DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS, 88TH AIR BASE WING (AFMC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

20 August 2014

88 CS/SCOKIF
3810 Communication Blvd
Wright-Patterson AFB OH 45433-5706

Mr. John Greenwald
[redacted]

Mr. Greenwald,

This is in response to your FOIA request dated 6 May 14, received at Wright-Patterson AFB FOIA Office on 6 May 14.

The FOIA control number assigned to your request is 2014-03839-F ST2. Attached is the releasable record for this request.

It is a pleasure serving you. If you have any questions, please contact our office at (937) 522-3095.

Sincerely

Carmen Y. Oglesby
CARMEN Y. OGLESBY, Civ, DAF
Freedom of Information Act Analyst
Knowledge Operations Division

2 Attachments:
1. Responsive Document
2. Invoice

× Organization Logo

Invoice Summary

Report Date : 08/22/2014
Time : 11:49:00 AM

Requester Details
Mr. John Greenewald Jr.
[redacted]

Requester Invoice

Request No	:	2014-03839-F
Invoice No	:	00000044022
Invoice Date	:	08/22/2014
Requester Name	:	Greenewald, John
Requester Organization	:	-

Fee Items	Charged Value ($)
PROFESSIONAL - O1-O6/GS9-GS15 f. Other/Coordination/Denial	0.00

Total Amount : $ 0.00
Amount Paid : $ 0.00
Balance Due : $ 0.00

Request Description

Copy of AD0265306 entitled The Mission To a Comet Reported 11 Jul 1961

Sub Requests

Default

Memo

Make checks payable to:

THE MISSION TO A COMET

J. C. Lair

819550

9844-0023-MU-R01

THE MISSION TO A COMET

J. C. Lair

11 July 1961

Second Edition With Corrections, 18 September 1961

RESEARCH LABORATORY
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Los Angeles 45, California

ABSTRACT

The possibility and significance of launching a deep space probe to penetrate a comet are established.

CONTENTS

I. INTRODUCTION

Thinking of comets, we sum up the apparitions recorded long ago together with the observations we owe to an understanding ushered in by Halley, and find ourselves speaking of short- and long-period comets. In the short-period class is a Jupiter family consisting of a few dozen objects with periods strongly concentrated in the interval between five and eight years, regularly recurrent in the description of Keplerian ellipses about the Sun at one focus, and found to be at greatest distance from the Sun when not very far from the orbit of Jupiter. Per decade, about four of these objects pass near Earth as if driven by clockwork. If a probe could be passed through such an object there could be received on Earth information addressed to the question --- What is a comet? The consequence of such information is enhanced by a chain of thought beginning from the peculiar orbital uniformity of this Jupiter family, which originally signified to La Place the agency of Jovian gravitational selection imposed on a distinct and more extensive family of long-period comets. These objects -- so far from being many times observable within the lifetime of a single observer -- have periods which are astronomically long, and we speak of "new" comets. These happen also to pass near Earth at the rate of about four per decade, but at times and from directions we cannot specify until we have seen them. The status of the family of new comets, in turn, is considerable. Studies of the orbits of approach find them spherically distributed without bias in the direction of the Sun's own way, so that all these objects are known to have precisely shared the Sun's proper motion. The observed influx to the inner solar system must be supplied from a source which must also belong to the Sun. On logic due to Oort,* the source is deduced to be an encompassing spherical cloud about three light-years in diameter, containing about 10^{11} comets stirred by the nearer stars. Coming to rest in the stirring, an occasional object in this cloud has fallen in on the Sun and undergone observation as a new comet, or perhaps capture and observation as a Jupiter comet. On either understanding, the comets toward which we direct probes in the present essay may themselves be regarded as naturally provided probes into the deepest space and into the nature of Oort's cloud.

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* Oort, J. H., "The Structure of the Cloud of Comets Surrounding the Solar System and a Hypothesis Concerning Its Origin", Bulletin of the Astronomical Institute of the Netherlands (in English), XI, p. 91, 1950. The first page of Oort's paper has been made the inside back cover of the present essay.

II. THE SHORT-PERIOD COMETS

A. Accessibility

One can make a roster of the short-period comets which will return to the Sun in the next decade,[1] leaving out those which will not come inside the orbit of Mars and those which have gone unobserved on many passages since their discovery. There is thus a list of 14 reliable objects,[2] most of which will repeat themselves in any ten-year period, so that 24 perihelion passages are circled on the calendar which is Figure 1. Seventeen of these passages, involving 10 of these comets, will be closer to Earth's orbit than Venus can come. On sketching these passages we expect the approaches to Earth displayed in Figure 2. Because there was nothing preferential in our restriction to the 1961-1971 decade, Figure 2 (if names and dates of particular approaches are suppressed) justly represents the pattern of approaches to Earth made by this class of object in any ten-year interval.[3]

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[1] Westphal is expected in 1975; Crommelin, Halley, and Brorsen-Metcalf in the 1980's; Pons-Brooks, Olbers, Grigg-Mellish, and Herschel-Rigolet in the twenty-first century.

[2] 1927 I Neujmin 2 has been lost since 1927; 1955 i was a discovery by Mrkos but was undoubtedly a return of P/Perrine, missed on five returns since it was last seen in 1909. Objects like these are discussed in the annual forecasts of the British Astronomical Association and the annual surveys of the Royal Astronomical Society, and have been omitted from the present exposition.

[3] There are, of course, extremely close approaches in the record. 1770 I Lexell passed among Jupiter's satellites, then within 1-1/2 million miles of Earth, and has not been seen since. Pons-Winnecke in 1927 passed within 3-1/2 million miles of Earth. On October 9, 1946, Earth went within 130,000 miles of the spot Giacobini-Zinner had occupied eight days earlier. Finally, the Committee on Meteorites of the Academy of Sciences of the U.S.S.R. has found no meteoritic material in the many square miles of leveled trees in the Tungus Forest in Siberia, and takes the position that the explosion of June 30, 1908 was a collision with a comet.

