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Total solar eclipses of long duration in the British Isles

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An attempt is made to determine the longest possible duration for a total solar eclipse in the British Isles and to compare this with actual long eclipses.

Introduction

The greatest duration for a total eclipse of the Sun is 7 minutes. Eclipses approaching this length occur infrequently and are visible only from equatorial regions. In the British Isles totality can exceed five minutes, although none has done so during historical times.

Conditions necessary for the greatest duration of totality

Five geometrical considerations which influence the duration of a total solar eclipse were described by Simon Newcomb.[1] In approximate order of importance, these may be summarised as follows:

1. The Moon must be at perigee. The closer the Moon is to the Earth, the larger its apparent angular diameter and the greater the width of the umbral cone.
2. The Sun must be at apogee. The further the Earth is from the Sun, the smaller the Sun's apparent angular diameter and the greater the width of the umbral cone.
3. The Moon and the Sun must be in the observer's zenith. As the lunar shadow is conical its diameter increases as one approaches the Moon. Therefore the observer should be as close to the Moon as possible, it should be noon and the eclipse should be perfectly central.
4. The observer must be on the equator. With conditions 1 and 2 being satisfied, the shadow is moving at 62 km/min eastward, relative to the Earth's centre. At the equator, the diurnal rotation is approximately 28 km/min eastward, decreasing with the cosine of the latitude. To obtain the largest reduction in the relative speed of the lunar shadow, the rotational velocity of the observer should be as great as possible. This is achieved most effectively at latitude 0°.
5. The direction of the observer's motion must be parallel to that of the Moon's shadow. As the motion of the shadow is always within 6° of being parallel to the ecliptic, the observer's diurnal velocity should also lie close to the ecliptic.

Table 1. Maximum duration for a total solar eclipse at different latitudes

Latitude °N	*Duration* m s
70	4 36
60	5 09
50	5 45
40	6 19
30	6 50

Unfortunately due to the obliquity of the ecliptic (currently about 23½°), it is not possible to fulfil all the conditions simultaneously. For instance, if the eclipse is exactly central, condition 4 implies that the Sun is on the equator which occurs only at the equinoxes, while condition 5 is satisfied only at the solstices. Further, while condition 3 would be satisfied by an eclipse which is exactly central, condition 4 would be affected adversely because at the summer solstice the Sun and the Moon would be in the zenith of an observer in latitude 23½° north. But to satisfy condition 4, the Sun and the Moon would be 23½° from the zenith, thereby reducing the width of the shadow. From the British Isles, conditions 3 and 4 can never be satisfied since the Sun's altitude cannot be greater than 63° and the observer's latitude cannot be less than 50°.

However, the longitude of the solar apogee is a slowly varying function of time. It is sensibly constant at any particular epoch and currently it is 103°. Therefore, it is possible to fulfil conditions 1, 2 and 5 concurrently, and the conclusion is that the longest eclipses occur around the time of the summer solstice in late June and the solar apogee in early July, with the Moon being at perigee.

Greatest possible duration of totality

In a paper presented to the American Astronomical Society in Ottawa in 1929,[2] Isabel M. Lewis calculated the upper limit of totality to be 7m 31s, while Charles Smiley and Mary Quirk[3] listed actual eclipses having very long durations of totality.

A most comprehensive investigation into the occurrence of total solar eclipses with long durations of totality was made by Edward S. Light. In his excellent paper,[4] Dr Light examines eclipses having at least 7 minutes' totality occurring during the eight thousand years between –3000 and 5000. He concludes that, at the present epoch, the maxi-

