International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2015): 6.391

Investigation of the Dusty Plasma Characteristic in Different Region in Space

Ala' Fadhil Ahmed[1], Noorhan Karim[2]

Department of Astronomy and Space, College of Science, University of Baghdad, Baghdad, Iraq

Abstract: ***In this work, calculation the characteristics of dusty plasma exist in the space for different regions interstellar cloud, interplanetary space, Halley comet, Saturn rings (E and F), interstellar plasma ,solar wind and solar corona. It noticed the characteristic of dusty plasma different from one region to another region in the space. It shows the density of electrons is lower in interstellar cloud, interplanetary space and Saturn rings (F and E).High density of electrons in solar corona, solar wind and interstellar plasma. The temperature of electrons in the space is high in solar corona and Saturn rings (F and E).It noticed when electrons density increases due to plasma frequency for electron and ion, and coupling parameter of plasma increases too. It noted electrons temperature is increases led to the Debye length, Debye sphere, and electron velocity increases too.Another process is versa verse. According to the different in the electrons density and temperature in the space causes at different characteristics of dusty plasma exists in the different region in the space.***

Keywords: dusty plasma, plasma parameters, plasma in space, solar plasma

1. Introduction

Plasma is a quasi-neutral gas consisting of positively and negatively charged particles (usually ionsand electrons) which are subject to electric, magnetic and other forces, and which exhibit collective behavior. Plasmas can also contain some neutral particles which interact with charged particles via collisions or ionization. Examples include the Earth's ionosphere, upper atmosphere, interstellar medium, molecular clouds, etc. The simplest plasma is formed by ionization of atomic hydrogen, forming plasma of equal numbers of (low mass) electrons and (heavier) protons [1]. The majority of the matter of our visible universe is in the plasma state. The fascinating fact of these plasmas is their description by the same physical mechanisms and the same formulae, even if their parameters range e.g. from extremely low charged particle densities as in inter cluster gases, which are the plasmas between the clusters of galaxies in the universe [2]. One type of plasma is dusty plasmas consist of electrons, ions and charged dust particles observed in several Astros-and space-physical environments. The presence of heavy, highly charged dust may significantly influence various physical processes dusty plasmas are rather common in space, being found in planetary rings, interstellar clouds, cometary plasma tails, and the ionosphere of the Earth and other planets In the earth's ionosphere the origin of plasma components is from eruptions of volcanoes, meteorite showers as well as anthropogenic factors: rocket and airplane exhausts, large fires, explosions, [3]. In recent years, the study of systems consisting of dust and plasmas has become especially significant. This isperhaps due to the almost universal existence of the combination of dust and plasma in systems ranging from protostellar clouds to plasma processing environments[4].

2. Theory

Dusty plasmas are rather ubiquitous in space [5]. There are a number of well-known systems in space, such as interplanetary space, interstellar medium, interstellar or molecular clouds, circum-stellar clouds, comets, solar system, planetary rings, Earth's environments, etc. where charged dust particles are always present. The interstellar space (the space between the stars) is filled with a vast medium of gas and dust. The gas content of the interstellar medium continually decreases with time as new generations of stars are formed during the collapse of giant molecular clouds. The collapse and fragmentation of these clouds give rise to the formation of stellar clusters. The presence of dust in interstellar or circum-stellar clouds has been known for a long time (from star reddening and infrared emission). The dust grains in interstellar or circum-stellar clouds are dielectric (ices, silicates, etc.) and metallic (graphite, magnetite, amorphous carbons, etc.). The solar system is also full of dust [6].

Comet:
A bright comet is an excellent cosmic laboratory for the study of dust plasma interactions, and their physical and dynamical consequences. As the comet approaches the Sun, at few Astronomical Unit (AU), the nucleus is warming up and a long tail of evaporated molecules, carrying small solid particles, is formed the Sun's radiation. One type of comet is Hale-Bopp is an exceptionally bright long-period comet, after perturbation by Jupiter it was changed. Its strong activity and strong thermal emission features provide a rare opportunity to constrain the comet dust morphology, composition and size [7]. Pressure and the solar wind accelerate in different ways the components of comet's tail .The ion tail appears as a more or less straight line, opposite to the Sun, while the dust tail is slower accelerated, being much broader and tends to be curved[5].

