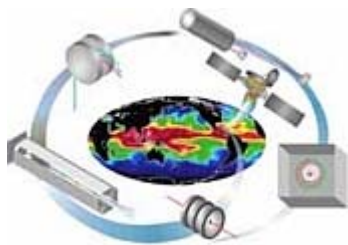


A Transportable Double-Focusing Mass Spectrometer

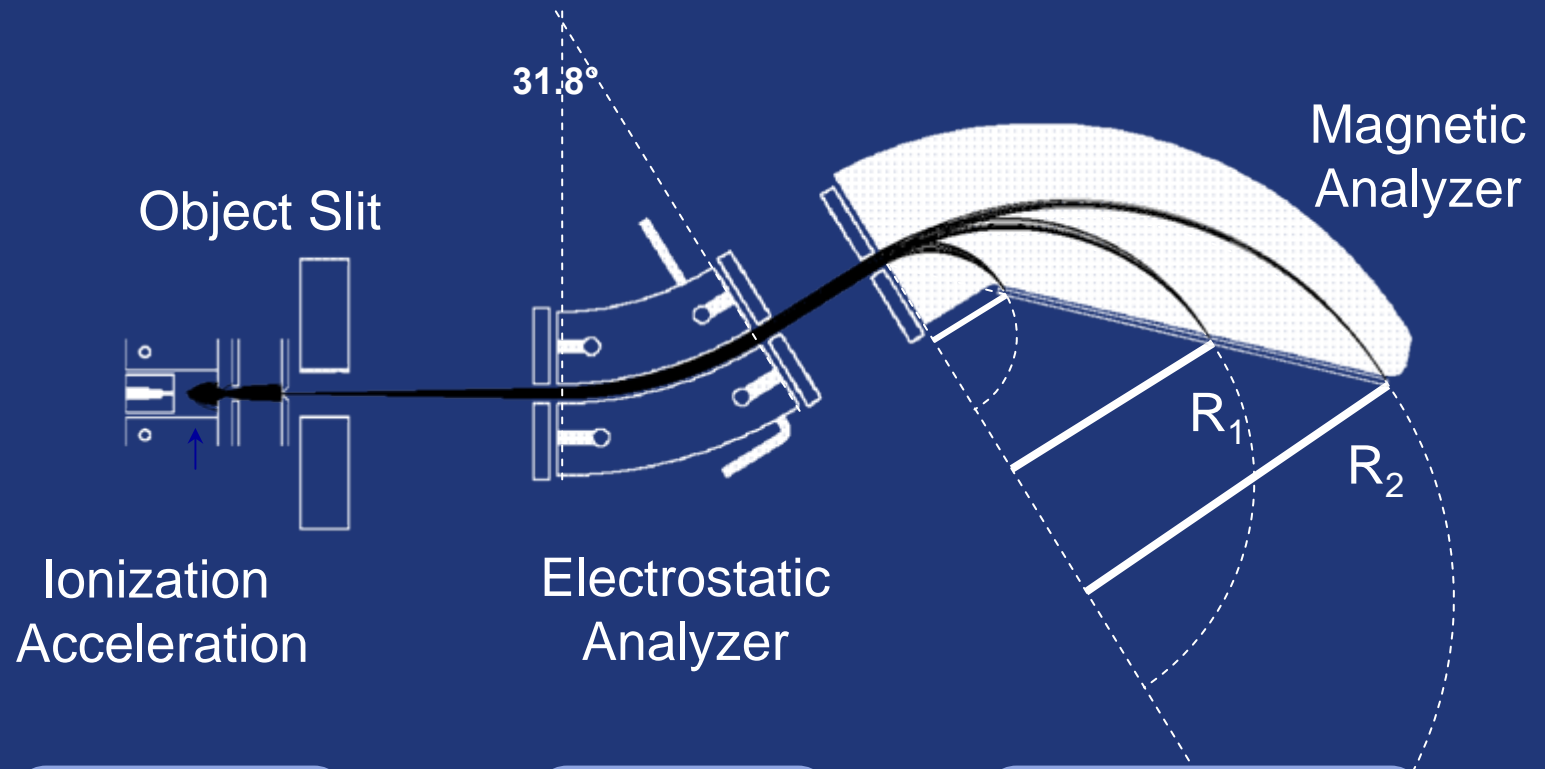
Gottfried Kibelka, Scott Kassan,
Omar Hadjar, Chad Cameron, Scott Shill



