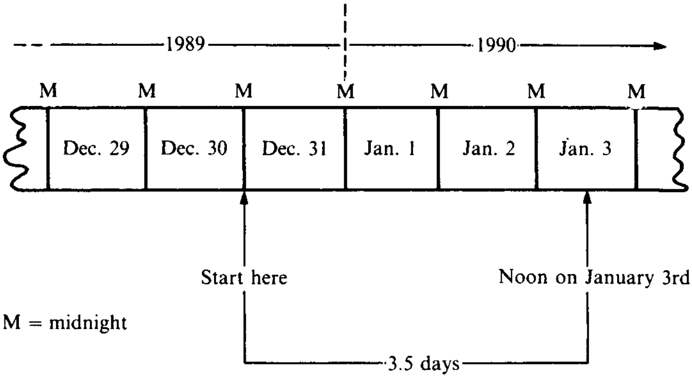
For example, the number of days elapsed since the epoch on February 17th 1985 is 48 − 1826 = −1778.

This calculation may also be done via the Julian day number; see section 4.

Routine R1. Converting the date to the day number.

1. Key in the month number (e.g. 11 for November).
2. Is it greater than 2?
   - If yes, go to step 8.
   - If no, proceed with step 3.
3. Subtract 1 from month number.
4. Multiply by 63 (or 62 in a leap year).
5. Divide by 2.
6. Take the integer part.
7. Go to step 12.
8. Add 1 to month number.
9. Multiply by 30.6.
10. Take the integer part.
11. Subtract 63 (or 62 in a leap year).
12. Add the day of the month. The result is the day number.

Figure 1. Defining the epoch.



4 Julian day numbers

It is sometimes necessary to express an instant of observation as so many days and a fraction of a day after a given fundamental epoch. Astronomers have chosen this fundamental epoch as the Greenwich mean noon of January 1st 4713 B.C., that is midday as measured on the Greenwich meridian on January 1st of that year. The number of days which have elapsed since that time is referred to as the *Julian day number*, or *Julian date*.* It is important to note that each new Julian day begins at 12h 00m UT, half a day out of step with the civil day in time zone 0.

The term 'before Christ', or B.C. for short, usually refers to the chronological system of reckoning negative years. In this system, there is no year zero. The Christian era begins with the year 1 A.D. ('anno domini'); the year immediately preceding it is designated 1 B.C. For astronomical purposes, the year immediately preceding 1 A.D. is designated 0; the other years B.C. are denoted by negative numbers, each of which has an absolute value which is one less than the B.C. value. Thus 10 B.C. corresponds to the (astronomical) year −9, and 4713 B.C. corresponds to −4712. We shall adopt this convention throughout the book. Where you see a B.C. year, subtract one from it and change its sign before using it in any of the calculations. Similarly, if the result of a calculation is a negative year, remove the minus sign, add one to the year number, and append the letters 'B.C.' after it.

The Julian date of any day in the Julian or Gregorian calendars may be found by the method given below. Here, and throughout the book, the expression INT refers to the integer part of the number within the bracket following it. Thus INT(22.456) is 22, and INT(−3.914) is −3. Note that many computers, and some calculators, use INT to refer to the least-integer function, that is the largest integer whose value is less than or equal to the number. Such machines would return −4 for INT(−3.914). Beware! You can avoid this worry by taking INT of the absolute value (positive) and inserting a negative sign before the result for negative numbers.

As an example, we shall calculate the Julian date corresponding to 1985 February 17.25 (i.e. 6 a.m. on February 17th).

Method	*Example*
1. Set y = year, m = month and d = day.	$y = 1985$ $m = 2$ $d = 17.25$
2. If $m = 1$ or 2 subtract 1 from y and add 12 to m. Otherwise $y' = y$ and $m' = m$.	$y' = 1984$ $m' = 14$
3. If the date is later than or equal to 1582 October 15 (i.e. Gregorian calendar) calculate: (i) A = integer part of $(y'/100)$; (ii) $B = 2 - A$ + integer part of $(A/4)$. Otherwise $B = 0$.	$A = \mathrm{INT}(1984/100)$ $= 19$ $B = 2 - 19 + \mathrm{INT}(19/4)$ $= -13$
4. If y' is negative calculate $C = \mathrm{INT}((365.25 \times y') - 0.75)$. Otherwise, $C = \mathrm{INT}(365.25 \times y')$.	$C = \mathrm{INT}(365.25 \times 1984)$ $= 724\,656$
5. Calculate D = integer part of $(30.6001 \times (m' + 1))$..	$D = \mathrm{INT}(30.6001 \times 15)$ $= 459$
6. Find $\mathrm{JD} = B + C + D + d + 1\,720\,994.5$. This is the Julian date.	JD = **2 446 113.75**

The Julian date of the epoch 1990 January 0.0 is 2 447 891.5. We can easily find the number of days which have elapsed since the epoch by subtracting this number from the Julian date.

