Second Year Science

Medical Physics & Health Science

MEDICAL ULTRASOUND

David Andrews

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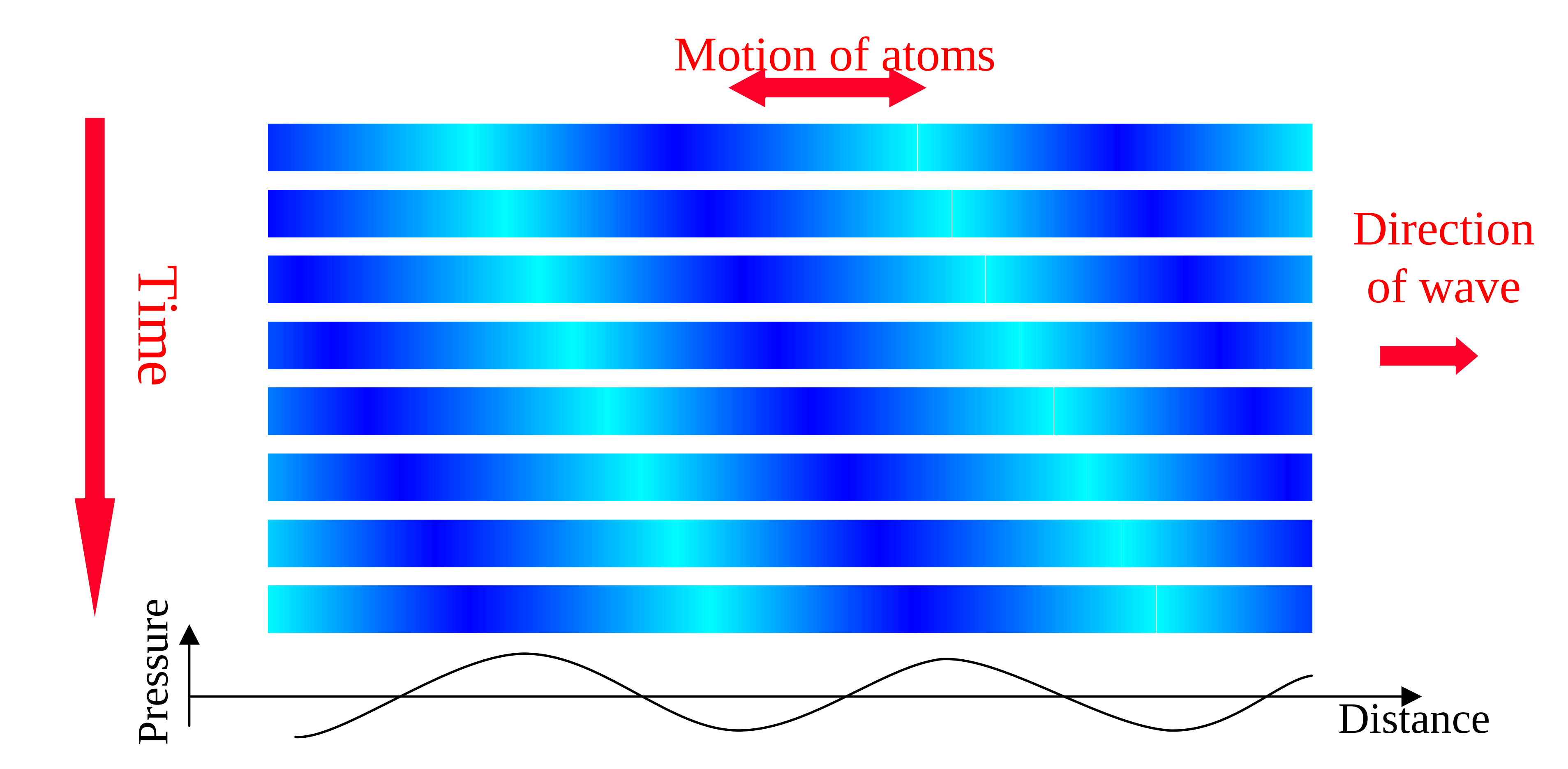
Waves

- **Moving disturbance**
  - **Disturbance advances, not medium**
  - **Carries energy**
- **Wavelength, λ**
  - **Distance of one oscillation, *m***
- **Frequency, *f***
  - **Number of oscillations in one second, *Hz***
- **Speed of wave, *v***
  - $v = \lambda f$
    - ***m/s***

Sound

- **Compression wave**
  - **Longitudinal wave**
    - **Oscillations in direction of motion**



Ultrasound

- **Frequency greater than limit of human hearing**
  - about 20kHz and above.
- **Higher frequency means lower wavelength**
  - Smaller features can be detected and measured.
- **For medical ultrasound**
  - Frequencies of about 3 MHz and above.

Velocity of Sound

- **Velocity dependent on**
  - **bulk modulus, *B* and density, r**

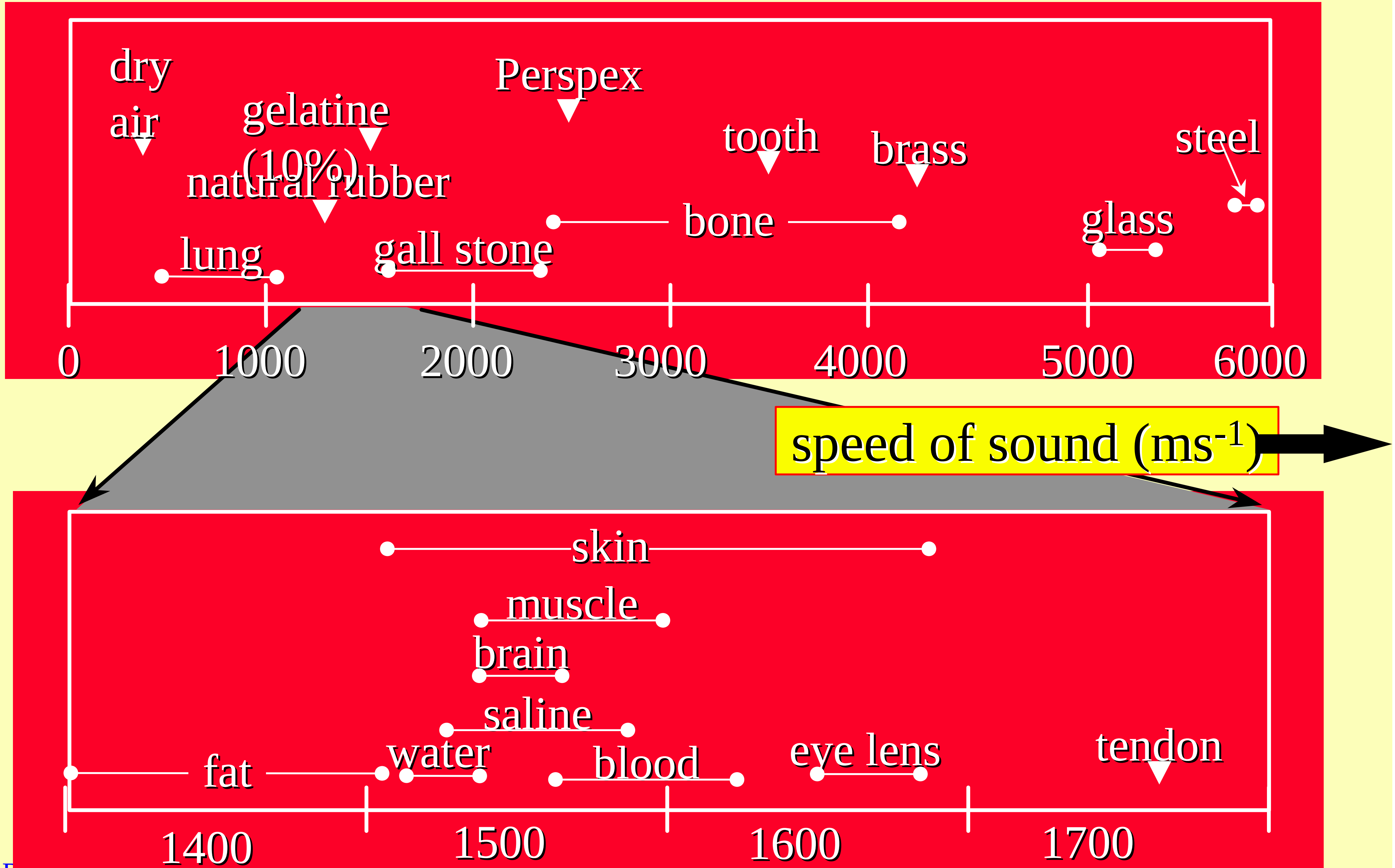
$$v = \sqrt{\frac{B}{\rho}}$$

- **Bulk modulus defined as**
  - **ratio of increase in pressure to factional change in volume**
  - **units are N/m^2**

$$B = -\frac{\Delta P}{\Delta V / V}$$

- ★ **Air, *B* = 1.5×10^5 N m^{-2}, r = 1.27 kg m^{-3}**
  - ☞ *v* = 345 m s^{-1} (at room temperature & pressure)
- ★ **Water, *B* = 2.05×10^9 N m^{-2}, r = 1×10^3 kg m^{-3}**
  - ☞ *v* = 1432 m s^{-1} (at room temperature & pressure)

