# Piezoelectric valve for atmospheric descent sampling

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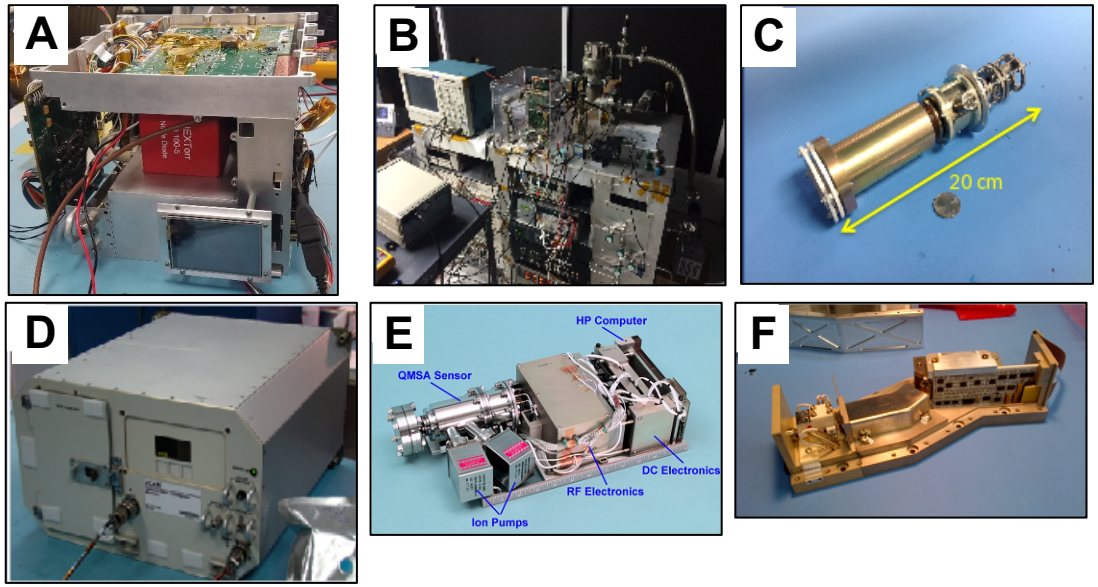
# OVERVIEW

1.) Who we are
2.) Our instrument
3.) Atmospheric descent
4.) State of the art inlet systems
5.) Homesteader- first attempt
6.) Piezo Valve - history, schematics
7.) Piezo – theory of operation
8.) Piezo – package
9.) Piezo – testing & results
10.) Piezo – what's next

