On Resolving Olbers' Paradox with Interstellar-Space-Induced Light Filaments

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***Abstract*— The interstellar medium is far from a vacuum containing Hydrogen, Helium and various heavier atoms in a plethora of states including neutral, ionized, gas and solid. The formation of light filaments has been demonstrated since the early 1960s as a nonlinear optical response by the material to the incident electromagnetic energy creating self-focusing of the beam by the material resulting in filaments of light to form. We provide insight into the formation of filaments in plasma to introduce a unified theory of filament formation in both plasma and pure electromagnetic energy throughout interstellar space in pursuit of answering a simple question - why space is dark.**

***Index Terms*— Light Filaments, Light Propagation, Lasers, Nonlinear Optics, Plasma Physics, Space Science**

I. INTRODUCTION

The night sky is a universal experience for all, forming one half of the day-night cycle which is synchronized with the sleep-wake cycle of humans. This relationship between the cycle of the external world and the internal cycle of man is summarized by the images of Robert Fludd depicting the macrocosm universe encapsulating the microcosm of man [1]. Investigations into the fundamental behavior of phenomena such as light and plasma has reinvigorated questions of antiquity as to the true properties of the universe. Specifically, should the universe be full of ionized plasma, and this plasma emit electromagnetic radiation with frequencies in the visible light range, with this radiation experiencing minimal attenuation through absorption, is it not to be expected then that our experience in space would be one full of color, or of retinal photoreceptor saturation, as if looking into the sun itself. Olbers proposed the following proposition [2]: Given that space itself is infinite, and space consists of stars (suns) placed at equal distances or grouped in solar systems such as the Milky Way, then each point in space should have a star at some distance from the observer; therefore, the entirety of space should appear as bright as the surface of the Sun, that is, each point in space contains a star emitting light, where each star is positioned somewhere in the infinite space. This is of course, contradicted by the physical experience of the darkness of space. The conclusion for Olbers, is in the properties of space itself, that is, space having the property of translucency as to attenuate the light of distant suns, allowing man to study the limited region of space in view around Earth.

We find through the work of Birkeland and Alfven the existence of plasma filaments known as *Birkeland Currents* [3],[4] which explain the connection between solar activity and the auroras experienced on earth, which we extend to be a fundamental constituent of solar, planetary and galactic interactions of the universe. We then postulate the existence of filaments of light as explaining the experienced intensity of light from distance starts, offering a novel explanation and alternate conception for the macrocosm of outer space.

II. PLASMA FORMATION AND Z-PINCH

An electrostatic potential in volts is applied to a column of gas, containing an anode and cathode on each end forming a capacitor with the gas serving as the dielectric. and the potential across the column as well as the current of this column is measured. For plasma discharges this curve, depicting the resistance $R = \frac{V}{I}$, is typically highly non-linear [5]. The plasma grows from the dark current mode, to the point at which the gas ionizes in the glow mode, then breaks down in the arc mode (See Fig 1).
During the arc mode, the medium breaks down forming a channel which minimizes the potential between the anode and cathode, collapsing the electrostatic field within the path created as the anode and cathode become equipotential, causing the arc to form. The conduction current in this case is produced from the ions contained in the gas. From the context of plasma, the conduction current is produced by the movement of charged particles. Keeping the quantity of charged particles fixed, as we do in the container of gas, an avalanche of particle movements forms during the glow to arc transition, whereby a path is formed minimizing the potential difference allowing the conduction current to move with little resistance, minimizing the potential across the column [7].

