
BREKKE STRAND

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# SIMULATIONS AND SUBJECTIVE RATING OF ACOUSTIC CONDITIONS IN A SYMPHONY ORCHESTRA - A CASE STUDY

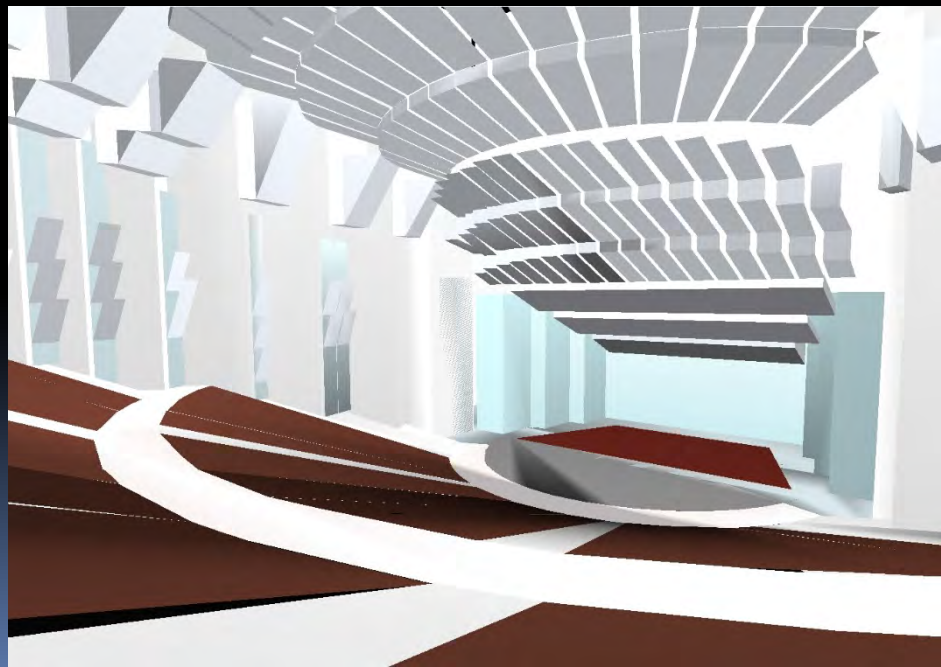
# Summary

- Subject: Acoustic conditions in a symphony orchestra on concert hall stage
- Occupied conditions very different from empty stage conditions
  - Sound is absorbed, reflected, obstructed and diffracted by musicians, chairs, stands and instruments
- Occupied conditions easier to simulate than to measure
- Case study of inter-orchestral sound transmission:
- 1 symphony orchestra, 8 familiar venues: concert halls, rehearsal hall and pit
- Subjective rating (N=50) of the 8 venues
- Simulated conditions in 3D-models (Odeon) of the 8 venues
- Comparison: Simulated conditions vs subjective rating
- Many metrics tested for correlation with subjective rating, $r^2$ ranged from 0.09 to 0.85
- Result: Inter-orchestral sound-transmission average Gd-Gr ≈0 ↔ average D-R ≈ 0
- Interpretation: Orchestra preferred a balance between direct and reverberant sound
- Implication: Fraction of co-musicians inside/outside critical radius is a critical factor

# Domestic venues

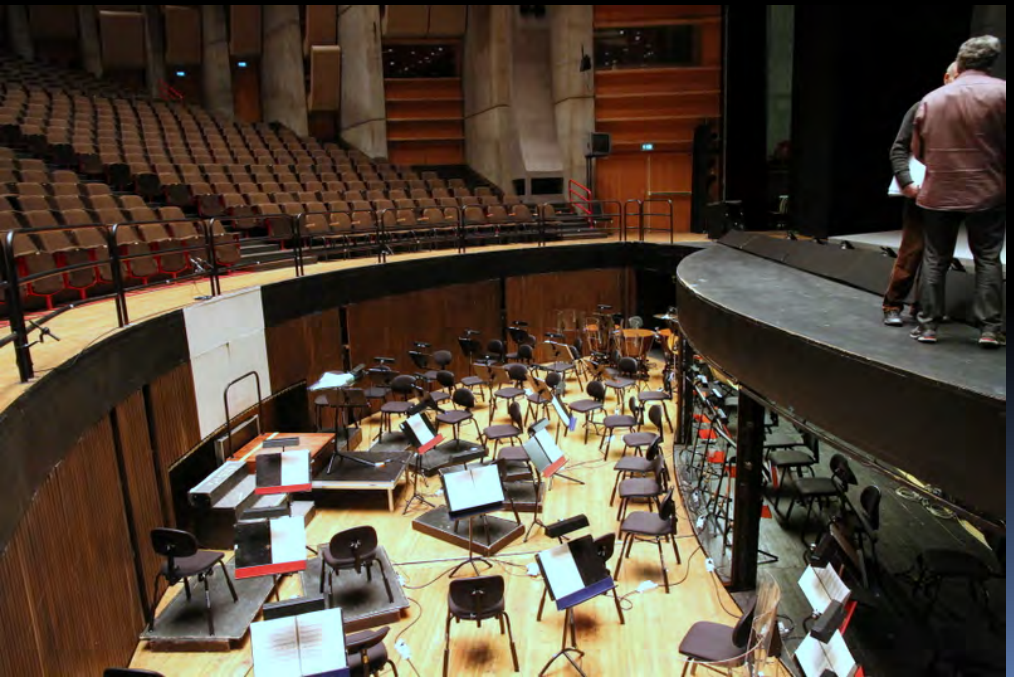
Concert hall

Computer model (Odeon)

