PLASMA FOR FUN, PLASMA FOR PROFIT

Remembering Predhiman Kaw

P. I. John

6 Nov 2017 Gandhinagar, Gujarat

Plasma for Fun

1985+

ADITYA Commissioning

Theme for a Small Experiment

Magnetically confined clouds of electrons are experimental manifestations of 2-D vortices in an inviscid fluid.

Surface perturbations (diocotron modes) are like surface ripples on extended vortices

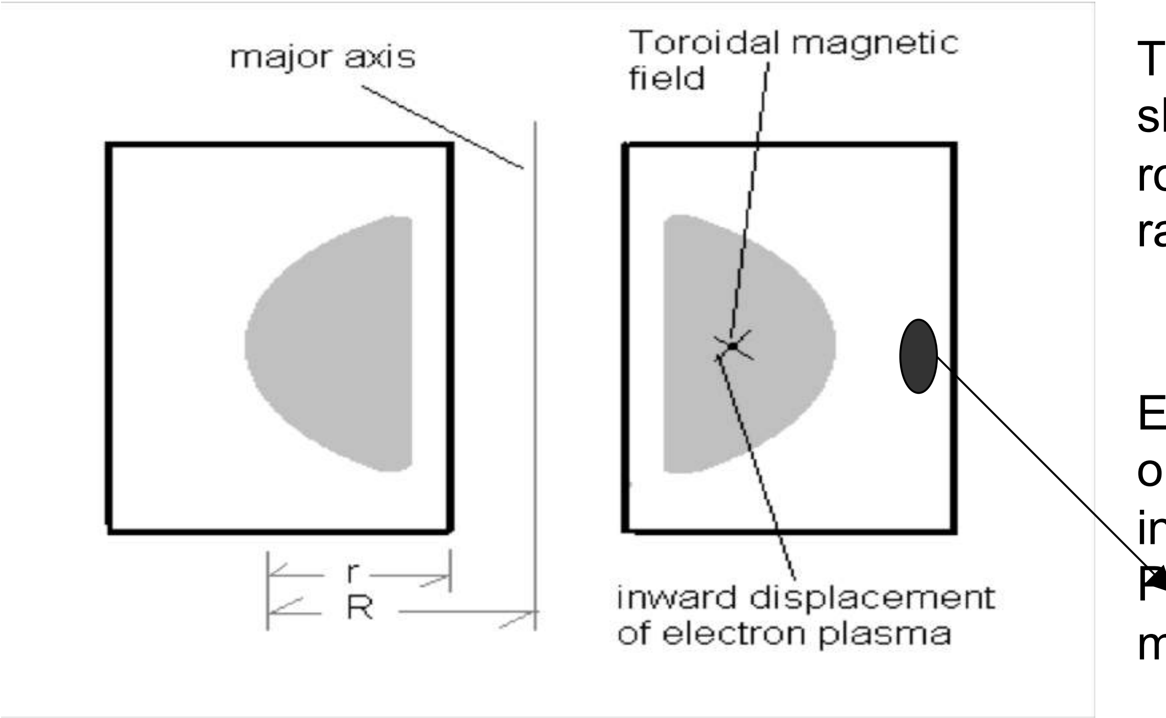
Unstable diocotron modes on hollow columns are examples of the K–H instability.

Malmberg's pioneering experiments on linear non-neural plasma columns.

Early toroidal experiments (Daugherty 1969, Clark 1976) functioned in a regime where toroidicity did not play a role.

Application-driven to form deep potential wells for ion acceleration.

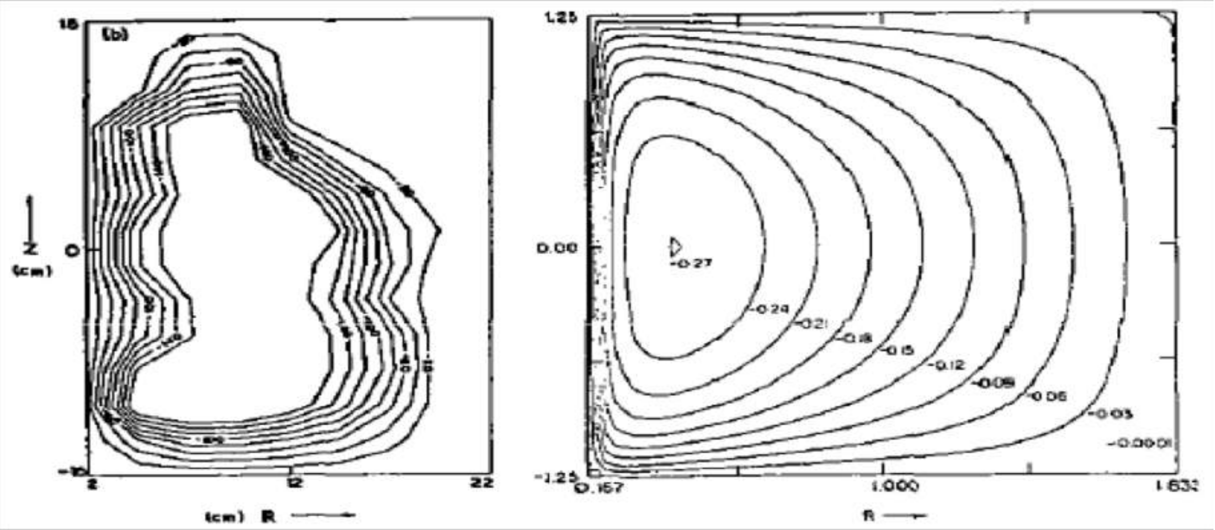
Low aspect ratio toroidal electron plasmas



Toroidal effects such as radial shifts and deviations from rigid rotation increase as the aspect ratio approaches unity.

Electrons injected in the outer boundary are carried in the direction of the Poynting vector in a rising magnetic field by ExB drifts.

