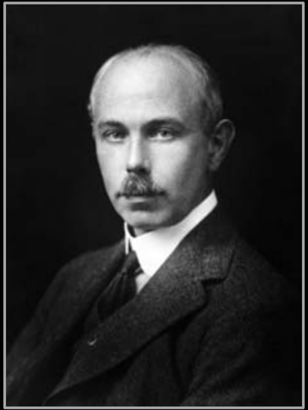
# Fast GC meets Fast Miniature MS

Christopher D. Brown
chris@908devices.com

11 October 2016

J.J. Thompson

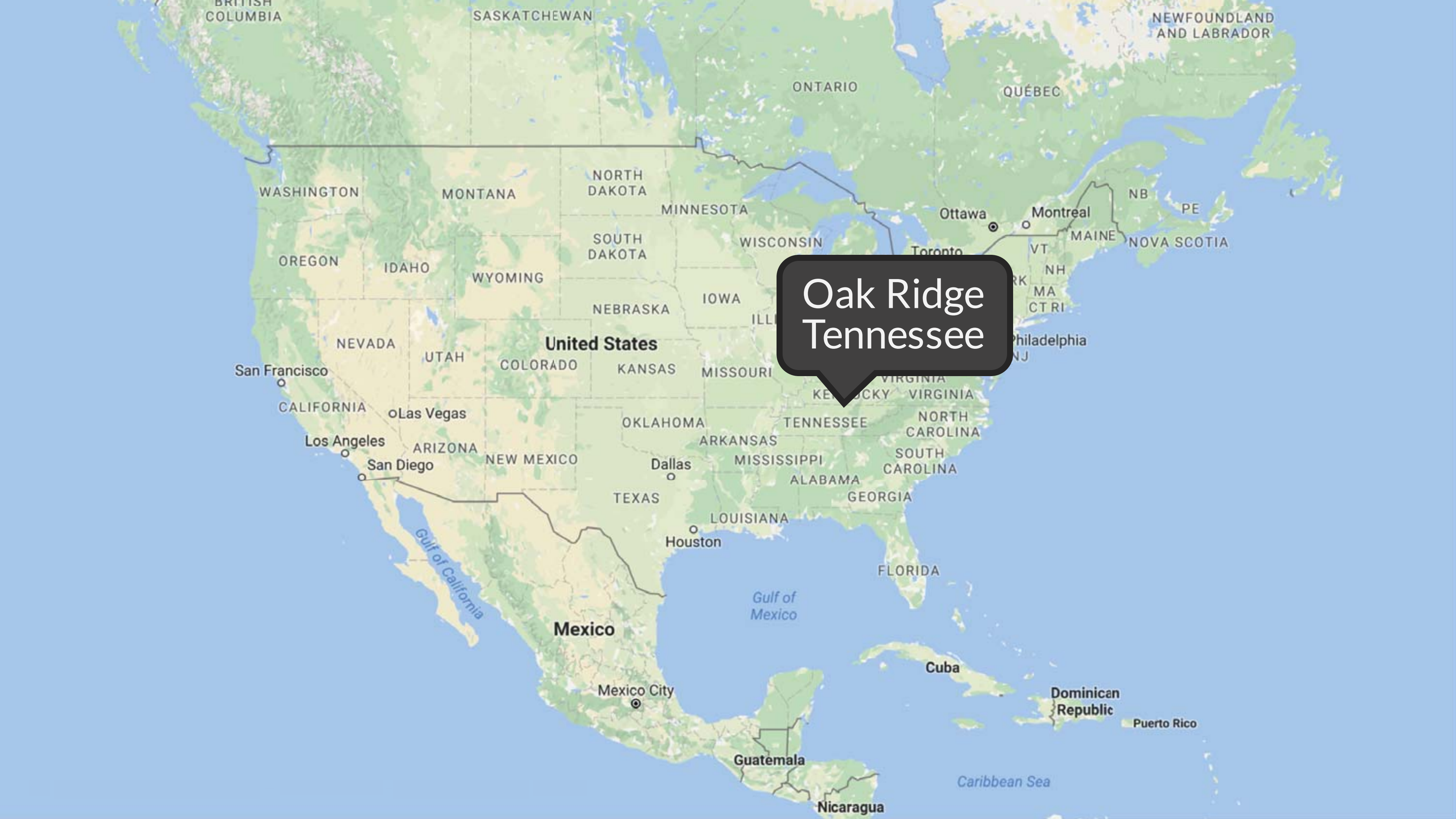


F. Aston

E. Lawrence

Westinghouse

**1913** **1919** **1931** **1943**


Oak Ridge
Tennessee
United States
Mexico
BRITISH COLUMBIA
SASKATCHEWAN
ONTARIO
QUÉBEC
NEWFOUNDLAND AND LABRADOR
WASHINGTON
MONTANA
NORTH DAKOTA
MINNESOTA
SOUTH DAKOTA
WISCONSIN
OREGON
IDAHO
WYOMING
IOWA
NEBRASKA
NEVADA
UTAH
COLORADO
KANSAS
MISSOURI
CALIFORNIA
OKLAHOMA
ARKANSAS
TENNESSEE
ARIZONA
NEW MEXICO
MISSISSIPPI
ALABAMA
GEORGIA
TEXAS
LOUISIANA
FLORIDA
VIRGINIA
NORTH CAROLINA
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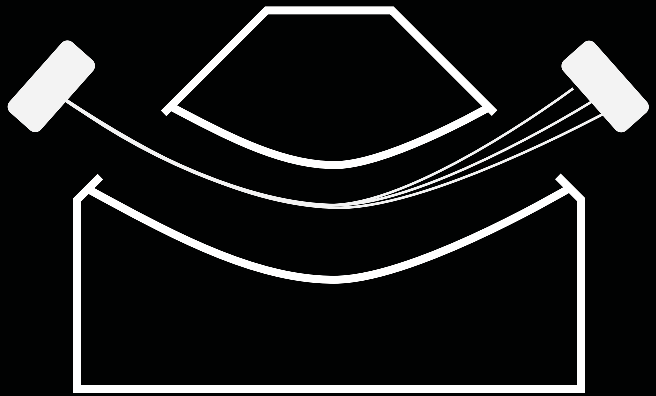
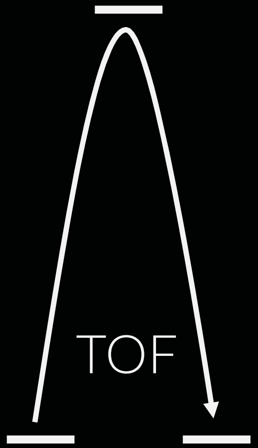
MAINE
VT
NH
MA
CT RI
NJ
NB
PE
NOVA SCOTIA
Ottawa
Montreal
Toronto
Philadelphia
San Francisco
Las Vegas
Los Angeles
San Diego
Dallas
Houston
Mexico City
Gulf of California
Gulf of Mexico
Cuba
Dominican Republic
Puerto Rico
Guatemala
Nicaragua
Caribbean Sea


