Mass SURFER underwater mass spectrometer system development

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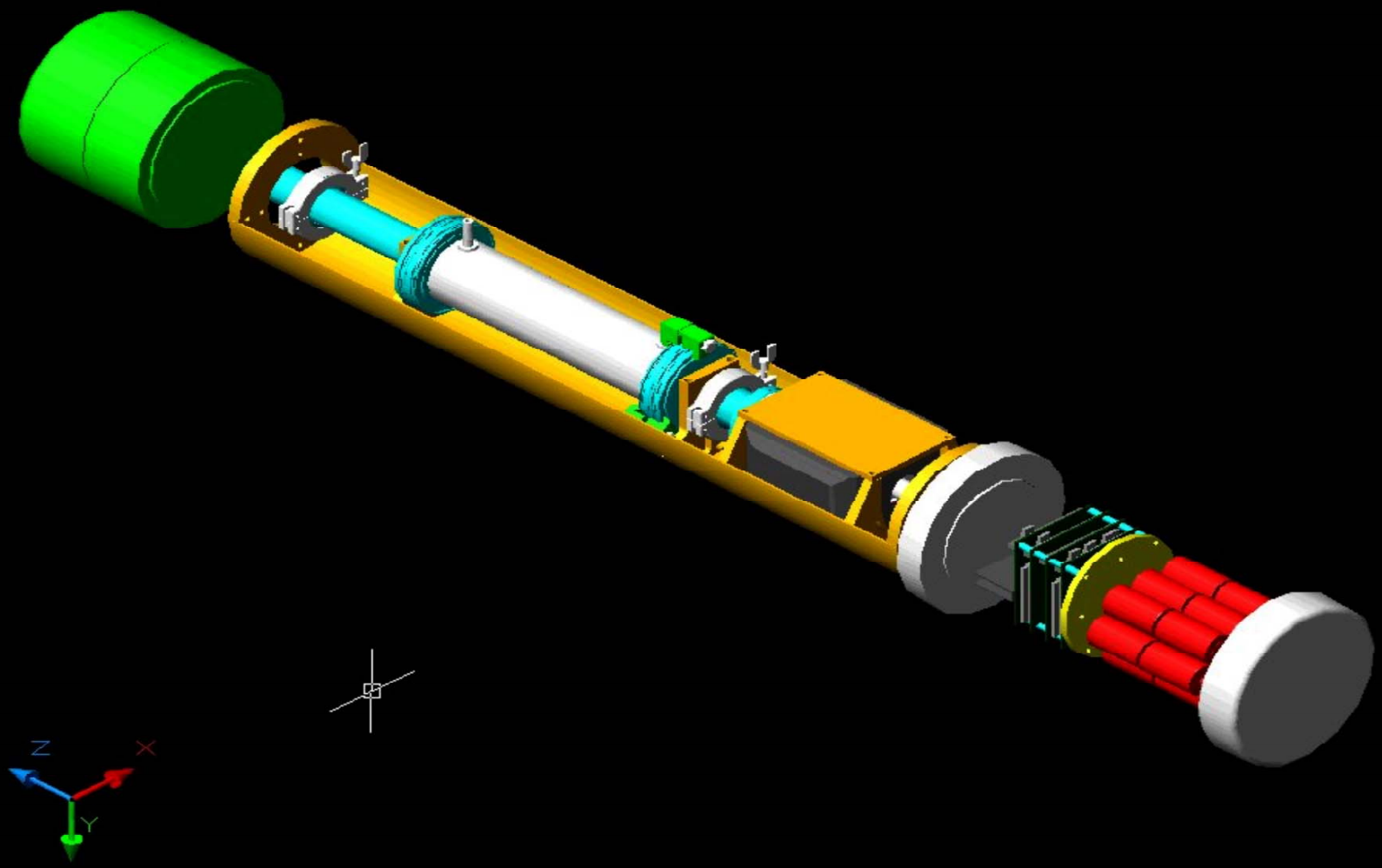
Project Goals

- Develop low-power submarine ms system (<10 watts peak power)
- Attempt direct injection of liquids to include dissolved ions and compounds as well as dissolved gases and volatile compounds (via MEMS)
- Design ms system to go as deep as possible, with full ocean depth as goal
- Explore use of capillary electrophoresis (CE) to separate large organics, etc.
- Capitalize on unique features of RFMS
  - Rugged, compact design
  - Modest vacuum (10-100 mT) operating conditions
  - Low-power RF generation
  - High mass resolution (to 1000)
  - High mass range (1 - >100,000 amu) with soft ionization techniques

