Inertial Electrostatic Confinement (IEC) devices for propulsion of satellites used for disaster monitoring

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Outline

- Motivation
- Summary of various systems
- Introduction to IEC devices
- Functioning of IEC devices
- Modes of thrust generation
  - Ion propulsion
  - CXNT
  - NIT
  - FAIP
- Comparison
- Conclusions

Motivation

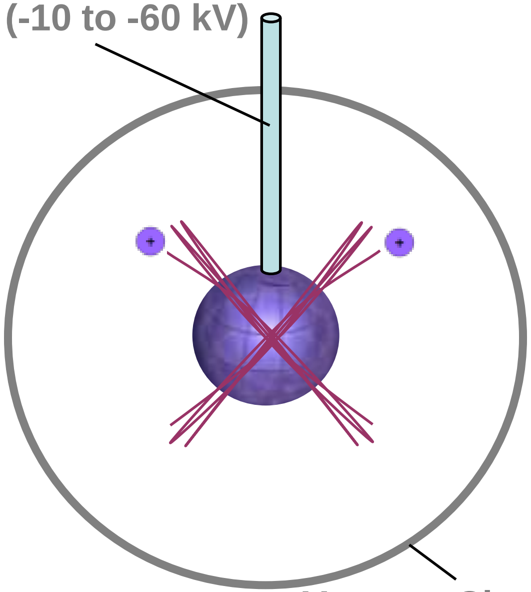
- Weather satellites can probably get away with low thrust high specific impulse systems once they are in LEO
- Low cost, Low payload and Simple systems are preferable over other systems
- Inertial Electrostatic Confinement offers some unique features suitable for space propulsion

What is an IEC device?

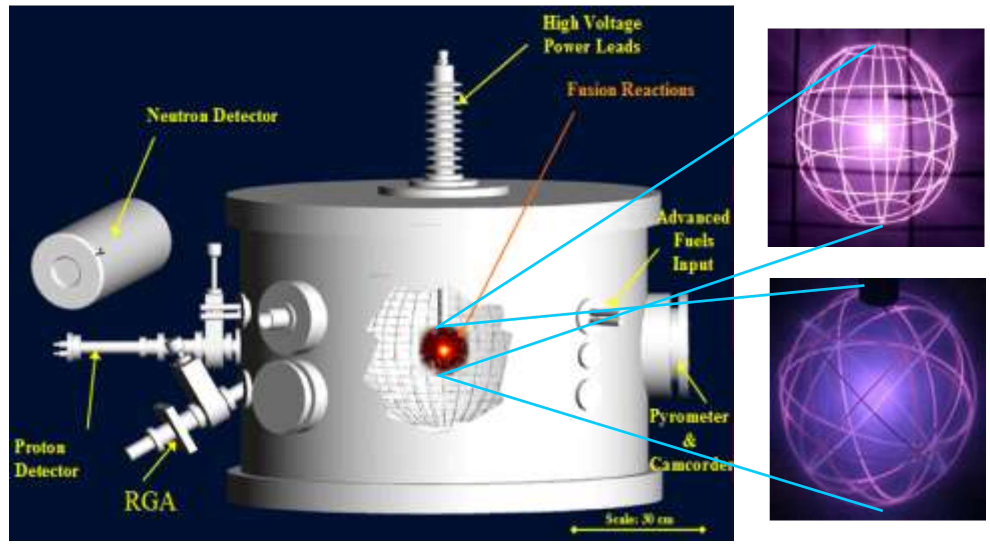
IEC Technology

Basic functioning is simple

Cathode Grid Voltage (-10 to -60 kV)

