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# Investigation of the comet 29P/Schwassmann-Wachmann 1 at the SOAR telescope

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## Abstract

We carried out photometric and spectroscopic observations of comet 29P/Schwassmann–Wachmann 1 at the SOAR 4.1-meter telescope (Chile) on August 11, 2016. The spectra revealed the presence of $CO+$ and $N_2^+$ emissions in the cometary coma at a distance of 5.9 AU from the Sun. The ratio $[N_2^+]/[CO^+]$ within the projected slit be of 0.01. The images obtained through BVRI filters showed a faint, dust coma. We estimated a color index and a color excess for the comet. The parameter $Af\rho$, which is used as an indicator of a cometary activity, was measured. We also investigated the morphology of the comet using digital filters and found two jets in the coma.

## 1. Introduction

Small bodies with orbits beyond that of Neptune are of interest because they must have undergone minimal changes since the Solar System formation. The equilibrium temperature ($\leqslant$140 K) at these distances is too low to ensure a significant level of physical activity caused by the sublimation of water ice. As of today, the active centaur 29P/Schwassmann-Wachmann 1 (SW1) is still the most interesting and studied distant object. In this work we carried out investigation of comet SW1 at the SOAR 4.1-meter telescope. The comet was observed at the heliocentric distance of 5.9 AU, and showed low activity and faint coma.

## 2. Observations

Photometric and spectrophotometric observations were made at the SOAR 4.1 m telescope in Cerro Pachón - Chile during August 11, 2016. The Goodman imaging/spectrograph was used with a 600 l/mm grid, which provides for the spectroscopic mode a reciprocal dispersion of 0.065 nm/pixel and, using a 1.68 arcsec slit width, a spectral element resolution of 0.73 nm. The SOAR Goodman spectrograph blue camera features one 4096 x 4096 pixel Fairchild CCD and a 7.2 arcsec in diameter field of view in the imaging mode. The photometry was done with Bessel BVRI filters. The seeing was stable during the night, with a mean value of 0.8 arcsec FWHM. The cometary spectra were acquired with 10 exposures, which were also co-added to increase the final signal-to-noise ratio. The spectrophotometric standard stars LTT 9491 was observed with a long slit of 3 arcsec width, allowing a more precise flux calibration. Data reduction was performed using the IRAF package, following the standard procedure for ccd reduction, i.e. correction of bias and flat-field. The spectral images were extracted and calibrated in wavelength and flux. Atmospheric extinction was corrected through mean coefficients derived for the CTIO observatory.

## 3. Results

From the spectral and photometrical data, it was possible to obtain the distribution of energy in wavelength, to identify the molecular emissions, and to estimate the dust color and dust production rate (like [1]). The comet SW1 shows long-term outburst activity in the form of dust jets, which can be considered typical for this comet. To select the weak contrast structures (jets) in the images of the dust coma, we used the special software Astroart, which is provided with a number of digital filters. To eliminate false details, each of the filters was separately applied to each image. After this filtering we selected jets structures.

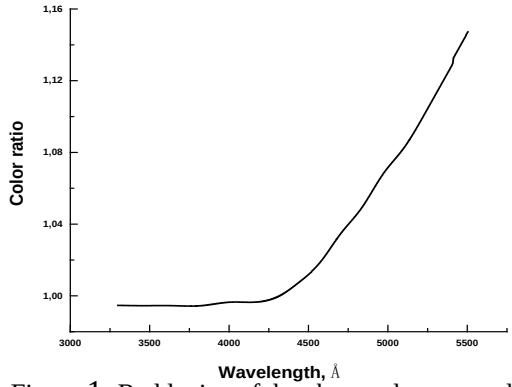


Figure 1: Reddening of the observed spectra relative to the solar spectrum

Using the median filter with wide window, we obtained a smoothed curve that reproduces spectral dependence of the solar radiation scatter efficiency caused by the cometary dust particles. The result is given in Figure 1, and one can see that there is a nonlinear increase with the wavelength of the scattering efficiency. For our observations the normalized reflection ability:

$\boldsymbol{S'(\lambda_1, \lambda_2)}$ = 11,31 ± 0,04% for the range 4430-5260 Å

The strongest features seen along the whole observed spectral window are the $CO^+$ bands from the comet tail. The lines (2,0), (3,0), (2,0), (1,0), (5,1), (3,1) , (2,1), (4,2), (3,2), (0,0), and (1, 1) of the vibrational transitions band system ($A^2\Pi$–$X^2\Sigma$) of the $CO^+$ are clearly seen in Figure 2. Two weak bands, (0,1) and (1,2) from the ($B^2\Sigma$–$A^2\Pi$) system (Baldet–Johnson) of the $CO^+$ ion, were detected as well. The $N_2^+$ of the ($B^2\Sigma$-$X^2\Sigma$) electronic system is shown also.

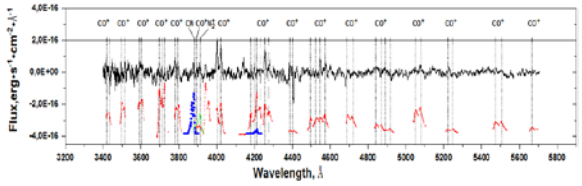


Figure 2: Linear spectrum and molecular emissions of the comet SW1. Color lines in bottom are the theoretical spectra predicted for the molecules *CN* (blue), $N_2^+$ (green) and $CO^+$ (red).

The $N_2^+/CO^+$ ratio is important in our understanding of the Solar System nebula formation. To estimate that ratio, we used integrated intensities of the $CO^+$ (2, 0) and $N_2^+$ 0, 0) bands. The column density ($N$) is defined by $N=L_{gv'v''}$, where $L$ is the integrated band intensity and $gv'v''$ is the excitation factor. We used excitation factors of $7.0\times10^{-2}$ photons·$s^{-1}$·$mol^{-1}$ for the $N_2^+$ (0, 0) band and $3.55\times10^{-3}$ photons·$s^{-1}$·$mol^{-1}$ for the $CO^+$(2, 0) band. Finally, the ratio can be derived using the following expression:

$$\frac{N_2^+}{CO^+} = \frac{g_{CO^+}}{g_{N_2^+}} \cdot \frac{L_{N_2^+}}{L_{CO^+}}$$

If only the (2,0) band column density of $CO^+$ is used, then $[N_2^+] / [CO^+]$ should be equal to 0.01. The sublimation temperatures of *CO* and $N_2$ are 25 K and 22 K, respectively. Recent laboratory experiments indicate that the ice grains, which accumulated to produce the comet nuclei, were formed by freezing of water vapour at about 25 K. So, the comets may have been formed either beyond Neptune orbit, or at an early stage of the Solar System formation.

## Summary and Conclusions

Using digital filters, we succeeded to isolate some structures in cometary coma (2 jets). Spectral dependence of the light scattering by the cometary dust obtained from the spectral observations of comet SW1 is typical for earlier observed comets: the mean value of the normalized spectral gradient equals to 11,31 ± 0,04% for the range 4430–5260 Å. SW1 is a $CO^+$ and $\boldsymbol{N_2^+}$ rich comet. The result suggests that the comets were possibly formed in a low temperature (about 25 K) environment. The value of $[\boldsymbol{N_2^+}]/[CO^+]$ is equal to 0.01.

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## References

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