INTERACTION OF THE PLASMA TAIL OF COMET BRADFIELD 1979L ON 1980 FEBRUARY 6 WITH A POSSIBLY FLARE-GENERATED SOLAR-WIND DISTURBANCE

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ABSTRACT

Solar-wind plasma data from the ISEE-3 and Helios 2 spacecraft have been examined in order to explain a uniquely rapid 10° turning of the plasma tail of comet Bradfield 19791 on 1980 February 6. An earlier study conducted before the availability of *in situ* solar-wind data (Brandt *et al.*, 1980) suggested that the tail position angle change occurred in response to a solar-wind velocity shear across which the polar component changed by ~50 km s^{-1}. The present contribution confirms this result and further suggests that the comet-tail activity was caused by non-corotating, disturbed plasma flows probably associated with an Importance 1B solar flare.

Introduction

It is widely believed that most (if not fully all) rapid and large-scale changes in the plasma tails of comets are caused by structures and disturbances in the solar wind (Biermann and Lüst, 1963; Brandt and Mendis, 1979; Niedner and Brandt, 1980). This coupling is a result of the strong interaction which takes place between the magnetized solar wind and the sunward cometary ionosphere via mass loading of the solar wind by CO^+ and other cometary molecular ions. The basic picture of the plasma tail is of a magnetic flux tube consisting of swept-up interplanetary magnetic field (IMF) and guiding ions initially created in the head region in a small ($<10^3$ km) production zone (Alfvén, 1957). Thus, the tail is formed in a manner similar to that of the Venusian magnetotail (cf. Russell *et al.*, 1982). The detailed physics of the comet/solar-wind interaction have recently been summarized for the head region by Schmidt and Wegmann (1982) and by Ip and Axford (1982), and for the tail region by Brandt (1982; also see Ip and Axford, 1982).

The branch of cometary study which examines associations between comet-tail transients and solar-wind structures is a dual one in the sense that *in situ* solar-wind measurements are often necessary to establish the cause of a particular plasma-tail disturbance, whereas classes of tail transients whose solar-wind cause(s) are *generally* well known may be used as solar-wind probes when *in situ* coverage is lacking. This latter aspect--the use of comets as interplanetary probes--is especially important for high-latitude solar-wind studies and examples are the use of tail orientations as diagnostics of the global solar-wind velocity structure over many solar cycles (e.g., Brandt *et* al., 1972), and plasma tail disconnection events as probable sector boundary markers (Niedner, 1982).

The 10° turning (on the plane of the sky) of the inner plasma tail axis of comet Bradfield 1979l which occurred on 1980 February 6, and which was reported by Brandt et al. (1980), is primarily an example of the first kind of cometary/solar-wind associations. The comet was a low ecliptic latitude ($-5^{\circ}.3$) object less than 0.5 AU from Earth--geometric circumstances ideal for establishing a solar-wind association--but the unavailability of interplanetary solar-wind measurements at the time of the original study (Brandt et al., 1980) restricted the analysis to a general windsock approach in which the observed tail position angle variation yielded an infinite set of vector solar-wind velocity solutions (due to the 2-D nature of the photographs). The explanation considered most likely by Brandt et al. was that the comet encountered a ~50 km s^{-1} shear in the polar component of the solar-wind speed in <30 minutes. The reader is referred to Brandt et al. (1980) for additional details.

The purpose of the present comment is to report an updated analysis based on recently available ISEE-3 and Helios 2 plasma data (Helios 2 data were kindly made available by H. Rosenbauer and R. Schwenn through the National Space Science Data Center, Greenbelt, MD). The study confirms and extends some of Le Borgne's (1982) conclusions based on the same cometary and spacecraft data.

Spacecraft Observations

The relative positions of comet Bradfield, Helios 2, and ISEE-3 at the time of the tail turning on 1980 February 6.1 UT are shown in Figure 1.

