Isotopic and Trace Species Measurements using the JPL Quadrupole Ion Trap

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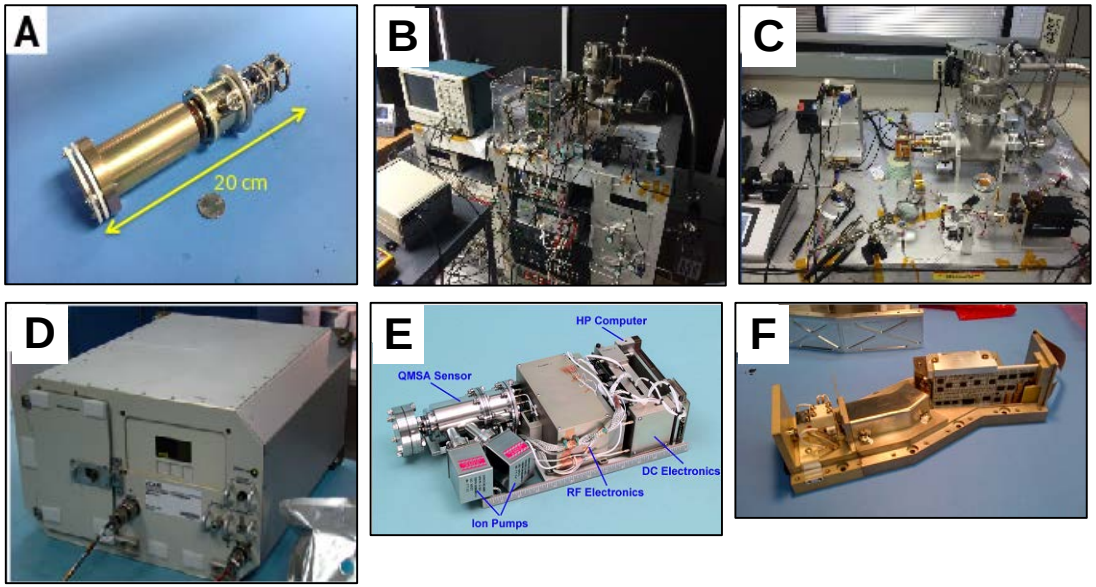
JPL MS GROUP



(A) Flyby MS Sensor Head for Europa (MARINE) Prototype.
(B) Geochronology and Atmospheric noble gas workstation.
(C) Benchtop version of Spacecraft Atmosphere Monitor (S.A.M)
(D) VCAM deployed in the International Space Station's Destiny Laboratory. Launched aboard STS-131 (Discovery) in 2010, operated for two years and came back on Dragon in 2013.
(E) The JPL Quadrupole MS Array (QMSA), 2" in length - the smallest analytical linear quadrupole mass spectrometer sent to space, pictured here with electronics for the Trace Gas Analyzer (TGA).
(F) The JPL Miniature Mass Spectrometer (MMS), a miniature magnetic sector MS - base-lined to be deployed on the Resource Prospector Mission (RPM) to the South Polar Region of the moon.

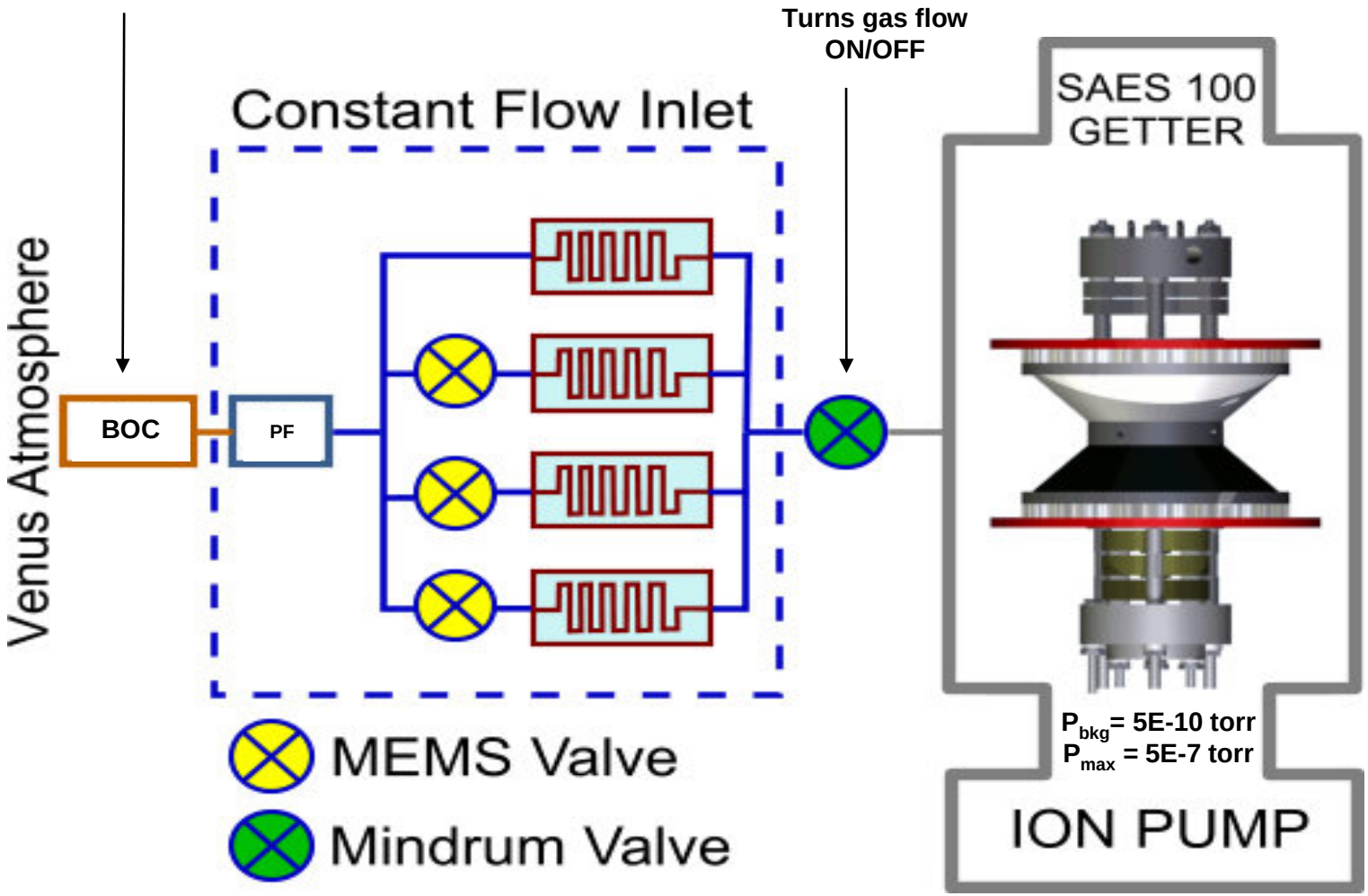
JPL MS GROUP

The aggregate total funding is approximately $65M since 1997.