Speed of Sound



Sound Intensity & Attenuation

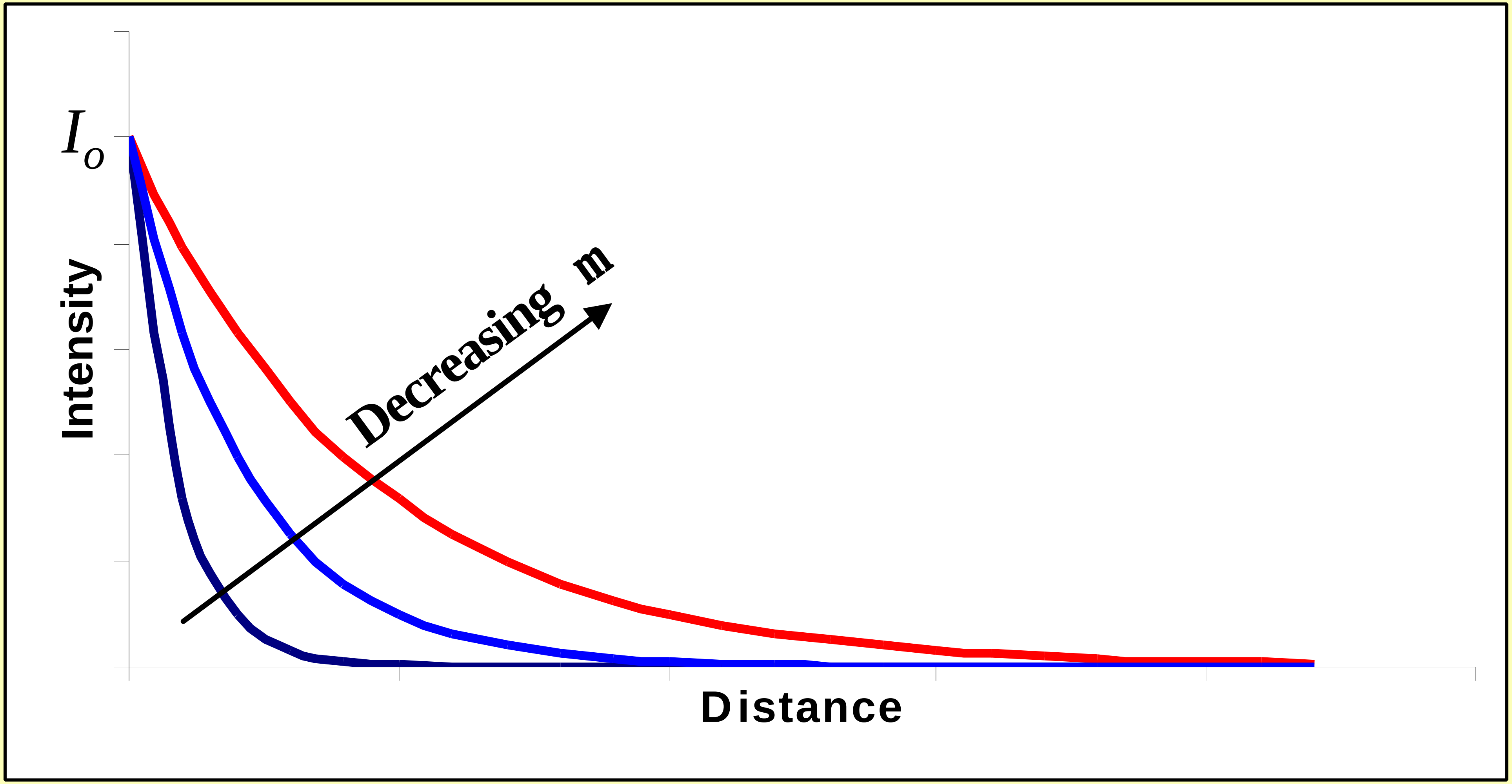
- **Intensity of a wave:**
  - ➪ Energy per unit time per unit area
    - ⋆ Units: Wm^{-2}; Symbol: I
- **Sound is scattered & absorbed by matter**
  - ➪ Reduction in intensity called attenuation
  - ➪ change in intensity µ distance ´ intensity
    - ⋆ m = attenuation constant, dependent on material

$$\Delta I = -\mu I \Delta x$$

Attenuation of Sound

- **Integrating gives:**
  - ★ I_o is the original intensity

$$I = I_o e^{-\mu x}$$



Attenuation Coefficient

- **Rearranging last equation**
- **Taking natural logarithms**

$$I/I_o = e^{-\mu x}$$

$$\ln\left(I/I_0 \right) = -\mu x$$

⇨ **Attenuation coefficient is therefore**

$$\mu = -\left(1/x\right)\ln\left(I/I_0 \right)\,\mathrm{m}^{-1}$$

Attenuation in Decibels

- **Change in decibels (dB) defined as:**

$$10\log_{10}\left({}^{I}\!/_{I_o}\right)$$

- **attenuation coeff. in dB/m (a)**

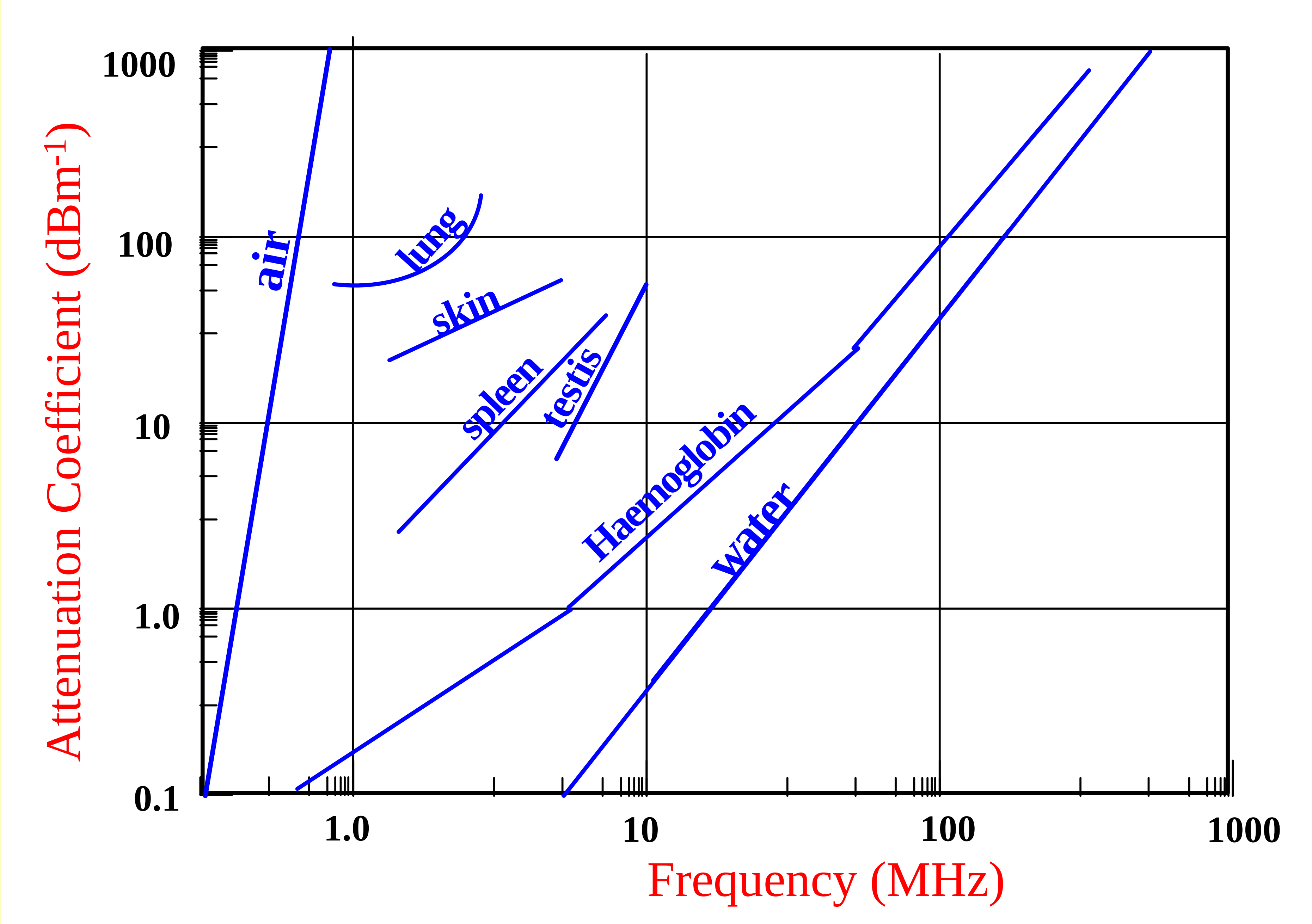
$$\alpha = -10\left({}^{1}\!/_{x}\right)\log_{10}\left({}^{I}\!/_{I_o}\right)$$

