

A Guide To Make a Human Orrery

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Introduction

This guide provides a step-by-step description of how to make a simple, but precise Human Orrery. This will enable predictions to be made about the positions of planets at a certain date and time. The main aims of this Human Orrery are to show the elliptical orbit for each planet around the Sun, and using a time-step of 16 days to show the positions of the planets at different dates. Each ellipse is marked out using the string and pin method; that is using a circular template with the Sun at the centre and with a pre-drilled hole to represent the second focus of the elliptical orbit for each planet. The Sun and the pre-drilled holes create the two focus points required for each planet's orbit and allow an ellipse to be drawn by looping a string of length L , found in Table 1, around the two focus points (or pins), and a piece of chalk to draw the ellipse.

Method

The basic template will be 1.2m in diameter, and can be made from wood or a perspex plastic. This can be used both as a large protractor and as a means to define the orientation of each planetary ellipse. Having chalked out the shape of each object's orbit, then paint can be used to identify the location of the planets at certain dates. To make this orrery, a tape-measure, large protractor, string, chalk and paint will be needed to map out the ellipses.

The comets' orbits and that of Saturn will be drawn using pins beyond the main template, since their orbits are too large to draw using the template. A table of the points for Halley, Encke, Phaethon and Tempel-Tuttle is given to provide points to draw their respective orbits. The orbits are placed in order from the Sun and with regular intervals to determine dates and to make predictions of where the planets will be at a particular date. This can be done by dividing the number of time-steps or multiples of 16 days from the start-date of the orrery by the number of points in each planetary orbit to leave a remainder. This remainder will give the location of the planet at that date.

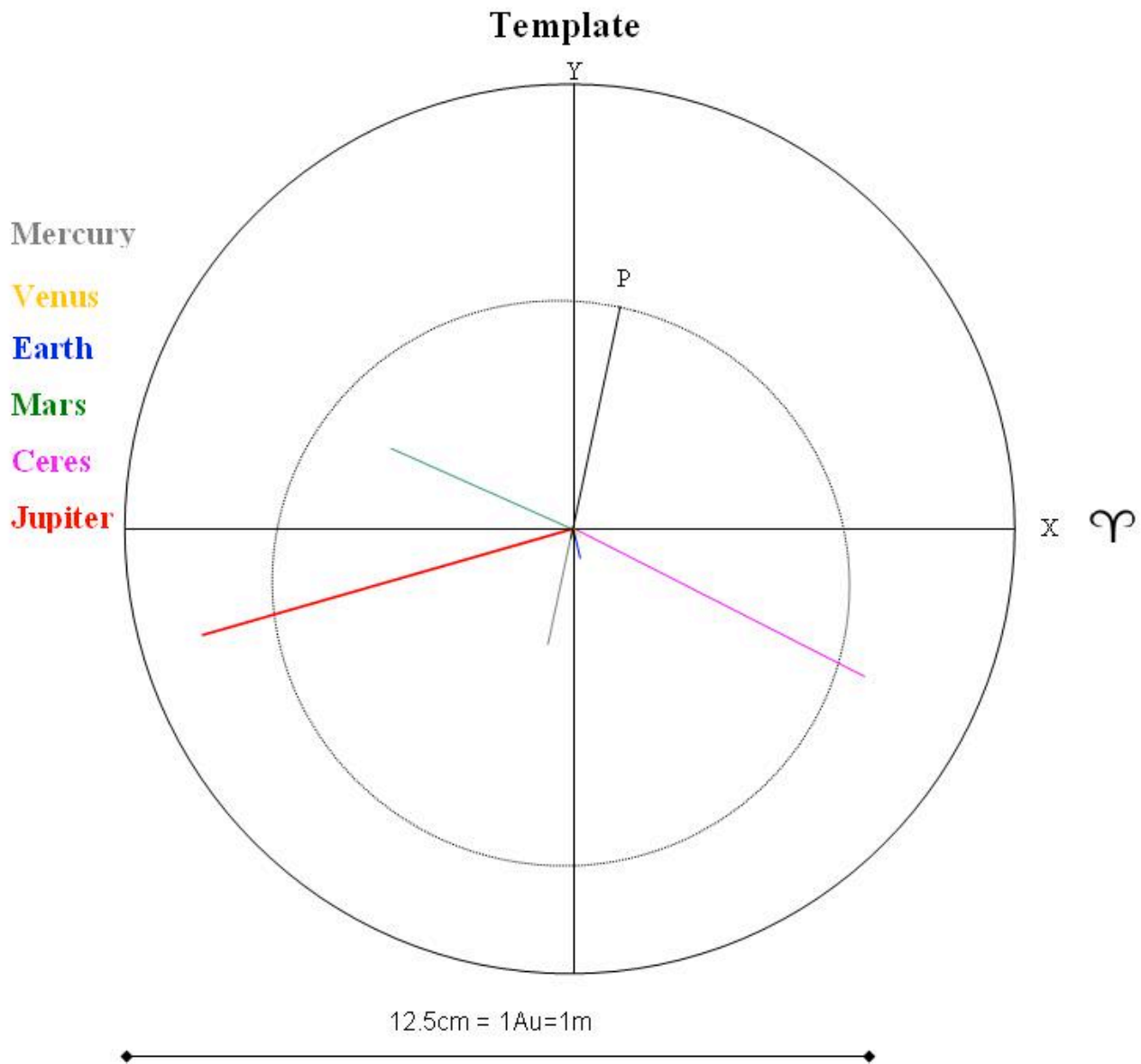
Table 1.

