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Interpretation of the event in the plasma tail of comet Bradfield 1979 X on 1980 February 6

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Summary. The tail event observed by Brandt et al. (1980) in comet Bradfield 1979 X on 1980 February 6 is shown to be due to an interplanetary solar wind disturbance detected aboard Helios 2 and at Earth. Helios 2 was at 0.15 AU from the comet. The tail follows the bulk direction of the solar wind. Acceleration of cometary ions seems to result from small scale hydrodynamic instabilities. Cometary ion density and temperature are deduced.

Key words: comets – comet Bradfield 1979 X

1. Observations

Observation of a very rapid turning of the plasma tail of comet Bradfield 1979 X has been reported by Brandt et al. (1980). Three photographs taken on 1980 February 6 between 2 h 32.5 UT and 3 h 00 UT (mid-exposure) show a growing undulation of the ion tail.

Spacecraft solar wind data have been gathered to look for an interplanetary disturbance which could have been responsible for this comet event. Spacecraft data are available from ISEE 3, Helios 2, Helios 1 and Pioneer 12-Venus. Helios 2 was especially well situated relative to the comet (Fig. 1 and Table 1).

Comet Bradfield and Helios 2, both close to the ecliptic plane, were 0.15 AU from each other and approximatively on the same solar radial. Helios 2 data (Fig. 2) show a solar wind disturbance on February 5 at 16 h 30 UT: the solar wind velocity increases rapidly from 350 km s^{-1} to 880 km s^{-1} and subsequently decreases to ~650 km s^{-1}. It then decreases gradually further during the following days. This disturbance was preceded by an exceptionally low solar wind density (<1 cm^{-3}). The density increased to 8 cm^{-3} when the velocity went up to 650 km s^{-1}. During the disturbance, the velocity direction showed big changes with amplitudes of 20°. The disturbance was also seen on ISEE 3 on 1980 February 6 at ~3 h 00 UT (exact time is not available because of a data gap). At Earth, a sudden commencement (SSC) followed by a magnetic storm was reported by 21 geophysical observatories on February 6 at 3 h 20 UT (Solar Geophysical Data, n^0. 431, July 1980). The ISEE 3 data do not show any density variation during the disturbance. No disturbance has been observed by Pioneer 12 and Helios 1. A low density is however recorded by Pioneer 12 (SGD, n^0. 426 and 427, February and March 1980) between January 30 and 31, and by Helios 1 between February 2 and 3.

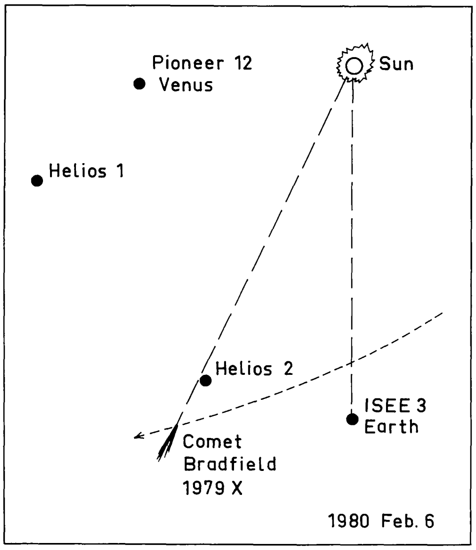

Fig. 1. Relative positions of comet Bradfield, Earth, and spacecraft in the solar system

Table 1. Position relative to Sun of comet Bradfield and Helios 2

	Distance from Sun (AU)	Relative heliocentric longitude	Relative heliocentric latitude
		Difference to earth	
Comet	1.13	25°.3	-3°.2
Helios 2	0.98	24°.5	−5°.2

2. Discussion

The situation can be summarized as follows:

A low density zone seems to have rotated around the Sun at a speed of 17° per day at least between January 30 and February 6, between Venus and Earth, inside the Earth orbit (a corotating feature is expected to rotate at 14°.2 per day). The low density feature no longer existed at Earth position. A solar wind disturbance, originating on the Sun, has propagated in and outside

