SCIENCE ASPECTS OF 1980 BALLISTIC MISSIONS TO COMET ENCKE, USING MARINER AND PIONEER SPACECRAFT

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Introduction

This paper considers science aspects of a 1980 spacecraft reconnaissance of Comet Encke. The mission discussed is a ballistic flyby (more exactly, a fly-through) of P/Encke, using either a spin-stabilized spacecraft, without despin of instruments, or a 3-axis-stabilized spacecraft. Celestial mechanics and imaging aspects of such a mission have been considered in more detail by Bender (1) and by Jaffe et al (2), respectively. Engineering designs[1] (3, 4) and more detailed accounts of science aspects[2,3] are given in other documents. A different approach to an Encke ballistic flyby has been suggested by Farquahar et al (5). Yeomans (6) has considered ephemeris uncertainties associated with such missions.

Objectives and Observables

Science objectives that appear appropriate to this mission are:

To determine the existence of a cometary nucleus and, if it exists, its dimensions and albedo.

To determine the primary composition and concentration of neutral gases and ions in the coma and tail.

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[1] J. W. Moore et al, "A 1980 Mariner Encke Ballistic Mission Study." Not yet issued, Jet Propulsion Laboratory, California Institute of Technology, Pasadena (internal document).

[2] L. D. Jaffe, C. Elachi, C. E. Giffin, W. Huntress, R. L. Newburn, R. H. Parker, F. W. Taylor, T. E. Thorpe, "Science Aspects of a 1980 Flyby of Comet Encke with a Pioneer Spacecraft," Doc. 760-96, Jet Propulsion Lab., California Institute of Technology, Pasadena, 1974 (internal document).

[3] L. D. Jaffe, D. Bender, R. O. Hughes, B. R. Markiewicz, and T. E. Thorpe, "Imaging on Ballistic Missions to Comet Encke," Doc. 760-112, Jet Propulsion Lab., California Institute of Technology, Pasadena, 1974 (internal document).

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To determine the composition and concentration of solid particles in the coma and tail.

To determine the nature of the interaction of the coma and tail with the solar wind.

These objectives have been discussed by the Comet and Asteroid Mission Study Panel[4] and by Clay et al[5].

With a mission of this kind, it does not appear practical to determine detailed topography of the nucleus, or its temperature, mass, or spin, or to measure the temperature of an icy halo, if one exists[1,2]. With a spinning spacecraft (camera not despun), it is impractical to assure imaging at 100-m feature resolution, but there is some chance of a very few pictures at this resolution, depending on luck in not suffering a destructive dust hit when very close to the (postulated) nucleus[2,3] (2). With a 3-axis-stabilized spacecraft (or despun camera on a spinning spacecraft), feature resolution significantly better than 100-m should be possible[1,3] (2).

Trajectory and Encounter Geometry

It is felt that encounter should be prior to perihelion passage of Encke, at 0.4-0.9 AU from the sun. Encounters later in the apparition would have the disadvantages of a major decrease in coma size and a probable decrease in comet activity. Important in this regard is evidence (7)

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4. Comet and Asteroid Mission Study Panel, "Comets and Asteroids: A Strategy for Exploration," NASA TM X-64677, National Aeronautics and Space Administration, Washington, D. C., 1972.

5. D. Clay, C. Elachi, C. E. Giffin, W. Huntress, L. D. Jaffe, R. L. Newburn, R. H. Parker, P. W. Schaper. F. W. Taylor, T. E. Thorpe, B. Tsuritani, "Science Rationale and Instrument Package for a Slow Flyby of Comet Encke," Doc. 760-90, Jet Propulsion Lab., California Institute of Technology, Pasadena, 1973 (internal document).

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that the activity of Encke has often dropped significantly before. perihelion passage. Thus, an encounter at or after perihelion. seems likely to result in obtaining significantly less extra-nuclear data than one some days before perihelion. This consideration is quite independent of the engineering factor that the launch energy required for the spacecraft is lower for an earlier encounter than for one at or soon after perihelion (1).

