Boletim da Sociedade Astronômica Brasileira, **32**, no. 1, 91-92

Analysis of water production rates for the hyperactive comet 46P/Wirtanen

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Abstract. The Comet 46P/Wirtanen was discovered on 1948 January 17 by Carl A. Wirtanen. After its first apparition, there were 13 passages close to the Sun, with orbital period of about 5.44 years. This comet reveals nucleus dimensions of about 1.4 km and high levels of activity, that is, with water production rates higher than expected for its small nucleus. In this way, it is considered a hyperactive comet. The main objective of this work, as part of an International Observation Campaign (http://wirtanen.astro.umd.edu/), which includes ground and space observations, is to contribute with improvements in the model for the comet activity, using a semi-empirical method for determining the water (H_2O) and hydroxyl (OH) production rates from the photometric observations. Besides that, it is possible to determine gas mass release rates and estimate the minimum nuclear radius of the comet.

Resumo. O cometa 46P/Wirtanen foi descoberto em 17 de janeiro de 1948 por Carl A. Wirtanen. Após sua primeira aparição, houve 13 passagens próximas ao Sol, caracterizando um período orbital de cerca de 5,44 anos. Este cometa revela dimensões nucleares de cerca de 1,4 km e altos níveis de atividade, ou seja, com taxas de produção de água acima do esperado para o seu pequeno núcleo. Desta forma, é considerado um cometa hiperativo. O objetivo principal desse trabalho, como parte de uma Campanha de Observação Internacional (http://wirtanen.astro.umd.edu/), a qual inclui observações terrestes e espaciais, é contribuir para melhorias na modelagem da atividade cometária, utilizando um método semi-empírico para determinar as taxas de produção de água (H_2O) e hidroxila (OH) a partir das observações fotométricas. Além disso, é possível determinar as taxas de liberação de massa de gás e estimar o raio nuclear mínimo do cometa.

Keywords. Comets: general – Comets: individual – Astrochemistry

1. Introduction

For a long time, studies have been carried out to obtain answers about processes that occur in our Solar System, including its formation and evolution. Despite the great discoveries already achieved, there is still much to explore. Due to the eccentric orbits and small sizes, comets preserve information about their physicochemical composition from formation to final evolution. Characterized by high volatility, they interact with the solar wind, leading to sublimation and ejection of ice, the nucleus main compound, thus forming the coma that surrounds the nucleus (where processes of molecular dissociation occur, responsible for the formation of various chemical compounds), and the tail (composed of gas and dust).

The Comet 46P/Wirtanen was discovered using a photographic plate exposure and described as a diffuse comet, with a central condensation and magnitude 16 mag. It was the original target of the Rosetta Mission. However, due to the delay in launching the spacecraft, the mission was reappointed to Comet 67P/Churyumov-Gerasimenko.

Due to its hyperactivity, Wirtanen has interesting features, making it a target of international campaign of ground and space observations. In particular, we have been able to study its behavior with great success because of its close proximity (reaching a geocentric distance of 0.077 AU in December 2018).

The main objective of this work is to contribute to improvements in the model for the comet activity, using the semi-empirical method described in details by de Almeida, Singh & Huebner (1997), for determining the water and hydroxyl (OH) production rates from the photometric observations (visual brightness), taken from the database disposed in Comet Observation Database (COBS). We are determining gas mass release rates and estimating the minimum nuclear radius of the comet. The results obtained are compared to those determined by orbiting satellites such as SOHO/SWAN.

2. Theoretical Considerations

The water production rate was calculated from the ratio obtained through the semi-empirical method of visual magnitudes ($SEMVM$). This is given by de Almeida et al. (2016):

$$Q(H_2O) = \frac{r^2 10^{0.4(-26.8-m'_V)} - pR_N^2\phi_N}{l_r R_1[1+\delta(r,\theta)]}^{0.82}, \quad (1)$$

where $m'_V = m_{6.78} - 5log\Delta$, $m_{6.78} = [m_v - b(d - 6.78cm)]$, with $b = 0.019\ magcm^{-1}$ for reflectors, $b = 0.062\ magcm^{-1}$ for refractors and $b = 0.066\ magcm^{-1}$ for naked eye, $p = 0.04$, $l_r = 6.6x10^4 r^2$, $R_1 \approx 1.7x10^{-38} cm^2 s$ and $\phi_N = 0.9982e^{-1.842\alpha}$, where α (in rad) is the phase angle of the comet.

