On the Relationship Between Gas and Dust in Comets: an Application to Comet 85P/Boethin

Sobre a relação entre o gás e a poeira em Cometas: uma aplicação ao Cometa 85P/Boethin

Daniel Trevisan Sanzovo
Central Western State University - UNICENTRO
Department of Physics
dsanzovo@unicentro.br

Gilberto Carlos Sanzovo
State University of Londrina - UEL
Laboratory of Molecular Astrophysics, Department of Physics

Amaury Augusto de Almeida
University of São Paulo - USP
Department of Astronomy, Institute of Astronomy, Geophysics and Atmospheric Sciences - IAG

Abstract: Except for some narrowband photometric observations obtained by A´Hearn et al. (1995), in literature there is no other information available about Comet 85P/Boethin´s activity, such as mass loss and nuclear size for this short-period (~11.2 years) comet. In an effort to find more information about this object, we have used visual magnitude measurements available from *International Comet Quarterly* (ICQ) to obtain the water production rates (in molecules s^{-1}) related to its perihelion passage of 1986 by applying the Semi-Empirical Method of Visual Magnitudes-SEMVM (de Almeida et al., 1997; Sanzovo et al., 2001). When associated to Delsemme's (1982) water vaporization theory, these rates allowed for the calculus of the dimension of the effective minimum nuclear radius of the comet. The water production rates were then converted into gas production rates (in g s^{-1}) so that, applying the correlation between gas and dust found for eleven periodic and three non-periodic comets deduced by Trevisan Sanzovo (2006), we have obtained the dust loss rates (in g s^{-1}), its behavior with the heliocentric distance and the dust-to-gas ratios for this little-known comet.

Key words: gas release rates; dust release rates; dust-to-gas ratios; short-period comets; non-periodic comets; Comet 85P/Boethin.

Resumo: Com exceção de algumas observações fotométricas de banda estreita realizadas por A´Hearn et al. (1995) não há, na literatura, nenhuma outra informação disponível sobre a atividade do Cometa 85P/Boethin, tais como perda de massa e dimensão nuclear para este cometa de curto-período (~11,2 anos). Em um esforço no sentido de encontrar mais informações a respeito deste objeto, nós usamos, neste trabalho, medidas de magnitudes visuais disponíveis no periódico *International Comet Quarterly* (ICQ) para obter, aplicando o método Semi-Empírico das Magnitudes Visuais - MSEMV (de Almeida et al., 1997; Sanzovo et al., 2001), as taxas da produção da água (em moléculas s^{-1}) relativas à sua passagem periélica de 1986. Quando associadas à teoria de vaporização da água de Delsemme (1982), essas taxas permitiram o cálculo da dimensão do raio nuclear mínimo efetivo do cometa. As taxas da produção de água foram convertidas, então, em taxas de produção de gás (em g s^{-1}) de modo que, aplicando a correlação entre o gás e a poeira encontrada para onze cometas periódicos e três não-periódicos, deduzida por Trevisan Sanzovo (2006), nós obtivemos as taxas da perda de poeira (em g s^{-1}), seu comportamento com a distância heliocêntrica e as razões poeira-gás deste cometa pouco conhecido.

Palavras-chave: taxas de perda de gás; taxas de perda de poeira; razões poeira-gás, cometas de curto-período; cometas não-periódicos; Cometa 85P/Boethin.

1. Introduction

Comet 85P/Boethin was discovered on 1975 January 4.5 in Abra, The Phylippines, by Reverend Leo Maximilian Boethin with an estimated visual magnitude of ~ 12, and observed again only in 1986. On the occasion of its return in 1997, the comet could not be observed from the Earth since it was behind the Sun. Today it is known that the comet has an orbital period of ~ 11.2 years and that as to perihelion passage of 1986, the inclination of its orbit with respect to the ecliptic plane and the perihelion distance were ~ 5.7° and 1.114 AU, respectively, and with perihelic date reached on 1986 January 16.4 (Marsden & Williams, 1993). For this return, ICQ makes available a set of 188 visual magnitudes measurements taken between 1985 November 3.4 and 1986 March 28.8, corresponding to r = 1.513 AU in the pre-perihelion phase and r = 1.491 AU, in the post-perihelion phase. These observational data were obtained by several observers and were published in various issues of ICQ. The maximum brightness of the comet was reached on 1986 January 8.97, resulting in a visual magnitude $m_V = 7.0$, obtained using a 20.3 cm aperture reflector. In this work, the application of the Semi-Empirical Method of Visual Magnitudes (SEMVM) to this visual magnitude data - unique in literature - obtained during the perihelion passage of 1986 of Comet 85P/Boethin allowed the deduction of the water production rates (in molecules s^{-1}), which together with the vaporization theory of Delsemme (1982) allowed for the determination of the comet's nuclear dimension, besides its gas loss rates (in g s^{-1}). We also used the gas-to-dust correlation found by Trevisan Sanzovo (2006) for ten Jupiter Family (JF) comets with the purpose of estimating the corresponding dust loss rates. This correlation is applied to Comet 85P/Boethin. To this date, there is no information in literature concerning its activity, such as nuclear dimension, mass, and mainly, those associated to the amount of matter lost in the form of gas and dust. To the best of our knowledge, the only information available in literature is from A'Hearn et al. (1995) who provide an average estimate for the water release rates at r = 1.12 AU. The use of the correlation found between the gas and dust made possible the estimate the dust-loss rates, as well as the dust-to-gas ratios.

