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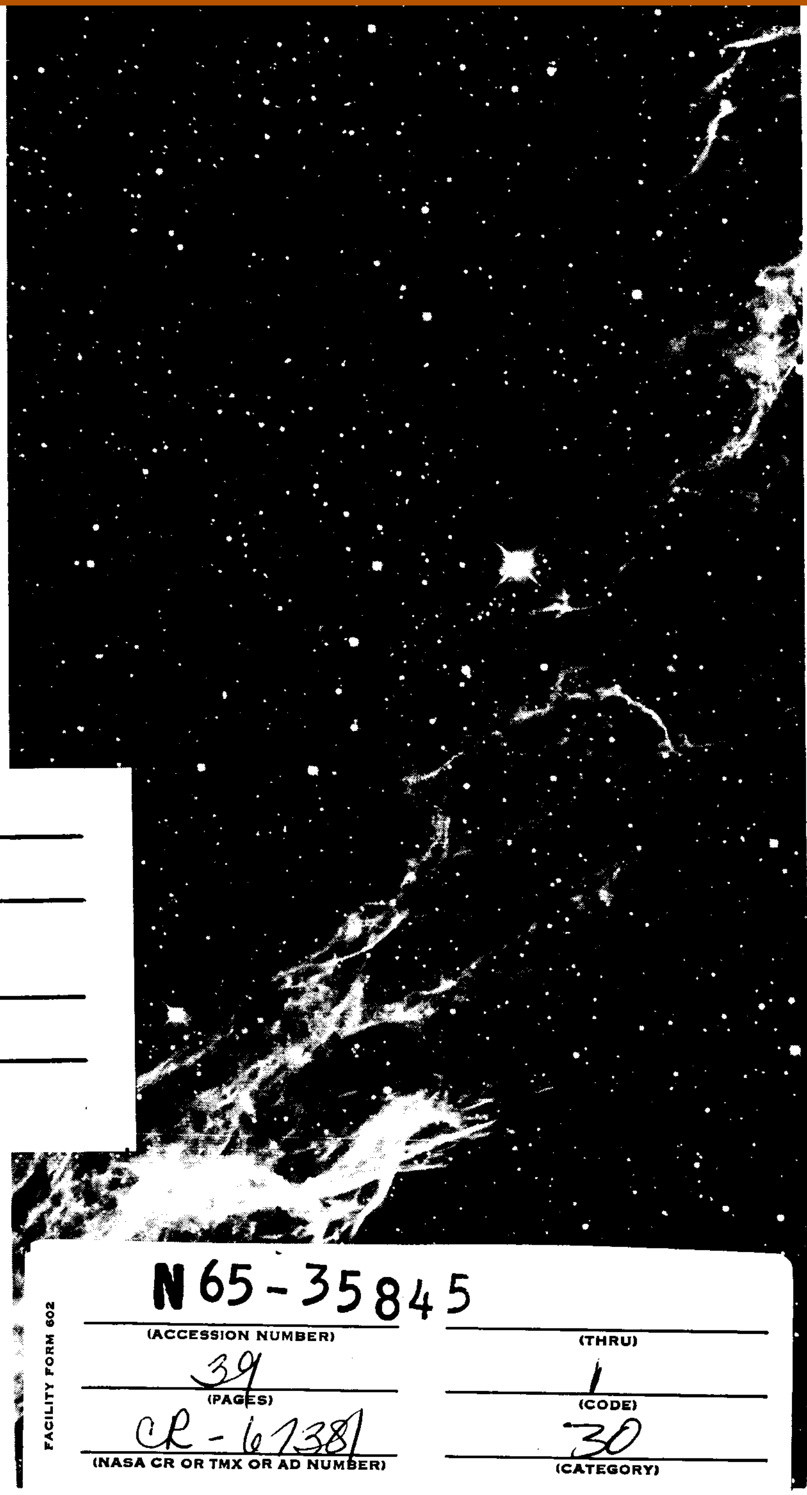

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TRAJECTORY AND SIGHTING ANALYSIS FOR FIRST-APPARITION COMETS

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TRAJECTORY AND SIGHTING ANALYSIS FOR FIRST-APPARITION COMETS

by

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SUMMARY

Previous studies of scientific objectives and trajectory requirements for missions to comets (cf. Appendix 2) have suggested the possibility of missions to long-period, first-apparition comets. In general first-apparition* comets are more active, potentially more primordial, and three magnitudes brighter than short-period comets. Further, the relatively frequent sighting of these new comets, about three per year, implies that the waiting time between attainable missions may not be prohibitive.

The essential question can be stated as follows: Are there enough launch opportunities over a given interval of time to seriously consider a mission to a first-apparition comet?

Fifty-four long-period, first-apparition comets sighted between 1945 and 1960 were chosen as a sample. This sample was checked by means of the χ^2 (chi-square) comparison with 378 similar comets sighted prior to 1945 in order to determine if the 54 were sufficiently representative. The results indicated significant differences between the two samples. These differences appear to be attributable to the improvement in

* The first-apparition comets considered in this report all have periods $>$ 1000 years.

observational techniques and instruments in recent years. Since this bias is likely to continue, it was concluded that the 1945-1960 comets were representative for predictive purposes.

Calculation of ballistic trajectories to each of the 54 comets resulted in the ideal velocity and associated flight parameters for a range of launch dates. To determine the launch windows from the trajectory data the following criteria were imposed.

1. After discovery, two-month allowance for orbit determination before launch could occur.
2. During this two-month period, a two-hour period for photographing the comet each night.
3. Ideal velocity less than 55,000 ft/sec for the 30-day launch window.
4. Time of flight less than 400 days.

The comets were assumed to be discovered at three levels of brightness:

1. Discovery at magnitude 20 provided an upper bound on the number of opportunities, since it approximately represents the limiting magnitude for the largest telescopes. Two launch opportunities per year could be expected. However, a program to search the entire sky at this magnitude would be extremely difficult.
2. Assuming launch could occur two months after the comet was discovered under present observing conditions provided a lower bound. On the average, this means discovery at magnitude 10.

At this magnitude two opportunities per decade could be expected. This is probably too infrequent for mission consideration, since random clustering could easily reduce the frequency to one opportunity per decade.

