"Test of a Miniature Double-Focusing Mass Spectrometer for the Variable Specific Impulse Magnetoplasma Rocket (VASIMR) at the Advanced Space Propulsion Laboratory "

Project by:

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In Conjunction with:

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Astronaut and Director. Advance Space Propulsion Laboratory (ASPL). NASA-JSC

Collaboration:

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(ASPL-NASA-JSC)

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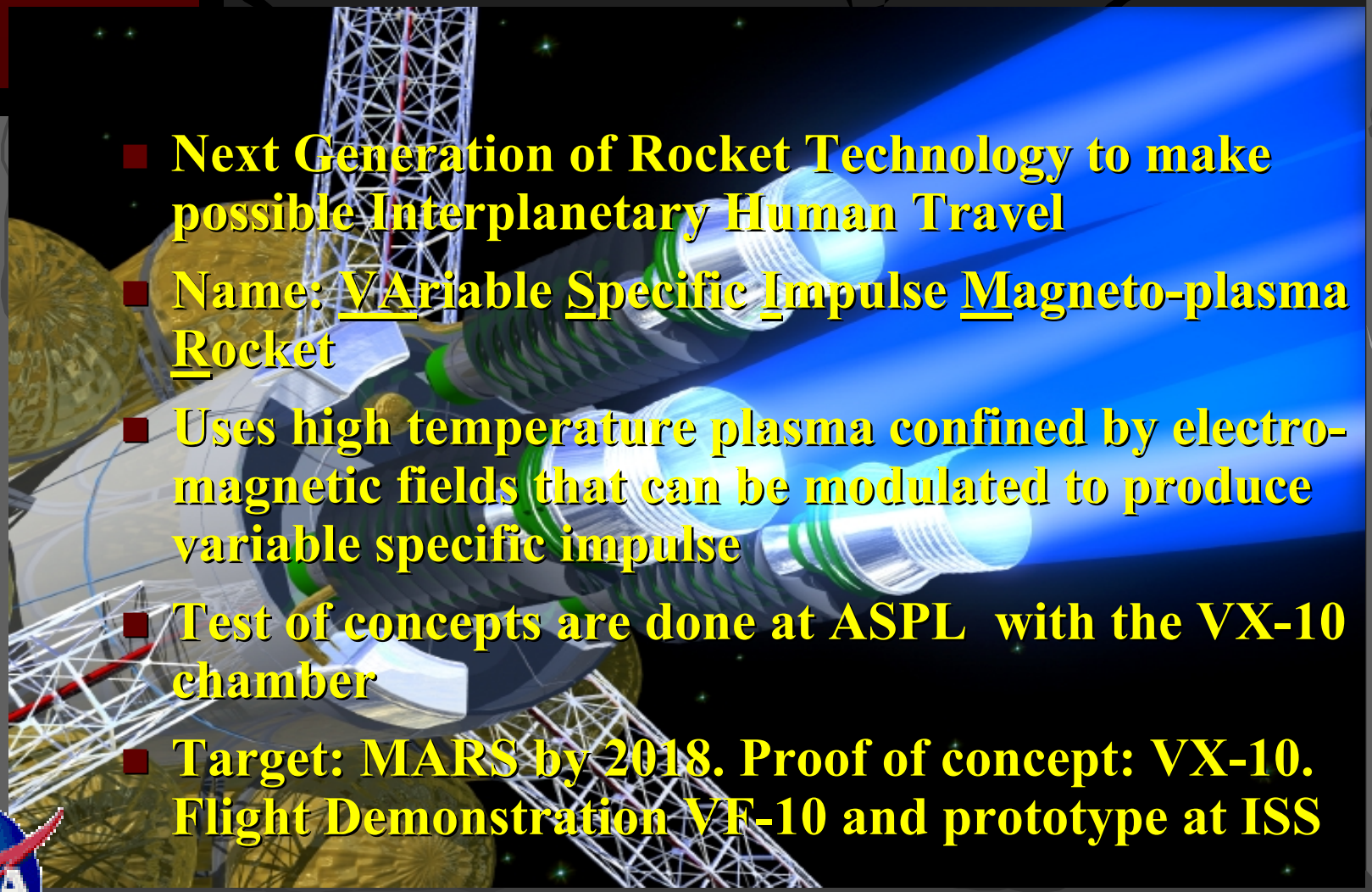
(Mass Sensors Inc.)

A.M.G.D.

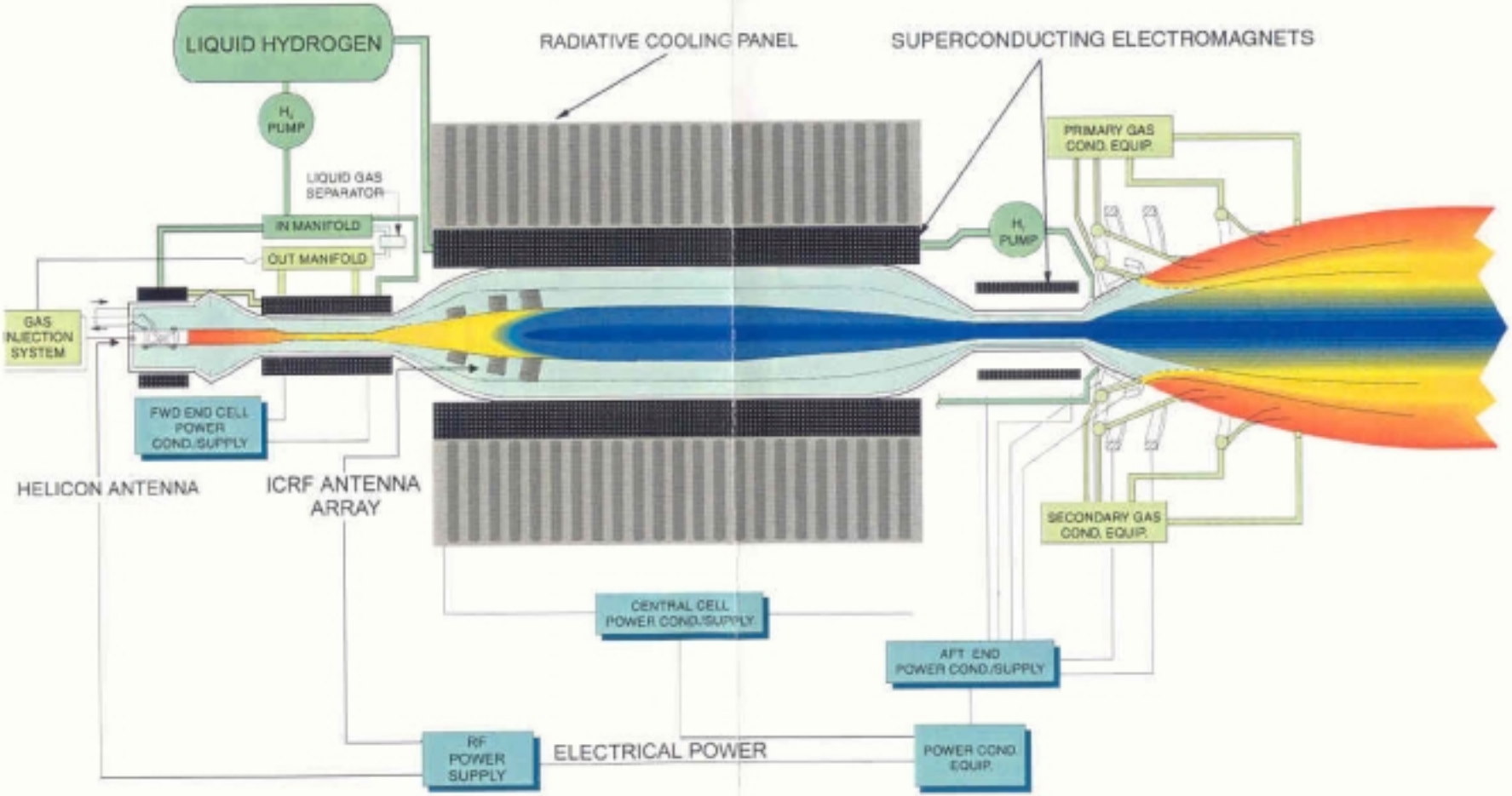
The Application:

What is VASIMR?

