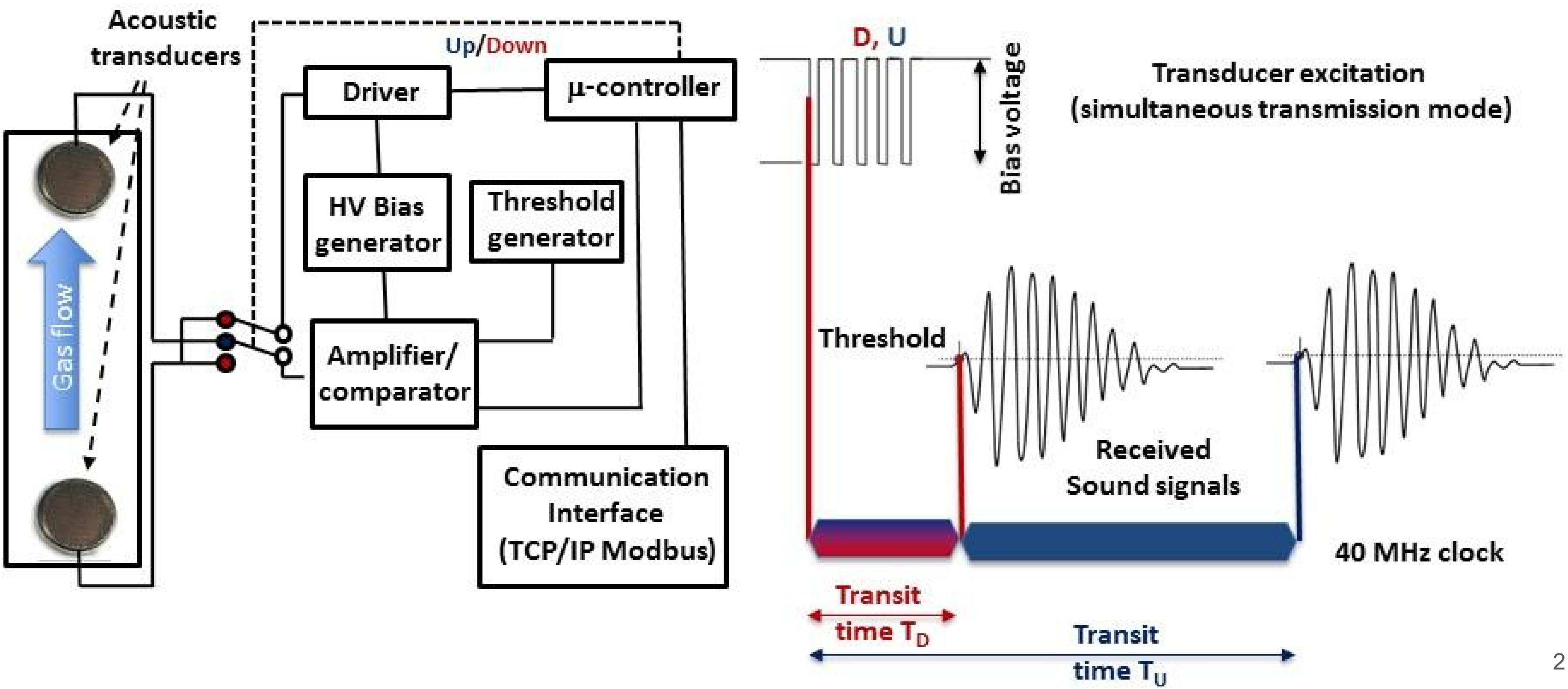
SONAR

Alexander Madsen

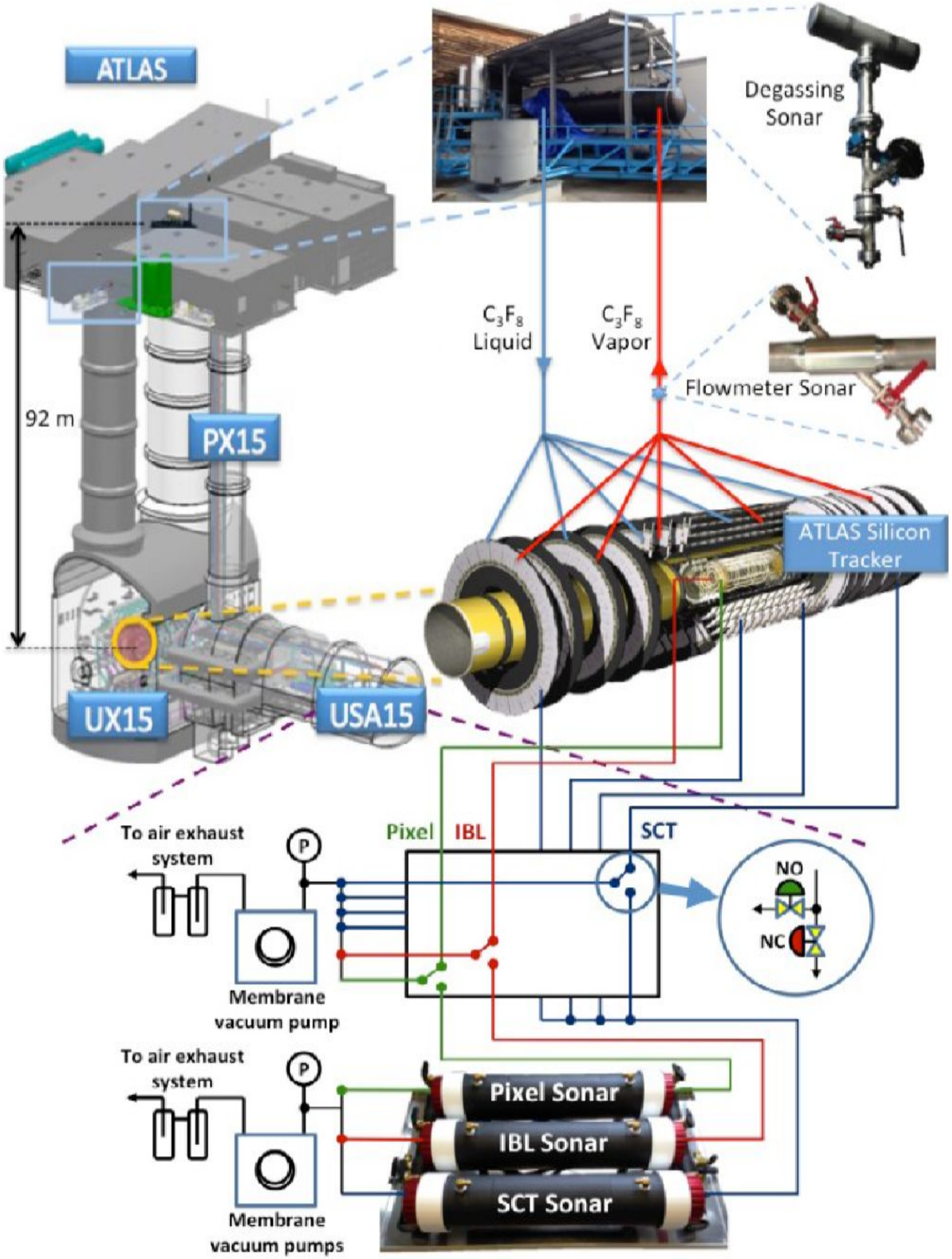
The sonar instrument

1. The transmitting transducer is excited by a 350V wave pulse.
2. Signal is received by 2nd transducer and passed to an amplifier and a comparator.
3. The transit time is recorded.



Applications in ATLAS

1. Detect coolant leaks in IBL, Pixel, SCT detector envelopes.
2. Detect air ingress in Thermosiphon circuit.
3. Monitor gas flow in Thermosiphon circuit.



Degassing sonar
- Measure air ingress into thermosiphon circuit and trigger venting

Flowmeter sonar
- Measure vapor return flow at speeds >20 m/s

IBL, Pixel, and SCT sonars
- Measure coolant leaks into detector envelopes with 0.002% precision

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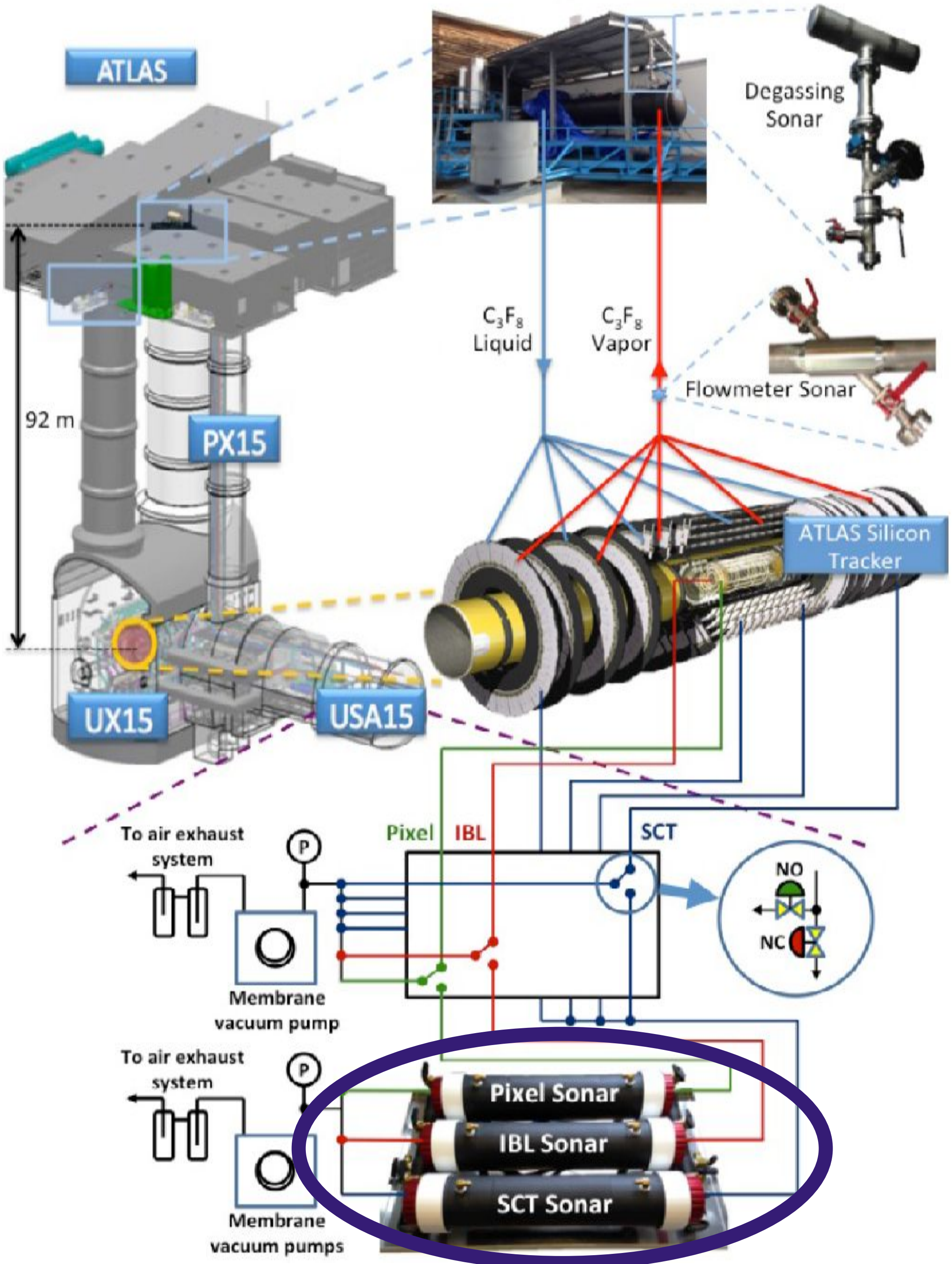

