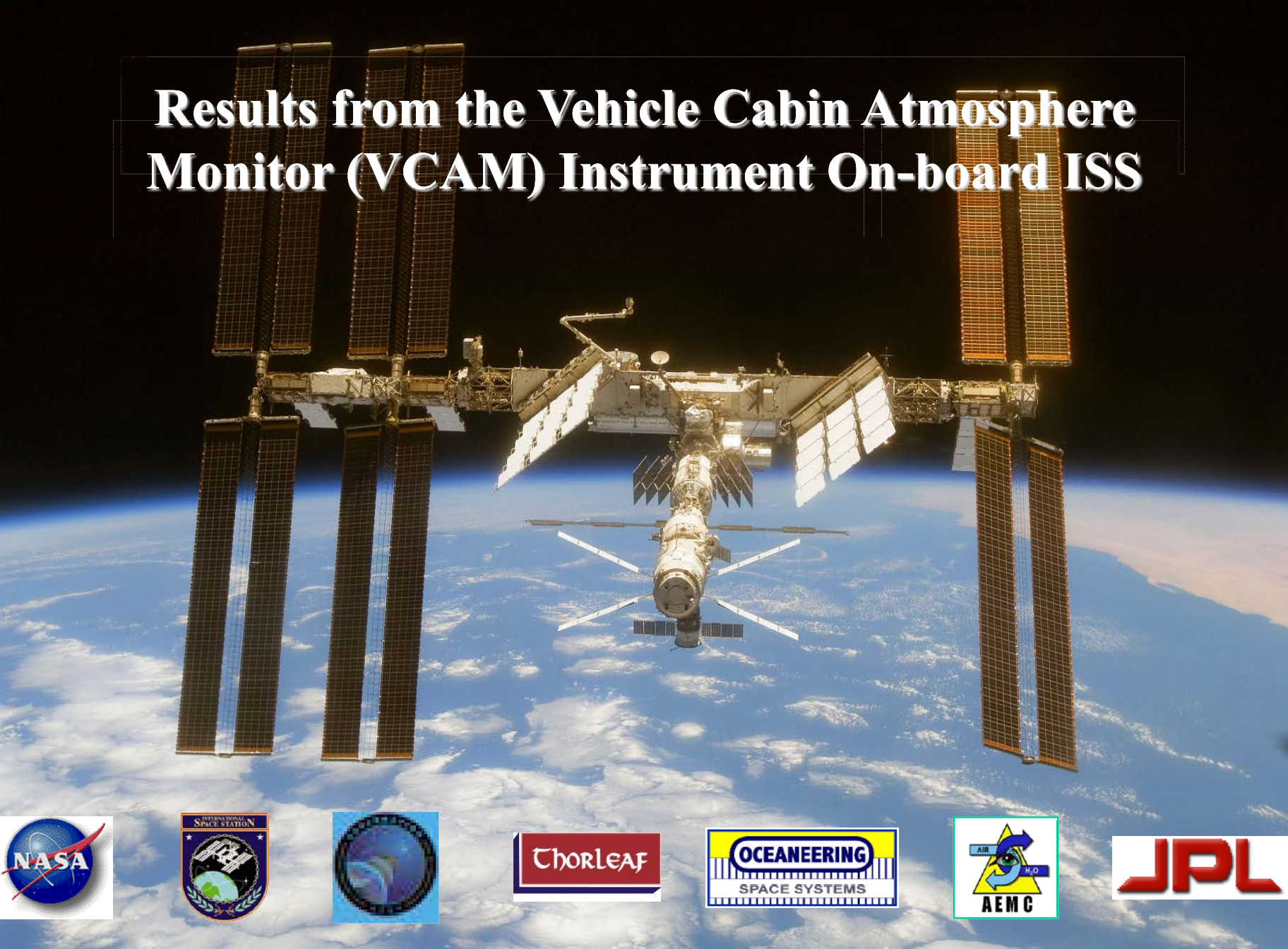
Results from the Vehicle Cabin Atmosphere Monitor (VCAM) Instrument On-board ISS



VCAM Operations Team

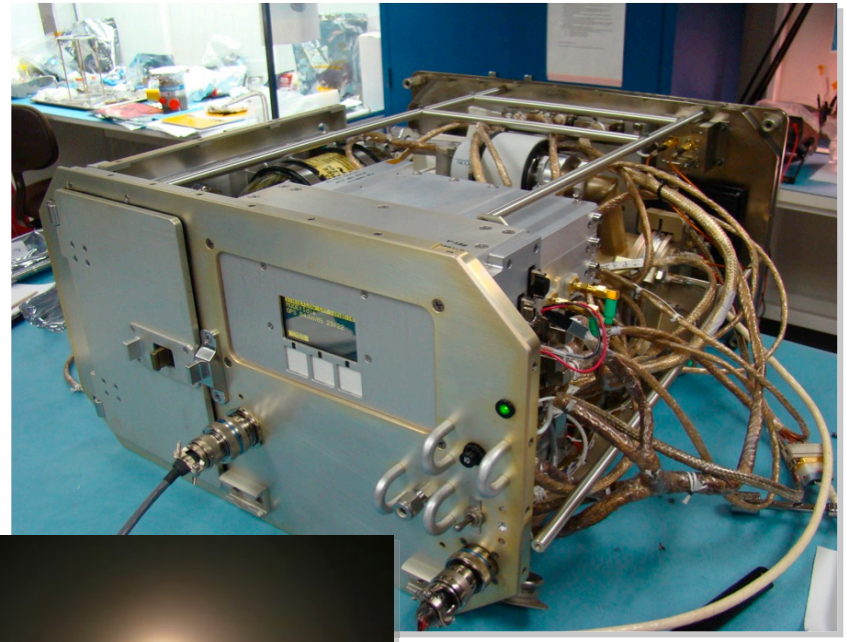
A. Chutjian - Principal Investigator
M. R. Darrach - Co-Investigator
N. Toomarian – Task Management
S. M. Madzunkov, J.A. MacAskill, R. Kidd – Project Scientists
B. J. Bornstein, J. Hofman – Software and OPs
A.P. Croonquist – Systems Engineering and OPs

Acknowledgment
D. Jan (JPL), Y. Park (JPL), and J. Joshi (NASA HQ)
T Limero (JSC), A. Macatangay (JSC), and P. Mudgett (JSC),
J. Perry (MSFC)

Vehicle Cabin Atmosphere Monitor - VCAM

Salient Features

- A gas-chromatograph/mass-spectrometer (GCMS) system for the International Space Station.
- ISS used as a flight test-bed to demonstrate reliable operations on orbit, and to simulate *human* & *robotic planetary* exploration environments.
- Instrument Delivery: *September 2009*
- Launched: *April 5, 2010*
- Launch Vehicle: *Shuttle STS-131*
- Commenced Measurements: *June 22, 2010*
- Operational life: 1 year
- Mass: 24.3 kg, Power(Avg): 100 W

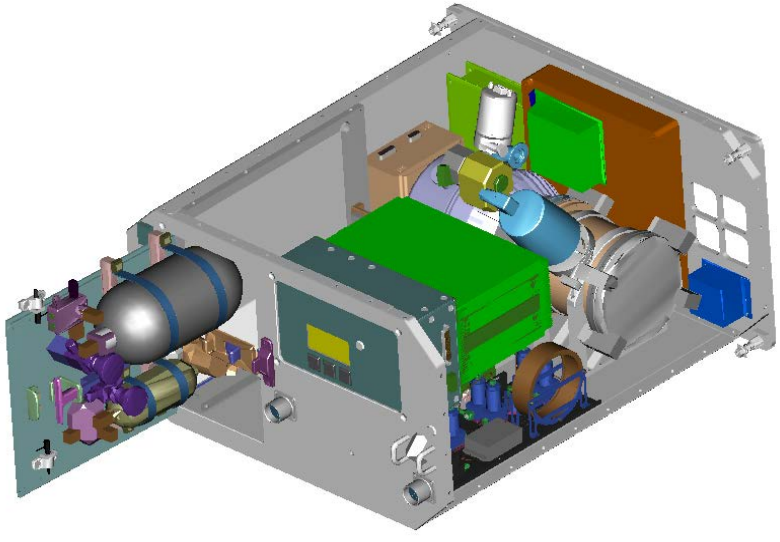


Science

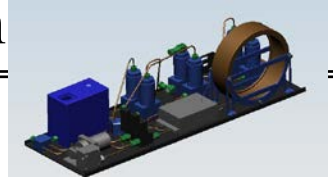
- Autonomously identify and quantify the presence of trace amounts of known potentially toxic species as well as identify unexpected threats to the human crew.
- Perform measurements of major atmospheric constituents.

EMOS VCAM

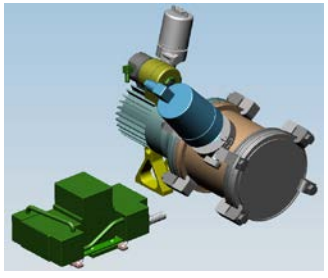
Configuration



Instrument

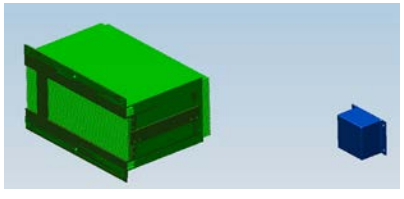


Preconcentrator/
Gas Chromatograph



Sensor

Electronics

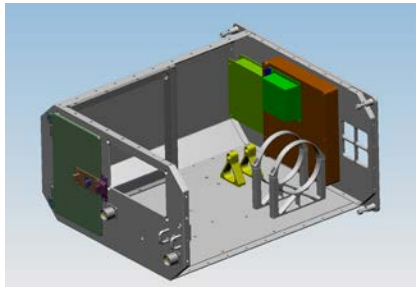


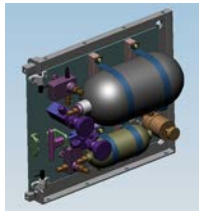
Processing Electronics

Monitor & Control Electronics

Mechanical

Enclosure





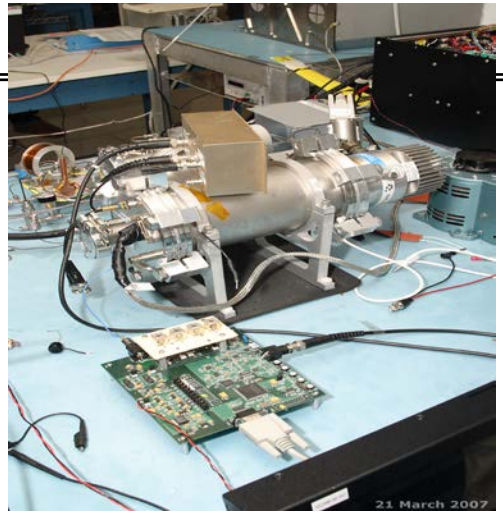
Consumables Orbital Replacement Unit

Software

Command & Data
Data Analysis

Monitor & Control
Computer A…

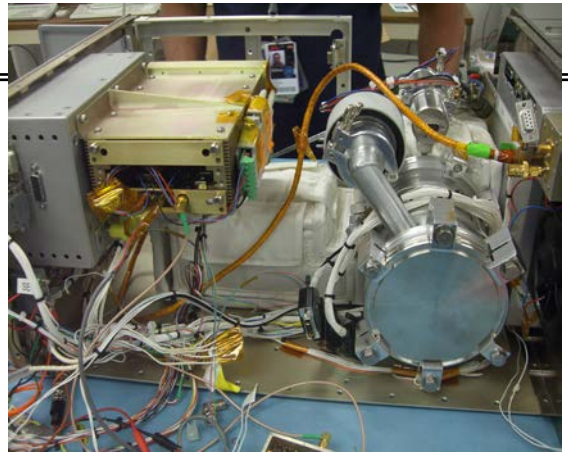
Developing and Testing VCAM



Lab Standard (LS): open system

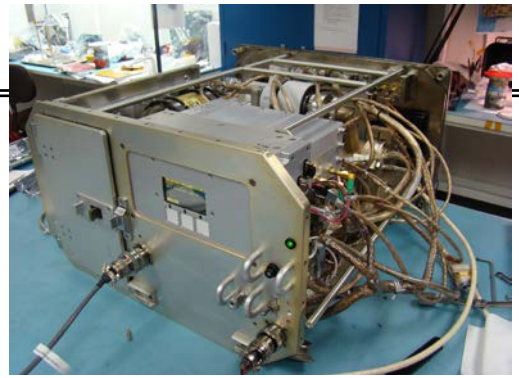
compound testing and design proofing

- ✓ Following contamination: Very reliable workhorse.
- ✓ Did all the compound testing
- ✓ Provided all the underpinning data for science and on-board autonomous data-analysis
- ✓ All "lessons learned " implemented
- ✓ Now "retired"



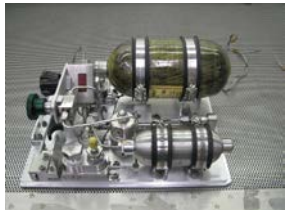
Testbed: flight like closed system.

