AES 59th INTERNATIONAL CONFERENCE

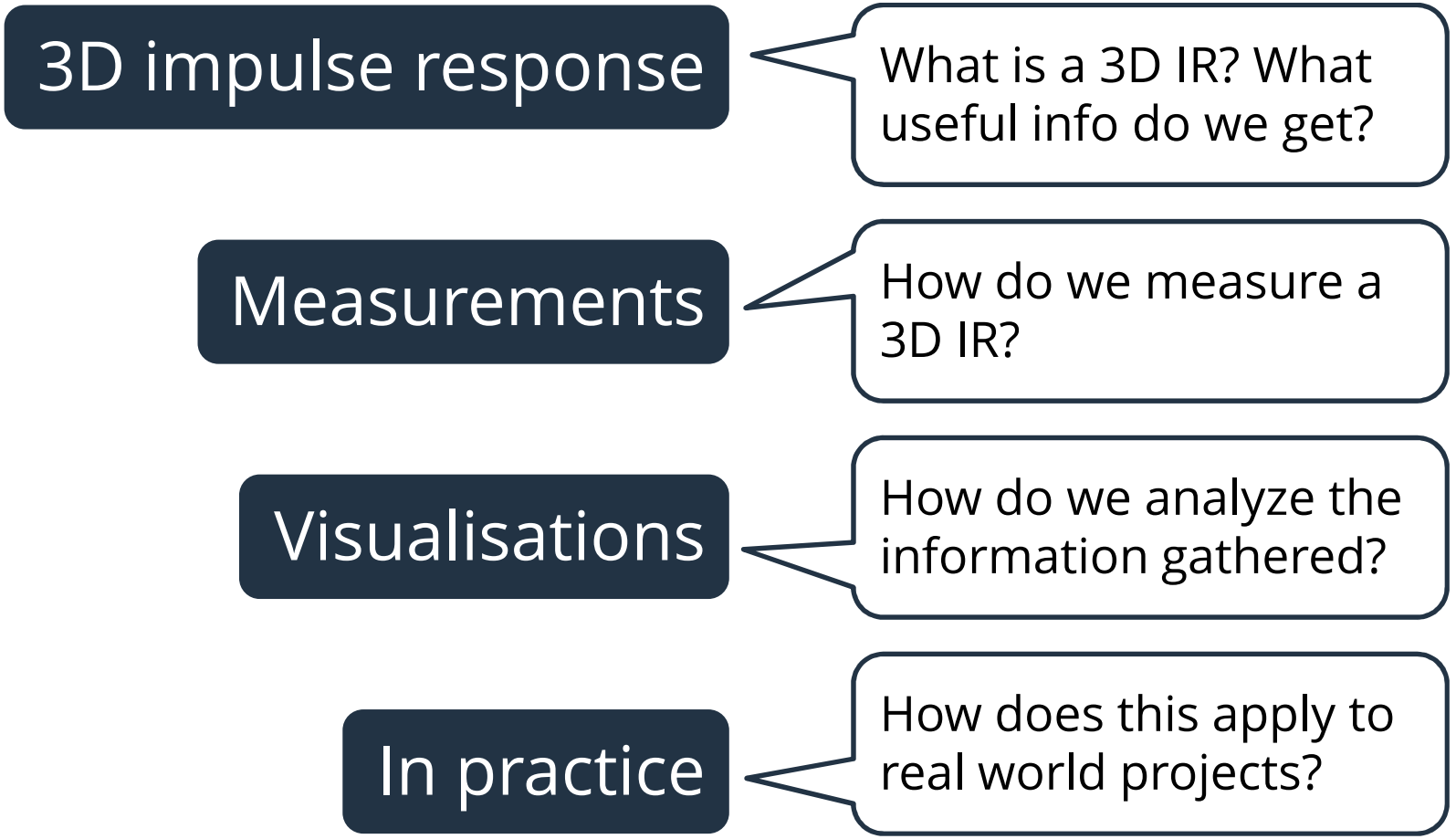
3D impulse response measurements and visualisations in practice

Malcolm Dunn

IRIS

MARSHALL DAY Acoustics

3D impulse response measurements and visualisations in practice

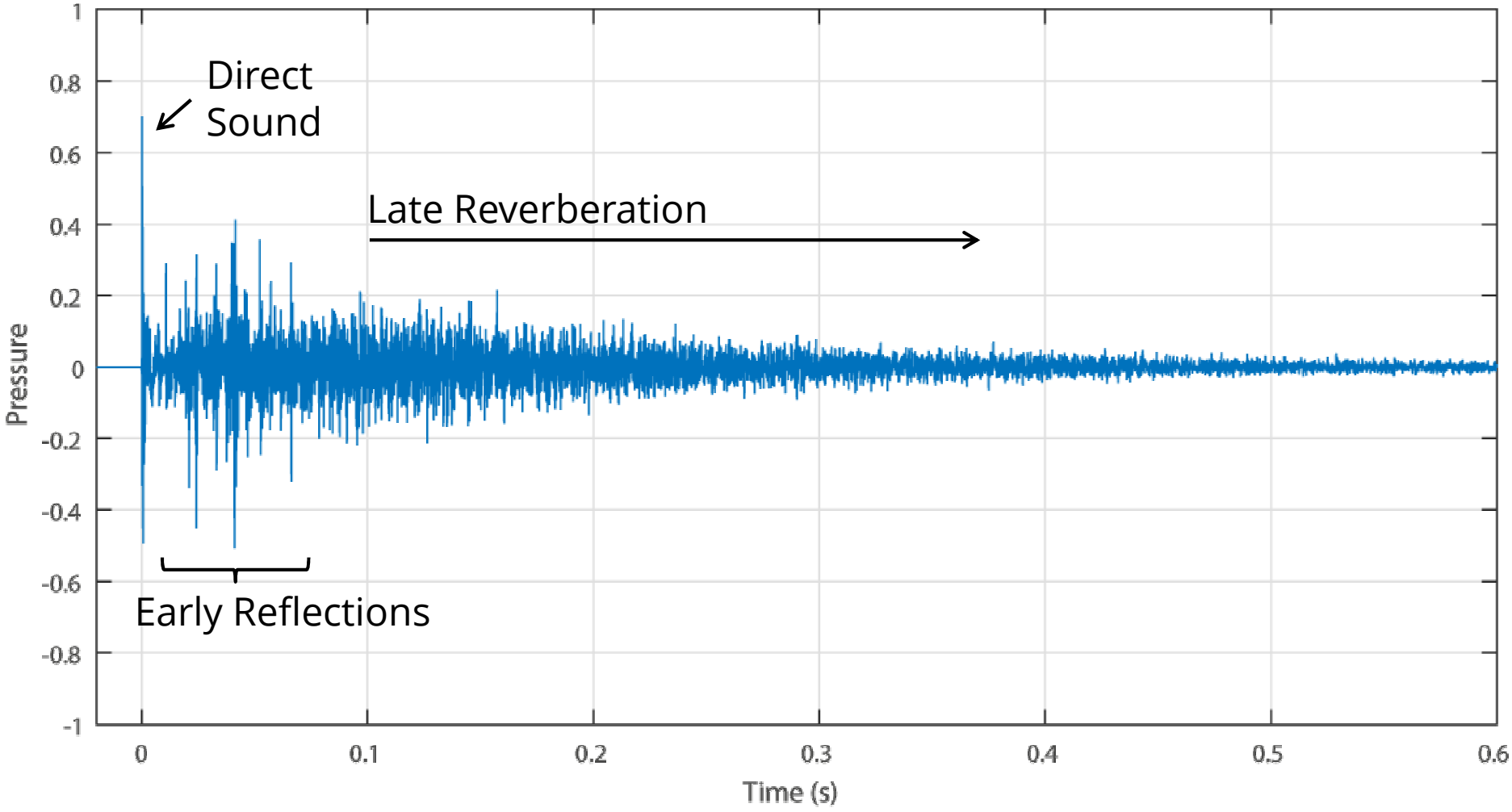


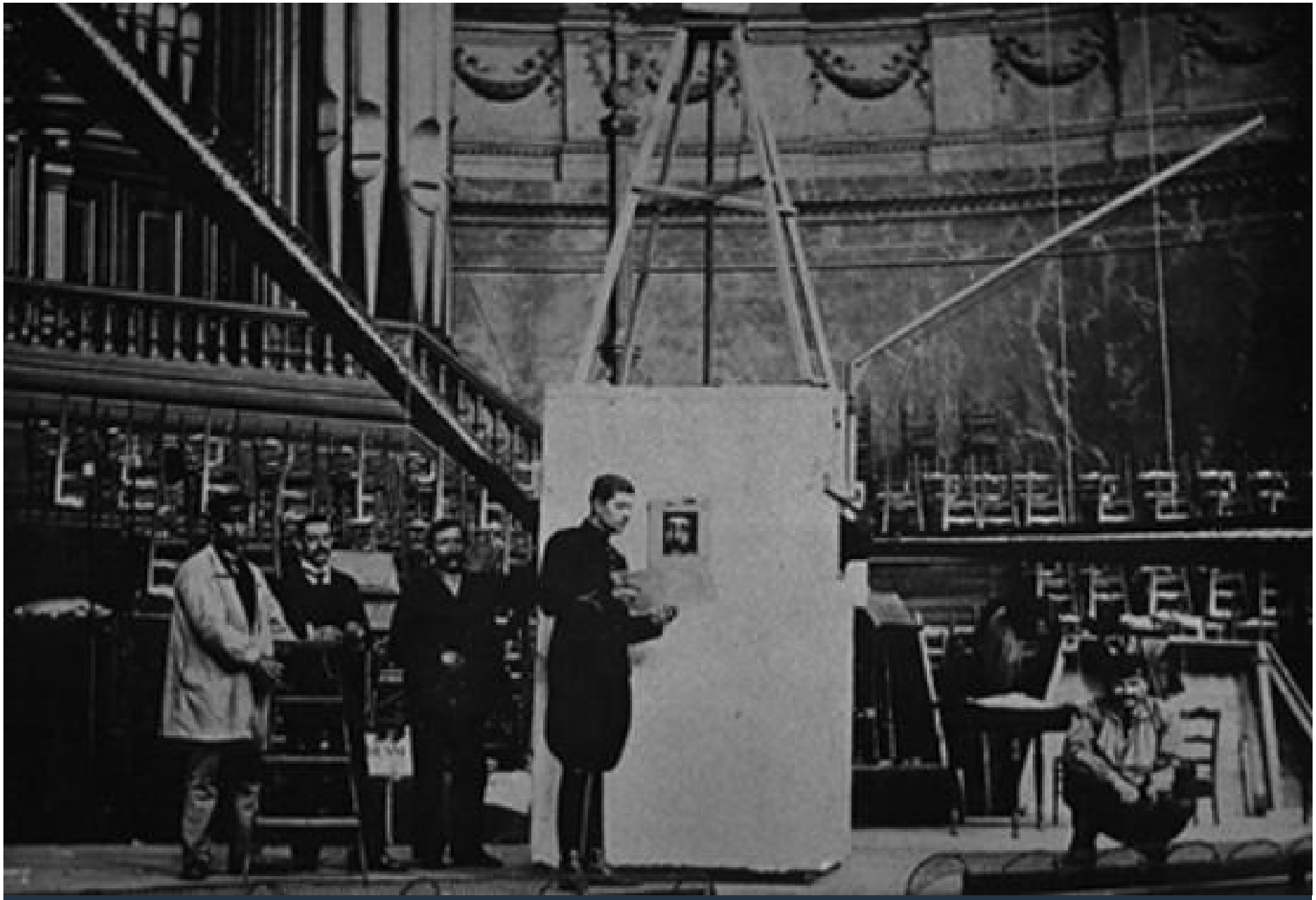
Impulse response

- Describes the sound field at a position in a room

- Mono (omni-directional) IR measurements of rooms have been conducted since 1900s

Impulse response





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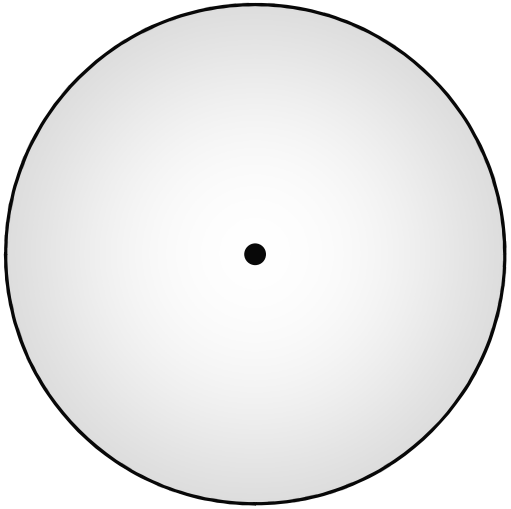
Since the 1970s - Directional microphones used to quantify lateral energy



Omnidirectional Microphone

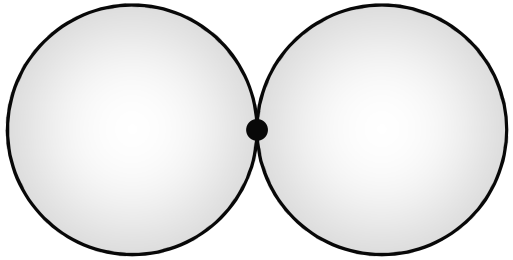


Figure-of-8 Microphone

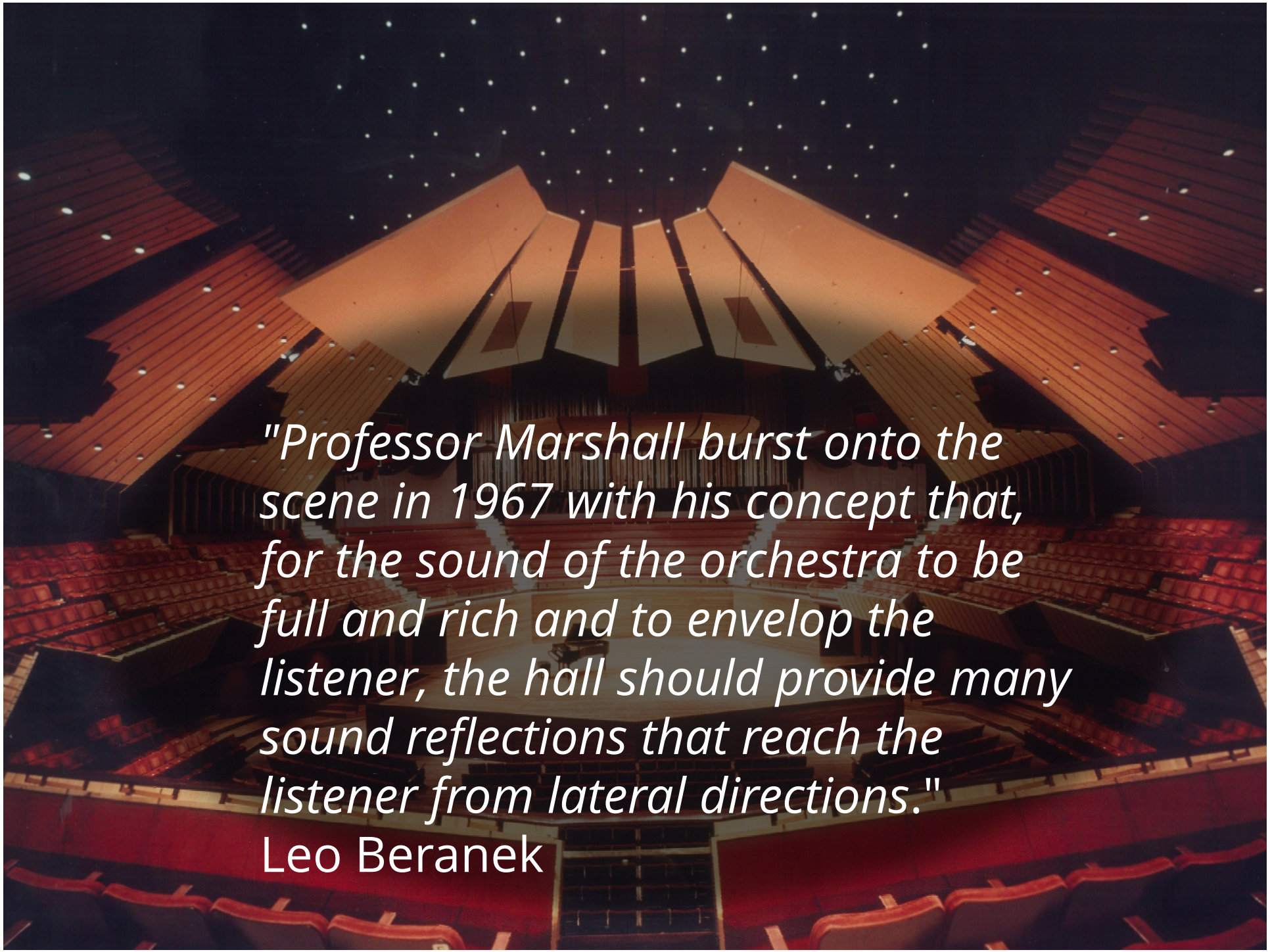
$$\mathrm{LF} = \frac{\text{Early Lateral Energy}}{\text{Early Total Energy}} = \frac{\int_{0.005}^{0.08} p^2(t)\cos^2\theta\, dt}{\int_0^{0.08} p^2(t) dt}$$

3D impulse response

- Includes directional information
  - **Level**, **time** and **direction**
- Why is this useful?
  - Direction is a critical part of our **perception** of sound
  - Better understand the interaction between the source and **the room**

Perception of sound

- Hearing is not omni-directional
- Perception governed by
  - content/quality of sound
  - direction of arrival
- Directional information places us ‘in the space’ and establishes our relationship to the sound source.
- Critical to our sense of envelopment.


