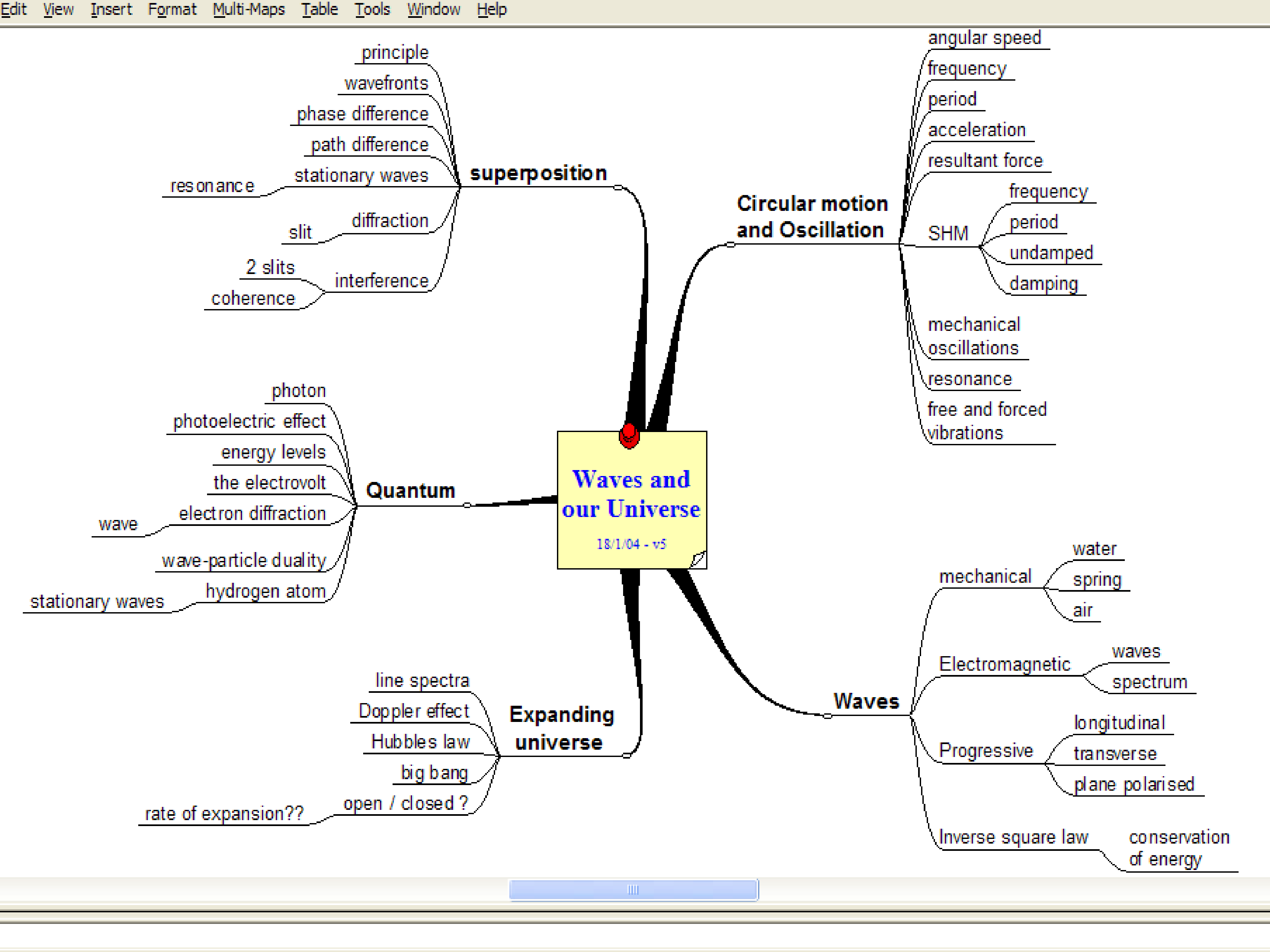
Our Universe

Dr P Lawson



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Waves and our Universe
18/1/04 - v5
superposition
principle
wavefronts
phase difference
path difference
stationary waves
resonance
diffraction
slit
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2 slits
coherence
Circular motion and Oscillation
angular speed
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period
acceleration
resultant force
SHM
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period
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damping
mechanical oscillations
resonance
free and forced vibrations
Quantum
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photoelectric effect
energy levels
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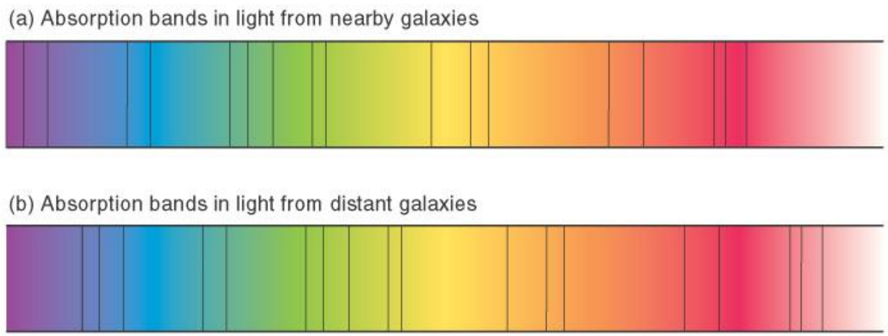
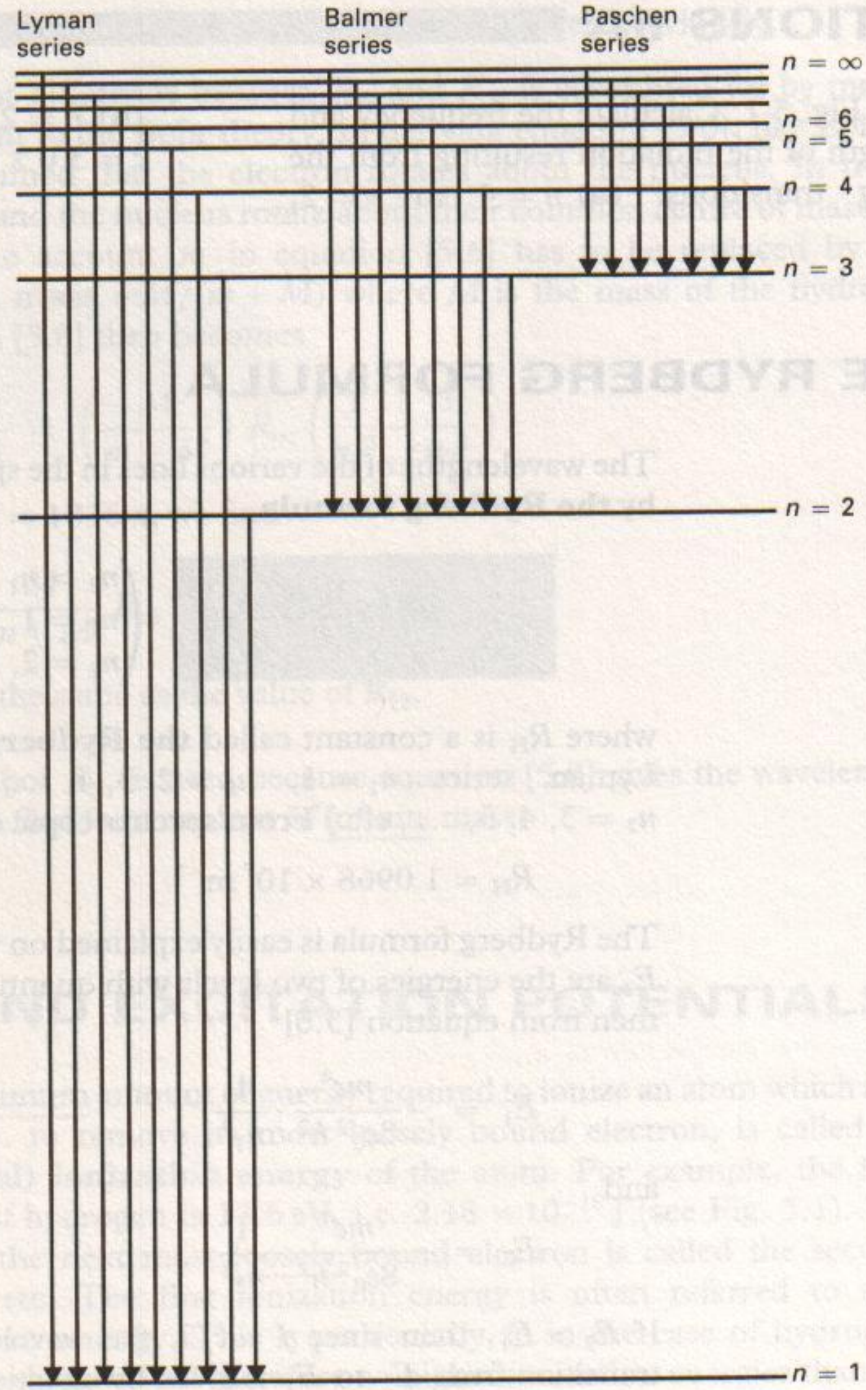
open / closed ?
rate of expansion??
Waves
mechanical
water
spring
air
Electromagnetic
waves
spectrum
Progressive
longitudinal
transverse
plane polarised
Inverse square law
conservation of energy

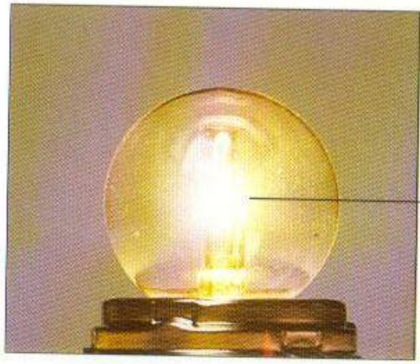
Line Spectra




Lyman series
Balmer series
