

Sound

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Speed of Sound

$$v_{\text{sound}} \approx 343 \text{ m/s}$$

At room temperature.

Speed of Sound

<u>Gas</u>	<u>v (m/s)</u>
Hydrogen (0°C)	1286
Helium (0°C)	972
Air (20°C)	343
Air (0°C)	331
<u>Liquids at 25°C</u>	
sea water	1533
water	1493
<u>Solids</u>	
glass	5640
iron	5950
aluminum	6420

Speed of Sound

$$v = 331 \text{ m/s} + \left(0.6 \frac{\text{m}}{\text{s} \cdot ^\circ\text{C}} \right) T_c$$

Characteristics:

Loudness – related to intensity [$I = P / A = (E/t)/A$]

Pitch – depends on the frequencies.

Audible Range – 20 Hz to 20,000 Hz

Ultrasonic – Frequencies $> 20,000$ Hz

Supersonic – Speed greater than the speed of sound.
(Not a characteristic of sound.)

Infrasonic – Frequencies < 20 Hz

Sound Level:

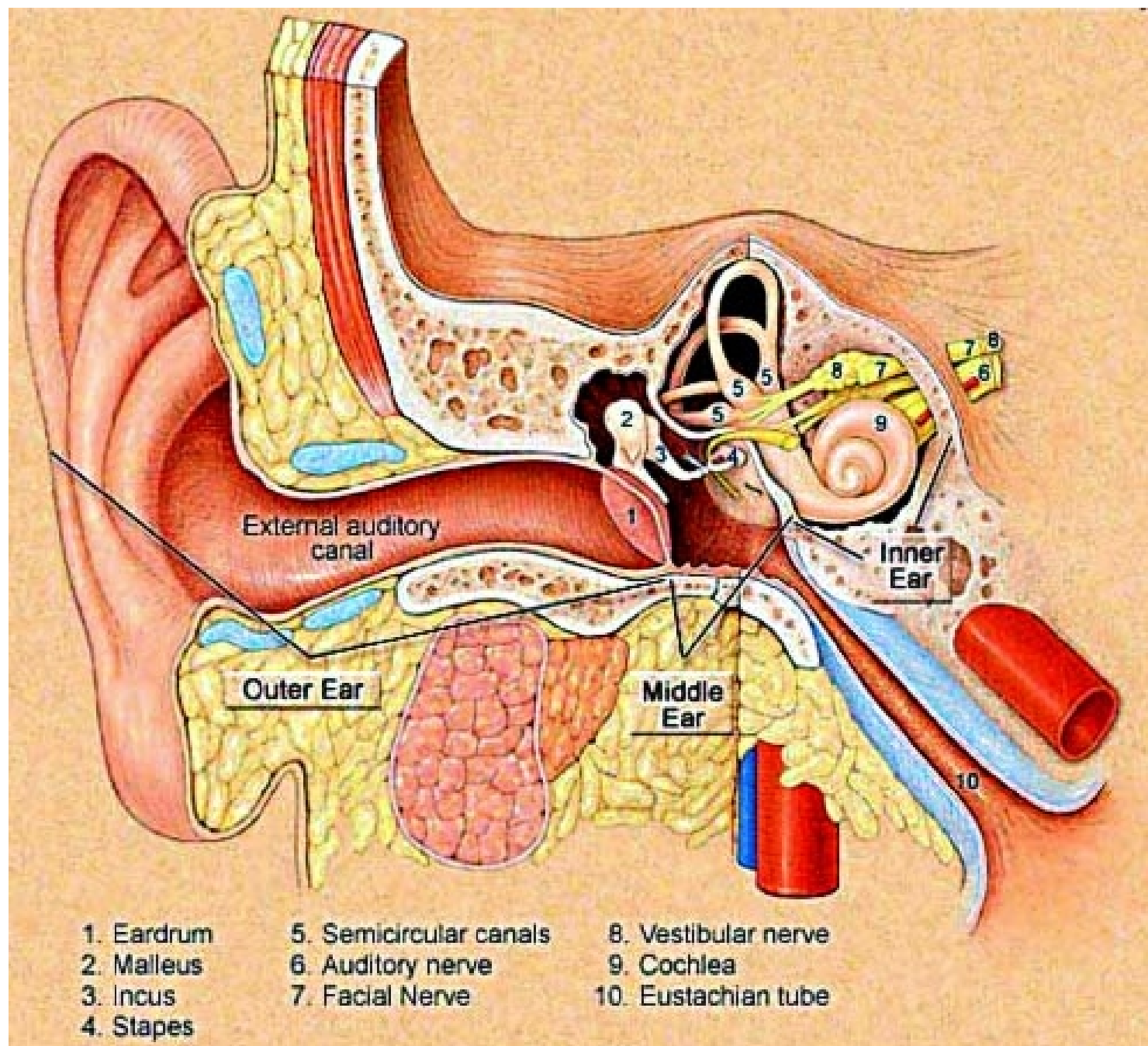
$$SL = 10 \text{ dB} \log \left(\frac{I}{I_o} \right)$$

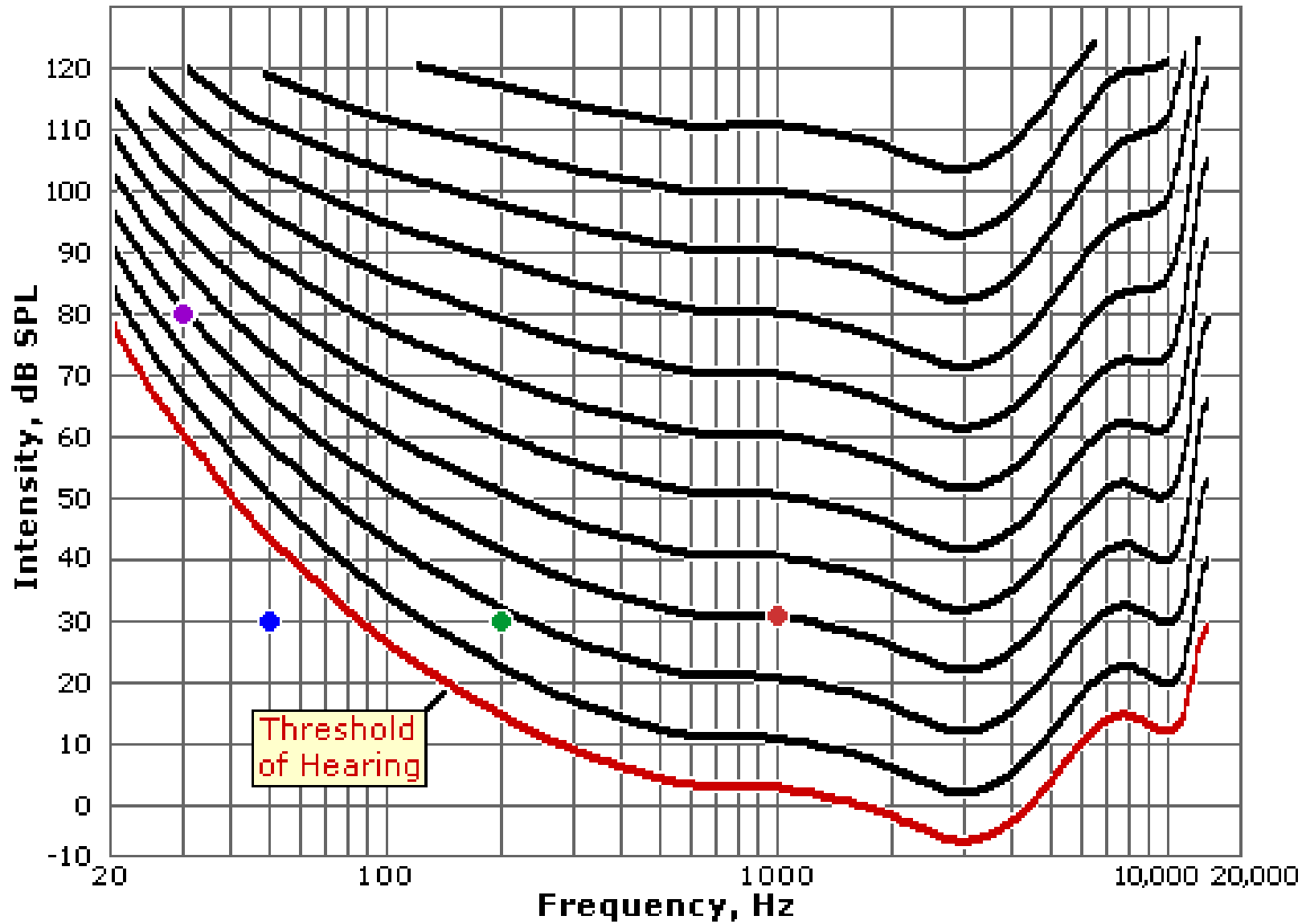
$$I_o = 1 \times 10^{-12} \frac{W}{m^2}$$

Minimum Sound Level Intensity $I_o = 1 \times 10^{-12} \text{ W / m}^2 = 0 \text{ dB}$

Sound Level for Pain $I_{pain} = 1 \text{ W / m}^2 = 120 \text{ dB}$

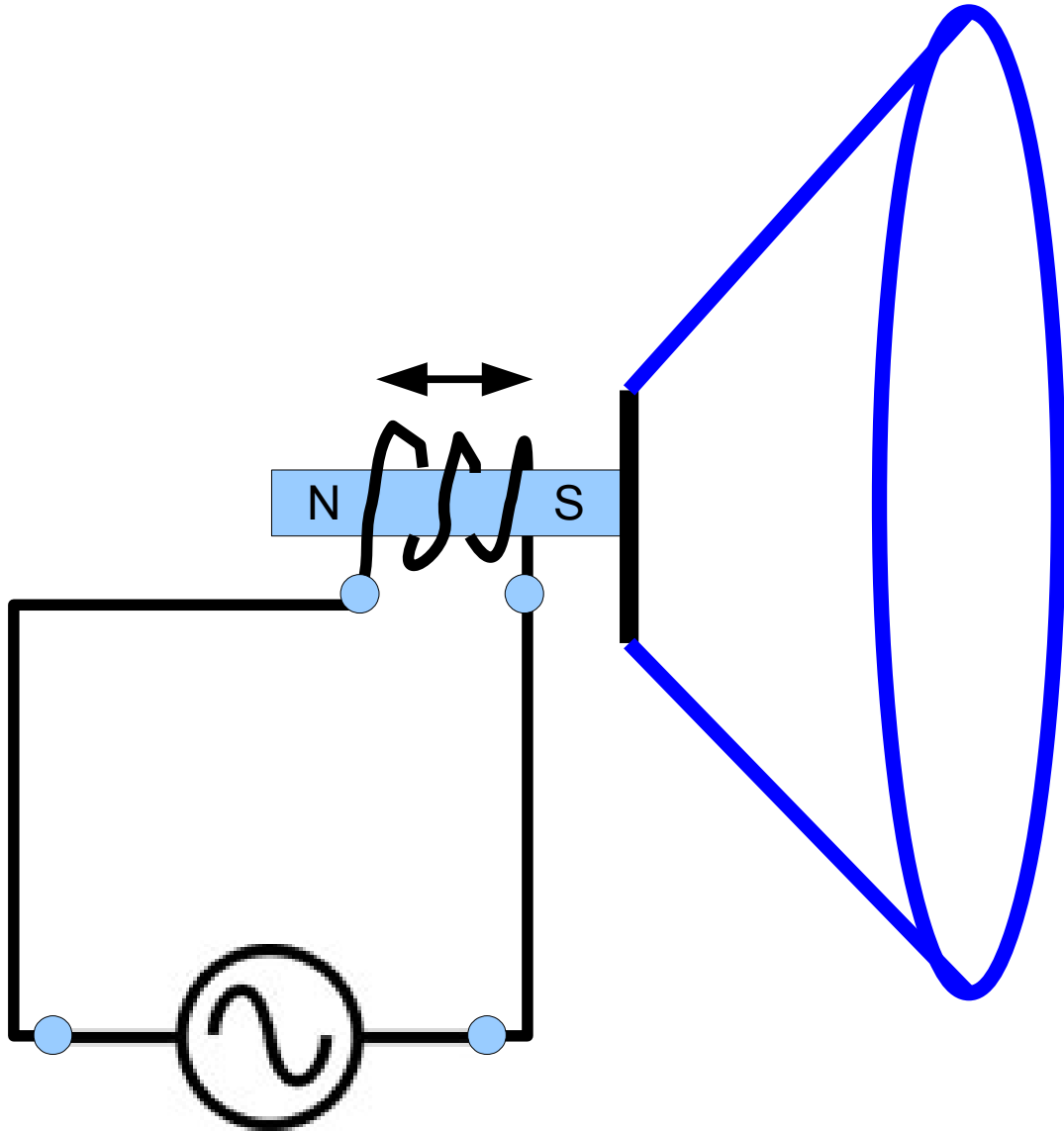
Source	Sound Level (dB)	Intensity (W / m^2)
Jet Plane at 30 m	140	100
Threshold of Pain	120	1
Loud Rock Concert	120	1
Vacuum	80	1×10^{-4}
Busy street traffic	70	1×10^{-5}
Whisper	20	1×10^{-11}
Threshold of Hearing	0	1×10^{-12}



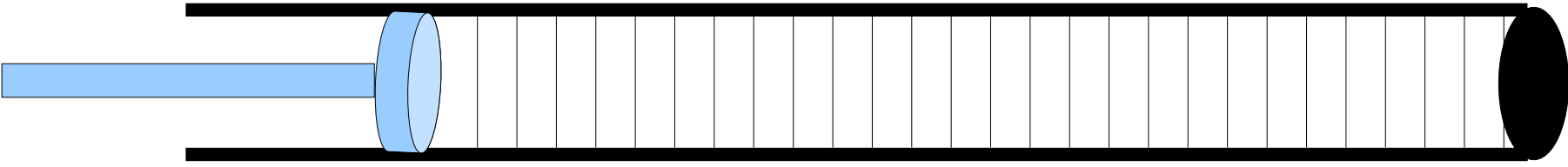


Equal "Loudness" Curves

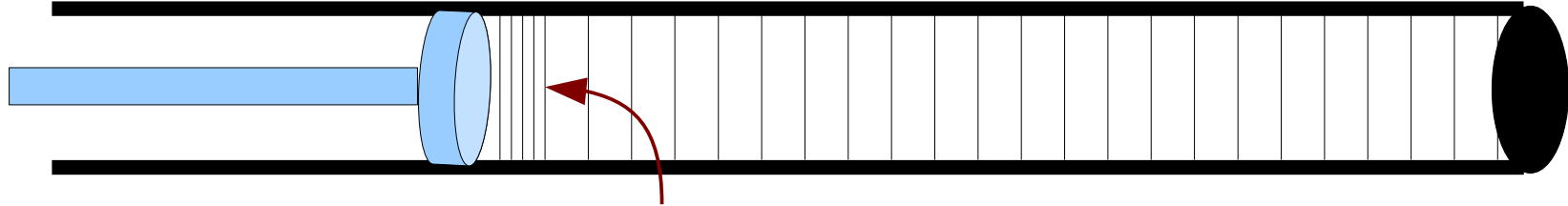
How does a speaker work?



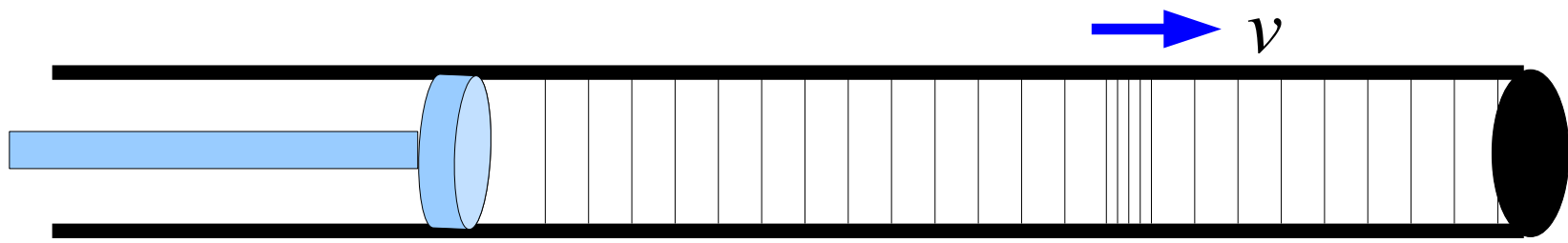
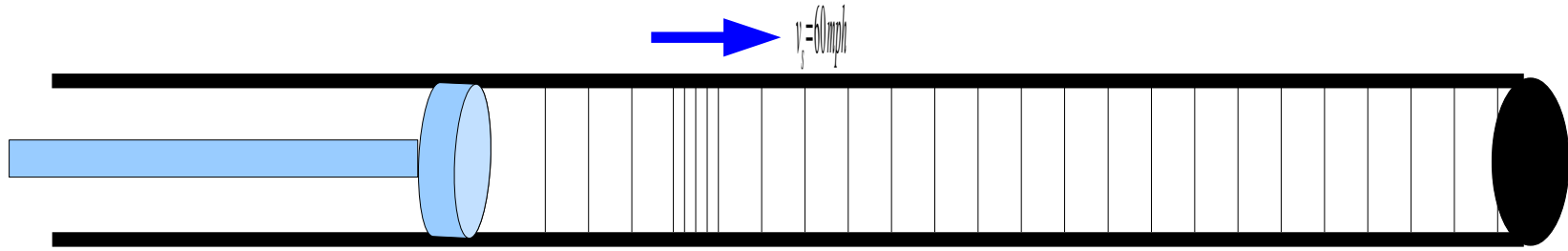
Speaker