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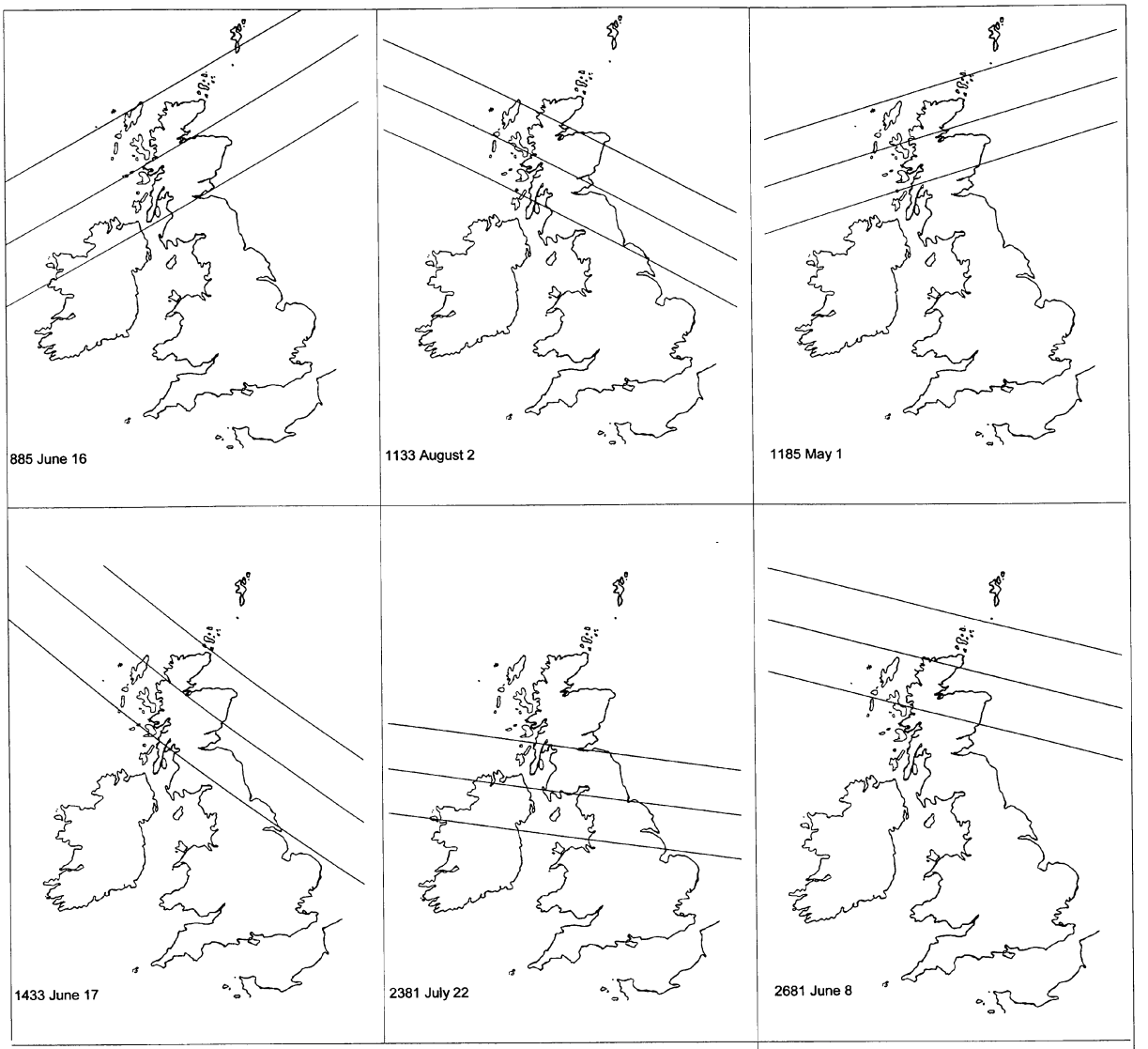

Figure 1. Tracks of the total eclipses discussed in this article.

Table 2. Long total solar eclipses in the British Isles, 1–3000

	UT *h m*	*Duration* *m s*	*Area of visibility*
2726 July 21	11 00	5 30	southwestern England
2381 July 22	10 22	5 08	Northern Ireland, southern Scotland and northern England
885 June 16	09 45	4 52	northwestern Ireland and most of Scotland
2681 June 8	13 43	4 49	northern Scotland
1185 May 1	13 55	4 46	northern Scotland
1433 June 17	15 08	4 27	most of Scotland and northeastern England
1133 August 2	11 21	4 22	most of Scotland and northeastern England

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mum possible duration of totality is 7m 31s. This occurs around the early part of July when the Sun is near apogee, the Moon is at perigee and near its ascending node and the observer is near apparent noon at latitude 5°N, which agrees well with Lewis.[2] He also concludes that the eclipse which most closely approaches the theoretically optimum conditions occurs on 2186 July 16 with a duration of 7m 29s, which agrees well with Smiley & Quirk[3] and with Mucke & Meeus.[5]

It is unfortunate that this great duration of totality occurs in the Atlantic Ocean around longitude 46°W latitude 7°N.

