



ACCORD

Determining flare gas composition without a sampler

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Agenda



Agenda



Agenda

ECO2



Agenda

ECO2

Sampling issues



Agenda

ECO2

Sampling issues

SOS



Agenda

ECO2

Sampling issues

SOS

CHARM



Agenda

ECO2

Sampling issues

SOS

CHARM

Data rec.



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ECO2

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Data rec.

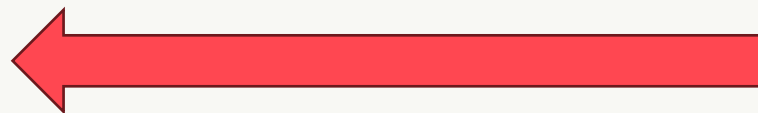
Fourier



Flare Composition Measurement

For emissions reporting need to calculate ECO2 emissions factor

Require a representative composition of the flare gas at this point



Flare stack

Flare header

M

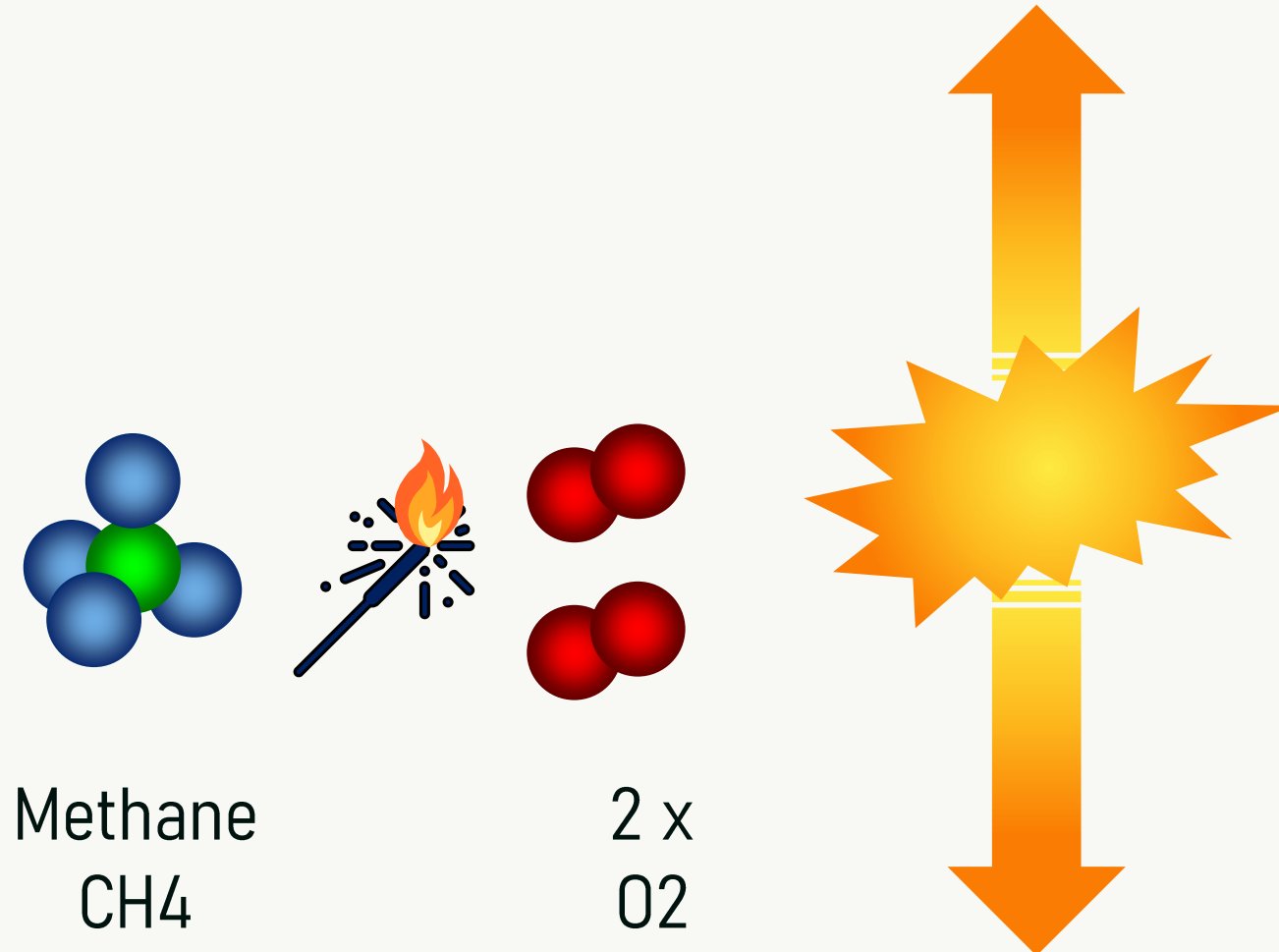
S

Flare Knock Out Drum

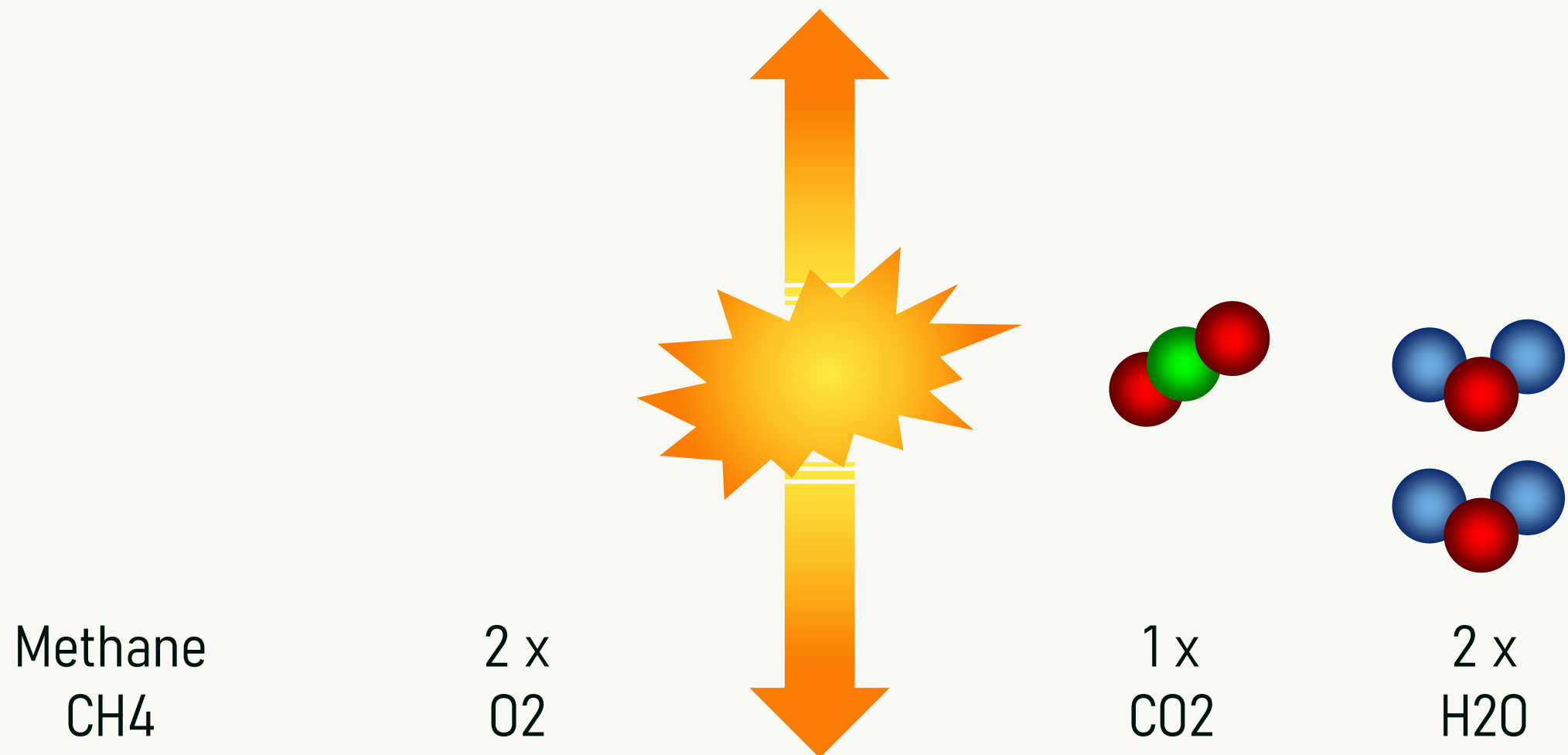
Sample Continuous?
Intermittent?



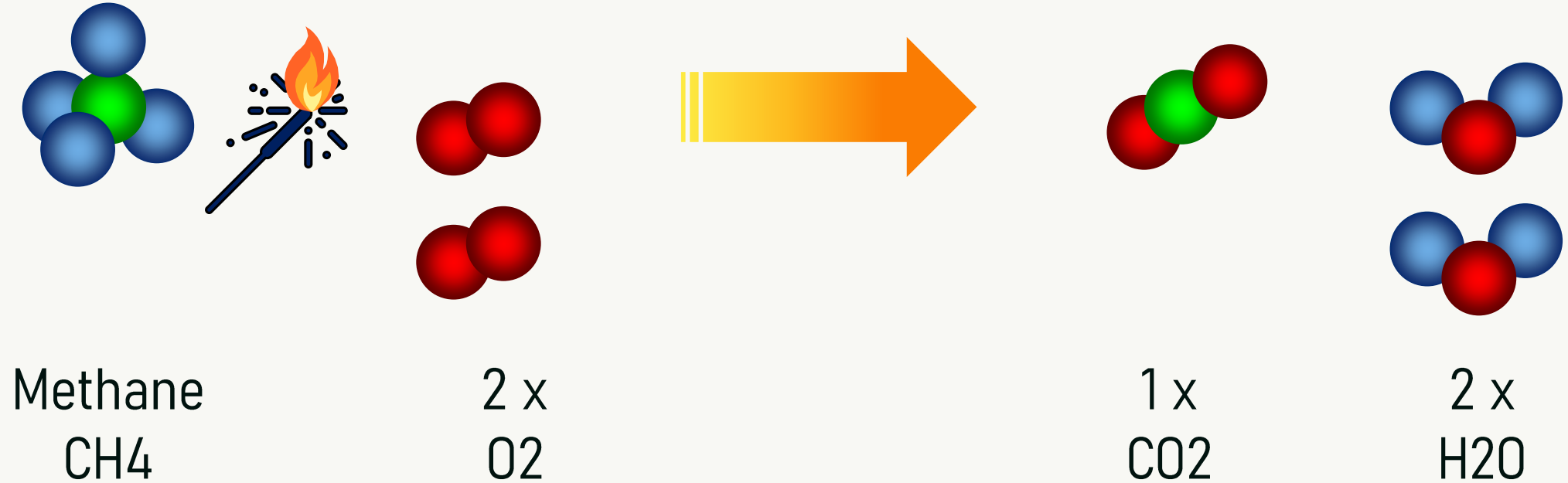
CO2 Emissions Factor (ECO2)



CO2 Emissions Factor (ECO2)

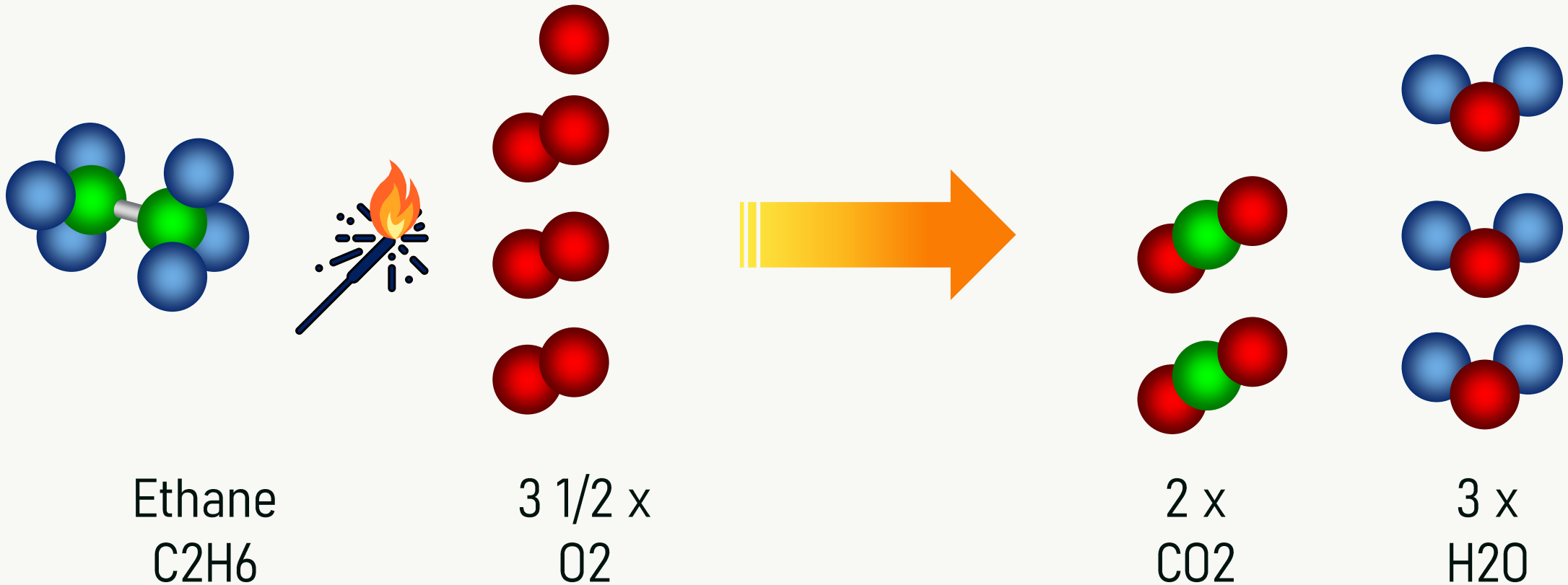


CO2 Emissions Factor (ECO2)



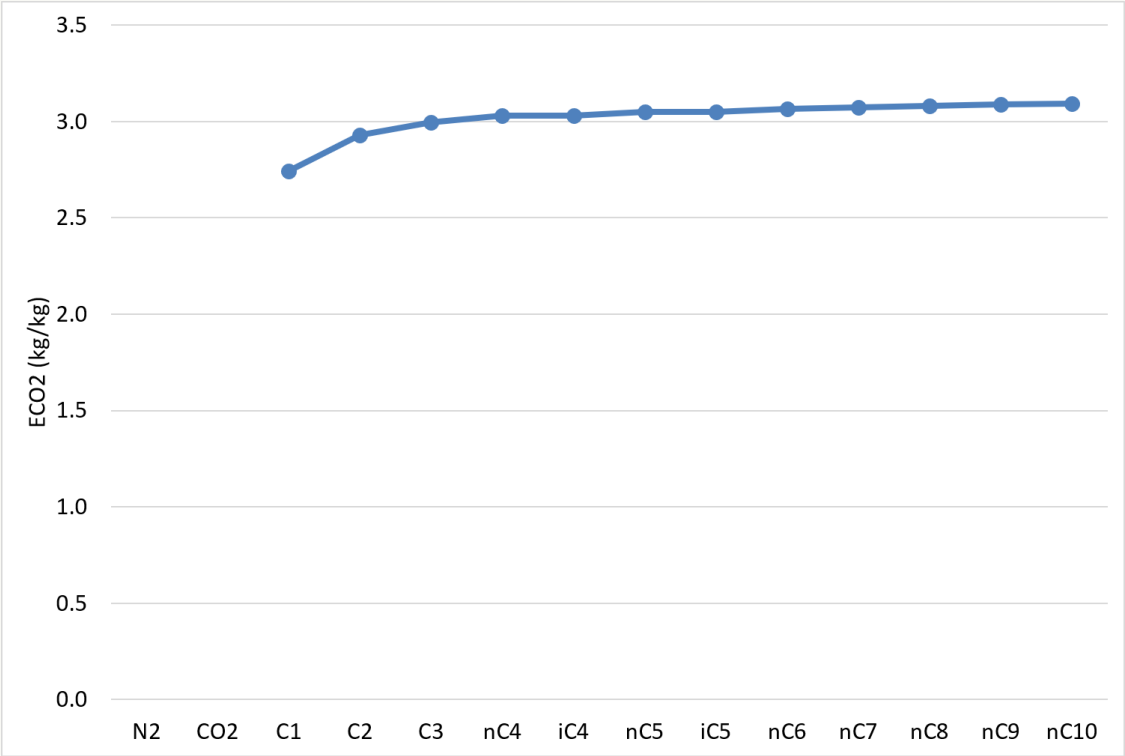
Moles of flare gas	1	kmol
Mass of flare gas		kg
Moles of CO ₂ produced		kmol
Mass of CO ₂ produced		kg
EC _{CO2}		kg/kg
EC _{CO2}		t/Nm ³

CO₂ Emissions Factor (EC_{CO2})



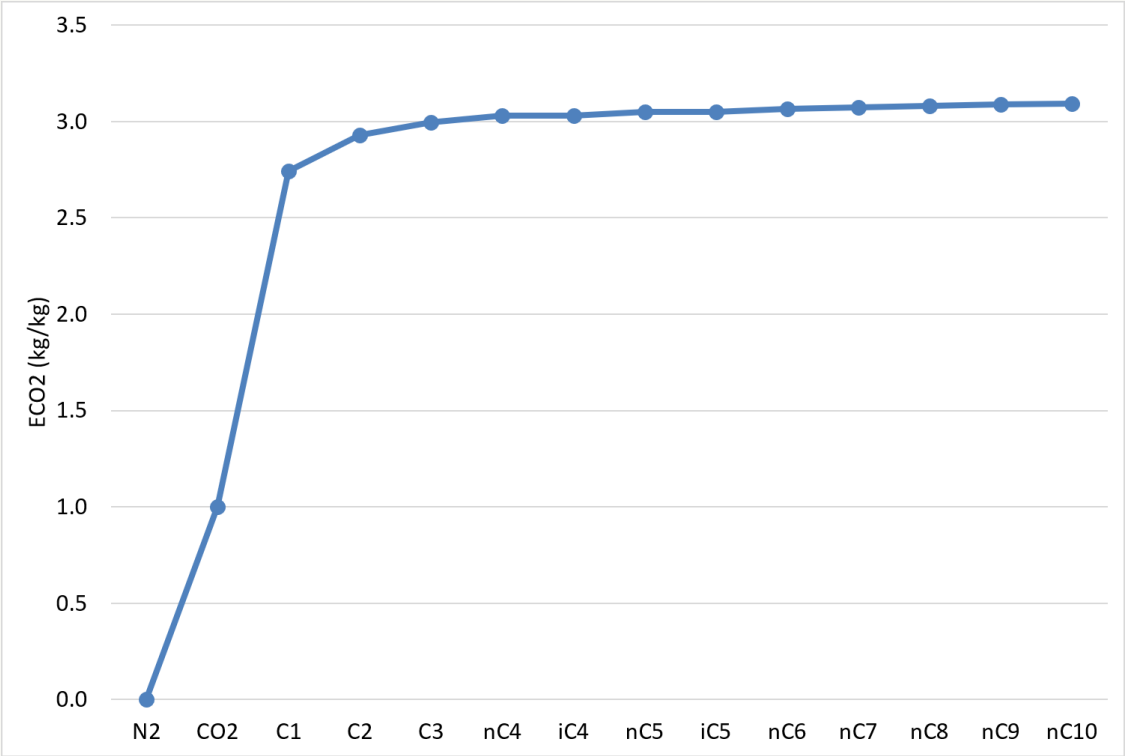
Component	Weight %	ECO2 (kg/kg)
C1	70%	2.74
C2	20%	2.93
C3	10%	2.99
Total	100%	2.81

CO2 Emissions Factor (ECO2)



Component	Weight %	ECO2 (kg/kg)
C1	66%	2.74
C2	19%	2.93
C3	9%	2.99
CO2	5%	1.00
N2	1%	0.00
Total	100%	2.70

CO2 Emissions Factor (ECO2)



Flare Composition Measurement

For emissions reporting need to calculate ECO2 emissions factor

Require a representative composition of the flare gas at this point



Flare stack

Flare header

Flare Knock Out Drum

M

S

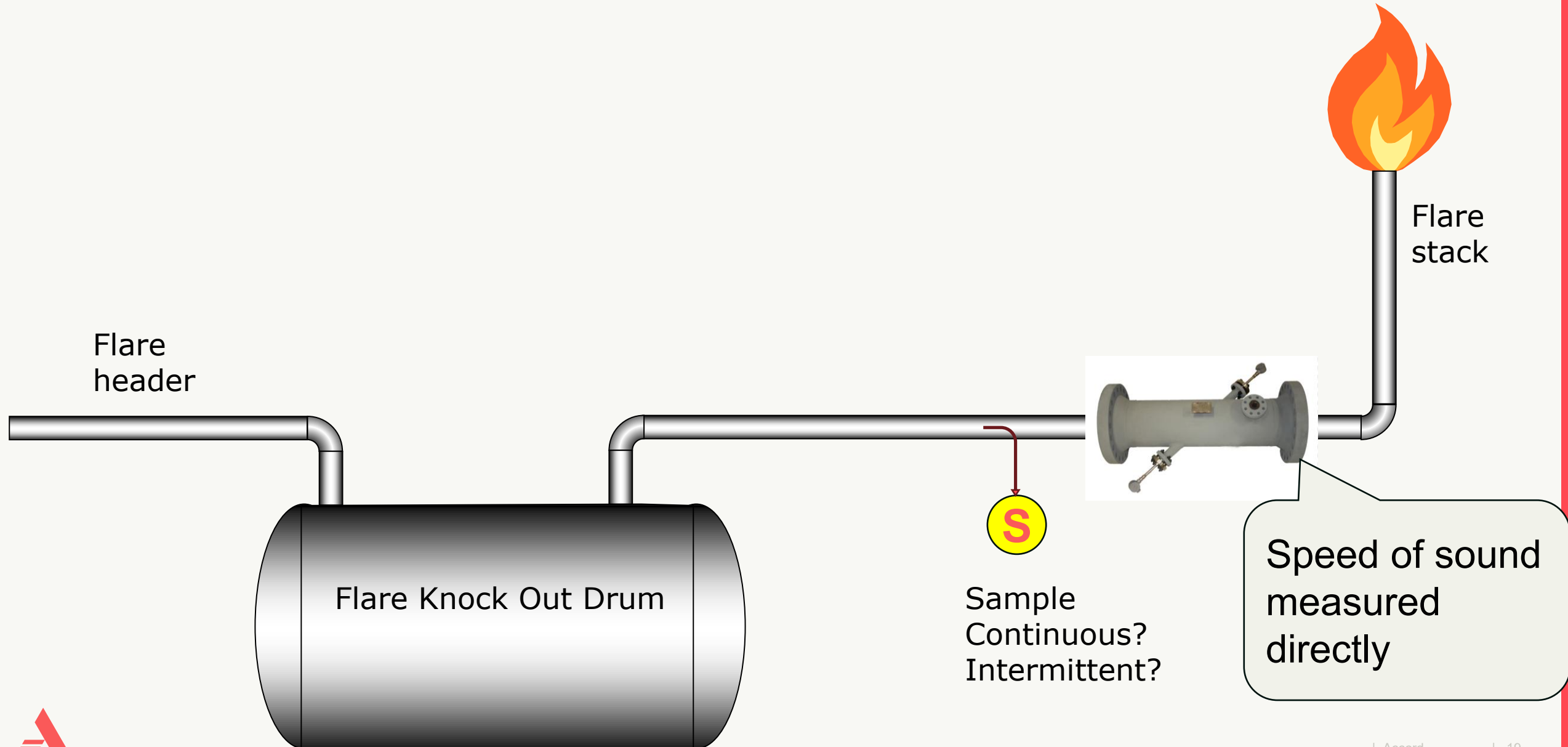
Sample Continuous?
Intermittent?

