# THE NEAR-NUCLEAR COMA OF COMET HALLEY IN MARCH 1986

KAROLY SZEGÖ
*KFKI Research Institute for Particles and Nuclear Physics, P.O. Box 49, H-1525 Budapest, Hungary*
*E-mail: szego@rmki.kfki.hu*

JEAN-FRANÇOIS CRIFO
*Service d'Aéronomie du CNRS, BP 3, F 91371 Verrières le Buisson Cedex, France*

ALEXANDER V. RODIONOV
*Central Research Institute on Machine Building (TsNIIMASCH), Pionyerskaya St., 4, Korolev, Moscow Region, 141070, Russia*

MARCO FULLE
*Osservatorio Astronomico di Trieste, Via Tiepolo, 11, I-34131 Trieste, Italy*

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**Abstract.** The cameras carried onboard the flyby missions to comet P/Halley in 1986 imaged the near nuclear jet activity from several spatial directions. The observed, very structured near nuclear dust jets were considered at that time as the result of dust emission from well localized active surface regions (without supporting 3-D model computations, however). Based on the first, recently developed 3-D gas dynamical model of P/Halley's activity, we have been shown that jet features can be reproduced assuming a homogeneous dusty ice nucleus surface. The dust in the collisional near nuclear coma is concentrated along the gas flow discontinuities resulting from the complicated surface orography, creating the visual impression of dust jets. We present here the results of these calculations for the near nucleus dust distributions, and we compare them with the direct observations made during the three Halley flybys (Vega 1, Vega 2, and Giotto).

**Keywords:** 3-D gas dynamics, dust jets, P/Halley

## 1. Introduction

Recently Rodionov et al. (2002) have developed the first 3-D gas dynamical model capable to calculate the near nuclear coma of comets for which the nucleus shape is known; an outline of this model is given in this volume (Crifo et al., 2002). Whereas the model can accommodate any degree of surface inhomogeneity (i.e., active and inactive areas), our starting point here is trying to reproduce observations within this model assuming that the surface is homogeneous; this minimizes the number of free parameters. When the nucleus is homogeneous, differences in surface flux result only from the differences in solar illumination due to shape and orography: this is sufficient to create quite an inhomogeneous gas and dust coma (Crifo and Rodionov, 1999). If the results were not satisfactory, then (and only then) it will be necessary to introduce surface inhomogeneities. An essential ingredient of the

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model is the nucleus shape. For the time being (and prior to the publication of a topographic map of the recently observed nucleus of comet P/Borrelly), the method can be applied only to P/Halley's nucleus. Its shape was derived from the 63 images taken during the VEGA 1 flyby on 6 March, 1986; the view directions of these images covered a $\simeq$ 160° angular range around the nucleus (Merenyi et al., 1990), a detailed comparison of the model and the images can be found in Szegö et al. (1995), a brief description of the flyby and image processing is also given in Crifo et al. (2002). To satisfy the requirements of the numerical code, the shape was smoothed by expanding it into a series of spherical harmonics, in the present calculation we used the first ten harmonics which means that we filtered out the topographic noise of spatial dimensions smaller than several 100 m.

In a nuclear centred ecliptic frame of reference (where the X-axis is parallel to the vernal equinox, the Z-axis points to ecliptic North, the longitude and latitude are denoted by $l$, $b$, respectively) the long axis of the nucleus – oriented from the centre towards the big end – pointed to $l = 79°$, $b = 15°$, and to $l = 310°$, $b = 9°$ during the VEGA 1 and VEGA 2 encounters, respectively (Szegö et al., 1995). During the GIOTTO flyby the angle between the Sun and long axis was $-32° \pm 10°$ (Keller et al., 1995). From this and other observations (Sadeev et al., 1995) concluded that the long axis orientation during the GIOTTO encounter was $l = 276°$, $b = -27°$. The error is about ±5°, higher for $l$ than for $b$. The nucleus rolled about its long axis between the encounters, the roll angular values were 0°, 30°, $-10°$ at the time of the VEGA 1, 2, and GIOTTO encounters. For the computation of the inner coma (i.e., in the strict fluid regime) we define a nucleus-attached longitude-colatitude system ($\lambda$, $\beta$): the origin of the longitude, $\lambda$ is at the big end, and the colatitude $\beta = 180°$ ($0 \leq \beta \leq 180°$) corresponds to the Northward pole of the nucleus. In this coordinate system the subsolar points during the encounters were ($\beta = 73°$, $\lambda = 344°$) for VEGA-1, ($\beta = 74°$, $\lambda = 112°$) for VEGA-2, and ($\beta = 75°$, $\lambda = 134°$) for GIOTTO. As can be seen, the Sun positions (subsolar points) between the VEGA 2 and GIOTTO encounters differed only by about 22°.