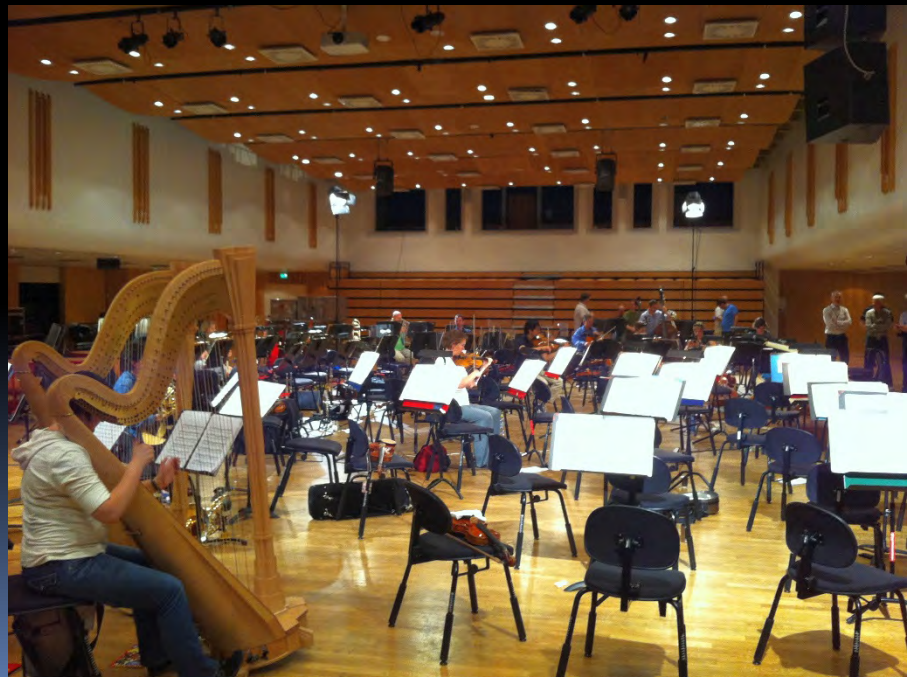


# Domestic venues

Orchestra pit in concert hall

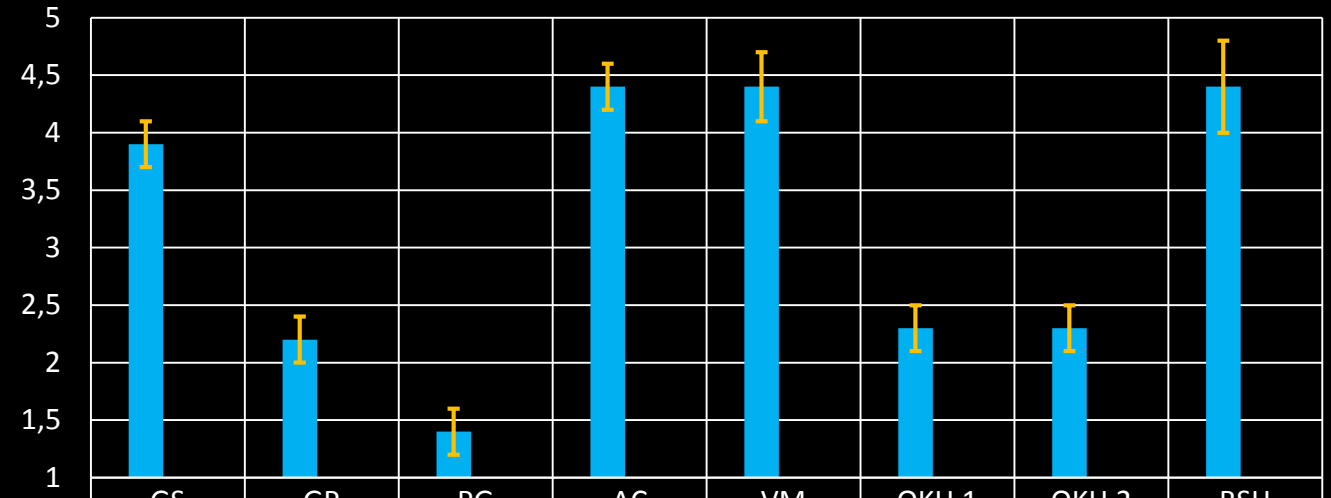


Rehearsal in multi-purpose hall



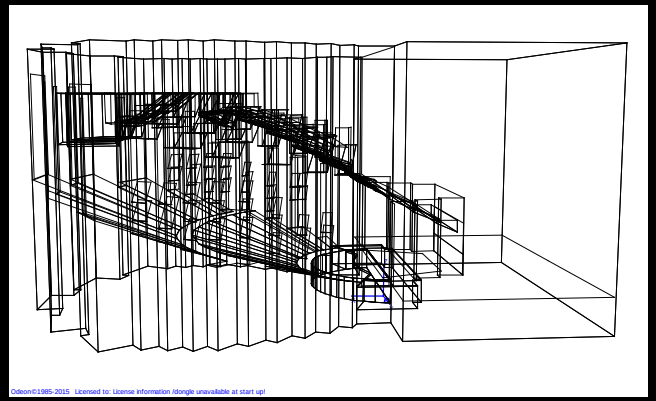
# Overall preference 8 venues

Average preference in 95% confidence intervals

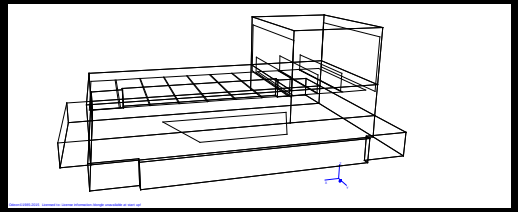



| | GS | GP | PG | AC | VM | OKH 1 | OKH 2 | BSH |
|---|---|---|---|---|---|---|---|---|
| score | 3,9 | 2,2 | 1,4 | 4,4 | 4,4 | 2,3 | 2,3 | 4,4 |