Can we check the composition?





Flare Composition Measurement



Ideal
Gas

$$SOS = \sqrt{\frac{\gamma RT}{MW}}$$

Ideal
Gas

$$\gamma = \frac{C_p}{(C_p - R)}$$

$$SOS = \sqrt{\frac{\gamma RT}{MW}}$$



Ideal
Gas

$$SOS = \sqrt{\frac{\gamma RT}{MW} \frac{C_p}{(C_p - R)}}$$

Ideal
Gas

$$SOS = \sqrt{\frac{RT \sum_i C_{p_i} x_i}{MW (\sum_i C_{p_i} x_i - R)}}$$

Ideal Gas

$$SOS = \sqrt{\frac{RT \sum_i C_{p_i} x_i}{\sum_i x_i MW_i (\sum_i C_{p_i} x_i - R)}}$$

Ideal
Gas

SOS is related to
composition x_i

True for a real gas.
SOS calculated using
AGA8 or GERG

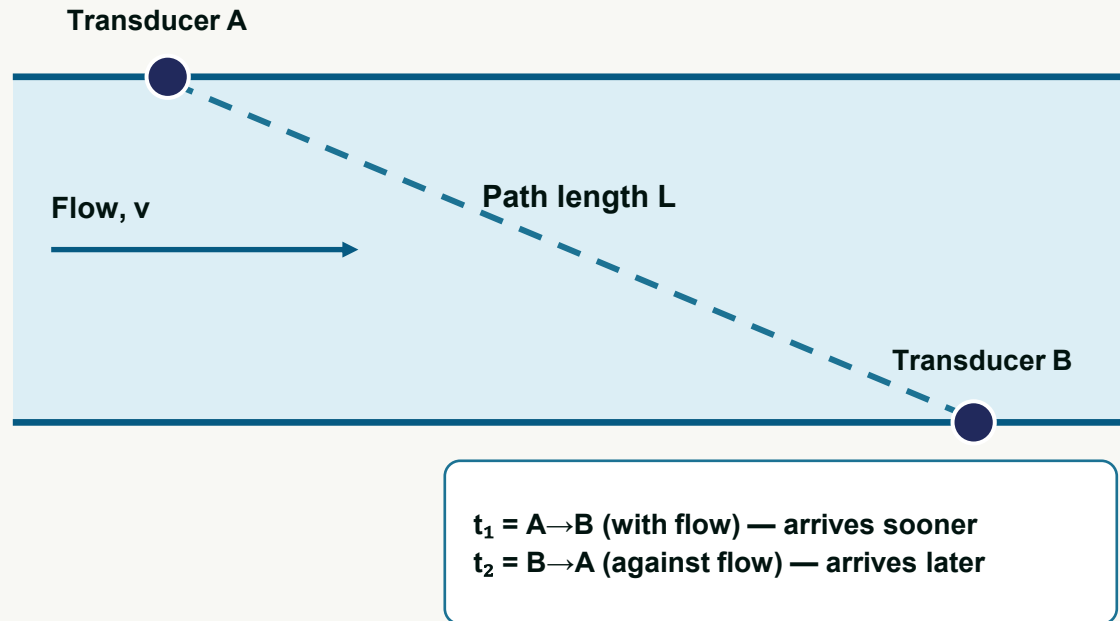
$$SOS = \sqrt{\frac{RT \sum_i C_{p_i} x_i}{\sum_i x_i MW_i (\sum_i C_{p_i} x_i - R)}}$$

Able Instruments



Why Ultrasonic Speed-of-Sound Measurement Is So Accurate

A transit-time meter derives both flow velocity and speed of sound (SOS) from the same two pulses — but SOS is built from the sum of the transit times, so the flow-dependent error term cancels out.



1

Fixed, calibrated path length

Transducer spacing L is set mechanically and calibrated once — it doesn't drift with flow rate, pressure or velocity profile.

2

The flow term cancels out

$c = L/2 \times (1/t_1 + 1/t_2)$. SOS uses the SUM of the two transit times, so the velocity-dependent term in each path algebraically drops out.

3

Sub-nanosecond timing resolution

Digital correlation of the received waveform locates pulse arrival to a fraction of a nanosecond, against a microsecond-scale transit time.

4

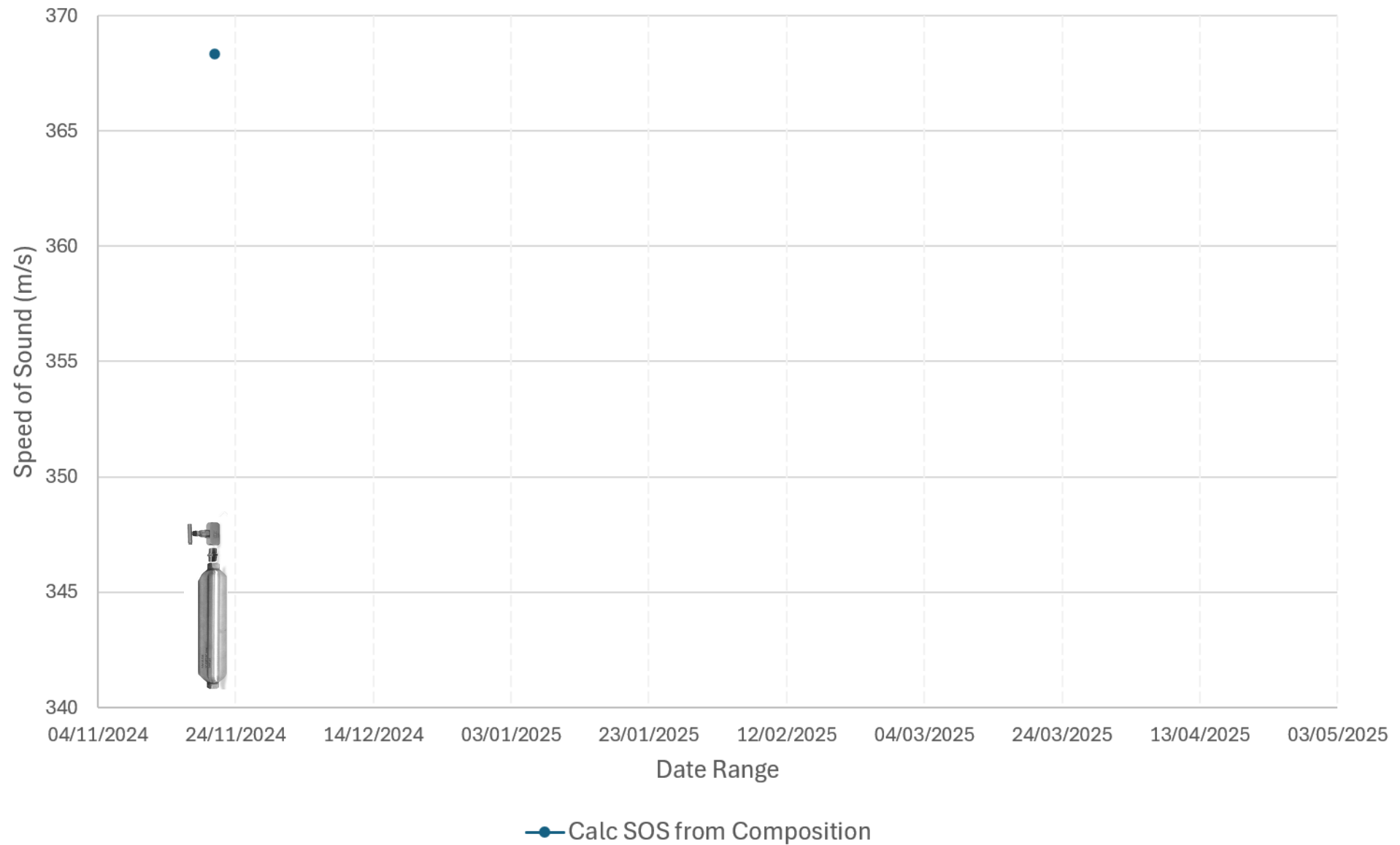
Accurate measurement

Typical uncertainty $\pm 0.2\%$

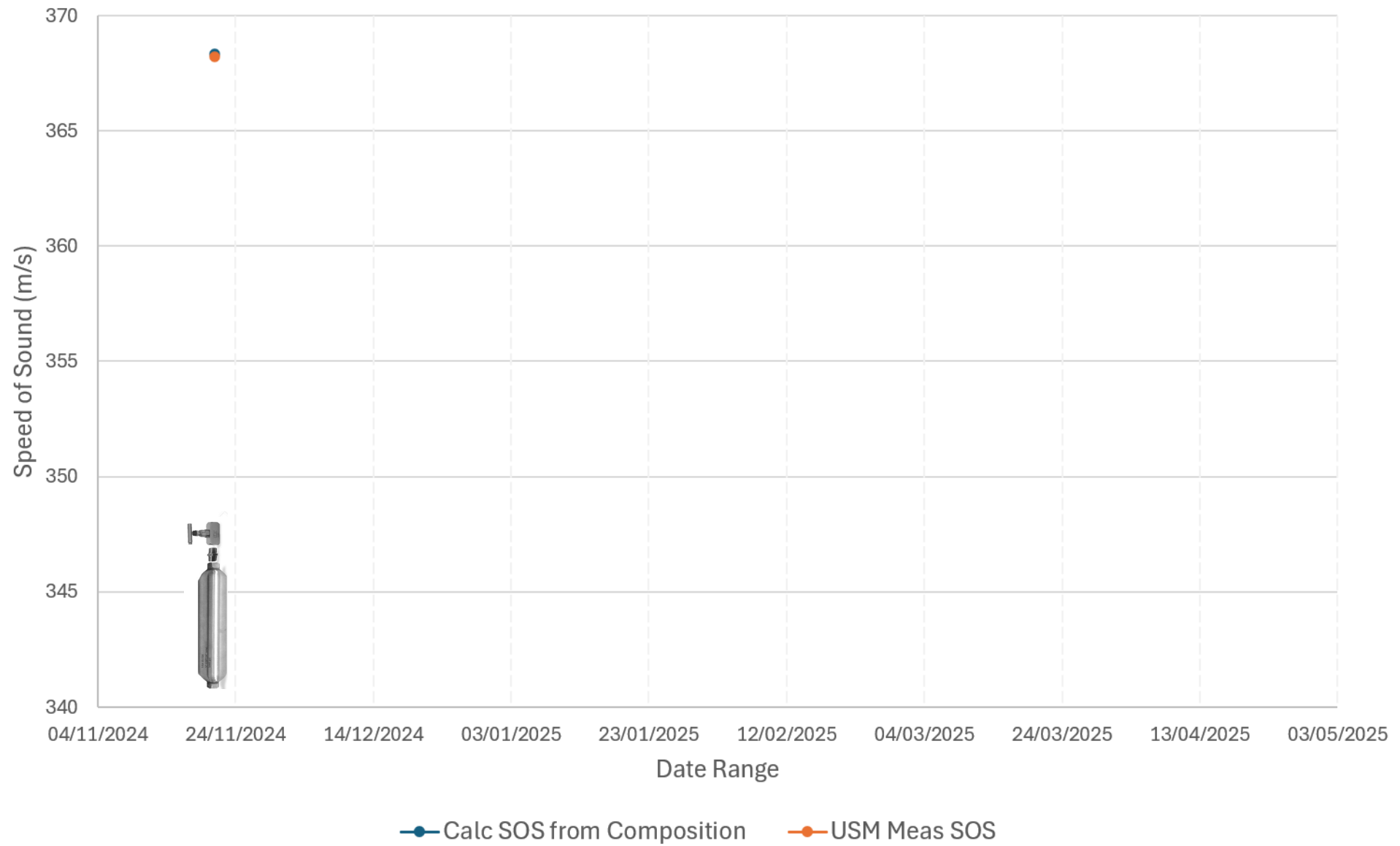
$$c = L/2 \times (1/t_1 + 1/t_2)$$

SOS depends only on the SUM of the transit times — the same flow-dependent term that must be subtracted out for velocity never enters the SOS result.

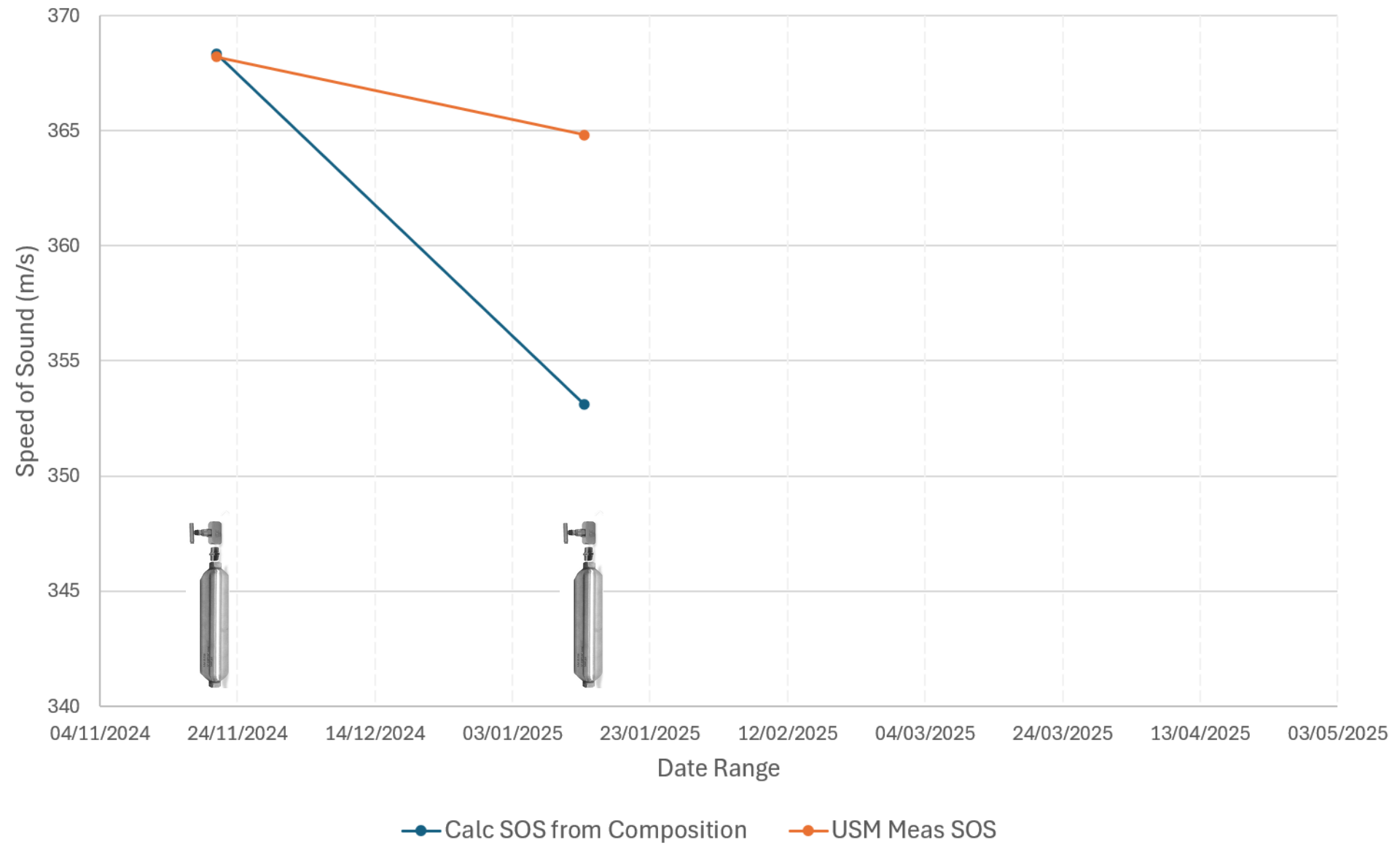
Calculated SOS - Sampled Composition vs USM Measured



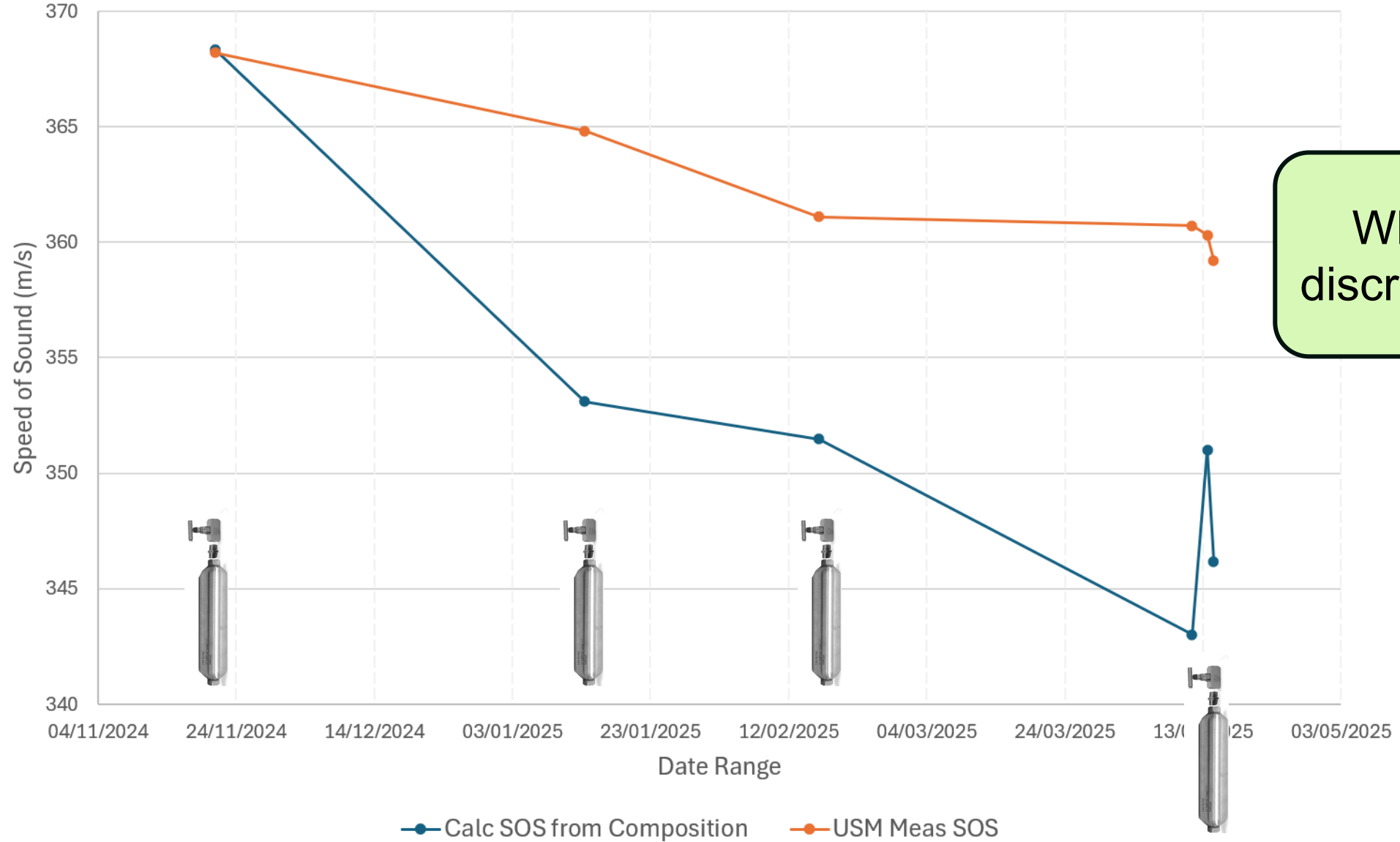
Calculated SOS - Sampled Composition vs USM Measured



Calculated SOS - Sampled Composition vs USM Measured



Calculated SOS - Sampled Composition vs USM Measured



Why the discrepancy?



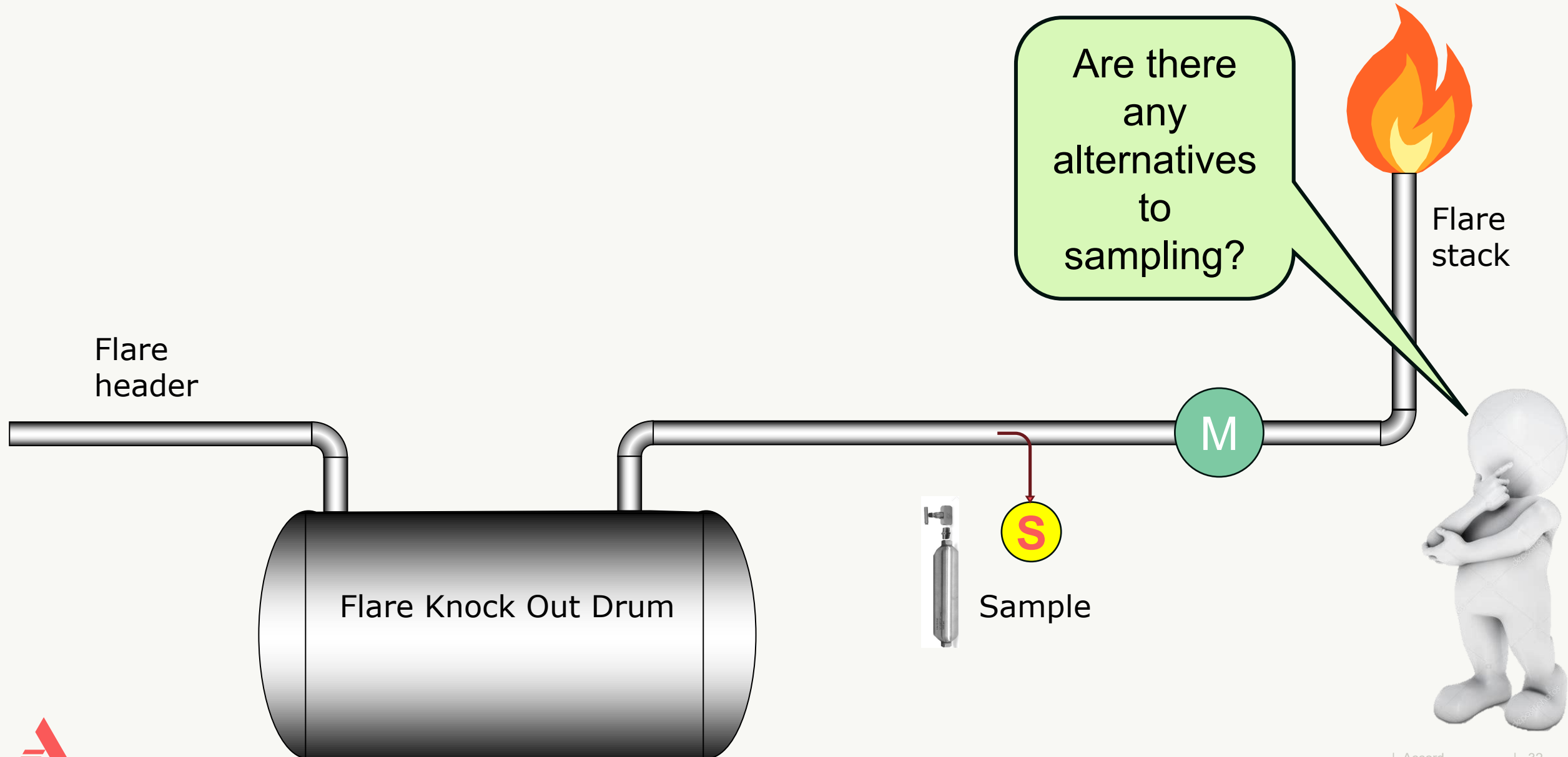
Sampling issues with Sampling

- ☐ Sample point location may be less than ideal
- ☐ No dedicated sample quill or sample equipment installed