Greatest duration of totality in the British Isles

In a previous paper,[6] I investigated total eclipses having durations of more than four minutes in the British Isles during the period from 1 to 2500, using the Besselian elements given by Hermann Mucke and Jean Meeus.[5] I thought it would be worthwhile to determine the greatest possible duration for these islands and to extend the data for another five hundred years.

The eclipse in 2186 comes so very close to the maximum duration that calculations were made from the elements for other latitudes. The results, which I believe provide a fair indication, are given in Table 1. From this it appears that an eclipse of more than 5 minutes' totality may occur over any part of the British Isles, while the longest duration of approximately 5m 45s could be reached only in southern Cornwall.

Actual long eclipses in the British Isles

For the period beyond 2500, a program was written which calculates the approximate Besselian elements of solar eclipses. Two were identified as having long durations and accurate elements were kindly provided by Jean Meeus.[7] These two are included in Table 2 which lists long eclipses taking place between the years 1 and 3000. Throughout this paper, dates before 1583 are expressed in the Julian calendar. Rather than include eclipses having durations of about 4 minutes which appeared in my earlier paper,[6] totalities are confined to those of well over 4 minutes. The instant and duration of greatest eclipse are given, together with the area of visibility. The results agree closely with those obtained by Sheridan Williams who has undertaken an extensive review[8] of all total and annular solar eclipses visible from the British Isles during the same period.

Conveniently, the entries fall into three divisions – those with totalities greater than 5, 4½ and 4 minutes. It will be seen that two eclipses attain durations of more than 5 minutes, and that they both occur in the future. The eclipse of 2381 July 22 will be total for a little over 5 minutes across southern Scotland and northern England. The central line runs from the eastern tip of County Antrim and passes near

Table 3. Curves of central eclipse

	UT	*Long.*	*Lat.*	*Duration*	*Alt. of Sun*	*Width of track*
	h m	° ′	° ′	*m s*	°	*km*
885 Jun 16	09 35	+10 50	54 54	4 42	43	328
	09 40	+07 15	56 19	4 47	45	327
	09 45	+03 33	57 37	4 52	47	326
	09 50	−00 16	58 48	4 55	48	325
	09 55	−04 14	59 52	4 58	49	324
1133 Aug 2	11 10	+12 43	58 45	4 11	43	238
	11 15	+08 00	57 44	4 16	46	240
	11 20	+03 47	56 36	4 22	48	241
	11 25	00 00	55 25	4 26	50	243
	11 30	−03 26	54 09	4 30	52	244
1185 May 1	13 50	+11 33	56 09	4 52	49	268
	13 55	+07 17	57 08	4 46	47	266
	14 00	+02 33	58 00	4 40	44	265
	14 05	−02 43	58 43	4 32	41	264
1433 Jun 17	15 00	+12 16	60 19	4 33	47	311
	15 05	+08 25	59 02	4 30	46	313
	15 10	+04 42	57 39	4 26	44	314
	15 15	+01 08	56 09	4 22	43	315
	15 20	−02 21	54 33	4 16	41	316
2381 Jul 22	10 10	+12 03	55 10	4 50	43	272
	10 15	+07 14	55 02	4 58	46	274
	10 20	+02 44	54 43	5 06	49	275
	10 25	−01 27	54 16	5 12	51	276
	10 30	−05 21	53 41	5 17	53	277
2681 Jun 8	13 35	+11 31	59 13	4 53	53	293
	13 40	+07 21	58 49	4 51	52	293
	13 45	+03 14	58 18	4 49	51	294
	13 50	−00 50	57 40	4 46	50	294
	13 55	−04 52	56 53	4 42	48	294
2726 Jul 21	10 55	+08 45	49 59	5 24	53	285
	11 00	+05 20	50 09	5 29	55	285
	11 05	+02 01	50 13	5 34	57	285
	11 10	−01 14	50 11	5 37	58	286