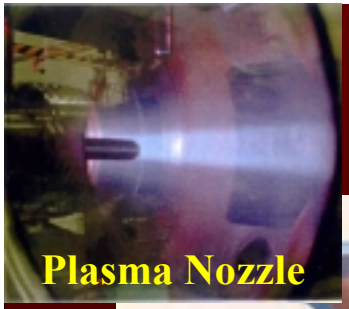


- Next Generation of Rocket Technology to make possible Interplanetary Human Travel
- Name: VAriable Specific Impulse Magneto-plasma Rocket
- Uses high temperature plasma confined by electro-magnetic fields that can be modulated to produce variable specific impulse
- Test of concepts are done at ASPL with the VX-10 chamber
- Target: MARS by 2018. Proof of concept: VX-10. Flight Demonstration VF-10 and prototype at ISS

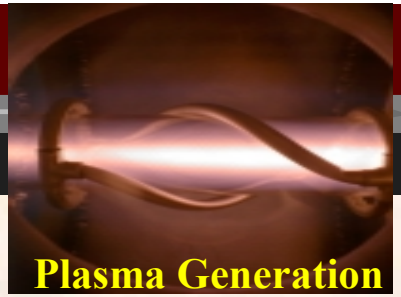
VASIMIR CONCEPT



Video: BEKUO STARSHIP using three VASIMR engines

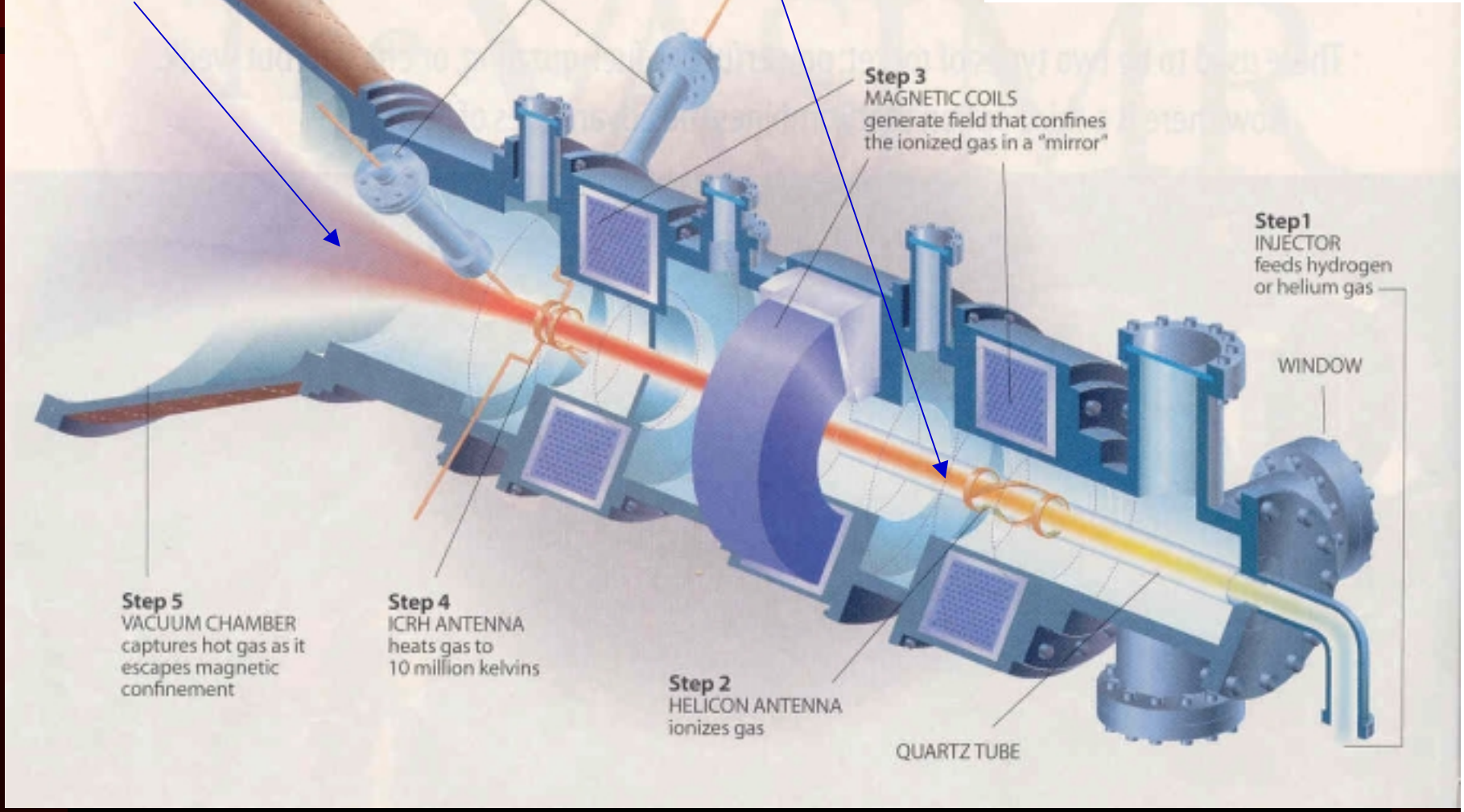


Plasma Nozzle

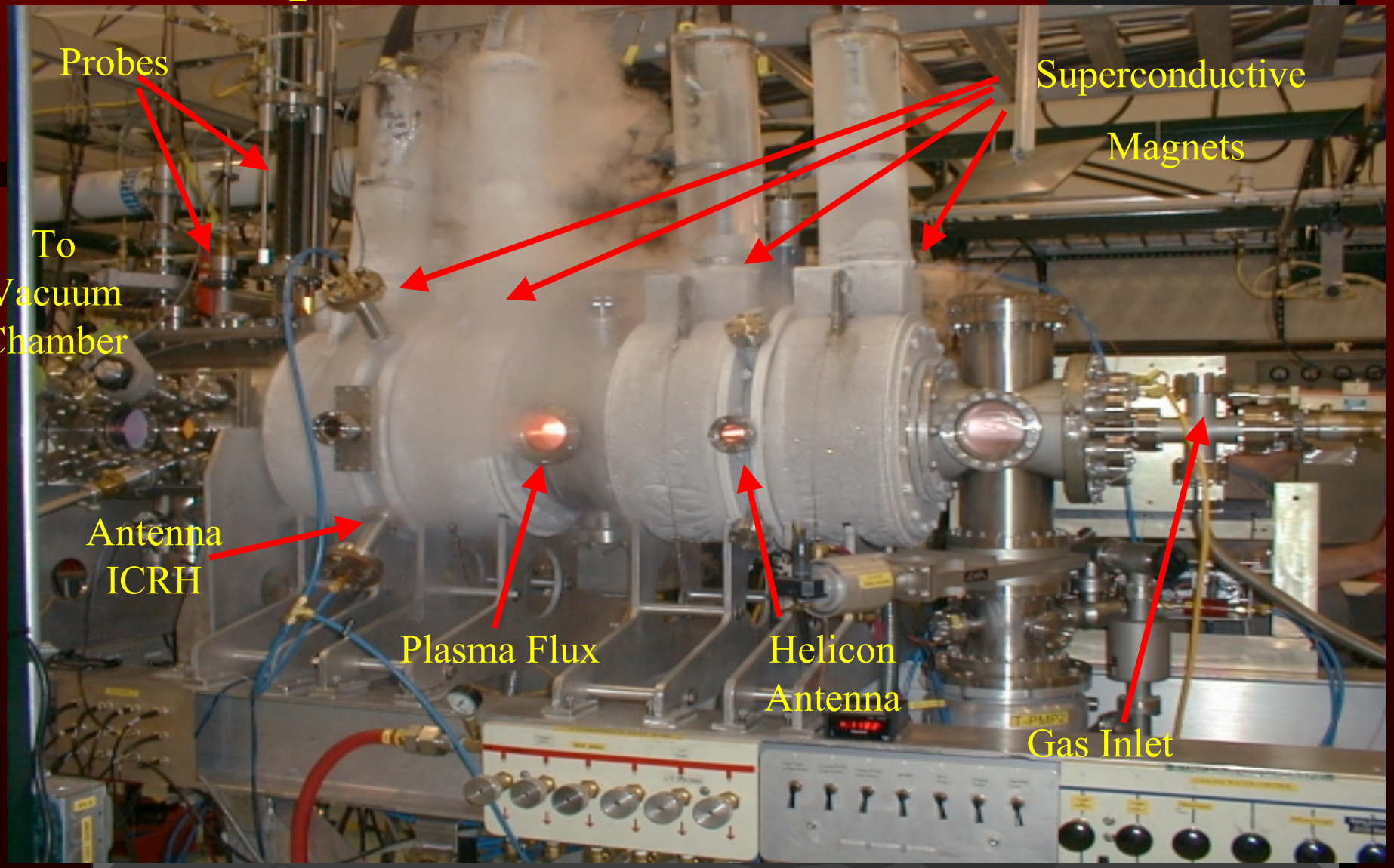


Plasma Generation

Test Bench on Earth: VX-10

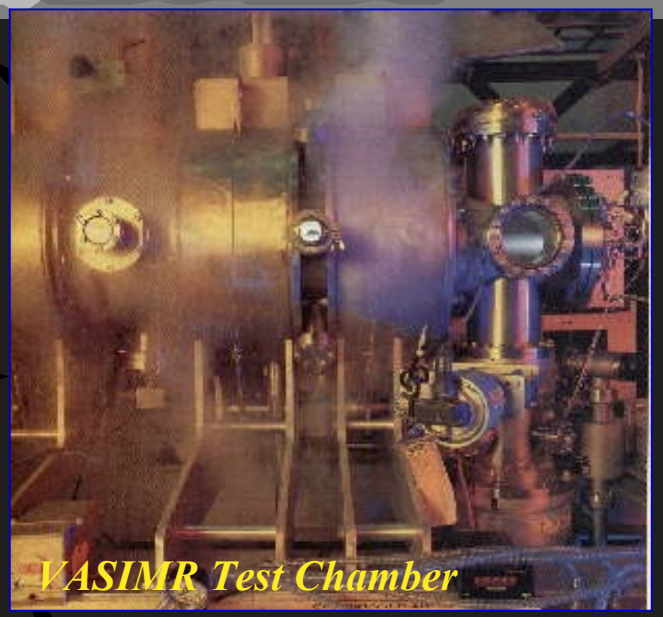


VX-10 Experiment at ASPL



Why This Project?

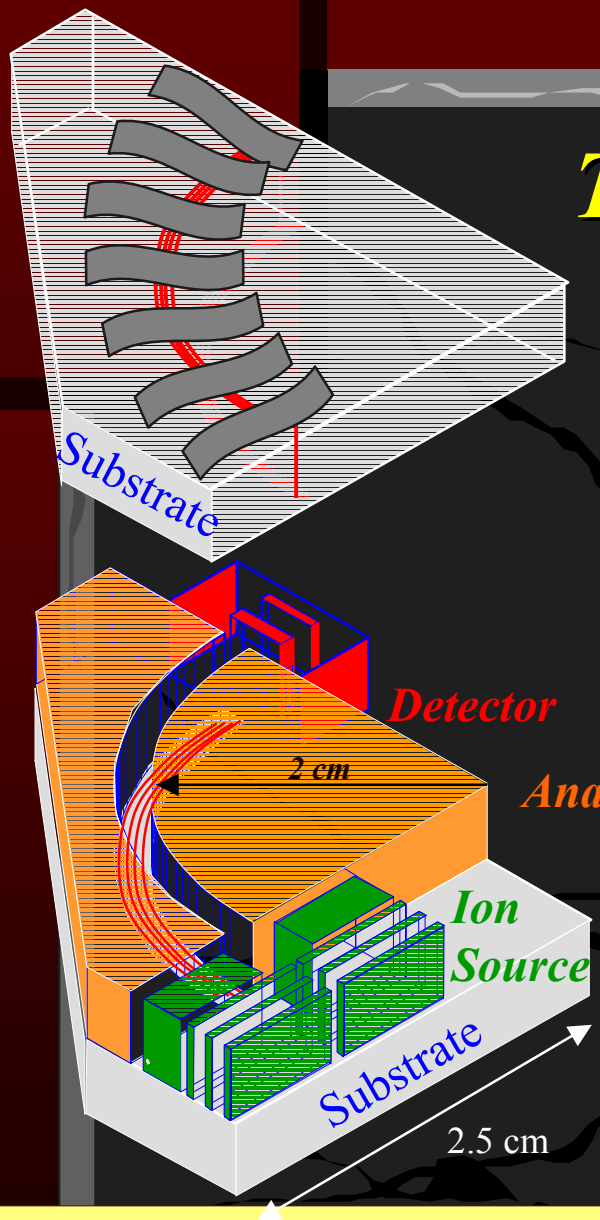
- Miniature Mass Spectrometer developed at UMN (CDFMS prototype)
  - Distributed Residual Gas Analysis
  - Prototype tested at NASA's Hazardous Gas Detection Lab (Kennedy Space Center)