- ✓ Thermal environment
- ✓ Acoustic emission
- ✓ Protoflight electronics functionality
- ✓ Protoflight Sensor verification
- ✓ EMI/EMC
- ✓ MSFC testing
  - ✓ Micro- gravity
  - ✓ Usability
  - ✓ Communication w/ Express Rack
- ✓ System SW testing
- ✓ System & subsystem configuration
- ✓ Compound testing and analysis

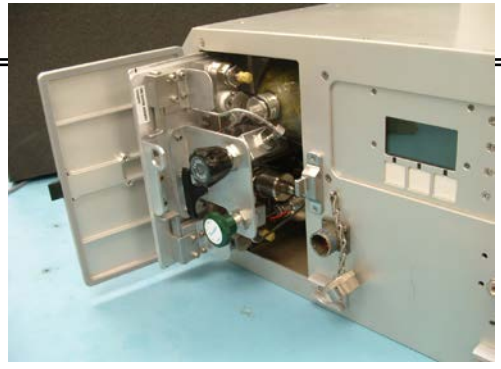


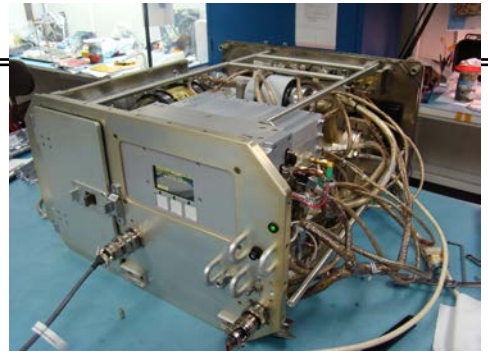
Protoflight: The deliverable

- ✓ Functionality
- ✓ Protoflight electronics thermal test (124 Hours)
- ✓ PF Mass Spectrometer (MS) vibration
- ✓ Conformal coating & staking (components, nuts & bolts)
- ✓ Running with released SW
- ✓ ORU vibration
- ✓ 500 burn- in is in process
- ✓ VCAM Vibration
- ✓ VCAM Acoustics Emission
- ✓ VCAM Thermal
- ✓ ORU HRCR and PSR



ORU and Sample Bags



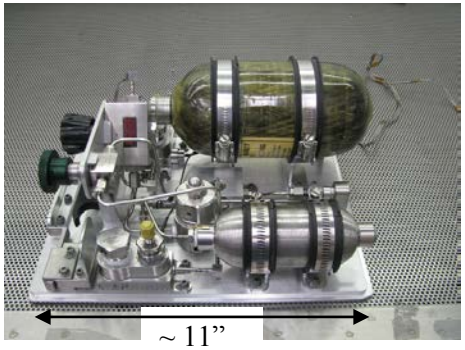


- ***ORU*** **(consumable On Orbit Replaceable Unit):**

  Provides He carrier gas and Calibrant gas

  (fluorobenzene, acetone & Freon 218) for VCAM operation.

- **Deliverable: One unit due on 9/25/08 for a November 08 Shuttle flight and 4 more with VCAM.**

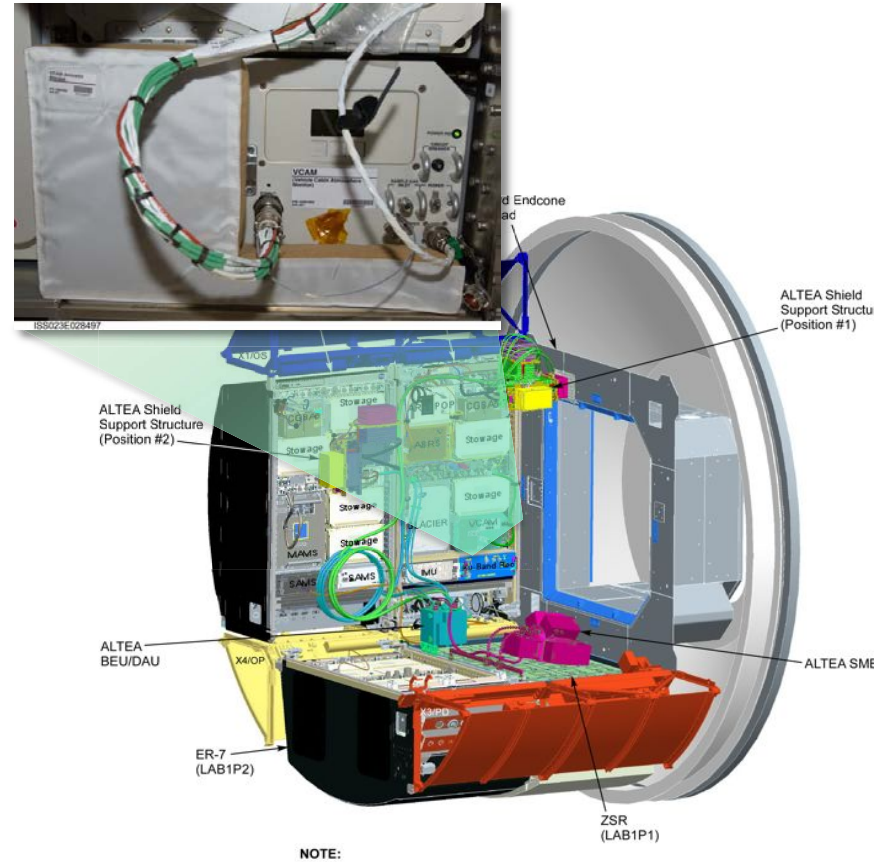


- ***Sample Air bag:*** **Provides the means to present a crew collected sample of ISS air to VCAM for analysis.**
- **Deliverable: 10 bags due on 9/25/08 for a Nov. shuttle flight.**

Post-Launch Activities and Results

Steady progress towards operations

- Activated April 27 and SW upgraded.
- ORU gas bottles inserted by Crew April 28. Slow calibrant leak was expected and dealt with.
- Background spectra and calibration runs indicate all components working
- Some computer resets have occurred, instrument has recovered. Cause under investigation.
- May 3 reached 7 x 10^{-8} torr (goal for major constituents mode)
- First trace VOC measurements performed on June 3rd
- TG VOC calibration being performed July 16th – July 20th.



VCAM TG Chemical Requirements

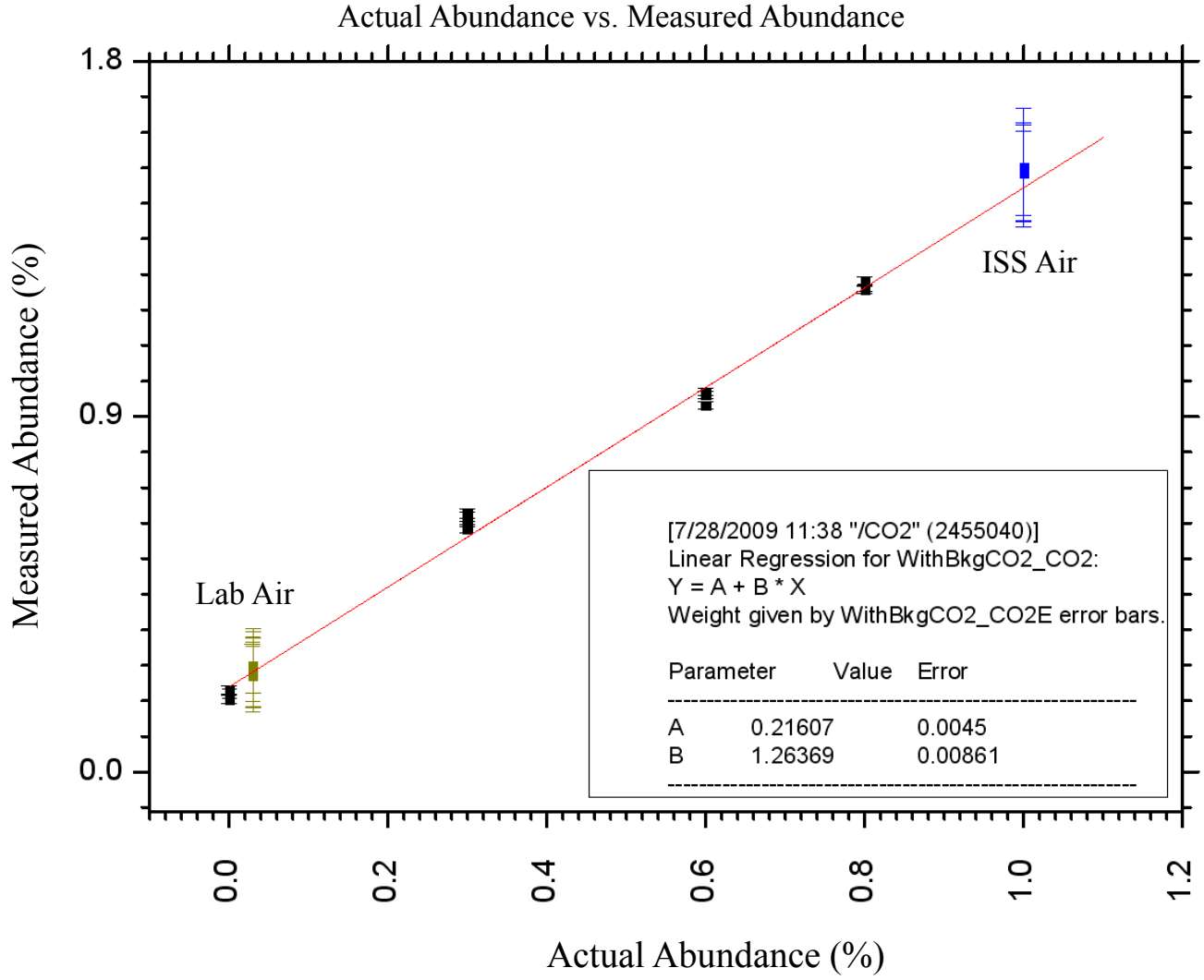
Target Trace Gases

- Identified and prioritized by JSC toxicology group
- Special cases
  - HMCTS and Propylene Glycol
  - qualitative detection only – no quantification
- Validation Testing
  - > 90% identification rate Success
  - 40% accuracy requirement Success
  - 24 hour / 20% precision requirement Success

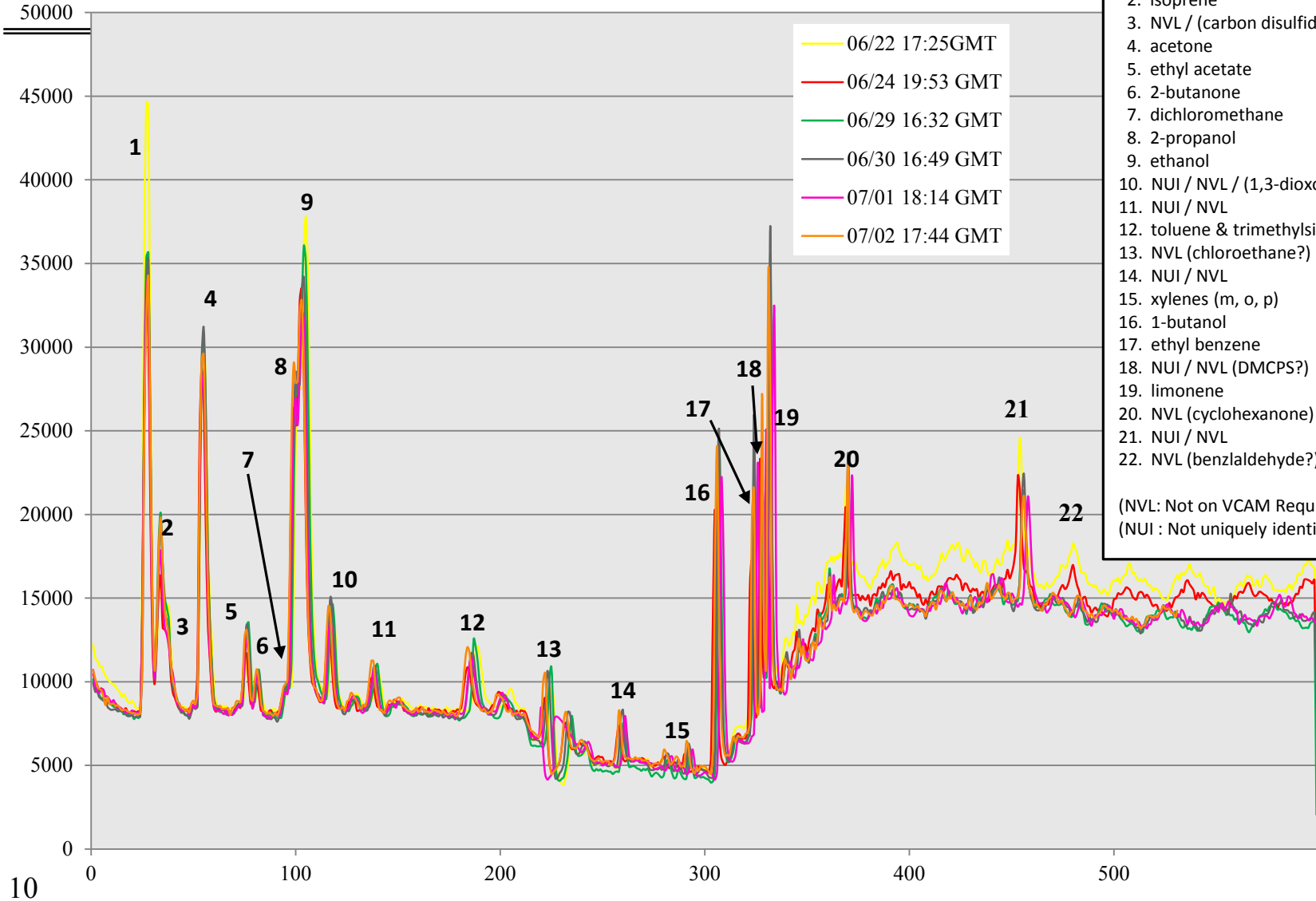
	Compound	*Concentration Range (ppm)*
Priority 1	Ethanol	1-10
	Acetaldehyde	0.1-3
	Acetone	0.5-5
	Dichloromethane	0.03-5
	Octamethylcyclotetrasiloxane	0.05-1
	Hexamethylcyclotrisiloxane	0.1-2
	Propylene glycol	0.5-5
	Perfluoropropane	10-100
Priority 2	1-Butanol	0.5-5
	Benzene	0.01-1
	C5 Alkanes (Pentane)	2-20
	C7 Alkanes (Hexane)	2-20
	C5 Aldehydes (Pentanal)	0.1-2
	C6 Aldehydes (Hexanal)	0.1-2
	Ethyl benzene	1-10
	Ethyl acetate	1-10
	2-propanol	1-10
	Freon 113	2-10
	Furan	0.01-1
	Toluene	1-10
	Xylenes (3)	1-10
Priority 3	1,2-Dichloroethane	0.01-0.1
	2-butanone	0.5-5
	4-methyl-2-pentanone	2-10
	Carbonyl sulfide	0.01-1
	Chloroform	0.02-1
	Freon 11	2-10
	Isoprene	0.05-1
	Limonene	1-10
	Vinyl chloride	0.05-1

