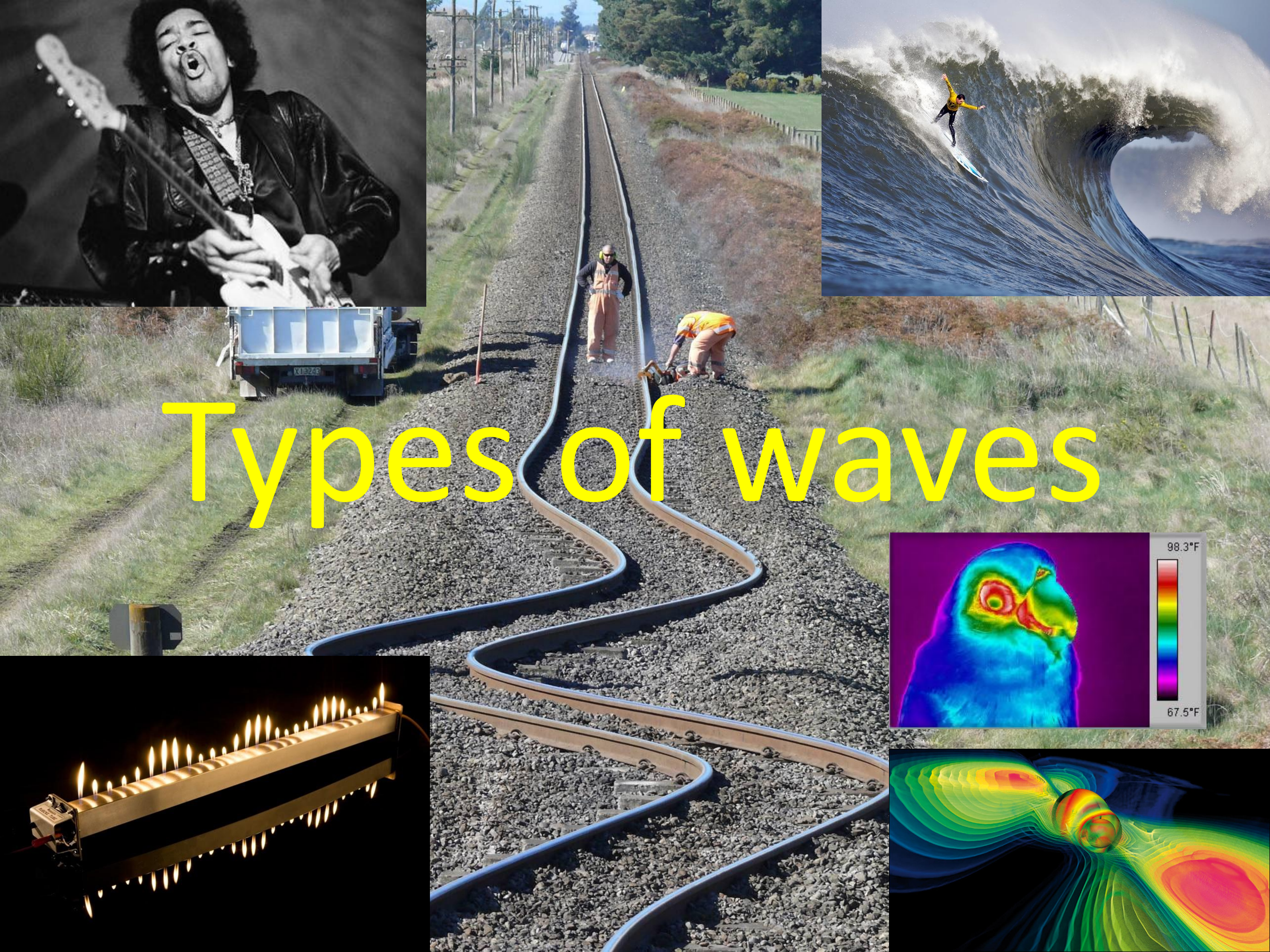
Types of waves



Sound waves

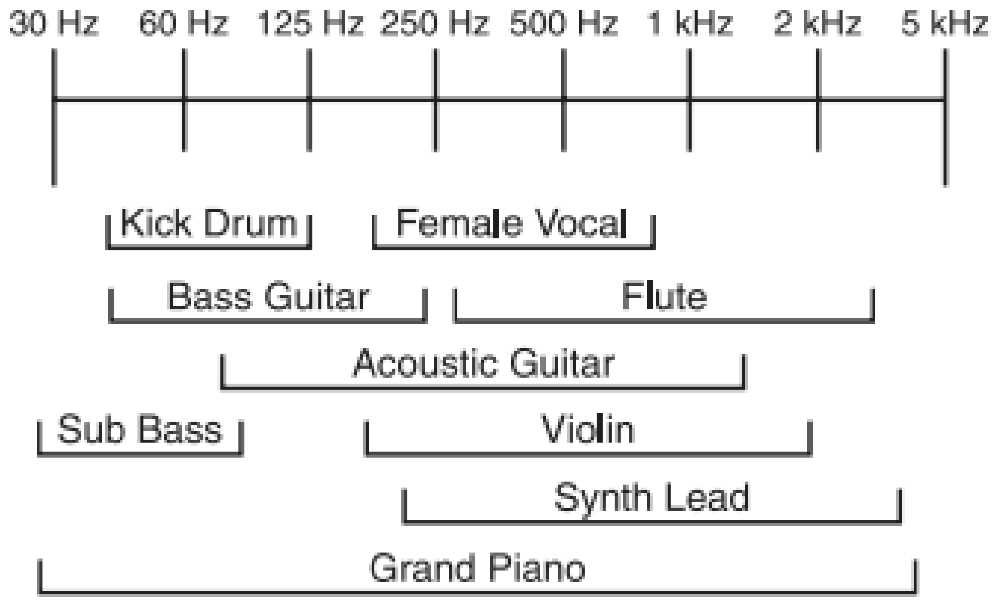
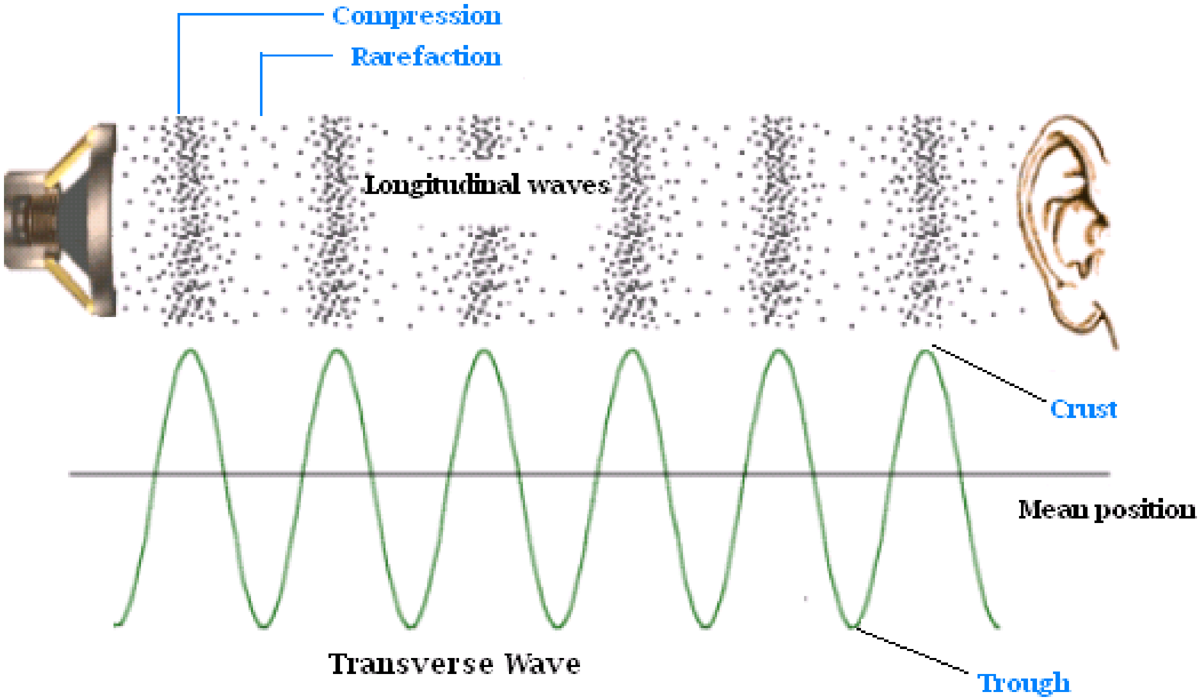
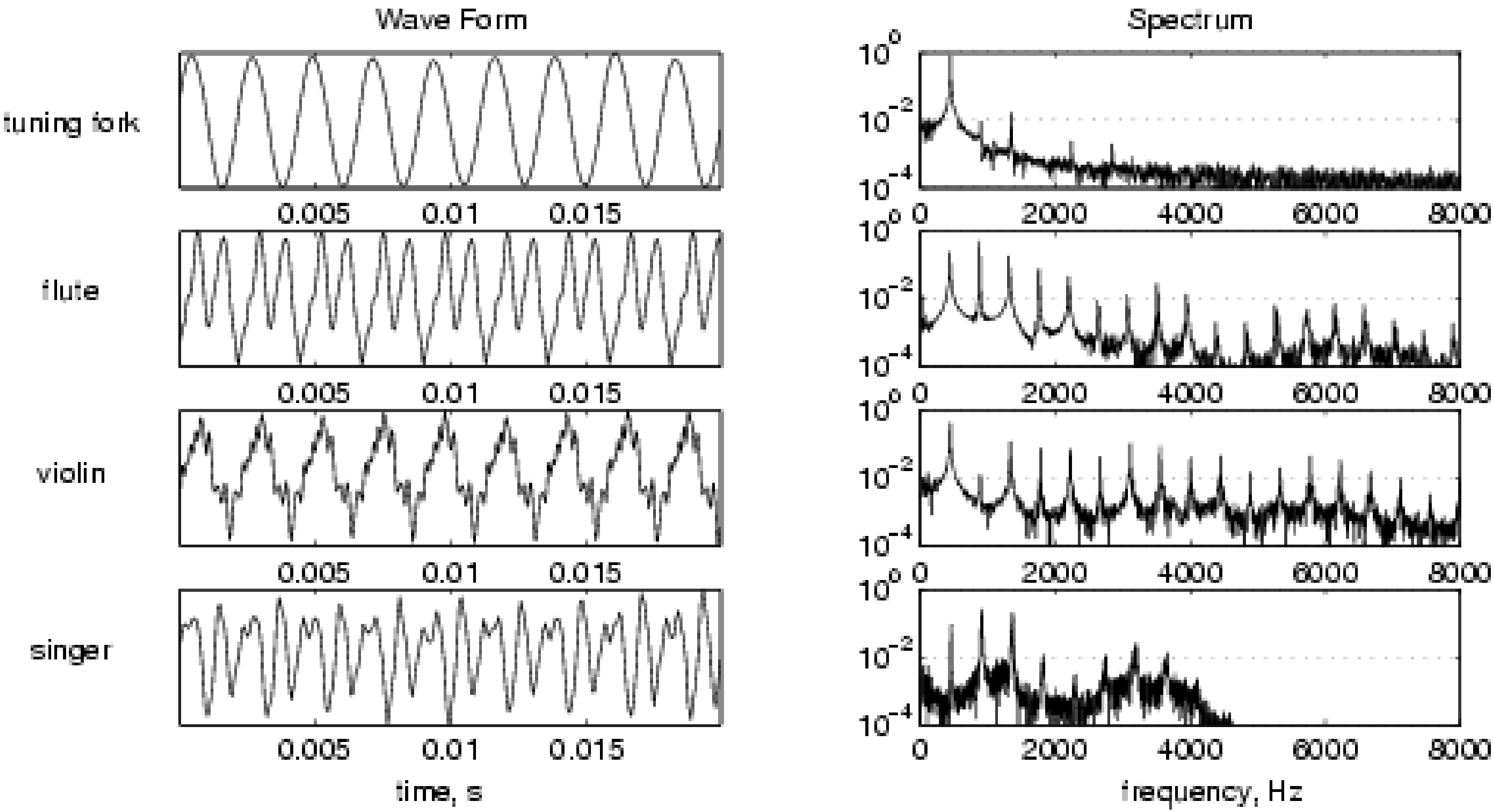
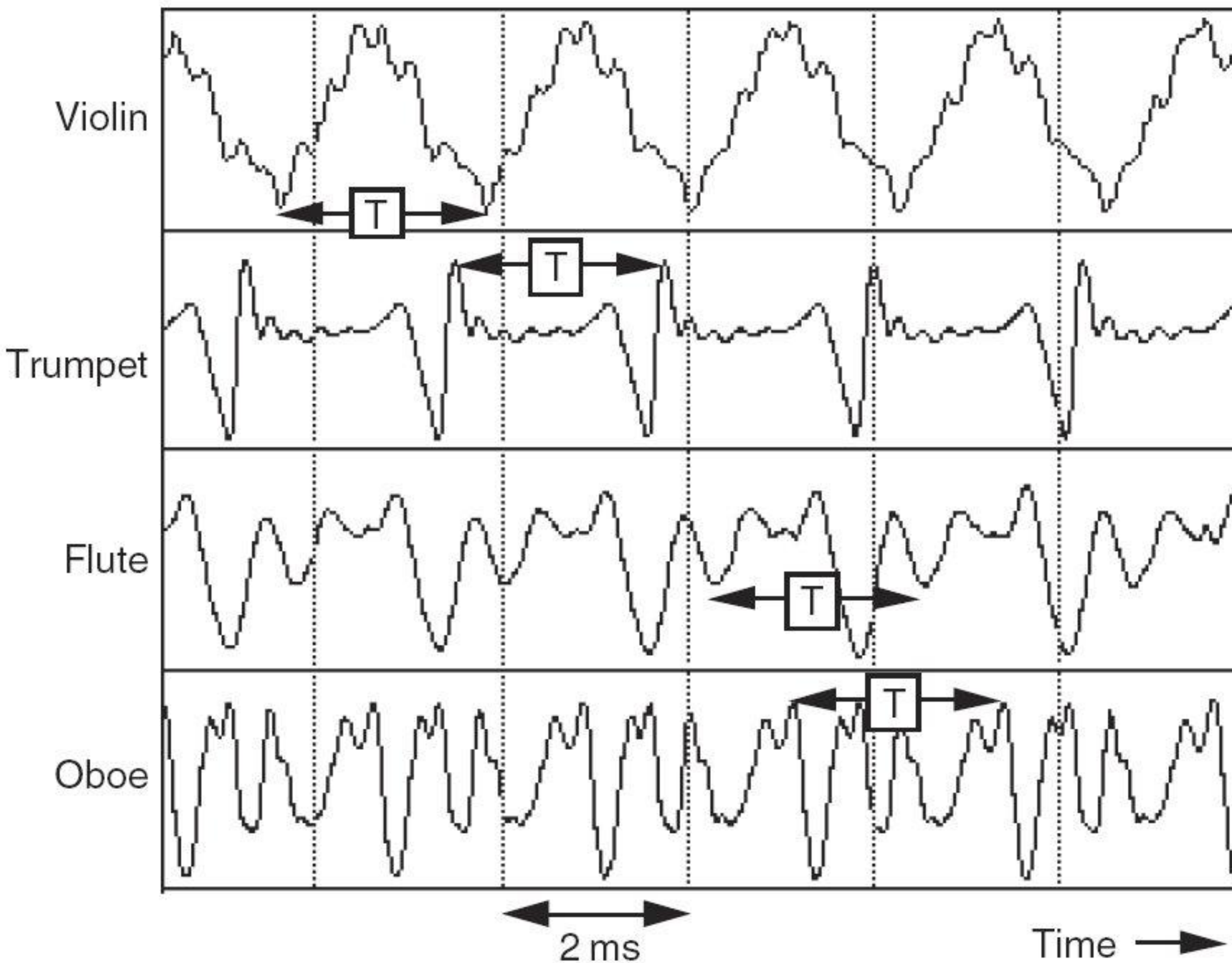
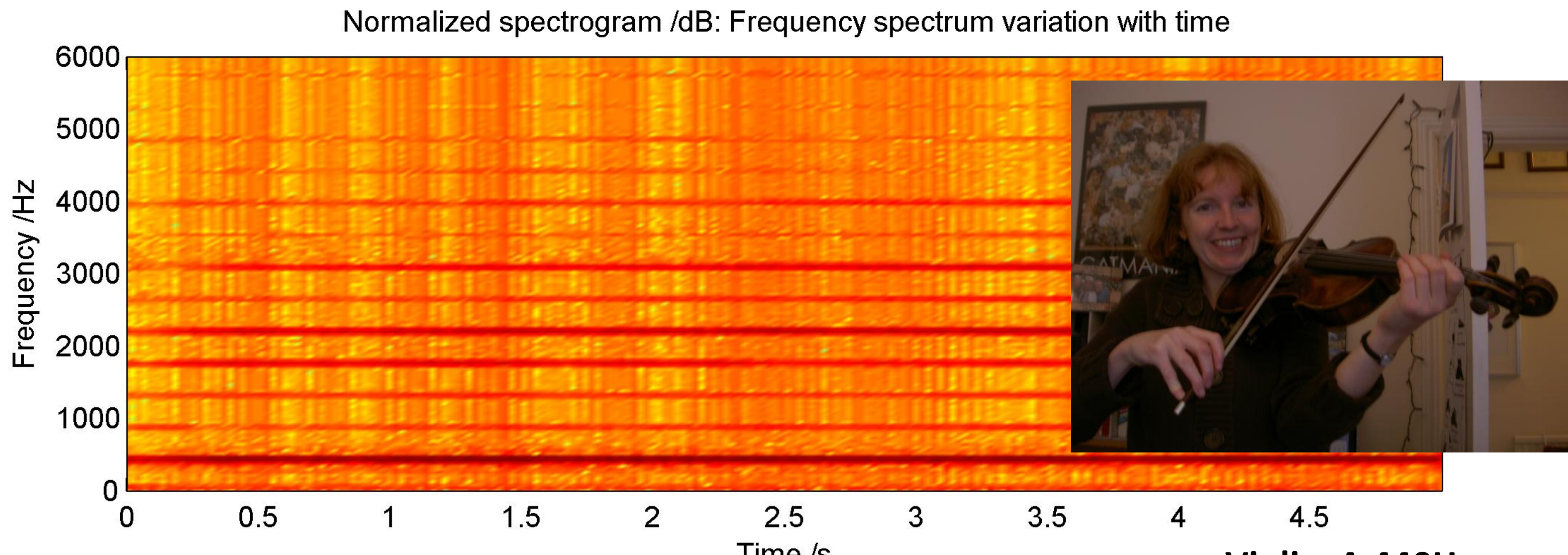


Figure 1.4 General pitch ranges of various instruments.

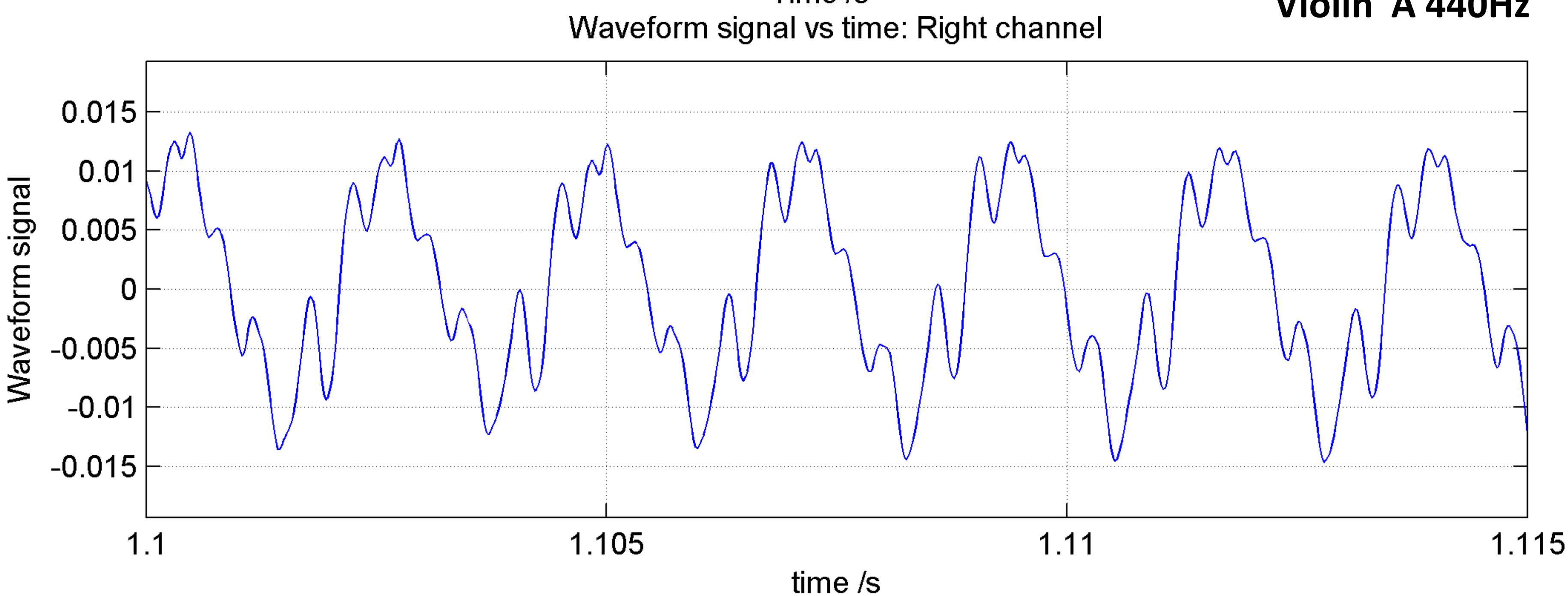


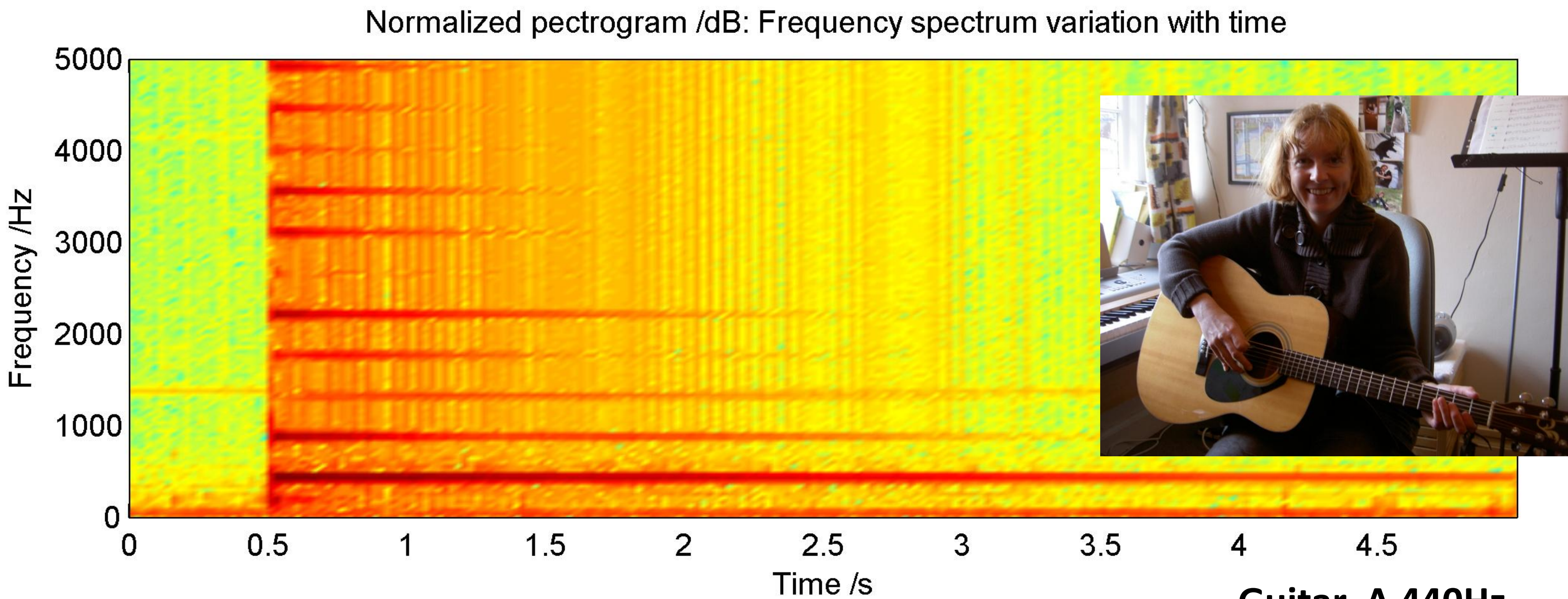

Wave Form
Spectrum
tuning fork
flute
violin
singer
0.005
0.01
0.015
time, s
10^0
10^{-2}
10^{-4}
0
2000
4000
6000
8000
frequency, Hz


