Chapter 16 - Acoutics

- Greek - *ἀκουστικός* (*akoustikos*) "of or for hearing, ready to hear"
- *ἀκουστός* (*akoustos*), "heard, audible"
- *ἀκούω* (*akouo*), "I hear
- Latin equivalent is "sonic" – sound
- Galileo "Waves produced by vibrations of sonorous body"
- Mersenne (1588–1648) – works out harmonics of strings
- Helmholtz and Lord Rayleigh apply rigorous mathematics

What distinguishes Acoustics from Mechanical Waves in Chap 15?

- Semantics to some extent
- Usually acoustics refers to propagation in gases not liquids or solid BUT there are liquid and solid acoustics
- So the distinction is really artificial
- We will focus on propagation is gases
- The critical difference is gases ONLY support a compression (longitudinal) wave not a shear (transverse) wave
- Solids can support BOTH transverse and longitudinal waves
- Depending on the viscosity of the liquid generally we think of liquids as supporting only compression (longitudinal) waves

Sound pressure levels

- Sound pressure is defined as the local deviation from the mean – units are Pa (N/m^2)
- Effective sound pressure =<RMS (sound pressure) > = time and space average Root Mean Square

$$p = \frac{F}{A} \quad p_{\text{total}} = p_0 + p$$

Sound Intensity

- Sound (Acoustic) Intensity
- I = Time ave Acoustic Power/ Area $I=P_{ac}/A$
- Let p_{inst} = instantaneous pressure (note the different P's p(pressure), P(power)
- Let v=bulk gas speed (not molecular speed)
- Then $$I = \frac{1}{T}\int_0^T p_{inst}(t)v(t)\,dt$$
- Recall Power = Force x speed
- Units of I are watts/m^2

How do Intensity and Pressure Scale with distance from a point Source?

- Energy is conserved so I x area = total power emitted P_{ac}
- At a distance r from the acoustic point source

$$I_r = \frac{P_{ac}}{A} = \frac{P_{ac}}{4\pi r^2}$$

- What causes the bulk gas flow?
- It is the sound wave
- V (bulk flow) ~ p (pressure)
- **Hence I_r ~ p(pressure)^2**

Scaling of Pressure and Intensity

- **Hence I ~ $1/r^2$ while p ~ $1/r$**
- **This is a critical difference**
- **Power/area ~ $1/r^2$ while Pressure ~ $1/r$**

Sound Pressure Level - SPL

$$L_p = 10\log_{10}\left(\frac{{p_{\mathrm{rms}}}^2}{{p_{\mathrm{ref}}}^2}\right) = 20\log_{10}\left(\frac{p_{\mathrm{rms}}}{p_{\mathrm{ref}}}\right)\ \mathrm{dB},$$

The unit is dB (SPL) commonly reduced to just dB (decibel)
This is a relative measure and we need a reference level
Typically for hearing in air we use **P_{ref} = 20 μP_a** (RMS) = **$2x10^{-5}$**
This is the typ threshold of human hearing - ~ Mosquito at 3 m
In water we normally use P_{ref} = 1 μP_a (RMS)
94 dB ~ 1 P_a
Note – 10 times the pressure = 20 dB increase in SPL

Notice that L_p ~ Log (p^2).
This is because Intensity I ~ p^2

Acoustic Impedance

$$I = \frac{p^2}{Z} = Z \cdot v^2 = \xi^2 \cdot \omega^2 \cdot Z = \frac{a^2 \cdot Z}{\omega^2} = E \cdot c = \frac{P_{ac}}{A}$$

Symbol	Units	Meaning
p	pascals	RMS sound pressure
f	hertz	frequency
ξ	m, metres	particle displacement
c	m/s	speed of sound
v	m/s	particle velocity
$\omega = 2\pi f$	radians/s	angular frequency
ρ	kg/m^3	density of air
$Z = c \cdot \rho$	$N \cdot s/m^3$	characteristic acoustic impedance
a	m/s^2	particle acceleration
I	W/m^2	sound intensity
E	$W \cdot s/m^3$	sound energy density
P_{ac}	W, watts	sound power or acoustic power
A	m^2	area