The string and pin method for drawing the ellipses for the planets and other objects shown on the Human Orrery. The Sun is located at the centre of the model and represents a common focus for every object. The scale of the model is such that 1m on the ground represents 1AU in space.

Object	Length of string, S (m)	Distance between foci, 2ae (m)	Direction of the second focus in heliocentric elliptic co-ordinates, measured from the first point of Aries (degrees)
Mercury	0.93	0.159	257.3
Venus	1.46	0.010	311.6
Earth	2.03	0.033	282.9
Mars	3.33	0.285	156.1
(1) Ceres	5.97	0.442	333.4
Jupiter	10.91	0.503	194.7
Saturn	20.10	1.027	272.6
1P/Halley	70.59	34.71	126.0
2P/Encke	8.19	3.76	341.1
55P/Tempel-Tuttle	39.40	18.72	242.4
(3200) Phaethon	4.81	2.26	49.5

The Template

When designing the template for drawing these orbits, a few design constraints were noticed. The template must be small enough and light enough to make it portable and accessible for various places. The template must be large enough to hold the two focus points for most of the objects. Pre-drilled holes must be a feature of the template so that they can be easily located on the ground without the need to calculate angles and distances from the centre. The template will have the Sun at the centre as a focus for all objects, with another hole for each object's second focus. If, as suggested, it is chosen to be large enough to encompass the two foci of Jupiter's orbit, it may also be convenient to provide pre-drilled holes for the eleven points that together define two revolutions of Mercury's orbit.



Curriculum

The Human Orrery, a dynamic model of the Solar System in which people play the role of the moving planets, can be used to encourage children to have a better understanding of the Solar System at Key Stages 1 and 2. At these stages, children learn basic details about the Solar System. The model can be aligned to the curriculum, for example, where children learn about number ratios and multiplications of ten. This is useful when working with powers of ten in the model, and can provide an understanding of the scale of the Solar System. Children in Key Stages 1 and 2 also learn how to divide leaving a remainder, and this is useful when working out the dates in each division of the planetary orbit which will give the position of the planet at the desired date. In these stages of development, children are encouraged to imagine a real-life situation, where they have a problem to solve based on a given situation. The model of the Human Orrery will allow children to imagine the proportion and size of the Solar System showing them the elliptical orbits in a simplified model. The Human Orrery, will enable children to use their knowledge of estimations and help them to solve a real-life problem to predict the positions of the planets at any given time.

Conclusion

This guide is designed to simplify the complications of making a Human Orrery by providing the basic astronomical information and describing equipment needed accurately to lay out the planetary orbit. The Human Orrery is designed to show the positions, orbits and relative distances of the planets around the Sun. This project allows anyone to make a Human Orrery. A key feature of the model is that it develops understanding of the motion of celestial bodies around the Sun and the Earth's changing position in space.

Acknowledgements

This project was done as part of our work-experience during the dates 27th June 2011 and 1st July 2011. We would like to thank the Armagh Observatory for their facilities, help and enthusiasm. We especially appreciate the help of Professor Mark Bailey who guided us through our project and gave us an insight into the aspects of an Astronomer's career. We would also like to thank our schools for their support in setting up work-experience at the Armagh Observatory.

Appendix:

These tables show the orbital periods, distances from the Sun and angles from the first point of Aries, for various objects shown on the Human Orrery at various times. The distance, r , and heliocentric ecliptic longitude, L , can be used to make the planetary positions at the given time.