3. Discovery at magnitude 15 provided a realistic estimate of what could be accomplished if a moderate search program were undertaken using existing facilities such as Baker-Nunn cameras or similar equipment. About one opportunity per year could be expected.

It was concluded that this third approach, i.e., discovery at magnitude 15, offered enough opportunities so that a mission could be reasonably planned if a moderate search program were initiated.

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TRAJECTORY AND SIGHTING ANALYSIS FOR FIRST-APPARITION COMETS

1. INTRODUCTION

Previous Astro Sciences Center reports have considered the scientific objectives and trajectory requirements for missions to short-period comets (cf. Appendix 2). This report discusses the feasibility, from a trajectory and sighting standpoint, of sending a probe to a long-period first-apparition comet as a complement to the short-period comet missions.

The first-apparition* comets are considerably more active than short-period comets. Three major differences are:

1. The bulk of accumulated data about cometary phenomena (i.e., envelopes, jets, streamers, tails, etc.) is derived from observations of first-apparition comets. These phenomena are found to a lesser degree, if at all, in short-period comets.
2. The average absolute magnitude of first-apparition comets ($\overline{M}_o = 7.8$) is brighter by three magnitudes than the average short-period comets ($\overline{M}_o = 10.8$).

* The first-apparition comets considered in this report all have periods > 1000 years.

The brightness of first-apparition comets would enable better and more detailed ground observations to be made.

3. The average first-apparition comet makes 10^3 to 10^4 fewer perihelion passages than the average short-period comet over a given interval of time. It seems that the first-apparition comets would represent a relatively primordial state, and therefore investigations concerned with cometary origins might have a better chance of success if performed on first-apparition comets.

While of notable scientific interest, first-apparition comets present a more difficult target than short-period comets from trajectory and sighting considerations. First of all, no prior knowledge of the comet's orbit or discovery date can be assumed. This constraint necessitates some sort of continuous search procedure. Secondly, after the comet has been discovered, a launch vehicle and spacecraft would have to be readied concurrent with an intense tracking effort to determine the comet's orbit. To minimize this constraint a quick response launch facility would be needed.

The study was conducted by delineating the opportunities that would have occurred for flights to a sample of 54 comets that first appeared between 1945 and 1960. A statistical analysis indicated the sample used was representative of first-apparition comets. Trajectory and sighting computations on the sample determined the frequency of launch opportunities.

2. STATISTICAL ANALYSIS AND SAMPLES

The sample used to determine the frequency of launch opportunities consisted of 54 comets that had their first apparition between 1945 and 1960. Actually, 71 comets made their first appearance between 1945 and 1960, but of these 71, 14 were short-period comets (period $<$ 1000 years). These 14 were deleted because they did not exhibit the characteristics that are typical of the long-period, first-apparition comets mentioned in Section 1.

In attempting to verify the use of the 54 as representative, a statistical analysis was performed comparing them with 378 comets whose first appearance occurred between the years -465 and 1945. These 378 also did not include any short-period first-apparition comets. The orbital elements used for the comets were taken from The Catalogue of Cometary Orbits (Porter 1960), which contains orbital data for all comets observed prior to 1960. The absolute magnitude and physical data were taken from Physical Characteristics of Comets (Vsekhsvyatskii 1958), which contains the pertinent information and references on each comet observed until comet 1957 VI. Data for comets subsequent to these were found in the Publications of the Astronomical Society of the Pacific, the Harvard Announcement Cards, or the Astronomical Journal. The elements of the 1945-1960 comets and their absolute magnitudes are given in Appendix 1.

To ascertain whether the samples of 54 and 378 comets were from the same population, the χ^2 test was used. This test determines the probability that any differences noted between two samples are due to purely random or chance variations. The χ^2 test was performed on the radius of perihelion, the orbital inclination, and the absolute magnitude of the two samples. The other orbital elements were unsuitable for comparison because either there were not enough comets to yield a meaningful statistic or the test became trivial, i.e., the eccentricity is unity and the period infinite for practically all first-apparition comets.

The χ^2 test yielded negative results for each of the orbital elements that were compared which indicates a dissimilarity in the samples. Figures 1 to 3 show the frequency distribution for the three elements. The hatched area in Figures 1 and 3 indicates the interval that gave rise to a very high χ^2 result. On the basis of this testing and a consideration of the figures, it seemed reasonable to conclude that there was a fundamental difference between the two samples.

Both the radius of perihelion and the absolute magnitude showed their greatest change in the area where improved observational methods and equipment would have their effect, i.e., the ability to observe fainter objects further out. This same trend has been noted by others doing similar work on slightly different samples (Vsekhsvyatskii 1958, Richter 1963). Elizabeth Roemer of the U. S. Naval Observatory, Flagstaff Station,

