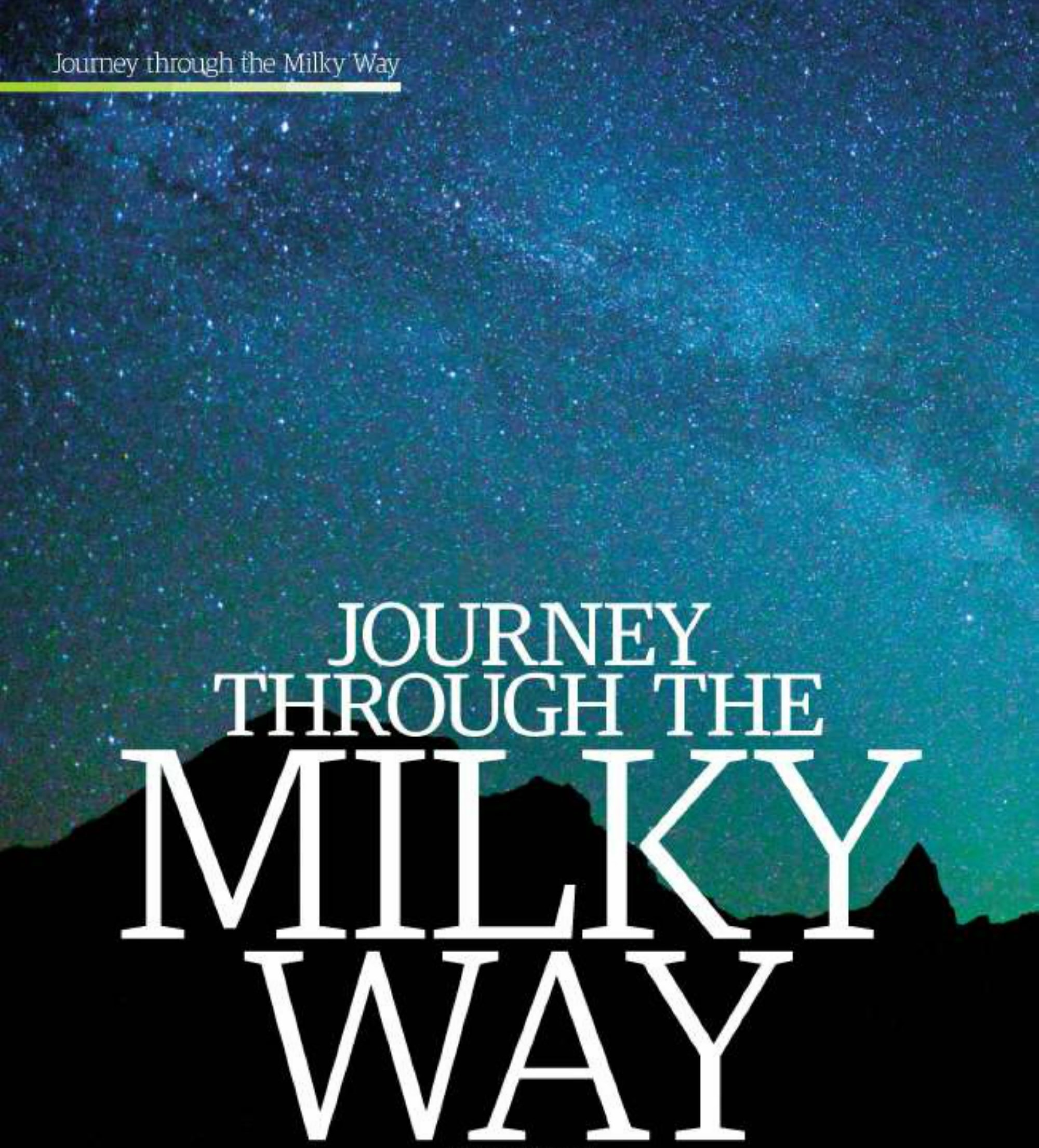


# JOURNEY THROUGH THE MILKY WAY

Written by Giles Sparrow

Our home in the universe is a giant spiral system containing many billions of stars – but how much do we really know about it, and what do we still have to learn?

Look up at the sky on a dark, clear night and you can't miss the Milky Way – a broad swathe of pale light winding its way around the sky among many of the brightest individual stars. Ancient astronomers saw it as a stream of milk spilt across the sky by the goddess Hera when she suckled the hero Hercules, but today we know the Milky Way is something very different – an enormous disc of stars some 100,000 light years across, containing (at the latest estimate) around 200 billion individual stars.

Unsurprisingly, then, our Solar System is an insignificant speck within the overall scale of the Milky Way – all the planets and other large bodies orbiting the Sun are confined to a region just a few light *hours* across. In our part of the galaxy, stars are spaced far enough apart that even our nearest stellar neighbours appear as mere specks of light. The closest of all, the triple star Alpha Centauri, is still around 4.3 light years away.

The overall shape of our galaxy has been likened to two fried eggs placed back to back, with a broad, flat disc of scattered stars, gas and dust surrounding a bulging central hub where stars are more densely packed together. Our Solar System and its neighbours lie in a relatively sedate, outlying region of the Milky Way, about halfway between the centre and the edge. With a little understanding of the Milky Way's structure, the band of light across the night sky is easy to understand: when we look across the plane of the Milky Way's disc, we see far more stars lying in any given direction and these effectively merge together into a generalised glow. On the other hand, when we look 'up' or 'down', out of the galactic plane, we are staring into largely empty intergalactic space, with only relatively nearby stars in our part of the disc to get in the way.

In 1785, astronomer William Herschel made the first attempt to map the Milky Way in detail, by exhaustively counting the number of stars he could see in different directions across the sky. He proved beyond doubt that the Milky Way was a flattened plane, but unfortunately misunderstood its shape because he believed that our own Solar System was near the centre of the galaxy.