JD	Tile No.	Year	Month	Day	L	r	f	Separation (cm)	DD	MM	ss	(metres)	Degrees	DD	MM	ss	
Mars																	
43 Tiles at 16-day intervals.																	
True period (days):					686.980												
Add a step (one tile) every 16 revolutions																	
JD	Tile No.	Year	Month	Day	L	r	f	Separation (cm)	DD	MM	ss	(metres)	Degrees	DD	MM	ss	L-f
2453371.5	0	2005	1	1	222.507	1.569	246.369	21.8	222	30	25	1.569	137.493	137	29	35	-23.862
2453387.5	1	2005	1	17	230.473	1.550	254.332	22.0	230	28	23	1.550	129.527	129	31	37	-23.859
2453403.5	2	2005	2	2	238.649	1.529	262.506	22.3	238	38	56	1.529	121.351	121	21	4	-23.857
2453419.5	3	2005	2	18	247.049	1.508	270.904	22.7	247	2	56	1.508	112.951	112	57	4	-23.855
2453435.5	4	2005	3	6	255.686	1.487	279.539	23.0	255	41	10	1.487	104.314	104	18	50	-23.853
2453451.5	5	2005	3	22	264.567	1.467	288.419	23.3	264	34	1	1.467	95.433	95	25	59	-23.852
2453467.5	6	2005	4	7	273.692	1.448	297.542	23.6	273	41	31	1.448	86.308	86	18	29	-23.850
2453483.5	7	2005	4	23	283.054	1.430	306.903	23.8	283	3	14	1.430	76.946	76	56	46	-23.849
2453499.5	8	2005	5	9	292.640	1.415	316.486	24.0	292	38	24	1.415	67.360	67	21	36	-23.846
2453515.5	9	2005	5	25	302.423	1.401	326.266	24.2	302	25	23	1.401	57.577	57	34	37	-23.843
2453531.5	10	2005	6	10	312.370	1.391	336.209	24.4	312	22	12	1.391	47.630	47	37	48	-23.839
2453547.5	11	2005	6	26	322.439	1.385	346.274	24.4	322	26	20	1.385	37.561	37	33	40	-23.835
2453563.5	12	2005	7	12	332.579	1.382	356.411	24.5	332	34	44	1.382	27.421	27	25	16	-23.832
2453579.5	13	2005	7	28	342.738	1.382	366.566	24.4	342	44	17	1.382	17.262	17	15	43	336.172
2453595.5	14	2005	8	13	352.861	1.386	376.866	24.3	352	51	40	1.386	7.139	7	8	20	336.175
2453611.5	15	2005	8	29	2.895	1.394	26.719	24.2	2	53	42	1.394	357.105	357	6	18	-23.824
2453627.5	16	2005	9	14	12.794	1.405	36.617	24.0	12	47	38	1.405	347.206	347	12	22	-23.823
2453643.5	17	2005	9	30	22.516	1.419	46.342	23.7	22	30	58	1.419	337.484	337	29	2	-23.826
2453659.5	18	2005	10	16	32.033	1.435	55.862	23.5	32	1	59	1.435	327.967	327	58	1	-23.829
2453675.5	19	2005	11	1	41.323	1.453	65.155	23.2	41	19	23	1.453	318.677	318	40	37	-23.832
2453691.5	20	2005	11	17	50.373	1.473	74.210	22.9	50	22	23	1.473	309.627	309	37	37	-23.837
2453707.5	21	2005	12	3	59.179	1.493	83.021	22.6	59	10	44	1.493	300.821	300	49	16	-23.842
2453723.5	22	2005	12	19	67.745	1.514	91.593	22.3	67	44	42	1.514	292.255	292	15	18	-23.848
2453739.5	23	2006	1	4	76.079	1.535	99.933	22.0	76	4	44	1.535	283.921	283	55	16	-23.854
2453755.5	24	2006	1	20	84.193	1.555	108.053	21.7	84	11	35	1.555	275.807	275	48	25	-23.860
2453771.5	25	2006	2	5	92.103	1.575	115.969	21.4	92	6	11	1.575	267.897	267	53	49	-23.866
2453787.5	26	2006	2	21	99.827	1.593	123.699	21.2	99	49	37	1.593	260.173	260	10	23	-23.872
2453803.5	27	2006	3	9	107.386	1.610	131.263	21.0	107	23	10	1.610	252.614	252	36	50	-23.877
2453819.5	28	2006	3	25	114.799	1.624	138.680	20.8	114	47	56	1.624	245.201	245	12	4	-23.881
2453835.5	29	2006	4	10	122.089	1.637	145.970	20.6	122	5	20	1.637	237.911	237	54	40	-23.881
2453851.5	30	2006	4	26	129.275	1.648	153.156	20.5	129	16	30	1.648	230.725	230	43	30	-23.881
2453867.5	31	2006	5	12	136.379	1.656	160.259	20.4	136	22	44	1.656	223.621	223	37	16	-23.880
2453883.5	32	2006	5	28	143.423	1.662	167.301	20.3	143	25	23	1.662	216.577	216	34	37	-23.878
2453899.5	33	2006	6	13	150.428	1.665	174.303	20.3	150	25	41	1.665	209.572	209	34	19	-23.875
2453915.5	34	2006	6	29	157.415	1.666	181.288	20.3	157	24	54	1.666	202.585	202	35	6	-23.873
2453931.5	35	2006	7	15	164.406	1.664	188.278	20.3	164	24	22	1.664	195.594	195	35	38	-23.872
2453947.5	36	2006	7	31	171.421	1.660	195.293	20.4	171	25	16	1.660	188.579	188	34	44	-23.872
2453963.5	37	2006	8	16	178.483	1.653	202.356	20.5	178	28	59	1.653	181.517	181	31	1	-23.873
2453979.5	38	2006	9	1	185.612	1.644	209.489	20.7	185	36	43	1.644	174.388	174	23	17	-23.877
2453995.5	39	2006	9	17	192.830	1.633	216.713	20.8	192	49	48	1.633	167.170	167	10	12	-23.883
2454011.5	40	2006	10	3	200.158	1.619	224.049	21.0	200	9	29	1.619	159.842	159	50	31	-23.891
2454027.5	41	2006	10	19	207.619	1.604	231.517	21.2	207	37	8	1.604	152.381	152	22	52	-23.898
2454043.5	42	2006	11	4	215.232	1.586	239.139		215	13	55	1.586	144.768	144	46	5	-23.907