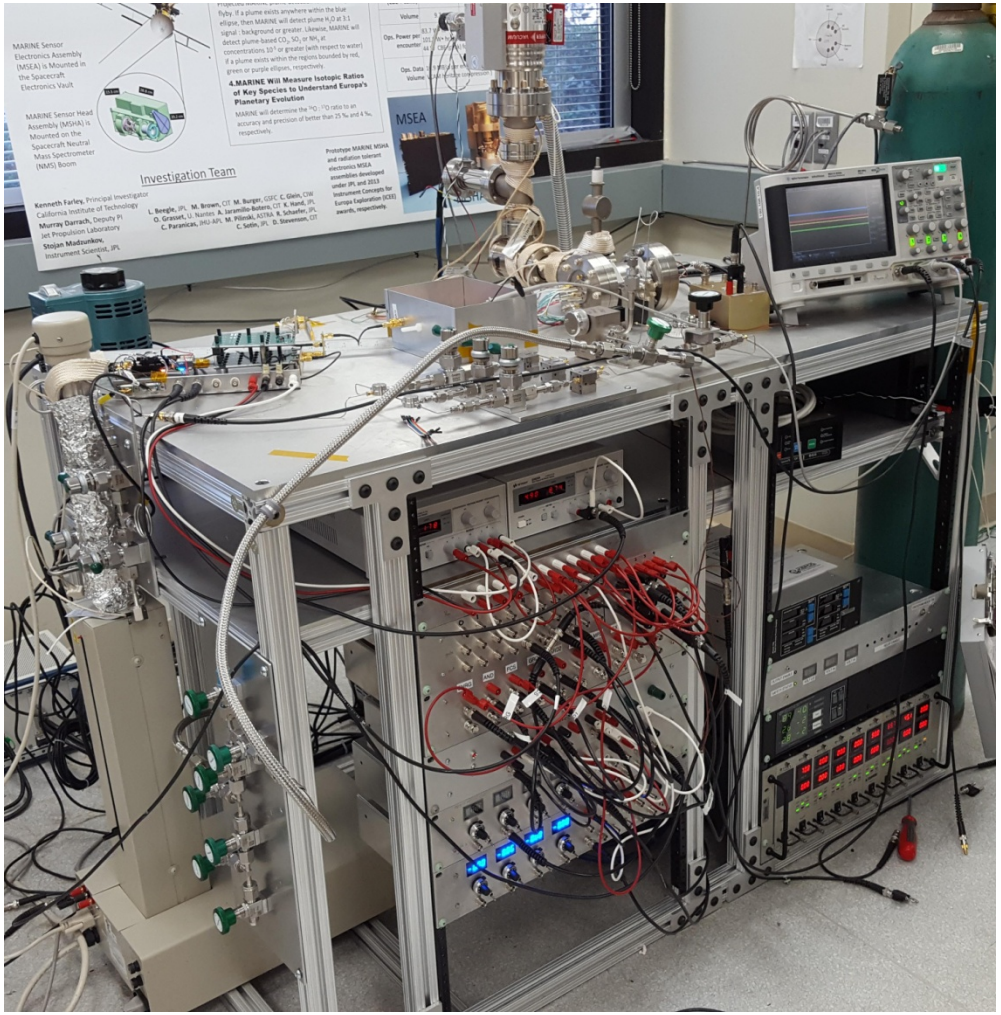
Program	Years	Main Development
NASA AEMC and ISS	1997–2004	Flight MS for ISS Trace Gas Analyzer (TGA)
NASA AEMC	2003–2005	QITMS for atmosphere monitoring
NASA AEMC and ISS	2005–2011	Flight project: QITMS-based Vehicle Cabin Atmosphere Monitor
NASA PIDDP	2011–2013	Miniature QITMS and gas chromatographs for planetary investigations
NASA ASTID	2012–2014	Miniature QITMS and liquid chromatographs for planetary investigations
NASA AEMC	2012–2019	Miniature QITMS and gas chromatographs for human exploration
JPL Strategic Funding	2012–2017	QITMS-based instrumentation for planetary missions
NASA ICEE	2013	Maturation of QITMS for flyby/orbiter mission to Europa
NASA Homesteader	2015	Maturation of QITMS for atmospheric probe missions
JPL Strategic Funding	2016–2018	Miniature QITMS

