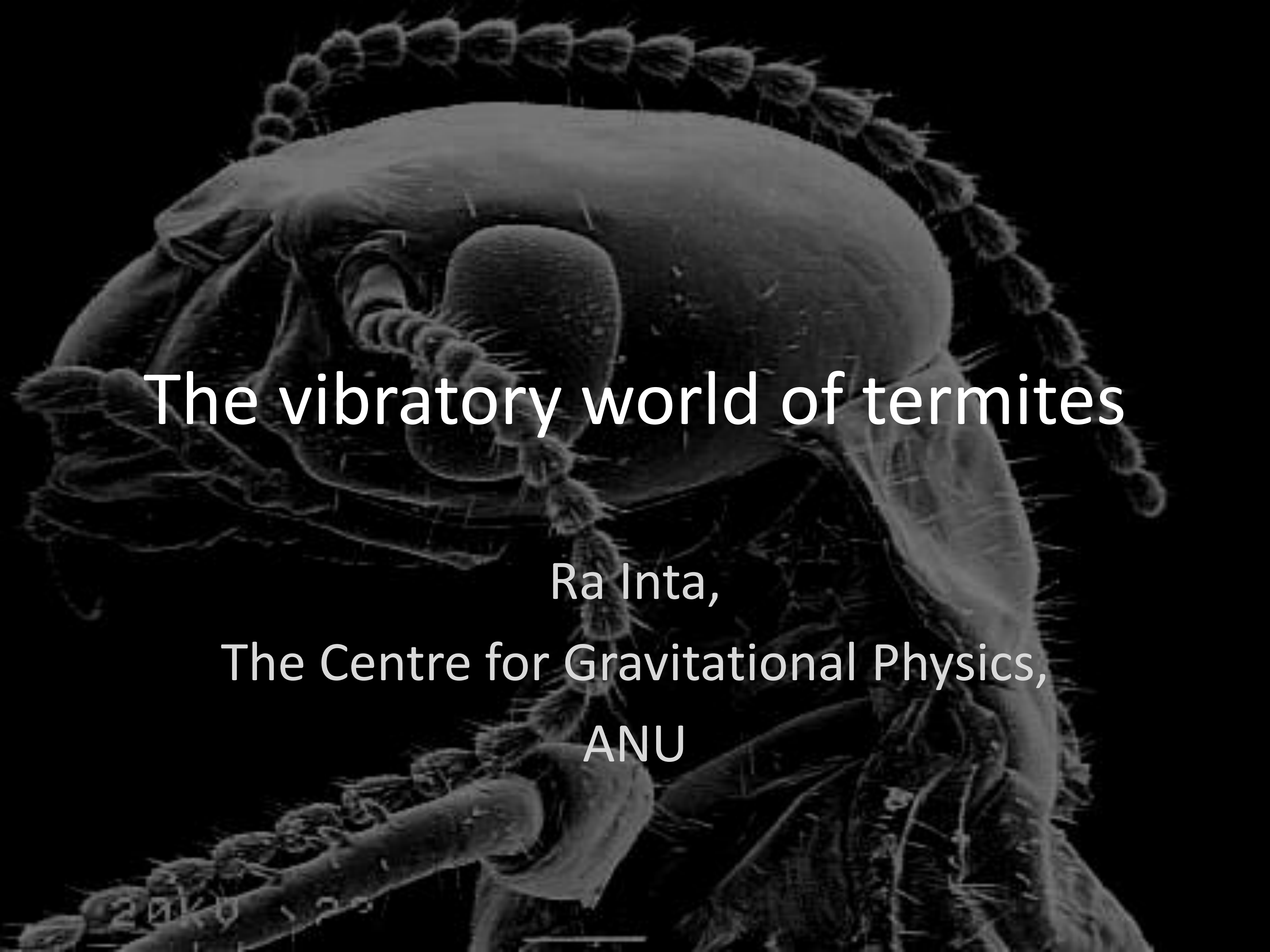


The vibratory world of termites

Ra Inta,
The Centre for Gravitational Physics,
ANU

Assumptions

Linearise Einstein field equations:

$$G^{\mu\nu} = 8\pi G/c^4 \, T^{\mu\nu}$$

By imposing constraints on metric tensor:

$$g^{\mu\nu} = \eta^{\mu\nu} + h^{\mu\nu}$$

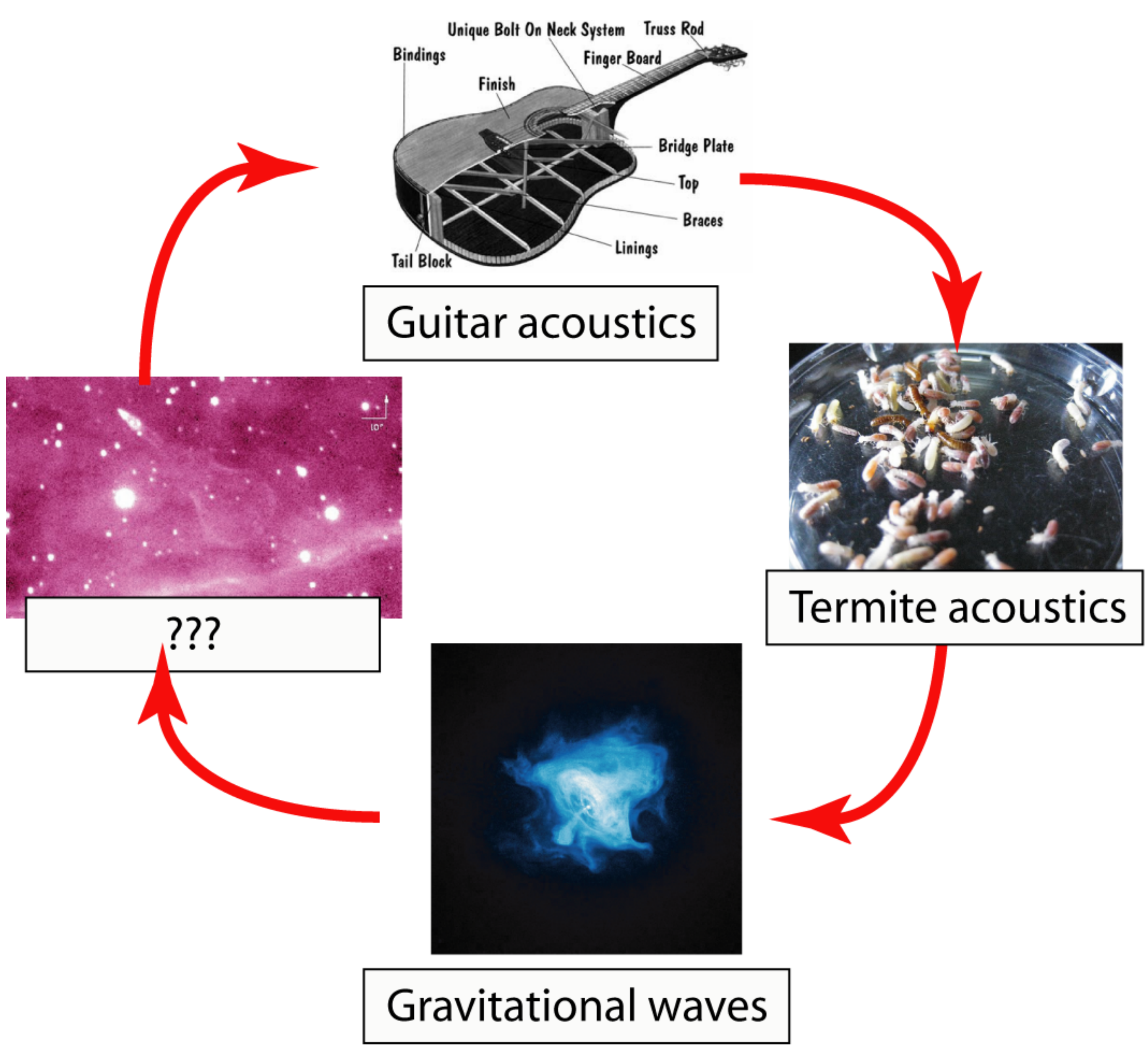
where $h^{\mu\nu}$ is a small perturbation ($|h^{\mu\nu}| << 1$) about Minkowski (flat) metric $\eta^{\mu\nu}$

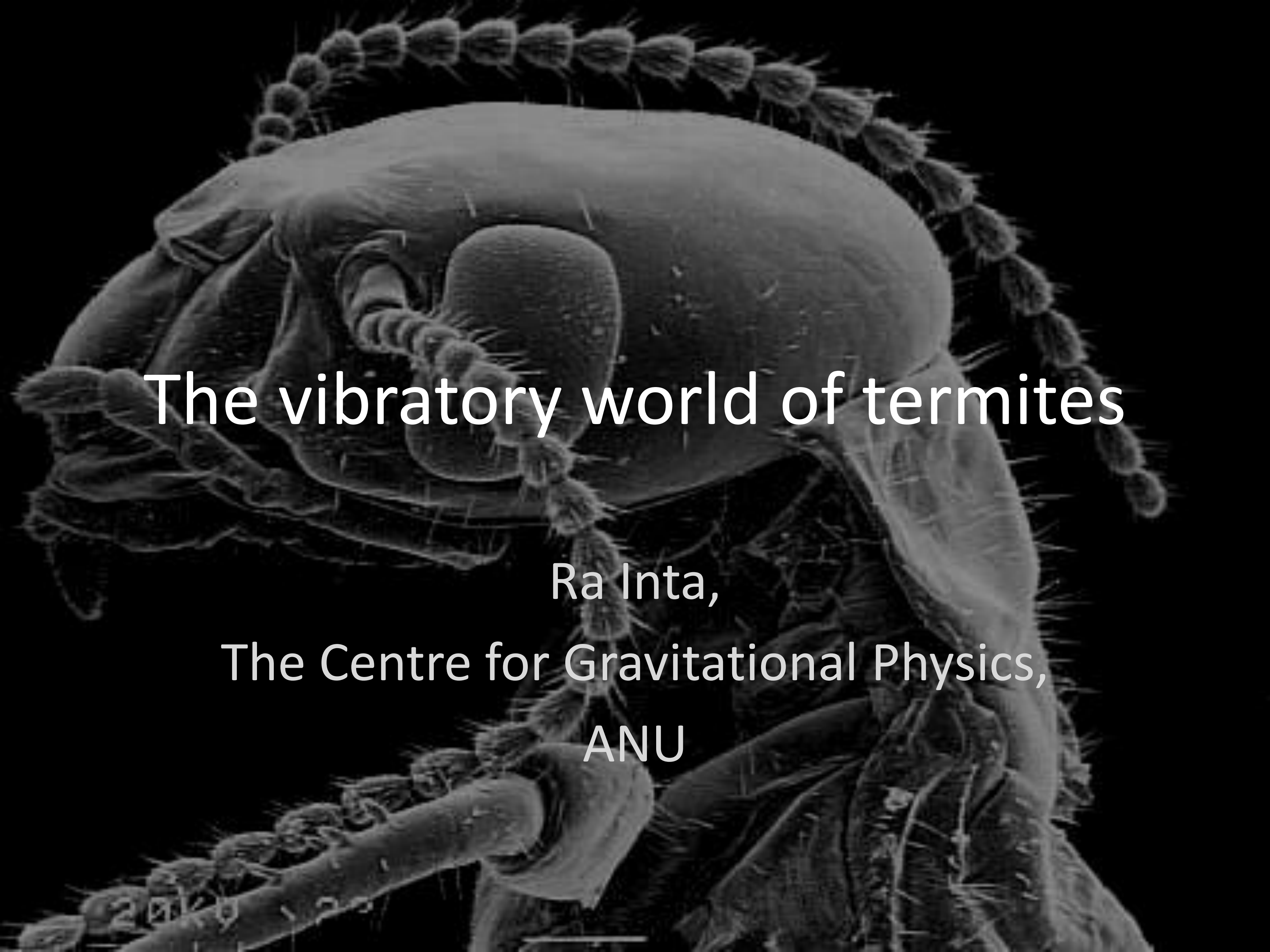
Termite perturbation tensor

Assume undulatory form for $h^{\mu\nu}$

However, because termites are very little insects, their perturbation tensor has to be written very small also:

$$h^{\mu\nu}_{\text{termite}} \rightarrow {\scriptstyle h^{\mu\nu}_{\text{termite}}}$$


Unique Bolt On Neck System
Truss Rod
Bindings
Finger Board
Finish
Bridge Plate
Top
Braces
Linings
Tail Block
Guitar acoustics
Termite acoustics
Gravitational waves
???



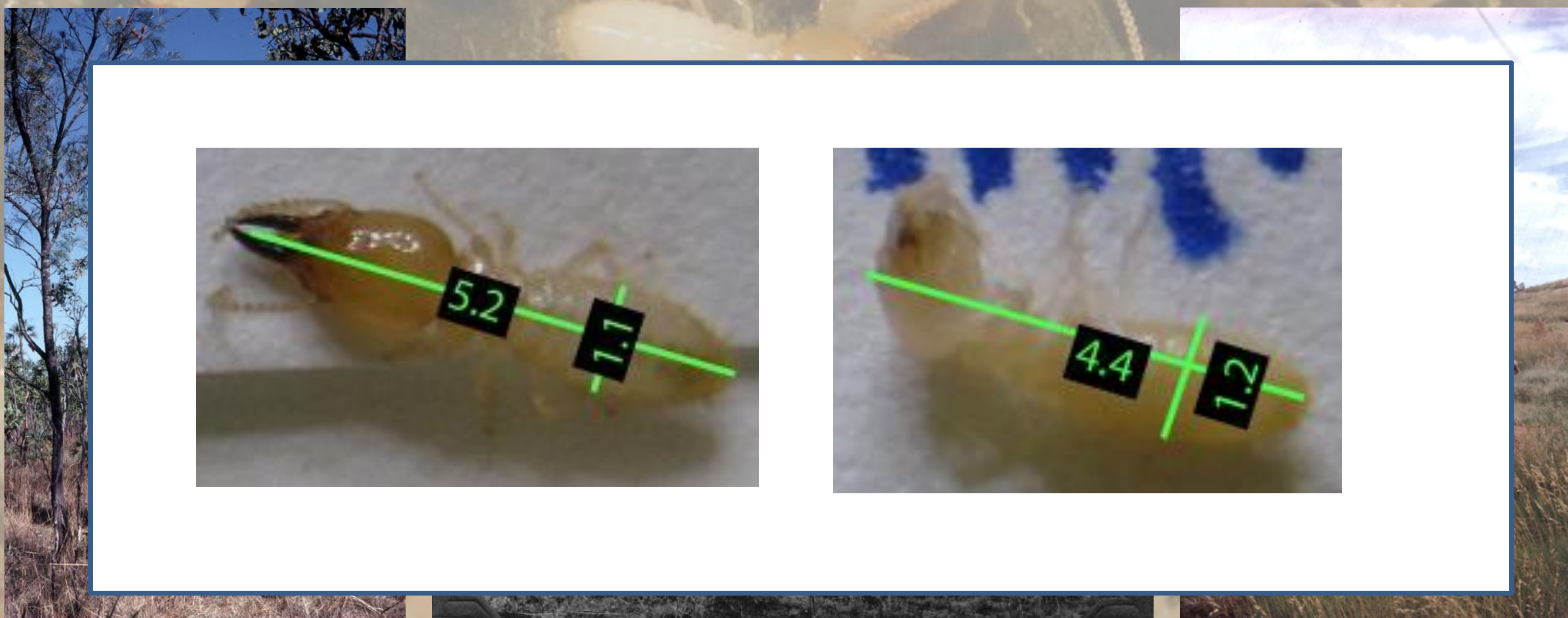
The vibratory world of termites

Ra Inta,
The Centre for Gravitational Physics,
ANU

Antennae

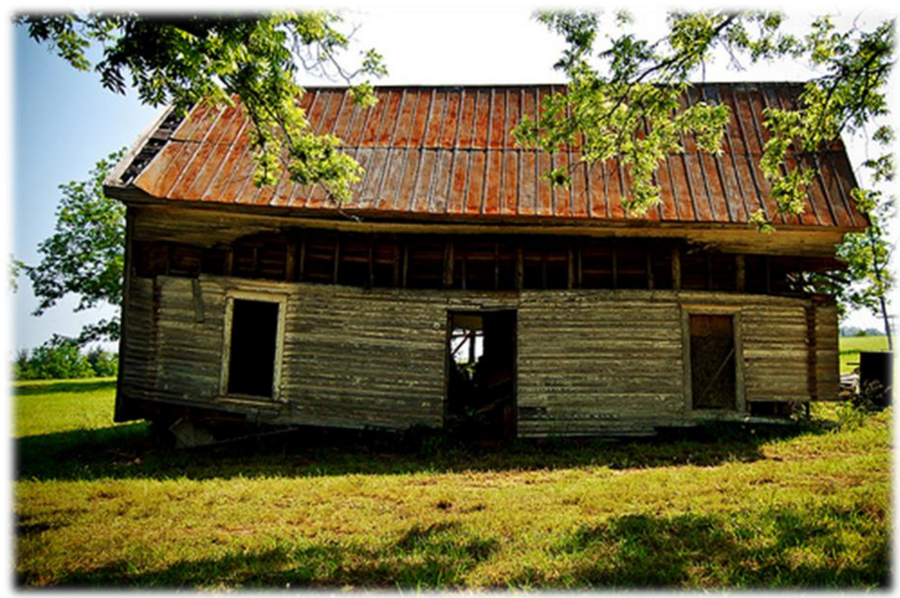
1. Justification/background
2. Vibration as an information source
3. Vibration as a survival aide
4. Vibration as a communication channel
5. Applications: exploiting termites’ vibrations

1: Justification: why termites?