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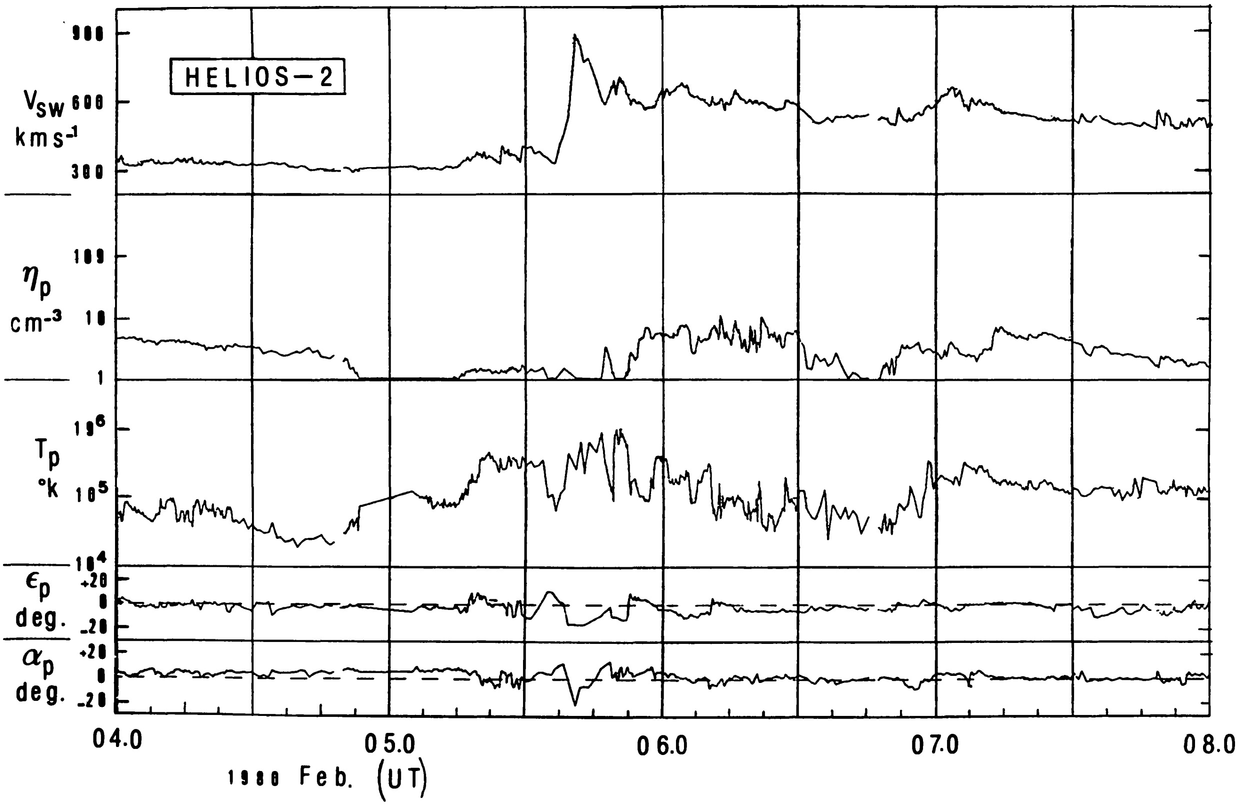

Fig. 2. Helios 2 solar wind data, between 1980 February 4 and 8. The data shown are the solar wind velocity V_{sw}, the solar wind density n_p, the solar wind temperature T_p, and the direction angles ε_p and α_p of the solar wind velocity. ε_p is the angle relative to Sun-spacecraft radius in the ecliptic plane (positive counter clockwise as seen from north of ecliptic) and α_p in the plane perpendicular to the ecliptic plane (positive to north)

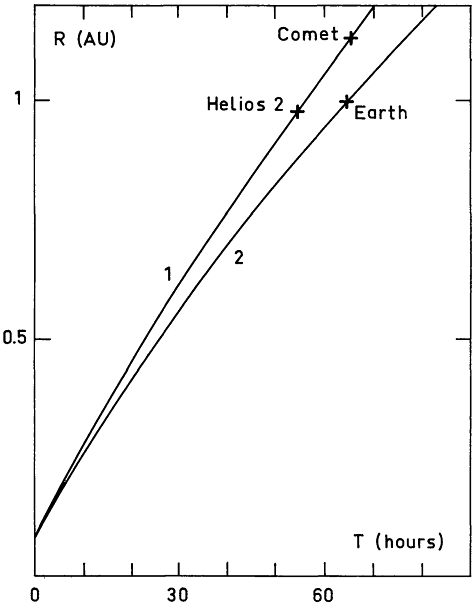

Fig. 3. Distance R (in AU) of disturbance front as a function of delay time T (in hours) for: 1) Sun-Helios 2 comet direction, and 2) Sun-Earth direction

this low density corotating zone. It has been observed by Helios 2 instruments and at Earth.

Among the Hα solar flares observed from Earth, the one most likely responsible for the disturbance may be the flare which occurred on the Sun on February 3 at 13 h 30 UT located at N 18°, E 13° (SGD, no. 247, March 1980), a little west relative to the radius comet-Helios 2-Sun, and associated with a type IV radioburst.

