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The interaction of comet 153P/Ikeya-Zhang with interplanetary coronal mass ejections: Identification of fast ICME signatures

Geraint H. Jones
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

John C. Brandt
Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA

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[1] The active comet 153P/Ikeya-Zhang possessed a highly-variable plasma tail. Favorable circumstances allowed the identification of the impact of fast ICMEs with the comet. The impact produces a specific morphology including a characteristic scalloped appearance which suggests that the ICME magnetic field drapes around preexisting tail density enhancements. This appears to be the first direct association between fast ICMEs and plasma tail structure and the specific structure should permit the identification of fast ICME locations in the heliosphere. *INDEX TERMS:* 2111 Interplanetary Physics: Ejecta, driver gases, and magnetic clouds; 2139 Interplanetary Physics: Interplanetary shocks; 6025 Planetology: Comets and Small Bodies: Interactions with solar wind plasma and fields; 6026 Planetology: Comets and Small Bodies: Ionospheres—composition and chemistry; 7513 Solar Physics, Astrophysics, and Astronomy: Coronal mass ejections. **Citation:** Jones, G. H., and J. C. Brandt (2004), The interaction of comet 153P/Ikeya-Zhang with interplanetary coronal mass ejections: Identification of fast ICME signatures, *Geophys. Res. Lett.*, *31*, L20805, doi:10.1029/2004GL021166.

1. Introduction

[2] The behavior of cometary ion or plasma tails was key evidence for the existence of the solar wind [*Biermann*, 1951; *Alfvén*, 1958]. Ionization of cometary neutral species leads to their addition to the solar wind flow. Assuming near-radial flow, an ion tail's orientation gives indications of the solar wind velocity at the comet. A tail's general appearance can also indicate whether a comet is immersed in the fast, steady coronal hole flow or the slower, more variable flow of the streamer belt [e.g., *Brandt et al.*, 1997, 2002; *Brandt and Snow*, 2000]. Disconnection events (DEs) are large-scale removals of essentially entire ion tails. These occur at heliospheric current sheet (HCS) crossings [*Niedner and Brandt*, 1978; *Yi et al.*, 1996; *Brandt et al.*, 1999; *Konz et al.*, 2004].

[3] Coronal mass ejections, CMEs, and their interplanetary counterparts, ICMEs, are large-scale ejections of solar plasma. Fast CMEs drive shocks in the heliospheric medium and are responsible for most major geomagnetic storms. The understanding of ICMEs' behavior and physical scales is important. Interplanetary spacecraft provide some information on ICMEs' extents, but these data could be complemented by the use of ion tails as ICME tracers. However, to the authors' knowledge, a direct association between a plasma tail structure and an ICME has not yet been identified. Some studies have suggested links between interplanetary structures and tail features: *Jockers and Lüst* [1973] associated features in C/1969 Y1 with an interplanetary shock. They noted narrow, brighter regions in the comet's tail, suggesting that they were regions of plasma sufficiently compressed by a shock to make them detectable. They noted that their study was limited by intermittent solar wind data and photographic coverage. *Brandt et al.* [1980] suggested that an abrupt ∼10° change in the tail orientation of C/1979 Y1 possibly resulted from an interplanetary shock. As discussed by *Le Borgne* [1982] and *Niedner et al.* [1983], and reviewed by *Jockers* [1986], Helios-2 data obtained 0.15 AU upstream agreed with the authors' conclusions that the comet encountered a large nonradial flow component. *Lundstedt* [1986] suggested a link between a forked tail structure in C/1975 N1 and a magnetic cloud ICME detected concurrently near Earth. *Wegmann* [1995] modeled interplanetary shocks' effects on an ion tail, concluding that expected visible signatures included the formation of tail rays and an ion cloud. Since 1995, the LASCO coronagraph [*Brueckner et al.*, 1995] aboard the Solar and Heliospheric Observatory, SOHO, has provided excellent temporal coverage of CMEs. Here, as preliminarily reported by *Jones and Brandt* [2004], we present the first evidence for a direct correlation between CMEs and large-scale disruptions of a comet's ion tail. One of the ICMEs was also detected at Earth, and its in-situ characteristics agree well with our interpretation.

2. Observations

[4] 153P/Ikeya-Zhang's trajectory with respect to a fixed Sun-Earth line is shown in Figure 1. Its orbital inclination of 28.1° kept it at low heliolatitudes, but it encountered varied solar wind conditions due to elevated solar activity [e.g., *McComas et al.*, 2003]. Using the technique of *Jorda et al.* [1992], the comet's peak visual magnitude (IAU Circulars 7858, 7883) suggests a water production rate of $\sim 7 \times 10^{29}$ molec s^{-1} at 0.5 AU, i.e., comparable to 1P/Halley at 0.9 AU [*Krankowsky et al.*, 1986]. The images used were acquired and kindly made available for study by the amateur astronomers listed in the acknowledgement section.