"Professor Marshall burst onto the scene in 1967 with his concept that, for the sound of the orchestra to be full and rich and to envelop the listener, the hall should provide many sound reflections that reach the listener from lateral directions."
Leo Beranek

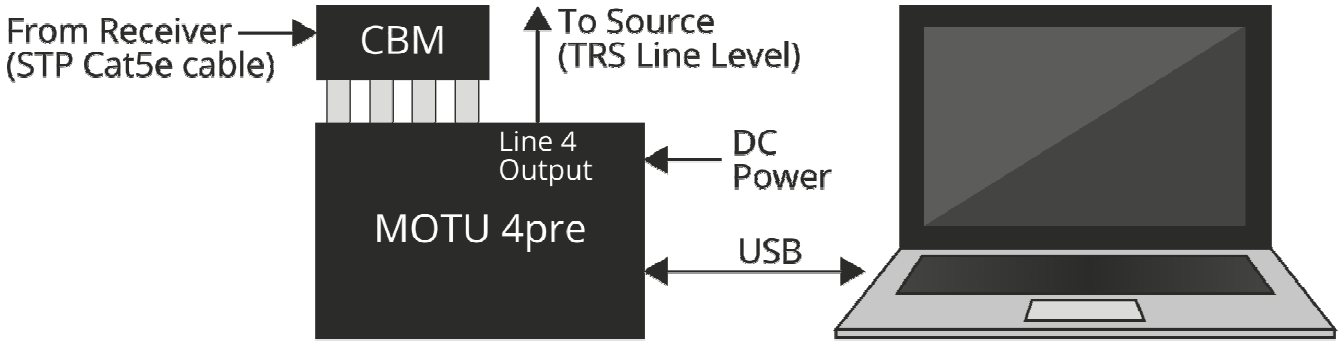
Understand the room

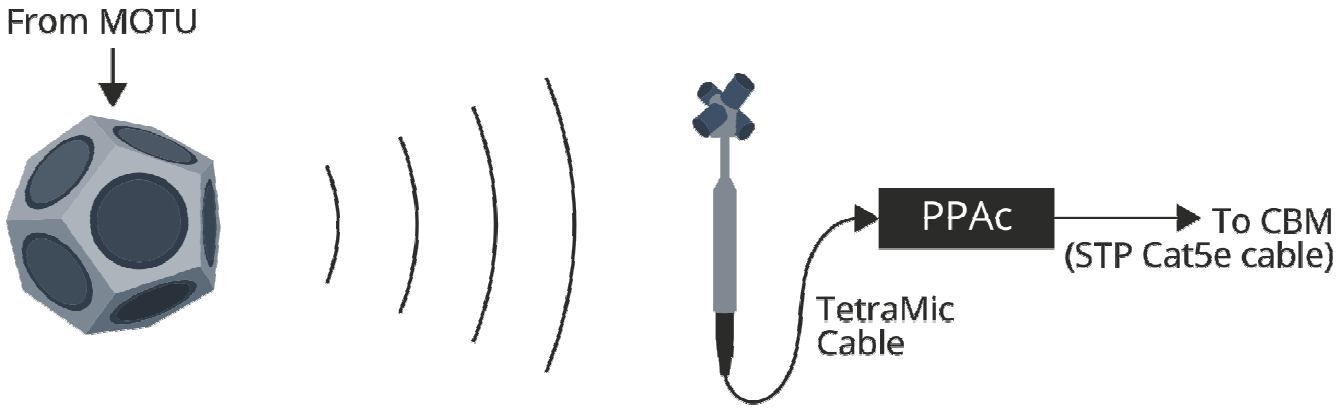
- See the relative strength of the direct, early and late energy and where it is arriving from
- Identify the location of problematic reflections
- Check direction and alignment of loudspeakers

Capture 3D impulse response

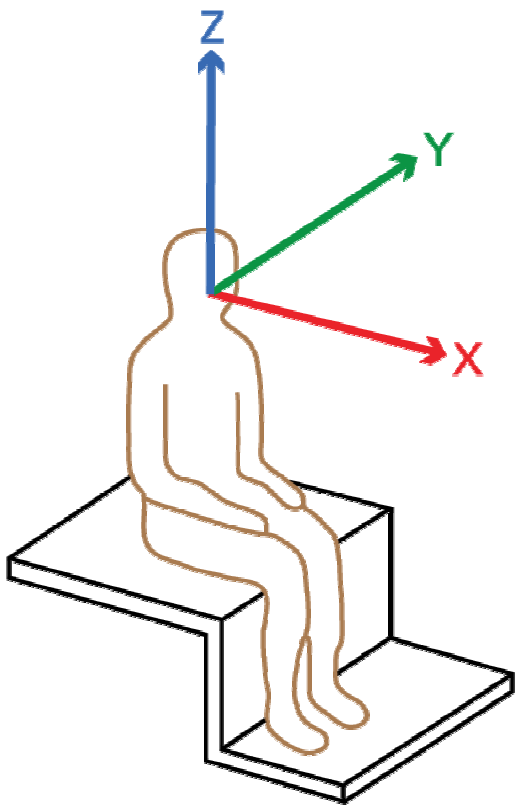
- Tetrahedral microphone array (Core Sound TetraMic)
- The room is excited with exponentially swept sine wave
  - Very good noise & distortion rejection
  - Enables a wide variety of sound sources

Capture 3D impulse response



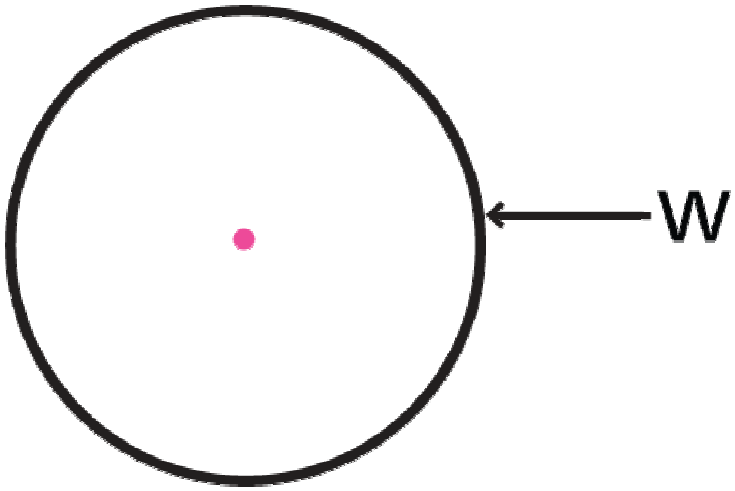


Capture 3D impulse response

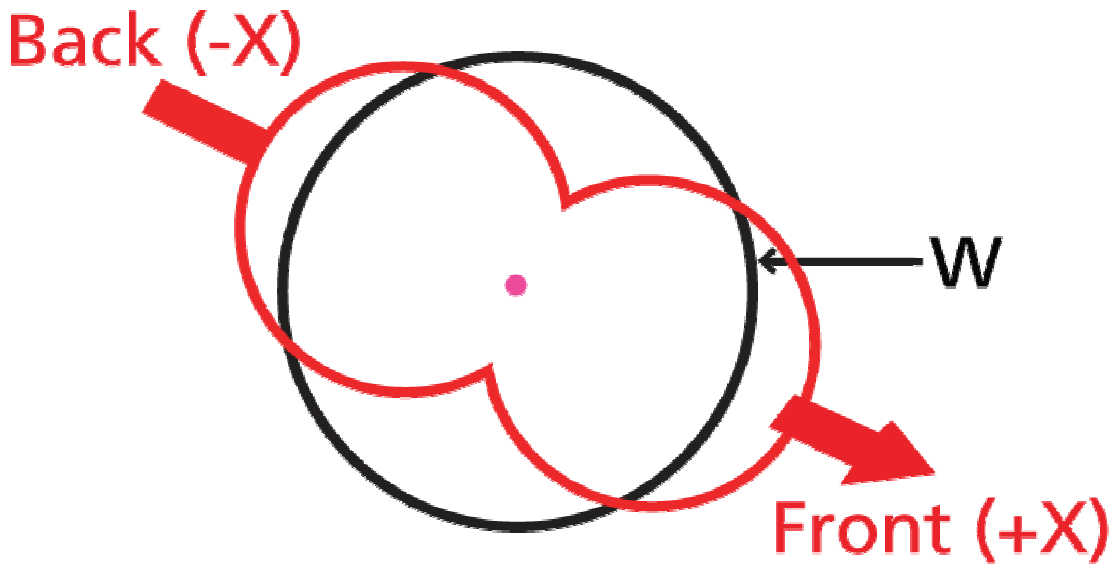


- Four signals: B-format
  - Sound pressure (omni)
  - Particle velocity in the X, Y, Z directions (fig-8)

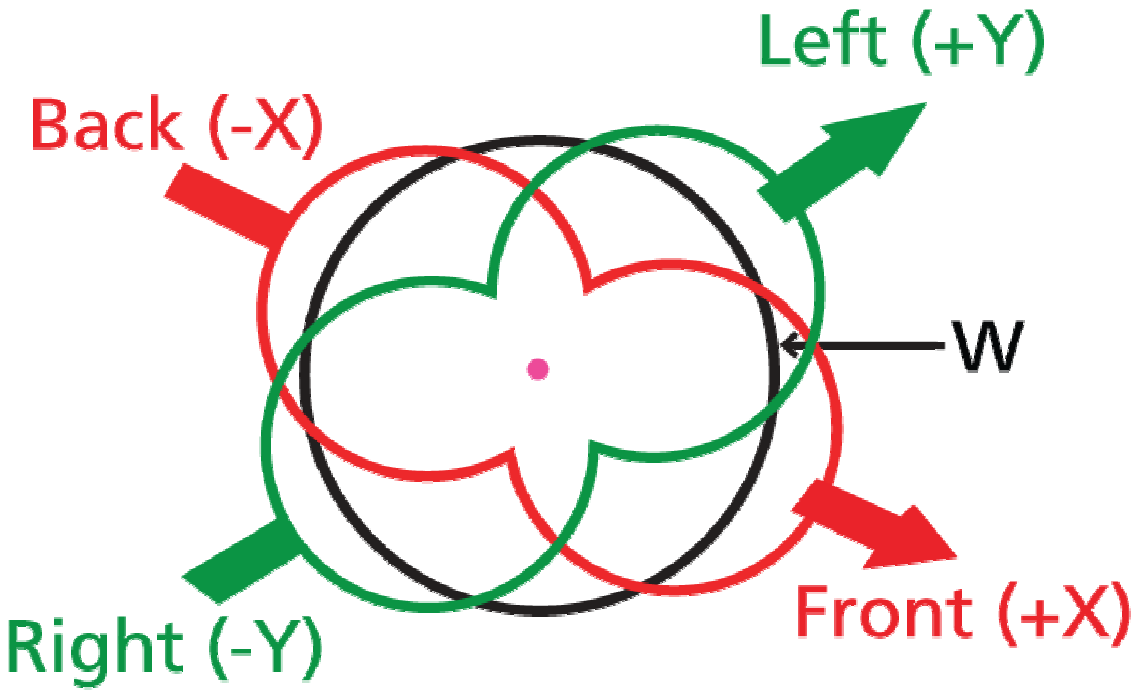
B-format



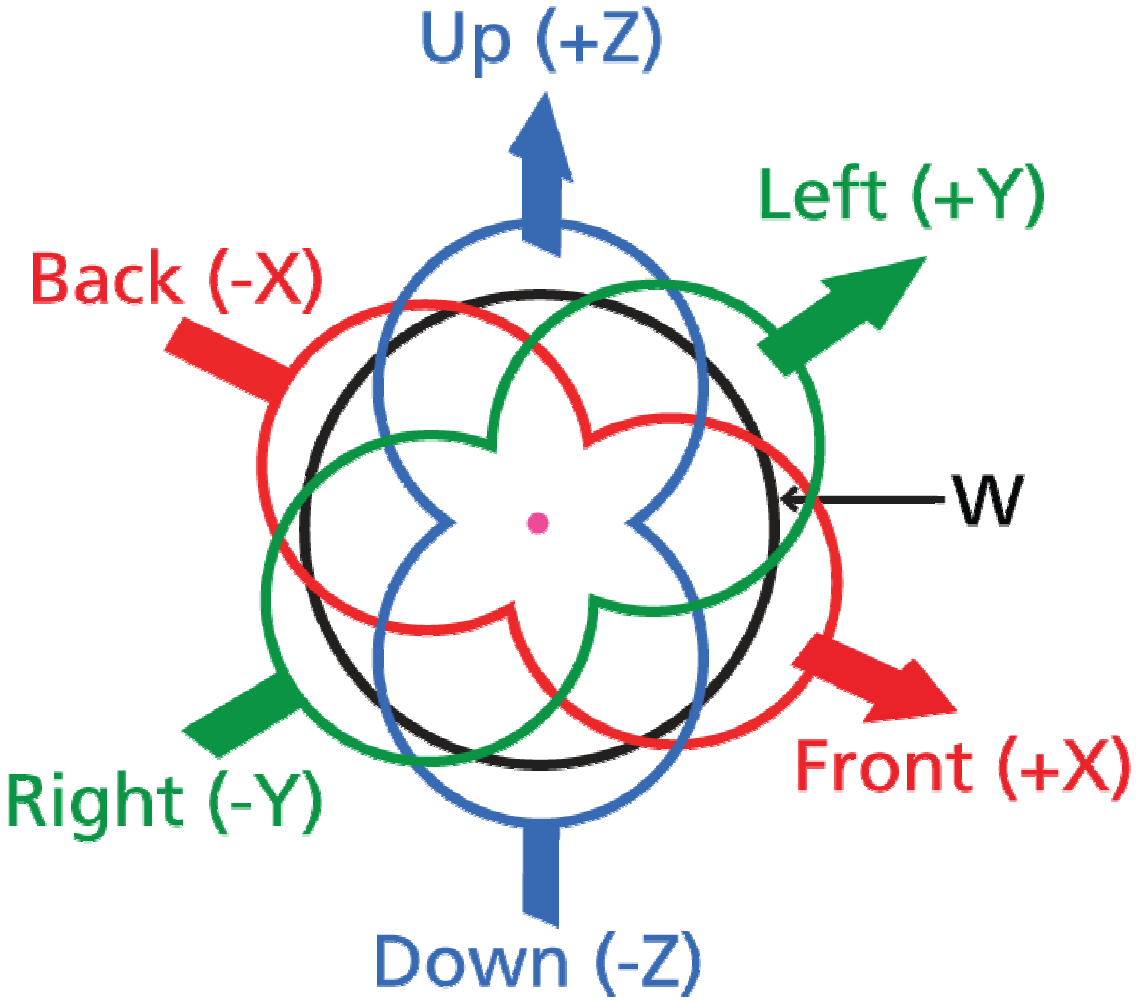
B-format



B-format



B-format

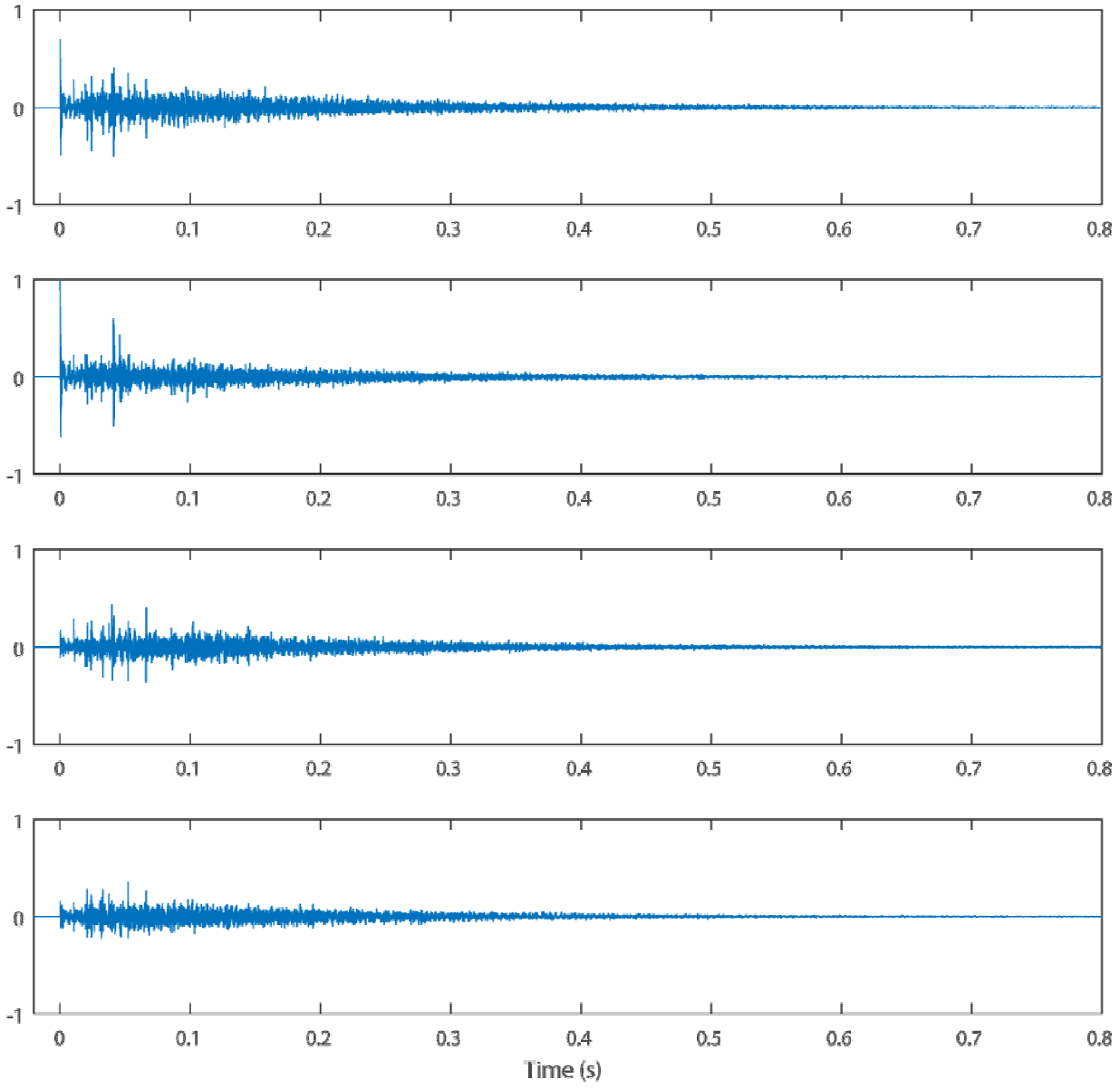


W (Pressure)