Interplanetary Space:
The interplanetary space is full of dust known as 'interplanetary dust. The existence of interplanetary dust particles was known from the zodiacal light. The zodiacal light is due to dust grains distributed throughout the inner solar system, with strong contributions from the asteroid belt. These have probably originated from decay by collisional fragmentation of debris from comets, The other important sources of the interplanetary dust are asteroids that

produce most of their dust during mutual collisions in the asteroid belt [5]. The Zodiacal light, results from scattering of sunlight off interplanetary dust particles [8].

- **Saturn's Ring System:**

The rings of Saturn have puzzled astronomers since they were first discoveredby Galileo in 1610 using his first telescope [9].One of the most intriguing puzzles, though, was Saturn's dynamic and ever changing F Ring, first discovered by Pioneer 11The F Ring lies within the inner part of Saturn's magnetosphere, which contains plasma that rigidly correlates with the planet, and thus the dust in Saturn's F Ring can become charged. Since the plasma parameters in the vicinity of the F Ring are poorly constrained, the magnitude of the charge on the dust grains is not well known. Charged grains' orbits will be perturbed by the planetary magnetic field with the magnitude of this perturbation depending primarily on the grain's charge-to-mass ratio. In addition, the gravitational interaction of a nearby satellite with a narrow ring produces a wave downstream of the moon. Eccentricities in the orbit of either the satellite or the ring can produce azimuthal clumping, having a spatial periodicity initially equal to the wavelength due to the perturbing satellite The magnetic field around a planet can be regarded as the sum of the contributions from the planetary dynamo (internal sources) and the exterior plasma sheet produced by the interaction of the solar wind with the planetary magnetic field [10].

3. Basic Dusty Plasma Characteristics

To understand the basic dusty plasma principles properly, it seems useful to re-examine some basic characteristics such as Debye length, macroscopic neutrality, intergrain spacing, Coulomb coupling parameter and characteristic frequencies, etc. In the following few sections, these basic characteristics and various notations are elaborated [11].

- **Debye Length**

The Debye length is an important physical parameter in plasma: it provides the distance over which the influence of the electric field of an individual charged particle is felt by other charged particles (such as ions) inside the plasma. The charged particles actually rearrange themselves in order to shield all electrostatic fields within a Debye distance. In dusty plasmas, Debye length ($\boldsymbol{\lambda_D}$)can be defined as follows [11]:

$$\lambda_D = \frac{\lambda_{De} \cdot \lambda_{Di}}{\sqrt{\lambda_{De}^2 + \lambda_{Di}^2}} \quad (1)$$

where $\boldsymbol{\lambda_{De}} = \sqrt{\frac{K_B T_e}{4\pi n_e e^2}}$ and $\boldsymbol{\lambda_{Di}} = \sqrt{\frac{K_B T_i}{4\pi n_i e^2}}$

K_B is Boltzmann constant (K_B=1.38x10^{-23} JK^{-1}) , λ_{De} , $\lambda_{Di}$are Debye lengths associated to electrons and ions respectively, and T_e , T_i ,n_e and n_i are the electron and ion temperatures and densities. Dust particles of radius a, separated by a given distance d, can only be considered as individual isolated grains if the criterion a<<λ_D<<d is met, i.e. if the physical dimensions of the plasma are large enough for the shielding to take place. If so, considering that the electron's mobility is higher than that of the ions, shielding is primarily performed by electrons and equation (1) becomes:

$$\lambda_D \approx \lambda_{De} \sqrt{\frac{K_B T_e}{4\pi n_e e^2}} \quad (2)$$

Another plasma parameter related to the Debye length is the number of particles (N_D) in a Debye sphere has radius equal to λ_D. The shielding effect can occur only if the Debye sphere contains a large number of electrons. Due to the exponential decay of the potential, it can be assumed that the shielding is caused by the electrons in the Debye sphere [12], whose number is given by [13]

$$N_D = \frac{4\pi}{3} n_e \lambda_D^3 = \frac{1.718*10^9\, T_e^{\frac{3}{2}}\ (\mathrm{eV})}{n_e^{1/2}} \quad (3)$$

According to above equation$N_D$has to be much larger than unity to fulfill the collective characteristic of the plasma N_D>>1[13].