VCAM MCA PERFORMANCE

MCA Validation: Carbon Dioxide Calibration Curve



Ion Chromatograms for VCAM Trace VOC Measurements of ISS Cabin Atmosphere

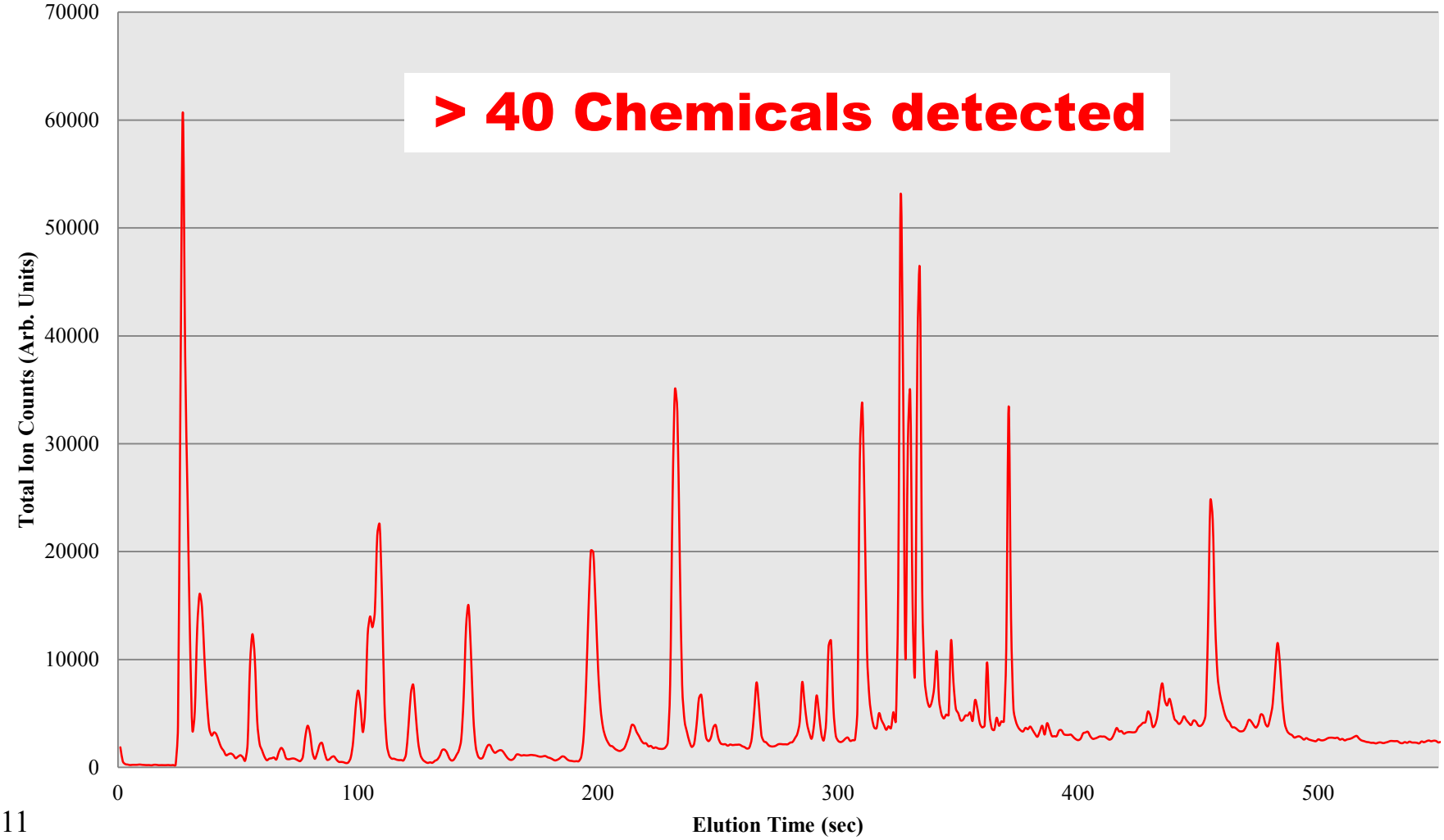


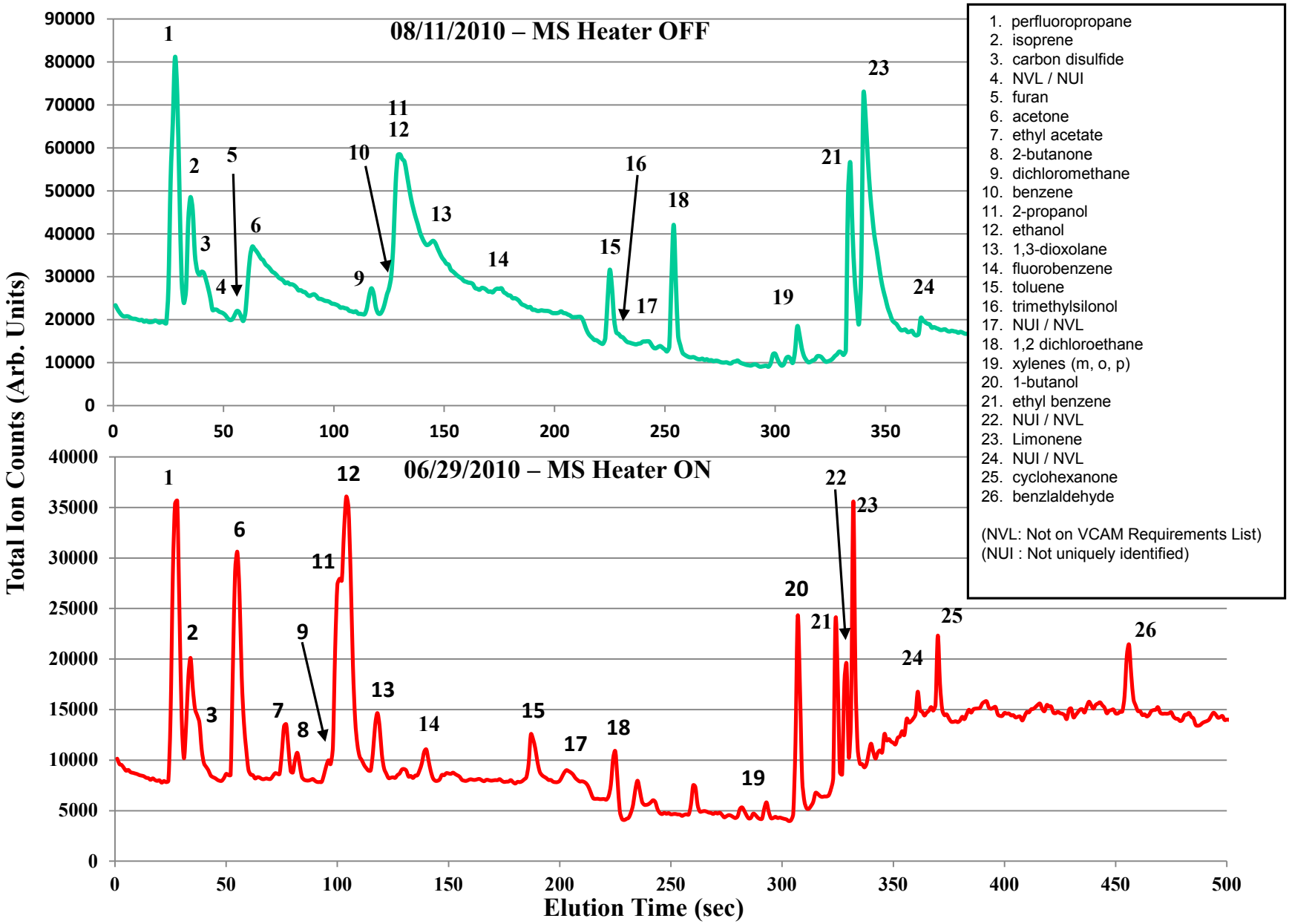
1. perfluoropropane
2. isoprene
3. NVL / (carbon disulfide?)
4. acetone
5. ethyl acetate
6. 2-butanone
7. dichloromethane
8. 2-propanol
9. ethanol
10. NUI / NVL / (1,3-dioxolane?)
11. NUI / NVL
12. toluene & trimethylsilonol (NVL)
13. NVL (chloroethane?)
14. NUI / NVL
15. xylenes (m, o, p)
16. 1-butanol
17. ethyl benzene
18. NUI / NVL (DMCPS?)
19. limonene
20. NVL (cyclohexanone)
21. NUI / NVL
22. NVL (benzlaldehyde?)

(NVL: Not on VCAM Requirements List)
(NUI : Not uniquely identified)

Total Ion Chromatogram for VCAM Trace VOC Measurement of ISS Cabin Atmosphere

(preconcentrator load time ~ 3x nominal level)




08/11/2010 – MS Heater OFF
06/29/2010 – MS Heater ON
Total Ion Counts (Arb. Units)
Elution Time (sec)
1. perfluoropropane
2. isoprene
3. carbon disulfide
4. NVL / NUI
5. furan
6. acetone
7. ethyl acetate
8. 2-butanone
9. dichloromethane
10. benzene
11. 2-propanol
12. ethanol
13. 1,3-dioxolane
14. fluorobenzene
15. toluene
16. trimethylsilonol
17. NUI / NVL
18. 1,2 dichloroethane
19. xylenes (m, o, p)
20. 1-butanol
21. ethyl benzene
22. NUI / NVL
23. Limonene
24. NUI / NVL
25. cyclohexanone
26. benzlaldehyde
(NVL: Not on VCAM Requirements List)
(NUI : Not uniquely identified)

VCAM TG Measurements

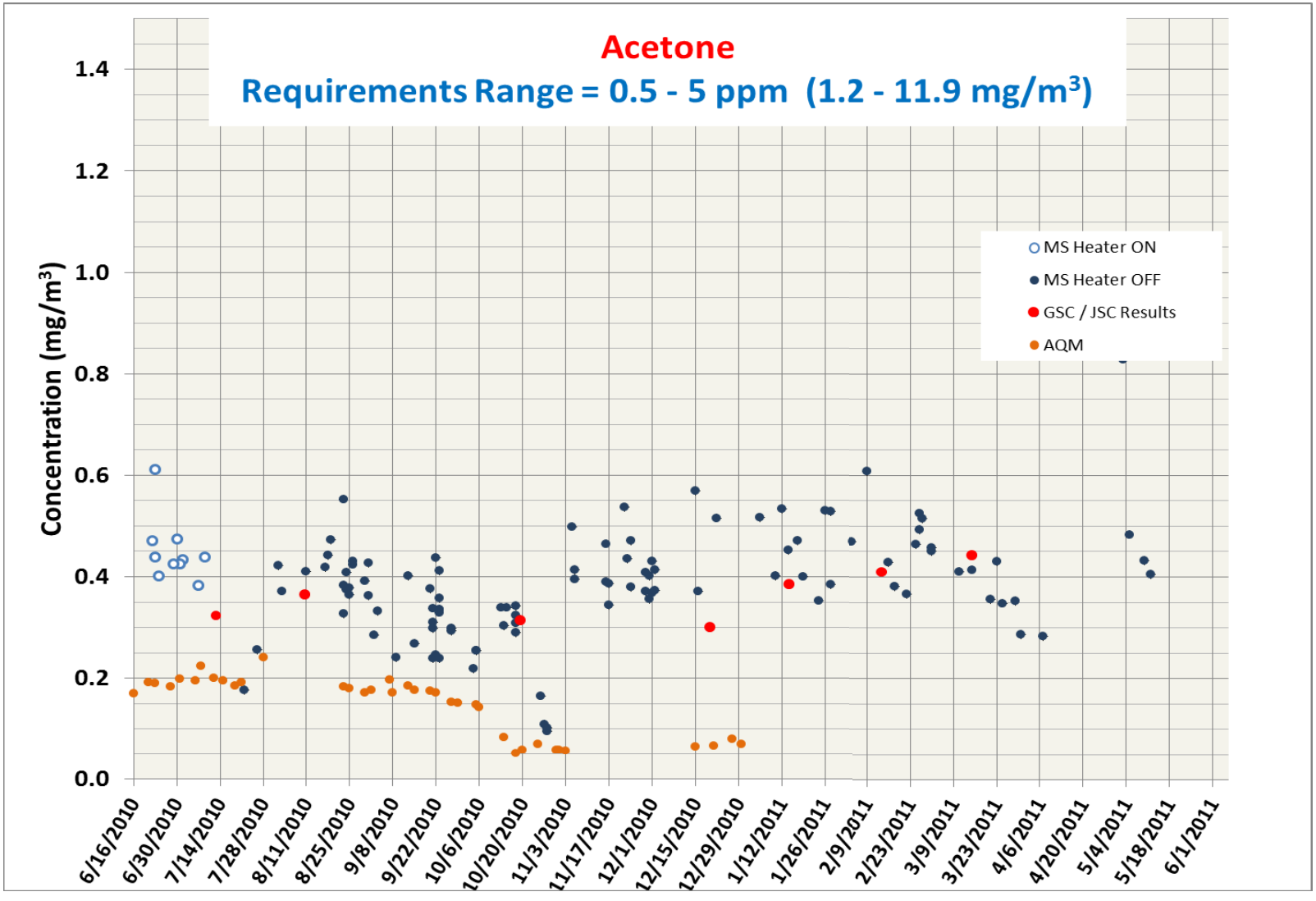
Trace Chemical Species	VCAM Requirements Range	Current Capability	Post-IFM Capability	Updated Quantization Range
VCAM Validation Species	ppm	I = Identify Q = Quantify	I = Identify Q = Quantify	ppm
1,2-dichloroethane	0.01 - 1	IQ	IQ	0.003 - 1
1-butanol	0.5 - 5	-	IQ	0.02 - 5
2-butanone	0.5 - 5	I(ok) Q(in progress)	IQ	0.01 - 5*
2-propanol	1 - 10	I(ok) Q(in progress)	IQ	1 - 10*
4-methyl 2-pentanone	2 - 10	-	IQ	2 - 10
acetaldehyde	0.1 - 3	I(ok) Q(in progress)	IQ	0.1 - 3*
acetone	0.5 - 5	IQ	IQ	0.1 - 5
benzene	0.01 - 1	I(ok) Q(in progress)	IQ	0.01 - 1*
carbonyl sulfide	0.01 - 1	I(ok) Q(in progress)	IQ	0.01 - 1*
chloroform	0.02 - 1	I(ok) Q(in progress)	IQ	0.002 - 1*
dichloromethane	0.03 - 5	IQ	IQ	0.01 - 5
ethanol	1 - 10	IQ	IQ	0.5 - 10
ethyl acetate	1 - 10	IQ	IQ	0.05 - 10
ethyl benzene	1 - 10	IQ	IQ	0.01 - 10
Freon 11	2 - 10	I(ok) Q(in progress)	IQ	2 - 10*
freon 113	2 - 10	I(ok) Q(in progress)	IQ	2 - 10*
furan	0.01 - 1	I(ok) Q(in progress)	IQ	0.002 - 1*
hexanal	0.1 - 2	-	IQ	0.01 - 2*
hexane	2 - 20	I(ok) Q(in progress)	IQ	2 - 20*
HMCTS	Identify only	-	I	Identify only
isoprene	0.05 - 1	IQ	IQ	0.05 - 1
limonene	1 - 10	IQ	IQ	0.02 - 10
OMCTS	0.05 - 1	-	IQ	0.05 - 1
pentanal	0.1 - 2	-	IQ	0.01 - 2*
pentane	2 - 20	I(ok) Q(in progress)	IQ	0.05 - 20*
perfluoropropane	10 - 100	IQ	IQ	10 - 100
propylene glycol	Identify only	-	I	Identify only
toluene	1 - 10	IQ	IQ	0.01 - 10
vinyl chloride	0.05 - 1	-	IQ	0.05 - 1*
xylenes (o, m, p)	1 - 10	IQ	IQ	0.01 - 10