7th HEMS Workshop, Santa Barbara, CA
September 21–24, 2009



Mass Spectrometer – Mattauch-Herzog Geometry

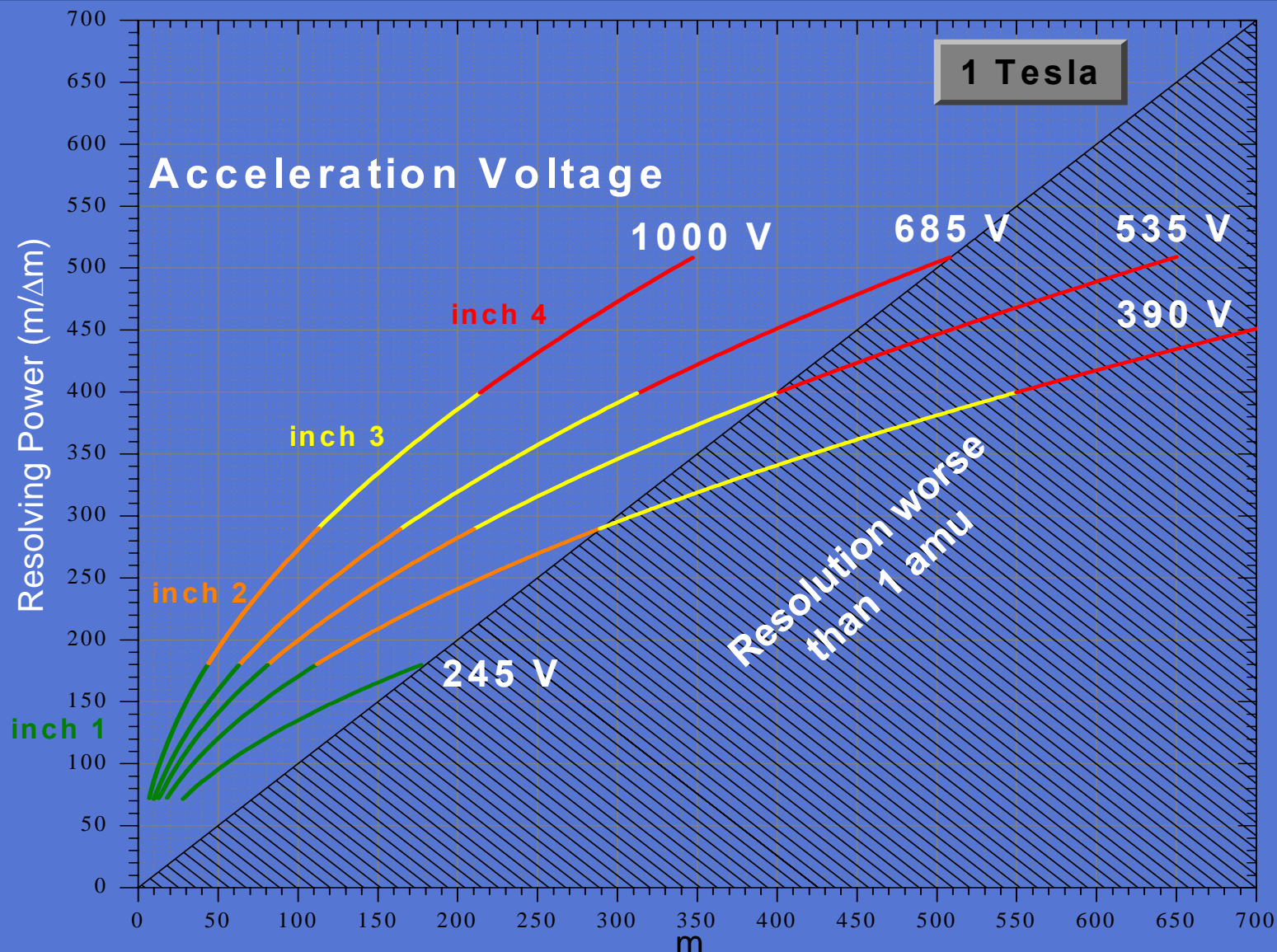


$$qeV = \frac{mv^2}{2}$$

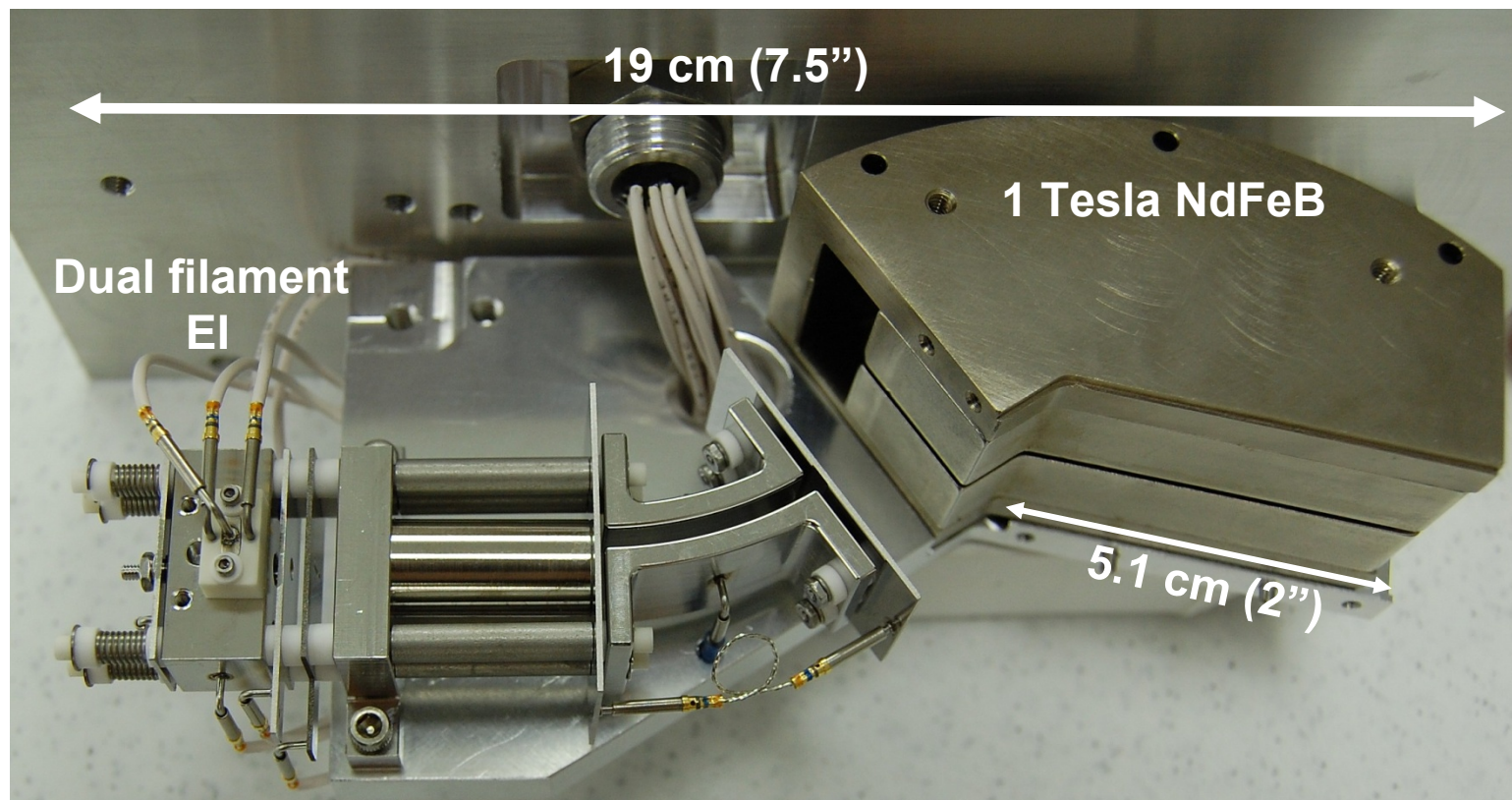
$$r_e = \frac{2V}{E}$$

$$R = \frac{1}{B} \sqrt{\frac{2mV}{q}}$$

Size vs. Resolution vs. Mass Range

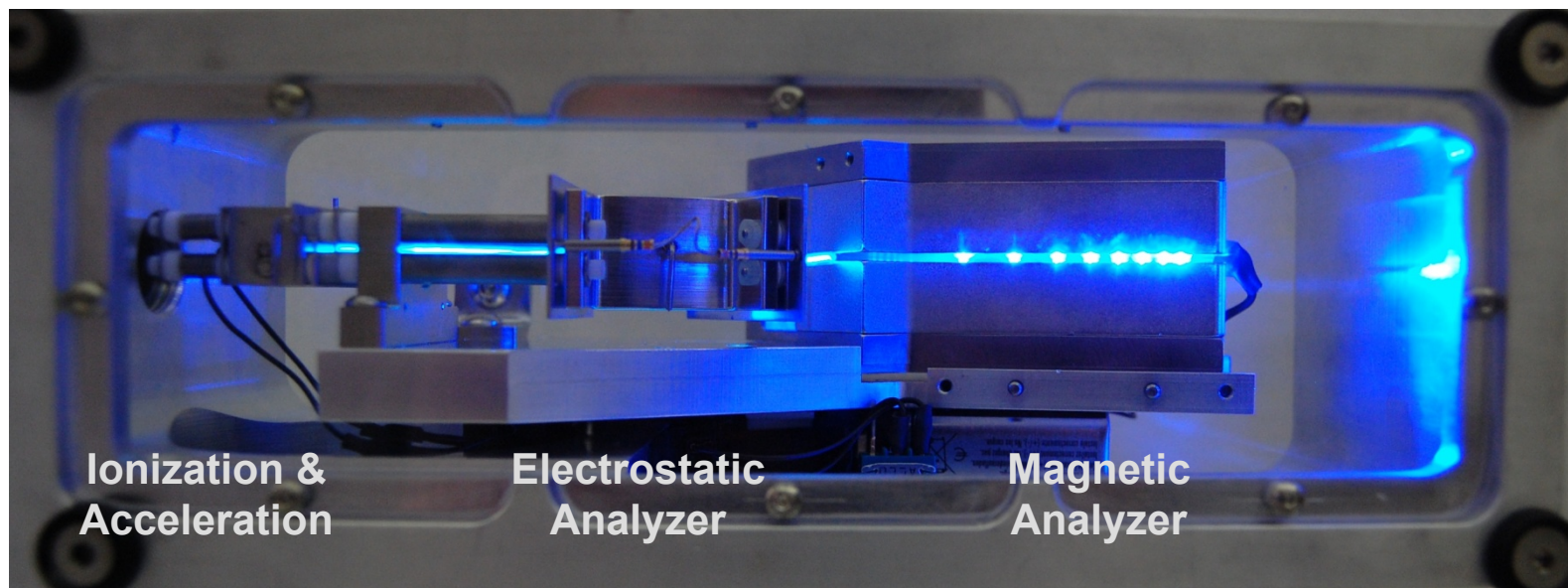


Ion-Camera – Transportable



- Magnetic Field Strength: 1 Tesla
- Acceleration adjustable: 350 V – 1000 V
- Mass range between 6 and 250 amu

