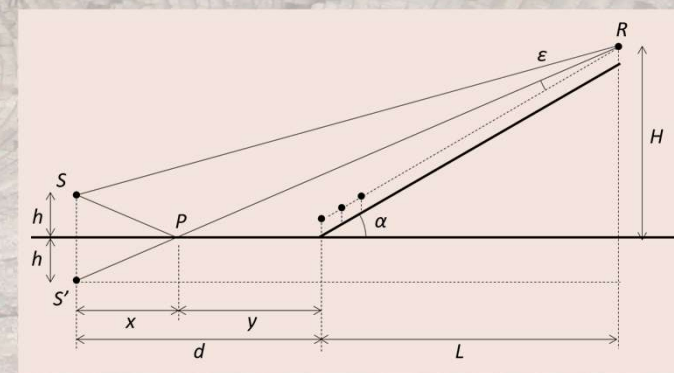


# Acoustics of ancient Greek theatres

Architectural development in the 4th century BCE

Jens Holger Rindel  
Multiconsult



# Outline

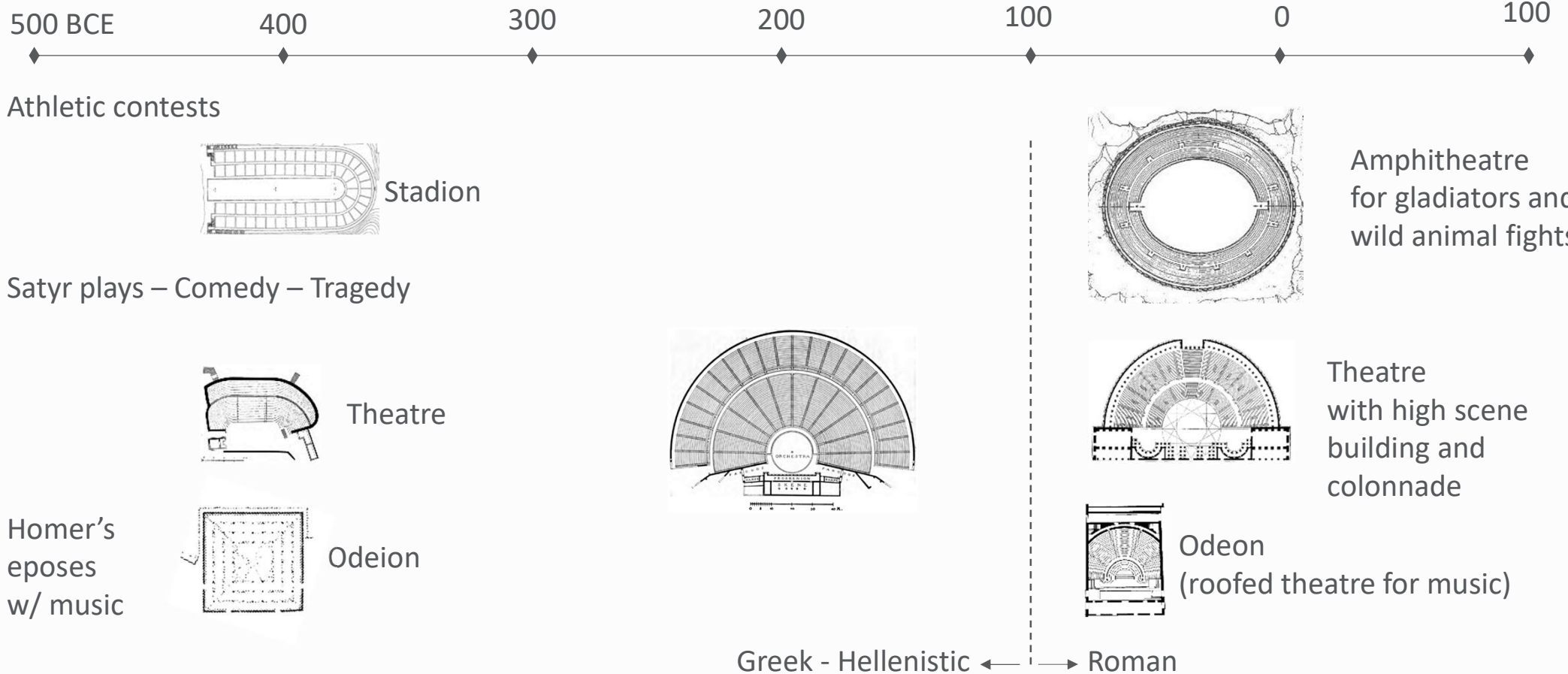
- Ancient theatres - timeline
- Origin and use of Greek theatres - festivals
- Sound reflections in the theatre
- Selected theatres for acoustic analysis
- Loudness, clarity and how to avoid an echo
- Conclusions

## Origin and use of Greek theatres - festivals

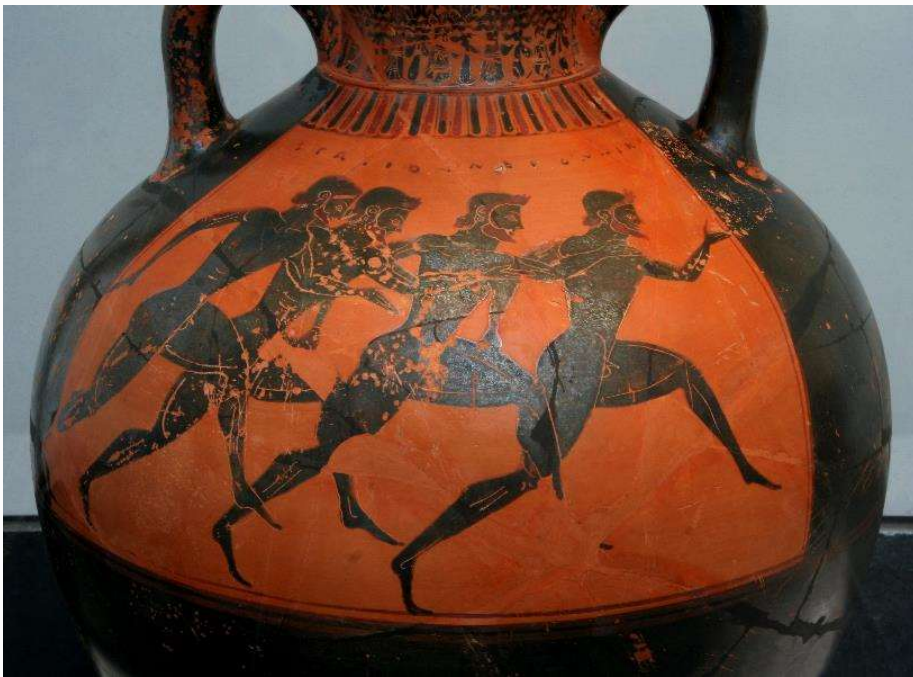
- Festivals and games from 5 – 6 century BCE originally related to the Dionysus cult
- These Games incorporated religious festival, ceremony (including prize-giving), athletic competitions, and cultural events hosted within different architectural spaces:
  - a stadium, for athletic competitions
  - a theatre for drama (satyr plays, comedy, tragedy)
  - an *odeion* (roofed building) for song accompanied by a stringed instrument (lyre or cithara)