Stranraer, Penrith and Middlesbrough. Across Antrim totality should touch 5 minutes, but the maximum duration of 5m08s will be obtained along the Yorkshire coast, not far from Whitby. The path of the eclipse is approximately 275km in width so that Glasgow and Edinburgh will just be included within the northern limit, while the southern limit will take in Manchester and Sheffield.

On 2726 July 21 all records will be broken when the Moon and the Sun conspire to produce an eclipse of such outstanding proportions that totality will be visible for 5 minutes in southwestern England. The central line crosses southern Cornwall passing close to Penzance and Falmouth, where totality lasts for 5m30s. The width of the path is approximately 285km; the northern limit includes Bristol but just misses London, while the southern limit passes to the south of the mainland but includes the Channel Isles.

The longest eclipse to date occurred on 885 June 16 and was total for a little less than 5 minutes over northern Scotland. Most of Scotland fell within the Moon's shadow, but the full splendour of totality was visible across the Highlands – the central line passing close to Inverness, where totality lasted 4m52s. The path was approximately 325km wide, taking in the Outer Hebrides to the north and Glasgow to the south. This eclipse ranks as the finest ever to be seen from these islands, and we know that it was since mention of it is made in the *Chronicon Scotorum*: 'An

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Table 4. Some members of a 300-year series

	UT	*Gamma*	*Saros*	*Type*	*Mag or dur.*	*Remarks*
	h m				*m s*	
1826 Nov 29	11 14	+1.1764	149	p	0.68	visible in the British Isles
2126 Oct 16	09 07	+0.8347	155	t	4 00	total in Scandinavia and the Russian Federation, partial in the British Isles
2426 Sep 2	09 27	+0.6137	161	t	5 15	total in the British Isles, northern and eastern Europe
2726 Jul 21	11 31	+0.4813	167	t	5 43	total in the British Isles, central and eastern Europe

eclipse of the Sun; and stars were seen in the heavens.' What a wonderful sight it must have been.

Two other eclipses, those of 1185 May 1 and 2681 June 8 have durations approaching 5 minutes across northern Scotland.

Two great eclipses from mediaeval times were total for almost 4 minutes across Scotland. The eclipse of 1133 August 2 was recorded in the *Anglo-Saxon Chronicle*: 'In this year went the King Henry over sea at Lammas, and the next day, as he lay asleep on ship, the day darkened over all lands and the Sun was all, as it were, a three-night old Moon, and the stars about him at midday. Men said a great event would come, and the same year was the king dead, the day after St. Andrew's mass-day in Normandy.' The entry is made under 1135. Henry I died in that year, but the date of the eclipse had become confused since it took place two years earlier.

The eclipse of 1433 June 17 was the last to be total from the British Isles during the middle ages. Totality arrived shortly after 3 o'clock and for generations afterwards this time was referred to as the 'black hour'.

Curves of central eclipse are given in Table 3. The position of the central line is shown at intervals of 5 minutes, together with the duration of totality, the Sun's altitude and the width of the track. Western longitudes are reckoned positively while the latitudes are obviously northern. The widths of the tracks are measured perpendicular to the direction of the shadow. The tracks of the eclipses are illustrated in Figure 1. It will be noted that the central line of each eclipse crosses the mainland. As the eclipses occur over a period of many centuries, unpredictable variations in the rotation of the Earth introduce an uncertainty of some minutes in the circumstances of distant events. Accurate calculations can be made in the uniform time system known as Dynamical Time (TD), which is not dependent on the rotation of the Earth. As soon as this is converted to Universal Time (UT), or any civil time, the results are subject to irregular fluctuations in the Earth's rotation. The difference ΔT (TD–UT) can be determined purely by observation; consequently for ancient and future years, as the fluctuations are unknown, only an approximate value can be given. Any revision in the value of ΔT will shift the predicted longitude of the track. If the value of ΔT turns out to be more than estimated, the track will be shifted eastward and the eclipse take place earlier than predicted; conversely, if the value is less than estimated, the track will be shifted westward and the eclipse take place later than predicted. Where the track extends virtually from west to east, as in 2726, a shift in longitude is not critical as the area of visibility would remain unaltered, but where the track falls obliquely the effect could be more significant, with locations close to the northern and southern limits being included in or excluded from the total track, according to the shift.