Potential mapping with high impedance probes show equipotential contours depicting toroidally symmetric equilibrium



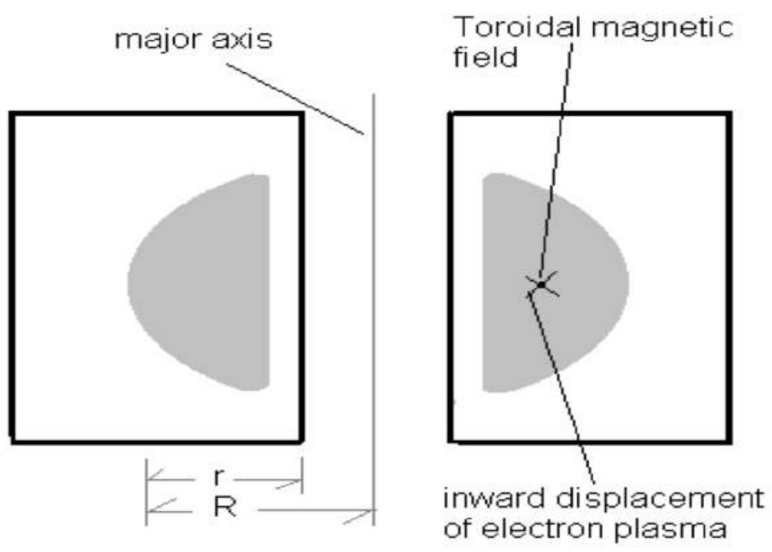
$$\nabla^2\phi = \frac{I}{R^2}\frac{dI}{d\phi}$$

two dimensional
axisymmetric equilibrium

Radial shift

$$\frac{d\Delta}{dr} = \frac{1}{r R_0 \phi_0'^2}\int_0^r \phi_0'^2 r\, dr + r/R_0$$

Low aspect ratio toroidal electron plasmas



space charge electric fields give a rotation to the electron fluid which overcomes curvature drifts and provides confinement

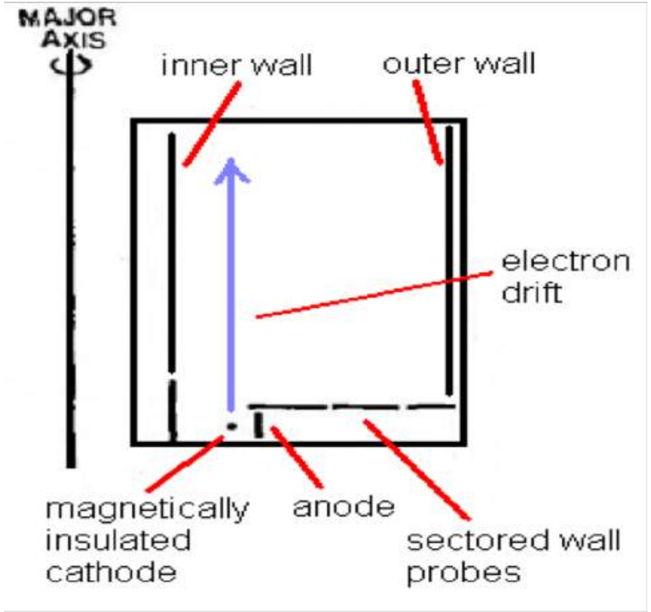
Balance between outward electrostatic hoop force, diamagnetism or centrifugal forces and the inward image forces generate equilibrium

Low-aspect-ratio toroidal equilibria of electron clouds

Puravi Zaveri, P. I. John, K. Avinash, and P. K. Kaw
Phys. Rev. Lett. **68**, 3295 – Published 1 June 1992

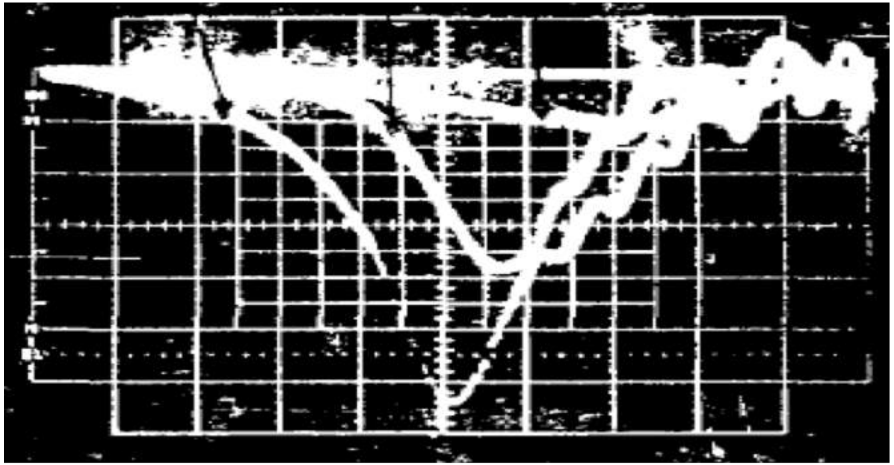
image currents, repel the ring, forming outward shifted equilibrium.	Image charges on the inner conductor attracts the ring
Needs externally imposed rotational transform	Self-consistently provided by E x B drift
Shapes of magnetic surfaces determined by diamagnetism	Shape independent of diamagnetism (diamagnetism, hoop force and restoring force are functions of density)
Equilibrium by vertical magnetic fields	Equilibrium by radial electric fields
Magnetic islands	Vortex structures

In contrast to magnetic induction charging, our experiments utilize toroidal drift and radial electric field to charge the trap

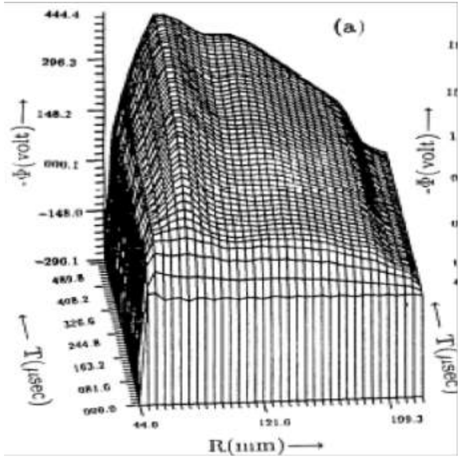


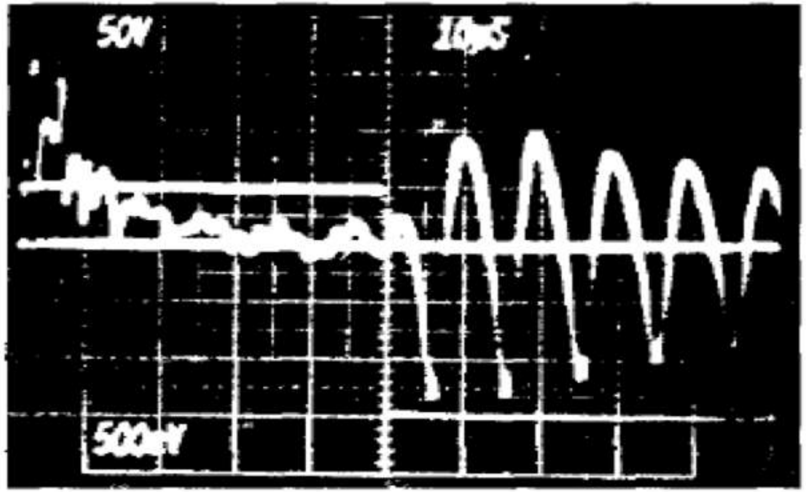
Toroidal drift near the inner wall induces radial electric field, slows down the drift and traps electrons

amplitude difference and time delay between the signals from wall probes indicate changes in the cloud capacitance due to evolution of the cloud



The low frequency instability, may be due to the excitation of the diocotron instability seen in early toroidal electron plasma experiments





