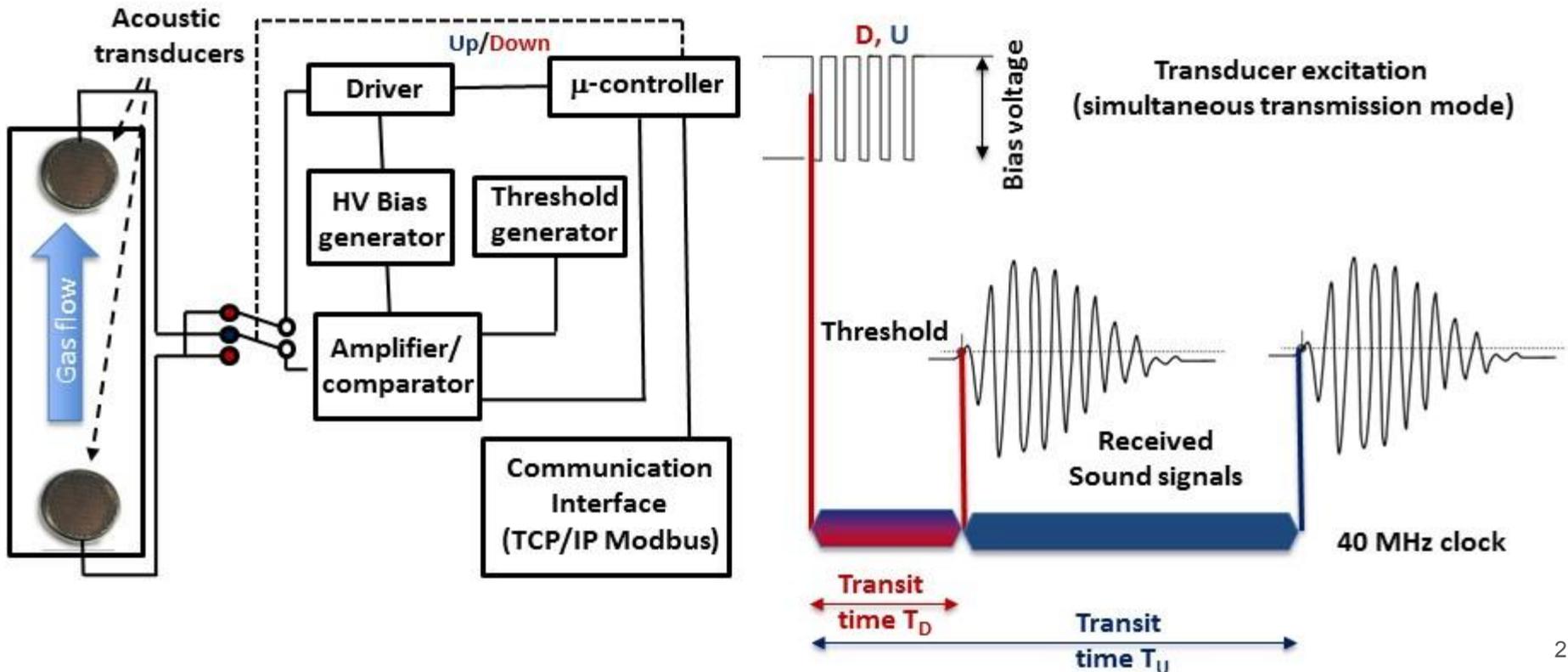


# SONAR

ALEXANDER MADSEN

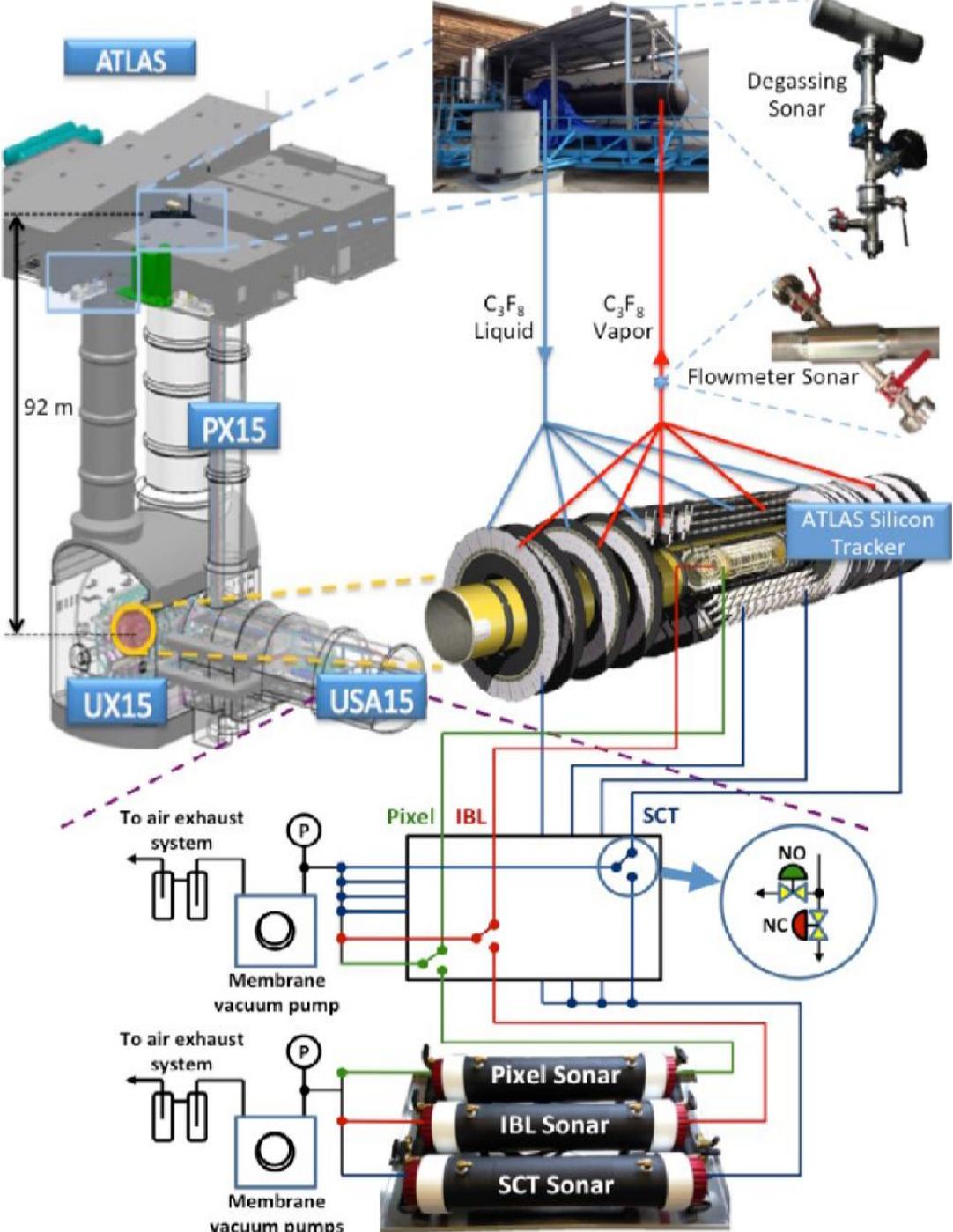
# The sonar instrument

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.



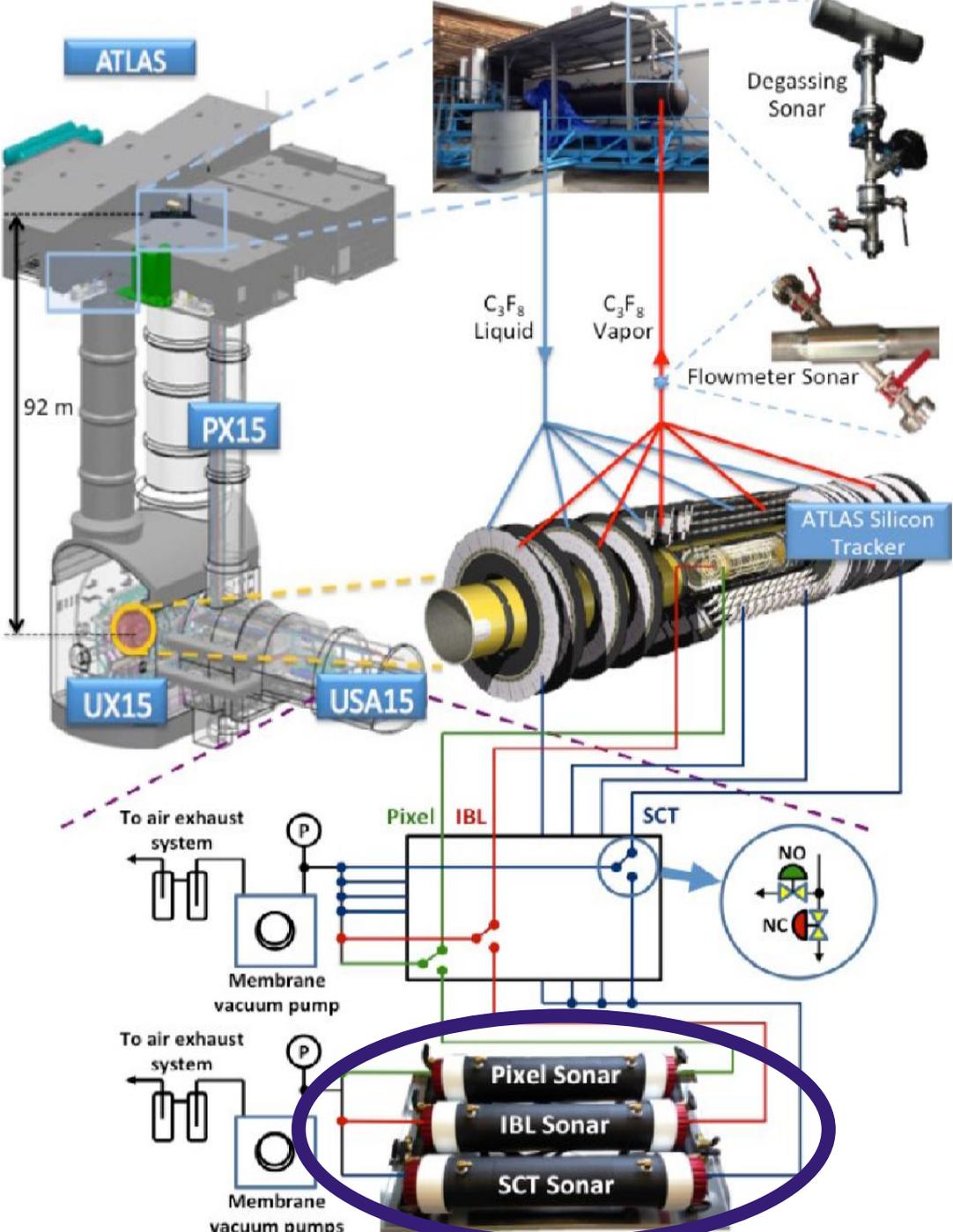
Degassing sonar  
 Measure air ingress into  
 thermosiphon circuit  
 and trigger venting

