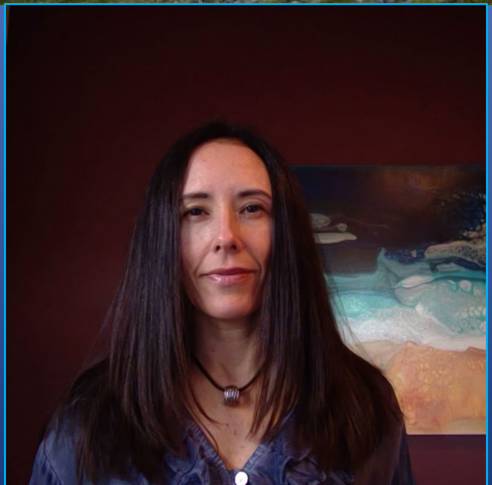
Fundamentals for Success

Carotid Duplex & Transcranial Doppler



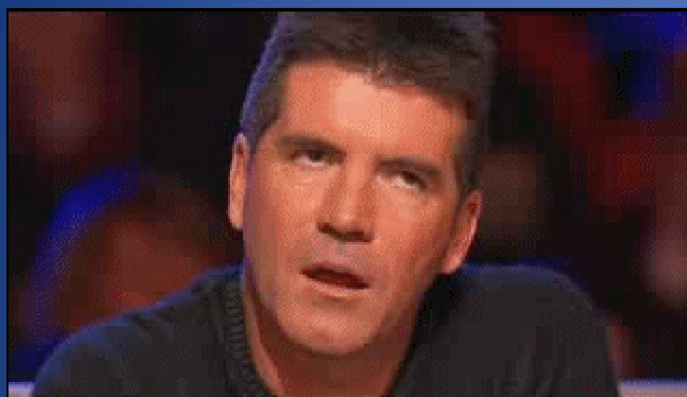
Leni N. Karr, BA, RVT

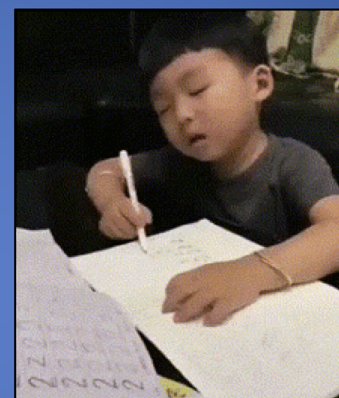
Vascular Sonographer
Swedish Medical Center
&
University of Washington
Medical Center
Seattle, WA

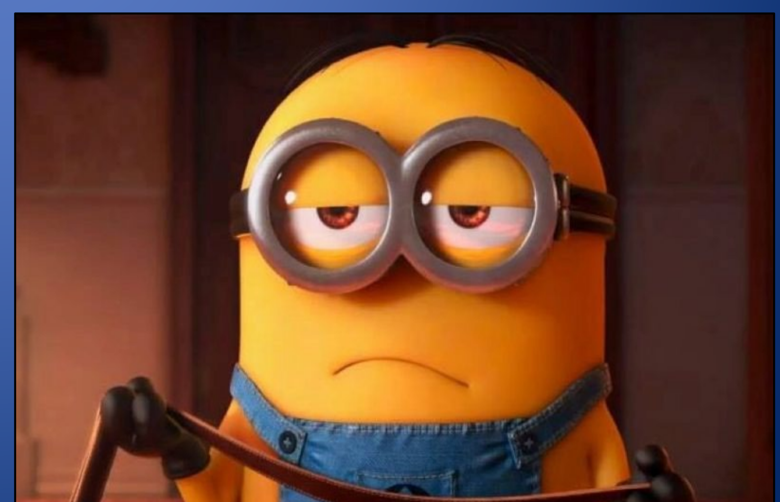
Adjunct Professor
Bellevue College
Bellevue, WA

No disclosures…except…

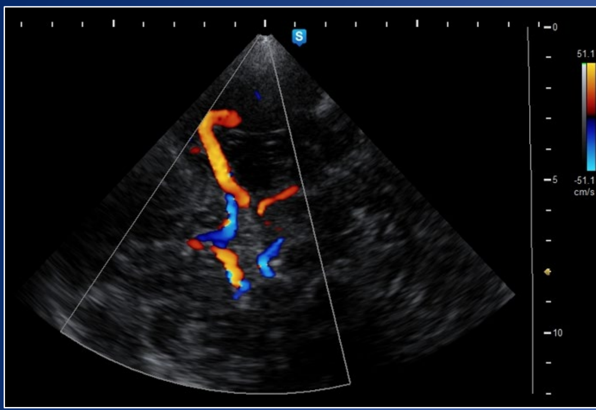
US Physics and Instrumentation

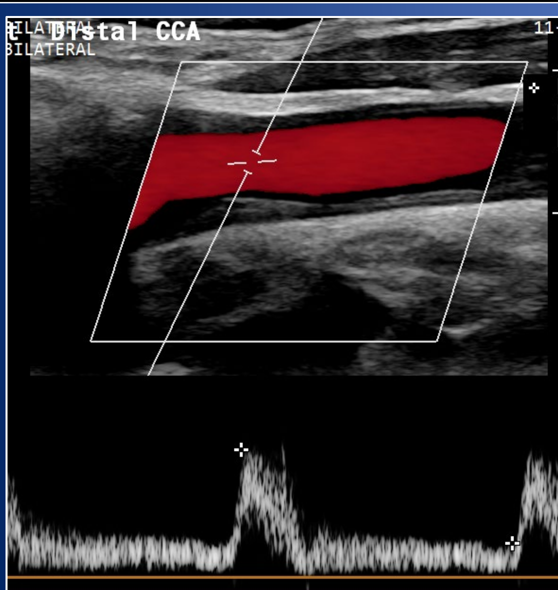


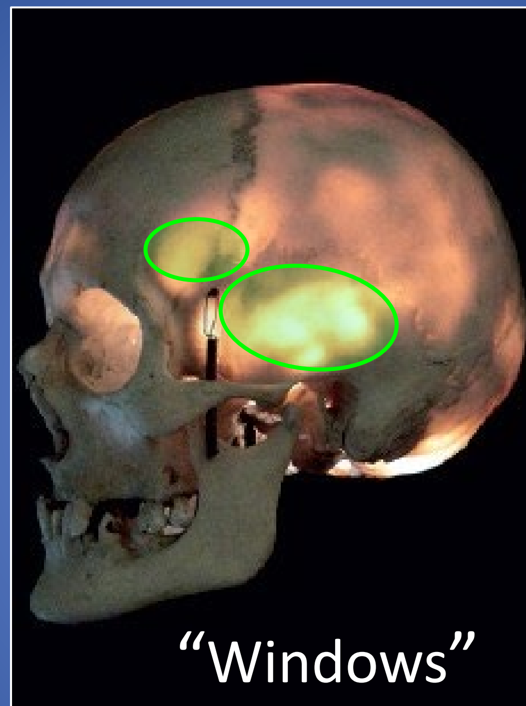




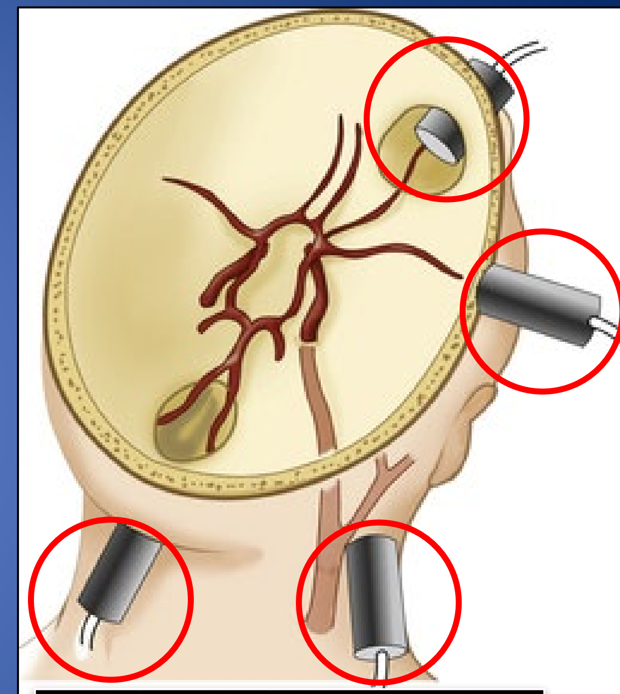
How it Works – *The Short Story*

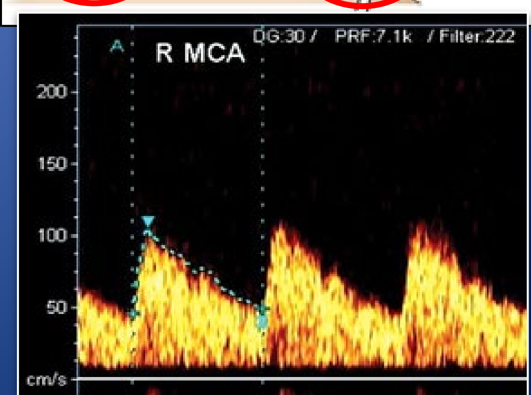






- Direct Testing
- Dynamic/Live
- Repeatable
- Safe
- Cheap





All US Instrumentation

Subject to limitations:

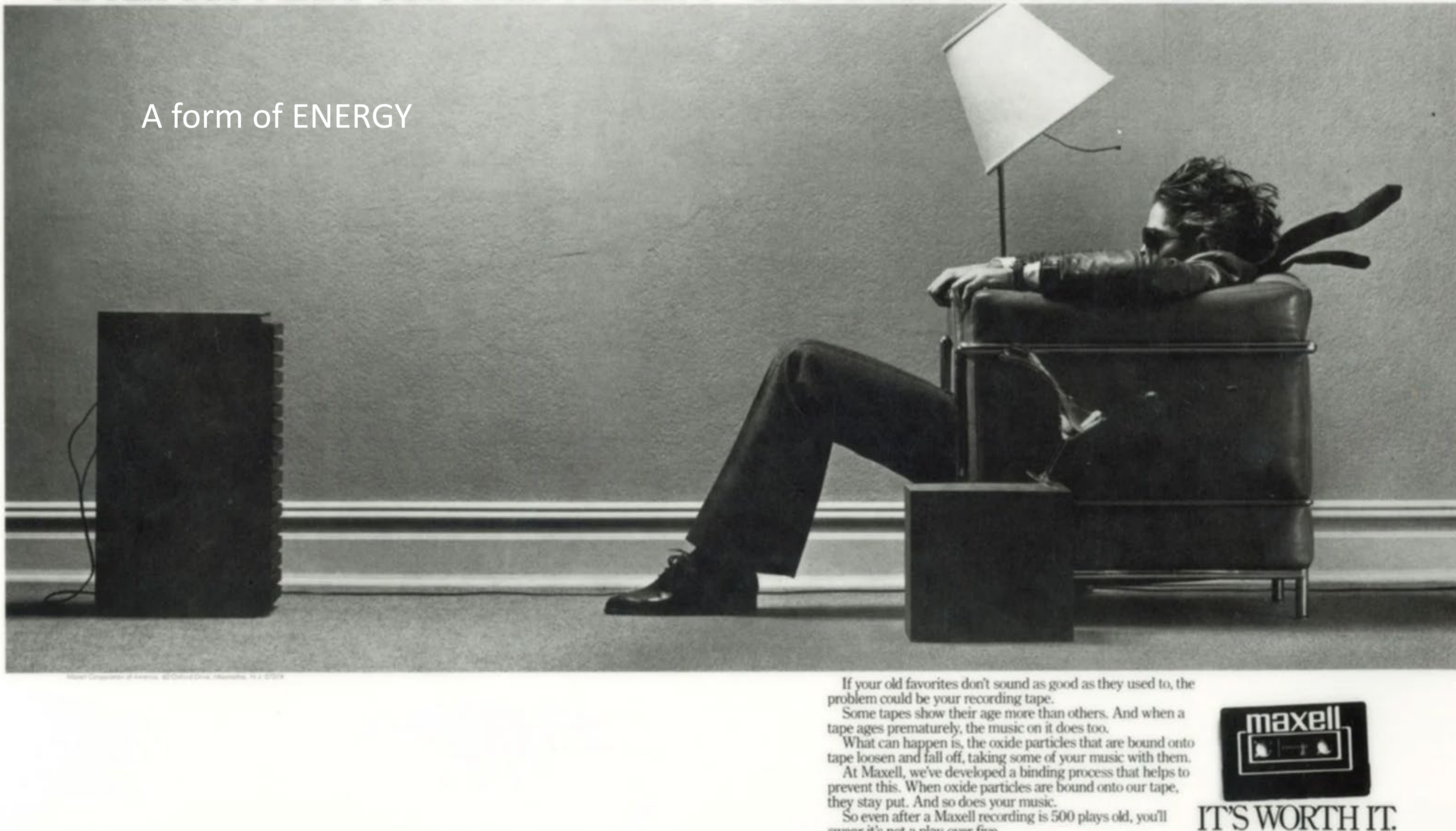
- ✓ Sound & Instrument Design
- ✓ Operator/Interpreter
- ✓ Patient/Physiology/Hemodynamics

The Rest of the Story
(Objectives)

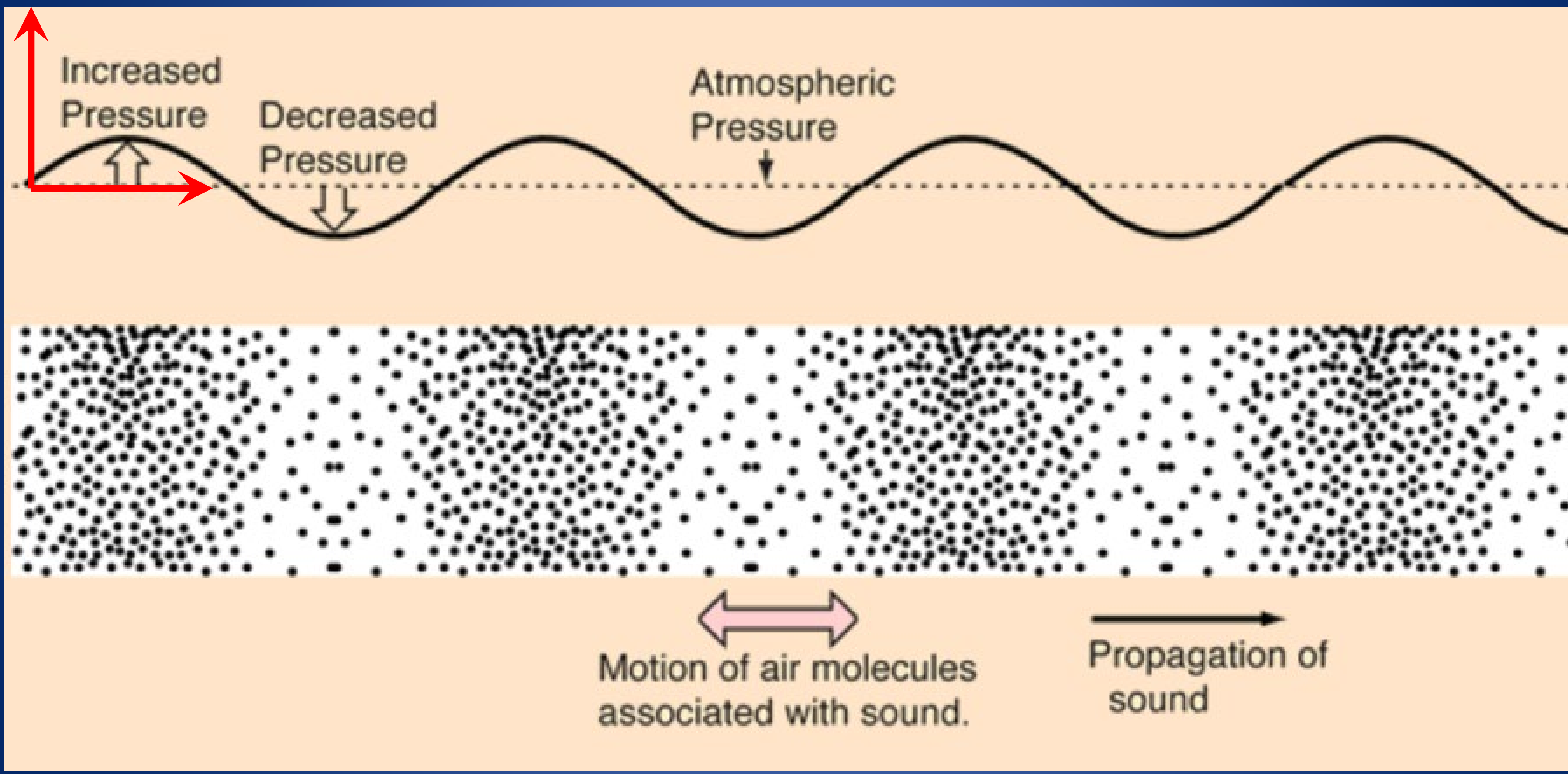
What you need to know:

- Parameters of sound (Quantification)
- Properties of sound (Behavior)
- The Doppler Effect
- Instrumentation
- Capabilities and limitations:
  - ✓ sound
  - ✓ Instrumentation