## 2. Results

The gas coma was computed using only one adjustable parameter, the icy area fraction $f$ (the relative fraction of the exposed ice and dust in any element of the surface), which was set to 0.4 to meet the measured total gas production. Then, 0.9 $\mu$m radius spherical dust grains with specific mass 1 g cm$^{-3}$ were released (with a constant dust-to-gas mass ratio) into the flow, to create a single-size dust coma.

The very irregular nucleus shape creates a quite structured coma. We can illustrate this by presenting the dust and gas parameters on three spheres centred on the nucleus, with radii 9, 18, and 36 km, respectively; because, as can be seen, the major coma structures actually develop within less than ten nucleus radii. We present the gas density results by contour plots, the gas flux results are exhibited by vector plots.

Figure 1 shows the gas density during the VEGA 1, 2, and GIOTTO encounters, respectively, on the three spheres. The GIOTTO and VEGA 2 densities are very similar, (though not identical) as can be expected from the fact that they have close subsolar points. Each sequence shows that the gas evolves very dynamically with increasing distance and the density distribution forms narrower structures. In all cases the gas coma is structured, and in fact it can be expected that the gas coma remains structured farther out from the nucleus as well. The gas distribution is of course not symmetric to the Sun-comet line.

The gas fluxes for the three encounters are shown on Figure 2, only within a region close to the (nucleus-attached) equatorial plane[⋆] for the sake of figure clarity. The flux patterns, as opposed to the density patterns, are broadening outwards: the strong variation seen at 9 km from the nucleus centre is smoothed outwards.

We present the dust results in a different way because we wish to compare them with the images obtained during the encounters. The plots show the nucleus surface in addition to the three previously used spheres, and we view the nucleus and these surfaces from the actual view direction of the cameras. Furthermore, we show that fraction of each sphere only, where the dust density exceeds 2/3 of the maximal value it assumes on that sphere. Finally, vectors are attached to the outermost sphere, proportional to the dust flux vectors at each of the plotted points.

Figure 3 compares two model results and the corresponding two images obtained during the VEGA 1 encounter; Figure 4 does the same for three VEGA 2 images. The image numbering convention, Sun direction, exposure times and spacecraft positions of the VEGA 1 and 2 images, as well as the comparison of the images with the nucleus shape model can be found in Szegö et al. (1995). Figure 5 shows the comparison of our model result with the synthetic image taken by the GIOTTO camera (Keller et al., 1995). It should be noted that whereas the model shows a 36 km wide region around the nucleus in 3-D form, the images cover a much broader volume around the nucleus, and are evidently column densities. Also, the optical signal is integrated over the full dust size spectrum. Yet, the images and the model results coincide surprisingly well, even though certain deviations are also evident. More dust jets are visible in the model than in the images, and especially for VEGA 1 the two computed lower jets are missing on the images. This, however, might be due to the significant camera intensity offset (cf. Szegö et al. (1995)). In all cases the dust distribution is smoother closer to the nucleus, however, jets are formed quickly as we move farther away.

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[⋆] Note that the nucleus-attached coordinates bear no relation to the nucleus rotation, so the word "equator" has here a purely geometrical, and not a dynamical meaning.

