Progress in Two-Plate Ion Trap Mass Analyzers

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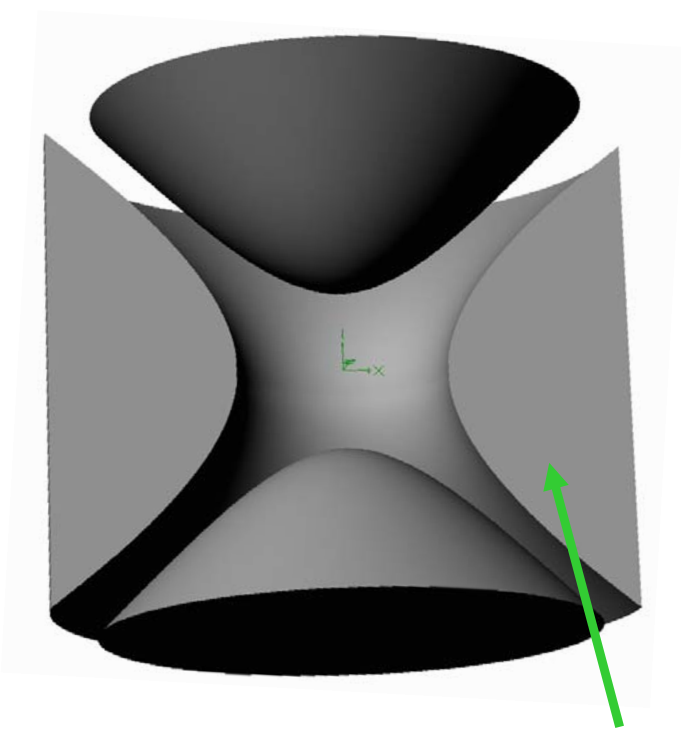
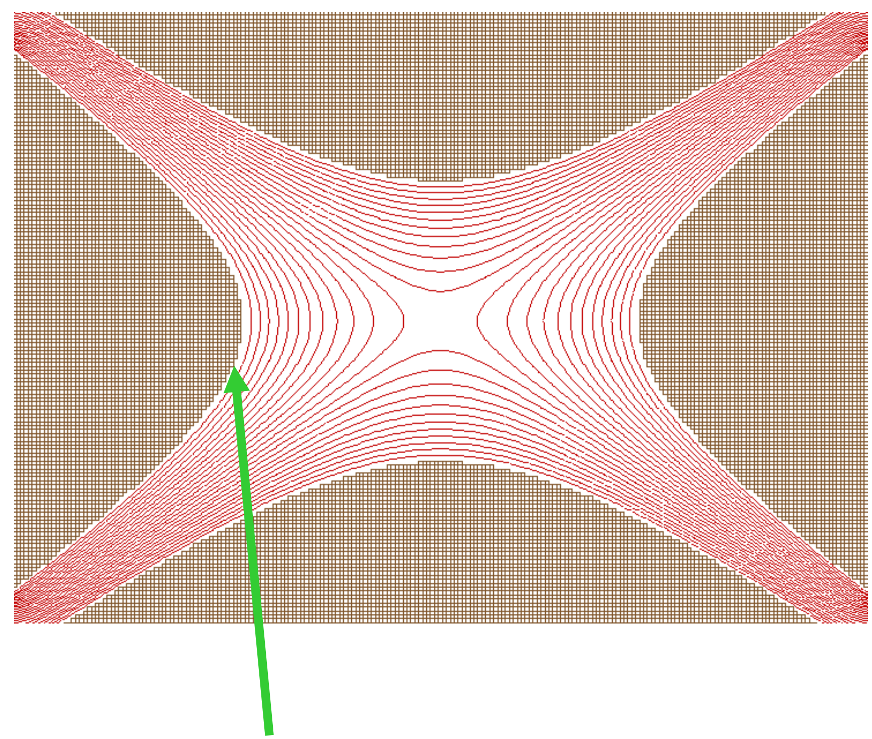
Quadrupolar Potential Distributions

- Potential varies quadratically in x,y or in r,z
- Electric field is linear over the same variables
- Metal electrodes represent equipotential boundary conditions
- RF applied to metal electrodes produces quadrupolar field
- Time-varying quadrupolar fields allow trapping, mass analysis

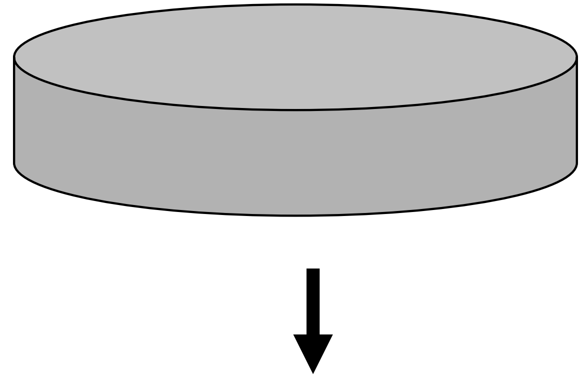


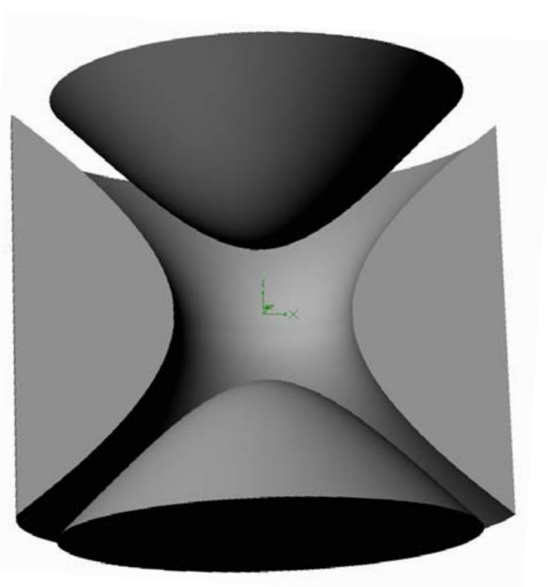


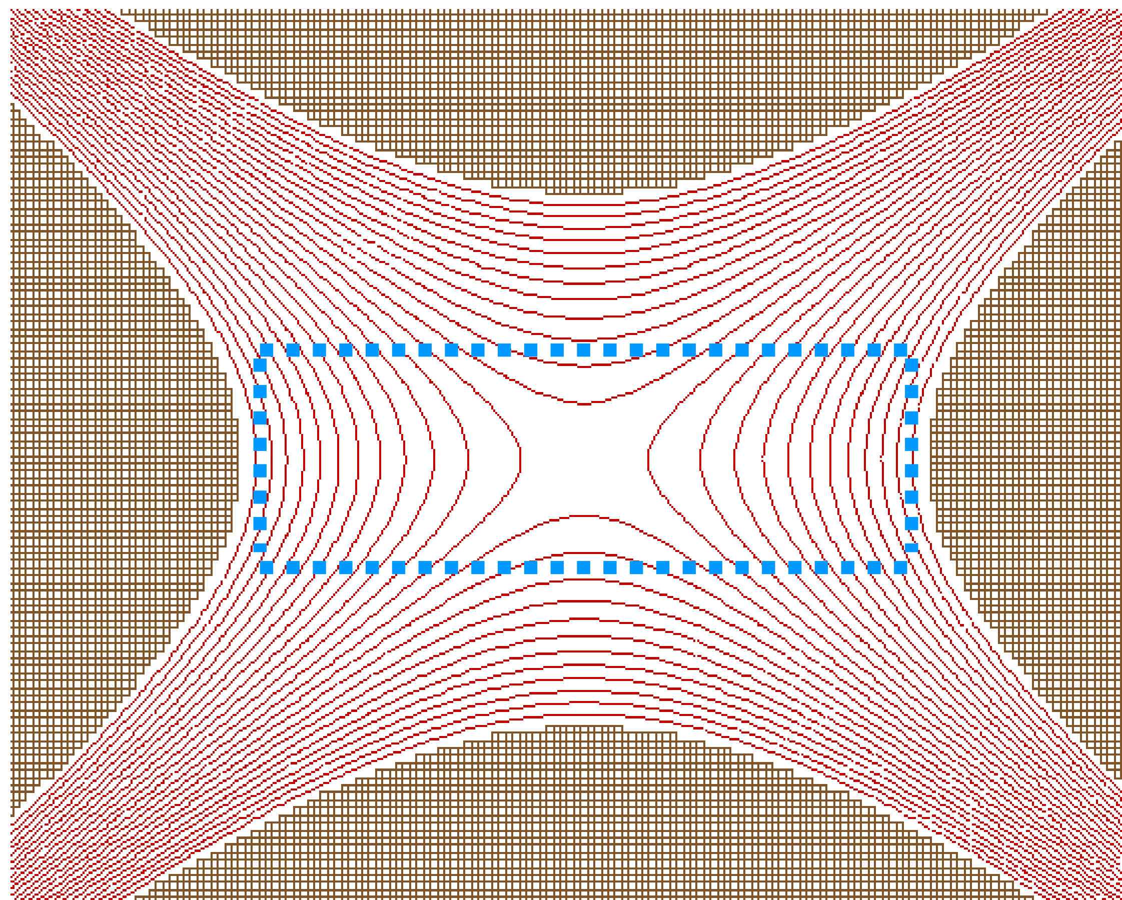
Hyperbolic surfaces produce quadrupolar fields

oundary Conditions
efine Fields

New boundary
conditions:
cylindrical surface
with quadratic
potential functions
fields inside are th
same!