Sound Intensity level and Reference Level

$$L_I = 10\log_{10}\frac{|I|}{I_o}$$

We define the reference level to be about the threshold of human hearing

$I_0 = 10^{-12}$ w/m^2

For some interesting comparisons see

http://www.sengpielaudio.com/calculator-levelchange.htm

Source of sound	Sound pressure	Sound pressure level
Sound in air	pascal	dB re 20 μPa
Shockwave (distorted sound waves > 1 atm; waveform valleys are clipped at zero pressure)	>101,325 Pa (peak-to-peak)	>194 dB
Krakatoa explosion at 100 miles (160 km) in air[dubious – discuss]	20,000 Pa (RMS)	180 dB
Simple open-ended thermoacoustic device [6]	12,619 Pa	176 dB
.30-06 rifle being fired 1 m to shooter's side	7,265 Pa	171 dB (peak)
M1 Garand rifle being fired at 1 m	5,023 Pa	168 dB
Jet engine at 30 m	632 Pa	150 dB
Threshold of pain	63.2 Pa	130 dB
Hearing damage (possible)	20 Pa	approx. 120 dB
Jet at 100 m	6.32 – 200 Pa	110 – 140 dB
Jack hammer at 1 m	2 Pa	approx. 100 dB
Traffic on a busy roadway at 10 m	2×10^{-1} – 6.32×10^{-1} Pa	80 – 90 dB
Hearing damage (over long-term exposure, need not be continuous)	0.356 Pa	78 dB
Passenger car at 10 m	2×10^{-2} – 2×10^{-1} Pa	60 – 80 dB
TV (set at home level) at 1 m	2×10^{-2} Pa	approx. 60 dB
Normal conversation at 1 m	2×10^{-3} – 2×10^{-2} Pa	40 – 60 dB
Very calm room	2×10^{-4} – 6.32×10^{-4} Pa	20 – 30 dB
Light leaf rustling, calm breathing	6.32×10^{-5} Pa	10 dB
Auditory threshold at 1 kHz	2×10^{-5} Pa (RMS)	0 dB

Acoustics In water

Source of sound	Sound pressure	Sound pressure level
Sound under water	pascal	dB re 1 µPa
Pistol shrimp	79,432 Pa	218 dB[7]
Sperm Whale	141-1,000 Pa	163-180 dB[8]
Fin Whale	100-1,995 Pa	160-186 dB[9]
Humpback Whale	16-501 Pa	144-174 dB[10]
Bowhead Whale	2-2,818 Pa	128-189 dB[11]
Blue Whale	56-2,511 Pa	155-188 dB[12]
Southern Right Whale	398-2238 Pa	172-187 dB[13]
Gray Whale	12-1,778 Pa	142-185 dB[14]
Auditory threshold of a diver at 1 kHz	2.2×10^{-3} Pa	67 dB[15]

Adding sources of incoherent sound
Total intensity = sum of intensities

$$L_\Sigma = 10 \cdot \log_{10} \left(\frac{{p_1}^2 + {p_2}^2 + \cdots + {p_n}^2}{{p_\mathrm{ref}}^2} \right) = 10 \cdot \log_{10} \left(\left(\frac{p_1}{p_\mathrm{ref}} \right)^2 + \left(\frac{p_2}{p_\mathrm{ref}} \right)^2 + \cdots + \left(\frac{p_n}{p_\mathrm{ref}} \right)^2 \right)$$

$$L_\Sigma = 10 \cdot \log_{10} \left(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}} + \cdots + 10^{\frac{L_n}{10}} \right) \mathrm{dB}$$

$$\left(\frac{p_i}{p_\mathrm{ref}} \right)^2 = 10^{\frac{L_i}{10}}, \qquad i = 1, 2, \cdots, n$$