  - Visit to Houston and conversations with Dr. Franklin Chang Diaz about possible collaboration
  - Provided novel usage of commercial alpha and beta units in harsh environment applications
- VASIMR VX-10 Test Chamber at NASA's Advanced Space Propulsion Lab
  - No residual gas detection capabilities at that point
  - Interest of monitoring ion species (H2, D2, He, Xe, Ar, …)



VASIMR Test Chamber

CDFMS Core

The MMS Project at UMN



Compact Double Focusing Mass Spectrometer (CDFMS) Concept

Research Goal:

To develop a novel miniature mass spectrometer suitable for in situ environmental and harsh environment (e.g. volcanic gaseous emissions)

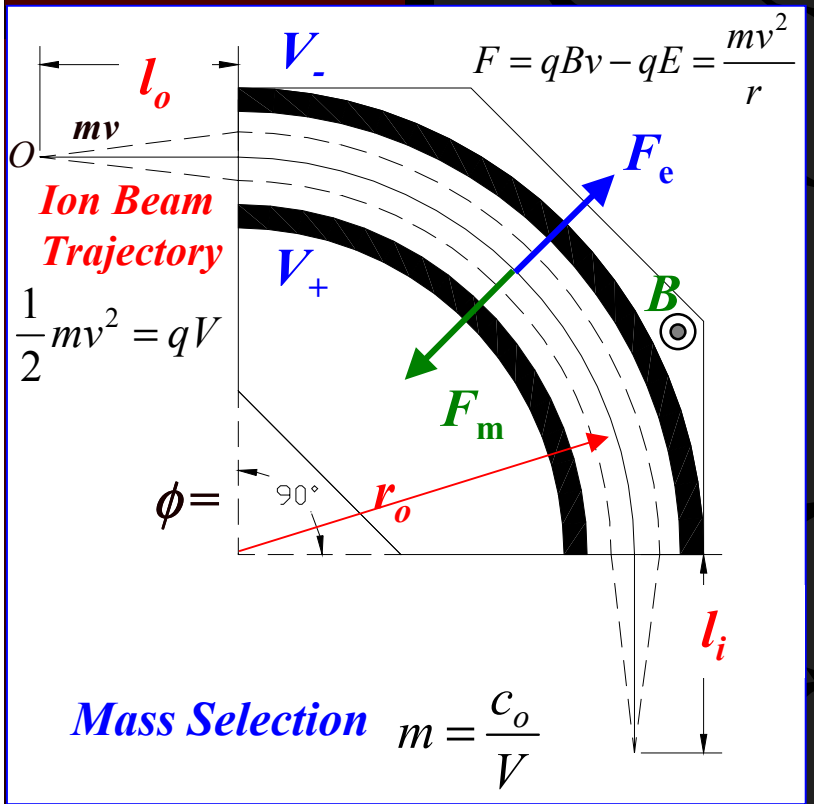
Specific Objective:

Design and construction of "proof of concept" miniature mass spectrometer prototype:

- Compatible with mass production manufacturing techniques
- Low cost (in large quantities)
- Portable

CDFMS Mass Analyzer: Theory

It is based on the mass separation capabilities of sector field analyzers



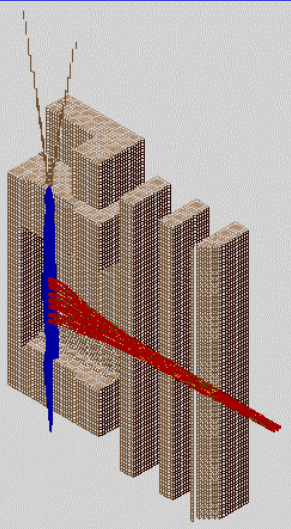
90^o Cylindrical ExB Sector Field Analyzer

