In-situ Volcanic Plume Monitoring at Solfatara Volcano and Vulcano Island, Italy with Small Portable Mass Spectrometer Systems designed for Field Deployment and Unmanned Aerial Vehicles (UAV)

10th Harsh Environment Mass Spectrometer Workshop, Baltimore MD 14 Sept 2015

Solfatara Volcano , Italy 31 Aug 2015

Vulcano Island, Italy 7 Sept 2015

Dr. Kenneth Wright
Chief Scientist -Mass Spectrometry
ISS Engineering. INFICON Inc.

Dr. Jorge Andres Diaz
Professor. Physics School.
University of Costa Rica
Head GasLab. CICANUM. UCR

Collaborators

David Pieri. PI
JPL, NASA

Fabrizia Buongiorno, Malvina Silvestri,
Fawzi Doumaz, Massimo Mussachio
INGV, Rome, Italy
Stefano Caliro
INGV- Osservatorio Vesuviano, Napoli

Jamie Winfield, Peter Santariello
INFICON Inc. East Syracuse, NY
Jochen Puchalla, Volker.Trieb
INFICON. Cologne Germany

Robert Kline-Shoder
CREARE Inc. Hanover, NH

Ernesto Corrales, Alfredo Alan,, Francinie Arias, Oscar Alegria
Universidad de Costa Rica. Physics School. GasLab. CICANUM, Costa Rica

Matthew Fladeland Co-I
NASA Ames Research Center. Moffett Field, CA

Motivation:
Volcanic Emissions Characterization

- Volcanic airborne emissions can have devastating economic effects, and directly threaten human life.
- Current remote sensing retrieval and transport models lack in situ validation data.
- Chronic and pervasive problem, identified in domestic and international forums
- Need for better understanding of the properties and internal chemical and physical processes within volcanic plumes, and the boundary conditions for both mass retrieval models and predictive models for cloud trajectories.

In Situ UAV Plume Characterization Project

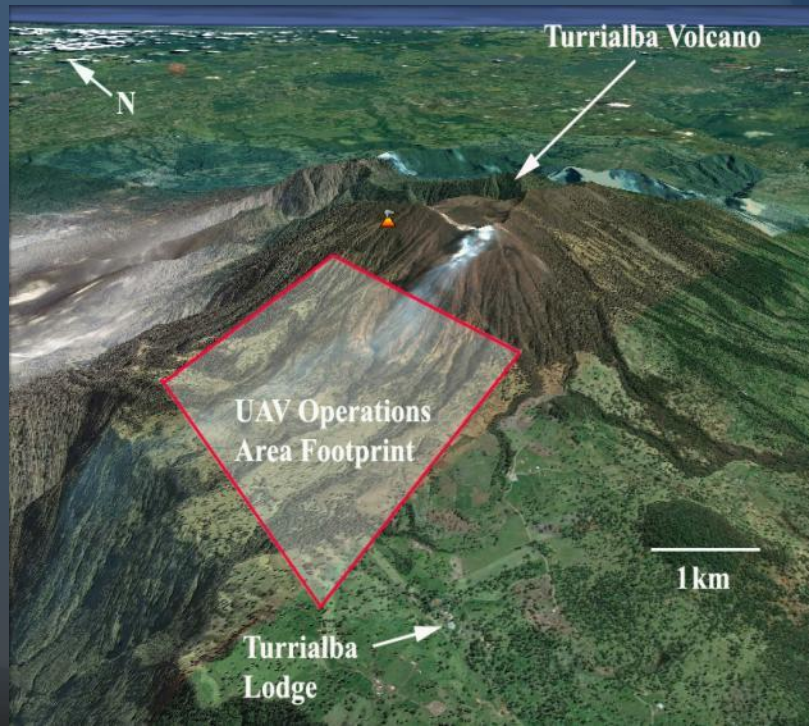
Objective:

In-situ volcanic plume analysis from small UAVs for volcano monitoring and satellite CAL/VAL

Measurements:

- *SO_2, H_2S, CO_2, He, CH_4 and other gases*
- *Temperature + pressure + humidity;*
- *GPS location and altitude*
- *Particle count by size*
- *Solid aerosol (ash) samples for post-flight analysis*

Instruments: *Mini-mass spectrometer, Electro-chem MEMS based SO_2, CO_2, H_2S, CH_4 sensors; radiometer particle drum-impactors, laser diode/optical particle counters, size, frequency analyzer, ash samplers.*



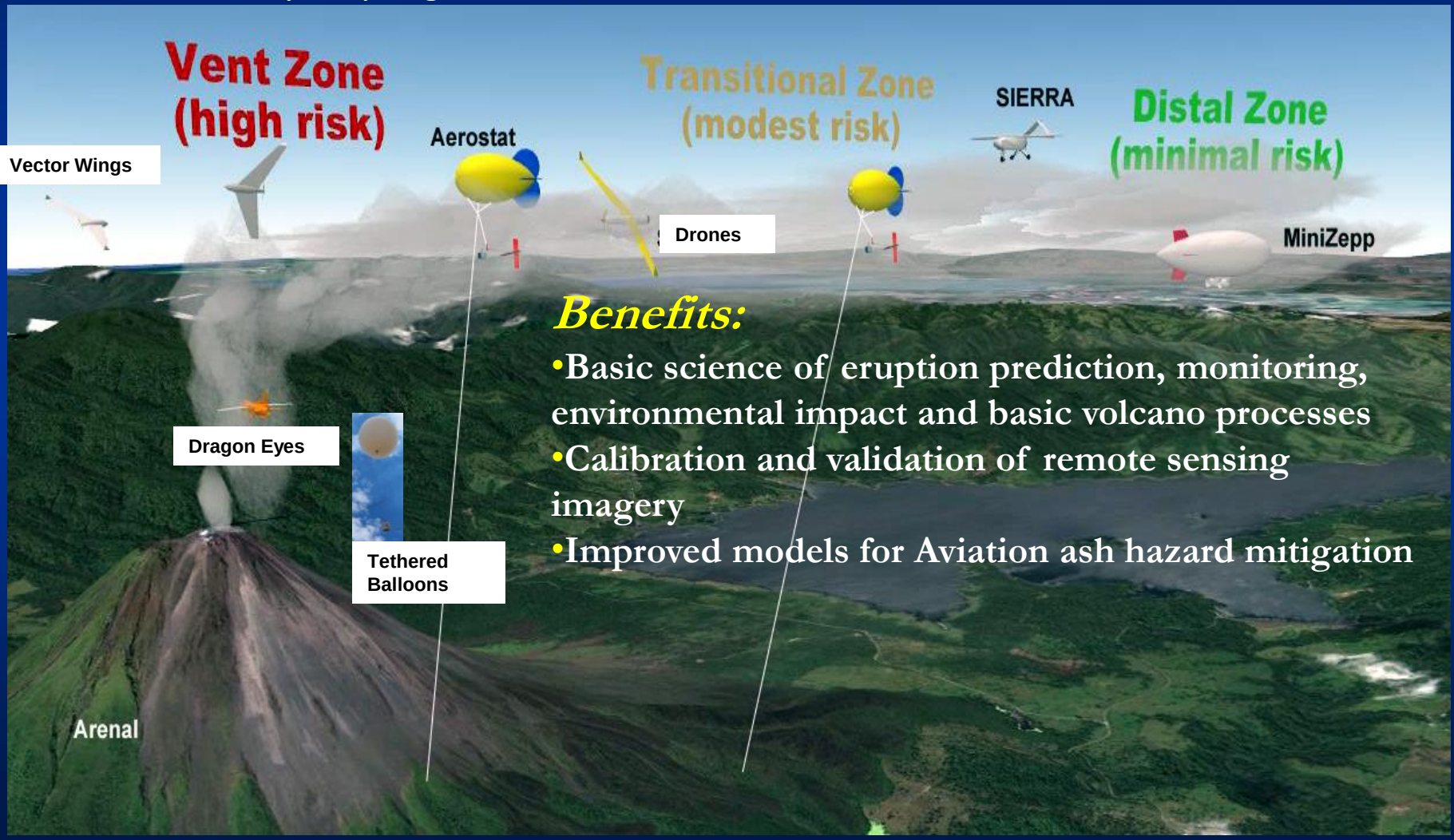
Where: *Turrialba Volcano (COSTA RICA)*
Solfatara a & Vulcano island, (ITALY)
Kilauea Volcano (HAWAII)

How:

CARTA Missions (1/yr) , Italy Volcano Missions (1 / yr)
InSitu Deployments (every 16 days)

Long term CARTA-UAV In situ Deployment Strategy:

Simultaneous fixed-wing, blimp, and tethered aerostats UAS airborne observations, integrated with in-situ instrumentation with simultaneous orbital and ground-based remote sensing. Operate in airspace too dangerous for manned aircraft—over and around actively erupting volcanoes.



Previous MS Developments from this project for Volcanic Monitoring

1) **QMS: Kilauea Volcano (Quadrupole) 1997, 32 kg**

   Feasibility Study. In situ ground based deployment

2) **Compact Double Focusing MS: Poas & Irazu Volcanoes (Miniature Magnetic Sector) 1999, 8.2 kg**

   Univ. of Minnesota Ph.D Thesis & US Patent #6,501,074

   Technical Implementation . In situ ground based deployment

   Inficon Tool Check RGA Implementation .

