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THE STUDY OF THE PHYSICS OF COMETARY NUCLEI

Grant NSG 7082

Semiannual Progress Report No. 2

1 March 1975 to 31 August 1975

Principal Investigators

Dr. Fred L. Whipple
Dr. Brian G. Marsden
Dr. Zdenek Sekanina

Prepared for

National Aeronautics and Space Administration
Washington, D.C. 20546

September 1975

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

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The Smithsonian Astrophysical Observatory
and the Harvard College Observatory
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The NASA Technical Officer for this grant is Stephen E. Dwornik, SL/Planetary Programs, NASA, Washington, D.C. 20546.

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THE STUDY OF THE PHYSICS OF COMETARY NUCLEI

Semiannual Progress Report No. 2

Individual reports on the progress of research by F. L. Whipple, B. G. Marsden, and Z. Sekanina follow. The Catalogue of Cometary Orbits (1975) by B. G. Marsden has been used as a basis for a detailed computer search for comet groups.

SPLIT AND HYPERBOLIC (?) COMETS

Whipple's paper "Do Comets Play a Role in Galactic Chemistry and γ-Ray Bursts?" was published in the Astronomical Journal, vol. 80, no. 7, July 1975. His paper "A Speculation About Comets and the Earth" was presented at the Twentieth Liège International Astrophysical Colloquium at Liège, Belgium on 19 June 1975, and will soon appear as a Center for Astrophysics Preprint. It will eventually be published in the Liège Colloquium volume. An abstract is attached (see Addendum I). Work on this intriguing subject is postponed because of other research and writing commitments, some mentioned below.

With W. F. Huebner, Whipple is completing a chapter entitled "The Physics of Comets" for Reviews of Astronomy and Astrophysics (1976), which will appear as a Preprint from the Center for Astrophysics.

His earlier reported paper on "Criteria for the Identity of Comet Orbits" with M. Lecar is under preparation and will first appear as a Preprint of the Center for Astrophysics.

Whipple's research on split comets continues and will soon be presented in a three-part series of papers that will feature:

a) A report on the study of the phenomena of split comets, showing that gravitationally double comets are an unlikely cause for those not tidally disrupted and that jet-action "spin-up" appears to be the most likely of the intrinsic splitting mechanisms.

b) A report on the study of split-comet criteria among the orbits of parabolic and very long-period comets with inclinations in the range 79° to 100°.

c) An analysis of E. J. Öpik's comprehensive study "Comet Families and Transneptunian Planets" (Irish Astronomical Journal, vol. 10, pp. 35-92, 1971). By statistical methods, Öpik proves to his satisfaction that most very-long period comets occur in a number of orbitally associated groups that must have involved either multiple comet splitting or large original cohesive groups in the Öpik–Oort cloud. Whipple is finding by the Monte-Carlo method of statistics and by probability theory that much of Öpik's statistical evidence is untrustworthy.

F. L. Whipple

ORBITAL CALCULATIONS

Further calculations have been made on the nongravitational forces affecting short-period comets, notably P/Westphal, a comet having a period of some 62 years that was observed in 1852 and 1913 and that should now be about to return. Since the comet faded out before reaching perihelion in 1913 there is some doubt as to whether it will now in fact be observed. Considerable difficulty has been experienced in linking the 1852 and 1913 observations, both without and with recourse to nongravitational terms in the equations of motion. It is not yet clear whether this difficulty is peculiar to this comet (perhaps because of its fade-out) or a potential problem with the other periodic comets (e.g., P/Halley) that have periods of 60 years and more. The availability of recently measured positions of P/Pons-Winnecke, P-Grigg-Skjellerup, and P/Honda-Mrkos-Pajdušáková has made it possible for us to extend the earlier calculations of the nongravitational forces on these comets.