$$= -10\left({}^{1}\!/_{x}\right)\ln\left({}^{I}\!/_{I_o}\right)\Big/\ln(10) = \mu\left({}^{10}\!/_{\ln(10)}\right)$$

$$= 4.343\,\mu$$

- **a(dBm^{-1}) = 4.343m(m^{-1})**

Attenuation against Frequency



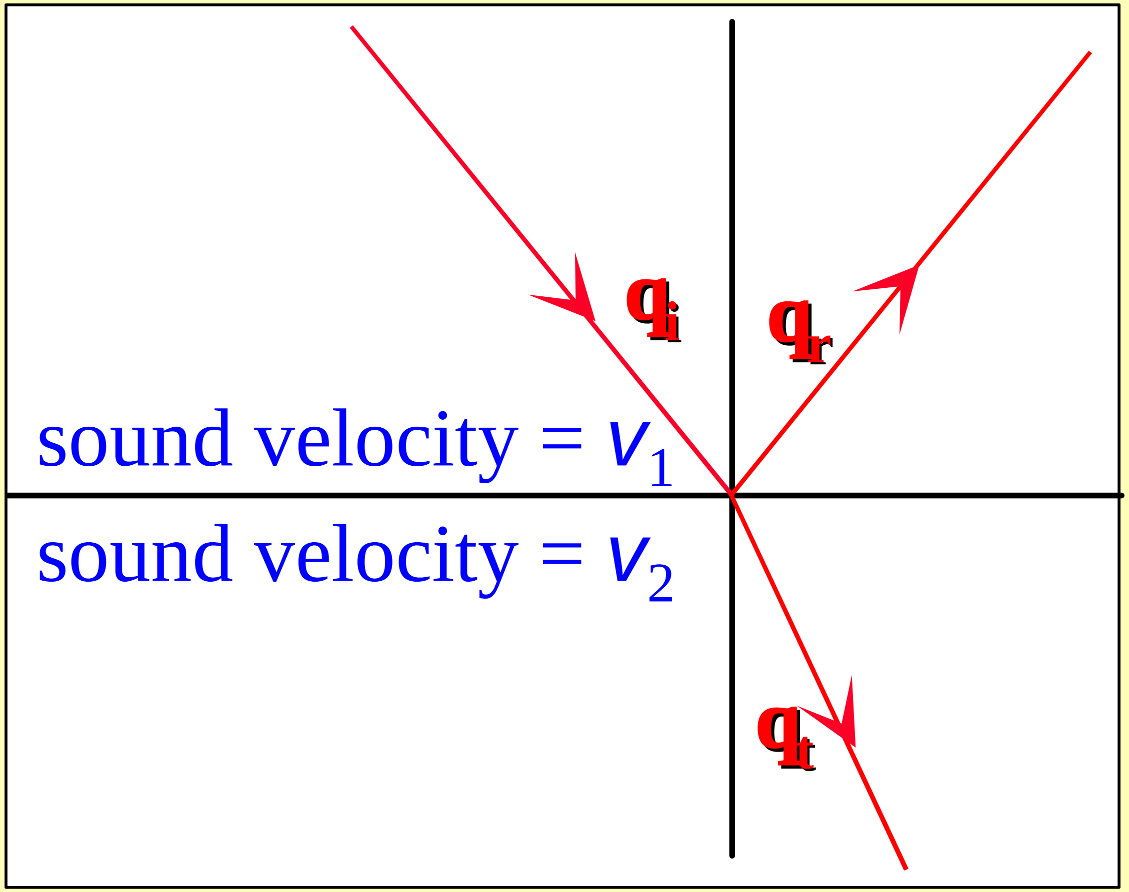
Scattering of Ultrasound

- **Attenuation made up from:**
  - ➪ **absorption (heating)**
  - ➪ **scattering**
    - ⋆ **depends on relative size of particle (a) wavelength (l)**

Scale of Interaction	Frequency Dependence	Scattering Strength	Examples
a >> λ geometrical region	$f^0=1$ (no dependence)	Strong	Diaphragm, large vessels, soft tissue/bone, cysts
a ~ λ Stochastic region	variable	Moderate	Predominates for most structures
a << λ	f^4	Weak	Blood

Geometrical region (a>> l)

- **Sound reflected & refracted like light**
  - **from a flat interface**
    - **Some reflected and some transmitted**



- **laws of reflection & refraction hold**

$$\theta_i = \theta_r$$

$$\frac{\sin\theta_i}{\sin\theta_r} = \frac{v_1}{v_2}$$

Reflection and Refraction

- **At normal incidence, fraction of energy reflected between media 1 and 2 is**

$$R = \left(\frac{Z_1 - Z_2}{Z_1 + Z_2} \right)^2$$

  - **Z is acoustic impedance given by**

$$Z = \rho v$$

    - **v is sound velocity and r is density**
  - **for minimum reflection, impedances should be as close as possible**
- **Fraction transmitted is** $$T = \frac{4 Z_1 Z_2}{(Z_1 + Z_2)^2}$$

Acoustic Impedances

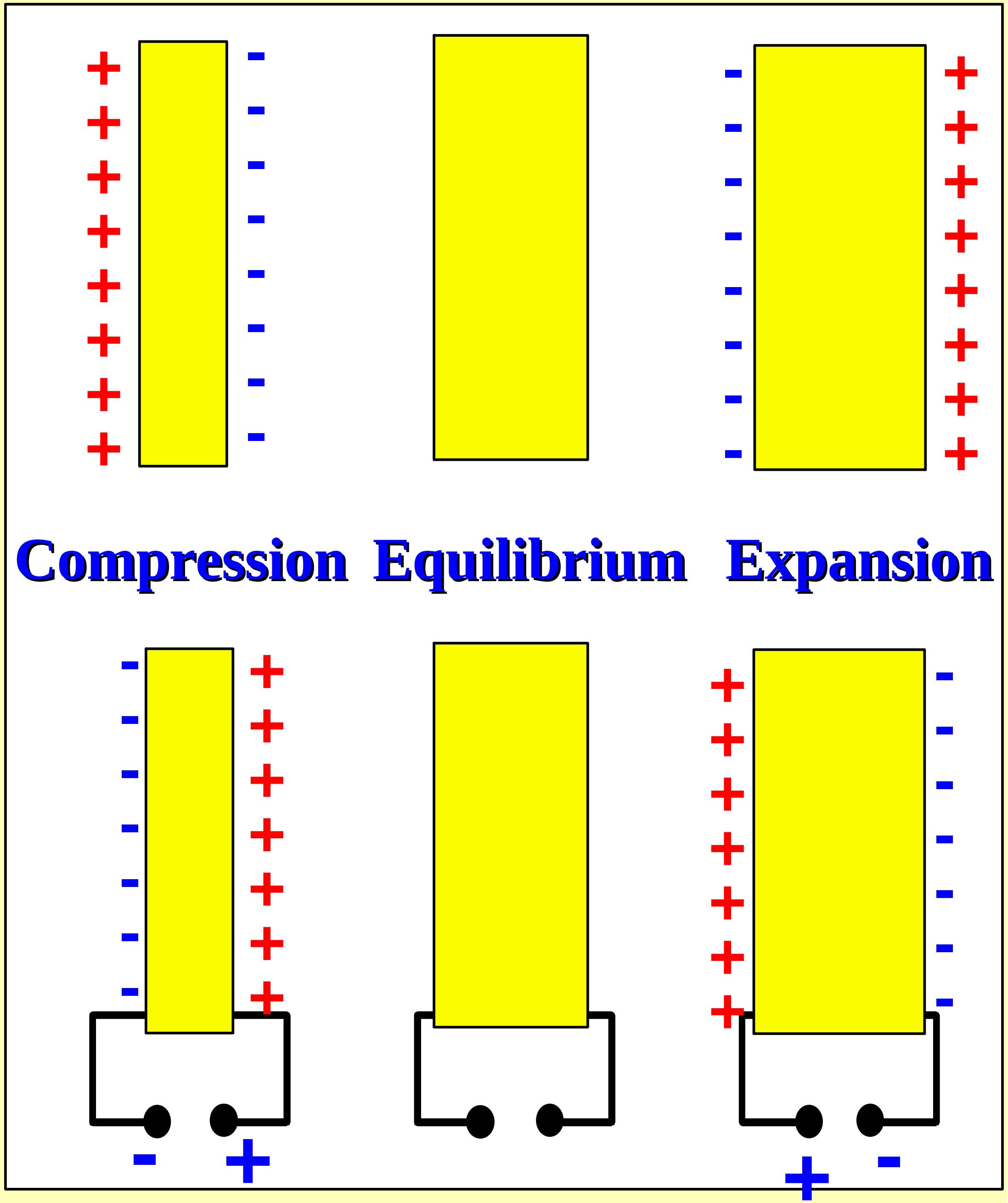
Material	Impedance, Z (kg m^{-2} s^{-1})
Air	0.0004×10^6
Blood	1.61×10^6
Brain	1.58×10^6
Fat	1.38×10^6
Human soft tissue	1.63×10^6
Kidney	1.62×10^6
Liver	1.65×10^6
Muscle	1.70×10^6
Skull Bone	7.80×10^6
Water	1.48×10^6

