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Low energy plasma focus simulate astrophysical phenomena

Abstract

Several phenomena recorded in dense plasma focus (DPF) discharges seem to reproduce astrophysical observations. Time-integrated ion measurements were performed with pinhole cameras equipped with solid-state nuclear track detectors (of type CR-39). The ion-pinhole cameras were placed at an angle zero degreewith respect to the anode axis. The plasma ion tracks (cluster of micro-beam) is laboratory analog to the formation of globular clusters in Milky-way galaxy. CCZ model (core surrounded by co-central zones) is proposed to estimate the ion track density of dense plasma focus discharge. The cluster morphology of plasma ion tracks formed by DPF are laboratory similar to the formation of the globular cluster of our galaxy.

Keywords

Ion-pinhole; Plasma focus; Globular clusters; Galaxy; Track detectors.

INTRODUCTION

A dense plasma focus is like a Z-pinch discharge produced by a high voltage pulse when applied to a low-pressure gas between coaxial electrodes generating a short duration, high density and high temperature plasma. Many astrophysical phenomena for example, solar flares, aurora, corona, plumes, comet ion tails and planetary nebulae[1-2] are based on plasmas that present filaments like plasma focus discharge[3]. Plasma pinches have been under study in the laboratory for a long time now and sausage perturbations are observed in them.

The dense plasma focus device, or "plasma gun" provides a mechanism by which cosmic electric currents can influence space structures, whether they be moons or galaxies. The dense plasma focus (DPF) consists of an open ended coaxial gun loaded with static gas and driven by capacitor bank[5], as shown in Figure 1.

Typically, dense plasma focus (DPF) devices generate high temperature and high density plasmas[6]. The maximum pinch compression should coincide with the peak current in order to obtain the best efficiency[7]. Experiments showed that the performance of the plasma focus (PF) depends on many parameters such as the energy of the capacitor bank, current, voltage, and the curvature of the current sheath in the axial phase[8].

When a large current is discharged across the cylinder of a plasma focus device it rapidly ionizes the plasma and forms into many pairs of filaments which twist together into one filament called plasmoid. The entire energy stored in the magnetic field of the device is now contained in a very small area and the electrons orbit in smaller circles as the field increases, giving off radiation of a higher frequency. The falling magnetic field generates a huge electrical field which shoots two high-energy beams out of the plasmoid, the electrons one way, the protons in the opposite direction. Some ions are heated to such high temperatures that they fuse.

A globular cluster is a spherical collection of stars that orbits a galactic core as a satellite. Globular clusters are very tightly bound by gravity, which gives them their spherical shapes and relatively high stellar densities toward their centers[9]. The Galaxy contains approximately 140 globular clusters (the exact number is uncertain because of obscuration by dust in the Milky Way band, which probably prevents some globular clusters from being seen).

They are arranged in a nearly spherical halo around the Milky Way, with relatively few toward the galactic plane but a heavy concentration toward the center. The radial distribution, when plotted as a function of distance from the galactic center, fits a mathematical.

The formation of globular clusters remains a poorly understood phenomenon and it remains uncertain whetherthe stars in a globular cluster form in a single generationor are spawned across multiple generations over a periodof several hundred million years.

Hubble Space Telescope took the image of the dense globular cluster M80 (NGC 6093) (Figure 2)[20]. The image has shown districts of very high blue straggler densities, suggesting that the center of the cluster is likely to have a very high capture and collision rate[4]. M80 is located midway between á Scorpii (Antares) and â Scorpii in a field in the Milky Way that is rich in nebulae. It contains several hundred thousand stars, and is among the more densely populated globular clusters in the Milky Way Galaxy.

Experimental setup and results

Mather-type 112.5 J plasma focus device consists of an outer electrode, which is formed of eight copper rods, each of 130 mm length and 10 mm diameters. The outer diameter of center electrode is 18 mm and inner diameter of squirrel cage (outer electrode) is 55 mm. The cylindrical insulator ring is of 130 mm diameter and 35 mm thickness. The electrode system is enclosed in a vacuum chamber made of stainless steel tank of 350 mm length and 100 mm diameter. There are several ports in the vacuum chamber for diagnostic purposes. The condenser bank of plasma focus device consists of one condenser of 25 kV and 1 ìF low inductancecondenser. A capacitor bank charged at 15 kV (112.5 J), giving peak discharge current of about 10 kA, powered the focus device[11]. In order to register the particle radiation within the pinhole camera, the use was made of nuclear track detectors of the CR-39 type as shown in Figure 3[16-17]. After irradiation those detectors were etched under standard conditions (in a 6.25-N solution of NaOH, at a temperature of 70°C) for a period ranging from one hour to several hours[13].