VCAM TG Measurements

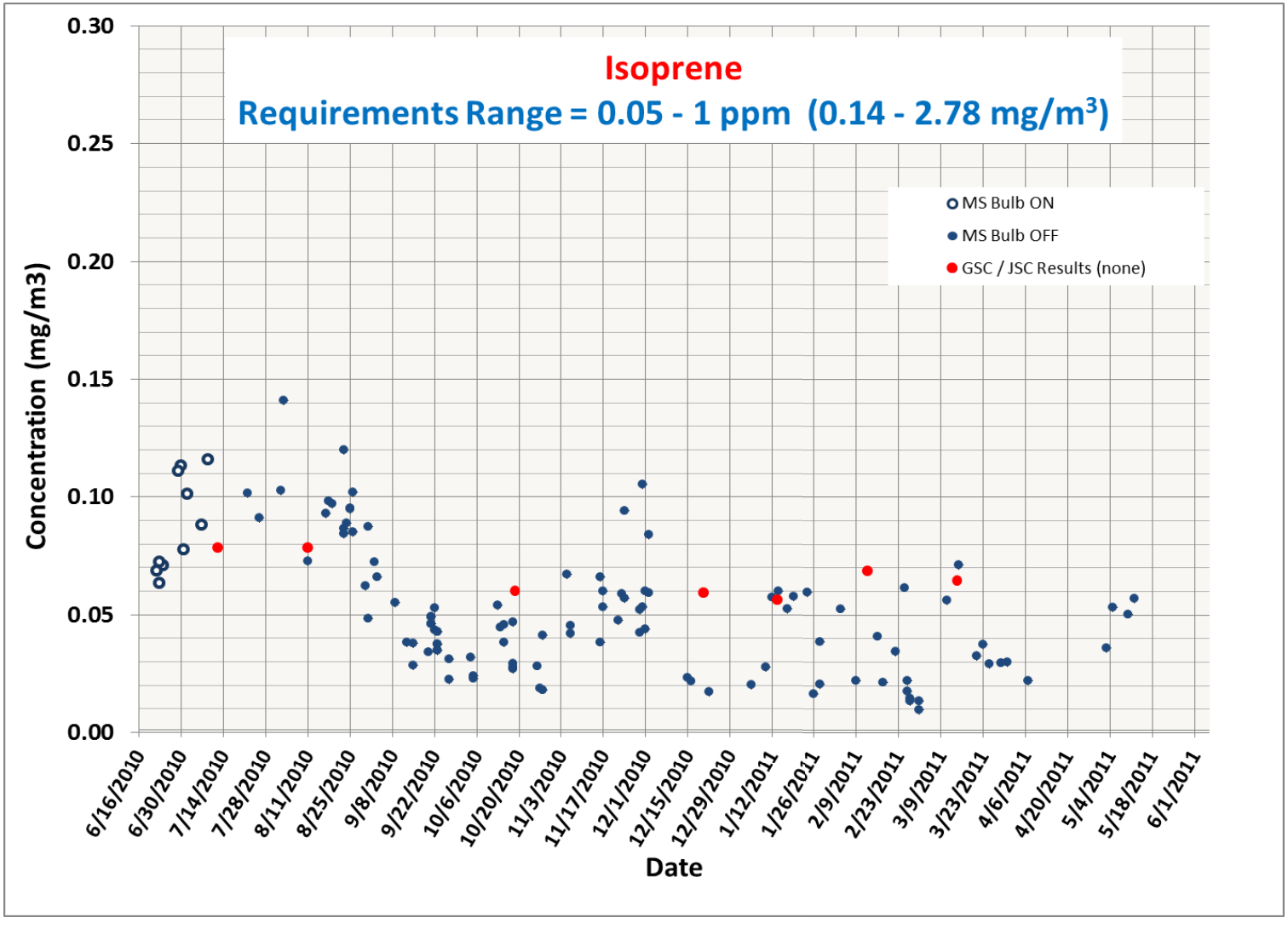
Additional chemicals detected by VCAM in ISS Atmosphere

Trace Chemical Species
Species Detected in ISS Trace Gas Measurements
1,3 dioxolane
1-butene
2-butenal
2-methyl 2-propanol
2-methyl butane
benzaladehyde
carbon disulfide
chlorobenzene
cyclohexanone
dichlorobenzene
decamethylcyclopentasiloxane
ethoxyethanol
hexanal
methyl acetate
styrene
trimethylbenzene
trimethylsilanol

