THE ASTROPHYSICAL JOURNAL, 572:679–684, 2002 June 10

RECURRING OUTBURSTS AND NUCLEAR FRAGMENTATION OF COMET C/2001 A2 (LINEAR)

ZDENEK SEKANINA
Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109; zs@sek.jpl.nasa.gov

EMMANUEL JEHIN, HERMANN BOEHNHARDT, XAVIER BONFILS, AND OLIVER SCHUETZ
European Southern Observatory, Alonso de Cordoba 3107, Santiago 19, Chile; ejehin@eso.org, hboehnha@eso.org, xbonfils@eso.org, oschuetz@eso.org

AND

DANIEL THOMAS
Universitäts-Sternwarte München, Scheinerstrasse 1, D-41679 Munich, Germany; daniel@usm.uni-muenchen.de

Received 2001 December 19; accepted 2002 February 14

ABSTRACT

Analysis of the visual light curve and fragmentation sequence of comet C/2001 A2 (LINEAR) shows a strong temporal correlation between the onset of outbursts and separation of companion nuclei. This scenario conforms to Sekanina's conceptual model for the release of sizable fragments of an inert dust mantle from the nucleus surface: an outburst is triggered as some of the mass rapidly disintegrates into fine dust.

Subject headings: comets: general — comets: individual (C/2001 A2) — methods: data analysis

1. INTRODUCTION

Comet C/2001 A2 was discovered as an asteroidal object on 2001 January 15 with a 1 m f/2.15 folded prime-focus Cassegrain reflector of the Lincoln Near Earth Asteroid Research (LINEAR) Project using a surveillance technology (Green 2001a). The telescope is located at the Experimental Test Site on the White Sands Missile Range in Socorro, New Mexico, and the LINEAR Project is operated by Massachusetts Institute of Technology's Lincoln Laboratory in Lexington, Massachusetts. The cometary nature of the object was recognized by Pravec & Šarounová (2001) at the Ondřejov Observatory about 17 hr after its discovery and by Tichý & Kočer (2001) at the Kleť Observatory some 20 hr later. The comet was discovered 129 days before perihelion, when it was 1.31 AU from Earth and 2.28 AU from the Sun. Its prediscovery images were identified subsequently on four Lowell Observatory-LONEOS exposures from January 3 and on 17 LINEAR exposures from January 3, 5, and 6 (Marsden 2001a).

2. UNEXPECTED DEVELOPMENTS

At the time of discovery, the object was reported by the LINEAR Project to be near nuclear magnitude 16 (Marsden 2001a), while both Pravec & Šarounová (Marsden 2001a) and Tichý & Kočer (2001) found it to be total magnitude ~17. The comet was brightening gradually but remained a fairly inconspicuous object, fainter than magnitude 10, until nearly the very end of 2001 March.

A dramatic brightening of the comet between March 29.5 and 30.5 UT was noticed by a number of observers (Green 2001b, 2001c). In the images taken with the Catalina 1.54 m reflector of the Lunar and Planetary Laboratory, University of Arizona, 1 month later on April 30.12 UT, Hergenrother, Chamberlain, & Chamberlain (2001) detected two condensed, about equally bright nuclei $3''.5$ apart in the east-west direction, whereas a single nucleus had been observed 6 days earlier. The nuclear duplicity was reported subsequently by other observers (Marsden 2001b, 2001c). According to Broughton (2001a, 2001b), the eastern component was 0.3 mag fainter than the western on May 9 and 10, virtually disappeared on May 11, and was at least 2 mag fainter on May 12 and 16. On May 14, images taken with the European Southern Observatory's (ESO) 8.2 m Very Large Telescope (VLT) Melipal also showed the two nuclei, the western being elongated and ~1 mag brighter than the eastern; in images taken with the 8.2 m VLT Yepun on May 16, the western nucleus was already double, its components about equally bright (Jehin et al. 2001). Naked-eye observations made around mid-June indicated that the comet reached magnitude 3–4 (Green 2001e, 2001f), with another flare-up evidently in progress. In images taken during an ESO monitoring campaign on June 16–21 in both the optical region and the thermal infrared, Schuetz et al. (2001) detected further companion nuclei, different from the fragments observed earlier. The companions were last seen in the images taken at ESO on June 27–28 (§ 4).

