STUDY OF COMETS COMPOSITION AND STRUCTURE

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Abstract

The present paper focuses on the nature of the different interactions between cometary nucleus and tail with solar wind. The dynamics of the comet will impose many features that provide unique behavior of the comet when entering the solar system. These features are reviewed in this paper and few investigations are made. The calculations made in this work represent the analysis and interpretation of the different features of the comet, such as perihelion and eccentricity dependence on the gas production rate, and the dependence of the latter on the composition of the comet nucleus. The dependences of the heliocentric, bow shock, contact surface, and stand-off distances with gas production rate for many types of comets that cover linear and non-linear types are studied in this work. Important results are obtained which indicated the different physical interactions between cometary ions and solar wind. Furthermore, the important relation between mean molecular weight and gas production rate are analyzed and studied in this work and a conclusion is made that, as the gas production rate increases, the mean molecular weight will decrease exponentially. A detailed discussion for this unique relation is given.

Introduction

According to the "dirty ice" model [1], the cometary nucleus consists of water ice contaminated by other chemical species. When it approaches the sun, the comet neutral molecules as will as dust will emerge from the kilometer-sized body under the action of the solar radiation. These particles leave the surface of the nucleus with a speed of the order of one km/s and are ionized due to solar radiation. Time scale for this event is ~ 10^6 s. Hence the typical length scale of the ionized region will be around 10^6 km. This is why the size of the cometary obstacle in the solar wind is much larger than the actual size of the nucleus. The mass production rate $\dot{\rho}_c(r)$ at a distance r from the nucleus, under the assumption of spherical symmetry, constant molecular mass m_c, molecular velocity v_c, and ionization rate σ can be calculated analytically from the equation of continuity for the neutral gas: [1]:

$$\dot{\rho}_c(r) = \sigma \rho_c(r) = \frac{G\ \sigma\ m_c}{4\pi r^2\ v_c} e^{-\frac{\sigma}{v_c} r} \quad .... (1)$$

Which describes the r^{-2} dependence of the density in spherical symmetry modified by the exhaustion $\exp(-\frac{\sigma r}{v_c})$ due to ionization processes over a length scale $R_i = \frac{v_c}{\sigma . G}$ G is the total production rate of cometary molecules. These processes are affected by many different properties of the comet such as the production rate, the dynamics of the comet, its composition and its different types of interactions with the solar wind.

The aim of the present work is to understand the different relations between dynamical and structural properties of the comet according to its different characteristics. The dependence of the mean molecular weight of cometary rays on the gas production rate as well as the dynamical distances are discussed here and reviewed, with practical calculation made.

1-Physical Model:

When ions are generated from of cometary nucleus, they are implanted in the solar wind and gyrate around the field lines of the inter-planetary magnetic field (IMF). Since the velocity of these ionized particles is small compared to that of solar wind, protons will mainly add mass and a negligible amount of energy and momentum to the plasma. Therefore the additional mass of the cometary ions dominates the comet-solar wind interaction. Usually, the velocity of the plasma components is established quickly and there will be a redistribution of the plasma flow near the comet. From direct spacecraft measurements, it was shown [2,3] that a common velocity distribution along the field lines establishes quickly due to pitch angle scattering, and specific heat is chosen in this case $\gamma = \frac{5}{3}$ for three dimensional system.

When the solar wind approaches the comet with supersonic speed, the production of cometary ions increases with decreasing distance from the nucleus. Biermann et al. [3] showed first that the supersonic motion of plasma can just be maintained solar wind remains below $\frac{1}{\gamma^2} - 1$ times the weight of the undisturbed flow. If the mean molecular weight increases to higher values, the bow shock is formed. It will divert the flow around the comet. This shock is believed [2] to force the solar wind protons to slowed down. At the shock, an additional relative mass load of $\frac{1}{\gamma^2} - 1$ can be carried by the cometary ions, therefore, the stand off distance R_B of the bow shock from the nucleus can be estimated as a solution of the equation of continuity with the mass source Eq.(1):

$$\frac{\rho_\Theta v_\Theta}{\gamma^2 - 1} = \int_{R_B}^{\infty} \dot{\rho}_c(r)dr \quad (2)$$

where ρ_Θ is the density and v_Θ the velocity of the solar wind. Eq.(2) gives, using the ionization scale length $R_i = \frac{v_c}{\sigma}$, an integral equation for R_B [4]:

$$\int_{\frac{R_B}{R_i}}^{\infty} \frac{e^{-\xi}}{\xi^2} d\xi = \frac{4\pi v_c^2 \rho_\Theta v_\Theta}{(\gamma^2 - 1) G \sigma^2 m_c} \quad (3).$$

