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H_2O^+ STRUCTURES IN THE INNER PLASMA TAIL OF COMET AUSTIN

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Abstract

We present images of comet Austin $1989c_1$ in the light of H_2O^+ from which the contribution of dust continuum and gas coma has completely been removed. We describe the behaviour of the H_2O^+ plasma in the inner coma where it is reliably observed for the first time.

OBSERVATIONS AND DATA REDUCTION

To study the spatial distribution and temporal behaviour of water ions in the inner coma, comet Austin $1989c_1$ was observed with our focal reducer/CCD camera and tunable Fabry-Perot interferometer (FPI) at the 1m Cassegrain telescope of Hoher List Observatory in the period Apr 30 - May 7 1990. On May 7 the comet's heliocentric distance was 0.789 AU and the geocentric distance 0.453 AU. The phase angle was 105.5°. The piezoelectrically controlled FPI has a spectral resolution of 3.7Å. Images were taken at wavelengths of 6203 (one image per night) and at 6199Å (all other images) to register continuum and the line doublet at 6198.747 and 6200.030 Å of the 0-8-0 transition of the $\tilde{A}^2A_1 - \tilde{X}^2B_1$ electronic system of H_2O^+. At the 1m telescope the angular size of one image element is 1.6 arcsec which corresponds to approximately 600 km at the comet. The exposure time was 20 min and the time difference between individual images was 22 - 23 min. In total 25 frames of the plasma tail were obtained.

A special formalism was applied to correct the spatial modulation of the monochromatic signal introduced by the FPI and to completely remove the continuum (Bonev and Jockers 1991). The doublet structure of the emission was explicitly taken into account. The images were absolutely calibrated and converted to column densities. After the full processing cycle a portion of approximately 2×10^5 km of the cometary images contains useful information. The images show the spatial and temporal behaviour of the H_2O^+ plasma in the inner coma where it is usually hidden by the neutral and dust coma emissions. Some examples are presented below.

DESCRIPTION OF THE IMAGES

The following desciption refers to the whole data set of 25 plasma frames. Figure 1 shows isocontours of the images obtained May 6 (left side) and May 7 (right side). The lowest contour corresponds to 1.6×10^{10} particles cm^{-2} and each subsequent contour increases by a factor of $\sqrt[3]{2}$. The level of 10^{11} particles cm^{-2} is enhanced. The coordinate system is centered at the photocenter of the raw ion frames (i.e. before removal of the continuum)