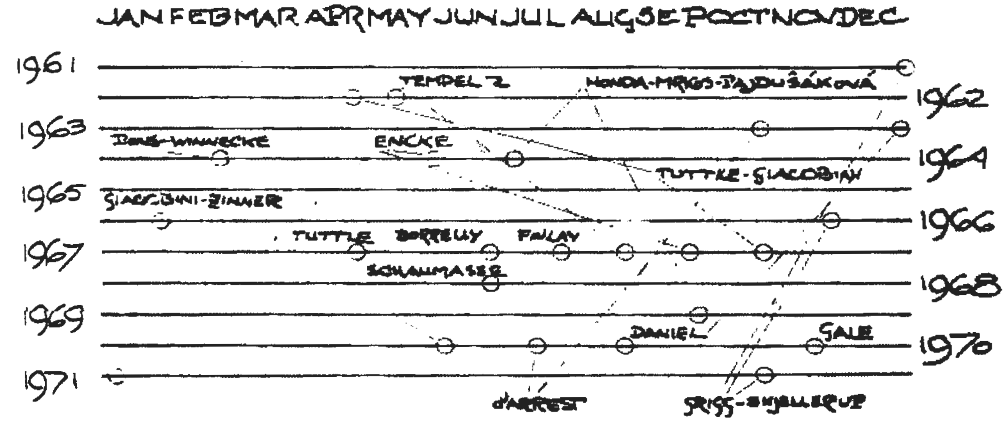

Figure 1 - A calendar of perihelion passages expected inside the orbit of Mars. Tempel 2, d'Arrest, Daniel, and Borrelly have perihelion distances larger than 1.35 AU and thus lose attractiveness by being always further away than Venus is at her inferior conjunction.

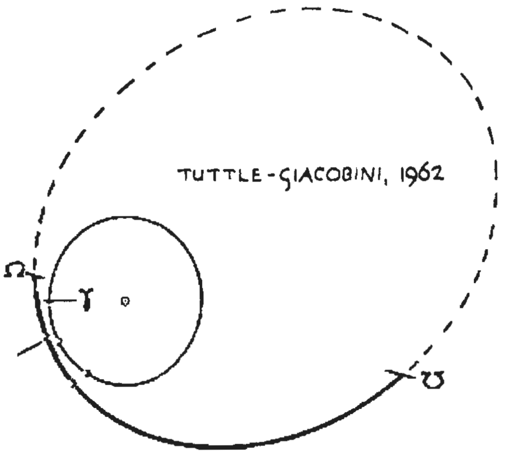

Fig. 2a. Kresak's discovery of April 1951 was observed 90 times in performance of an orbit which corresponded to Tuttle 1858 III and Giacobini 1907 III, and Kresak's object has come to be identified with Tuttle-Giacobini, which had gone unobserved since 1907 and was thought to be lost. Elements for the 1956 passage were: T = 1956 Oct 30, ω = 37.9, Ω = 165.8, i = 13.8, q = 1.118, e = 0.64, a = 3.11, P = 5.48 (HBAA, 1956, 1957), but the comet was extremely unfavorably situated, remaining for five months before and four months after the perihelion passage within 30 degrees of the Sun, and we have found no record that it was recovered.

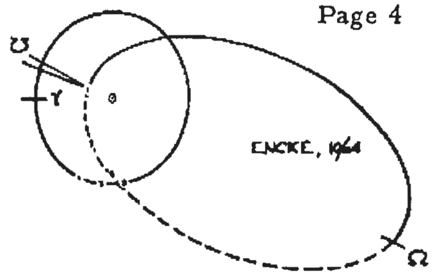

Fig. 2b. S. G. Makover's elements (HBAA, 1960) are as follows: T = Feb 5.58, 1961, ω = 185.2, Ω = 334.7 i = 12.36, q = 0.339, e = 0.847, a = 2.22, P = 3.300. Encke is the periodic comet of shortest period and is a dependable performer, having been observed on 46 returns, and having been recovered as much as 10 months before perihelion. Whipple has studied the case of Encke and the November Taurid and day-time β-Taurid meteor streams (See A.C.B. Lovell, Meteor Astronomy, Oxford, 1954, p. 415-21). From many points of view Encke is thus a distinguished comet--the preeminent trophy in the short period family. It should be observed that the orbits do not actually intersect as they appear to do in the sketch; they are linked.

As the present note is written, Encke's whereabouts is known exactly: Dr. Elizabeth Roemer of the U.S. Naval Observatory in Flagstaff recovered the comet on August 17, 1960, (Harvard Announcement Card, 1502). On January 6 and 7 she observed Encke's "faint narrow tail, 10 minutes of arc long." (HAC 1520). A spectrum is reported from Copenhagen: "Le Dr. P. Maffei a obtenu des spectres...le 9 janvier avec le télescope de 122 cm de l'Observatoire Astrophysique d'Asiago. Dispersion 278 A/mm à Hγ. Le spectre de la Encke montrait, intenses, les bandes du C_2 de Swan et les deux bandes du CN à 3883. Visible à peine le groupe du C_3 à 4050. Pas de continu." (Union Astronomique Internationale, Circulaire No. 1751, Feb. 1, 1961).

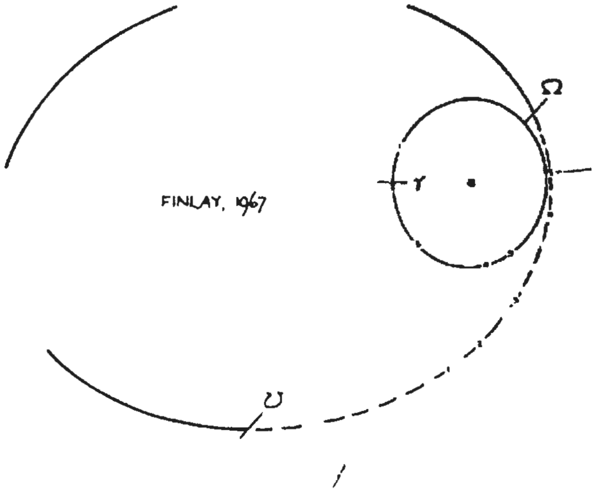

Fig. 2c. M. P. Candy's elements (HBAA, 1960) are based on observations of the apparition of 1953-54: T = Sep 2.28, 1960, ω = 321.6, Ω = 42.1, i = 3.64, q = 1.076, e = 0.703, a = 3.62, P = 6.899. Finlay has been observed on 7 returns, but was not seen between 1926 and 1953. The orbit is less steeply inclined to the ecliptic at i = 3.64° than that of any other periodic comet.