The bow shock distances calculated from Eq.(3) can be considered as lower limits. Typical values are $m_c = 20 m_p$, $\sigma = 10^{-6} s^{-1}$ and $v_c = 1 km.s^{-1}$ for the neutral gas, and $\rho_\Theta = 5 m_p cm^{-3}$ and $\rho_\Theta = 400 kms^{-1}$ for the solar wind at heliocentric distance of 1 AU. In the limit $R_B >> R_i$ an approximate solution of Eq.(3) is [4]:

$$R_B = \frac{G m_c \sigma (\gamma^2 - 1)}{4\pi v_c \rho_\Theta v_\Theta} \quad (4)$$

For such comets, the bow shock distance will increase linearly with the total gas production rate. Such comets are called as linear comes and the change of cometary specifications will change with G if R_B is comparable to or greater than the neutral gas density in the outer parts of the coma, then the comets are named by nonlinear comets [4] and the parameters will change with G^2.

Between the bow shock and the nucleus, there will be slow plasma flow [5, 6]. Experiments from spacecraft missions discovered boundaries in the plasma flow that were thought to be caused by complicated plasma processes. Such boundaries were hard to be explained by magneto-hydrodynamic (MHD) models. Magnetopause and stagnation of the solar wind are treated in the MHD approximation as a “contact surface” where the net pressure of cometary ions equals the solar wind pressure. Beyond this surface, no plasma of solar wind origin and no magnatic field can be found. We can find the stand off distance of the contact surface by equalizing the ram pressures, and using the source term Eq.(1) with,

$$\sigma\, r/v_c << 1 \quad (5)$$

is given as,

$$R_c = \frac{\Omega\, \sigma m_c}{4\pi \rho_\theta\, v_\theta^2} G \quad (6)$$

Where, Ω describes the influence of chemical processes like photodissociation, elastic collision with neutrals or the kinetic energy of photoelectrons wich tends to enhance R_c, and the stress of the magnetic field wich diminishes R_c. For comet Halley in 1986 the system parameters were found with $G=6.910 \times 10^{29}\ s^{-1}$ [7], $\rho_\theta \sim 7\ m_p$, $v_\theta = 380\ km\ s^{-1}$, $\sigma = 10^{-6}\ s^{-1}$ and $m_c = 20\ m_p$. From Eq.(6), $R_c = 1100$ km, which is about a factor of $\Omega = 4.2$ smaller than 4600 km measured by Giotto [3, 7]. Hence the interaction of plasma and neutral gas is very important, at least near the nucleus.

2-Composition:

The original model for cometary nucleus com-position by Whipple contained a mixture of ices of the species, H, C, N and O with H_2O

being the most abundant constituent in the nucleus. It was pointed out that, dust was embedded in the icy co-nglomerate. The inference of the relative abun-dances of species in the nuclear ices from the obs-erved spectra is presently an unsolved problem [1].

Molecules released directly from the subliming ices have a variety of (short) lifetimes against photo dissociation in the solar radiation field. Dissociation products of the sublimed parents are observed in the optical spectra. Moreover, any polyatomic molecules which might be released directly as a result of the vaporization of the cometary ices (e.g. H_2O, CO_2) have their resonance transitions outside the ultraviolet and optical windows (~ 0.12 to 1 μm). Until direct samples of cometary ices or direct observations of parent molecules are obtained, any knowledge of the chemical composition of the nuclear ices must remain extremely model-dependent at best.

The identification of H_2O ice has been proven to be a universal characteristic. There seem to be some observational evidence that CO_2 (or CO) ice may play a significant role in controlling the gas production rates in some comets [8-10]. Indeed large variations in H_2O^+/CO^+ emission band strength ratios from one comet to another (at comparable heliocentric distances) might possibly indicate abundance differences in H_2O and CO_2 (or CO) [11, 12].