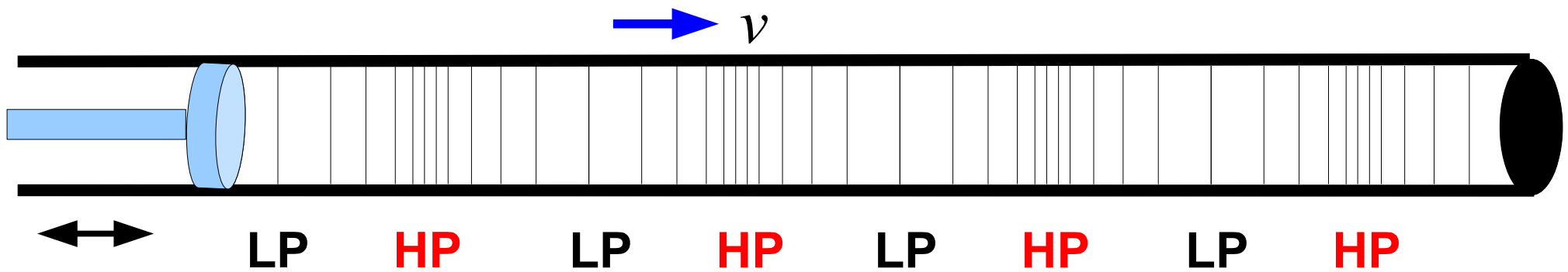


Undisturbed State

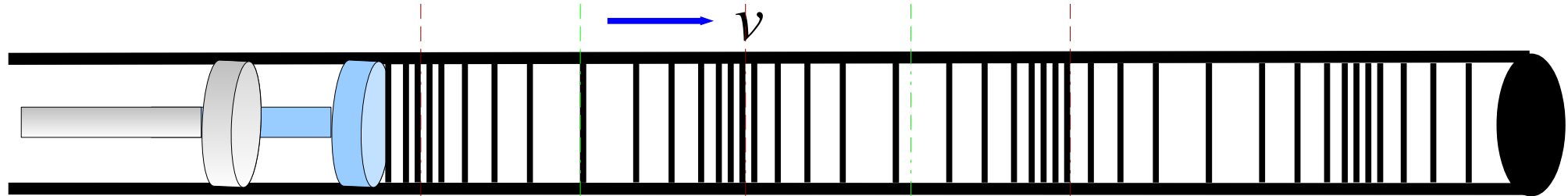


Compressed Gas





High Pressure – Compression
Low Pressure - Rarefaction



LP

HP

LP

HP

LP

HP

LP

HP

ΔP

$+\Delta P_{max}$

$-\Delta P_{max}$

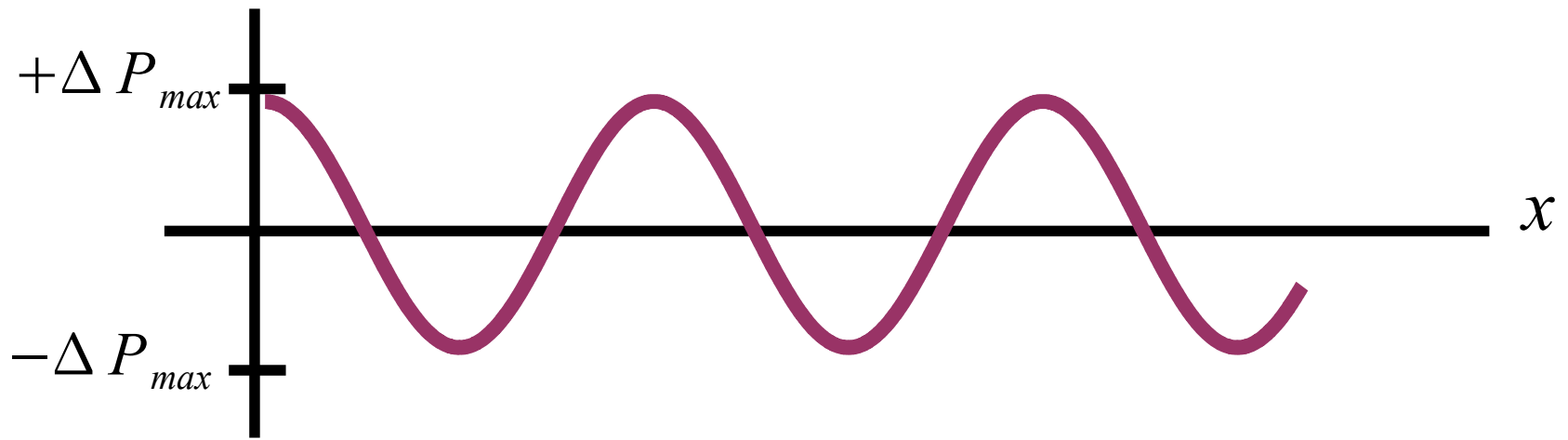
x

S

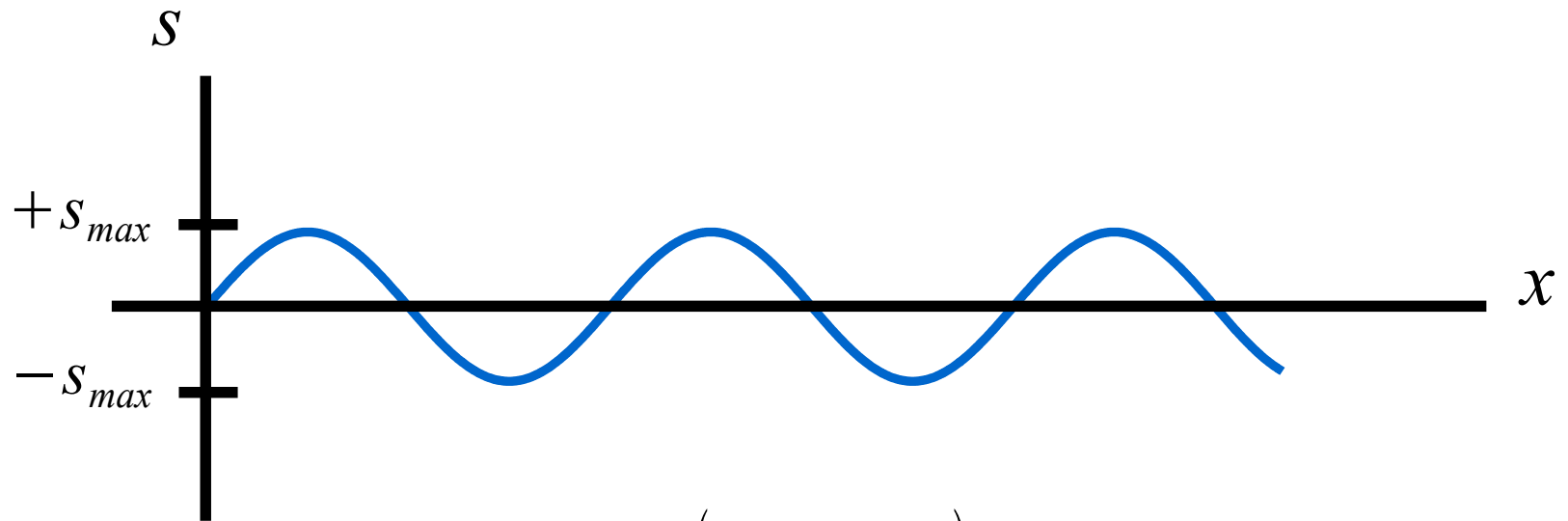
$+S_{max}$

$-S_{max}$

x



$$\Delta P = \Delta P_{max} \cos(kx - \omega t)$$



$$s = s_{max} \sin(kx - \omega t)$$

Doppler Shift

$v \equiv$ Speed of sound $\approx 343 \text{ m/s}$

$v_o \equiv$ Speed of Observer

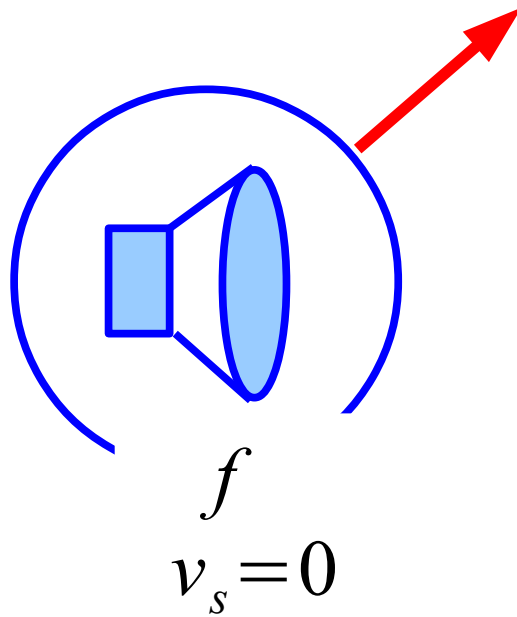
$v_s \equiv$ Speed of Source

$f \equiv$ Actual Frequency of the Source

$f' \equiv$ Observed Frequency by the Observer

$$f' = f$$

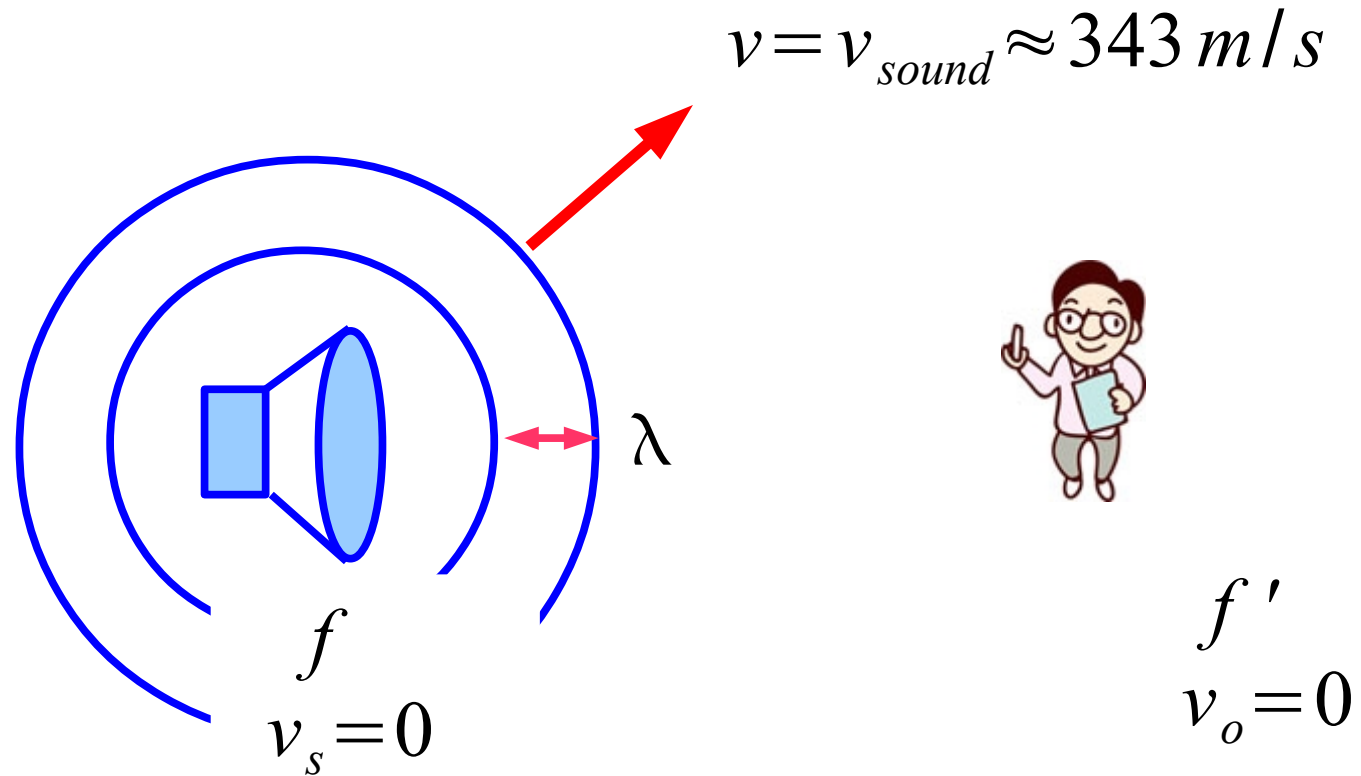
$$v = v_{\text{sound}} \approx 343 \text{ m/s}$$



$$f'$$
$$v_o = 0$$

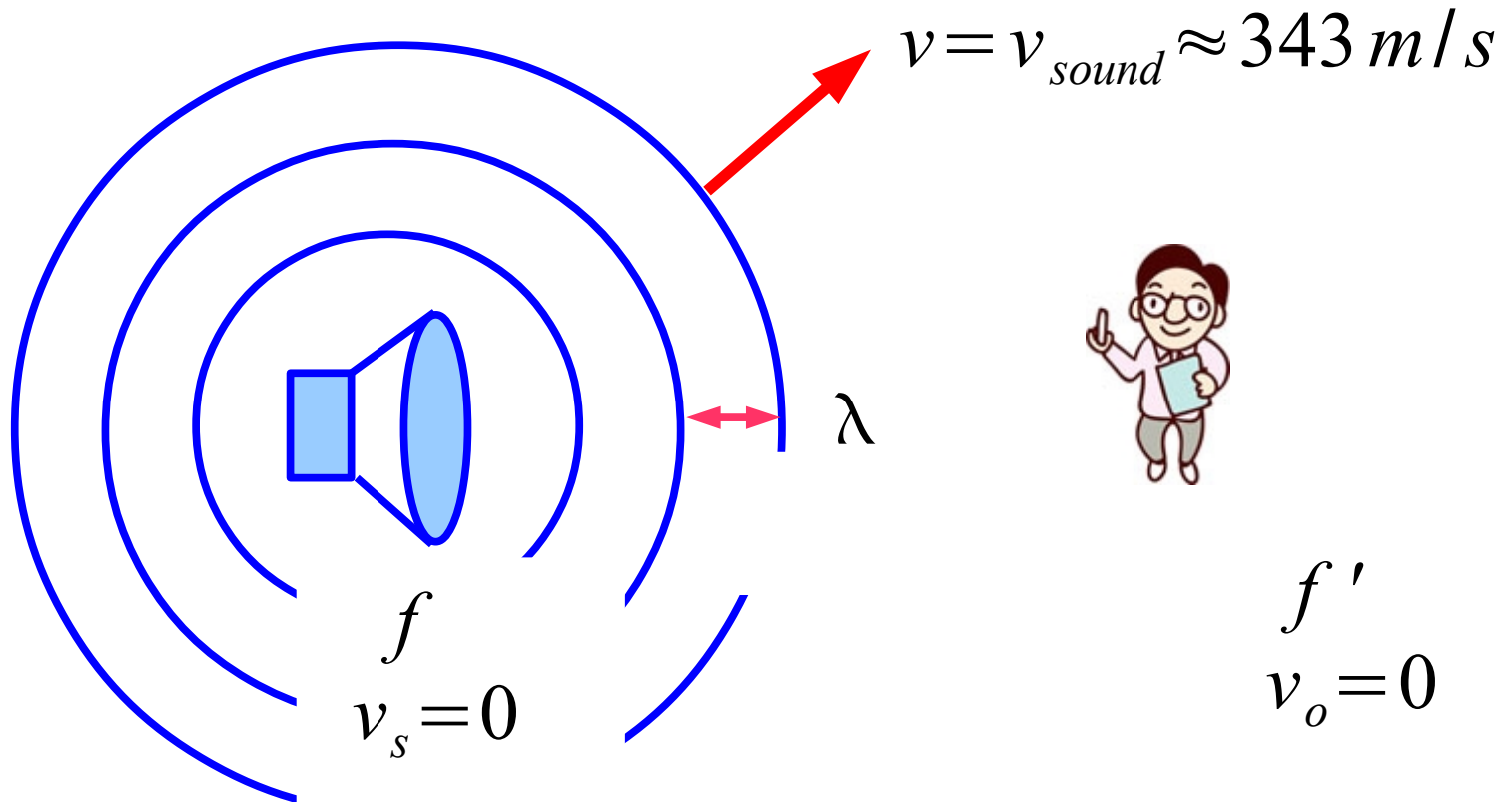
**Observer at rest,
Source at rest.**

$$f' = f$$

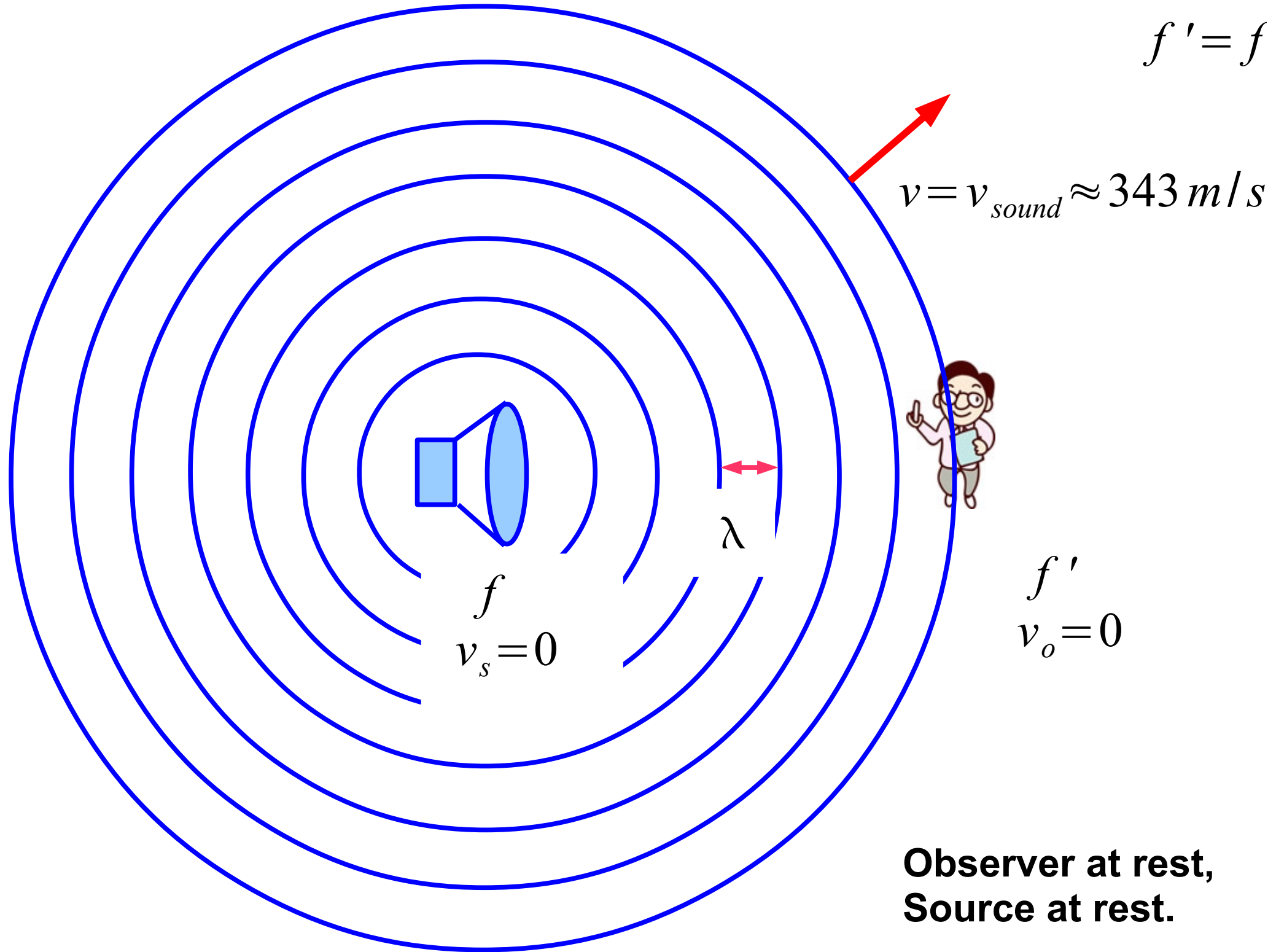


**Observer at rest,
Source at rest.**

$$f' = f$$



**Observer at rest,
Source at rest.**



$$f' = f$$

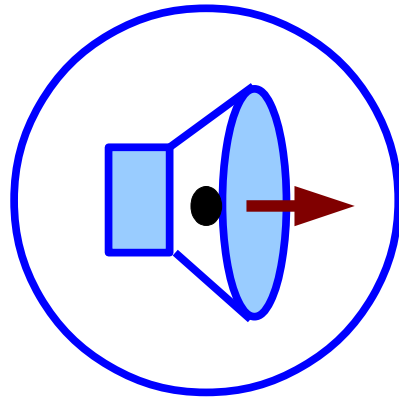
$$v = v_{sound} \approx 343 m/s$$

$$f$$
$$v_s = 0$$

$$\lambda$$

$$f'$$
$$v_o = 0$$

**Observer at rest,
Source at rest.**

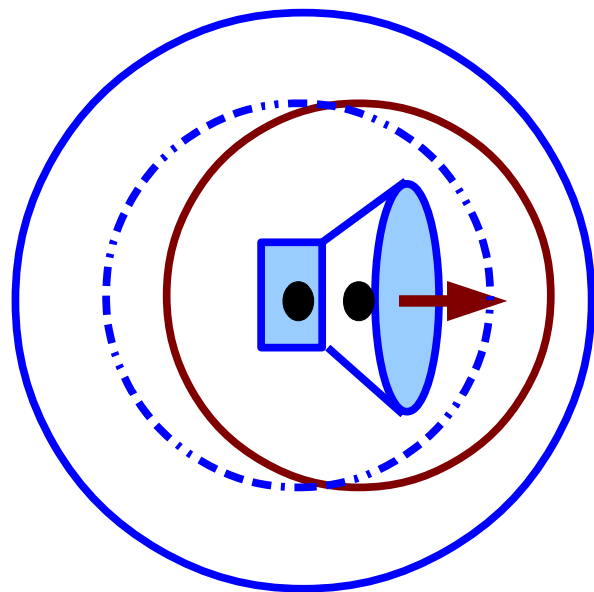


$$f$$
$$v_s \neq 0$$

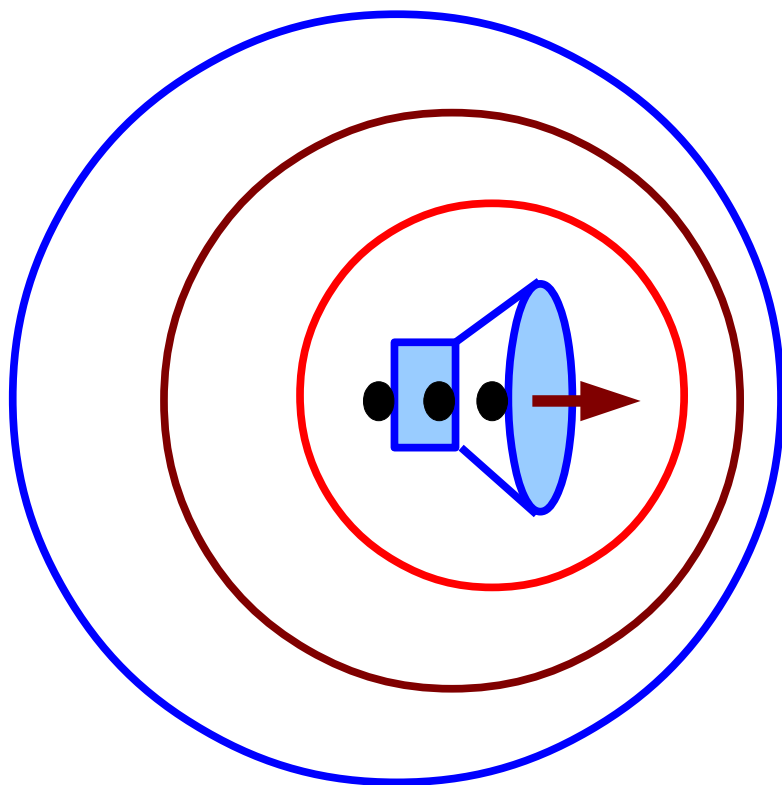


$$f'$$
$$v_o = 0$$

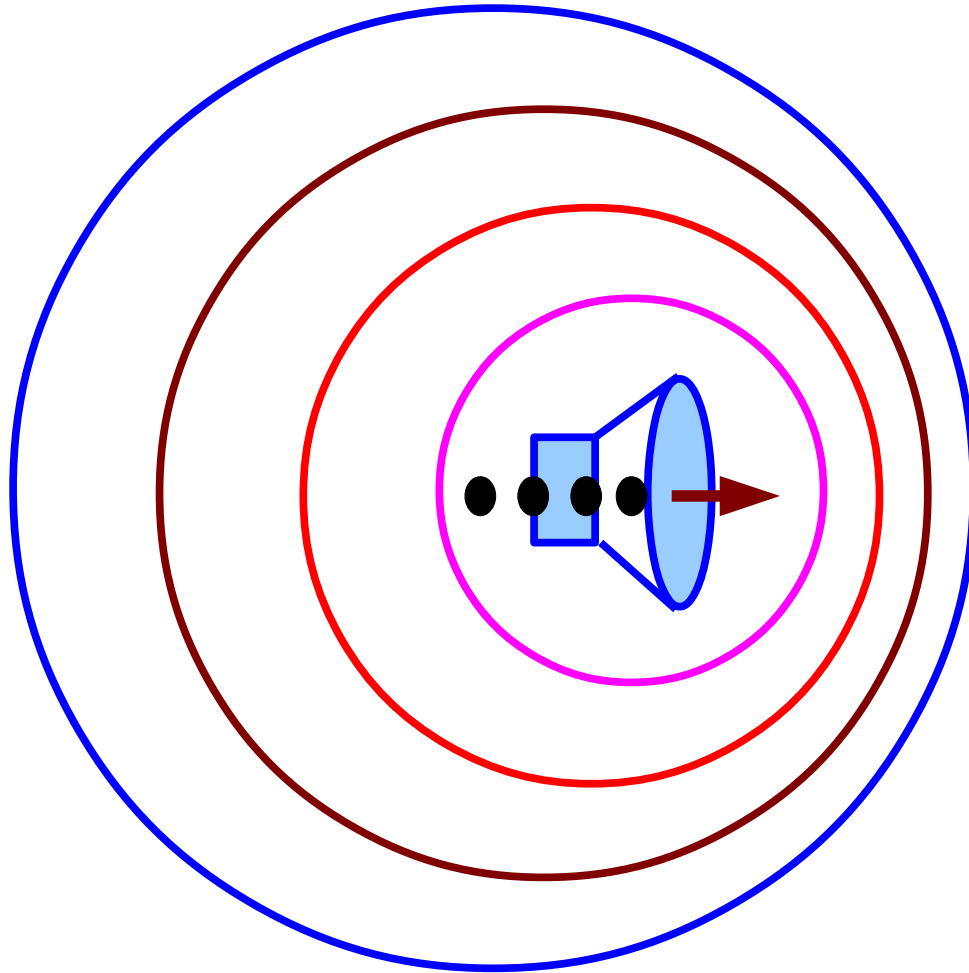
**Observer at rest,
Source moving
towards observer.**