| N | 50 | 50 | 50 | 49 | 48 | 46 | 46 | 42 |

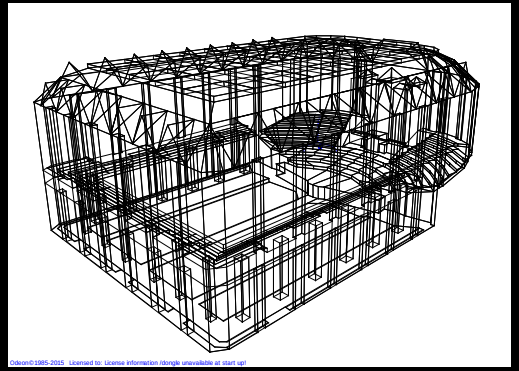
# 3D models of the venues



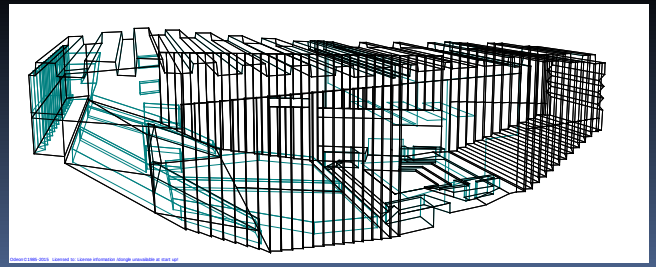

GS (stage) and GP (pit)



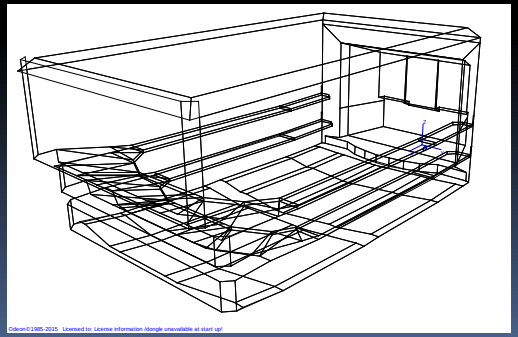
PG (rehearsal studio)



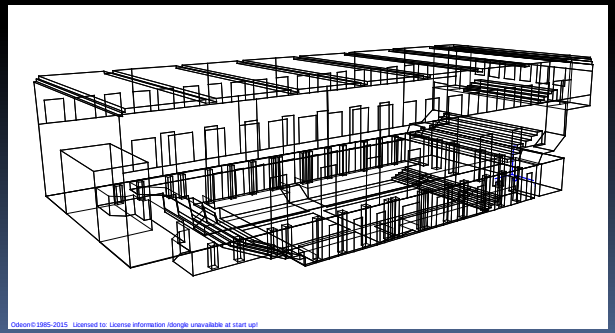

AC



OKH1 and OKH2




BSH




VM

# Simulated metrics in 8 models

8 metrics, results from simulations in the 8 venue models. "X" = Optimum values.

