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Letter to the Editor

Rosetta target comet 67P/Churyumov-Gerasimenko

Postperihelion gas and dust production rates*

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Abstract. The evolution of the activity and composition of the coma of Rosetta target comet 67P/Churyumov-Gerasimenko was studied along its postperihelion orbit from 2.29 AU to 3.22 AU. The comet had a major drop of activity between 2.5 AU and 2.9 AU, which manifested most obviously in its light curve (the brightness decreased by 3 mag), but is also confirmed by the production rates derived from spectrophotometric measurements. The strong decrease of activity indicates a change in the outgassing behaviour of the nucleus and might be due to water sublimation becoming less efficient. The spectrophotometric measurements at 2.9 AU show that the coma is at least slightly depleted in C_2 with respect to CN.

Key words. comets – Rosetta – 67P/Churyumov-Gerasimenko – production rates

1. Introduction

The *Rosetta* mission of the European Space Agency was launched 2 March 2004 to comet 67P/Churyumov-Gerasimenko, a short-period comet of the Jupiter family. Originally, *Rosetta* was targeted at another Jupiter-family comet, 46P/Wirtanen, with launch in January 2003. However, the launch had to be delayed owing to unforeseen problems with the launch vehicle and 67P/Churyumov-Gerasimenko was identified as the new target comet. *Rosetta* will go in orbit around the comet nucleus when it is still far from the Sun and accompany the comet along its way to and through perihelion, while 11 scientific instruments will monitor the comet's evolution along the orbit. In addition, *Rosetta* carries *Philae*, which will land on the nucleus to perform a detailed investigation of its physical and compositional properties. The mission had been optimized to the characteristics of the original target, comet 46P/Wirtanen, e.g. its gas and dust activity as determined from ground. It is therefore of utmost importance to determine the properties of the new target comet, 67P/Churyumov-Gerasimanko, and adjust the mission scenario, particularly the planning of the science operations, to achieve an optimal scientific return. A first report on optical observations of this comet is provided by Weiler et al. (2004). Here we report the gas and dust activity of 67P/Churyumov-Gerasimanko determined from spectrophotometric observations and broad-band images.

2. Observations and data reduction

Comet 67P/Churyumov-Gerasimenko was monitored from the European Southern Observatory between 11 February 2003 and 26 June 2003. Postperihelion observations (spectrophotometry and broad-band filter imaging) were obtained between 2.295 AU and 3.224 AU heliocentric distance whereby spectra could be taken up to 2.89 AU. Out to $r_{\rm h}$ = 2.6 AU we used the 3.6-m telescope equipped with the EFOSC2 instrument. Beyond $r_{\rm h}$ = 2.8 AU all observations were taken with the FORS1 instrument mounted on the VLT 1 (Antu). To facilitate a calibration of the broad-band images, appropriate fields from the list of Landold 1992 were observed at different airmasses each night. For the flux calibration of the spectra, observations of the spectrophotometric standards Feige 56 (EFOSC2) and Feige 66 & EG 274 (FORS1) were taken.

All frames were bias subtracted and flat fielded. All observations were flux calibrated, assuming the standard atmospheric conditions described by Tüg (1977) for the extinction correction. Because of the long slit of the spectrographs

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* Based on observations obtained at ESO La Silla within ESO programmes 70.C-0505 and 270.C-5035.

Table 1. Photometric fluxes, *F*, and production rates, *Q*, of comet 67P/Churyumov Gerasimenko.

Date 2003	Feb. 11	Mar. 9	Apr. 30– May 5
r_h/AU	2.3	2.5	2.9
Δ/AU	1.4	1.5	2.3
Aperture/″	2.0×6.6	2.0×6.6	2.0×5.0
$F_{CN}/10^{-19}$ W/m^2	22.6 ± 3.6	17.1 ± 2.4	4.7 ± 0.3
$F_{C_2}/10^{-19}$ W/m^2	<25.2	<14.4	<0.9
$F_{C_3}/10^{-19}$ W/m^2	<15.3	<13.5	<0.5
$F_{NH_2}/10^{-19}$ W/m^2	<11.4	<6.0	<0.5
$Q_{CN}/10^{23}$ s^{-1}	24.2 ± 3.4	24.7 ± 5.5	5.0 ± 0.3
$Q_{C_2}/10^{23}$ s^{-1}	<27.9	<21.9	<3.1
$Q_{C_3}/10^{23}$ s^{-1}	<0.87	<1.05	<0.09
$Q_{NH_2}/10^{23}$ s^{-1}	<116.7	<82.3	<14.4
$Af\rho$/cm	63.1 ± 1.3	44.6 ± 1.3	2.9 ± 0.1

(EFOSC2: 5 arcmin; FORS1: 6.8 arcmin), the sky contamination in the spectra could be determined from the spectrum frames themselves. The wavelength calibration was done via HeAr-frames.