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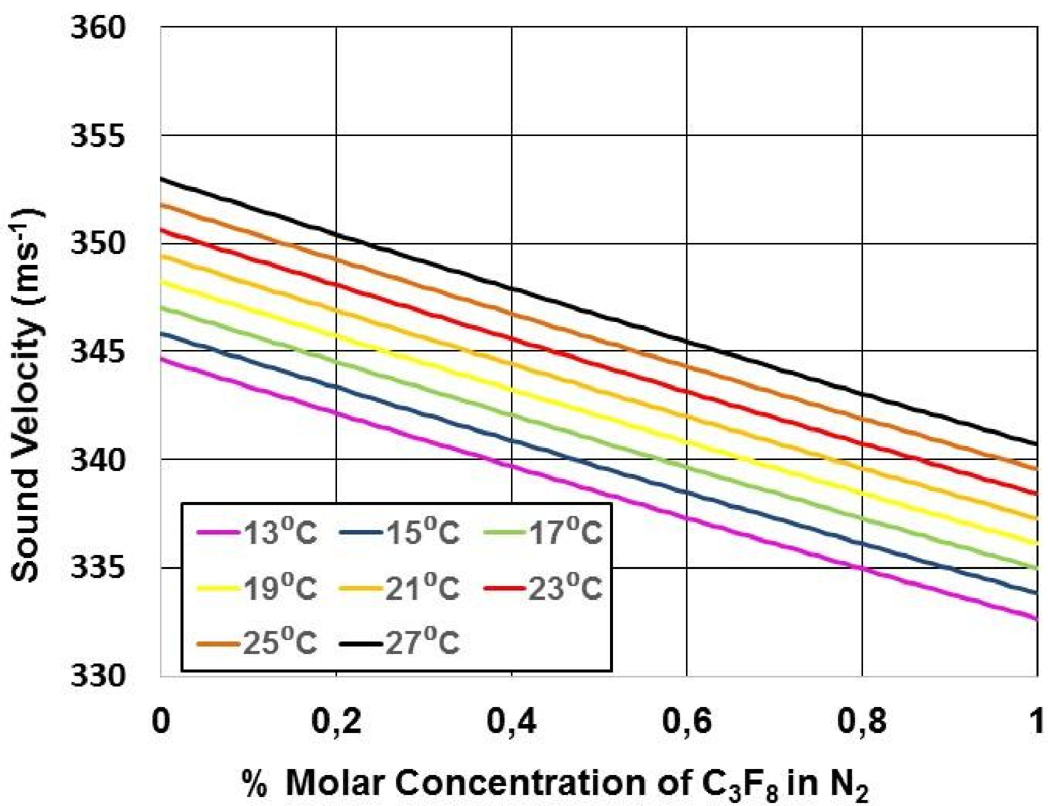
Measuring binary gas mixtures with sonar

Taking the **average of the transit times** Tup and Tdown, and the known length of the tube, we obtain the **speed of sound** in the gas mixture, independent of flow.



$$v_s = \sqrt{\frac{\gamma_m \cdot R \cdot T}{M_m}},$$

$$M_m = \sum_i \omega_i M_i \qquad \gamma_m = \frac{\sum_i \omega_i C_{P_i}}{\sum_i \omega_i C_{V_i}},$$

ω_i = molar fraction of component *i*

C_{pi} = molar specific heat at constant pressure
C_{vi} = molar specific heat at constant volume
(obtained from NIST REFPROP)

Adopting the hypothesis of a **binary mixture**, and simultaneously measuring temperature and pressure, we can **solve for the concentration** of each component.

Performance

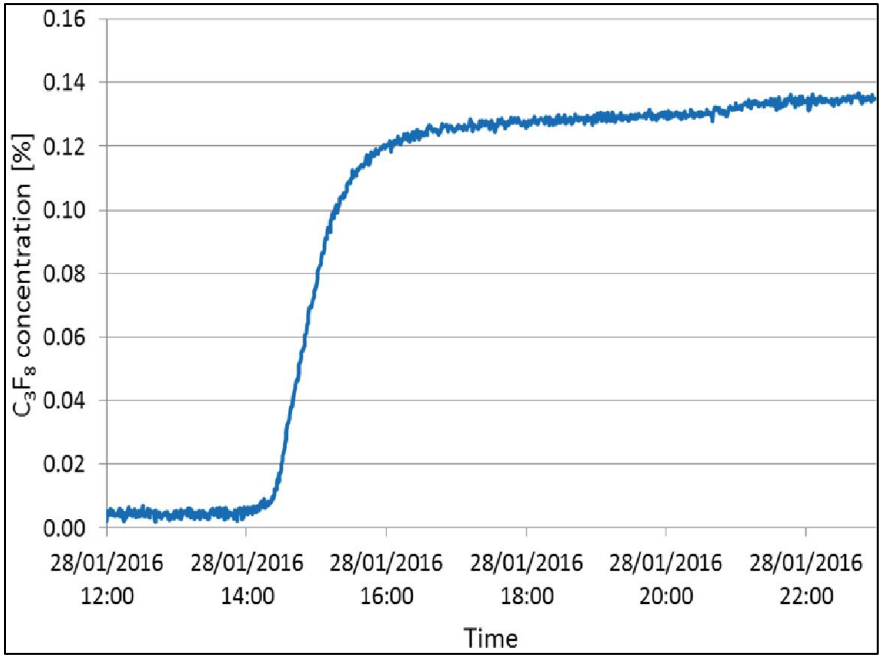
Typical **slope of the sound velocity vs C3F8/N2 concentration curve** is -12.5 m/s/%

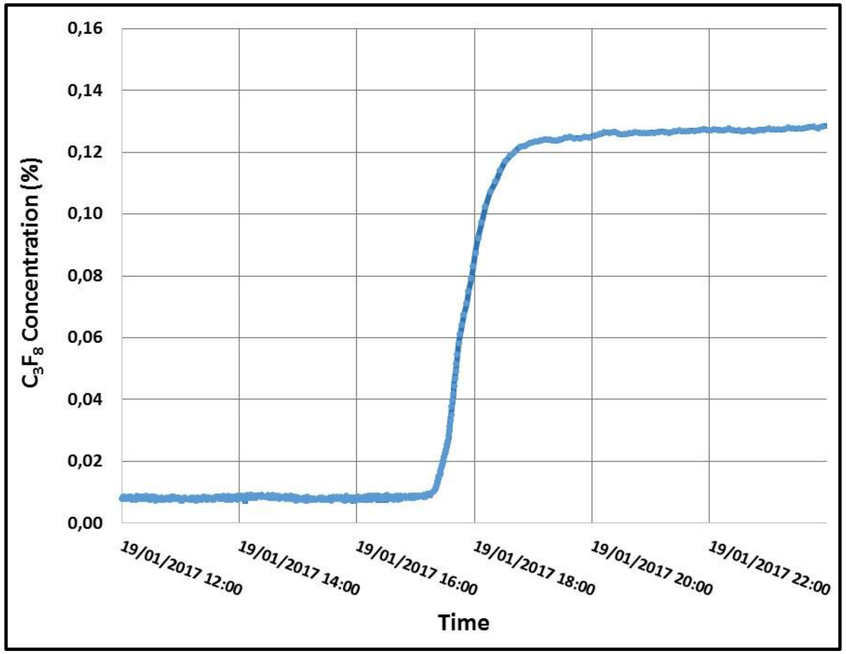
Source	Uncertainty	Impact
Temperature sensitivity in sonar tube	0.1 °C	0.022 m/s
Pressure sensitivity in sonar tube	1 mbar	0.003 m/s
Distance between transducers	0.1 mm	0.018 m/s
Transit time measurement	25 ns	0.0005 m/s
Total	**-**	**0.025 m/s**

Precision on sound velocity measurement is ~0.025 m/s => 0.025m/s / 12.5 m/s/% ~ **0.002% precision** on concentration.

Pixel envelope C_3F_8 concentration

Comparing cooling start-ups January 2016 & January 2017





No increase seen in pixel detector C_3F_8 coolant leak into the pixel N_2 environmental volume over the last 12 months.