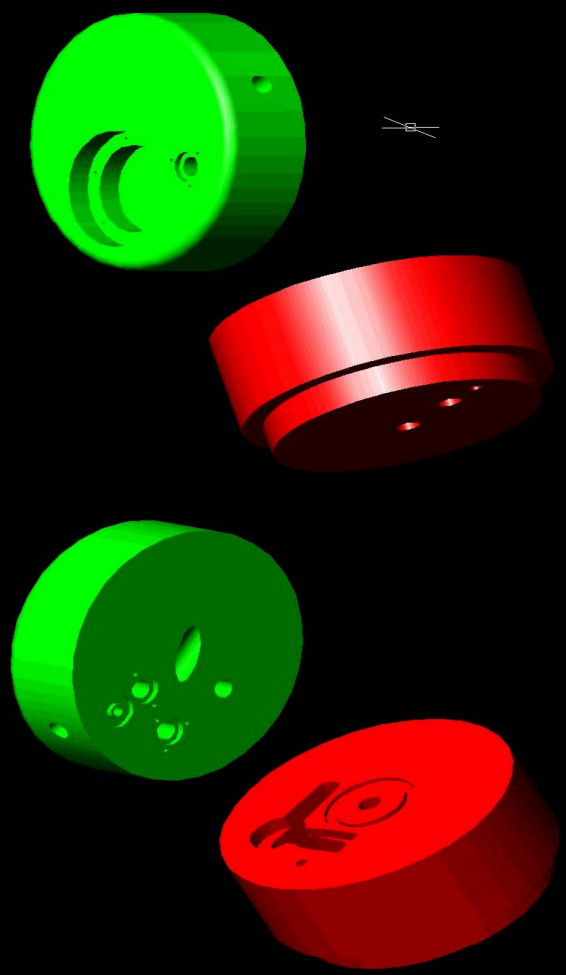
Mass SURFER Prototype

*(Mass **S**pectrometer **U**sing **R**otating **F**ields for **E**xploratory **R**anging)*

CAD schematic of the Mass SURFER with sample inlet assembly (green)



The Mass SURFER sample inlet assembly



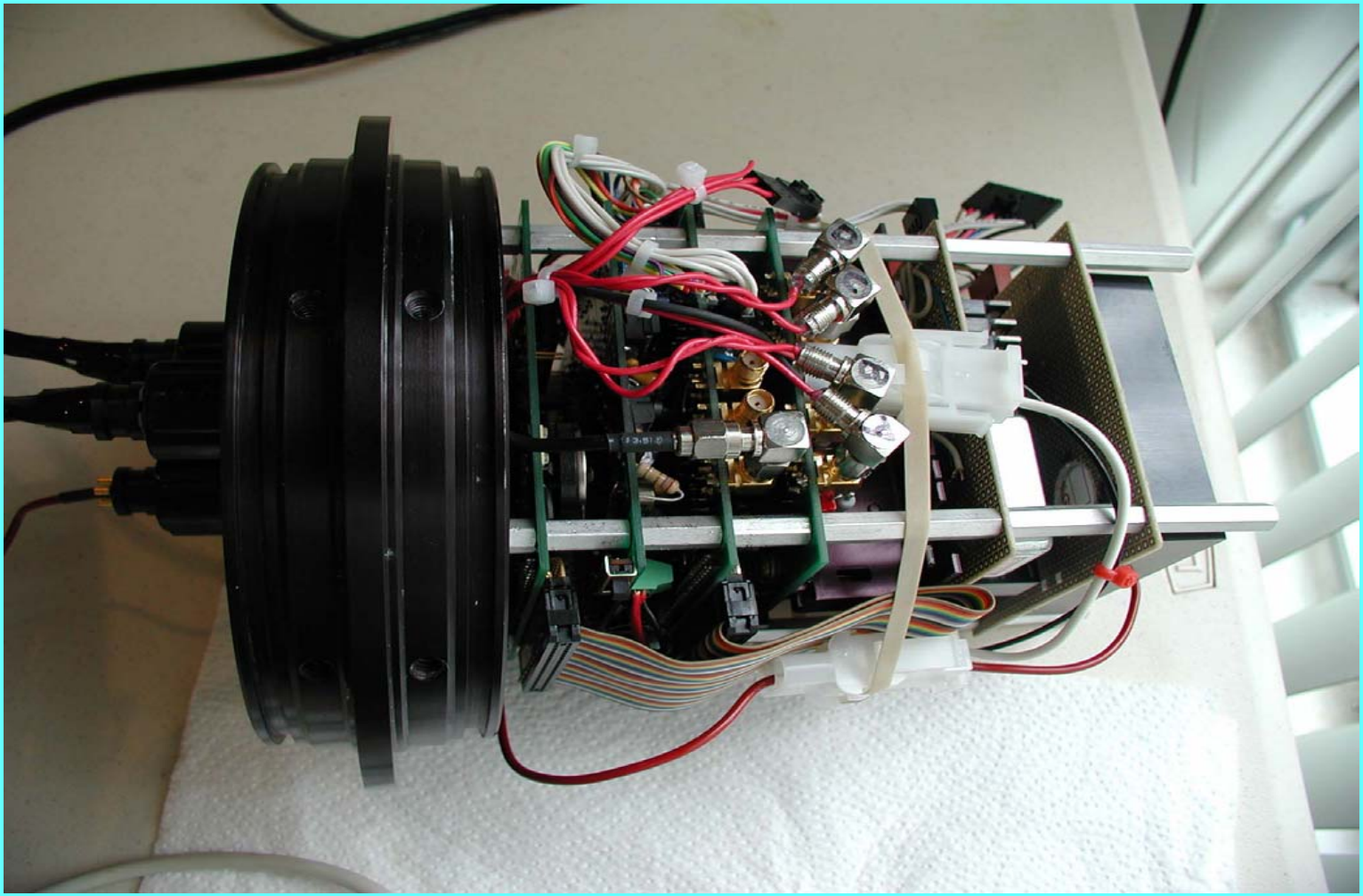
- Top: Front (green) and rear (red) halves of the Mass SURFER sample inlet assembly. Large hole on face denotes location for reference standard reservoir bladder (a pressure compensation); small hole denotes sampler rod inlet. Small hole on side denotes location of vacuum valve for external rough pump of waste vacuum.
- Bottom: Internal views of Mass SURFER sample inlet assembly. Oval hole is entry path for sample and reference standard to primary vacuum and RFMS. Round holes denote locations of dual rods for sampler and link to stepper motor driver (not shown).