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

# Applications in ATLAS

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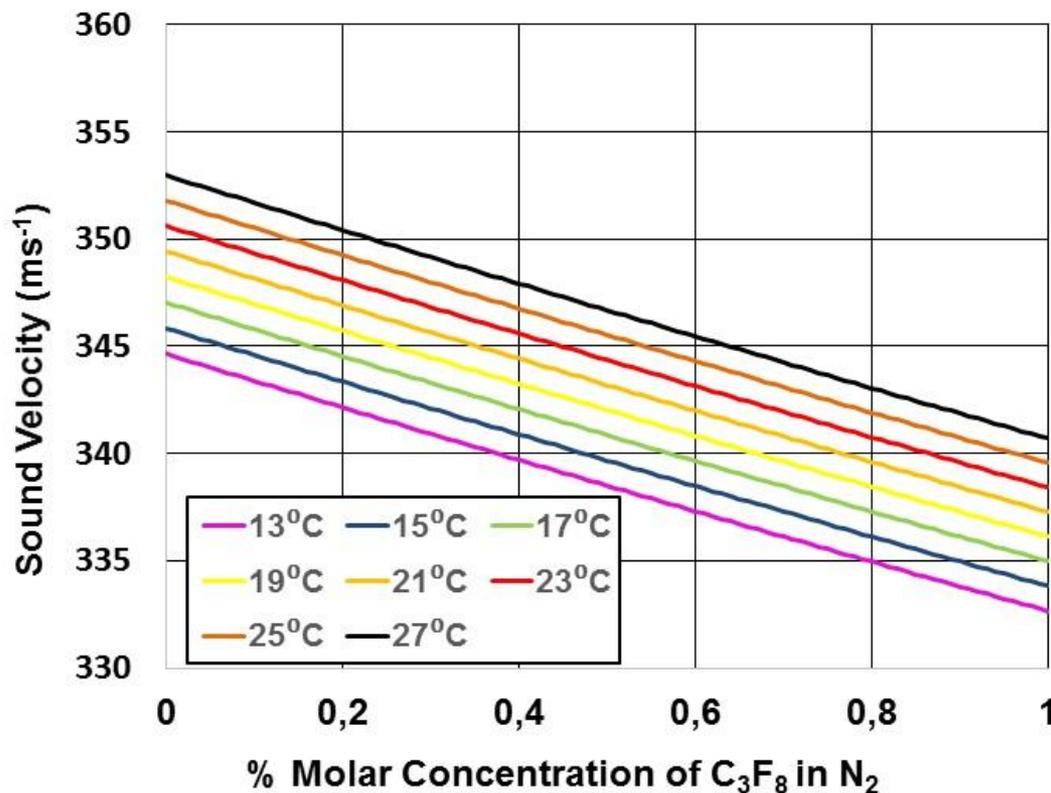
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# Measuring binary gas mixtures with sonar

Taking the **average** of the transit times  $T_{up}$  and  $T_{down}$ , and the known length of the tube, we obtain the **speed of sound** in the gas mixture, independent of flow.



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

$$M_m = \sum_i \omega_i M_i \quad \gamma_m = \frac{\sum_i \omega_i C_{p_i}}{\sum_i \omega_i C_{v_i}}$$

$\omega_i$  = molar fraction of component  $i$

$C_{p_i}$  = molar specific heat at constant pressure

$C_{v_i}$  = 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

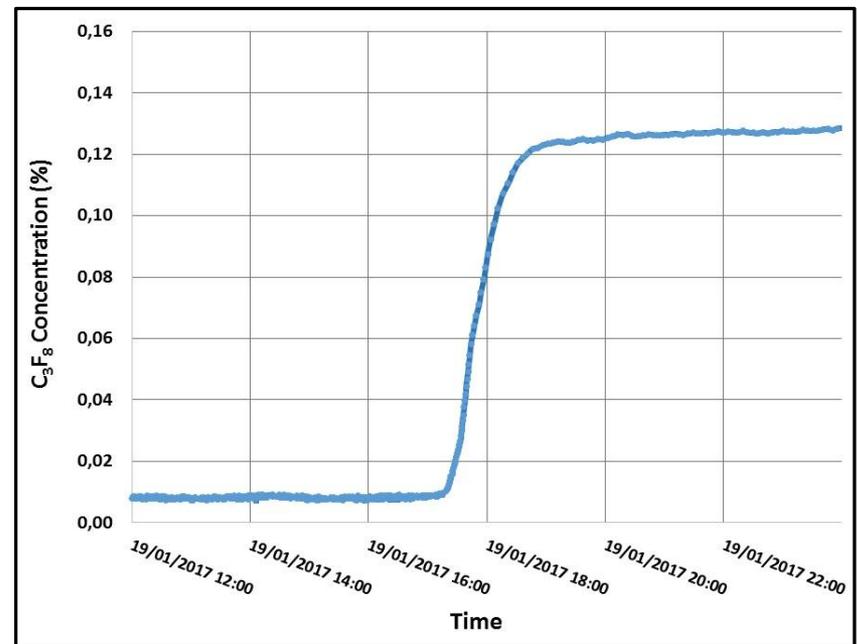
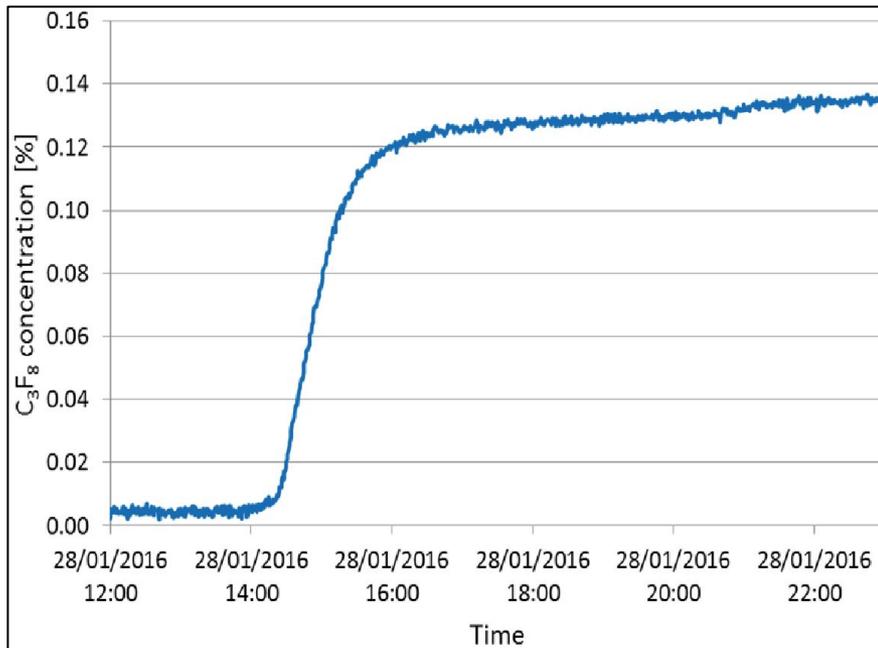
Typical **slope of the sound velocity vs C3F8/N2 concentration curve** is -12.5 m/s/%

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
<b>Total</b>	-	<b>0.025 m/s</b>

Precision on sound velocity measurement is  $\sim 0.025$  m/s  $\Rightarrow$   
 $0.025\text{m/s} / 12.5 \text{ m/s/\%} \sim \mathbf{0.002\%}$  precision on concentration.

