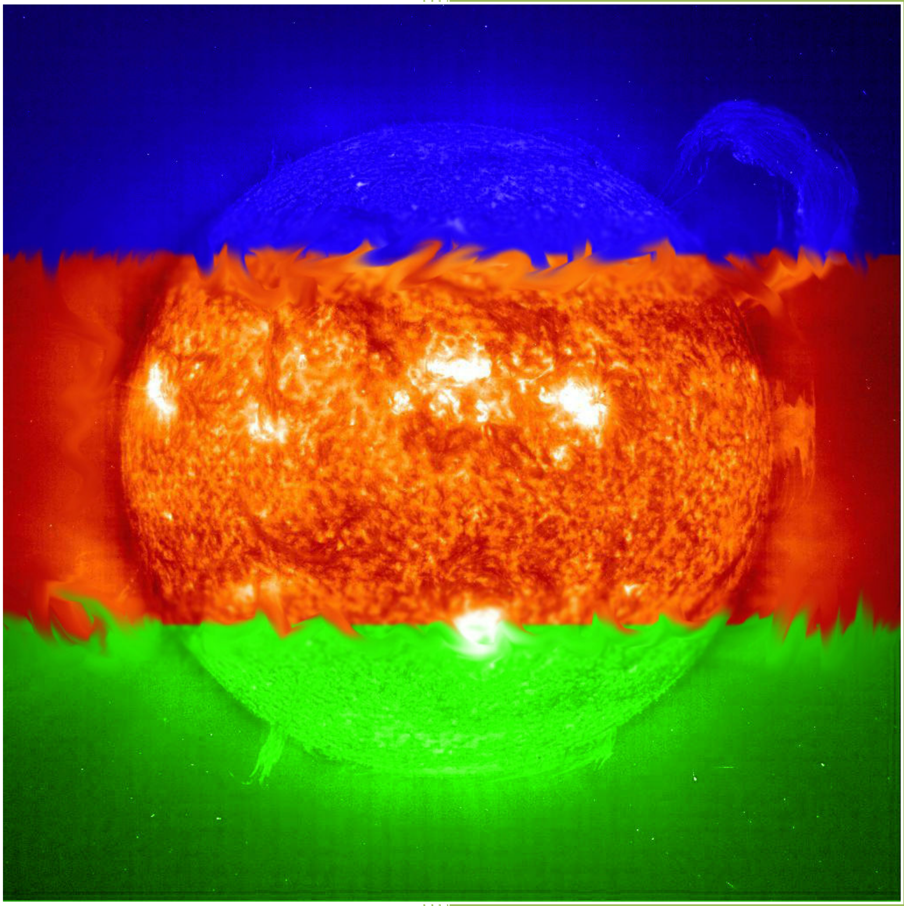
2009

Investigating Sunspots



Determining the Speed of Rotation of the Sun and Inspecting Sunspot Morphology

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Acknowledgements

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Introduction

Sunspots have been of astronomical interest for centuries. Essentially, these are dark patches that are changing in shape and size, observed on the surface of the sun and are visible by the naked eye. The sunspot region is characterised by intense magnetic activity inhibiting convection and forming areas of reduced surface temperature. It is also responsible for coronal loops and solar flares. Sunspot occurrence is periodic in nature in the form of an 11 year cycle. On average it rises to a maximum in about 4 years and drops to a minimum in 7 years. However, recently the expected solar minimum was forecasted to end around late 2007 and yet this minimum has extended till mid 2009 and its tenure still cannot be predicted. It has been claimed that there is a relationship between sunspot activity and global temperatures. The longest period of sunspot inactivity was record in the 17th century and this coincided with a little ice age at the time. In these times of climate change and rising global temperatures, many believe that this extended solar minimum could play a factor in reducing global temperatures. The unusual nature of sunspots has made it responsible for events that intrigue the scientific community.

This investigation aims to study sunspots and their properties. The first part of the study intends to determine the differential speed with the use of sunspots. This process includes analysing SOHO images and determining the speed of rotation of the sun in days. The result will be compared to literature values and it will be examined whether this method is a liable process. The second part of the analysis investigates sunspot morphology. A relationship will be examined between sunspot area and time. Sunspot size will be observed in context with how it increases and decreases during its life cycle.

Theory

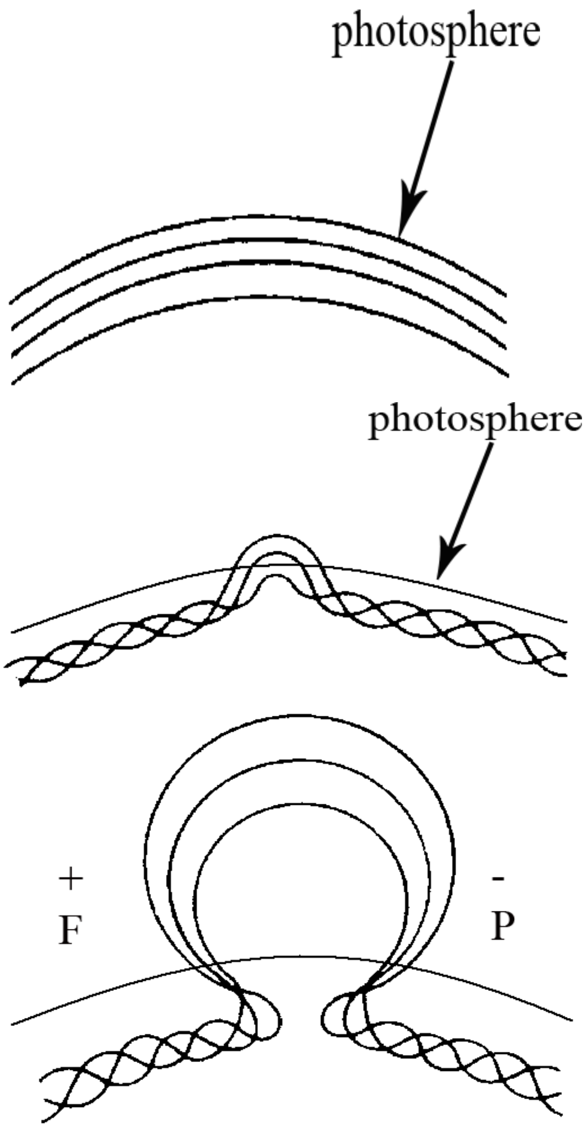
The theory below is the basis of this research. Each aspect studied can be directly linked with the methodology and conclusion reached.

Characteristics of sunspots:

A typical sunspot consists of a darker central region called umbra surrounded by a lighter penumbra. The diameter of penumbra is on average 2.5 times that of the umbra. The Penumbra is made up of pattern of lighter and darker filaments spreading out approximately radially outward from umbra. The umbra and penumbra appear dark by contrast with the brighter photosphere because they are cooler than the average photospheric temperature the central umbra has a temperature of around 4000k compared to about 5600k for the penumbra and about 6000k for the photospheric granules. Since the amount of radiation emitted by a hot body is proportional to 4^{th} power of its effective temperature the umbra emits only about 30% of the light emitted by an equal area of photosphere and the penumbra has the brightness of about 70 % of the photospheric value.

The size of a sunspot can range from tiny pores about size of individual granules (about 1000km in diameter) to complex structures covering areas up to 10^9 km^2.

Sunspots occur in pairs or groups, isolated spots being infrequent. Magnetograph observations show that sunspots are seats of intense magnetic fields. A typical sunspot group consists of two spots of opposite magnetic polarity. The leading spot of the pair in terms of the direction of solar rotation is referred to as the preceding or the p-spot while the other is known as the following spot or f spot. Generally the p-spots are bipolar groups in one hemisphere have the same magnetic polarity, while all the p-spots in the other hemisphere have the opposite polarity. Furthermore, the following spots on either side of the equator will have opposite polarities.



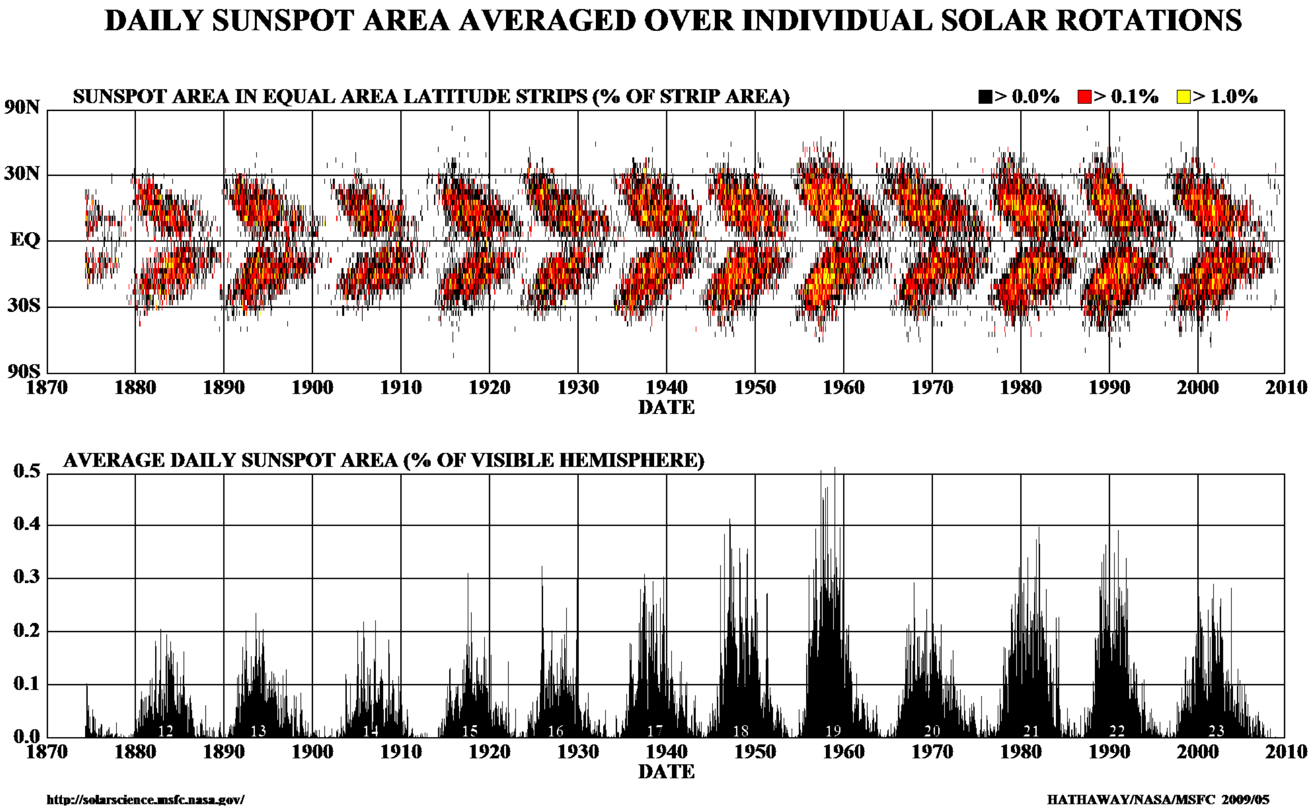
Field lines are brought together to form tubes of magnetic flux (side sequence pictures) which become twisted by the effects of convection. Bundles of tubes may be wound together into structures rather like ropes, this process amplifying still further the magnetic field strength. When the field strength in the tubes or the ropes become significantly great, they float to the surface, and where kinks in the bundles of tubes penetrate the photosphere, a sunspot group is formed. Below a sunspot magnetic tubes of force are squeezed together despite their natural tendency to push apart by powerful convective currents.

The Sunspot Cycle:

The spots found on the sun are variable. As mentioned previously, the sun cycle it rises to a maximum in about 4 years and drops to a minimum in about 7 years, hence the cycle is approximately 11 years in length.

Throughout the whole of the cycle from sunspot minima to next sunspot maxima all the sunspot group in one hemisphere have the same magnetic alignment. This means all leader spots have identical polarities, follower spots have the reverse polarity, and in the other hemisphere the sense of polarity is opposite While in the next cycle the magnetic polarities reverse in each hemisphere. Thus the magnetic cycle is 22 years long consisting of two 11 years sunspot cycles.

The second regular feature is the variation in the average sunspot latitude with the cycle. The first sunspots of the new cycle lie around 30^{o}N top 30^{o}S and on rare occasions as high as +/-40^{o}. As the cycle progresses the average sunspot latitude decreases. At maximum spots tend to be found in the



zones at about +/-15^{o} and by minimum the mean latitude of sunspots is between 5^{o} and 7^{o}; as the last spots of the old cycle are occurring in low latitudes, the first spots of the new cycle are beginning to emerge at higher latitudes once more. The progression of regions of the spot activity towards the equator during each cycle is known as Sporer's law: the effect having been discovered in 1858 by R. Carrington and then investigated by Sporer. This is graphically represented in the Maunders butterfly diagram. In sunspot groups the p-spot is usually found to lie at slightly lower latitudes than the f-spots, whereas near the equator the line joining the 2 principal spots in a group may be inclined to the equator by as little as 1^{o}, at high latitudes the inclination may be as great as 20 deg.

The third important property of the cycle is the reversal of the polar fields around the time of sunspot maximum. Magnetic fields are presents not only in sunspots but are widely distributed over the surface of sun, on the whole, but not necessarily at any one time, the north and south poles of the sun have opposite magnetic polarities, the polarities reverse around sunspot maximum, but by no means in a definite way, and they may oscillate several times before settling down. In a consequence, both north and south poles may have the same magnetic polarities at times. The polar magnetic polarities tend to reverse about a year or so after the sunspot maximum, in other words since the rise to maximum activity tends to be more rapid than the decline to minimum (the average rise time is 4.6 years compared to the average decline of 6.7 years). The change over at opposite poles generally does not occur simultaneously, and on occasions one polarity can change as much as a year or two before the other.

The fourth significant attribute is the torsional oscillation of the sun, or oscillation in its rate of rotation discovered recently. At any latitude the rate of rotation oscillates with an 11 year period, sometime faster than average, sometimes slower. The time of maximum rate of rotation varies with latitude. An oscillation starts at about the same time in the two polar zones and drifts down to the equator in 22 years. New cycle sunspots break out soon after the maximum rate of rotation arise at about 30^{o} north or $30\ ^{o}$ south. Clearly the rotational oscillation is connected with closely with both the 11 year sunspot cycle and the 22 year magnetic cycle.

Babcock-Leighton Model:

This model is the accepted model for sunspots for most astronomers. The weak magnetic field may be imagined permeating the outer solar layers possibly as far down as the base convective zone some 200000 km below the photosphere the field can be represented initially by lines of force running along meridians from north to south the high conductivity of solar material ensures that these field lines will be frozen into the matter. Because of sun's differential rotation the field lines will be stretched out and wrapped around the solar globe like elastic threads. As the lines are stretched out they are concentrated closer and closer together, amplifying strength of the surface field in effect the differential rotation of the sun "winds up" the initially weak fields too much higher strengths. Recent studies show the magnetic field lines are concentrated in thin tubes of magnetic "flux" (which measures the total field passing through an area perpendicular to the direction of the field; it can be regarded as the number of field lines passing perpendicularly through a given area.)

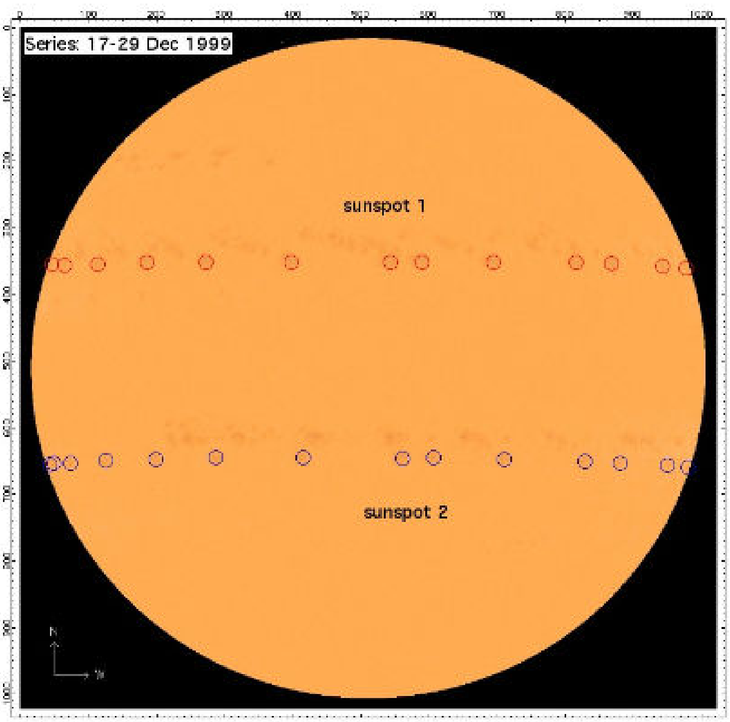
The flux tubes are a few hundred km in radius and within them strength of the field reaches value between a few hundred gauss and about 2000G. Hot bubbles of rising gas will carry magnetic flux with them, destroying the field lines such convection effects cause the flux tubes to become twisted, thus amplifying further the magnetic fields contained in them. Bundles of flux tubes become tangled together and compressed, eventually producing field strengths as great as 2000 or 4000 G. With increasing field strength the magnetic pressure in the tangled flux tubes become sufficiently great for them to become buoyant and float up to the surface. Where the bundles of twisted flux tubes pierce the photosphere the field spreads out to form sunspot group. Individual flux tubes penetrating the surface probably correspond to spicules.

The winding up of the field causes this process to occur first at latitudes around $+/-40^{o}$, for it is here that the shearing motion between adjacent zones of gas is at its greatest. As spots emerge at these relatively high latitudes the fields at lower latitudes are enhanced, and the zones in which magnetic eruptions take place migrate progressively towards the equator. This is in accordance with the observed pair of sunspot groups. Since the field lines slope towards the equator, the preceding spot of an emerging pair should occur at slightly lower latitude than the following one.