Finlay was recovered by R. Burnham at the Lowell Observatory in Flagstaff, on June 21, 1960, and by Elizabeth Roemer and B. G. Marsden at the U.S. Naval Observatory on June 22 (HAC, 1488, 1492). From these and subsequent observations there is the orbit (HAC 1506): T = Sep 1.1, 1960, ω = 321.6, Ω = 42.0, i = 3.64, a = 3.62, e = 0.703.

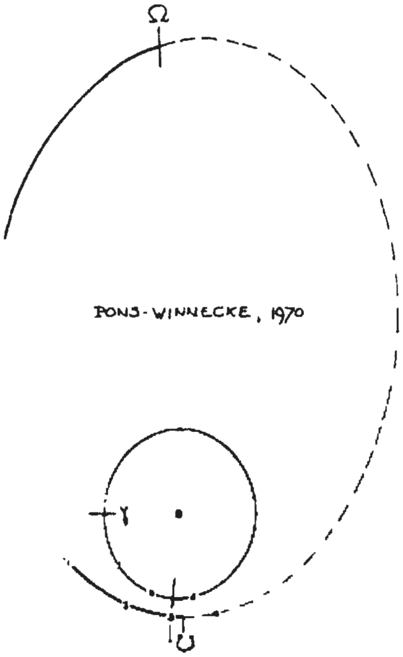

Fig. 2d. The elements were (HBAA, 1957): T = Nov 23, 1957, ω = 172, Ω = 93, i = 22.3, q = 1.23, e = 0.64, a = 3.40, P = 6.259. Pons-Winnecke is associated with the June Draconid meteors, and with a strong meteor shower in 1916, but has disappointed expectations since then. (Lovell, op. cit., p. 359). The comet has a period which is evenly divisible into that of Jupiter and has been considered (J. G. Porter, Comets and Meteor Streams, p. 63) the exemplary case of a Jovian comet undergoing Jupiter perturbations. There is thus an influence of these perturbations on the distance of nearest approach to Earth in 1970. Pons-Winnecke is credited with 16 observed returns.

FIGURE 2. FOUR SHORT-PERIOD COMETS AS THEY WILL PRESENT THEMSELVES DURING THE NEXT DECADE. At the vernal equinox, Earth is at the left end of a horizontal diameter through the Sun, and heliocentric angles originate at the right end of this diameter. The plane of the comet's orbit has been folded about the line of nodes into the ecliptic through the angle of inclination i.

B. Brightness

Limits on the masses of comets are set by the record of close approaches and by the fact that what is observed in Keplerian motion must be material, but the mass of any particular comet is uncertain by a factor of a million. The fundamental clue to the quantity of material present and active in an apparition is thus simply the brightness. From a welter of data, handbook values of the brightnesses of these 14 short-period comets are available according to the formulation $m = m_o + 15 \log r + 5 \log \Delta$, in which m_o is the absolute brightness of the object at unit heliocentric and geocentric distance.[4] Brightness values are given in Table I in stellar magnitudes.

TABLE I

	Orbital perihelion distance	Handbook values of the absolute brightness	Greatest visual brightness registered in the handbook ephemerides, 1951-60,	Derived brightness at perihelion and unit distance from the earth,
	q	m_o	m_{min}	$m=m_o+15\log q$
Grigg-Skjellerup	0.85	14.5, 13.4	12.5	12.4
Tuttle-Giacobini	1.12	11.7	17.4	12.4
Tempel 2	1.39	10.5, 10.5	13.7	12.6
Pons-Winnecke	1.23	11.0, 12.4	12.7	13.7
D'Arrest	1.37	9.5	15.2	11.6
Daniel	1.46	12.0	15.1	14.5
Encke	0.34	11.5, 11.5, 11.5	5.1	4.5
Honda-Mrkos	0.56	14.5, 14.5	8.9	10.7
Giacobini-Zinner	0.99	11.3, 11.5	8.8	11.5
Tuttle	1.03	9.5	12.1	9.2
Borrelly	1.45	8.6, 10.0	13.9	12.4
Finlay	1.08	11.5	10.2	12.0
Schaumasse	1.19	11.0, 10.0	9.8	11.1
Gale	1.15	12.0	16.2	12.9

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[4] The total brightness is thus uniformly dependent on the inverse square of the geocentric distance and the inverse sixth power of the heliocentric distance in the ephemerides printed in the *Handbook of the British Astronomical Association*, *1951* through *1960*. Where plural values are given in the second column, the last is more up-to-date and presumably reflects observation of the earlier apparition.

C. The Recent Records of Optical Recovery

The accuracies of Figures 1 and 2 are sufficient for purposes of planning but in the sequence of execution one must literally lay for the visitation, recover the object optically, track the run into the apse of the ellipse, compute the precise passage, and finally shoot the comet in cold blood. Optical recovery is thus an absolute precondition on success, but there are three ways in which an anticipated return of a periodic comet may be disappointed: the object may have broken up on its last passage, it may have been subject to perturbations which invalidate the expected positions, or it may be so situated near the Sun as to remain an invisible day-time object. The first difficulty is uncommon and the last does not occur in the four returns pictured in Figure 2. Table II sets forth the recent records of optical recovery of these objects.

D. Choice of an Object for an Interception Experiment

We choose an object for experiment from the facts set forth in Figures 1 and 2, Tables I and II. From calendar considerations, Encke is preferred and Tuttle-Giacobini excluded. From consideration of closeness of approach to Earth, Encke is preferred. From consideration of brightness, Encke is strongly preferred. From consideration of recovery records, Encke is preferred, followed by Pons-Winnecke.

Encke is chosen. Implicit in the foregoing exposition are the following substantiating reasons for the choice.