| Venue | $G_r$-$G_d$ [dB] | $G_r$ [dB] | $T_{30}$ [s] | $G_{late}$ [dB] | $ST_{late}$ [dB] | G [dB] | $ST_{early}$ [dB] | $G_d$ [dB] |
|---|---|---|---|---|---|---|---|---|
| GS | 1 | 8 | 1,7 | 2 | -18 | 11 | -15 | 7 |
| GP | 5 | 10 | 1,0 | -4 | -25 | 12 | -14 | 5 |
| PG | 6 | 13 | 1,4 | 9 | -13 | 14 | -12 | 7 |
| AC | -2 | 5 | 2,1 | 1 | -20 | 9 | -19 | 6 |
| VM | 0 | 7 | 2,0 | 2 | -18 | 10 | -12 | 7 |
| OKH 1 | -3 | 4 | 1,5 | 0 | -21 | 9 | -16 | 7 |
| OKH 2 | -3 | 3 | 1,6 | 0 | -21 | 9 | -18 | 7 |
| BS | -1 | 5 | 2,2 | 0 | -22 | 9 | -19 | 6 |
| | | | | | | | | |
| X | 0 | 7 | 2,2 | 2 | -19 | 10 | -20 | 6 |

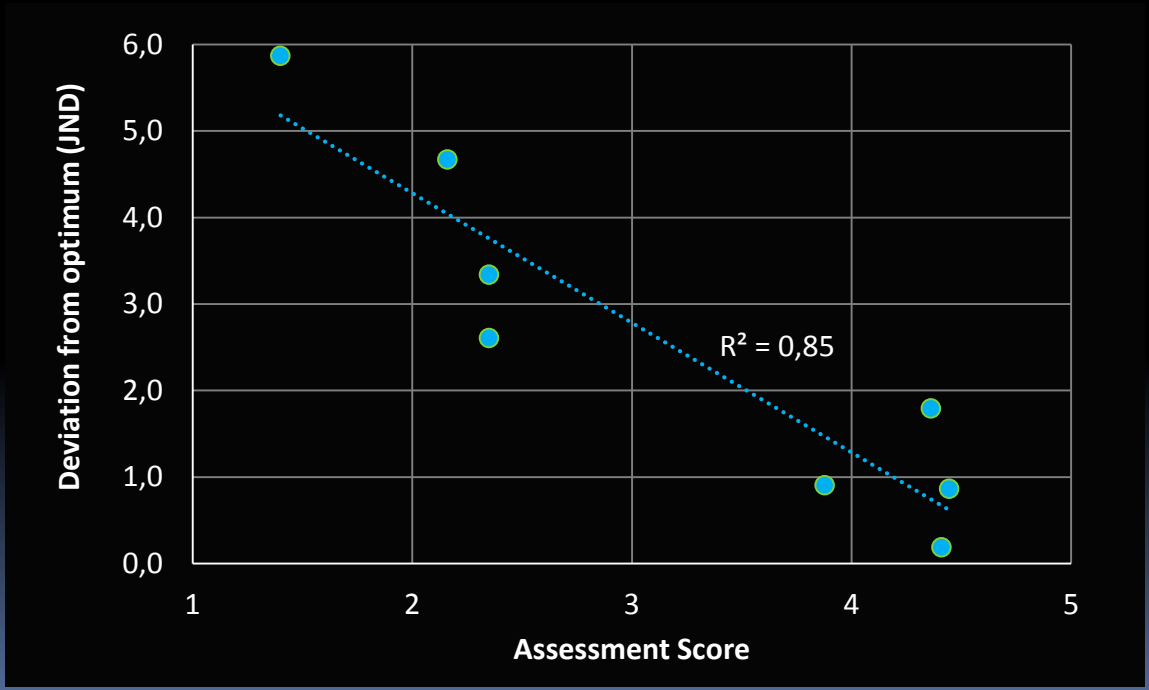
# Deviations from Optimum, vs Score

8 metrics, their absolute deviations (JND) from Optimum, and correlation r and r2 between deviations and Score, in 8 venues.

| Venue | $G_d$-$G_r$ [JND] | $G_r$ [JND] | $T_{30}$ [JND] | $G_{late}$ [JND] | $ST_{late}$ [JND] | G [JND] | $ST_{early}$ [JND] | $G_d$ [JND] | Score |
|---|---|---|---|---|---|---|---|---|---|
| **GS** | 1 | 1 | 4 | 0 | 1 | 1 | 5 | 1 | **3,9** |
| **GP** | 5 | 3 | 11 | 6 | 6 | 2 | 6 | 1 | **2,2** |
| **PG** | 6 | 6 | 7 | 7 | 6 | 4 | 8 | 1 | **1,4** |
| **AC** | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 0 | **4,4** |
| **VM** | 0 | 0 | 2 | 0 | 1 | 0 | 8 | 1 | **4,4** |
| **OKH 1** | 3 | 3 | 6 | 2 | 2 | 1 | 5 | 1 | **2,3** |
| **OKH 2** | 3 | 3 | 5 | 2 | 2 | 1 | 2 | 1 | **2,3** |
| **BSH** | 1 | 1 | 0 | 2 | 3 | 1 | 1 | 0 | **4,4** |
| | | | | | | | | | |
| **r2** | 0,85 | 0,74 | 0,71 | 0,64 | 0,51 | 0,49 | 0,22 | 0,09 | 1.0 |
| **r** | -0,92 | -0,86 | -0,84 | -0,8 | -0,71 | -0,7 | -0,47 | -0,29 | -1.0 |