Production of Ultrasound

- **Cannot use loudspeaker to generate high frequencies**
  - **Inertia of system to great.**
  - **Most ultrasound transducers use piezo electric disc or plate**
  - **Usually use lead zirconate titanate (PZT)**
    - **Ceramic alloy**
  - **Produces ultrasound from 50kHz to 50 MHz**

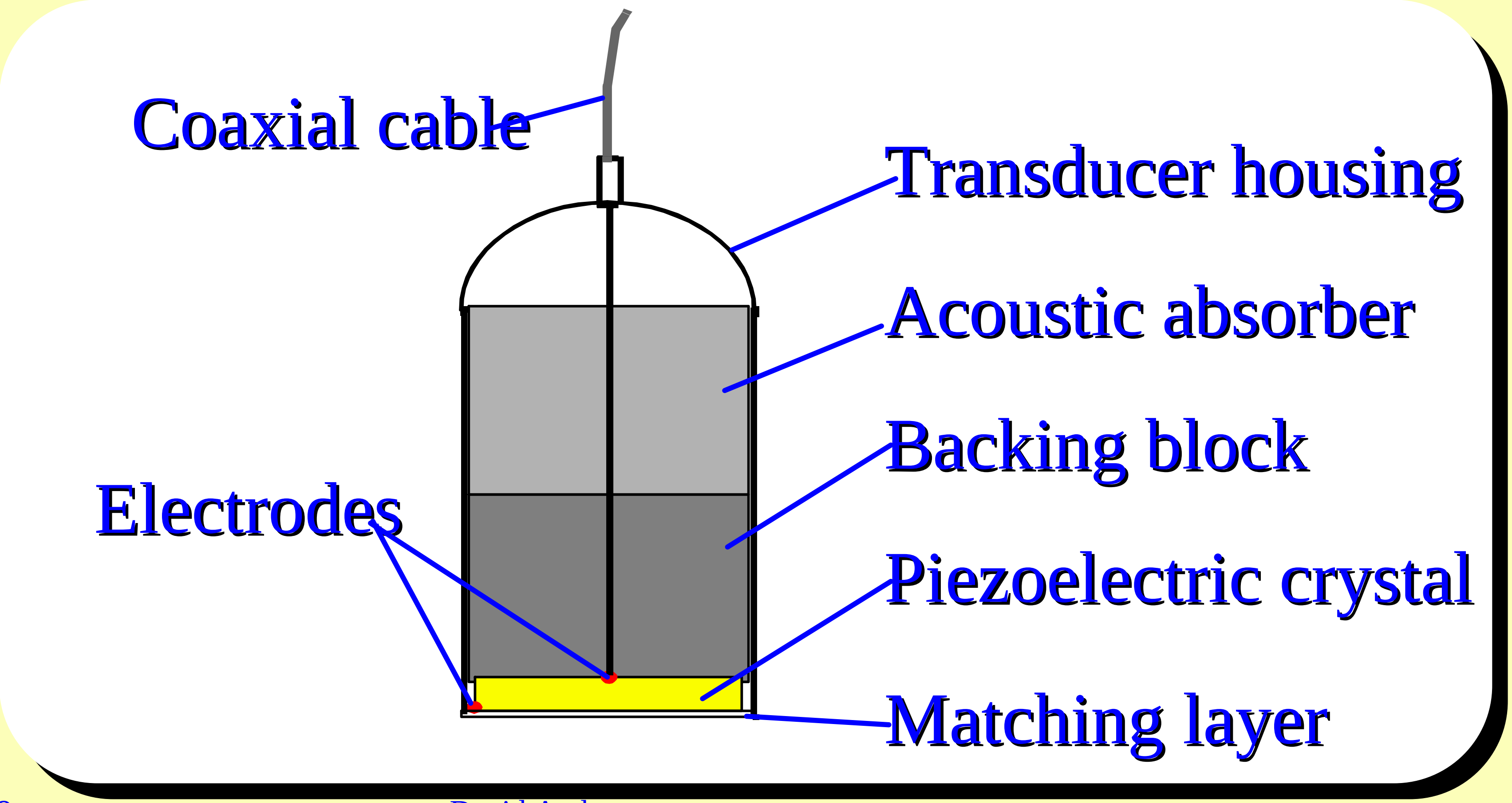
Piezoelectric Crystals

- **Surface charge when compressed or expanded**
  - ➪oscillating voltage used to give ultrasound
- **Expand or contract as voltage applied.**
  - ➪ultrasound falling on crystal will produce oscillating voltage.



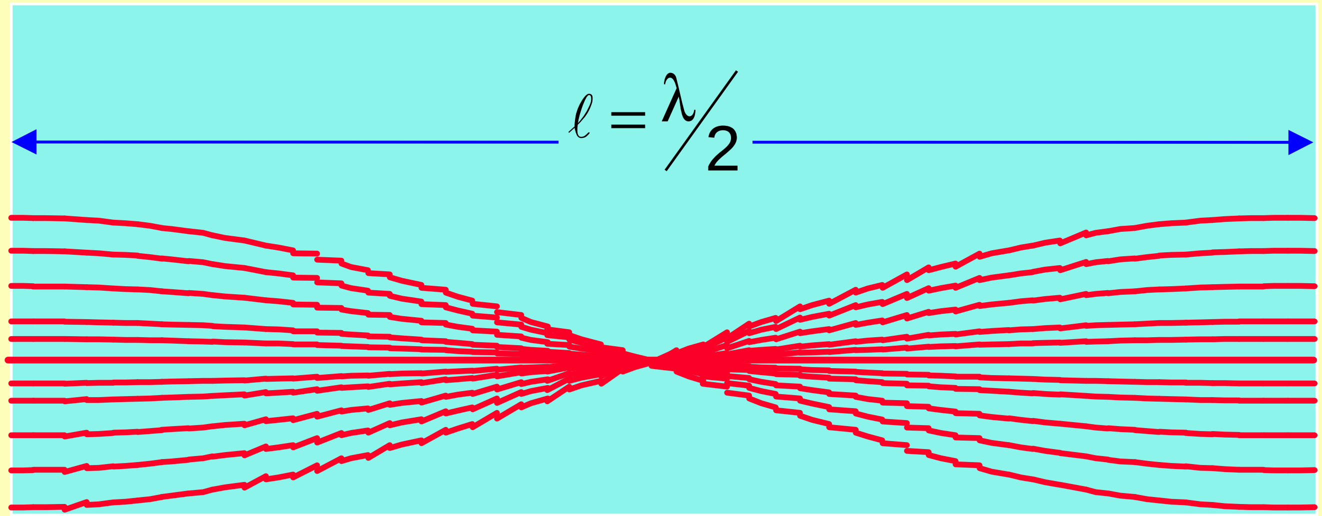
Ultrasound Transducers

- Typical arrangement shown below.
- Can be used both to transmit & receive ultrasound.



