Journal of High Energy Physics, Gravitation and Cosmology, 2019, 5, 181-192
http://www.scirp.org/journal/jhepgc
ISSN Online: 2380-4335
ISSN Print: 2380-4327

Galaxies "Boiling off" Electrons Due to the Photo-Electric Effect Leading to a New Model of the IGM and a Possible Mechanism for "Dark Matter"

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How to cite this paper: Ashmore, L. (2019) Galaxies "Boiling off" Electrons Due to the Photo-Electric Effect Leading to a New Model of the IGM and a Possible Mechanism for "Dark Matter". *Journal of High Energy Physics, Gravitation and Cosmology*, **5**, 181-192.
https://doi.org/10.4236/jhepgc.2019.51010

Received: October 23, 2018
Accepted: December 26, 2018
Published: December 29, 2018

Abstract

The Intergalactic Medium (IGM) is commonly thought to be occupied by approximately one atom of Hydrogen per cubic metre of space either as neutral Hydrogen or partially/fully ionised. This cannot be true as galaxies will "boil off" electrons from their outer surfaces by the photo-electric effect and so the IGM must be filled with electrons. UV and X-ray photons, as they leave the galaxy, can remove an electron from a Hydrogen atom at the surface of the galaxy, give it sufficient energy to escape the gravitational pull of the galaxy and go on to fill the IGM. A typical galaxy emits approximately 5×10^{47} X-ray photons each second. All of which pass through the outer surface of the galaxy and have sufficient energy to eject an electron and send it off to the IGM. Adding to these photons in the UV and gamma, we can see that galaxies are ejecting large amounts of electrons each second that go on to fill the IGM. Data from FRB 121102 give the value for the electron number density in the IGM as $n_e \approx 0.5\ \text{m}^{-3}$. Under certain conditions, an electron gas will crystallise into a Wigner-Seitz crystal. Here the electrical potential energy of repulsion between the electrons dominates their kinetic energy and the electrons form on a BCC lattice structure. The electrons oscillate, performing SHM about their lattice positions. With $n_e \approx 0.5\ \text{m}^{-3}$ the electrons in the IGM satisfy the energy criteria for crystallisation to occur when interacting with other electrons within a sphere far less in radius than the corresponding Debye sphere. Thus, the conditions are met for the electrons to form an "electron glass." Since the electrons in their BCC formation are spatially coherent, light will travel through the crystals in a straight line and thus objections to "Tired Light" theories are now removed since images will neither be destroyed nor "blurred." Charges are not created but separated, if the electrons are removed from the galaxy and sent to fill the IGM; the remaining protons are left behind. These are "thermal" and will not have sufficient energy to escape but will be held gravitationally to that galaxy. Could these too form a spherical Wigner-Seitz sphere around that galaxy? Since the structure would be transparent, light would pass through in straight lines and thus we would not see it. They would however, interact gravitationally with the galaxy and have an effect on the rotation curves of single galaxies and on the motion of galactic clusters. Just as we cannot see the clear water in a fish tank when we look at the fish, the transparent, crystalline sphere of protons around galaxies would be "dark".

Keywords

Intergalactic Medium, IGM, Galaxies, Dark Matter, Redshifts, CMBR, Tired Light, Wigner Crystals

1. Introduction

The classical view of the Universe is one of relatively "peaceful" galaxies—groups of billions of stars held together by their mutual gravitational attraction, "drifting" in a relatively empty space known as the Intergalactic Medium (IGM). Presently, the popular view is that the IGM is sparsely populated with neutral or ionised Hydrogen atoms [1]. But this cannot be true since the galaxies must be "boiling off" electrons from their outer surfaces by the photo-electric effect and these electrons will go on to fill the IGM.

Every star is pumping out radiation at all frequencies in every direction and some photons will strike an atom within the body of the galaxy and ionise it. However, the ejected electron will collide with other constituents of the galaxy, lose energy and will eventually recombine with a positive ion and reform a neutral Hydrogen atom. But what if the photon ionises a Hydrogen atom at the very edge of the galaxy? The photon is absorbed and an electron is ejected by the photo-electric effect. If the velocity of this electron is greater than the escape velocity at that point then it will have sufficient kinetic energy to overcome the gravitational pull of that galaxy and travel off into the IGM. Here it will interact by long range electrostatic forces with other electrons emitted in the same way. Under certain circumstances, when the balance between temperature and electron number density satisfy certain conditions, the electrons will form a "Wigner Crystal." Here the properties of electrons are determined by their electrical potential energy and not by their kinetic energies. The electrons assume a Body Centred Cubic (BCC) crystalline structure held in position by their mutual repulsion with the electrons merely vibrating about their lattice positions. Whilst the electrons move off into the IGM, the protons are left behind held there by gravitational forces. Is it possible that these protons form the illusive "*Dark Matter*?"