For each observing run, all flux calibrated spectra obtained with the same slit orientation, were co-aligned and an average spectrum as well as its rms was computed. From these spectra spatial profiles were extracted by averaging over certain wavelength bands. Furthermore the two dimensional spectra were added up along the slit over the innermost 5″ to obtain the wavelength dependence of the cometary flux in the inner coma. To the resulting one dimensional spectra (of $S/N > 100$) a "reddened" spectrum of a solar analog star was fitted, while excluding regions of cometary emission, resulting in an approximation of the cometary continuum flux. Subtraction of this continuum from the measured flux distribution then yields the flux of the cometary emission. These emission spectra were then used to compute gas production rates (or 3-σ upper limits, in case of non-detections). The production rates in Table 1 were determined with the Vectorial model using the procedures and parameters described in detail in Schulz et al. (1998). The dust production is given in *Afρ* (A'Hearn et al. 1984). It was derived from a region in the spectrum (5200 Å–5250 Å) which is know to represent clean continuum.

3. Results and discussion

Figure 1 shows the co-added spectra of the three observing runs that incuded spectrophotometry. The emission band of CN, at 3875 Å, is clearly present in all spectra, hence up to at least 2.9 AU. No other gas coma species could be detected in any of the spectra. Table 1 shows the resulting production rates and 3σ upper limits for CN, C_2, C_3 and NH_2 and the *Afρ* values approximating the dust production. Between 2.3 AU and 2.9 AU the CN production rate decreased by a factor of 4.8

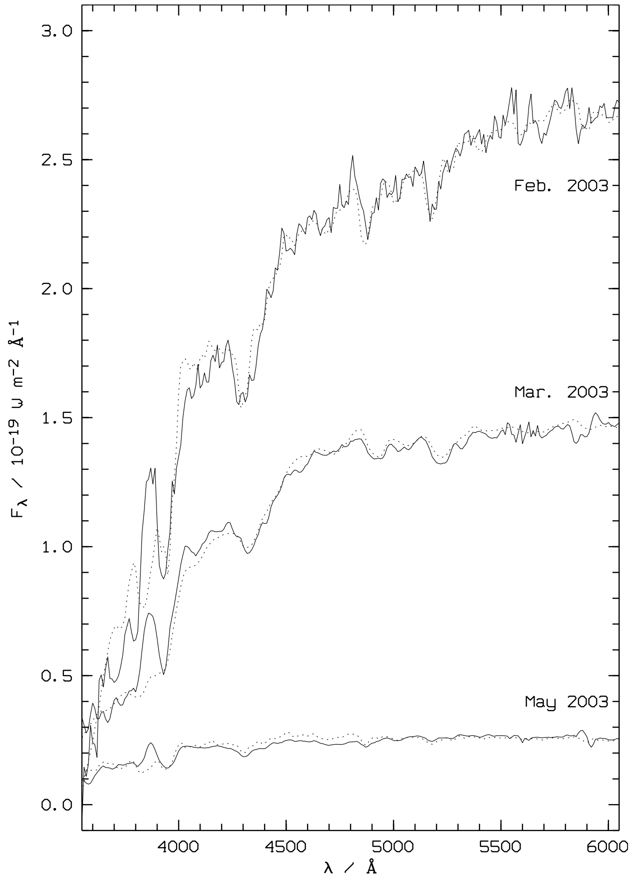

Fig. 1. Evolution of the spectrum of comet 67P/Churyumov-Gerasimenko. The continuum is fitted as a dotted line.

and the *Afρ* value decreased by a factor of 21! The VLT observations at 2.9 AU resulted in very low values for the upper limits to the production rates of C_2 and C_3. The 3σ upper limit for C_2 is almost a factor of 2 lower than the detected CN production rate, which results in a ratio of $C_2/CN < 0.62$. Hence, at 2.9 AU comet 67P/Churyumov-Gerasimenko is at least slightly depleted in C_2 according to the classification scheme introduced by A'Hearn et al. (1995), in which comets are *depleted* if $C_2/CN < 0.66$. The 3σ upper limits determined at lower heliocentric distances, from the observations obtained with the 3.6-m telescope, are too high to allow any firm conclusions on abundance ratios. However, observations obtained during the comet's apparition in 1982/83 also resulted in a depleted abundance ratio ($C_2/CN \approx 0.49$) at a heliocentric distance of about 1.4 AU (A'Hearn et al. 1995). As we could only determine an upper limit for the C_2/CN ratio at 2.9 AU, it cannot be decided whether both values are indeed different. It should be mentioned, however, that A'Hearn et al. (1995) have investigated the r_h dependence of the C_2 and CN production rates in this comet. Their results show that the CN production rate decreased faster with increasing r_h than that of C_2. This would effectively increase the C_2/CN ratio at larger r_h, which is consistent with our result. Hence, if the difference between the two values is real, it can be attributed in a straighforward way to the change of the C_2/CN ratio with heliocentric distance already indicated by A'Hearn et al. (1995).