# Ancient theatres – time line

multiconsult.no



## Festivals – Competitions in athletics, music, drama + +

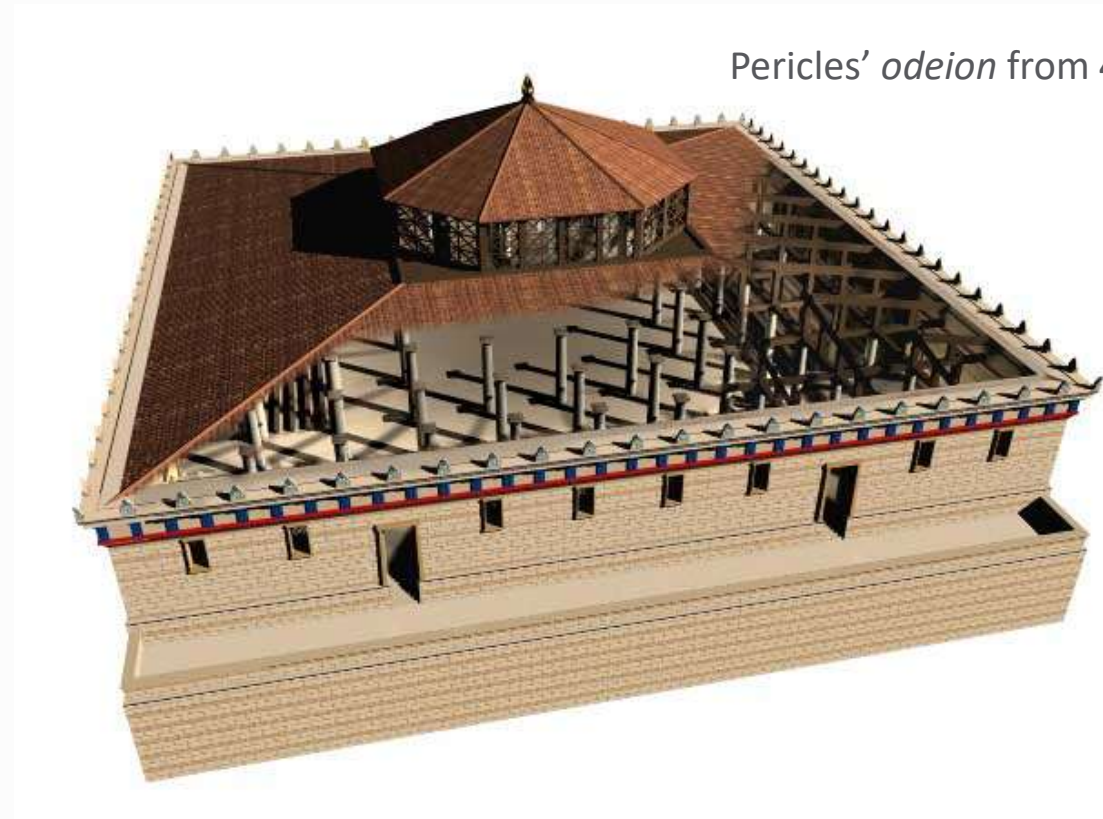


Greek vase depicting runners at the Panathenian Games c. 530 BC



The ancient stadium at Epidauros

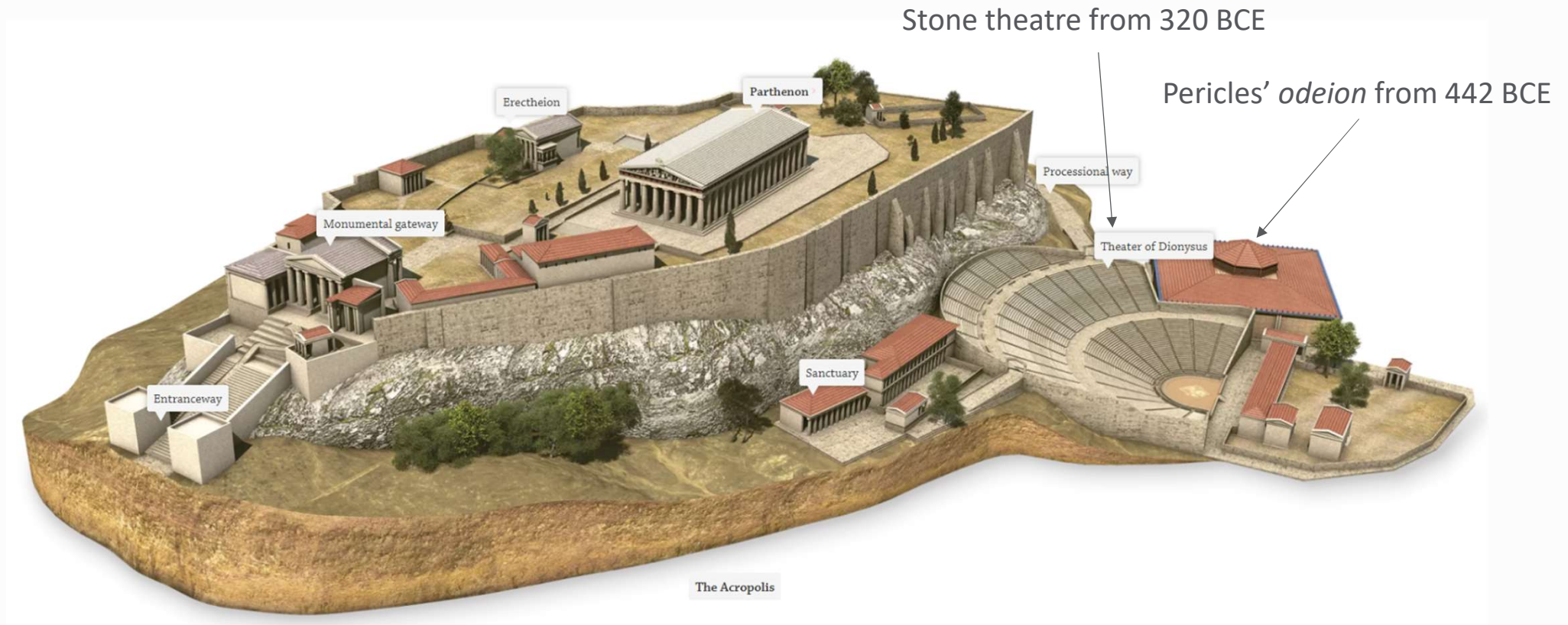
## *Odeion* – Recitation of epos to the lyre (cithara)



Pericles' *odeion* from 442 BCE

Image copyright the University of Warwick. Created by the [THEATRON Consortium](#).