For example, the number of days elapsed since the epoch to 1985 February 17.0 is 2 446 113.5 − 2 447 891.5 = −1778, as found in the previous section.

* Sometimes the *modified Julian date*, MJD, is quoted. This is equal to JD − 2 400 000.5; MJD zero therefore began at 0h on November 17th 1858.

5 Converting the Julian day number to the calendar date

It is sometimes necessary to convert a given Julian date into its counterpart in the Gregorian calendar. The method shown here works for all dates since January 1st 4713 B.C.* For example, let us find the Gregorian date corresponding to JD = 2 446 113.75.

Method	*Example*
1. Add 0.5 to JD. Set I = integer part and F = fractional part.	JD = 2 446 113.75 +0.5 = 2 446 114.25 I = 2 446 114 F = 0.25
2. If I is larger than 2 299 160, calculate:	
(i) A = integer part of $\left(\frac{I - 1\,867\,216.25}{36\,524.25}\right)$;	A = 15.0
(ii) $B = I + 1 + A$ − integer part of $(A/4)$. Otherwise, set $B = I$.	B = 2 446 127.0
3. Calculate $C = B + 1524$.	C = 2 447 651.0
4. Calculate D = integer part of $\left(\frac{C - 122.1}{365.25}\right)$.	D = 6 700.0
5. Calculate E = integer part of $(365.25 \times D)$.	E = 2 447 175.0
6. Calculate G = integer part of $\left(\frac{C - E}{30.6001}\right)$.	G = 15.0
7. Calculate $d = C - E + F$ − integer part of $(30.6001 \times G)$. This is the day of the month (including the decimal fraction of the day).	d = **17.25**
8. Calculate $m = G - 1$ if G is less than 13.5, or $m = G - 13$ if G is more than 13.5. This is the month number.	m = **2**
9. Calculate $y = D - 4716$ if m is more than 2.5, or $y = D - 4715$ if m is less than 2.5. This is the year.	y = **1985**

Hence the Gregorian date is 1985 February 17.25.

* See section 4 about the meaning of B.C.

6 Finding the day of the week

It is sometimes useful to know on what day of the week a particular date will fall. This can be found very easily once the Julian date has been calculated. Here, we shall find the day of the week corresponding to February 17th 1985.

Method	*Example*
1. Find the Julian day number corresponding to 0h UT on the day in question (§ 4).	1985 February 17.0 JD = 2 446 113.5
2. Calculate $A = \left(\frac{\text{JD} + 1.5}{7}\right)$.	$A = 349\,445.0000$
3. Take the fractional part of A, multiply by 7, and round to the nearest integer.* This is the weekday number, n. The day of the week is then as follows: Sunday, $n = 0$; Monday, $n = 1$; Tuesday, $n = 2$; Wednesday, $n = 3$; Thursday, $n = 4$; Friday, $n = 5$; Saturday, $n = 6$.	Fractional part = 0.0 $n = \mathbf{0}$ **Sunday**

* This may be done by taking the integer part of (fractional part + 0.5).

7 Converting hours, minutes and seconds to decimal hours

Most times are expressed as hours and minutes, or hours, minutes and seconds. For example, twenty to four in the afternoon may be written as 3.40 p.m., or 3h 40m p.m., or on a 24-hour clock as 15h 40m. In calculations, however, the time needs to be expressed in decimal hours on a 24-hour clock. The method of converting a time expressed in the format hours, minutes and seconds into decimal hours is given below. Some calculators have special keys to do this for your automatically.