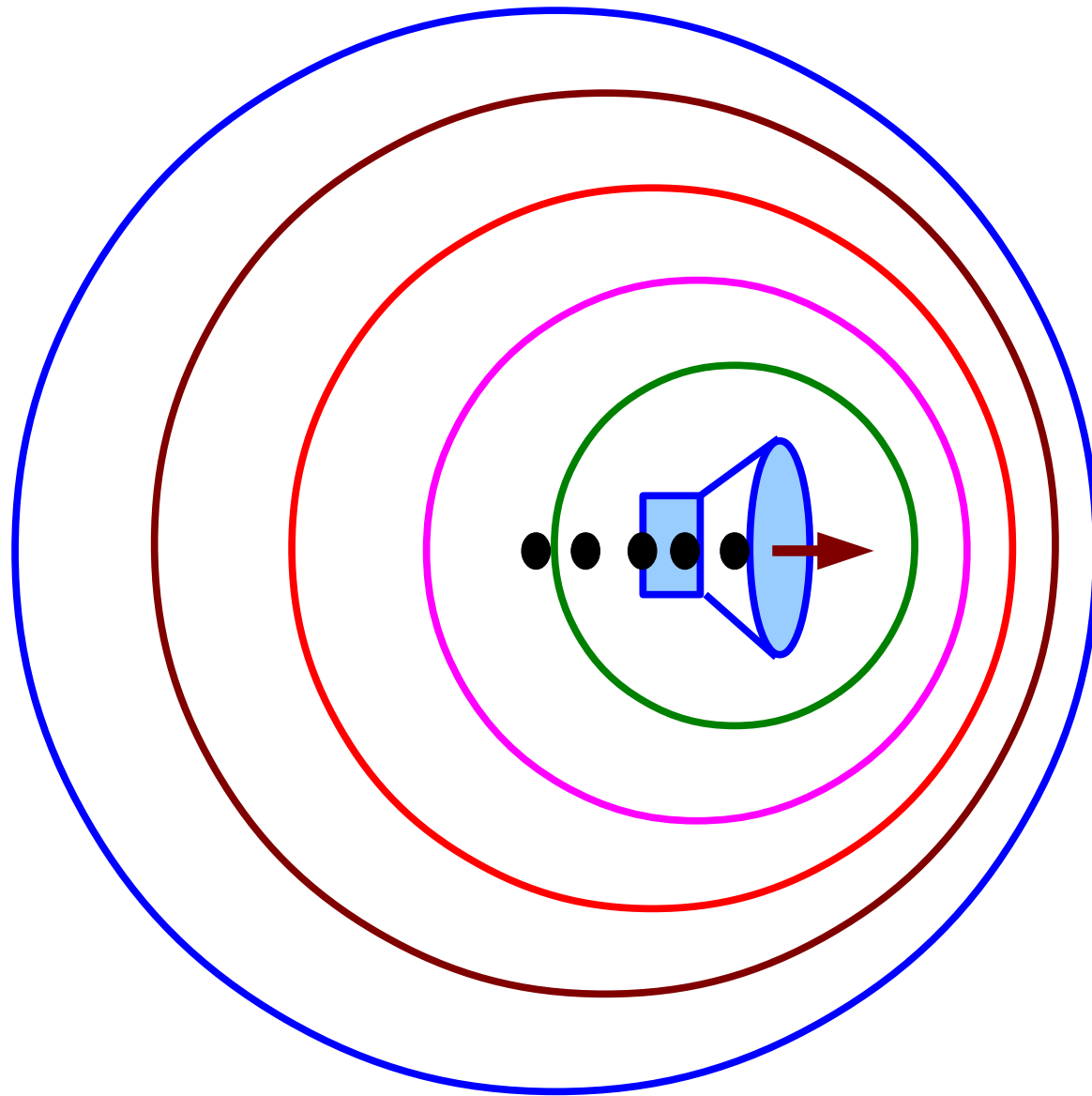
$$f'$$
$$v_o = 0$$



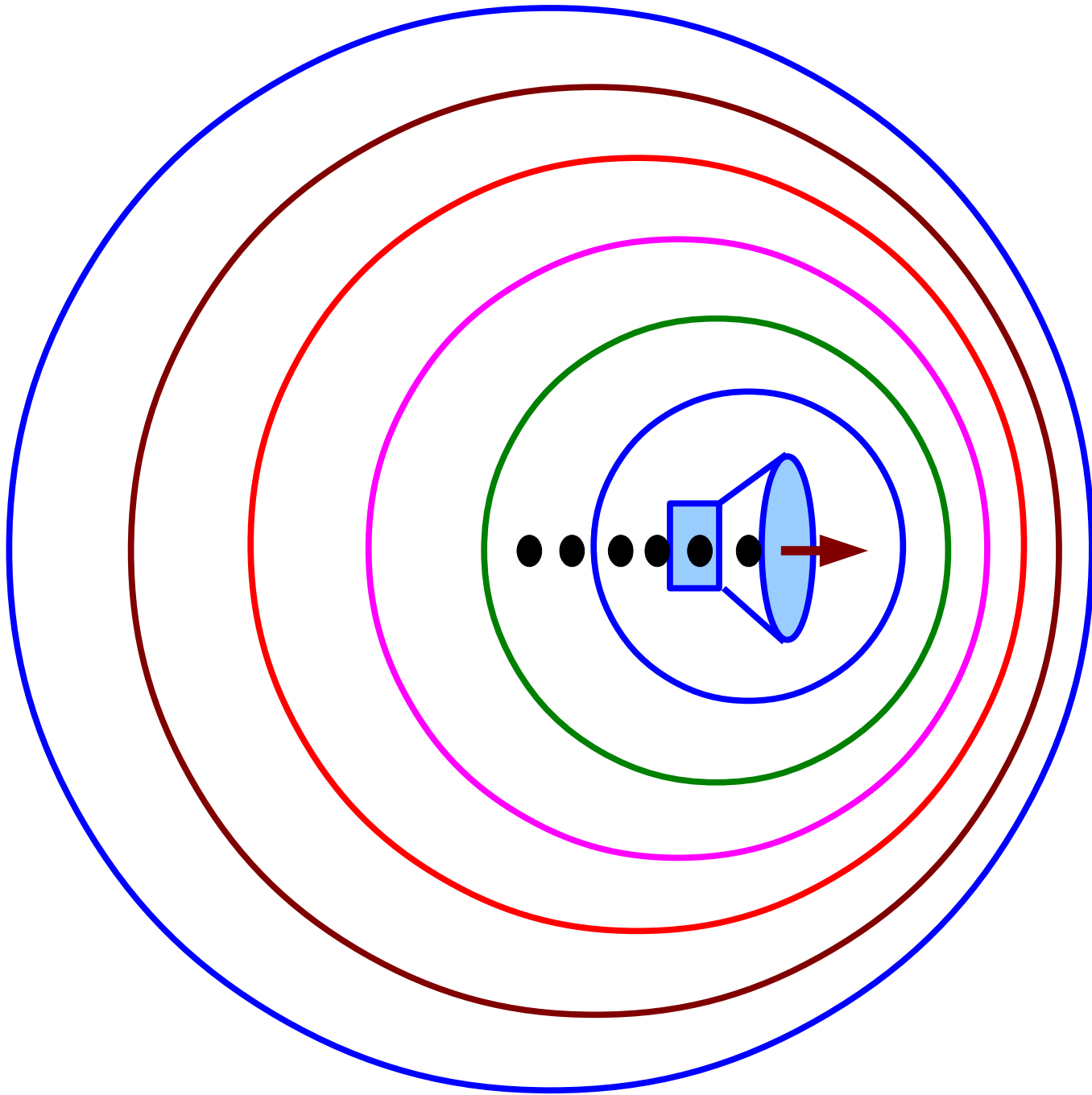
$$f'$$
$$v_o = 0$$



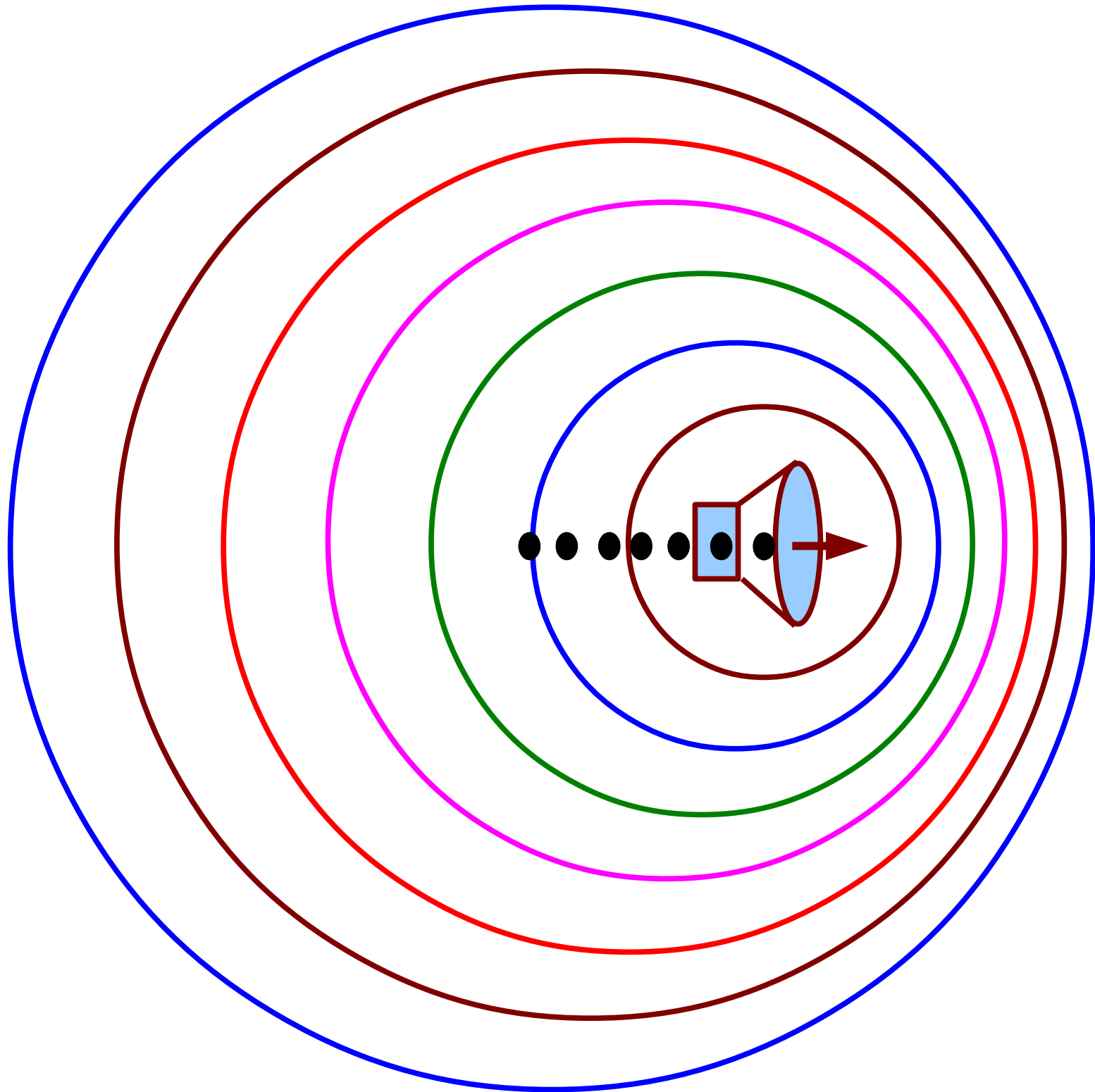
$$f'$$
$$v_o = 0$$



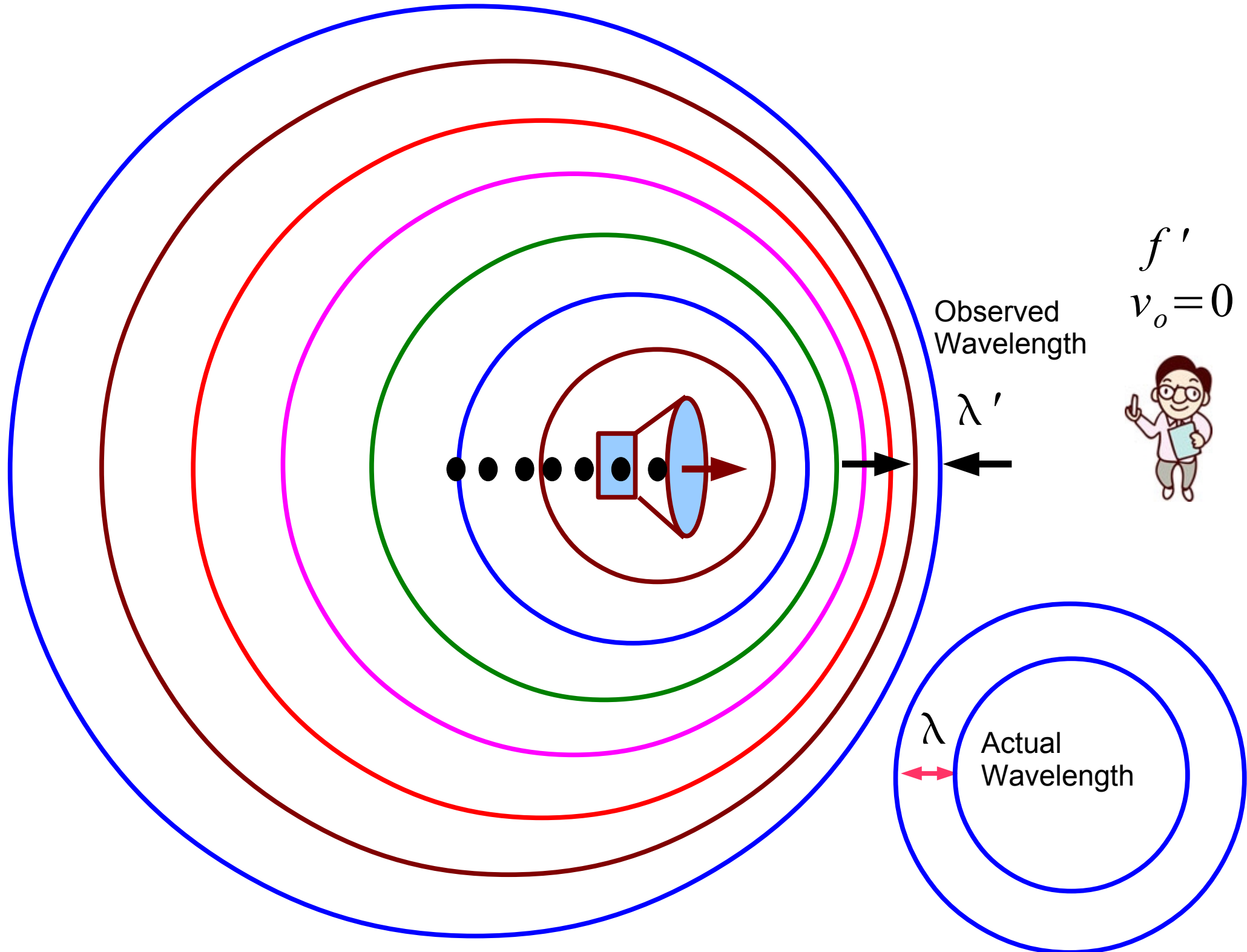
$$f'$$
$$v_o = 0$$



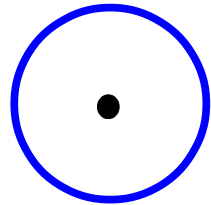
$$f'$$
$$v_o = 0$$



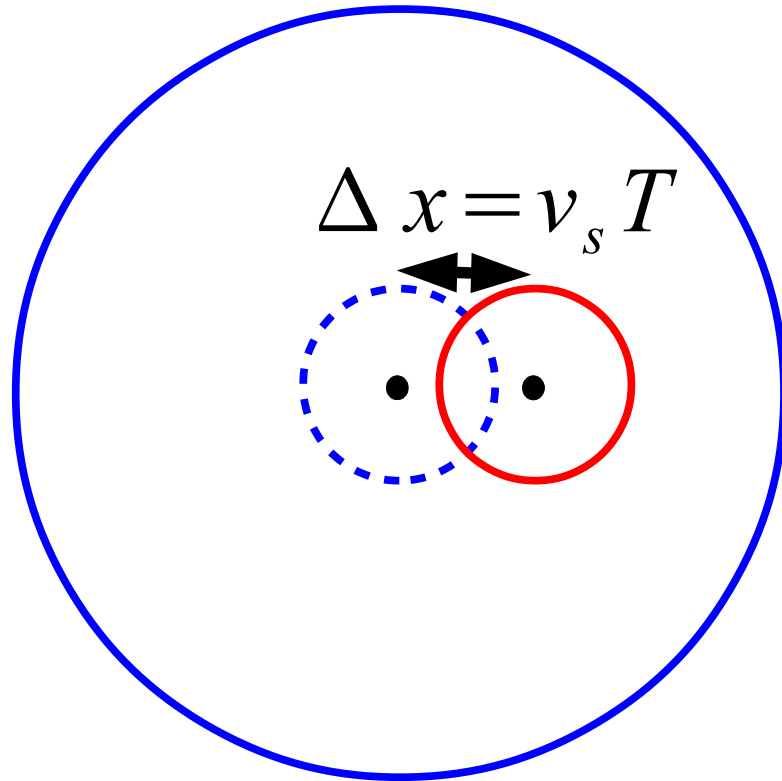
$$f'$$
$$v_o = 0$$



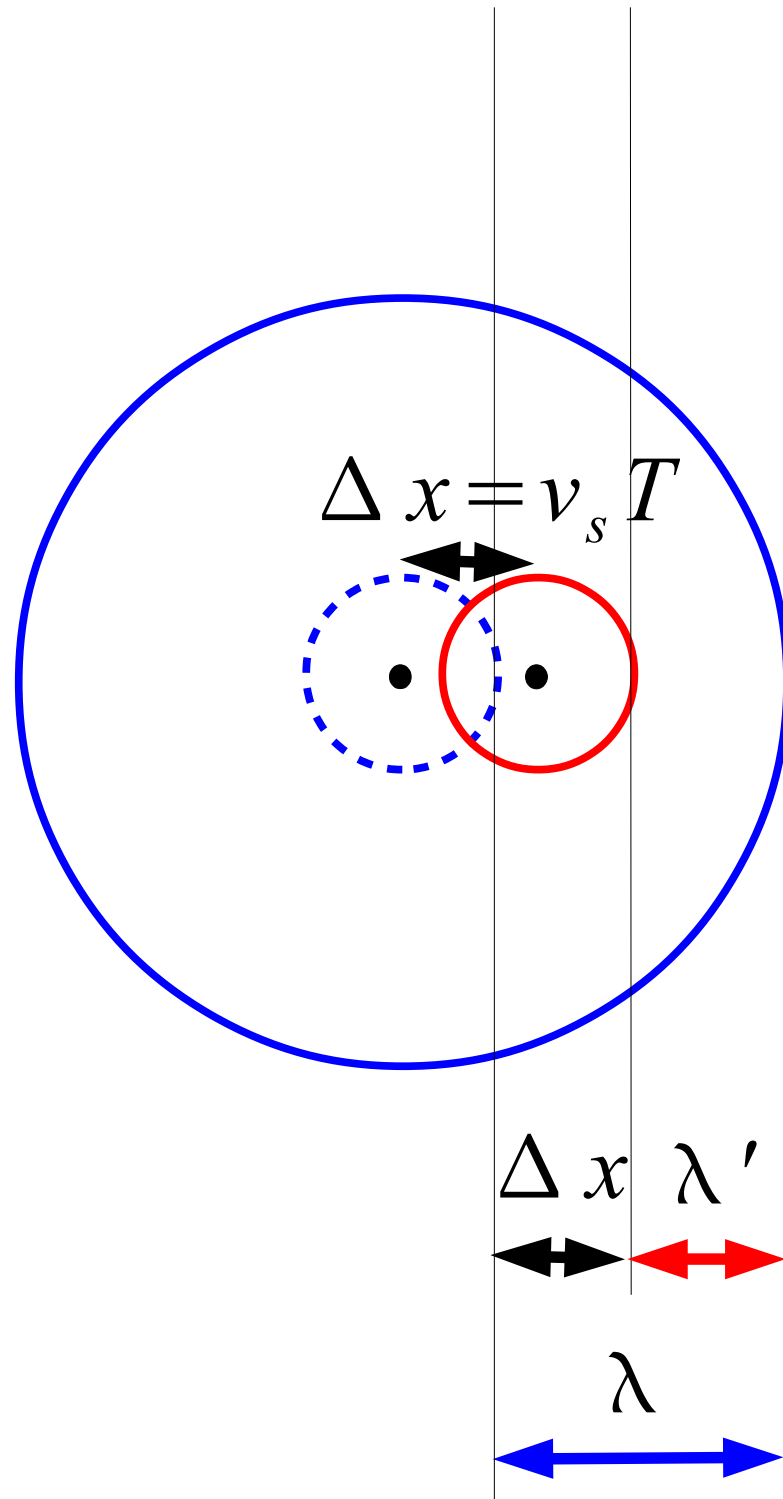
Picture taken every T .



