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# GEOMETRY OF THE DISTRIBUTION OF PLASMA TAIL RAYS IN A COMETARY TYPE 1 TAIL

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## RESUMEN

Se presenta un estudio de la orientación de los rayos de plasma existentes en cometas con colas tipo 1. Este estudio supone una interacción del plasma del cometa con el viento solar similar a la que tiene lugar en el planeta Venus y está fundamentado en el hecho de que en ambos casos la magnetización interna es muy baja. Mediante la adopción de los resultados teóricos y experimentales más recientes de la configuración del flujo de plasma en la estela de Venus es posible predecir que los rayos en las colas de los cometas deben formarse y evolucionar preferentemente en la vecindad del plano de la media noche del cometa. La coplanaridad del sistema de rayos hace su observación difícil en cometas localizados a altas latitudes eclípticas y por tanto permite una explicación autoconsistente del decrecimiento de la frecuencia de detección de tales estructuras a altas latitudes.

## ABSTRACT

A study of the orientation of plasma tail rays in type 1 cometary tails is carried out by considering a solar wind interaction similar to that observed in the planet Venus. The absence of an internal magnetic field in this planet allows a purely ionospheric interaction similar to that expected to occur in a cometary environment. Application of the most recent experimental and theoretical results of the flow configuration in the Venus wake lead to the prediction that the cometary tail rays must be preferably formed and evolve in the vicinity of the midnight plane of the comet. The suggested coplanarity of the system of tail rays makes its observation difficult for comets located at high ecliptic latitudes, and thus provides a selfconsistent explanation of the observed precipitous decrease of the detection frequency of such structures at high latitudes.

*Key words:* SUN-SOLAR WIND – COMETS – SOLAR SYSTEM-GENERAL

## I. INTRODUCTION

Significant advances have been achieved over the last few years in the understanding of the solar wind nteraction with a non-magnetic object. The *in-situ* observation of the plasma and magnetic environments of the planet Venus has provided detailed information on the overall flow configuration of the solar wind as it streams around and behind the local planetary ionosphere. These observations indicate that in the absence of an appreciable magnetic field of internal origin, the oncoming solar wind impinges directly on the ionospheric material which is consequently confined in the dayside hemisphere and swept downstream to form a complicated tail structure.

One of the most remarkable experimental results obtained during the Pioneer Venus Orbiter mission has been the identification of a region of enhanced interplanetary magnetic fluxes immediately outside of the onopause (or outer boundary of the planetary ionosphere). This is believed to be due to the draping of the nterplanetary magnetic field lines around the ionospheric obstacle, which acts as an effective perfect electrical conductor immersed in the solar wind (Russell et al. 1979; Johnson and Hanson 1979). The draping process has the effect of producing an accumulation of magnetic fluxes which transfers the directed pressure of the solar wind to the ionospheric plasma.

This peculiar feature of the Venus ionopause appears to be present throughout the entire dayside hemisphere, where the solar wind is deflected around by the ionospheric obstacle. We should note, however, that immediatly outside of the planetary polar regions the interplanetary magnetic field lines are expected to skim past the ionosphere rather than being draped around the planet. In fact, the tendency of the magnetic field vector of the solar wind to occur on planes of approximately constant solar latitude makes the transit of interplanetary magnetic fluxes past the planet (whose motion takes place near the ecliptic plane) to experience the least accumulation in the vicinity of the planetary polar regions. Consequently, it is there where a more direct contact between the solar wind and the local ionospheric plasma is expected to take place (at lower planetary latitudes the enhanced interplanetary magnetic fluxes act as a buffer zone between both plasmas forcing the solar wind particles to remain above the ionopause as they stream around the planet).

Some of the implications of this contact between both plasmas near the polar regions were examined by

Pérez-de-Tejada (1980) in connection with the development of a viscous boundary layer at the polar terminator, where an efficient transfer of momentum of the solar wind to the ionospheric material is believed to take place. As can be appreciated from considerations of mass flux, the effective loss of momentum of the solar wind implies a commesurate increase of the cross sectional area of the streaming fluxes, which should then deviate its course in the direction of the region occupied by the ionospheric plasma. The geometry expected in this situation is illustrated in Figure 1 for a planar flow configuration suitable for laboratory tests. A streaming flow representing the solar wind is assumed to move from the left and to make contact with a stationary plasma at the end of a splitter plate. This location corresponds to a position, slightly upstream from the polar terminator, where the accumulation of the interplanetary magnetic fluxes does not grow to be strong enough to prevent the interaction of both plasmas.

