

OBSERVATIONAL DATA NEEDS FOR  
PLASMA PHENOMENA

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Abstract

Bright comets display a rich variety of interesting plasma phenomena which occur over an enormous range of spatial scales, and which require different observational techniques to be studied effectively. Wide-angle photography of high time resolution is probably the best method of studying the phenomenon of largest known scale: the plasma tail disconnection event (DE), which has been attributed to magnetic reconnection at interplanetary sector boundary crossings. These structures usually accelerate as they recede from the head region and observed velocities are typically in the range  $50 < V < 100 \text{ km s}^{-1}$ . They are often visible for several days following the time of disconnection, and are sometimes seen out past 0.2 AU from the cometary head. The recession velocity and repulsive acceleration are observable parameters which could be incorporated into theoretical models to estimate, for example, the plasma tail's magnetic field and mass density. The primary observational requirement is that enough photographs to be taken with which to assemble an accurate kinematical description. For all but circumpolar comets, this really requires a network of observatories.

Helical formations, "condensations," arcade loops, "kinks", and folding tail rays, are smaller scale plasma tail features which tend to accompany DEs, and whose morphology and kinematics can also be studied photographically. Possible origins of these features will be discussed.

The following areas pertaining to plasma phenomena in the ionosphere will also be addressed: the existence, size, and heliocentric distance variations of the contact surface, and the observational signatures of magnetic reconnection at sector boundary crossings.

It would be difficult indeed to overestimate the important and unique role of comets in the study of cosmic plasmas. It is also difficult to summarize this topic in 10 minutes, however, and so the first order of business is to disclaim that this talk is comprehensive.

Since cometary plasma is created in the head and then flows down the plasma tail, I would like to follow that route in the discussion, pointing out along the way a few of those problems which I feel are of particular importance.

The contact surface proposed to stand off the solar wind has been the subject of some recent and interesting work by Delsemme and Combi. Briefly, using calibrated slit spectrograms, they constructed ion brightness profiles along the Sun-comet line for comets Bennett 1969i (Delsemme and Combi 1979) and West 1975n (Combi and Delsemme 1980). Figure 1 shows some of the results for  $\text{H}_2\text{O}^+$  in comet Bennett. The diagram displays the brightness profiles for 2 spectra taken on the same night,  $20^m$  apart. On the sunward side the brightness falloff is rather smooth until a distance of a few times  $10^4 \text{ km}$  is reached, beyond which the profile is turbulent and wavy. In the tailward profiles, wavy features were seen in each spectrum which appeared to have counterparts in the other spectrum. By lining up the crests and troughs as shown in Figure 2, they deduced that the speed of these features was  $17 \text{ km s}^{-1}$  in the tailward direction. In Delsemme and Combi's model, the waves are bulk motions first induced on the sunward side when cometary plasma crosses the contact surface and hits the turbulent magnetosheath plasma and embedded magnetic field.

Using  $\text{CO}^+$  profiles in comet West, Combi and Delsemme estimated the position of the contact surface and were even able to deduce a heliocentric distance variation of its size over the range  $0.44 < r < 0.84 \text{ AU}$ .