The objectives of this paper are to determine the comet's best possible light curve in order to identify outbursts (flare-ups), to model the sequence of nuclear fragmentation and address the issue of separation times, to examine temporal correlations between the outbursts and fragmentation, and to offer an interpretation of the results.

3. VISUAL LIGHT CURVE

A comet's light curve describes its intrinsic-brightness variations with time t and/or heliocentric distance $r(t)$. A successful search for outbursts requires brightness data with superior temporal coverage, which is more critical than high accuracy. The data that satisfy this condition better than any other are visual-magnitude estimates, which are indeed very plentiful for C/2001 A2. These magnitudes, which are reported mostly by amateur observers, need to be standardized to the extent possible by applying a correction for personal and instrumental effects and then normalized to a unit geocentric distance Δ by an inverse-square power law before the data can be employed in a light-curve study. Thus, a normalized magnitude $H_\Delta(t)$ is related to an apparent magnitude $H(t, \Delta)$, as reported by an observer using a given telescope, by

$$H_\Delta(t) = H(t,\ \Delta) + \mathrm{corr} - 5\log\Delta\ , \tag{1}$$

where corr is the observer- and telescope-dependent magnitude-standardization correction applied.

The bulk of the data employed here comes from the usual source of cometary magnitudes (Green 2001g, 2001h), supplemented with information that at the time of this writing is available only at the *International Comet Quarterly*'s Web site.[1]

The resulting light curve in Figure 1 is based on 1065 visual-magnitude estimates obtained by 82 observers at times less than 140 days from perihelion. The upper panel shows H_Δ plotted against time reckoned from perihelion $t - T$, while the dependence of H_Δ on heliocentric distance is exhibited in the middle and lower panels for the preperihelion and postperihelion observations, respectively. The light curve shows four distinct outbursts, two of which have already been mentioned in § 2. The outbursts are described in Table 1 by three parameters: the onset time t_0, the rise time τ defined as the temporal difference between onset and peak brightness, and the amplitude ΔH defined as the difference in magnitude H_Δ between peak and onset. The uncertainties are estimated at ±1 day in t_0 and τ and a fraction of 1 mag in ΔH, as shown in the table. The amplitude of the first outburst exceeds considerably those of the other events because of the comet's faintness at the time. The rise time is typically 3 days but reaches as much as 8 days for one episode (see § 5). After peaking, the brightness subsides gradually to a "quiescent-phase" level, which, however, tends to be elevated in comparison with the preoutburst brightness. The cumulative effect, measured by a heliocentric-distance–corrected difference between H_Δ prior to the first outburst and following the last one and estimated at 5.8 mag in Figure 1, is a nontrivial fraction of the sum of the amplitudes of the outbursts, which equals 9 mag. At 2.28 AU, the distance from the Sun at discovery, the comet was still fully ~4 mag brighter intrinsically after perihelion than before it.

4. SEQUENCE OF NUCLEAR FRAGMENTATION

The accurate astrometric observations of the various companions relative to the primary are listed in Table 2. Following the previously introduced system of designation (Green 2001d; Marsden 2001b), the primary and usually the brightest nucleus is called B, while the fragment first detected by Hergenrother et al. (2001) on April 30 is called A. The fragment first observed by Jehin et al. (2001) on May 16 is called C, whereas the three fragments detected during the ESO monitoring campaign of June 16–21 are D, E, and F, as previously described (Schuetz et al. 2001). Only after embarking on this investigation did we realize that the May 21–24 observations that had originally been assumed to refer to A were instead signaling the existence of a yet another companion, called G. The object identification in column (4) of Table 2 is based on our results that follow.