3. Event Analysis

3.1. Event of 11 March 2002

[5] Near-continuous monitoring of 153P required the combination of data obtained over a range of geographical

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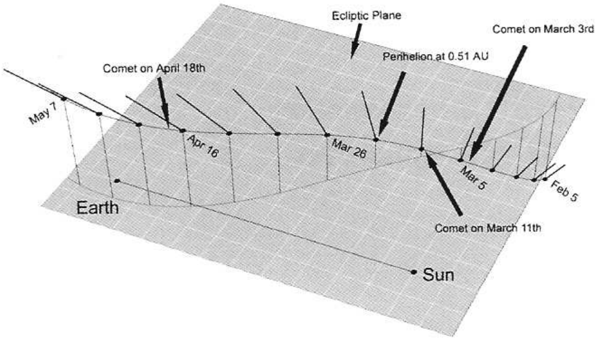

Figure 1. Comet 153P's trajectory with respect to the Sun-Earth line and ecliptic plane. Positions are shown every 7 days. See color version of this figure in the HTML.

longitudes. Figure 2 shows such a sequence. There is a temporal bias due to the large number of European observers, who generally imaged the comet between 1800 and 1900 UT on 11 March. At ~1800 UT, a prominent forked disturbance began to propagate down the tail at ~86 kms^{-1}. By ~0030 UT on 12 March, the tail traced a broad curve extending to the forked tail disturbance, the position of which was consistent with its initial velocity. The final image, a mosaic obtained during 0246–0330 UT, shows the tail undergoing a highly unusual large-scale disruption with a condensation moving at ~305 kms^{-1}. Note the "scalloped" structure of the downtail region. The region upstream of this was aligned with the Sun-comet direction, suggesting an extremely high solar wind velocity, or a flow direction shift. The tail disturbance's two stages, i.e., the relatively quiescent forking of the tail followed several hours later by the abrupt and large-scale tail disruption, suggest that two CMEs, not one, were influencing the comet. We suggest that the CMEs responsible were those appearing in LASCO images at ~2300 on 9 March and ~2300 on 10 March [*Yashiro et al.*, 2004, and references therein]. Both of these erupted in the comet's general direction. Their plane-of-sky velocities were ~600 and 1093 kms^{-1}, i.e., broadly consistent with arrival at the comet within a space of a few hours during March 11–12. The initial propagation of the forking is accompanied by an apparent "twisting" of the ion tail current sheet. This may indicate that the March 9 CME was a magnetic cloud and that the twisting is a response to the rotating magnetic fields within a magnetic flux rope [*Saito et al.*, 1987].

3.2. Event of 18 April 2002

[6] During a period of only 37 minutes on 18 April, the tail's appearance again changed from a relatively quiescent state to an unusual, highly disturbed one; see Figure 3. The first images show one tail edge sharp with some undulations, and the other diffuse. By 1825, the scalloped regions are markedly stronger, with significant portions of the tail undergoing transverse shifts. In the remaining images, the most dense tail regions are shifted the least, while the least dense regions are pierced by a flow with a strong lateral component. We also note a sharp, near-linear feature in the 2nd and 3rd images. Only tail regions sunward of this appear to be disrupted.