1. A launch date in the spring of 1964 is manageable in the context of programmed space exploration and rocket availability.
2. Encke is associated with four large meteor streams and thus with a large quantity of meteoritic material.
3. Encke's 1964 presentation is the best it will make in five returns which have been looked at through 1977, but each of these offers accessibility in the perspective of a reasonably developing

TABLE II

	PERIHELION PASSAGE	OPTICAL RECOVERY	LEAD TIME
Tuttle-Giacobini	1940	lost since 1907	
	1945	lost	--
	1951 May 9	1951 Apr 25, Kresak's re-discovery	14 days
	1956 Oct 30	badly situated in Sun	--
Encke	1941 Apr 18	1941 Jan 19, by van Biesbroeck	3 months
	1944 Jul 21	unobserved	--
	1947 Nov 26	1947 Aug 14, by Jeffers with Crossley 36-in at Lick	3 months
	1951 Mar 16	1950 Aug 16, by Cunningham with 60-in at Mt. Wilson	7 months
	1954 Jul 2	1953 Sep 3, by Cunningham with 100-inch at Mt. Wilson	10 months
	1957 Oct 20	1957 Jul 25, on plates from the Crossley 36-in at Lick	3 months
	1961 Feb 5	1960 Aug 17, by Elizabeth Roemer with 40-in at Flagstaff	6 months
Finlay	1926	observed, but not subsequently seen until passage of 1953	
	1932	not seen	--
	1939	not seen	--
	1946	not seen	--
	1953 Dec 19	1953 Dec 7	12 days
	1960 Sep 2	1960 Jun 21 by Burnham at Lowell	3 months
Pons-Winnecke	1933	observed, as was every return since 1909	
	1939 Jun 22	1939 Mar 17 by Jeffers at Lick	[illegible] months
	1945 Jul 8	1945 Jun by Giclas at Lowell	[illegible]
	1951 Sep 9	1951 Feb 3	7 months
	1957 Nov 22	no record of observation	--

space program. Scientific interest is thus attracted to this object which will be recurrently available for experimentation, in a sense which cannot be developed for any other comet.

4. Encke has received more attention than any other comet, having been observed on 46 passes and having been selected by Whipple as the basis on which to build his comet model.* Ground-based investigations having been already focused on this object, it is more valuable to amplify our understanding of this one comet with a space probe than to try to link our present knowledge of Encke with observations made on a space probe of another comet.

Figure 3 is a recent picture of Encke, which is further characterized by the values set forth in Table III.

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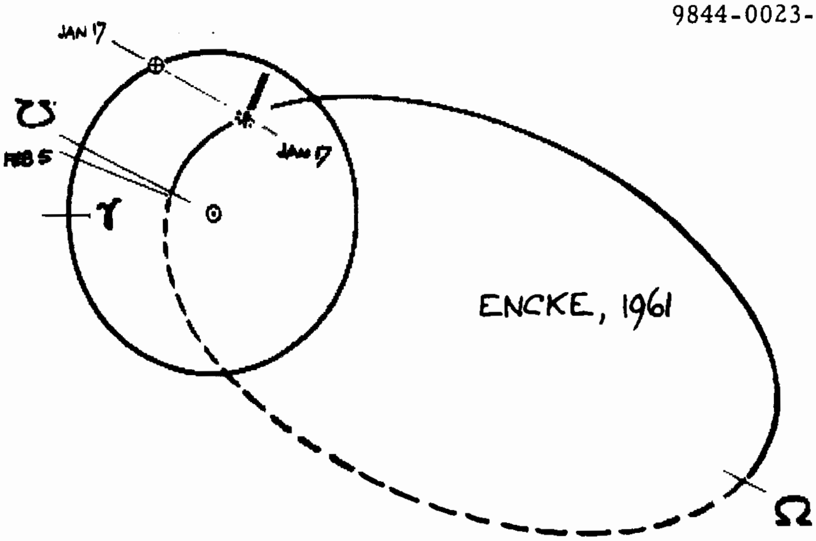
* Whipple, Fred L. , Astrophysical Journal 111, 375 (1950) 113, 466 (1951)



The celestial situation as Miss Roemer took the pictures below.

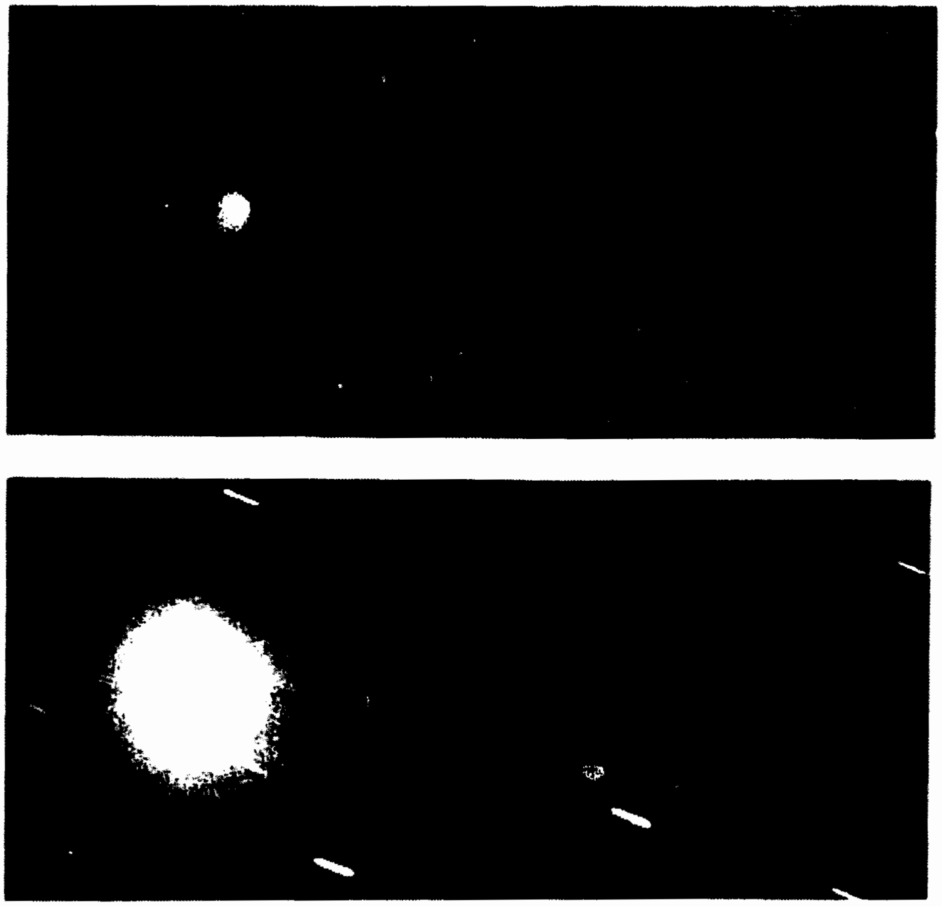


Fig. 1. Dr. Elizabeth Roemer's pictures of 1960 i P/Encke taken January 17, 1961 with the 40-inch reflector, U. S. Naval Observatory, Flagstaff Station. Exposures: 30 sec. and 30 min. with Film 103a-0. The scale is 7.9"/mm. Dr. Roemer writes that the tail is at least 28 minutes of arc long on the original plate. OFFICIAL U.S. NAVY PHOTOGRAPHS.

