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## FORCED PRECESSION OF THE COMETARY NUCLEUS WITH RANDOMLY PLACED ACTIVE REGIONS

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### ABSTRACT

The cometary nucleus is assumed to be triaxial or axisymmetric spheroid rotating about its axis of maximum moment of inertia and is forced to precess due to jets of ejected material. Randomly placed regions of exposed ice on the surface of the nucleus are assumed to produce gas and dust. The solution of the heat conduction equation for each active region is used to find the gas sublimation rate and the jet acceleration. Precession of the comet nucleus is followed numerically using a phase-averaged system of equations. The gas production curves and the variation of the spin axis during the orbital motion of the comet are presented.

### MODEL

The cometary nucleus is modelled as a rotating, triaxial or axisymmetric ellipsoid that precesses under the torque from gas and dust jets escaping from active spots on its surface. The activity of these regions is controlled by time dependent insolation which is a function of the zenith angle of the Sun (changing due to the nucleus rotation) and the heliocentric distance of the comet nucleus. The insolation function describes the solar energy influx and is included in the energy balance equation on the nucleus surface as one of the boundary condition for the heat conduction equation. The heat conduction equation is solved for each active region. The obtained solution i.e. the surface temperature distribution is then used to calculate the sublimation flux of H<sub>2</sub>O molecules and the jet acceleration. The jet acceleration from the outgassing acting on the nonspherical nucleus produces the torque. The nucleus rotates about its axis of maximum moment of inertia ( $C$ ) and its rotational axis is forced to precess. The precession of the spin axis produces changes in the pattern of the insolation of any region on the nucleus surface which, in turn affect the magnitude of the torque. To describe the precessing motion of the nucleus a phase-averaged system of equation is used (Julian, 1988) in which the torque is averaged over a rotation and a nutation is suppressed. Then the rate of change of averaged angular momentum is of the form:

$$C\omega \frac{d\mathbf{u}}{dt} = l(\mu)\mathbf{u} \times \mathbf{F}$$

where:  $\omega$  is the angular velocity magnitude,  $\mathbf{u}$  is the unit vector in the direction of the rotation axis,  $l(\mu)$  is function of cometographic latitude ( $\mu$ ) of point of integrated outgassing and  $\mathbf{F}$  is the reaction force of the jet. The phase averaging allows to extend the precession model of Whipple-Sekanina (1979) as applied to an oblate comet nucleus on the prolate and triaxial ones.