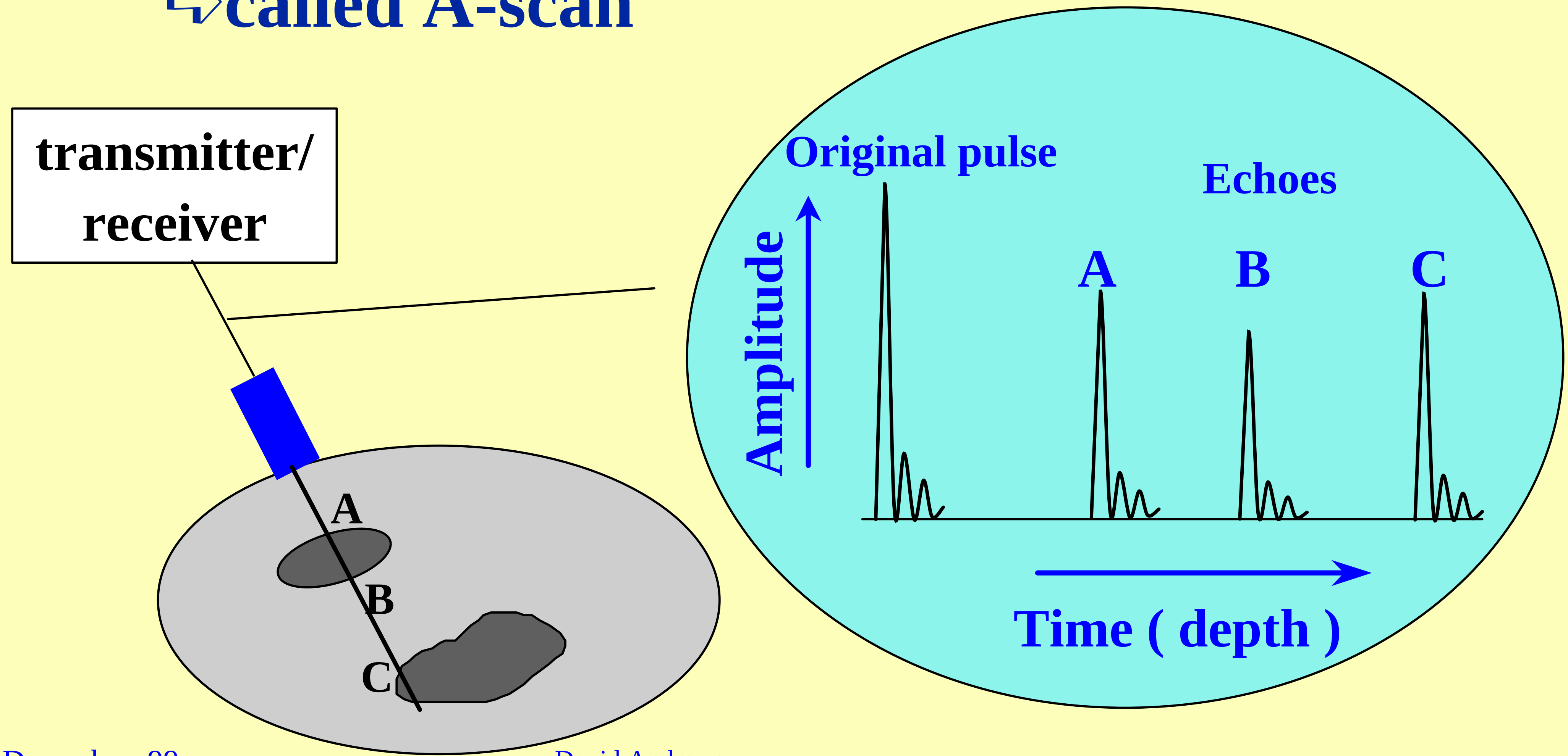
Ultrasound Transducers

- **For maximum output**
  - ➪ driven at resonance of PZT plate
- **Since both sides move**
  - ➪ at resonance, both are antinodes
    - ⋆ Thickness is half a wavelength

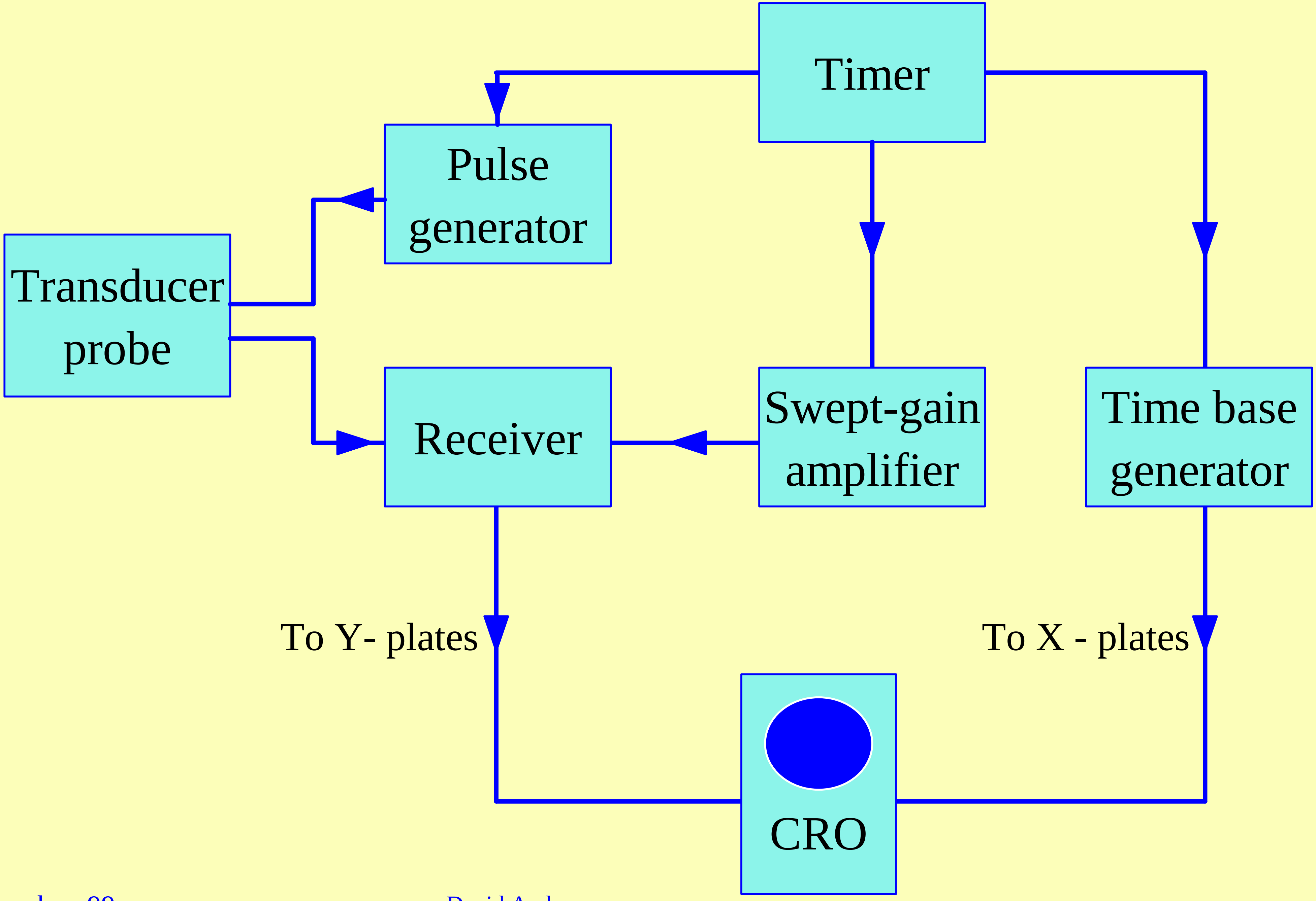


Pulse Echo Technique

- **A short pulse is send out, and the time for the return pulses is measured**
  - ➪ called A-scan