TABLE III

FACTS AND EXPECTATIONS ON PERIODIC COMET ENCKE

A. NUCLEUS

1. Constitution: meteoritic material and ices of H_2O, NH_3, CH_4, C_2H_2, CO, CO_2, perhaps C_2N_2
2. Effective Diameter: $2 < D_n < 10$ km. (This is the cross-section for the scattering of sunlight; we do not know if it is one piece or many pieces each about 10 cm in diameter. If it is many pieces, the ensemble cannot be distributed over more than 1000 km.)
3. Mass: $10^{15} < M_n < 10^{21}$ gm (It is strongly desired to shrink, experimentally, the large uncertainty of this specification.)
4. Gas Production: $10^{24} < p_n < 10^{27}$ molecules/sec.

B. COMA

1. Constitution: gases of CN, C_2, C_3 NH_2, NH, CH, OH, CH^+ and Na, all of which are observed spectroscopically in emission, having been excited by fluorescence. Meteoritic dust is also present.
2. Diameter of Emitting Region: $1 \times 10^5 < D_c < 2 \times 10^5$ km
3. Gas Densities: $10^3 < \rho_c < 10^{10}$ molecules/cc. (The density should be taken to fall off inversely with the square of the distance from the nucleus.)
4. Nature of the Gas Source: Sublimation, de-adsorption and photo-decomposition of the solid nucleus.
5. Kinetic Temperature of Gases: $200 < T < 300^\circ$ K
6. Mean Lifetime of Gases before Photo-dissociation or photo-ionization: 10 hours

C. TAIL

1. Constitution: gases of CO^+, $CO_2{}^+$, $N_2{}^+$, CH^+ and free electrons
2. Length: $L_t = 10^6$ km
3. Breadth: $D_t = 10^4$ km
4. Gas Densities: $10^2 < \rho_t < 10^4$ molecules/cc
5. Velocities of Mass Motion Down the Tail: $10 < \vec{V} < 100$ km/sec.

III. THE NEW COMETS

A. Accessibility

There are about 450 new comets registered in the catalogues, and Porter combed these for close approaches to Earth, finding 68 approaches within 0.1 AU.[5] Secondly, the observed new comet rate is about 300 per century, with Crommelin.[6] Applying 68/450 to this rate results in a statistical expectation of about four close approaches to Earth per decade. These differ from those sketched for short-period comets in Figure 2 by being at arbitrary angles to the Earth's orbital motion. Whatever their directions of approach, such new comets would be within the range of any space probe which is capable of intercepting Encke in 1964.

B. Brightness

The brightness of an unobserved new comet is again a matter of statistics, and it is enough to say here that the new comets are larger and brighter than the periodic comets. For example, observers including Newton and Halley agreed that the comet of 1680, which was a new comet, was brighter than the comet of 1682, which was the object now known as Halley's comet. Other differences are that the new comets display larger and more complicated comae and tails.[7] Discovery may antedate closest approach to Earth by many months.

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[5] J. G. Porter, Comets and Meteor Streams, London, 1952, p. 93

[6] A. C. D. Crommelin, article "Comets" in Encyclopedia Britannica, 14th ed.

[7] D. H. Robey, "On the Nature of Comets and Some New Ideas Relating to Their Origin", p. 25 of preprint (61-8), 7th Annual Meeting of American Astronautical Society, Jan. 1961. See also M. Schmidt and J. H. Oort, Bulletin of the Astronomical Institute of the Netherlands (in English), XI, p. 259, 1951.

IV. BALLISTICS OF THE ENCKE SHOT

Encke's orbit is linked to Earth's so that the two objects cannot draw closer together than about 20 million miles and the closest actual approach to be expected in the next four returns of the comet is that of about 12 July 1964 when the two objects will be about 24 million miles apart. Much of this Earth-to-comet distance is in the direction of the ecliptic south pole, and the Earth-to-comet transfer orbit is thus of a different kind from those encountered in studies of the interplanetary missions to Venus and Mars.

Probes to penetrate the comet in mid-July of 1964 may be launched from Cape Canaveral three or four months earlier. To hold the date of interception near mid-July while varying the date of launch from late February into early May is to test possibilities of the orbit, and Table IV has been prepared in this spirit directly from the digital computer runs.

TABLE IV

Date of Launch	Time of Flight in Days	Date of Interception	Distance from Earth to probe at penetration in millions of nautical miles	Burnout velocity at 22 million feet from Earth in feet per second	Uncorrected miss at the target in thousands of nautical miles	Velocity of closing on the comet in feet per second
3-31-64	108	7-17-64	28.0	40210	245	85254
4-16-64	92	7-16-64	27.0	40896	165	86901
4-25-64	80	7-14-64	25.0	41818	139	90594
2-24-64	140	7-13-64	23.6	41848	664	92009
3-10-64	125	7-13-64	23.6	40570	446	92149
3-25-64	115	7-18-64	29.1	40123	297	84087
4-5-64	104	7-18-64	29.1	40351	210	83665
5-5-64	70	7-14-64	25.0	43223	125	90462

We notice that the closing velocity is well-behaved and large enough to exclude the question of landing on this comet via these orbits. The interplay of the other parameters in the computer investigations sampled above leads us to state four types of orbits below, bringing out the peculiar advantages of each.

1. Launch 31 March and fly 108 days. The Earth-to-probe distance is 28 million nautical miles at penetration, after which the probe recedes from Earth at 300, 000 nmi/day. The burnout velocity required is 40, 200 ft/sec. which is near the minimum which will accomplish the mission. The miss without mid-course correction is 250, 000 nmi, to correct which 1500 ft/sec. of velocity must be available at mid-course. This velocity can be provided by the expenditure of 100 lbs. of monopropellant hydrazine from a 400 lb. payload.

2. Launch 14 April and fly 92 days. The Earth-to-probe distance is 25 million miles at penetration, increasing thereafter at 250, 000 nmi/day, and the uncorrected miss is 170, 000 miles. The cost of these improvements is a burnout velocity increased to 41, 000 ft/sec.

3. Launch 25 April and fly 80 days. The Earth-to-probe distance is further reduced to 23 million miles, increasing at 240, 000 nmi/day. The uncorrected miss is reduced to 139, 000 miles, and the burnout velocity required is increased to 41, 800 ft/sec. Associated with the small uncorrected miss is a small requirement for correcting midcourse hydrazine, which fact could become an important aspect of a definitive weight budget on the payload.