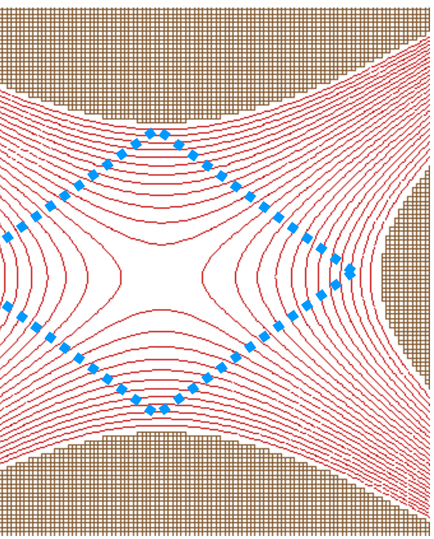


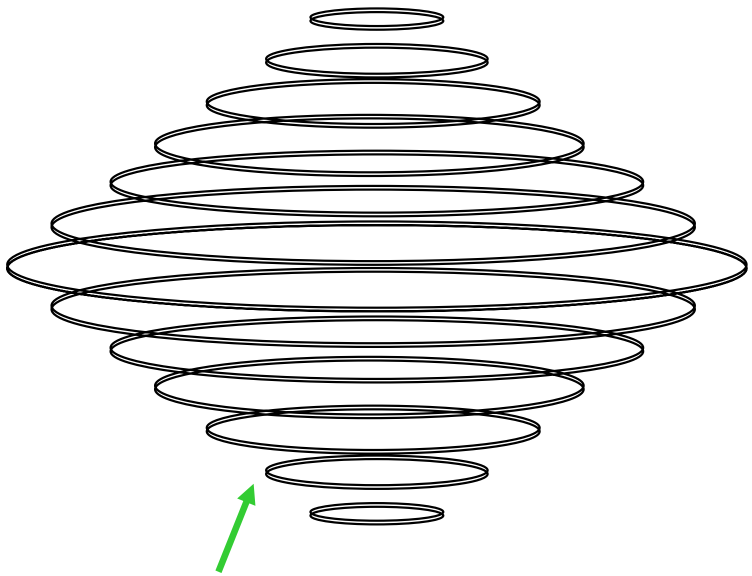


Equipotential
boundary conditions:
three hyperboloidal
electrodes

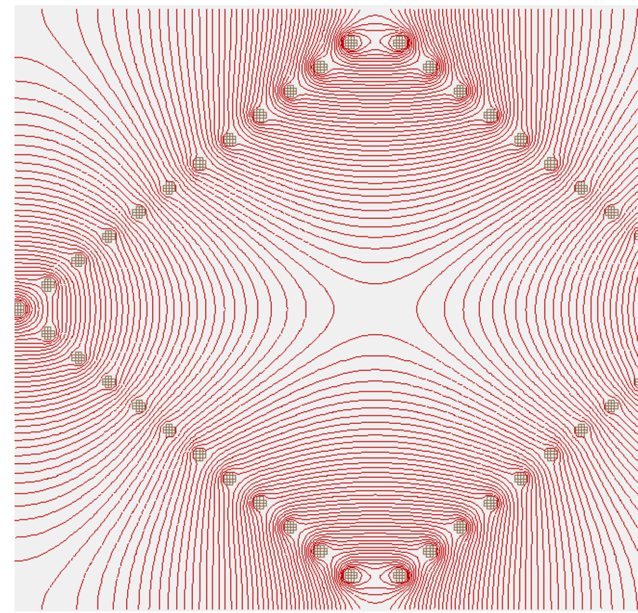
Example: Wang's conic section trap

- Quadrupolar field made using two cones of wire rings
- Potential between rings varies linearly
- Resulting field is (approximately) quadrupolar





Wire rings connected with resistors



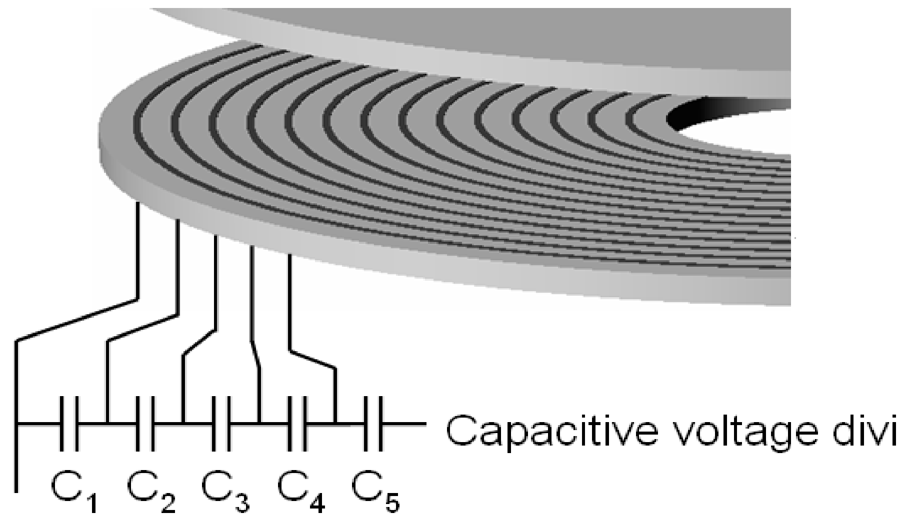
In the limiting case of an infinite number of rings this resembles a resistive materia

However, good fields are obtained with only a few rings due to averaging

Wang, Y.; Wanczek, K. P. J. Chem. Phys. 1993, 98, 2647-2652

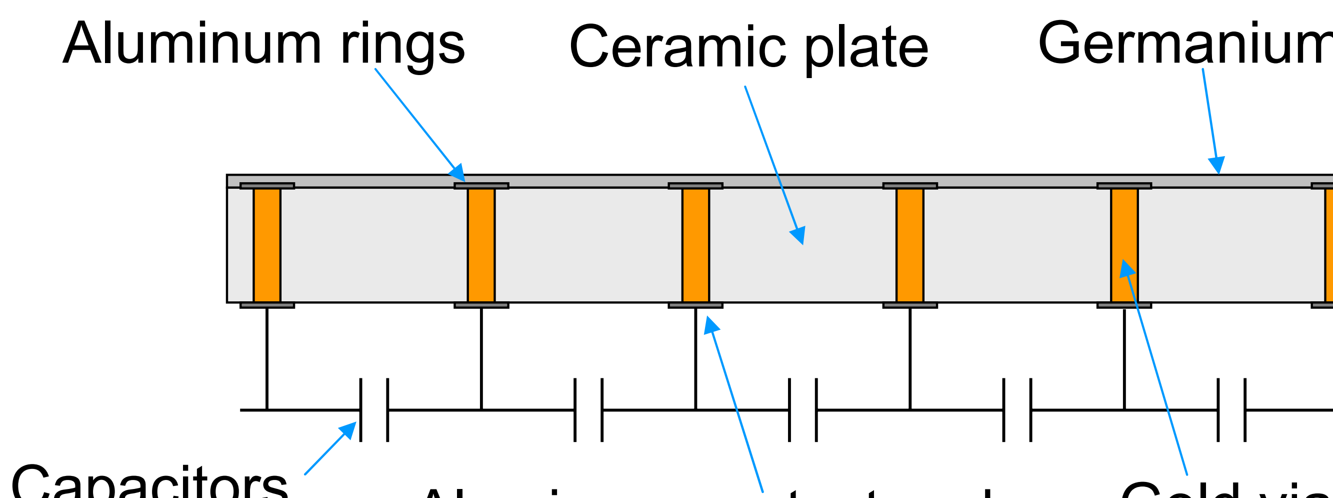
Two-Plate Ion Traps

ach plate contains series of
hographically-defined metal
vires", overlaid with resistive
ermanium