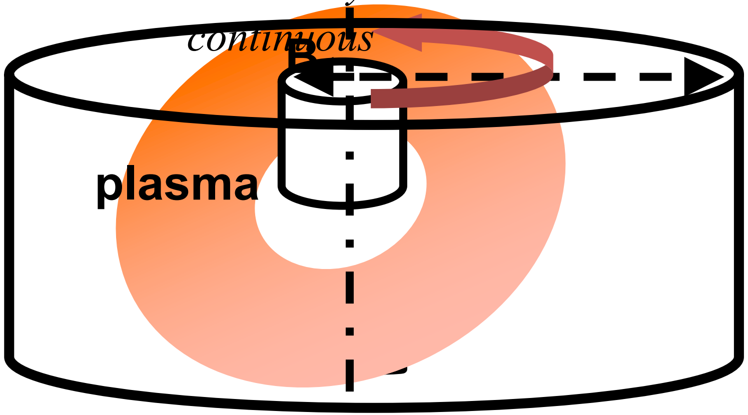
External radial electric field can enhance trapping and stability

Deviations from the rigid rotor circular flow provide free energy for driving high frequency oblique plasma waves unstable

IPR has made pioneering contributions in Small Aspect Ratio *Toroidal* Experiments (SMARTEX).

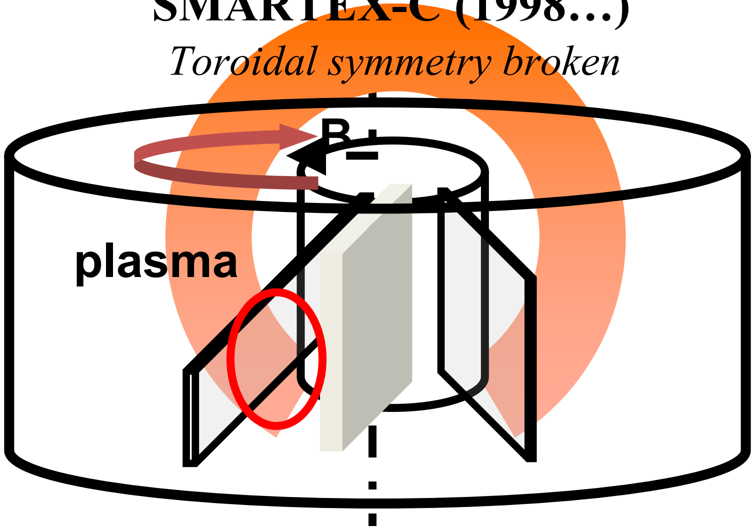
SMARTEX-T (1988-1996)

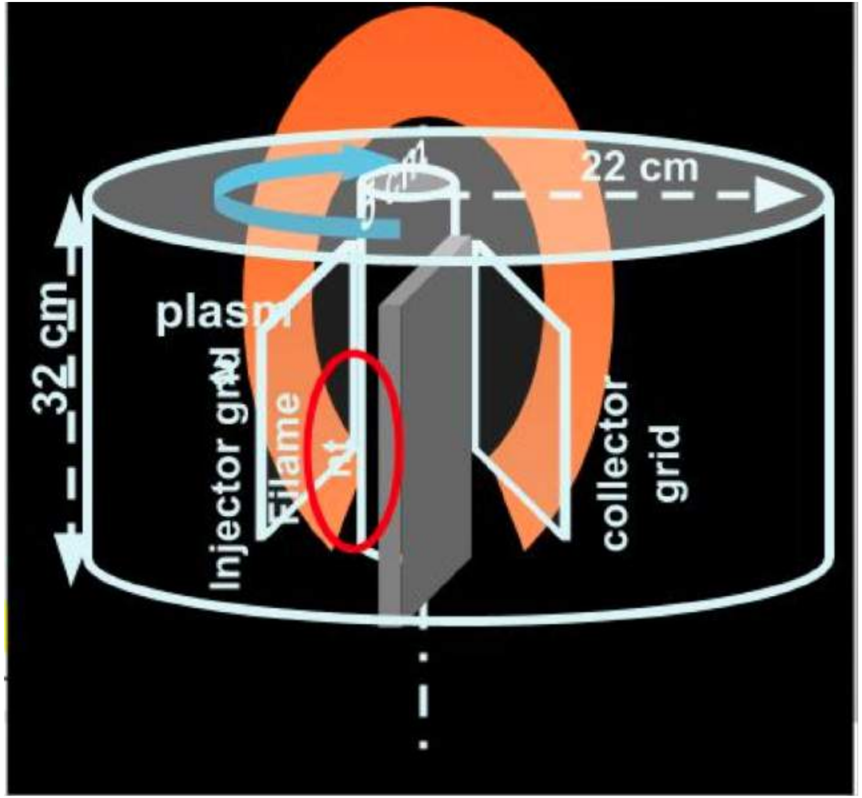
Toroidally continuous



SMARTEX-C (1998…)

