Coronal transients: Loop or bubble?

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CORONAL TRANSIENTS: LOOP OR BUBBLE?

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Abstract. Many coronal transient exhibit a circular aspect, which has been interpreted up to now as a loop structure. From polarization measurements of the 10 August, 1973 transient observed by the ATM coronagraph, which allows the location of material away from the plane of the sky, we show that this particular transient is more likely to be a 3-dimensional, bubble-shaped structure, than a loop. The radial component of the speed is evaluated. A thin streamer close to the transient is displaced by its passage, both in the plane of the sky and in the direction perpendicular to it.

1. Introduction

Since their discovery by white light coronagraphs on board spacecrafts, coronal transients have been studied extensively in terms of morphology, statistics and theoretical models. They exhibit quite complex and various shapes; from Munro *et al.* (1979), about one third appear as loops on coronagraph pictures. However, their precise geometrical structure, although necessary for reasonable modelling, is still uncertain: are these features loop-like, or are they bubbles?

Loop models, such as those developed by Mouschovias and Poland (1979) or Pneuman (1980) seem very reasonable, since the transients are often associated with eruptive prominences observed in Hα, whose loop structure is clear; conversely, however, numerical simulations such as conducted by Dryer and Maxwell (1979) imply more complex 3-dimensional structures which occupy a significant volume in the corona and spread out in interplanetary space as shock fronts. The Hα ejecta seem to be a part of the event in the vicinity of the Sun.

We try here to answer this question and to locate the material along the line-of-sight through the use of polarized white light images from the Skylab coronagraph. In order to find clear, simple and easy-to-test geometrical criteria, we selected a simple event, appearing on the images very close to circular, and which can thus be represented either by a circular loop or by a spherical bubble: the transient of 10 August, 1973. This event has been studied previously by several authors: Gosling *et al.* (1974) describe it and determine the speed of the outermost loop as projected on the plane of the sky; Mouschovias and Poland (1978) assume it is an arch crossing the plane of the sky; Anzer and Poland (1979) evaluate its thickness and density, assuming it is a typical loop-shaped structure.

Using the above papers, we note for this event that the transient was observed above an eruptive prominence located approximately in the plane of the sky, and that its outermost edge rises at a constant speed of about 400 km s^{-1} in projection on the plane of the sky. The appearance of this transient may be found in illustrations in the work by Gosling *et al.* (1974), Jackson and Hildner (1978), and Anzer and Poland (1979).

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Previous studies of this transient thus assume a loop structure primarily because the underlying eruptive prominence exhibits one. However, we feel that this is not a sufficient argument. For instance, composite pictures published by Poland and Munro (1976) for the transient of 21 August, 1973 show that the geometry of the transient strongly differed from that of the accompanying prominence.

2. Principle of the Study

The assumption is made that the true geometrical shape (loop or bubble) is unknown, and following logic paths are used:

(a) If the transient is a spherical hollow bubble of uniform density (see Figure 1a), the largest intensity is observed for the lines of sight having the longest path through the shell. The corresponding emitting material behaves approximately as if it were all located in a plane parallel to the plane of the sky and passing through the bubble's center, at a mean distance x from the sky (see the justification in Appendix). For totally ionized material, polarization measurements allow the distance x to be evaluated for many lines of sight; from results given in the Appendix it should be approximately the same for all points of the bright edge. As the transient rises radially, the bubble center moves away from the plane of the sky, and so the distance x should increase with time, remaining constant all along the transient's edge. Of course, possible inhomogeneities on the bubble's surface would not follow this scheme and alter the distance x for the corresponding lines of sight. Therefore only rather homogeneous and spherical transients should be selected to check this hypothesis.

(b) If the transient has a loop structure (see Figure 1b), there is no reason for x to be constant along the transient's edge, except for the case of a loop lying in a plane parallel to the sky, which might happen. However, this last configuration is very unlikely to be maintained during the rise of the transient, as sketched in Figure 1c.