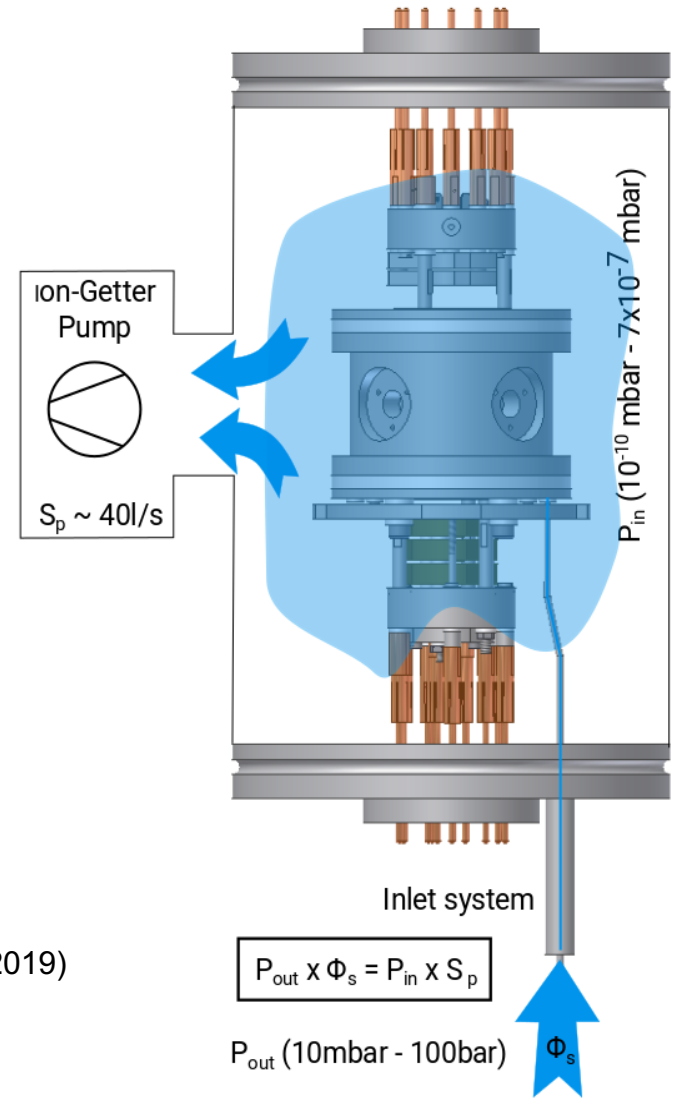
# JPL MS GROUP

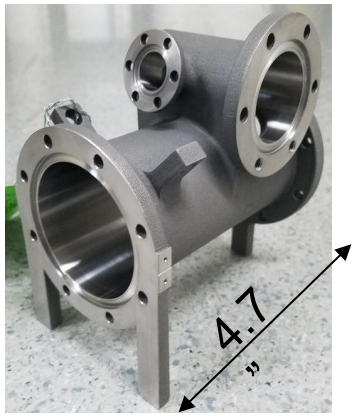


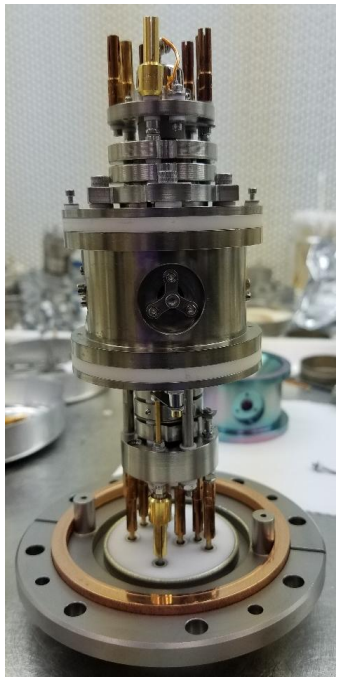

(A) Development Unit of Spacecraft Atmosphere Monitor (S.A.M)
(B) Geochronology and Atmospheric noble gas workstation.
(C) Flyby MS Sensor Head for Europa (MARINE) Prototype.
(D) VCAM deployed in the International Space Station's Destiny Laboratory. (Launched aboard STS-131 Discovery in 2010, operated 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 - developed to be deployed on the Resource Prospector Mission - RPM to the South Polar Region of the moon)

# INSTRUMENT OVERVIEW

- QITMS* base pressure high $10^{-11}$ torr
- Operates without He buffer gas
- Different modes of operation (dynamic, static, resonant ejection)
- S.A.M** operating pressure ~$5x10^{-9}$ torr
- S.A.M. operating sensitivity $5x10^{12}$ cnts /torr/sec (dynamic)
- Inlet = fussed silica tube (single)
- Allows for MCA every 2 sec

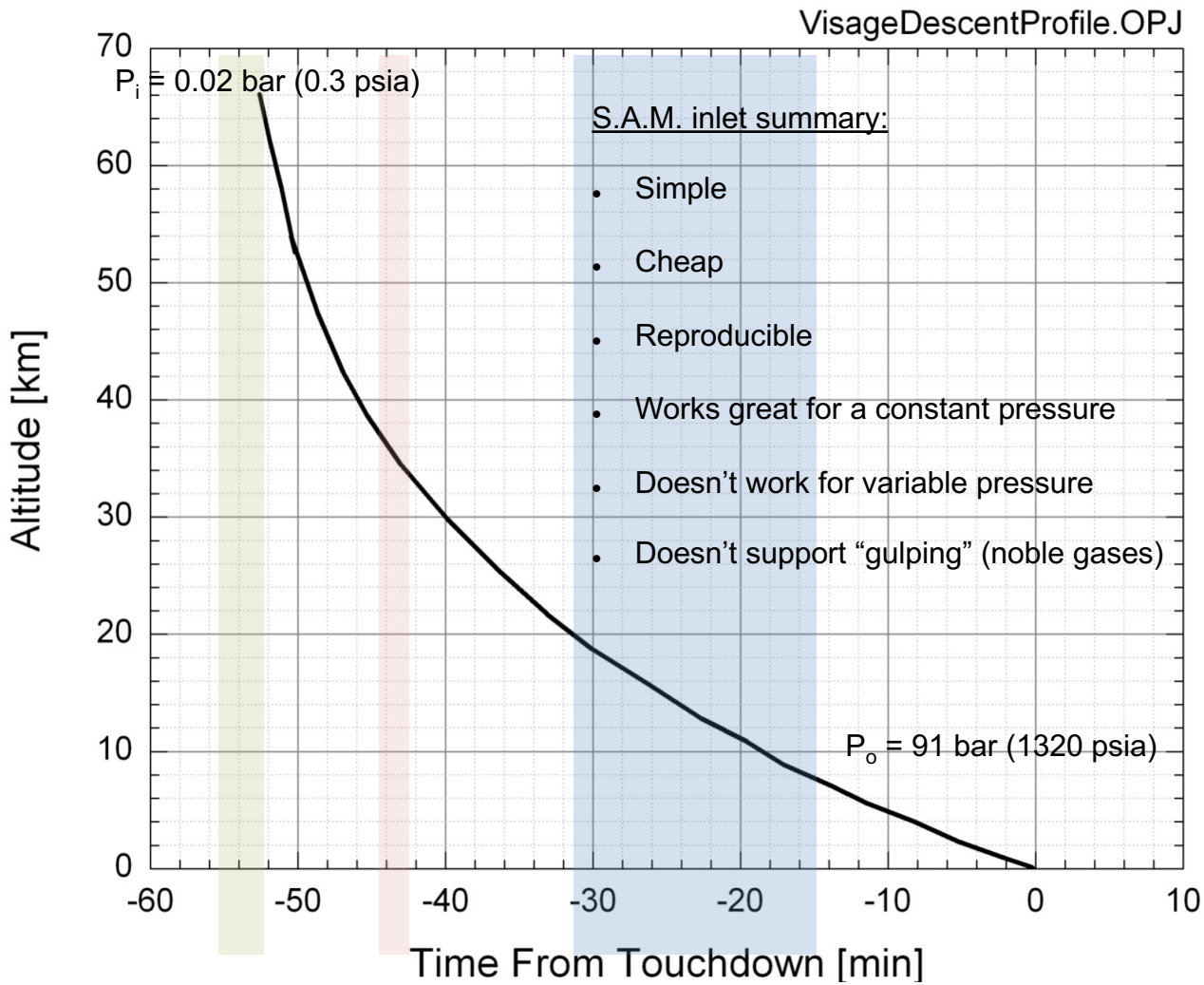


- *QITMS = Quadrupole Ion Trap Mass Spectrometer
- **S.A.M. = Spacecraft Atmosphere Monitor (launch 2019)