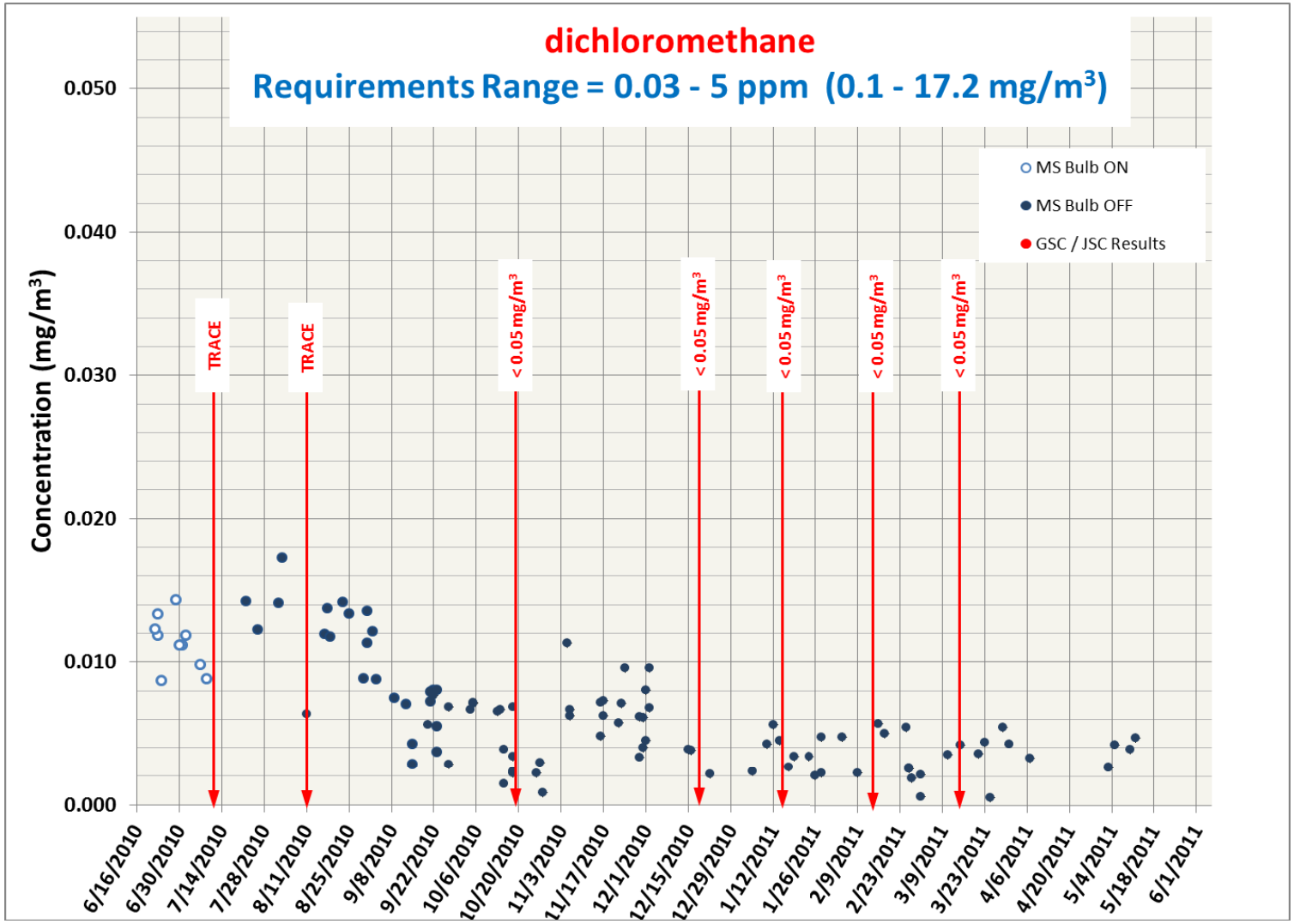
VCAM TG Measurements



VCAM TG Measurements



VCAM TG Measurements



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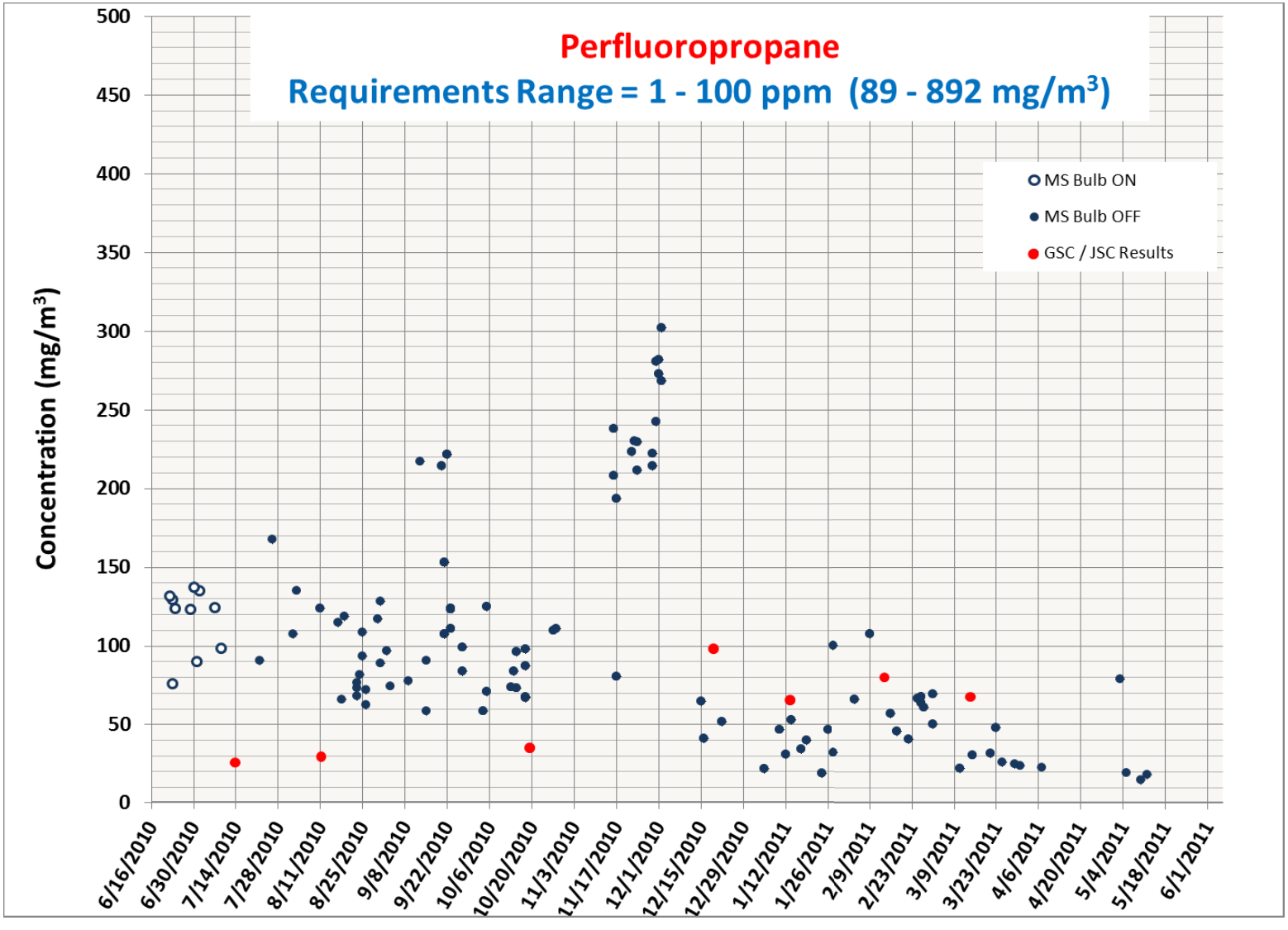
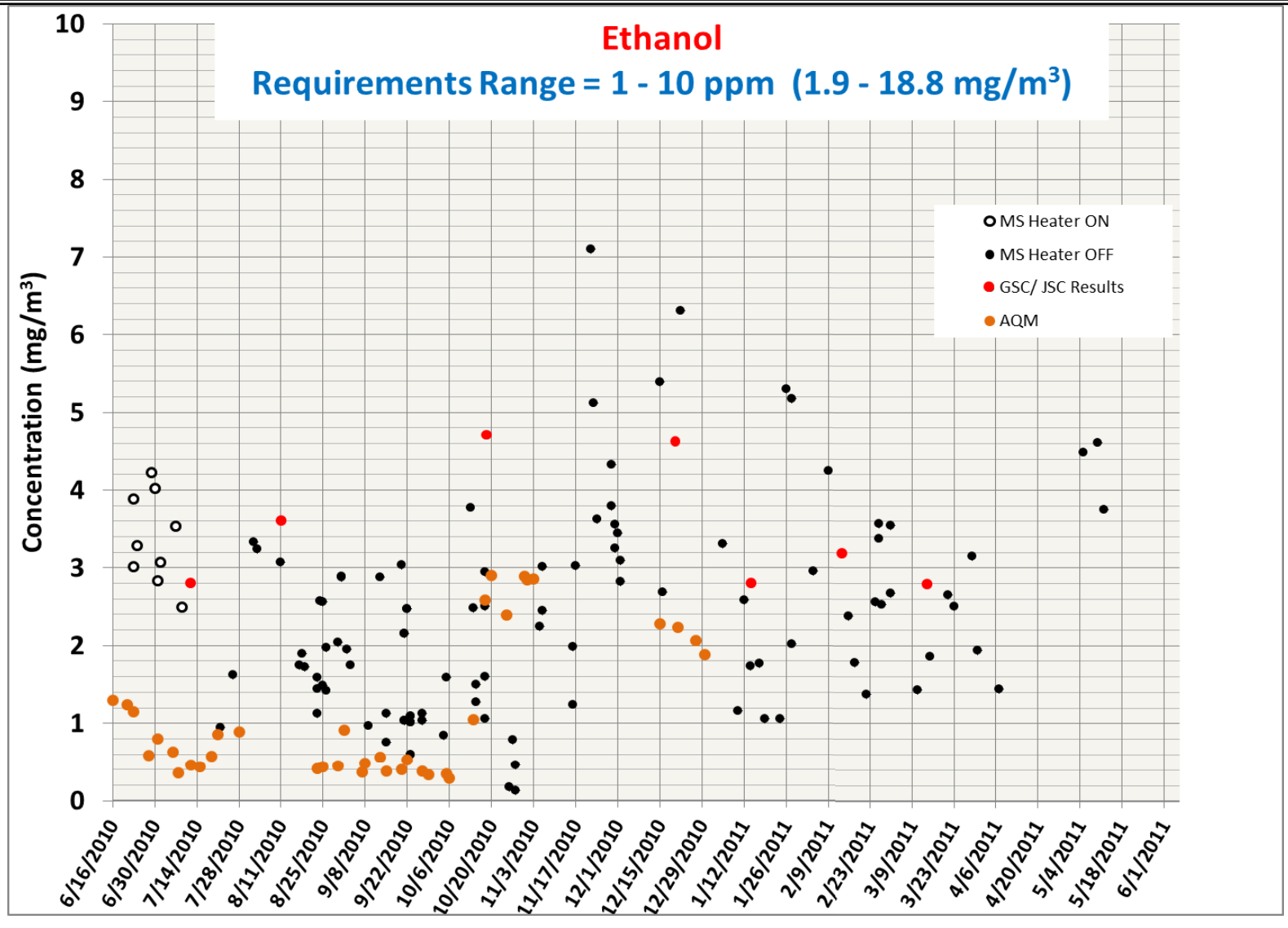
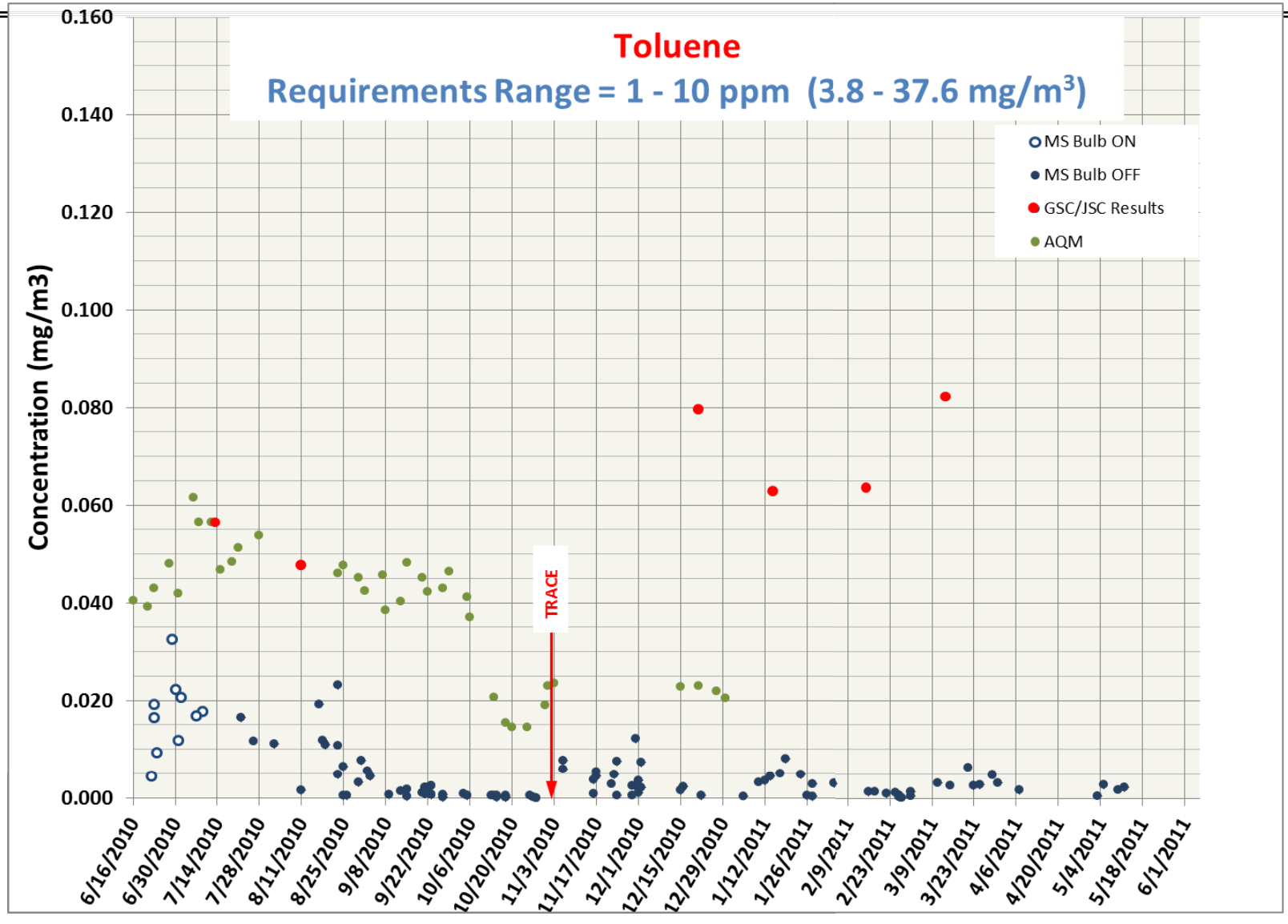