Method	*Example*
	6h 31m 27s p.m.
1. Take the number of seconds and divide by 60.	27/60 = 0.450 00
2. Add this to the number of minutes and divide by 60.	31.45/60 = 0.524 17 + 6.0
3. Add the result to the number of the hours.	= 6.524 17
4. If the time has been given on a 12-hour clock, and it is p.m., add 12.	+ 12.0 = **18.524 17 hours**

8 Converting decimal hours to hours, minutes and seconds

When the result of a calculation is a time, it is normally expressed as decimal hours, and we need to convert it to hours, minutes and seconds. The method of doing so is given below. Again, some calculators have special keys to carry out this function automatically.

Method	*Example*
	18.524 17 hours
1. Take the fractional part and multiply by 60. The integer part of the result is the number of minutes.	0.524 17 × 60 = **31**.4502
2. Take the fractional part of the result and multiply by 60. This gives the number of seconds.	0.4502 × 60 = **27**.012
	18h 31m 27s

9 Converting the local time to UT

The basis of civilian time-keeping is the rotation of the Earth. Universal time (UT) is related to the motion of the Sun as observed on the Greenwich meridian, longitude 0°. The Earth is not a perfect time keeper, however, and today a more uniform flow of time is available from atomic clocks. International atomic time (TAI) is the scale resulting from analyses by the Bureau International de l'Heure in Paris of atomic standards in many countries. A version of universal time, called coordinated universal time (UTC), is derived from TAI in such a manner as to be within 0.9 seconds of UT and a whole number of seconds different from TAI. (On July 1st 1985 TAI-UTC = 23 s). This is achieved by including occasional leap seconds in UTC, usually at the ends of June and December. UTC is the time broadcast by some national radio stations (the 'time pips') and by standard time transmission services such as MSF and WWV. It is now the basis of legal time keeping on the Earth. UTC is thus an atomic time standard (and hence as uniform as we know how to measure) but with discontinuities to keep it in line with the irregular rotation of our planet.

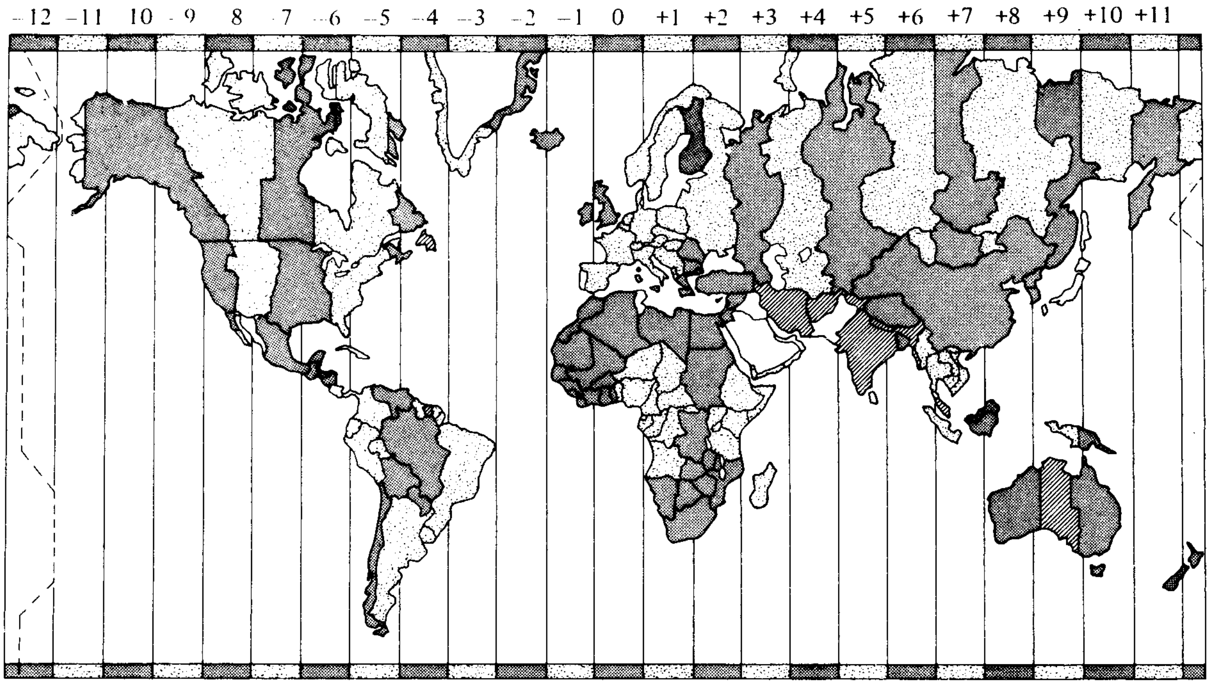
The amateur astronomer need not be too concerned by all this complexity. For our purposes, we can take UT = UTC = GMT without noticing the difference. Where we need greater accuracy, we will use terrestrial dynamic time (TDT) for events after 1984 January 0.0, and Ephemeris time (ET) before then. TDT is equal to TAI + 32.184 seconds and took over from ET at the beginning of 1984 (see section 16).