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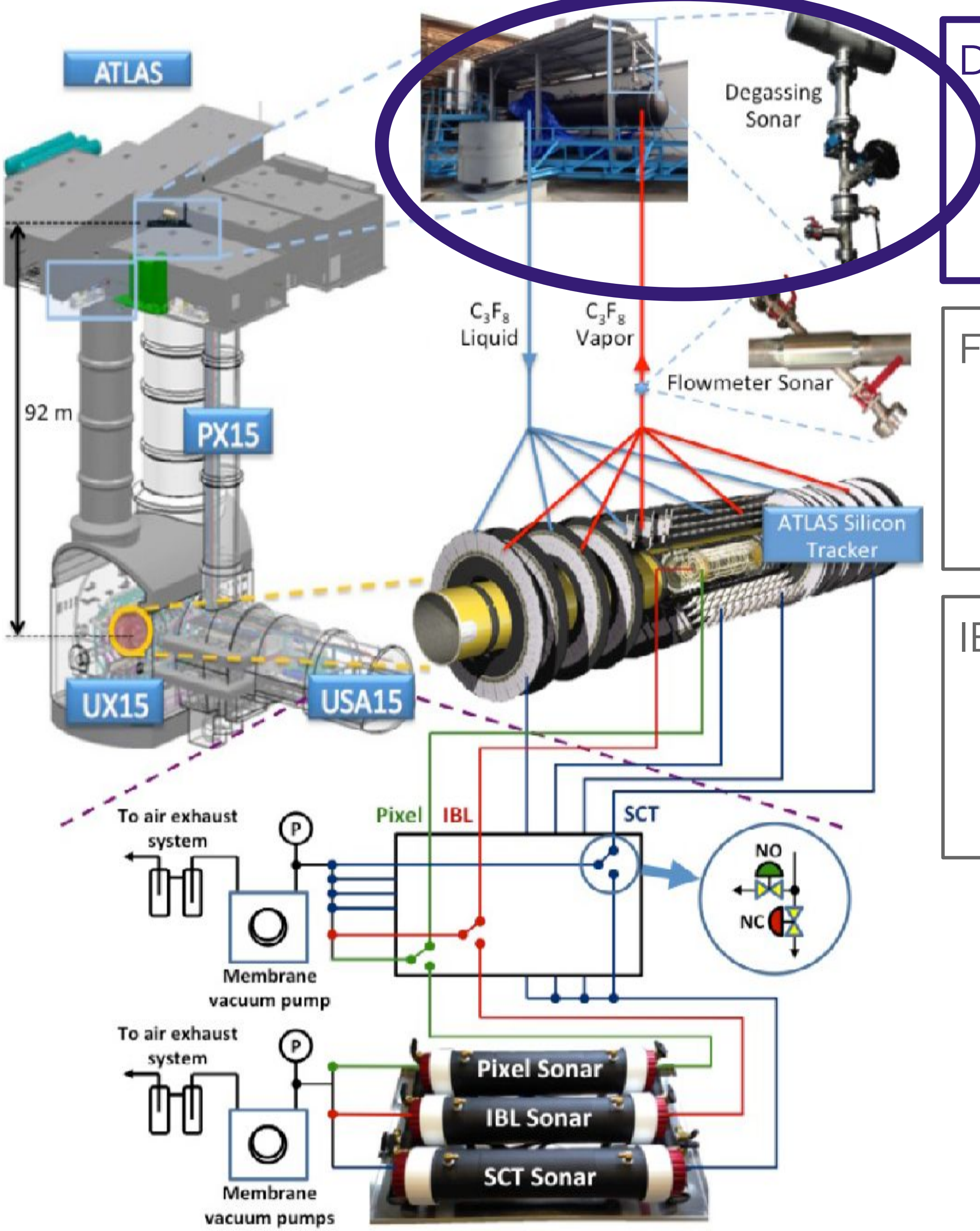

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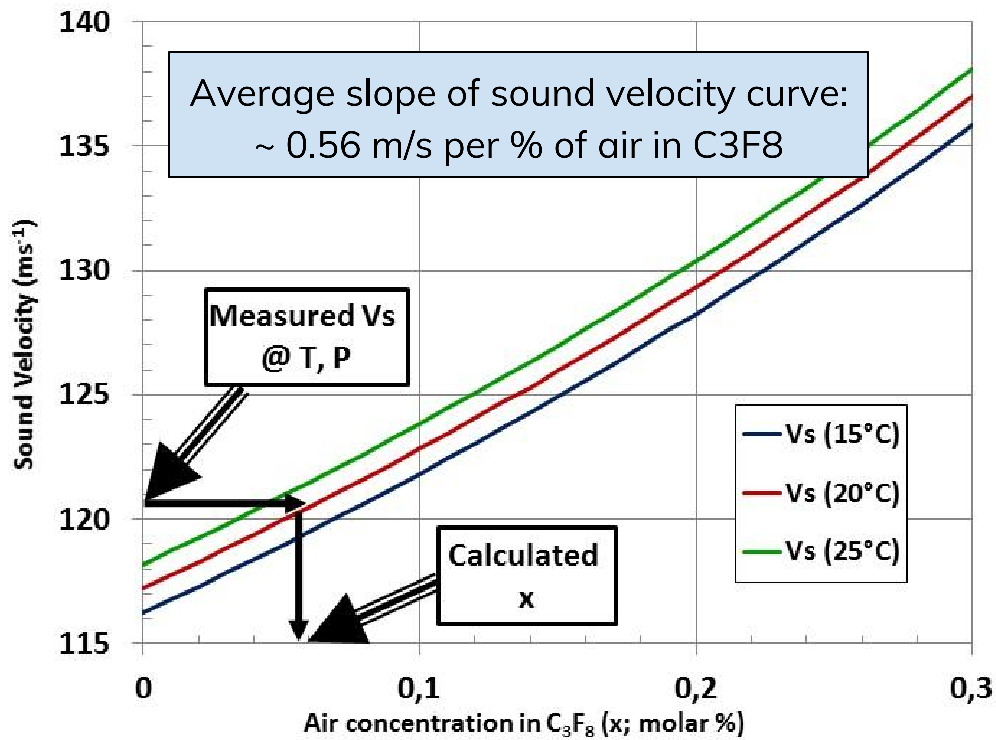
Degassing sonar

Complementary to leak monitoring, we can also search for air ingress into the cooling loop.



Precision on sound velocity measurement is ~0.025 m/s => 0.025m/s / 0.56 m/s/% ~ **0.05% precision** on concentration.

In the new thermosiphon cooling system, the highest point (lowest pressure: <1 bar) is monitored with a dedicated sonar. Here, the **concentration of air in the C3F8** coolant is measured.

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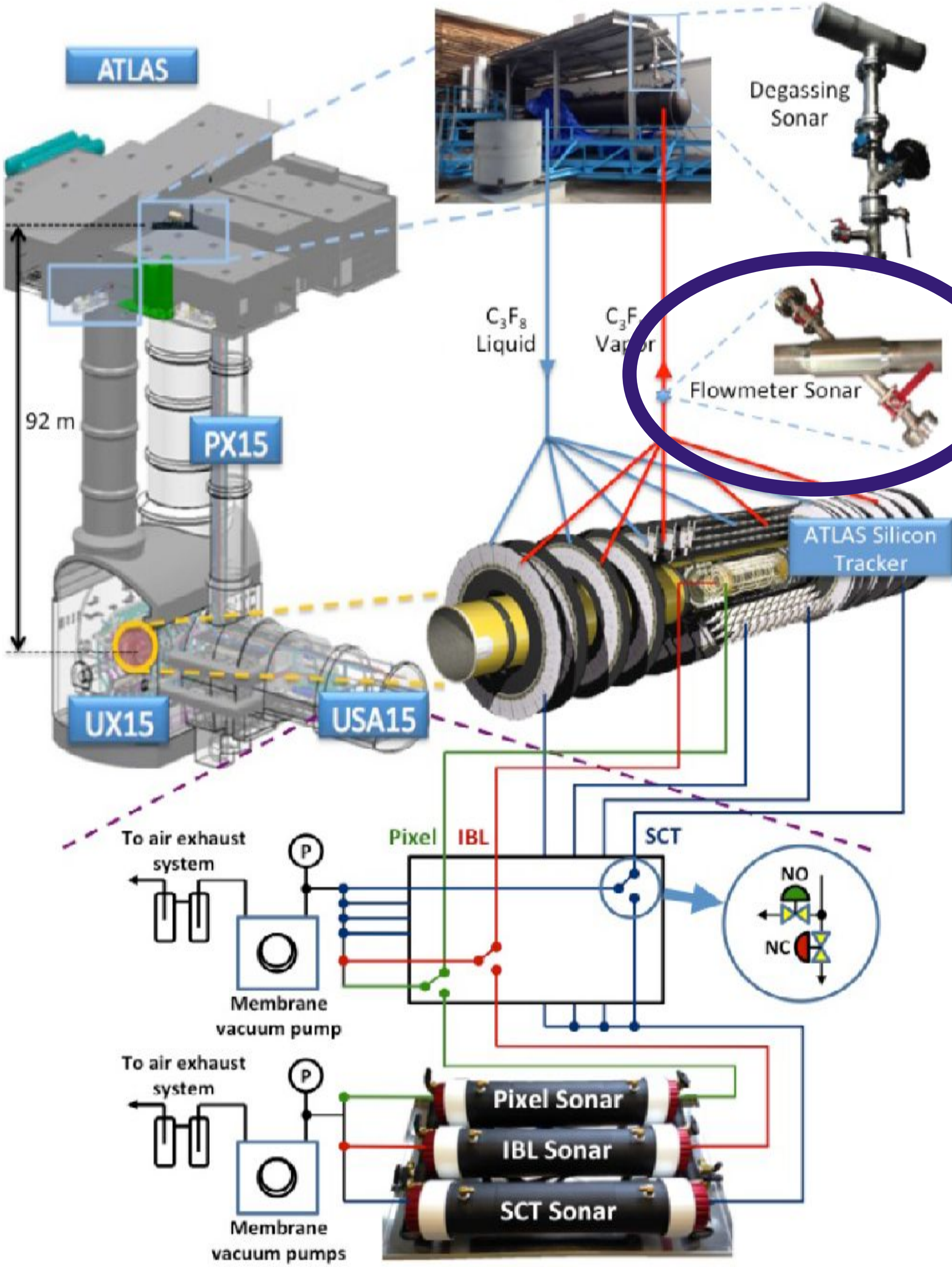