Paschen series
n = ∞
n = 6
n = 5
n = 4
n = 3
n = 2
n = 1

in the incoming light.

SOURCES OF LIGHT



BRIGHT FILAMENT LAMP

This spectrum shows which colours are produced

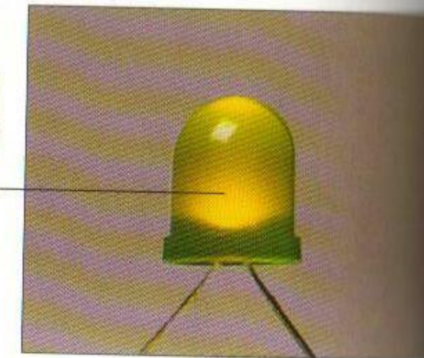
All colours of light together combine to produce white

BRIGHT FILAMENT LAMP
With a high **electric current**, the whole spectrum of visible light is produced (see p. 39).

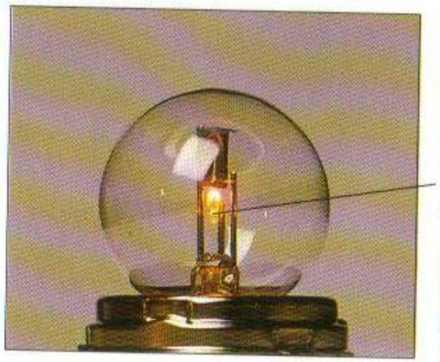
LED produces colours in the green part of the spectrum

LED appears green

GREEN LED
An LED (light-emitting diode) is made of a **semiconductor**, and produces certain colours of light.



GREEN LED



DIM FILAMENT LAMP

Red, yellow, and green light combine to produce orange

Lamp appears orange

No blue light produced

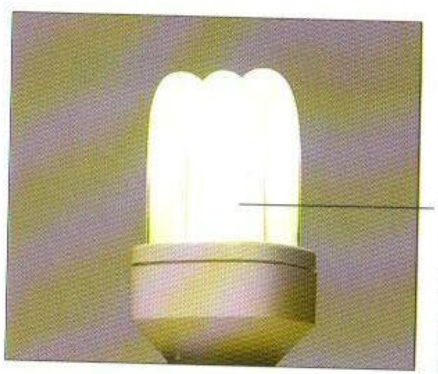
DIM FILAMENT LAMP
With a smaller current, the **temperature** of the **filament** (see pp. 32-33) is low.

Two colours of light very close together in the orange part of the spectrum are produced

Lamp appears orange

SODIUM LAMP
In a sodium lamp, an electric current excites electrons in sodium vapour, giving them extra energy. The electrons give the energy out as light.