- ***Single Focusing***
  - Direction Focusing (angular spread)
    MAGNETIC SECTOR
  - Energy Focusing (energy spread)
    ELECTROSTATIC SECTOR
- ***Double Focusing (DF)***
  - Ion beam is focused both in direction and energy
    Higher Resolving Power
  - Usually achieved by analyzers placed in tandem
    Nier, Mattauch-Herzog MS
- ***Crossed ExB DF Analyzer***
  - Superimposed elec. & magnetic fields
    Compact Assembly

$$\frac{dr}{dv} = \left(\frac{Bv - 2E}{Bv - E}\right)\frac{r}{v} = 0$$

$$\frac{F_m}{F_e} = -2$$

DF Condition



Ion Source

CDFMS Ion Simulation SIMION 3D

Tuned for Mass 28

Ionization from -1 to 1 mm in z

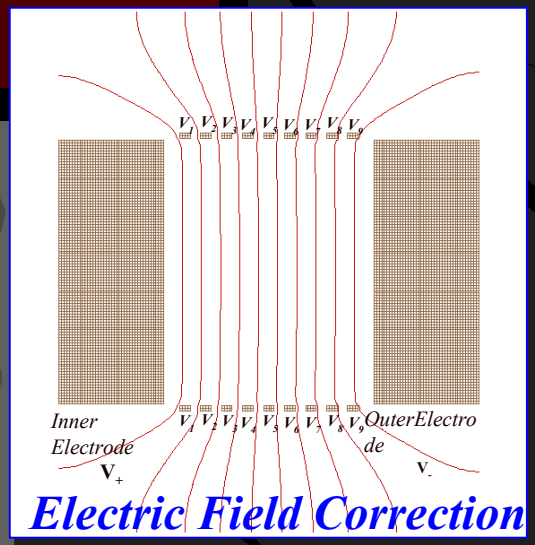
Mass 27 amu -------

Mass 28 amu -------

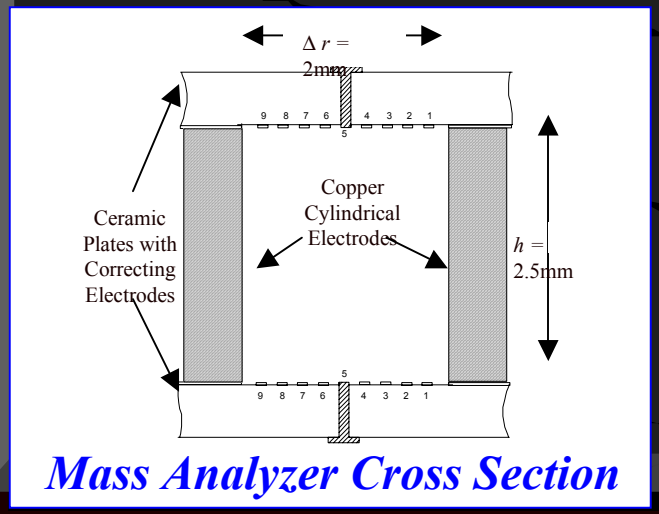
Mass 29 amu -------

Microfabricated Mass Analyzer

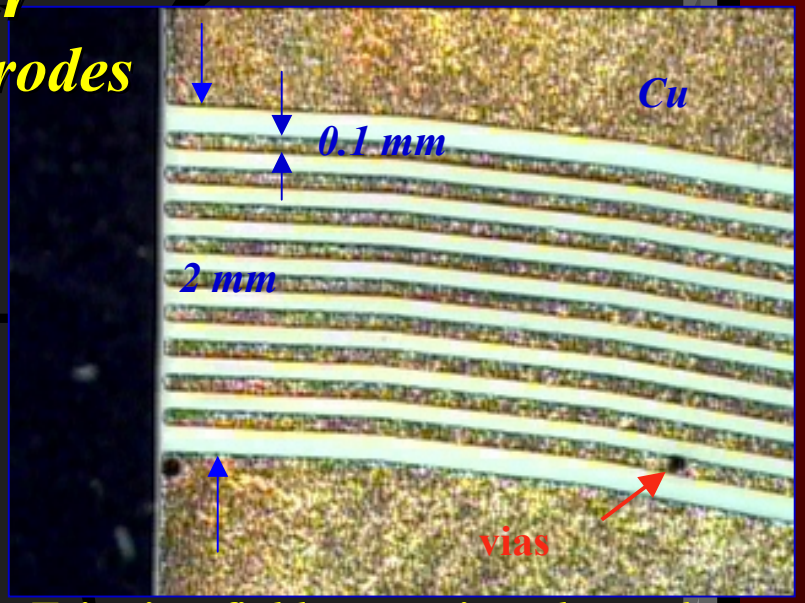
Electric Fringing Field Correcting Electrodes



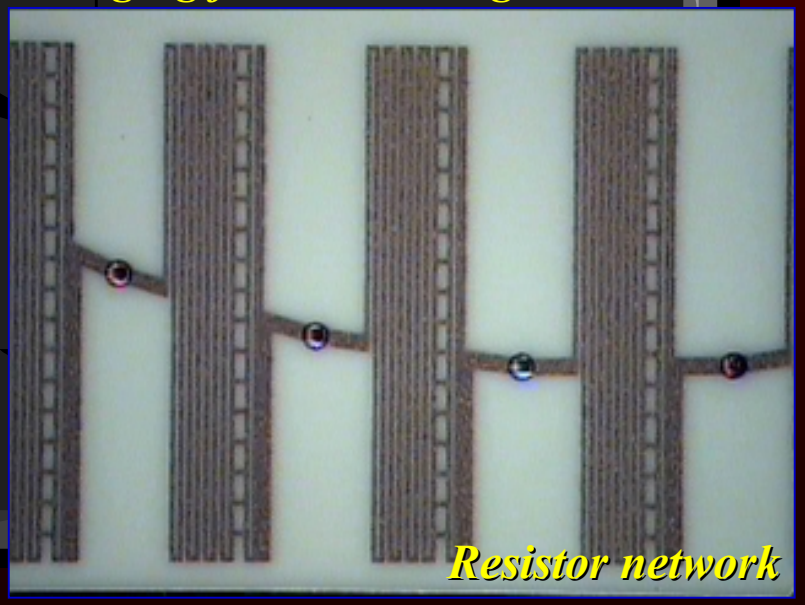
Electric Field Correction



Mass Analyzer Cross Section



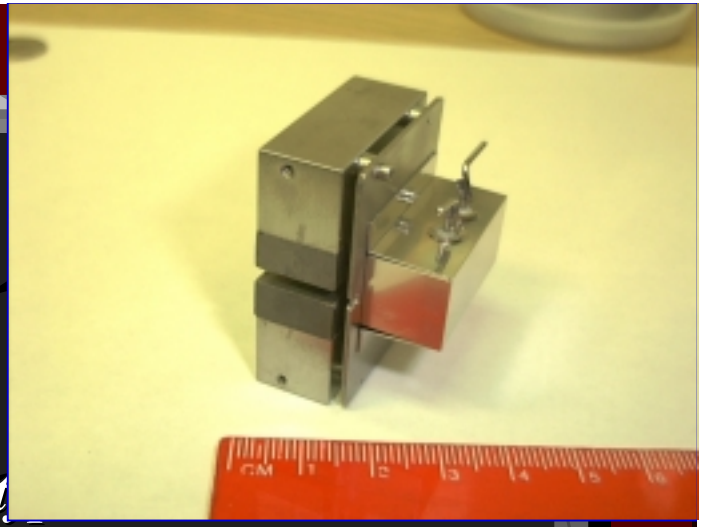
Fringing field correcting electrodes



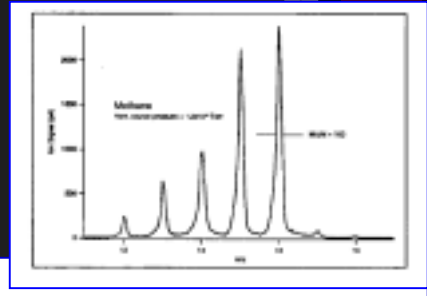
Resistor network

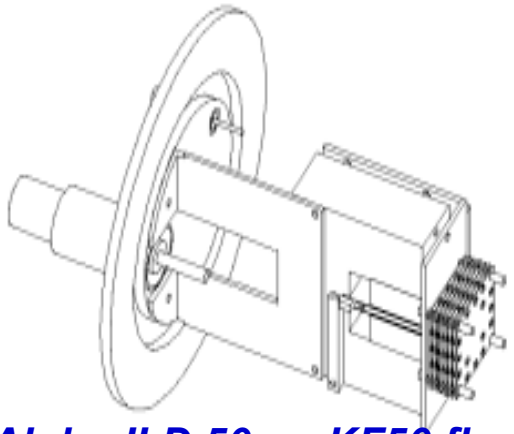
Instrument Tested at ASPL

Alpha Version of the Integrated Leak Detector (Acronym: α-ILD 50)