Calutron MS at “Y-12” Plant
Oak Ridge, Tennessee
1943



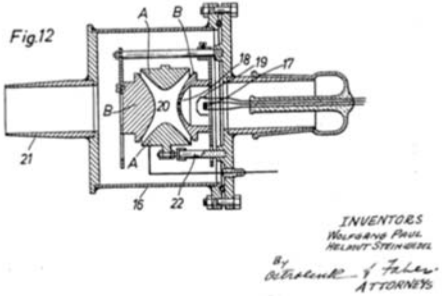


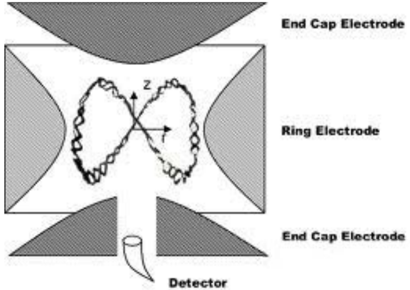

**1943**
ORNL
Mag Sector

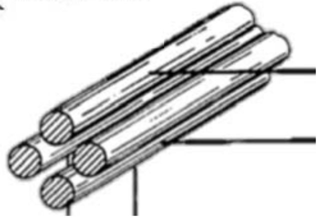
**1946**
ORNL
Time-of-Flight

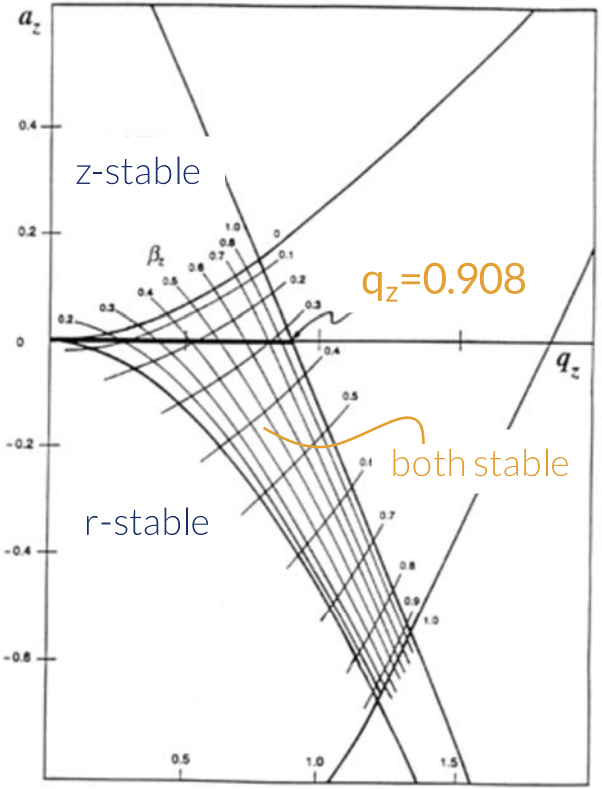
# Electrodynamic Ion Trap (1953)

Wolfgang Paul





Nobel Prizes and Laureates
Physics Prizes 1989
▼ About the Nobel Prize in Physics 1989
Summary
Press Release
Illustrated Information
Award Ceremony Speech
▶ Norman F. Ramsey
▶ Hans G. Dehmelt
▶ Wolfgang Paul
All Nobel Prizes in Physics
All Nobel Prizes in 1989

The Nobel Prize in Physics 1989
Norman F. Ramsey, Hans G. Dehmelt, Wolfgang Paul

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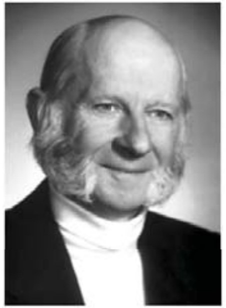
# The Nobel Prize in Physics 1989

**Norman F. Ramsey**
Prize share: 1/2



**Hans G. Dehmelt**
Prize share: 1/4

**Wolfgang Paul**
Prize share: 1/4

The Nobel Prize in Physics 1989 was divided, one half awarded to Norman F. Ramsey *"for the invention of the separated oscillatory fields method and its use in the hydrogen maser and other atomic*

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Watch the 2016 Nobel Prize Announcements
2016 NOBEL PRIZE ANNOUNCEMENTS
*Full schedule*
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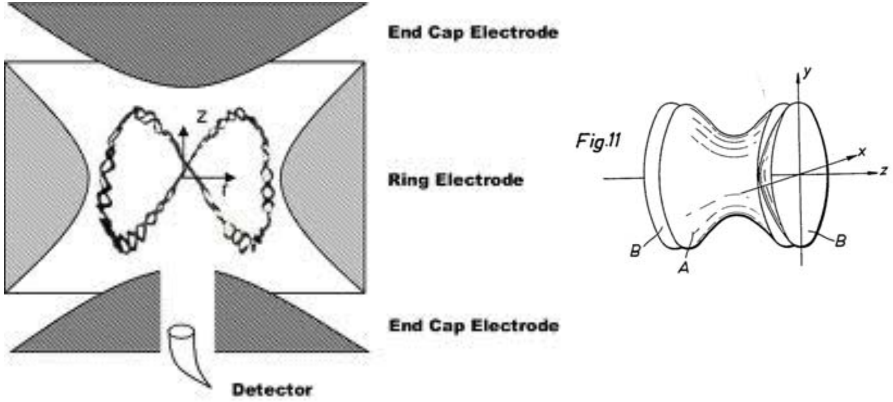
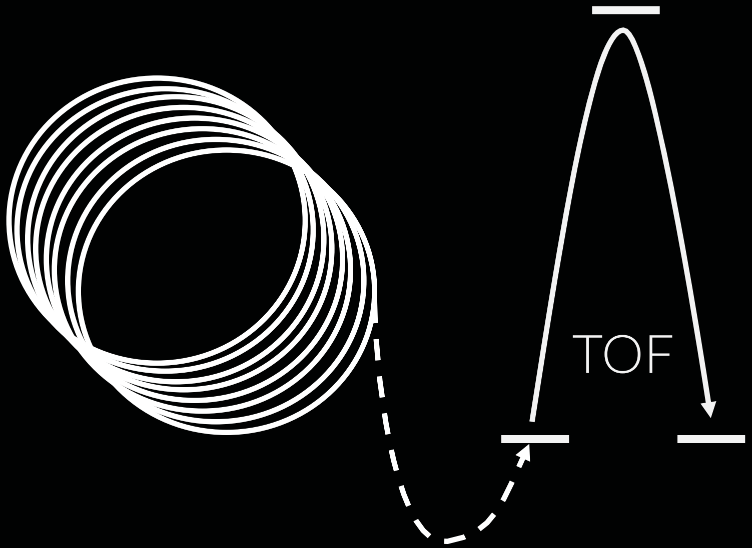
# Electrodynamic Ion Traps