So the calculation of the distances x all along the bright edge of the transient, if done accurately enough, allows a determination of the structure of the transient. Finding x approximately constant along the bright edge means that the transient is either a bubble or a planar feature parallel to the plane of the sky. If this property holds during the rise, with an increase of x, then the transient is very likely to have a bubble structure.

The transient of 10 August, 1973 is very suitable for such a test. We note that Webb and Jackson (1981) analyzed in a similar way the flare-associated transient of 17 January, 1974 and found that the legs and the outer loop could have been planar structures located in the same plane inclined to the plane of the sky. Munro (1977) analyzed the transient of 10 January, 1974 and concluded from polarization properties that it was an arched tube seen approximately along the plane of the arch; unfortunately, the detailed analysis was never published. Hildner *et al.* (1975) analyzed the event of 10 June, 1973, which is very similar in appearance to the one studied here, but they did not make use of polarization measurements, instead assuming a loop structure concentrated near the plane of the sky.

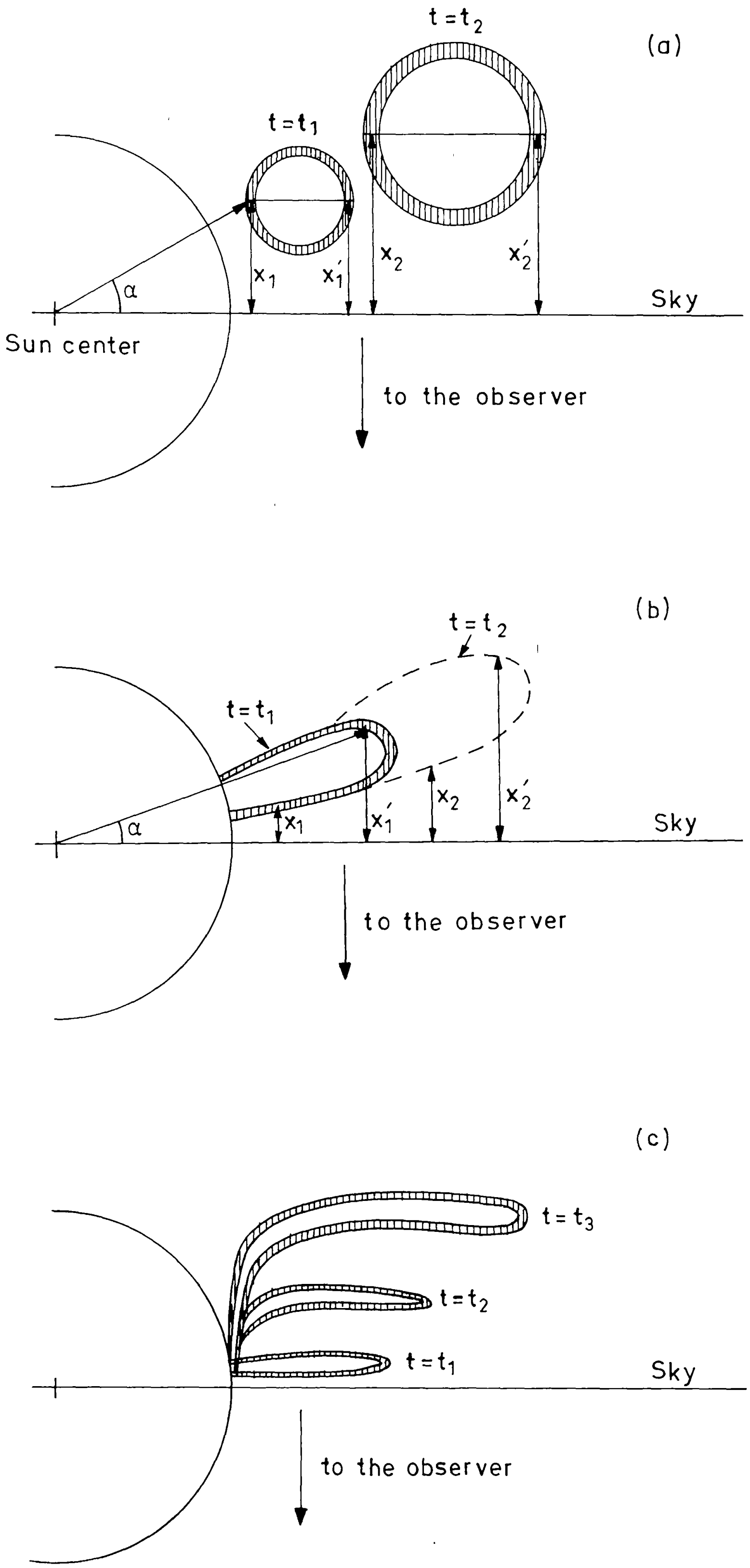

Fig. 1. Geometry of the problem. Hypothetical transients viewed from above the ecliptic plane. (a) Hollow bubble. $x_1 = x_1'$; $x_2 = x_2'$; $x_2 > x_1$. The largest contribution originates in planes parallel to plane of the sky. (b) Loop. General case: $x_1 \neq x_1'$. For clarity, the loop has been drawn tipped somewhat from north–south. (c) Rising loop remaining parallel to the plane of the sky. This configuration would be needed for a loop to behave as a bubble.

3. Results

Three well-defined structures have been investigated (see Figure 2). Structure 1 seems to be a small, narrow, independant streamer which is pushed aside and bent as the transient rises (see Gosling *et al.*, 1974). 'Structures' 2 and 3 are the two sides of the transient. The polarization sequences studied started at 14:24 UT (frame 8961) and 14:50 UT (frame 9008).

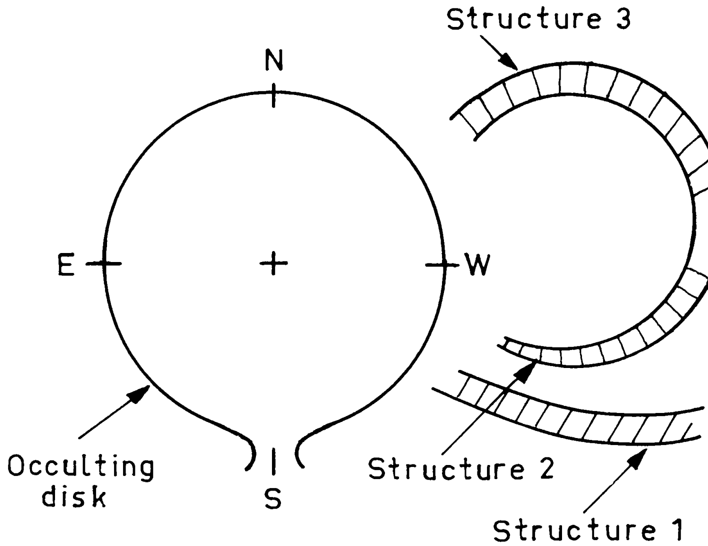

Fig. 2. The transient of 10 August, 1973 and the three structures studied: frame 8961, 14:24 UT.