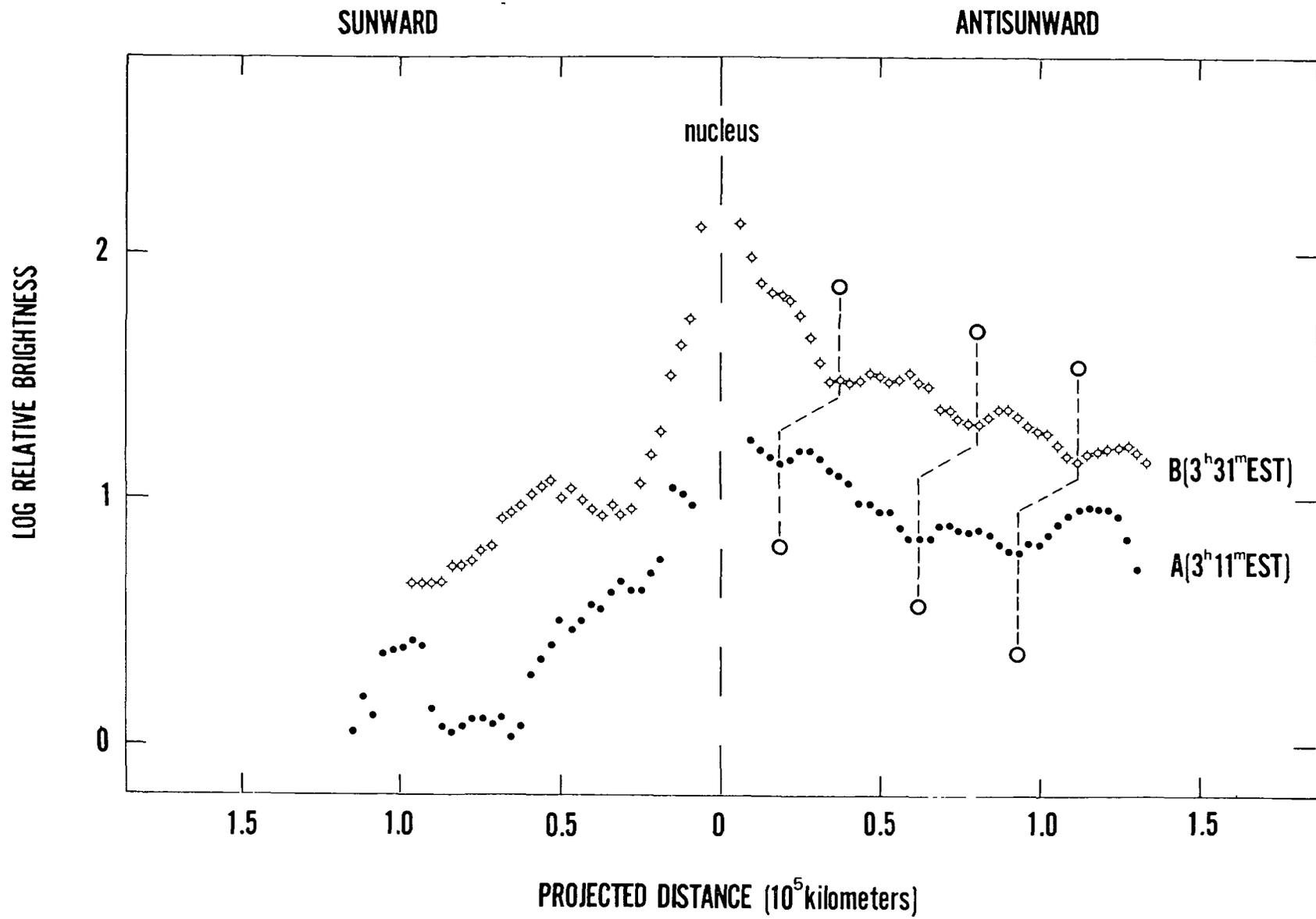


Figure 1.  $\text{H}_2\text{O}^+$  brightness profiles obtained by Delsemme and Combi (1979) for comet Bennett 1969i. The profiles were obtained from calibrated slit spectra centered on the head and oriented along the Sun-comet line. Two profiles taken 20<sup>m</sup> apart are pictured.

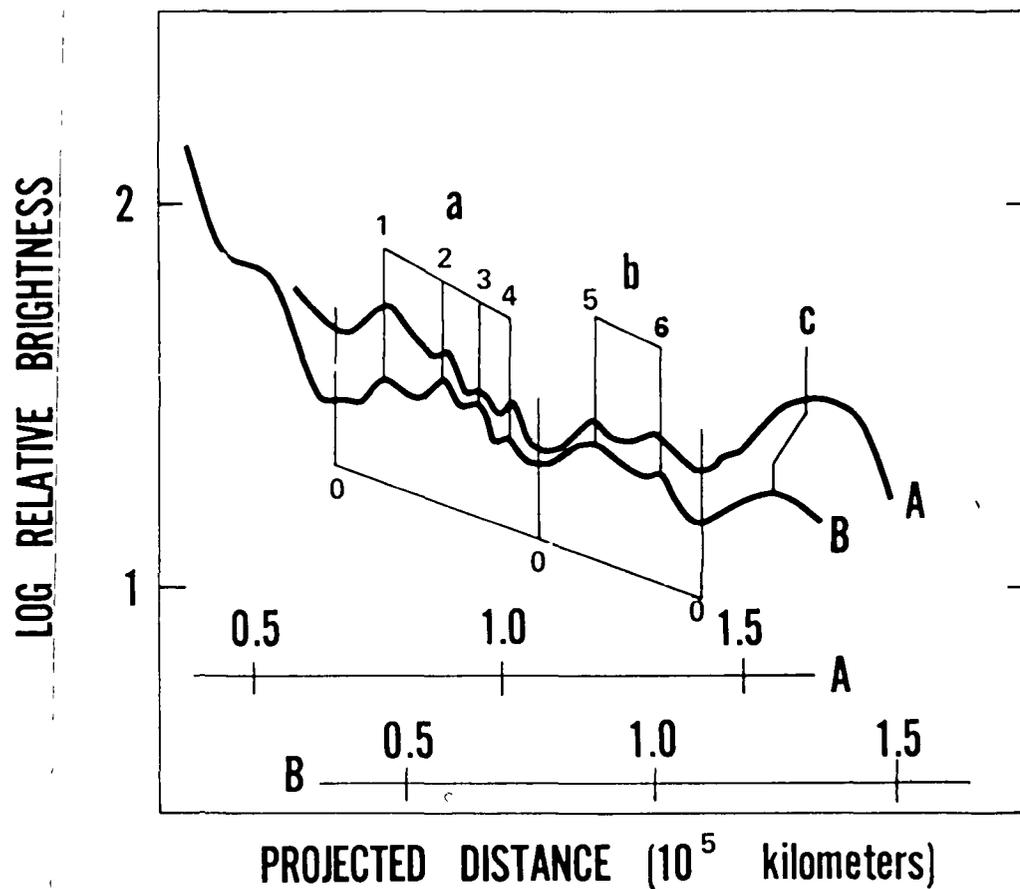


Figure 2. The antisunward profiles of Figure 1 have been shifted 18,000 km relative to one another, bringing the crests and troughs visible in each profile into coincidence. The inferred speed of these features down the tail is  $17 \text{ km s}^{-1}$  (from Delsemme and Combi 1979).