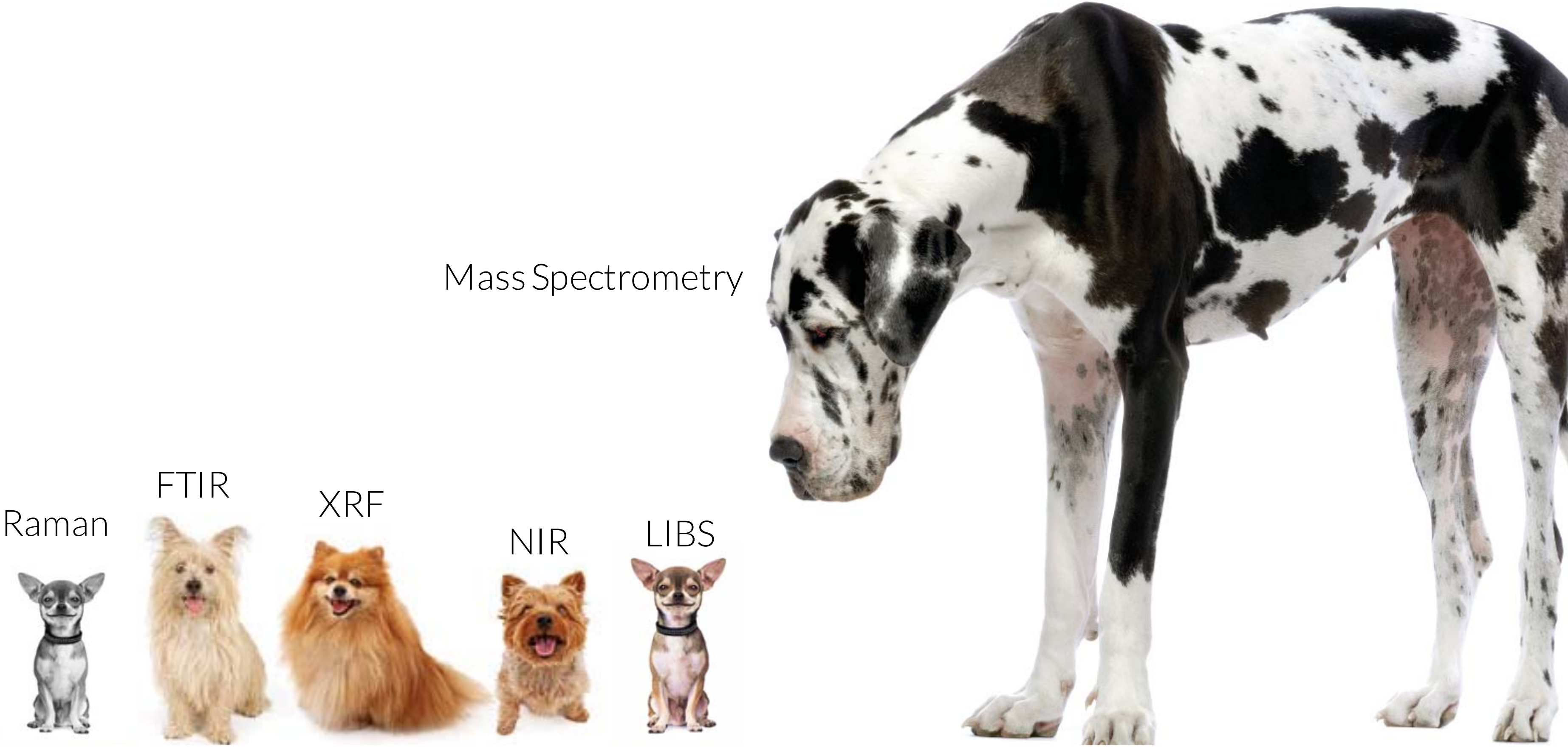
## Linear Quad Ion Trap



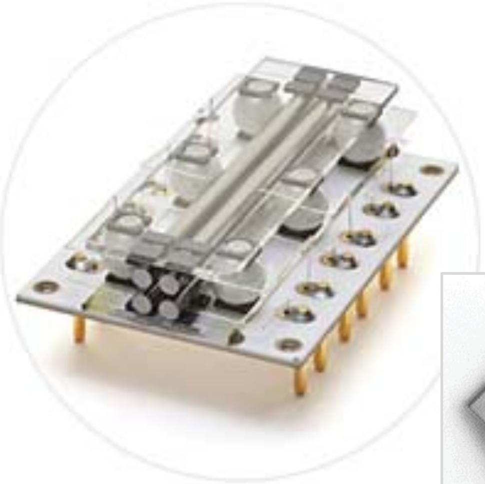

## Quadrupole Ion Trap (1983, Finnegan)

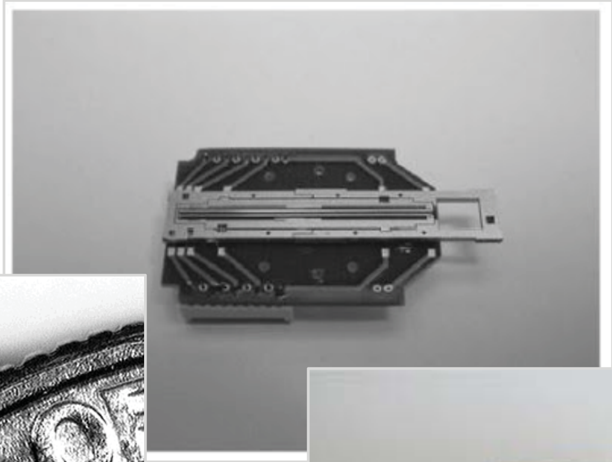


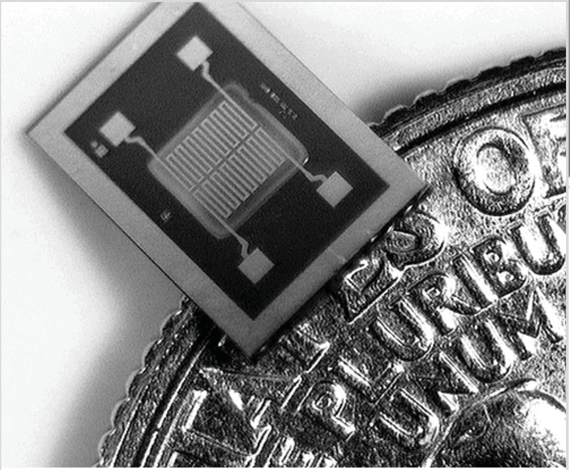

**1957**
DOW
GCMS


Mass Spectrometry
FTIR
Raman
XRF
NIR
LIBS

# Miniature Mass Spectrometers







1. Sitting on the edge of a quarter coin, this MEMS device promises big results for the detection and analysis of chemicals.

Mass Analyzer

Vacuum System

# Micro-scale Ion Traps

RAPID COMMUNICATIONS IN MASS SPECTROMETRY
*Rapid Commun. Mass Spectrom.* **13**, 50–53 (1999)

## Micro Ion Trap Mass Spectrometry

**Oleg Kornienko, Peter T. A. Reilly, William B. Whitten*, and J. Michael Ramsey,**
Oak Ridge National Laboratory, P.O. Box 2008 MS 6142, Oak Ridge, TN 37831-6142, USA

**Experiments to perform mass spectrometry with ion traps of submillimeter dimension are described. Several trap geometries amenable to microfabrication have been explored. In these experiments, vapor-phase molecules were ionized by a pulse from a frequency-quadrupled Nd:YAG laser. The ions were trapped and mass analyzed by manipulating the radiofrequency voltages on the trap electrodes. Effects of**

RAPID COMMUNICATIONS IN MASS SPECTROMETRY
*Rapid Commun. Mass Spectrom.* 2004; **18**: 1749–1752
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/rcm.1549

RCM

## High-pressure ion trap mass spectrometry

**William B. Whitten*, Peter T. A. Reilly and J. Michael Ramsey**
Oak Ridge National Laboratory, PO Box 2008 MS 6142, Oak Ridge, TN 37831-6142, USA

Received 14 April 2004; Revised 9 June 2004; Accepted 10 June 2004

**The effects of buffer gas pressure on ion trap stability, mass resolution/calibration, and choice of mass scanning are described. Pressure effects were treated phenomenologically by adding a drag term to the ion equations of motion. The resulting collisional damping enlarges the mass-dependent stability region but reduces the region in which mass-selective resonance ejection can be performed. The pressure effects can be reduced by increasing the frequency of the alternating quadrupole field. Copyright © 2004 John Wiley & Sons, Ltd.**

There is a growing interest in small portable mass spectrometers for environmental or personal exposure monitors. Conventional vacuum systems are often inappropriate, either because of size and weight, or because of mechanical considerations. Most of the small pumps that are com-

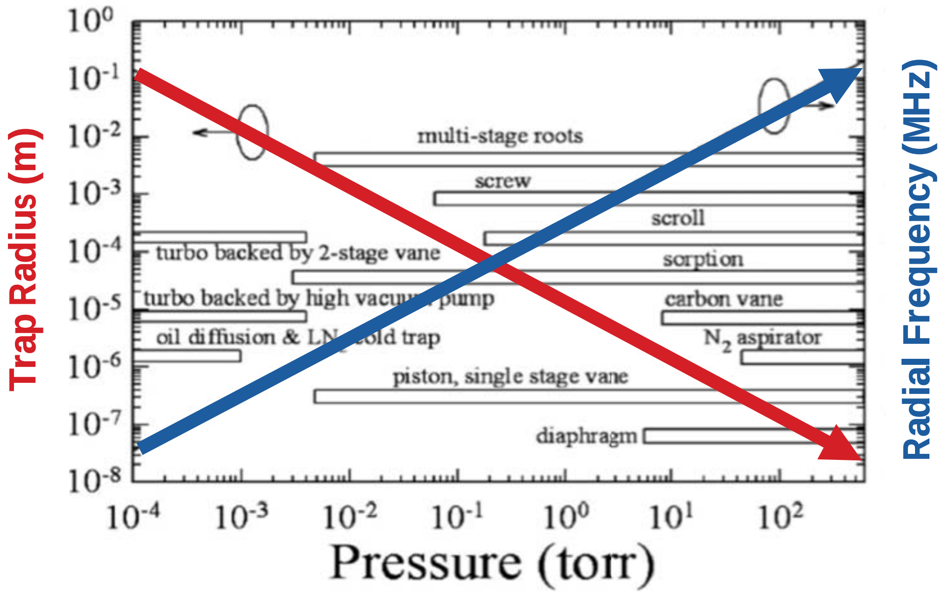
and solutions described. We extend these results to more substantial buffer gas pressures in the present investigation.

The effect of buffer gas pressure on mass resolution for resonance ejection mass spectrometry at various scan rates was discussed by Goeringer *et al.*[3] They showed that, at non-

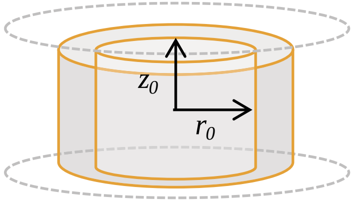
Mike Ramsey – UNC chemistry

Oak Ridge National Laboratory

# Trade-offs in Ion Trap Operation




**reduced size, improved ruggedness**




$\boldsymbol{\Omega}$ radio frequency Hz

$\boldsymbol{V}_{\max}$ operating peak voltage

$\boldsymbol{q}_{\max}$ 0.908

## Upper Mass Limit

$$\left(\frac{m}{e}\right)_{\max} = \frac{8V_{\max}}{q_{\max}\Omega^2(r_0^2 + 2z_0^2)}$$