The analysis of the collected data has proceeded by applying the extensively tested standard fragmentation model (Sekanina 1978, 1982), which offers a choice to solve for up to five parameters: the time of fragmentation t_f, the RTN components of the companion's separation velocity (i.e., radial, transverse, and normal in the coordinate system referred to the comet's orbit plane and aligned with the comet-Sun direction), and the companion's nongravitational deceleration relative to the primary nucleus. The method involves a least-squares, differential-correction, iterative algorithm that searches for an optimized solution, with an option to solve for any combination of fewer than the five unknowns. Because of the limited number of observations (Table 2), this important option has been extensively exploited.

Companion A.—A linkage of Hergenrother et al.'s (2001) data point from April 30 with the ESO observations from May 14, 16 (cf. Jehin et al. 2001), and 18 has shown that residuals of up to at least 0″.8 are unavoidable even for positions derived from high-resolution images, probably because of a complex morphology of the primary. Subsequently, our data sample has been augmented thanks to the images sent to us in digital form by D. Scarpa and A. Más, Montevideo[2] (May 12 and 18) and by G. J. Garradd, Loomberah (May 17–24; cf. Marsden 2001c, 2001d). We processed these frames to enhance the image quality and facilitate our measurement of the offsets of A relative to B. These results and a number of published positions obtained by J. Broughton between May 9 and 19 (Marsden 2001c, 2001d), which we found to fit nicely as well, are also included in Table 2. Of the 18 data points thus collected, 15 have been satisfied by an optimized solution to within 1″. Fragment A does not appear to have been detected after May 19, as the last three observations, on May 21, 22, and 24, yield intolerably large systematic residuals of about +3″ in right ascension and −4″ to −5″ in declination, considerably exceeding the expected measurement uncertainties (see below).

Companion C.—We were able to derive only four accurate positions for this companion, two from the ESO observations on May 16 (Jehin et al. 2001) and 18 plus two from Garradd's computer-processed images obtained on May 22 and 24.

Companion G.—We investigated several possible hypotheses for this object in order to understand its motion during the period of May 21–24. We found that its measured separations from the predicted locations of A were 5″.1 in a position angle 147°.6 on May 21.36 UT, 5″.6 in 146°.7 on May 22.34, and 6″.0 in 148°.3 on May 24.35 (equinox 2000). The object displayed a tail whose length was measured to be, respectively, 16″, 14″, and 9″ in the three images, always in P.A. 150° (within a few degrees). The object's head was recognized clearly on the first date but was fading away rapidly in the subsequent images. The position of G relative to A was therefore essentially in the direction of its own tail, which in turn was oriented nearly along the prolonged radius vector, whose P.A. was, respectively, 150°, 152°, and 156° on the three dates. A seemingly plausible hypothesis that G was in fact a condensation in the tail of fragment A failed, since it required a much higher rate of recession than observed. Similarly unsuccessful were the hypotheses that G separated from either A or C. The only scenario that we found not to be contradictory was one in which G separated from the primary in mid-April, becoming only briefly observable after it flared up 5 weeks later. Indeed, the pre-

---

[1] See http://cfa-www.harvard.edu/icq/CometMags.html.

[2] See http://heavy.fisica.edu.uy/astronomia/kappacrucis.