Frequency and distribution

During the three thousand years investigated, seven eclipses may be considered to have long durations. Of these, two exceed 5 minutes, three almost attain 5 minutes and two approach 4 minutes. Their occurrence is far from regular, intervals between such eclipses ranging from 45 years (2681 and 2726) to 948 years (1433 and 2381). There is no example before the ninth century, while the twelfth century has two (1133 and 1185). Not surprisingly, the eclipses take place during the summer months, within about six weeks of the solstice.

An inspection of the entries will reveal three 'pairs' of eclipses separated by an interval of 300 years: 885 and 1185, 1133 and 1433, 2381 and 2681. This is no coincidence. A period of 3709 synodic months or lunations equals not only 3975 anomalistic months (apse to apse) but also 4025 draconic months (node to node) to within less than half a day. This interval amounts to 109,529 days, or a little less than 300 years. Consequently, after such a time, a large eclipse at a given place is likely to be followed by another of a similar character. The second eclipse takes place about six weeks earlier in the year and within a few hours of the day. Table 4 lists the members of a series from its inception until the end of the period under review. For each entry is given the instant of greatest eclipse for the Earth generally. The value of gamma is the least distance of the axis of the lunar shadow to the centre of the Earth, which is positive or negative according to whether the axis passes north or south of the Earth's centre; the saros number; the type of eclipse (p = partial, t = total) and the greatest magnitude or duration for the Earth generally together with some remarks concerning the visibility. Each is visible, to some extent, from the British Isles.

Eclipses with odd saros numbers occur at the Moon's ascending node, while those with even saros numbers take place at the Moon's descending node. The system of saros numbering was introduced in 1955 by Professor van den Bergh,[9] and for each successive member of a 300-year

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series the saros number increases by 6. As with the saros, in the 300-year series eclipses taking place at the Moon's ascending node move progressively to the south (gamma decreasing), while those occurring at the Moon's descending node move progressively to the north (gamma increasing). Unlike the saros, where the reverse is the case, in the 300-year series there is a smaller change in the value of gamma between each eclipse when the Earth is near aphelion than when it is near perihelion. As a result we may expect a series to hold for perhaps three or even four large returns during the summer when the longest total eclipses can occur.

In the present example the eclipses take place at the Moon's ascending node, therefore the series is moving to the south. The eclipse in 2426 will be total across central Scotland for nearly 4 minutes, while as we have seen already, that in 2726 will be total in southwestern England for 5 minutes. This great eclipse will be followed by the long eclipse of 3026 June 7, total for 5 minutes in France and visible as a large partial eclipse in the British Isles. Other eclipses also provide good evidence of the 300-year series, those not already noted as total in the British Isles being visible as very large partial eclipses: 585 August 1, 885 June 16, 1185 May 1 and 1485 March 16; 1133 August 2, 1433 June 17 and 1733 May 13; 2081 September 3, 2381 July 22 and 2681 June 8.

The period of 109,529 days is a multiple of 7, therefore it follows that eclipses belonging to one 300-year series occur on the same weekday. As the long eclipses belong to four such series, we might expect them to be distributed evenly, but a curiosity is that they all take place on the same day of the week – Wednesday. As far as I can tell, this is no more than coincidental.

Conclusions

It appears that a duration of totality of about 5m45s could be obtained in the extreme southwest of England. In the period under consideration, two eclipses, those in 2381 and 2726 exceed 5 minutes and must be considered remarkable. Of these, the eclipse on 2726 July 21 will be total for about 5m30s – not far short of the maximum possible. It is unlikely to be rivalled for a very long time.

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