Together with Z. Sekanina, B. G. Marsden has continued the determinations of improved orbits for long-period comets. During the six months ending 13 August 1975, they derived orbits for comets 1844 III, 1895 IV, 1937 IV, 1948 I, 1955 V, 1966 II, 1967 II, 1972 VIII, 1972 IX, 1972 XII, 1973 II, 1973 VII, 1973 X, and 1974b.

B. G. Marsden

INTERSTELLAR COMETS

Z. Sekanina completed his work on the probability theory of encounters with interstellar comets (Sekanina, 1975a) and submitted the paper for publication in Icarus. The results of the investigation were presented at the 146th meeting of the American Astronomical Society, held at San Diego, California, in August 1975 (Sekanina, 1975b; see Addendum II).

NUCLEAR PROPERTIES FROM ANOMALOUS TAILS AND BAND STRUCTURES IN DUST TAILS

Sekanina has further advanced his study of the emission processes of large dust particles from comets. The preliminary results of his statistical investigation of anomalous tails (antitails), which are composed of the large particles, were presented at the IAU Colloquium No. 31 on Interplanetary Dust and Zodiacal Light, held at Heidelberg, Germany, in June 1975. Also part of this research was Sekanina's August trip (connected with his travel to the American Astronomical Society meeting at San Diego) to the Lunar and Planetary Laboratory of the University of Arizona at Tucson, Arizona, where images of a number of comets from Dr. E. Roemer's collection of photographic plates were examined for potential displays of antitails. The results of the inspection in regard to periodic Comet Encke were incorporated in the written version of the Heidelberg paper and will appear in the Colloquium's Proceedings (Sekanina, 1975c; see Addendum III). Work on this whole subject is still continuing and is expected to result in a number of papers.

While dust tails are usually structureless, a few comets did display temporary, nearly parallel bands of light in their dust tails. These structures may retain important information on the material they are composed of and thus on the solid component of the cometary nucleus. Unfortunately, comet photographs showing such formations in the dust tails are extremely rare. Through a good deal of correspondence and personal contacts, however, Sekanina gathered sequences of photographs of two comets, where the development of the band structures was observed most completely: Comet

Mrkos 1957 V (1957d) and the Great January Comet 1910 I (1910a). It is judged that the essential information can be derived from the study of the motions of the bands through the tail. Since none of the photographs was photometrically calibrated, the intensity distribution in the bands cannot be determined. The available photographic material consists in part of loaned originals, in part of copies, some of them gained, some on loan. The photographs of Comet Mrkos come from the following observers: John A. Farrell, now at the Los Alamos Scientific Laboratory, Los Alamos, New Mexico, who photographed the bands at Fort Worth, Texas, on 1957 August 14.1, 15.1, 16.1, and 17.1 (UT) with a 19-cm f/1.5 Schmidt camera using a Royal Pan film; Alan McClure, Hollywood, California, observing from Frazier Mountain, near Frazier Park, California, on August 10.2, 11.2, 12.2, and 14.2 with a 10-cm f/5 camera and using 103a-E plates and a filter; and Henry L. Giclas, Lowell Observatory, Flagstaff, Arizona, who used the Observatory's 33-cm f/5.1 astrograph and an 103a-0 plate on August 16.2. The photographs of Comet 1910 I (not calibrated, either) were obtained by C. O. Lampland, Lowell Observatory, with the Observatory's Voigtlander 3.7-cm f/5.4 camera on two different emulsions, and copies of the plates from 1910 January 27.1, 28.1, 29.1, and 30.1 (UT), showing the bands, were acquired courtesy of Mr. Giclas during Sekanina's stay at the Observatory in August (after the meeting at San Diego). Also available are copies of other plates of Comet 1910 I, taken with a Brashear doublet 12.7-cm f/7 camera between January 27 and 30, and showing an antitail. It is expected that a significant fraction of Sekanina's next research period would be spent on the photographic material of the two comets.