2. Theoretical Considerations

2.1 The Semi-Empirical Method of Visual Magnitudes (SEMVM) and the Gas-to-Dust correlation

Assuming that m_V' (= $m_{6.78}$ – 5 log Δ) is the total visual magnitude observed from the coma of a comet, reduced to the standard diameter of 6.78 cm when the observer is placed at a standard geocentric distance Δ = 1 AU (Morris, 1973), and the comet at a heliocentric distance r(AU), the water production rate (in molecules s^{-1}) is given by (Newburn 1981; de Almeida et al., 1997; Sanzovo et al., 2001)

$$Q(H_2O\left\{\frac{r^2.10[0.4(-26.8-m_v')-p.R_N^2.\phi_N}{R.l_r.[1+\delta(r,\theta)]}\right\}^{0.825} \quad (1)$$

where p=p(λ) is the geometric visual albedo of the comet's nucleus with radius RN, and ΦN = 0.9982e–1.842α, where α is the phase angle (in rad) of the comet (Sanzovo et al., 1996; Singh et al., 1997). A'Hearn et al. (1995) showed that JF comets are carbon-depleted having low abundances of carbon-chain species like C2, C3, and CN when compared to Halley-type (HT) and long-period (LP) comets. Equation (1) represents an average correlation between water release rates and C2 production rates, obtained using observational data from Comet Levy (C/1990 K1) and seven JF comets (6P/d´Arrest, 9P/Tempel 1, 10P/Tempel 2, 22P/Kopff, 26P/Grigg-Skjellerup, 67P/Churyumov-Gerasimenko, and 81P/Wild 2), as reported by Sanzovo et al. (2001). The parameter R, the resonance fluorescence efficiency constant, takes in account the water release rates, an assumed known value for the nucleus radius RN, and is determined empirically, varying between ~ 10–39 and ~ 10–37 cm2 s-1 according to the periodicity of the comet. We adopted 8 x 10–38 cm2 s-1 for JF comets, 2 x 10–38 cm2 s-1 for HT comets, and 5 x 10–39 cm2 s-1 for LP comets like Levy (C/1990 K1). If we knew the fluorescence process by which C2 is formed (see for instance Rousselot et al., 2000 and other references therein), we might have been able to derive a theoretical value for R; while lr (=6.6 x 104.r2) is the scale-length for photodissociation of C2 radical

(Randall et al., 1992; A'Hearn et al., 1995). In equation (1) the nucleus makes a significant contribution only when the phase angle 〈 of the comet is small. For the 1986 return of Comet 85P/Boethin, ICQ observational data provide phase angles varying between ~ 35° and ~ 47°. Therefore, it should be noted that in equation (1) the nuclear radius RN may be ignored with the used measurements, and was a free parameter in order to run the computer code. The dust-to-gas ratio in a comet can be expressed by (Ney 1982)

$$\partial(r,\theta) = \frac{\partial(r,90)\partial(\theta)}{\partial(90)} \qquad (2)$$

in which the scattering function $\delta(\theta)$ is obtained from the observational curve proposed by Divine (1981), for the scattering angle $\theta=180°-\alpha$, and $\delta(90)=0.0362$. We have determined and applied in equation (1) the dependencies of $\delta(r,90)$ on r for each individual comet studied in our sample.