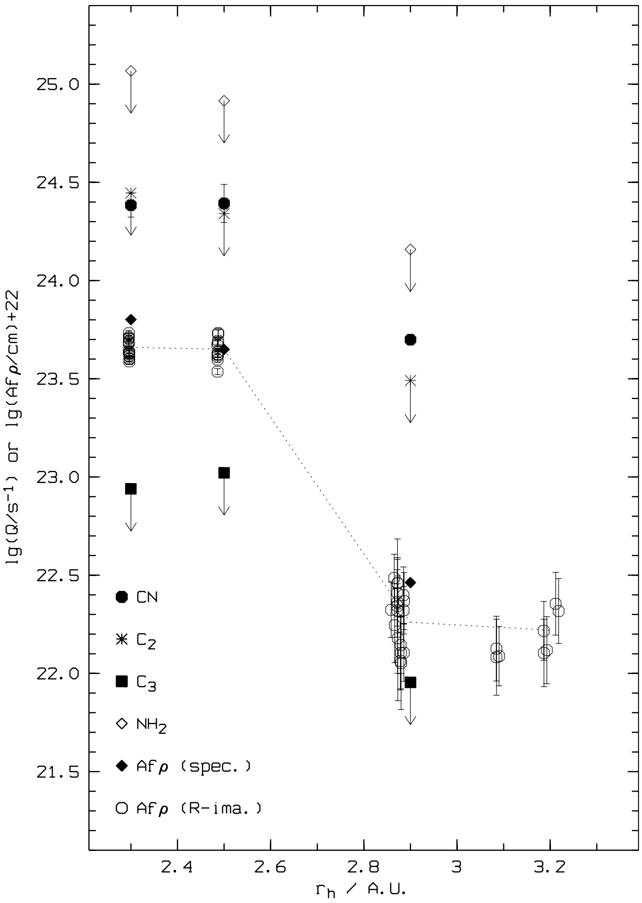

Fig. 2. The activity of comet 67P/Churyumov-Gerasimenko. Gas production rates and $AF\rho$ values are plotted as a function of heliocentric distance.

Figure 2 depicts the postperihelion activity of comet 67P/Churyumov-Gerasimenko between 2.3 AU and 3.2 AU heliocentric distance. The comet showed a very rapid decrease in $Af\rho$ between 2.5 AU and 2.9 AU. This indicates that a major change in the outgassing behaviour of the comet nucleus occured at this part of the orbit, which might be connected to water becoming a less dominant species. The latter would also be consistent with the results obtained from the long-term monitoring of comet C/1995 O1 (Hale-Bopp) which showed that water was the main driver of activity only up to about 3 AU, whereas beyond this distance the activity of Hale-Bopp was driven by CO (Biver et al. 2002). Between 2.9 AU and 3.2 AU comet 67P/Churyumov-Gerasimenko continued fading, but at a much lower pace. Recent observations of the comet obtained at r_h = 4.48 AU (Δ = 3.96 AU) showed the comet as almost point like with an R brightness of 21.6 mag (ESO 2004).

Table 2. Comparison of 67P/Churyumov-Gerasimenko with 46P/Wirtanen.

Comet	r_h/AU	$Q_{CN}/10^{23}$ s^{-1}	$Af\rho$/cm	Reference
46P/Wirtanen	2.81	<12.0	<14	(1)
67P/C-G	2.89	5.0 ± 0.3	2.9 ± 0.1	This paper
46P/Wirtanen	2.34	6.9 ± 2.4	14 ± 6	(1)
67P/C-G	2.30	24.2 ± 3.4	63.1 ± 1.3	This paper

(1) Schulz et al. (1998).

4. Comparison with Comet 46P/Wirtanen

The production rates and upper limits obtained for comet 67P/Churyumov-Gerasimenko were compared to those of comet 46P/Wirtanen at similar heliocentric distances. Table 2 shows that before 67P/Churyumov-Gerasimenko had the major drop of brightness, its $Af\rho$ value was a factor of 4.5 higher than that of comet 46P/Wirtanen. However, at around 2.9 AU it was almost a factor of 5 lower than the upper limit determined for 46P/Wirtanen. Note, 67P/Churyumov-Gerasimenko was observed along its postperihelion orbit, while 46P/Wirtanen was covered preperihelion. During their postperihelion phase, comets usually show higher activities than at the same preperihelion distance to the Sun. It is therefore very likely that comet 67P/Churyumov-Gerasimenko will be at a similar or even lower activity level than comet 46P/Wirtanen at around r_h = 3 AU preperihelion, i.e. at the time *Philae* will land on the nucleus.

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