SODIUM LAMP



FLUORESCENT LAMP

Lamp produces certain colours in each part of the spectrum

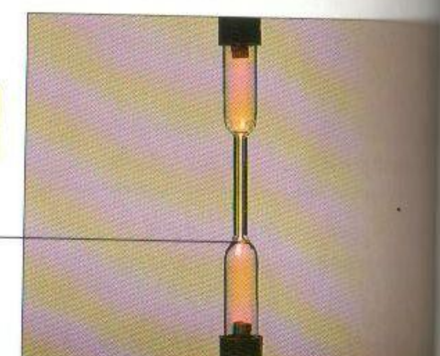
All three types of cone are stimulated and lamp appears white

FLUORESCENT LAMP
In a **fluorescent** lamp, chemicals called **phosphors** produce colours in many parts of the spectrum.

Only certain colours characteristic of neon are produced

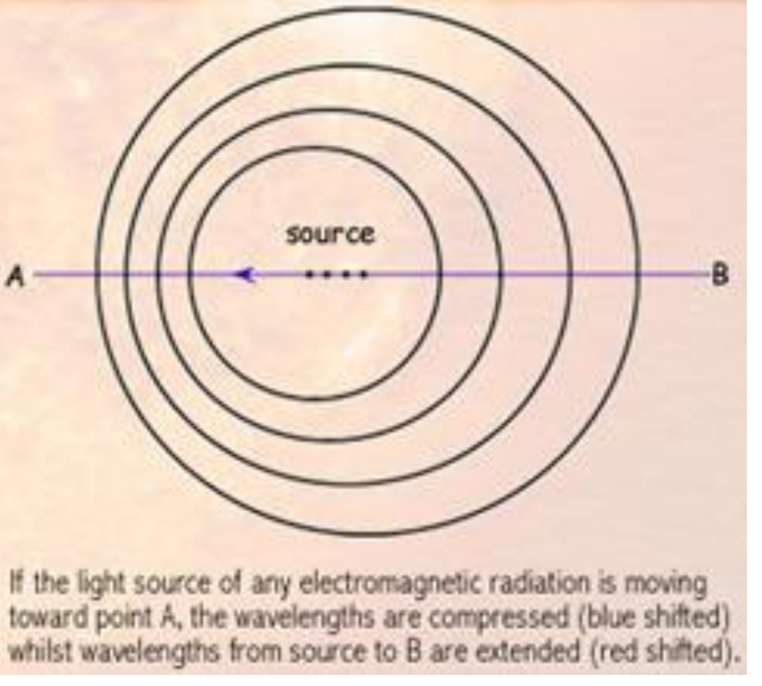
Lamp appears orange

NEON TUBE
In a similar way to a sodium lamp, a neon discharge lamp produces a characteristic orange glow.



NEON TUBE

Doppler effect



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By comparing the absorption lines produced in a star's or galaxy's spectrum by a variety of chemical elements, with laboratory produced line spectra for the same elements, a line shift and so wavelength shift can be measured.

When a light source is moving away from the Earth, its wavelength becomes stretched. The increase in wavelength produces a red shift in the spectrum. In contrast, when a light source is moving toward the Earth, its wavelength becomes compressed. The decrease in the wavelength produces a blue shift in the spectrum.

Doppler Effect

The greater the velocity of the light source relative to the Earth, the greater is the amount of red or blue shift observed. For all electromagnetic radiation this Doppler effect is given by,

$$\frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$ when the velocity of the light source, v is much less than c

where Δf and $\Delta\lambda$ are the changes in frequency and wavelength, and f and λ are the frequency and wavelength of the emitted electromagnetic radiation.

For light which is red shifted, as the wavelength increases, its frequency must decrease.
For light which is blue shifted, as the wavelength decreases, its frequency must increase.

Example

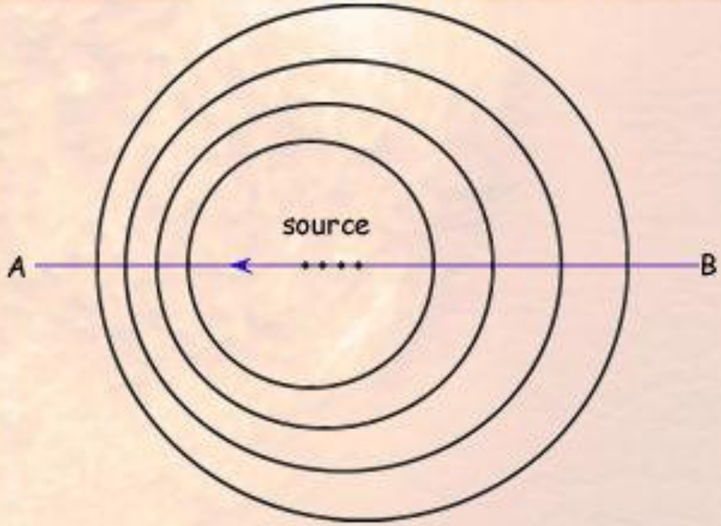
If the hydrogen absorption line in the spectra of a star is 6.6570×10^{-7} m, and the same element in a laboratory test is 6.5628×10^{-7} m then the velocity of the star can be found from the Doppler effect.

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c} = \frac{(6.5628 - 6.6570) \times 10^{-7}}{6.5628 \times 10^{-7}} = 0.01435$$