## Resolution

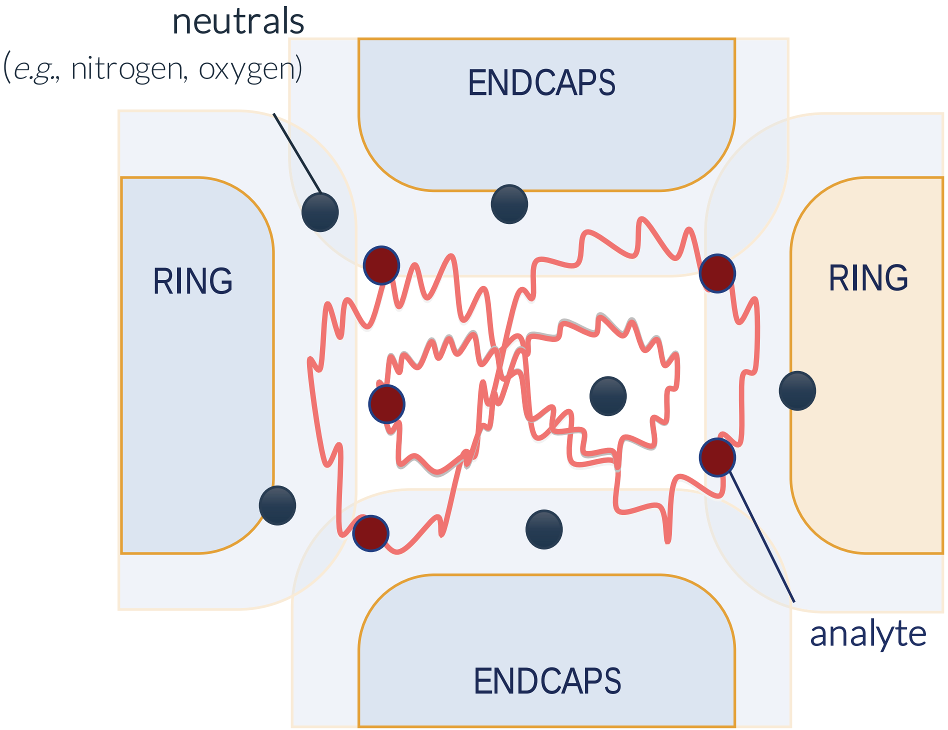
$$\frac{\Delta m}{m} \propto \frac{2\sqrt{3}c}{\Omega}$$

## Well-depth

$$D_r = \frac{eV^2}{4mr_0^2\Omega^2} \geq \frac{k_B T}{e}$$

Pau (Ramsey) *et al.*, Microfabricated quadrupole ion trap for mass spectrometer applications, Phys. Rev. Lett. 96 (2006) 120801

908devices // Oscillations in the ion trap




Mass Spec is typically done in deep vacuum, because this reduces the number of collisions with neutrals and

1. Improves the MS resolution
2. Reduces collisional losses

Mean-free path: average distance a particle travels between collisions with other particles.

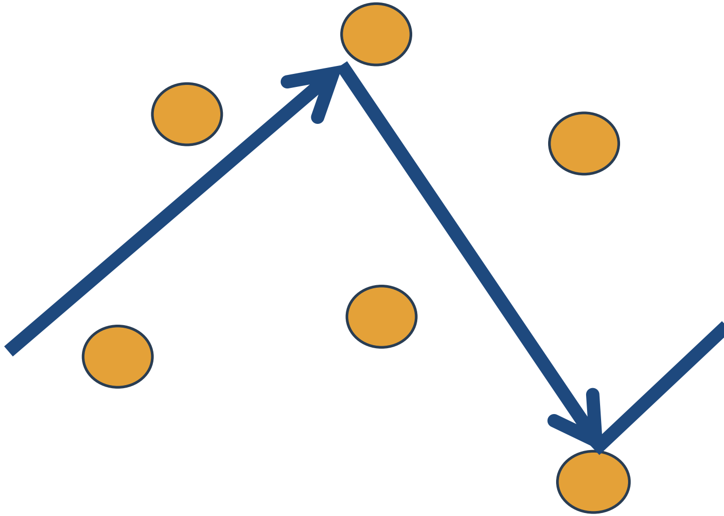
Atmospheric pressure (760 torr): ~ 100 nm

Low vacuum 1 torr: ~1 mm

Medium vacuum 1e-3 torr: ~ 10 cm

High vacuum 1e-6 torr: 100 m

Ultra high vacuum 1 e-12 torr: 100 km



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Low vacuum 1 torr: ~1 mm

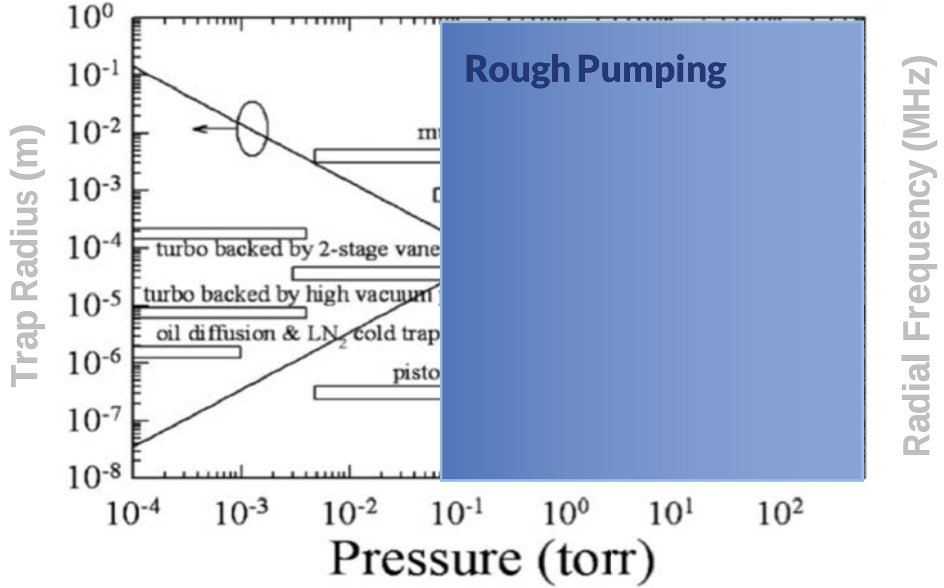
**Medium vacuum 1e-3 torr: ~ 10 cm**

**High vacuum 1e-6 torr: 100 m**

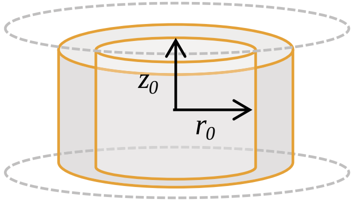
Ultra high vacuum 1 e-12 torr: 100 km


laboratory scale 3D ion trap

# 908devices // Trade-offs in Ion Trap Operation




reduced size, improved ruggedness




$\boldsymbol{\Omega}$ radio frequency Hz

$\boldsymbol{V}_{\max}$ operating peak voltage

$\boldsymbol{q}_{\max}$ 0.908

**Upper Mass Limit**

$$\left(\frac{m}{e}\right)_{\max} = \frac{8V_{\max}}{q_{\max}\Omega^2(r_0^2 + 2z_0^2)}$$

**Resolution**

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**Well-depth**

$$D_r = \frac{eV^2}{4mr_0^2\Omega^2} \geq \frac{k_B T}{e}$$

Pau (Ramsey) *et al.*, Microfabricated quadrupole ion trap for mass spectrometer applications, Phys. Rev. Lett. 96 (2006) 120801

## 908devices // Mean-free path vs. pressure

Mean-free path: average distance a particle travels between collisions with other particles.