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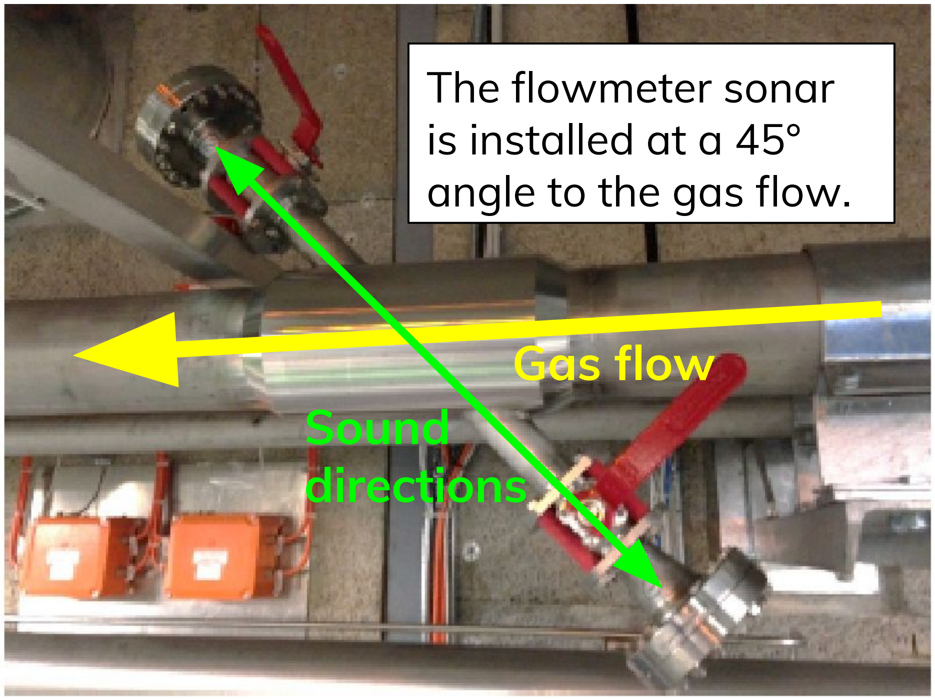
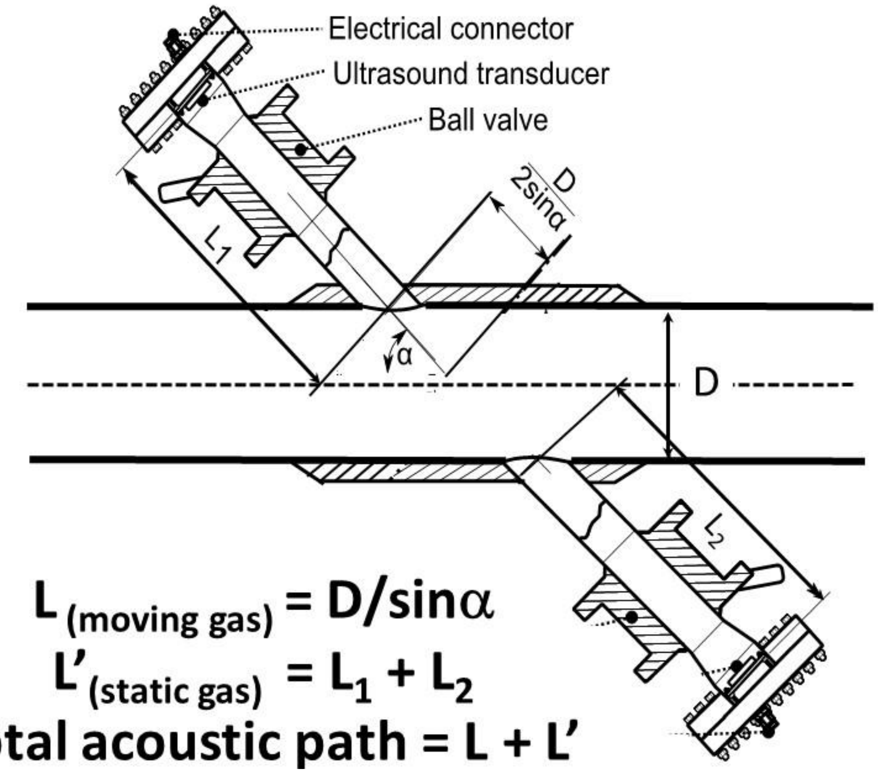
Flowmeter





$L_{(\text{moving gas})} = D/\sin\alpha$

$L'_{(\text{static gas})} = L_1 + L_2$

Total acoustic path = L + L'

The speed of sound is:

$$v_s = \frac{A \pm \sqrt{A^2 - 16L' t_{up} t_{down} \left(L' + \frac{D_{Main}}{\sin\alpha}\right)}}{4 t_{up} t_{down}}$$

$$A = (t_{up} + t_{down})\left(2L' + \frac{D_{Main}}{\sin\alpha}\right)$$

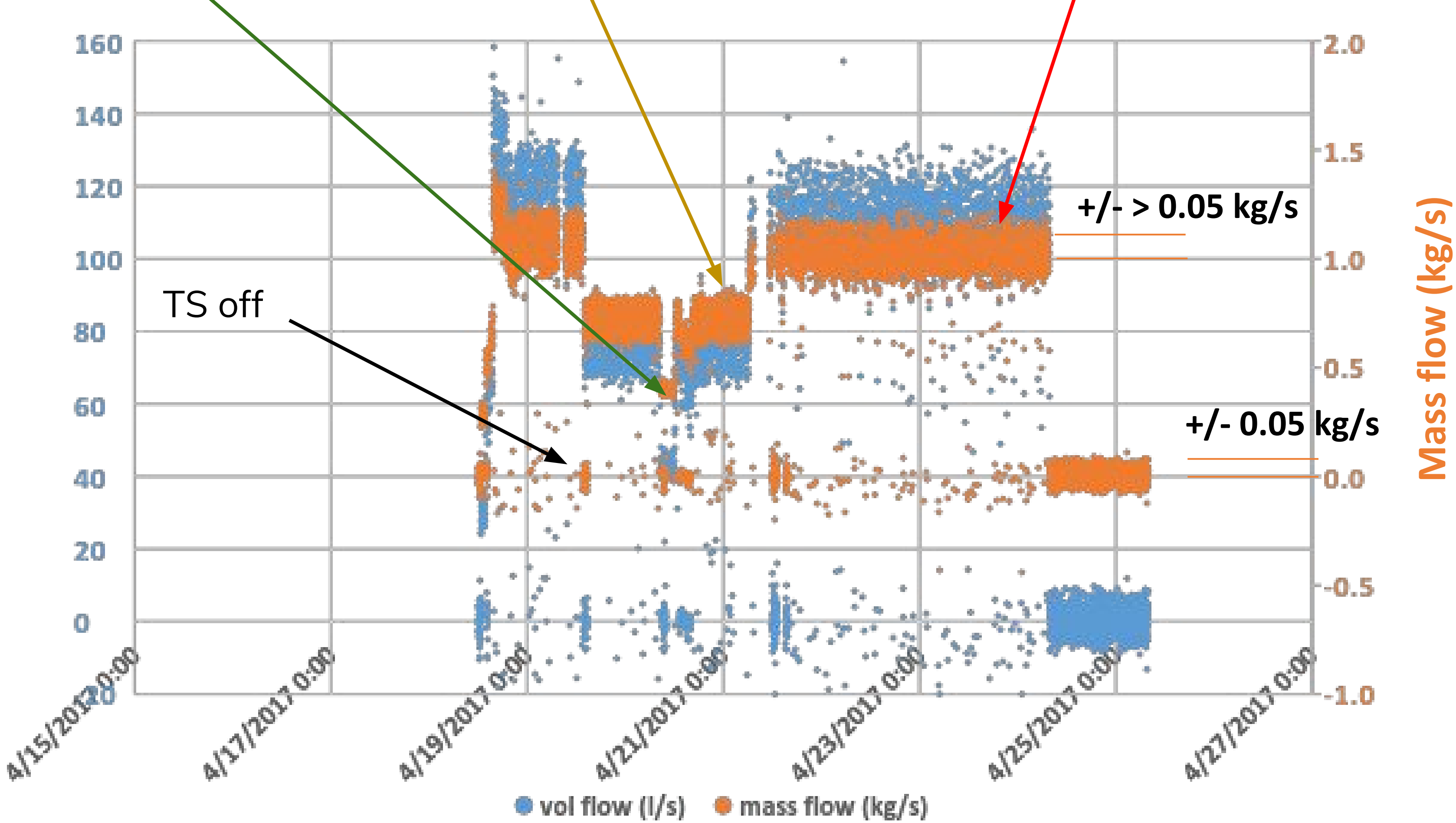
The **gas flow velocity** is:

$$v_g = \frac{v_s \left(\frac{D_{Main}}{\sin\alpha} + L' - v_s t_{down}\right)}{\cos\alpha (v_s t_{down} - L')}$$

D_{Main} = diameter of main tube through which the gas flows,
L' = combined length of static gas in the two sidearms.

TS commissioning April 19-24, 2017

The thermosiphon was operated with 33%, 70%, and 100% nominal C3F8 flow, cooling the ATLAS **SCT end-caps**, **SCT end-caps + SCT barrel**, **SCT end-caps + barrel + pixel** detectors.



Vapor pressure held constant at 1.2 bar.

Flowmeter sonar measurements agree with the tested flow rates of 0.34, 0.74, 1.03 kg/s.

Degassing sonar C6F14 contamination search during the TS tests

Concern during in-situ thermosiphon studies made over several months in 2016 with a 60 kW dummy electric load about possible **contamination of C3F8 coolant by C6F14** “brine” used in heat exchanger.

