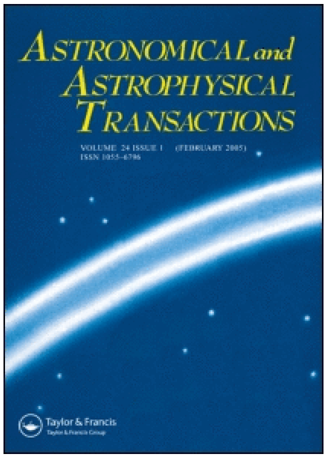

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THE MONTE CARLO APPROACH TO P/HALLEY'S ACTIVITY ON APRIL, 1986

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The simulation of the OH light curve observed by Schleicher and Millis on April, 1986, has been carried out using a Monte Carlo model. It was shown that this light curve is produced by four active zones on the nuclear surface which restore their orientation with respect to the Sun every 7.37 days. Our simulation necessitates the $\cos^3(\alpha)$ law for the dependency of the sublimation rate of discrete sources on the angle α between the normal to the nuclear surface and the sunward direction. In our opinion, this is caused by a crater structure of the nuclear surface. The realistic variation of the H_2O production rate, as well as the predicted H_2O light curve and OH radio curve are presented and discussed.

KEY WORDS Comet P/Halley, light curve, OH molecule, Monte Carlo model.

1. INTRODUCTION

One of the most important among the problems connected with Comet P/Halley appearance is its activity and rotation. Analyzing the morphology of the comet dust jets during its previous apparition, Secanina and Larson (1984) predicted the rotational period of the Halley's Comet of about 2.2 days.

For some time, this result exerted a magic influence on the investigators, and their efforts were directed to confirm this value of the period (see e.g., Belton *et al.*, 1986; Celnic *et al.*, 1987; Sagdeev *et al.*, 1986; Schlosser *et al.*, 1986; Secanina and Larson, 1986).

However, narrowband observations carried out by Schleicher and Millis on Spring, 1986, clearly showed the 7.4 day light curve periodicity (Millis and Schleicher, 1986; Schleicher and Millis, 1989; Schleicher *et al.*, 1986). The same variations were found by McFadden *et al.* (1987) in the IUE data, by Colom and Gerard (1988) in the OH radio data, and by Meech and Jewitt (1987), Neckel and Munch (1987), and Sterken *et al.* (1987) in the visible range. A vast collection of narrowband photometric measurements from four sites shows a distinct 7.4 day periodicity throughout the postperihelion window (Schleicher *et al.*, 1990).

Later, a theory of the spinning motion of an axisymmetric ellipsoidal nucleus was developed to accommodate both periods. Such model simulations were carried out by Festou *et al.* (1987), Samarasinha and A'Hearn (1991) and others. Unfortunately, the spatial orientation of the cometary nucleus and the distribution of active areas on its surface are badly known, and it makes the modelling more complicated. Moreover, the direct comparison of these numerical experiments with observations is somewhat troublesome.

So, this problem is still far from being solved.

2. THE MODEL AND DATA

We have proposed another, non-standard approach to the solution of this problem. Recently, the Monte Carlo modelling became one of important tools for the cometary atmosphere investigation. We use it to explain the periodicity of P/Halley's light curve on Spring, 1986 (Korsun, 1990a; Korsun, 1990b).

In this model, the distribution of the cometary matter is simulated by tracing the trajectories of many individual particles over a long time. To simulate the observed picture, we computed the location of every radical at the moment of the observation. In the model simulations we take into account the following physical processes: 1) the existence of discrete sources of volatile matter on the nuclear surface, 2) the rotation of the nucleus, 3) the exponential lifetimes of the radicals and their parents, 4) the isotropic ejection of the daughters owing to the excess of their photolysis energy, 5) multiple neutral-neutral collisions, 6) the distribution of the ejection velocities of the radicals and their parents, 7) the solar radiation pressure, 8) the dependence of the gas outflow velocity on the distance from the nucleus, 9) the variability of the parent production rates, 10) the heliocentric distance dependence of such model parameters as the gas production rate, molecular velocity, lifetime, and the solar radiation pressure, and 11) the influence of CO on the gas kinematics controlled mainly by H_2O.

