Quadrupole Ion Trap Mass Spectrometer for Ice Giant Atmospheres Exploration

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OVERVIEW

INTRODUCTION

Why Ice Giants:

- Different from terrestrial planets
- Different from gas giants
- Largely unexploited (only CH_4 and H_2S)

What species: NH_3, H_2O, trace species, noble gases & their isotope ratios

Why probe: Noble gases & isotope ratios require in-situ measurements

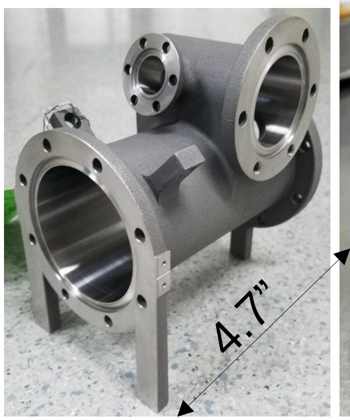
In what conditions – challenging:

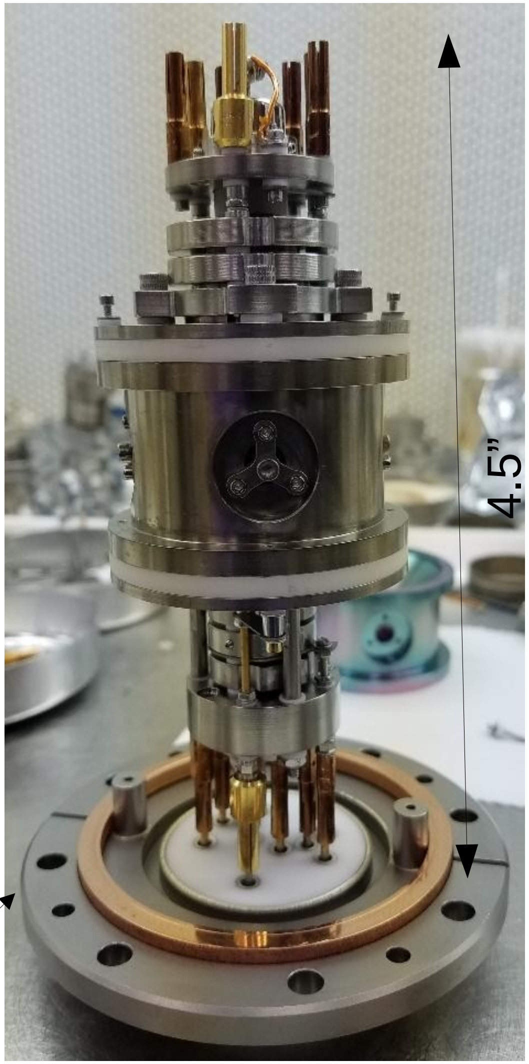
- Short time window for relaying data
- Absorption of the signal in the atmosphere
- Battery life
- Increasing pressure and temperature

Solution: Robust and lightweight instrument with low power consumption and high sensitivity, capable of operating in rapidly changing environment

OUR INSTRUMENT

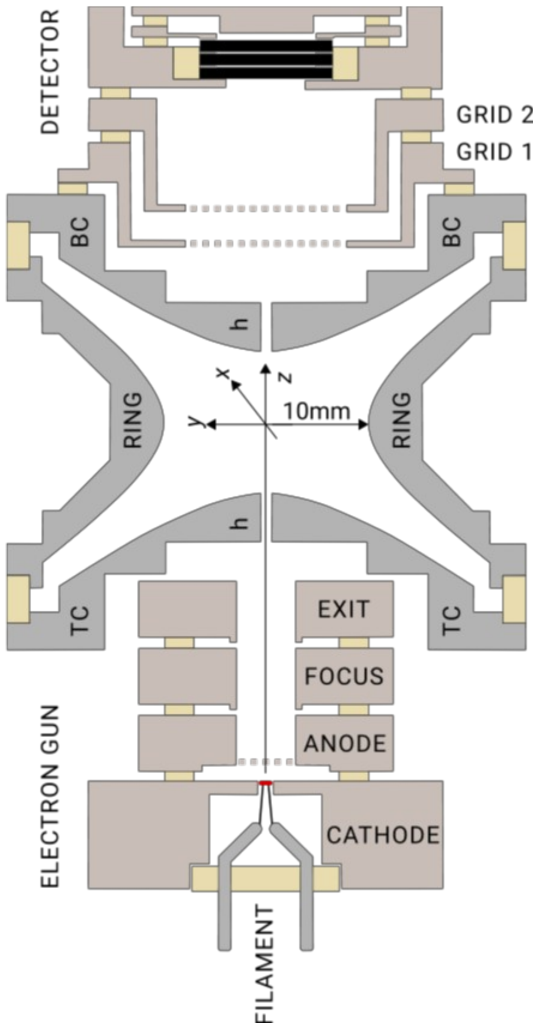
- Quadrupole Ion Trap based, 7.5kg, ~30W, no wires, no moving parts
- 10^{13} counts/torr/sec, 1-600 Th, $m/\Delta m$ = 12000 @ 40 Th
- Operates without He buffer gas at base pressure of 1×10^{-10} torr
- Different modes of operation
- Electronics fits into 4U
- Measuring MCA on ISS since beginning of August 2019
- Novel inlet system (up to 60bar, <1ms response time, adjustable)
- Autonomous operation

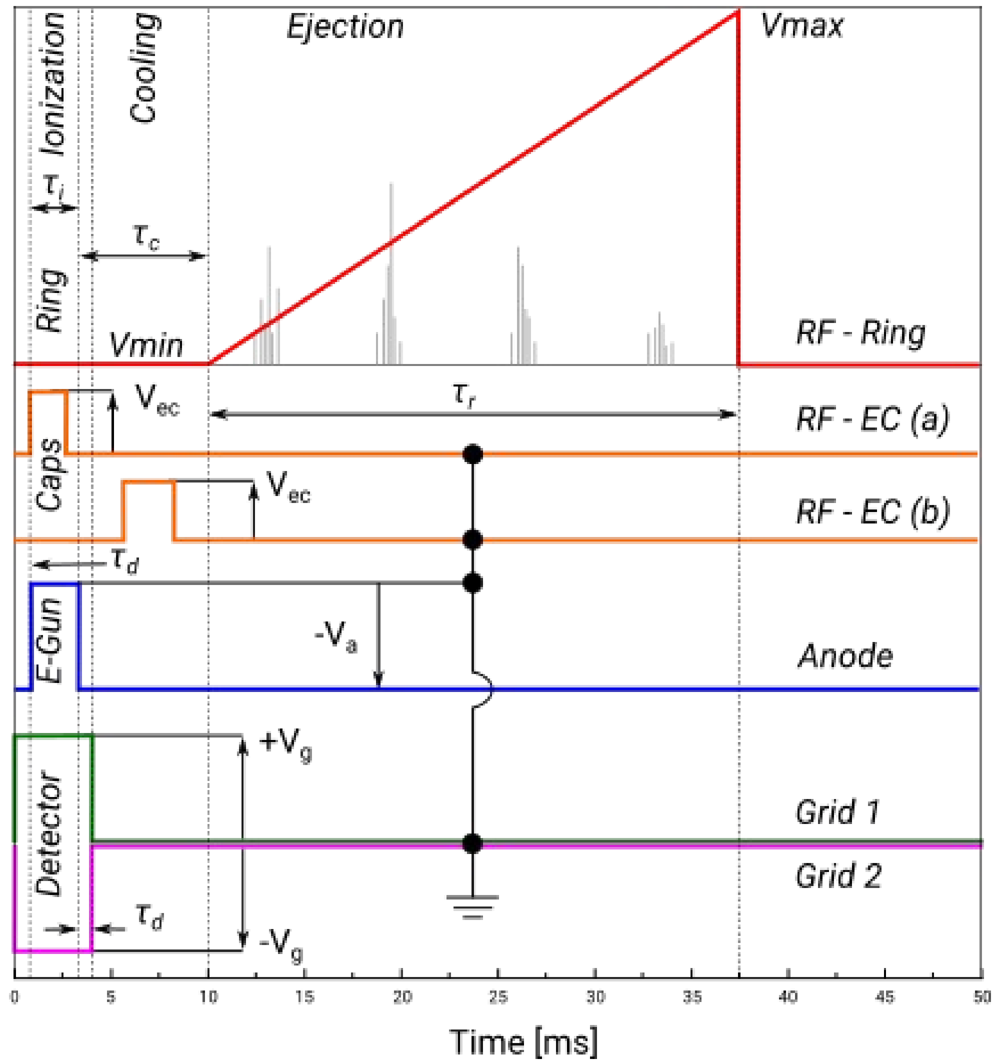




OUR INSTRUMENT - MODES OF OPERATION

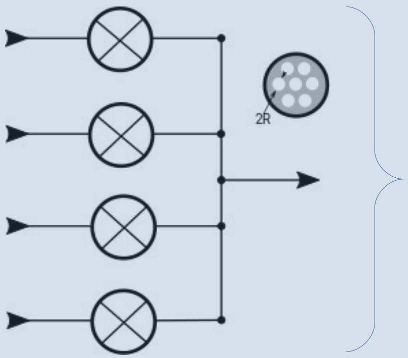
dynamic, static	dipole excitation, resonant ejection	piece-wise ramping





