PHAS 1511: Foundations of Astronomy

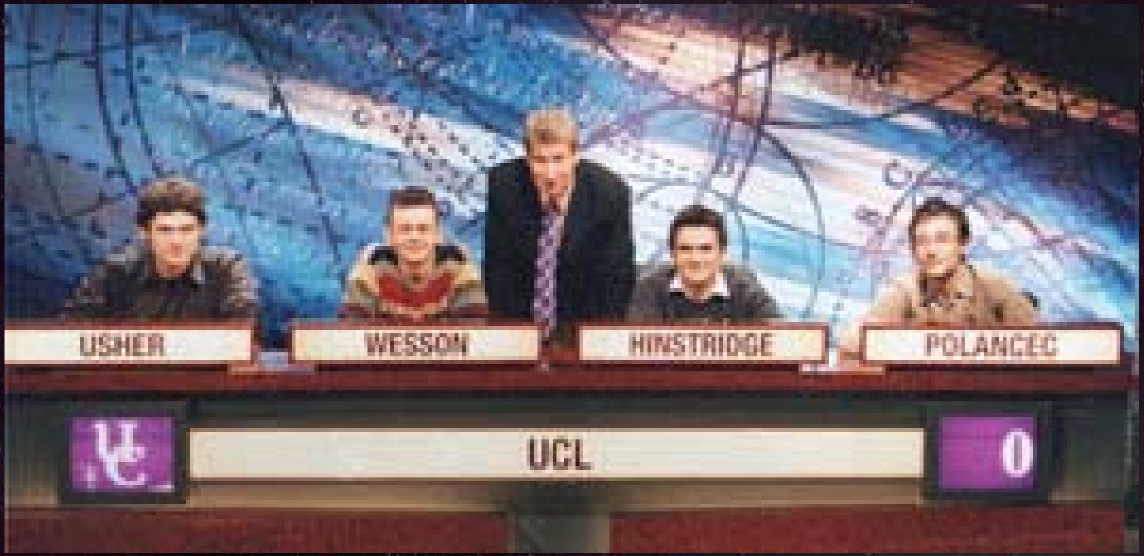
Dr Roger Wesson

Research interests: deaths of stars. Planetary nebulae, novae and supernovae.

Not as famous as previous lecturer, but....

PHAS 1511: Foundations of Astronomy

... still a tiny bit famous :)



PHAS 1511: Foundations of Astronomy

Dr Roger Wesson

http://www.star.ucl.ac.uk/~rwesson/PHAS1511.html

I will put each week's lecture notes on this page shortly after the lecture

PHAS 1511: Foundations of Astronomy

Course text book: Universe (Freedman and Kaufmann), eighth edition

Available from Waterstones – approx £38

Also from Amazon - £38 new or cheaper second hand

This course will cover Part I – chapters 1 to 6

Course overview

We will learn about:

- The contents of the universe: planets, stars, galaxies and clusters
- How we study the universe: particles, radiation, telescopes and detectors
- Some history of how today's understanding of the universe has developed

Useful resources

My web page will become one:

http://www.star.ucl.ac.uk/~rwesson/PHAS1511.html

The *Universe* web page has many useful things:

http://bcs.whfreeman.com/universe8e

Astronomy Picture of the Day is great:

http://www.star.ucl.ac.uk/~apod

This lecture

We will cover:

- How astronomy works – the scientific method.
- Angles and measurements used in astronomy
- A convenient way to write large numbers
- Then a broad overview of:
  - The Solar System
  - The Galaxy
  - Extragalactic astronomy

Astronomy: basics

Astronomy (Greek: *astron* + nomos = star law) is the oldest science. Ancient civilisations produced star charts and mapped the paths of the planets through the sky.

Early astronomy was all about measuring positions. Today, this is known as **astrometry** (*astron* + *metria* = measuring the stars).

Astrometry is crucial – before we can study the stars, we need to be able to find them.

Astronomy: the scientific method

Astronomy and astrology: an unfortunate similarity...

Astronomy is a science: astrology is not. They both spring from a desire to understand our place in the universe, but the distinguishing factor is the methods.

Science proceeds by *testing hypotheses*: developing theories which make predictions. If the predictions are validated by observation, then the theory is OK... for now. If they are not, then it's back to the drawing board.

Astrology makes no testable predictions... or if it does, it ignores the observations which disprove them!

Astronomy: the scientific method

Observations drive theory. Even the most elegant and wonderful theory can be disproved by one contradictory observation.

BUT! Sometimes observations are wrong!

Famous example: in 1910, the universe was thought to be static. Einstein's theory of relativity predicted that this was impossible, so he invented a repulsive force to balance the force of gravity. Soon after, Edwin Hubble showed that all galaxies outside the Local Group were receding. Einstein described it as his 'greatest blunder'

Astronomy: the scientific method

To make sense of the universe, we have to assume that it can be described by fundamental laws, and that these laws are the same everywhere and at all times.

For example, the speed of light is 300,000 km/s, and we assume that this is a constant.

Astronomy: angles

The sky appears to us like a sphere: everything is so far away that there is no perspective.

So, positions in astronomy are measured with *angles*. A circle is divided into 360 degrees, so from the horizon to directly overhead (the *zenith*) is 90 degrees.

The 'pointers' in the Plough are about 5 degrees apart

Astronomy: angles

Astronomy: angles

Degrees are subdivided: 1/60 of a degree is an arcminute, and 1/60 of an arcminute is an arcsecond.

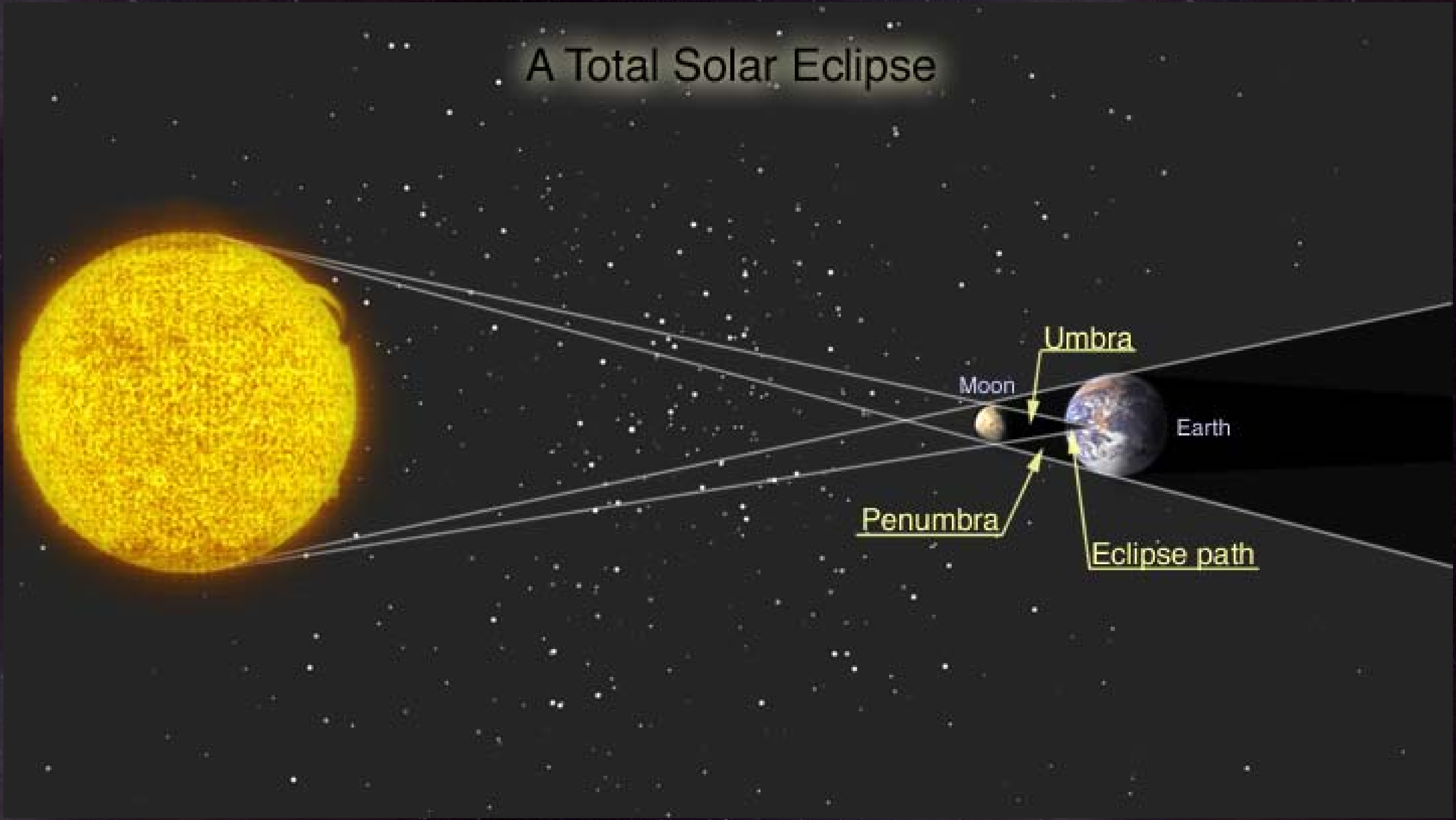
A two-pound coin at a distance of three and a half miles would have an angular diameter of one arcsecond.