3) **AVEMS: Turrialba Volcano (Quadrupole) 2003, 32 kg**

   NASA-KSC Collaboration.

   In Situ and 3D Gas mapping with on Board calibration

   Ground based and airborne deployments

4) **ULISSES: Turrialba Volcano (Quadrupole) 2008, 10 kg**

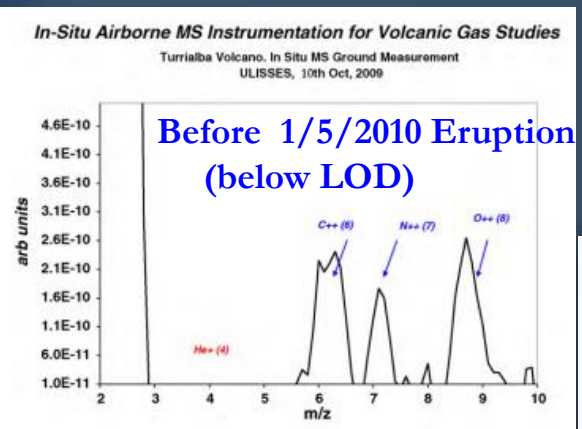
   In Situ MS analysis and 3D Gas mapping

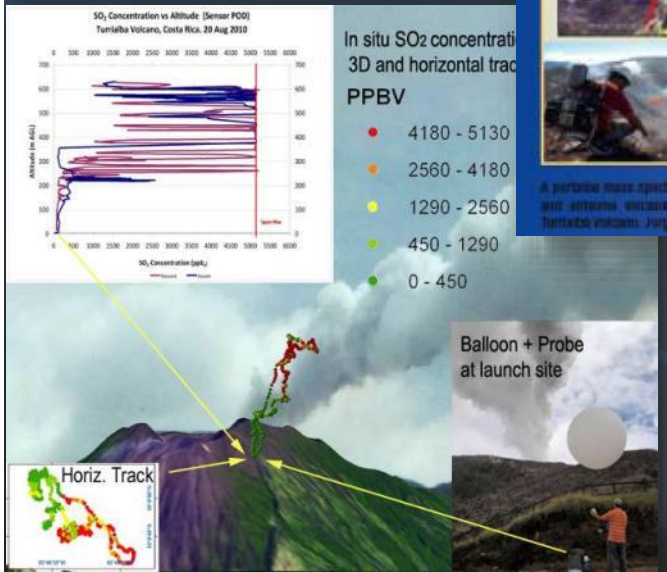
   Ground based and airborne deployments

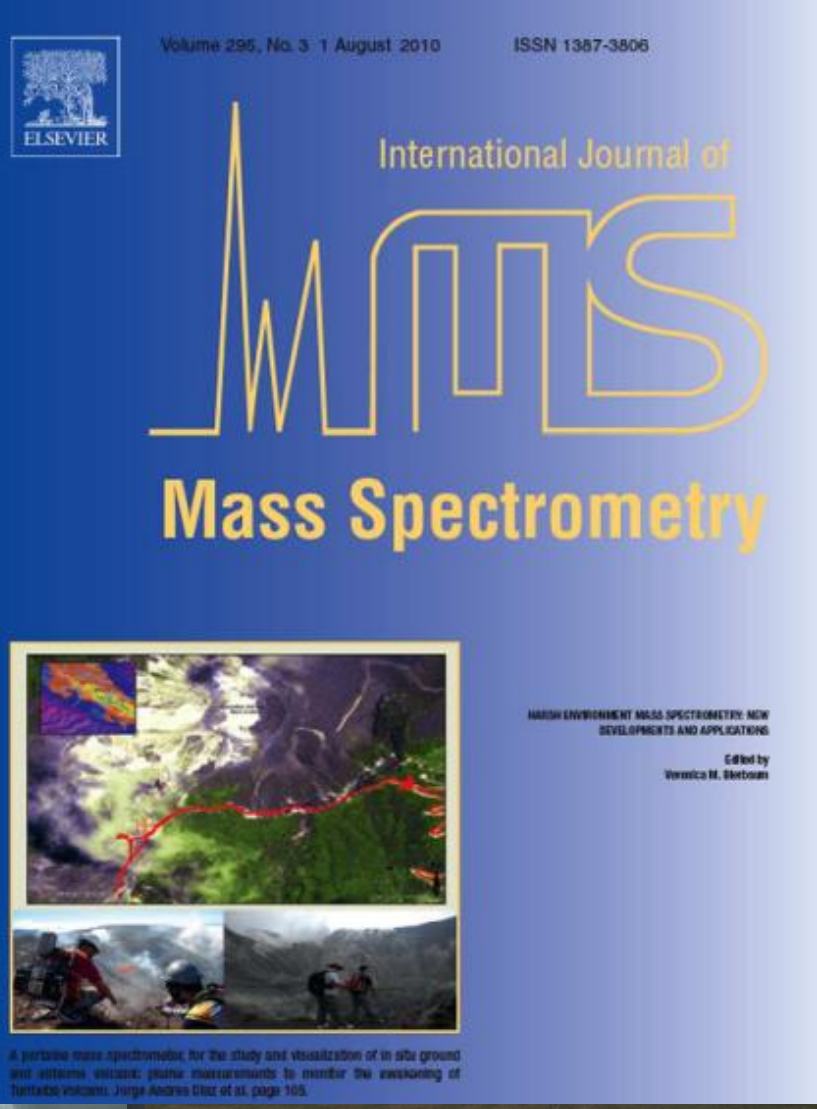
   First Satellite Cal/Val campaigns

In-situ MS data milestones

- MS data on awakening of Turrialba Volcano (IJMS Cover page)
- Helium signal before and after eruption
- Moved away from in-situ ground data due to high risk
- Moved to UAV platforms (Delta wings and tethered balloon measurements)







UAV MS Platforms for In–situ Analysis

RESPONDER UAV

AUTONOMOUS HELICOPTER

Span: 32 in

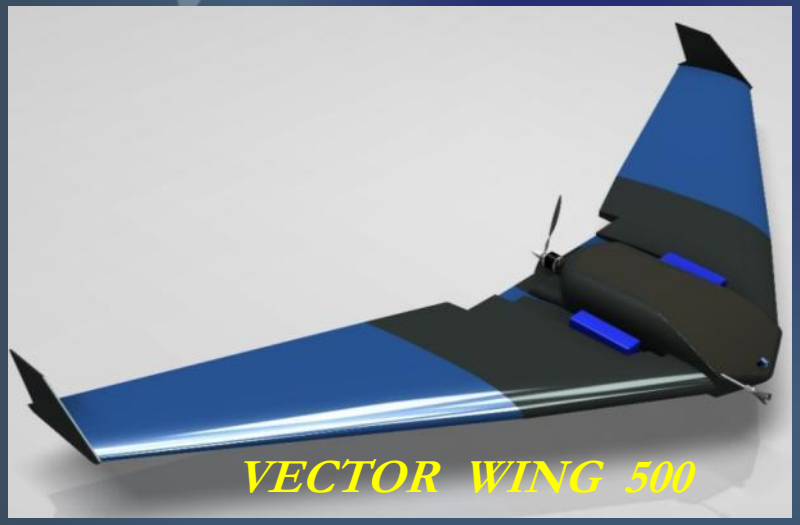
- Payload: 6 kg
- Range: 10 mile
- Flight Duration: 30 min
- RTF Weight: 12 kg
- Max Altitude: 7000 ft AGL

OCTOCOPTER

ITALDRONE

- Diameter: 10 t
- Payload: 10 kg
- Range: 1 mile
- Flight Duration: 30 min
- RTF Weight: 23 kg
- Max Altitude: 6,500 ft AGL

UAV Platforms and In–situ Analysis



VECTOR WING 500

- Wingspan:150in
- Payload: 5 kg
- Range: 3 mile
- Flight Duration: 45 min
- RTF Weight: 30 lbs
- Max Altitude: 7,000 ft agl
- Air Speed: 20-50 knots

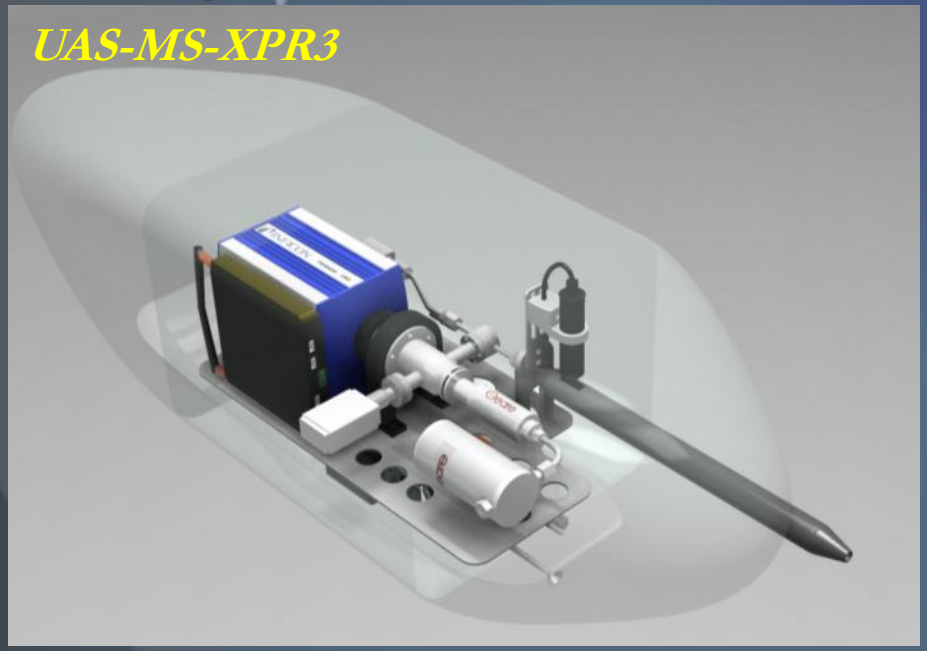
INVERTED V-TAIL UAV

- Wingspan: 20ft
- Length: 11.8 ft
- Payload: 100lbs
- Range: 600 miles
- Flight Duration: 10 hrs
- RTF Weight: 400 lbs
- Max Altitude: 12,000 ft
- Air Speed: 50-80 knots

