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FIRST IMAGES OF A POSSIBLE CO+–TAIL OF COMET P/SCHWASSMANN–WACHMANN 1 OBSERVED AGAINST THE DUST COMA BACKGROUND

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Abstract

Comet P/Schwassmann–Wachmann 1 was observed with the 2m-Ritchey-Crétien Telescope of the Bulgarian National Observatory, Rozhen, Bulgaria, using the CCD-camera and focal reducer of the Max-Planck-Institute for Aeronomy. Images were taken in a red continuum window and in the 2–0 $A^2\Pi - X^2\Sigma^+$ band of CO^+ located in the blue part of the spectrum. The red images reveal an extended dust coma. From a comparison of the red and blue images a dust reddening of 13.2 % per 1000 Å is derived. At 642 nm the magnitude of the comet within a square diaphragm of 4.5 arcsec is 16.6. The blue images, taken in the CO^+ band, show a significantly different brightness distribution which is interpreted as presence of a CO^+ coma and tail superimposed on the continuum. A column density of several 10^{10} CO^+ molecules cm^{-2} is derived. The tail thickness of 10^5 km is unexpectedly small. We estimate the CO^+ production rate to about 6×10^{26} CO^+ particles s^{-1}. This value does not support the idea that the outbursts of this comet are caused by crystallization of amorphous water ice. An extended version of this paper has been submitted to Astronomy and Astrophysics.

INTRODUCTION

Cochran et al. (1980) and Larson (1980) have observed the presence of CO^+–emission in otherwise featureless spectra of comet Schwassmann-Wachmann 1 (SW1 in the following). More recently, Cochran and Cochran 1991 have been able to determine column densities of CO^+ and CN (derived from the 0–0 vibrational band). Like the brightness outbursts, also the CO^+–emission seems to occur only sporadically but unrelated to the outbursts (Larson 1980). In order to supplement the spectrographic observations an attempt was made to image comet SW1 in the 2–0 band of the CO^+ comet tail system ($A^2\Pi - X^2\Sigma^+$) and in a continuum window to study the spatial extent of the dust coma and possibly detect the CO^+–tail.

OBSERVATIONS

Comet SW1 was observed with the 2m-RCC-Telescope of the Bulgarian National Observatory, Rozhen, Bulgaria in the night 2/3 Sep 1989. Attached to the telescope was the focal reducer with CCD camera of the Max-Planck-Institute for Aeronomy. This instrument transforms the F/8 telescope beam via collimator and camera lens to F/1.5 and is therefore well suited to detect extended weak emissions. At the 2m-telescope, 1 CCD pixel corresponds to 1.5 arcseconds and the full field is 14.4 × 9.6 arcmin. The images analyzed in this study

were obtained in the night 2/3 Sep 1989 from 22:09 to 01:25. They consist of a sequence of five 30 min exposures taken in the (2–0) band of CO^+ through a filter centered at 426 nm with halfwidth of 6 nm and of a pair of 15 min exposures taken in a red continuum window through an interference filter of 3 nm halfwidth centered at 642 nm. The spectrophotometric standard stars 70 Psc and ϕ Gem were observed for absolute calibration of the comet images (Voloshina et al. 1982).

IMAGE ANALYSIS

Data reduction of the images was standard but had to be done extremely carefully because of the low signal to noise ratio. Images taken with the same filters were combined and put to absolute scale to yield a single red and blue image. To derive an image of the CO^+ tail the continuum contribution must be removed from the blue image. We cannot simply use the red image because the dust of comet SW1 is known to be reddened. Therefore we determine a maximum value of the number c such that the equation

$$\text{(blue image)} - c \times \text{(red continuum)} \geq 0 \tag{1}$$

is satisfied everywhere in the image. This procedure assumes that the dust colour is uniform in the observed dust coma. A value of $c = 0.75$ is derived which corresponds to a reddening of 13.2 % per 1000 Å. The resulting difference image was transformed to CO^+ column densities using the known transmission function of the interference filter and the g-factor given by Magnani and A'Hearn (1986). Figure 1 shows traces through the nucleus of CO^+ column densities at position angle 109° (horizontal in Figure 2) derived for c-values of 0.5 (30.9% reddening), 0.75 and 1.0 (no reddening) and indicates the satisfactory continuum subtraction achieved with $c = 0.75$.
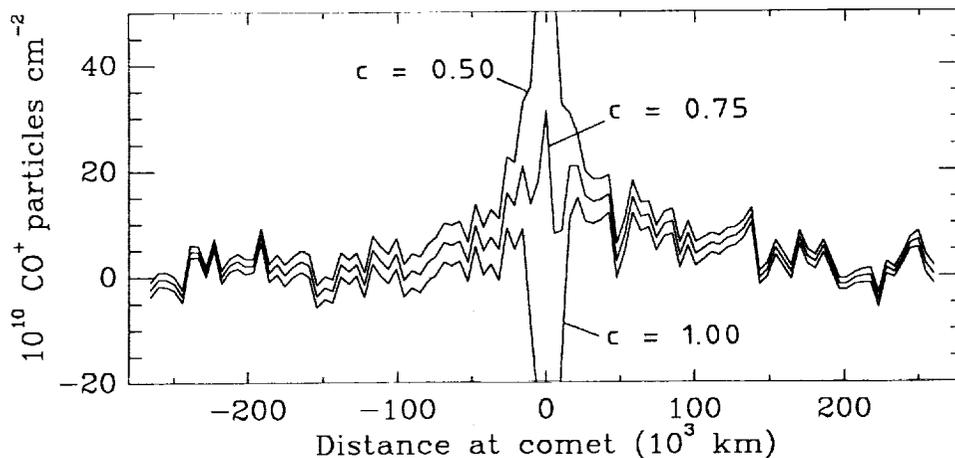

Fig. 1: Traces through "CO^+" images with different constants c.