Violin
Trumpet
Flute
Oboe
T
T
T
T
2 ms
Time

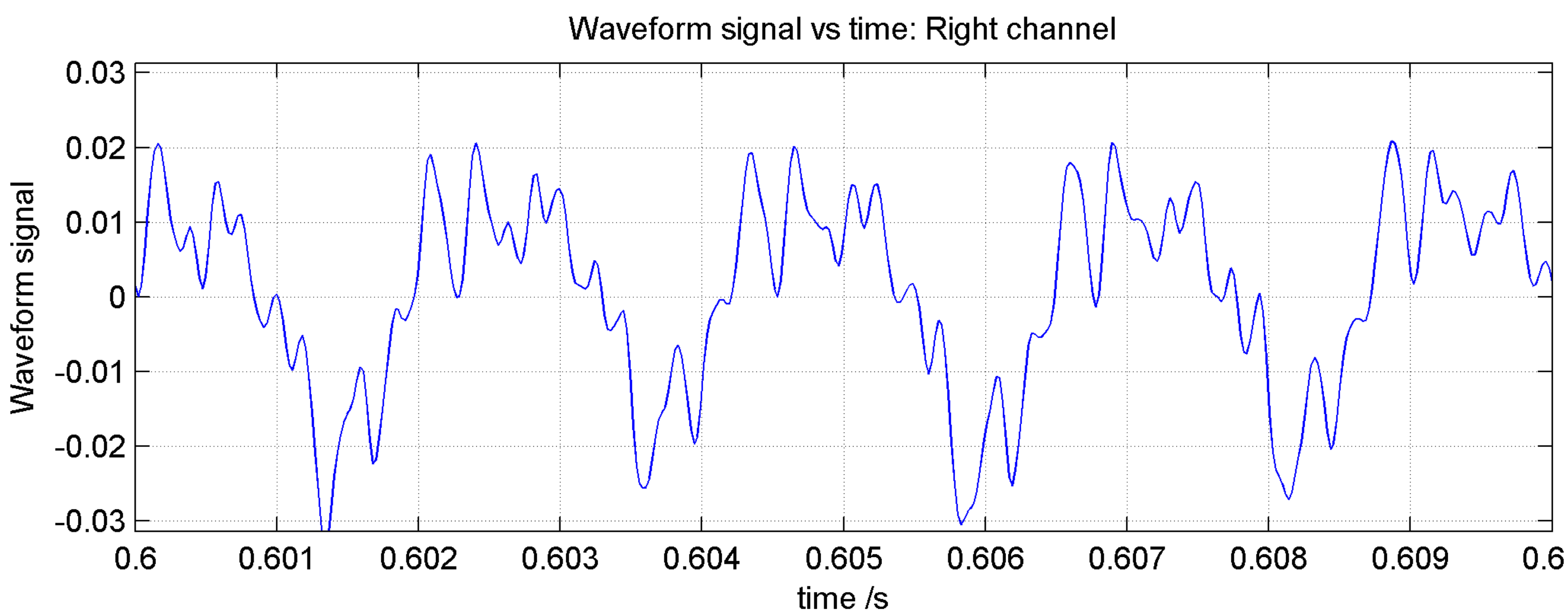


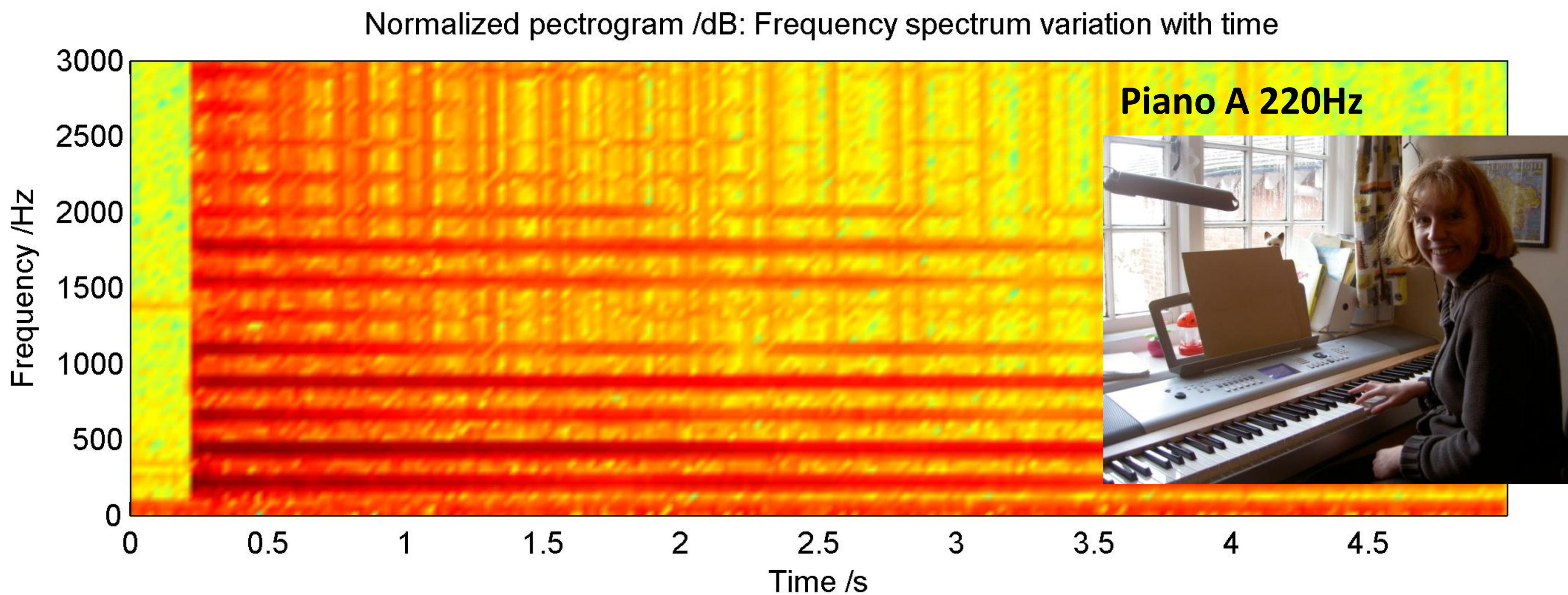
Violin A 440Hz

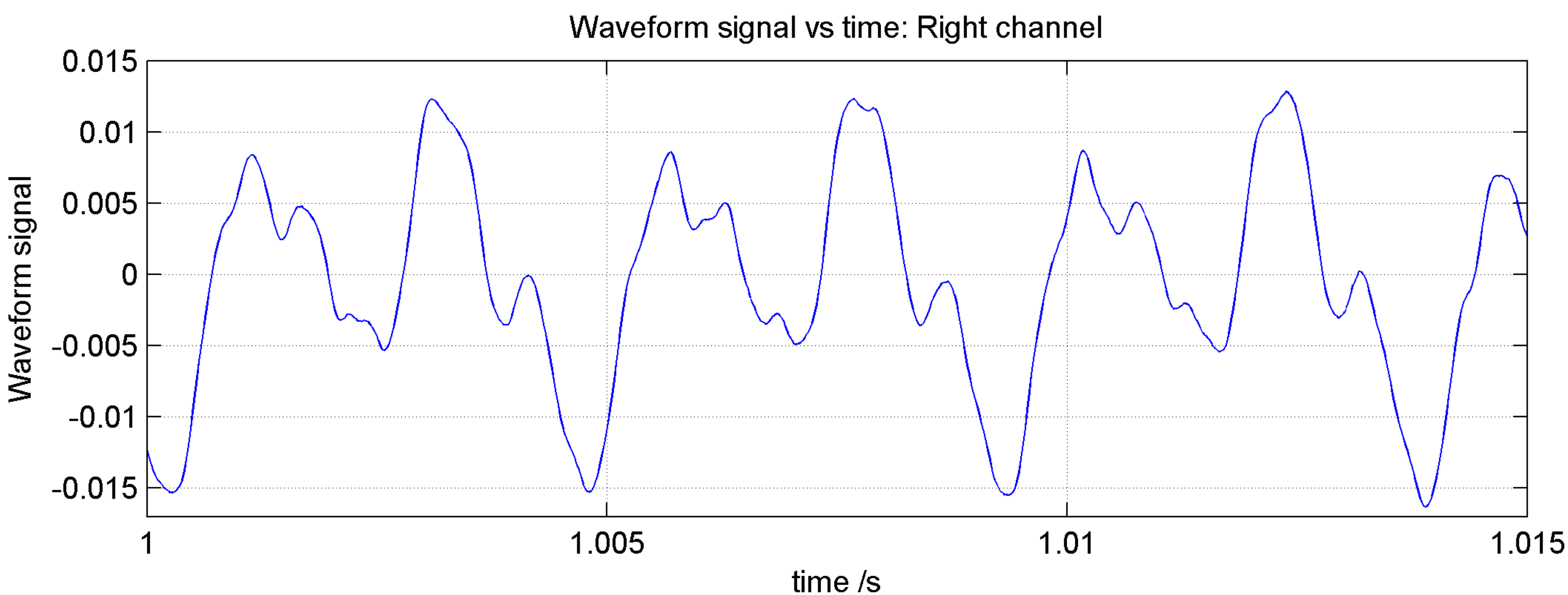


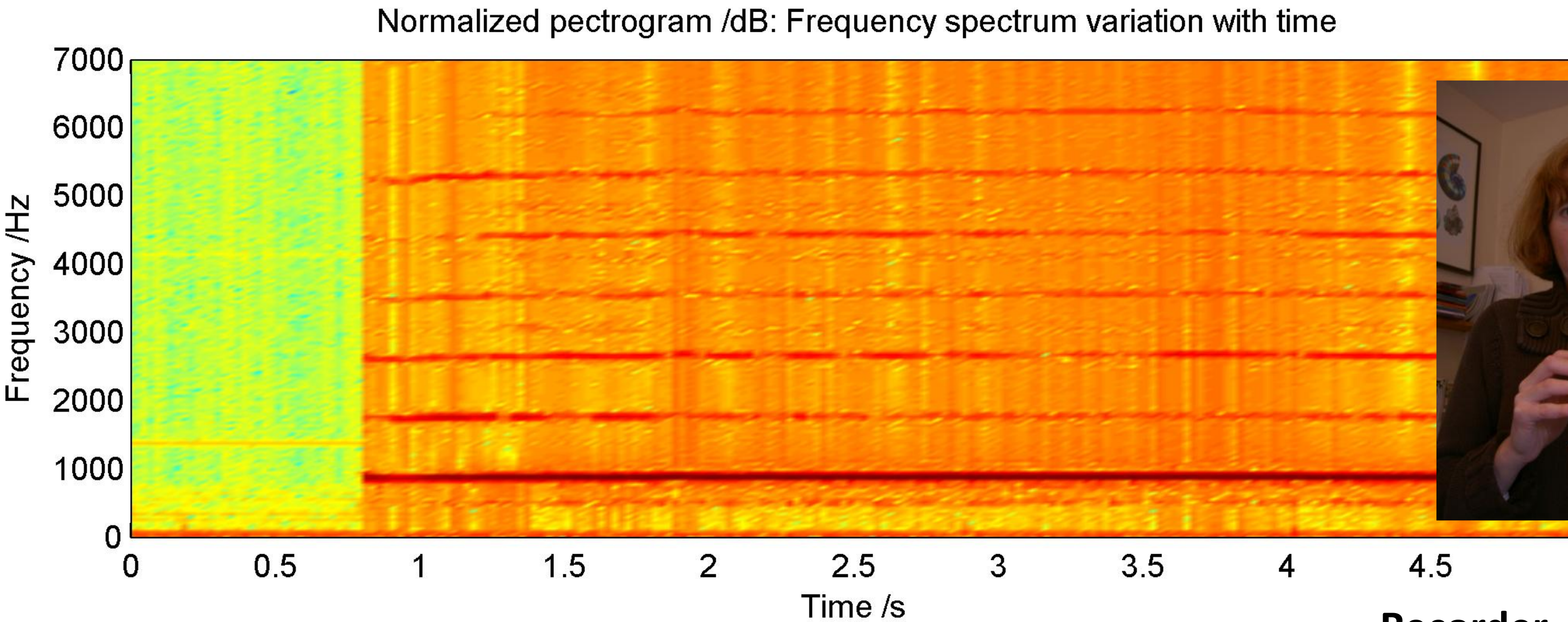


Guitar A 440Hz

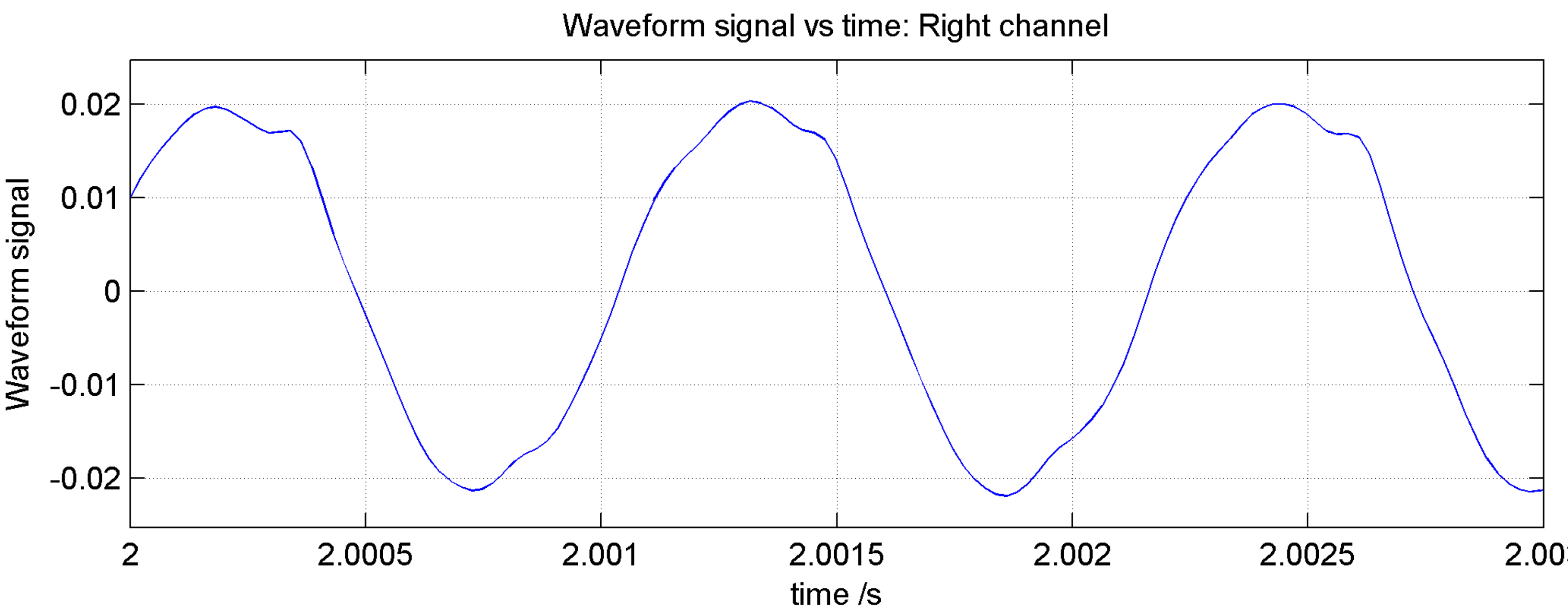


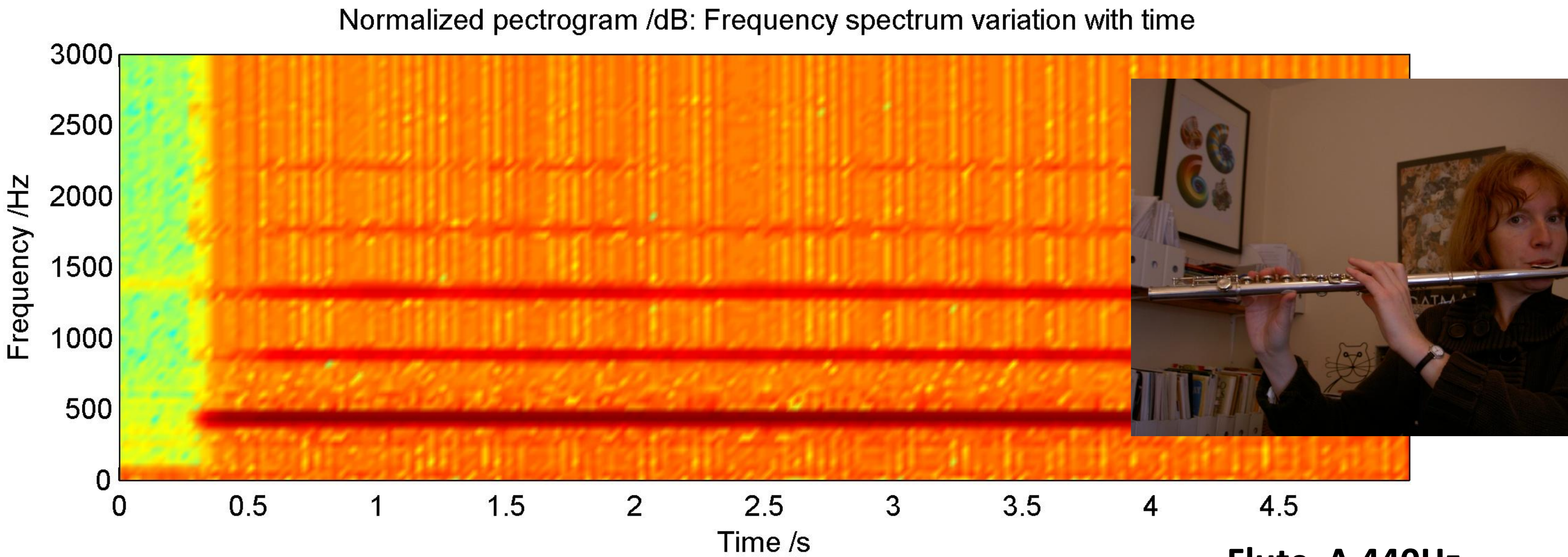

Normalized pectrogram /dB: Frequency spectrum variation with time
Piano A 220Hz
Frequency /Hz
3000
2500
2000
1500
1000
500
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time /s


Waveform signal vs time: Right channel
Waveform signal
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
1
1.005
1.01
1.015
time /s

