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## I. Introduction

The apparation of comet P/Halley during 1985 and 1986 permitted extensive observations of all types to be made. One important technique which was available only shortly before this apparation was the ability to obtain CCD images of the coma using various filters. This project deals with the analysis of selected CCD images of the coma of comet P/Halley which were taken using specially designed filters that isolate regions of a comet's spectrum such that only sunlight which has been scattered by the dust in the coma is recorded. The images are subsets of two larger datasets which also contain images taken with filters designed to pass regions of the spectrum which in addition to dust continuum include the spectral emissions of certain gas species. One of the sets of CCD images were taken with the 61-inch Wyeth telescope at the Oak Ridge Observatory by Dr. R.E. McCrosky of the Center for Astrophysics/Smithsonian Astrophysical Observatory. The second set were taken with the 61-inch telescope at Mt. Lemmon by Dr. Uwe Fink and co-workers at the Lunar and Planetary Laboratory of the University of Arizona. Table 1 gives the original three-year work plan expected for completion of this project.

The modeling analysis objective of this project is to make use of the skills developed in the development of Monte Carlo particle trajectory models for the distributions of gas species in cometary comae (Combi and Smyth 1988 a&b; Combi 1989) and to use those models as a basis for a new dust coma model. This model will include a self-consistent picture of the time-dependent dusty-gas dynamics of the inner coma and the three-dimensional time-dependent trajectories of the dust paricles under the influence of solar gravity and solar radiation pressure in the outer coma. We intend to use this model as a tool to analyze selected images from the two sets of CCD images with the hope that we can help to understand the effects of a number of important processes on the spatial morphology of the observed dust coma. The study will proceed much in the same way as our study of the spatially extended hydrogen coma (Combi and Smyth 1988b) where we were able to understand the spatial morphology of the Lyman-alpha coma in terms of the partial thermalization of the hot H atoms produced by the photodissociation of cometary $H_2O$ and OH.

The processes of importance to the observed dust coma include:

(1) the dust particle size distribution function,

(2) the terminal velocities of various sized dust particles in the inner coma,

(3) the radiation scattering properties of dust particles, which are important both in terms of the observed scattered radiation and the radiation pressure acceleration on dust particles,

(4) the fragmentation and/or vaporization of dust particles, and

(5) the relative importance of CHON and silicate dust particles as they contribute both to the dusty-gasdynamics in the inner coma (that produce the dust particle terminal velocities) and to the observed spatial morphology of the outer dust coma.

**Table 1. Three Year Work Plan for Dust Image Analysis**

| Subject Area | First Year | Second Year | Third Year |
|---|---|---|---|
| | | | |
| Theoretical Model Development | Initial Development of Dust Coma MCPTM | Refine Model Attributes as Indicated by Image Analysis | |
| CfA/SAO Oak Ridge and LPL/ U. of Arizona | | Analysis of Dust Coma Images | |

## II. Progress during this First Year

Although the original three-year plan included work only on the initial development of the dust coma model we have also taken on some of the preliminary work in the area of looking at the image data. The major task set forth in the area of data manipulation for the first year has been the organization and inspection of the dust-continuum images from both datasets. Although we have had all of the Oak Ridge CCD image data for some time, the images were in a non-standard format, called CCD format at CfA/SAO. During this year all of the images in that dataset were converted to FITS (Flexible Image Transport System) format, written to magnetic tape and brought to the computer center at the Space Physics Research Laboratory (SPRL) at the University of Michigan for manipulation and display using the SPRL VAX 8600. These images had already been flat-fielded. The CCD images taken at the Lunar and Planetary Laboratory of the University of Arizona are already available in FITS format on magnetic tape. Tables 2 and 3 provide summaries of the continuum images contained in the two CCD image data sets.

The areas of work for the first year in the area of model development have concentrated on making the necessary modifications to the Monte Carlo particle trajectory model (MCPTM) code, which was developed for treating the hydrogen coma problem (Combi and Smyth 1988 a&b), in order to treate the dust problem. First we constructed the basic computer code for a given dust-distribution model and tested it successfully. The model included a time dependent dust production rate however the dust particle size terminal velocity distribution function was frozen to that appropriate for the conditions at the time of the "observation". Figures 1 and 2 show the model results for this test, for both the inner coma region which will be important for direct analysis of most of the image data and for the outer coma region indicative of the wide field pictures of the typical dust tail. The dust distribution here was taken from the dusty-gasdynamic model results of Gombosi et al. (1986) for Halley. It is a 'Hanner type' size distribution where the dust particle terminal velocities were computed by Gombosi et al. using their dusty-gasdynamic model. The contours in the Figures indicate the brightness variation.