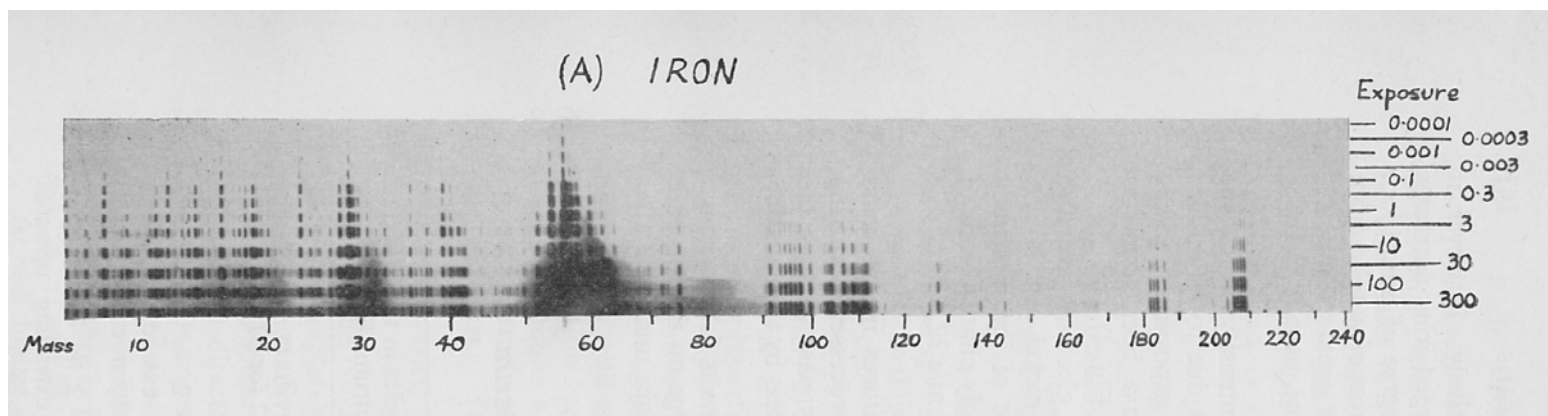
Mattauch-Herzog – Non Scanning



- Double-focusing geometry
- Ions of all m/z focused onto focal plane
- Ions created together are detected together
- Robust against environmental disturbance
- No radio frequencies, less EMC, less controls
- Highly reproducible, abundance stability

Ion-Camera - Array Detector

- Photographic Plate (Historic)
- Strip Charge Detector Array (SCDA)
- Faraday Cup Detector Array (FCDA)¹
- Electro-Optical Ion Detector (EOID)²
- Complementary Metal-Oxide Semiconductor (CMOS)³
- Charge-Coupled Device (CCD)⁴

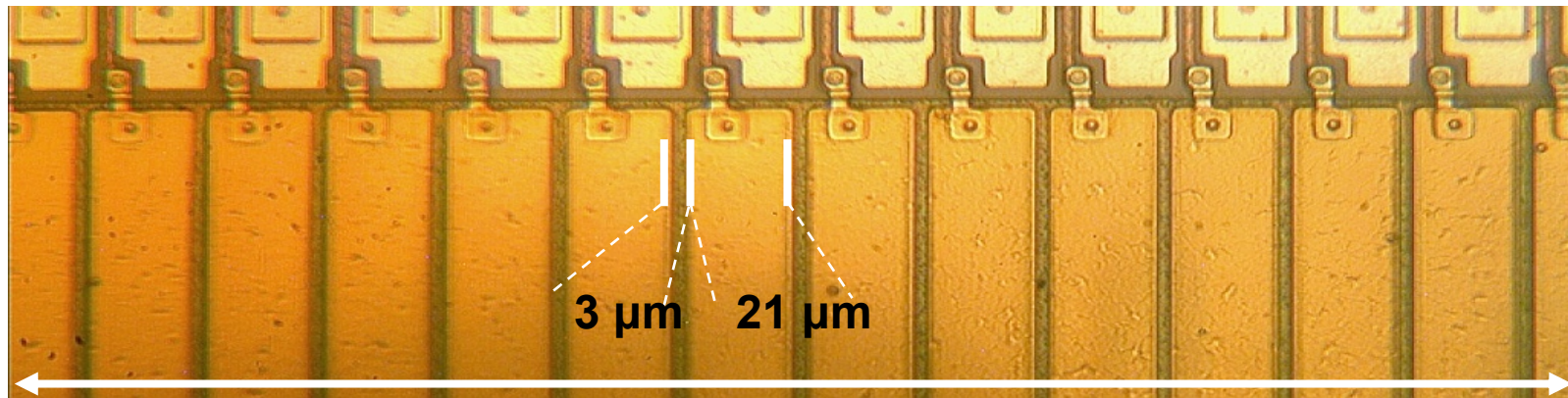


Advances in Mass Spectrometry, Conference Proceedings, 24th-26th September, London 1958, J.D. Waldron (ed.)

- 1) Scheidemann, A., et al ; J. of Vac. Sci. Technology, 20 (2002) 597
- 2) Giffin, C. E., et al.; Int. J. Mass Spectrom. 11 (1973) 409
- 3) Birkinshaw, K. et al.; Int. J. Mass Spectrom. 132 (1994) 193
Schilling, G. et al.; Anal. Chem. 78, (2006) 4319
- 4) Fuerstenau, S., et al.; Int. J. Mass Spectrom. 215 (2002) 101

Charge-Coupled Device - Ion-CCD

- Linear CCD with pitch of $24\text{ }\mu\text{m}$ (87.5% active area)
- Integration time analog to exposure time
- Integration from $80\text{ }\mu\text{s}$ to 5 s
- Readout time 2.6 ms
- 350 frames per second