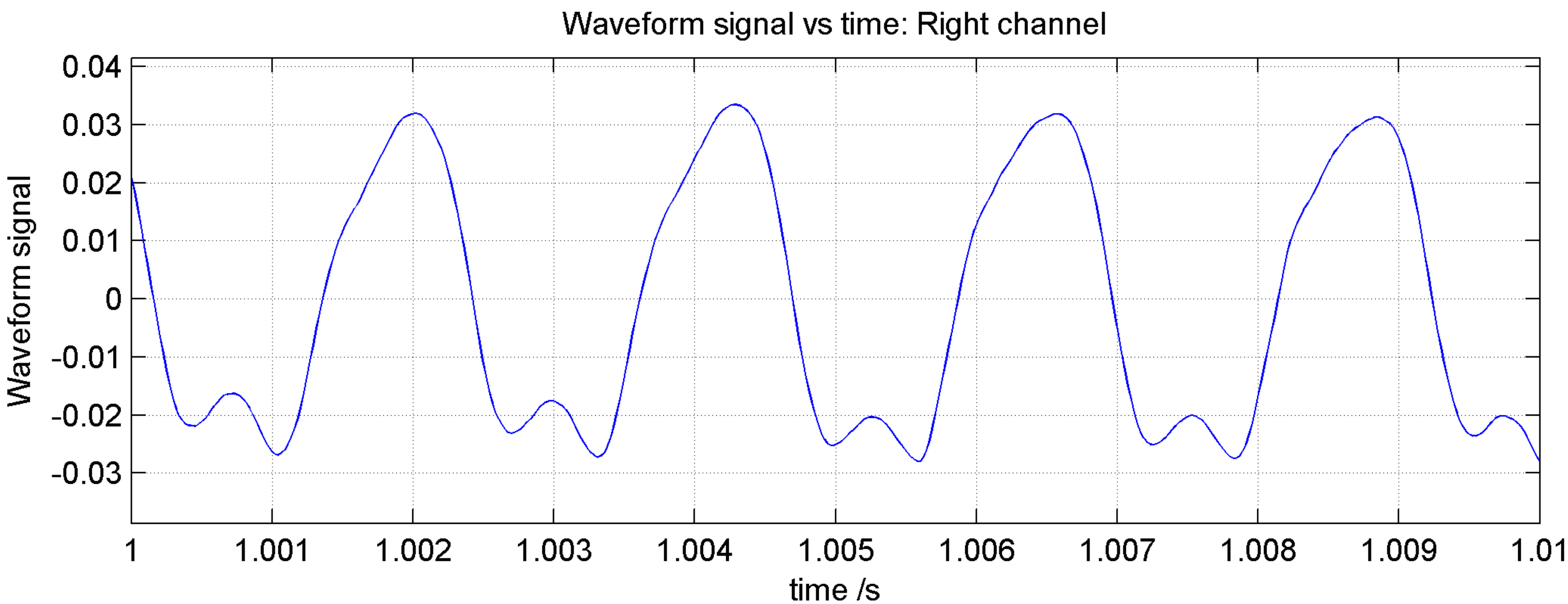


Recorder A 880Hz



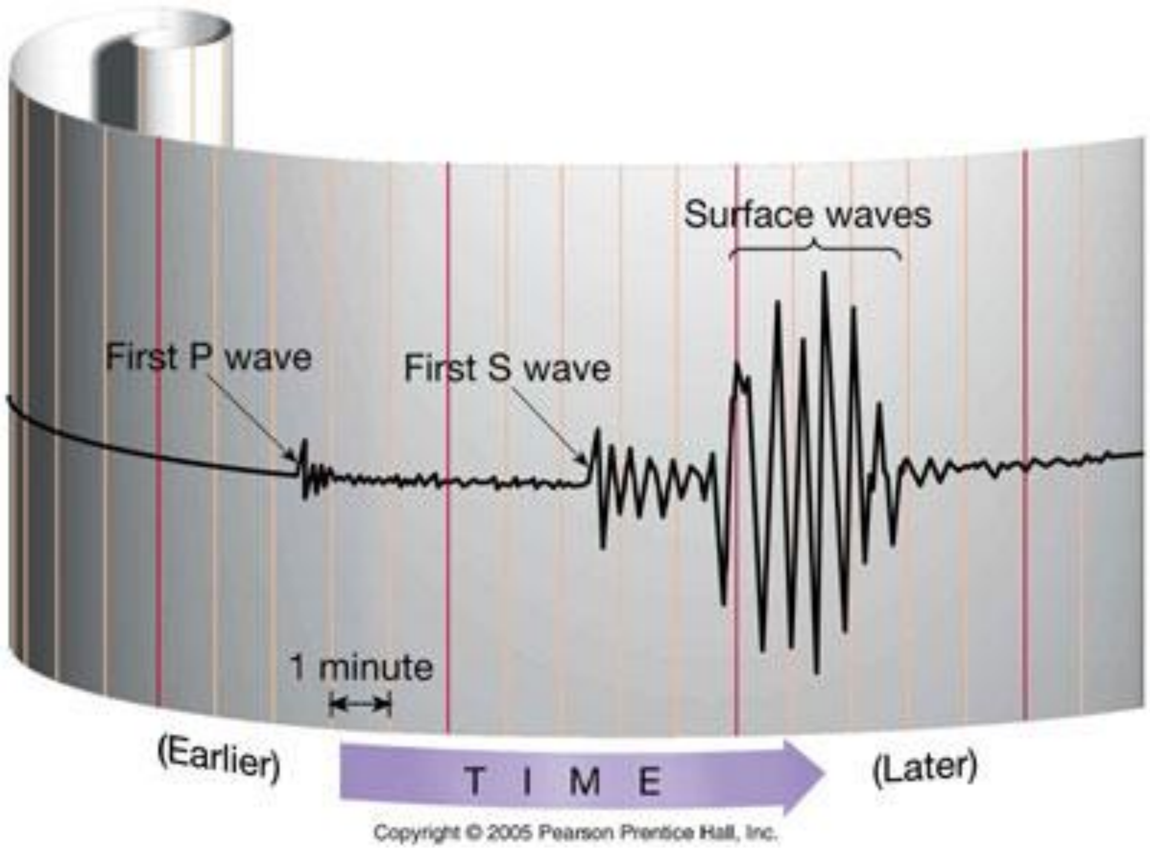


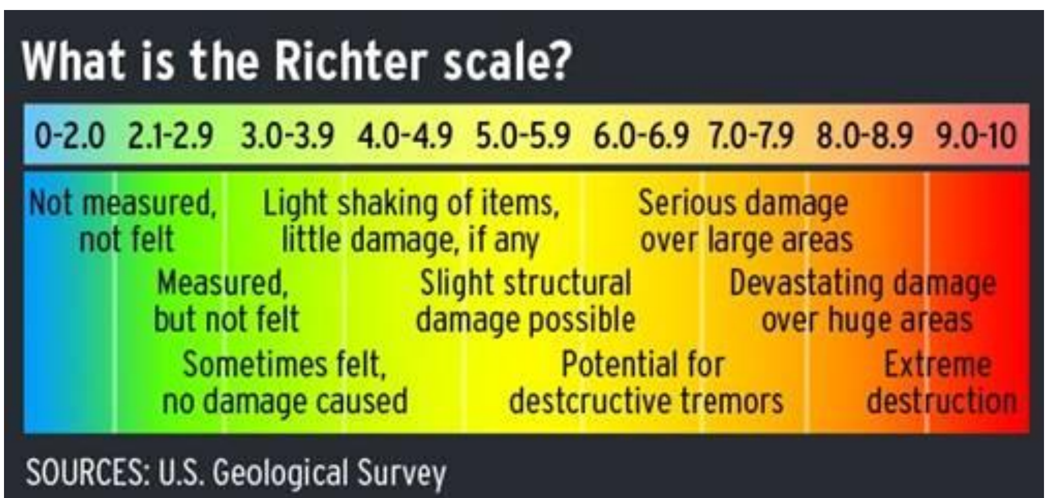
Flute A 440Hz

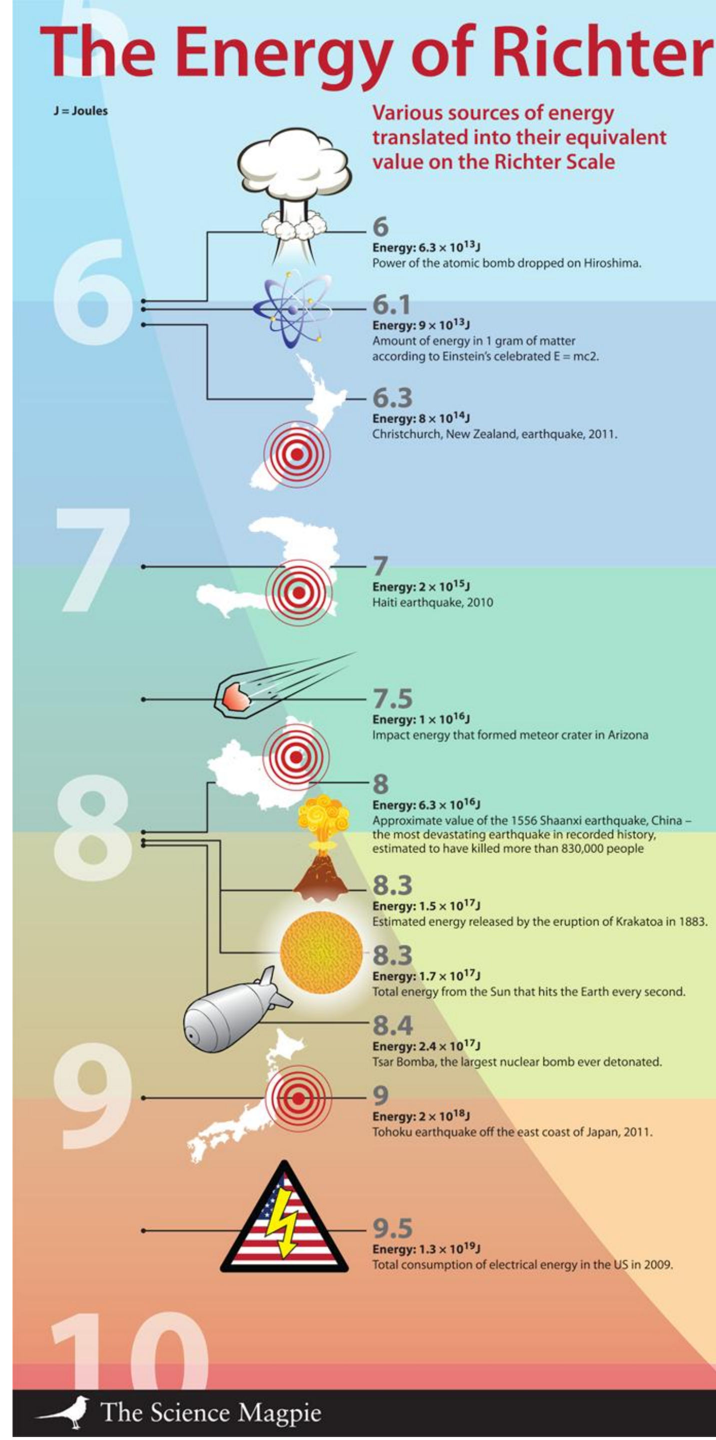


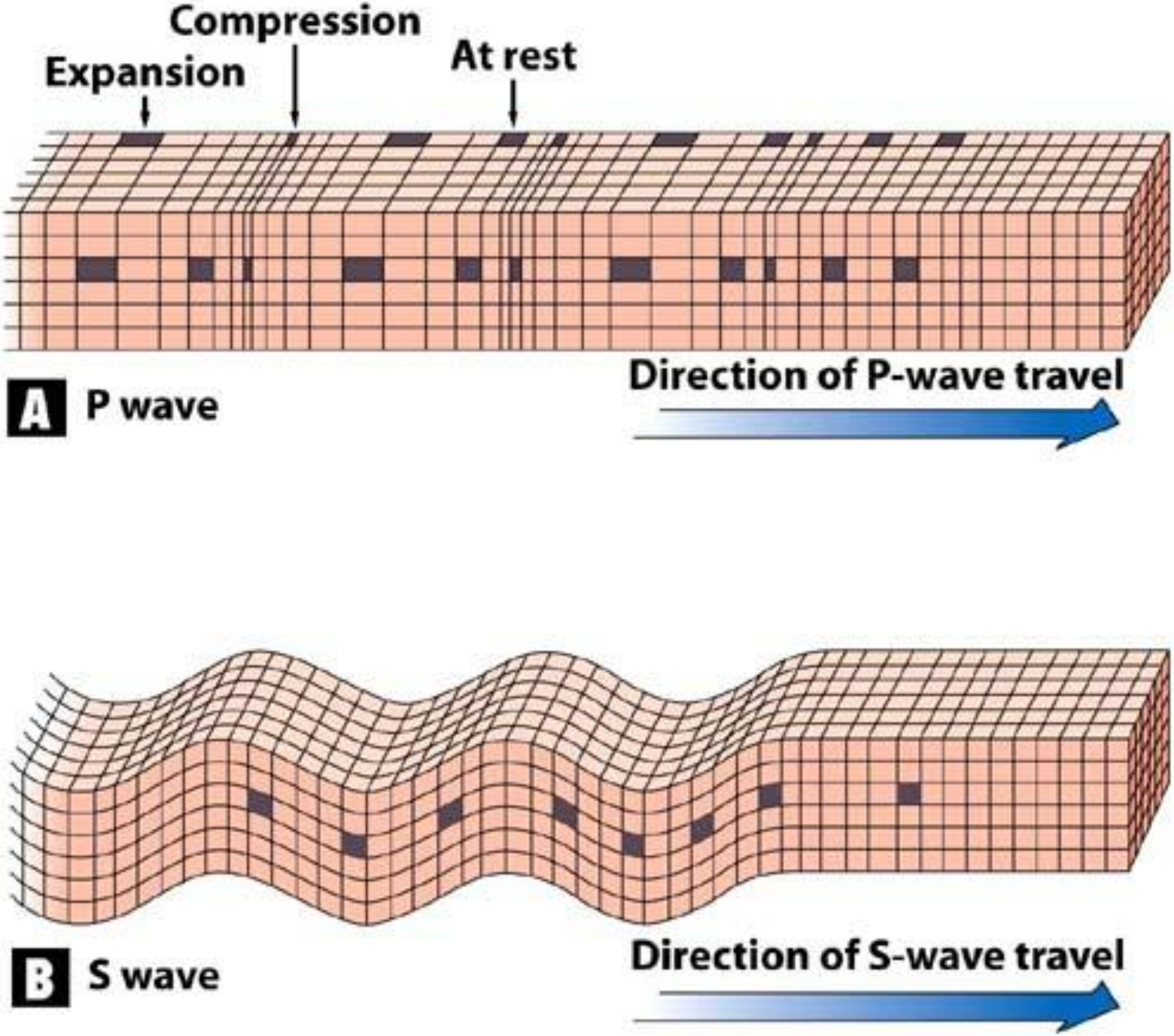
Rubens tube


Earthquakes

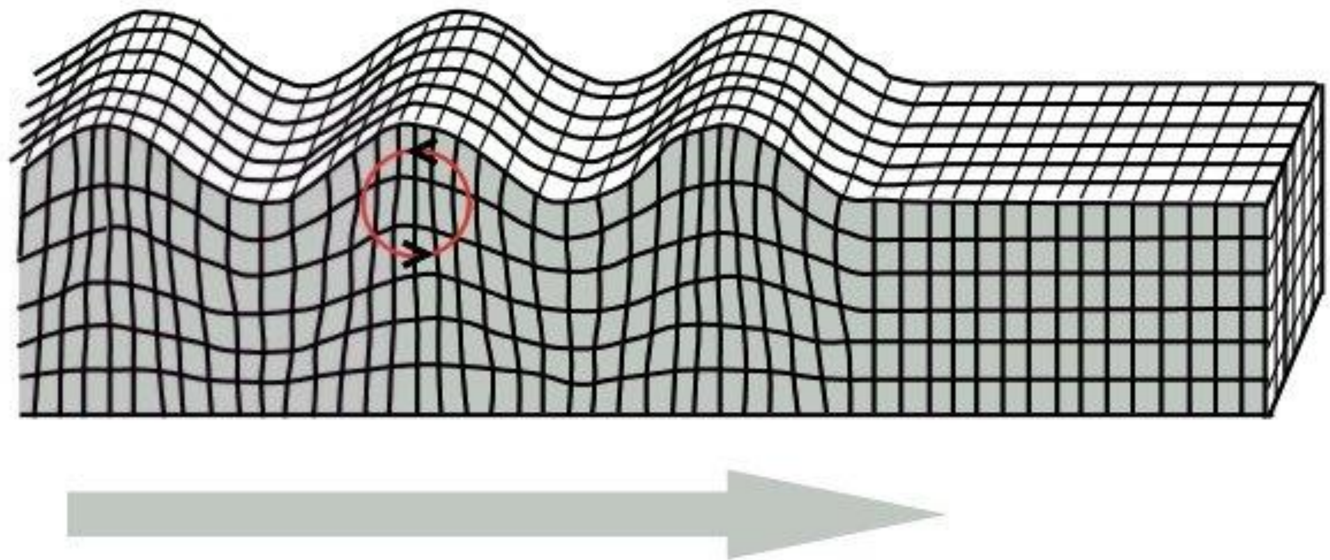

Surface waves
First P wave
First S wave
1 minute
(Earlier)
T I M E
(Later)
Copyright © 2005 Pearson Prentice Hall, Inc.


What is the Richter scale?
0-2.0
2.1-2.9
3.0-3.9
4.0-4.9
5.0-5.9
6.0-6.9
7.0-7.9
8.0-8.9
9.0-10
Not measured, not felt
Measured, but not felt
Sometimes felt, no damage caused
Light shaking of items, little damage, if any
Slight structural damage possible
Potential for destcructive tremors
Serious damage over large areas
Devastating damage over huge areas
Extreme destruction
SOURCES: U.S. Geological Survey

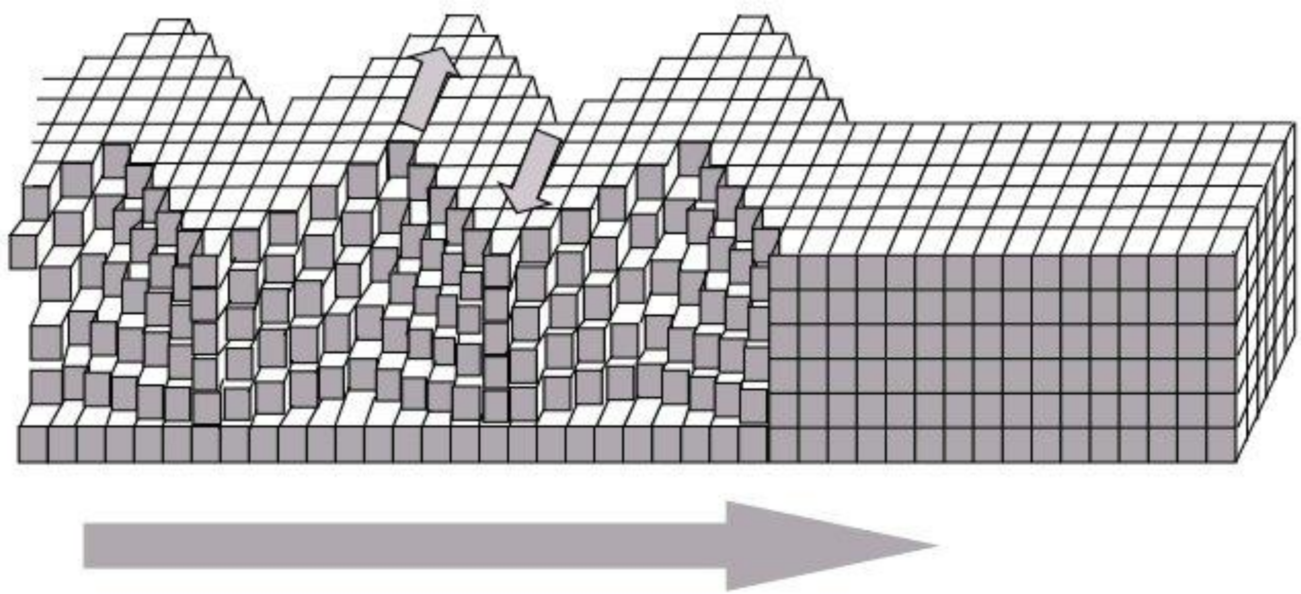

The Energy of Richter
J = Joules
Various sources of energy translated into their equivalent value on the Richter Scale
6
Energy: 6.3×10^{13}J
Power of the atomic bomb dropped on Hiroshima.
6.1
Energy: 9×10^{13}J
Amount of energy in 1 gram of matter according to Einstein's celebrated E = mc2.
6.3
Energy: 8×10^{14}J
Christchurch, New Zealand, earthquake, 2011.
7
Energy: 2×10^{15}J
Haiti earthquake, 2010
7.5
Energy: 1×10^{16}J
Impact energy that formed meteor crater in Arizona
8
Energy: 6.3×10^{16}J
Approximate value of the 1556 Shaanxi earthquake, China – the most devastating earthquake in recorded history, estimated to have killed more than 830,000 people
8.3
Energy: 1.5×10^{17}J
Estimated energy released by the eruption of Krakatoa in 1883.
8.3
Energy: 1.7×10^{17}J
Total energy from the Sun that hits the Earth every second.
8.4
Energy: 2.4×10^{17}J
Tsar Bomba, the largest nuclear bomb ever detonated.
9
Energy: 2×10^{18}J
Tohoku earthquake off the east coast of Japan, 2011.
9.5
Energy: 1.3×10^{19}J
Total consumption of electrical energy in the US in 2009.
10
The Science Magpie

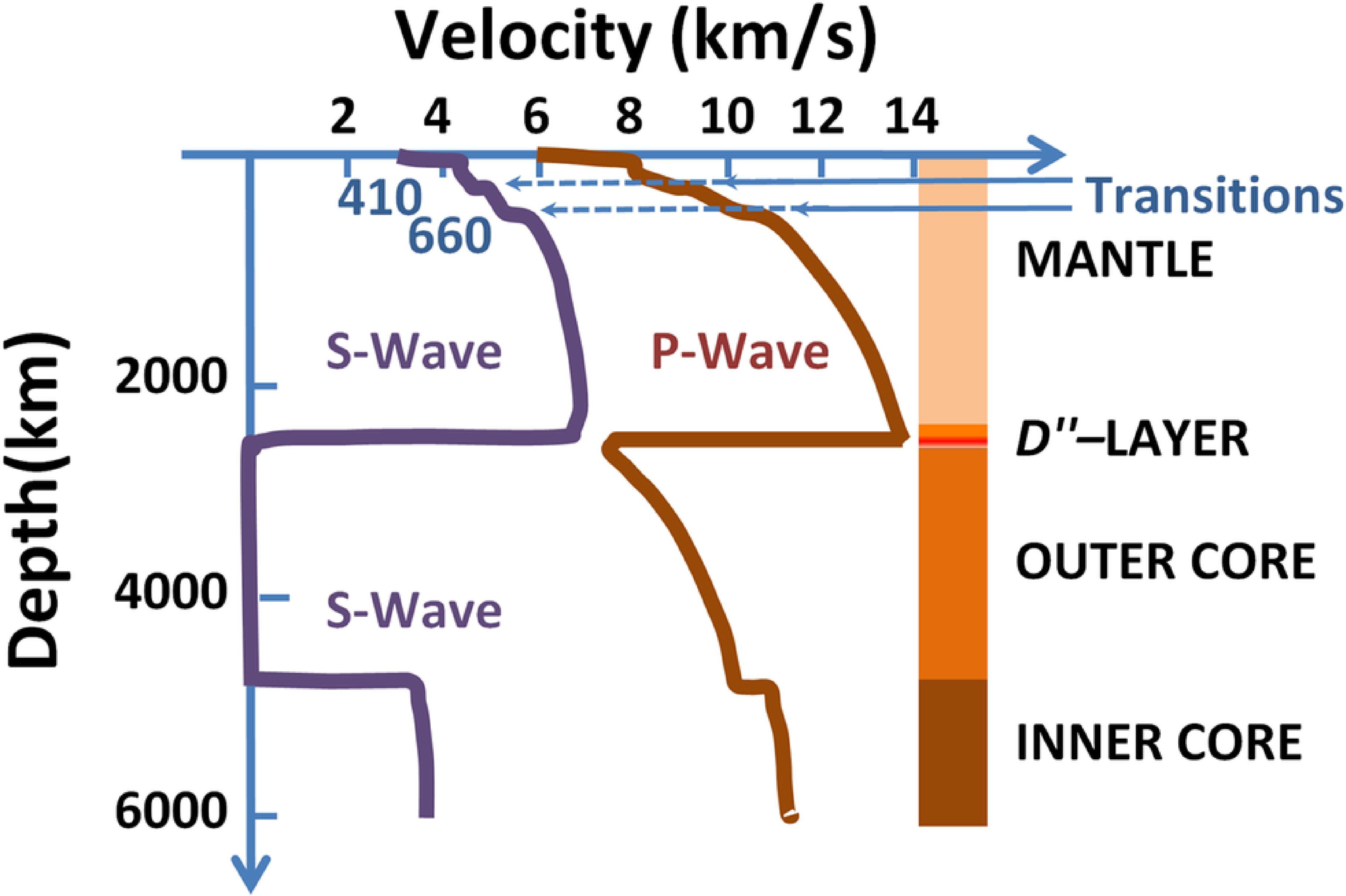

Compression
Expansion
At rest
Direction of P-wave travel
A
P wave
Direction of S-wave travel
B
S wave

Rayleigh Wave

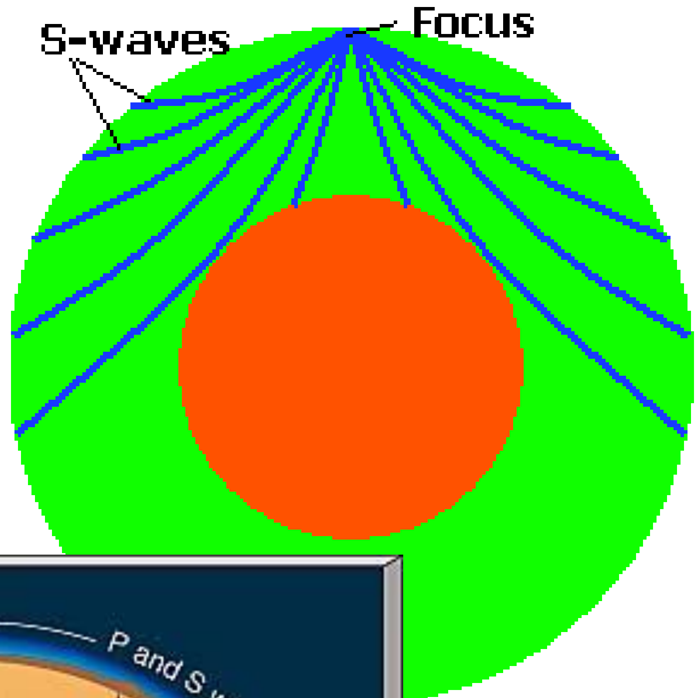


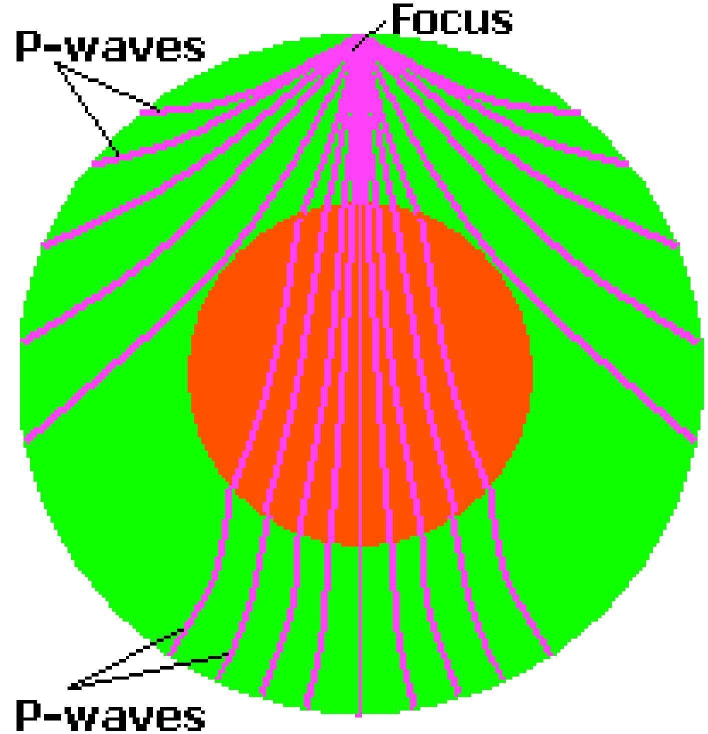
Love Wave

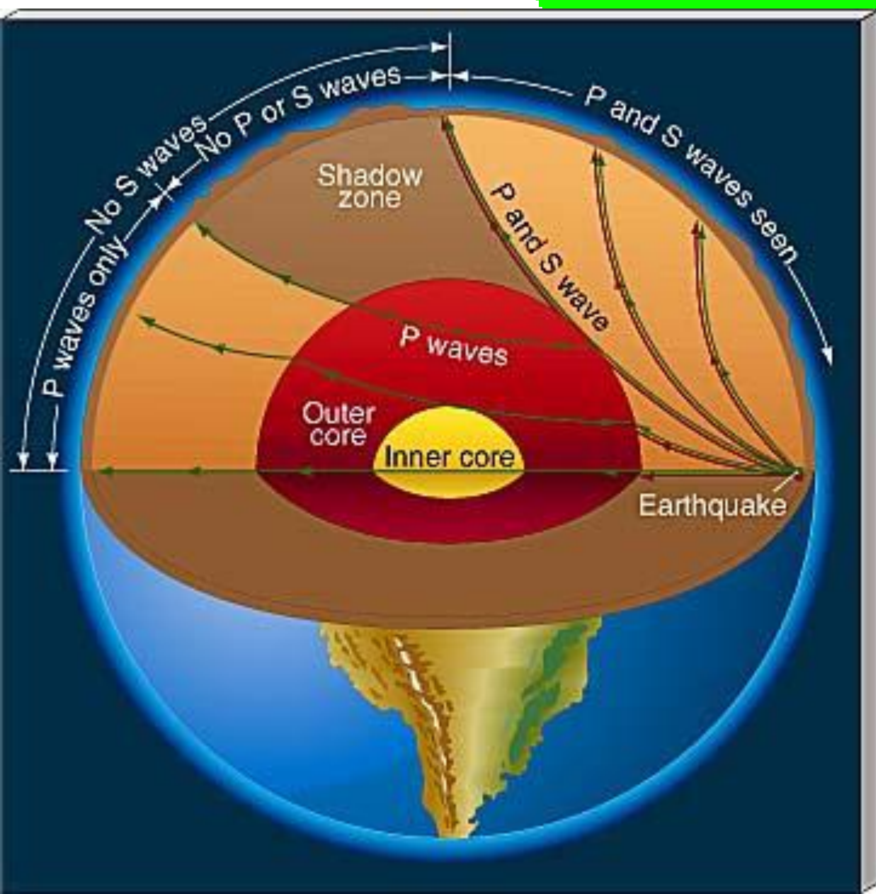


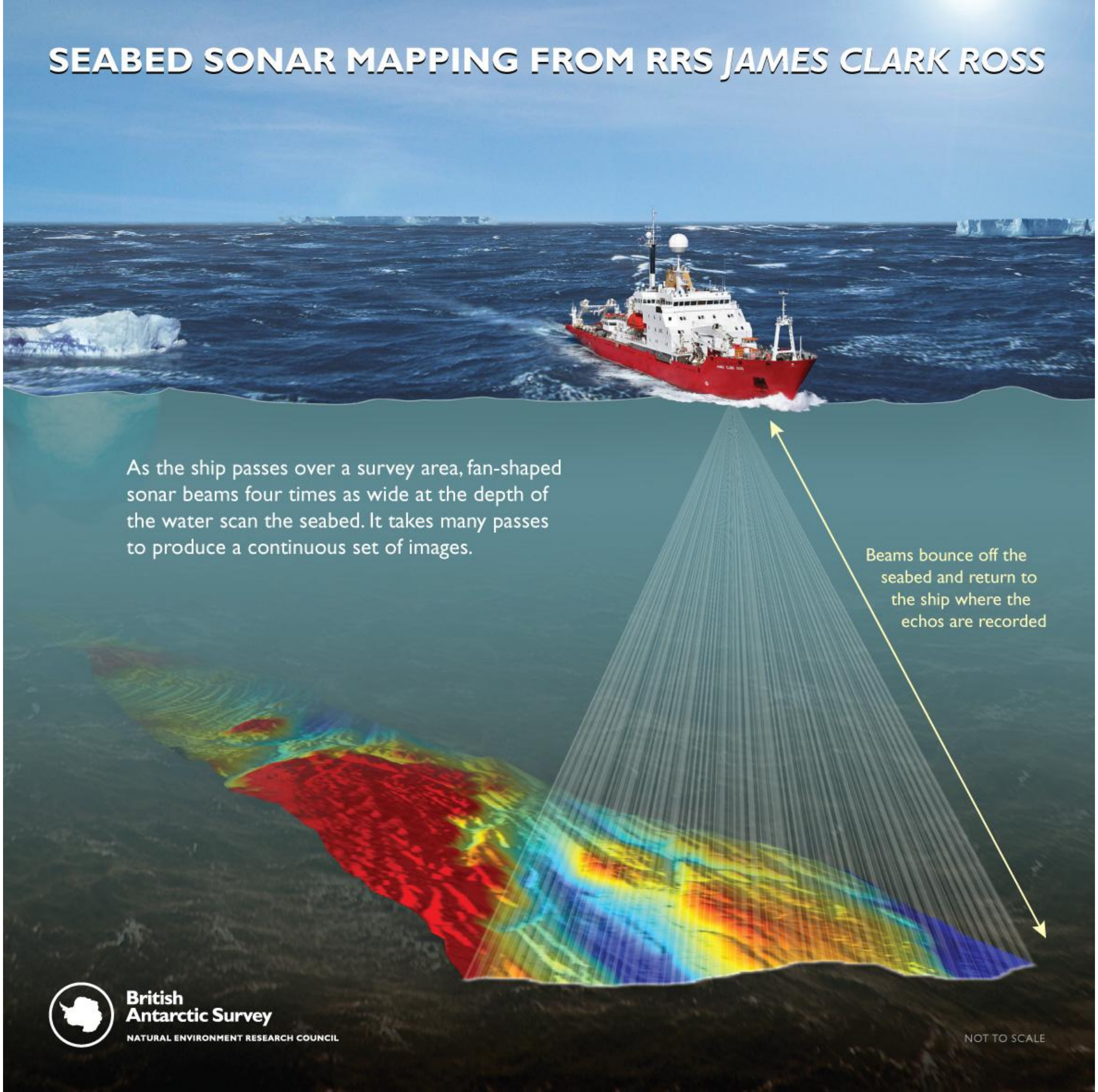


Velocity (km/s)
2
4
6
8
10
12
14
410
660
Transitions
MANTLE
S-Wave
P-Wave
2000
D''–LAYER
Depth(km)
OUTER CORE
4000
S-Wave
INNER CORE
6000