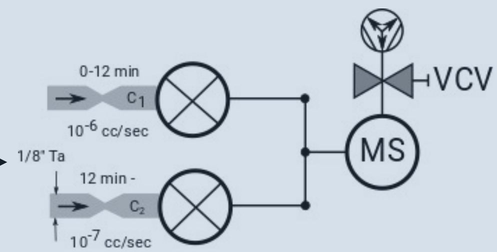
INLET SYSTEM - STATE OF THE ART

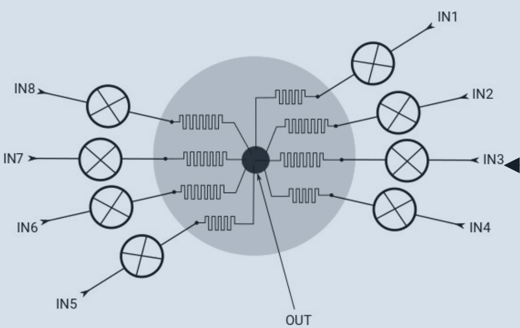
Glass capillaries + Valves



Galileo (Jupiter): 0.15-20bar, ~60 min
Huygens Probe (Titan): 0.003-1.5bar, 170km-0
Phoenix (Mars): 6mbar, surface

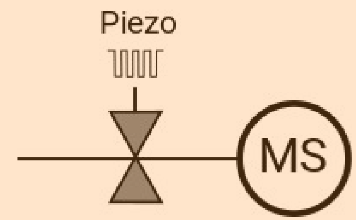
Pioneer (Venus): 0.1-100bar, ~60min





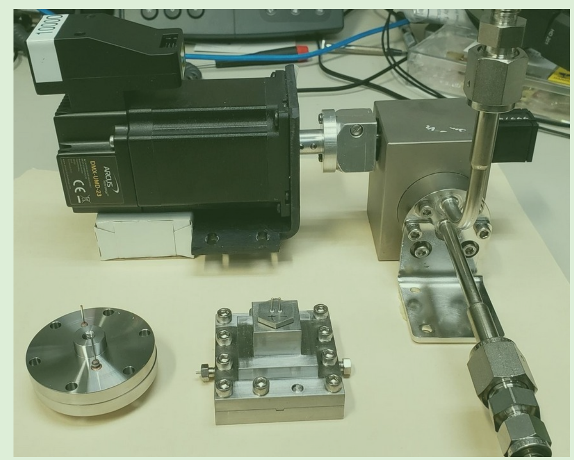
Goddard microleak: 1-100 bar (200psi with Mindrum), MEMS