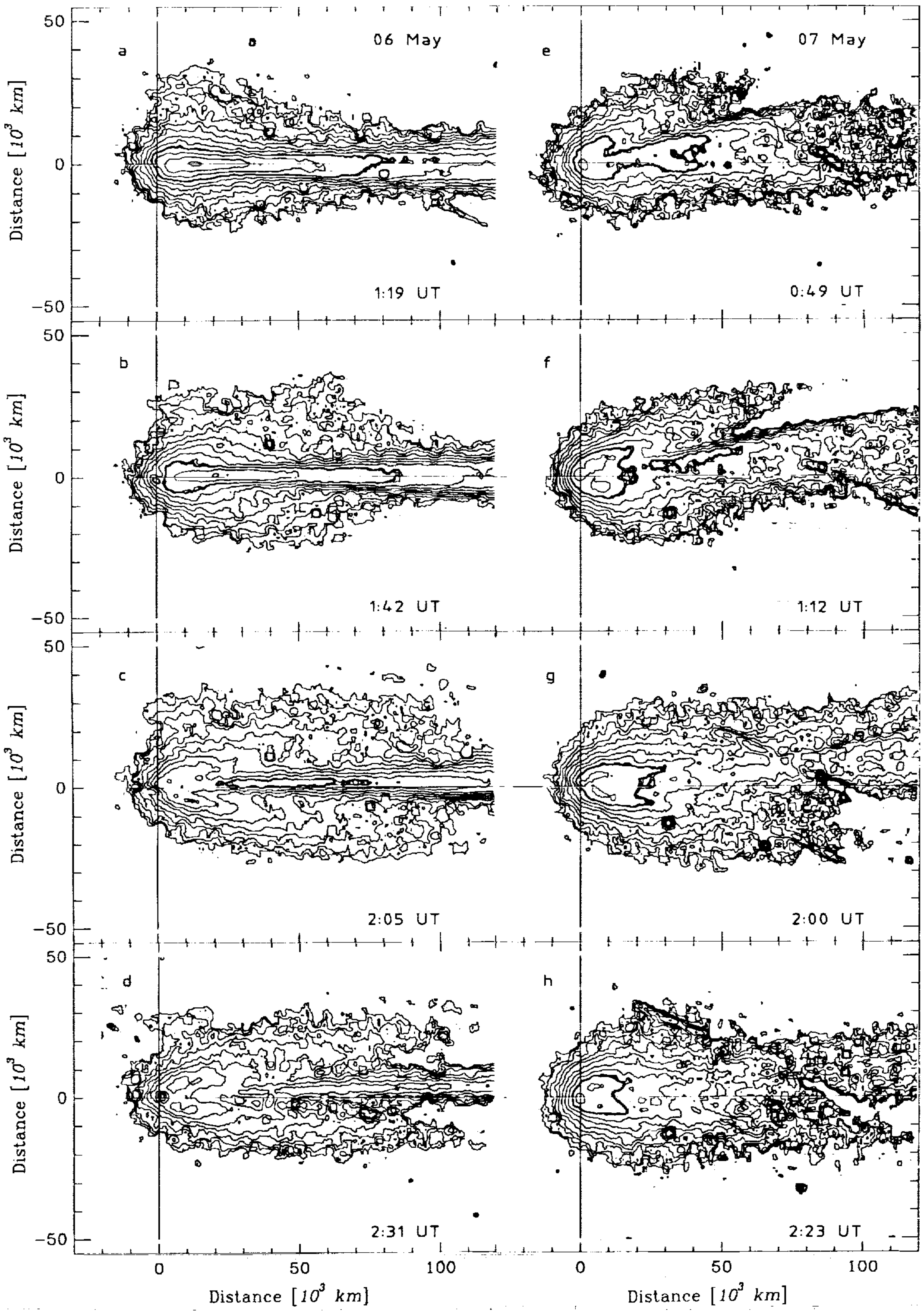

Fig. 1: Isophotes of the H_2O^+ coma and inner tail of comet Austin 1989c$_1$ Left: May 6, 1990. Right: May 7, 1990. Isocontours increase with factors $\sqrt[3]{2}$. The enhanced contour is at 10^{11} H_2O^+ particles cm^{-2}.

and oriented along the solar-antisolar direction. From the big changes between subsequent images it is clear that the temporal plasma behaviour is only insufficiently resolved.

Around the nucleus there is an "ion coma", i.e. the plasma distribution is extended in a coma-like fashion and not as narrow as the ion tail itself. Before generation of new rays the ion coma is particularly extended. The region represented approximately by the enhanced contour of 10^{11} particles cm^{-2}, is very flat in contrast with the sharply peaked dust and gas coma and changes its shape in a characteristic fashion. A two-lobed "boomerang-shaped" structure resembles the "root" of the youngest tail rays present (see Figure 1d and g). When the rays move towards the tail axis new lobes will form out of the diffuse ion coma at the outer sides of the old ones. When this happens it seems that the old rays are not anymore supplied with plasma and their column densities decrease (see Hoffmeister, 1943). Often, but not always, the old rays will merge. If their density is still sufficient, together with the new rays they will give the inner contours a three-lobed "mushroom" type appearance (Figure 1e). In two cases (both shown, Figure 1c and f) the stem of the mushroom disconnects from the mushroom's hat. A separate ion column density maximum forms and moves down the tail. The observation of separate maxima demonstrates the close connection between the tail ray phenomenon and the disconnection events. In the two observed cases the disconnection occurs tailwards of the nucleus and represents a local column density minimum.