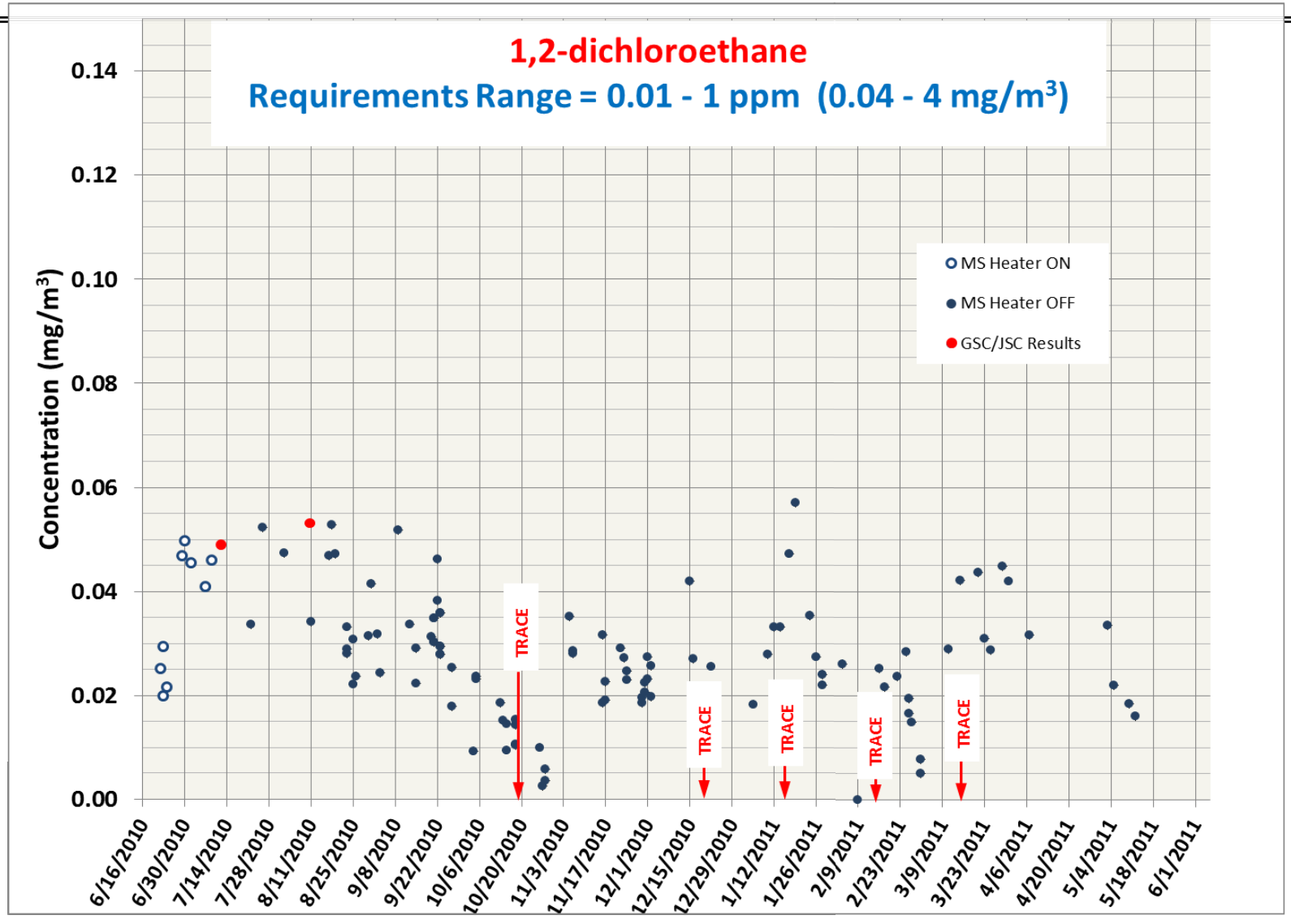
VCAM TG Measurements



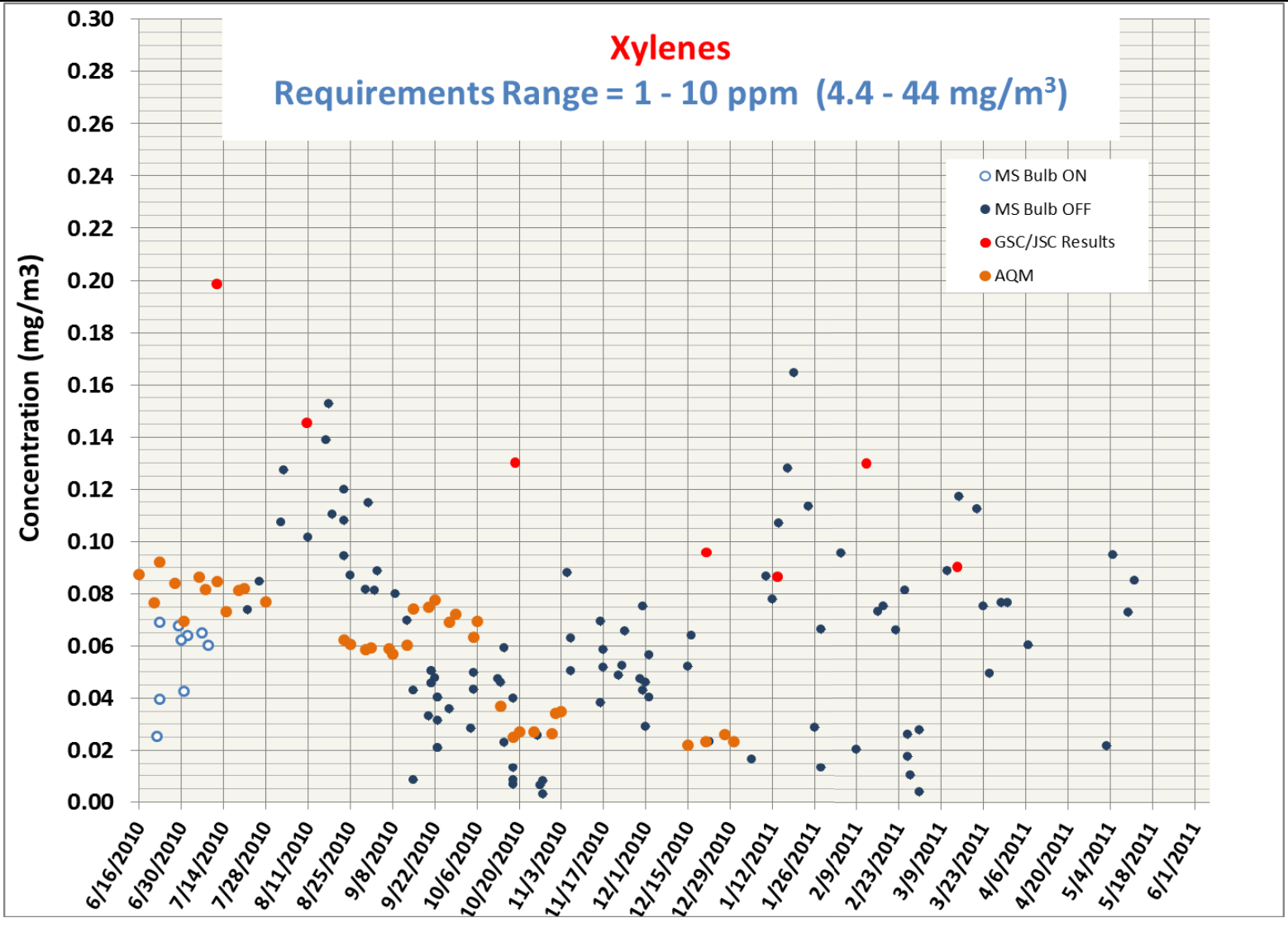
VCAM TG Measurements



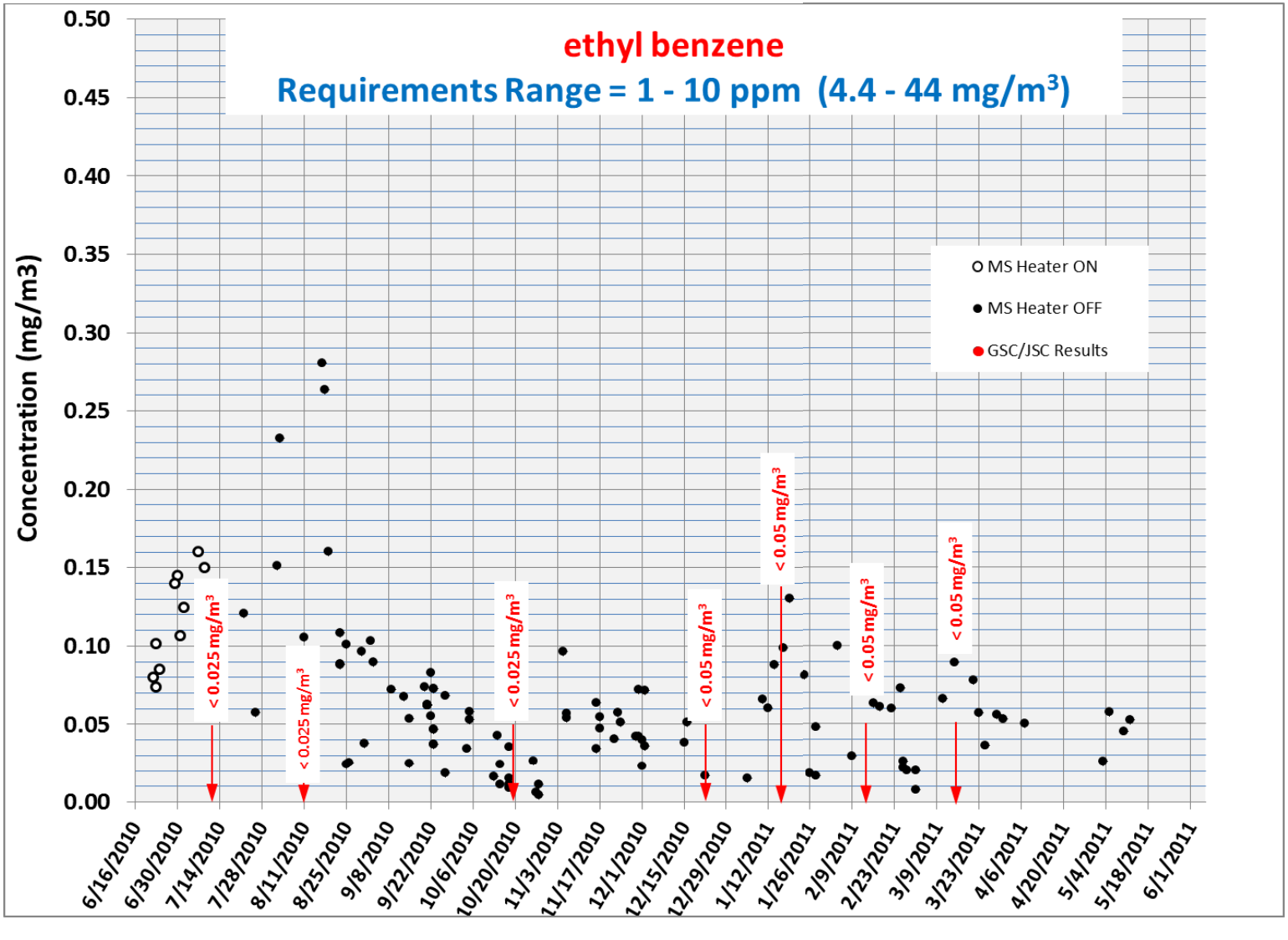
VCAM TG Measurements



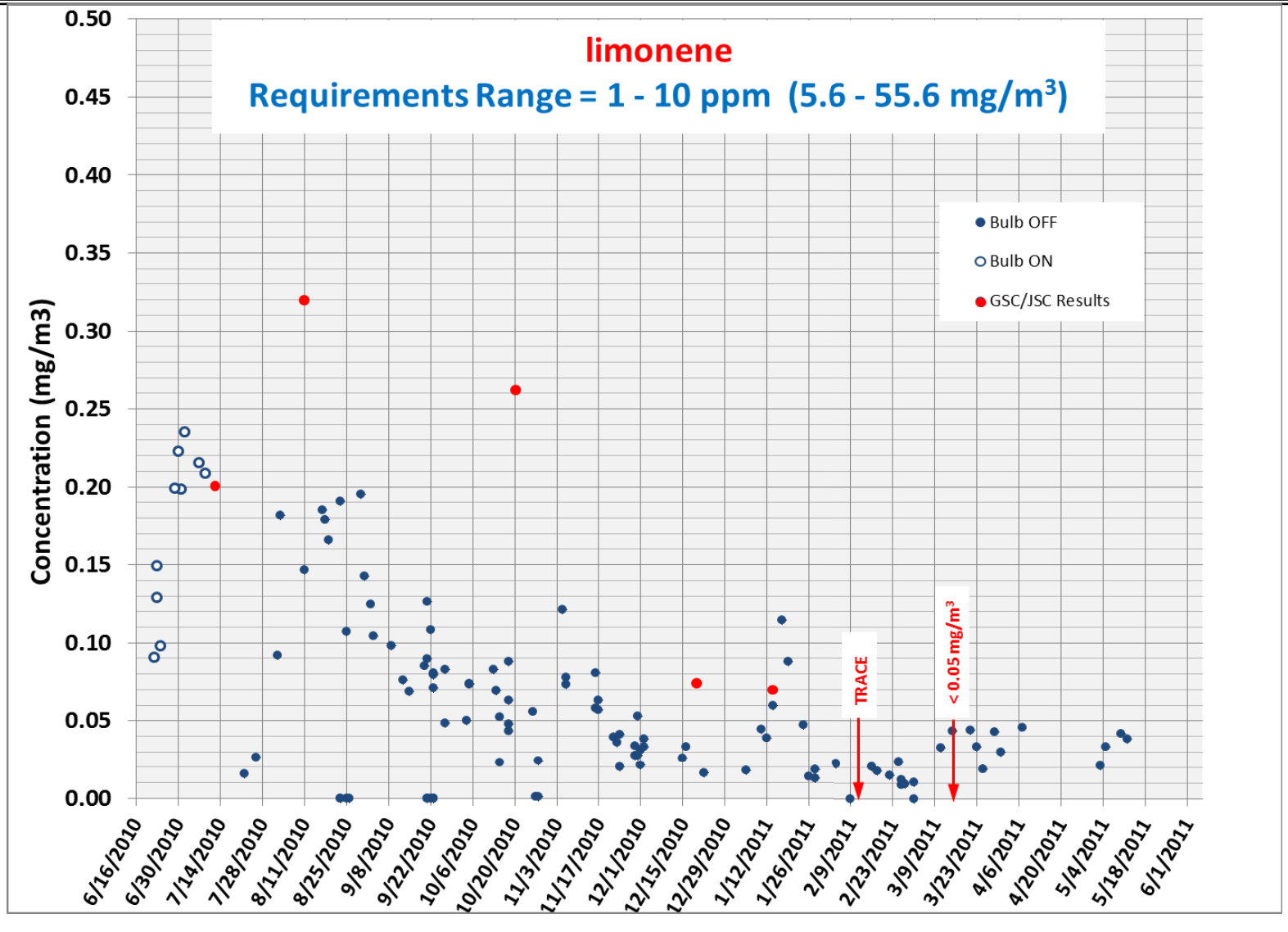
VCAM TG Measurements



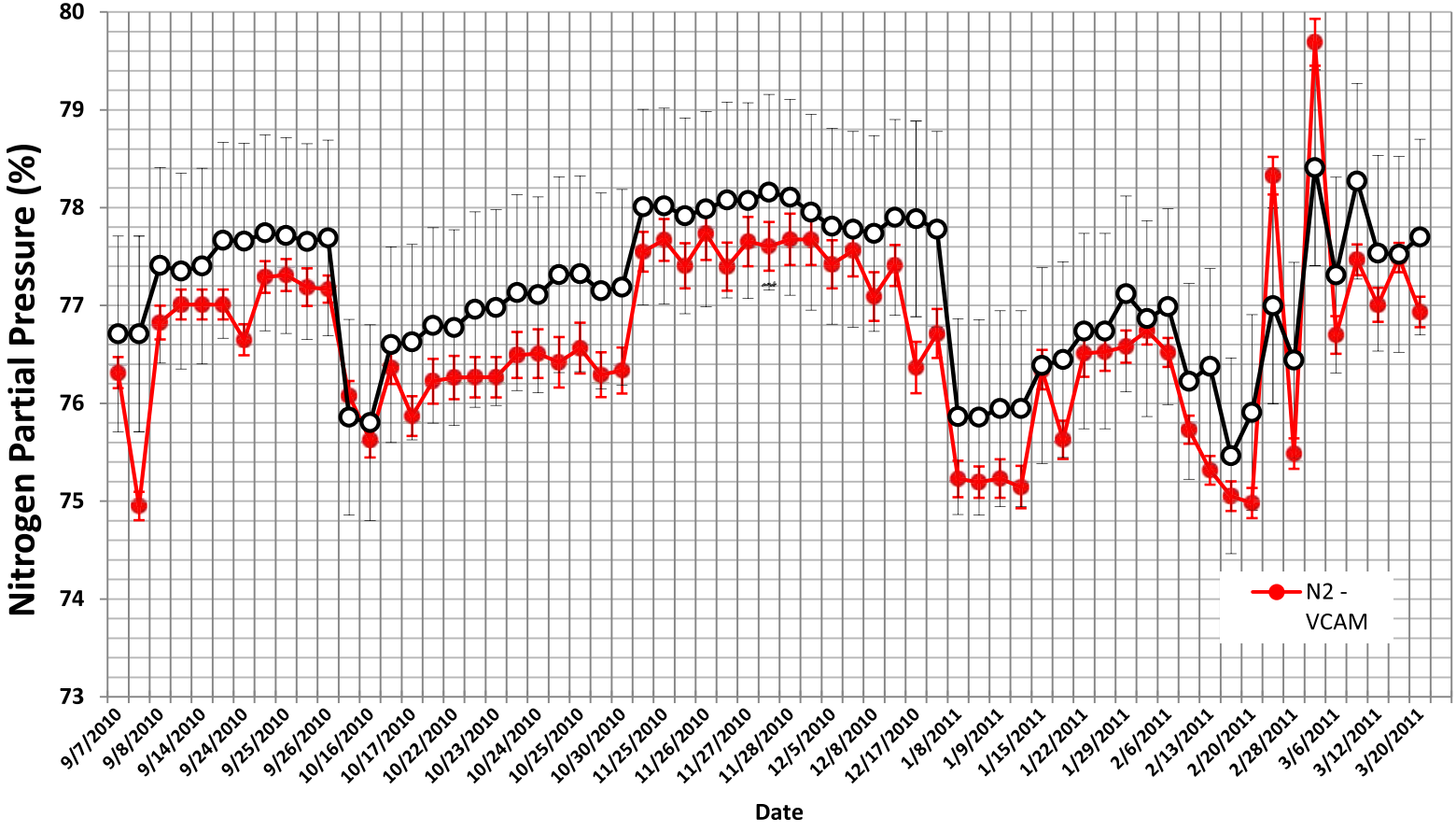
VCAM TG Measurements



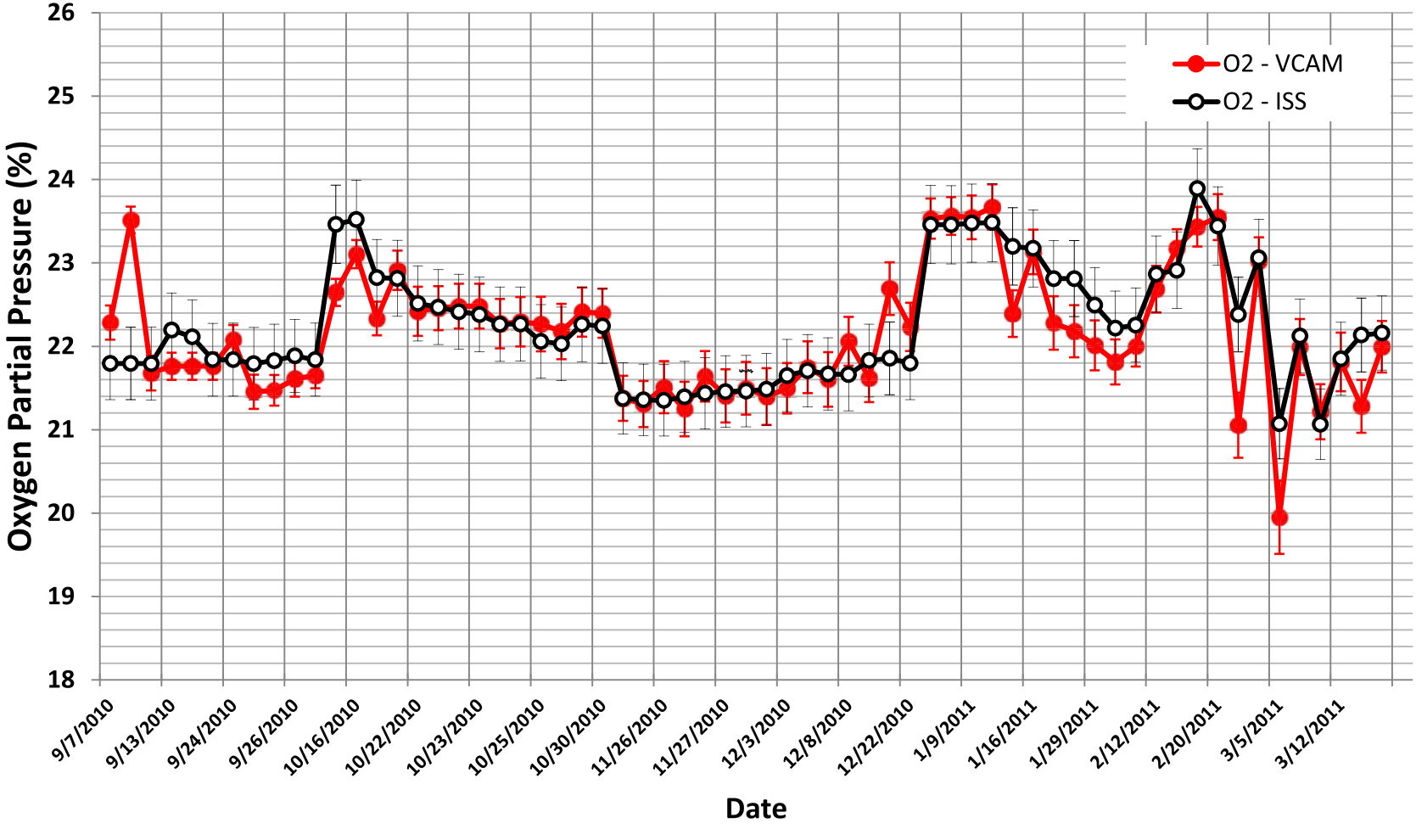
VCAM TG Measurements



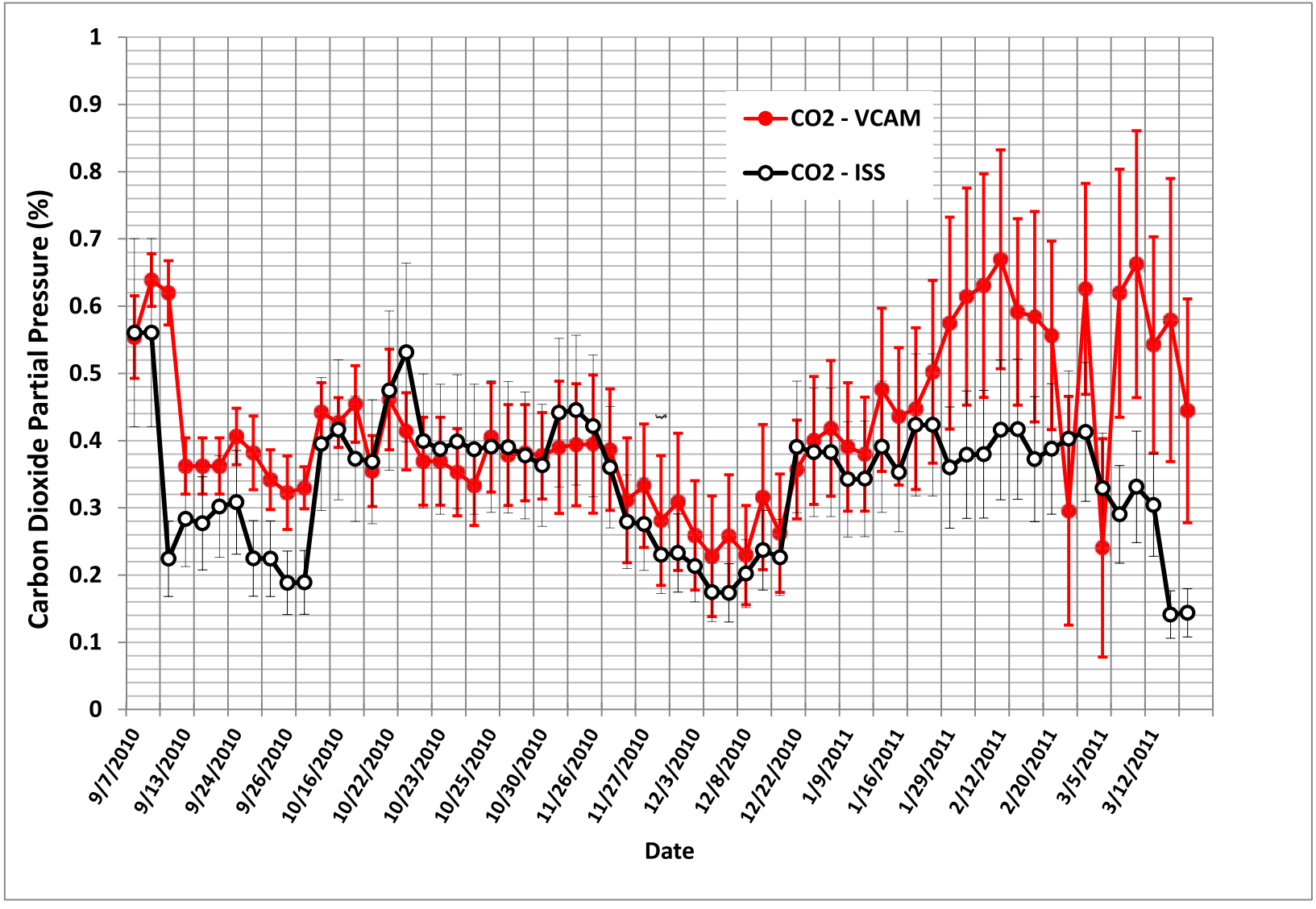
VCAM MCA Measurement Status for Nitrogen



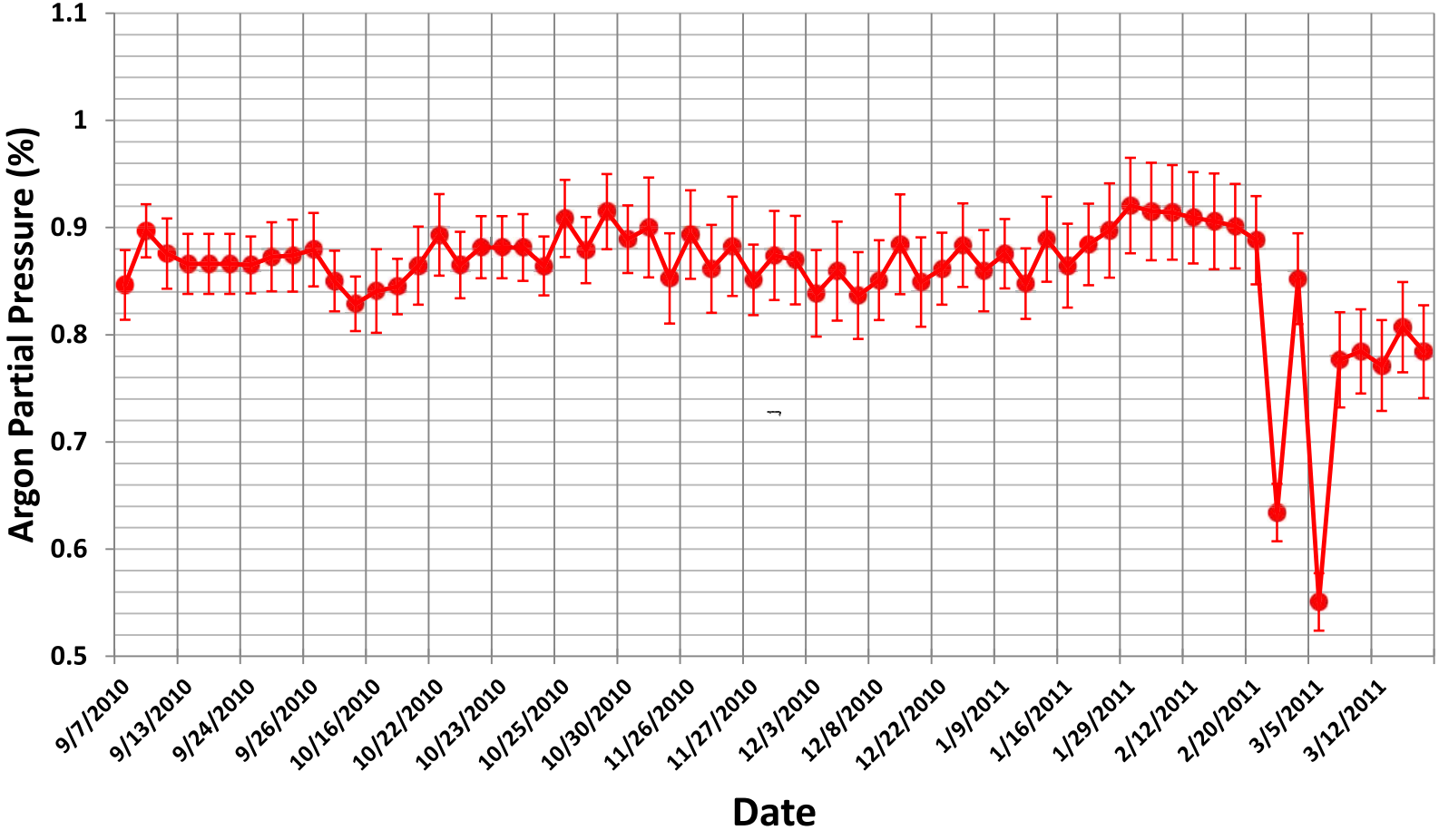
VCAM MCA Measurement Status for Oxygen



VCAM MCA Measurement Status for Carbon Dioxide



VCAM MCA Measurement Status for Argon



Conclusions, Summary, and Recommendations

Jay Perry (MSFC/ VCAM Referee):

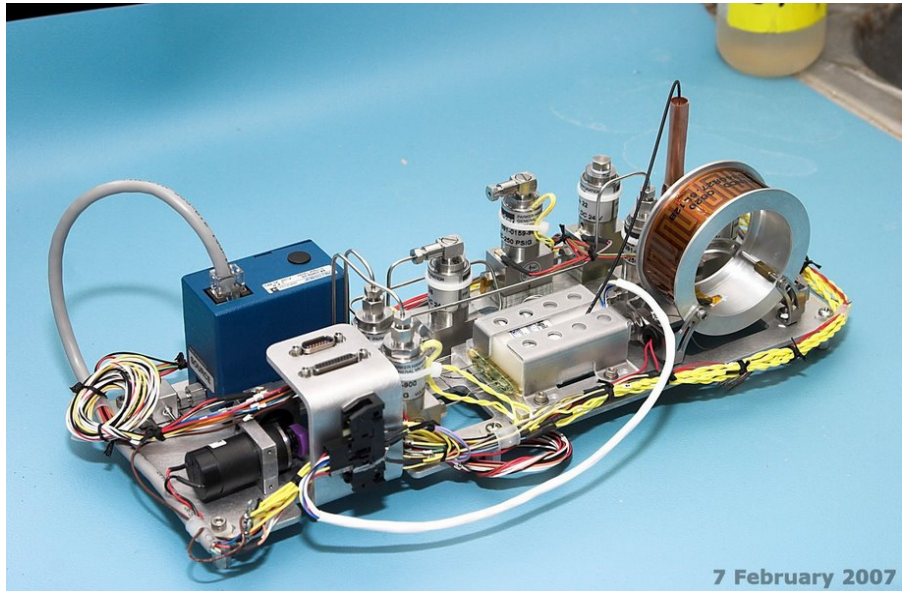
1. VCAM continues to return results for targeted VOCs that meet or exceed performance requirements. Although the instrument is operating in an environment that is typically below its requirement range, for nearly all the targeted VOCs, the instrument continues to compare exceptionally well with air quality results reported via the GSC sampling/ground analysis.