JD	Tile No.	Year	Month	Day	L	r	f	Separation (cm)	DD	MM	ss	(metres)	Degrees	DD	MM	ss
Saturn																
67 Tiles at 160-day intervals.																
True period (days):					10759.227											
Miss a step (one tile) every					4 revolutions											
JD	Tile No.	Year	Month	Day	L	r	f	Separation (cm)	DD	MM	ss	(metres)	Degrees	DD	MM	ss
2453371.5	0	2005	1	1	113.327	9.058	18.904	93.7	113	19	37	9.058	246.673	246	40	23
2453531.5	10	2005	6	10	119.247	9.077	24.832	93.4	119	14	49	9.077	240.753	240	45	11
2453691.5	20	2005	11	17	125.138	9.100	30.843	93.2	125	8	17	9.100	234.862	234	51	43
2453851.5	30	2006	4	26	130.995	9.127	36.870	92.9	130	59	42	9.127	229.005	229	0	18
2454011.5	40	2006	10	3	136.815	9.159	42.966	92.5	136	48	54	9.159	223.185	223	11	6
2454171.5	50	2007	3	12	142.591	9.194	49.082	92.2	142	35	28	9.194	217.409	217	24	32
2454331.5	60	2007	8	19	148.321	9.232	55.274	91.8	148	19	16	9.232	211.679	211	40	44
2454491.5	70	2008	1	26	154.002	9.273	61.363	91.4	154	0	7	9.273	205.998	205	59	53
2454651.5	80	2008	7	4	159.632	9.316	67.496	91.0	159	37	55	9.316	200.368	200	22	5
2454811.5	90	2008	12	11	165.208	9.361	73.571	90.5	165	12	29	9.361	194.792	194	47	31
2454971.5	100	2009	5	20	170.729	9.408	79.504	90.1	170	43	44	9.408	189.271	189	16	16
2455131.5	110	2009	10	27	176.196	9.455	85.337	89.6	176	11	46	9.455	183.804	183	48	14
2455291.5	120	2010	4	5	181.607	9.503	91.003	89.2	181	36	25	9.503	178.934	178	23	35
2455451.5	130	2010	9	12	186.963	9.552	96.548	88.7	186	57	47	9.552	173.037	173	2	13
2455611.5	140	2011	2	19	192.266	9.600	101.797	88.3	192	15	58	9.600	167.734	167	44	2
2455771.5	150	2011	7	29	197.517	9.647	106.959	87.9	197	31	1	9.647	162.483	162	28	59
2455931.5	160	2012	1	5	202.718	9.693	111.928	87.5	202	43	5	9.693	157.282	157	16	55
2456091.5	170	2012	6	13	207.871	9.738	116.711	87.1	207	52	16	9.738	152.129	152	7	44
2456251.5	180	2012	11	20	212.978	9.781	121.425	86.7	212	58	41	9.781	147.022	147	1	19
2456411.5	190	2013	4	29	218.041	9.822	126.039	86.4	218	2	28	9.822	141.959	141	57	32
2456571.5	200	2013	10	6	223.065	9.861	130.627	86.0	223	3	54	9.861	136.935	136	56	6
2456731.5	210	2014	3	15	228.052	9.897	135.118	85.7	228	3	7	9.897	131.948	131	56	53
2456891.5	220	2014	8	22	233.004	9.930	139.707	85.5	233	0	14	9.930	126.996	126	59	46
2457051.5	230	2015	1	29	237.926	9.959	144.287	85.2	237	55	34	9.959	122.074	122	4	26
2457211.5	240	2015	7	8	242.822	9.986	148.893	85.0	242	49	19	9.986	117.178	117	10	41
2457371.5	250	2015	12	15	247.693	10.009	153.583	84.8	247	41	35	10.009	112.307	112	18	25
2457531.5	260	2016	5	23	252.544	10.028	158.342	84.7	252	32	38	10.028	107.456	107	27	22
2457691.5	270	2016	10	30	257.380	10.043	163.198	84.6	257	22	48	10.043	102.620	102	37	12
2457851.5	280	2017	4	8	262.202	10.055	168.091	84.5	262	12	7	10.055	97.798	97	47	53
2458011.5	290	2017	9	15	267.016	10.062	173.143	84.4	267	0	58	10.062	92.984	92	59	2
2458171.5	300	2018	2	22	271.825	10.065	178.248	84.4	271	49	30	10.065	88.175	88	10	30