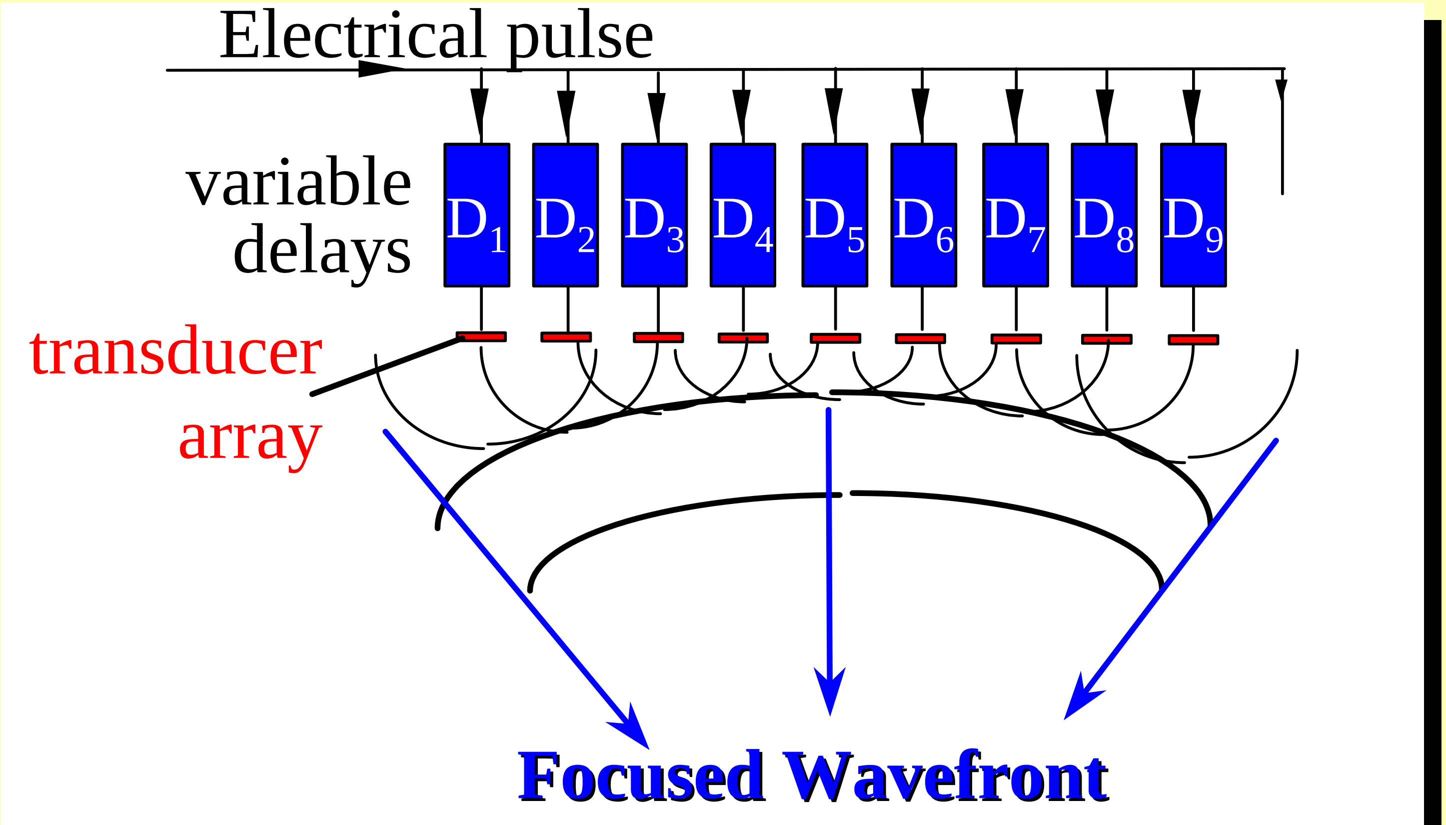


A-Scan


Timer
Pulse generator
Transducer probe
Receiver
Swept-gain amplifier
Time base generator
To Y- plates
To X - plates
CRO

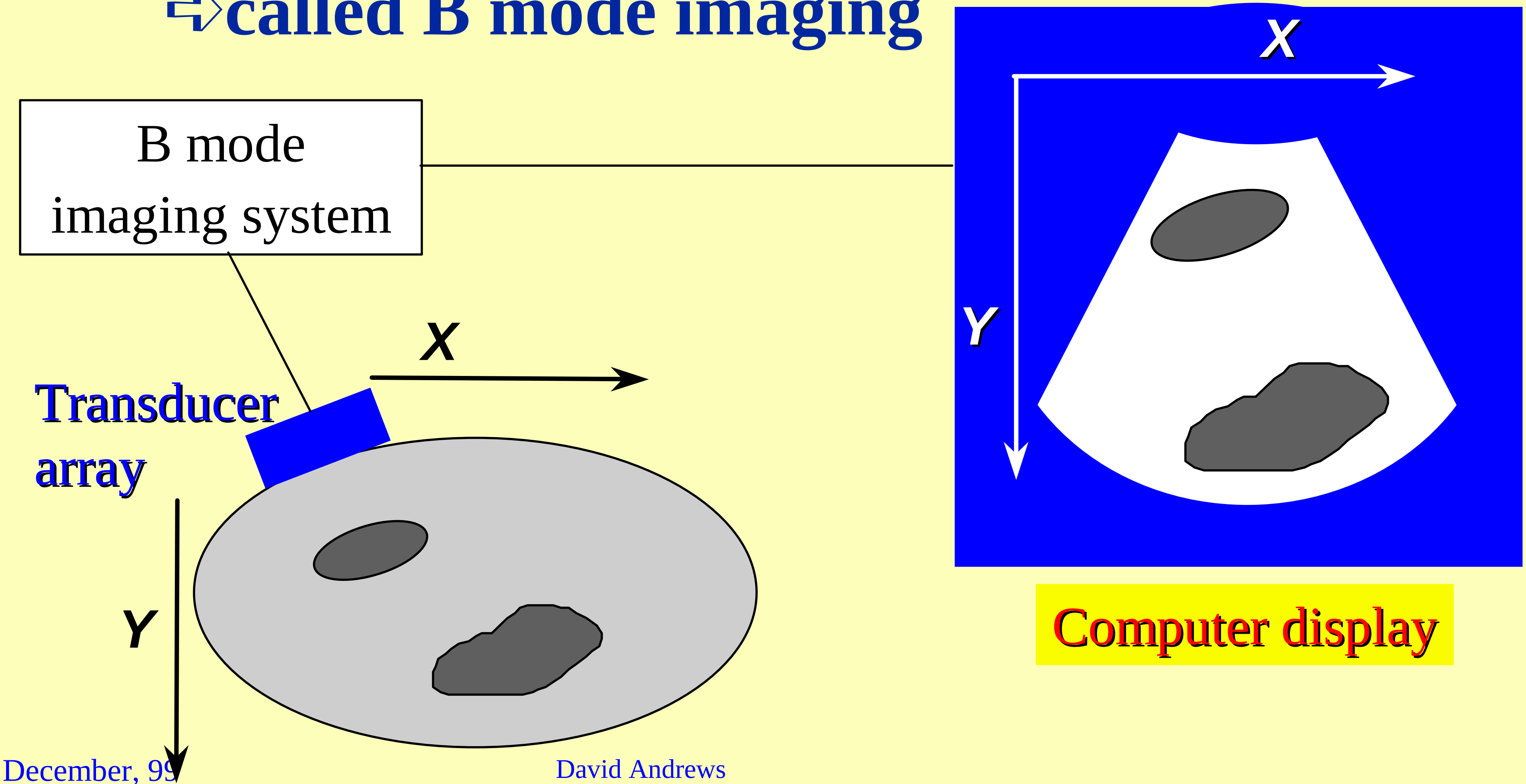
Multi-element Transducers

- **Ultrasound focused**
  - **time of arrival of pulse at each transducer gives direction**
  - **Called a B-scan**



Two Dimensional Imaging

- **Using multi-element array, 2-D image can be constructed**
  - ➪ called B mode imaging



Sample Images

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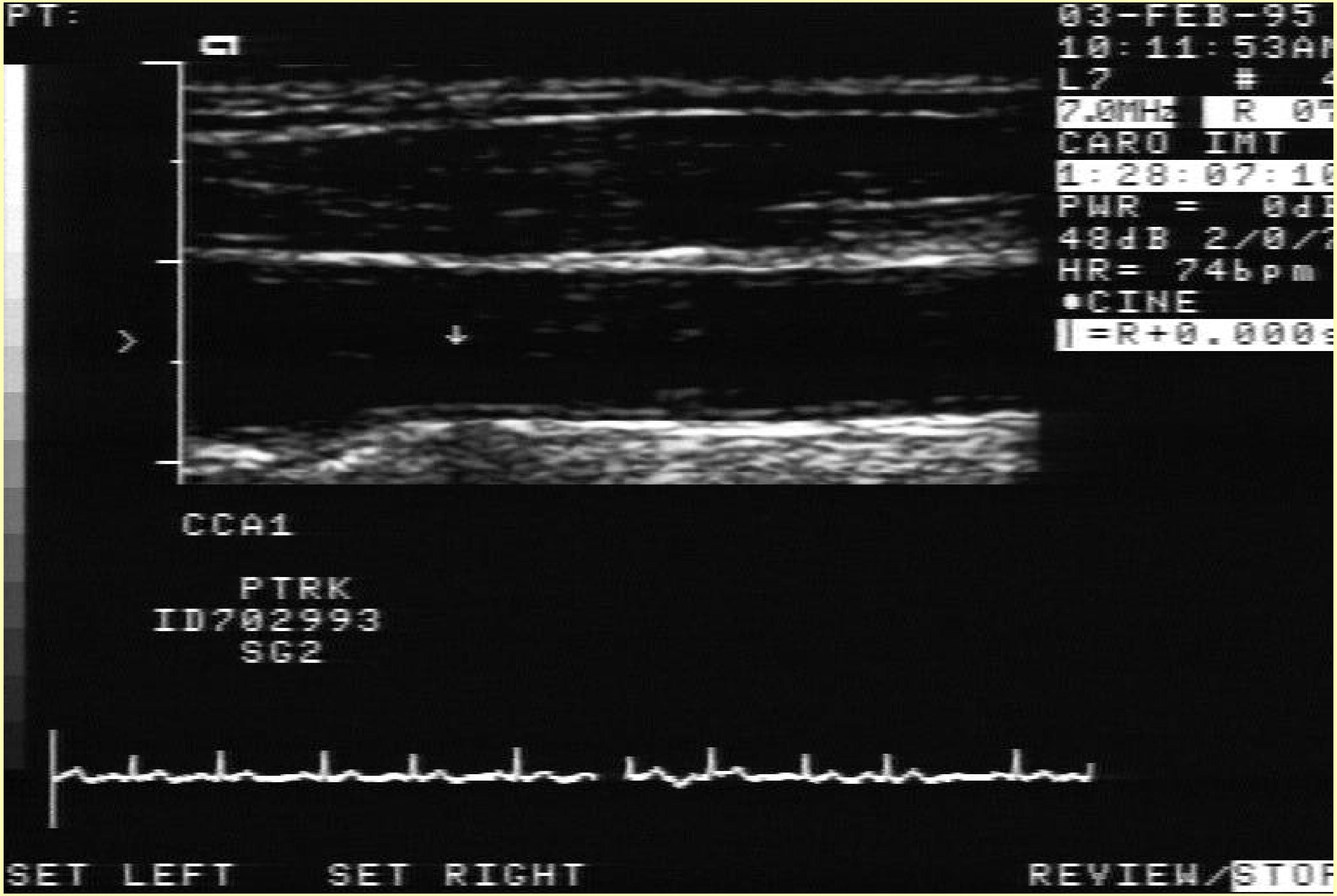