In the radial phase, shock front and the piston starts together at $r=a$ length of the pinch is zero at this time. In any plane the velocity of the shock front is larger than the piston velocity, so the distance between them is a time dependent quantity. The shock front accelerates onto the axis, hitting it; a reflected shock develops and moves in radial outwards (Figure 4). The piston continuous to compress inward until it hits the outgoing reflected shock front. The meeting point between reflected shock and a piston called point of maximum compression of the pinch (minimum radius). The dimension and lifetime of the pinch dependent on the radius of the anode.

Compression phase start after transformation of plasma structure to plasma column. This plasma column will compressed adiabatically to form the pinch of final focus. The rapid compression of relatively dense plasma leads to heating plasma to a thermonuclear (fusion) temperature. The plasma collapses toward the center with approximately constant acceleration and flutes which subsequently develop on the outer surface of the plasma are interpreted as Rayleigh-Taylor[14].

Rayleigh-Taylor instability prevents the compression of the plasma column to get uniformly radial[15]. The magnetic field starts diffusing into the plasma column, leading to an anomalous high plasma resistance as well as increasing the inductance of the system because of increasing the density of plasma column. The sharp change in plasma inductance and high plasma resistance induces high electric field inside the plasma column. This electric field will accelerate the ions and electrons in opposite direction. As result for that, the relative drift between ions and electrons leads to an increasing electron thermal velocity.

If the density clump occurs in plasma, an electric field can cause the ions and electrons to separate, generating another electric field. If there is feedback mechanism that causes the second electric field to enhance the first one, an electric field grows indefinitely and the plasma is unstable. Such instability called drift instability. In some cases, drifts can be self-perpetuating (charge separation leading to a drift, leading to more charge separation and so on), so that plasma instability results.

Generation of high energy particles and radiation in the plasma focus are considered to be an indication of non-thermodynamic equilibrium of the pinch. The presence of a beam of charged particles that forms in the plasma is explained by the appearance of electric fields which can be caused by the development of a Rayleigh-Taylor instability, plasma turbulence, magneto-acoustic wave propagation in the pinch.

In plasma focus, especially in the pinch phase the plasma gets more compressed at the onset of hydrodynamic instabilities ($m = 0$) as shown in Figure (5)[18-19]. The charged particles (ions and electrons) are trapped between two layers of plasma current sheath which acts like two moving magnetic mirrors with radius R and these particles initially have a velocity V_i.

Yousefi et al,[12] were observed in the plasma column, a ring-shape around the dense plasma column (necking) that it can be attributed to the ion shape in the pinhole image. In fact, it seems that, $m = 0$ instability (necking) cause the ions acceleration with periods of few to tens of nanoseconds.

During compression phase the plasma density is high, then coulomb collisions between electrons and ions will efficiently thermalize the plasma. The dissipated energy

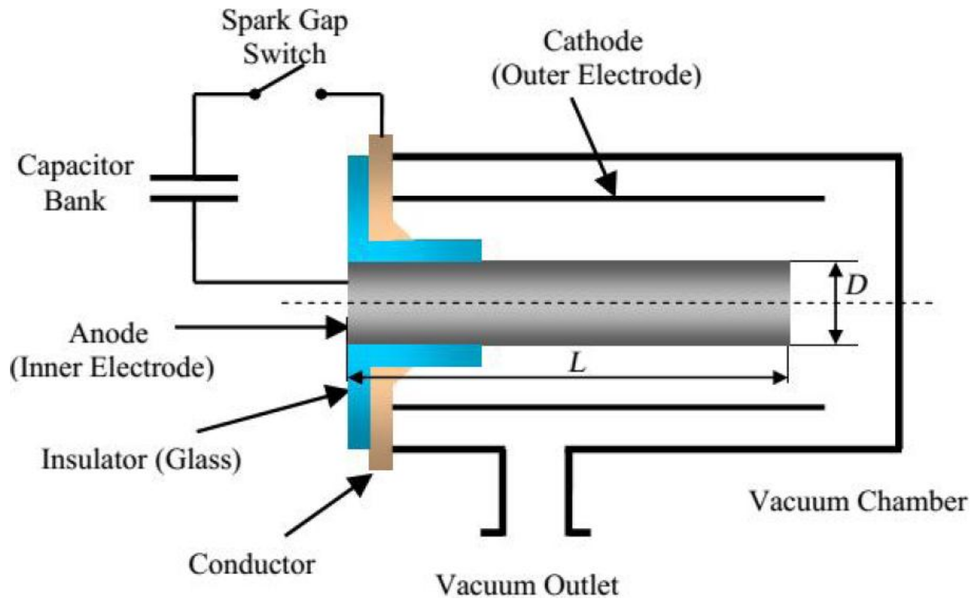

Figure 1 : Dense plasma focus(DPF) device mather type scheme

Figure 2 : Hubble Space Telescope photograph of the dense globular cluster M80 (NGC 6093)[20]