Termites are evil!

- High cost: A$ 800M per year, US$5-10 G worldwide
- Complex, successful societies---more so than humans (biomass, anyway)



Vibrations: mounding evidence

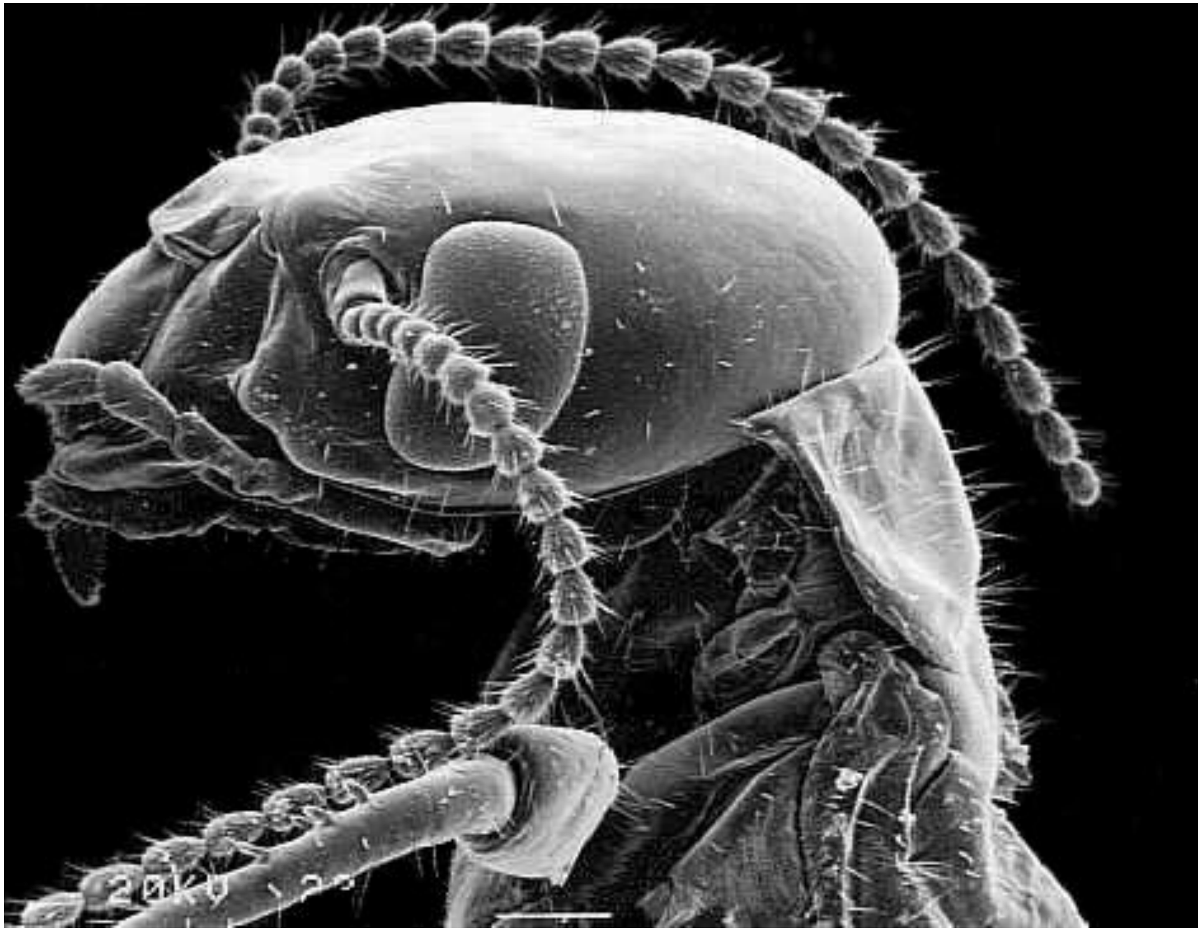
It has been known for more than 2,000 years that termites use vibrations in communication: Their name is derived from the Greek 'Termes', meaning 'the end'.

Henry Smeathman reports to the Royal Society (1781)

Biological clues

- (Eu)social, complex societies
- Blind
- Limited pheremonal repertoire
- Simple (10^5 nerve cells in cerebral ganglia)
- Pathetic
- Over 80% of arthropod species use vibration
- Sensitive mechanoreceptors in termites
- Observed responses to vibrations

Threshold of subgenual organ: $\theta \sim 0.2$ nm



S.R. Shaw: “Re-evaluation of the absolute threshold and response mode of the most sensitive know vibration detector, the cockroach's subgenual organ: A cochlea-like displacement threshold and a direct response to sound,” *Journal of Neurobiology*, **25**(9), *pp.*1167-1185 (1994)

2: Vibration as an information source

Termites use vibrations to gather information about food sources, competitive species and other potential dangers

- Background
- Characteristics of feeding and mechanical signals and material properties
- Bioassay experiments

Assessment of food structures

Classic experiment (opposite blocks) a result/extension of Lenz

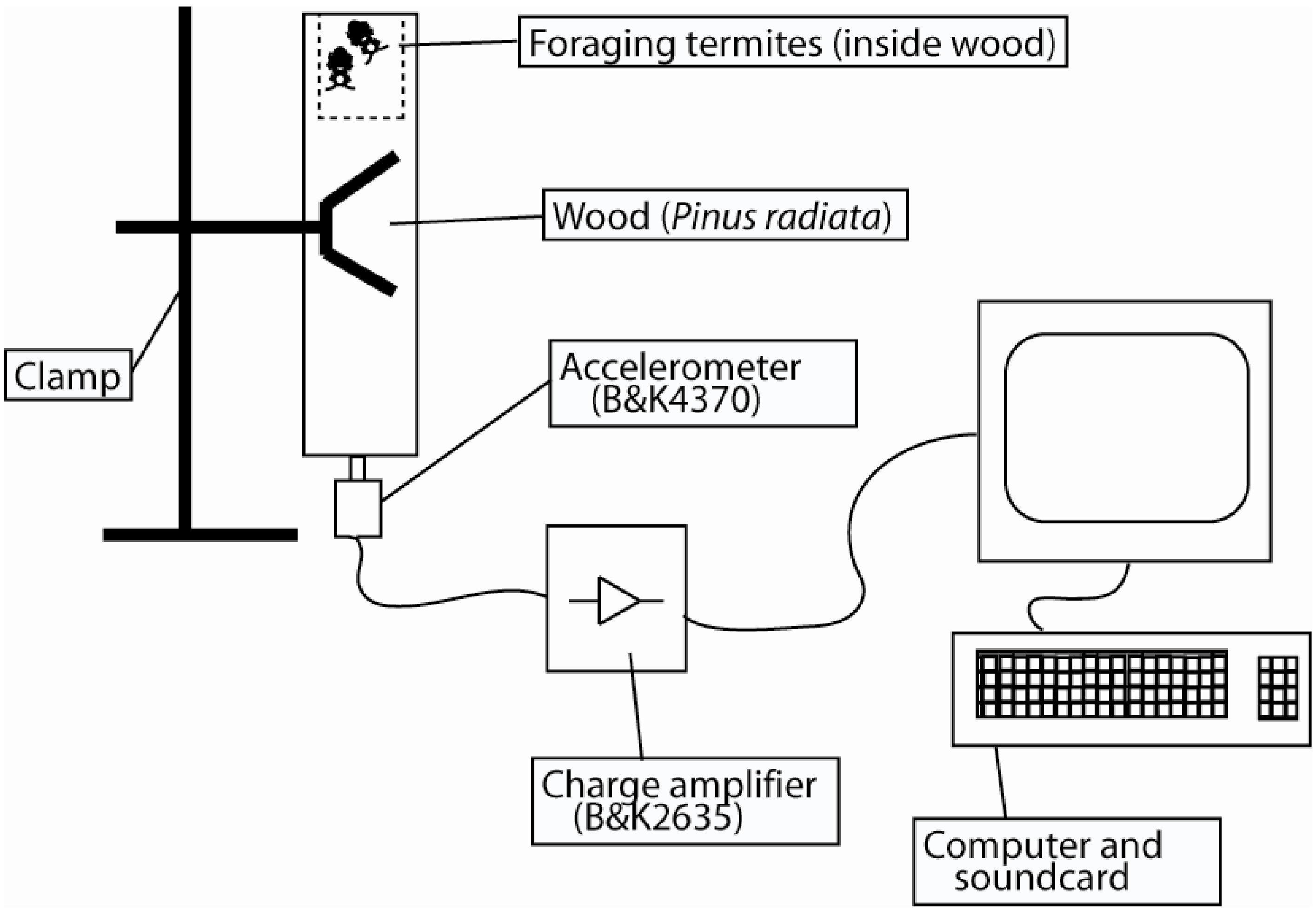
Lenz, M.: “Food resources, colony growth and caste development in wood-feeding termites,” in Nourishment and Evolution in Insect Societies, Oxford and IB H Publishing Co. Pty. Ltd. (1994)

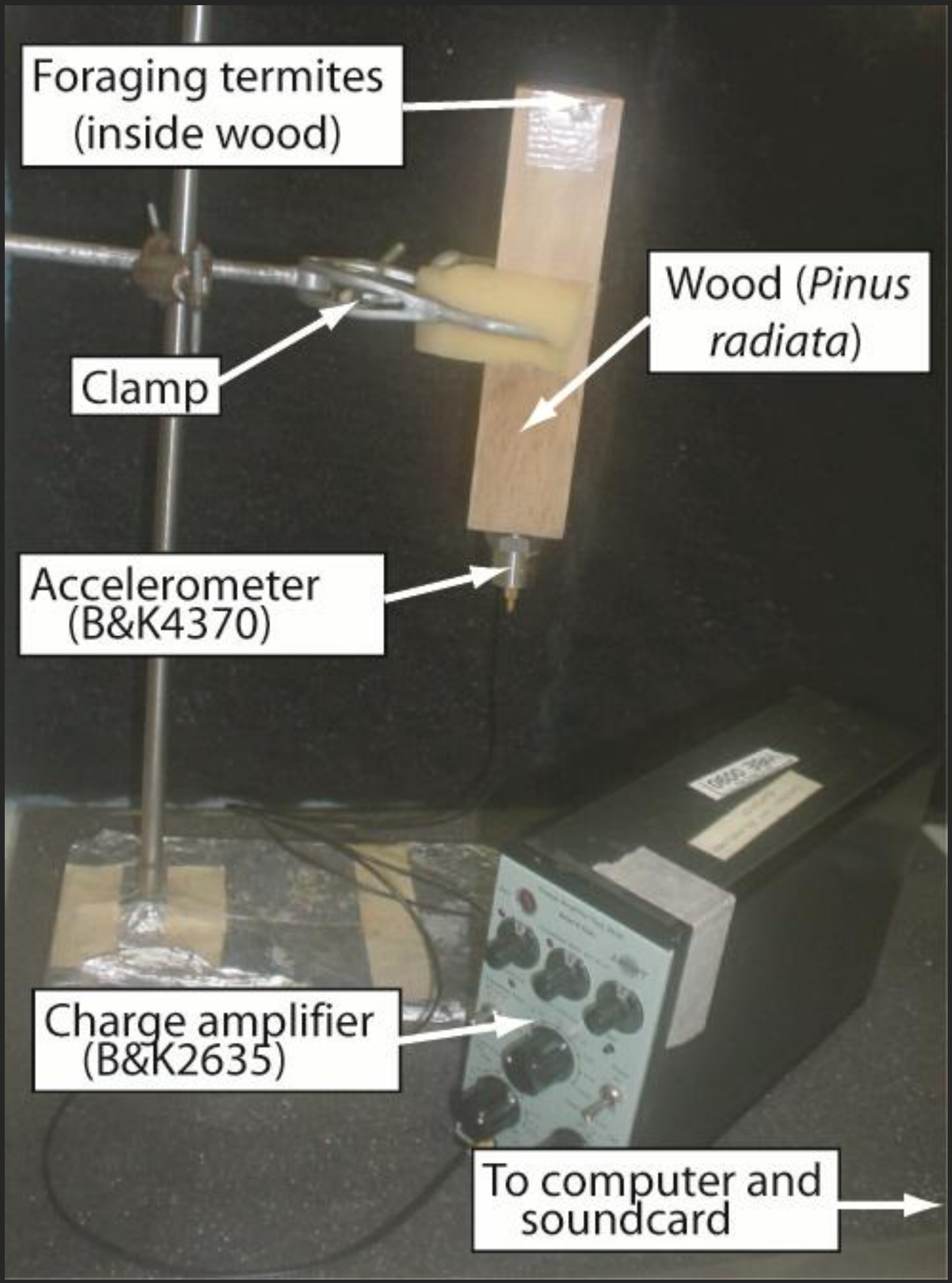
Somehow, termites know the extent of their food resources and make reproductive decisions based on this.

How do they know?