Toroidal symmetry broken

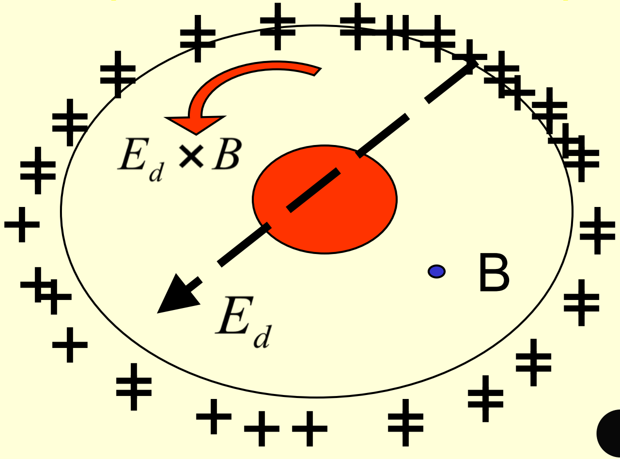


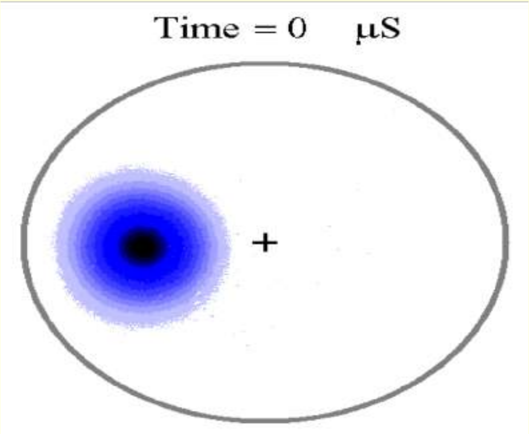

22 cm
32 cm
plasm
collector grid

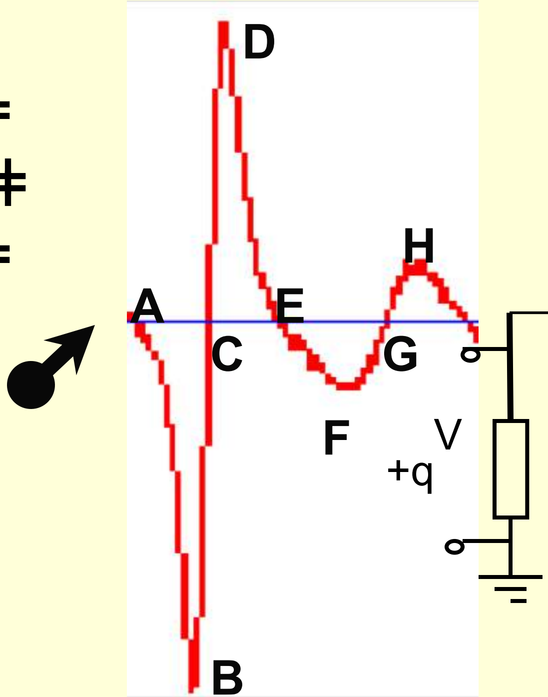

23 2 2004

Vortex Dynamics:
Flute ($k_\perp$) mode with Toroidal signatures

Experiments : P-M trap

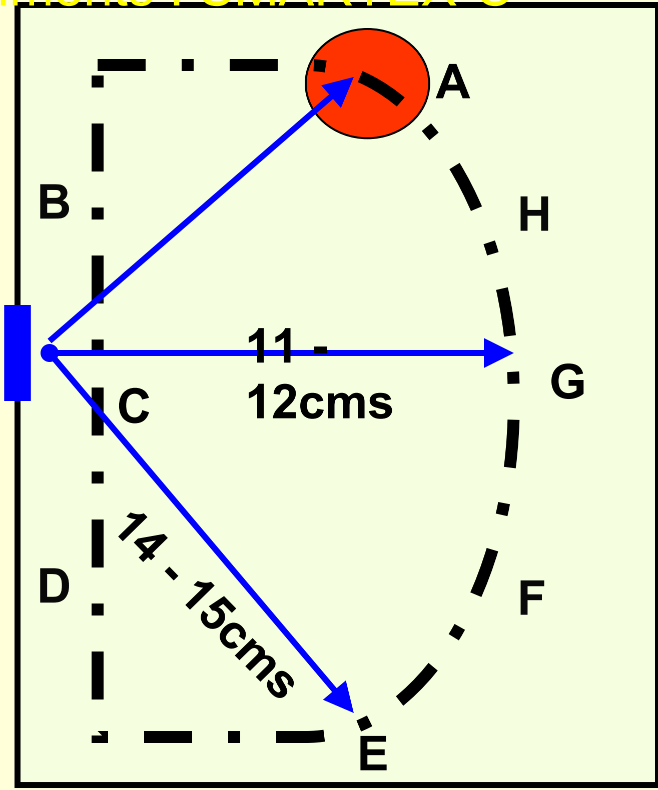




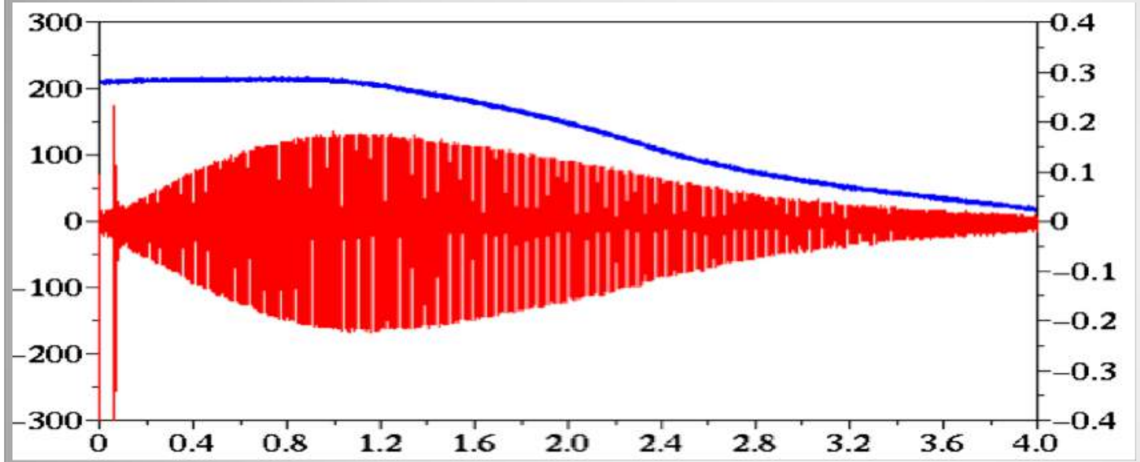


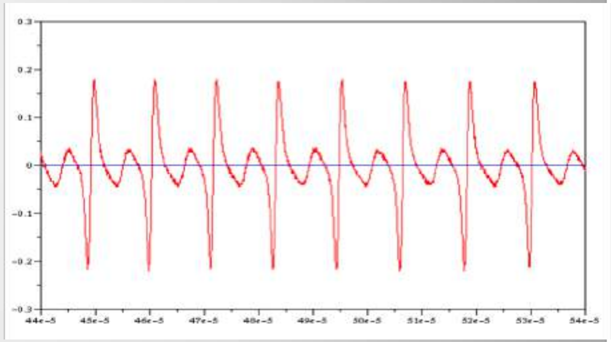
Diocotron Mode

Experiments : SMARTEX-C



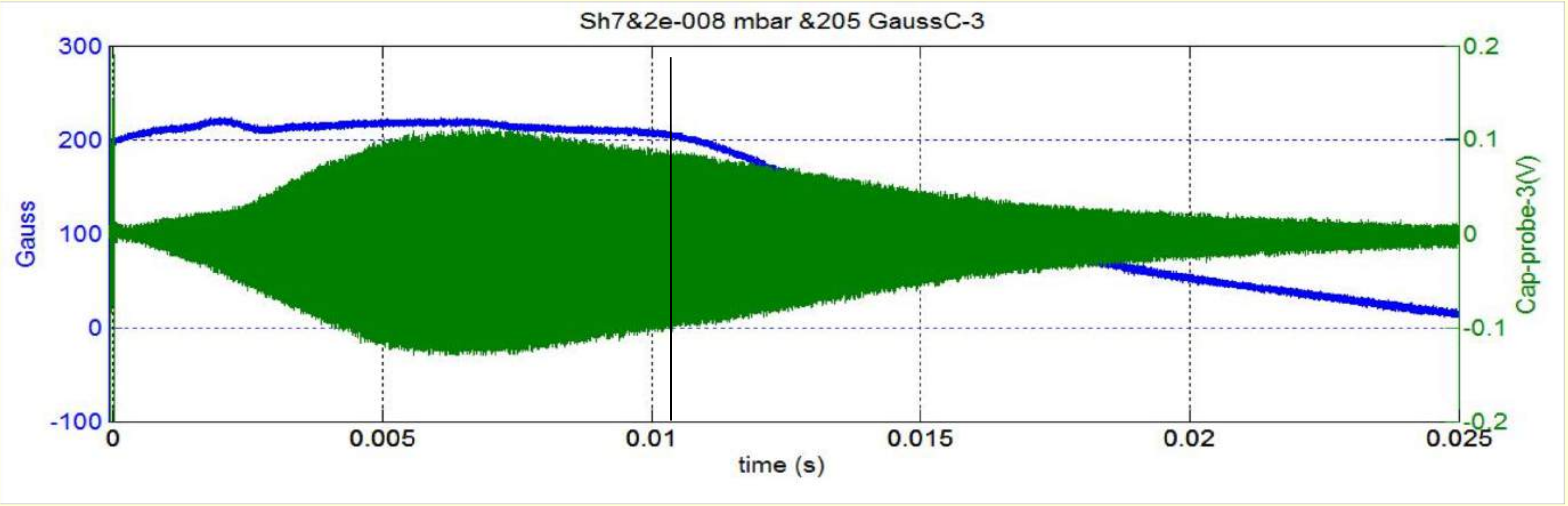
Pressure :9.2 X 10^{-8} Torr





Improved Confinement due to control of instability

Pressure – 2.0 x 10^{-8} mbar B-field – 200 Gauss



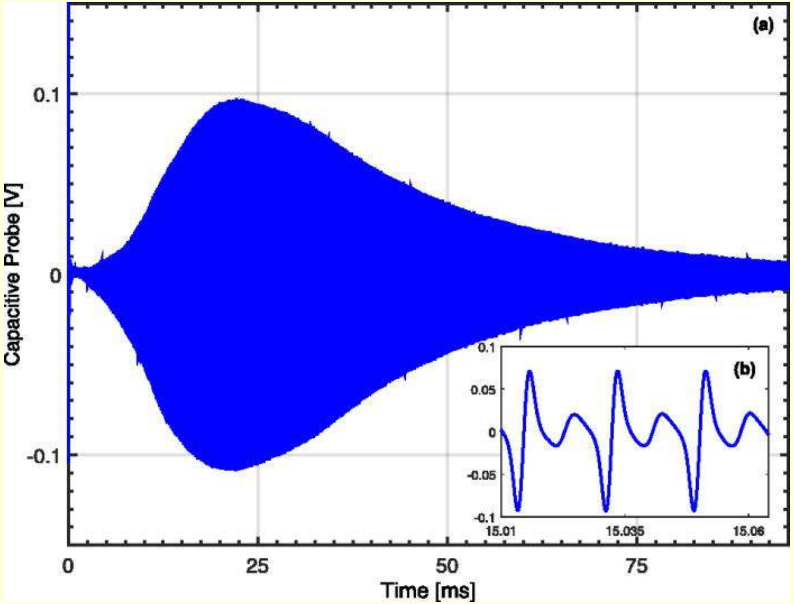


FIG. 1. Time evolution of (a) capacitive probe signal for a charge cloud trapped with a magnetic field of ~210 gauss. (b) Coherent, periodic, large amplitude double peaked oscillations (zoomed).

Published in: Lavkesh Lachhvani; Sambaran Pahari; Sudip Sengupta; Yogesh G. Yeole; Manu Bajpai; P. K. Chattopadhyay; *Physics of Plasmas* **2017,** 24,
DOI: 10.1063/1.5009013

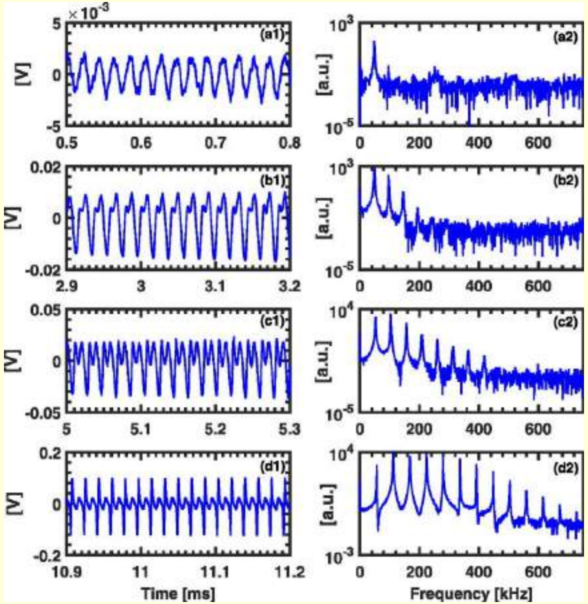