Piezoelectric-pulsed

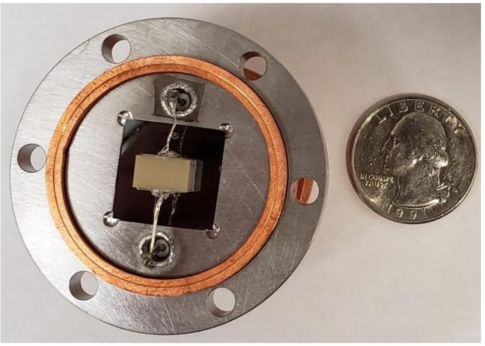


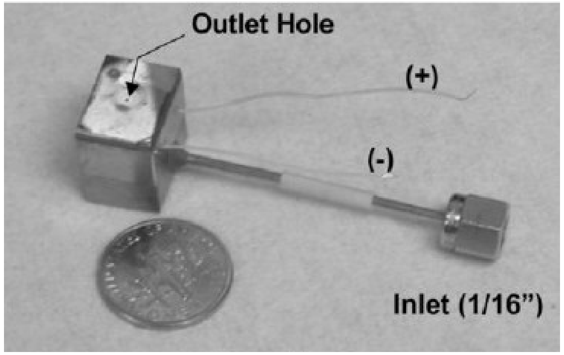
Venera 11/12 (Venus): 23km-2km

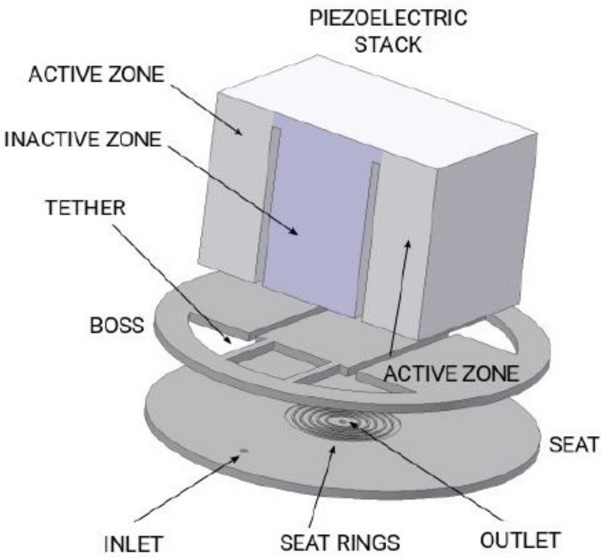
Lab standard



INLET SYSTEM - OVERVIEW





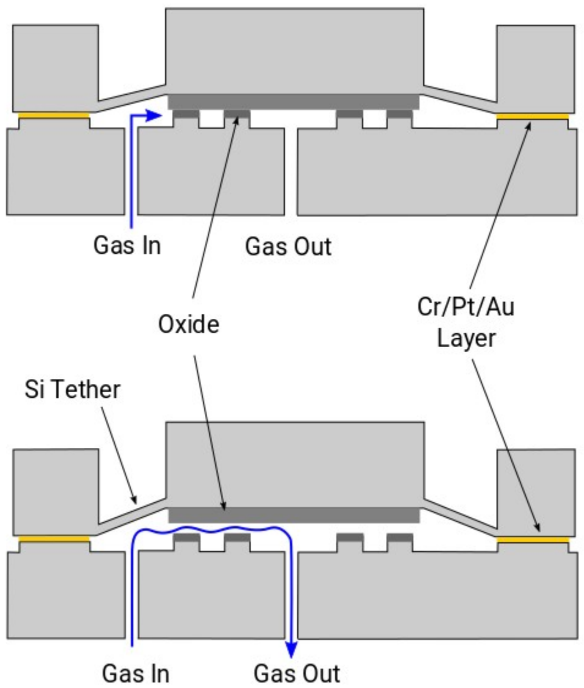


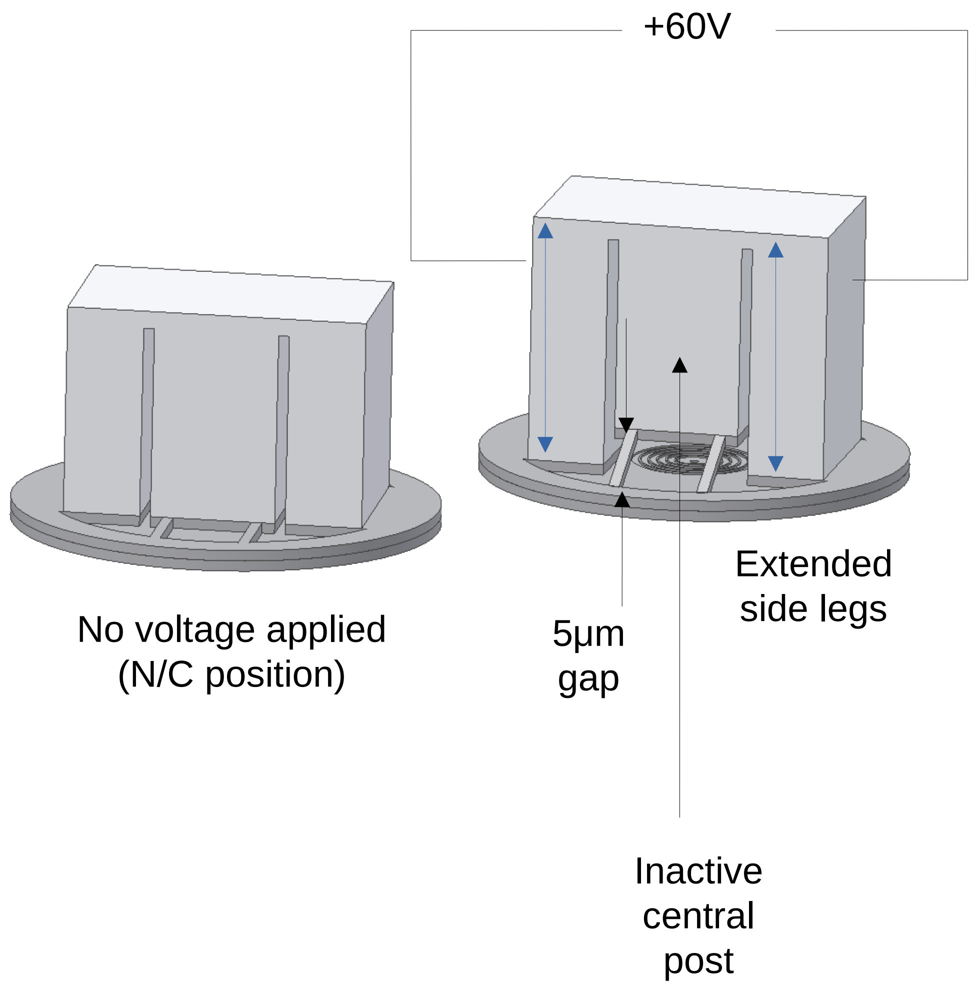
PZT properties	Specifications
Max Voltage	+60V
Min Voltage	-10V
Displacements	+5um @ +60V -1um @ -10V
Blocking Force	1000N
Capacitance	1700nF
Curie Temp	235^{o}C
Max op. Temp	125^{o}C

Developed at JPL 12 years ago for high-pressure gas micro-propulsion applications

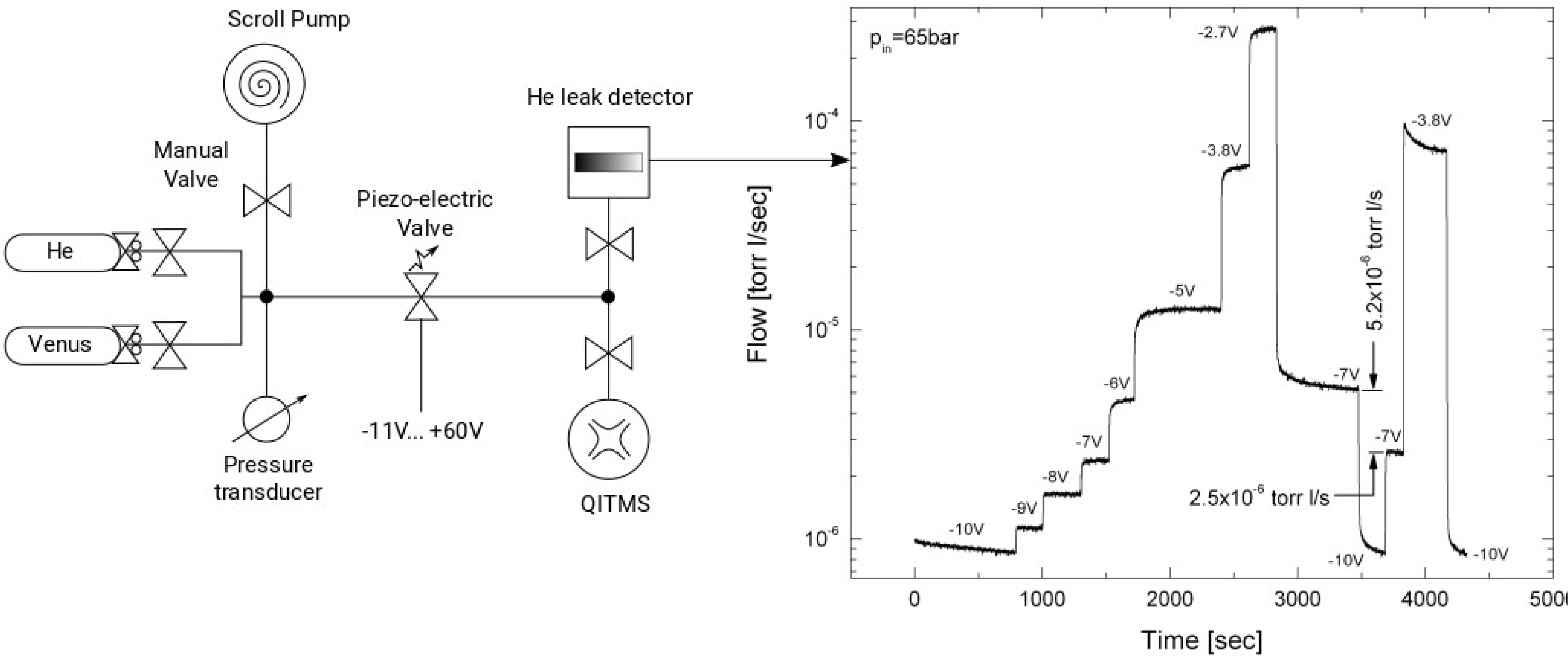
- Measured He leak rates of 1×10^{-6} torr l/s @ 55 bar in its "normally closed" position.
- Tested up to pressure difference of 69 bar (maximum allowed pressure of the test rig)
- Could operate up to 125^{o}C.
- Pulsed (1kHz) or static operation