2458331.5	310	2018	8	1	276.633	10.065	183.455	84.5	276	37	59	10.065	83.367	83	22	1
2458491.5	320	2019	1	8	281.443	10.060	188.724	84.5	281	26	35	10.060	78.557	78	33	25
2458651.5	330	2019	6	17	286.260	10.051	194.106	84.6	286	15	36	10.051	73.740	73	44	24
2458811.5	340	2019	11	24	291.088	10.038	199.538	84.7	291	5	17	10.038	68.912	68	54	43
2458971.5	350	2020	5	2	295.930	10.021	204.995	84.9	295	55	48	10.021	64.070	64	4	12
2459131.5	360	2020	10	9	300.790	10.000	210.535	85.1	300	47	24	10.000	59.210	59	12	36
2459291.5	370	2021	3	18	305.674	9.975	216.042	85.4	305	40	26	9.975	54.326	54	19	34
2459451.5	380	2021	8	25	310.584	9.946	221.514	85.7	310	35	2	9.946	49.416	49	24	58
2459611.5	390	2022	2	1	315.525	9.913	226.811	86.0	315	31	30	9.913	44.475	44	28	30
2459771.5	400	2022	7	11	320.500	9.878	232.058	86.3	320	30	0	9.878	39.500	39	30	0
2459931.5	410	2022	12	18	325.513	9.839	237.090	86.7	325	30	47	9.839	34.487	34	29	13
2460091.5	420	2023	5	27	330.567	9.798	241.966	87.0	330	34	1	9.798	29.433	29	25	59
2460251.5	430	2023	11	3	335.664	9.754	246.786	87.5	335	39	50	9.754	24.336	24	20	10
2460411.5	440	2024	4	11	340.808	9.709	251.503	87.9	340	48	29	9.709	19.192	19	11	31
2460571.5	450	2024	9	18	346.000	9.662	256.202	88.3	346	0	0	9.662	14.000	14	0	0
2460731.5	460	2025	2	25	351.243	9.614	260.846	88.7	351	14	35	9.614	8.757	8	45	25
2460891.5	470	2025	8	4	356.539	9.565	265.635	89.2	356	32	20	9.565	3.461	3	27	40
2461051.5	480	2026	1	11	361.889	9.515	270.401	89.6	361	53	20	9.515	358.111	358	6	40
2461211.5	490	2026	6	20	367.294	9.466	275.261	90.1	367	17	38	9.466	352.706	352	42	22
2461371.5	500	2026	11	27	372.754	9.417	280.282	90.5	372	45	14	9.417	347.246	347	14	46
2461531.5	510	2027	5	6	378.270	9.369	285.374	91.0	378	16	12	9.369	341.730	341	43	48
2461691.5	520	2027	10	13	383.841	9.323	290.614	91.4	383	50	28	9.323	336.159	336	9	32
2461851.5	530	2028	3	21	389.426	9.278	295.946	91.8	389	27	58	9.278	330.534	330	32	2
2462011.5	540	2028	8	28	395.143	9.236	301.495	92.2	395	8	35	9.236	324.857	324	51	25
2462171.5	550	2029	2	4	401.870	9.196	307.083	92.5	401	52	12	9.196	319.130	319	7	48
2462331.5	560	2029	7	14	408.644	9.159	312.830	92.8	408	38	38	9.159	313.356	313	21	22
2462491.5	570	2029	12	21	415.460	9.126	318.736	93.1	415	27	36	9.126	307.540	307	32	24
2462651.5	580	2030	5	30	422.316	9.096	324.702	93.4	422	18	58	9.096	301.684	301	41	2
2462811.5	590	2030	11	6	429.206	9.071	330.779	93.6	429	12	22	9.071	295.794	295	47	38
2462971.5	600	2031	4	15	436.125	9.050	336.913	93.8	436	7	30	9.050	289.875	289	52	30
2463131.5	610	2031	9	22	443.068	9.034	343.155	93.9	443	4	5	9.034	283.932	283	55	55
2463291.5	620	2032	2	29	450.028	9.022	349.357	94.0	450	1	41	9.022	277.972	277	58	19
2463451.5	630	2032	8	7	457.099	9.016	355.586	94.0	457	59	56	9.016	272.001	272	0	4
2463611.5	640	2033	1	14	464.175	9.015	361.872	94.0	464	58	30	9.015	266.025	266	1	30
2463771.5	650	2033	6	23	471.264	9.019	368.214	93.9	471	56	56	9.019	260.051	260	3	4
2463931.5	660	2033	11	30	478.364	9.028	374.613	93.8	478	54	54	9.028	254.085	254	5	6