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Sekanina, Z. (1975b). On the existence of interstellar comets and the probability of their encounter with the sun. Presented at the 146th meeting of the American Astronomical Society, San Diego, California, August 1975; abstract in Bull. Amer. Astron. Soc., vol. 7, p. 467.

Sekanina, Z. (1975c). Predicted favorable visibility conditions for anomalous tails of comets. Presented at the IAU Colloquium No. 31, Interplanetary Dust and Zodiacal Light, Heidelberg, Germany, June 1975; to be published in the Proceedings from the Colloquium.

Z. Sekanina

ADDENDUM I

DO COMETS PLAY A ROLE IN GALACTIC CHEMISTRY AND γ-RAY BURSTS?

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This paper explores the plausibility of the assumption that enough material from interstellar space is locked up in comets to reduce significantly the apparent growth rate of "heavy" elements (mass greater than H_e) and, therefore, the present abundance of heavy elements in the interstellar medium and in the disk stars. A related suggestion concerns the influx of comets on neutron stars as a source of γ-ray bursts. Although no interstellar comets have been observed, reasonable upper limits to the observed numbers and masses do not rule out the first suggestion. The γ-ray-burst suggestion appears unlikely. A surprisingly large total mass of comets could be gravitationally bound to the Sun and, of course, to other stars, but remain undetected. The nature of the 1908 Tunguska explosion is discussed briefly. It was probably not an encounter with an active comet.

ADDENDUM II

BULLETIN

OF THE

AMERICAN ASTRONOMICAL SOCIETY

PUBLISHED BY THE AMERICAN INSTITUTE OF PHYSICS INC.

VOLUME 7, NUMBER 3, PART I — *1975*

THE 146TH MEETING OF THE AMERICAN ASTRONOMICAL SOCIETY HELD 18–21 AUGUST 1975 AT SAN DIEGO, CALIFORNIA

Abstracts of Papers Presented

(Numbers preceding abstract titles indicate: session, sequence of presentation, and category.)

WEDNESDAY, 20 AUGUST

Session 34: Rooms KLMN, 0915–1215

34.06.02 On the Existence of Interstellar Comets and the Probability of Their Encounter with the Sun. Z. Sekanina, Center for Astrophysics. — A general theory is formulated establishing the relation among the space density of interstellar comets, their influx rate to the observable region of the solar system, the degree of dispersion in the Maxwellian distribution of comet velocities in the interstellar cloud, and the cloud's systematic velocity relative to the sun. The theoretical expression for the probability of encounter of the sun with an interstellar comet is then combined with the observed absence of strongly hyperbolic comet orbits to determine an upper limit of 6×10^{-4} solar masses per cubic parsec, or 4×10^{-26} g cm^{-3}, for the space density of interstellar comets. The distribution of semimajor axes among the orbits of interstellar comets relative to the sun, calculated from the model, indicates that a strong hyperbolic excess must be typical for an overwhelming majority of interstellar comets regardless of the dynamical behavior of the cometary cloud, except when the cloud follows the motion of the sun and the dispersion of individual velocities is very low. This case, however, becomes the problem of an Oort-type cloud, since it implies a possibility of capture by the sun. This research was supported by grant NSG 7082 from the National Aeronautics and Space Administration.

ADDENDUM III

To appear in
Interplanetary Dust and Zodiacal Light
Proceedings from IAU Colloquium No. 31
Heidelberg, Germany, 10-13 June 1975

PREDICTED FAVORABLE VISIBILITY CONDITIONS FOR ANOMALOUS TAILS OF COMETS

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It was shown elsewhere (Sekanina, 1974) that the observability from the earth of an anomalous tail (antitail) of a comet can be rather straightforwardly predicted from the dynamical and geometric conditions. The physical presence or absence of the antitail at a precalculated time is then a measure of the comet's production rate, at the relevant emission times, of relatively heavy dust particles (mostly of submillimeter size) that constitute such an antitail. Because the large grains are emitted from the nucleus at very low velocities (typically meters or tens of meters per second), an antitail is essentially a two-dimensional formation in the orbit plane of the comet and can be recognized best when projected edge-on, i.e., when the earth crosses the nodal line of the comet's orbit. In general, however, this condition is not essential for the recognition of antitails (cf., e.g., Comet Kohoutek 1973 XII).