- **Plasma Coupling Parameter:-**

Plasma coupling parameter Γ is the ratio of the dust potential energy to the dust thermal energy and is given by[14]

$$\Gamma = 1.45*10^{-5}\left(\frac{n^{1/3}}{K_B T_e}\right) \quad (4)$$

It determines the coupling between the dust grain which indicates the likeliness of the cloud forming a dusty plasma crystal. Dusty plasma is strongly coupled when Γ>> 1 and weakly coupled when Γ <<1 [15].

- **Intergrain Spacing:**

Multi-component dusty plasma is composed of electrons, positively charged ions, and extremely massive charged dust grains, in a neutral background. The dust grain radius a is usually much smaller than the dusty plasma Debye length λ_D . When the intergrain spacing d is much smaller than , the charged dust particulates can be treated as massive point particles similar to multiply charged negative (or positive) ions in a multi-species plasma[11].

- **Characteristic Frequency:**

Another important parameter of the plasma is the plasma frequency. We distinguish plasma frequencies for electrons and for ions. These parameters correspond to the typical electrostatic oscillation frequency appearing as a result of small charge separation in the plasma for electrons (*e*) and ions (*i*), respectively[16] is given by [17].

$$\omega_{pe} = \left(\frac{n_e e^2}{\varepsilon_\circ m_e}\right)^{1/2} \quad (5)$$

Where $\varepsilon_\circ$ is the permittivity of free space($\varepsilon_\circ$=8,85x10^{-12} Fm^{-1}), m_e is the mass of electron (m_e=9.11x10^{-31}Kg) ,n_e is the number density of electrons (electrons per cubic meter), and *e* is the elementary charge (*e* = 1.602x10^{-19} C) .The electrons oscillate around the ions with a frequency ω_{pe} which is called electron plasma frequency Similar arguments apply for ions and the ion plasma frequency ω_{pi} is also defined for the positive charges is given by:

$$\omega_{pi} = \left(\frac{n_i e^2}{\varepsilon_\circ m_i}\right)^{1/2} \quad (6)$$

ω_{pe} is usually called plasma frequency. It should be underlined that both ion and electron Plasma frequencies only rely on the equilibrium charged particle density (n_o) and equation (5) and (6) becomes [14]:

$$\omega_p \approx \omega_{pe} = \left(\frac{n_o e^2}{\varepsilon_\circ m_i}\right)^{1/2} \quad (7)$$

The frequency ω_{pe} determines the fast time scale of the plasma, where the lighter particles (electrons) respond to the time dependent fluctuations of the local electric field. We may also interpret the time scale associated to the plasma frequency ω_{pe} as proportional to the time that a velocity thermal electron is given by [14]:

$$V_{Te}=\left(\frac{2\,K_B\,T_e}{m_e}\right)^{\frac{1}{2}} \qquad (8)$$

4. Calculate Dusty Plasma in Space

Calculation theory characteristic of dusty plasma in space for different position such as Interstellar Cloud, Interplanetary Space, Halley Comet, Saturn rings (E and F), Interstellar plasma ,solar wind and solar corona) by using Excel Program show in figures (1).