4. Launch 26 February and fly 137 days. The Earth-to-probe distance is 21 million miles, with the feature that the probe remains within 22 million miles of Earth throughout the interval from 20 May to 22 August, which fact may have useful consequences in terms of radio communication with the probe. The burnout velocity required is 41, 700 ft/sec, and 60 lbs. of hydrazine in a 320 lb. payload will correct the miss.

The comet Encke will be very far south and the transfer trajectory should include a coast period in parking orbit to limit the problems of range safety while leading to a maximum of the useful payload.

Summing up, a ballistic problem of a kind new to us discloses features which remain to be reconciled in a best solution. We find low energy orbits requiring burnout velocities above 40, 000 ft/sec and higher energy orbits requiring less than 42, 000 ft/sec. Checking these velocities against our experience of the requirements for fly-by missions to the 1962 presentations of Mars and Venus, we find that payloads in the presently available weight range we have discussed can be delivered to Encke in 1964 by such combinations as Atlas-Agena B-30KS or -ABL254. The misses are comparable with those on Venus and smaller than those on Mars, where the nucleus of Encke is much smaller than either planet, and the coma much larger. For a low energy orbit, Atlas-Centaur propulsion leads to payloads weighing many hundreds of pounds. The mid-course fuel penalties on these payloads range between 15 and 25 percent, so that the weight of structure, power supply, telemetering apparatus and scientific payload ranges from 150 lbs. upwards. There is a variety of acceptable launch dates in a family of orbits associated with a mid-July interception. Late June interceptions characterize a dual family not yet investigated. Finally, the practical choices are thus numerous enough to require measured distinction leading to a recommendation.

V. TELEMETRY AND INFORMATION FROM ENCKE

The mission is again analogous to a fly-by of the 1962 presentation of Venus, on the understanding that the transmission distances from probe-to-Earth are smaller for the comet mission. We prefer at present to leave open such parameters of the telemetry question as depend from the trajectory parameters left unclosed in the foregoing Part IV, but briefly discuss four topics for the constraints the discussion imposes on the experimental physics of Part VI which follows.

A. Ground Stations

The ground station facilities compatible with this mission are the JPL-NASA network, and a 250-foot antenna like the Jodrell Bank installation. The JPL Deep Space Instrumentation Facilities (DSIF) by 1964 will be converted to S-band operation at 2100 - 2300 mc. Ground stations for DSIF will be located in Australia and South Africa. Eighty-five foot parabolic antennae already exist at the Goldstone facility. The 250-foot antenna at Jodrell Bank has been used for deep space (Pioneer V). The STL facilities provided the tracking, telemetry and command facilities. The disadvantages of the Jodrell Bank antenna in the present application are the limitation on its upper frequency of about 500 mc, and its location in the northern hemisphere.

B. Effective Radiated Power

The effective radiated power depends on the power generated and the gain of the transmitting antenna. The amount of r-f power which can be generated depends on frequency, heat dissipation capability and primary power availability. The STL Pioneer V probe generated 150 watts of 400 mc power with an overall efficiency of about 35%. At S-band, lower efficiency will be experienced and the higher power levels will be more difficult to attain. At S-band a power output of 25 - 50 watts appears feasible, and is chosen.

If the spacecraft uses spin stabilization, a dipole antenna with its axis colinear with the spin axis must be used. The ratio of received power to transmitted power is independent of frequency. However, if a parabolic reflector is utilized on the spacecraft, the largest diameter and the highest practical frequency become most desirable. A directional antenna will require attitude stabilization and pointing accuracies of 1 - 2 degrees. The choice is fundamental.

C. Data Acquisition

The peculiar nature of the mission, i. e., being on target for one hour after three months of flight, places constraints on the data gathering system. Information rates across 30 million miles are small and make appropriate the use of a data storage device. Data storage devices are presently being designed with a capacity of 10^8 bits for the OGO program. The use of a storage system will allow considerable high frequency data to be taken and stored while the probe is in the coma. These data may be transmitted to the ground at a compatible rate after the probe has passed through the comet. En route to the comet, mapping measurements may be returned to Earth at higher rates or with smaller power expended.

D. System Configuration

If the vehicle is to be spin stabilized, the communication system should be designed to use a 250-foot dish. The transmitting frequency should be in the 400 - 401 mc band allocated for space vehicles.

The use of directional antennas greatly reduces the r-f power requirements. Vehicles using directional antennas should use the DSIF facilities at S-band.

The communication system will consist of a coherent transponder to provide accurate two-way doppler data. The ground-to-air signal will be used for command also. A telemetry encoder to digitally encode all data for storage or transmission will be included.

The available bit rate for various telemetry systems at a range of 30 million miles is shown in Table V. A low quality picture, the equivalent of a 200-line TV with 16 levels of gray will require approximately 10^5 bits. Thus at 500 bits per second a picture could be transmitted in approximately 3.5 minutes.

TABLE V

	Antenna					
	Vehicle		Ground			
Frequency (mc)	Size (feet)	Gain (db)	Size (feet)	Gain (db)	Transmitted Power (watts)	Bit Rate (bps)
400	Dipole	0	250	47	50	12
400	5	13	250	47	50	250
2300	Dipole	0	85	53	25	.1
2300	5	28	85	53	25	500
2300	10	34	85	53	25	2000

The above figures are based upon

1. Effective receiving system temperature of 70° K
2. Error rate of 10^{-2}
3. One-half of the transmitter power for tracking
4. Miscellaneous system losses of 2.0 db
5. System margin of 8 db

VI. TOWARD AN EXPERIMENTAL PHYSICS OF COMETS

Our understanding of the nature and constitution of comets is faced at present with a number of unsolved questions, but new information bearing on these questions will become part of a rich context which has been accumulated in the observations made from ground. It may be said that a comet is a loosely bound conglomerate of matter in the solid form, undergoing under the action of the electromagnetic and corpusular radiation from the Sun irreversible processes of degasification and disruption, which processes operate effectively in the inner regions of the solar system. On this account, then, the differences observed in the behavior of comets with short period and the new comets with nearly parabolic orbits are easy to visualize qualitatively. When a quantitative understanding of the course of events during the apparition of a comet is attempted, however, one immediately encounters the nearly complete lack of basic information regarding

(a) The degree of aggregation of the solid matter constituting the nucleus.