In the late-Twenties, Jan Oort set out to study the movement of individual stars in different parts of the sky. He soon confirmed that the Milky Way is rotating, showed that its centre lies in the direction of the constellation Sagittarius, and also proved that galaxies do not rotate like solid bodies – instead the stars closer to the galactic hub move more quickly along their orbits, while stars further out circle more slowly – a phenomenon known as 'differential rotation'. The Sun, for instance, takes around 200 million years to complete a single orbit. Later measurements in different parts of the disc showed that orbital speeds do not change as dramatically as they should do if they are governed by the mass of the Milky Way's visible matter alone – evidence that our galaxy contains large amounts of transparent but weighty 'dark matter'.

Even today, our understanding of our galaxy is constantly evolving thanks to new theories and new observing technologies. Radio, infrared, ultraviolet and X-ray observations can pierce the dense clouds of stars and dust that obscure large parts of the Milky Way in visible light, while new analytical techniques allow astronomers to learn far more from the stars we can observe. So what is our current understanding of this enormous stellar system?

The Milky Way is a barred spiral galaxy, around 100,000 light years across and with a disc roughly 1,000 light years thick in most places. Its central hub is formed by a densely packed ball of stars roughly 8,000 light years in diameter, out of which a bar of stars some 27,000 light years long emerges. The bar points more or less directly towards our Solar System, and as a result its existence was uncertain until it was finally confirmed by NASA's infrared Spitzer Space Telescope in 2005.

Two major spiral arms emerge from the ends of this bar. Until recently, our galaxy was thought to have four major arms, but further observations have led to two of them being 'downgraded'. The two survivors are known as the Scutum-Centaurus Arm and the Perseus Arm. They alternate with the two recently demoted arms – the Sagittarius and Norma arms. The picture is complicated by numerous other disconnected regions that follow the general sweep of the spiral arms. For instance, our own Solar System lies on the inside edge of a 10,000 light year fork in the Sagittarius Arm, known as 'Orion Spur', while both the Sagittarius and Norma arms are thought to trail off into disconnected clumps that wrap their way around the galaxy's outer perimeter. The outer extension of the Norma Arm, which lies on our side of the galactic centre and is therefore more easily seen, is known as the Outer Arm.

The Milky Way's spiral arms are not permanent, linked structures – otherwise the differential rotation discovered by Jan Oort would cause them to 'wind up' after just a few rotations. Instead, they perpetually renew themselves. In fact, the arms seem to be celestial traffic jams, created where stars and gas in circular orbits around the galactic hub enter a spiral 'density wave' region where they are slowed down and jammed together. This triggers the creation of new star-forming nebulas that light up the spiral arms with the pinkish glow of hydrogen emission, and ultimately give birth to 'open clusters' of stars.

However, these stellar foundries are short-lived on a galactic timescale – they exhaust their supplies of star-forming gas within a few million years, and the heaviest stars squander their fuel in a few million more. As a result, the most brilliant stars don't survive long enough for their orbits to carry them out of the spiral arms – instead it's the more sedate, longer-lived stars like our own Sun that make it out of the traffic jam to continue their orbits around the galactic disc over billions of years.

"The most brilliant stars don't survive long enough for their orbits to carry them out of the spiral arms"


## Viewing our galaxy from Earth

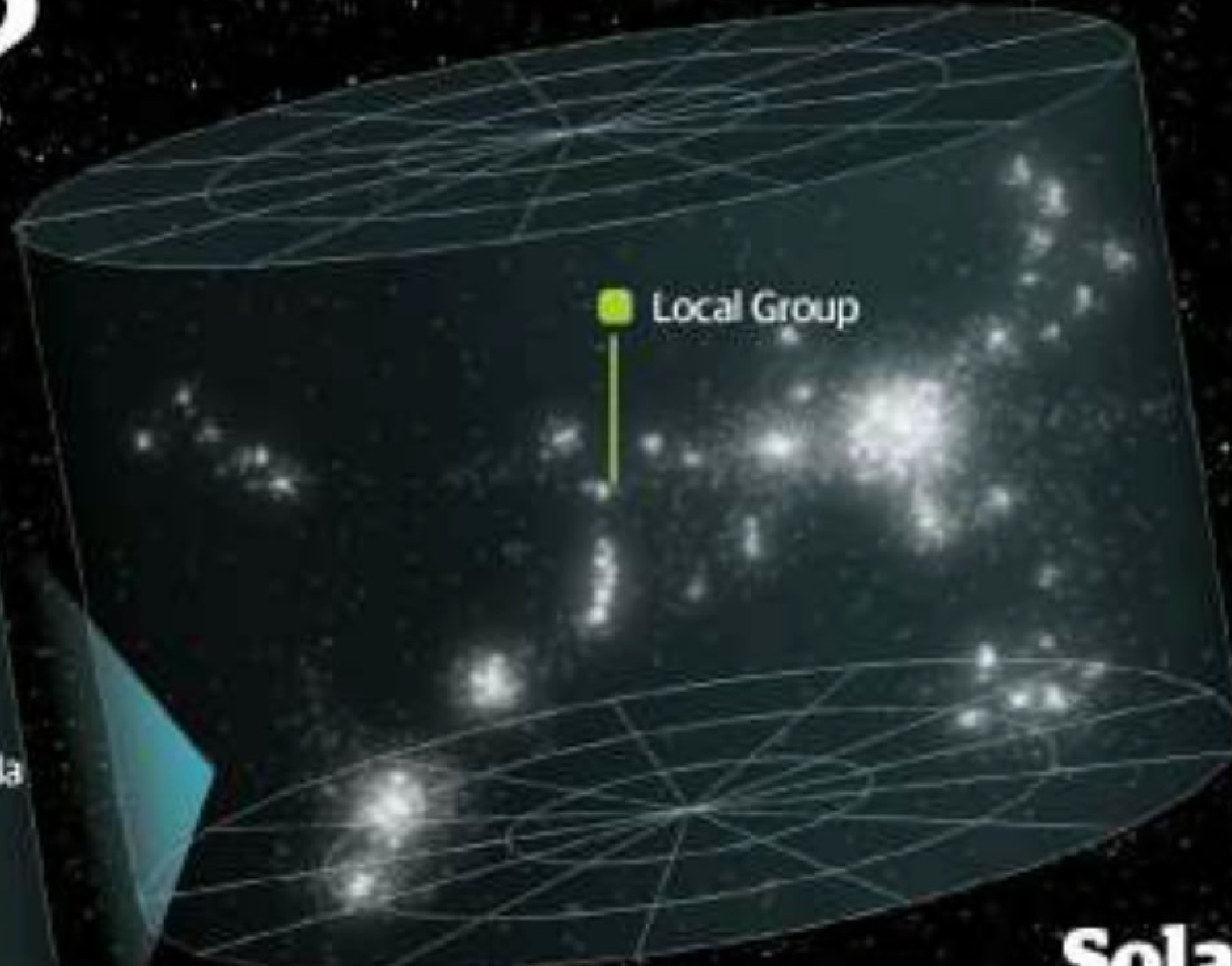
As early as the 18th Century, astronomers realised that the winding path of the Milky Way across the sky is a result of our location in a broad, relatively flat plane of stars. But our Solar System's location sandwiched between the major spiral arms complicates the picture considerably, so that different arms in different parts of the sky run together and overlap in places to form a seamless river of light. The picture is further complicated by the presence of dark dust lanes that obscure the light of more distant star clouds: perhaps the most famous of these is the Great Rift, which runs through the constellations of Cygnus and Aquila. The brightest and broadest part of the Milky Way, meanwhile, lies in the direction of Sagittarius and Scorpius. It consists largely of the Carina-Sagittarius Arm and marks the direction of the hub and galactic centre. On the opposite side of the sky, meanwhile, the Perseus Arm runs around the outer edge of the galaxy as seen from our point of view.