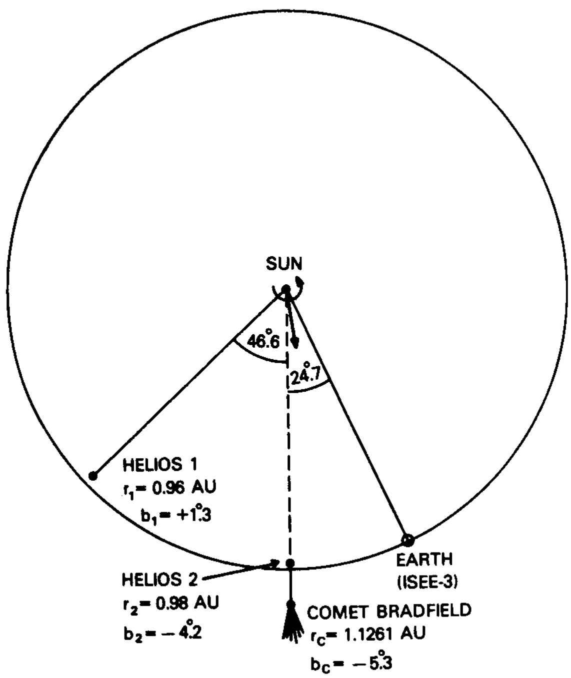

Figure 1. Ecliptic plane projection of comet Bradfield and the three spacecraft--ISEE-3, Helios 2, and Helios 1--which were making solar-wind measurements near the time of the comet-tail disturbance on 1980 February 6.1 UT. The cited latitudes are ecliptic.

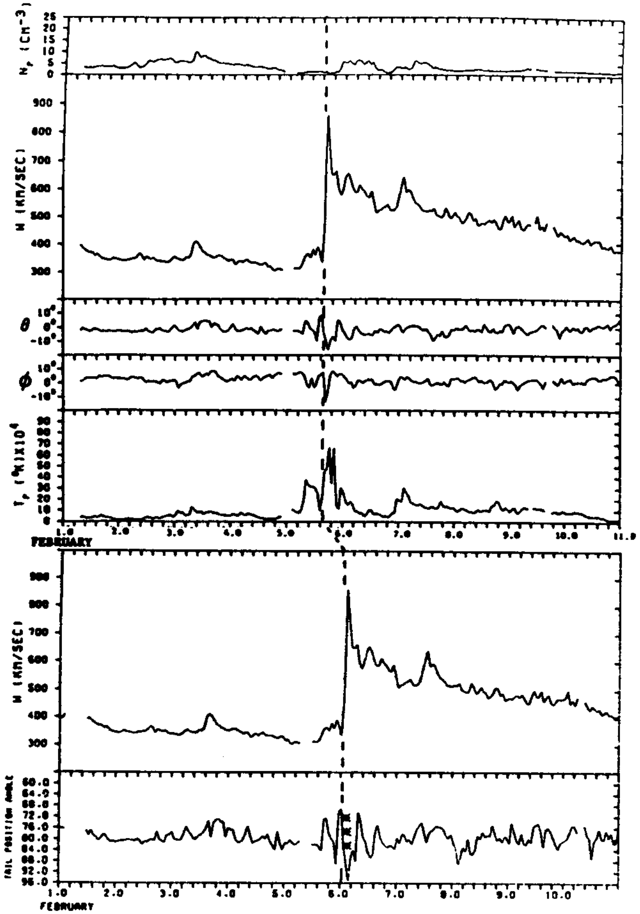

Figure 2. Top five panels present Helios 2 solar-wind plasma data (1-hour averages) for 1980 Febr. 1-11. From top: proton number density N_p, bulk speed W, polar flow angle θ, azimuthal flow angle φ, and proton temperature T_p. The lower two panels contain the bulk speed measured by Helios 2 and theoretical comet-tail position angles generated from the Helios 2 data, both shifted to the comet's position.