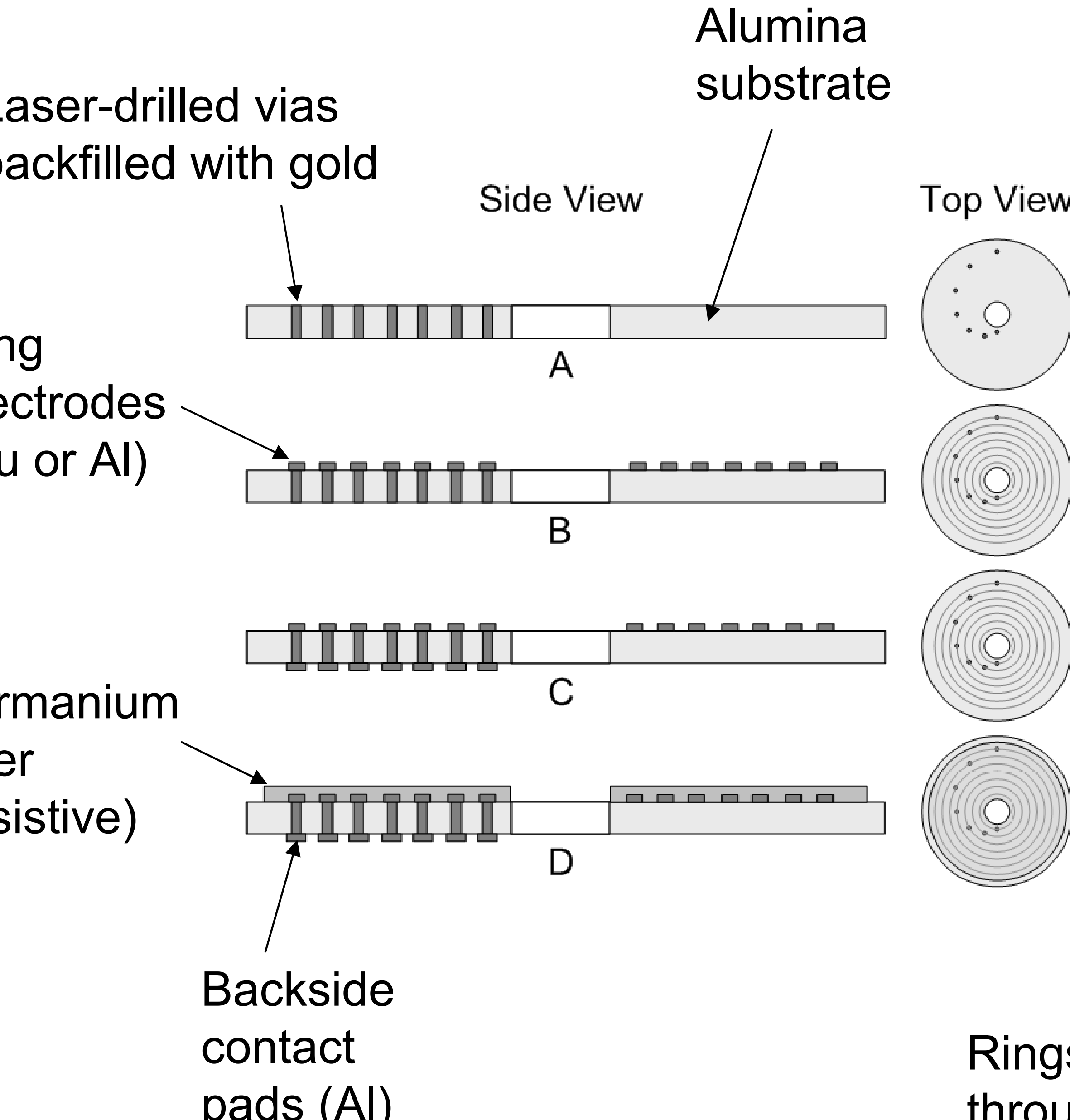


ifferent RF amplitudes applied
o each "wire" produce trapping
elds

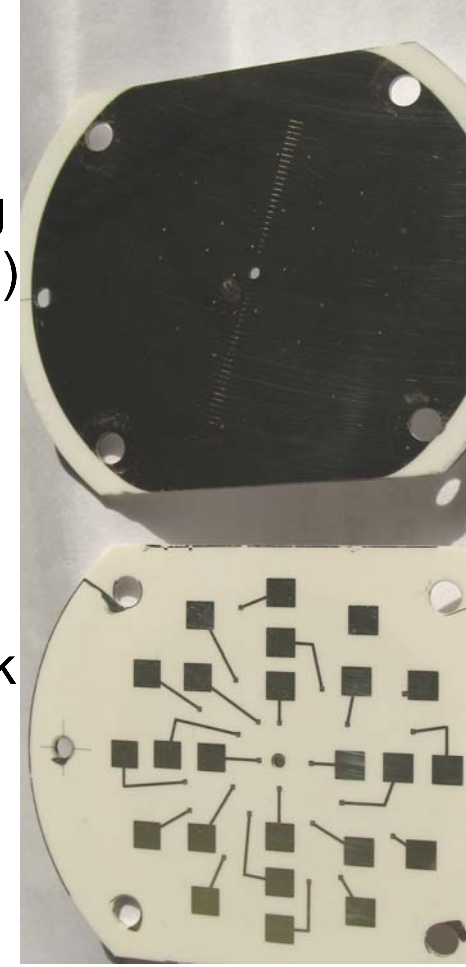
) nm germanium
yer prevents
arge build-up and
ovides continuous
rface potential



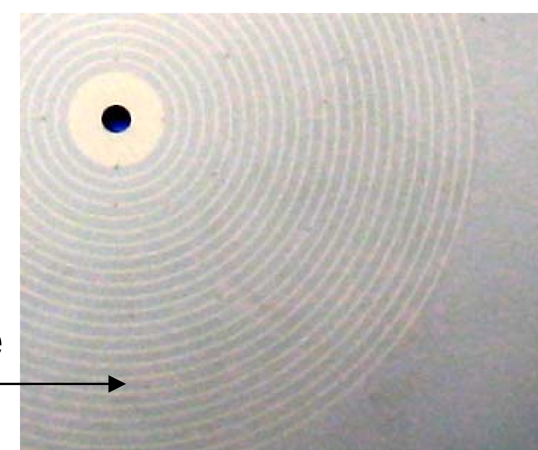
Trap plate fabrication



Trapping side (top)



Back side



Rings visible through

Three-fold Motivation Behind This Work:

- Explore Electric Fields

  Independently adjust higher order multipoles

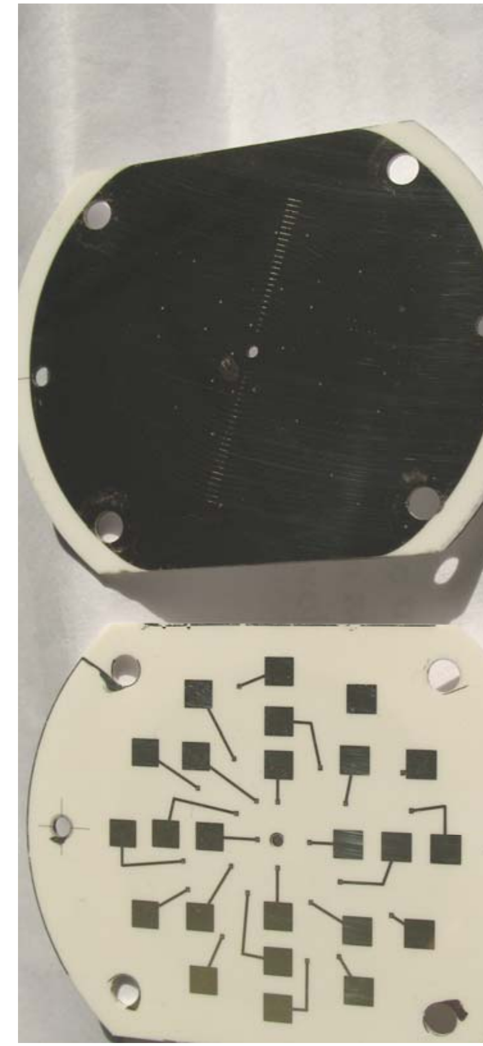
- Novel Trap Geometries Possible

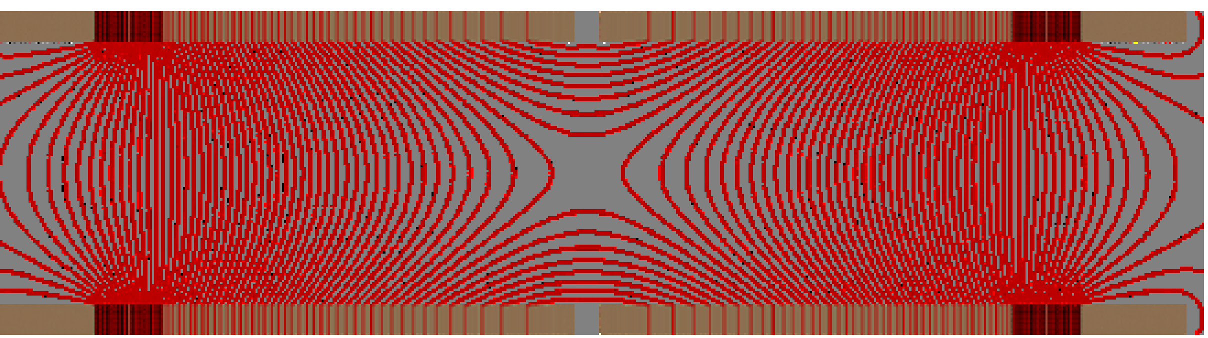
  Paul trap, toroidal, coaxial, others

- Mass Analyzer Miniaturization

  Combines microlithography with accurate electric fields

A Quadrupole Ion Trap made using microfabricated electrodes





Made using two plates, each lithographically imprinted with concentric ring electrodes, coated with germanium