JD	Tile No.	Year	Month	Day	L	r	f	Separation (cm)	DD	MM	ss	(metres)	Degrees	DD	MM	ss					
1P/Halley	A total of 14+13 = 27 Tiles at 80-day intervals																				
	(The true total would be 1723 Tiles at 16-day intervals.																				
	True period (days):				27563.247																
	Add a step (one tile) every				3 revolutions																
JD	Tile No.	Year	Month	Day	L	r	f	Separation (cm)	DD	MM	ss	(metres)	Degrees	DD	MM	ss	L-f				
2446471.0	0.0	1986	2	9	306.011	0.587	0.000		306	0	40	0.587	53.989	53	59	20	306.011				
2446511.0	2.5	1986	3	21	225.818	1.015	81.805		225	49	5	1.015	134.182	134	10	55	144.013				
2446551.0	5.0	1986	4	30	200.952	1.625	107.406	68.6	200	57	7	1.625	159.048	159	2	53	93.546				
2446591.0	7.5	1986	6	9	189.113	2.190	119.255	60.3	189	6	47	2.190	170.887	170	53	13	69.858				
2446631.0	10.0	1986	7	19	181.885	2.709	126.375	54.6	181	53	6	2.709	178.115	178	6	54	55.510				
2446671.0	12.5	1986	8	28	176.871	3.191	131.267	50.4	176	52	16	3.191	183.129	183	7	44	45.604				
2446711.0	15.0	1986	10	7	173.116	3.642	134.909	47.1	173	6	58	3.642	186.884	186	53	2	38.207				
2446751.0	17.5	1986	11	16	170.159	4.069	137.765	44.5	170	9	32	4.069	189.841	189	50	28	32.394				
2446791.0	20.0	1986	12	26	167.745	4.476	140.090	42.2	167	44	42	4.476	192.255	192	15	18	27.655				
2446831.0	22.5	1987	2	4	165.721	4.865	142.034	40.4	165	43	16	4.865	194.279	194	16	44	23.687				
2446871.0	25.0	1987	3	16	163.988	5.238	143.696	38.7	163	59	17	5.238	196.012	196	0	43	20.292				
2446911.0	27.5	1987	4	25	162.481	5.599	145.140	37.3	162	28	52	5.599	197.519	197	31	8	17.341				
2446951.0	30.0	1987	6	4	161.151	5.947	146.412	36.0	161	9	4	5.947	198.849	198	50	56	14.739				
2446991.0	32.5	1987	7	14	159.966	6.284	147.546	34.9	159	57	58	6.284	200.034	200	2	2	12.420				
2447031.0	35.0	1987	8	23	158.898	6.612	148.565	33.9	158	53	53	6.612	201.102	201	6	7	10.333				
2447071.0	37.5	1987	10	2	157.930	6.930	149.490	32.9	157	55	48	6.930	202.070	202	4	12	8.440				
2447111.0	40.0	1987	11	11	157.046	7.241	150.334	32.0	157	2	46	7.241	202.954	202	57	14	6.712				
2447151.0	42.5	1987	12	21	156.233	7.544	151.109	31.2	156	13	59	7.544	203.767	203	46	1	5.124				
2447191.0	45.0	1988	1	30	155.482	7.839	151.826	30.5	155	28	55	7.839	204.518	204	31	5	3.656				
2447231.0	47.5	1988	3	10	154.784	8.129	152.491	29.8	154	47	2	8.129	205.216	205	12	58	2.293				
2447271.0	50.0	1988	4	19	154.134	8.412	153.110	29.2	154	8	2	8.412	205.866	205	51	58	1.024				
2447311.0	52.5	1988	5	29	153.526	8.689	153.690	28.6	153	31	34	8.689	206.474	206	28	26	-0.164				
2447351.0	55.0	1988	7	8	152.955	8.961	154.234	28.0	152	57	18	8.961	207.045	207	2	42	-1.279				
2447391.0	57.5	1988	8	17	152.417	9.227	154.746	27.5	152	25	1	9.227	207.583	207	34	59	-2.329				
2447431.0	60.0	1988	9	26	151.909	9.489	155.230	27.0	151	54	32	9.489	208.091	208	5	28	-3.321				
2447471.0	62.5	1988	11	5	151.429	9.747	155.688	26.5	151	25	44	9.747	208.571	208	34	16	-4.259				