## Birth of the Milky Way

# Where is our galaxy?

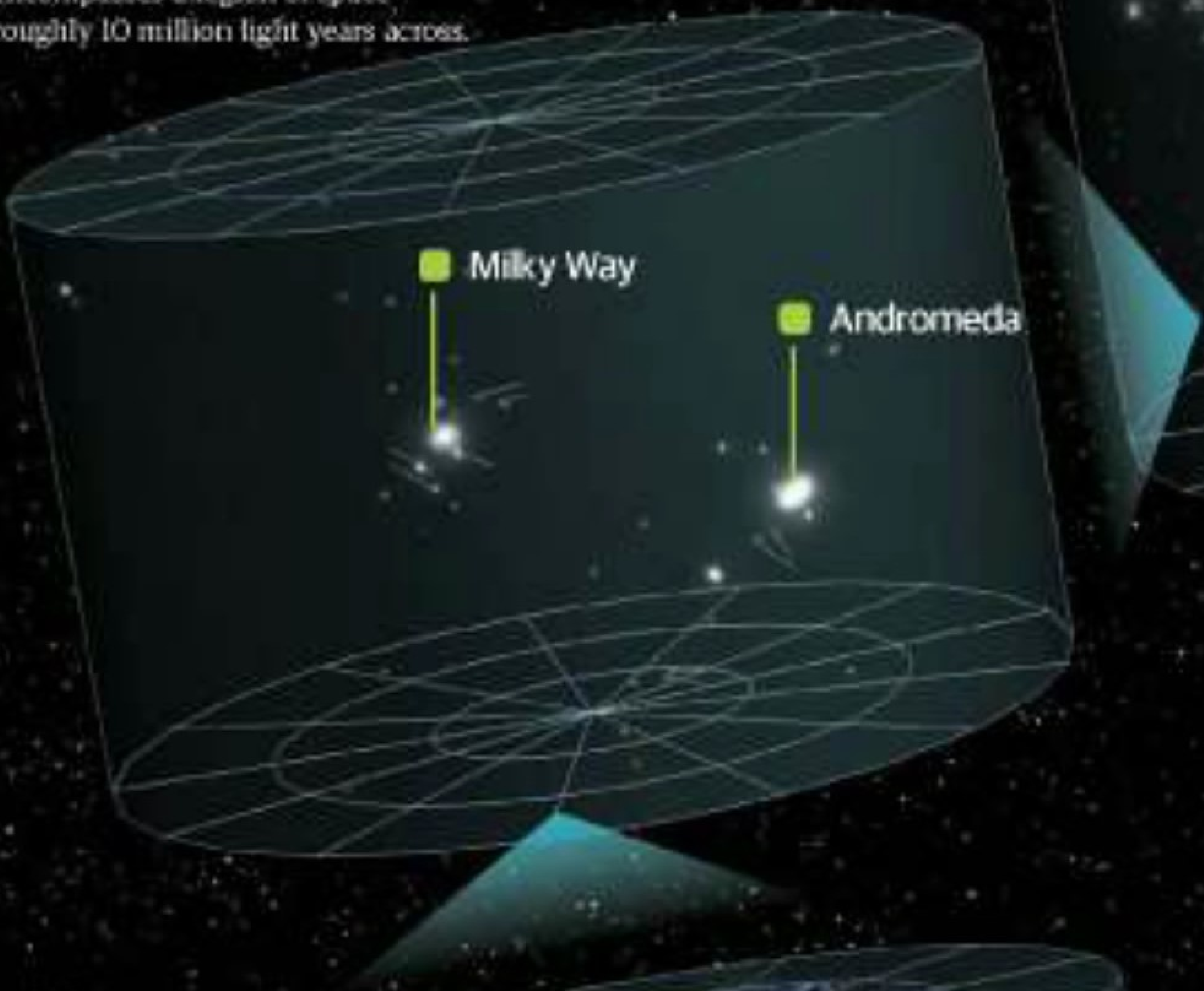
## Virgo Supercluster

The Local Group lies on the outskirts of a galaxy supercluster centred around the Virgo Cluster, some 60 million light years away.