The Moon and the Sun are both about 30 arcminutes across.

The human eye can resolve things as small as an arc-minute across.

The Hubble Space Telescope can resolve things as small as 0.05 arcseconds across – much better!

Astronomy: angles



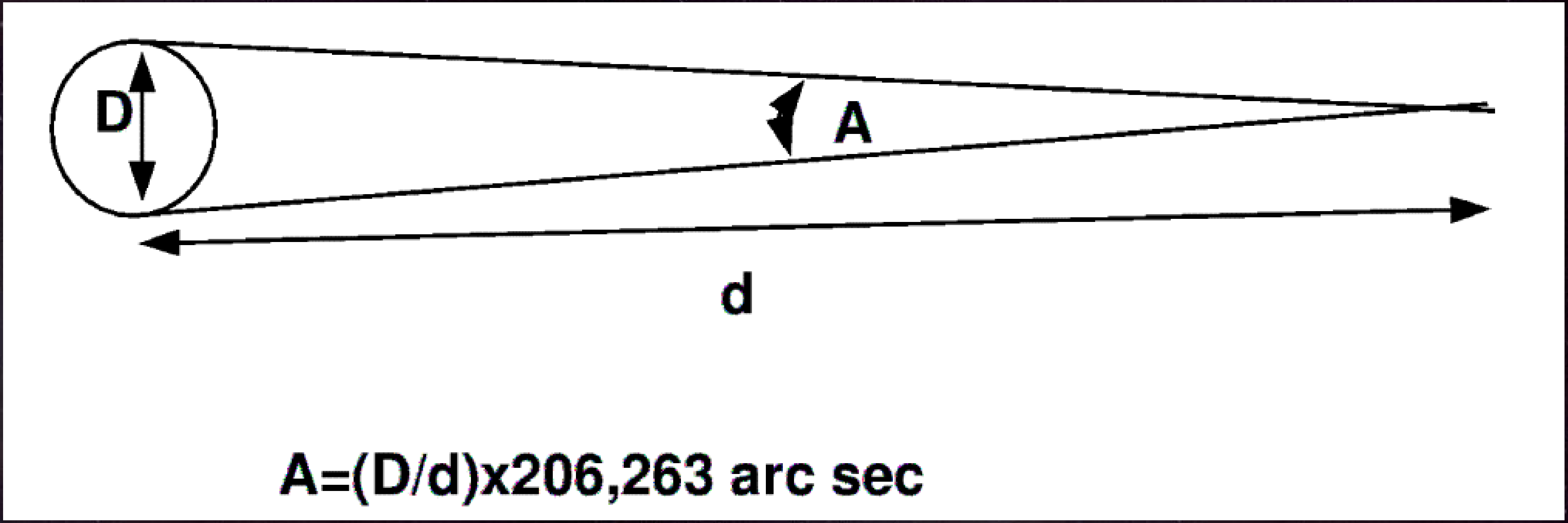
Astronomy: angles

Astronomy: angles

Astronomy: angles

Relating angles and distances: if we know the actual size of an object, and its angular size, we can work out its distance.

Or, if we know its distance, and its angular size, we can work out its actual size:

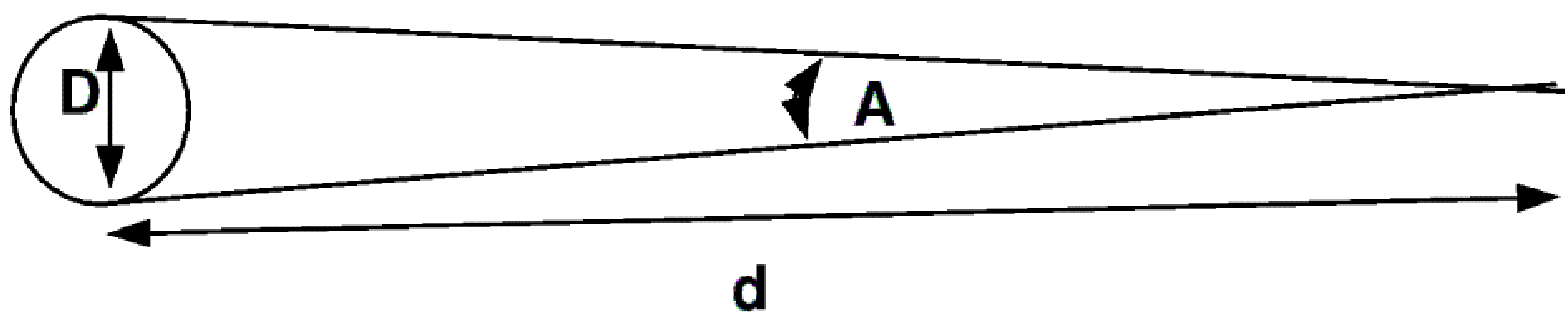


Astronomy: angles

Example: the Sun is half a degree (=1800 arcseconds) across.

Its distance is 1 Astronomical Unit (150,000,000km)

So, its diameter is 1,300,000km



A=(D/d)x206,263 arc sec

Astronomy: distances

A warning: sensible scientists would use the SI (*Systeme Internationale*) system of units – metres, seconds, kilogrammes. Astronomers are not sensible scientists!

There are many distance units in common use. Here are some:

The average distance from the Earth to the Sun is called an *Astronomical Unit* or *AU.* There are about 150,000,000km in an AU

The distance that light travels in a year is called a light year. There are 9,460,000,000,000 kilometres in a light year. The nearest star is almost four light years away.

Astronomy: distances

Light-seconds, light-minutes, light-hours and other light-distances are also sometimes used:

The Moon is 1.25 light-seconds away from Earth

The Sun is 8 light-minutes away

The *Voyager* probe, launched in 1977, is about 14 light hours away

Astronomy: distances

Another very common unit of distance is the *Parsec*. We learned about arcseconds: just as a two pound coin at a distance of 3.5 miles would appear an arcsecond across, something an *Astronomical Unit* across, at a distance of a parsec, would appear an arcsecond across.