2. The Photo-Electric Effect

The photo-electric effect is a well documented phenomenon whereby photons with a frequency above the threshold frequency, f_0 (the minimum frequency of radiation required to remove an electron from the surface of a material) have enough energy to release an electron. The classical experiment being where UV radiation falls on a negatively charged clean zinc plate and electrons are emitted from the surface.

The Einstein equation being:

$$hf = \phi + \frac{1}{2} m v_{\max}^2 \tag{1}$$

Here h is the Plank constant, f the frequency of the incoming radiation, ϕ the work function or "minimum energy needed to release an electron from the surface of the metal," m is the mass of the electron (usually taken as the rest mass) and v is the velocity of the ejected electron.

Galaxies contain billions of stars and each one is pumping out photons of all frequencies and many will pass through the innards of the galaxy intact and escape to pass through to the IGM and "light up" the Universe. Some though, as they leave, will interact with a hydrogen atom at the surface of the galaxy and eject an electron. This is exactly the same as the photo-electric effect but instead of the radiation falling on a surface from the outside of the metal, with our galaxy the radiation is coming from the inside—but still ionising an atom at the surface as it passes. In order for the photon to release an electron from a Hydrogen atom in the ground state the energy of the photon must be greater than $13.6\ \text{eV} = 2.18 \times 10^{-18}\ \text{J}$. This is the value of the work function, ϕ (Equation (1)). In order for the electron to escape the gravitational pull of the galaxy $v_{\max}$ must be greater than the escape velocity for that galaxy at that point.

The escape velocity, v_{esc} is given by:

$$v_{esc} = \sqrt{\frac{2GM}{R}} \tag{2}$$

Consider the Milky Way Galaxy. The gravitational constant, $G = 6.674 \times 10^{-11}\ \text{N} \cdot \text{kg}^{-2} \cdot \text{m}^2$, The total mass of the galaxy (visible plus dark), $M = 1.9891 \times 10^{42}\ \text{kg}$ up to a radius $R = 200\ \text{kpc} = 6.17 \times 10^{21}\ \text{m}$ [2] giving for v_{esc} at the outer regions of our galaxy:

$$v_{esc} = 2.1 \times 10^5\ \text{m} \cdot \text{s}^{-1} \tag{3}$$

Substituting $v_{esc} = 2.1 \times 10^5\ \text{m} \cdot \text{s}^{-1}$ and $\phi = 2.18 \times 10^{-18}\ \text{J}$ in Equation (1) gives the minimum value for the frequency ($f_{\min}$) of a photon capable of ionising an electron in a Hydrogen atom at the very edge of the Milky way galaxy and for that electron to escape and enter the IGM of:

$$f_{\min} = 3.3 \times 10^{15}\ \text{Hz} \tag{4}$$

This corresponds to a maximum wavelength ($\lambda_{\max}$) of:

$$\lambda_{\max} = 9.0 \times 10^{-8} \text{ m}$$
$$\lambda_{\max} \approx 10^{-7} \text{ m} \quad (5)$$

This wavelength is in the low ultra violet region. That is, any photon in the UV, X-ray or Gamma range of the electro magnetic spectrum ionising a Hydrogen atom at the edge of the Milky Way galaxy will give that electron sufficient energy to escape and enter the IGM. This calculation is for a photon ionising a Hydrogen atom on the outer reaches of the galaxy. If we perform the same calculation for an electron emerging from the edge of the central bulge we find $\lambda_{max} = 2.9 \times 10^{-9}$ m—in the low X-ray region. In 1978 NASA launched the Einstein (HEAO 2) satellite which made sensitive x-ray imaging observations of over 200 galaxies and the measurements showed that ordinary galaxies of any morphology emit X-rays over the entire surface with a luminosity of between 10^{31} - 10^{35} Joules per second [3]. If we take a typical wavelength of an X-ray photon as $\lambda = 10^{-10}$ m, this means that every second, 5×10^{47} X-ray photons pass through the outer surface of the Milky Way (and every other galaxy) and should they interact with a Hydrogen atom on the outer surface, they will contribute "free" electrons to the IGM. Since we have the UV and gamma photons on top of this, it is no overstatement to say that every galaxy in the Universe is "boiling off" electrons which go on to fill the IGM. Consequently we must no longer think of the Universe as being a group of "passive" galaxies "drifting" amid great voids of almost empty space, we must picture all galaxies as being dynamic, pouring out electrons from their outer surfaces and filling the spaces between them with pure electron clouds.