ends up distributed equally amongst the particles, forming a Maxwellian distribution. The particles are accelerated in the current sheath medium as result of many collisions which act as a scattering center. Here the charged particles impinging on the oscillating sheath edge suffer a change of a velocity upon reflection back into the bulk plasma. As the sheath moves into the bulk, the reflected particles gain energy, as the sheath moves away, the particles lose energy. As the particle goes deeper into the sheath which acts as a potential barrier, it is slowed down by the retarding space charge field. After it has entirely lost its velocity, it turns back and increases its velocity under the action of an accelerating field, returning to the

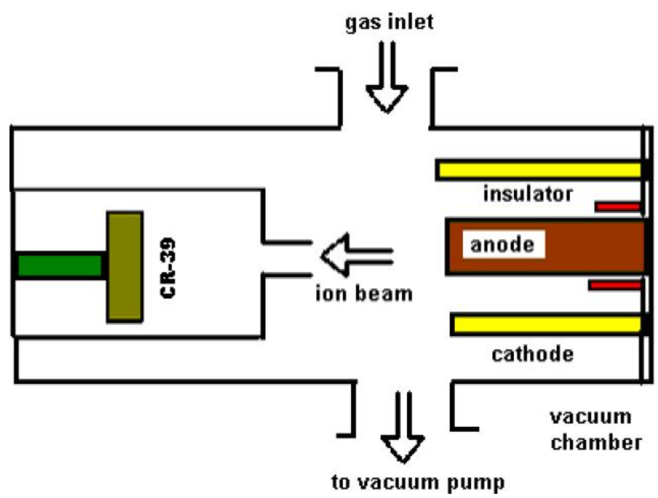

Figure 3 : Schematic of experimental setup

plasma.

The image of plasma ion tracks (Figure 6) shows a collection of several clusters (bunches) of micro beams have a circular cross-section area ranged from 9.5 to 28 ìm$^{2.}$ The cluster of micro beams contains a large numbers of tracks (ions) which are distributed uniformly or quasiuniformaly over the beam cross-section.

The ion beam of the present image has a circular cross-sectional area 28 $\mu m^{2.}$ The beams contain a large number of fast ions which are distributed uniformly or quasi-uniformly over the beam cross-section. A majority of quasi-uniform ion density, where the density of ions is distributed in an increasing trend toward the beam center.

To estimate the ion flux density of an individual micro-beam, a model consists of a Core surrounded by Co-central Zones(CCZ model) is proposed[13]. The model assumes that the beam cross section consists of a main core of a highest track density surrounded by several co-central zones of lower densities (see Figure 7-right). The near-

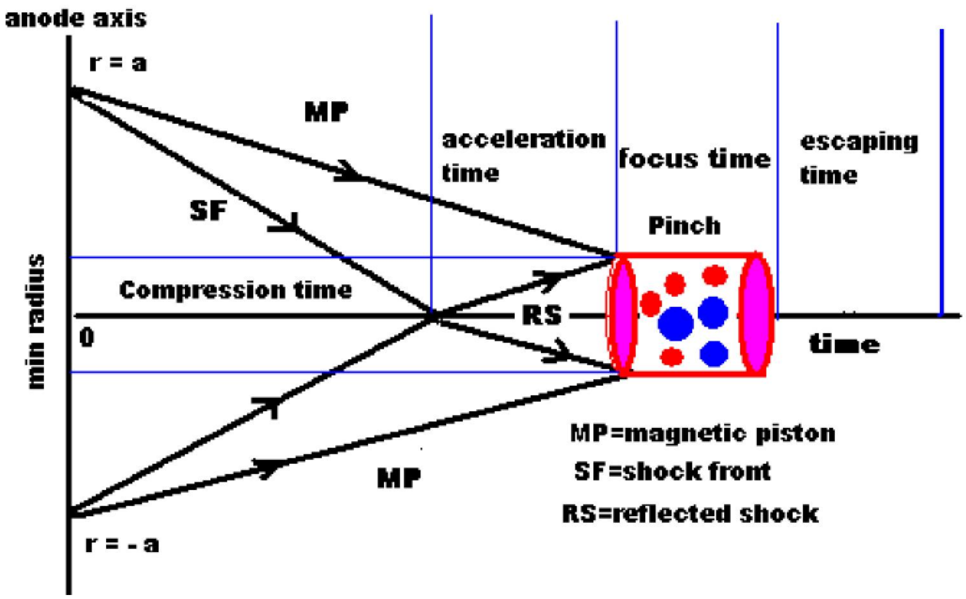

Figure 4 : Schematic of radial phase development when magnetic piston separates from the inward going shock