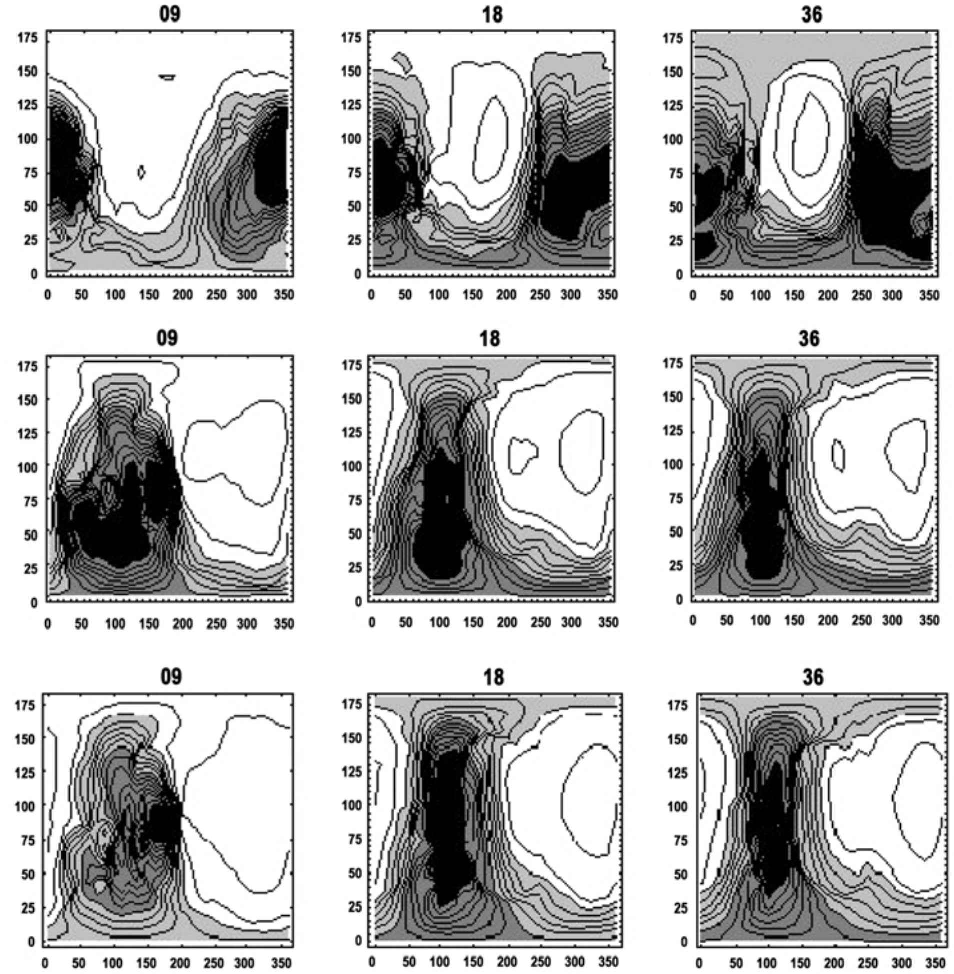

*Figure 1.* The gas density contour plots are shown during the VEGA 1 (top), VEGA 2 (middle), and GIOTTO (bottom) encounters, on three spheres centred on the nucleus, with radii 9 km (left), 18 km (center), and 36 km (right). The horizontal axis indicates longitude values, the vertical axis is colatitude. The greyscale for all plots is linear between the following minimum (light gray) and maximum (dark) values, in multiples of $10^{-6}$g/m$^3$: for VEGA 1 at 9 km: (1.8, 130), at 18 km (0.24, 28), at 36 km (0.059, 6.8); for VEGA 2 at 9 km: (2, 150), at 18 km: (0.21, 16), at 36 km: (.036, 3.5); for GIOTTO at 9 km: (1.24, 136), at 18 km: (0.17, 21), at 36 km: (0.034, 5.2).

## 3. Discussion and Conclusions

The most important conclusion of this study is that there is no need to introduce active and inactive areas on the surface of P/Halley nucleus to reproduce the observed structured near-nucleus coma. It is sufficient to allow for the observed nucleus shape, and to take into account properly the collisional dusty gas dynamics in its vicinity. Whereas any non-spherical shape will always produce coma structures,