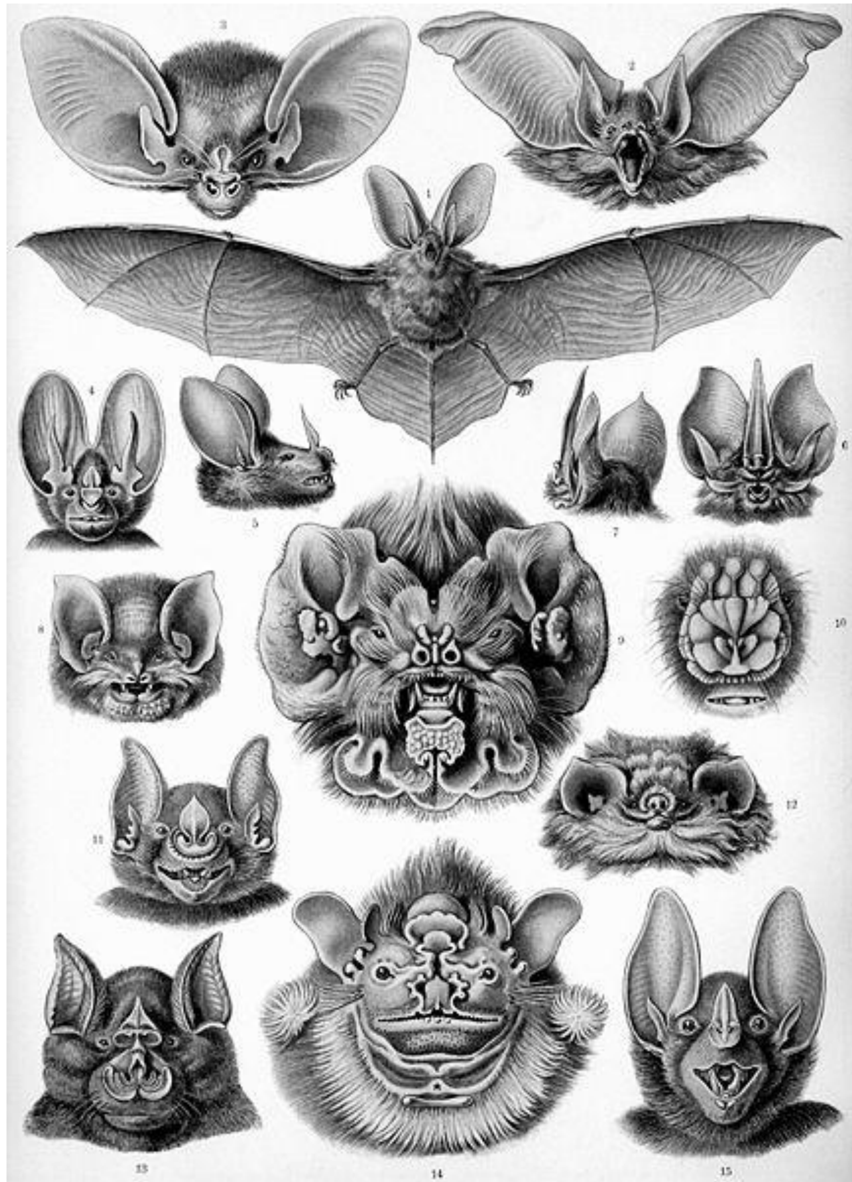
Frequency Response

- Humans typically hear 12Hz -20 KHz under ideal conditions
- BUT too many ear buds (this Buds for You)
- Too many rock concerts == loss of hearing
- High freq response goes first (after age 8)
- Woman have better high freq response
- Humans can feel infrasonic 4-16 Hz

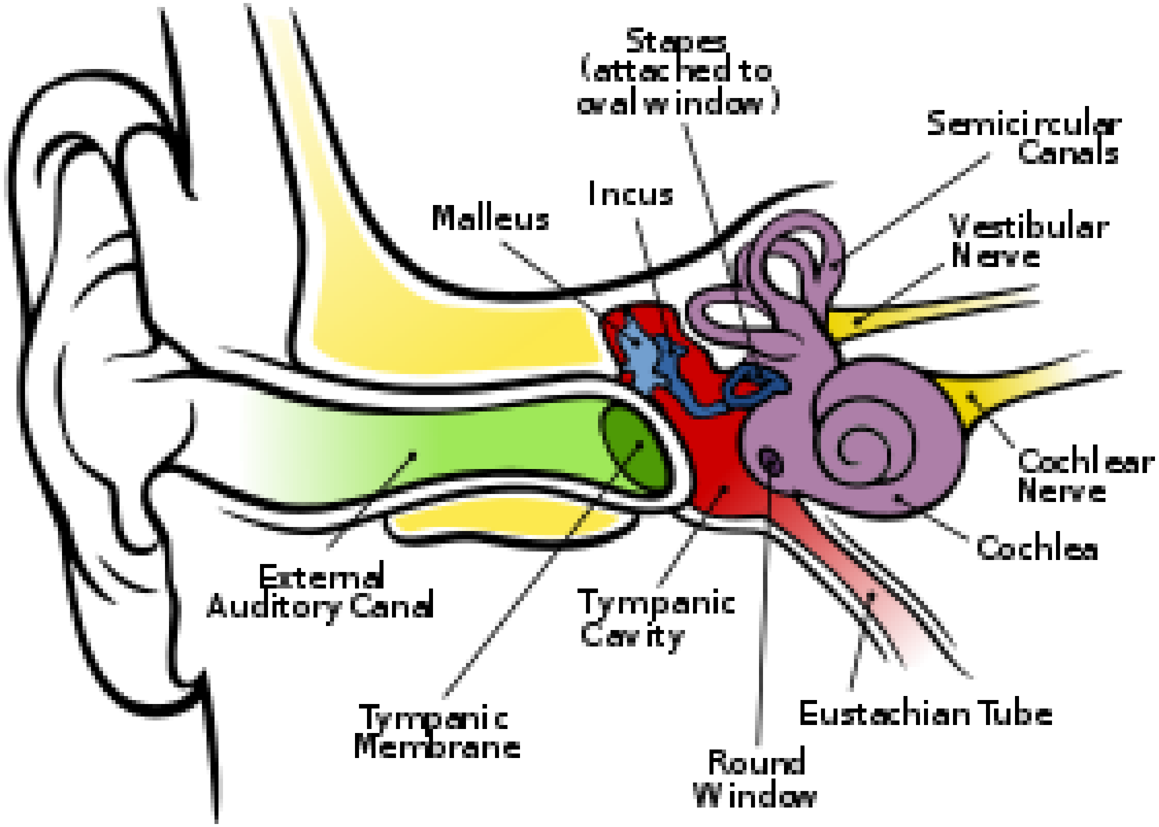
Other animals

- Dogs can hear 40 Hz to 60 KHz
- Bats 20 Hz to 120 KHz – Use Freq Modulation to get Doppler shift of target
- Mice 1 KHz to 90 KHz – communicate above our hearing – we do not hear them
- Bottlenose Dolphins 0.25 to 150 KHz
- Harbour Porpoise typ emit at 2 KHz and 110 KHz
- Bats and many sea animals use echolocation for hunting (sonar)