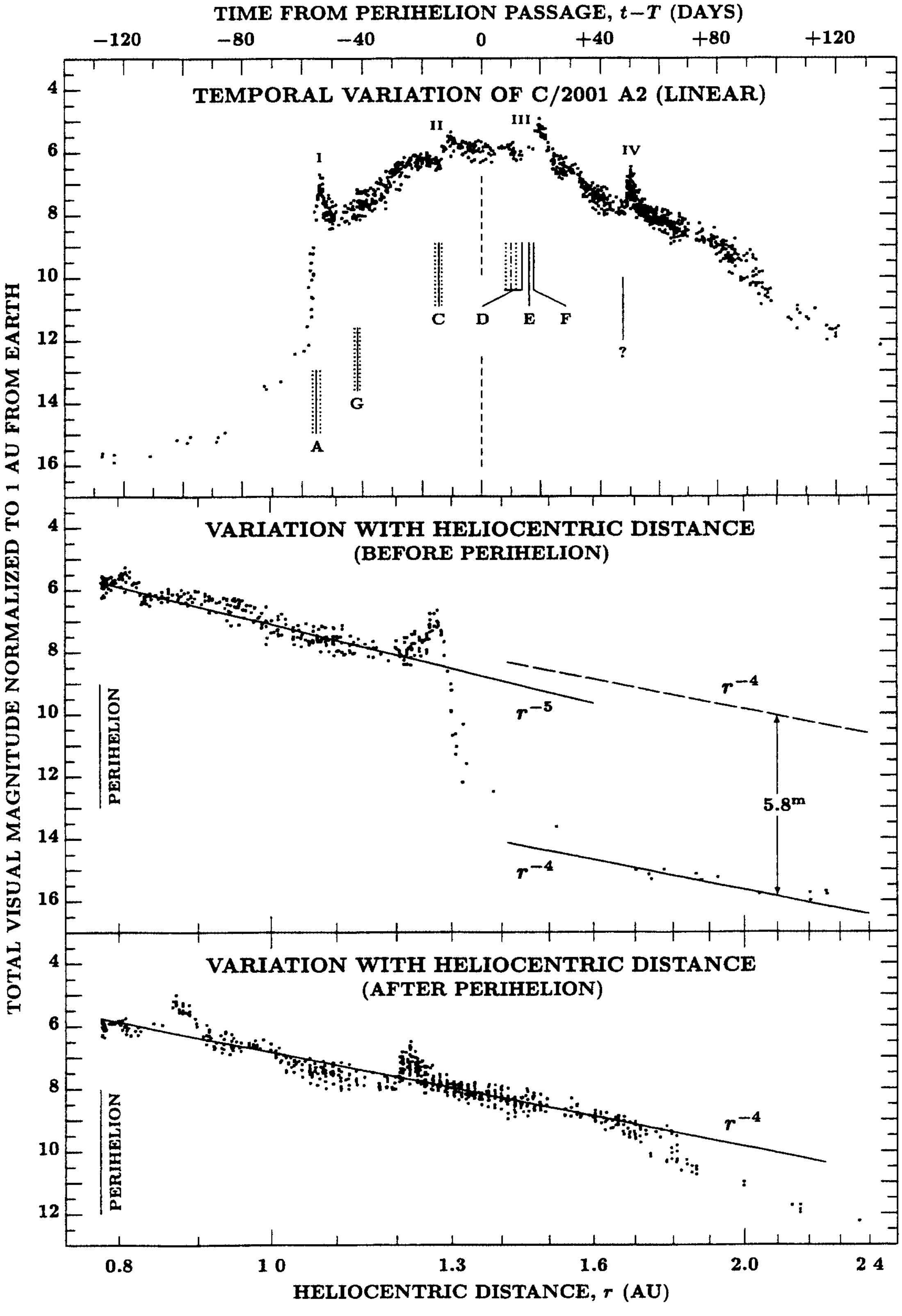

FIG. 1.—Light curve of comet C/2001 A2 (LINEAR). The total visual magnitude H_Δ, corrected for personal and instrumental effects and normalized to 1 AU from Earth, is plotted vs. time in the upper panel and vs. heliocentric distance in the middle and bottom panels for, respectively, the pre- and postperihelion legs of the orbit. A total of 1065 magnitude estimates obtained by 82 observers between 140 days before perihelion (2001 January 4) and 140 days after perihelion (2001 October 11) have been used. The presence of four major outbursts is indicated in the upper panel by the Roman numerals consistent with the designation in Table 1. The perihelion time (2001 May 24) is depicted by a broken vertical line; the calculated separation times for fragments A, G, C, D, E, and F by the solid lines; and an alternative solution for the separation time of companion D by a dash-dotted line. The rms error bars of the separation times, when exceeding ±0.5 day, are shown by the dotted lines. The missing fragmentation event, which would correlate with outburst IV, is identified by the question mark. The middle and bottom panels show that on its approach to the Sun, the comet brightened approximately as r^{-4} before it reached a heliocentric distance of ~1.7 AU, whereas when receding from the Sun, the comet followed the same law (except during the outbursts) at distances smaller than ~1.7 AU. At 1.7 AU from the Sun, the comet was approximately 5.8 mag, or a factor of more than 200, brighter after perihelion. The rate of brightening between 1.2 AU preperihelion and perihelion followed approximately an r^{-5} law.

