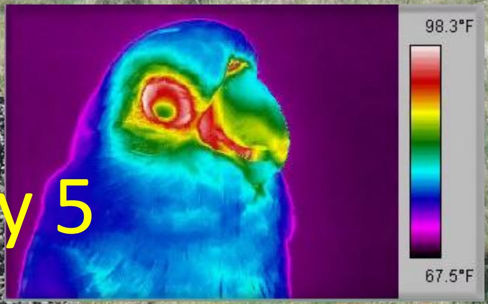


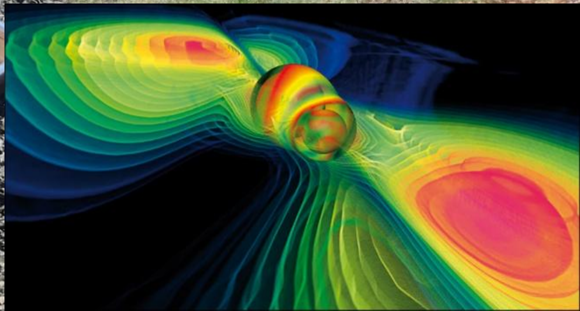

Sound, Light, Waves



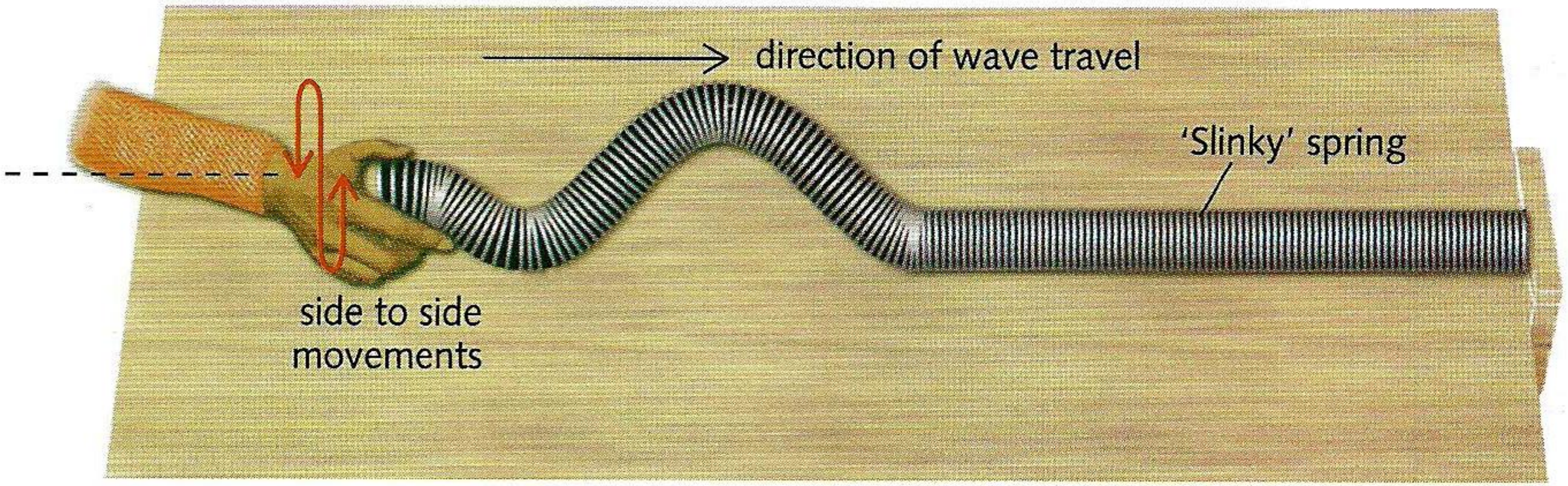
Universe by Numbers: Day 5

July 2016

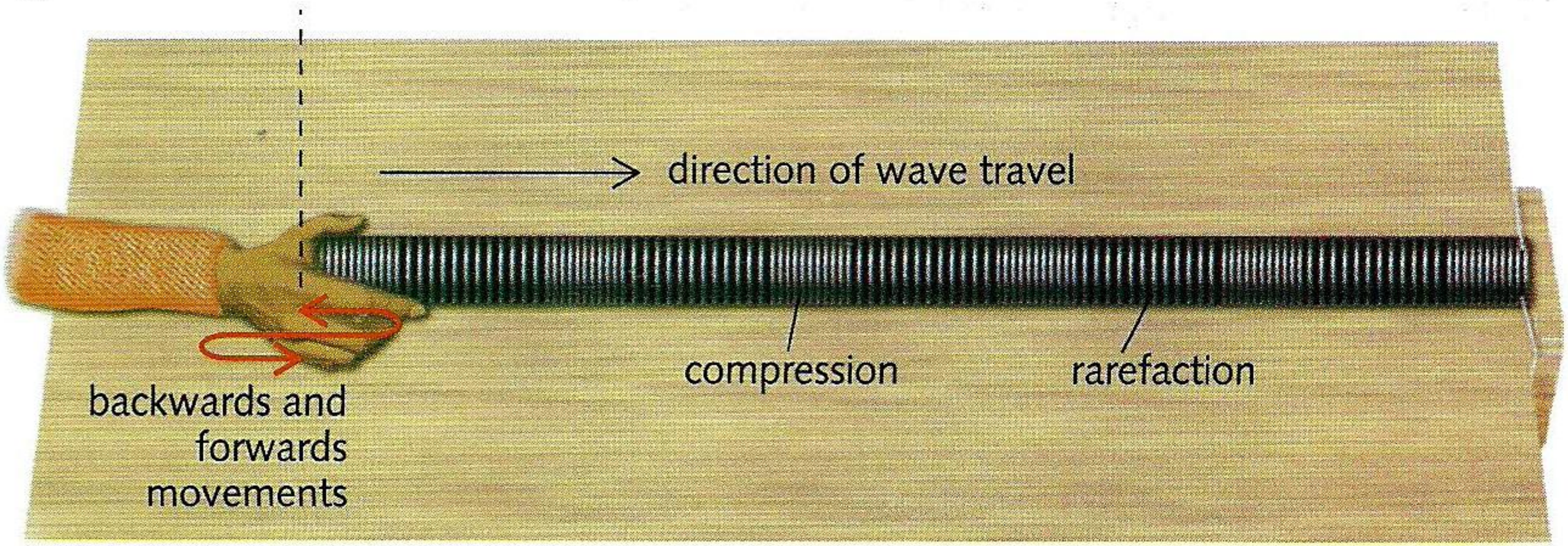
Dr Andrew French

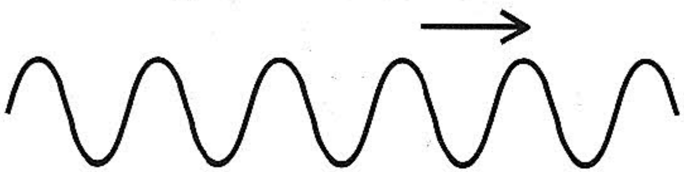
Transverse waves



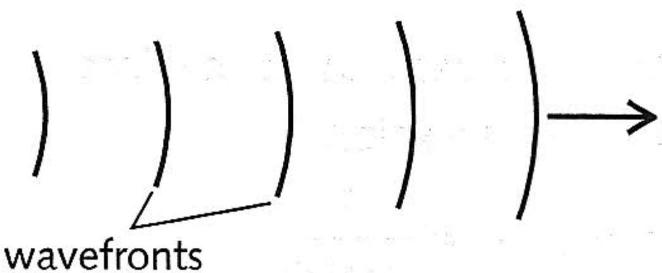
Longitudinal waves



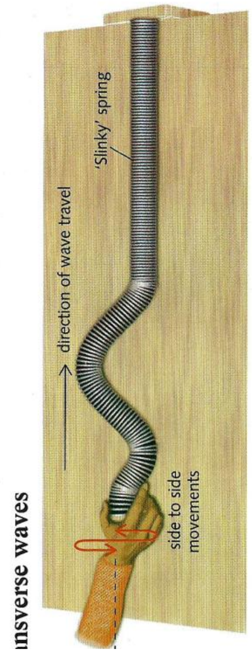
Drawing waves

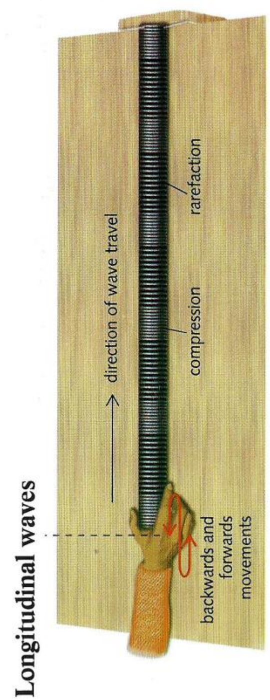


Transverse waves can be drawn as above.



Waves can also be drawn using lines called **wavefronts**. You can think of each wavefront as the 'peak' of a transverse wave or the compression of a longitudinal wave.



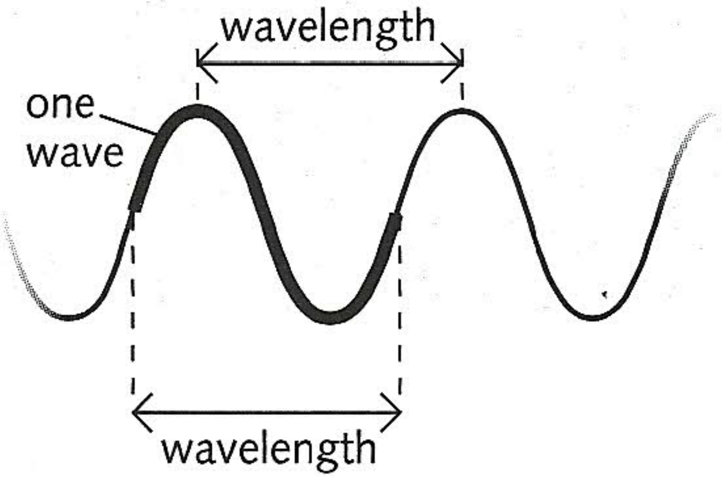


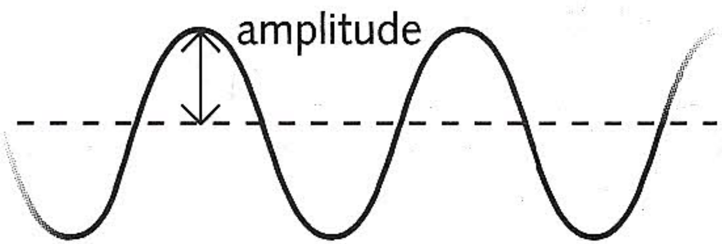
Transverse waves

- Earthquake S waves
- Electromagnetic waves
  - radio
  - microwave
  - infrared
  - visible light
  - ultraviolet
  - X-rays
  - gamma rays

Logitudinal waves

- Sound
- Earthquake P waves





Frequency (in Hz) is the number of oscillations per second.

Period (in seconds) is the time for one oscillation.

$$\text{frequency} = \frac{1}{\text{period}}$$

speed = frequency × wavelength

$$c = f\lambda$$

Speed of sound

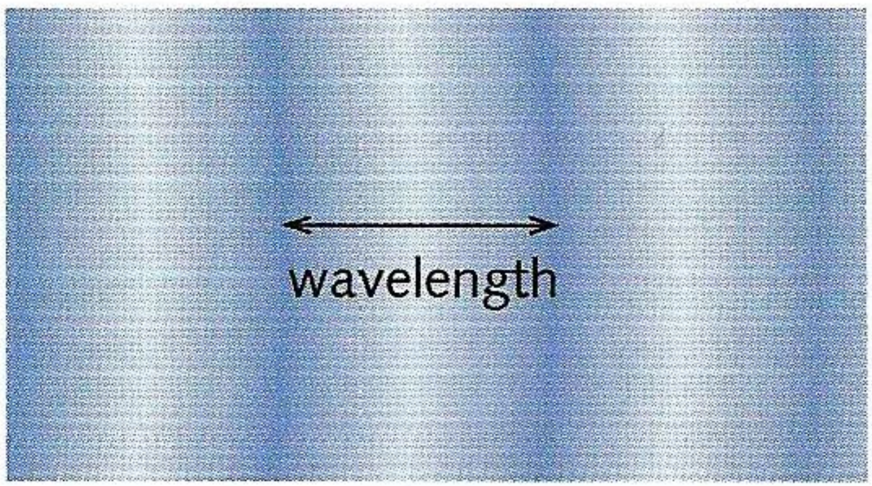
air	332 ms^{-1}
water	1500ms^{-1}
rock	4800-9200ms^{-1}

Speed of light

$c = 2.998 \times 10^8\ ms^{-1}$

Sound wave essentials

Sound waves are a series of compressions ('squashes') and rarefactions ('stretches') that travel through the air or other material.



The number of waves per second is called the **frequency**. It is measured in hertz (Hz).

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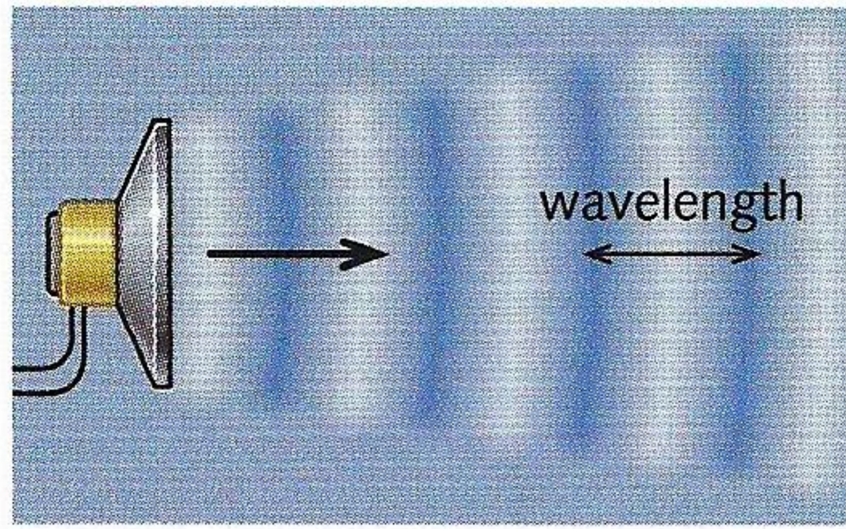