We can relate the hydroxyl (OH) and water (H_2O) production rates by Hubner, Kenedy & Lyon (1992):

$$Q(OH) \approx 0.85 Q(H_2O). \quad (2)$$

The comet coma is composed of 77% water, 11% to 13% of carbon monoxide (CO) and 10% other compounds. In this way, the rates for water and the total gas are related by (1):

$$Q_g \approx 4,425x10^{-23} Q(H_2O). \quad (3)$$

The minimum nuclear radius size can be found by considering an active surface area (A_A) from:

$$A_A = \frac{Q(H_2O)}{f_{AA} Z(T)}, \quad (4)$$

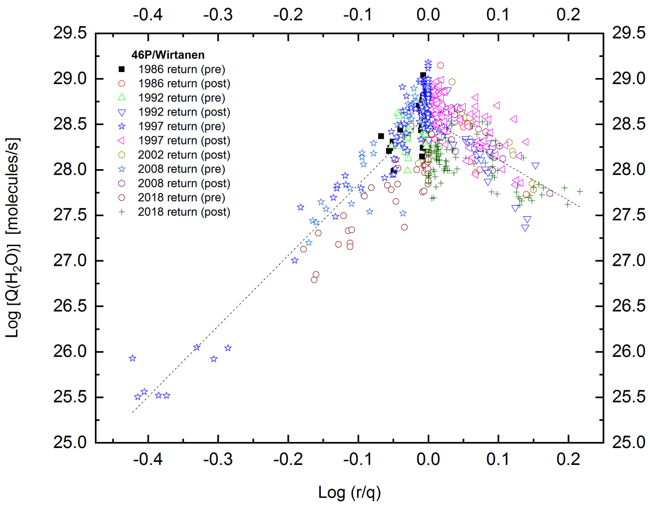

FIGURE 1. Variation of water (H_2O) production rates as a function of the ratio between heliocentric and perihelic distances.

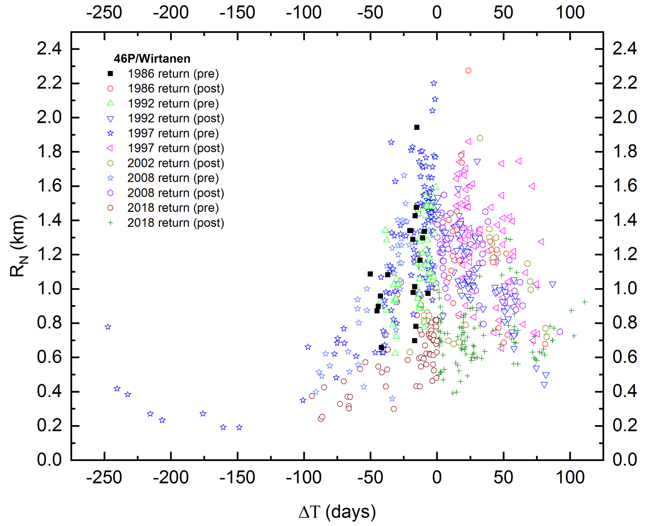

FIGURE 2. Correlation between nuclear radius and the time from perihelion.

where $Z(T)$ is the water sublimation rate per unit area [in molecules/($cm^2.s$)] and f_{AA} is the fraction of the active surface area ($0 < f_{AA} < 1$).

An approach is being taken, considering all surface as active ($f_{AA} = 1$) and $A_A = 4\pi(R_N)^2$.

This summarizes the method used to calculate production rates.

3. Results

The survey of the database was made from the data platform COBS (*Comet Observation Database*) with the combination of ICQ (*International Comet Quartely*) and BAA (*British Astronomical Association*) libraries. For this work, the six passages with available data were used, having their perihelion in the years of 1986, 1992, 1997, 2002, 2008 and 2018.

In Figure 1 is shown the increasing in water production rate when the comet approaches to perihelion in all passages analyzed. It is also observed the steep inclination which is a common feature of periodic comets. The following relations represent the behavior of the pre and post perihelic phases, respectively:

$$Q(H_2O) = 2.67x10^{12}(r/q)^{7.76684} \tag{5a}$$

$$Q(H_2O) = 2.52x10^{12}(r/q)^{-4.47202} \tag{5b}$$

The coefficients for the correlations are, respectively, 83.44% and 67.2%.

Analyzing the relation between nuclear radius and the production rate, it was possible to explain the behavior presented in Figure 2. For the minimum values of interest, we obtain the following results:

- 1986: $R_N(min) = 0.65$ km;
- 1992: $R_N(min) = 0.44$ km;
- 1997: $R_N(min) = 0.37$ km;
- 2002: The value was not determined due to the lack of data;
- 2008: $R_N(min) = 0.36$ km;
- 2018: $R_N(min) = 0.24$ km.

As seen in the equations 5a and 5b, the post-perihelic phase tends to be flatter than the pre-perihelic phase. That can indicate a decrease in the activity of the comet with the passages and, consequently, of the fraction of active surface area.

Considering the maximum and the minimum values, we get a f_{AA} close to 0.05% in 2018. With the application of equation (4) and the values of $Q(H_2O)$ and $Z(T)$ determined, we obtained an effective radio of 1.072 km, agreeing with the dimensions informed previously.

As a way of expanding the results and increasing the database for the comparative study, we will also use additional data taken from the literature.

Acknowledgements. To my advisor and CAPES, Brazil, for the master's scholarship.

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