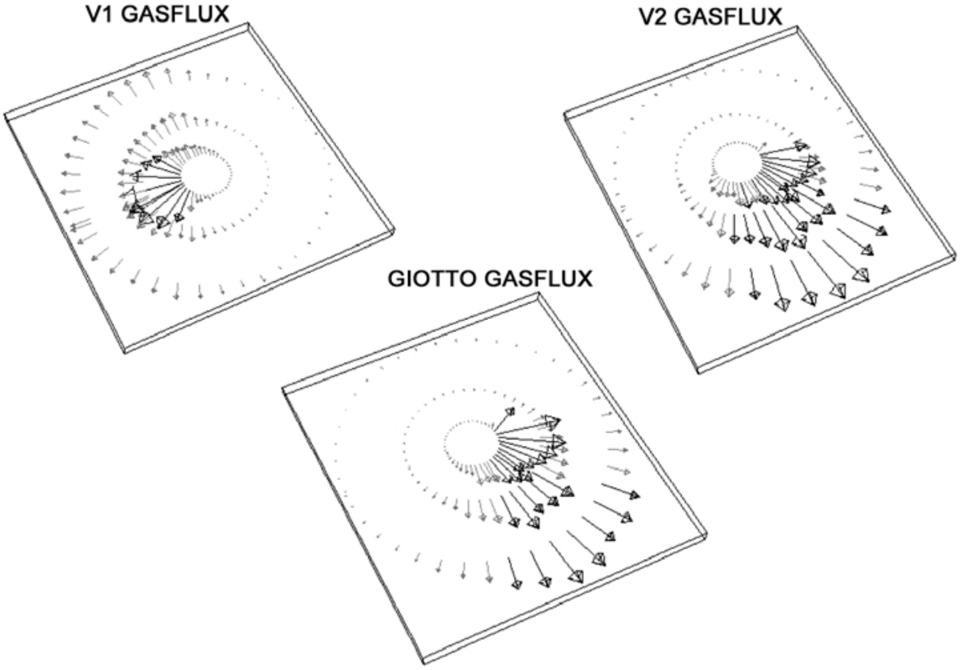

*Figure 2.* The gas flux vectors are shown around the nucleus during the VEGA 1, VEGA 2, and GIOTTO encounters, respectively, on three circles centred on the model nucleus of radii 9, 18, and 36 km. The circles lie in the equatorial plane of the model nucleus, and provide the feet of the vectors. The vector lengths, heads and gray scale densities are proportional to the gas flux. The square frame width indicates the magnitude of the off-plane $Z$-components.

there is simply no way known to us to interpret such structures when the nucleus shape is unknown. It seems to us that to fit large scale dust structures (spirals, …) assuming trivial rectilinear emissions from a rotating sphere with discrete areas is a totally misleading exercise: not only because, as already shown long since by Kitamura (1990) the interaction between gas jets from postulated active areas results in dust density patterns totally different from the trivial rectilinear emission, but also because here we have shown that unless the nucleus is really a smooth sphere, the topography will still structure the coma (in addition to the active-inactive area network).

We believe that these results will open a new chapter in cometary studies: it hopefully will change the way how observations will be related to nuclear properties.

A further indication that the present jet reconstruction is correct, is provided by a special event during the VEGA 2 flyby on 9 March, 1986 when the spacecraft crossed a dust jet at about 7:20 UT. This jet was clearly detected by the SP-1 dust counter onboard (Vaisberg et al., 1986). The spacecraft in this moment was about 10,000 km from the nucleus. According to the dust counter data, dust of