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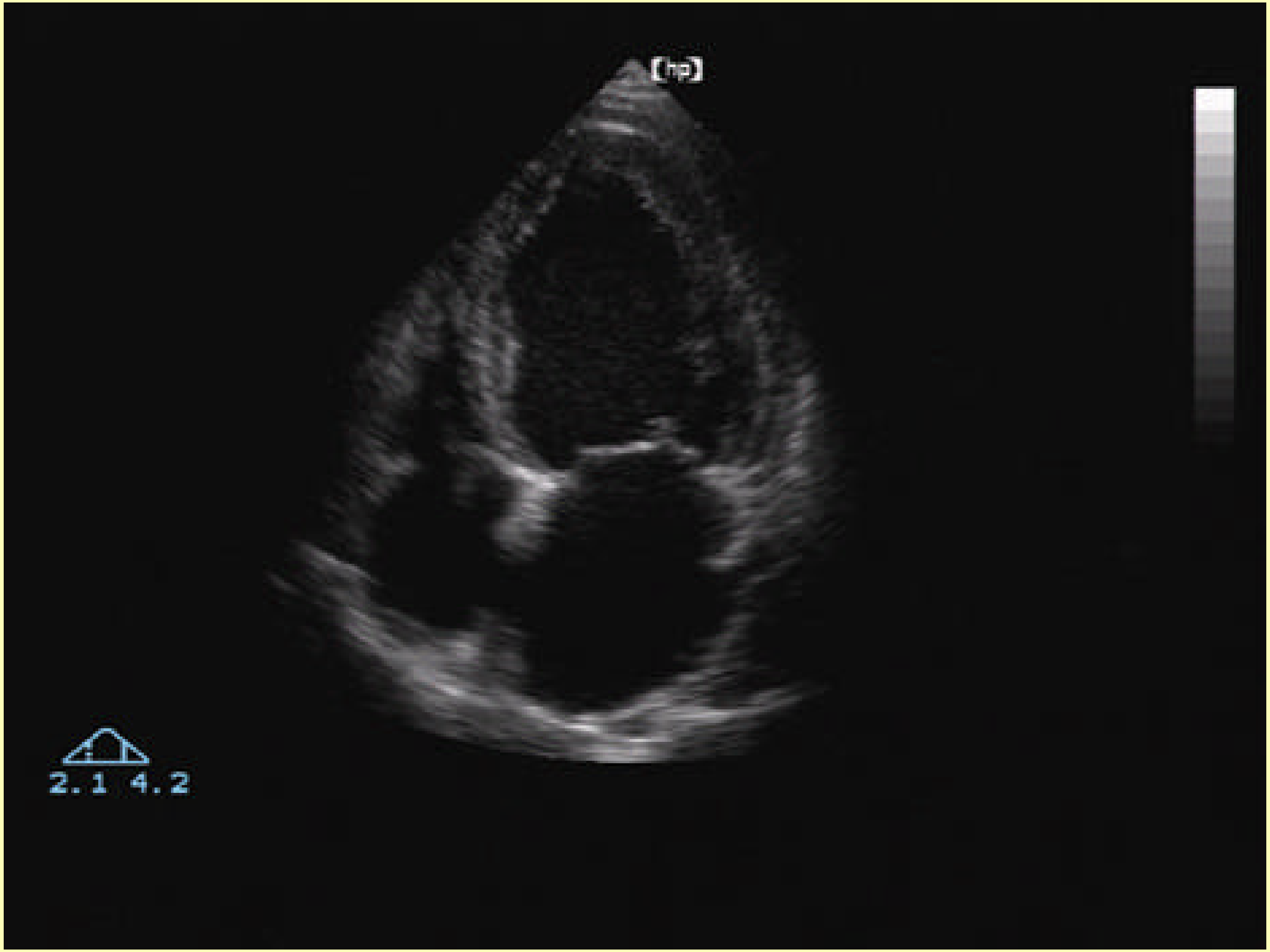

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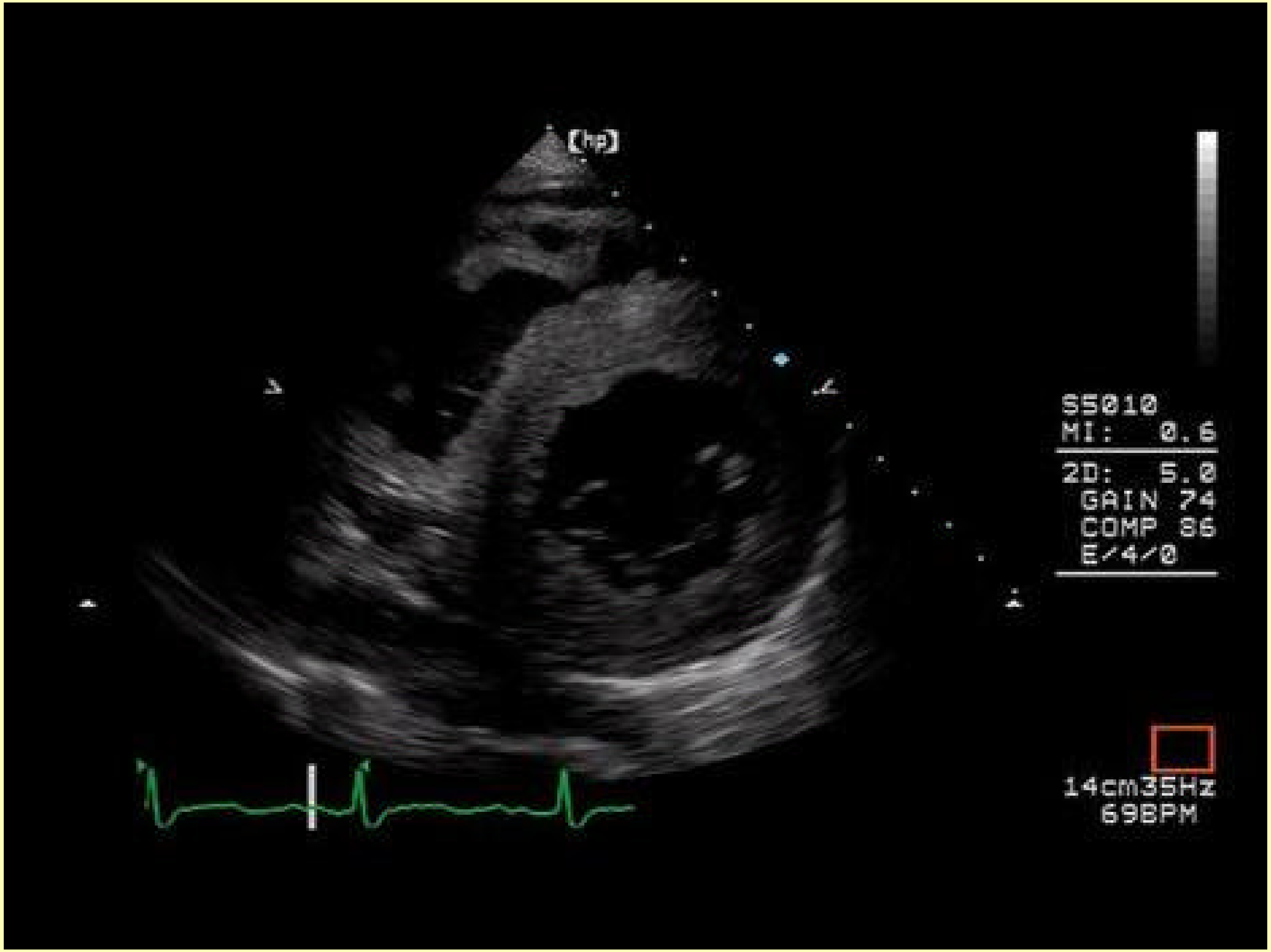