A form of ENERGY

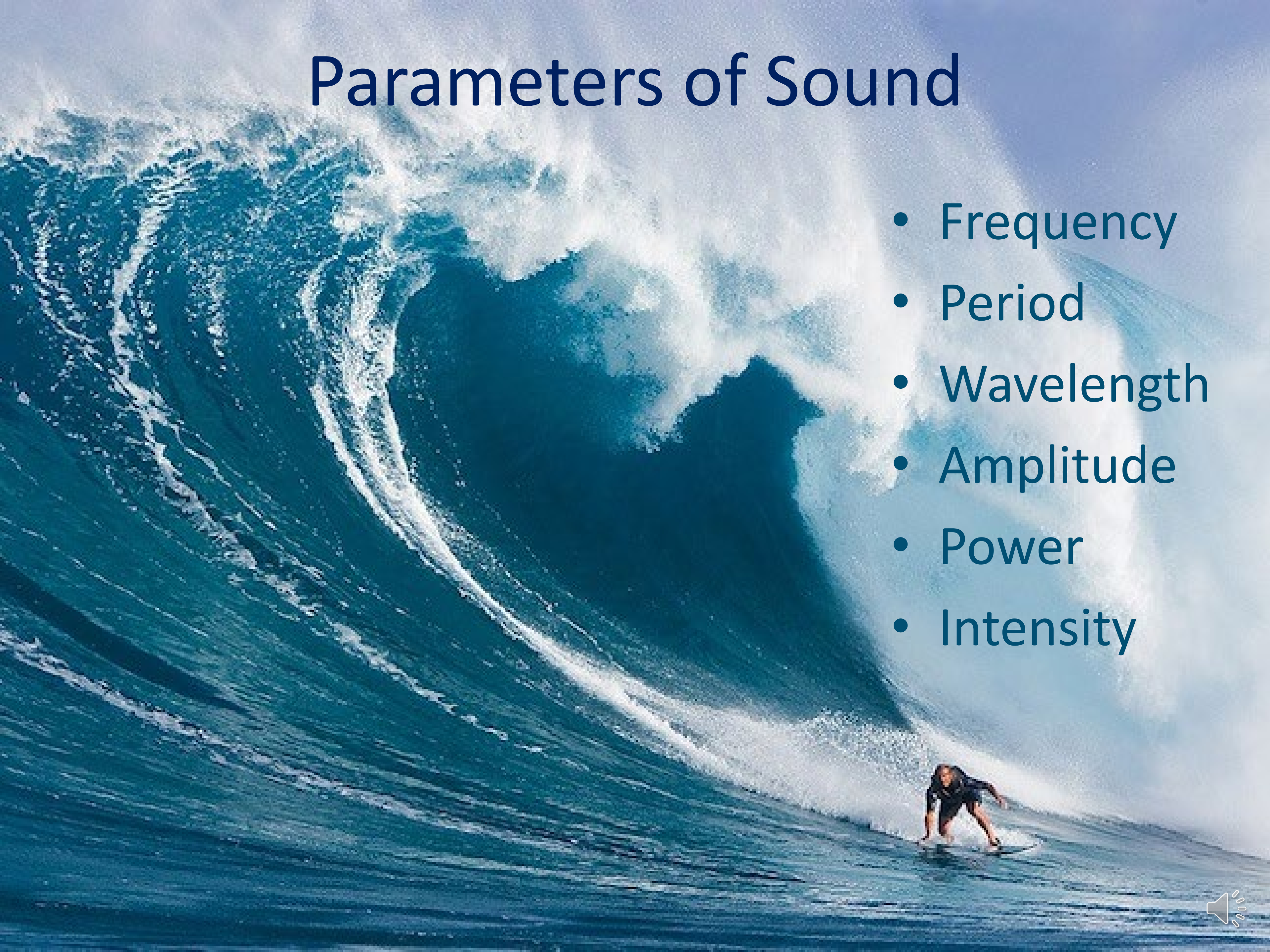


Wave-Particle Theory



http://hyperphysics.phy-astr.gsu.edu/hbase/Sound/tralon.html

Parameters of Sound

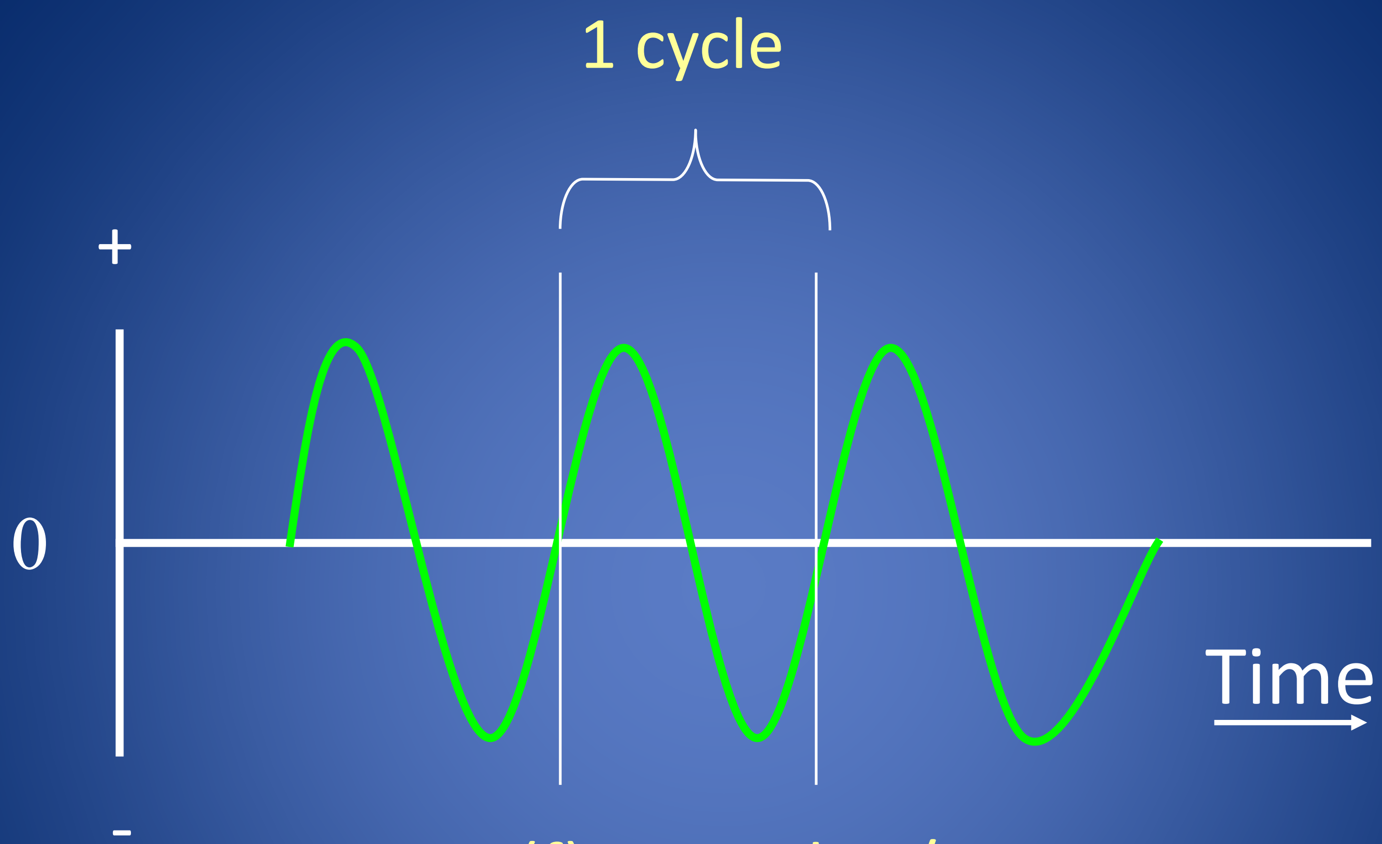


- Frequency
- Period
- Wavelength
- Amplitude
- Power
- Intensity

Parameters of Sound

- Frequency
- Period
- Wavelength
- Amplitude
- Power
- Intensity

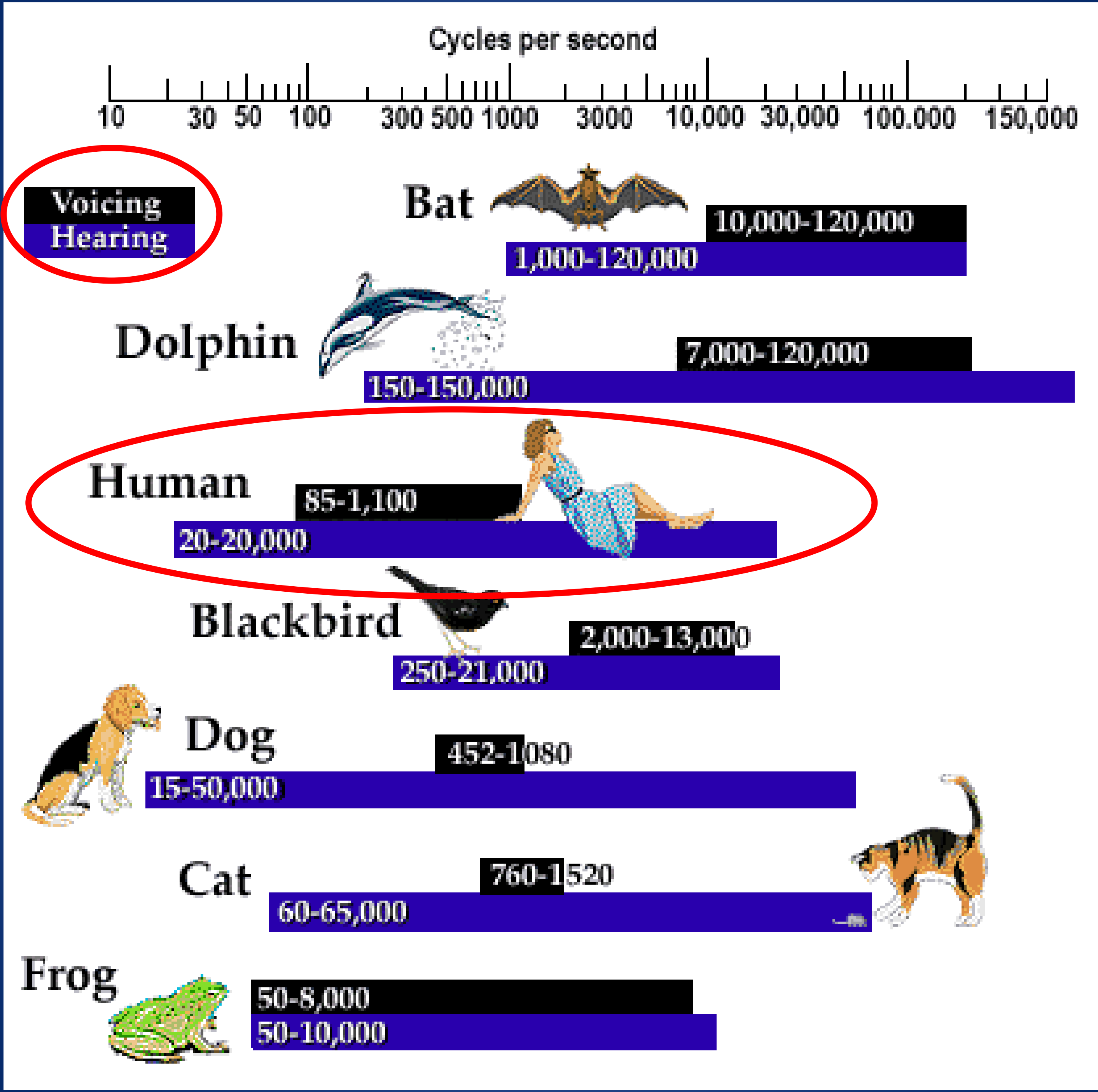
So…?



Frequency (f) = # cycles /unit time

Hertz (Hz) = 1 cycle /second

Megahertz (MHz) = 1,000,000 cycles/second

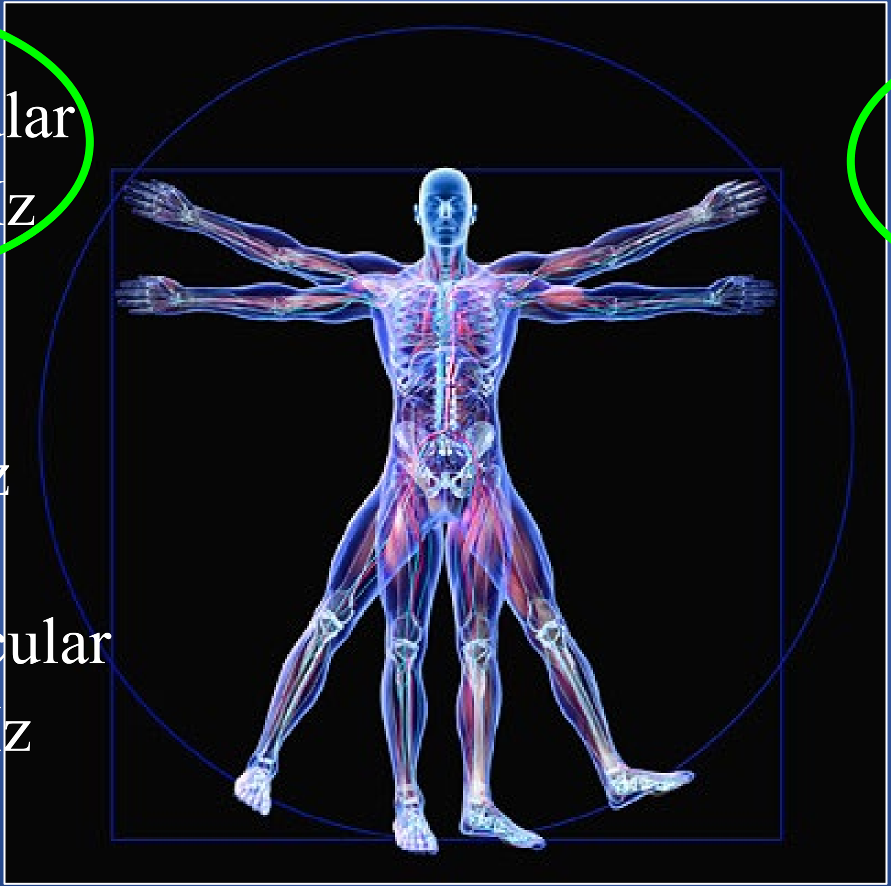

Cycles per second
10
30
50
100
300
500
1000
3000
10,000
30,000
100.000
150,000
Voicing
Hearing
Bat
10,000-120,000
1,000-120,000
Dolphin
7,000-120,000
150-150,000
Human
85-1,100
20-20,000
Blackbird
2,000-13,000
250-21,000
Dog
452-1080
15-50,000
Cat
760-1520
60-65,000
Frog
50-8,000
50-10,000

Typical frequencies used in US

Cerebrovascular
5.0-15.0MHz

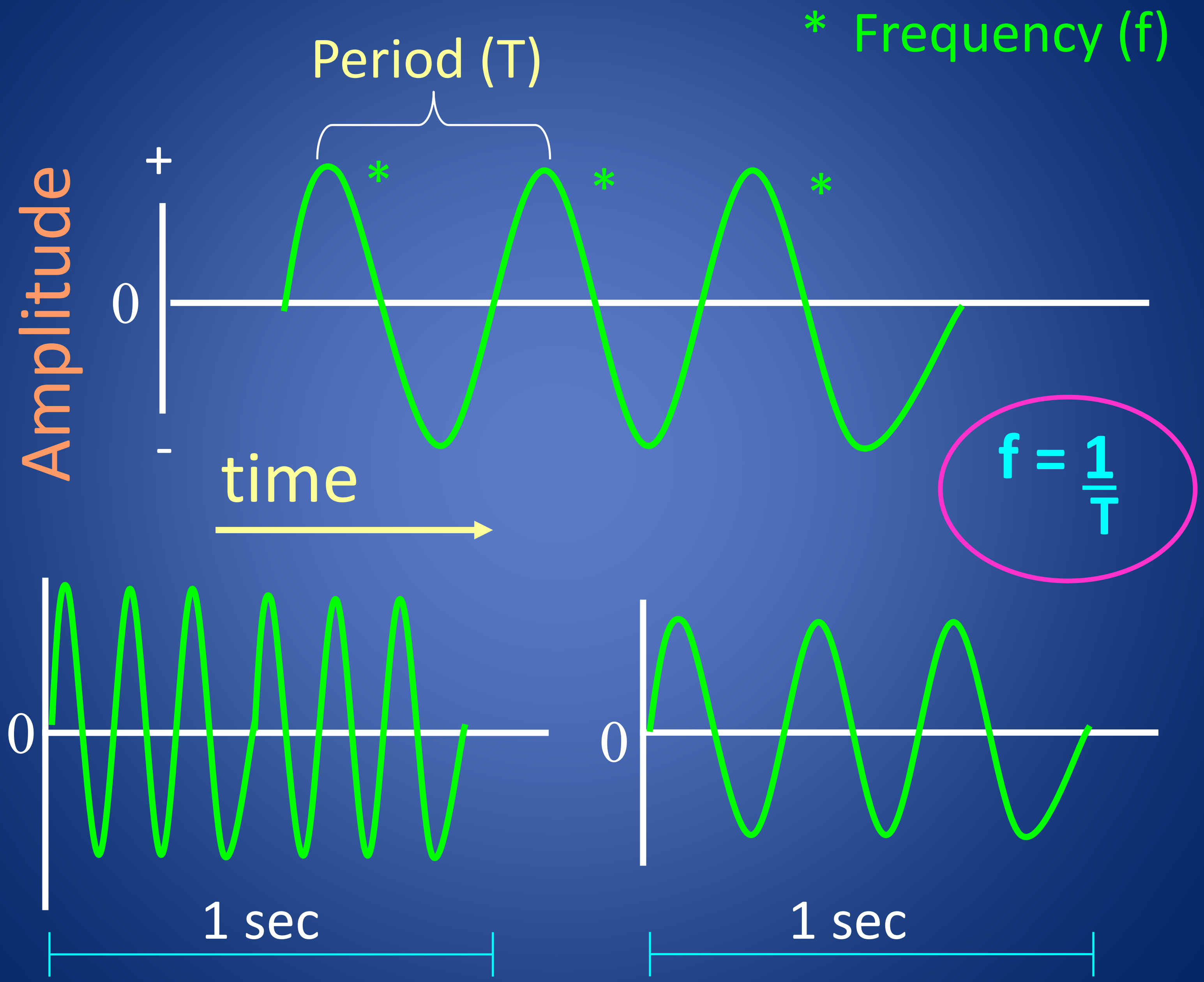
Abdominal
2.0-5.0MHz

Peripheral Vascular
3.0-15.0MHz

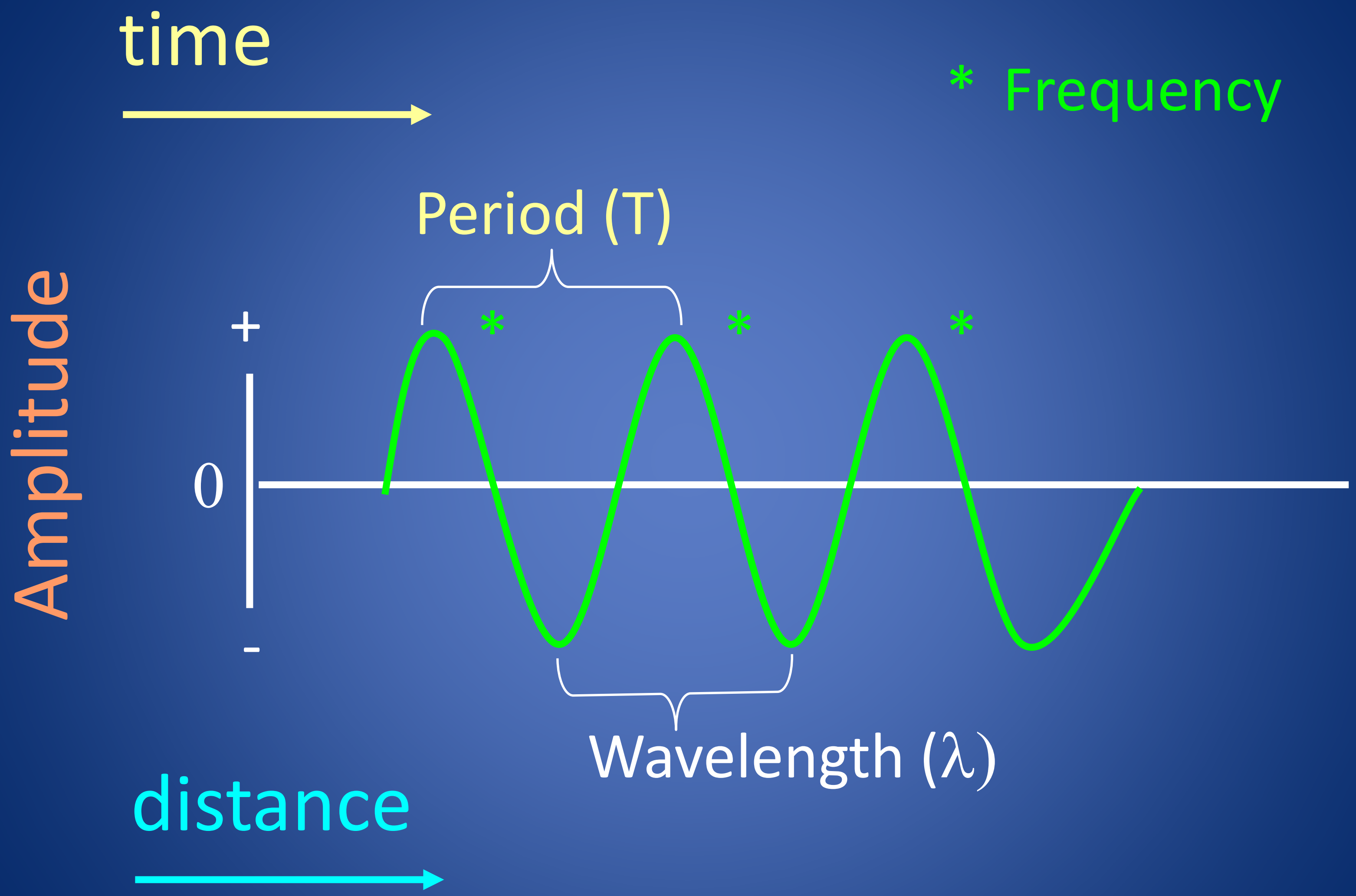


Transcranial
1.0-2.5MHz

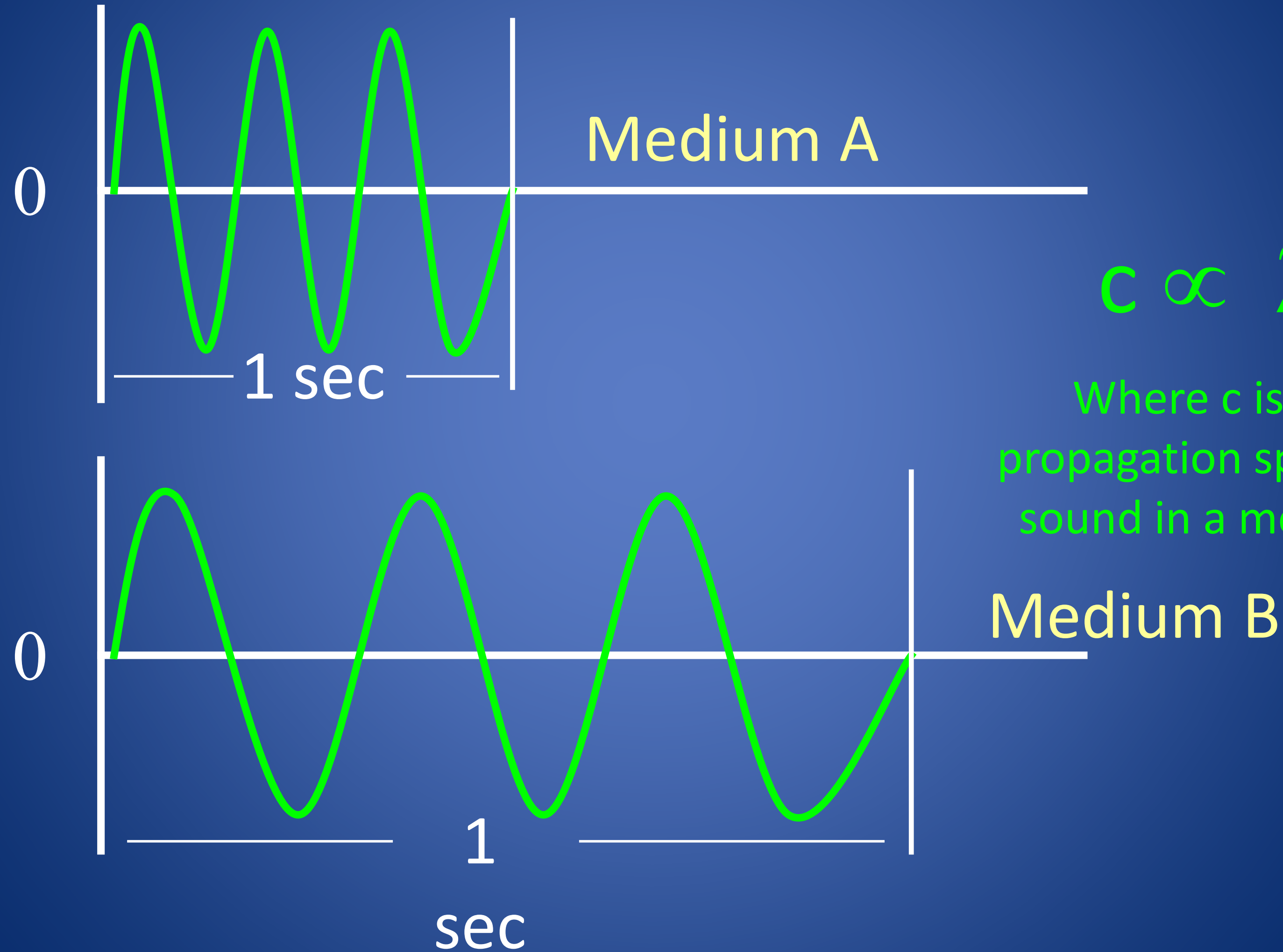
Cardiac
1.5-5.0MHz



* Frequency (f)
Period (T)
Amplitude
+
0
-
time
f = 1/T
0
1 sec
0
1 sec


time
* Frequency
Period (T)
Amplitude
+
0
-
*
*
*
Wavelength (λ)
distance

Same f, same λ, different medium



$c \propto \lambda$

Where c is the propagation speed of sound in a medium

Speed of Sound
"c"

Medium	m/sec
air	331
fat	1450
soft tissue	1540
blood	1570
muscle	1585
bone	4080
water	1482
steel	5960

Parameters of Sound

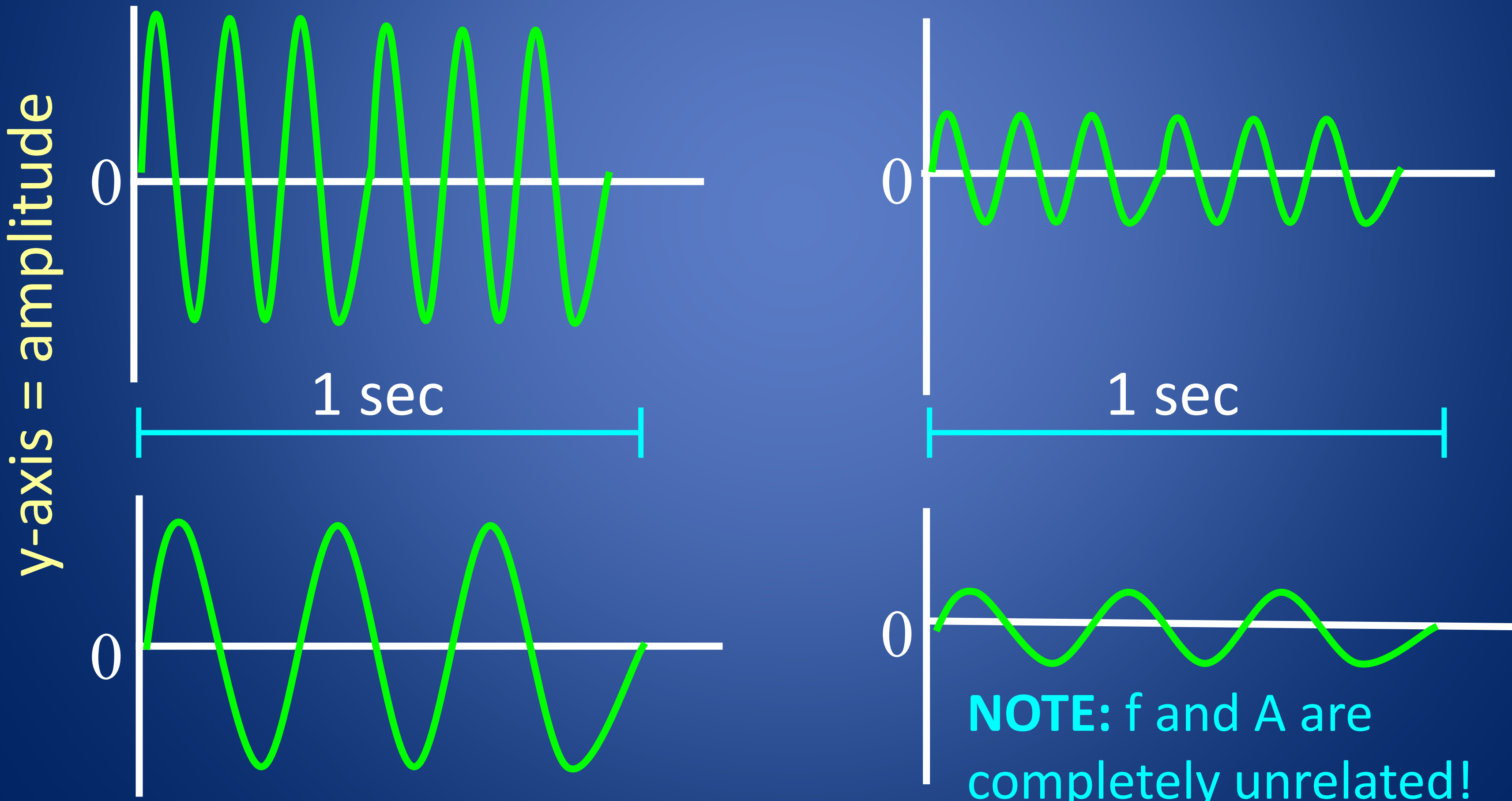
- Frequency
- Period
- Wavelength
- Amplitude
- Power
- Intensity

So…?