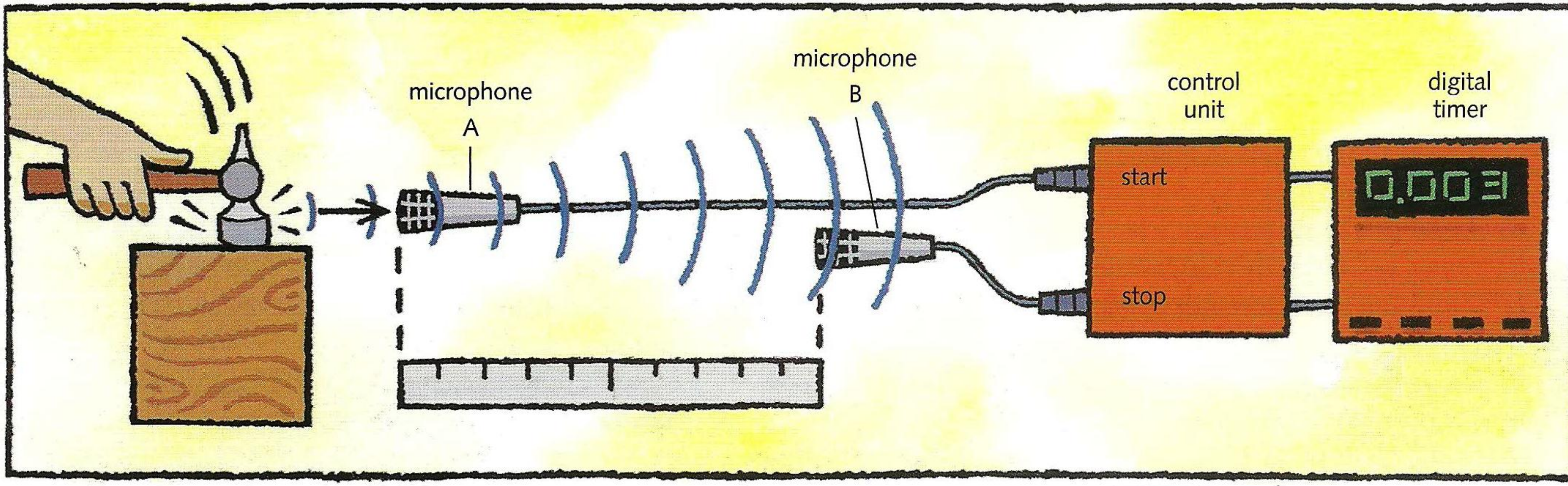

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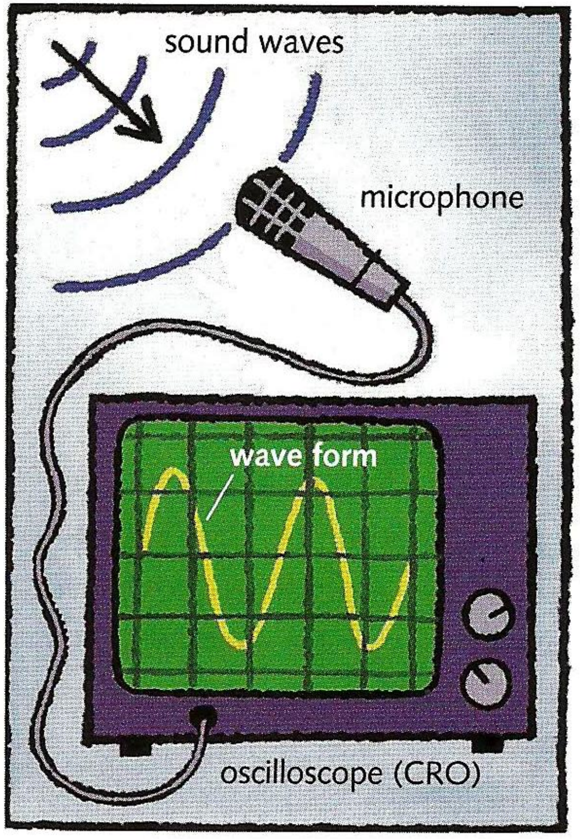
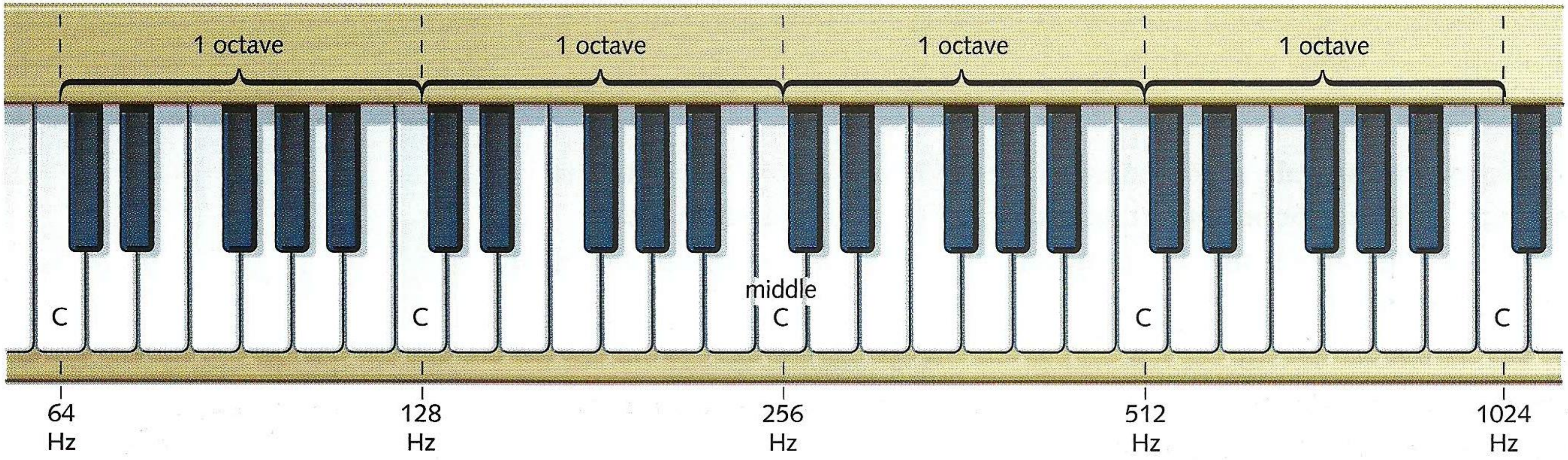
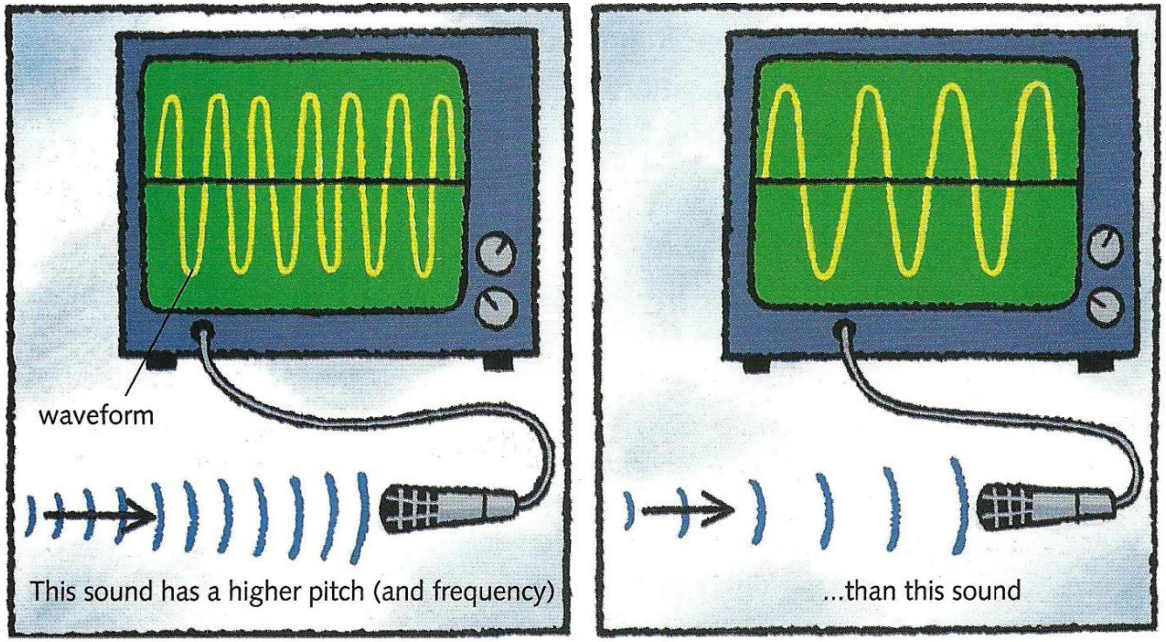
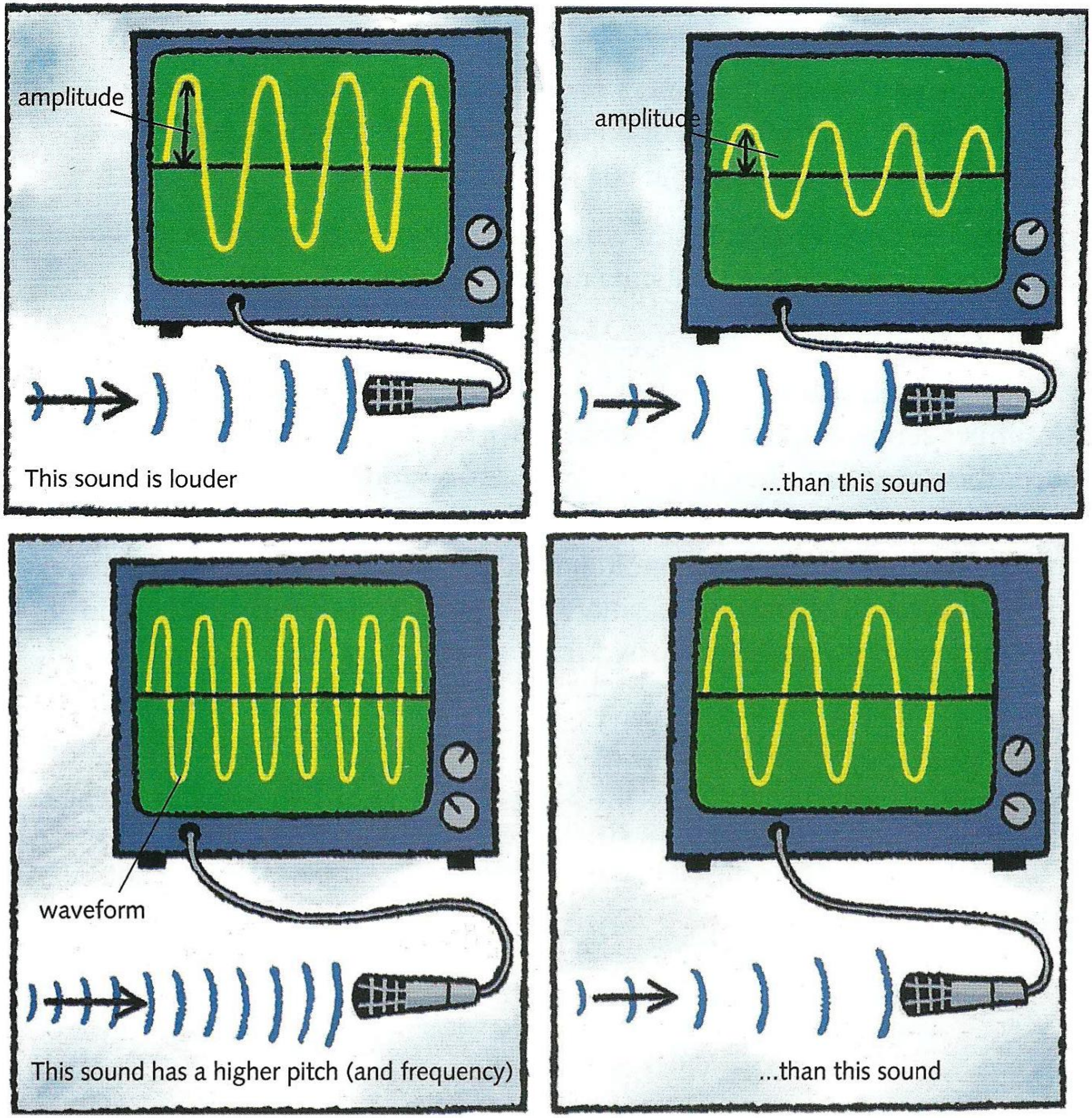


Measuring the speed of sound



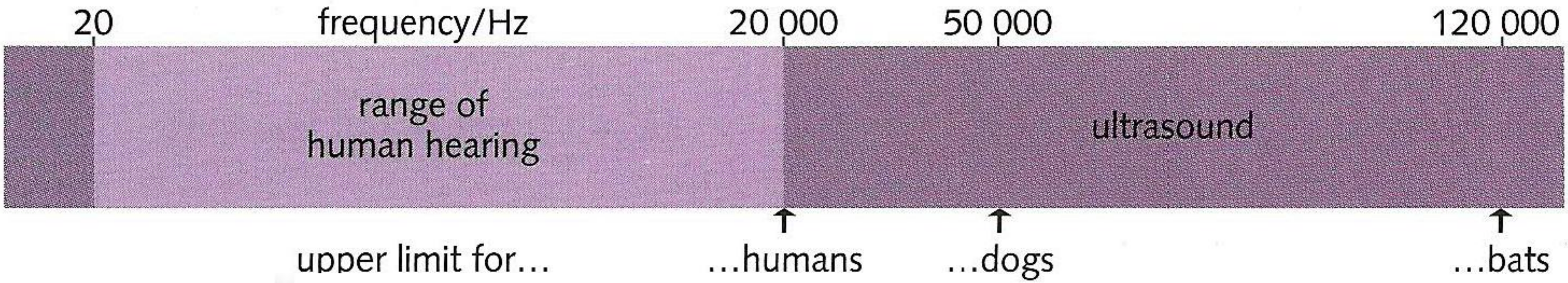
pitch		frequency
high	upper limit of hearing	20 000 Hz
	whistle	10 000 Hz
	high note (soprano)	1000 Hz
	low note (bass)	100 Hz
low	drum note	20 Hz

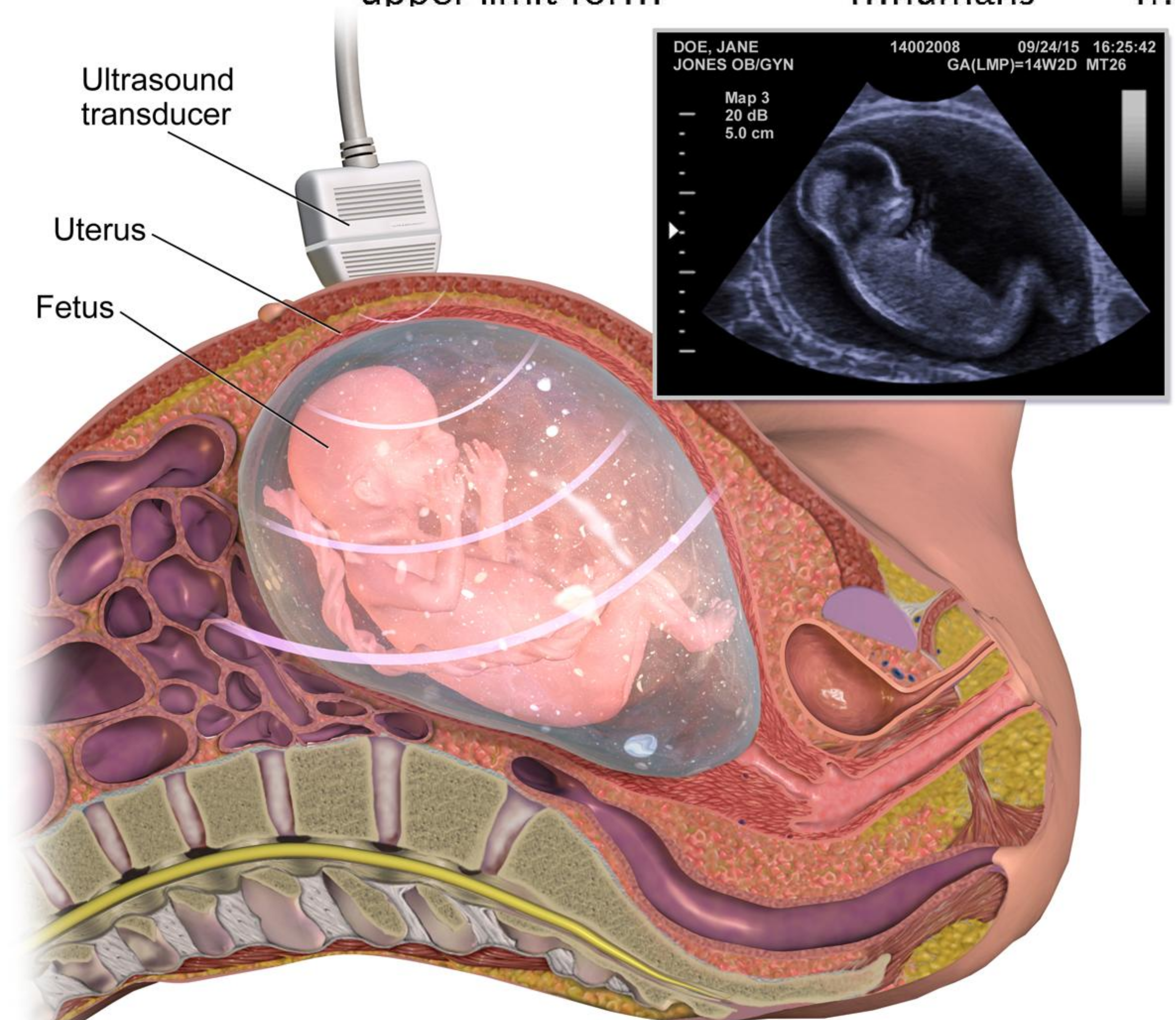




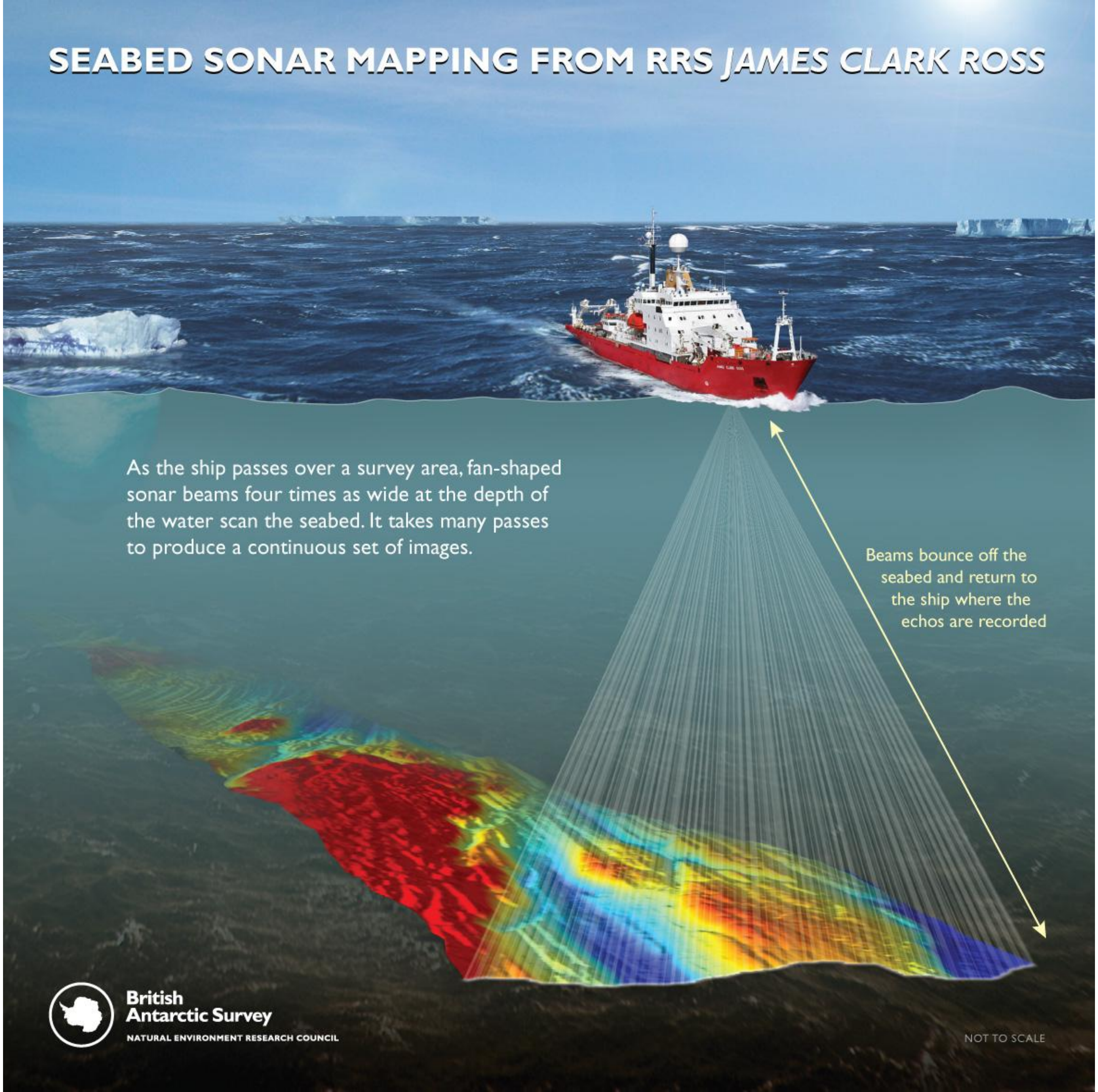
Amplitude
(Loudness)

Frequency
(Pitch)





