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# Mysteries of the Milky Way

It may be our home Galaxy but there are still big questions that remain unanswered

WORDS: GOVERT SCHILLING

**With astronomers studying galaxies at the edge of the observable Universe, you might be forgiven for thinking our own Milky Way had no secrets left to hide. But it does.**

**The trouble is that planet Earth orbits an inconspicuous star at the edge of a spiral arm in the outskirts of the Milky Way. There's nowhere we can easily go for a revealing, bird's eye view. It's a bit like trying to map the whole of London when it's foggy and your Travelcard only covers Zone 4.**

**It's true that over the past centuries, astronomers have learned a great deal about the structure of our home Galaxy. In 1610, Galileo's telescope revealed countless stars in the hazy band of light that stretches across our sky. In the 1780s, William Herschel compiled a first, crude map by counting the number of stars he could see in different directions. And in the early 20th century, Dutch astronomer Jacobus Kapteyn used photographic plates to improve on Herschel's work and concluded (erroneously) that we live close to the centre of a relatively small, flattened disc of stars.**

**After World War II, radio telescopes confirmed that the Milky Way is a huge spiral disc galaxy. But many questions remain unsolved. Here, we take a look at five Milky Way mysteries. ▸**

An artist's impression of the Milky Way. Note the spiral arms and the bar that crosses the centre

# How did the Milky Way form?

▲ A galaxy merger, whereby one galaxy 'swallows' another. The Milky Way may be the end result of many such mergers

SHORTLY AFTER THE Big Bang, some 13.7 billion years ago, there were no galaxies. The many billions of galaxies that pepper the present Universe, including our own Milky Way, must have formed later, probably by the clumping together of primordial gas and dark matter under gravity. But the details of this process are poorly understood.

Ever since the pioneering work of Walter Baade during World War II, astronomers have known of two populations of stars in the Milky Way. Older stars are found in the central bulge and the spherical halo surrounding the Galaxy. Younger stars populate the thin galactic disc. In the early 1960s, this led astronomers Olin Eggen, Donald Lynden-Bell and Allan Sandage to propose that a large cloud of gas had started to collapse under its own gravity. The oldest stars formed when the cloud was still more or less spherical. Later on, the cloud started to rotate faster, just like an ice skater rotates faster when she draws her arms inward. The cloud also started to flatten. As a result, younger stars – like our own Sun – only tend to show up in the thin, rotating disc of the Milky Way.

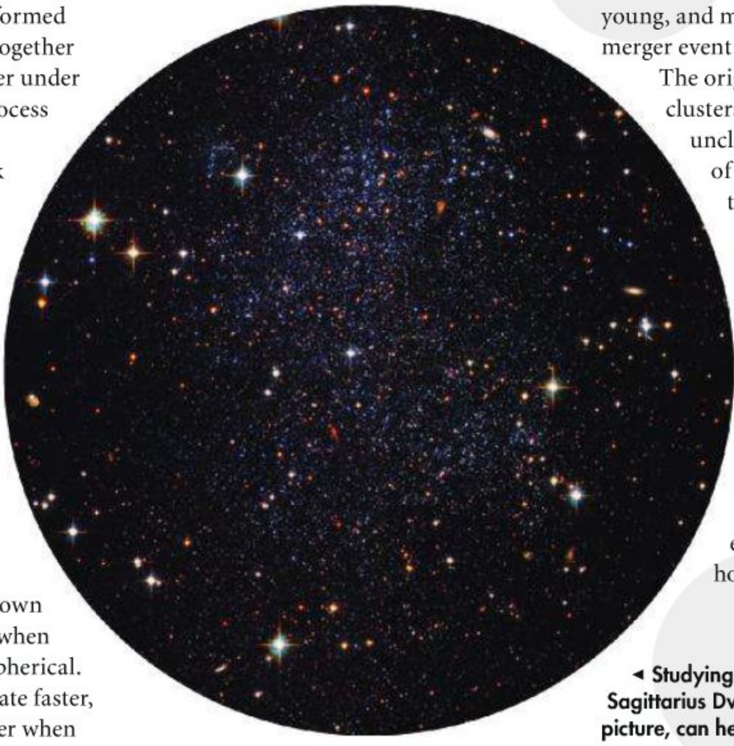
However, subsequent computer modelling has shown that Eggen, Lynden-Bell and Sandage couldn't possibly be right. Instead, the Milky Way probably formed and grew by gobbling up smaller galaxies. The process is still going on, as evidenced by the discovery in 1994 of the Sagittarius Dwarf galaxy, which is in the process of being torn apart by the tidal forces of the Milky Way.