Quadrupole Ion Trap

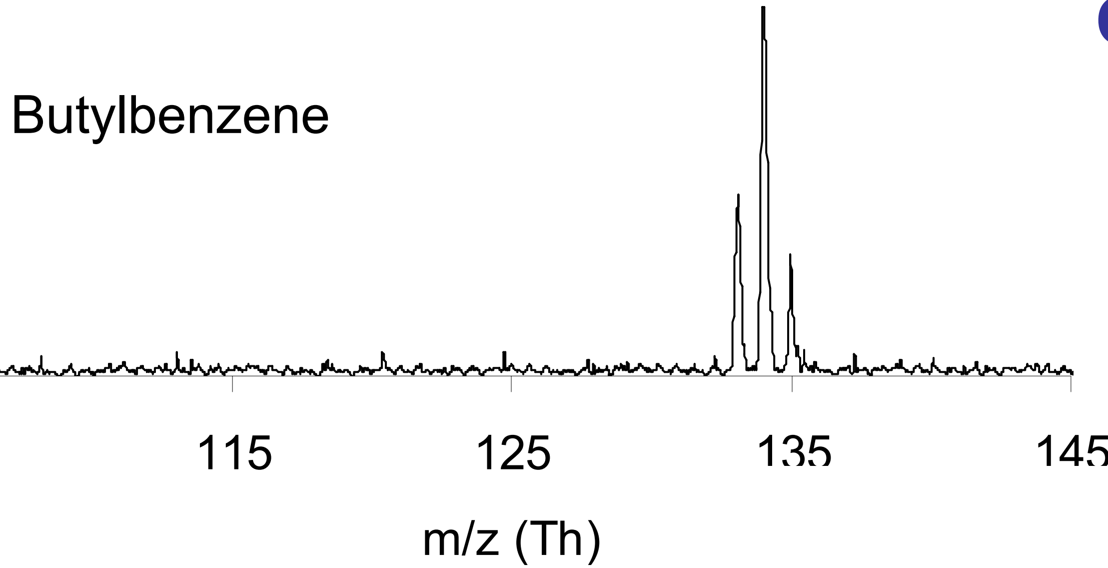
z_0 = 2 mm

RF 100-700 $V_{0\text{-}p}$

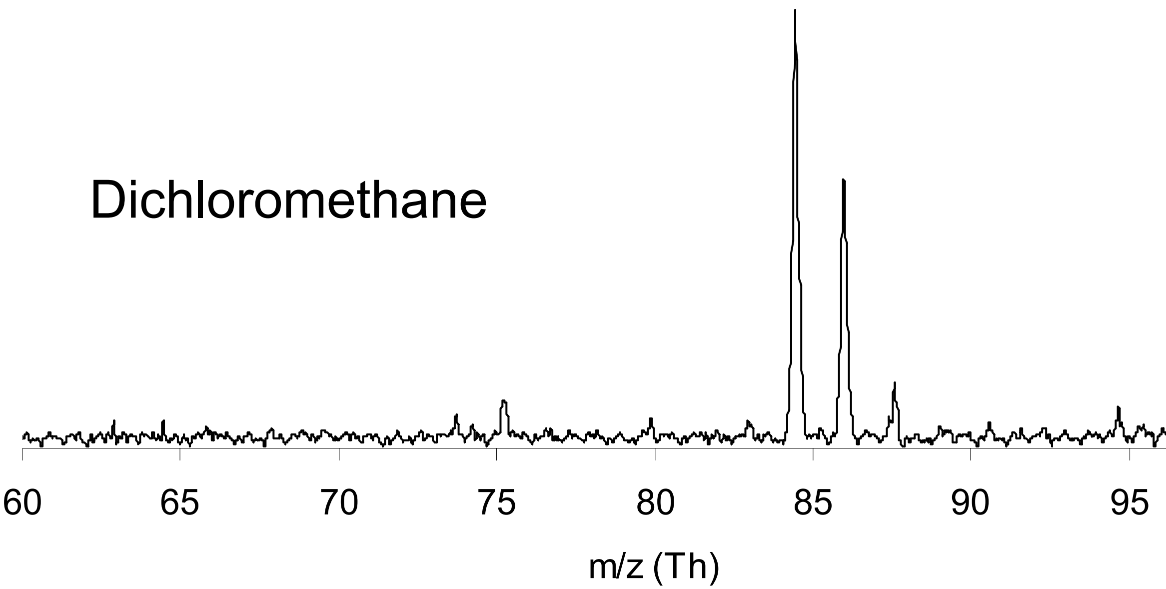
Drive frequency 1.2 MHz

Dipole resonant ejection at β=0.4

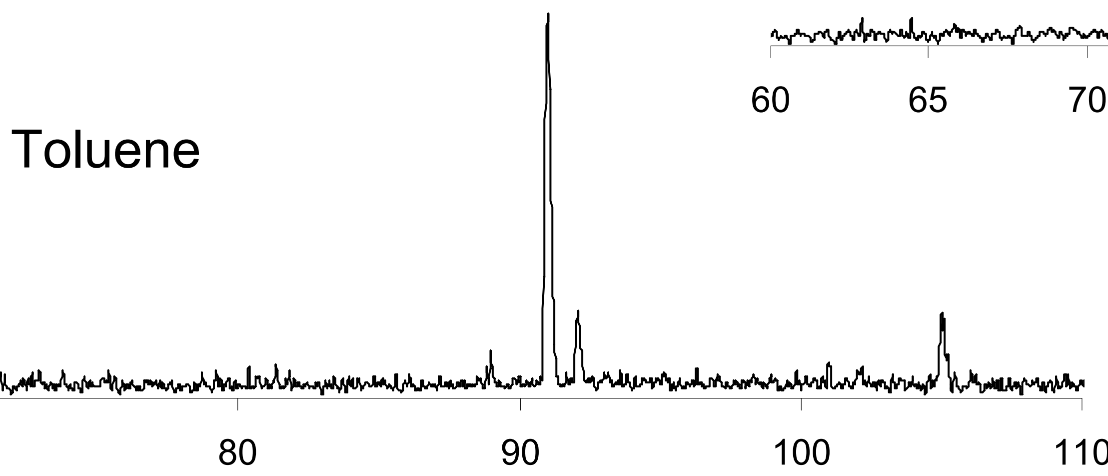
Butylbenzene



Dichloromethane

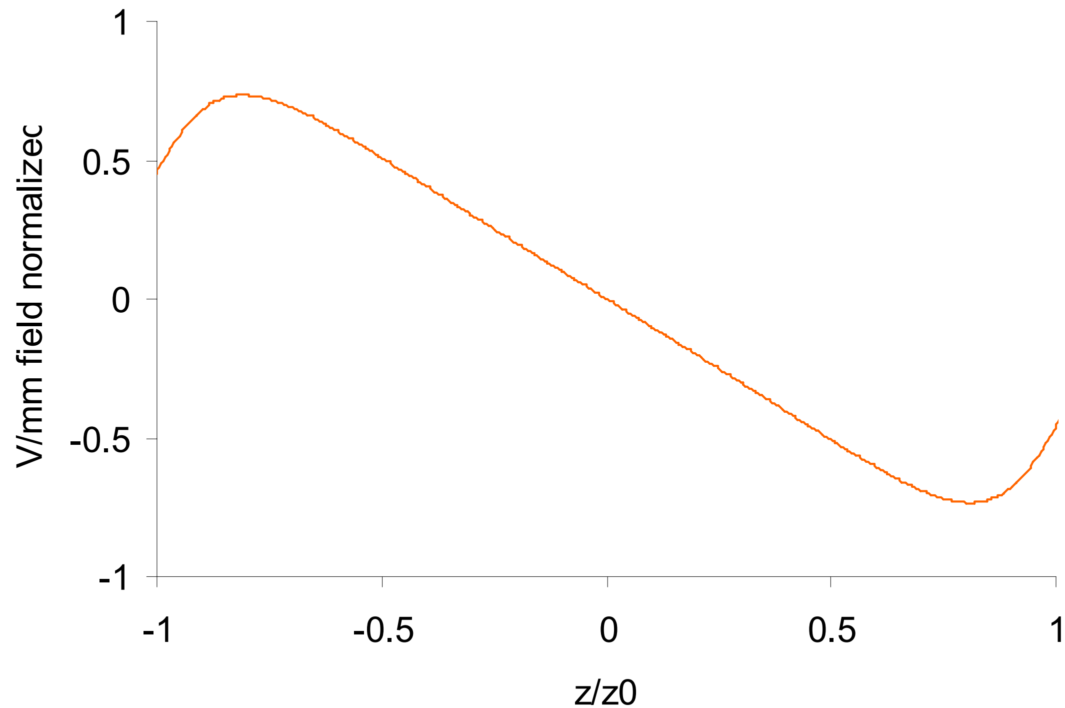


Toluene

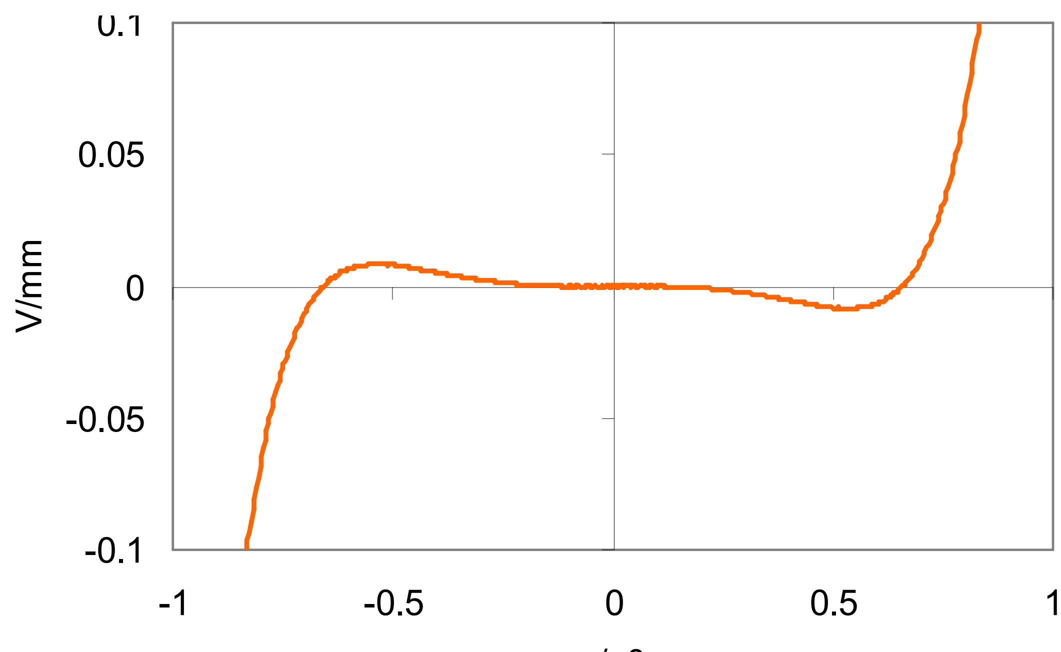


Electric fields in planar quadrupole trap

Axial electric field



igher order components
axial field



Field components easily
djustable by varying
potentials on rings

Modifying Higher-order Multipoles

All cylindrically symmetric potentials can be expressed as:

$$\Phi(\rho,\theta,\phi,t) = \Phi_0(t)\sum_{l=0}^{\infty} A_l \left(\frac{\rho}{r_N}\right)^l P_l(\cos\theta)$$

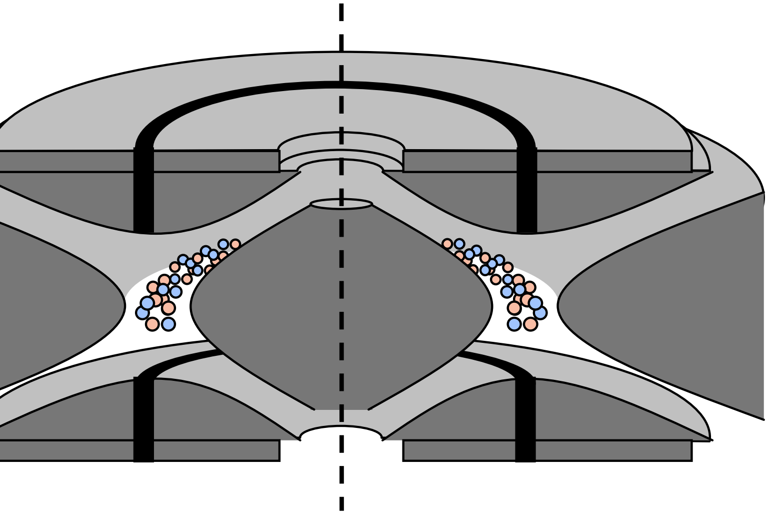
quadrupole (l=2), hexapole (l=3), octopole (l=4), etc.

Variables: position and voltage on each ring, plate spacing, hole size

For a given physical design, superposition allows us to combine multipole expansio
esulting from each ring:

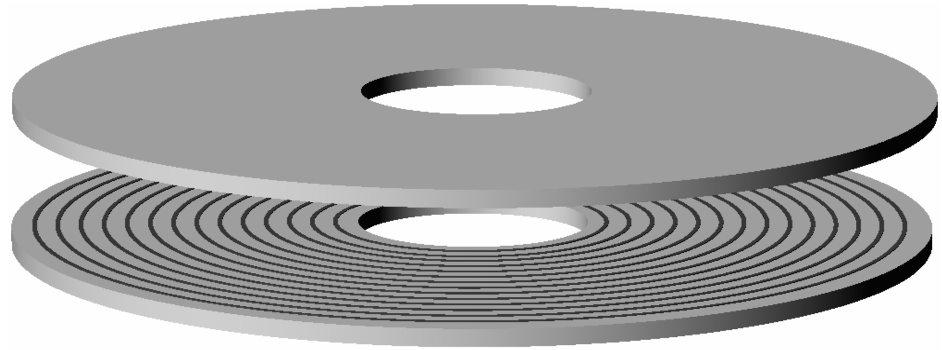
	Ring 1	Ring 2	Ring 3	...	Ring m
A_2	-0.100032	0.103965	0.155169	...	A_2m
A_4	0.568701	0.330117	0.155211	...	A_4m
A_6	0.352728	-0.001885	-0.071216	...	A_6m
A_8	-0.360680	-0.170844	0.146052	...	A_8m
⋮	⋮	⋮	⋮		⋮
A	A 1	A 2	A 3		A m

A toroidal ion trap using the same approach



Toroidal Ion Trap

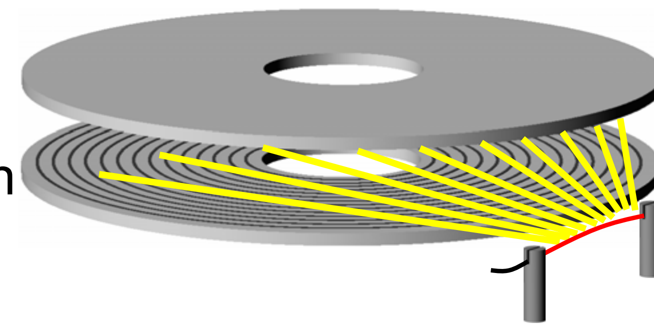
Lammert et al, *IJMS*, 2001.