3-Dust Production

The smaller dust grains have velocities ~1 km s^{-1}, which is larger than the escape velocity from the comet nucleus (few ms^{-1}). Mass lost in the form of dust is observed to vary continuously with heliocentric distance with the production rates proportional to r^{-2}. The infrared luminosity is a measure of the dust production rate, because there is no dependence on particle size (for small particles) [4]. Mass loss rates can also be determined from photometric measurements in the visible, but the size distribution of particles and the scattering phase function must be known.

Dust mass-loss rates at~1 AU determined for four long-period comets are 4×10^6 gm s^{-1} and for comet p/Encke, 2×10^4 gm s^{-1} [4]. The dust-plus-gas production rates (by mass) for the same long-period comets, G (of both dust and H_2O) ~ 1.4×10^7 gm s^{-1} and for comet p/Encke ~ 2.2×10^5 gm s^{-1}. Thus the mass-loss rate from the short-period comet is less than for the long- period comet, a difference which could reflect a difference in the sizes of the nuclei.

4-Bow Shock and Stagnation:

The stagnation pressures p_w of the solar wind can be calculated for given γ from gas dynamics, when $\rho_w u^2_w$ and the Mach number M_{aw} of the unperturbed solar wind are known [13]. For hypersonic solar wind ($M_{aw} \to \infty$) and γ =2 can be defined as [4, 14, 15]:

$$p_w = 0.84\rho_w u_w^2 \quad (7)$$

The source term (Eq.2) reduces this stagnation pressure continuously, but not by as much as an order of magnitude. The numerical results is give $p_w = 0.6\ \rho_w u^2_w$ for a wide range of parameters. For the stagnation pressure p_c of the cometary plasma we assume by analogy to Eq.(7).

$$p_c = 0.84\rho_c\ w^2 = 0.84\frac{G\,m_c}{4\pi R^2 w}\frac{\sigma R}{w}w^2 \quad (8)$$

Since $p_c\ w^2$ varies as R^{-1}, the stagnation pressure (Eq. 8) would be correct only at position of the inner shock; i.e., the finite thickness of the layer between the inner shock and ionopause is neglected and Eq.(8) gives only a lower limit. It was estimated that [16, 17] the layer thickness for a point source of cometary ions but no estimates exist for the realistic case of an extended source of ions. From equilibrium between the two pressures (Eqs. 7 and 8) we get an estimate of the stand-off distance

$$R_s = \frac{G\,\sigma\,m_c}{4\pi\rho_w\,u_w^2} \quad (9)$$

There are several other effects which can modify this estimate. The stagnation pressure of the cometary plasma can be enlarged due to the surplus energy of dissociation products [4, 15] or photoelectrons, or it can be reduced by cooling of the electrons which by collisional excitation gives rise to radiative losses.

Results and Discussions

The aim of this paper is to understand the different relations between dynamical and structural properties of the comet according to its different properties. These properties are reviewed above for detailed description of the comet system.

1. Heliocentric Distance Dependence on Gas Production Rate

The gas production rate, G, plays an important rule in the analysis of the comet properties. Therefore, this physical quantity reflects many of the dynamical and structural properties of the comet. Starting from this point, we have analyzed some dynamical and structural features of different comets depending on their gas production rates.

The first calculation made here is between the heliocentric distances for seven comets (in AU) with their G. The results of this investigation taken from Ref. [17] are shown in Fig.(1). This figure contains a practical comparison between theoretical formulas for R_B/R_I with experimental values measured from spacecraft missions [18, 19]. For comets where $\zeta=R_B/R_I \ll 1$, the bow shock distance R_B will increases linearly with the total gas production rate. This is also accompanied with increase of the typical size of cometary atmosphere. Such comets are named as linear comets. As when the relation between these distances, i.e., R_B and cometary atmosphere, and G do not fall in the above classification, we name these comets by non-linear comets [4].

The figure indicates the comparison between theory and experimental measures. It is seen that at the interval between values of about $G=10^{29}$ and 10^{30} s^{-1}, a transition occurs between linear and non-linear cases. Specially, when $\zeta=0.5$, we have critical dependence which represents the transition between these linear and non-linear cases. This is seen from Fig.(1) where a rapid change occurs at the range named above. Such important phenomenon was explained before [19, 20] to be due to the effect of “tail condensation”. When the gas production rate increases somewhere above 10^{29} s^{-1}, the number of free ions added to the solar wind will tend to interact more severely than in lower *G* values. Such interaction cause more dependence of the density of the comet tail on G, hence the heliocentric distance will begin to depend slowly on G. This phenomenon was strongly thought to occur at critical $G\sim1.910\text{x}10^{29}$ s^{-1} [20]. Also, in Fig.(1), it is indicated how does the factor ζ depends on both G and the heliocentric distance, and the critical value of ζ is shown as a dashed line.