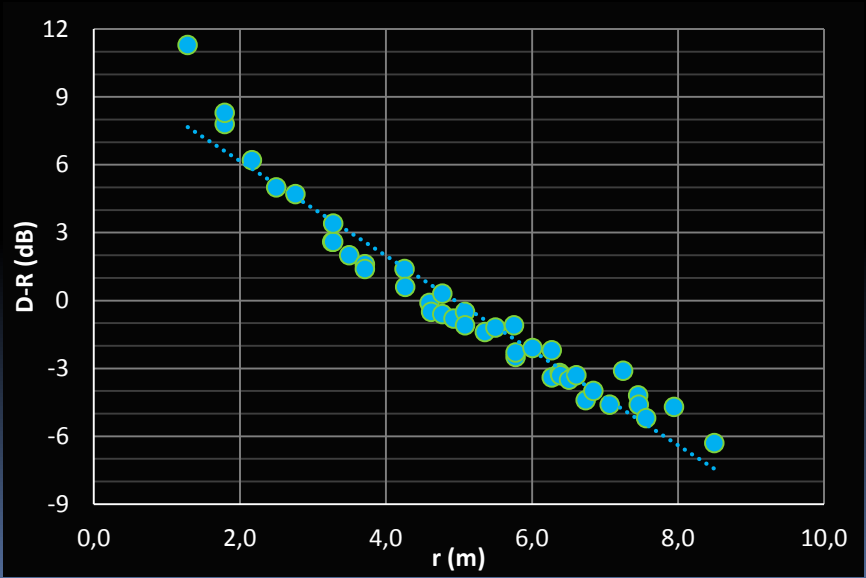
# $| G_d - G_r |$ vs Score, 8 venues

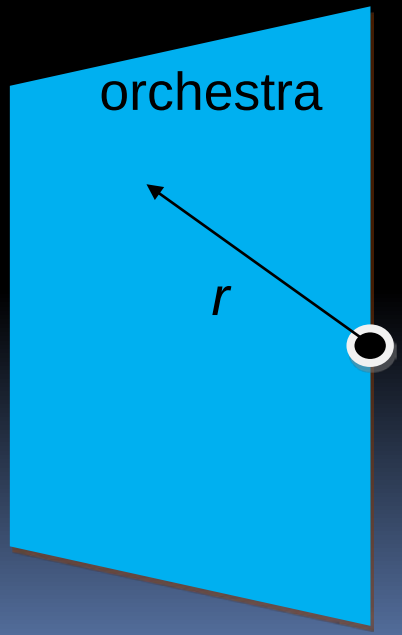
Absolute deviations (in JND) from Optimum, correlation $r^2=0.85$



# *D-R (dB)* vs distance *r (m)*

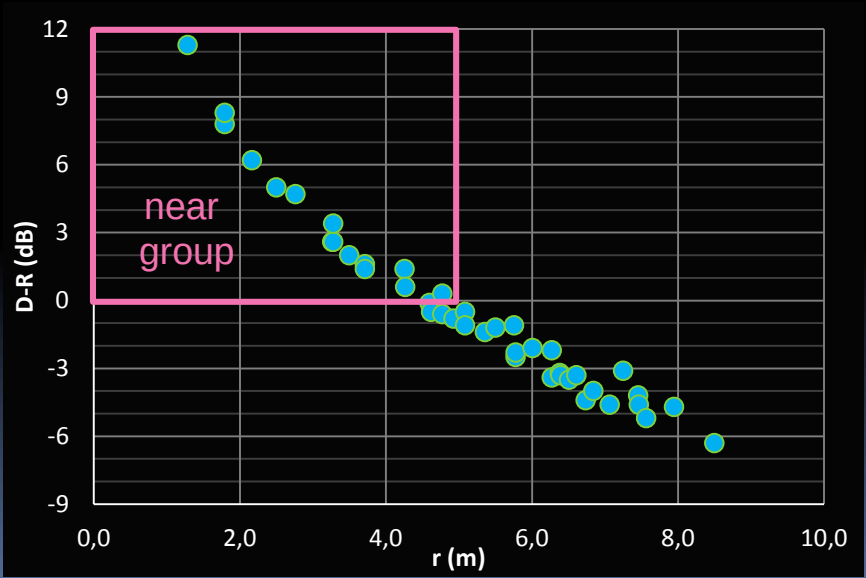
Mid-frequency average (500 and 1000 Hz octaves)
Trend line D-R = 10dB – 2*r (dB)