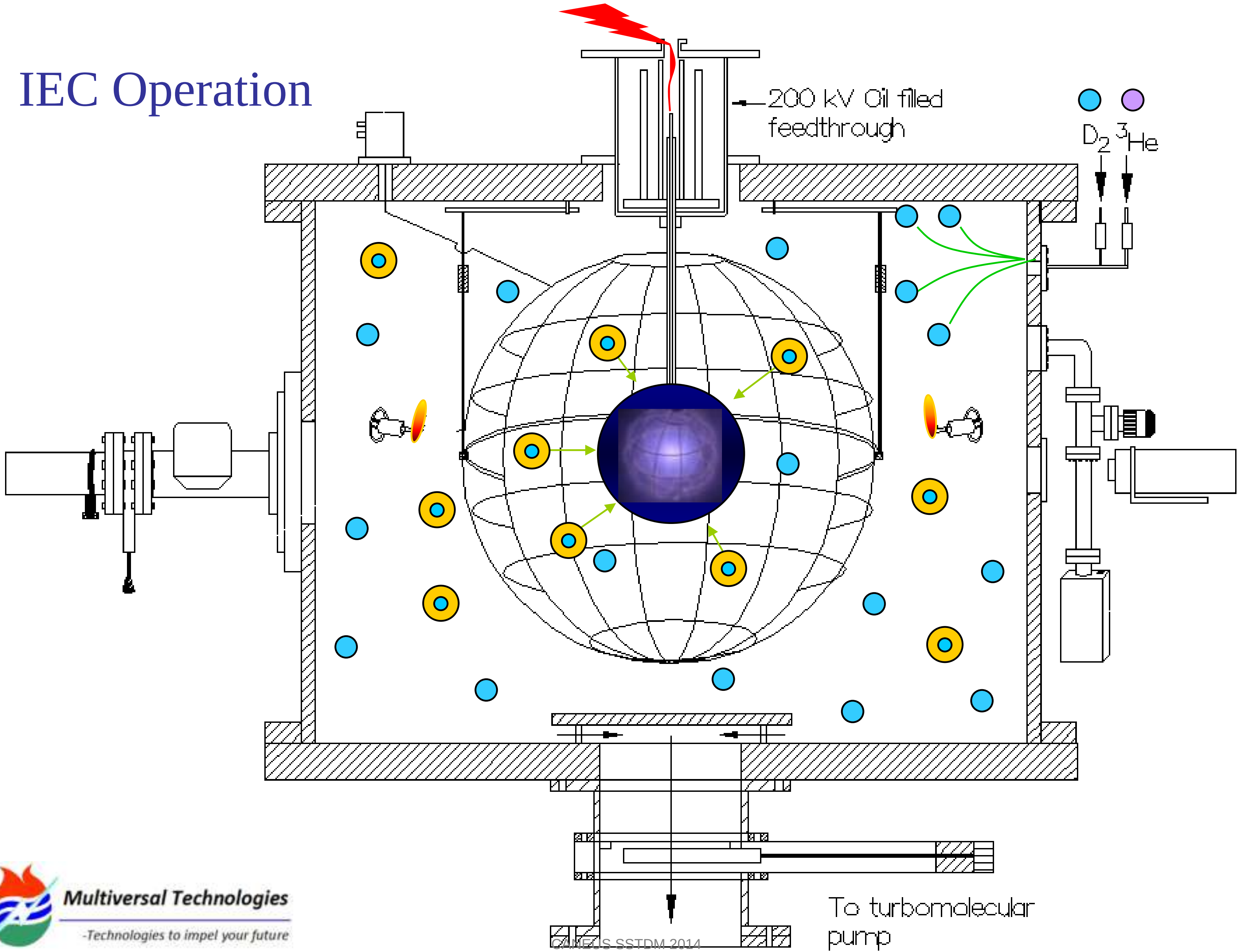


Vacuum Chamber (anode V=0V)



- IEC stands for
  “Inertial Electrostatic Confinement”
- Produces fusion reactions by static electricity

IEC Operation



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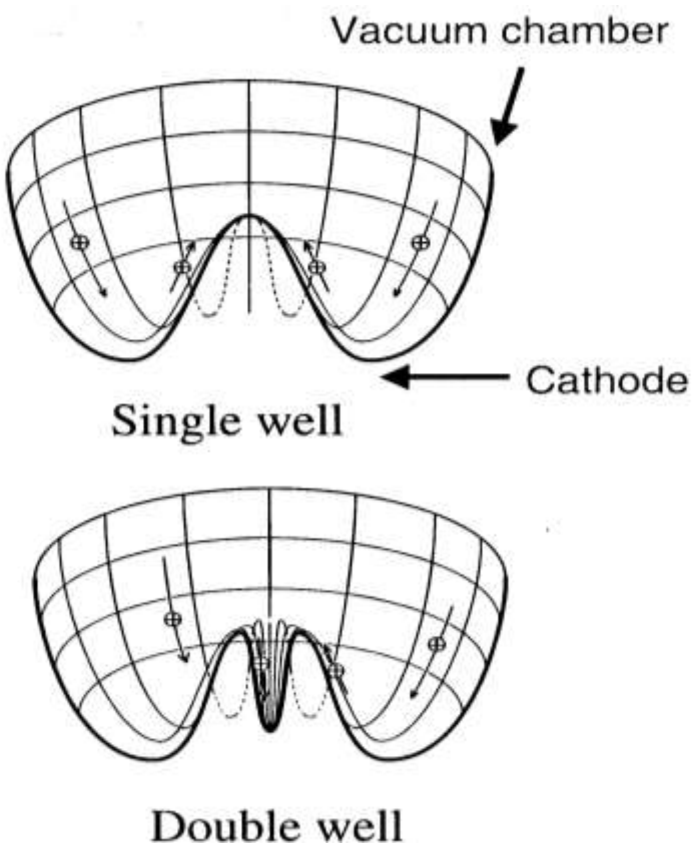
Formation of Poissor Structures

- Space charge cloud at the center of the device causes “Poissor” to be formed which enhances the reaction rate.



- At high enough currents a potential structure (theoretically predicted) forms and could cause an I^3 and eventually an I^5 scaling of fusion rate, Miley et al.
- Several tests have both confirmed the presence or absence of these potential wells.
- More work is needed to establish their presence.
- Even without these poissor structures, this device is still useful.