Once the water production rates are obtained, its conversion into gas loss rates can be accomplished, considering a gaseous mixture of ~ 77% H_2O, ~ 13% CO, and ~ 10% of other molecular species with average molecular weight of ~ 30 amu (Sanzovo et al., 1996; Singh et al., 1997). Following this, the gas loss rates (in g s^{-1}) correlates to the water production rates (in molecule s^{-1}) through the expression

$$q_g = 3.42x10^{-23} Q(H_2O) \qquad (3)$$

Besides the water (and gas) production rates, the structure of SEMVM can be combined with the water vaporization theory, described by Delsemme (1982), in order to obtain an estimate of the minimum and effective nuclear dimension of a comet. If A_{AA} is the total active surface area on the nucleus at a heliocentric distance r, and Z(T) is the sublimation rate of this volatile, per unit area, then A_{AA} = $Q(H_2O)/f_{AA}.Z(T)$, where $Q(H_2O)$ is the water production rate (in molecules s^{-1}) inferred through the SEMVM for that same heliocentric distance, and f_{AA} is the fraction of active surface area. Assuming a slow rotation hypothesis for the nucleus with spherically symmetric f_{AA} = 1, this active surface area will be bound to the comet's minimum nuclear radius by (de Almeida et al., 1997)

$$\frac{A_{AA}}{2\pi(R_N)^2} \leq 1 \qquad (4)$$

Once the f_{AA} parameter is fixed, the Delsemme´s theory (1982) can be used to calculate the effective nuclear radius for comets. Tancredi et al. (2000) present a catalog of a sample of 105 JF comets with "best estimates" of their absolute visual nuclear magnitudes. They discarded 33 JF comets, for which they were not able to adopt or even approach a reasonable estimate of a nuclear magnitude mainly because there are very few data. 85P/Boethin is amongst these comets.

In view of the very scant information in literature referring to Comet 85P/Boethin, except for the visual magnitude data available in several issues of ICQ, we used for the estimate of the dust loss rates, q_d, the gas-to-dust correlation found by Trevisan Sanzovo (2006) for Comets 9P/Tempel 1, 10P/Tempel 2, 21P/Giacobini-Zinner (21P/GZ), 22P/Kopff, 24P/Schaumasse, 26P/Grigg-Skjellerup (26P/GS), 46P/Wirtanen, 62P/Tsuchinshan 1, 67P/Churyumov-Gerasimenko (67P/CG), and 81P/Wild 2 determined for λ = 4845 and 4770 Å, and dust particle density ρ_d = 0.5g cm^{-3}. The correlation is given by

$$\log(q_g) = (2.052 \pm 0.187) + (0.755 \pm 0.043) \mathrm{x} \log(q_d) \qquad (5)$$

and appear illustrated in Figure 1. The same figure shows another dust-to-gas correlation [$\log(q_g) = (-0.200 \pm 0.203) + (1.067 \pm 0.031) \times \log(q_d)$] valid for Comets C/Hale-Bopp, C/Hyakutake, C/Levy, and also including 1P/Halley. To estimate those correlations, Trevisan Sanzovo (2006) used continuum data given by Schleicher et al. (1998) and Catalano et al. (1986) for Comet 1P/Halley; Miguel Torres (2001) for Comets 10P/Tempel 2, 67P/CG, and 81P/Wild 2; Schleicher et al. (1987) for Comet 21P/GZ; Storrs et al. (1992), and Schleicher (2006) for Comets 9P/Tempel 1, 22P/Kopff, 24P/Schaumasse, 26P/GS, 62P/Tsuchinshan 1, and 67P/CG; Osip et al. (1992) for Comets 10P/Tempel 2 and 81P/Wild 2; Farnham & Schleicher (1998) for Comet 46P/Wirtanen; Schleicher & Osip (2002) for Comet C/Hyakutake; Schleicher et al. (1991) for Comet C/Levy, and Schleicher et al. (1997) for Comet C/Hale-Bopp. The use of equation (5) correlating the gas and dust for JF cometary sample made the estimate of the dust loss rates possible, as well as the dust-to-gas ratios for the 1986 return of Comet 85P/Boethin.