External Ear



Human Ear

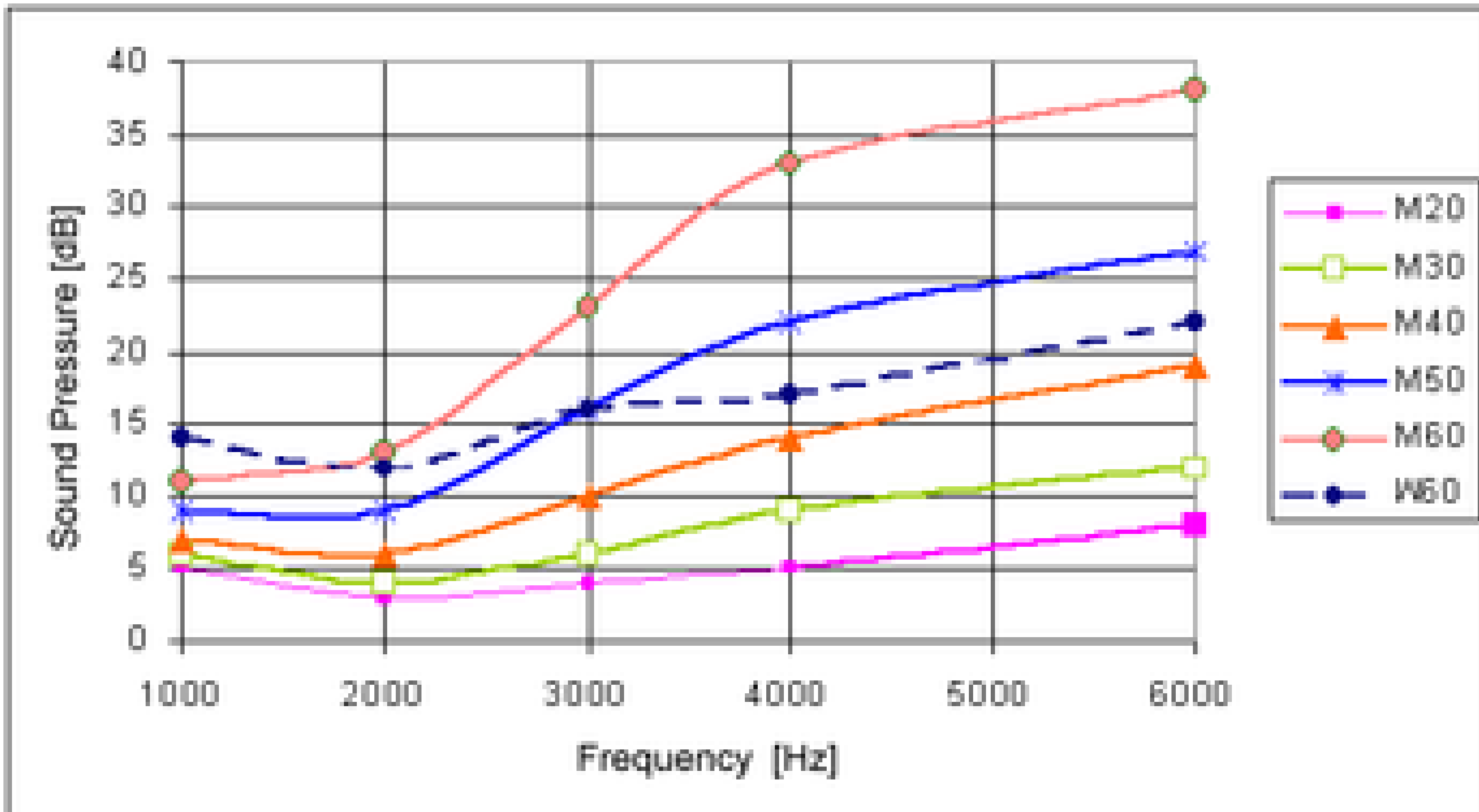


Stapes (attached to oval window)
Semicircular Canals
Incus
Malleus
Vestibular Nerve
Cochlear Nerve
Cochlea
External Auditory Canal
Tympanic Cavity
Tympanic Membrane
Eustachian Tube
Round Window