$v = -0.01435c$

$v = -4.3 \times 10^{6}\,\mathrm{ms^{-1}}$

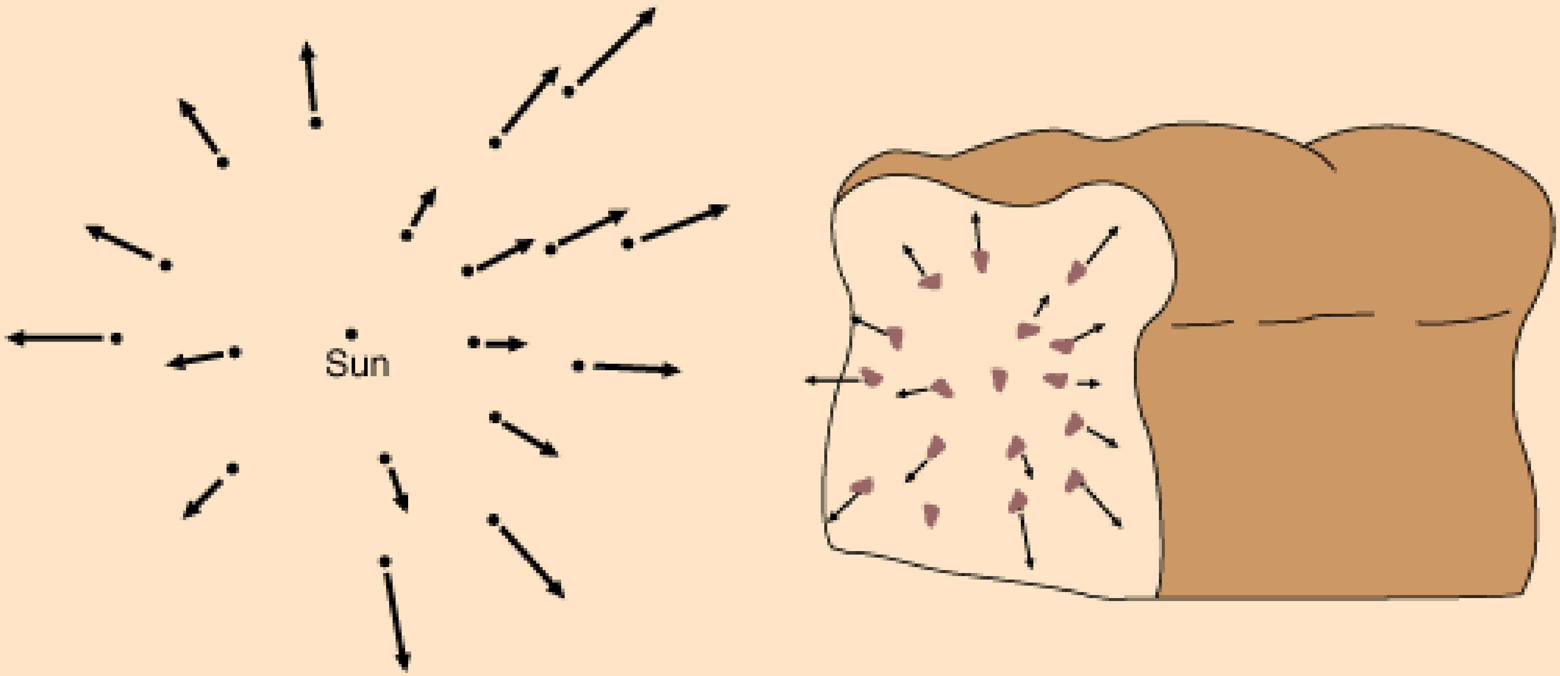
The wavelength in the star's spectra is longer (red shifted) so the star's radial speed must be away from the Earth.



If the light source of any electromagnetic radiation is moving toward point A, the wavelengths are compressed (blue shifted) whilst wavelengths from source to B are extended (red shifted).

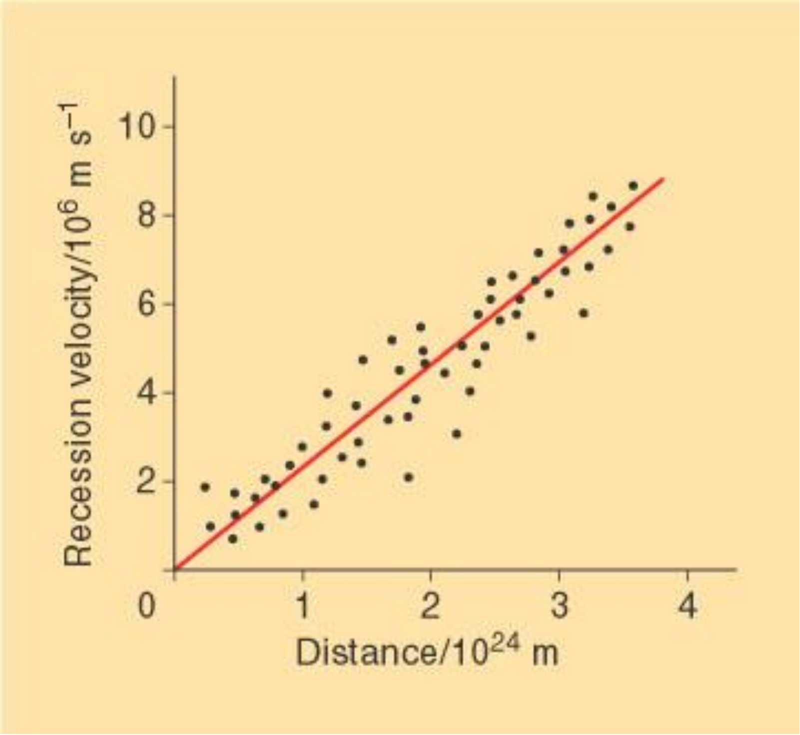
Expanding Universe

The galaxies we see in all directions are moving away from the Earth, as evidenced by their red shifts. Hubble's law describes this expansion.



The fact that we see all stars moving away from us does not imply that we are the center of the universe! All stars will see all other stars moving away from them in an expanding universe. A rising loaf of raisin bread is a good visual model: each raisin will see all other raisins moving away from it as the loaf expands.