Fetal Ultrasound


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

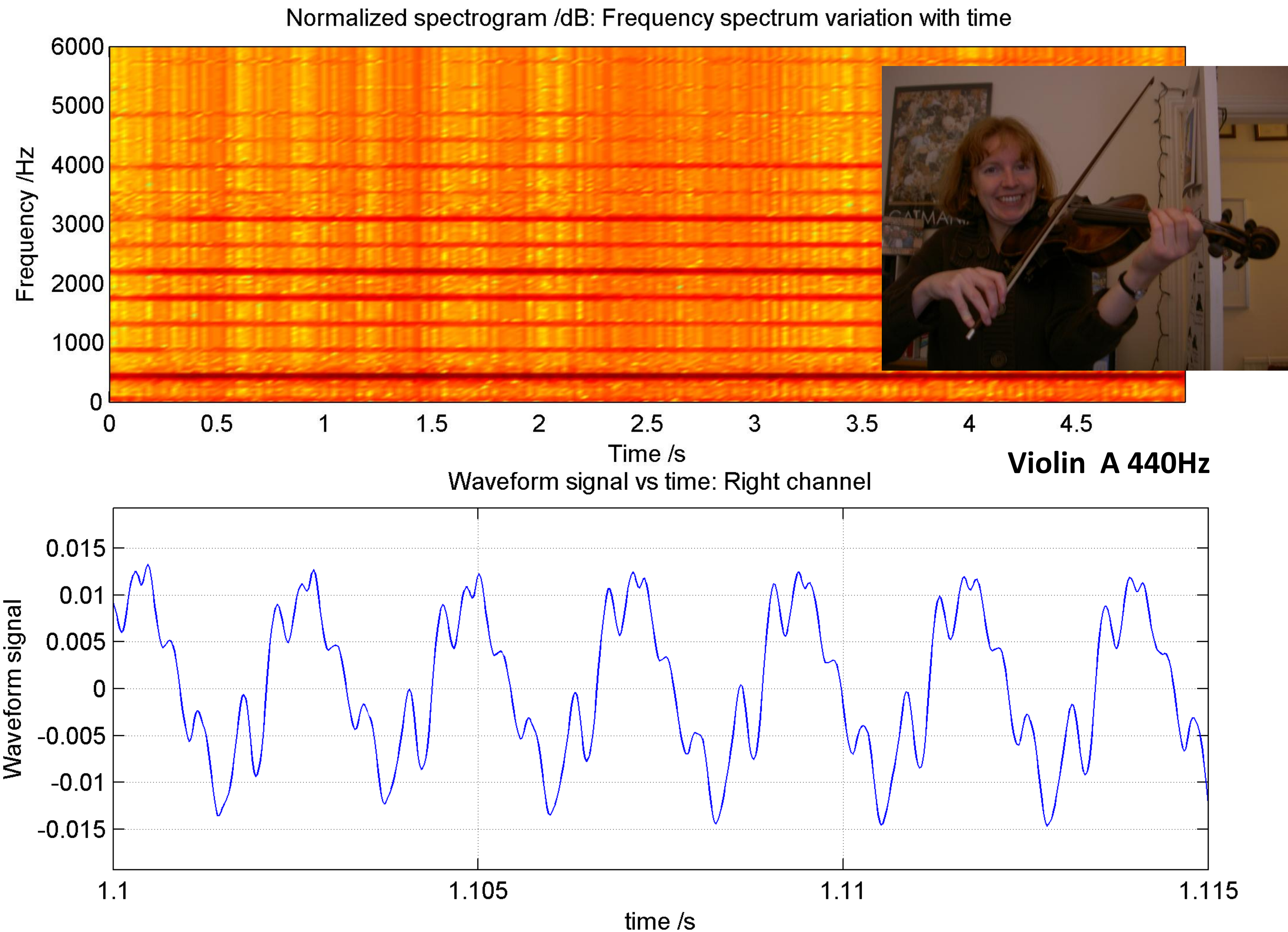
Musical harmony

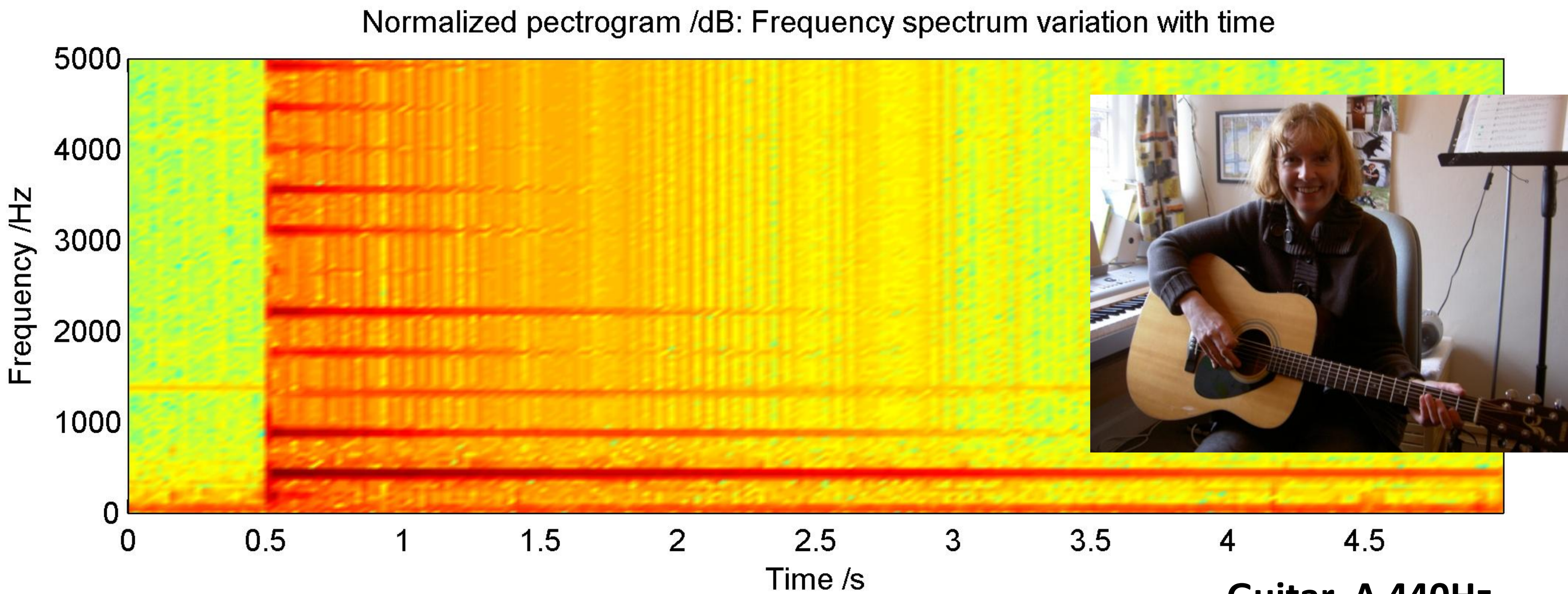
- The mathematics of music has been known since the time of Pythagoras, 2500 years ago
- Frequency intervals of simple fractions e.g. 3:2 (a fifth) yield 'harmonious' music
- An **octave** means a **frequency ratio of 2**. An octave above concert A (440Hz) is therefore 880Hz. An octave below is 220Hz.
- The modern 'equal-tempered scale' divides an octave (the frequency ratio 2) into twelve parts such that

$$F_n = 2^{n/12} = \sqrt[\frac{n}{12}]{2}$$

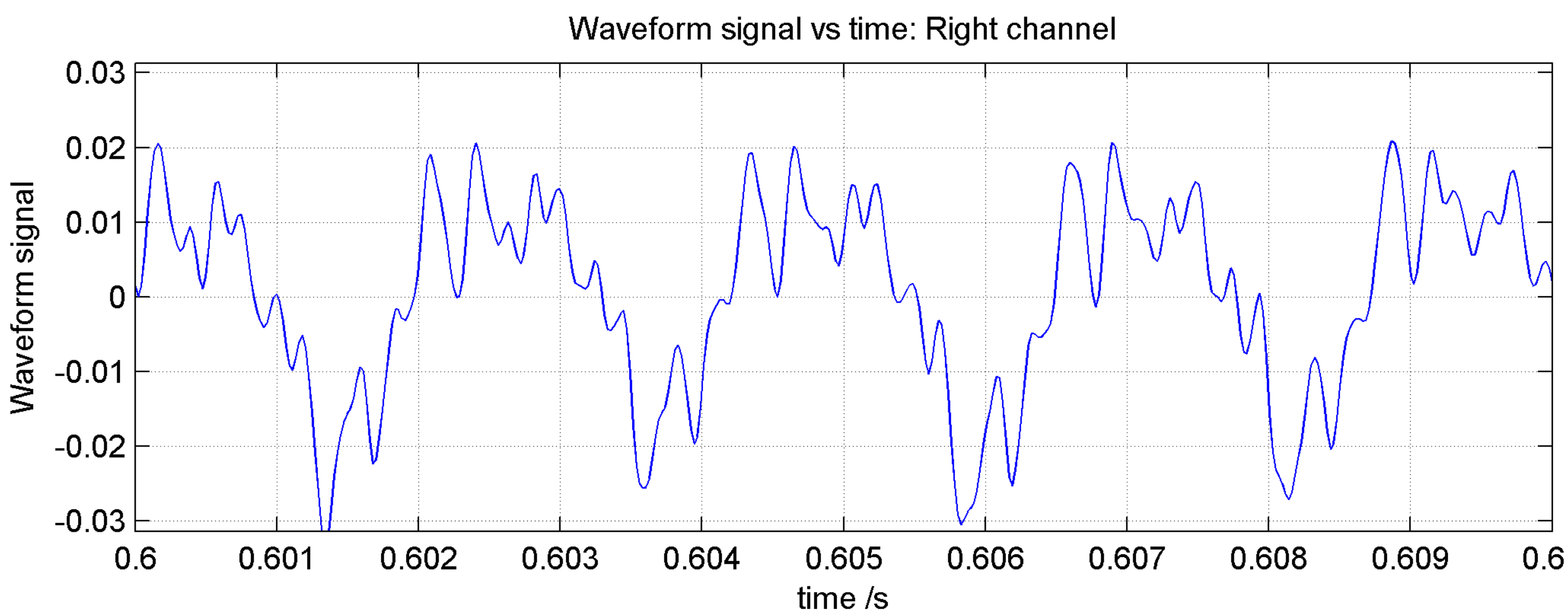
Musical harmony

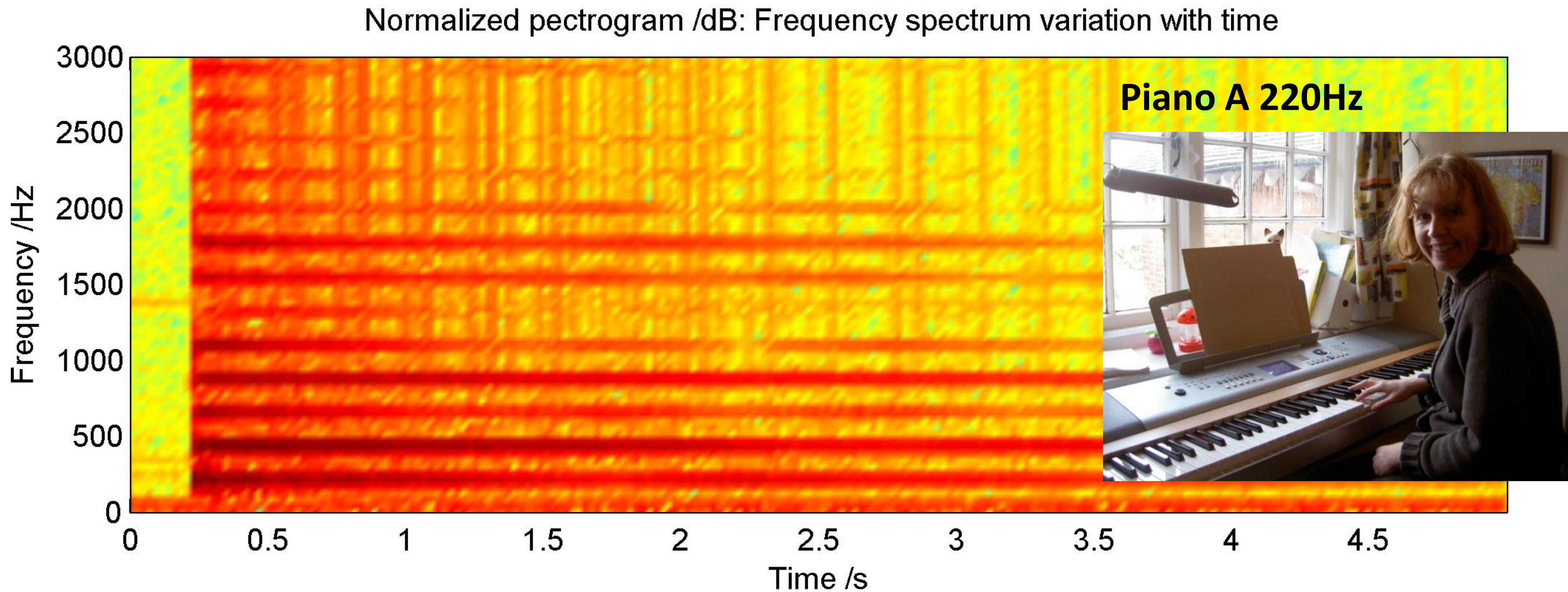
Name	Exact value in 12-TET	Decimal value in 12-TET	Cents	Just intonation interval
Unison (C)	$2^{0/12} = 1$	1.000000	0	$\frac{1}{1}$ = 1.000000
Minor second (C♯/D♭)	$2^{1/12} = \sqrt[12]{2}$	1.059463	100	$\frac{16}{15}$ = 1.066667
Major second (D)	$2^{2/12} = \sqrt[6]{2}$	1.122462	200	$\frac{9}{8}$ = 1.125000
Minor third (D♯/E♭)	$2^{3/12} = \sqrt[4]{2}$	1.189207	300	$\frac{6}{5}$ = 1.200000
Major third (E)	$2^{4/12} = \sqrt[3]{2}$	1.259921	400	$\frac{5}{4}$ = 1.250000
Perfect fourth (F)	$2^{5/12} = \sqrt[12]{32}$	1.334840	500	$\frac{4}{3}$ = 1.333333
Augmented fourth (F♯/G♭)	$2^{6/12} = \sqrt{2}$	1.414214	600	$\frac{7}{5}$ = 1.400000
Perfect fifth (G)	$2^{7/12} = \sqrt[12]{128}$	1.498307	700	$\frac{3}{2}$ = 1.500000
Minor sixth (G♯/A♭)	$2^{8/12} = \sqrt[3]{4}$	1.587401	800	$\frac{8}{5}$ = 1.600000
Major sixth (A)	$2^{9/12} = \sqrt[4]{8}$	1.681793	900	$\frac{5}{3}$ = 1.666667
Minor seventh (A♯/B♭)	$2^{10/12} = \sqrt[6]{32}$	1.781797	1000	$\frac{7}{4}$ = 1.750000
Major seventh (B)	$2^{11/12} = \sqrt[12]{2048}$	1.887749	1100	$\frac{15}{8}$ = 1.875000
Octave (C)	$2^{12/12} = 2$	2.000000	1200	$\frac{2}{1}$ = 2.000000

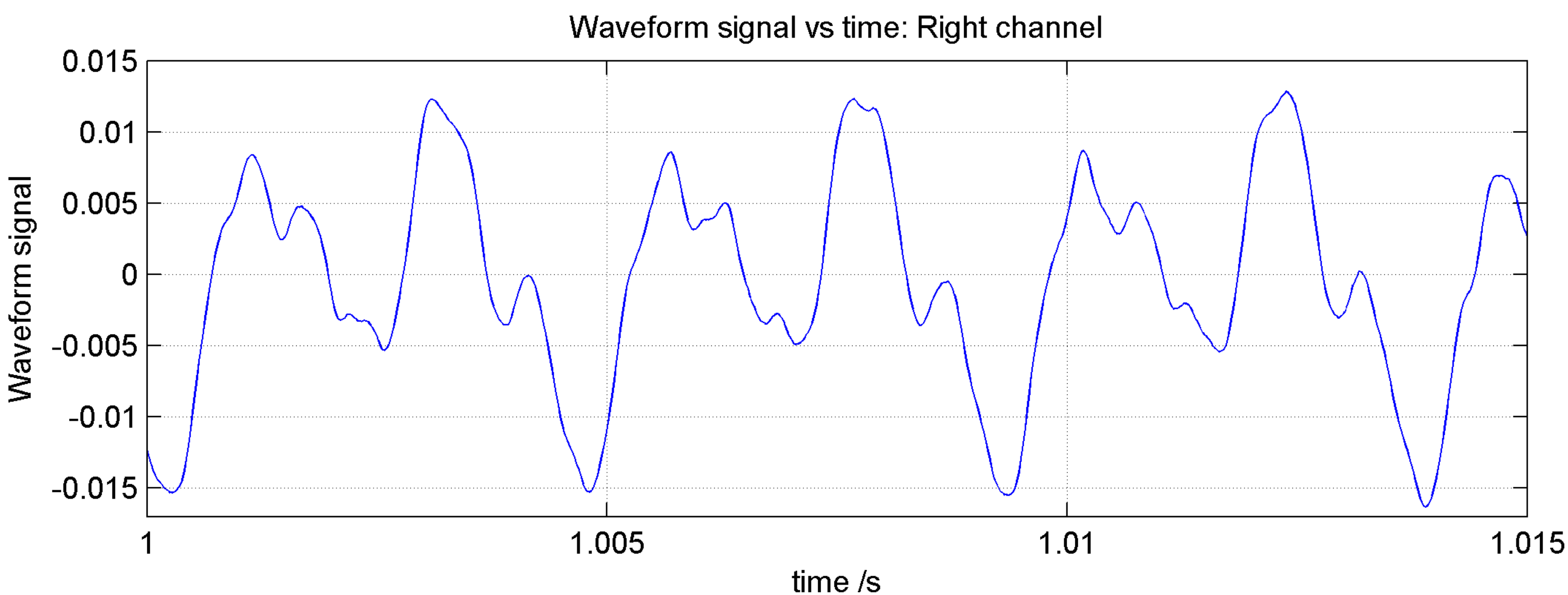

Normalized spectrogram /dB: Frequency spectrum variation with time
Frequency /Hz
6000
5000
4000
3000
2000
1000
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time /s
Violin A 440Hz
Waveform signal vs time: Right channel
Waveform signal
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
1.1
1.105
1.11
1.115
time /s