INLET SYSTEM - PRINCIPLE OF OPERATION





INLET SYSTEM - PERFORMANCE



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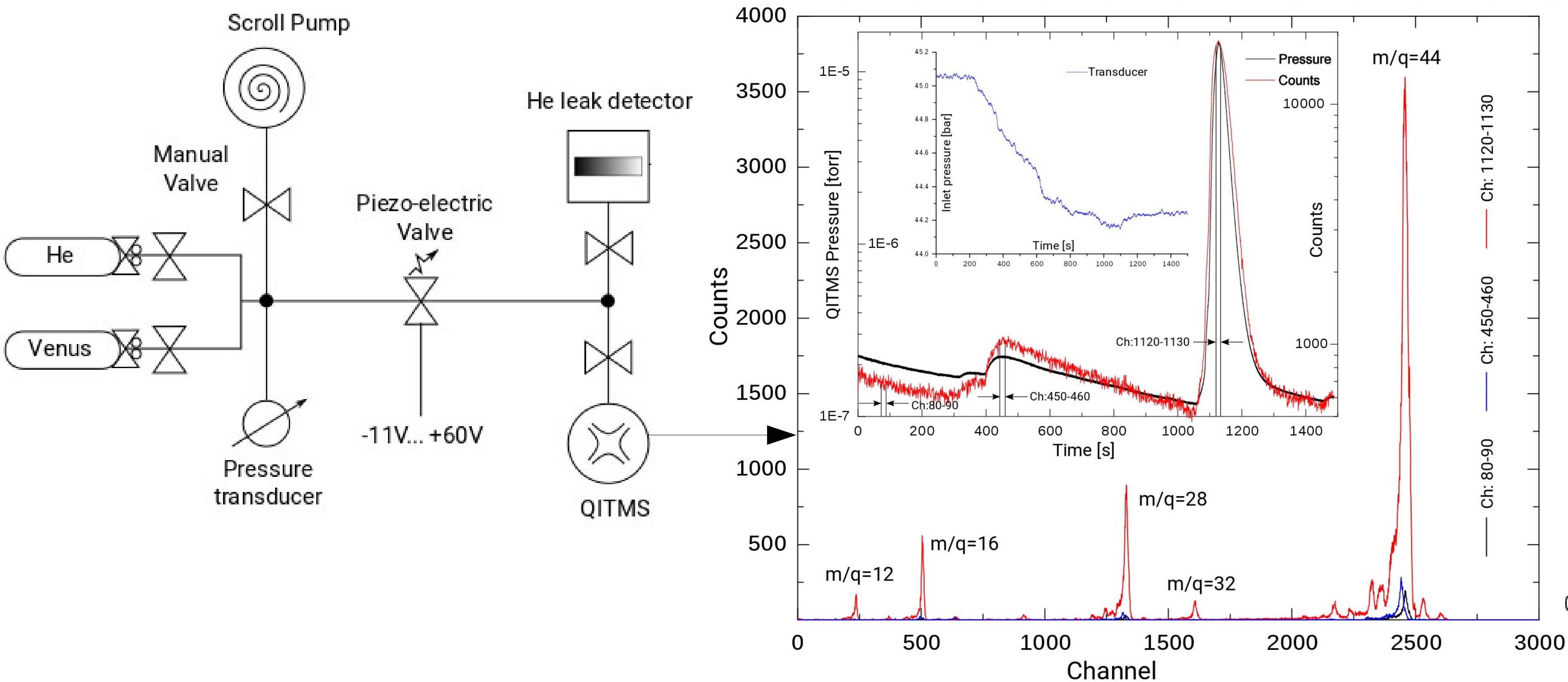
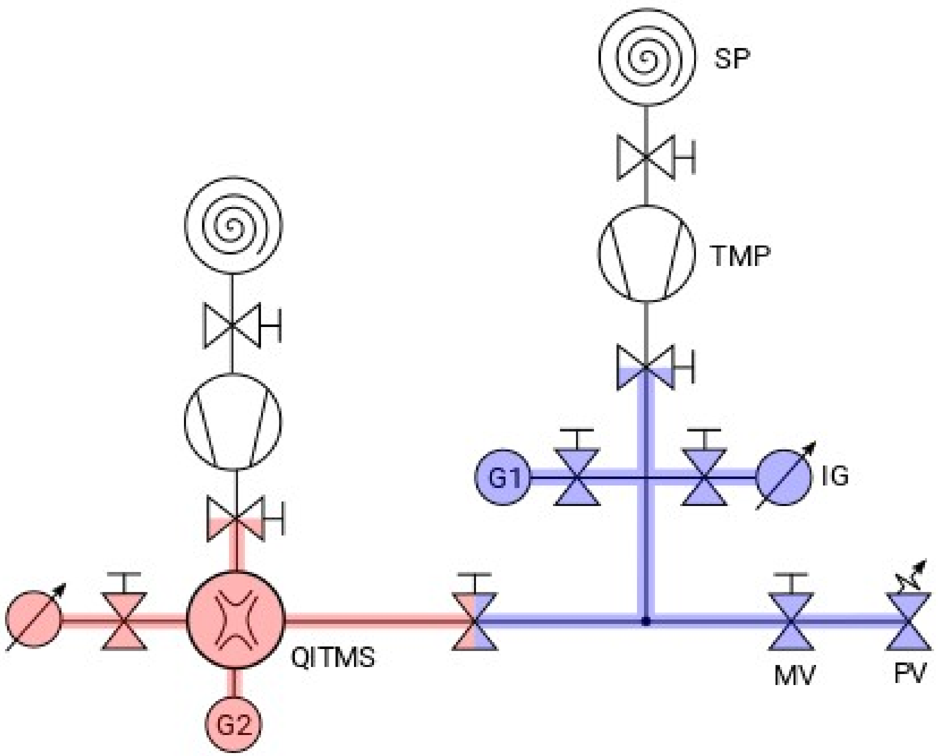
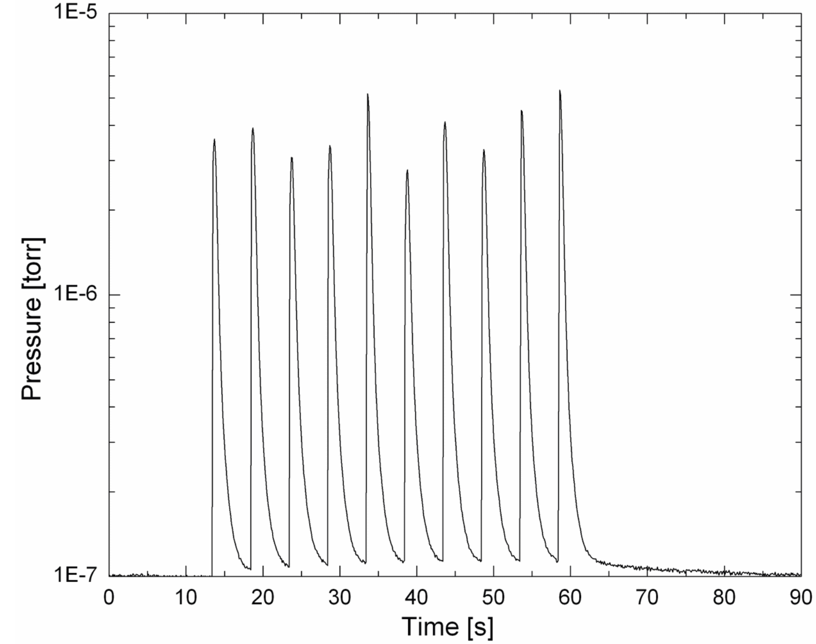
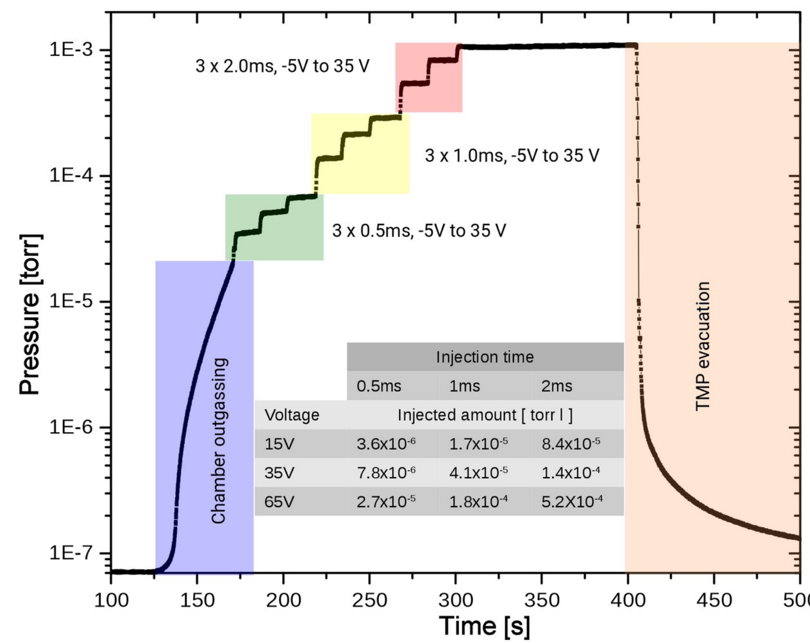