# Acropolis in Athens around 320 BCE



## Theatre – satyr plays, comedy, tragedy



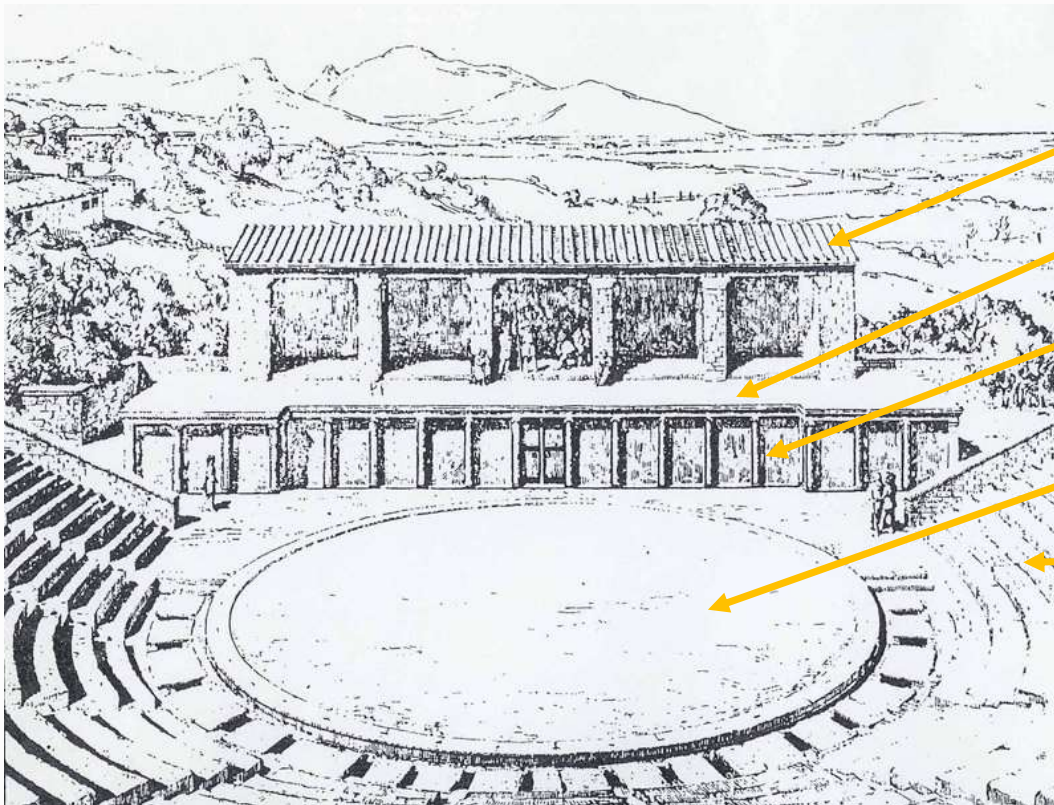
Marble relief with a scene from a comedy. The National Archaeological Museum of Naples.



The theater of Thorikos



## The Greek theatre – main architectural elements



Scene building (*skena*)