Sampler Head Assembly

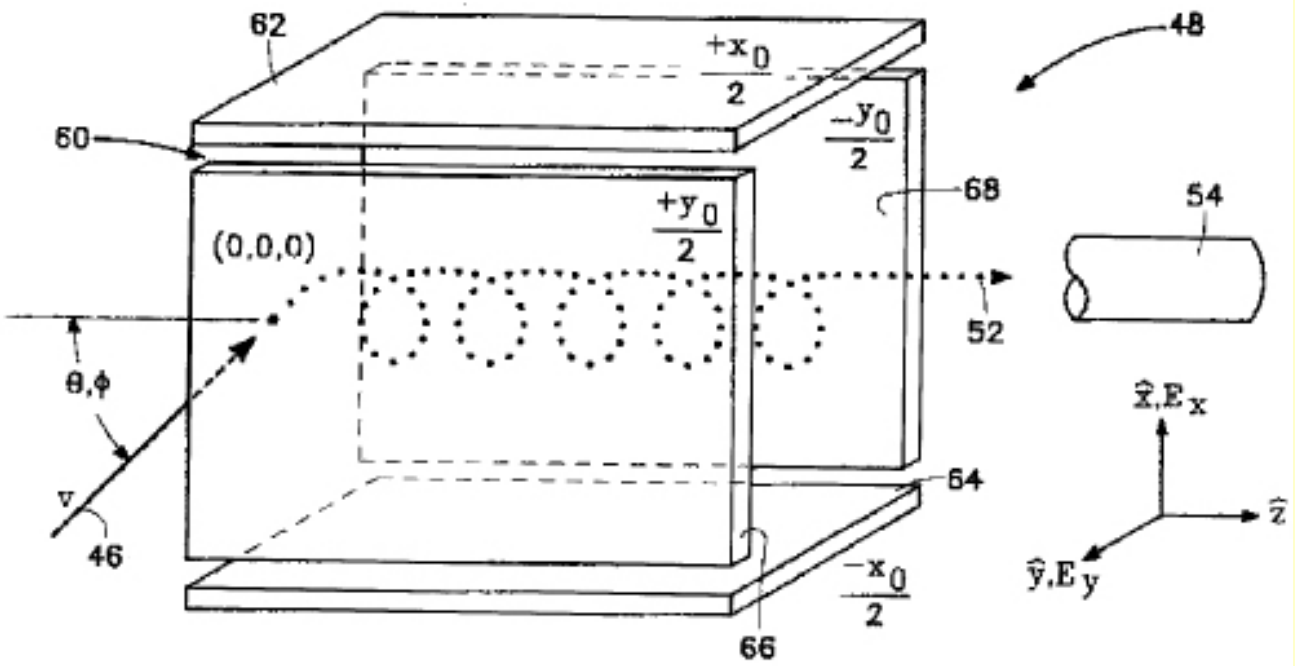
- Reciprocating grooved rod for sample and internal standard
- Sampler plenum
- Waste vacuum access port
- Silicon pressure-compensation bladder

Mass SURFER Electronics Stack

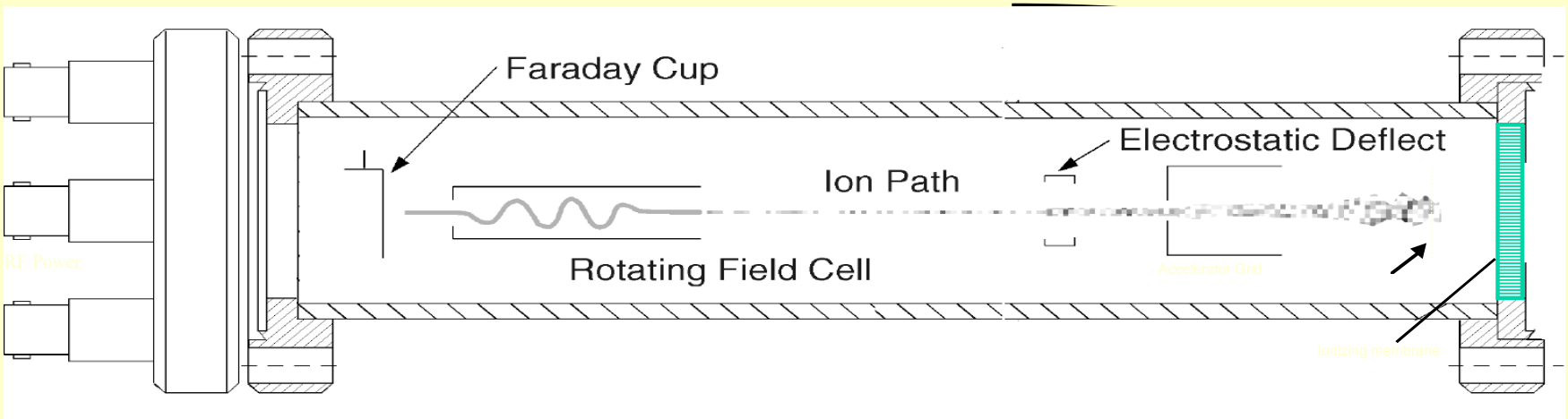
including High Voltage Supplies for ion optics and ion pump (topmost cards)