2447511.0	65.0	1988	12	15	150.972	9.999	156.123		150	58	19	9.999	209.028	209	1	41	-5.151				
1P/Halley	13 Tiles at 80-day intervals.																				
	The 14th tile (perihelion) coincides with the zeroth one above.																				
JD	Tile No.	Year	Month	Day	L	r	f	Separation (cm)	DD	MM	ss	(metres)	Degrees	DD	MM	ss	L-f				
2472994.2	1658.0	2058	9	23	101.935	9.985	203.965		101	56	6	9.985	258.065	258	3	54	-102.030				
2473034.2	1660.5	2058	11	2	101.499	9.733	204.403		101	29	56	9.733	258.501	258	30	4	-102.904				
2473074.2	1663.0	2058	12	12	101.039	9.476	204.864		101	2	20	9.476	258.961	258	57	40	-103.825				
2473114.2	1665.5	2059	1	21	100.554	9.215	205.352		100	33	14	9.215	259.446	259	26	46	-104.798				
2473154.2	1668.0	2059	3	2	100.041	8.949	205.868		100	2	28	8.949	259.959	259	57	32	-105.827				
2473194.2	1670.5	2059	4	11	99.497	8.677	206.416		99	29	49	8.677	260.503	260	30	11	-106.919				
2473234.2	1673.0	2059	5	21	98.917	8.400	207.000		98	55	1	8.400	261.083	261	4	59	-108.083				
2473274.2	1675.5	2059	6	30	98.299	8.118	207.624		98	17	56	8.118	261.701	261	42	4	-109.325				
2473314.2	1678.0	2059	8	9	97.636	7.829	208.294		97	38	10	7.829	262.364	262	21	50	-110.658				
2473354.2	1680.5	2059	9	18	96.922	7.534	209.015		96	55	19	7.534	263.078	263	4	41	-112.093				
2473394.2	1683.0	2059	10	28	96.151	7.231	209.796		96	9	4	7.231	263.849	263	50	56	-113.645				
2473434.2	1685.5	2059	12	7	95.312	6.921	210.647		95	18	43	6.921	264.688	264	41	17	-115.335				
2473474.2	1688.0	2060	1	16	94.395	6.603	211.578		94	23	42	6.603	265.605	265	36	18	-117.183				
2473514.2	1690.5	2060	2	25	93.385	6.276	212.605		93	23	6	6.276	266.615	266	36	54	-119.220				
2473554.2	1693.0	2060	4	5	92.265	5.939	213.746		92	15	54	5.939	267.735	267	44	6	-121.481				
2473594.2	1695.5	2060	5	15	91.010	5.591	215.028		91	0	36	5.591	268.990	268	59	24	-124.018				
2473634.2	1698.0	2060	6	24	89.588	5.231	216.483		89	35	17	5.231	270.412	270	24	43	-126.895				
2473674.2	1700.5	2060	8	3	87.955	4.858	218.157		87	57	18	4.858	272.045	272	2	42	-130.202				
2473714.2	1703.0	2060	9	12	86.050	4.470	220.116		86	2	60	4.470	273.950	273	56	60	-134.066				
2473754.2	1705.5	2060	10	22	83.779	4.064	222.458		83	46	44	4.064	276.221	276	13	16	-138.679				
2473794.2	1708.0	2060	12	1	80.999	3.637	225.335		80	59	56	3.637	279.001	279	0	4	-144.336				
2473834.2	1710.5	2061	1	10	77.467	3.186	229.004		77	28	1	3.186	282.533	282	31	59	-151.537				
2473874.2	1713.0	2061	2	19	72.742	2.705	233.935		72	44	31	2.705	287.258	287	15	29	-161.193				
2473914.2	1715.5	2061	3	31	65.898	2.187	241.109		65	53	53	2.187	294.102	294	6	7	-175.211				
2473954.2	1718.0	2061	5	10	54.543	1.623	253.046		54	32	35	1.623	305.457	305	27	25	-198.503				
2473994.2	1720.5	2061	6	19	29.807	1.016	278.788		29	48	25	1.016	330.193	330	11	35	-248.981				
2474034.2	1723.0	2061	7	29	306.318	0.593	0.000		306	19	5	0.593	53.682	53	40	55	306.318				