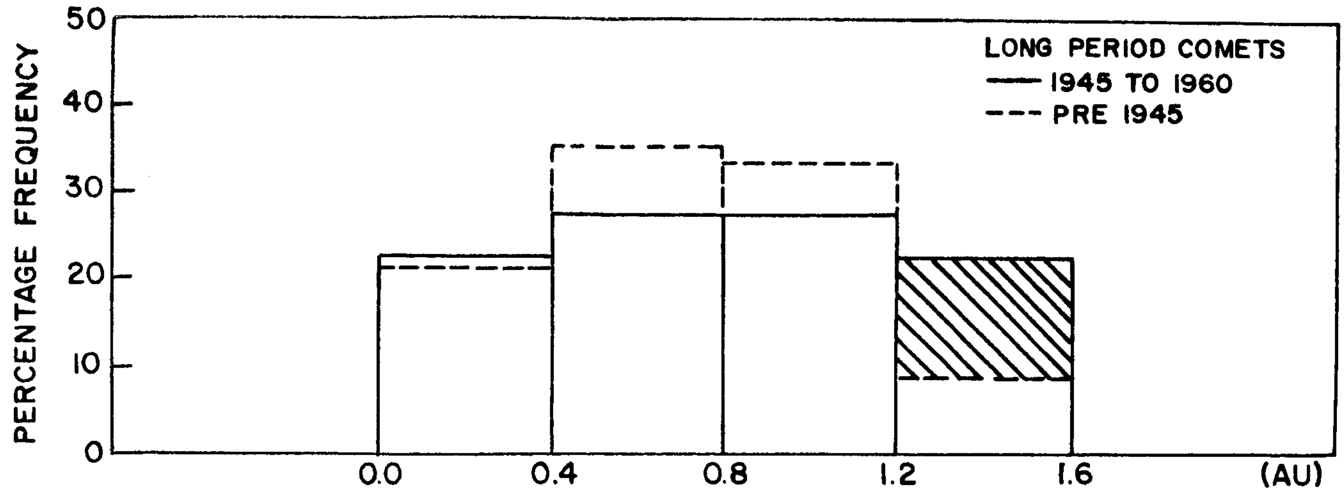

FIG. I
FREQUENCY DISTRIBUTION FOR RADIUS OF PERIHELION OF LONG PERIOD COMET SAMPLES

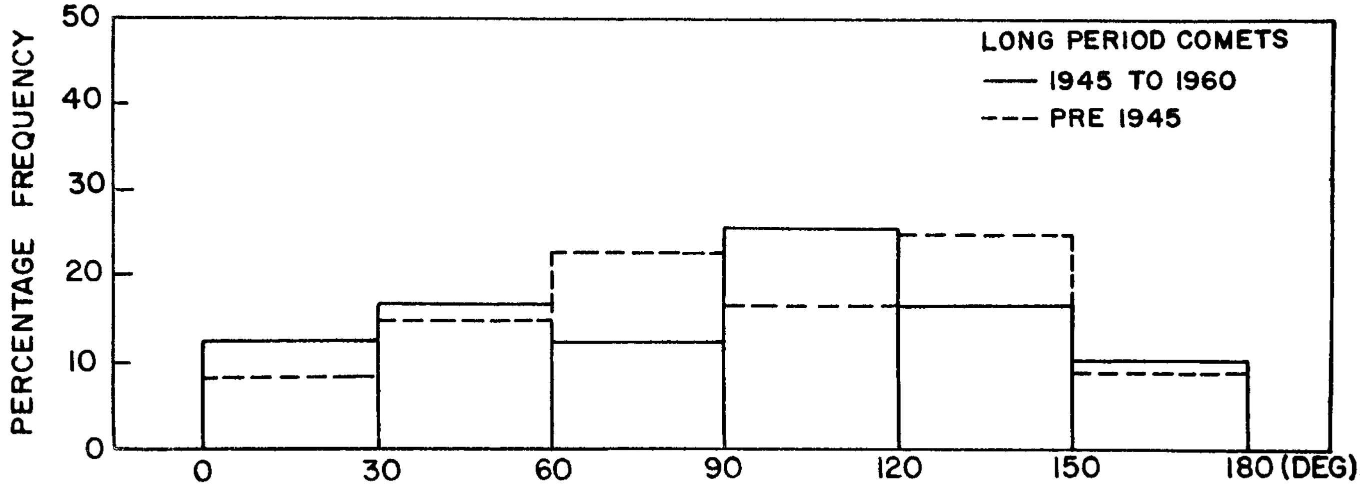

FIG. 2
FREQUENCY DISTRIBUTION FOR INCLINATION OF LONG PERIOD COMET SAMPLES

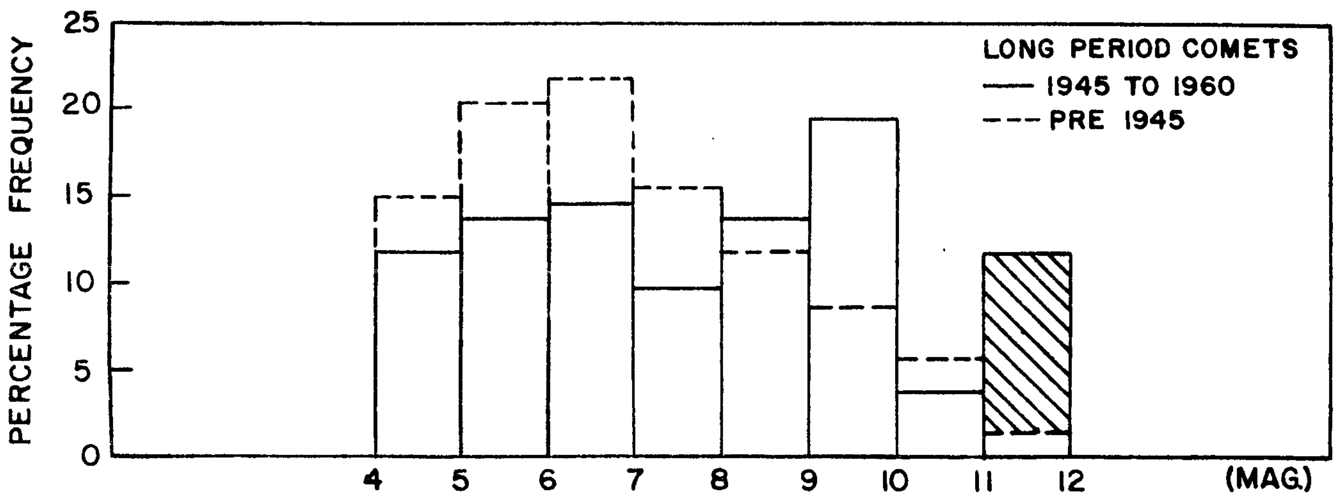

FIG. 3
FREQUENCY DISTRIBUTION FOR ABSOLUTE MAGNITUDE OF LONG PERIOD COMET SAMPLES

attributes this to the fact that "Most new comets reported in recent years have been found by professional astronomers on photographic plates exposed with wide-field instruments for other purposes." (Roemer 1963a).

In summary then the statistical analysis checked whether the present first-apparition comets are similar to those which have been observed over the previous centuries. It appears as if the comets recently discovered are different and this difference can be attributed to improved observational techniques. It was concluded that the 54 first-apparition comets from 1945 to 1960 were representative of the present comets being discovered and gave a reasonable indication of those that will be discovered in the next few decades. Any significant change in observational techniques, such as an all-sky comet search, could only serve to increase the number of launch opportunities.