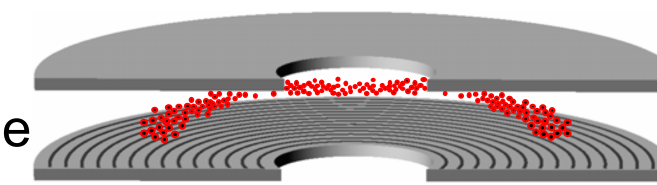
The Halo Ion Trap

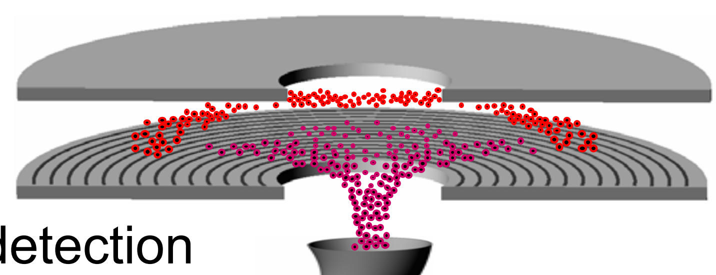
Austin et al, *Anal. Chem.* 2007

Electron ionization



Ion storage



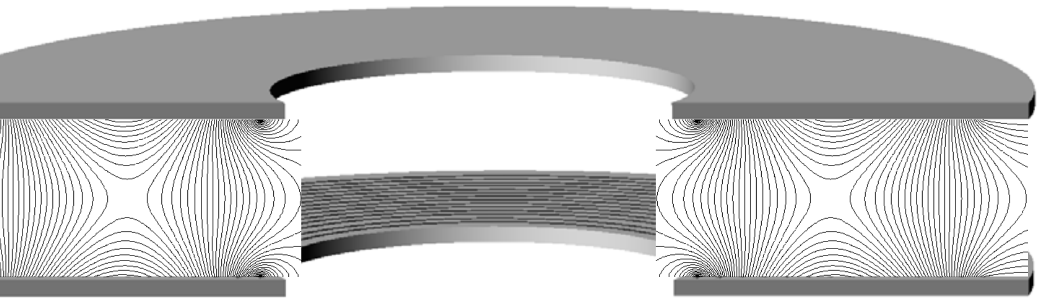


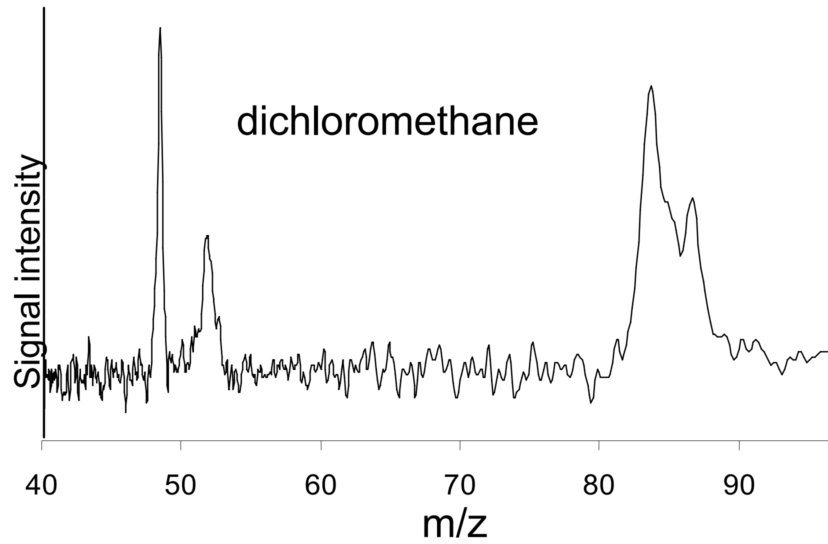
Ejection and detection

- ons trapped, stored in a torus (ring)
- Slits in endcaps for ion ejection and ectron beam
- Large storage capacity