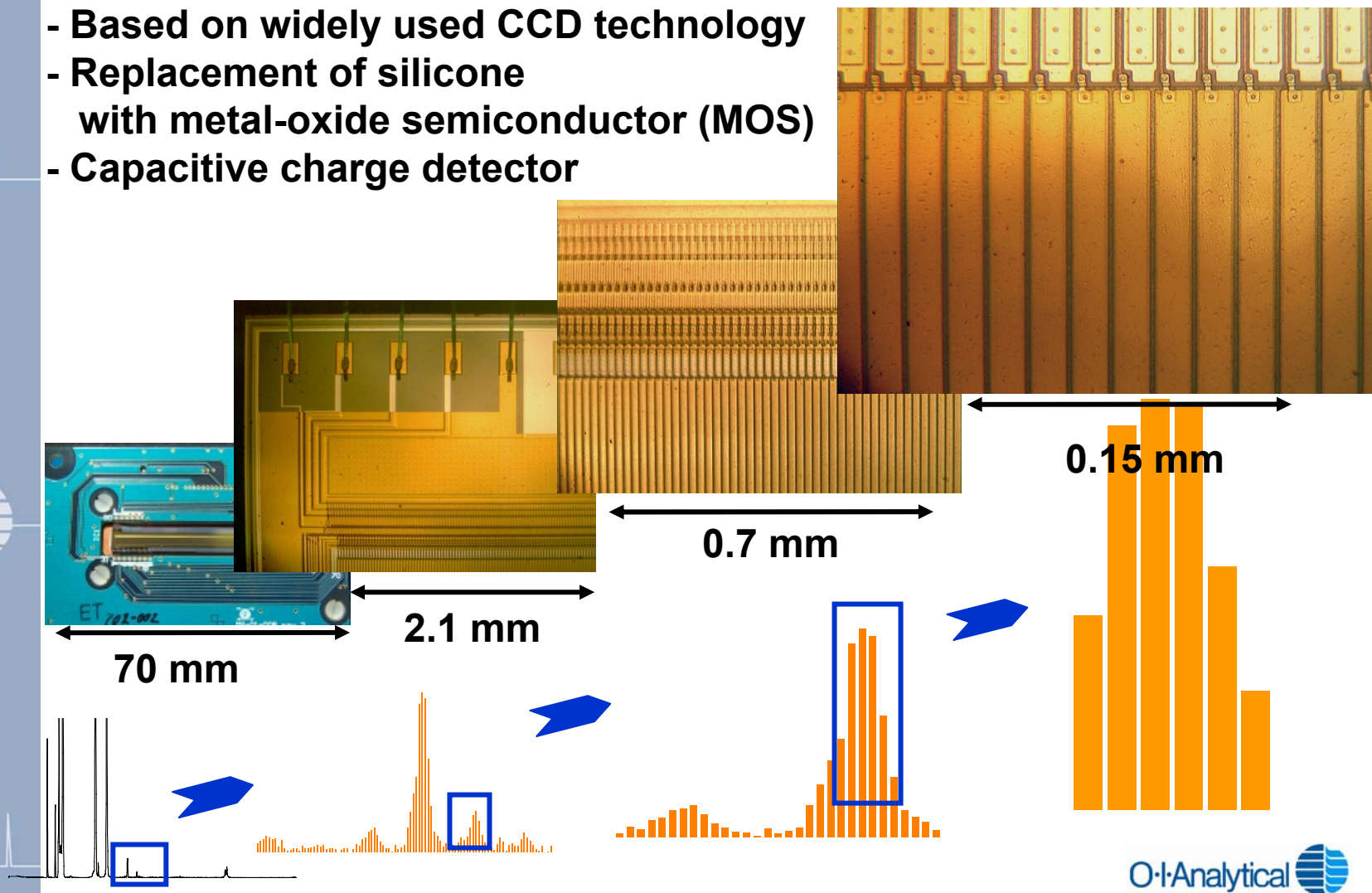


2126 pixel over 5.1 cm

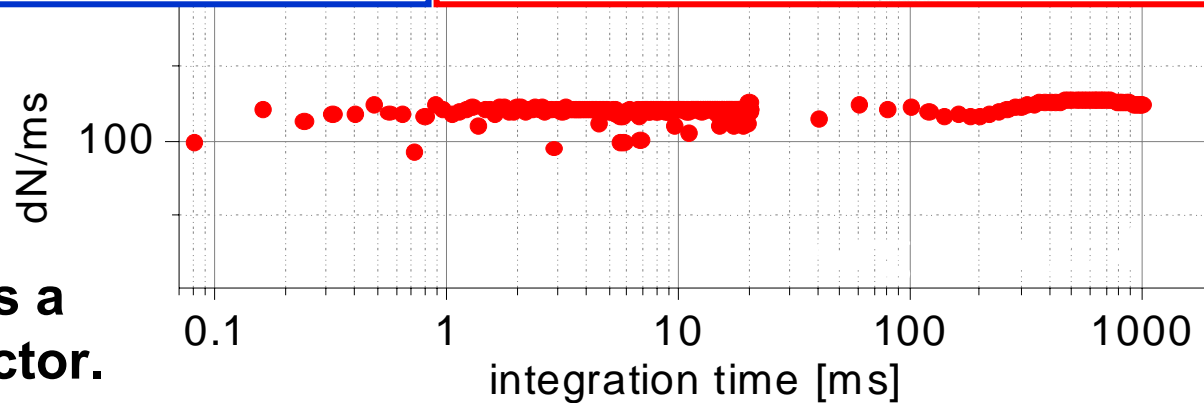
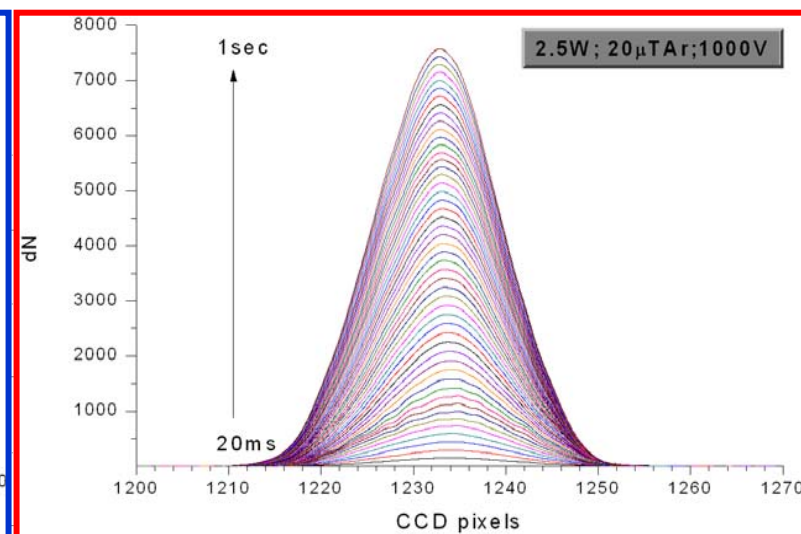
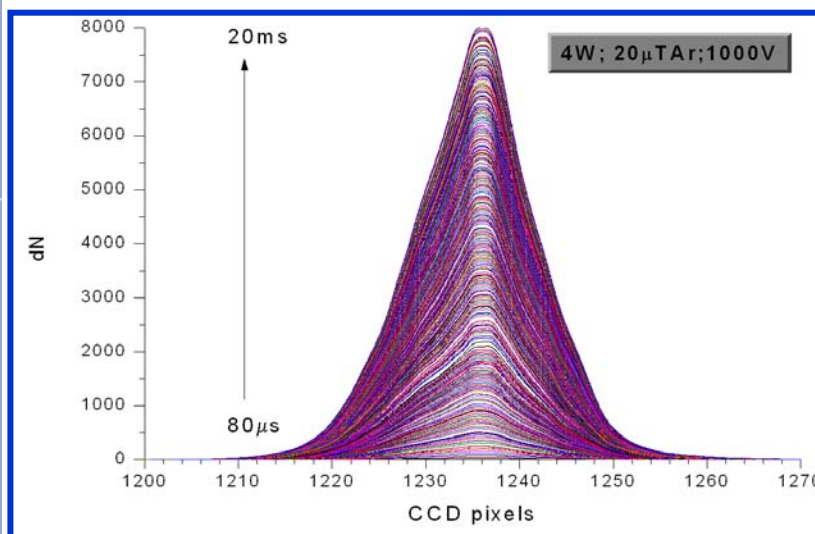
“Miniature focal plane mass spectrometer with 1000-pixel modified-CCD detector array for direct ion measurement” Sinha, M. P., Wadsworth, M., Rev. Sci. Instrum. 76, 025103 (2005)

Ion-CCD - Signals

- Based on widely used CCD technology
- Replacement of silicone with metal-oxide semiconductor (MOS)
- Capacitive charge detector