(b) The composition and effective pressure of the gas liberated from the nucleus.

(c) The nature of the forces acting on the gases forming the coma.

Secondly, we make explicit two conditions on the presently proposed probing experiment which obtain throughout what we say below

(a) It is seen from inspection of Table III that the densities to be encountered are small by standards of the terrestial laboratory, but large against the background of the void itself. This condition is fundamental to space physics, and requires investigation of the thermal control and outgassing rates of the scientific apparatus during the three months of its exposure to the void before it enters the comet.

(b) It is seen from inspection of Table IV that the velocities of encounter are large by standards of the terrestial laboratory, being not smaller than about 30 km/sec.[8]

Thirdly, we know of no precedent to guide design of this penetration experiment and assembly of the best package of scientific instruments, and certain criteria remain to be established, especially from two sources.

(a) Recommendations from the best available sources in astrophysics and cometary astronomy.

(b) Experience from the current space efforts concerned with orbiting observatories, like OGO and OAO.

A. Relayed Optical Examination of the Solid Phase

Encke's nucleus is provisionally specified in Table III. A 6-inch telescope passing within 10,000 km would resolve objects larger than 0.1 km, would see a single compacted nucleus as bright as the moon, and a distributed ensemble 6000 times less bright and well within capacity of photographic and electronic scanning.

At 10 km, a 2 cm piece of meteoritic material would be of apparent visual magnitude +4 and be parallactically distinguishable from the stellar background.

Polarization measurements of nucleus-scattered and dust-scattered light can give information on the surface of the nucleus and the orientation of the dust. Öhman's measurements of 1941 c are unique on the polarization of sunlight scattered by a comet: the polarizations

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[8] Investigation of comets at small relative velocities has been discussed, but is excluded here. The experiment is equivalent dynamically to injecting a satellite of the Sun on a prescribed cometary orbit, see J. C. Lair, "Prolegomenon Toward a Proposal to Execute an Encounter With a Comet", Space Technology Laboratories, Inc., Research Laboratory Technical Memorandum 9844-0002-MU-000, 10 February 1961. Replying to our inquiry, Prof. F. L. Whipple has expressed his interest in pacing the motion of the probe with the motion of the comet. We believe this thought to belong to a second generation of experiments on comets, (see Les Spectres des Astres, dans L'Ultraviolet Lointain, Cointe-Sclessin, 1961, p. 646) and that the experiment on Encke in 1964 should be designed to exploit the large relative velocity.

were 20 - 27%, the phase angles 58 - 90°, which values differ from measurements made on the moon. Encke should be examined at several angles and several wavelengths from UV to IR for data which can be reconciled with laboratory data to establish the nature of the comet's scattering surfaces.

Radar observation of the nucleus depends on a pass closer than 1000 km and is discounted.

B. Data to be Derived from Passage Through the Coma

Encke's coma is provisionally specified in Table III and there are three groups of questions involved:

1. pressure and composition of the gases
2. electromagnetic and magnetohydrodynamic situation
3. presence and distribution of dust

The charged particle density, on the estimated ionization, can be measured with a Faraday cup as in Explorer X. Further, the convective ion current through the probe admits of mass spectroscopy in a Massenfilter.

Of neutral particles the total density is measurable. The dynamic pressure of molecular impact is near 5×10^{-6} dynes at 10^4 molecules of weight 30 per cc, which pressure is within the range of a Golay detector. The heat at impact is 1 microwatt/cm^2 which is sensed by many detectors. STL is currently developing a counter for fast neutral hydrogen: this instrument consists of an electrostatic deflector to eliminate the low-energy charged particle background, an open-faced electron multiplier with a secondary emission cathode upon which the fast neutral particles impinge, a scaler, and a rotatable absorbing wheel which will provide a measurement of any ultraviolet background present. We are not yet artful enough to design a mass spectrometer for the neutrals. Molecules of N_2, O_2, CH_4, NH_3, and H_2 almost surely exist in the coma, and their amounts are of great cosmological interest. A search of the fluorescence of the coma in the spectral regions blacked out to earthbound telescopes should be rewarding. To obtain specific information regarding hydrogen in molecular form is very important. If comets were formed by the aggregation of matter with cosmical composition at low temperatures ($< 5^{\circ}$K), the hydrogen should be their primary constituent, as Swings, Bosman-Crespin and Arpigny (1960) have recently remarked. These same authors have called attention to the possibility of detecting molecular hydrogen by observing the bands excited by strong emission lines in the ultraviolet solar spectrum. Pending a detailed calculation of the population of the rotational levels of H_2 in a comet, it would appear feasible to detect fluorescent radiation in a number of bands of the Lyman system ($B'\Sigma_u^+ - A'\Sigma_g^+$). The solar Lyman β, for example, would be expected to excite a number of resonant series of doublets in this system, at wavelengths between $\lambda\lambda$1265 and $\lambda\lambda$1364 Å. For this particular spectral region an ionization chamber filled with nitric oxide and with a SrF_2 window, as used at NRL, would be almost ideally appropriate (transmission band $\lambda\lambda$1290 - 1350).

The multifarious and spectacular phenomena related to the development of structural features (halos) in the coma and rays and knots in the tails have for long offered puzzling problems. A beginning towards their understanding has been made only recently, when the relevance of electromagnetic processes to such phenomena was realized. It is known that the neutral gases liberated from a cometary nucleus have a lifetime of the order of a few days before becoming ionized under the action of the ultraviolet and corpusular radiation from the Sun. Once the conductivity of cometary material becomes appreciable it becomes subject to forces arising from the magnetic field that may be carried by the comet itself, the interplanetary fields or their mutual interaction. As an example of an observed fact that is readily understood in terms of magnetohydrodynamic forces, we may mention the contraction[9] of cometary comae

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[9] The variation of the coma diameter of comet Encke has been discussed by Borska and Suestka, Bulletin of the Astronomical Institute of Czechoslovakia, 1 (8), 123, (1949)

with decreasing heliocentric distances. So it is that a plasma with ionic density of the order of $10^2 m^{-3}$ moving with a velocity of 30 km/sec would be expected to be dynamically affected by a magnetic field strength of only 10^{-4} oersted. At the boundary between the plasma and the static field, there would be considerably higher field strengths arising by compression effects. It would be thus within the reach of a magnetometer with a large dynamic range to find the nature of the fields existing at the boundary between a comet and the interplanetary space. To supplement the information obtained in this fashion, measures of ionic densities should be simultaneously made. A magnetometer system for use in a comet probe must have a sensitivity of one gamma (10^{-5} gauss) or less, and be able to provide vector measurements in magnetic fields whose magnitudes may be as low as one or two gamma. A system made up of a search coil magnetometer and a flux gate magnetometer with adequate characteristics were constructed for the Able-5 program. For the comet probe, such a system can be improved substantially. For measurements within the comet itself, a small package containing a search-coil magnetometer can be ejected and its output telemetered back to the payload. In this way, simultaneous measurements can be made at two points. This procedure would permit the measurement of the velocities and, possibly, the dispersion of magnetohydrodynamic waves.