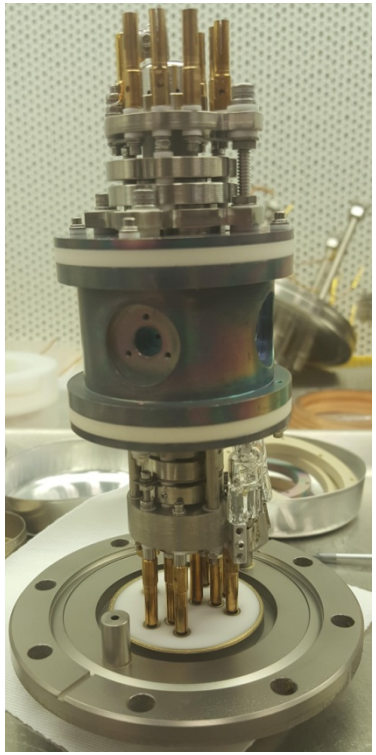
INSTRUMENT OVERVIEW

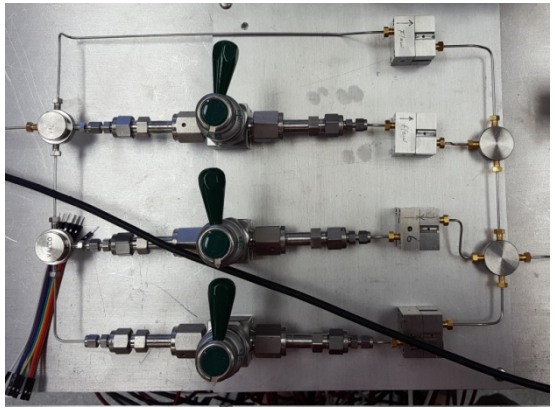
ACES = CFI + QIT



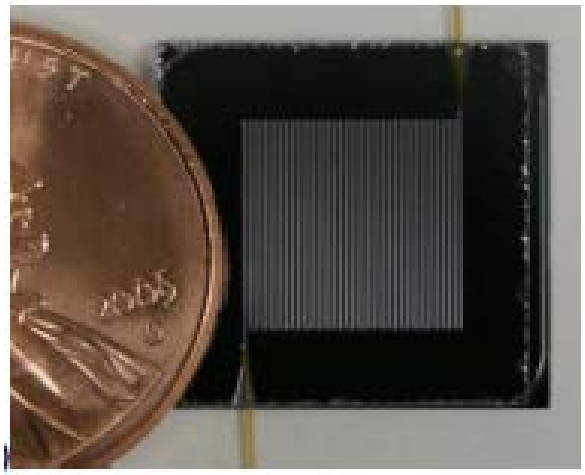
INSTRUMENT OVERVIEW

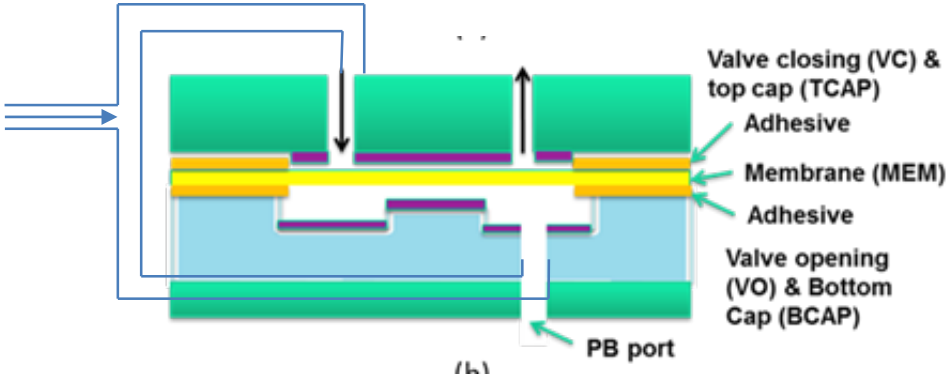


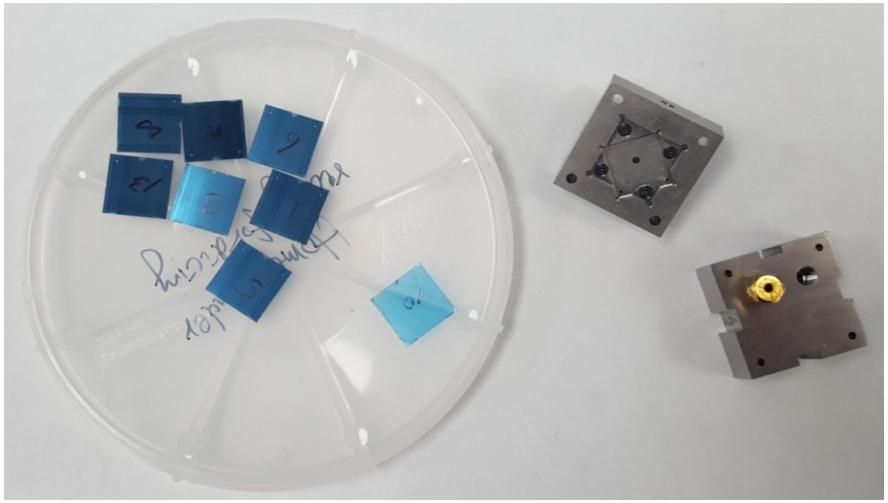




INSTRUMENT OVERVIEW - CFI







INSTRUMENT OVERVIEW - QIT

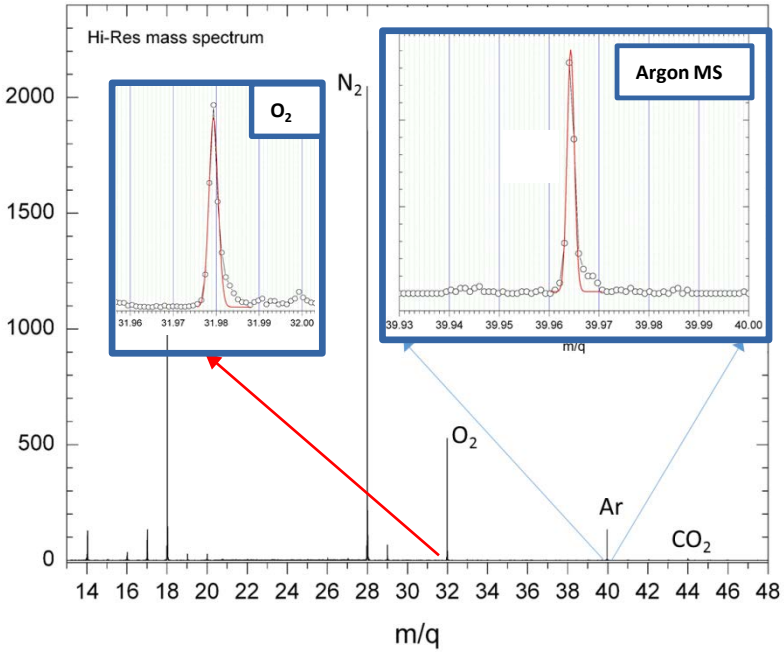
ACES will vary the QITMS mass resolution during a full range mass scan (4000 ≤ m/Δm ≤ 14,000 FWHM) in order to minimize spectral overlap, maximize the duty cycle (sensitivity) and minimize the number of mass channels.

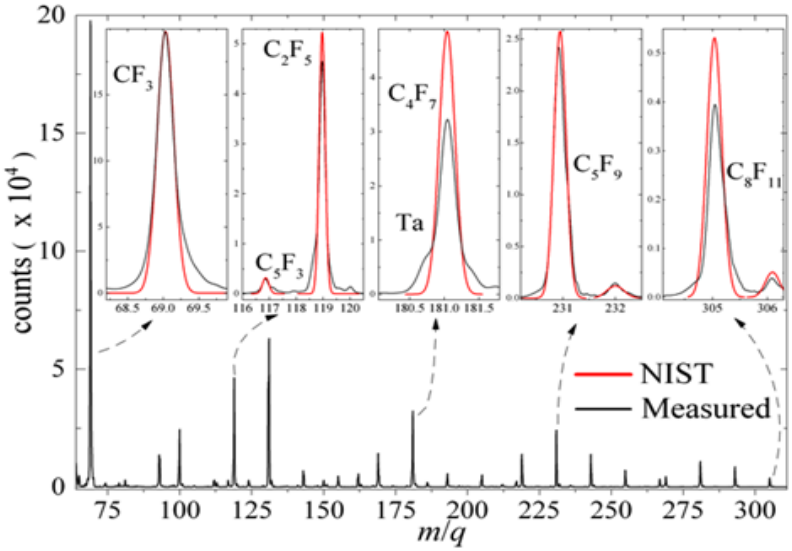
By monitoring the Ta+ (third inset) and Ta++ detected by the QITMS, ACES can be absolutely calibrated, for both sensitivity and mass number, during flight without calibrant gases.

These mass lines are available every mass scan (1 per second) and as such, provides built-in calibration on a second-by-second basis.

The QITMS electron source is a Ta button cathode. The quantity of Ta neutrals that enter the ion trap are related only to the color temperature of the Ta button and the electron-lens aperture sizes in the QITMS electron gun.

Likewise the Ta+ and Ta++ ions detected by the QITMS is directly proportional to the electron beam current and the trapping and detection efficiency of the QITMS.