X Velocity

Y Velocity

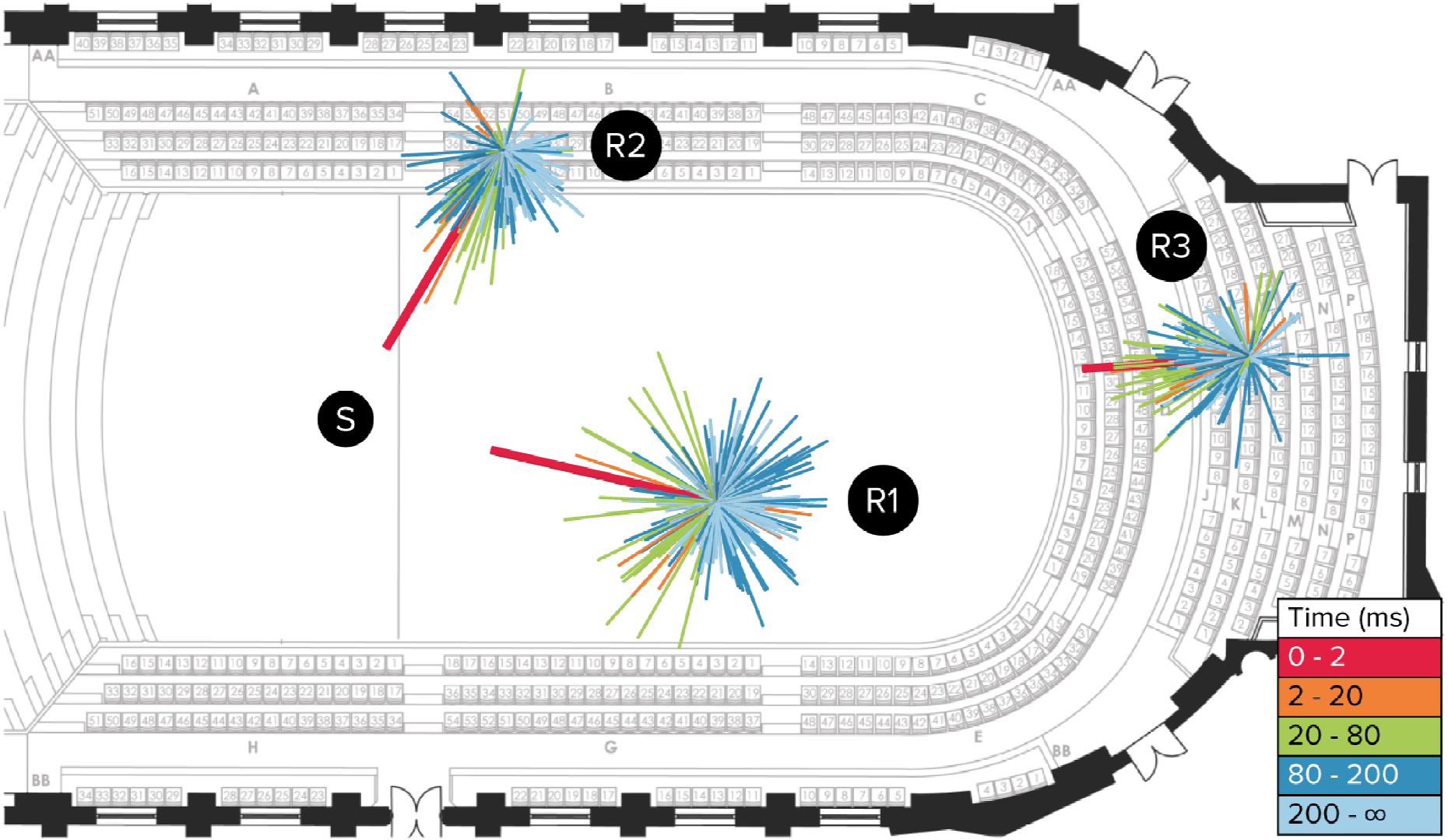
Z Velocity

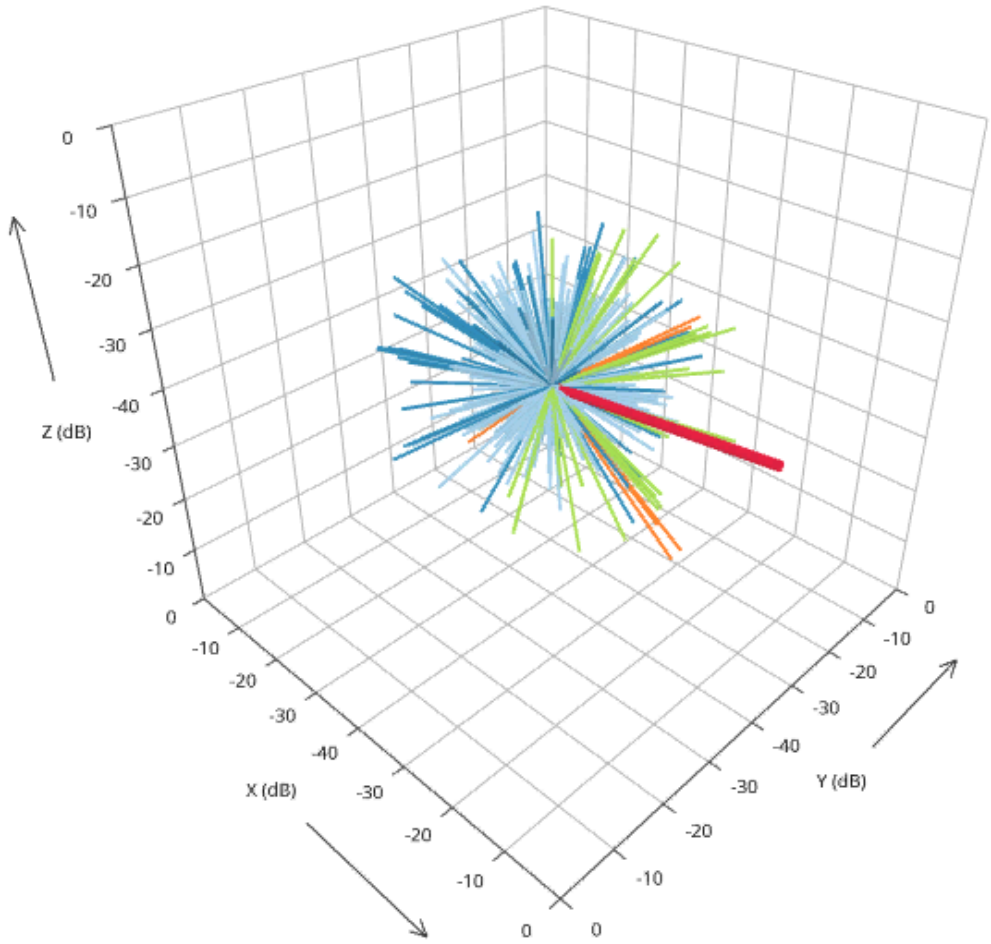


Visualisation

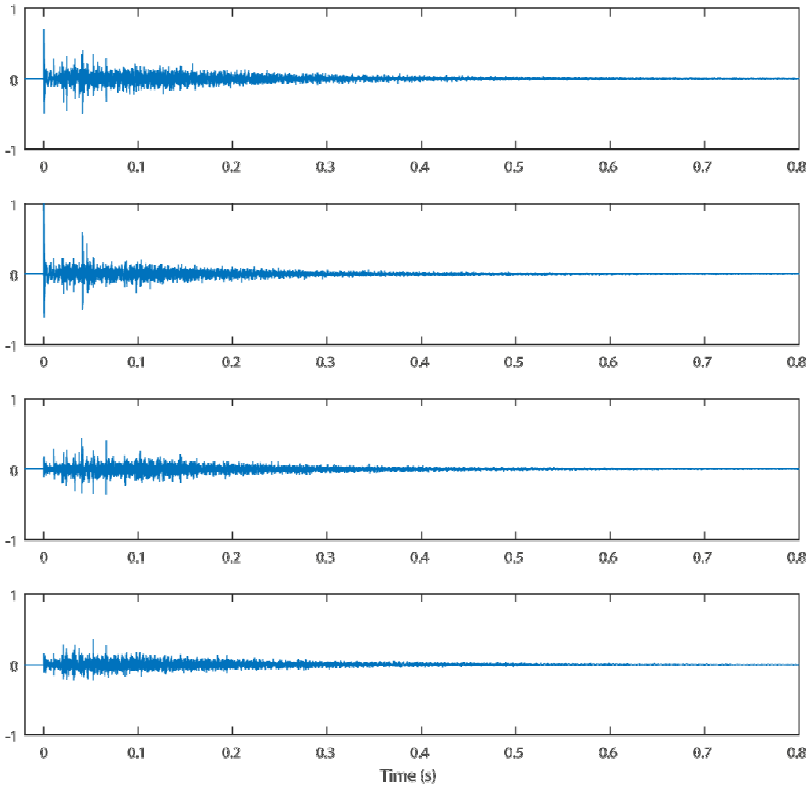
- Challenge – how do we get meaningful information from these 4 signals?

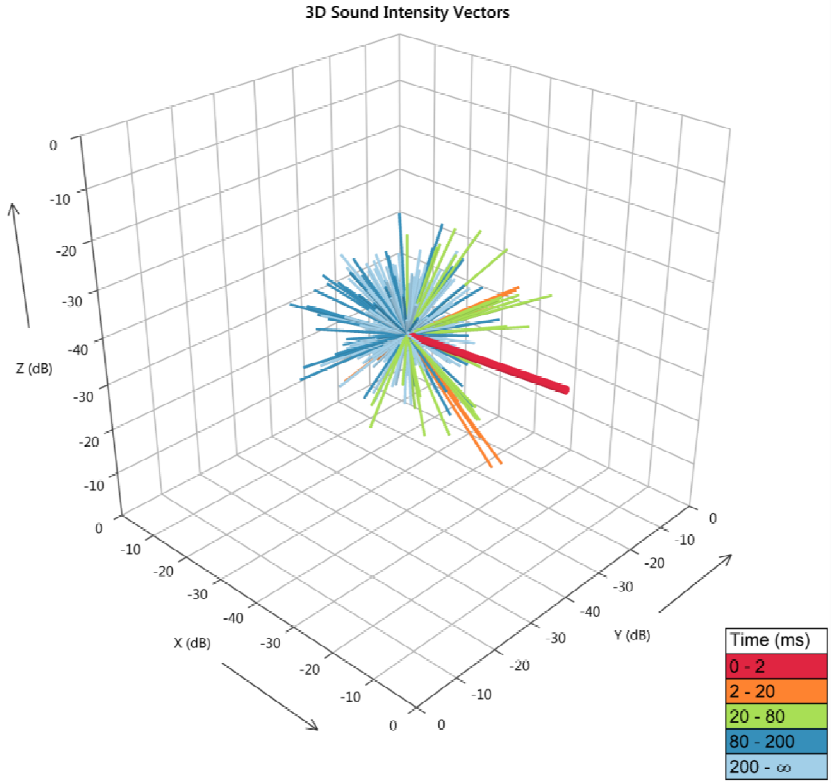
Visualisation – IRIS plot



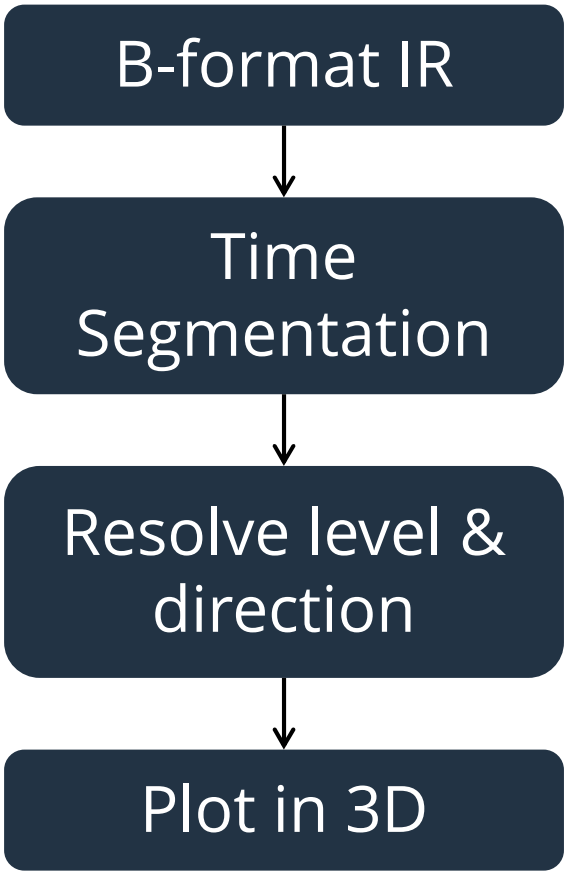

0
-10
-20
-30
-40
Z (dB)
-30
-20
-10
0
-10
-20
-30
-40
X (dB)
-30
-20
-10
0
0
-10
-20
-30
-40
Y (dB)
-30
-20
-10
0