As the bipolar magnetic region spreads out and declines, the magnetic flux is carries away and spread around by the formation and destruction of super granular cells and by differential rotation. Because of f-spot is closer to the pole in each case, its polarity tends preferentially to be carried to the polar regions if the hemisphere in which it is located, building up sufficient strength by around the time of sunspot maximum to reserve the existing polarity there. It is thought that polarity in a polar region changes, it begins to change the slope of the fields line in the locality; as the strength polar fields builds up (a result of the continued diffusion of f- spot polarity) so the zone in which slope reversal occurs moves closer to the equator. When the slope of the field line changes from downwards (in the direction of solar rotation) to upwards, the effect of differential rotation is to unwind the field's lines, rather than winding them up. The concentrated fields required for the production of the sunspot groups declines and activity diminishes. Eventually a stage is reached where, once again, the lines of force run approximately from north to south and the winding up process begins again. Since the field is in the opposite direction, the polarities of p- and f-spots will be reversed compared to the previous cycle. As the reversal begins to produce spots in higher latitudes, the residual field from the old cycle still gives rise to some spots of the old polarity close to the equator.

<u>The Coordinate System of the Sun and Realisation of the Nature of the Graphs</u>:

This section of the Theory will not deal particularly with the physics behind Sunspots but will elaborate on the technicalities of image processing and the mathematics behind the investigation. As we all know, the Sun is a 3 dimensional object (we are considering it to be a sphere). Hence, we need to work in a 3 dimensional Cartesian/Spherical Coordinate system. However, any image used of the sun will be in 2 dimensions. The images (in tiff and gif format) used in this project are 512x512 in resolution therefore the coordinates of each pixel (and hence the sunspot) can be found by using suitable image processing software, MATLAB in this case. The origin of this system lies at the top left corner of the image (as show in the image on the right).



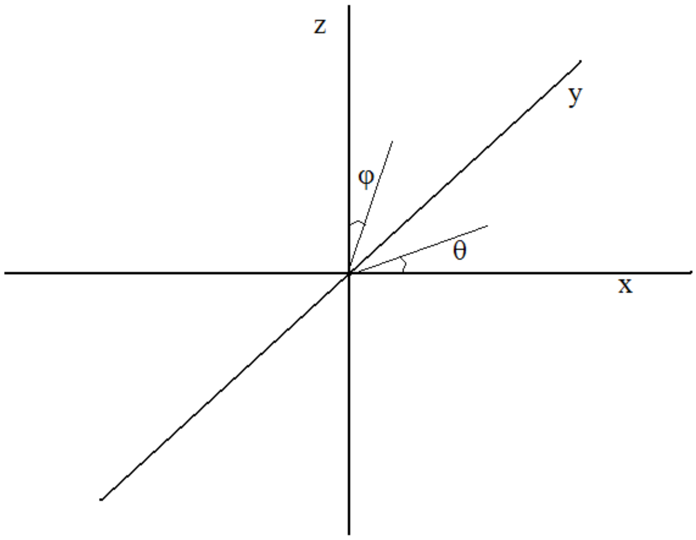
But being a spherical body it is better to convert these coordinates into spherical system for easier data processing. Now this can be done by using the following relations

$X = r\cos(\theta)\sin(\phi)$

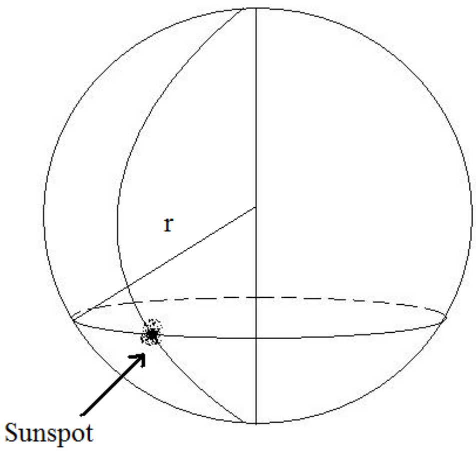
$Y=r\sin(\theta)\sin(\phi)$

$Z=r\sin(\phi)$

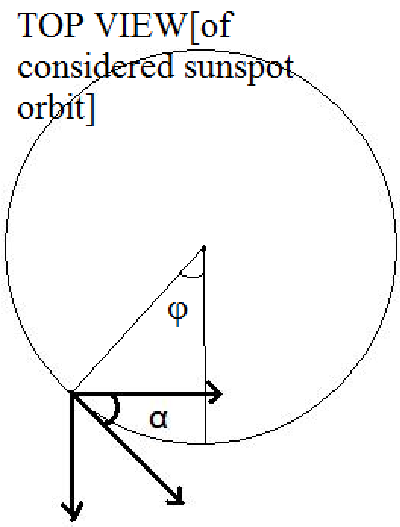
The X, Y, and Z system used in the above relations have their origin at the centre of the spherical body.



They figure on the right shows a typical spherical system with a sunspot with corresponding latitude and longitude. Now due to the differential rotation of sun, the sunspot travels across the surface of the sun. This means that the longitude of the sunspot changes linearly with time, if the sun rotates with constant speed and latitude being constant.



Tracing the x coordinate would mean tracking the horizontal component of the velocity vector of sunspot which is actually the cosine component. Clearly seen the cosine component first increases and then decreases, as α which is also equal to the acute part of ϕ first decreases and then increases. This means that the rate of change of longitude and the x coordinate (dx/dt) first increases reaches maximum and becomes constant and then again it decreases.



Furthermore, we know for certain that the graph will not be linear and a variety of different options may be available to us when fitting the curve, including a polynomial function or a trigonometric function. In order to be certain of the kind of equation we are dealing with let's try the following:

We know that

$X = r\cos(\theta)\sin(\phi)$

$Y = r\sin(\theta)\sin(\phi)$

$Z = r\sin(\phi)$

The X, Y, and Z system used in above relations have their origin at the centre of the spherical body the x and y coordinates found through image processing will have their origin at the top left corner. Clearly X, Y, and Z system is obtained after a shift of the origin. This gives us:

$X = x - 256$

$Y = y - 256$

So we have

$x = 256 + r\cos(\theta)\sin(\phi)$

As already discussed the latitude of the sunspot is almost constant (hence θ and r are constants).

So we have

$x = 256 + C\sin(\phi)$

Also since ϕ changes periodically with time can be replaced with ct (ϕ is directly proportional to t)

$x = 256 + C\sin(ct)$

Thus, $F(t) = 256 + C\sin(\omega t + b)$

Hence it is expected that our results take their final form of the equation above.

NOTE: Since we are more concerned with the coefficient of t (as it will be used to calculate the time period) the some variation in the value of 256 and phase difference does not affect the results as it merely shifts the graph up/ down or right /left.

The time period can easily be calculated by evaluating the expression ($2\pi/\omega$) since $\omega = 2\pi/t$ form f(t).

Method

The crux of this investigation lies in image processing and MATLAB programming. In order to implement these, SOHO images of the sun were collected from www.spaceweather.com. Daily images of the sun were processed from the months of January 2002, October 2002 and April 2001. These images were put in TIFF (Tagged Image File Format) and of size 512x512 as they are images of compatible quality for MATLAB Programming.

Various sunspots over these months were observed and their coordinates in the image's pixel map were determined. By typing "`imtool('filename')`" on the command window of MATLAB, we open the Image tool window which allows us to 'Inspect pixel value'; through this we can examine the any coordinate of the image in its pixel map. By observation we see that a sunspot occupies a fairly large amount of pixels and hence it's difficult to determine the exact centre of the sunspot. In order to distinguish the sunspot's pixels from the sun's pixel we considered all sunspot pixels to have index values less than 150. The MATLAB programme to determine the centre of a sunspot (in terms of x and y coordinates of the pixel map) and the procedure of how the results will be used is given in Appendix i.

We then observe this sunspot image by image (in other words by a day to day basis) until it dies or shifts out of the frame of view. Assuming that the y coordinates of the image remains constant we plot a graph of the x coordinates against days. We observed a sin curve and we determined the function with "*cftool*" in MATLAB and curve fitting software called Graph 4.3. Once we achieved the function we found its period and this gives us the speed of rotation of the sun in days. This method was repeated for several trials and the mean sunspot speed was calculated and compared with literature values.

To understand the concept of differential speed, the speed of each individual sunspot was plotted against its latitude. The latitude was determined using the software HelioV. The procedure of using this software is given in Appendix ii.

In order to analyse the morphology of sunspots we have already determined its area. By plotting the sunspot area over a period of time, we attempted to determine a relationship about the life cycle of a sunspot.

Data Collection

The following sunspots were taken for the month of January 2002.

Sunspot #1

Sunspot description	Over the period of 11 days it grows and shrinks. Initially it has two sunspots behind it but eventually it leaves them as they die out.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
01.01.02	1	(62,324), (75,339)	(68.6835, 331.4937)	68.6835	79
02.01.02	2	(94,325), (107,336)	(100.1034, 30.2874)	100.1034	86
03.01.02	3	(149,322), (161,336)	(156.0674, 328.5618)	156.0674	89
04.01.02	4	(214,323), (223,333)	(218.8718, 327.6538)	218.8718	78
05.01.02	5	(262,321), (276,331)	(268.2785, 325.6076)	268.2785	79
06.01.02	6	(309,320), (319,329)	(314.0128, 324.7692)	314.0128	76
07.01.02	7	(362,321), (372,330)	(367.0625, 325.7344)	367.0625	64
08.01.02	8	(390,322), (398,332)	(394.2105, 326.7193)	394.2105	57
09.01.02	9	(434,325), (440,333)	(437.6000, 329.2000)	437.6000	40
10.01.02	10	(460,328), (466,336)	(463.0000, 331.7188)	463.0000	32
11.01.02	11	(487,335), (490,338)	(488.8462, 336.6154)	488.8462	13

Sunspot #2

Sunspot description	This sunspot emerges from the top left centre of the Sun. It grows and shrinks during its observed life cycle. It is not surrounded by any other sunspot over the course of 11 days.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
08.01.02	1	(44,131), (48,138)	(45.7778, 134.1667)	45.7778	18
09.01.02	2	(64,125), (71,133)	(67.8065, 129.5806)	67.8065	31
10.01.02	3	(89,123), (95,130)	(92.0789, 126.0263)	92.0789	38
11.01.02	4	(145,119), (153,127)	(148.7843, 122.6275)	148.7843	51
12.01.02	5	(165,119), (172,126)	(168.6939, 122.3878)	168.6939	49
13.01.02	6	(211,117), (219,125)	(214.6250, 121.1429)	214.6250	56
14.01.02	7	(259,117), (267,127)	(262.7778, 120.5370)	262.7778	54
15.01.02	8	(323,118), (330,125)	(326.4681, 121.0638)	326.4681	47
16.01.02	9	(366,119), (373,126)	(369.6591, 122.7045)	369.6591	44
17.01.02	10	(405,122), (412,129)	(408.4286, 125.4000)	408.4286	35
18.01.02	11	(437,125), (442,132)	(439.3333, 128.9167)	439.3333	24
19.01.02	12	(458,129), (463,135)	(460.6000, 132.0000)	460.6000	15

Sunspot #3

Sunspot description	This sunspot appears from the bottom left centre of the Sun. During its life cycle, the sunspot remains relatively small and its growth and death is easily observed in an 11 day period.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
04.01.02	1	(31,315), (35,321)	(33.8333 ,318.3333)	33.8333	12
05.01.02	2	(55,312),(59,318)	(56.8947 ,315.4211)	56.8947	19
06.01.02	3	(85,310),(89,316)	(87.0000, 313.0000)	87.0000	25
07.01.02	4	(131,308),(135,313)	(133.0000, 310.6786)	133.0000	28
08.01.02	5	(160,307),(165,313)	(162.1290, 310.0323)	162.1290	31
09.01.02	6	(219,307),(224,312)	(221.5000, 309.5000)	221.5000	32
10.01.02	7	(266,307),(271,313)	(268.5455, 309.9091)	268.5455	33
11.01.02	8	(347,310),(352,316)	(349.5000, 312.5000)	349.5000	28
12.01.02	9	(370,311),(374,317)	(372.0769, 313.8077)	372.0769	26
13.01.02	10	(413,314),(418,320)	(416.5000, 317.0000)	416.5000	18
14.01.02	11	(450,319),(453,323)	(452.0000, 320.8333)	452.0000	12
15.01.02	12	(483,324),(484,327)	(483.5000, 325.5000)	483.5000	6

Sunspot #4

Sunspot description	This sunspot moves across the equator over a period of 12 days. It is followed by two sunspots to its left.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
11.01.02	1	(23,271),(26,276)	(24.7692, 273.3077)	24.7692	13
12.01.02	2	(34,268),(37,274)	(35.5000, 271.0000)	35.5000	22
13.01.02	3	(65,263),(69,268)	(66.9259, 265.7407)	66.9259,	27
14.01.02	4	(106,258),(111,265)	(108.5128, 261.8974)	108.5128	39
15.01.02	5	(173,254),(179,261)	(176.1556, 257.8222)	176.1556	45
16.01.02	6	(229,252),(235,259)	(231.9565, 255.7826)	231.9565	46
17.01.02	7	(286,252),(293,259)	(289.4600, 255.6800)	289.4600	50
18.01.02	8	(342,253),(349,261)	(345.7872, 256.8085)	345.7872	47
19.01.02	9	(394,256),(399,263)	(396.4865, 259.2162)	396.4865	37
21.01.02	11	(473,263),(476,268)	(474.8667, 265.7333)	474.8667	15
22.01.02	12	(494,269),(496,272)	(495.4286, 270.2857)	495.4286	7

Sunspot #5

Sunspot description	This sunspot moves just below the line of the equator. As it moves across, and when it reaches its maximum size, it seems to have to regions of extreme intensity. Towards the end of its life these centre's merged.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
13.01.02	1	(18,292),(22,302)	(20.3871 297.0000)	20.3871	31
14.01.02	2	(37,288),(42,299)	(39.4706 293.2745)	39.4706	51
15.01.02	3	(78,284),(87,295)	(82.8861 289.2911)	82.8861	79
16.01.02	4	(120,281),(130,292)	(125.2299 286.9195)	125.2299	87
17.01.02	5	(169,280),(181,291)	(174.7879 285.2323)	174.7879	99
18.01.02	6	(223,279),(235,290)	(228.9082 284.3061)	228.9082	98
19.01.02	7	(279,279),(289,289)	(283.7528 284.4607)	283.7528	89
21.01.02	9	(386,283),(394,293)	(388.7971 288.0725)	388.7971	69
22.01.02	11	(429,287),(435,296)	(431.7727 291.6136)	431.7727	44
23.01.02	12	(486,299),(488,305)	(487.0000 301.6842)	487.0000	19

Sunspot #6

Sunspot description	This sunspot moves slightly above the line of the equator. When the sunspot reaches its maximum size small speck of sunspots are seen surrounding it. However, these specks disappear around the death of the sunspot.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
11.01.02	1	(15,217),(18,229)	(16.7500, 222.5714)	16.7500	28
12.01.02	2	(23,216),(26,227)	(24.6757, 221.5135)	24.6757	37
13.01.02	3	(46,213),(53,223)	(49.9077, 218.0308)	49.9077	65
14.01.02	4	(82,209)(91,219)	(86.2625, 214.4875)	86.2625	80
15.01.02	5	(145,206),(155,216)	(150.0722, 210.7938)	150.0722	97
16.01.02	6	(199,204),(210,214)	(204.3396, 209.0094)	204.3396	106
17.01.02	7	(257,203),(268,213)	(262.2718, 208.1748)	262.2718	103
18.01.02	9	(314,204),(325,214)	(319.3118, 208.9140)	319.3118	93
19.01.02	10	(368,206),(378,215)	(372.7051, 210.5128)	372.7051	78
21.01.02	12	(458,214),(462,221)	(460.3667, 217.3333)	460.3667	30
22.01.02	13	(494,269),(496,272)	(495.4286, 270.2857)	495.4286	7

Sunspot #7

Sunspot description	This sunspot seems to be largest single appearing in the month of January. It also shows accumulation of small specks of sunspots surrounding it when it reaches its maximum size.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
18.01.02	1	(13,264),(18,287)	(15.3279, 280.8361)	15.3279	61
19.01.02	2	(30,270),(37,283)	(33.3626, 276.5275)	33.3626	91
21.01.02	4	(98,263),(113,279)	(106.1788, 270.8939)	106.1788	179
22.01.02	5	(146,262),(162,278)	(155.1000, 269.7526)	155.1000	190
23.01.02	6	(255,260),(272,277)	(264.2765, 268.9078)	264.2765	217
25.01.02	8	(301,262),(317,277)	(309.4925, 269.5226)	309.4925	199
26.01.02	9	(379,261,),(393,280)	(386.1163, 271.4942)	386.1163	172
28.01.02	10	(433,267),(444,285)	(438.1045, 276.0672)	438.1045	134
29.01.02	11	(484,275),(489,291)	(487.0156, 283.2969)	487.0156	64
30.01.02	12	(494,280),(498,295)	(496.4043, 286.7660)	496.4043	47

Sunspot #8

Sunspot description	We begin the examination of the sunspot when it's near the centre of the sun. It follows the path of two sunspots which are in front of it to the right.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
01.01.02	1	(131, 219),(137,226)	(134.4118, 222.5294)	134.4118	34
02.01.02	2	(173,218),(178,224)	(175.5000, 221.1667)	175.5000	36
03.01.02	3	(239,216),(245,223)	(242.1951, 219.7317)	242.1951	41
04.01.02	4	(307,216),(313,222)	(309.5897, 219.0000)	309.5897	39
05.01.02	5	(357,216),(363,222)	(360.2778, 219.1944)	360.2778	36
06.01.02	6	(401,218),(406,223)	(403.7241, 220.4828)	403.7241	29
07.01.02	7	(447,221),(451,227)	(449.0435, 224.2609)	449.0435	23
08.01.02	8	(467,224),(471,229)	(469.2941, 226.7647)	469.2941	17
09.01.02	9	(494,229),(496,234)	(495.4444, 231.2222)	495.4444	9

The following sunspots were taken for the month of April 2001.