To my knowledge, observations of this type are unique to these 2 studies and I would personally like to see a lot more of this work in the future. Assuming that this is a valid technique for detecting the contact surface, important questions that could be addressed in the future are these:

- 1) Does the solar wind penetrate down to the nucleus of faint comets with low gas production rates, or is it stood-off by a contact surface.
- 2) Is the observed disappearance of the plasma tail with increasing heliocentric distance a result of sub-detection brightness levels, or of the destruction of the contact surface.
- 3) What correlation, if any, exists between local solar-wind conditions and the size of the contact surface.

For the rest of the talk, I would like to discuss a subject on which Jack Brandt and I have collaborated for the last few years: plasma tail disconnection events, or "DEs" (Niedner and Brandt 1978, 1979, 1980). Two reasons why I think DEs are so fascinating are, first, they constitute the only really predictable response of a plasma tail to a particular feature in the solar wind, and second, so much more goes on than just the tail coming off. In fact, the disconnection process may provide a unification of many disparate forms of plasma tail activity, as is suggested in Table 1. Note that activity in the head, as well as in the tail, is thought to be related to the DE phenomenon. I will try to justify these connections shortly, but first, I would like to present a quick review of our model of DEs.

Figure 3 shows the arrival of a sector boundary to a comet (Niedner and Brandt 1978). Starting in panel B, after the sector boundary has just swept past, reconnection of field lines in the head progressively severs the plasma tail fields which had been frozen-in. About 18 hours later, the tail has become totally disconnected (panel C). The capture of flux from the new magnetic sector then starts building a new tail, and the entire process repeats when the next sector boundary comes along. Thus, a bright comet which is observed for several weeks might experience several events. I am personally aware of 5 DEs in Halley's Comet during the 1910 apparition, and of 9 events in comet Morehouse in 1908. I would be very remiss if I did not point out that Ip and Mendis (1978) have proposed a different mechanism for DEs which involves high-speed streams. We still prefer the sector boundary model (Niedner and Brandt 1979), however, and I will stick with it in the following discussion.

The reconnection phase of a DE (panel B in Figure 3) could produce noticeable effects in the head as a result of the dissipation of magnetic energy, namely, an ionization surge and brightness increase (Niedner 1980). There is observational evidence that this actually happens. Figure 4 is a qualitative light curve constructed from Barnard's descriptions of naked eye observations of comet Morehouse; he was convinced that two major brightness flares occurred, one on about October 14, the other on October 29. Both of these brightenings correlate beautifully with DEs, and Figure 5 shows the first one in a photograph taken at Indiana University on October 15. Such associations between brightness flares and tail disconnections are very exciting and convincing, but they will actually be useful to theoretical reconnection models only when we have observed absolute flux increases during the time of a DE. Narrow-band photometry centered on the wavelengths of ion emissions would be particularly useful.

If reconnection is indeed the mechanism of DEs, then it would also be extremely worthwhile to look for ion radial velocities in the head. Figure 6 shows the rationale for this assertion. Heated plasma flows out of both sides of the reconnection region (the hatched rectangle) at the Alfvén speed, which is probably about  $5 \text{ km s}^{-1}$ , but might be as high as  $10 \text{ km s}^{-1}$ . Probably more promising is the jetting of material perpendicular to the plane of the figure in response to the curl of the magnetic field in the field reversal region. These speeds may be significantly higher and would be worth looking for. Also, filtered photographs of short exposure which isolate particular ions might actually show some of these jets and reconnected flux tubes.

Figure 7 is a schematic of 4 phases in the life of a plasma tail which qualitatively illustrates the interrelationships mentioned earlier in Table 1. In Phase I, the main tail is clumpy and full of "condensations," and a widely-inclined ray pair (or pairs) is also present. Time sequences of comets in this phase sometimes show that the inner part of the plasma tail is narrowing down. Physically, we interpret this phase as the final phase of reconnection after a sector boundary has been traversed, but before the tail has actually come off. The tail rays are flux tubes composed of magnetic fields captured from the new sector; the narrowing is caused by

Table 1

THE MANY MANIFESTATIONS  
OF A DISCONNECTION EVENT (DE)

REGION	FEATURES
HEAD	IONIZATION SURGE AND BRIGHTNESS FLARE PLASMA JETTING
PLASMA TAIL	NARROWING DOWN OF INNERMOST TAIL PRIOR TO DISCONNECTION "CONDENSATIONS" BEFORE AND AFTER DISCONNECTION ENHANCED TAIL BRIGHTNESS IMMEDIATELY BEFORE DISCONNECTION PROMINENT TAIL RAY ACTIVITY DISCONNECTED TAIL HELICES AND WAVES IN DISCONNECTED TAIL (SOMETIMES).

Table 2

PLASMA TAIL STUDIES

TYPE OF OBSERVATION	OBJECTIVE
PHOTOGRAPHIC TIME SEQUENCES, MOVIES	MANNER OF FORMATION AND EVOLUTION OF TAIL STRUCTURES  KINEMATICS OF TAIL STRUCTURES (ESPECIALLY ACCELERATIONS)  PLASMA TAIL TAXONOMY AND DERIVATION OF INTERRELATIONSHIPS
RADIAL VELOCITIES	RESOLUTION OF BULK VS. WAVE MOTION DEBATE
BRIGHTNESS MEASUREMENTS	ION DENSITIES IN TAIL, AND VARIATIONS
IN SITU MEASUREMENTS OF HALLEY'S COMET	BOW SHOCK, CONTACT SURFACE, MAGNETIC FIELD STRENGTHS, CURRENTS, DENSITIES, ETC.