3. Mean Electron Number Density in the IGM

The mean electron number density, n_e, can be found from fast radio burst (FRB) data [4] [5]. The fast radio burst FRB 121102 **Table 1** is a repeating FRB reported to be of known host galaxy and hence the distance and Dispersion Measure, DM are known [6] [7] [8].

The relationship between the DM and n_e is given by:

$$DM_{IGM} = n_e d \quad (6)$$

Table 1. Data for FRB 121102.

DM (measured)	558.1 ± 3.3 pc cm^{-3}
DM_{NE2001}	≈188 pc cm^{-3}
DM_{halo}	≈30 pc cm^{-3}
DM_{host}	?
DM_{IGM}	≈ (340 − DM_{host}) pc cm^{-3}
D_A	≈683 Mpc
D_L	≈972 Mpc
host redshift, z	0.19273 ± 0.00008

Using the angular-diameter distance gives:

$$n_e \approx 0.498 \text{ m}^{-3} \tag{7}$$

Whilst using the luminosity distance gives:

$$n_e \approx 0.350 \text{ m}^{-3} \tag{8}$$

It should be noted that the DM for the IGM includes any contribution from the host galaxy and assumes the electrons are evenly distributed throughout the IGM.

4. Wigner Crystals

The concept of an electron crystal was first proposed by Wigner in 1934 [9] [10]. In "Condensed Matter Physics," an electron gas condenses to a crystal state when both the Fermi energy and electron temperature are small compared to the energy of mutual repulsion. In a classical Wigner crystal, the Fermi energy is negligible compared to the electron temperature, Pauli exclusion can be neglected and the kinetic energy of the electrons is purely classical. The electrons form on a body centred cubic lattice held in place by their mutual repulsion.

The Wigner-Seitz sphere encloses a volume around an electron on a lattice point and anything within that sphere is closer to that electron than any other. In three dimensions:

$$r_0 = (3/4\pi)^{-1/3} n_e^{-1/3} \tag{9}$$

In the IGM $n_e \approx 0.5 \text{ m}^{-3}$ and so r_0 has the value ≈ 0.79 m.

4.1. Electrical Potential at a Point in the Crystal

In order for the electrons in the IGM to form a Wigner crystal the electrical potential energy, E_{PE} of the electron must be greater than the kinetic energy, E_K. To determine the electric potential at point P consider a spherical shell of charge of thickness dr at a distance r from P. We assume that the charge is "smeared out" evenly over the whole volume such that the charge density is ρ. Since there are 0.5 electrons per cubic metre of space the charge density is, $\rho = 0.5e = 8.0\times10^{-20} \text{ m}^{-3}$.

The volume of this shell is $4\pi r^2 dr$ and the charge on this shell is $4\pi r^2 \rho dr$. Figure 1 The electrical potential is given by

$$V_E = \frac{1}{4\pi\varepsilon_0}\frac{4\pi r^2 \rho dr}{r} \tag{10}$$

Which simplifies to $9\times10^{-9} r dr$. To find the potential due to all the shells within the sphere surrounding the electron with which it interacts electrostatically we must integrate this function from $r = 0$ to R where R is the radius of that sphere.

$$V_E = 4.5\times10^{-9} R^2 \tag{11}$$

To find the electric potential energy of the electron, E_{PE} we must multiply this by the charge on the electron, e.

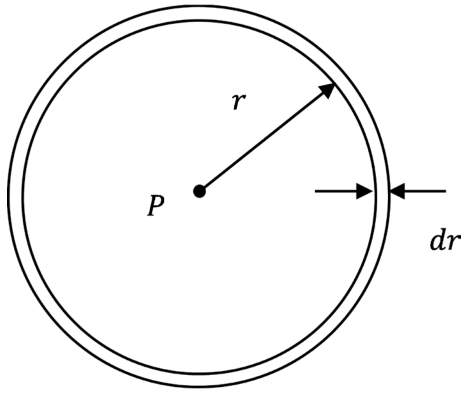

Figure 1. The spherical shell of radius r and width dr surrounding point P.