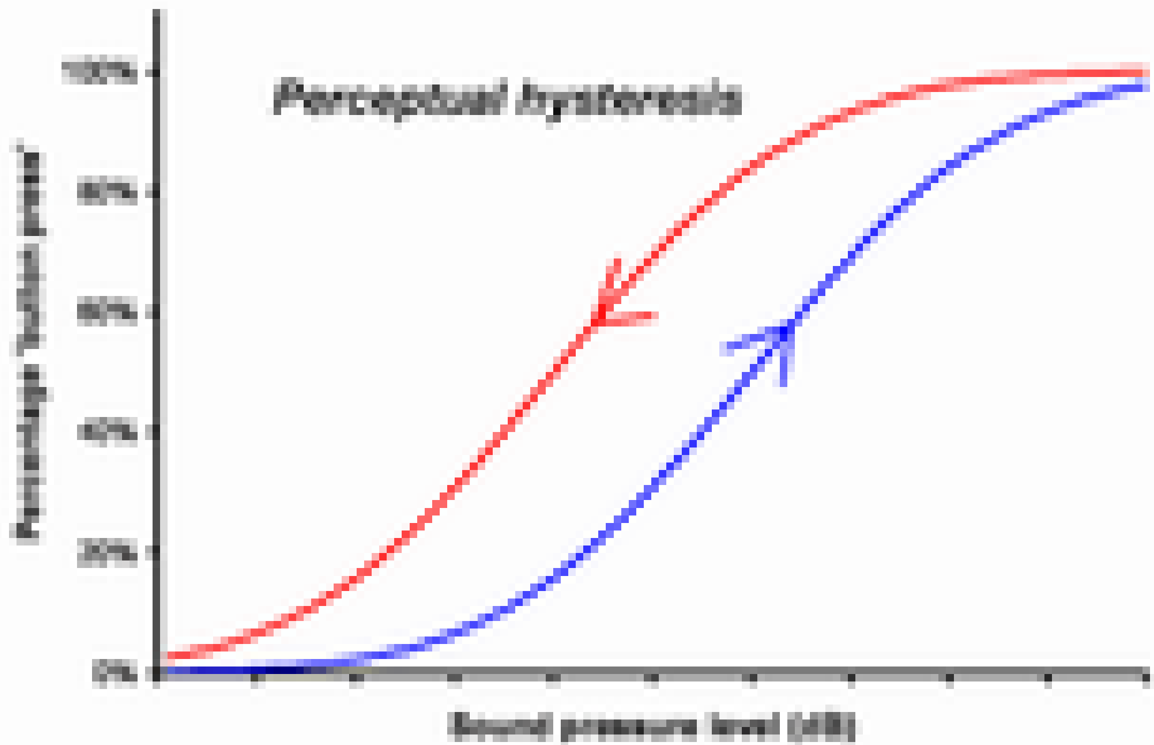
Frequency Range and Variation with Age and Gender

Degradation is very dependent on exposure

Protect your ears – DO NOT blast IPods



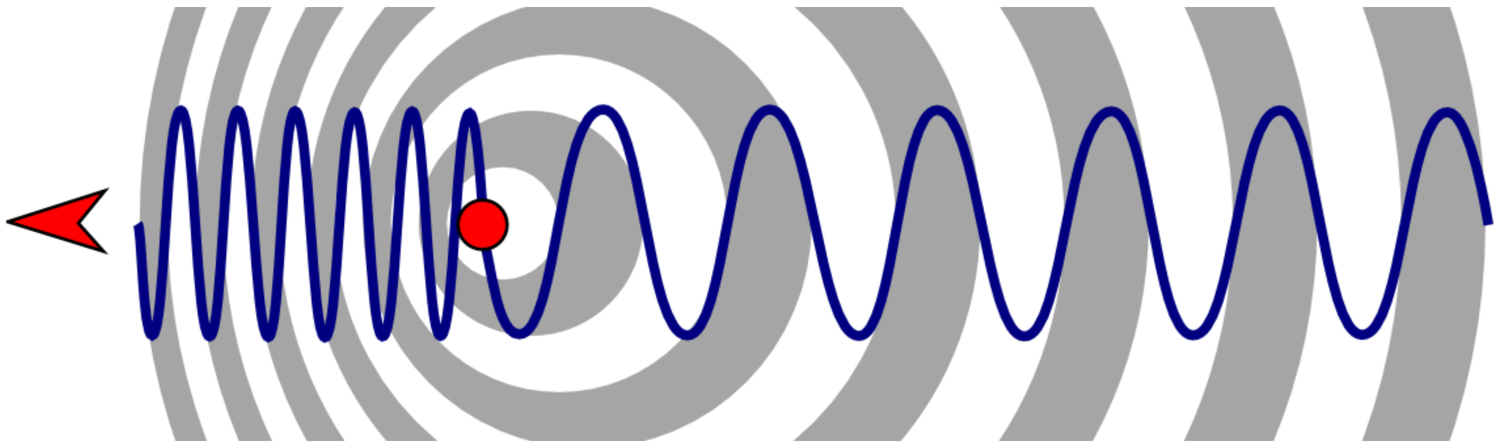
Hearing Threshold and Hysteresis
Threshold is lower going from higher to lower intensity