3. Results and discussion

We study the space-temporal behavior presented by the gas and dust in Comet 85P/Boethin, comparing the results with those for a sample which includes Comet 1P/Halley, 3 LP comets, namely C/Hale-Bopp, C/Hyakutake, and C/Levy, and 10 JF comets - 9P/Tempel 1, 10P/Tempel 2, 21P/GZ, 22P/Kopff, 24P/Schaumasse, 26P/GS, 46P/Wirtanen, 62P/Tsuchinshan 1, 67P/CG, and 81P/Wild 2 - obtained by Trevisan Sanzovo (2006), also using ICQ data archives, and applying the SEMVM. The gas production rates (in g s^{-1}) were deduced through the SEMVM while the dust production rates (in g s^{-1}) were obtained using equation (5). Our analysis is based on Figures 1 to 6 and also on Table I, which summarizes main results. There, in addition to the nomenclature, the first column shows the perihelion passages corresponding to the gas and dust analysis quoted between parenthesis and brackets, respectively. In column 2, we have the orbital period (in years) of the objects, while the nuclear radius (in km), the fraction of active area (in %), and the active surface area (in km^2) are shown in column 3 of the same table. For completeness, the result from A'Hearn et al. (1995) observations is also plotted in our Figures 1 and 6.

3.1. Nuclear Dimensions and Masses

We fixed the active surface area in 20% for the nuclear hemisphere lit by the Sun (Möhlmann, 1999), and the water production rates obtained through the application of SEMVM were combined with the vaporization rates of Delsemme (1982), resulting in an effective nuclear radius of ~ 1.9 km for Comet 85P/Boethin. As can also be inferred from Figure 3, if f_{AA}=1.0, the water vaporization and production rates will be compatible with a minimum nuclear radius of ~ 0.8 km.

We have verified, therefore, that Comet 85P/Boethin has, amongst the JF comets of the sample, about the same dimension as Comet 21P/GZ, whose effective nuclear radius is ~ 1.7 km. In contrast, for an activity of 100%, 85P/Boethin is nearly twice smaller than Comet 1P/Halley whose minimum nuclear radius is 1.5 km. We also make an estimate of the nuclear masses which are shown in column 4 of Table I. For this calculation, we considered a spherical nucleus and adopted a mean nuclear density $\rho_N = 0.5$ g cm^{-3}, given by Keller et al. (1986). With this procedure we verify that Comet 85P/Boethin is a JF comet with intermediary mass, being comparable to 21P/GZ, and about one order of magnitude less massive than Comet 22P/Kopff.

3.2 Gas, Dust, Dust-to-Gas Ratios and Productivity

The application of SEMVM to Comet 85P/Boethin yield average gas production rates (in g s^{-1}) which vary with the heliocentric distance according with the power-law:

$$q_g = (4.323 \pm 0.081) x 10^6 . r^{-5.21(\pm 0.45)} \quad (6)$$

in the pre-perihelion phase 1.513 $\leq$ r (AU) $\leq$ 1.114, and

$$q_g = (4.267 \pm 0.115) x 10^6 . r^{-5.34(\pm 0.56)} \quad (7)$$

in the post-perihelion phase comprehended between r = 1.115 and 1.491 AU. The behavior of these rates with the r/q ratio, where q (=1.114 AU) is the perihelion distance, can be visualized in Figure 2.

The application of equation (5) yield dust loss rates (in g s^{-1}) which vary with r according with the power-law

$$q_g = (1.177 \pm 0.087) x 10^6 . r^{-7.04(\pm 0.45)} \quad (8)$$

for both pre- and post-perihelion phases, and those temporal variations (in days, with respect to perihelion) are shown in Figure 4. In Figure 5 we show the behavior of the dust-to-gas ratios (χ) with r. The variation of the total mass production rates with r/q for Comet 85P/Boethin together with short-period comets 1P/Halley, 9P/Tempel 1, 10P/Tempel 2, 21P/GZ, 22P/Kopff, 24P/Schaumasse, 26P/GS, 46P/Wirtanen, 62P/Tsuchinshan 1, 67P/CG, 81P/Wild

2, and the LP comets C/Hyakutake, C/Levy, and C/Hale-Bopp, studied by Trevisan Sanzovo (2006) is shown in Figure 6. Using the power law represented by (6), we find that, at perihelion (r = 1.114 AU), Comet 85P/Boethin lost gas at an average rate of ~ 2.5 x 106 g s-1, while Figure 2 shows a maximum of gas production rate estimated as qg ≅ 7 x 106 g s-1. At this same heliocentric distance, A'Hearn et al. (1995) found a maximum for water release rates of 3.3 x 1028 molecules s-1 (qg ≅ 1×106 g s-1).