Visualisation – IRIS plot

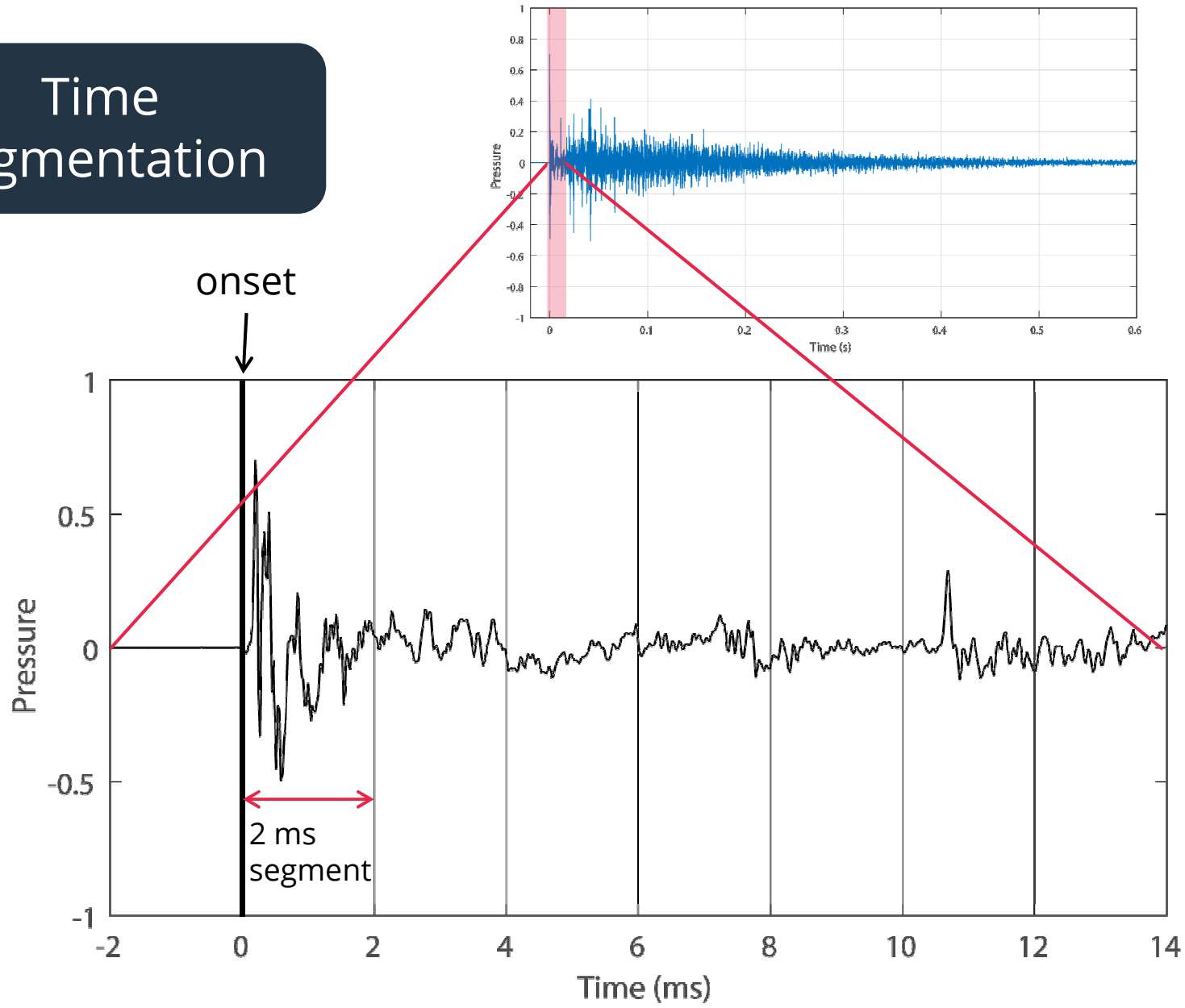




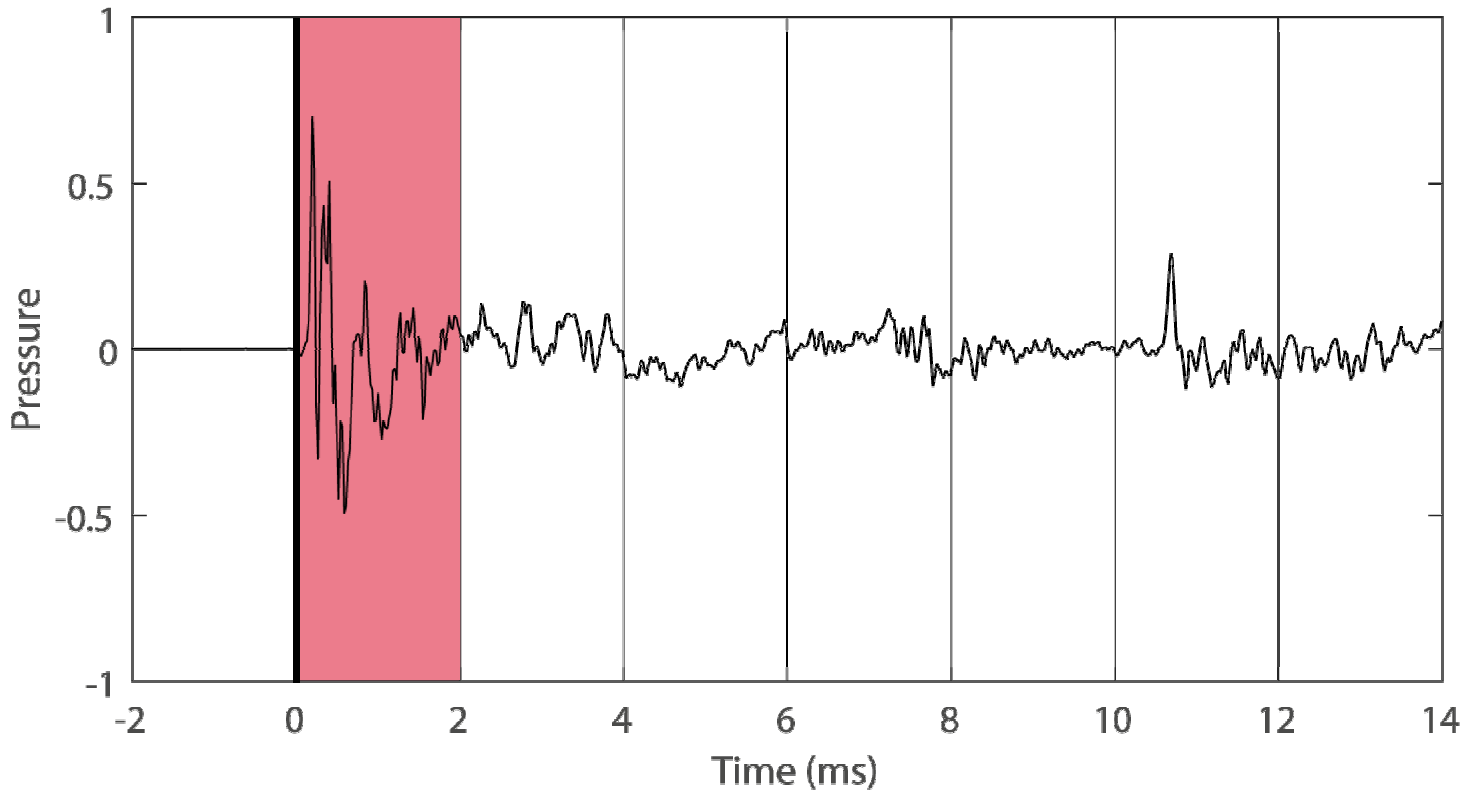
Visualisation – IRIS plot



Time Segmentation



Time Segmentation → Resolve level & direction



Resolve level & direction

Sound intensity - a quantity that describes rate of sound energy flow through a unit area, in a certain **direction**

$$\mathbf{I} = \overline{p(t)\mathbf{u}(t)}$$

Time averaged 3D sound intensity vector

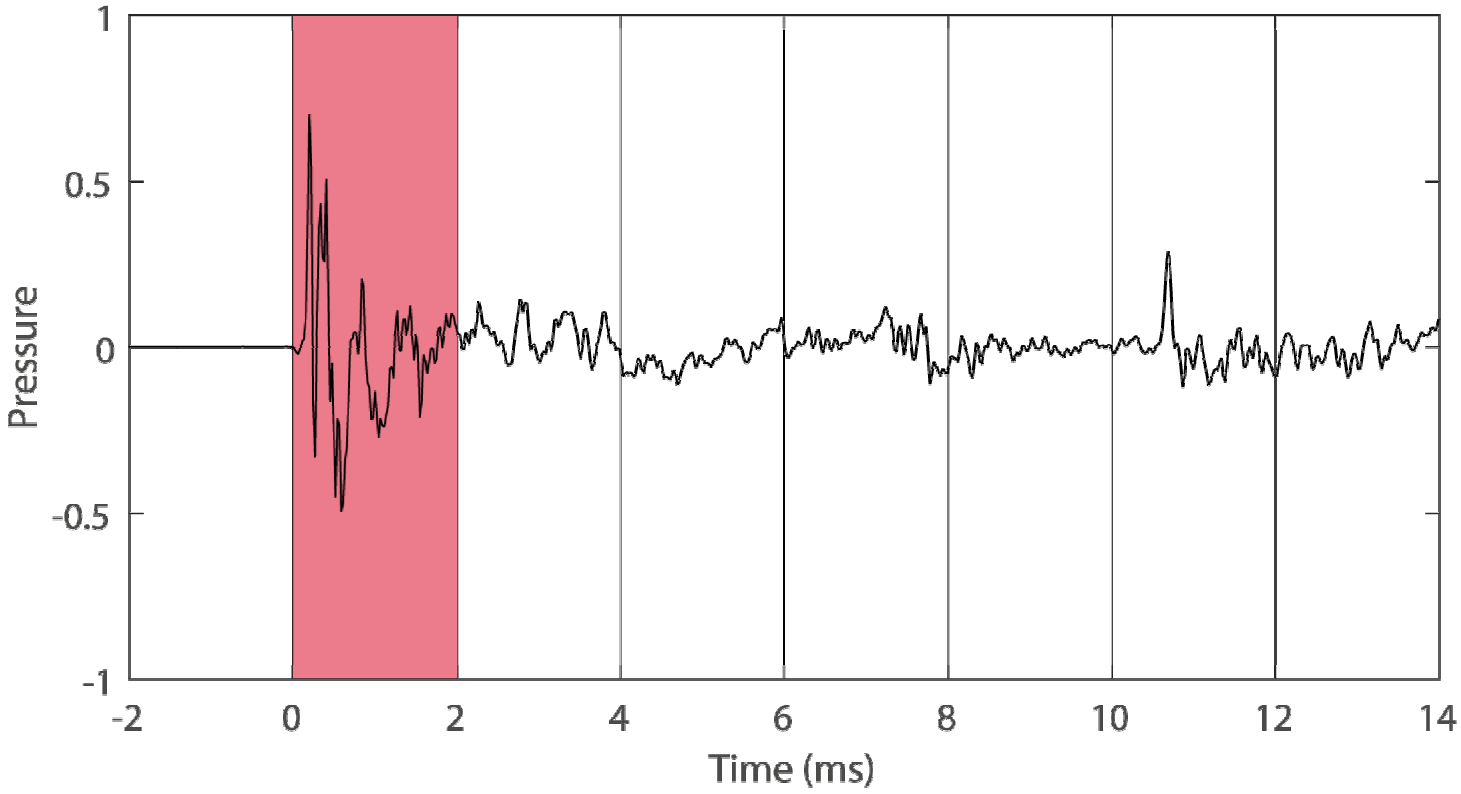
Sound pressure

3D particle velocity vector

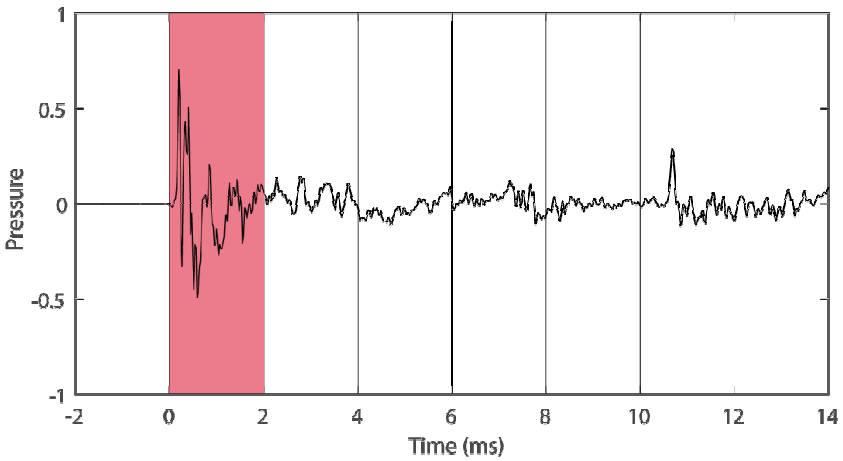
(B-format)