Since the emission rate of heavy dust particles is a potentially significant parameter for a physical classification of comets, we made use of the visibility conditions to list the comets that should have displayed a sunward tail around the time of the earth's passages through the orbit plane. This type of the antitail observability will be termed the nodal appearance. A computer program executing the conditions for a nodal appearance was applied to the Catalogue of Cometary Orbits (Marsden, 1975), starting with the comets of 1737. However, we excluded all comets that were at the critical times located near the antisolar point in the sky (elongations exceeding 135°), where the definition of the sunward direction becomes meaningless. We also excluded all cases at heliocentric distances larger than 2 AU in order not to confuse the antitails with the icy tails (Sekanina, 1973, 1975) that are observed far from the sun and point fairly frequently in the general direction of the sun.

The statistics of the nodal appearances of antitails of comets, whose conditions were satisfied within, or not more than 5 days outside, the period of observation, are listed in Table I, separately for nearly-parabolic comets (revolution periods more than 200 years) and for short-period comets. The calculations were done for dust particles with a ratio $1-\mu$ of radiation pressure to solar gravity of 0.01 (known to be common in observed antitails) and for two different starting emission times. Whereas the choice of $1-\mu$ is not crucial, Table I shows that the time of onset of dust production affects the statistics substantially. The comets with a sunward tail reported to have been detected near the predicted time are listed in Table II, where columns 2 to 4 give, respectively, the perihelion distance, the reciprocal value of the original semimajor axis (for P/Encke the revolution period), derived from Marsden (1975) and from Everhart and Raghavan (1970), and the absolute magnitude (Vsekhsvyatsky, 1958). We remark that with the exception of 1937 IV the comets have perihelia well inside the earth's orbit, and that apart from the controversial case of P/Encke (see details below) the comets' revolution periods are longer than 7000 years and their absolute magnitudes brighter than 8.

Table I points consistently to a conclusion that only about 20 to 30% of the nearly-parabolic comets that should have displayed an antitail at the node were actually observed to do so. Indeed, if we count only the comets with nearly-ideal observing conditions, the figure is 22% for the onset of emission at 4 AU and increases to 30%, if the condition is relaxed to 2 AU. If we count all comets that were observed near the node, the fraction of positive observations is lower, as can be expected, but not very substantially: we find 19% for 4 AU emissions and 23% for 2 AU emissions.

The results are dramatically different for short-period comets. Although there were numerous opportunities for observing a nodal appearance of an antitail, we do not yet have a single clearly positive observation. The only promising case so far is that of P/Encke in 1964, for which Roemer (Roemer and Lloyd, 1966) secured a pair of plates only 2.5 days after the earth's nodal passage; the comet was 88 days after perihelion. A close inspection of the plates by Dr. Roemer and the writer revealed two extensions emanating from the weak, nearly stellar image of the comet in the opposite directions, one of them pointing right toward the sun. Although this sunward tail does not, in the writer's opinion, resemble the gas jets, frequently observed in P/Encke before perihelion, there is still no more than a 50% chance that it is a true antitail.