# Pixel envelope $C_3F_8$ concentration

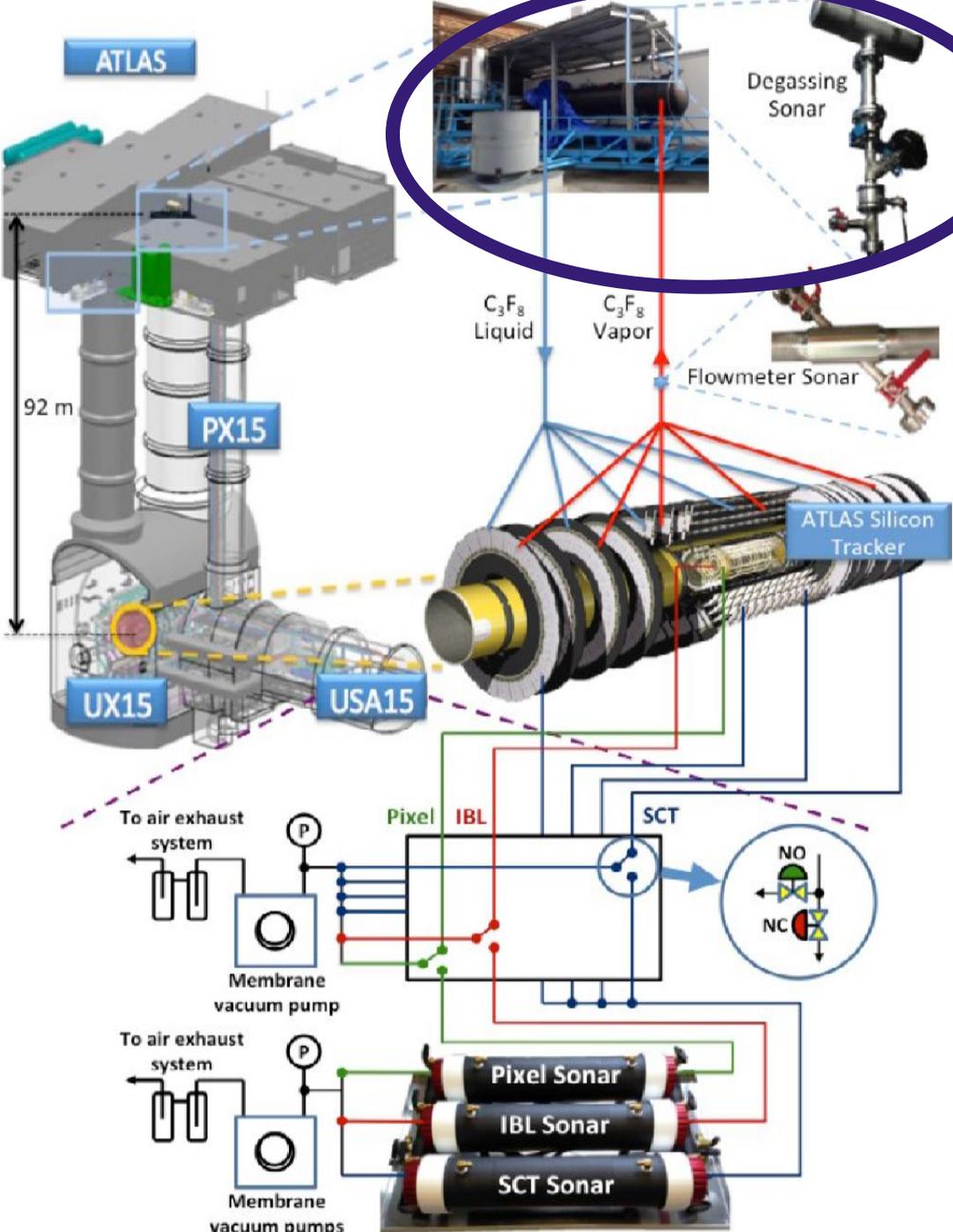
Comparing cooling start-ups January 2016 & January 2017



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

# 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.



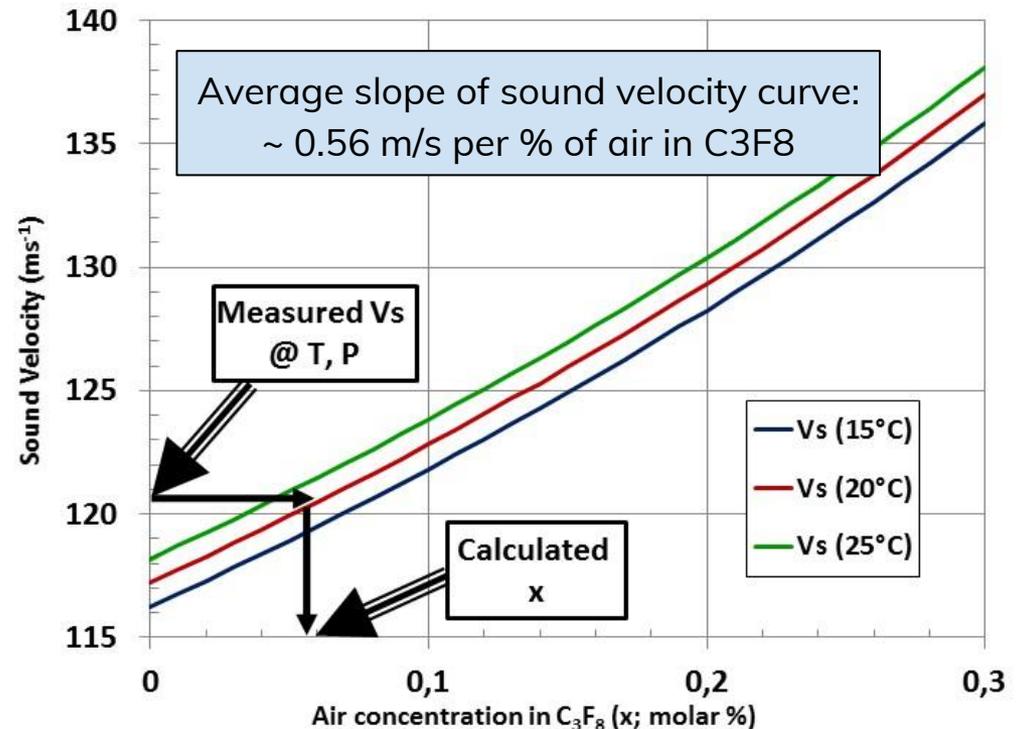
Degassing sonar  
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# Degassing sonar

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

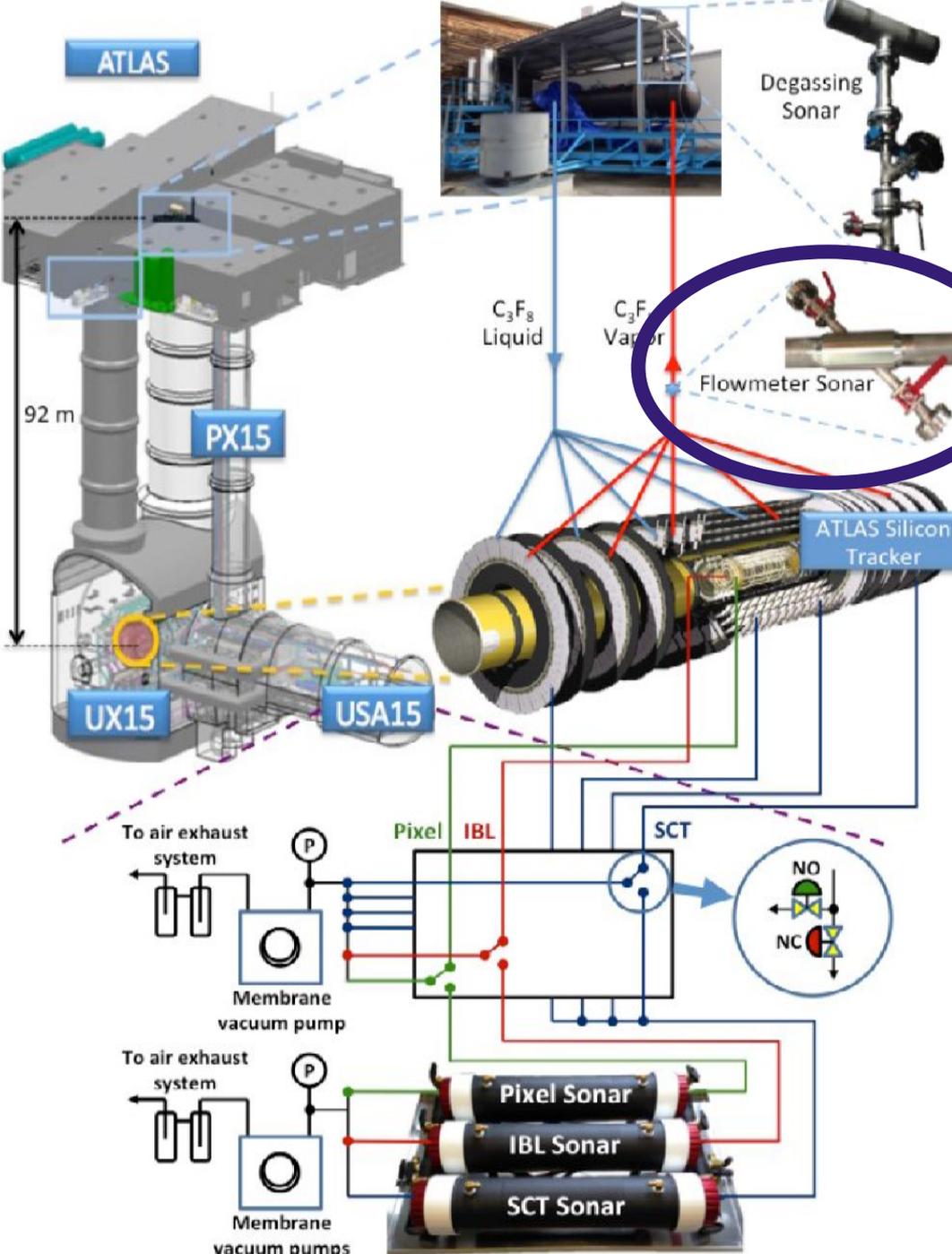


Precision on sound velocity measurement is ~0.025 m/s => 0.025m/s / 0.56 m/s/% ~ **0.05% precision** on concentration.