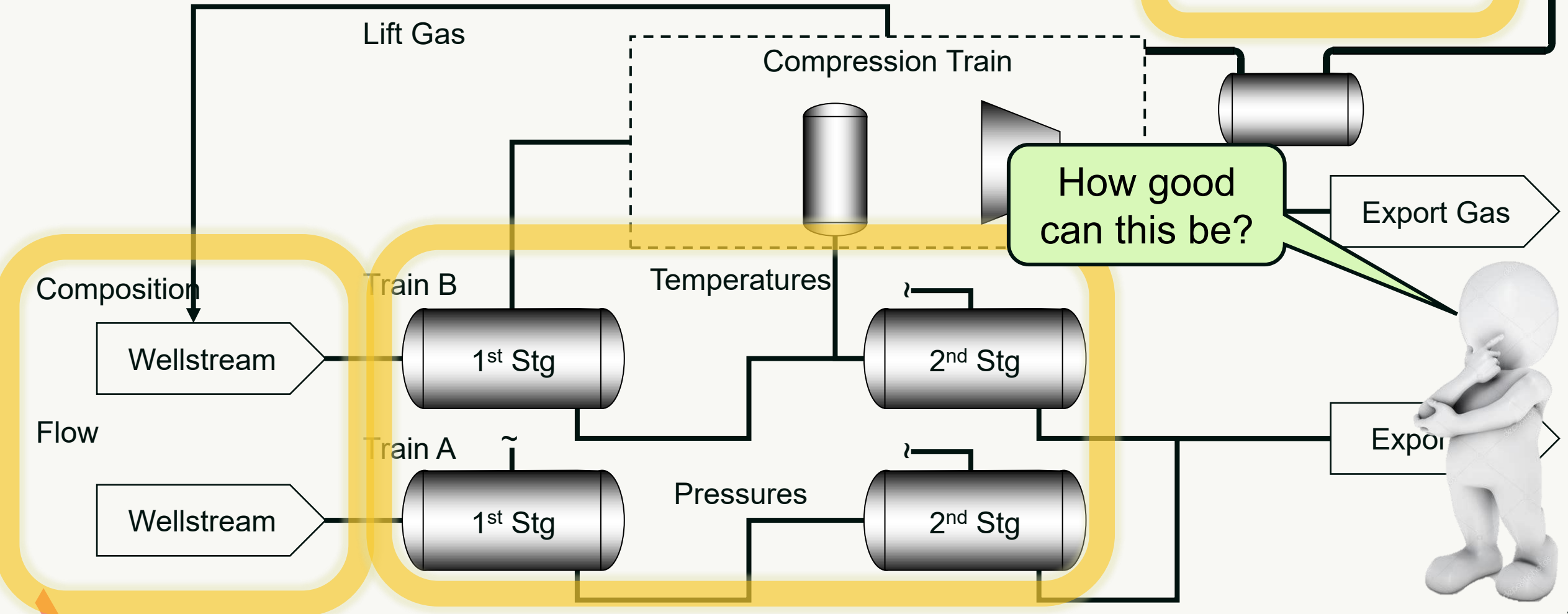
- ☐ Low process pressure in the flare gas system
- ☐ The presence of liquids or other contaminants at the sample location

Flare Composition Measurement

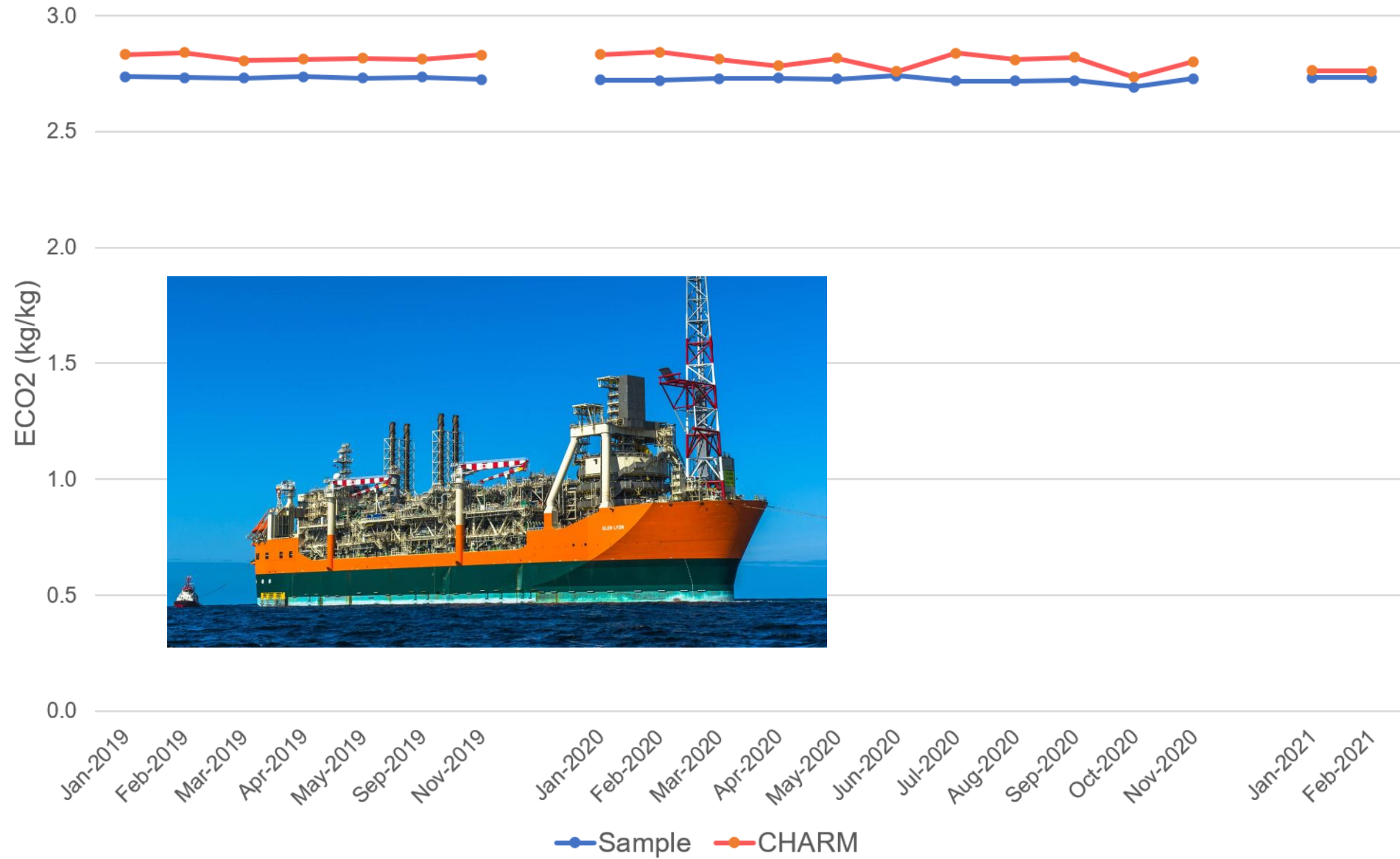


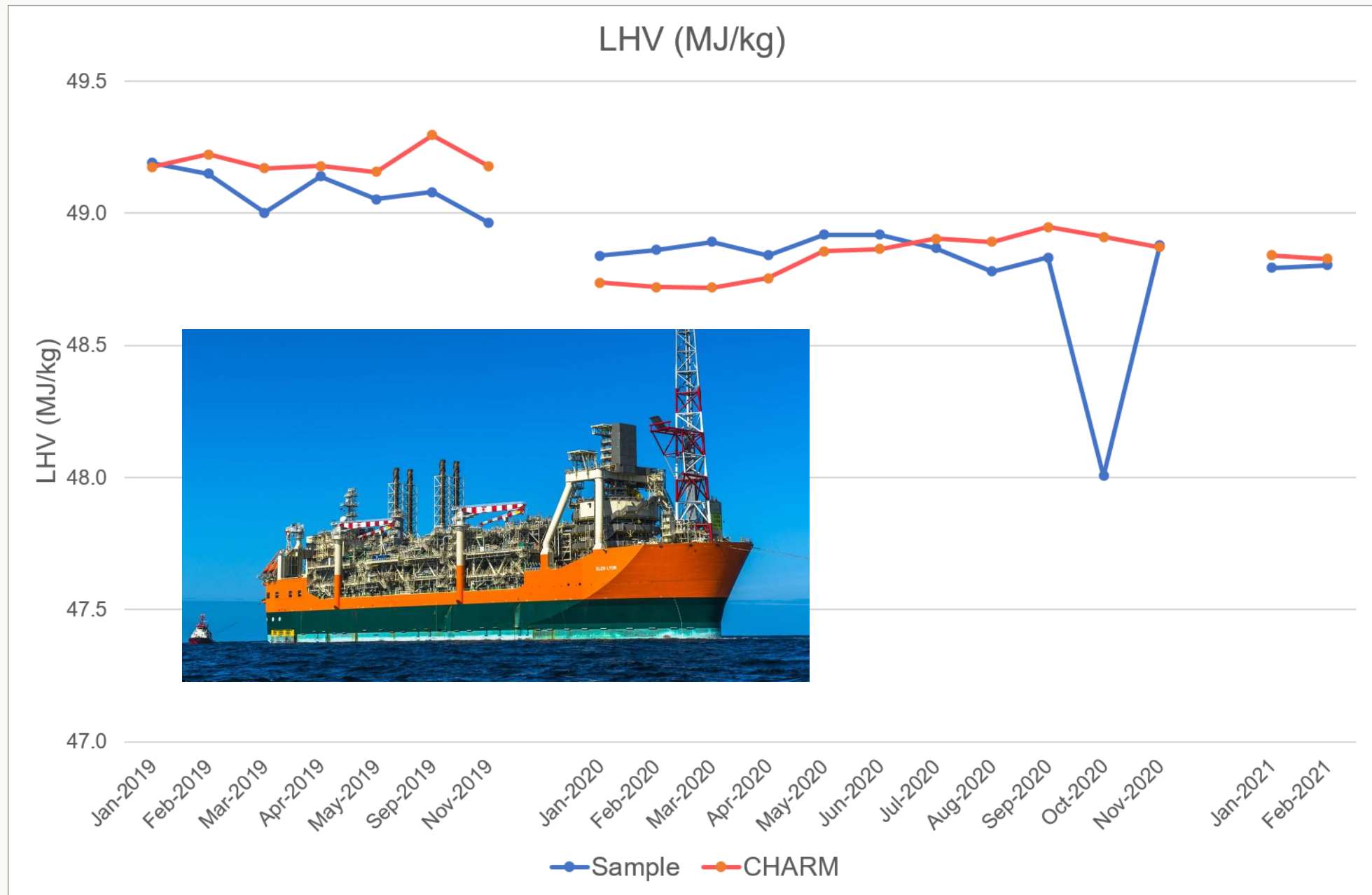
Process Simulation by ACCORD

Composition
Emissions Factor Value
(ECO2)



Glen Lyon HP Flare ECO2 (kg/kg)



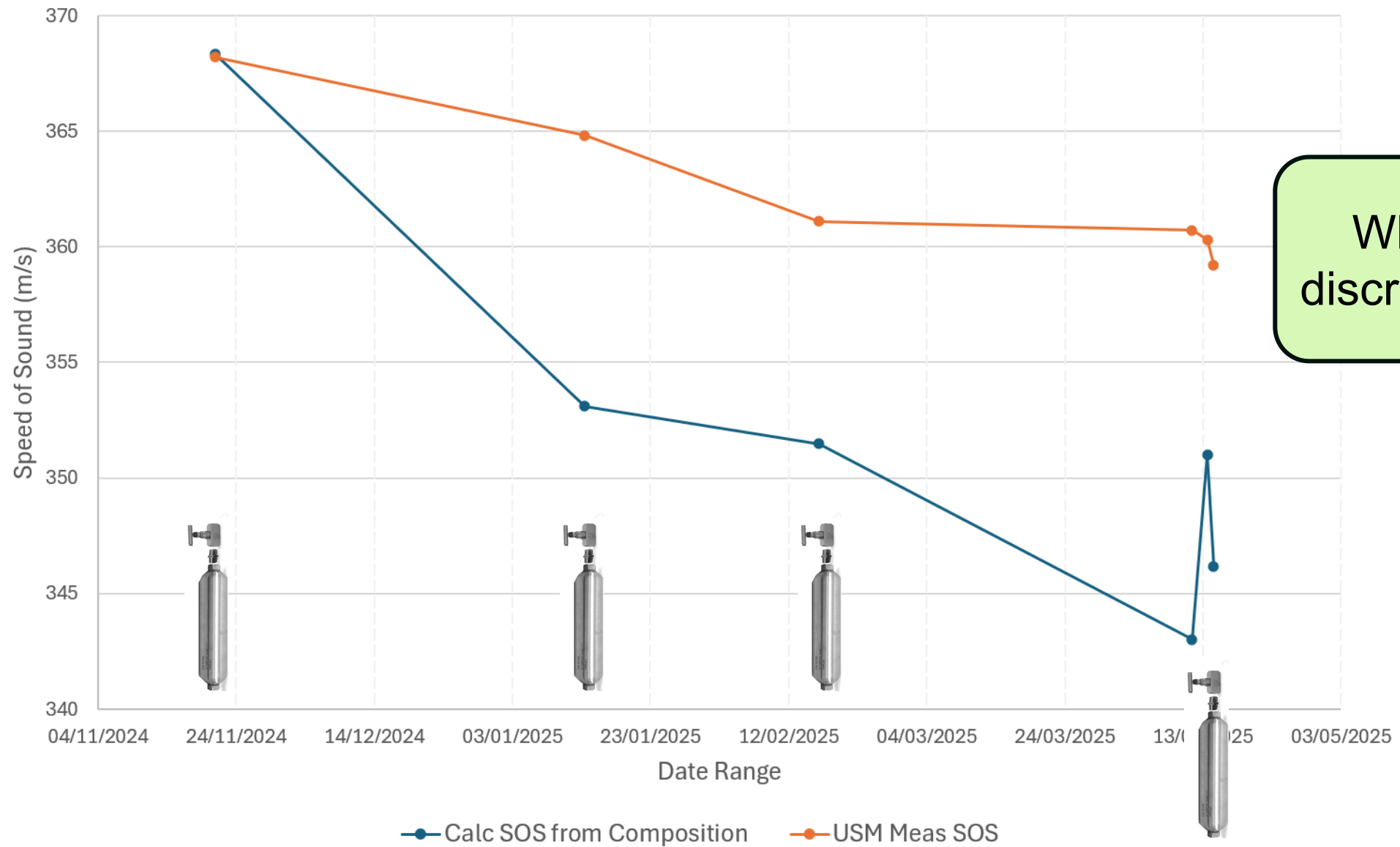


EU ETS Monitoring and Reporting Regulation (MRR) Guidance Document No. 5 on Sampling and Analysis, Article 35 (Dutch Tool)

- Purpose: lets an operator justify a lower analysis frequency than the MRR's default minimums (Annex VII) — weekly for natural gas.
- Core test: the variation in historical analytical values (LHV, ECO₂, carbon content, etc.) must not exceed 1/3 of the uncertainty value the operator is required to meet for activity data at the applicable tier. If it doesn't, fewer analyses are allowed.
- Basis of "variation": the standard deviation of the historical analytical results, converted to a 95% confidence-interval uncertainty
- Effect in practice: high-variability streams get pushed toward the Annex VII default (or more); low-variability, well-characterised streams can qualify for materially fewer analyses per year, cutting lab costs while staying compliant.
- It sits alongside — but is distinct from — the separate "unreasonable costs" justification (Article 18) for reducing frequency.



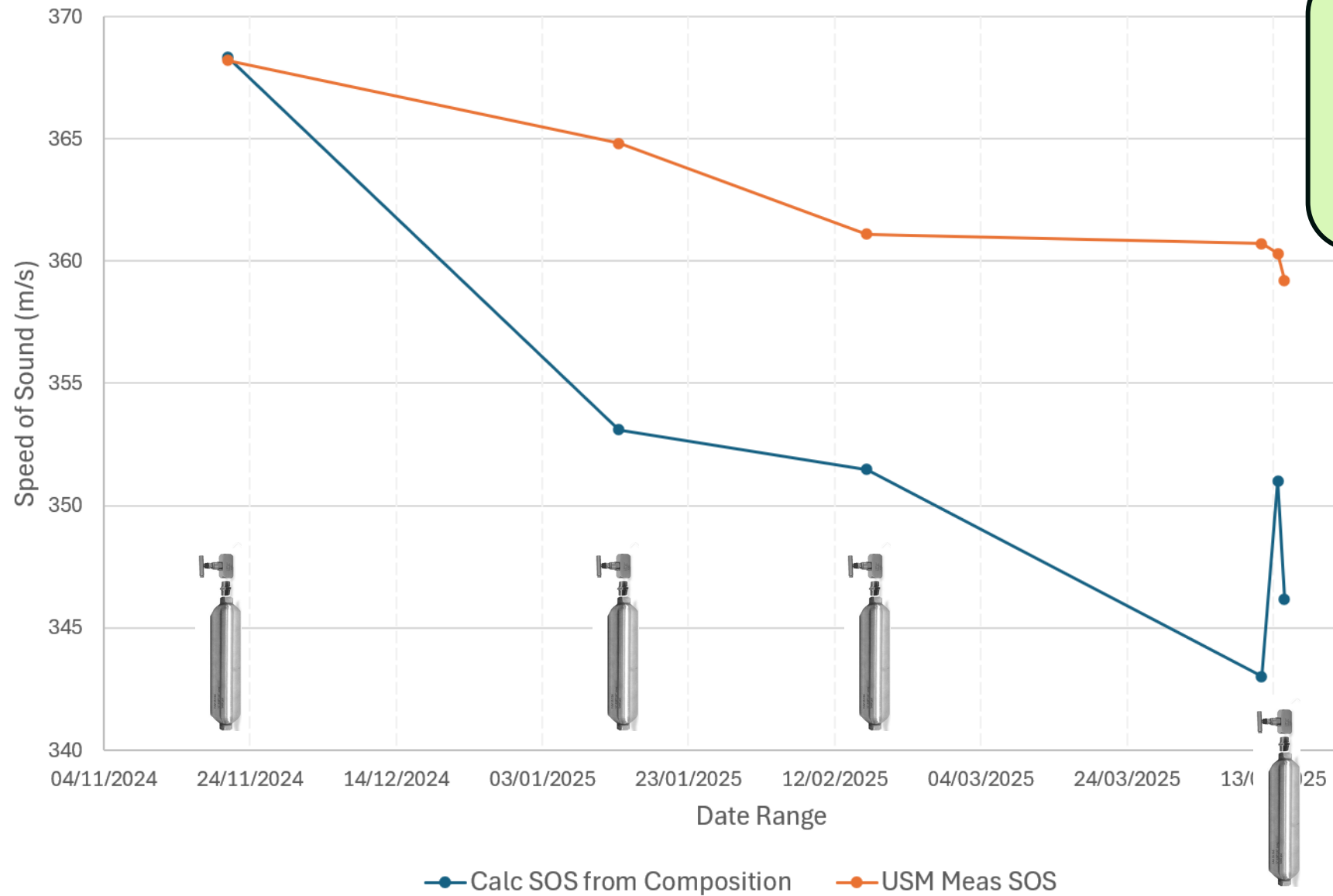
Calculated SOS - Sampled Composition vs USM Measured



Why the discrepancy?



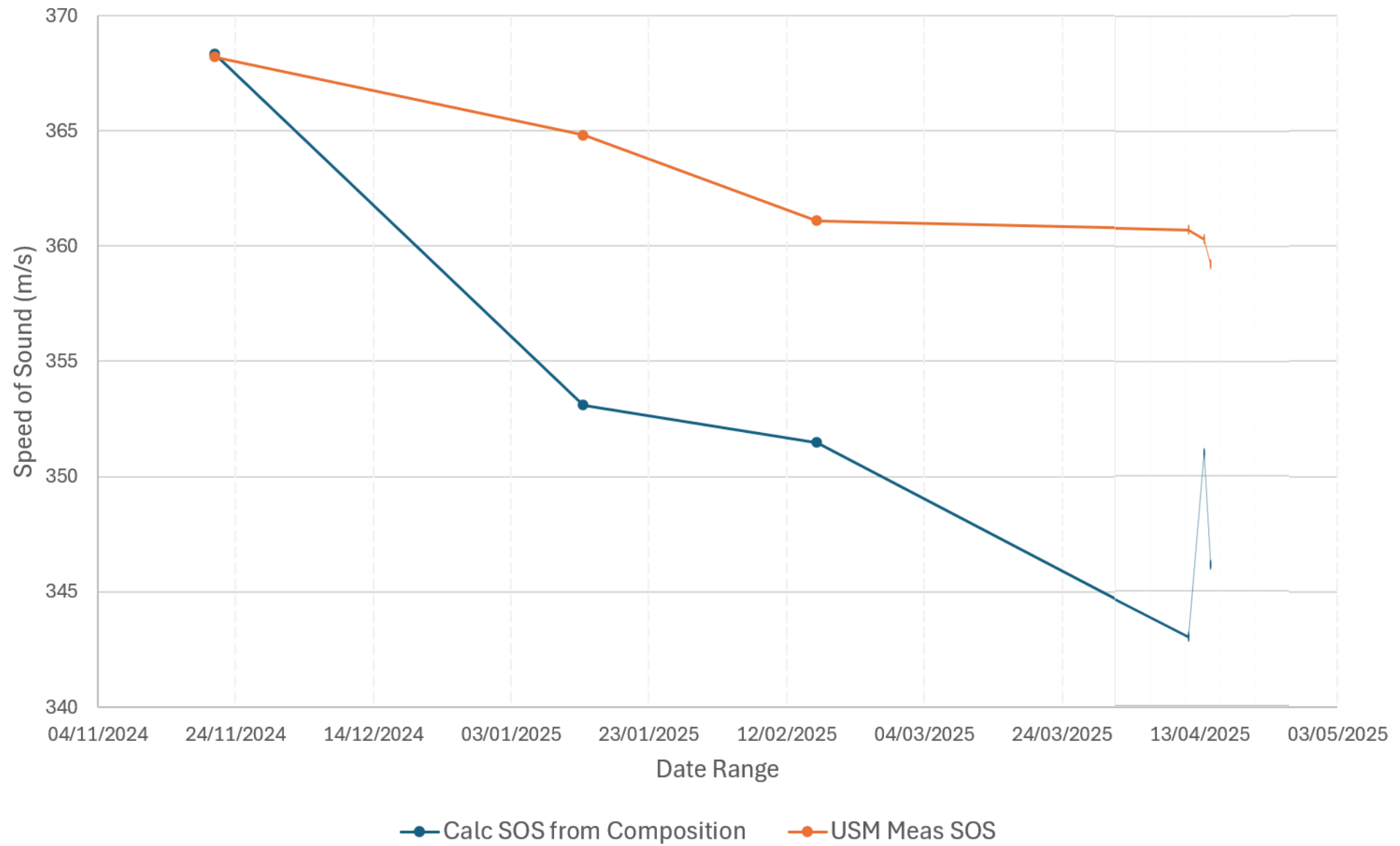
Calculated SOS - Sampled Composition vs USM Measured