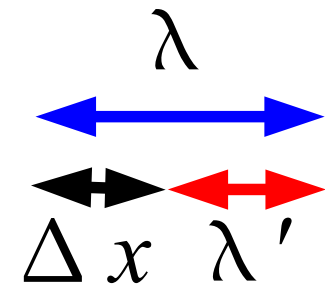
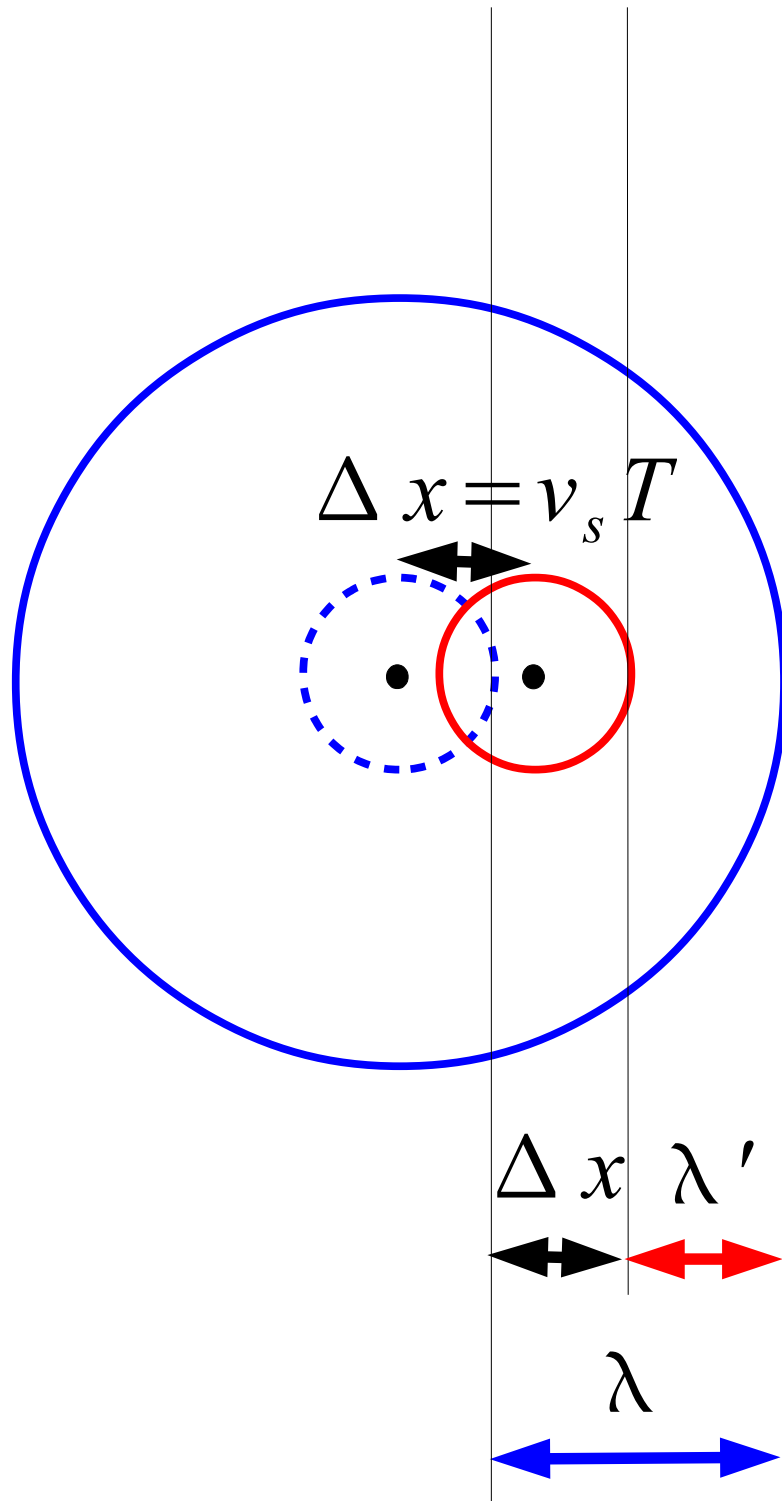
Picture taken every T .



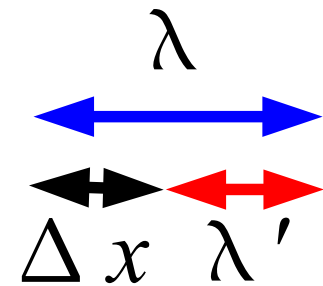
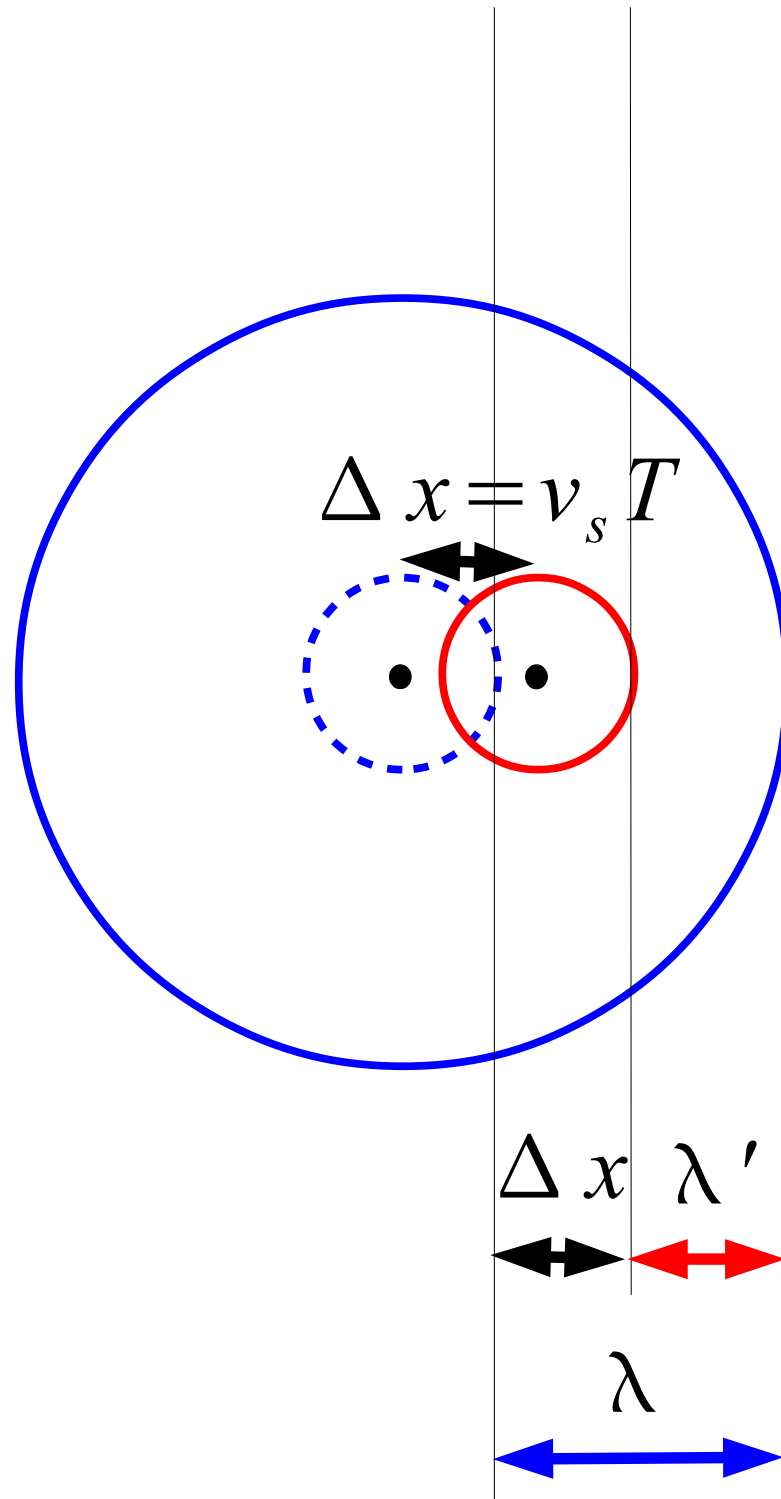
Picture taken every T .



Picture taken every T .



Picture taken every T .

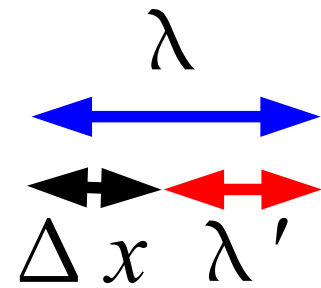
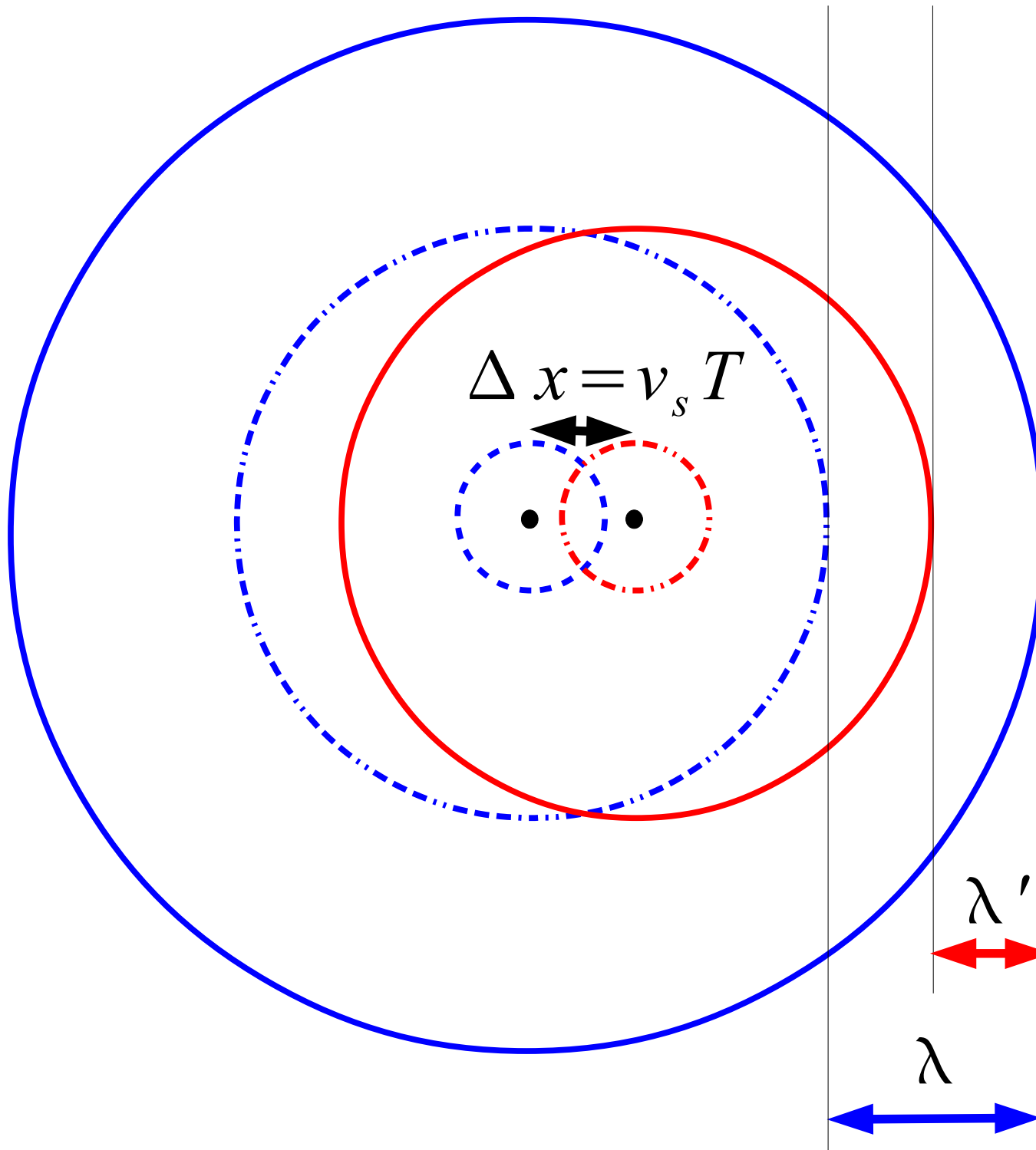


$$\lambda = \lambda' + \Delta x$$

$$\lambda' = \lambda - \Delta x$$

$$\lambda' = \lambda - v_s T$$

Picture taken every T .



$$\lambda = \lambda' + \Delta x$$

$$\lambda' = \lambda - \Delta x$$

$$\lambda' = \lambda - v_s T$$

Doppler Shift – Source approaching the Observer

$$\lambda' = \lambda - v_s T = \lambda - \frac{v_s}{f}$$

$$f' = \frac{v}{\lambda'} = \frac{v}{\lambda - \frac{v_s}{f}} = \frac{v}{\frac{\lambda f - v_s}{f}} = f \left[\frac{v}{v - v_s} \right]$$

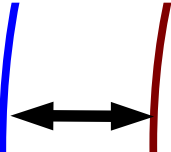
$$f' = f \left[\frac{v}{v - v_s} \right]$$

**Observer at rest,
Source moving
away from
observer.**

$$f'$$
$$v_o = 0$$

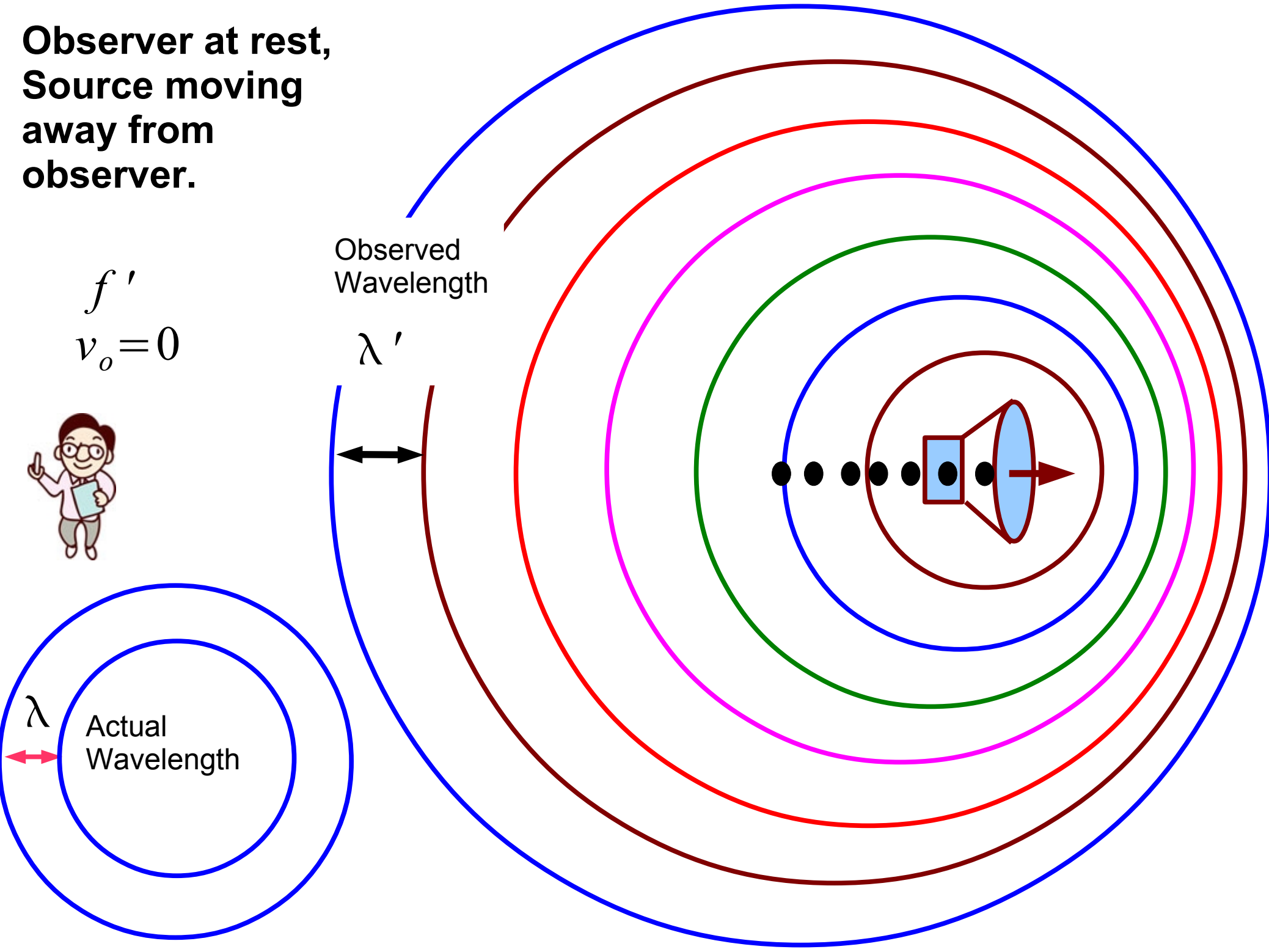
Observed
Wavelength

$$\lambda'$$



$$\lambda$$

Actual
Wavelength



Doppler Shift – Source receding from the Observer

$$\lambda' = \lambda + v_s T = \lambda + \frac{v_s}{f}$$

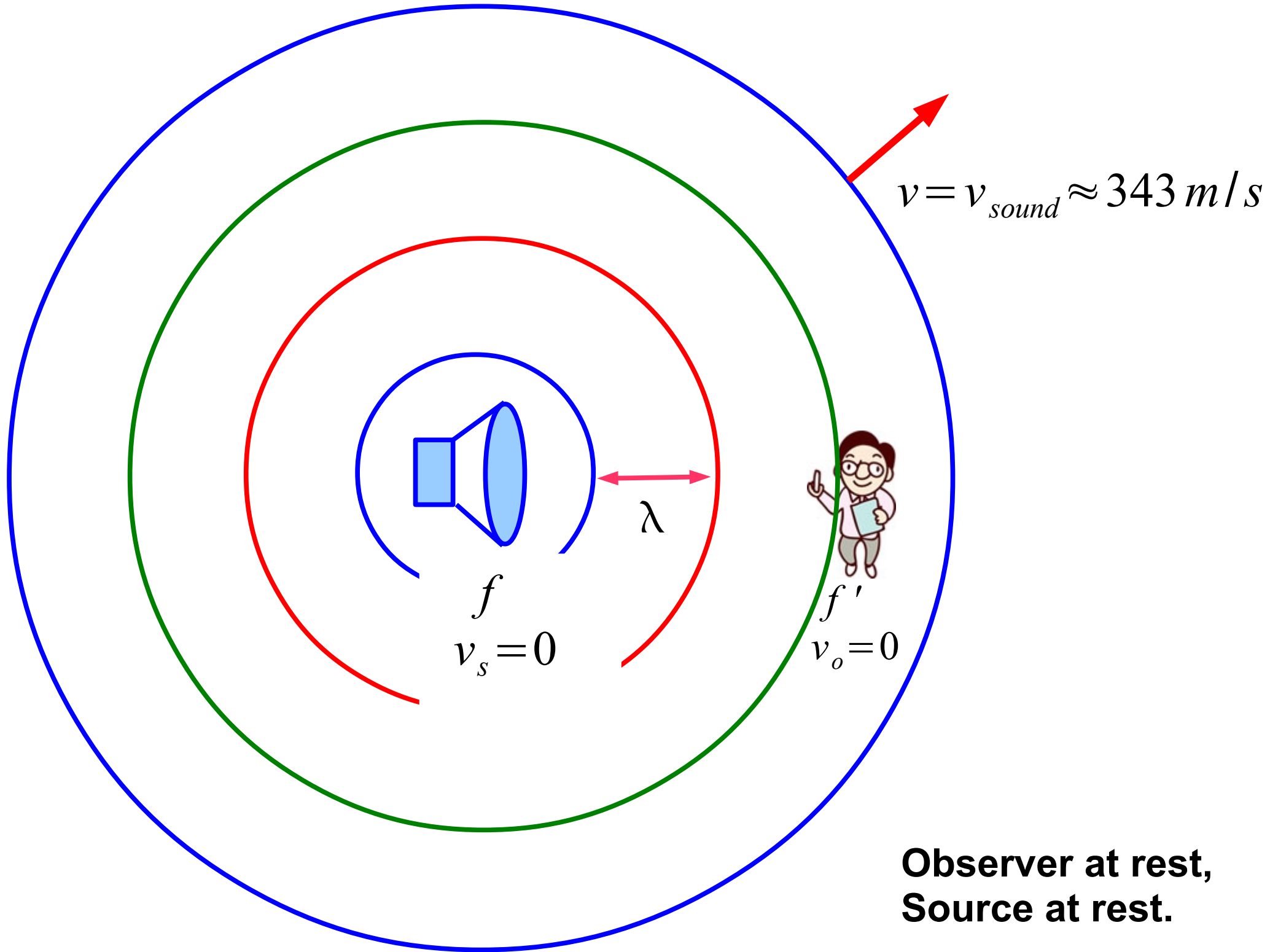
$$f' = \frac{v}{\lambda'} = \frac{v}{\lambda + \frac{v_s}{f}} = \frac{v}{\frac{\lambda f + v_s}{f}} = f \left[\frac{v}{v + v_s} \right]$$

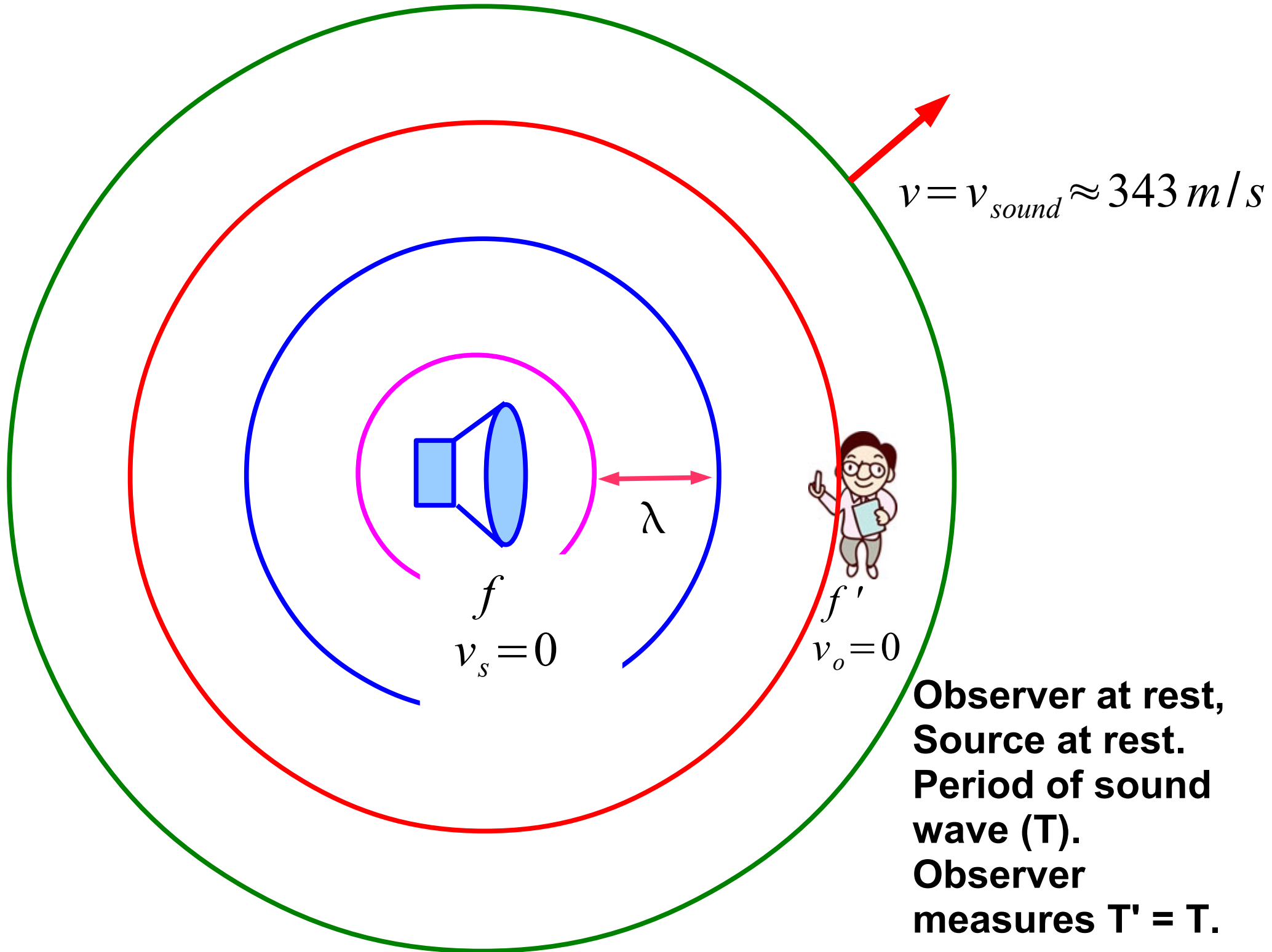
$$f' = f \left[\frac{v}{v + v_s} \right]$$

Doppler Shift – Source moving, observer at rest.