Table I. Statistics of predicted nodal appearances of antitails of comets in the past ($1-\mu = 0.01$)

Comets	Nearly-parabolic		Short-period	
Assumed sun-comet distance at ejection (before/at perihelion) . .	4 AU	2 AU	2 AU	Perihelion
(A) Number of comets (apparitions) whose predicted nodal appearances of antitail lie within the observed arc of orbit . .	69	45	21 (32)	6 (7)
(B) Number of comets (apparitions) under (A) that were observed near the node	48	30	16 (23)	6 (7)
(C) Number of comets (apparitions) under (B) with significant predicted characteristic length of antitail	38	28	15 (20)	2 (2)
(D) Number of comets (apparitions) under (C) with elongations exceeding 30° from the sun at the node	30	20	15 (19)	2 (2)
(E) Number of comets (apparitions) under (D) that were free from severe moonlight interference at the node	18	10	7 (10)	2 (2)
(F) Number of comets (apparitions) under (B) whose antitail was actually observed	9	7	1?(1)?	1?(1)?
(G) Number of comets (apparitions) under (E) whose antitail was actually observed	4	3	1?(1)?	1?(1)?

Table II. Comets with antitails observed at node

Comet	q (AU)	$(1/a)_{orig}$ $(AU)^{-1}$	H_{10} (mag)	Date of node crossing	Antitail seen	Conditions at node and remarks
1823	0.23	.	4.2	1824/1/24	1/22-25, 27, 31	Very favorable conditions
1844 II	0.86	+0.001007	4.9	1844/10/25	11/3, 8	Close to sun; moonlight interfering
1844 III	0.25	+0.002592	4.9	1845/1/18	1/11, 16, 25, 27	Moonlight interfering
1895 IV	0.19	-0.000168	5.2	1896/2/9	2/15, 19-21	Close to sun
1937 IV	1.73	+0.000063	6.0	1937/7/31	7/30, 8/1	Favorable; but early emissions only
1954 VIII	0.68	+0.000051	7.0	1954/7/25	7/30, 8/1, 3, 6-7	Node crossed 3 days before discovery
1957 III	0.32	+0.000009	5.4	1957/4/25	4/22-30	Very favorable conditions
1961 V	0.04	+0.002211	7.5	1961/7/21	7/25-26, 8/1	Node crossed 2 days before discovery; close to sun; moonlight interfering
1964 IV	0.34	(3.30 yr)	13-15	1964/8/27	8/30	P/Encke; nature of tail not clear
1969 IX	0.47	+0.000507	5.8	1970/1/2	12/26-28, 30-31, 1/2	Antitail short; early emissions only

The general absence of antitails among the short-period comets appears to be incompatible with the existence of meteor streams known to be associated with many of these comets. Unfortunately, at their observed returns, the parent comets of the three spectacular-storm producing meteor streams – P/Biela, P/Giacobini-Zinner and P/Tempel-Tuttle – were never placed favorably enough for a nodal appearance of an antitail. And, of all the other comets known to be related to meteor streams, only two had such very favorable apparitions: P/Encke in 1878, 1888 and 1964, and P/Pons-Winnecke in 1909, although P/Pons-Winnecke is not apparently associated with a permanent stream (Cook, 1973). The other comets with favorable conditions were P/Tempel 1 in 1867, P/Finlay in 1919, P/Kopff in 1945, P/Grigg-Skjellerup in 1947, and P/Schaumasse in 1952 and 1960. Streams that could be associated with P/Finlay or P/Grigg-Skjellerup have never been reported; the other comets have perihelia well beyond 1 AU.

With one doubtful and two negative results in the three nearly-ideal returns, P/Encke presents probably the most solid evidence to date against the positive correlation between the antitails and the meteor streams. In order to obtain more data, positive or negative, on the occurrence of the antitails, we investigated their visibility conditions in the future returns of the short-period comets. Among 166 returns of 60 comets with perihelia within 2 AU between 1976 and 1999 (orbital elements courtesy of Dr. Marsden), the following instances – most of them outside nodal areas – are considered as most significant: P/d'Arrest in 1976/77, P/Encke in 1977 and 1987, P/Schwassmann-Wachmann 3 in 1979, P/Honda-Mrkos-Pajdušáková in 1980, P/Grigg-Skjellerup in 1982 and 1987, P/Crommelin in 1984, P/Pons-Winnecke in 1989/90, and P/Giacobini-Zinner in 1999.

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