## New developments

New insights suggest that galaxies like the Milky Way grew big from the 'bottom up', through the accretion of dozens or even hundreds of lumps of dark matter, some of which may once have shone feebly as dwarf galaxies. In 1999, Amina Helmi at the University of Groningen in the Netherlands discovered 'fossil' stellar streams in the Milky Way. They are the tell-tale remains of those disrupted dwarfs.

Still, says Helmi, many riddles remain. "Forming a thin disc through mergers is not easy. Maybe the galactic disc formed relatively recently, some eight billion years ago." Interestingly, recent computer simulations by French and Chinese astronomers suggest that the current structure of our nearest neighbour, the Andromeda Galaxy, is also relatively young, and may result from a major merger event only 5.5 billion years ago.

The origin of the very old globular clusters in the Milky Way is also unclear. Were they already part of the merging systems, or did they form as a result of the merging activity? "We really need to learn much more about the merging history of the Milky Way," says Helmi. She looks forward to the future European Gaia mission, which will map the motions and determine the ages of about a billion stars. "Gaia should enable us to reconstruct our home Galaxy's past."



◄ Studying other galaxies, such as the Sagittarius Dwarf Galaxy in the centre of this picture, can help us learn more about our own

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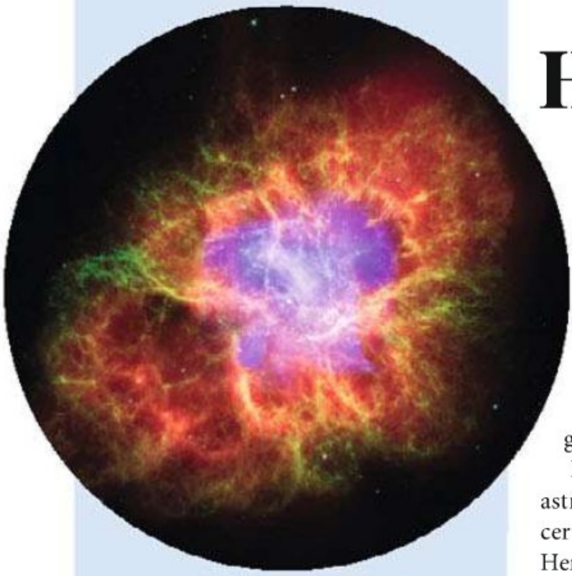


▲ Supernovae leave behind tell-tale signs – such as the Crab Nebula, seen here

# Where are all the supernovae?

Danish astronomer Tycho Brahe was lucky. In 1572, he saw a bright supernova explosion in the constellation of Cassiopeia. Just 32 years later, his German pupil Johannes Kepler observed a similar event in Ophiuchus. Ever since, the Milky Way has produced not a single visible supernova, although John Flamsteed may have observed a pretty faint one in 1680. Indeed, there have only been eight in the past 2,000 years. Yet astronomers believe there should be at least three per century. So where are they?

In all likelihood, a supernova probably does pop off in the Milky Way every few decades. But since they occur in the thin Galactic disc, their light is heavily obscured by interstellar dust. "The supernovae seen by Tycho and Kepler were relatively close to us in the Galaxy," says David Green of the Cavendish Laboratory in Cambridge. "No doubt there have been others much further away, which would have been obscured more."

Supernova explosions leave expanding gaseous remnants, like the famous Crab Nebula. Also, the cores of the exploding stars collapse into dense neutron stars, some of which are detected as pulsars. But counting supernova remnants and pulsars doesn't help much in pinning down the true supernova rate. Ages of older remnants are poorly known; our inventory is far from complete, and most neutron stars go unnoticed.