A. Z-Pinch

As the conduction current is increased by the concentration of ionized particles into the arc formed within the gas, the magnetic field perpendicular to each point of

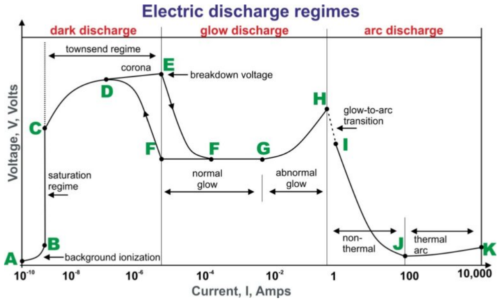

Fig. 1. Dynamic Resistance Graph of Plasma Discharge [6].

the arc increases in strength in accordance to Ampere's Circuital Law.

$$\oint B \cdot dl = \int \mu_0 (J + \frac{\partial D}{\partial t}) \cdot dS$$

This magnetic field causes a Lorentz force [9] to be exerted onto the ions contained within the column.

$$F = q(E + v \times B)$$

Given an arc, we take a positively charged particle with velocity v moving left to right. By the right hand rule, the B field moves outward from the page on top and inward on the bottom. Excluding the Electric field, $v \times B$ produces a ↓ directed force on top of the column and a ↑ directed force on the bottom of the column, thereby pinching the column. Repeating this with a negatively charged particle produces the same results, since $q = -q$ and $v = -v$ from the positively charged case, assuming the electric field is the same.

This result is shown experimentally in [8] in which a soda can is induced with a strong magnetic field from a high voltage discharge into a solenoid around the can. This by Lenz's Law produces an Electromotive force to oppose the applied magnetic field, resulting in a current along the surface of the can, in which the can itself acts as a solenoid. The magnetic field, which moves longitudinally along the direction of the inside of the can and wraps, longitudinally around the surface of the can, results in a Lorentz force inward to the can, where the velocity is along the surface of the can and the magnetic field is orthogonal pointing from the bottom to the top of the can, depending on the direction of the applied magnetic field. This results in a crushing of the can, known as *Z-Pinch*, named through the historic direction of current given a vertically oriented column of ionized gas [10].

III. LIGHT FILAMENTS

With the background in plasma formation and the z-pinch effect, we now investigate filament formation in beams of light to view the similarities. Light filaments is a phenomenon observed in beams of light from a laser within a medium as a result of the non-linear optical interaction of the light with the medium. In [11] it is observed that the transverse inhomogeneity, that is, the transverse distribution of intensity for a strong beam of electromagnetic energy through a medium has the effect of ejecting electrons and atoms from the path of the beam in the medium, causing a rarefaction, when the frequency of the beam is greater than the natural frequency of the electron oscillations [11]. When the frequency is below the natural frequency of the electron oscillation, the particles are pulled in. This changes the refractive index of the medium along the path of the medium, forming a gradient, effectively transforming the medium into a lens based on the change in density of particles along the beam path.

The beam of a laser, that is, the inhomogeneity of the transverse components to the direction of propagation are characterized with the profile modeled by the Gaussian distribution in radial intensity.

$$I = I_0 e^{\frac{-2r^2}{w^2}}$$

Where I_0 is the maximum Intensity r is the radius from the center of the beam and w is the distance where the Irradiance decreases by 13.5% of the maximum intensity value, I_0 [12].

A. NONLINEAR SUSCEPTIBILITY

Where [11] provides the description of plasma induced optical non-linear effects through the mechanical description of electron oscillators. This field is more generally known as Nonlinear optics, and feature additional effects from applied DC in addition to AC fields, in which the change in refractive index from these fields is known as the Kerr Effect. To explain this nonlinear phenomena, we must define the fundamental quantities of Nonlinear Optics. $P(t)$ is the time variation of the electric dipole moment per unit volume. In the linear case, we find the following relationship

$$P = \epsilon_0 \chi_e^{(1)} E$$

In which $\chi_e^{(1)}$ is the first order linear susceptibility of the material, expressed as $\chi_e^{(1)} = \epsilon_r - 1$. In order to define the Polarization as a result of nonlinear interactions with the applied Electric field, that is $P(t)$ varies in a nonlinear manner with $E(t)$, we express $P(t)$ as a power series:

$$P(t) = \frac{p_k}{N_a} \frac{N_a}{\Delta v}$$

$$P(t) = P_0 + \epsilon_0 \chi^{(1)} E(t) + \epsilon_0 \chi^{(2)} E^2(t) + \epsilon_0 \chi^{(3)} E^3(t) + ...$$

Where in $P(t) = \frac{p_k}{N_a} \frac{N_a}{\Delta v}$ p_k is the number of dipole moments per number of atoms and N_a is the number of atoms and Δv is the unit volume. $\chi_e^{(2)}$ and $\chi_e^{(3)}$ are the second and third-order nonlinear susceptibility of the material. Where this is defined to be in the one dimension case, or in other words, at a fixed point in space varying only in time, in the spatial varying case the susceptibility is defined as a tensor of rank equal to its respective order plus one [13].