UT is used as the local civil time in Britain during the winter months, but one hour is added during the summer to form British summer time (BST) so that the working day fits more conveniently into daylight hours. Many other countries adopt a similar arrangement; sometimes the converted time is known as daylight saving time.

Countries lying on meridians east or west of Greenwich do not use UT as their local civil time. It would be impractical to do so as the local noon, the time at which the Sun reaches its maximum altitude, gets earlier or later with respect to the local noon on the Greenwich meridian as one moves east or west respectively. The world is therefore divided into time zones, each zone usually corresponding to a whole number of hours before or after UT, and small countries, or parts of large countries lying withing a zone, adopt the zone time as their local civil time (see Figure 2). It is often convenient in making astronomical calculations to use UT, and the local civil time may be converted into UT in the following manner. For an example we convert daylight saving time 3h 37m on longitude 64° E (zone +4 hours) to UT.

Method	*Example*
1. Convert local civil time to zone time if necessary to correct for daylight saving. Convert to decimal hours (§ 7).	03h 37 m − 01h 00m = 02h 37m Zone time = 2.616 667 hours
2. Subtract the zone correction.	− 4.00
3. If the answer is greater than 24, subtract 24. If the answer is negative, add 24. Convert back to hours, minutes and seconds (§ 8).	= − 1.383 333 hours + 24.00 = 22.616 667 UT = **22h 37m**

Figure 2. International time zones. This small-scale map can show only the general distribution of time zones around the world. If you are unsure of your own zone correction, you can check it by tuning your short-wave radio to the BBC World Service and comparing your watch with the time pips broadcast every hour from London.



10 Converting UT to local civil time

Given the time as UT, what is the corresponding local civil time? For example, what is the local civil time on longitude 64° E (zone +4 hours) during daylight saving when the UT is 22h 37m?

Method	*Example*
1. Convert UT to decimal hours (§ 7).	22h 37m
	= 22.616 667 hours
2. Add the zone correction.	+ 4.00
If the answer is greater than 24, subtract 24.	= 26.616 667 hours
If the answer is negative, add 24.	− 24.00
	= 2.616 667
3. Convert to hours, minutes and seconds (§ 8) and	= 2h 37m
correct for daylight saving (if necessary).	+ 1h 00m
This is the local civil time.	= **3h 37m**

11 Sidereal time (ST)

Universal time (UT), and therefore the local civil time in any part of the world, is related to the motion of the Sun. Roughly speaking, we may take one solar day as the time between two successive passages of the Sun across the meridian as observed at a particular place. Astronomers are interested, however, in the motion of the stars; in particular they need to use a clock whose rate is such that any star is observed to return to the same position in the sky after exactly 24 hours have elapsed according to the clock. Such a clock is called a sidereal clock and its time, being regulated by the stars, is called sidereal time (ST). Solar time, of which UT is an example, is not the same as sidereal time because during the course of one solar day the Earth moves nearly one degree along its orbit round the Sun. Hence, the Sun appears progressively displaced against the background of stars when viewed from the Earth; turning that around, the stars appear to move with respect to the Sun. Any clock, therefore, which keeps time by the Sun does not do so by the stars.

There are about 365¼ solar days in the year,* the time taken by the Sun to return to the same position with respect to the background of stars. During this period, the Earth makes about 366¼ revolutions abouts its own axis; there are therefore this many sidereal days in the year. Each sidereal day is thus slightly shorter than the solar day, 24 hours of sidereal time corresponding to 23h 56m of solar time. Universal time and Greenwich sidereal time agree at one instant every year at the autumnal equinox (around September 22nd). Thereafter, the difference between them grows in the sense that ST runs faster than UT, until exactly half a year later it is 12 hours. After one year, the times again agree.