Sunspot #9

Sunspot description	This sunspot comes out form the top left of the sun. It is a single sunspot that grows and shrinks. It has two specks of sunspots following it till its death. These specks die out as well when they die.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
05.04.01	1	(63, 133), (68,140)	(65.6071, 136.2143)	65.6071	28
06.04.01	2	(74,130), (79,139)	(76.3143, 133.7714)	76.3143	35
07.04.01	3	(116,123), (123,132)	(119.2200, 127.3800)	119.2200	50
08.04.01	4	(171,119), (181,127)	(176.3333, 123.4561)	176.3333	57
09.04.01	5	(218,118), (229,126)	(224.2679, 122.7321)	224.2679	56
10.04.01	6	(269,119), (279,127)	(273.7846, 123.5385)	273.7846	65
11.04.01	7	(318,120), (327,129)	(323.2308, 125.8077)	323.2308	52
12.04.01	8	(365,125), (373,133)	(368.7955, 128.8409)	368.7955	44
13.04.01	9	(405,129), (412,136)	(408.6364, 132.8182)	408.6364	33
14.04.01	10	(437,134), (443,141)	(440.0417, 137.3333)	440.0417	24
15.04.01	11	(460,139), (464,145)	(462.0000, 142.3750)	462.0000	16

Sunspot #10

Sunspot description	This sunspot emerges from just below the equator. It is a relatively small sunspot that dies with other small specks of sunspots.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
06.04.01	1	(18,275),(20,280)	(19.0000, 277.5000)	19.0000	4
07.04.01	2	(42,268),(46,274)	(44.2667, 271.0000)	44.2667	15
08.04.01	3	(89,262),(93,268)	(91.1304, 265.2174)	91.1304	23
09.04.01	4	(134,260),(139,265)	(136.7143, 262.3810)	136.7143	21
10.04.01	5	(186,259),(191,264)	(188.5769, 261.7692)	188.5769	26
11.04.01	6	(241,259),(247,264)	(244.1250, 261.3333)	244.1250	24
12.04.01	7	(297,260),(303,265)	(300.0000, 262.3500)	300.0000	20
13.04.01	8	(352,263),(256,267)	(353.5000, 264.6000)	353.5000	10
14.04.01	9	(401,267),(403,270)	(401.8333, 268.8333)	401.8333	6
15.04.01	10	(442,273),(444,274)	(443.0000, 273.5000)	443.0000	2

Sunspot #11

Sunspot description	In the beginning of the cycle, this sunspot remains a single sunspot and is not surrounded by any other sunspot. However by the end of the cycle it is surrounded by smaller spots preceding it. It originates from slightly above the equator from the left.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
14.04.01	1	(28,210),(31,217)	(29.4615, 213.7692)	29.4615	13
15.04.01	2	(53,206),(57,212)	(55.1739, 208.8696)	55.1739	23
16.04.01	3	(109,200),(115,207)	(111.8529, 203.0588)	111.8529	34
19.04.01	6	(223,196),(230,202)	(226.8611, 199.6111)	226.8611	36
20.04.01	8	(299,198),(305,204)	(301.7576, 200.6364)	301.7576	33
21.01.01	9	(352,199),(359,205)	(355.2857, 201.9286)	355.2857	28
22.01.01	10	(400,202),(405,207)	(402.5556, 204.3889)	402.5556	18
23.01.01	11	(441,206),(444,210)	(442.1250, 207.8750)	442.1250	8
25.01.01	13	(485,213),(487,215)	(486 , 214)	486	1

Sunspot #12

Sunspot description	This sunspot seems to move across the equator and is one of the largest sunspots of the month.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
21.04.01	1	(18,289),(22,298)	(20.0000, 293.2000)	20.0000	20
22.04.01	2	(33,284),(38,293)	(35.6296, 288.2222)	35.6296	27
23.04.01	3	(60,280),(66,289)	(62.7333, 284.3111)	62.7333	45
25.04.01	5	(126,275),(134,285)	(129.6230, 280.1639)	129.6230	61
26.04.01	6	(193,274),(202,284)	(197.2794, 279.0882)	197.2794	68
27.04.01	7	(229,274),(238,284)	(233.5000, 279.3857)	233.5000	70
28.04.01	8	(302,276),(310,285)	(306.2535, 280.4366)	306.2535	71
29.04.01	9	(358,278),(265,287)	(361.3684, 282.1754)	361.3684	57
30.04.01	10	(401,280),(408,289)	(404.5745, 284.7872)	404.5745	47

The following sunspots were taken for the month of October 2002.

Sunspot #13

Sunspot description	This sunspot moves across the top of the equator and is followed by two large groups of sunspots.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
09.10.02	1	(24,209),(27,215)	(25.1176, 212.1765)	25.1176	17
10.10.02	2	(46,215),(50,222)	(47.9655, 218.6207)	47.9655	29
11.10.02	3	(78,220),(83,227)	(80.6111, 223.3611)	80.6111	36
12.10.02	4	(134,225),(141,232)	(137.5909, 228.3409)	137.5909	44
13.10.02	5	(191,228),(198,235)	(194.6061, 232.6970)	194.6061	33
14.10.02	6	(247,230),(254,237)	(250.0851, 233.1064)	250.0851	47
15.10.02	7	(275,230),(282,237)	(278.1458, 233.3542)	278.1458	48
16.10.02	8	(327,229),(334,236)	(330.5745, 233.0426)	330.5745	47
17.10.02	9	(381,227),(387,233)	(384.1579, 230.2105)	384.1579	38
18.10.02	10	(429,223),(435,230)	(432.2500, 226.3125)	432.2500	32
20.10.02	12	(483,216),(486,222)	(484.8000, 218.6000)	484.8000	15

Sunspot #14

Sunspot description	This sunspot moves above the equator. It is followed a large group of sunspots and it also appears to be the largest single sunspot of the month.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
18.10.02	1	(39,153),(47,166)	(42.5775, 160.0000)	42.5775	71
20.10.02	3	(79,160),(91,175)	(84.7518, 167.3972)	84.7518	141
21.10.02	5	(115,163),(127,178)	(121.3312, 170.2994)	121.3312	157
22.10.02	6	(160,165),(174,181)	(167.3497, 172.3169)	167.3497	183
23.10.02	7	(204,166),(220,181)	(212.4646, 173.2475)	212.4646	198
24.10.02	8	(277,166),(293,182)	(285.1196, 173.5072)	285.1196	209
25.10.02	9	(309,164),(325,181)	(316.9747, 172.6162)	316.9747	198
26.10.02	10	(356,163),(372,178)	(363.8108, 170.7027)	363.8108	185
27.10.02	11	(410,160),(422,174)	(416.2517, 167.1119)	416.2517	143
28.10.02	12	(434,157),(445,171)	(439.5000, 164.0000)	439.5000	180
29.10.02	13	(461,152),(469,167)	(464.8333, 159.8056)	464.8333	72

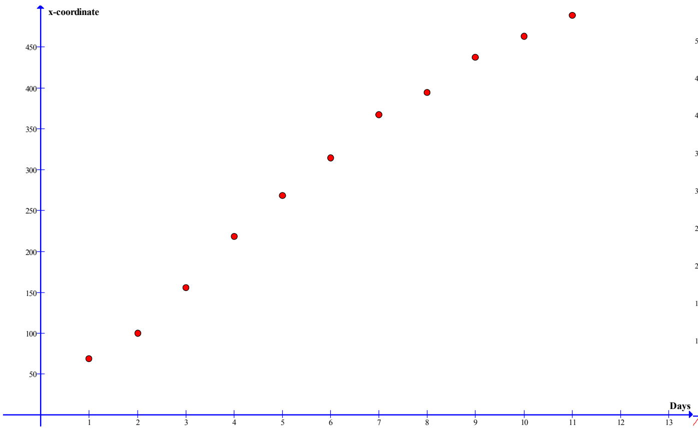
Sunspot #15

Sunspot description	This sunspot lies fairly below the equator. It is almost a small speck but it is surrounded by smaller specks of spot below and behind it.				
Date	Day	Coordinates of sunspot matrix	Coordinates of centre of sunspot	x-coordinate	Area
13.10.02	1	(32,299),(37,307)	(34.3750, 303.4167)	34.3750	24
14.10.02	2	(60,305),(65,312)	(62.5676, 308.5676)	62.5676	37
15.10.02	3	(78,307),(84,314)	(81.0526, 310.6316)	81.0526	38
16.10.02	4	(119,311),(125,318)	(122.0638, 314.5532)	122.0638	47
17.10.02	5	(172,314),(179,321)	(175.0638, 317.7872)	175.0638	47
18.10.02	6	(232,316),(239,323)	(235.6458, 319.3958)	235.6458	48
20.10.02	8	(333,315),(339,321)	(335.8421, 318.2105)	335.8421	38
21.10.02	9	(384,313),(389,318)	(386.2000, 315.4333)	386.2000	30
22.10.02	10	(429,309),(434,315)	(431.8462, 311.5385)	431.8462	26
23.10.02	11	(461,305),(465,311)	(463.2500, 308.0625)	463.2500	16

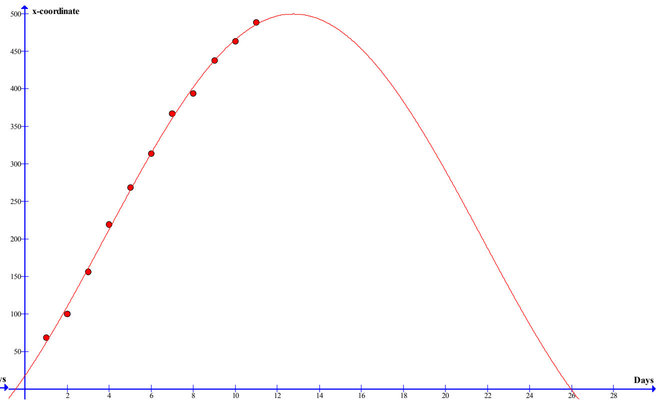
Data Processing

Sunspot #1

Distance sunspot travels in days:



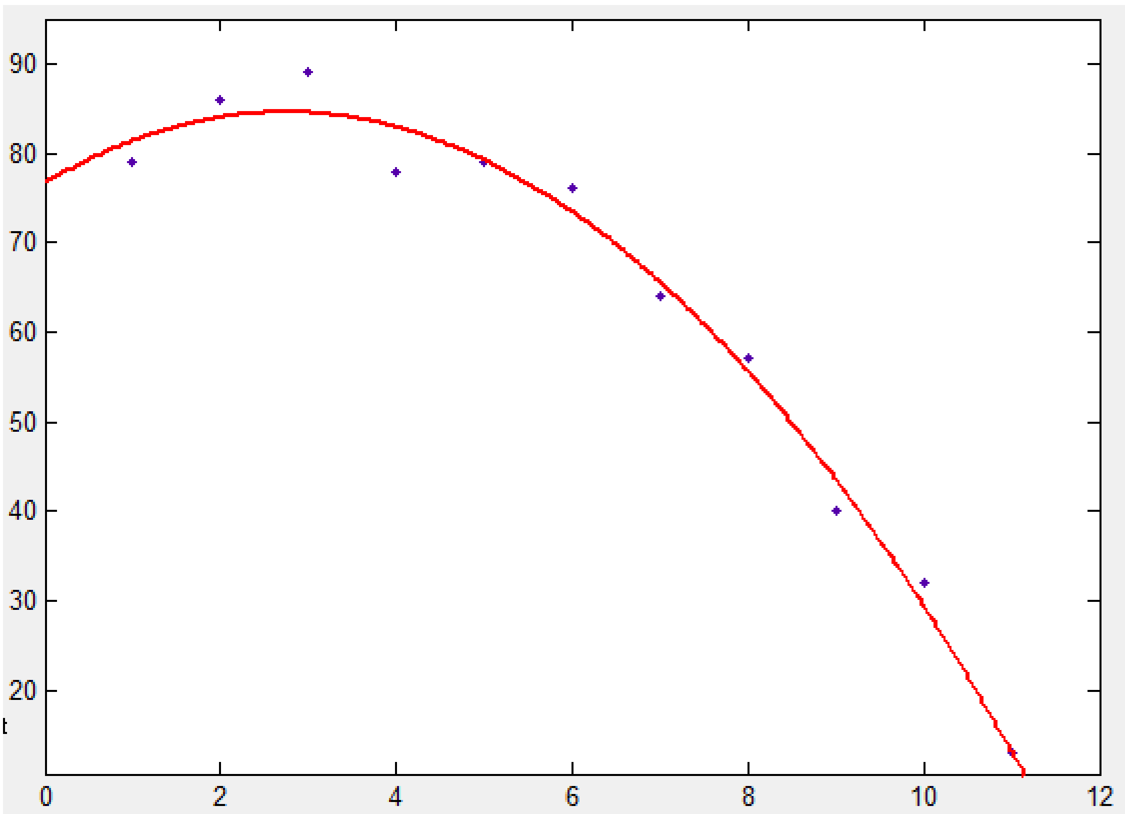
Function that best fits the curve:



Function: $f(x) = 201.06549 + 298.56821 \sin(0.207722x - 0.7971333))$

Speed of rotation of the sun (period of function): 30.24804935 days

Morphology of sunspot area over a period of days:

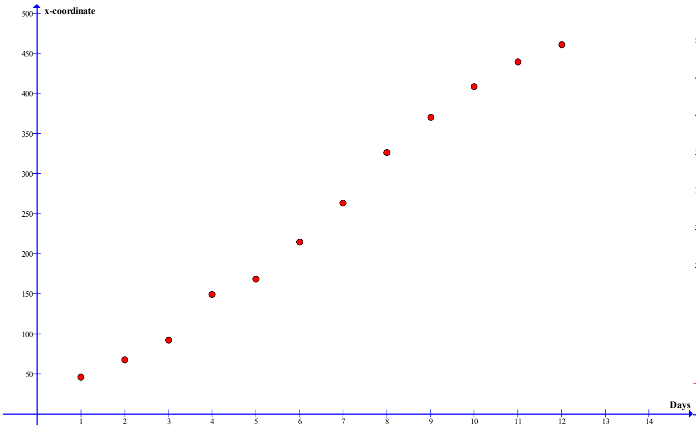


Function: $f(x)= -1.0466x^2 + 5.7413x + 76.697$

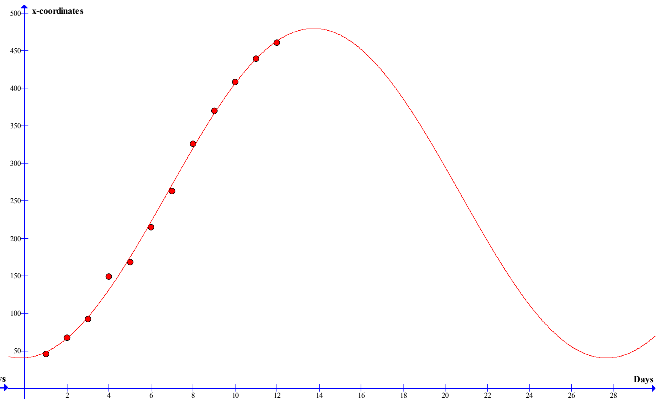
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #2

Distance sunspot travels in days:



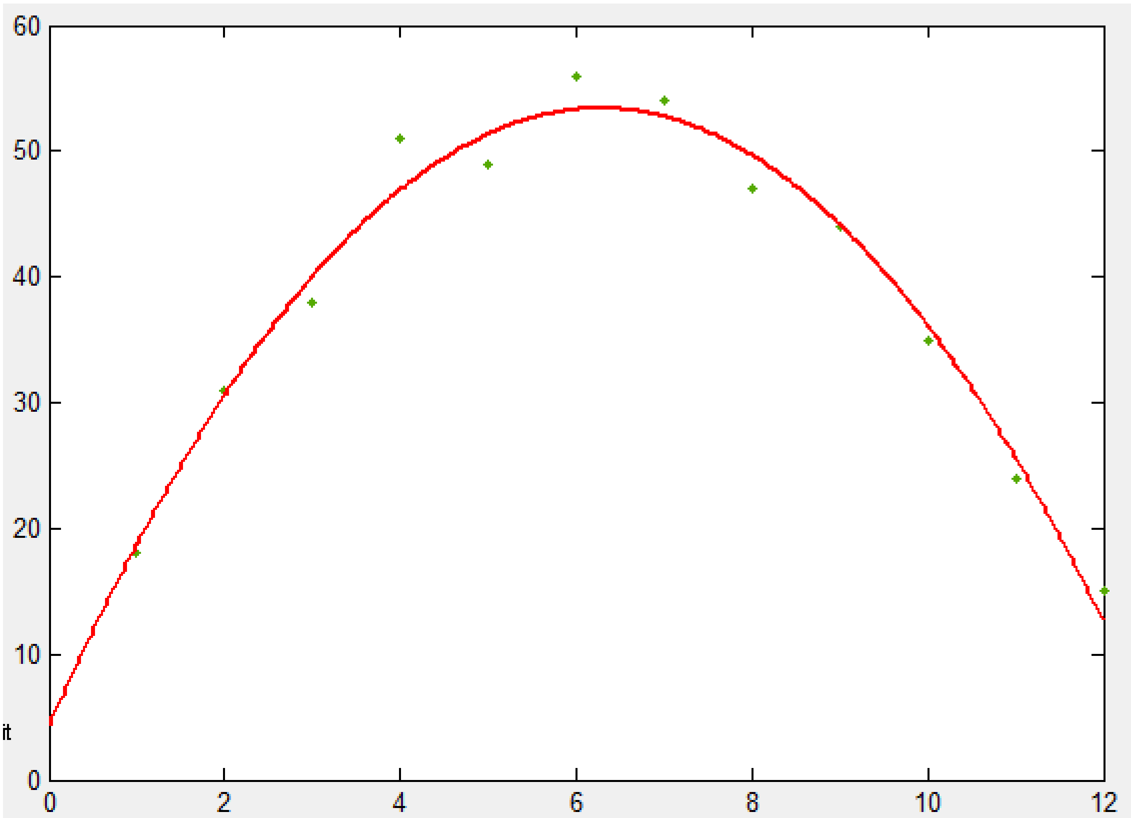
Function that best fits the curve:



Function: f(x) = 260.02374 -219.56915 sin(0.2255221x + 70.73021)

Speed of rotation of the sun (period of function): 27.66385207 days

Morphology of sunspot area over a period of days:

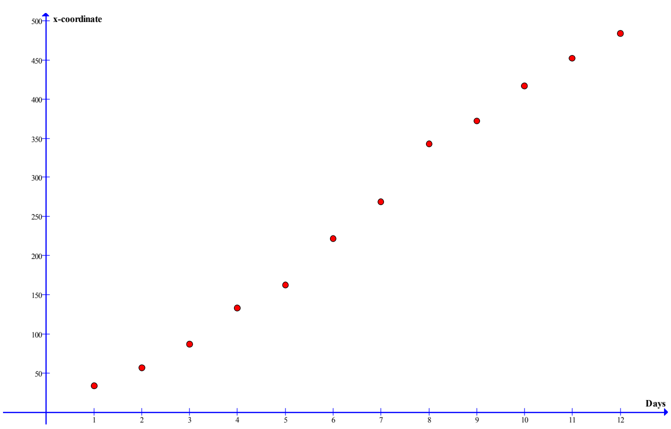


Function: $f(x) = -1.2453x^2 + 15.629x + 4.3636$

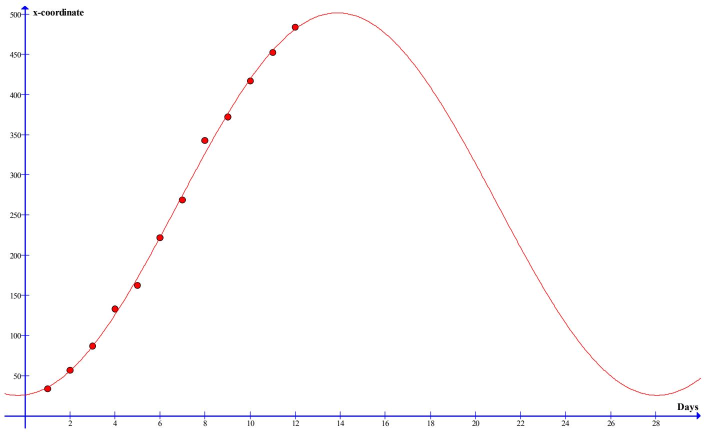
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #3

Distance sunspot travels in days:



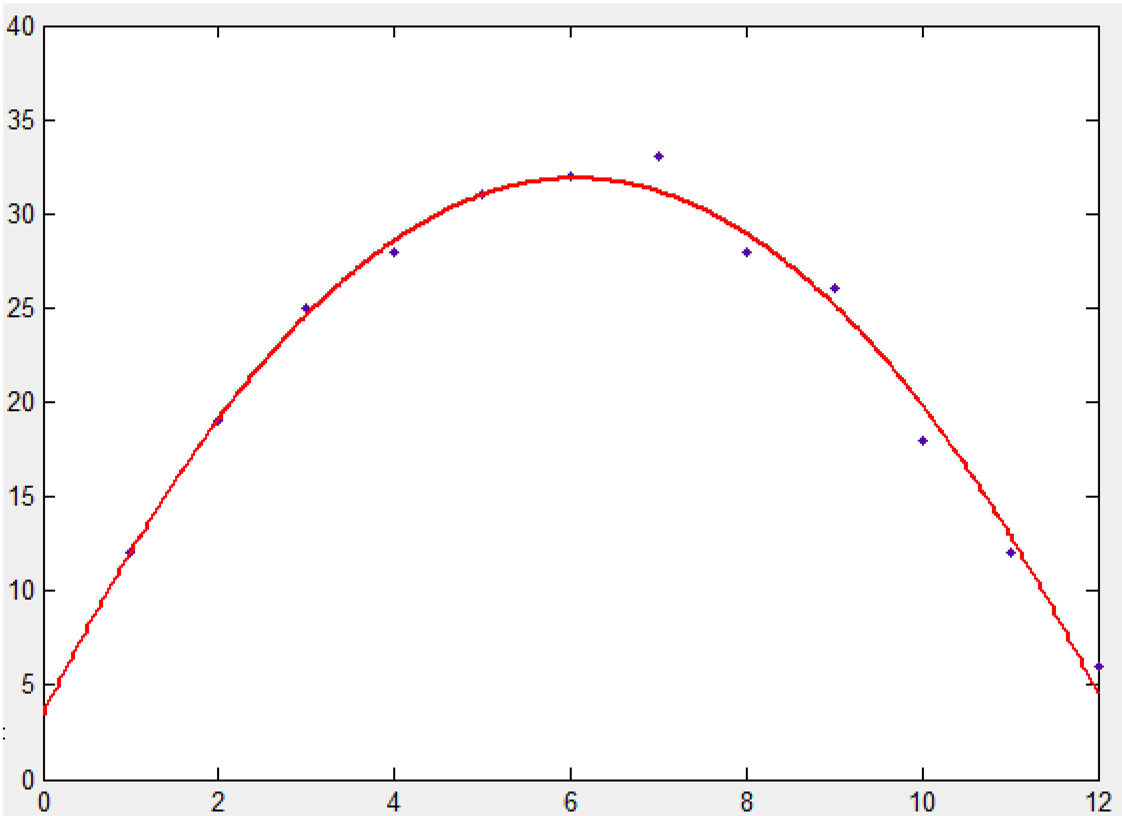
Function that best fits the curve:



Function: $f(x) = 263.50188 + 238.08583 \sin(0.22148594x - 1.5030709)$

Speed of rotation of the sun (period of function): 28.36832544 days

Morphology of sunspot area over a period of days:

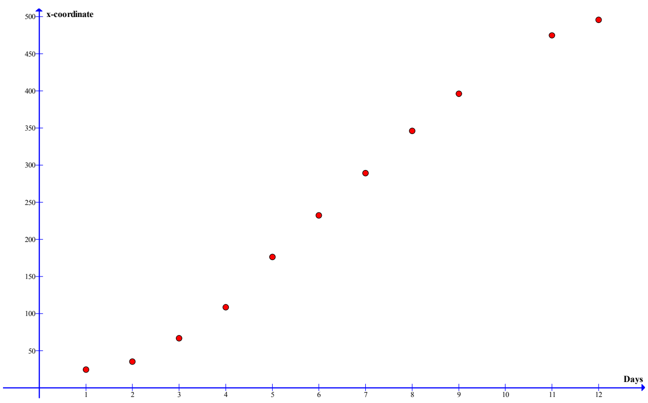


Function: $f(x) = -0.7732x^2 + 9.3666x + 3.5$

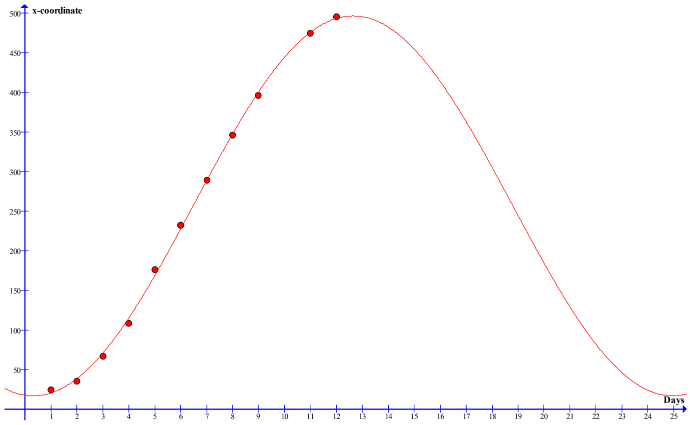
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #4

Distance sunspot travels in days:



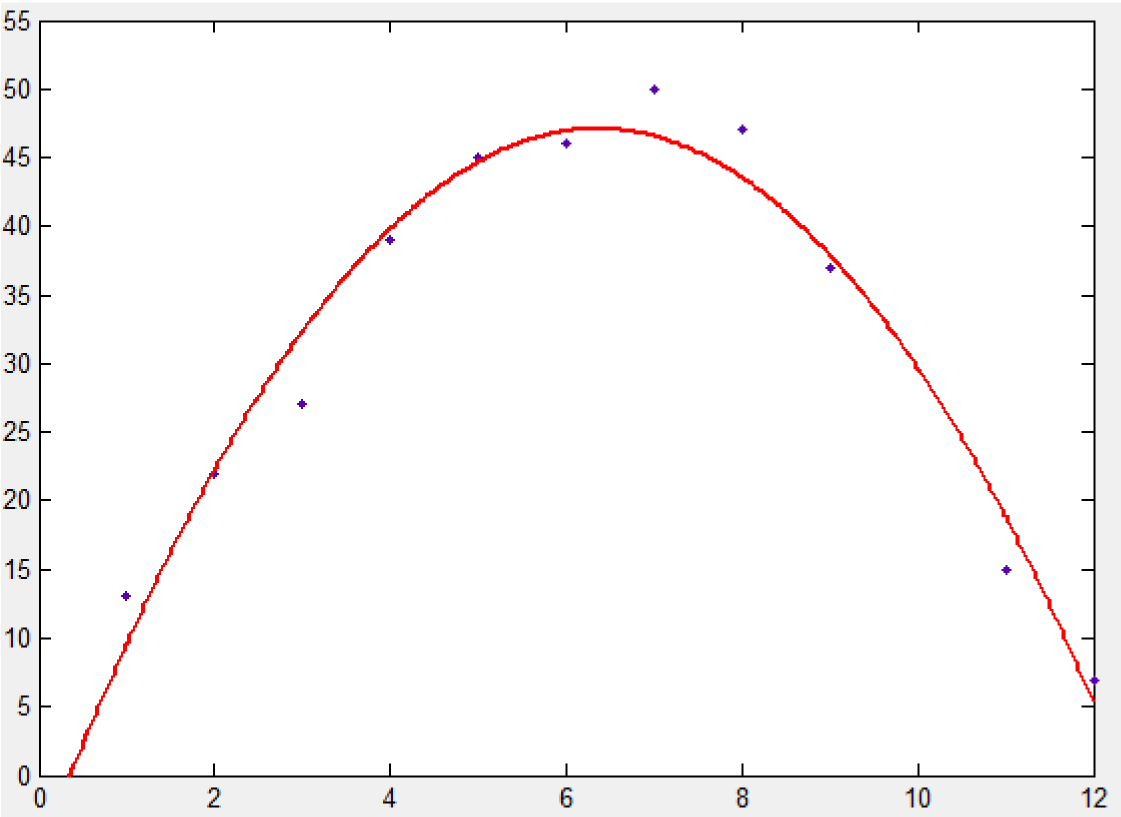
Function that best fits the curve:



Function: f(x) = 256.68658 + 239.87712 sin(0.2549724x + 130.29479)

Speed of rotation of the sun (period of function): 25.28036586 days

Morphology of sunspot area over a period of days:

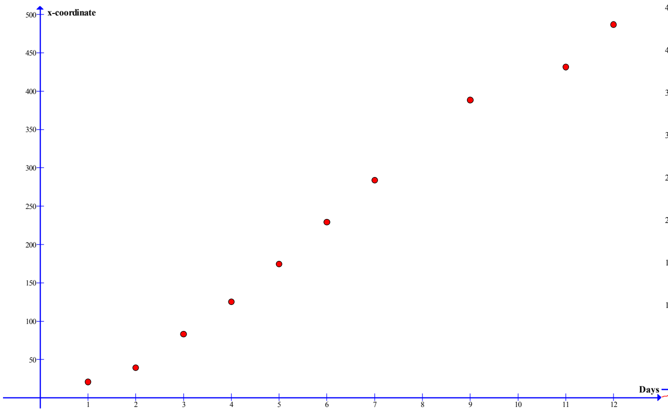


Function: f(x)= -1.3083x^2 + 16.622x - 5.7061

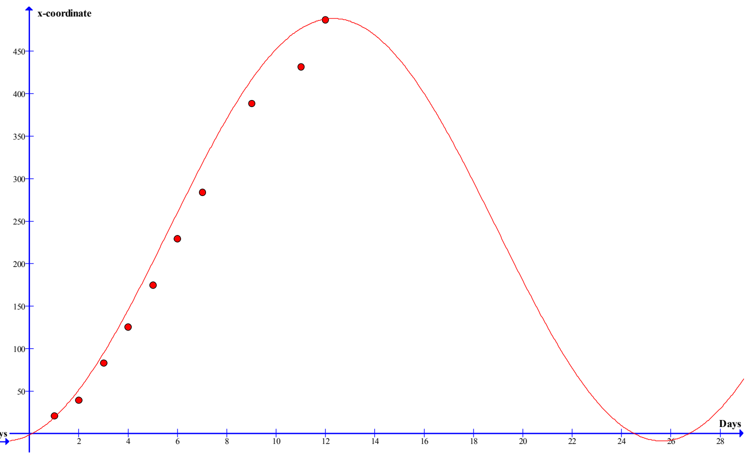
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #5

Distance sunspot travels in days:



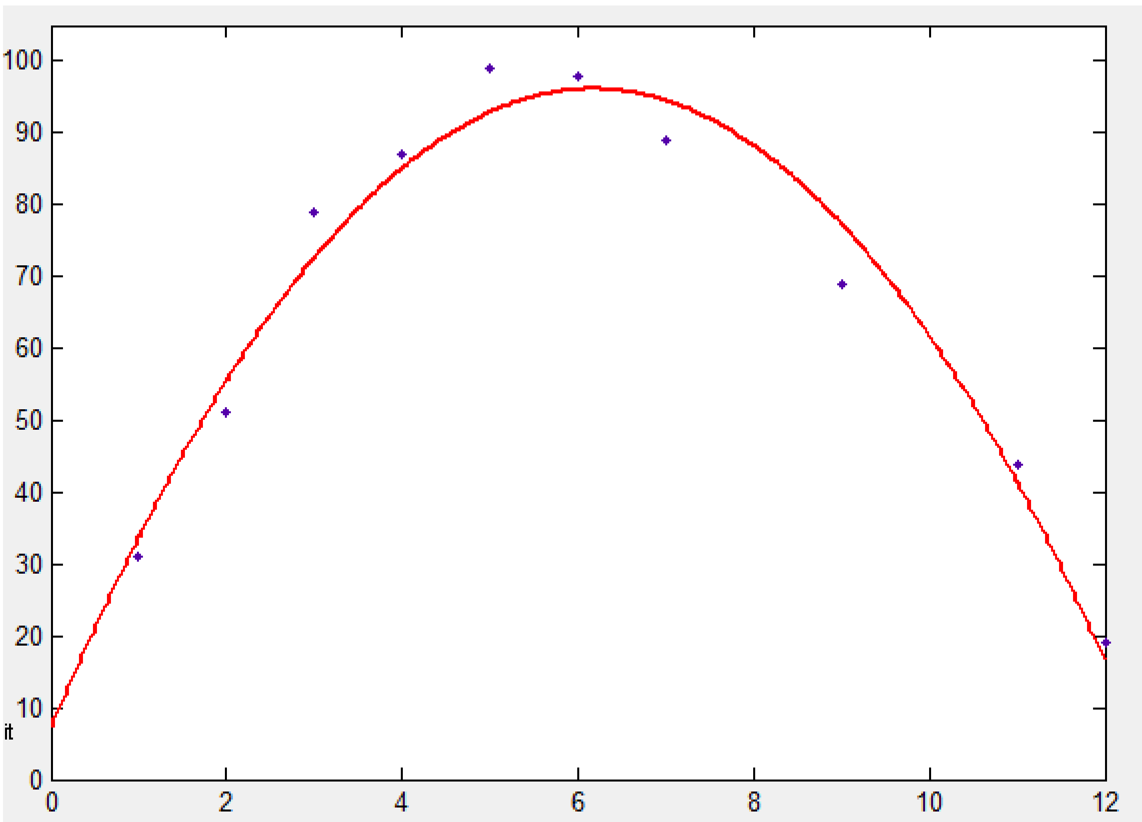
Function that best fits the curve:



Function: f(x) = 239.84608 + 248.55512 sin(0.23571051x- 1.3312602)

Speed of rotation of the sun (period of function): 26.65636465 days

Morphology of sunspot area over a period of days:

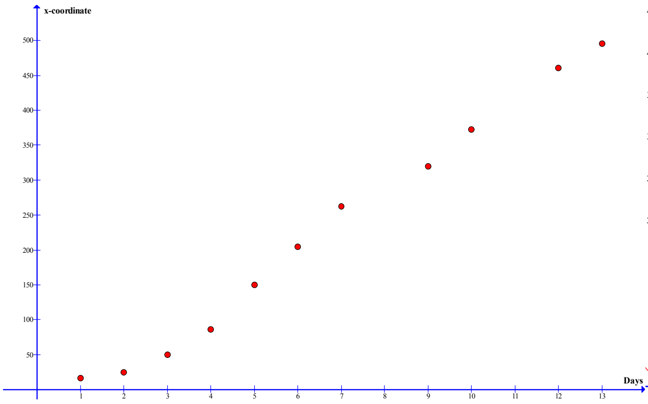


Function: $f(x) = -2.3381x^2 + 28.832x + 7.2369$

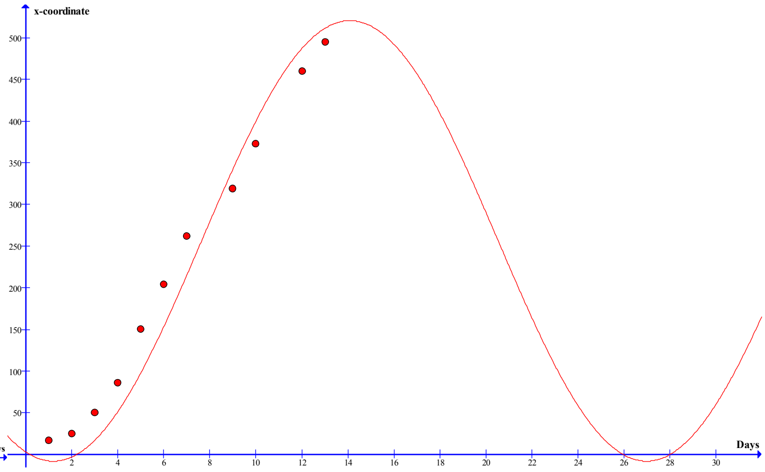
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #6

Distance sunspot travels in days:



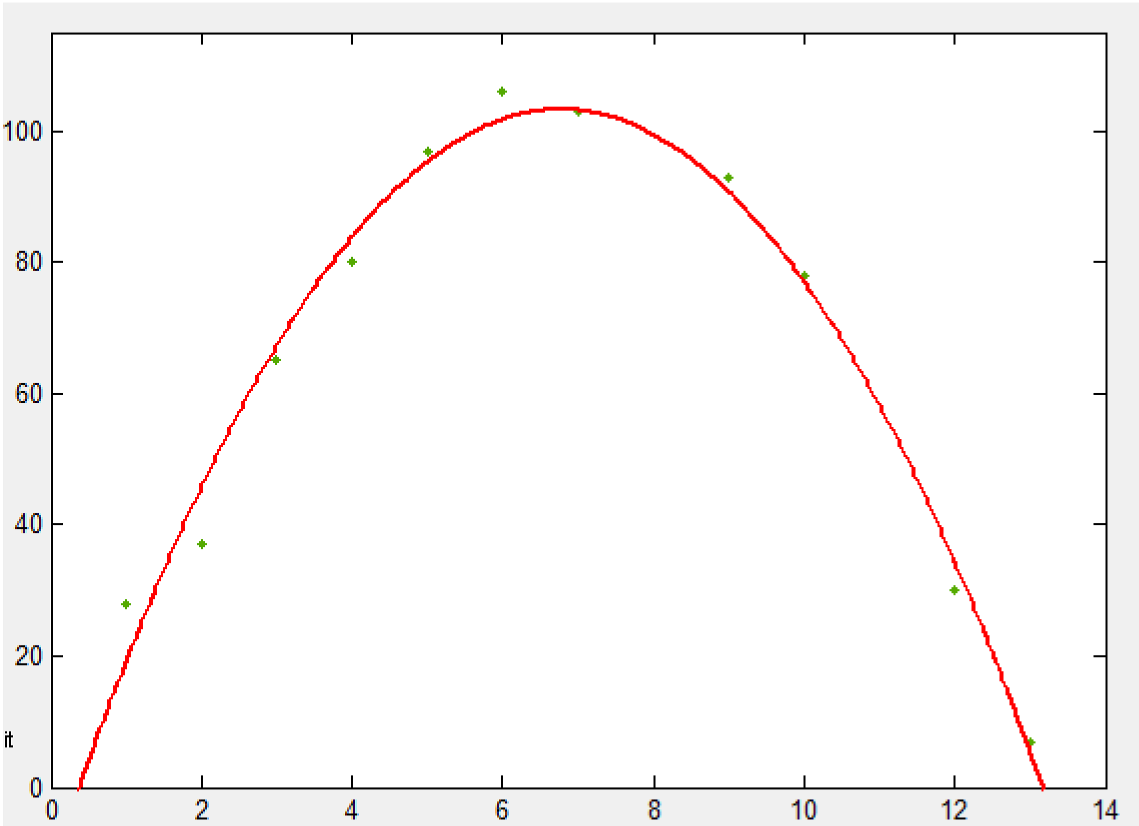
Function that best fits the curve:



Function: f(x) = 256.18878 + 264.48122 sin(-0.24531808x+105.10328)

Speed of rotation of the sun (period of function): 25.6124021 days

Morphology of sunspot area over a period of days:

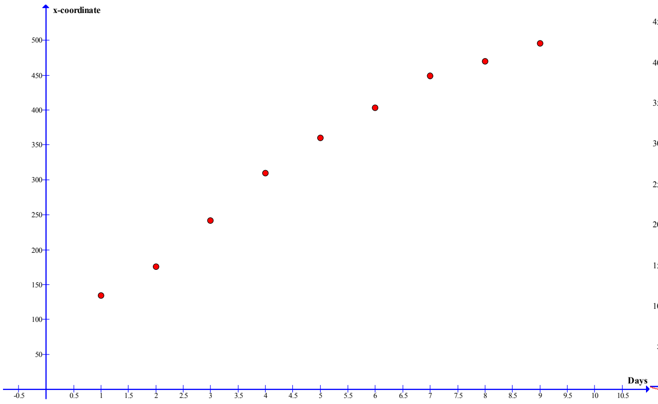


Function: $f(x) = -2.5223x^2 + 34.165x - 12.431$

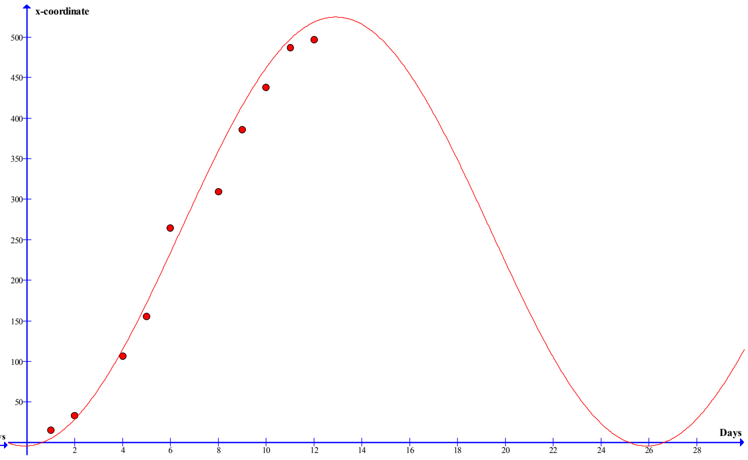
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #7

Distance sunspot travels in days:



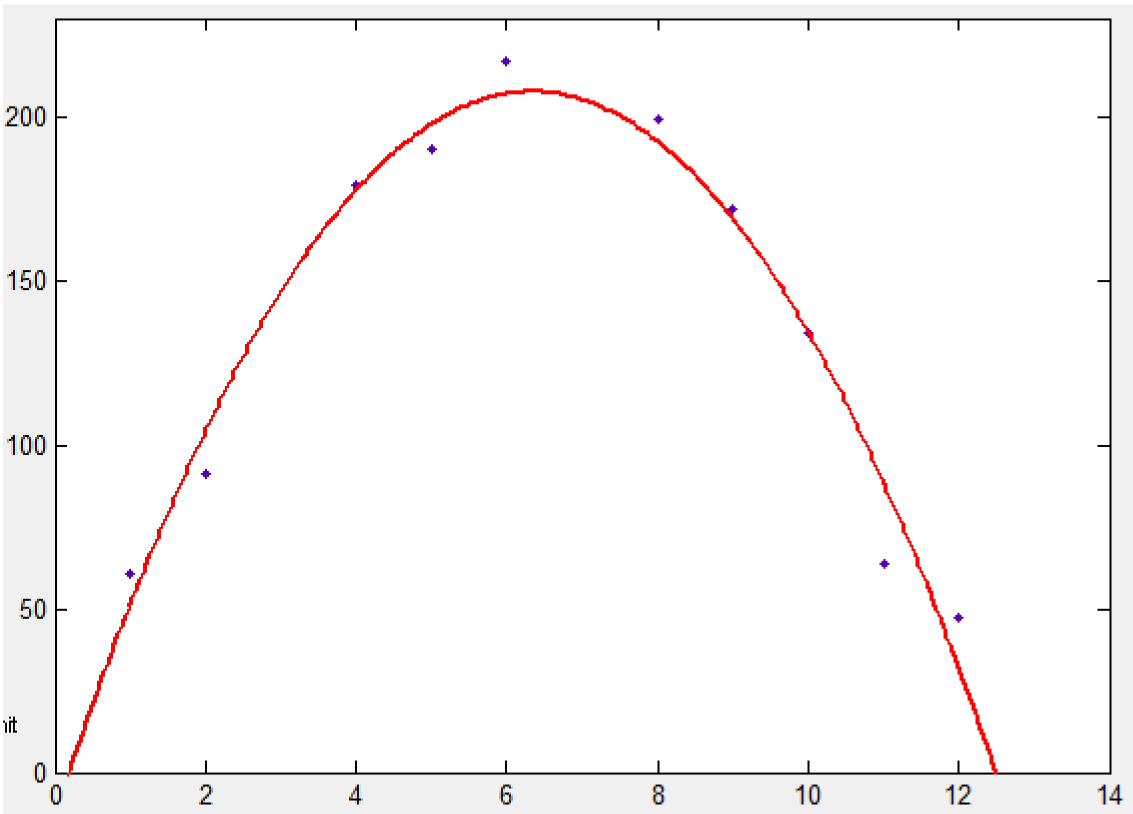
Function that best fits the curve:



Function: f(x) = 260.33577 - 264.65004 sin(0.241609318x - 1.5481306)

Speed of rotation of the sun (period of function): 26.00555872 days

Morphology of sunspot area over a period of days:

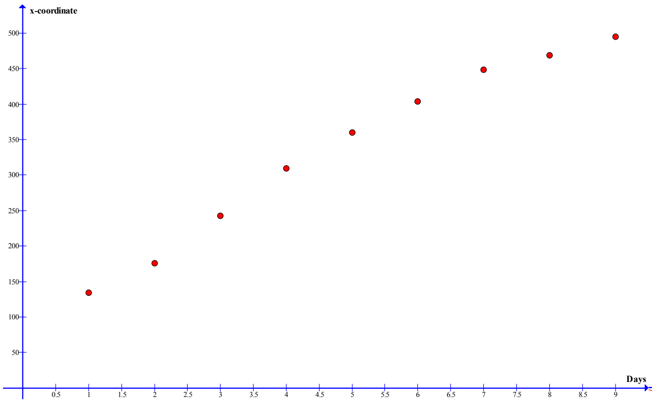


Function: $f(x) = -5.4764x^2 + 69.431x - 12.523$

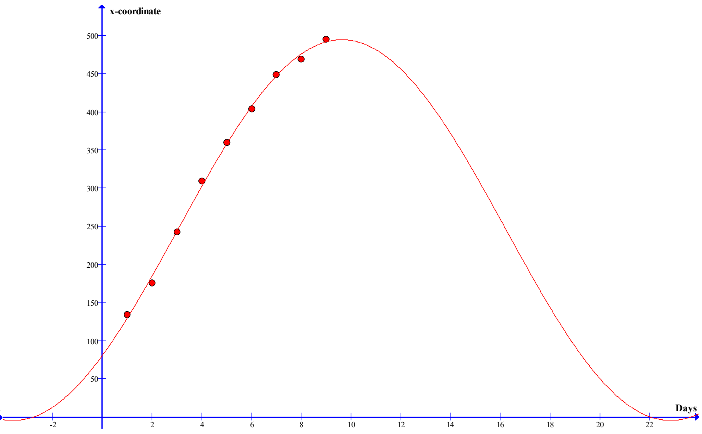
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #8

Distance sunspot travels in days:



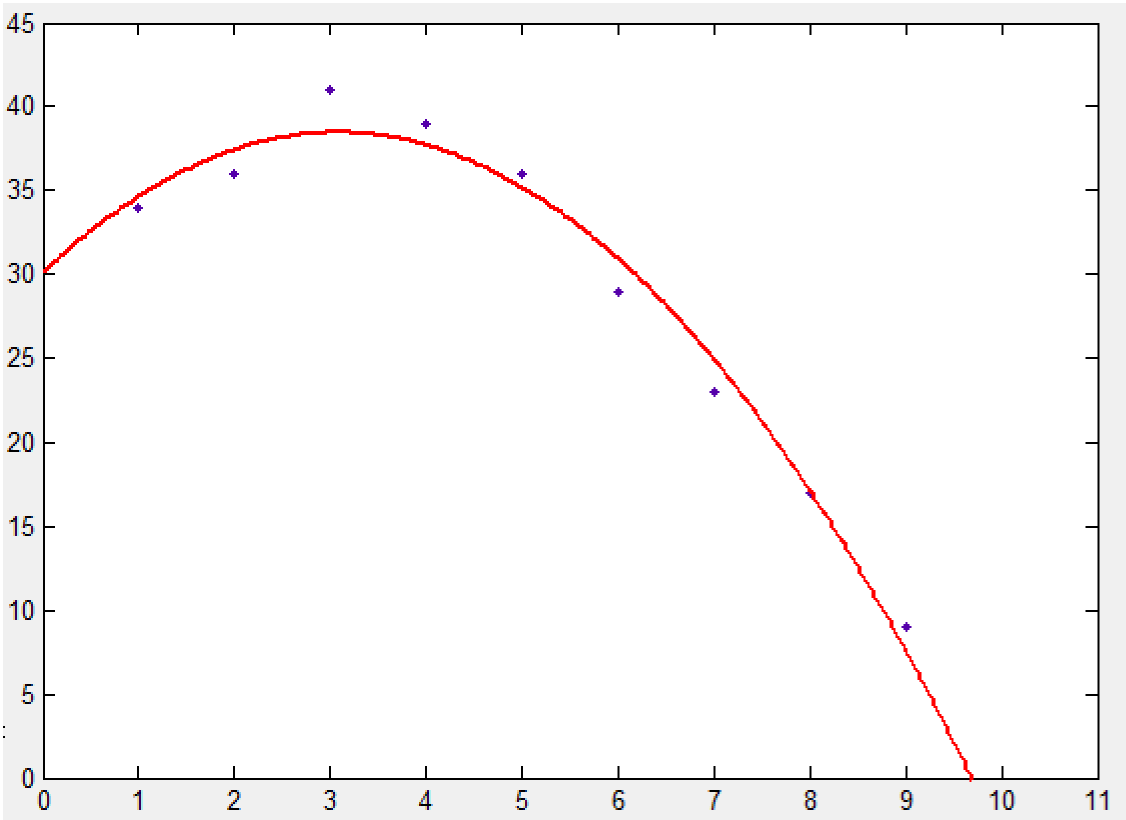
Function that best fits the curve:



Function: f(x) = 244.79842 + 249.59478 sin(0.23753543x - 0.71770959)

Speed of rotation of the sun (period of function): 26.45157106 days

Morphology of sunspot area over a period of days:

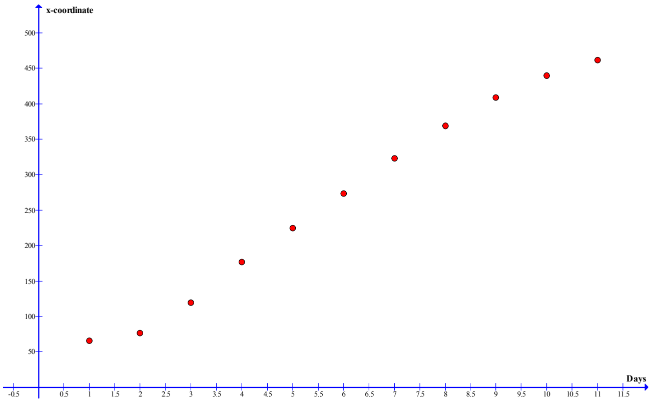


Function: $f(x) = -0.8799x^2 + 5.4154x + 30.119$

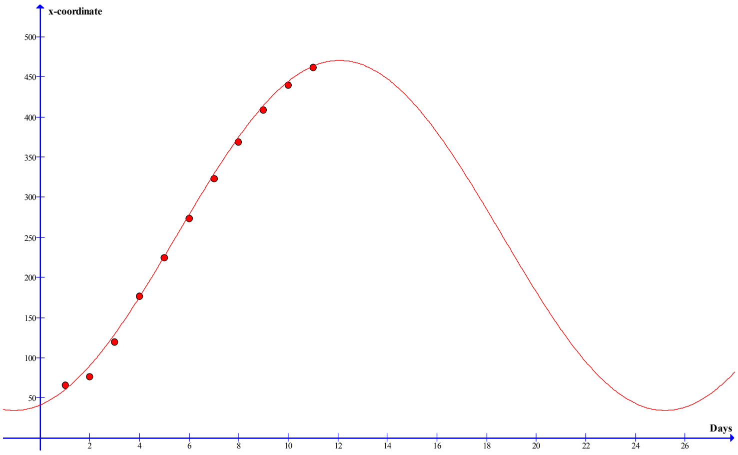
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #9

Distance sunspot travels in days:



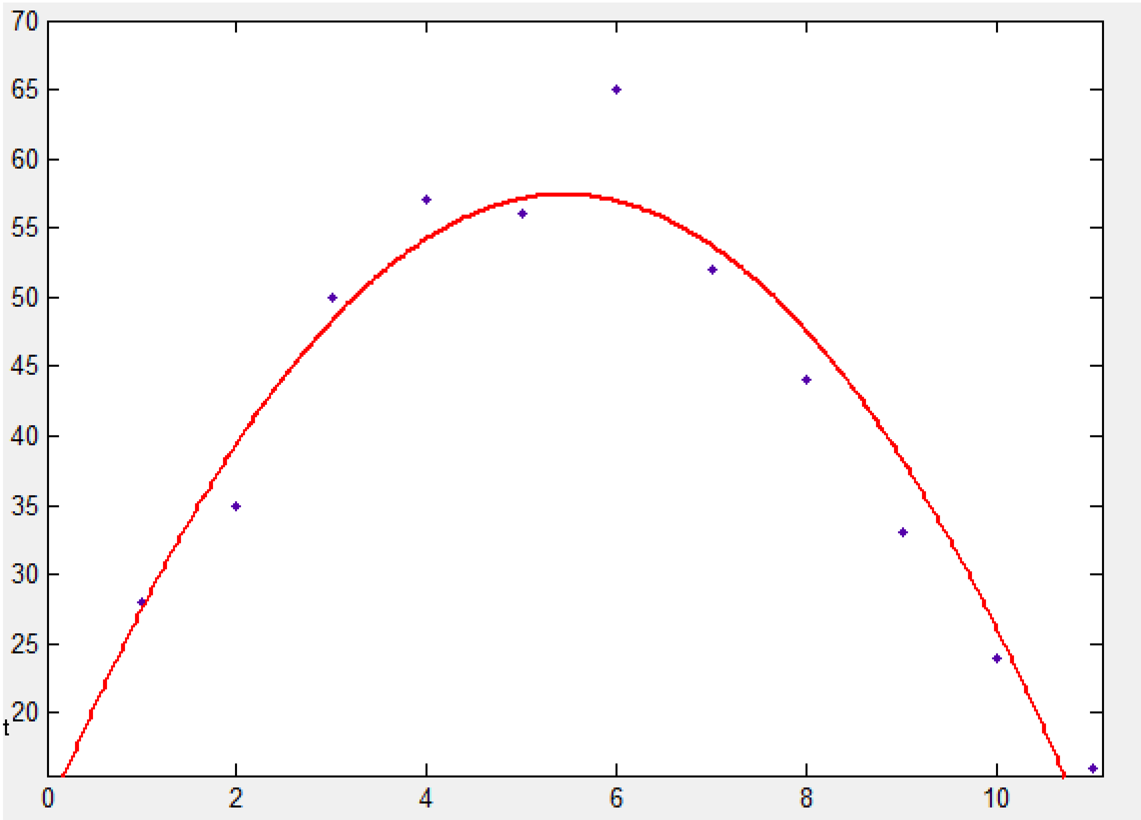
Function that best fits the curve:



Function: f(x) = 252.35941 - 218.1495 sin(-0.23935x+164.67989)

Speed of rotation of the sun (period of function): 26.25103533 days

Morphology of sunspot area over a period of days:

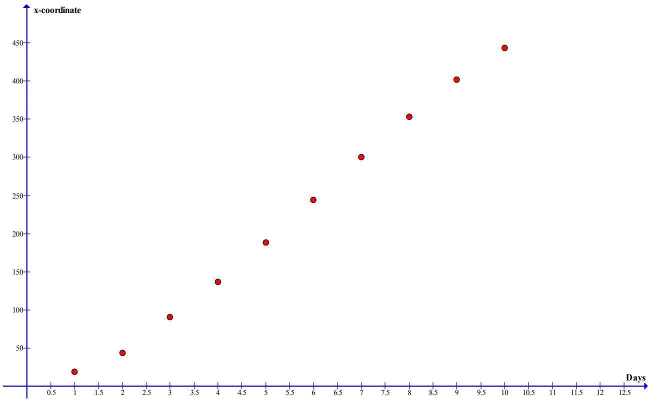


Function: $f(x) = -1.5117x^2 + 16.458x + 12.606$

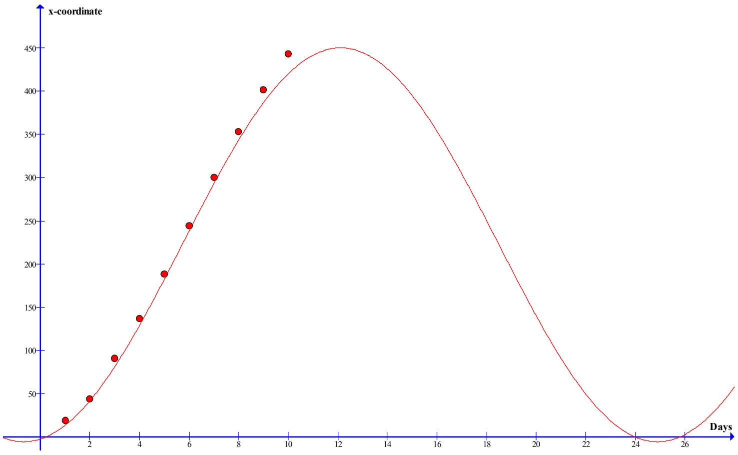
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #10

Distance sunspot travels in days:



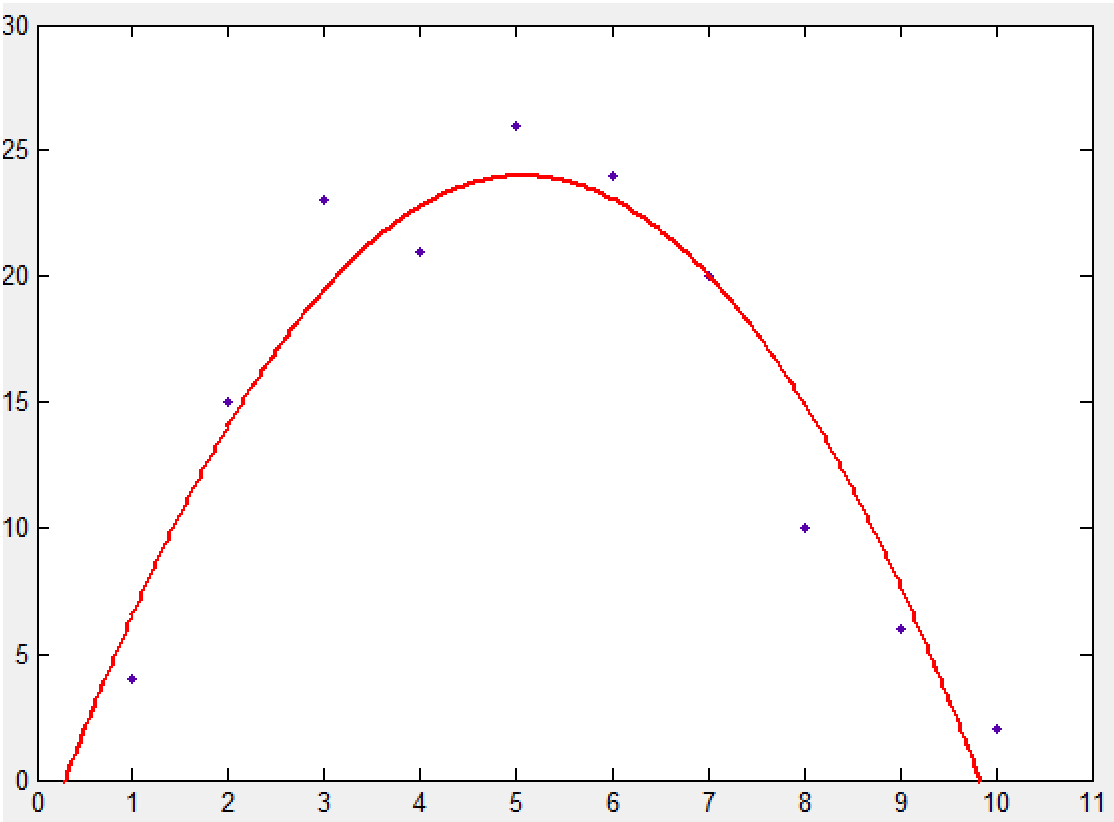
Function that best fits the curve:



Function: f(x) = 222.23598 + 227.800681 sin(-0.245765x + 287.28994)

Speed of rotation of the sun (period of function): 25.56582632 days

Morphology of sunspot area over a period of days:

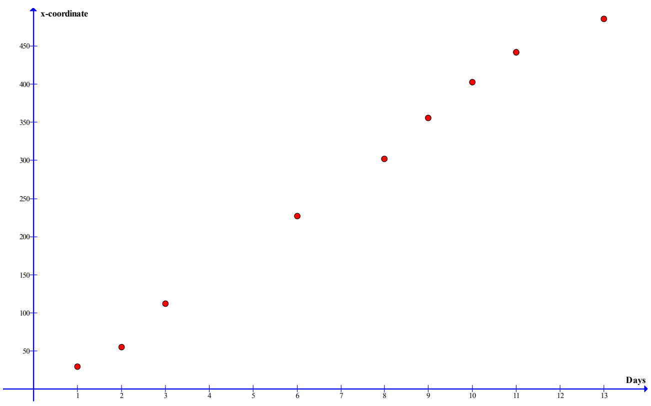


Function: f(x) = $-1.053x^2 + 10.668x - 3.0333$

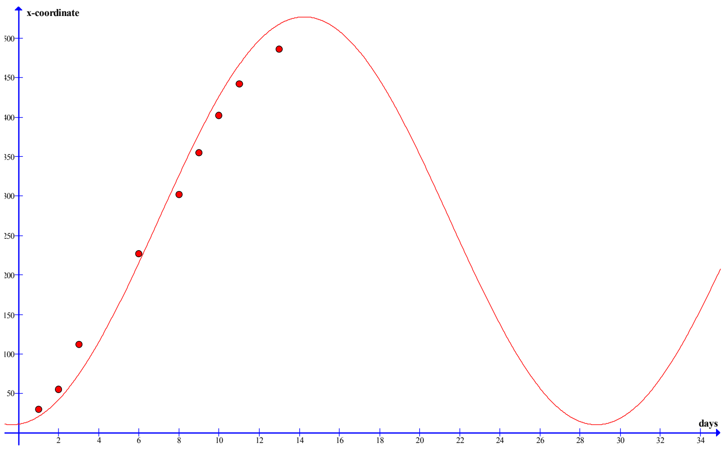
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #11

Distance sunspot travels in days:



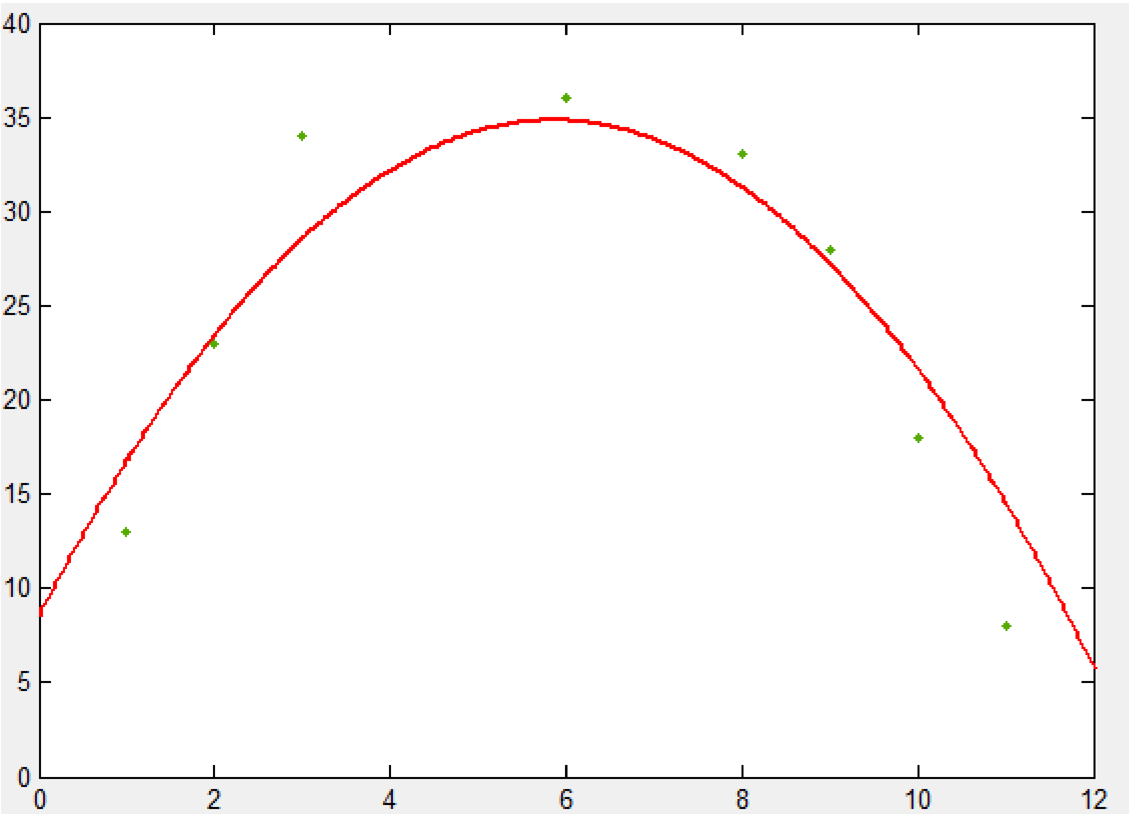
Function that best fits the curve:



Function: f(x) = 268.75292 + 258.52682 sin(0.242840367x + 4.78435875)

Speed of rotation of the sun (period of function): 25.87372678 days

Morphology of sunspot area over a period of days:

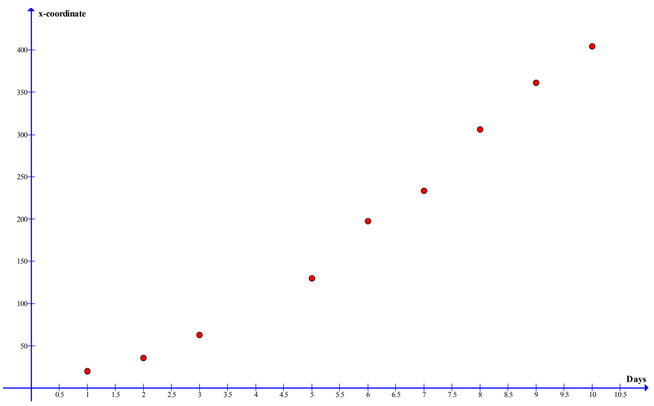


Function: $f(x) = -0.7665x^2 + 8.9739x + 8.5595$

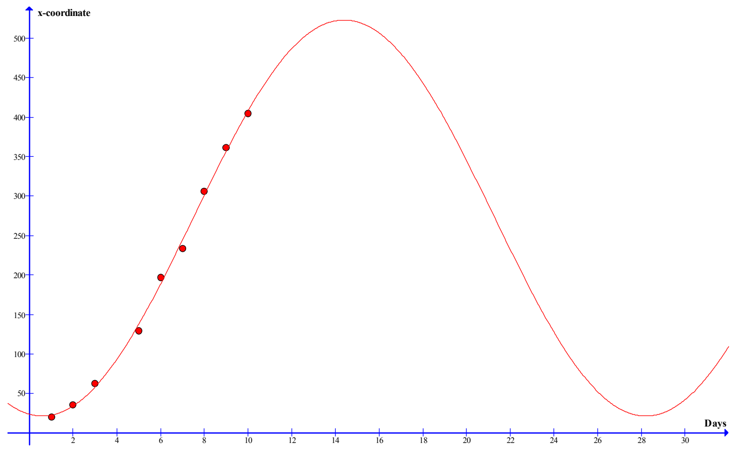
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #12

Distance sunspot travels in days:



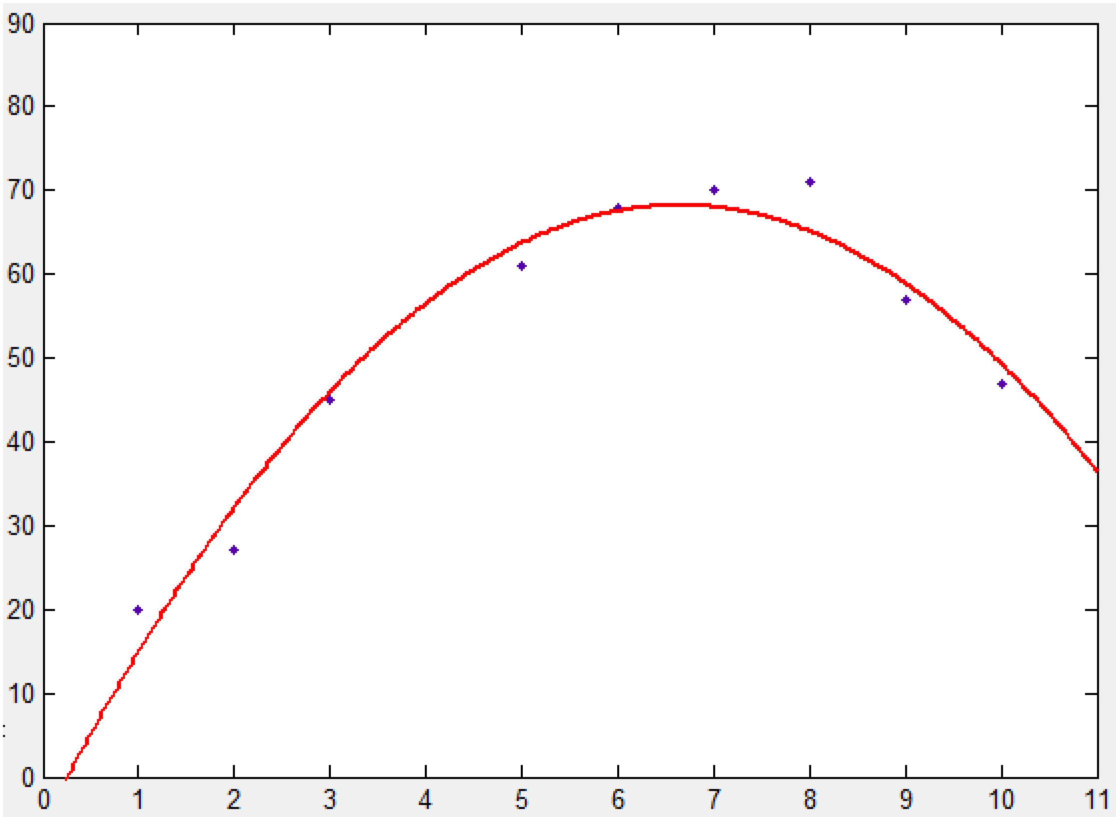
Function that best fits the curve:



Function: f(x) = 272.28082 + 250.96129 sin(0.22756662x - 1.7049027))

Speed of rotation of the sun (period of function): 27.61031193 days

Morphology of sunspot area over a period of days:

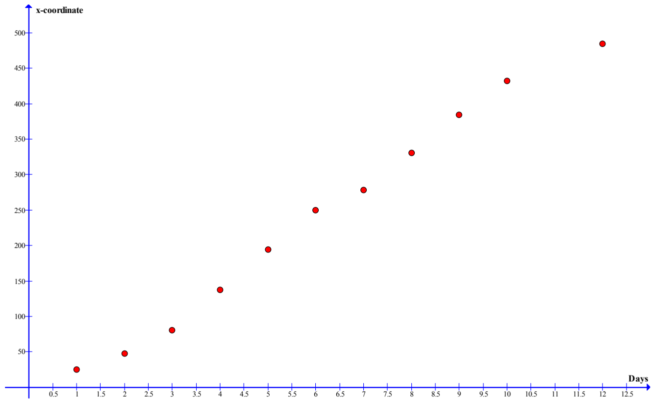


Function: $f(x) = -1.6731x^2 + 22.224x - 5.5616$

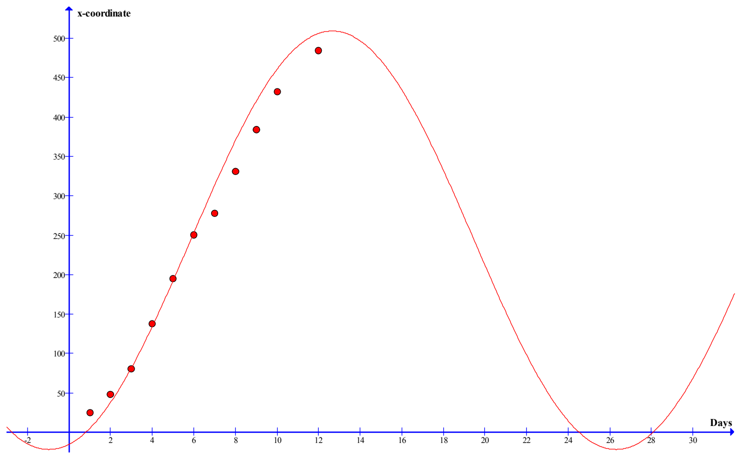
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #13