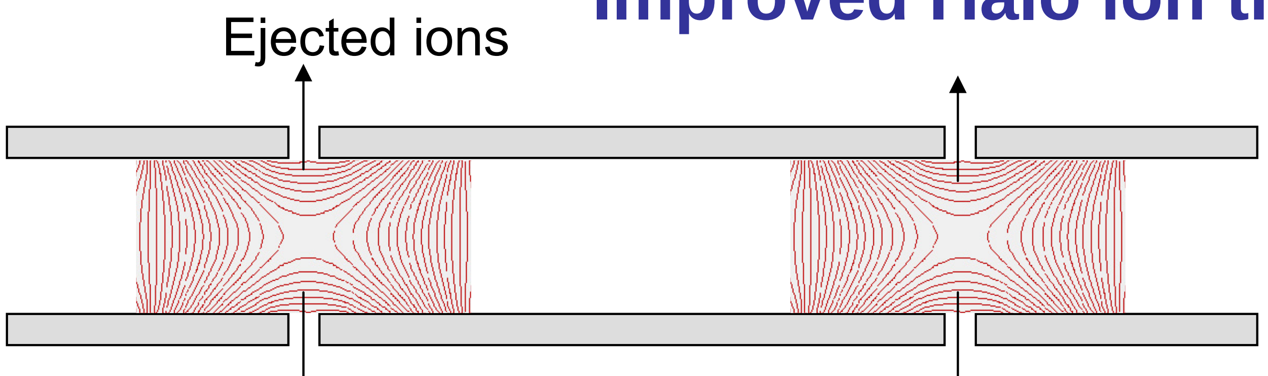
Original Halo ion trap

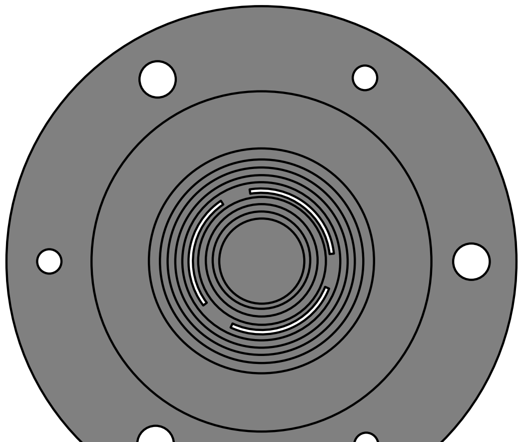
Radial ejection





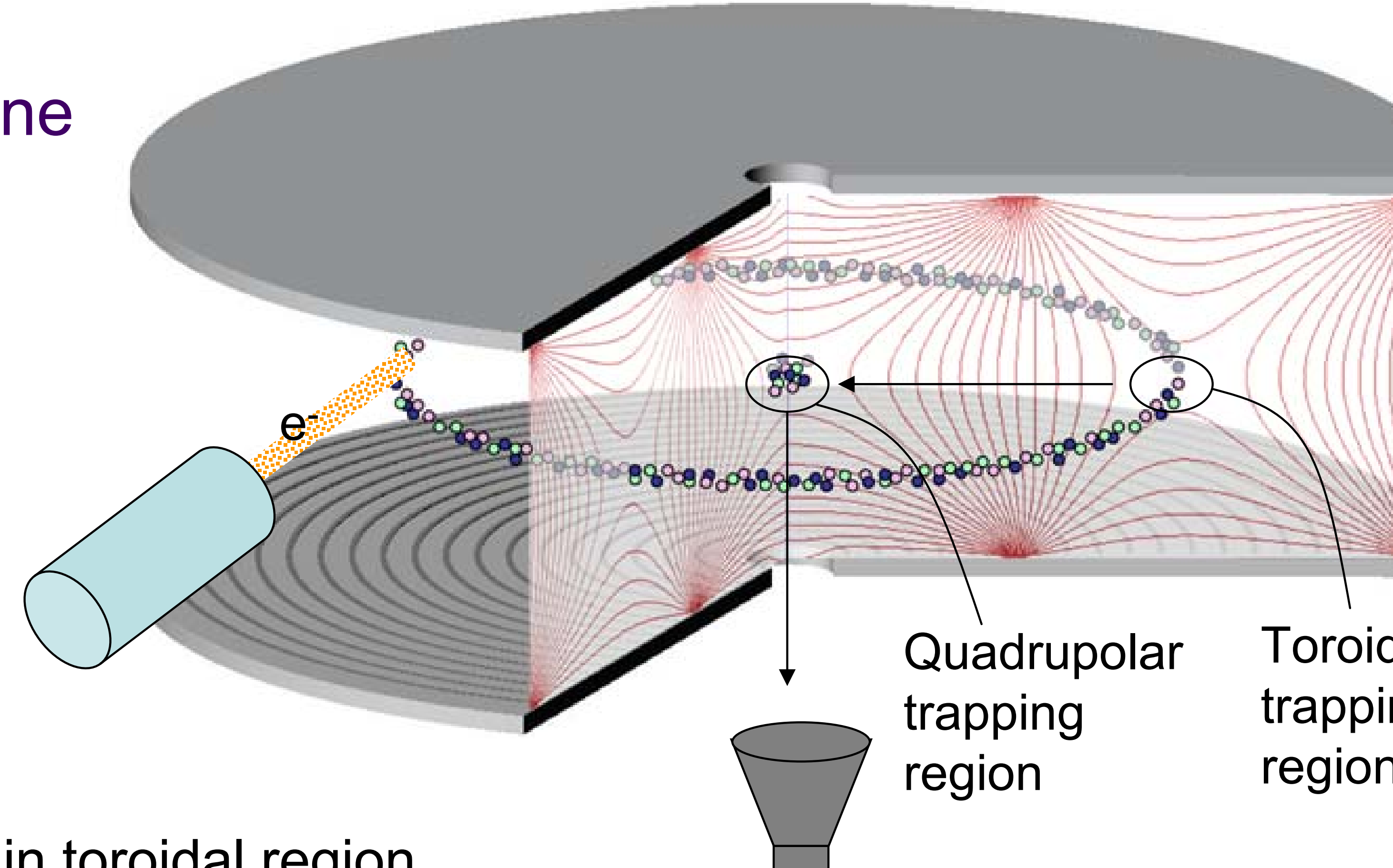
Improved Halo ion trap



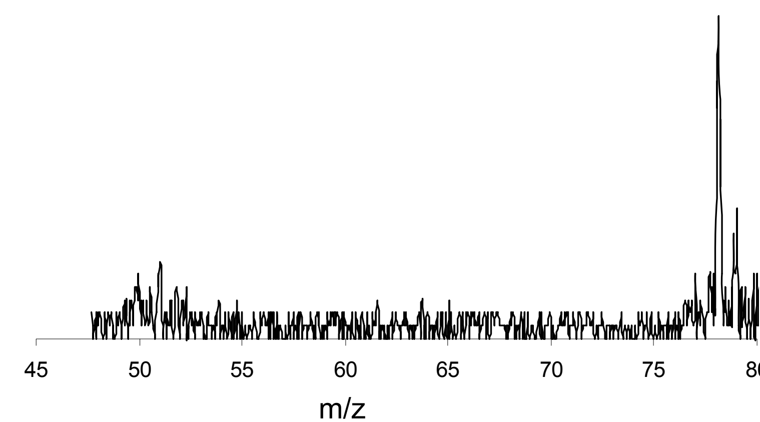


Coaxial ion trap

Two traps in one

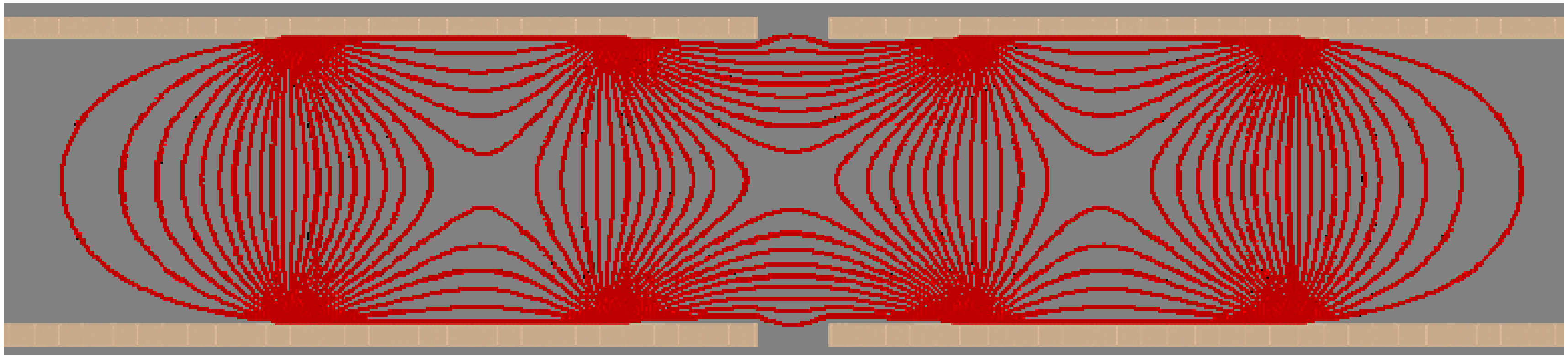


- s can be trapped in toroidal region, nsferred to quadrupole region, and cted out
- ssibilities for tandem-in-space periments
- verage advantages of both trapping ometries

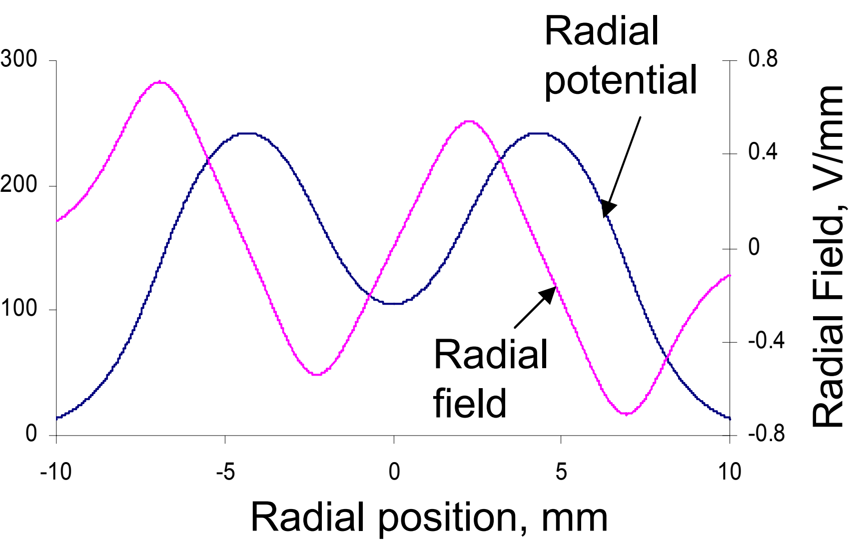


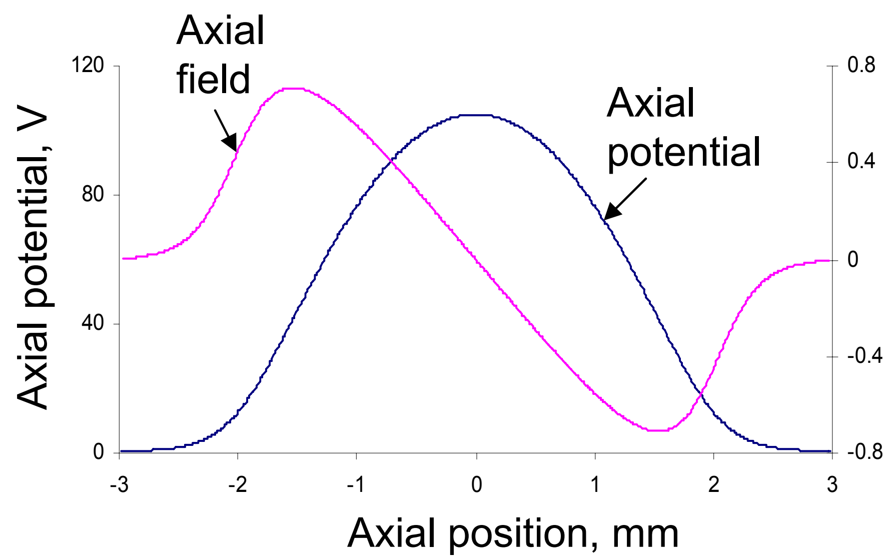
“Double” spectrum of benzer

Isopotential lines in the coaxial ion trap



Radial and axial potentials and fields





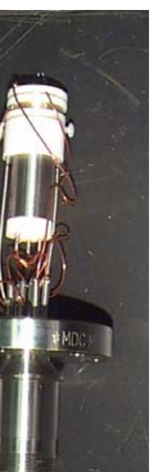
Mass Analyzer Miniaturization

otivation

- Smaller mean free path → higher operating pressure, smaller pump