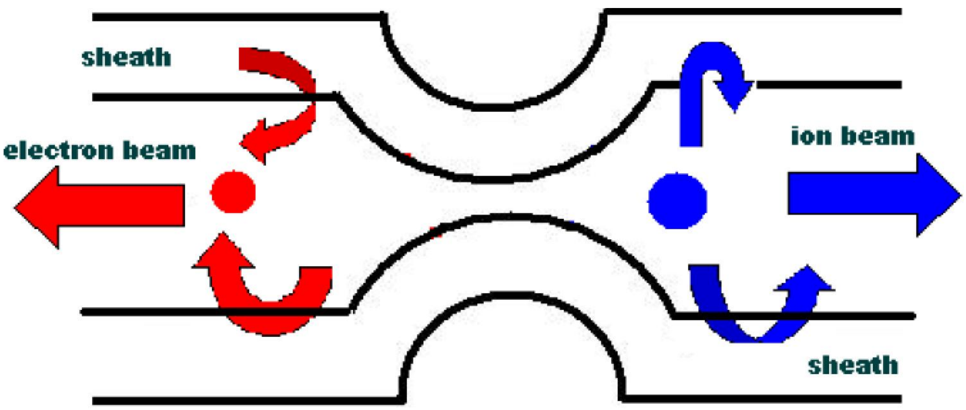

Figure 5 : Shows the plasma pinch and emission beams of charged particles onset of instability inducing micro instabilities

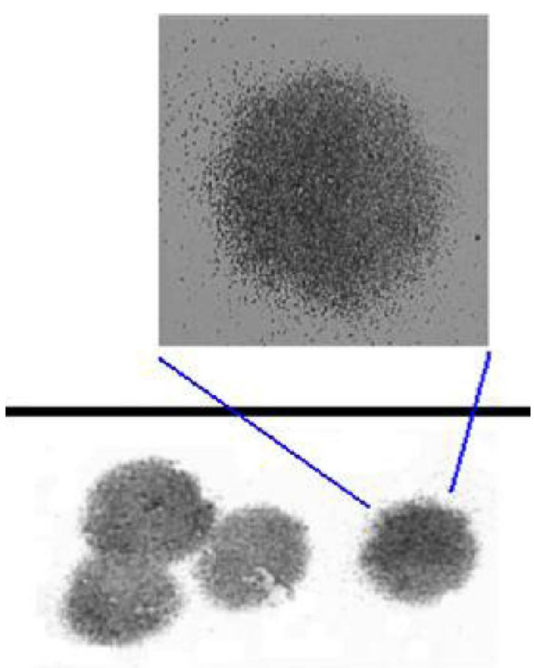

Figure 6 : Image of a collection of clusters microbeam of plasma ion tracks and one individual cluster is illustrated after magnification under microscope

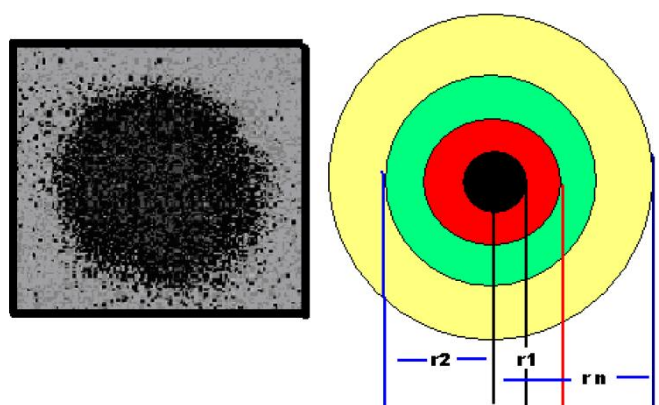

Figure 7 : Image of ion tracks (left) as obtained from plasma focus discharge with CR-9 film and schematic diagram of equivalent CCZ model, where r_0 is the radius of the core, r_1, r_2 and r_n are the radii of the first, second and n zones, respectively

est the zone to the core the highest its track density, while the track density of each zone is assumed to be uniform.