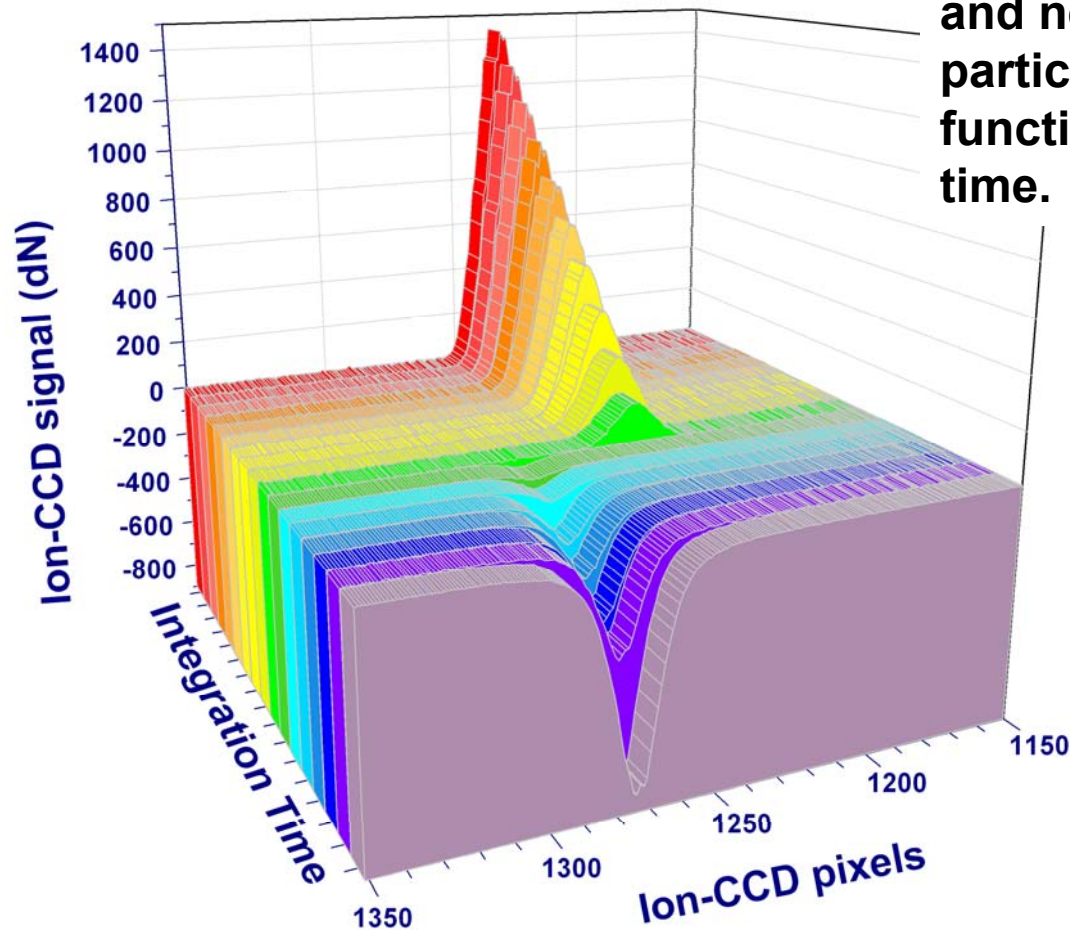


Ion-CCD - Linearity



The ion-CCD is a counting detector. Response is linear with integration

Ion-CCD - Bipolar Detector



Detection of positive and negative beam particles as linear function of integration time.

Ion-CCD - Summary

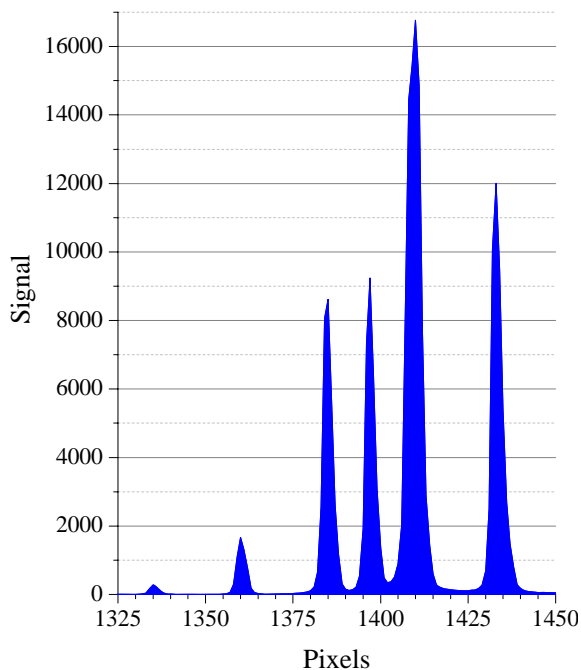
- **Fast data acquisition and high duty cycle**
 - Full mass spectra at 350 Hz
 - Integration time scalable between 80 μ s and 5 s
- **High spatial resolution**
 - Pixel pitch 24 μ m
 - 2" CCD has 2126 active detector elements
- **Pressure independent**
 - 10⁻⁷ Torr to 10³ Torr
- **Direct detection of ions**
 - Charge detector, not energy detector
 - Highly linear response
- **Bipolar Detector**