2. Bow Shock and Contact Surface Dependence on Gas Production Rate

We saw how the bow shock and contact surface develop during cometary rays interaction with the solar wind and how this affects the heliocentric distance, as discussed in paragraph 5.1 above. When the gas production rate increase the bow shock size will be affected according to few parameters such as the molecular weight of the ions emitted from the nucleus of the comet, and the rate of emission as well. In both dependences the primary rule is due to energy conservation concepts. Heavy molecular weights will ensure more energy transfer between the solar wind and cometary rays of ions. The same is expected when the rate of production increases. This lead to increase the bow shock distance. Study of these relations between G and R_B will therefore reflect the changes of the system according to the specification of the comet. The stand-off distance R_s, accordingly, will increase with G.

In Fig.(2), we show how the distance R_s calculated from eq.(9) will change with *G* for the same comet type. Then comparing these calculations for each comet and comparing with the bow shock distance for five hydrodynamic models, the distance R_B is shown to be very close to R_s. This indicates that the bow shock is caused by contamination with cometary ions rather than by the obstacles of the cometary ionpopause.

Due to the interaction between the cometary ions and solar wind, there will be a certain and specific balance between the two pressures according the relation of the bow shock, eqs.(7 and 8), and we get a proper estimation of the stand-off distance. This can be interpreted due to different plasma densities occurring for two streams opposing in directions, one is due to the solar wind flow, and the second is due to cometary ion beam.

When these two flows contact with each other, the stand-off distance will then be analyzed according to the specifications of these plasma flows. Since the solar wind parameters change smoothly with distance, then the main change of the stand-off distance will then be mainly due to the changes of the comet characteristics.

Comparison between the present calculations with experimentally evaluated data [21, 22] are also shown in Fig.(2) (empty dots and stars). The agreement is quite good. This also reflects the consistency of the present theory to understand the dependence of R_s and R_B on G.

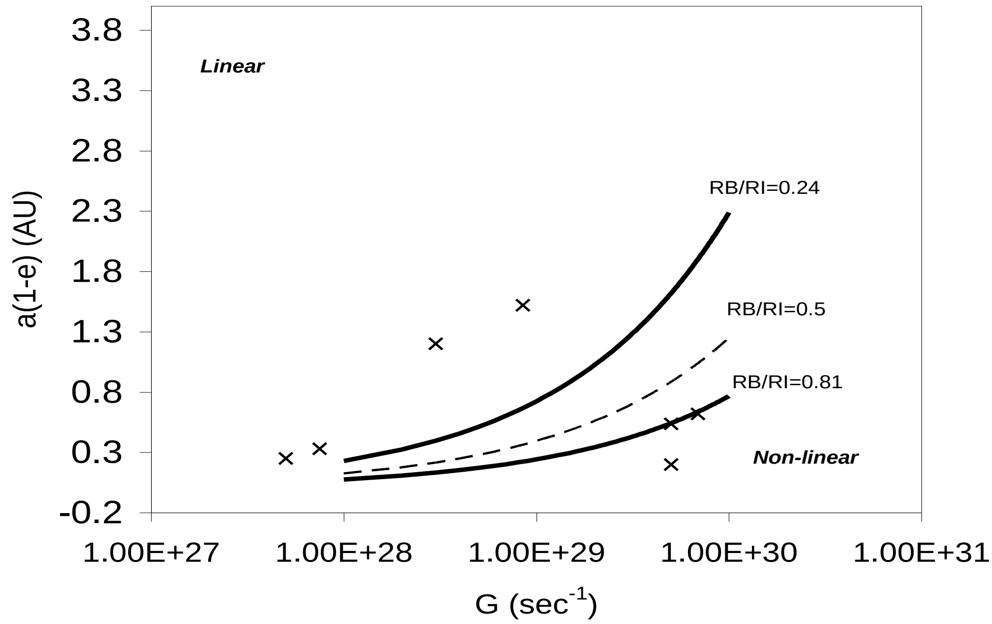

Fig.(1) : Analyzing different comets according to heliocentric distance and the log of total gas production rates. The regions of linear and non-linear comets types dependence on G are shown and the critical value of ζ is indicated as a dashed line.