Level of $2 \cdot 10^{-4}$ molar previously indicated by gas chromatography (unknown measurement uncertainty).

Will the condenser leak during the SCT and pixel tests?

The degassing sonar was given a new function to search for C6F14 in C3F8.

Degassing sonar C6F14 contamination search during the TS tests

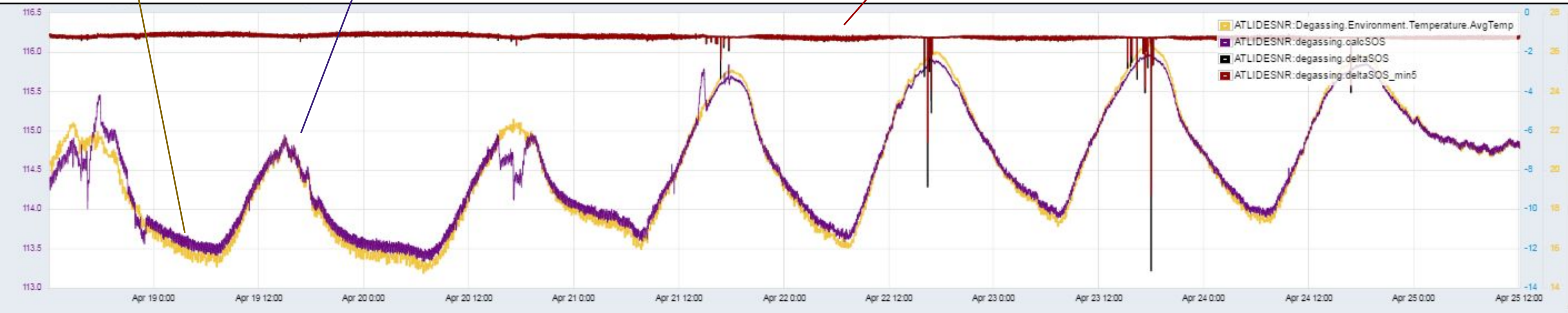
Descendant C3F8 extracted, evaporated and injected into degassing sonar.

Presence of C6F14 would reduce the speed of sound by 0.3 $ms^{-1}.\%(C_6F_{14})^{-1}$
With sonar we achieve a precision of 0.025 $m.s^{-1}$
Precision in concentration could be (0.025/0.3)% ➔ 0.075%

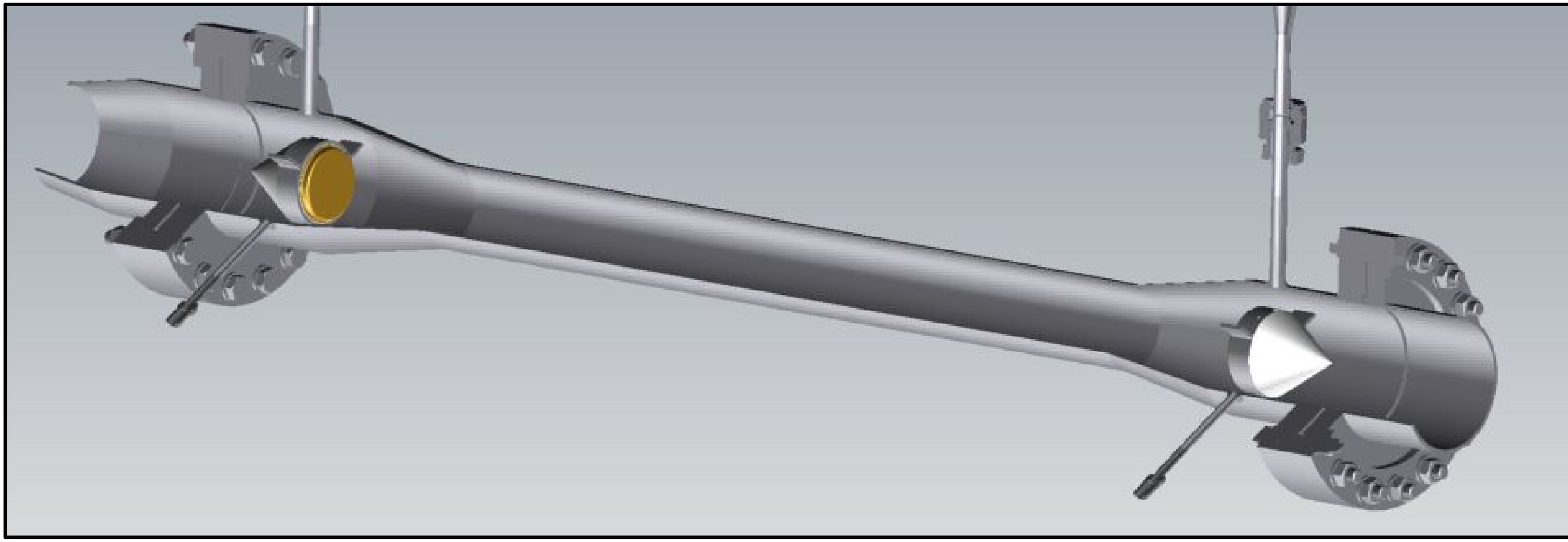
(C6F14 is the only gas around ATLAS that can make sound velocity slower in combination with C3F8)

No evidence for any increase in apparent C6F14 concentration during the tests!

Temperature Measured speed of sound Difference wrt prediction for pure C3F8

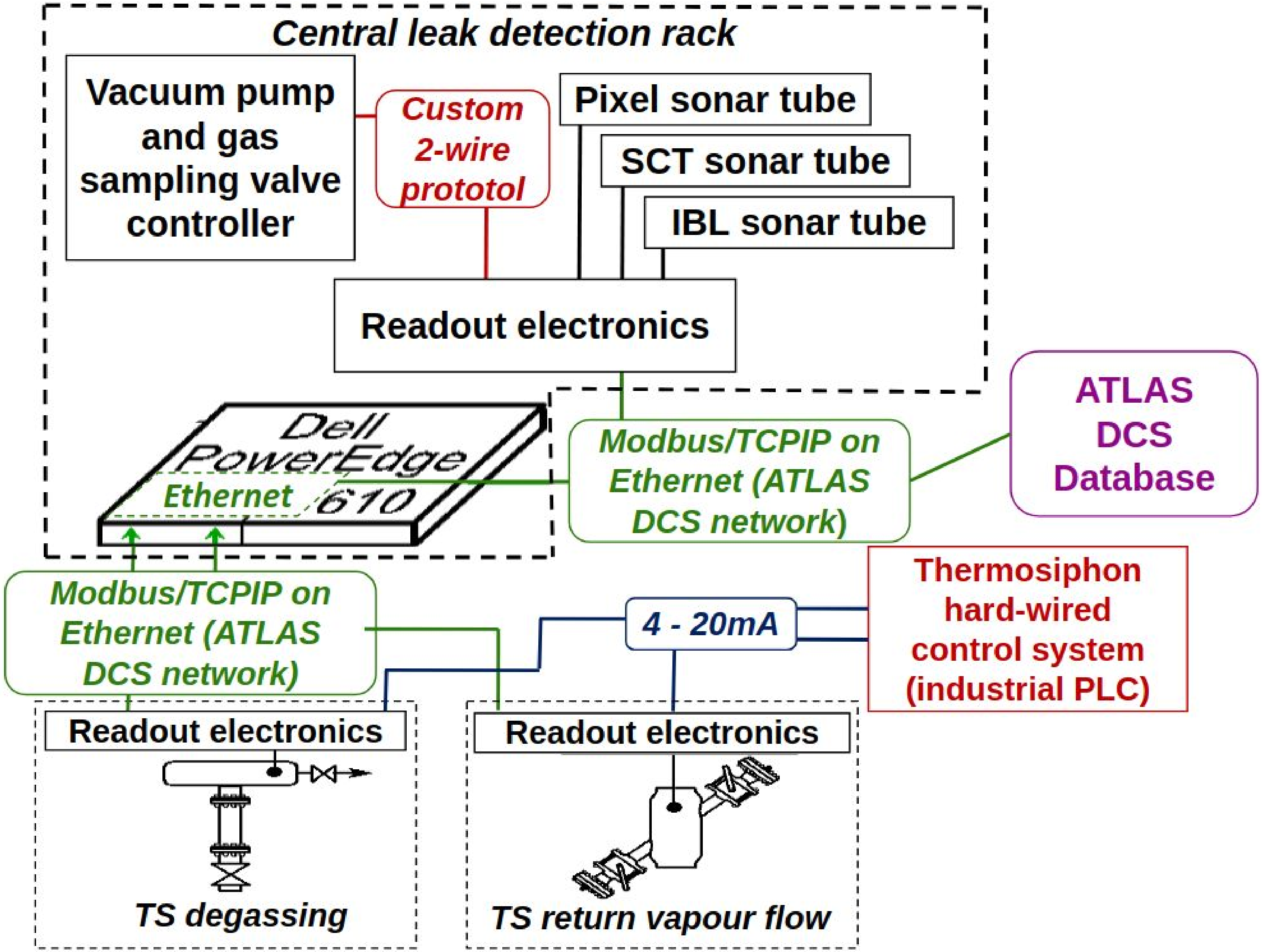


New dedicated C_6F_{14}/C_3F_8 sonar



Following the successful use of the degassing sonar for this purpose, now planning to install an additional sonar (number 6 in ATLAS) dedicated to C_6F_{14}/C_3F_8 measurements in the TS circuit.