Simultaneous detection of Krypton & Xenon

Krypton

0.35 | 2.28 | 11.58 | 11.49 | 57.00

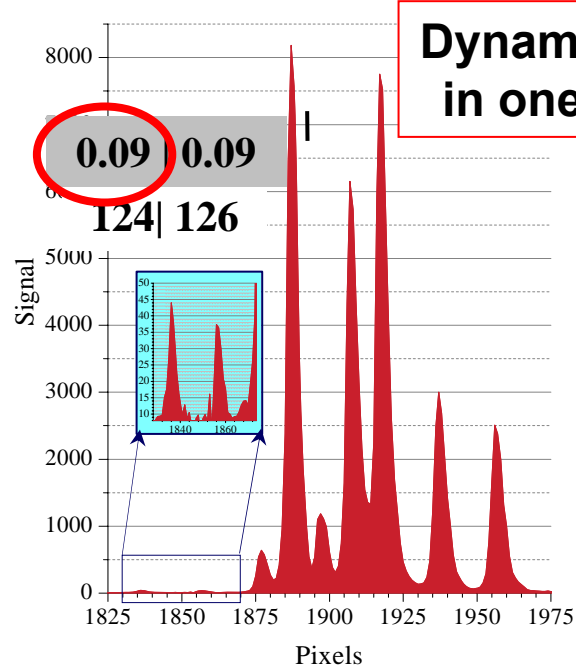
78 | 80 | 82 | 83 | 84 | 86



Xenon

1.92 | 26.44 | 4.08 | 21.18 | 26.89 | 10.44 | 8.87

128 | 129 | 130 | 131 | 132 | 134 | 136

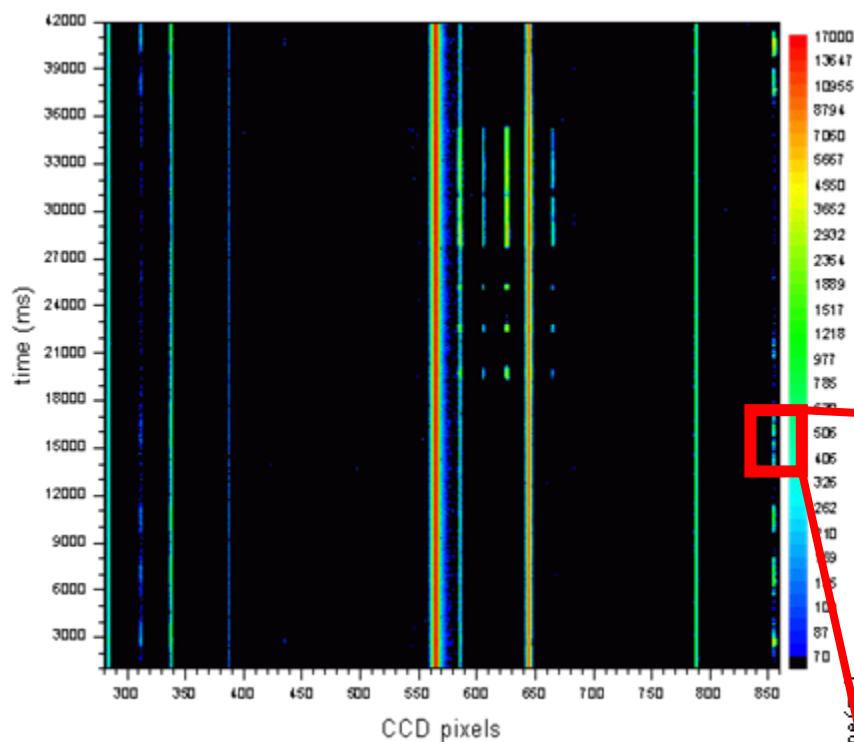


**Dynamic range
in one frame**

Natural Abundance %

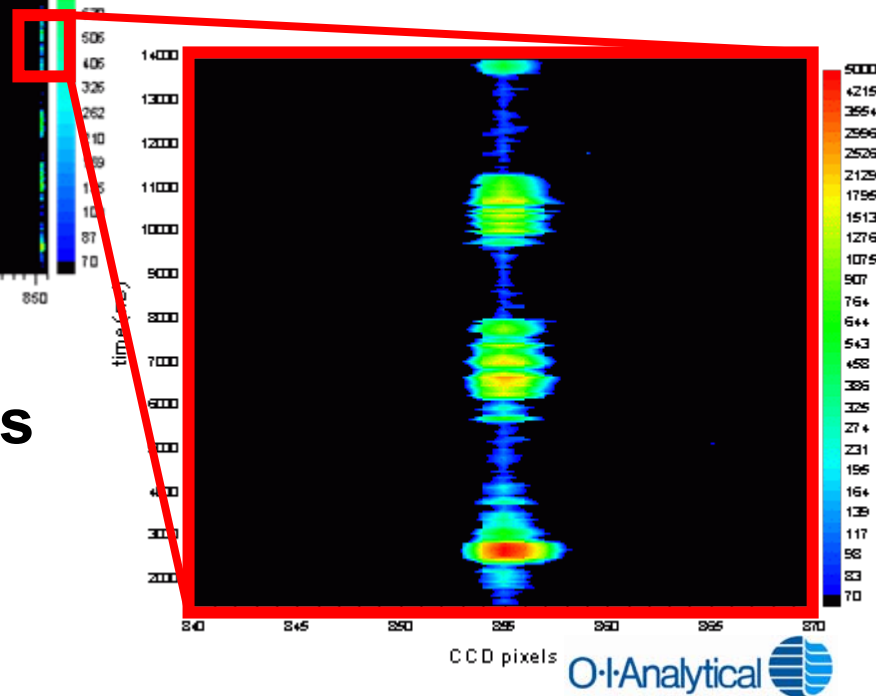
atomic mass unit

CO₂ in Breath - Speech Modulated

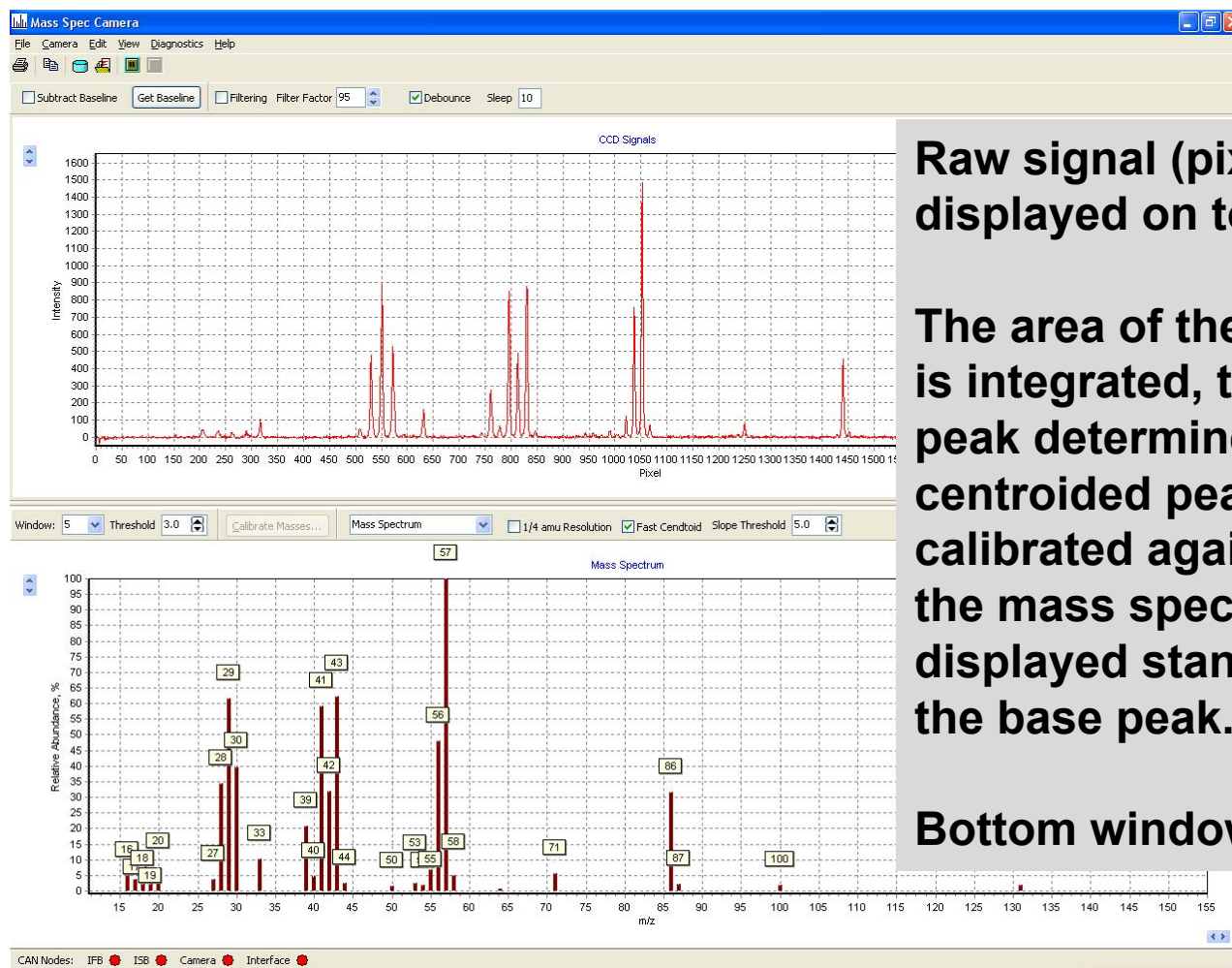


Full spectra every 20 ms

Direct inlet,
FS capillary 15 cm,
ID 50 μ m



Ion-CCD Signal and Mass Spectrum



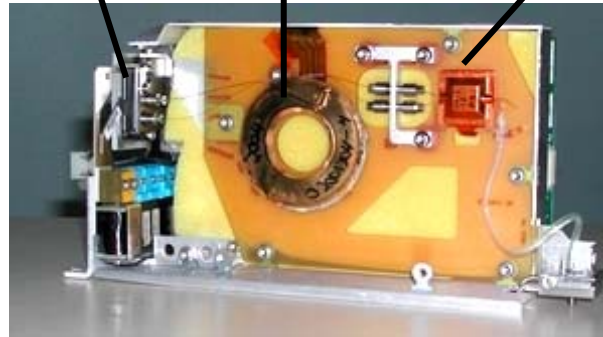
Raw signal (pixel) is displayed on top.