Schematic of rotating field spectrometer

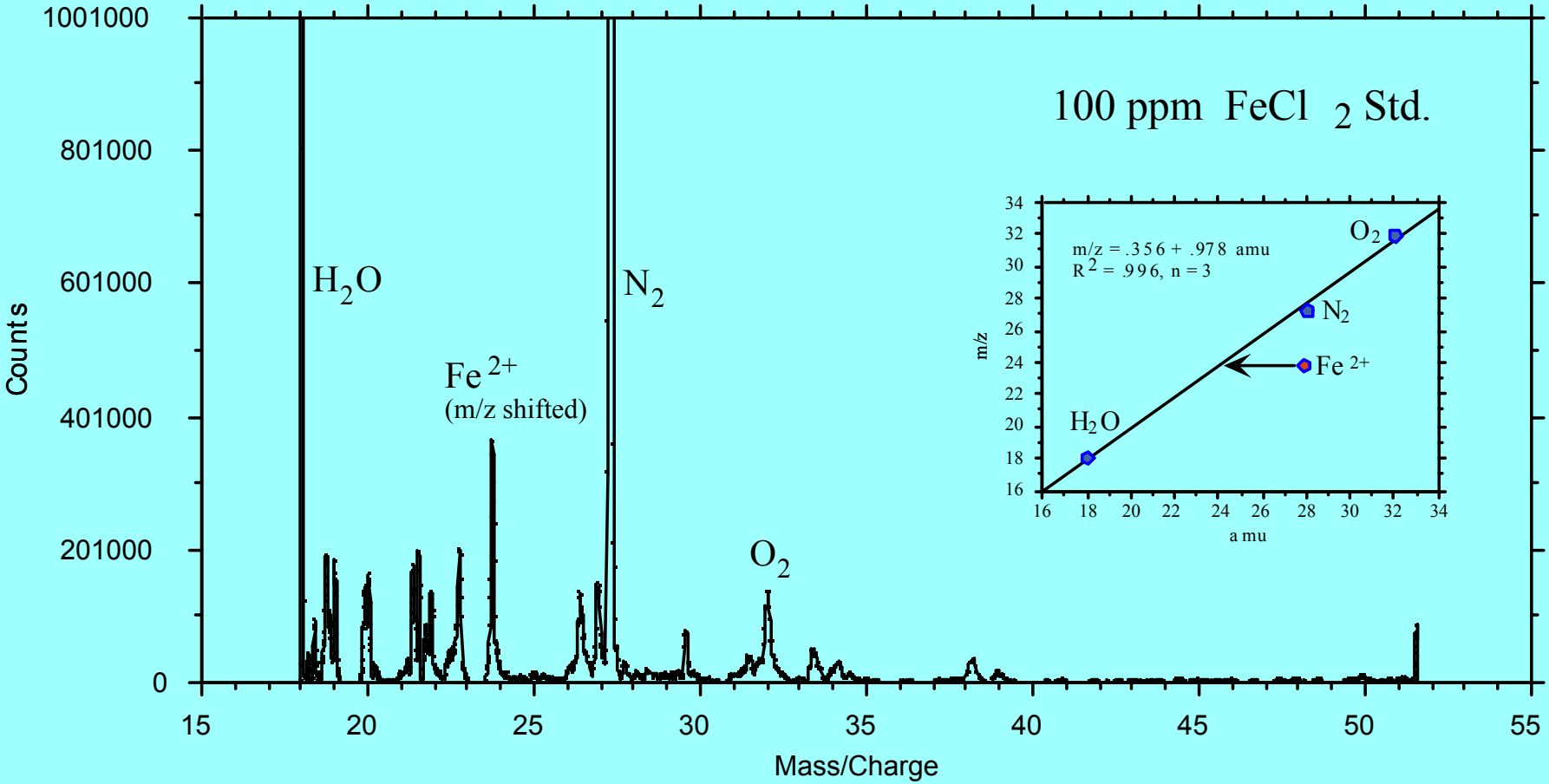


Field Ionization - Rotating Field Mass Spectrometer (FI-RFMS)