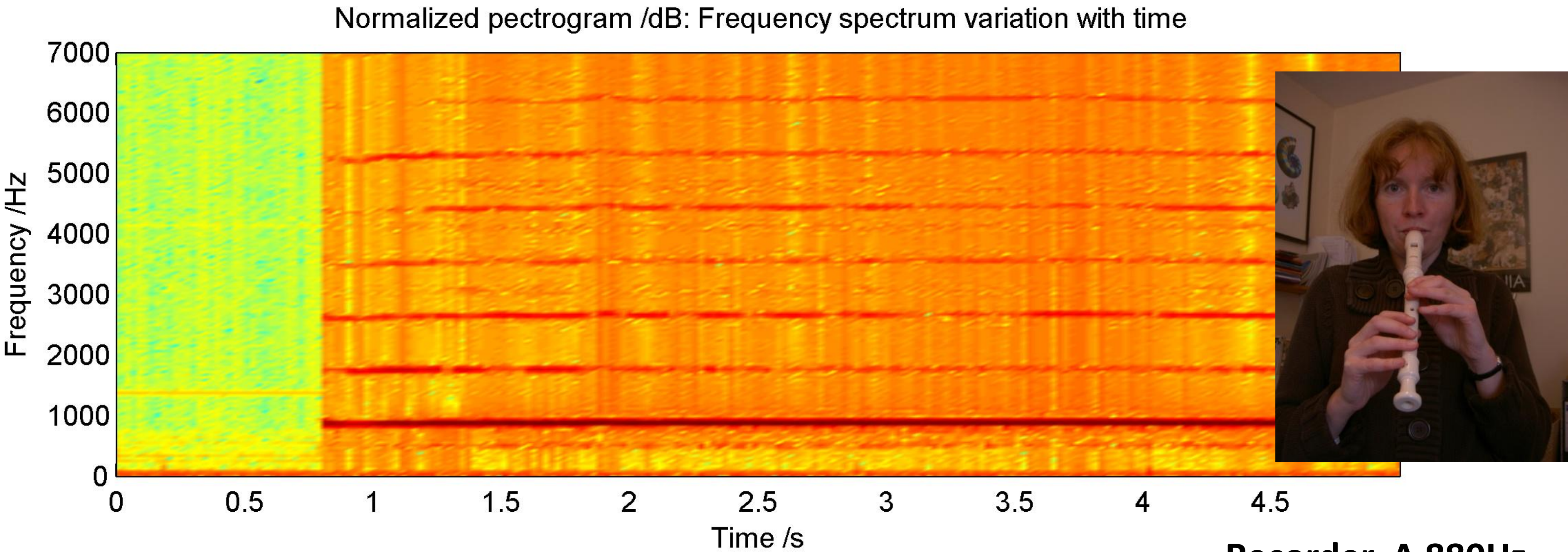


Guitar A 440Hz

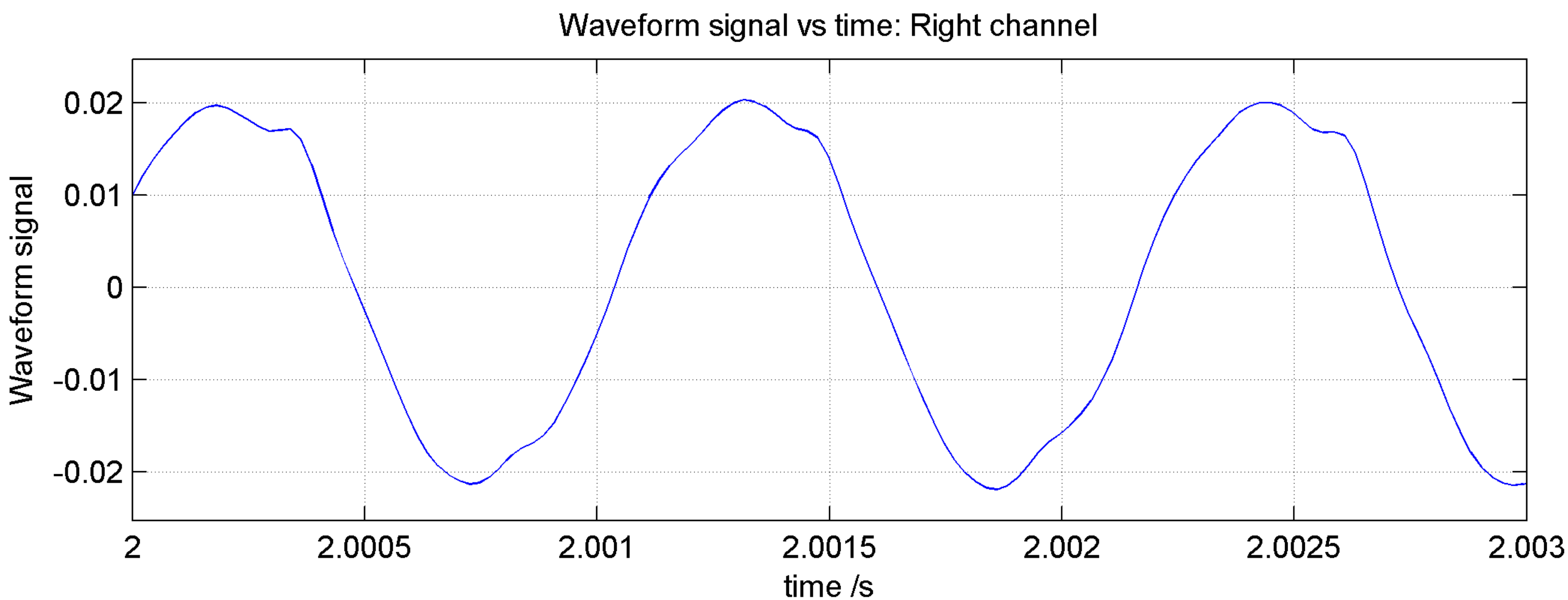


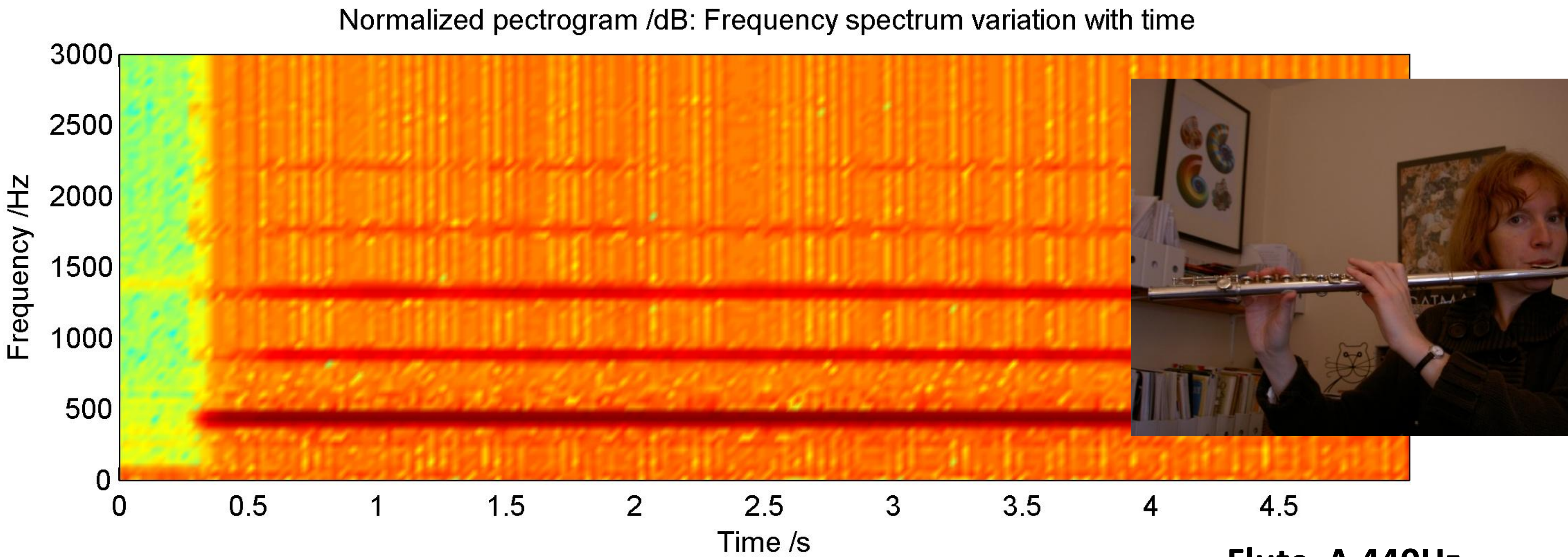

Normalized pectrogram /dB: Frequency spectrum variation with time
Piano A 220Hz
Frequency /Hz
3000
2500
2000
1500
1000
500
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time /s


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

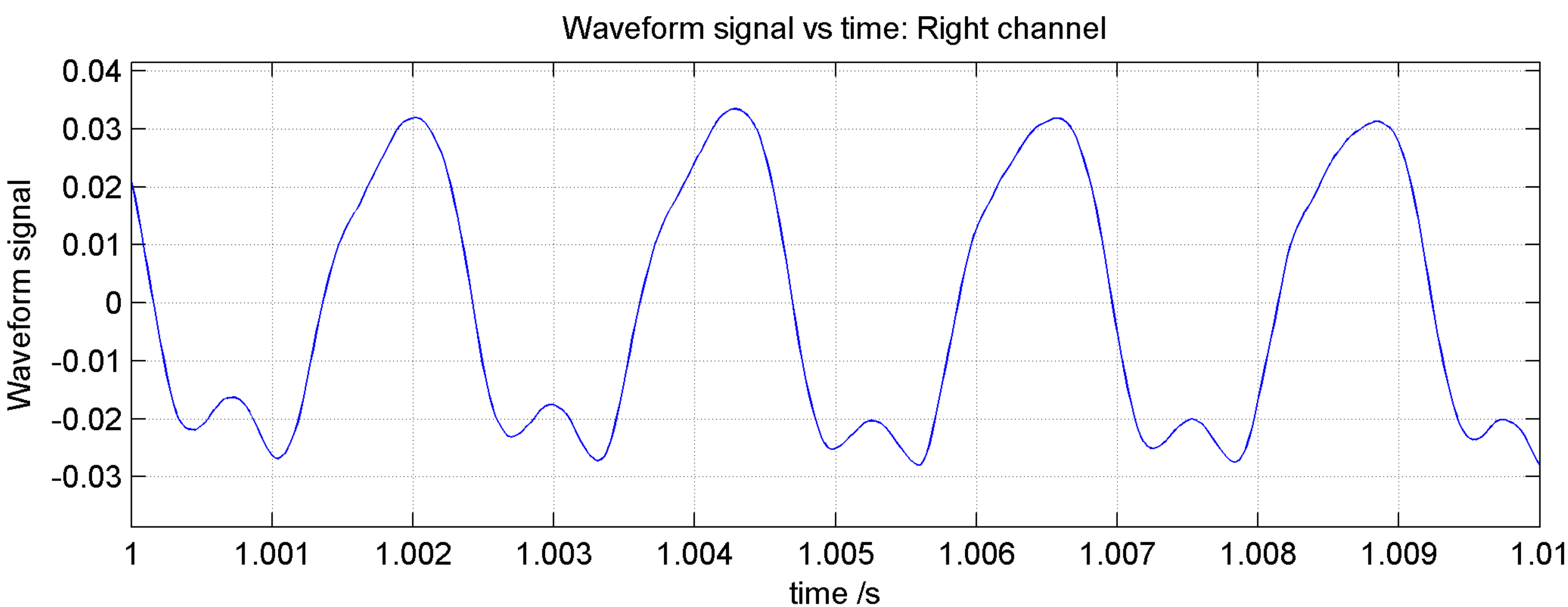


Recorder A 880Hz





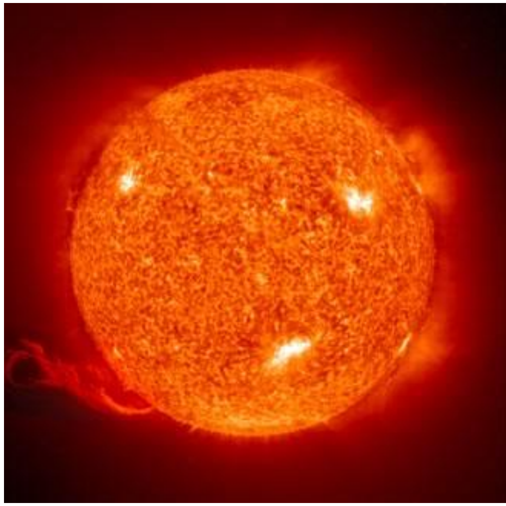
Flute A 440Hz



Rubens tube

Light

Light is form of **radiation** i.e. it spreads out from its source. **Ray-lines** indicate the direction of propagation.



In a medium where the *speed of light is constant*, **light travels in straight lines**. When the wave speed changes, this causes light rays to bend. This is called *refraction*.

Light **transfers energy**. In many ways, light is the 'purest' form of energy. Materials gain energy when they absorb light. Special materials such as solar cells can convert absorbed light into electricity.

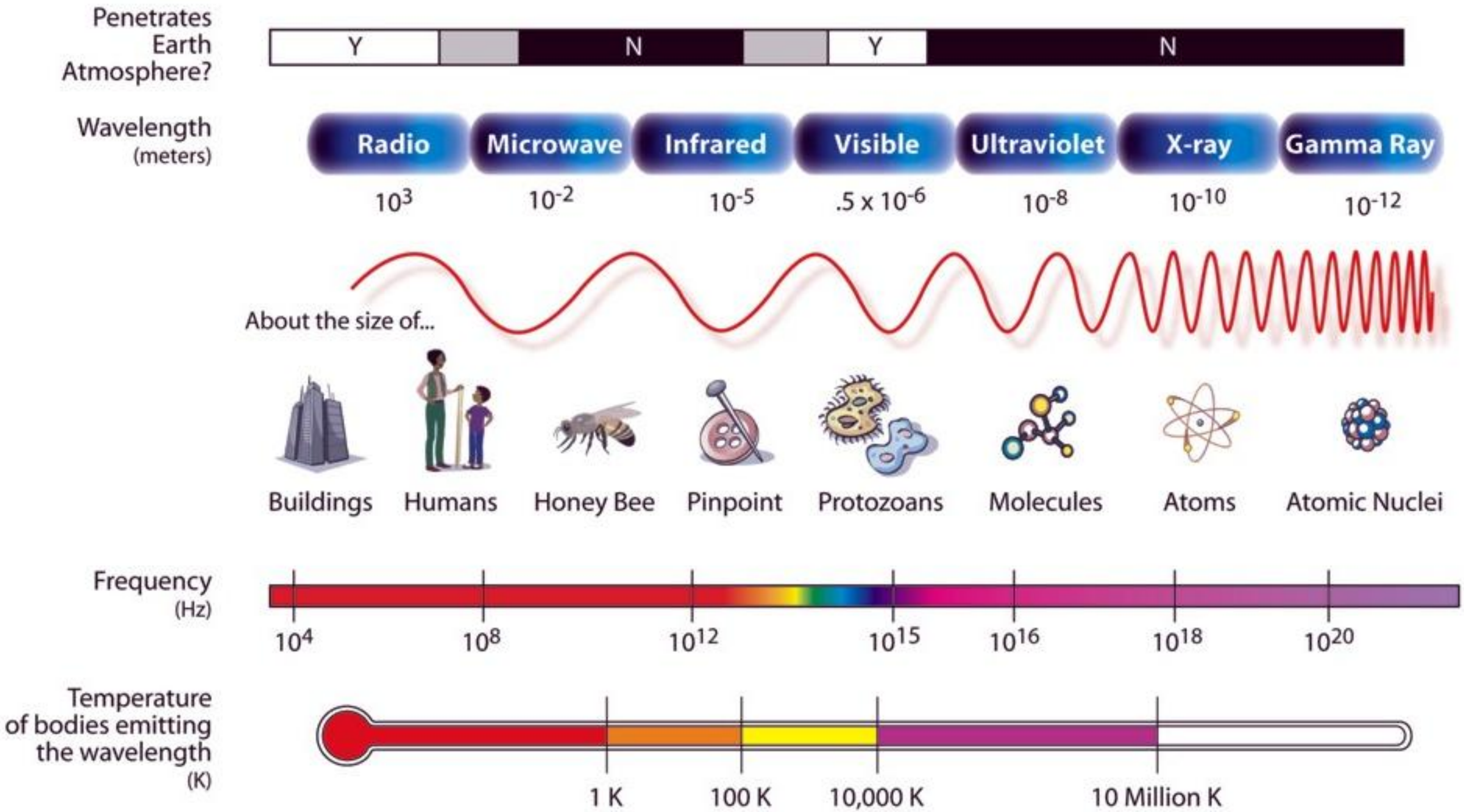
Light is both a **wave** (i.e. will reflect, refract, diffract and interfere) but can also be thought of as a tiny stream of **particles** called **photons**. The energy of each particle is proportional to the frequency of the light.

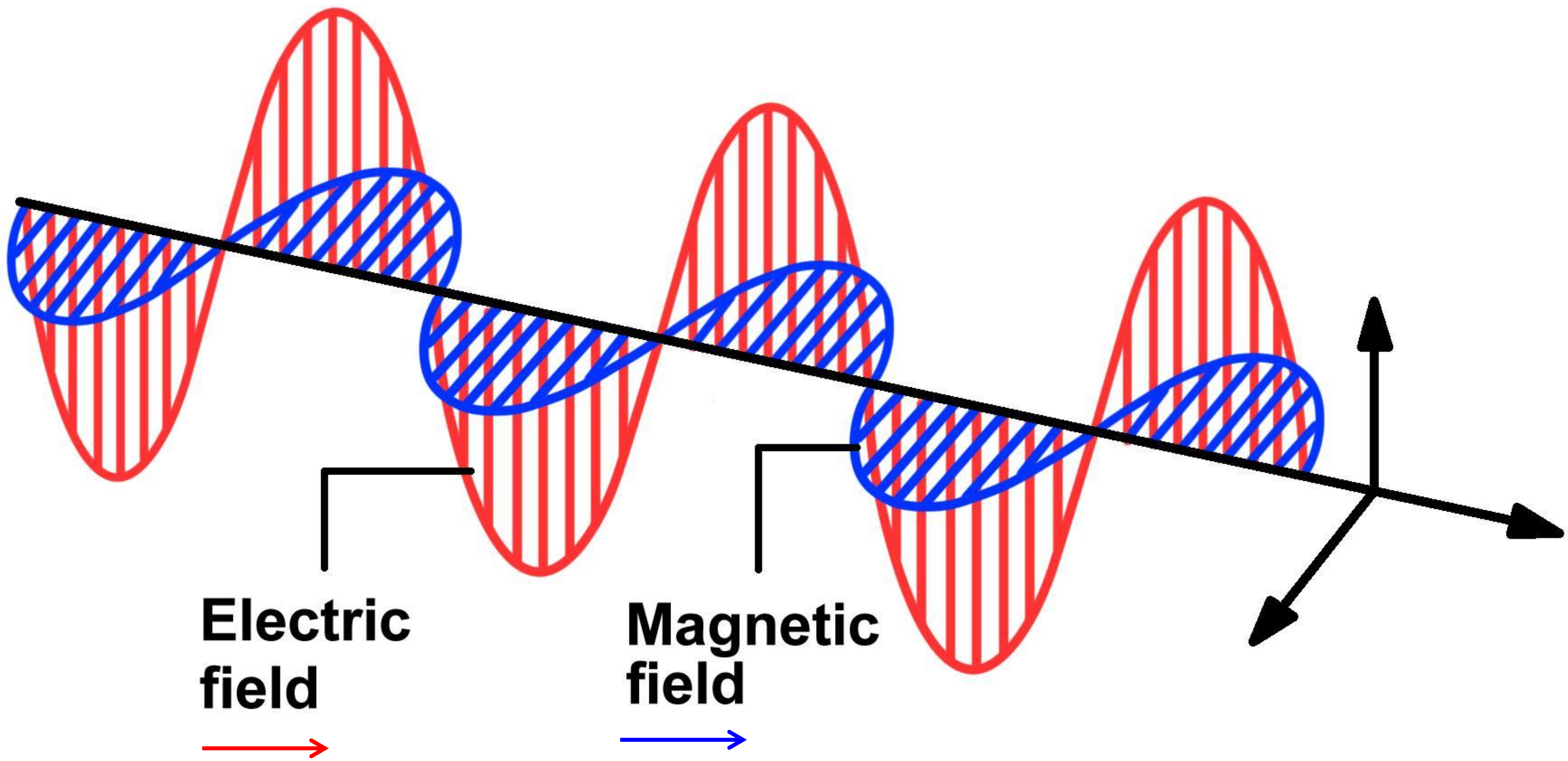
Unlike sound waves, **light waves can travel through empty space** i.e. a vacuum.

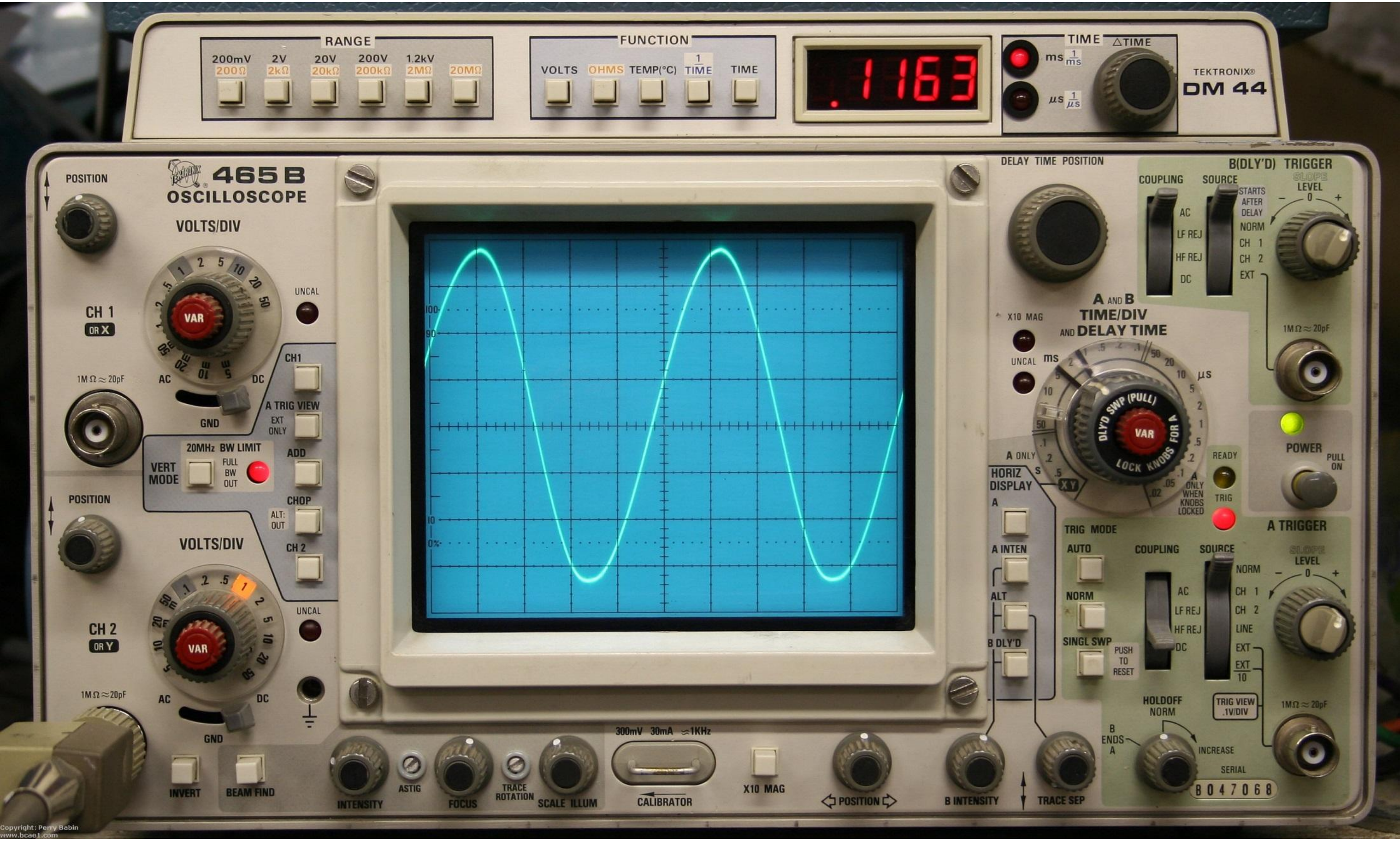
The speed of light in a vacuum, about 3×10^8 ms^{-1}, seems to be a *universal speed limit*. As one approaches the speed of light, strange *relativistic* effects happen to space and time!