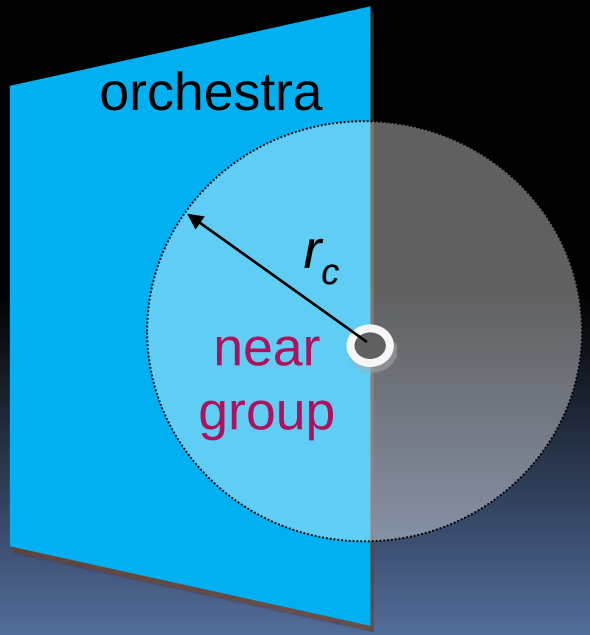


# *D-R=0*, critical radius, near – far

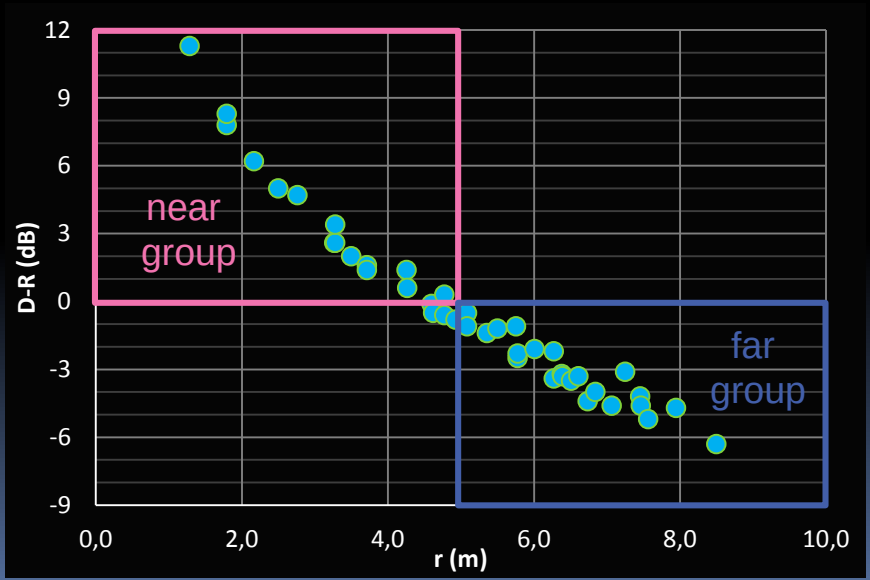
Near group heard via Direct Sound

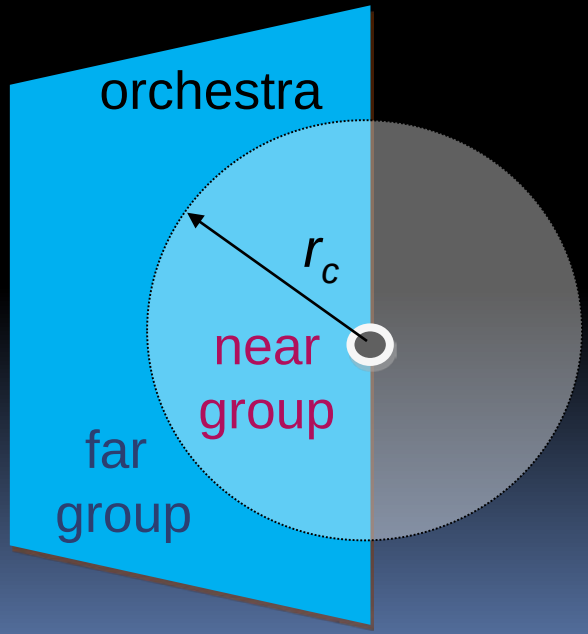


# *D-R=0*, critical radius, near – far

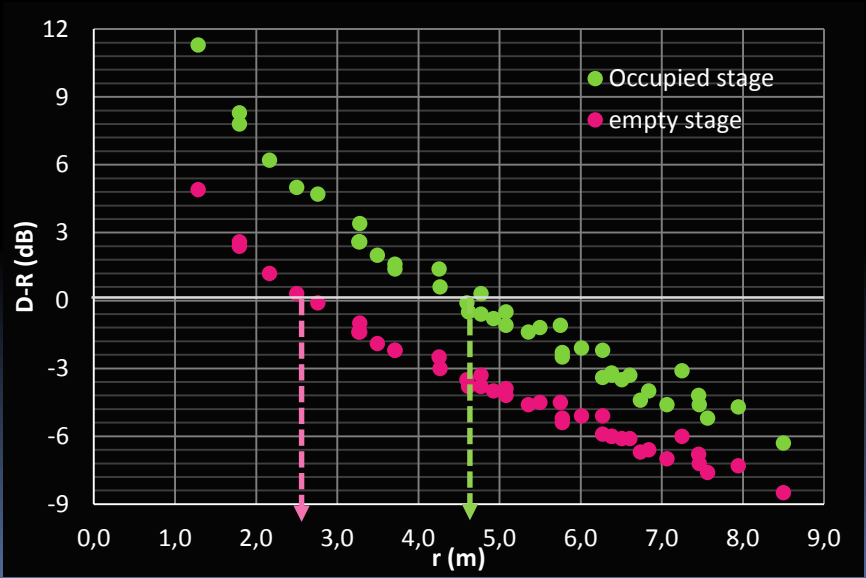
Near group heard via Direct Sound
Far group heard via Reverberant Sound