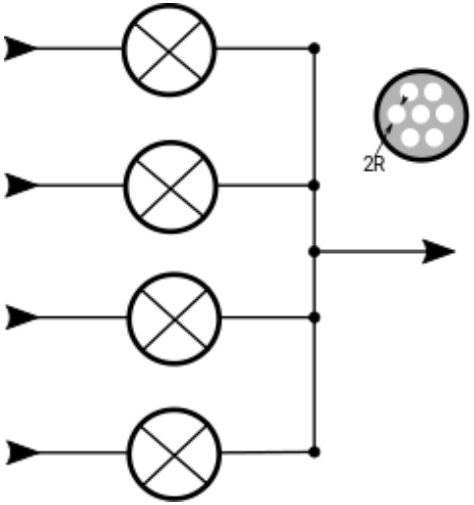
# ATMOSPHERIC DESCENT



# STATE OF THE ART

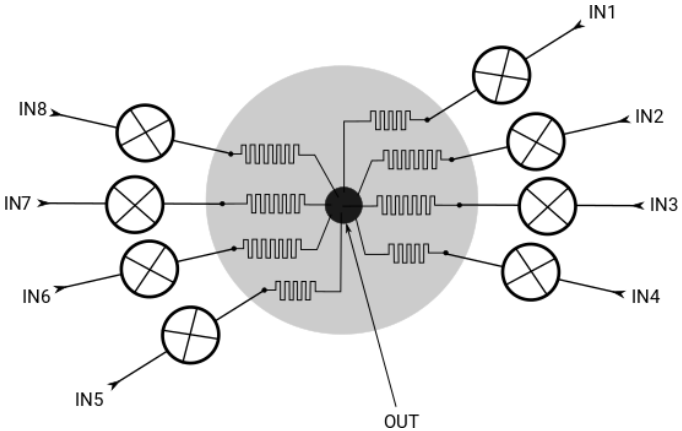
## Glass capillaries + Valves

| Mission | Inlet Type | Comment |
|---|---|---|
| Galileo (Jupiter)[1]<br>0.15-20bar,<br>~60 min | N=4<br>2r = 1.5 – 6 µm<br>$P_{max}$ =$10^{-4}$ mbar | • Difficult to manufacture<br>• Prone to single point failure<br>• Characteristics of the leaks vary<br>• Complex<br>• No continuous regulation of mass flow |
| Huygens Probe (Titan)[2]<br>0.003-1.5bar,<br>170km-0 | N=2<br>2r = 2–20 µm<br>Pmax = $10^{-4}$ mbar | |
| Mars Phoenix[3]<br>6mbar,<br>surface | N=2<br>2r < 1 µm<br>C=$10^{-5}$ $cm^3/sec$<br>Pmax = $8x10^{-6}$ mbar. | |




## MEMS Si capillaries +

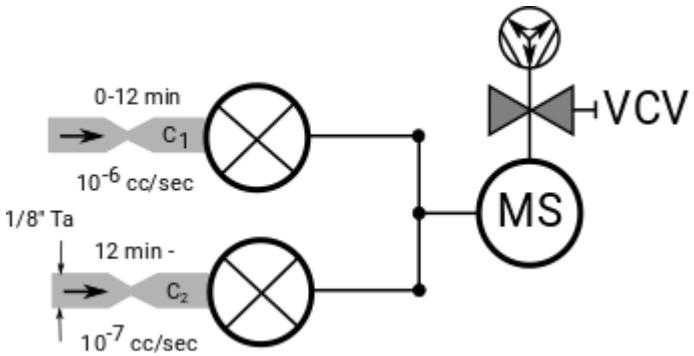
| Mission | Inlet Type | Comment |
|---|---|---|
| Goddard microleak<br>1-100 bar* | D=1.5 x 1µm$^2$<br>P = $10^{-6}$ – $5x10^{-5}$ mbar | MEMS technology, batch manufacturing, no continuous regulation of mass flow, macroscopic solenoid valves (bulky, expensive)[4,5] |

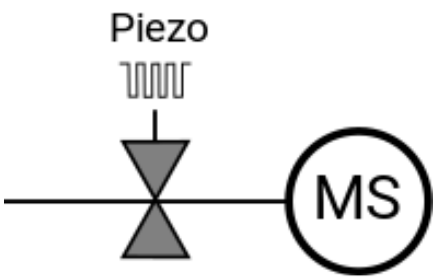



[1]
[2] H. B. Niemann, D. N. Harpold, and S. K. Atreya, Space Sci. Rev. 60, 111 (1992).
[3] H. B. Niemann, S. K. Atreya, and S. J. Bauer, Space Sci. Rev. 104, 553 (2002).
[4] Mike Lee Hoffman (ed) "Applied Mass Spectroscopy Handbook," Chapter 31: John H., Griffin, Timothy P., Limero, Thomas, Arkin, C. Richard, "Space Applications of Mass Spectrometry," John Wiley and Sons (2010)
[5] B. G. Jamieson et al, Review of Scientific Instruments 78, 065109 (2007)
NASA Tech Briefs, Vol.40, No.7, p38, July 2016
* not with Mindrum valves

# STATE OF THE ART CONTD.

| Mission[1,2] | Inlet Type | Comment |
|---|---|---|
| Pioneer (Venus)<br>0.1-100bar,<br>~60min | Crimped tube +<br>2 x Valves + VCV<br>$P_{max}$ <$10^{-5}$ mbar | • Difficult to produce (crimping method highly irreproducible)<br>• Continuous regulation of mass flow (via Variable Conductance Valve (VCV) that regulates the pumping speed)<br>• Prone to single point failure (the clogging by a sulfuric acid droplet was the reason that instrument didn't collect meaningful data over a portion of its descent trajectory) |
| Venera 11/12[3,4]<br>23km-2km | Piezoelectric valve<br>pulsed mode<br>t < 5 ms<br>$P_{max}$ = N/A | • Significant valve dead volume (resulted in pressure bursts which required minutes to stabilize)<br>• Poor temporal resolution.<br>• Continuous regulation of mass flow achieved through the pulse width regulation. |