TABLE 1

Detected Outbursts

Outburst	Time t_0 of Onset[a]			
	Date (2001 UT)	$t_0 - T$ (days)	Rise Time τ (days)	Amplitude ΔH (mag)[b]
I	Mar 28.5	−57.0	3.0	~5
II	May 10.5	−14.0	3.5	1.1
III	Jun 5.0	+11.5	8.0	1.4
IV	Jul 11.5	+48.0	2.5	1.5

[a] Date and time from perihelion passage (minus sign: preperihelion; plus sign: postperihelion). Estimated uncertainty is ±1 day.

[b] Uncertainty estimated at ±0.5 mag or more for outburst I, but at less than ±0.5 mag for outbursts II–IV.z

TABLE 2

Observed Offsets of Companion Nuclei from Primary B

Time of Observation (2001 UT)	Separation Distance (arcsec)	Position Angle (deg)	Companion(s)	Note
Apr 30.1186	3.5	90	A	1
May 9.3386[a]	7.4	97.7	A	2
May 12.9549	10.4	104	A	3
May 14.3514[a]	11.6	103.4	A	2
May 14.9972	12.6	105	A	4
May 16.3353[a]	14.1	103.5	A	2
May 16.3421[a]	14.5	102.7	A	2
May 16.9746	15.6	109	A	5
	1.6	136	C	5
May 17.3735	16.3	108	A	6
May 18.3660	17.5	109.3	A	6
May 18.9431	17.9	108	A	3
May 18.9695	18.1	108	A	3
May 18.9854	18.6	111.4	A	7
	3.2	136	C	7
May 19.3334[a]	18.2	109.5	A	2
May 19.3387[a]	18.0	108.8	A	2
May 21.3582	25.3	117.8	G	6
May 22.3385	6.1	141	C	6
	27.4	118.5	G	6
May 24.3504	9.6	135	C	6
	31.3	120	G	6
Jun 16.4215	2.8	212	D + E + F	8
Jun 17.4465	4.6	215	E + F	8
Jun 18.4090	6.7	222	F	9
Jun 18.4493	6.5	219	F	8
Jun 18.4563	6.6	222	F	10
Jun 19.4333	4.7	222	D	9
	7.2	222	E	9
Jun 19.4493	5.0	223	D	10
	8.5	223	F	10
Jun 20.4326	6.1	231	D	9
	8.3	222	E	9
Jun 21.4368	11.0	223	E	8
Jun 21.4424	7.2	231	D	10
	10.6	222	E	10
Jun 27.3958	26.4	230	E	11
Jun 28.4067	19.9	242	D	12