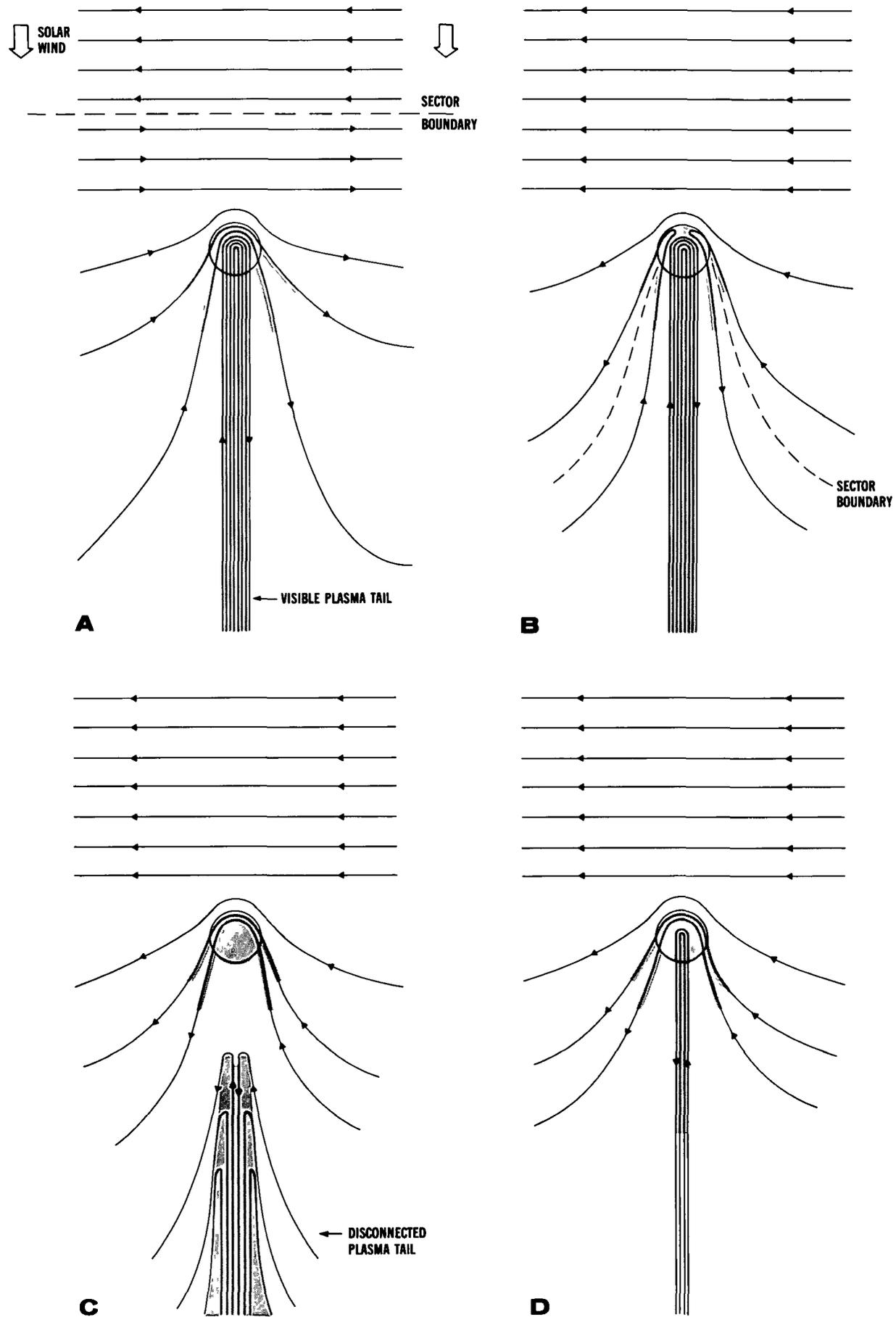


Figure 3. The sector boundary model of plasma tail disconnection events (DEs) (from Niedner and Brandt 1978).