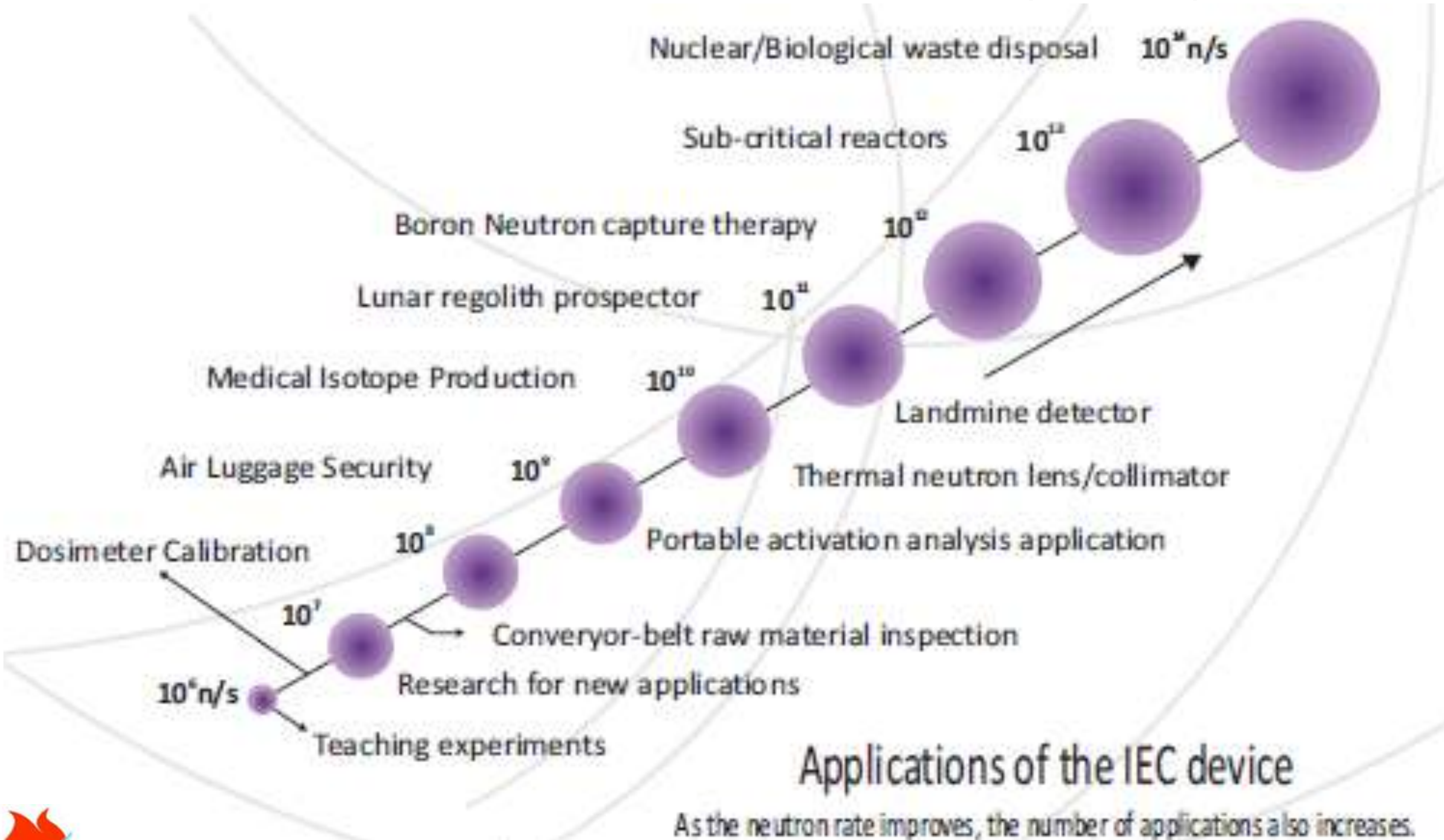
Advantages of IEC device

- Compact source of all kinds of radiation
  - Ions, electrons, energetic neutrals, x-rays, neutrons, protons and charged particles.
- Power supply can be made very compact.
- Works in both steady state and pulsed mode.
- Can produce nuclear fusion in very small geometries
- Vacuum pumps not needed for operation in outer space
- Can be easily controlled
- Consumes less power and hence can be operated using solar power
- Sturdy design, can take micro meteorite impact and still keep working

Applications

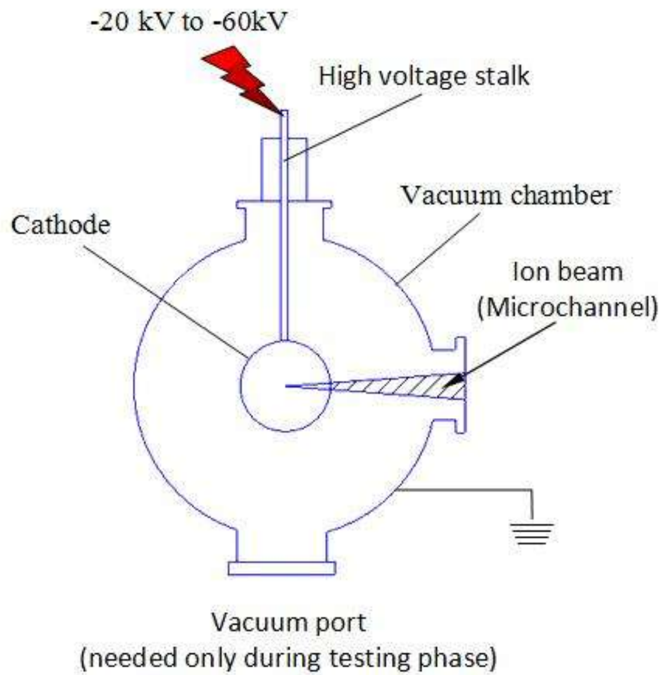
Number of applications increases with increasing device application