RESULTS AND DISCUSSION

The red continuum image

Isocontours of the red continuum image are presented in Figure 2a. We provide the absolute continuum in units of mean solar disk intensities (Schwarzschild and Kron 1911). The

outermost contour of 12.5×10^{-15} mean solar disk intensities corresponds to 22.7 stellar mag arcsec^{-2}. In all panels of Figure 2 subsequent contour levels are related by a factor of $\sqrt{2}$. The dust coma is elongated in the direction of η (the vector perpendicular to the antisolar direction pointing in the direction opposite to the cometary motion). In our red passband at 642 nm we find for comet SW1 within a square diaphragm of 4.5 arcsec $m = 16.6$ and within 10.5 arcsec $m = 15.9$. These values agree with those published by Jewitt (1990) for quiescent periods of the comet.

The CO$^+$ image

The isophotes of the blue image are shown in Figure 2b and isophotes of the resulting CO$^+$ image in Figure 2c. The comet is very close to opposition. The phase angle earth-comet-sun was 4°. Therefore we look nearly along the plasma tail. Because the solar wind direction frequently deviates from the radial direction any position angle is possible with angles close to η slightly more probable. The plasma tail appears as a cloud, similar to images of the CO$^+$-rich comet Humason 1962 VIII when it was observed close to opposition (Guigay 1966)
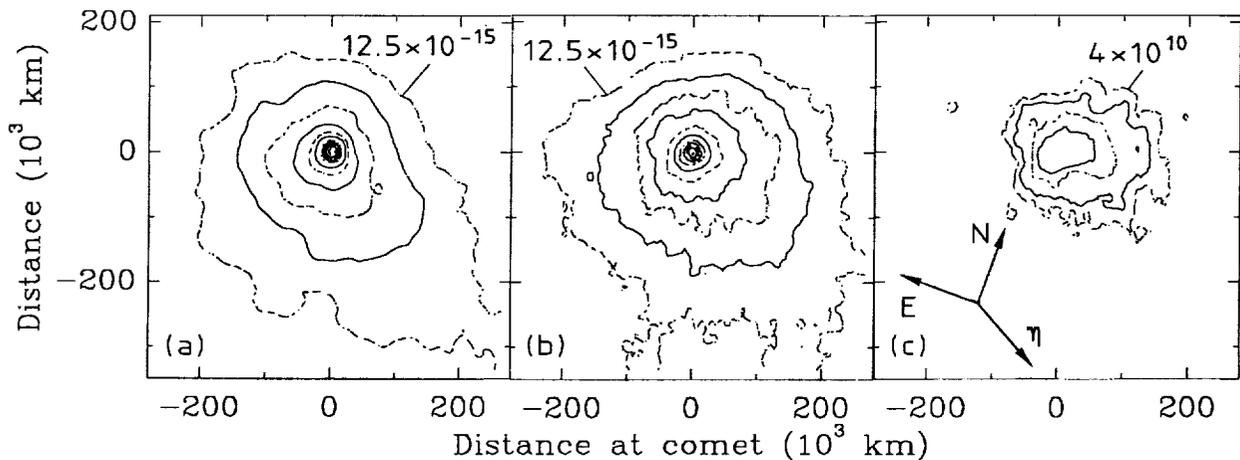

Fig. 2: a: red (continuum) image, b: blue image, both in mean solar disk intensity units, c: CO$^+$ image (particles cm^{-2}). Contours increase with factors $\sqrt{2}$.

around August 21, 1962. The CO$^+$ column densities are similar to those found by Cochran and Cochran (1991). The thickness of the tail of 10^5 km is similar to the thickness of ion tails observed around 1 AU and therefore seems not to scale with the square of the heliocentric distance. The spectra of Cochran and Cochran (1991) are consistent with such a short CO$^+$ scale length. It is, however, likely that a huge, less dense, CO$^+$ cloud surrounds the observed tail which is below the detection limit. A crude estimate of the CO$^+$ production of SW1 can be obtained from the product

column density $\times$ tail width $\times$ ion velocity, projected on sky (this value most uncertain)

$$\approx 6 \times 10^{10} \text{ cm}^{-2} \times 10^{10} \text{ cm} \times 10^6 \text{ cm s}^{-1} = 6 \times 10^{26} \text{ CO}^+ \text{ particles s}^{-1}. \tag{2}$$

Assuming for SW1 a nucleus of 40 km diameter (Cruikshank and Brown 1983), which is CO$_2$ dominated, we find a production rate in excess of 10^{28} CO$_2$ molecules s^{-1} (Cowan and A'Hearn 1982). Our estimated production rate of 6×10^{26}, which is likely to be a lower limit, can be provided by such a nucleus (and even more by a CO dominated nucleus), if

only part of the surface is active, but not by a water dominated nucleus. If SW1's outbursts were caused by crystallization of amorphous water ice (Jewitt 1990) most of the CO^+ would be released during the outbursts. During quiet times evaporation would be controlled by crystalline water ice and only very little CO^+ is expected in contrast to our observations.

Is the CO^+ image spurious?

We have very carefully checked many possibilities which may produce a spurious CO^+ image. Remaining image defects caused by cosmic rays, stars, bad columns and hot lines introduced by a bright star which was accidentally exposed during aquisition of the comet can be ruled out as well as inaccurate flatfielding and background subtraction. The time difference between blue and red exposures is to by far too small to explain the difference between blue and red image by temporal evolution of the dust tail. The red interference filter is centered on a very good continuum window. The blue filter also transmits the CN 0–1 band but so far this band has not been detected spectroscopically. Reflections in the focal reducer optics of bright stars close to the comet may produce such spurious images but we tend to think that the CO^+ image is real.

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