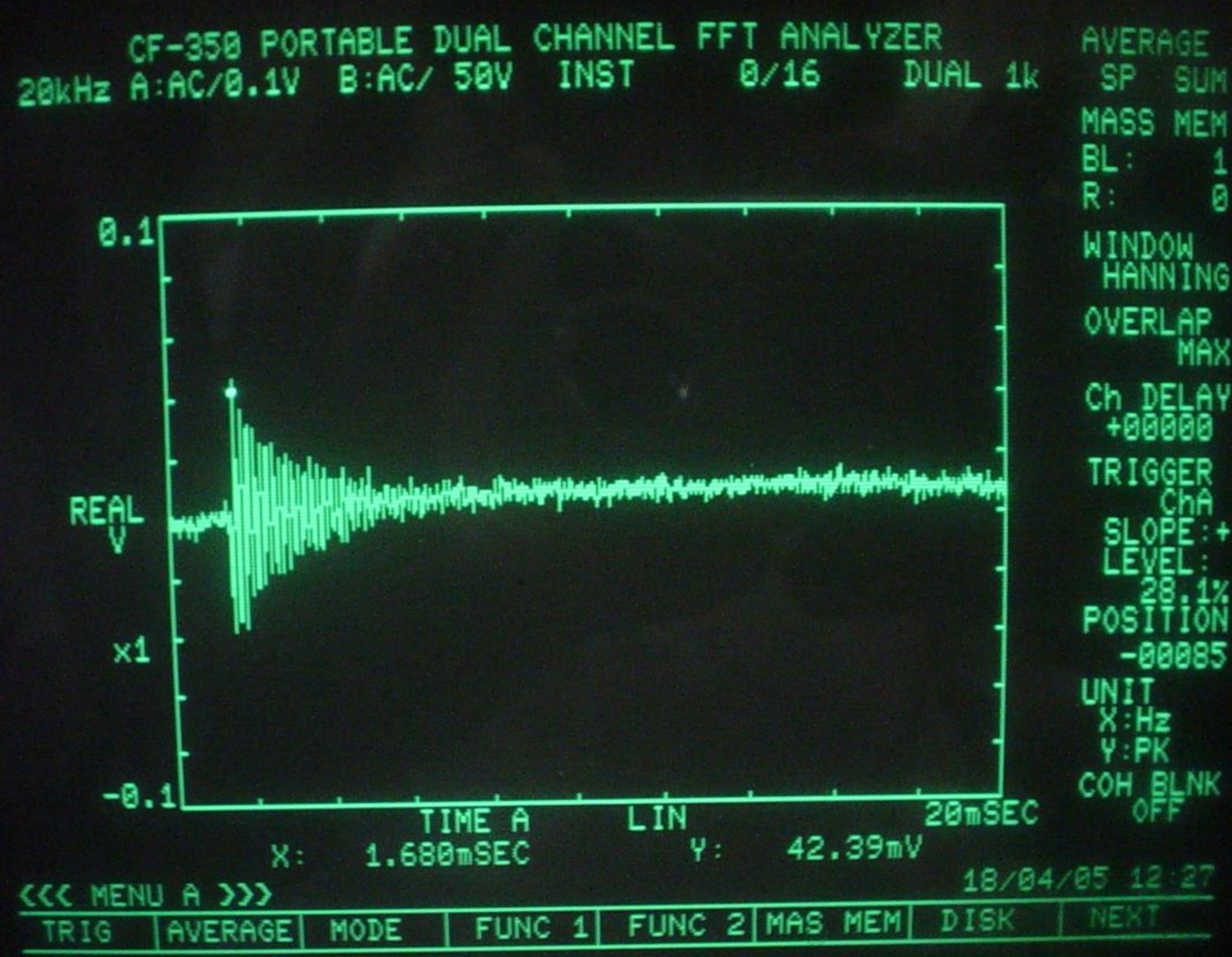
Control of substrate

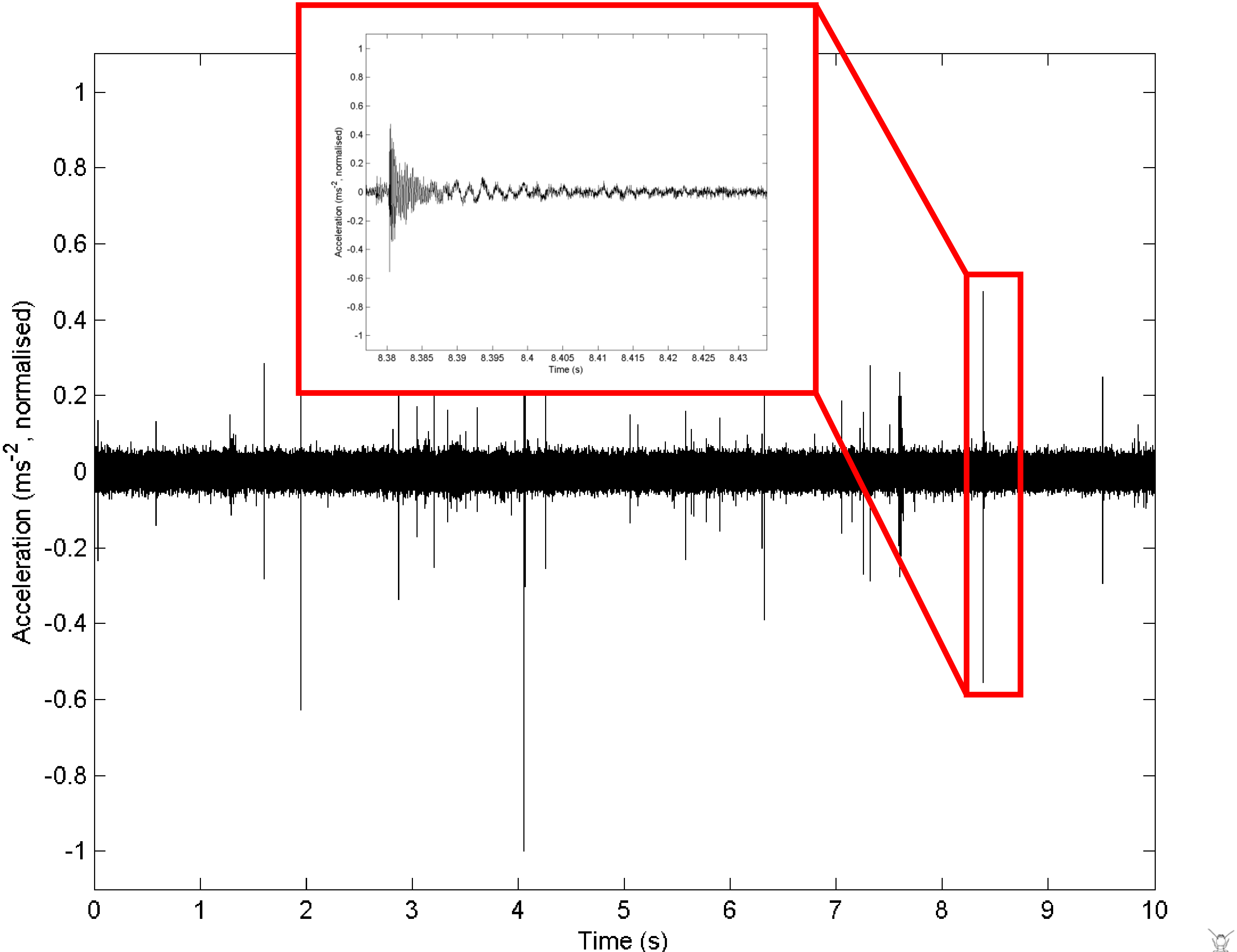
Measurement of foraging signals



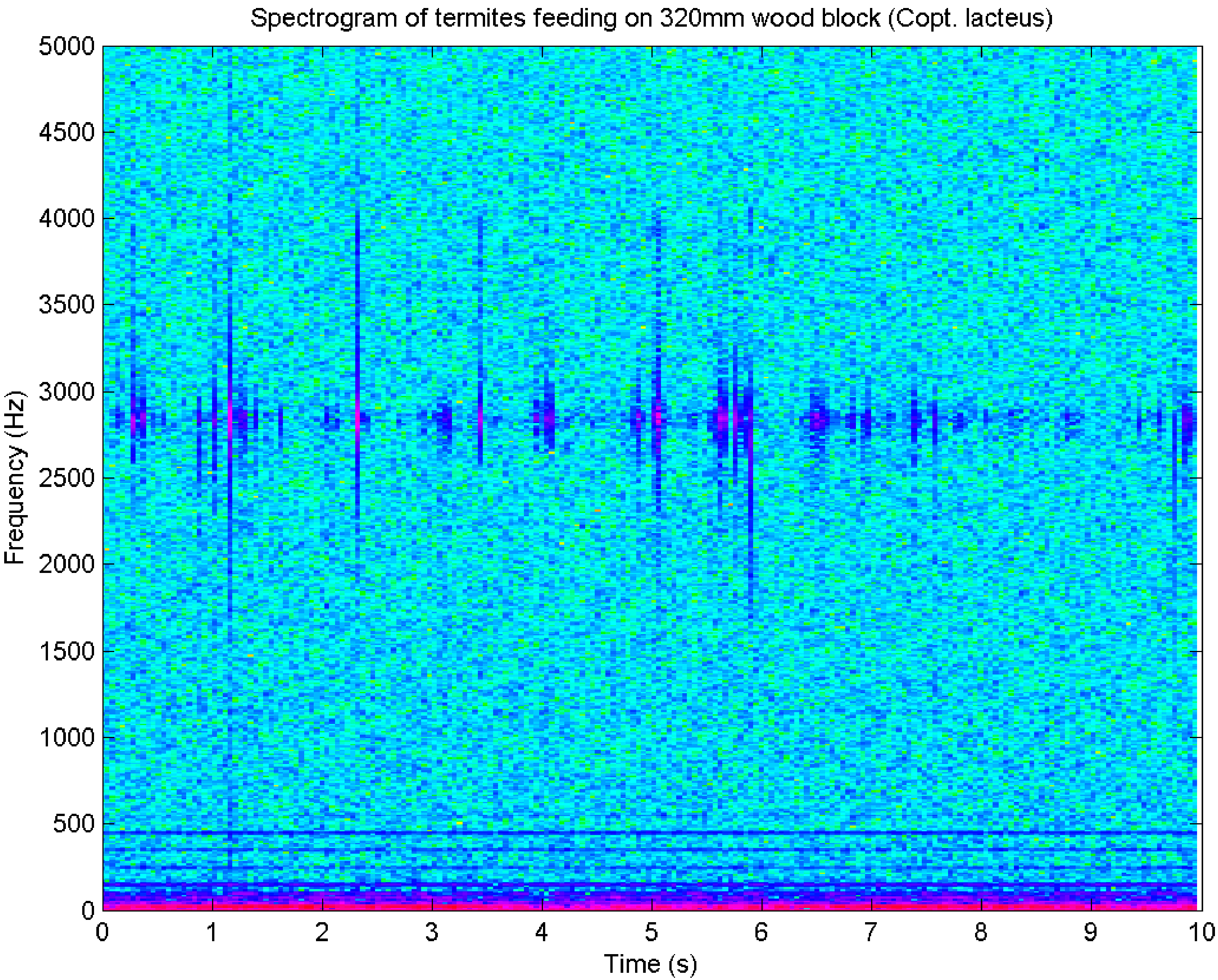


Foraging termites (inside wood)
Wood (*Pinus radiata*)
Clamp
Accelerometer (B&K4370)
Charge amplifier (B&K2635)
To computer and soundcard


CF-350 PORTABLE DUAL CHANNEL FFT ANALYZER
20kHz A:AC/0.1V B:AC/ 50V INST 0/16 DUAL 1k
AVERAGE
SP SUM
MASS MEM
BL: 1
R: 0
WINDOW
HANNING
OVERLAP
MAX
Ch DELAY
+00000
TRIGGER
ChA
SLOPE:+
LEVEL:
28.1%
POSITION
-00085
UNIT
X:Hz
Y:PK
COH BLNK
OFF
0.1
REAL
V
x1
-0.1
TIME A
LIN
20mSEC
X: 1.680mSEC
Y: 42.39mV
18/04/05 12:27
<<< MENU A >>>
TRIG
AVERAGE
MODE
FUNC 1
FUNC 2
MAS MEM
DISK
NEXT



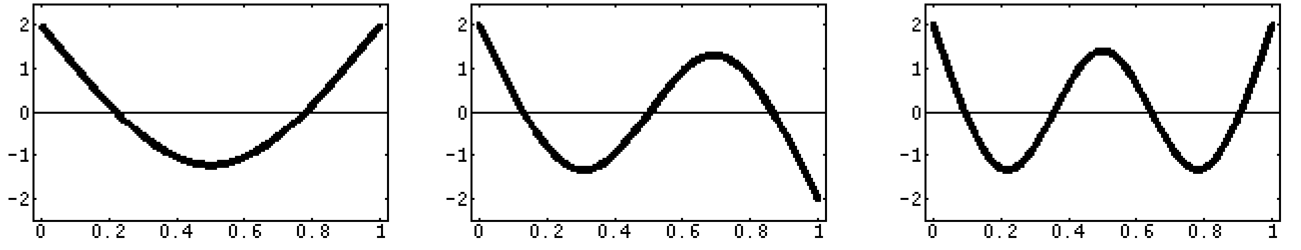
Acceleration (ms-2, normalised)
Time (s)
0
1
2
3
4
5
6
7
8
9
10
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
8.38
8.385
8.39
8.395
8.4
8.405
8.41
8.415
8.42
8.425
8.43



Spectrogram of termites feeding on 320mm wood block (Copt. lacteus)
Frequency (Hz)
Time (s)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
8
9
10