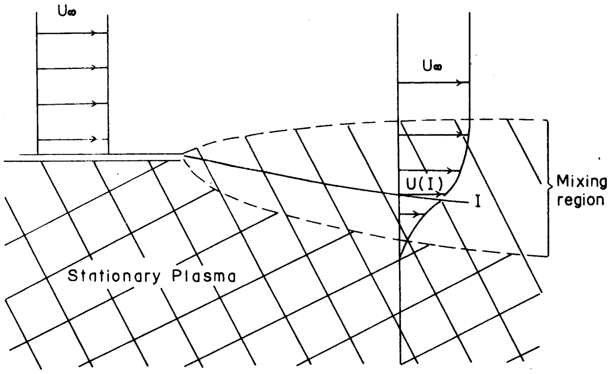

Fig. 1. Schematic diagram of the region of interaction between a streaming flow and a stationary plasma. The geometry is intended to represent the solar wind past a local ionosphere near the polar terminator of a non-magnetic object.

The lateral deflection of the solar wind, as well as of the dragged ionospheric particles, has the most important consequences in regard to the formation of a plasma tail behind Venus. In fact, it is clear that an inward motion to the interior of the planetary umbra must result from the downward deviation of such fluxes at the terminator. Experimental evidence in support of this peculiar flow configuration has been accumulating over the years from various of the *in-situ* observations carried out with Soviet and American space probes (Verigin *et al.* 1978; Breus 1979; Intriligator *et al.* 1979). These experiments have shown, among other results, the presence of significant particle populations within the planetary umbra, downstream from the planet, and the existence of a well defined ionopause thoroughout the nightside hemisphere. This latter observation suggests that the entry of the ionospheric plasma remains confined throughout most of the nightside hemisphere (Brace *et al.* 1979).

Despite the fact that the composition and spatial configuration of a cometary ionosphere is expected to be different from that measured at Venus, the solar wind interaction with a comet should present a similar aspect. This assertion can be supported by the low internal magnetization which is believed to characterize cometary bodies. In such conditions the solar wind flow must also impinge directly on the local ionosphere which should, likewise, become compressed and confined by a region of enhanced interplanetary magnetic fluxes.

Theoretical estimates of the position of the corresponding cometary ionopause, upstream from the nucleus, range between 10000 km and 100000 km depending on the conditions assumed to be present at the bottom of the cometary ionosphere. Effects associated with the expansion of its sublimating atmosphere may, in fact, result in a strong outward kinetic pressure giving, in turn, place to a large scale ionospheric cavity. The accumulation of the interplanetary magnetic field lines outside such a cavity should prove, however, to be a dominant feature of the interaction process and to hinder, throughout the dayside hemisphere, the direct contact between the solar wind and the ionospheric plasma. As in Venus, we should expect that this condition must not operate outside the corresponding cometary polar regions, where the interplanetary magnetic field lines skim past the obstacle without draping and hence accumulate around the local ionopause.

The consequences of the corresponding polar entry of the solar wind and ionospheric fluxes into the ionospheric cavity behind the cometary nucleus may prove, however, to be more dramatic than the flow distribution seen in the Venus wake. Evidence for the inward motion of plasma to the interior of a cometary tail was first presented by Opik (1964) in a study of the actual trajectories of the cometary light-emitting ions which form the cometary tail rays. These are thin and filamentary structures which are believed to result from the impulsive emission of a jet of cometary material into the solar wind, and which is subsequently swept downstream in a pattern reminiscent of a folding umbrella. Opik noted, however, that a component of the motion of the particles is actually transverse to the direction of the tail rays and that as result of this the material tends to accumulate in the interior regions of the tail (see also Wurm 1968, 1975).

Figure 2 shows a qualitative description of the paths of cometary ions which form the tail ray structures. The inward motion inferred from these observations is entirely consistent with that measured in the Venus planetary umbra and thus supports the similar character of the solar wind interaction with cometary plasmas. The distribution of the solar wind and ionospheric fluxes behind a comet may, however, exhibit conditions different from those present in the Venus wake. In fact,