Space Propulsion



IEC based Ion Propulsion System

Principle of Thrust Generation



- Jets (called microchannels) are naturally formed in an IEC device. First observed by Prof. G. H. Miley, from UIUC, proposed **ion propulsion** with it but would require charge neutralization.
- This system uses electrostatic acceleration achieved through simple application of high voltage between the two concentric electrodes.
- The major advantage with this system is the ion optics design is rather easy.

Charge Exchanged Neutral Thruster **(CXNT)**

Charge Exchanged Neutral Thruster **(CXNT)**

- An inertial electrostatic confinement device operating in the gaseous discharge pressure regime units to tens of mTorr is shown to consist of a substantial flux of neutrals diverging from the cathode center.*

- Using Doppler shift spectroscopy, it is shown that directional ion beams, originating from the center, increase in energy as they move away from the center.

- Through charge-exchange, these ions become energetic neutrals and travel out of the cathode to the anode.

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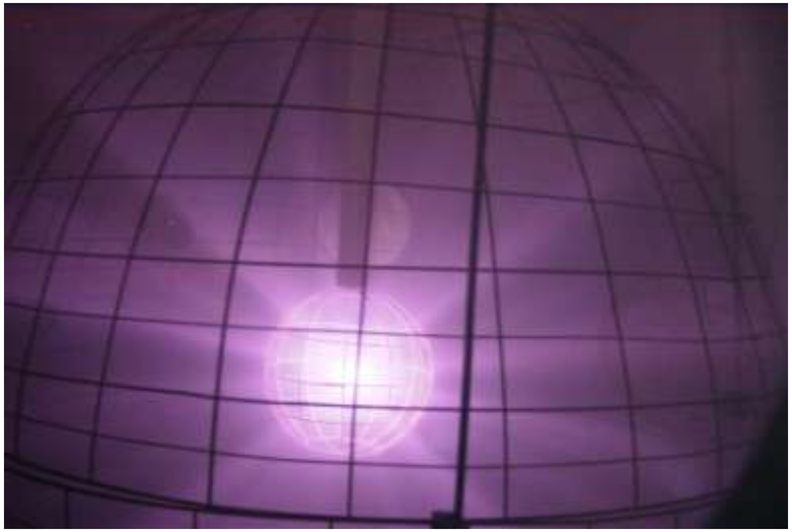
J. Khachan, Phys. Plasmas 13, 012703 (2006)

Charge Exchanged Neutral Thruster **(CXNT)**

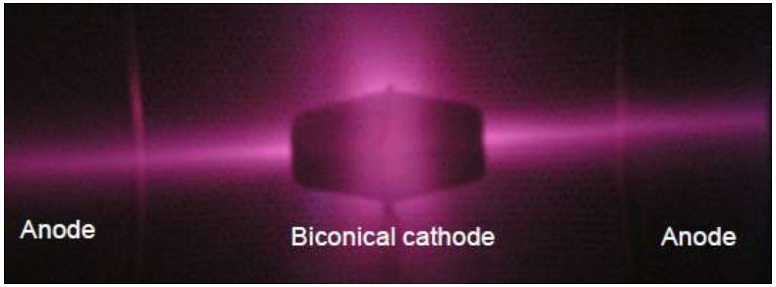


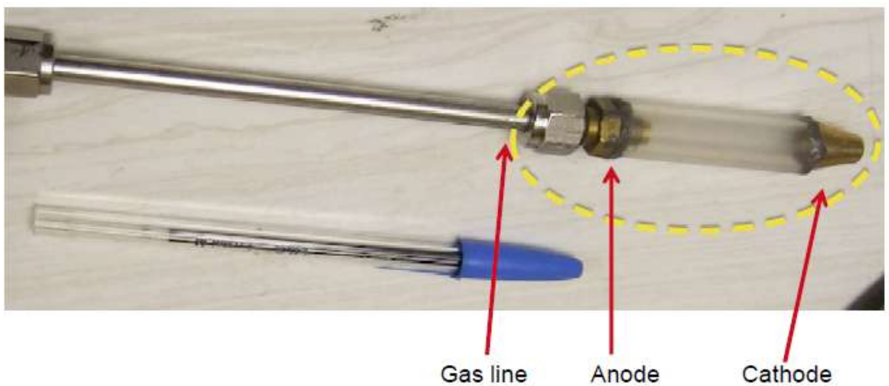
- Diagnostics show collimated and energetic neutral hydrogen travelling away from the center in each of the microchannels shown in the picture.
- Microchannels are formed all around the cathode, but can be focused through E-field optics.

$$H^+ + H_2 \rightarrow H^* + H_2^+$$

Energetic neutral hydrogen produced through charge exchange

Charge Exchanged Neutral Thruster (CXNT)





- Isolating micro-channels using conical cathodes is being used for electric propulsion of spacecrafts
- This thruster produced 100μN thrust while using 40 nW of power.*
- The major advantage of CXT is the potential for size reduction for application to nanosatellite propulsion.