FIG. 2. Time trace of capacitive probe signal at different instances of evolution. (a1)-(d1) 4 distinctive stages of evolution showing transition from small amplitude oscillation to large amplitude, double-peak oscillation during the trapped phase of the electron plasma. (a2)-(d2) Corresponding power spectra of each stage showing the presence of single harmonic to the gradual appearance of multiple harmonics with dominance in m = 2.

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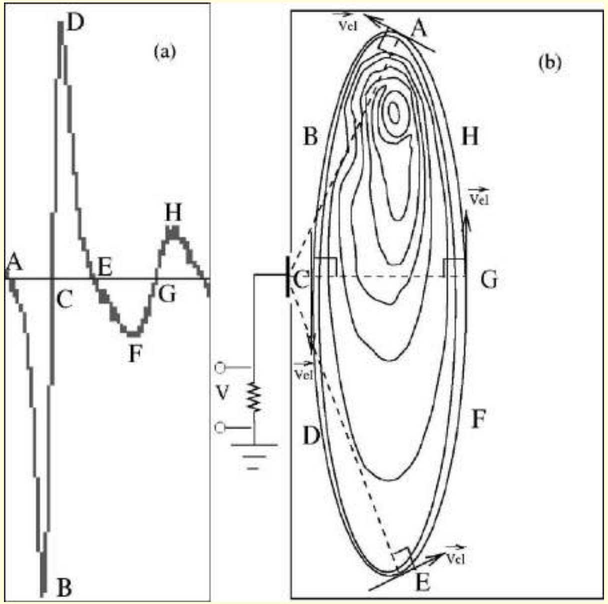


FIG. 3. A schematic showing a possible orbit corresponding to a single period of oscillation resulting from one azimuthal drift. (a) A single period of oscillation from wall probe signal. (b) The plasma profile depicted in the poloidal cross section; also shown are velocity vectors at orbit positions that correspond to zero currents on the probe. Reprinted with permission from Phys. Plasmas ***13****, 092 111 (2006). Copyright 2006 AIP Publishing LLC.*

Published in: Lavkesh Lachhvani; Sambaran Pahari; Sudip Sengupta; Yogesh G. Yeole; Manu Bajpai; P. K. Chattopadhyay; *Physics of Plasmas* **2017,** 24,
DOI: 10.1063/1.5009013

Plasma for Profit

1990+

ADITYA in Routine Operation

Industrial Plasma: Short Term Applications

Newsletter: Plasma Processing Update

Plasma Processing Programme

FCIPT Challenges

No pre-existing models in research organizations in India.