✓ Attenuation
✓ Artifacts & Resolution
✓ Acoustic Variables

Amplitude

The maximum variation from an undisturbed value or baseline (“gain” or volume)



NOTE: f and A are completely unrelated!

Power

The amount of energy transported per second by a sound wave; the ability to do work over time (units = joules/sec or Watts)

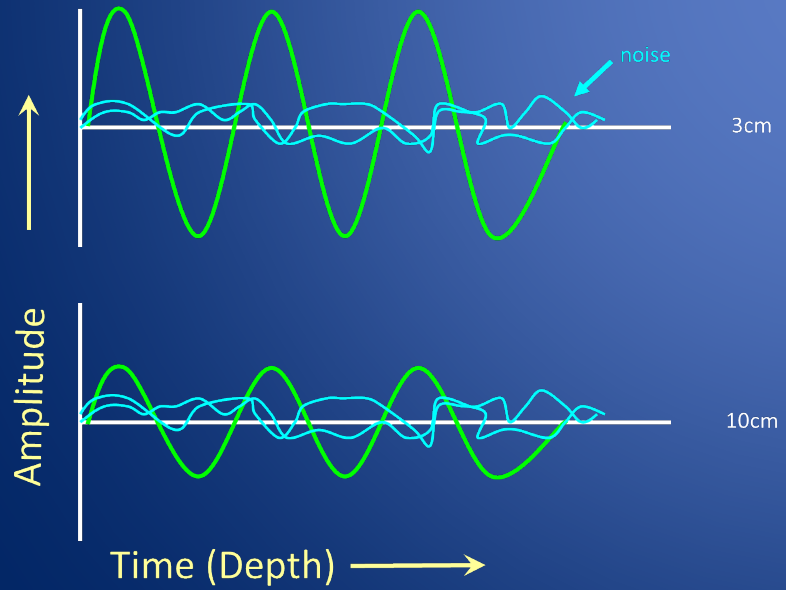
$$P \propto A^2$$

Parameters of Sound

- Frequency
- Period
- Wavelength
- Amplitude
- Power
- Intensity

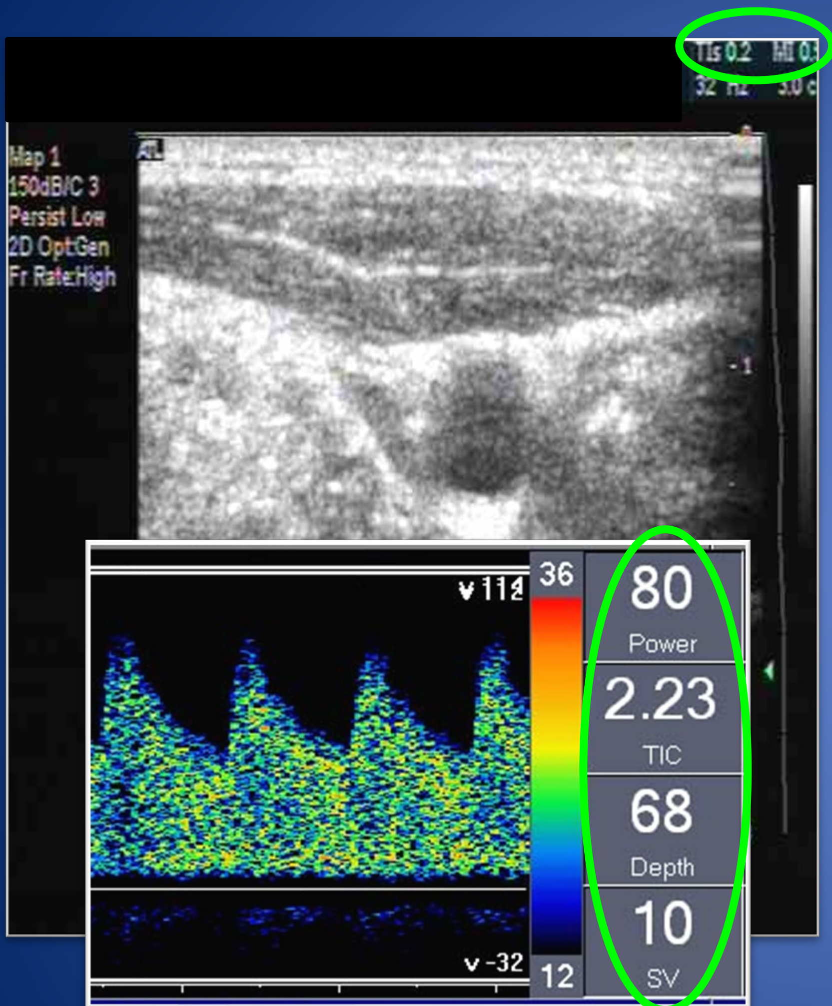
So…?
This should this affect how you scan!

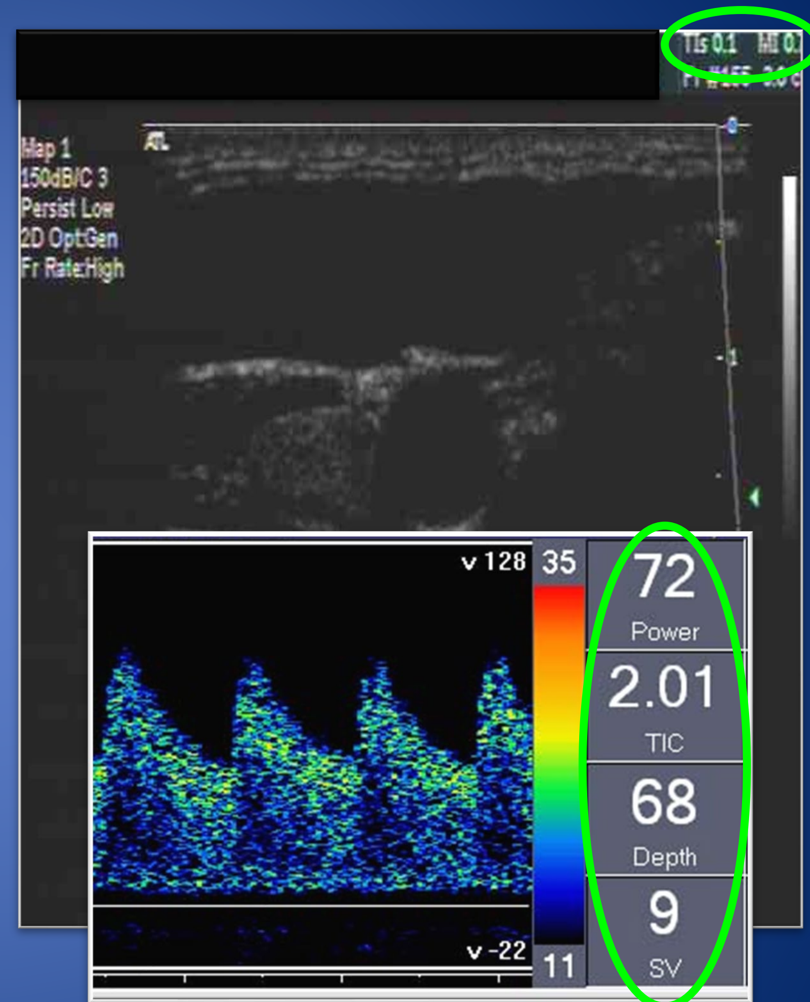
How to use your Power



- The signal to noise ratio decreases as depth increases
- Increasing Power typically improves the signal to noise ratio
- Increasing Power increases the energy sent into the body
- Increasing the Gain, amplifies signals *returning* from the body
- Do not confuse Power with Receiver Gain! (Know your knobs)

About Power and Gain…

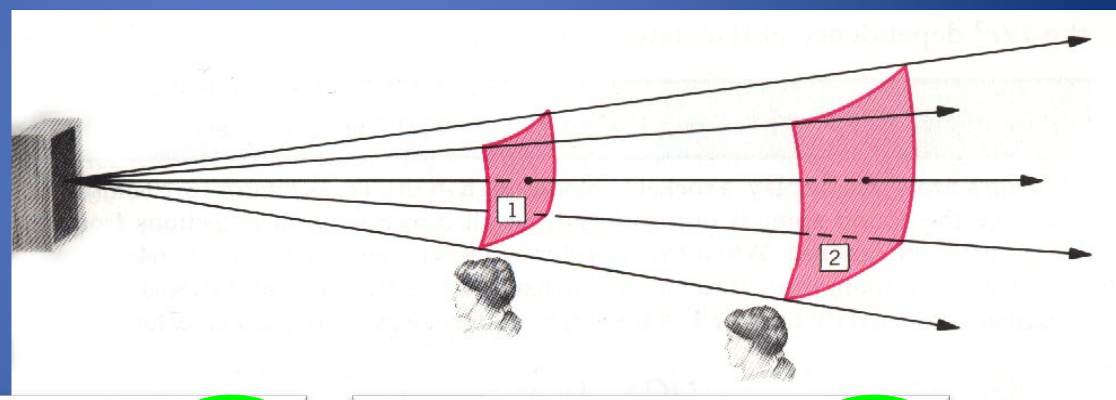


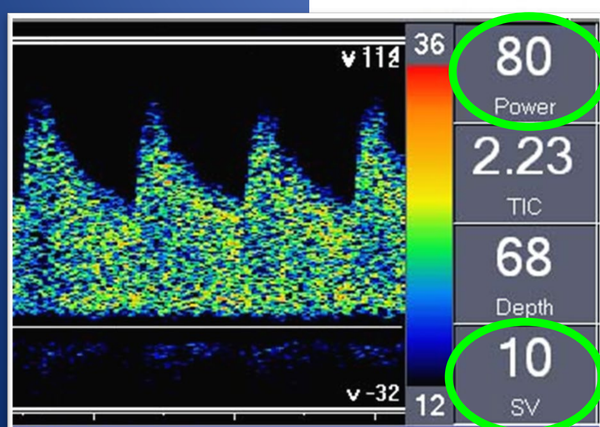


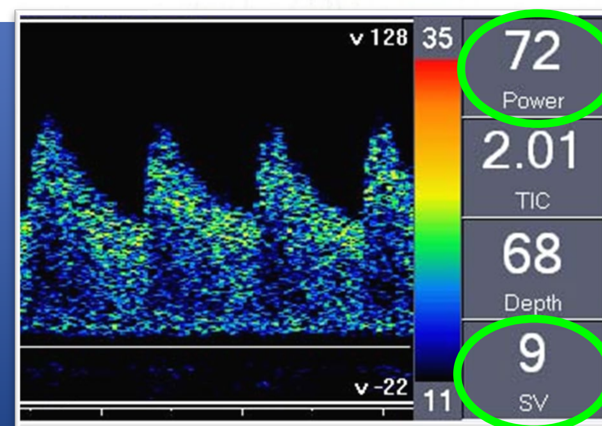
Increasing Power or Gain will both visually brighten an image. Increasing Power, increases intensity whereas increasing Gain does not. Thermal Index (TI) and Mechanical Index (MI) correlate to Power output and relative risk of bioeffects.

Intensity

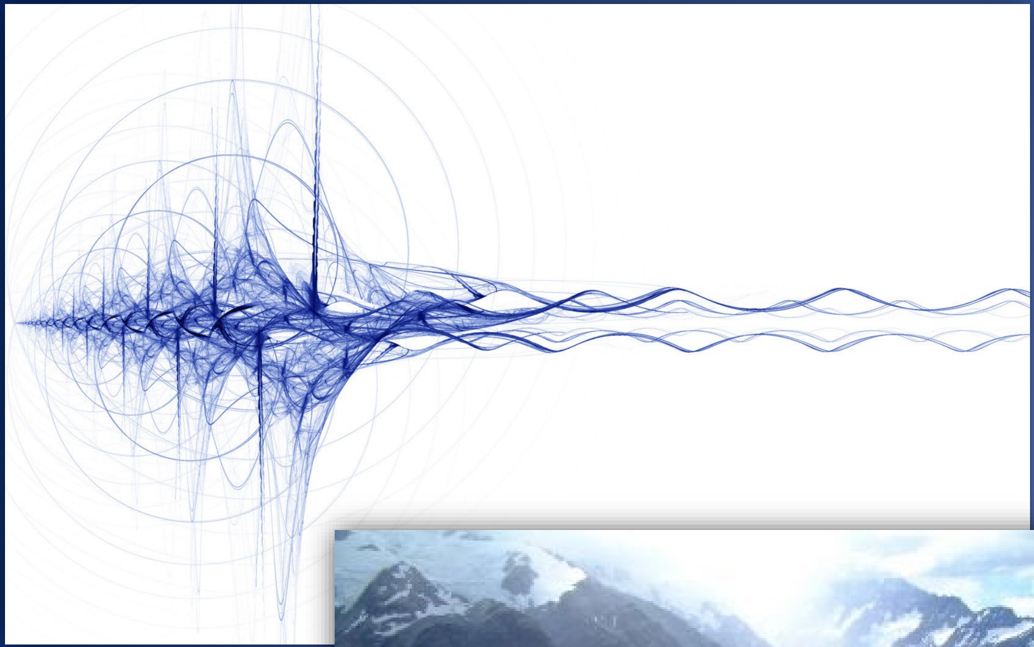
- ✓ equal to power/beam area
- ✓ focusing decreases area and increases intensity







Properties of Sound



Attenuation:

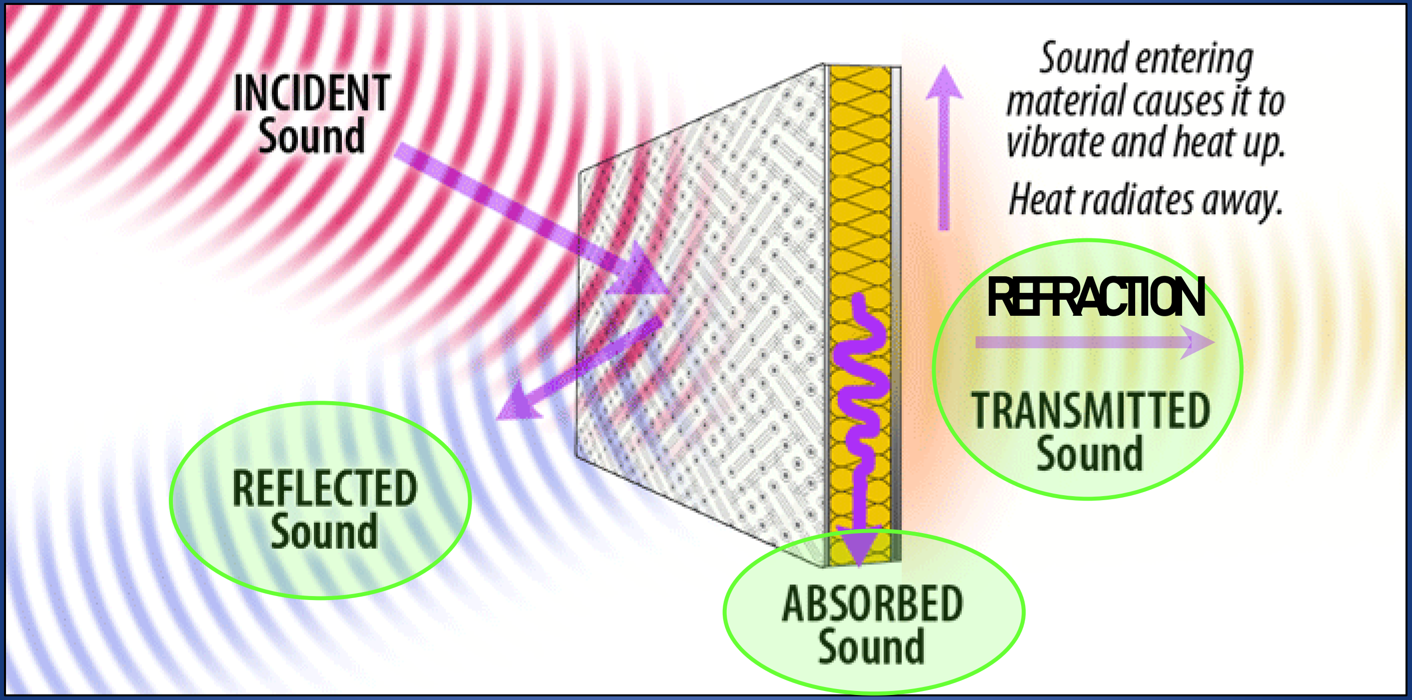
amplitude decreases with propagation

Acoustic Variables:

qualities that vary within a sound wave

Attenuation

amplitude decreases with propagation



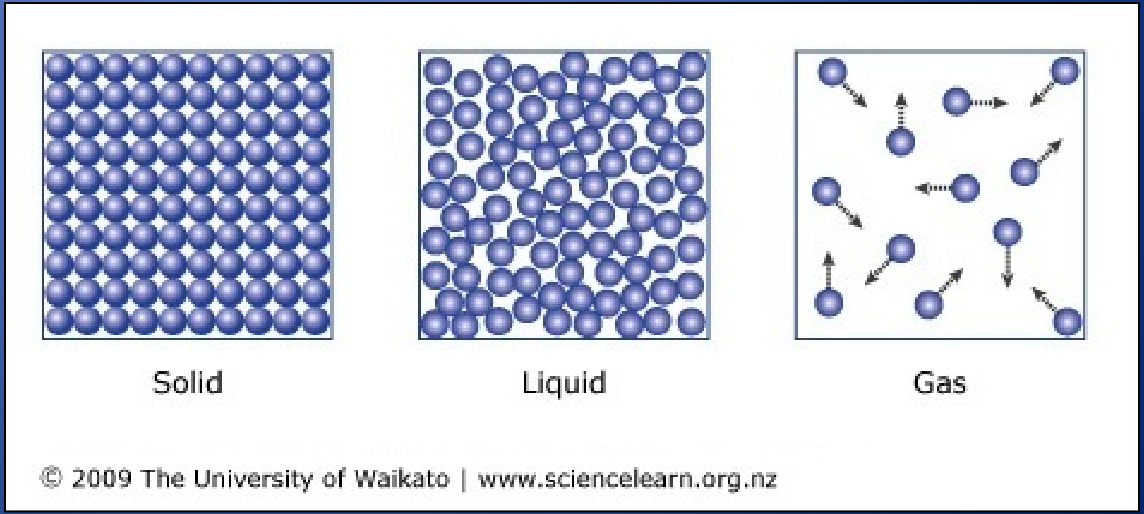
http://www.acousticsciences.com/solutions/absorption

Properties of Sound

↕ & ↕

Properties of a Medium

$$\lambda = \frac{c}{f}$$

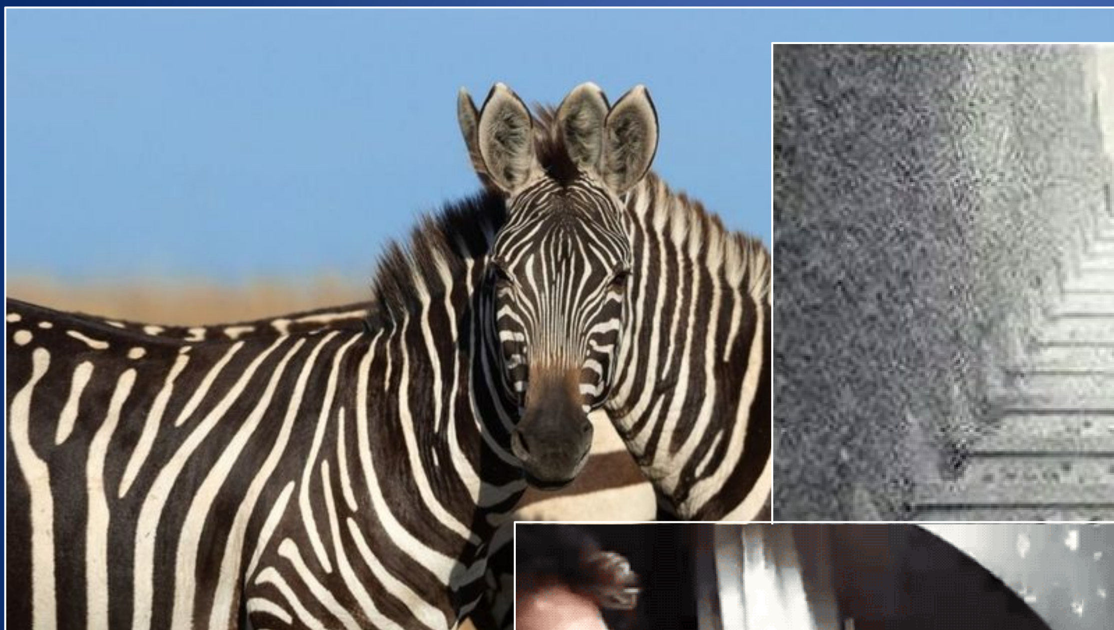


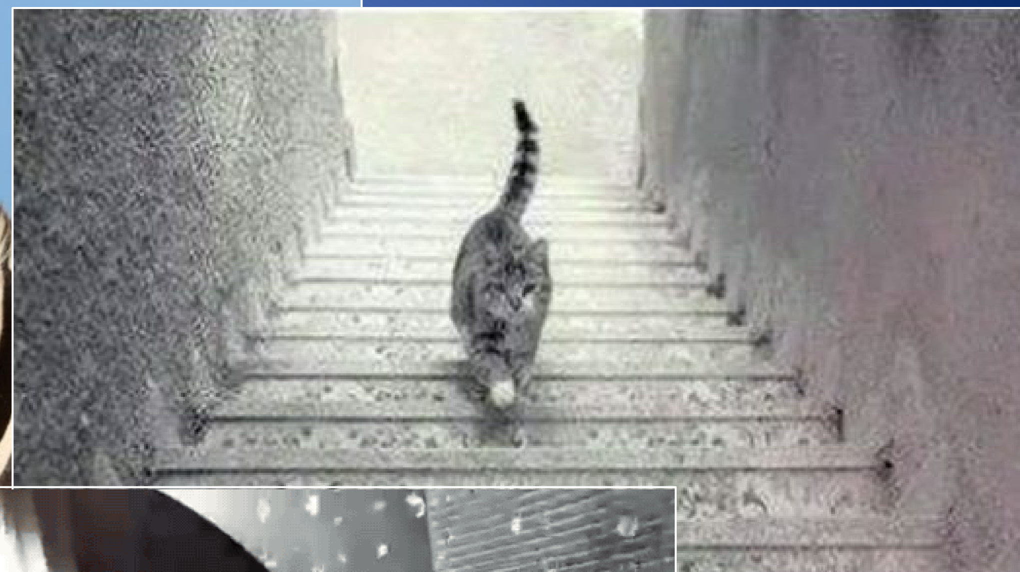
Acoustic Variables

- **Pressure:** particle motion; feel a "beat" of sound
- **Density:** mass/volume
- **Temperature:** friction; heat energy as wave propagates
- **Particle motion:** distance travelled

✓ Consider focal and global factors: different tissues, hct, temperature, other pharmacological effects, etc.