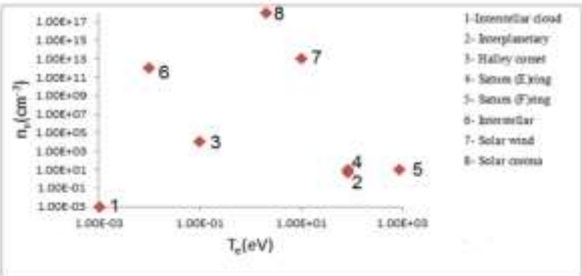

Figure 1: Represented electron density (cm^{-3}) as a function of electron temperature (eV) for different region in space

The electron density and temperature variations in space from region to another as a result of different locations in space, chemical composition, and magnetic field. Also has been found under some specific conditions. The region within the solar system will be affected by the pressure of solar radiation, solar flux, and solar magnetic field, they are also affected by nearby planets and stars as in solar corona, solar wind. The chemical elements that make up the solar system are hydrogen and helium make up more than 99% of all atoms in the solar system. The next most abundant elements after hydrogen and helium are oxygen, carbon, neon, nitrogen, magnesium, silicon, iron, and sulfur. According to figure(1) show high electron density through solar corona, solar wind, interstellar plasma. Some regions contain light elements, which are hydrogen and helium, so their density is low seen through an interstellar cloud, interplanetary space, Saturn ring(F and E rings). As for temperature,the regions close to the sun are high energy, As a result, the temperature will be as high seen through solar corona. The farther away from the sun the less the temperature will be in the interstellar cloud .

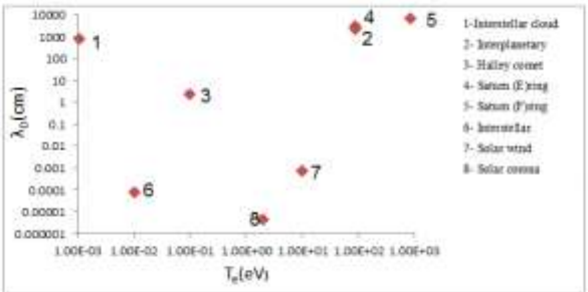

Figure 2: Represented Debye length (cm) as a function of electron temperature (eV) for different region in space

The relation between Debye length and electron temperature are directly proportional due to equation (2). When the temperature increases Debye length will increase too, due to the increase in electron energy and vice versa . According figure(2) show Debye length is decreased in space seen through an interstellar plasma, Solar wind, Solar corona. Increases Debye length in space seen through Interplanetary space, Saturn rings (F and E)

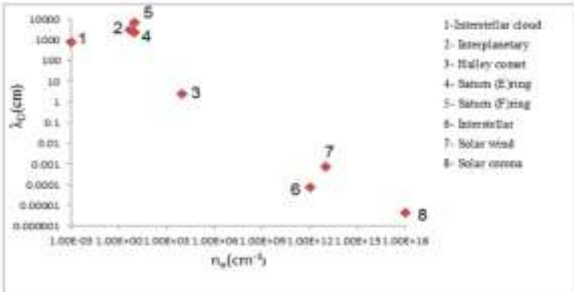

Figure 3: Represented Debye length (cm) as a function of electron density (cm^{-3}) for different region in space

Through the equation (2) observing the relation between Debye length and electron density are inversely proportional. Whenever increased density will work to decrease energy and therefore Debye length decrease too and vice versa. According to figure (3) show Debye length decrease was seen through solar corona, solar wind, interstellar plasma because electron density is high. Increases were seen through Interplanetary space,Saturn rings (F and E).

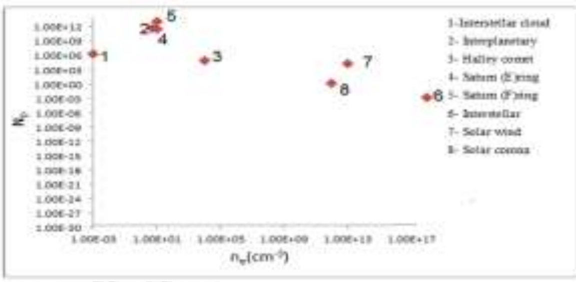

Figure 4: Represented Debye sphere as a function of electron density (cm^{-3}) for different region in space

Debye sphere is inversely proportional to electron density due to equation(3).Debye sphere increases when electron density is decreased and decrease when electron density is increased. According to figure(4) show Debye sphere decrease seen through interstellar plasma because electron density is high.And increase through Saturn ring(F ring) because electron density is low.