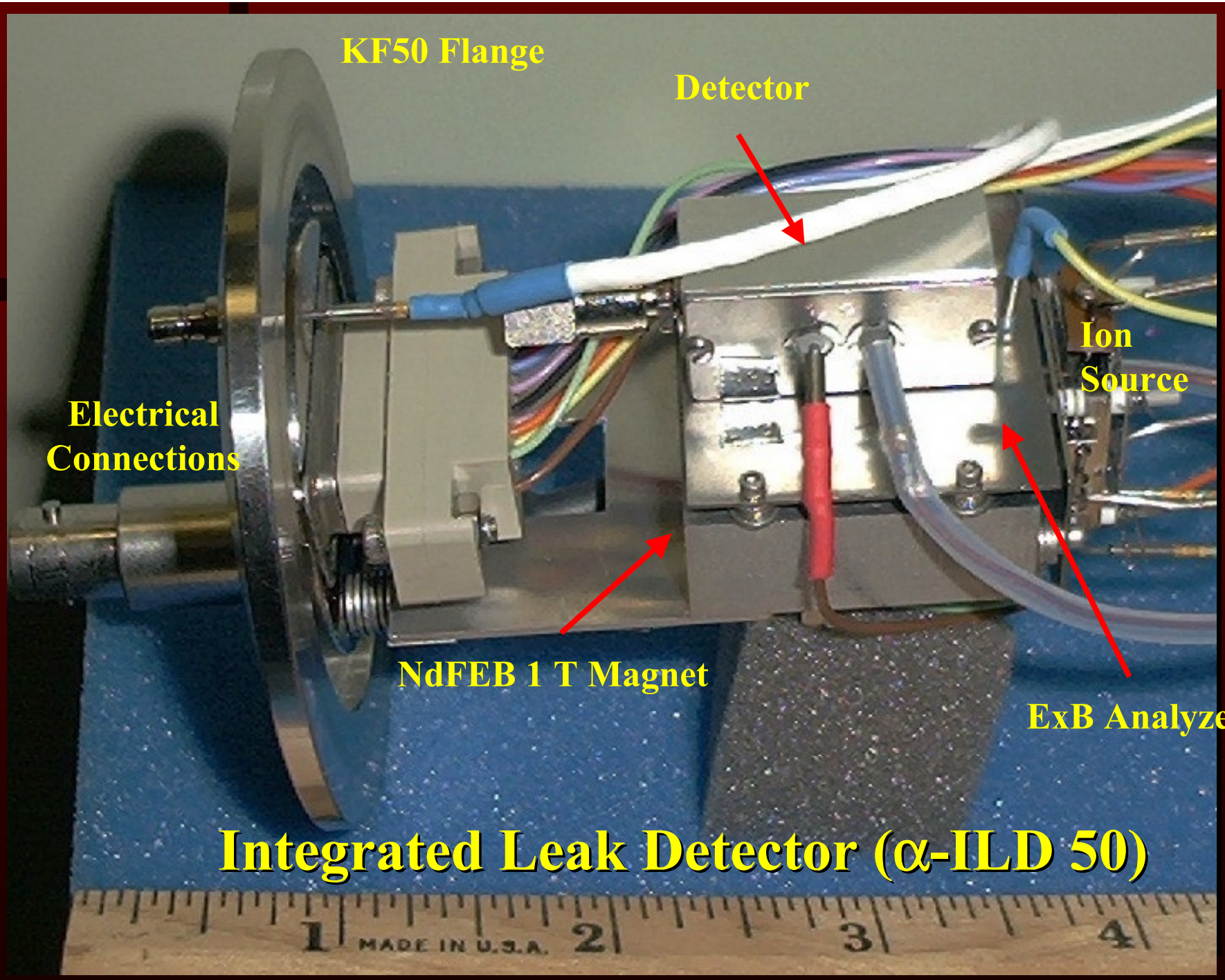


- *Novel Miniature Mass Spectrometer*
  Instrument based on CDFMS protot
- *(Patent Application. Licensed by UMN to Mass Sensors)*
- *Designed for low cost batch manufacturing*
- *Basic element (OEM) for a Field Portable MS*
- *Distributed sensing. Internet protocol*
- *ILD 50 Specs:*
  - Analyzer : 8 mm ExB Double-Focusing Magnetic Sector Mass Spect.
  - Mass Range: 1-50 amu
  - M/Δ M: 40
  - Operating pressure: 10^{-4}
  - Weight: 153g
  - Size: 40H x 52L x 32W (mm)
  - Remote control through: Internet or wireless

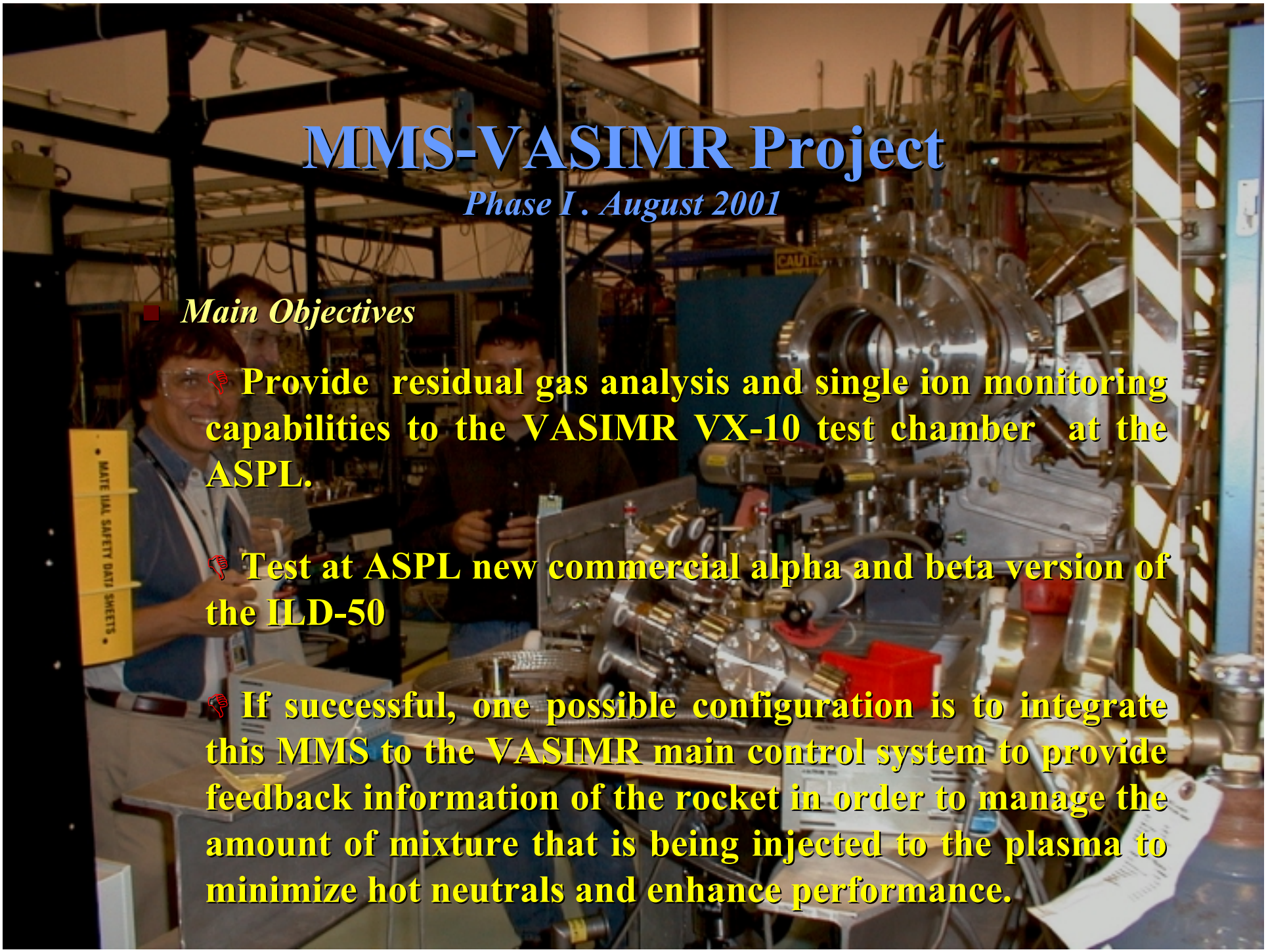




Alpha-ILD 50 on KF50 flange



Integrated Leak Detector (α-ILD 50)



MMS-VASIMR Project

Phase I . August 2001

- *Main Objectives*
  - **Provide residual gas analysis and single ion monitoring capabilities to the VASIMR VX-10 test chamber at the ASPL.**
  - **Test at ASPL new commercial alpha and beta version of the ILD-50**
  - **If successful, one possible configuration is to integrate this MMS to the VASIMR main control system to provide feedback information of the rocket in order to manage the amount of mixture that is being injected to the plasma to minimize hot neutrals and enhance performance.**