**JKhachan, et al, US Japan workshop on IEC 2012*

Charge Exchanged Neutral Thruster **(CXNT)**

- A reduced size CXT is being installed on a Cube satellite similar to the one shown in the figure for orbit and attitude control
- Launch date 2015 as part of the QB50 international project organized by the Von Karman Institute Belgium
- A comparison with Hall-effect thruster shows that CXNT is superior

	Hall-effect thruster (Xenon)	CXT (Argon)
Thrust/Power (μN/W)	60	215
Specific impulse (s)	1660	2600

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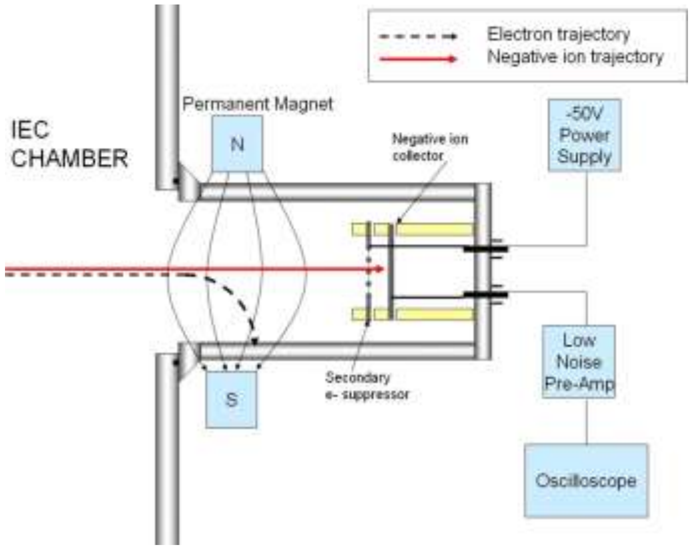
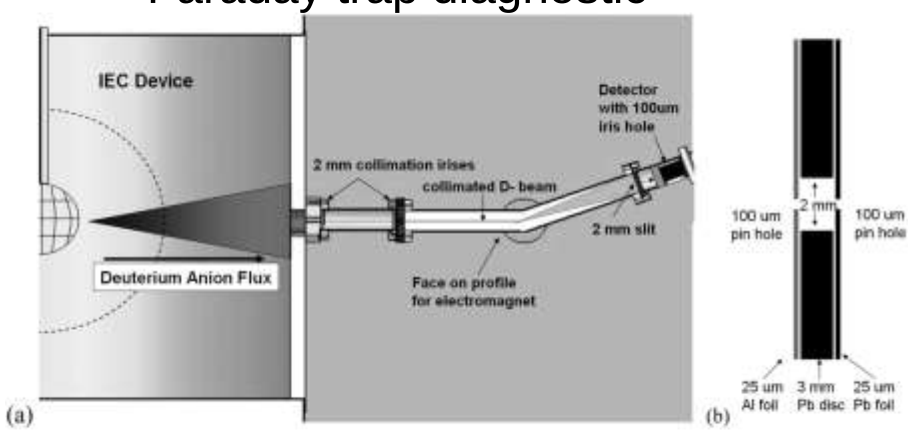
Negative Ion Thruster

A new IEC propulsion mode

Discovery of Negative Ions



Faraday trap diagnostic



Magnetic Deflection Energy Analyzer

- Negative ions were observed in the UW-IEC device using a Faraday trap diagnostic,* consisting of a current collection plate with a secondary electron suppression grid, situated so as to collect the divergent negative ion flux from the spherical potential well.
- The charge to mass ratio and velocity of the divergent deuterium anions were measured using a magnetic deflection energy analyzer

$$H_3^+ + H_2 \rightarrow H^- + 2H^+ + 2H,$$

$$H_2^+ + H_2 \rightarrow H^- + 2H^+ + H,$$

$$H^{fast} + H_2 \rightarrow H^- + H^+ + H,$$

$$H^+ + H_2 \rightarrow H^- + 2H^+.$$

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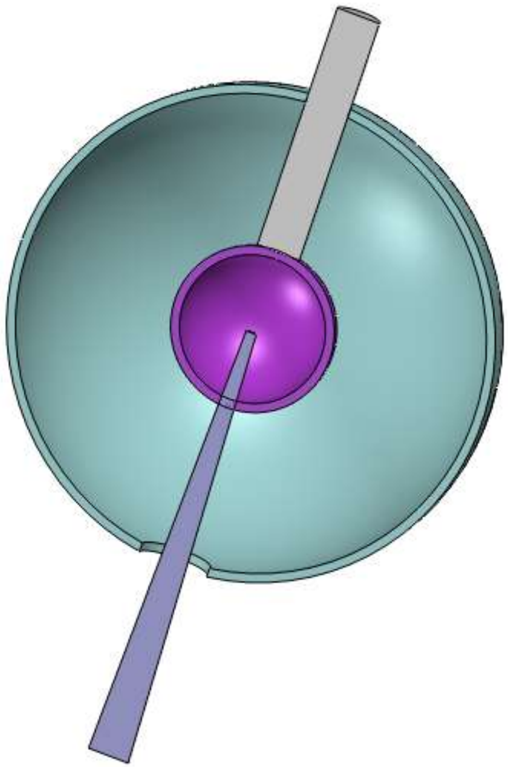
D.R.Boris et al., Phys. Rev E, 80, 036408 (2009)

Why Negative Ion Thruster?