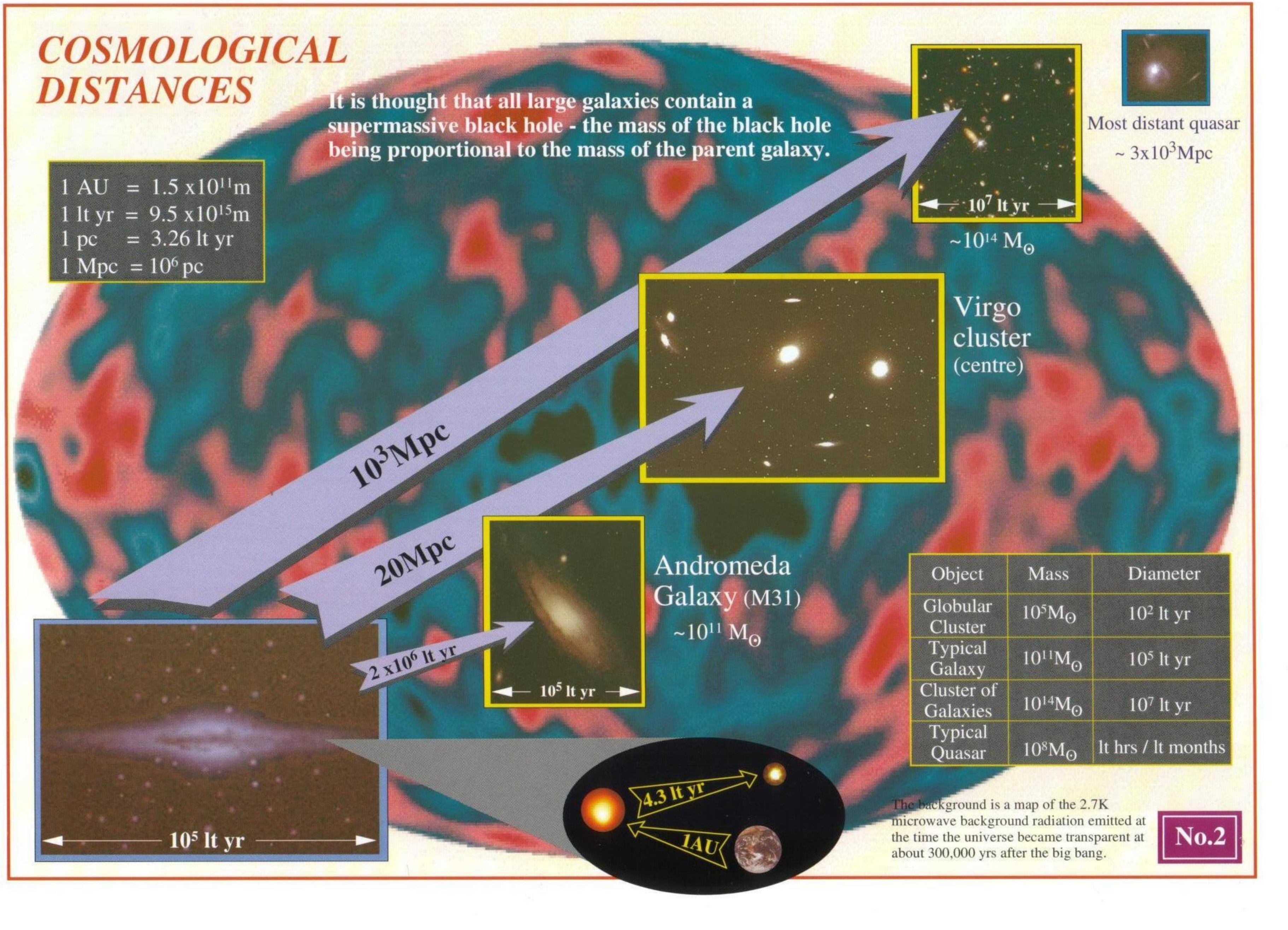
Hubbles Law



COSMOLOGICAL DISTANCES

It is thought that all large galaxies contain a supermassive black hole - the mass of the black hole being proportional to the mass of the parent galaxy.

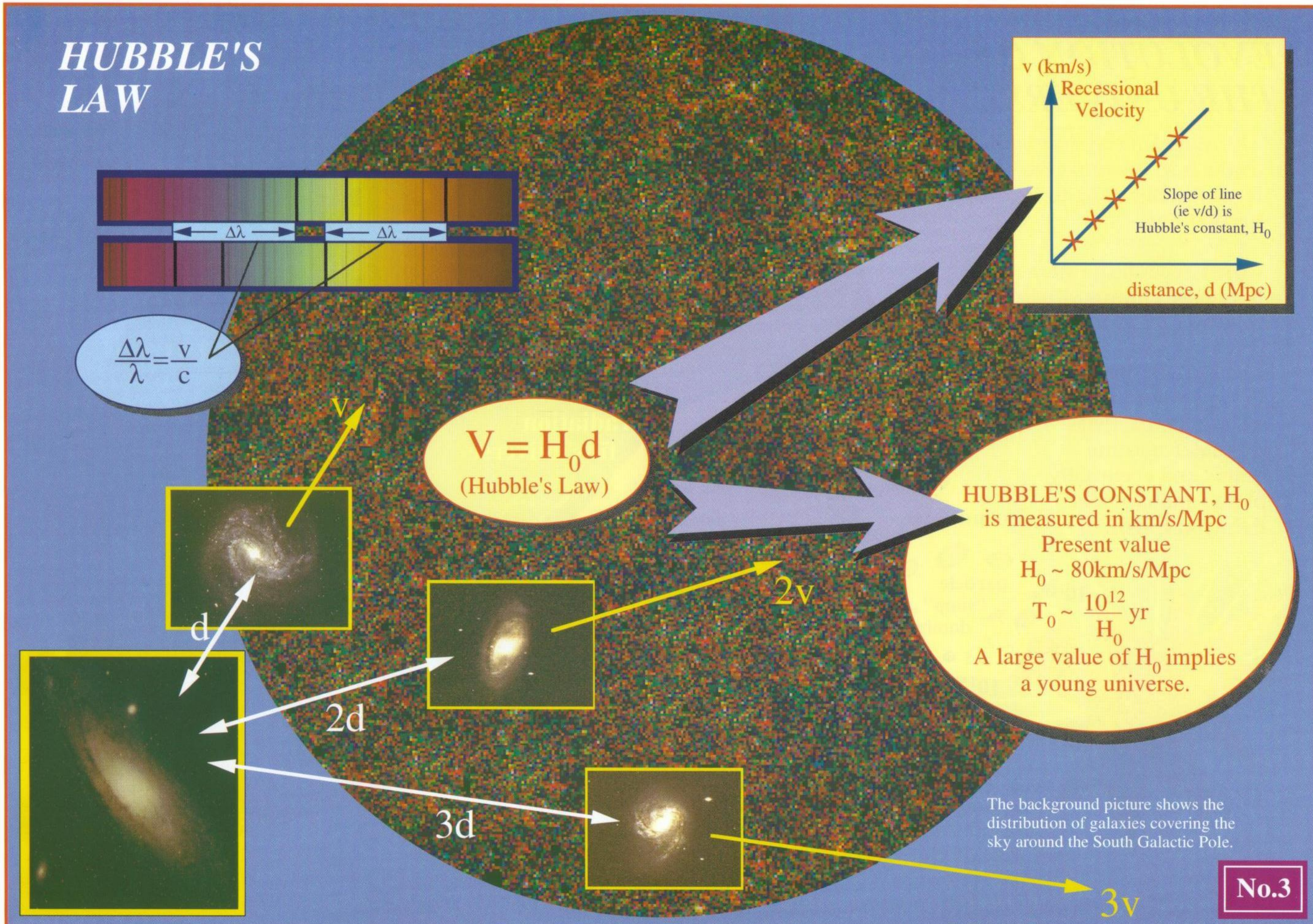
1 AU	= 1.5×10^{11} m
1 lt yr	= 9.5×10^{15} m
1 pc	= 3.26 lt yr
1 Mpc	= 10^{6} pc



Object	Mass	Diameter
Globular Cluster	$10^{5} M_{\odot}$	10^{2} lt yr
Typical Galaxy	$10^{11} M_{\odot}$	10^{5} lt yr
Cluster of Galaxies	$10^{14} M_{\odot}$	10^{7} lt yr
Typical Quasar	$10^{8} M_{\odot}$	lt hrs / lt months

The background is a map of the 2.7K microwave background radiation emitted at the time the universe became transparent at about 300,000 yrs after the big bang.