Business plan evolved with our learning curve

Industry-driven to make it agile

Responsive to Market

Focus on a few thrust areas for immediate impact.

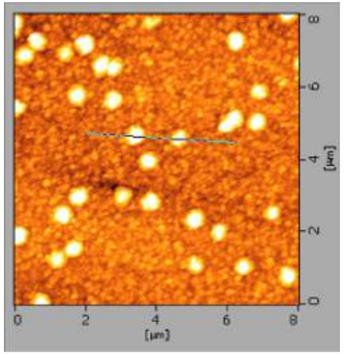
Financial self-reliance

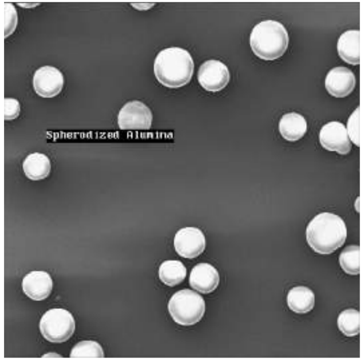
IPR initiative to exploit the knowledge base in plasma sciences for industrial, environmental and strategic applications

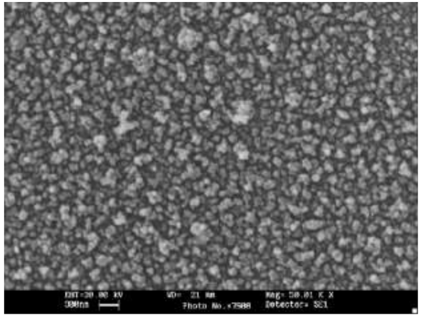
Development, Incubation,
Job Shops, Database
Field Trials, Commercialization

1997 Facilitation Centre for Industrial Plasma Technologies

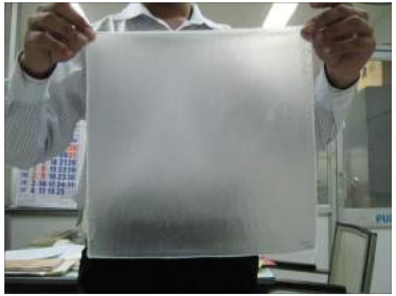
IPR's Link with Industry

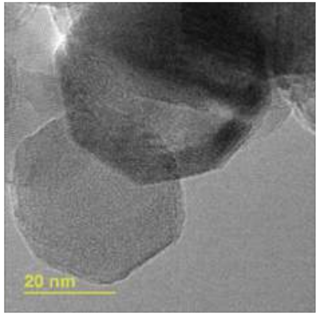


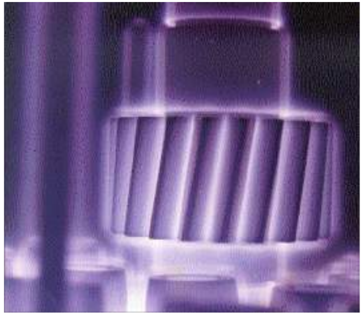


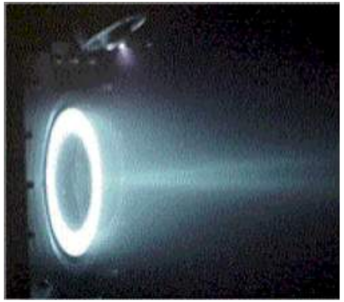


A Variety of Processes









Challenges in Process and Product Development for a Market

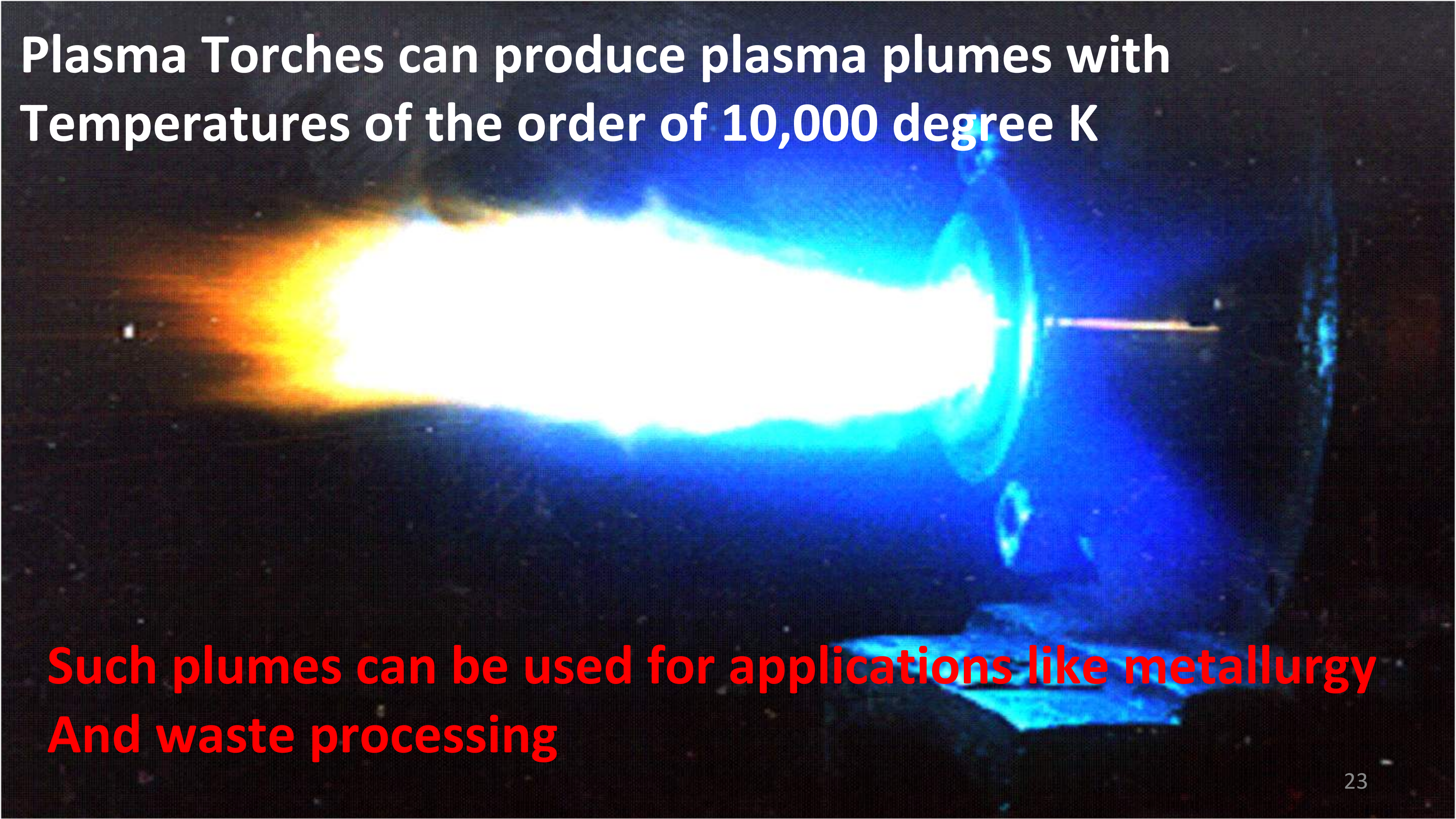
There are many challenges in an activity where the end product is a process or an equipment acceptable to a client or the market.