Examination of the celestial mechanics (1, 3) suggests desirability of a launch in August 1980, when the Earth is close to the plane of Encke's orbit (Fig. 1). Encounter options near 0.4, 0.55, and 0.8 AU from the sun have been specifically examined: The dates are 8, 16, and 30 days prior to Encke perihelion (which will be on 7 Dec. 1980), and the spacecraft velocities relative to the comet at encounter[1,3] (1, 2) are 12, 18 and 27 km/s. The approach is from almost directly sunward of the comet (Fig. 2).

The spacecraft should fly through the shock front (sunward of the coma), the coma, the tail, and, if possible, the contact surface (if one exists) between the solar wind and the ionized cometary gas. Imaging of the nucleus should be from the sunward hemisphere and from as close as is reasonably safe, to improve resolution. Mass spectroscopy should be carried out as close to the nucleus as is reasonably safe - if possible, within 500-1000 km - to assure that the concentration of some minor constituents is measurable. The minimum distance of safe approach is presumably limited by the hazard of cometary dust impacts on the spacecraft. A preliminary calculation using the most conservative of several Encke models suggested by Taylor et al (8) indicated that the hazard is tolerable with a minimum distance of 500 km.

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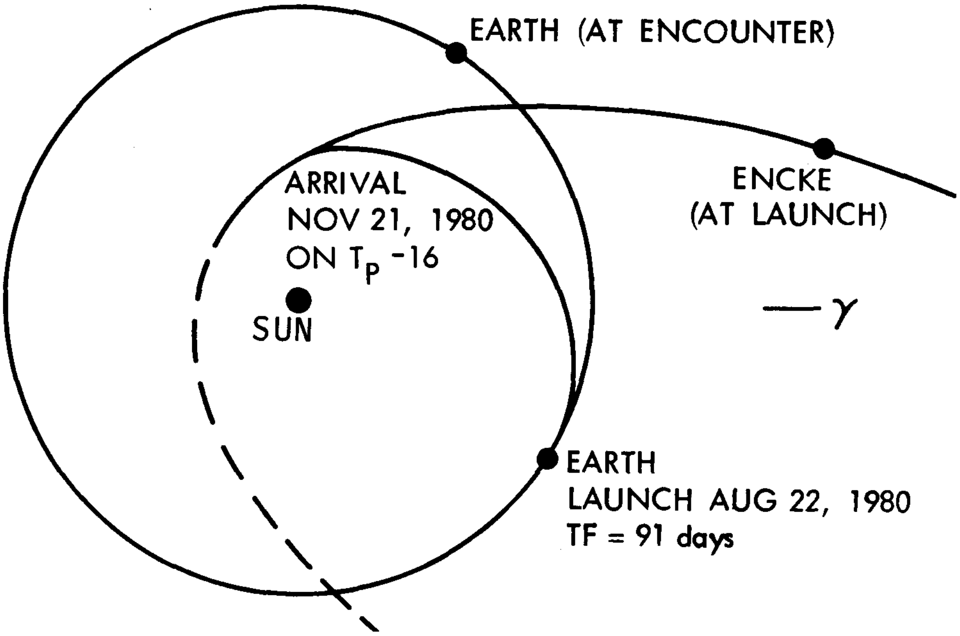
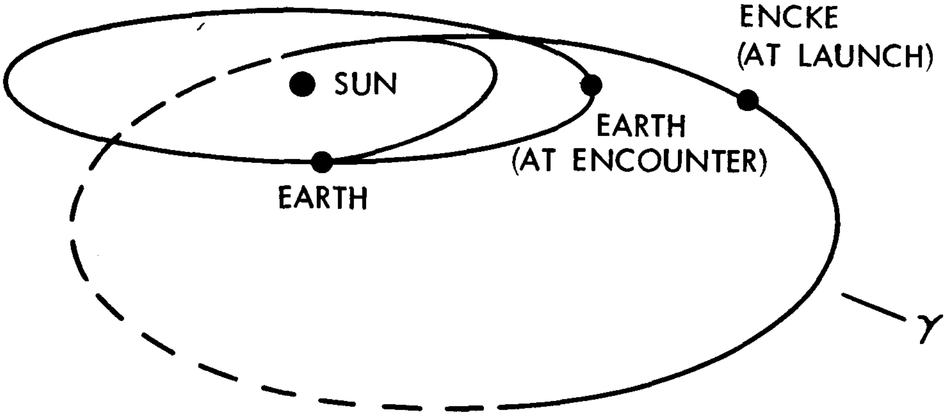


ECLIPTIC PLANE PROJECTION



OBLIQUE VIEW

Fig. 1. Encke orbit with typical spacecraft trajectory. After Bender (1).