The inspection of Table I shows that 85P/Boethin is nearly two orders of magnitude less active than Comet 1P/Halley, and about two orders and a half of magnitude less productive than Comet C/Hale-Bopp. Besides the orbital period, dimensions and nuclear masses, Table I also presents in columns 5, 6, and 8 the dependencies with heliocentric distance of the gas and dust loss rates, and dust-to-gas mass ratios, respectively. In the last two columns of the same Table I we present nuclear radii and respective references found in literature, for comparison. In his analysis of 14 comets applied to Comet 85P/Boethin, Trevisan Sanzovo (2006) found an average ratio of 1.44 ± 1.58 at 1-σ level amongst his results and those in literature. The errors are derived mainly from propagation of the visual magnitudes uncertainties within the framework of the SEMVM. With the accuracy of both the method and ICQ observational data which has a typical scattering of ±0.4 magnitude (Green & Morris, 1987), it seems difficult to be more precise in the estimation of those values. A factor 2 error is estimated by Newburn & Spinrad (1985) from their photometric method for dust cometary particles. In view of the significant uncertainties involved in both methods, we conclude that our results for R_N are in reasonably good agreement with those found in literature, as shown in Table I.

The total mass loss rates, Q_T (in kg s^{-1}), in the form of gas and dust, are shown in column 7 of the table, being obtained fixing r = 1.6 AU. This heliocentric distance was chosen from a rigorous analysis of the perihelion distance presented by the comets of the sample. The results indicate that Comets 22P/Kopff and 81P/Wild 2 in 1996 and 1997 apparitions, respectively, lost nearly twice more mass than Comet 85P/Boethin which in the pre-perihelic phase was more productive than Comets 9P/Tempel 1, 10P/Tempel 2, 21P/GZ, 24P/Schaumasse, 26P/GS, 46P/

Wirtanen, and 62P/Tsuchinshan 1. From Figure 5, we can conclude that Comet 85P/Boethin has predominantly 0.15< χ <0.30, being classified as belonging to the family of comets with intermediate dust-to-gas ratios (Sanzovo et al., 1996). Also, our results given in Figures 2, 4 and 6 show that the comet has intermediary gas and dust loss rates close to perihelion suggesting a slight pre-perihelion asymmetry. However, this conclusion should be verified by future observations of the evolution of gas and dust components from ground-based telescopes.

Acknowledgments

D.T.S. is thankful to CAPES/PROPPG/UEL, G.C.S. is thankful to PROPPG/UEL, and A.A.A. is very grateful for the financial support from FAPESP (São Paulo, SP, Brazil) under contract No. 04/01215-1.

References

A´HEARN, M. F.; MILLIS, R. L.; SCHLEICHER, D. G.; OSIP, D. J.; BIRCH, P. V. The ensemble properties of comets: results from narrowband photometry of 85 comets, 1976-1992. *Icarus 118*, p.223-270. 1995.

CATALANO, F. A.; BARATTA, G. A.; PRESTI, C. L.; STRAZZULLA, G. Pre-perihelion photometry of P/Halley (1982 i) at Catania (Italy) Observatory. *A&A 168*, p.341-345. 1986.

de ALMEIDA, A. A.; SINGH, P. D.; HUEBNER, W. F. Water release rates, active areas, and minimum nuclear radius derived from visual magnitudes of comets – an application to Comet 46P/Wirtanen. *Planet. Space Sci. 45*, p.681-692. 1997.

DELSEMME, A. H. Chemical composition of cometary nuclei. In *Comets*. Ed. L. L. Wilkening, Univ. of Arizona Press, Tucson, p.85-130. 1982.

DIVINE, N. Simple Radiation Model of Cometary Dust for P/Halley. In *Comet Halley Dust and Gas*. Enviroment Workshop, ESA SP, p.47-53. 1981.

FARNHAM, T. L.; SCHLEICHER, D. G. Narrowband photometric results for comet 46P/Wirtanen. *A&A 335*, L50-L55. 1998.

GREEN, D. W. E.; MORRIS, C. S. The Visual Brightness Behavior of P/Halley during 1981-1987. *A&A 187*, n.1, p.560, 1987.

KELLER, E. P.; ARPIGNY, C.; BARBIERI, C.; BONNET, R. M.; CAZES, S.; et al. First Halley multicolour camera imaging results from Giotto. *Nature 321*, p.320-326. 1986.

MARSDEN, B. G.; WILLIAMS, G. V. *Catalogue of Cometary Orbits 1993*, 8th Edn. Minor Planet Center, Cambridge, 102p. 1993.