Still, the predicted supernova rate is consistent with the figure derived from supernovae detected in other galaxies, so it seems likely that we just haven't seen them. But it's not all bad news: future telescopes will operate in a wide range of wavelengths, giving us a better chance of observing them, and therefore proving that they're really happening.

# How many stars are there in the Galaxy?

IT'D BE REASONABLE to think that counting the number of stars in our own Galaxy would be pretty simple. Not so. "It's not an easy question to answer," says Ed Guinan of Villanova University. But estimates, or educated guesses, can still be made.

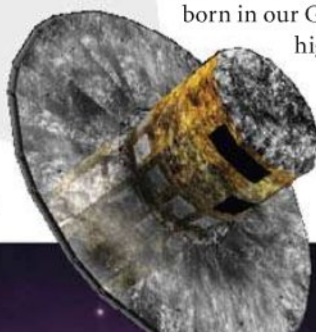
For a start, the figure found in most astronomy books (200 billion) is almost certainly too low. Both Guinan and Todd Henry of Georgia State University think it's at least 400 billion, and might even be as high as one trillion. Most of these are low-mass dwarf stars. "Stars like our Sun are relatively uncommon," says Guinan.

From studying the motion of stars, we know the mass of the Milky Way within the orbit of our Sun: some 200 billion solar masses. Since we know that the average mass of stars, based on an inventory of the immediate solar neighbourhood, is 0.3 to 0.4 solar masses, there must be at least 600 billion stars in the Milky Way.

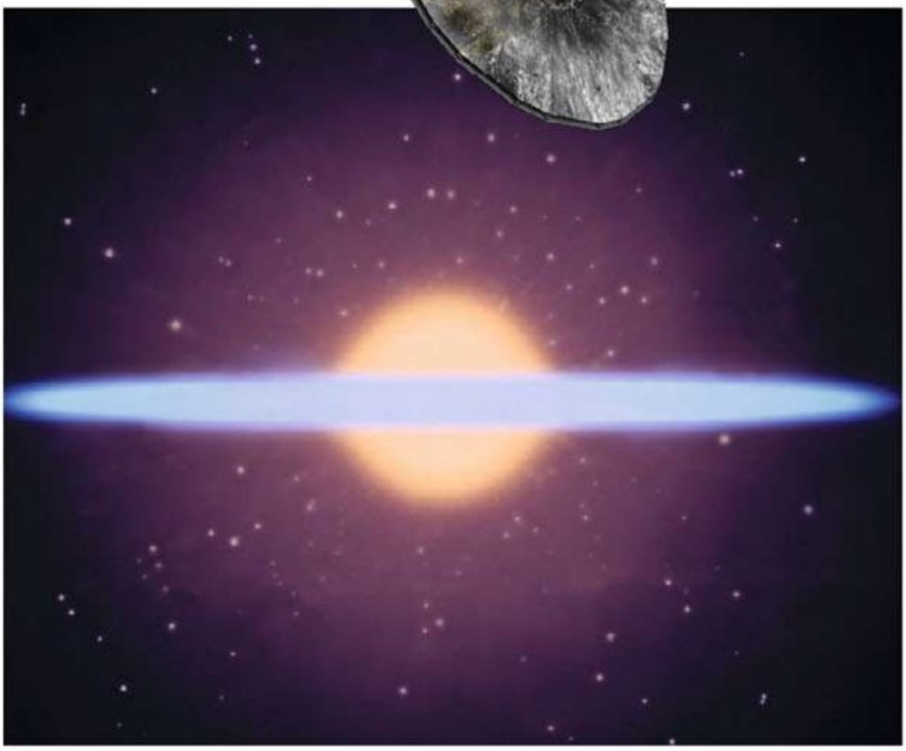
However, the immediate solar neighbourhood may not be truly representative, and it's unclear which part of the Milky Way's mass is in the form of dark matter. "If you compute volumes for the disc, the bulge and the halo of the Milky Way, and make estimates of the stellar densities in each, you arrive at a total of some 400 billion stars," says Henry. However, he explains that the galactic halo might be much larger than previously believed, and that we don't even know where the stellar disc ends – in any direction. "We could go wrong at every turn," he warns.