One parsec = 3.26 light years, or 206,264 astronomical units.

Astronomical Units are very convenient in the Solar System. Light years and parsecs are convenient in the galaxy and beyond.

Astronomy: distances

Very large distances can be expressed with prefixes. You are probably familiar with these:

1 kiloparsec = 1000 parsecs

1 megaparsec = 1,000,000 parsecs

Astronomy: mass and luminosity

Masses in the solar system are often expressed in terms of the mass of the Earth, Jupiter or the Sun.

Earth and the Sun have their own special symbol:

$1M_{\oplus} = 0.003M_J = 0.000003M_{\odot} = 5.97\text{x}10^{24}$ kg

$318M_{\oplus} = 1M_J = 9.5\text{x}10^{-4}M_{\odot} = 1.89\text{x}10^{27}$ kg

$333000M_{\oplus} = 1060M_J = 1M_{\odot} = 5.97\text{x}10^{24}$ kg

Astronomy: mass and luminosity

The luminosity of stars is often described in units of the Solar Luminosity: the amount of energy emitted by the Sun every second.

$1\ L_{\odot} = 3.84 \times 10^{26}$ W

The size of stars is often described in units of the Solar Radius:

$1\ R_{\odot} = 696{,}000$ km

Astronomy: unit conversion

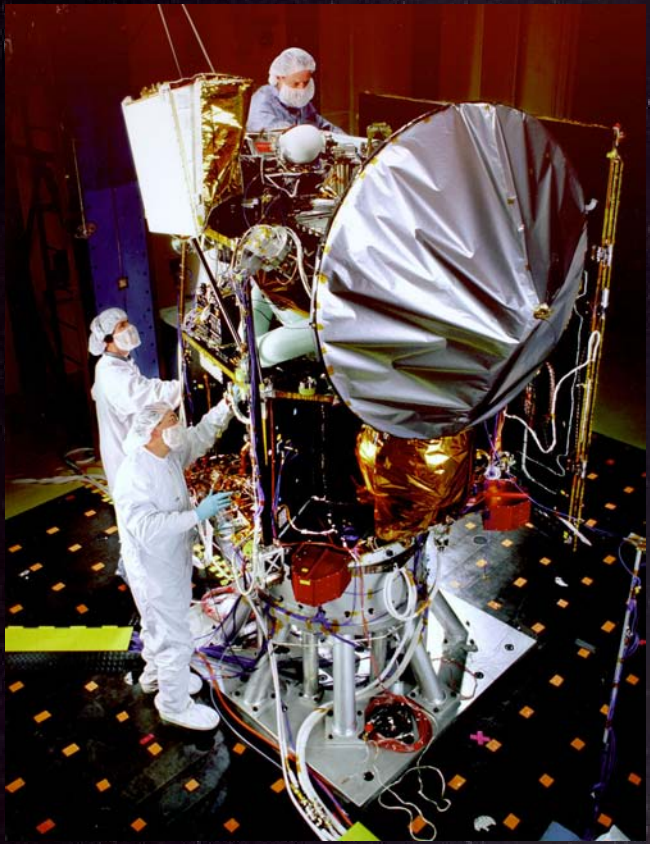
Converting between different units is a crucial skill in astronomy

Google is very handy – type 'one AU in furlongs' and it will tell you

(astronomers use many strange units, but luckily the furlong is not actually one of them)

Astronomy: unit conversion – a cautionary tale

Mars Climate Orbiter was launched in 1998. Due to a unit conversion error, the rockets which should have slowed it down on arrival at Mars did not fire with enough force, and it burned up in the Martian atmosphere



Astronomy: some maths

You can see that distances in astronomy are huge. If we wanted to use centimetres to measure vast things, writing out so many zeroes would be inconvenient.

So we use a shorthand notation.

$10^3 = 10 \times 10 \times 10$

$10^5 = 10 \times 10 \times 10 \times 10 \times 10$

$= 10^2 \times 10^3$

$10^{-1} = 1/10$

$10^{-3} = 1/(10 \times 10 \times 10)$

$10^0 = 1$

Astronomy: some maths

Generally:

$$10^{x+y} = 10^x \times 10^y$$

$$10^{x-y} = 10^x / 10^y$$

Large numbers are commonly written in the form

$$1.5 \times 10^8$$

This is the number of kilometres in an Astronomical Unit. It could also be written 15×10^7 or 0.15×10^8. It is like describing 1000 as ten hundreds, or a hundred tens – it's the same number.

Astronomy: some maths

Sometimes, a number like 1.5×10^8 (the number of kilometres in an AU) is written 1.5e8 or 1.5E8.

Watch out for this! They are easily confused but 1.5e8 and 1.5^8 are very different numbers!

The Solar System

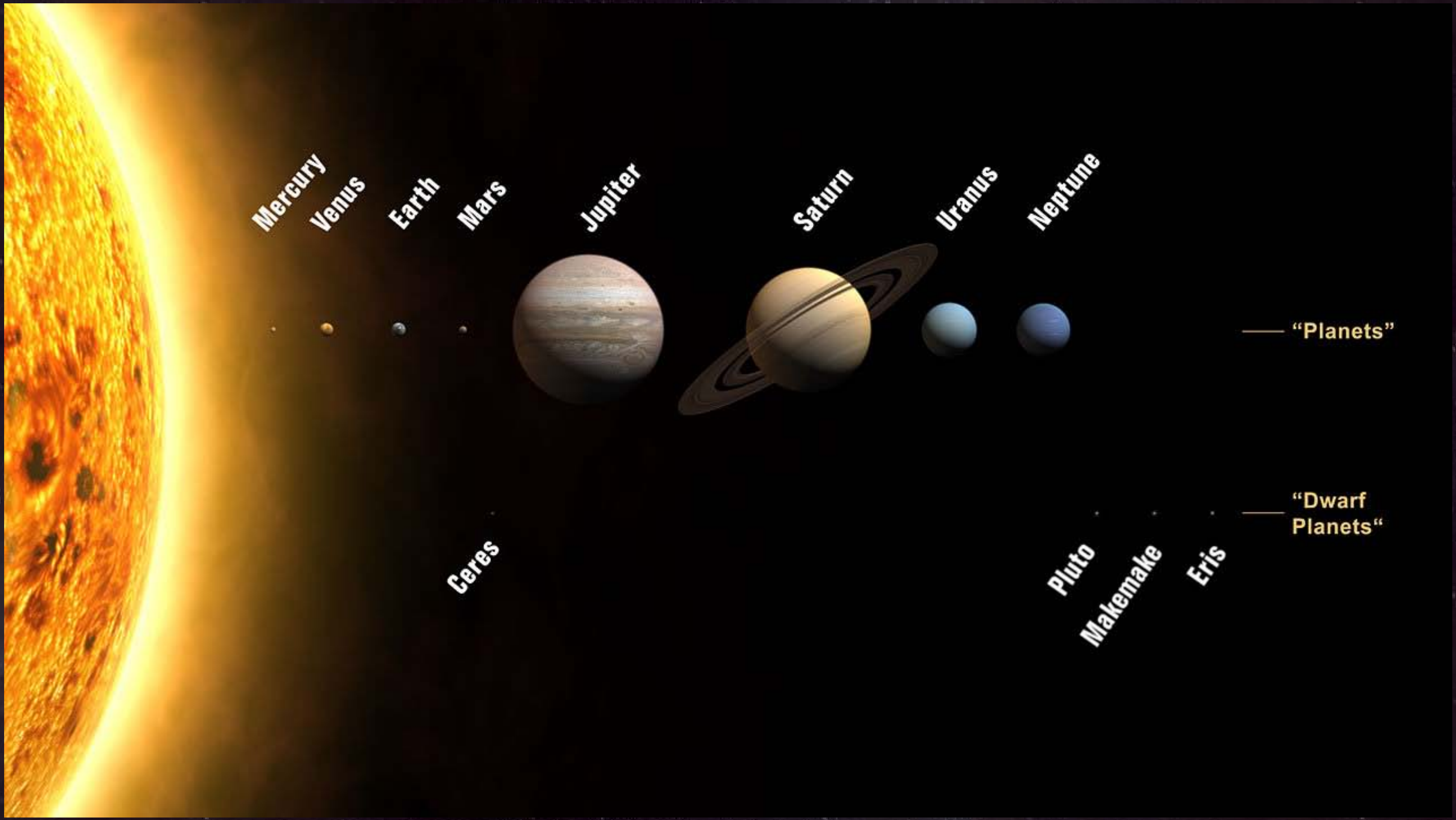
So, with some basics under our belt, now for some actual astronomy!