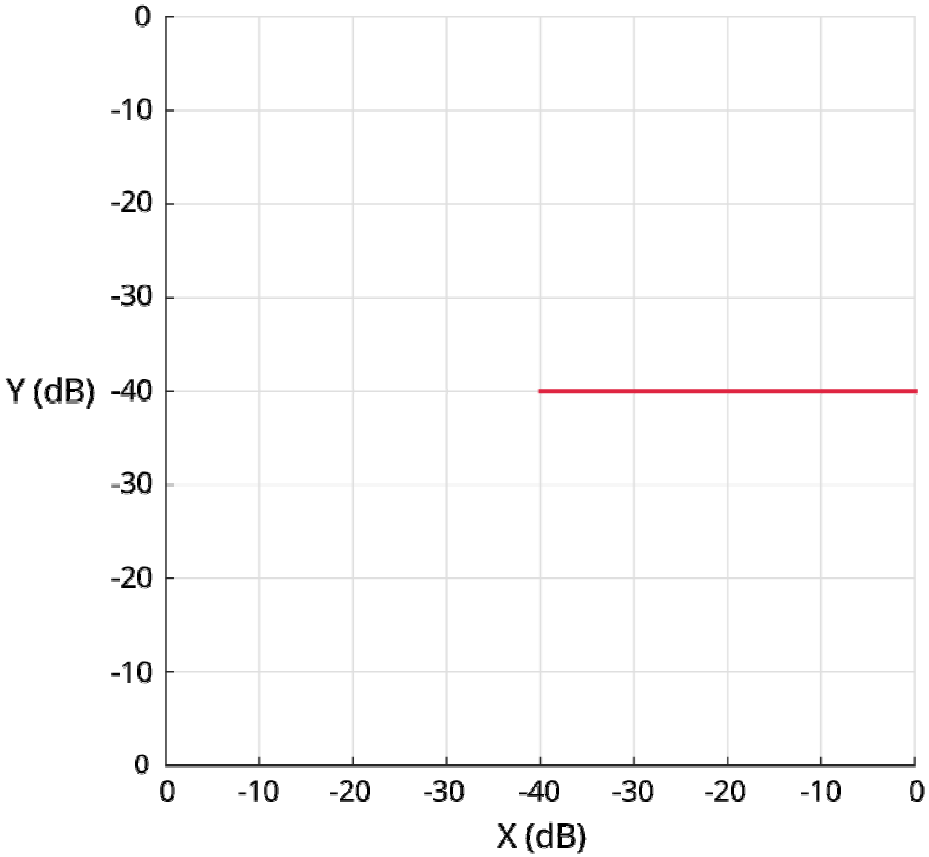
Resolve level & direction

Level = 0 dB
Azimuth = 0°
Elevation = -1.6°
Time = 0 ms



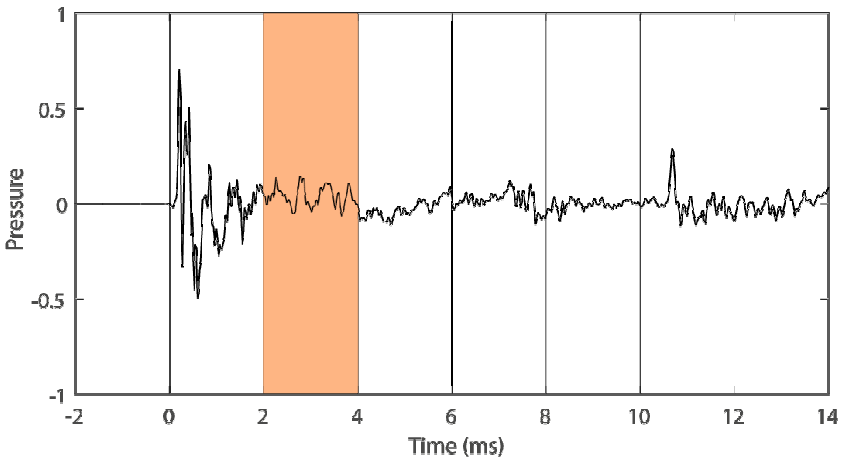
Plot in 3D

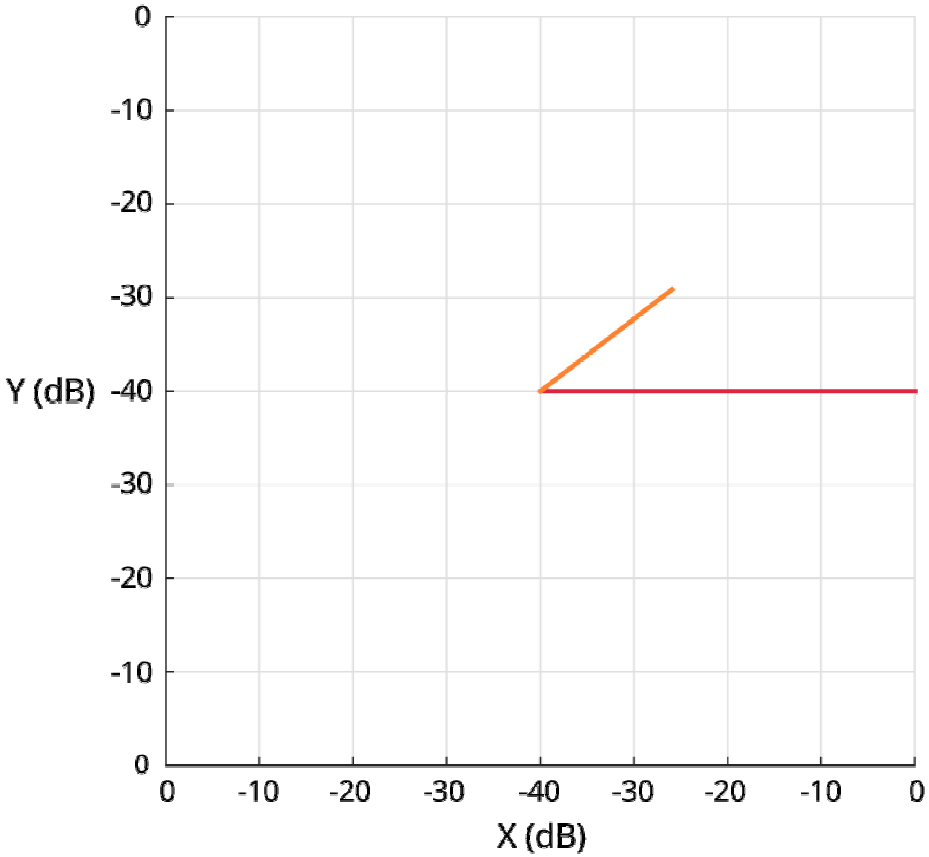




Level = 0 dB
Azimuth = 0°
Elevation = -1.6°
Time = 0 ms

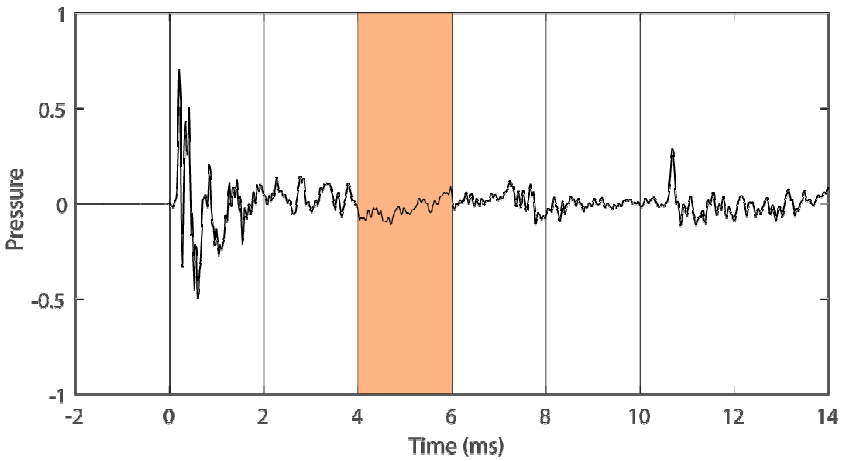
Plot in 3D

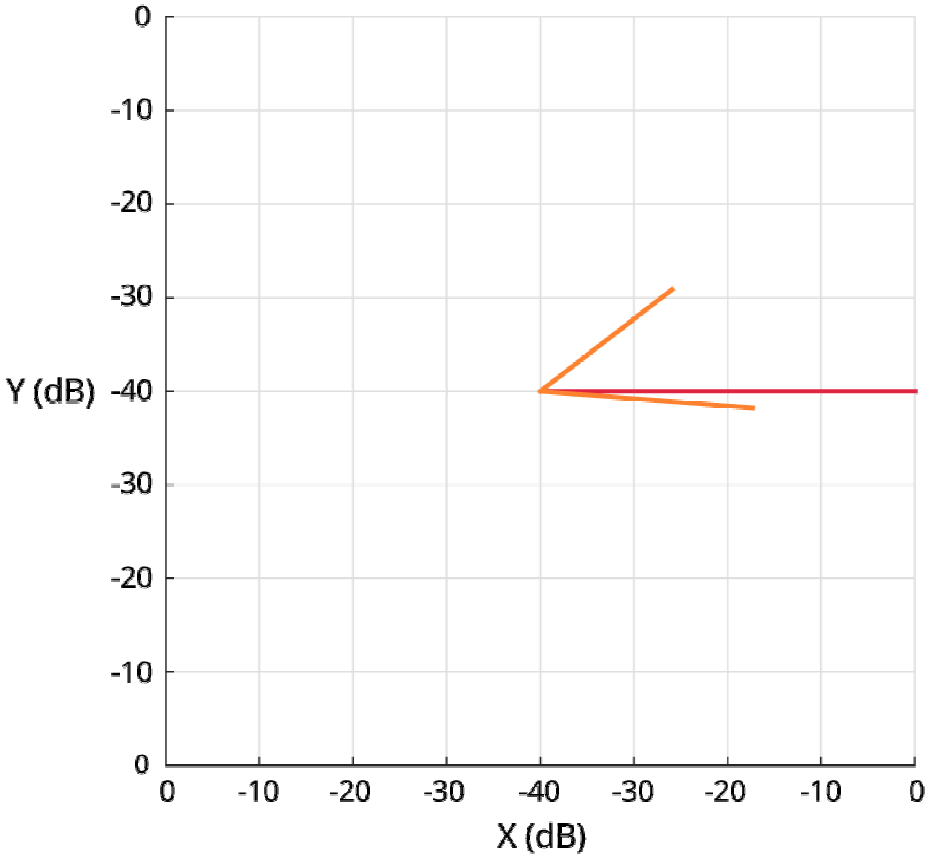




Level = -10 dB
Azimuth = 37.7°
Elevation = -53.6°
Time = 2 ms

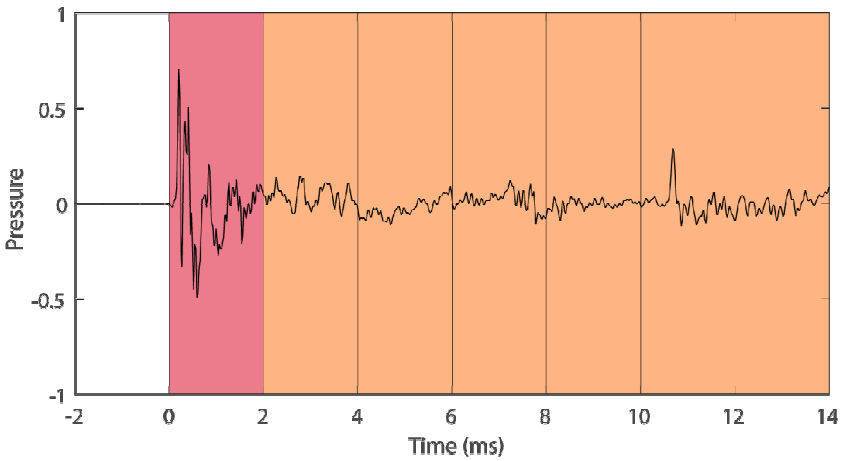
Plot in 3D

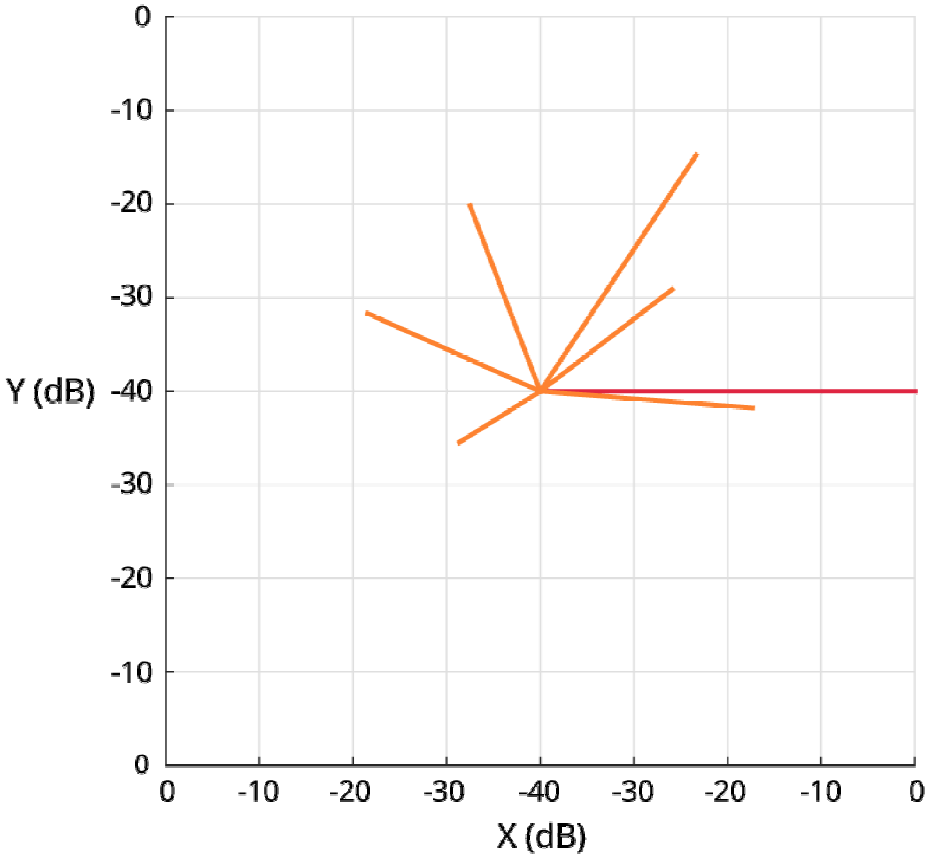




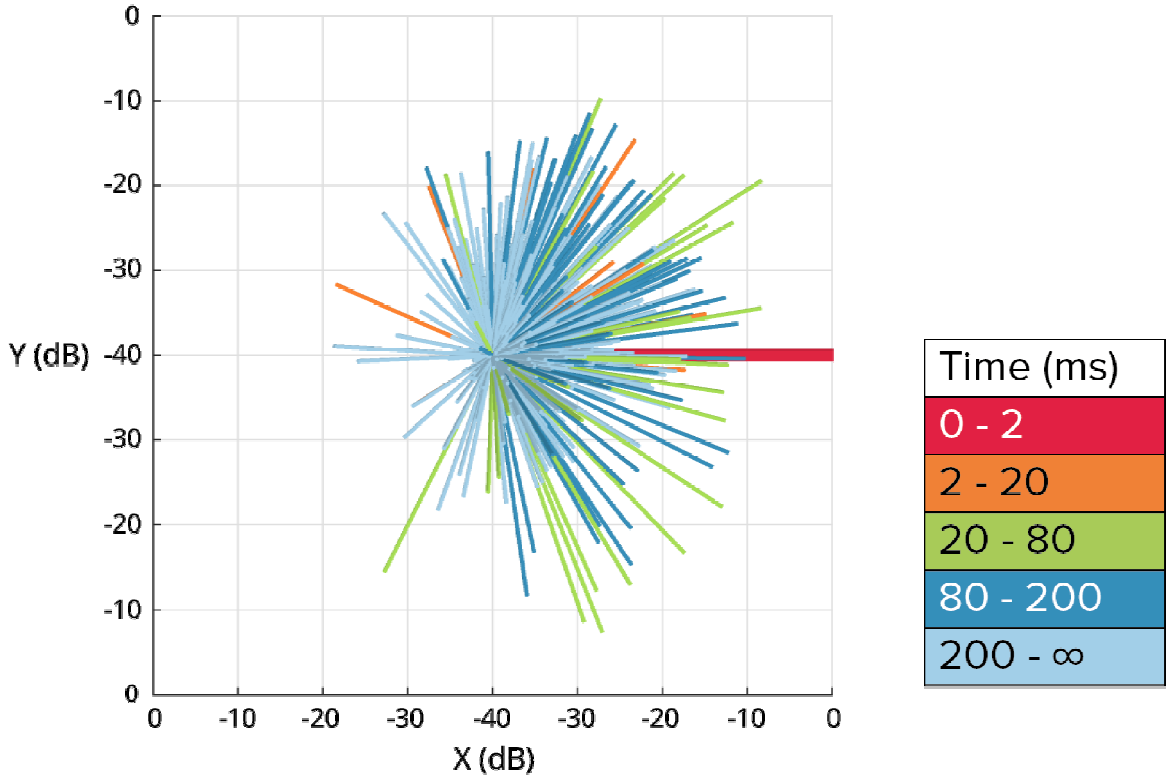
Level = -12.2 dB
Azimuth = -4.5°
Elevation = -35.7°
Time = 4 ms

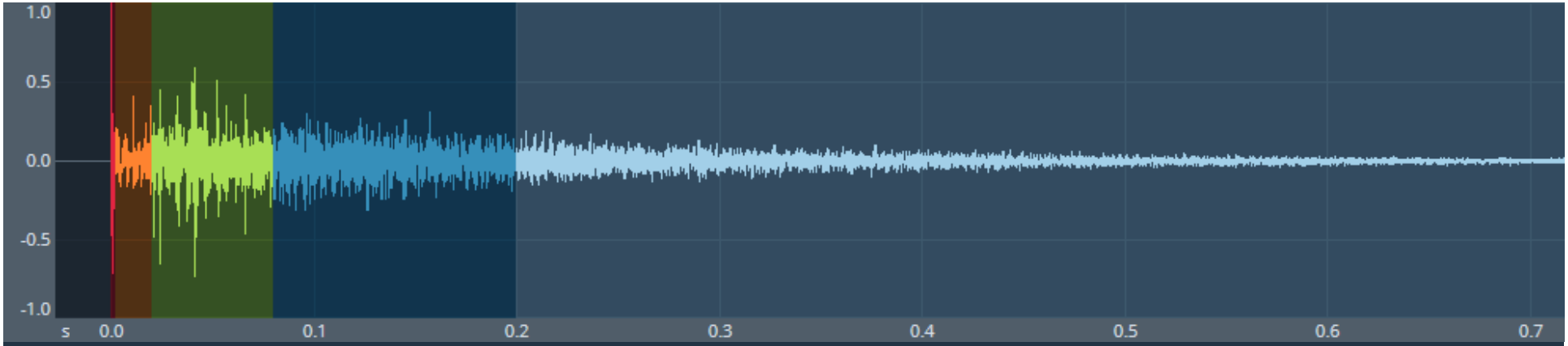
Plot in 3D


Pressure
Time (ms)
1
0.5
0
-0.5
-1
-2
0
2
4
6
8
10
12
14


Y (dB)
X (dB)
0
-10
-20
-30
-40
-30
-20
-10
0

Plot in 3D





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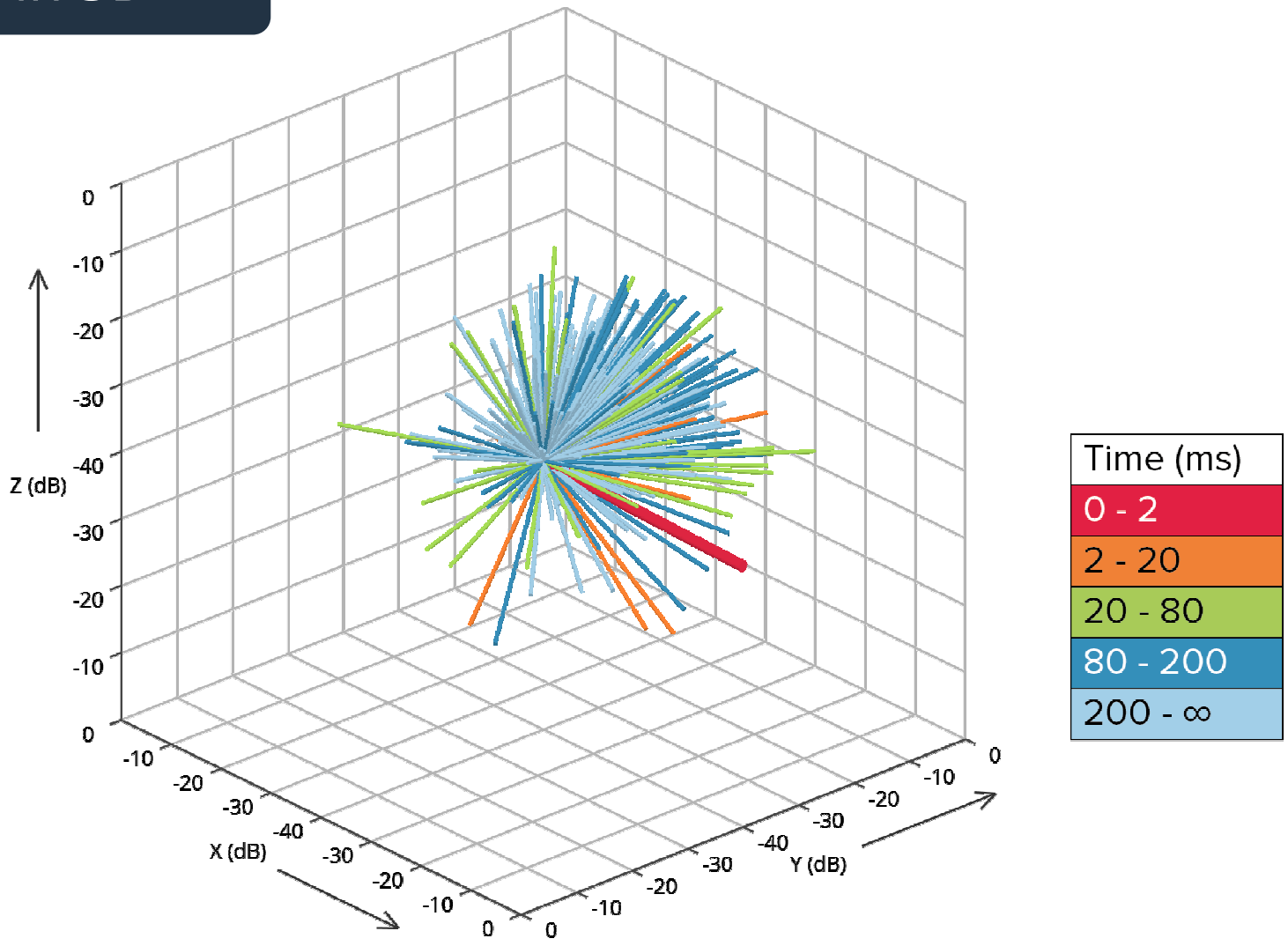
Plot in 3D


Z (dB)
0
-10
-20
-30
-40
-30
-20
-10
0
X (dB)
0
-10
-20
-30
-40
-30
-20
-10
0
Y (dB)
0
-10
-20
-30
-40
-30
-20
-10
0
Time (ms)
0 - 2
2 - 20
20 - 80
80 - 200
200 - ∞

3D IR in practice – Case studies

- Concert hall
- Tunnel announcement system
- Acoustic enhancement system
- Interaction with drawing programs and other software

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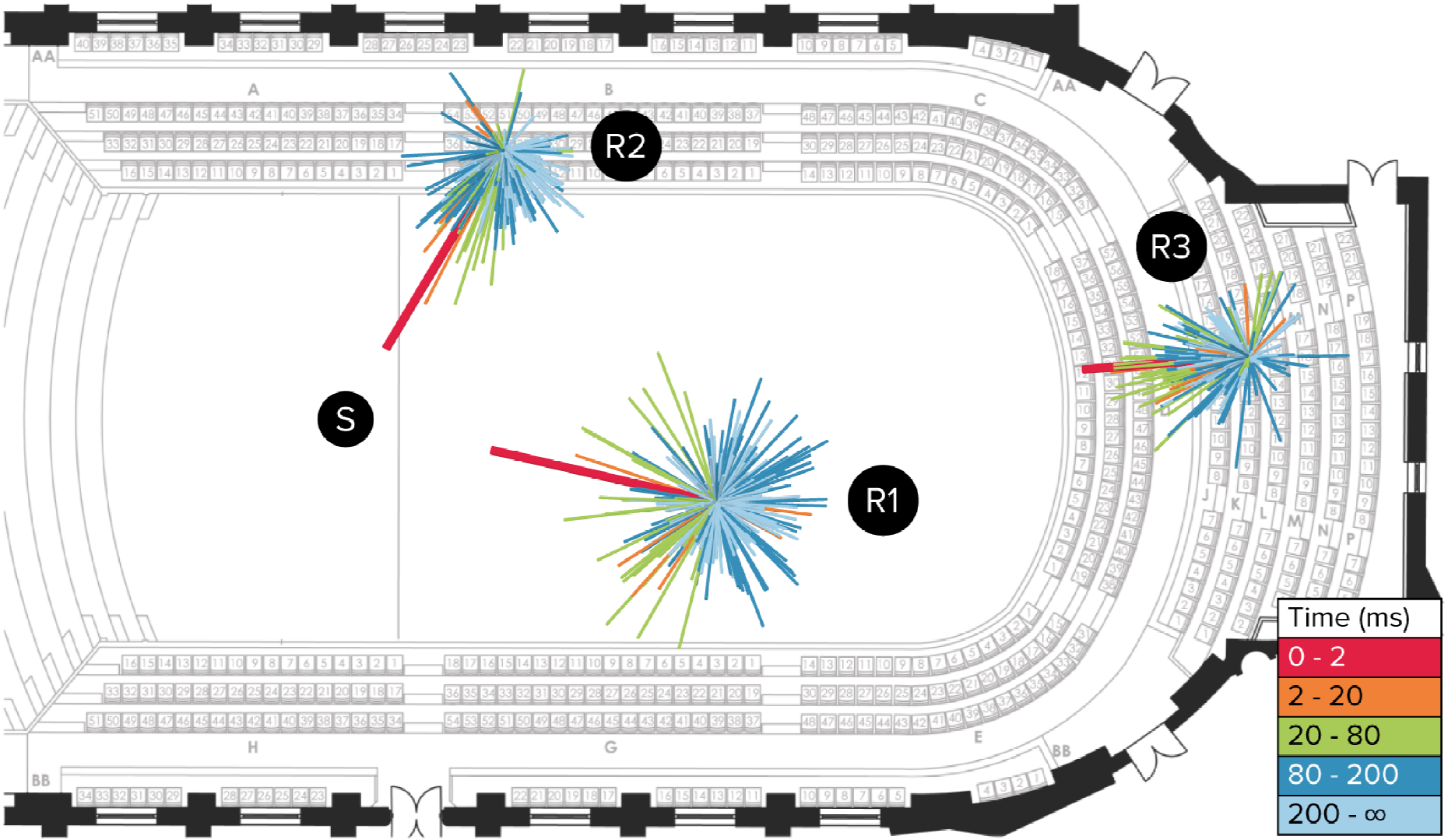
Auckland Town Hall