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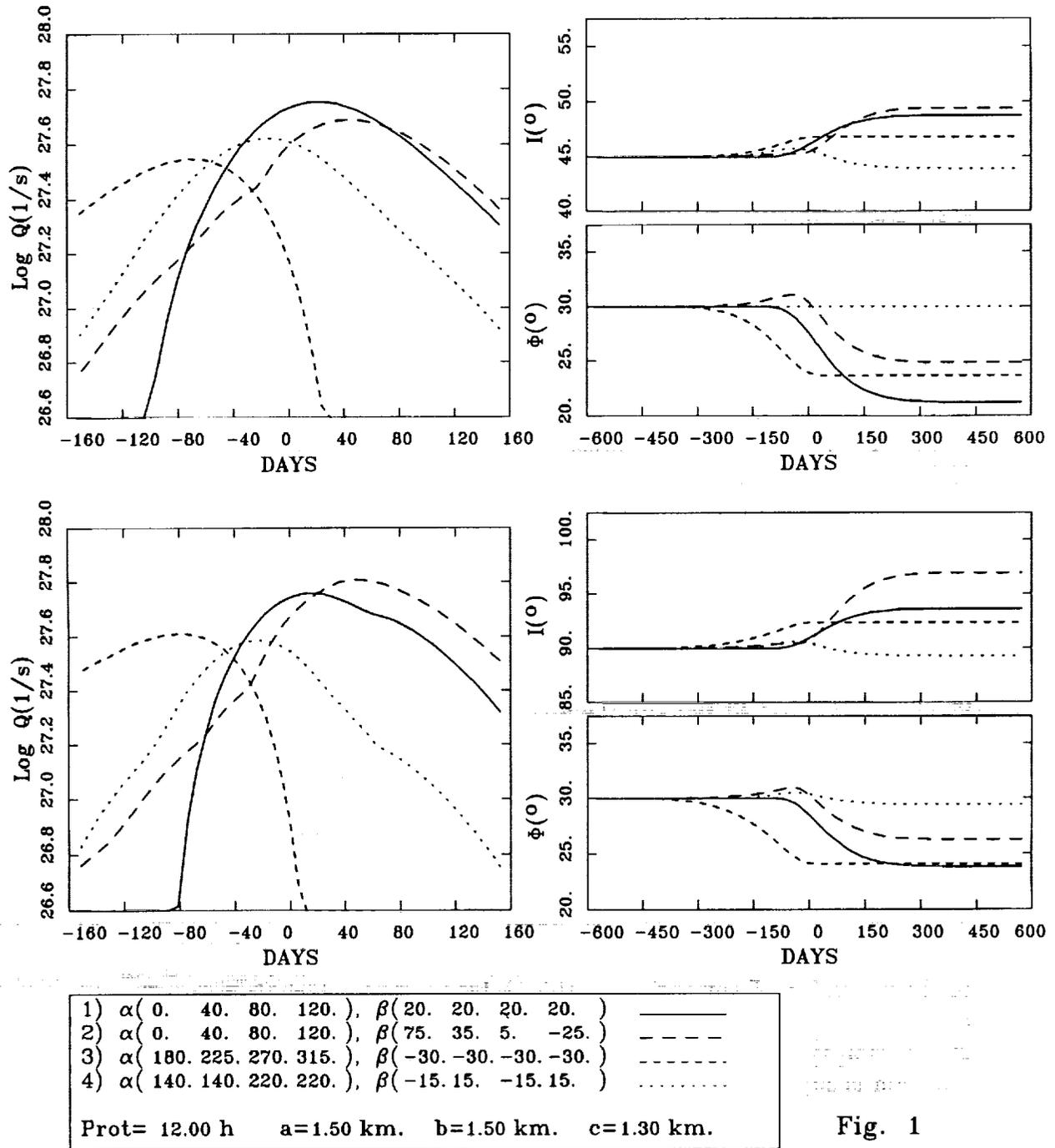
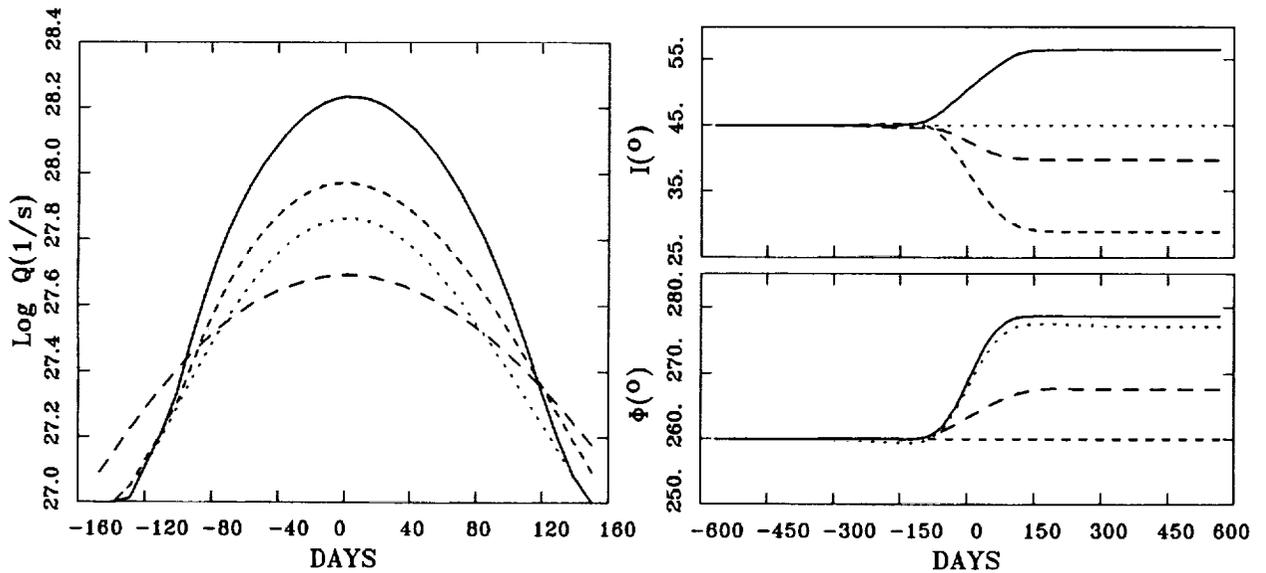