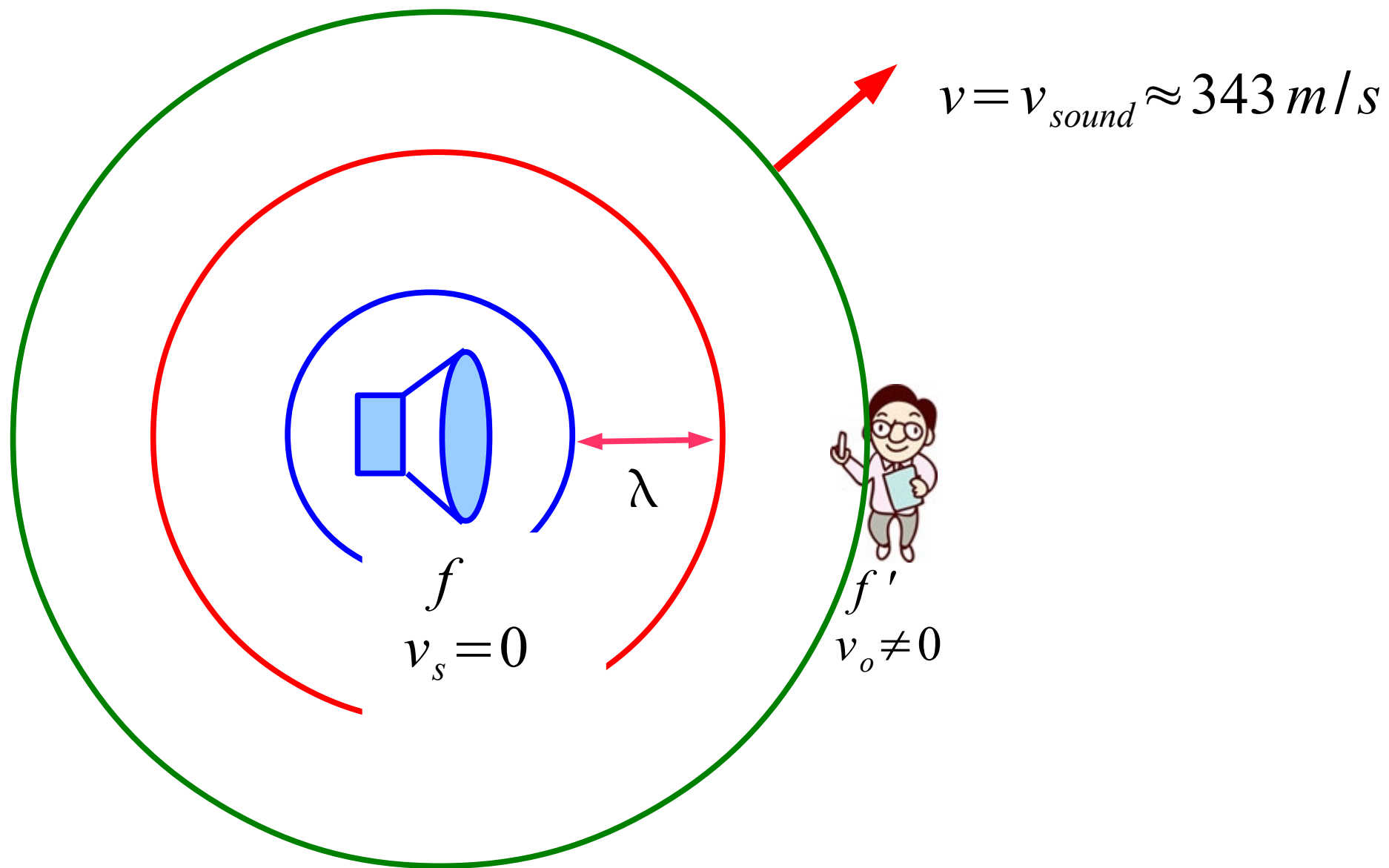
$$f' = f \left[\frac{v}{v \mp v_s} \right]$$

**Top sign for
approaching.**



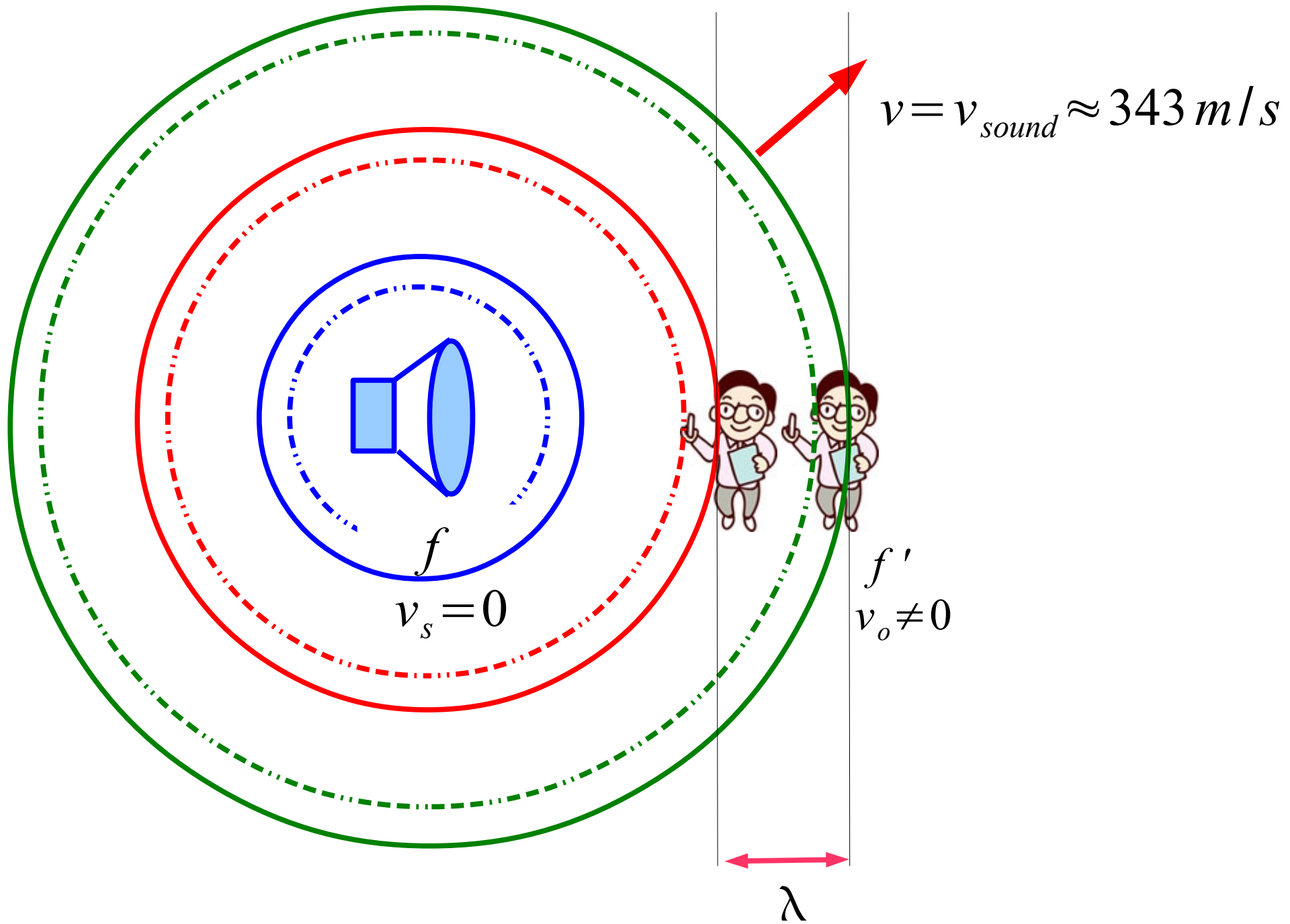


**Observer at rest,
Source at rest.
Period of sound
wave (T).
Observer
measures $T' = T$.**

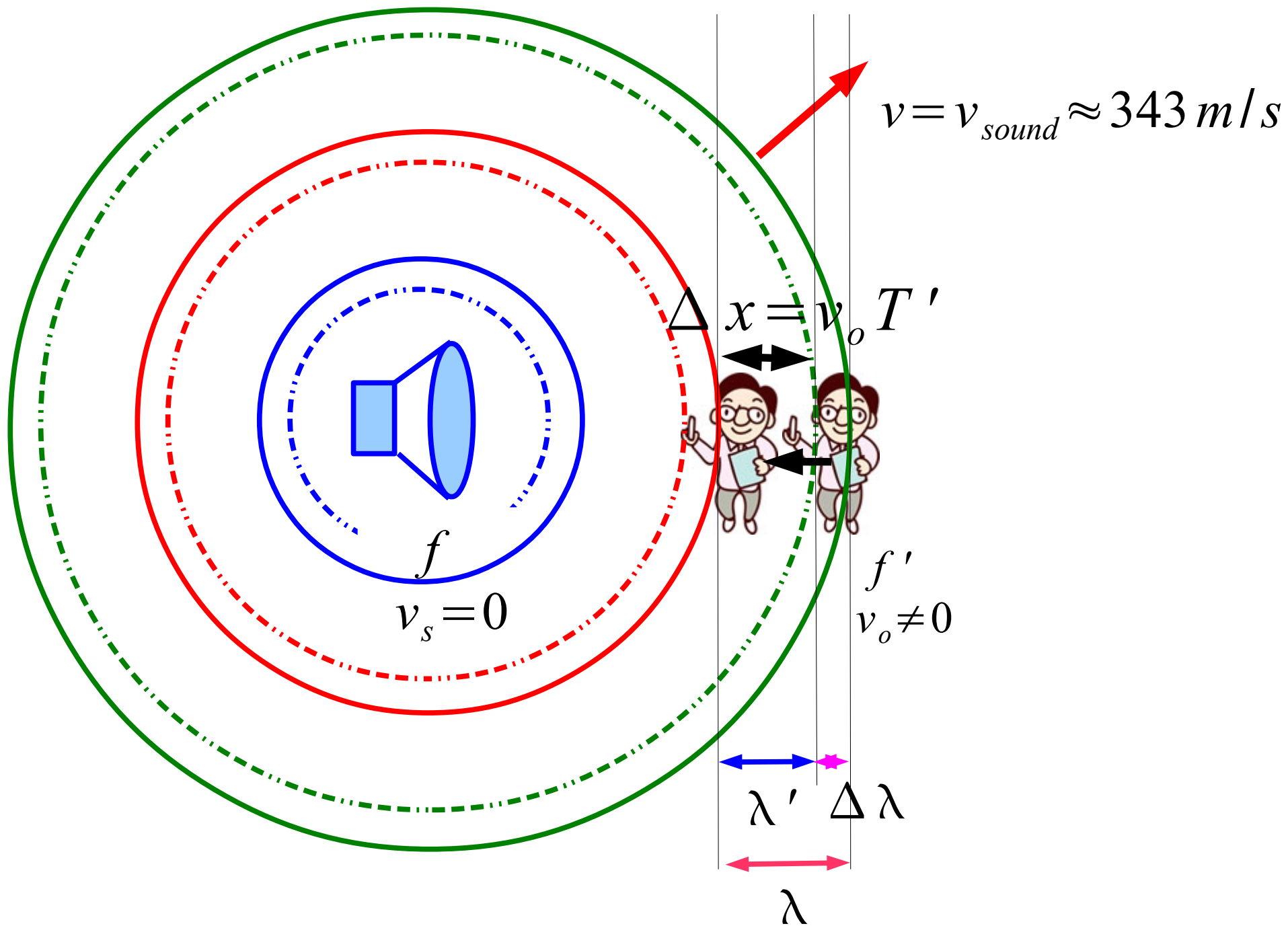


**Observer in motion,
Source at rest.**

**Observer in motion,
Source at rest.**



**Observer in motion,
Source at rest.**



Doppler Shift – Observer approaching Source.

$$\lambda' = \lambda - \Delta \lambda$$

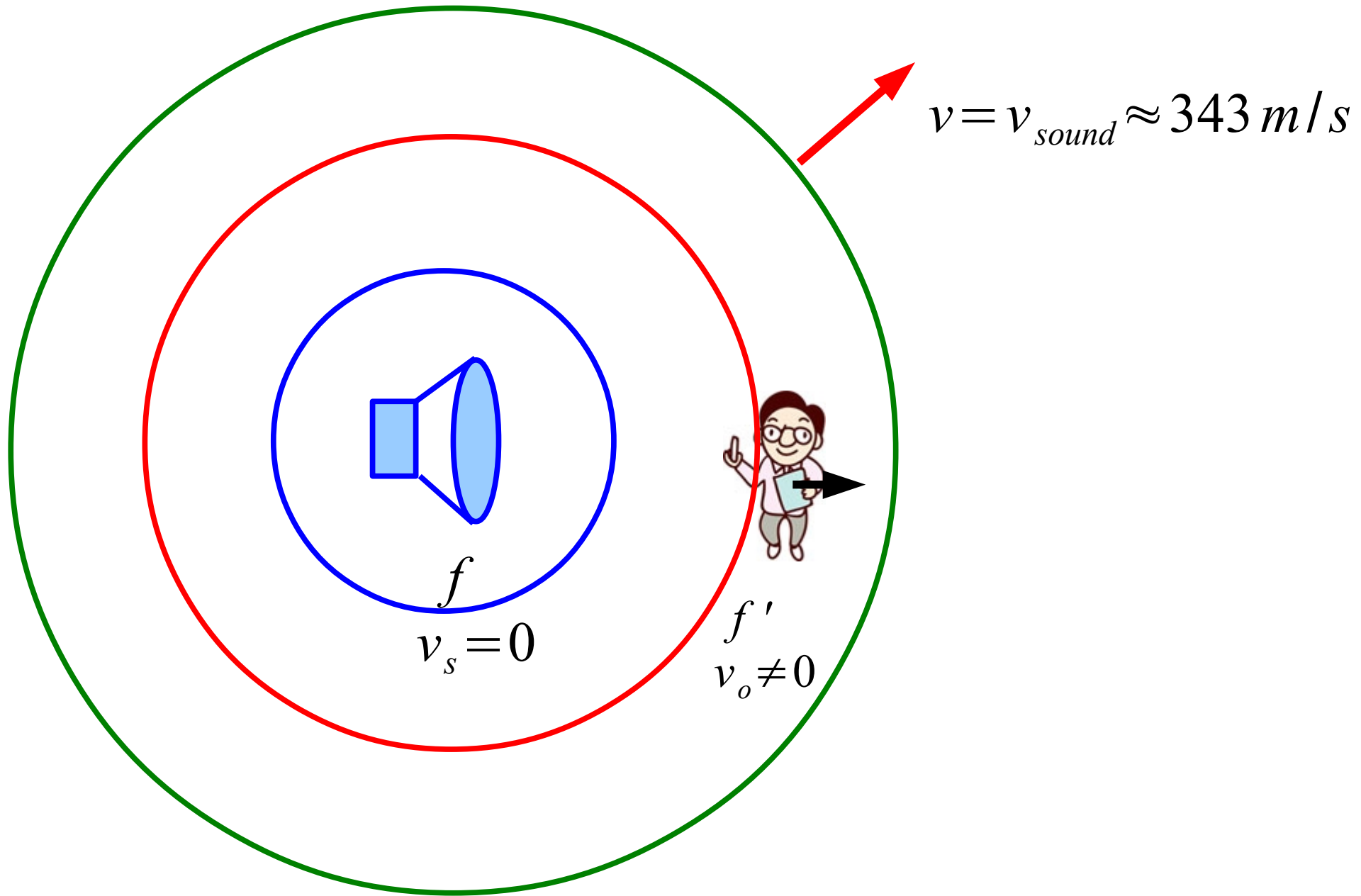
$$v_o T' = v T - v T'$$

$$(v + v_o) T' = v T$$

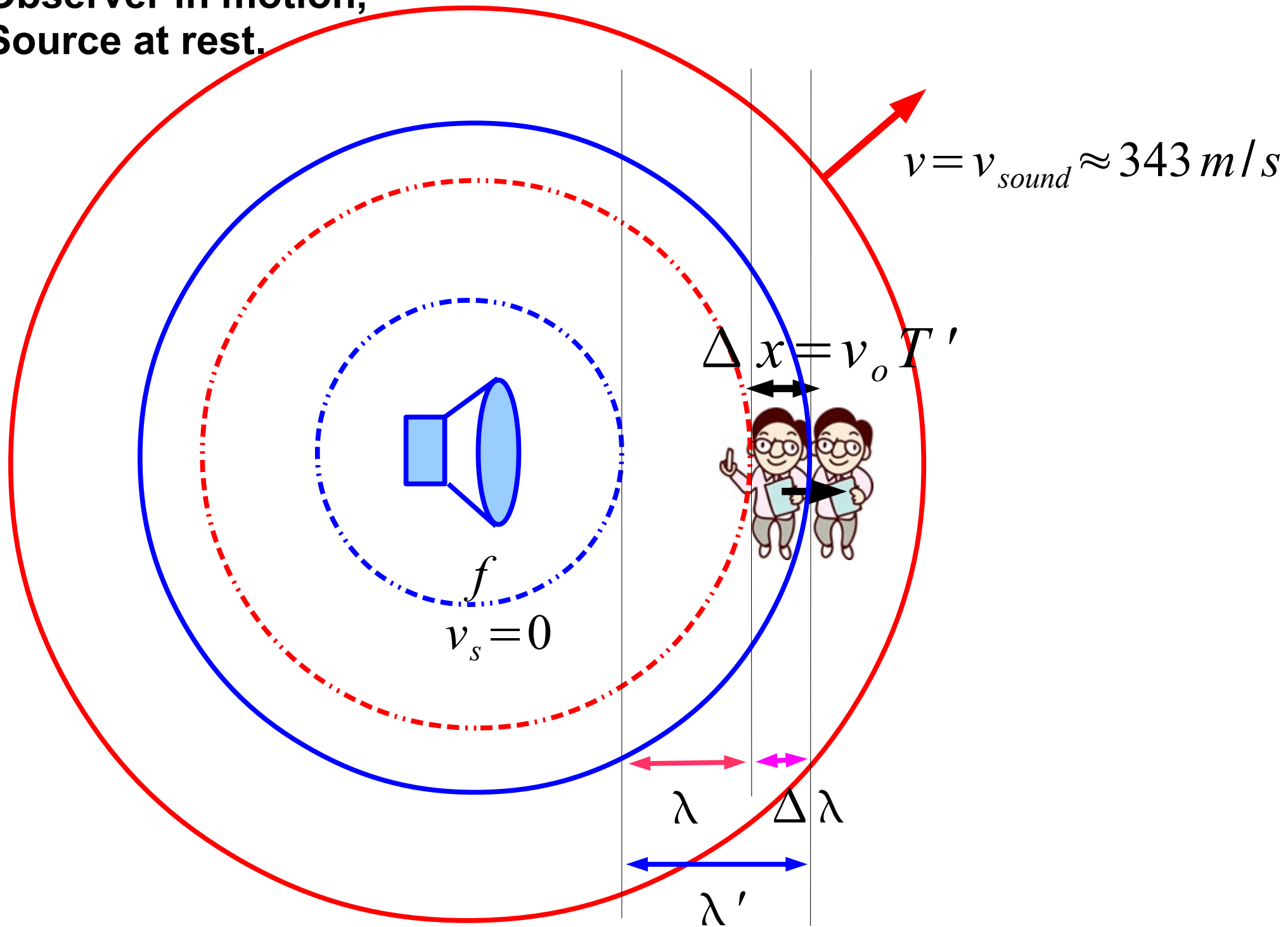
$$(v + v_o) \frac{1}{f'} = \frac{v}{f}$$

$$f' = \left[\frac{v + v_o}{v} \right] f$$

**Observer in motion,
Source at rest.**



**Observer in motion,
Source at rest.**



Doppler Shift – Observer receding from Source.