*Proskenion*

*Pinakles* – painted decorations on wooden board

*Orchestra* – place for dance and acoustic reflector

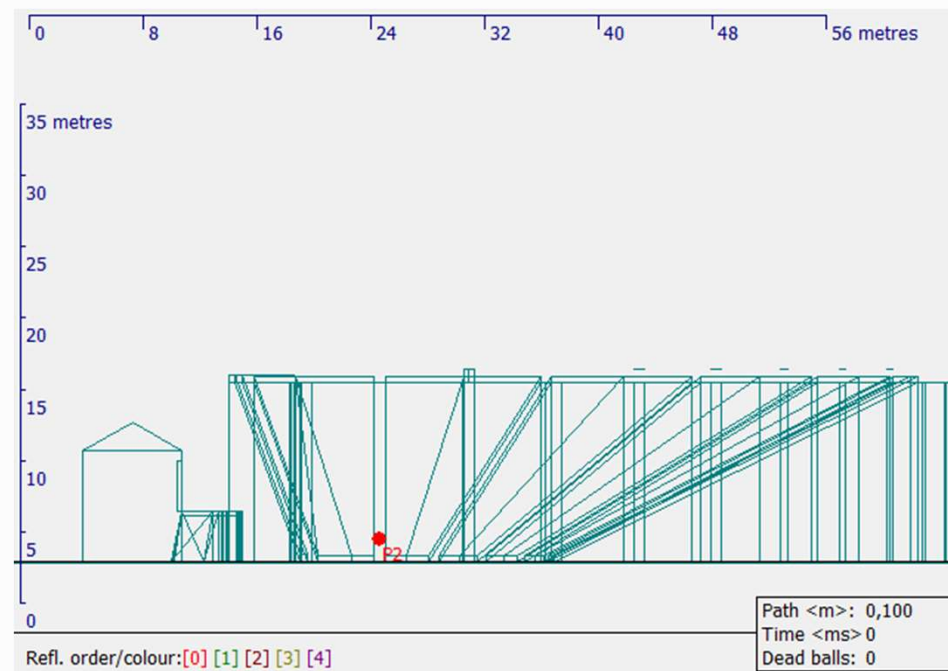
*Koilon* – seats for the spectators

# Analysis of sound propagation

Source on proskenion

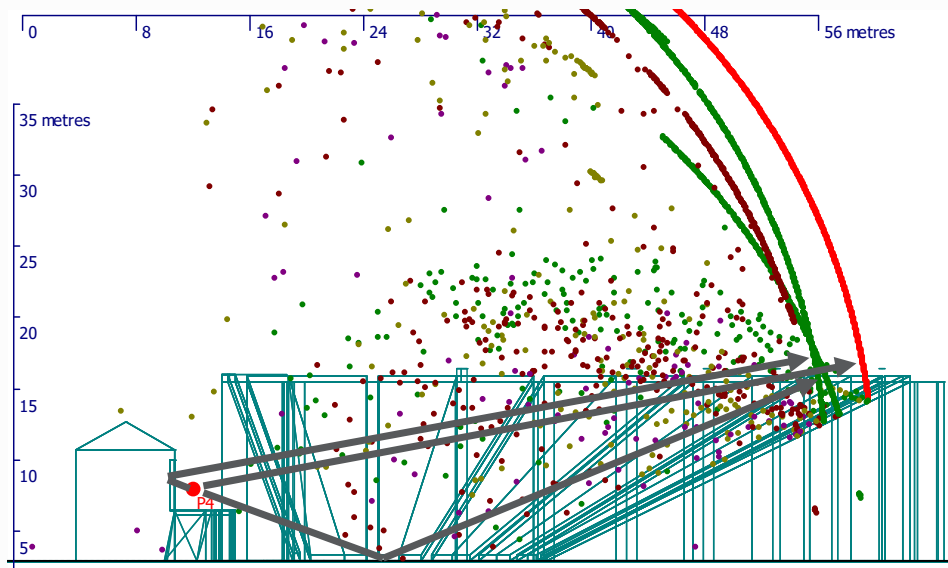


Source in centre of orchestra



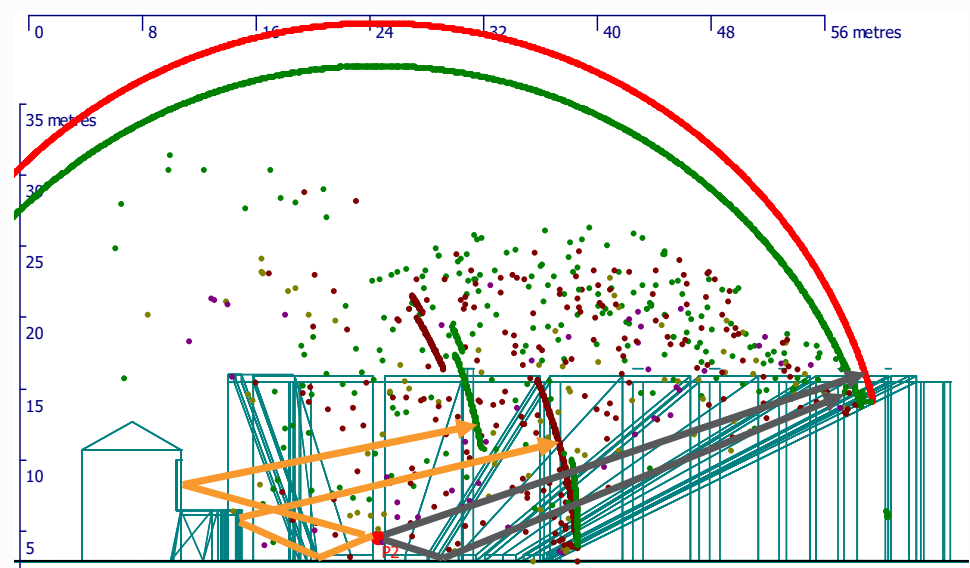
# Importance of source position

Good reflections (< 50 ms delay)



**Consonant** reflections “are those in which the voice, reinforced from below, rises with this increment and reaches the ears with precise clarity”

Bad reflections (> 50 ms delay)

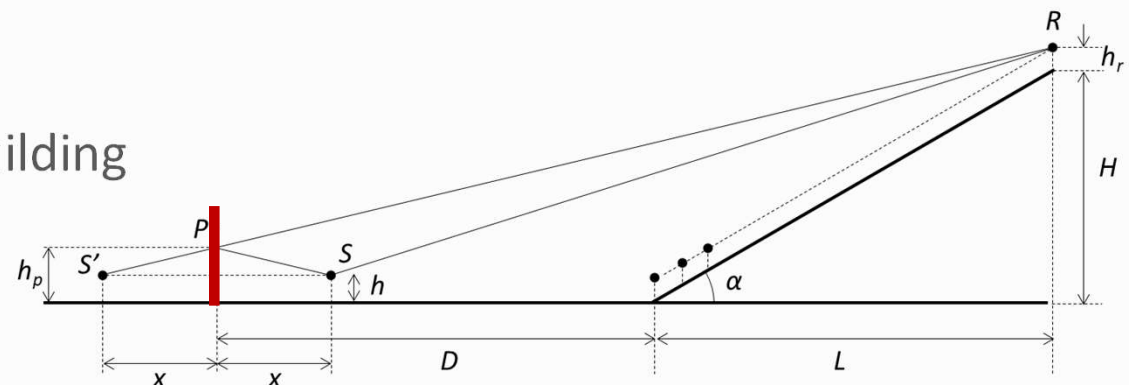
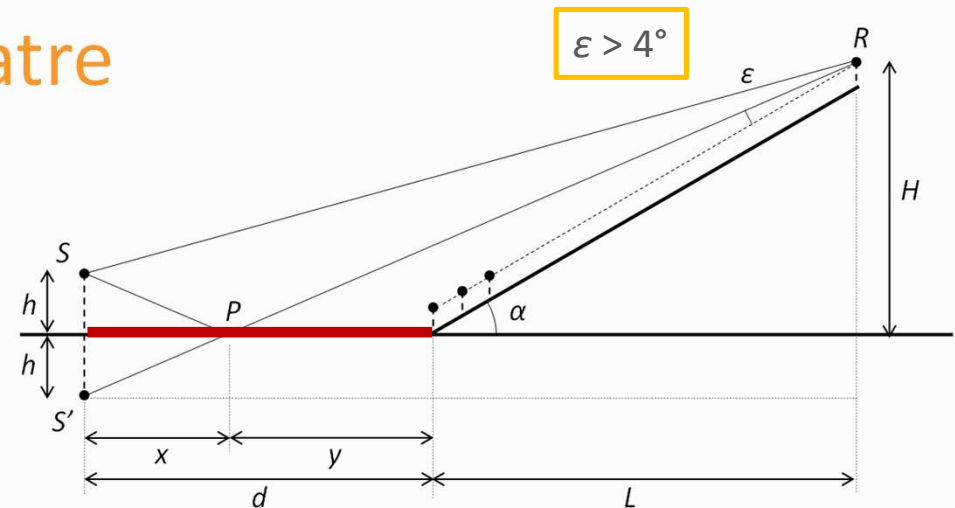


**Resonant** reflections “are those in which the voice, striking against some hard body, is echoed in the last syllables so that they appear doubled”

Vitruvius 5.8.2

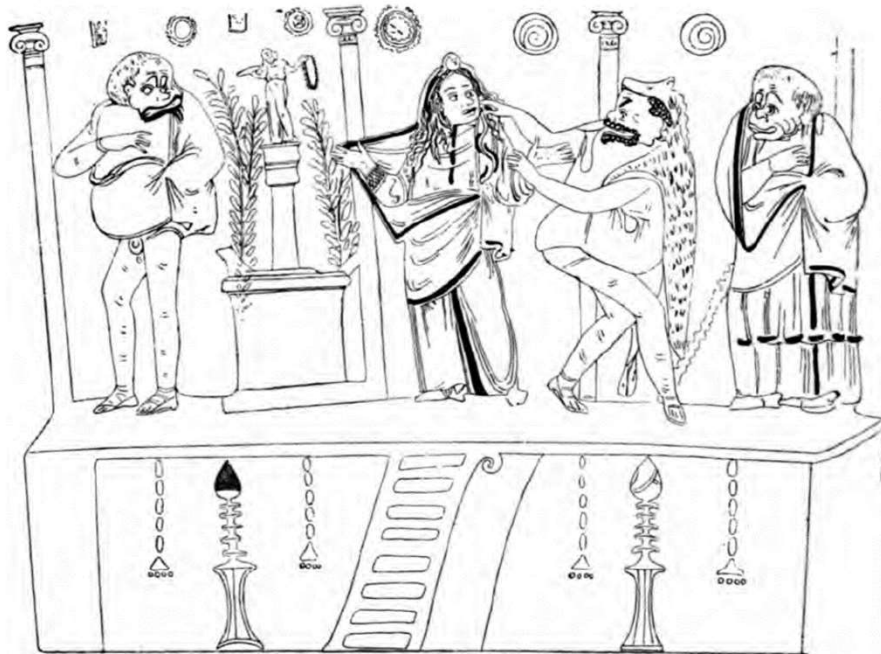
## Sound reflections in the theatre

- Sound reflection from the *orchestra* is very important for achieving loud and clear sound
- Sound reflection from the scene building can be beneficial or it can cause echo problems – that depends on the source position
- The sound source should be sufficiently close to the scene building or on the *proskenion*