INLET SYSTEM- CALIBRATIONS

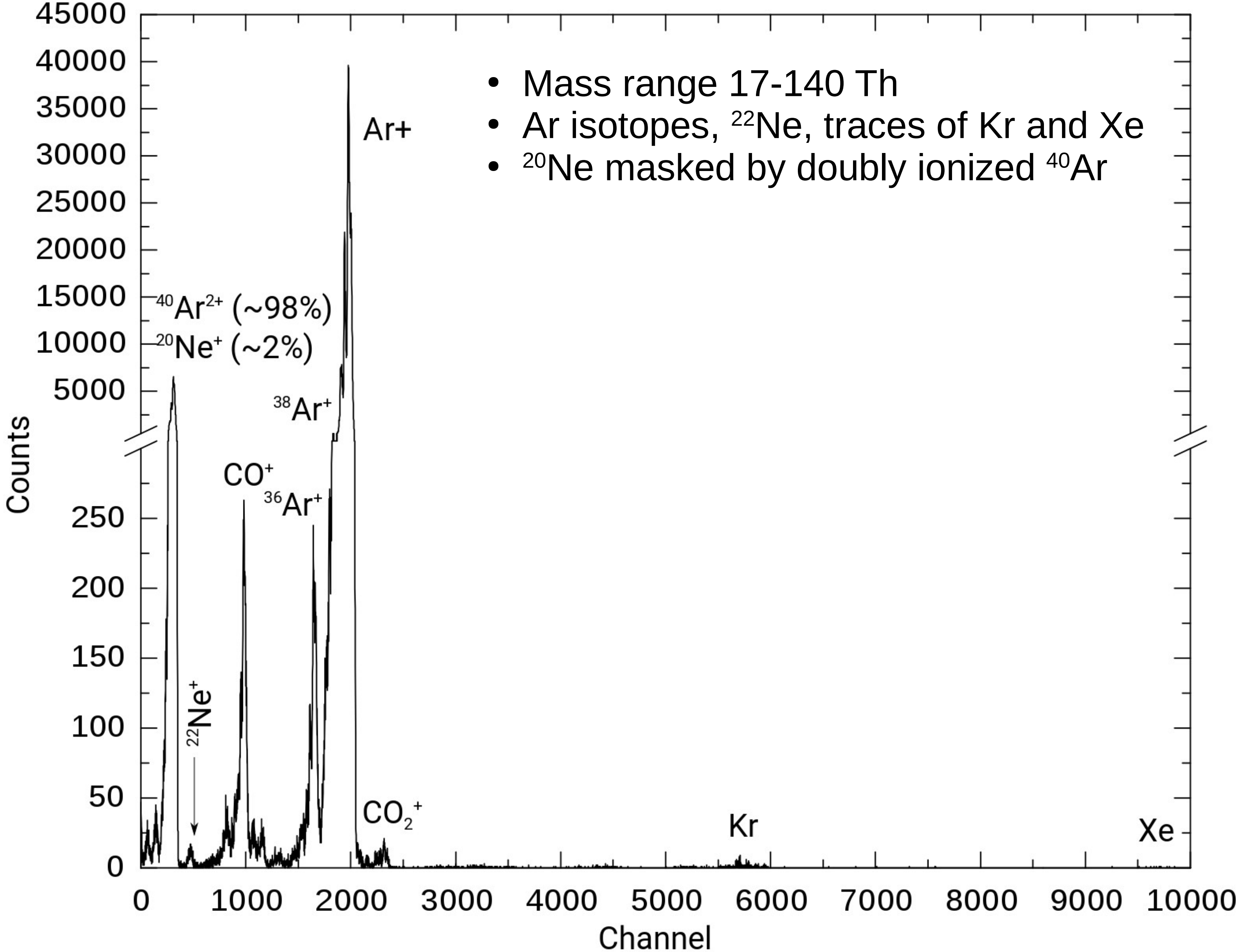




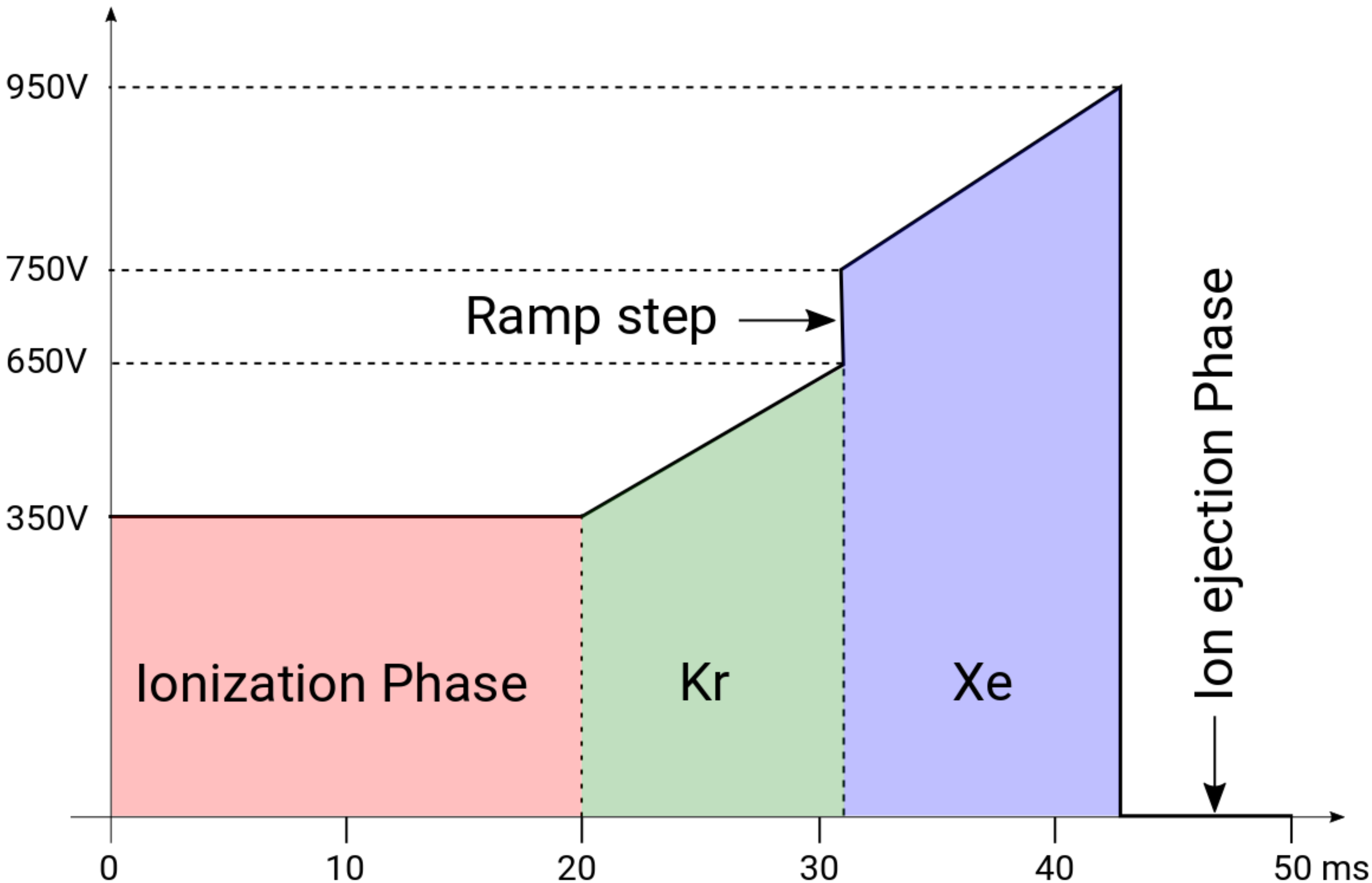


	Injection time		
	0.5ms	1ms	2ms
Voltage	Injected amount [torr l]		
15V	$3.6x10^{-6}$	$1.7x10^{-5}$	$8.4x10^{-5}$
35V	$7.8x10^{-6}$	$4.1x10^{-5}$	$1.4x10^{-4}$
65V	$2.7x10^{-5}$	$1.8x10^{-4}$	$5.2X10^{-4}$