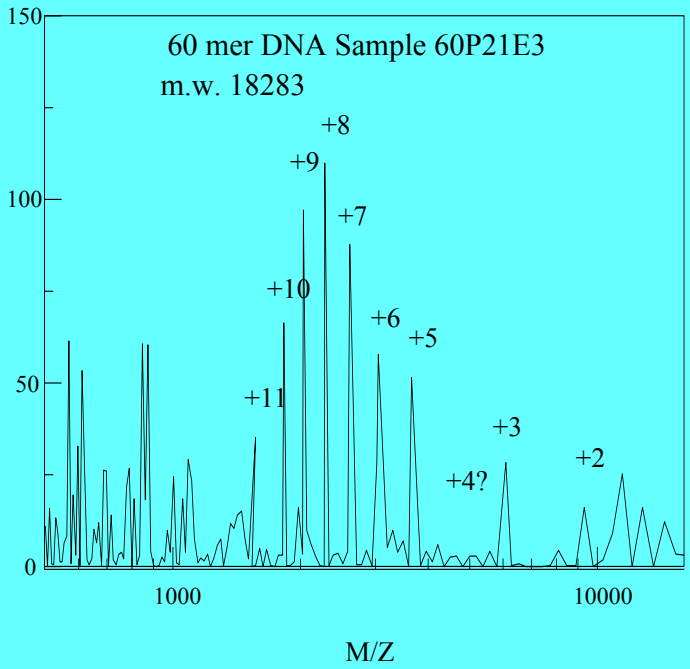


- **Unique mass spectrometer consisting of the field ionizer array, simple ion beam accelerator and lens optics, Rotating Field Mass Spectrometer (RFMS) and an ion detector**
- **Field ionizer array completely ionizes transit gas:**
  - **ionization is 'soft' - no species fragmentation**
  - **operates under Paschen curve - no plasma breakdown at any gas pressure**
  - **ion currents great enough to accommodate beam attenuation at pressures > 7 Torr**
  - **operational at both high and cryogenic temperatures**

Dissolved Fe^{2+} Determination



Sample RFMS DNA Spectrum



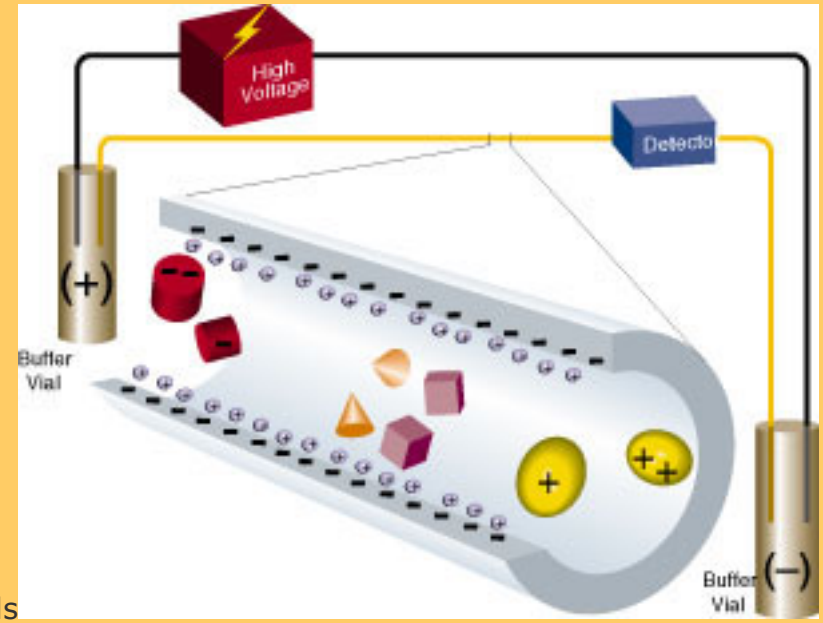
This is a mass/charge spectrum of a **60 mer DNA**, with some reasonable frequency corrections.

The spectral width at the high mass (low frequencies) was due to the RF oscillator skipping over a linear digital range.

For the RFMS large mass ions, we should have a log frequency scan.

Capillary Electrophoresis: A Simple Technique

The large selection of separation mechanisms combined with its "in solution" approach has allowed capillary electrophoresis to excel where many analytical techniques have failed. CE has been successful primarily with complex hydrophilic macromolecules and highly charged solutes. These techniques have led to the rapid separation and quantitation of:



* Nucleic Acids
* Proteins
* Glycoproteins
* Peptides
* Carbohydrates
* Basic Pharmaceuticals
* Chiral Isomers
* Inorganic and Organic Ions

