

THE ELECTROMAGNETIC RAM ACTION OF THE PLASMA FOCUS AS A PARADIGM FOR THE GENERATION OF COSMIC RAYS AND THE GIGANTIC JETS IN ACTIVE GALAXIES.

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ABSTRACT

Recent measurements⁽¹⁾ of the energy spectrum of the plasma-focus-generated deuteron beam yield a spectrum of the form $N(E) \sim E^{-2.7}$ for $1\text{MeV} < E < 13\text{MeV}$. Other measurements⁽²⁾ show that the $\beta \rightarrow 1$ electron beam which is generated simultaneously with the deuteron beam is interrupted into segments of spacing 25ps and duration $\sim 4\text{ps}$. A stuttering-electro-magnetic-ram (ser) model of the plasma focus is proposed which is similar to Raudorf's electronic ram⁽³⁾ which produces a similar spectrum for an electron beam for $1\text{MeV} < E < 10\text{MeV}$. It is proposed that the cosmic ray spectrum and the gigantic galactic jets are both generated by ser action near the centers of active galaxies.

Raudorf⁽³⁾ has shown experimentally and explained theoretically that a 20keV, rotating, electron beam traveling in an axial magnetic field will, upon running into a magnetic mirror, generate a stuttering electron beam (at the mirror) with energies up to 14 MeV, with an energy spectrum of $N(E) \sim E^{-3}$. Raudorf has called it an electronic ram. The plasma focus machine which is a discharge of a capacitor between two coaxial electrodes in a chamber filled with deuterium gas at 3 torr produces a current sheath which travels axially down the annular region of the coax as it conducts current from the center conductor to the outer conductor. Near the end of the center conductor the current sheath collapses radially to form what is loosely called a "pinch". In a typical small (5kJ) plasma focus machine, 45 μf charged to 15kV produces a peak current at the time of the pinch of about 0.5MA in 1.3 μs . This current of 0.5MA in the column of the pinch far exceeds the Alfvén limit of 17000 $\beta\gamma$ Amperes, but the current sheath automatically constructs itself into pairs of Beltrami-like, force-free, minimum-free-energy vortex filaments where the current density vector \vec{j} , magnetic field \vec{B} , mass flow velocity \vec{V} , and vorticity $\vec{\omega}$ are all parallel or antiparallel. The filaments are thus Lorentz and Magnus force free, with electrons everywhere flowing parallel to a local magnetic field, and the Alfvén limit does not hold. But as the column "pinches", by its self-magnetic forces, down to a diameter of about 5mm it executes an action which is functionally similar to Raudorf's electronic ram: With a hollow center electrode a relativistic electron beam is generated which passes back (180°) through the hollow center electrode. The energy spectrum of the hard x-rays generated by this beam as it strikes metallic targets indicates an electron energy (up to a few Mev) spectrum of the form $N(E) \sim E^{-3}$. Measurements by the Darmstadt plasma focus group⁽²⁾ show that the electron beam is segmented with segments of about 4ps duration and 25ps spacing. A deuteron beam is generated in the forward direction (0°) whose energy spectrum has been measured by the Stevens group⁽¹⁾ with both magnetic deflection and time of flight to have an overall shape of $N(E) \sim E^{-2.7}$ for $1\text{MeV} < E < 13\text{MeV}$ with mild peaks at 50keV, 300keV and 1.5Mev. Pinhole camera "photos" of the deuteron beam recorded on CR39etchable plastic (nuclear particle track detectors) indicate a

diameter of the beam source of $\leq 0.5\text{mm}$. X-ray (0.8keV-5keV) pinhole photos at 80° of the dense accelerating region (bremsstrahlung of electrons on deuterium) indicate dense electron beams and dense plasma of densities 10^{19} to $10^{21}/\text{cm}^3$ and dimension as low as $30\mu\text{m}$ in diameter and $100\mu\text{m}$ in length. dI/dt signals show a violent interruption of the column current.

Image-converter photos and time-resolved Mach Zender interferograms show that a rupturing of the Beltrami-like filaments occurs rapidly around the circumference of the column, probably on a picosecond time scale, and the well-organized current flow structure has been chopped in two, as if with a meat cleaver. In this cloven region the conduction current carried by the electrons can no longer flow because of the magnetic insulating effect which is produced by the displacement current in the cloven region. The inductive energy stored by the 0.5MA in the plasma column and the coaxial structure will not permit the net current to change with infinite abruptness, so the displacement current flows and charges up the plasma capacitor. However, the magnetic field of the displacement current is zero at the geometrical center of the column and it is here that a beam can flow and its electrons and deuterons can be accelerated by the voltage existing across the "capacitor". As the beam current approaches the Alfvén limit it must organize itself into paired Beltrami-like filaments if its electron current is to continue, and this