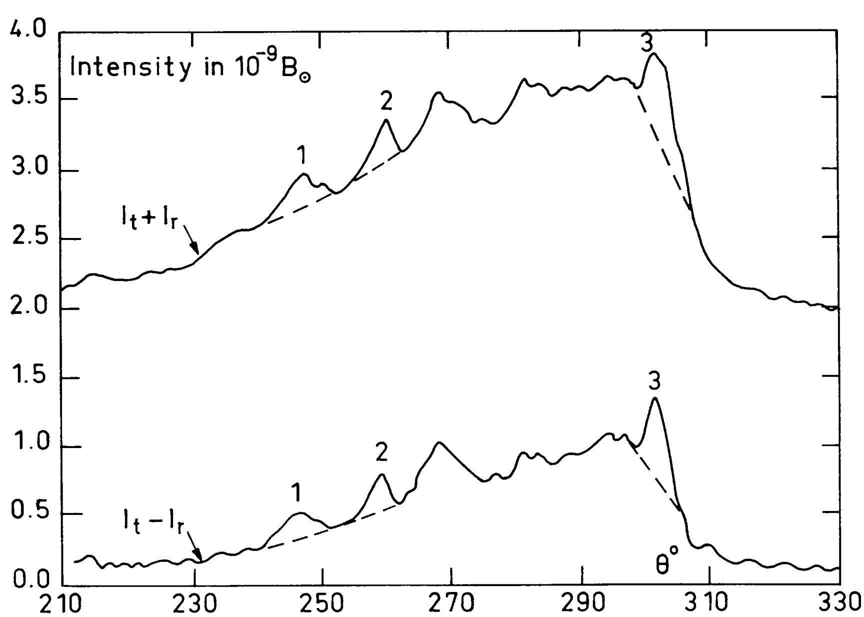

Fig. 3. Plots of total and polarized intensities, with interpolation of the background at the bottom of the structures 1, 2, 3 at height $r = 3.6\ R_{\odot}$ on frame 8961. Intensities have been slightly smoothed with a gaussian formula 0.8° wide in θ.

Let I_t and I_r be the two polarized components (radial and tengential) of the intensity. On azimuthal scans of $(I_t + I_r)$ and $(I_t - I_r)$, a manual subtraction of the background was performed: see Figure 3. From the remaining intensities $(i_t + i_r)$ and $(i_t - i_r)$, the polarization degree P_K due to the transient alone was calculated: $P_K = (i_t - i_r)/(i_t + i_r)$. Although this particular transient has a very well defined structure, this interpolation across the transient may be hazardous and is the main source of error. The angle α between the radius vector to the point and the plane of the sky, and the distance x of the bulk of material from the plane of the sky are calculated from the Van de Hulst (1950) formulae. Values obtained for x in the structures 2 and 3 (transient's edge) in each polaroid sequence are plotted on Figures 4 and 5. Numerical values for polarization

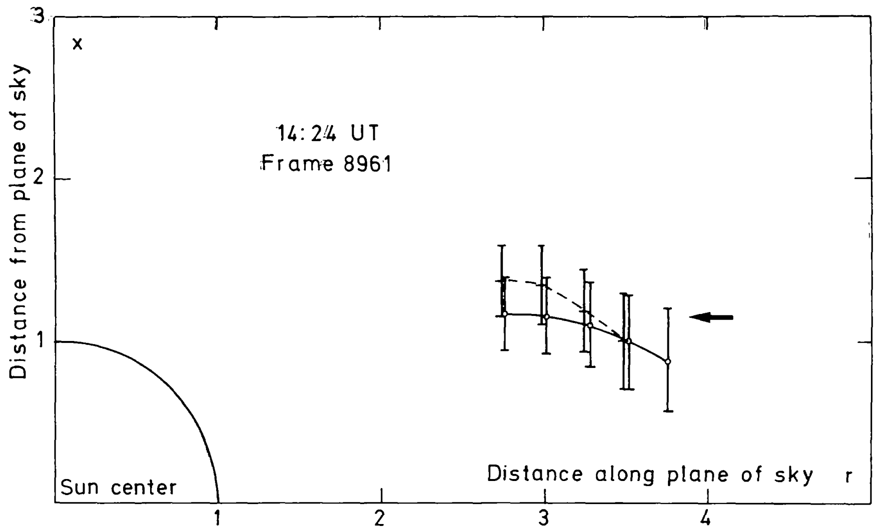

Fig. 4. Distances from the plane of the sky for the transient at 14 : 24 UT (frame 8961). + + South segment of the transient (structure 2). □□ North segment of the transient (structure 3). Arrow indicates probable distance of center of bubble from sky permitted by the error bars.