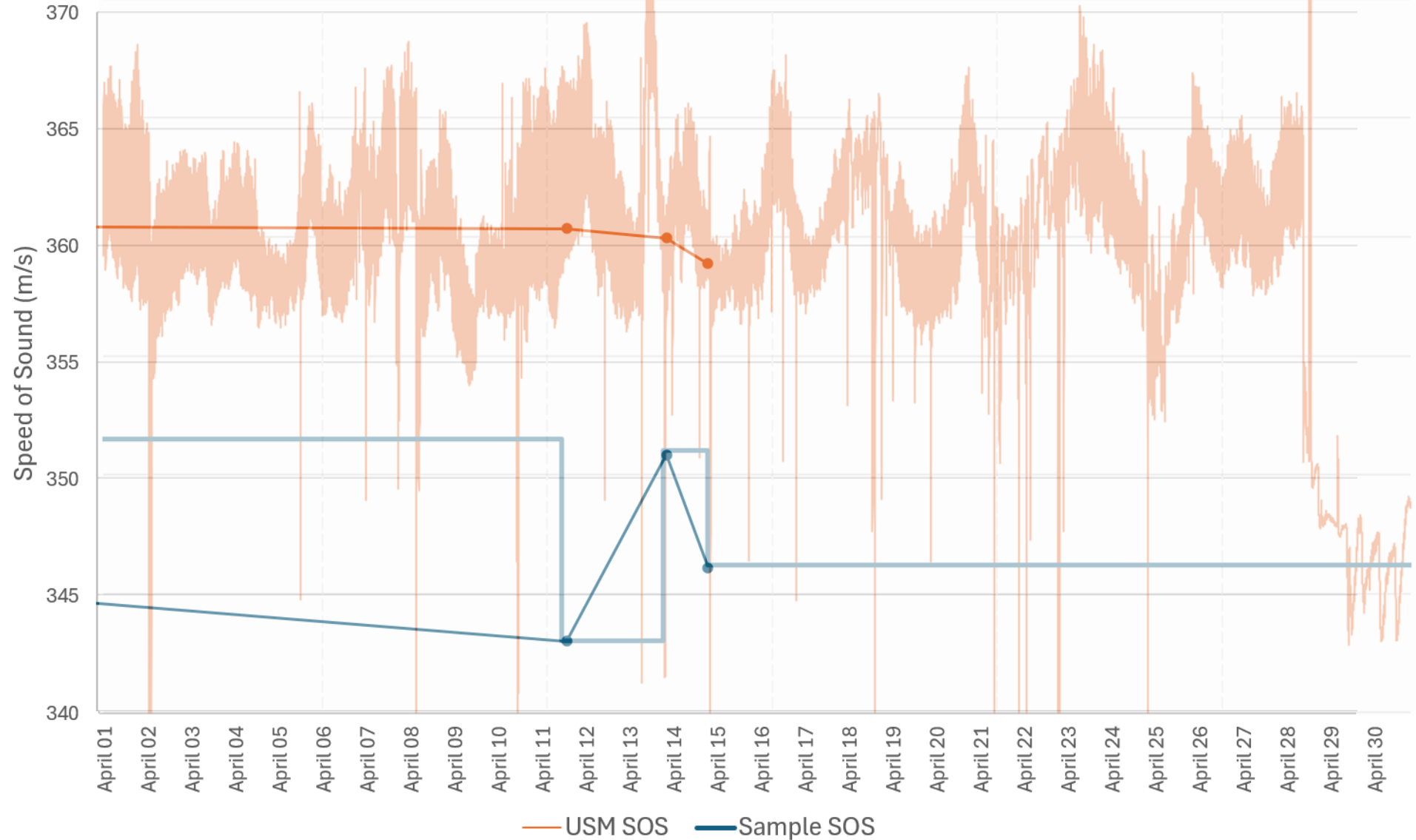
Build a
CHARM
model of this
process



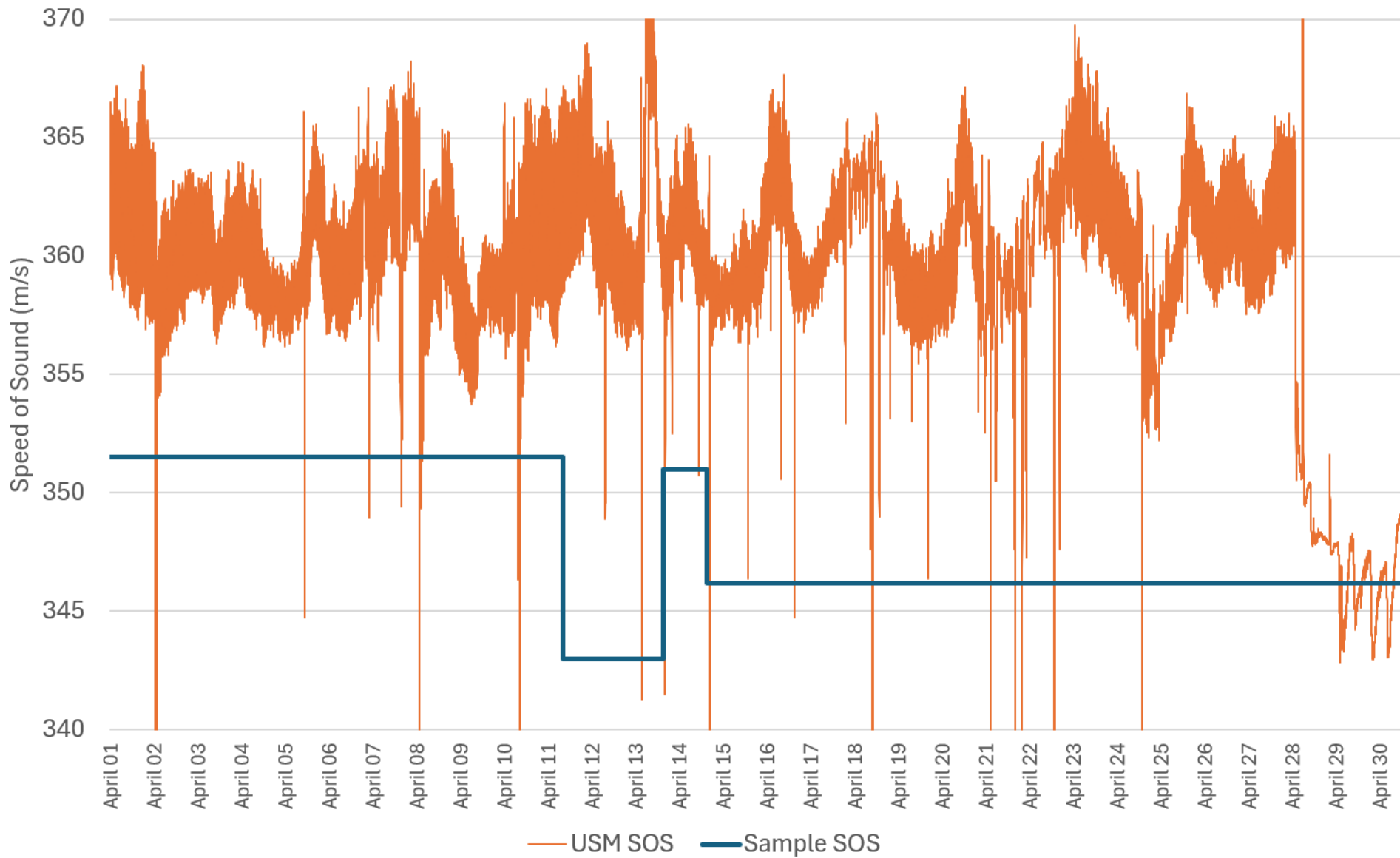
Calculated SOS - Sampled Composition vs USM Measured



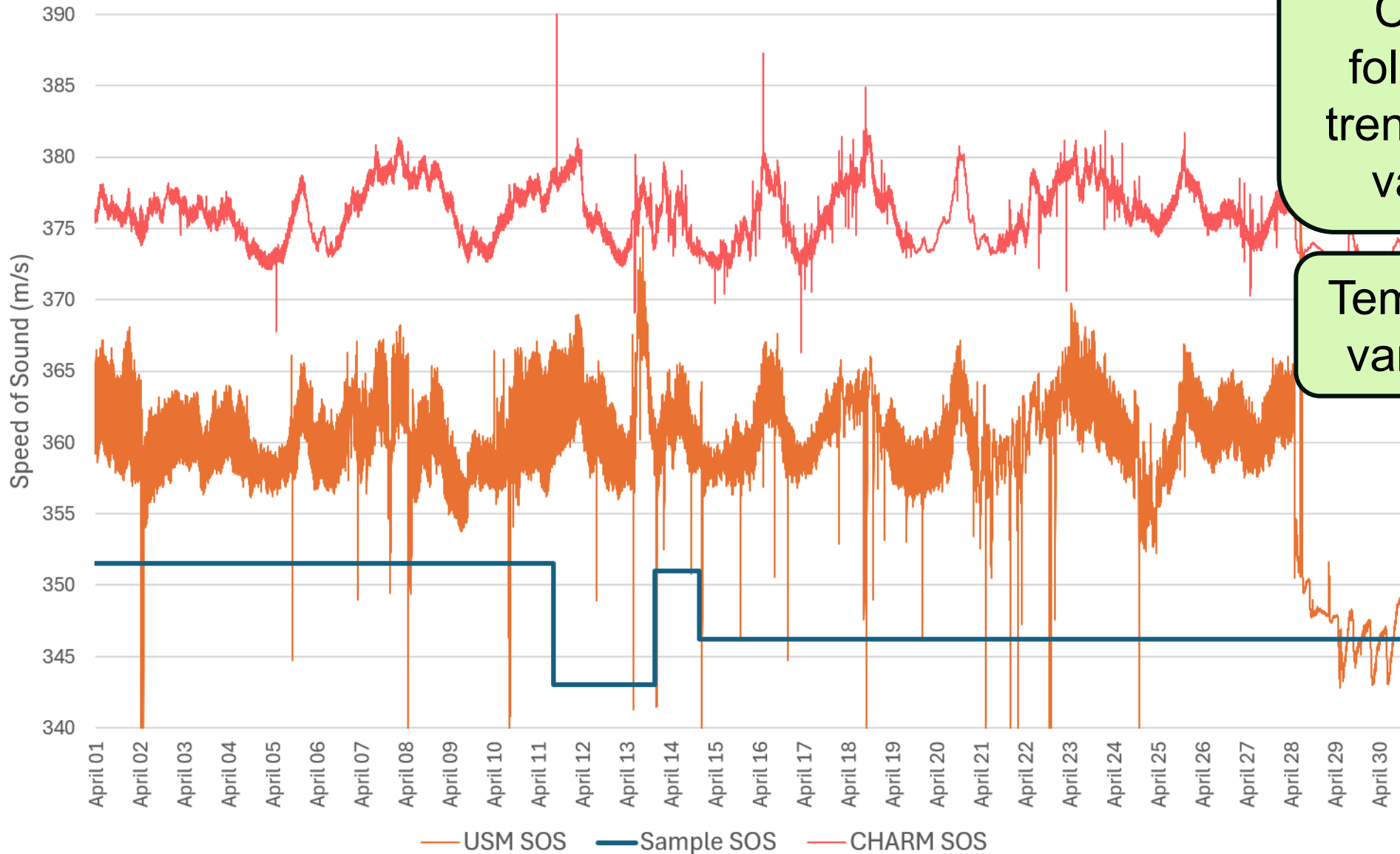
Calculated SOS - Sampled Composition vs USM Measured



Speed of Sound LP Flare



Speed of Sound LP Flare

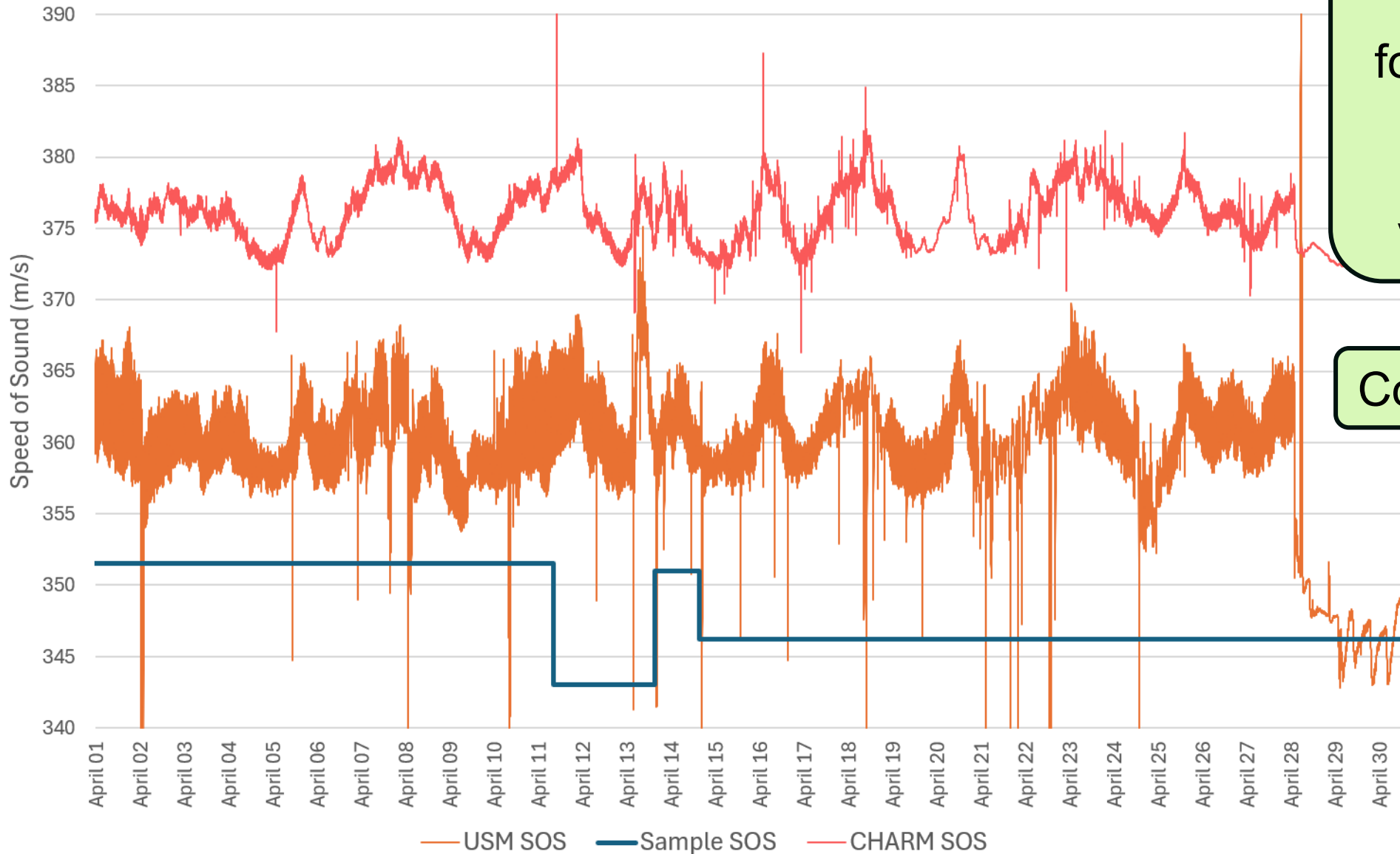


Offset but
CHARM
follows the
trend in SOS
variation

Temperature
variations?



Speed of Sound LP Flare

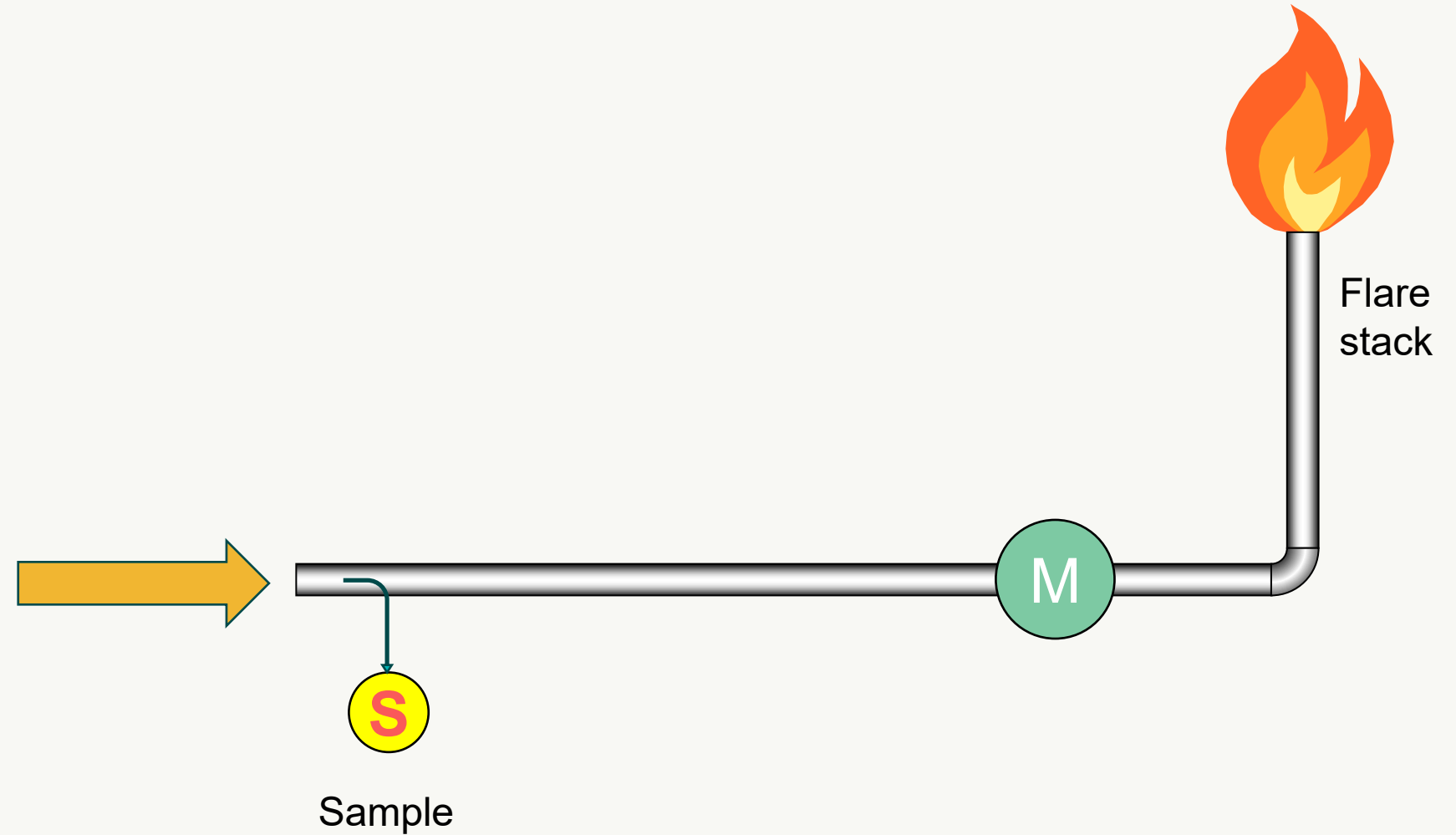


Offset but
CHARM
follows the
trend in
SOS
variation

Composition

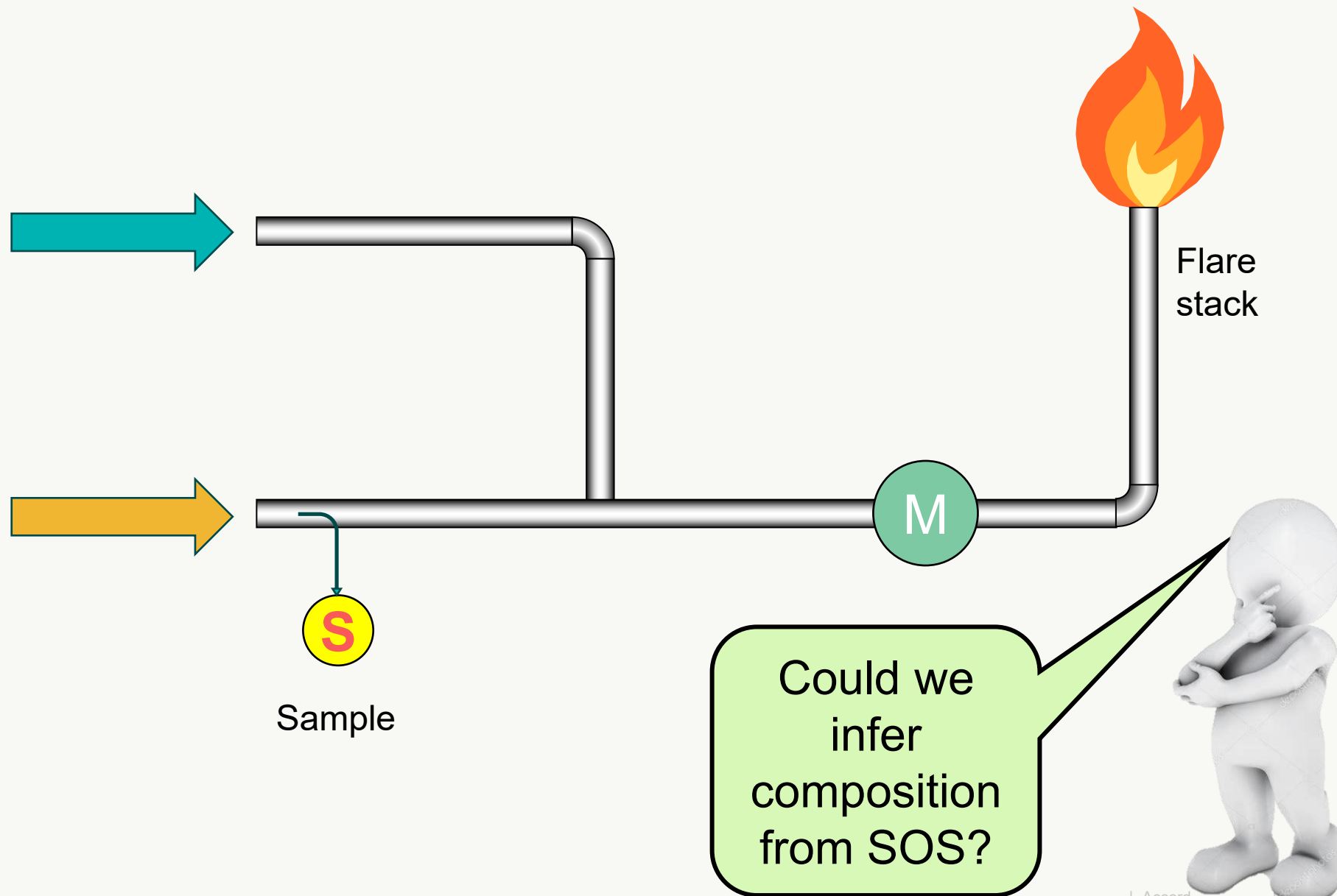


Unmeasured streams



Unmeasured streams

Compressor seal gas
chiefly nitrogen



Reconciliation

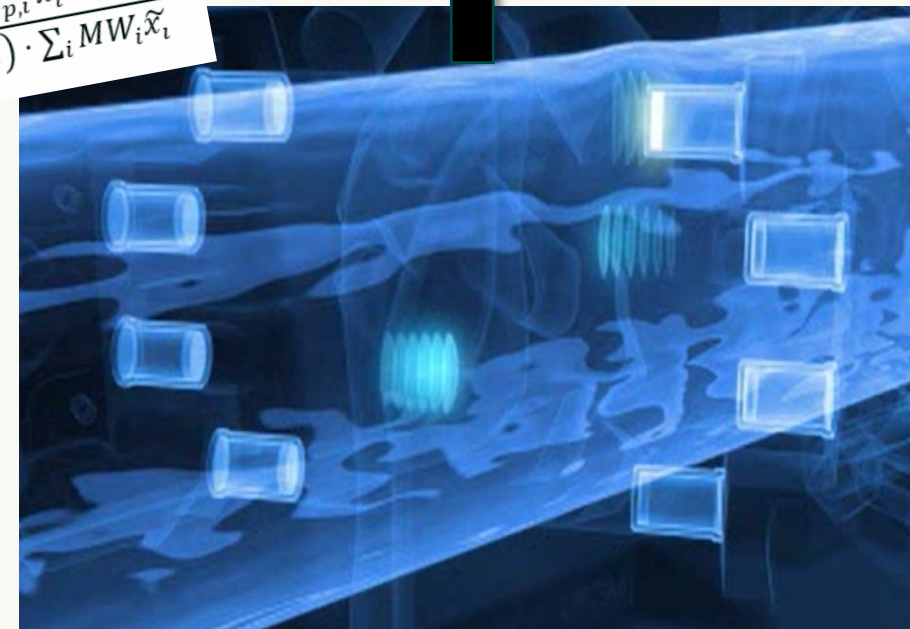
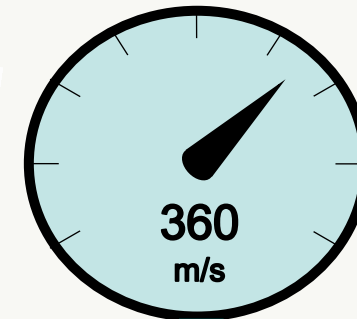
Recon SOS = 360 m/s