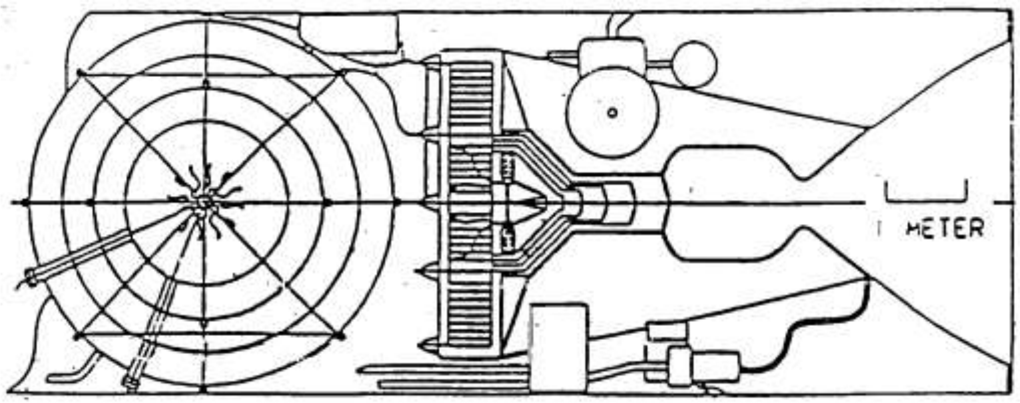
- IEC based negative ion thruster have the distinct advantage that the space craft wouldn't have to deal with charge buildup.
- Charge transfer in hydrogen occurs at much higher energies than electron attachment that involves a transfer of two electrons from background neutral to a positive ion at high energy.
- Instead of electrons leaving the system, we have heavy negative ions leaving the system.
- Such a system would also cause the ions to leave the system for charge balance.
- The thrust generated would therefore be higher than even the CXN thruster

Negative Ion thruster

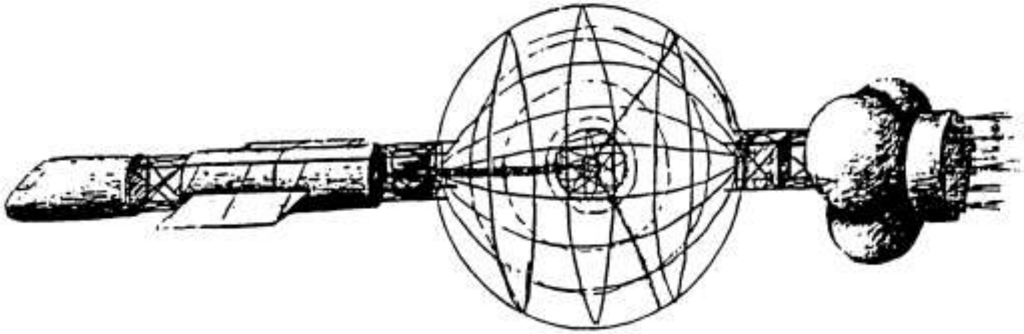


- The major advantage is the simplicity of the design.
- The ion optics could be easily designed into the system to optimize thrust
- These jets could be pulsed and be directed out rather easily to generate the necessary thrust.
- Exact design is now being patented