$$E_{PE} = 7.2\times10^{-28} R^2 \tag{12}$$

4.2. Kinetic Energy of an Electron in the Crystal

The Kinetic energy is purely thermal in a classical crystal and given by:

$$KE = \frac{3}{2} k_B T \tag{13}$$

where k_B is the Boltzmann constant and T the absolute temperature. In the IGM the temperature is taken to be the temperature of the CMBR, 2.73 K [11] giving a kinetic energy of 5.6×10^{-23} J. Equating this with our equation for the electric potential of the electron in the plasma gives $R = 280$ m. If we take the temperature of the plasma to be 50,000 K then the radius of the sphere with which the electron must interact in order that the potential energy dominates the kinetic energy is $R = 38$ km.

In plasma physics an often quoted measure of the interaction length is the Debye length. This is the radius of a sphere within which an electron in a plasma will interact with all other electrons in that sphere. However, this applies to neutral plasma and this sphere represents the maximum distance over which interactions can take place before shielding by opposite charges cancels the effect. Here, there are only electrons and so this does not apply. However, the reader may be interested to know that at $T = 2.7$ K the Debye length λ_D, is $\lambda_D = 8.3\times10^{6}$ m and at $T = 50000$ K, $\lambda_D = 2.1\times10^{9}$ m. These values do not contradict our results. Consequently electrons in the IGM satisfy the condition that their electric potential energy is greater than their kinetic energy and will form Wigner crystals. The electrons in the IGM form on a BCC space lattice, vibrating about their "pinned" positions.

5. The Transmission of Light through the IGM

Since the electrons in these crystals oscillate about their lattice point with simple harmonic motion they can, and do, absorb and emit photons and hence light and other forms of radiation can pass through the crystal. "The transmission and reflection of light is nothing more than an electron picking up a photon, scratching it"s head so to speak and emitting a "*new*" *photon*" [12]. This is the way light travels through the crystals. A photon collides with an electron and is absorbed by it. The energy of the photon is transferred to the oscillating electron and, after a short delay, a "new" photon is emitted. Since the IGM consists of Wigner crystals the electrons themselves in their BCC crystal structure form scattering centres which are spatially coherent and so there is no destruction or "blurring" of the image by the medium—the light travels in straight lines. Indeed, these crystals are often known as "electronic glasses" or "Wigner glass." [13] These crystals open the opportunity to revisit alternative theories on redshift since the main objections to Tired Light theories (that images would blur) have now been removed—especially those which rely on a transfer of energy from photon to electron due to recoil on absorption and re-emission [14] [15].

5.1. The Collision Cross-Section

The collision cross-section, σ for a photon-electron interaction is known from the low frequency interaction of X-rays with matter [16] [17] [18]

$$\sigma = 2r\lambda f' \tag{14}$$

where, r is the classical electron radius, λ the photon wavelength and f' is the photo absorption coefficient. Collision cross-sections have dimensions of area and represent the probability of a photon interacting with an electron. The values of " f' " vary from atom to atom and for atoms with a low atomic number has values from zero up to the number of electrons in the neutral atom. For Hydrogen, f' has values from 0 → 1. For Helium, f' has values from 0 → 2 and so on. When $f' = 0$, The frequency of the incoming photon is well away from the resonant frequency of the atom and the photon is re-emitted. With Hydrogen, when $f' = 1$ the frequency of the incoming photon is exactly equal to the resonant frequency of the atom and the photon is absorbed and not re-emitted. Since we have one photon interacting with a single electron in the crystal we use the photo absorption coefficient for Hydrogen, $0 \le f' \le 1$.

There are only two possible outcomes and these are mutually exclusive. If $\sigma = 2r\lambda f'$ is the probability of the photon being absorbed and not re-emitted (resonant absorption) then the collision cross-section for a photon to be absorbed and re-emitted (transmission) will be $\sigma = 2r\lambda(1 - f')$.