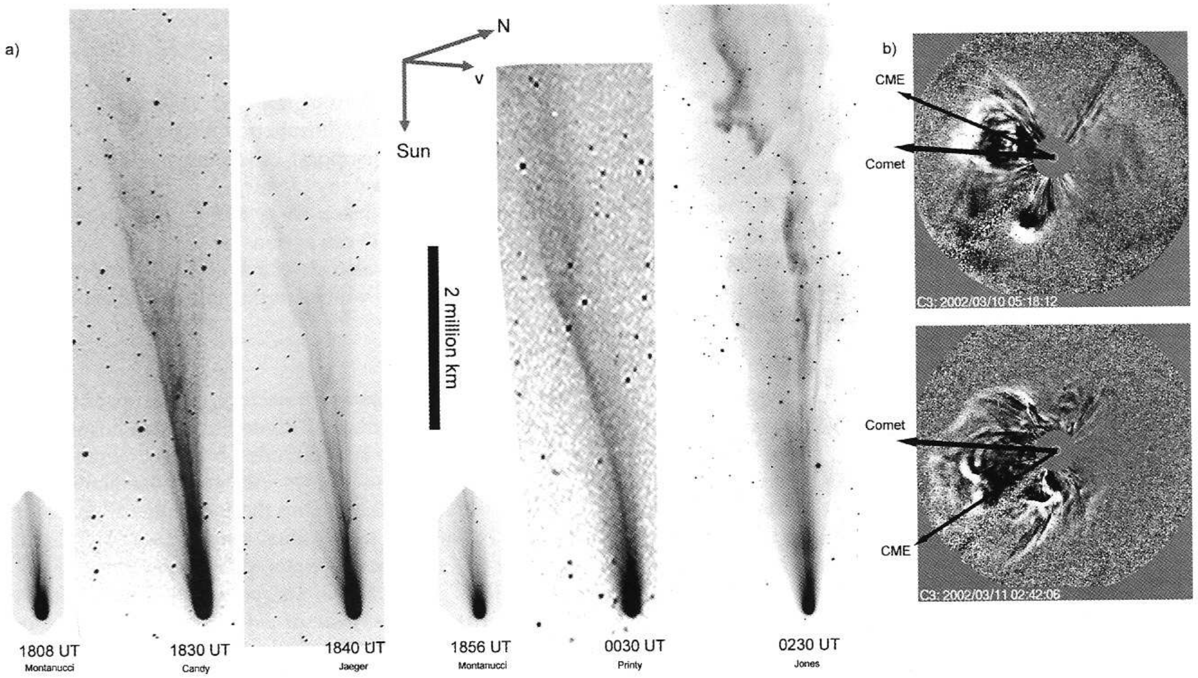

Figure 2. (a) Sequence of images obtained on 11–12 March 2002. 153P was 0.54 AU from the Sun, and 0.96 AU from Earth. The Sun-comet-Earth angle was 77.9°. Also shown are directions of the Sun, celestial north (N), and the comet's orbital velocity vector mapped onto the sky plane (v). (b) LASCO C3 difference images of the two CMEs believed to be responsible for the event. The computed CME center's direction and the direction to 153P are shown projected onto the sky plane. See color version of this figure in the HTML.

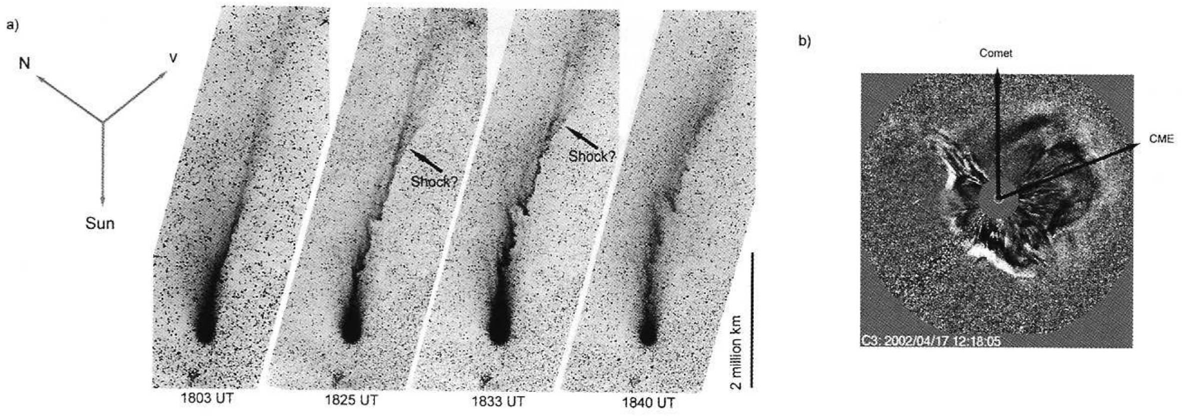

Figure 3. (a) 18 April 2002 image sequence by Numazawa. 153P was 0.86 AU from the Sun, and 0.43 AU from Earth. The Sun-comet-Earth angle was 80.8°. Some image changes result from differing photographic emulsions. (b) LASCO C3 difference image of the halo CME probably responsible for the tail disruption, traveling toward Earth. Other features are as in Figure 2. See color version of this figure in the HTML.

[7] We associate this event with a front-side halo CME that appeared in LASCO data $\sim$0826 UT on 17 April with a plane-of-sky velocity of 1218 kms^{-1}. The Sun-to-comet velocity implied by the tail disturbance's timing was 1068 kms^{-1}. At this velocity, the associated ICME would reach Earth around 2300 UT on 18 April, but did so at $\sim$0835 UT on 19 April [*Cane and Richardson*, 2003]. The measured peak velocity at the near-Earth ACE spacecraft was $\sim$700 kms^{-1}, and the velocity implied by its ACE arrival time was $\sim$875 kms^{-1}. As well as indicating deceleration of the ICME, the events' relative timings suggest that the ICME's fastest part was closer to 153P than to the Earth, agreeing with its appearance in LASCO images. The direction of the apparent lateral flow that disrupted the tail is also consistent with the CME's direction of propagation.