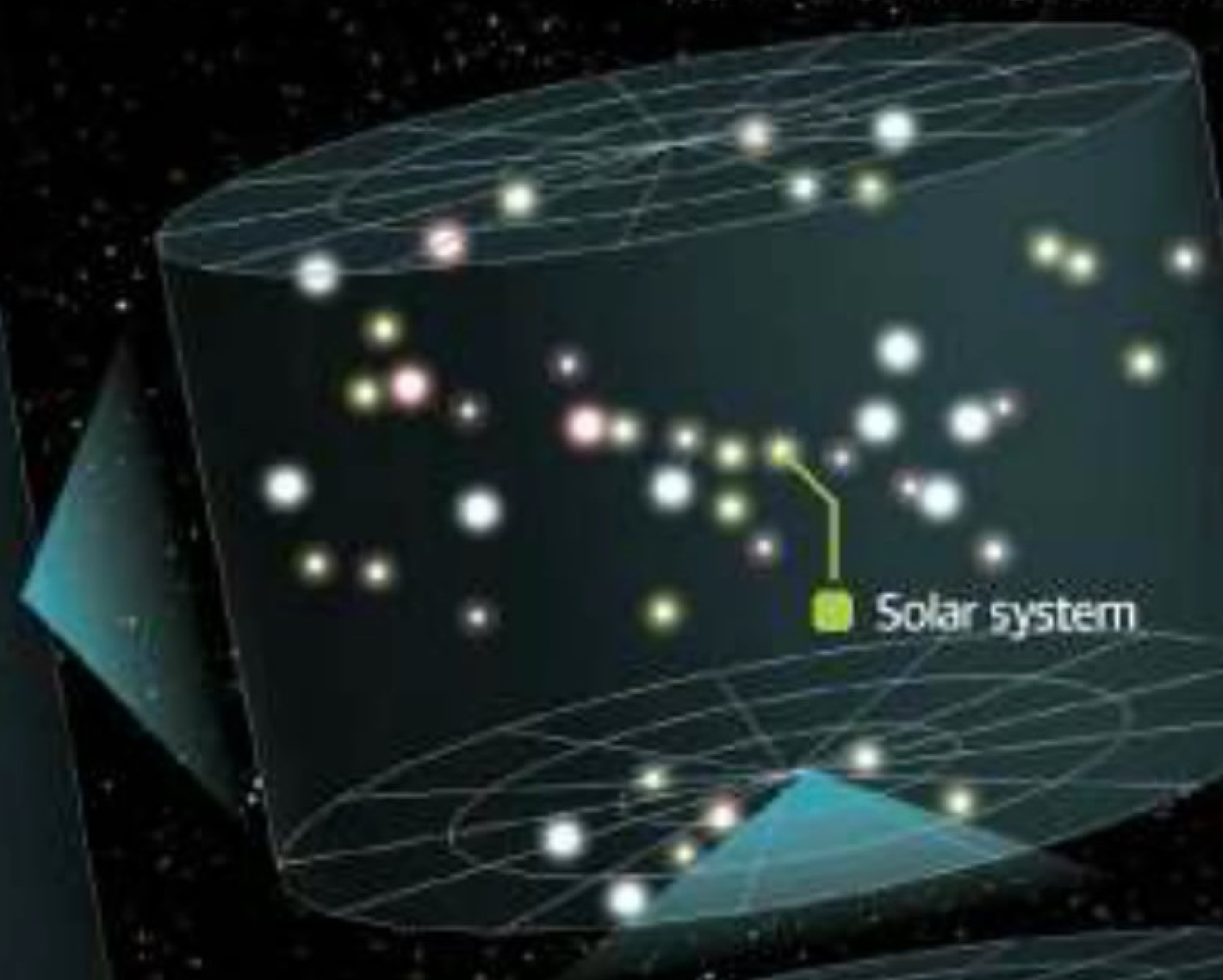

## Local Group

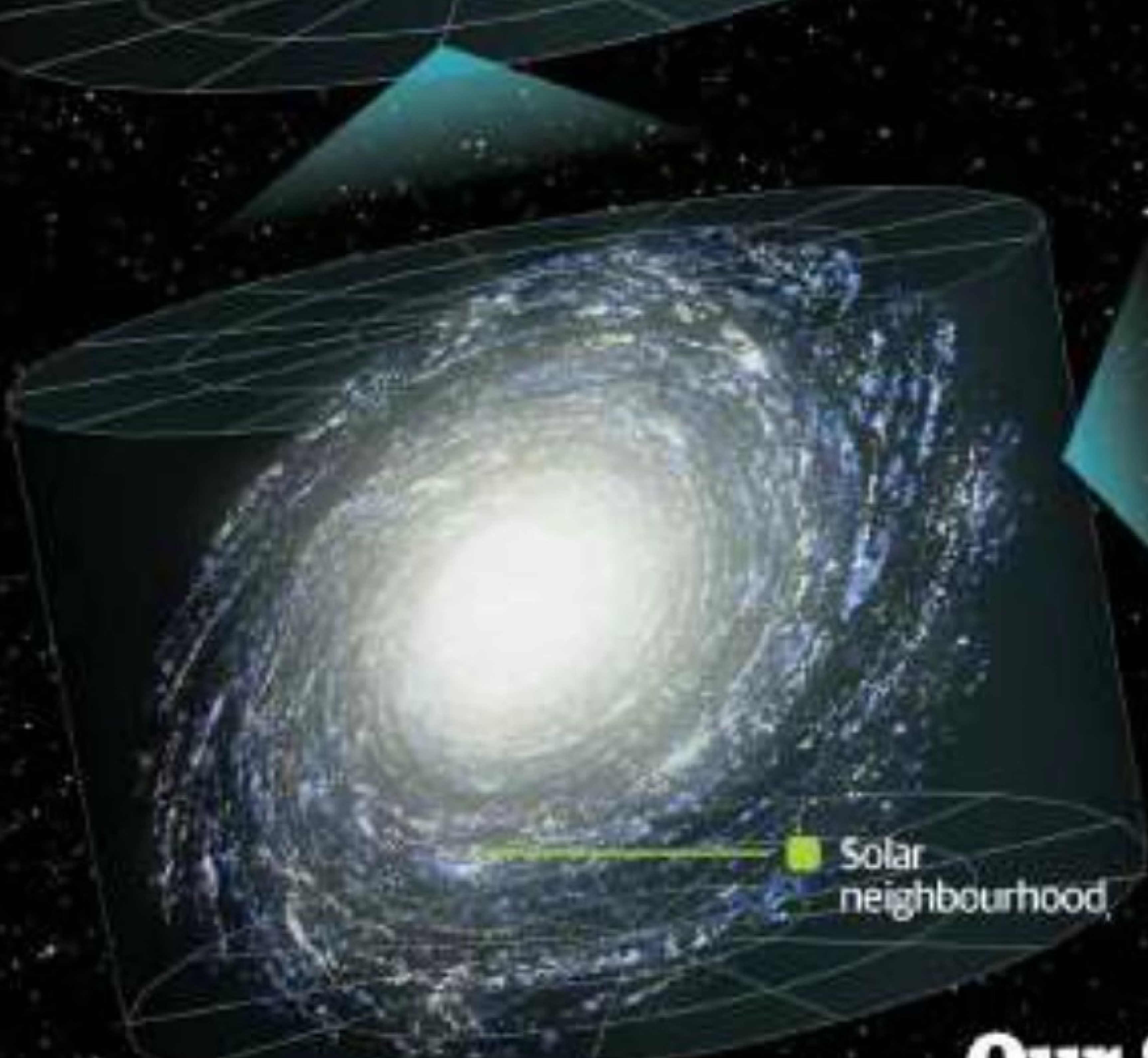
This cluster of galaxies, dominated by the Milky Way and Andromeda, encompasses a region of space roughly 10 million light years across.