This model has already been used for the investigation of the C_2 spectral profiles of Comet P/Halley (Korsun, 1991). It was shown that an active process on the comet nucleus took place on December 3, 1985. Moreover, using the calculated model parameters we simulated the temporal evolution of this outburst in the cometary atmosphere under the actual conditions of observations.

The most suitable observational data for our purpose are the narrowband measurements of Schleicher and Millis (1989). To reproduce their light curve, the number of molecules in the aperture projected on the cometary atmosphere should be evaluated. We chose the size of the aperture to be 0.7′, as in the observations of Schleicher and Millis.

3. THE LIGHT CURVE MODELLING

Since the model has a great number of free parameters, we fixed them in our calculations except the water production rate from a few discrete sources which come back to the same orientation with respect to the Sun after a certain period of time: we recall that our main goal is just to simulate active processes in the cometary coma.

For our fixed parameters we assumed standard values available in the literature. The background outflow speed we took from GIOTTO measurements (Lammerzahl *et al.*, 1986). The OH lifetime was adopted as $1.2 \cdot 10^5$ s following Van Dishoeck and Dalgano (1984). The H_2O life time, $8.0 \cdot 10^4$ s, we took from Gerard *et al.* (1987). The OH ejection velocity after the dissociation of H_2O is assumed to be $1.35\,\mathrm{km} \cdot \mathrm{s}^{-1}$ (Huebner, 1985). And we adopted the OH acceleration owing to the solar radiation pressure to be $0.9 \cdot 10^{-2}\,\mathrm{cm} \cdot \mathrm{s}^{-2}$ (Boice, 1990).

As a basis for our simulations we adopt the following results of the P/Halley's light curve analysis by Schleicher *et al.* (1990): 1) the photometric variations are determined by four sources of volatile matter, 2) these sources come back to the same orientation with respect to the Sun approximately every 7.4 days.

For Monte Carlo simulations we choose the April OH light curve. This one shows a clear periodic nature and is rather detailed. The same is true for the March data. But, unfortunately, they are published in terms of the gas production rate (Schleicher *et al.*, 1986; Schleicher *et al.*, 1990) while our model works with either fluxes or column densities. We consider only OH because its parameters and parents are well known, and the light curves of this and other species are all similar.

We assume the presence of four H_2O sources which come back to the sunlit face every 7.37 days. Moreover, we consider the nucleus as a simple rotator without precessional motion.

Thus, we pay special attention to such model parameters as the power of H_2O sources, the moments of their crossing of the subsolar point, and the dependence of the sublimation rate of the discrete sources on the angle α between the normal to the nucleus surface and the sunward direction. The latter factor was introduced because a simple $\cos(\alpha)$ law did not allow us to obtain acceptable results.

In our simulations, we adopted the $\cos^3(\alpha)$ law. As the main reason for this we consider the crater structure of the cometary nucleus surface: the sublimation of the parents occurs mainly in these active regions.

It should be noted that the idea of the crater morphology of the nucleus surface was proposed by Wallis in 1986 (Wallis, 1986).

In order to obtain a single simulated point of the model light curve, we computed the trajectories of $1.5 \cdot 10^5$ particles. The computational time for one point is 70 s on ES-1061 computer. Each calculated point is separated in time from another one by 12 hours. To obtain the final light curve we used the trial and error procedure.

4. RESULTS AND DISCUSSION

The best fit to the April data is shown in Figure 1 and one can see that the agreement between the computed curve and the observed one is quite good.

The model parameters are given in Table 1. Since we examine the observed light curve for a period of a few weeks, so that the same H_2O sources appear recurrently, we assigned them the numbers. These numbers are displayed in column I. In column II we give the moments (U.T.) when the source crosses the subsolar point. Column III gives the increment of the gas production rate for a separate source with respect to the background level of the H_2O sublimation of P/Halley's nucleus.