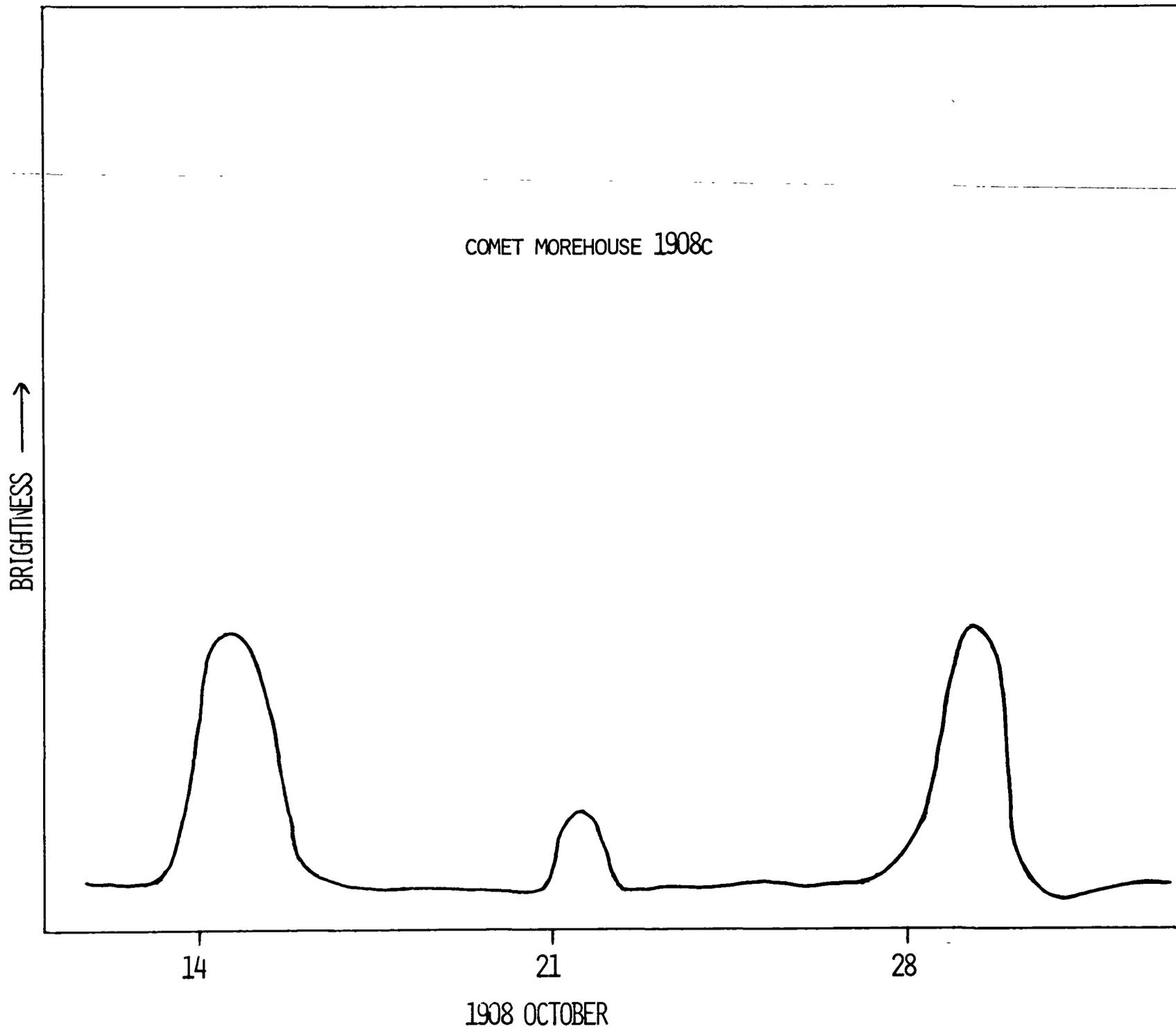


Figure 4. A qualitative light curve of comet Morehouse 1908c, constructed from Barnard's naked-eye observations. Note that major light outbursts are inferred to have occurred on October 14 and October 29.