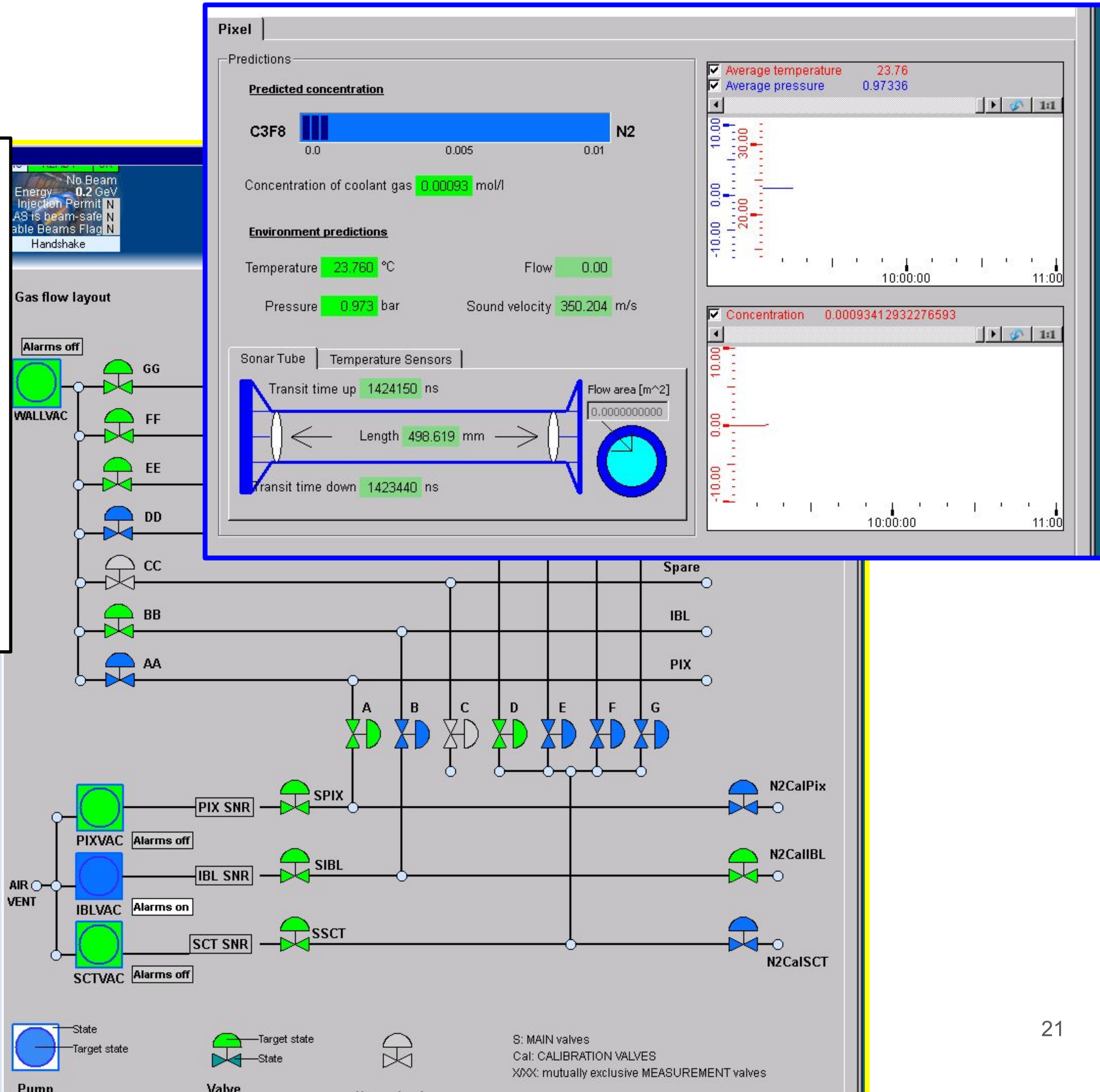
Control system



Software

Sonar system is fully integrated in the **ATLAS Detector Control System**

- **State & status** propagated to high-level systems
- **Alarm handling**
- **User interfaces** for control and monitoring

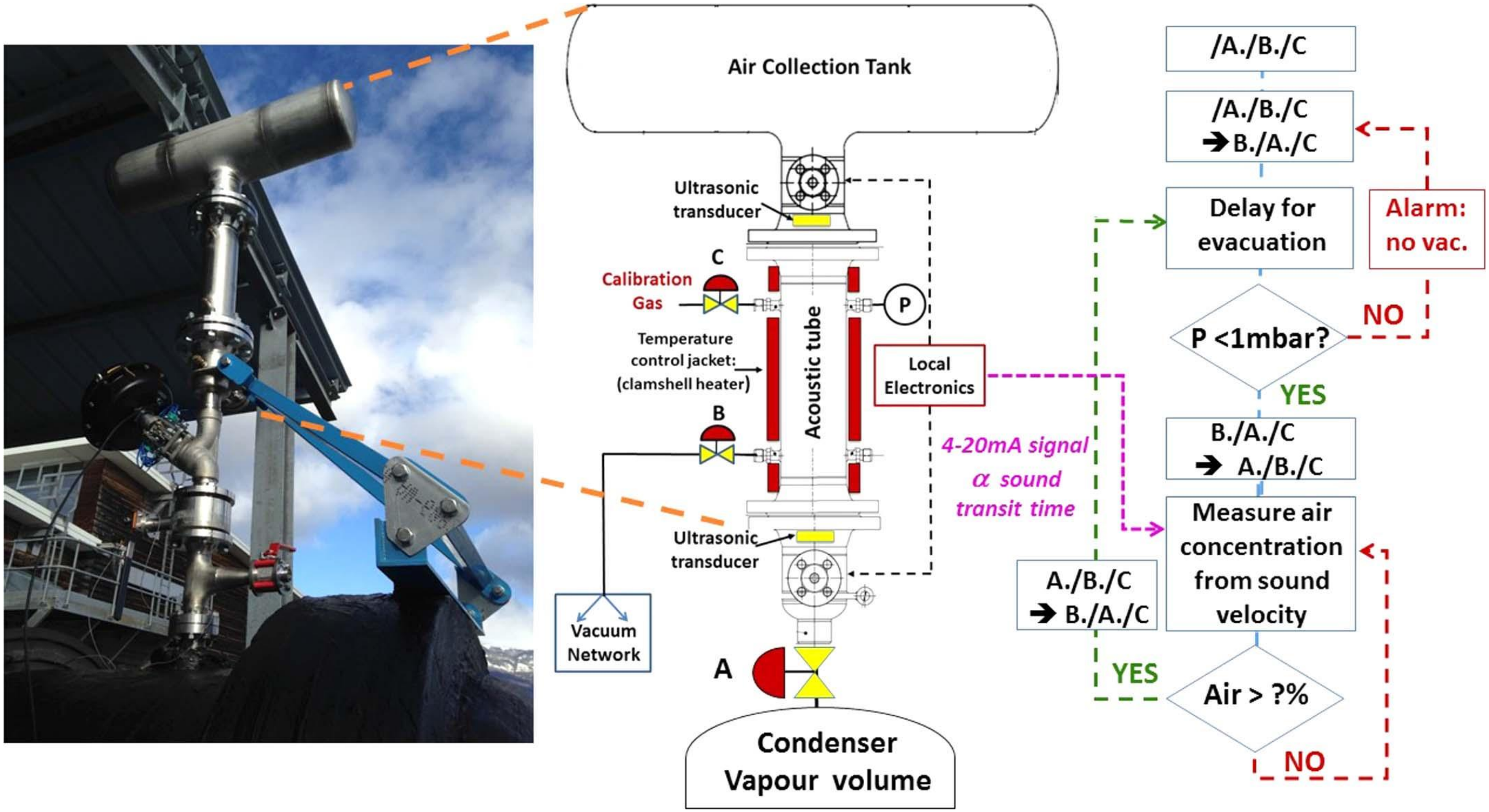


Summary

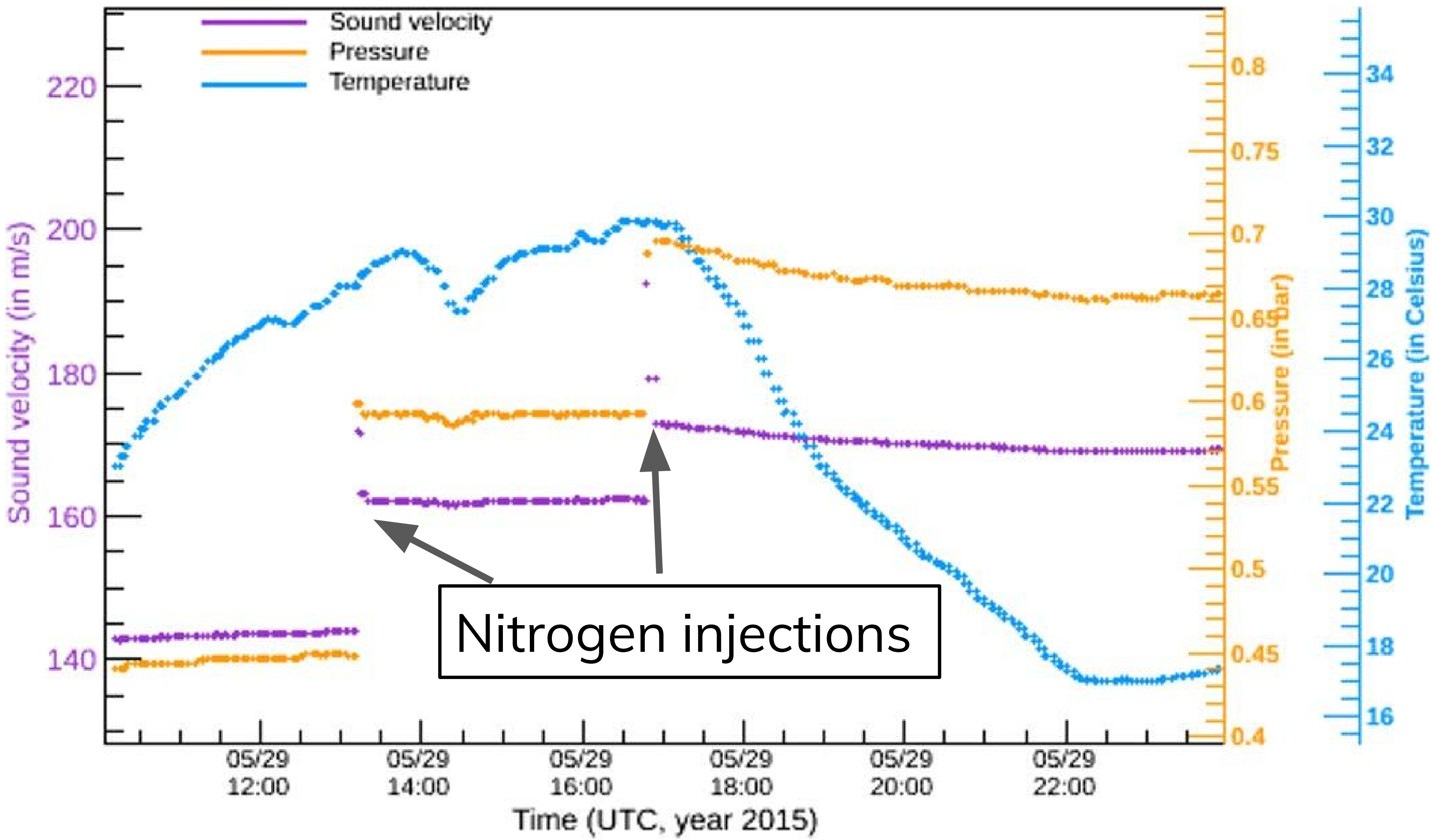
- Custom ultrasonic “sonar” instruments are used in ATLAS for continuous analysis of binary gas mixtures and flow.
- Monitoring of coolant leaks into Pixel, IBL and SCT detector envelopes (C_3F_8/N_2 fraction with 0.002% precision).
- Monitoring of gas flow and air accumulation in the Thermosiphon. New instrument to measure C_6F_{14} in C_3F_8 to be installed.