For this first simple test a radiation scattering efficiency directly proportional to the geometrical cross section for each dust particle, reminiscent of the Probstein (1968) model, was used. Similarly the radiation pressure acceleration was calculated assuming the particles were perfectly absorbing to solar radiation in proportion again to their geometrical cross sections.

## Table 2. Oak Ridge Continuum CCD Images of Comet P/Halley

| Date (1985-86) | r | Δ | β | θ | 4845 Å | 6840 Å |
|---|---|---|---|---|---|---|
| Oct. 1 | 2.34 | 2.04 | 25.2 | 94.8 | - | 1 |
| Oct .11 | 2.21 | 1.72 | 25.8 | 105.8 | - | 1 |
| Oct. 16 | 2.14 | 1.56 | 25.5 | 112.8 | - | 1 |
| Oct. 21 | 2.07 | 1.40 | 24.9 | 118.9 | - | 2 |
| Oct. 25 | 2.02 | 1.28 | 23.9 | 124.8 | 1 | 1 |
| Oct. 28 | 1.98 | 1.19 | 22.8 | 129.7 | 3 | 2 |
| Nov. 8 | 1.82 | 0.89 | 15.1 | 151.5 | 1 | 1 |
| Nov. 18 | 1.68 | 0.69 | 1.4 | 177.0 | 1 | 3 |
| Dec. 3-4 | 1.45 | 0.66 | 36.0 | 121.0 | 1 | 1 |
| Dec. 18 | 1.22 | 0.88 | 52.8 | 81.8 | 1 | 2 |
| Dec. 27 | 1.08 | 1.06 | 54.6 | 63.9 | 1 | 1 |
| Dec. 30 | 1.04 | 1.12 | 54.1 | 58.7 | 1 | 1 |

r = heliocentric distance in AU.

Δ = geocentric distance in AU.

β = Sun-comet-Earth angle in degrees.

θ = Sun-Earth-comet angle in degrees.
4845 Å and 6840 Å are the central wavelengths of the two continuum filters.

**Table 3. LPL/U of Arizona Continuum CCD Images of Comet P/Halley**

| Date (1985-86) | r | Δ | 6259 Å | 8520 Å | 8600 Å |
|---|---|---|---|---|---|
| Sep. 23 | 2.45 | 2.30 | - | 1 | - |
| Oct. 19 | 2.10 | 1.46 | 1 | - | 1 |
| Nov. 14 | 1.73 | 0.76 | 1 | - | 2 |
| Nov. 16 | 1.71 | 0.72 | 3 | 1 | 3 |
| Dec. 7 | 1.39 | 0.69 | 2 | 1 | 3 |
| Jan. 8 | 0.90 | 1.29 | 2 | - | 2 |
| Jan. 13 | 0.83 | 1.37 | 3 | - | - |
| Jan. 19 | 0.75 | 1.46 | 3 | - | 2 |
| Feb. 28 | 0.71 | 1.29 | 2 | - | 2 |
| Apr. 17 | 1.42 | 0.47 | 3 | - | - |
| Apr. 18 | 1.44 | 0.48 | 1 | - | 2 |
| May 10 | 1.76 | 1.08 | 1 | - | - |
| May 11 | 1.78 | 1.11 | 1 | - | 1 |

r = heliocentric distance in AU.

Δ = geocentric distance in AU.

6250 Å, 8520 Å and 8600 Å are the central wavelengths of the three continuum filters.