## Solar neighbourhood

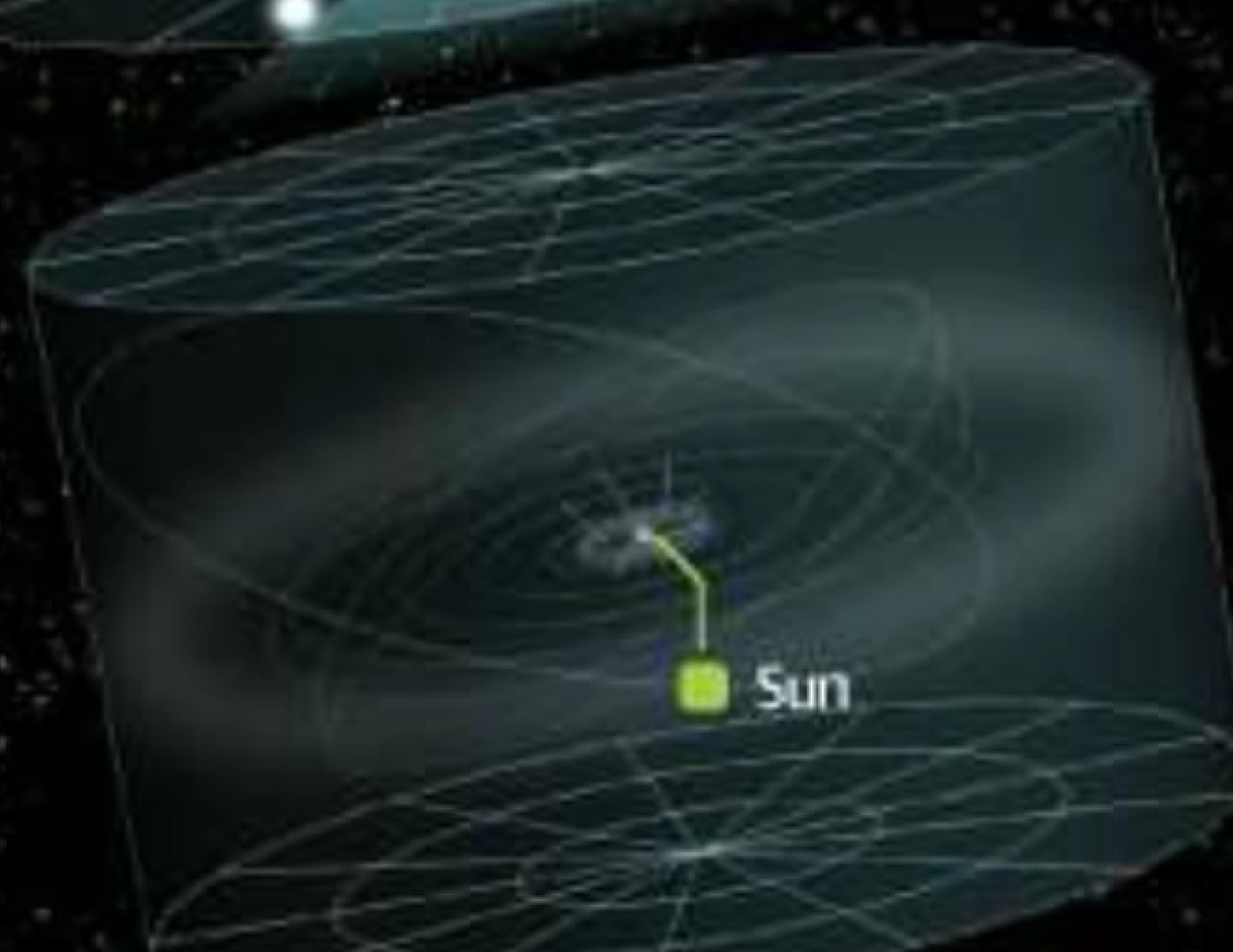
Our region of the Milky Way contains a mixture of single and multiple stars of many different types, separated by a few light years on average.