The area of the raw signal is integrated, the center of peak determined, the centroided peak is calibrated against m/z and the mass spectrum is displayed standardized to the base peak.

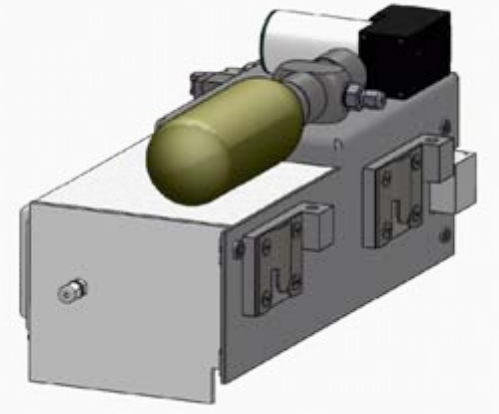
Bottom window: n-Hexane

Gas Chromatograph

MEMS injector **Capillary column** **MEMS TCD Detector**

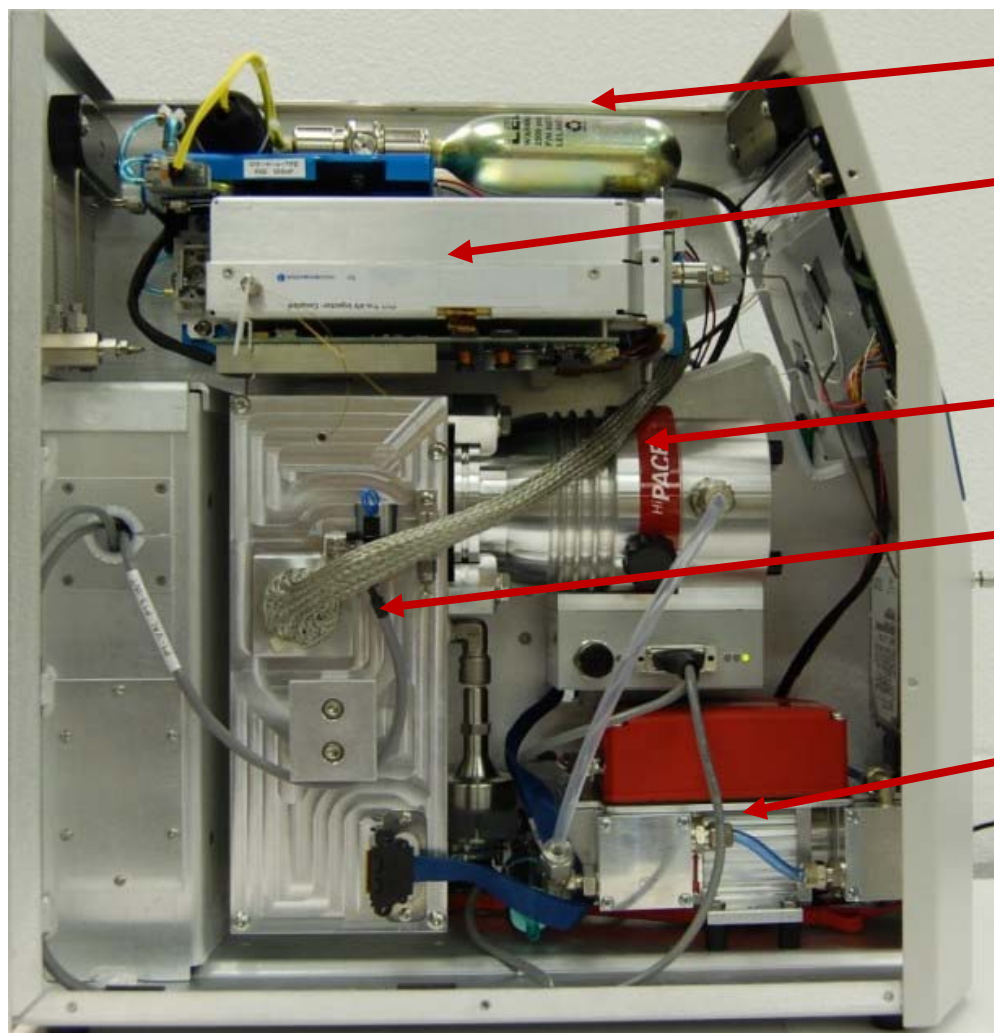


GC assembly



- Non-destructive TCD can be used in series with Ion- Camera
- Carrier gas onboard for >8 h
- Heated MEMS injector allows short injections
- Flexible column choices
- Typical GC chromatograms in 1-3 min