The disturbance observed by Helios 2 is believed to be the same which produced the comet Bradfield event. If we assume this to be true, the mean velocity of the disturbance between Helios 2 and the comet was 623 km s^{-1}. The projection of the maximum velocity of the solar-wind on the comet-Sun radius was 750 km s^{-1}: this is more than the apparent disturbance velocity. But considering that there is some uncertainty in the determination of the distances, 750 km s^{-1} correspond to a distance Helios 2-Comet of 0.18 AU. Thus the error in the distance should be 0.03 AU.

According to commonly accepted models of propagation of solar flare associated disturbances (De Young and Hundhausen, 1971; D'Uston et al., 1981), observations of the disturbance at Helios 2, Comet Bradfield and Earth fit with the possibility of its origin on the Sun on February 3.56 as suggested earlier. Figure 3 shows the adopted time evolution of the disturbance front toward Earth and toward Helios 2-comet. The curves have been obtained by fitting a power law $R=aT^b+0.084$ (R = Sundisturbance front distance in AU, T = delay time in hours) (D'Uston et al., 1981).

A tentative time sequence of the event is summarized in Fig. 4.

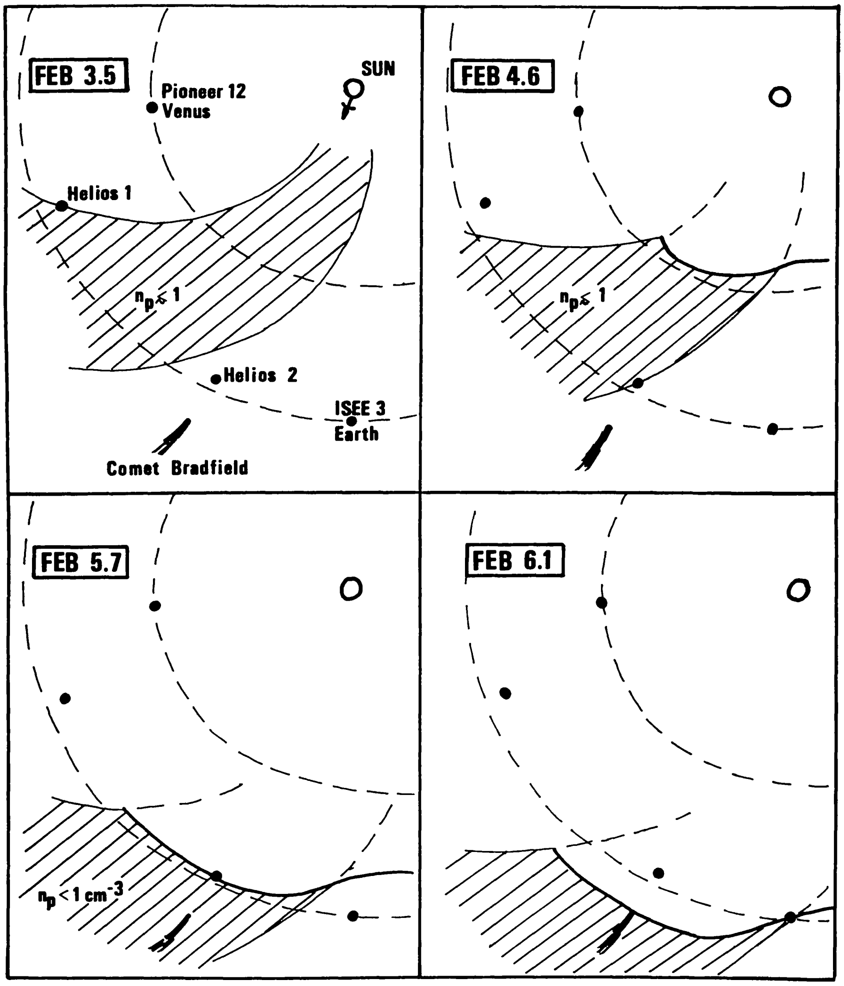

Fig. 4. Time sequence for the comet Bradfield event

3. Interaction model

Assuming now that the solar wind observed at Helios 2 reached comet Bradfield without any change ten hours later, let us try to understand what influence the solar wind had on the comet tail shape. As Brandt et al. (1980) predicted from the tail orientation the Helios-2 data show that the solar wind was directed first northward then southward (Fig. 2). As a consequence the cometary ions seem to follow the bulk direction of the solar wind particles at the scale of 10^6 km as predicted by the "windsock" theory (Brandt and Rothe, 1976). If magnetohydrodynamic instabilities are responsible for cometary ion acceleration, they would act on a scale smaller than the observed undulations.