As one can see from Table 1, the observed light curve of April, 1986, is determined by four discrete sources on the nucleus surface. These sources have different strengths and somewhat vary in time. Moreover, our result cannot be reduced to the 2.2 day periodicity in any reasonable way.

As it occured, our Monte Carlo model gives the temporal variation of the H_2O and OH amounts in the cometary atmosphere as they are observed using various detectors in different spectral regions. Such predictions are displayed in Figure 2.

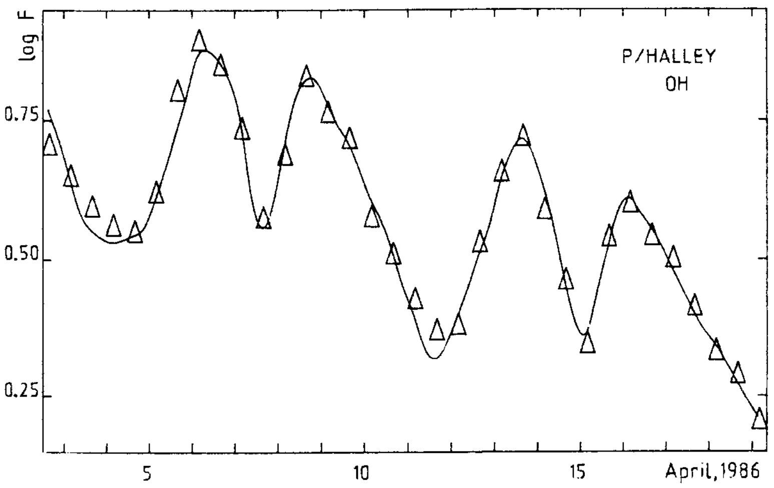

Figure 1 The observed and simulated P/Halley's OH light curves for April, 1986. The full line is the observed curve and triangles are the simulated points.

Figure 2D shows the model variation of the H_2O production rate in April, 1986. We should note that in our model, contrary to Hazer's model, this curve gives real H_2O sublimation rate from P/Halley's surface.

Prediction of the temporal variation of the amount of H_2O molecules in the 41″ aperture, as well as in the Kuiper Airbone Observatory case, is displayed in Figure 2C. Unfortunately, there are no such published observations for April to test the predicted correlation.

The temporal variation of the OH amount for the instrumental aperture 0.7′ is plotted in Figure 2B. This result is the same as discussed above.

The same is shown in Figure 2A for radio observations with the beam of 29′ in diameter (Instituto Argentino de Radioastronomia, IAR, and Dominion Radio Astrophysical Observatory, DRAO). There are no DRAO observations for April (Galt, 1987). The IAR data are mixed with a signal from the galactic plane and Cen A (Mirabel *et al.*, 1986; Schloerb and Gerard, 1985). Moreover, these data have low signal-to-noise ratio and low time resolution (1 day). Some conclusions

Table 1 P/Halley's activity on April, 1986

Source's numbers *I*	*Subsolar point crossing* (*April,* 1986) *II*	*Increment* *III*
III	6.12	2.8
IV	8.62	2.9
I	9.99	1.0
II	11.62	0.4
III	13.37	3.0
IV	15.95	2.8
I	17.46	0.9