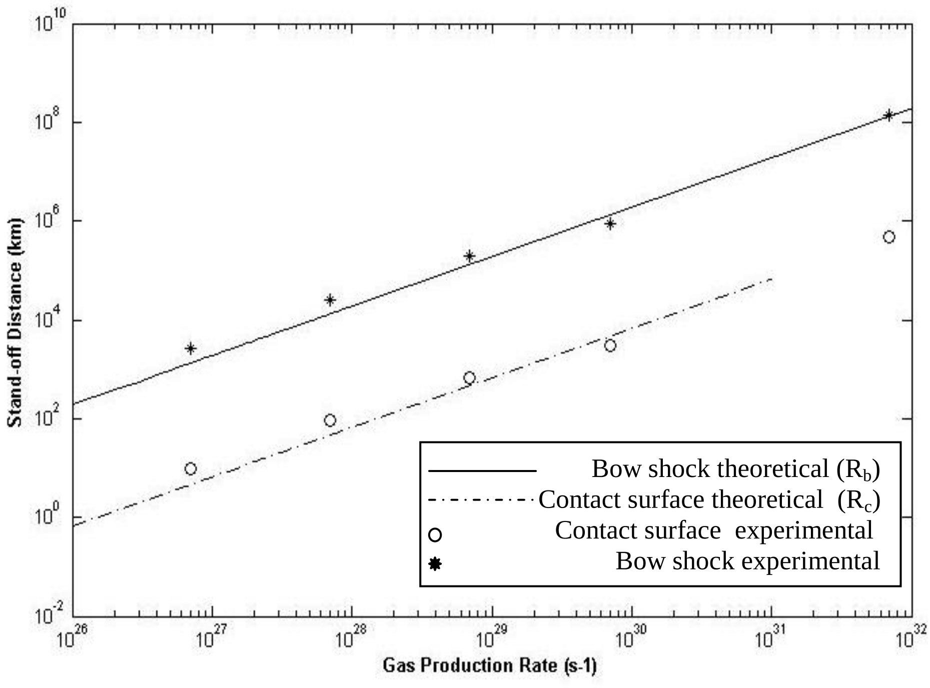

Fig.(2) : Stand-off distance of bow shock R_B, and stagnation point R_c as a function of gas production rate, G, calculated for five hydrodynamic models.