$$\lambda' = \lambda + \Delta \lambda$$

$$v_o T' = v T + v T'$$

$$(v - v_o) T' = v_o T$$

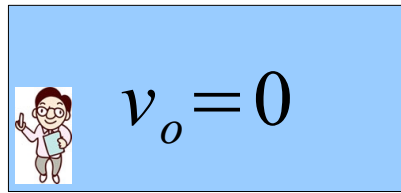
$$(v - v_o) \frac{1}{f'} = \frac{v}{f}$$

$$f' = \left[\frac{v - v_o}{v} \right] f$$

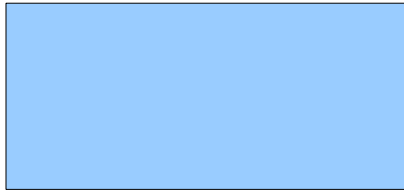
Doppler Shift

$$f' = \left[\frac{v \pm v_o}{v \mp v_s} \right] f$$

**Top sign for approaching,
bottom sign for receding.**



$f = 100 \text{ kHz}$  $v_s = 60 \text{ mph}$

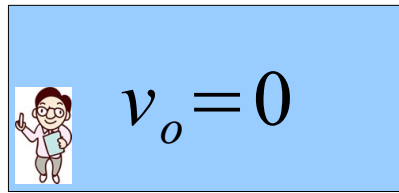


$$v_s = 60 \frac{\text{mi}}{\text{h}} \left(\frac{1609 \text{ m}}{1 \text{ mi}} \right) \left(\frac{1 \text{ h}}{3600 \text{ s}} \right) = 26.8 \frac{\text{m}}{\text{s}}$$

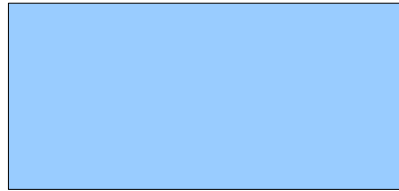
$$v \approx 343 \frac{\text{m}}{\text{s}}$$

$$f' = \left[\frac{v \pm v_o}{v \mp v_s} \right] f \quad \text{Top sign approaching.}$$

$$f' = \left[\frac{343 \text{ m/s} + 0 \text{ m/s}}{343 \text{ m/s} - 26.8 \text{ m/s}} \right] 100 \text{ kHz} = 108.5 \text{ kHz}$$



$f = 100 \text{ kHz}$  $v_s = 60 \text{ mph}$



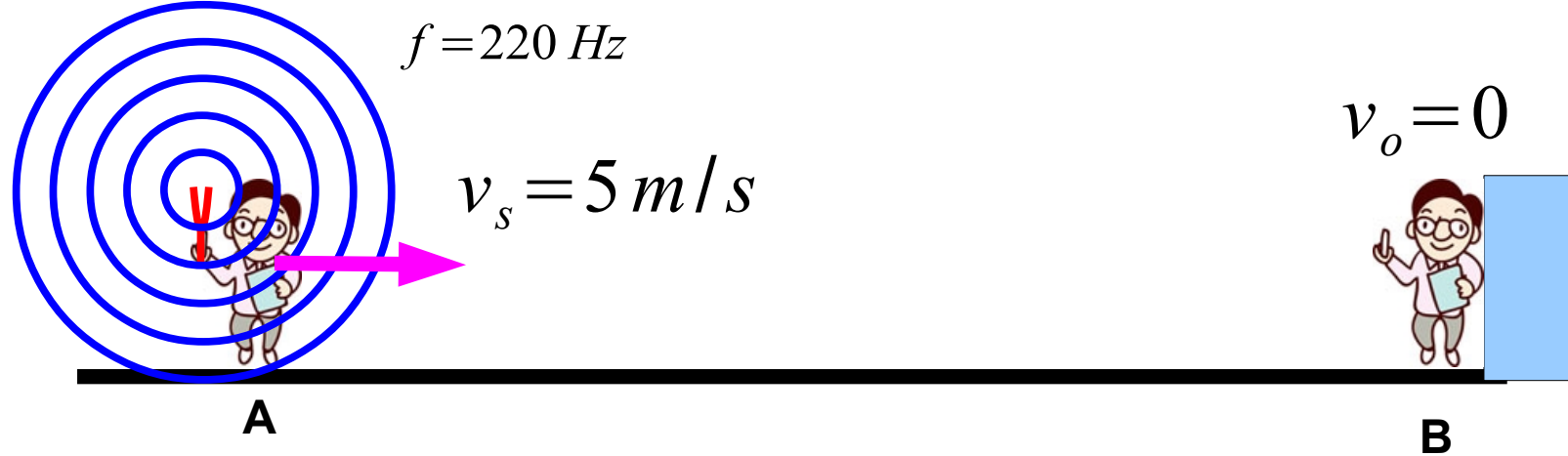
$$v_s = 60 \frac{\text{mi}}{\text{h}} \left(\frac{1609 \text{ m}}{1 \text{ mi}} \right) \left(\frac{1 \text{ h}}{3600 \text{ s}} \right) = 26.8 \frac{\text{m}}{\text{s}}$$

$$v \approx 343 \frac{\text{m}}{\text{s}}$$

$$f' = \left[\frac{v \pm v_o}{v \mp v_s} \right] f \quad \text{Bottom sign receding.}$$

$$f' = \left[\frac{343 \text{ m/s} + 0 \text{ m/s}}{343 \text{ m/s} + 26.8 \text{ m/s}} \right] 100 \text{ kHz} = 92.8 \text{ kHz}$$

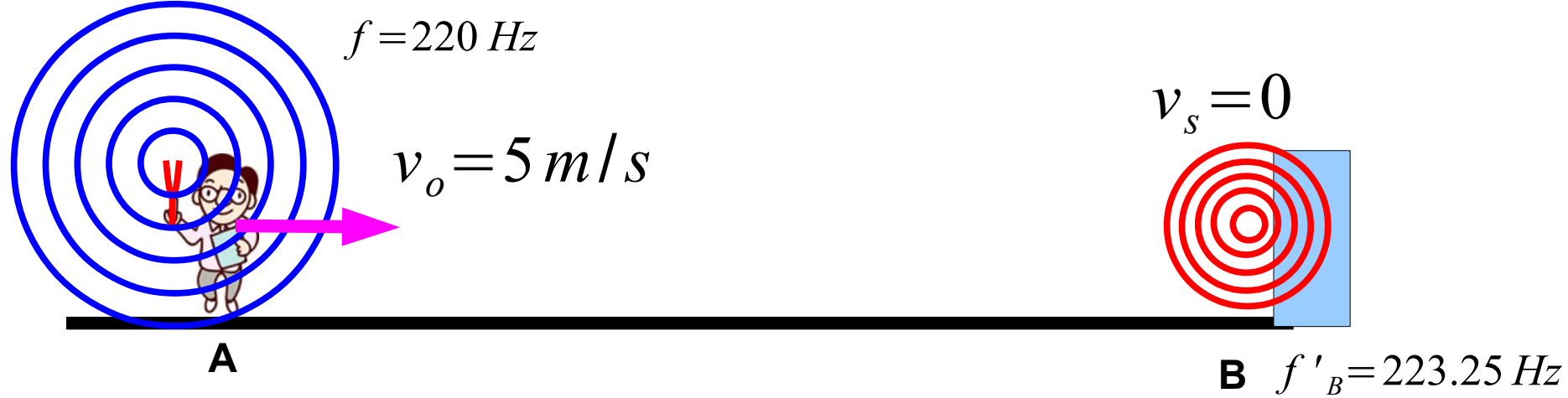




Student B is at rest at a hard wall. The apparent frequency Student B hears from the 220 Hz tuning fork that Student A is holding is:

$$f'_B = \left[\frac{v \pm v_o}{v \mp v_s} \right] f \quad \text{Top sign approaching.}$$

$$f'_B = \left[\frac{343 \text{ m/s} + 0 \text{ m/s}}{343 \text{ m/s} - 5 \text{ m/s}} \right] 220 \text{ Hz} = 223.25 \text{ Hz}$$



Student A hears the echo off the wall. The apparent frequency Student A hears from the echo off the wall:

$$f'_A = \left[\frac{v \pm v_o}{v \mp v_s} \right] f \quad \text{Top sign approaching.}$$

$$f'_A = \left[\frac{343 \text{ m/s} + 5 \text{ m/s}}{343 \text{ m/s} - 0 \text{ m/s}} \right] 223.25 \text{ Hz} = 226.50 \text{ Hz}$$



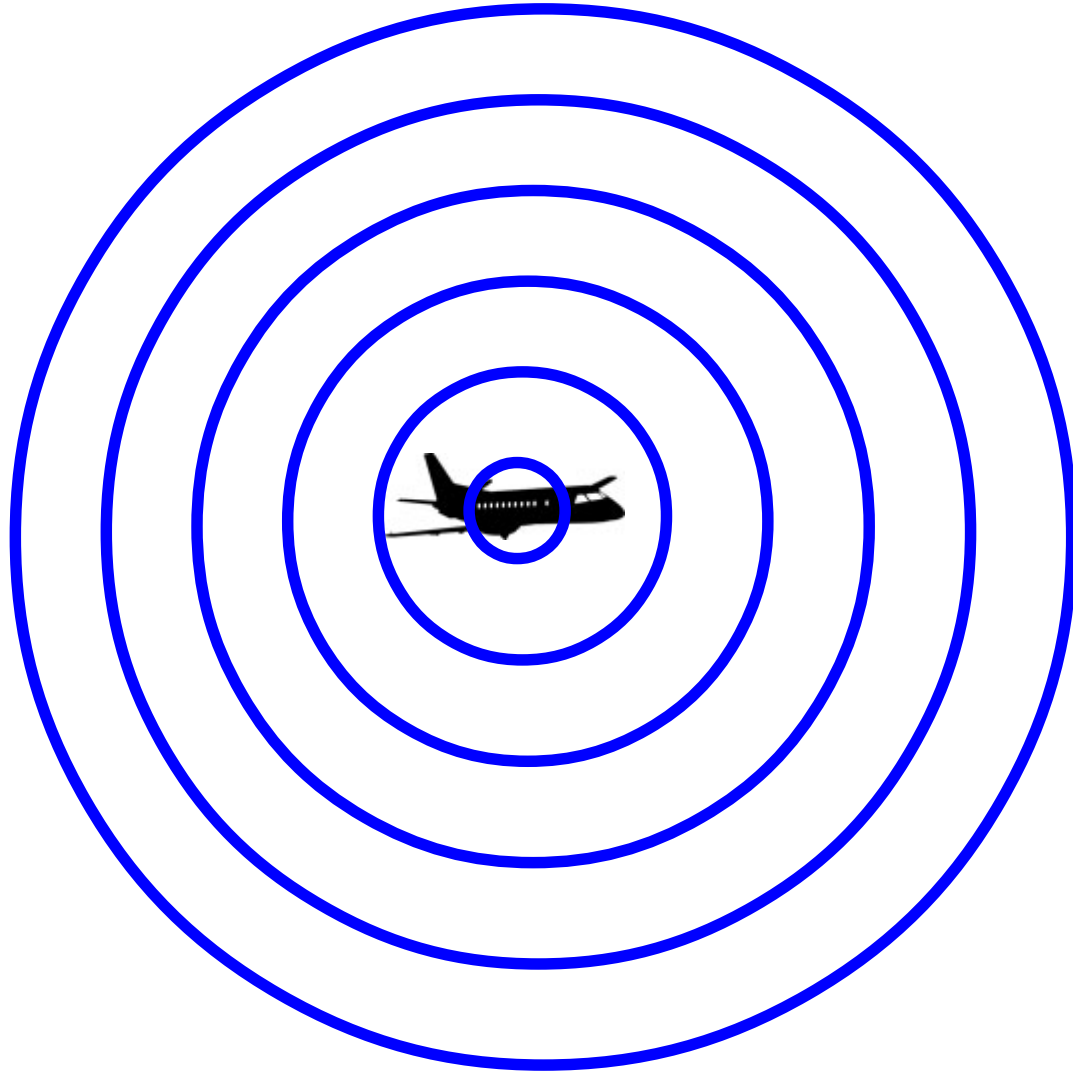
Student A hears the echo off the wall. Student A also hears the tuning fork he is holding. What is the beat frequency he hears?

$$f = 220 \text{ Hz}$$

$$f'_A = 226.50 \text{ Hz}$$

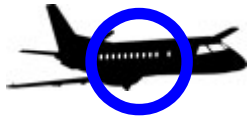
$$f_{\text{beat}} = |f'_A - f| = |226.5 \text{ Hz} - 220 \text{ Hz}| = 6.5 \text{ Hz}$$