USM SOS = 360 m/s

Nitrogen	6.9%
CO2	3.4%
Methane	70.8%
Ethane	9.8%
Propane	4.7%
i-Butane	1.0%
n-Butane	1.6%
i-Pentane	0.6%
n-Pentane	0.5%
C6*	0.5%
C7*	0.2%
C8*	0.0%
C9*	0.0%
C10*	0.0%

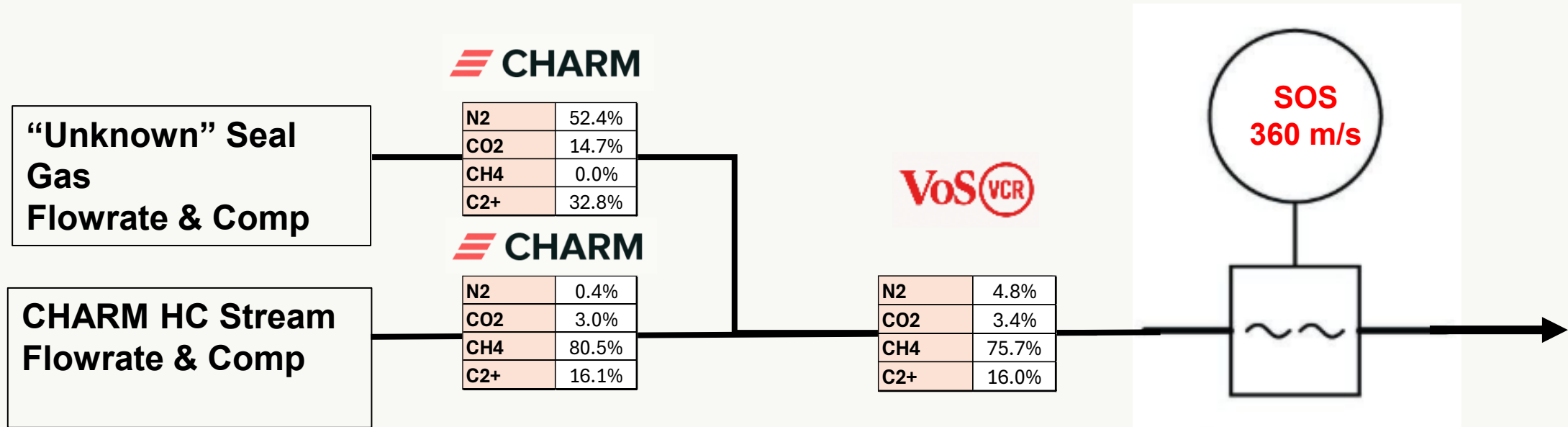
$$\mathcal{O} = \frac{(\hat{w} - \tilde{w})^2}{\sigma_w^2} + \sum_i \frac{(\hat{x}_i - \tilde{x}_i)^2}{\sigma_{x_i}^2}$$

$$\begin{aligned} \varphi^0 &= w^2 - \tilde{w}^2 \\ &= w^2 - W^{o^2}(X) \\ &\stackrel{(4)}{=} w^2 - \frac{RT \sum_i C_{p,i} \tilde{x}_i}{(\sum_i C_{p,i} \tilde{x}_i - R) \cdot \sum_i MW_i \tilde{x}_i} \end{aligned}$$

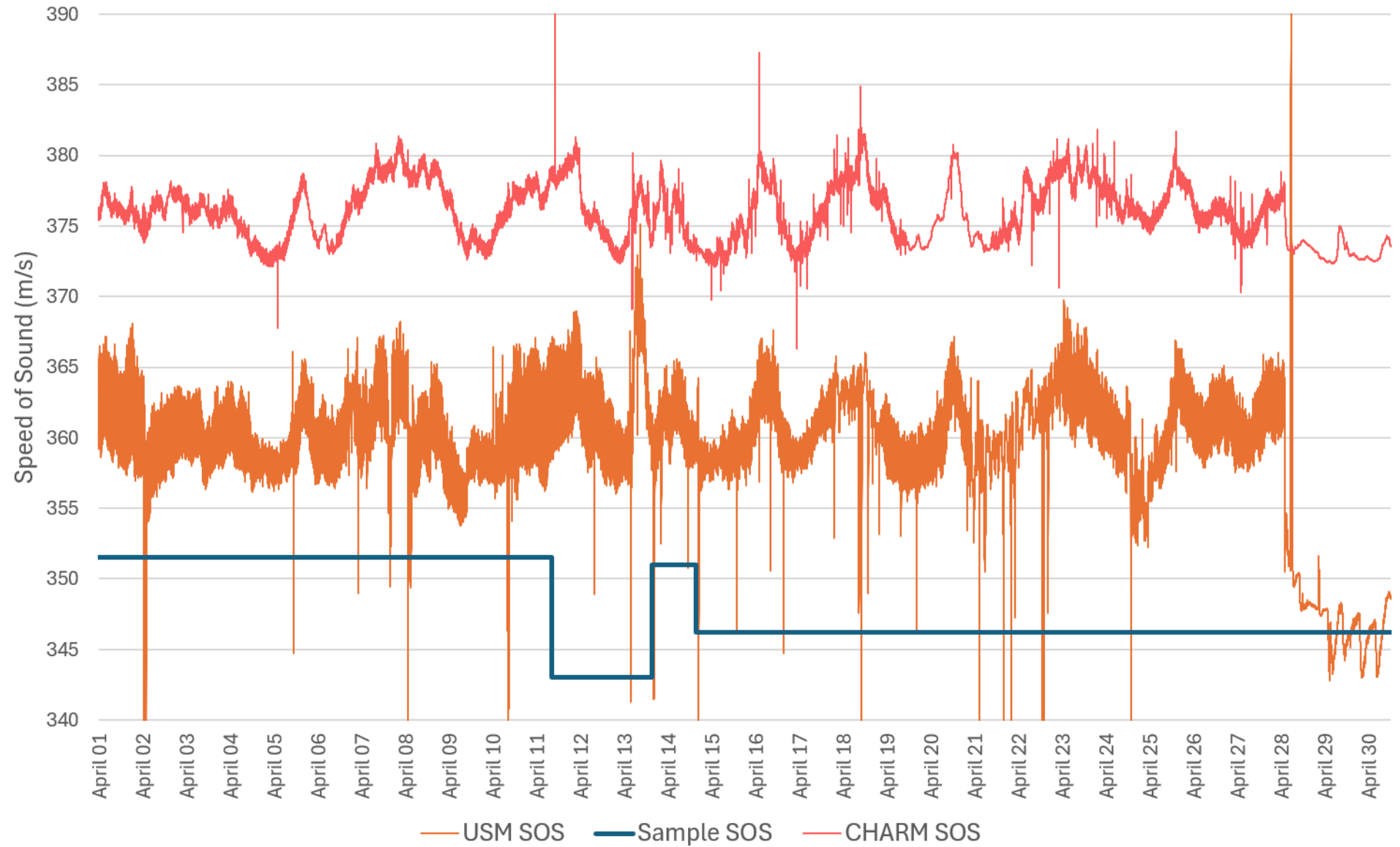


VoS VCR Example Case

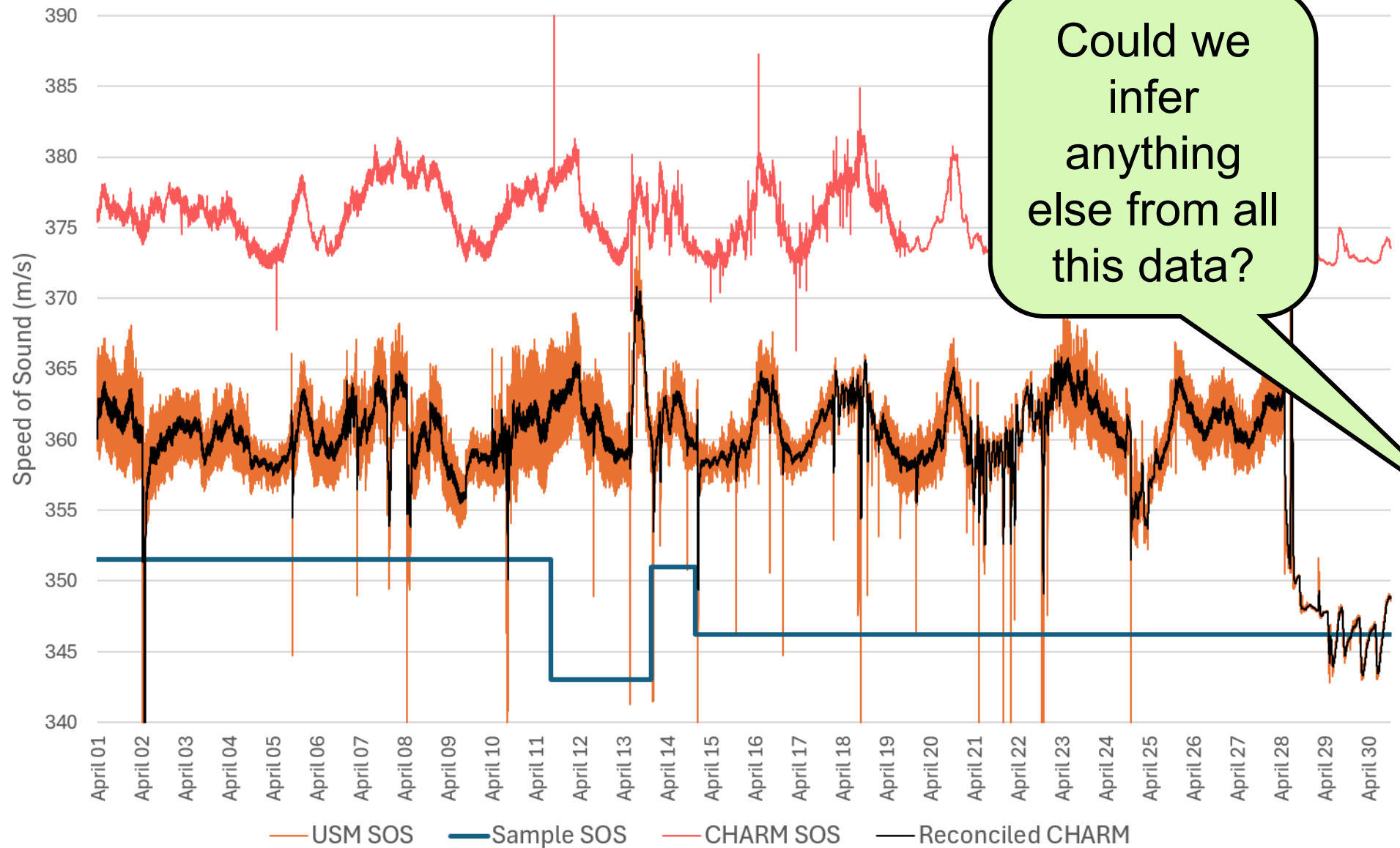
Constrained nonlinear optimization
used for data reconciliation



Speed of Sound LP Flare

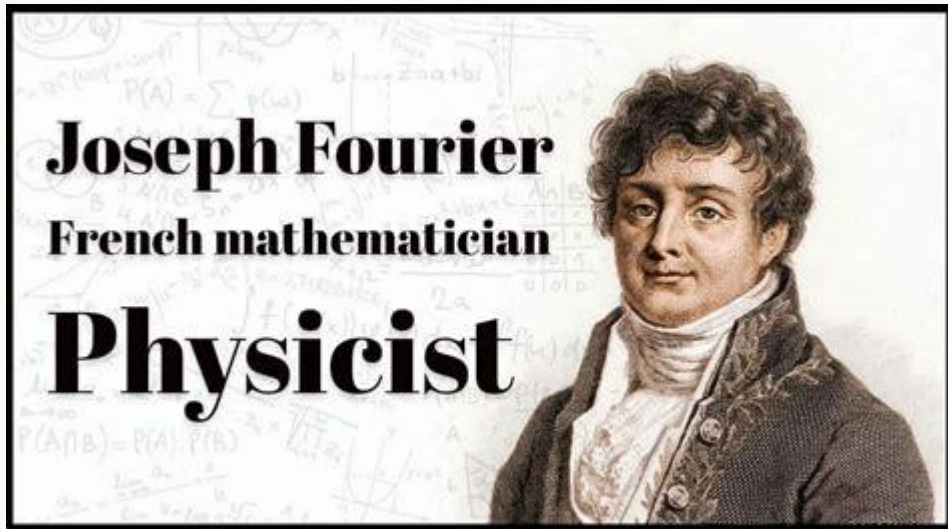


Speed of Sound LP Flare



Joseph Fourier

1768 – 1830 · Mathematician, physicist, and Egyptologist



Jean-Baptiste Joseph Fourier was a French mathematician and physicist whose work on heat produced one of the most far-reaching ideas in mathematics: that almost any function, however irregular, can be built from a sum of simple sine and cosine waves.



1798

Joins Napoleon's expedition to Egypt as scientific adviser, later contributing to the Description de l'Égypte.



1807

Presents his heat equation to the Paris Academy, proposing that periodic functions decompose into sums of sines and cosines.



1822

Publishes *Théorie analytique de la chaleur*, formalising what we now call the Fourier series.



1824

First to describe the mechanism now known as the greenhouse effect, reasoning about Earth's heat balance.

Any Hidden Structure Can Be Read Out of a Signal



A molecule

An X-ray diffraction pattern decomposes into the electron-density waves that reveal its shape.



A body scan

MRI signals decompose into frequency components that reconstruct a 3D image of tissue.



A radio sky

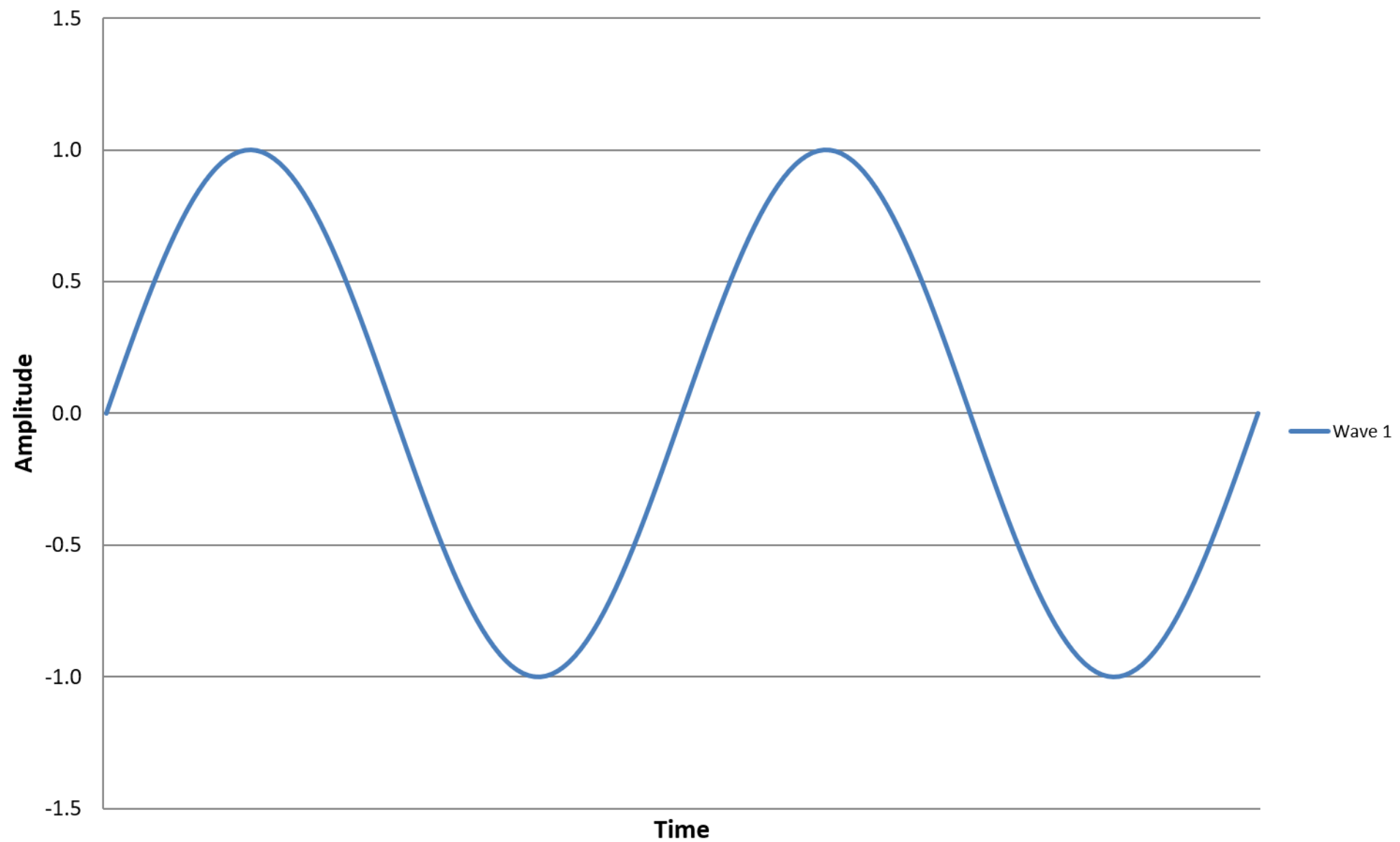
Combined antenna signals are Fourier-transformed into an image of deep space.



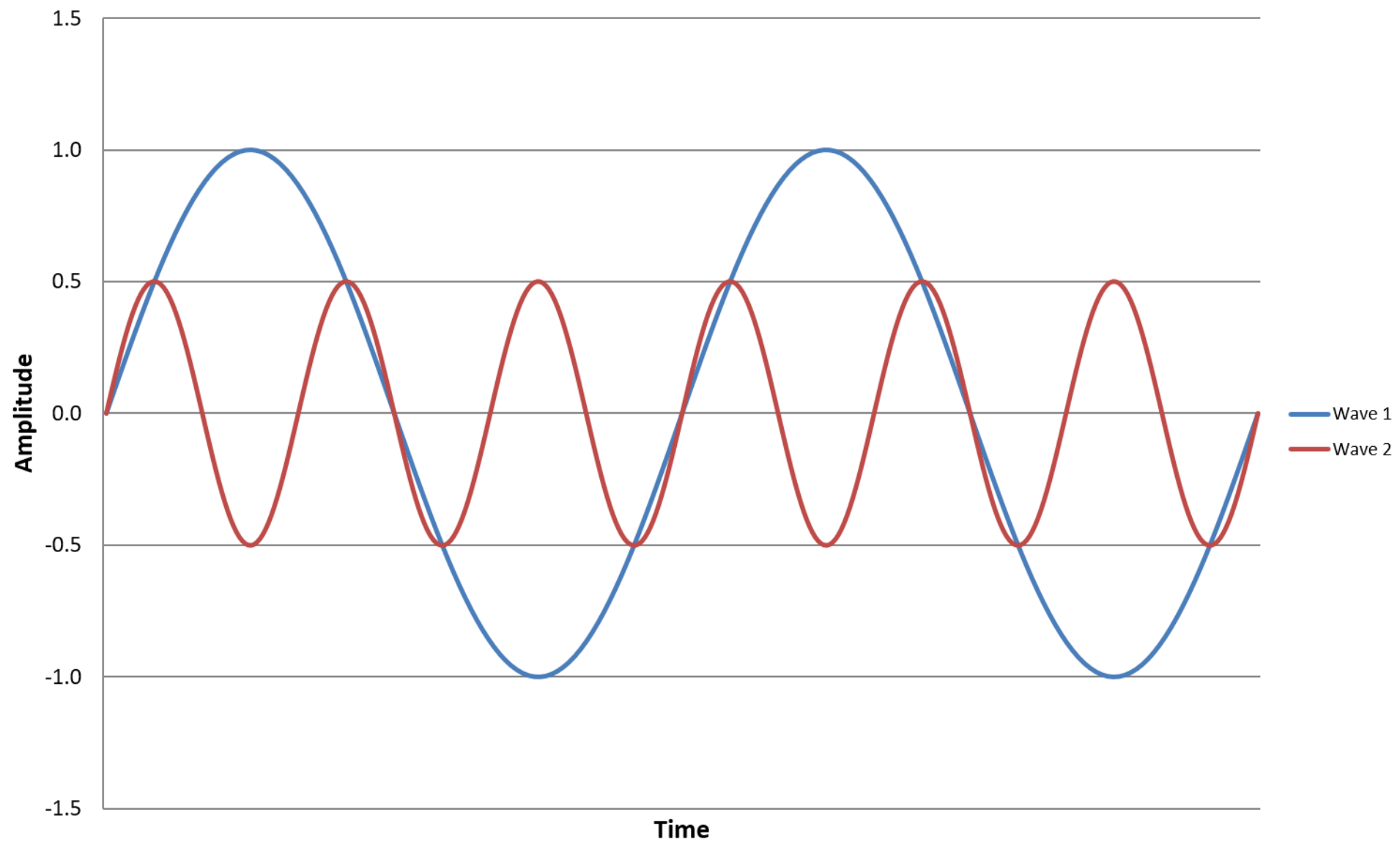
A vaccine

Cryo-EM decodes a virus's protein shape the same way, guiding how vaccines are designed.