Atmospheric pressure (760 torr):~ 100 nm

Low vacuum 1 torr: ~1 mm

Medium vacuum 1e-3 torr: ~ 10 cm

High vacuum 1e-6 torr: 100 m

Ultra high vacuum 1 e-12 torr: 100 km


laboratory scale 3D ion trap

# 908devices // Strong Government Support & Interest

Defense Advanced Research Projects Agency

**$10M**

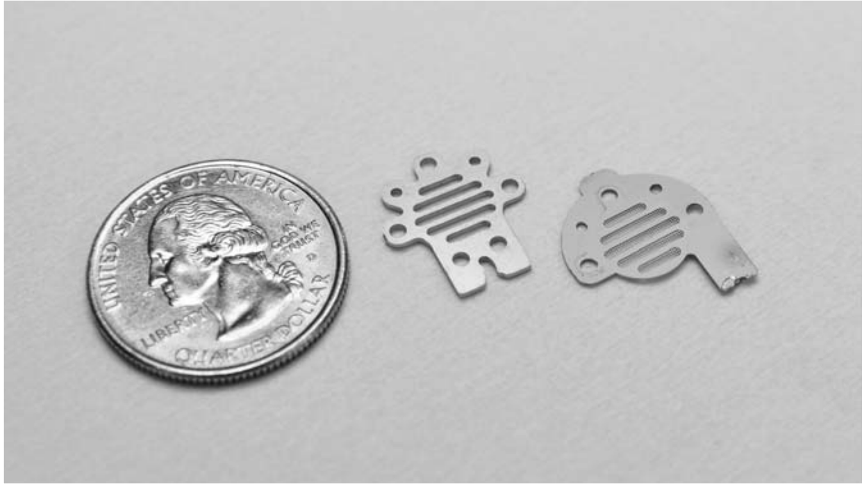
Defense Threat Reduction Agency

**$15M**

908devices

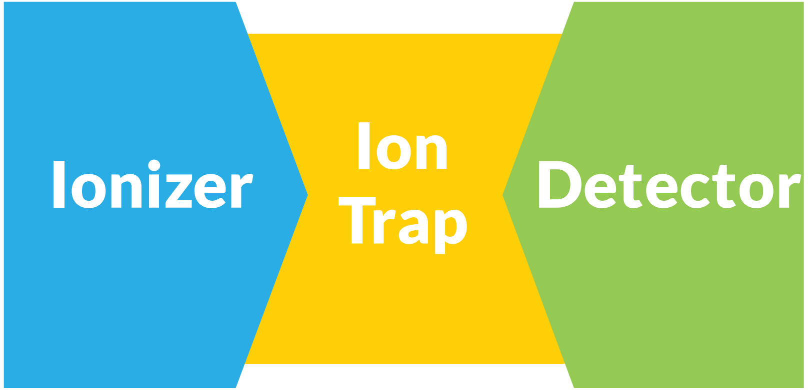
**$20M**

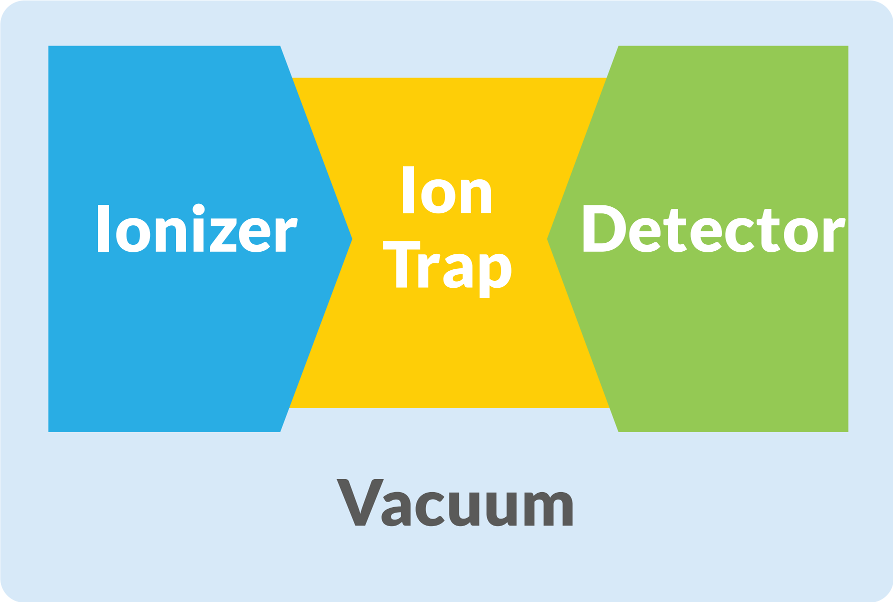
**Ion Trap**

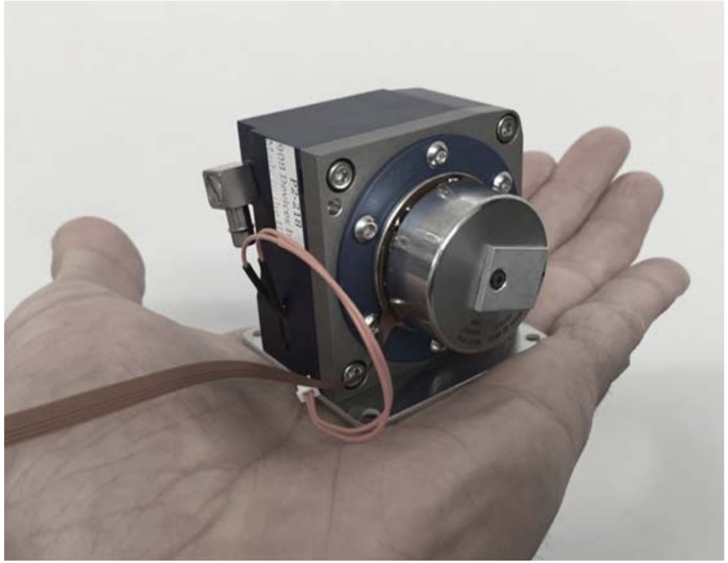