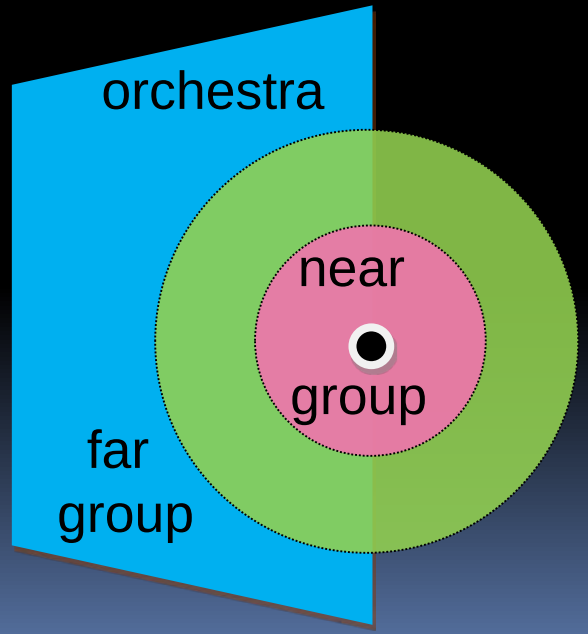


# Occupied stage vs Empty stage

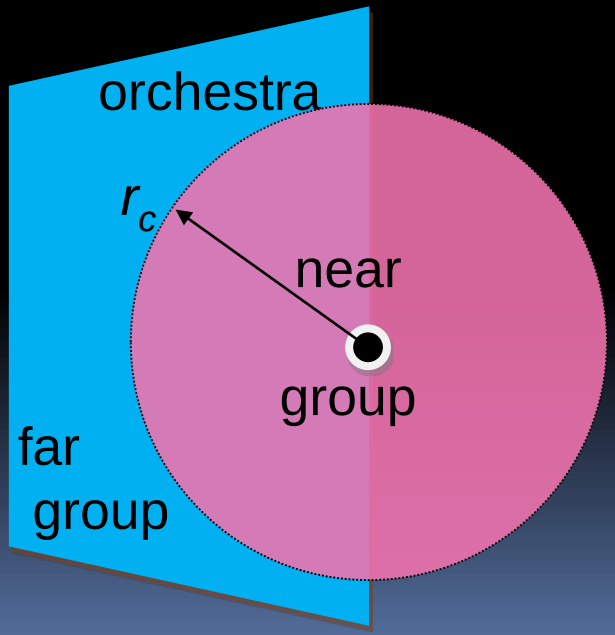
Critical Radius ≈ 4.6 m with orchestra present
Critical Radius ≈ 2.5 m on empty stage