Note.—Information for notes is listed as follows: Observer(s) and/or data owner(s), telescope used (with instrument or detector), and spectral region (if known). (1) C. W. Hergenrother, M. Chamberlain, & Y. Chamberlain, 1.54 m + CCD, *R* band; (2) J. Broughton, 0.25 m f/6.3 + CCD, unfiltered; (3) D. Scarpa & A. Más, 0.25 m f/10 and f/3.3 + CCD, unfiltered (images processed and measured by E. Jehin); (4) E. Jehin & H. Boehnhardt, 8.2 m VLT Mepal + test camera, *R* band; (5) E. Jehin & A. Jaunsen, 8.2 m VLT Yepun + test camera, *R* band; (6) G. J. Garradd, 0.5 m f/5.4 + CCD, unfiltered (images processed and measured by E. Jehin); (7) D. Thomas & E. Jehin, 3.5 m NTT + EMMI, *R* band; (8) O. Schuetz, 3.6 m + TIMMI2, 10 μm; (9) X. Bonfils, 2.2 m ESO-MPG + WFI, *R* band; (10) E. Jehin, 3.5 m NTT + EMMI, *R* band (service-mode observation); (11) E. Jehin, 8.2 m VLT Antu + FORS1, *R* band (service-mode observation); (12) E. Jehin, 3.5 m NTT + SUSI, *V* and *R* bands (service-mode observation).

[a] Derived from absolute astrometry (Marsden 2001b, 2001c).

TABLE 3

Fragmentation Solutions for Companion Nuclei A, G, C, D, E, and F from Primary Nucleus B

Parameter	Companion					
	A	G[a]	C	D[b]	E	F
Time of fragmentation t_f from perihelion[c] (days)	-55.2 ± 1.3	-41.5 ± 0.9	-14.5 ± 1.1	$+13.9 \pm 0.5$	$+16.3 \pm 0.3$	$+17.8 \pm 0.5$
Date of fragmentation (2001 UT)	Mar 30.3	Apr 13.0	May 10.0	Jun 7.4	Jun 9.8	Jun 11.3
Normal component of separation velocity (m s^{-1})	...	...	...	$+0.72 \pm 0.05$	...	$+0.76 \pm 0.20$
Relative nongravitational deceleration[d]	16.3 ± 0.6	29.7 ± 1.0	53 ± 9	27.3 ± 1.7	54 ± 2	102 ± 13
Number of offset pairs employed	15	3	4	6	7	6
Mean residual (arcsec)	±0.58	±0.43	±0.44	±0.28	±0.33	±0.21

[a] Origin and nature of this companion are somewhat uncertain; see text for details.

[b] Fragmentation time depends rather critically on June 28 observation (see Table 2); when excluded, $t_f =$ June 3.5 ± 1.8 UT.

[c] Minus sign: time before perihelion; plus sign: time after perihelion.

[d] Units are 10^{-5} times the solar gravitational acceleration, or 0.593×10^{-5} cm s^{-1} at 1 AU from the Sun.

TABLE 4

Residuals from Observed Offsets Left by the Fragmentation Solutions

Time of Observation (2001 UT)	Residuals (arcsec)		Companion
	R.A.	Decl.	
Apr 30.1186	−0.4	+0.6	A
May 9.3386	−1.0	+0.9	A
May 12.9549	−0.8	+0.3	A
May 14.3514	−0.8	+0.7	A
May 14.9972	−0.5	+0.4	A
May 16.3353	−0.2	+0.9	A
May 16.3421	+0.2	+1.0	A
May 16.9746	+0.2	−0.5	A
	−0.2	+0.1	C
May 17.3735	+0.5	−0.2	A
May 18.3660	+0.5	−0.4	A
May 18.9431	+0.3	+0.2	A
May 18.9695	+0.5	+0.1	A
May 18.9854	+0.6	−1.0	A
	0.0	0.0	C
May 19.3334	0.0	−0.1	A
May 19.3387	−0.1	+0.2	A
May 21.3582	+0.3	−0.3	G
May 22.3384	−0.4	+0.1	C
	+0.3	−0.3	G
May 24.3504	+0.9	+0.3	C
	−0.5	+0.3	G
Jun 16.4215	−0.2	−0.4	D
	+0.1	+0.2	E
	+0.3	+0.1	F
Jun 17.4465	−0.3	−0.3	E
	+0.2	−0.2	F
Jun 18.4090	−0.3	−0.1	F
Jun 18.4493	+0.1	−0.1	F
Jun 18.4563	−0.2	0.0	F
Jun 19.4333	+0.2	+0.1	D
	−0.6	+0.2	E
Jun 19.4493	0.0	−0.1	D
	+0.1	+0.2	F
Jun 20.4326	−0.4	+0.4	D
	−0.1	+0.6	E
Jun 21.4368	−0.5	0.0	E
Jun 21.4424	−0.1	+0.3	D
	−0.1	+0.1	E
Jun 27.3958	+0.2	−0.1	E
Jun 28.4067	+0.1	−0.2	D