Fig. 1

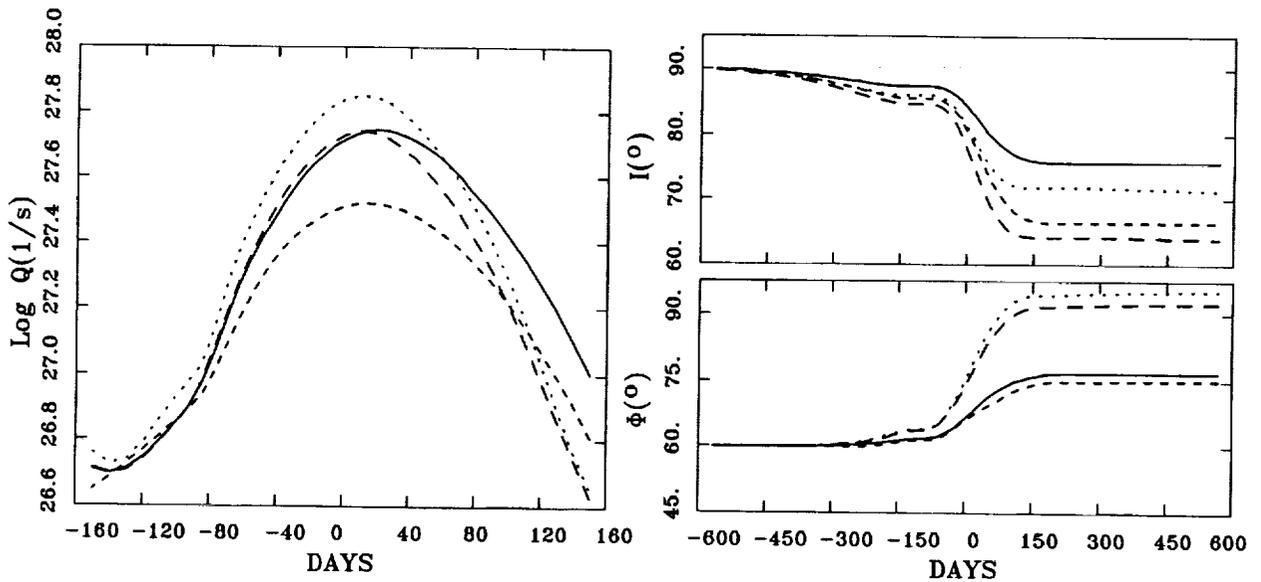
Figs. 1, 2, 3, 4. The gas production rate ( $Q$ ) and the orientation of the spin axis ( $I, \Phi$ ) with respect to the orbital plane as a function of time (relative to perihelion passage). Each curve shows the results for the comet nucleus with 4 active regions which positions are prescribed by cometocentric longitude  $\alpha$  and latitude  $\beta$ . The rotational period  $P_{rot}$  and the size ( $a, b, c$ ) of the comet nucleus are given.



1)	$\alpha(0. 60. 120. 180. )$ ,	$\beta(-90. -60. -30. -5. )$	———
2)	$\alpha(0. 90. 180. 270. )$ ,	$\beta(-25. -5. 15. 35. )$	- - - -
3)	$\alpha(0. 0. 0. 0. )$ ,	$\beta(-75. -35. -5. 25. )$	· · · · ·
4)	$\alpha(90. 90. 90. 90. )$ ,	$\beta(-50. -15. 15. 50. )$	· · · · ·

Prot= 24.00 h    a=2.00 km.    b=2.00 km.    c=1.50 km.

Fig. 2



1)	Prot= 12.0 h	a=1.5 km.	b=1.5 km.	c=1.0 km.	———
2)	Prot= 24.0 h	a=1.5 km.	b=1.5 km.	c=1.0 km.	- - - -
3)	Prot= 24.0 h	a=1.5 km.	b=1.0 km.	c=1.0 km.	· · · · ·
4)	Prot= 24.0 h	a=2.0 km.	b=1.5 km.	c=1.0 km.	· · · · ·