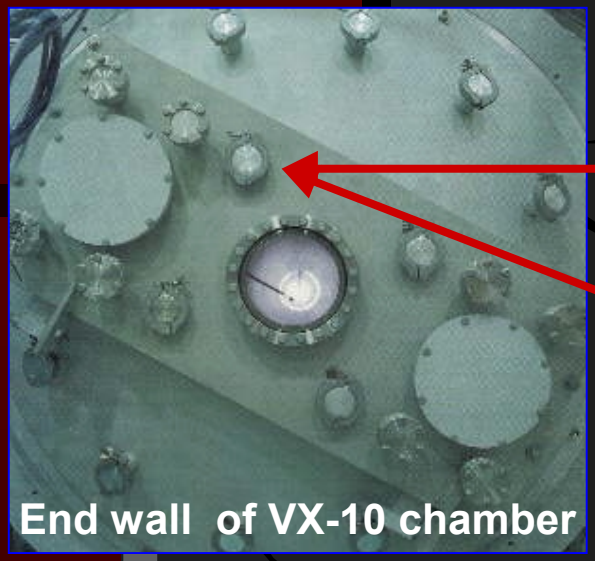
MMS-VASIMR Project

Phase I . August 2001

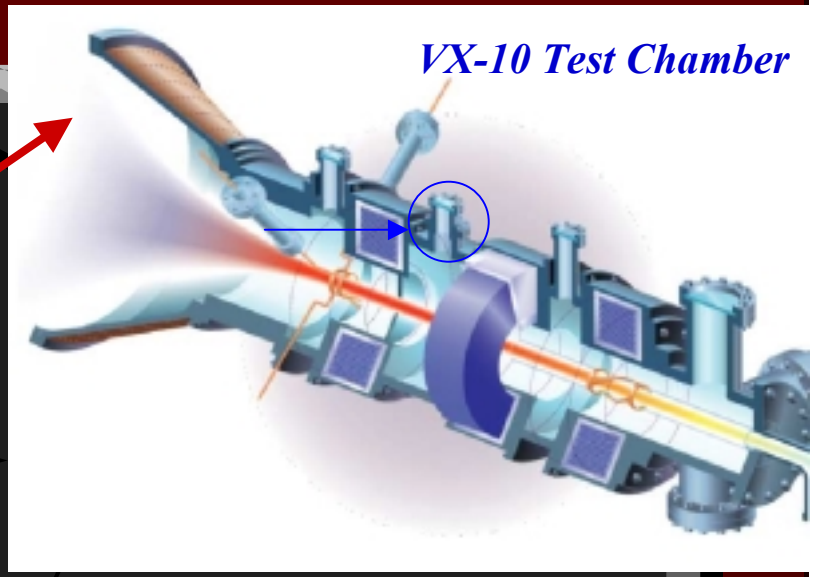
- **Activities**
  - 2 week visit of Dr. Diaz to ASPL (August, 2001)
  - Installation of alpha unit provided by Mass Sensors Inc at one of the ports of the VASIMR VX-10 test chamber
  - Analyze residual gas concentrations
  - Establish time monitoring of specific ion concentrations both at steady state and while beam is being fired
  - Evaluate high pressure operation of MMS and optimize sensor components to achieve operability at 10 mtorr
  - Optimize hardware and software for user friendly operation