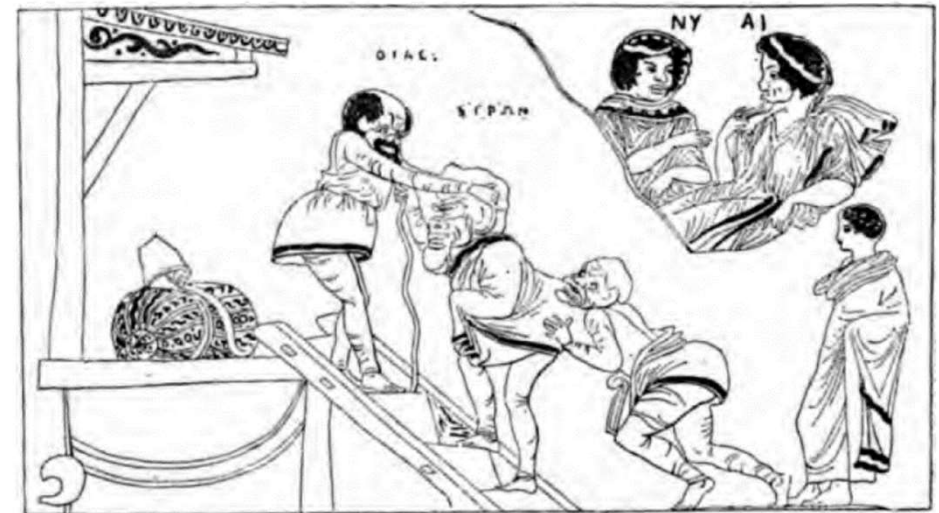
$$x < 8 \text{ m}$$

## Where did the actors perform?



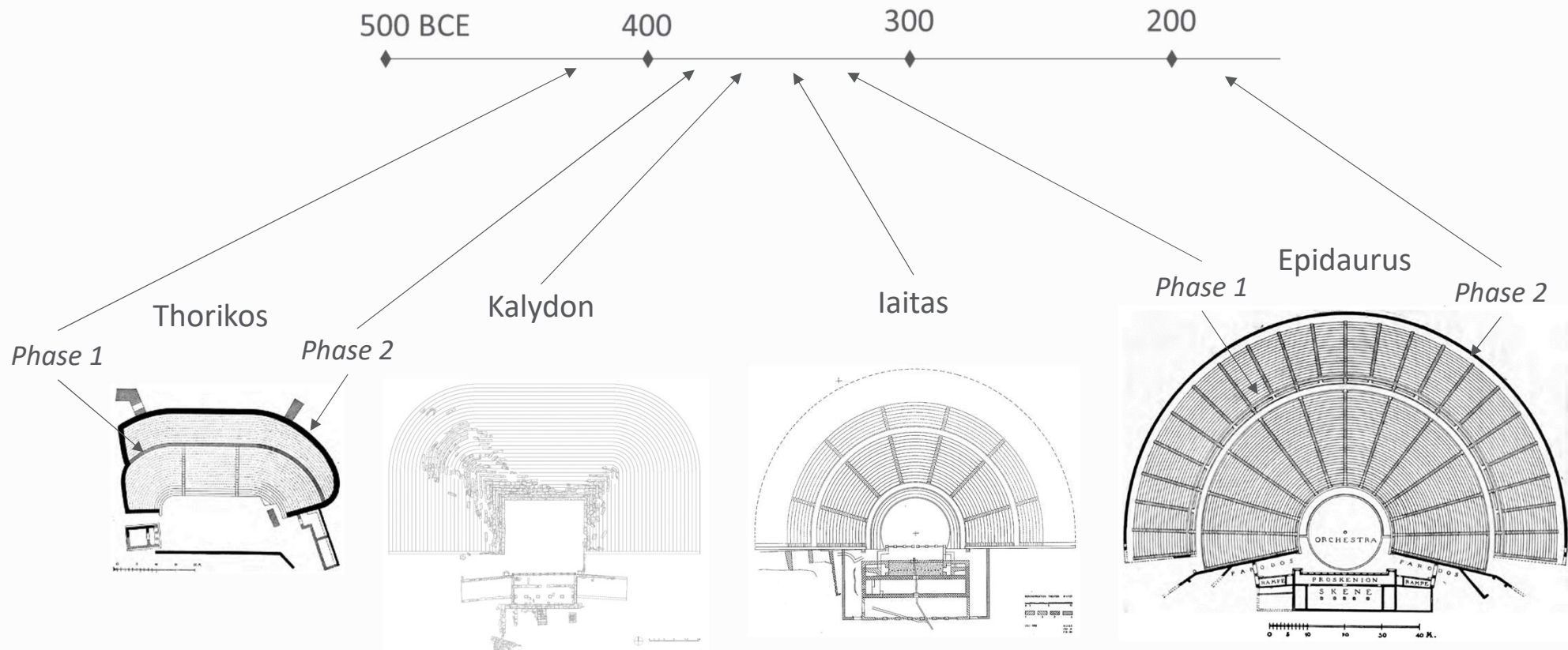
Scene from a tragedy from a vase found in Lentini, Sicily. Note the stairway connecting the *proskenion* with the *orchestra*. (Dörpfeld & Reisch, 1896)

- On the proskenion (elevated)?
- In front of the proskenion?
- Probably both



Scene from a comedy (Dörpfeld & Reisch, 1896)

# Selected theatres (around 4<sup>th</sup> century BCE)



Thorikos



Iaitas



Kalydon



Epidaurus



# Clarity of speech ( $D_{50}$ )

Source position

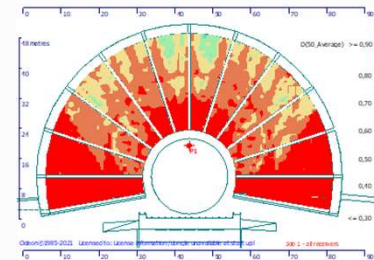
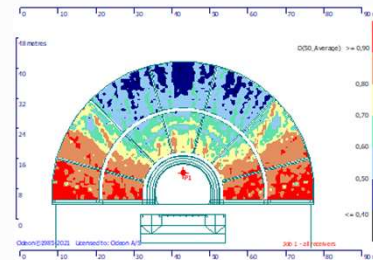
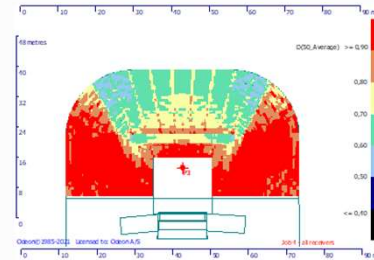
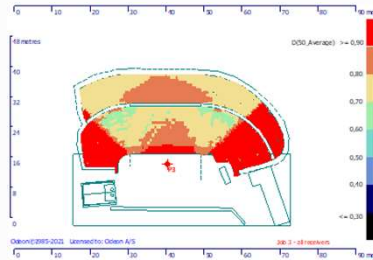
Thorikos 2