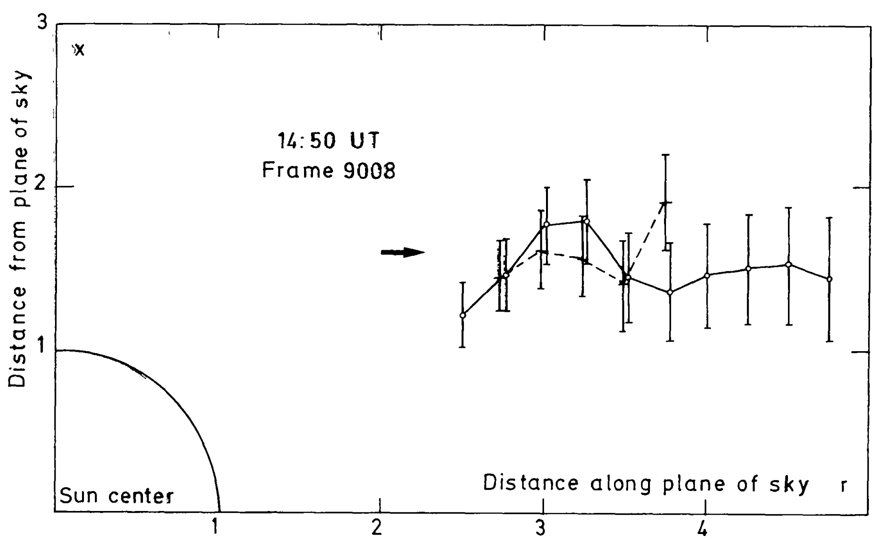

Fig. 5. Distances from the plane of the sky for the transient at 14 : 50 UT (frame 9008). + + South segment of the transient (structure 2). □□ North segment of the transient (structure 3). Arrow indicates probable distance of center of bubble from sky permitted by the error bars.

TABLE I

Numerical results for structures 1, 2, 3

Frame 8961 – 14:24 UT

$r/R_\odot$	Structure 1			Structure 2			Structure 3		
	P_k (%)	$\alpha°$	$x/R_\odot$	P_k (%)	$\alpha°$	$x/R_\odot$	P_k (%)	$\alpha°$	$x/R_\odot$
2.50	60	26	1.22						
2.75	59	27	1.40	60	26.5	1.37	65	23	1.17
3.0	60	27	1.53	65	24	1.34	70	21	1.15
3.25	65	24.5	1.48	72	20	1.18	75	18	1.09
3.5	72	20.5	1.31	80	16	1.0	80	16	1.0
3.75	75	20	1.36				85	13	0.87
4.0	75	20	1.46						

Frame 9008 – 14:50 UT

$r/R_\odot$	Structure 1			Structure 2			Structure 3		
	P_k (%)	$\alpha°$	$x/R_\odot$	P_k (%)	$\alpha°$	$x/R_\odot$	P_k (%)	$\alpha°$	$x/R_\odot$
2.50	56	29	1.39				60	26	1.22
2.75	57	28	1.46	58	28.2	1.47	57	28	1.46
3.0	57	29	1.66	58	28.4	1.62	55	30.5	1.77
3.25	64	25	1.52	63	25.7	1.56	57	29	1.80
3.50	62.5	26.5	1.75	70	22	1.41	69	22.5	1.45
3.75	60	28.2	2.01	62	27	1.91	75	20	1.36
4.0	60	28.5	2.17				75	20	1.46
4.25	62	27.5	2.21				76	19.5	1.51
4.50	70	23	1.91				77	18.8	1.53
4.75	72.5	22	1.92				80	17	1.45
5.0	82	16.5	1.48						

degree, α-angle and distance x are found in Table I. The error on angle α is estimated to be $\pm 3°$ due mainly to the difficulty of interpolating the background. The corresponding error bars are indicated on Figures 4 and 5. From Figures 4 and 5 we conclude that:

(a) Structures 2 and 3 are not located in the plane of the sky, despite the error bar, whereas from Mouschovias and Poland (1978) they should be extremely close to it.