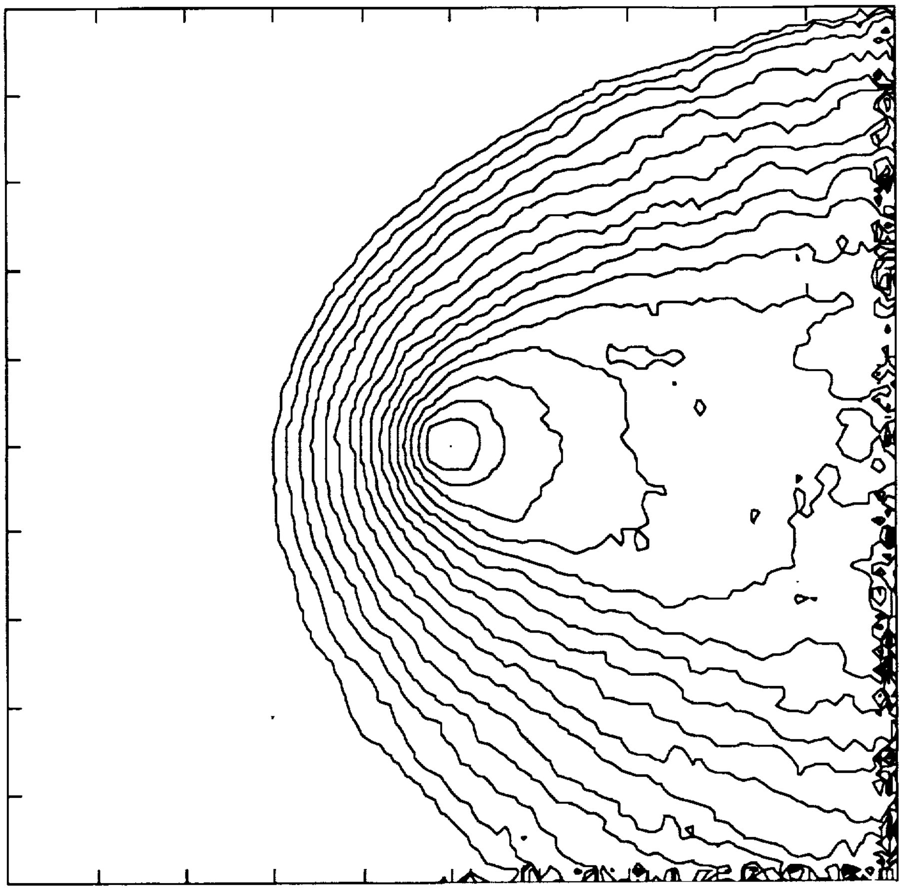

Figure 1. Model for the Inner Dust Coma of Comet P/Halley. The intensity contours are shown for the inner portion of the coma as determined for a model run for the case of comet Halley near perihelion as would be observed from outside the orbit plane of the comet. The model represents the first test of the new Monte Carlo dust model developed for this project. The underlying assumptions are (1) a Hanner type size distribution function, (2) terminal dust particle velocities from a dusty-gas dynamic calculation, and (3) simple radiation scattering proportional only to the dust particle geometrical cross sections. The dust trajectories are calculated in a gemeral time-dependent and three-dimensional manner. Adjacent contours correspond to brightness levels of factors of two. Tic marks on the circumscribed box are separated by 1 x $10^4$ km. A comparison with the large scale of Figure 2 shows that the effects of the solar orbital motion are important even on this small scale. This is indicated by the fact that the coma is not exactly symmetric about the comet-sun line (i.e. the horizonal axis through the dot which is the location of the nucleus).