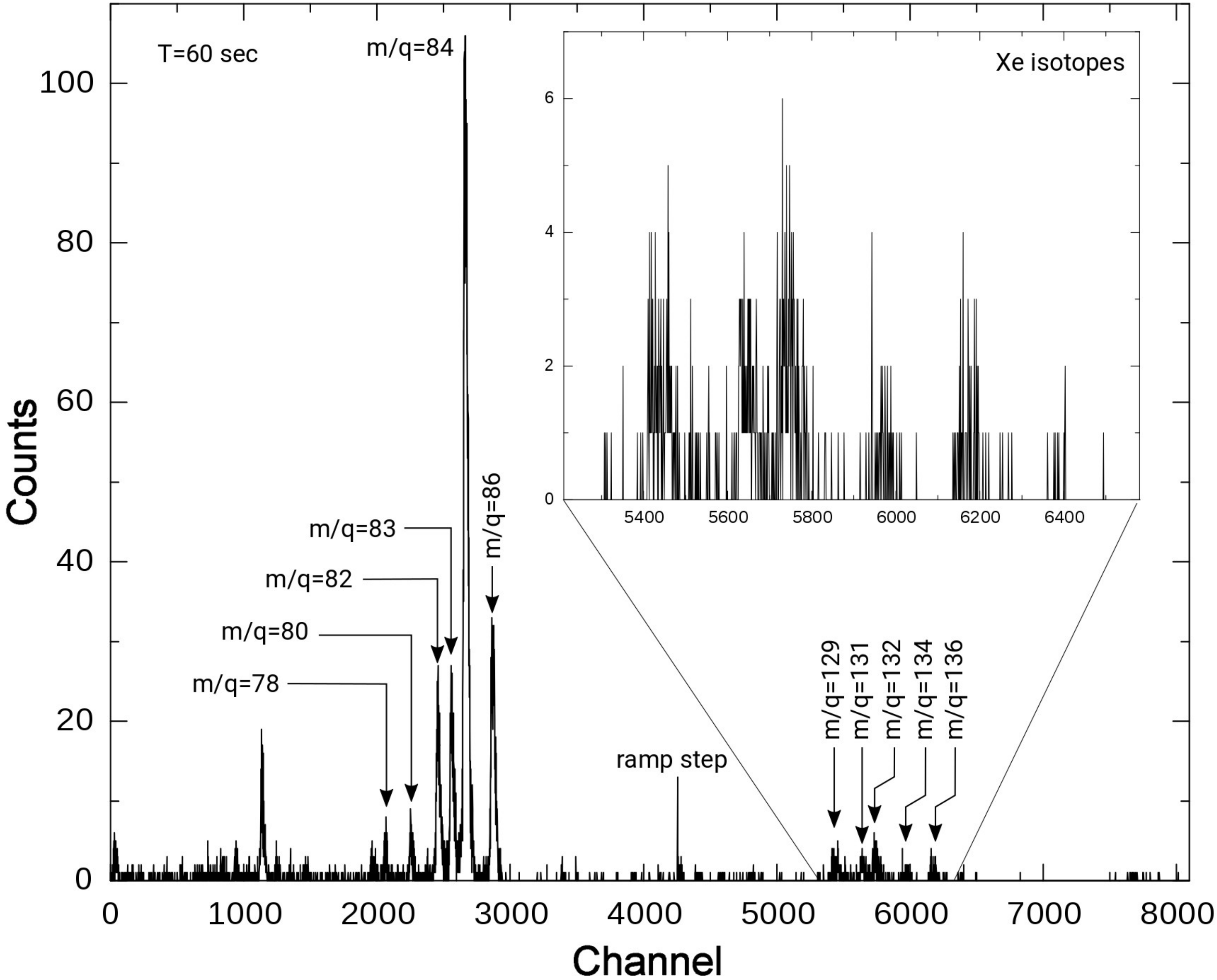
NOBLE GASES FROM AIR – SIMPLE RAMP



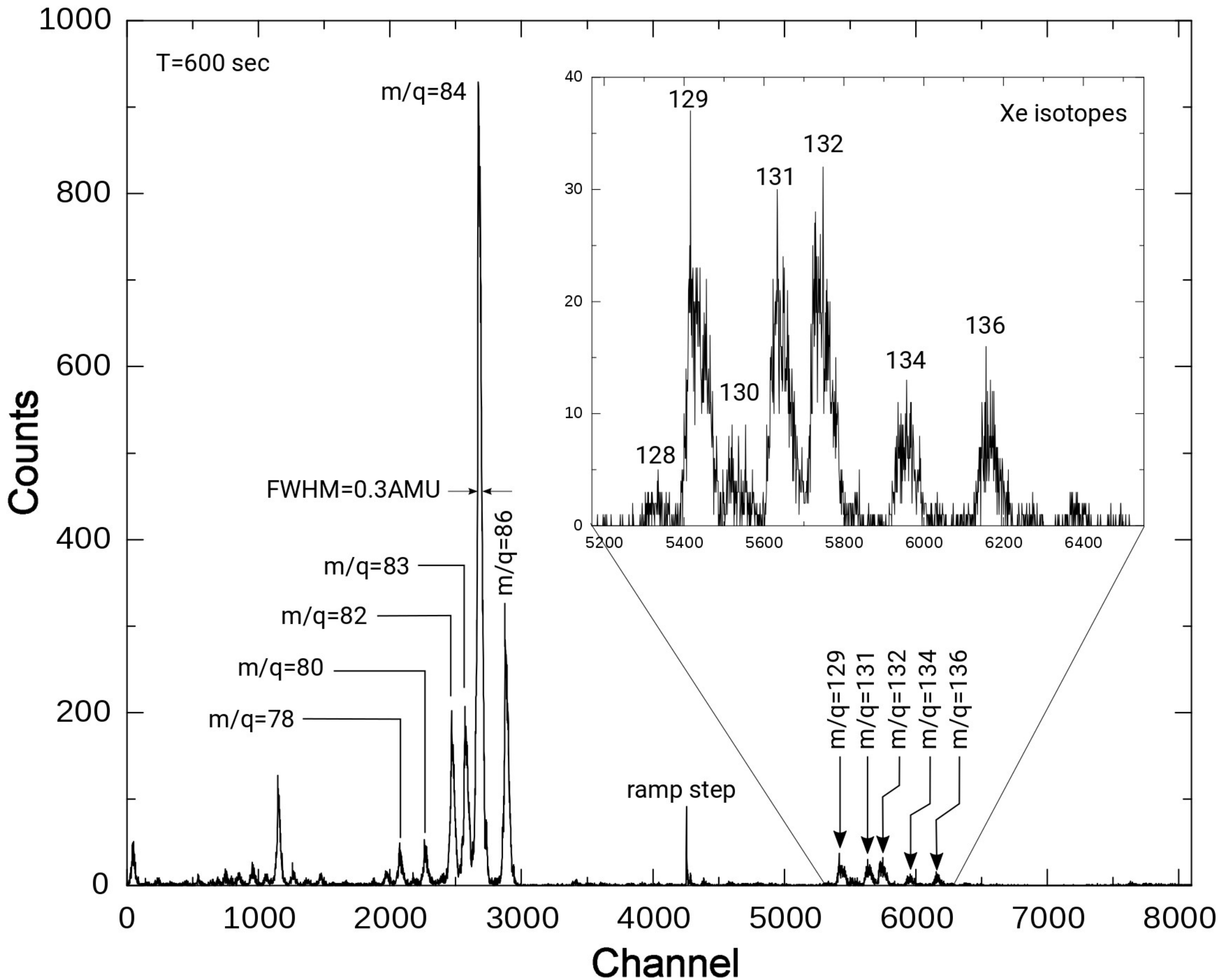
NOBLE GASES FROM AIR – PIECE-WISE RAMP



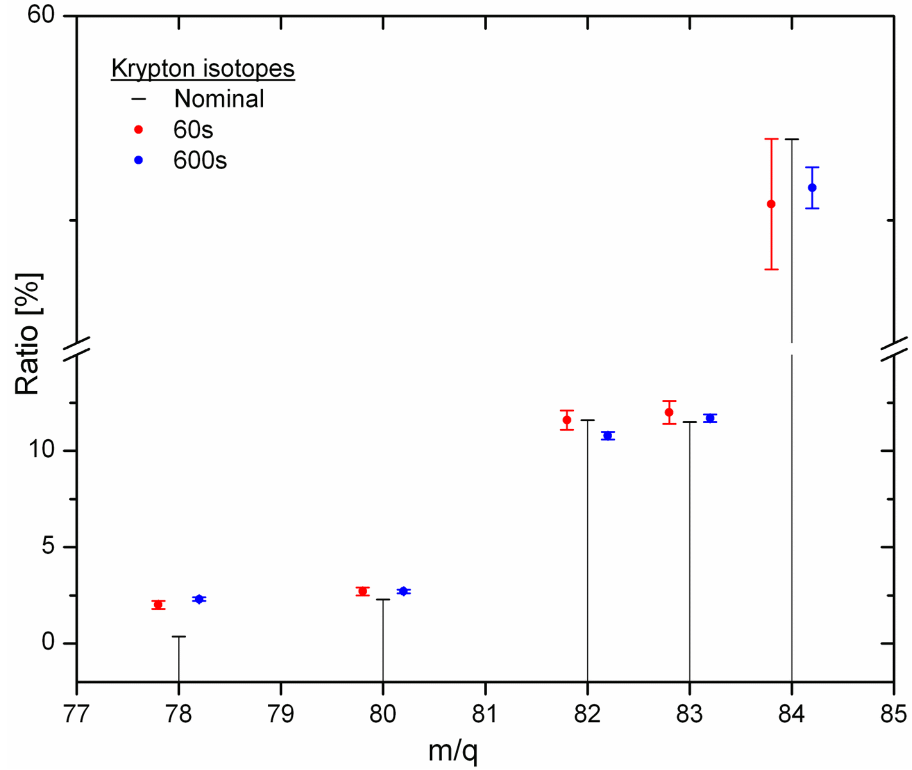
NOBLE GASES FROM AIR – 60 SEC



NOBLE GASES FROM AIR – 600 SEC

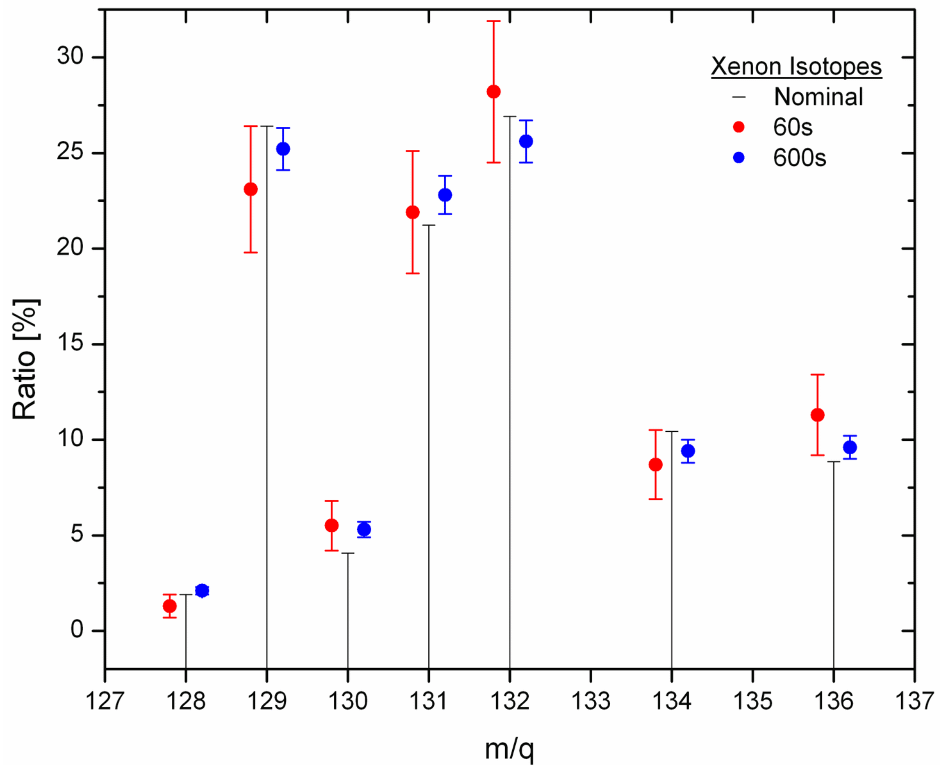


NOBLE GASES – RESULTS (KRYPTON)



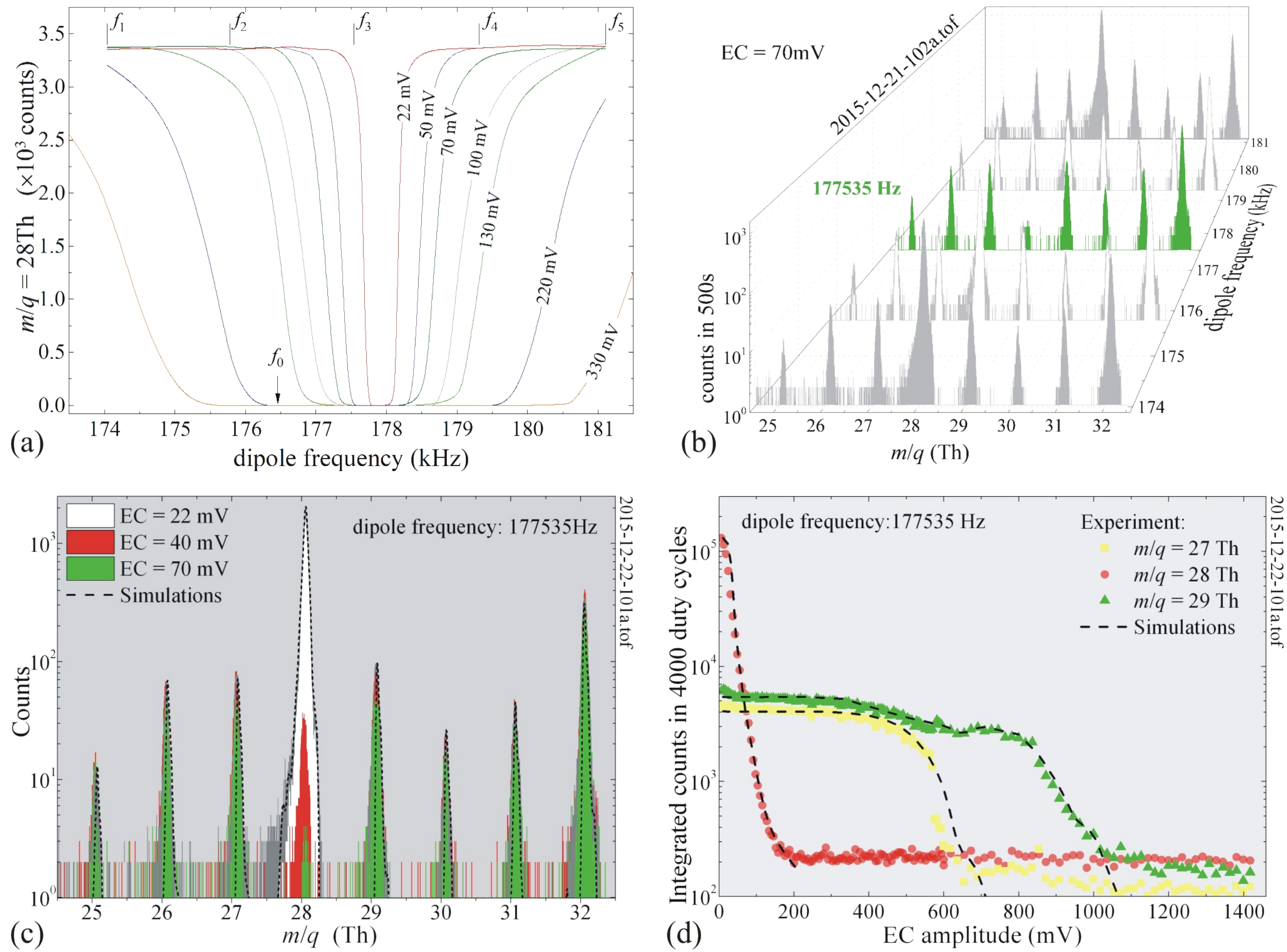
	Acquisition time = 60s			Acquisition time = 600s			
m/q	Cnts	St. Err ±	Ratio %	Cnts	St. Err ±	Ratio %	Nom. %
78	140	11.8	**2.0 ± 0.2**	1523	39.0	**2.3 ± 0.1**	**0.355**
80	186	13.6	**2.7 ± 0.2**	1738	41.7	**2.7 ± 0.1**	**2.286**
82	796	28.2	**11.6 ± 0.5**	7048	84.0	**10.8 ± 0.2**	**11.593**
83	824	28.7	**12.0 ± 0.6**	7620	87.3	**11.7 ± 0.2**	**11.500**