3.3. Event of 3 March 2002

[8] A tail disruption also occurred on 3 March, when the comet was 0.62 AU from the Sun and 1.11 AU from Earth. Imaging coverage was limited to the event's initial stages and to well afterwards [e.g., *Jäger*, 2002]. The tail displayed a sharp kink at which a clear tail break is seen at 1811–1841 UT. We associate this event with a partial halo CME that erupted at 1506 UT on 2 March, with a sky plane velocity of 1131 kms^{-1}. The minimum propagation velocity implied by the event's timing was 912 kms^{-1}. No ICME was detected at Earth. The small number of images precludes an in-depth investigation of this event, but we note its existence and its agreement with the disruption pattern described above.

4. Conclusion and Discussion

[9] The tail disturbances described above are interpreted as ICMEs' arrival at the comet. Each ICME overtakes the comet, draping its magnetic field around the pre-existing cometary magnetotail. If the ICME's dynamic pressure is not too great, this disturbance propagates through the tail, forming a tail ray pair and density enhancement, possibly as modeled by *Wegmann* [1995]. This process may be operating during most of the 11–12 March sequence. However, from the final 12 March image and in the 18 April and 3 March cases, the ion tail clearly cannot remain as a coherent magnetic structure under the pressure of fast ICMEs. The lateral motion of impinging material appears to propagate through the ion tail, with the degree of penetration being controlled by the local tail ion number density. The images suggest that the ICMEs' magnetic field drapes around the densest tail regions, forming several miniature tail condensations, each possessing magnetotails inclined at considerably different orientations to the parent ion tail.

[10] We interpret the 18 April sequence's linear feature as the ICME-driven shock penetrating the ion tail, possibly corresponding to the tail ray of *Wegmann*'s [1995] simulation. A similar feature was described previously by *Jockers and Lüst* [1973]; they suggested that the shock orientation was changed by propagation through the comet - an interpretation with which we agree. Given the magnitude of the nonradial tail material shifts, it appears that the shock front approached the comet from one side. The disrupted tail's appearance, with sharp and diffuse edges, followed by undulations in the sharp edge, clearly share morphological similarities to events reported by *Jockers and Lüst* [1973] and *Niedner et al.* [1978]. We also note that the final image presented by *Brandt et al.* [1980] also possesses similar scalloped structuring. *Jockers* [1986, 1991] suggested that such features are manifestations of the Rayleigh-Taylor instability.

[11] As ICMEs are basic solar wind features, other comets should show structures similar to the above. *Gosling* [1996] reported that the Earth intercepted $\sim$72 and $\sim$8 ICMEs per year near solar maximum and minimum, respectively. These can serve as rough estimates for a comet like 1P/Halley that never exceeds 18° from the ecliptic even considering that our morphological signature applies only to fast ICMEs and uncertainties in coverage and comet image interpretation. The atlases of Halley in 1910 and in 1985–1986 were searched for examples. In 1910, we found one event around May 27.3 [e.g., *Donn et al.*, 1986, Figure 538], and a possible event showing some similarities to our Figure 2, but with no pronounced scalloping, occurred around May 7.9 [e.g., *Donn et al.*, 1986, Figure 258]. The comet

had a well-developed plasma tail for ∼50 days, suggesting ∼7–15 events per year. For 1985–1986, events were found around March 14.4 and 20.4, and April 17.2 [e.g., *Brandt et al.*, 1992, Figures 306, 385, 389, 634]. The comet was observed with a well-developed plasma tail for ∼4 months [*Brandt et al.*, 1999], yielding an annual rate of ∼9. Both apparitions were well away from solar maximum, and the ICME rate inferred from cometary signatures is roughly consistent with the solar minimum values of *Gosling* [1996]. We did not count scalloped appearance associated with DEs. The ideas presented here thus pass a straightforward consistency check.

[12] The evidence presented is entirely consistent with the comet morphology being produced by interactions with fast ICMEs, and we suggest that this morphology can be used to identify fast ICMEs' locations. As the scalloped tail features apparently last less than one hour, good temporal coverage of comets is required to capture all fast CMEs using this method. In combination with other data sources, some information can be obtained regarding the ICMEs' large-scale structure, as we demonstrate for the 18 April event. The quality of observational data acquired by amateurs is now excellent. A network of dedicated amateurs could serve as a valuable monitor of heliospheric conditions at the time of a bright comet's passage.

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J. C. Brandt, Department of Physics and Astronomy, University of New Mexico, 800 Yale Blvd. NE, Albuquerque, NM 87131, USA. (jcbrandt@unm.edu)

G. H. Jones, Mail Stop 169-506, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA. (geraint.h.jones@jpl.nasa.gov)