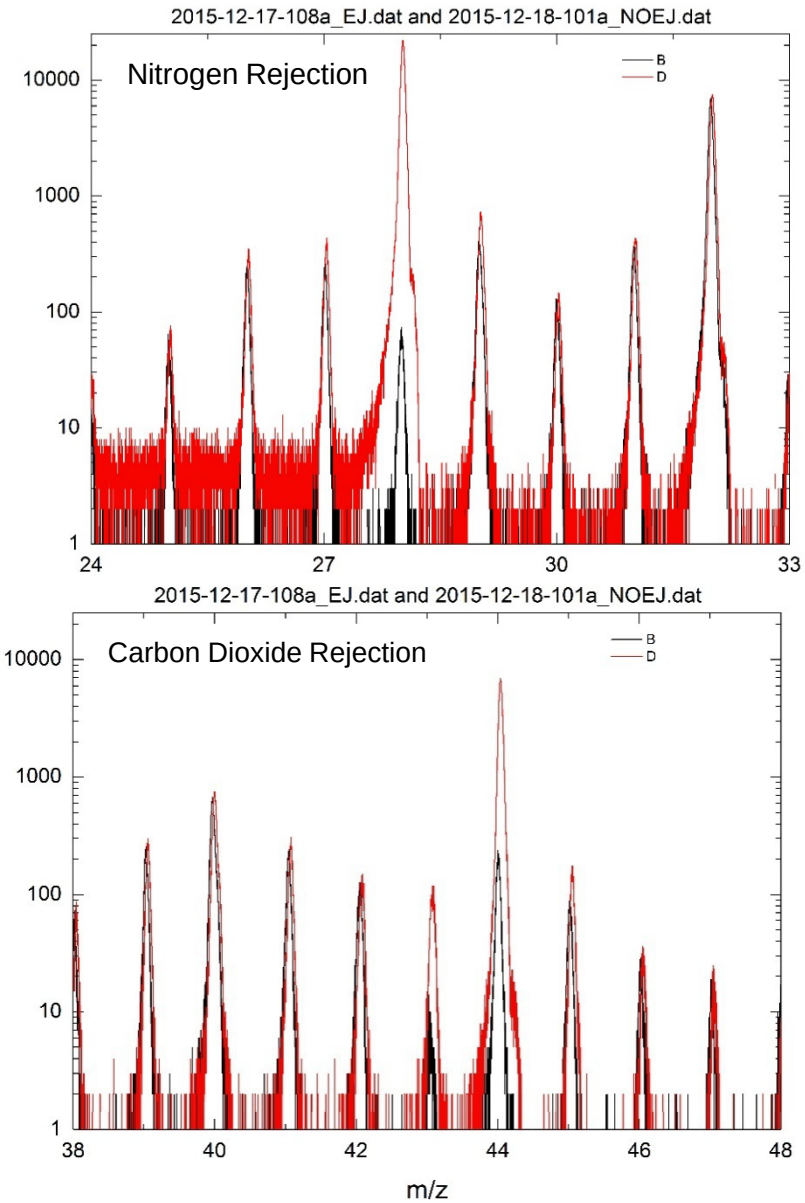


INSTRUMENT OVERVIEW - QIT

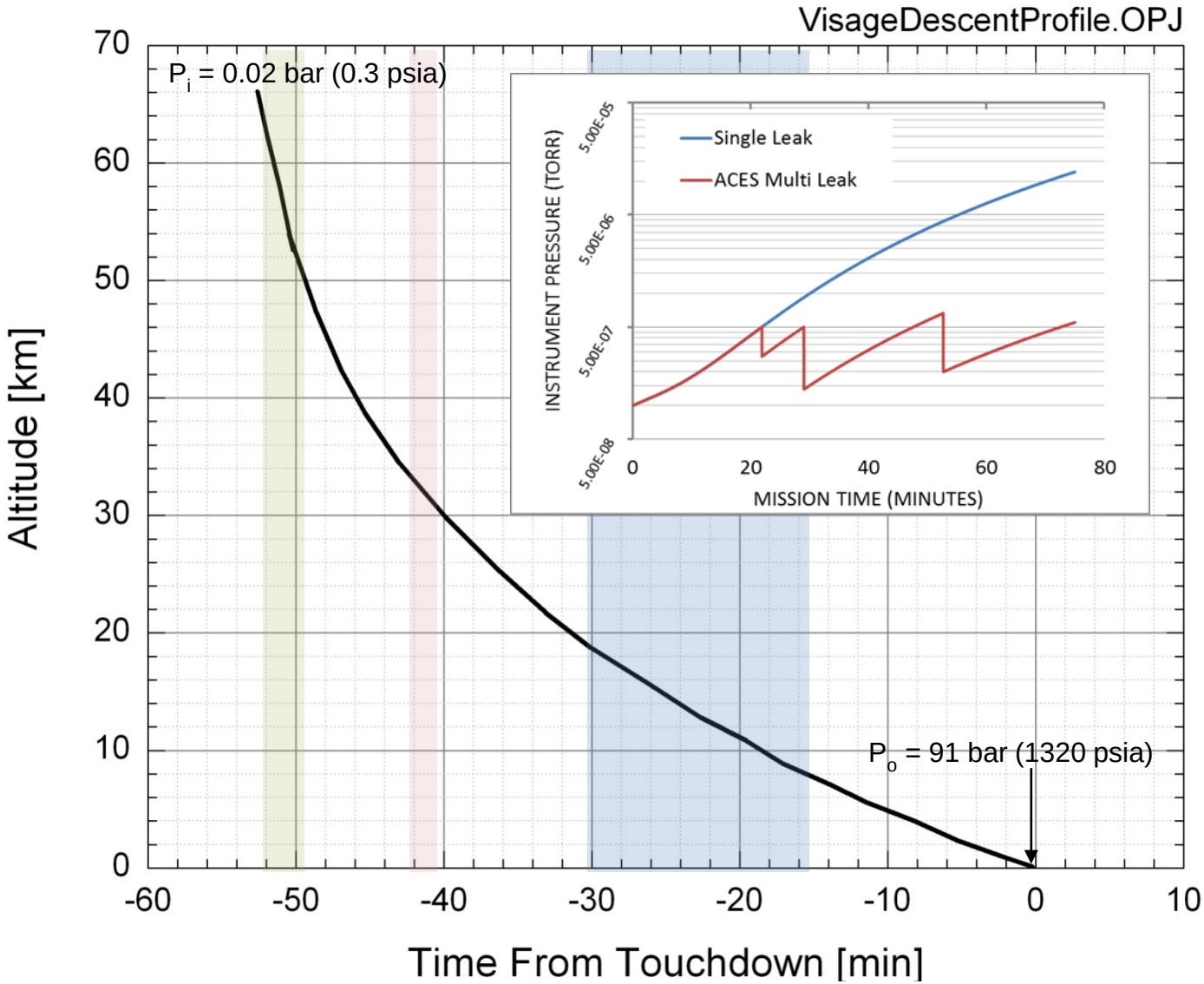
Measuring ppm Trace Species in presence of dominant CO_2 and N_2 atmosphere can be quite challenging.

Luckily we can use Ion Trap operational flexibility to reject trapping of CO_2 and N_2 without affecting neighboring mass peaks. Note logarithm scale, factor of 100 was achieved.

Red = Normal operational mode
Black = Rejection trapping mode



FLIGHT PATTERN



NOBLE GASES

Noble gas mode:
The gas flows into the chamber for 15s with ion pump off. All but noble gases are removed by getter. 15s later we turn the IP on and close the gas flow to remove noble gases (15s). Then ready for another sequence.