3. TRAJECTORY AND SIGHTING ANALYSIS

3.1 Trajectories

Since the 1945-1960 sample was verified to be statistically representative, the next step was to determine which of the 54 new comets were attainable with moderate energy and flight time requirements. A reasonable energy was defined as an ideal velocity (ΔV) less than 55,000 ft/sec. This velocity can be achieved by an Atlas-Centaur + a hydrogen fluorine kick stage carrying a 800 lb. spacecraft or by a Saturn 1B-Centaur carrying a 1500 lb. spacecraft. In general, only times of flight less than 400 days were considered. Calculations with flight times greater than 400 days revealed no new opportunities because the low-energy shots arrive relatively close to 1 AU and therefore require shorter trip times.

A trajectory survey to each comet was then run using the ASC/IITRI Conic Section Trajectory System (Pierce and Narin 1964), which calculates ballistic trajectories between two points for a given launch date and time of flight. From these results plots were made of launch date versus each of the following parameters: minimum ΔV for that date and the corresponding time of flight (TF), hyperbolic approach velocity (VHP), communication distance at intercept (RC), magnitude of the comet at intercept, and intercept date relative to perihelion. Consideration of these plots and the sighting restrictions yielded the launch windows and their associated range of parameters.

The minimum energy launch windows for the first-apparition comets corresponded to an essentially fixed arrival date, with the time of flight varying daily to achieve this condition. The constant arrival date is a result of the high inclinations of the new comets in contrast to other Solar System objects, which all tend to lie within a few degrees of the ecliptic plane. Thirty-six of the 54 new comets have inclinations between 40° and 140° and only six are within 10° of the ecliptic. The intercept date for minimum energy flights usually occurred when the comet was passing through the ecliptic plane.

A second and more important result of this high inclination was the large approach velocities (VHP) encountered. The mean VHP of the comets with launch windows was 43 km/sec, with a standard deviation of $\pm$ 20 km/sec. With 30 of the 54 comets having retrograde orbits and the majority having inclinations greater than 45°, the resultant difference between the velocity vectors of the spacecraft and comet tended to be additive.

For most missions of a noncometary nature this high VHP might be prohibitive because the brevity of encounter could place excessive restrictions on the spacecraft. With a first-apparition comet, however, the high VHP does not seem to negate the feasibility of a fly-by mission because of the large dimensions of the comet's coma and tail. A one-hour period of encounter would result if it is assumed that the spacecraft has the mean VHP of 43 km/sec and intercepts halfway between the center and the outer edge of a typical coma of diameter 10^5 km. This long stay time, however, does not benefit experiments concerned with the nucleus (about 10 km in diameter).

On the other hand, a rendezvous mission is severely restricted by the high VHP. In this case a large amount of propellant must be expended in order to decelerate the vehicle. Calculations assuming specific impulse (I_{SP}) of 225 sec (solid, storable propellant) revealed that a maximum of 4 km/sec could be trimmed from the VHP. This calculation used a 15 percent weight factor for the structure and tankage. Increasing the

I_{SP} to 350 sec increased the maximum to only 6.5 km/sec, which is still only 15 percent of the velocity change required for a rendezvous mission.

3.2 Sighting

The general problem of optically recovering and tracking a comet is referred to as the "sighting" problem. Sighting is an essential step in the determination of launch windows because launches should be considered only after the comet's orbit has been verified by numerous observations. Sighting restrictions are characteristic of all comet missions (Narin and Pierce 1964), and in particular for first-apparition comet missions, since their orbits are unknown prior to discovery.

Sighting a comet from an Earth-based observatory is primarily a function of three factors:

1. Visible Hours

At any given latitude how many night hours (exclusive of daylight and twilight) will an object be visible above the horizon. A minimum number of two visible hours per observation was required, dictated by the fact that accurate observations within 15° or one hour of the horizon would be hampered by atmospheric distortion and that adequate time must be allowed for exposing the photographic plate to the very faint object.

2. Brightness

The comet must be bright enough to be optically seen from Earth. Brightness was estimated quantitatively by using the relation

$$I = \frac{Io}{\Delta^2 \, r^n} \qquad (1)$$

where

Io = intrinsic brightness,

Δ = Earth to comet distance,

r = Sun to comet distance.

Because comets are in part self-luminescent, their brightness curve does not follow the inverse r^2 relation with respect to the Sun. For most comets n ranges between 2 and 8; for new comets n is close to 4 (Roemer 1963a). Given the absolute magnitude Mo at Δ and r = 1 AU, equation (1) reduces to the standard magnitude equation

$$M = Mo + 2.5 \, n \log r + 5 \log \Delta \, . \qquad (2)$$

By using n = 4 a comparison was made between the published sightings and magnitudes (Vsekhsvyatskii 1958) and those calculated from equation (2) for ten of the comet sample. The equation provided estimates correct to within two magnitudes, which was considered accurate enough for purposes of gross prediction.

3. Observing Conditions

Poor climatic conditions or the presence of a near-full moon can make sighting difficult. Bad weather problems can presumably be solved by having a worldwide tracking system. The moon can obscure faint objects for as many as two weeks per month. The two weeks can be considerably reduced, though, if the comet happens to rise or set a couple of hours before or after the moon, thus making observation possible. The weight of both these factors was not estimated except indirectly, by being pessimistic on the time interval needed for sighting.

Assuming that at each observation the comet satisfied the three sighting criterion mentioned above, a period of two months of tracking after discovery was considered necessary in order to establish a preliminary orbit of sufficient accuracy to attempt a launch. During these two months the decision of whether this comet was of sufficient interest to warrant a probe would be made; meanwhile, simultaneous launch vehicle preparation would be taking place at Cape Kennedy. Presently a mission of this kind is not feasible because of the long lead times required for the numerous phases of launch preparation. In the future, however, it is felt that systems might be designed such that this lead time could be greatly diminished.

To perform the sighting computations automatically, a FORTRAN IV program, SIGHT, was written for the IBM 7094 computer. The program determines the number of visible hours and the magnitude of a comet given a calendar date, a latitude, and the comet's absolute magnitude. SIGHT was run for each comet from 1.5 years before perihelion until 4 months after for latitudes -50° to +50° every 25°.