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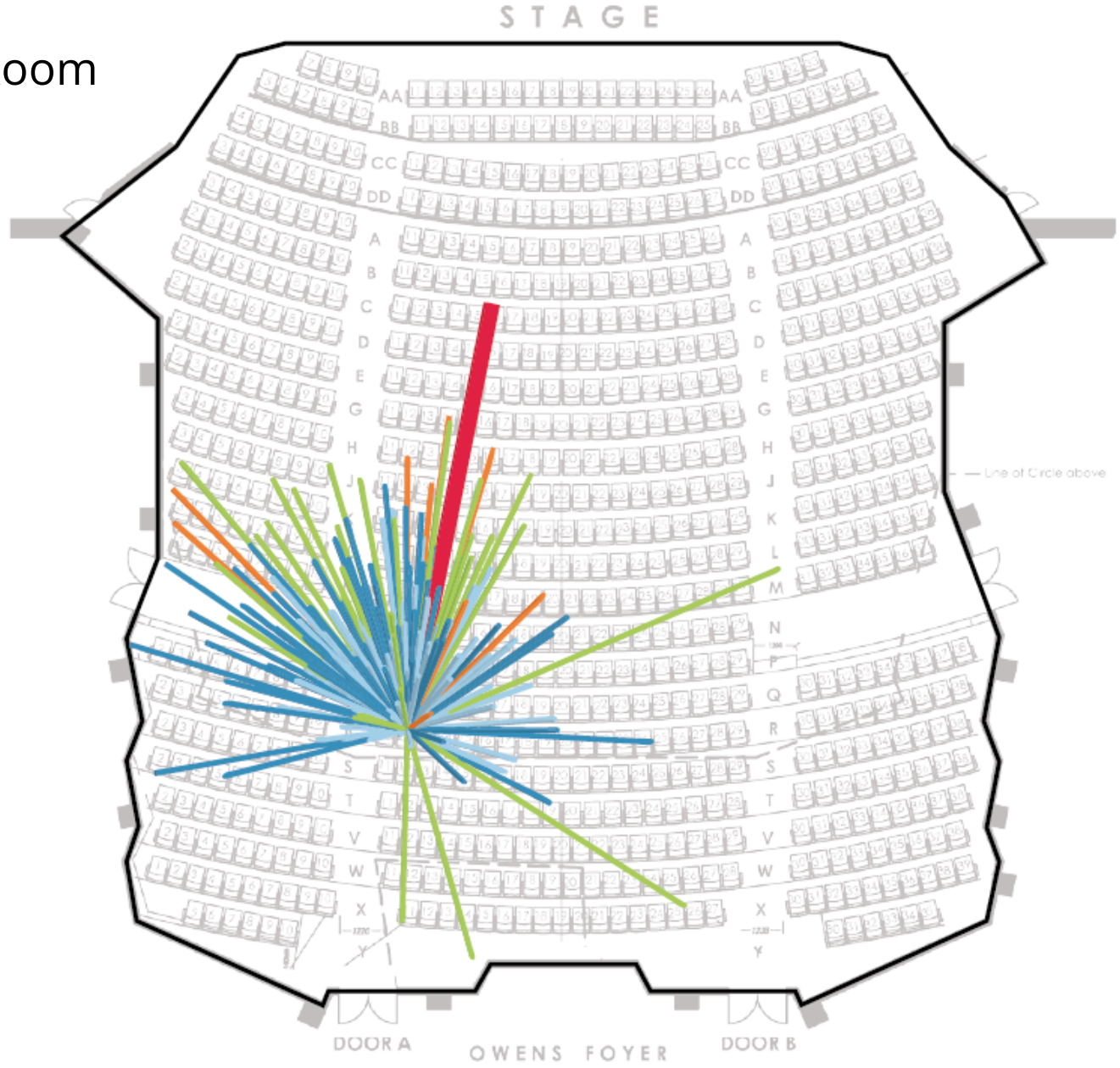
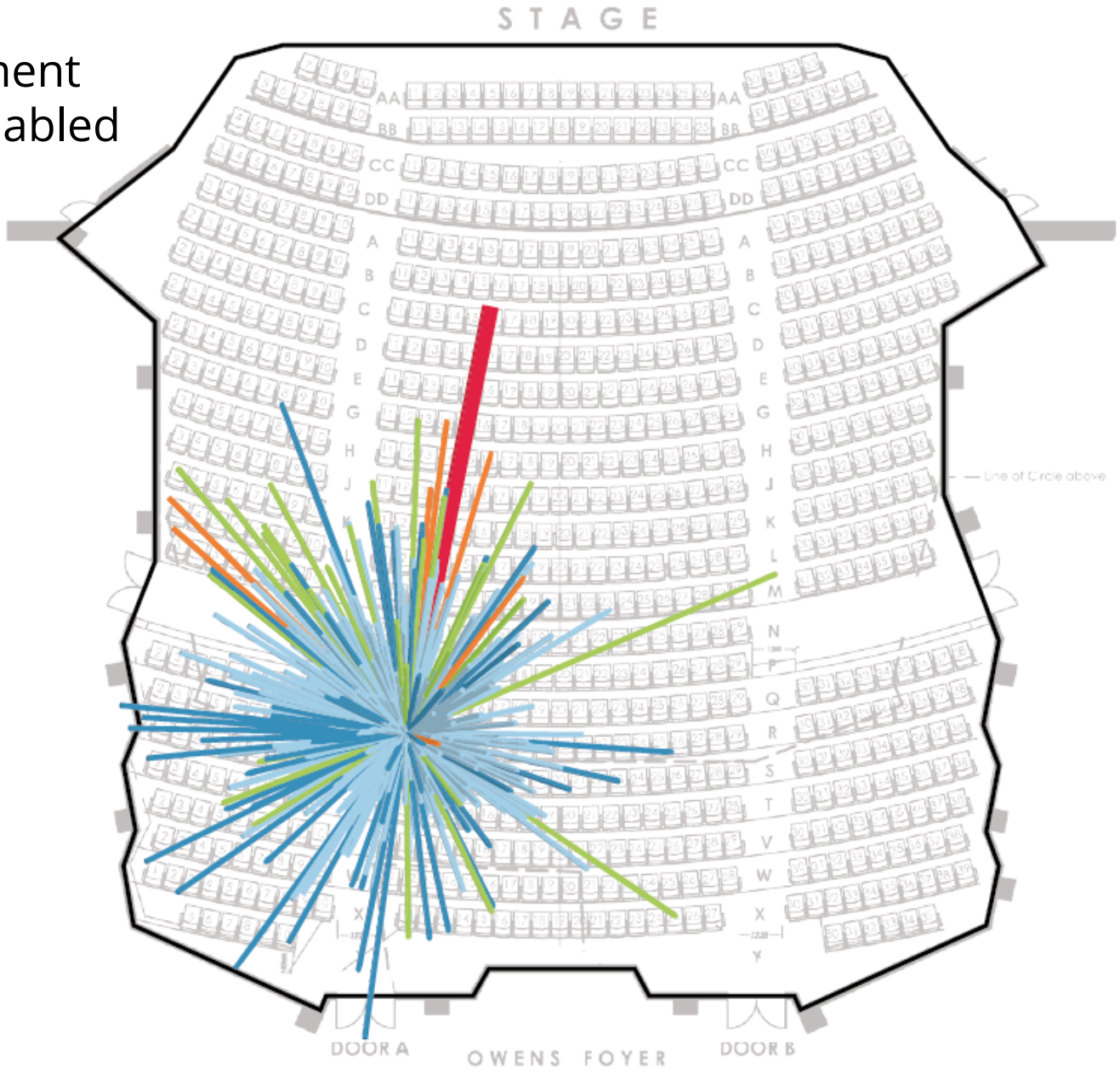
Natural Room



Time (ms)
0 - 2
2 - 20
20 - 80
80 - 200
200 - ∞

Enhancement system enabled



Time (ms)
0 - 2
2 - 20
20 - 80
80 - 200
200 - ∞

Tunnel Announcement System

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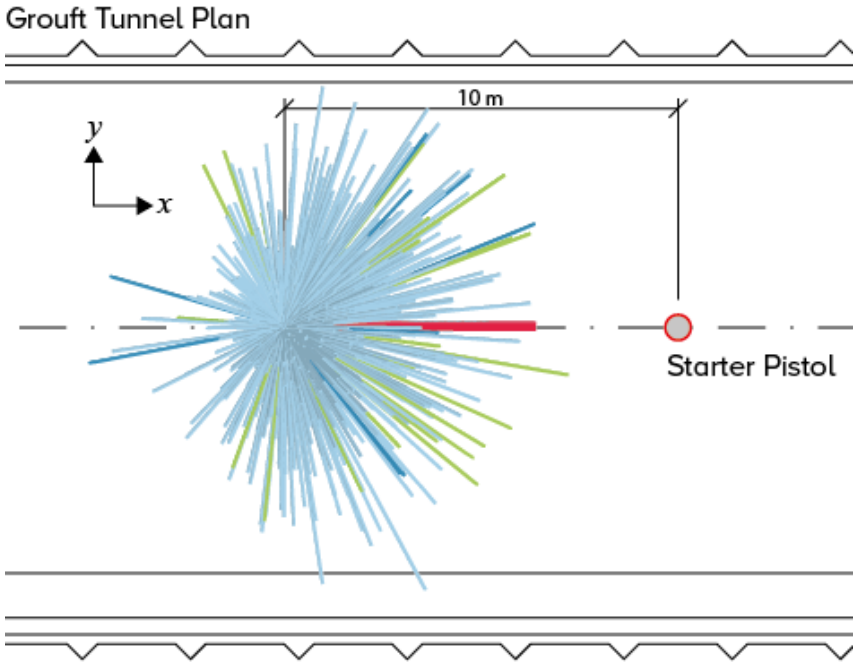

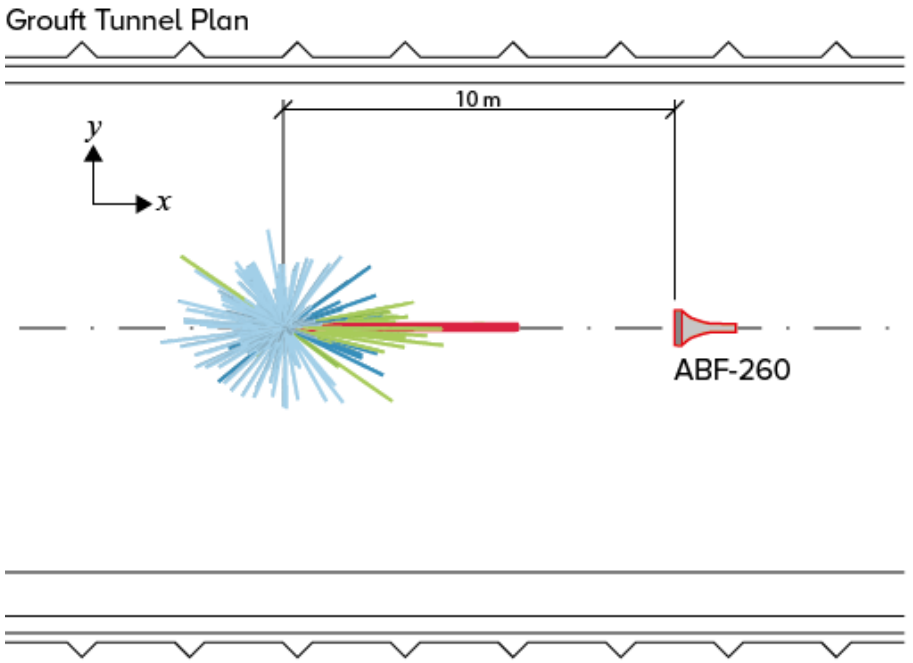

Time (ms)
0 - 2
2 - 50
50 - 80
80 - ∞

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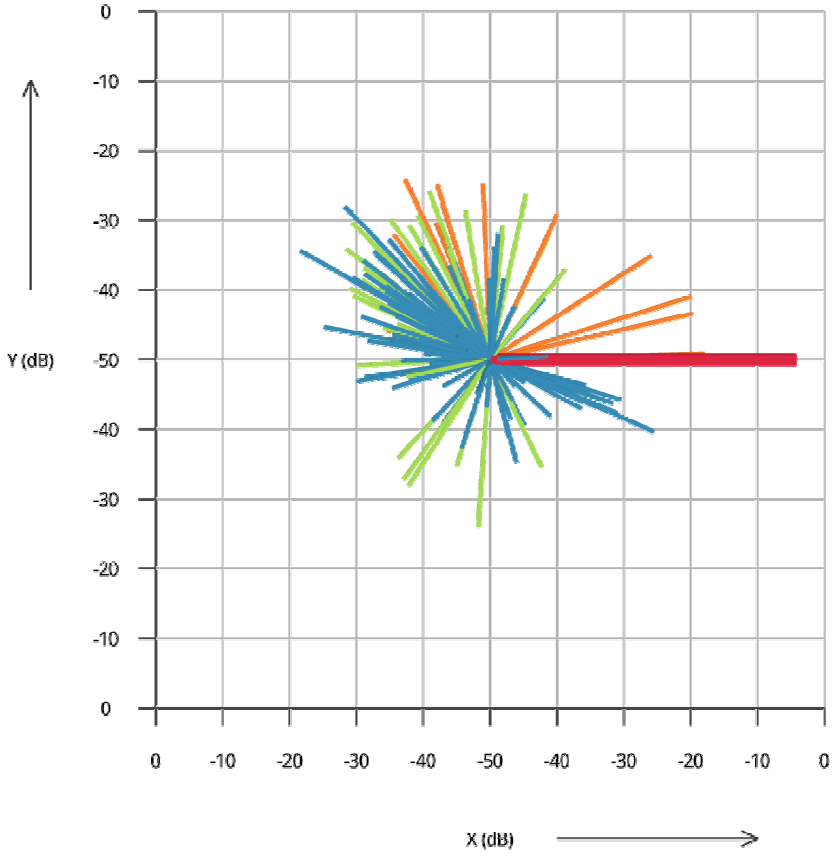
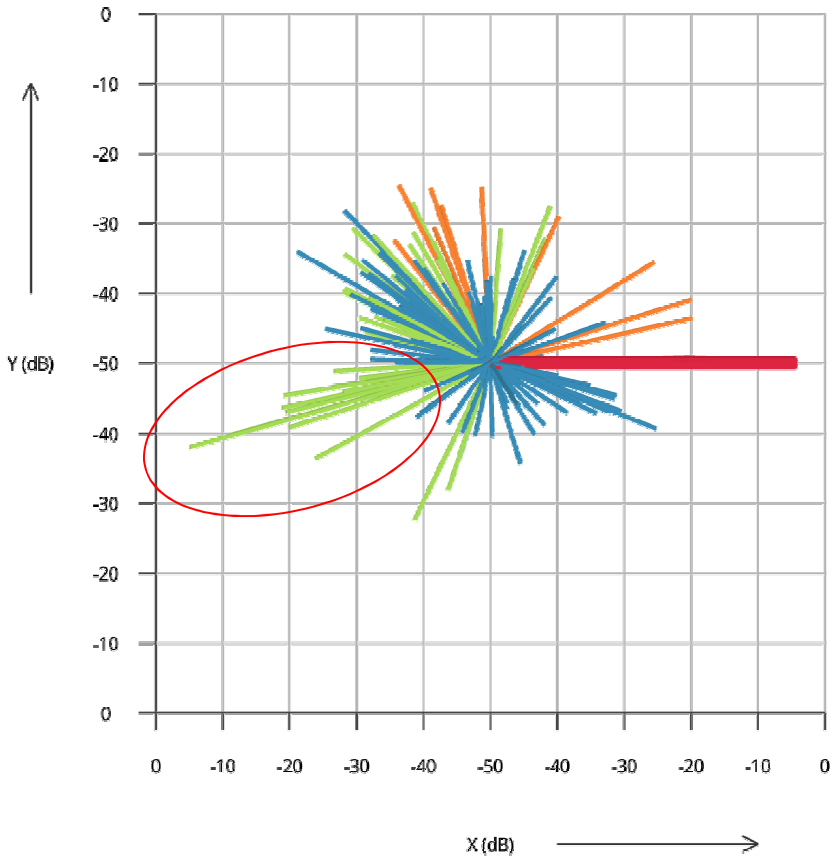
Identification of Problematic reflection

