Water Production Rate in the Comets

Tasa de Producción de Agua en los Cometas

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***Abstract*— In the atmosphere or coma of a comet, the dissociation of water gives the OH radical, that is detectable by radioastronomical methods. Analyzing the spectral emission line of 18 centimeters, corresponding to the hydroxyl OH, can be deduced its rate of production, and, consequently, is possible infer the rate of water production. The results of the measurements carried in France with the Nancay radio telescope, in Puerto Rico with the Arecibo Radio Telescope, in Hawaii with the J. C Maxwell telescope and in Chile with ALMA radiotelescope, are allowing currently trying to build unified models of evolution and activity cometary.**

***Key Word* — Comet, atmosphere, coma, water sublimation, emission, spectral, hydroxyl, evolution.**

***Resumen*— En la atmósfera o coma de un cometa, la disociación del agua origina el radical OH, cuya presencia es detectable por métodos radio astronómicos. Analizando la linea de emisión espectral de 18 centímetros, correspondiente al hidroxilo OH, se puede deducir su tasa de producción, y, en consecuencia es posible inferir la tasa de producción de agua. Los resultados de las mediciones realizadas en Francia con el radiotelescopio de Nancay, en Puerto Rico con el Radiotelescopio de Arecibo, en Hawai con el Radiotelescopio J. C. Maxwell y en Chile con ALMA, están permitiendo actualmente intentar construir modelos unificados de la evolución y actividad cometaria.**

***Palabras clave*— Cometa, atmósfera, coma, agua, sublimación, emisión, espectral, hidroxilo, evolución.**

I. INTRODUCTION

When a cometary nucleus enters the inner solar system, it undergoes a fast and dramatic process of sublimation of its volatile components, which leads to the formation of an atmosphere called coma,
in the that are identify in its espectrum, water, carbon monoxide, carbon dioxide, methane, propane, ethanol, methanol, hydrogen cyanide, hydrogen sulfide, ammonia, acetylene and abundant dust. The dissociation of water originates the OH radical, whose presence is detectable by radio astronomical methods. The 18 cm emission line of the OH hydroxyl is produced in the transitions between the hyperfine structure of the two levels corresponding to the doublet$\Lambda$of the states of minimum energy electronic, rotatory and vibratory of the OH molecule. The fundamental state of the hydroxyl molecule, is the rotatory state $J=\frac{3}{2}$ of the electronic state $^2\prod_{\frac{3}{2}}$, in it state are possible two different orientations of the electrons distributions with respect to the axis of molecular rotation: one along the axes of rotation and the other in the plane of rotation, therefore the rotatory state $J=\frac{3}{2}$ of the electronic state $^2\prod_{\frac{3}{2}}$ it unfolds on two levels; This phenomenon is called doublet Λ. The transitions between these two levels originate the emission line of 18 centimeters. The analysis of the emission line of 18 centimeters of the OH allows to calculate its abundance, to later determine the water production rate. [1] Pacholczyk A. G. (1979).
In France, using the Nancay Radio Telescope and in Puerto Rico, with the Arecibo Radio Telescope, in the last three decades the emission line of 18 centimeters has been observed in a considerable number of comets.

II. THEORETICAL MODEL

The physical model for the OH production rate is assumed from the analysis presented in [2] Schloerb and Gérard (1985), [3] L. E. Tacconi-Garman, F. Peter Schloerb, M. J. Claussen (1990). Then, the OH production rate can be calculated with the following expression

$$Q_{OH}=\frac{S_\nu 4\pi\Delta^2}{A_{\mu l} ikT_{BG}}\frac{8}{c}\frac{2V_{Max}\nu}{(2F_\nu+1)\tau_{OH}}\frac{molecules}{s} \quad (1)$$

where $S_\nu$is the spectral flux density in mJy-km/s for a frequency ν , 1 Jansky =10^{-26}watts, $\Delta$is the distance earth-comet in astronomical units AU, $A_{\mu l}$ is Einstein's coefficient, i is the inversion of the ground state Λ-doublets levels, k is the Boltzmann constant, T_{BG} is the cometary background temperature, c is the

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electromagnetic waves speed in the vacuum, V_{Max} is the maximum expansion velocity of OH, F_v is the statistical weight of the upper level of the transition, $\tau_{OH}$is the lifetime of the OH molecules.
as in average one of every 555 molecules of water dissociates, then

$$Q_{H_2O} = 555x10^6 Q_{OH} \frac{molecules}{s} 3x10^{-26} \frac{kg}{molecules} \quad (2)$$