SIERRA: **Science Instrumentation Evaluation Remote Research Aircraft**

New developments for a UAV MS:
2 systems

UAS-MS-XPR3



UAS-MS-MPH

UAS-MS-XPR3

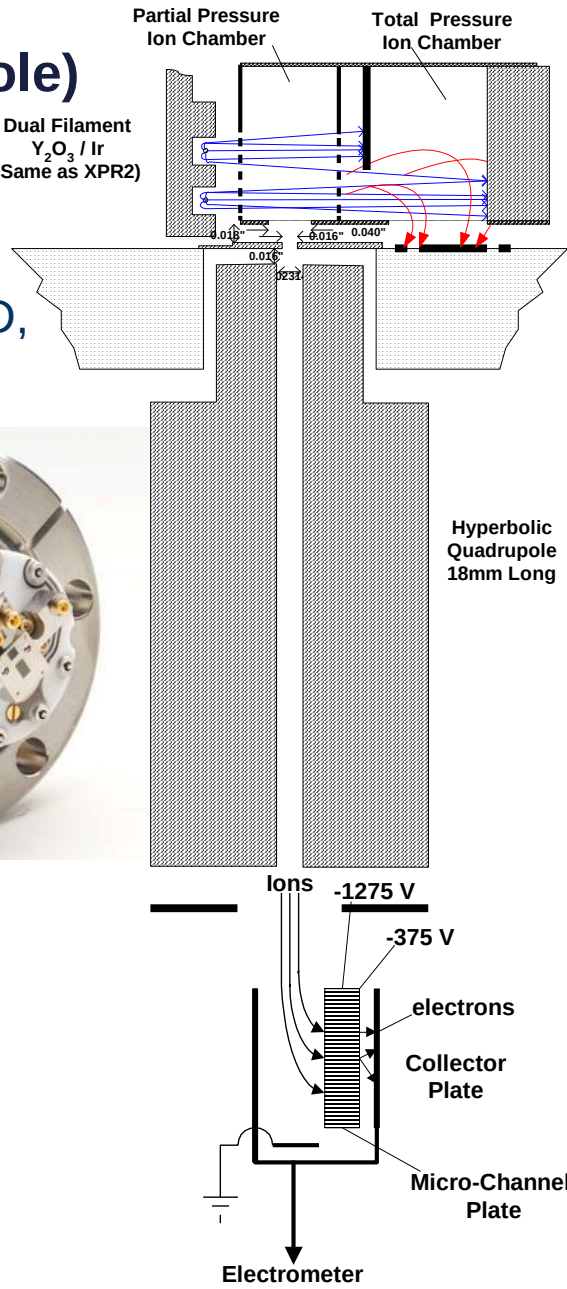
- XPR3 miniature quadrupole MS
- CREARE Drag + Scroll Pumps
-10-3 Torr operation. Direct sampling

UAS-MS-MPH

-New MPH fast response quadruplole MS
- New Pfeiffer Turbo Molecular Pump + Diaphragm pump combo
-10-5 Torr operation. Direct sampling. On Board calibration

MS: Transpector XPR3 (Miniature Quadrupole)

- **High Pressure Residual Gas Analyzer (eXtended Pressure Range)**
- Developed for monitoring processes at high pressures : PVD, preclean chambers, contamination control and PR detection
- **Key Features**
  - Max operating pressure of 20 mTorr
  - Two filaments & Two ion chambers
    -Partial Pressures with mass filter
    -Total Pressure with separate chamber
  - L=1.8cm quadrupole r0< 0.015”(380um)
  - MDPP = $6x10^{-12}$ Torr (ppm LOD)
- **Other Advantages**
  - Yttria-coated iridium filaments
  - Dual electron energy (40 or 70 eV)
  - Pirani Interlock for filament protection
  - Off-axis Micro-channel Plate Electron Multiplier operates at pressures up to 20 mTorr



Miniature Drag-Only Pump

- Molecular Drag-Only Pump Application
  - For miniature small mass specs, (shorter mean free path, higher operating pressures)
  - Lack of turbomolecular stages reduces complexity and cost, while increasing durability
  - Can pump down below 10^{-4} torr
- Key Specifications for Pump
  - Operation from -40°C to +50°C
  - Survival -55°C to +120°C
  - Compression ratio of > 10^5
  - Exhaust to 10 torr
  - Inlet flow rate > 1 liter/sec
  - Compact size enabled by high-speed operation at 200 krpm

Creare's Drag-Only Miniature Pump:

- **Power: < 10 Watt**
- **Mass: 150 gr**
- **Size: 3.3-in x 1.3-in (ø)**

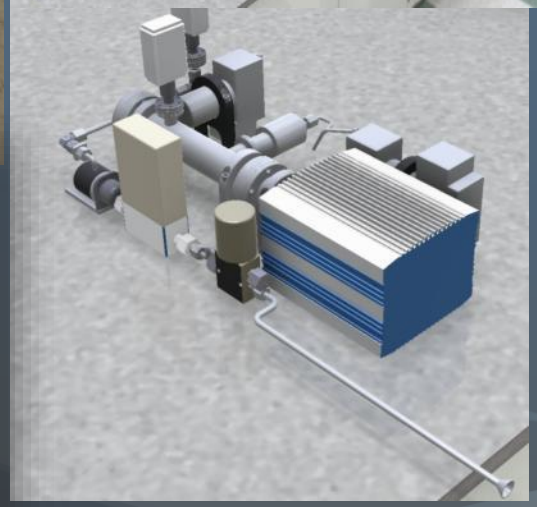
Miniature Scroll Pump (Backing)

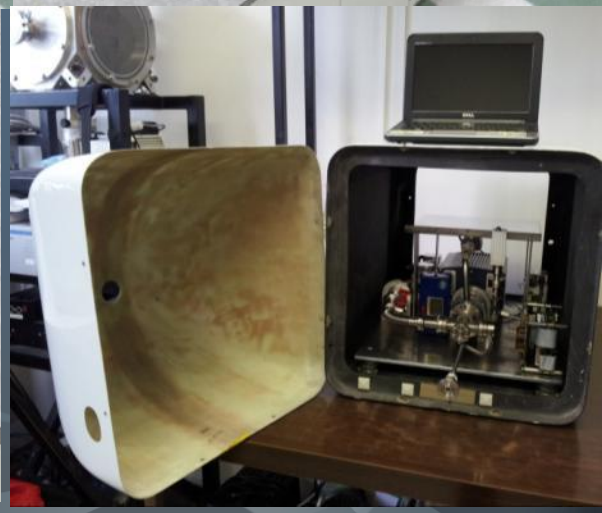
- Miniature Scroll Pump (MSP) Applications
  - MSP is a rough pump, enabling Creare's High-Vacuum Pumps to exhaust to Earth atmosphere
  - The scroll pump uses two interleaved spiral-like vanes to pump or compress gases to 760 torr
  - One vane is stationary, while the other rotates at relatively low speed with a fixed orbit
  - The orbital motion causes the formation of sealed gas pockets, which compress the gas as they move inwards toward the exhaust
- Key Specifications for Pump
  - Operation from -30°C to +50°C
  - Survival from -30°C to +85°C
  - Compression ratio of > 10^3
  - Exhaust pressure of 760 torr
  - Inlet flow rate > 1 liter/min at 1 torr
  - Lifetime of > 2500 hrs

Creare's Miniature Scroll Pump:

- **Power: < 5 Watt**
- **Mass: 350 gr**
- **Size: 4.1-in x 2.3-in (ø)**

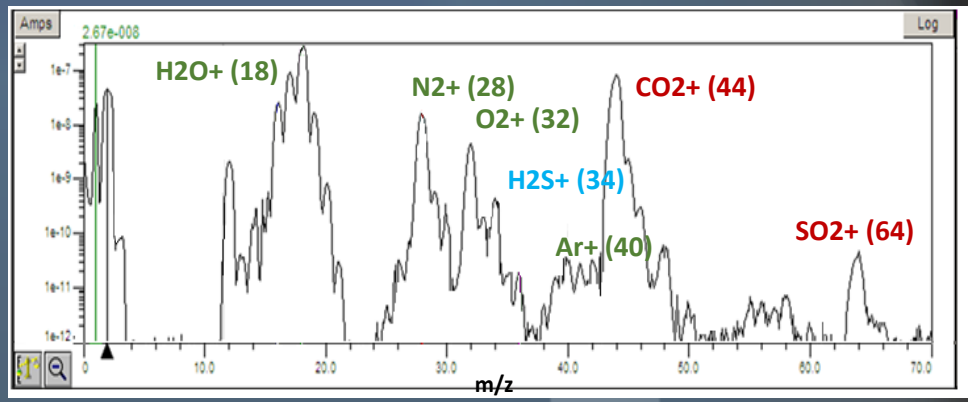
XPR3 in SIERRA UAV

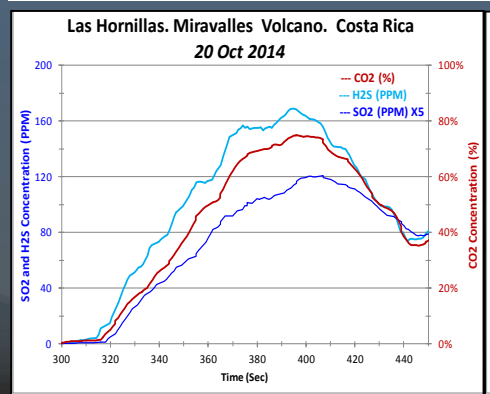


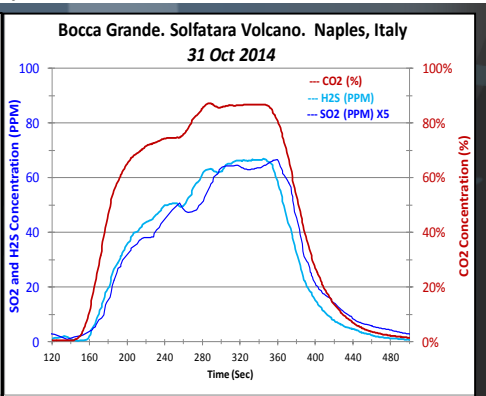


Integration Done May 2015. Fly test in Oct 2015

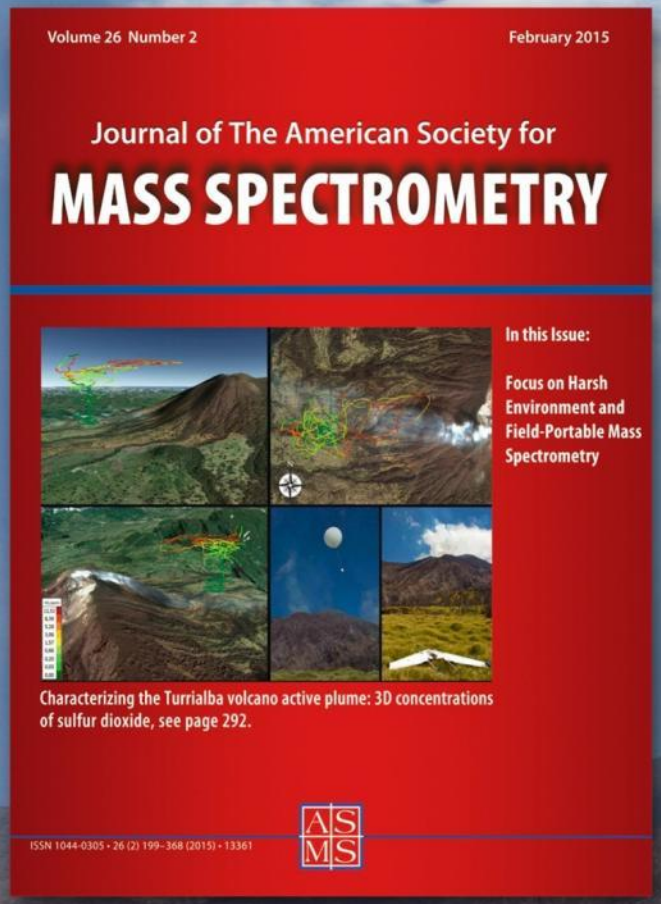
UAV-MS XPR3 Field Deployment Testing







Unmanned Aerial Mass Spectrometer Systems for *In-Situ* Volcanic Plume Analysis



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FOCUS: HARSH ENVIRONMENT AND FIELD PORTABLE MASS SPECTROMETRY: RESEARCH ARTICLE

Unmanned Aerial Mass Spectrometer Systems for In-Situ Volcanic Plume Analysis

Jorge Andres Diaz,[1] David Pieri,[2] Kenneth Wright,[3] Paul Sorensen,[4] Robert Kline-Shoder,[4] C Richard Arkin,[5] Matthew Fladeland,[6] Geoff Bland,[7] Maria Fabrizia Buongiorno,[8] Carlos Ramirez,[9] Ernesto Corrales,[1] Alfredo Alan,[1] Oscar Alegria,[1] David Diaz,[1] Justin Linick[2]

[1]Physics School, GasLab, CICANUM, Universidad de Costa Rica, San José, Costa Rica
[2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
[3]INFICON Inc., East Syracuse, NY, USA
[4]CREARE LLC., Hanover, NH, USA
[5]Engineering Services Contract, Kennedy Space Center, Cape Canaveral, FL, USA
[6]National Aeronautics and Space Administration (NASA), Ames Research Center, Mountain View, CA, USA
[7]National Aeronautics and Space Administration (NASA), Goddard Space Flight Center, Wallops Flight Facility, Wallops Island, VA, USA
[8]Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome, Italy
[9]Escuela Centroamericana de Geología, Centro de Investigaciones en Ciencias Geológicas, Red Sísmológica Nacional (RSN), Universidad de Costa Rica, San José, Costa Rica

Abstract. Technology advances in the field of small, unmanned aerial vehicles and their integration with a variety of sensor packages and instruments, such as miniature mass spectrometers, have enhanced the possibilities and applications of what are now called unmanned aerial systems (UAS). With such technology, in situ and proximal remote sensing measurements of volcanic plumes are now possible without risking the lives of scientists and personnel in charge of close monitoring of volcanic activity. These methods provide unprecedented, and otherwise unobtainable, data very close in space and time to eruptions, to better understand the role of gas volatiles in magma and subsequent eruption products. Small mass spectrometers, together with the world's smallest turbo molecular pump, have being integrated into NASA and University of Costa Rica UAS platforms to be field-tested for in situ volcanic plume analysis, and in support of the calibration and validation of satellite-based remote sensing data. These new UAS-MS systems are combined with existing UAS flight-tested payloads and assets, such as temperature, pressure, relative humidity, SO_2, H_2S, CO_2, GPS sensors, on-board data storage, and telemetry. Such payloads are capable of generating real time 3D concentration maps of the Turrialba volcano active plume in Costa Rica, while remote sensing data are simultaneously collected from the ASTER and OMI space-borne instruments for comparison. The primary goal is to improve the understanding of the chemical and physical properties of emissions for mitigation of local volcanic hazards, for the validation of species detection and abundance of retrievals based on remote sensing, and to validate transport models.

Keywords: Miniature mass spectrometer, In-situ gas analysis, Harsh environment, Unmanned aerial system, Validation and calibration, Remote sensing comparison, Volcanic plume analysis, Volcanic monitoring, Airborne instrumentation, Volcanic emissions analysis

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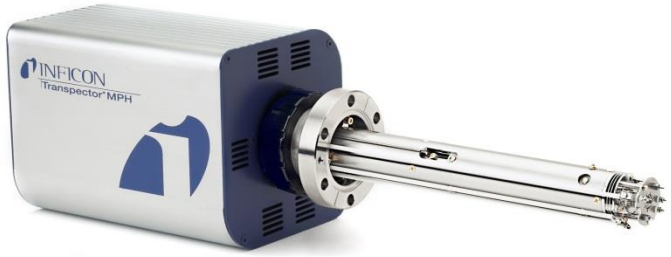
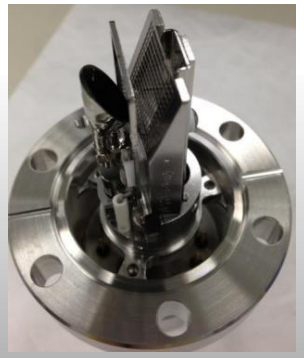
Transpector MPH w/ HiPace10 Lite

- Transpector MPH (0-200 m/z linear quadrupole MS)
- dual filament open ion source
- 1.5 m capillary inlet
- 50-53 W (4-5 hours on battery)
- ~19 kg
- Pfeiffer HiPace10 Lite turbo
- Windows computer (7 W)
- 1510 Pelican (carry-on size)

INFICON's Transpector MPH

- Ultra Fast Measurements Lower Minimum Detectable Partial Pressure (<1E-15 torr).
- Smaller and Lighter (>30% weight reduction)
- Nine Decades of Dynamic Range.
- Field Replaceable EM/FC Detector (Detector Technology)
- Field Replaceable Dual Filament Assemblies (W or Y2O3/Ir).
- Easy to Use Programming Interface - JSON over HTTP or LabVIEW.