Stretched Length Micro-Ion Trap

# Building Blocks

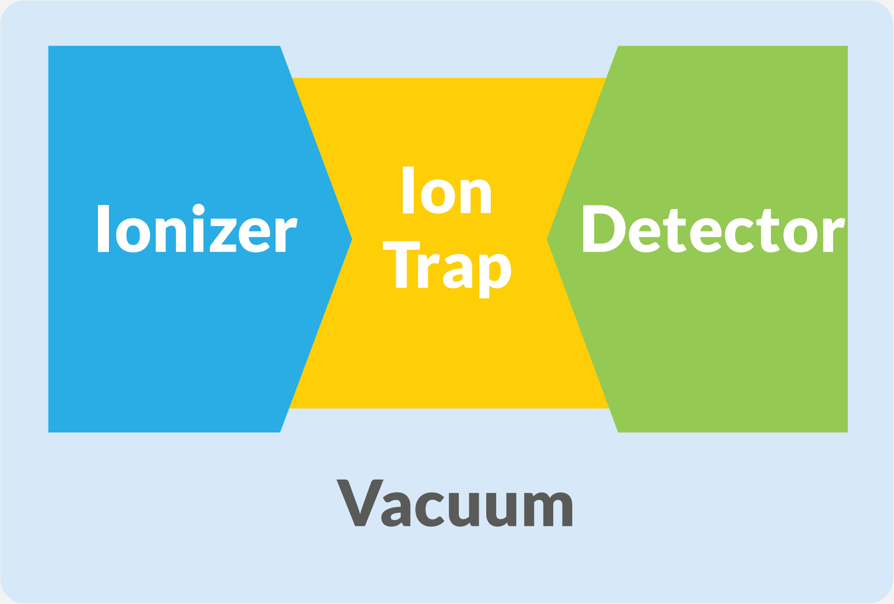


Custom Zero Maintenance Multistage Scroll

# Building Blocks




MS Electronics

Operating Software

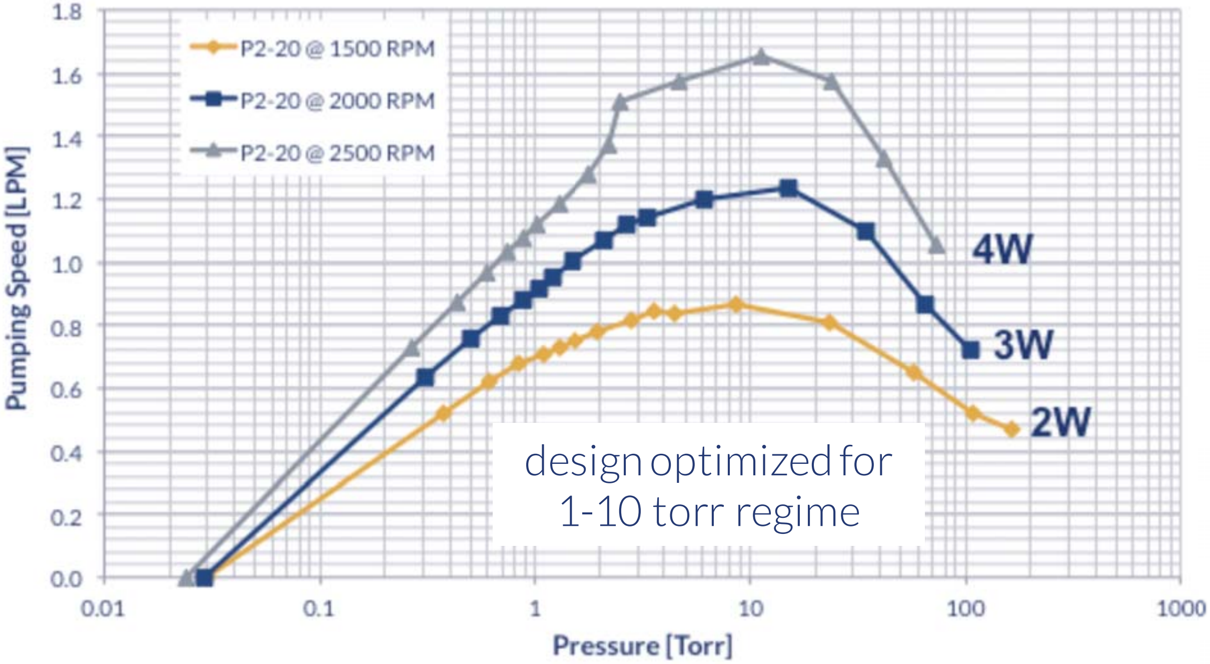
Signal Processing, Informatics

Mechanical Design

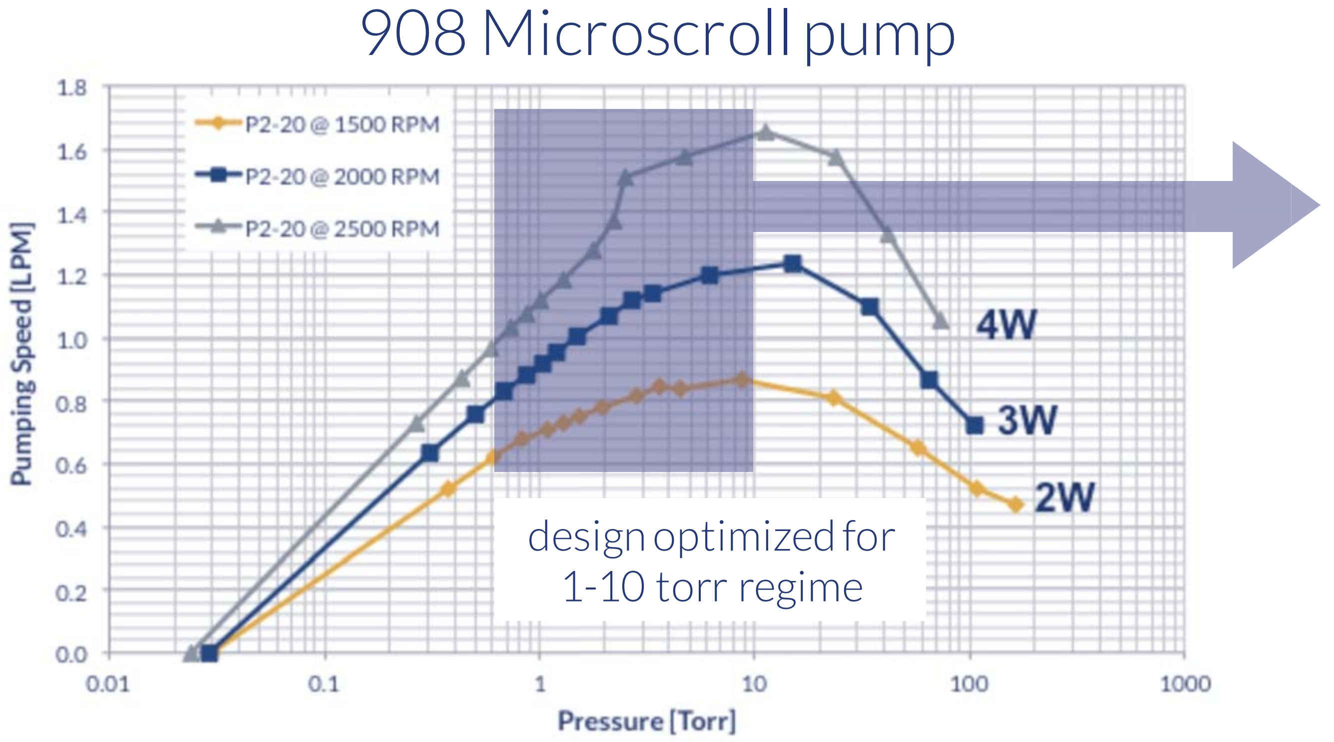

4”
321

# Small, power efficient vacuum pump

## 908 Microscroll pump



# Small, power efficient vacuum pump

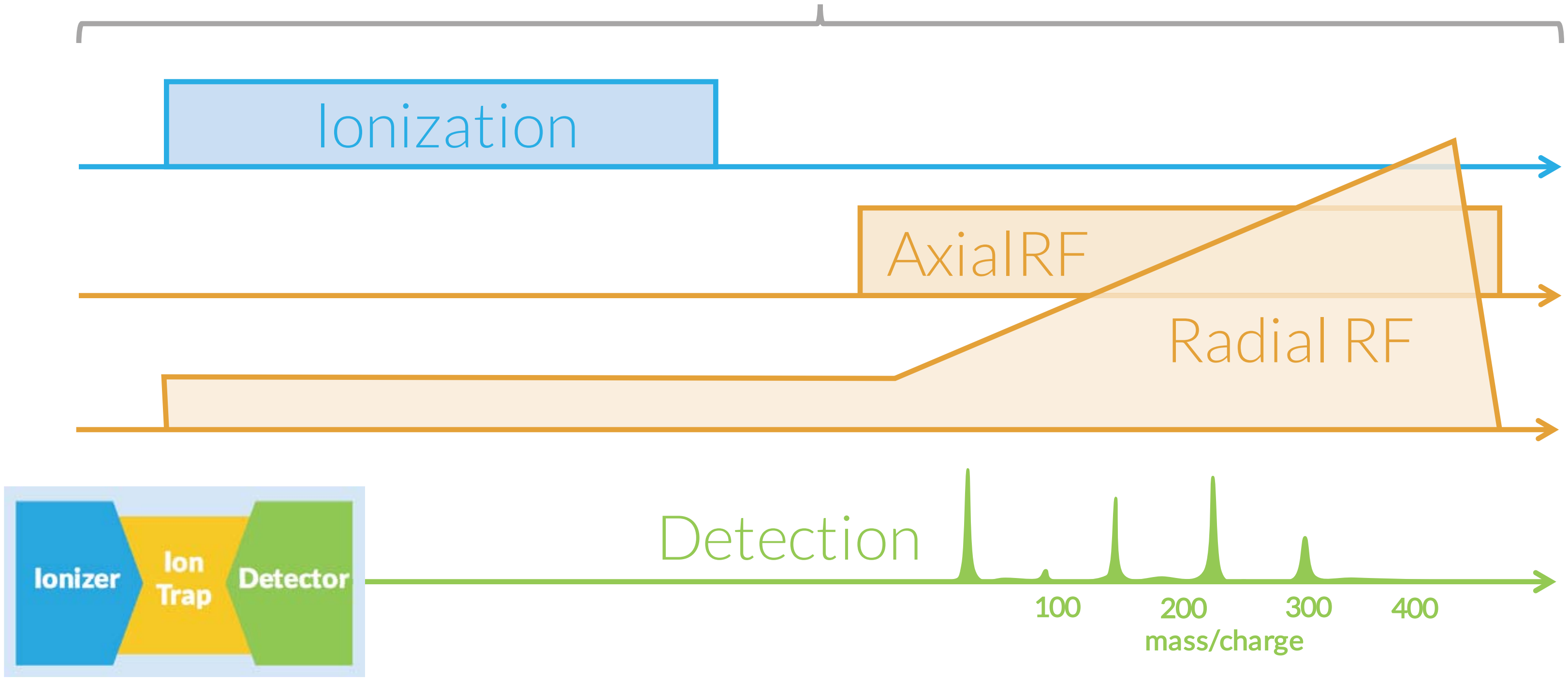



MS inlet flow supports 1-10 mL/min of continuous flow.