Sensitivity	1E14 cnts / Torr / s
Max Pressure	5E-7 Torr
Accumulation Time	15s
Mass flow	2.5E-5 Torr ℓ / s
Pumping Speed	50 ℓ / s (CO2)
Total Noble Gas Pressure	3E-8 Torr
Time to fill up D100 getter	2.2 hr

Specific Isotope	Abun. (ppm)	Pressure (Torr)	Count Rate (Hz)	Accum. cnts in 15s	Statistical Precision
^{3}He	0.0001	2.50E-15	0.3	26	19.5%
^{4}He	1.0	2.50E-11	2500	262500	0.2%
^{20}Ne	7.0	1.75E-10	18000	1837500	0.1%
^{21}Ne	0.019	4.73E-13	47	4961	1.4%
^{22}Ne	0.6	1.48E-11	1500	155720	0.3%
^{36}Ar	5.4	1.34E-10	13000	1404730	0.1%
^{38}Ar	29.7	7.43E-10	74000	7804054	0.0%
^{40}Ar	33.0	8.25E-10	83000	8662500	0.0%
^{80}Kr	0.0036	9.00E-14	9	945	3.3%
^{82}Kr	0.0120	3.00E-13	30	3150	1.8%
^{83}Kr	0.0070	1.75E-13	18	1838	2.3%
^{84}Kr	0.0250	6.25E-13	63	6563	1.2%
^{86}Kr	0.0040	1.00E-13	10	1050	3.1%
^{128}Xe	0.0001	2.68E-15	0.3	28	18.9%
^{129}Xe	0.0007	1.70E-14	2	178	7.5%
^{130}Xe	0.0003	7.14E-15	1	75	11.5%
^{131}Xe	0.0010	2.50E-14	3	263	6.2%
^{132}Xe	0.0007	1.79E-14	2	188	7.3%
^{134}Xe	0.0005	1.18E-14	1	124	9.0%
^{136}Xe	0.0004	1.04E-14	1	110	9.5%

TRACE GASES

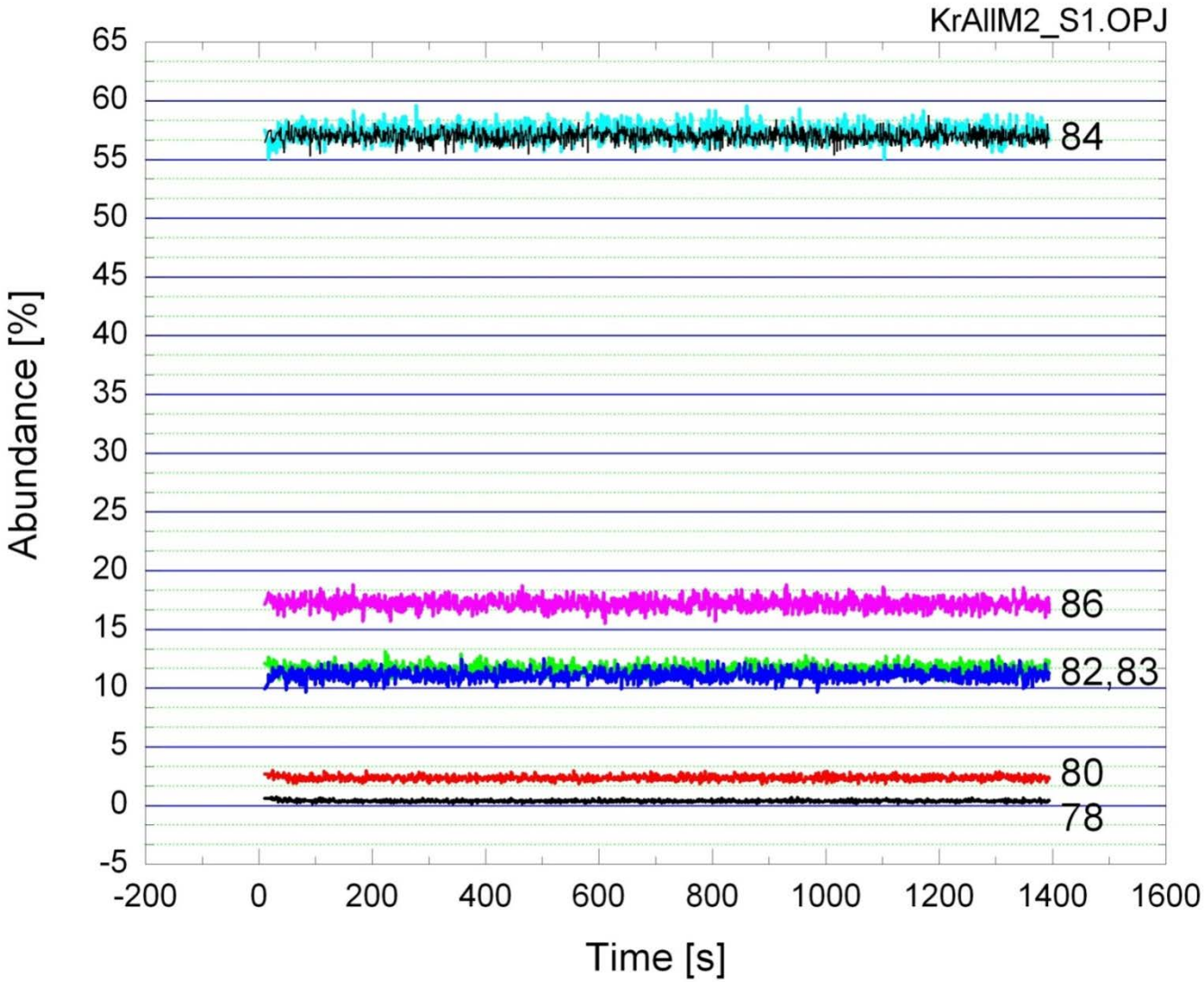
Trace gas mode:
The gas flows into the chamber, ion pump is ON and data is accumulated.

The pressure is kept below 5E-7Torr.