The formal definition of sidereal time is that it is the hour-angle of the vernal equinox (see section 18).

* See the definition of year in the Glossary.

12 Conversion of UT to GST

This section describes a simple procedure by which the universal time may be converted into Greenwich mean sidereal time (GST). It is accurate to better than one tenth of a second. It is slightly different from the method given in previous editions of this book; in particular, the calculation of 'constant B' is now incorporated into the procedure.

For example, what was the GST at 14h 36m 51.67s UT on April 22nd 1980?

Method	*Example*
1. Find the Julian date corresponding to 0h on this calendar date (§ 4).	JD = 2 444 351.5
2. Calculate $S = \text{JD} - 2\,451\,545.0$	$S =$ −7 193.5
3. Calculate $T = S/36\,525.0$	$T =$ − 0.196 947
4. Find $\text{T0} = 6.697\,374\,558$	T0 = − 465.986 246
$+ (2\,400.051\,336 \times T)$	
$+ (0.000\,025\,862 \times T^2)$.	+ 24 × 20
Reduce the result to the range 0–24 by adding or subtracting multiples of 24.	T0 = 14.013 754
5. Convert UT to decimal hours (§ 7).	UT = 14.614 353
6. Multiply UT by 1.002 737 909.	× 1.002 737 909
	= 14.654 366
7. Add this to T0 and reduce to the range 0–24 if necessary by subtracting or adding 24.	+ 14.013 754
This is the GST.	GST = 4.668 119
8. Convert the result to hours, minutes and seconds (§ 8).	GST = **4h 40m 5.23s**

13 Conversion of GST to UT

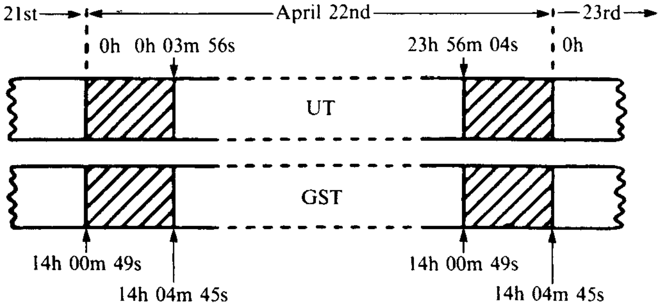
Here we deal with the reverse problem of the previous section, namely that of converting a given Greenwich mean sidereal time into the corresponding universal time. The problem is complicated, however, by the fact that the sidereal day is slightly shorter than the solar day so that on any given date a small range of sidereal times occurs twice. This range is about 4 minutes long, the sidereal times corresponding to UT 0h to 0h 4m occurring again from UT 23h 56m to midnight (see Figure 3). The method given here correctly converts sidereal times in the former interval, but not in the latter.

The accuracy of this method is the same as that of section 12, namely better than one tenth of a second. It replaces the slightly longer procedure given in previous editions of this book.

For example, at GST = 4h 40m 5.23s on April 22nd 1980, what was the UT?

Method	*Example*
1. Find the Julian date corresponding to 0h on this calendar date (§ 4).	JD = 2 444 351.5
2. Calculate $S = \text{JD} - 2\,451\,545.0$	$S =$ −7 193.5
3. Calculate $T = S/36\,525.0$	$T =$ − 0.196 947
4. Find $\text{T0} = 6.697\,374\,558 + (2\,400.051\,336 \times T) + (0.000\,025\,862 \times T^2)$.	T0 = − 465.986 246
	+ 24 × 20
Reduce the result to the range 0–24 by adding or subtracting multiples of 24.	T0 = 14.013 754
5. Convert GST to decimal hours (§ 7).	GST = 4.668 119
6. Subtract T0 and reduce to the range 0–24 if necessary by subtracting or adding 24.	− 14.013 754
	= 14.654 366
7. Multiply by 0.997 269 566 3.	× 0.997 269 566 3
The result is the UT.	UT = 14.614 353
8. Convert the result to hours, minutes and seconds (§ 8).	UT = **14h 36m 51.67s**

Figure 3. UT and GST for April 22nd 1980. The shaded intervals of GST occur twice on the same day.