(reflection created for demonstration with plywood reflector)





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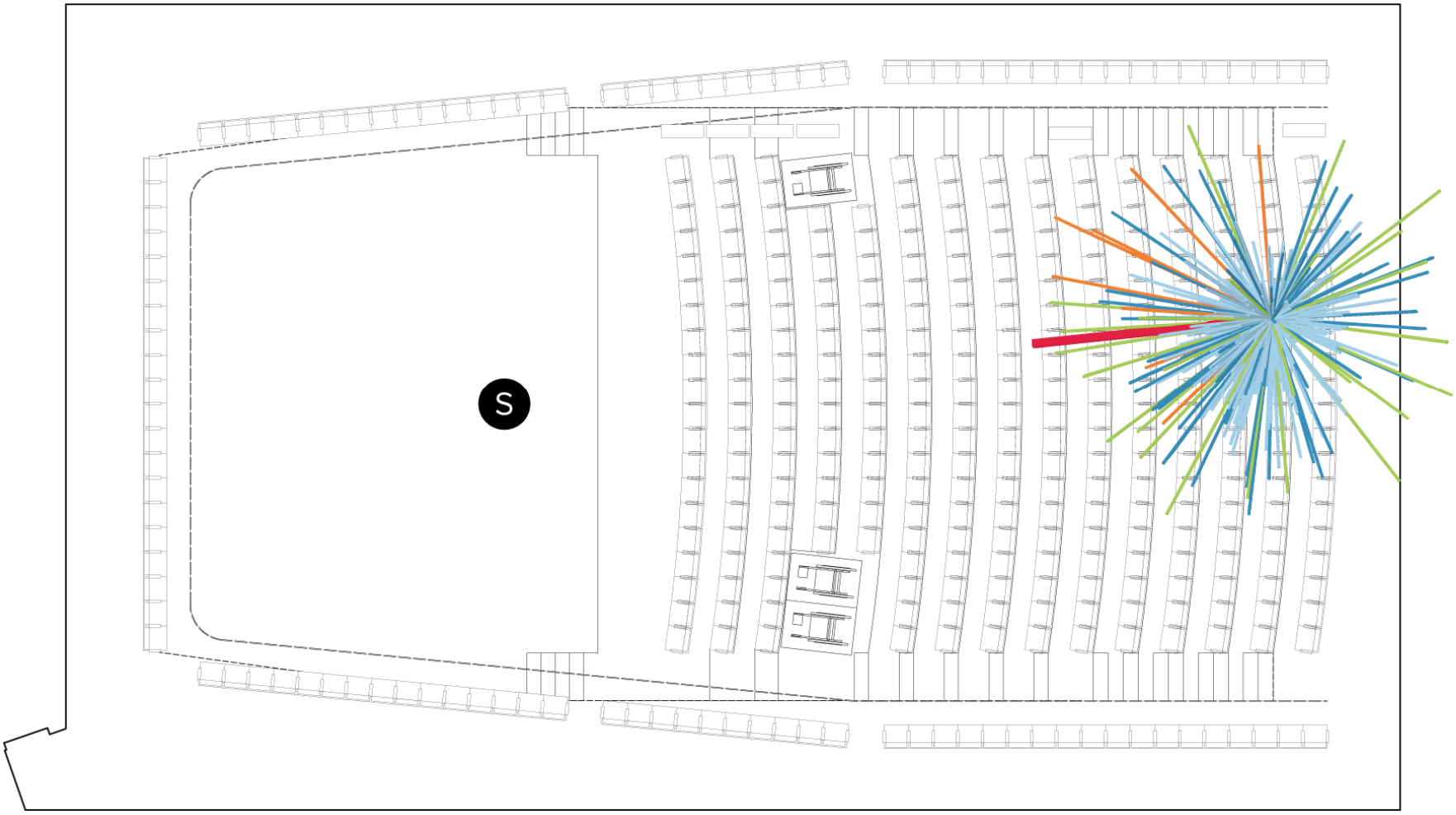
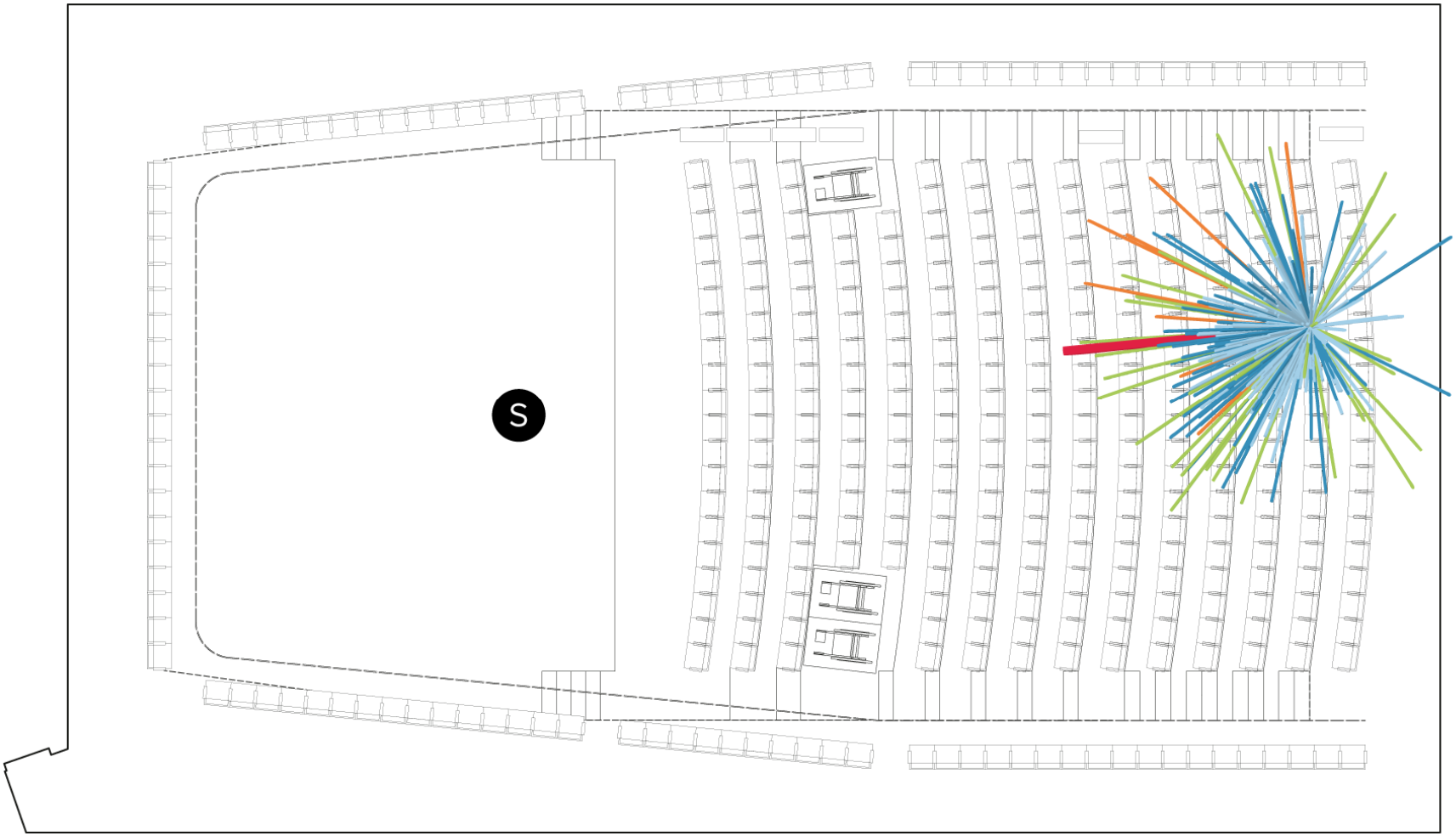
Iona College – Louvres Closed



Iona College – Louvres Open

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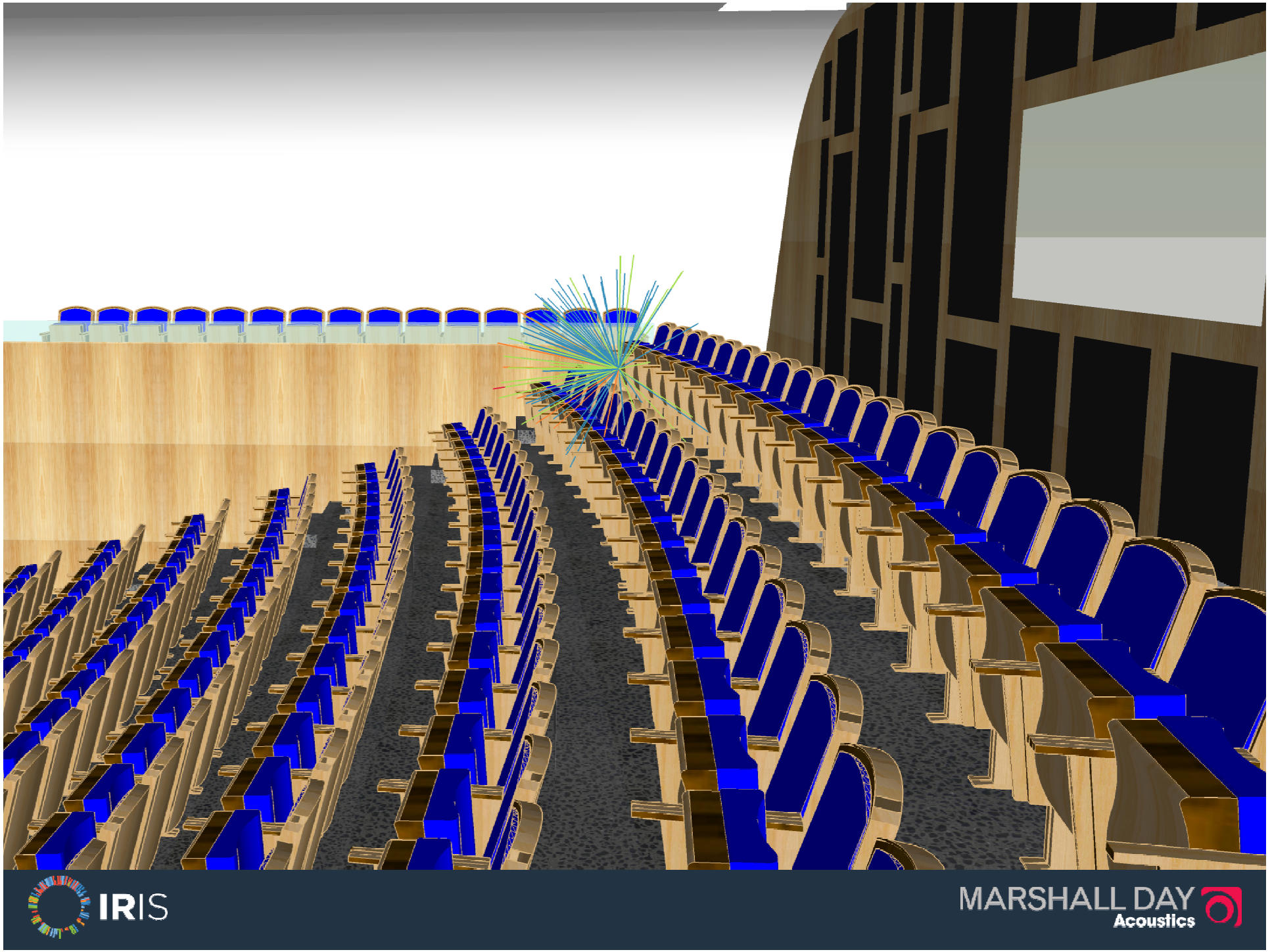
Acoustics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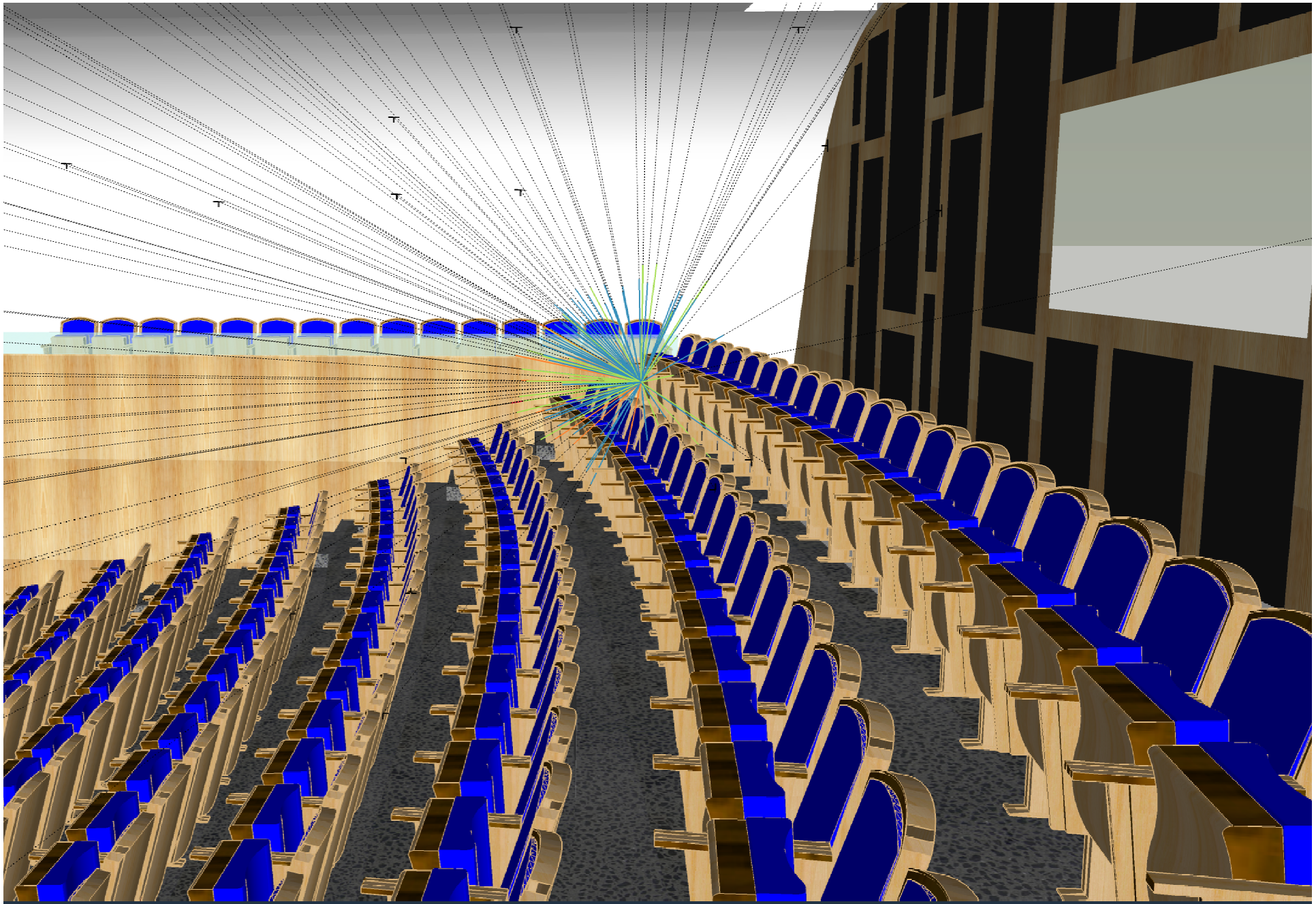
Acoustics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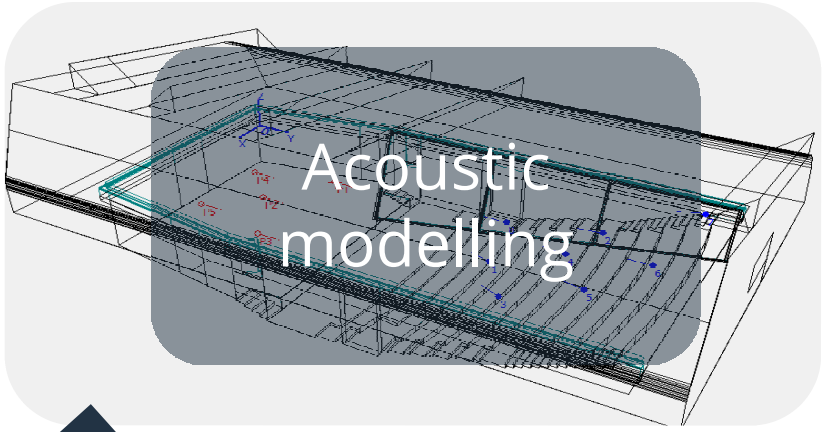
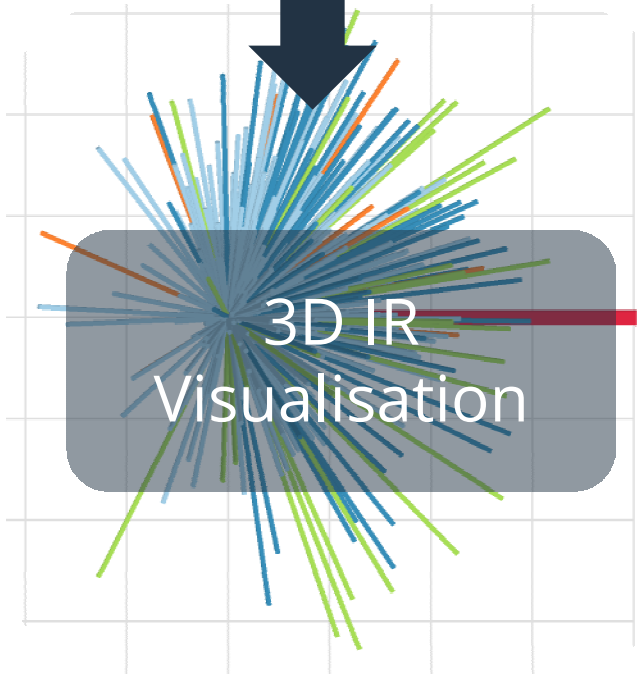
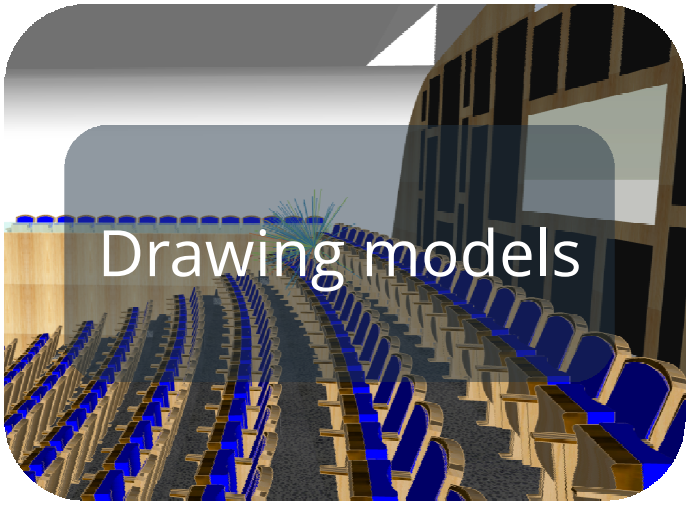
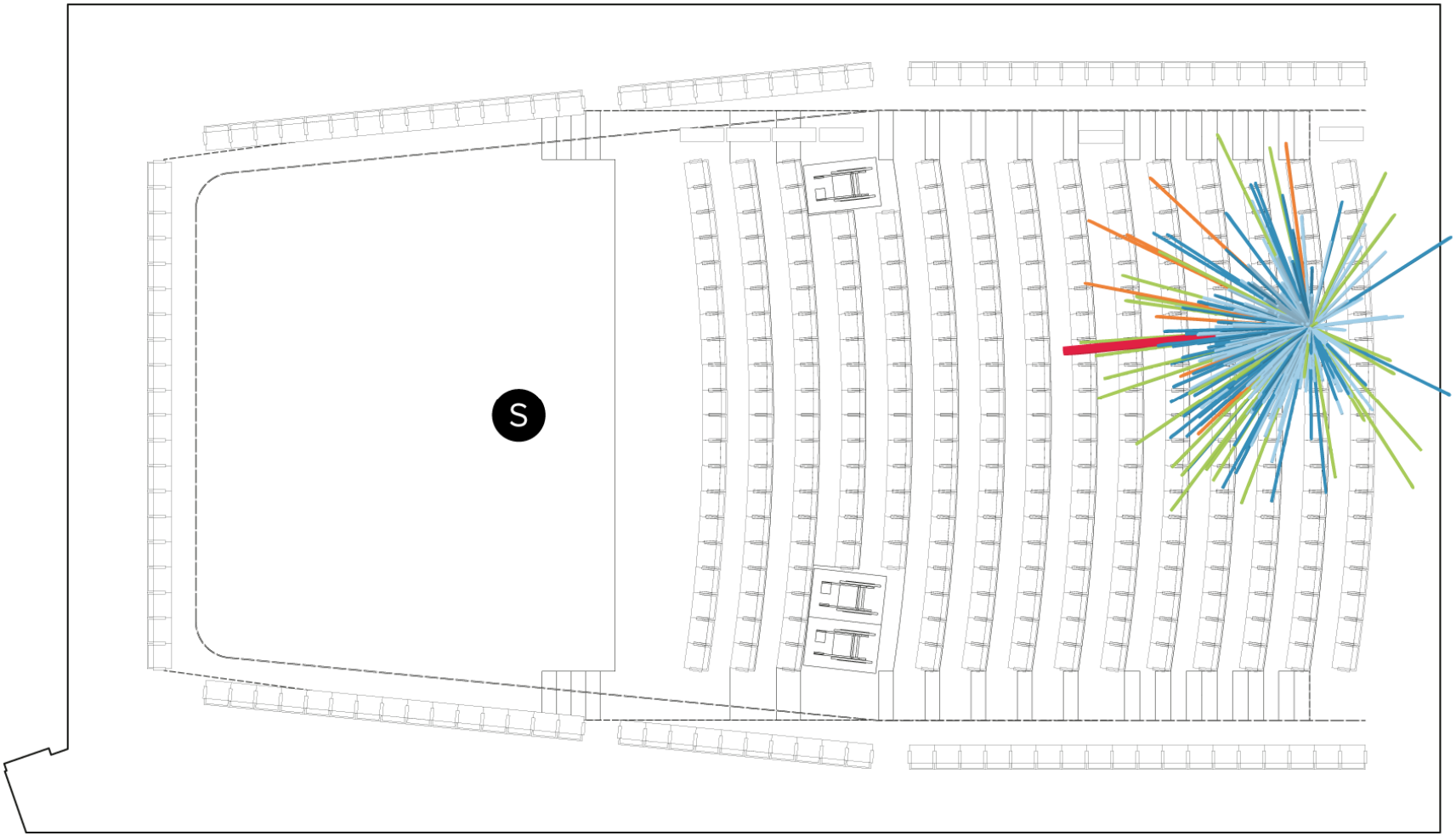
3D IR
measurement