When Seeing is Believing





Artifacts

- Anything not properly indicative of structures evaluated
- Imaging Artifacts: Attenuation (Brightness) & Propagation (Location)
- Doppler Artifacts (Spectral & Color): Location, Direction, Timing/Speed

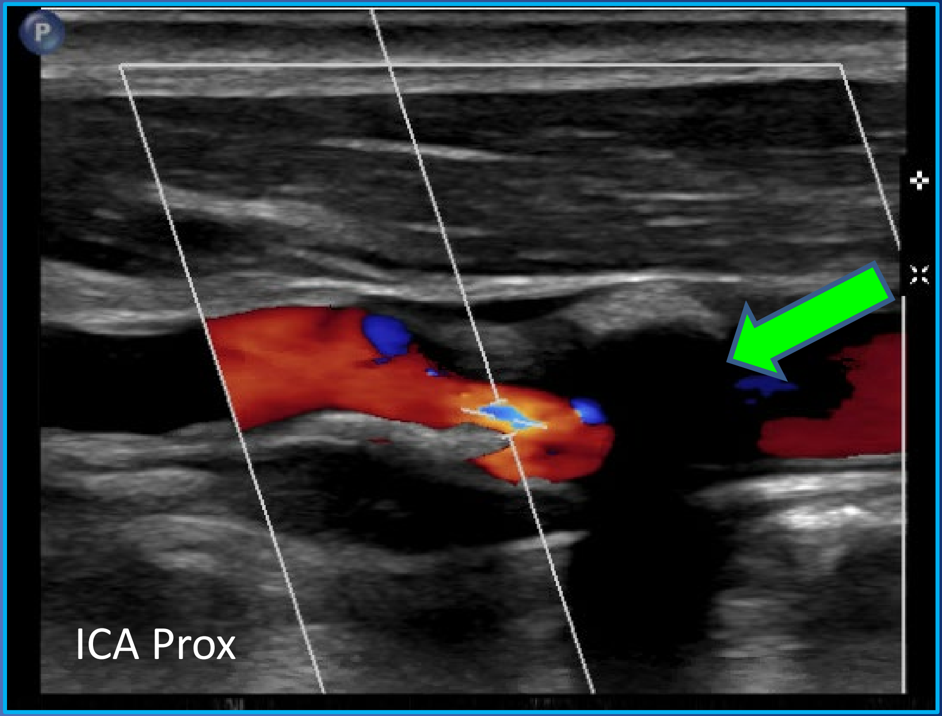
Why artifacts occur

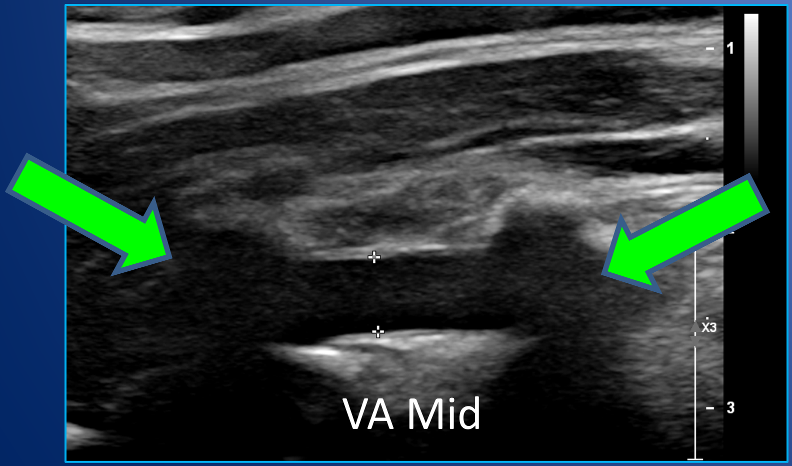
Assumptions:

1. Sound only travels in a straight line
2. Echoes only originate from objects in the beam pathway
3. Amplitude of echoes only represents reflectiving properties of objects along the axis
4. Distance (depth) to an object is proportional to the RT time of 13µs/cm (speed of sound in soft tissue)

Shadowing

- Weakening of echoes distal to a strongly attenuating or reflecting structure or from the edges of a refracting structure (“edge shadowing”)

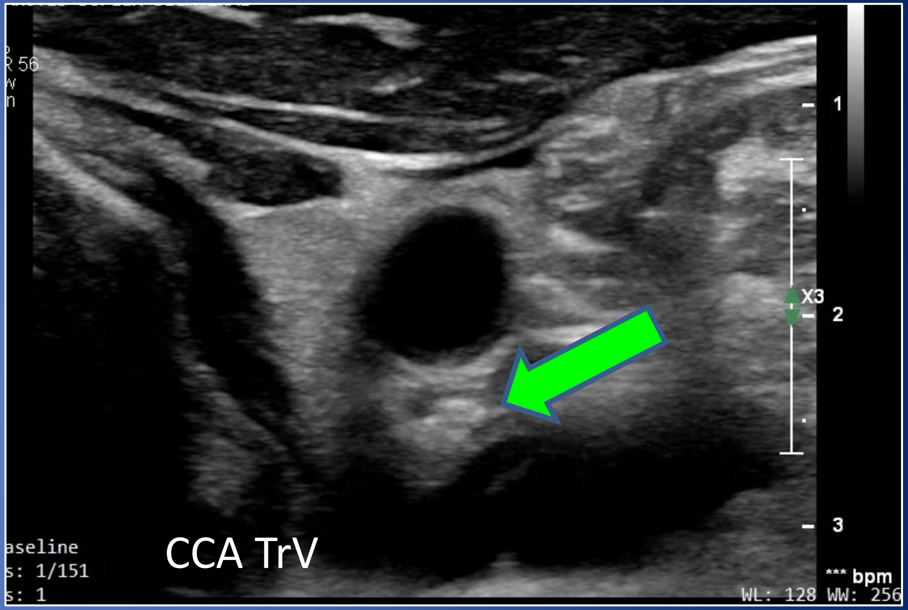




Solution: use spatial compounding and other speckle reduction techniques; use different approaches

Enhancement

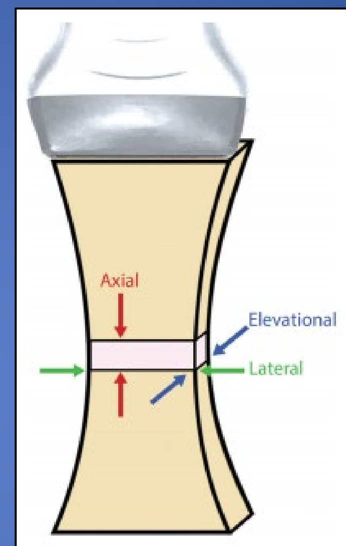
- Strengthening of echoes distal to a weakly attenuating structure
- Increased brightness behind a weakly attenuating structure
- Often a useful artifact
- “Focal Enhancement” – increased enhancement at the focus; solution: spatial compounding

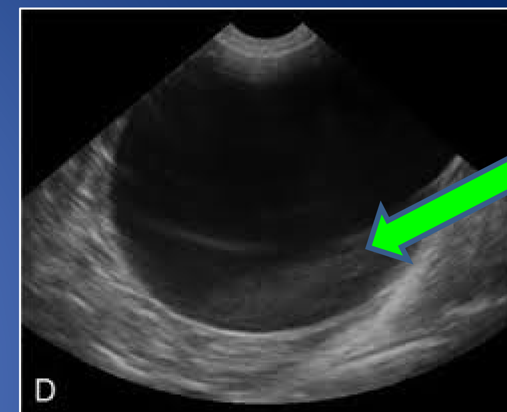


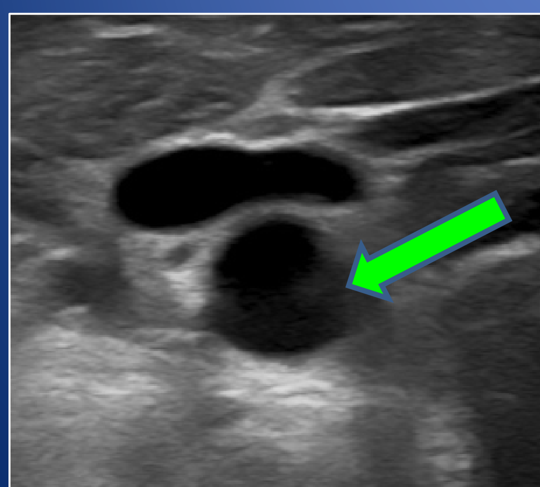
Solution: use different approaches; know posterior wall appears thicker/brighter

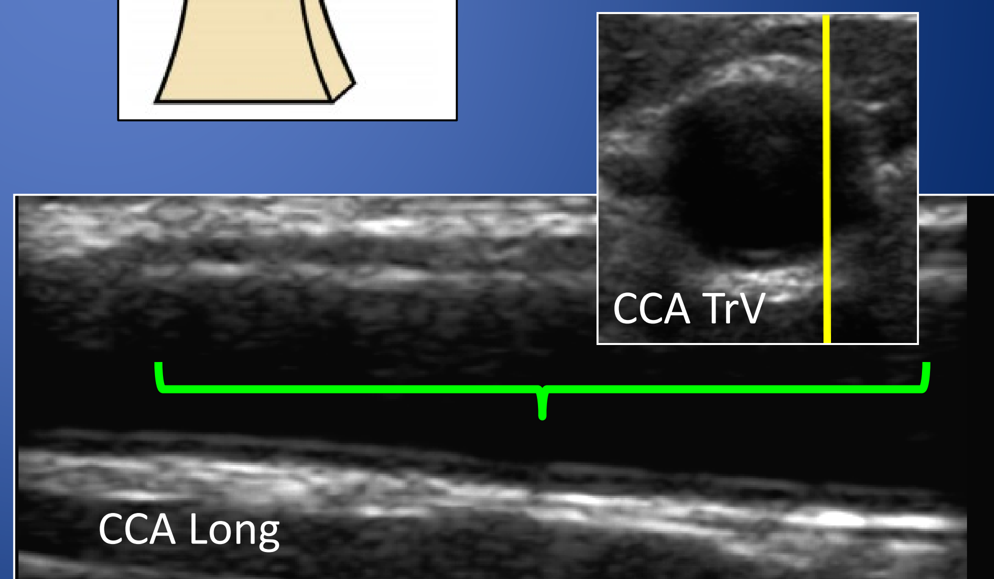
Slice Thickness

- Third dimension
- Beam width perpendicular to the scan plane
- Solution: possible to resolve by using tissue harmonic imaging



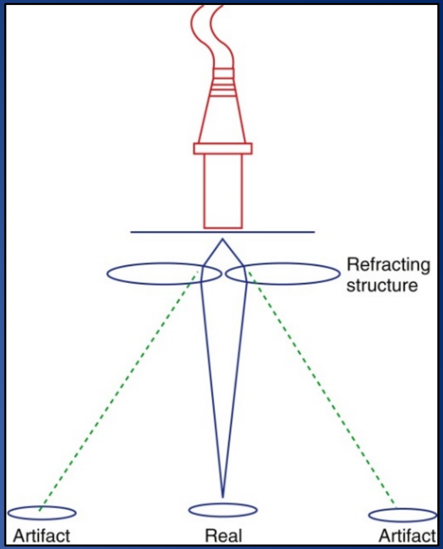


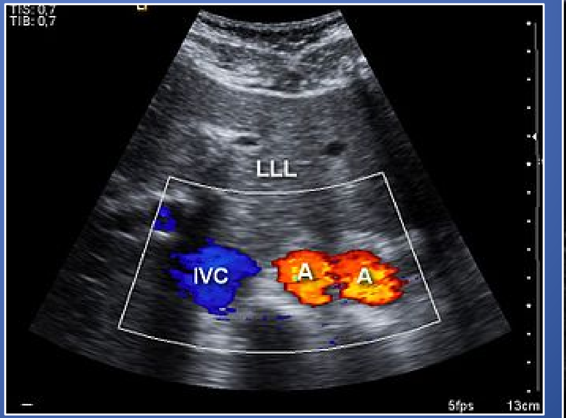


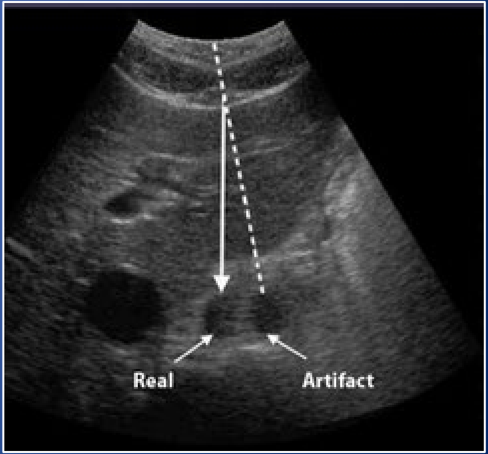


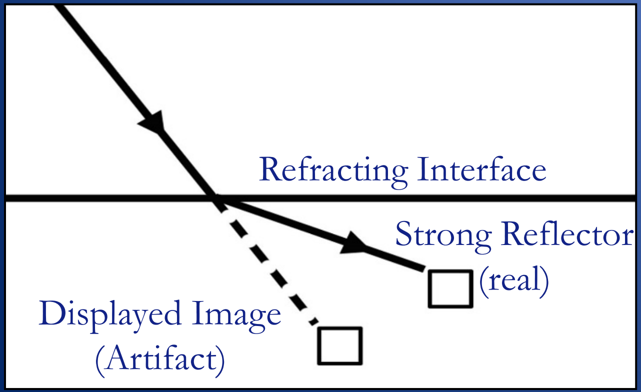
Refraction

- Change of direction of the sound beam from one medium to the next
- Displaces (and sometimes duplicates) structures laterally from their correct locations
- Solution: change approach or vary angle across a wider area



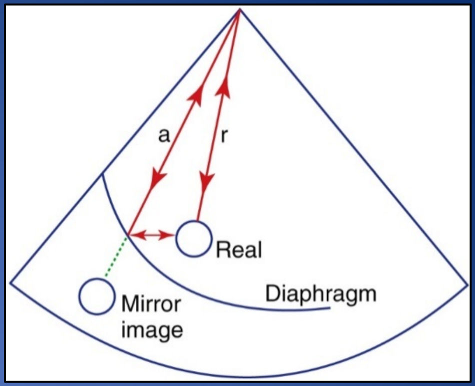


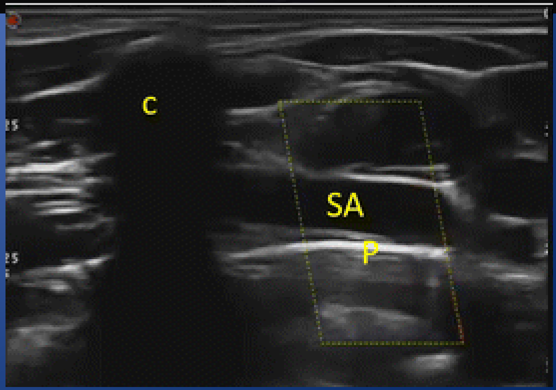




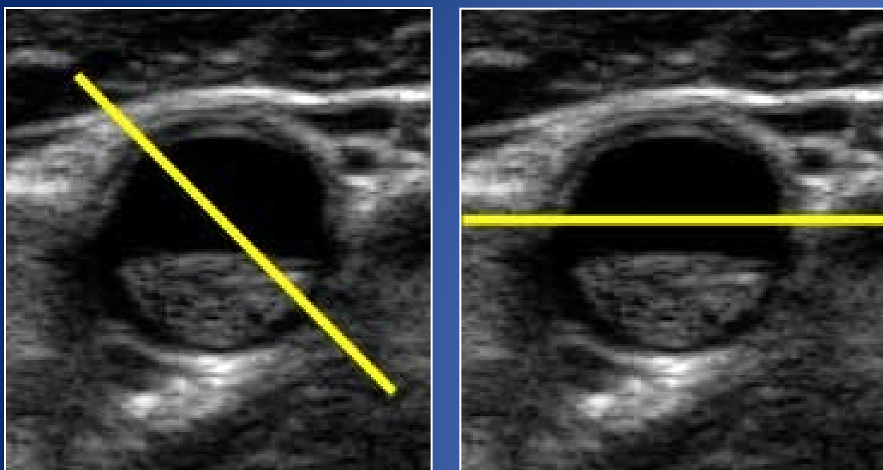
Mirror Image

- Duplication of a structure on the opposite side of a strong reflector
- Form of reverberation
- Common around the pleura and diaphragm
- Solution:
  - ✓ change angle/window
  - ✓ adjust focal zone or TGC to reduce high reflectivity of strong reflector

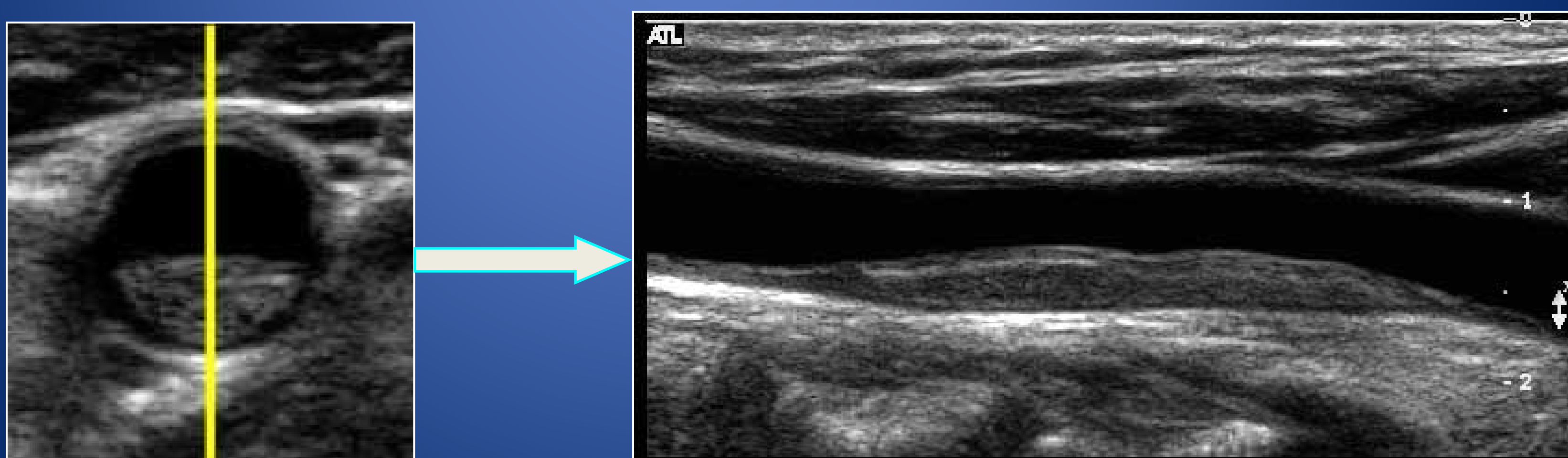




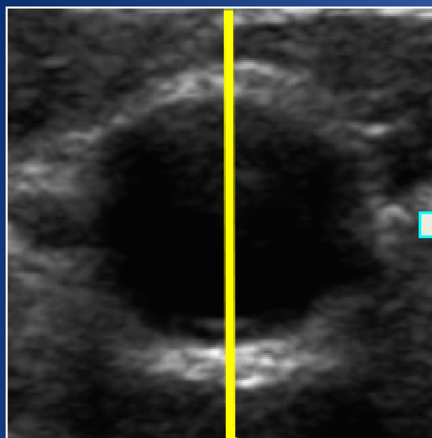
2D (B-mode) Imaging Angle Effects

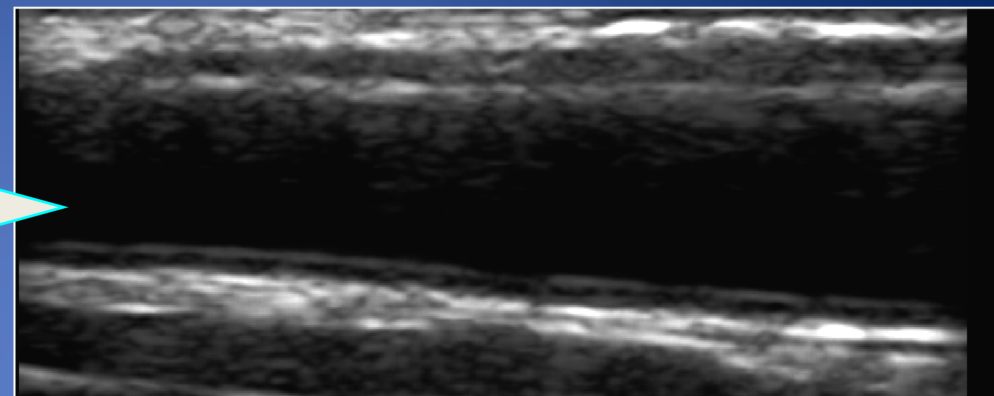


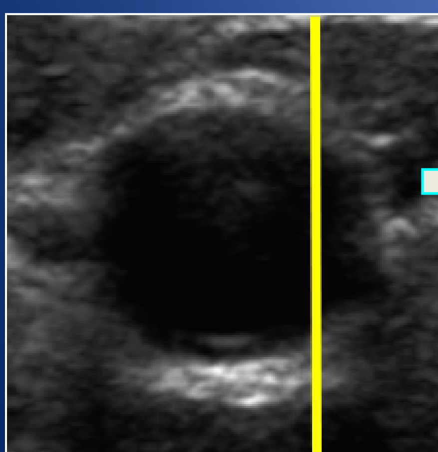
- Diameter reduction dependent on scan plane