Measuring stellar distances out to 300,000 lightyears would help to obtain a true Milky Way census. "Gaia [an upcoming space-based instrument] will be able to do that, but it won't reach fainter than 20th magnitude," says Henry. That means it won't see the faintest stars, even at distances of 100 lightyears.

Chances are, therefore, that we will be underestimating the number of stars in the Milky Way for some time to come. Moreover, the true number may well be increasing, albeit pretty slowly. Indications are that the rate at which stars are being born in our Galaxy is significantly higher than the rate at which they die.



◄ Even NASA's Gaia spacecraft won't be able to see our Galaxy's faintest stars



▲ A side-on view of the Milky Way. Note the globular clusters that surround the central disc

# How many spiral arms does

WE REALLY SHOULD ask alien astronomers in the Sombrero galaxy. They have a nearly face-on view of our Milky Way. For them, it's easy to count our Galaxy's number of spiral arms. For Earth-bound astronomers, though, the question is all but impossible to answer. We can only go on evidence from our imperfect vantage point.

Although some astronomers had begun speculating about our Milky Way's spiral structure as early as the mid-19th century, final confirmation only came in the 1950s, when radio telescopes – then at the cutting edge of stargazing technology – were able to map out the distribution of neutral hydrogen gas in our Galaxy. At that stage, four major spiral arms were recognised: the Perseus arm, the Sagittarius arm, the Norma arm and the Scutum-Centaurus arm, each named after the constellation in which it is seen from Earth. Our own Sun is located in the Orion spur, a small adjunct arm between Sagittarius and Perseus.

However, more recently, detailed star counts based on observations by NASA's Spitzer Space Telescope have shown that there may in fact be just two major arms: Perseus and Scutum-Centaurus.

## Arms limitation

As Robert Benjamin of the University of Wisconsin-Whitewater and colleagues reported in June 2008, the infrared Spitzer data failed to reveal significantly higher star counts in the direction of the Sagittarius and Norma arms. And Benjamin's results were confirmed in January 2009, when a team led by Martin Pohl of Iowa State University used archival data from NASA's Cosmic Background Explorer – and some clever modelling – to confirm that the inner part of the Milky Way has just two prominent spiral arms. Further out, they appear to branch into the four arms we've known about for decades.

Discovering that the Milky Way has just two major spiral arms was no great shock to most astronomers. In 2005, earlier Spitzer data had shown our Galaxy to be a so-called 'barred spiral': straddling the centre is a 25,000 lightyear-long 'bar', comprised mostly of older stars. Most barred spirals have two spiral arms, originating at the bar's tips; it would have been more surprising if the Milky Way was any different.

Astronomers now have a pretty good idea of the basic anatomy of the Milky Way Galaxy. The biggest structure is an almost-spherical halo of dark matter and faint stars, hundreds of thousands of lightyears across. No one knows the true nature of the dark matter, but the halo's existence is revealed by its gravitational influence on the motions of stars and gas clouds. Concentrated toward the centre of the halo are some 200 globular clusters, which are perhaps the oldest objects in the Galaxy.

Within the halo lies the 'visible' part of the Milky Way. Shaped like a flying saucer some 120,000 lightyears across, it consists of three main components. The first is the fat central bar or bulge mentioned above, consisting mainly of old stars. The second is the 'thick disc' – younger stars with relatively large vertical velocities, that bob up and down

If you lived in the Sombrero Galaxy, you'd have a top-down view of the Milky Way. We see the Sombrero almost side-on

LYNETTE COOK/SCIENCE PHOTO LIBRARY, NASA AND THE HUBBLE HERITAGE TEAM (STSCI/AURA)