3.3 Method of Trajectory and Sighting Analysis

To determine the frequency of launch opportunities and to quantitatively assess the feasibility of a mission to a first-apparition comet, three approaches were taken:

1. To establish an upper bound, the trajectory data for the 54 comets were analyzed according to the requirement that launch occur at least two months after the comet reached magnitude 20, which is approximately the limiting magnitude for the largest telescopes. This approach corresponded to the most sophisticated search possible.
2. To establish a lower bound, the data were analyzed according to the assumption that launch could occur at least two months after the comet was discovered under observation conditions as they are today with no search program specifically concerned with discovery of first-apparition comets.
3. To establish a workable alternative by asking what tracking systems would achieve a significant advance over the present observation methods and what is the frequency of opportunities associated with each system. A survey of the current optical tracking systems revealed that a system is already operational (Baker-Nunn cameras), and that magnitude 15 represented a reasonable limit for expected discovery if this system were used for comet search. A brief discussion of this system and its applicability to comets is contained in Section 3.4.

An example of the type of analysis performed and the effects of sighting on the trajectories are illustrated in Figure 4. The plots show the minimum ΔV for a launch date as well as the time of flight, approach velocity, and communications distance corresponding to that ΔV for comet 1945 III.* SIGHT then generated the following data.

Magnitude	Date	Visible Hours	Latitude
20	8/20/44	2.5	+50°
15	12/28/44	11.0	+50°

The actual discovery of the comet occurred on 6/11/46 at magnitude 10.

The comet reached magnitude 20 on 8/20/44. Thus, according to the first approach taken, launches could occur after 10/20/44. Figure 4 shows that the minimum 30-day launch window has an overall ΔV of 42,500 ft/sec and begins 12/26/44, in this case the launch would be held until then and the extra time would be utilized for more extensive tracking. The launch window then determines the ranges for the other variables, as indicated on the curves. Delaying the launch until two months after comet 1945 III reaches magnitude 15, which corresponds to the third approach, raises the launch window ΔV to 45,000 ft/sec because by this time the minimum has passed and the ΔV curve is ascending. In the second approach the ΔV curve is well over 60,000 ft/sec by 8/11/45, two months after the historical discovery. By this time no launches would be energetically possible. This analysis was typical of that which resulted with the other comets.

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* The official comet numbering system was used rather than their names to preserve uniqueness. Often an observer has discovered more than one comet.

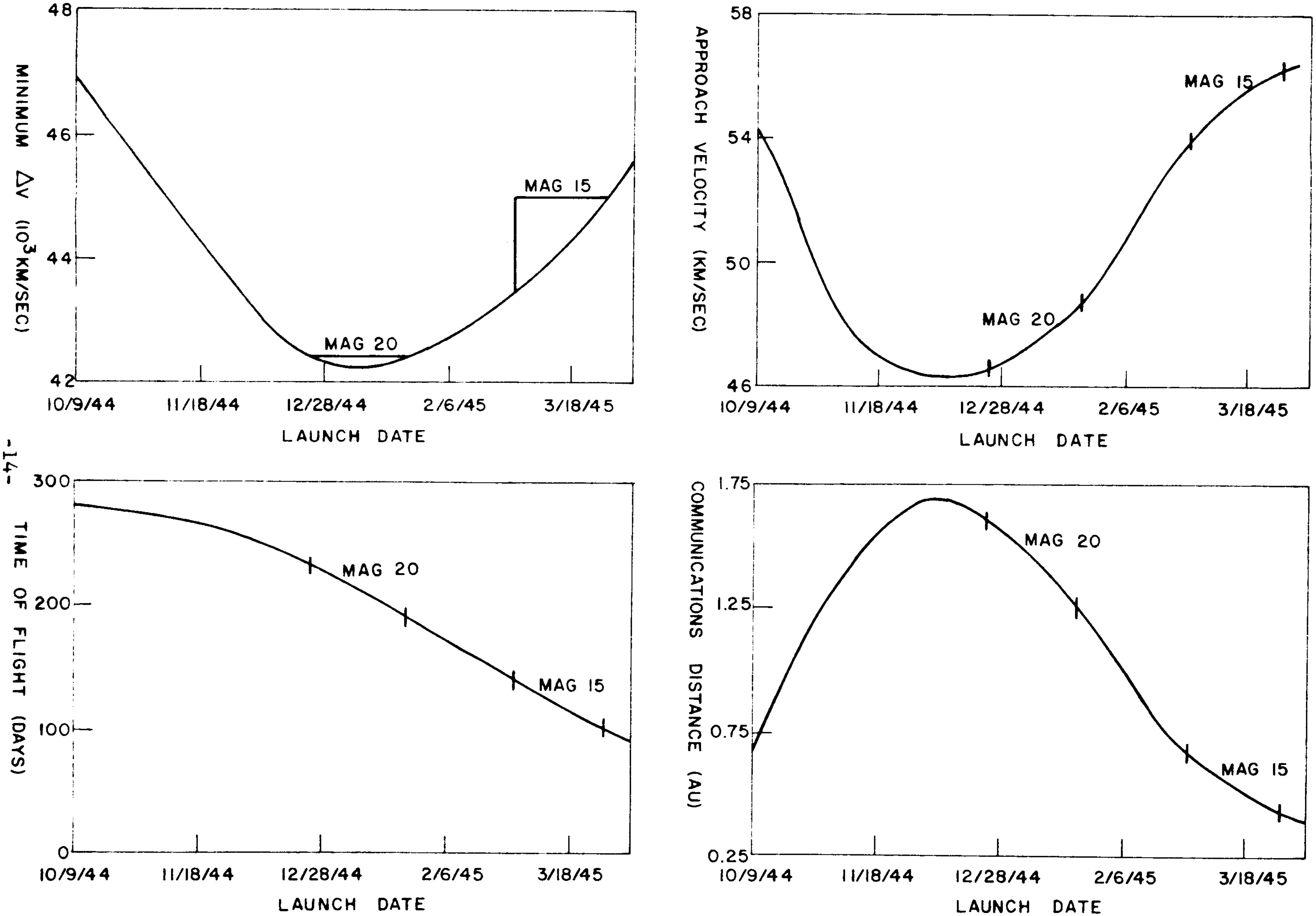

FIG 4 FLIGHT PARAMETERS FOR COMET 1945 III

3.4 Comet Watch

In 1957 the Smithsonian Astrophysical Observatory received a NASA contract to set up a worldwide system of 12 Baker-Nunn cameras to track artificial satellites. It is suggested that the Baker-Nunn camera system could be used to discover and track first-apparition comets. The suitability of the cameras to carry out this task has been demonstrated by the recording of numerous new comets on their patrol films (Roemer 1963b, 1964, 1965).