Adapted from [Pople, Complete Physics for IGCSE]

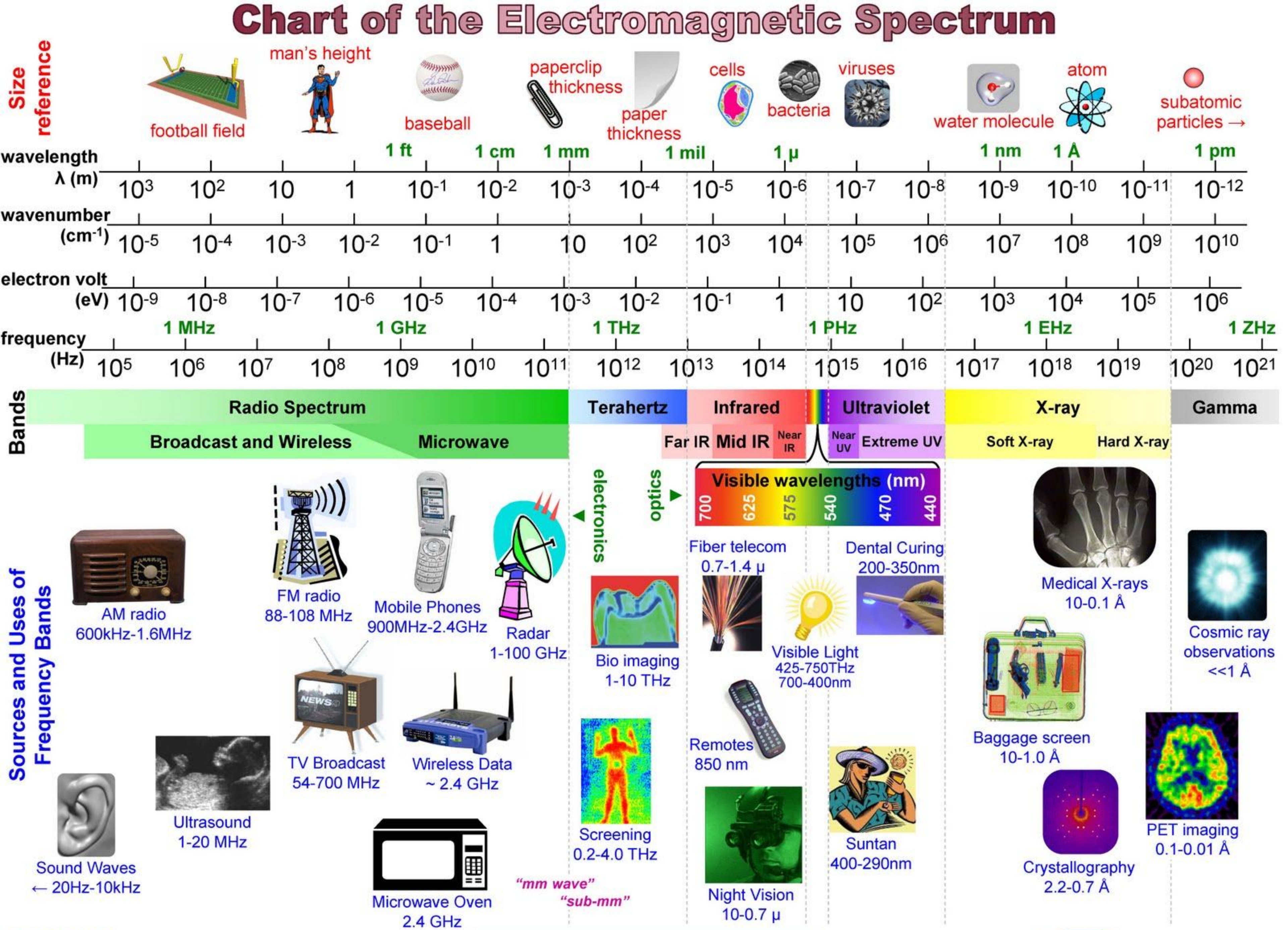
THE ELECTROMAGNETIC SPECTRUM




Electric field
Magnetic field



Cathode Ray Oscilloscope (CRO)



$\lambda = 3\times10^8/freq = 1/(wn*100) = 1.24\times10^{-6}/eV$

SURA Southeastern Universities Research Association ®

RAdio Detection And Ranging

Radars detect the presence of a physically remote object via the reception and processing of **backscattered electromagnetic waves**.

Unlike optical systems, (which are responsive to frequencies ≈10^{15}Hz), Radar is typically associated with frequency bands ranging from a **few MHz** (High Frequency or HF band) up to **hundreds of GHz** (mm wave).

Nikola Tesla (1856-1943)

“We may produce at will, from a ***sending station****, an* ***electrical effect*** *in any particular region of the globe; (with which) we may determine the relative* ***position*** *or* ***course*** *of a moving object, such as a vessel at sea, the* ***distance*** *traversed by the same, or its* ***speed****.”*

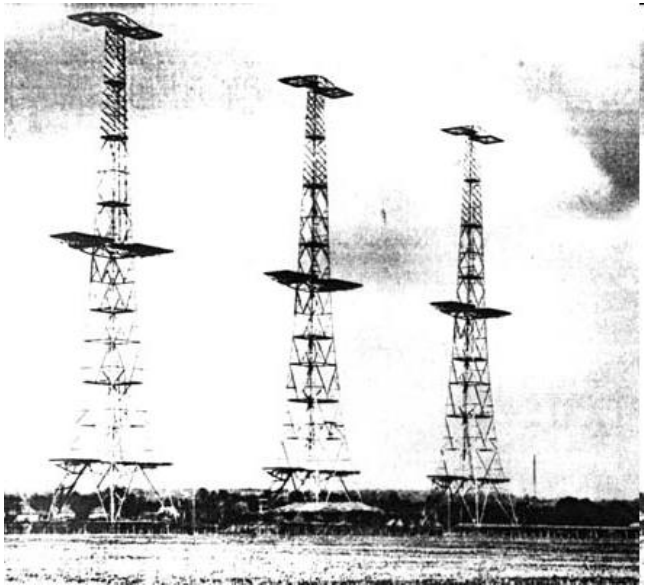
- Most targets of interest (especially those constructed from **metal**) are **highly reflective** at Radar frequencies.

- Radar can be used in **darkness** and can **penetrate haze, fog, snow and rain.**

- **Atmospheric propagation attenuation is much less severe** for Radar than higher frequency electromagnetic disturbances. This means Radar can be used for **long range surveillance**. A **military** air defence system may have an operational range of **hundreds of km**.

- Radar has been used to successfully measure the distance between the Earth and other planets in the solar system. Note Mars is 56 million km from Earth!

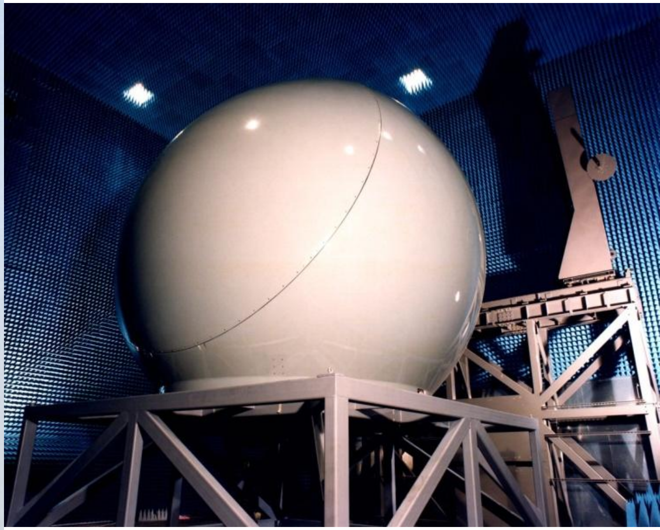
- The technology to generate, receive and process Radar signals has been continuously refined for nearly **100 years**
- Military and civilian air traffic control have employed Radar as a key sensor extensively since the Second World War.



- Magnetron transmitters, which are stable sources of microwaves (0.1 - 100 GHz approximately) are ubiquitous as a fundamental element of modern domestic ovens.

- Given the size of a Radar antenna roughly scales with the wavelength it transmits / receives; Radars (with modest directivity, i.e. a beamwidth of a few degrees) tend to be of dimensions well suited to human use i.e. of the order of a few metres.