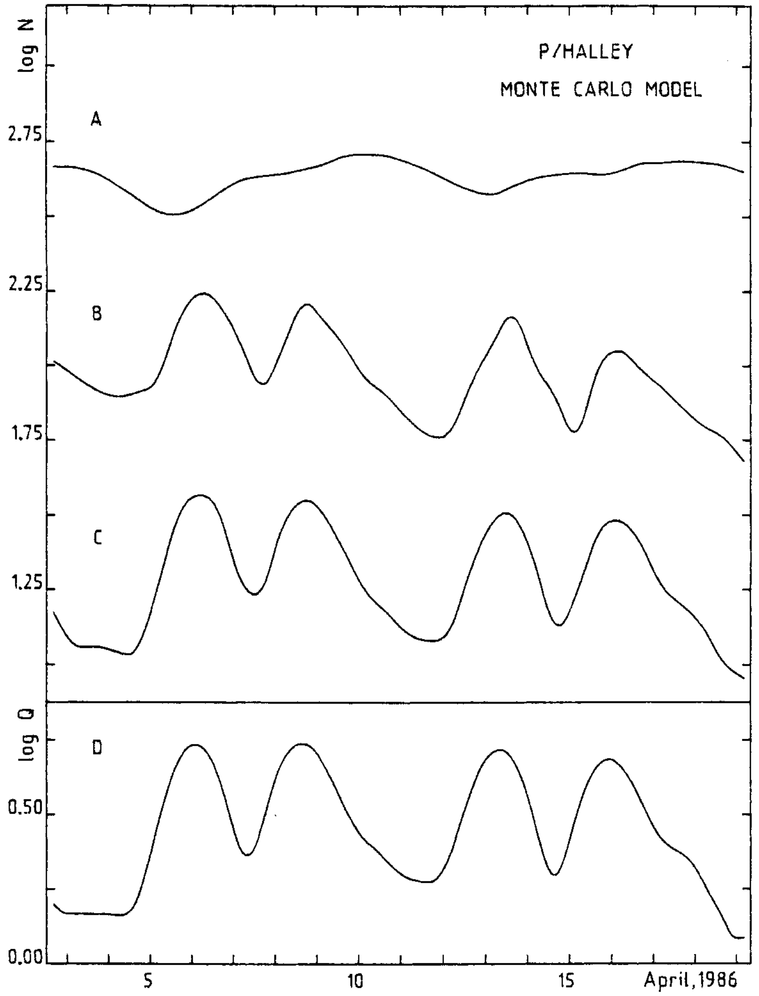

Figure 2 The simulated water production rate and the predicted H_2O and OH light curves for IR, visible, and radio ranges.

can be made by comparing our model results with the average radio energy curve of the Nancay series for April and the IAR series (Colom and Gerard, 1988). As one can see, the shape of the radio energy curve, figure 9 in Colom and Gerard (1988) and our one are similar. Moreover, in figure 9 of Colom and Gerard (1988) there is a shift between the peaks of the optical light curve and the radio one. In our case, this shift is about one day. The same fact has been reported by Silva and Mirabel (1988), namely all the optical observations show a peak near 25 March and the radio OH data have a maximum near 26 March.

It should be noted, that our simulations imply that all determinations of the gas production rates using Hazer's model or Festou's vectorial model are incorrect if the comet is active. Observations through a narrow diaphragm provide more realistic results than those with a wide one.

This is connected with the expansion rate of the species considered. This discrepancy is determined by the projected diaphragm size and by the outflow speed. On the other hand, observational results depend on the lifetimes of the radicals as well.

Moreover, it becomes clear that investigators may meet difficulties in the determination of the active process periodicity because of the smoothing of each individual peak in radio observations and the effect of the generation and decay of the active zones at the nucleus surface. In our opinion, we have the same situation in the search for periodicities in the OH radio emission by Colom and Gerard (1988).

Another fact which we should note is a smaller maximum-to-minimum amplitude ratio in the radio data as compared to the visual ones. The reason of this is the same as discussed above.

5. CONCLUSIONS

The main results of the present analysis can be summarized as follows:

1. Monte Carlo simulations clearly show the 7.37 day periodicity of active processes in April, 1986, as it was suggested by Millis and Schleicher. There is no evidence for the 2.2 day periodicity in our analysis.
2. The observed light curve is determined by four active zones on the nucleus surface. Parameters of active processes are presented in Table 1.
3. Our simulations became successful as soon as we adopted the $\cos^3(\alpha)$ law for the dependence of the sublimation rate from discrete sources on the angle α between the normal to the nucleus surface and the sunward direction.
4. We have obtained a realistic variation of the H_2O production rate and predicted the light curves of H_2O emission and OH radio emission.
5. A discussion of the peculiarity of the OH radio curve when a comet shows activity has been presented.

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