Astronomy can be roughly divided into three parts: solar system, galactic, and extra-galactic astronomy.

Solar system astronomy starts about 50 miles above the surface of the Earth – an arbitrary dividing line between Earth and 'space'.

The Solar System

The Solar System is the name given to the array of planets, moons asteroids, comets and dust which orbit the Sun (Latin: *Sol*).



The Sun

The Sun contains 99.8% of all the mass in the Solar System.

It is a star, just like all the stars we see in the night sky, but much, much closer.

It is not an unusual star – slightly heavier than average but generally very nondescript.

If it was thirty light years away, it would certainly be invisible to an observer in London.

The Solar System

All the planets have been visited by space craft. They are an extremely diverse bunch, but are broadly divided into two groups:

1. the 'Terrestrial planets' – relatively small, rocky, solid bodies, orbiting within 2 Astronomical Units of the Sun.

2. the 'Gas Giants' or 'Jovian planets' – much larger, gaseous bodies, orbiting beyond 5AU

All the planets orbit the Sun on slightly elliptical but almost circular orbits

The Solar System: Earth & Moon

Earth: the only planet with liquid water. Very active – surface is constantly changed by volcanoes, earthquakes and erosion.

The Solar System: Earth & Moon

Moon: incredibly different. Very old surface, no atmosphere, no water. Surface is covered in craters, formed by the impact of small rocky bodies throughout its history.

The Solar System: Terrestrial planets

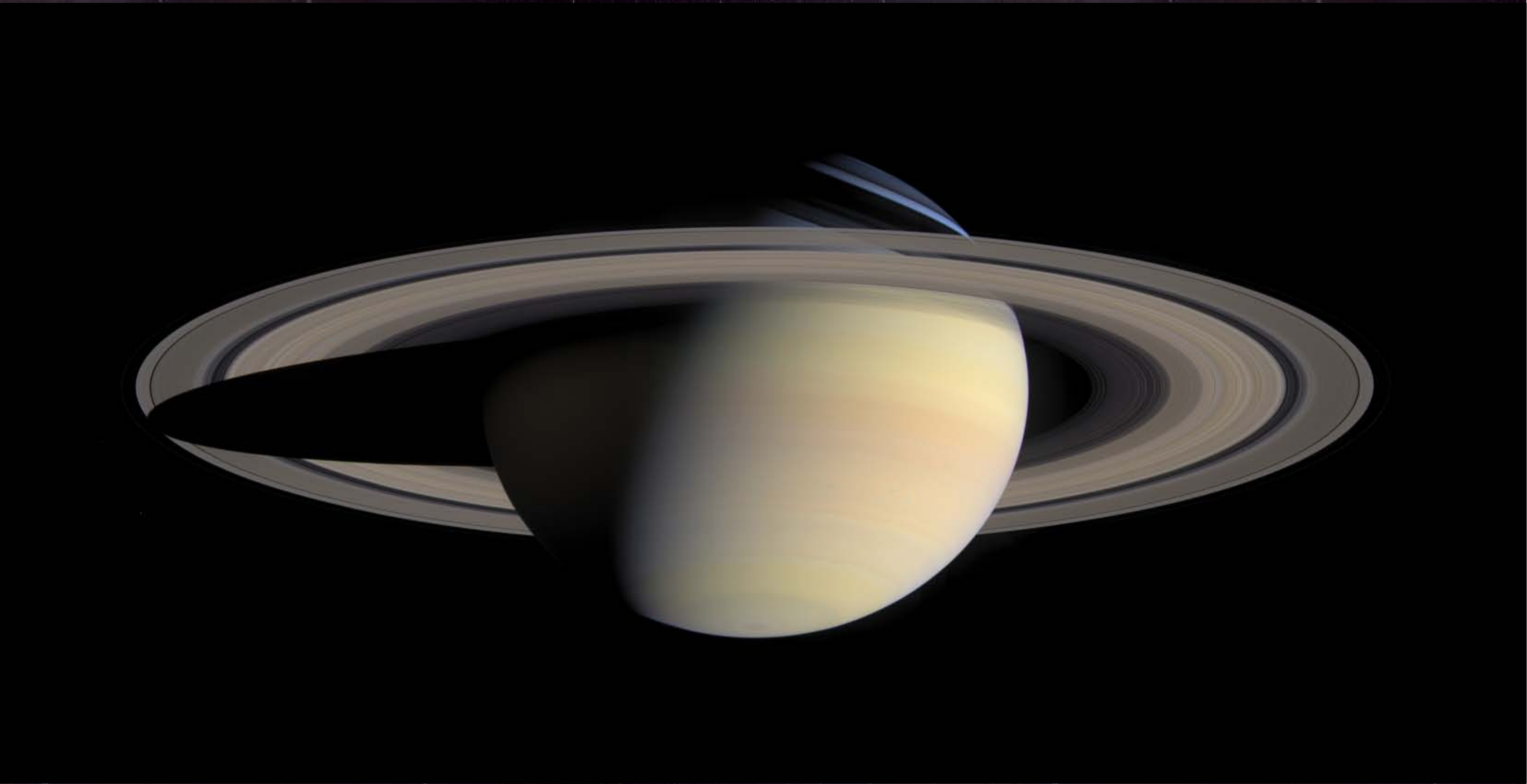
Mercury is the innermost planet. It looks very similar to the Moon. Its surface is old, it has no atmosphere and no oceans.

Venus is next. We cannot see its surface from Earth – the planet is covered by thick clouds of sulphuric acid, concealing a carbon dioxide atmosphere at tremendous temperatures and pressures

Outside Earth's orbit is Mars. Mars has a thin atmosphere, almost certainly once had running water, maybe even oceans. Life probably once existed on Mars, and some believe it still does

The Solar System: Gas Giants

Jupiter, Saturn, Uranus and Neptune are all far larger than Earth.
They also all have ring systems, but only Saturn's is easily visible:



The Solar System: Smaller bodies

There are now considered to be four 'dwarf planets': since Pluto was demoted, it is one of these. The others are Ceres, the largest object in the asteroid belt, Eris in the distant outer solar system which is larger than Pluto, and two other large bodies.

Asteroids are smaller than dwarf planets, and orbit primarily in two groups – the Main Belt between the orbits of Mars and Jupiter, and the Kuiper Belt, beyond the orbit of Neptune.

Comets are smaller than asteroids, and orbit the Sun in very eccentric orbits. Bright ones appear about once a decade and can be spectacular sights.

The Solar System: Comet Hale-Bopp

The edge of the Solar System

The Sun emits a constant stream of energetic particles called the Solar Wind.