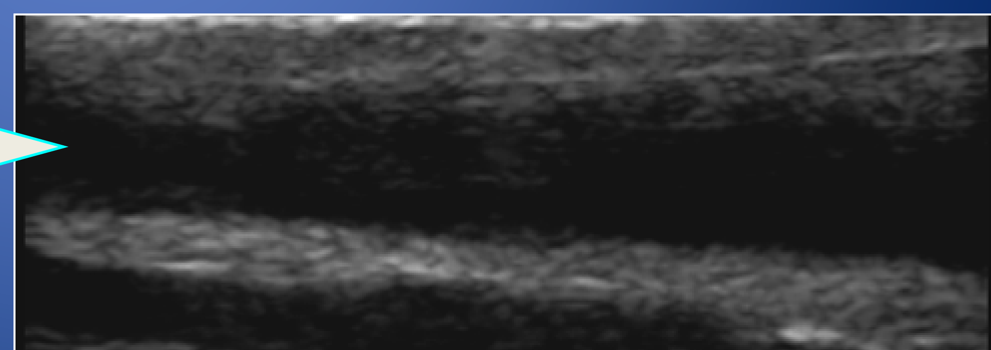


Normal Vessel







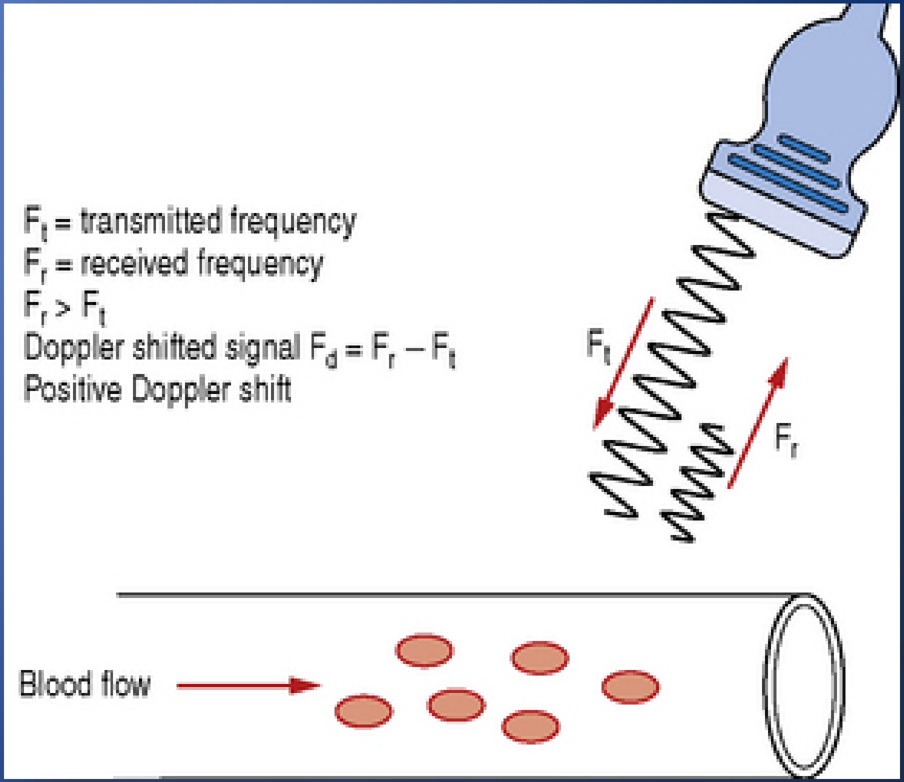


Off Axis Plane

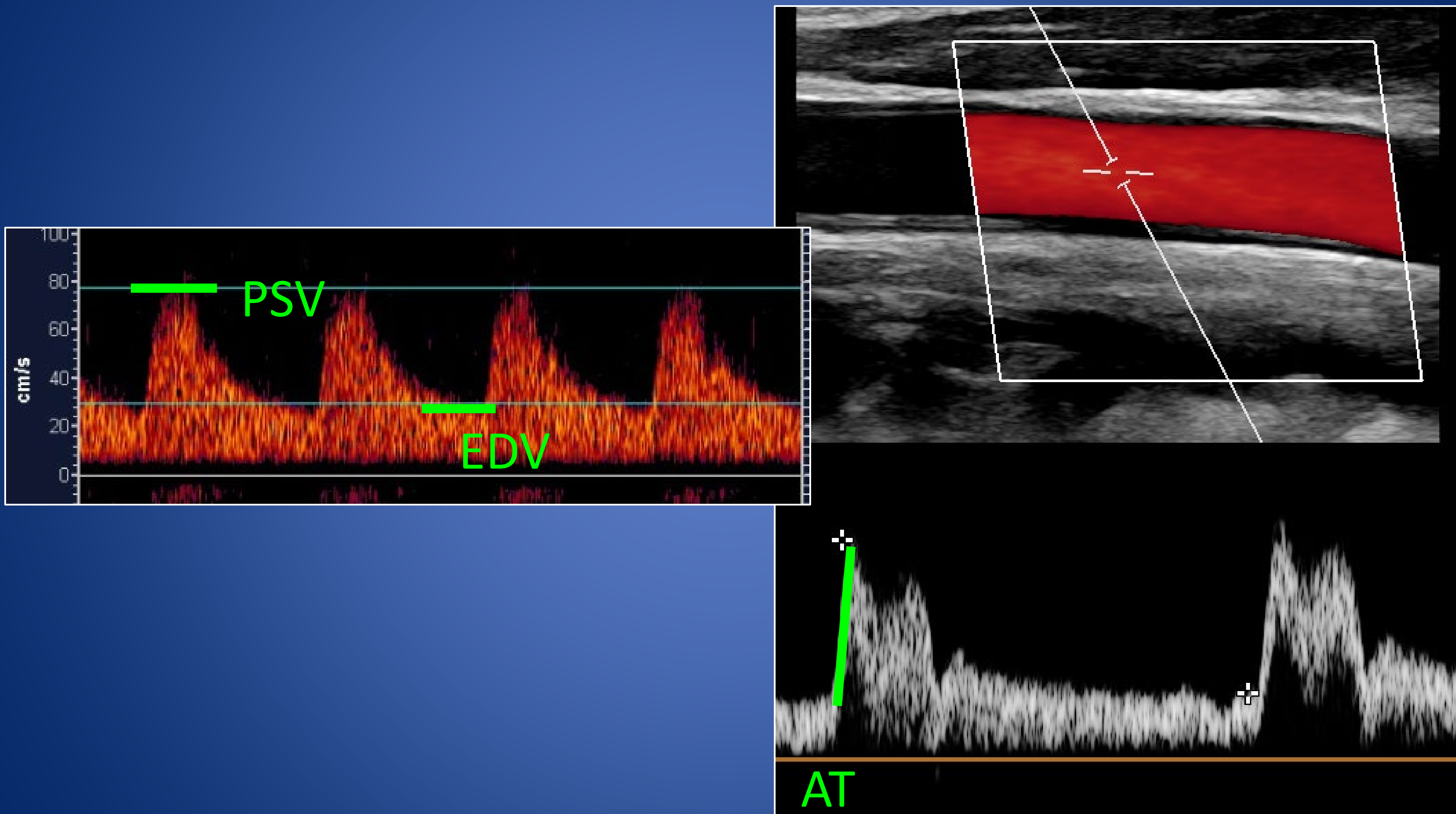
The Doppler Effect

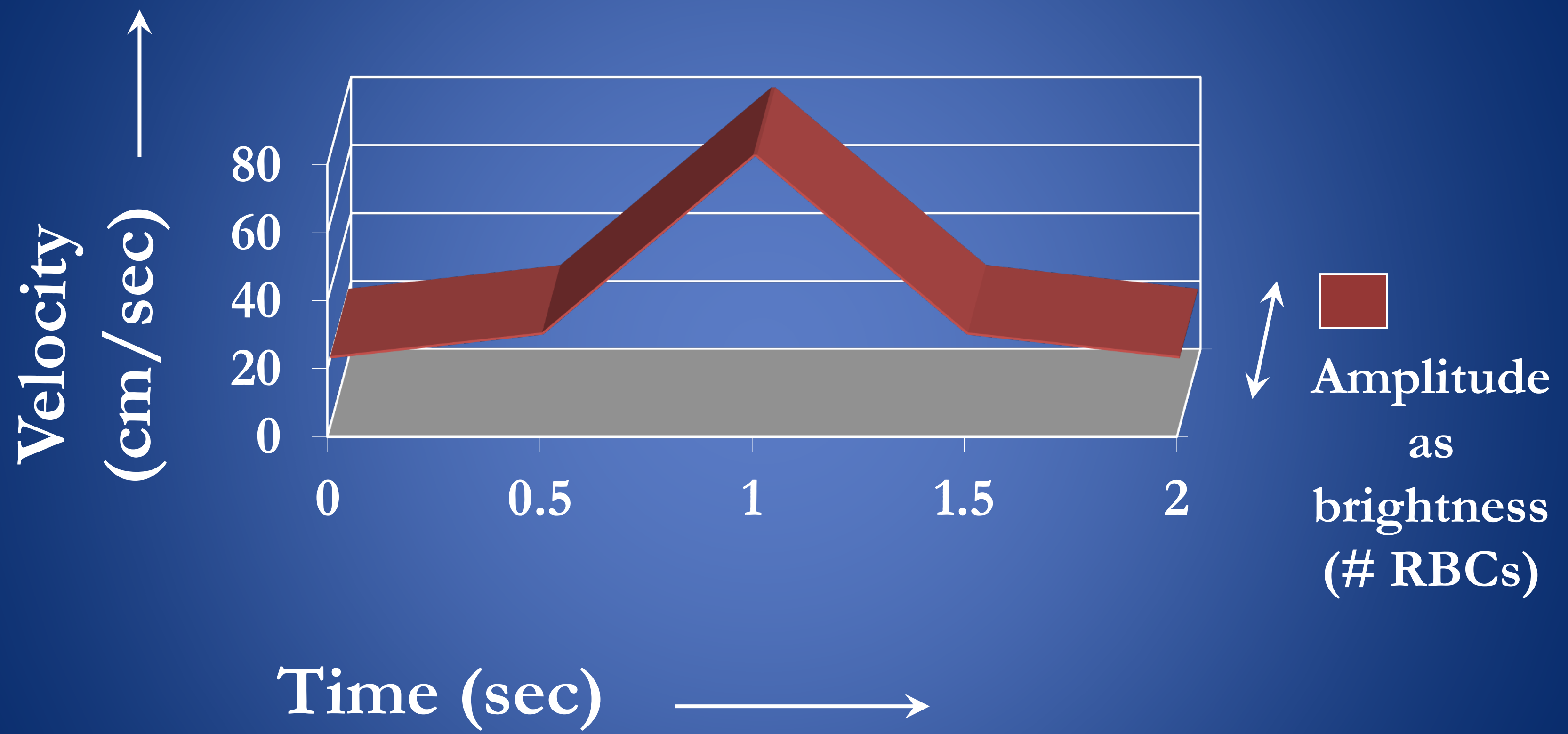
- The change in the frequency of sound due to motion of the source of the sound or the observer (or both)

$$\Delta f = \frac{2f_t v\cos\theta}{c}$$



Quantifying Data: Spectral Analysis





Velocity (cm/sec)
80
60
40
20
0
0
0.5
1
1.5
2
Amplitude as brightness (# RBCs)
Time (sec)

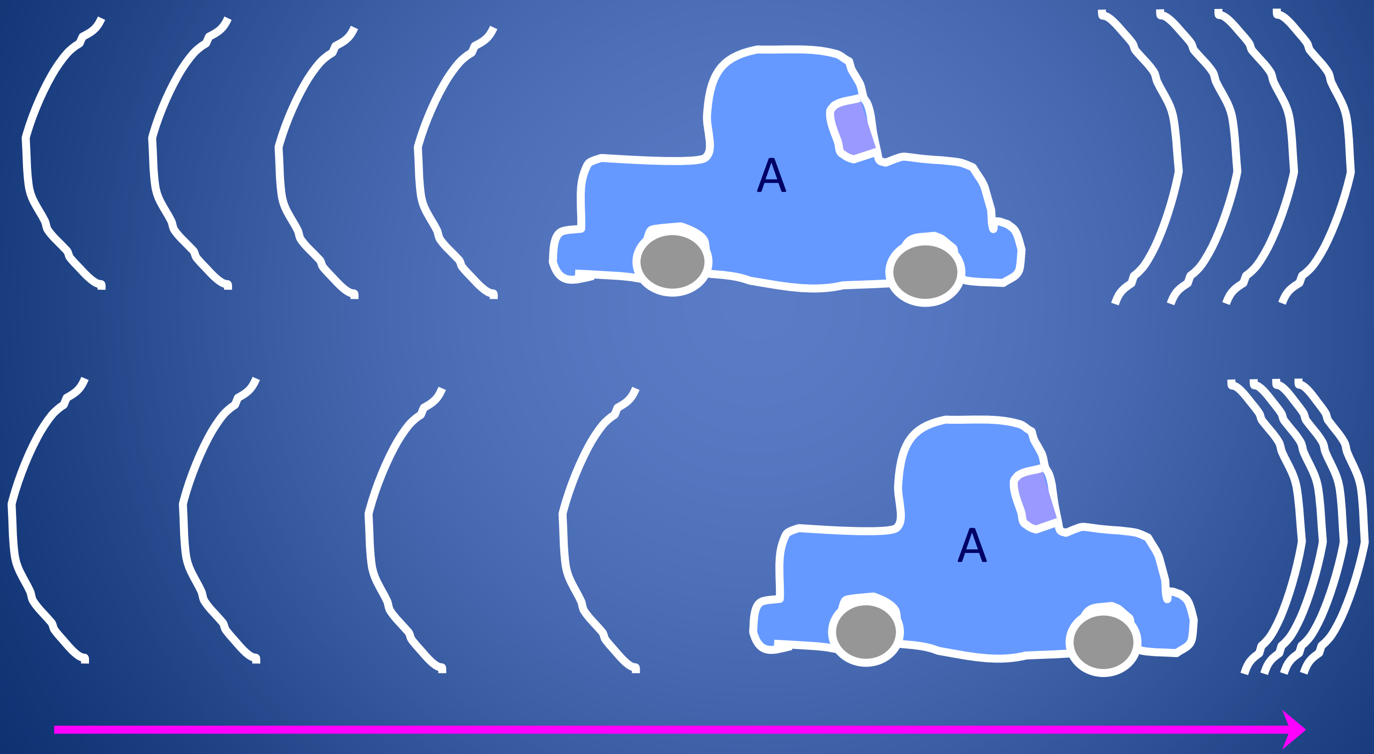
The Doppler Shift

$$\Delta f = \frac{2 f_t v \cos\theta}{c}$$

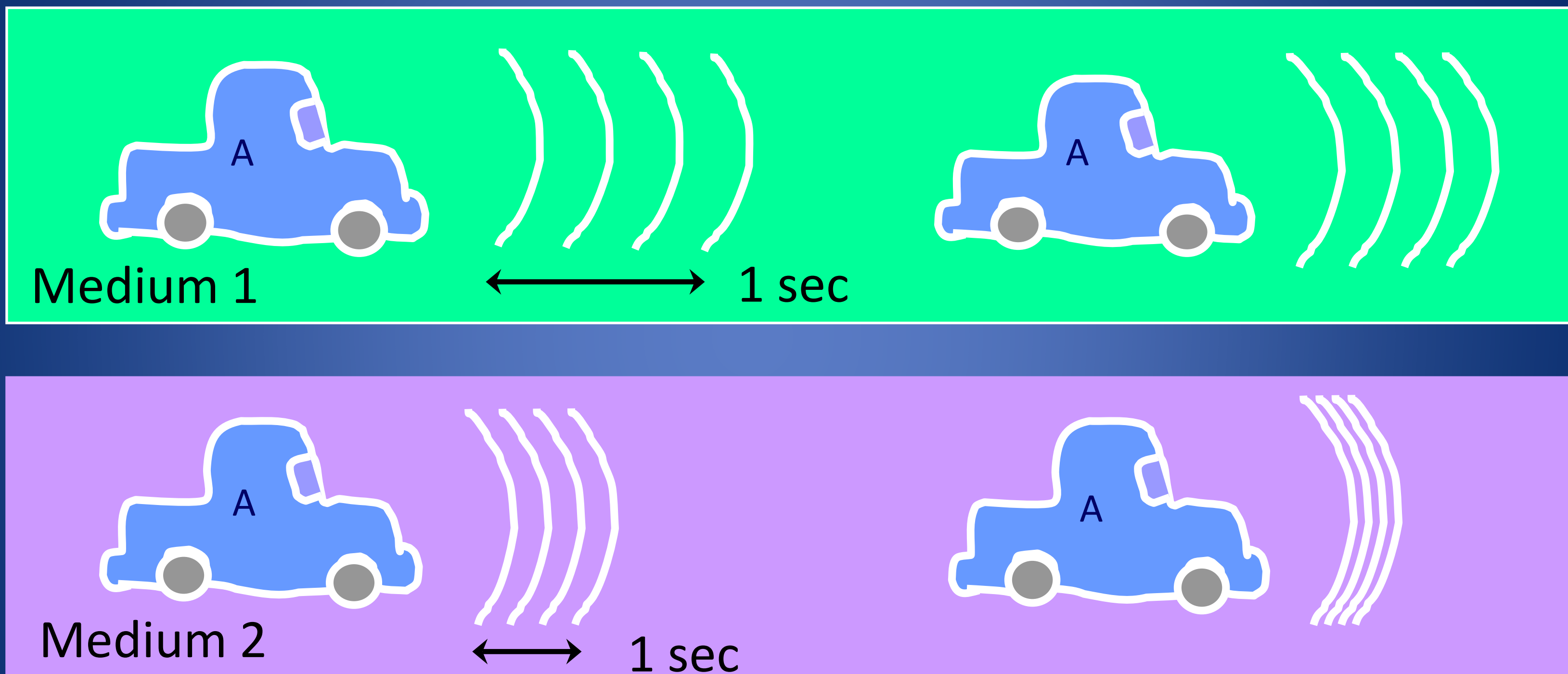
$$\Delta f = \frac{2 f_t v \cos\theta}{c}$$

$$f_{t_A} > f_{t_B}$$

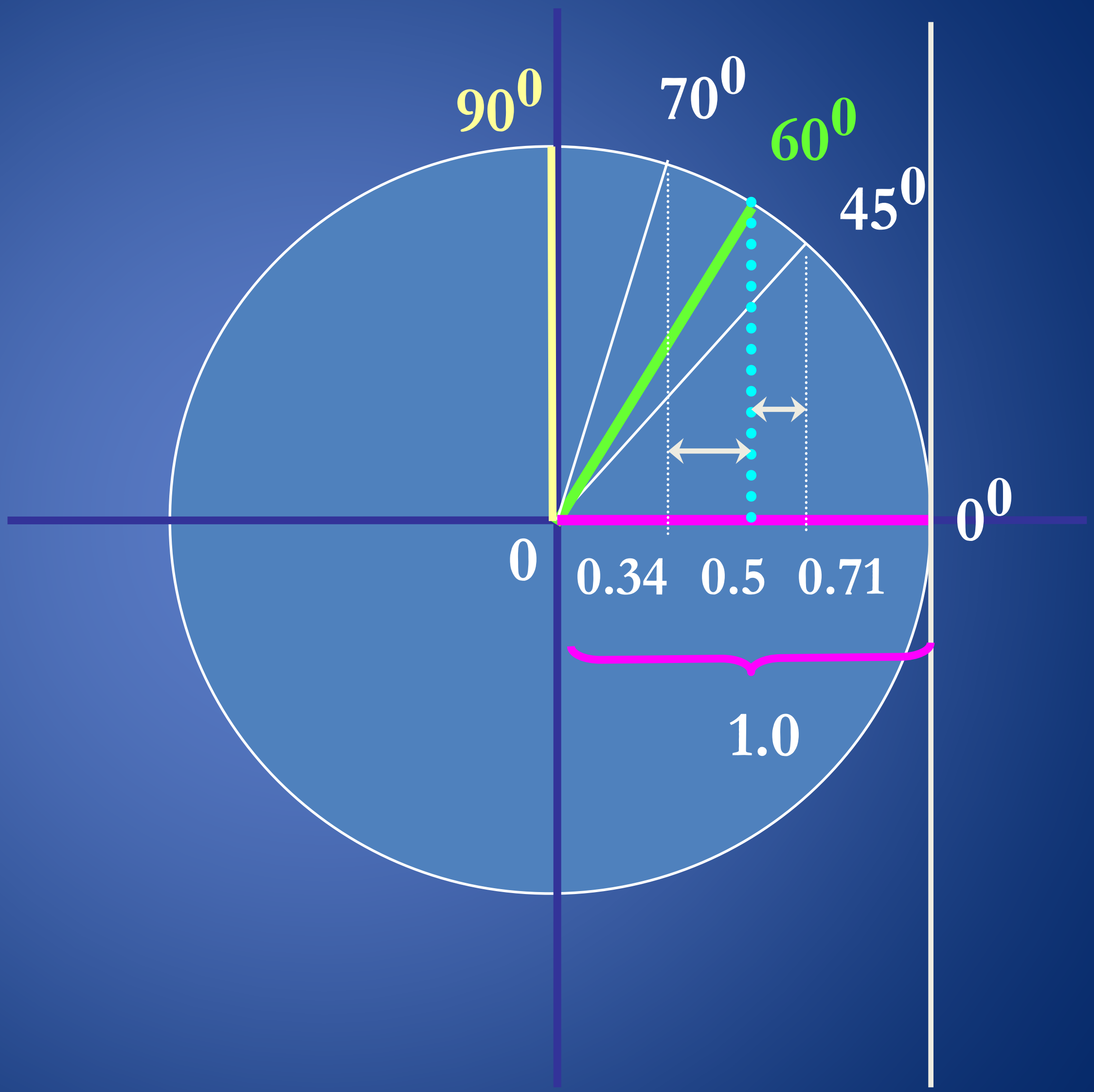
$$\Delta f = \frac{2 f_t v \cos\theta}{c}$$



$$\Delta f = \frac{2f_t v\cos\theta}{c}$$

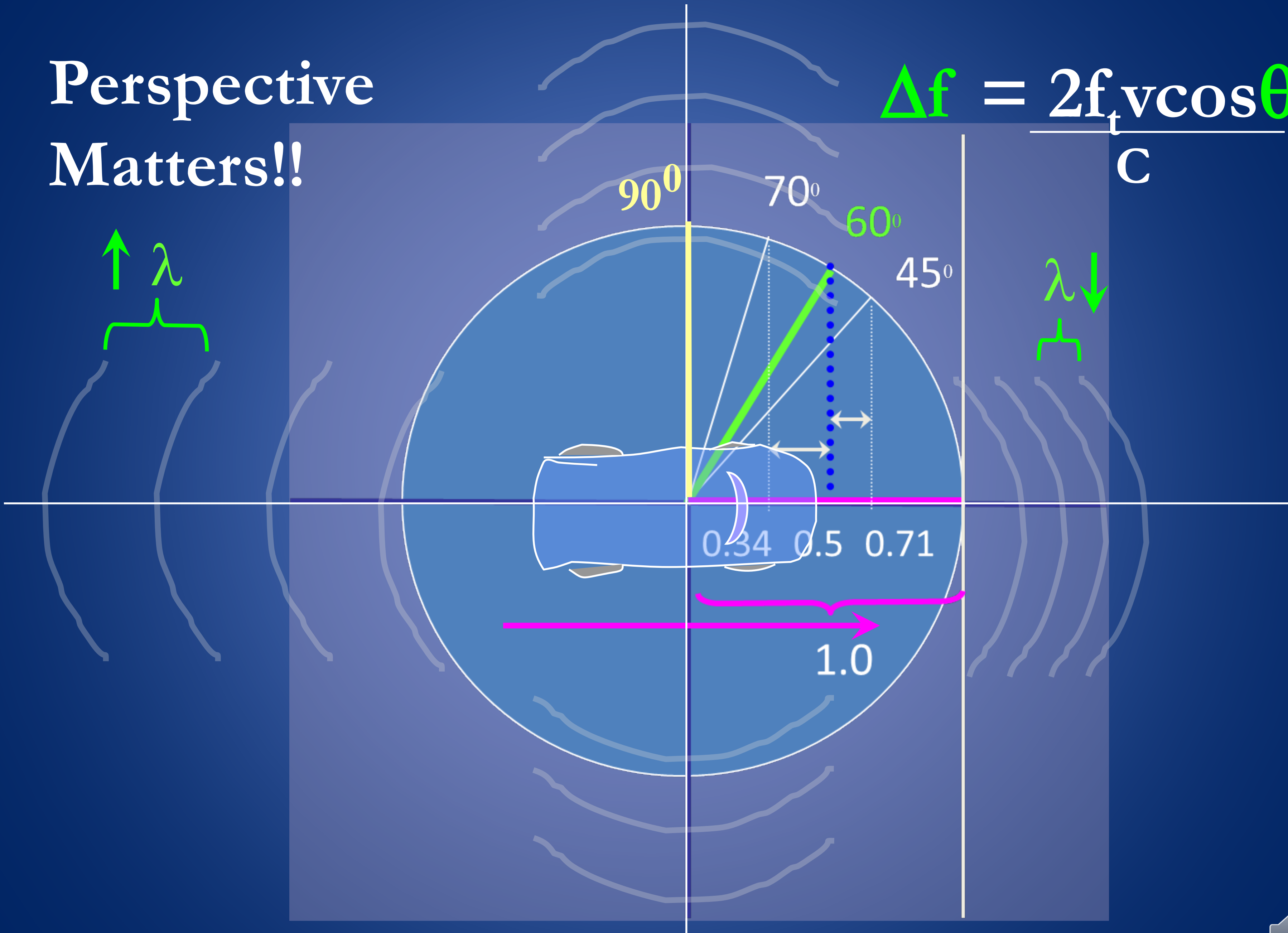


Degrees	Cos θ
0	1.0
10	.98
20	.94
30	.87
40	.77
50	.64
60	.50
70	.34
80	.17
90	0.00



Perspective Matters!!

$$\Delta f = \frac{2 f_t v \cos\theta}{c}$$



Velocity is not affected by the θ*

…right?

$$V = \frac{\Delta f c}{2 f_t \cos\theta}$$

* In theory this is true based on $\theta = 60^0$; in reality there is more than one angle and frequency