No.2


HUBBLE'S LAW
Δλ
Δλ
Δλ/λ = v/c
v
V = H₀d
(Hubble's Law)
v (km/s)
Recessional Velocity
Slope of line (ie v/d) is Hubble's constant, H₀
distance, d (Mpc)
HUBBLE'S CONSTANT, H₀
is measured in km/s/Mpc
Present value
H₀ ~ 80km/s/Mpc
T₀ ~ 10¹²/H₀ yr
A large value of H₀ implies a young universe.
2v
d
2d
3d
3v
The background picture shows the distribution of galaxies covering the sky around the South Galactic Pole.
No.3

Hubble's Law

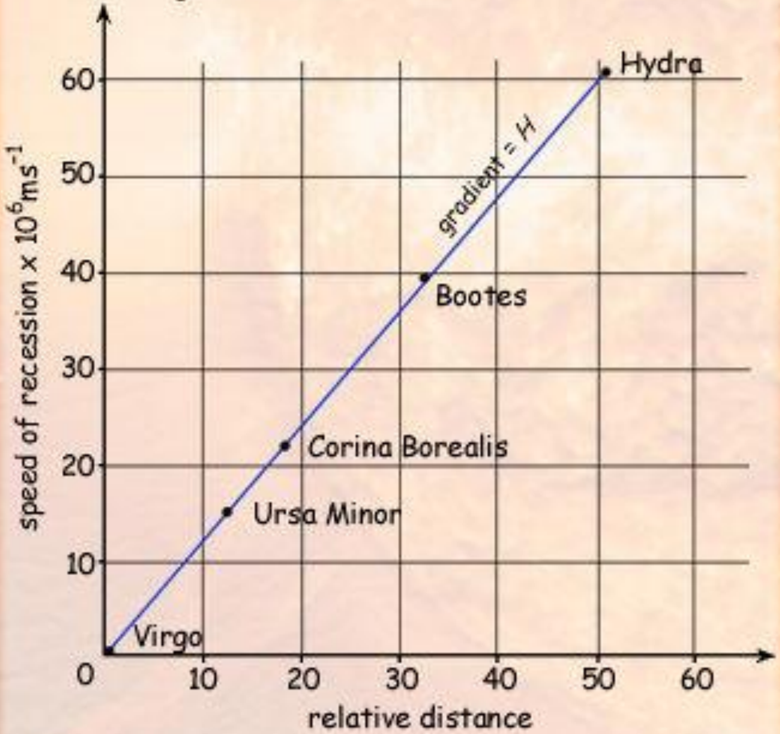
Galaxies are observed to have line spectra, that are red shifted. They are therefore considered to be receding from the Earth, and from each other. The only exceptions to this are the local galaxies, some of which have blue shifts. This is because of their rotational motion relative to each other which blurs any recessional motion.

Hubble's law states that the speed v, of a galaxy's recession is proportional to its distance, given by,

$v = Hd$ where H = Hubble's constant, and d = distance from Earth.

This means that the more distant a galaxy is, the greater is its recessional velocity and so the greater is its red shift.

The graph shows the increase in recessional speed with increased distance for the five brightest clusters in each of the galaxies named.



The constant H, probably lies in the range $50 - 100\,kms^{-1}Mpc^{-1}$

$$\text{time} = \frac{\text{distance}}{\text{velocity}} = \frac{d}{v} \text{ therefore, } t = \frac{1}{H}$$

As time began with the Big Bang when space began to expand, then the age of the universe is: $\frac{1}{H}$

This assumes that the Hubble constant H, has remained constant through time. For this to be true the universe would have had to expand at a constant rate. The actual rate may be slowing due to gravitational effects. If, however, a value of $50\,kms^{-1}Mpc^{-1}$ is taken, then that means a galaxy 1Mpc away is receding at $50kms^{-1}$.

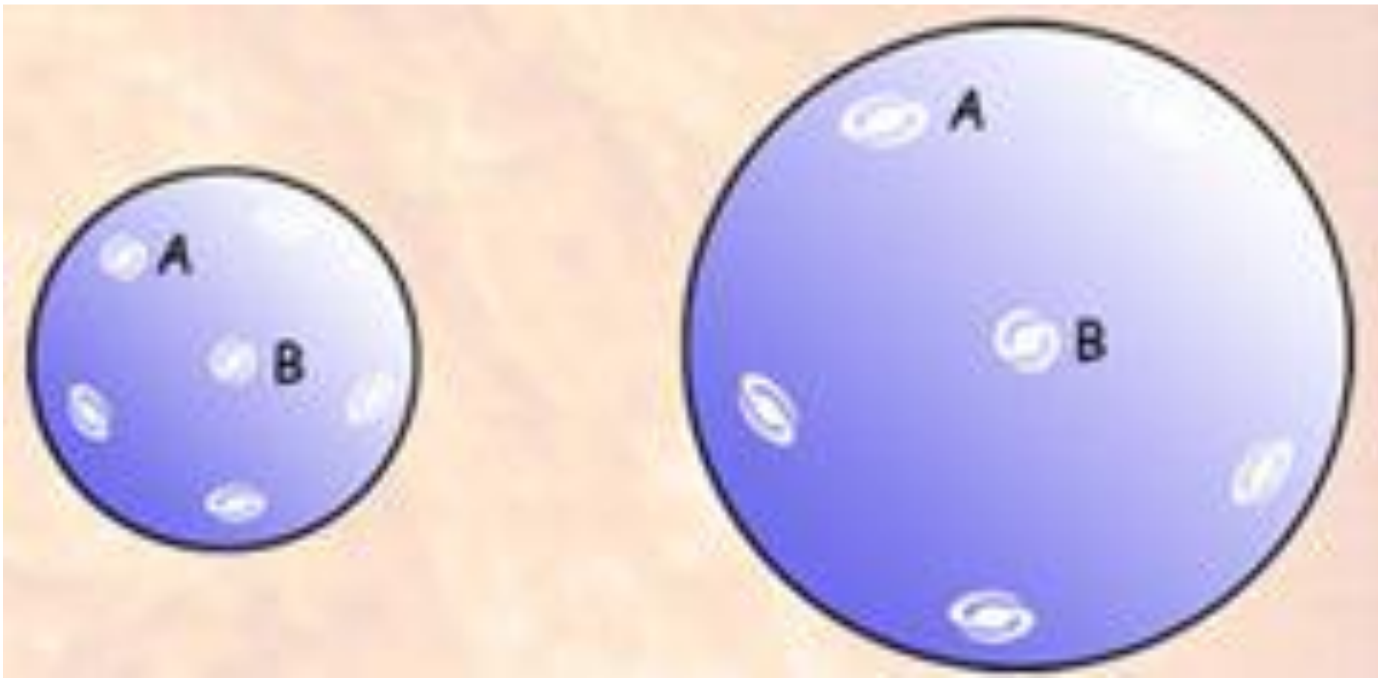
As $1pc = 3.086 \times 10^{16}m$, therefore $1Mpc = 3.086 \times 10^{22}m$