The limiting magnitude of the camera, 17, is restricted by sky fogging of the photographic strip film used. Allowing two magnitudes as a safety factor would virtually assure discovery of any object of magnitude 15 or brighter; this was the number used in the third approach. Each strip of film covers 5 x 30 sq deg of sky and requires a three-minute exposure plus a two-minute allowance for reset of the camera, i.e., a total of five minutes per exposure (Henize 1957, 1960). An entire search of the night sky or 2×10^4 sq deg would take 11 hours for one camera or 55 minutes for the twelve cameras.

This figure of one hour per camera demonstrates that the Baker-Nunn cameras could conceivably carry out an all-sky comet search. No time was allotted for the overlapping of sky survey regions or for failure due to overexposure, etc., but it is believed that these factors would not alter the validity of the approach.

This process might be repeated twice per month or more. The set of 133 exposures could be compared by day to a standard set of sky photographs by means of a microscopic blink process, which can detect any differences in the two films. The detection of any bright new comet would then be relayed to various observatories so that numerous positions over the two-month span of time could be used to determine the orbit. By waiting until the comet reaches magnitude 15, better position estimates will be obtained because comparison will be possible with brighter stars, whose positions are generally better known.

These cameras are located roughly within ± 30° latitude. This setup gives a wide range of coverage. Some gain in observation time would result if two or more stations were set nearer to the poles, since new comets generally approach from high declinations.

The additional scientific output of a program of this scope is considerable. Undoubtedly a continuous and systematic search of the entire sky would yield a wealth of new data on comets, asteroids, and meteors besides providing a constant monitor for novae and other sky phenomena.

3.5 Results and Conclusions

A summary of the results of the trajectory and sighting analysis is contained in Table 1. This table lists the means, standard deviations, and the frequency of favorable apparitions for each approach corresponding to the three brightness levels assumed for discovery. Table 2 lists the results for each of the 54 comets.

Approach 1

If discovery occurred at 20th magnitude, 35 of the 54 comets would be accessible over the fifteen-year period. This corresponds to two per year. It was concluded that while ample opportunities exist and the ranges of mission parameters are reasonable, the discovery system needed to cover the entire night sky at this magnitude would be prohibitive. Only the largest telescopes have the light-gathering power to achieve magnitude 20, and the fields of view of these instruments are relatively small.

Approach 2

Launches restricted to two months after actual discovery eliminated all but 3 of the 54 comets. This corresponds to two per decade. This figure is probably so low because no large-scale coordinated detection programs exist for early discovery of first-apparition comets. It was concluded that no effective mission planning could be done on the basis of such infrequent opportunities. At present new comets are discovered either by accident with a large telescope searching for something else or by amateurs, who detect them months later and usually too late for launch purposes.

Approach 3

If discovery occurred at 15th magnitude, 13 of the 54 would be accessible. This corresponds to 1 opportunity every

14 months, or roughly one per year. This group assumes discovery by the Baker-Nunn camera system, which is well suited for this purpose and is currently operational. It was concluded that this third approach offered sufficient opportunities for the effective planning of a mission and that discovery requirements are within reasonable limits.

A question remains as to the likelihood of having a long interval during which no launch opportunities would occur. In other words, assuming some interval of time, what is the probability that at least one favorable opportunity will appear? The Poisson distribution is a valid representation of the favorable opportunities occurring randomly with a mean rate of 1 every 14 months. Calculations showed that there would be better than a 50% chance of a favorable opportunity in less than 1 year. In 2.75 years the probability is 90% that at least one good opportunity would appear. This possible waiting period will be a constraint on any first-apparition comet mission but not one that appears insurmountable.

A comparison of the mean values of Approaches 1 and 3 in Table 1 show them to be roughly the same. As seen from Table 1 these values are within the attainable limits of currently planned vehicles and serve to define a range within which a new comet mission could be planned. The approach velocity is rather high with a large deviation, but, as noted before, this appears to be the case with all comets.

An interesting aspect of the new comets is that their mean magnitude at intercept is 10. Thus, for the average new and accessible comet, relatively good spectroscopic measurements will be possible. With this brightness it would be possible to correlate the telemetered data from the spacecraft with the optical observations from Earth at the time of intercept.

The main conclusion of this report is that if a moderate comet search is undertaken, there will be sufficient opportunities for a mission to a new comet. A more detailed mission study to define a payload and to further examine the guidance and midcourse problems appears to be a useful successor to this preliminary analysis.

Interest in this type of mission seems justified from the fact that first-apparition comets are in general more active and may represent a more primordial state than short-period comets. The real and reasonable concern over the lack of a definite launch date and the requirement for a ready launch vehicle and spacecraft should be viewed against the background of the future. In a decade the launching of present-generation vehicles should be more routine, and a standardized spacecraft "bus" for a comet mission might be possible. With the experience gained in the successful completion of missions to short-period comets, a mission to a first-apparition comet would be a logical follow on.

Table 1

SUMMARY OF TRAJECTORY AND SIGHTING RESULTS

Number of 30 day launch windows with $\Delta V < 55,000$ ft/sec and TF < 400 days at least two months after reaching the given brightness.