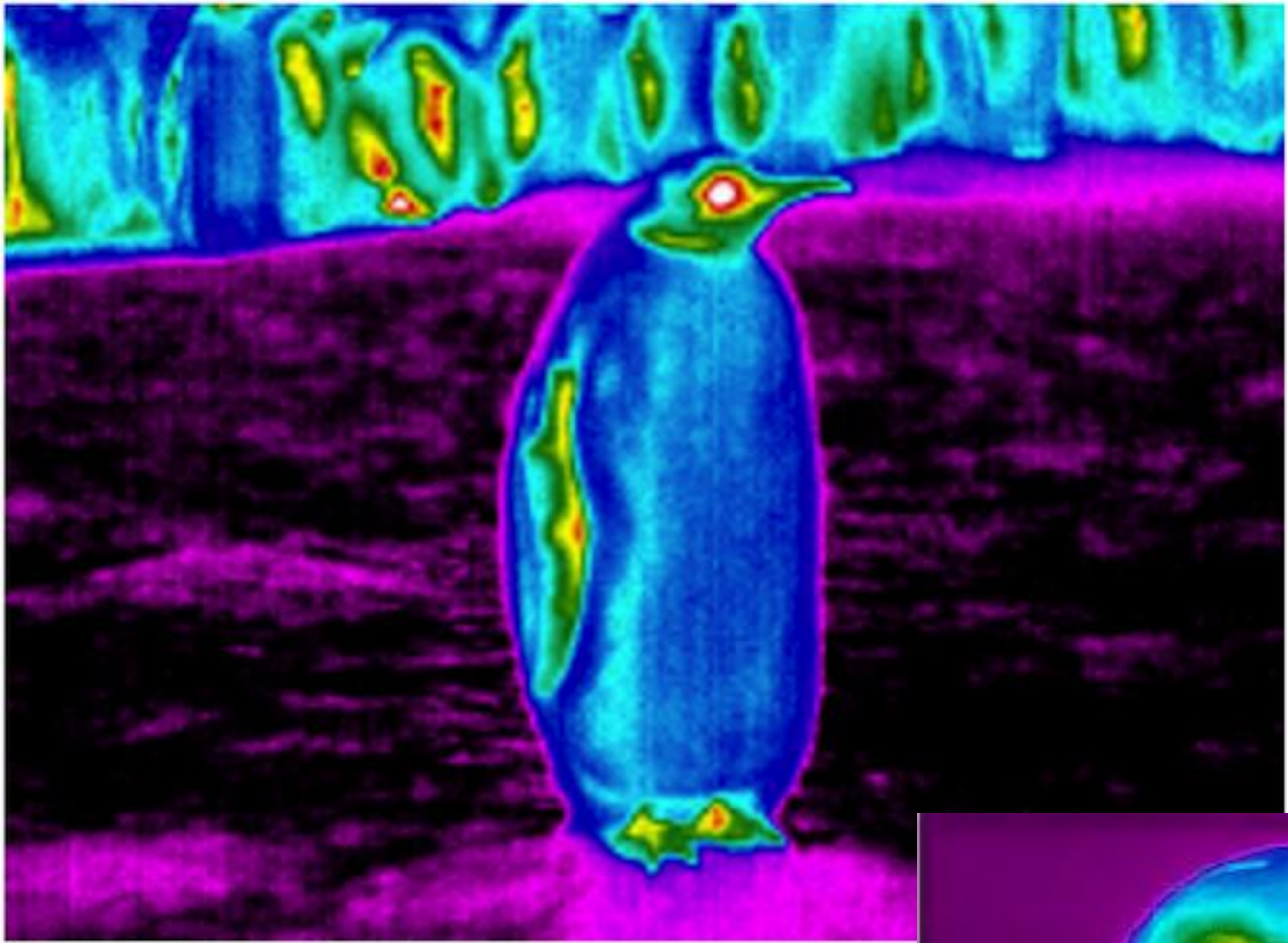

LIFTING POINT
DO NOT FORK LIFT
BXA

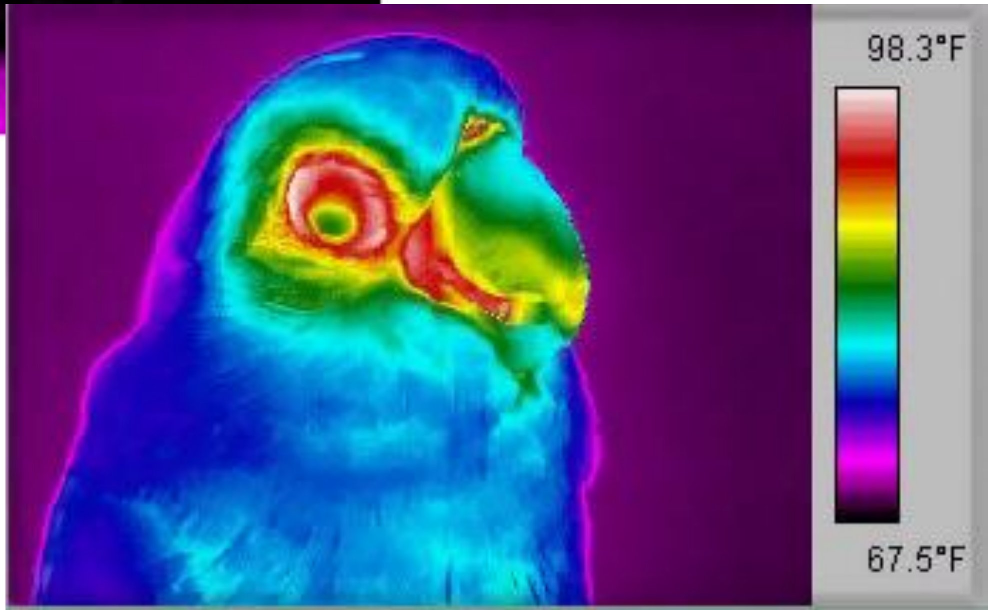


D32

GSM spectrum (microwaves)
380 MHz – 1.8GHz

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

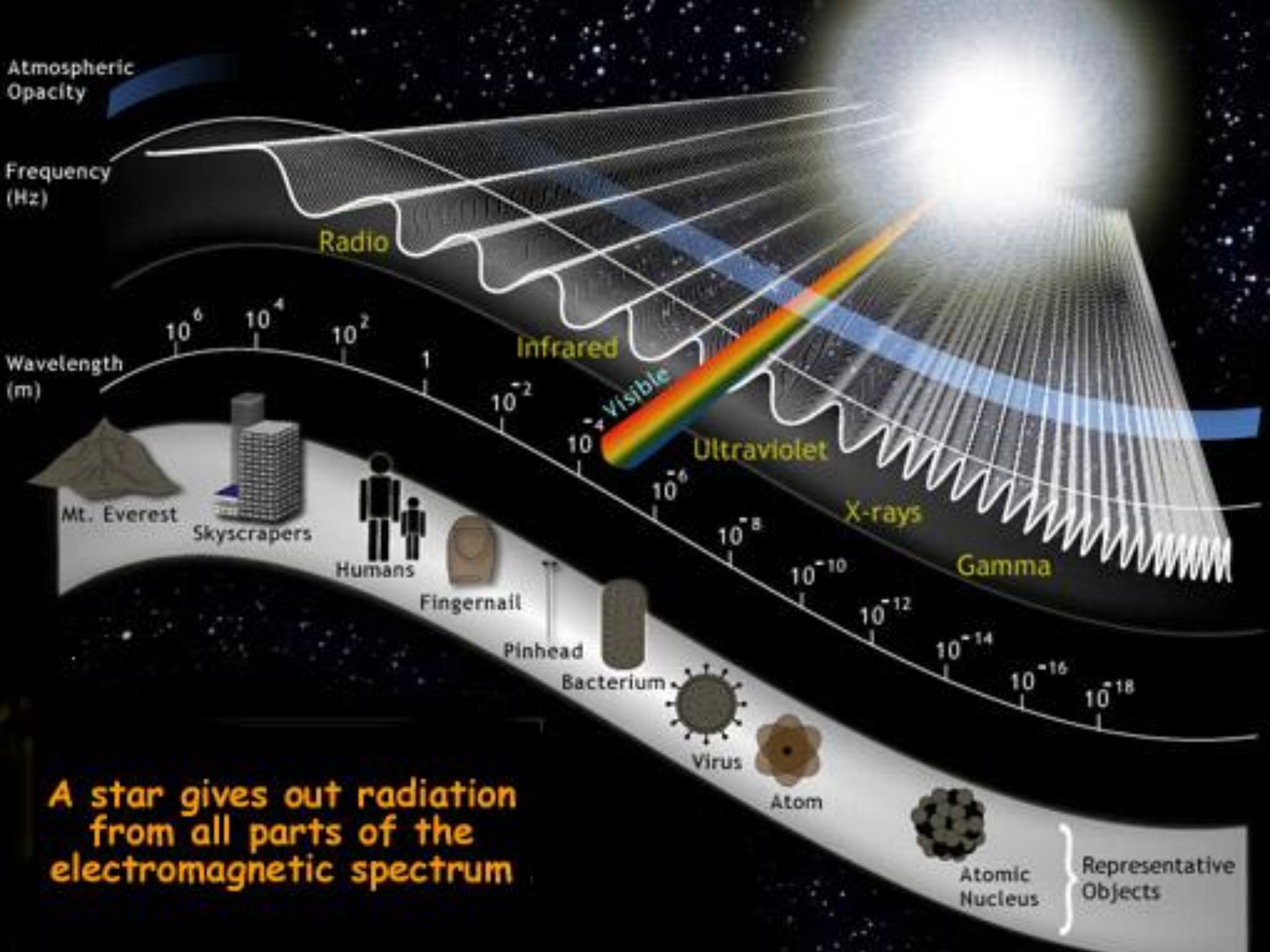




Infra Red

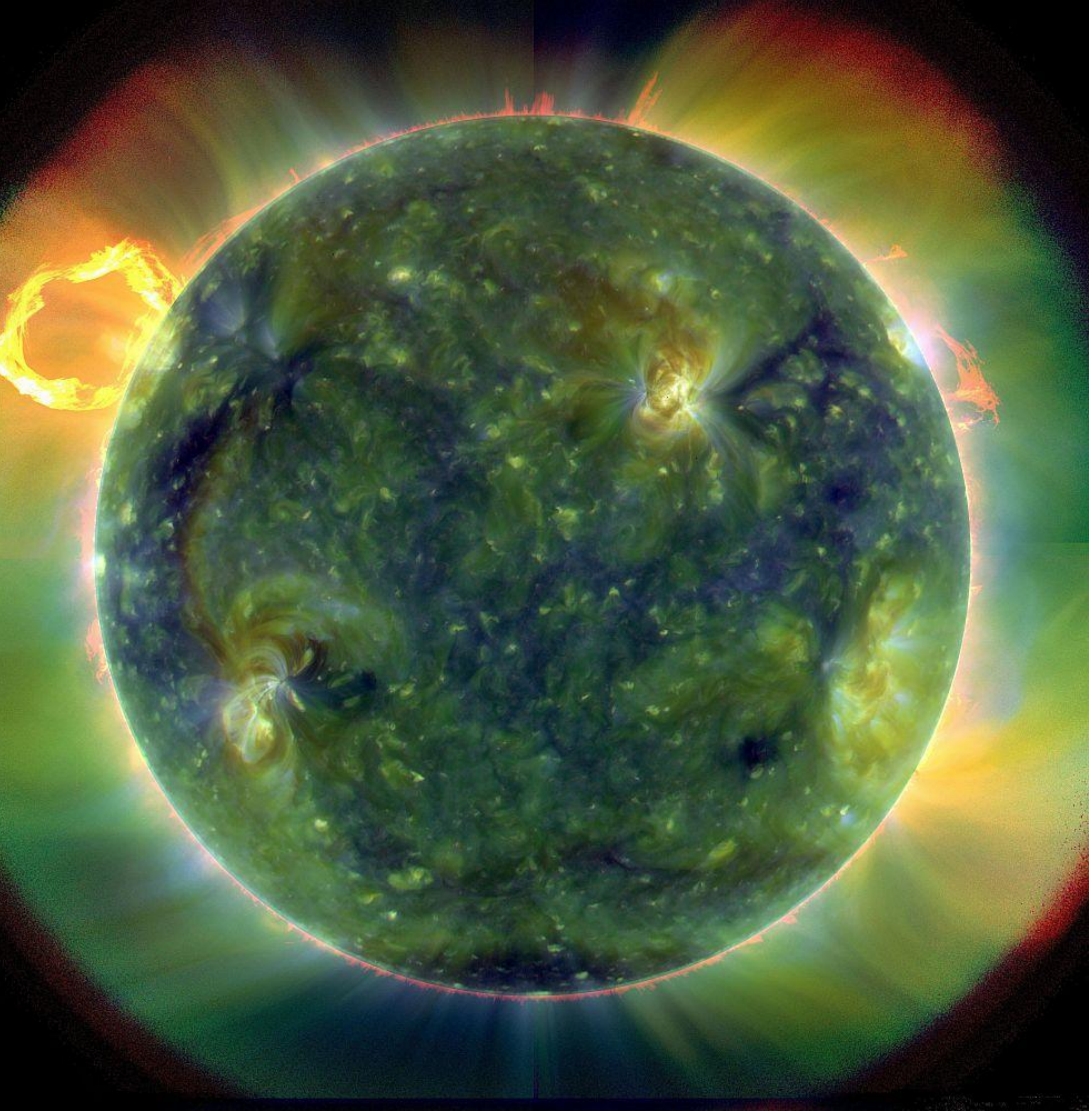

Ultraviolet
Visible
Infrared

X-Rays



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

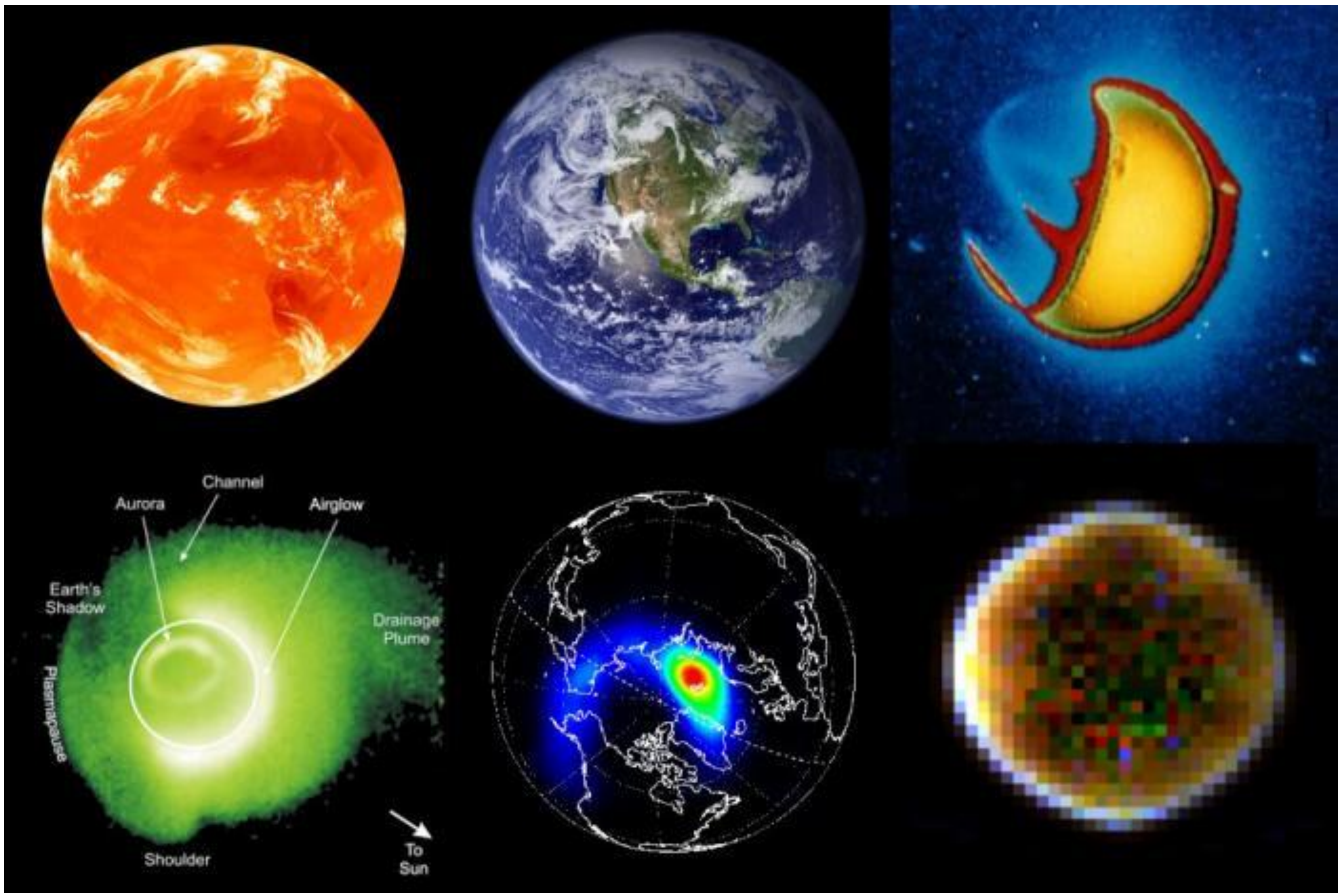
NASA space telescopes



Hyper-Spectral Imagery

http://orbitingfrog.com/2008/06/25/earth-and-friends-in-multiple-wavelengths/

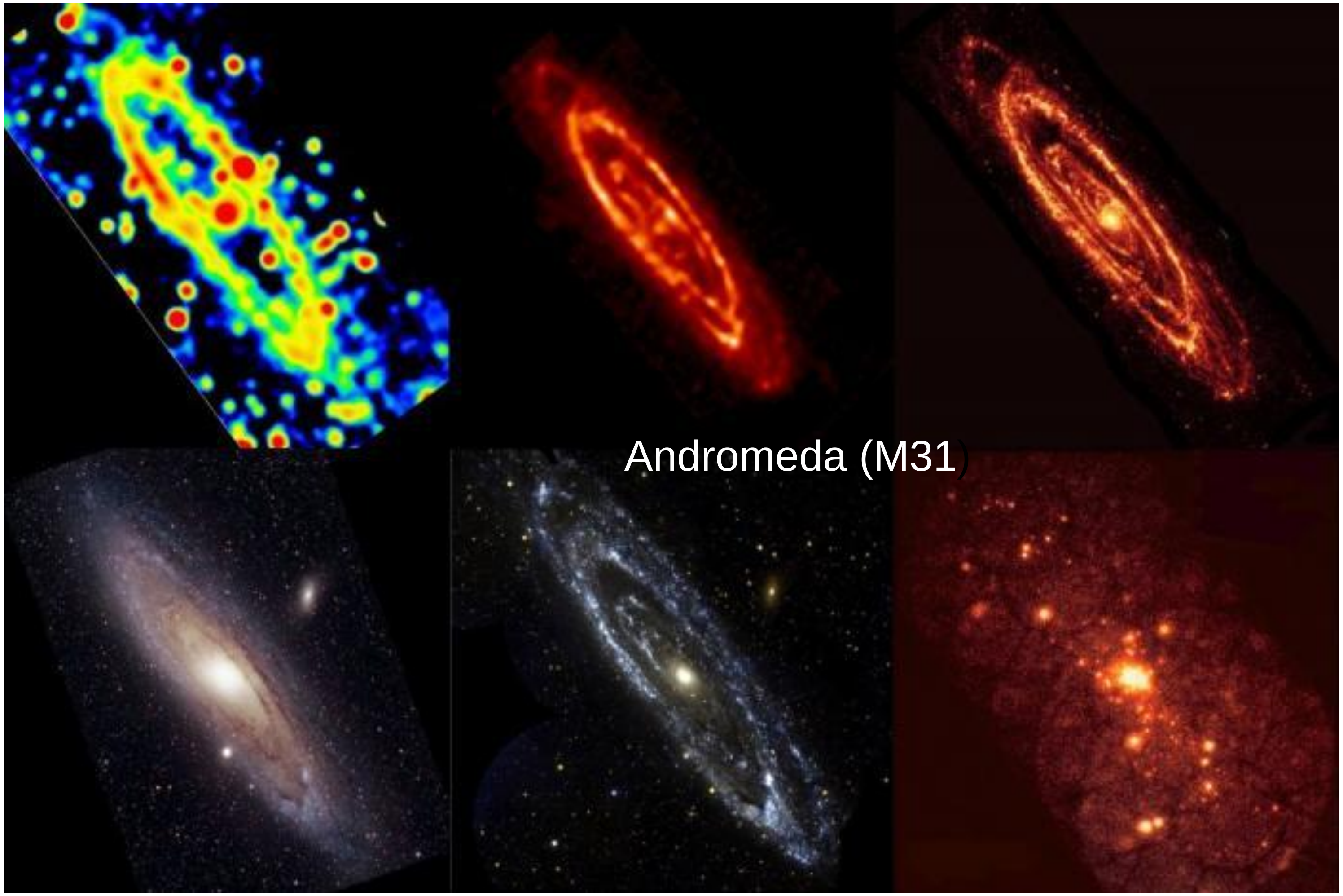
Infrared Visible UV



Extreme-UV X-Ray Gamma Ray

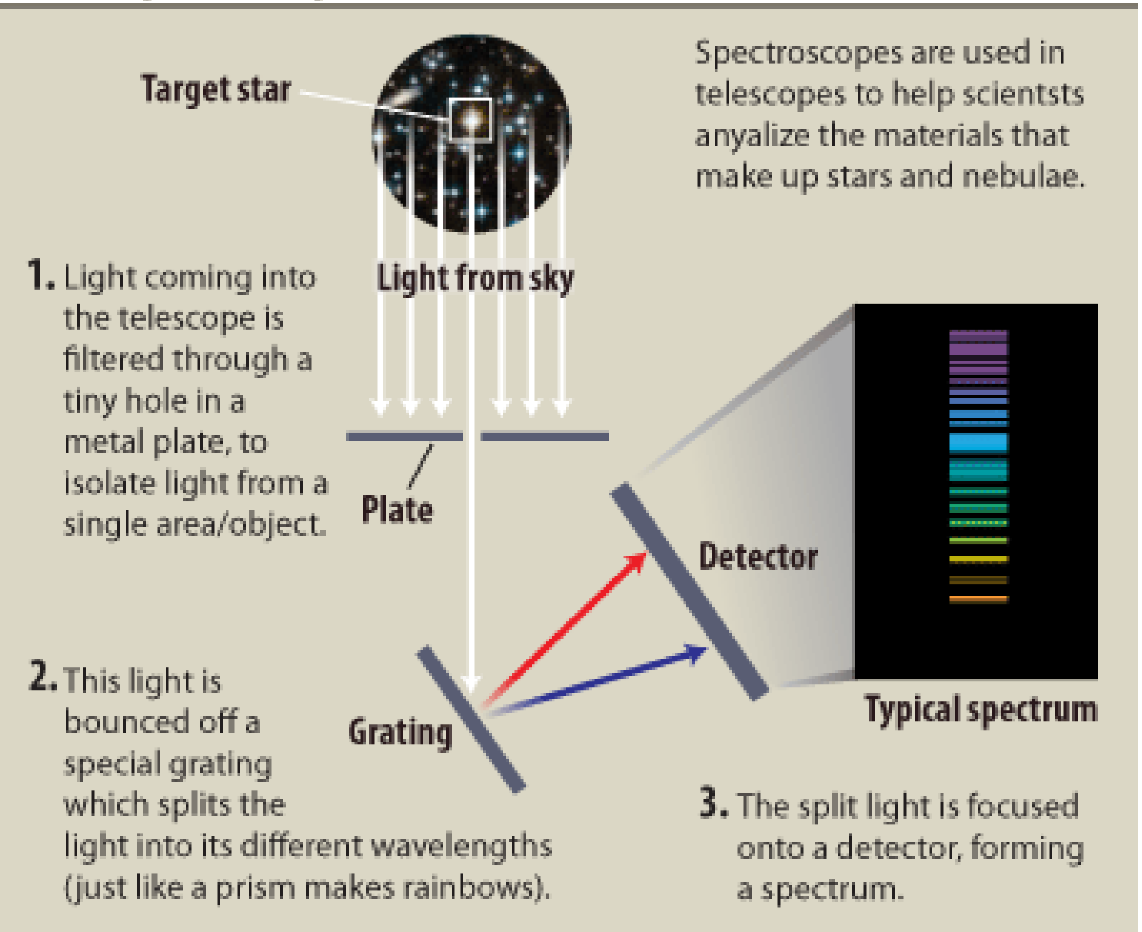
http://orbitingfrog.com/2008/06/25/earth-and-friends-in-multiple-wavelengths/

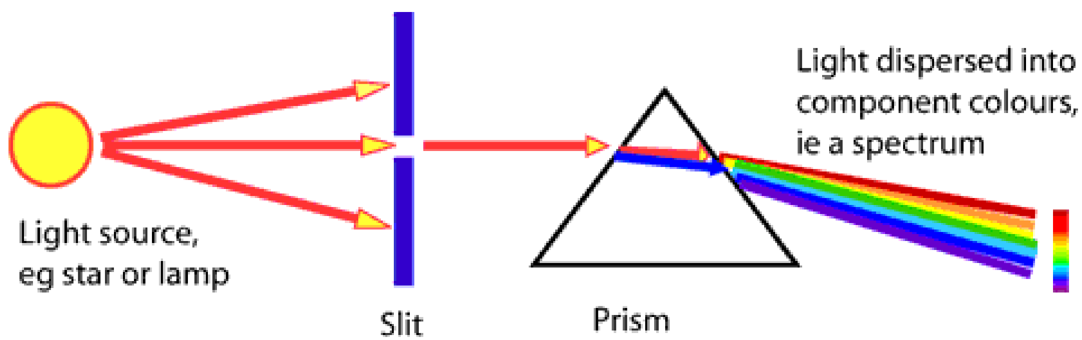
Radio Microwave Infrared



Visible UV X-Ray

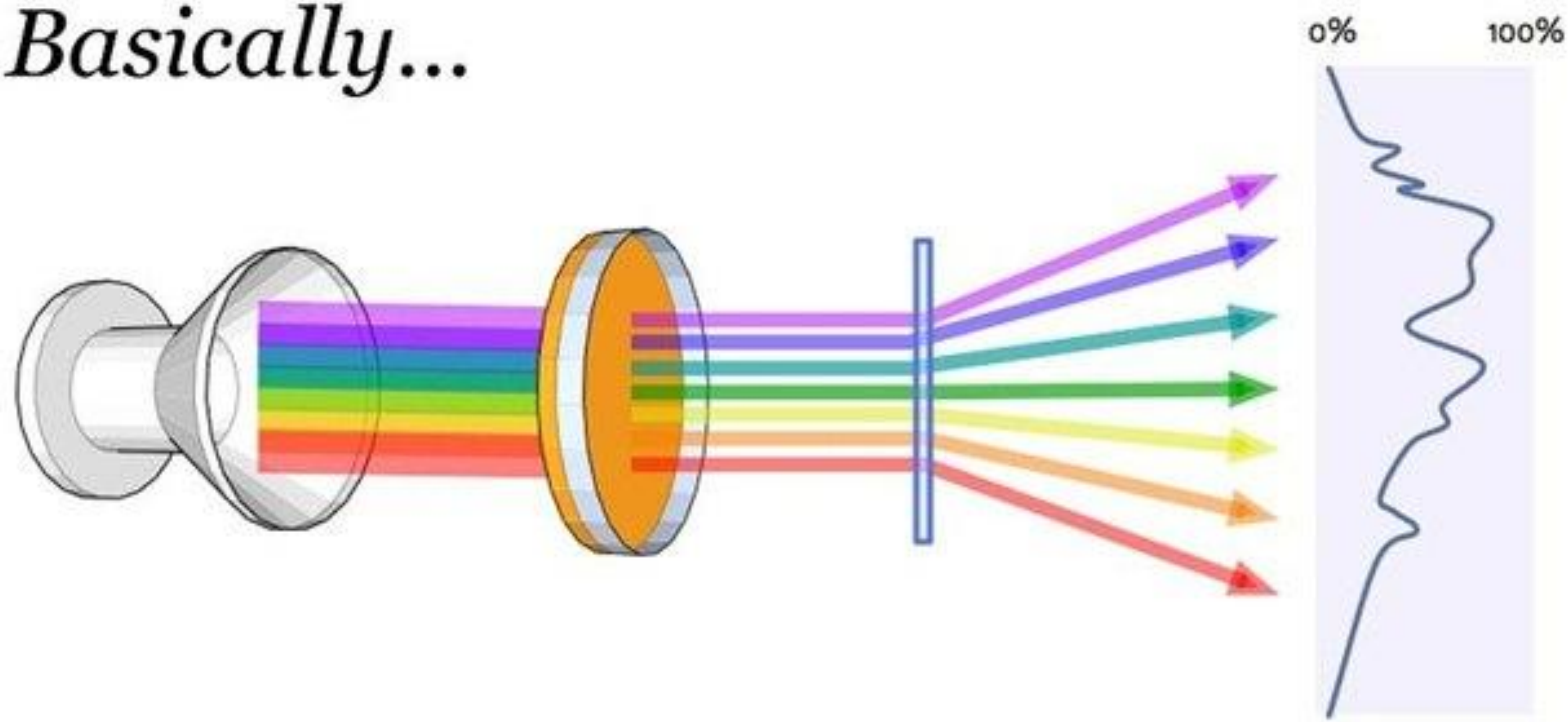
How a Spectroscope Works





Dispersion of light through a prism

Basically...