No compromises in performance or specifications will be acceptable. Cost and operational economics are major features.

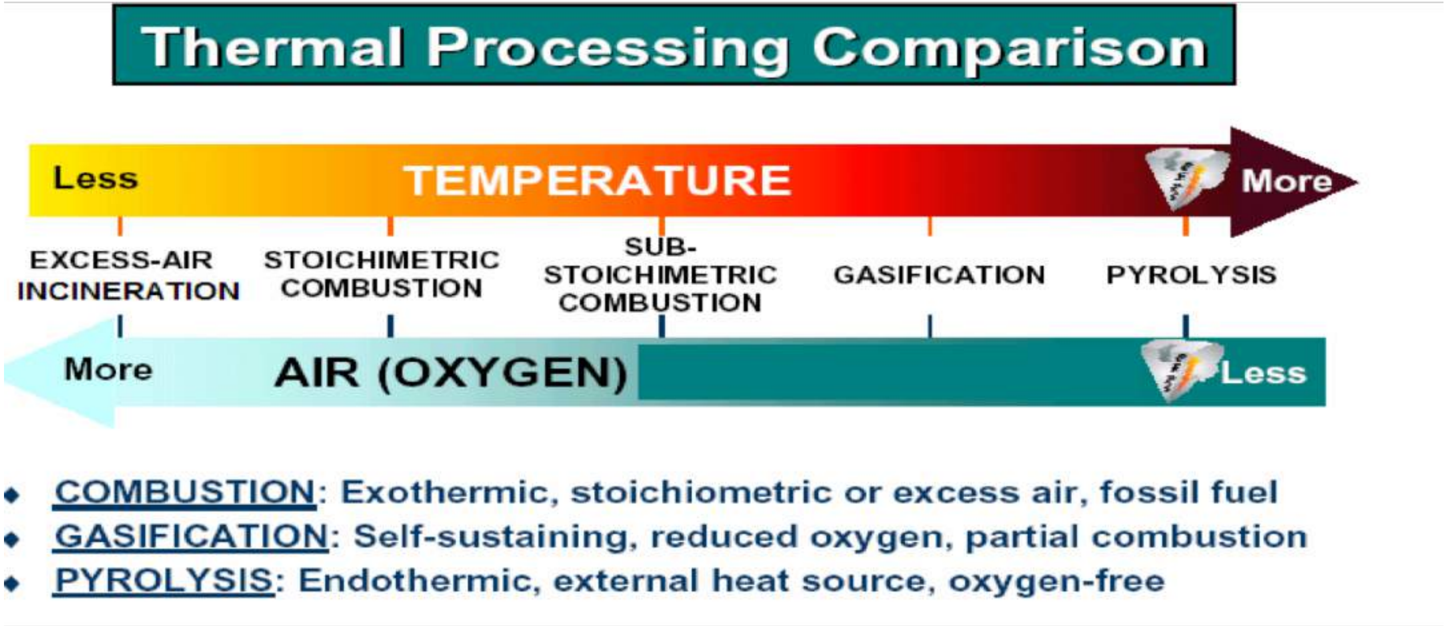
No downtime is acceptable.

The effort to meet these aspects is clear in our project on Plasma Pyrolysis for Medical Waste Remediation.

Plasma Torches can produce plasma plumes with Temperatures of the order of 10,000 degree K



Such plumes can be used for applications like metallurgy And waste processing



Heat causes organic material to disintegrate forming fragments promoted by the high chemical reactivity of the plasma environment. Most likely products are H, CH_4, C_2H_6, CO etc. 10% remain as Char/Ash

Evolution of Plasma Pyrolysis Technology

Extreme temp, corrosive environment, complex pyrochemistry = toxic products

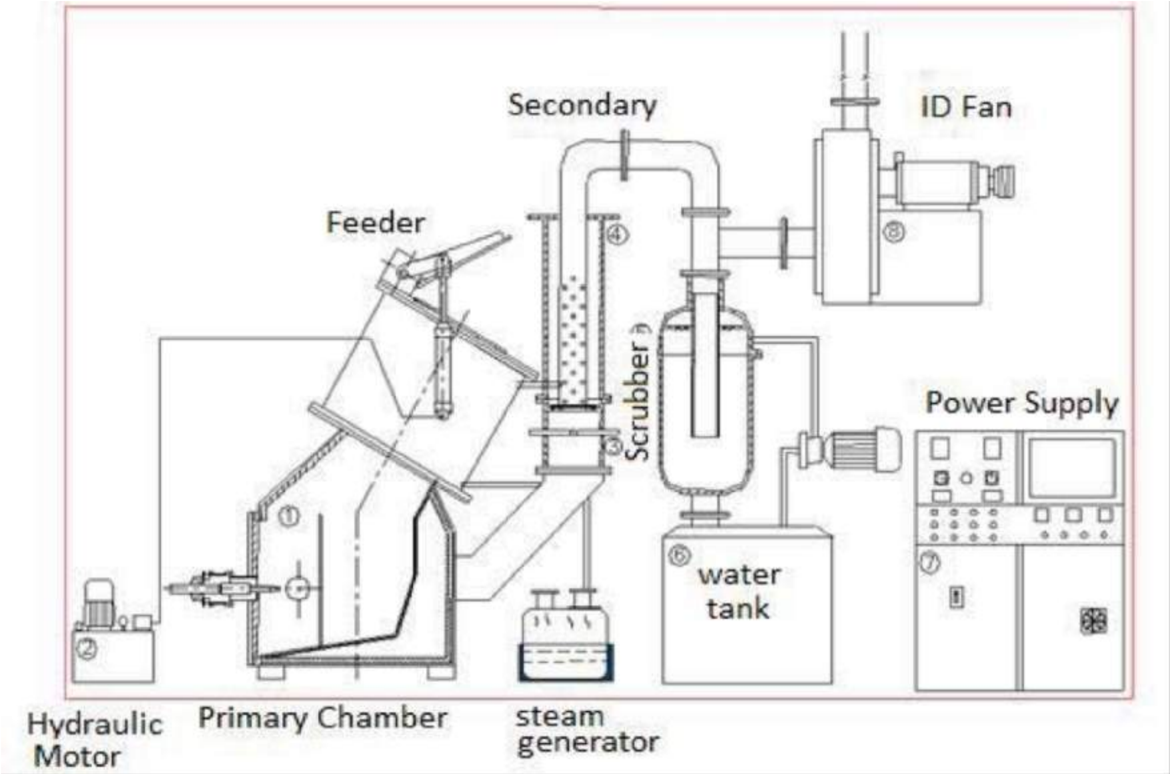
Low packing density, nonstandard composition