The plasma frequency and the electron density of the coma can be inferred from the transmission properties for electromagnetic waves. The most direct method would be to split a transmitter of the appropriate test frequencies from the main payload and observe the transmission behavior (perhaps across a fixed intervening distance) as the pair plunges through regions of changing electronic density.

At small weight penalty, standard equipment to sense charged particles of high energy, nuclear and cosmic radiation, must be included in the apparatus on the chance, however remote, that there are seats of these phenomena in comets.

A comet may be looked on as a repository of free radicals at low temperature and as a natural storehouse of information on the chemistry of cosmically cold processes. It is desirable to prepare practical approaches to the investigation of these phenomena.

Finally, the art of hypervelocity studies is currently being developed in several laboratories, among them our own, in which iron spheres a few microns in diameter are being electrostatically accelerated to velocities larger than 10 km/sec. Such laboratory experiments are rapidly leading to a better understanding of meteoritic impact phenomena and are being used to calibrate devices for the detection and measurement of micrometeors. Above all, they should be used for the testing of new and more accurate devices, for it is essential that a probe of Encke's comet should carry first class equipment for the measurement of the micrometeors with which the comet is believed to be associated.

The micrometeor experience of the probe passing south from the ecliptic toward Encke will be as important to space physics in general as the measurements made at passage through the coma. Indeed, it should be emphasized that, en route to the comet, very valuable information can be collected on all aspects of space environment outside of the plane of the ecliptic. The dependence of particle density, micrometeor distribution, and magnetic field strengths on this extra dimension has never been measured directly, and such data will provide a fundamental contribution to our understanding of the solar system.

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COMMUNICATION FROM THE OBSERVATORY AT LEIDEN

THE STRUCTURE OF THE CLOUD OF COMETS SURROUNDING THE SOLAR SYSTEM, AND A HYPOTHESIS CONCERNING ITS ORIGIN,

BY J. H. OORT

The combined effects of the stars and of Jupiter appear to determine the main statistical features of the orbits of comets.

From a score of well-observed original orbits it is shown that the "new" long-period comets generally come from regions between about 50000 and 150000 A.U. distance. The sun must be surrounded by a general cloud of comets with a radius of this order, containing about 10^{11} comets of observable size; the total mass of the cloud is estimated to be of the order of 1/10 to 1/100 of that of the earth. Through the action of the stars fresh comets are continually being carried from this cloud into the vicinity of the sun.

The article indicates how three facts concerning the long-period comets, which hitherto were not well understood, namely the random distribution of orbital planes and of perihelia, and the preponderance of nearly-parabolic orbits, may be considered as necessary consequences of the perturbations acting on the comets.

The theoretical distribution curve of $1/a$ following from the conception of the large cloud of comets (Table 8) is shown to agree with the observed distribution (Table 6), except for an excess of observed "new" comets. The latter is taken to indicate that comets coming for the first time near the sun develop more extensive luminous envelopes than older comets. The average probability of disintegration during a perihelion passage must be about 0·014. The preponderance of direct over retrograde orbits in the range from a 25 to 250 A.U. can be well accounted for.

The existence of the huge cloud of comets finds a natural explanation if comets (and meteorites) are considered as minor planets escaped, at an early stage of the planetary system, from the ring of asteroids, and brought into large, stable orbits through the perturbing actions of Jupiter and the stars.

The investigation was instigated by a recent study by **VAN WOERKOM** on the statistical effect of Jupiter's perturbations on comet orbits. Action of stars on a cloud of meteors has been considered by **ÖPIK** in 1932.

1. *Sketch of the Problem.*

Among the so-called long-period comets there are 22 for which, largely by the work of **ELIS STRÖMGREN**, accurate calculations have been made of the orbits followed when they were still far outside the orbits of the major planets [1]). Approximate calculations of the original orbits by **FAYET** [2]) are available for 8 other comets with well-determined osculating orbits. For the present limiting ourselves to the comets for which the perturbations were rigorously determined, and excluding 3 for which the mean error of the reciprocal major axis, $1/a$, is larger than 0·000 100, the values of $1/a$ for the remaining 19 comets are distributed as shown in Table 1.

The mean errors of $1/a$ are all smaller than 0·000 061; their average is ±·000027. The steepness of the maximum for small values of $1/a$ indicates that the real mean errors of the original $1/a$ cannot greatly exceed these published mean errors. The 22 comets do not form a representative sample of the long-period comets; there has been a selection for small values of $1/a$, so that the real proportion of comets with $1/a$ > ·000 50 is much larger than indicated in the table. It can be shown, however, that the selection has not appreciably influenced the relative numbers in the rest of the table. Among the comets in the first division there are two with negative values of $1/a$, viz. −·000007 and −·000016, probably due to observational errors.

TABLE 1

Distribution of original semi-major axes
(a in Astronomical Units)

$1/a$	n
< ·000 05	10
·000 05 – 10	4
10 15	1
15 20	1
20 25	1
25 50	1
·000 50 75	1
> ·000 75	0

It is evident from Table 1 that the frequency curve of $1/a$ shows a steep maximum for very small values. The average for the 10 orbits in the first interval is ·000 018, thus corresponding to a major axis of 110 000 A.U. We may conclude that a sensible fraction of the long-period comets must have come from a region of

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[1]) A list of these is given by **SINDING**, *Danske Vidensk. Selsk., Mat.-Fys. Medd.* 24, Nr 16, 1948, or *Publ. o. Mindre Medd. Københavns Obs.* Nr 146. **VAN BIESBROECK**'s orbit for comet 1908 III has been added to this list.

[2]) *Thèse*, Paris, 1906; also in *Ann. Paris, Mém.* 26A, 1910.