Doppler Shift – Frequency Change with Motion

- Named after Austrian physicist Christian Doppler 1842
- The effect is simple to understand if you think of the total number of waves emitted being constant
- Motion of you (the receiver) or the emitter (the source) causes the waves to "bunch up" or "spread out" in time
- Hence you measure a larger or smaller frequency
- This is true in acoustics and electromagnetic waves
- Examples are:
- Radar guns for speed control or baseball speed
- Ultrasound for heart monitoring or imaging
- Measurement of redshift in astronomy
- Blood flow monitoring and testing of arteries
- Sonar – detecting fish, submarines, bats detecting bug motion

Doppler shift



Doppler shift calculations

- In a medium such as water, air etc
- Let v= speed of sound in the medium
- V_r = speed of receiver relative to medium
- V_r positive if receiver is moving toward emitter, negative if moving away
- V_s = speed of emitter relative to medium
- V_s positive if source moving towards receiver, negative if away
- f_0 = frequency emitted
- f = frequency detected (received)

$$f = \left(\frac{v + v_r}{v - v_s}\right) f_0$$

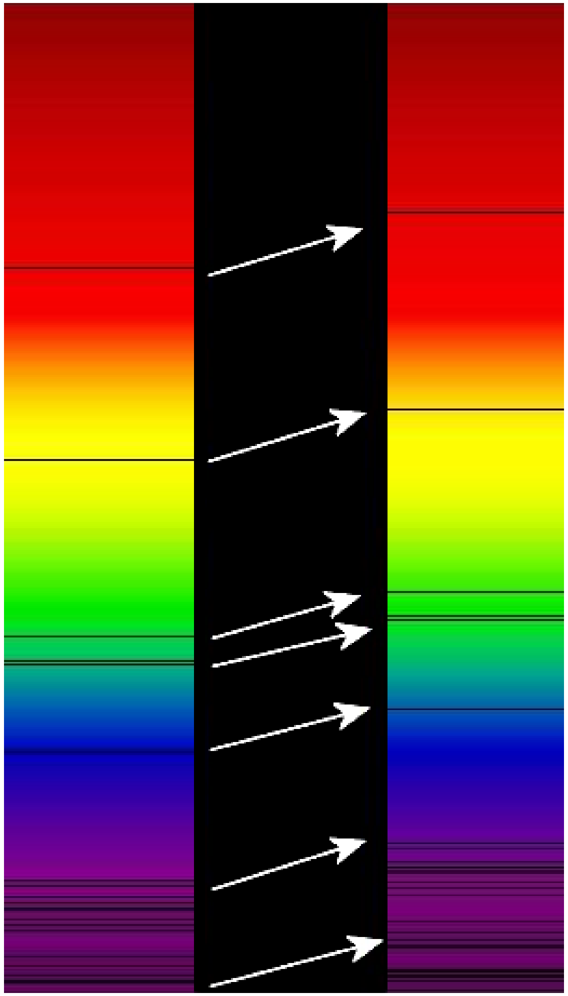
Redshift in EM waves – used to measure velocities to stars, galaxies etc

Measure shift in specific emission or absorption lines

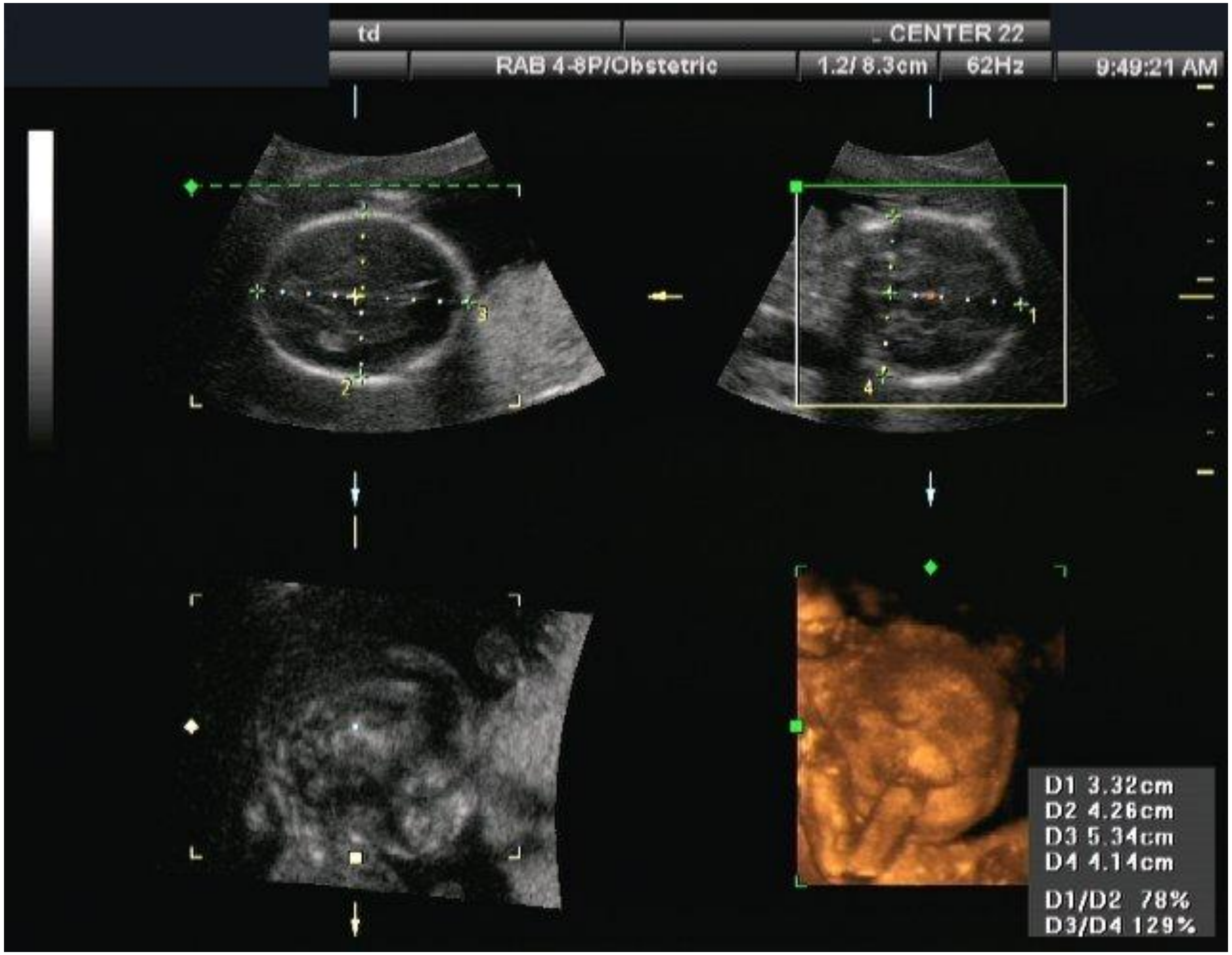
This is one way we search for extra-solar planets