1. Magnitude 20 - mean parameters and standard deviation

ΔV	46100 ± 4600 ft/sec
Time of flight	250 ± 90 days
Approach velocity	40 ± 18 km/sec
Communications distance	1.9 ± 1.2 AU
Magnitude at intercept	11.0 ± 3.6 mag.
Intercept date relative to perihelion	30 ± 100 days
Opportunities per year	2

2. Actual Discovery

1948 I	
1949 IV	
1959 K	
Opportunities per decade	2

3. Magnitude 15 - mean parameters and standard deviation

ΔV	46800 ± 4400 ft/sec
Time of flight	190 ± 80 days
Approach velocity	43 ± 20 km/sec
Communications distance	1.6 ± 1.5 AU
Magnitude at intercept	9.9 ± 4.0 mag.
Intercept date relative to perihelion	58 ± 100 days
Opportunities per year	1

Table 2

TRAJECTORY AND SIGHTING DATA FOR THE 1945-1960 FIRST APPARITION COMETS

Name	Launch Date After* Mag 20 / Mag 15	ΔV (ft/sec)	TF (days)	VHP (km/sec)	RC (AU)	Magnitude at Intercept	Intercept Date Relative to Perihelion**
1945 I	12/15/43	52,000	250-260	22	3.4	14	110B
		60,000					
1945 III	12/26/44	42,500	170-240	48	1.4	14	85A
	2/28/45	45,000	95-140	57	.7	12	75A
1945 VI		60,000					
1945 VII		60,000					
1946 I		60,000					
1946 II	8/20/45	41,900	240-265	69	1.0	9	3A
	2/22/46	43,700	75-105	68	0.2	6	20A
1946 VI	10/30/45	52,300	350-400	39	2.2	8	38A
		60,000					
1947 I	5/15/46	46,600	275-300	35	3.2	12	30A
	5/15/46	SAME					
1947 III		60,000					
1947 IV	12/11/46	43,300	150-185	32	1.4	9	24A
		60,000					

* For each comet the first line gives the parameters for a 30 day launch window beginning at least 2 months after reaching magnitude 20; the 2nd line gives the same data for magnitude 15. If ΔV was $\geq$ 55,000 ft/sec and/or TF $\geq$ 400 days no launch window is given.

** B indicates before, A after.

Table 2 (Cont'd)

Name	Launch Date After Mag 20 (1st line) Mag 15 (2nd line)	ΔV (ft/sec)	TF (days)	VHP (km/sec)	RC (AU)	Magnitude at Intercept	Intercept Date Relative to Perihelion
1947 V	12/22/46	42,000 60,000	135-165	50	0.6	12	5A
1947 VI		60,000					
1947 VIII		60,000					
1947 X	3/22/47	42,500 60,000	190-220	64	1.4	10	21B
1947 XII	12/27/46	50,000 60,000	380-390	51	2.9	7	30A
1948 I	8/24/47 8/24/47	44,800 SAME	150-185	76	1.5	6	9A
1948 II		60,000					
1948 III		60,000					
1948 IV	2/17/47	42,150 60,000	360-400	30	2.4	12	54B
1948 V		60,000					
1948 X	6/28/48 6/28/48	47,200 SAME	225-255	27	2.8	14	140A
1948 XI	3/ 8/48 3/ 8/48	54,700 SAME	235-265	42	0.6	4	30A
1949 I		60,000					
1949 IV	8/31/49 8/31/49	54,800 SAME	340-385	20	4.9	17	335A

Table 2 (Cont'd)

Name	Launch Date After Mag 20 (1st line) Mag 15 (2nd line)	ΔV (ft/sec)	TF (days)	VHP (km/sec)	RC (AU)	Magnitude at Intercept	Intercept Date Relative to Perihelion
1950 I	11/28/48	49,600 60,000	260-300	38	3.7	14	117B
1951 I	11/ 3/49 11/ 3/49	47,000 SAME	360-400	38	3.5	11	38B
1951 II	8/11/50	45,200 60,000	265-295	29	2.9	16	130A
1952 I	4/29/51	41,700 60,000	295-320	55	2.0	13	68A
1952 VI	5/20/52 5/20/52	51,400 SAME	130-170	17	1.3	13	120A
1953 I	6/ 4/52 6/ 4/52	43,600 SAME	165-195	30	1.3	9	17B
1953 II	4/24/52	49,750 60,000	185-215	52	1.3	12	56B
1953 III		60,000					
1954 I	12/19/52	44,200 Mag. always > 15	350-400	43	3.0	17	5B
1954 II		60,000					
1954 V		60,000					
1954 VIII	4/19/53	58,600 60,000					
1954 X	6/12/53	42,100 60,000	350-380	34	1.4	7	10B

Table 2 (Cont'd)

Name	Launch Date After Mag 20 (1st line) Mag 15 (2nd line)	ΔV (ft/sec)	TF (days)	VHP (km/sec)	RC (AU)	Magnitude at Intercept	Intercept Date Relative to Perihelion
1954 XII	9/19/53	40,750 60,000	270-300	46	0.7	9	46B
1955 IV	11/ 4/54	54,400 60,000	210-250	28	0.7	9	10B
1955 V	12/ 9/54 4/ 6/55	41,150 42,600	215-245 120-145	64 64	0.4 0.3	6 9	5A 32A
1955 VI		60,000					
1956 I		60,000					
1956 III		60,000					
1957 III	5/ 3/56	43,100 60,000	230-265	42	1.9	9	80B
1957 V	12/ 4/56	47,400 60,000	365-400	24	3.8	13	165A
1957 VI		60,000					
1957 IX	6/18/57 6/18/57	40,800 SAME	95-125	63	0.1	4	45B
1958 III	12/18/57	53,000 60,000	140-150	16	1.4	15	32A
1958 E		60,000					
1959 D	3/ 5/59	42,050 60,000	100-130	15	0.2	10	3B

Table 2 (Cont'd)

Name	Launch Date After Mag 20 (1st line) Mag 15 (2nd line)	ΔV (ft/sec)	TF (days)	VHP (km/sec)	RC (AU)	Magnitude at Intercept	Intercept Date Relative to Perihelion
1959 E	3/18/59	41,550	180-210	27	1.0	12	57A
	5/11/59	45,800	130-170	27	1.0	12	74A
1959 F	2/16/59	42,000	160-180	67	1.2	10	30B
		60,000					
1959 J		60,000					
1959 K	12/28/59	45,200	80-110	73	0.3	9	28A
		60,000					