JD	Tile No.	Year	Month	Day	L	r	f	Separation (cm)	DD	MM	ss	(metres)	Degrees	DD	MM	ss	
Encke																	
15 Tiles at 80-day intervals.																	
True period (days):					1205.764												
Miss a step (one tile) every					14 revolutions												
JD	Tile No.	Year	Month	Day	L	r	f	Separation (cm)	DD	MM	ss	(metres)	Degrees	DD	MM	ss	L-f
2453003.377	0	2003	12	30	160.951	0.338	0.000	181.0	160	57	4	0.338	199.049	199	2	56	160.951
2453019.377	1	2004	1	15	239.058	0.532	78.088		239	3	29	0.532	120.942	120	56	31	160.970
2453035.377	2	2004	1	31	268.022	0.823	106.495		268	1	19	0.823	91.978	91	58	41	161.527
2453051.377	3	2004	2	16	281.967	1.092	120.295		281	58	1	1.092	78.033	78	1	59	161.672
2453067.377	4	2004	3	3	290.521	1.334	128.826		290	31	16	1.334	69.479	69	28	44	161.695
2453083.377	5	2004	3	19	296.510	1.553	134.832	101.7	296	30	36	1.553	63.490	63	29	24	161.678
	6																
	7																
	8																
	9																
2453163.377	10	2004	6	7	312.513	2.415	151.000	72.4	312	30	47	2.415	47.487	47	29	13	161.513
	11																
	12																
	13																
	14																
2453243.377	15	2004	8	26	320.802	3.025	159.432	55.1	320	48	7	3.025	39.198	39	11	53	161.370
	16																
	17																
	18																
	19																
2453323.377	20	2004	11	14	326.586	3.468	165.330	42.9	326	35	10	3.468	33.414	33	24	50	161.256
	21																
	22																
	23																
	24																
2453403.377	25	2005	2	2	331.218	3.781	170.059	33.9	331	13	5	3.781	28.782	28	46	55	161.159
	26																
	27																
	28																
	29																
2453483.377	30	2005	4	23	335.254	3.982	174.182	28.2	335	15	14	3.982	24.746	24	44	46	161.072
	31																
	32																
	33																
	34																
2453563.377	35	2005	7	12	338.995	4.082	178.003	26.0	338	59	42	4.082	21.005	21	0	18	160.992
	36																
	37																
	38																
	39																
2453643.377	40	2005	9	30	342.642	4.085	181.727	27.9	342	38	31	4.085	17.358	17	21	29	160.915
	41																
	42																
	43																
	44																
2453723.377	45	2005	12	19	346.374	3.992	185.534	33.4	346	22	26	3.992	13.626	13	37	34	160.840
	46																
	47																
	48																
	49																
2453803.377	50	2006	3	9	350.391	3.799	189.627	42.1	350	23	28	3.799	9.609	9	36	32	160.764
	51																
	52																
	53																
	54																
2453883.377	55	2006	5	28	354.983	3.495	194.298	54.2	354	58	59	3.495	5.017	5	1	1	160.685
	56																
	57																
	58																
	59																
2453963.377	60	2006	8	16	0.684	3.062	200.082	71.1	0	41	2	3.062	359.316	359	18	58	-199.398
	61																
	62																
	63																
	64																
2454043.377	65	2006	11	4	8.761	2.466	208.243	99.1	8	45	40	2.466	351.239	351	14	20	-199.482
	66																
	67																
	68																
	69																
2454123.377	70	2007	1	23	23.871	1.627	223.385		23	52	16	1.627	336.129	336	7	44	-199.514
2454139.377	71	2007	2	8	29.301	1.415	228.787		29	18	4	1.415	330.699	330	41	56	-199.486
2454155.377	72	2007	2	24	36.803	1.182	236.216		36	48	11	1.182	323.197	323	11	49	-199.413
2454171.377	73	2007	3	12	48.345	0.924	247.583		48	20	42	0.924	311.655	311	39	18	-199.238
2454187.377	74	2007	3	28	69.828	0.638	268.632		69	49	41	0.638	290.172	290	10	19	-198.804
2454203.377	75	2007	4	13	124.760	0.373	323.146		124	45	36	0.373	235.240	235	14	24	-198.386