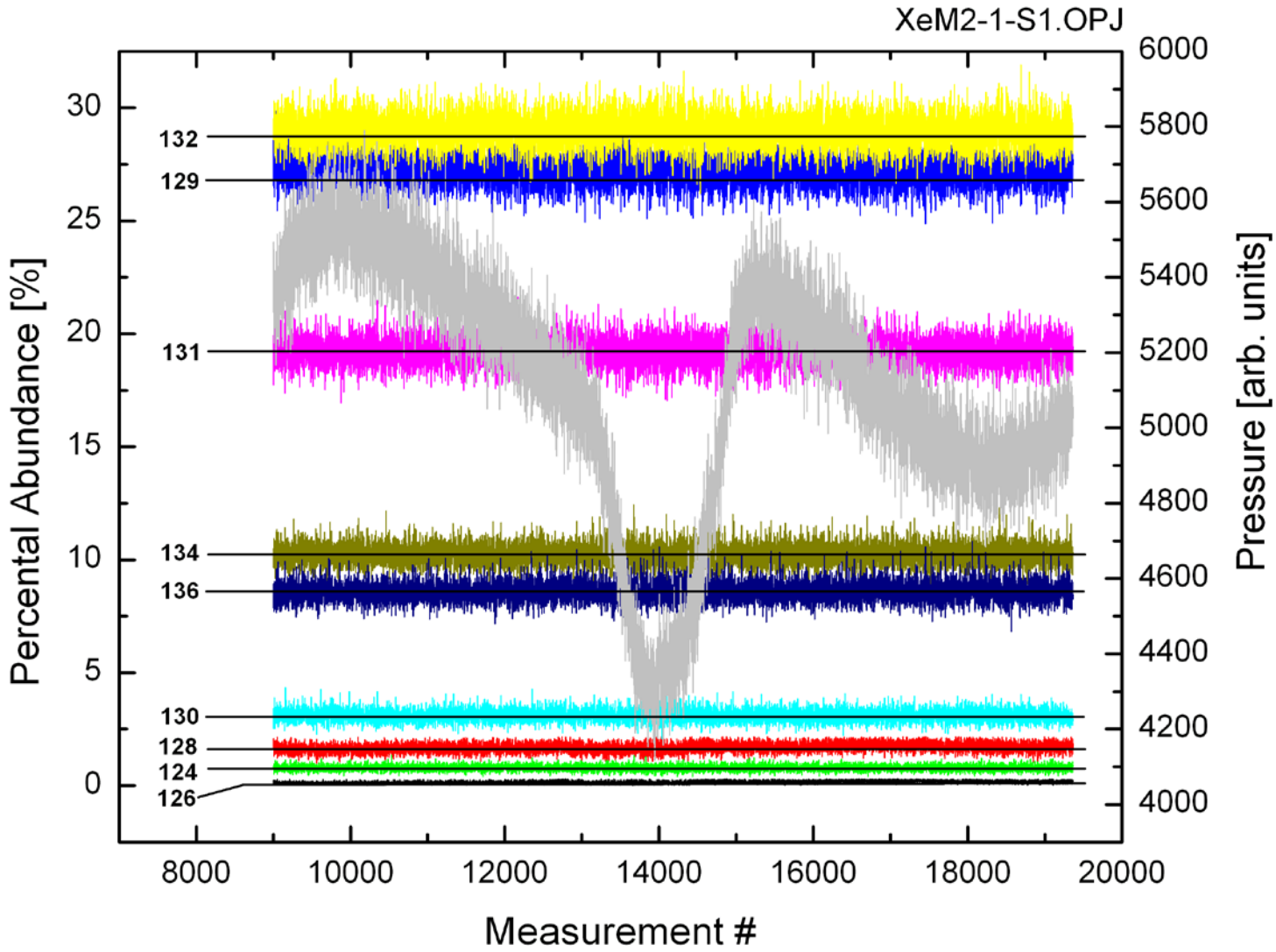
In the trace gas mode, the ions of high abundance species have to be ejected for low abundance ions to be detected.

Molecule	Isotope	Abund(ppm)	CR (Hz)	Prec (%)	Acq. Time
CO2	$^{12}C^{16,16}O$	9.5E+05	4.7E+07	1	<1s
CO2	$^{13}C^{16,16}O$	1.0E+04	5.2E+05	5	<1s
CO2	$^{12}C^{16,18}O$	4.0E+03	2.0E+05	5	<1s
CO2	$^{13}C^{16,18}O$	4.4E+01	2.2E+03	5	<1s
N2	$^{14}N^{14}N$	3.5E+04	1.7E+06	1	<1s
N2	$^{14}N^{15}N$	2.5E+02	1.3E+04	1	<1s
SO2	$^{32}S^{16,16}O$	1.4E+00	7.1E+01	1	2m
SO2	$^{32}S^{16,17}O$	1.1E-03	5.6E-02	5	2hr
SO2	$^{33}S^{16,16}O$	6.4E-02	3.2E+00	5	2m
SO2	$^{34}S^{16,18}O$	2.7E-04	1.3E-02	5	>8hr
CO	$^{12}C^{16}O$	1.7E-01	8.4E+00	2	5m
CO	$^{13}C^{16}O$	1.9E-03	9.3E-02	10	18m
CO	$^{12}C^{18}O$	3.5E-04	1.8E-02	10	1.5hr
H2O	$HH^{16}O$	3.0E-01	1.5E+01	1	11m
H2O	$HHH^{16}O$	3.0E-03	1.5E-01	5	45m
OCS	$^{16}O^{12}C^{32}S$	4.1E-02	2.1E+00	3	9m
OCS	$^{18}O^{12}C^{32}S$	8.7E-05	4.3E-03	5	>25hr
OCS	$^{16}O^{13}C^{32}S$	4.6E-04	2.3E-02	5	5hr
OCS	$^{16}O^{12}C^{34}S$	1.9E-03	9.3E-02	15	8m
H2S	$HH^{32}S$	2.8E-02	1.4E+00	3	13m
H2S	$HH^{34}S$	1.3E-03	6.4E-02	2	11hr
NO		1.0E-02	5.0E-01	6	9m