Experimental Set-up

Single Point Sampling Scheme

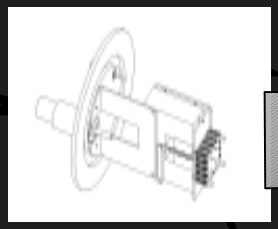


Sampling point
KF40 port



VX-10 Test Chamber

IDL 50 on KF50 flange



Gate valve

Needle valve

KF50 T

KF40 T

KF40 T

Calibration gas

KF40 to KF25 adapte

View port

KF40 to KF50 adapter

Micro Ion Gauge

90° tree to avoid high energetic ions from reaching ILD 50 analyzer

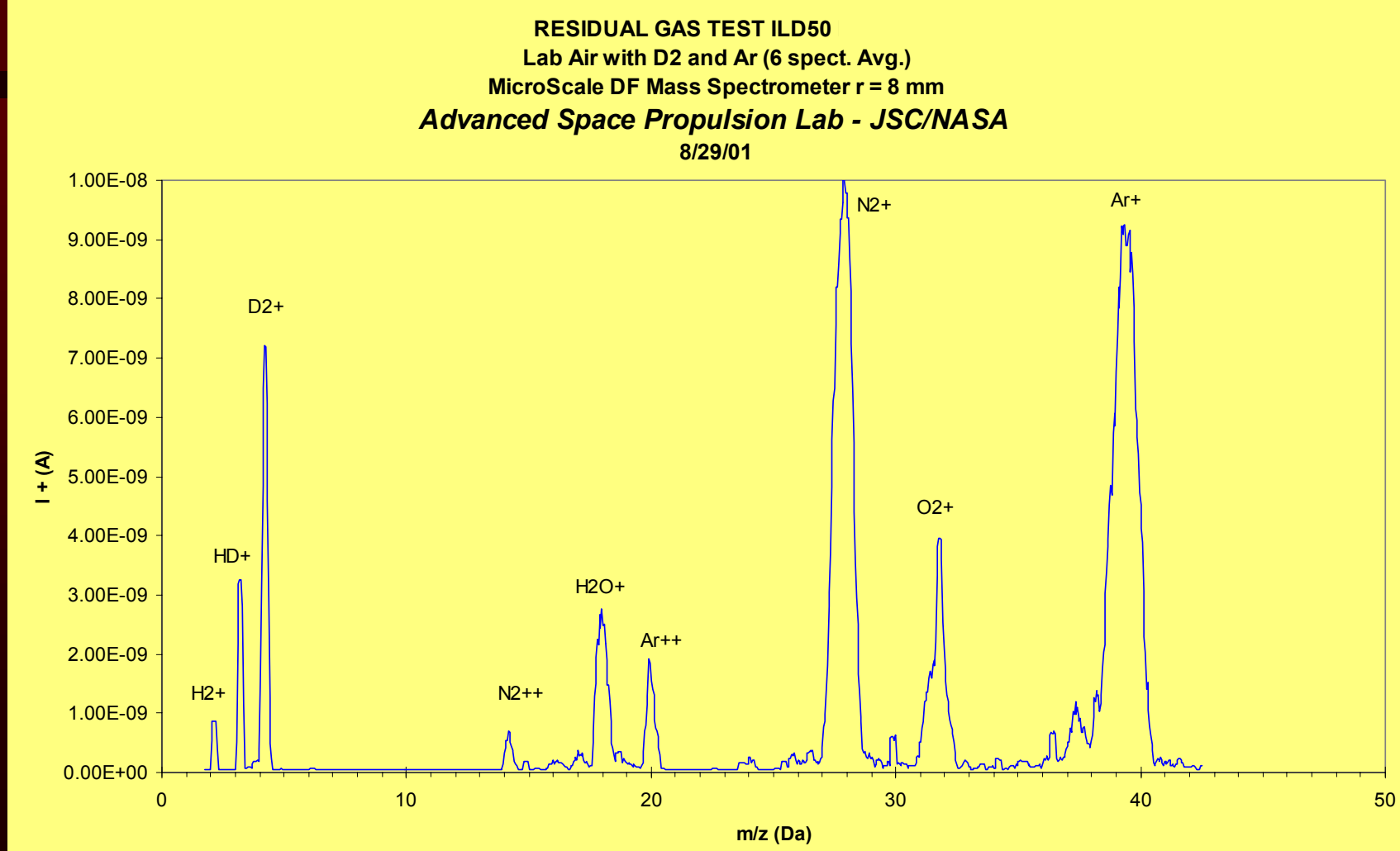
Experimental Set-up

Electronics and Data acquisition

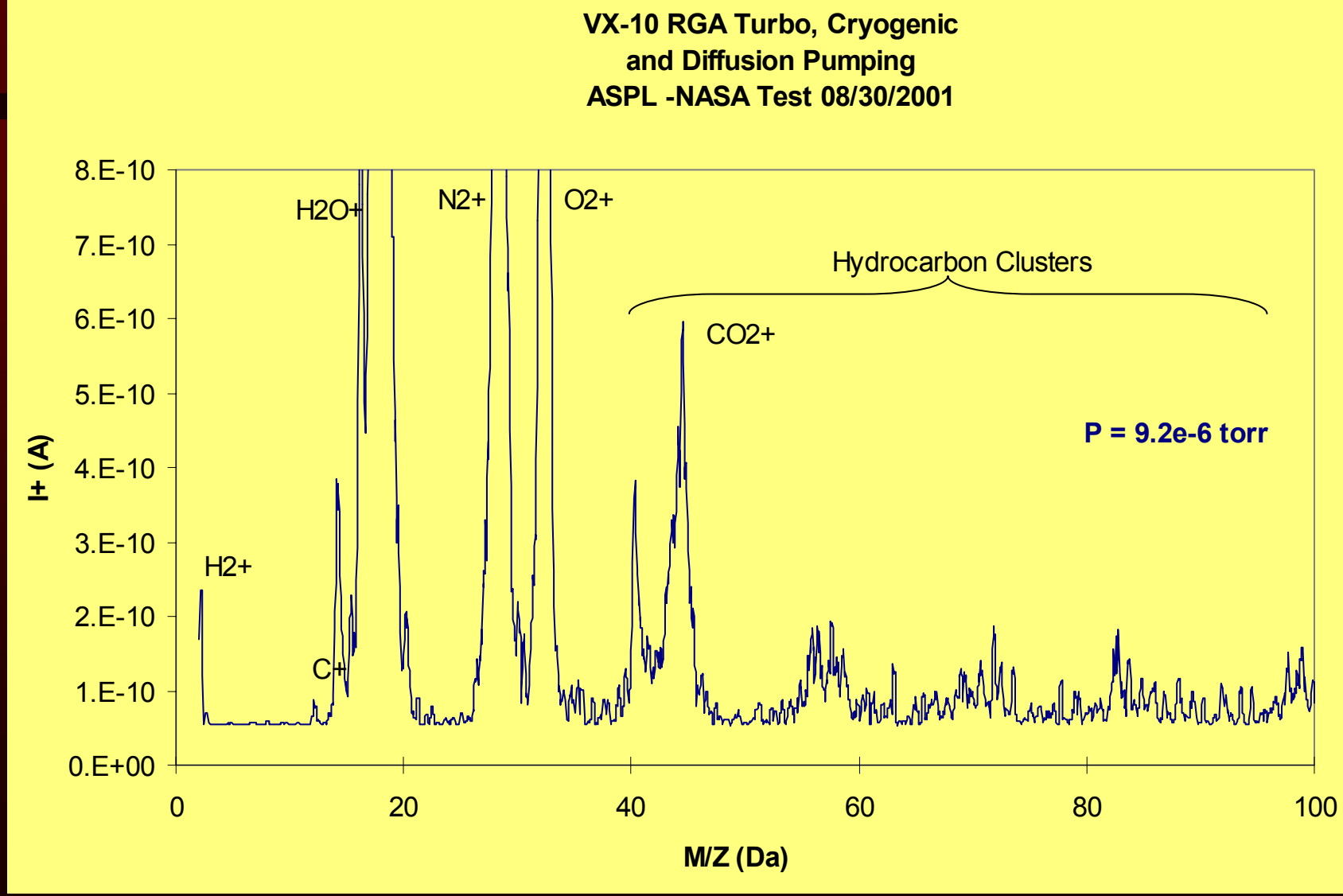
Experimental Set-up

Data Collection

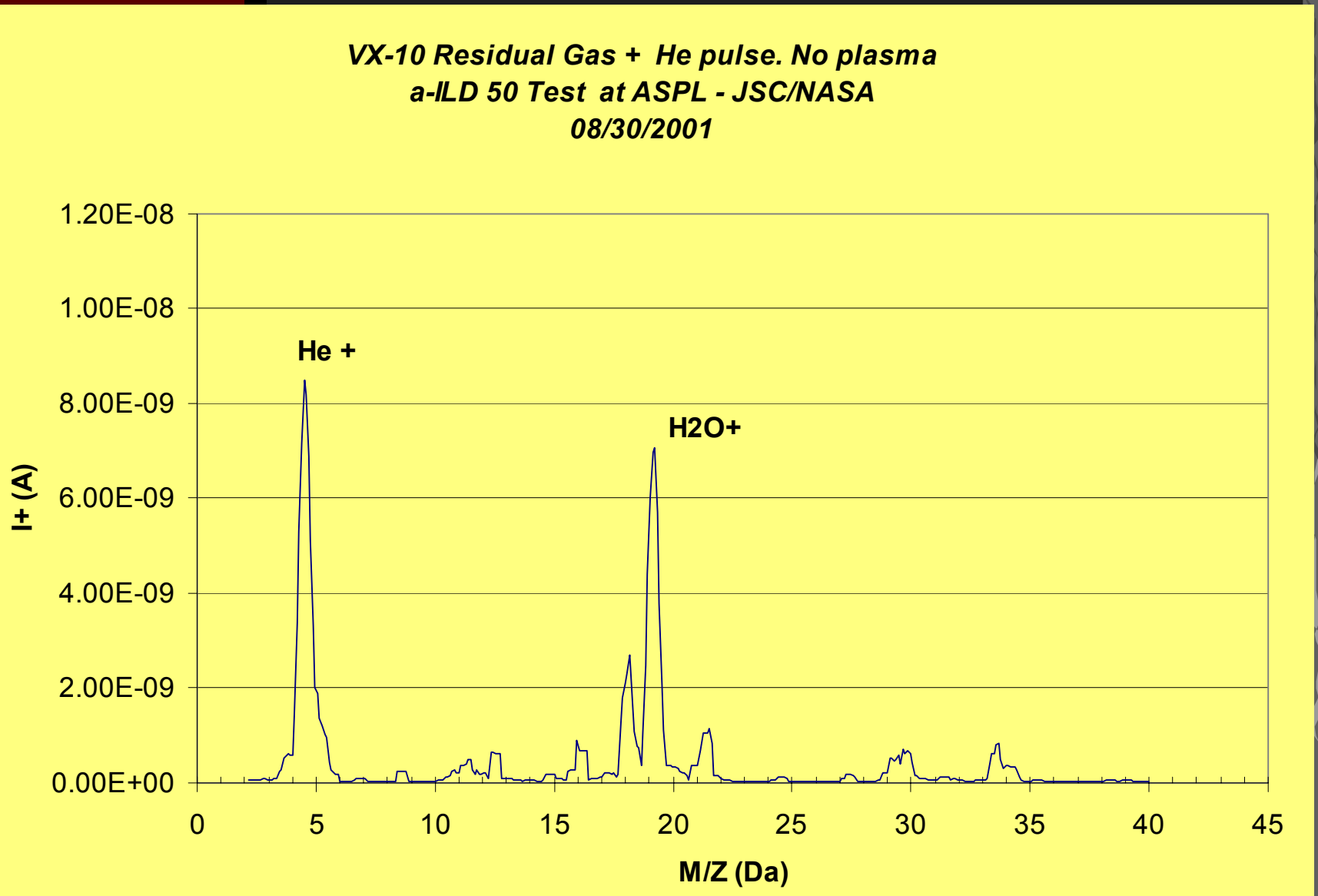
Propellant Gas Analysis



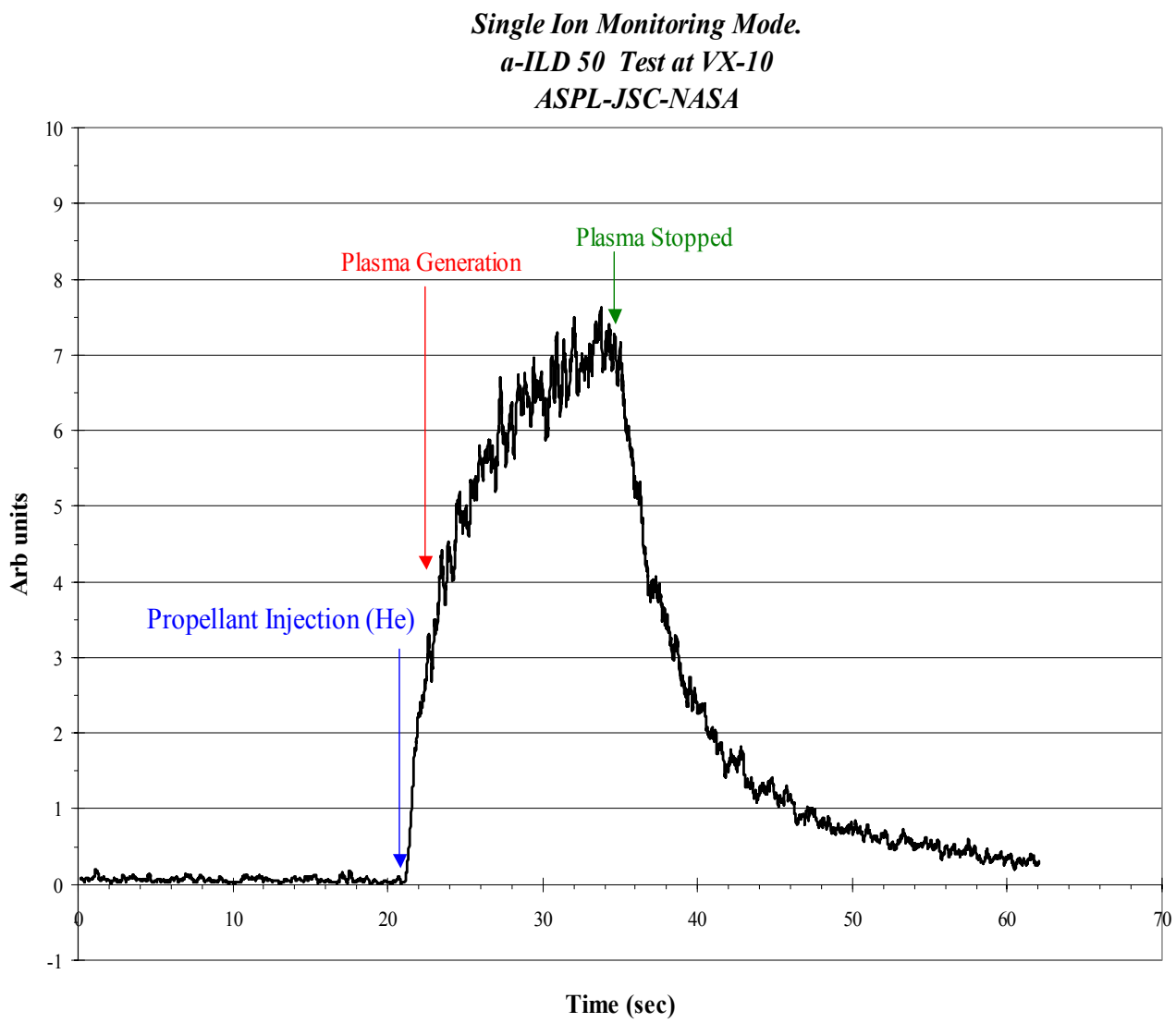
Residual Gas Analysis



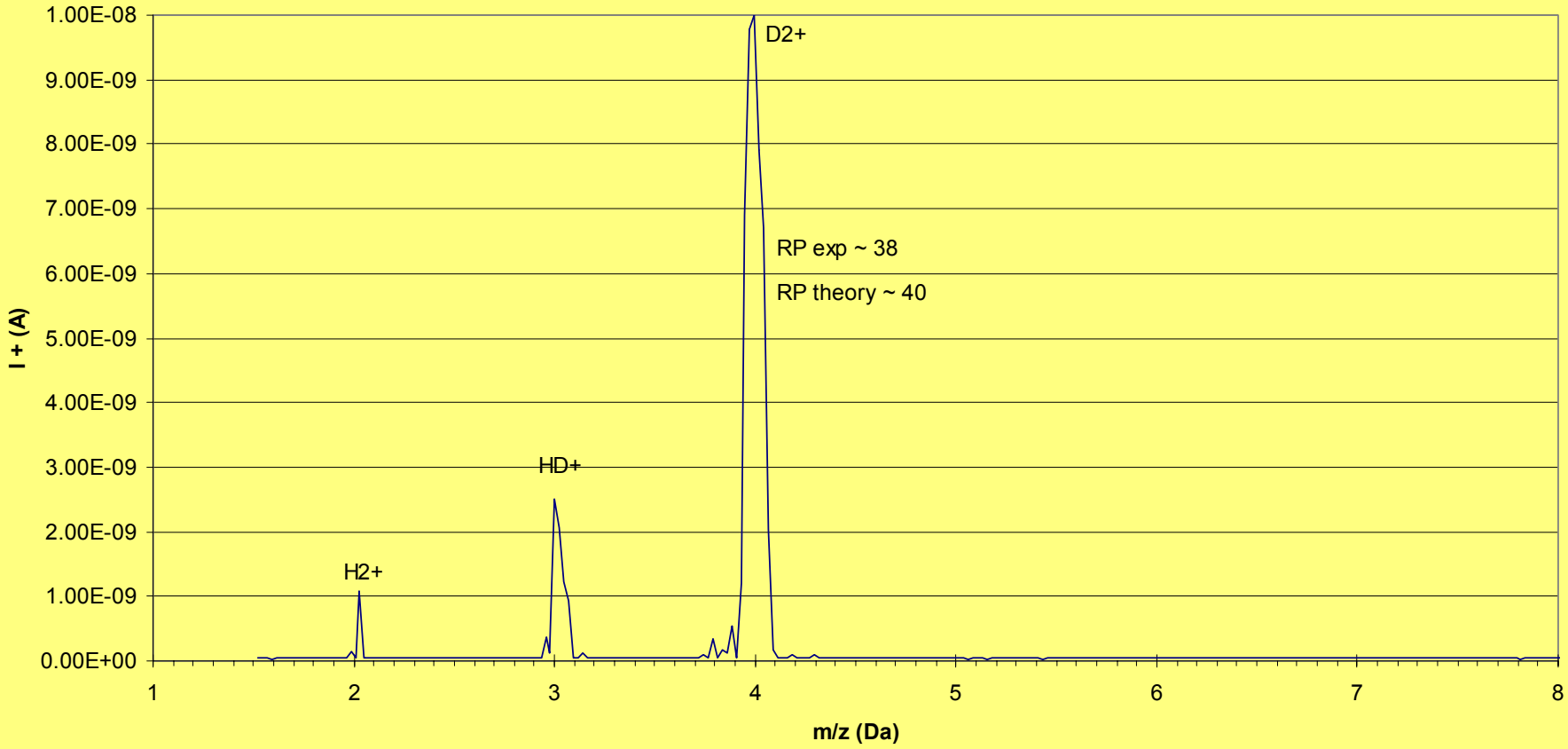
VASIMR Plasma Rocket being fired at VX-10 chamber.
ASPL-JSC/NASA


VX-10 Residual Gas + He pulse. No plasma
a-ILD 50 Test at ASPL - JSC/NASA
08/30/2001
1.20E-08
1.00E-08
8.00E-09
6.00E-09
4.00E-09
2.00E-09
0.00E+00
I+ (A)
He +
H2O+
0
5
10
15
20
25
30
35
40
45
M/Z (Da)

Plasma Monitoring at VX-10.
Unit: α-ILD 50, Propellant: He

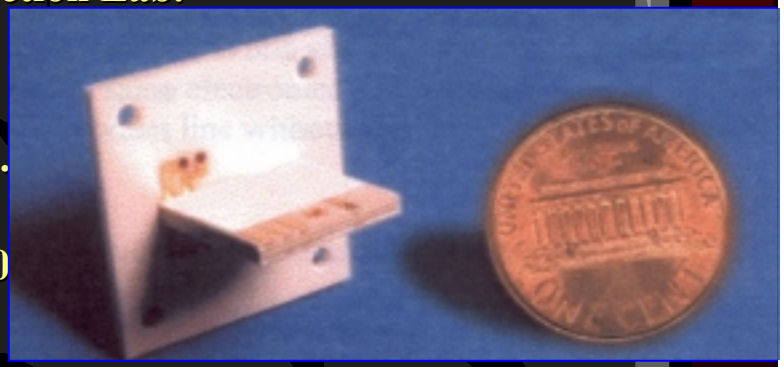


RESIDUAL GAS TEST ILD50
90% D2 / 10% H2 Bottle