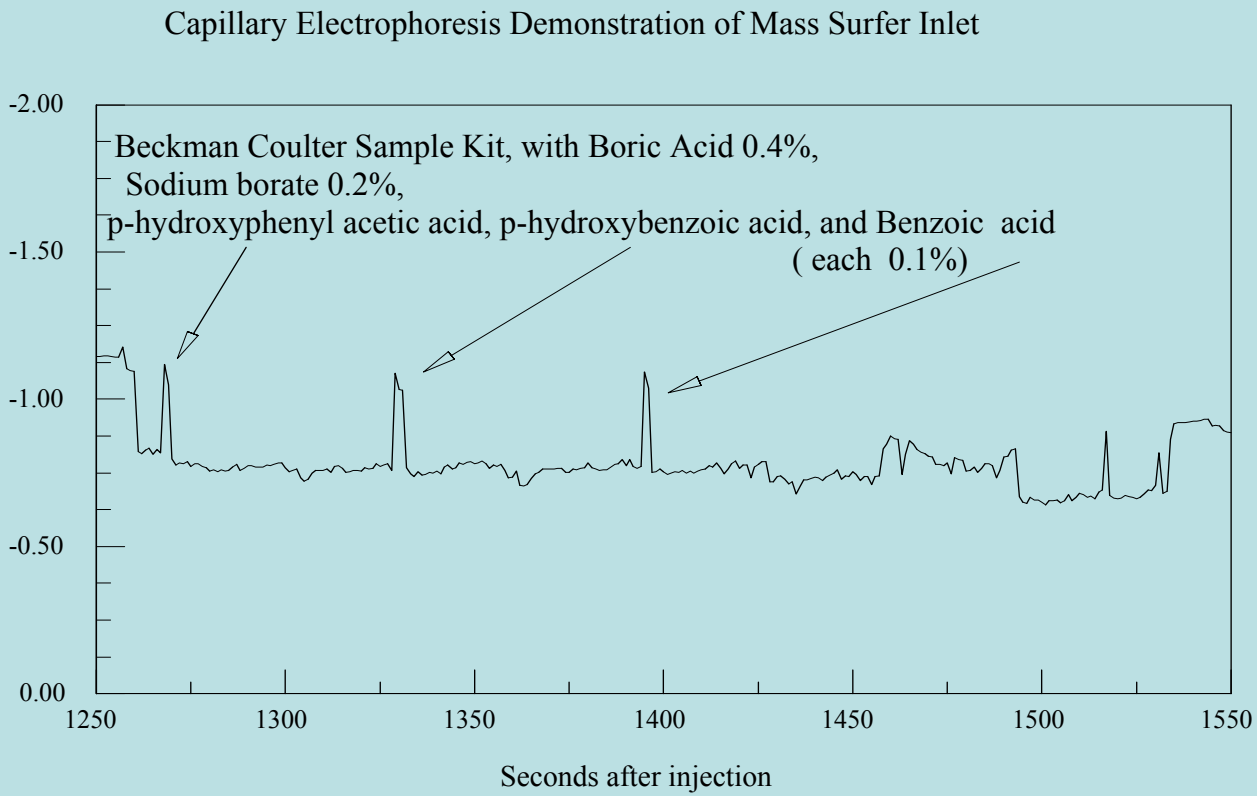
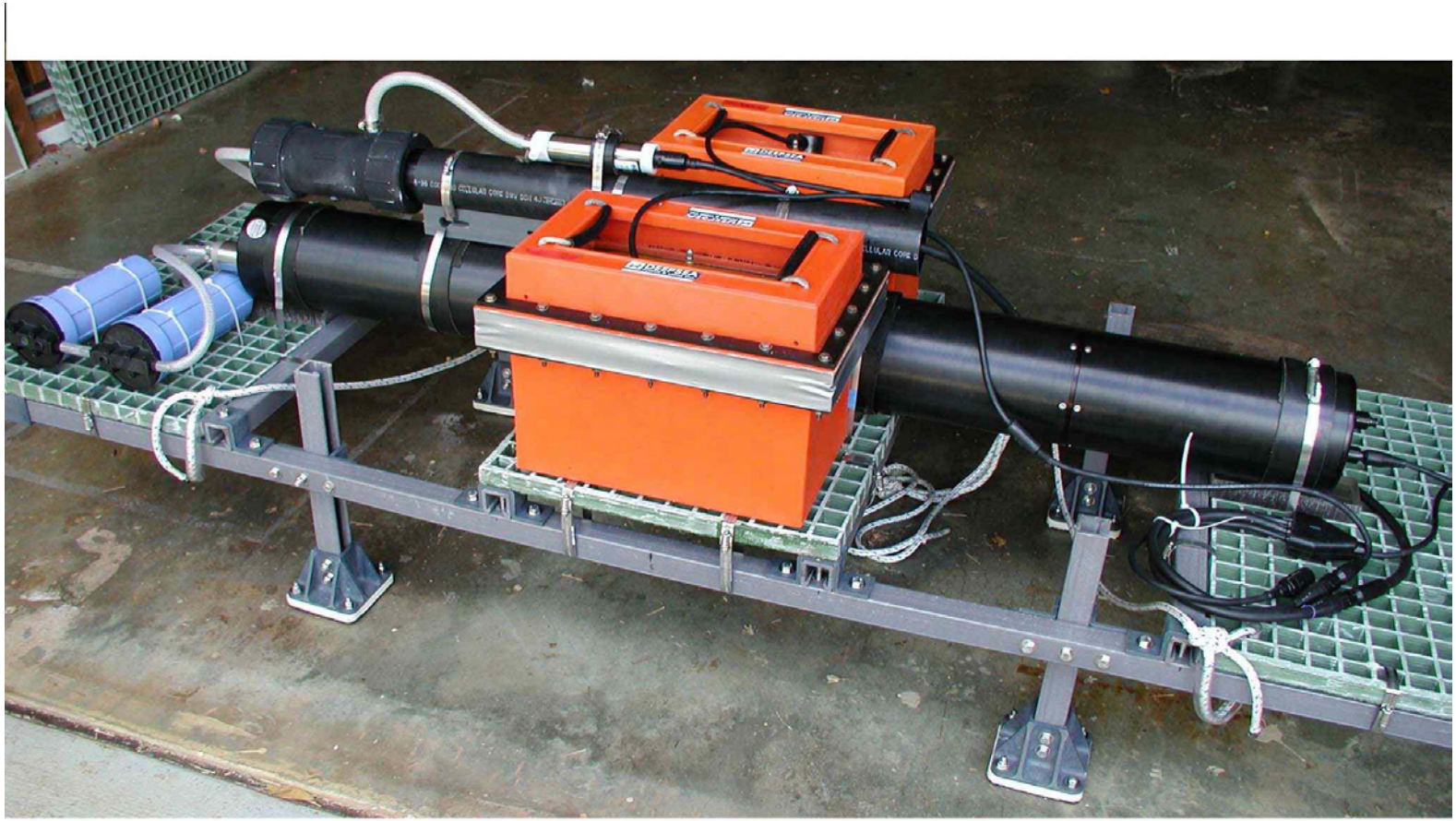