- Reduced power → smaller batteries
- Instrument portability
- Lower cost

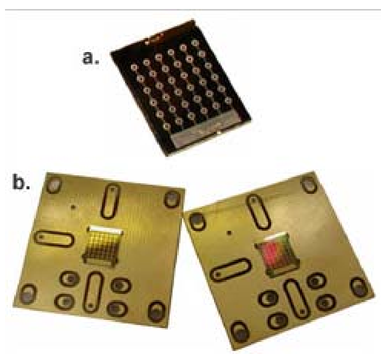
Why ion traps?

- Higher tolerance to pressure
- Amenable to GC-MS, LC-MS
- Tandem MS capabilities
- Frequency, voltages scale favorably



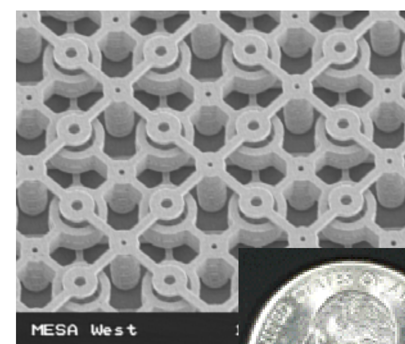
ak Ridge

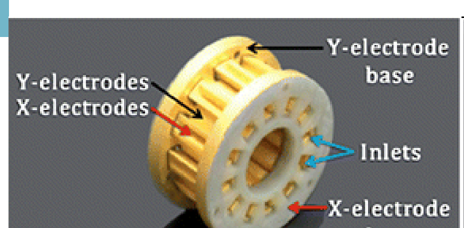
JPL



U South Florida

UNC





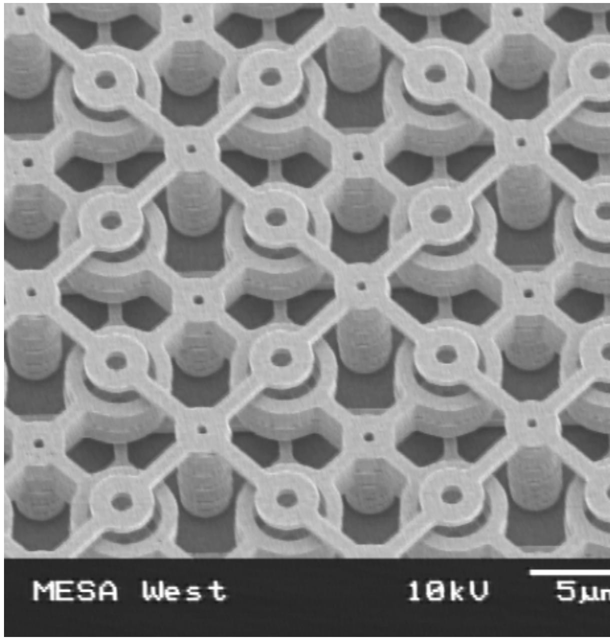
(esp. ion traps)

aking accurate fields:

- Machining / fabrication accuracy
- Electrode alignment
- Surface roughness

ractical issues:

- Reduced access for ions or ionizing radiation
- Reduced ion count (space charge)
- Keeping arrayed traps parallel
- Insufficient stopping distance to trap ions



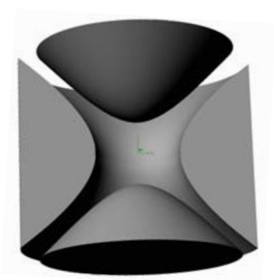
from Austin et al, *JASMS* 200

3 dimensions or 2?