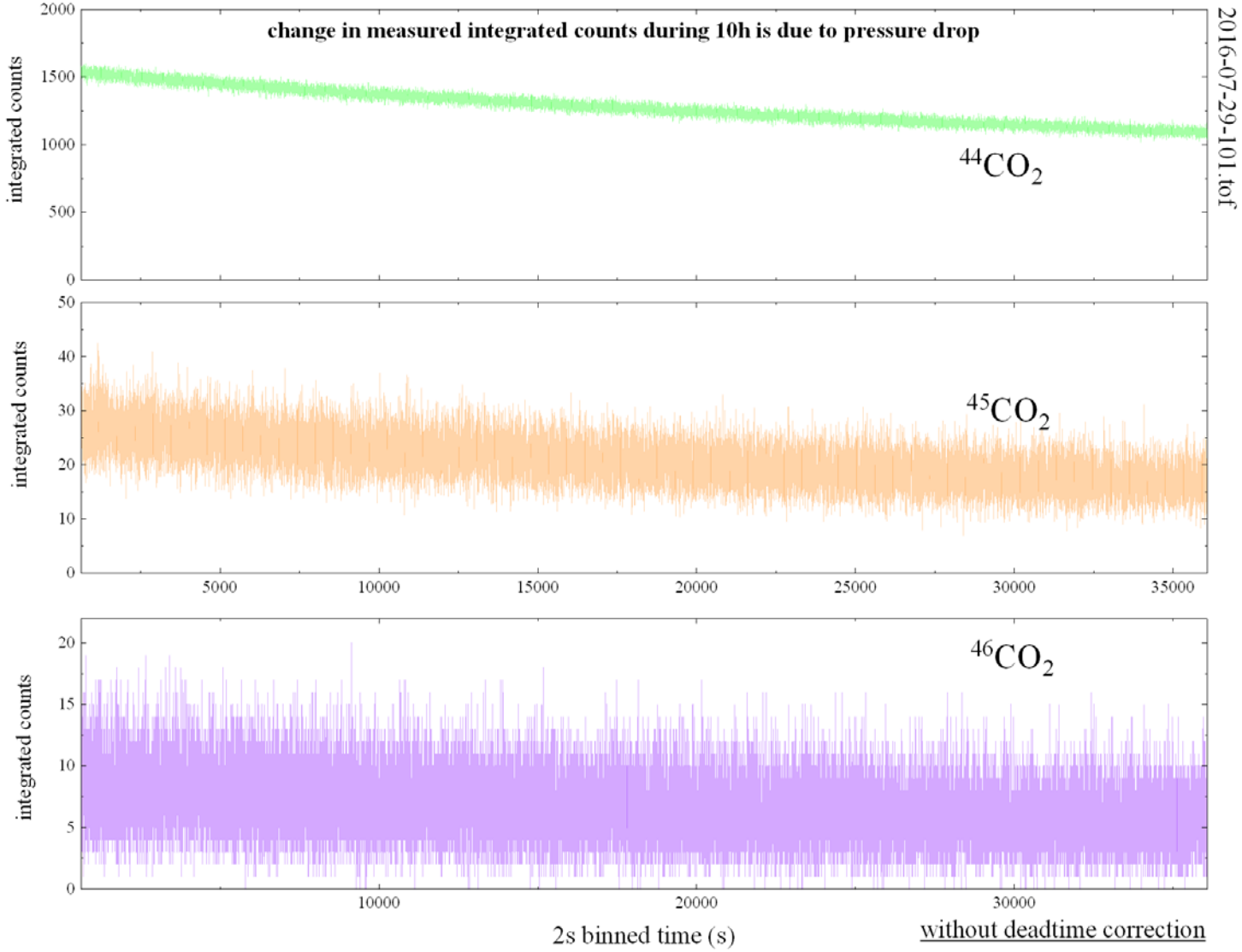
NOBLE GAS - KR


KrAllM2_S1.OPJ
Abundance [%]
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-200
0
200
400
600
800
1000
1200
1400
1600
Time [s]
84
86
82,83
80
78

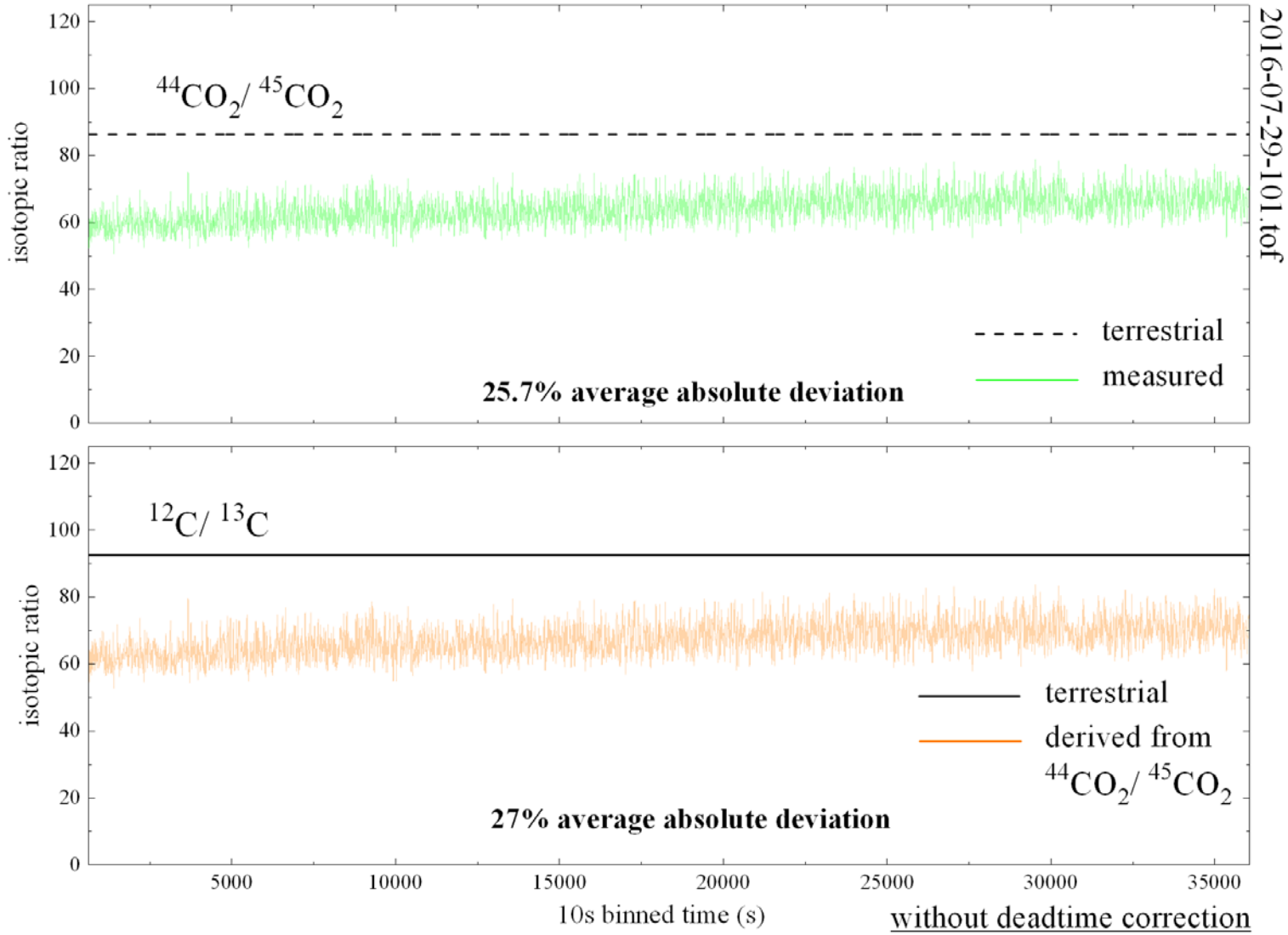
NOBLE GAS - XE


XeM2-1-S1.OPJ
Percental Abundance [%]
Pressure [arb. units]
Measurement #
132
129
131
134
136
130
128
124
126
30
25
20
15
10
5
0
6000
5800
5600
5400
5200
5000
4800
4600
4400
4200
4000
8000
10000
12000
14000
16000
18000
20000