When the Solar Wind strikes Earth's upper atmosphere, the *northern/sourthern lights* or *aurora borealis/australis* result.

Aurorae are also seen on all the other planets except Mercury.

The edge of the Solar System

The edge of the Solar System

Far beyond Pluto, the solar wind eventually becomes indistinguishable from the gas that lies in interstellar space: the *Interstellar Medium (ISM)*.

Beyond this point, we are no longer in the solar system.

The *Voyager* space probes are thought to be reaching the very edge of the solar system now, three decades after they were launched.

The Milky Way

The Milky Way

Beyond the Solar System, we get into the realm of galactic astronomy. Our galaxy, the Milky Way, appears to us as a faint band of diffuse light stretching across the sky (if there are no street lights around....)

It is paradoxically difficult to work out its structure, because we are inside it. Dust obscures much or most of it from our view.

First person to describe its structure accurately was Thomas Wright of County Durham (but Immanuel Kant often gets the credit)

The Milky Way

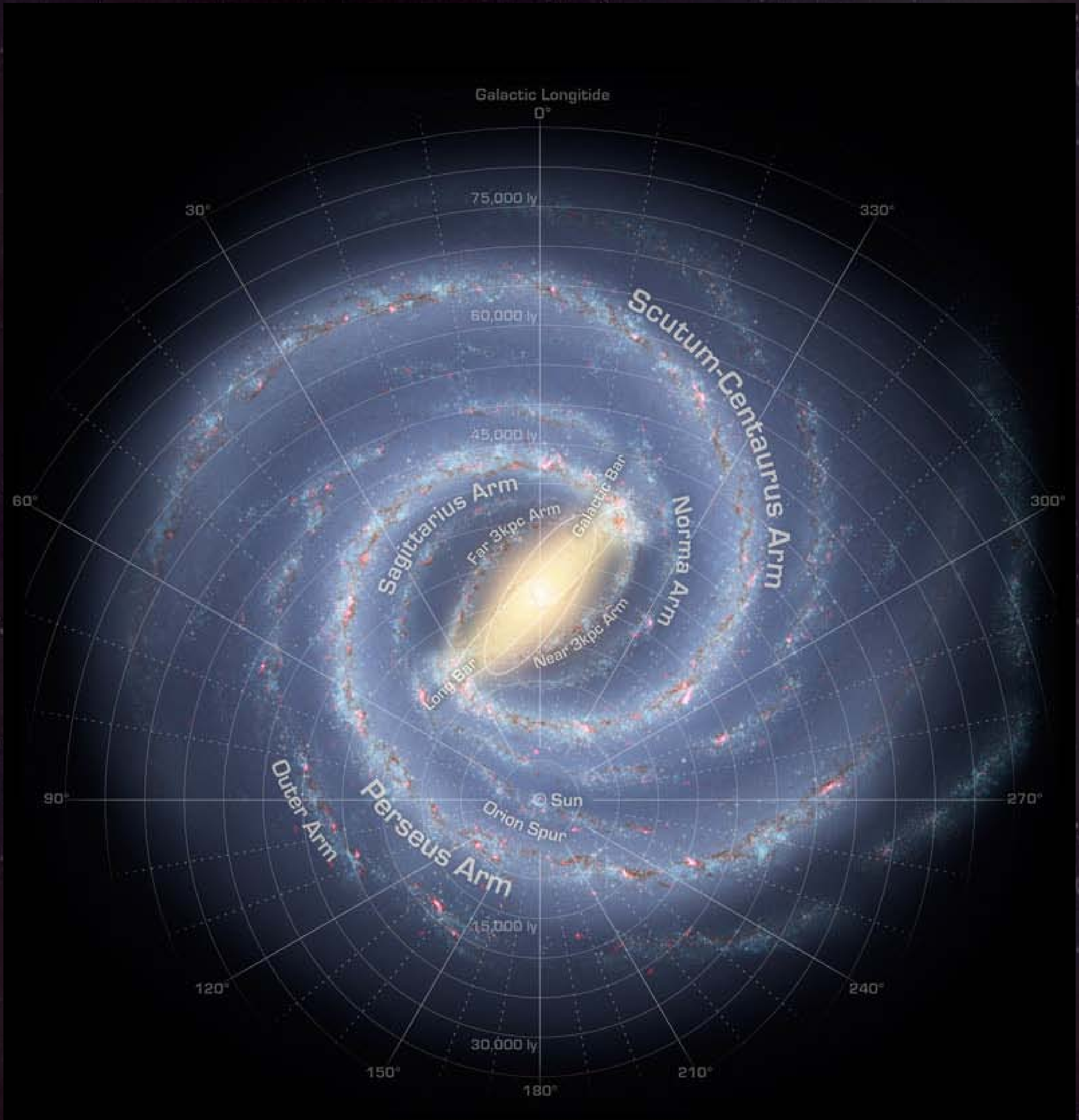
The Milky Way

The Milky Way is a *spiral galaxy*. It consists of a central bulge, with several arms of stars and gas winding outwards from it.

It is about 100,000 light years across.

We are about two thirds of the way out from the centre to the edge.

The Milky Way



The Milky Way

There are about 200 billion stars in the galaxy ($2x10^{11}$). As well as stars, there are also *nebulae*, which appear diffuse.

Some of these are *star clusters*, and with a telescope you can see the individual stars which comprise them

Others are not stars but clouds of gas. These are where stars form.

Most famous example: the Orion Nebula.

The Milky Way

The Milky Way

Stars form when huge clouds of gas begin to collapse under the force of gravity. The gas cloud fragments as it collapses, eventually resulting in the birth of hundreds or thousands of stars.

The Milky Way

Over millions of years, star clusters tend to disperse gradually.

Stars range in mass from about a tenth of a Solar Mass, up to ~100 solar masses. The lightest stars live for hundreds of billions of years, the heaviest for a few million.

Stars shine because of *nuclear fusion* occurring in their cores. At the huge temperatures and densities, hydrogen atoms colliding can fuse to form helium.

The greater the temperature and density, the faster the fusion proceeds.