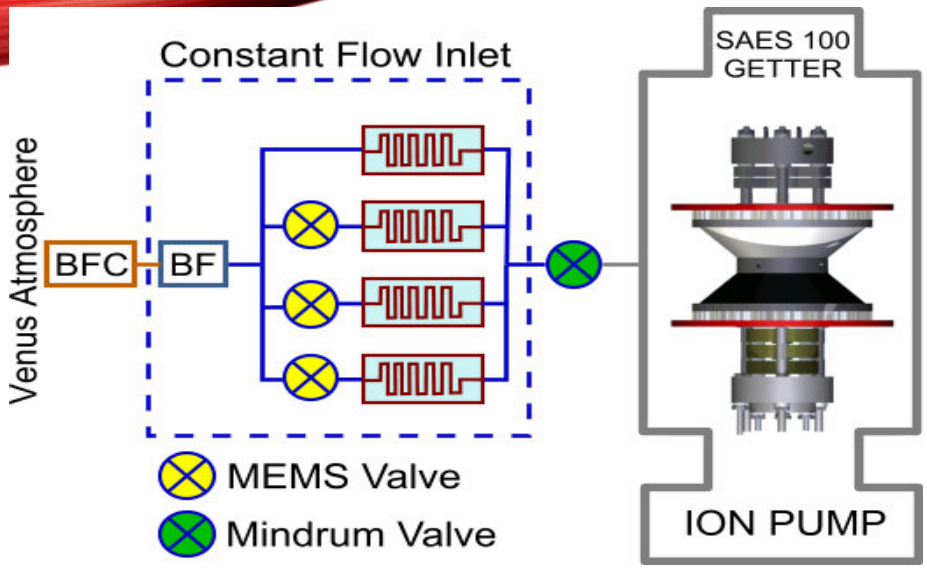


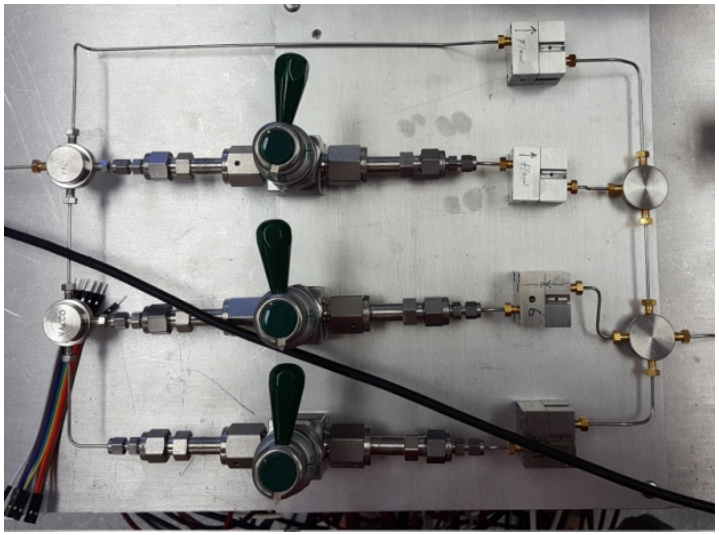



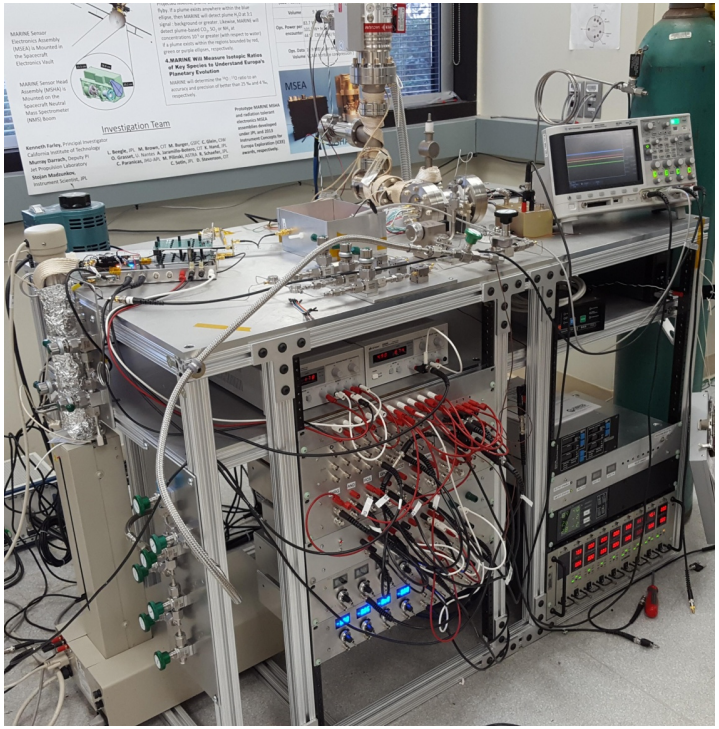


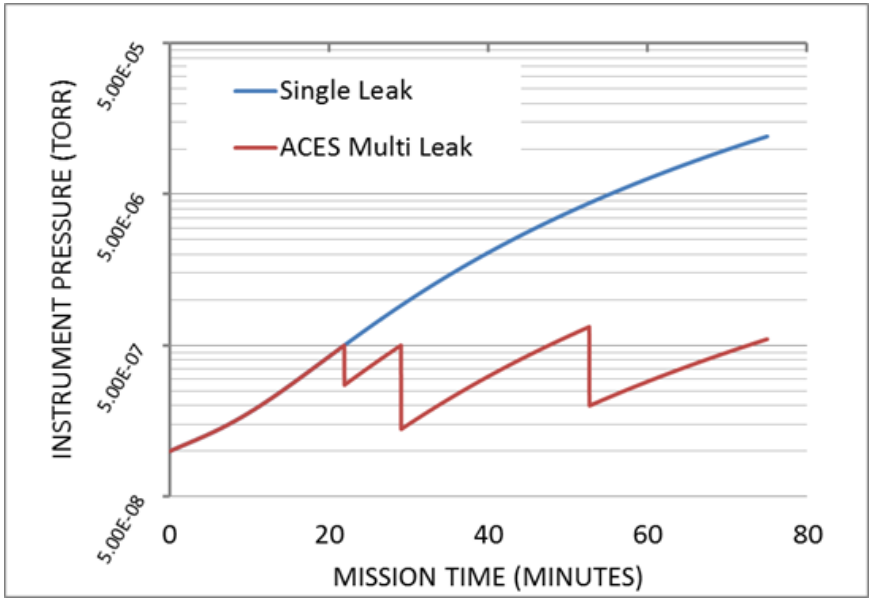
[1]
[2] J. H. Hoffman, R. R. Hodges, and K. D. Duerksen, J. Vac. Sci. Technol. 16, 692 (1979).
[3] J. H. Hoffman, R. R. Hodges, Jr., M. B. McElroy, T. M. Donahue, and M. Kolpin, Science, 205, 49 (1979).
[4] K. V. Grechnev, V. G. Istomin, L. N. Ozerov, and V. G. Klimovitskii, Kosm. Issled. 17, 697 (1979).
V.G. Istomin, K.V. Grechnev and V.A. Kochnev, Pisma Astron. Zh. 5, 211-216, (1979)