Shock Waves and Sonic Booms



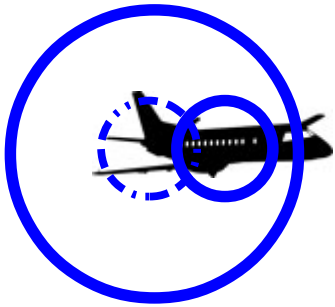
$$v_s = 0 \text{ m/s}$$

Shock Waves and Sonic Booms



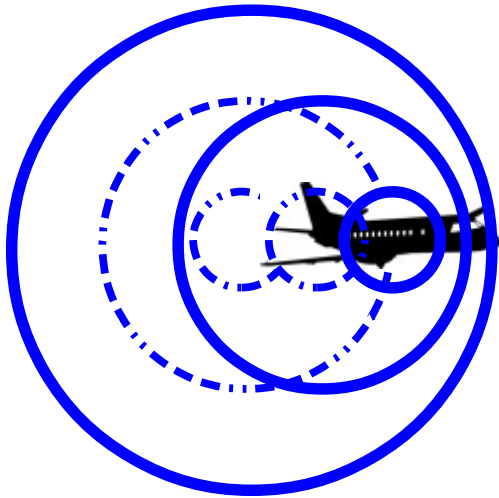
$$v_s < v_{\text{Sound}}$$

Shock Waves and Sonic Booms



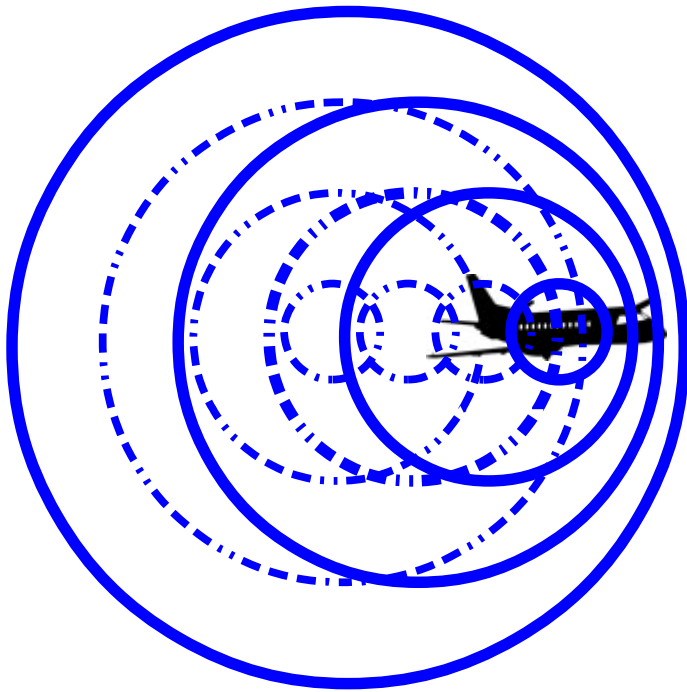
$$v_s < v_{\text{Sound}}$$

Shock Waves and Sonic Booms



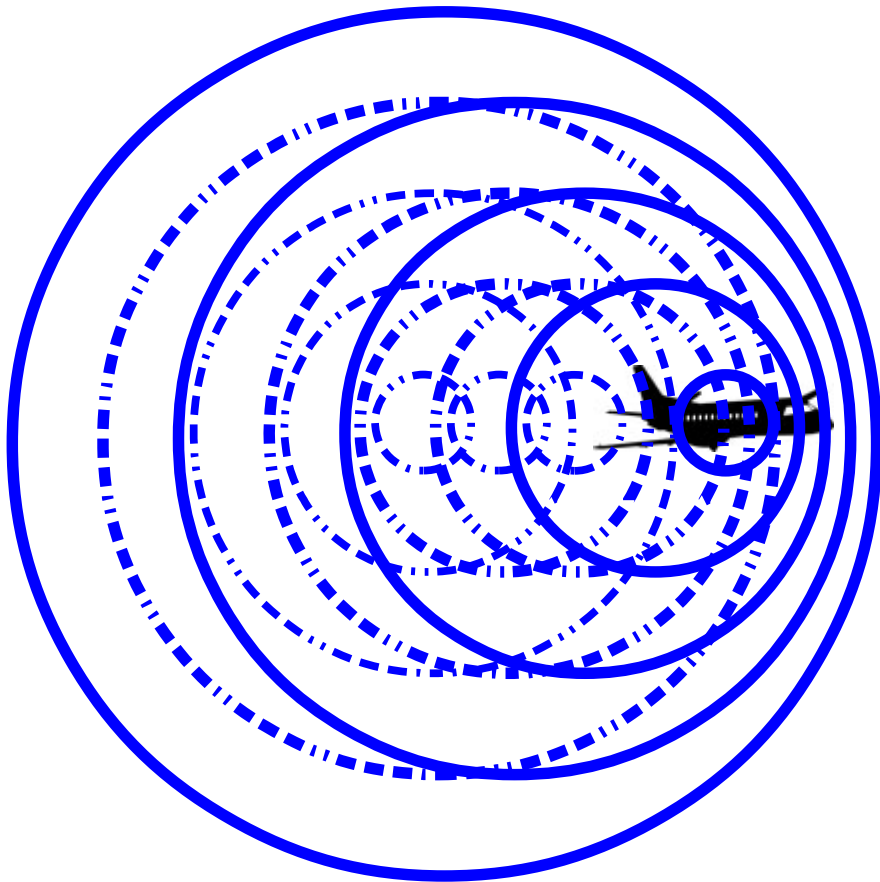
$$v_s < v_{\text{Sound}}$$

Shock Waves and Sonic Booms



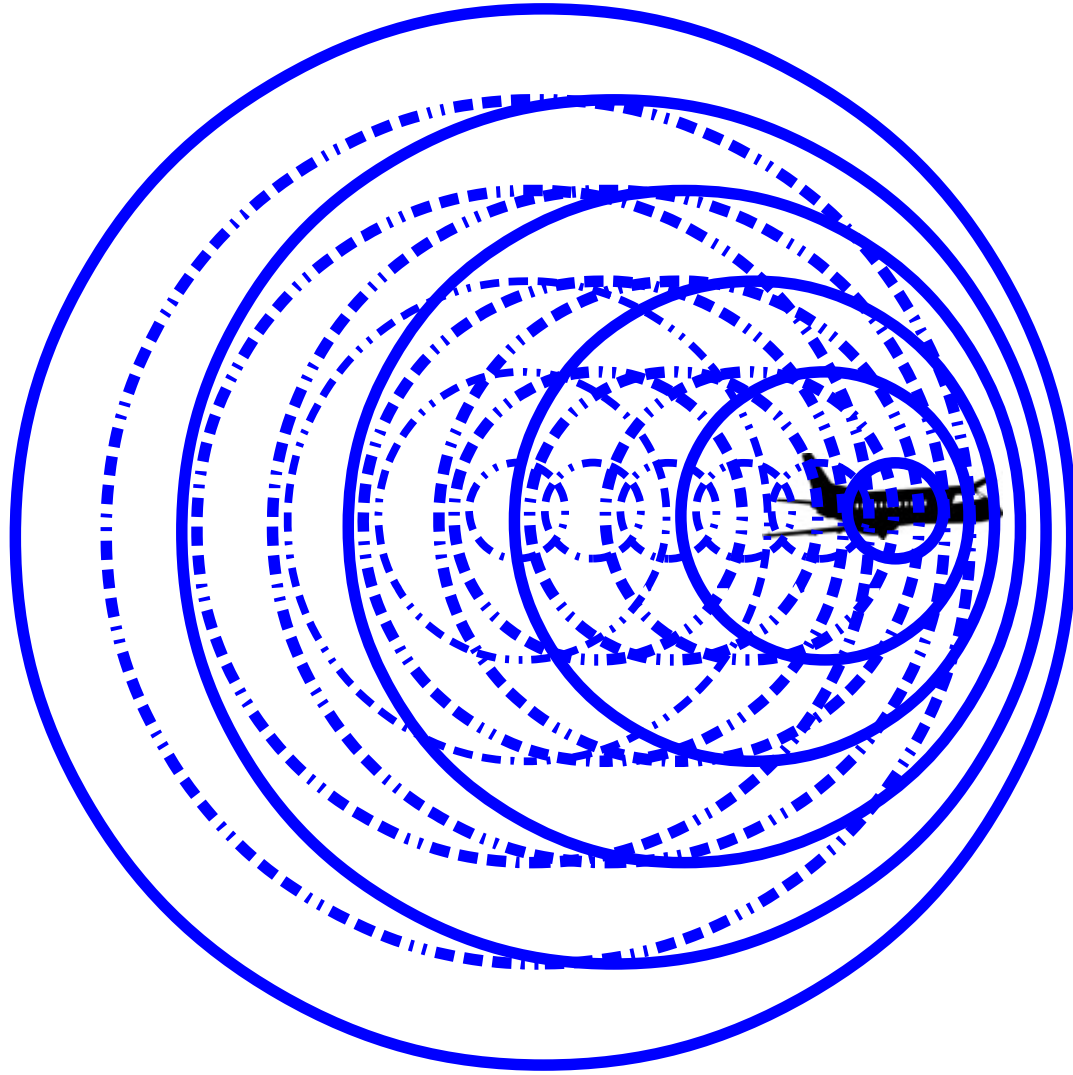
$$v_s < v_{\text{Sound}}$$

Shock Waves and Sonic Booms



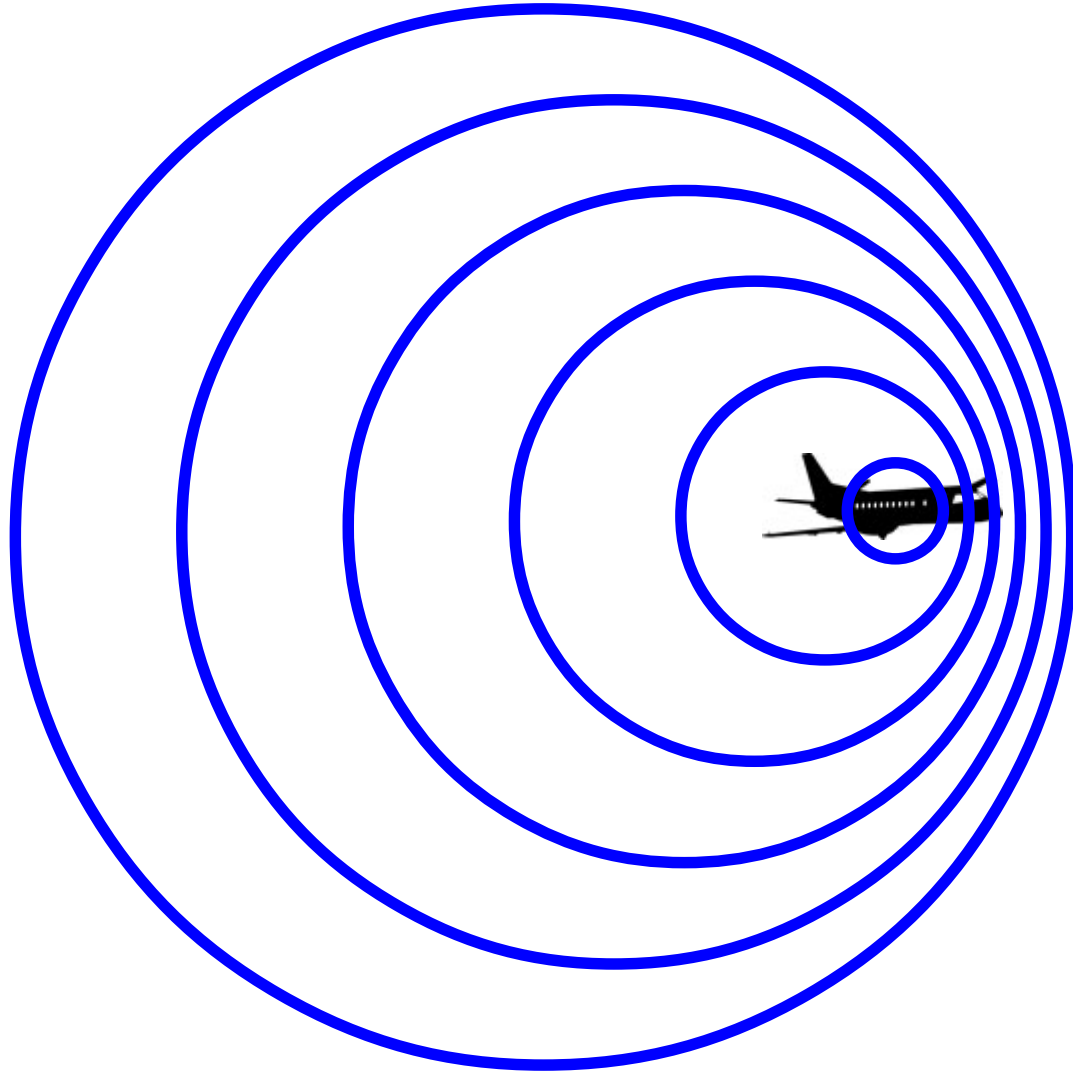
$$v_s < v_{\text{Sound}}$$

Shock Waves and Sonic Booms



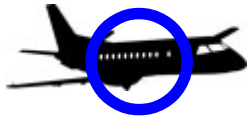
$$v_s < v_{\text{Sound}}$$

Shock Waves and Sonic Booms



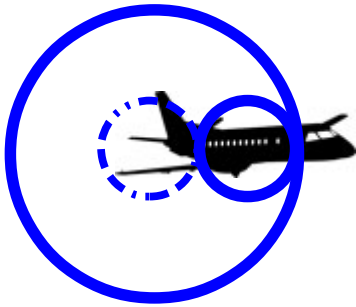
$$v_s < v_{\text{Sound}}$$

Shock Waves and Sonic Booms



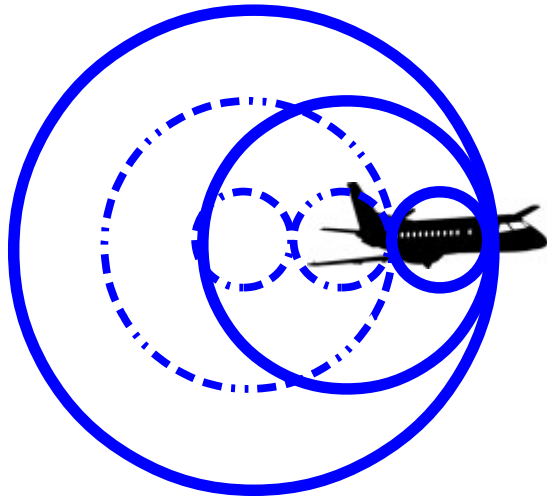
$$v_s = v_{\text{Sound}}$$

Shock Waves and Sonic Booms



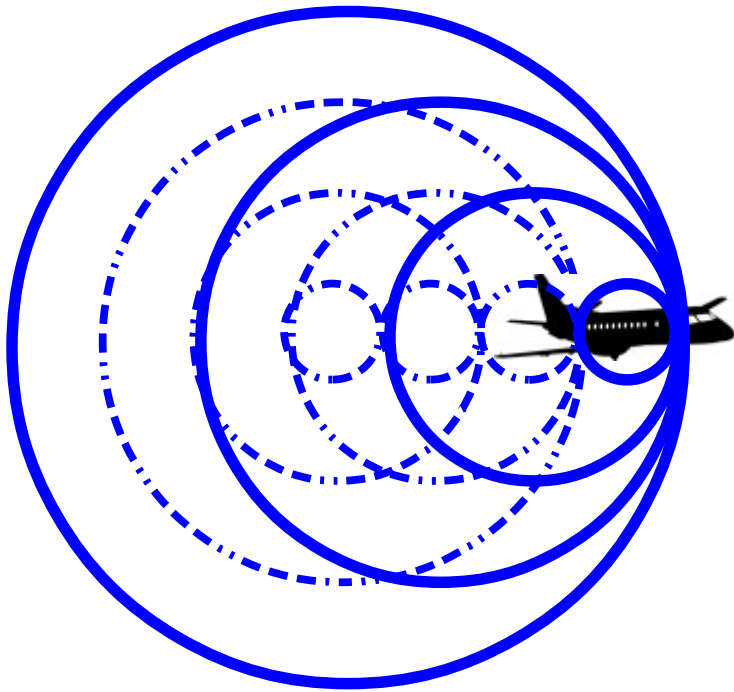
$$v_s = v_{\text{Sound}}$$

Shock Waves and Sonic Booms



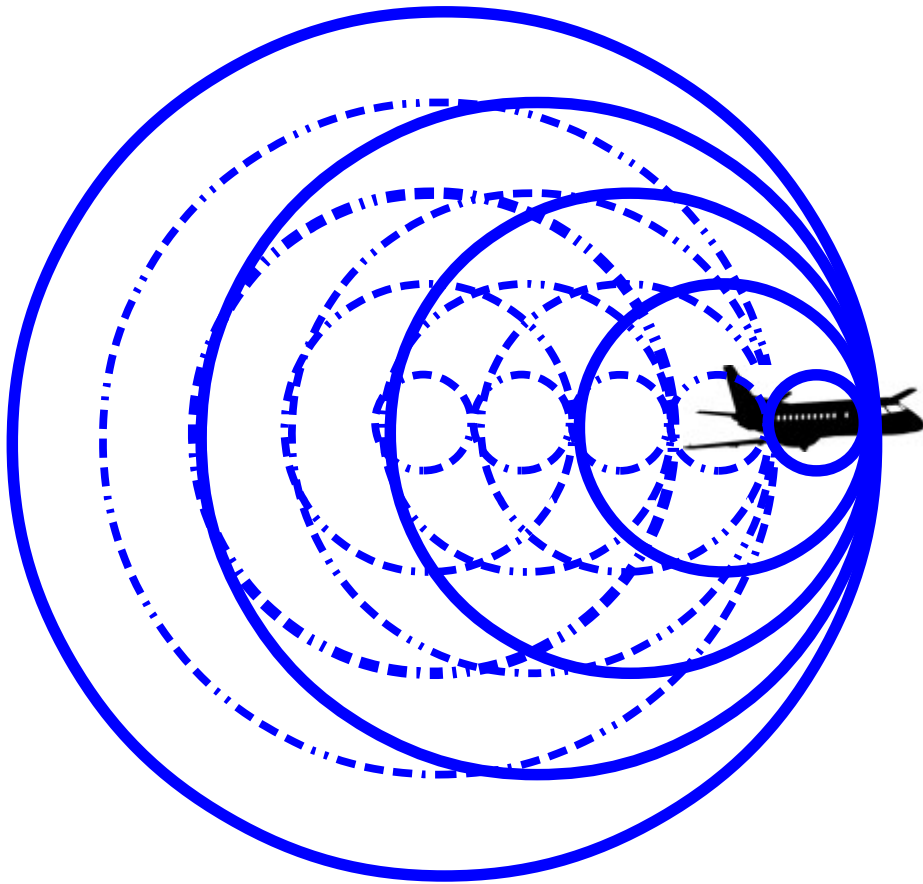
$$v_s = v_{\text{Sound}}$$

Shock Waves and Sonic Booms



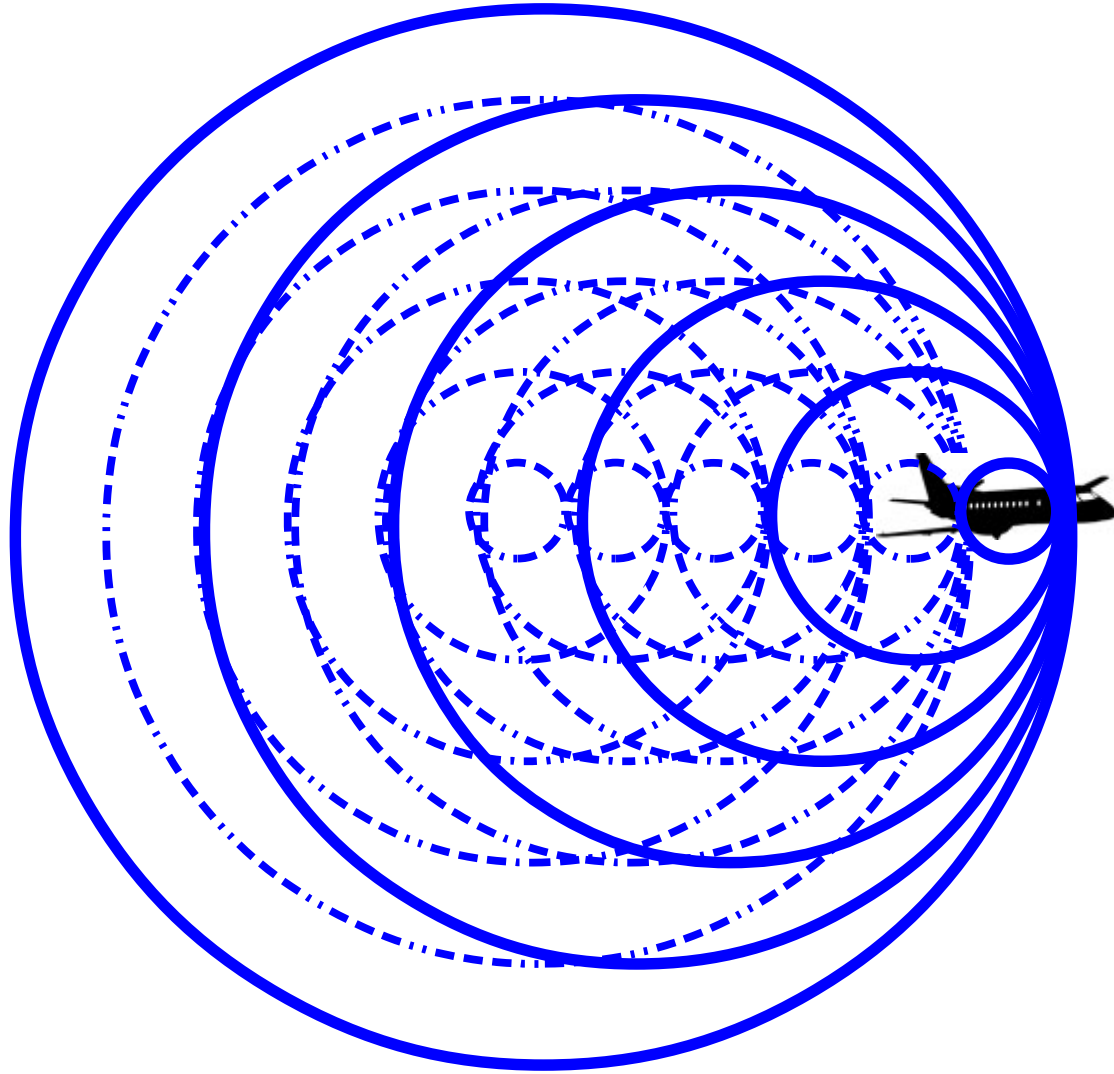
$$v_s = v_{\text{Sound}}$$

Shock Waves and Sonic Booms



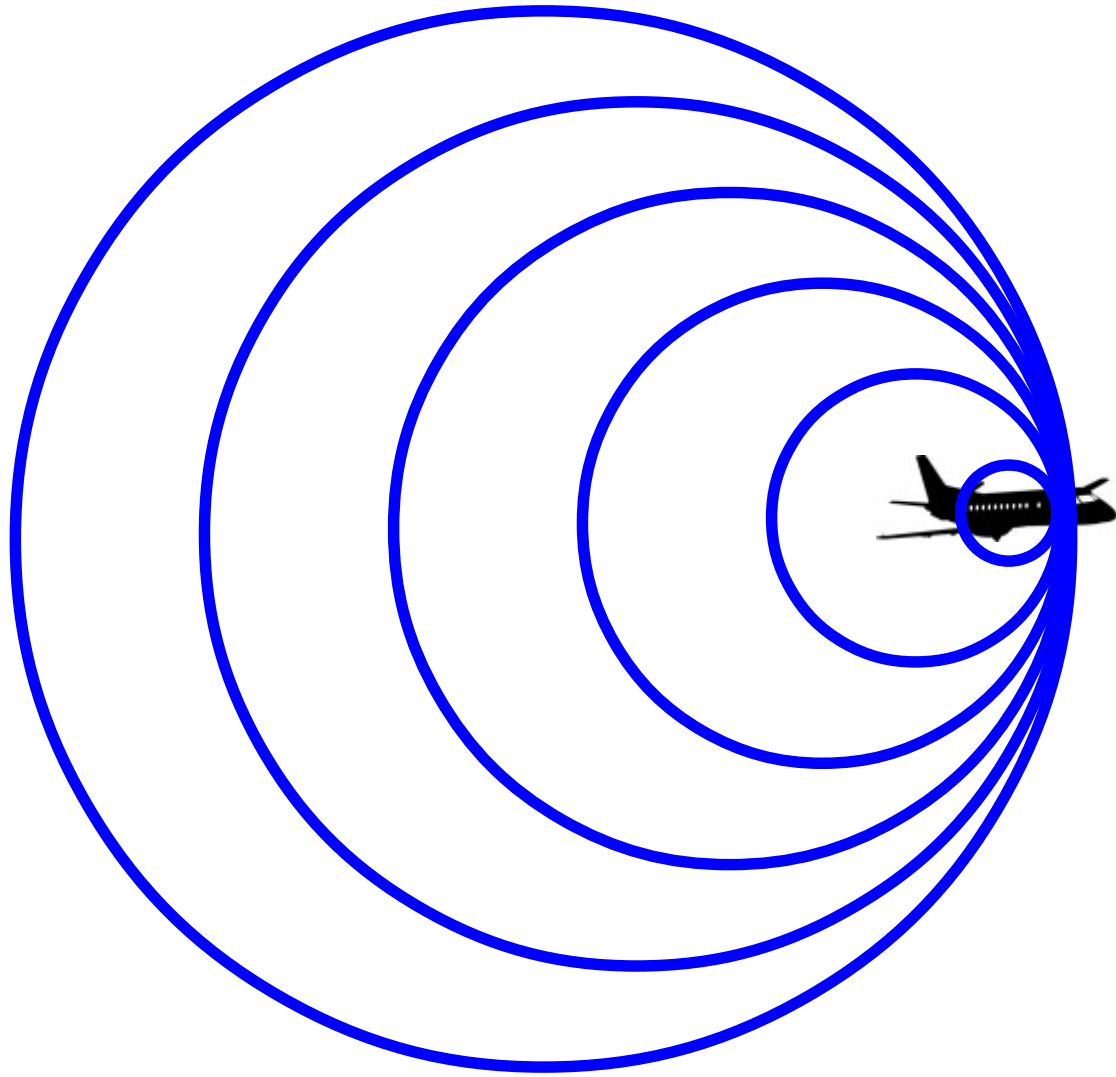
$$v_s = v_{\text{Sound}}$$

Shock Waves and Sonic Booms



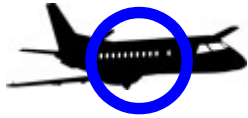
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Shock Waves and Sonic Booms