Angle of Incidence (θ) | Error

Degrees	Cos θ	> Angle (5^0)	< Angle (5^0)	% Velocity Overestimation	% Velocity Underestimation
0	1.0	0.996	0.996	0.38%	0.38%
10	.98	0.966	0.996	1.95%	-1.14%
20	.94	0.906	0.966	3.68%	-2.72%
30	.87	0.819	0.906	5.72%	-4.44%
40	.77	0.707	0.819	8.34%	-6.48%
50	.64	0.574	0.707	12.07%	-9.10%
60	.50	0.423	0.574	18.31%	-12.83%
70	.34	0.259	0.423	32.15%	-19.07%
80	.17	0.087	0.256	99.24%	-32.91%

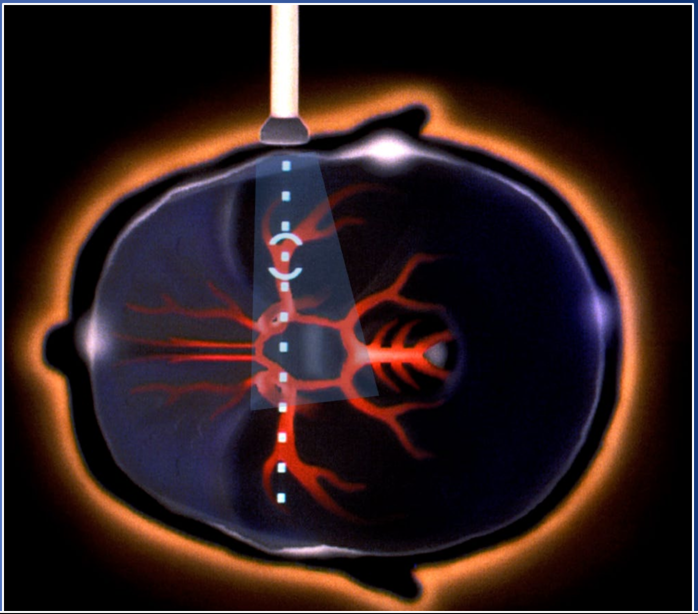
Putting it all together

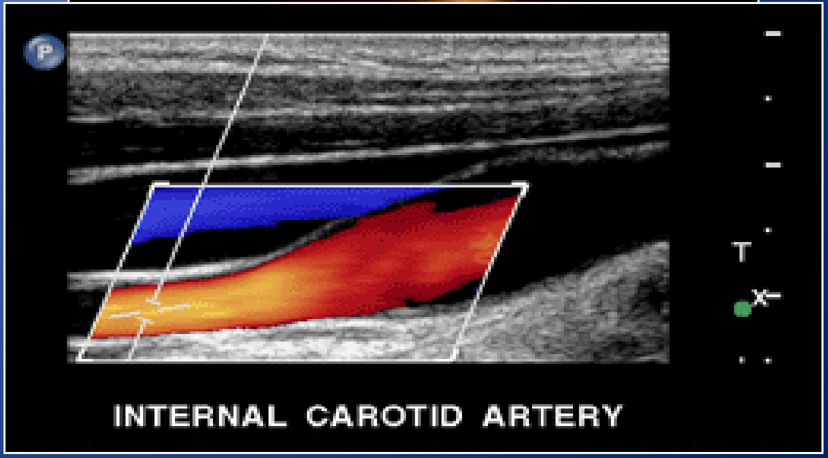
$$\Delta f = \frac{2f_t v\cos\theta}{C}$$

- 2 = constant (2 Doppler shifts occur)
- f_t = constant; transmit frequency
- C = constant; speed of sound (1540 m/s)
- v = what we're measuring
- Δf = what is calculated based on $\cos\theta$
- $\cos\theta$ = controlled by user/instrument

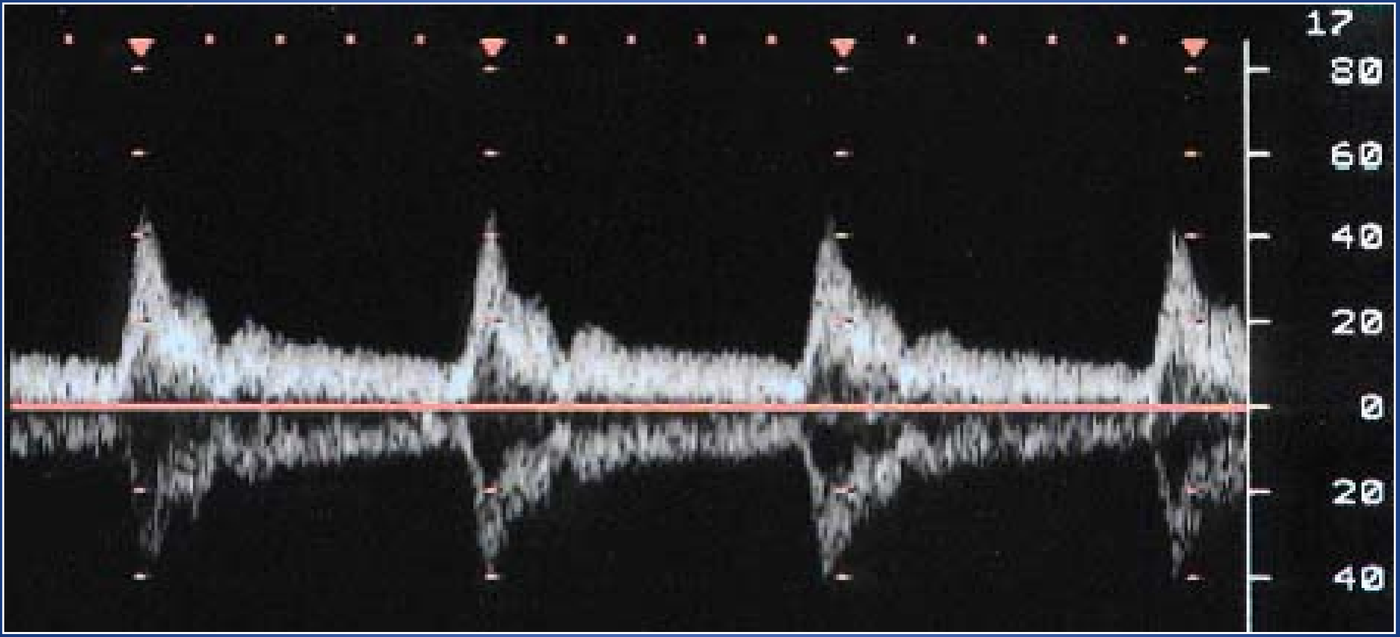
What’s your angle?

- Anatomy: Most major intracranial arteries are parallel to θ_i vs Extracranial, which are perpendicular
- Error: Velocity calculation error increases $\theta > 60^0$
- Highest audible shift: Listen!
- When to Align or “Angle Correct”? With TCDI, often not necessary; record angles used; remain $<20^0$

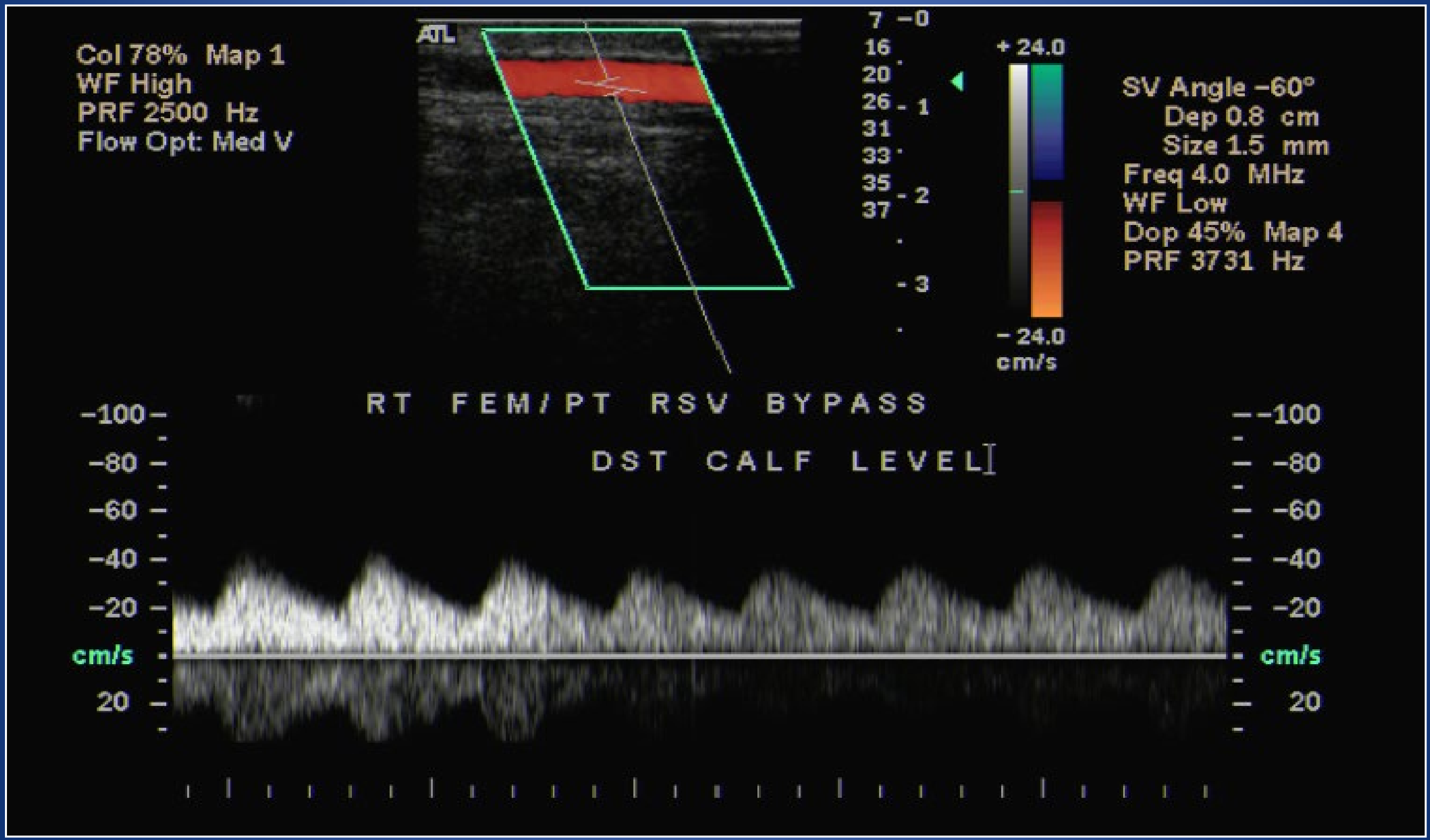




Doppler Artifacts: Spectral Mirroring



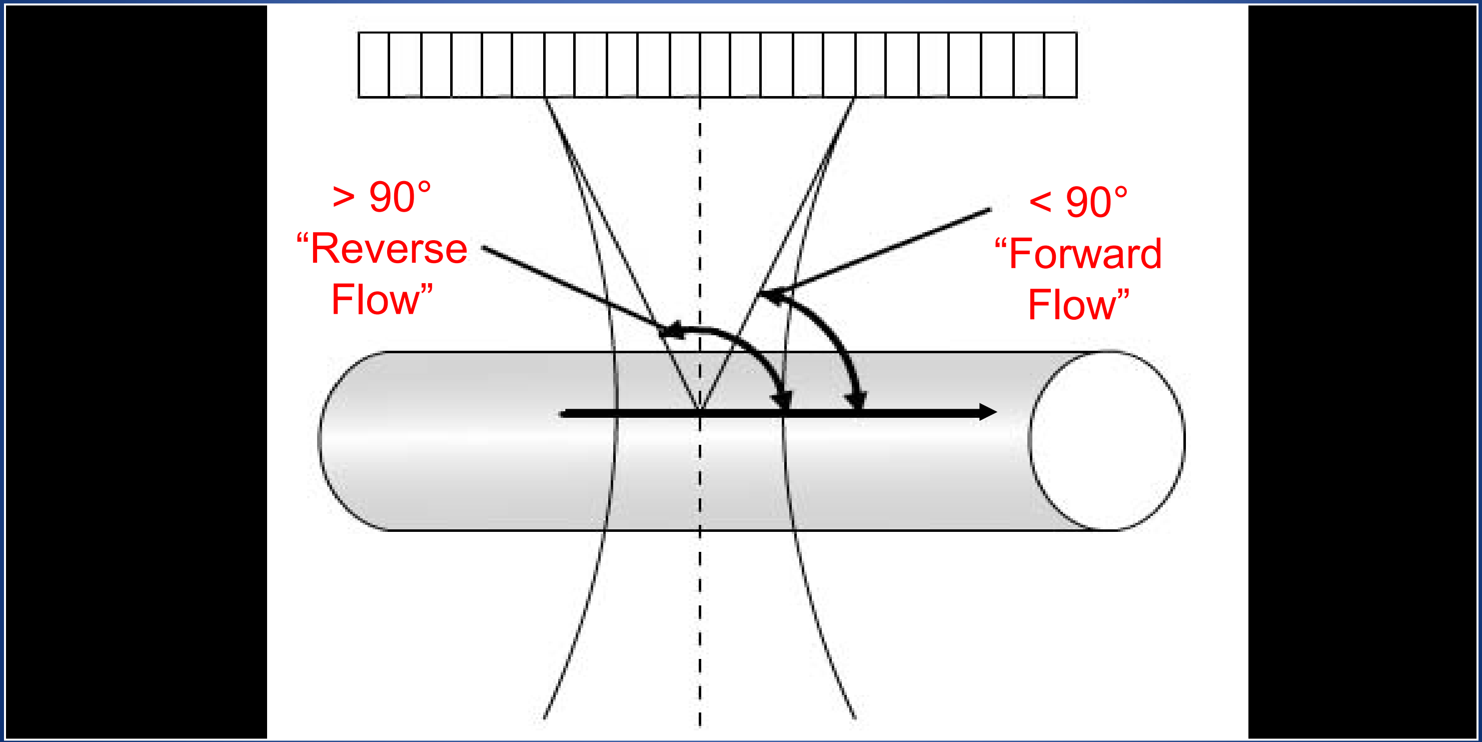
Spectral Mirroring (Overgain)



(Pg 613 A)

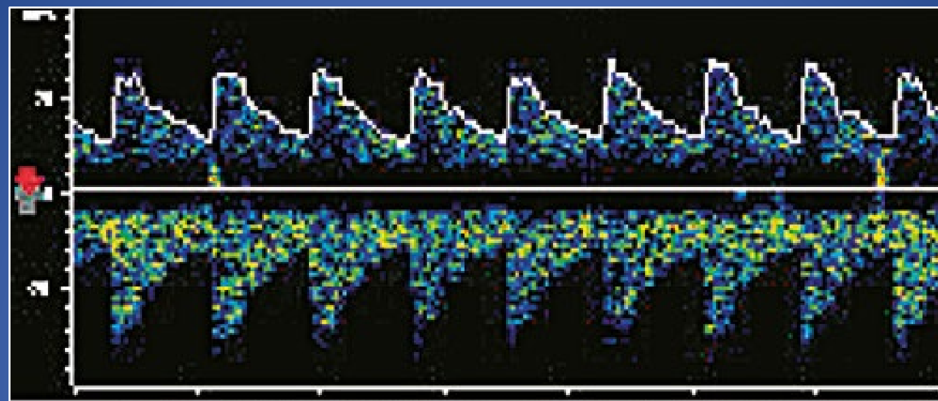
Solution: decrease Doppler gain

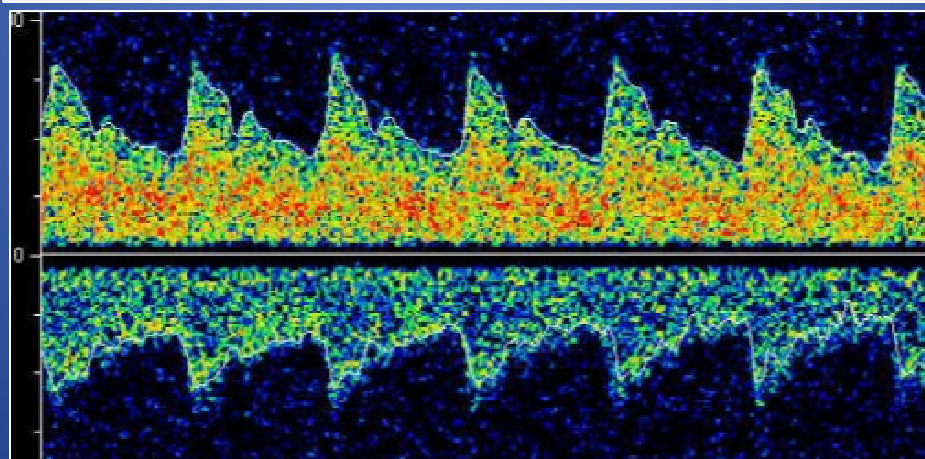
Spectral Mirroring Caused By Angle



Solution: change angulation/approach of transducer

Mirroring or Reverse Flow?



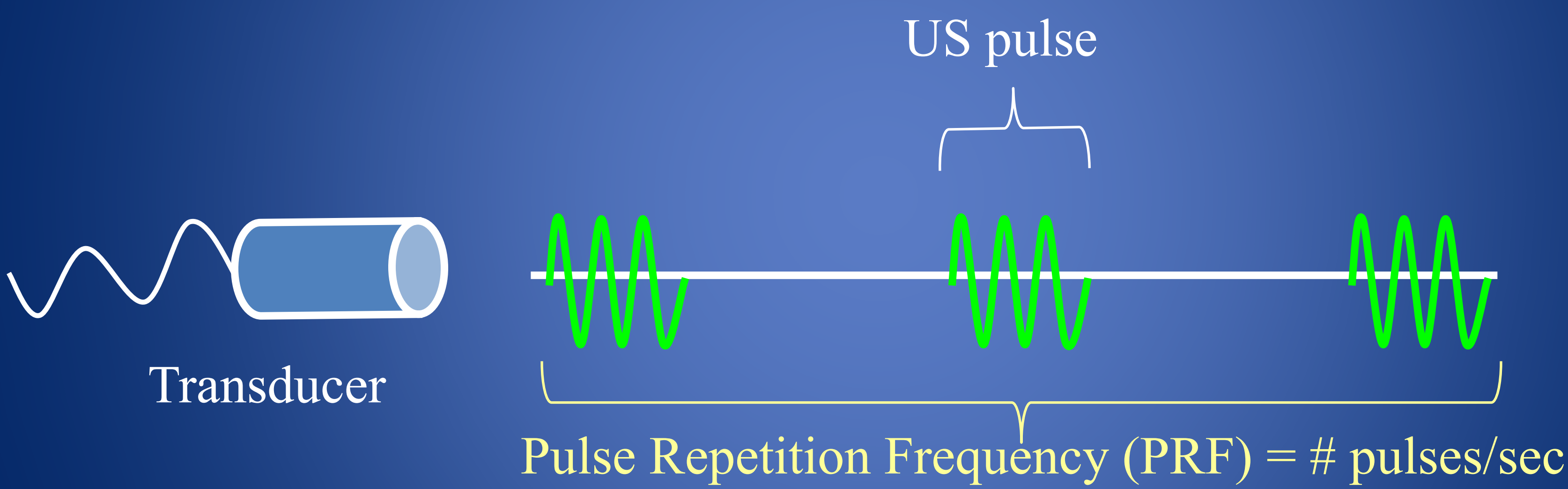


Answer: Real flow at MCA/ACA Birfurcation

TIP: be suspicious of perfect symmetry

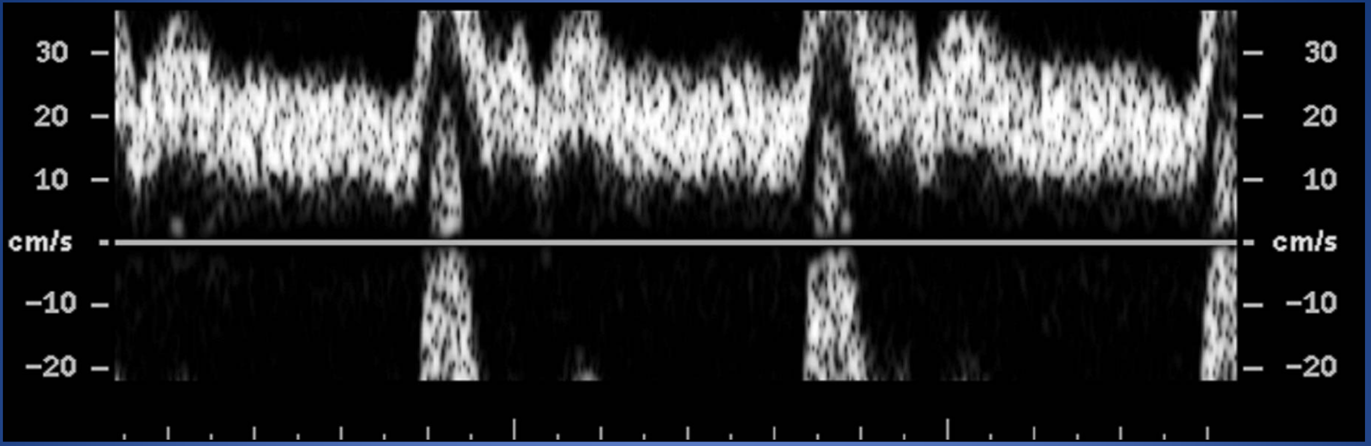
Pulsed Wave Doppler

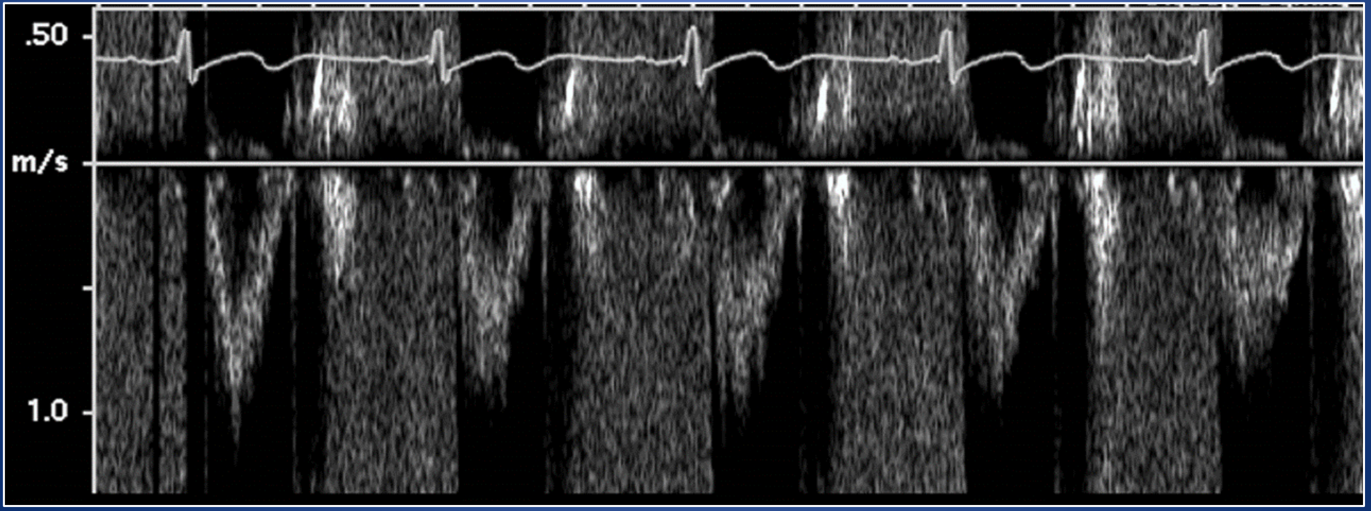
- Uses one crystal that alternately transmits and receives



- PW Doppler is a SAMPLING system; discrete depths
- Range gate - depth by timing; adjusted by user