Search for the effects of dark Matter

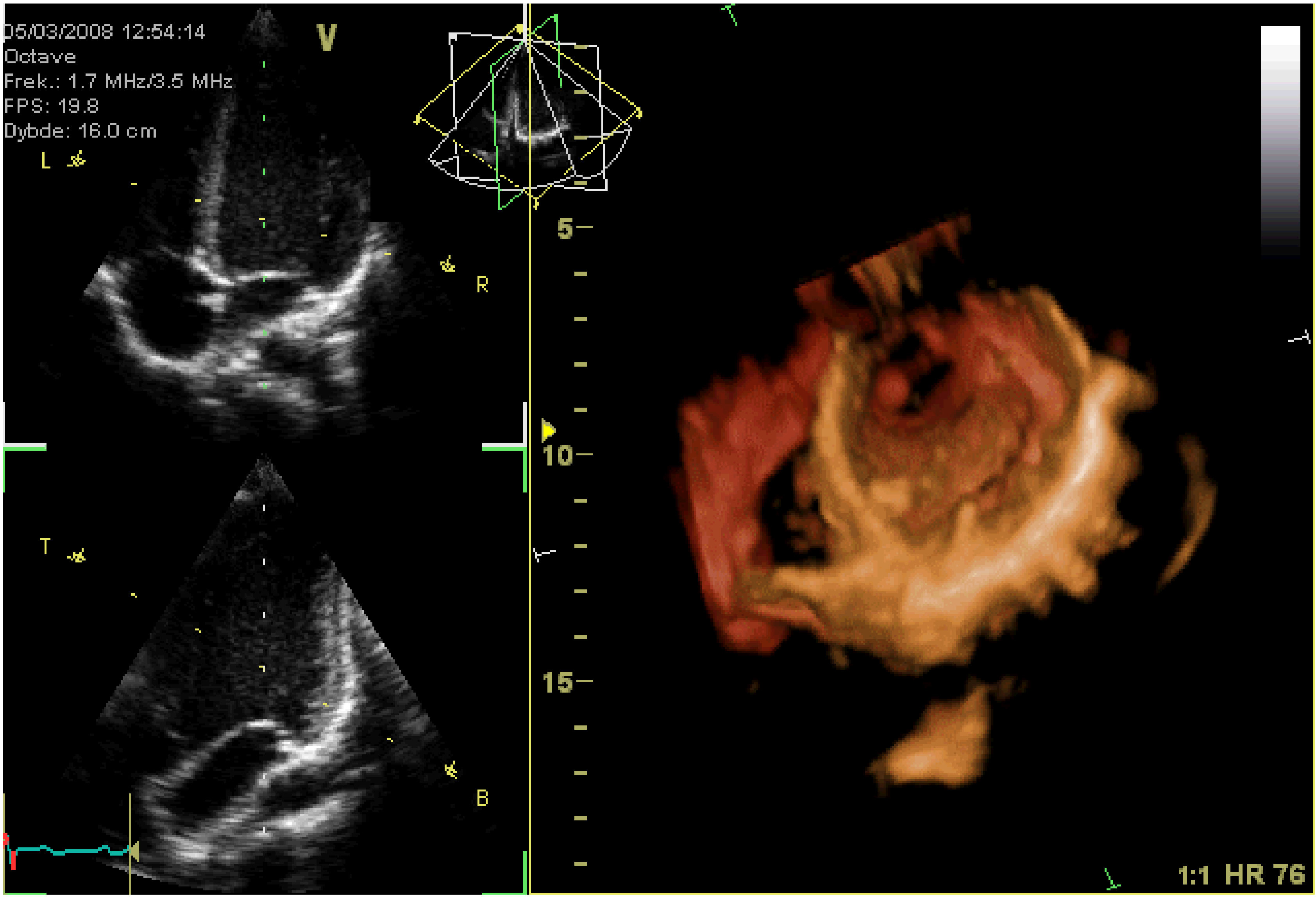
Measure the expansion of the universe



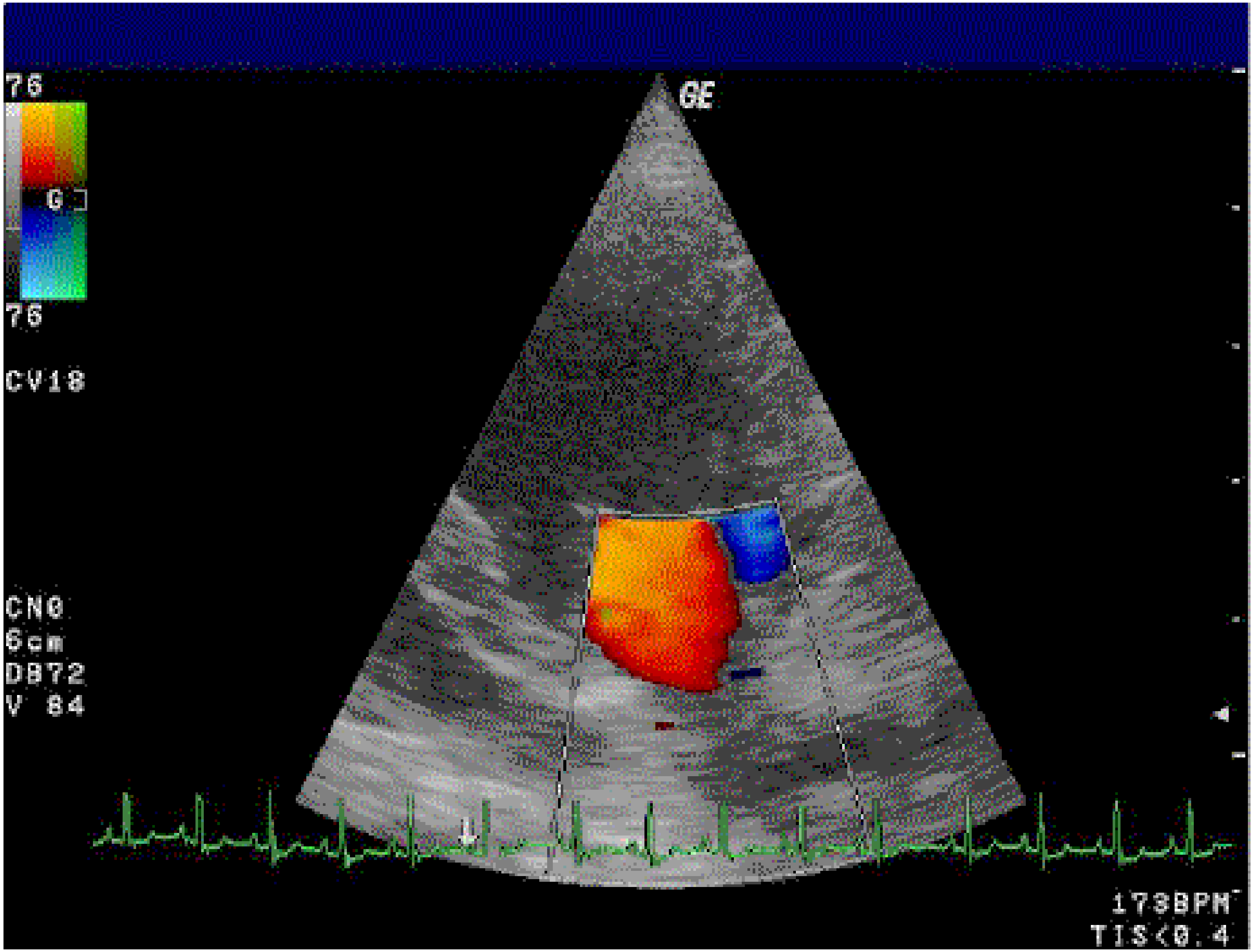
Ultrasound imaging – typ 2-20 MHz



Heart ultrasound imaging
Echocardiogram



Doppler Echocardiogram



Sonoluminescence – Light emission from sound waves – bubble implosion
Still largely unexplained – some claim fusion