84	3817	61.8	**55.4 ± 1.6**	36515	191.1	**55.8 ± 0.5**	**56.987**
86	1127	33.6	**16.4 ± 0.7**	10960	104.7	**16.8 ± 0.2**	**17.279**
Total	6890	83.0		65404	255.7		

NOBLE GASES – RESULTS (XENON)



	Acquisition time = 60s			Acquisition time = 600s			
m/q	Cnts	St. Err ±	Ratio %	Cnts	St. Err ±	Ratio %	Nom. %
128	6	2.4	**1.3 ± 2.0**	102	10.1	**2.1 ± 5.0**	**1.9102**
129	109	10.4	**23.1 ± 0.9**	1224	35.0	**25.2 ± 1.9**	**26.4006**
130	26	5.1	**5.5 ± 1.2**	256	16.0	**5.3 ± 3.3**	**4.0710**
131	103	10.1	**21.9 ± 0.9**	1108	33.3	**22.8 ± 1.9**	**21.2324**
132	133	11.5	**28.2 ± 0.9**	1243	35.3	**25.6 ± 1.9**	**26.9086**
134	41	6.4	**8.7 ± 1.0**	456	21.4	**9.4 ± 2.6**	**10.4357**
136	53	7.3	**11.3 ± 1.0**	467	21.6	**9.6 ± 2.6**	**8.8573**
Total	471	21.7		4856	69.7		