Kalydon

Iaitas

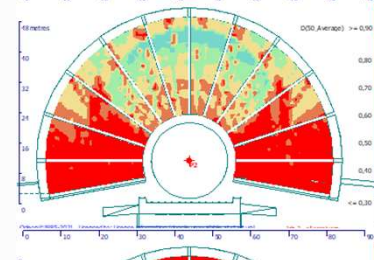
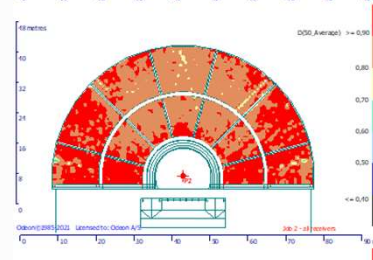
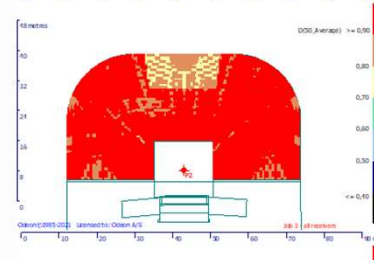
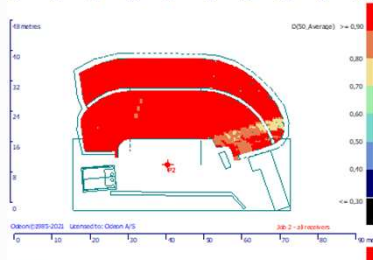
Epidaurus 1

Front



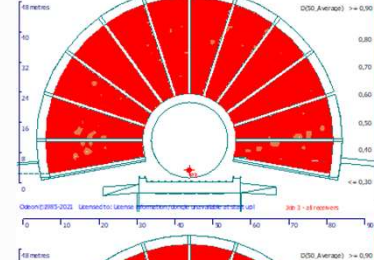
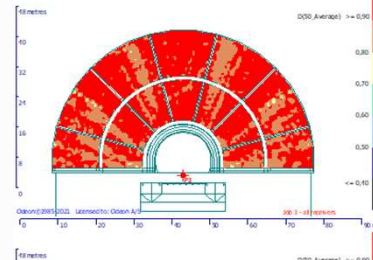
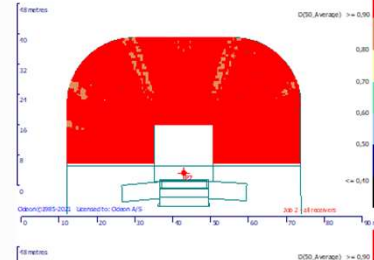
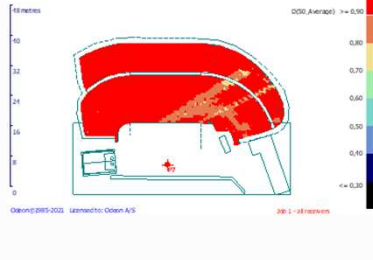
Bad

Centre



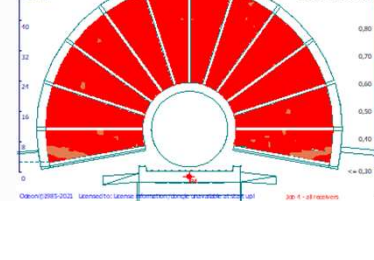
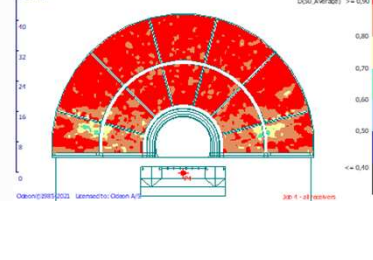
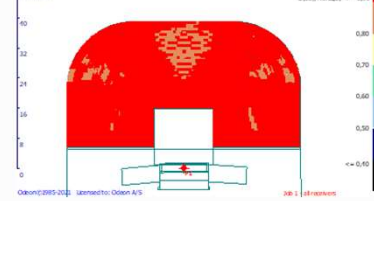
Some problems

Back



Good

On proskenion



Good



# Echo – depends on source position

Source position

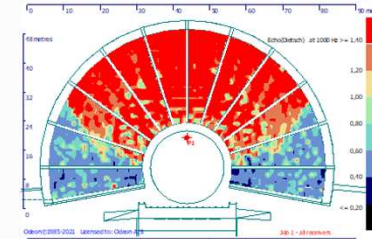
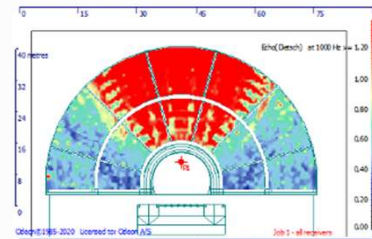
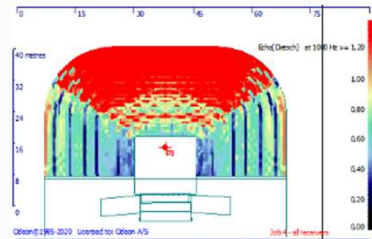
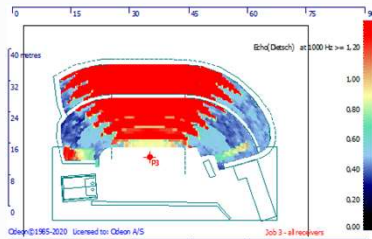
Thorikos 2

Kalydon

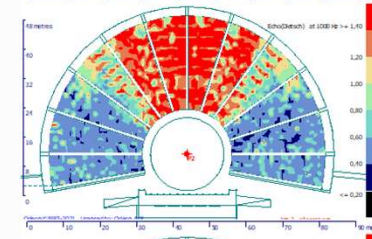
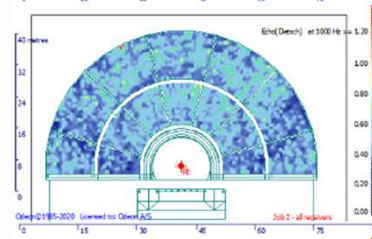
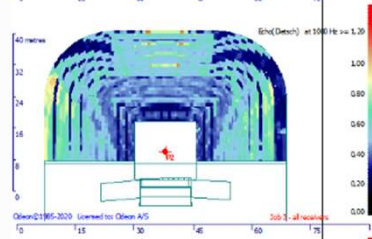
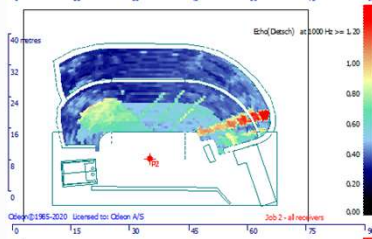
Iaitas