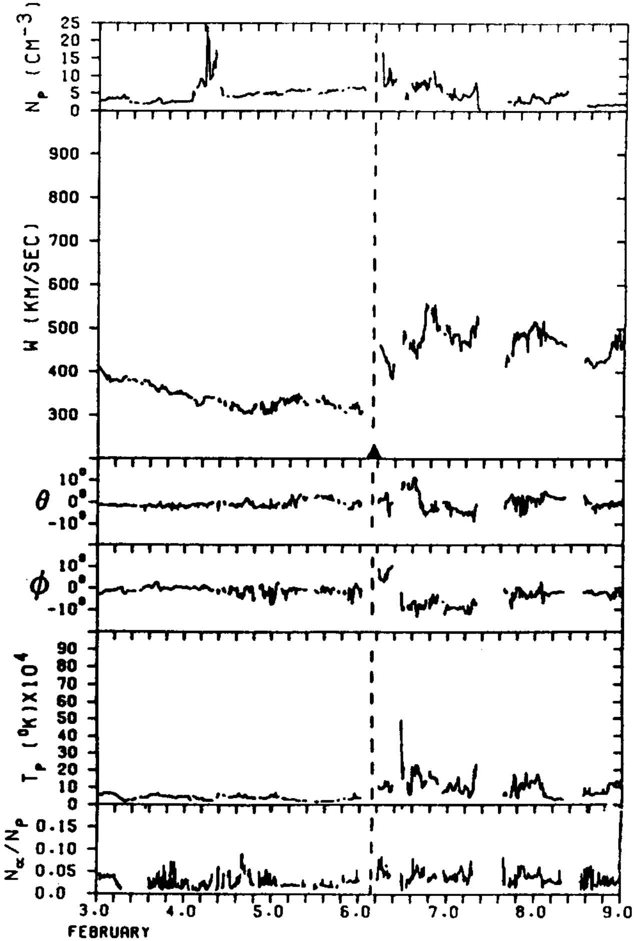

Figure 3. ISEE-3 solar-wind plasma measurements (5-minute averages) for 1980 February 3-9. The plotted quantities are identical to those in the top five panels in Figure 2 with the addition, in the last panel, of the fractional helium abundance N_α/N_p.

Although the position of Helios 1 is also shown, the present paper will address only plasma data from Helios 2 and ISEE-3. It is important to note that the comet was observed at the low ecliptic latitude of $-5\overset{\circ}{.}3$ and that Helios 2 was $< 1^{\circ}$ off the Sun-comet line (in longitude). Specifically, Helios 2 was 0.15 AU almost directly upstream of the comet and hence should have observed, some short time (<0.5 days) earlier, whatever solar-wind feature created the comet-tail disturbance. The relatively small separation of the comet and ISEE-3 (longitudinal separation $\sim 25^{\circ}$) also favored the observation of any associated solar-wind structure by ISEE-3.

Data from the Helios 2 plasma detector (H. Rosenbauer, PI) are shown in the top five panels of Figure 2. The data are one-hour averages. The feature of maximum interest is the ΔW = 300-500 km s^{-1} increase in the bulk speed which took place in less than 2 hours on ~February 5.6 UT. By its steep slope, this feature looks more like an interplanetary shock (see Figure 1 of Borrini _et al_., 1982) than the (much more slowly changing) leading edge of a corotating high-speed stream (see Figure 1 of Gosling _et al_., 1978), but a feature of this structure which is distinctly unlike both shocks _and_ streams is the lack of a density spike or compression region accompanying the velocity rise (R. Schwenn, private communication). Le Borgne (1982) has discussed this interesting aspect and further commented on the region of exceptionally low proton density ($N_p < 1$ cm^{-3}) preceding the velocity rise.