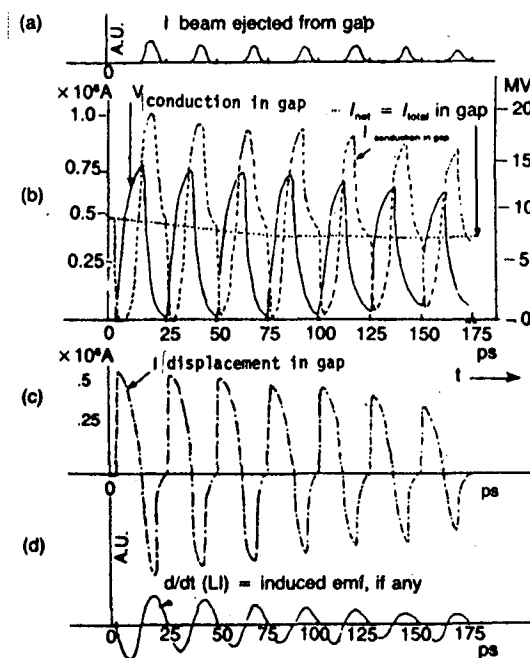


Fig. 1. Estimated wave forms produced by plasma focus as a stuttering electromagnetic ram. AU = arbitrary units.

the beam very likely does and then ruptures itself again, and so on through a number of cycles. Fig. 1 is an attempt to construct on paper this series of cycles, which we call a stuttering electromagnetic ram. This process of increase of voltage across the "plasma capacitor" is adorned, in the profession, with the nomenclature of "anomalous resistance". The power, V^2/R , delivered to this resistance takes the form of accelerating the beams of electrons and deuterons to high energies.

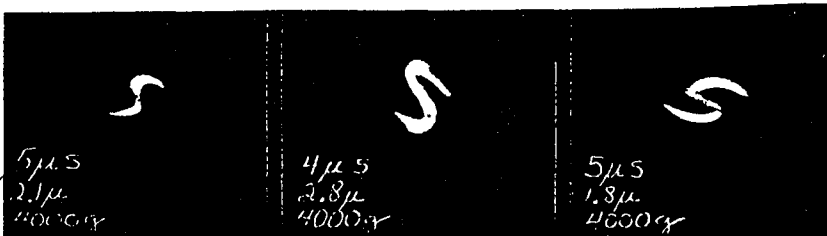
In the portion of the cycle where the displacement current reverses direction the V_{cap} would be expected to approximate $V_0 e^{-t/RC}$ which would give a spectrum for the electron and ion beams of $N(E) \sim E^\gamma$ where $\gamma = -1$. However, if it is recognized that the increase of magnitude of the reversed $|I_{\text{disp}}|$ also will increase the radius r of the electron and

ion beams, and that the resistance $R \sim 1/r^2$, it can then be argued that the energy spectrum should be approximated by $N(E) \sim E^\gamma$ where $\gamma = -3$. This electromagnetic ram effect represents only one of several morphological varieties of ion and electron acceleration by explosive magnetic field reconnection. The Stevens plasma focus machine has produced (5) for

example a "contact print" on CR-39 track-detector plastic of a filamentary "barber pole" structure with dimensions of $\sim 1\text{cm}$. This "fossil" imprint of a plasmoid as it died in its encounter with the track-detector plate was engraved by deuterons whose energy ($\cong 2.4\text{MeV}$) was imparted to each of them locally as they delineated the print. It has been recognized at least as early as 1966 that the plasma focus was the laboratory-produced paradigm (b) of the solar flare phenomenon.

The stage has now been irresistibly set for this text to advance the hypothesis that the ser action of the plasma focus is the laboratory-produced paradigm for the generation of the primary cosmic ray spectrum. To identify the sources in the Universe where this ser action might be occurring this text recollects the galactic-genesis paradigms that were accidentally discovered by one of the authors when, in 1955, he projected plasma jets at one another across a magnetic field in the presence of an ionized background gas(7): Barred-spiral galactic morphology (see Fig. 2) was displayed with high fidelity and led to a model of galactic genesis and evolution in which the "bar" is the armature of a homopolar generator whose currents flow perpendicularly outward from each side of the center of the galactic disc, through force free filaments in a pattern in the halo which sustain and increase the overall dipole field of the galaxy, and return via the arms of the spiral. There is a nexus (an ser site) for these currents on each side of the center of the galactic disc. Here the cosmic ray primaries (the protons and heavier ions, and electrons) are accelerated by ser action which also can be conveniently responsible for the gigantic segmented jets in active galaxies(8).

Fig. 2. Kerr-cell (time-resolved, 0.1 μsec exposure) photos of barred-spiral configurations generated by firing two plasma guns at one another across a magnetic field. Pressure of background gas in the chamber is indicated in microns; magnetic field in gauss.



(+) This implies that the current carrier flow and the self-magnetic field lines in a filament are not exactly collinear. More appropriately, a quasi-force free rather than a force-free configuration should be used to describe the internal structure of a filament.

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