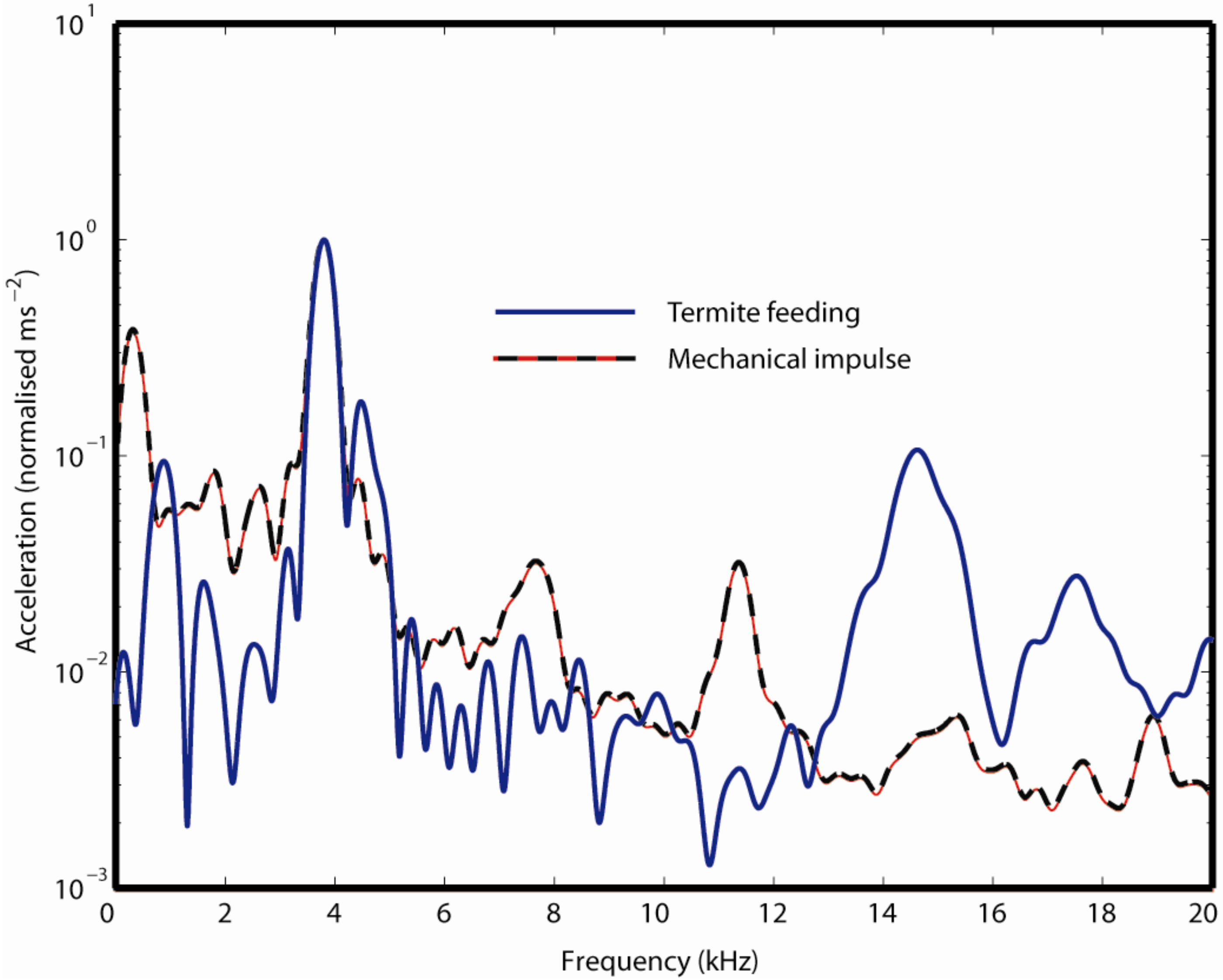
Beam mechanics

Food substrate acts like a free-free beam



Animation courtesy of Dr Dan Russell, Kettering University

Dominant signal is of the substrate

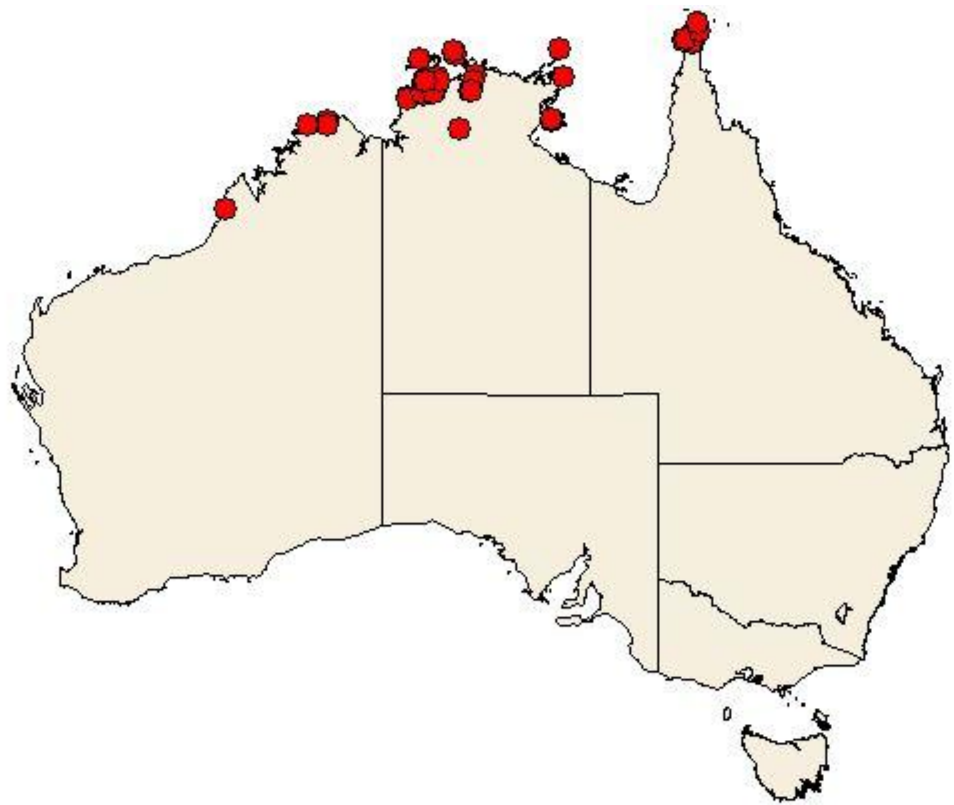


Bioassays

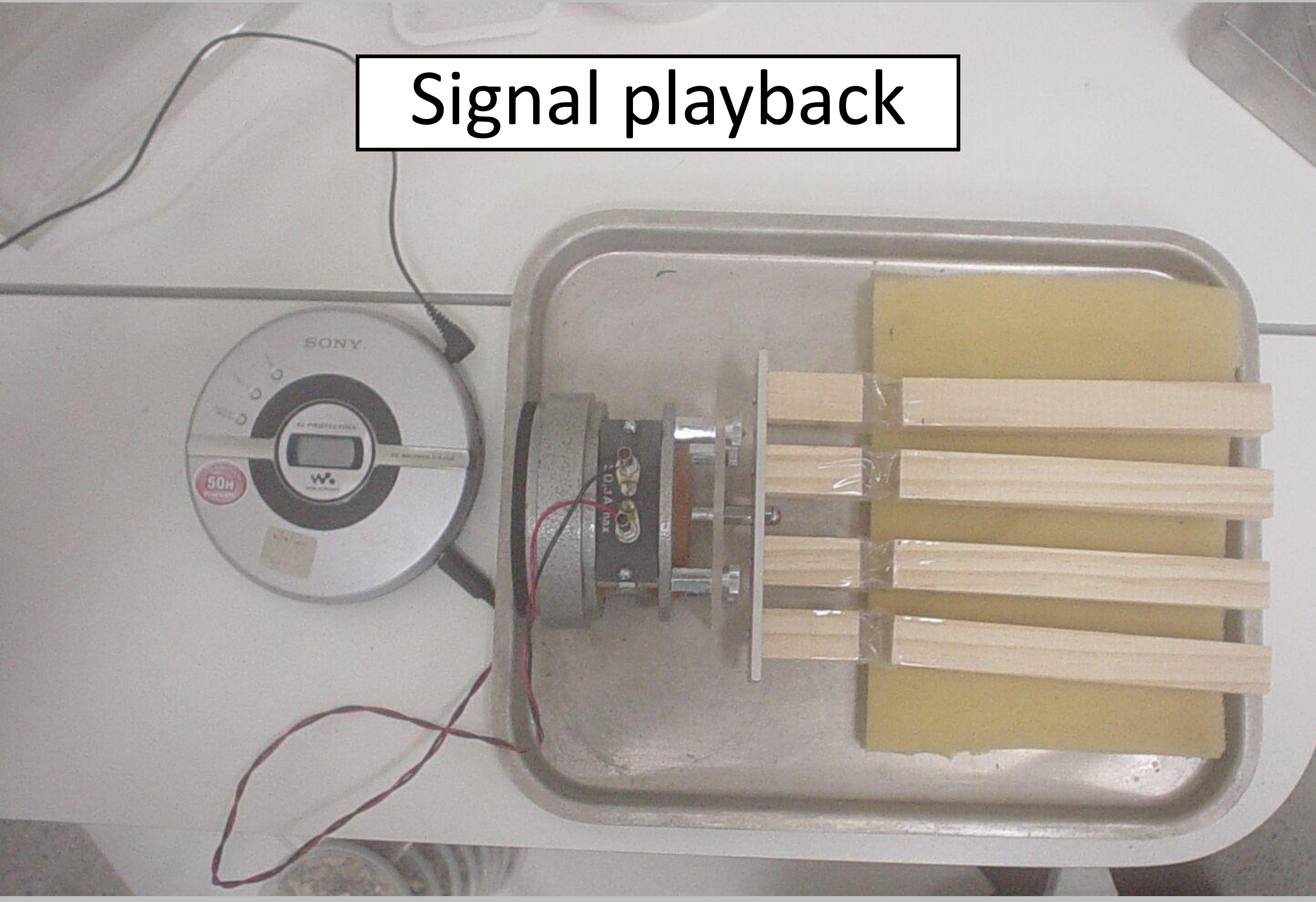
- Opposite blocks, choice experiments
- Species: *Cryptotermes domesticus* and *Cr. secundus*
- Fourteen days at 30 deg. C, 80% R.H.
- Preference measures: Tunnelling activity, movement
- Have to interpret results using statistics

Cryptotermes secundus

Good test termite because:
•Can seal them into blocks of wood
•Prefer larger blocks



Signal playback



Termites assess wood size using vibration signals

T.A. Evans, J.C.S. Lai, E. Toledano, L. McDowall, S. Rakotonarivo and M. Lenz, “Termites assess wood size by using vibration signals”, *Proceedings of the National Academy of Science USA* **102**, 3732-3737 (2005)

Photo courtesy of CSIRO

Playback experiments positively show *Cr. domesticus* use vibrations, preferring *smaller* blocks of wood

What are they responding to in the signal?

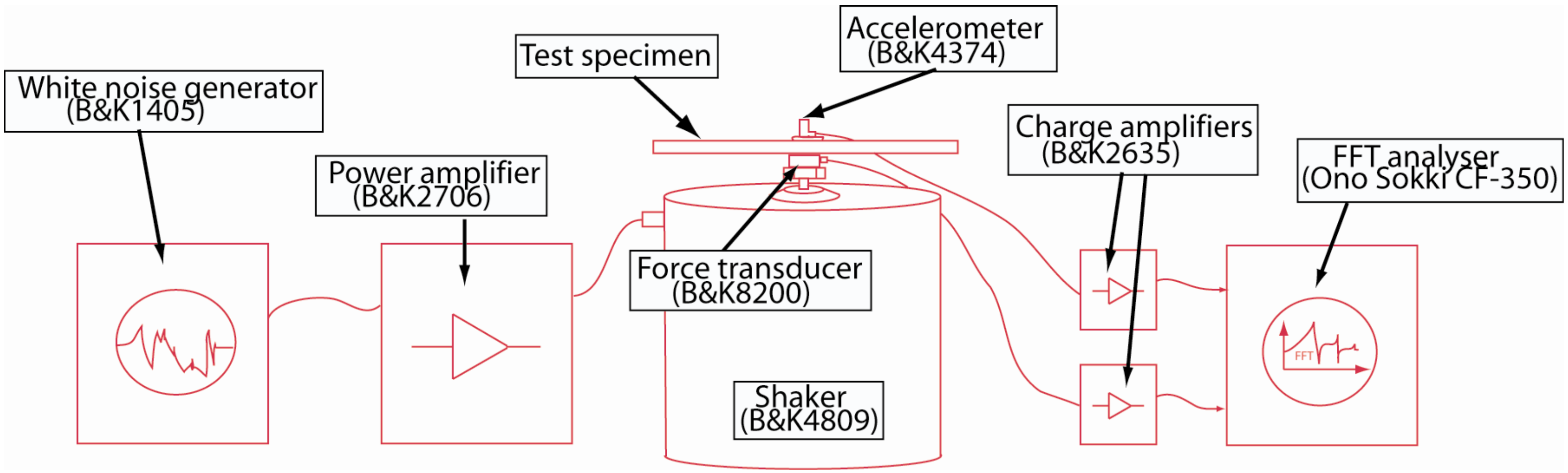
Assumption: simple animal→ simple feature of vibratory signal

Not clear that they respond to substrate only or convolved with voiceprint

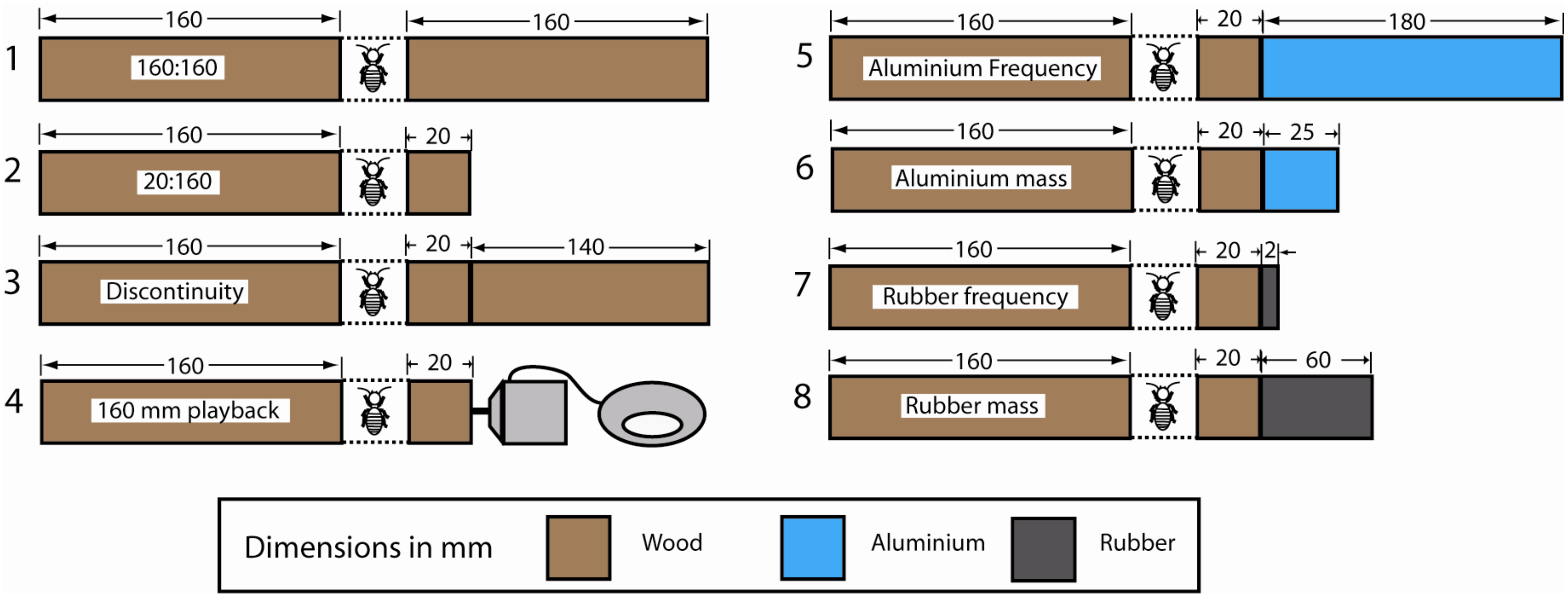
For simple geometry, and material, the key measure could be either:

i. Frequency (f_0)
ii. Amplitude of acceleration ($|\mathbf{a}|=|\mathbf{F}|/m$)
iii. Damping (Q)?
iv. Time of flight (Δt)?

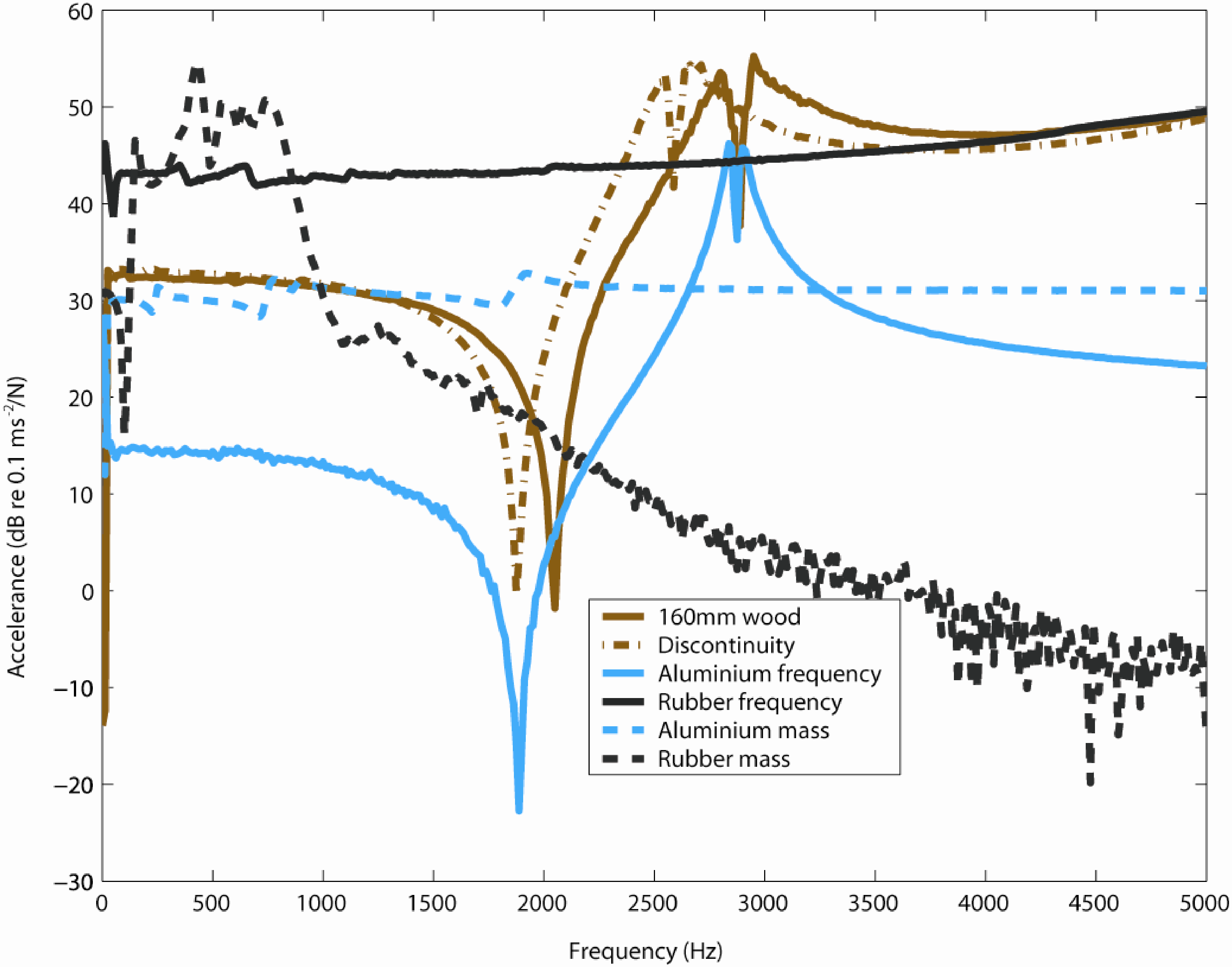
Material properties



Material	**Speed of sound, *c*** (m s^{-1})	**Density, *ρ*** (kg m^{-3})	**Damping factor, *d***
Aluminium	5040±103	2700±28	10^{-4}
Pinus radiata	4930±100	420±30	10^{-2}
EPDM rubber	45±1	504±30	10^{-1}