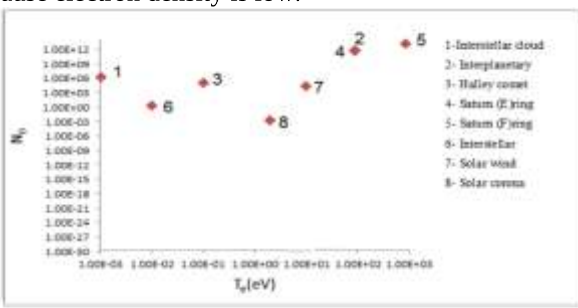

Figure 5: Represented Debye sphere as a function of electron temperature (eV) for different region in space

The correlation between Debye sphere and electron temperture are direct proportional due to equation (3). Debye sphere is increase when electron temperture is increase and decrease when electrontemperture is decrease . According to figure(5) show debye sphere is decrease in the space seen through solar corona, Interstellar palsma because electron temperture is decreases . Increased seen through Interplanetary space, saturn ring (F and E rings) because electron temperture is increases.

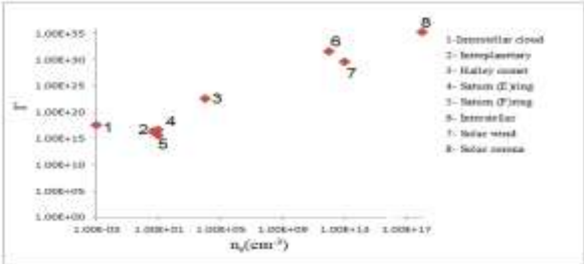

Figure 6: Represented coupling parameter of plasma as a function of electron density (cm^{-3}) for different region in space

Coupling parameter of plasma increases as the density increases as in the equation (4) electron density is directly proportional to coupling parameter of plasma. According to figure (6) show coupling parameter of plasma increase seen through solar corona, interstellar plasma, solar wind because electron density is high and decreases through interplanetary space, Saturn ring(F and E rings) because electron density is low.

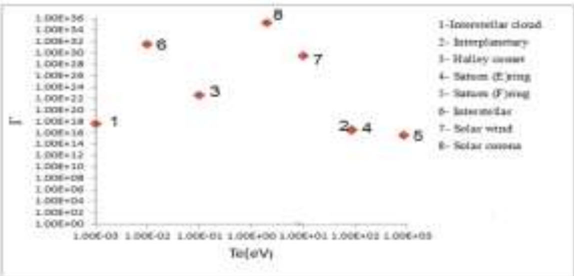

Figure 7: Represented coupling parameter of plasma as a function of electron temperature (eV) for different region in space

The relation between coupling parameter of plasma and electron temperature are inversely proportional due to equation(4). Coupling parameter of plasma increase when electron temperature is decreasing and decrease when electron temperature is increased. According to figure (7) show coupling parameter of plasma increase seen through solar corona because electron temperature is low.Decreased through Saturn ring(F ring) because electron temperature is high.

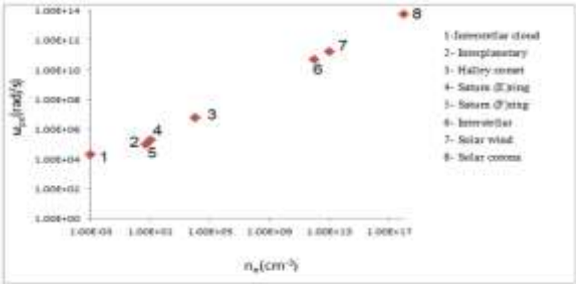

Figure 8: Represented plasma frequency of electron (rad/s) as a function of electron density (cm^{-3}) for different region in space

The plasma frequency of electron and electron density are direct proportional due to equation(7).Plasma frequency of electron increase when electron density is increased. According to figure(8) show plasma frequency of electron increase seen through solar corona because electron density is high and decrease through interstellar cloud because electron density is low.