# FIRST ATTEMPT

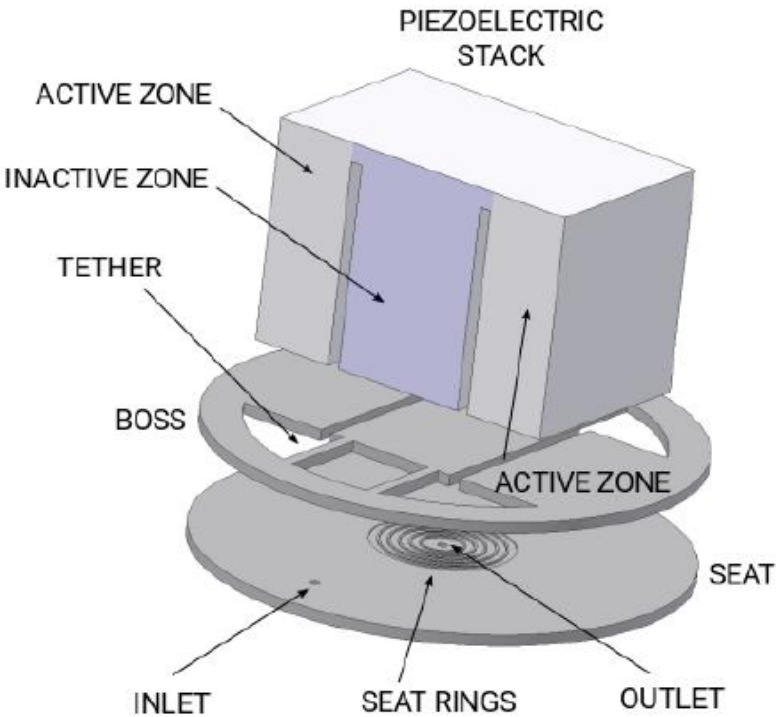


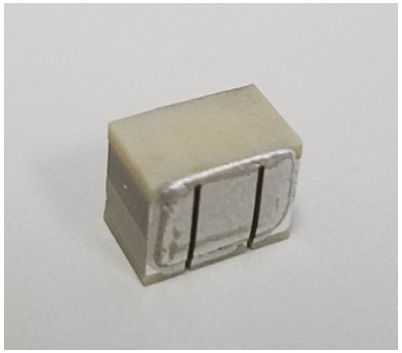



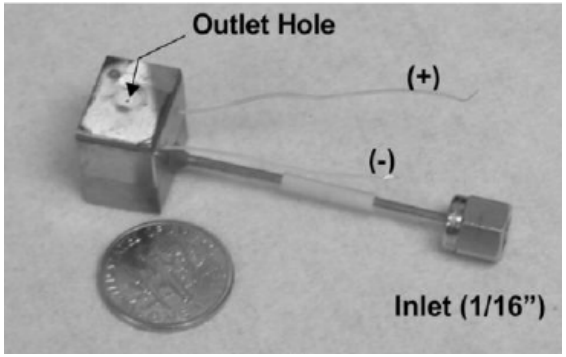




# PIEZOELECTRIC VALVE -GENERAL INFO



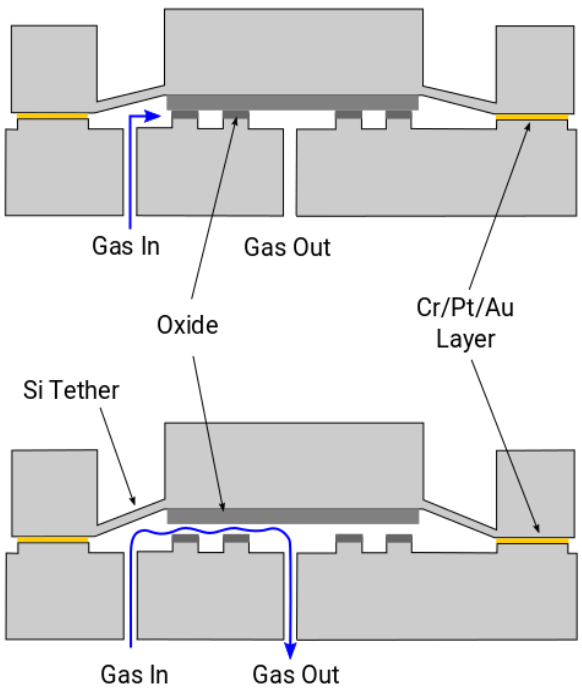


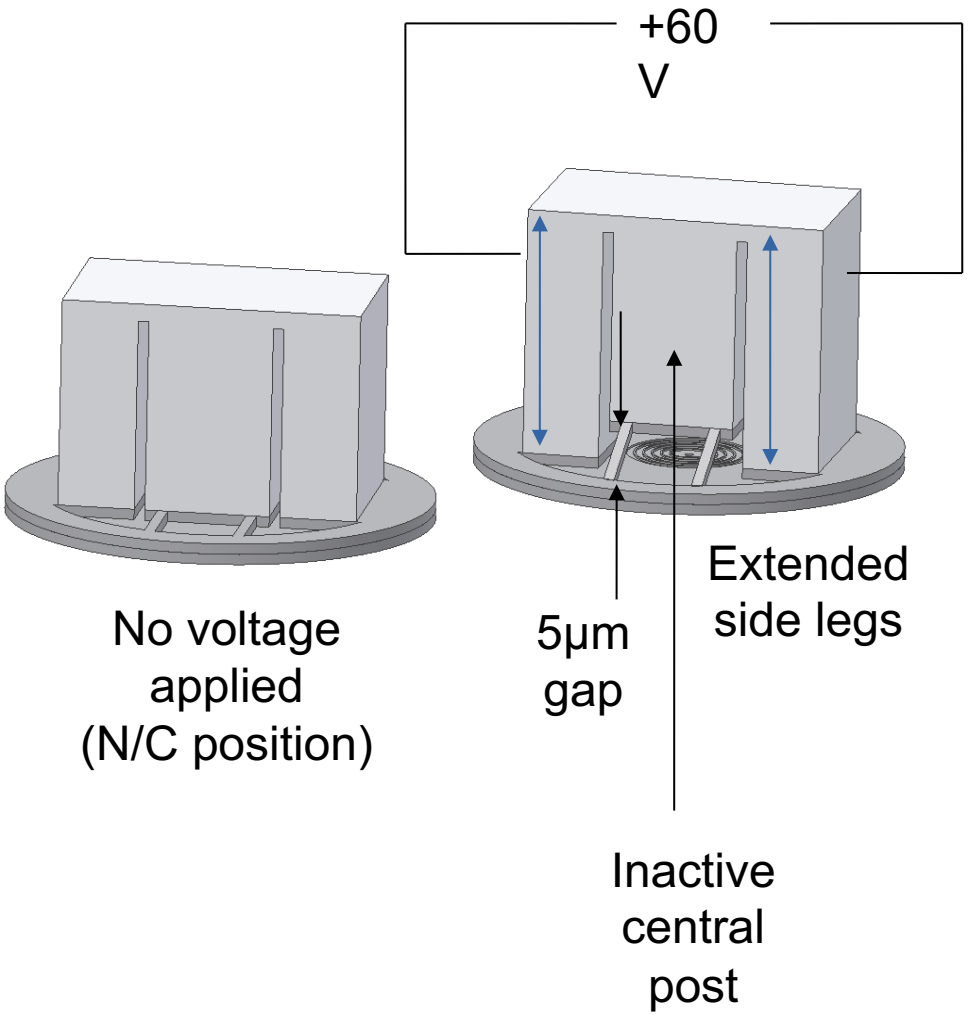

| PZT properties | Specifications |
|---|---|
| Max Voltage | +60V |
| Min Voltage | -10V |
| Displacements | +5um @ +60V<br>-1um @ -10V |
| Blocking Force | 1000N |
| Capacitance | 1700nF |