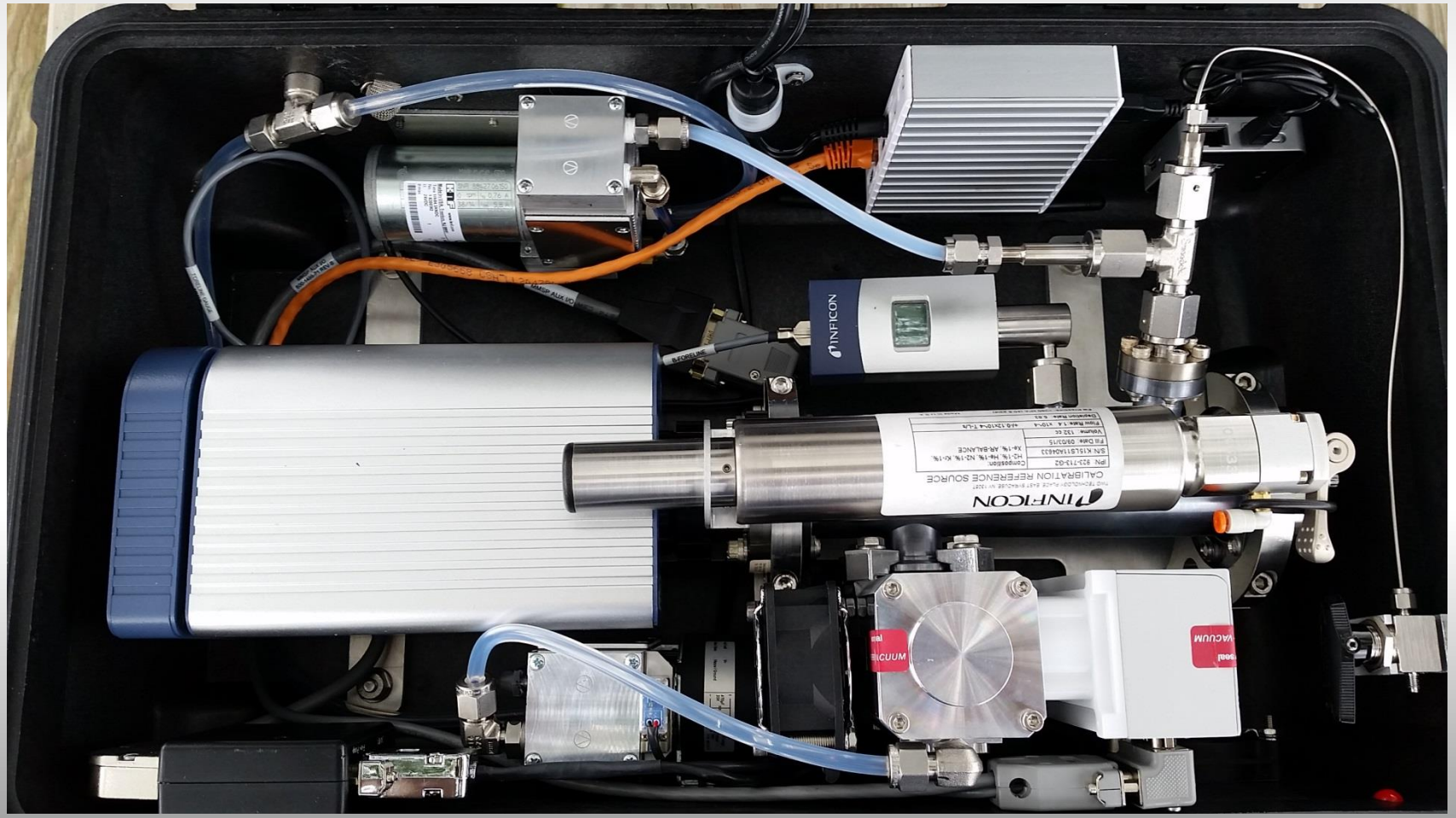




New Transpector CPM Controller

- More Compact
- Controls any Pfeiffer Turbo
- Gauge inputs w/built in protection for MS
- Relays and I/O for valve control, etc…
- Control software with powerful FabGuard software or write your own JSON scripts
- Quickly make any sampling system using any ion source (open, crossbeam, closed) and any Pfeiffer pump

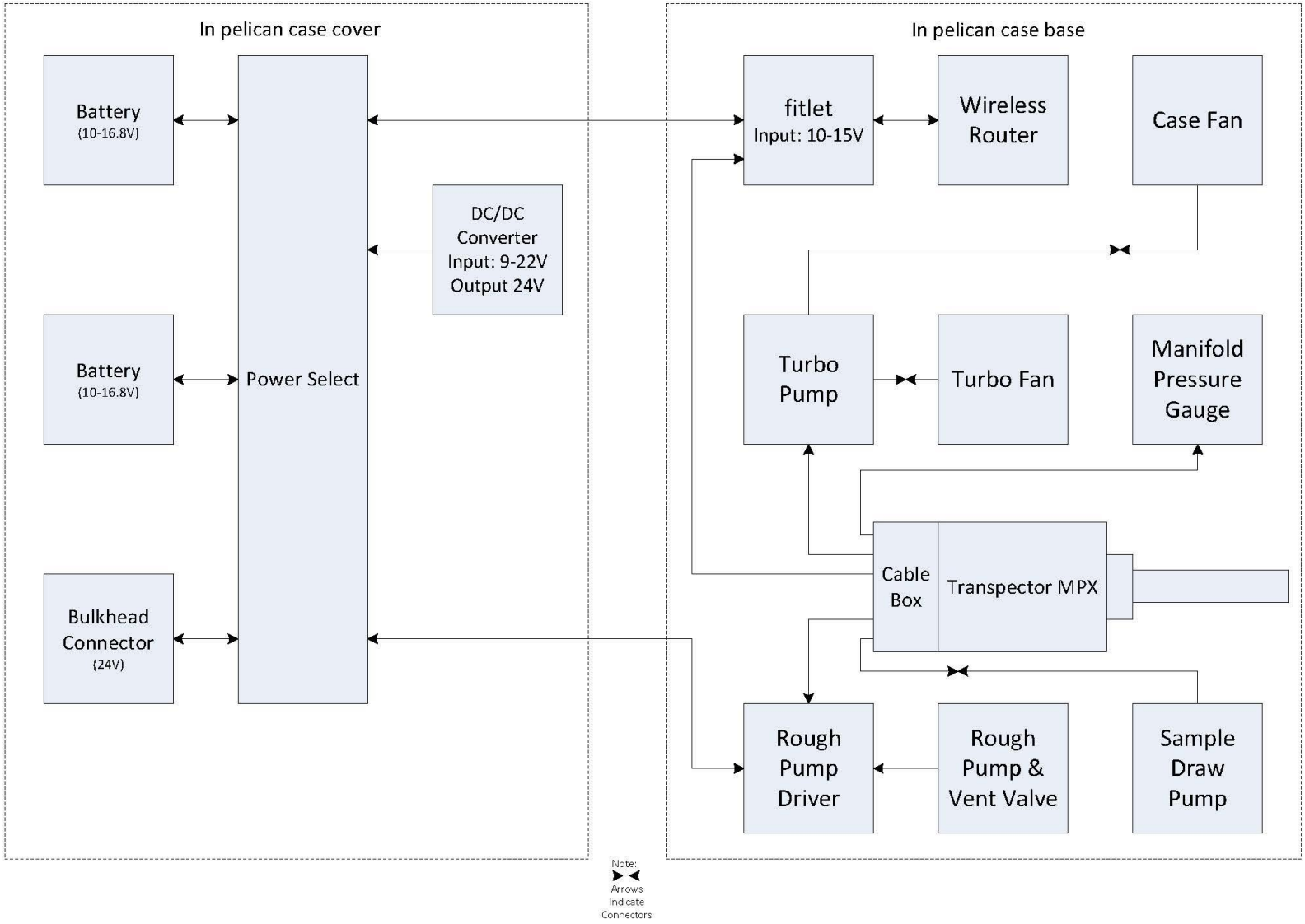
Transpector MPH & HiPace10 Lite



Battery and AC Power

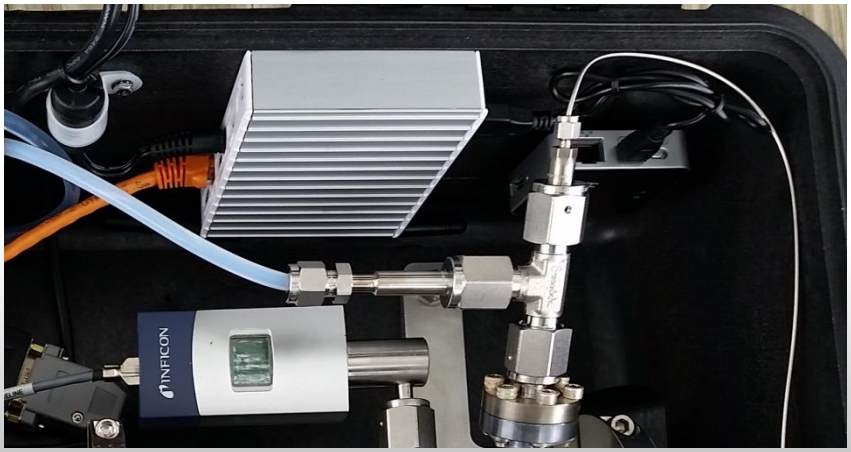
- System requires ~ 50 W with on board computer option.
- Power distribution with 2 small boards.
- Hot swap batteries
- Uninterrupted switching from AC to batteries
- 2 lithium ion batteries for ~ 4-5 hours of run time.
- Battery LI-145, 140-150 Wh, 12V, smart circuit tech, charge indicator.
- Vehicle power adaptor (10-30V, civilian or military)

Transpector MPX electrical interconnects as of 20150909



Control and Connectivity

- Fitlet PC is a small computer running Windows. FabGuard can be loaded on here so that the system can run by itself.



