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HCN and CN in Comet 2P/Encke: Models of the non-isotropic, rotation-modulated coma

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Abstract

Axisymmetric models of the outgassing of a cometary nucleus have been constructed. The outgassing capability of the nucleus (response of outgassing to solar energy input) is assumed symmetric with respect to an axis different from the rotation axis. Such models can be used to describe a nucleus with a single active region, in particular if the active region is located not far from one of the rotation poles of the nucleus. The models may include a solar zenith angle dependence of the outgassing. They retrieve the outgassing flux at distances from the nucleus where collisions between molecules are unimportant, as function of the angle θ with respect to the outgassing axis. The observed emissions must be optically thin. Furthermore the models assume that the outflow speed at large distance from the nucleus does not depend on direction. The value of the outflow speed is retrieved.

The models are applied to CN images and HCN spectra of Comet 2P/Encke, obtained nearly simultaneously in November 2003 with the 2m optical telescope on Mount Rozhen, Bulgaria, and with the 10m Heinrich Hertz Submillimeter Telescope on Mount Graham, Arizona, USA. According to Sekanina (1988), at that time, more than one month before perihelion, of his two outgassing sources source I was still active, the source receiving sunlight during most of Comet Encke's orbit. This means that conditions on Comet Encke were favorable for the application of an axisymmetric model.

Input parameters to the models like the rotation period of the nucleus and a small correction to Sekanina's rotation axis are determined from a simpler jet position angle model. In this model the up and downward motion of the position angle of elongation of the near nucleus part of Comet Encke's CN coma is interpreted as position angle of a jet. The rotation is prograde with a synodic period of 11.028 ± 0.024 hours, in agreement with literature values (Fernández et al, 2005, Harmon and Nolan 2005, Lowry and Weissmann 2007).

The inverse models constructed for Comet Encke rely mostly on four CN images obtained at phases of synodic rotation of 0.21, 0.41, 0.57, and 0.70. The HCN spectra are used to derive the best fit parent outflow speed, and, together with the CN images, the sense of rotation.

The best fit model has an outflow speed of 0.95 ± 0.04 km s^{-1}. The same value has been derived from the corkscrew appearing in the CN images. The location of the outgassing axis is at colatitude $\delta_a = 7.4° \pm 2.9°$.

Figures 1 and 2 illustrate our results. Figure 1 shows the nucleus, assumed spherical, as seen from the Earth during our observations. The north pole of Comet Encke receives sunlight and the north polar cap experiences polar day. The south polar cap has been in darkness for almost the full orbital period of Comet Encke. The outgassing, expressed by the so-called density function $\bar{\rho}(\theta)$ derived from the inverse modeling, is displayed in Figure 2, for four models with different outflow speeds. Note that, as compared with Figure 1, Comet Encke's north pole is now on the left side. The full line with diamonds describes the best fit model. The solar energy $\langle E_\odot(\delta)\rangle$ received on a spherical nucleus and averaged over one spin period is shown for the four CN images to which the model was fitted. The density functions have a functional form similar to $\langle E_\odot(\delta)\rangle$. The following conclusions can be drawn from the shape of the retrieved density function:

(i) $\bar{\rho} \approx \langle E_\odot\rangle$ suggests that a major part of the nucleus contributes to the outgassing, and that the CN production rate is not modulated by rotation. A dependence of the CN production rate on rotational phase is also not apparent from the CN production rates derived from our CN images. The HCN spectra, however, show a trend with maximum at phase 0.75, when

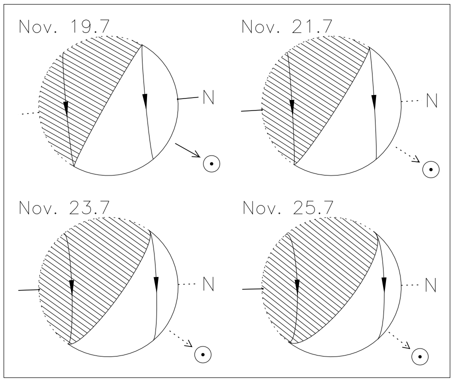

Figure 1: Perspective view of Comet Encke's nucleus as seen from the Earth end of November 2003. The four panels refer to four equidistantly spaced times during our observations. The nucleus is represented by a sphere. The terminator and the latitudes separating the mid-latitude nucleus surface with alternating day and night from the polar caps of permanent daylight (polar day) or permanent night (polar night) are shown. Arrows at these latitudes indicate prograde rotation. The rotation axis (N denotes north pole) and the apparent direction to the Sun are marked with full lines, if in front of sky plane, and with dotted lines, if behind sky plane.

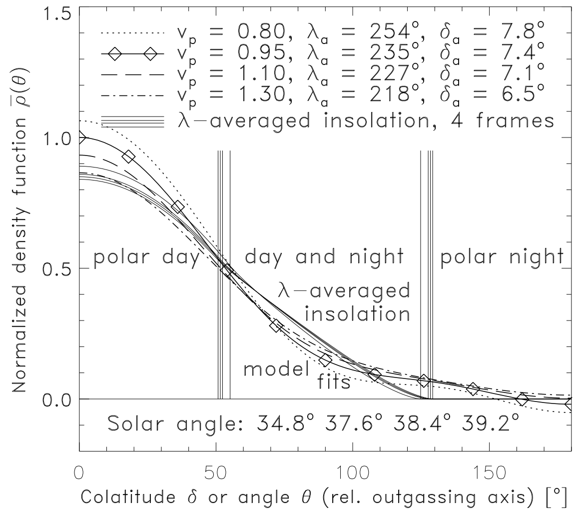

Figure 2: Normalized density function $\bar{\rho}(\theta)$ plotted versus opening angle θ for models with different outflow speeds v_p. Line styles and model parameters are indicated on top of the figure. The diamonds mark the best fit model. The density functions are compared with the solar input $\langle E_\odot(\delta)\rangle$, averaged over one rotation period. δ denotes colatitude on a spherical nucleus. The vertical lines indicate the latitude borders between polar day, alternating day and night regime, and polar night for the four frames. The angles between rotation axis of the comet and comet-Sun direction of the four frames are provided as numbers in the bottom of the plot

the solar zenith angle is highest.

(ii) The outgassing is nonzero at the south polar cap experiencing polar winter at the time of the observations. This is interpreted as evidence for gas flow across the terminator from the illuminated to the dark part of the nucleus (Keller and Thomas 1989, Crifo and Rodionov 1999, Skorov et al. 2004).

(iii) As compared to $\langle E_\odot\rangle$, $\bar{\rho}(\theta)$ has a deficit at nucleus midlatitudes. This is easily explained by an oblate shape of the nucleus (Harmon and Nolan 2005, Lowry and Weissmann 2007). Part of the missing flux, however, is needed to supply the dark polar cap with flow across the terminator.

(iv) The fit of both, CN images and HCN spectra, can be improved if to the constant expansion velocity a random speed is added obeying a Maxwellian distribution with a temperature of the HCN molecules of ≈ 120 K.

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