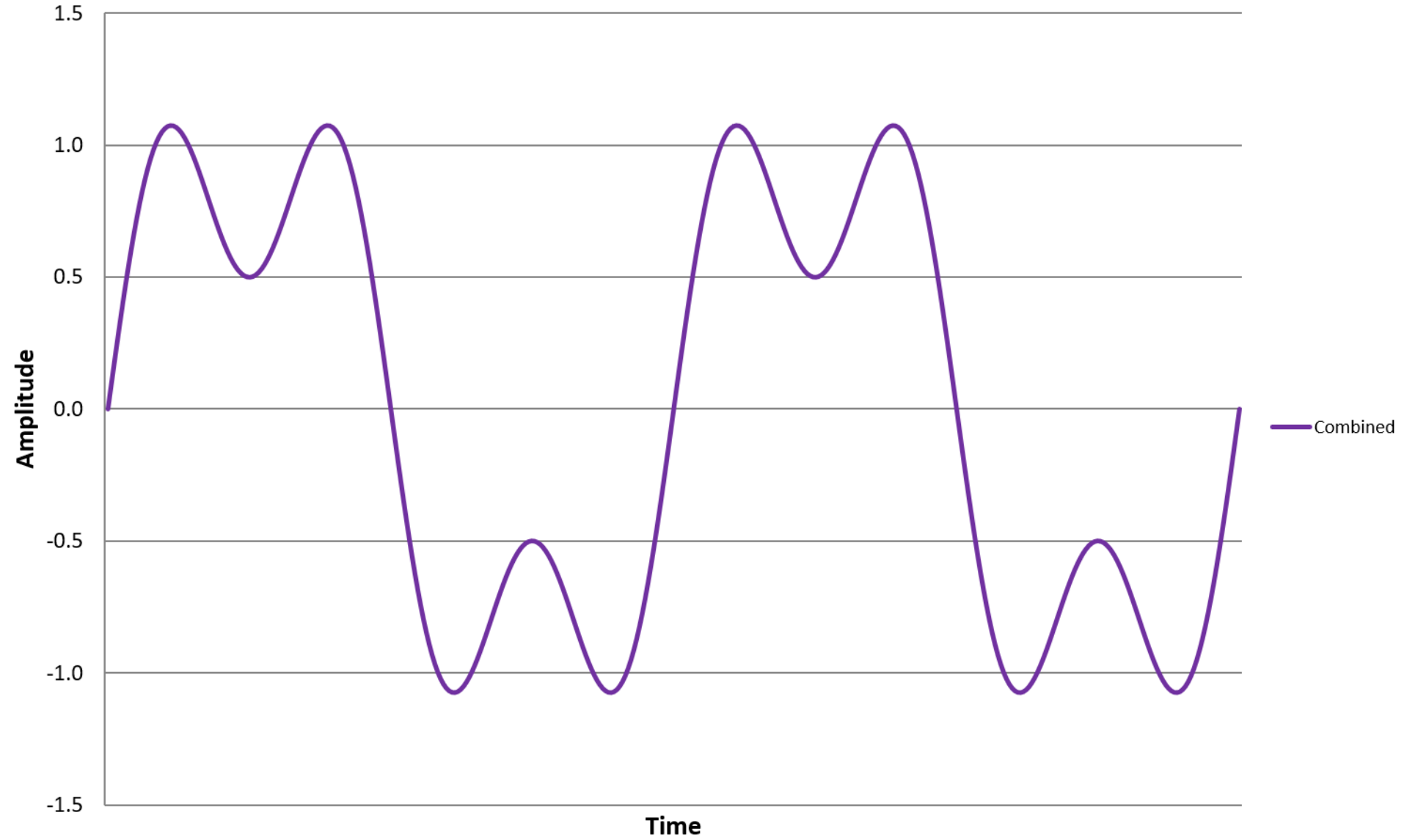
Wave 1 and Wave 2 (Individual)

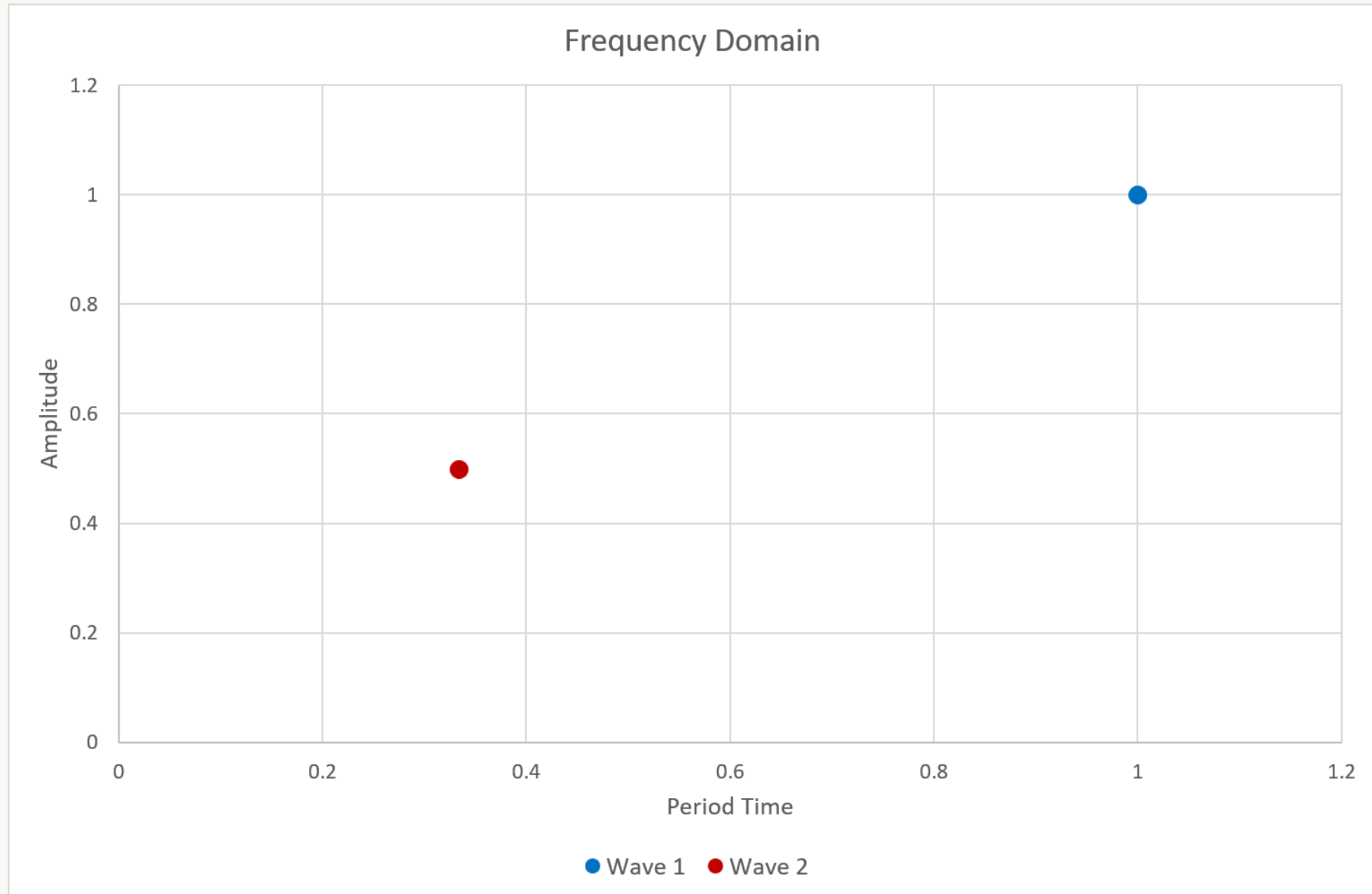


Wave 1 and Wave 2 (Individual)

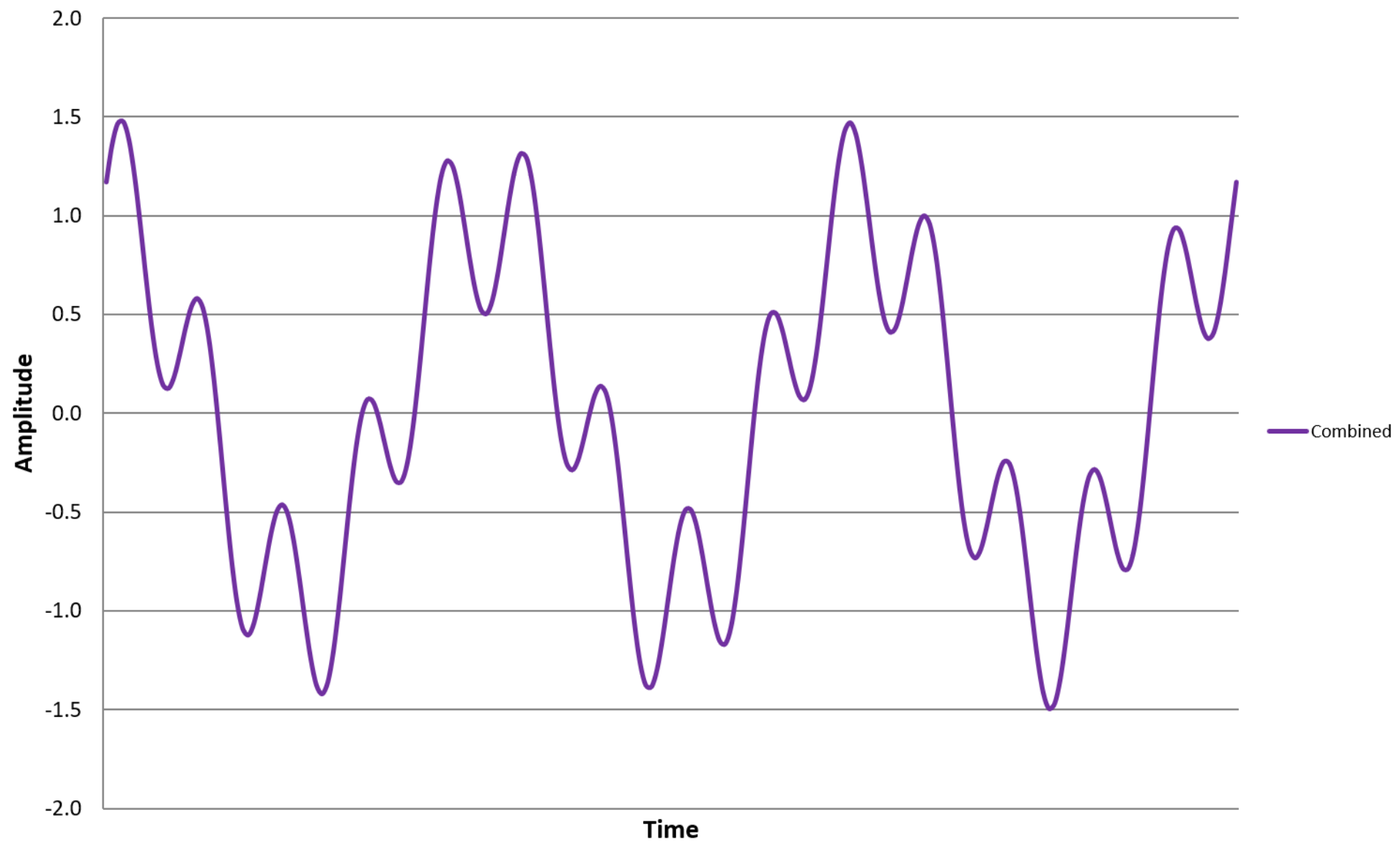


Combined Wave (Wave 1 + Wave 2)

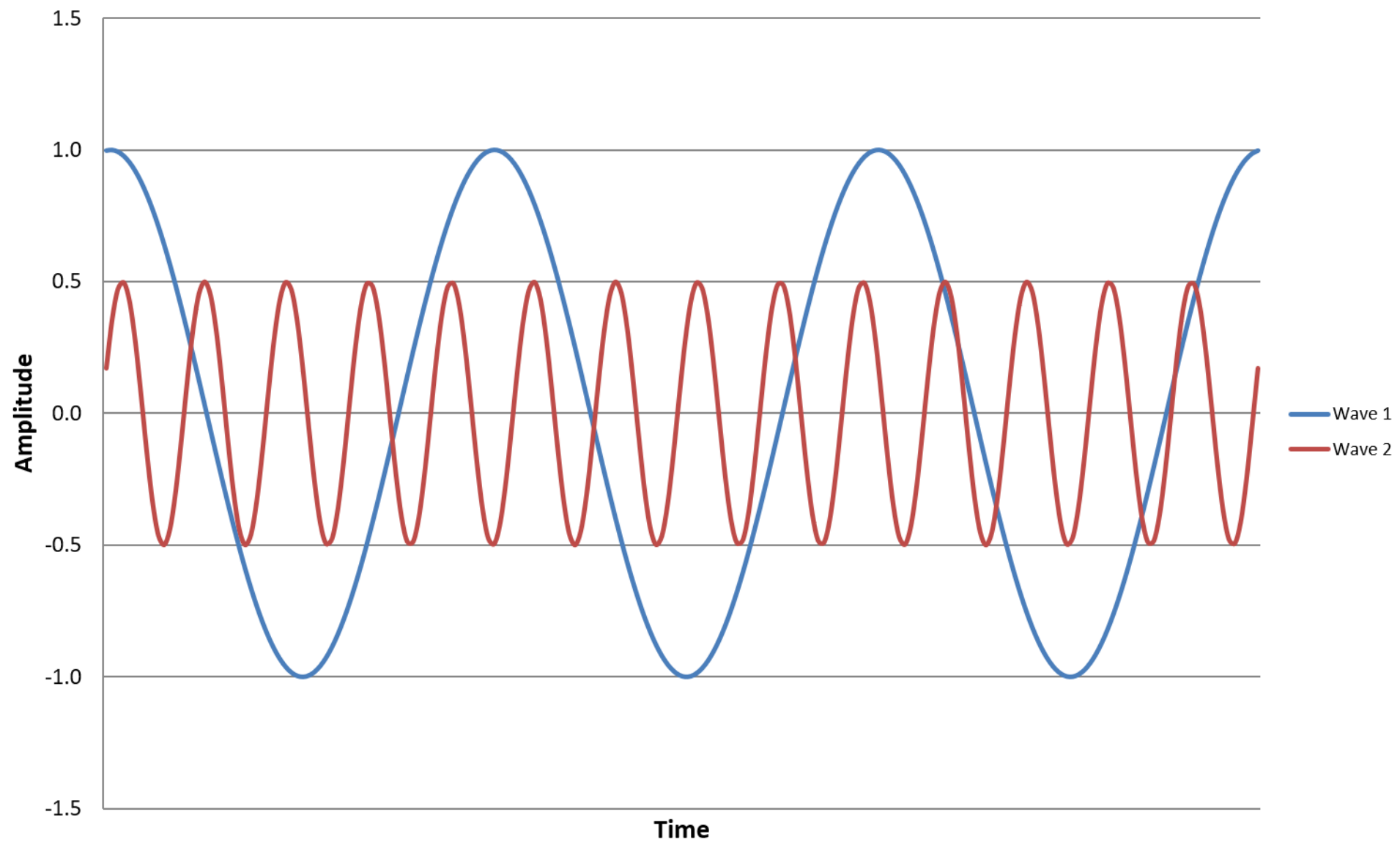




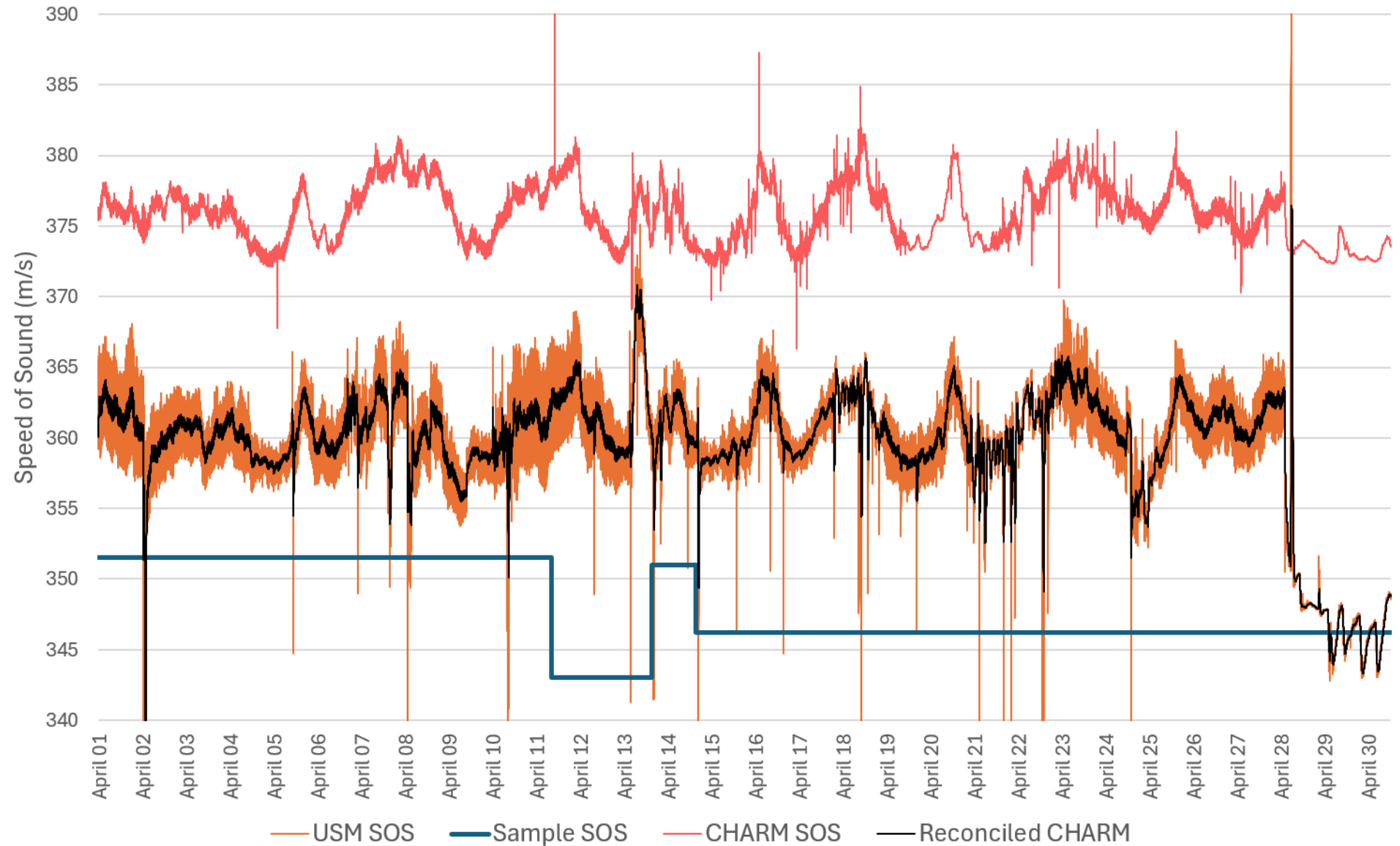
Combined Wave (Wave 1 + Wave 2)

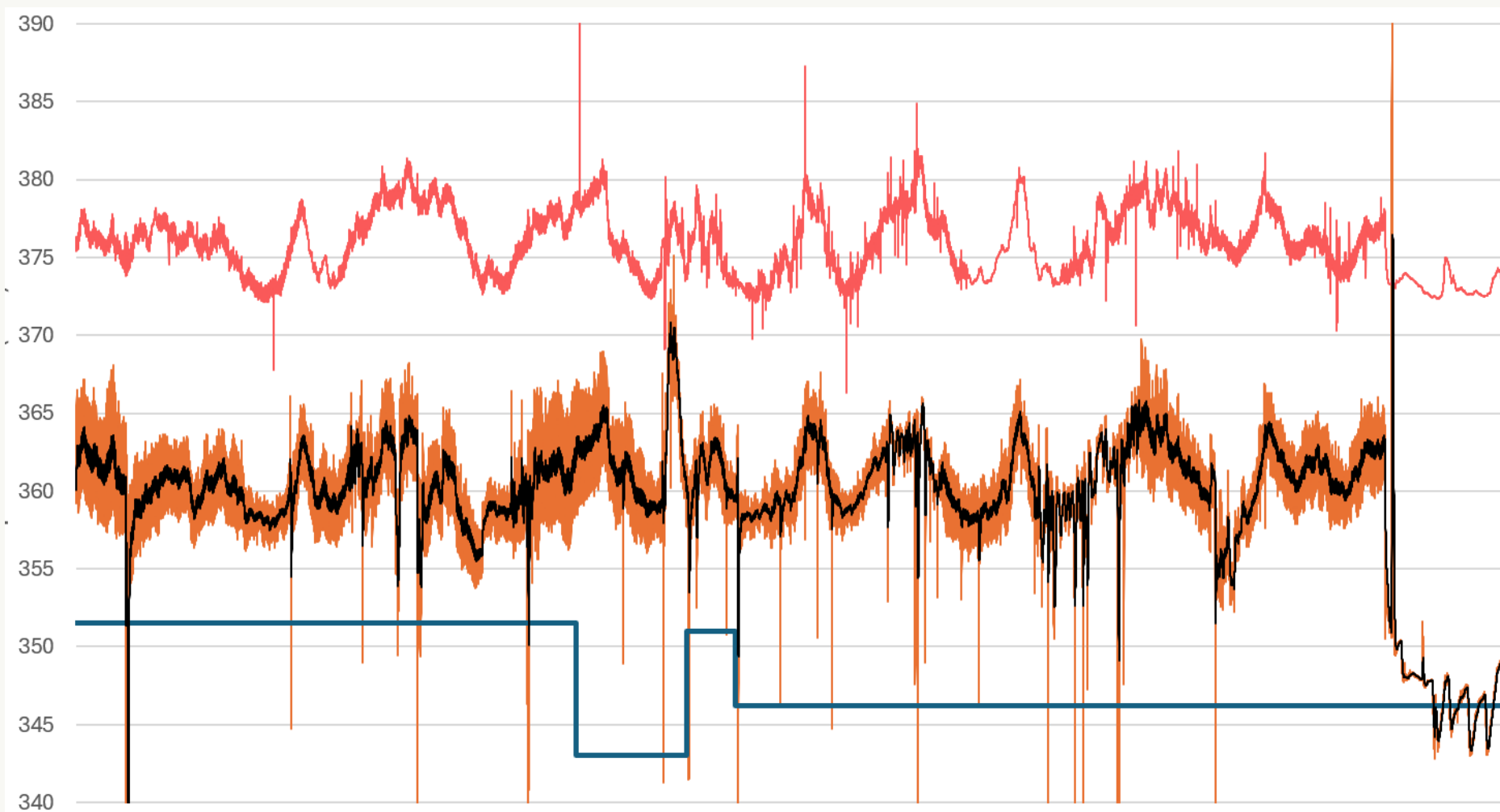


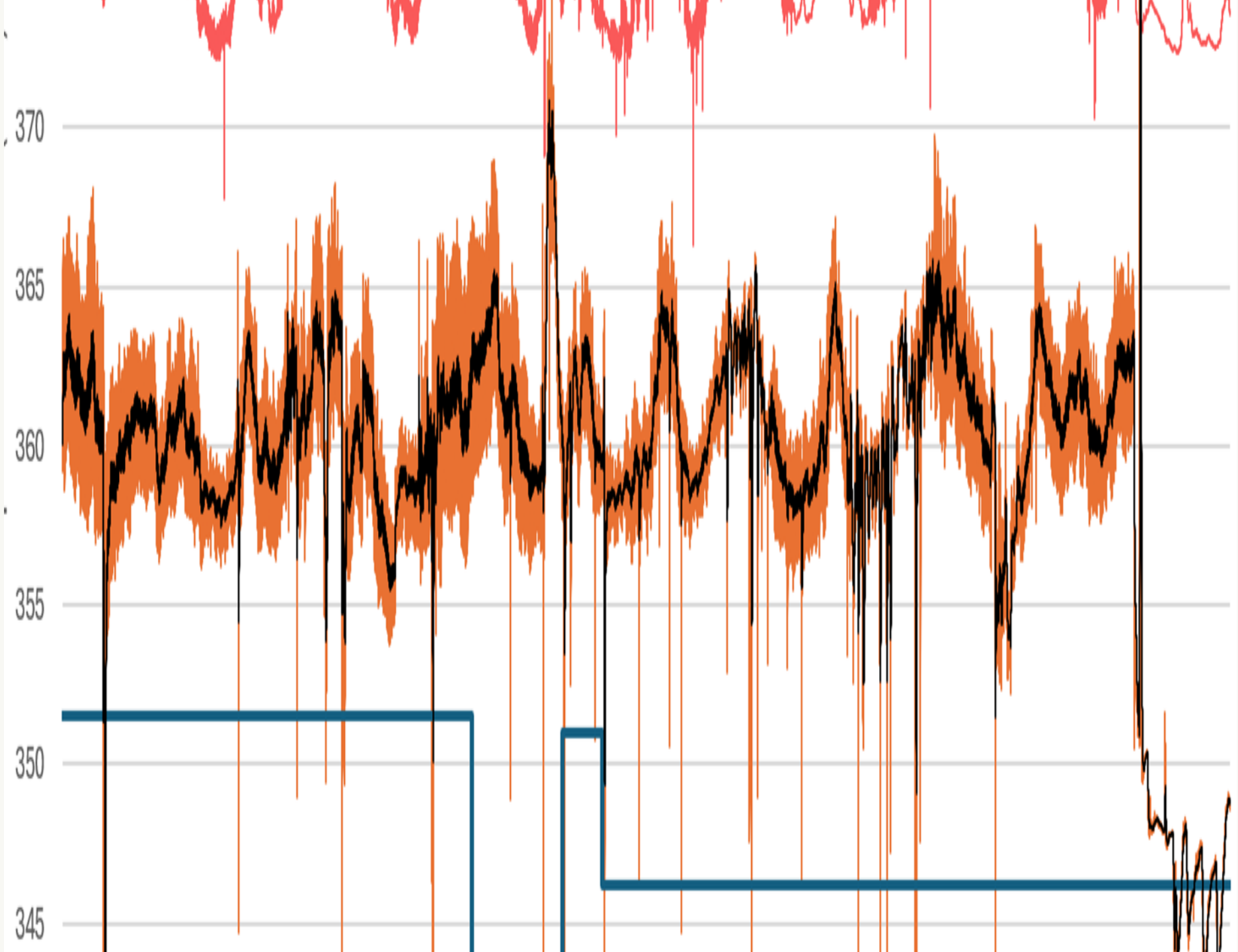
Wave 1 and Wave 2 (Individual)