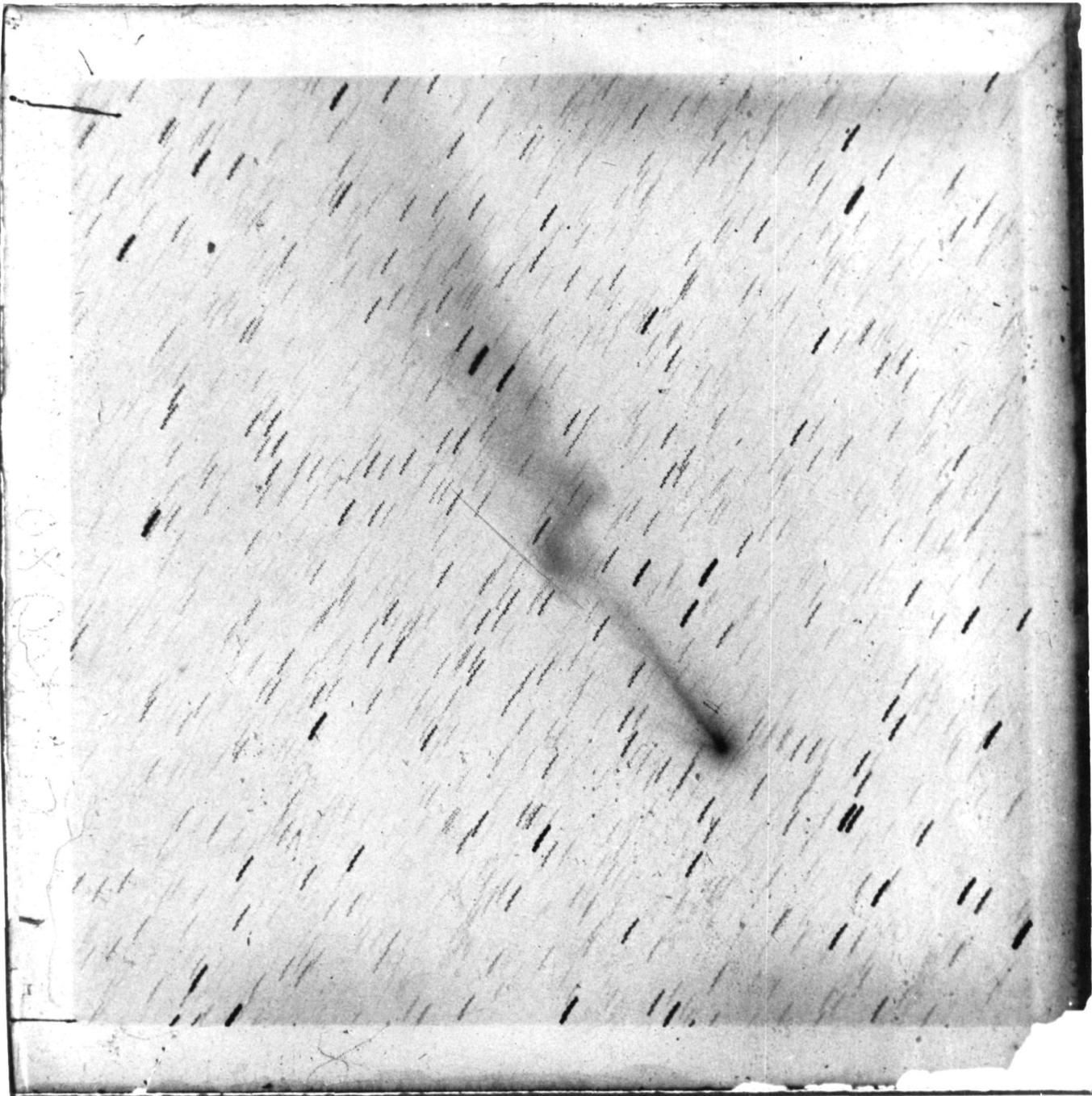


Figure 5. Indiana University photograph of comet Morehouse 1908c on October 15, 1908, showing a detached plasma tail. This DE is associated with the light outburst which occurred on October 14 (see Figure 4).

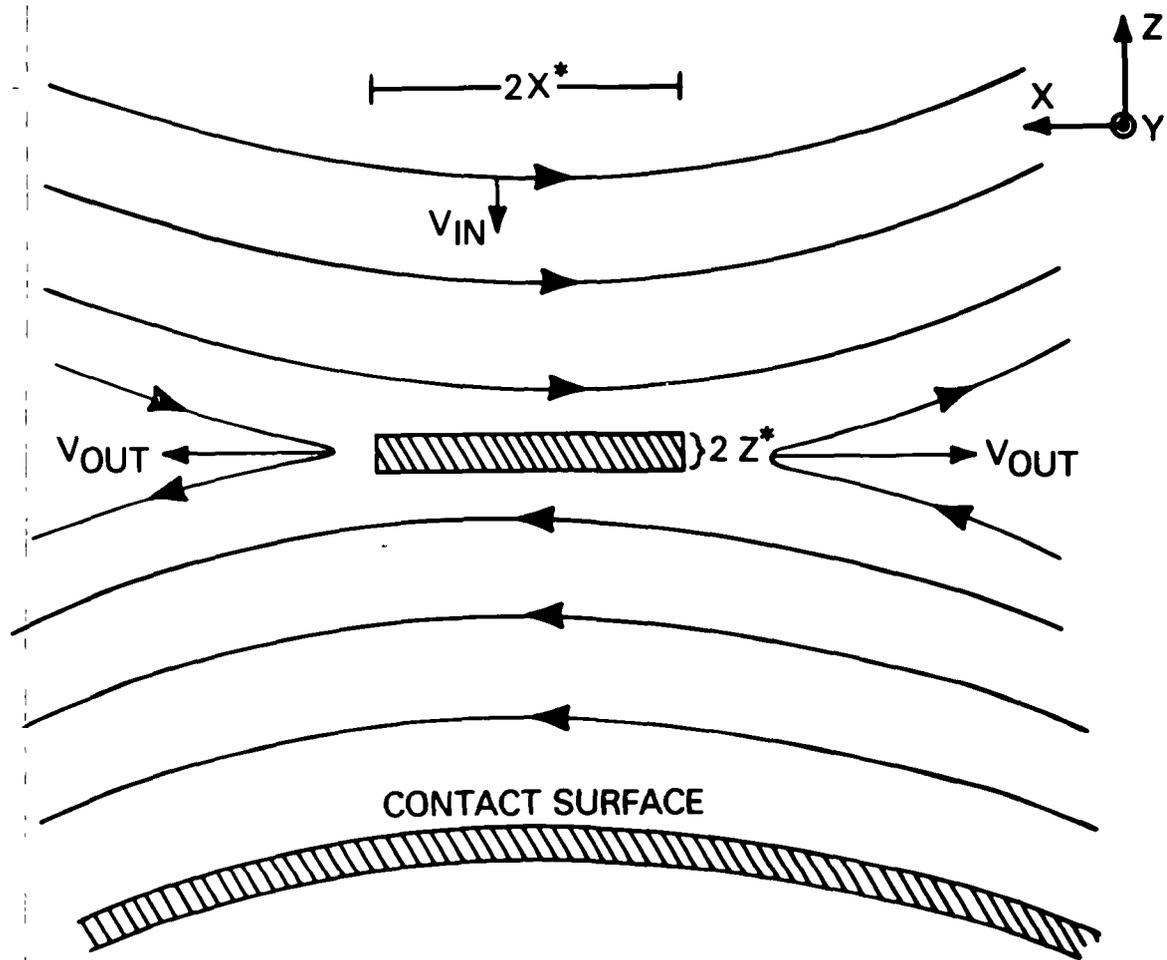


Figure 6. Schematic diagram showing the topology of magnetic fields upstream of the contact surface at the time of a sector boundary crossing.