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.

# 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.**

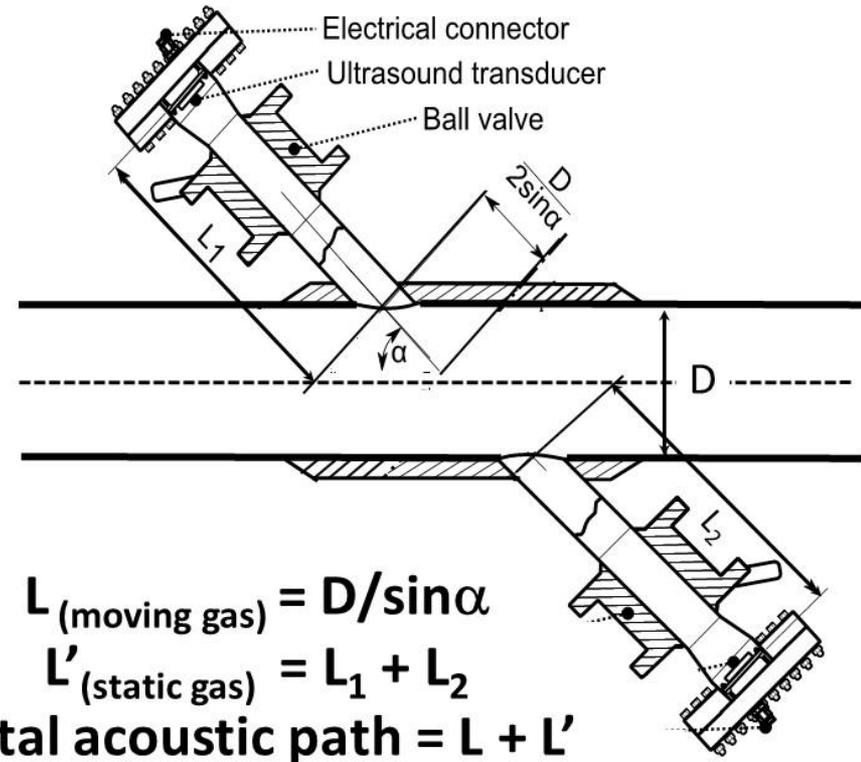
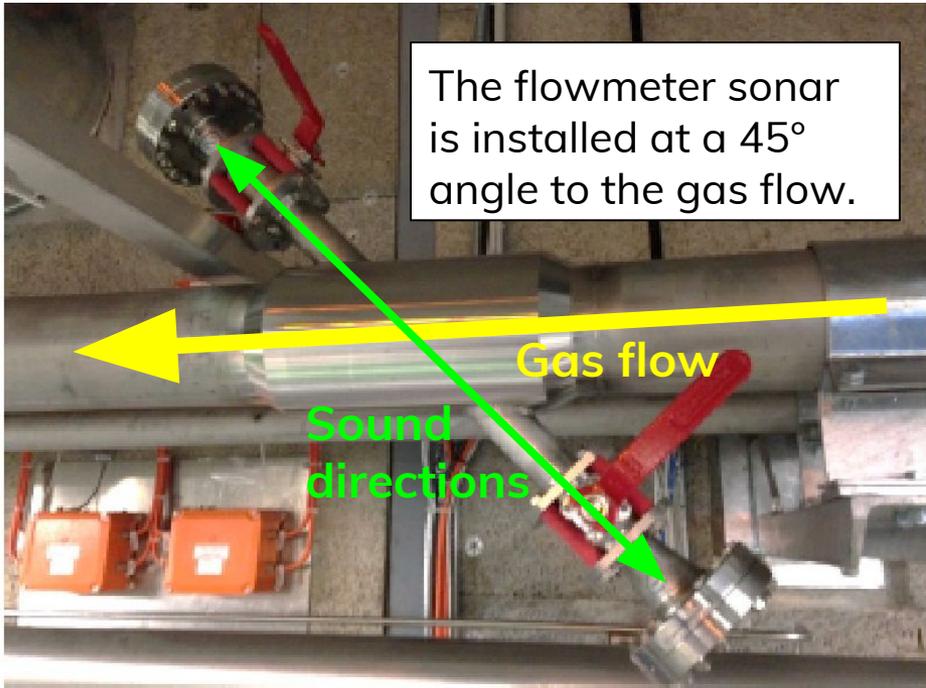


Degassing sonar  
 Measure air ingress into thermosiphon circuit and trigger venting

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

# Flowmeter



The speed of sound is:

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

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

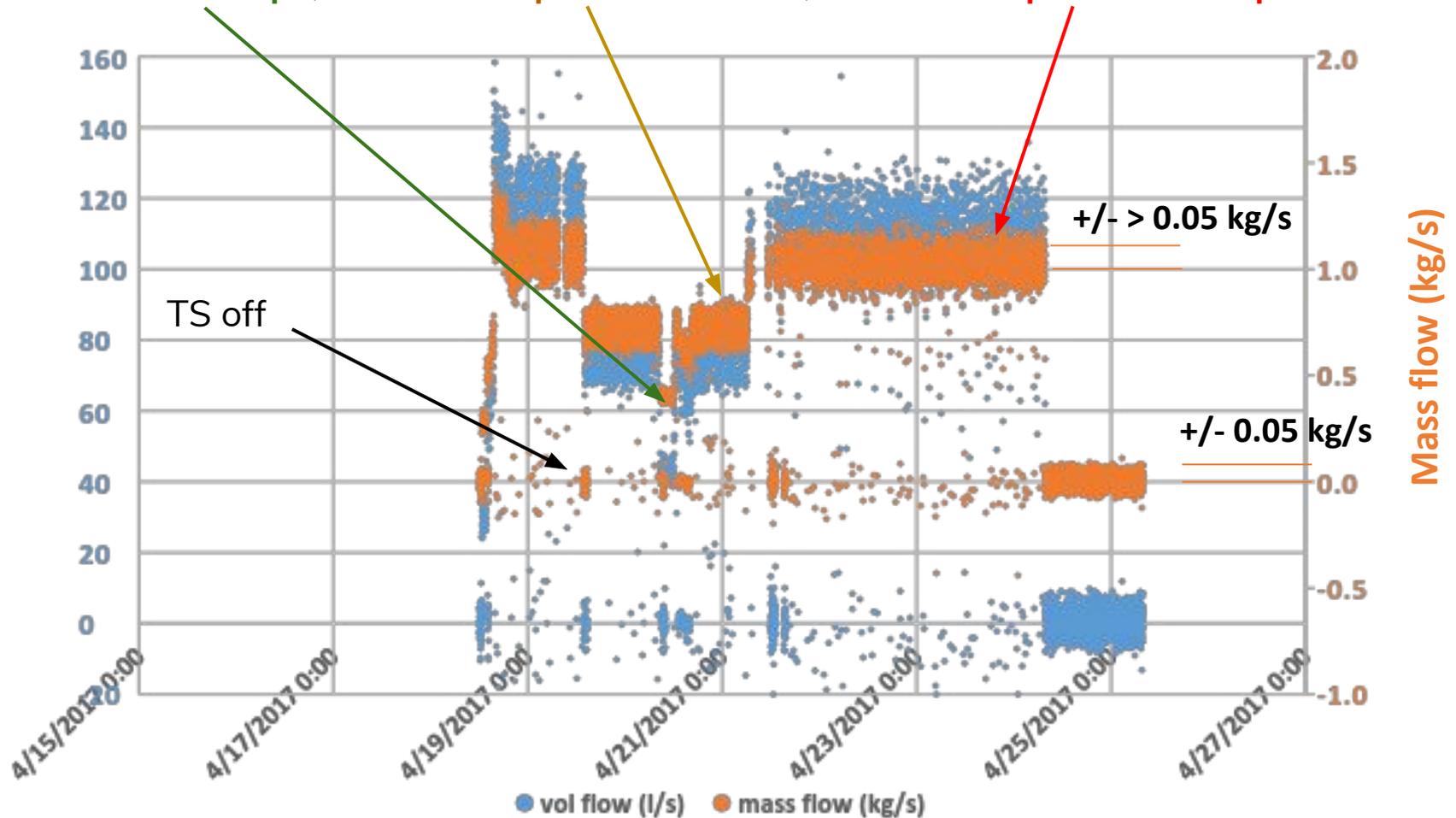
The gas flow velocity is:

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

$D_{Main}$  = 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



TS Condenser: 15m above ground level

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?**



C6F14 “Brine” Chiller circuit: Ground level

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  $0.3 \text{ ms}^{-1} \cdot \%(\text{C}_6\text{F}_{14})^{-1}$