BONUS

Degassing sonar & air venting mechanism

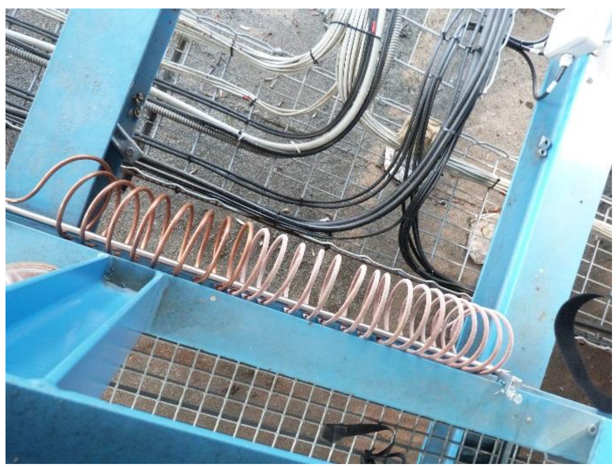


Degassing sonar tests



C3F8 descendant liquid extraction & injecton into degassing sonar

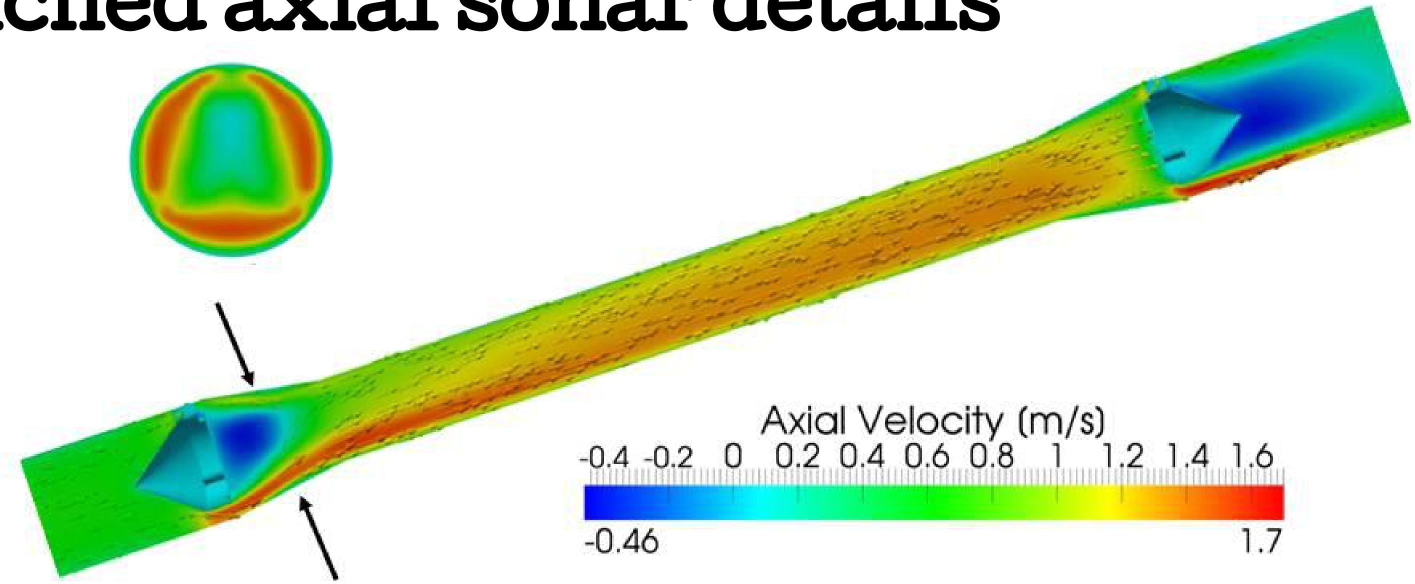
Extraction (roof level)

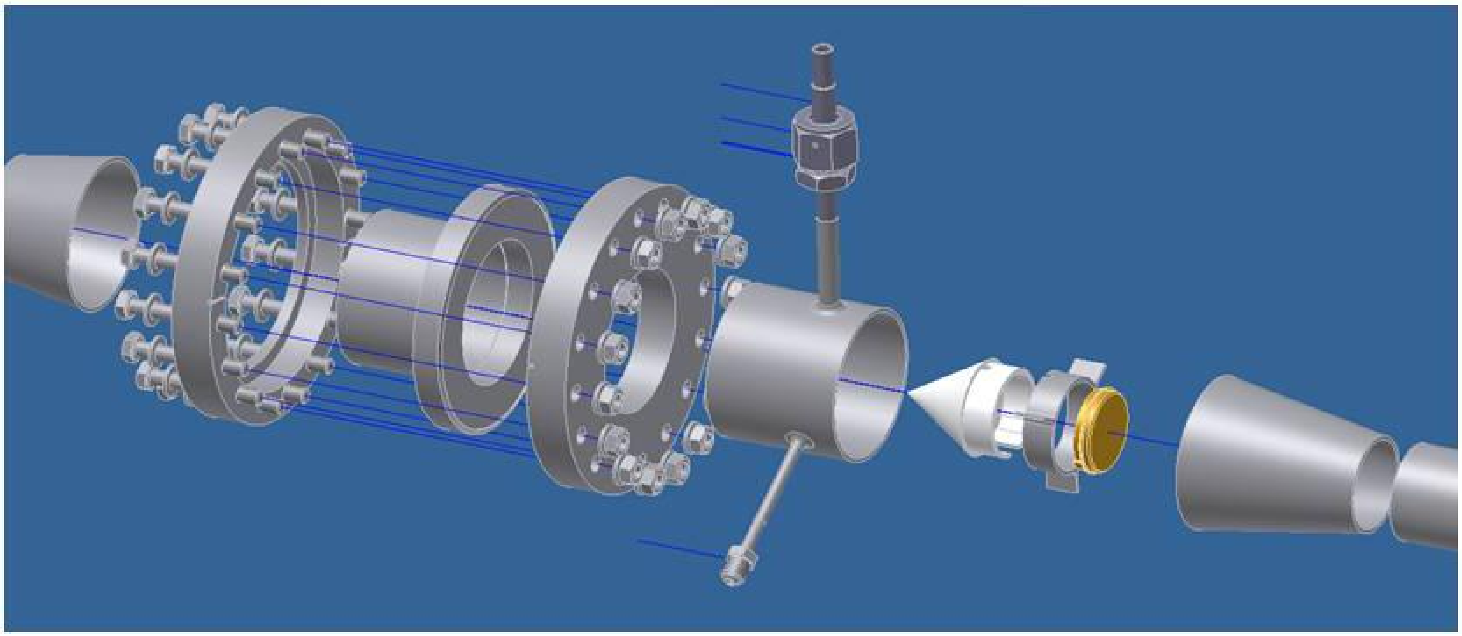


Evaporation (roof level)