# PLASMA TAILS: A MORPHOLOGICAL SEQUENCE

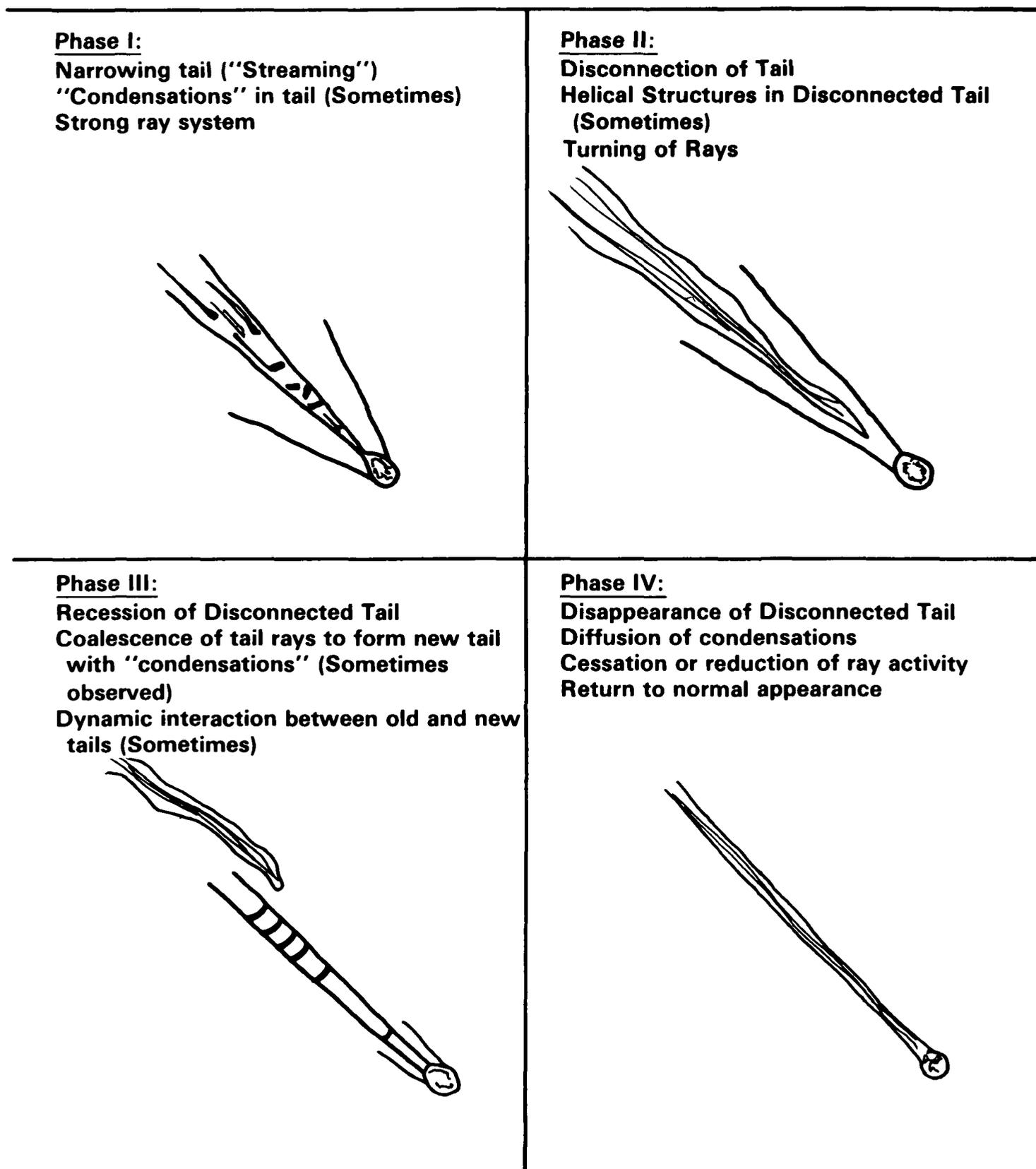


Figure 7. Schematic diagram of the morphological sequence which is observed to occur around disconnection events.