## Galactic influence

The Milky Way is roughly 100,000 light years across, but its gravitational influence covers a region several hundred thousand light years wide.




## Our Solar System

Out to the edge of the Kuiper belt (the zone of small, distant icy dwarf worlds) our Solar System is roughly a light day across.

At the inner limit of the spiral arms, the bar and hub are surrounded by a structure known as the 5 kiloparsec Ring (one kiloparsec is around 3,260 light years). Although we cannot see it in visible light, the ring seems to contain huge concentrations of star-forming nebulas and young stars: it's probably the main generator of new stars in the Milky Way.

Above and below the main disc lies a relatively empty region known as the halo. Many faint, long-lived stars pass through this region on tilted orbits, but the halo's most obvious occupants are globular clusters - dense balls containing many tens of thousands of old, red and yellow stars that are generally found above and below the galactic hub. Similar red and yellow stars dominate the hub and bar - they are relatively poor in heavy elements, which allows them to shine for billions of years without evolving significantly. As a result, they are known as 'Population II' stars, in contrast to the younger, faster-evolving and heavy-element-enriched 'Population I' stars in the galactic disc.

Among all these stars, the huge majority are low-mass red and orange dwarfs - stars with a fraction of the mass of the Sun, which shine so faintly that they can only be seen when they are relatively nearby. Brighter and more massive stars are much rarer, but tend to shine out over huge distances and so appear more prominently in our skies. Similarly, ageing but brilliant red and orange giants are common among the naked-eye stars seen from Earth, but in fact far rarer than they might appear at first glance.

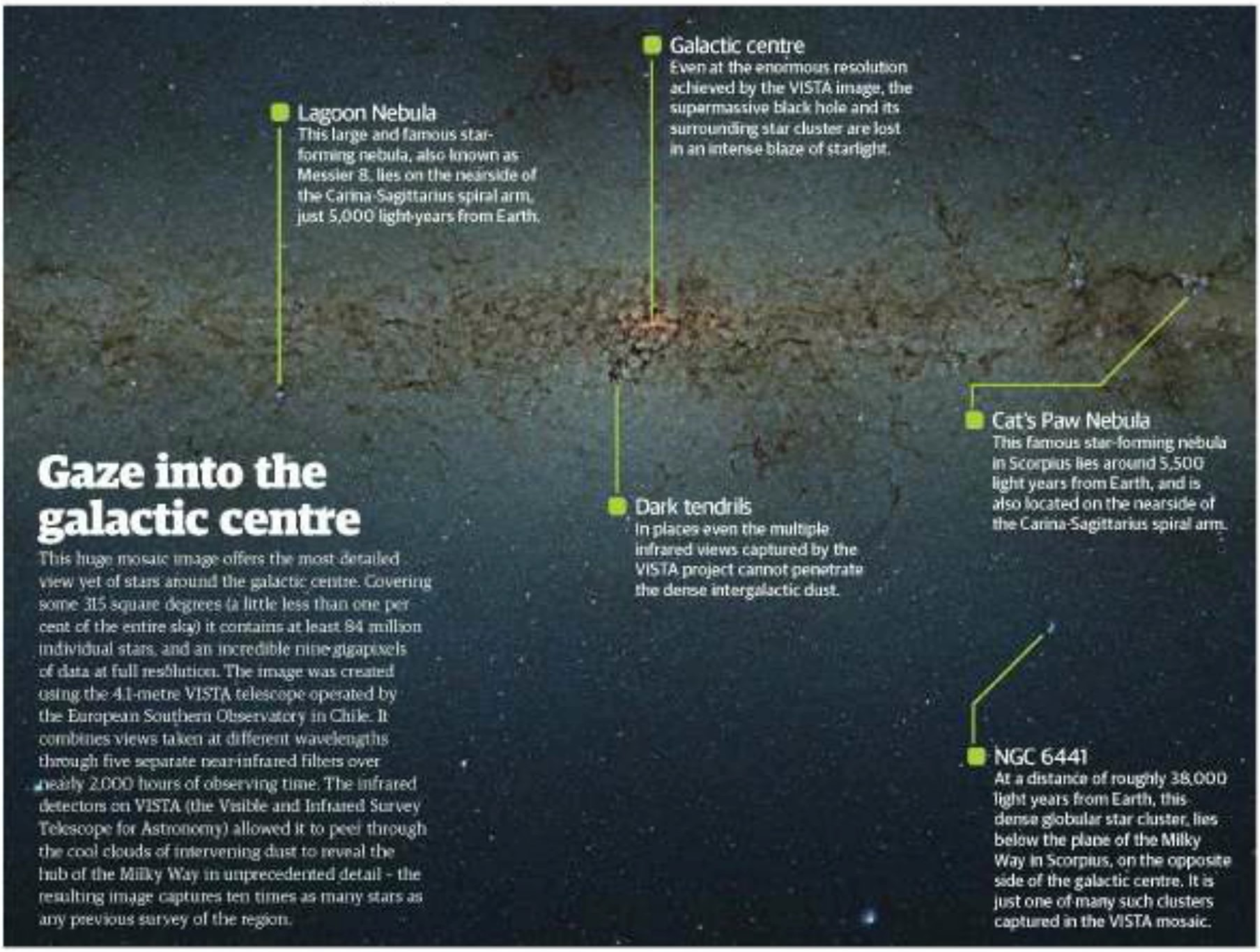
What's more, stars in our galaxy seem to be gregarious - although they gradually drift apart from the open clusters in which they form, many stars remain together in binary or multiple star systems. Recent research also suggests that planetary systems are also common - there may be at least as many planets as there are stars in the sky.