Doppler Artifacts: Aliasing

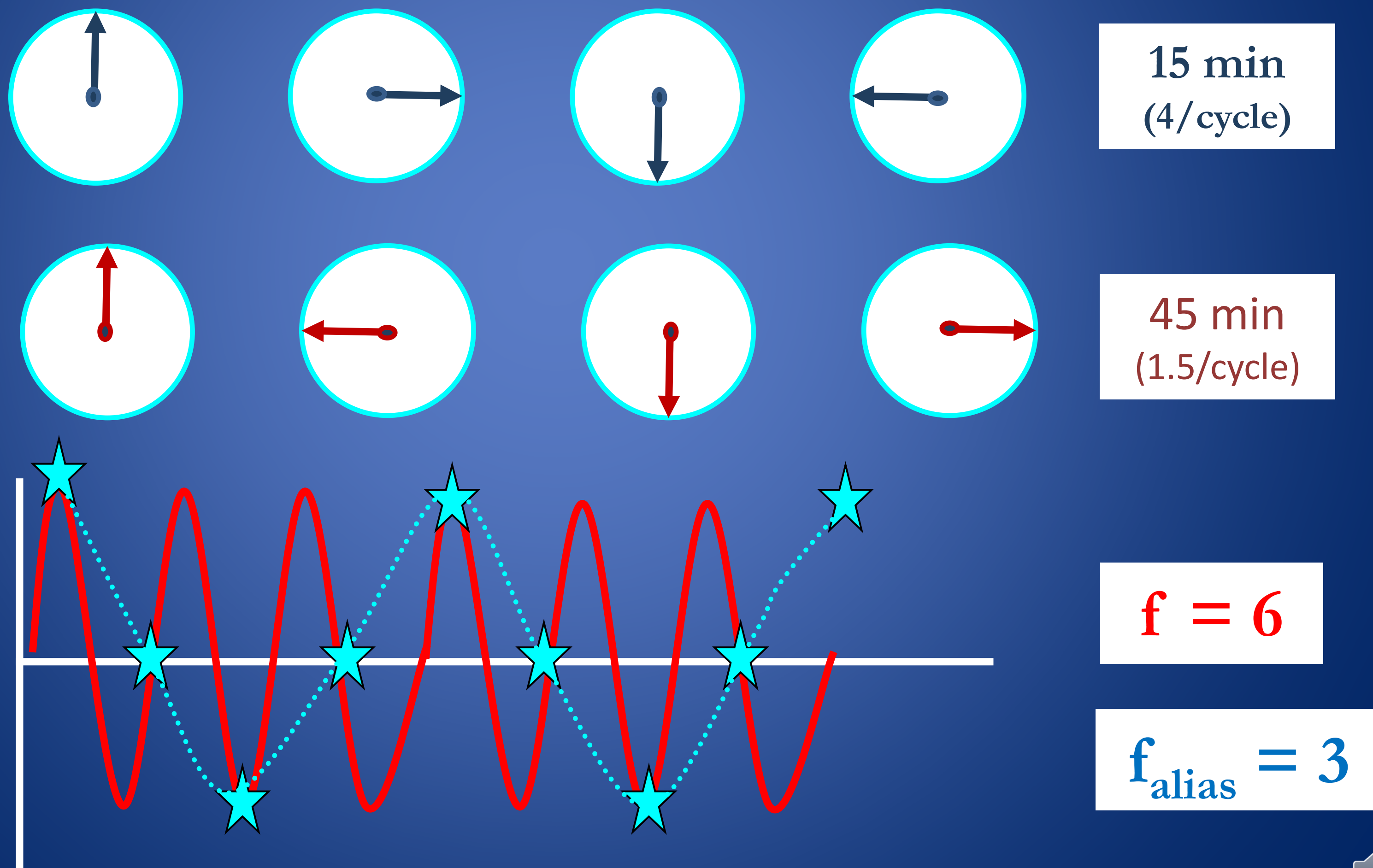




Ultrasound Physics and Instrumentation, Pegasus Lectures, 2006; pg 611

Aliasing

Alias: *to be misidentified; a false or assumed identity*

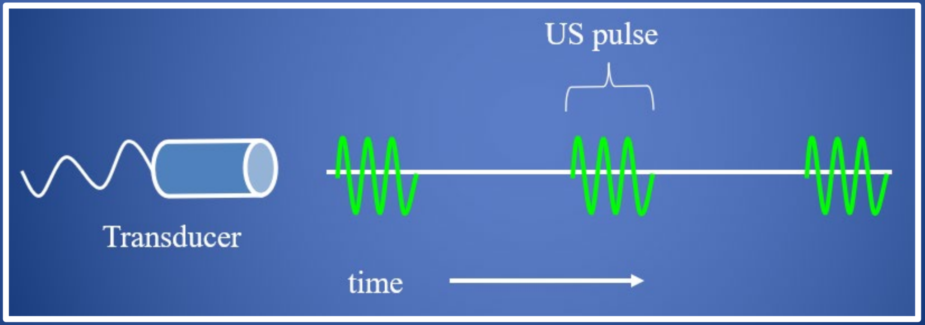


Nyquist Limit

- The highest frequency in a sampled signal which is represented unambiguously
- NL is the minimum number of samples required to avoid aliasing

$$NL = \frac{1}{2} PRF$$

PRF = Pulse Repetition Frequency



Aliasing Examples

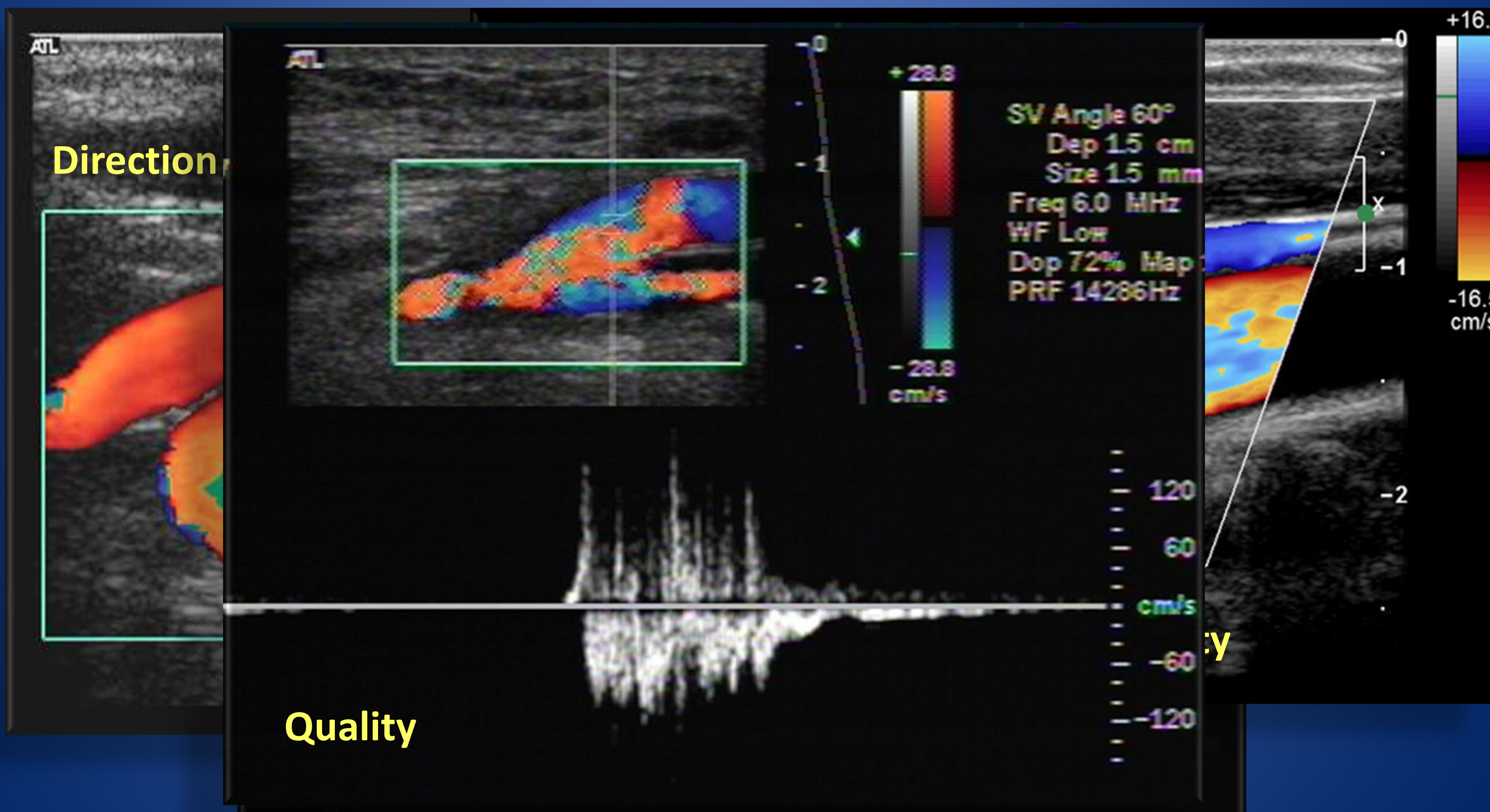
Frame rate of our brain isn't fast enough to keep up with rate of wheel turn

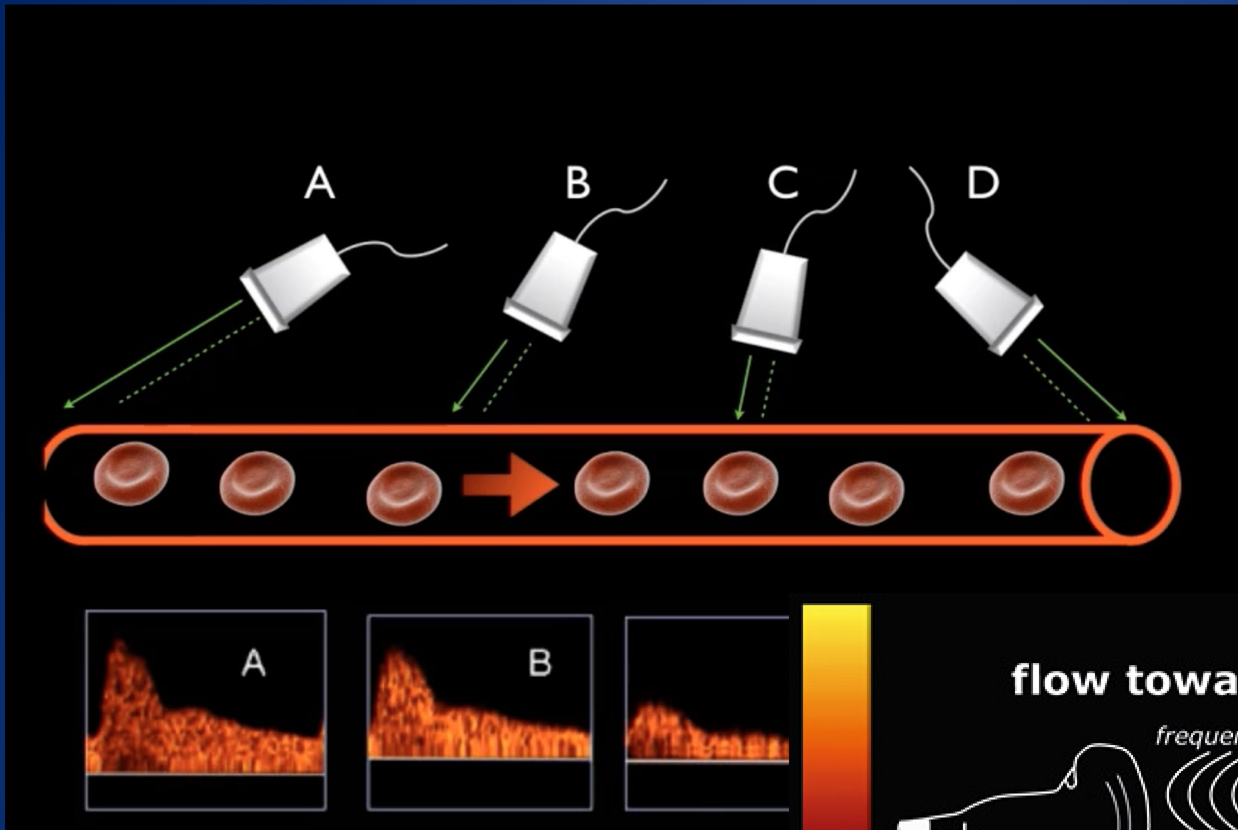
Frame rate of camera set to same rate of propeller

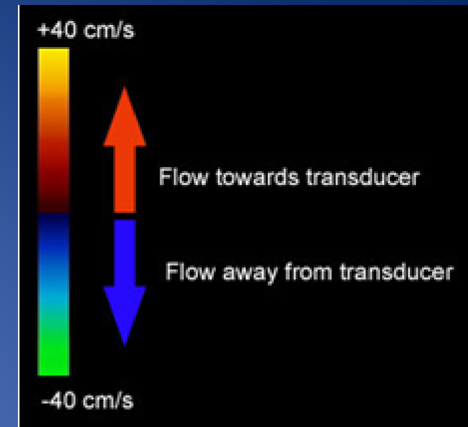
Troubleshooting Aliasing

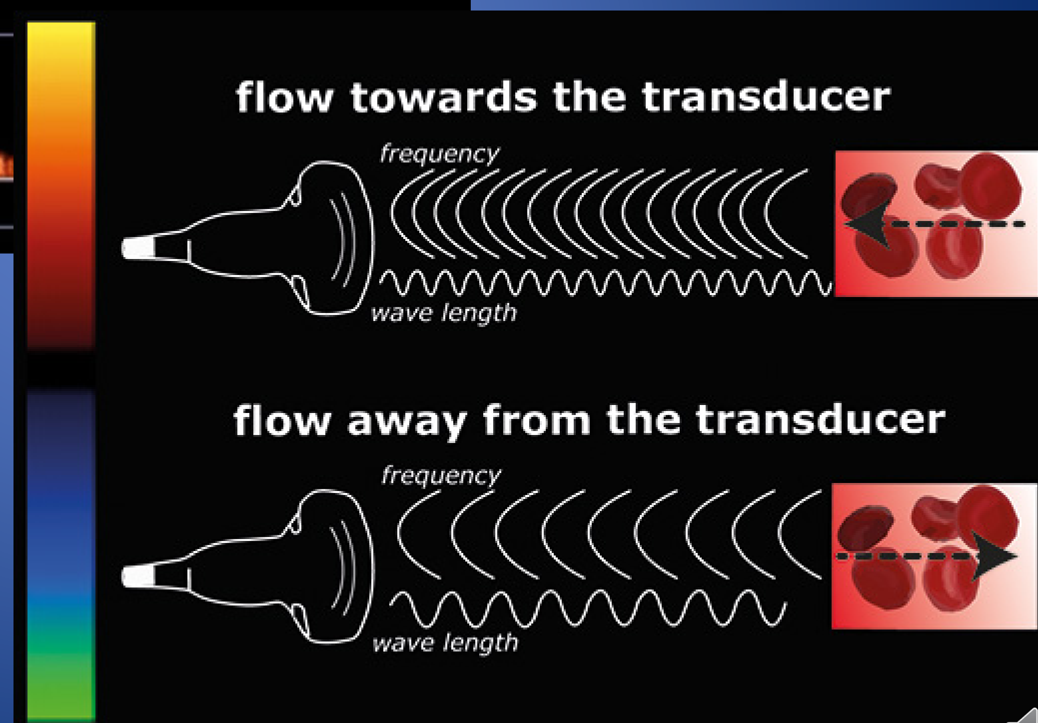
- ✓ ↑ PRF (scale)
- ✓ drop baseline
- ✓ decrease depth (allows ↑PRF)
- ✓ ↓f_t (↓Δf)
- ✓ Use CW (if possible)
- ✓ ↑Doppler angle (↓Δf)

Color Doppler

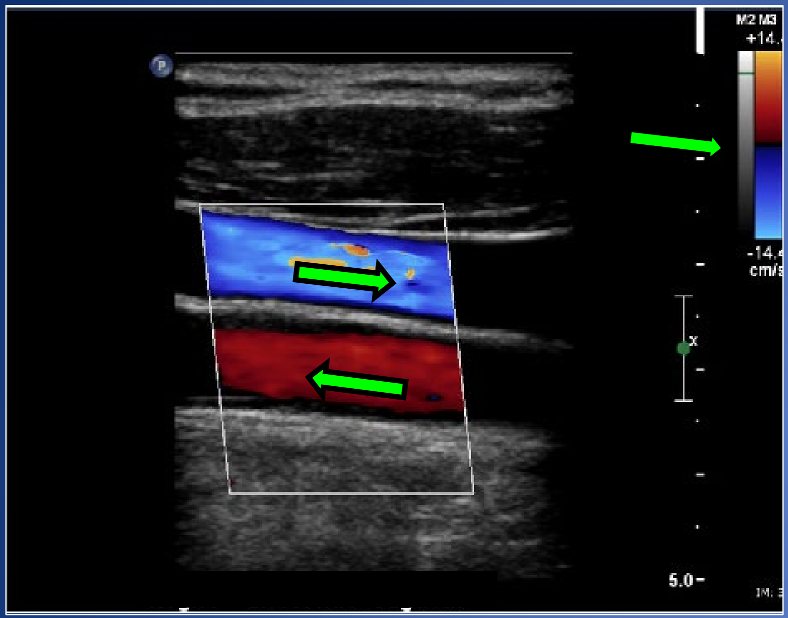


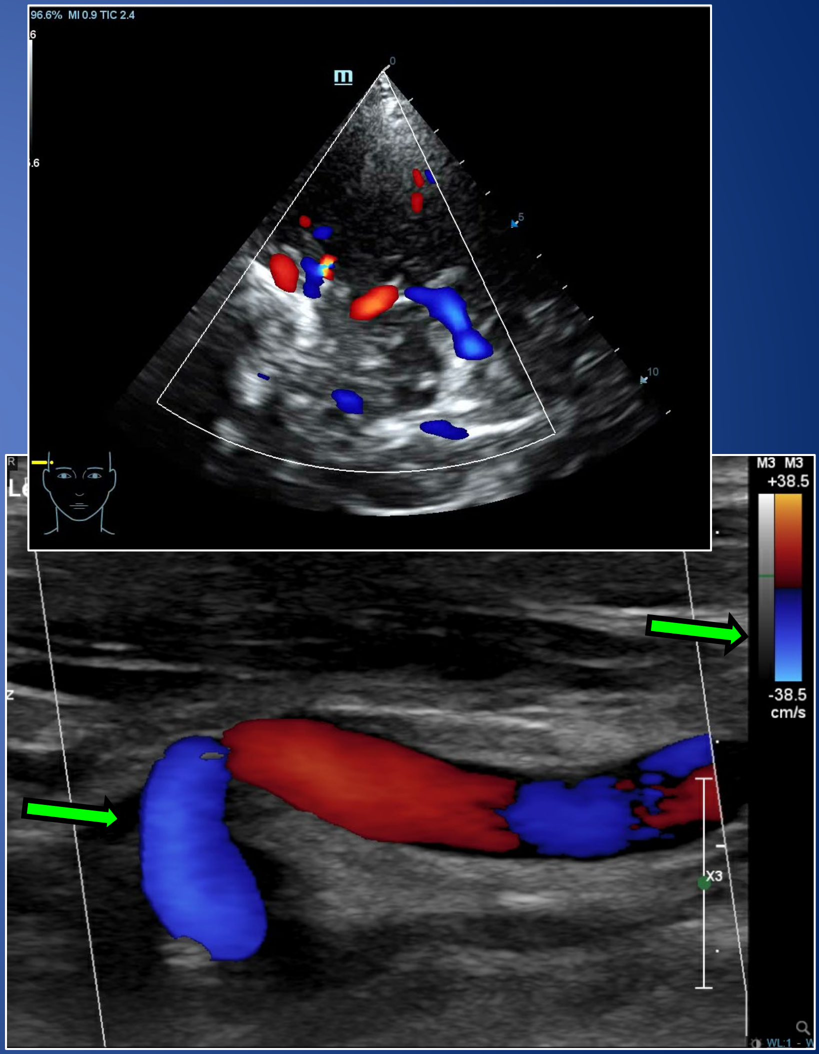

A
B
C
D
A
B


+40 cm/s
Flow towards transducer
Flow away from transducer
-40 cm/s


flow towards the transducer
frequency
wave length
flow away from the transducer
frequency
wave length

Flow Direction w/Color





Color Doppler

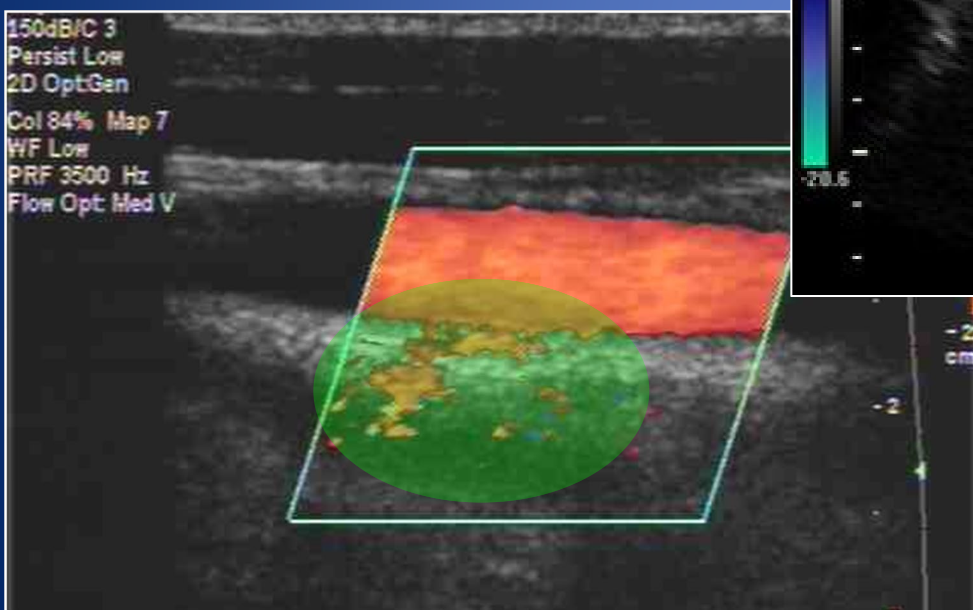
Advantages

- Presence of flow
- Flow direction
- Assess blood flow quality
- Stenosis location