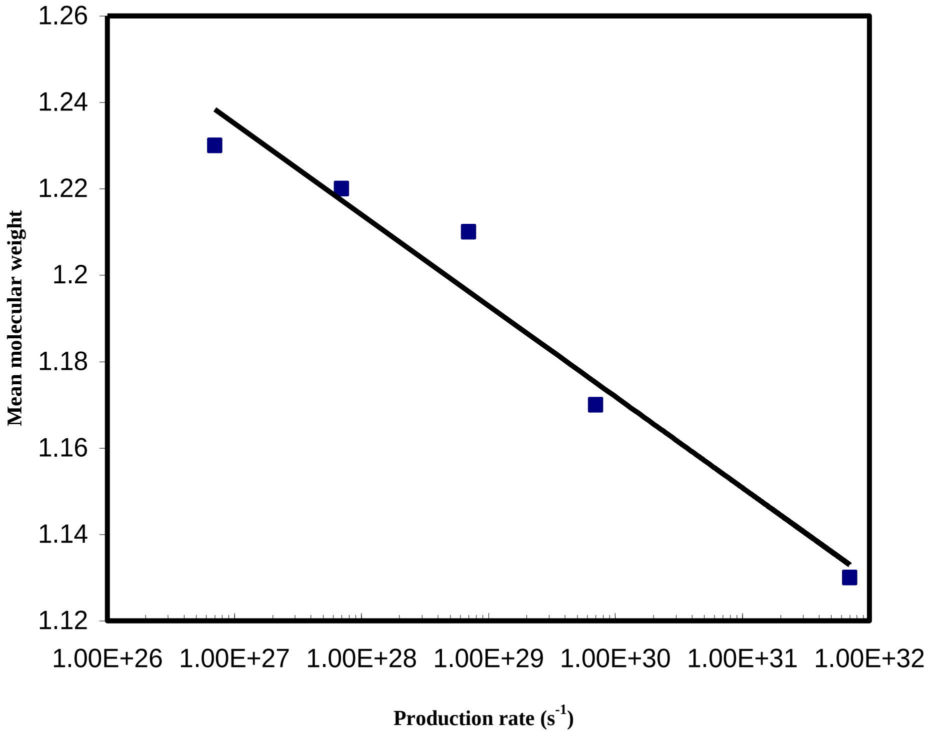

Fig.(3) : The relation between gas production rate, G, and the mean molecular weight.

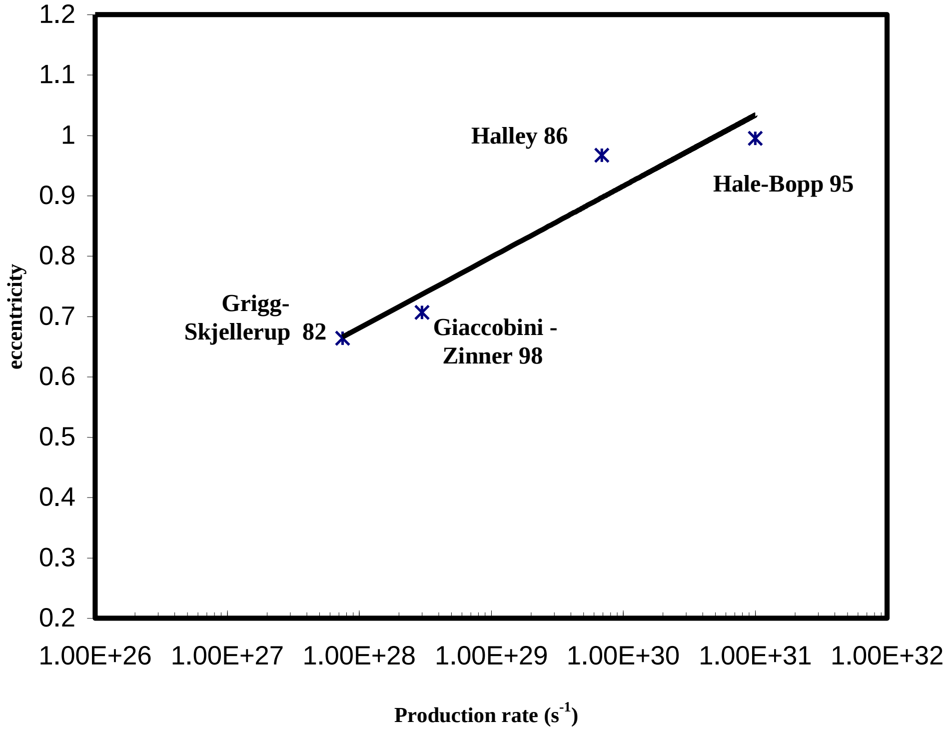

Fig.(4) : The relation between gas production rate, G, and the eccentricity.

3. Molecular Weight and Production Rate

From Fig.(3), the relation between the gas production rate and the mean molecular weight is reported here, based on experimental data [21] with fitting. The abscissa is based logarithmic scale.

The interesting behavior shows that mean molecular weight will decrease exponentially as G increases. This indicates that there is a constant (units of time) that determines the dependence of mean molecular weight on G. From the exponential behavior of the molecular weight we expect that the molecular weight reaches a minimum value at extremely high G. The minimal value here should not be less than the rest mass of the proton.

The fitted curve is in acceptable variances with the experimental data. It should be mentioned that the attempt made here to assume exponential relation between G and the mean molecular weight be convincing for estimating the molecular weight from the measured G. This result actually is very important in the present level of theoretical analysis of comets.