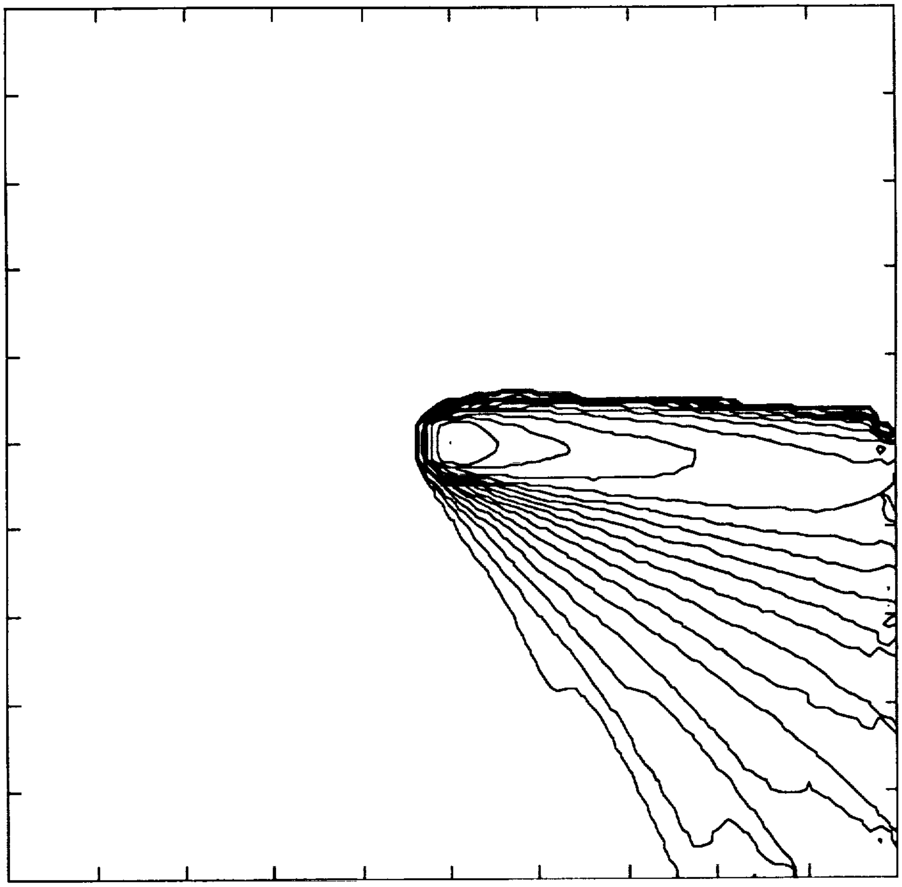

Figure 2. Model for the Outer Dust Coma of Comet P/Halley. The intensity contours are shown for the inner portion of the coma as determined for a model run for the case of comet Halley near perihelion as would be observed from outside the orbit plane of the comet. The model represents the first test of the new Monte Carlo dust model developed for this project. The underlying assumptions are (1) a Hanner type size distribution function, (2) terminal dust particle velocities from a dusty-gas dynamic calculation, and (3) simple radiation scattering proportional only to the dust particle geometrical cross sections. The dust trajectories are calculated in a gemeral time-dependent and three-dimensional manner. Adjacent contours correspond to brightness levels of factors of two. Tic marks on the circumscribed box are separated by 2 x $10^5$ km.

Gombosi (1990, private communication) has also proved the results of a dusty-gas-dynamic model run for a number of times distributed over the orbit of comet P/Kopff, thereby enabling us to construct a fully time-dependent dust model. Comet P/Kopff is currently the target comet for the Comet-Rendezvous Asteroid Flyby mission and although not directly relevant to the comet Halley case it proved the opportunity to generalize the model. It furthermore is important in its own right. Table 4 gives the results of his model run which come in the form of terminal velocities for a complete range of dust particle sizes at a set of heliocentric distances. Modifications were made to the Monte Carlo dust model in order to use the time dependent descriptions for the gas production rate and the dust terminal velocities. The now fully time dependent dust model was run for this case.

Figures 3 and 4 show the radiation scattering contour maps for the inner dust coma and outer dust coma and tail determined using the time-dependent dust model for the case of comet Kopff. The model corresponds to the earth view geometry on January 1, 2003 which is just at the end of the current CRAF mission plans for comet Kopff. Notice the extreme difference from the Halley models where the perihelion distance is only .58AU contrasted with 1.58 AU for comet Kopff. The radiation pressure acceleration is about 7.5 time greater for the same size dust particle for the Halley perihelion case. This range is also indicative of the range of heliocentric distances covered by the two sets of image data.

## III. Plans for the Future

Although this is a final report for this particular grant-year, this project as implied by the work plan (Table 1) is actually a three-year program. Gombosi (1990, private communication) has agreed to provide us with a number of his dusty-gasdynamic model results needed in order to construct a suitable fully time-dependent description for the dust terminal velocities relvant for the whole orbit of Halley's comet. With this information and the newly constructed Monte Carlo dust particle model we will now be in a position to examine in a detailed manner the wealth of CCD dust coma images we have at our disposal.