S-waves
Focus


Focus
P-waves
P-waves


P waves only
No S waves
No P or S waves
P and S waves seen
Shadow zone
P and S wave
P waves
Outer core
Inner core
Earthquake


SEABED SONAR MAPPING FROM RRS *JAMES CLARK ROSS*
As the ship passes over a survey area, fan-shaped sonar beams four times as wide at the depth of the water scan the seabed. It takes many passes to produce a continuous set of images.
Beams bounce off the seabed and return to the ship where the echos are recorded
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
NOT TO SCALE

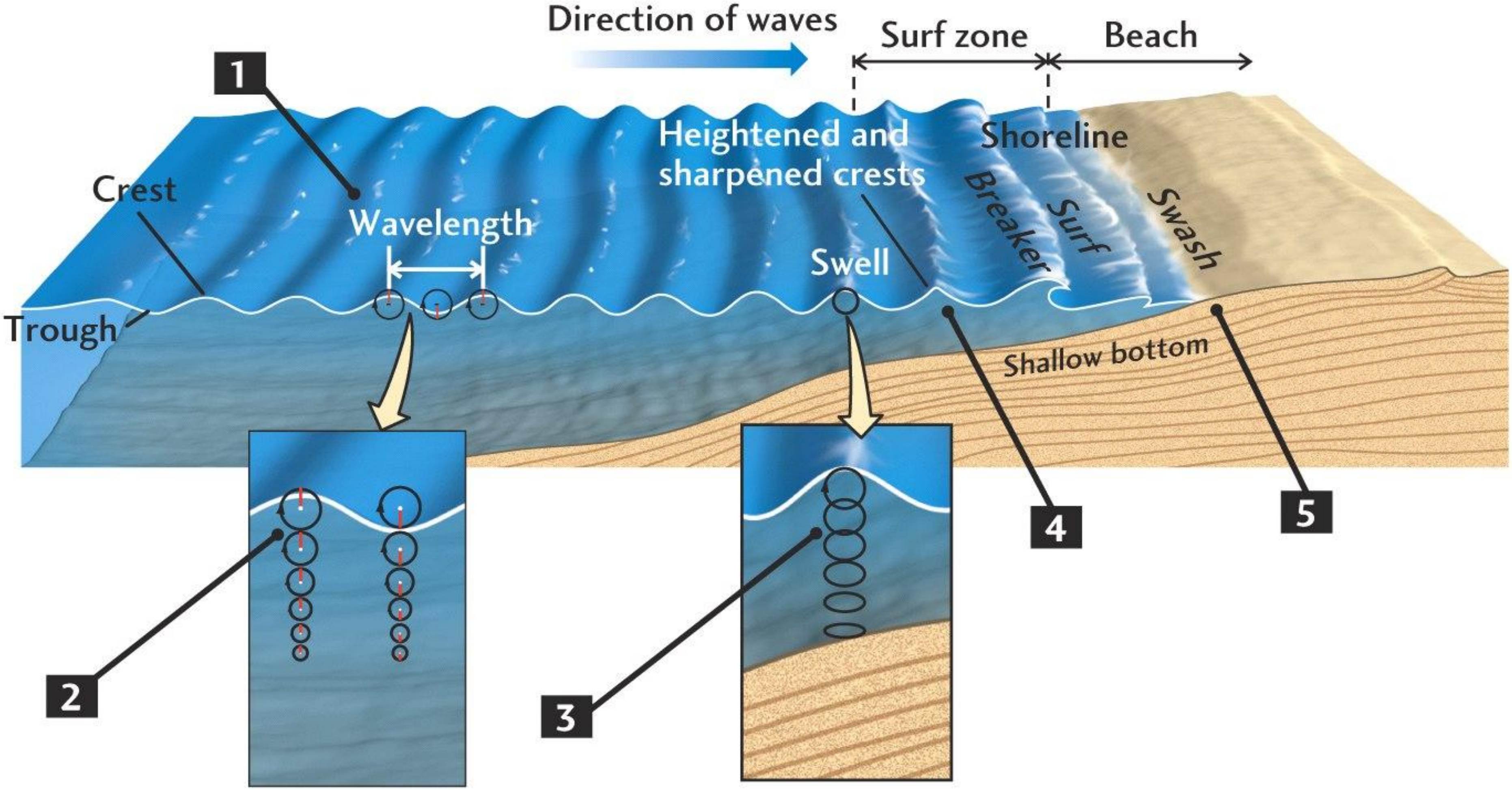
Mavericks, California

Garrett McNamara surfs a 100ft wave! (January 2013, off the coast of Portugal)

Garrett McNamara surfs a 100ft wave!
https://www.youtube.com/watch?v=IlrqyHIE4wc

https://www.youtube.com/watch?v=5XpU5M0ZCKM

WAVE MOTION IS INFLUENCED BY WATER DEPTH AND SHAPE OF THE SHORELINE



Ripples and *caustics*

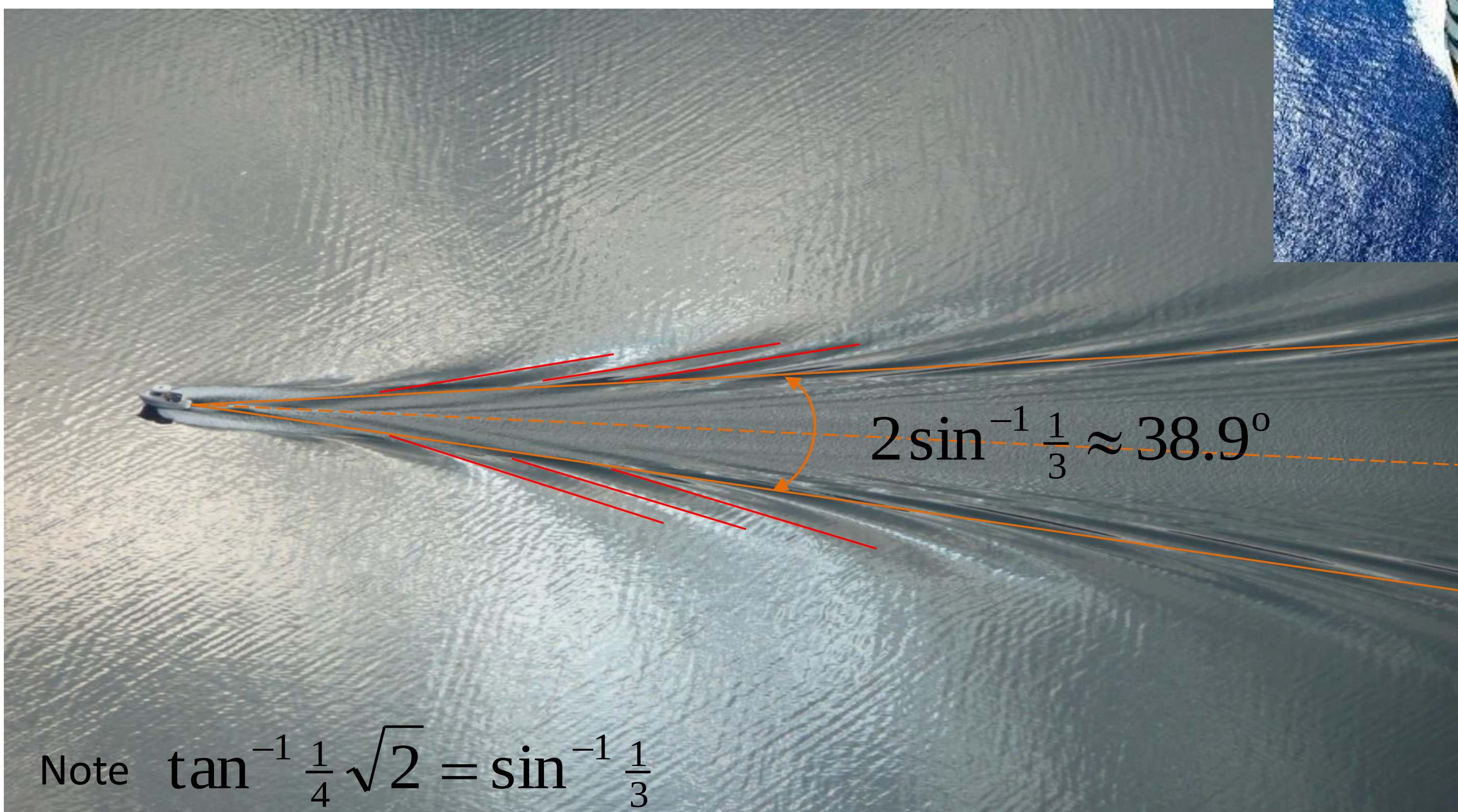
Surface tension is important!



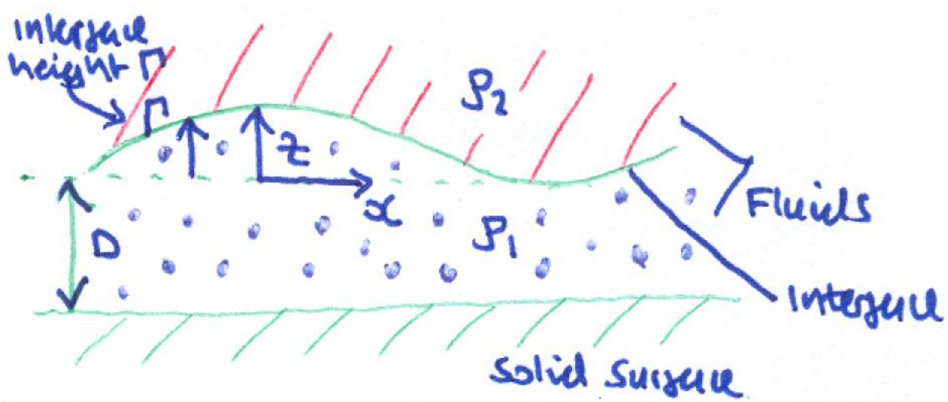

A wake is an *interference pattern* of waves formed by the motion of a body through a fluid. Intriguingly, the angular width of the wake produced by ships (and ducks!) in deep water is the same (about 38.9^{o}). A mathematical explanation for this phenomenon was first proposed by [Lord Kelvin](#) (1824-1907). The triangular envelope of the wake pattern has since been known as the *Kelvin wedge*.

http://en.wikipedia.org/wiki/Wake

The Kelvin Wedge



In general, for *vorticity* free waves on the interface of two *incompressible, Newtonian* fluids, the dispersion relationship can be shown to be, for waves with amplitude $\Gamma \ll D$



surface tension

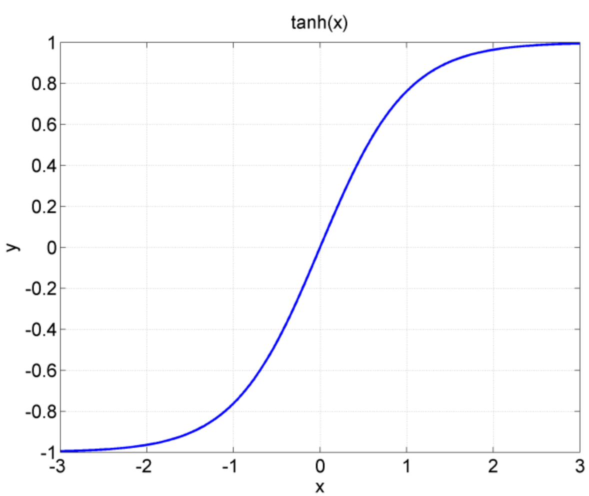
$$\omega^2 = \frac{\sigma k^3 + g(\rho_1 - \rho_2)k}{\rho_2 + \rho_1 \operatorname{cotanh}(kD)}$$

fluid densities

depth

For waves on a water, air interface $\rho_1 \approx 1000\rho_2$, so ignore ρ_2

$$\omega^2 = \left(\frac{\sigma k^3}{\rho_1} + gk\right)\tanh(kD)$$



For **shallow water** waves $\tanh(kD) \approx kD$

$$\omega^2 = \frac{\sigma k^4 D}{\rho_1} + gk^2 D$$

For **deep water** waves $\tanh(kD) \approx 1$

$$\omega^2 = \frac{\sigma k^3}{\rho_1} + gk$$

Since $k = \frac{2\pi}{\lambda}$ the higher powers of *k* will contribute less for longer wavelengths

Hence for shallow water gravity waves

e.g. waves coming ashore just before they break, or waves in a shallow river or canal

$$\boxed{\omega^2 = gk^2 D} \qquad c_p = \frac{\omega}{k} = \boxed{\sqrt{gD}}$$

Similarly for deep water waves

$$\boxed{\omega^2 = gk} \qquad c_p = \frac{\omega}{k} = \sqrt{\frac{g}{k}} = \boxed{\sqrt{\frac{\lambda g}{2\pi}}}$$

Note for deep water *ripples* (or 'capillary waves') this approximation is invalid.

We must use the full dispersion relation

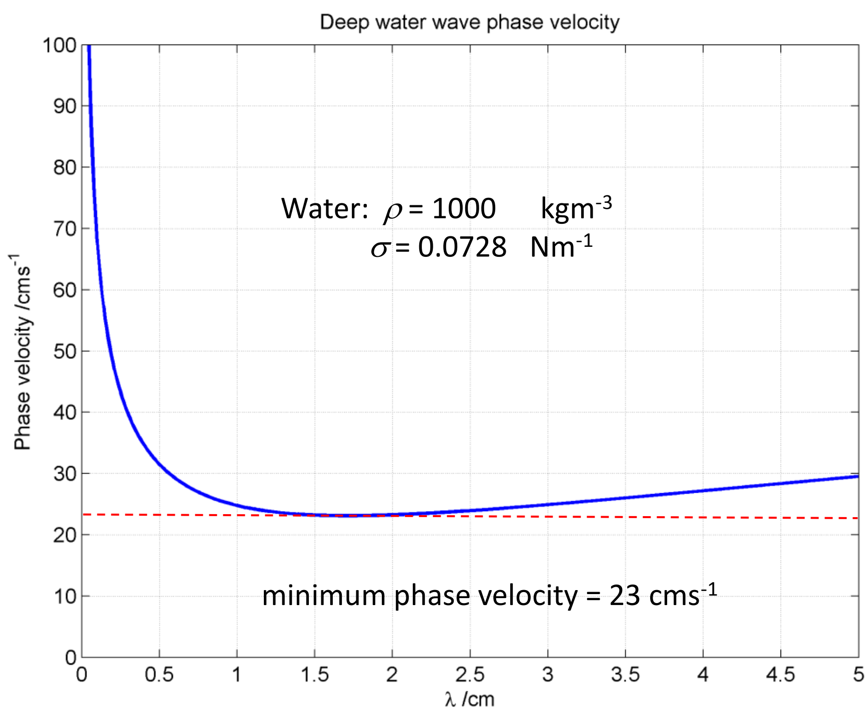
$$\omega = \sqrt{\frac{\sigma k^3}{\rho_1} + gk}$$

Ripple phase velocity is:

$$c_p = \frac{\omega}{k} = \sqrt{\frac{\sigma k}{\rho_1} + \frac{g}{k}} = \boxed{\sqrt{\frac{2\pi\sigma}{\lambda\rho_1} + \frac{g\lambda}{2\pi}}}$$

Which has a *minima* at

$$\boxed{c_p = \sqrt[4]{\frac{4g\sigma}{\rho_1}}}$$



Lenticular clouds

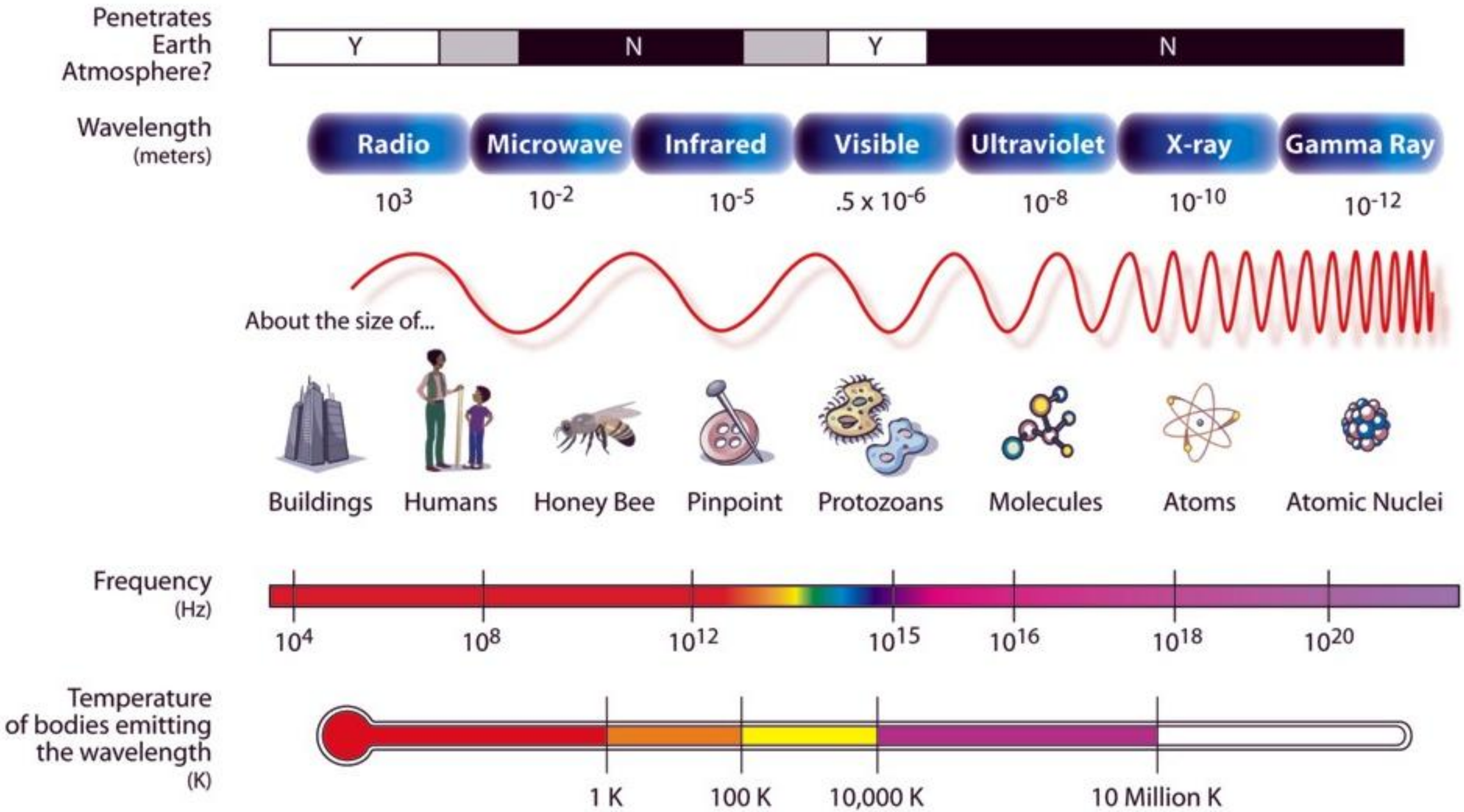
Kelvin Helmholtz instability on Earth

Kelvin Helmholtz instability on Jupiter

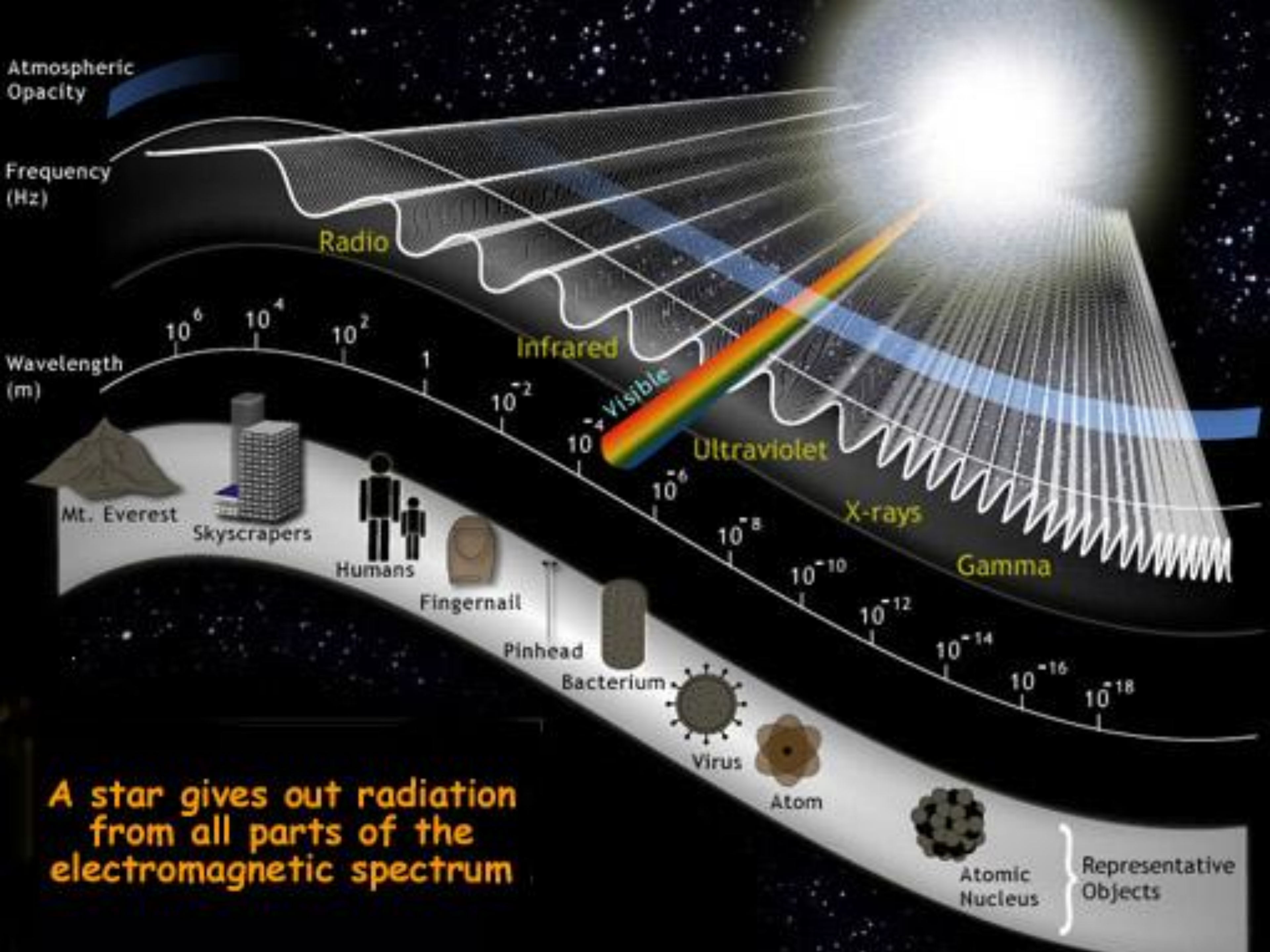
Shock waves



THE ELECTROMAGNETIC SPECTRUM

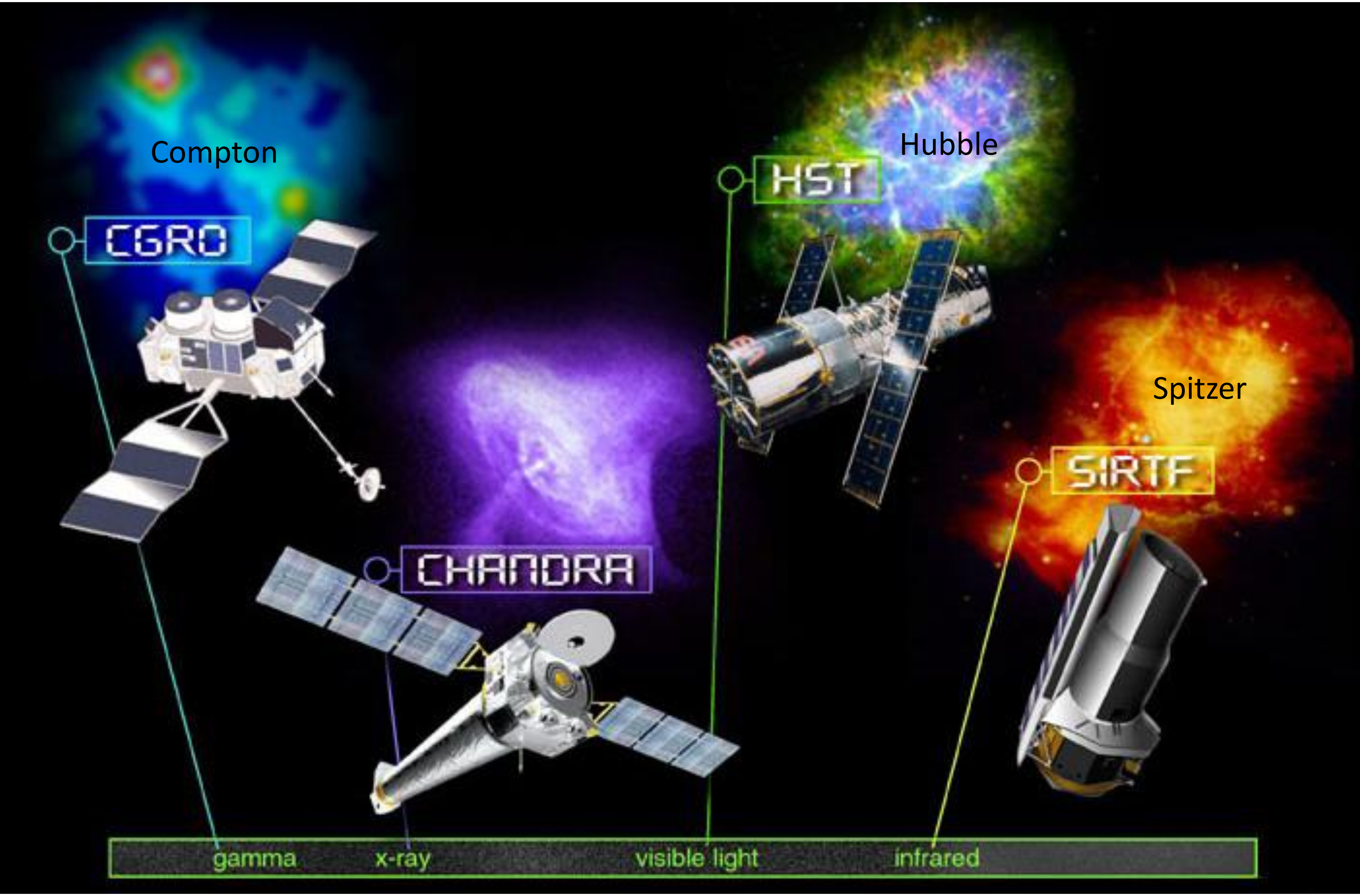


Convert wavelength into frequency using $c = f\lambda$ $\quad c = 2.998 \times 10^8 \,\mathrm{ms}^{-1}$