2. VCAM is proving to possess operational flexibility beyond expectations for an instrument of its class.
3. VCAM is proving to be a viable part for the overall technical solution of crewed spacecraft cabin atmospheric quality analysis and monitoring.
4. Exploring further development to include combining the VCAM with Fourier transform infrared (FTIR) spectrometry and other portable methods for broad spectrum analysis and portable instruments for highly specific analytical targets is recommended to realize the most powerful analytical instrument combination for crewed spacecraft cabin atmospheric quality analysis and monitoring

BACKUP SLIDES

VCAM Components : Sensor (GC/MS)

Paul Ion Trap Mass Spectrometer

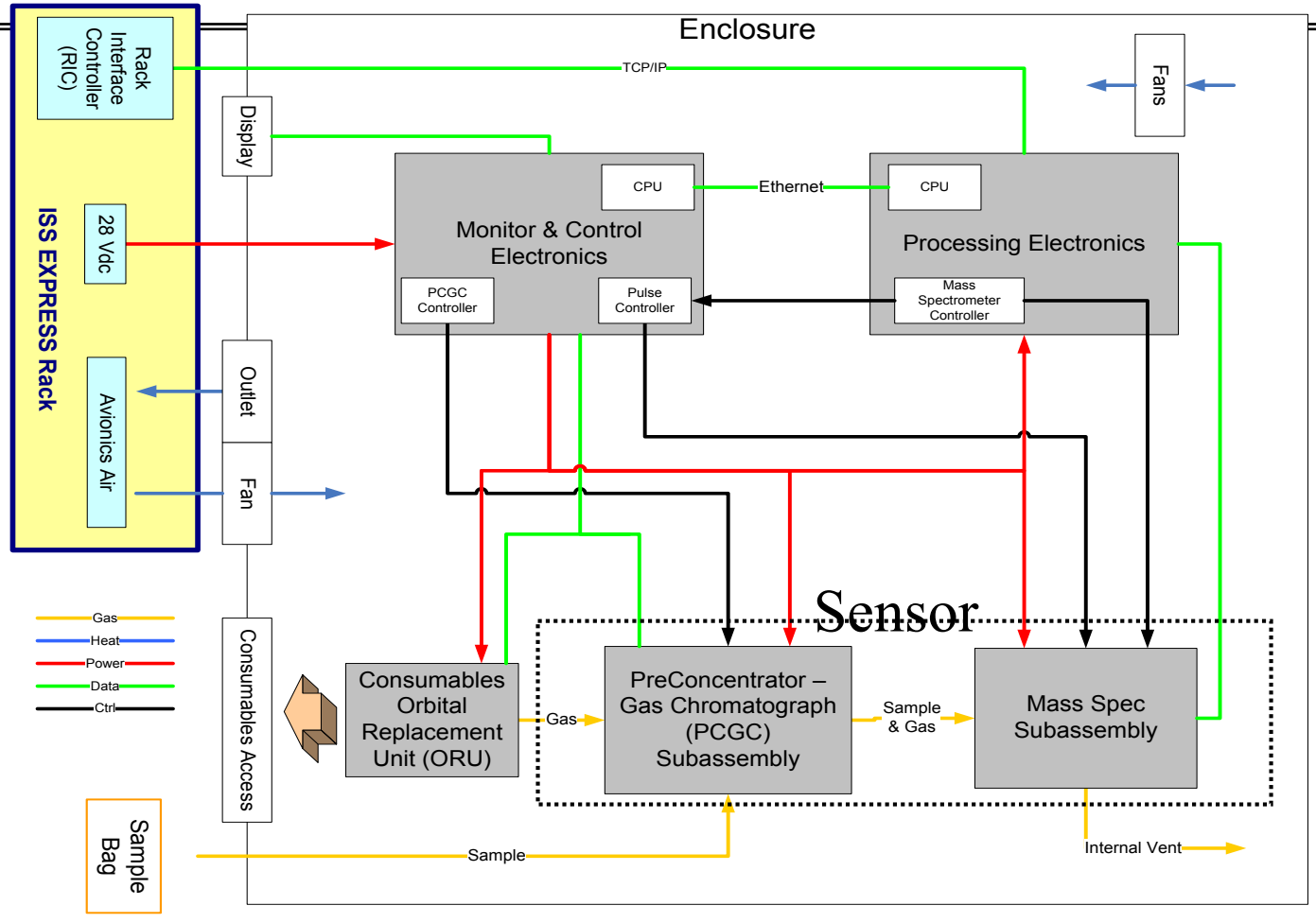
mass range	24 - 350 u
sensitivity	10 picomoles
mass resolution (m / Δ m)	> 250
mass crosstalk	1 : 50,000