| Curie Temp | 235 $^{o}$C |
| Max op. Temp | 125 $^{o}$C |

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

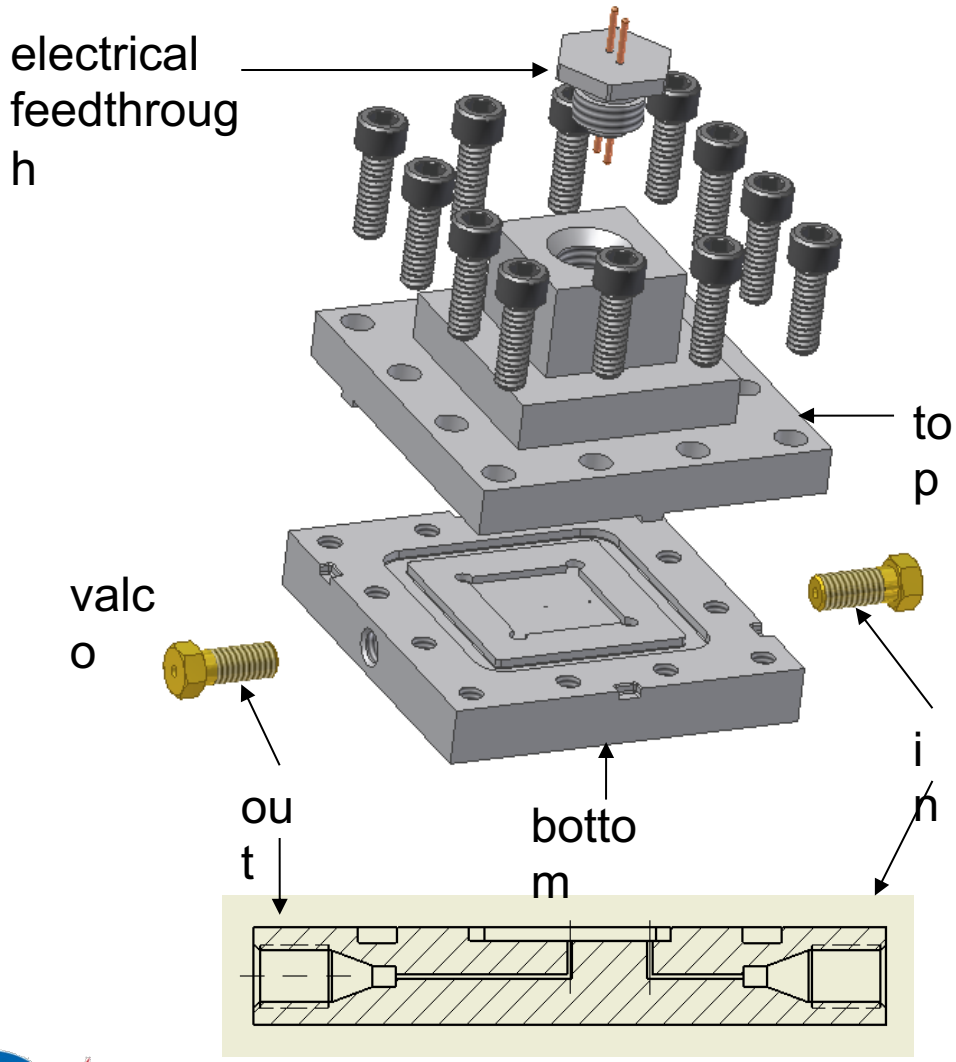
- Measured He leak rates of $1.67 \times 10^{-6}$ mbar l/s @ 55 bar in its "normally closed" position.
- Tested up to pressure difference of 69 bar (maximum allowed pressure of the test rig)
- Could operate up to 125 $^{o}$C.
- Pulsed (1kHz) or static operation (8mW of power when fully opened)