MIGUEL TORRES, R. T*axas de perda de massa em cometas periódicos*. PhD Thesis. University of São Paulo, IAG, SP, 145p, Brazil. 2001.

MÖHLMANN, S. Activity and nucleus properties of 46/Wirtanen. *Planet. Space Sci. 47*, p. 971-974. 1999.

MORRIS, C. S. On aperture corrections for comet magnitude estimates. *PASP 85*, p.470-473. 1973.

NEY, E. P. Optical and infrared observations of bright comets in the range 0.5 micrometers to 20 micrometers. In *Comets.* Ed. L. L. Wilkening, Univ. Arizona Press, p.323-340. 1982.

NEWBURN, R. L.; SPINRAD, H. Spectrophotometry of seventeen comets. II - The continuum. *AJ 90*, p.2591-2608. 1985.

NEWBURN, R. L. A semi-empirical photometric theory of cometary gas and dust production: Application to P/Halley's gas production rates. In *Comet Halley Dust and Gas*. Enviroment Workshop, ESA SP-174, p.3-18. 1981.

OSIP, D. J.; SCHLEICHER, D. G.; MILLIS, R. L. Comets: groundbased observations of spacecraft mission candidates. *Icarus 98*, p.115-124. 1992.

RANDALL, C. E.; SCHLEICHER, D. G.; BALLOU, R. G.; et al. Observational Constraints on molecular scalelengths and lifetimes in comets. *BAAS 24*, p.1002, 1992.

ROUSSELOT, P.; HILL, S. M.; BURGER, M. H.; et al. Theoretical modeling of the C2 fluorescence spectrum in Comet Hale-Bopp. *Icarus 146*, Issue 1, p.263-269. 2000.

SANZOVO, G. C.; de ALMEIDA, A. A.; MISRA, A.; et al. Mass-loss rates, dust particle sizes, nuclear active areas and minimum nuclear radii of target comets for missions STARDUST and CONTOUR. *MNRAS 326*, p.852-868. 2001.

SANZOVO, G. C.; SINGH, P. D.; HUEBNER, W. F. Dust colors, dust release rates, and dust-to-gas ratios in the comae of six comets. *A&A 120*, p.301-311. 1996.

SCHLEICHER, D. G. Compositional and physical results for Rosetta's new target Comet 67P/Churyumov Gerasimenko from narrowband photometry and imaging. *Icarus 181*, Issue 2, p.442-457. 2006.

SCHLEICHER, D. G.; OSIP, D. J. Long- and short-term photometric behavior of Comet Hyakutake (1996 B2). *Icarus 159*, p.210-233. 2002.

SCHLEICHER, D. G.; MILLIS, R. L.; BIRCH, P. V. Narrowband photometry of Comet P/Halley: variation with heliocentric distance, season, and solar phase angle. *Icarus 132*, p.397-417. 1998.

SCHLEICHER, D. G.; LEDERER, S. M.; MILLIS, R. L.; et al. Photometric behavior of Comet Hale-Bopp (C/ 1995 O1) before perihelion. *Science 275*, p.1913-1915. 1997.

SCHLEICHER, D. G.; MILLIS, R. L. OSIP, D. J.; et al. Comet Levy (1990c): groundbased photometry results. *Icarus 94*, p.511-523. 1991.

SCHLEICHER, D. G.; MILLIS, R. L.; BIRCH, P. V. Photometric observations of Comet P/Giacobini-Zinner. *A&A 187*, p.531-538. 1987.

SINGH, P. D.; HUEBNER, W. F.; COSTA, R. D. D.; et al. Gas and dust release rates and color of dust in Comets P/Halley (1986 III), P/Giacobini-Zinner (1985 XIII), and P/Hartley-Good (1985 XVII). *Planet. Space Sci. 45*, p.455-467. 1997.

STORRS, A. D.; COCHRAN, A. L.; BARKER, E. S. Spectrophotometry of the continuum in 18 comets. *Icarus 98*, p.163-178. 1992.

TANCREDI, G; FERNÁNDEZ, J. A.; RICKMAN, H.; et al. A catalog of observed nuclear magnitudes of Jupiter family comets. *A&A 146*, p.73-90. 2000.

TREVISAN SANZOVO, D. *Correlação gás-poeira em 14 cometas: uma aplicação ao Cometa 85P/Boethin*. Msc Thesis, State University of Londrina, Londrina, PR, 107p. Brazil. 2006.