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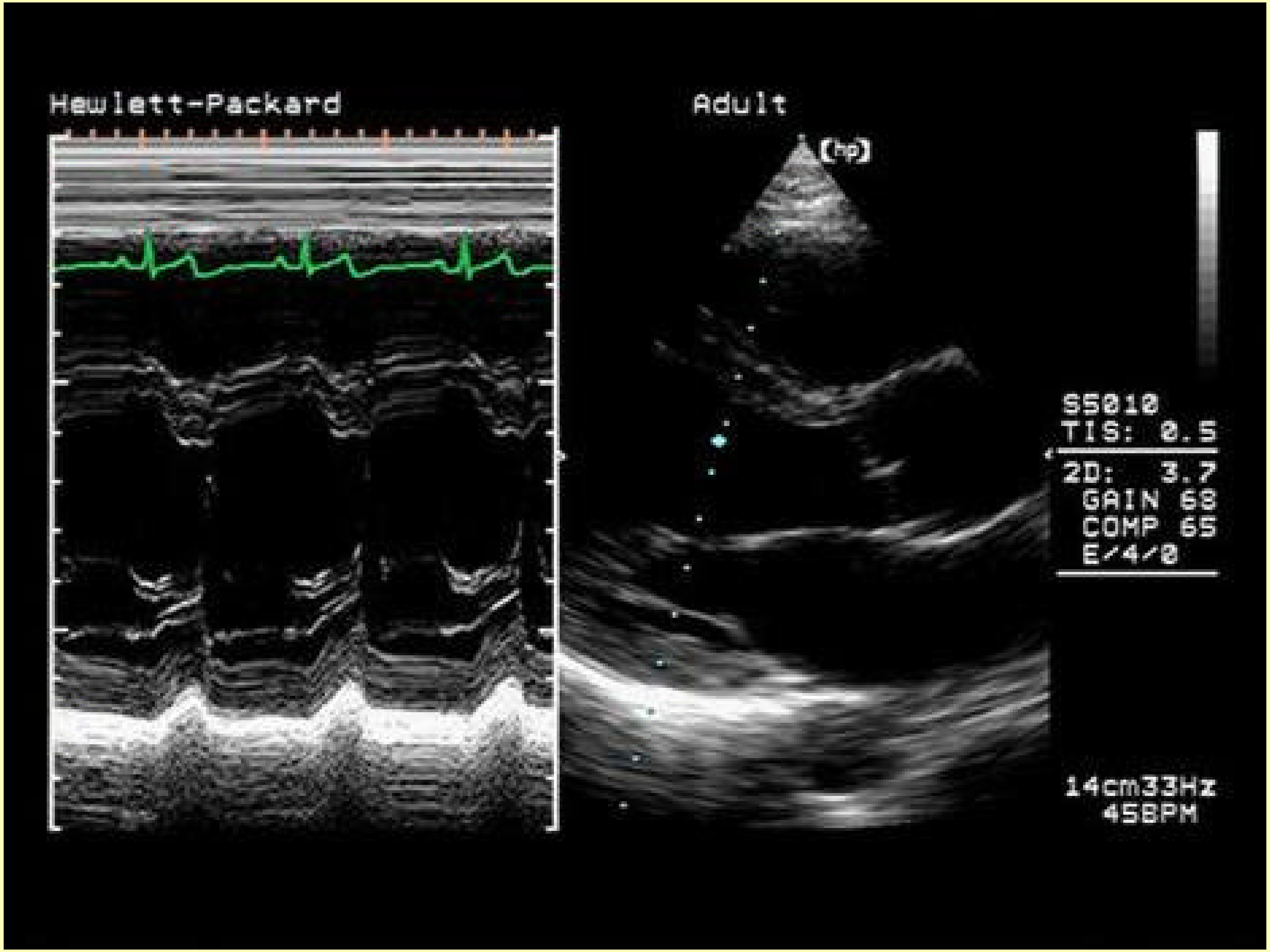


Doppler Ultrasound

- **Waves reflected off moving surfaces have changed frequency**
  - ⇨ **fractional change µ velocity**

$$\Delta f = \frac{2 f_s v_{surface}}{v}$$

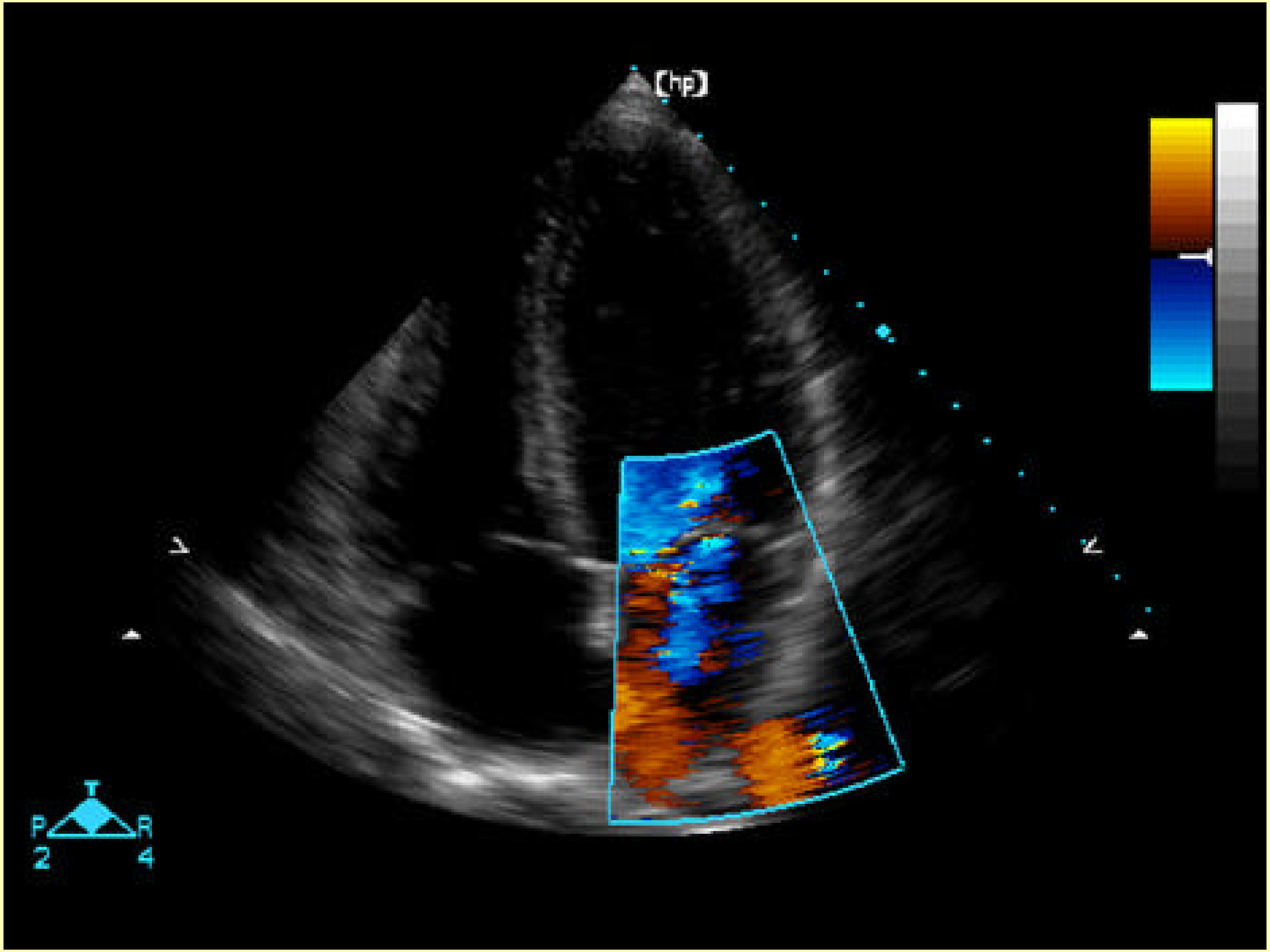
- ★ $v_{surface}$ = velocity of surface
- ★ v = velocity of sound
- ★ f_s = frequency of source
- ★ Df = change in frequency

- **Measuring frequency of returned signal gives velocity**

Doppler Ultrasound

- Used to monitor heartbeats, blood flow, etc.
- Can produce images showing motion
  - ⇨ i.e. Imaging beating heart

Sample Images



Safety Issues

- **High intensity ultrasound causes heating**
- **Could damage body tissues**
  - ➪ **Diagnostic ultrasound always used at low intensities**