The lower two panels of Figure 2 show, respectively, the Helios 2 bulk velocity data shifted to the comet on the assumption of radial propagation at approximately constant wind speeds of 600 km s^{-1}, and theoretical comet-tail position angles calculated from the windsock theory (Brandt and Rothe 1976) and the shifted Helios 2 flow angles. The asterisks are position angles measured from the three photographs presented in Brandt _et al_. (1980). Note the very close agreement between the predicted arrival time of the velocity feature at the comet and the time of the tail disturbance. Also significant is the very close match-up of the observed position angle variation with a steep, predicted variation caused mainly by a $\sim 20^{\circ}$ change in the polar flow angle immediately following the velocity increase.

Figure 3 shows 5-minute averaged data for the same time period from the Los Alamos plasma instrument on ISEE-3. The format is similar to Figure 2 except for the last panel, which gives the fractional helium abundance N_{α}/N_p. Despite the presence of a $\sim 4^h 40^m$ data gap, a ~150 km s^{-1} velocity rise can be seen starting early on February 6. An associated storm sudden commencement (ssc), shown on the abscissa of the velocity panel, occurred at $3^h 20^m$ UT. Although of lesser amplitude and smaller maximum speed (600 vs. >800 km s^{-1}), the velocity feature seen by ISEE-3 is almost certainly the same structure as was observed by Helios 2 ~12 hours earlier.

Definitive resolution of the question of origin of the velocity feature is not possible here, but it is noteworthy that the 12 hr. time delay, when combined with the $\sim 25^{\circ}$ longitude separation between Helios 2 and ISEE-3, is incompatible with a corotating stream hypothesis ($\dot{\Phi}$ = $50\overset{\circ}{.}4$/day, P = 7.1 days). At the present time we favor a flare origin for this feature although the lack of a density spike prevents its classification as an interplanetary shock. The candidate flare is the same as that mentioned by Le Borgne (1982): 1980 February 3, ~13:28 UT, S15E15, Importance 1B, with associated Type IV radio emission (Le Borgne actually quotes the _Solar Geophysical Data Prompt Reports_ position of N18E13, which was in error; the group line average for the same flare in the Comprehensive Reports is S15E15). It should be pointed out that probably not all five days of elevated solar-wind speed at Helios 2 (Figure 2) contain actual flare ejecta; as discussed by Borrini et al. (1982), the general persistence of high-speed wind for several days during flare-induced interplanetary disturbances may be due to a magnetic re-arrangement of the corona at and near the flare site.

The projected flare meridian is shown in Figure 1 as the Sun-centered linear arrow. Note its close proximity to the Sun-comet/Helios 2 line ($\Delta\Phi = 7^\circ.5$) and the larger distance to ISEE-3 ($\Delta\Phi = 17^\circ.5$). If it had a flare origin as tentatively suggested here, then the larger amplitude and maximum speed of the velocity structure at Helios 2 is qualitatively in agreement with many models of flare-generated interplanetary disturbances (e.g., DeYoung and Hundhausen, 1973; D'Uston et al., 1977; Borrini et al., 1982) which predict maximum plasma speeds and minimum transit times at or near the flare longitude. Assuming identification with the above-mentioned flare, the mean transit speeds between the Sun and spacecraft were 815 km s^{-1} (Helios 2) and 662 km s^{-1} (ISEE-3); the resulting longitudinal gradient of ~15 km s^{-1} deg^{-1} is approximately double the values resulting from D'Uston et al.'s (1981) models.

Summary

In summation:

1.) A solar-wind disturbance seen in both the Helios 2 and ISEE-3 plasma data was found which produced the tail turning event in comet Bradfield. Theoretical tail position angles generated from the in situ data showed that the tail event was probably caused by an observed shear in the polar speed component immediately behind a large rise in the bulk speed (ΔW = 300-500 km s^{-1}), thus confirming the earlier study by Brandt et al. (1980).

2.) Observations of the feature's arrival times at ISEE-3 and Helios 2 strongly suggest a non-corotating trajectory. Although the lack of a density enhancement prohibits classfication of this system as an interplanetary shock ensemble, a plausible solar flare origin for the feature is proposed (as first suggested by Le Borgne, 1982).