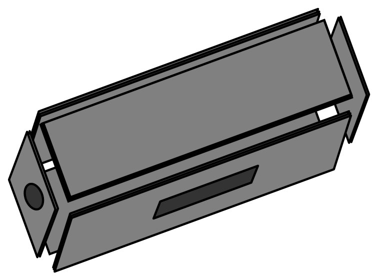
urrent paradigm: take a 3-dimensional structure (the ion trap), scale it down smalle ith minor simplifications in geometry. Essential 3-D device structure remains.

icrofabrication technology produces 2½ dimensional devices

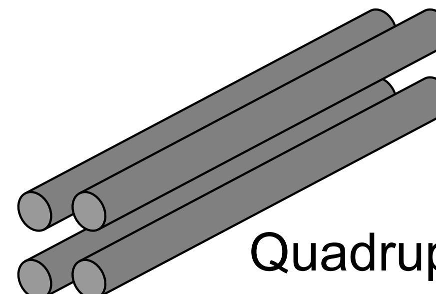
ow do we exploit the high precision of 2 dimensions?



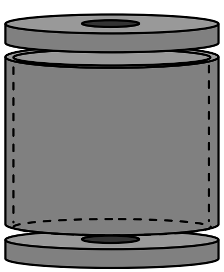
Quadrupole ion trap
or Paul trap



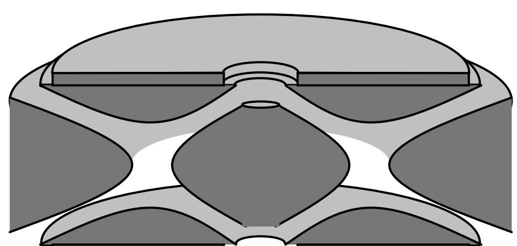
Rectilinear ion trap



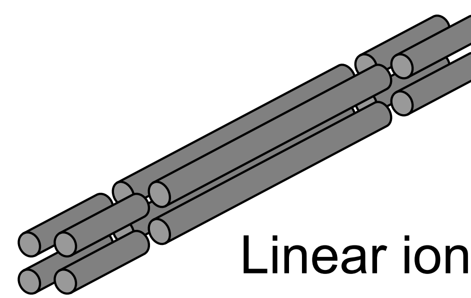
Quadrupole
mass filter



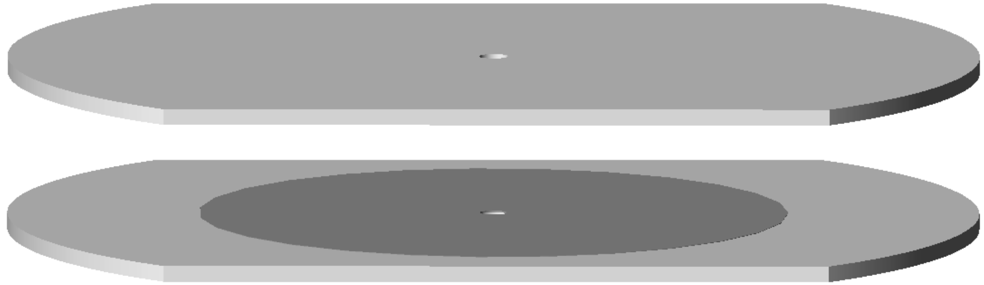
Cylindrical ion trap



Toroidal ion trap



Linear ion
trap



- Surface planarity, roughness controlled to within tens of nanometers
- Uses microfabrication methods
- Sub-micron mechanical tolerances
- Alignment simplified: only two pieces
- Larger access area for ionization or pumping
- Sturdy—no tiny parts as there are with MEMS
- Ceramic disks can be any thickness—greater strength
- The two plates have identical potential distributions, so capacitance does not increase as they are moved together
- Economy of scale—potentially lower cost than machined electrodes

Who is doing all the work at BYU?

Austin Group

Dr. Zhiping Zhang

Ying Peng

Terik Daly

Seth Call

BYU Microfabrication Lab

Prof. Aaron Hawkins

Brett Hansen

Collaborators

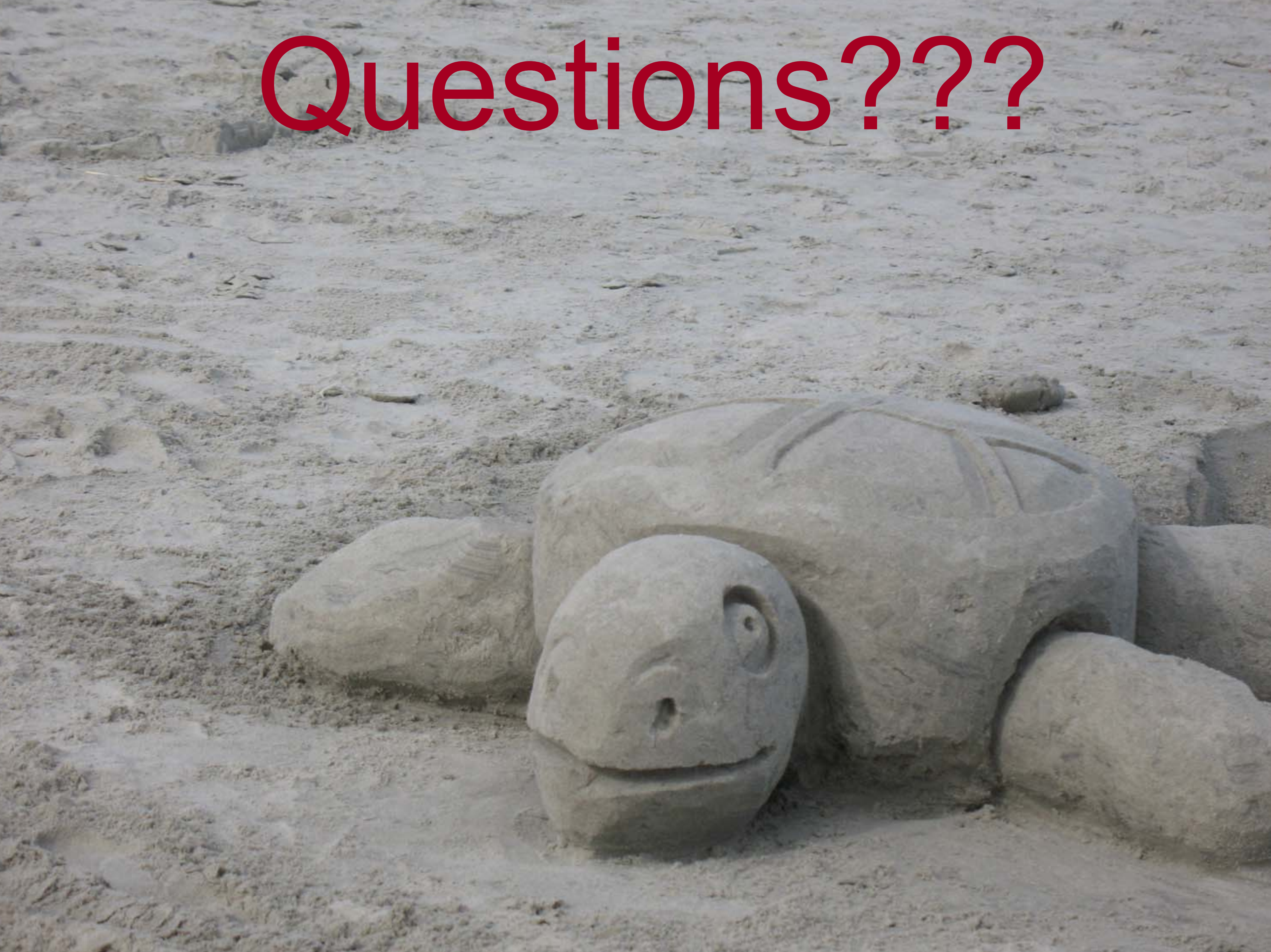
Miao Wang

Prof. Milton Lee

Dr. Steve Lammer

…And who is paying for it

Funding on this project from NASA


Questions???