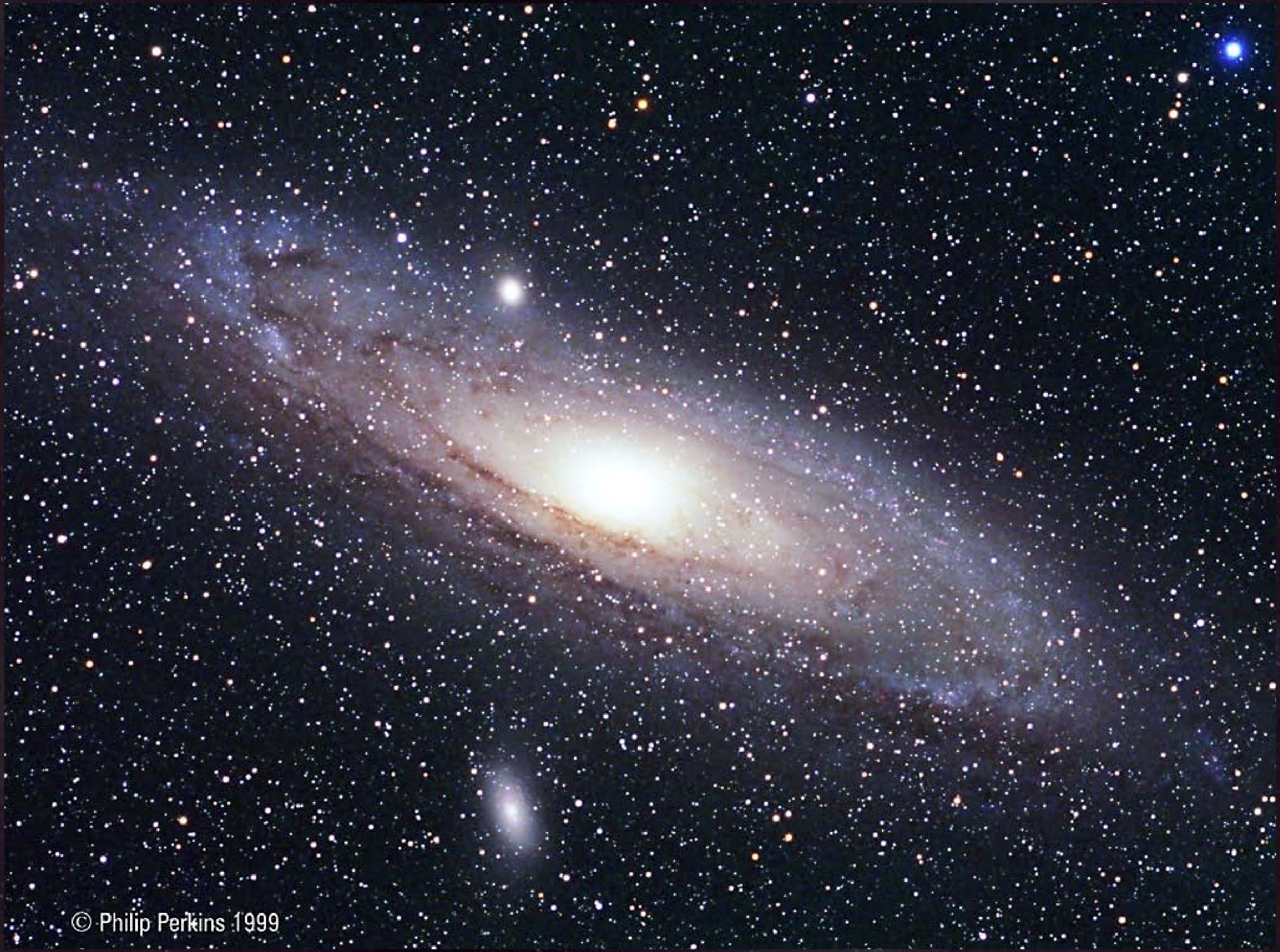
Beyond the Milky Way

Our galaxy belongs to the Local Group – a collection of about thirty galaxies at distances of up to about ten million light years.

There are three large spiral galaxies in it: the Milky Way, Andromeda and Triangulum. Andromeda is the largest of the three.

The rest of the galaxies are dwarf galaxies.

Beyond the Milky Way



Beyond the Milky Way

Beyond the Milky Way

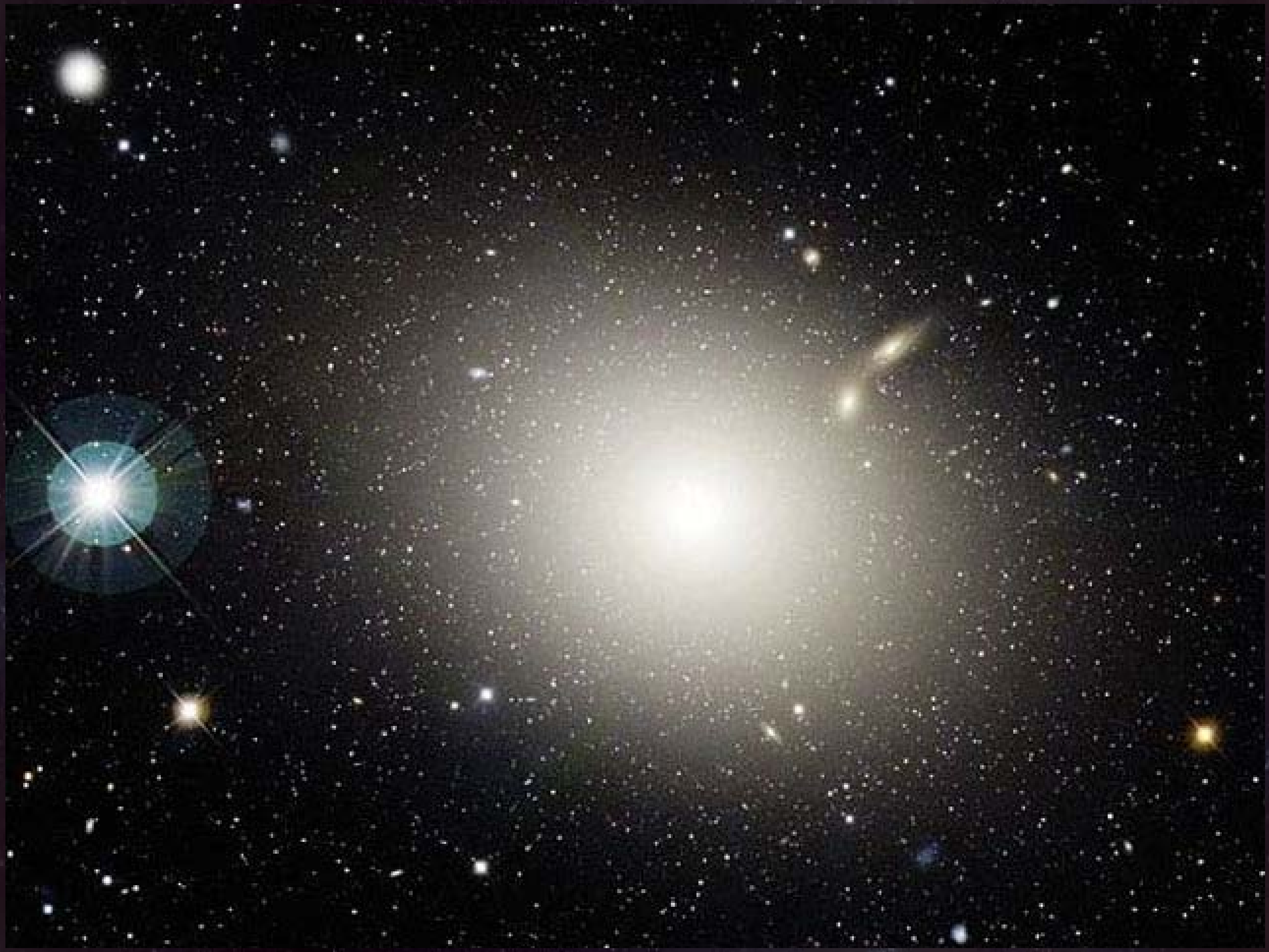
Types of galaxies

The three large galaxies in the local group are *spiral galaxies*.