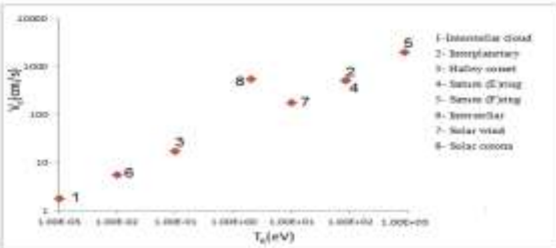

Figure 9: Represented electron velocity (cm/s) as a function of electron temperature (eV) for different region in space

The relation between electron velocity and electron temperature are directly proportional due to equation(8). electron velocity increase when electron temperature is increased. According to figure(9) show electron velocity increase seen through Saturn ring (F ring) because electron temperature is high and decrease through interstellar cloud because electron temperature is low.

5. Conclusion

The results explained in many features which can index as a conclusion:

1- Electron temperature is decrease in many regionssuch as interstellar cloud, interstellar plasma and Halley comet led to the Debye length, Debye sphere, and electron velocity decreases too. Increases electron temperature in many region such as: solar corona, Saturn rings (F and E) and interplanetary space are verse versa.

2- Electron density is increases in many region such as: solar corona, solar wind and interstellar plasmaled to plasma frequency of electron, and coupling parameter of plasma increases too. .Another region electrons density is decreased such as interstellar cloud; interplanetary space and Saturn ring (F and E rings)are verse versa.

Different characteristic dusty plasma in space result to difference electron density and temperature in the space.

References

[1] S. J. Schwartz, C. J. Owen, and D. Burgess, "Astrophysical plasma" , University of London,2004.
[2] A. Dinklage T.Klinger G.Marx L. Schweikhard "Plasma Physics" Springer Berlin Heidelberg New York,2005.
[3] N.Ya. Kotsarenko,S.V. Koshevaya, and A. N. Kotsarenko, " Dusty plasma in space "Geophysical International,, Vol.(37), No(2), pp:71-86,1998.
[4] T.J.M. Boyd, J.J. Sanderson "The Physics of Plasmas" Cambridge University Press ,2003.
[5] P. Shukla and A. Mamun,"Introduction to Dusty Plasma Physics", Institute of Physics Publishing Ltd, Bristol, 2002.
[6] A.A. Mamun,A Rahman," Electro-Acoustic Shock Waves in Dusty Plasmas "United Nations Educational Scientific and Cultural Organization And International Atomic Energy Agency,2005.
[7] J. M. Greenberg ,and Aigen LI," Morphological Structure and Chemical Composition of Cometary Nuclei and Dust" Kluwer Academic Publishers, Space Science Reviews Vol(90),pp: 149–161,1999.
[8] Ingrid Mann, Nicole Meyer-Vernet ,Andrzej Czechowski," Dust in the Planetary System: Dust Interactions in Space Plasmas of the Solar System" Physics Reports,2013.
[9] A.Melzer,"Introduction to colloidal(Dusty) Plasmas" Ernst-Moritz-Arndt-university Greifrswald,2012.
[10] L. S. Matthews and T. W. Hyde "Charge Grains in Saturn's F-Ring: Interaction with Saturn's Magnetic Field "Baylor University, P.O. 97310, PP:76798-7310, USA ,2003.
[11] M . Shafiq. "Test Charge Response of Dusty Plasma with Grain Size Distribution and Charging Dynamics". PhD. Thesis. University of Stockholm, 2006.
[12] R.O.Dendy, "Plasma Dynamics"Clarendon Press.Oxford ,1990.
[13] F.F.Chen, "Introduction plasma physics and Controlled Fusion",Plenum Press,New York,(1984).
[14] Dr. L. Conde." An Introduction to Plasma Physics and its Space Applications "ETS Ingenieros Aeronáuticos Universidad Politécnica de Madrid,2014.
[15] A. Anuar, "A Study of Dusty Plasma Environment",Ph.D. thesis, Lancaster University, England, 2013.
[16] G. V. Paeva."Sheath Phenomena in Dusty Plasmas".Ph.D thesis, Technical University of Eindhoven. 2005.
[17] Patrick Ludwig, Wojciech J Miloch, Hanno Kahlert, and Michael Bonitz," On the wake structure in streaming complex plasmas",New Journal of Physics 14 ,053016,2012.