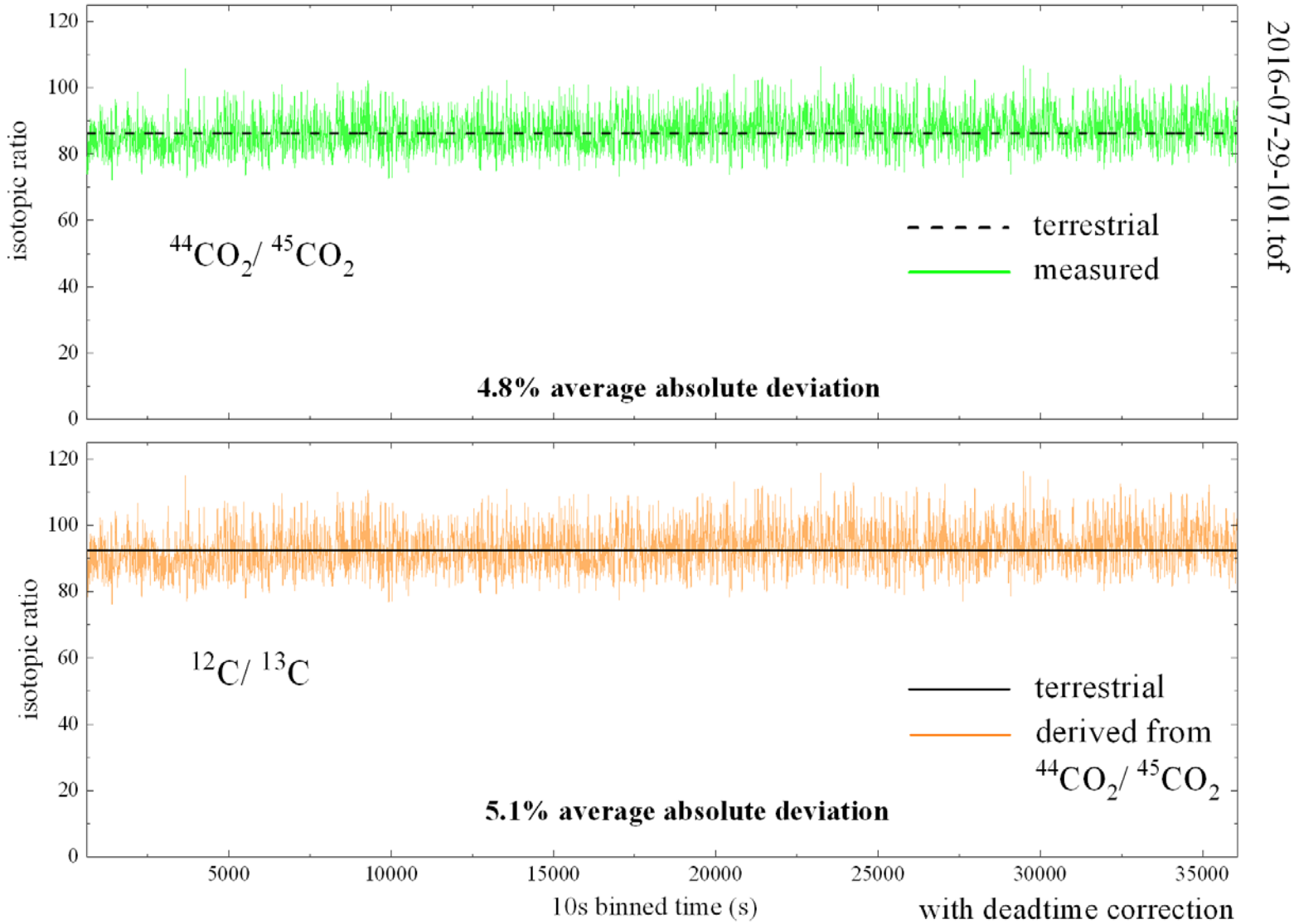
STABILITY


change in measured integrated counts during 10h is due to pressure drop
integrated counts
$^{44}CO_2$
$^{45}CO_2$
$^{46}CO_2$
2s binned time (s)
without deadtime correction
2016-07-29-101.tof

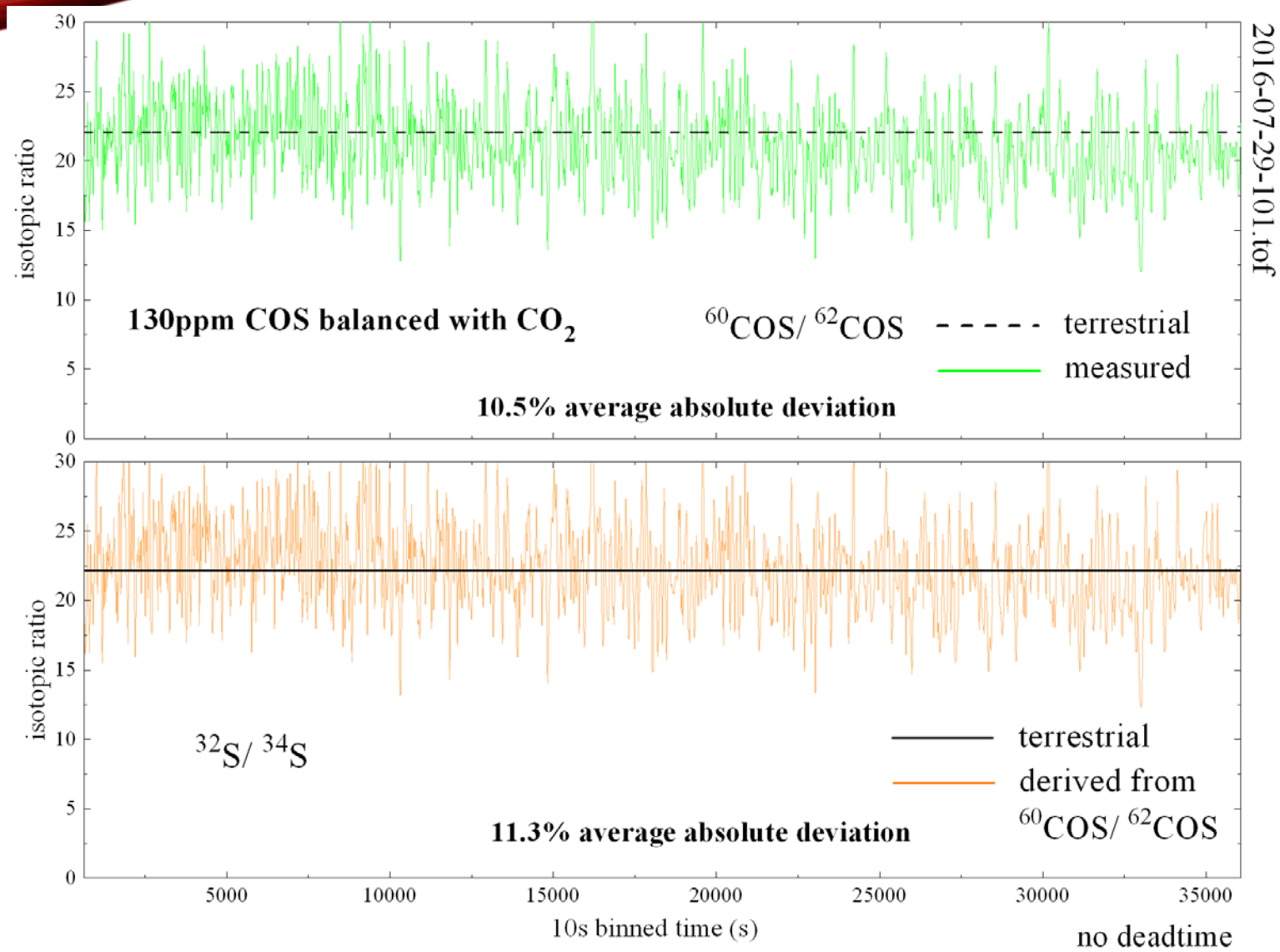
ELEMENTAL ABUNDANCE



ELEMENTAL ABUNDANCE



TRACE GAS



We can measure (1E12 cnts/Torr/s, P=5E-8 Torr) in Venus atmosphere analogue isotopic composition of 130ppm of COS within 10% in 10s. QIT measured (nominal) sensitivity is 1E14 cnts/Torr/s.