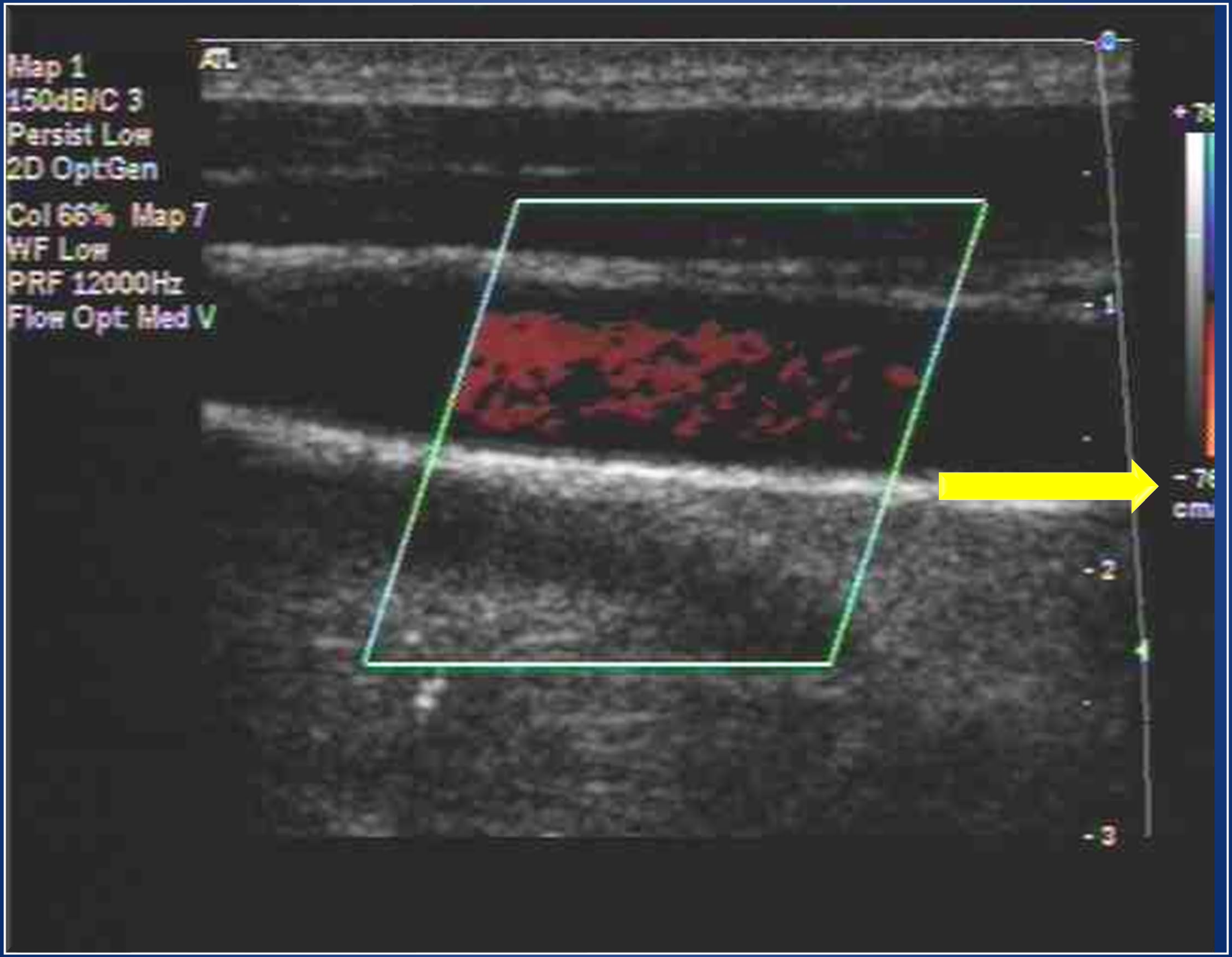
Limitations

- Frame rate
- Angle of color box
- PRF/color scale
- Gain setting
- Motion artifact

Gain Setting

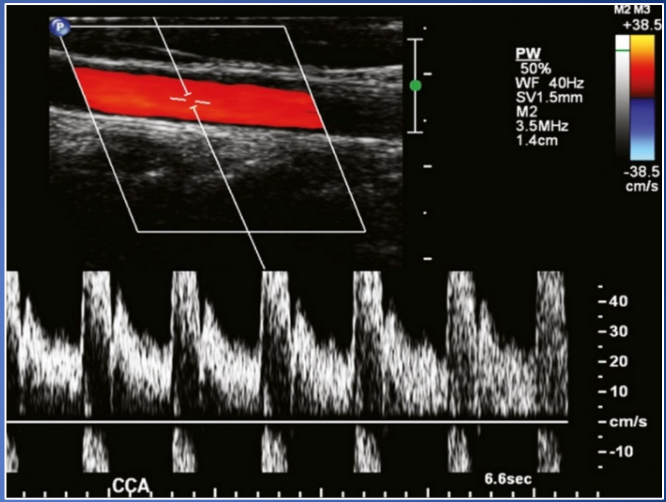


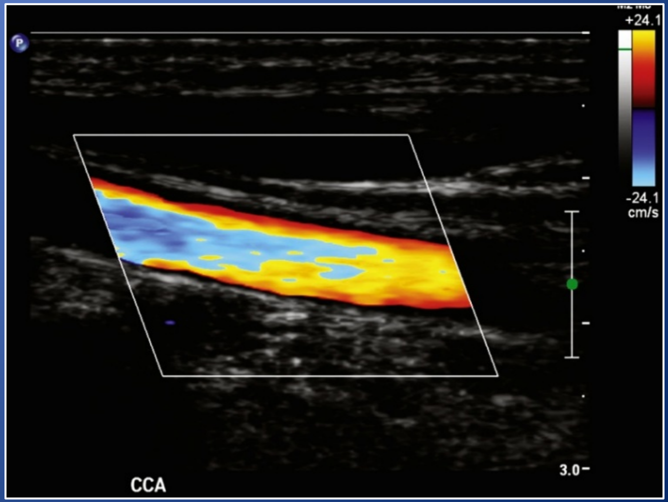
Scale/PRF…too high



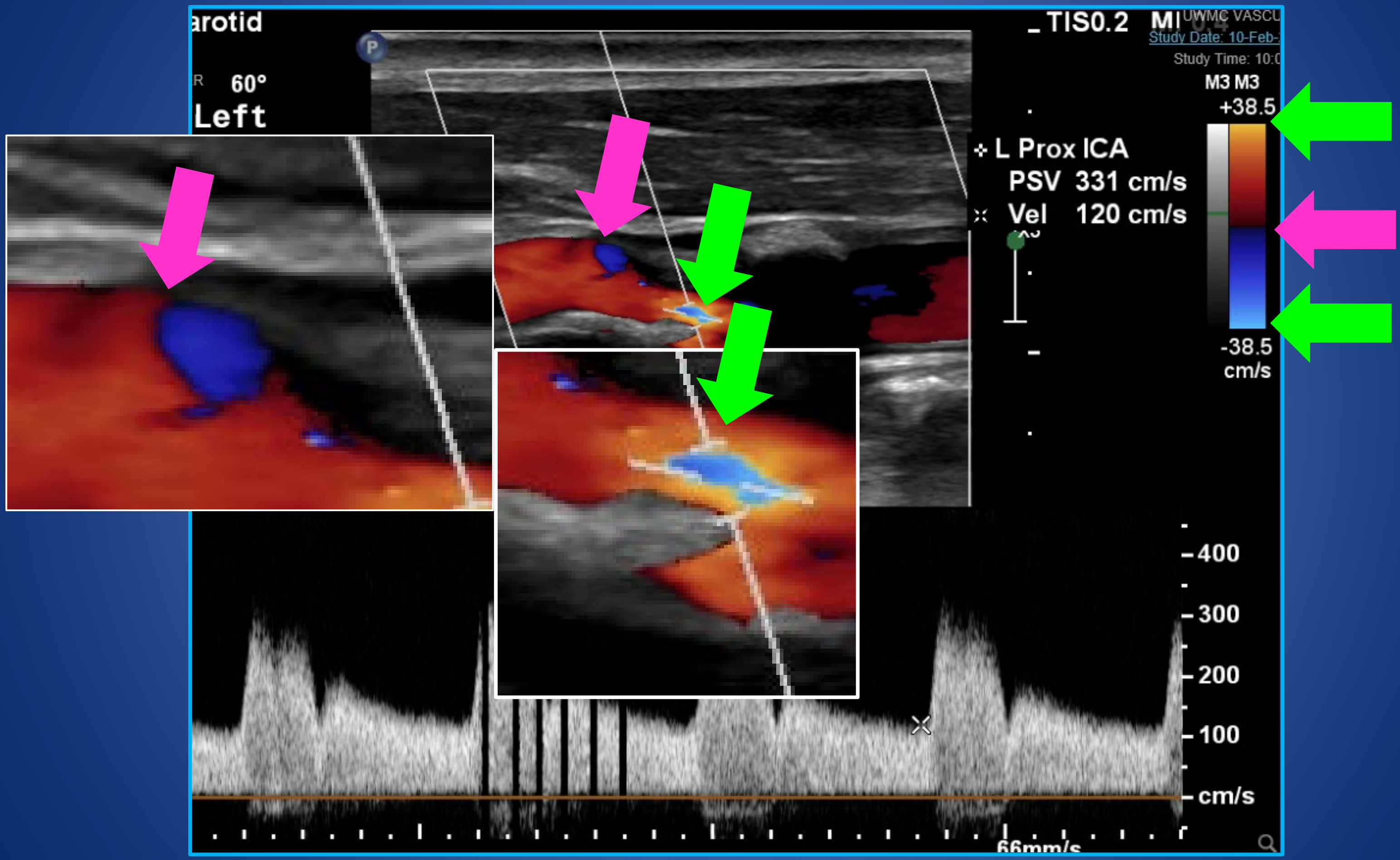
Aliasing

- Under sampling of the Doppler shifts in a pulsed Doppler system
- Appearance of Doppler information (spectral or color) on the wrong side of the baseline



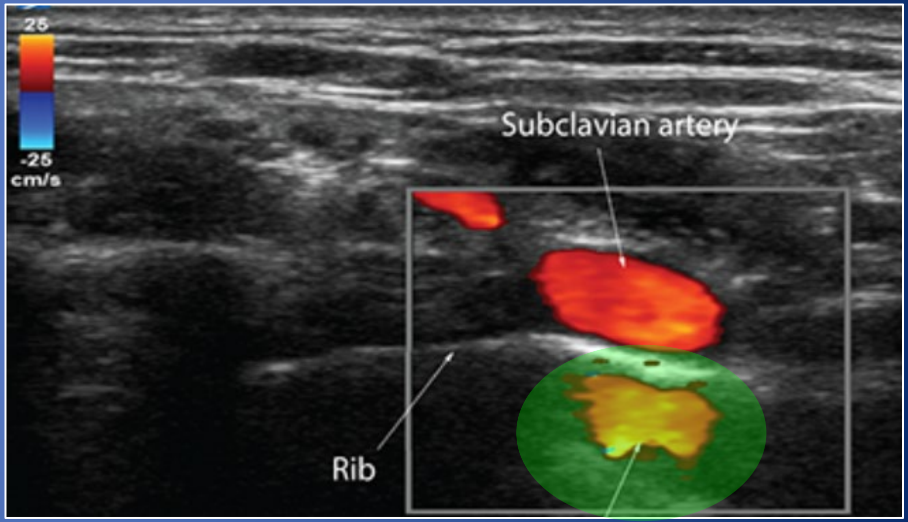


Color Aliasing

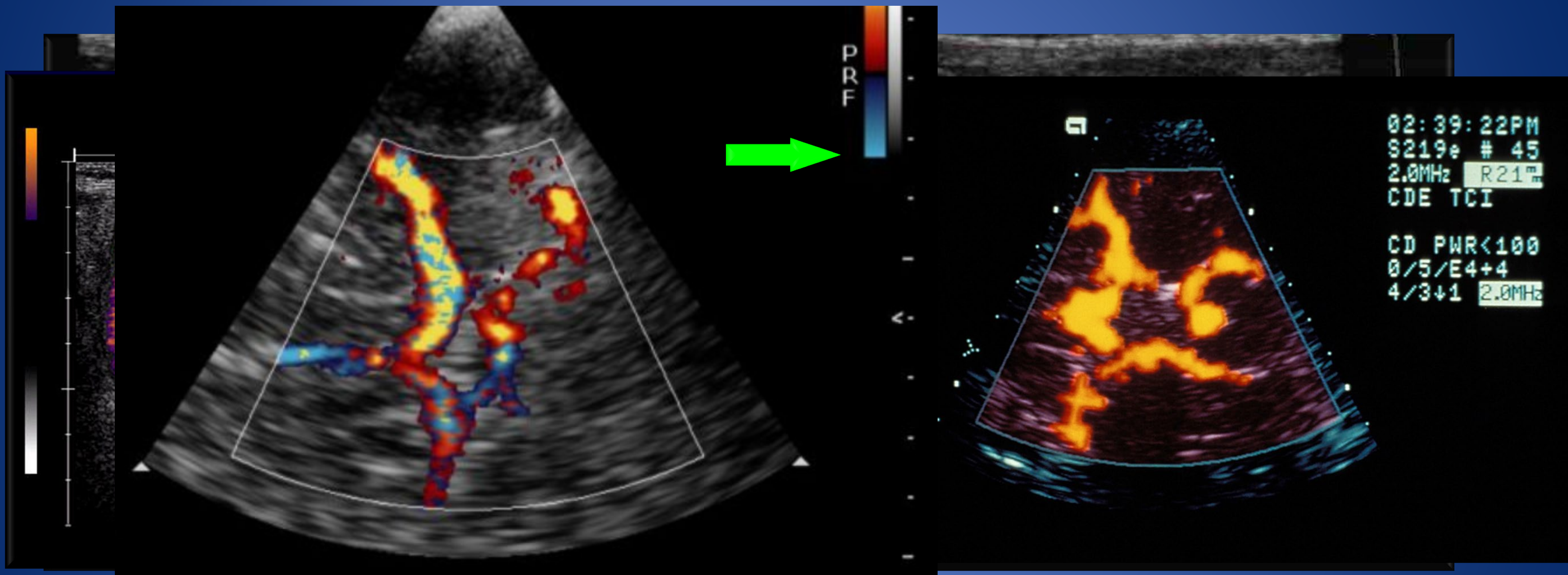


Mirror Image

- Duplication of a vessel or Doppler shift on the opposite side of a strong reflector
- Mirror vessel will demonstrate color and spectral flow
- Solution: reduce gain; change approach to avoid strong reflector'; mostly be aware of what it is



Power Doppler



- Represents presence/volume of RBCs (amplitude)
- It is NOT angle dependent
- Does <u>NOT</u> represent velocity

Power Doppler

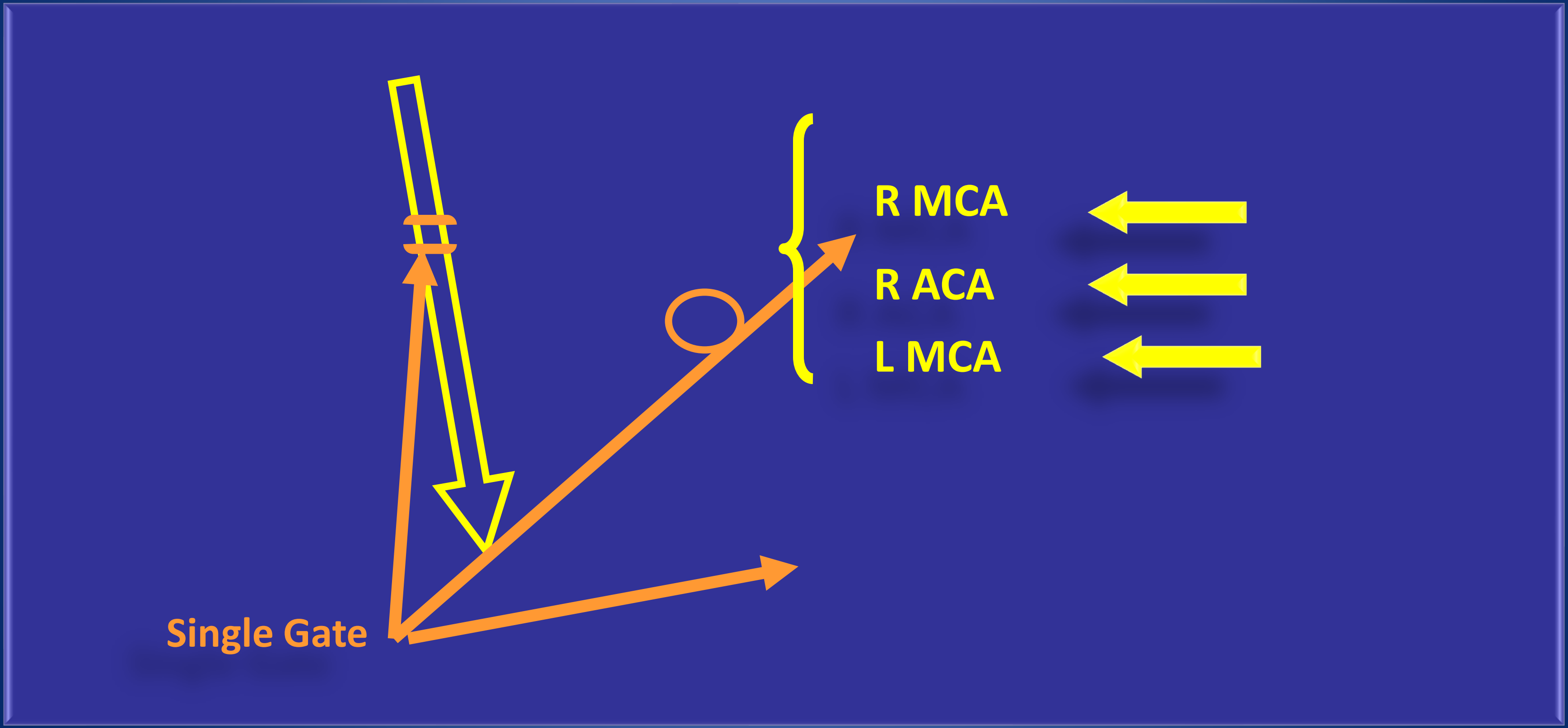
Advantages

- Vessel identification & orientation
- Identify presence of flow
- Useful in "low flow" states
- NOT angle dependent

Limitations

- No velocity information
- Sensitive to motion artifact
- Flow direction <u>not always</u> depicted
- Can be confused with Color Doppler

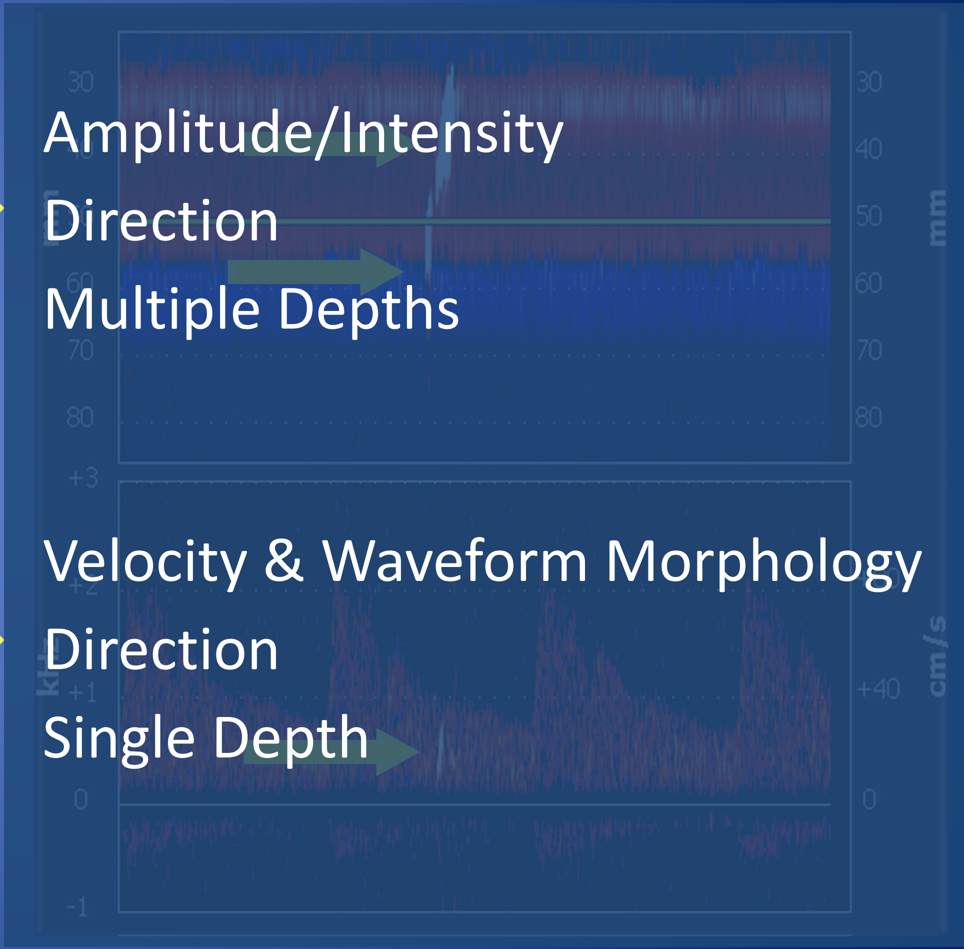
Power M-Mode Doppler (Non-Imaging – Multi Gate)



Multi Gate (33)

Power m-mode Doppler

Single gate Doppler



Amplitude/Intensity

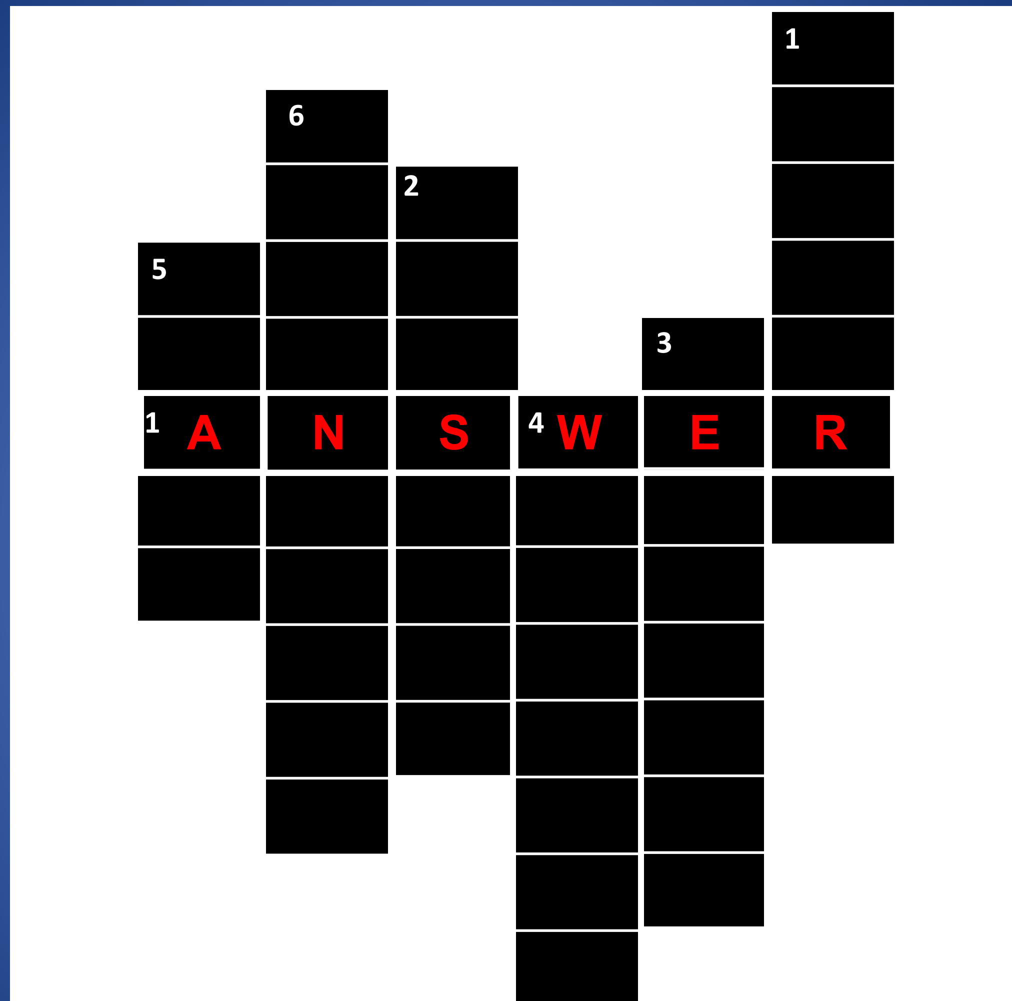
Direction

Multiple Depths

Velocity & Waveform Morphology

Direction

Single Depth


1
6
2
5
3
1 A N S 4 W E R

leni@leadingedgeinsight.com
206-412-6127 m
@Leni_Karr