This means that a galaxy $3.086 \times 10^{22}m$ away is receding at $50\,kms^{-1}$. If this has always been the rate then recession has occurred for,

$$t = \frac{3.086 \times 10^{22}}{50 \times 10^{3}} = 6.0 \times 10^{17}s^{-1}$$ This is about 20 billion years.

The value of H which is often taken is $H = 75\,kms^{-1}Mpc^{-1}$. This gives an age for the universe of 15 billion years.

Big Bang

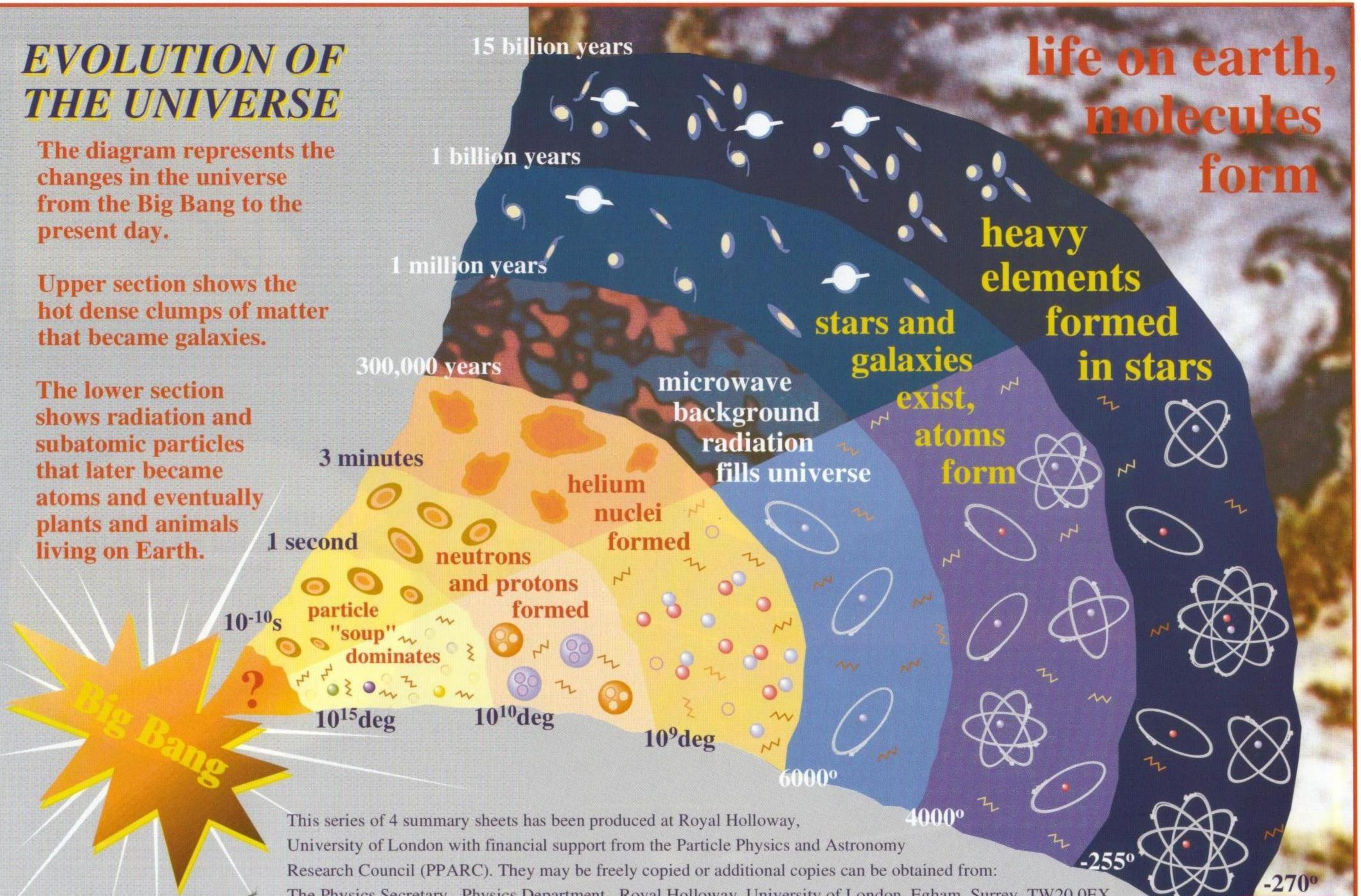


EVOLUTION OF THE UNIVERSE

The diagram represents the changes in the universe from the Big Bang to the present day.

Upper section shows the hot dense clumps of matter that became galaxies.

The lower section shows radiation and subatomic particles that later became atoms and eventually plants and animals living on Earth.



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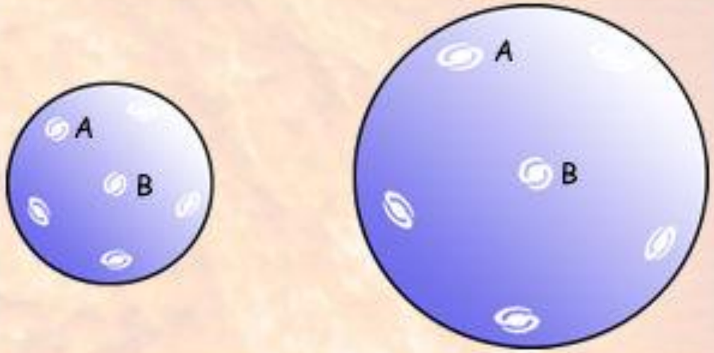
The Big Bang theory is an attempt to explain how the Universe came into existence, and what has happened to it since. According to the model if the Universe has been expanding for a time $t = \frac{1}{H}$, then it is this time ago when time and space must have started. Before this, space-time must have been infinitely curved. The Universe must have been incredibly small and had infinite density. Any event, which may have taken place before the Big Bang would be irrelevant to the physical laws we see in the Universe today.