Distance sunspot travels in days:



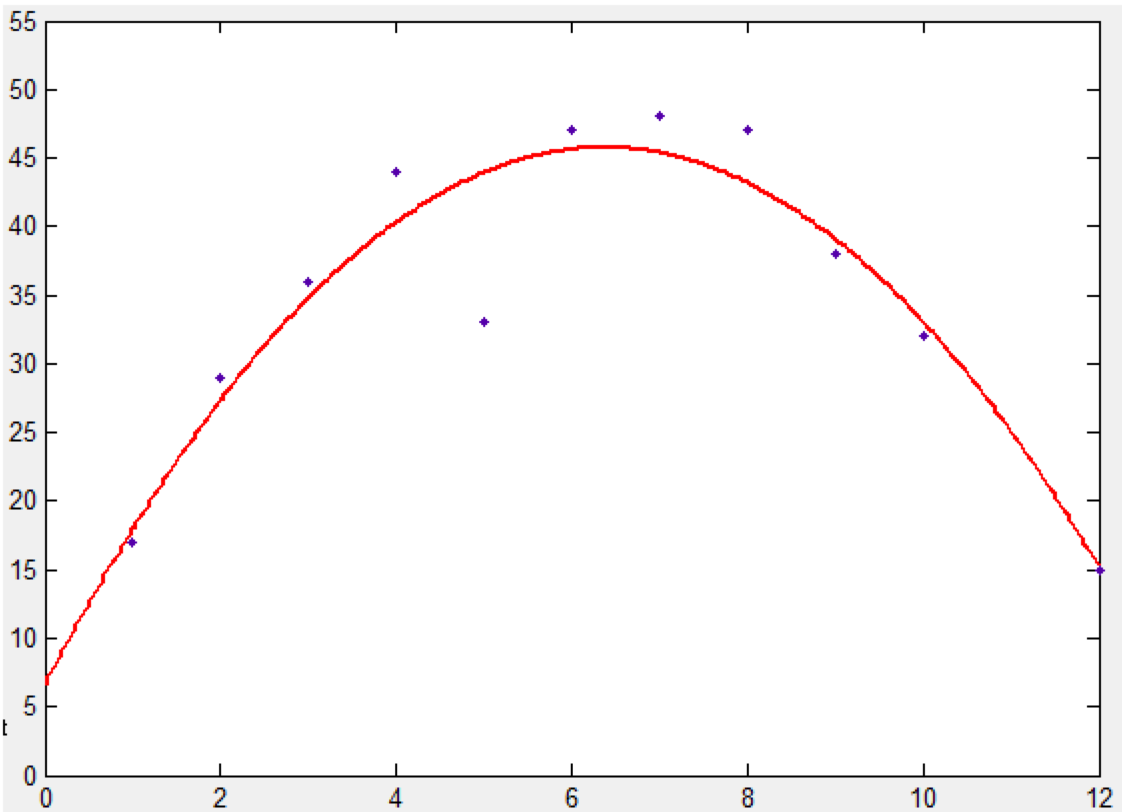
Function that best fits the curve:



Function: f(x) = 243.53225 + 265.63814 sin(0.23036359x -1.3467055)

Speed of rotation of the sun (period of function): 27.27480633 days

Morphology of sunspot area over a period of days:

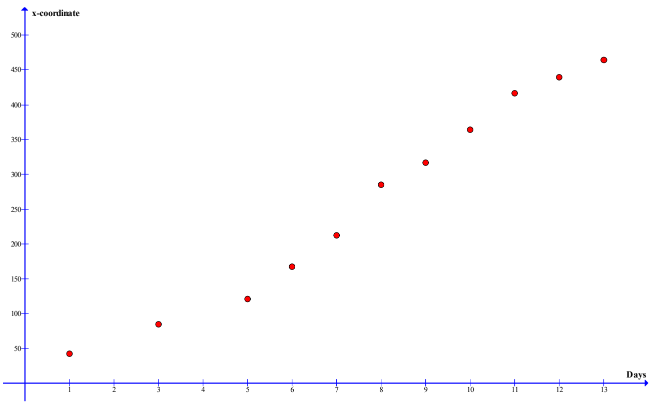


Function: f(x) = $-0.9637x^2 + 12.276x + 6.6653$

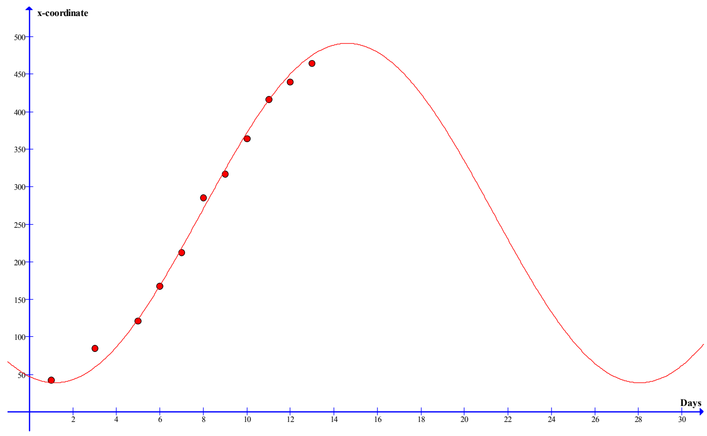
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #14

Distance sunspot travels in days:



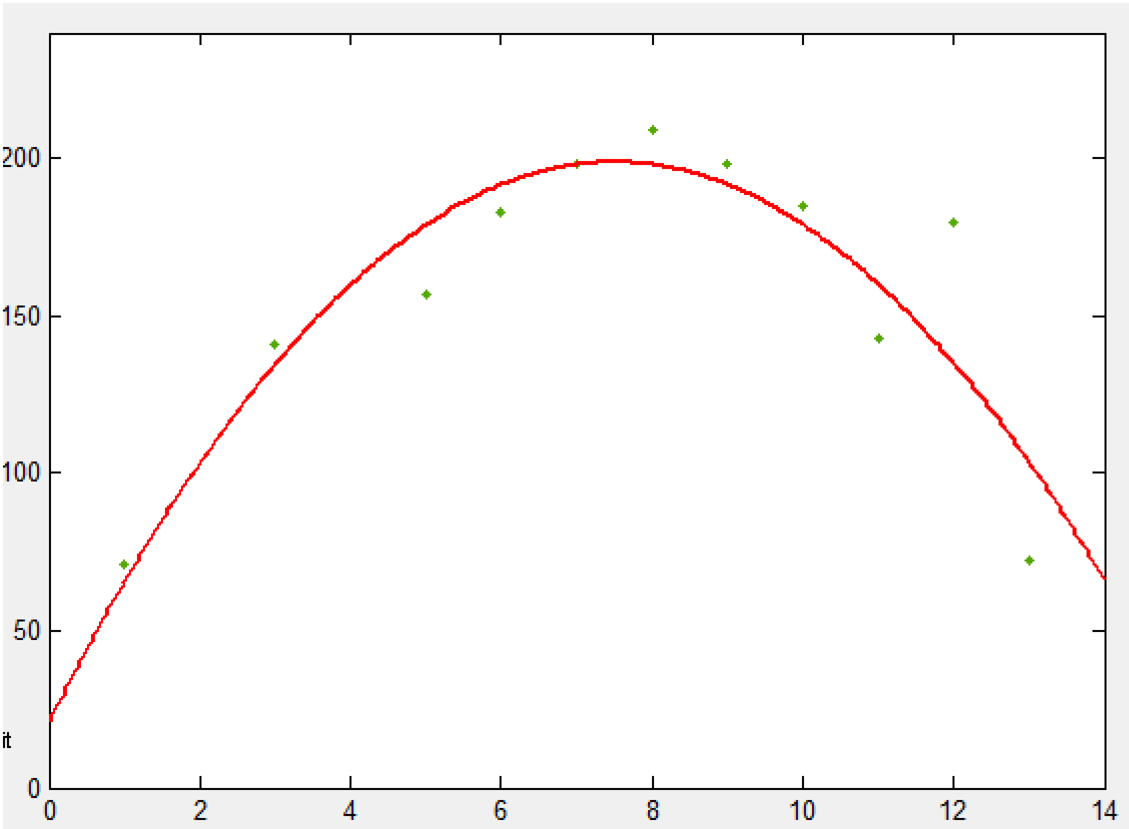
Function that best fits the curve:



Function: f(x) = 265.00219 + 226.24628 sin(0.23367195x - 1.8438654)

Speed of rotation of the sun (period of function): 26.88891545 days

Morphology of sunspot area over a period of days:

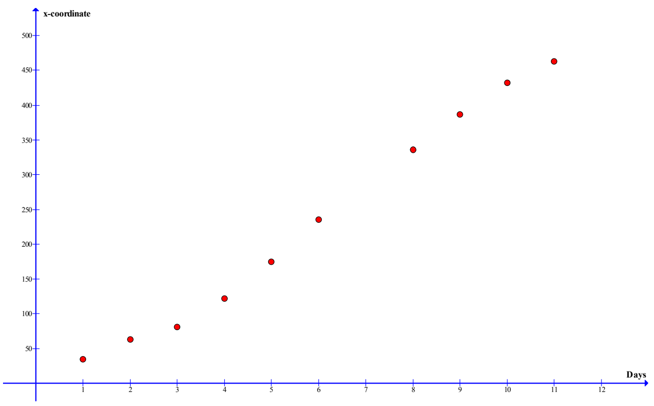


Function: $f(x) = -3.1538x^2 + 47.343x + 21.152$

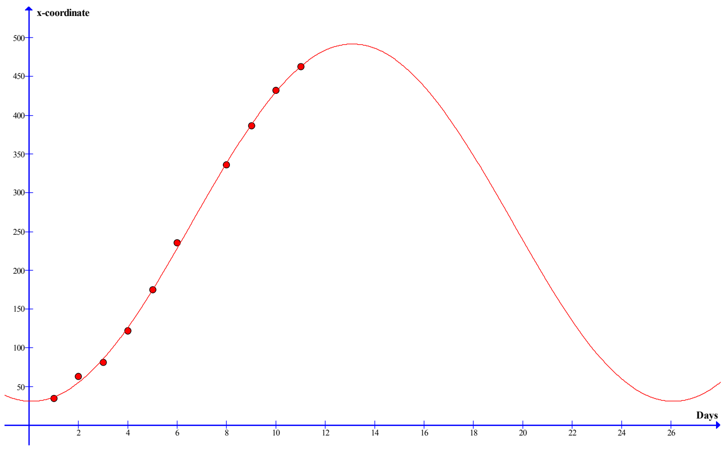
[Labels: x-axis: Days, y-axis: Area(pixels)]

Sunspot #15

Distance sunspot travels in days:



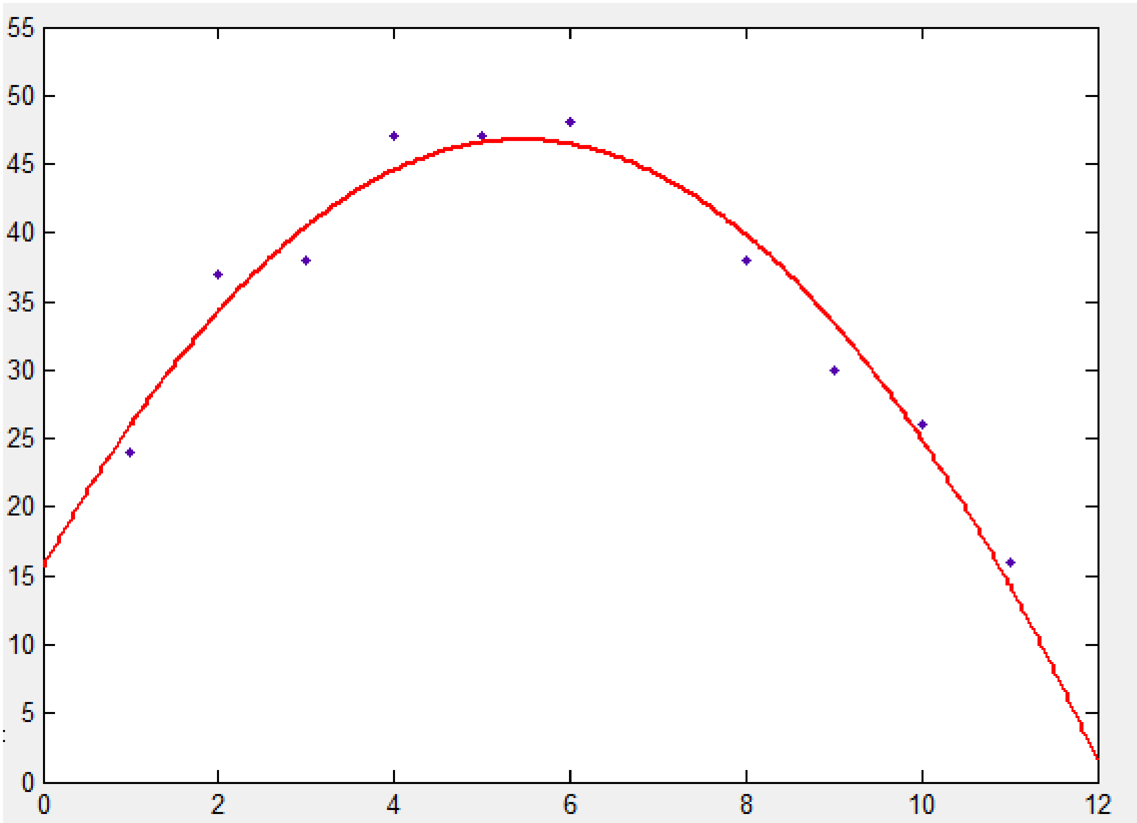
Function that best fits the curve:



Function: $f(x) = 261.42838 + 230.36886 \sin(0.24164718x - 1.5923997)$

Speed of rotation of the sun (period of function): 26.0014837 days

Morphology of sunspot area over a period of days:



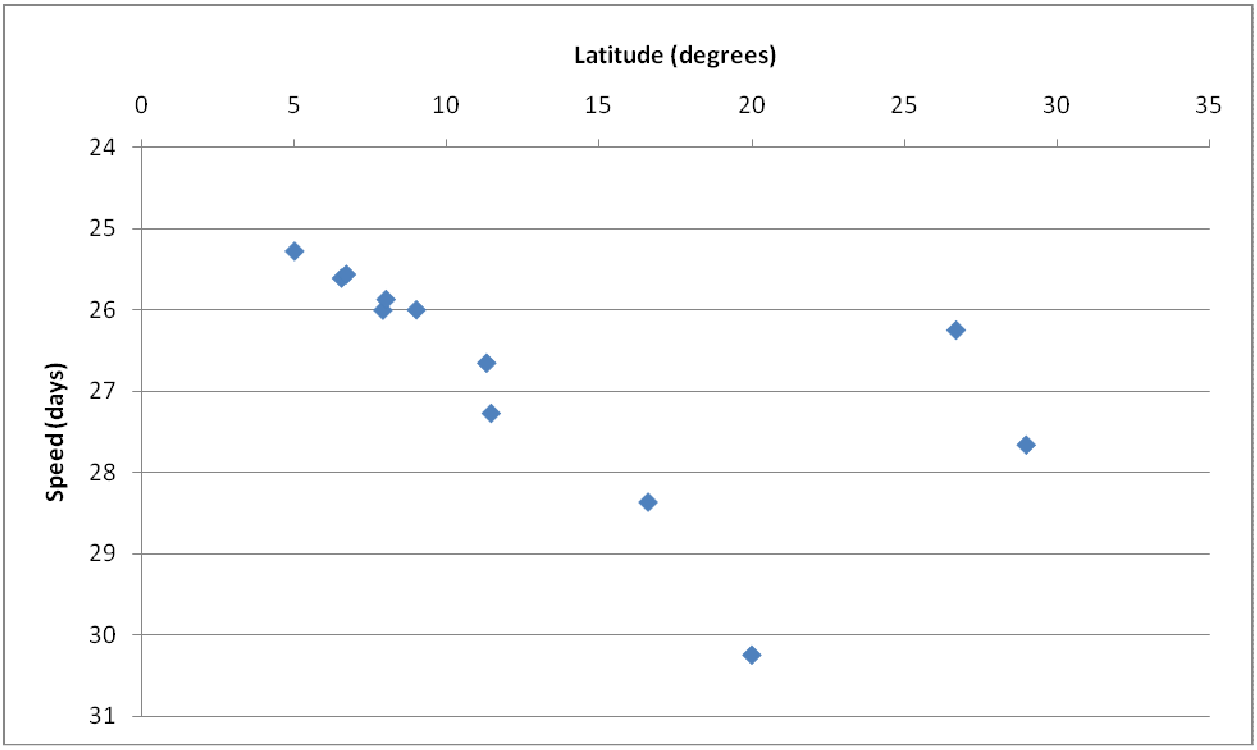
Function: $f(x) = -1.05x^2 + 11.429x + 15.654$

[Labels: x-axis: Days, y-axis: Area(pixels)]