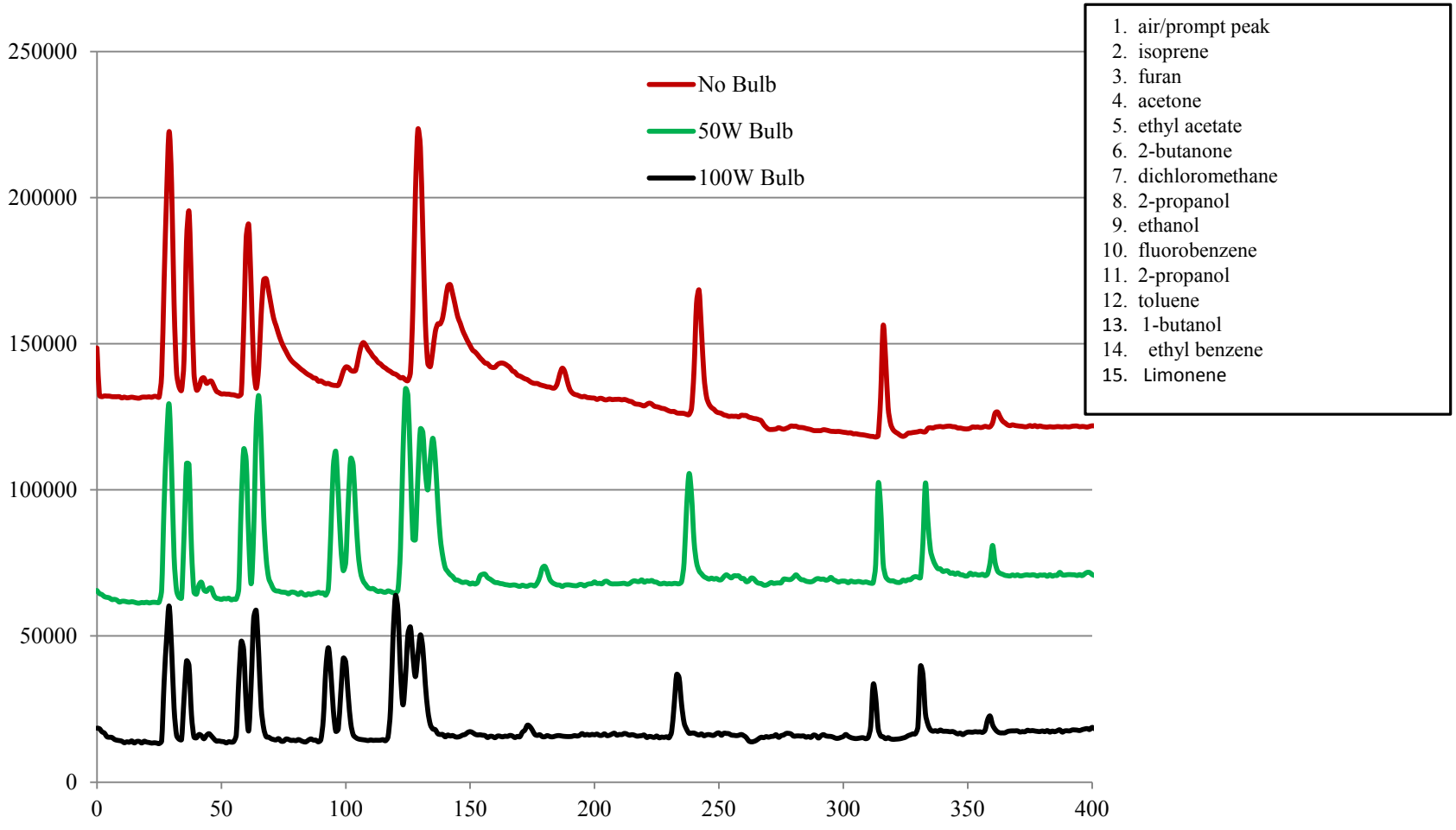
Pre-Concentrator / Gas Chromatograph (PCGC)

PC performance	> 50 x enrichment
GC type	10m DB-Wax
Elution time for all SMAC species	1200 sec
Elution peak width	8 sec (FWHM)

VCAM Block Diagram



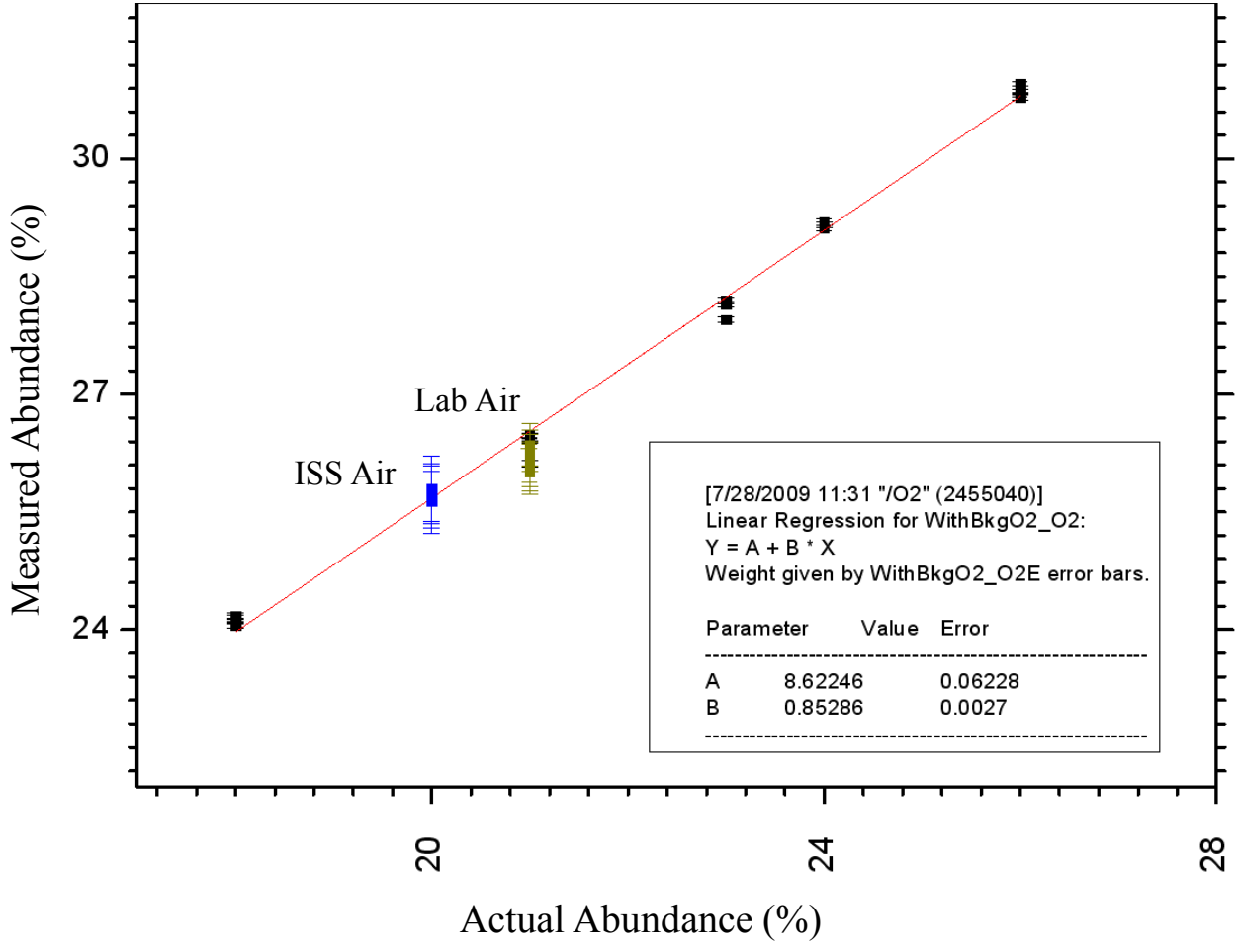
Schematic presentation of the VCAM subassemblies. The Paul ion trap is contained in the Sensor vacuum chamber; the calibration gas and He carrier gas are part of the Consumables ORU.


250000
200000
150000
100000
50000
0
0
50
100
150
200
250
300
350
400
No Bulb
50W Bulb
100W Bulb
1. air/prompt peak
2. isoprene
3. furan
4. acetone
5. ethyl acetate
6. 2-butanone
7. dichloromethane
8. 2-propanol
9. ethanol
10. fluorobenzene
11. 2-propanol
12. toluene
13. 1-butanol
14. ethyl benzene
15. Limonene

PERFORMANCE VALIDATION

MCA Validation: Oxygen Calibration Curve

Actual Abundance vs. Measured Abundance



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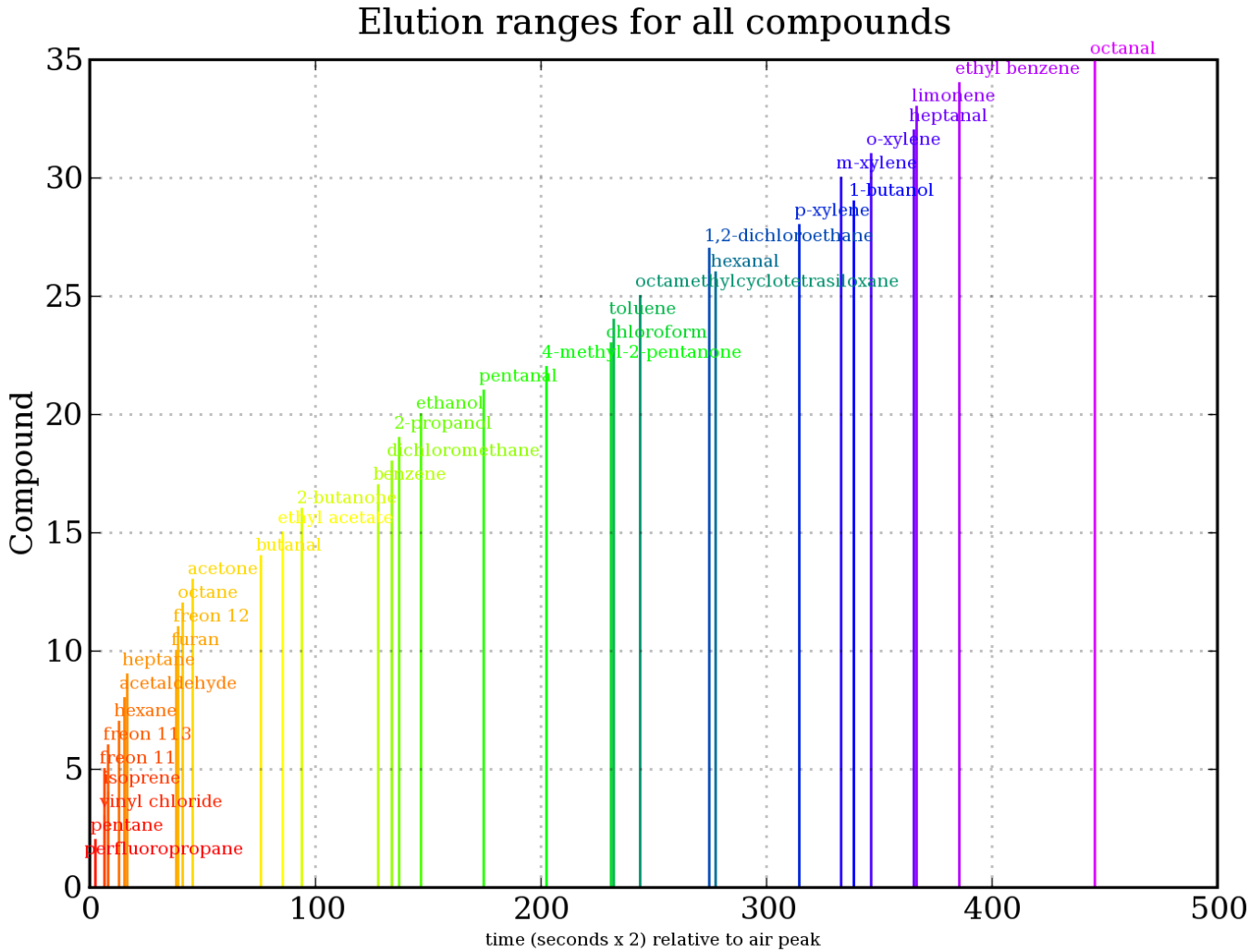
Software (Data Analysis): Identification Using Elution Time Gating