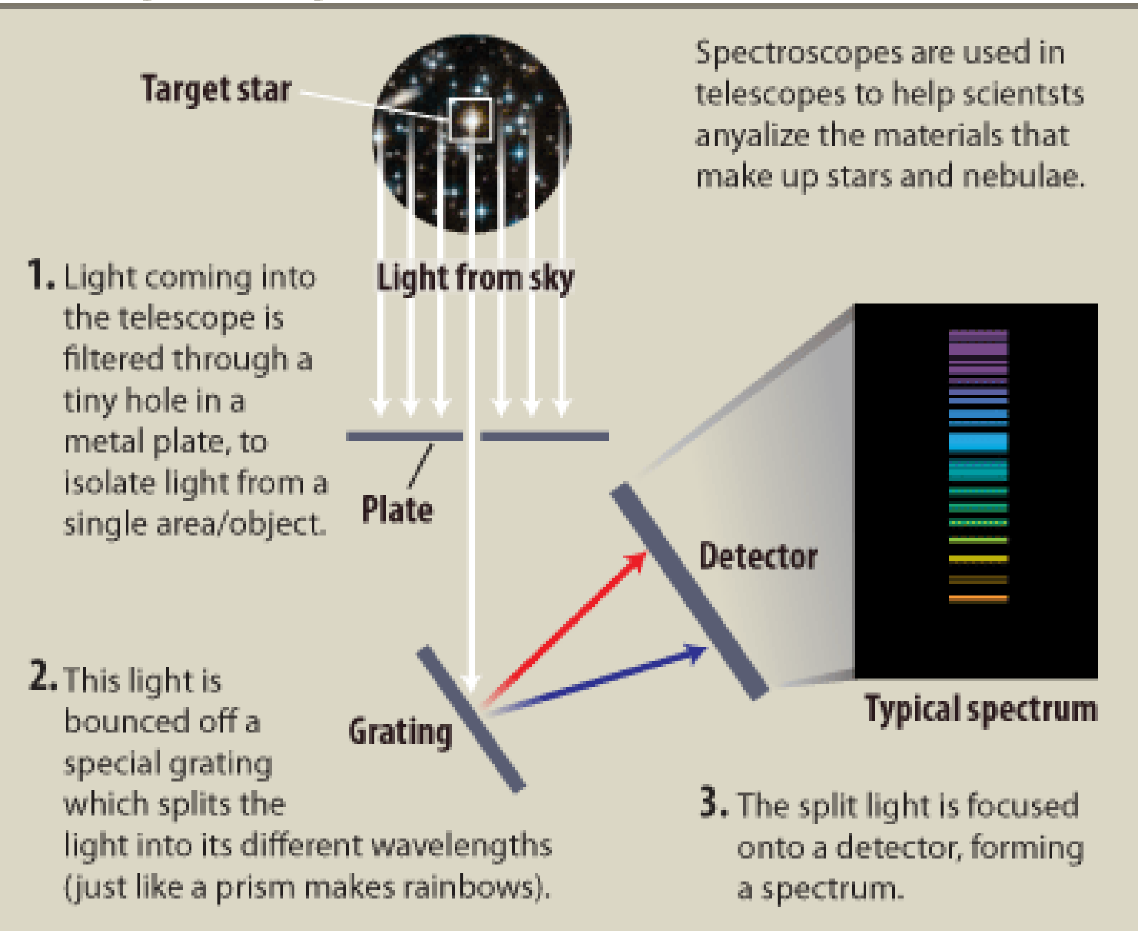


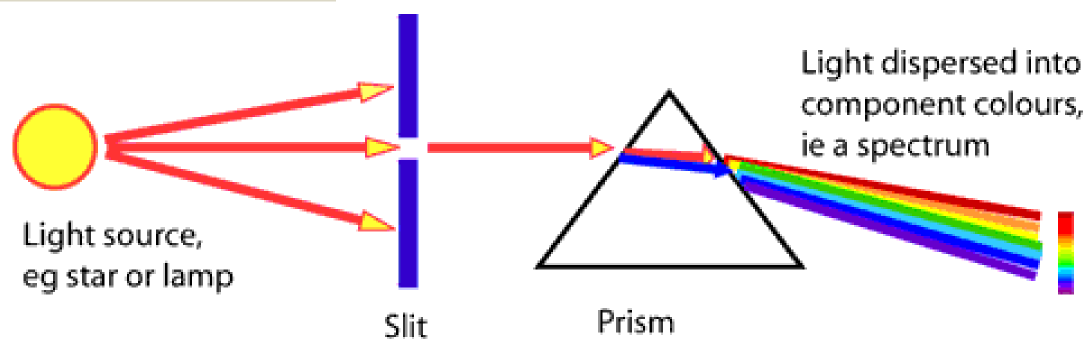
A star gives out radiation from all parts of the electromagnetic spectrum

NASA space telescopes



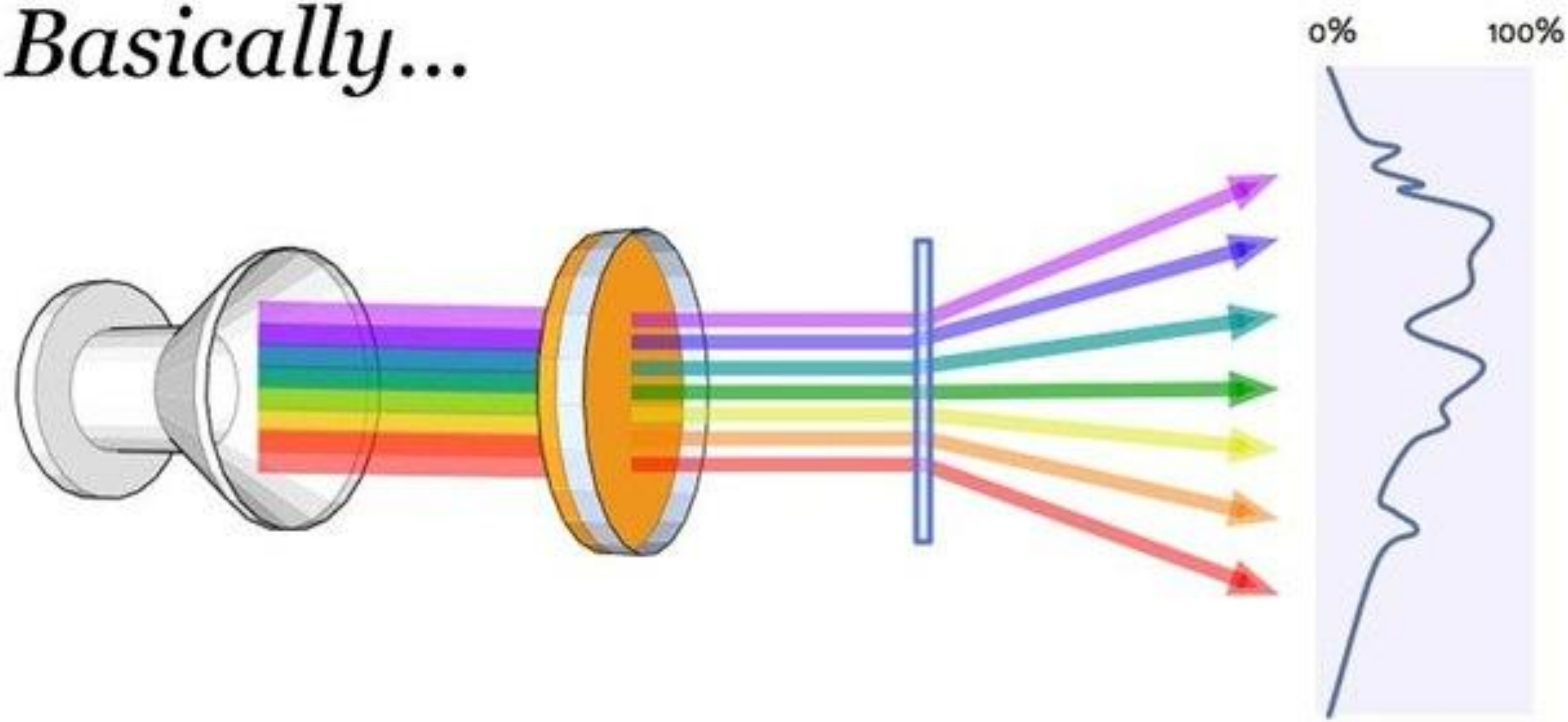
How a Spectroscope Works





Dispersion of light through a prism

Basically...



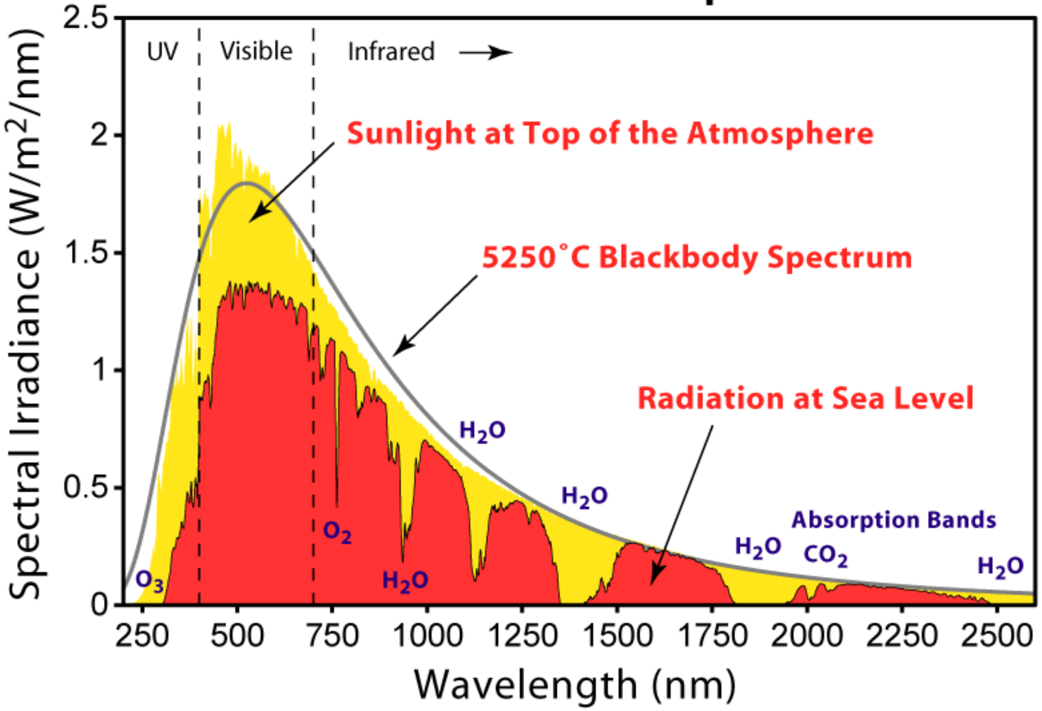
1. A broad-spectrum light (halogen, incandescent) is shone through a sample

2. Some colors are absorbed more than others depending on its composition

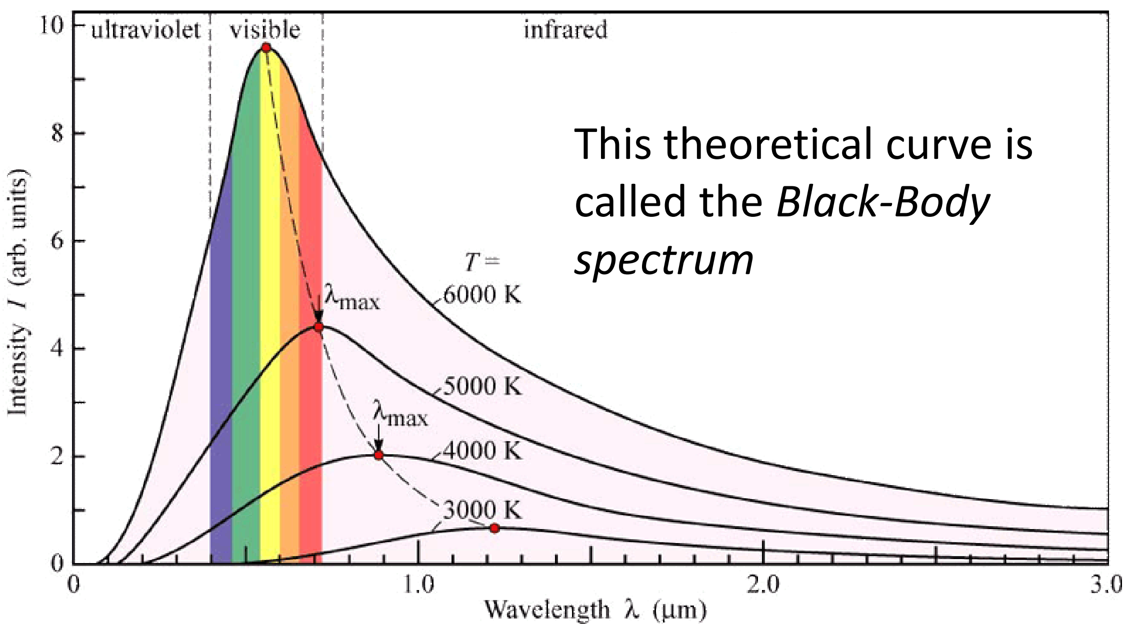
3. Diffraction grating splits light into colors so they can be measured separately

4. A webcam measures each color and graphs their intensities. This is compared to known samples.

Solar Radiation Spectrum



Note solar energy is absorbed in atmosphere by oxygen, water vapour, carbon dioxide etc. Hence *dips* in the solar spectra at sea level.



This theoretical curve is called the *Black-Body spectrum*

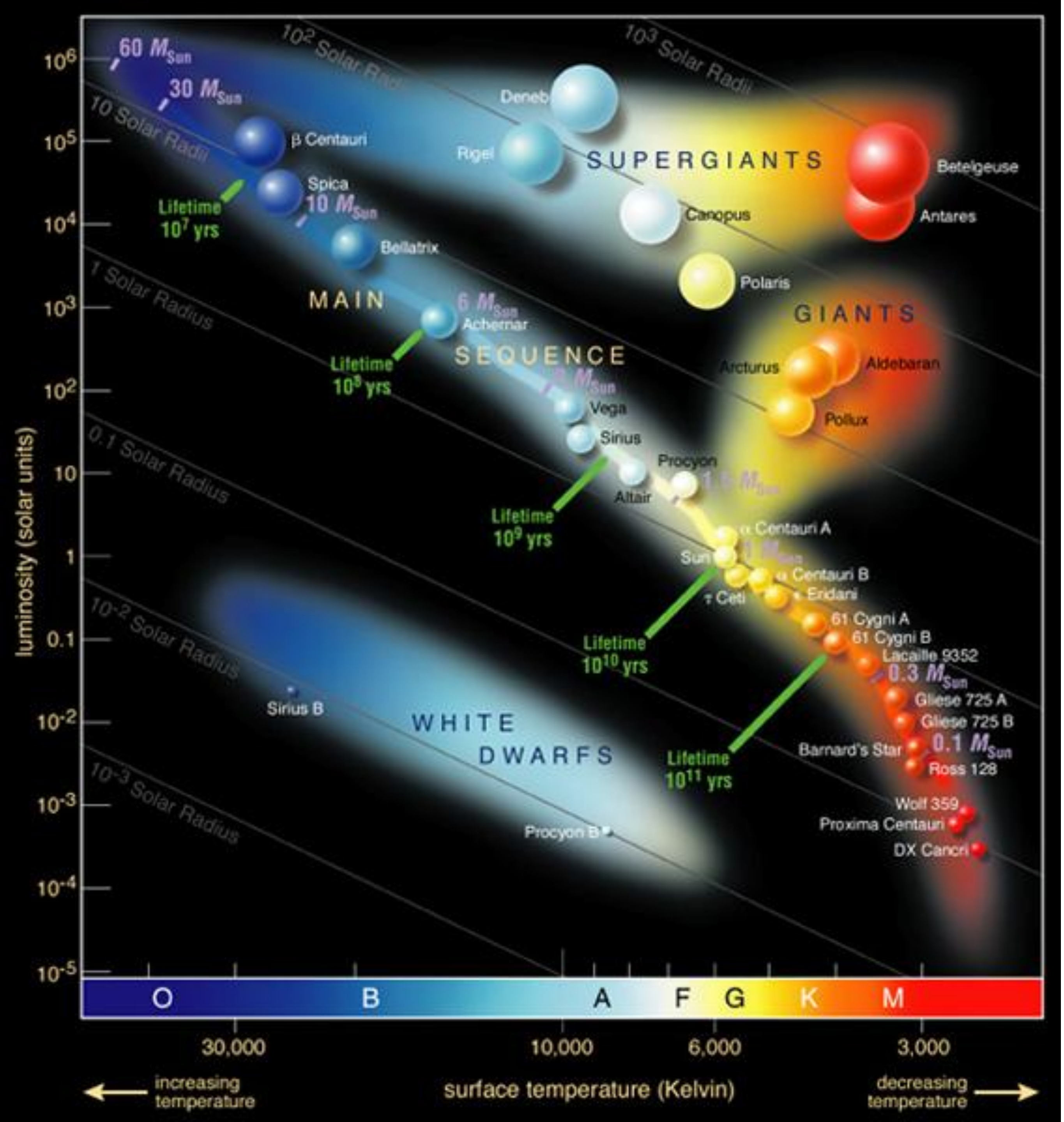
Measure **surface temperature** of a star from the spectral shape

(i.e. brightness at different wavelengths)

Convert wavelength into frequency using

$$c = f\lambda$$

Hertzsprung-Russell diagram

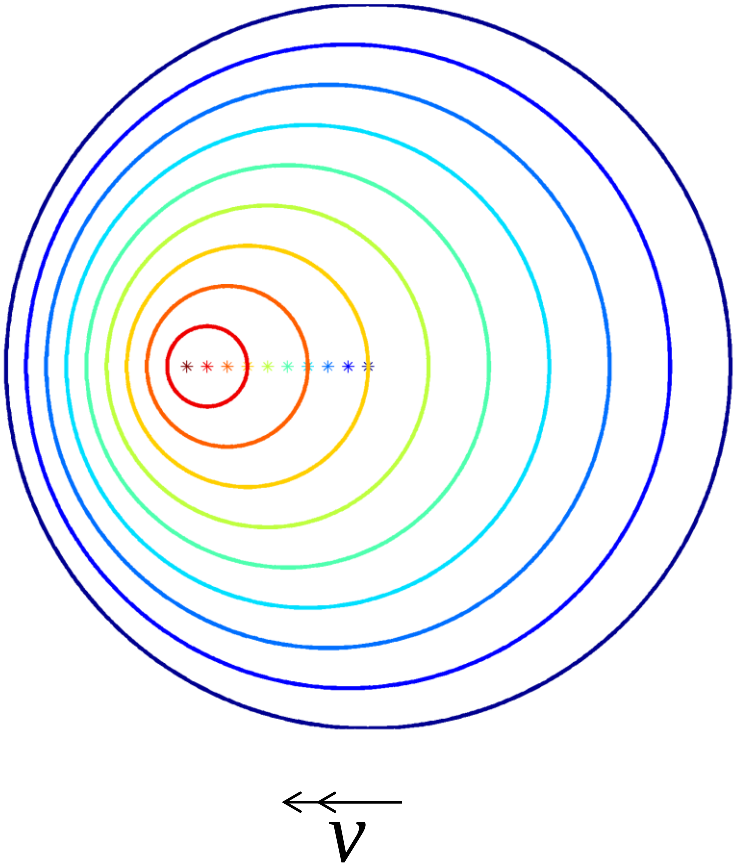


1910 by Ejnar Hertzsprung and Henry Norris Russell

Doppler shift method for measuring radial velocity

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

If an object emitting radiation at frequency *f* moves radially towards an observer at velocity *v*, the observer will measure a *slightly higher frequency* of radiation as the emitted waves ‘bunch up’.



Velocity of emitter towards observer

Frequency of emitted radiation

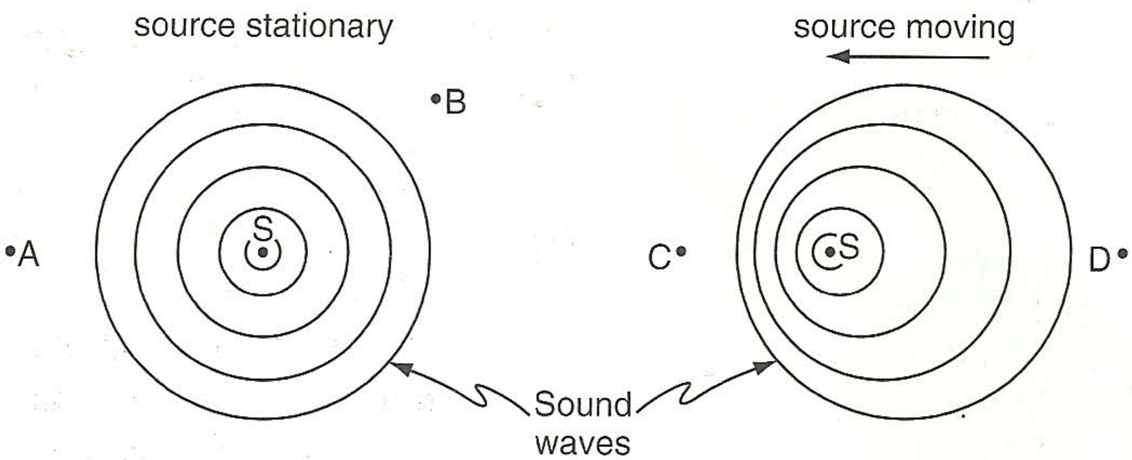
frequency change

$$\boxed{\Delta f = \frac{v}{c} f}$$

Speed of radiation

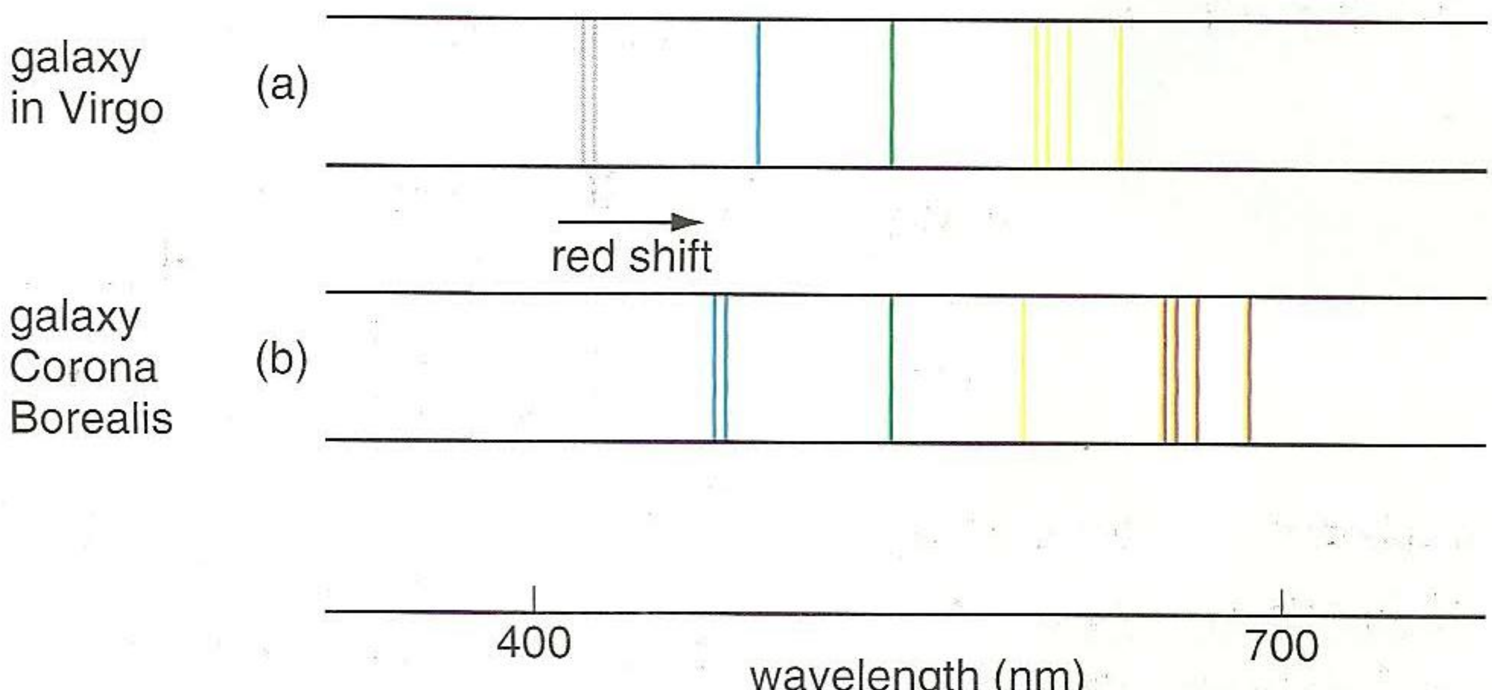
Note this formula is ‘Classical’. It is valid when v << c, otherwise a relativistic version must be used