Epidaurus 1

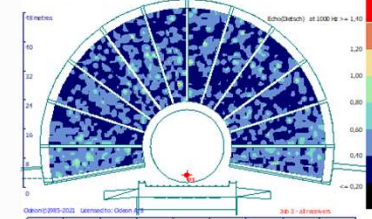
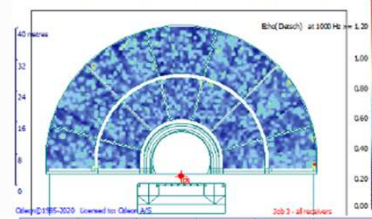
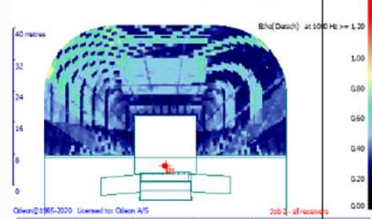
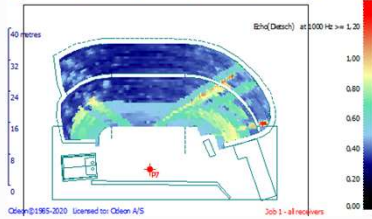
Front



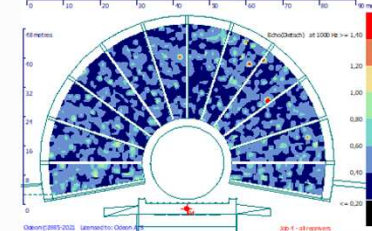
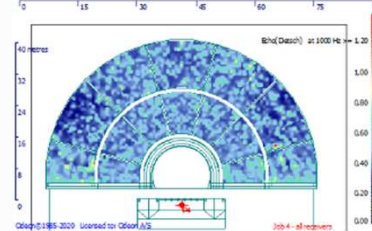
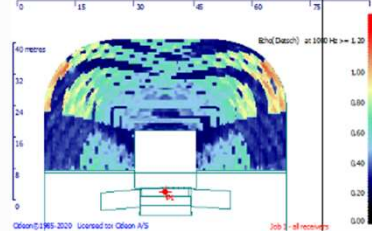
Centre



Back



On proskenion



Bad

Some problems

Good

Good

## Vocal effort

$L_{(S,A,1\text{ m})}$ dB	Vocal effort
36	Whispering (Private)
42	Soft (Private)
48	Relaxed (Private)
54	Relaxed
60	Normal
66	Raised
72	Loud
78	Very loud
84	Shouting
90	Maximal shout
96	Maximal shout (individual)



- A-weighted sound pressure level in a distance of 1 m in front of the mouth
- The human voice has a very large dynamic range
- The performing actor is assumed to speak with the vocal effort

$$L_{S,A,1\text{ m}} = 80\text{ dB}$$

# Loudness of speech from actor

Source position

Thorikos 2

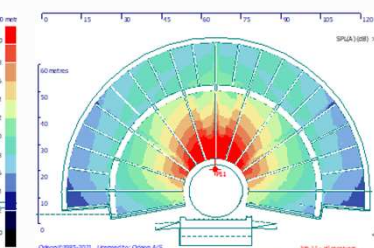
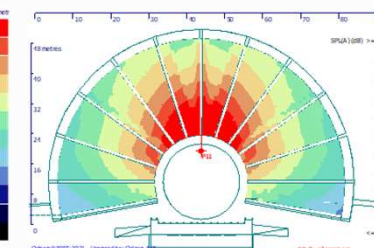
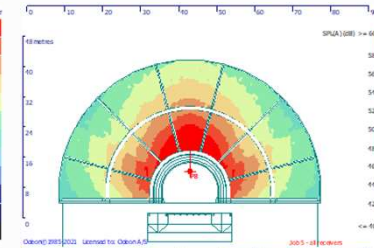
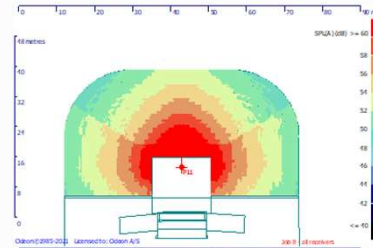
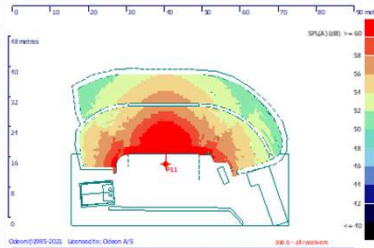
Kalydon

Iaitas

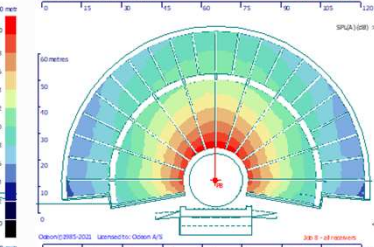
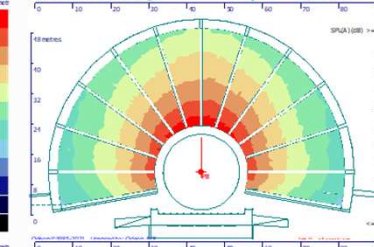
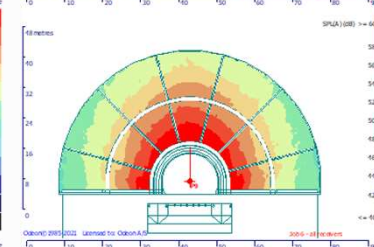
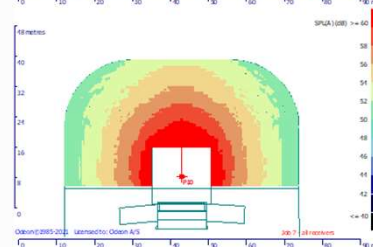
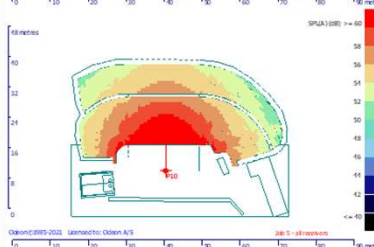
Epidaurus 1

Epidaurus 2

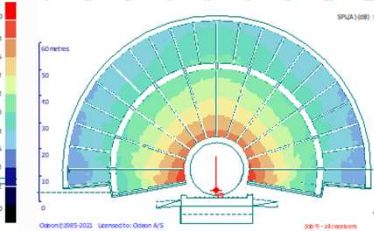
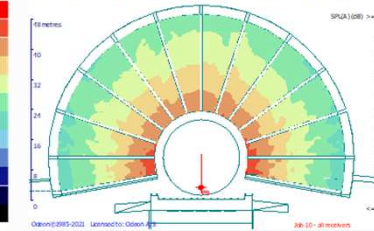
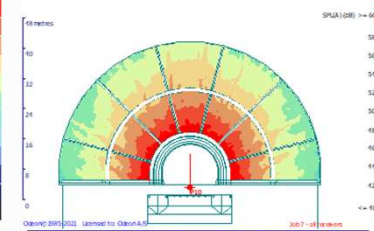
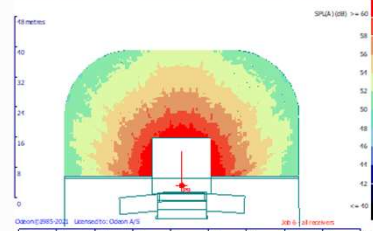
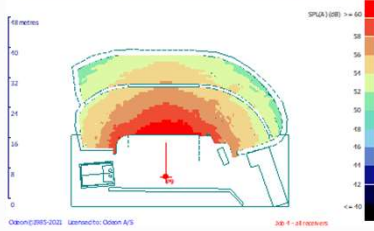
Front