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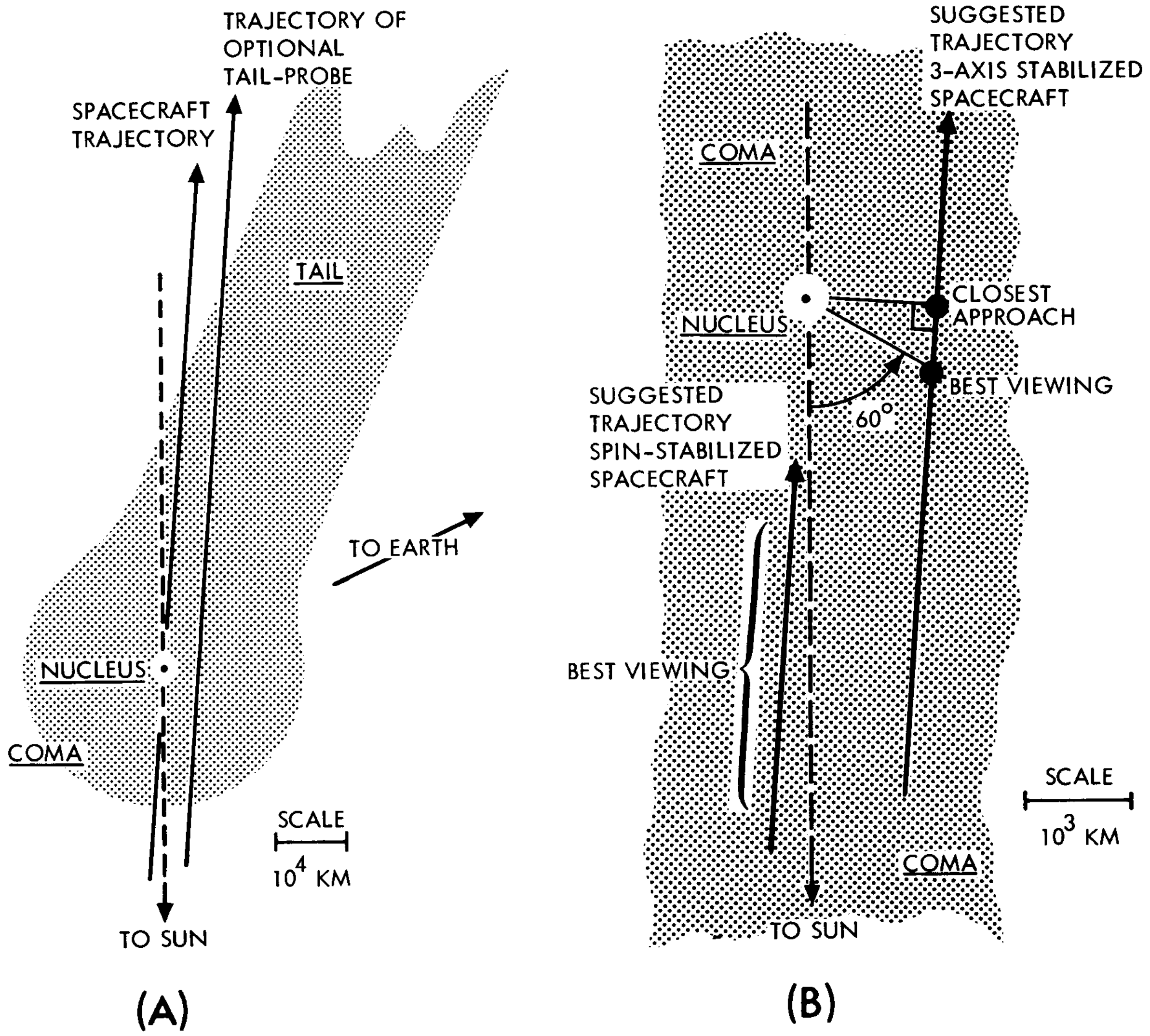

Fig. 2. Suggested encounter geometries. (B) is an enlargement of (A). Nucleus is not to scale.