5.2. The Plasma Frequency

The plasma frequency, f_{pe} is the frequency at which resonance occurs in the plasma and is also equal to the natural frequency of oscillation of the electrons in the plasma.

$$f_{pe} = \frac{1}{2\pi}\sqrt{\frac{n_e e^2}{m^* \varepsilon_0}} \tag{15}$$

where, e is the electronic charge, m^* the effective mass of the electron

($m^* = 9.1\times10^{-31}$ kg here since the plasma is sparsely populated and velocities non-relativistic) and ε_0 is the permittivity of free space. Inserting the value $n_e \approx 0.5\ \text{m}^{-3}$ (Equation (7)) found from the FRB data gives $f_{pe} \approx 6$ Hz. Consequently the frequency of all the e-m radiation travelling through the plasma is far, far higher than the resonant frequency and so the photons will always be re-emitted and the photo-absorption cross-section, $f' = 0$. The collision cross-section for absorption followed by re-emission is therefore, $\sigma = 2r\lambda$. Radio waves have the longest wavelength and even when $\lambda = 1000$ m the collision cross-section is of the order of 10^{-11} m—which is negligible compared to the radius of the Wigner-Seitz sphere (0.79 m). Consequently, it is a one photon to one electron interaction. For radiation having frequencies in the radio and above, the electron absorbs the photon as before and oscillates at a very high frequency. There is not time for the neighbouring electrons to react and so the entire energy of that photon is constrained to that single electron which goes on to emit a "new" photon. Note that photons have a "length" inversely proportional to the frequency of the photon [19] and this can be considerably long—especially in the radio frequencies. However, it is the collision cross-section that is important since, should two electrons lie exactly along the same line of sight, the first electron would absorb the photon and then re-emit it only for the same to occur with the second electron. The first electron effectively "shields" the second. Each photon interacts with one electron in the crystal at a time.

6. Exploding and Static Crystal Structures

A great deal of work has been done on trapped Wigner crystals and the conditions under which they will crystallise [20] when confined in a Penning trap. However, in the IGM the electrons are not confined by static electric and magnetic fields and so these conditions do not apply directly. As was seen in section 4.2, the electrostatic potential energy is greater than the kinetic energy for electrons with a number density of $n \approx 0.5\ \text{m}^{-3}$ and the electrons in the IGM crystallise onto a BCC space lattice. In a finite Universe the crystal would "explode" since the electrons are mutually repelling each other with nothing on the outside to hold them in place. The electron crystal would be expanding around the neutral matter with photons travelling through this expanding crystal structure. The photons are absorbed and re-emitted by the electrons and redshifts could be produced by a combination of Tired Light [14] [15] and a "Doppler shift" due to the "exploding" crystal.

In an infinite Universe the crystal would be static since every cell of the crystal would be surrounded by other identical cells on all sides—wherever it was in the Universe. The equally repulsive forces acting on each cell would cancel and the cell remain a constant size. As electrons recombined with the protons surrounding the galaxies, new ones would be emitted and so the number density would be in dynamic equilibrium. In this case redshifts in a static Universe would be explained by recoil of the electrons as they absorb and re-emit the photons as they travel through the IGM.

7. A Possible Mechanism for "Dark Matter"

"Dark matter" has been a "hot topic" in cosmology for some time as a means of explaining the peculiar rotation curves of galaxies and the rotation of galaxy clusters [21] [22]. Whilst the dark matter problem could be, in principle, achieved through the so called extended theories of gravity [23] the photoelectric effect and its application as applied to galaxies as described in this paper also offers a possible mechanism by which it could be explained.

We have seen how the photo-electric effect is responsible for filling the IGM with electrons but what of the remaining positive ions? The protons left behind from the ionisation process will be "thermal" and so they will not have sufficient energy to escape the gravitational field of the galaxy. These will form a Wigner crystal made up of protons surrounding the galaxy. This crystal will have long range order and will form a sphere [24]. The spherical crystal will surround a single galaxy and fill the region both within and outside a cluster of galaxies up to the point where the electrostatic forces of repulsion are equal and opposite to those of gravity. It is proposed that since electrostatic forces of repulsion are much stronger than gravitational attraction forces then this region will extend well beyond the region of the galaxy that is visible. The sphere will not keep increasing in size but will reach dynamic equilibrium at a certain radius when the rate of recombination is equal to the rate at which atoms are ionised. Since protons absorb and emit photons and the protons are spatially coherent, it will be transparent. Light will pass through it in straight lines as if it were not there. It will be "dark." Most people have walked into a pane of glass not having seen it. The glass is "dark." Some jelly fish are transparent meaning they cannot be seen in deep water thus providing the perfect camouflage. They will be "dark." Thus the transparent Wigner crystal surrounding galaxies will be "dark." However, whilst mutually repelling each other, the crystalline sphere of protons will interact gravitationally with the galaxies themselves and thus form a possible mechanism for the "dark" matter thought to surround galaxies.