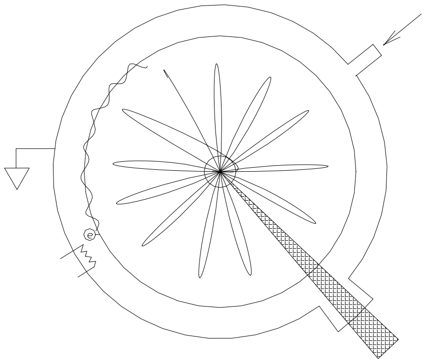
Other IEC Based Conceptual Designs



R.W. Bussard and L.W. Jameson
ARC/QED engine system



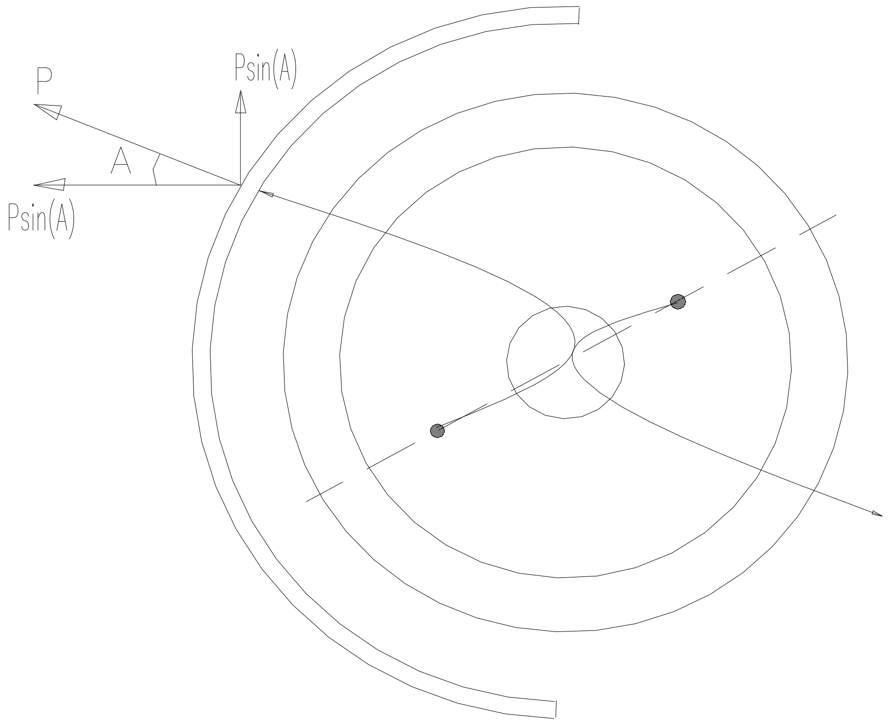
G.H. Miley et al.
IEC/DEC Ion Drive system.



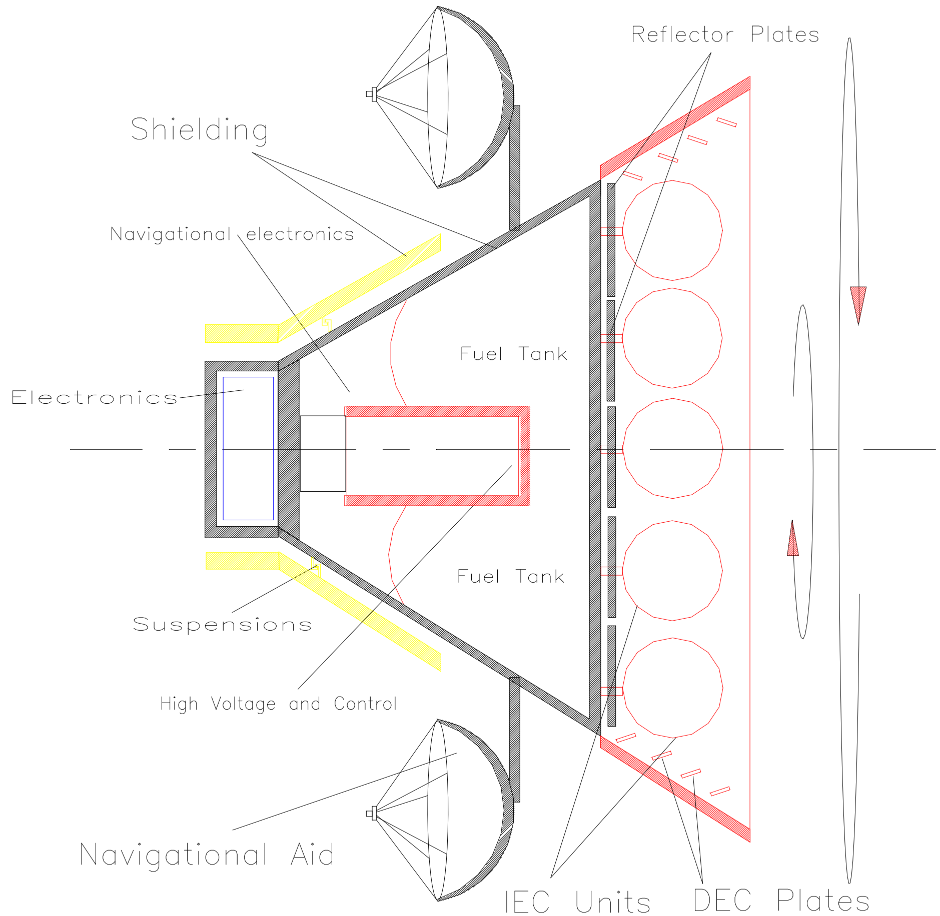
G.H. Miley et al.,
IEC Plasma Jet propulsion

Fusion Ash Impact Propulsion

Momentum is directly transferred to the spaceship through impact of Fusion ash (MHD cycles are avoided)



FAIP based spacecraft has a stable configuration



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Comparison of Specific Impulses of Various Propulsion schemes

Propulsion Scheme	Specific Impulse (s)
Chemical	460
Fission Thermal	900
Fission Electric	5000
Gas-Core Fission	1870
Magnetic Fusion	27500
LAPP	3.2×10^6
Antimatter	10^3 - 10^6
Hall effect thruster	1660
IEC Electrothermal	3000
IEC - CXNT	2600
IEC – QED	1.5×10^5
FAIP	5.6×10^6

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- Terry Kammash, "A Nuclear Powered Laser-Accelerated Plasma Propulsion System," in *Space Technology and Applications International Forum – STAIF 2003,* El-Genk, Ed. American Institute of Physics, 2003, CP654.