As we have seen in [11] the electron oscillations are the result of the applied electromagnetic field oscillating at particular frequencies with characteristics based on the deviation from the natural frequency of the electron cloud. This oscillation creates a dipole moment within the atom, as the cloud is pulled toward and away from the nucleus. This polarization moment must therefore be included into the linear polarization equation, which is based on the static case resulting from an electrostatic potential. The first two $P_0 + \epsilon_0 \chi^{(1)} E(t)$ form the linear optical response to the applied electric field. To describe the linearity of this term we recall the refractive index n

$$n = \frac{c}{v}$$

Where $n = 1$ in the case of free space and $n > 1$ in dielectric medium. For optical medium there is generally change in permeability $\mu_r = 1$, using $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$ and $v = \frac{1}{\sqrt{\mu_r \mu_0 \epsilon_r \epsilon_0}}$

$$n = \sqrt{\epsilon_r} = \sqrt{1 + \chi_e^{(1)}}$$

Which proves the relationship between the refractive index, linear susceptibility and linear optics resulting from the linear polarization of the medium. $\chi_e^{(1)}$ measures the material response to the applied electric field, in the case of the vacuum with linear optics, $\chi_e^{(1)} = 0$ resulting in the refractive index $n = 1$. Other responses in addition to the electron oscillation include atomic dipole alignment, in which the atom orients itself in the direction of the field and the effects of compression and rarefaction described earlier.

In order to trigger self-focusing therefore creating filaments, we list the intensity dependent refractive index

$$n = n_0 + n_2 I$$

Where n is the linear refractive index defined above and n_2 is the refractive index proportional to $\chi_e^{(3)}$[14]

$$n_2 = \frac{3\chi_e^{(3)}}{4 n_0^2 \epsilon_0 c}$$

Where n_2 describes the third order refractive index dependent on the third order nonlinear susceptibility $\chi_e^{(3)}$. Creating the conditions for self-focusing due to the inhomogeneity of beam intensity within the medium.

B. INTERSTELLAR-SPACE-INDUCED FILAMENTS

Interstellar space is far from empty, being composed predominately of hydrogen, helium and various heavy metals throughout. The state of these atoms consists of molecules, ions, in gaseous and solid states [15]. Since the interstellar medium contains matter, the question of whether this matter creates nonlinear optical responses in the radiant energy of distant stars becomes viable. The proposal in this paper is that in fact a nonlinear, self-focusing result is obtained through the interstellar medium, and this creates light filaments to form from the radiant energy of distant stars. The appearance of the darkness of space is then due to the quantity of these filaments hitting the optical system, be it the human eye or semiconductor. When the filaments hit bulk matter, such as the atmosphere, scattering due to a combination of reflection, refraction, and diffraction occur since it is in the path of the filament. This would allow for the distant light to be visible from earth, as it is modified by the surrounding atmosphere. This in addition explains the lack of light seen in transit through space, also explained with classical electromagnetic theory, since an observer transverse to the direction of propagation would require the wave to be scattered in the direction of the observer in order to view, while an observer on the receiving end on the longitudinal path will receive and view the wave.

IV. CONCLUSION

We describe the formation of plasma filaments and z-pinch as a natural produce of plasma streams and describe the formation of light filaments through nonlinear optical responses in materials in order to provide a unified introduction to filaments as a core interaction connecting intergalactic radiant energy with solar and planetary interactions within the solar system. Future investigation into the nonlinear optical response of the interstellar medium is necessary to determine the formation of light filaments through space in addition to the dependencies on intensity and frequency of radiant energy on this medium including the effects of variation within the medium such as ionization and variations in material composition as the radiant energy travels across the dynamic, plasma filled environment of the universe.

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