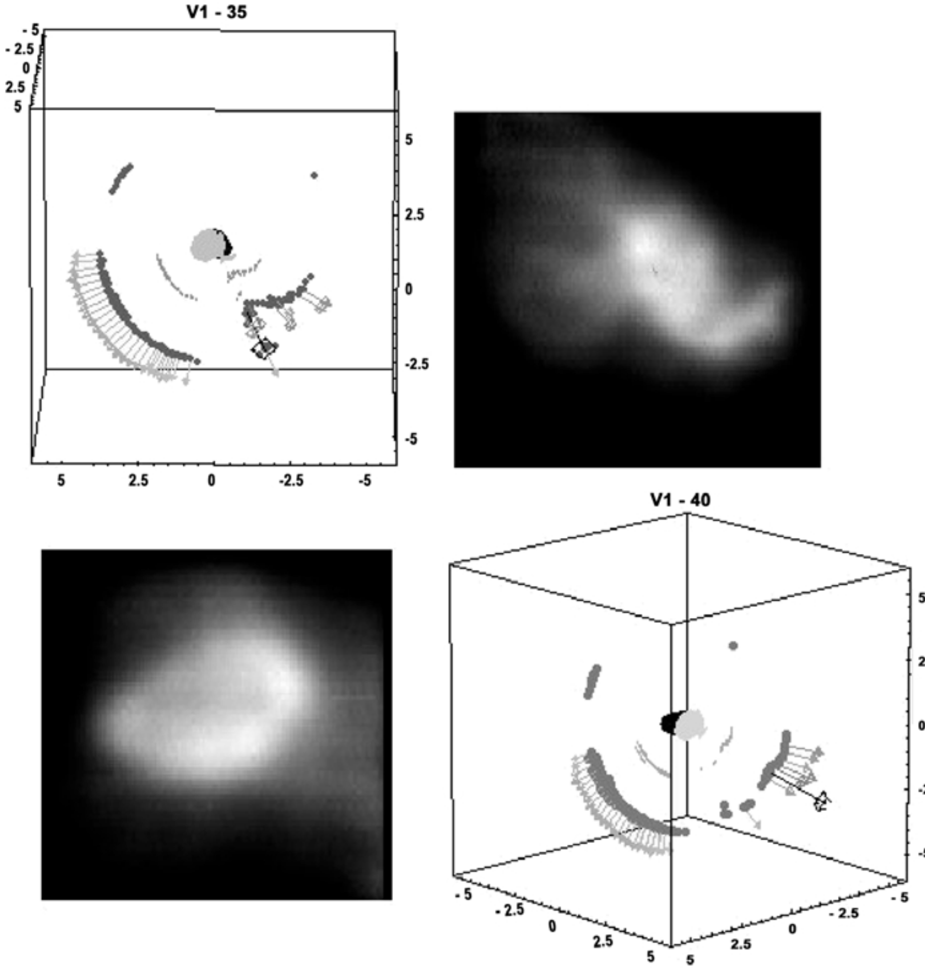

*Figure 3.* Two images taken by the VEGA 1 cameras and the corresponding model prediction of the jets. See the text for explanations.

different masses arrived at different times, in harmony with their expected different terminal velocity and with the prograde rotation of the nucleus. Within the same time interval image #94 was obtained; on that image the nucleus is dim and definitely obscured, this is what we expect if we had been inside the jet during the exposure. The raw version of this image contains several bright pixels, very likely light scattered from close dust particles. Our model shows that around that time the dust jets were oriented towards the spacecraft.

The three dimensional jet structure seen around Halley's nucleus on 9 March, 1986 was derived in Sagdeev et al. (1987) based on the 11 VEGA 2 images that covered a wide angular range around the nucleus, on those images the jets are very clearly identifiable. In that paper we have already concluded that the jets during the