8. Conclusions and Discussion

The photo-electric effect is standard, accepted physics and there can be no doubt that it will occur at the "surfaces" of galaxies. Ultra Violet, X-ray and gamma ray photons transfer enough energy to the ejected electrons to allow them to escape the gravitational field of that galaxy. As a consequence, every galaxy must be a source of free electrons that go on to fill the IGM. The number of free electrons in the IGM can be determined from the data on the repeating FRB 121102 and is found to have a value of $n_e \approx 0.5\ \mathrm{m}^{-3}$—assuming they are evenly distributed along the line of sight. The phenomenon of Wigner crystals are well established within the scientific community and are thought to occur in the interiors of white dwarf stars and if we apply these principles to the plasma in the IGM, the electron gas will crystallise into a BCC crystalline structure when the electrostatic potential energy is greater than the kinetic energy of the electrons. The electric potential at a point in the lattice can be calculated by adding the potentials from neighbouring electrons within a sphere centred on that point. Using the data from the repeating FRB 121102, we see that the conditions for the electrons to crystallise into a Wigner BCC crystal are met by a sphere of radius $R = 280\ \text{m}$ at a temperature of 2.73 K and 38 km for a temperature of 50,000 K. A term used often in plasma physics is the Debye length which gives the radius of a sphere electrons interact with each other. Whilst this length refers to an overall neutral plasma, it is interesting to note that at an electron number density of $n \approx 0.5\ \text{m}^{-3}$, the Debye lengths at 2.73 K and 50,000 K are $8.3\times10^{6}\ \text{m}$ and $2.1\times10^{9}\ \text{m}$ respectively. The Debye lengths are far greater than those needed to satisfy the conditions for a Wigner crystal to form and thus the electrons in the IGM arrange themselves so that they are "pinned" to a fixed location, vibrating about that point—thus forming an electron "glass."

Electrons absorb and re-emit photons and so the photons will interact with the electrons in these crystals. However, since the arrangement of the electrons on a body centred cubic lattice is spatially coherent, transmission will take place along a straight line and thus images will not be destroyed or blurred. Since the IGM is no longer considered to be sparsely occupied by single Hydrogen atoms (fully ionised or not) but filled with electrons this removes many of the arguments against Tired Light Theories allowing them to be revisited.

As to whether the Universe is finite or infinite leads to interesting possibilities. In a finite Universe the Wigner crystal will not be bounded and so will be "exploding"—the electrons moving further and further apart with the possibility of newly ejected electrons from the surfaces of galaxies filling the space in-between created by this expansion—a sort of "steady state" Wigner crystal. This in itself leads to a possible explanation of redshifts in a static Universe. As the photons travel through the crystal they will be absorbed and re-emitted by the electrons and, as well as a shift due to Tired Light, also suffer a Doppler shift each time.

In an infinite Universe, the crystal would not expand but be static since each negative cell would be surrounded by other negative cells and suffer repulsive forces from all sides. This would occur throughout the Universe. Electrons recombining with positive charges surrounding galaxies would be replaced by other electrons newly released from a galaxy surface by the photo-electric effect. In this case, redshifts in a static Universe could be explained by a recoil action on the electrons as they absorb and re-emit photons on their journey through the IGM.

Since charges are not created but separated, if the electrons are released by the photo-electric effect from the surface of a galaxy and escape into the IGM, protons must be left behind. Could these too form a Wigner crystal in the form of a sphere surrounding single galaxies and filling the spaces within galaxy clusters? Could the protons also form a spatially coherent BCC crystal around galaxies?

Since they also absorb and emit photons, the structure would be transparent and thus invisible to detection. Could it be this "dark matter" that interacts gravitationally with the rotation of single galaxies and clusters.

Acknowledgements

Up until recently I too had been stuck in the popular belief that the IGM is sparsely populated with ionised Hydrogen atoms. I must thank John G Williamson, an ex university lecturer and member of the of the "*Quicycle society*" who, after listening to my presentation on "New Tired Light" at the Vigier 11 conference, Liege 2018, joined me at breakfast the following morning and suggested the theory would work better if the IGM was full of electrons and not just ionised Hydrogen since "at low temperatures and number densities the electrons from a crystal structure." Doubtful at first, I went away and considered the idea and it was then that I realised that galaxies had to be boiling off electrons from their outer surface by the photo-electric effect and thus the IGM must be filled with electrons as he suggested. Had it not been for John and that breakfast, I too would probably still be stuck in the mindset of an IGM consisting of ionised Hydrogen for some time to come.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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