Within the hub, stars become more densely packed towards the centre of the Milky Way - the galactic core. Only X-rays, radio waves and some infrared waves can pass through these dense star clouds unaffected, but they reveal an intriguing picture of the strange and violent conditions in the core itself.

At radio wavelengths, the core is marked by a complex radio source known as Sagittarius A - it consists of a bubble-like structure (Sagittarius A West) a few tens of light years across - probably the remnant of an enormous supernova explosion. Embedded within this is a three-armed spiral called Sagittarius A East, roughly ten light years across. The middle of the spiral coincides with the densest concentration of stars in the Milky Way, and a third, point-like source of radio waves known as Sagittarius A* that is believed to mark the Milky Way's centre.

X-ray emissions reveal huge bubbles and twisted lobes of superhot gas across the region - a mix of supernova remnants and the effects of hot stellar

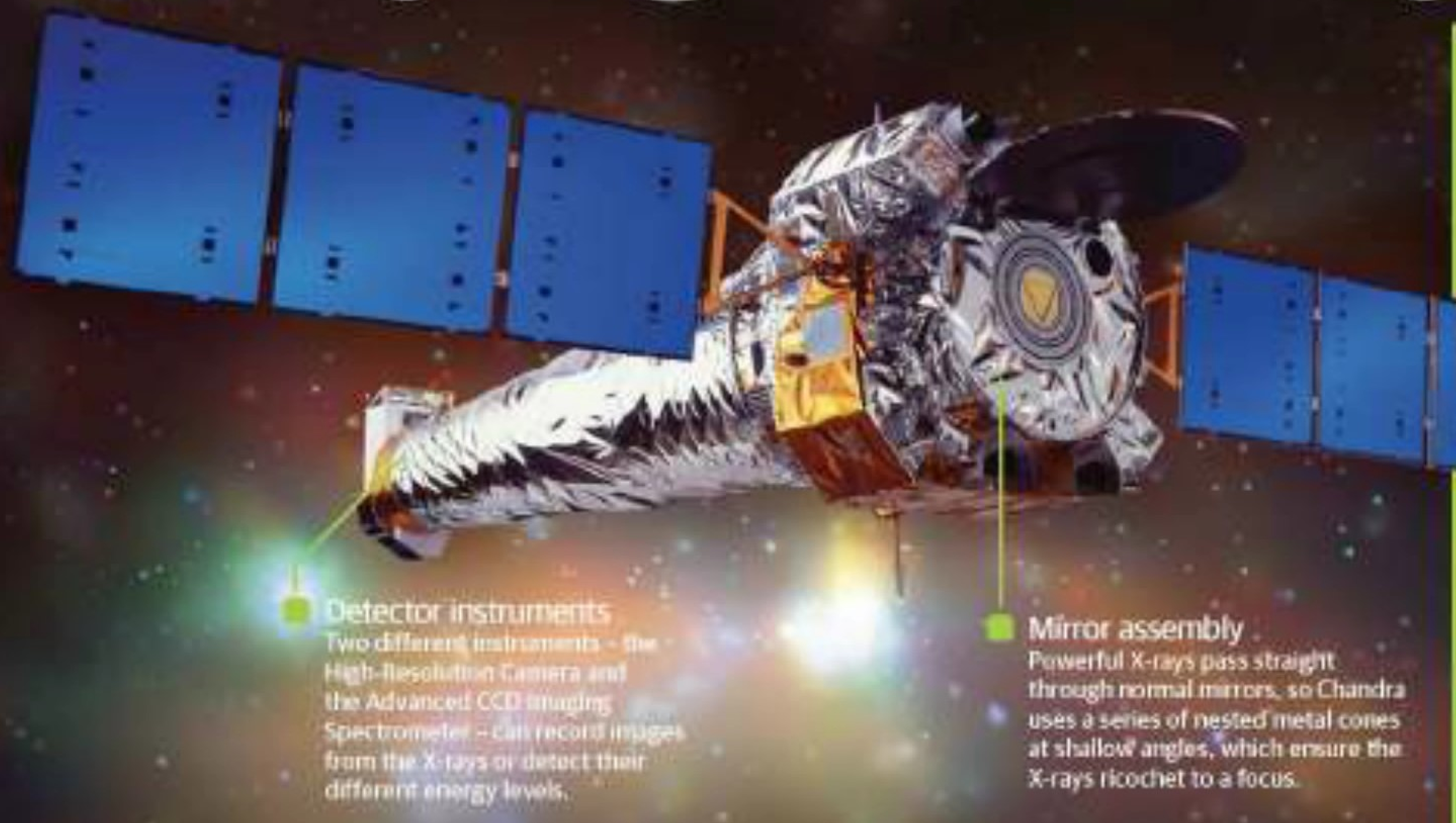
"The Milky Way is a major component of the Local Group - a small galaxy cluster some 10 million light years across"




## Gaze into the galactic centre

This huge mosaic image offers the most detailed view yet of stars around the galactic centre. Covering some 315 square degrees (a little less than one per cent of the entire sky) it contains at least 84 million individual stars, and an incredible nine gigapixels of data at full resolution. The image was created using the 4.1-metre VISTA telescope operated by the European Southern Observatory in Chile. It combines views taken at different wavelengths through five separate near-infrared filters over nearly 2,000 hours of observing time. The infrared detectors on VISTA (the Visible and Infrared Survey Telescope for Astronomy) allowed it to peer through the cool clouds of intervening dust to reveal the hub of the Milky Way in unprecedented detail - the resulting image captures ten times as many stars as any previous survey of the region.