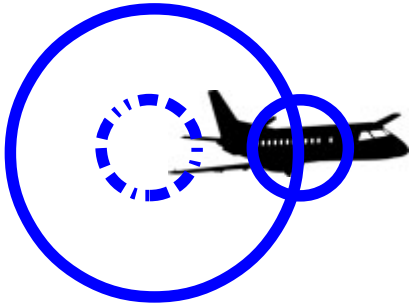
$$v_s = v_{\text{Sound}}$$

Shock Waves and Sonic Booms



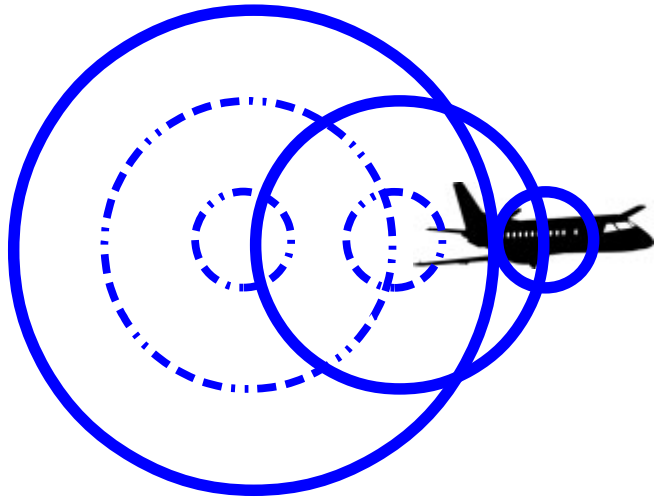
$$v_s > v_{\text{Sound}}$$

Shock Waves and Sonic Booms



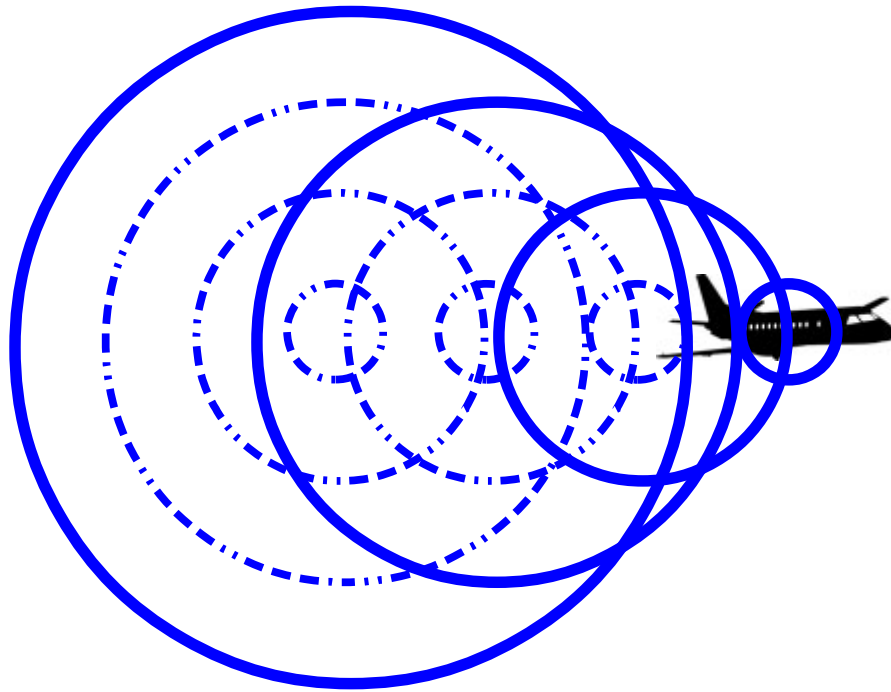
$$v_s > v_{\text{Sound}}$$

Shock Waves and Sonic Booms



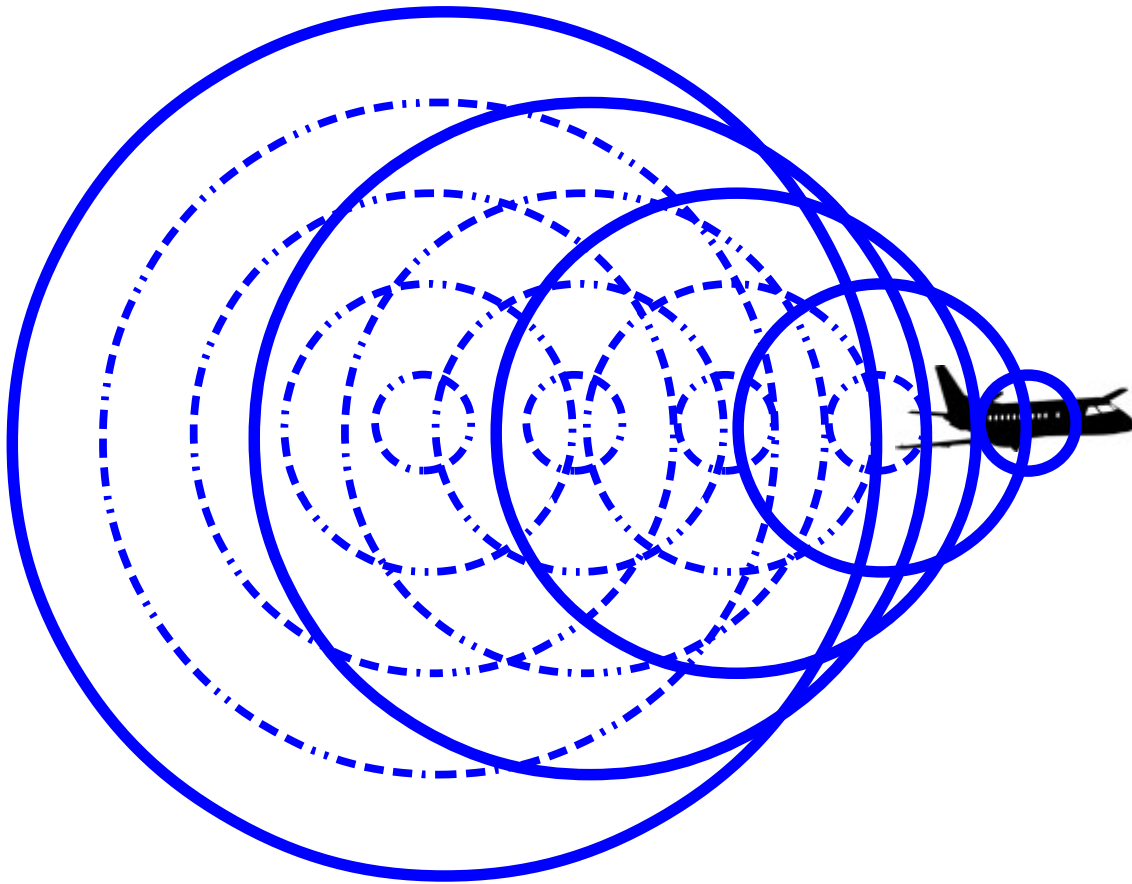
$$v_s > v_{\text{Sound}}$$

Shock Waves and Sonic Booms



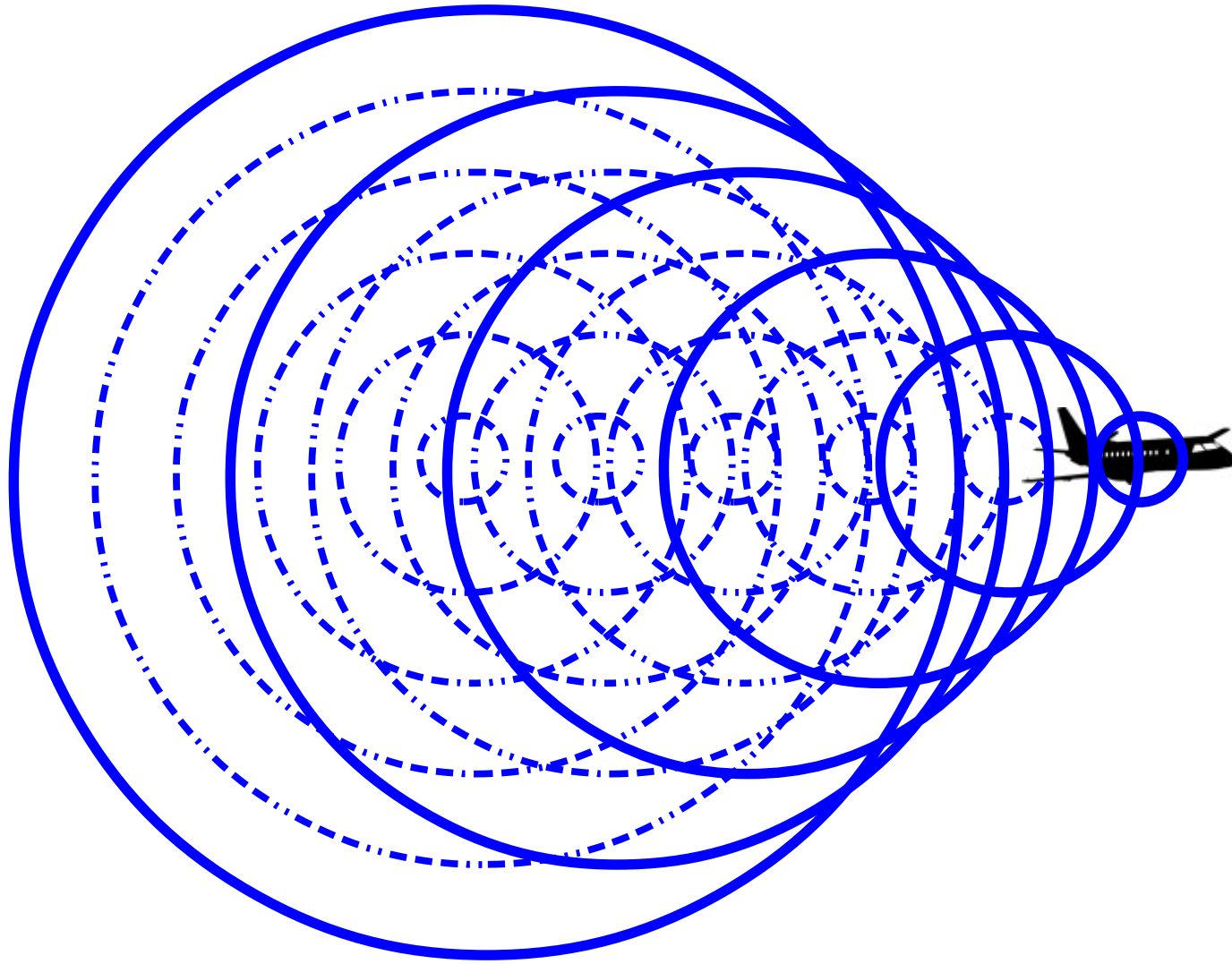
$$v_s > v_{\text{Sound}}$$

Shock Waves and Sonic Booms



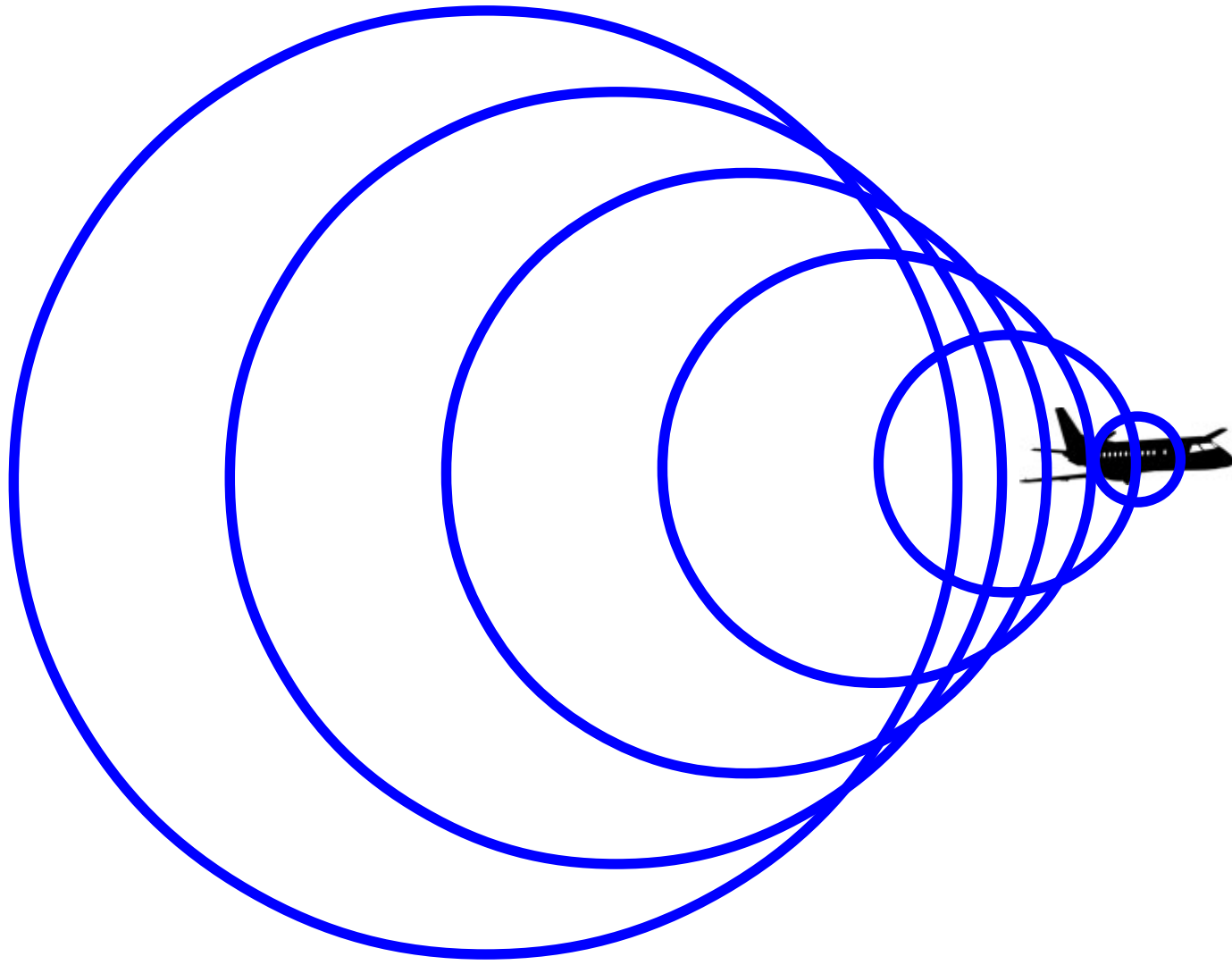
$$v_s > v_{\text{Sound}}$$

Shock Waves and Sonic Booms

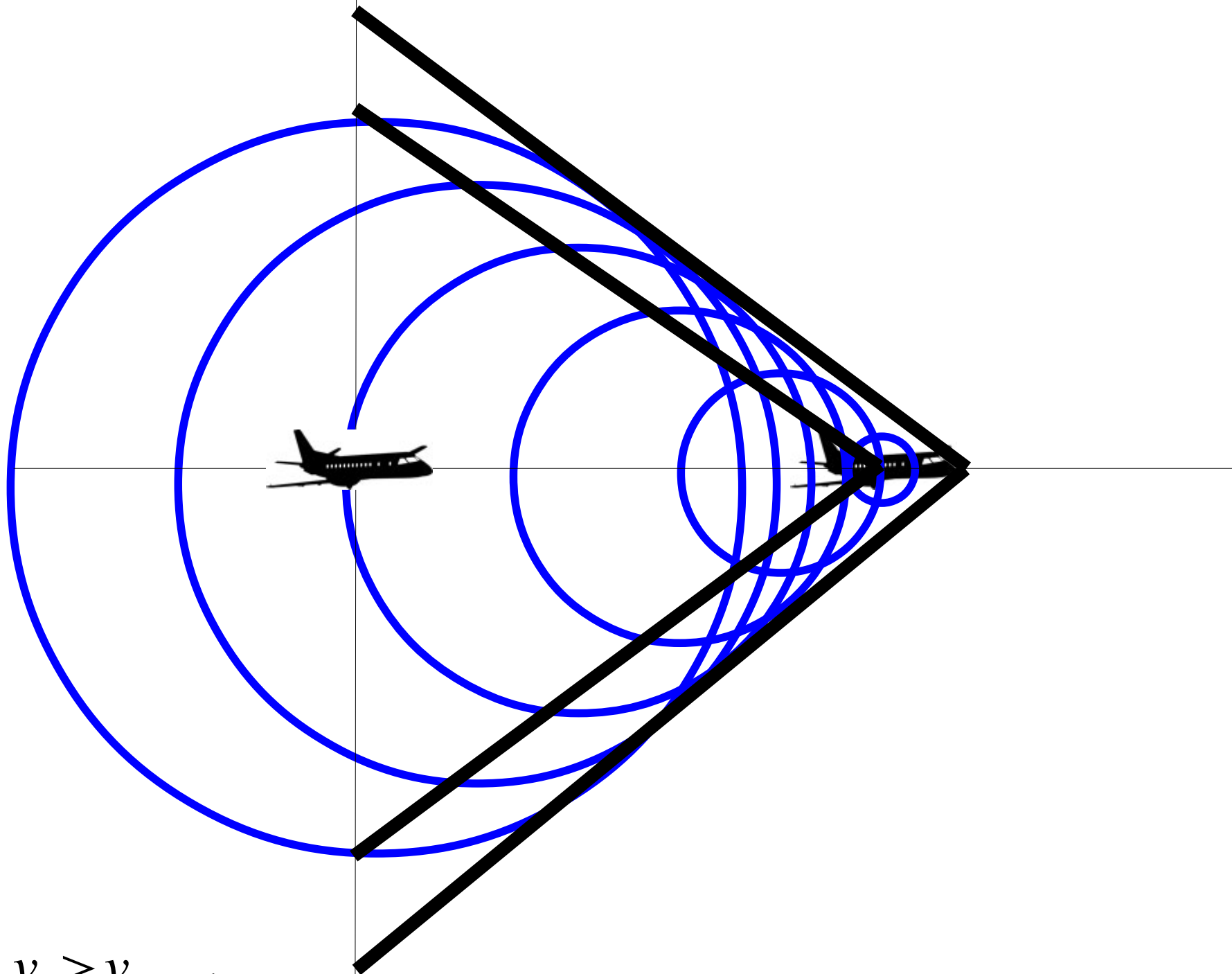


$$v_s > v_{\text{Sound}}$$

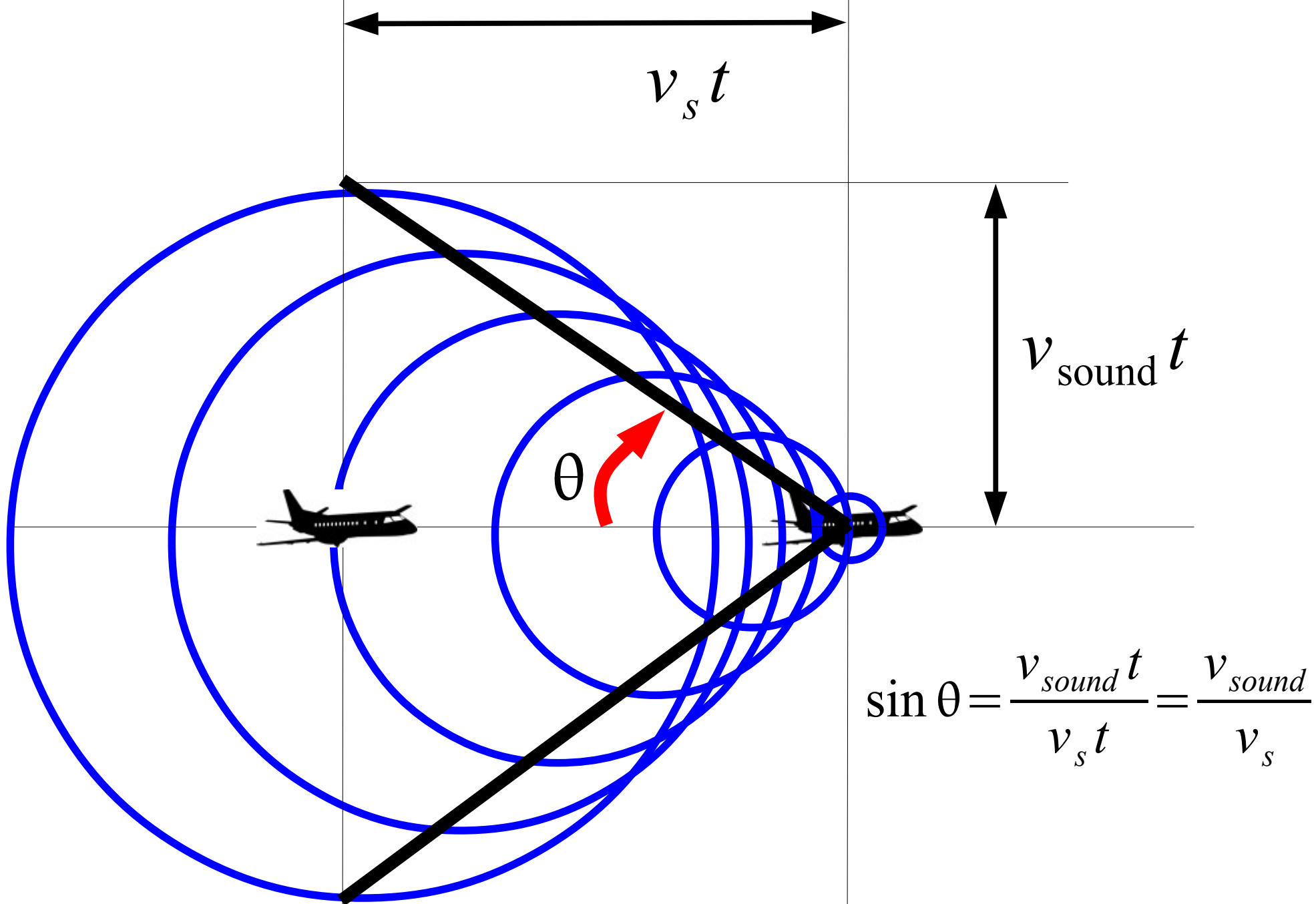
Shock Waves and Sonic Booms



$$v_s > v_{\text{Sound}}$$



$v_s > v_{\text{Sound}}$

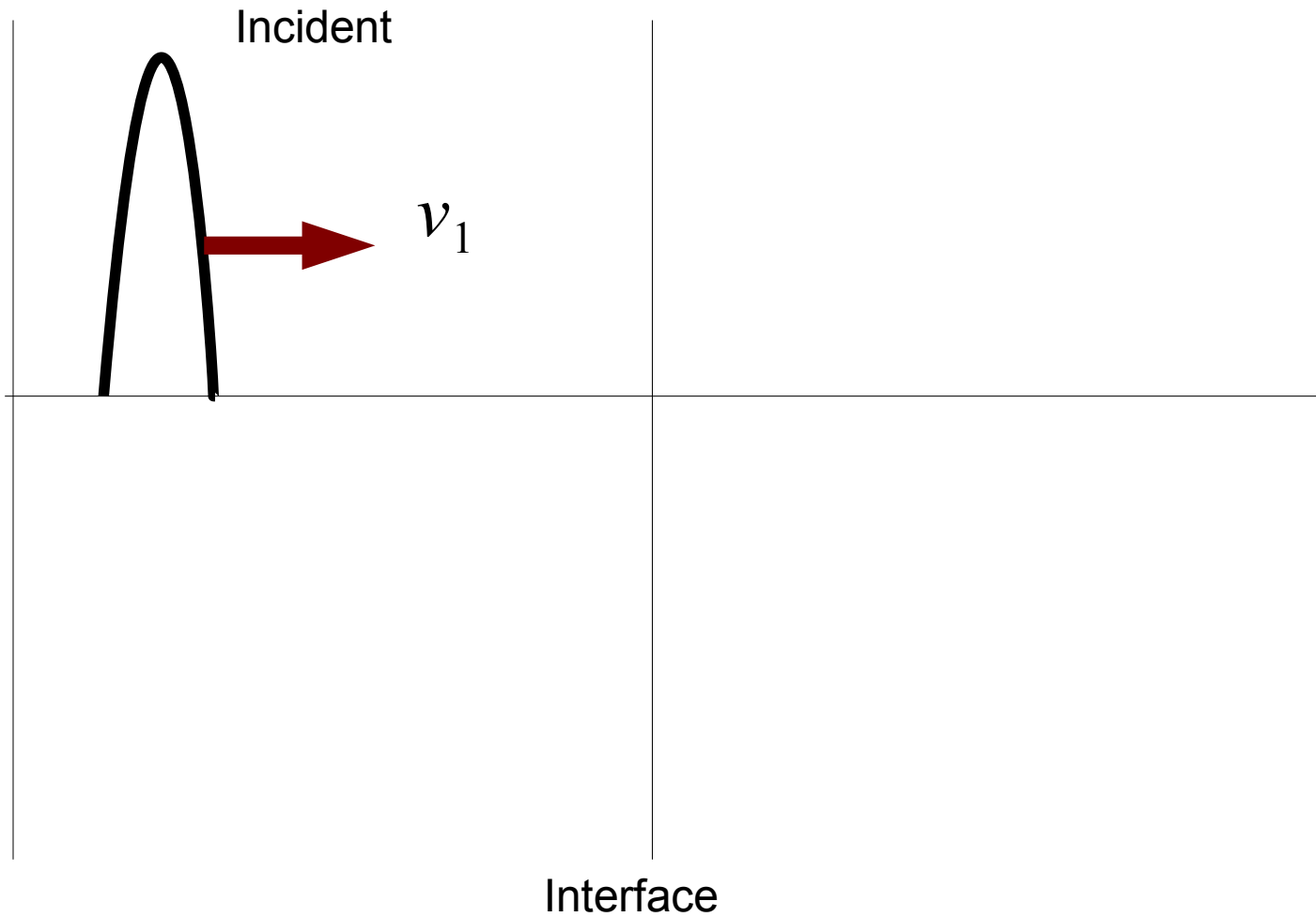


$$v_s > v_{\text{Sound}}$$

Ultrasound



Ultrasound



Ultrasound