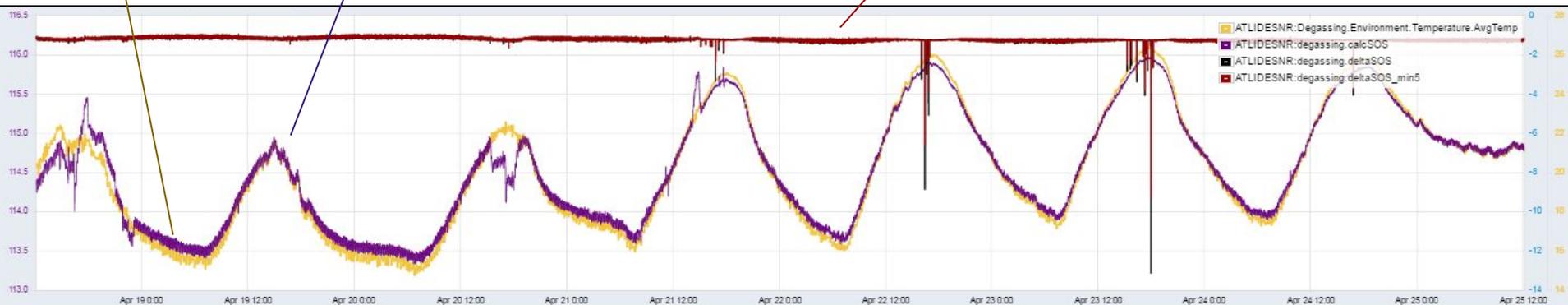
With sonar we achieve a precision of  $0.025 \text{ m}\cdot\text{s}^{-1}$

Precision in concentration could be  $(0.025/0.3)\% \rightarrow 0.075\%$

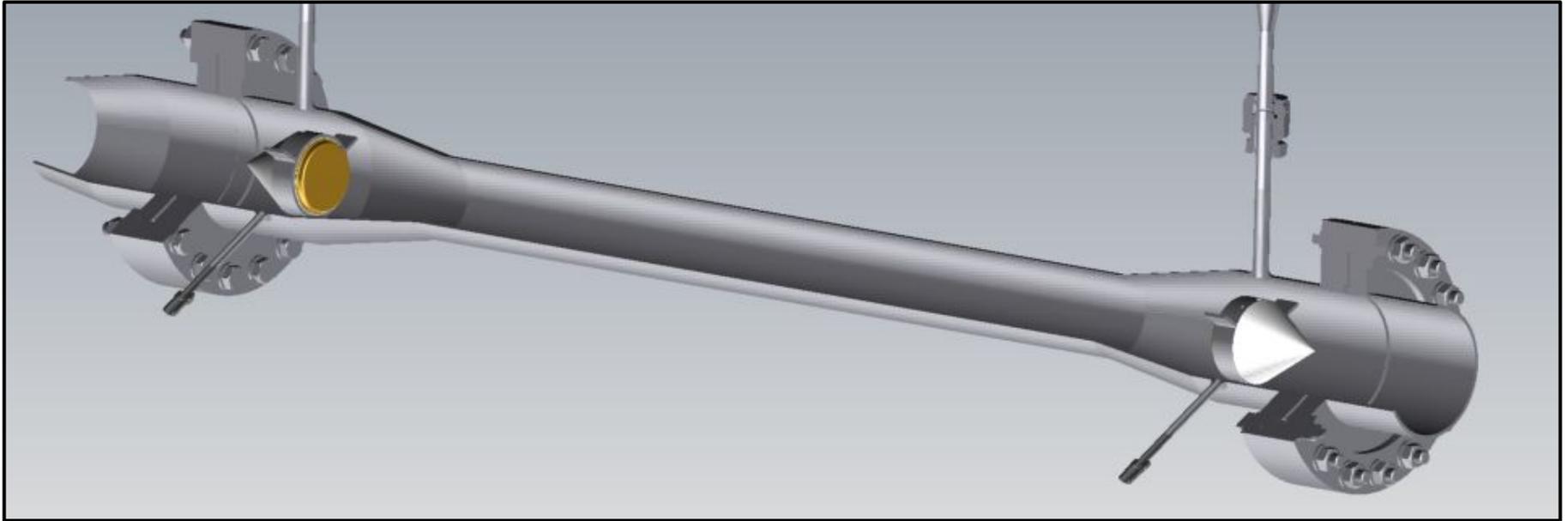
(C6F14 is the only gas around ATLAS that can make sound velocity slower in combination with C3F8)

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

Temperature      Measured speed of sound      Difference wrt prediction for pure C3F8

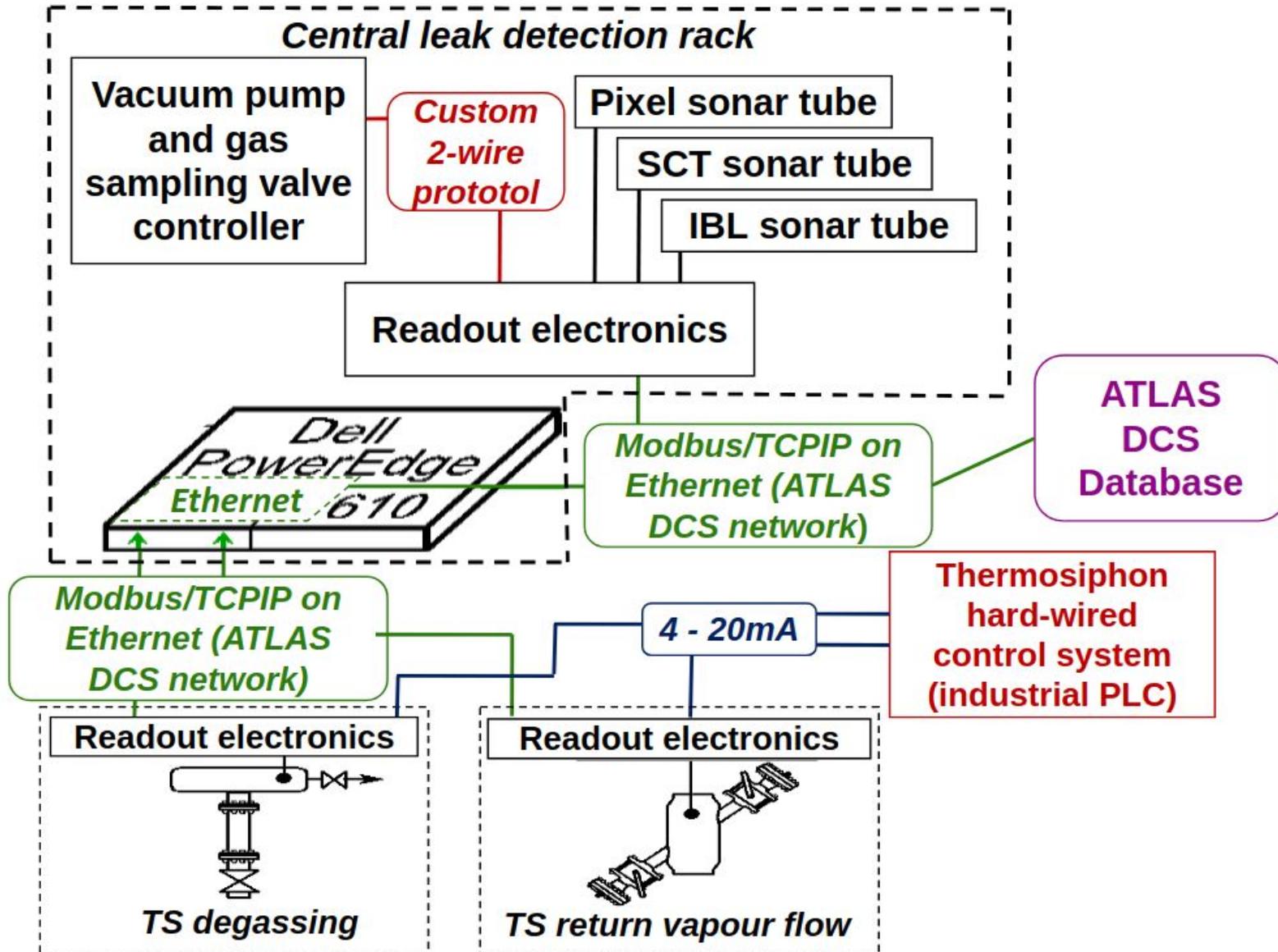


# New dedicated C6F14/C3F8 sonar



Following the successful use of the degassing sonar for this purpose, now planning to install an additional sonar (number 6 in ATLAS) dedicated to C6F14/C3F8 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**

The screenshot displays the ATLAS Detector Control System interface, divided into several key sections:

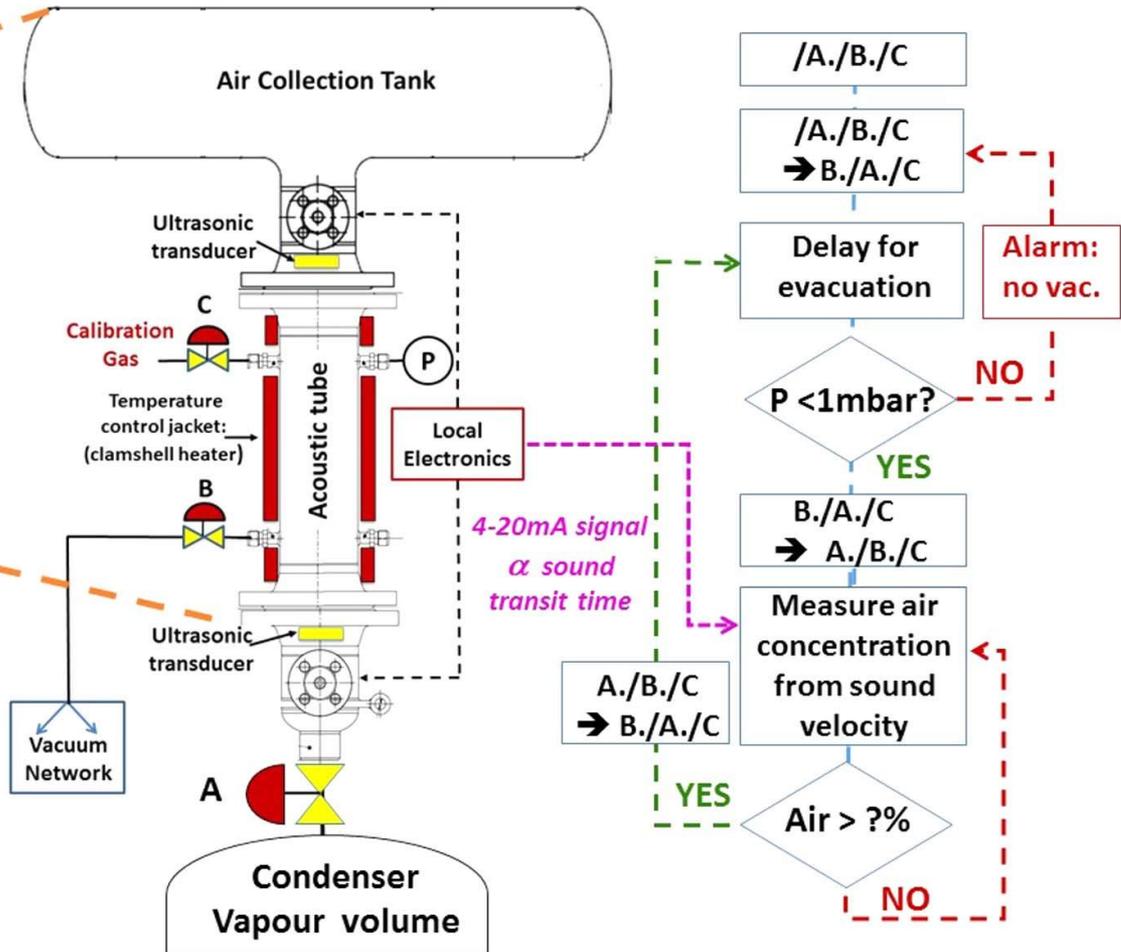
- Top Left:** System status indicators including "No Beam", "Energy: 0.2 GeV", "Injection Permit N", "AS is beam-safe N", "able Beams Flag N", and "Handshake".
- Top Right:** "Predictions" panel showing "Predicted concentration" for C3F8 (0.0 to 0.01 N2) and "Environment predictions" for Temperature (23.760 °C), Flow (0.00), Pressure (0.973 bar), and Sound velocity (350.204 m/s).
- Bottom Right:** "Sonar Tube" diagram with parameters: "Transit time up: 1424150 ns", "Length: 498.619 mm", "Transit time down: 1423440 ns", and "Flow area [m^2]: 0.0000000000".
- Center:** "Gas flow layout" diagram showing a network of pipes and valves labeled AA through GG, with "Alarms off" status.
- Bottom Left:** "IDE" (Instrumentation Data Entry) table showing the status of various systems (FYCOOL, ENV, TEH, RAD, BCM, BLM).
- Bottom Center:** "AIR VENT" section with valves labeled PIX SNR, IBL SNR, and SCT SNR, and their respective "Alarms" status.
- Bottom Right:** "PIX" section with valves labeled N2CalPix, N2CalIBL, and N2CalSCT.
- Legend:** Symbols for "State" (blue circle), "Target state" (green circle), "Pump" (blue circle with arrow), and "Value" (green circle with arrow).
- Footnote:** "S: MAIN valves", "Cal: CALIBRATION VALVES", "XXXX: mutually exclusive MEASUREMENT valves".

# Summary

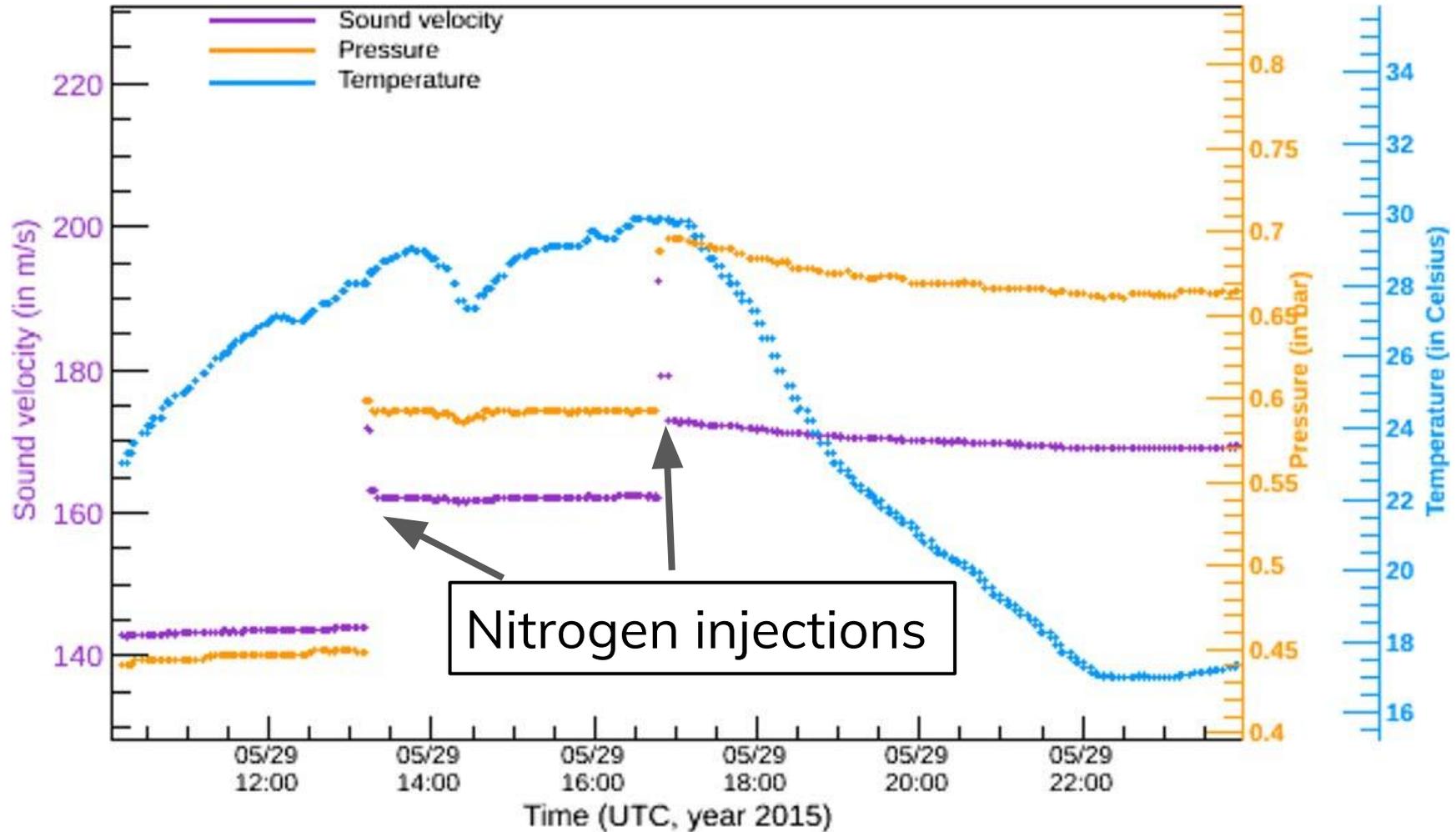
- Custom ultrasonic “sonar” instruments are used in ATLAS for continuous analysis of binary gas mixtures and flow.
- Monitoring of coolant leaks into Pixel, IBL and SCT detector envelopes (C3F8/N2 fraction with 0.002% precision).
- Monitoring of gas flow and air accumulation in the Thermosiphon. New instrument to measure C6F14 in C3F8 to be installed.