Spiral galaxies are either *barred* or *non-barred*

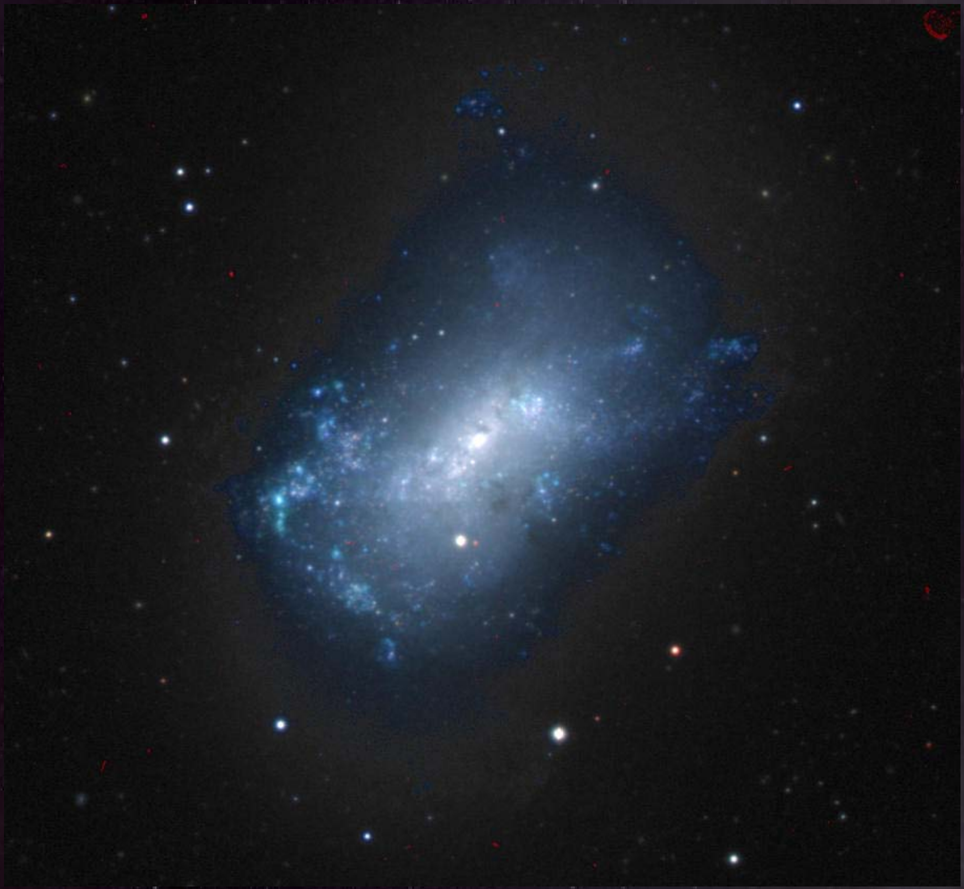
Types of galaxies

Many of the smaller galaxies are *elliptical galaxies*. Ellipticals can be very large as well.



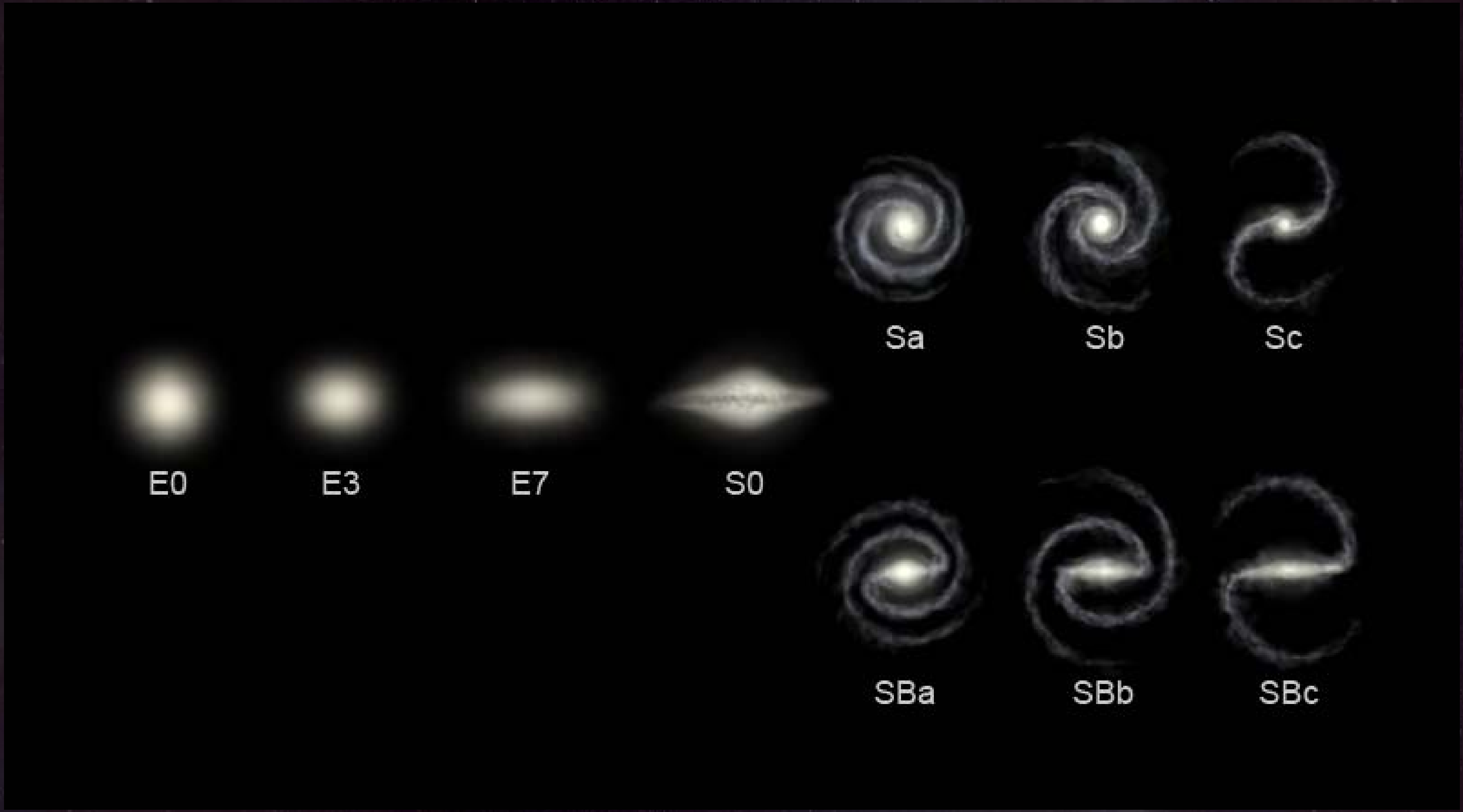
Types of galaxies

Most small galaxies are *irregular* – they have no definable shape.



The 'Tuning fork' diagram

Edwin Hubble presented galaxies on this sort of diagram:



The 'Tuning fork' diagram

Hubble thought that this represented an evolutionary sequence. He referred to elliptical galaxies as 'early-type', and spirals as 'late-type'.

This terminology is occasionally still encountered. Something to watch out for in astronomy – outdated terminology!

In fact, ellipticals contain the oldest stars. Spirals are much younger

Galaxy types

Elliptical galaxies are made of old, yellow stars. No new star formation is occurring, and no star-forming nebulae are seen.

Spiral galaxies and irregular galaxies are sites of active star formation, sometimes extremely vigorous. Nebulae are common.

Ellipticals do not 'evolve' into spirals.

The opposite can happen though...

Galaxy collisions

A typical star is about 500,000km across, but the typical distance between stars is about 3 light years – 50 million times larger.

Stars are following broadly circular orbits around the galaxy, all in the same direction.

So, collisions between stars are extremely rare

Galaxy collisions

For galaxies, the situation is different: for example, the distance from the Milky Way to the Andromeda Galaxy is about twenty times as large as the diameter of the Milky Way.