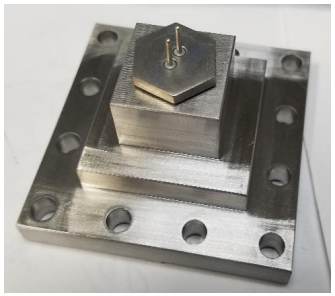
# PIEZOELECTRIC VALVE - PRINCIPLE OF OPERATION

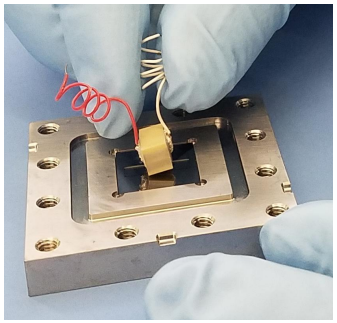


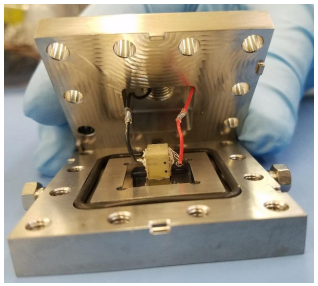



# PIEZOELECTRIC VALVE - PACKAGE

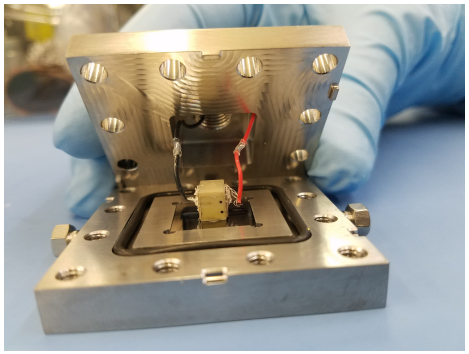


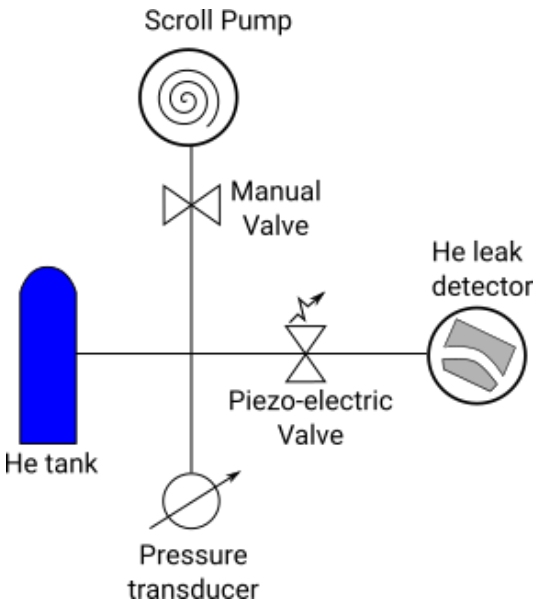





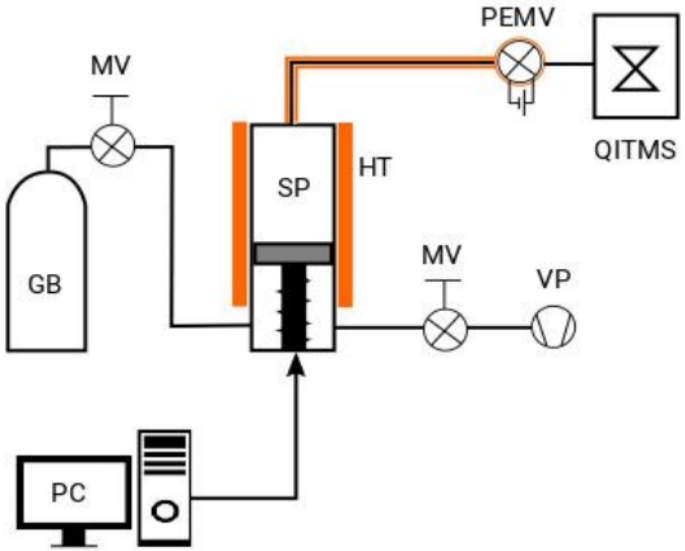


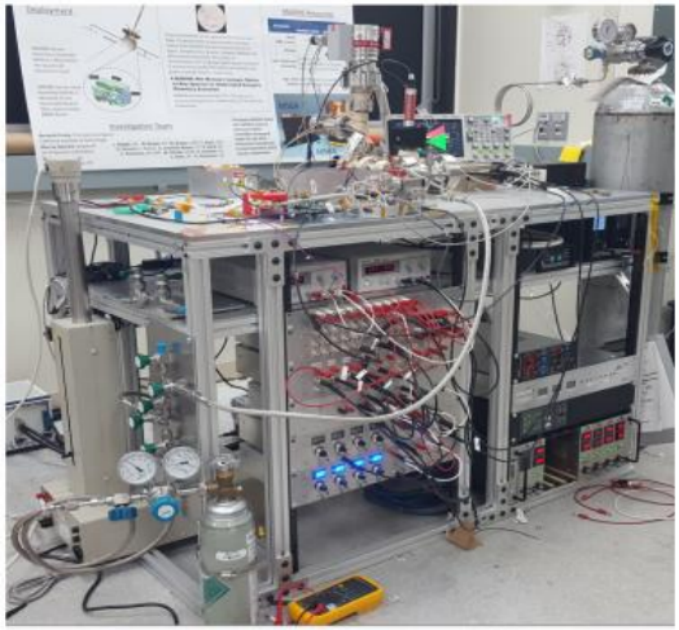