3.) The study clearly underscores the sensitivity of cometary plasma tails to sudden large-scale changes in the bulk flow of the solar wind.

References

Alfvén, H., On the Theory of Comet Tails, Tellus, 9, 92, 1957.

Biermann, L., and Rh. Lüst, Comets: Structure and Dynamics of Tails, in The Moon, Meteorites and Comets (B. M. Middlehurst and G. P. Kuiper, eds.) (Univ. of Chicago Press), p. 618, 1963.

Borrini, G., J. T. Gosling, S. J. Bame, and W. C. Feldman, An Analysis of Shock Wave Disturbances Observed at 1 AU from 1971 through 1978, J. Geophys. Res., 87, 4365, 1982.

Brandt, J. C., Observations and Dynamics of Plasma Tails, in Comets (L. L. Wilkening, Ed.) (Univ. of Arizona Press), p. 519, 1982.

Brandt, J. C., J. D. Hawley, and M. B. Niedner, A Very Rapid Turning of the Plasma-Tail Axis of Comet Bradfield 19791 on 1980 February 6, Astrophys. J. (Lett.), 241, L51, 1980.
Brandt, J. C., and D. A. Mendis, The Interaction of the Solar Wind with Comets, in Solar System Plasma Physics. Volume II (C. F. Kennel et al., eds.) (North-Holland Publishing Co.), p. 255, 1979.
Brandt, J. C., R. G. Roosen, and R. S. Harrington, Interplanetary Gas XVII. An Astrometric Determination of Solar-Wind Velocities from Orientations of Ionic Comet Tails, Astrophys. J., 177, 277, 1972.
Brandt, J. C., and E. D. Rothe, The Wind-Sock Theory of Comet Tails, in The Study of Comets (B. Donn et al., eds.) (NASA SP-393), p. 878, 1976.
DeYoung, D. S., and A. J. Hundhausen, Simulation of Driven Flare-Associated Disturbances in the Solar Wind, J. Geophys. Res., 78, 3633, 1973.
D'Uston, C., J. M. Bosqued, F. Cambou, V. V. Temny, G. N. Zastenker, O. L. Vaisberg, and E. G. Eroshenko, Energetic Properties of Interplanetary Plasma at the Earth's Orbit following the August 4, 1972 Flare, Solar Phys., 51, 217, 1977.
Gosling, J. T., J. R. Asbridge, S. J. Bame, and W. C. Feldman, Solar Wind Stream Interfaces, J. Geophys. Res., 79, 1349, 1978.
Ip, W.-H., and W. I. Axford, Theories and Physical Processes in the Cometary Comae and Ion Tails, in Comets (L. L. Wilkening, Ed.) (Univ. of Arizona Press), p. 588, 1982.
Le Borgne, J.-F., Comet Bradfield 1979X Event on 1980 February 6: Correlation with an Interplanetary Solar Wind Disturbance, Proceedings of ESO Workshop "The Need for Coordinated Ground-based Observations of Halley's Comet", p. 217, 1982.
Niedner, M. B., Interplanetary Gas XXVIII. A Study of the Three-Dimensional Properties of Interplanetary Sector Boundaries Using Disconnection Events in Cometary Plasma Tails, Astrophys. J. (Suppl.), 48, 1, 1982.
Niedner, M. B., and J. C. Brandt, Structures Far from the Head of Comet Kohoutek II. A Discussion of the Swan Cloud of January 11 and of the General Morphology of Cometary Plasma Tails, Icarus, 42, 257, 1980.
Russell, C. T., J. G. Luhmann, R. C. Elphic, and M. Neugebauer, Solar Wind Interaction with Comets: Lessons from Venus, in Comets (L. L. Wilkening, Ed.) (Univ. of Arizona Press), p. 561, 1982.
Schmidt, H. U., and R. Wegmann, Plasma Flow and Magnetic Fields in Comets, in Comets (L. L. Wilkening, Ed.) (Univ. of Arizona Press), p. 538, 1982.

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