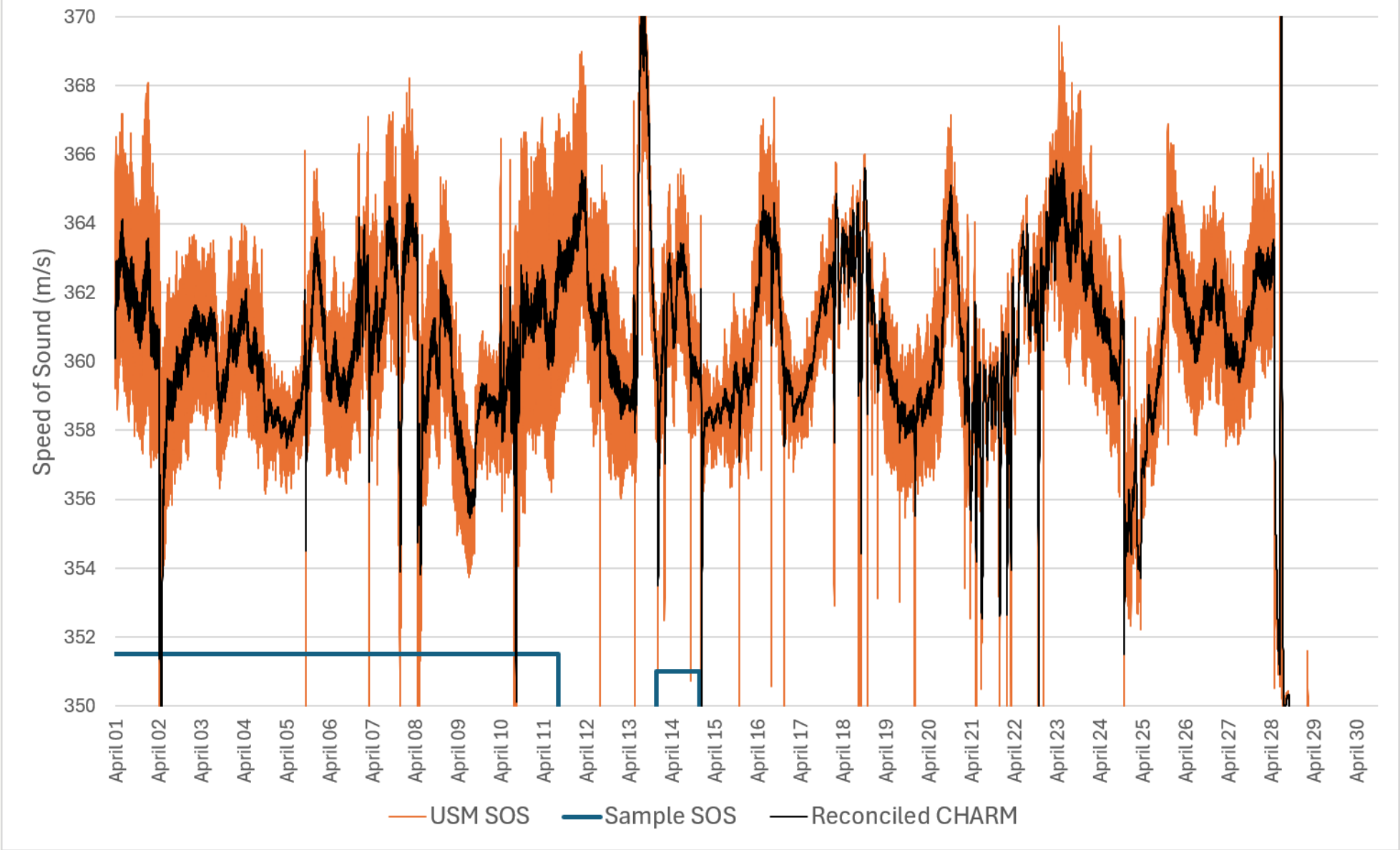
Speed of Sound LP Flare

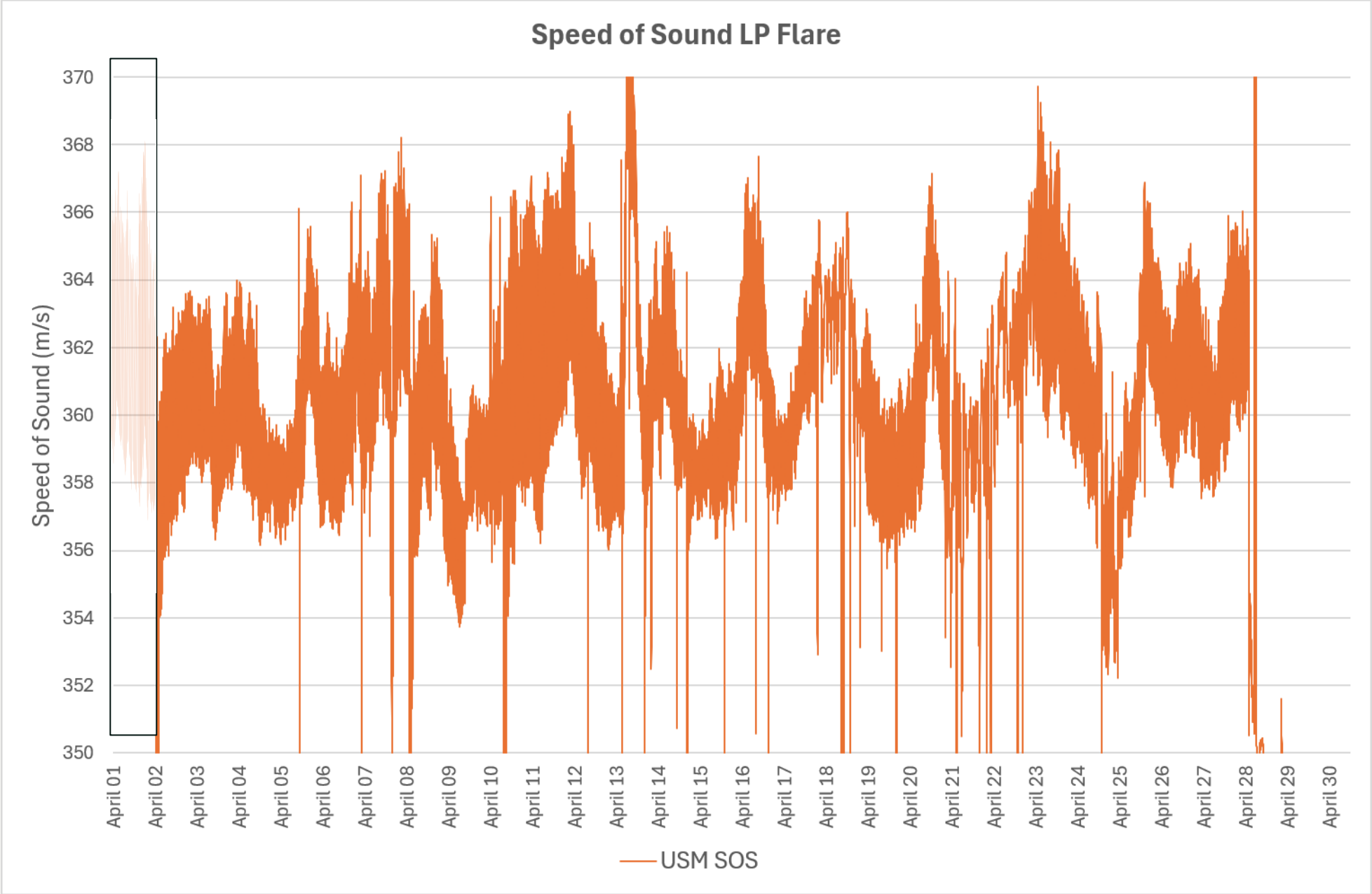




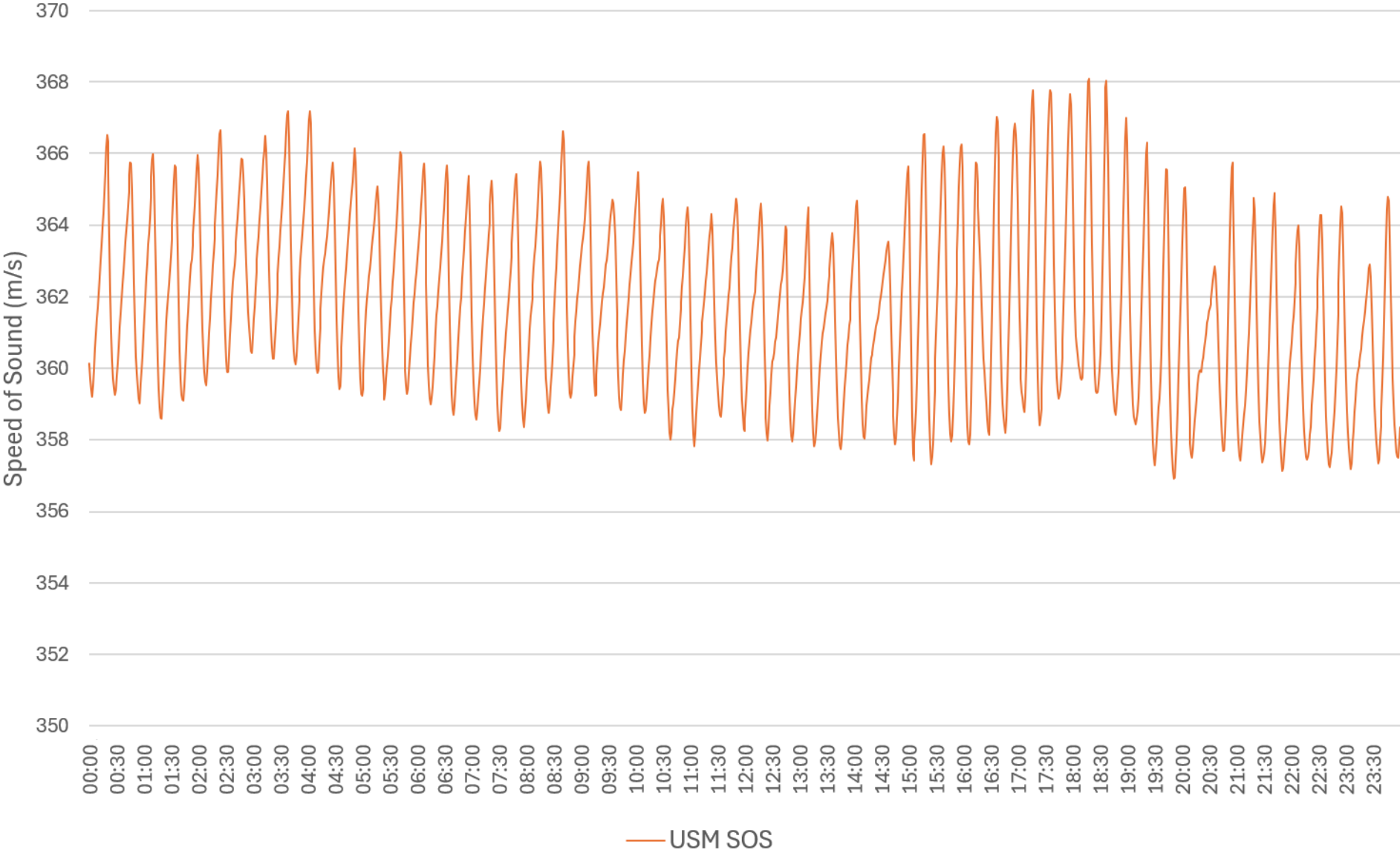


Speed of Sound LP Flare

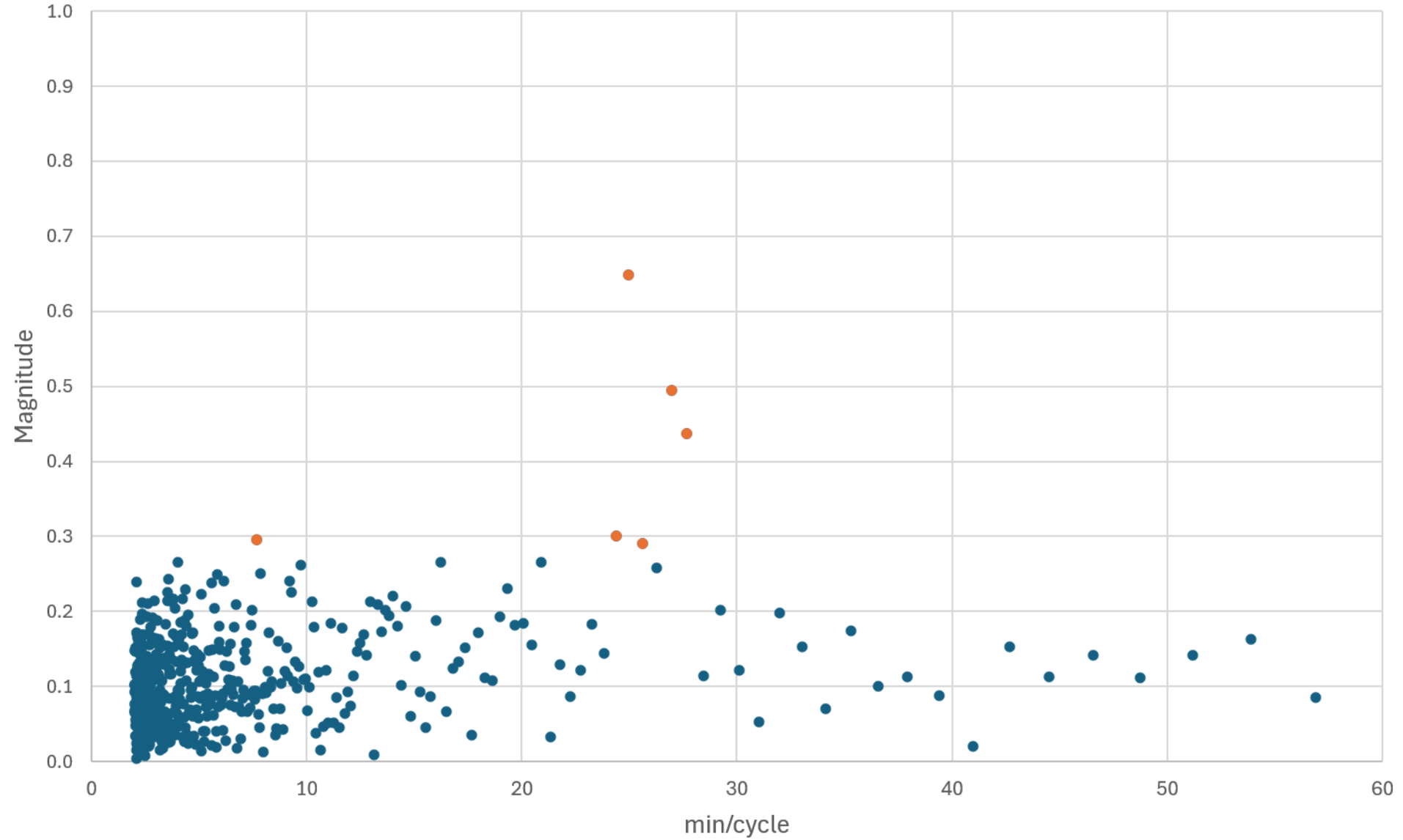




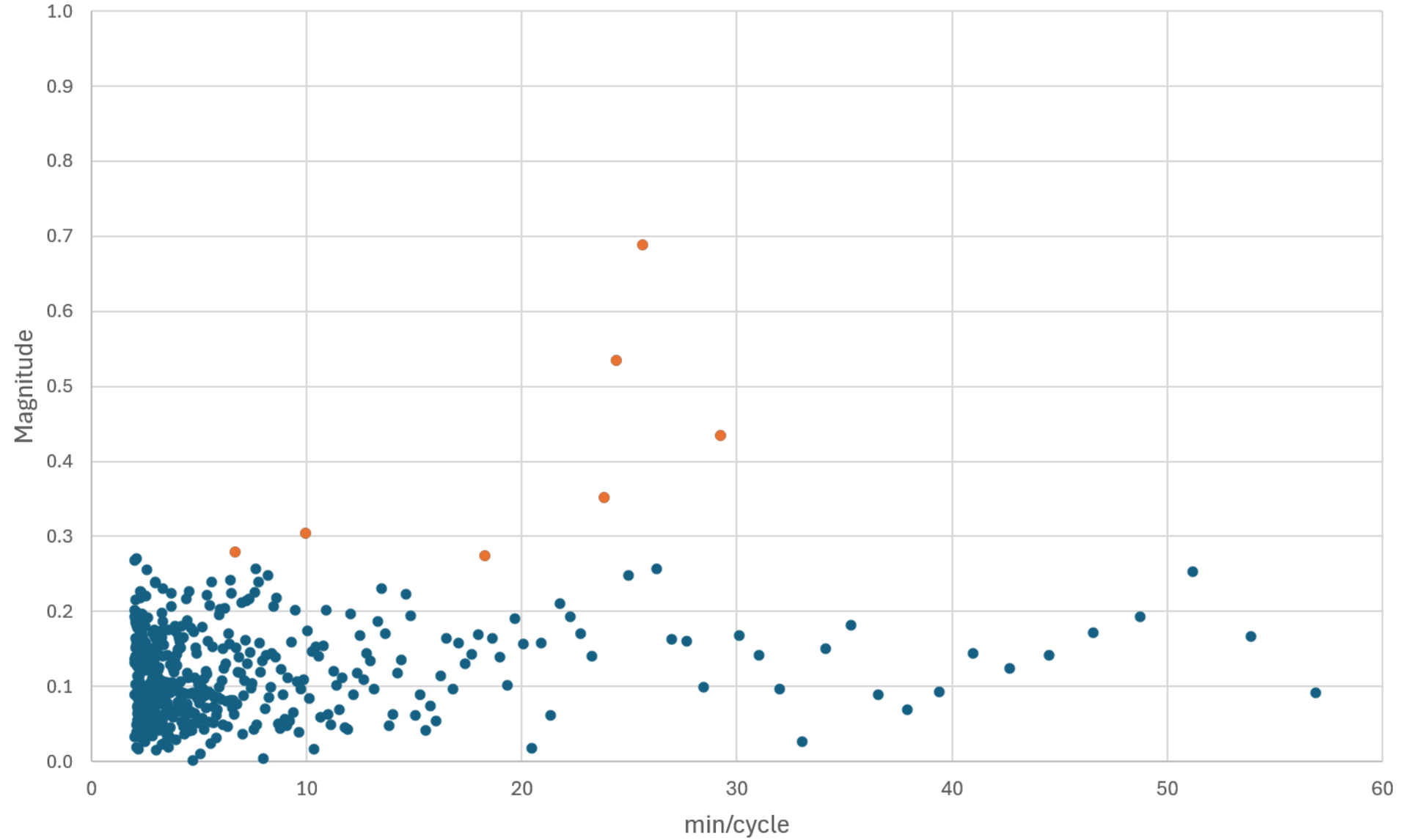
Speed of Sound LP Flare



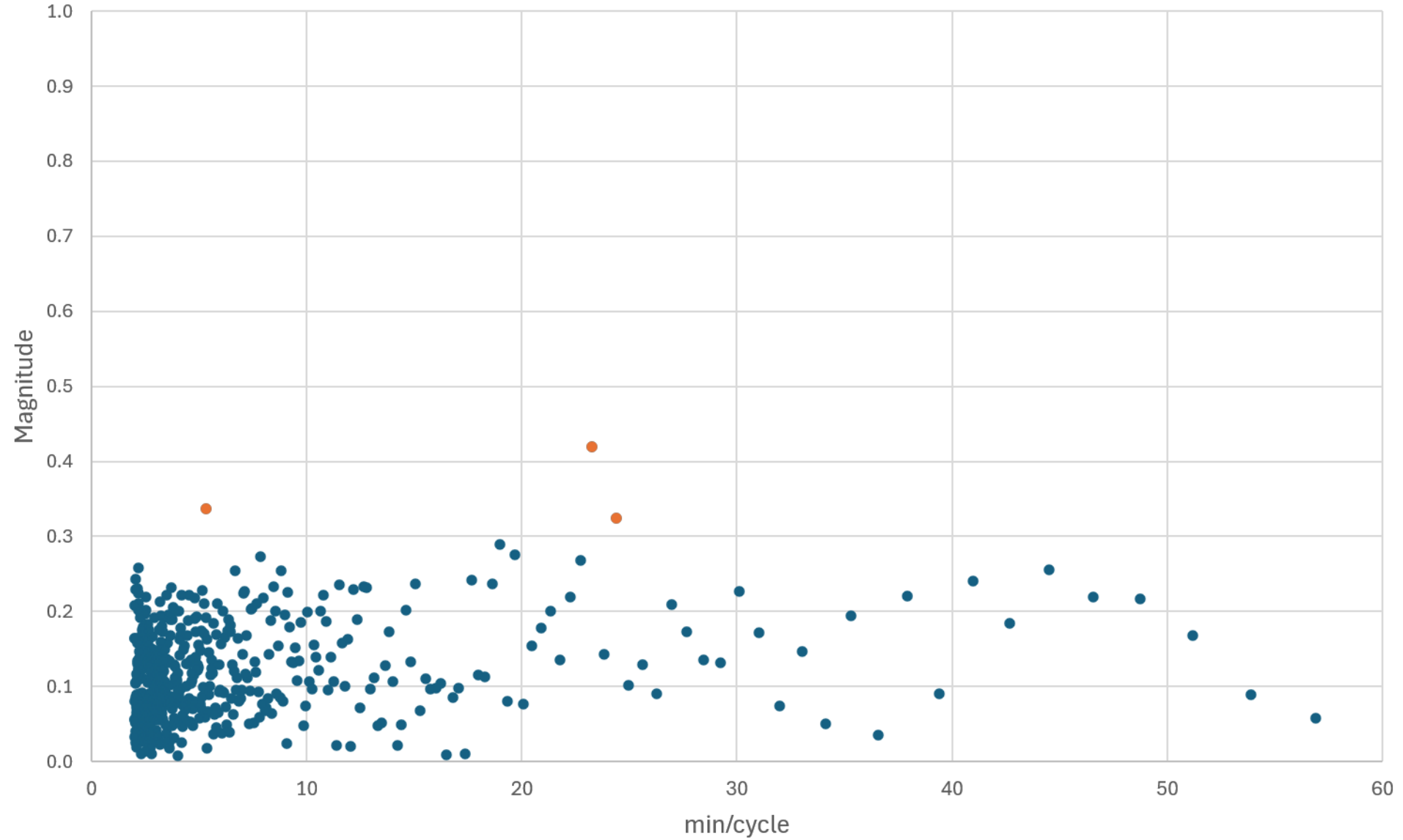
Fourier Transform Results, commencing 2025-04-01 00:00