Christian Doppler
1803-1953

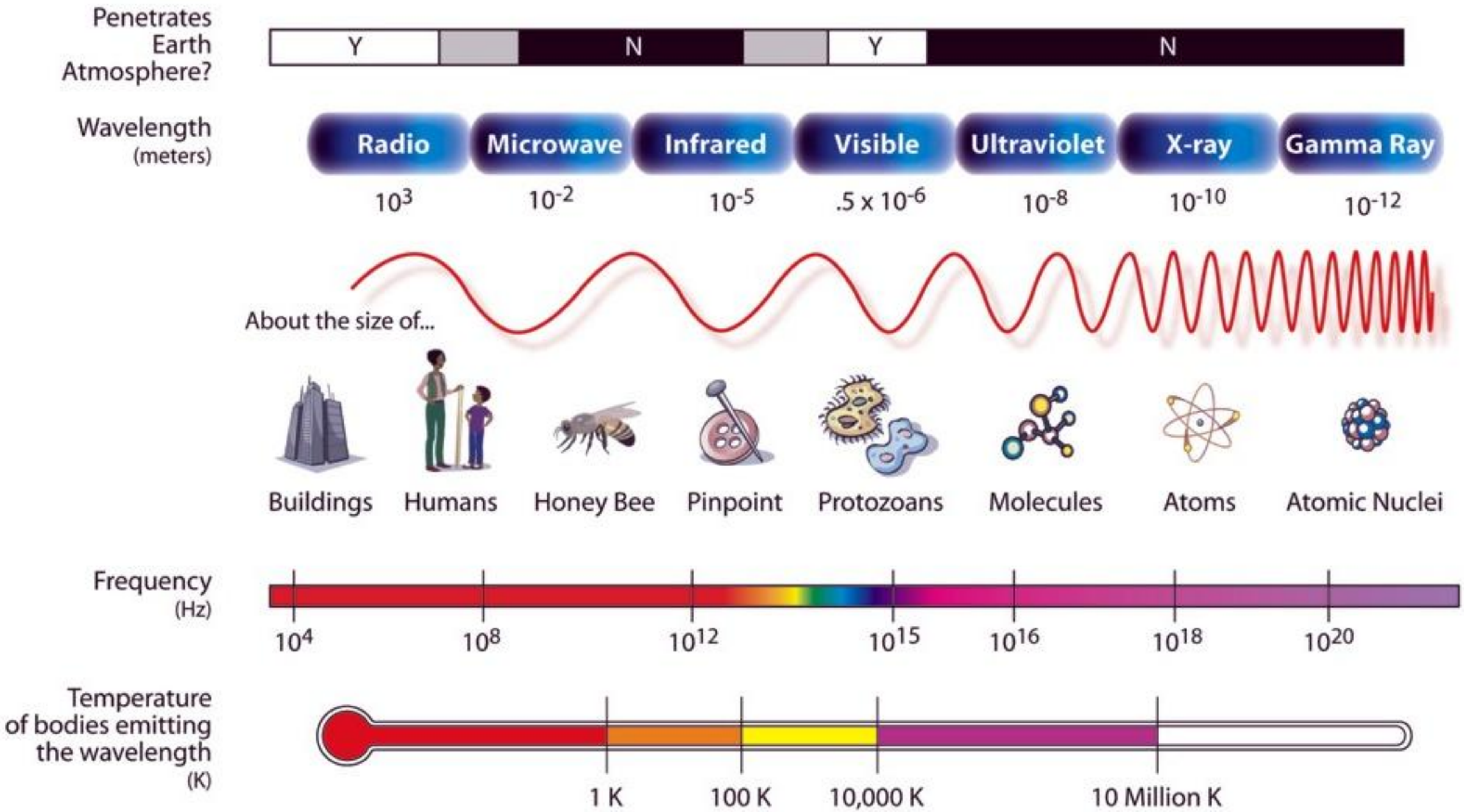


Redshift *z* is the fractional change in wavelength of light due to the Doppler effect

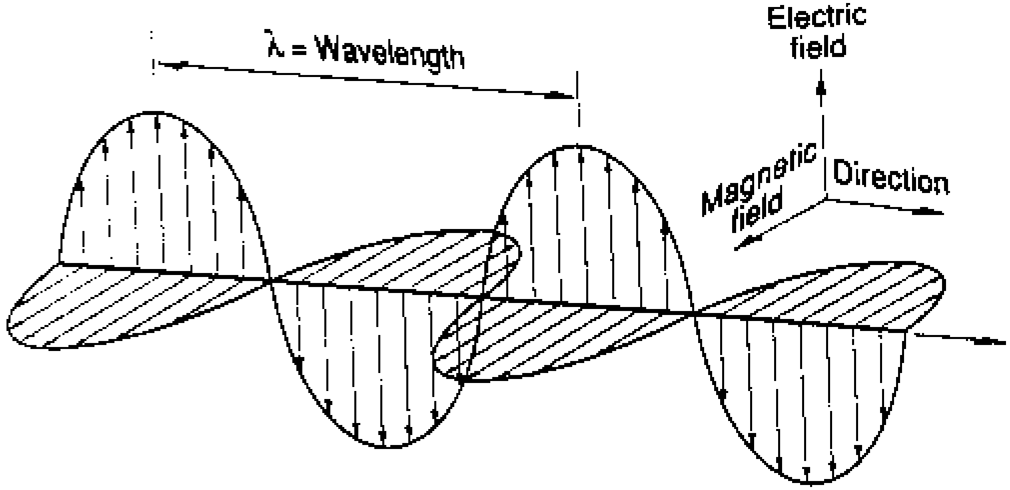
$$z = \frac{\lambda_{\text{observed}} - \lambda_{\text{emmitted}}}{\lambda_{\text{emmitted}}}$$



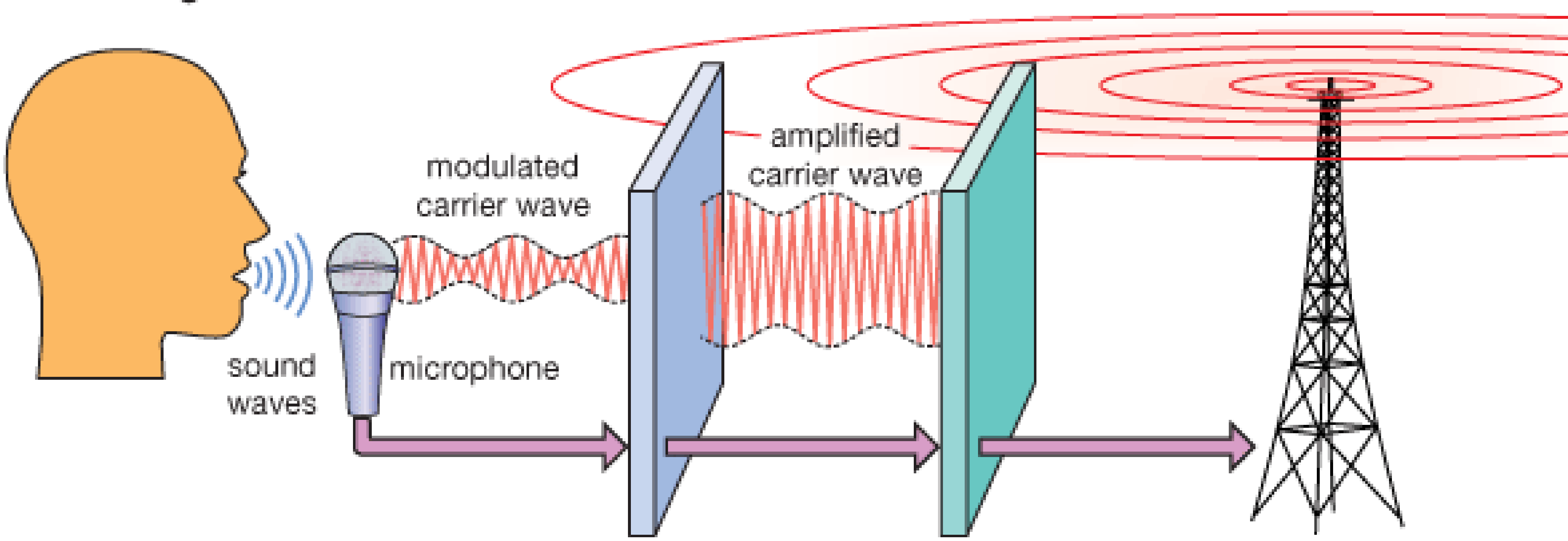
THE ELECTROMAGNETIC SPECTRUM



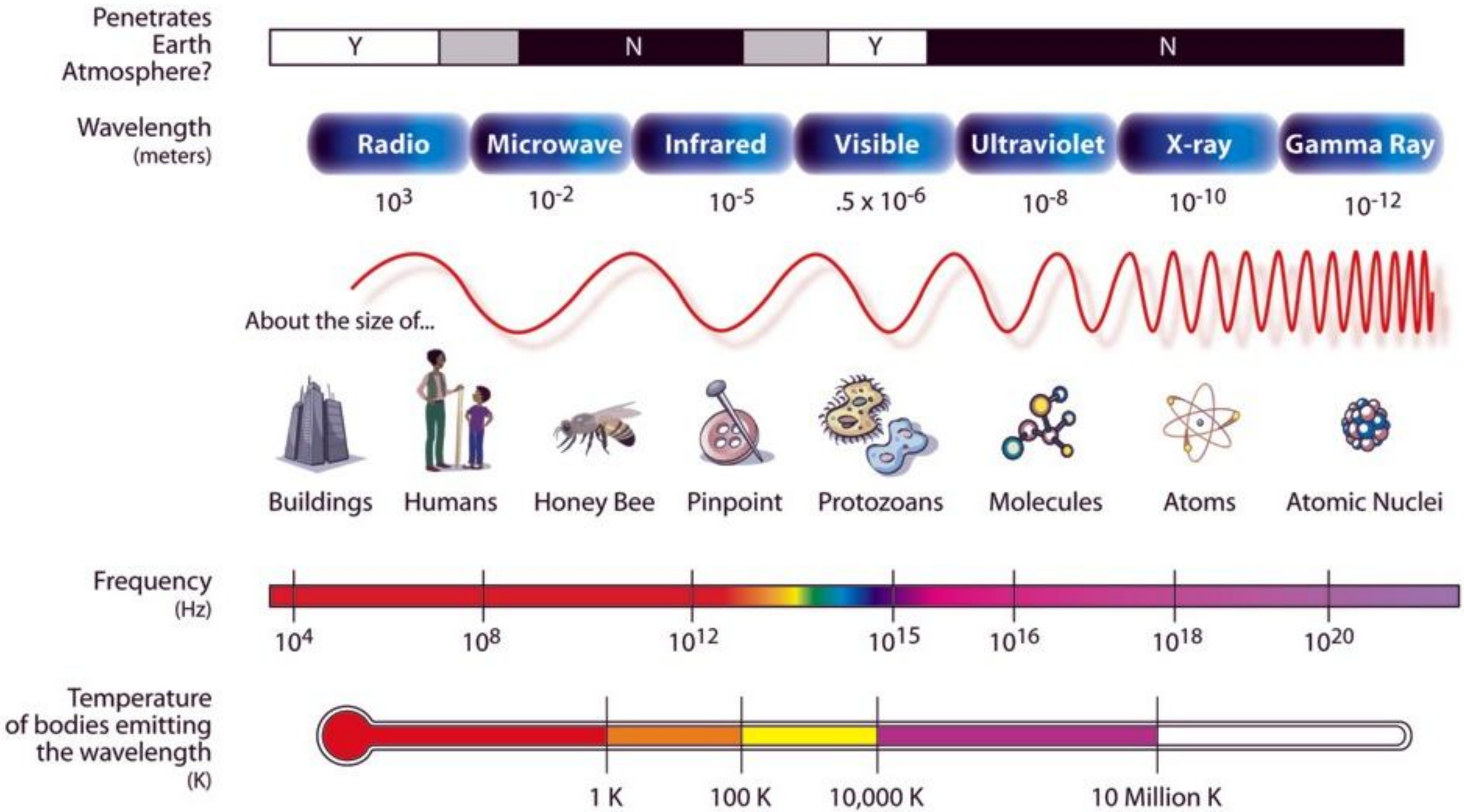
Convert wavelength into frequency using $c = f\lambda$ $\qquad c = 2.998 \times 10^8\,\mathrm{ms}^{-1}$



Transmitting Radio Waves



THE ELECTROMAGNETIC SPECTRUM



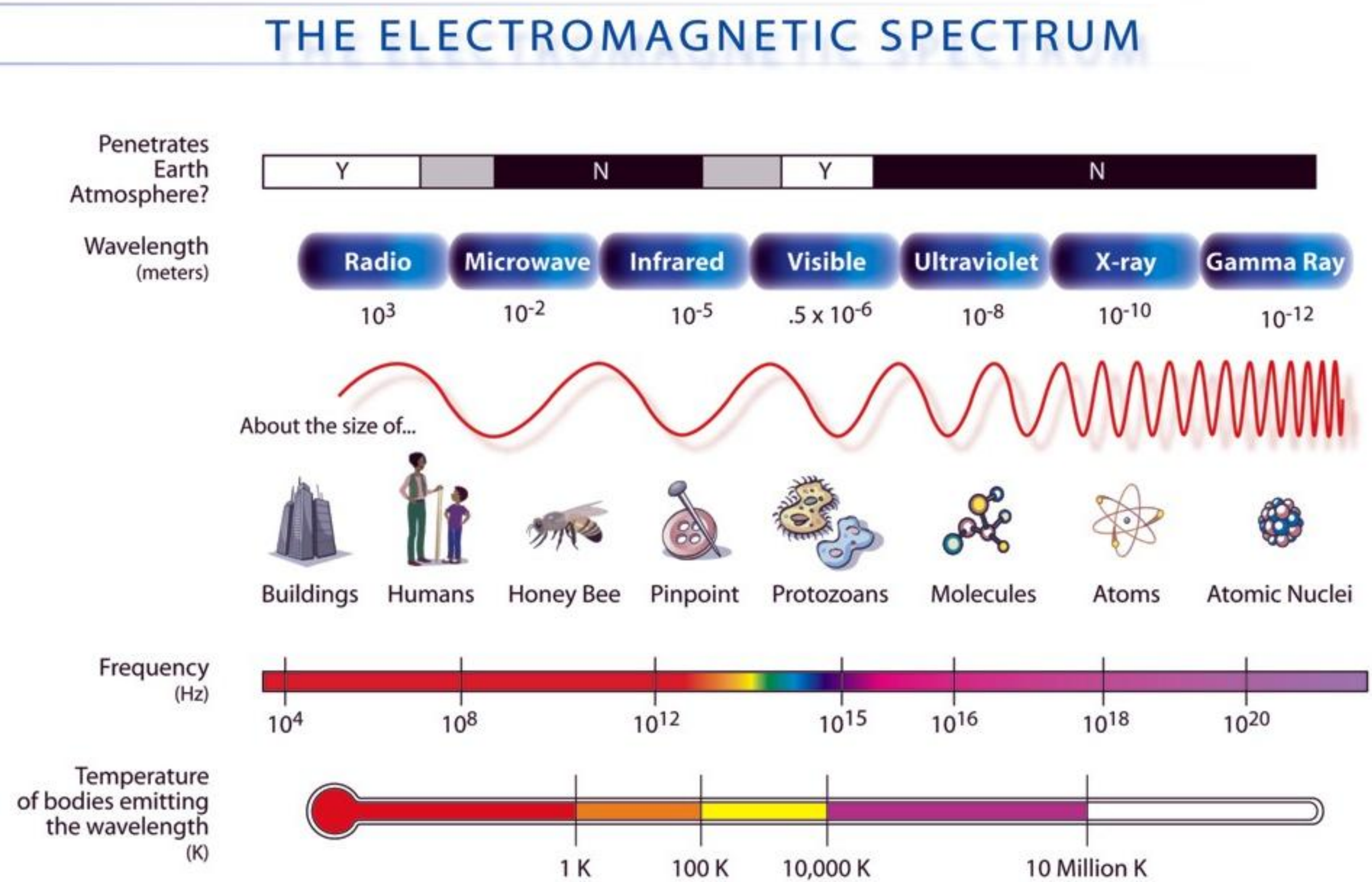
Convert wavelength into frequency using $c = f\lambda$ $\quad c = 2.998 \times 10^{8}\,\mathrm{ms}^{-1}$


Panasonic

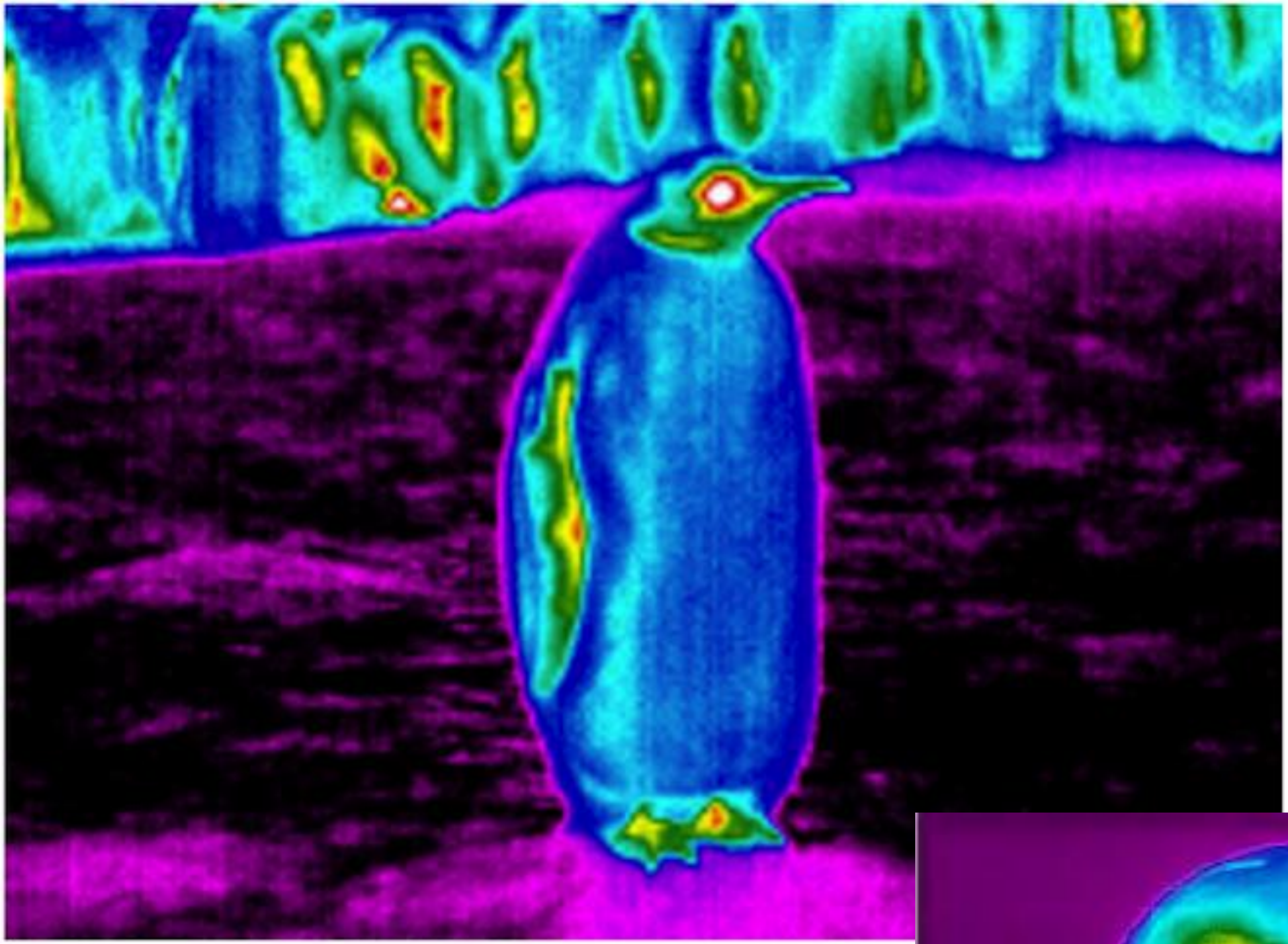

T45

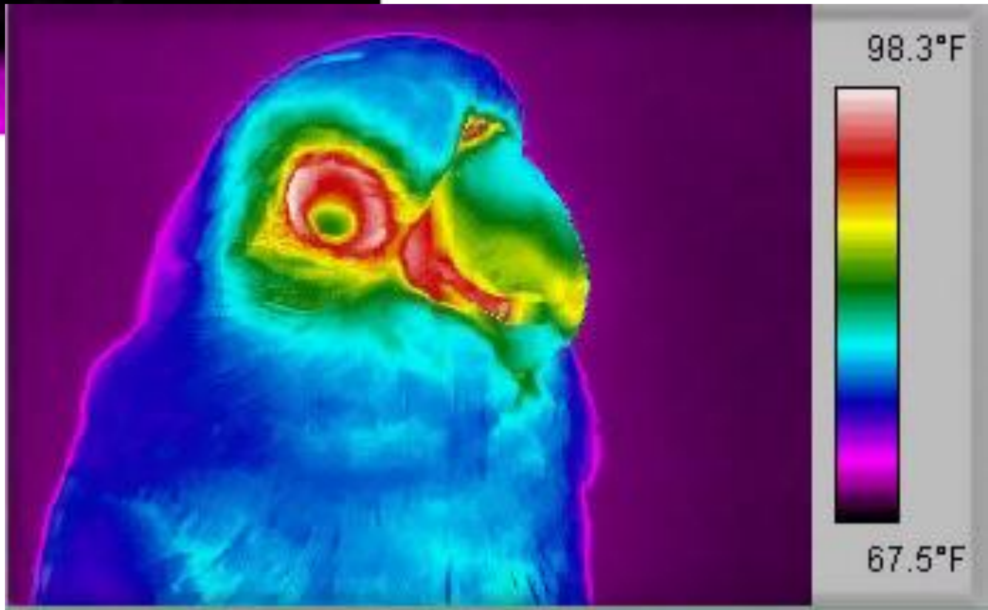
GSM spectrum (microwaves)
380 MHz – 1.8GHz

Global System for Mobile Comminication (**GSM**)
first deployed in Finland in July 1991

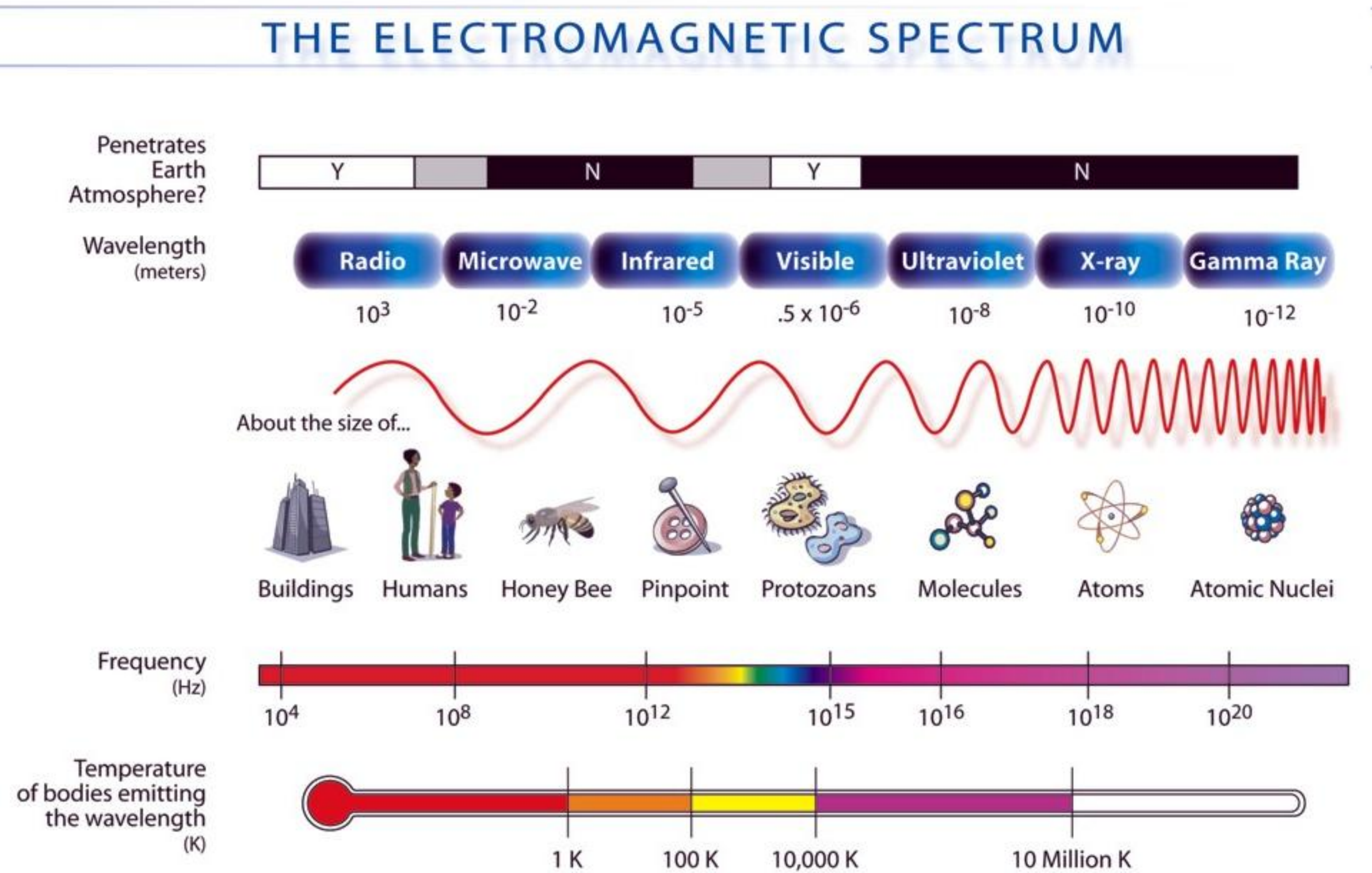


Convert wavelength into frequency using $c = f\lambda$ $\quad c = 2.998 \times 10^{8}\,\mathrm{ms}^{-1}$