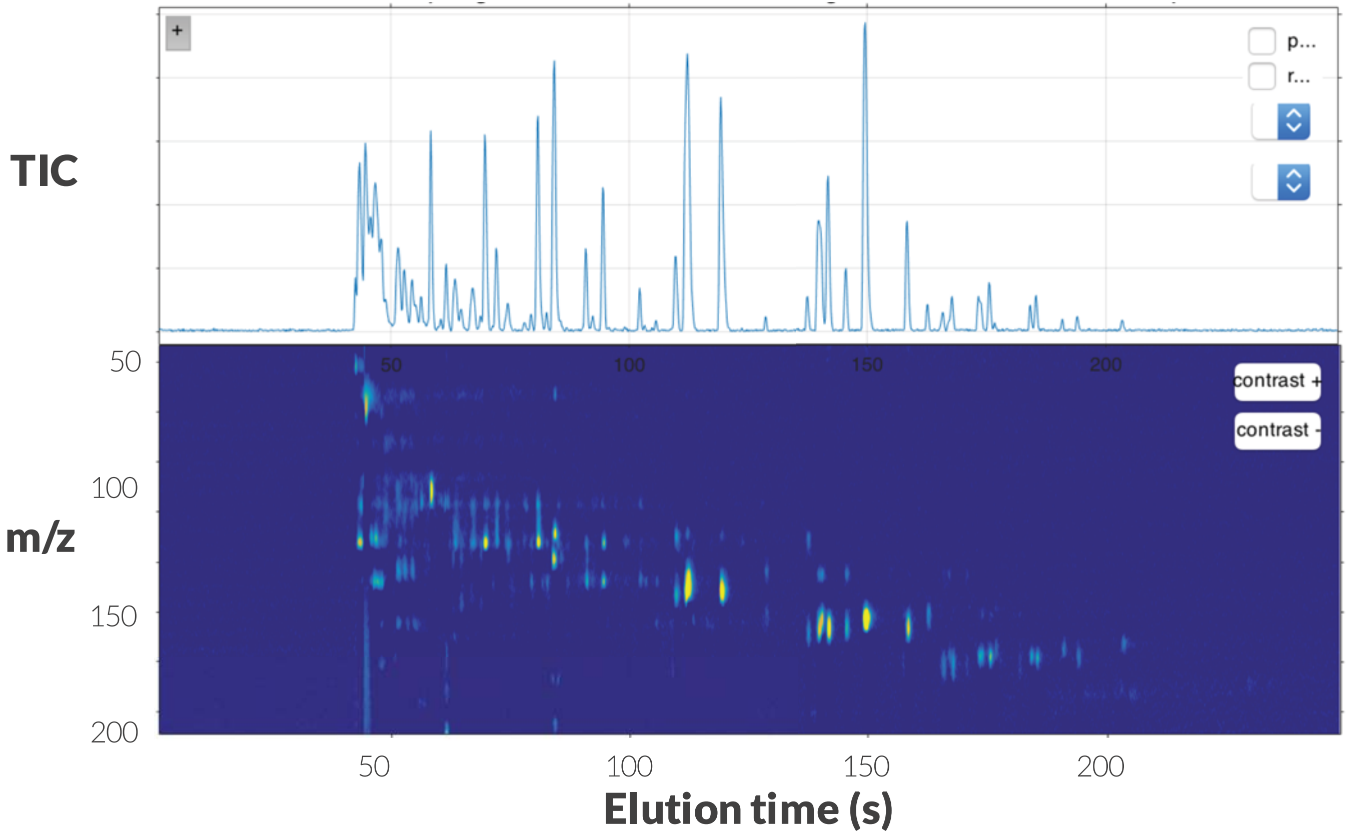
**Excellent match for capillary GC flows.**

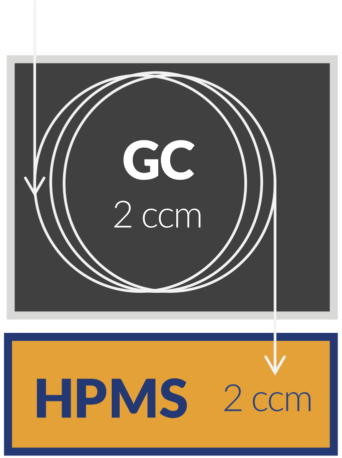
# Duration: 4-100 ms

(10 to 250 scans/second 15-450 m/z)