dicted path of G fits no astrometric observations other than those in the May 21–24 period of time.

Companions D, E, and F.—A detailed analysis was necessary to sort out the companions observed in June (see Schuetz et al. 2001 for preliminary results). The projected positions of the three fragments virtually coincided in the ESO exposure of June 16, and the positions of E and F merged also in the June 17 exposure. Fragment F was not detected after June 19. The data listed in Table 2 for June 27 and 28 are ESO observations reported here for the first time. Fragment D was too faint to be measured accurately on June 27. An apparently extraneous object was located $3''$–$4''$ away from the predicted position of fragment E on two June 28 exposures, but E was not detected.

The fully optimized fragmentation solutions are listed in Table 3. The residuals left by these solutions never exceed $1''$ and are presented in Table 4. For companions A, G, C, and E, only the basic two-parameter version of the model could be applied, yielding a fragmentation time and a deceleration. The solutions for companions A and C are similar to the early ones, derived from much more limited data sets (Sekanina 2001). Three-parameter solutions for these four fragments (not presented in Table 3) have shown the separation velocity to be always poorly determined. For fragments D and F, however, solutions that include a normal component of the separation velocity are meaningful and are incorporated in Table 3. For companion D, the derived separation time is affected significantly by the last observation (June 28); if it is retained, the separation is found to have taken place about 4 days later than if this observation is ignored. No such effect is apparent for the other fragments. Experimentation has confirmed that an attempt to solve for more than three parameters is always futile, as all such solutions have failed to converge. All searches for solutions in which the presumed origin of a fragment is not the primary nucleus have likewise turned out to be unsuccessful.

5. RESULTS, DISCUSSION, AND CONCLUSIONS

The principal result of this study is a remarkable temporal correspondence between the onset of the first three outbursts and the fragmentation episodes that gave birth to fragments A, C, and D, as is apparent from the upper panel of Figure 1. The calculated difference $t_f - t_0$ is $+1.8 \pm 1.7$

days for outburst I and fragment A, -0.5 ± 1.5 days for outburst II and fragment C, and, taking an average of the two solutions listed in Table 3 for D, $+1.7 \pm 3.3$ days for outburst III and fragment D. The numbers are distinctly positive, $+4.8 \pm 1.0$ days and $+6.3 \pm 1.1$ days, for outburst III and fragments E and F, respectively. This crowded sequence of three fragments separating from the primary during a period of 4–8 days illustrates the complex nature of the fragmentation process and explains the long rise time of outburst III (Table 1).

A sudden brightening with no associated nuclear breakup—perhaps because the fragment was too faint to detect—is demonstrated by outburst IV. On the other hand, companion G offers an example of fragmentation without an accompanying outburst. In summary, C/2001 A2 provides a remarkably broad variety of relationships between the two categories of events.

A correlation between outbursts and nuclear fragmentation was found for some comets before. For example, Sekanina & Farrell (1978) found a high degree of correspondence between the timing of a major flare-up of the celebrated comet C/1975 V1 (West) and the splitting of its parent nucleus into components A and D some 6 days before perihelion. Supporting evidence of this kind for other comets can be found in the literature; e.g., four such cases are listed by Sekanina (1982).