MicroScale DF Mass Spectrometer r = 8 mm
Advanced Space Propulsion Lab - JSC/NASA
8/29/01



CONCLUSIONS and FUTURE WORK

- The α-ILD 50 unit was installed at VASIMR VX-10 test chamber for residual gas analysis and single ion monitoring
- The theoretical RP (40) was almost achieved over the mass range
- The designed Mass Range (1-50 Da) was verified. Capable of higher mass range with decreased performance
- Problems: Electronics was not reliable and ion signal to noise problems. Not good sensitivity. But it is not necessary for this particular application.
- New β-ILD 50 units are being tested at:
  - KSC in collaboration with the Hazardous Gas Detection Lab. (Dec 2001 and May 2002)
  - University of Costa Rica for volcanic monitoring
  - ASPL on the 2nd phase of the MMS-VASIMR proj.
  - Portable ILD 50 system for 8 months unattended He monitoring at Mammoth Lakes, CA (Aug 20



- New CDFMS based units :
  - 5mm EXB sector for He, H2 leak detection (Mass Sensors Inc.)
  - 30mm ExB sector for high mass range (300 amu) and high sensitivity (ppm) gas analysis (Mass Sensors Inc.)
  - TOTALLY MICROFABRICATED MASS SPECTROMETER (J. Diaz)