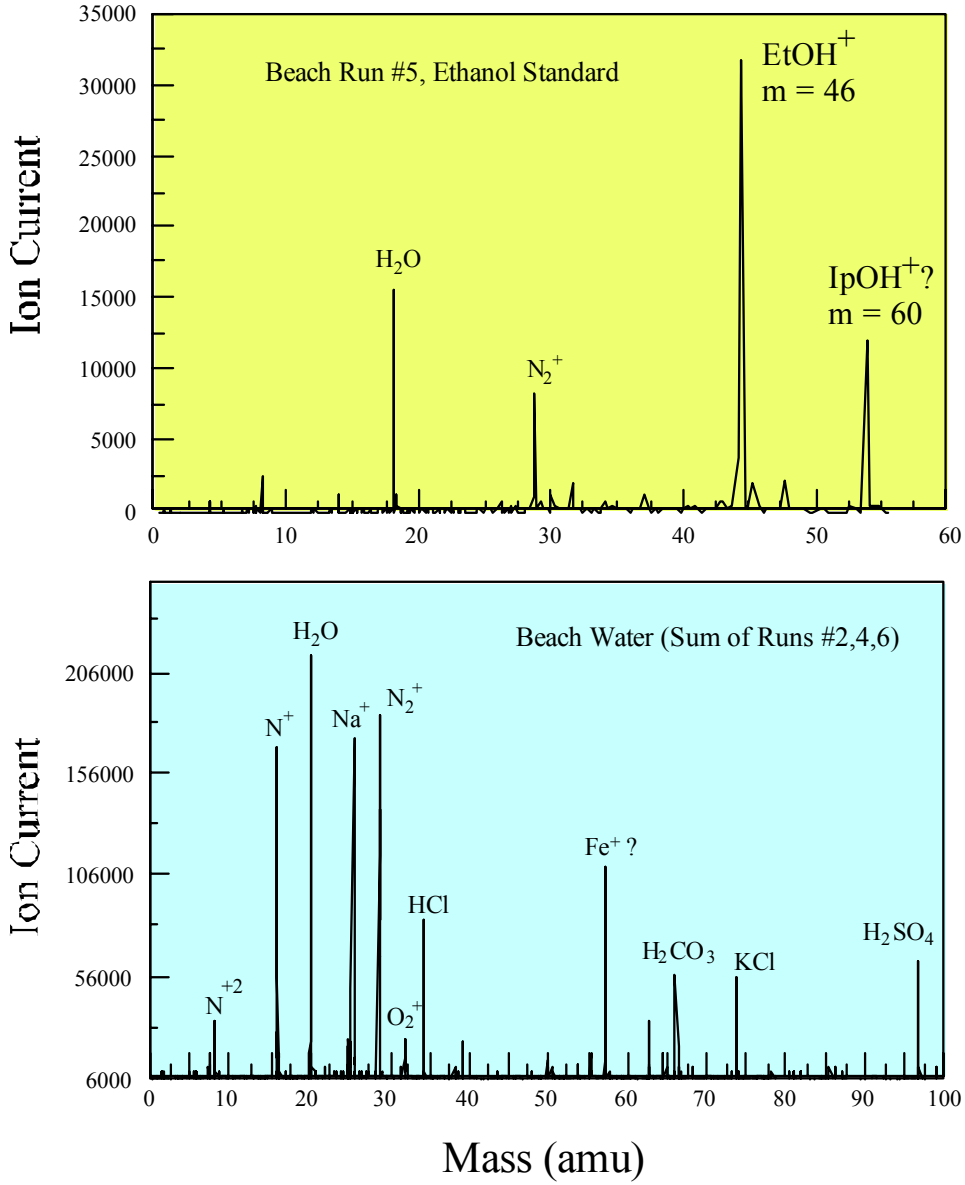