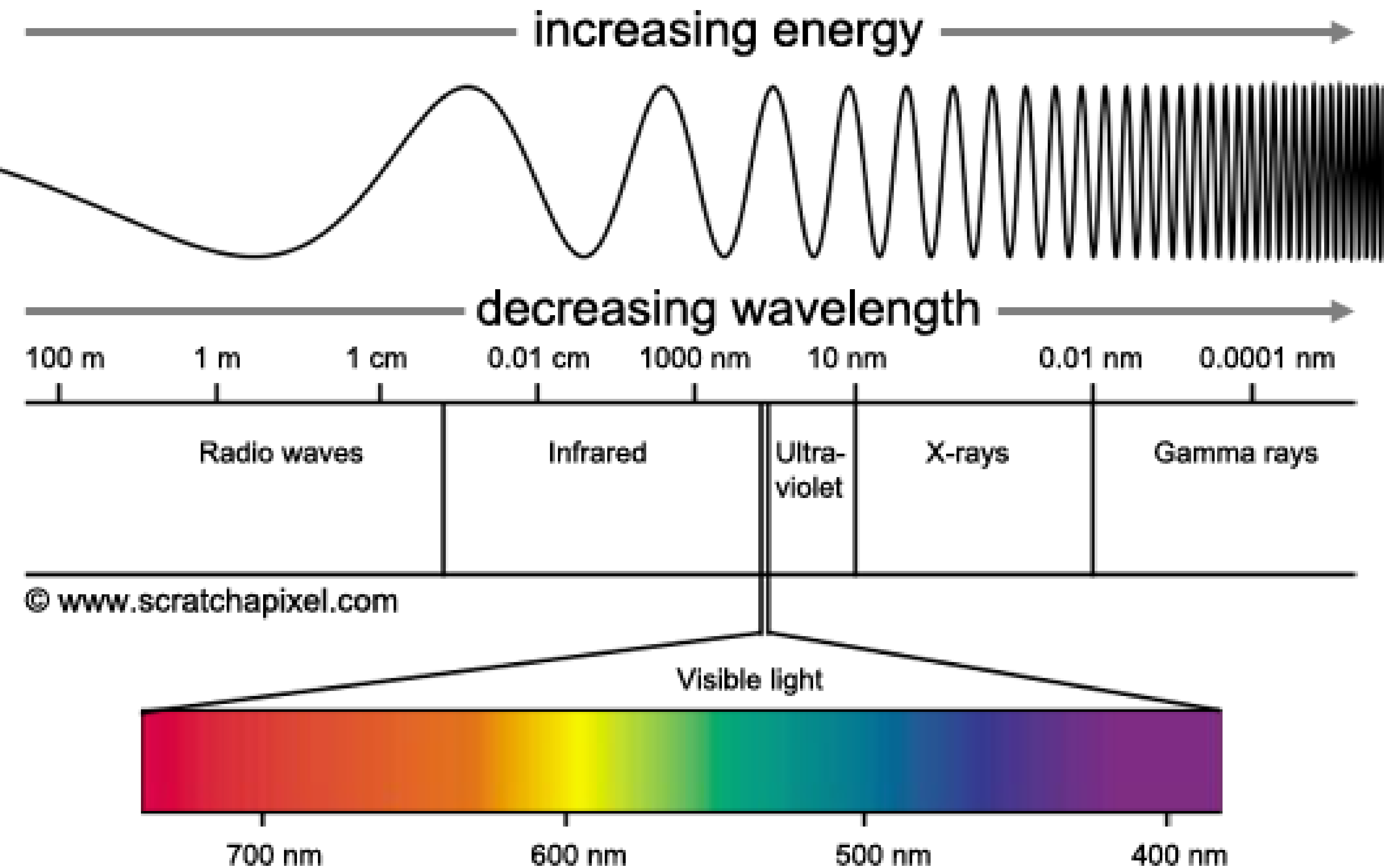


Infra Red

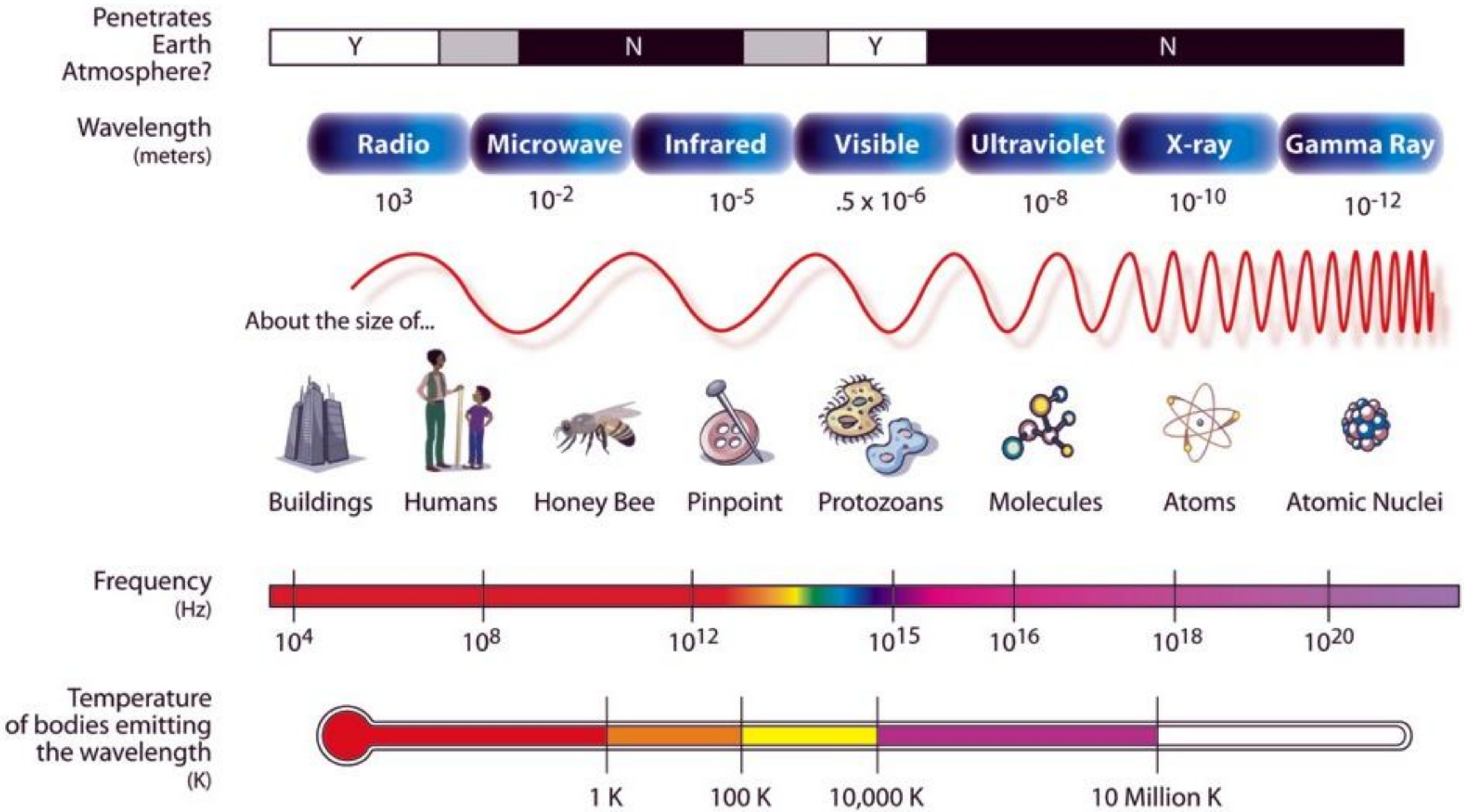


Convert wavelength into frequency using $c = f\lambda$

$$c = 2.998\times10^{8}\,\mathrm{ms}^{-1}$$

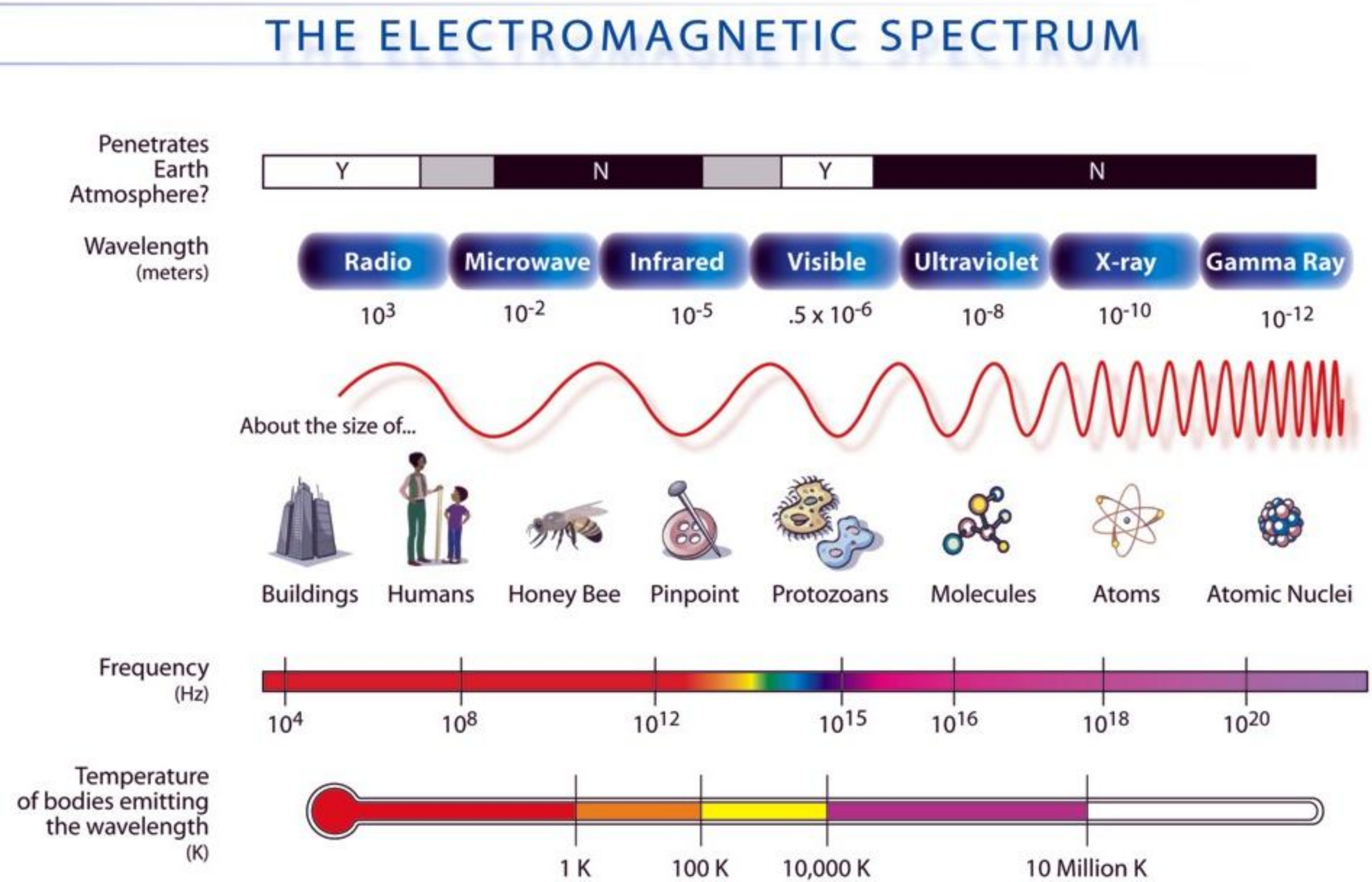

increasing energy
decreasing wavelength
100 m
1 m
1 cm
0.01 cm
1000 nm
10 nm
0.01 nm
0.0001 nm
Radio waves
Infrared
Ultra-
violet
X-rays
Gamma rays
© www.scratchapixel.com
Visible light
700 nm
600 nm
500 nm
400 nm

THE ELECTROMAGNETIC SPECTRUM



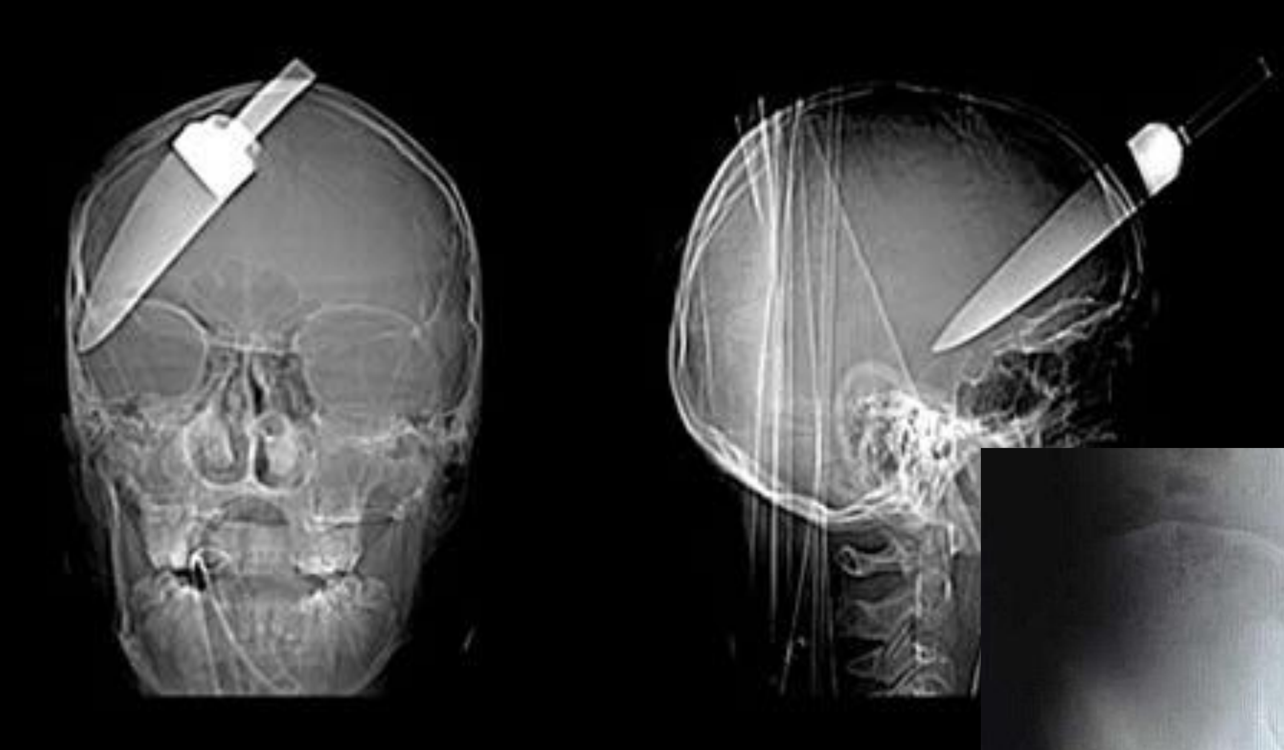
Convert wavelength into frequency using $c = f\lambda$ $\qquad c = 2.998 \times 10^{8}\,\mathrm{ms}^{-1}$


Ultraviolet
Visible
Infrared



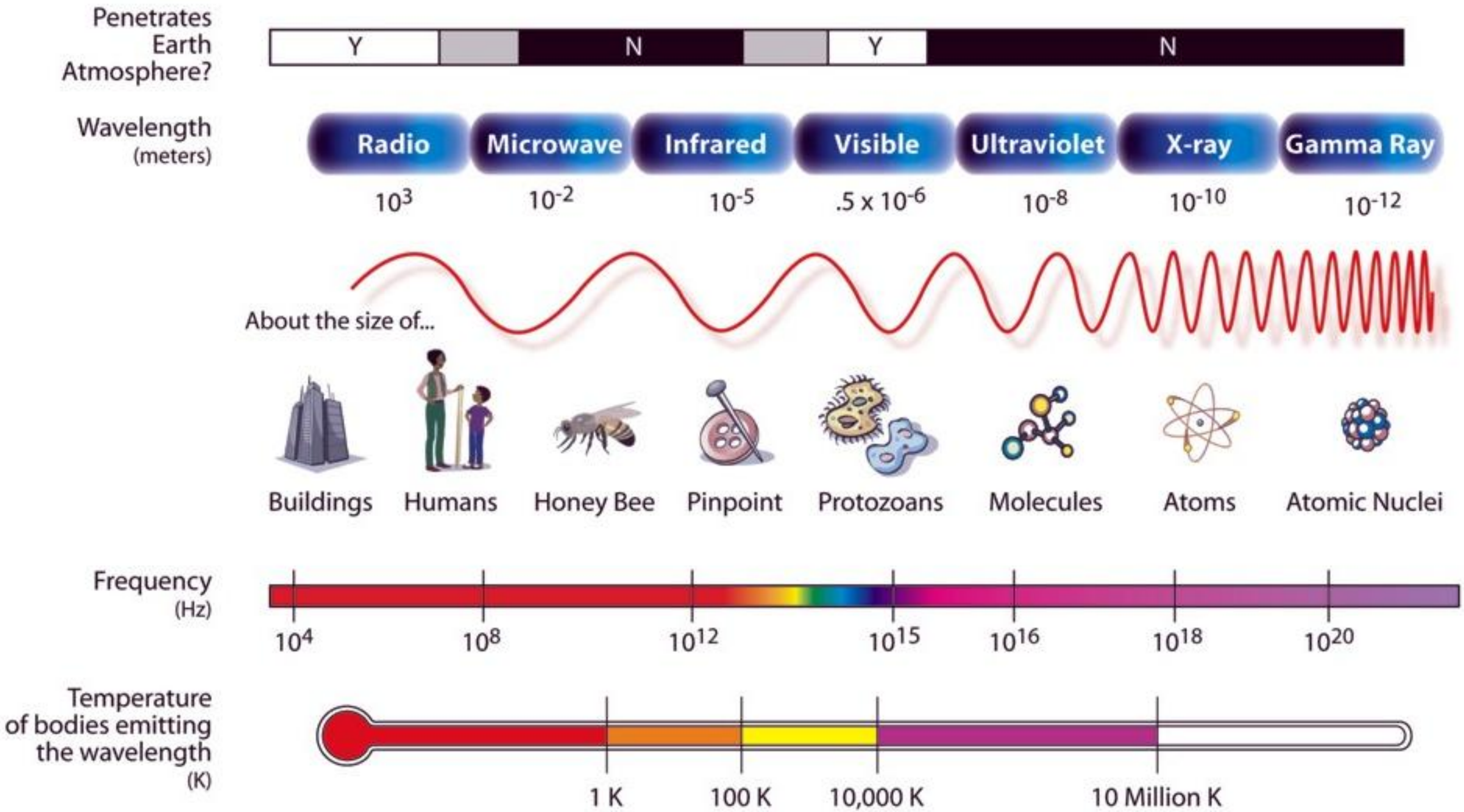
Convert wavelength into frequency using $c = f\lambda$ $\qquad c = 2.998 \times 10^{8}\,\mathrm{ms}^{-1}$