# the Milky Way have?

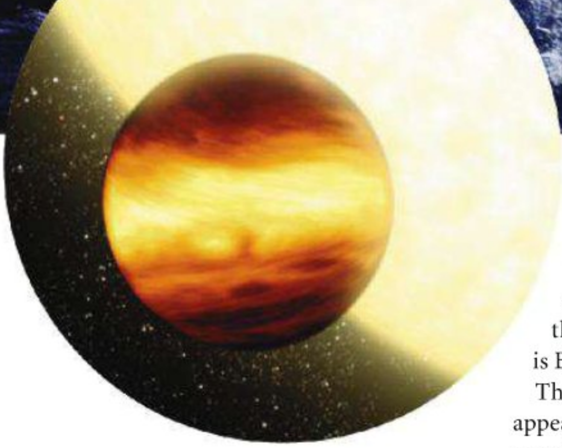
through the central plane. The thick disc measures some 3,500 lightyears on either side of the plane. The third component is the 'thin disc', which is at most 2,000 lightyears thick. Its spiral arms contain most of the Milky Way's gas, dust, star-forming regions, open star clusters and young stars. Most objects here have high orbital velocities, in the plane of the disc, and almost no vertical velocities.

Hidden in the very core of the Milky Way – a reassuring 27,000 lightyears from the Sun – lurks the central supermassive black hole, weighing in at some four billion solar masses. This is probably fed by gas and stars driven to the core by the eccentric motions in the central bar. It is believed that this black hole regulates star formation in the Milky Way's inner regions, and recent gamma-ray observations by NASA's Fermi Space Telescope indicate that it last experienced a huge outburst as recently as a few million years ago.

Many mysteries remain, however. For instance, no-one knows why some spiral galaxies have central bars while others don't. Recently, the 'citizen science' project Galaxy Zoo 2 (www.galaxyzoo.org) confirmed earlier indications that regular spirals have higher star formation rates than barred spirals. Although the details are unclear, this suggests bars might act as galactic 'contraceptives', slowing down or even stalling the birth of new stars.

Our Galaxy is believed to be a barred spiral with two main arms

# Is Earth the only habitable planet in the Milky Way?



◄ Huge 'hot Jupiters' make up the bulk of the exoplanets found so far

NASA/JPL-CALTECH

JUST 16 YEARS ago, no-one had a clue, although the discovery of protoplanetary discs surrounding newborn stars suggested that solar systems might be common. Since then, over 500 extrasolar planets have been discovered, and it's just a matter of time before astronomers hit upon the very first near-identical twin of Earth.

There's one catch, though: so far, most planetary systems found around other stars are very different from our own. They sport massive gas giants in extremely tight orbits, whirling around their parent star in a few days or even less. Such planets must have been born at much larger distances, probably migrating inward as a result of drag. Any smaller, Earth-like planets that formed closer to the parent star would have been flung into space, or into the star, by a giant's gravitational disturbance. If these 'hot Jupiters' are the rule in the Milky Way, how unique is Earth?

The good news is that smaller planets appear to be far more numerous than massive ones. This past autumn, a planet-hunting team led by Geoff Marcy of the University of California at Berkeley, randomly selected 166 nearby stars. Two turned out to be orbited by Jupiter-like planets; six had a planet the size of Neptune, while 12 had a 'super-Earth' a few times more massive than our home world. According to the team, this trend suggests that the abundance of really small planets is even higher.

## Counting on Kepler

Of course, to be really Earth-like (and habitable to life as we know it), a planet should orbit its parent star at just the right distance for liquid water to exist on its surface. At present, such planets are very hard to detect, but NASA's Kepler satellite might succeed within a few years. But even now, few doubt that the number of potentially habitable planets in the Milky Way runs into billions.

One additional mystery remains: does our home Galaxy have its own habitable zone? The answer is probably 'yes'. In the outer reaches of the Milky Way, stars contain far lower amounts of heavy elements, and exoplanet research has shown that such 'metal-poor' stars are much less likely to be accompanied by planets. On the other hand, a planet orbiting a star in the central regions of the Milky Way is exposed to huge doses of lethal radiation from supernova explosions, which are more common in the inner parts of our Galaxy, and other high-energy processes.

How many of these habitable planets could give rise to intelligent life in our Galaxy is another question entirely. In 1961, radio astronomer Frank Drake set out to answer this question. He formulated the Drake Equation, which famously came up with a figure of 50,000 civilisations able to communicate with us using radio waves. It was, however, based on assumptions, not least the likelihood of basic life forms developing intelligence. To date, we know of only one planet with intelligent life – Earth.