(b) Within the error bar, it is possible to admit that the various points of the transient are all at about the same distance to the plane of the sky; this indicates a bubble, or an arch parallel to the plane of the sky.

(c) Between the two polaroid sequences, the transient moves away from the plane of the sky, and stands approximately parallel to it.

In conclusion, it appears that the transient is more likely to be a bubble than a loop.

From Figures 4 and 5, the displacement Δx is on the order of 0.4 or 0.5 $R_\odot$ while Table I shows that the mean α-angle does not change very much between the two frames. Thus the ascension of the transient is approximately radial.

It was also possible to determine the position of structure 1 (the nearby streamer) before the transient (frame 8882, at 11:26 UT), in order to study better the displacement of this thin streamer. During the rise of the transient it is pushed away from the plane of the sky. Between frames 8882 and 8961 its bottom (at $r = 2.5\ R_\odot$) moves aside; then between frames 8961 and 9008 its outer part ($r > 3\ R_\odot$) is distorded too. This is clearly visible on Figure 6.

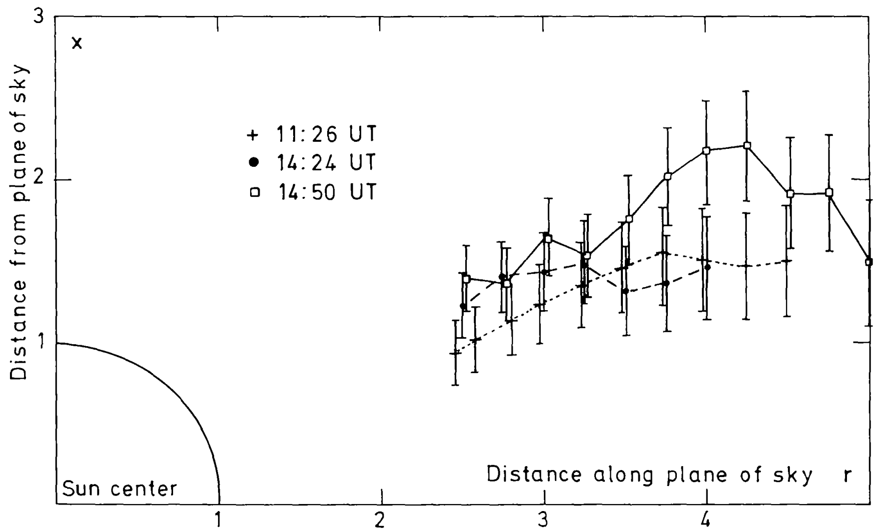

Fig. 6. Behavior of the streamer located on South of transient (structure 1) before and during the transient's passage, at 11:26 (frame 8882), 14:24 (frame 8961), and 14:50 (frame 9008).

4. Rising Speed

Mouschovias and Poland (1978) estimate the speed component in the plane of the sky to be 400 km s^{-1} for the top of the bright edge. Our results give the speed component V_x perpendicular to the plane of the sky: $V_x = \Delta x/(t_2 - t_1)$. Taking $\Delta x = 0.5\ R_\odot$ and $t_2 - t_1 = 26$ min, we find: $V_x \simeq 200$ km s^{-1}.

Hence the radial speed is:

$$V_{\text{radial}} = \sqrt{V_x^2 + V_{\text{sky}}^2} = \sqrt{200^2 + 400^2} = 450 \text{ km s}^{-1} .$$

5. Check on the Method

This work is strongly dependent on how precisely structures may be located along the line of sight. Van de Hulst formulae directly give the α angle between the emitting point, the Sun center and the plane of the sky. Errors come from the photometry and from the interpolation of the background. The random error is this process is estimated to be about ± 3 degrees for α in the transient; it might be a little smaller for the nearby streamer (structure 1). However, a systematic error due to the subtraction of the background, as large as $10°$ on α for the transient, might be found. Such an error would modify the speed component V_x, but not our conclusion on the geometry.