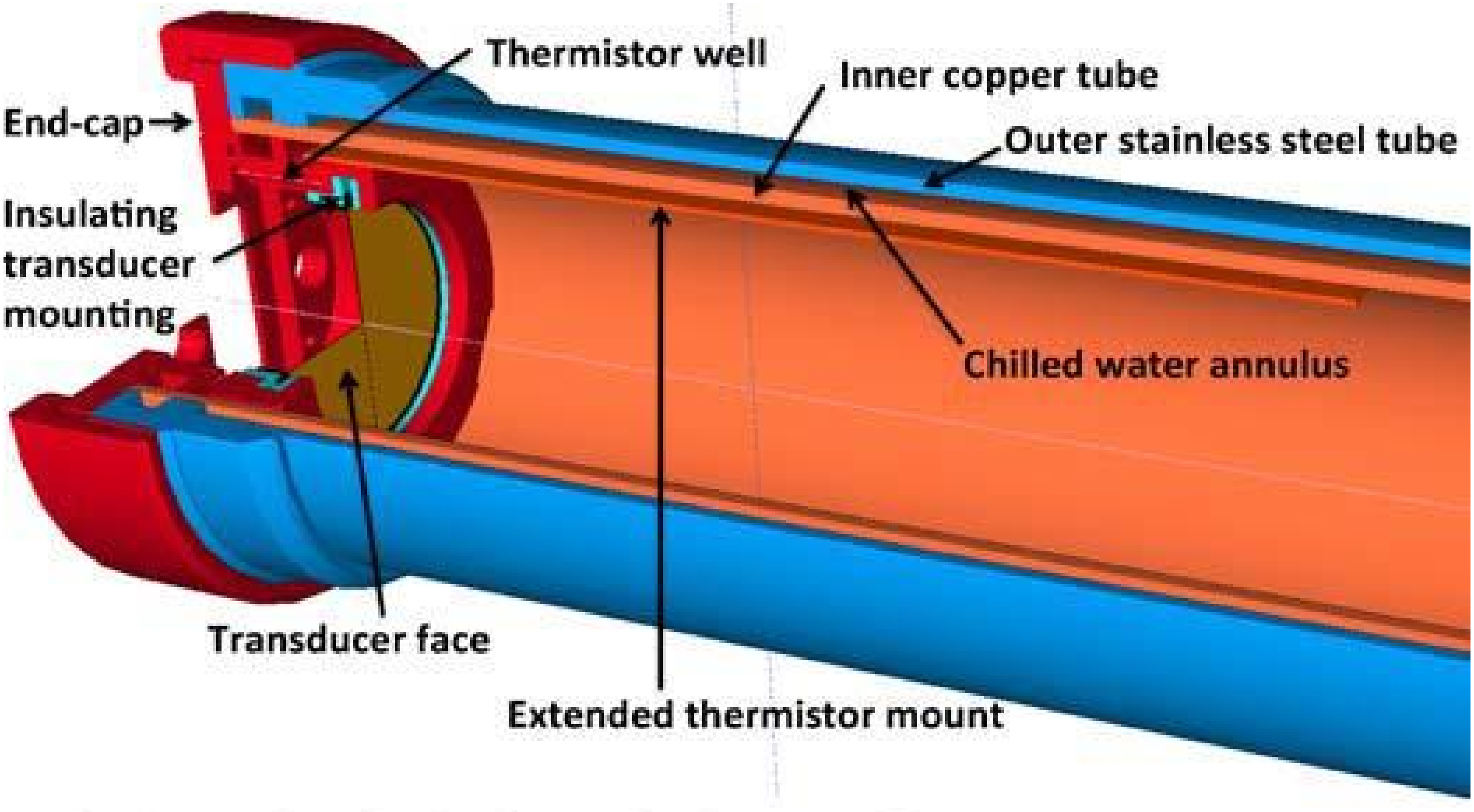
Reinjection (roof level)

Pinched axial sonar details



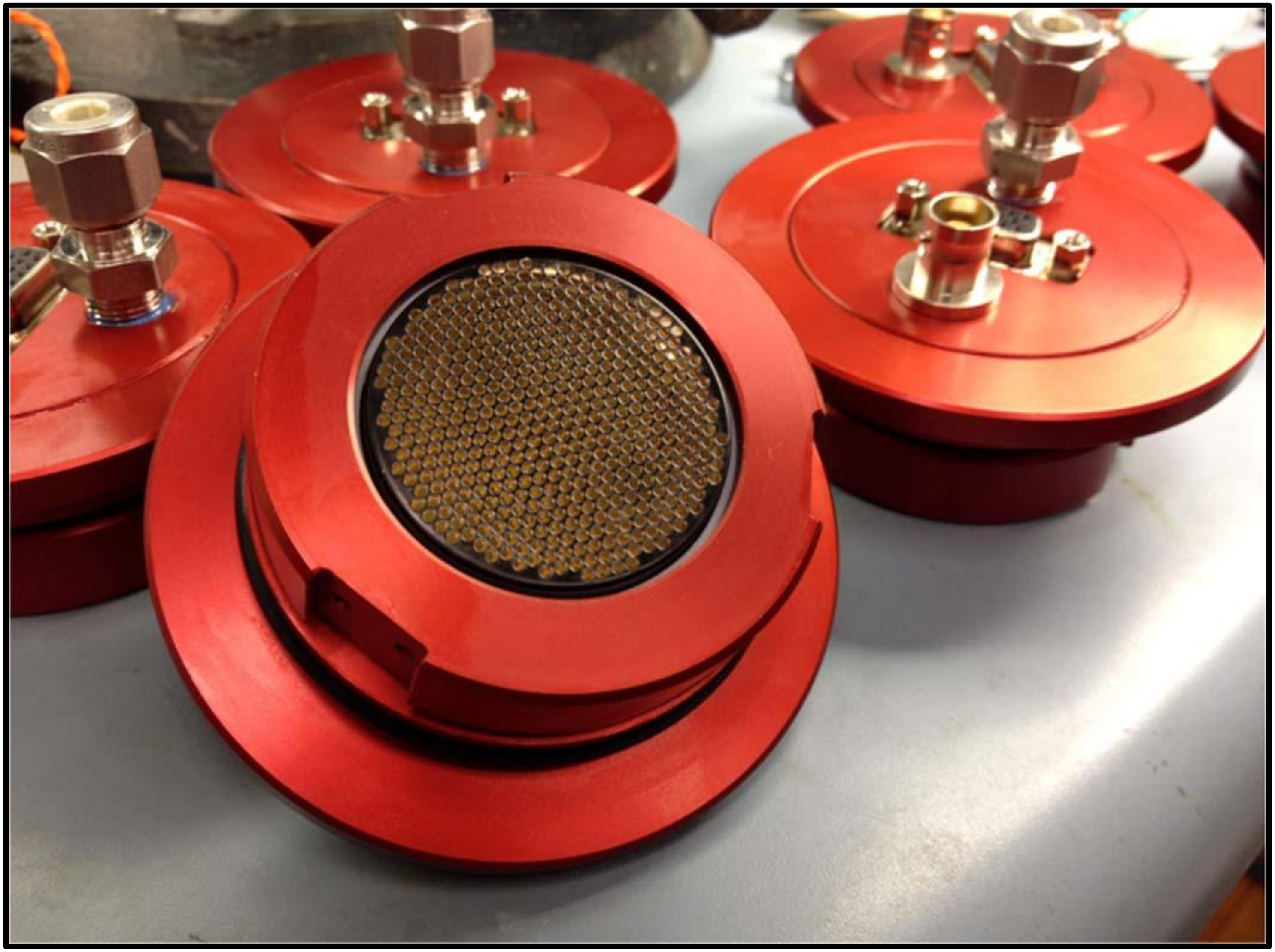


Aspirating sonar details

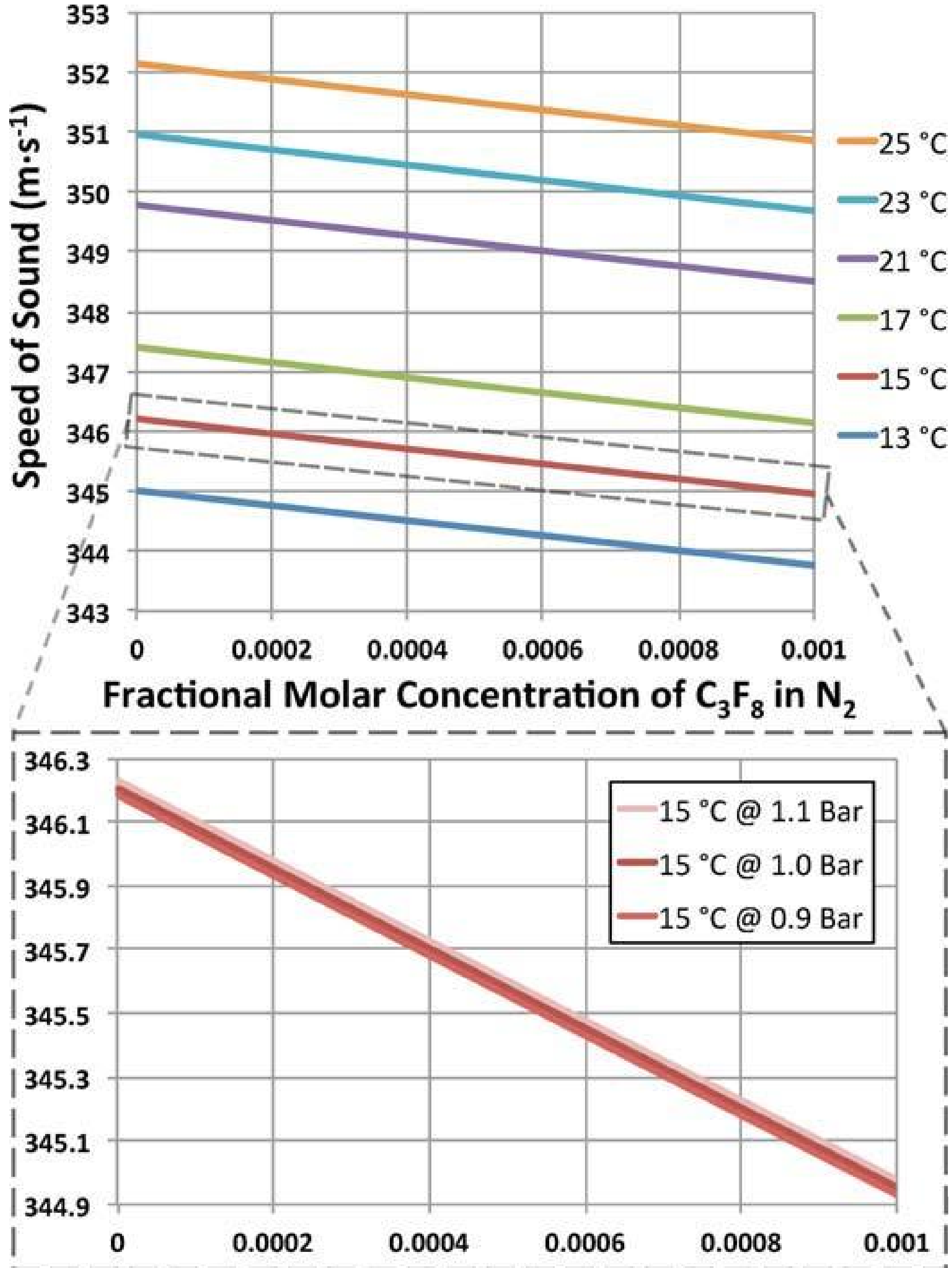


IBL, Pixel and SCT sonar tubes

Aspirating sonar end flanges



Temperature vs pressure Effect on the speed of sound



% C3F8 in SCT barrel & end-caps envelopes