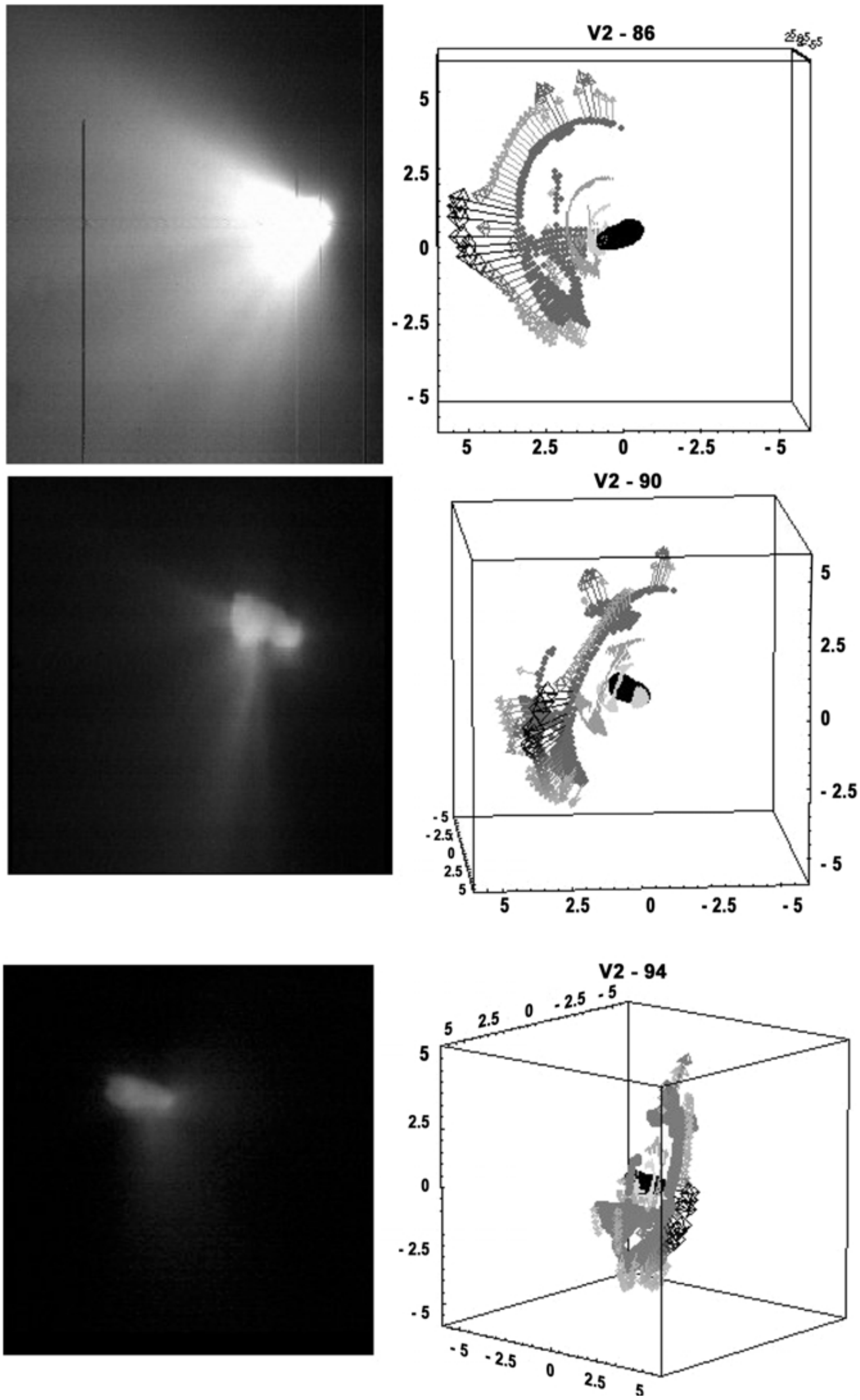

*Figure 4.* Three images taken by the VEGA 2 cameras and the corresponding model prediction of the jets. See the text for explanations.

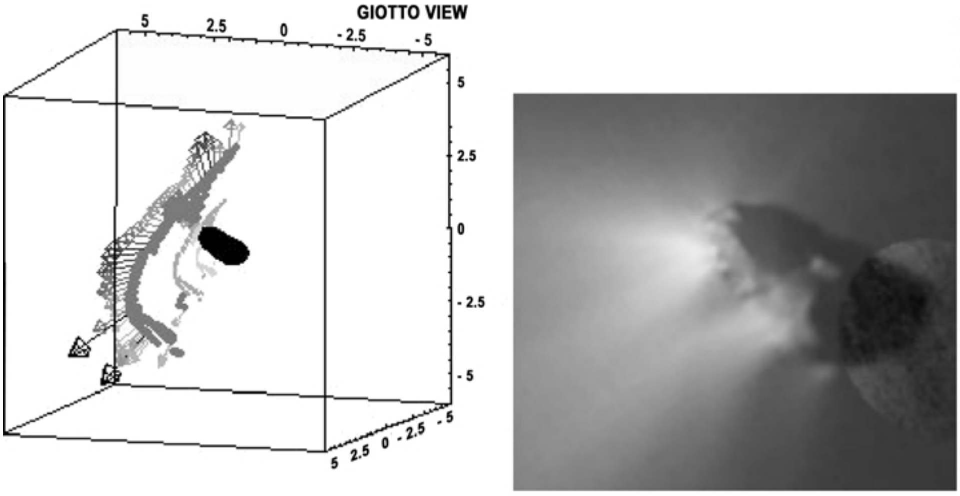

*Figure 5.* The GIOTTO composite image and the corresponding model prediction of the jets. See the text for explanations.

VEGA 2 formed a long, linear structure; this is very well reproduced by the model results presented here.

A limitation of our present calculations is the use of a single size dust fluid, which cannot reproduce the richness of the real dust distribution in a coma; it is not difficult to overcome this in the future. Another limitation (much more difficult to overcome) is that the coma we computed is time-stationary: We rotated the nucleus into its observed position taken during the encounters, and we calculated the near nuclear environment as if it were time-independent. That is the reason why we limited ourselves to the very close regions where the time dependence is not yet important. The real images, however, collected light from a much larger volume, a few tens of square km width in the image plane, and of the order of 10,000 km perpendicular to it. We plan to work out time-dependent solutions in the future.

We suspect that because the calculated gas coma is structured close to the nucleus, this might yield a structured coma farther at large distances as well. To confirm this conjecture numerically, we have to add gas-phase chemistry to the model, because the ground based observations do not identify water directly. This is also a task for the future.

We have shown that at the top of the collisional regime dust particles are accumulated into “jets”; these accumulations correspond to the feet of the dust jets seen from ground. Higher up dust particles already move freely with their terminal velocity on Keplerian orbits. The yet unresolved question is how their velocity perpendicular to the radial direction can be related to the rotation of the nucleus. As we have investigated static cases only, we cannot answer it yet. It is evident, however, that if such relationship holds, it is not simple, because inside the gas-dust interaction region perpendicular momentum is exchanged between dust and gas. Accordingly, to assume that the transverse dust velocity is equal to the initial angular velocity of the nucleus is on shaky grounds, therefore it is a non-trivial, open question how one can derive the nucleus rotation from dust (or gas) jet curvatures.

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