Acoustic
modelling

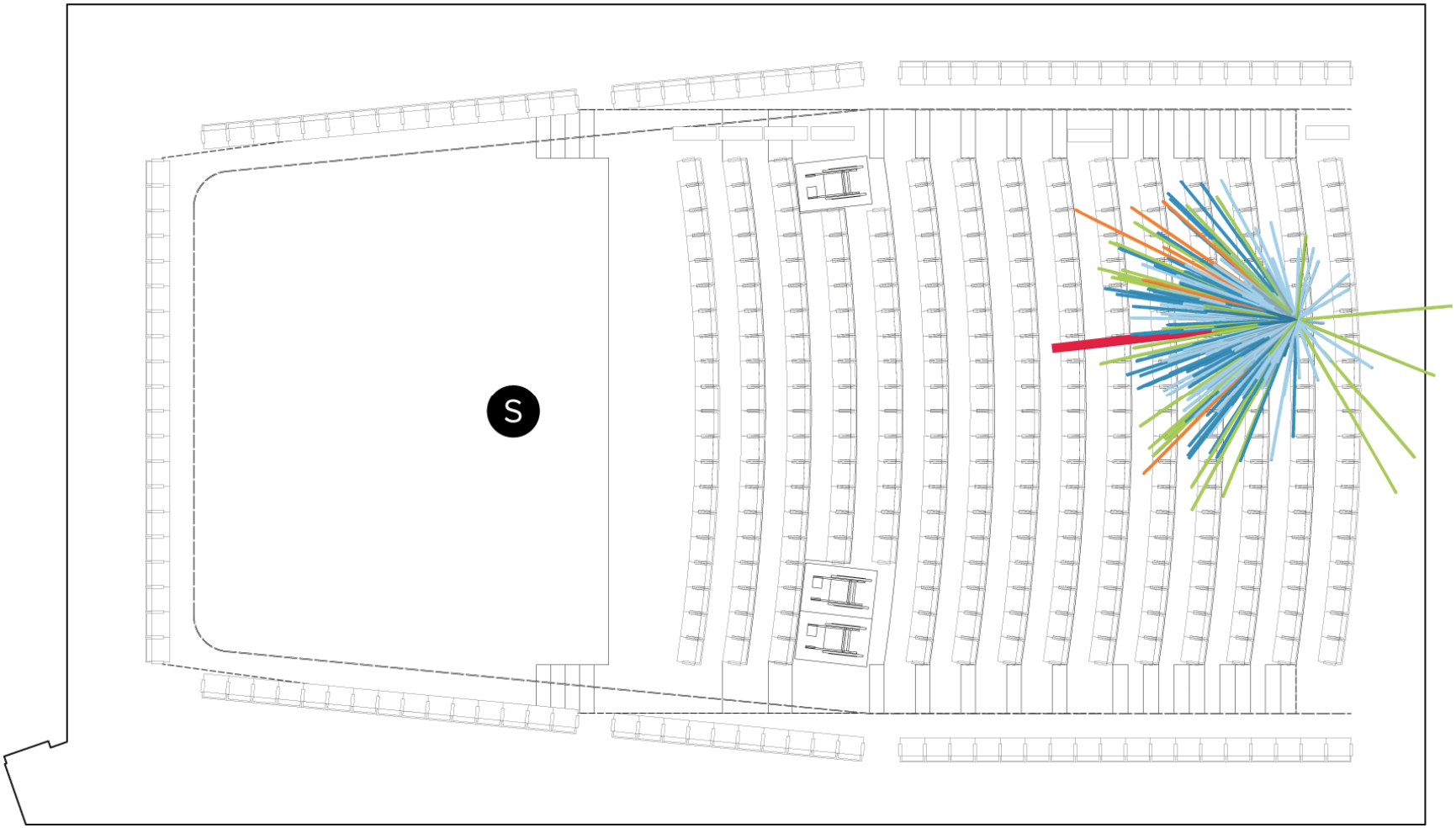

3D IR
Visualisation


Drawing models

Iona College – Louvres Open



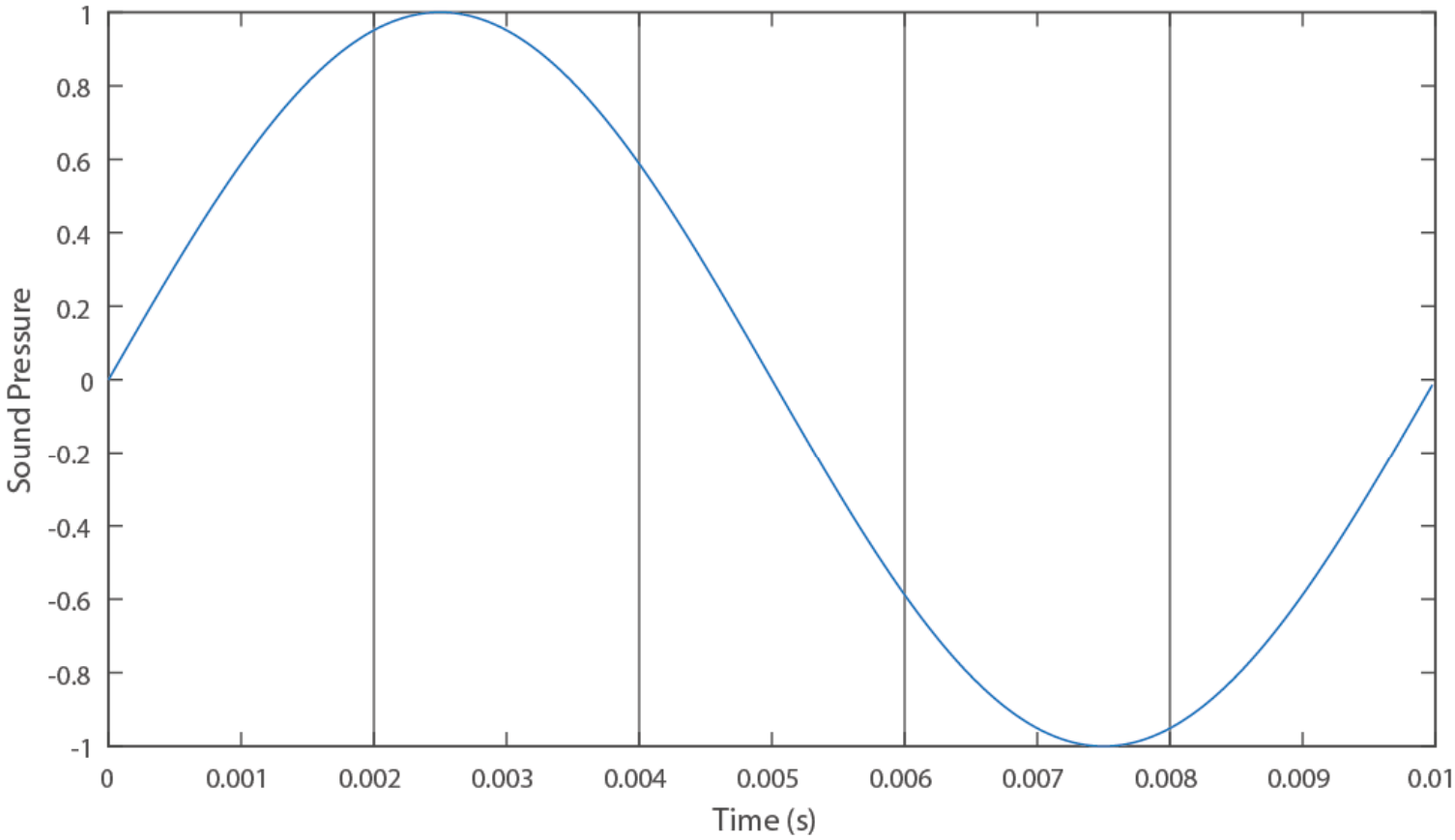
Iona College – Louvres Open, Model

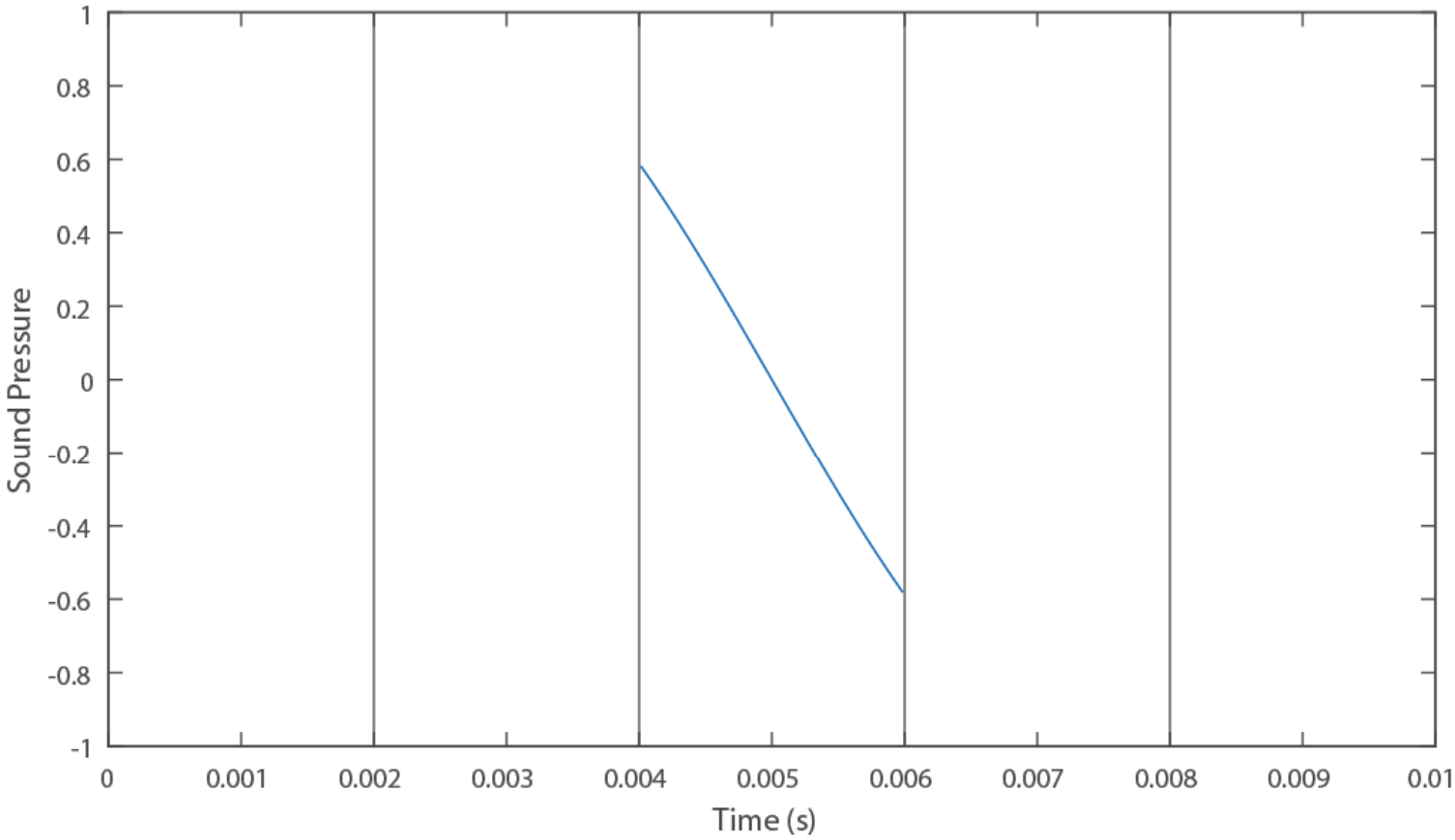


Demonstration

Frequency Analysis

- Time segmentation limits the ability to discern the direction of low frequency sound
- The shorter the time window the higher the Low Frequency Limit (LF limit)
- 2ms window = LF Limit 500 Hz


Sound Pressure
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
Time (s)


Sound Pressure
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
Time (s)

- **All frequency information** is still retained in B-format signals – which includes traditional omni-directional impulse response

- Frequency information can be processed from Omni impulse response

- Directional microphone patterns can also be used