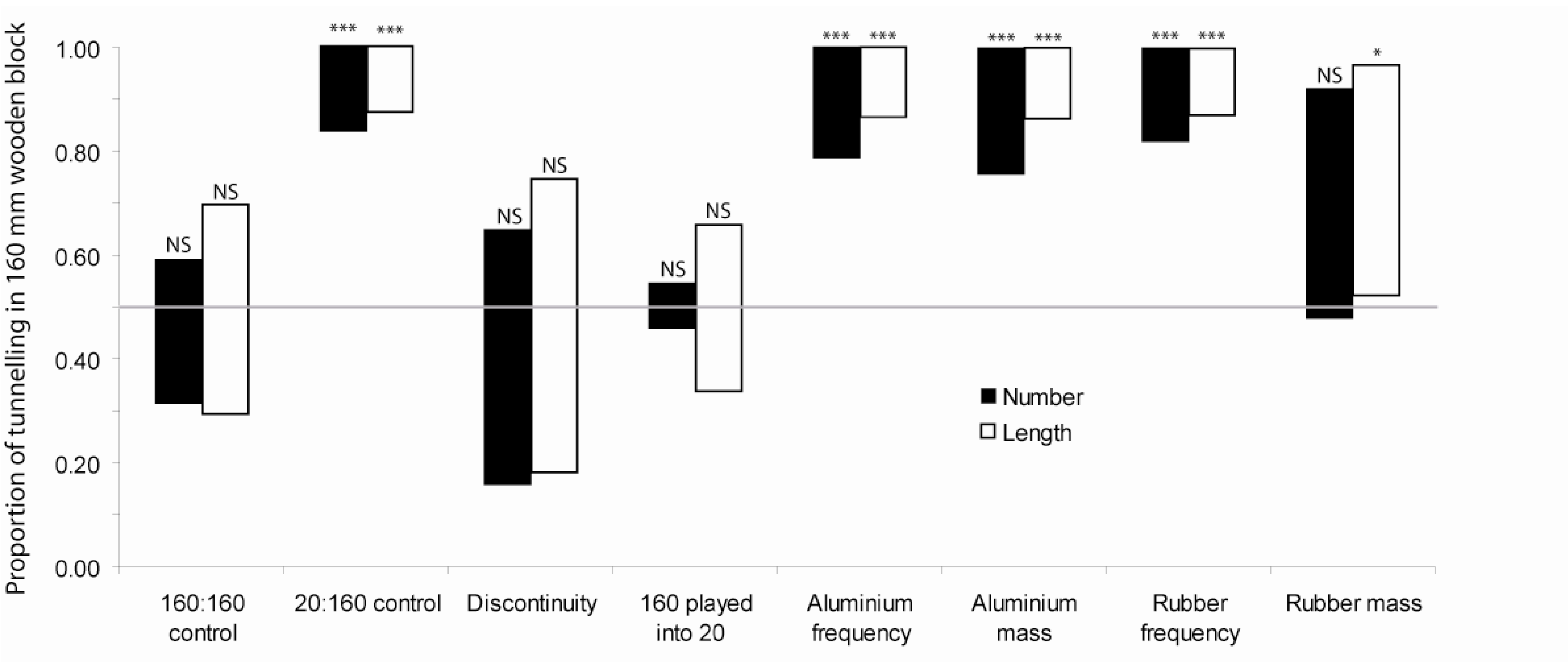


1
160
160
160:160
2
160
20
20:160
3
160
20
140
Discontinuity
4
160
20
160 mm playback
5
160
20
180
Aluminium Frequency
6
160
20
25
Aluminium mass
7
160
20
2
Rubber frequency
8
160
20
60
Rubber mass
Dimensions in mm
Wood
Aluminium
Rubber



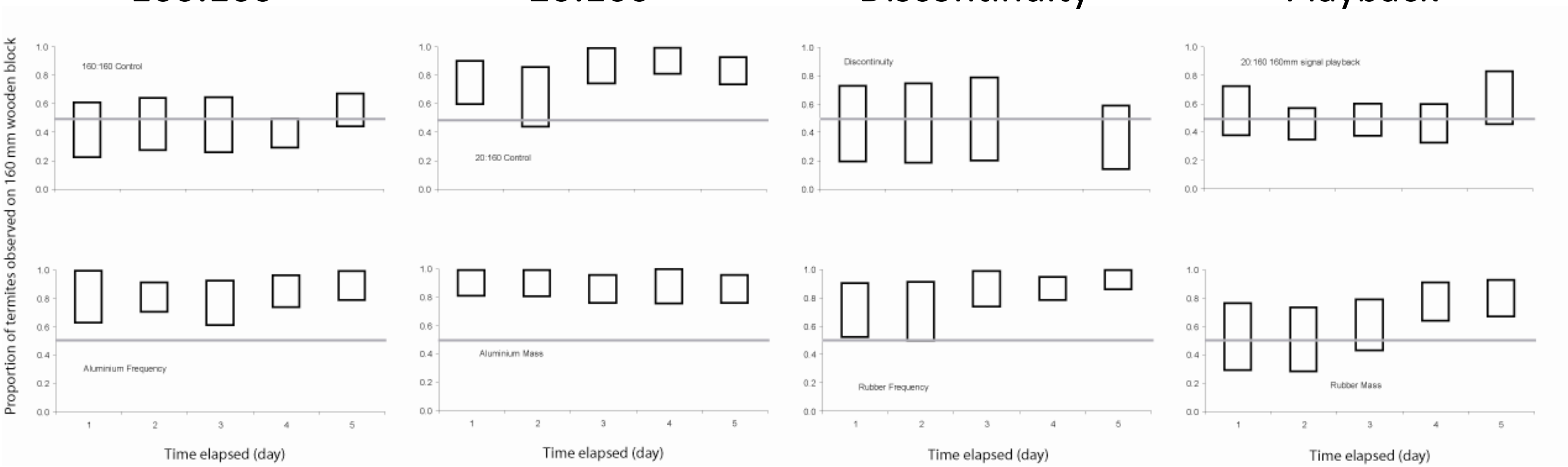
60
50
40
30
20
10
0
−10
−20
−30
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Acceleration (dB re 0.1 ms^{-2}/N)
Frequency (Hz)
160mm wood
Discontinuity
Aluminium frequency
Rubber frequency
Aluminium mass
Rubber mass

Results: tunnelling



Results: movement

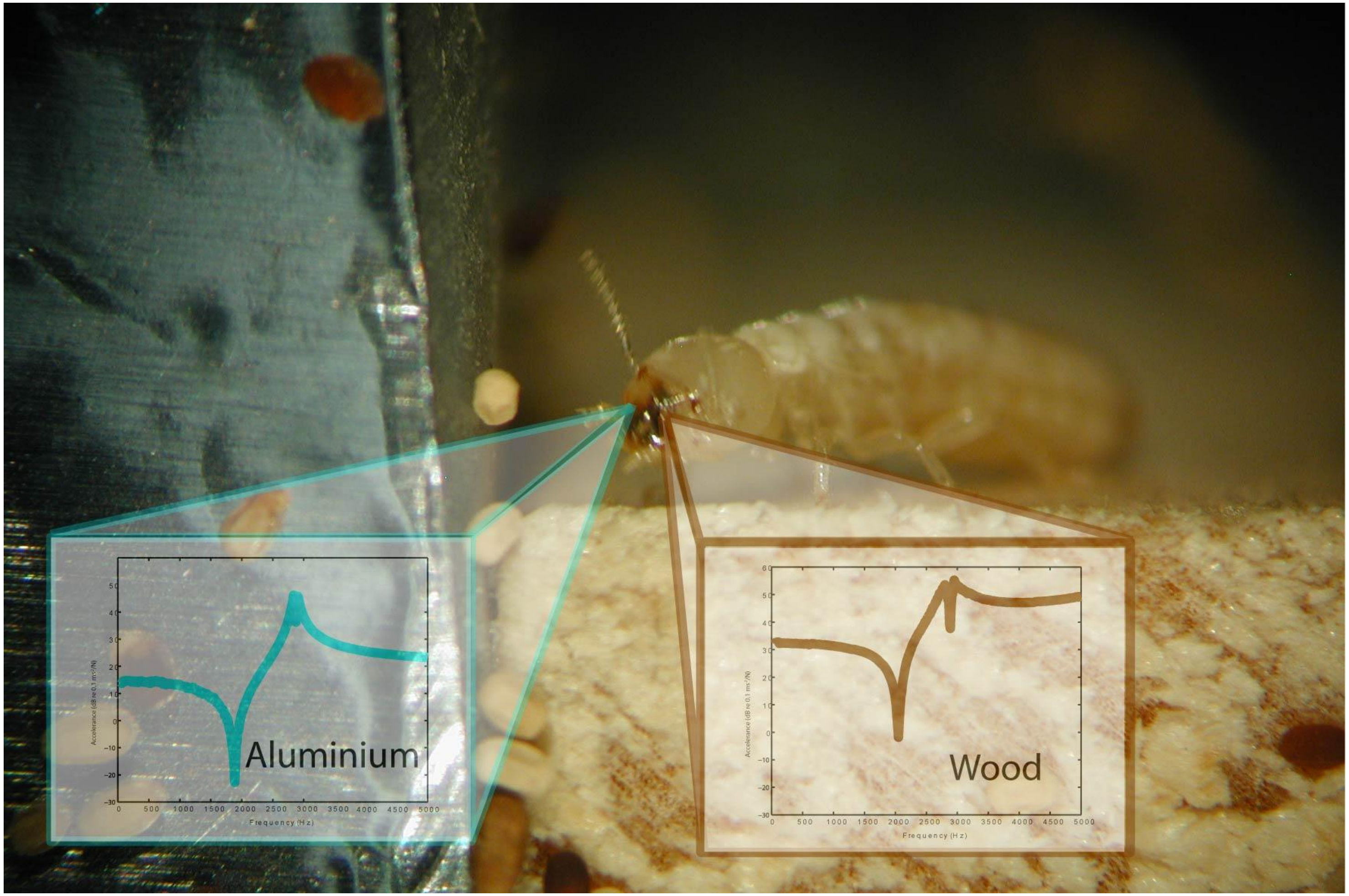
160:160 | 20:160 | Discontinuity | Playback



Al freq. | Rubber freq. | Al mass | Rubber mass

Summary:

Termites always preferred the blocks with the most amount of wood, implying a very high level of sophistication (*i.e.* not a single simple measure i-iv)



Termites gain information about wood size using vibration signals

- Playback experiments---therefore vibrations
- Specific vibrations: their own species foraging (unaffected by pink noise, deterred by other species)

Inta, R. Evans, T.A., Lai, J.C.S. and Lenz, M.: "What do vibrations have to do with termites' food choice?," *Acoustics Australia*, **35**(3), pp. 73-77 (2007)

T.A. Evans, J.C.S. Lai, E. Toledano, L. McDowall, S. Rakotonarivo and M. Lenz, "Termites assess wood size by using vibration signals", *Proceedings of the National Academy of Science USA* **102**, pp. 3732-3737 (2005)

They can also distinguish material properties

- Not clear that they respond to substrate only or voiceprint
- Simple geometry; key measure could be f_0, $\mathbf{a}=\mathbf{F}/m$, Q or Z

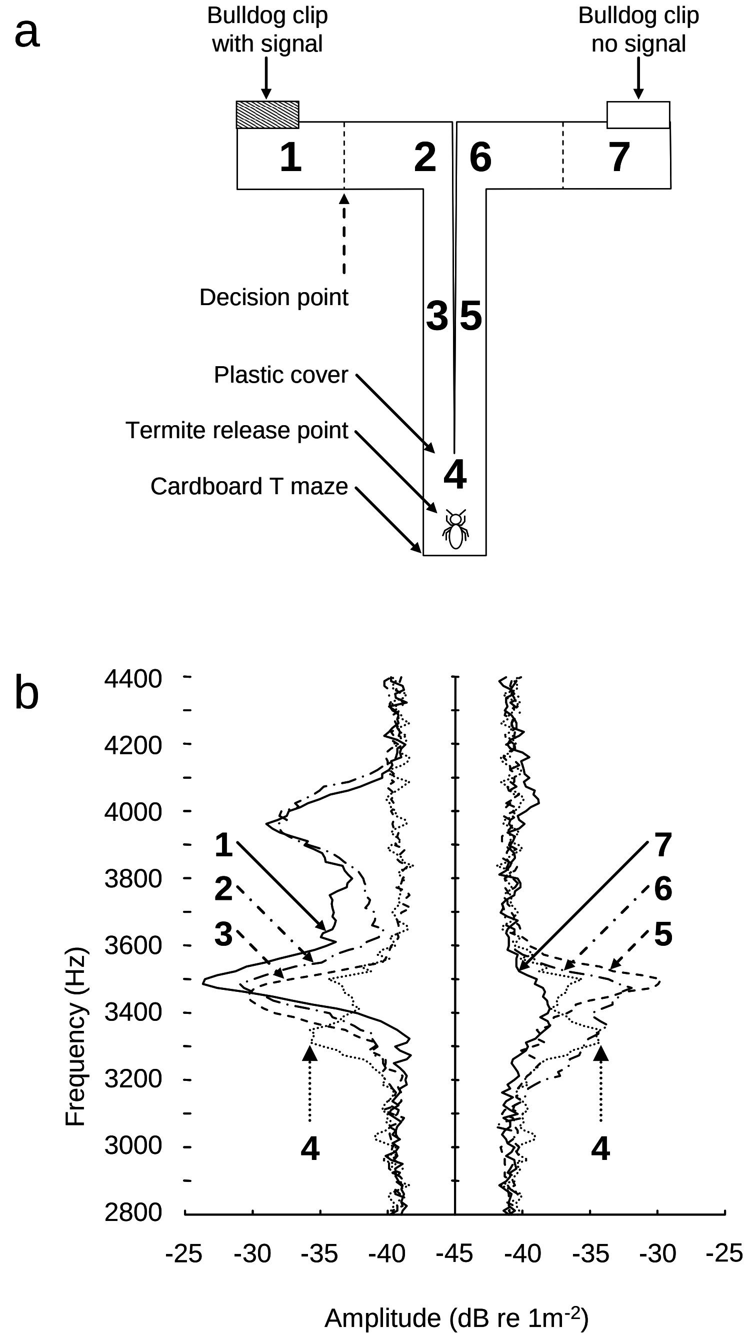
R Inta, JCS Lai, EW Fu and TA Evans: "Termites live in a material world: exploration of their ability to differentiate between food sources," *J. R. Soc. Interface* **4**(15), *pp.*735-744 (2007)

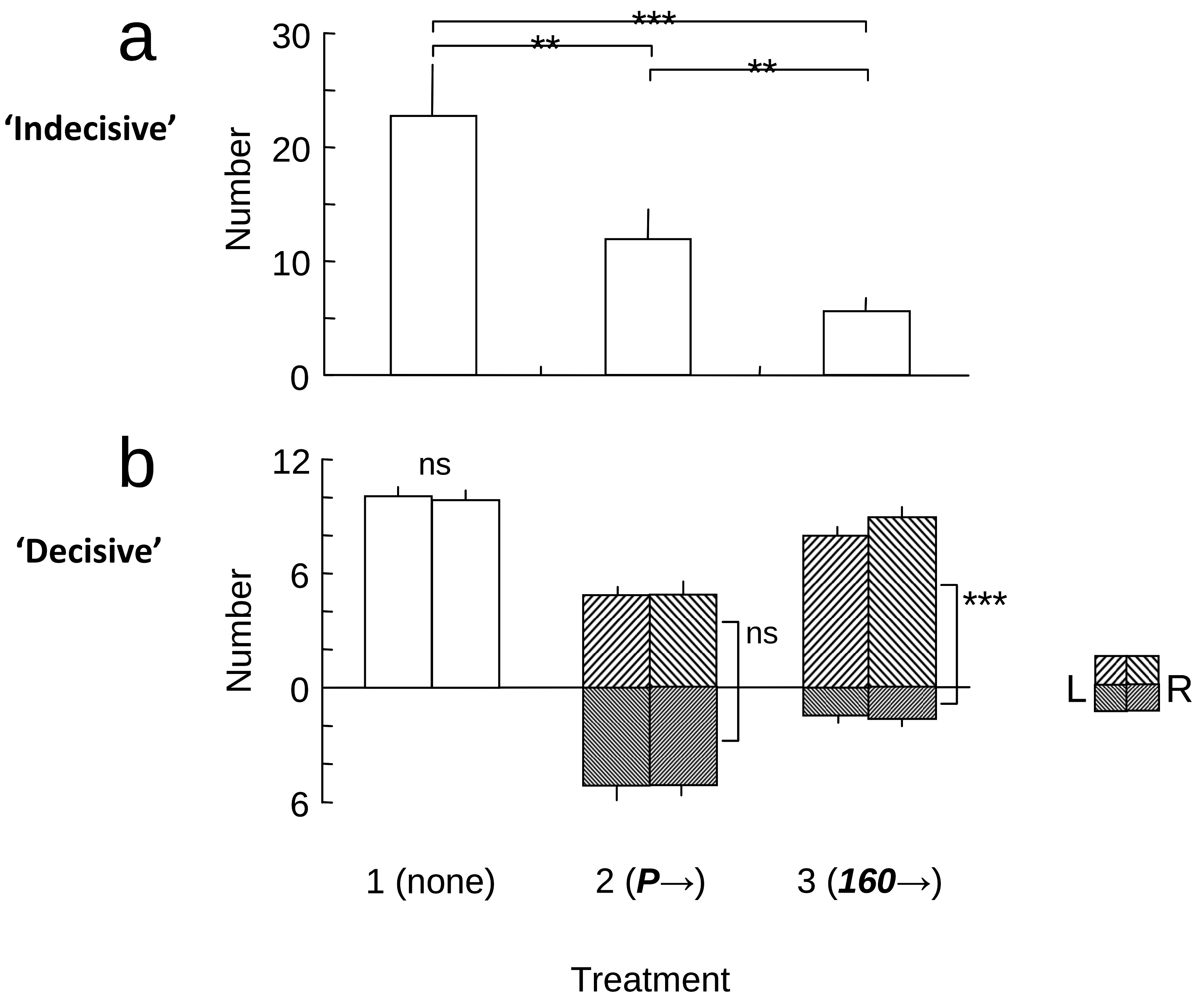
Rapidity of response

- Able to assess and make decisions relatively quickly
- Good correlation between tunnelling and movement in first five days
- Significant results in running on vibratory ‘mazes’

Evans, T.A., Inta, R., Lai, J.C.S. and Lenz, M.: “Foraging vibration signals attract foragers and identify food size in the drywood termite, *Cryptotermes secundus*,” *Insectes Sociaux*, **54**(4), pp. 374-382 (2007).