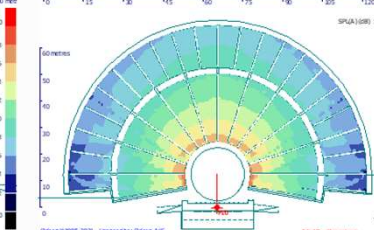
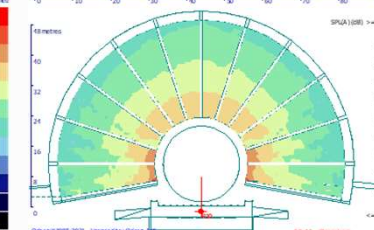
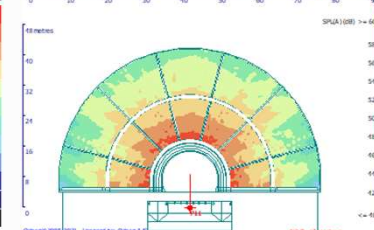
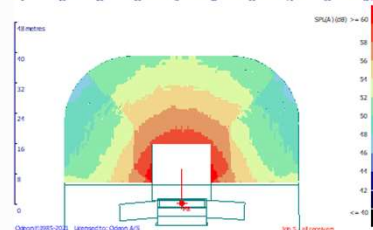
Centre



Back



On proskenion

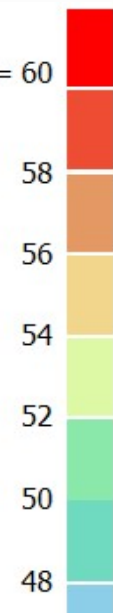


# Loudness of speech

Calculations with best source position (on the orchestra near the scene wall)

Maps of A-weighted SPL

SPL(A) (dB)  $\geq 60$



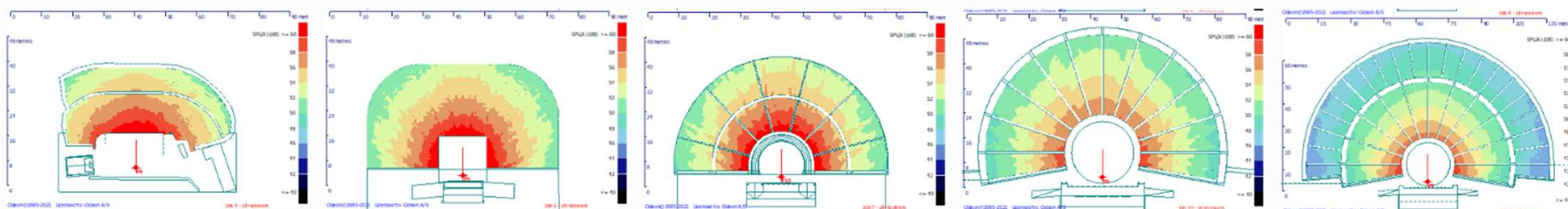
Thorikos 2

Kalydon

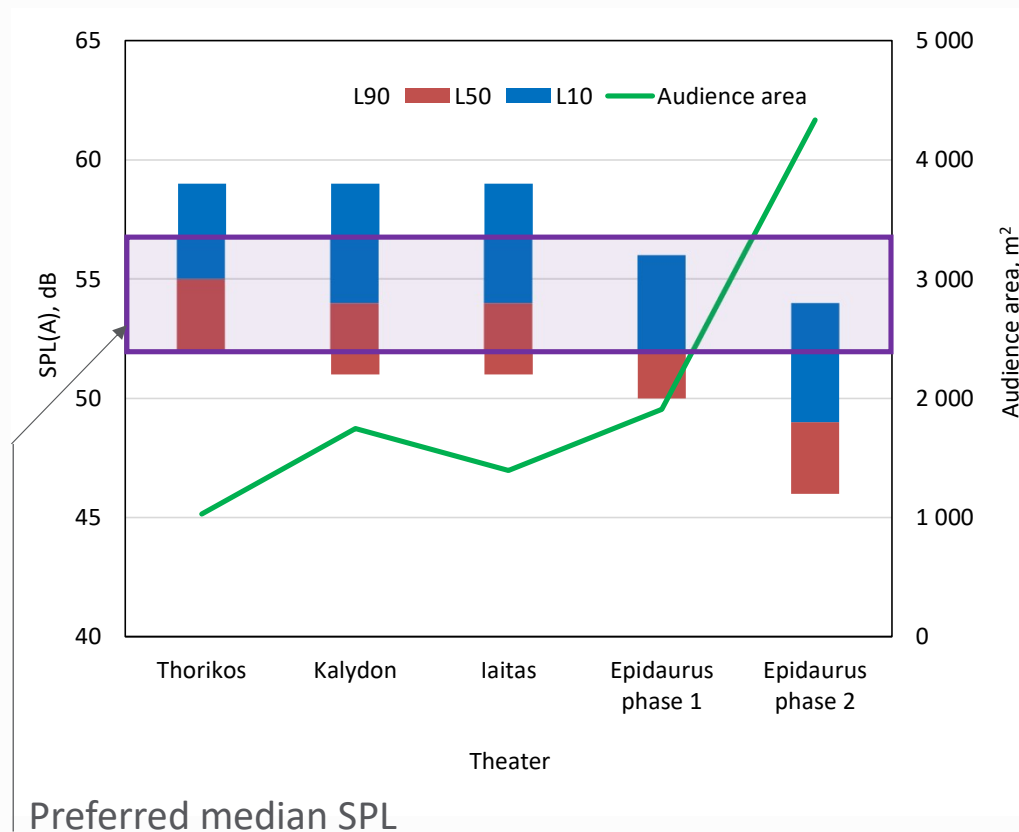
Iaitas

Epidaurus 1

Epidaurus 2



# Loudness of speech and size of theatre



- Source position in front of scene building
- Speech in very loud voice  $L_{S,A,1\text{ m}} = 80\text{ dB}$
- A-weighted sound pressure level in audience area (90, 50, and 10 percentiles)
- Preferred median SPL for listening to speech is 52 – 57 dB (background noise 40 dB or below) \*
- Theatres with audience area  $< 2\ 000\text{ m}^2$  give median SPL within optimum range

\*) E. van Heusden, R. Plomp, L.C.W. Pols, Applied Acoustics 12, 31-43, 1979.

## Conclusions

- During the 4<sup>th</sup> century BCE the theatre architecture became controlled by geometrical principles
- The slope of the seats (in the *koilon*) and the size of the *orchestra* must allow free sound propagation
- Acoustics depend on source position. Best position is on the orchestra near the stage building
- Loudness of speech is optimum in the old theatres with audience area up to 2000 m<sup>2</sup>
- Clarity of speech is no problem as long as there is no echo
- Echo depends on source position and can be avoided
- Sound reflections from the orchestra and the front of the stage building are most important for the acoustics