A qualitative estimate to determine the comet tail shape from the Helios 2 solar wind data has been done. Figure 5 shows the result: the projection on the sky of the calculated comet tail as seen from Earth. The model which fits exactly on Brandt's et al. (1980) photographs uses two kinds of cometary ion acceleration. In steady state (no disturbance) the cometary ion velocity V_i grows exponentially up to the solar wind velocity V_{sw}:

$$V_i = V_{sw}[1 - \exp(-k_1 t)],$$

where t is the time (in mn) from ejection from the nucleus and $k_1 = 0.01\ \mathrm{mn}^{-1}$. When the disturbance arises ($V_{sw} > 500\ \mathrm{km\ s}^{-1}$) this model does not fit any more. A larger acceleration is needed. The model chosen for cometary ion acceleration a_i is then:

$$a_i = k_2/(V_{sw} - V_i).$$

When V_i is close to V_{sw}, cometary ions are considered as part of the solar wind. k_2 is a constant:

$$k_2 = 4.6\ 10^{11}\ \mathrm{cm}^2\ \mathrm{s}^{-3}.$$

According to Chernikov (1975) such an acceleration is likely to occur due to ion-sound instabilities, with

$$k_2 = 10^{-2}\,\omega_i (m_e/m_i)^{1/2} (n_p/n_i)^2 k T_e/m_p,$$

where m_e, m_p, m_i are electron, proton, cometary ion masses respectively; n_p, n_i are proton, ion densities; T_e is the electron temperature; ω_i is the cometary ion plasma frequency; k is the Boltzmann constant. These instabilities occur when the solar wind velocity exceeds a critical value V_{CR}:

$$V_{\mathrm{CR}} = (n_i/n_p)\, v_s [1 + (m_i/m_e)^{1/2}\ (T_e/T_i)^{3/2} \exp(-3/2 - T_e/2\,T_i)],$$

where v_s is the sound velocity in cometary plasma, and T_i the ion temperature.

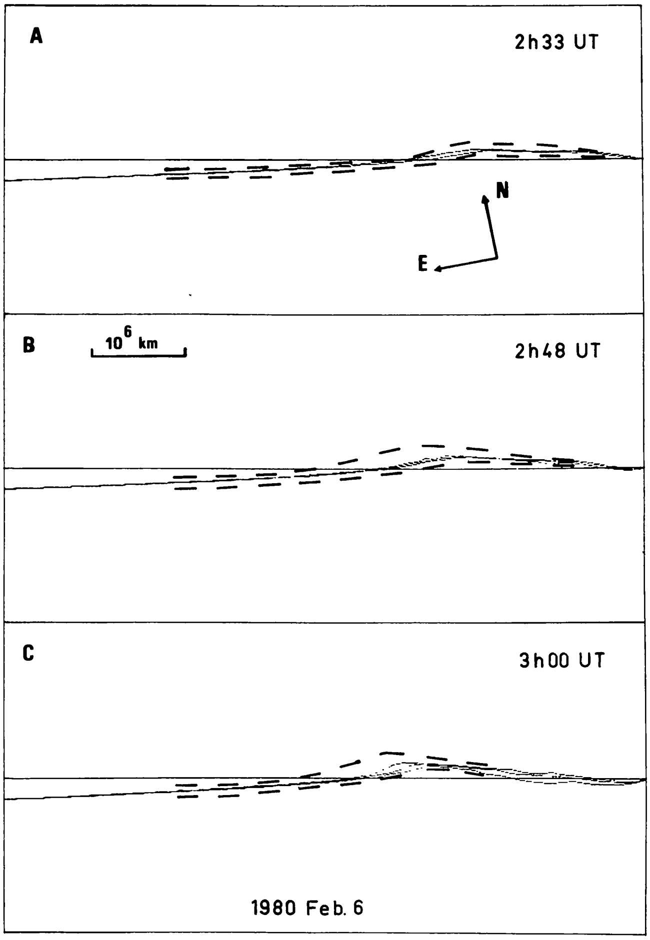

Fig. 5. Comet Bradfield tail shape evolution obtained with solar wind interaction model using Helios 2 data. Times and scales correspond to plates in Fig. 2 of Brandt et al. (1980). Horizontal line is the Sun direction. Observed width of the tail from Brandt et al.'s photographs is shown as discontinuated line both sides of computed center line of the tail. The observed width is shown when larger than the computed tail. Center lines of the tail have been computed for various times from the beginning to the end of the exposures

If we take as a hypothesis that ion-sound instabilities have developed in comet Bradfield's tail when $V_{sw} > 500$ km s^{-1}, and that $k_2 = 4.6\ 10^{11}$ cm^2 s^{-3}, some cometary plasma parameters can be determined. For $n_p = 1$ cm^{-3} and $m_i = 25\, m_p$, the above values of k_2 and $V_{\rm CR}$, one obtains for values of T_e between 10^5 and 10^6 K, n_i between 1 and 3.5 cm^{-3}, and T_i between 5 10^4 K and 9 10^4 K. These values agree with commonly used values, although often higher values for n_i (10–1000 cm^{-3}) are used.

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