4. Eccentricity and Production Rate

In Fig.(4), the relation is plotted between the eccentricity and gas production rate for four comets. The selected comets are chosen in order to cover a wide range of production rate as well as various periods. From this figure, the important relation clearly shows that the eccentricity reaches its maximum at G values ~ 10^{32} s^{-1}. The long-period of comet Hale-Bopp has eccentricity almost a unity, which shows that this physical quantity is also majorly connected to G. The abscissa is also plotted in logarithmic form, so that the relation is actually an exponential. These results of eccentricity are consistent with Refs. [23, 24], and can be well understood on the bases of the main cause that affects G, i.e., the solar wind strength and direction. This figure also clearly illustrates the points mentioned above that eccentricity is related to G based on the fact that the gas production rate, G, highly depends on the trajectory of the comet about the sun.

Conclusions

In the present paper, the nature of the different interactions between cometary nucleus and tail with solar wind are given. Comet dynamics that impose important characteristics on the gas production rate are reviewed and important investigations are made. The calculations made in this work represent the analysis and interpretation of the different features of the comet, including perihelion, eccentricity, composition of the comet nucleus, heliocentric, bow shock, contact surface, and stand-off distances with gas production rate for many types of comets (linear and non-linear).

The results obtained here indicated that the different physical interactions between cometary ions and solar wind can actually alter the comet dynamical specifications to a high degree. The important relation between mean molecular weight and gas production rate showed that as the gas production rate increases, the mean molecular weight will decrease exponentially. This was shown in section 5.3, where the values of the molecular weight were taken for many comets and studied in the relation shown in Fig.(3).

References

[1] Whipple, F. L., (1950), “Comet Structure” Astrophys. J., vol. 111, pp.375-382.

[2] Neugebauer, M., Lazars, A.J., Altwegg, K., Balsiger, H., Golstein, B. E., Neubauer, F. M., Rosenbarer,H., schwenn,R., Shelley., E.G., and Ungstrup,E., (1987), “Measurements of Giotto-Zinner and Halley Comets Dynamic Parameters”, Astron. Astrophys. Vol.187, pp.119-131.

[3] Biermann, L., and Trefftz, E. (1964) “Vberdie mechanismen der Ionisation under Anregungin Kometen” Atmospheren. ZS. f. Astrophys. Vol.59, pp.1-28.

[4] Schmidt, H.U., and Wegmann, R. (1982), in “Comets”, L. Wilkening, Ed., Univ. of Arizona Press, Tucson, USA, pp.538.

[5] Galeev, A. A. (1987), Astro. Astrophys, vol. 187, pp.12-27.

[6] d'Usto, C., Rerme., H., Sauvaud, J.A., Cros, Anderson, K.A., Carlson, C.W., Cartis, D., Lin, R.P., Korth, A., Richter, and A.K. Mendis. (1987) Astron. Astrophys. vol.187 pp.131-137.

[7] KrandKowsky, D., Lammerzahl, P., Errwert, I., Woweries, J., Eberhardt, P., Dolder, U., Errmann, U., Sculte, W., Berthelier,J,J., Irlliano, J.M., Hodger, R.R., and Hoffman, J.H (1986) Nature, vol.321,pp. 326-341.

[8] Johnstone, A., Coates, A., Kellock, S., Wilken, B., Jockers, K., Rosenbauer, H., Studemann, W., Weiss, W., Formisano, V., Amata, E., Cerullirelli, R., Dobrowthy, M., Terenzi, R., Eigidi, A., Borg, H., Haltauist, B., Winningham ,J., Gurgiolo, C., Boyant, D., Edwards, T., Feldman, W., Thomsen, M., Wallis, M. K., Biermann, L., Schmidt, H. U., Lust, R., Haerended, G., and Paschmann, G. (1986) Nature vol. 321, pp.342-353.

[9] Spinrad, H. ,Stauffer, J. and Newburn, R. L. (1979), "Optical Spectrophotometery of Comet Temple-2" Publ.Astron.Sco.Pacific vol. 91 pp. 707-711.

[10] Cochran, A. L., and Mccall, M. L. (1980), "Spectrometry Observation of Comet Bowell" Publ.Astron.Soc.Pacific vol. 92, pp. 854-857.

[11] Larson, S.M. (1980) "CO in Comet Schwassmann-Wachmann Inearminiman Brightness" Astrophys.J. vol. 238, pp. L47-L48.

[12] Feston, M.C. (1981) "The density distribution of nature compounds in cometary atmospheres". Astron.Astrophys. vol.95 pp. 69-79.

[13] Ahearn, M.F. and Cowan J.J.(1980) "vaporization in comets :The icy grain halo of comet west', Moon and planets vol. 22, pp. 41-52.