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Appendix 1

ORBITAL ELEMENTS AND ABSOLUTE MAGNITUDE FOR 1945-1960 FIRST-APPARITION COMETS

ORBITAL ELEMENTS AND ABSOLUTE MAGNITUDE FOR 1945-1960 FIRST-APPARITION COMETS

Comet	Abs. Mag.	Radius of Perihelion	Eccen-tricity	Inclination	Ω	ω	Time of Perihelion
1945 I	7.4	2.400280	1.0	17.2726	28.4314	239.4321	1/ 4/45
1945 III	10.4	0.998063	1.0	156.5093	254.2932	280.1413	5/17/45
1945 VI	9.6	0.1945	1.0	49.48	325.47	216.72	12/17/45
1945 VII	10.8	0.006305	1.0	137.02	321.69	50.93	12/28/45
1946 I	6.1	1.724132	1.001177	72.8474	128.9679	54.3235	4/13/46
1946 II	9.5	1.018251	1.0	169.57	301.30	22.26	5/11/46
1946 VI	4.8	1.136222	1.000794	56.9684	237.6345	320.4217	10/27/46
1947 I	5.2	2.407373	1.0	108.1684	34.8615	348.6415	2/ 7/47
1947 III	11.2	0.961836	1.0	129.15	322.38	183.13	5/ 4/47
1947 IV	9.2	0.559816	0.997503	39.2917	353.2048	303.7646	5/21/47
1947 V	11.5	1.402874	1.0	111.4114	232.3663	357.3970	5/31/47
1947 VI	8.0	2.827976	1.001045	97.3270	311.0980	9.3839	7/18/47
1947 VIII	4.1	3.266529	1.0	155.0732	121.4251	73.5236	9/ 4/47
1947 X	9.9	0.75309	1.0	106.2863	311.9618	221.2407	11/18/47
1947 XII	6.0	0.110071	1.000032	138.5129	336.6043	196.2059	12/ 3/47
1948 I	6.4	0.748329	1.0	140.5690	270.7366	350.2122	2/16/48
1948 II	7.7	1.499362	1.0	77.5400	198.5928	61.9223	2/17/48
1948 III	4.3	4.709302	1.0	53.2438	139.7497	191.8477	4/ 9/48

Comet	Abs. Mag.	Radius of Perihelion	Eccen- tricity	Inclination	Ω	ω	Time of Perihelion
1948 IV	8.4	0.207707	1.0	23.1615	203.1610	317.0430	5/16/48
1948 V	5.3	2.106870	1.0	92.9194	246.9482	66.9066	5/17/48
1948 X	8.5	1.274137	1.0	87.6233	66.9469	274.2554	10/23/48
1948 XI	5.5	0.135420	0.999935	23.4222	210.3318	107.2618	10/27/48
1949 I	6.2	2.517909	1.0	130.2685	119.8925	229.9279	5/ 1/49
1949 IV	7.5	2.058879	1.0	105.7731	309.0238	89.4887	10/26/49
1950 I	6.8	2.553225	1.000671	131.3542	221.6317	40.0973	1/19/50
1951 I	4.0	2.572433	1.001304	144.1505	38.1833	192.4596	1/15/51
1951 II	9.8	0.719848	1.003119	87.8858	310.5008	68.7218	1/30/51
1952 I	9.0	0.740426	0.999820	152.5323	76.1815	269.6041	1/13/52
1952 VI	9.1	1.202005	1.0	45.5644	187.9428	96.5895	7/15/52
1953 I	6.6	1.664975	0.995947	59.1204	220.6901	191.6310	1/ 5/53
1953 II	9.5	0.777749	1.000660	97.1764	342.8868	253.8217	1/25/53
1953 III	8.2	1.02245	1.0	93.8491	275.2028	85.7111	5/26/53
1954 I	11.7	2.060608	1.0	136.6415	292.0390	1.4262	1/18/54
1954 II	11.1	0.072091	1.0	13.5739	114.5845	94.0709	1/25/54
1954 V		4.500594	1.0	123.9149	320.6669	73.8689	3/24/54
1954 VIII	7.3	0.677080	1.0	116.1581	122.1855	357.2280	6/ 2/54
1954 X	6.2	0.970385	1.0	53.2146	2.3149	194.3991	7/ 7/54
1954 XII	9.3	0.746437	1.0	88.5567	74.8671	254.7204	8/30/54

Comet	Abs. Mag.	Radius of Perihelion	Eccen-tricity	Inclination	Ω	ω	Time of Perihelion
1955 IV	7.5	1.428936	1.002788	50.1275	303.8239	13.2319	7/12/55
1955 V	8.4	0.88461	1.0	107.5026	338.7200	348.1852	8/ 4/55
1955 VI	4.3	3.870352	1.0	100.3908	264.6402	144.6542	8/13/55
1956 I	5.4	4.07392	1.0	79.6250	72.1852	57.3325	1/27/56
1956 III	11.2	0.842240	1.0	148.4560	226.0253	81.0109	4/14/56
1957 III	5.1	0.316062	1.000230	119.9495	215.1591	308.7808	4/ 8/57
1957 V	6.0*	0.354924	0.999351	93.9397	67.6249	40.3122	8/ 1/57
1957 VI	4.4	4.44611	1.00086	33.200	232.944	13.263	9/ 2/57
1957 IX	5.4	0.53913	1.0	156.721	210.186	277.623	12/ 5/57
1958 III	14.0	1.322577	0.999272	15.7913	150.5106	16.4598	4/16/58
1958 E	8.0	1.628380	1.0	61.2588	323.0806	100.7341	3/12/59
1959 D	12.0	1.250122	1.0	12.8175	105.0689	186.4912	7/18/59
1959 E	9.7	1.150237	1.0	48.2559	159.2326	124.6963	8/18/59
1959 F	8.0	0.165597	1.0	107.9074	225.1081	300.6002	9/16/59
1959 J	11.0	1.253416	1.0	19.6344	99.9488	84.6614	11/13/59
1959 K	12.5	0.504192	1.0	159.6006	251.9620	306.6692	3/21/60

* Magnitudes from here on were not in Vsekhsvyatskii; in these cases the magnitudes were calculated from magnitude estimates or were available in the Harvard Announcement Cards.

Appendix 2

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