**BONUS**

# Degassing sonar & air venting mechanism



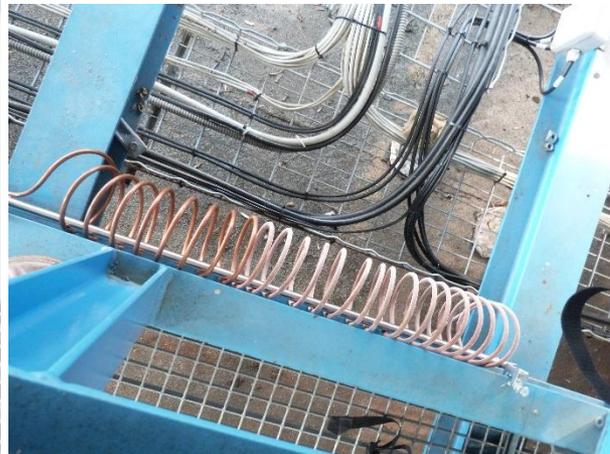
# Degassing sonar tests



# C3F8 descendant liquid extraction & injection into degassing sonar



Extraction (roof level)

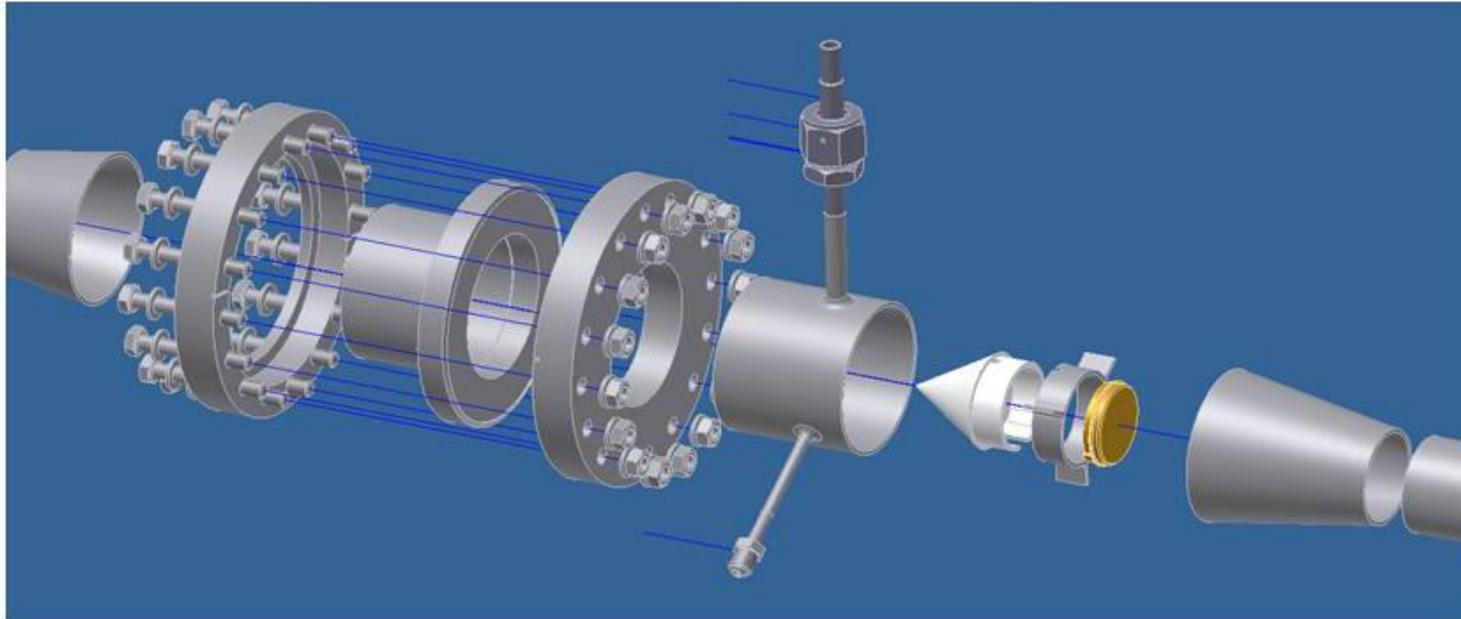
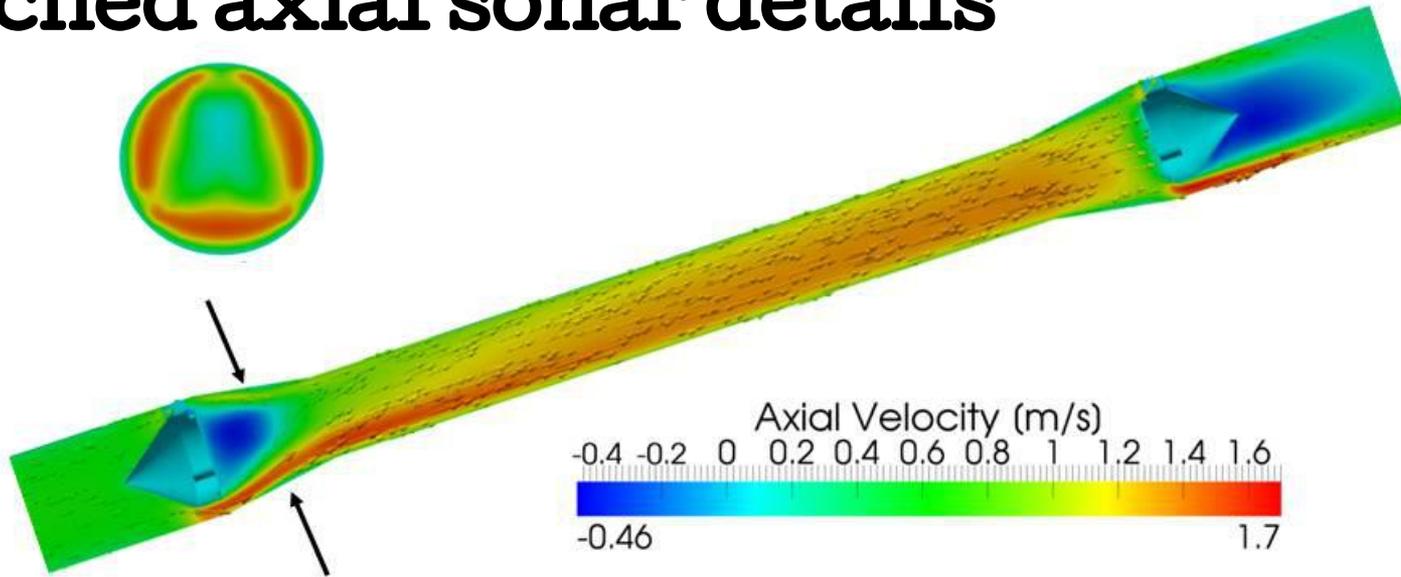


Evaporation (roof level)

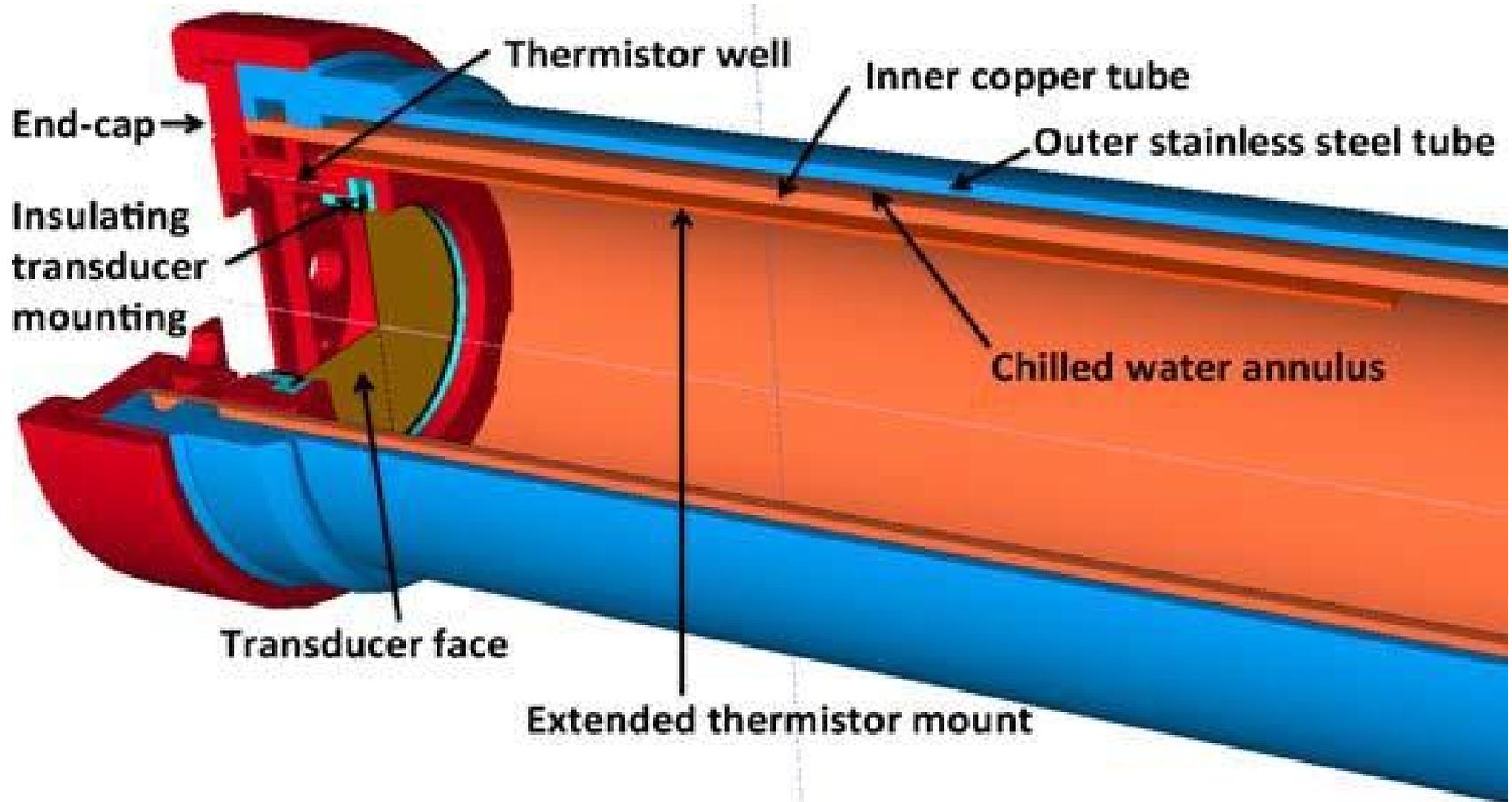


Reinjection (roof level)