The number of tracks (n_{tr}) inside a predefined small area (ä) is first counted for the core and each zone. The total number of tracks (N_{tr})inside an individual micro-beam is then giving by:

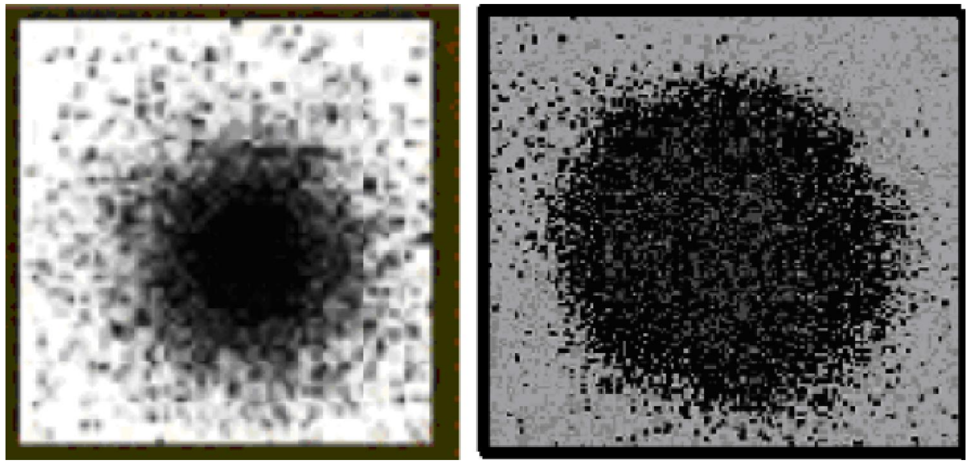

Figure 8 : (Left) Image shows, globular clusters, (Right) Ion tracks registered with pinhole camera with CR-39 SSNTD

$$N_{tr} = \pi \, r_o^2 \frac{(n_{tr})_o}{\delta_o} + \sum_{i=1}^{n} (r_i - r_{i-1}) \, 2\pi \, r_i \frac{(n_{tr})_i}{\delta_i} \quad (1)$$

where, $(n_{tr})_o$ number of tracks inside a small area ä$_o$ of the core, $(n_{tr})_i$ number of tracks inside a small area ä$_i$ of the ith zone, r_o is the radius of the core, r_i is the radius of the ith zone and n is the number of zones.

The ion flux density (ñ$_{tr}$) of an individual micro-beam is given by:

$$\rho_{tr} = N_{tr} / A_{mb} \quad (2)$$

Where, A_{mb} is the area covered by the micro-beams in m^2.

The micro-beams of the present plasma image (see Figure 7-left) are classified into two main categories according to their track density distribution. First, a majority of quasi-uniform ion density micro-beams where, the density of ions is distributed in an increasing trend towards the beam center. The total number of tracks for this kind of micro-beams is estimated by using equation (1). Second, a minority of uniform ion density micro-beams. Here, the micro-beam is considered to be a core without zones i. e. equation (1) is reduced only to the first term.

There is, however, a very seldom third category where the core has a sided crescent shape and the rest of beam is a uniform density area. To estimate the number of tracks, author consider that it consists of a core and a single zone. The ratio of core radius and the single zone radii was considered however to be equivalent to ratio of core and zone areas.

The cluster morphology plasma ion tracks formed by dense plasma focus (Figure 8) are laboratory similar to the formation of the globular cluster of our galaxy. The cluster of micro-beam show a whirlpool shape with dark spot in the core analog of observations of black holes in globular clusters. The rotation is driven principally by the electricalenergy input via the tornadic motion of the Birkeland filaments. Also, the plasmoid formed by the DPF is a laboratory analog of an active galactic nucleus (AGN). The periodic activity of an AGN and the production of axial jets can be viewed as the breakdown of a plasmoid due to increasing particle collisions along the central axis of the plasmoid.

According to *CCZ* model, it is possible to estimate the total number of tracks (ions) of an individual micro-beam. For instance, Figure (7) shows a life photo of a micro-beam of total cross sectional area of 22 ìm^2. The estimated total number of tracks (using equation 1) is equal to 915 tracks. The ion flux density (using equation 2) is 4.15×10^{9} track/cm^2. One can observe that lower energy ions are strongly deflected by electromagnetic fields associated with plasma focus discharges. The most energetic particles (higher kinetic energy) tend to toward to the core of the cluster of micro-beam. On the other hand, the image of the globular star clusters shows the lower mass of stars deflected by collision or by the fields between them and the stars of greater mass (higher velocity) move toward the center of the cluster

CONCLUSION

The plasma ion tracks (cluster of micro-beams) formed by Low energy plasma focus experiments is laboratory analog to the Globular clusters. More extensive study is needed for the possible use of lower energy plasma focus device to improve the proposed simulation of astrophysical phenomena.

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