14 Local sidereal time (LST)

The Greenwich sidereal time discussed in the previous sections is the sidereal time correct for observations made on the Greenwich meridian, longitude 0°. It is the local sidereal time for the Greenwich meridian. As you move west or east from longitude 0°, however, the local sidereal time gets earlier or later respectively because the hour-angle of the vernal equinox, which defines the local sidereal time, changes. You can calculate your local sidereal time, given the Greenwich sidereal time, very easily as the difference between the two times in hours is simply the geographical longitude in degrees divided by 15. Longitudes west give local sidereal times earlier than GST and longitudes east later. Take the example: what is the local sidereal time on the longitude 64° W when the Greenwich sidereal time is 4h 40m 5.23s.

Method	*Example*
1. Convert GST to decimal hours (§ 7).	GST = 4.668 119 hours
2. Convert longitude difference in degrees to difference in time by dividing by 15.	64° = 4.266 667 hours
3. If the longitude is W, subtract. If the longitude is E, add. If the result is greater than 24, subtract 24. If the result is negative, add 24. This is the LST in hours.	LST = 0.401 453 hours
4. Convert LST to hours, minutes and seconds (§ 8).	LST = **0h 24m 5.23s**

15 Converting LST to GST

This problem is the reverse of that treated in section 14, namely given the local sidereal time at a particular place what is the corresponding Greenwich sidereal time. As an example, we shall calculate the GST when the LST on longitude 64° W is 0h 24m 5.23s.

Method	*Example*
1. Convert the LST to decimal hours (§ 7).	LST = 0.401 453 hours
2. Convert the longitude difference in degrees to difference in time by dividing by 15.	64° = 4.266 667 hours
3. If the longitude is W, add. If the longitude is E, subtract. If the result is greater than 24, subtract 24. If the result is negative, add 24. This is the GST in hours.	GST = 4.668 119 hours
4. Convert GST to hours, minutes and seconds (§ 8).	GST = **4h 40m 5.23s**

16 Ephemeris time (ET) and terrestrial dynamic time (TDT)

Universal and sidereal time are both tied directly to the period of the rotation of the Earth about its polar axis. The Earth is being used in effect as the balance-wheel of a cosmic clock whose tick defines the length of the day. With the advent of extremely accurate atomic clocks, however, it has become apparent that the Earth's rotation is not strictly uniform but shows small erratic fluctuations which are not well understood. UT and ST, being reckoned by this irregular cosmic clock, are therefore not strictly uniform either. Astronomers need a system of time which *is* uniform since the theories of celestial mechanics assume that such a quantity exists. For example, two solid bodies in orbit about one another far away from any external influences should have an unchanging orbital period when measured on a regular clock. Before 1984, astronomers adopted *ephemeris time* (ET) for this purpose. It was calculated from the motion of the Moon and assumed to be uniform. Nowadays, atomic clocks provide the most uniform measure of time, and since 1984 *terrestrial dynamic time* (TDT) has been used instead. TDT is tied to the atomic time scale, TAI (see section 9), by the equation:

$$\text{TDT} = \text{TAI} + 32.184\,\text{s}.$$

The constant offset of 32.184 seconds was chosen to make TDT equal to ET at the beginning of 1984. ET itself was chosen to agree as nearly as possible with the measure of universal time during the nineteenth century, and it is unlikely that TDT will differ by more than a few minutes in the twentieth.

The primary unit of ET was the length of the tropical year at 1900 January 0.5 ET which contained 31 556 925.974 7 ephemeris seconds. The primary unit of TAI, and hence TDT, is the SI second, defined to be the duration of 9 192 631 770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the caesium 133 atom. We need not be too concerned by all this since very high accuracy is not the aim of the book. In almost every case we can take ET = TDT = UT without noticing the difference. Only when calculating the motion of the Moon, and predicting eclipses, will it pay us to take account of the difference between ET/TDT and UT. In January 1986 this was 54.87 seconds, UT being behind TDT; that is $\text{TDT} - \text{UT} = \Delta\text{T} = 54.87$ seconds.

Figure 4 shows how ΔT has varied since 1620; we can predict that its value in the year 2000 might be between 60 and 70 seconds, but only direct observations at that time will confirm this. Recently, pulsars with very stable rates of spin have been discovered which appear to be even more precise than our best atomic clocks. TAI may well lose its place as the fundamental measure of time during the next century, and be replaced by another scale based on the pulsars – GBT perhaps (galactic barycentric time).

Figure 4. The variation of ΔT since 1620.