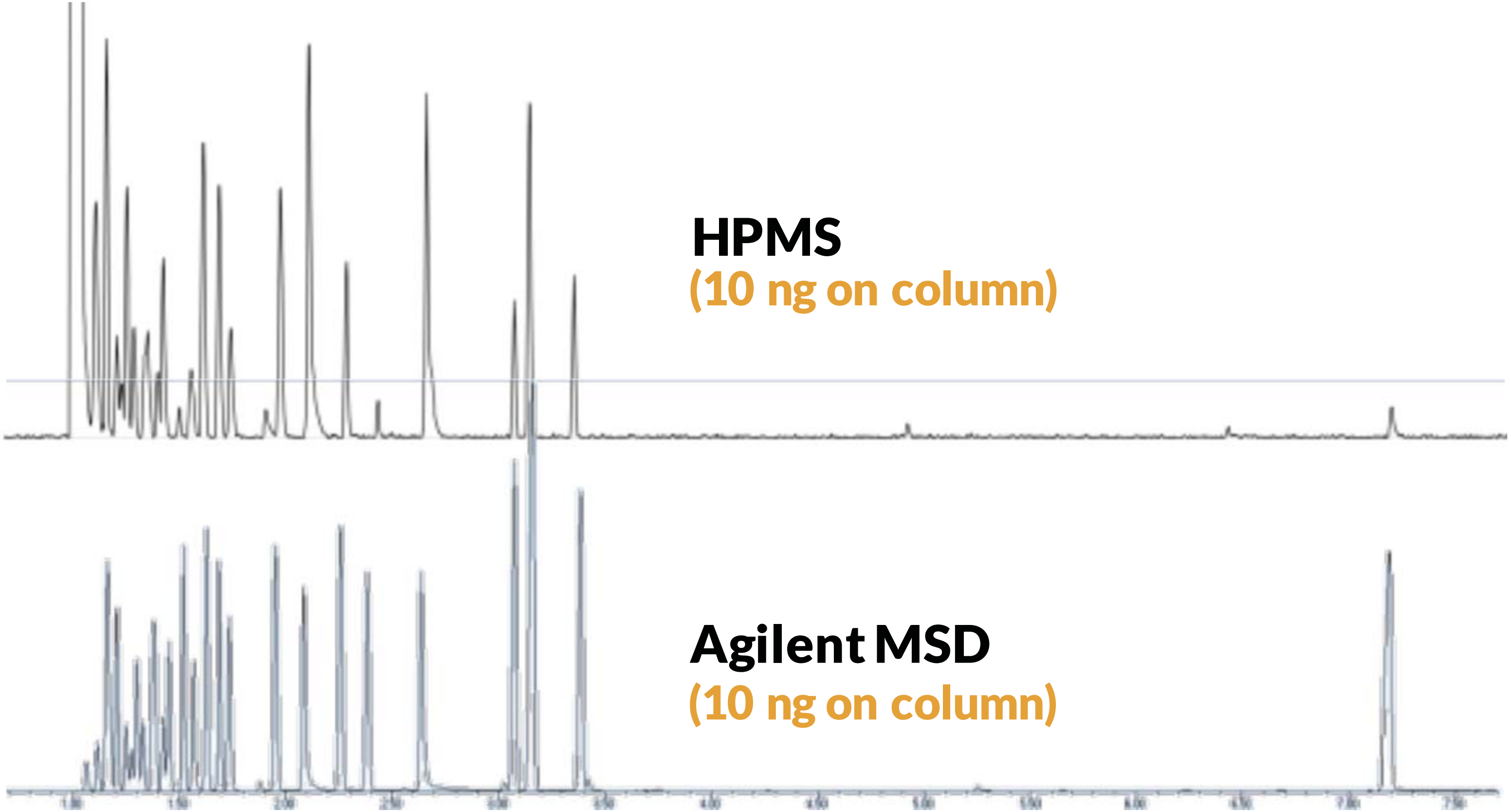


# 908devices // Gasoline via GC-miniMS

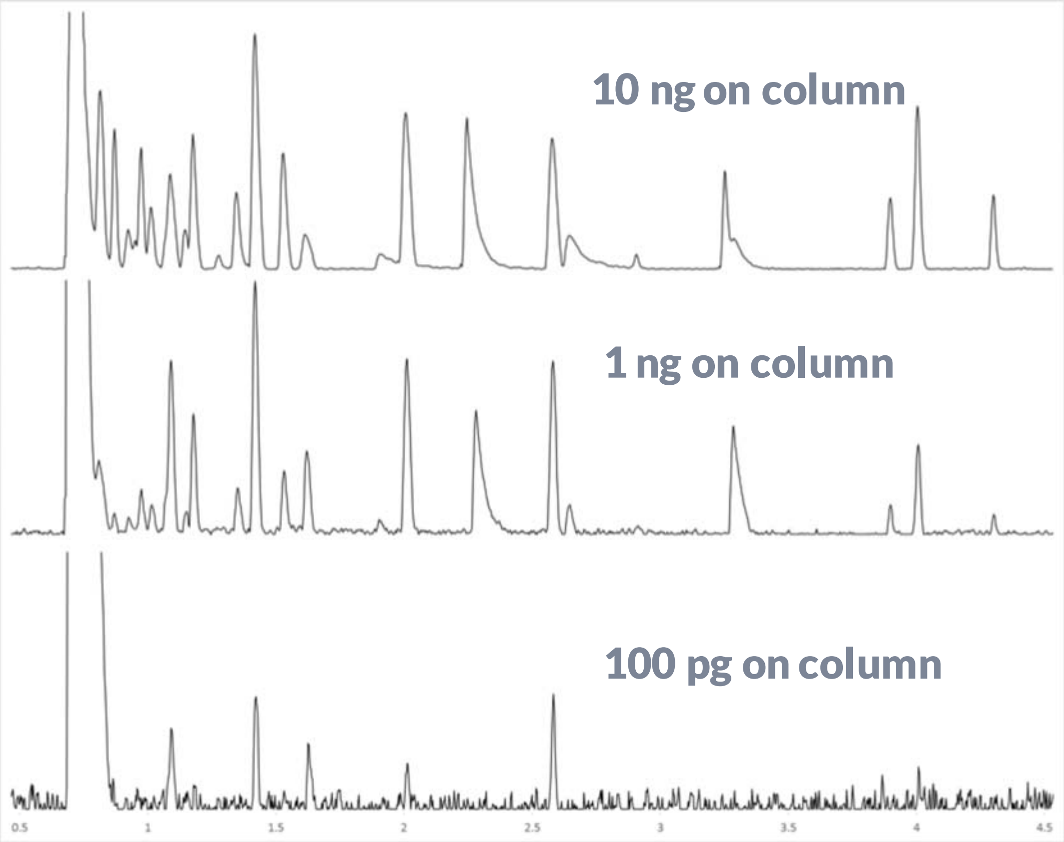


908devices // HPMS vs. Agilent Single Quad



# 908devices // Serial Dilutions of 8015C mix



# Ballistic GC (single or dual column) + MS + FID/TCD helium/hydrogen/air carrier


G908


TIC
Peak Integration – TIC
Peak Identification – TIC

# Thanks!

chris@908devices.com
978.979.5413

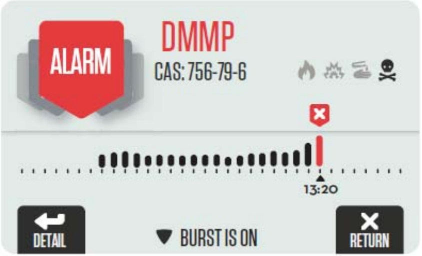
Products and Prototypes are protected by US and international patents, including US 6,469,298; JP 2001-5,252,000; UK 1,218,921; DE 1,218,921; US 7,838,820; US 6,822,225; JP 4,522,866 B2; EPO 3,816,115.4; US 6,933498; US 8,525,111 B1; US 8,878,127; additional patents pending


# M 908

**Threat Detection Focus w/ Minimum SWAP**

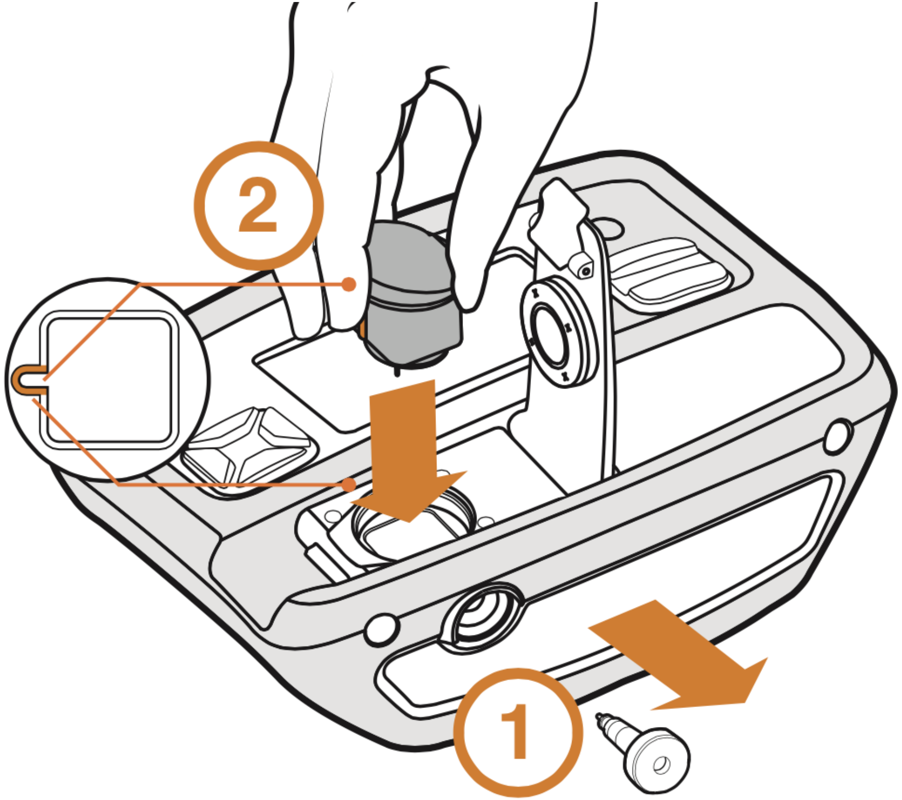
Vapor / Thermal desorption
>5 hour battery life
30-60 second startup
4 pounds
Mass range  60 to >450
No helium burden

# M908 – worlds first handheld MS

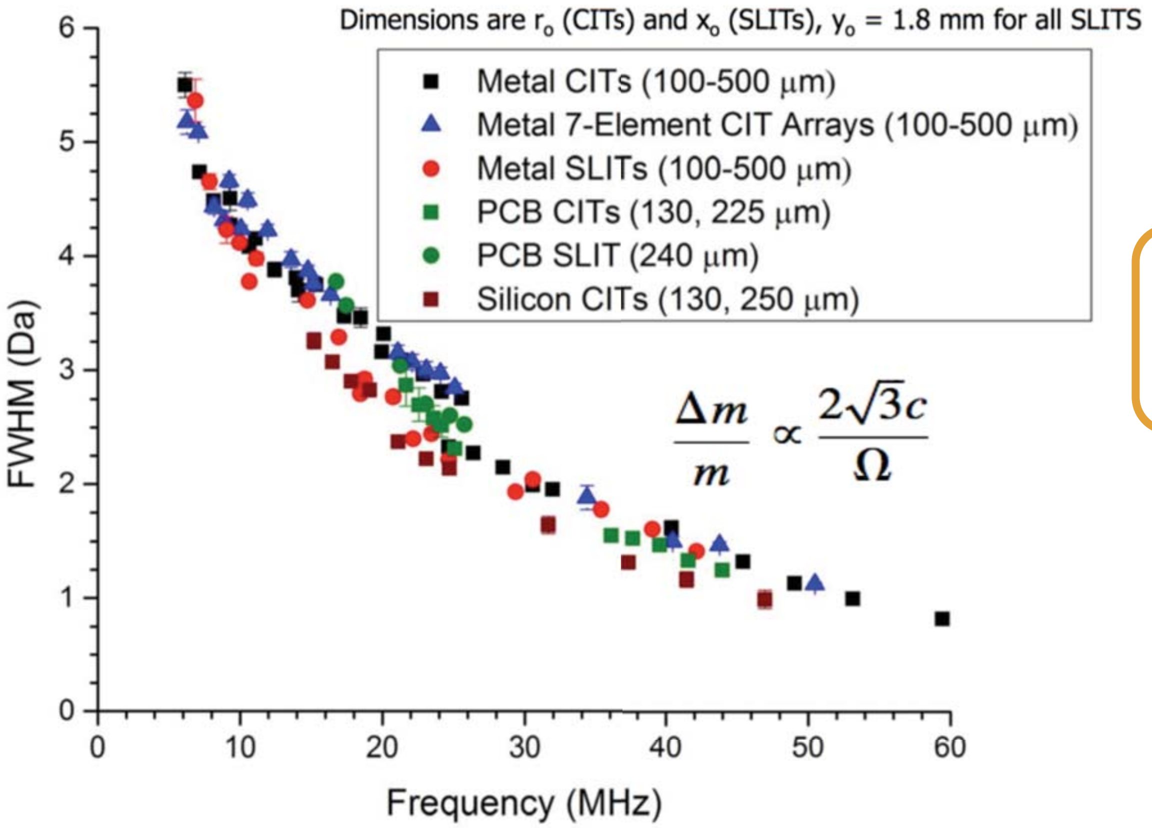





# Swappable 'cores'

# 908devices // Resolution v. Radial Frequency - AIR




Xylene 106 Da FWHM
MS pressure **1 torr** (air)

Blakeman & Ramsey, *in preparation*