# PIEZOELECTRIC VALVE - TESTING



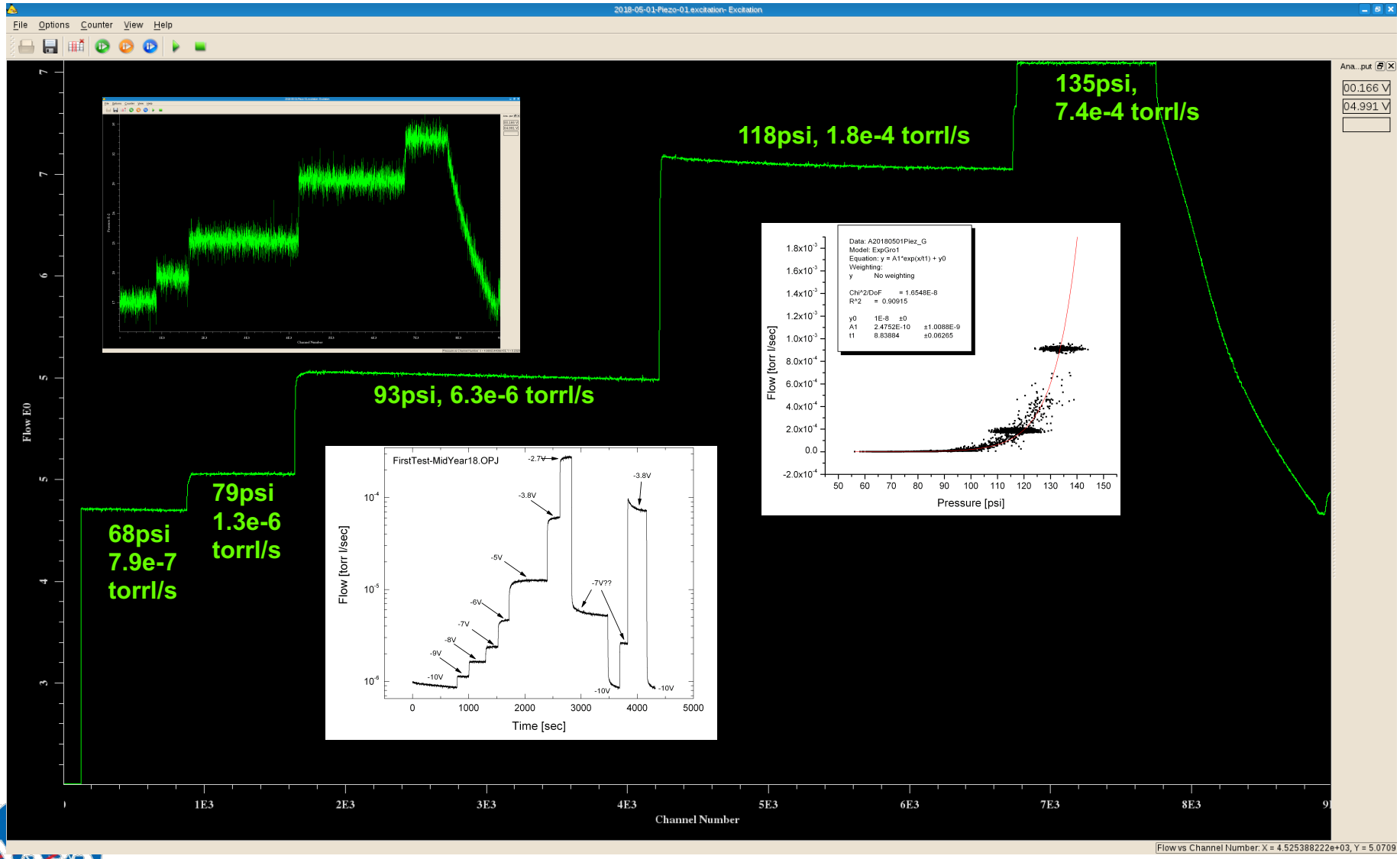


# PIEZOELECTRIC VALVE - QITMS STATION



# PIEZOELECTRIC VALVE - RESULTS



# PIEZOELECTRIC VALVE - WHAT'S NEXT

- Fabricate more valves & test
- Eliminate epoxy by direct PZT to Si bonding
- Machine lighter, more compact package

*THANK YOU FOR YOUR KIND ATTENTION*