If the value of H = 75 $kms^{-1}Mpc^{-1}$, then space and time began 15 billion years ago at what is called the Big Bang singularity.

The expansion of space can be thought of like the expansion of the surface of a blown up balloon. There is no limiting boundary, and no centralised point.



The Big Bang

Evidence for the Big Bang theory include the following predicted features which have all been verified by observation:

- Background microwave radiation. This is received from all directions and is believed to be surviving black body radiation following the Big Bang which has cooled to 2.7K
- The ratio of hydrogen to helium is 3:1
- The red shifts of galaxies and their speeds of recession are proportional to distance, with the most distant galaxies (quasars) having the largest red shifts and highest recessional speeds.

According to the Big Bang:

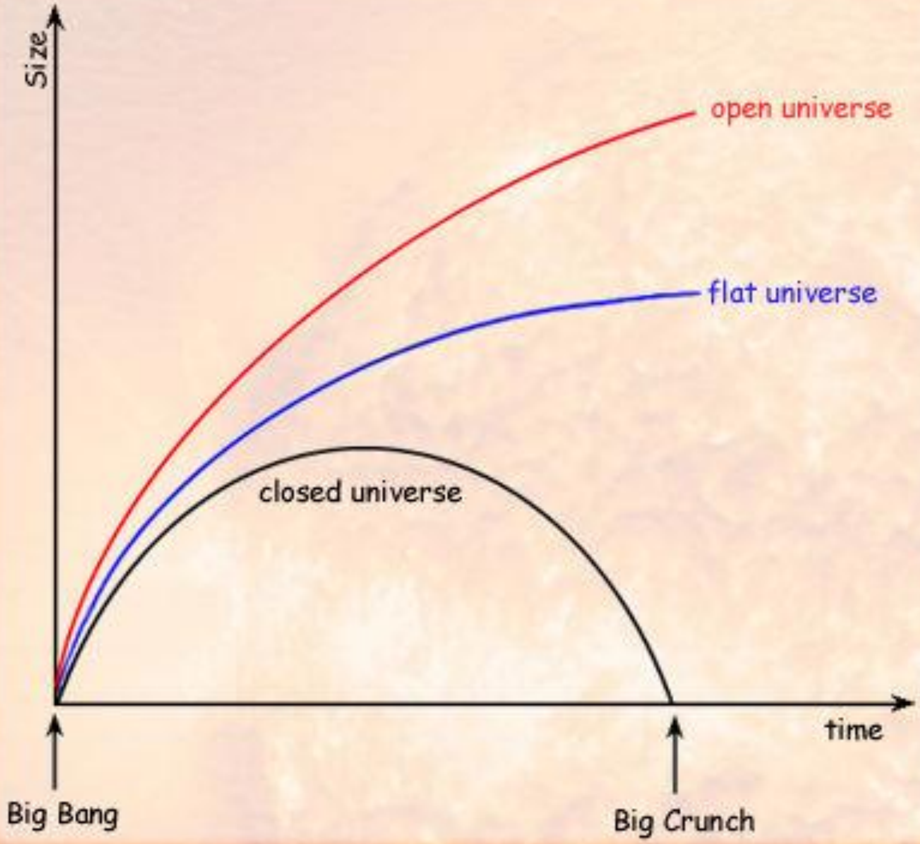
- Within the first millionth of a second fundamental particles formed. The universe inflated rapidly, and nuclear protons and neutrons formed from quarks. The temperature began to fall to $\approx 10^{13}$K
- Within a hundredth of a second matter-antimatter nucleon collisions had annihilated virtually all the less abundant antimatter nucleons
- Within a few seconds electron-positron collisions had annihilated most positrons
- Within a minute or two helium nuclei formed as some protons and neutrons joined as the temperature fell to $\approx 10^{9}$K.

At this point the universe would have been very small, very dense and not too dissimilar to the plasma state conditions found in the core of a star.

- Over the next few hundred thousand years the temperature fell to 3000K allowing atoms to form as electrons combined with nuclei. This allowed photons of em radiation to travel unhindered. (Background radiation detected today is thought to be the cooled remnants of this early photon energy). Stars and galaxies started to form under gravitational attraction.

Rate of expansion?
Open or closed

Fate of the Universe



At present the ultimate fate of the universe is not known. There are three possible outcomes, but which one actually takes place depends on how the average density ρ of the universe compares with the critical density ρ_c.

The universe may be open, that is, it will continue to expand forever. This will occur if the average density of matter in the universe is less than the critical density ($\rho < \rho_c$).

The universe may be flat, that is, the rate of expansion slows until the universe reaches a point where no more expansion takes place. This will occur if the average density of matter in the universe is equal to the critical density ($\rho = \rho_c$).

The Universe may be closed, that is, it will reach a maximum expansion and then contract under the influence of gravity. This will occur if the average density of matter in the universe is greater than the critical density ($\rho > \rho_c$).

As the Hubble constant H, is not known exactly, the value for the critical density is not known. From estimates made from visible matter, that is, matter that emits electromagnetic radiation, the average density of matter is well below the critical density. On this evidence the universe is likely to continue to expand as an open universe.

From the theory of relativity the relationship between critical density and the Hubble constant is given by, $\rho_c = \frac{3H^2}{8\pi G}$ A higher calculated value for the Hubble constant will increase the value for the critical density, and so make an open universe more likely.

The actual amount of matter in the universe may, however, be much higher than the value found from visible matter. There may be a huge amount of dark matter not seen. Neutrinos may have a finite mass and be sufficiently abundant to allow the average density to equal or even surpass the critical density. The universe therefore could at some time in the future begin to contract. This would eventually lead to a Big Crunch.

EXPANSION

In a thousandth of the time it takes to blink an eye the universe expanded to the size of a grapefruit.
This expansion is equivalent to a molecule expanding to the size of a galaxy in the same time period.

New evidence suggests that the rate of expansion is **increasing**.
(This suggests a type of antigravity pushing things apart)

Dark Matter?
Neutrinos?
String theory?
M Theory?
Quantum Gravity?
Consciousness?