## Table 4. Dust Terminal Velocities for Comet Kopff

| | Heliocentric Distance (in AU) | | | | | | |
|---|---|---|---|---|---|---|---|
| **Size (µm)** | **1.58** | **2.00** | **2.50** | **3.00** | **4.00** | **5.00** | **5.35** |
| Gas | 733.8 | 790.8 | 798.4 | 769.4 | 727.6 | 690.0 | 680.8 |
| 0.013 | 672.2 | 702.5 | 643.0 | 575.1 | 381.6 | 285.2 | 183.9 |
| 0.024 | 656.2 | 677.7 | 598.9 | 520.5 | 319.2 | 232.0 | 145.0 |
| 0.042 | 636.7 | 647.0 | 543.2 | 457.0 | 261.1 | 185.5 | 113.0 |
| 0.075 | 613.0 | 608.3 | 478.0 | 390.0 | 209.8 | 146.2 | 87.3 |
| 0.133 | 583.9 | 559.1 | 408.7 | 324.7 | 166.1 | 114.0 | 67.0 |
| 0.237 | 547.6 | 499.2 | 340.8 | 264.7 | 129.9 | 88.1 | 51.1 |
| 0.422 | 501.3 | 432.5 | 278.3 | 212.1 | 100.6 | 67.6 | 38.9 |
| 0.750 | 445.2 | 364.7 | 223.2 | 167.4 | 77.3 | 51.5 | 29.4 |
| 1.334 | 383.6 | 300.5 | 176.3 | 130.7 | 59.1 | 39.2 | 22.2 |
| 2.371 | 321.8 | 242.8 | 137.7 | 101.0 | 44.9 | 29.7 | 16.8 |
| 4.217 | 263.9 | 193.1 | 106.6 | 77.6 | 34.1 | 22.4 | 12.6 |
| 7.499 | 212.4 | 151.5 | 81.8 | 59.2 | 25.8 | 16.9 | 9.5 |
| 13.335 | 168.3 | 117.7 | 62.5 | 45.0 | 19.4 | 12.7 | 7.1 |
| 23.714 | 131.7 | 90.7 | 47.5 | 34.1 | 14.6 | 9.6 | 5.4 |
| 42.170 | 102.1 | 69.4 | 36.0 | 25.8 | 11.0 | 7.2 | 4.0 |
| 74.990 | 78.5 | 52.9 | 27.2 | 19.4 | 8.3 | 5.4 | 3.0 |
| 133.352 | 60.0 | 40.1 | 20.5 | 14.6 | 6.2 | 4.1 | 2.3 |
| 237.138 | 45.7 | 30.3 | 15.5 | 11.0 | 4.7 | 3.0 | 1.7 |
| 421.697 | 34.6 | 22.9 | 11.6 | 8.3 | 3.5 | 2.3 | - |
| 749.895 | 26.2 | 17.3 | 8.7 | 6.2 | 2.6 | 1.7 | - |
| 1333.524 | 19.8 | 13.0 | 6.6 | 4.7 | - | - | - |
| 2371.377 | 14.9 | 9.8 | 4.9 | 3.5 | - | - | - |
| 4216.973 | 11.2 | 7.3 | 3.7 | 2.6 | - | - | - |
| 7498.955 | 8.4 | 5.5 | 2.8 | 2.0 | - | - | - |

Dust terminal velocities in meters per second.