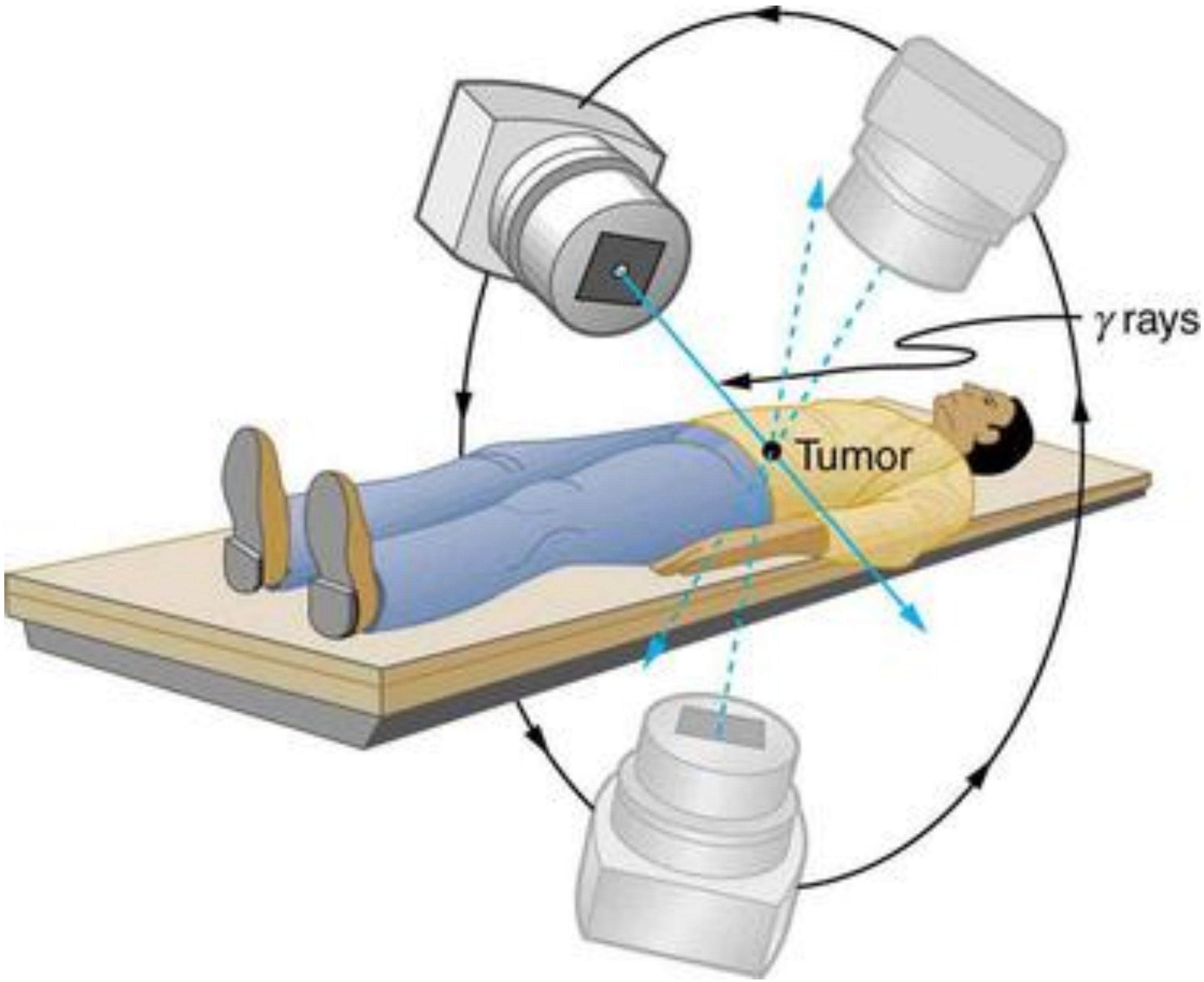


1. A broad-spectrum light (halogen, incandescent) is shone through a sample

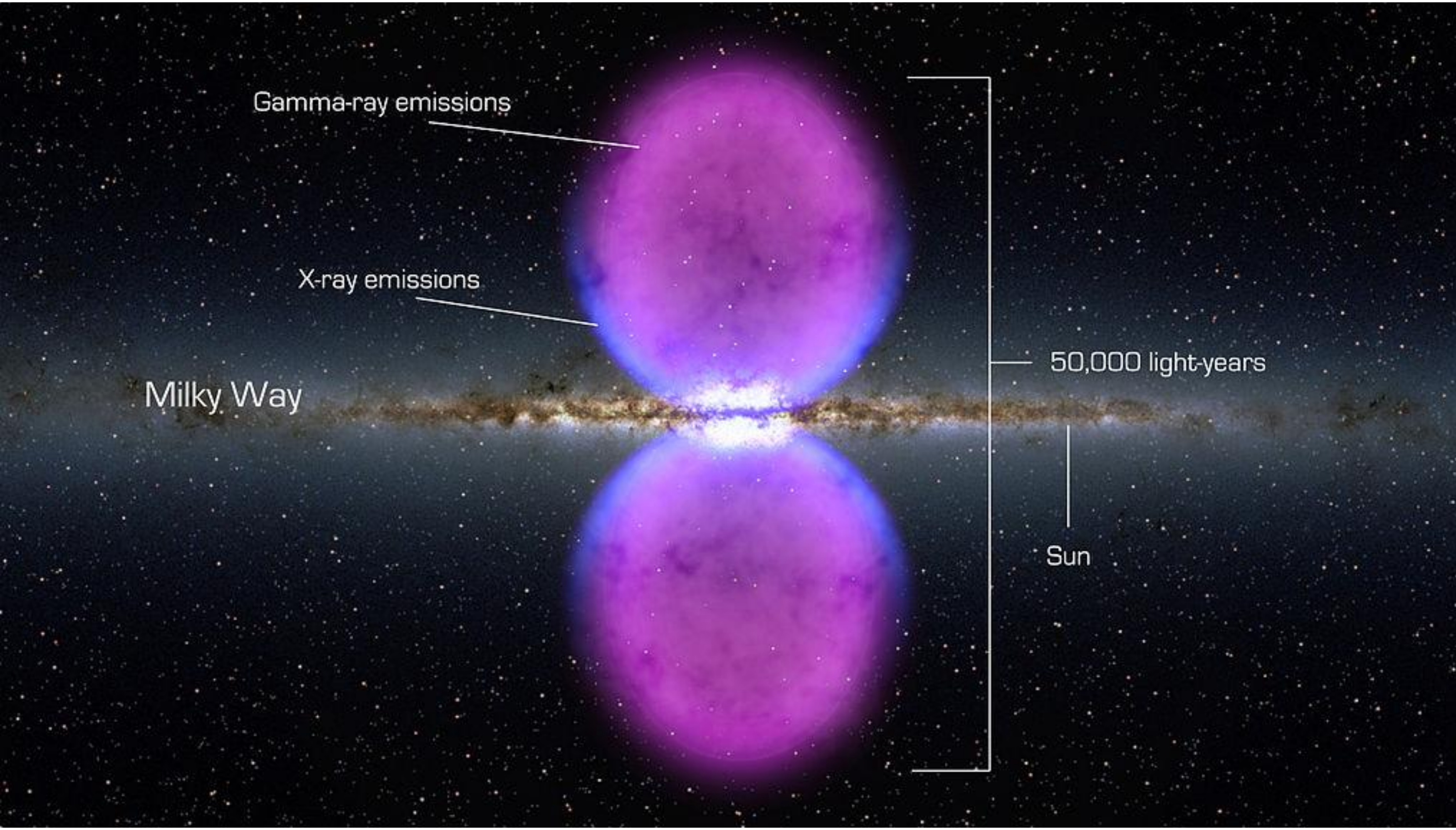
2. Some colors are absorbed more than others depending on its composition

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.

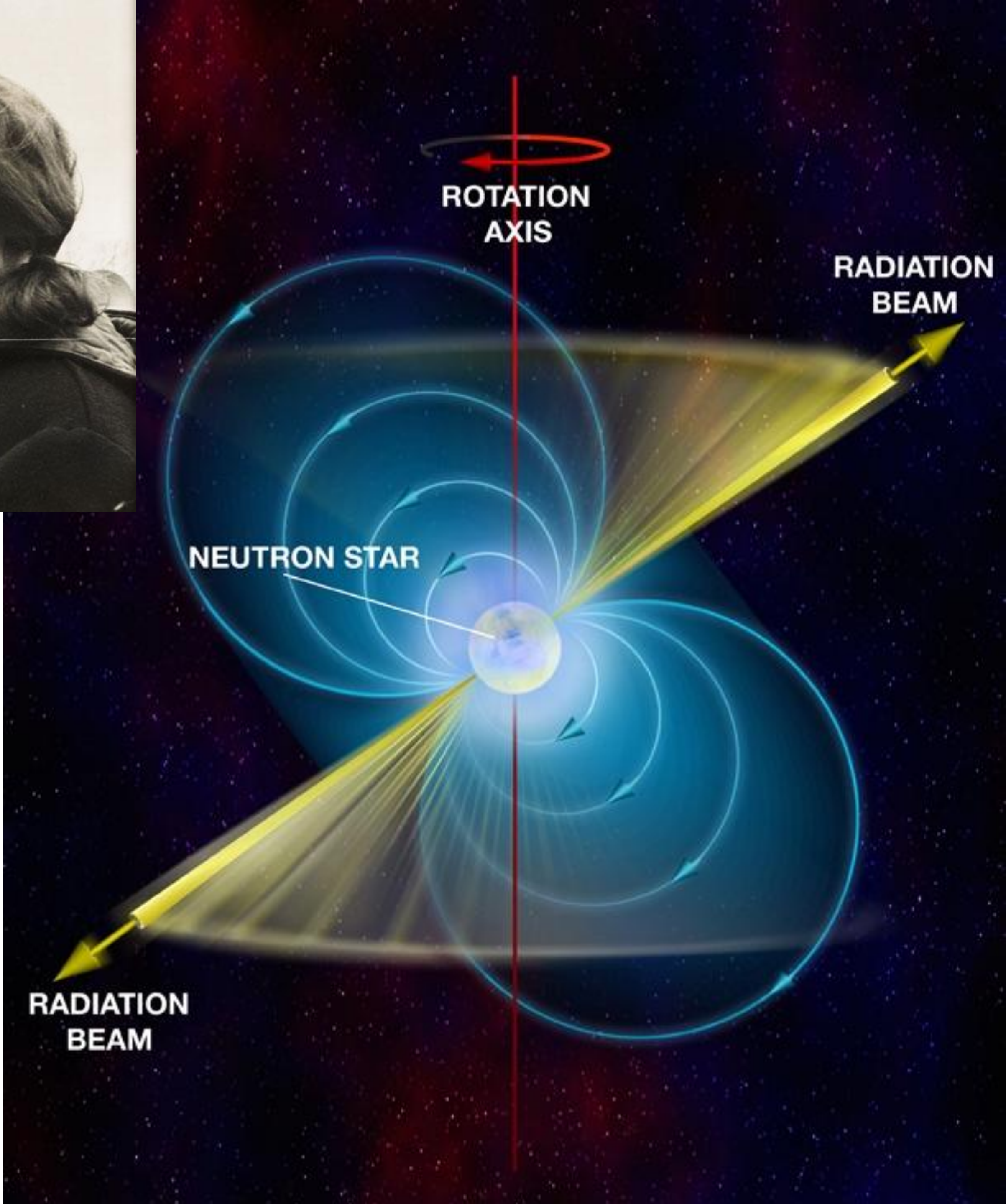


Gamma Rays

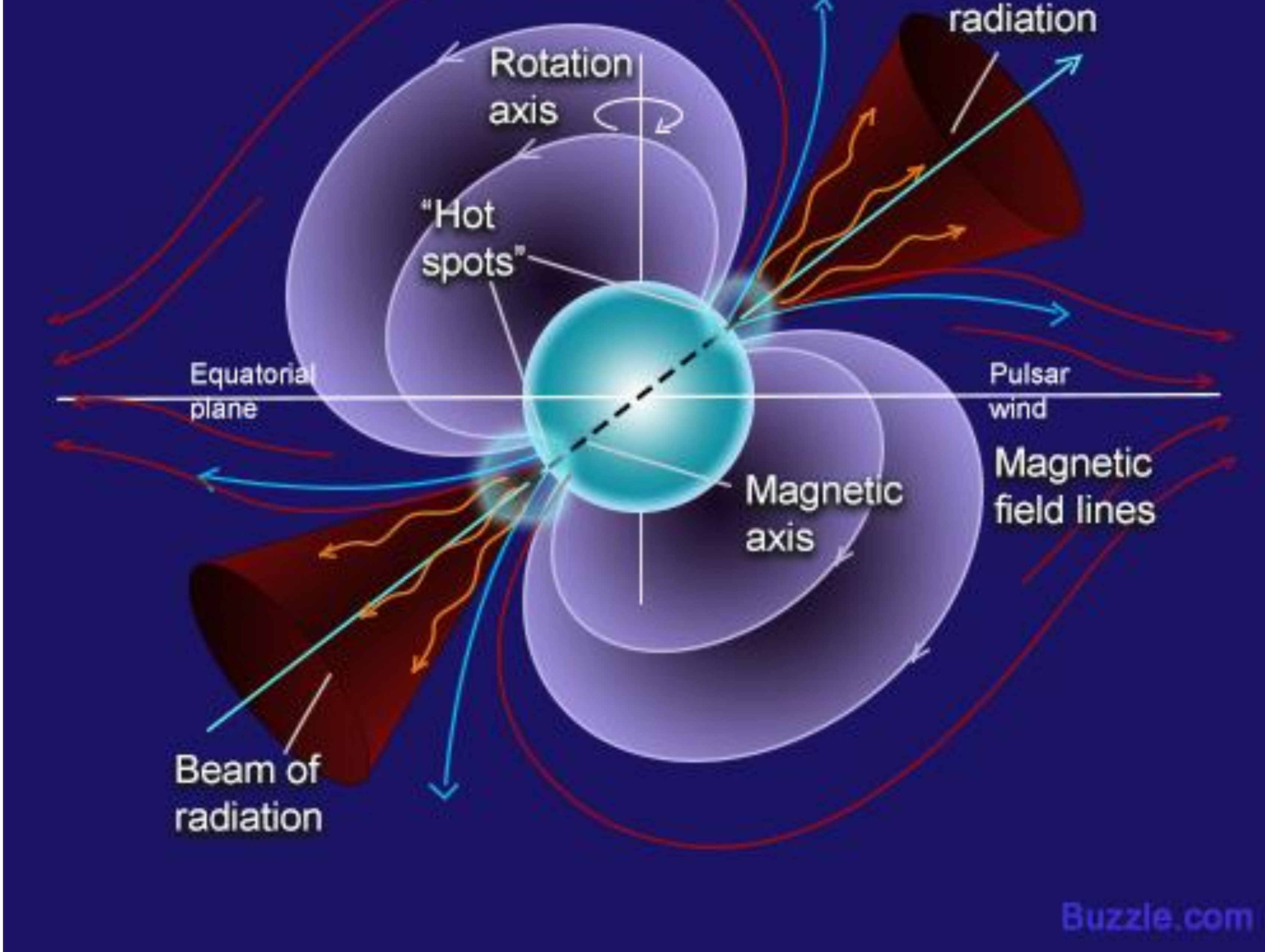

Gamma-ray emissions
X-ray emissions
Milky Way
50,000 light-years
Sun

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.