RESONANT EJECTION – COOLING PHASE



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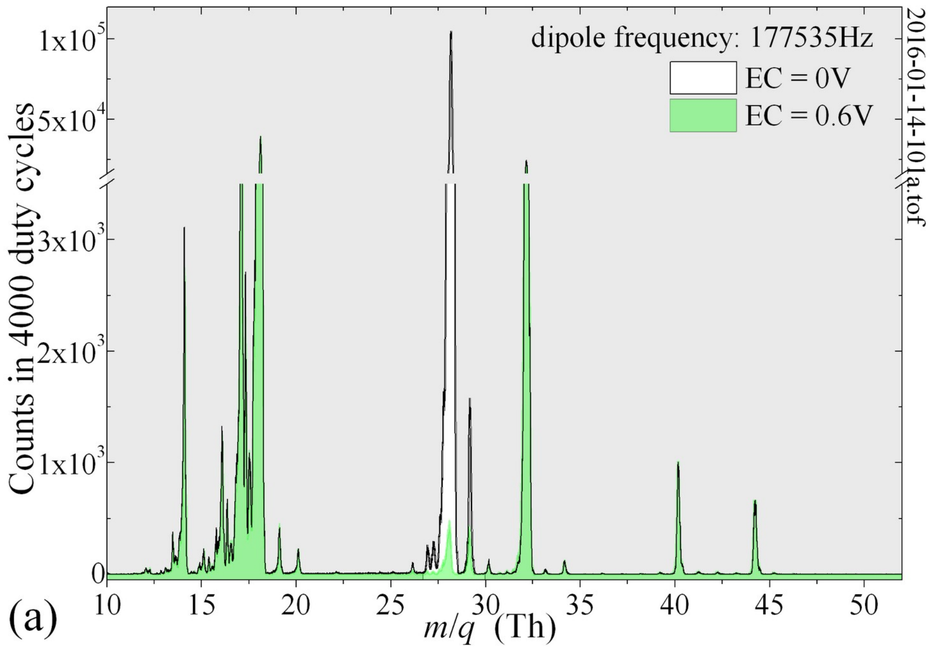
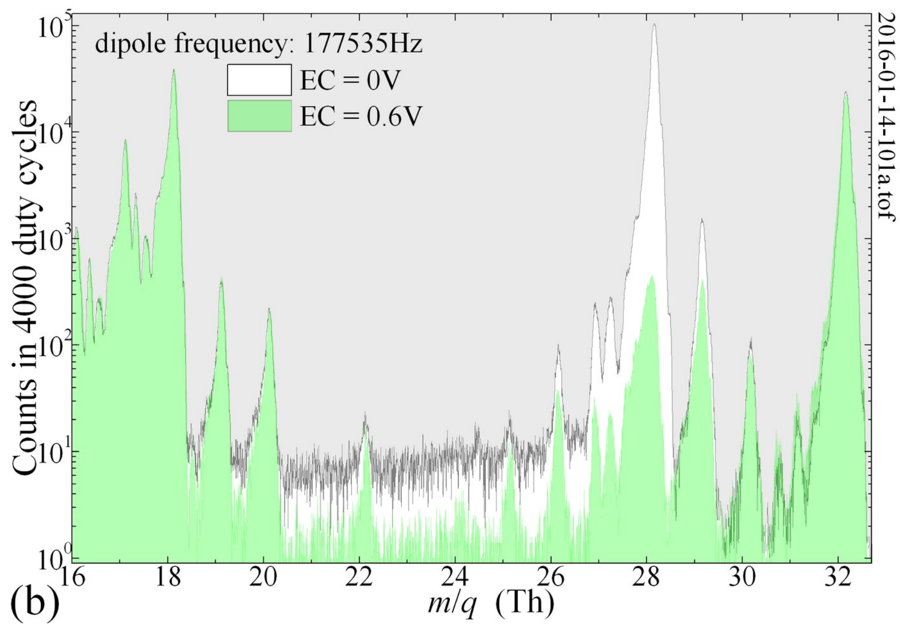
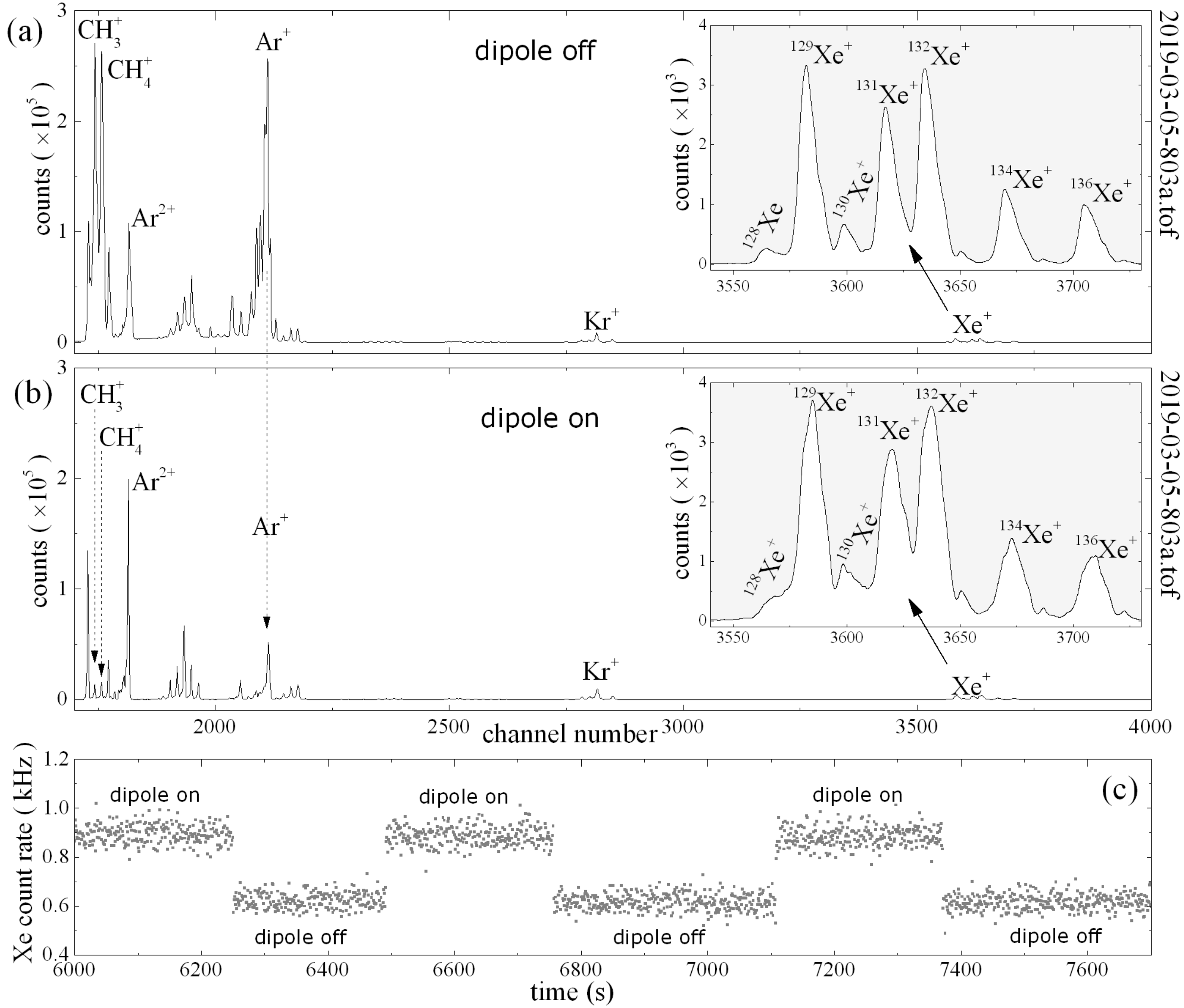
RESONANT EJECTION – IONIZATION PHASE





RESONANT EJECTION – STATIC MODE



CONCLUSION

- Atmospheric descent probes require lightweight, low power, versatile, robust & highly sensitive instruments. In our opinion QIT-MS fits the description.

- Fast responsive inlet system, which can tolerate pressure differences of tens of bars, and can regulate gas flow continuously in very fine steps, is required as a front end to a mass spectrometer of choice for the atmospheric probe.

- QIT-MS can utilize different modes of operation, to suppress dominant mass peaks, where such intervention is needed.

- By utilizing above techniques, meaningful results from relevant environment were obtained in matter of tens of seconds.

THANK YOU FOR YOUR KIND ATTENTION