X-Rays

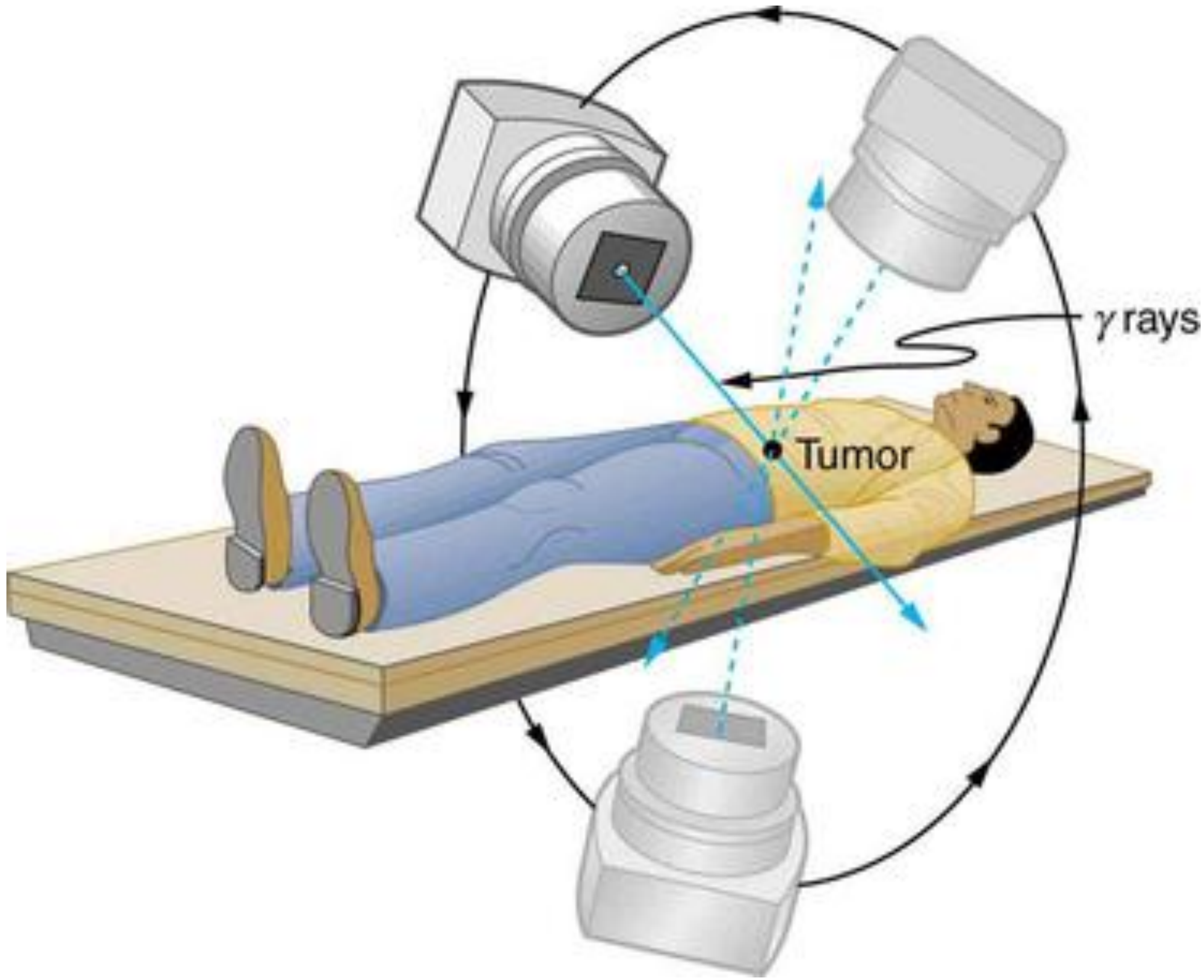



R

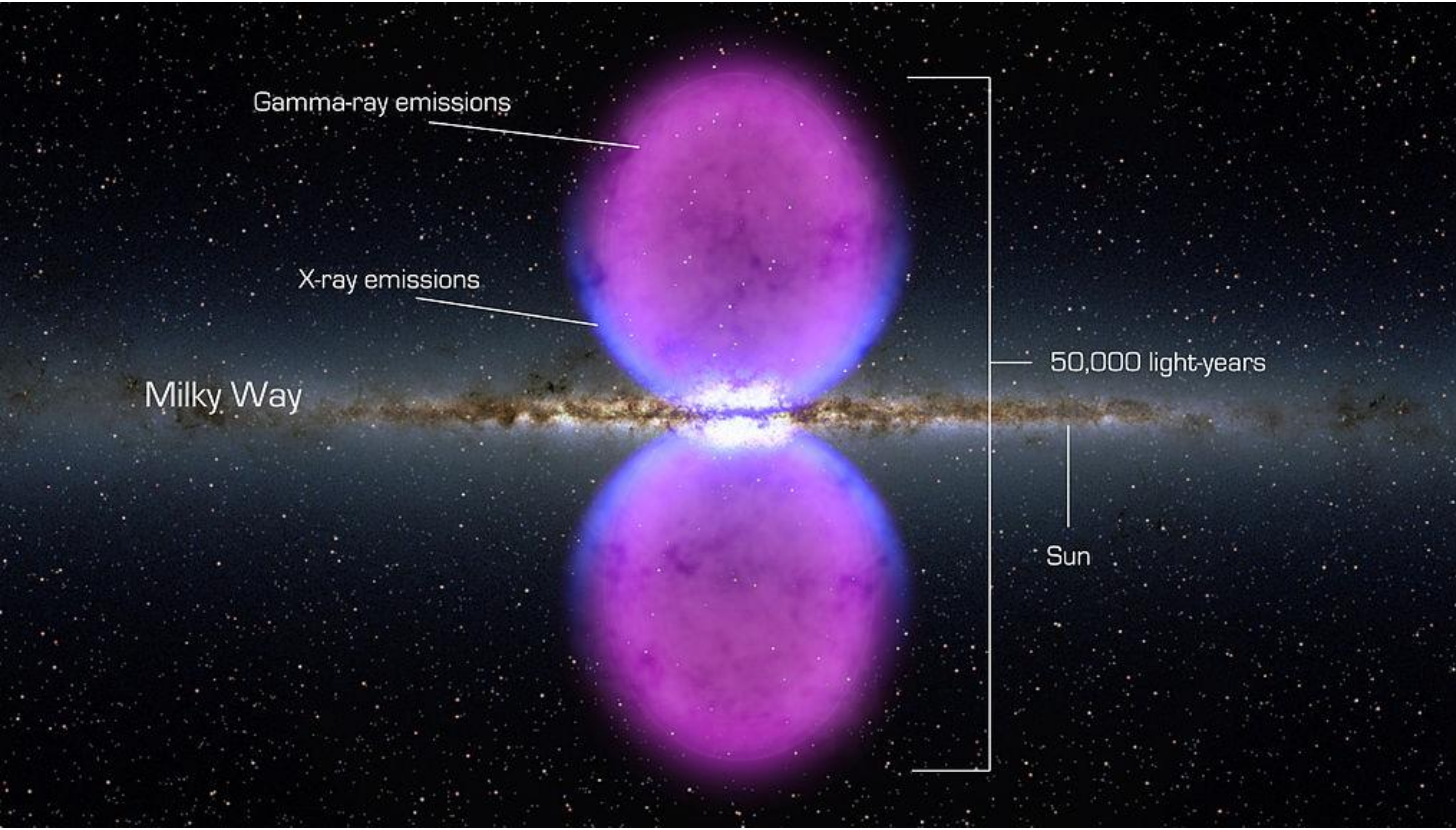
THE ELECTROMAGNETIC SPECTRUM



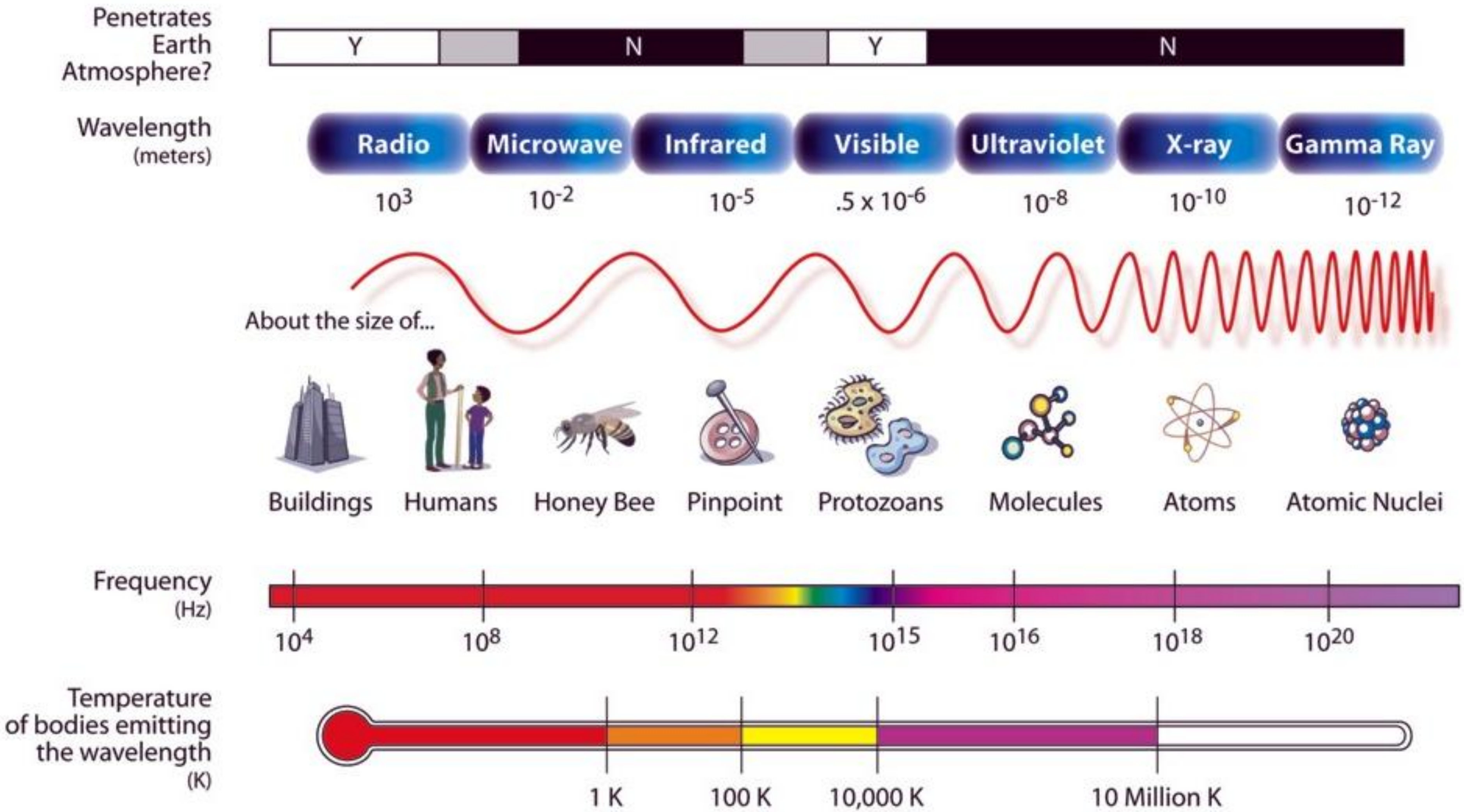
Convert wavelength into frequency using $c = f\lambda$ $\qquad c = 2.998 \times 10^{8}\,\mathrm{ms}^{-1}$



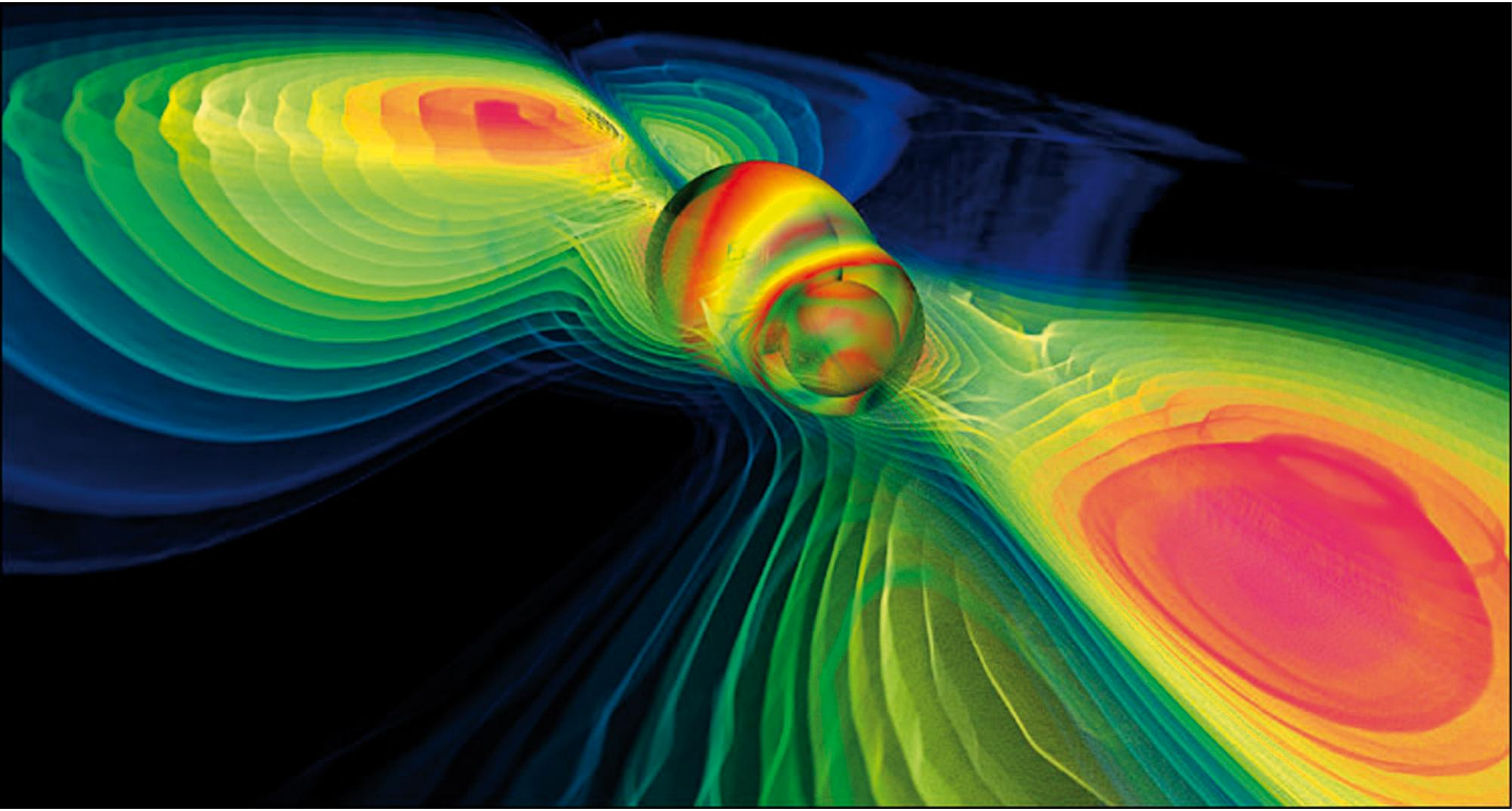
Gamma Rays


Gamma-ray emissions
X-ray emissions
Milky Way
50,000 light-years
Sun

THE ELECTROMAGNETIC SPECTRUM

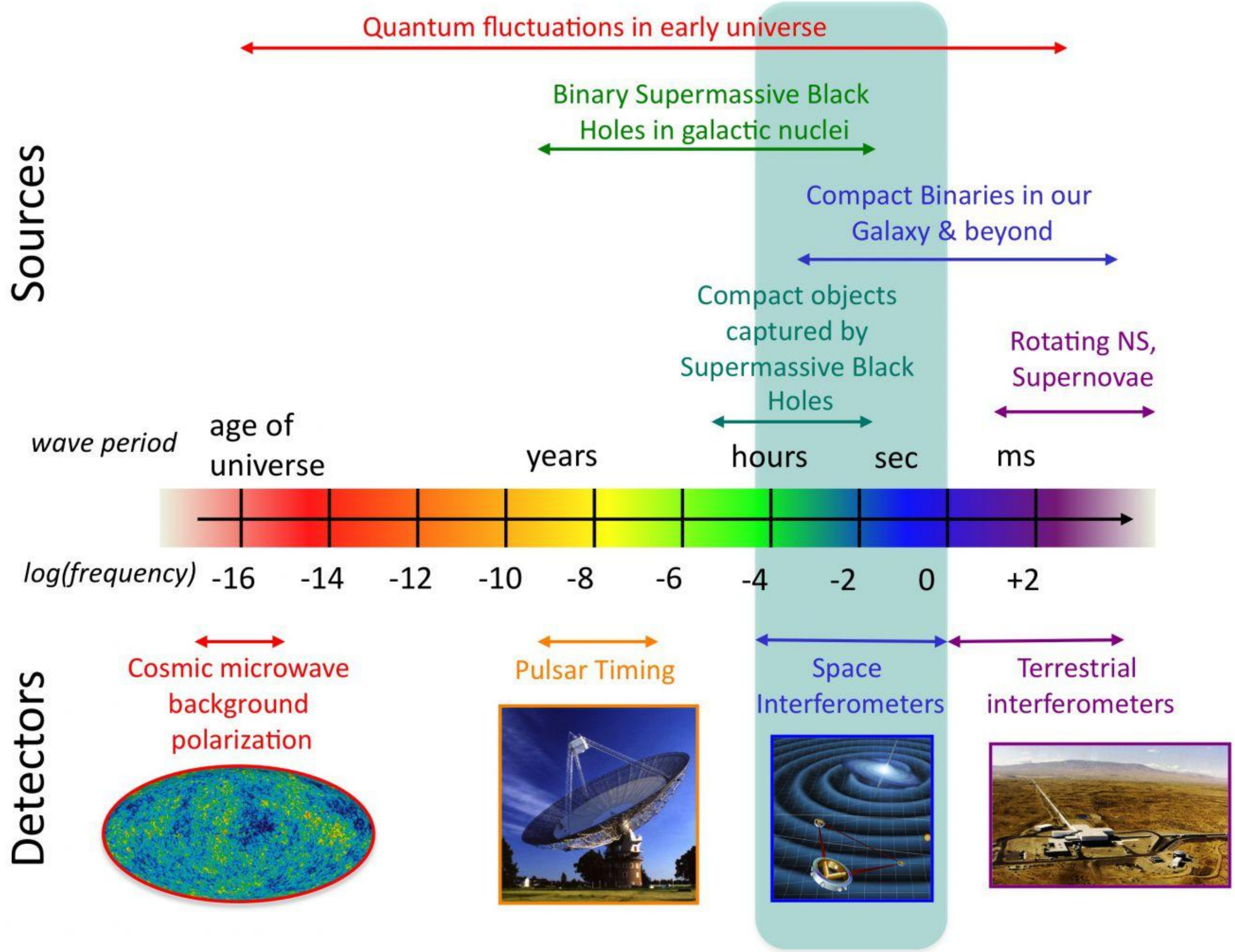


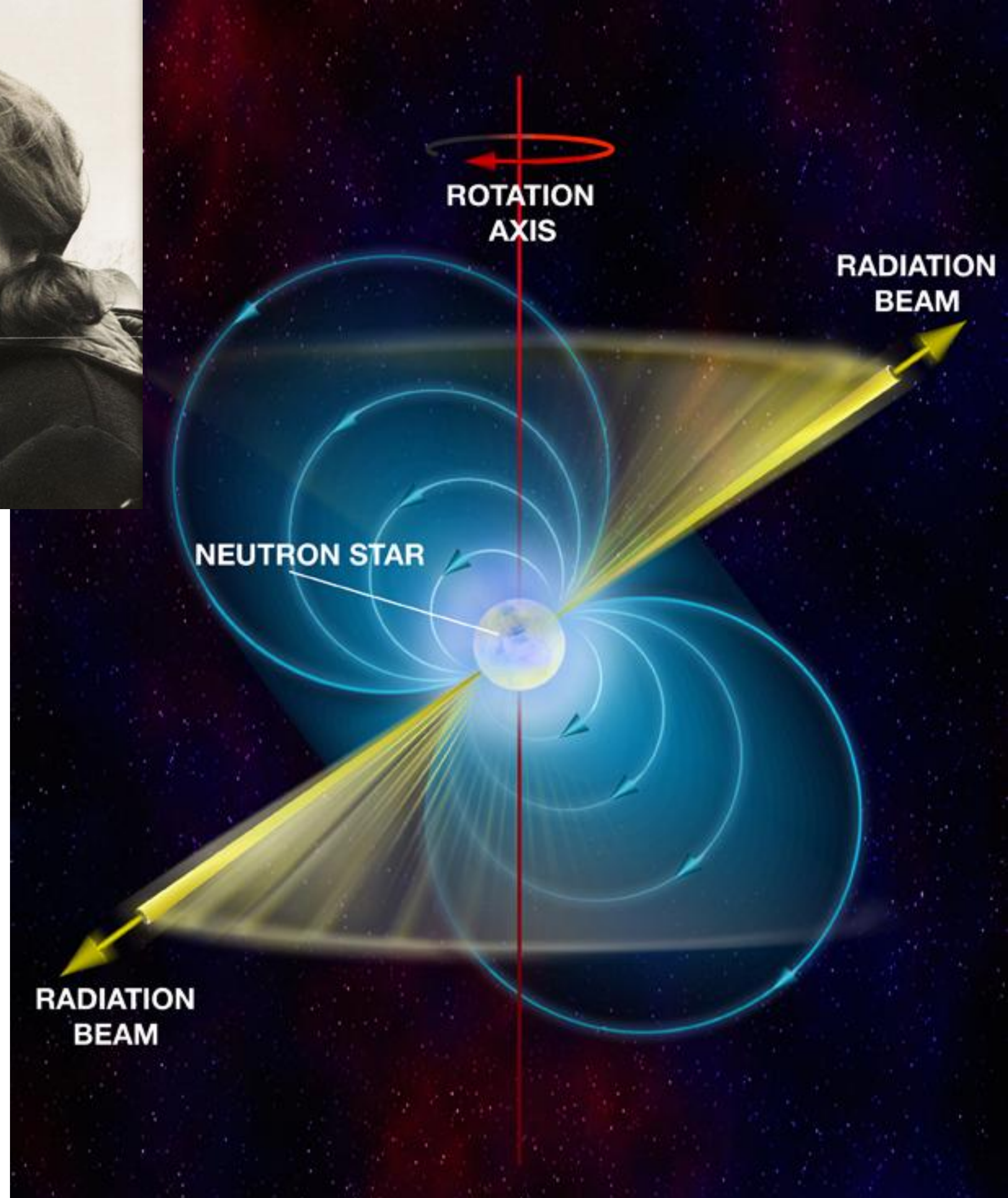
Convert wavelength into frequency using $c = f\lambda$ $\qquad c = 2.998 \times 10^{8}\,\mathrm{ms}^{-1}$



Gravitational waves emitted from two colliding black holes (!)

The Gravitational Wave Spectrum

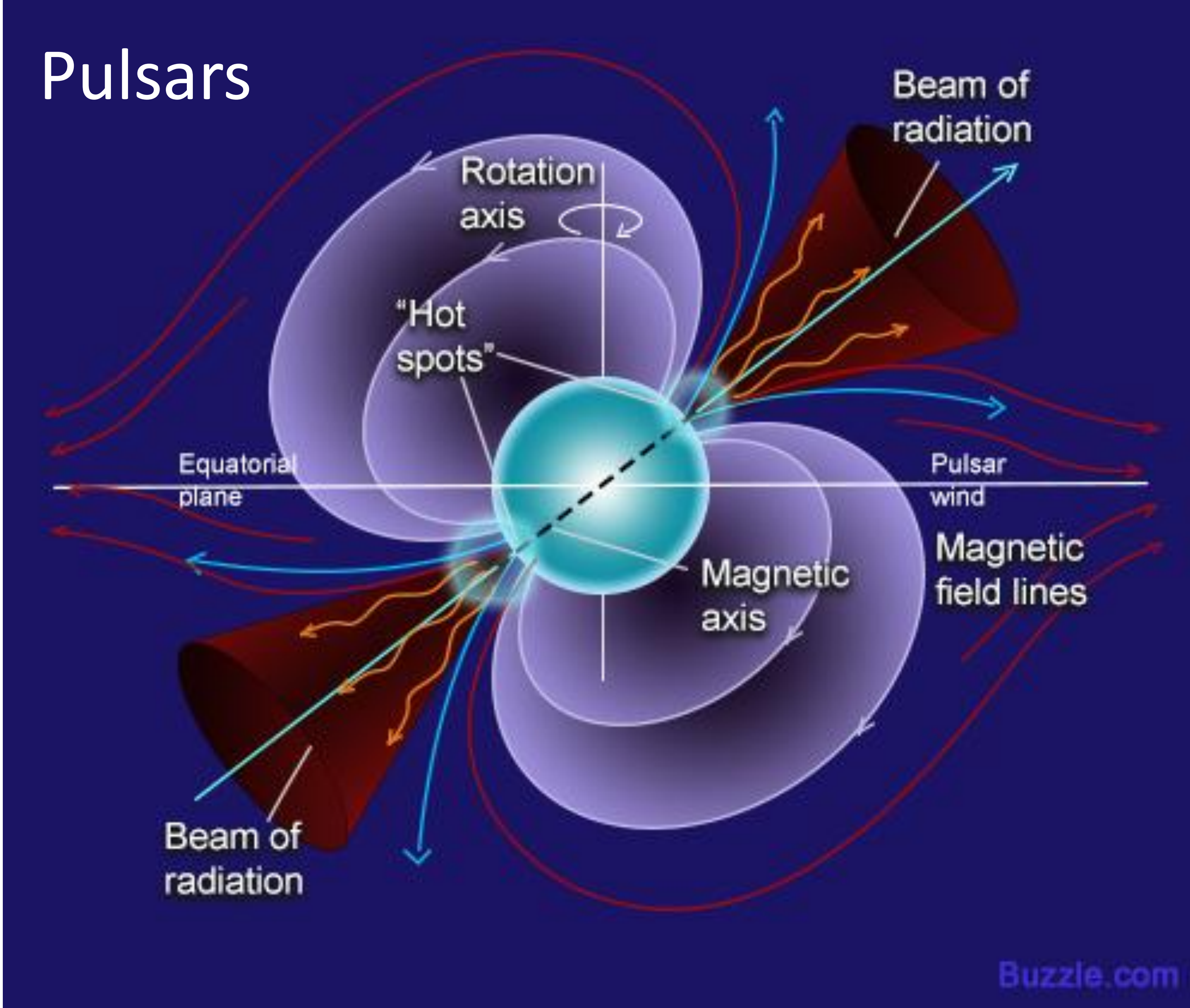




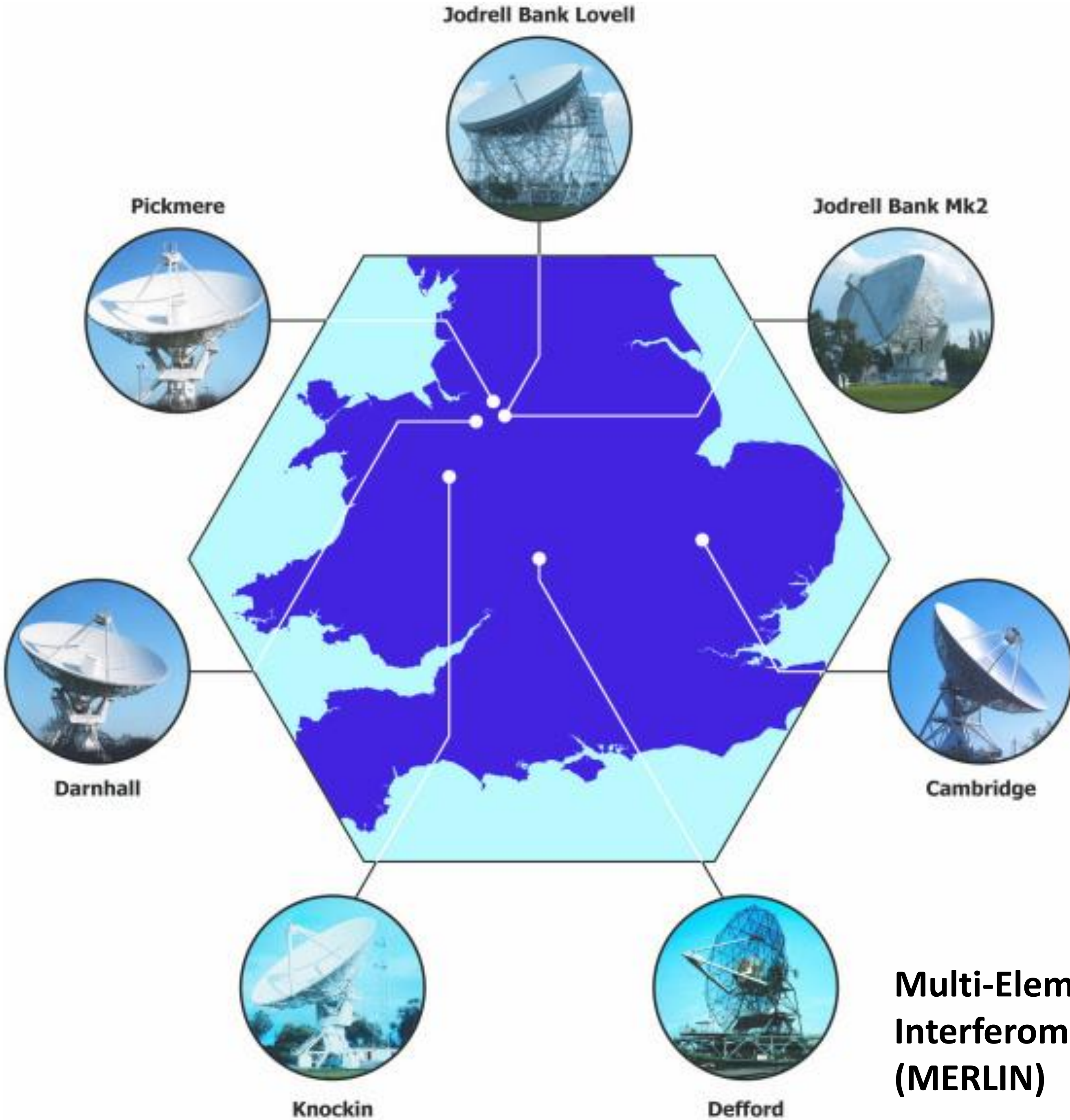
Pulsars were discovered by accident in 1967 while **Jocelyn Bell** and Antony Hewish were looking for twinkling sources of radio radiation.

The explanation for the radio pulses proved the existence of **neutron stars**, incredibly dense remains of massive collapsed stars.

Pulsars


Beam of radiation
Rotation axis
"Hot spots"
Equatorial plane
Pulsar wind
Magnetic field lines
Magnetic axis
Beam of radiation
Buzzle.com

The 76 m **Lovell Telescope** at Jodrell Bank Observatory (Cheshire)



Multi-Element Radio Linked Interferometer Network (MERLIN)