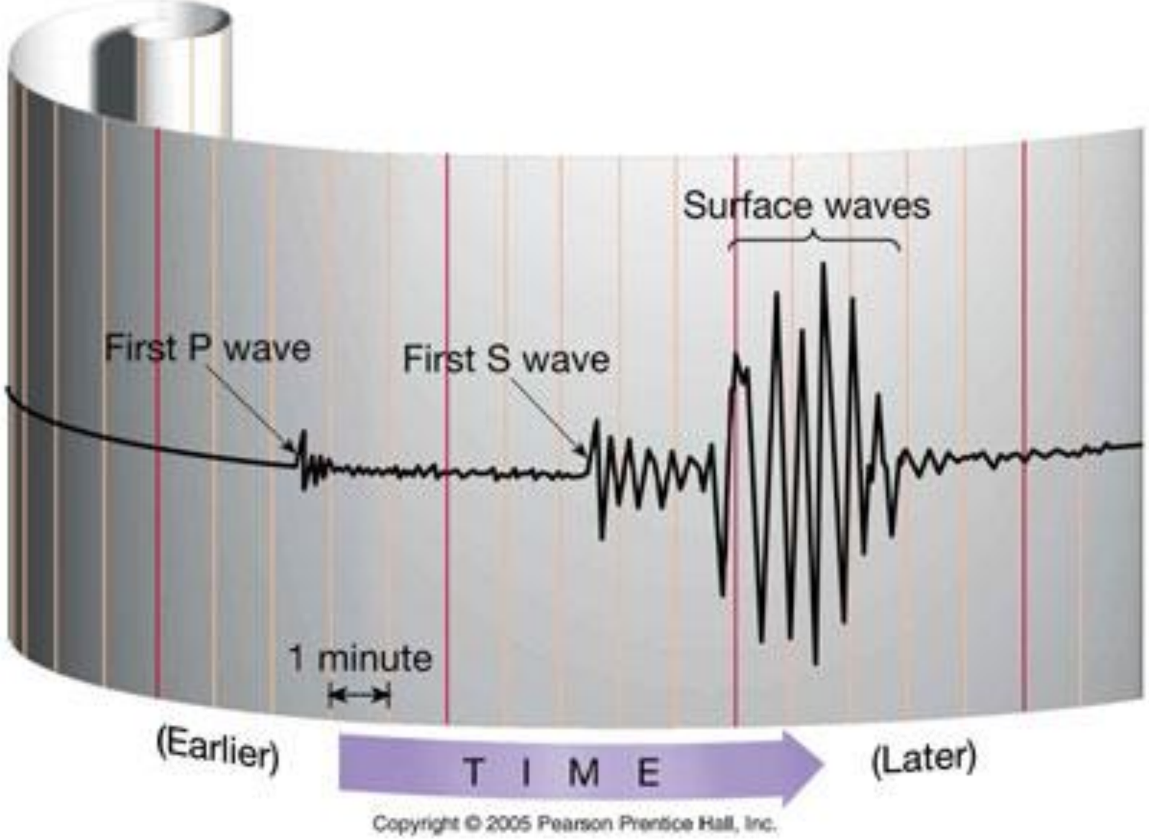


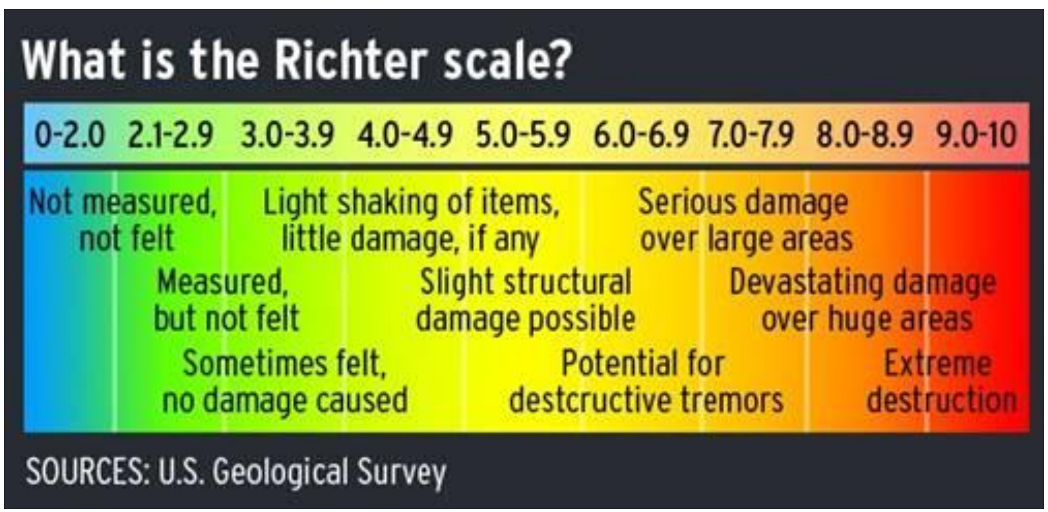
Pulsars

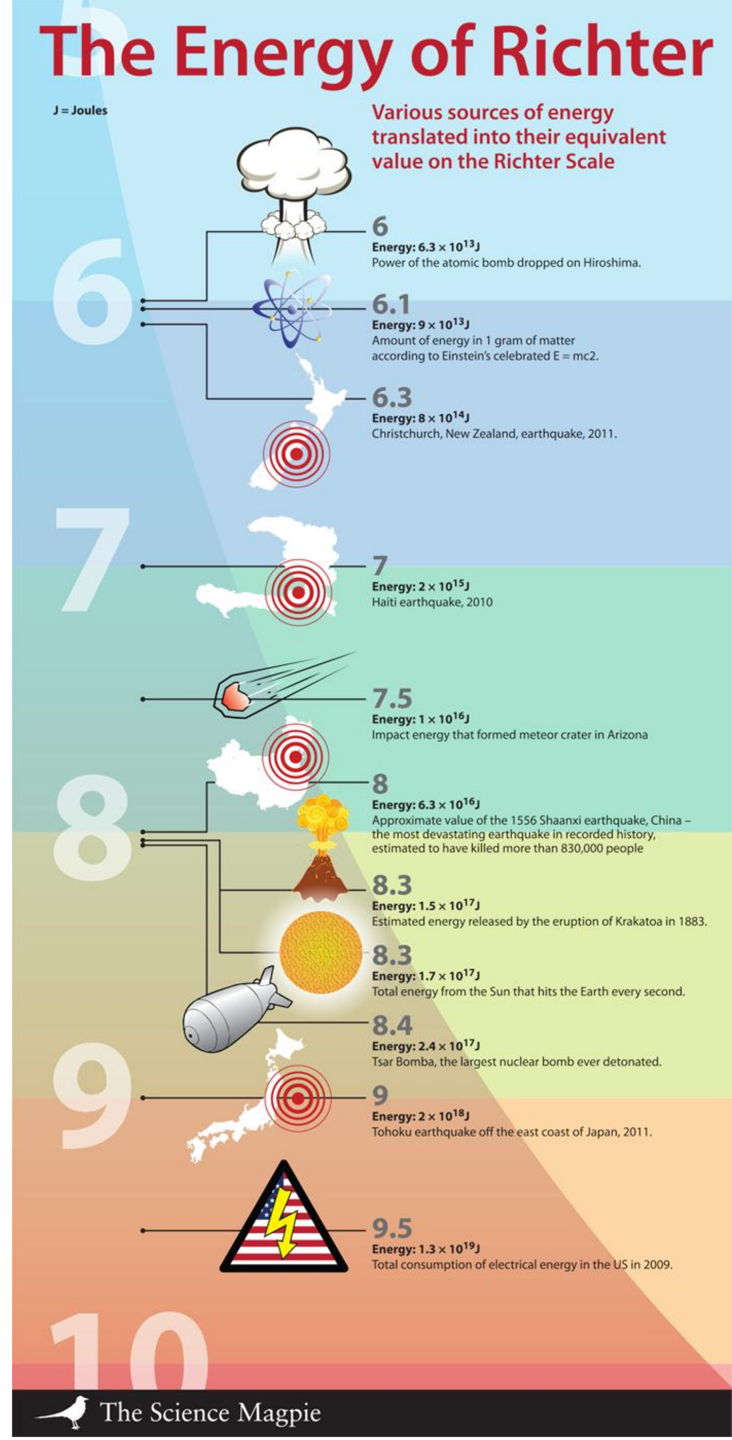


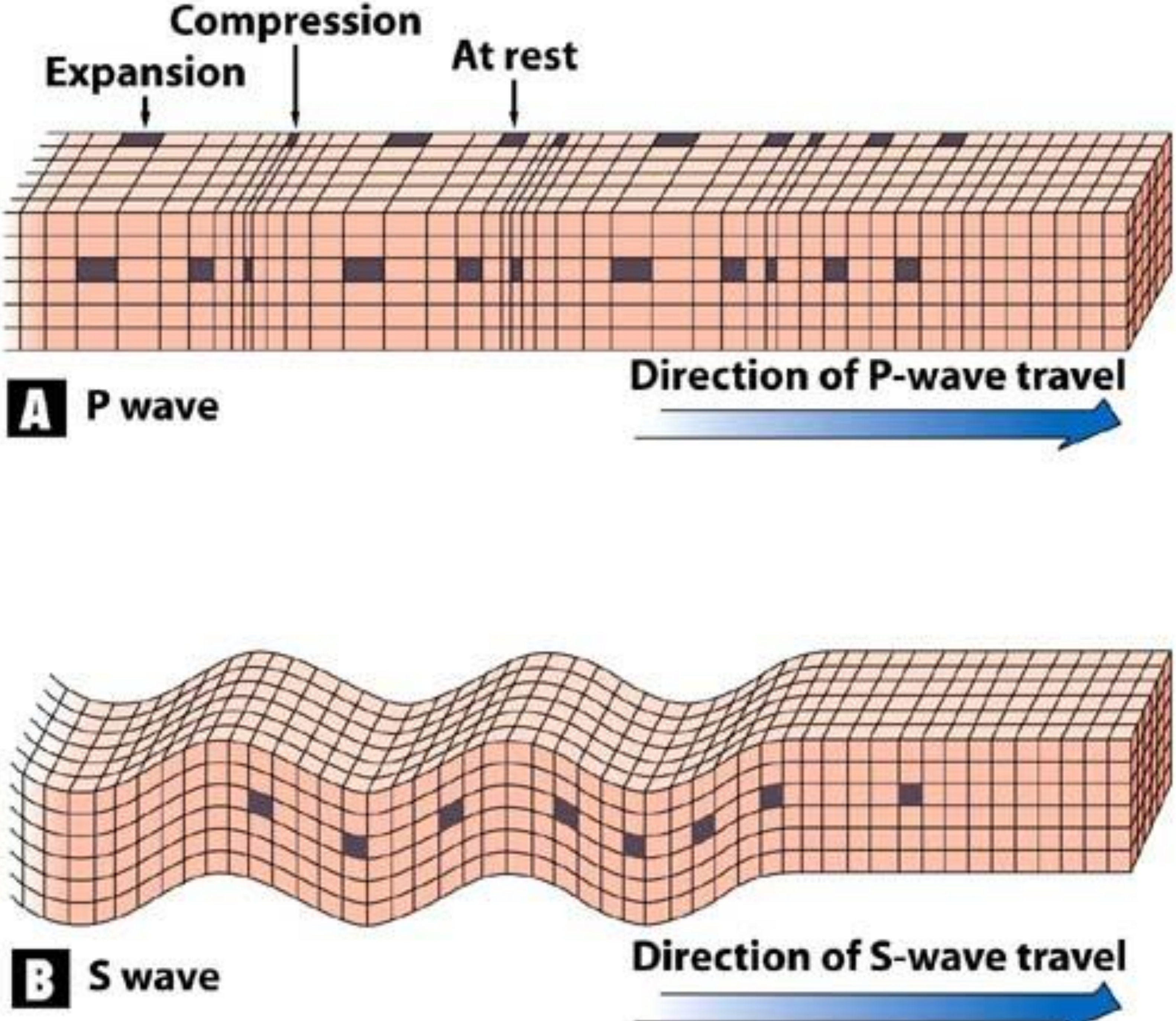
Beam of radiation
Rotation axis
"Hot spots"
Equatorial plane
Pulsar wind
Magnetic field lines
Magnetic axis
Beam of radiation
Buzzle.com


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.
6
7
8
9
10
The Science Magpie


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


JEAN GUICHARD
Kéréon | France | Ouessant

Mavericks, California

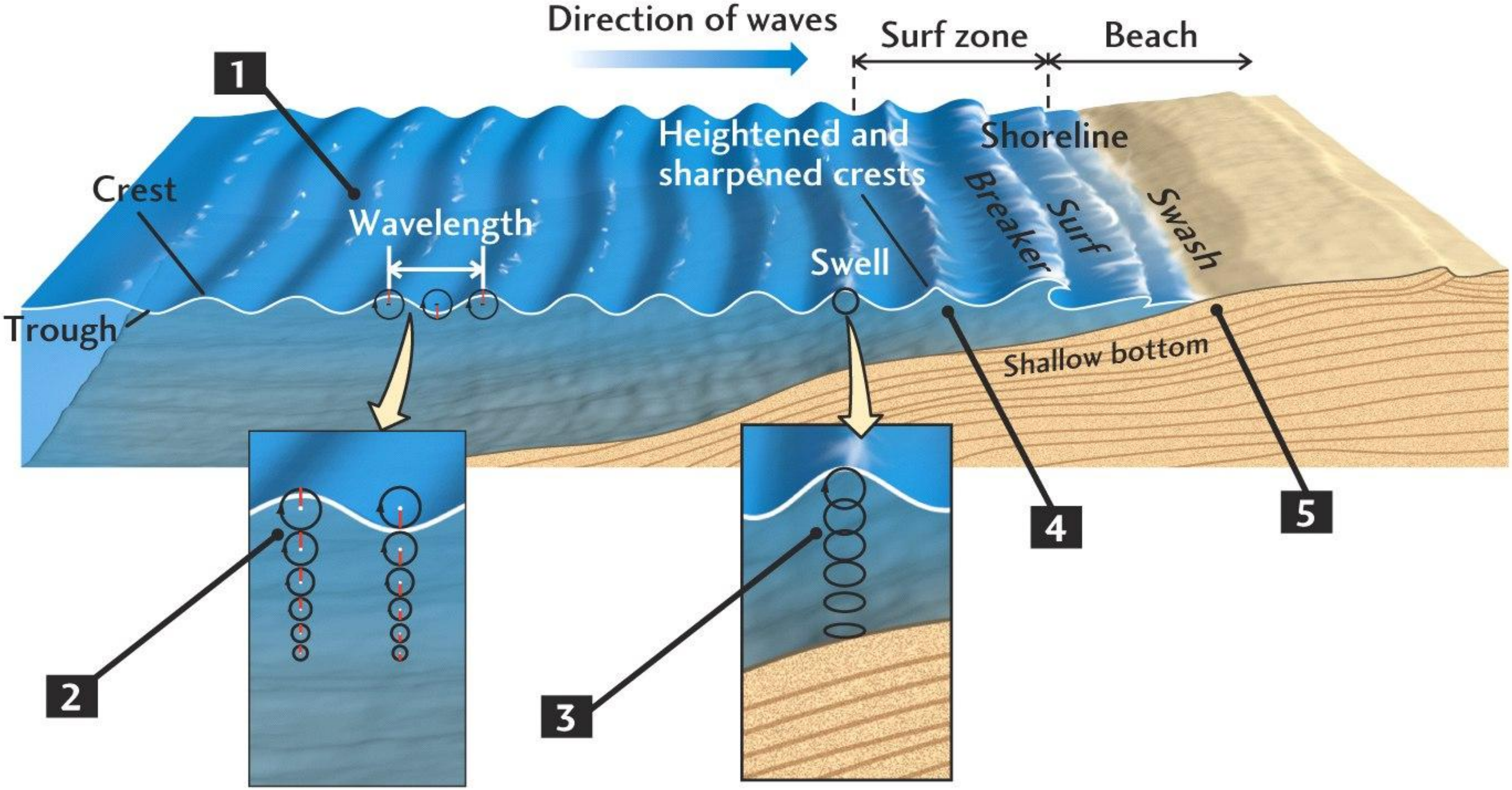
Garrett McNamara surfs a 100ft wave! (January 2013, off the coast of Portugal)

Garrett McNamara surfs a 100ft wave!

https://www.youtube.com/watch?v=IlrqyHIE4wc

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

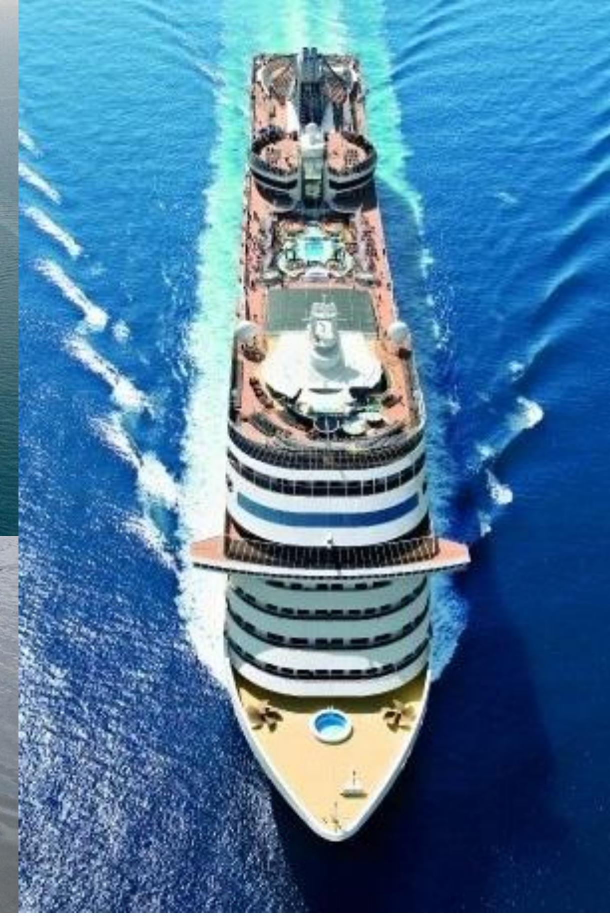
WAVE MOTION IS INFLUENCED BY WATER DEPTH AND SHAPE OF THE SHORELINE



Ripples and *caustics*

Surface tension is important!

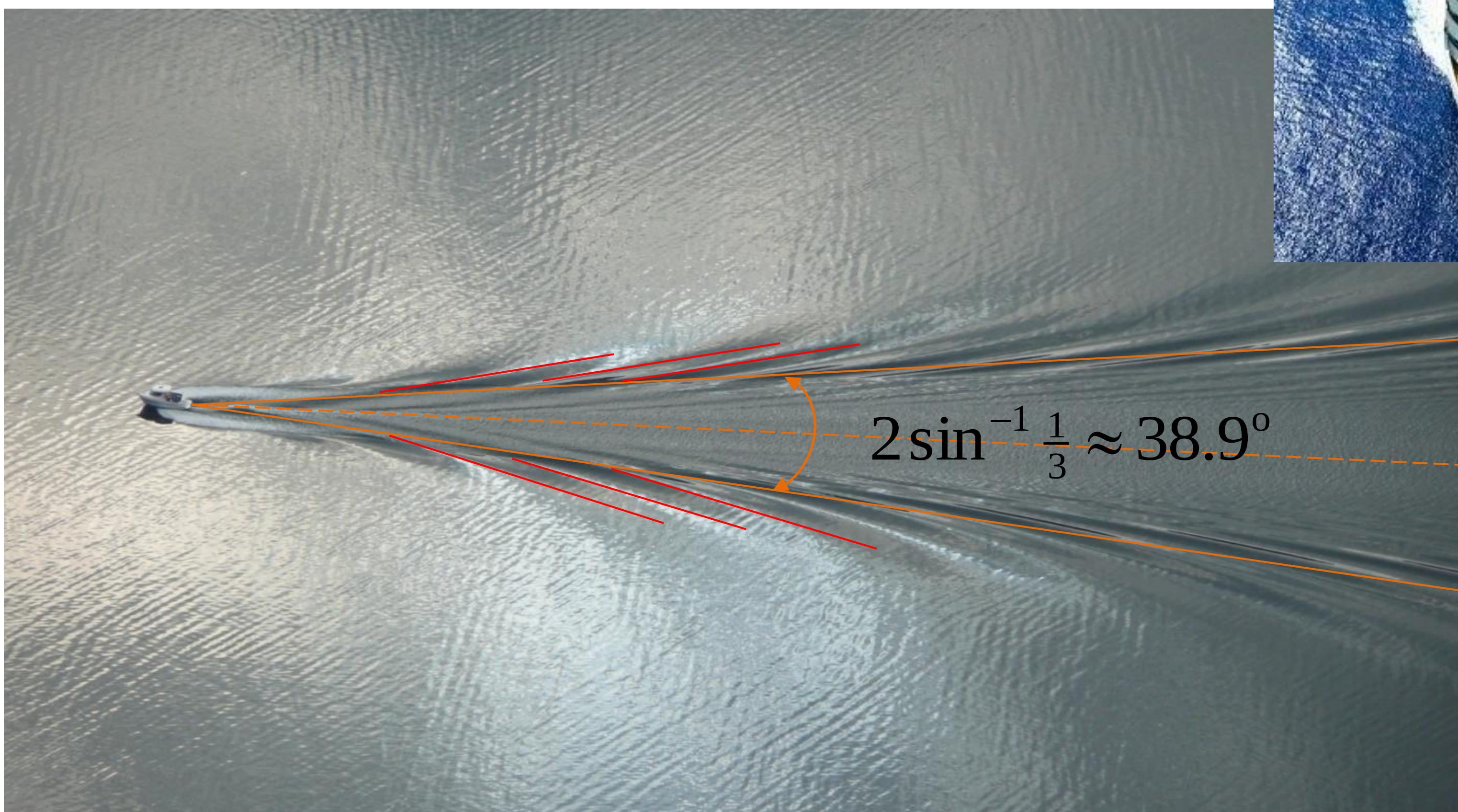


A wake is an *interference pattern* of waves formed by the motion of a body through a fluid. Intriguingly, the angular width of the wake produced by ships (and ducks!) in deep water is the same (about 38.9^{o}). A mathematical explanation for this phenomenon was first proposed by Lord Kelvin (1824-1907).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

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

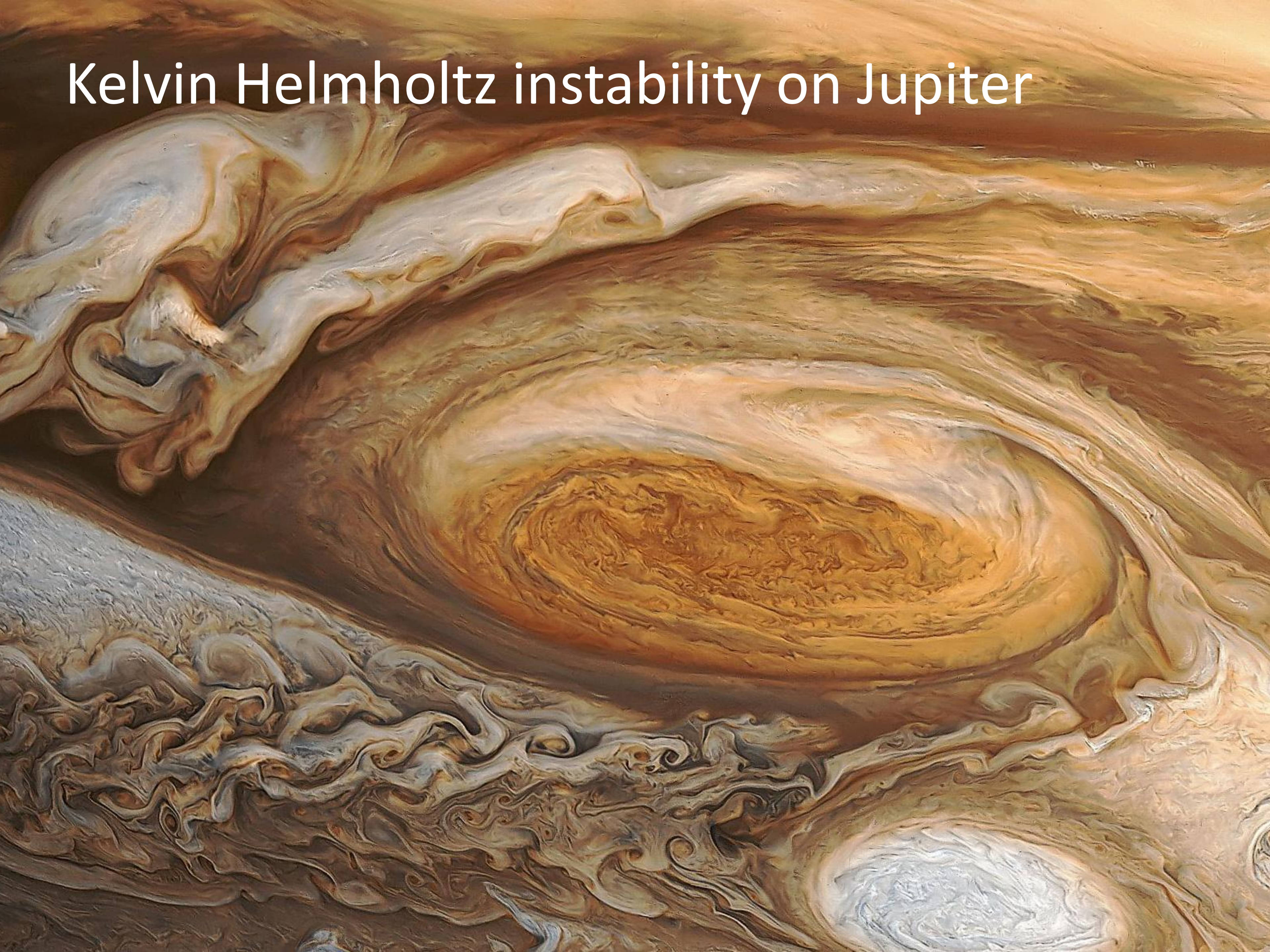
The Kelvin Wedge



Lenticular clouds

Kelvin Helmholtz instability on Earth

Kelvin Helmholtz instability on Jupiter



Shock waves



Topics to reflect on:

Transverse and Longitudinal waves

Sound waves

Pitch (frequency), Loudness (amplitude), wavelength, period
wave speed = frequency x wavelength

Light and the Electromagnetic Spectrum
(Radio, Microwave, IR, Visible, UV, X-Ray, Gamma)

Earthquakes

Water waves

Shock waves

Depending on your course, we may not cover all of these. Review the topics you did meet. If you have time to spare, read on!