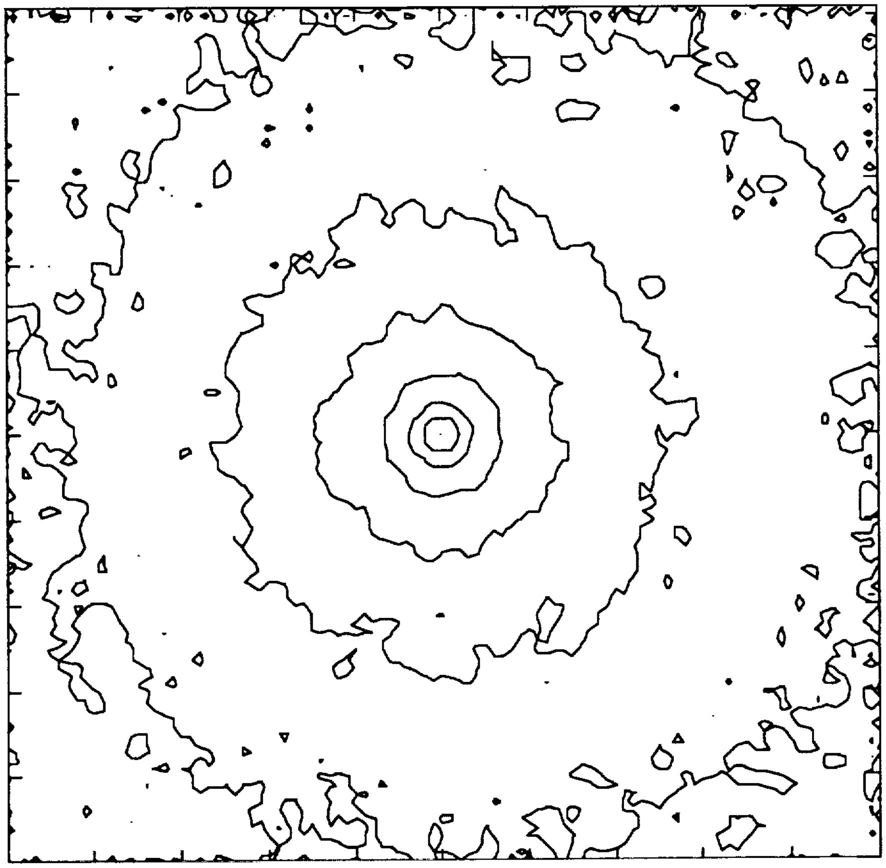

Figure 3. Model for the Inner Dust Coma of Comet P/Kopff. The intensity contours are shown for the inner portion of the coma as determined for a model run for the case of comet Kopff near perihelion as would be observed from outside the orbit plane of the comet. The model represents the second test of the new Monte Carlo dust model developed for this project. The underlying assumptions are (1) a Hanner type size distribution function, (2) terminal dust particle velocities from a dusty-gas dynamic calculation, and (3) simple radiation scattering proportional only to the dust particle geometrical cross sections. The dust trajectories are calculated in a general time-dependent and three-dimensional manner. Adjacent contours correspond to brightness levels of factors of two. Tic marks on the circumscribed box are separated by 1 x $10^4$ km. A comparison with the large scale of Figure 4 shows that the effects of the solar orbital motion are important even on this small scale. This is indicated by the fact that the coma is not exactly symmetric about the comet-sun line (i.e. the horizonal axis through the dot which is the location of the nucleus). The second model includes a full time-dependent description for the dust particle terminal velocities.

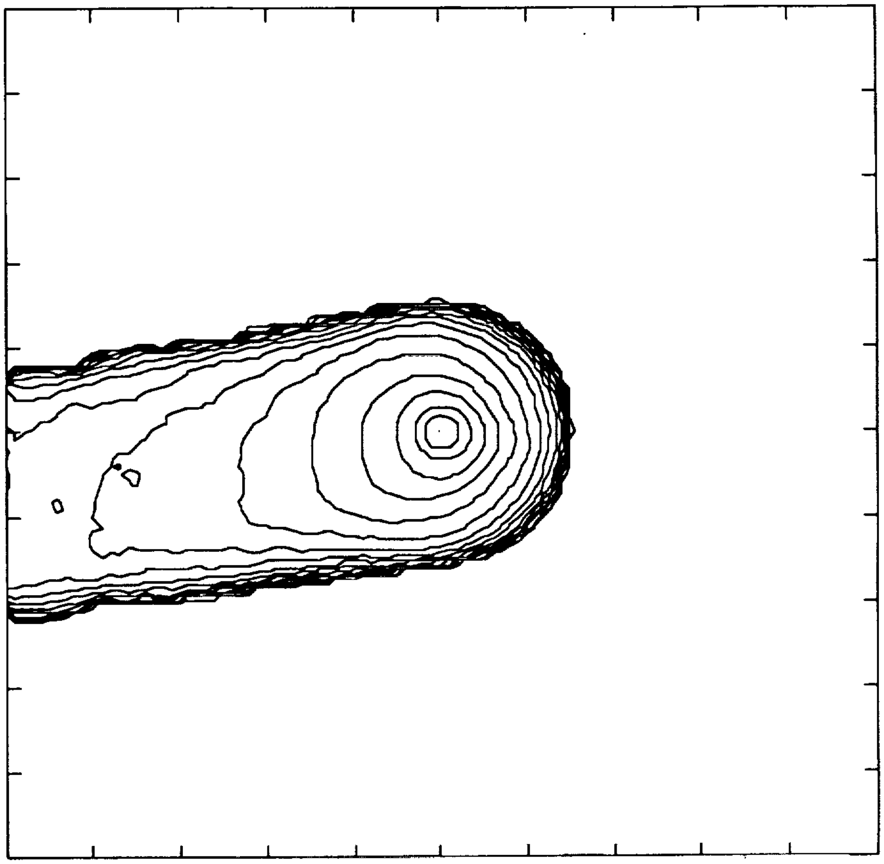

Figure 4. Model for the Outer Dust Coma of Comet P/Kopff. The intensity contours are shown for the inner portion of the coma as determined for a model run for the case of comet Kopff near perihelion as would be observed from the earth on January 1, 2003, just after the CRAF flyby perihelion. The model represents the second test of the new Monte Carlo dust model developed for this project. The underlying assumptions are (1) a Hanner type size distribution function, (2) terminal dust particle velocities from a dusty-gas dynamic calculation, and (3) simple radiation scattering proportional only to the dust particle geometrical cross sections. The dust trajectories are calculated in a gemeral time-dependent and three-dimensional manner. Adjacent contours correspond to brightness levels of factors of two. Tic marks on the circumscribed box are separated by 2 x $10^5$ km. The second version of the model includes a fully time-dependent description for the dust particle terminal velocities.

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