# Studying the Milky Way




## Mission profile
### Chandra X-ray Observatory

**Launch date:** 23 July 1999
**Launch vehicle:** Space Shuttle Columbia
**Mass:** 4,790kg
**Telescope diameter:** 1.2m
**Mission:** Chandra was designed to image the high-energy X-ray sky at higher resolutions than ever before, detecting phenomena such as hot interstellar and intergalactic gas clouds, black holes and other stellar remnants.
**Key discoveries:** Chandra has allowed the region around Sagittarius A* to be imaged in detail, while the X-ray echoes it has detected have shown that the supermassive black hole has been active in the recent past.


## Mission profile
### Spitzer Infrared Space Observatory

**Launch date:** 25 August 2003
**Launch vehicle:** Delta II
**Mass:** 950kg
**Telescope diameter:** 0.85m
**Mission:** Spitzer was designed to study a wide range of objects, from star-forming nebulas and newborn solar systems to distant galaxies. Although the coolant required for its primary mission was exhausted in May 2009, it is still operational in its 'Warm Mission' phase.
**Key discoveries:** Spitzer's infrared vision allowed it to pierce the dust that blocks our view of the galactic centre, providing the first detailed images of the giant star clusters and tortured gas clouds found in the region.

# Map of the Milky Way

### Zone of Avoidance
This mysterious region lies on the opposite side of the hub from our Solar System, and is largely unknown. As well as features of the Milky Way, it also conceals galaxies in the space beyond.

### Carina-Sagittarius Arm
This minor arm runs in front of both the Scutum-Centaurus arm and the galactic hub as seen from Earth. It contains some of the richest starfields and most impressive nebulas in the sky.

### 5kpc ring
This ring of stars, gas and dust is thought to be the biggest and brightest centre of star formation within our galaxy.

### Perseus Arm
This major arm emerges on the far side of the central bar, and wraps its way around the opposite side of the sky from the hub, as seen from Earth. It contains many of the rich starfields and nebulas seen in the northern Milky Way.

### Galactic halo
The halo region above and below the galaxy's flattened disc is home to stray ancient stars and globular clusters – huge balls of long-lived red and yellow stars.

### You are here
Our Solar System lies roughly 26,000 light years from the galactic centre, about half way between the hub and the galaxy's visible edge. Here, the Sun orbits the centre every 200 million years.

**Scutum-Centaurus Arm**
This major spiral arm emerges from the near end of the galaxy's central bar, but lies largely on the opposite side of the hub from Earth.

**SagDEG**
Discovered in 1994 as an unusual concentration of stars on the far side of the galactic hub, the Sagittarius Dwarf Elliptical is a small galaxy in the process of being torn to shreds by the Milky Way's gravity.

**Sagittarius A***
The supermassive black hole at the centre of our galaxy weighs more than 4 million Suns, but only gives its presence away through X-ray and radio emission.

**Galactic hub**
The central bulge of the Milky Way is roughly 8,000 light years in diameter and dominated by tightly packed, long-lived red and yellow stars.

winds blowing out from massive stars. Infrared telescopes, meanwhile, show the distribution of stars themselves – the region is home to two of the largest open clusters in the galaxy, the Quintuplet Cluster and the Arches Cluster. A third cluster surrounds the Sagittarius A* region itself, but while its individual stars have been mapped, none coincides exactly with the mysterious radio source.

Since the Seventies, astronomers have suspected that Sagittarius A* might mark the location of an invisible black hole with the mass of millions of Suns, but the evidence to back this up has only recently been found. By mapping the central star cluster over several years, astronomers have plotted the orbits of two stars that orbit the object every few years. Based on the speed of these stars, Sagittarius A* must contain the mass of at least 4 million Suns concentrated in a region roughly the size of Uranus's orbit around the Sun. With such enormous density, it can only be a supermassive black hole.

However, Sagittarius A* seems surprisingly quiet compared to similar objects elsewhere in the universe – other supermassive black holes in distant galaxies wreak havoc with their surroundings. Astronomers think the big difference is that these black holes are feeding on material that strays too close. Sagittarius A*, on the other hand, seems to have long ago cleared out its immediate surroundings, and anything that still orbits in the central region stays safely out of reach.

Recent discoveries, however, suggest that Sagittarius A* may have been active surprisingly recently. In 2007, NASA's Chandra satellite discovered X-ray 'echoes', created as radiation when an event roughly 50 years previously affected gas clouds near the central black hole. It seems likely that Sagittarius A* took a substantial snack at this time, when a large gas cloud strayed too close. And in 2010, the Fermi Gamma-ray Space Telescope found evidence for an even larger outburst thousands of years ago.

There's one final question that's worth asking about our galaxy – where does it end? Although the spiral arms seem to lose their intensity and the number of disc stars falls off dramatically over 50,000 light years from the hub, a disc of neutral hydrogen gas extends out to almost 100,000 light years and seems to retain the overall spiral structure. The Milky Way's gravitational influence extends even further – the halo of stars and globular clusters reaches out to around 150,000 light years or more. However, beyond this distance the orbits of halo objects are disrupted by two interlopers – the Magellanic Clouds. Until recently, these two irregular clouds of gas were believed to be in orbit around our galaxy, but it now seems that they are merely passing by on their own paths through space.

On a larger scale, the Milky Way is one of the major components of the Local Group – a galaxy cluster 10 million light years across. The other is the Andromeda Galaxy, some 2.5 million light years away. These two galaxies exert a strong influence on everything in their vicinity, and are approaching each other at 110 kilometres per second. They will eventually collide and merge together about 4 billion years from now in a process that will signal the end of the Milky Way as an independent galaxy.