Superimposed on the birth and decay of tail rays are turns of the tail axis. On May 5 we see tail ray activity only at the lower side of the main tail. It is followed by a downward turn of the main tail in accordance with a rule derived by Jockers (1985). On May 4 and 7 the behaviour is mixed i.e. tail rays form on both sides of the main tail alternatingly. On May 6 the tail looks particularly narrow and symmetric. It is possible that the observer happens to be in the plane of the tail current sheet (see below).

COMPARISON WITH PUBLISHED MODEL CALCULATIONS

Numerical models of several authors show that under stationary conditions the ion tail becomes increasingly flatter with distance from the nucleus extending more in the plane perpendicular to the magnetic field, i.e. in the plane of the current sheet. We call this plane in the following the plasma plane. Already in the plasma coma the plasma density is enhanced in the plasma plane, perpendicular to the magnetic plane. On May 6 the plasma tail is narrow and has a large column density. Therefore it is suggestive to assume that at the time of the exposures, for the outer part of the tail, the observer was located close to the plasma plane and that the magnetic plane was closely coinciding with the sky plane.

Schmidt and Wegmann (1982) have proposed that ion clouds and associated tail rays may originate if a solar wind tangential discontinuity with a magnetic field rotation of about 90° is swept through the comet. Let us apply this idea to the images of May 6. On the tailward (right) side, the magnetic field would be in the plane of the sky squeezing the tail and making it narrow perpendicular to the line of sight and extended along the line of sight, thereby increasing its column density. On the upwind (left) side the magnetic field is along the line of sight. As it enters the plasma coma, it is increasingly wrapped around the comet, sweeping up the plasma and creating an ion cloud. The newly created plasma behind the discontinuity is separated from the old plasma on the right side by the turned magnetic field and is ejected sideways, forming the plasma lobes which later become tail rays. The described process will also work if the turn of the field is not exactly at right angle.

This idea has been followed up by Schmidt-Voigt (1989), who numerically simulated the passage of such a tangential discontinuity through a comet. The model successfully produces a cloud but, because of a limited number of grid points in the three-dimensional numerical grid, the resolution is insufficient to produce the tail rays. One model is available with a production rate of water of 10^{29} particles s^{-1}, very close to the one observed for comet Austin (Festou et al., 1990). Schmidt-Voigt provides a plot of the temporal development of the maximum column density in the cloud which is most useful for the comparison. The plot refers to our case with the original magnetic field in the sky plane. At the time of the separation of the cloud from the near-nucleus maximum the peak column density is 2.05×10^{11} cm^{-2}. This agrees with the observed value of 2×10^{11} cm^{-2} (Figure 1a). We would, however, expect the model value to be higher, because the model has only one ion channel and in reality H_2O produces several kinds of ions from which we observe only H_2O^+. After 72 minutes (Figure 1d) the maximum in the observed cloud is already by a factor of $\sqrt[3]{2} = 1.26$ less than the two maximum lobes close to the nucleus. In the model the cloud remains brighter than the near nucleus plasma for more than 210 minutes. It seems that the model underestimates the leakage of plasma into the rays, but there is at least some qualitative agreement.

So far we have discussed the case when the plasma plane turns from along the line of sight to the sky plane. In the framework of the Schmidt-Voigt model the opposite case should be about as frequent. Schmidt-Voigt points out that the cloud represents a real ion concentration and appears as column density enhancement no matter if the observer is in the plasma plane or not. If the original magnetic plane is in the line of sight, the associated tail rays extend along the line of sight and therefore would not be observable. In our data set there are only two cases when plasma clouds are ejected (Figure 1c and f). Both are assocoiated with tail rays. We have no case of a cloud without rays.

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