- 10.8 x 8.3 x 2.4 cm
- 250 g
- ~ 7 W
- Fillet: 64-bit quad core 1.2GHz, 8 GB RAM, 120GB SSD mSATA, Wireless: WLAN 802.11ac & Bluetooth, 2x USB 3.0 & 3x USB 2.0, 2x HDMI, microSD, serial….its pretty awesome.
- Can use your cell phone as hotspot to connect tablet/laptop to Fitlet OR ~ small wireless router.

Wireless Router is Sometimes Needed

- No cell coverage on volcano Island!
- If you want to use remote desktop to connect to onboard computer it needs to have a user name and password.
- TIP: At command prompt type “netplwiz” to make the account automatically login when computer starts!
- I prefer Teamviewer when using my cell as a hotspot.

Solfatara

Models predict 800,000 dead in first 20 minutes of eruption

Solfatara


SOLFATARA
WARNING
High temperature of soil and steam
Temp. 160° C ~ 320° F - Press. 15 mbar
Burning danger
Stay clear of the fumaroles
Do not climb up the slopes
arole Do not crowd around the fumaroles
Do not climb over the fences

Sampling @ Solfatara

Solfatara Fumaroles

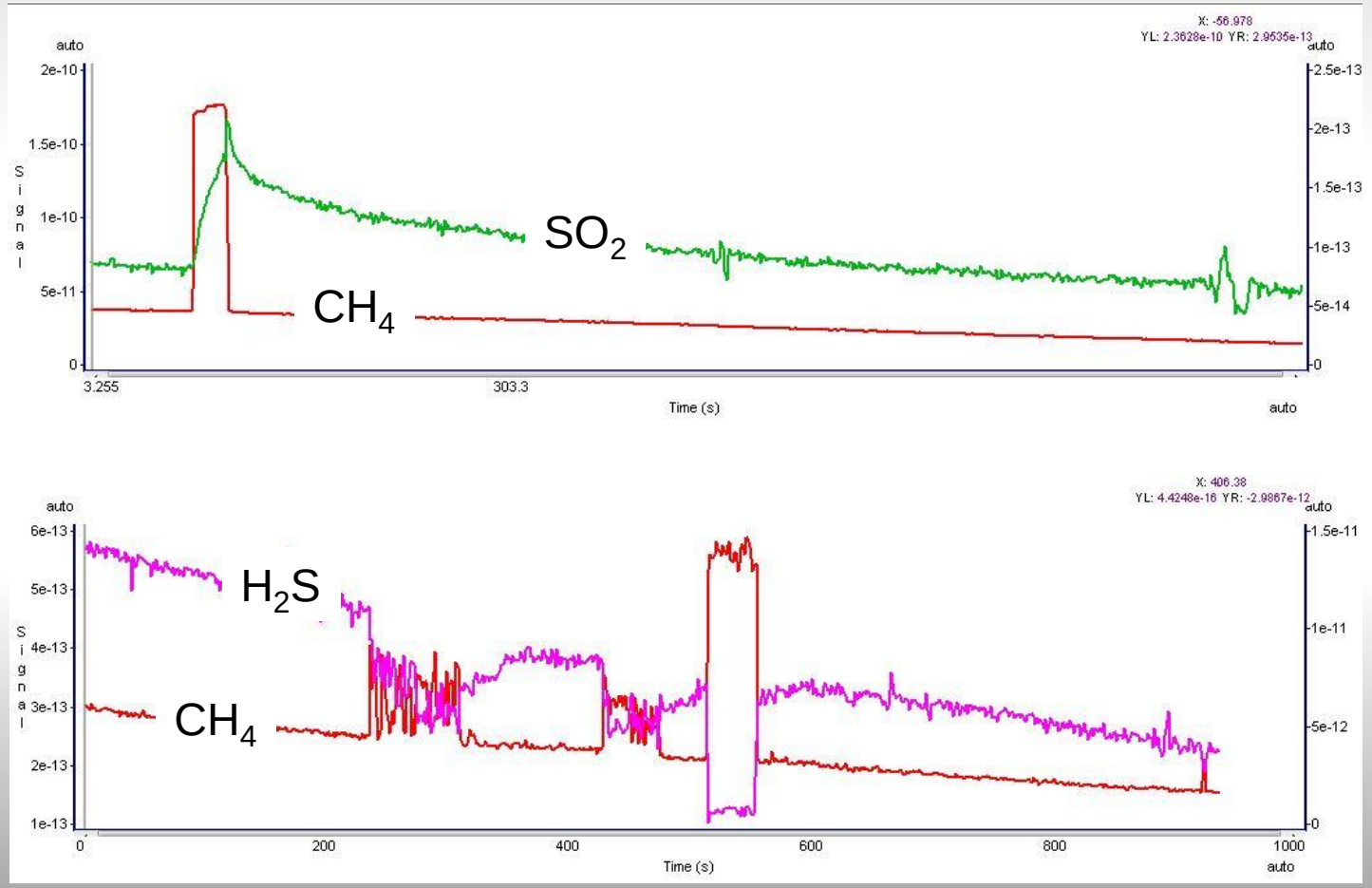
H_20

CO_2

SO_2

CH_4

H_2S

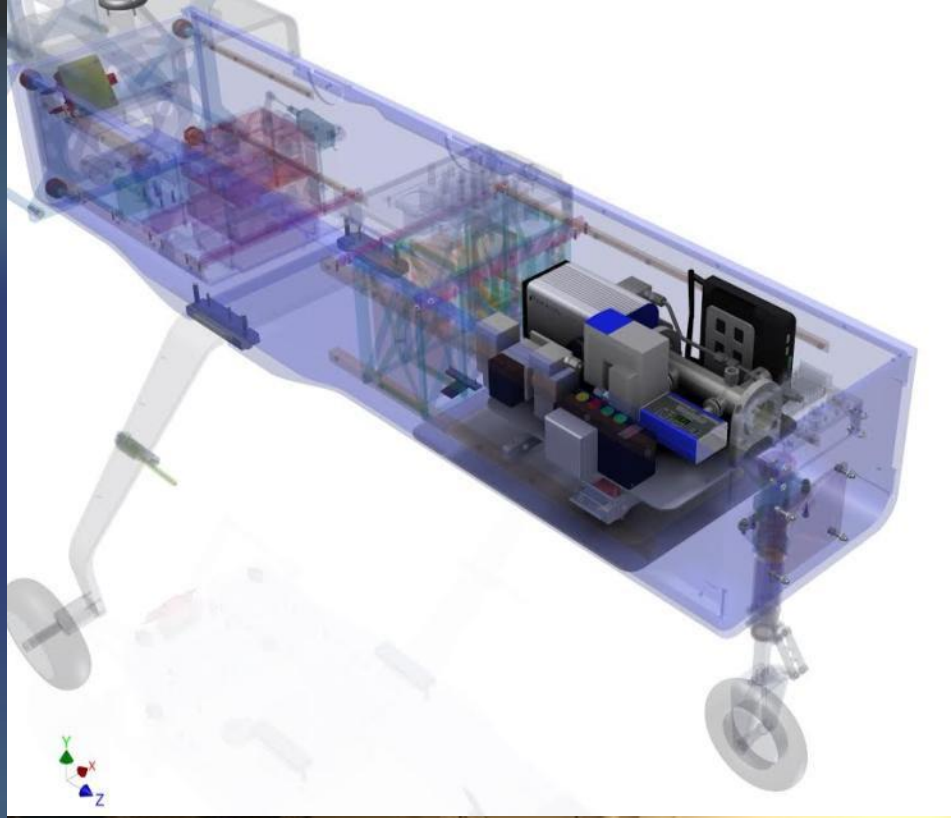


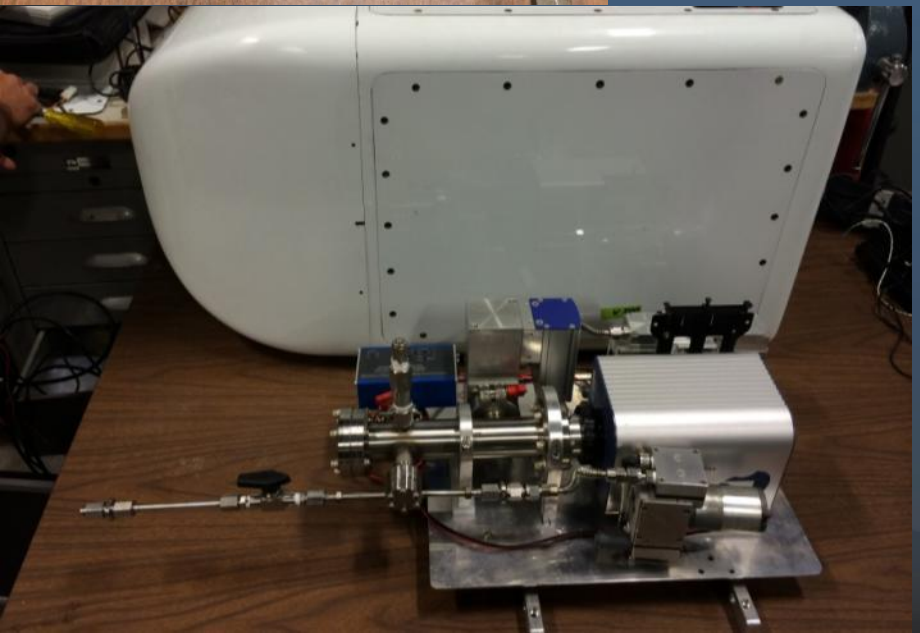
MPH on SIERRA UAV

Integration:
Jul 2015

Fly Test:
Nov 2015

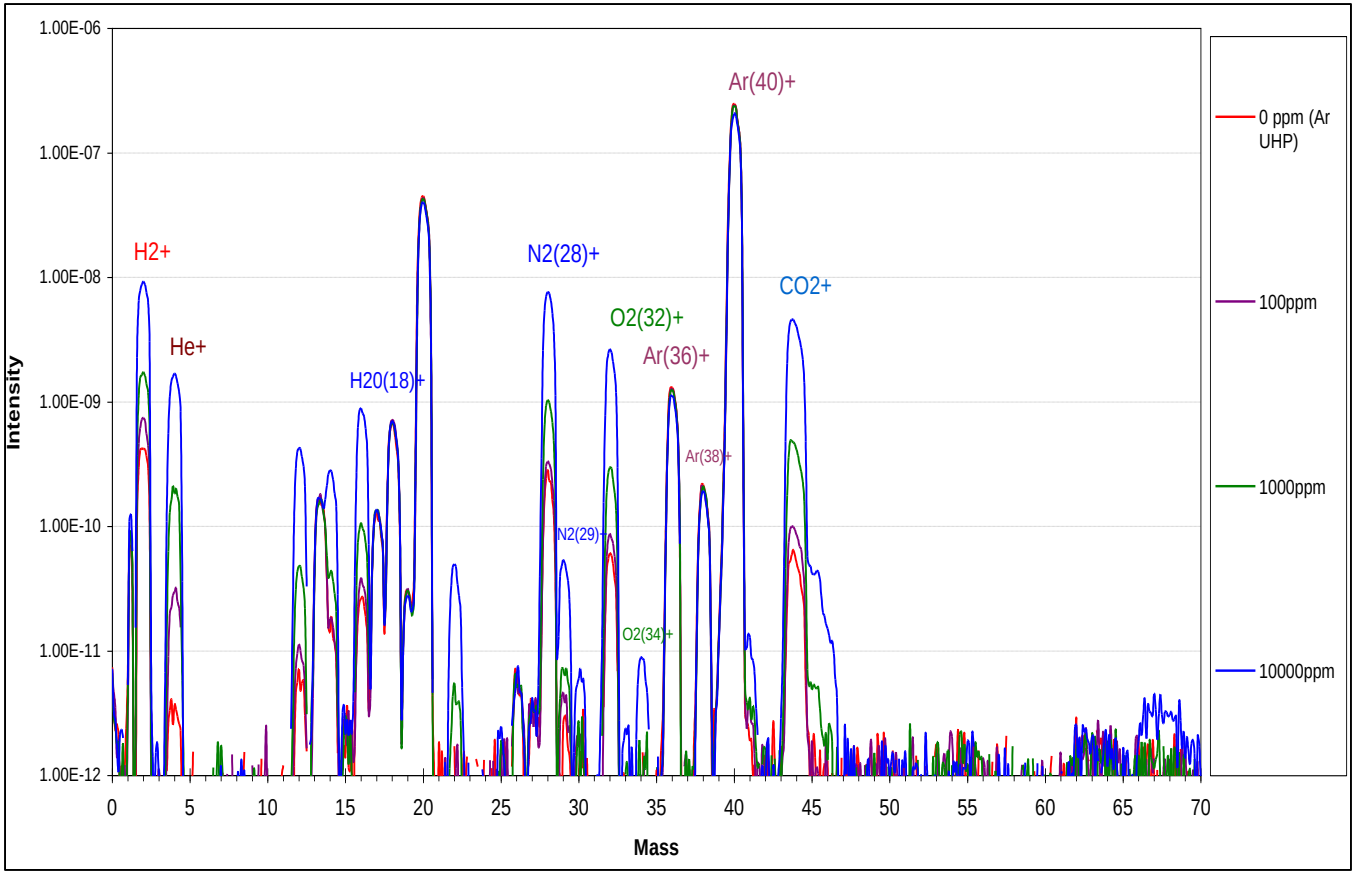
Deployment :
Mar 2016





Performance

- Very fast scanning capabilities (6 Hz, full scan)
- Large Dynamic Range

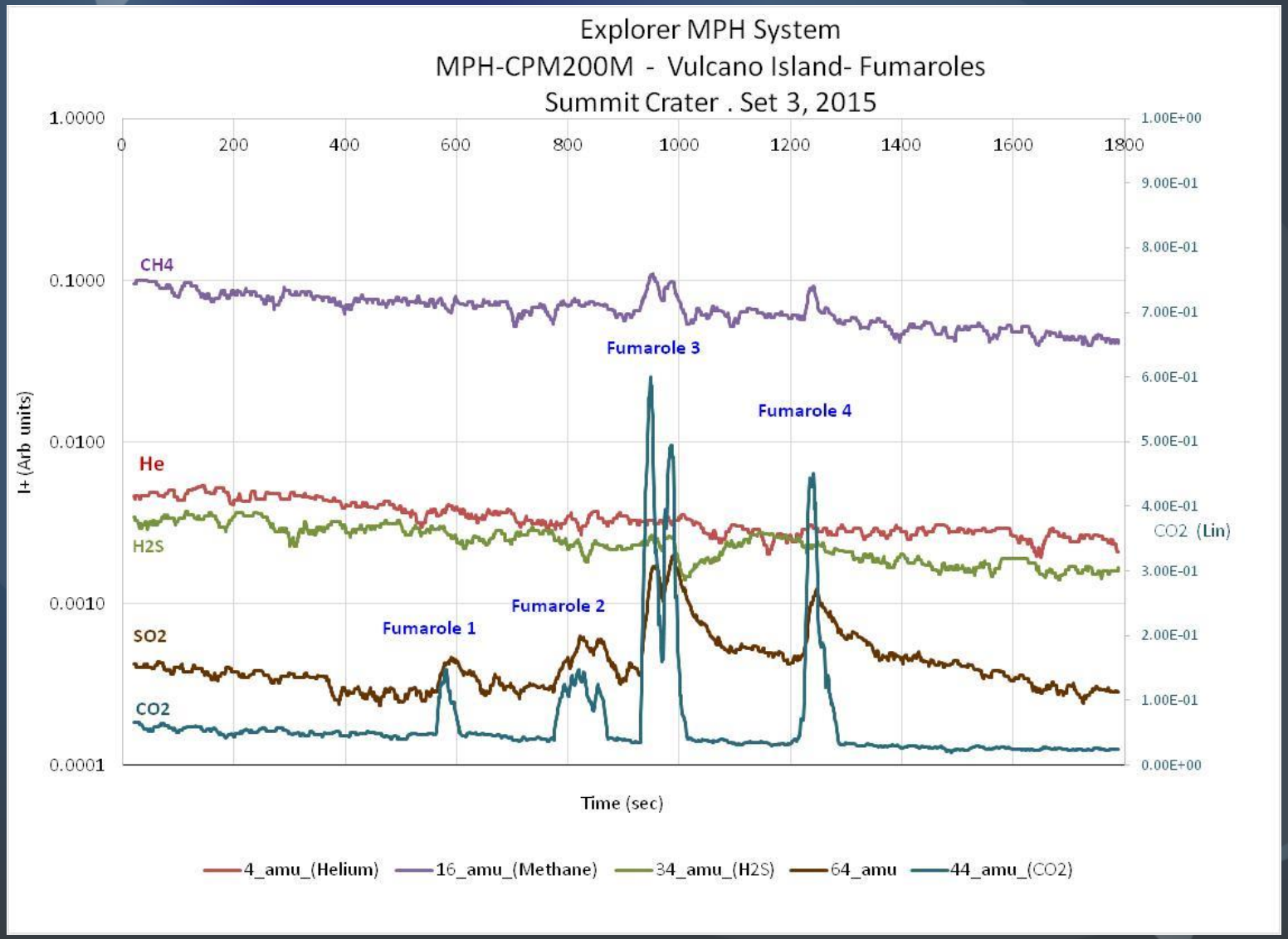


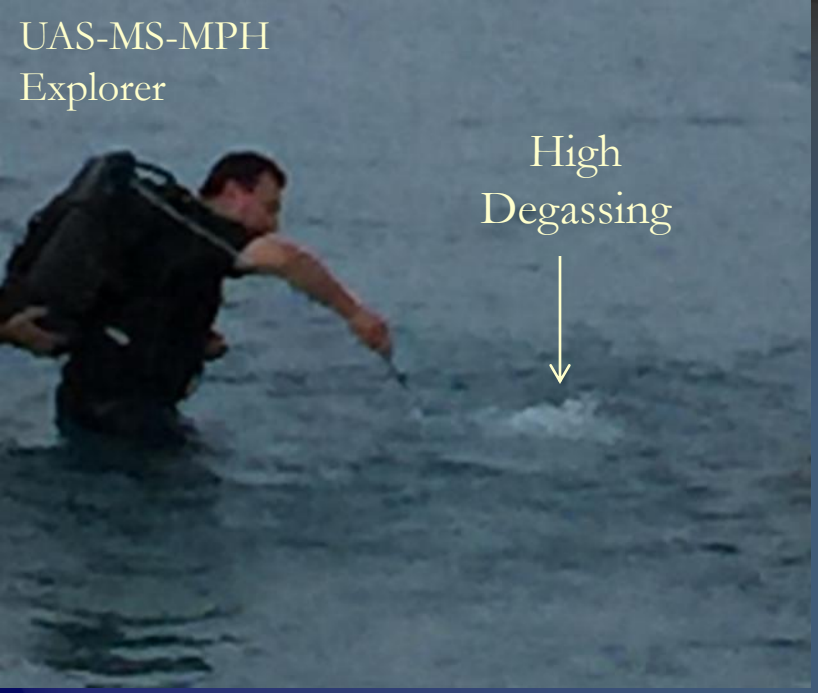
H2, He, N2, O2, CO2 cal gas sample : Zero, 100, 1000 and 10000 ppm in Ar balance