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A number of targeting options have been considered[1,2,3] (2). For a spin-stabilized spacecraft, it is recommended that targeting be directly at the nucleus (not expecting to hit it). Pictures of the nucleus would be taken as the spacecraft approaches to within 2000-5000 km. This targeting minimizes the slewing rate required for pointing any given distance, thus simplifying pointing and improving resolution of the television camera and of other instruments using near-optical wavelengths. Closed-loop pointing control should not be required[3] (2); indeed suitable pointing systems have not yet been developed for operation from a spinning mount. The trajectory chosen provides data closest to the nucleus for mass spectrometry and other in-situ measurements. It may involve relatively high hazard from cometary dust during closest approach. Therefore, a probe separated before encounter and transmitting data directly to Earth may be worthwhile to obtain data on the tail in case the spacecraft is damaged; this probe could fly by several thousand kilometers from the nucleus, where the risk is relatively low (Fig. 2). Even without the tail probe, the risk to the spacecraft is probably acceptable, on the basis of current information[1].

For a 3-axis-stabilized spacecraft, targeting to a nominal flyby distance of about 700 km is suggested. This is close enough to provide reasonable chance of observing parent molecules and of detecting minor constituents by mass spectroscopy, but far enough to keep the hazard from dust quite low. A 60° phase angle will give good discrimination of nucleus surface features; with this geometry it will be attained at about 800 km range and provide, with the cameras recommended, optical resolution considerably better than 100 m. Closed-loop nucleus optical sensing and

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tracking will be needed to keep the cameras properly pointed at close ranges; such systems have already been flown successfully on Mariners 6 and 7. The spacecraft passes through a position where the phase angle is 0° as it approaches the nucleus; this provides a phase angle range of 0° to 90° or greater for photometry. With a pre-selected target point biased away from the nucleus, it is relatively simple to design the spacecraft scan-platform so that its field-of-view can include the nucleus at encounter[1,3] (2).

The uncertainties in the ephemeris of P/Encke (6) are such that, for either of these targeting options, sightings of the comet from aboard the spacecraft will be needed during approach, with a terminal maneuver calculated from these sightings[3] (2). The science imaging devices suggested below should also be satisfactory for optical navigation, furnishing images of the nucleus against a star background starting at least four days before encounter.

If a spinning spacecraft is used, performance of several instruments is considerably enhanced if the spin axis orientation is approximately along the relative velocity vector during approach. (This is approximately equivalent to: directly away from the sun.) Optical axes can then be pointed very close to the spin axis, reducing the rate of image motion across the sensors. This greatly increases the effective sensitivity of optical and U.V. instruments during approach, as compared, for instance, with a spin axis orientation perpendicular to the ecliptic or toward the Earth. With the latter arrangement, it may be difficult to obtain enough sensitivity to sight the nucleus against a star background at sufficient range for a terminal maneuver[1,2] (2). A low spin rate during approach is also desirable to improve sensitivity; a higher spin rate at close