‘T-maze’ set-up


a
Bulldog clip
with signal
Bulldog clip
no signal
1
2
6
7
Decision point
3
5
Plastic cover
Termite release point
Cardboard T maze
4
b
4400
4200
4000
3800
3600
3400
3200
3000
2800
Frequency (Hz)
1
2
3
4
7
6
5
4
-25
-30
-35
-40
-45
-40
-35
-30
-25
Amplitude (dB re 1m-2)



a
'Indecisive'
Number
30
20
10
0
***
**
**
b
'Decisive'
Number
12
6
0
6
ns
ns
***
L
R
1 (none)
2 (P→)
3 (160→)
Treatment

Conclusion: how do termites gain information about food structures?

- Not known exactly, but is vibratory in nature and highly sophisticated
- Cannot be only: f_0
- Cannot be only: total mass
- Could be: Q
- Could be: Z

3: Vibration as a survival aide

- Invasive strategies
- Detection of other termite species

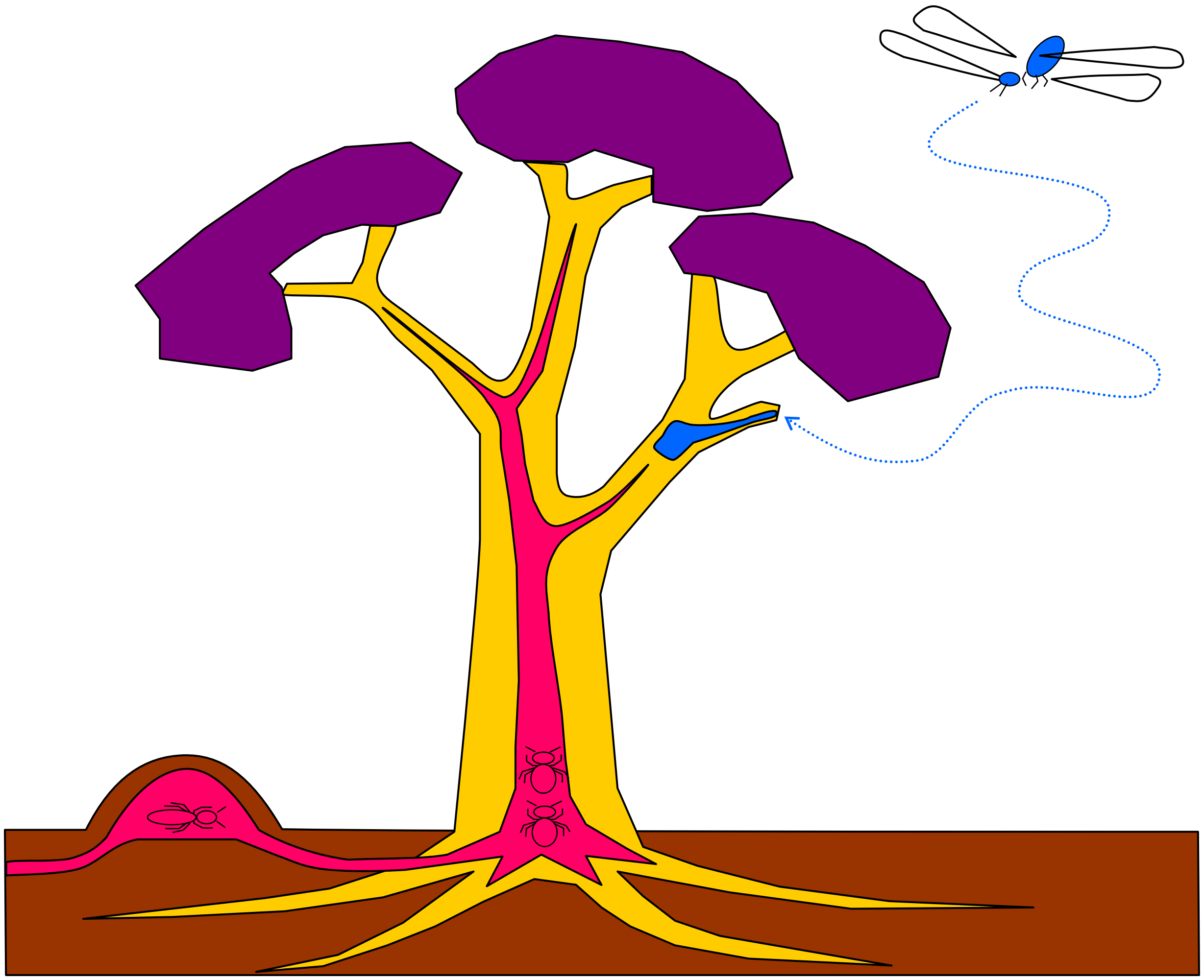
Invasive strategies

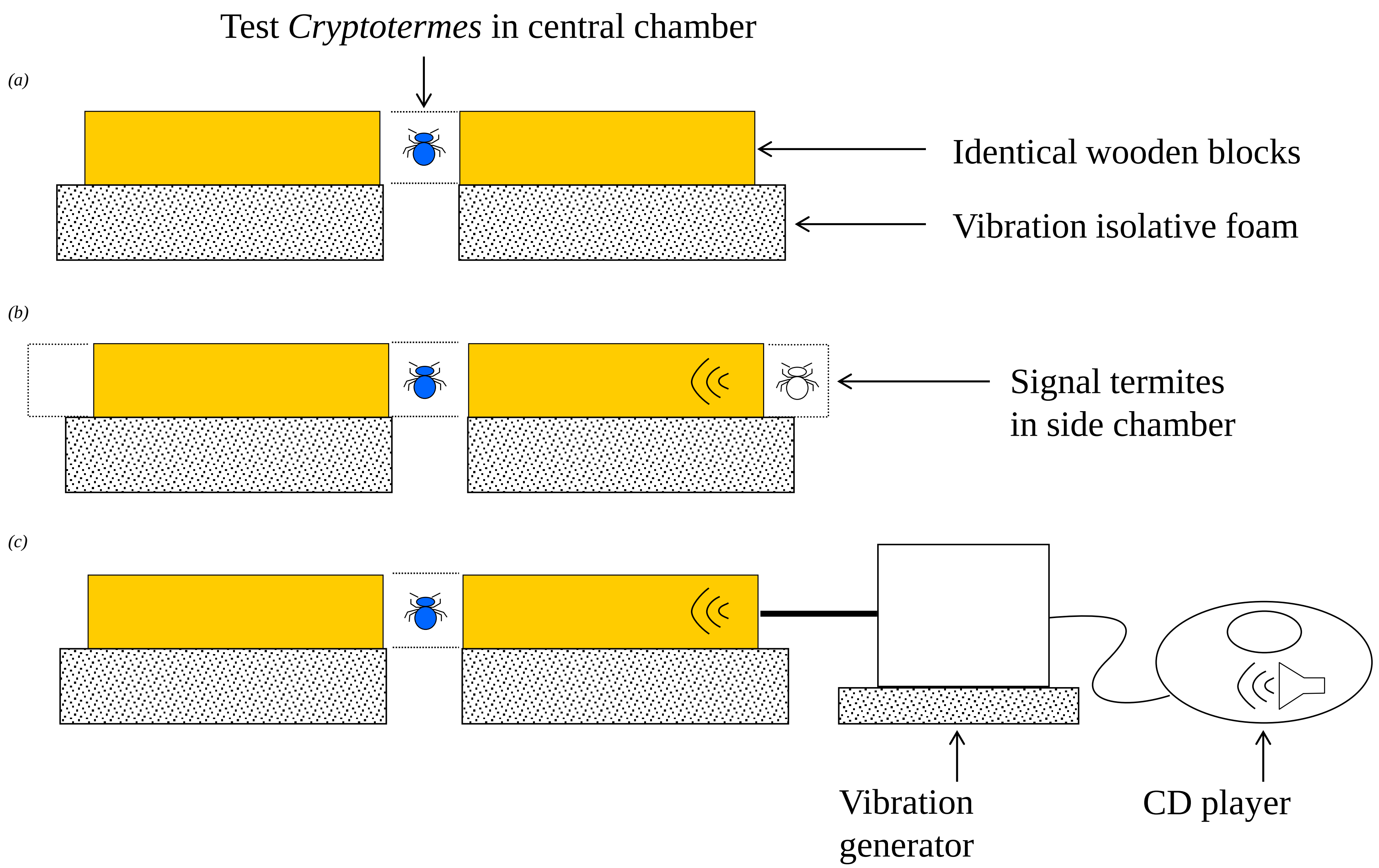
Crypt. domesticus (native, non-invasive): prefers *smaller* blocks of wood

Crypt. secundus (introduced, highly invasive): prefers *larger* blocks of wood

...highly invasive termite species prefer *smaller* blocks of wood!

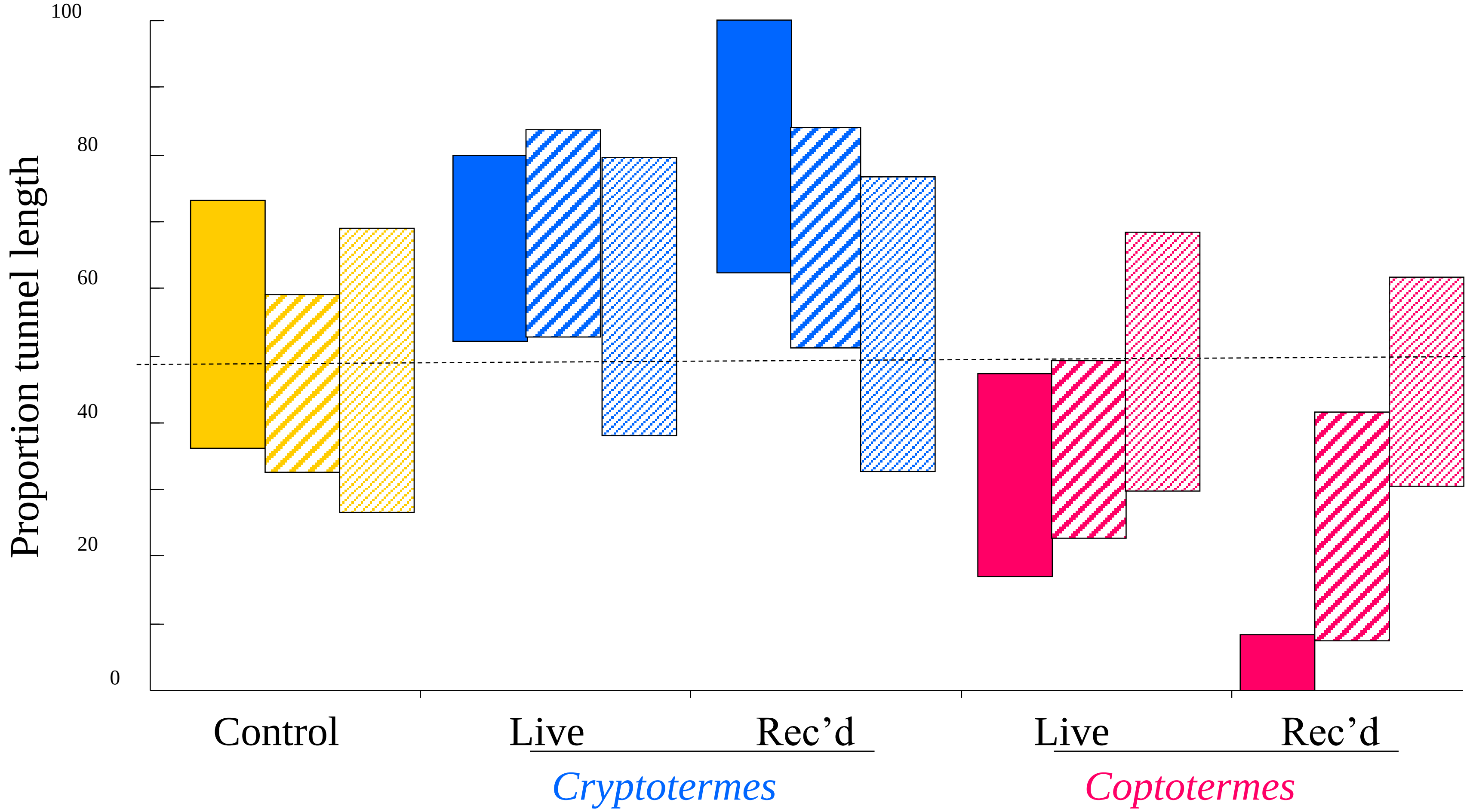
Distinguishing friend from foe





Test *Cryptotermes* in central chamber
(a)
Identical wooden blocks
Vibration isolative foam
(b)
Signal termites
in side chamber
(c)
Vibration
generator
CD player

Results



100
80
60
40
20
0
Proportion tunnel length
Control
Live
Rec'd
Live
Rec'd
Cryptotermes
Coptotermes

Termites can distinguish their own vibrations from those of competitors

Evans, T.A., Inta, R., Lai, J.C.S., Prueger, S., Foo, N.W., Fu, E.W. and Lenz, M.:"Termites eavesdrop to avoid competitors," *Proceedings of the Royal Society B* (accepted for publication, 26pp., July 2009)

4: Vibration as a communication channel

Termites are highly social, so have to communicate

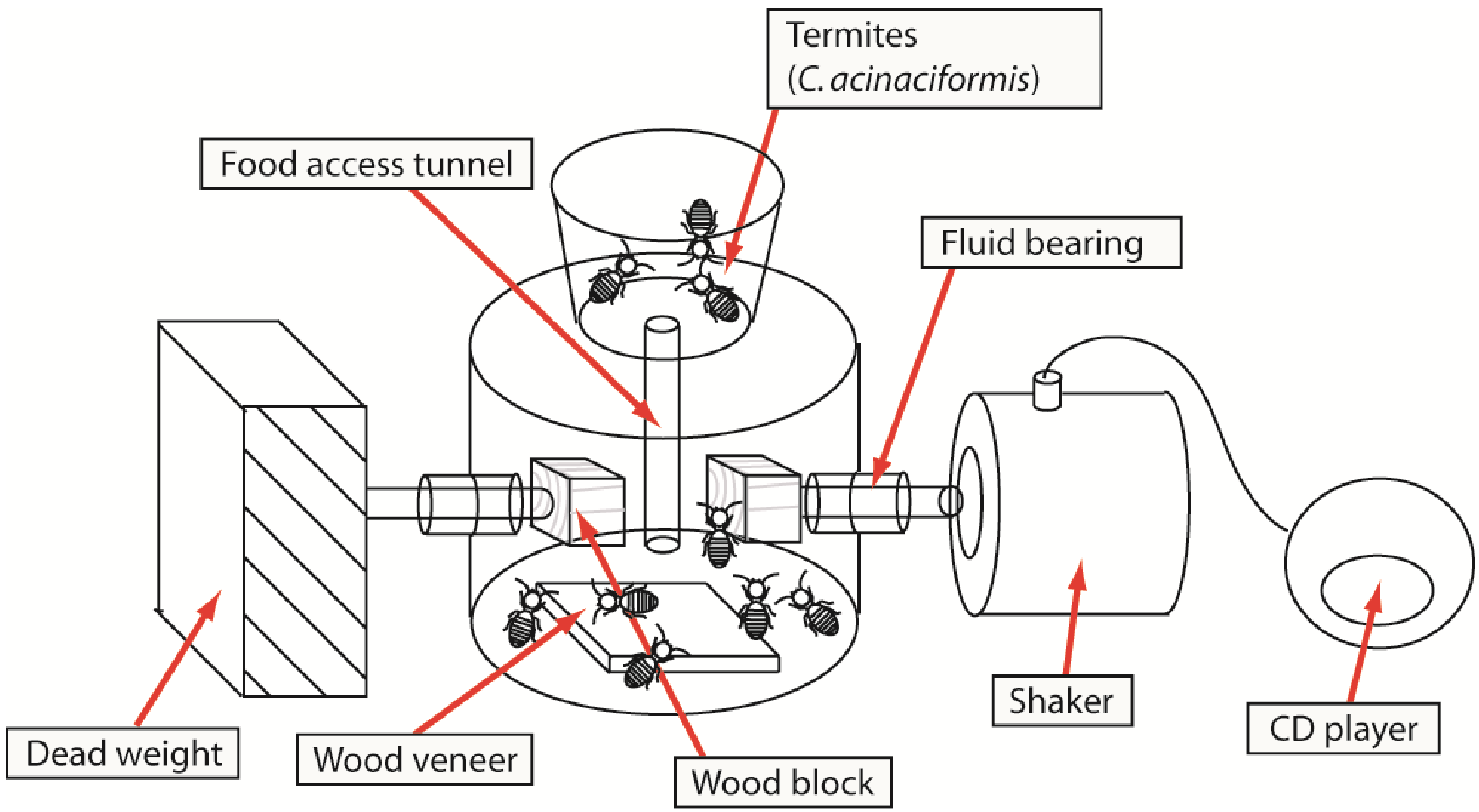
Two main uses of vibratory signals in communication:

1. Feeding
2. Alarm

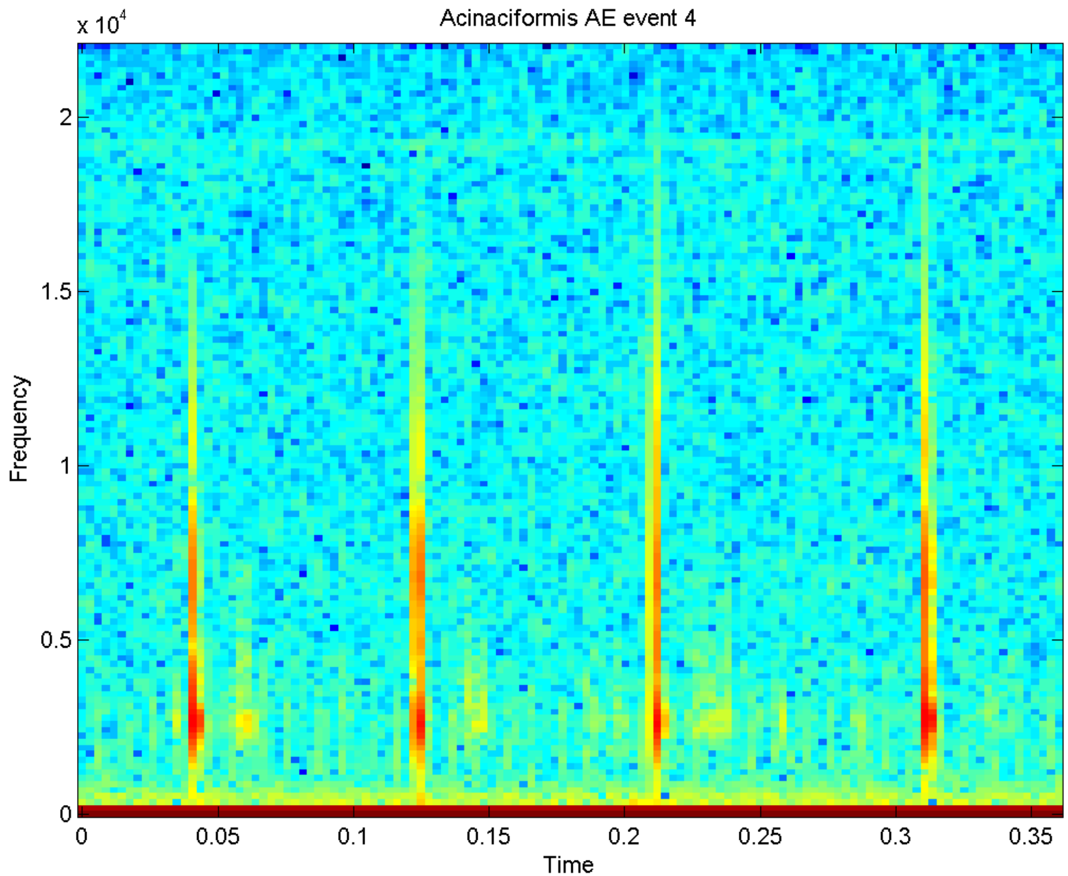
Cryptotermes experiments (feeding)
Attracted to similar species, deterred by competitive species

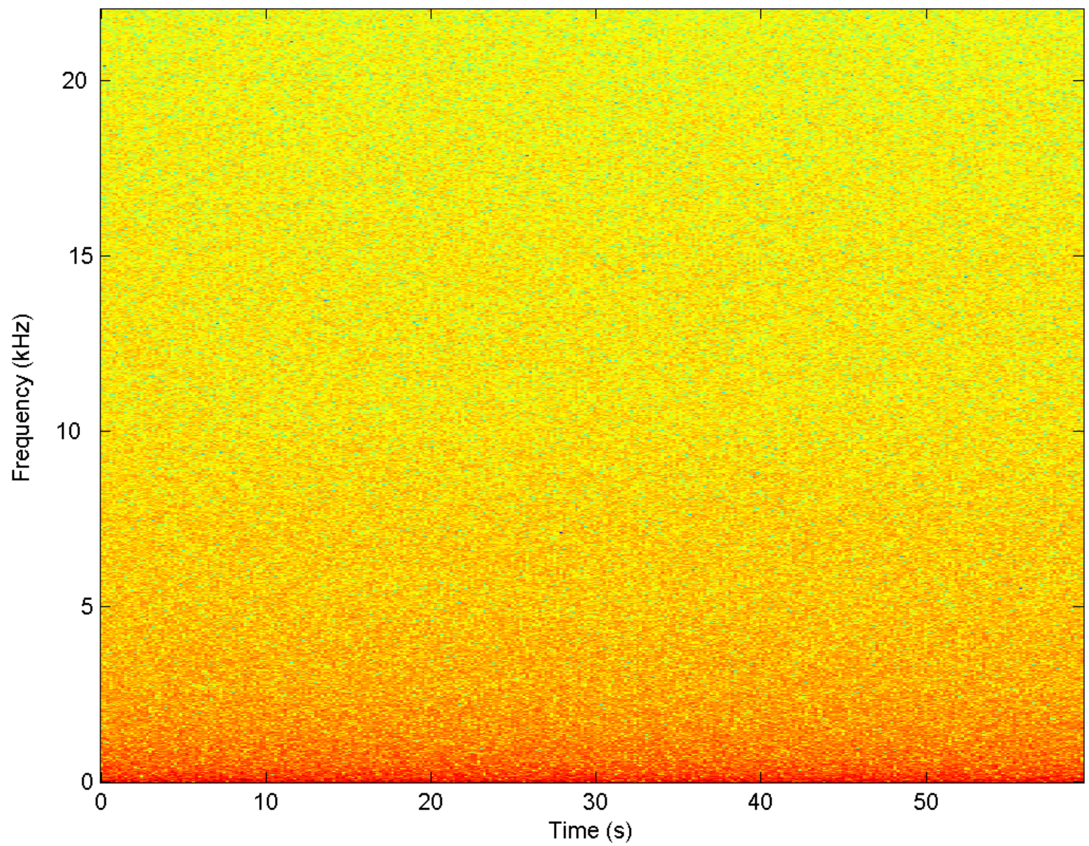
Most obvious signals: vibratory alarm

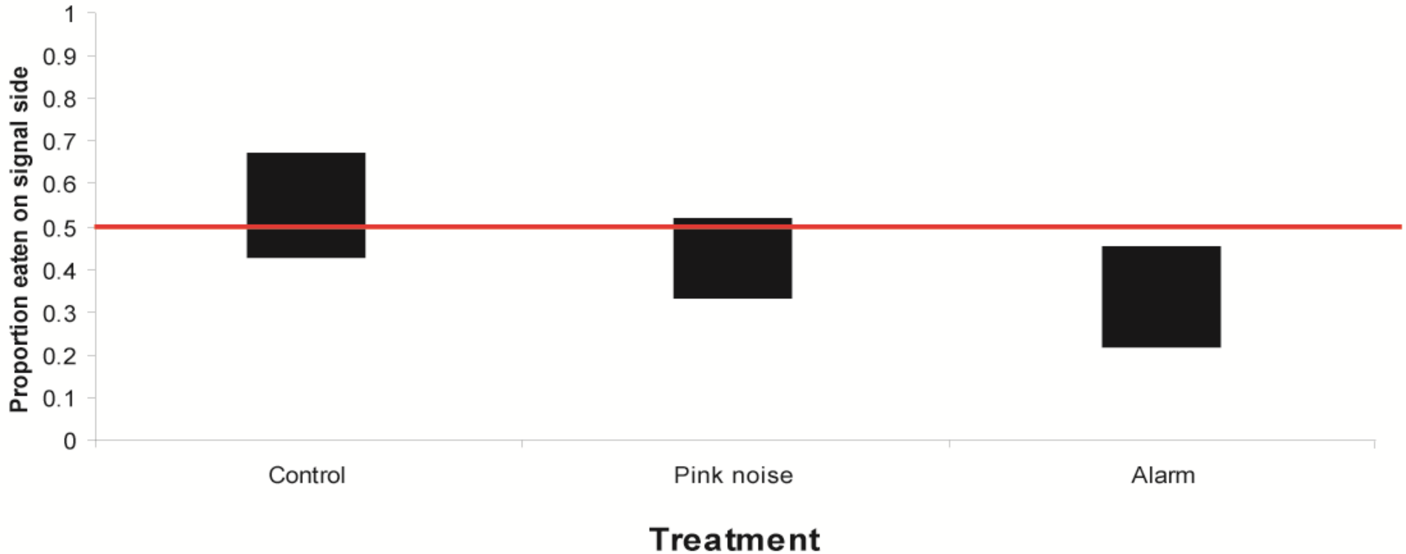
- Alarm signals produced by soldiers when they perceive a danger to the colony (mechanical breach, vibration, toxic fungal spores)
- Universal response from workers: Flee!



Termites
(C. acinaciformis)
Food access tunnel
Fluid bearing
Dead weight
Wood veneer
Wood block
Shaker
CD player


Acinaciformis AE event 4
x 10^4
Frequency
2
1.5
1
0.5
0
Time
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35

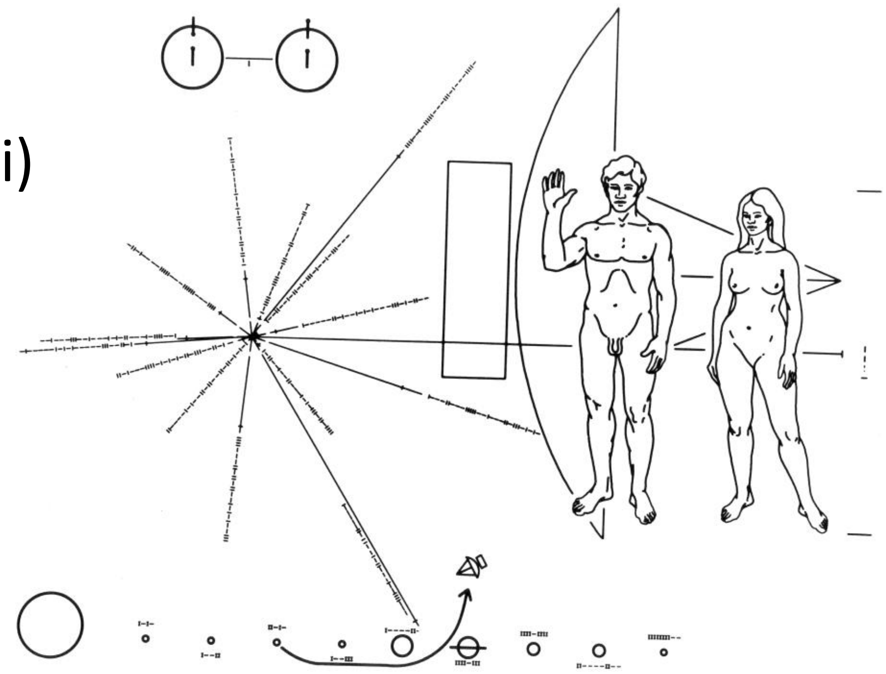

Frequency (kHz)
0
5
10
15
20
Time (s)
0
10
20
30
40
50



R. Inta, T.E. Evans, and J.C.S. Lai: 'Effect of Vibratory Soldier Alarm Signals on the Foraging Behavior of Subterranean Termites *(Isoptera: Rhinotermitidae),' Journal of Economic Entomology,* **102**(1), pp.121-126 (February 2009)

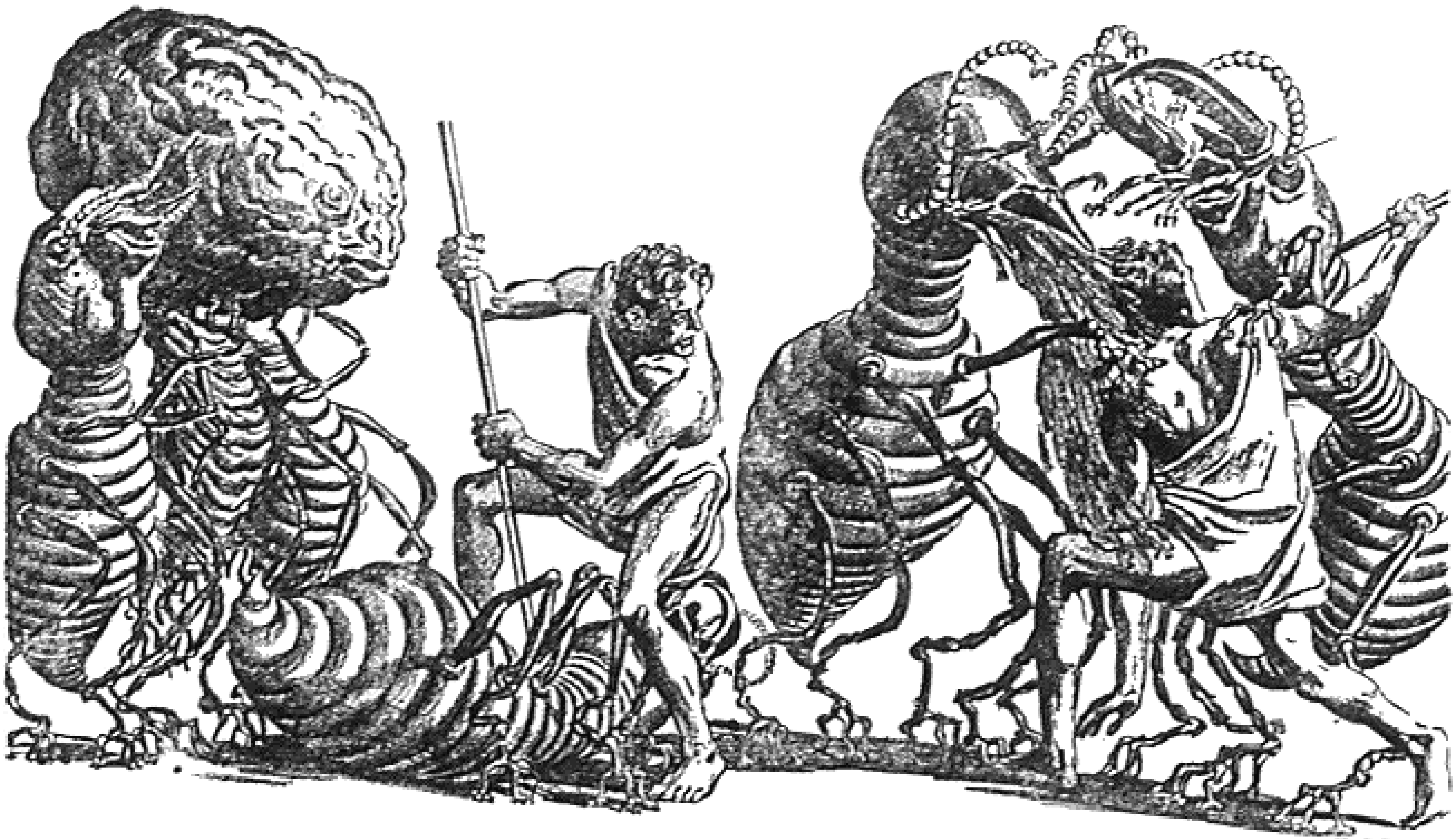
Signal encoding

Type of encoding in signal (spectral
vs. temporal)
e.g. tonal language (Cantonese, Thai)
vs. Morse code