III. METHODOLOGY

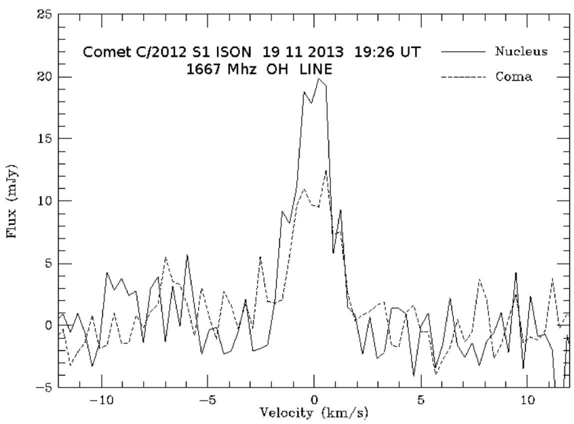

Figure 1. 18 centimeters emission line. Credits, Nancay radiotelescope. Spectra Database.

S_v is the area of the 18 centimeters emission line OH in mJy-km/s, the frequency $\nu$is 1667 MHz, T_{BG}= 3.3 K, according to L. E. Tacconi-Garman, F. Peter Schloerb, M. J. Claussen (1990) a graphic of the width FWHM
of the OH emission line as a function of the heliocentric distance allows to assume $V_{Max} = 2\,km/s$ or calculate it as in [1] D. Bockelee-Morvan, J. Crovisier and E. Gerard (1990) adjusting the best trapeze to the emission line of the OH.

IV. RESULTS

According to the theoretical model and using equations 1 and 2, the results of the observations of Mark Kidgers, can be reproduced and shown in table 1.

R Distance Sol-Comet **A. U.**	Q_{H_2O} Water Production Rate kg/s
1,10	1288,25
1,36	2344,23
1,37	2089,30
1,40	1047,13
1,41	955,00
1,54	1584,90
1,55	1348,96
1,56	912,00
1,97	1318,25
2,18	1202,26
5,12	251,19

Table 1. Results of the observations of the Water Production Rate for the Comet C/2012 S1 ISON by Mark Kidger`s. http://www.observadores-cometas.com/cometas/2012s1/qdust.html.

with data of the table 1 is obtained the graphic of the figure 2, that shows the Water Production Rate as a function of the Distance to the Sun for the Comet C/2012 S1 ISON.

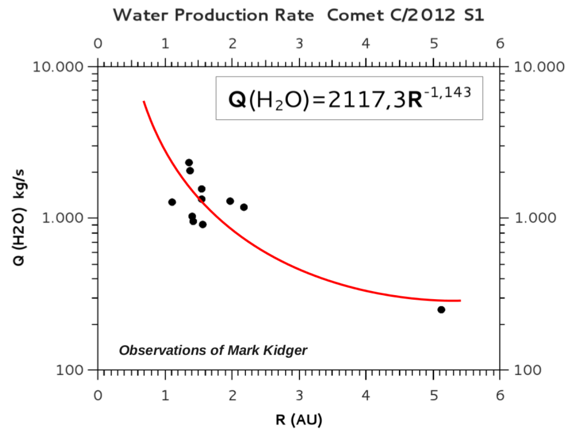

Figure 2. Water Production Rate for the Comet C/2012 S1 ISON. Graphic obtained with data of Mark Kidger`s.

Then, the water production rate as a function of the orbital movement can be expressed with the following equation.

$$Q_{H_2O} = 2117{,}3R^{-1{,}143} \quad (3)$$

This equation obtained from the radio astronomical observations is very important, because it allows to calculate critical points on the curve of evolution and activity of the cometary nucleus and consequently to calibrate the evolution. For example, the fig. 3 shows the critical points on the curve of the evolution and activity of the ISON comet nucleus. See [4]. Deaza R. Pedro I. (2013).

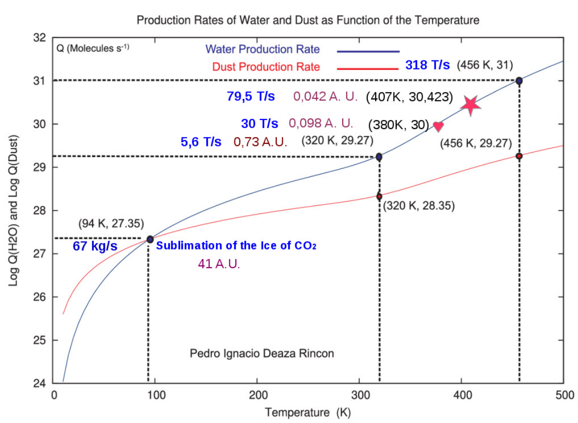

Fig. 3. Logarithm of the Water Production Rate as a function of the Temperature for the Comet C/2012 S1 ISON.

the magnitudes in red are in tons per second and their correspondence with the magnitudes of the vertical axis can be verified. for example, in the red star $79{,}5\frac{T}{s} = 10^{30{,}423}\frac{molecules}{s}$.