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approach may be worthwhile to increase scan rates and therefore information rates. Science return could be increased by despinning a camera or a science platform, but this technique seems inconsistent with the simplicity that generally characterizes a spin-stabilized spacecraft; such an alternative is considered in Ref. (3). Typical payloads are suggested in Table 1. For a spinning spacecraft, two imaging devices are suggested: (a) a framing camera with a charged-coupled device as the sensor and a 50 cm focal length f/1.5 telescope, to view the nucleus, and, (b) a spin-scan imaging photometer to view the coma. The framing camera would have at least 200 X 200 picture elements and include image motion compensation. For a 3-axis-stabilized spacecraft, two vidicon cameras are suggested, one with a 50-cm focal length f/2.35 telescope, the other with a 150 cm focal length f/8.34 telescope. These would be modified from existing Mariner 9 and 10 cameras by providing a commandable part-frame (250-line) imaging mode, reducing the frame interval to 30 s per camera or 15 s for the pair. Use of a tape recorder is considered undesirable, since stored data would be lost if the spacecraft were damaged near closest approach. Thus, it is suggested that all data be transmitted in real time, over a communications link (considered practical) of 120 kb/s for the 3-axis spacecraft and 20 kb/s for the spin-stabilized[1,2,3] (2). Detailed characteristics of the imaging devices are considered in Ref (2); appropriate spectral filters for coma, tail, and nucleus should be included.

A UV spectrometer should be carried on either spinning or non-spinning spacecraft. For the non-spinning, a water vapor profiler (pressure-modulated IR radiometer) to measure H_2O in the coma is also suggested. A neutral-gas mass spectrometer with retarding potential, and an ion mass spectrometer,

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TABLE I

TYPICAL SPACECRAFT PAYLOAD

Instrument	Mass kg	Power w	Average data rate at encounter, b/s	Typical technology base
For 3-axis-stabilized payload only				
2 vidicon cameras				
Wide-angle (50-cm focal length, f/2.35) Narrow-angle (150-cm focal length, f/8.34)	38	33	108,000	Mariner 9 camera B Mariner 10
Infrared water-vapor profiler	3	2	10	Nimbus G pressure-modulated radiometer
For spin-stabilized payload only				
Charge-coupled-device framing camera (50-cm focal length, f/1.5, 200 X 200 elements)	19	13	13,000	New
Imaging photometer	4	3	205	Pioneer 10
For both 3-axis and spin-stabilized payloads				
Ultraviolet spectrometer	3	3	500	Venus Pioneer
Neutral gas mass spectrometer with retarding-potential Ion mass spectrometer	5	9	250	Venus Pioneer
Impact-ionization time-of-flight mass spectrometer	4	8	100*	Helios
Optical particle detector	5	3	100*	Pioneer 10
Micrometeoroid penetration detector	2	1	400*	Pioneer 10
Magnetometer	2	3	200	Pioneer 10
Plasma probe	5	5	200	ALSEP
Langmuir probe	3(2)†	5(3)†	350(200)†	OGO-6
Plasma wave detector	5	5	300	OGO-6
Total, 3-axis-stabilized	75	77	110,000	
Total, spin-stabilized	56	56	15,000	
For flyby probe only (optional add-on for spin-stabilized)				
Mass spectrometer	5	9	45	Venus Pioneer**
Magnetometer	2	3	25	Pioneer 10
Plasma probe	5	5	25	ALSEP
Langmuir probe	2	3	25	OGO-6
Total, optional flyby probe	14	20	120	

*Peak rates are higher; must be buffered.

†Values in parentheses are for spin-stabilized.

**New if velocity selector is included.

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or a combined neutral/ion instrument is recommended for either spacecraft type. Retarding potential is needed for neutrals both to discriminate against material originating from the spacecraft (such as attitude-control gas) and to prevent contributions from cometary species which have impacted chamber walls at velocities that caused dissociation[1,2].

An impact-ionization time-of-flight mass spectrometer would analyze impacting cometary dust particles. An optical dust detector and a micrometeoroid (penetration) detector would be worthwhile. For charged-particle and field measurements, a magnetometer, plasma probe, Langmuir probe, and plasma wave detector are proposed. Characteristics of the non-imaging instruments are suggested in other documents[1,2]. The mass of the typical payload would be 55-75 kg, its power consumption 55-80 w.

An optional separable tail-probe might carry a mass spectrometer (perhaps with velocity selector[6]), magnetometer, plasma probe and Langmuir probe, with power consumption of 20 w, and a total bit rate for the tail-probe of 128 b/s.