Figure 24. *Capillary Electrophoresis demonstration of Mass SURFER sample inlet. Four sharp peaks are detected, the first three of which are identified and labeled.*

Mass SURFER on deep deployment frame

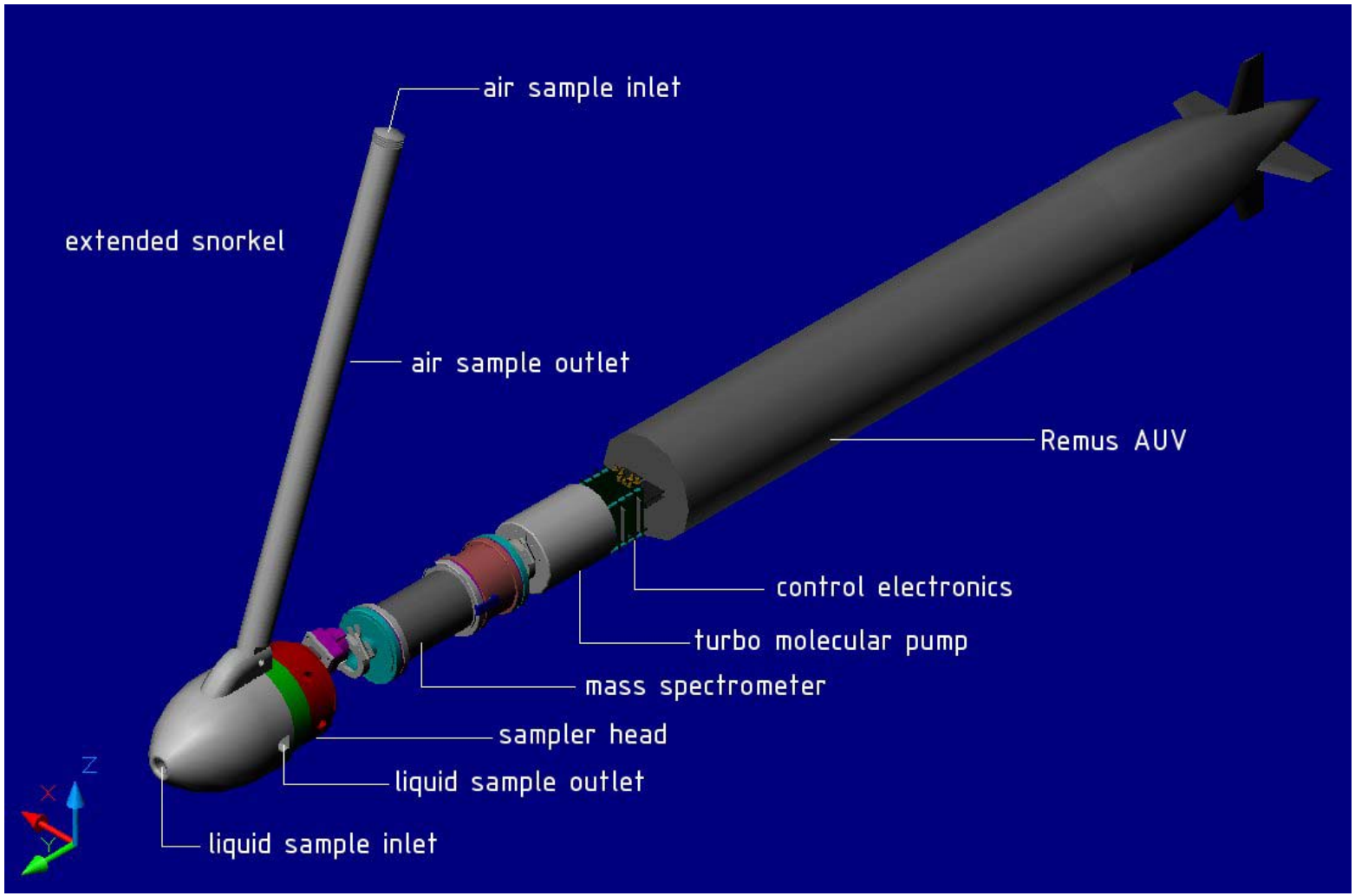


Maunalua Bay, Oahu, Hawaii Test



R/V Kilo Moana deployment, Sept., 2002

Schematic of US Navy STTR



Progress Summary

- Achieved low-power consumption (<10 Watts peak power).
- Sampler head can directly sample aqueous environment (e.g., seawater) to full-ocean depth.
- Mass SURFER system test successful to 2500 m (primary, waste vacuums, RFMS).
- RFMS used to directly analyze seawater, but nano-ESI and RFMS needs further work to stabilize flow and obtain better precision.
- Long-term monitoring will require method to eliminate or reactivate ion pump, presently the system power hog.