The lower limit in the evolution and activity of Comet C / 2012 S1 ISON results from the cut of the curve of the water production rate and the curve of the dust production rate, in the graph corresponds to a Temperature of T=94 K already a water production rate of $Q_{[H_2O]} = 10^{27{,}35}$= 67 kg/s, is the point of sublimation of the iceCO_2, the comet is orbitally at a distance of 41 A.U.

The upper limit is the maximum water production rate in the orbital position of minimum distance to the sun, The perihelion, and is calculated using equation 3, which in the case of Comet C/2012 S1 ISON is R = 0.012472 A.U., and its result is $Q_{[H_2O]} = 318000\, kg/s = 1{,}06x10^{31}\, molecules/s$

The previous result allows to infer a temperature in the perihelion of T = 456 K.

Now the interval on the domain and the codomain of the function is defined. In the temperature domain from T = 94 K to T = 456 K, for the water production rate from $Q_{[H_2O]} = 67\, kg/s$to $Q_{[H_2O]} = 318\, T/s$.

The beginning of the processes of activity and sublimation on the surface of the cometary nucleus, is the point of sublimation of the CO2 ices. In the graph, we observe from this point, a gradual increase in temperature and consequently an increase in the water production rate. When the comet reaches a temperature T = 320 K and a water production rate$Q_{[H_2O]} = 5{,}6\, T/s$at a distance of 0.73 A.U. , from this point, we observe an increase of the slope, that is equivalent to an increase of the activity and the processes of sublimation that lead to the comet to the first ourburst and generation of fragments in an orbital position at a distance to the sun of 0.098 A.U., a temperature T = 380 K and a water production rate of$Q_{[H_2O]} = 30\, T/s$

Finally, the catastrophic fragmentation occurs when the comet is at a distance of 0.042 A.U. with a temperature T = 407 K and a water production rate$Q_{[H_2O]} = 79{,}5\, T/s$. As a consequence, the comet passes through the perihelion, fragmented and in rapid process of extinction.

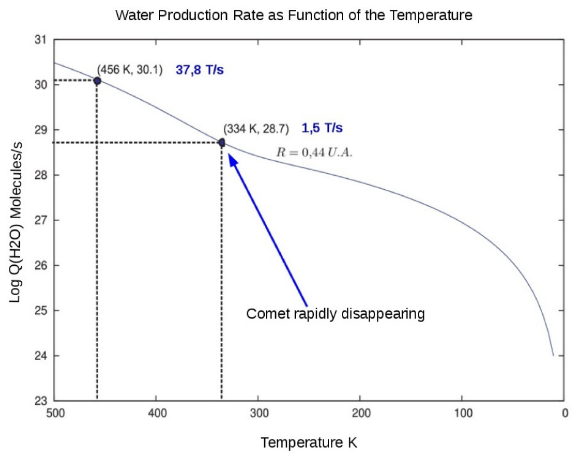

Fig. 4. Logarithm of the Water Production Rate as a function of the Temperature for the Comet C/2012 S1 ISON, after its passage through perihelion.

The graph of fig. 4, reveals the asymmetry in the water production rate with respect to perihelion. According to the physical behavior before the perihelion, the comet should have reached perihelion with a water production rate $Q_{[H_2O]} = 318\,T/s$. But as its nucleus was fragmented before the perihelion, its consequence is revealed in its evolution, its production of water descended dramatically to $Q_{[H_2O]} = 37{,}8\,T/s$

Its rapid descent in the production of water continued its course and when its fragments, which moved orbitally closely linked to its center of mass reached a distance R = 0.44 U.A., distance at which the observers reported an average heliocentric magnitude of $m_{\Delta} = 7{,}5$its water production rate was$Q_{[H_2O]} = 1{,}5\,T/s$
at an average surface temperature for each fragment of T = 334 K. Finally the comet disappears.

V. CONCLUSIONS

The observations of the emission line of 18 cm of the OH, are a mechanism satisfactory and of precision high to deduce equations that allow to calculate the water production rate as a function of the orbital movement for each comet and use these equations to calculate critical points on the curve of the evolution and activity of a comet and consequently calibrate its evolution.
It is generally necessary to calculate the rate of water production in the perihelion and at some point of abrupt and unusual increase of the cometary activity and also at T = 94 K, that is, the start of CO2 sublimation.
The determination of these critical points is used to calibrate and validate the physical model of evolution and activity of the cometary nucleus.
The future of the unification of the physical, numeric and computational models of the activity of a cometary nucleus will depend of the radio astronomical observation in the different emission lines of the sublimated volatiles that are observed in the coma of a comet.

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