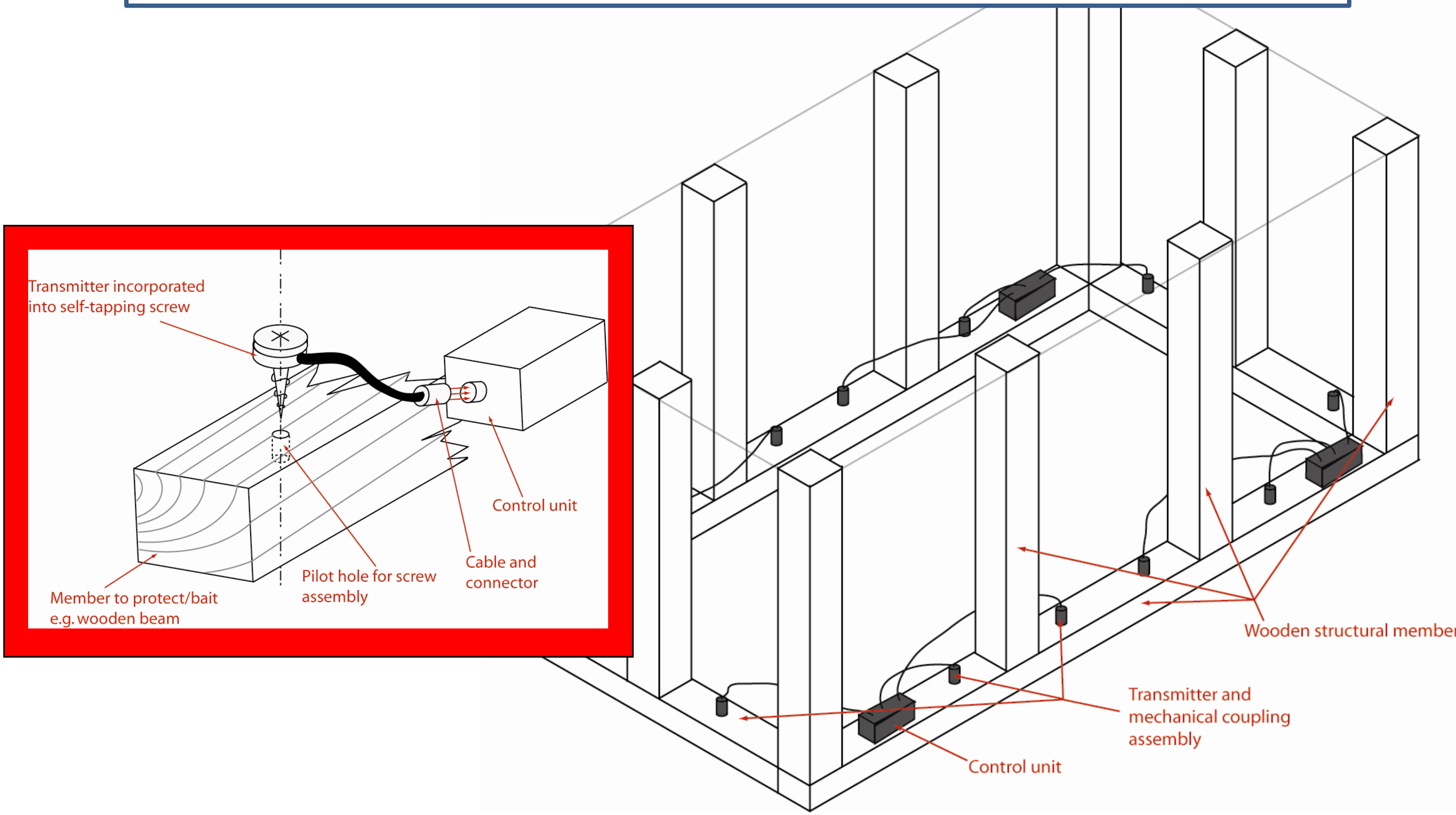


Alarm signals probably
independent of carrier
frequency---not always very well
understood in the literature

5: Applications: exploiting termites' vibrations



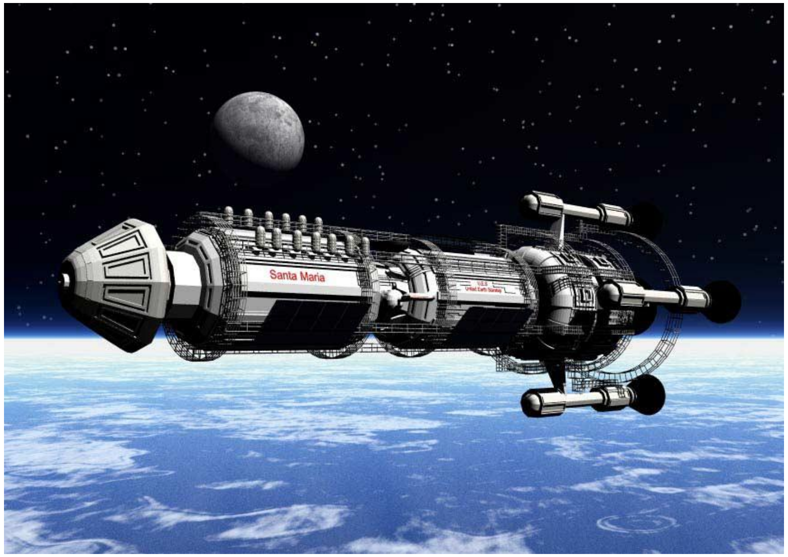
Non-chemical termite control



Evans, TA, Lenz, M, Lai, JCS and Inta, RA: "Method and System for Controlling Termites," Patent Application Number: PCT/AU2007/000215 (WIPO Patent WO/2007/095693) (August 30, 2007).

Next generation

- Signal synthesis: don't know temporo-spectral features termites respond to
- 'Passive sonar' mode: DSP triggering
- 'Active 'sonar' mode: elicit behaviour



6: Future work

- Separate substrate from voiceprint of vibratory signals---signal processing
- Material properties: Q or Z? ---New experiments
- Direct determination of frequency : frequency shift

Direct measurement of frequency preference

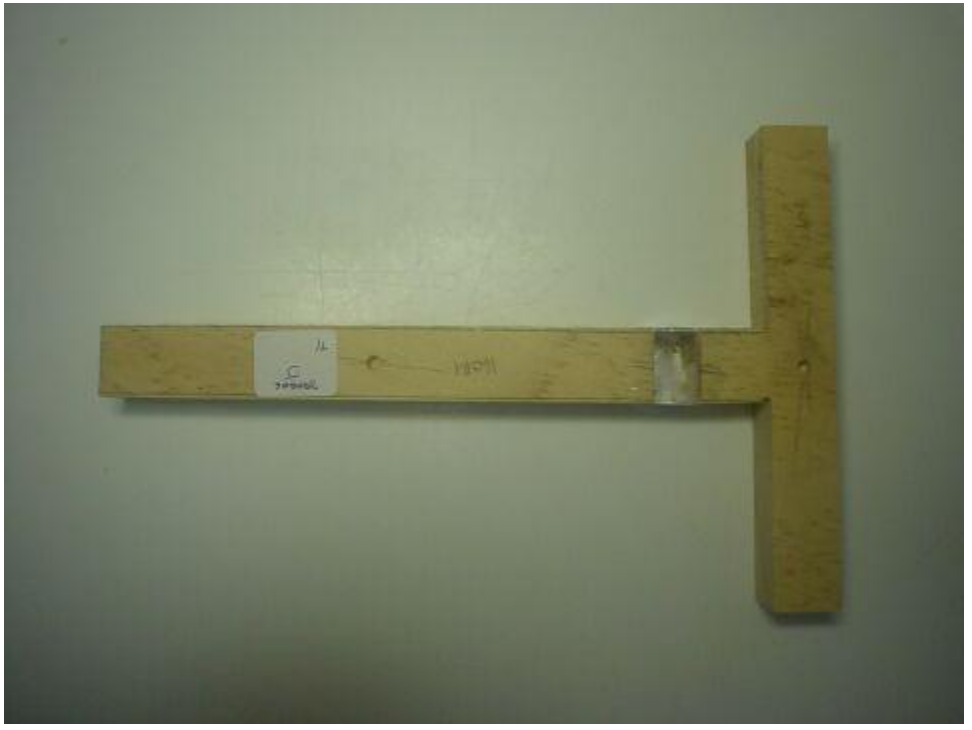
<u>Frequency shift:</u>
We know that termites are attracted to foraging signals in larger blocks of wood.

We can alter the frequency information in the signal but retain the temporal structure → phase vocoder algorithm

Original

Pitch shifted

Manipulation of preference using geometry



Problematic!
Variability of wood and construction of geometry

Plausible mechanism: assessment of structures using vibrations.
Experiments in field and laboratory.

Problematic!

Bioinspired vibration sensors

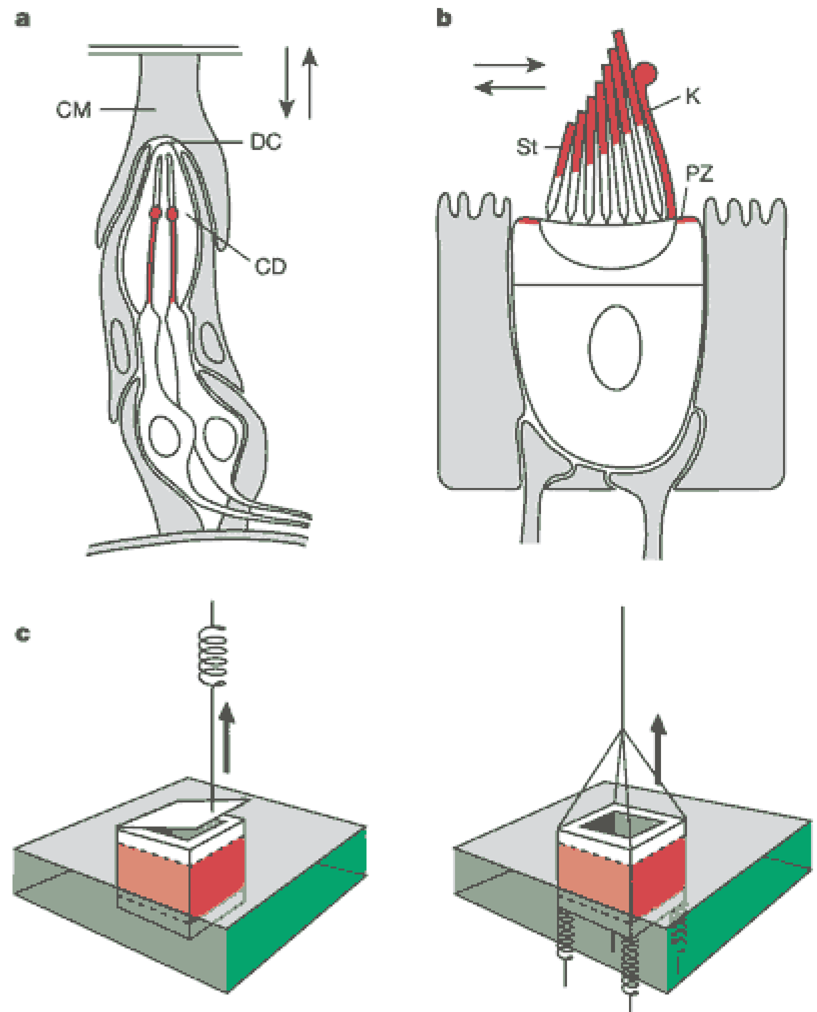


Image (without permission) from:

http://scienceblogs.com/pharyngula/2006/10/evolution_of_sensory_signaling.php

Subgenual organ: tiny accelerometer?

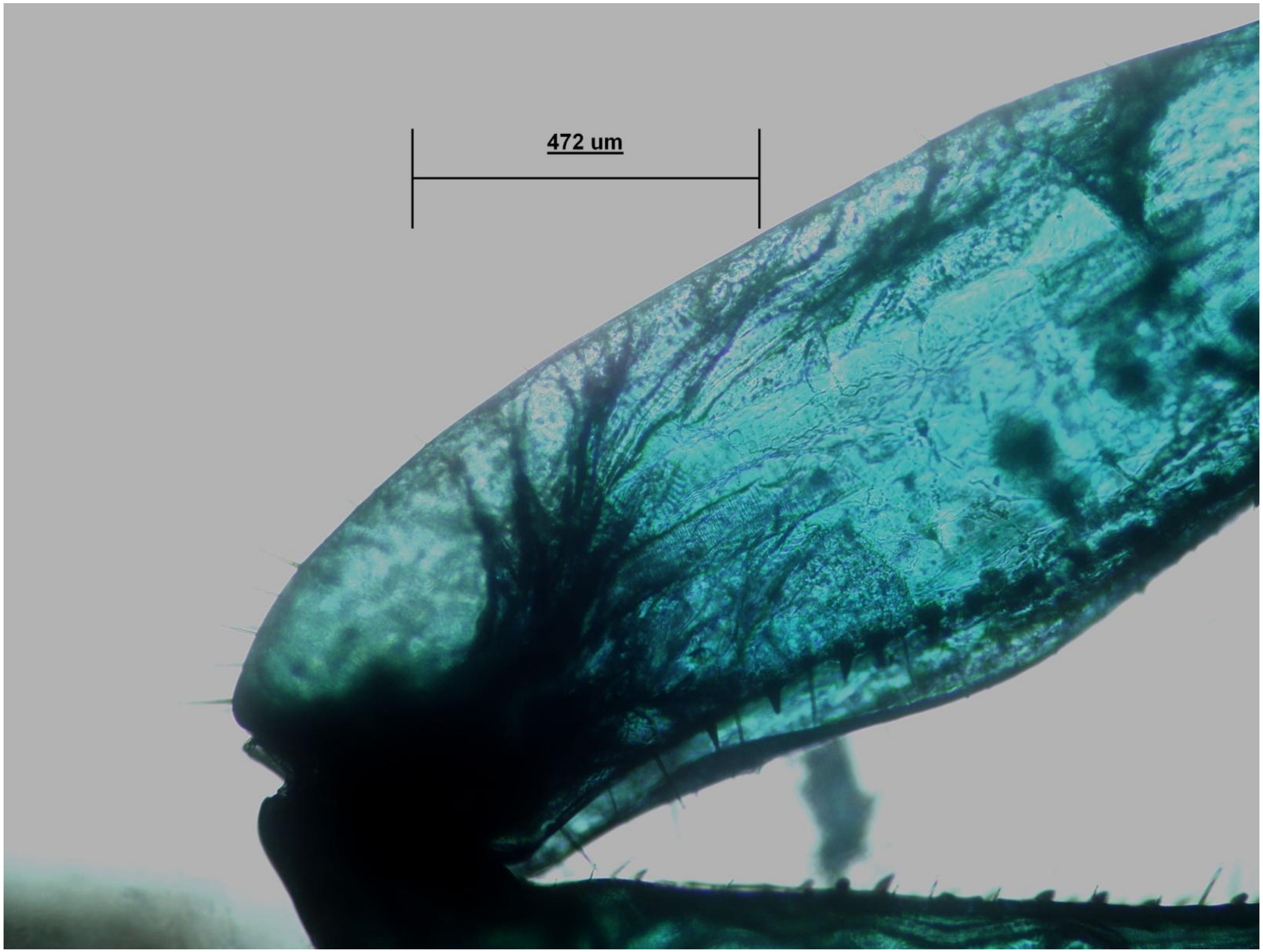


Image: Elizabeth Inta

DSP applications

Termites only have ~100,000 nerve cells in the central ganglium (pinhead size), yet are able to process vibratory signals buried in noise.

Distributed signal (pre-)processing

Depends on vibratory features used (e.g. Temporal/rate encoding vs. spectral encoding)

Parsimony of biologically based neural processors?

- Correlation with electrophysiological responses: better test validation
- Encoding type
- Information theory
- Limitations on processing efficiency of neural system (assessment and communication)

Thanks!

Professor Joseph Lai (UNSW@ADFA)
Dr Theodore Evans (CSIRO Entomology)
Support staff and students
Australian Research Council (Discovery grant DP0449825)

Ra.Inta@anu.edu.au

Australian Government
Australian Research Council

UNSW@ADFA
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Questions?