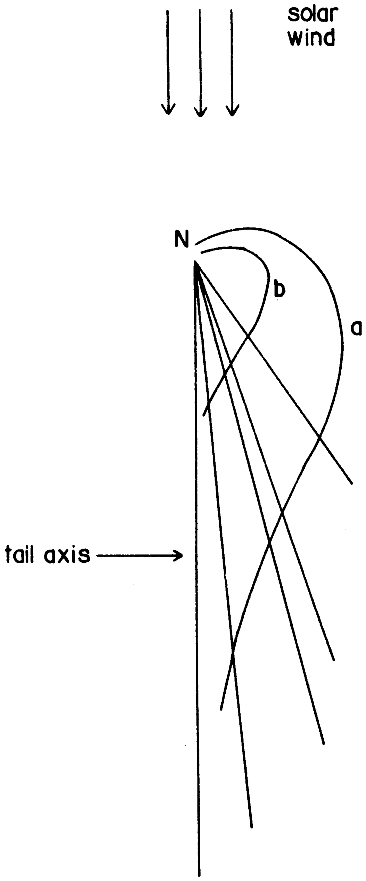

Fig. 2. Qualitative description of the evolution of cometary tail rays and of the actual trajectories (curves a and b) of the cometary ions which form the tails (from Wurm 1975).

the absence of a solid body with dimensions comparable to those of the ionospheric cavity, should have the effect of allowing the formation of locally produced ionization, so that a region devoid of plasma should not exist downstream from the nucleus. In these conditions the entry of solar wind and ionospheric material dragged from the sun facing regions of the ionosphere should be more restricted and should not result in an expansion of the plasma to fill a cavity as it is the case in the Venus near wake (see Fig. 1 in Pérez-de-Tejeda 1980). Instead, the deflection of the solar wind fluxes must proceed only toward the tail axis in the immediate vicinity of the midnight plane. This peculiarity confines the development of the tail ray structures, which are believed to evolve only within the region of interaction, to the vicinity of that plane.

A most important implication of this geometry is that the orientation of such structures will vary with that of the interplanetary magnetic field which, as in Venus, determines the position of the corresponding "polar" regions of the cavity where the field lines graze past the ionosphere. In addition, the suggested coplanarity of the tail ray structures imposes specific conditions to their observability from Earth, as the orientation of their planar arrangement in space will project in different ways onto the plane of the sky. We should note first that for comets located on the ecliptic plane the observation of the cometary tail ray plane (perpendicular to the direction of the magnetic vector of the solar wind) will vary with the difference of ecliptic longitude of the Earth with respect to the comet. The observing conditions will, in particular, be optimum for cases in which the phase angle of the comet is $\alpha = 90^\circ$ so that a frontal view of the tail ray structures is possible. For comets located at non zero ecliptic latitudes, however, it will never be possible to view the cometary tail ray plane in the direction perpendicular to it. As shown in the diagram of Figure 3 the tail ray formation will present, in such cases, a slant angle due to the different ecliptic latitudinal angle to the Earth. This means that the observation, and hence the detection of tail ray structures, should be more difficult with increasing ecliptic latitude.

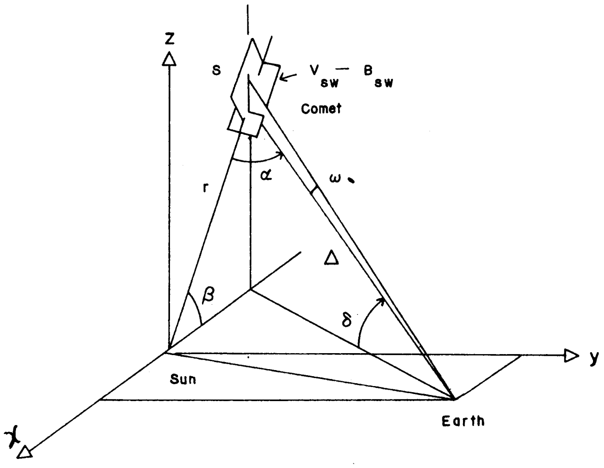

Fig. 3. Schematic diagram of the tail ray plane for an off the ecliptic position (the ecliptic plane is defined by the x and y axis). $V_{SW} - B_{SW}$ denotes the plane formed by the magnetic and velocity vectors of the solar wind.

A test of this contention can be carried out by comparing the way in which the projection of the cometary tail ray plane on the plane of the sky and the observed frequency of the tail ray structures varies with ecliptic latitude. Statistical studies of the observational distribution of comets with type 1 (plasma) tails have been reported by Stumpf (1961) and Antrack *et al.* (1964). These authors have shown that the existing observational evidence indicates that there is a noticeable decrease of the number of such comets with the ecliptic latitude of their perihelion, i. e., it is far less frequent to detect tail ray structures in comets which approach the sun at high ecliptic latitudes.