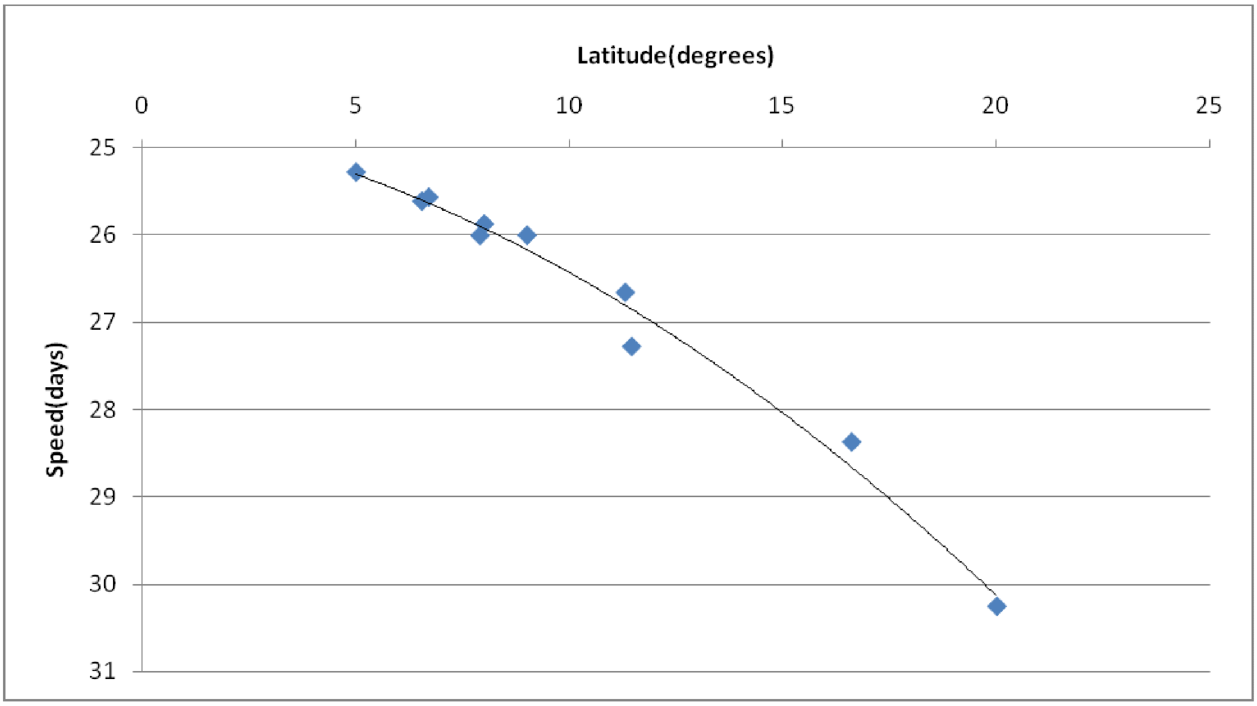
We can summarize the analysis above in the table below:

Sunspot#	Days of observation	Speed of Rotation of Sun (days)	Latitude (degrees)
1	01.01.02 -11.01.02	30.24804935	-20
2	08.01.02 - 19.01.02	27.66385207	29
3	04.01.02 - 15.01.02	28.36832544	16.583
4	11.01.02 - 22.01.02	25.28036586	-5
5	13.01.02 - 23.01.02	26.65636465	-11.3
6	11.01.02 - 22.01.02	25.6124021	6.54
7	18.01.02 - 30.01.02	26.00555872	-7.9
8	01.01.02 - 09.01.02	26.45157106	5
9	05.04.01 - 15.04.01	26.25103533	26.73
10	06.04.01 - 15.04.01	25.56582632	-6.7
11	14.04.01 - 25.01.01	25.87372678	-6.7
12	21.04.01 - 30.04.01	27.61031193	8
13	09.10.02 - 20.10.02	27.27480633	11.45
14	18.10.02 - 29.10.02	26.88891545	25
15	13.10.02 - 23.10.02	26.00148371	-9

Below is a plot of the speed against latitude (We have taken absolute values of the latitude).



From the plot above we cannot conclude to any known relationship. However, if we ignore the two points which are outliers, we can observe an inverted parabola as shown below:



This parabola can be defined by the function given: $f(x) = 0.0097x^2 + 0.0807x + 24.651$

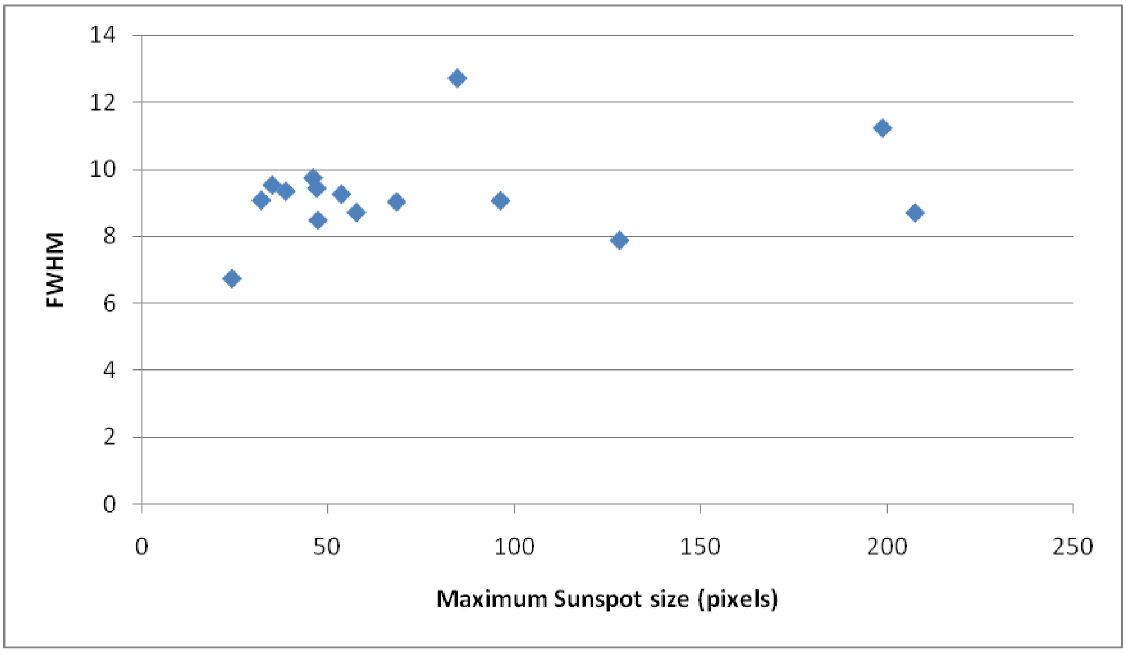
This plot shows that as latitude increases the speed of rotation of the sun decreases. This means that the sun rotates fastest along its equator. This agrees with theoretical facts.

Now moving to the second part of the project, it seems queer that in each of the function the sunspot shows a life time of approximately 11-14 days. To insure that the data is consistent let's plot the FWHM value of the functions against the maximum size of the sunspot.

Sunspot No.	Maximum Size	Half-Maximum	X_1	X_2	FWHM (X_2-X_1)
1	84.5707	42.28535	-3.61347	9.099138	12.71261
2	53.4011	26.70055	1.644745	10.90564	9.2609
3	31.8669	15.93345	1.517523	10.59655	9.079025
4	47.0897	23.54485	2.110289	10.59475	8.484458
5	96.1215	48.06075	1.631876	10.6995	9.067628
6	128.1237	64.06185	2.830339	10.71484	7.884498
7	207.5424	103.7712	1.986089	10.69213	8.706042
8	38.4514	19.2257	-1.5971	7.75166	9.348758
9	57.4009	28.70045	1.0863002	9.80078057	8.71448
10	23.9862	11.9931	1.690697	8.440357	6.74966

11	34.8253	17.41265	1.087574	10.62006	9.532484
12	68.2395	34.11975	2.12569098	11.15744	9.031745
13	45.7595	22.87975	1.496674	11.24173	9.745056
14	198.8234	99.4117	1.89133	13.12008	11.22875
15	46.7545	23.37725	0.723903	10.16086	9.436956

The plot below shows FWHM values against the maximum size:



This plot shows that the data is consistent because the range of number of days of a cycle is constant (averaging 9.266 days for FWHM values).

Conclusion and Evaluation

The results suggest that the average speed of rotation is 26.78351 days. However literature values suggest a speed of 27.2753 days. This gives an error of 1.8 %. Hence the method used to determine the rotational speed seems to be fairly accurate. Furthermore, the plot of speed against latitude concludes with the fact that speed of the rotation of the sun is fastest along its equator and it decreases as we move above and below in latitude. Nevertheless the plot of speed against latitude had two outliers. This suggests that there is definite room for improvement to increase accuracy of the result. The table below shows weaknesses and possible improvements to the investigation.

Weakness	Improvements
The SOHO images taken were taken on a day to day basis. Accuracy in terms of time could be improved if time was given in terms of hours, minutes or seconds. In addition to this, in the HelioV software which requires us to give the time was left as 12:00 as the default time. This is also not accurate as we don't have the actual time of when the picture was taken.	To improve this we have to collect data which can give us time of when the image was taken. Furthermore, we could use images in FITS format which gives additional information of image data.
The curve fitting software did produce some discrepancies in producing the graphs. Several trials were made in to get a fit. On numerous occasions Graph 4.3 and MATLAB '*cftool*' showed some form of instability suggesting inability to reduce mean squared error. This error was amplified by some days missing from archive data. This may have caused error in fitting routine as some data points went missing.	A more stable and reliable curve fitting software is required. Graph 4.3 did produce some accurate graphs in the form: $F(t)= A + C\sin(\omega t+b)$. Where A is more or less about 256, which suggest that the functions do meet what was expected from the theory. Moreover, it would be advisable to use archive data of sunspots that exist for a vast period of days without gaps in data in between.
The methods used to determine the sunspot centre and latitude may not be optimum.	A reliable method to determine the coordinates of sunspots is given in a research paper titled <u>Coordinate System for Solar Image Data</u> by W.T. Thompson. If we are able to determine coordinate points of a sunspot we can find speed and latitude. Then, we can plot latitude against speed and determine a relation regarding latitude and differential speed more accurately.
The two points that were outliers in the speed against latitude graph may have been cause because they were at high latitudes.	To be certain whether this was the reason for the two points to be outliers we have to take data of spots of higher and lower latitudes separately. Let's suppose we take data from latitudes 0^0-15^0 and then we attempt to develop a relationship; and then we move on to higher latitude to insure whether this method is applicable to spots on higher latitudes.

The range of latitudes of our sunspots was not well spread. We did not have any sunspot around the 45^0 range.	To improve this project we need to collect data from solar minimums in order to verify or correct the function we achieved in the speed and latitude plot.

The morphology of sunspots part of the investigation did confirm that in its life cycle a sunspot increases in size and then decreases. We will have an inverted parabola depicting its change in area in over a period of time. This conclusion we have achieved with sunspot morphology agrees with claimed scientific research.

However, we did doubt on the lifetime that was achieved by the functions which was 11-14 days. Theoretically, this cannot be always possible as some sunspots lasts 2-3 solar rotations. However, our plot of FHWM against maximum size sis show our data was consistent. This suggests that the analysis of sunspots along the centre of the sun is fairly accurate yet there can errors in the sunspots on the edge of the sun. This is can be explained through the fact that the parabolic curve is a consequence of the rotatory effect of the sun rather than the sunspot lifetime. It could be because of the apparent view of the sunspot as it moves to the edge of the solar sphere and hence reducing its area.

Appendix

i. MATLAB PROGRAMING :

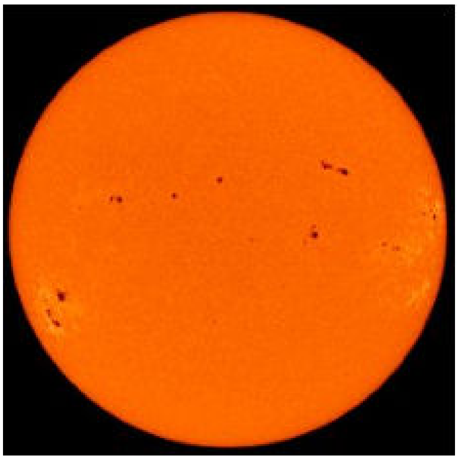
The programs below were used to determine the area and the centre of the sunspot:

```
% To determine Area of Sunspot
[a,emap]=imread('Jan01_02.tif');     % input the image required for
                                       examination
c =0;                                % assign pixel count variable the
                                       initial value 0
for i = [62:75];                     % input the range of the x-coordinates
                                       of sunspot matrix
for j = [324:339];                   % input the range of the y-coordinates
                                       of sunspot matrix
b= impixel(a,i,j);                   % use impixel function determine pixel
                                       value
x = [150 150 150];                   % assign variable pixel value 150
if b < x
c=c+1;                               % if the condition increase count
                                       variable by 1
end
end
end

% To determine Centre of Sunspot
sum1 = 0;                            % assign variable initial value 0
sum2 = 0;                            % assign variable initial value 0
for i = [62:75];
for j = [324:339];
b= impixel(a,i,j);
x = [150 150 150];
if b < x
sum1 = sum1 + (i/c);                 % Calculate mean value of x-coordinate
sum2 = sum2 + (j/c);                 % Calculate mean value of y-coordinate
end
end
end

Centre = [sum1, sum2], Area = c
```

It must be noted that the range of x and y values of the pixel map is given in the for loops in the form of *i* and *j* respectively. The file name is specified under the "`imread('Jan01_02.tif')`" function and has been assigned the variable `a` in the program above.

The sunspot considered for this program is examined when it is first seen at the central left of the sun. It is the circular singular p-spot budding out of the two remnant f-spots to its left. This sunspot was first observed on January 1 2002. The result of the program along with sunspot's image is given on the following page.

<table>
<tr><th>Program result</th><th>SOHO image</th><th>Pixel map of sunspot</th></tr>
<tr><td>Centre = 68.6835, 331.4937

Area = 79</td><td></td><td>
</td></tr>
</table>

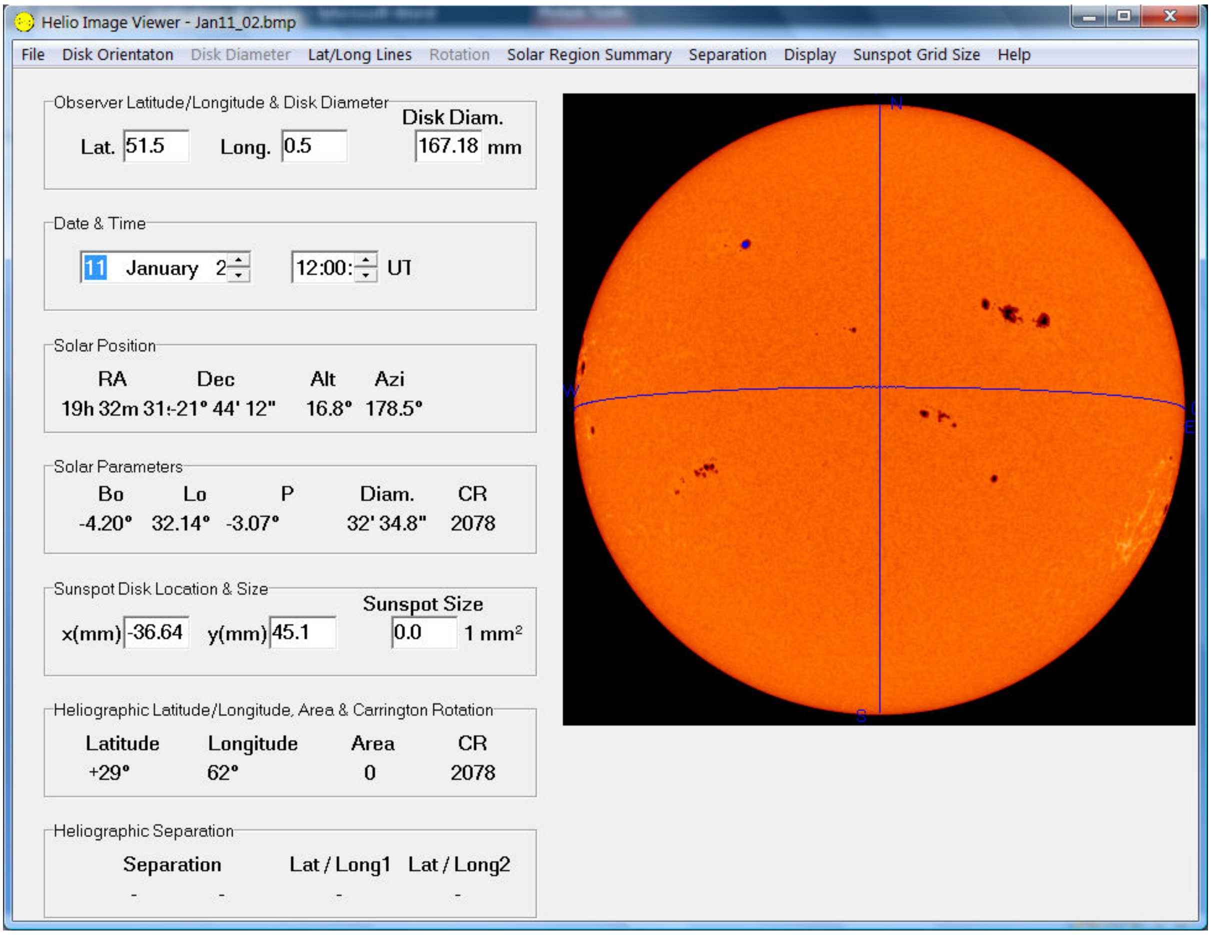
ii.) <u>HELIOV'S WORKING PROCEDURE</u>:

Helio Viewer is software specially designed for solar observers to measure various parameters and it drastically reduces the time required to analyse solar observations.

It can easily input of a user full disk image, such as those on this web site or those with a solar disk surrounded by a black background, in bitmap format. It can determine the solar position (RA, Dec, altitude and azimuth) and solar parameters (Bo, Lo, P, apparent diameter and Carrington rotation of the central meridian) for a given date and time, and observer latitude and longitude.

It also displays the central meridian, solar equator, latitude lines and longitude lines.

It inputs or selects the position of a sunspot directly by clicking on the solar disk and calculates the sunspot latitude and longitude.



__Working steps:__

Set the disk orientation to rotation axis

Convert your corresponding .gif/.tiff image formats into .bmp (as helioV works with .bmp only)

Load the image of solar disk

Set the date to the date of the image.

Point the mouse pointer to the sunspot under consideration and click over it, the latitude and the longitude of the corresponding sunspots are instantly visible on the HelioV panel.

Bibliography

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Nicolson, Ian. The Sun. 1982. London: Mitchell Beazley Publishers, 1982.

Spaceweather. May-June 2009. May-June 2009 <http://www.spaceweather.com/>.

Thompson, W.T. “Coordinate System for Solar Image Data.” Astronomy and Astrophysics. 4262 (2005): 1-13.