$\alpha(0. 90. 180. 270.)$ ,  $\beta(-50. -15. 50. 15. )$

Fig. 3

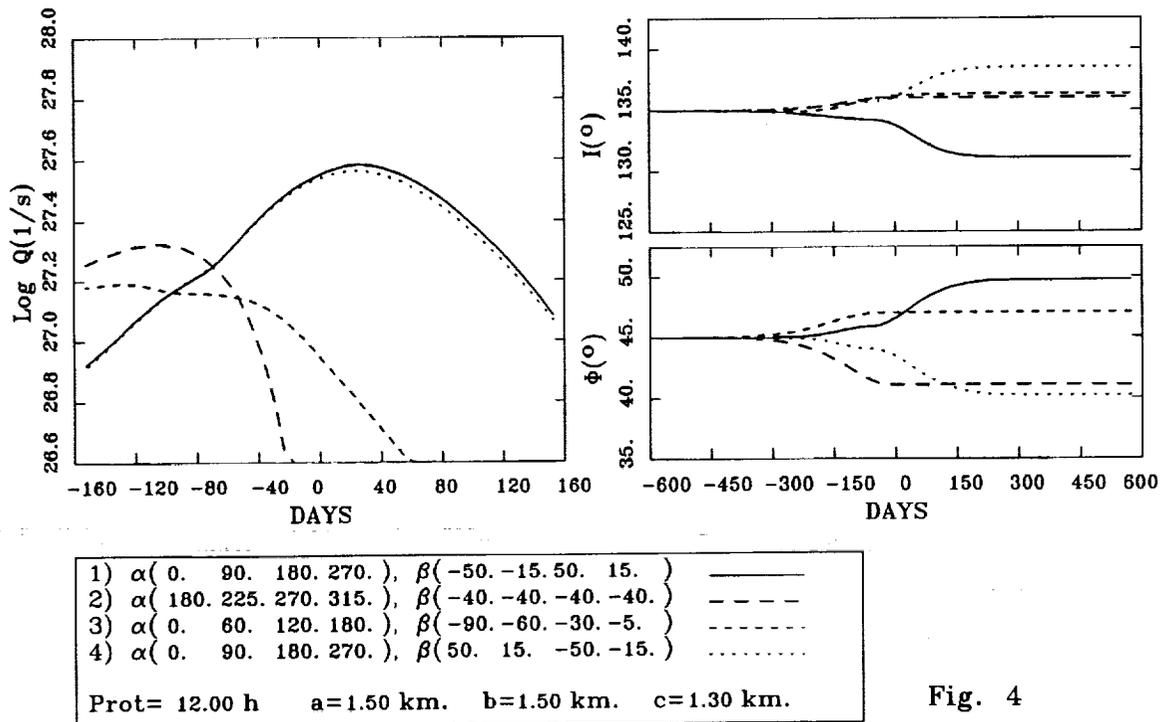


Fig. 4

## RESULTS

Obtained results are based on models computed with the following physical parameters of the nucleus: density  $\rho = 0.6 \text{ g/cm}^3$ , thermal inertia  $I_t = 1000 \text{ W s}^{1/2} \text{ m}^{-2} \text{ K}^{-1}$ , CO contents - 10%, dust/gas ratio - 0.5, albedos ( $A_{vis}$  and  $A_{ir}$ ) of active regions - 0.05. The size of the nucleus (semiaxes  $a \geq b \geq c$ ), the period of rotation ( $P_{rot}$ ), the initial orientation of the spin axis and location of active regions over the nucleus are all varied. The orbital elements of the comet Kopff are chosen. The orientation of the rotation axis is defined by the angles: the obliquity ( $I$ ) of the orbital plane to the nucleus equator and the longitude of the Sun at the ( $\Phi$ ) perihelion measured along the orbit plane from its ascending node on the equator. Each active region is identified by a cometocentric longitude ( $\alpha$ ) and latitude ( $\beta$ ) and is assumed to cover 3% of the nucleus surface. The effect of distribution of the active regions across the cometary nucleus, the shape and spin period of the comet nucleus on the profiles of the gas production curves ( $Q$ ) and the variation of the orientation of the spin axis during the orbital motion of comet are presented in figures 1, 2, 3 and 4. Each curve corresponds to 4 active regions. The figures demonstrate that the direction of the spin axis, the position of active regions and the shape of the nucleus play an important role in determining perihelion asymmetry and magnitude of the gas production curve. The size of the cometary nucleus is a scaling parameter. Furthermore, accumulated action of the jets disturbs more or less the orientation of the spin axis according to where the regions producing gas and dust are placed on the nucleus surface.

## REFERENCES

- Julian, W.H. (1988) Precession of Triaxial Cometary Nuclei. *Icarus* **74**, 377-382.  
 Whipple, F.L., and Sekanina Z. (1979) Comet Encke: Precession of the spin axis, non-gravitational motion, and sublimation. *Astron. J.* **84**, 1894-1909.