Outbursts associated with no detectable fragmentation are commonly observed in comets. For example, comet 29P/Schwassmann-Wachmann 1, notorious for its propensity for outbursts (e.g., Whipple 1980; Jewitt 1990), has never exhibited more than one nucleus. Nuclear fragmentation that is accompanied by no distinct outburst is perhaps somewhat less common yet well documented. Indeed, speaking of comet C/1975 V1, no brightening was observed when the short-lived fragment C was released from the nucleus 10 days after perihelion (Sekanina 1982).

Except for rare occasions (e.g., Whipple 1984), outbursts are believed to be triggered by the sudden activation of a previously dormant volatile reservoir. Flare-ups on visual light curves—sometimes accompanied by subsequent morphological changes in the tail (e.g., Sekanina & Farrell 1978)—are known to be dominated usually by dust, large amounts of which get entrained in the gas flow. Sekanina (1982) suggested that a nucleus companion, born in a nontidally triggered fragmentation event (Sekanina 1997), is a brittle, apparently pancake-shaped fragment of the inert dust mantle with some ice adhering to its base released from the nuclear surface with a rotation velocity on the order of 1 m s^{-1}. Depending on whether or not a significant fraction of the fragment's mass begins to disintegrate rapidly into fine dust upon its separation, the fragmentation event is or is not accompanied by an outburst. And if the fragment disintegrates in its entirety, the outcome is an outburst with no recognizable fragmentation. The variety of observed scenarios can thus be understood readily as a product of the size (or mass) distribution law intrinsic to the population of debris: the steeper the distribution's slope, the less likely the detection of a sizable fragment. Sekanina's conceptual model for nontidally split comets has enjoyed some support in the literature (e.g., Hughes & McBride 1992; Chen & Jewitt 1994), and we conclude that it is fully consistent with the seemingly complex outburst/fragmentation relationship that has now so compellingly been established for comet C/2001 A2.

We thank K. Brooks, O. Hainaut, P. Leisy, R. Madjewski, J. Navarete, H. Nunez, M. Sterzik, and E. Wenderoth for their assistance with the ESO high-resolution imaging of this comet. We are grateful to G. J. Garradd, Loomberah, and D. Scarpa and A. Más, Montevideo, for making their images of C/2001 A2 available to us. This research is based in part on observations obtained at the La Silla and Paranal Observatories of ESO in Chile and was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

REFERENCES

Broughton, J. 2001a, IAU Circ. 7625
———. 2001b, IAU Circ. 7627
Chen, J., & Jewitt, D. 1994, Icarus, 108, 265
Green, D. W. E., ed. 2001a, IAU Circ. 7564
———. 2001b, IAU Circ. 7605
———. 2001c, IAU Circ. 7611
———. 2001d, IAU Circ. 7625
———. 2001e, IAU Circ. 7645
———. 2001f, IAU Circ. 7653
———. 2001g, Internat. Comet Quart., 23, 67
———. 2001h, Internat. Comet Quart., 23, 130
Hergenrother, C. W., Chamberlain, M., & Chamberlain, Y. 2001, IAU Circ. 7616
Hughes, D. W., & McBride, N. 1992, J. British Astron. Assoc., 102, 265
Jehin, E., et al. 2001, IAU Circ. 7627
Jewitt, D. 1990, ApJ, 351, 277
Marsden, B. G. 2001a, Minor Planet. Circ. 42019
———. 2001b, Minor Planet. Circ. 42656
———. 2001c, Minor Planet. Circ. 42737-8
Pravec, P., & Šarounová, L. 2001, IAU Circ. 7564
Schuetz, O., et al. 2001, IAU Circ. 7656
Sekanina, Z. 1978, Icarus, 33, 173
———. 1982, in Comets, ed. L. L. Wilkening (Tucson: Univ. Arizona Press), 251
———. 1997, A&A, 318, L5
———. 2001, IAU Circ. 7630
Sekanina, Z., & Farrell, J. A. 1978, AJ, 83, 1675
Tichý, M., & Kočer, M. 2001, IAU Circ. 7564
Whipple, F. L. 1980, AJ, 85, 305
———. 1984, Icarus, 60, 522