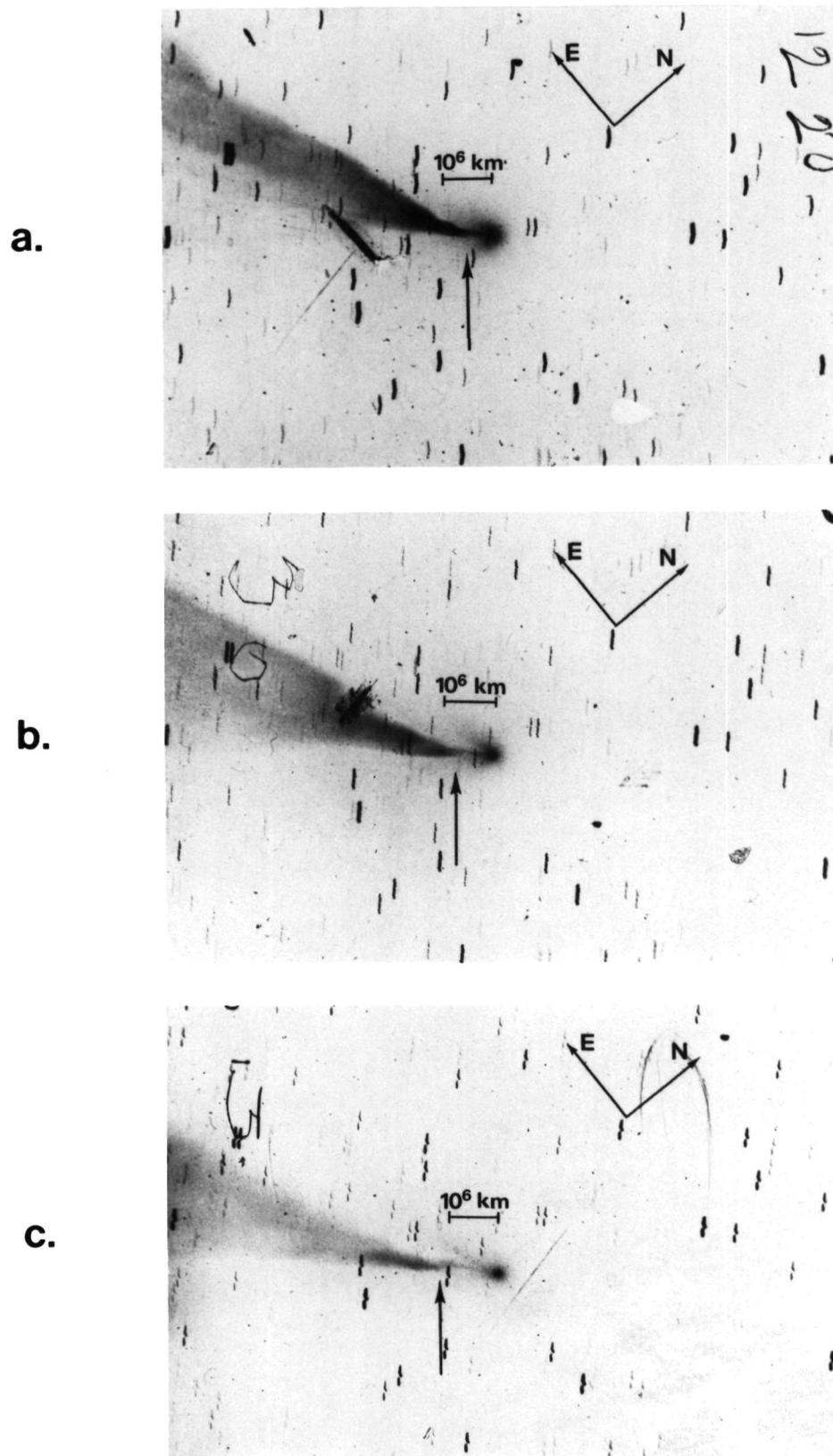


Figure 8. A three-hour sequence of Indiana University photographs of comet Morehouse 1908c showing the early recession of the end of a disconnected tail (arrows) from the cometary head, on 1908 September 30.

the destruction of the old tail, and the condensations in the tail are due to the unsteady reconnection of fields, probably a result of the tearing mode instability.

In Phase II, the tail has become disconnected, sometimes showing wavy and helical formations, and the rays are closing to form a new tail axis and a new tail. Typical recession speeds are  $50 < V < 100 \text{ km s}^{-1}$ . In Phase III, the new tail has been formed, but sometimes with the appearance of arcade loops normal to the rays where they came together. This seems to be a result of reconnection occurring between the oppositely-polarized rays. Finally, in Phase IV, the new tail has quieted down, and the comet awaits the next sector boundary.

Observational needs for plasma tail studies are fairly obvious, and they are listed in Table 2. Since most of the features we have been discussing are transients, photographic sequences of high time resolution are absolutely indispensable, and I have high hopes that the upcoming apparition of Halley's Comet will provide the organized networks required to carry out this task. We want to know, in more detail than ever before, how features develop and evolve, what their kinematics are, and how each class of structure fits into the grand puzzle of plasma tail morphology and time variations, so that plasma physics models can be based on observations to the greatest possible degree.

The time has also come for some definitive radial velocity measurements of plasma tail structures, with particular emphasis on the bulk vs. wave motion debate. I personally feel that both motions exist, and if I had to bet my life on one of the bulk variety, it would be the recession of the end of a disconnected tail. This is because the ions at the very end of the tail have an identity which doesn't change from one photograph to the next. Figure 8 is a 3-hour sequence of comet Morehouse just after its plasma tail had come off on 1908 September 30. The recession speed was  $61 \text{ km s}^{-1}$ , but more importantly, the component along the line of sight was a hefty  $49 \text{ km s}^{-1}$ . A spectrograph looking at the right place and at the right time would almost certainly have seen an obvious Doppler shift. The chances for future success in this area would be greatly aided by real-time monitoring of the plasma tail using an image intensifier, combined with accurate forecasting of DEs based on the times of past events and an up-to-date knowledge of the interplanetary sector structure.

Calibrated spectrophometry of the tail would be important for a determination of ion species and densities, their variations, and their correlation with solar-wind events.

Finally, although I have stressed ground-based observations, there is absolutely no substitute for in situ measurements. All we can do here is keep our fingers crossed.

To sum up, the plasma phenomena in comets are exciting, varied, and very worthy of future study. Magnetic reconnection (Niedner and Brandt 1978), the flute instability (Ip and Mendis 1978), the kink mode (Hyder, Brandt, and Roosen 1974), and the Kelvin-Helmholtz instability (Ershkovich 1979), are but a few of the exciting plasma processes proposed to operate in comets. Future observational programs devoted to plasma studies in comets have the chance not only to increase our understanding of astrophysical plasmas, but of the structure of comets themselves.

#### References

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