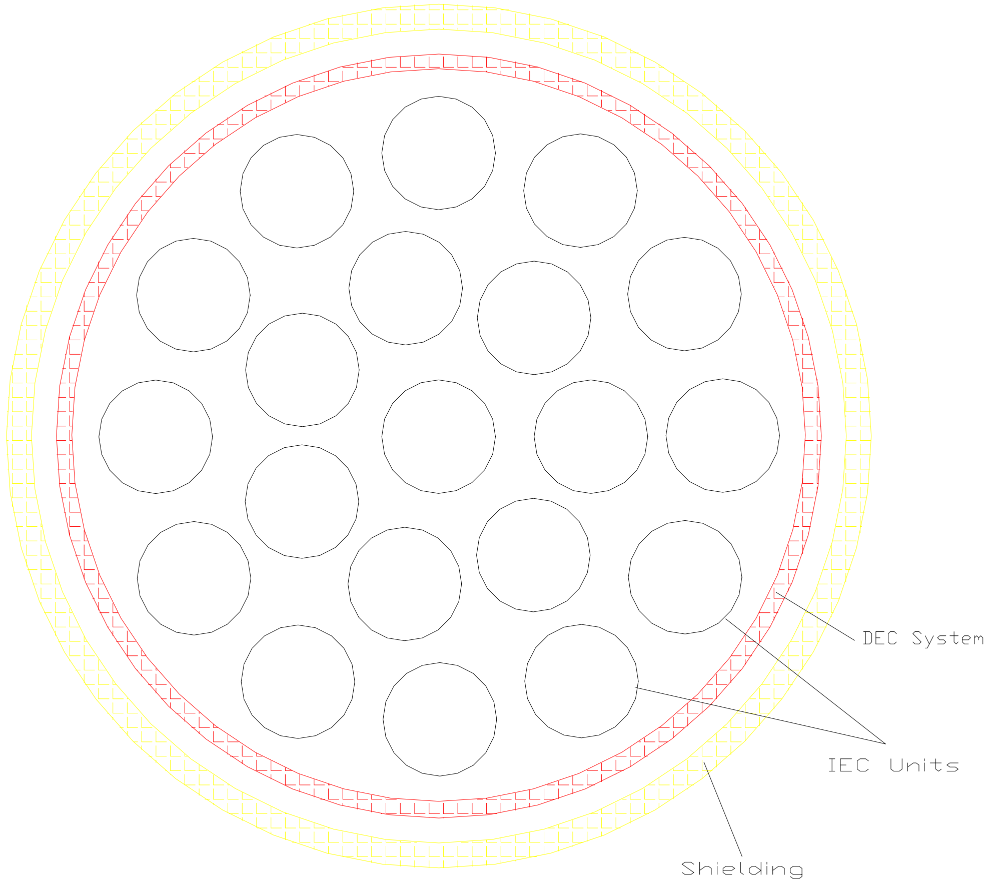
Conclusions

IEC devices are

- Most suitable for satellite space propulsion (beyond LEO), owing to their simplicity, compactness and safety
- Offer many ways to produce thrust
- CXN thruster is already in the implementation stage and could be adapted to other satellites
- New propulsion schemes (such as NIT) are on the horizon
- Very long range missions could also be driven by IEC driven systems (E.g., trip to the Oort cloud)
- Micro and mini satellites, disaster management satellites, any satellite for that matter could be propelled using these propulsion systems
- Have many other applications
- We are now open to collaboration for the development of these propulsion systems

Additional slides

Back-view of Spaceship with 20 IEC Units



Specific impulse
5.5×10^6s

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Sl. No.	Parameter considered	Parameter evaluated
1.	Q of the Power system	10
2.	Specific Power	100 kW/kg
3.	Fusion Rate (Miley et. al.)	10^{17} /s
4.	Number of IEC units in the spaceship	100
5.	Mass Pay load	1 kg
6.	Momentum Factor	$1/2\pi$
7.	Reflection Factor	2
8.	Mission Time	30 yrs
9.	Exhaust Velocities	5.307×10^{7} m/s
10.	Thrust generated	0.5651 N
11.	Power	2.94×10^{7} W
12.	Mass Power System	294 kg
13.	Power Injected	2.94×10^{6} W
14.	Mass of the propellant	79.12 kg
15.	Acceleration of the spaceship	0.00151 m/s
16.	Local Solar Gravity	0.005931 m/s^2
17.	Acceleration/local solar gravity (spiral trajectory or separate propulsion system may be required)	0.2547
18.	Thrust to weight ratio	0.000154
19.	ΔV (Assuming constant radial thrust, beginning at a point where the Sun's gravity can be neglected)	1.429×10^{6} m/s
20.	Δs	6.76×10^{14} m = 4519 AU

Thrust-to-Weight Ratios of Various Propulsion Systems