Certain other instruments warrant further consideration. For example, a gas-cell type of Lyman-alpha photometer might give D/H ratios if it can be established that the H atoms are thermalized rapidly enough to provide a narrow line-width. Perhaps higher-energy charged particles should be measured.

Some attention need be paid to compatibility of instruments. The spacecraft magnetometer would probably be mounted on a boom. This might not be practical for a small tail-probe and the effect of mass-spectrometer fields on the magnetometer would have to be considered.

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[6] M. Neugebauer, A. Bratenahl, D. R. Clay, B. E. Goldstein, T. W. Unti, H. D. Wahlquist, "A Preliminary Study of Cometary Plasma Spectrometers." In preparation.

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Imaging for navigation purposes would start four to ten days before encounter. The terminal maneuver, to bring the spacecraft near the nucleus, would occur 1.5 to 2 days before encounter. If no nucleus were identified by two days prior to encounter, the terminal maneuver should be targeted at the maximum brightness of coma or halo, and a search sequence started; this search should detect (though not resolve) particles as small as 1 m in diameter at ranges of 10,000 km or more[3]. An encounter science sequence would normally start after the terminal maneuver. The period of maximum science operations would last only about one hour. If a separable tail probe is used, its instruments should operate until about ten hours after closest approach, to provide data through the tail.

The spin-stabilized spacecraft, with 3-sigma errors in navigation and pointing, would be expected to provide pictures at a range of 5000 km. The corresponding pixel size would be 250 m and the imaging resolution 600 m. With 1-sigma errors, pictures should be obtainable to 1700 km range, with a pixel size of 80 m and imaging resolution of 200 m. The 3-axis spacecraft, with pointing control, should provide pictures at a range of 800 km or less, with a pixel size of 25 m and 8 m for the two cameras and corresponding image resolution of about 60 and 30 m. These resolution figures take into account smear during exposure. Over 600 pictures with a 4-km nucleus subtending 10 pixels or more, and at phase angle less than 130°, should be obtained with the 3-axis spacecraft and an 0.4 AU encounter, without using a tape recorder. With either spacecraft, the proposed gas mass spectrometer would provide[1,2], at an 0.4 AU encounter, a spatial resolution of 120 km for individual neutral and ion species and of 12 km for total number densities at detection thresholds of 5000 neutrals/cm^3 and 0.002 ions/cm^3.

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5. R. W. Farquahar, D. K. McCarthy, D. P. Muhonen and D. K. Yeomans, "Mission Design for a Ballistic Slow Flyby of Comet Encke 1980," NASA TN D-7726, National Aeronautics and Space Administration, Washington, 1974.

6. D. K. Yeomans, "Orbital Error Analysis for Comet Encke," this volume, 1975.

7. Z. Sekanina, "A Continuing Controversy: Has the Cometary Nucleus Been Resolved?", this volume, 1975.

8. F. W. Taylor, C. M. Michaux, R. L. Newburn, Jr., "A Model of the Physical Properties of Comet Encke," Tech. Rept. 32-1590, Jet Propulsion Lab., California Institute of Technology, Pasadena, 1973.

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DISCUSSION

F. L. Whipple: This week's symposium has substantiated in detail our objectives for cometary missions as developed over the last few years but with one important new addition: the urgent need for more data about the chemical and physical conditions in the region very close to the nucleus (say 100—400 km). Gas-phase chemistry now appears to be critical among the cometary processes. Hence we should attempt to go as close to the nucleus as is reasonably safe.

L. Jaffe: This would involve a 'gap' in the imaging at closest approach due to a problem in slewing the camera rapidly. Also, the data transmission should then be in real-time so as to prevent loss of data if the spacecraft were destroyed by dust impact.

L. Biermann: I would like to reemphasize that the plasma experiments on a cometary mission enable us to study an example of the applicability of magnetohydrodynamics as we understand it to an object which is quite different from the solar wind itself.

Plasma physics is applied to many problems in astrophysics, and only very rarely do we have occasion to test the theory by direct in-situ measurements. So I believe one should not just ask is there or is there not a contact surface, but rather is our present setup of magneto-hydrodynamics adequate or not in giving at least a rough representation of the situation which we really find.

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