Severe constraints imposed by regulatory standards

Capex/Opex constraints imposed by competing technologies

Critical information on crucial aspects unavailable

No peer group within India for consultations



Mark-4 Plasma pyrolysis reactor

Graphite plasma torch with no draft requirement. 8 hrs operation. No heat loss

Rectangular primary chamber with metal shell for heat transfer through conduction.

Feeder has a fish-mouth mechanism. Refractory lining to minimize heat losses.

2 m long secondary chamber with special design for reducing soot particles.

Srinagar Medical College Hospital

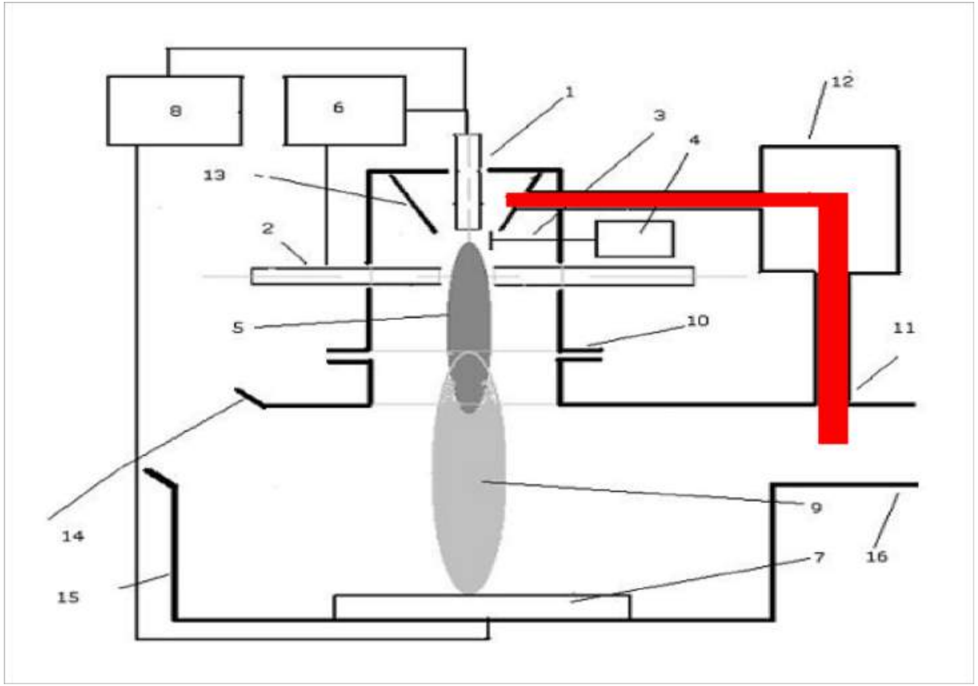
Emission measurements

- CPCB has monitored emissions from plasma pyrolysis system for bio-medical waste

Pollutants	CPCB standards	Emissions from Plasma Pyrolysis System
CO	≤ 100 mg / Nm^3	40-85 mg / Nm^3
Nox	≤ 400 mg / Nm^3	7-25 mg / Nm^3
PM	≤ 150 mg / Nm^3	31-52 mg / Nm^3
Dioxins & Furans	≤ 0.1 ng / Nm^3 TEQ	≤ 0.01 ng / Nm^3 TEQ

32 different samples of exhaust gas, sludge of scrubber water & residue (from primary) were analyzed for Dioxins & Furan by Vimta Lab Hyderabad & RRL Thiruvanantapuram.

Conventional plasma torches require large gas throughput to stabilize the arc. This results in product gas dilution and reduction in energy efficiency



pyrolysis product gas is extracted and used for the arc stabilization, improving heat transfer without diluting the pyrolysis gases

35 % increase in pyrolysis efficiency

improves the heat distribution in the primary chamber

increases electrode life by reducing the electrode erosion rate.

Mark 5: Endogenous Gas Fed Plasma Torch

क्रमांक : SI. No. : 022 14910

सत्यमेव जयते

INTELLECTUAL PROPERTY INDIA
PATENTS / DESIGNS / TRADE MARKS
GEOGRAPHICAL INDICATIONS

भारत सरकार
GOVERNMENT OF INDIA
पेटेंट कार्यालय
THE PATENT OFFICE
पेटेंट प्रमाणपत्र
Patent Certificate
(Rule 74 of Patents Rules)

Patent Number	:	281257
Application Number	:	2279/MUM/2007
Date of Filing	:	19/11/2007
Patentee	:	INSTITUTE FOR PLASMA RESEARCH

It is hereby certified that a patent has been granted to the patentee for an invention entitled PLASMA PYROLYSIS SYSTEM FOR SAFE DISPOSAL OF ORGANIC WASTE USING PLASMA TORCH WITH A NOVEL ENDOGENOUS GAS SOURCE as disclosed in the above mentioned application for the term of 20 years from the 19 day of NOVEMBER 2007 in accordance with the provisions of the Patents Act, 1970.

Controller of Patents

Controller General of Patents, Designs & Trademarks

Date of Grant:10/03/2017

Note: The fees for renewal of this patent, if it is to be maintained will fall/has fallen due on 19 day of NOVEMBER 2009 and on the same day in every year thereafter.

Patent in 2007 for Endogenous Gas Feed concept which improves Efficiency by 35%

MoEF, Govt of India Approval

[Published in the Gazette of India, Extraordinary, Part II, Section 3, Sub-section (i)] GOVERNMENT OF INDIA MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE NOTIFICATION New Delhi, the **28th March, 2016**

"Plasma Pyrolysis Technology Recognized for safe disposal of Biomedical Waste"

The Legacy

International presence in Plasma Physics and Applications

India's accession to the ITER project

Flourishing basic sciences programme

Societal benefits of Plasma Sciences

Capacity building in Universities through NFP

span of 50 odd years

Robin Williams

Can I play music here?

Policeman

Buddy! This is New York!

You can do anything here.

J: Can I do plasma processing here?

K: Buddy! You can do anything here. This is IPR!