Italia
Italy
Solfatara
Volcano
Tyrrhenian Sea
Adriatic Sea
Roma
Napoli
Firenze
Pisa
Livorno
Siena
Grosseto
Terni
Ancona
San Marino
Rimini
Cesena
Pescara
Chieti
Ascoli Piceno
San Benedetto del Tronto
Tivoli
Fiumicino
Frosinone
Latina
Foggia
Barletta
Bari
Brindisi
Taranto
Lecce
Potenza
Matera
Salerno
Pompei
Cosenza
Crotone
Lamezia Terme
Catanzaro
Messina
Palermo
Trapani
Cefalù
Zadar
Šibenik
Split
Trogir
Bol
Mostar
Medugorje
Dubrovnik
E76
E45
E842

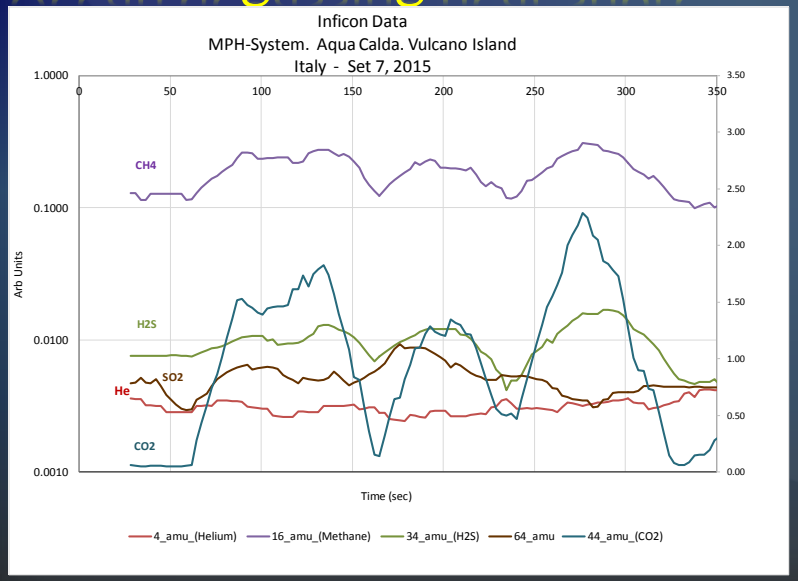
Vulcano Island Deployment (Summit)

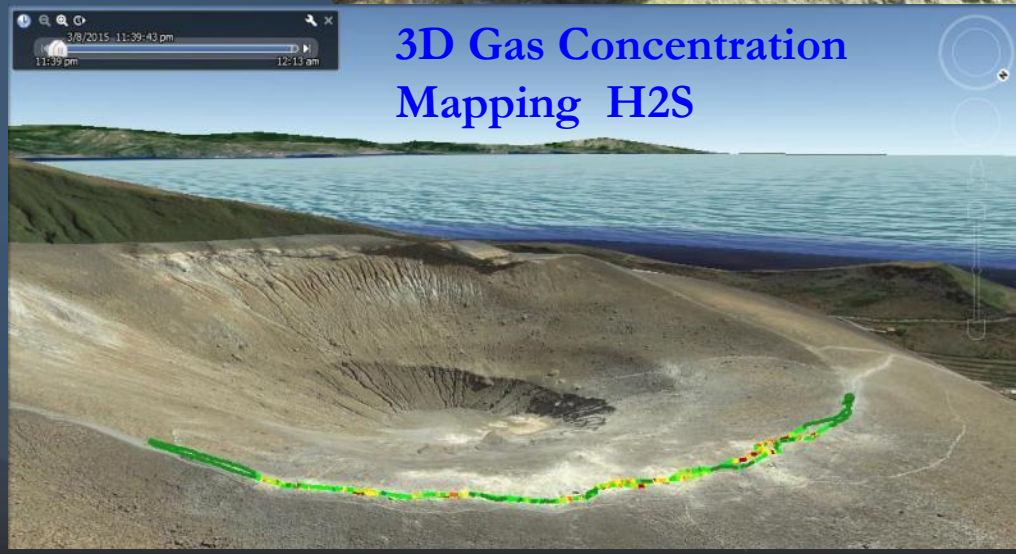
Vulcano Island Deployment Results





Aqua Calda:
Ocean degassing near shore

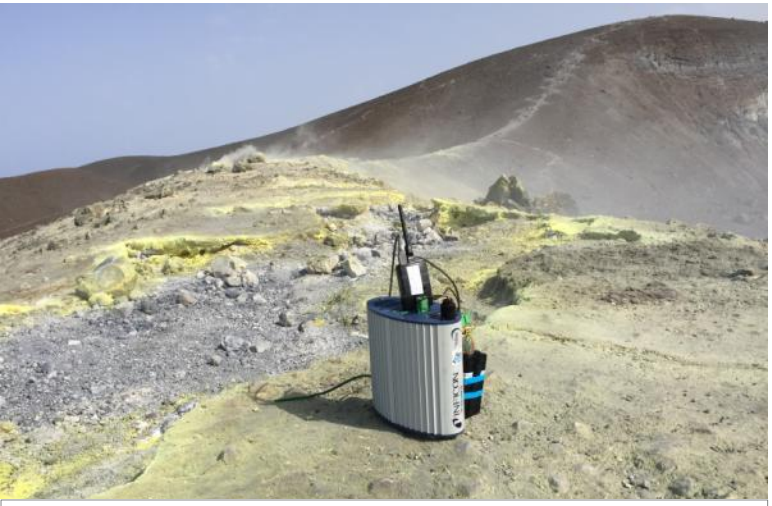


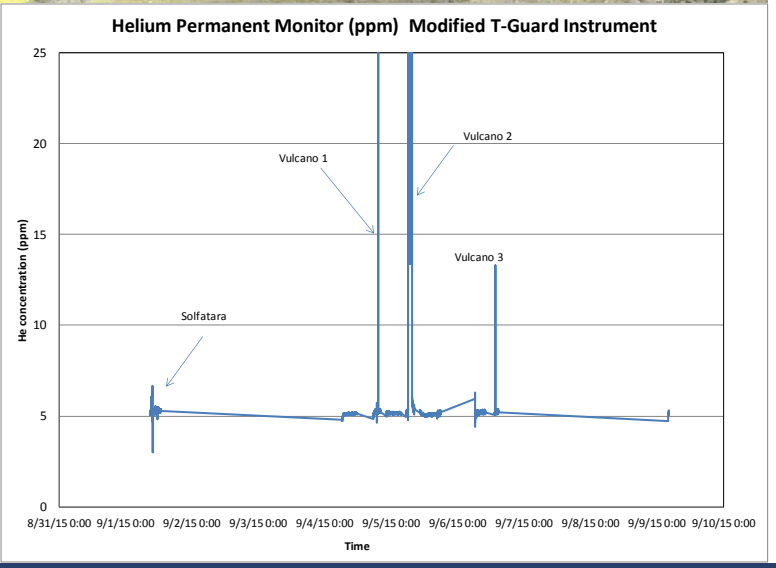


Other Volcanic Monitoring System

INFICON

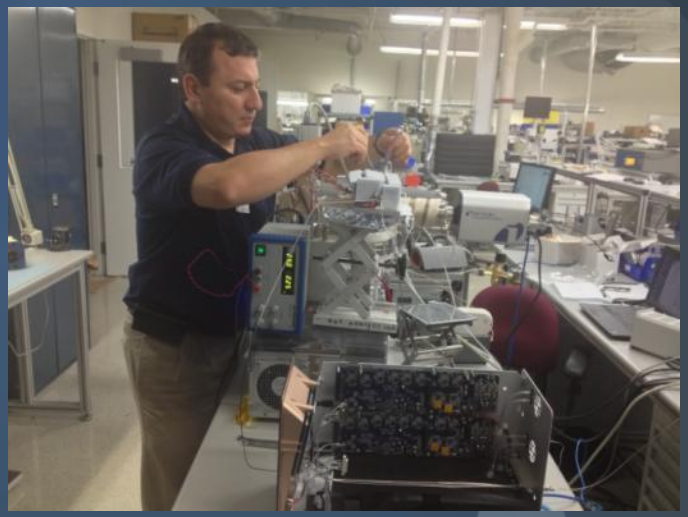
24 hour Helium Detection System base on T-Guard for Satellite triggered acquisition





Helium increase observed when instrument was brought close to fumaroles. Test station currently under development to filter Acids and provide continuous power

Resolve Project Collaboration (LUNAR Lander for ISRU)



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aka “Foxy”
aka “Krieger”

Thank You