[14] Wyckoff, S., and Wehinger, P.A., (1976) "Molecular ions in comet tails", Astrophys.J. vol. 204, pp. 640-615.

[15] Ney, E. P. (1974), "Multiband photometry of comets Kkoutek-Bennett-Brandfield and Encke", Icarus vol. 23, pp. 551-560.

[16] Ney, E. P., Merrill, K. (1976), "Comet west and scattering function of cometary dust", Science vol. 194, pp. 1051-1053.

[17] Wilkening, L., (1982), in "Comet", ed. L. Wilkening, University of Arizona Press, Tucson, Arizona; and Buti, B., (1988), "Cometary and Solar Plasma Physics", World Scientific Publishing Company, Singapore.

[18] Houpis, H. I. F. and Mendis, D. A., (1980) "Physico chemical and dynamical processes in cometary ion sphere .I. The basic flow profile', Astrophys.J, vol. 239, pp.1107-1118.

[19] Huebner. H. F., and Gigure, P. T. (1980) " A model of comet coma effects of Solar photo dissociatve ionization". Astrophys.J. vol. 328, pp. 753-762.

[20] Voigt S., (1986), "Time Dependent MHD simulations for Cometary Plasmas", Astron Atrophy., vol. 210, pp. 433-454.

[21] Schmidt-Voigt, M. (1987), "Interstellar Magnetic Fields" Eds. R. Beck, and M. Grave, Springer, Berlin, pp. 251.

[22] Wegmann, R., (1995), "MHD Model for the effect of interplanetary shocks on the plasma tail of comet", Astro. Astrophy., vol. 294, pp. 601-616; and Rauer, H., R. Wegmann, H. U. Schmidt, K. Jockers, (1995), "3-D MHD Simulation of the effect of commoving Discontinuity in the solar wind on cometary plasma tail", Astro.Astrophys, vol.295, pp.529-550.

[23] Voelzke, M. R., (2005) "Disconnection Events Processes in Cometary Tails", Earth, Moon, and Planets, vol. 97, pp. 399–409.

[24] Brandt. J. C., Snow, M., Yi, Y., Larson, S. M., Mikuz, H. C., Petersen, C., And Liller, W. (2002), "Large-Scale Structures In Comet Hale–Bopp Latitudinal Variations And Monster Disconnection Event", Earth, Moon and Planets vol. 90, pp. 15–33.

الخلاصة

إن البحث الحالي يركز على طبيعة وخصائص التفاعلات المختلفة بين ذنب ونواة المذنبات مع الرياح الشمسية. إن المواصفات الحركية للمذنبات تفرض العديد من الخصائص التي تشكل تصرفا مميزا للمذنبات عند دخولها الى نطاق المجموعة الشمسية. تم استعراض معظم هذه الخواص في البحث الحالي وتم أجراء بعض التفسيرات المتعلقة بهذا الموضوع. إن الحسابات التي أجريت في البحث الحالي تحاول أن تحلل وتفسر الخواص الفيزيائية المختلفة لعدد من المذنبات اعتمادا على معدل الانتاج الأيوني وعلاقته بمسافة الحضيض (perihelion) والشذوذية (Eccentricity distance)، واعتمادها على التركيب الجزيئي لنواة المذنب. تحديدا، تمت دراسة اعتماد المسافة المركزية للأوج (heliocentric distance)، موجة الرجة (bow shock distance)، سطح الاتصال (contact surface distance) و مسافة تعادل الضغط الحركي (stand-off distance)، مع معدل الإنتاج الأيوني ولأنواع متعددة من المذنبات والتي تشمل المذنبات الخطية واللاخطية. تم الحصول على عدد من النتائج المهمة التي تبين أهمية ونوع التفاعلات المختلفة التي قد تحدث بين الايونات المتولدة من نواة المذنب والرياح الشمسية. أيضا تمت دراسة العلاقة المهمة بين معدل الوزن الجزيئي ومعدل الإنتاج الأيوني للمذنبات، وقد بينت النتائج أن معدل الوزن الجزيئي سينخفض بصورة أسية مع زيادة معدل الإنتاج الأيوني. نوقشت هذه النتائج المميزة في البحث الحالي بصورة مستفيضة.