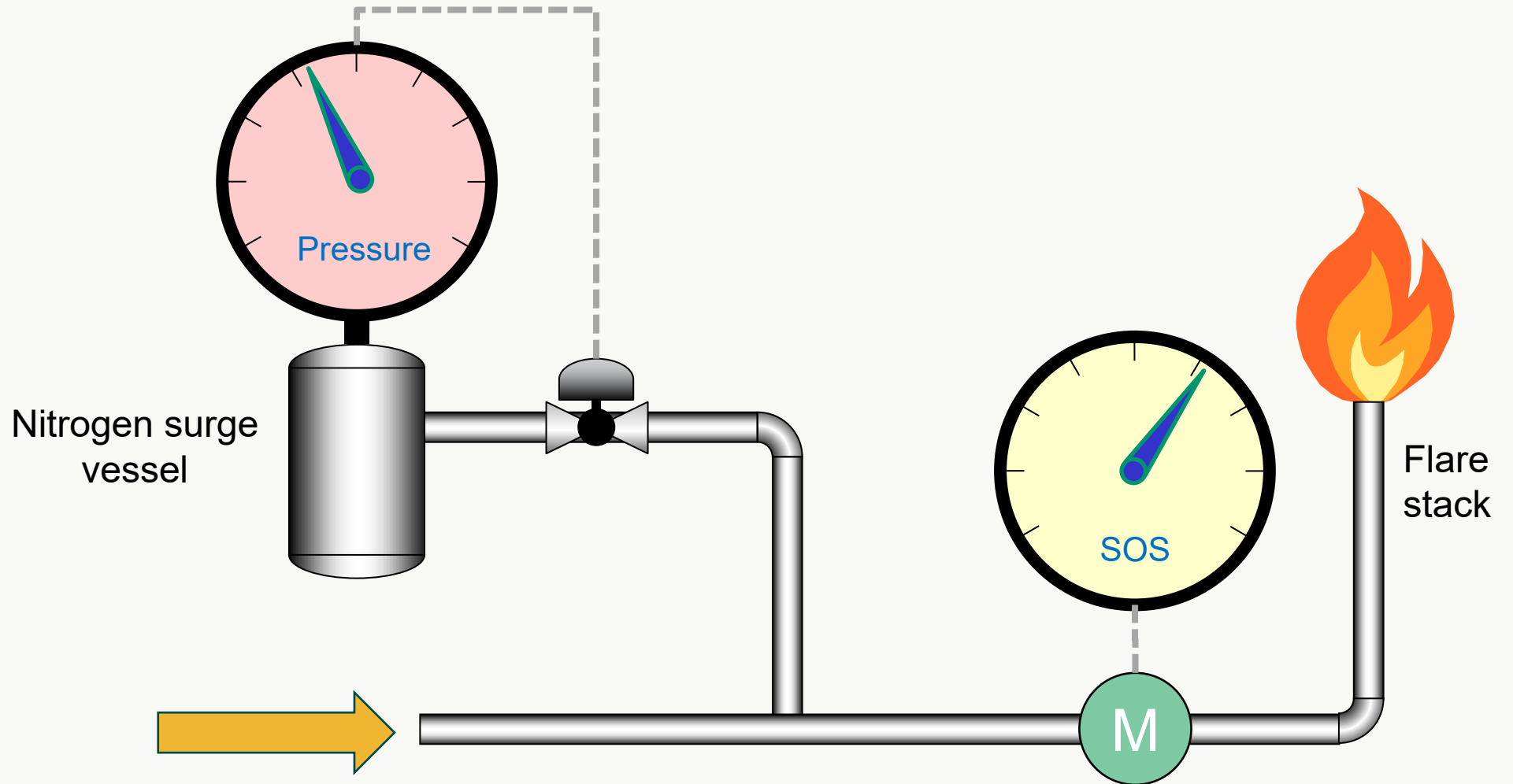
Fourier Transform Results, commencing 2025-04-08 02:40



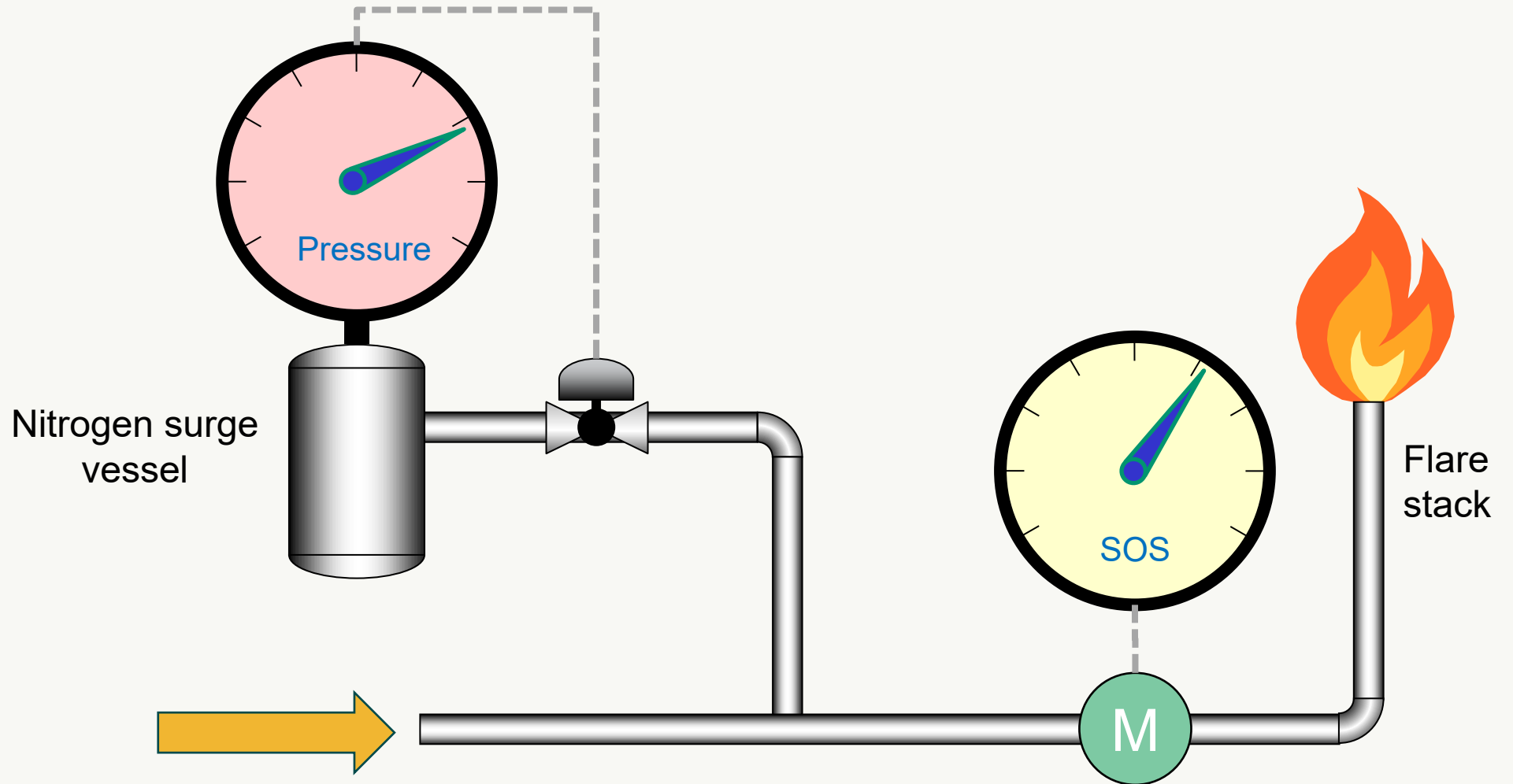
Fourier Transform Results, commencing 2025-04-18 18:42



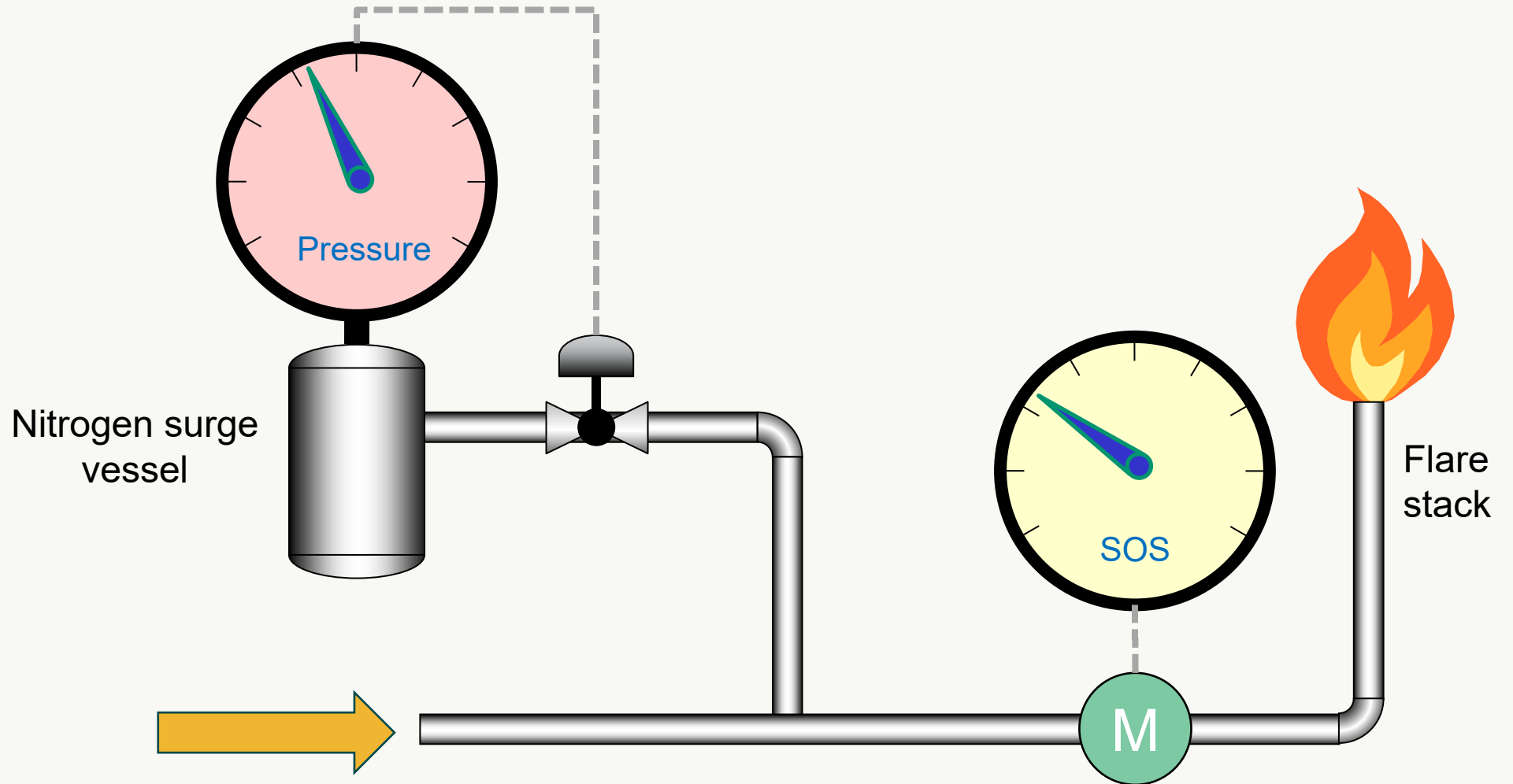
Periodic Venting



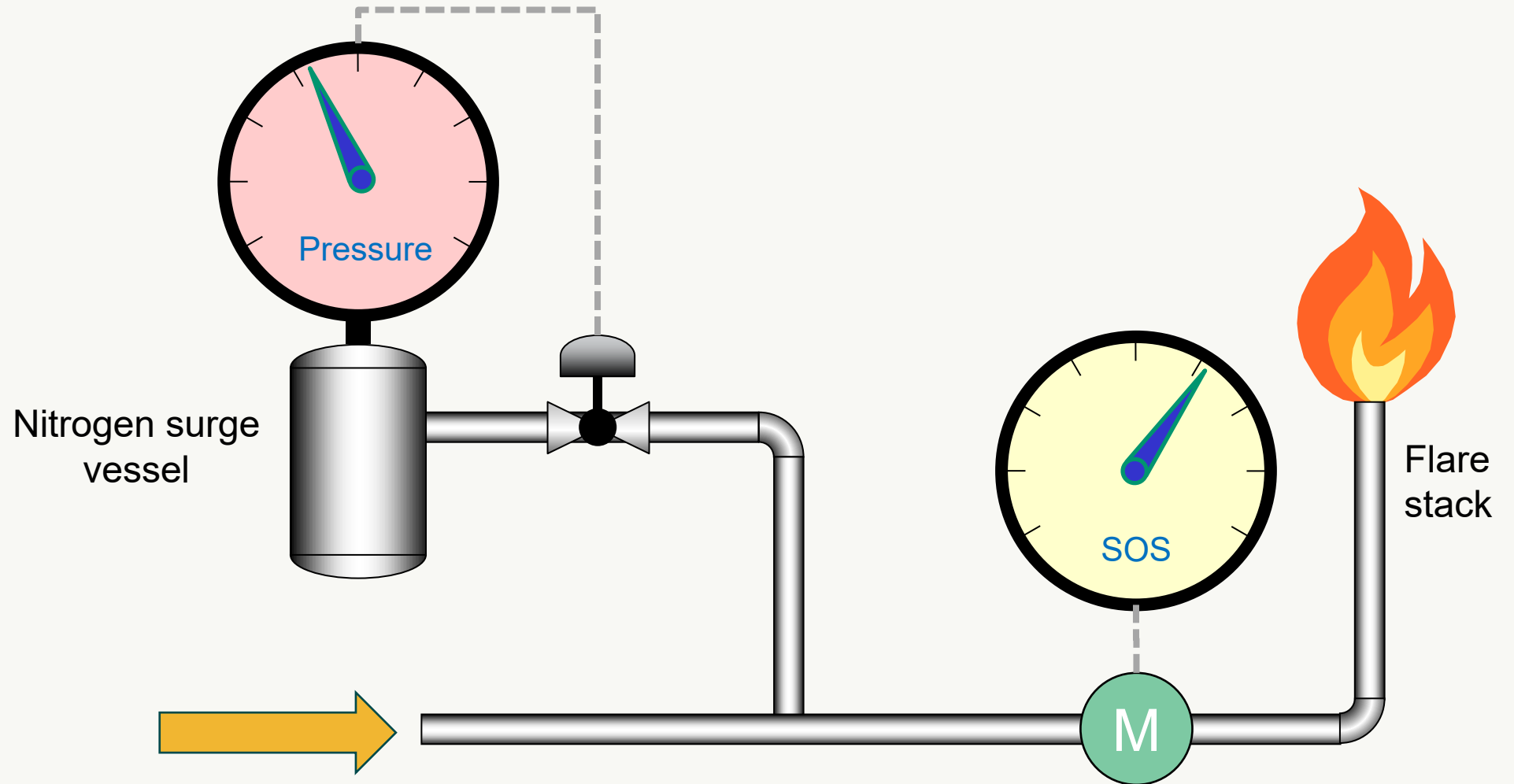
Periodic Venting



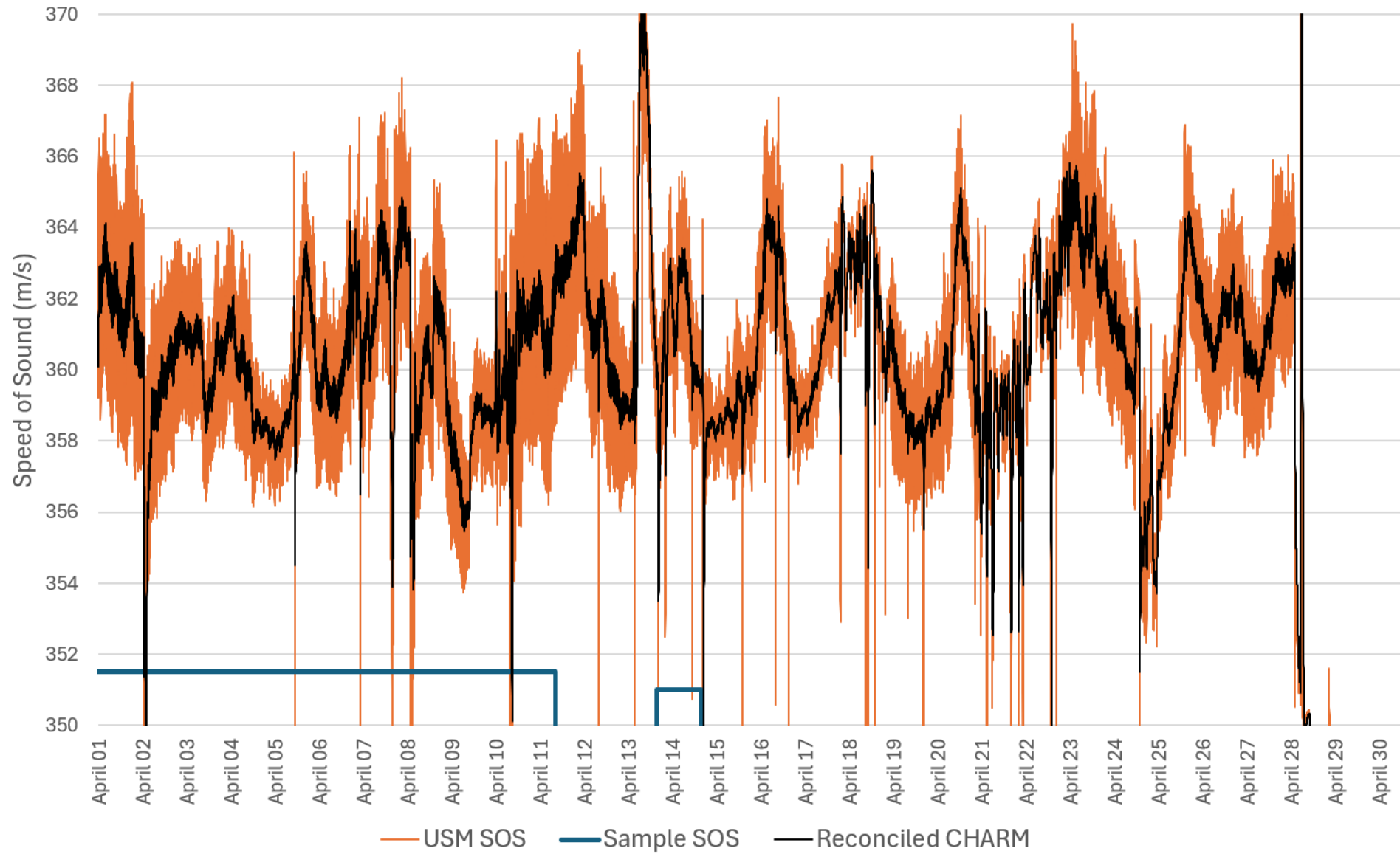
Periodic Venting



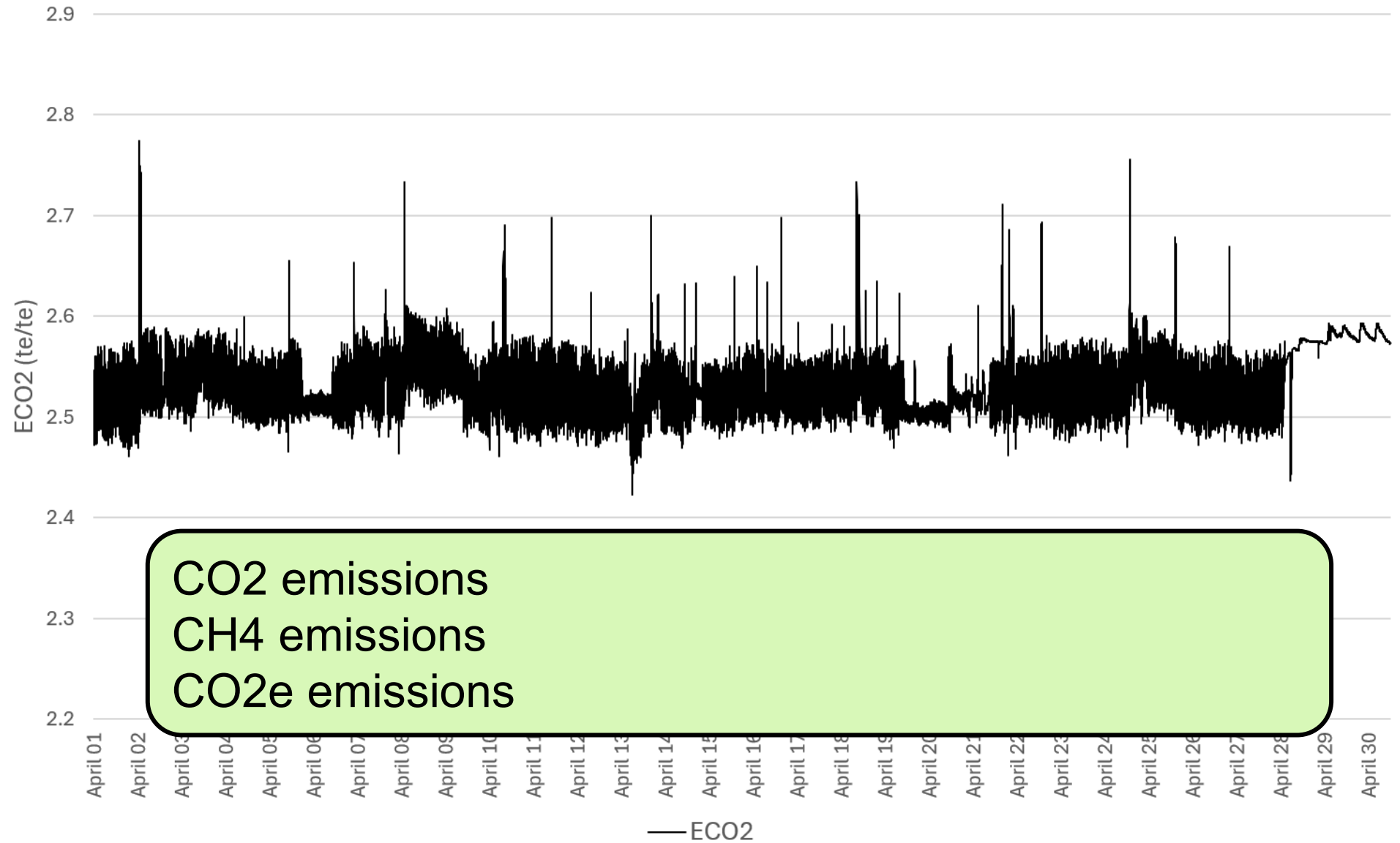
Periodic Venting



Speed of Sound LP Flare



ECO2 LP Flare



Conclusions



Conclusions

SOS verify



Conclusions

SOS verify

CHARM



Conclusions

SOS verify

CHARM

SOS recon.



Conclusions

SOS verify

CHARM

SOS recon.

Fourier transform



Conclusions

SOS verify

CHARM

SOS recon.

Fourier transform

Real time ECO2



Conclusions

SOS verify

CHARM

SOS recon.

Fourier transform

Real time ECO2

Combustor









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