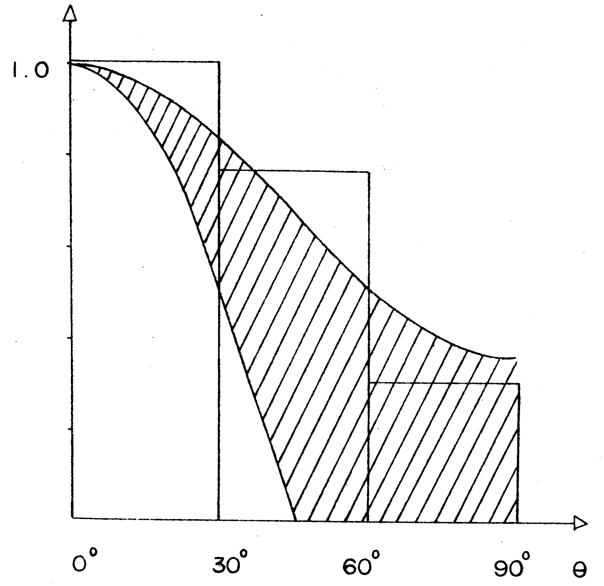

Fig. 4. Comparison of the observed comet density reported by Antrack *et al.*(1964) (vertical bars) and the predicted detectability of plasma tails with ecliptic latitude $\theta$.

Even though it is not possible to rule out conclusively that this dependence reflects strong latitudinal differences of the solar wind properties with ecliptic latitude, there is evidence indicating that the observed distribution may not be due to this effect. For example, no dependence appears to exist between the number of comets with tail ray structures (near the ecliptic plane) and the level of solar activity (changing solar wind conditions). Consequently, the suggestion that the observed decrease of detection frequency of such structures with ecliptic latitude is actually due to visual restrictions imposed by their spatial coplanarity provides a more likely explanation of this behaviour.

A quantitative account of the manner in which the projection of the cometary tail ray plane on the plane of the sky may reduce the detectability of the structures can be prepared from the geometry shown in Figure 3. The angular width w subtended by the structures on that plane to Earth-based observations can be shown to be related to the angle $\delta$ formed by the Earth-Comet axis with the ecliptic plane by:

$$\tan w = \cos^2 \delta \, \tan w_o \qquad (1)$$

where $w_o$ denotes the corresponding angular width for comets located on the ecliptic. The inferred decrease of w with $\delta$ can be expressed in terms of the ecliptic latitude $\theta$ by using:

$$\sin \delta = \sin \theta \, (r/\Delta) \ , \qquad (2)$$

so that at constant cometocentric Earth-Comet ($\Delta$) and Sun-Comet (r) distances the observation of plasma tails will be more difficult for increasing $\theta$ values. This dependence, which applies in particular near perihelion, is compared in Figure 4 with the observed comet density $\sigma$ (number of comets with plasma tail per unit area) reported by Antrack *et al.* (1964). Their comet distribution has been grouped into three main latitudinal regions and normalized with respect to the $\sigma$ value in the 0-30° latitude range. The hatched area represents values of the ($\tan w/\tan w_o$) ratio obtained in the $0.8 < r/\Delta < 1.4$ range consistent with the observation of most comets with type 1 tails as reported, for example, by Rahe *et al.* (1969). Since in an isotropic distribution of cometary perihelia with ecliptic longitude $\varphi$ there should be more cases with $r/\Delta < 1$, the detection of plasma tails should follow more closely that indicated near the upper edge of the hatched area of Figure 4.

Even though the comparison indicated in this figure should only be understood in a qualitative sense, it is clear that the predicted precipitous decrease of the detectability of the cometary tail rays with ecliptic latitude is entirely in agreement with the statistics of the observations. This contention is, in addition, substantiated by the fact that the suggested geometry can be directly inferred from general considerations of a solar wind interaction similar to that observed in Venus.

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## DISCUSSION

*Alvarez*: ¿Qué posibilidades hay de observar la dependencia que expones en tu trabajo?
*Pérez de Tejada*: La distribución coplanar de los rayos en las colas tipo 1 podría ser fácilmente observada al paso de un vehículo espacial que cruce la estela por detrás del núcleo. Existen planes para hacer esto durante el próximo estudio experimental del cometa Halley en 1986.
*Costero*: ¿Por qué en algunos cometas con latitudes eclípticas muy altas es posible observar colas del tipo 1?
*Pérez de Tejada*: La distribución estadística de cometas con cola tipo 1 mostrada en la última figura se refiere a problemas calculados sobre todas las posibles diferencias de longitudes eclípticas de los cometas con respecto a la de la tierra. Cuando esta diferencia es mínima es posible observar las colas tipo 1 aun si éstas se encuentran a latitudes eclípticas muy altas.

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