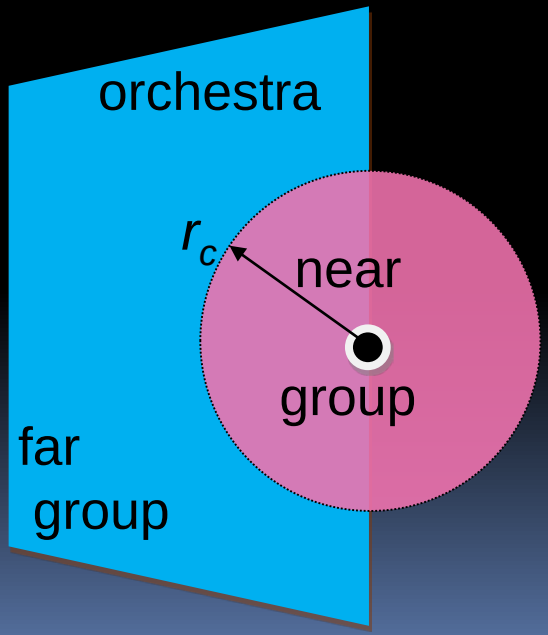



# Significance of reverberant level $G_r$

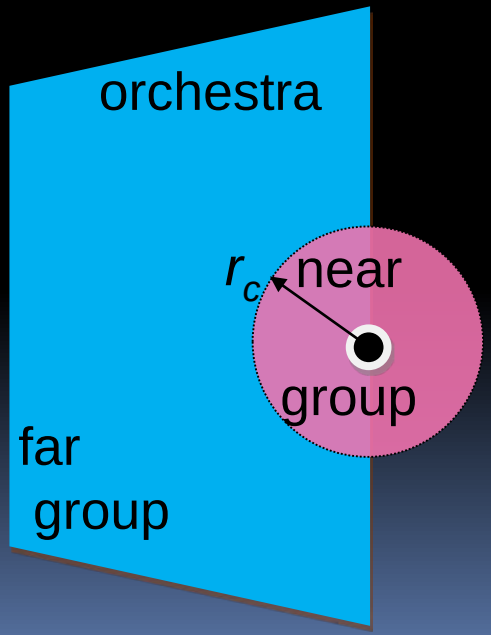
$G_r$ = 4dB




$G_r$ = 7dB



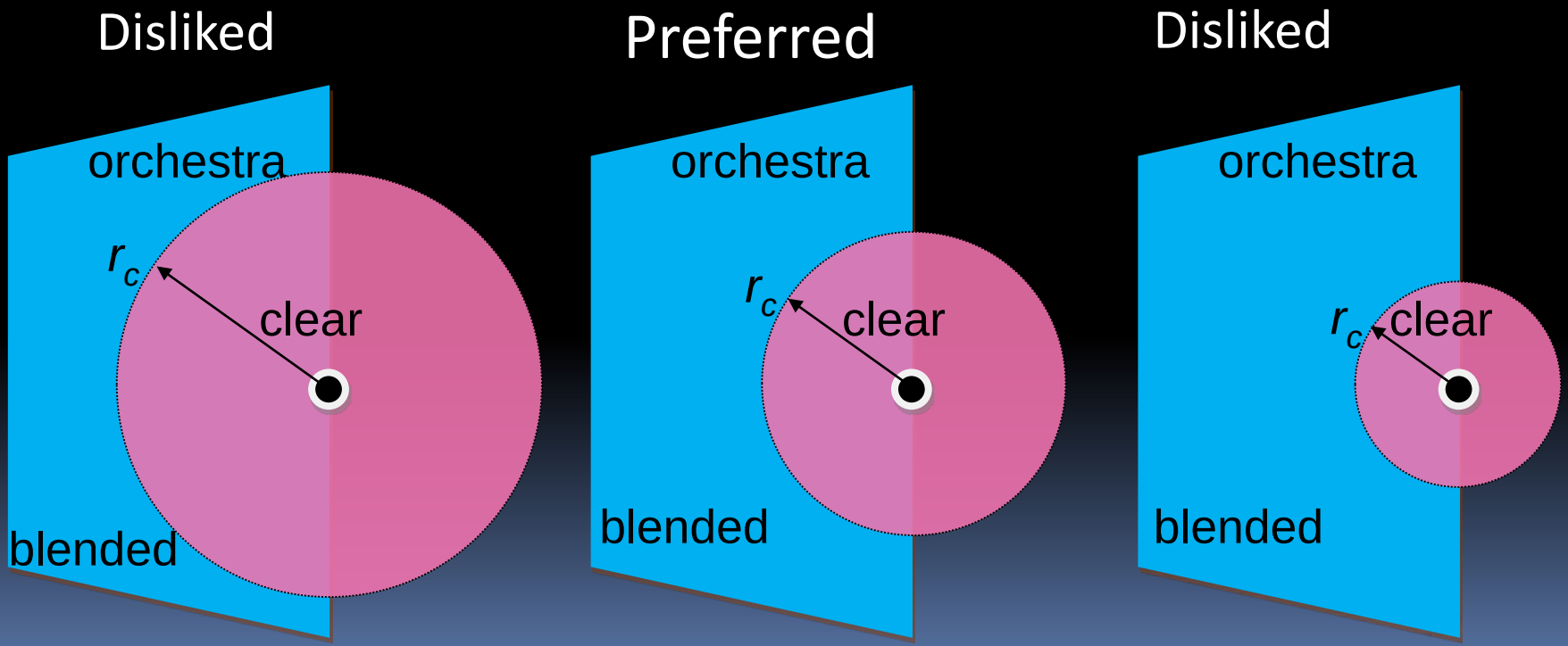

$G_r$ = 10dB



# Analogy: Visibility range


| | |
|---|---|
| Light | ↔ Sound |
| Vision | ↔ Hearing |
| Mist, Fog, Haze | ↔ Reflected sound |
| Visbility Range | ↔ Critical Radius |
| Misty | ↔ Blended |
| Clear | ↔ Clear |
| Diffuse | ↔ Diffuse |
| Discern | ↔ Discern |
| Transparent | ↔ Transparent |

# This orchestra's preferred balance



# Recommendation

- In terms of inter-orchestral D-R as discussed
  - Too low or too high D-R values
  - => escalating loudness and sound level exposure
  - => worsened conditions for inter-orchestral hearing
- Preliminary recommendation
  - simulate D-R over the orchestra in a 3D model
  - source in the position of Conductor/Concertmaster
  - Recommendation: D-R ≈ 0 dB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# Thank you

**More info?**

**The www center for search, research and open sources in acoustics**

**www.akutek.info**

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