GC/MS Ion-Camera



Carrier gas

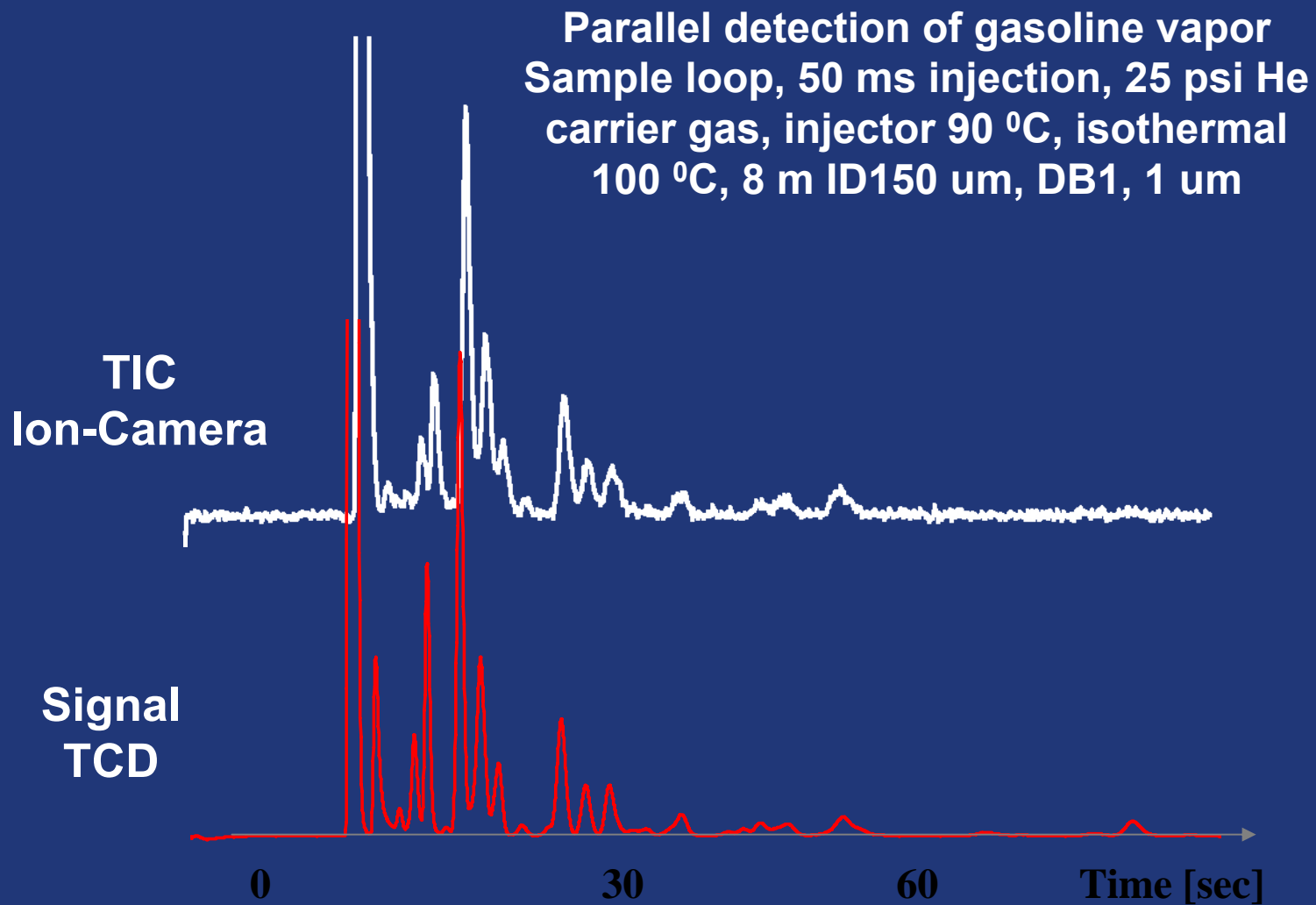
GC oven

Turbo-drag pump

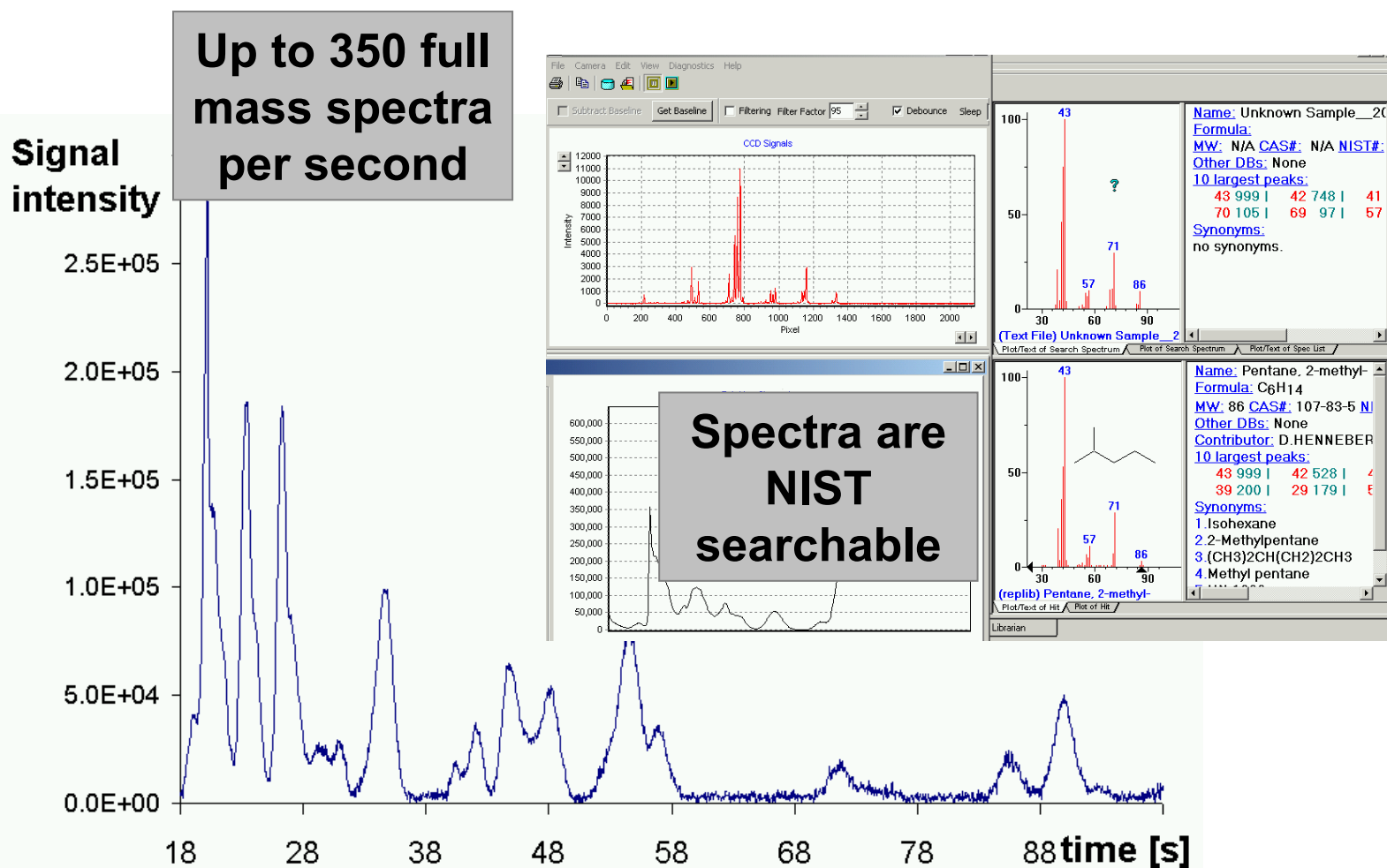
**Vacuum housing
containing MS**

Membrane pump

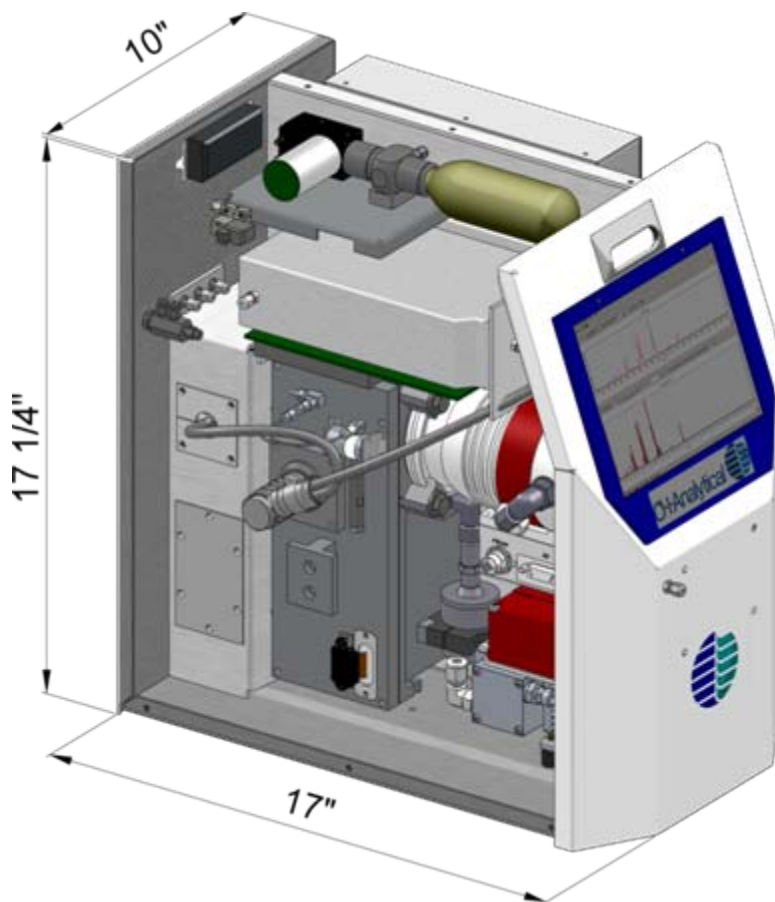
Detection: Ion-Camera and Micro GC TCD



Gas chromatogram and GC/MS data



Conclusion: Standalone GC/MS



- **Dimensions: 25 cm x 42 cm x 43 cm**
- **Weight: 21 kg (44 lbs),**
- **Power: Average 50 W (w/o data system)**
- **Vacuum system (2 ml/min carrier gas)**
- **Toggle between internal/ external carrier gas supply**
- **Dual 24 VDC input (enables battery to outlet swap)**
- **Embedded PC and large touch screen**

Compact GC/MS

Thank you for your attention