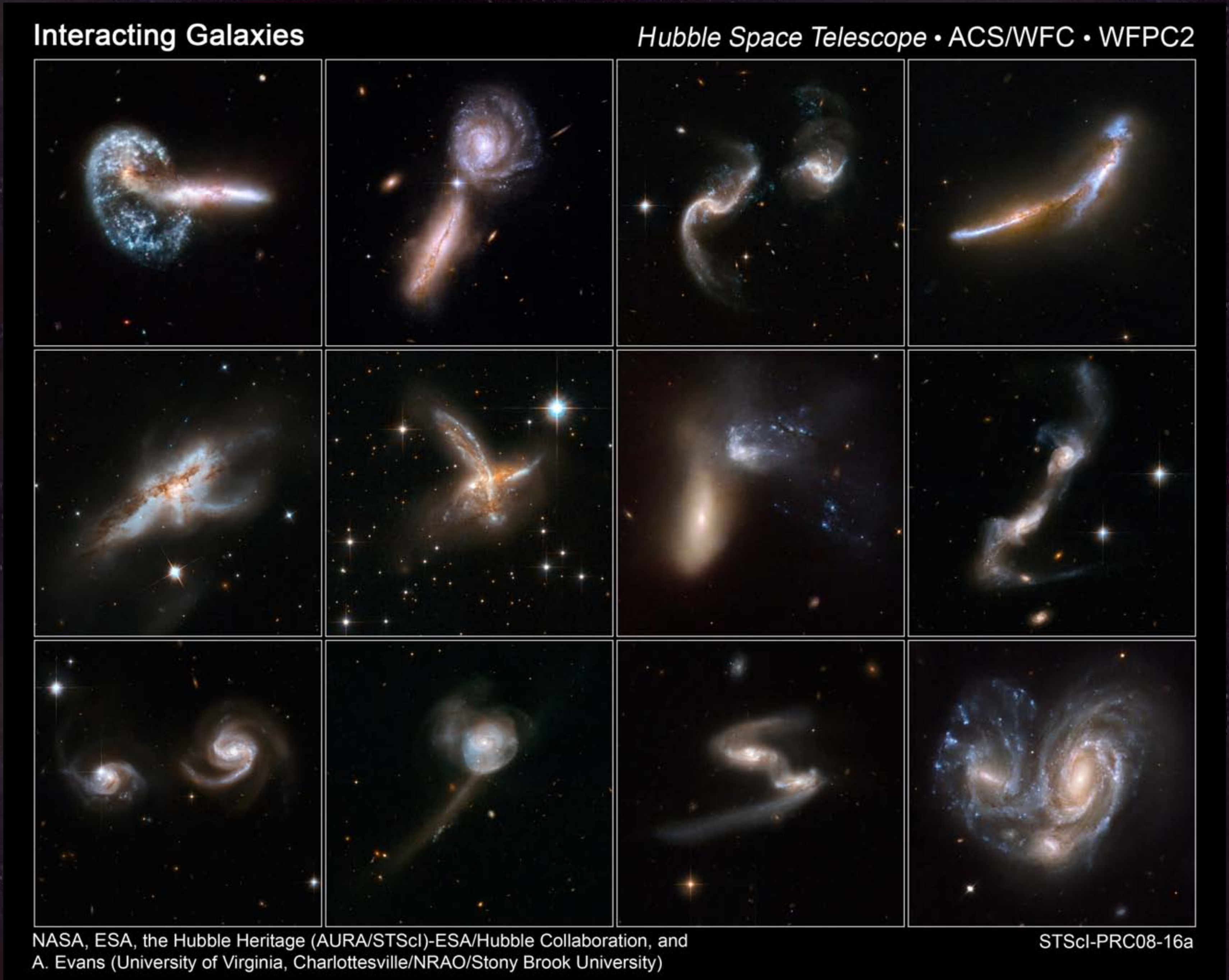
Motions within clusters are disordered

So, collisions are very common.

Collisions trigger massive bursts of star formation.

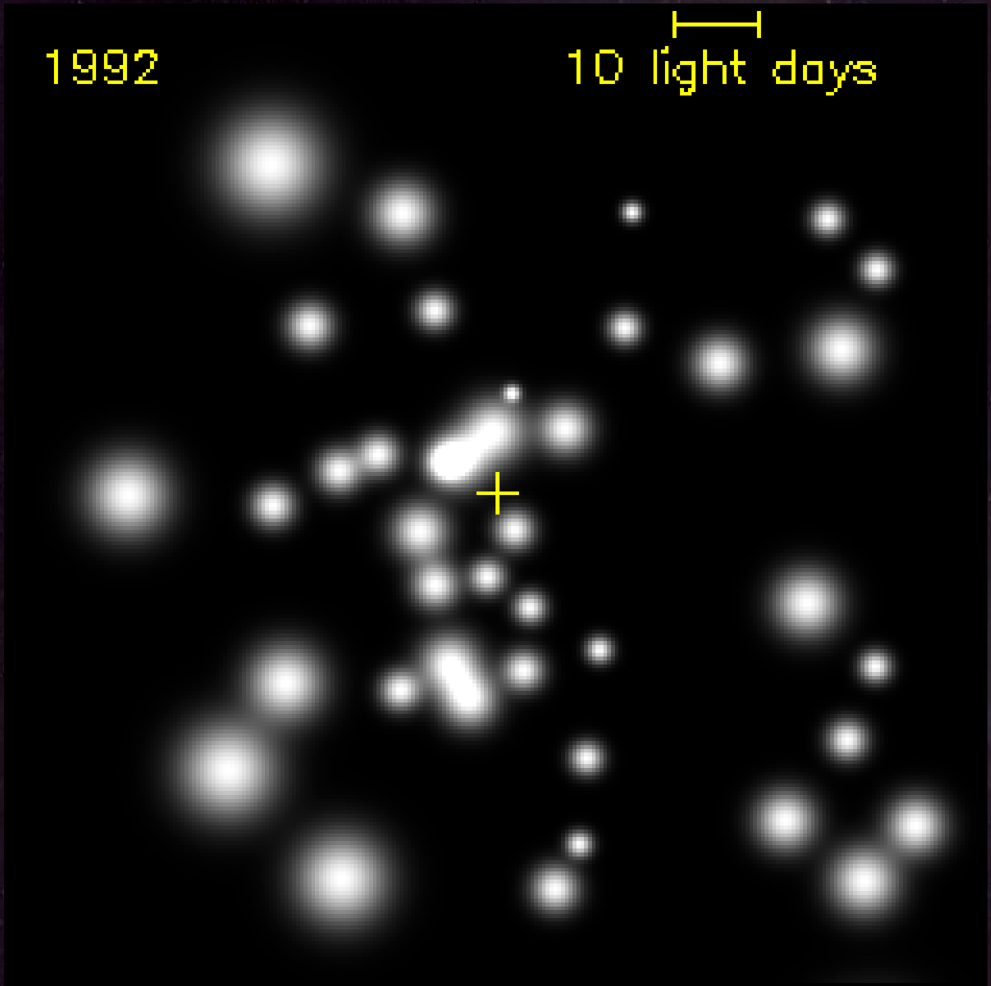
If two spirals merge, then all the gas and dust is stripped, the structure is lost, and what emerges afterwards is an elliptical galaxy.

Galaxy collisions



Active galaxies

Many galaxies contain vast amounts of matter (millions of times the mass of the Sun) in a very small region at their core (perhaps only a few light-hours across. Our galaxy is one such galaxy.



Active galaxies

You can see that whatever is at the centre of the Milky Way is not emitting any visible light.

It is thought to be a *black hole* – an object so massive that even light cannot escape its gravity.

Often, material orbiting a black hole gets so hot that emits extreme amounts of radiation.

'Light' and the electromagnetic spectrum

Every picture I've shown so far has been taken in visible light. This is just one form of radiation, defined by what the human eye can perceive.

Outside the range of our perception, other types of radiation exist that we cannot observe directly.

Beyond the violet is *ultraviolet, x-rays* and *gamma rays.* Beyond the red is *infra-red, microwaves* and *radio waves*

We will discuss this more in subsequent lectures, but it's important to realise that visible light does not tell the whole story.