The accuracy of the overall procedure has been checked on the following way. On east solar limb, near the equator, just at the opposite of the transient, are two narrow, well-defined and very stable streamers. The above described method was applied to them, using the first and last frames of our selection (frames 8882 and 9176, taken at 11 : 26 and 25 : 25 UT). A rotation of 8 degrees was found, for a time interval of 14 hr, which is in perfect agreement with the expected solar rotation.

6. Conclusion

From a simple geometrical test performed on a very homogeneous transient of circular shape, we conclude that the event is more likely to be a three-dimensional bubble that a loop-shaped structure, in spite of the rather large errors. However, other transients of various types (i.e., eruptive associated, or flare associated) should be studied in this way before a general conclusion on their geometry can be reached. Unfortunately, most transients are extremely inhomogeneous and exhibit complicated geometrical shapes on the pictures; they cannot be used for such a simple test, and only a very few are suitable for this analysis. Other methods for clarifying this problem would be welcome. We also hope to study transients observed by the SMM coronagraph.

Acknowledgements

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Appendix: Computation of the Polarization for a Spherical, Hollow Bubble Seen in White Light

The transient is approximated by a spherical shell of given thickness and radius. The mean distance x of the material from the plane of the sky, as inferred from polarized brightness, is studied for various lines of sight.

The shell is limited by its inner radius R_1 and outer radius R_2; the position of its center is defined by r_0 (distance to the Sun's center along the plane of the sky) and x_0 (distance from the plane of the sky). The emitting material is all located in the shell between R_1 and R_2. In order to maximize the effect due to the thickness of the shell, the polarization degree is calculated for those lines of sight having the largest path through the shell, i.e. tangential to the inner sphere. These lines are on a cylinder which intersects the plane of the sky along a circle. We call r the distance between a point of this circle and the Sun center. The path l of the line of sight in the shell is: $l = 2\sqrt{R_2^2 - R_1^2}$.

Using the Van de Hulst (1950) formulae and some given law for the density distribution along the line of sight, it is possible to calculate the polarization degree P_K for each line of sight. We then calculate the distance x from the plane of the sky where the material would lie if it were all concentrated in one point, instead of being spred along the line of sight. These distances x are then compared to x_0, distance of the bubble's center from the plane of the sky, and the differences $\Delta x = |x_0 - x|$ are evaluated as a function of r.

Calculations have been performed for values of R_1, R_2, and r_0 estimated from frames 8961 and 9008, and for a set of values of x_0, for both constant density and a density law taken equal to the Van de Hulst maximum model. Results are shown in Table II,

TABLE II

Systematic error due to the thickness of the shell (all distances in $R_\odot$)

	Frame 9008		Frame 9861	
	Thin case	Thick case	Thin case	Thick case
R_1 Inner sphere	1.80	1.70	1.43	1.35
R_2 Outer sphere	1.90	1.90	1.50	1.50
r_0	4	4	3.30	3.30
x_0	from 0.90 to 2.30		from 0.90 to 2.30	
l path in the shell	1.22	1.70	0.91	1.31
largest Δx for constant N_e	0.08	0.12	0.03	0.06
largest Δx for variable N_e	0.15	0.25	0.07	0.13

for various conditions of R_1, R_2, r_0, and x_0. Each frame was approximated with a 'thin' and a 'thick' bubble. We give only the largest value of Δx, found within the r-interval of the measurements; it represents the maximum error for our analysis. The largest systematic error is obviously found for the 'thick' case and a variable density; it is however still within the error bar and may therefore be neglected here; otherwise it might be taken into account.

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