# Pinched axial sonar details



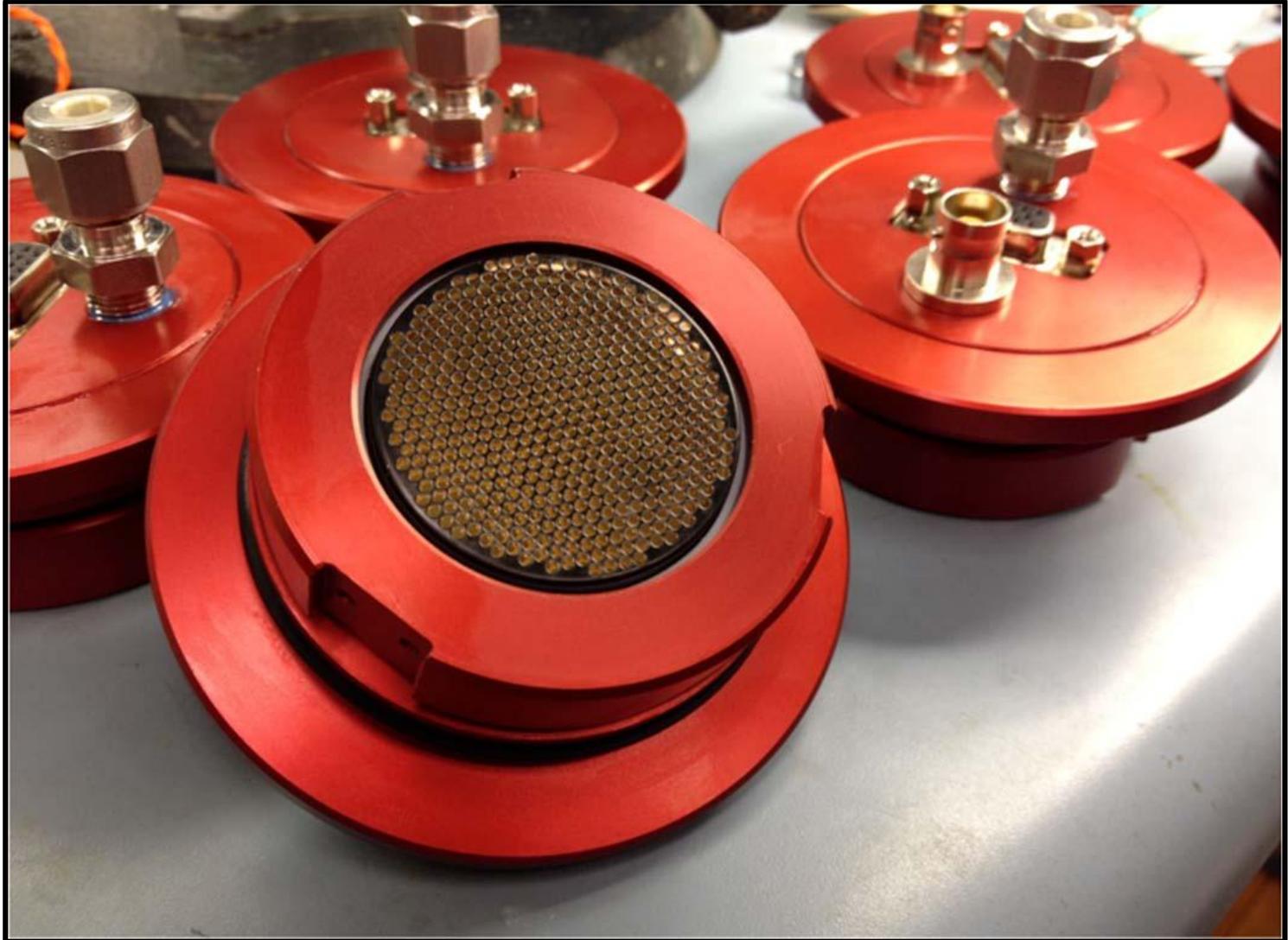
# Aspirating sonar details



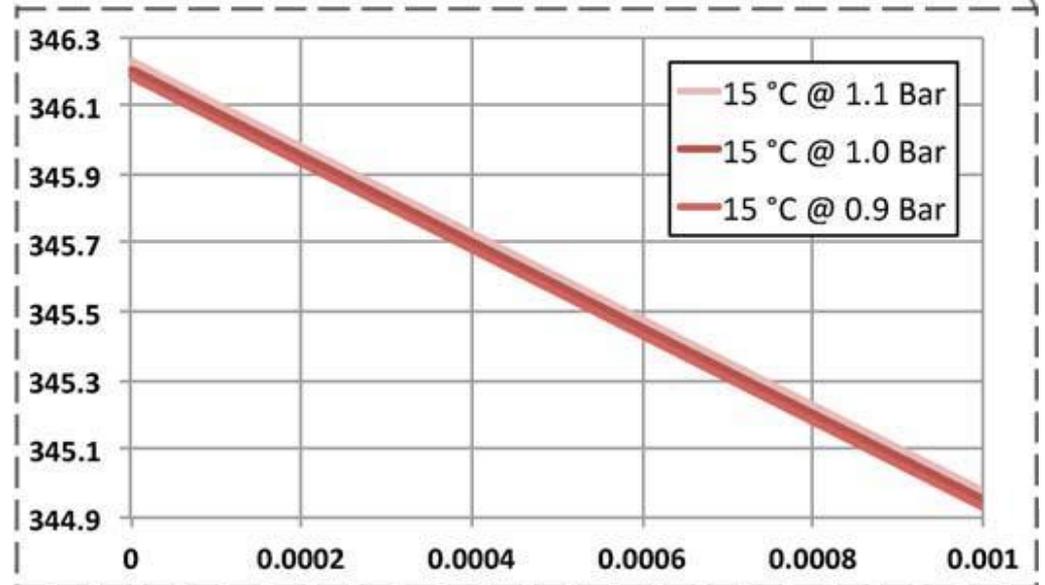
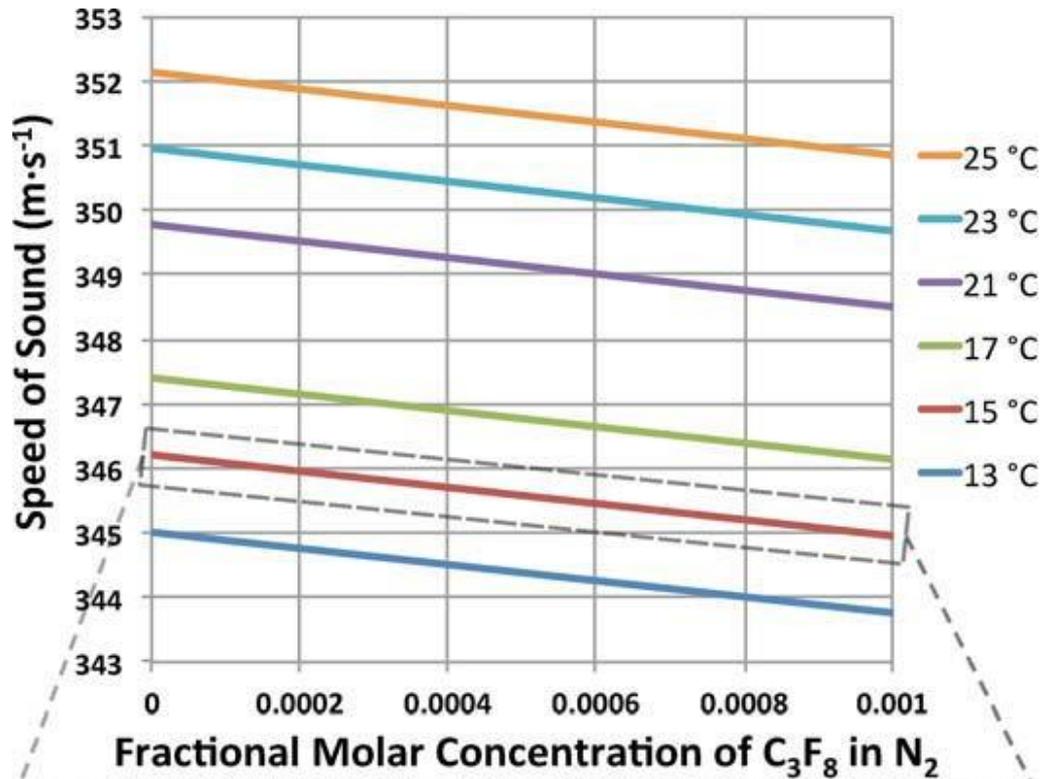
# IBL, Pixel and SCT sonar tubes



# Aspirating sonar end flanges



# Temperature vs pressure Effect on the speed of sound



# % C<sub>3</sub>F<sub>8</sub> in SCT barrel & end-caps envelopes

